THE UNIVERSITY of EDINBURGH

Edinburgh Research Explorer

Measurement of angular correlations in Drell-Yan lepton pairs to probe Z/gamma* boson transverse momentum at sqrt(s)=7 TeV with the ATLAS detector

OPEN ACCESS

Measurement of angular correlations in Drell–Yan lepton pairs to probe Z/γ^* boson transverse momentum at $\sqrt{s} = 7$ TeV with the ATLAS detector ☆,☆☆

ATLAS Collaboration ⋆

A B S T R A C T

A measurement of angular correlations in Drell–Yan lepton pairs via the ϕ_η^* observable is presented. This variable probes the same physics as the Z/γ^* boson transverse momentum with a better experimental resolution. The $Z/\gamma^* \to e^+ e^-$ and $Z/\gamma^* \to \mu^+ \mu^-$ decays produced in proton–proton collisions at a centre-of-mass energy of $\sqrt{s} = 7$ TeV are used. The data were collected with the ATLAS detector at the LHC and correspond to an integrated luminosity of 4.6 fb^{-1}. Normalised differential cross sections as a function of ϕ_η^* are measured separately for electron and muon decay channels. These channels are then combined for improved accuracy. The cross section is also measured double differentially as a function of ϕ_η^* for three independent bins of the Z boson rapidity. The results are compared to QCD calculations and to predictions from different Monte Carlo event generators. The data are reasonably well described, in all measured Z boson rapidity regions, by resummed QCD predictions combined with fixed-order perturbative QCD calculations or by some Monte Carlo event generators. The measurement precision is typically better by one order of magnitude than present theoretical uncertainties.

1. Introduction

In hadron collisions at TeV energies the vector bosons W and Z/γ^* are copiously produced with non-zero momentum transverse to the beam direction (p_T) because of radiation of quarks and gluons from the initial-state partons. In this context the signatures $Z/\gamma^* \to e^+ e^-$ and $Z/\gamma^* \to \mu^+ \mu^-$ provide an ideal testing ground for QCD due to the absence of colour flow between the initial and final state [1–3]. The study of the low p_T^Z spectrum ($p_T^Z < m_Z$), which dominates the cross section, has important implications on the understanding of Higgs boson production since the transverse-momentum resummation formalism required to describe the Z/γ^* boson cross section is valid also for the Higgs boson [4–7]. A precise understanding of the p_T^Z spectrum is also necessary to further improve the modelling of W boson production in QCD calculations and Monte Carlo (MC) event generators, since the measurement of the W mass is directly affected by uncertainties in the p_T^W shape [8,9].

The transverse momentum spectra of W and Z/γ^* bosons produced via the Drell–Yan mechanism have been extensively studied by the Tevatron Collaborations [10–14] and, recently, also by the LHC experiments [15–17]. However, the precision of direct measurements of the Z/γ^* spectrum at low p_T^Z at the LHC and the Tevatron is limited by the experimental resolution and systematic

uncertainties rather than by the size of the available data samples. This limitation affects the choice of bin widths and the ultimate precision of the p_T^Z spectrum. In recent years, additional observables with better experimental resolution and smaller sensitivity to experimental systematic uncertainties have been investigated [18–21]. The optimal experimental observable to probe the low-p_T^Z domain of Z/γ^* production was found to be ϕ_η^* which is defined [20] as:

$$\phi_\eta^* \equiv \tan(\phi_{\mathrm{acop}}/2) \cdot \sin(\theta_\eta^*), \tag{1}$$

where $\phi_{\mathrm{acop}} \equiv \pi - \Delta\phi$, $\Delta\phi$ being the azimuthal opening angle between the two leptons, and the angle θ_η^* is a measure of the scattering angle of the leptons with respect to the proton beam direction in the rest frame of the dilepton system. The angle θ_η^* is defined [20] by $\cos(\theta_\eta^*) \equiv \tanh[(\eta^- - \eta^+)/2]$ where η^- and η^+ are the pseudorapidities[1] of the negatively and positively charged lepton, respectively. Therefore, ϕ_η^* depends exclusively on the directions of the two lepton tracks, which are better measured than their momenta. The ϕ_η^* variable is positive by definition. It is correlated to the quantity $p_T^Z/m_{\ell\ell}$, where $m_{\ell\ell}$ is the invariant mass of the lepton pair, and therefore probes the same physics as the

---

[1] ATLAS uses a right-handed coordinate system with its origin at the nominal pp interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$ and the rapidity is defined as $y = \ln[(E + p_z)/(E - p_z)]/2$.

transverse momentum p_T^Z [22]. Values of ϕ_η^* ranging from 0 to 1 probe the p_T^Z distribution mainly up to ~ 100 GeV. The ϕ_η^* distribution of Z/γ^* bosons has been measured in three bins of the Z boson rapidity (y_Z) by the DØ Collaboration using 7.3 fb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV [23].

This Letter presents a measurement of the normalised ϕ_η^* distribution in bins of the Z boson rapidity y_Z using 4.6 fb^{-1} of pp interactions collected at $\sqrt{s} = 7$ TeV in 2011 by the ATLAS detector. The normalised differential cross section is measured in both the electron and muon channels in the fiducial lepton acceptance defined by the lepton ($\ell = e, \mu$) transverse momentum $p_T^\ell > 20$ GeV, the lepton pseudorapidity $|\eta^\ell| < 2.4$ and the invariant mass of the lepton pair 66 GeV $< m_{\ell\ell} < 116$ GeV. Correction factors allowing the extrapolation of the cross section from the fiducial lepton acceptance to the full lepton acceptance, restricted to 66 GeV $< m_{\ell\ell} < 116$ GeV, are also presented. The reconstructed ϕ_η^* distribution, after background subtraction, is corrected for all detector effects. The measurements are reported with respect to three distinct reference points at particle level regarding QED final-state radiation (FSR) corrections. The true dilepton mass $m_{\ell\ell}$ and ϕ_η^* are defined by the final-state leptons after QED FSR ("bare" leptons), or by recombining them with radiated photons within a cone of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.1$ ("dressed" leptons), or by the final-state leptons before QED FSR ("Born leptons"). The bare definition does not require any QED FSR correction for muons, whilst the dressed definition is the closest to the experimental measurement for electrons. The Born definition corresponds to the full correction for QED FSR effects, so that it can be used for the combination of the electron and muon channels. The combination of the electron and muon channels is compared to QCD predictions obtained by matching resummed and fixed order QCD calculations, as well as to the predictions of MC event generators implementing a parton shower (PS) algorithm.

2. QCD predictions

Non-zero p_T^Z is mainly generated through the emission of partons in the initial state. In the high p_T^Z region ($p_T^Z \gtrsim m_Z$) the spectrum is determined primarily by hard parton emission. Perturbative QCD calculations, based on the truncation of the perturbative series at a fixed order in α_s, are theoretically justified and provide reliable predictions. The inclusive cross-section prediction is finite but the differential cross section diverges as p_T^Z approaches zero. In this limit ($p_T^Z \ll m_Z$) the convergence of the fixed-order expansion is spoiled by the presence of powers of large logarithmic terms which have to be resummed to restore the convergence.

Differential cross sections calculated to $\mathcal{O}(\alpha_s^2)$ are available for Z/γ^* production through the FEWZ [24,25] and DYNNLO [26,27] programs. The RESBOS [28–30] generator resums the leading contributions up to next-to-next-to-leading logarithms (NNLL) and matches the result to fixed-order calculations at $\mathcal{O}(\alpha_s)$. This is corrected to $\mathcal{O}(\alpha_s^2)$ using a k-factor depending on p_T^Z and y_Z [31]. In addition, the RESBOS generator includes a non-perturbative form factor that needs to be determined from data [32]. A slightly different approach has been proposed recently to describe the Tevatron Run II data by matching NNLL accuracy to MCFM calculations [33], with no apparent need for non-perturbative contributions [34,22].

Similarly to resummed calculations, PS algorithms such as those used in PYTHIA [35] and HERWIG [36] provide an all-order approximation of parton radiation in the soft and collinear region through the iterative splitting and radiation of partons. The POWHEG [37–40] and MC@NLO [41] event generators combine next-to-leading order (NLO) QCD matrix elements with a PS algorithm to produce differential cross-section predictions that are finite for all p_T^Z. The

ALPGEN [42] and SHERPA [43] event generators implement tree-level matrix elements for the generation of multiple hard partons in association with the weak boson. They are matched to parton showers either by a PS algorithm using re-weighting procedures [44,45] or through a veto [42], in order to avoid the double counting of QCD emissions in the matrix element and the parton shower.

3. The ATLAS detector

The ATLAS detector [46] is a multi-purpose particle physics detector operating at one of the beam interaction points of the LHC. It covers nearly the entire solid angle around the collision region and consists of an inner tracking detector (inner detector or ID) surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer (MS).

Measurements in the ID are performed with silicon pixel and microstrip detectors covering $|\eta| < 2.5$. A straw-tube tracking detector follows radially and covers the range $|\eta| < 2.0$. The lead/liquid-argon electromagnetic calorimeter is divided into barrel ($|\eta| < 1.5$) and endcap ($1.4 < |\eta| < 3.2$) sections. The hadronic calorimeter is based on steel/scintillating tiles in the central region ($|\eta| < 1.7$), and is extended to $|\eta| = 4.9$ by endcap and forward calorimeters which use liquid argon. The MS comprises separate trigger and high-precision tracking chambers to measure the deflection of muons in a magnetic field generated by three large superconducting toroids arranged with an eightfold azimuthal coil symmetry around the calorimeters. The high-precision chambers cover a range of $|\eta| < 2.7$. The muon trigger system covers the range $|\eta| < 2.4$ with resistive plate chambers in the barrel, and thin gap chambers in the endcap regions.

4. Event simulation

MC simulations are used to calculate efficiencies and acceptances for the $Z/\gamma^* \rightarrow \ell^+\ell^-$ signal processes and to unfold the measured ϕ_η^* spectrum for detector effects and for different levels of QED FSR. The POWHEG MC generator is used with CT10 [47] parton distribution functions (PDFs) to generate both the $Z/\gamma^* \rightarrow e^+e^-$ and $Z/\gamma^* \rightarrow \mu^+\mu^-$ signal events. It is interfaced to PYTHIA 6.4 with the AUET2B-CTEQ6L1 tune [48] to simulate the parton shower and the underlying event. Generated events are re-weighted as a function of p_T^Z to the predictions from RESBOS, which describes the p_T^Z spectrum more accurately [15]. Simulated events are also used to estimate background contributions. The electroweak background processes $W \rightarrow \ell\nu$ and $Z/\gamma^* \rightarrow \tau^+\tau^-$ are generated using PYTHIA 6.4. The production of $t\bar{t}$ events is modelled using MC@NLO and diboson processes are simulated using HERWIG. The event generators are interfaced to PHOTOS [49] to simulate QED FSR for all of the simulated samples, except SHERPA which is interfaced to an implementation of the YFS algorithm [50,51].

Multiple interactions per bunch crossing (pile-up) are accounted for by overlaying simulated minimum bias events. To match the observed instantaneous luminosity profile, the simulated events are re-weighted to yield the same distribution of the number of interactions per bunch crossing as measured in the data. The response of the ATLAS detector to the generated particles is modelled using GEANT4 [52], and the fully simulated events [53] are passed through the same reconstruction chain as the data. Simulated event samples are corrected for differences with respect to the data in the trigger efficiencies, lepton reconstruction and identification efficiencies as well as in energy (momentum) scale and resolution. The efficiencies are determined by using a

Table 1

The measured normalised differential cross section $1/\sigma^{\mathrm{fid}} \cdot \mathrm{d}\sigma^{\mathrm{fid}}/\mathrm{d}\phi_\eta^*$ in bins of ϕ_η^* for $Z/\gamma^* \to e^+e^-$ and $Z/\gamma^* \to \mu^+\mu^-$ channels. The cross sections, which are to be multiplied for convenience by a factor f, are reported with respect to the three different treatments of QED final-state radiation. The relative statistical (δ_{stat}) and total systematic (δ_{sys}) uncertainties are given in percent. The overall point-to-point uncorrelated additional uncertainty in QED FSR of 0.3% is not included.

ϕ_η^* bin range	$Z/\gamma^* \to e^+e^-$						$Z/\gamma^* \to \mu^+\mu^-$					
	$1/\sigma^{\mathrm{fid}} \cdot \mathrm{d}\sigma^{\mathrm{fid}}/\mathrm{d}\phi_\eta^*$				δ_{stat} [%]	δ_{sys} [%]	$1/\sigma^{\mathrm{fid}} \cdot \mathrm{d}\sigma^{\mathrm{fid}}/\mathrm{d}\phi_\eta^*$				δ_{stat} [%]	δ_{sys} [%]
	Born	dressed	bare	f			Born	dressed	bare	f		
0.000–0.004	9.77	9.69	9.70	1	0.46	0.35	9.77	9.67	9.67	1	0.39	0.28
0.004–0.008	9.68	9.59	9.59	1	0.47	0.26	9.76	9.66	9.66	1	0.39	0.18
0.008–0.012	9.42	9.36	9.38	1	0.47	0.28	9.42	9.34	9.35	1	0.40	0.24
0.012–0.016	9.14	9.06	9.07	1	0.48	0.35	9.26	9.17	9.18	1	0.40	0.24
0.016–0.020	8.82	8.76	8.77	1	0.49	0.24	8.83	8.76	8.77	1	0.41	0.19
0.020–0.024	8.48	8.43	8.43	1	0.50	0.25	8.51	8.44	8.45	1	0.42	0.27
0.024–0.029	7.97	7.93	7.94	1	0.46	0.26	8.05	8.00	8.01	1	0.39	0.24
0.029–0.034	7.57	7.52	7.53	1	0.47	0.22	7.57	7.52	7.53	1	0.40	0.19
0.034–0.039	7.02	7.00	7.01	1	0.49	0.29	7.11	7.09	7.09	1	0.41	0.17
0.039–0.045	6.55	6.53	6.53	1	0.46	0.22	6.50	6.49	6.49	1	0.39	0.17
0.045–0.051	5.93	5.92	5.92	1	0.48	0.22	6.00	5.99	5.99	1	0.41	0.16
0.051–0.057	5.52	5.52	5.52	1	0.50	0.22	5.52	5.53	5.53	1	0.42	0.22
0.057–0.064	5.04	5.04	5.04	1	0.48	0.22	5.00	5.01	5.01	1	0.41	0.16
0.064–0.072	4.55	4.56	4.56	1	0.48	0.22	4.52	4.52	4.52	1	0.41	0.23
0.072–0.081	4.01	4.03	4.03	1	0.48	0.21	4.04	4.06	4.06	1	0.40	0.18
0.081–0.091	3.58	3.59	3.59	1	0.48	0.22	3.53	3.55	3.55	1	0.41	0.19
0.091–0.102	3.15	3.16	3.16	1	0.49	0.23	3.14	3.16	3.16	1	0.41	0.21
0.102–0.114	2.73	2.74	2.74	1	0.50	0.26	2.73	2.75	2.74	1	0.43	0.23
0.114–0.128	2.34	2.35	2.35	1	0.50	0.29	2.35	2.37	2.37	1	0.42	0.24
0.128–0.145	2.00	2.01	2.01	1	0.49	0.24	2.00	2.01	2.01	1	0.42	0.21
0.145–0.165	1.687	1.697	1.698	1	0.49	0.28	1.669	1.680	1.679	1	0.42	0.28
0.165–0.189	1.355	1.364	1.363	1	0.50	0.25	1.355	1.365	1.365	1	0.43	0.19
0.189–0.219	1.079	1.087	1.087	1	0.50	0.23	1.086	1.093	1.093	1	0.43	0.20
0.219–0.258	8.27	8.34	8.32	10^{-1}	0.50	0.24	8.22	8.28	8.27	10^{-1}	0.43	0.19
0.258–0.312	5.97	6.00	5.99	10^{-1}	0.50	0.25	5.94	5.97	5.97	10^{-1}	0.43	0.17
0.312–0.391	3.97	3.99	3.99	10^{-1}	0.51	0.22	3.94	3.96	3.96	10^{-1}	0.44	0.17
0.391–0.524	2.28	2.28	2.28	10^{-1}	0.52	0.24	2.29	2.29	2.29	10^{-1}	0.45	0.19
0.524–0.695	1.176	1.179	1.177	10^{-1}	0.64	0.29	1.164	1.168	1.166	10^{-1}	0.55	0.23
0.695–0.918	5.79	5.80	5.79	10^{-2}	0.79	0.37	5.77	5.79	5.78	10^{-2}	0.69	0.29
0.918–1.153	2.94	2.95	2.95	10^{-2}	1.07	0.47	2.91	2.91	2.91	10^{-2}	0.95	0.37
1.153–1.496	1.54	1.55	1.54	10^{-2}	1.22	0.52	1.50	1.51	1.51	10^{-2}	1.09	0.41
1.496–1.947	7.25	7.26	7.25	10^{-3}	1.55	0.66	7.05	7.06	7.06	10^{-3}	1.39	0.48
1.947–2.522	3.52	3.51	3.50	10^{-3}	1.97	0.78	3.56	3.56	3.55	10^{-3}	1.74	0.62
2.522–3.277	1.73	1.73	1.72	10^{-3}	2.46	0.96	1.79	1.80	1.80	10^{-3}	2.13	0.71

tag-and-probe method similar to the one described in Section 4.3 of Ref. [54] based on reconstructed Z and W events, while the energy resolution and scale corrections are obtained from a fit to the observed Z boson line shape.

5. Event reconstruction, selection and background estimation

Events recorded during periods with stable beam conditions and passing detector and data-quality requirements are selected. At least one primary vertex reconstructed from at least three tracks is required in each event.

Events in the electron channel are selected online by requiring a single electron candidate with a threshold in transverse momentum p_T that was increased during the data-taking from 20 GeV to 22 GeV in response to increased LHC luminosity. Electrons are reconstructed from a cluster of cells with significant energy deposits in the electromagnetic calorimeter matched to an inner detector track. Electron reconstruction uses track refitting with a Gaussian-sum filter to be less sensitive to bremsstrahlung losses and improve the estimates of the electron track parameters [55,56]. The typical angular resolutions in the electron direction measurements are 0.6 mrad for ϕ and 0.0012 for η. The highest and second highest p_T electrons are required to have a transverse momentum $p_T^e > 25$ GeV and $p_T^e > 20$ GeV, respectively. The electron pseudorapidity must satisfy $|\eta^e| < 2.4$ with the calorimeter barrel/endcap transition region $1.37 < |\eta^e| < 1.52$ excluded. Electrons are required to pass "medium" identification criteria based on shower

shape and track-quality variables, as described in Refs. [57,58]. The criteria are re-optimised for both higher pile-up conditions and higher instantaneous luminosity in 2011.

Events in the muon channel are selected online by a trigger requiring a single muon candidate with $p_T^\mu > 18$ GeV. Muons are identified as tracks reconstructed in the muon spectrometer matched to tracks reconstructed in the inner detector and are required to have $p_T^\mu > 20$ GeV and $|\eta^\mu| < 2.4$. Only isolated muons are selected by requiring the scalar sum of the p_T of the tracks within a cone $\Delta R = 0.2$ around the muon to be less than 10% of the muon p_T. Muons are required to have a longitudinal impact parameter with respect to the primary vertex less than 10 mm to reduce contributions from cosmic-ray muons and in-time pileup. In addition, the transverse impact parameter of the track with respect to the primary vertex divided by its uncertainty must be smaller than ten to reduce non-prompt muon backgrounds. The typical angular resolutions in the muon direction measurements are 0.4 mrad for ϕ and 0.001 for η.

$Z/\gamma^* \to \ell^+\ell^-$ events are selected by requiring two oppositely charged same-flavour leptons with an invariant mass 66 GeV $< m_{\ell\ell} < 116$ GeV. After these selection requirements $1.22 \cdot 10^6$ dielectron and $1.69 \cdot 10^6$ dimuon candidate events are found in data.

Background contributions from $Z/\gamma^* \to \tau^+\tau^-$, $W \to \ell\nu$, $t\bar{t}$ and diboson production are estimated using MC simulations. The cross sections are normalised to next-to-next-to-leading-order (NNLO) predictions for Z/γ^* and W production using Fewz, NLL-NLO predictions for $t\bar{t}$ production [54] and NLO predictions for diboson
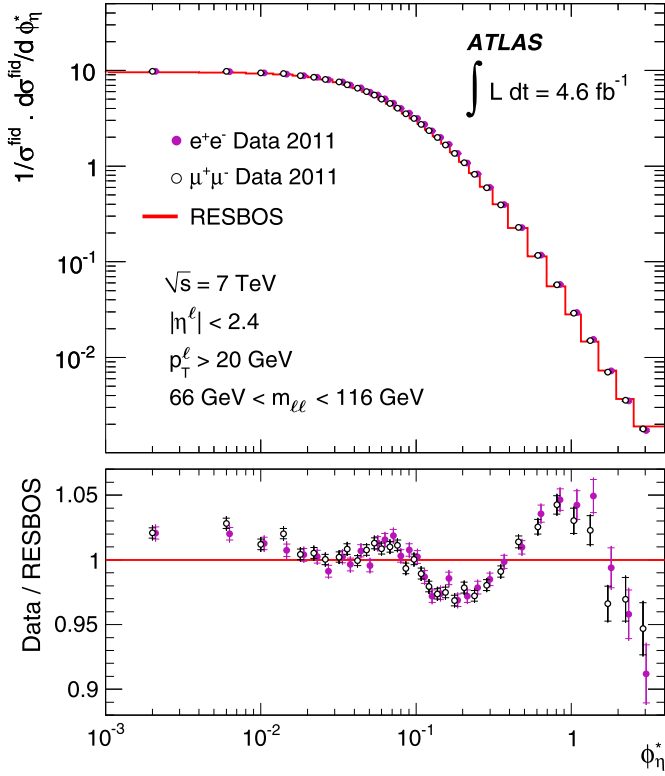
Fig. 1. The measured normalised differential cross section $1/\sigma^{\rm fid} \cdot {\rm d}\sigma^{\rm fid}/{\rm d}\phi_\eta^*$ as a function of ϕ_η^* for $Z/\gamma^* \to e^+e^-$ (closed dots) and $Z/\gamma^* \to \mu^+\mu^-$ (open dots) channels. The measurements are compared to RESBOS predictions represented by a line. The ratio of measured cross sections to RESBOS predictions is presented in the bottom panel. The measurements are displaced horizontally for better visibility. The inner and outer error bars on the data points represent the statistical and total uncertainties, respectively. The uncertainty due to QED FSR is included in the total uncertainties.

Table 2
The combined normalised differential cross section $1/\sigma^{\rm fid} \cdot {\rm d}\sigma^{\rm fid}/{\rm d}\phi_\eta^*$ in bins of ϕ_η^* at Born level. The statistical ($\delta_{\rm stat}$) and total systematic ($\delta_{\rm sys}$) uncertainties are given in percent. The normalised differential cross section extrapolated to the full lepton acceptance $1/\sigma^{\rm tot} \cdot {\rm d}\sigma^{\rm tot}/{\rm d}\phi_\eta^*$ is obtained at Born level by multiplication with the inverse acceptance correction factor A_c^{-1}. The uncertainty $\delta(A_c^{-1})$ on this acceptance correction factor is also given in percent. The overall point-to-point uncorrelated additional uncertainty in QED FSR of 0.3% is not included.

ϕ_η^* bin range	$1/\sigma^{\rm fid} \cdot {\rm d}\sigma^{\rm fid}/{\rm d}\phi_\eta^*$	$\delta_{\rm stat}$ [%]	$\delta_{\rm sys}$ [%]	A_c^{-1}	$\delta(A_c^{-1})$ [%]
0.000–0.004	9.77	0.30	0.21	1.06	3.8
0.004–0.008	9.73	0.30	0.20	1.06	3.0
0.008–0.012	9.41	0.31	0.18	1.06	3.7
0.012–0.016	9.21	0.31	0.22	1.06	2.4
0.016–0.020	8.82	0.31	0.16	1.05	2.5
0.020–0.024	8.49	0.32	0.18	1.05	2.2
0.024–0.029	8.01	0.29	0.18	1.05	1.8
0.029–0.034	7.56	0.30	0.14	1.04	2.4
0.034–0.039	7.07	0.31	0.15	1.04	2.2
0.039–0.045	6.52	0.30	0.14	1.03	2.2
0.045–0.051	5.97	0.31	0.13	1.02	2.8
0.051–0.057	5.52	0.32	0.16	1.01	2.1
0.057–0.064	5.02	0.31	0.13	1.01	1.9
0.064–0.072	4.54	0.31	0.18	1.00	2.0
0.072–0.081	4.03	0.31	0.13	0.99	1.8
0.081–0.091	3.56	0.31	0.15	0.99	1.0
0.091–0.102	3.15	0.32	0.16	0.98	1.1
0.102–0.114	2.731	0.32	0.17	0.97	1.3
0.114–0.128	2.347	0.32	0.19	0.97	1.3
0.128–0.145	1.996	0.32	0.16	0.96	1.7
0.145–0.165	1.677	0.32	0.19	0.95	2.0
0.165–0.189	1.355	0.32	0.16	0.95	2.7
0.189–0.219	1.084	0.32	0.15	0.94	2.3
0.219–0.258	$8.24 \cdot 10^{-1}$	0.33	0.15	0.94	2.9
0.258–0.312	$5.95 \cdot 10^{-1}$	0.33	0.14	0.93	2.9
0.312–0.391	$3.96 \cdot 10^{-1}$	0.33	0.14	0.92	3.4
0.391–0.524	$2.282 \cdot 10^{-1}$	0.34	0.15	0.92	3.5
0.524–0.695	$1.169 \cdot 10^{-1}$	0.42	0.18	0.92	4.4
0.695–0.918	$5.78 \cdot 10^{-2}$	0.52	0.23	0.93	4.0
0.918–1.153	$2.92 \cdot 10^{-2}$	0.71	0.29	0.94	5.3
1.153–1.496	$1.52 \cdot 10^{-2}$	0.81	0.33	0.98	10.5
1.496–1.947	$7.13 \cdot 10^{-3}$	1.04	0.40	1.04	10.3
1.947–2.522	$3.54 \cdot 10^{-3}$	1.30	0.49	1.11	17.5
2.522–3.277	$1.77 \cdot 10^{-3}$	1.61	0.58	1.19	16.2

production [59]. For both the e^+e^- and $\mu^+\mu^-$ channels, the main background at high ϕ_η^* values arises from $t\bar{t}$ and diboson production.

At low ϕ_η^* values the background is dominated by multi-jet production, where a jet is falsely identified as a primary e or μ. In this case the background is determined by data-driven methods. A data event sample dominated by jets faking electrons or muons in the final state is employed to determine the shape of the multi-jet background. For the e^+e^- channel, the multi-jet sample is obtained from electrons failing the medium identification criteria. In order to assess systematic uncertainties in the shape of the multi-jet background, an alternative multi-jet control sample was also selected using non-isolated electrons. For the $\mu^+\mu^-$ channel, the multi-jet sample is extracted by inverting the isolation requirement on muons. The uncertainty in its shape was studied by comparing same-sign and opposite-sign dimuon events. The normalisation of this multi-jet background template is determined by adjusting the sum of it and other background and signal MC predictions to data as a function of the invariant mass spectrum of the dilepton pair. An extended dilepton mass range, 50 GeV $< m_{\ell\ell} <$ 150 GeV (200 GeV for electrons), was employed to better constrain the off-resonance region and improve the accuracy of the multi-jet background normalisation.

The total fraction of background events is $(0.61 \pm 0.31)\%$ in the e^+e^- channel and $(0.56 \pm 0.28)\%$ in the $\mu^+\mu^-$ channel. The multi-jet background represents $\sim 50\%$ of the total background in both channels and dominates at low ϕ_η^* values. An irreducible background may also arise from the production of a lepton pair

via photon-photon interactions, $\gamma\gamma \to \ell^+\ell^-$. This contribution was evaluated at leading order using FEWZ 3.1 [24,60] and the MRST2004qed [61] PDF, currently the only available PDF set containing a description of the QED part of the proton. According to the LO cross section calculated in the fiducial lepton acceptance, the fraction of photon-induced events is expected to be below 0.1%, with an uncertainty of 50%. This contribution is six times lower than the sum of other background contributions and is therefore neglected.

6. Cross-section measurement and systematic uncertainties

The differential cross section is evaluated in bins of ϕ_η^*, or of (ϕ_η^*, y_Z), from the number of observed data events in each bin after subtraction of the estimated number of background events.

A bin-by-bin correction is used to correct the observed data for detector acceptances and inefficiencies, as well as for QED FSR. The correction factors are determined using signal MC events. For the chosen bin widths the purity, defined as the fraction of simulated events reconstructed in a ϕ_η^* bin which have generator-level ϕ_η^* in the same bin, is always more than 83% and reaches 98% in the highest ϕ_η^* bins. In each bin, the data are normalised to the cross section integrated over the fiducial acceptance region.

An analysis of systematic uncertainties was performed, in which the sensitivity of the measurements to variations in the efficiencies

and energy scales of the detector components and to the details of the correction procedure is tested. The systematic uncertainties in the measured cross section are determined by repeating the analysis after applying appropriate variations for each source of systematic uncertainty to the simulated samples. The systematic uncertainties which are correlated between ϕ^*_η bins are listed below.

- Uncertainties in the estimation of the number of background events from multi-jet, $W \to \ell\nu$ and $Z/\gamma^* \to \tau^+\tau^-$ decays, $t\bar{t}$ and diboson processes yield values of up to 0.3% in the e^+e^- and $\mu^+\mu^-$ channels, when propagated to the normalised differential cross section.
- Possible mis-modelling of the angular resolution of tracking detectors leads to uncertainties of up to 0.3% (0.2%) on the normalised differential cross section in the e^+e^- ($\mu^+\mu^-$) channel.
- The dependence of the bin-by-bin correction factors on the shape of the assumed ϕ^*_η distribution was tested by re-weighting simulated events to the measured ϕ^*_η cross section. An iterative Bayesian unfolding technique [62] was employed as an alternative approach to assess systematic uncertainties. The uncertainty in the correction procedure is found to be smaller than 0.1% in both channels and for the full ϕ^*_η range.
- As the definition of the ϕ^*_η variable is based on the lepton angles, the normalised differential cross section depends only weakly on uncertainties in the lepton energy/momentum scale and resolution. When propagated to the normalised differential cross section, these uncertainties amount to less than 0.1% and 0.03% in the e^+e^- and $\mu^+\mu^-$ channels, respectively.
- Uncertainties arising from the mis-modelling of lepton identification efficiencies and trigger efficiencies in the simulation amount respectively to 0.05% (0.03%) and 0.04% (0.02%) in the e^+e^- ($\mu^+\mu^-$) channel.
- Pile-up has only a weak influence on this measurement and results in an uncertainty of at most 0.05% on the normalised differential cross section.

A second class of systematic uncertainties, listed below, are considered uncorrelated across ϕ^*_η bins.

- Uncertainties on the bin-by-bin correction factors arising from the MC sample statistics are 0.2% (0.13%) at low ϕ^*_η in the e^+e^- ($\mu^+\mu^-$) channel, increasing to 0.9% (0.6%) in the highest ϕ^*_η bins.
- Possible local biases in angular measurements (ϕ, η) by tracking detectors yield an estimated constant uncertainty of 0.1% on the normalised differential cross section. The local effect of these biases allows bin-to-bin correlations to be neglected. The impact of this assumption on the combination of electron and muon channel results is small.
- A conservative systematic uncertainty of 0.3% due to ϕ^*_η-dependent modelling of QED FSR is assigned by comparing predictions from PHOTOS [49] and from the SHERPA implementation of the YFS algorithm [50,51]. This comparison provides the size of the uncertainty but however does not allow the shape of the ϕ^*_η dependence to be estimated. This uncertainty was therefore treated as uncorrelated across ϕ^*_η bins. The uncertainty is assumed to hold for cross sections at Born, dressed and bare levels and for both electron and muon channel measurements. It therefore does not affect the combination of them.

The total systematic uncertainty on each data point is formed by adding the individual contributions in quadrature.
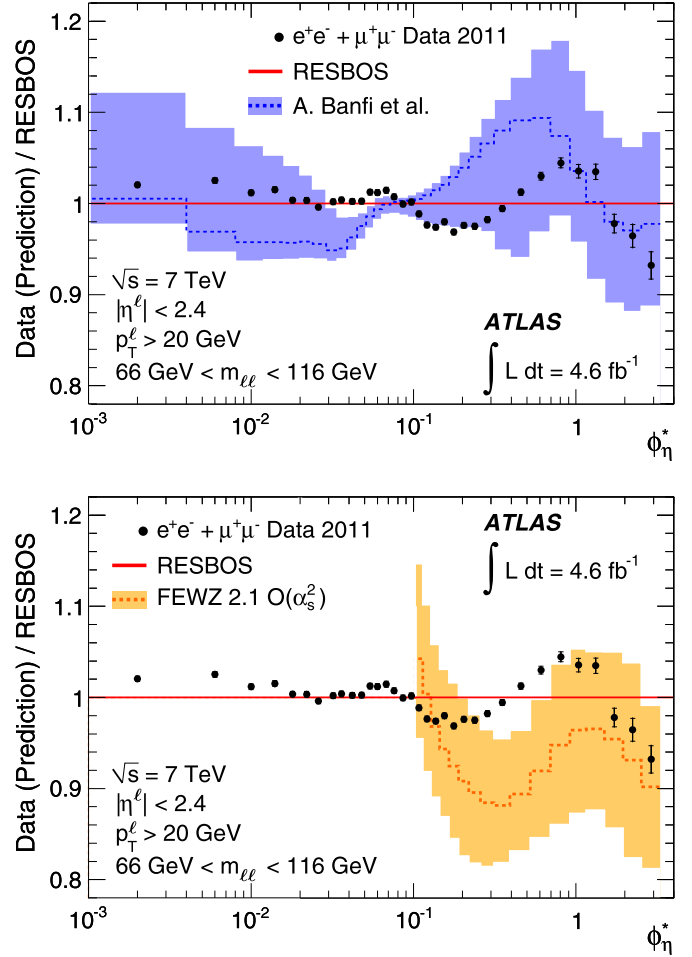

Fig. 2. The ratio of the combined normalised differential cross section $1/\sigma^{\rm fid} \cdot d\sigma^{\rm fid}/d\phi^*_\eta$ to RESBOS predictions as a function of ϕ^*_η. The inner and outer error bars on the data points represent the statistical and total uncertainties, respectively. The uncertainty due to QED FSR is included in the total uncertainties. The measurements are also compared to predictions, which are represented by a dashed line, from Ref. [22] and from FEWZ in the top and bottom panels, respectively. Uncertainties associated with these two calculations are represented by shaded bands. The prediction from FEWZ is only presented for $\phi^*_\eta > 0.1$.

7. Results and discussion

The normalised differential cross sections measured for $Z/\gamma^* \to e^+e^-$ and $Z/\gamma^* \to \mu^+\mu^-$ production in the fiducial acceptance are presented in Table 1. The measurements are reported with respect to the Born, dressed and bare reference points at particle level regarding QED FSR. The QED FSR corrections for the three levels are calculated using PHOTOS. The measured cross sections defined at the Z/γ^* Born level are shown in Fig. 1 for the e^+e^- and $\mu^+\mu^-$ channels and are compared to predictions from RESBOS.

The normalised differential cross sections measured in the fiducial acceptance for the two channels are combined using a χ^2 minimisation method which takes into account the point-to-point correlated and uncorrelated systematic uncertainties [63–65] and correlations between electron and muon channels. The procedure allows a model independent check of the electron and muon data consistency and leads to a significant reduction of the correlated uncertainties. The uncertainties due to the unfolding procedure, the pile-up, and QED FSR are considered to be completely correlated between the e^+e^- and $\mu^+\mu^-$ channels. The minimisation yields a total χ^2 per degree of freedom ($n_{\rm dof}$)

Table 3

The combined normalised differential cross section $1/\sigma^{\text{fid}} \cdot \text{d}\sigma^{\text{fid}}/\text{d}\phi_\eta^*$ in bins of ϕ_η^* and in three $|y_Z|$ ranges. The statistical (δ_{stat}) and total systematic (δ_{sys}) uncertainties are given in percent. The overall point-to-point uncorrelated additional uncertainty in QED FSR of 0.3% is not included.

ϕ_η^* bin range	$|y_Z| < 0.8$			$0.8 \leqslant |y_Z| < 1.6$			$|y_Z| \geqslant 1.6$		
	$1/\sigma^{\text{fid}} \cdot \text{d}\sigma^{\text{fid}}/\text{d}\phi_\eta^*$	δ_{stat} [%]	δ_{sys} [%]	$1/\sigma^{\text{fid}} \cdot \text{d}\sigma^{\text{fid}}/\text{d}\phi_\eta^*$	δ_{stat} [%]	δ_{sys} [%]	$1/\sigma^{\text{fid}} \cdot \text{d}\sigma^{\text{fid}}/\text{d}\phi_\eta^*$	δ_{stat} [%]	δ_{sys} [%]
0.000–0.004	9.73	0.45	0.25	9.81	0.48	0.21	9.79	0.75	0.33
0.004–0.008	9.65	0.45	0.23	9.81	0.48	0.26	9.77	0.75	0.35
0.008–0.012	9.37	0.46	0.24	9.45	0.49	0.23	9.45	0.76	0.30
0.012–0.016	9.12	0.46	0.24	9.31	0.49	0.25	9.25	0.77	0.38
0.016–0.020	8.81	0.47	0.21	8.88	0.50	0.22	8.72	0.79	0.31
0.020–0.024	8.49	0.48	0.20	8.48	0.51	0.25	8.52	0.80	0.38
0.024–0.029	7.99	0.44	0.23	8.05	0.47	0.21	7.99	0.74	0.29
0.029–0.034	7.54	0.46	0.21	7.64	0.48	0.19	7.45	0.77	0.28
0.034–0.039	7.12	0.47	0.19	7.07	0.50	0.21	6.99	0.79	0.31
0.039–0.045	6.53	0.45	0.18	6.57	0.47	0.19	6.38	0.75	0.27
0.045–0.051	5.92	0.47	0.18	6.01	0.50	0.19	6.02	0.78	0.28
0.051–0.057	5.52	0.48	0.20	5.50	0.52	0.21	5.53	0.81	0.30
0.057–0.064	5.06	0.47	0.18	5.00	0.50	0.19	4.97	0.79	0.28
0.064–0.072	4.53	0.46	0.22	4.53	0.49	0.21	4.56	0.77	0.30
0.072–0.081	4.02	0.46	0.19	4.04	0.49	0.18	4.02	0.77	0.27
0.081–0.091	3.56	0.47	0.19	3.55	0.50	0.20	3.55	0.78	0.27
0.091–0.102	3.15	0.47	0.20	3.14	0.50	0.21	3.15	0.79	0.28
0.102–0.114	2.72	0.49	0.20	2.73	0.52	0.21	2.75	0.81	0.29
0.114–0.128	2.34	0.48	0.22	2.34	0.52	0.22	2.37	0.81	0.31
0.128–0.145	2.00	0.47	0.19	2.00	0.51	0.22	1.99	0.80	0.27
0.145–0.165	1.667	0.48	0.20	1.677	0.51	0.21	1.707	0.80	0.38
0.165–0.189	1.342	0.49	0.19	1.356	0.52	0.21	1.385	0.81	0.28
0.189–0.219	1.073	0.49	0.19	1.085	0.52	0.19	1.112	0.81	0.28
0.219–0.258	$8.18 \cdot 10^{-1}$	0.49	0.18	$8.22 \cdot 10^{-1}$	0.52	0.19	$8.47 \cdot 10^{-1}$	0.81	0.28
0.258–0.312	$5.96 \cdot 10^{-1}$	0.49	0.18	$5.87 \cdot 10^{-1}$	0.53	0.19	$6.13 \cdot 10^{-1}$	0.81	0.26
0.312–0.391	$3.95 \cdot 10^{-1}$	0.50	0.18	$3.89 \cdot 10^{-1}$	0.54	0.19	$4.14 \cdot 10^{-1}$	0.82	0.26
0.391–0.524	$2.28 \cdot 10^{-1}$	0.50	0.20	$2.25 \cdot 10^{-1}$	0.55	0.20	$2.36 \cdot 10^{-1}$	0.84	0.28
0.524–0.695	$1.174 \cdot 10^{-1}$	0.62	0.24	$1.151 \cdot 10^{-1}$	0.67	0.25	$1.21 \cdot 10^{-1}$	1.03	0.34
0.695–0.918	$5.88 \cdot 10^{-2}$	0.77	0.30	$5.70 \cdot 10^{-2}$	0.84	0.31	$5.69 \cdot 10^{-2}$	1.32	0.42
0.918–1.153	$3.05 \cdot 10^{-2}$	1.04	0.40	$2.87 \cdot 10^{-2}$	1.15	0.42	$2.67 \cdot 10^{-2}$	1.86	0.58
1.153–1.496	$1.62 \cdot 10^{-2}$	1.17	0.44	$1.50 \cdot 10^{-2}$	1.30	0.47	$1.29 \cdot 10^{-2}$	2.21	0.71
1.496–1.947	$7.67 \cdot 10^{-3}$	1.50	0.56	$7.08 \cdot 10^{-3}$	1.65	0.58	$5.66 \cdot 10^{-3}$	2.91	0.95
1.947–2.522	$4.08 \cdot 10^{-3}$	1.83	0.70	$3.53 \cdot 10^{-3}$	2.06	0.69	$2.00 \cdot 10^{-3}$	4.35	1.39
2.522–3.277	$2.10 \cdot 10^{-3}$	2.22	0.80	$1.70 \cdot 10^{-3}$	2.59	0.87	$9.66 \cdot 10^{-4}$	5.39	1.92

of $\chi^2/n_{\text{dof}} = 33.2/34$, indicating a good consistency between the electron and muon data. Measured values of the combined normalised differential cross section $1/\sigma^{\text{fid}} \cdot \text{d}\sigma^{\text{fid}}/\text{d}\phi_\eta^*$ within the fiducial lepton acceptance are presented in Table 2. At lower ϕ_η^* values the statistical and systematic uncertainties are of the same order, whilst for large ϕ_η^* values statistical uncertainties are dominating. The acceptance correction factors A_c needed to extrapolate the measurement to the full lepton acceptance are determined using the POWHEG simulation with the CT10 PDF set and re-weighted as a function of p_T^Z to RESBOS predictions. The uncertainty in A_c is estimated from the extreme differences among predictions obtained with RESBOS, MC@NLO, SHERPA, ALPGEN, HERWIG and POWHEG interfaced to PYTHIA8. Uncertainties in A_c resulting from PDF uncertainties are below 1%.

The ratio of the combined normalised differential cross section to the RESBOS prediction is shown as a function of ϕ_η^* in Fig. 2. The measurement is also compared to a QCD calculation by A. Banfi et al. [22] and to another obtained with FEWZ 2.1. The ratios of these two calculations to RESBOS predictions are also shown in Fig. 2. The CTEQ6m [66] PDF set is used in the calculation of Ref. [22]. The theoretical uncertainties on this calculation are evaluated by varying the resummation, renormalisation and factorisation scales μ_Q, μ_R and μ_F between $m_Z/2$ and $2m_Z$, with the constraints $0.5 \leqslant \mu_i/\mu_j \leqslant 2$, where $i, j \in \{F, Q, R\}$, and $\mu_F/\mu_Q \geqslant 1$. Uncertainties coming from the PDFs are also considered [22]. For FEWZ, the CT10 PDF set is used. Uncertainties are evaluated by varying μ_R and μ_F by factors of two around the nominal scale m_Z with the constraint $0.5 \leqslant \mu_R/\mu_F \leqslant 2$, by varying α_s within a range corresponding to 90% confidence-

level (CL) limits [67], and by using the PDF error eigenvector sets.

The difference between the RESBOS prediction and data is $\sim 2\%$ for $\phi_\eta^* < 0.1$, increasing to 5% for higher ϕ_η^* values. This difference is smaller than the uncertainty in RESBOS predictions due to the propagation of PDF eigenvectors sets, which amounts to 4% for $\phi_\eta^* < 0.1$ and 6% above. The description of data provided by calculations from A. Banfi et al. [22] is less good than RESBOS but observed differences remain within the theoretical uncertainties of the calculation. The prediction obtained with FEWZ undershoots the data by $\sim 10\%$, as already observed for the p_T^Z spectrum in Ref. [15]. At low ϕ_η^* values, corresponding mainly to low p_T^Z, fixed-order perturbative QCD calculations are not expected to give an adequate description of the cross section. The prediction from FEWZ is therefore only presented for $\phi_\eta^* > 0.1$. It is normalised using the total cross section predicted by FEWZ, which accurately describes experimental measurements [58].

The cross section is also measured double differentially in bins of ϕ_η^* for three independent bins of $|y_Z|$ for both the e^+e^- and $\mu^+\mu^-$ channels. The double differential cross-section measurements in the two channels are combined using the same χ^2 minimisation procedure as used for the single differential cross section. The minimisation yields a total $\chi^2/n_{\text{dof}} = 118/102$. Measured values of the combined normalised differential cross section $1/\sigma^{\text{fid}} \cdot \text{d}\sigma^{\text{fid}}/\text{d}\phi_\eta^*$ within the fiducial lepton acceptance in all ϕ_η^* and $|y_Z|$ bins are presented in Table 3.

The ratio of the combined normalised differential cross section to the RESBOS prediction is shown as a function of ϕ_η^* for the three $|y_Z|$ ranges in Fig. 3. The measurement is also compared
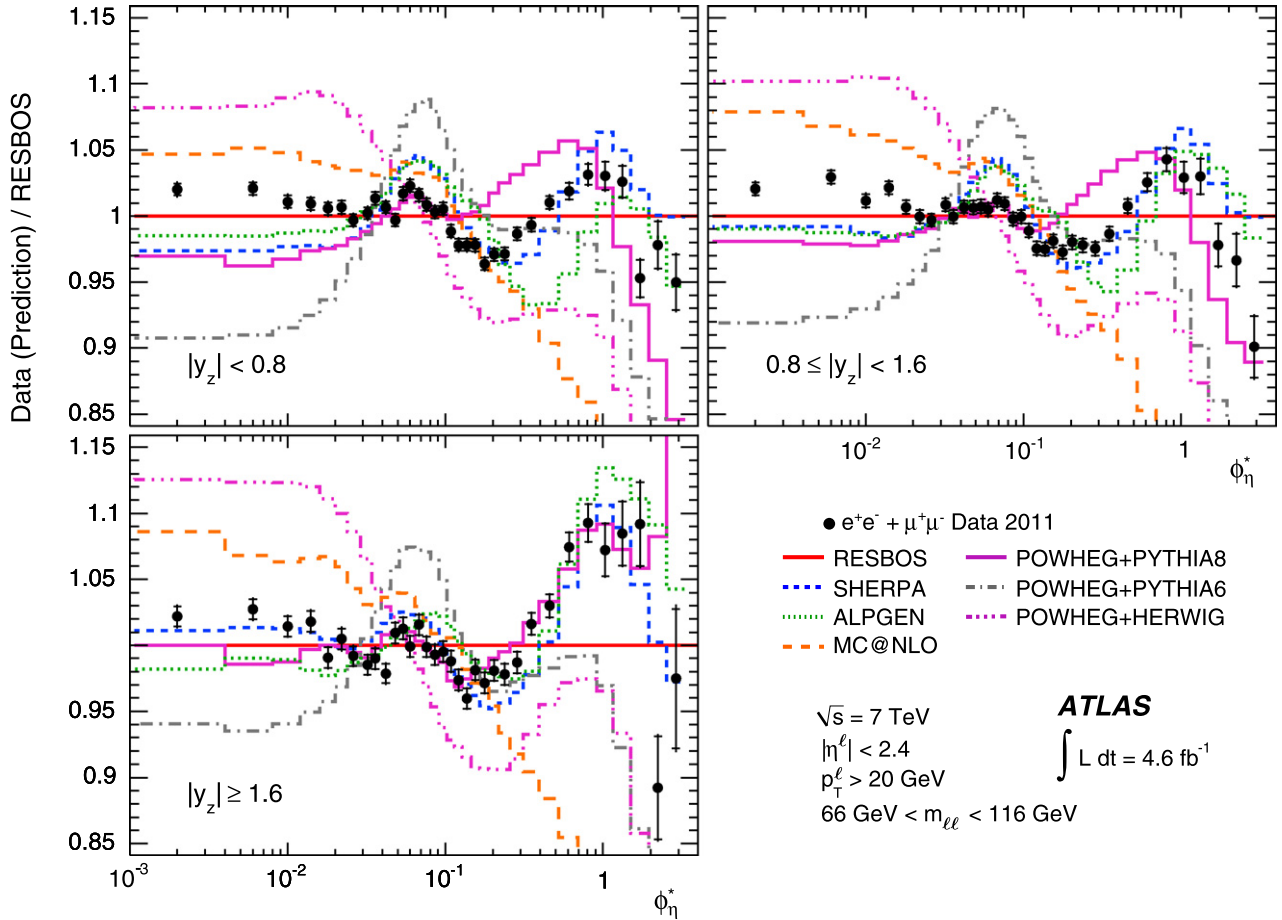
Fig. 3. The ratio of the combined normalised differential cross section $1/\sigma^{\text{fid}} \cdot d\sigma^{\text{fid}}/d\phi_\eta^*$ to the ResBos predictions as a function of ϕ_η^* in three ranges of $|y_Z|$. The inner and outer error bars on the data points represent the statistical and total uncertainties, respectively. The uncertainty due to QED FSR is included in the total uncertainties. The measurements are also compared to predictions from different MC event generators.

to predictions obtained using different MC event generators. The PDF set CT10 is employed in all calculations, except for Alpgen where the CTEQ6L1 PDF set is used. The parton-shower parameters of each MC generator are set to their default values, except for Pythia6 where a specific ATLAS re-tuning was used [48]. The generators Alpgen, interfaced to Herwig, and Sherpa provide a good description of the spectrum for $\phi_\eta^* > 0.1$. In particular, Sherpa describes the data better than ResBos over all $|y_Z|$ bins for $\phi_\eta^* > 0.1$. However, for $\phi_\eta^* < 0.1$ the deviations of Sherpa or Alpgen from the data are $\sim 5\%$, somewhat larger than those of ResBos. The Powheg generator interfaced to Pythia8 is also able to describe the data to within 5% over the whole ϕ_η^* range.

The effect of changing the PS tunings and algorithms interfaced to Powheg was investigated by using Pythia6 and Herwig interfaced to the same Powheg NLO calculation. These two variations give a worse description of data than Pythia8, and deviations from data of $\sim 10\%$ are observed. The Mc@nlo generator interfaced to Herwig does not properly describe the data for $\phi_\eta^* > 0.1$, and deviations from data of the order of 4–7% are observed for $\phi_\eta^* < 0.1$ depending on the $|y_Z|$ bin. The level of agreement between MC generators and data is very similar for comparisons at the dressed level.

8. Conclusion

A measurement of the ϕ_η^* distribution of Z/γ^* boson candidates in $\sqrt{s} = 7$ TeV pp collisions at the LHC is presented. The

data were collected with the ATLAS detector and correspond to an integrated luminosity of 4.6 fb^{-1}. Normalised differential cross sections as a function of ϕ_η^* have been measured in bins of the Z boson rapidity y_Z up to $\phi_\eta^* \sim 3$ for electron and muon pairs with an invariant mass 66 GeV $< m_{\ell\ell} < 116$ GeV. The high number of Z/γ^* boson candidates recorded permits the use of finer bins as compared to a similar study performed at the Tevatron. The typical uncertainty achieved by the combination of electron and muon data integrated over the whole Z rapidity range is below 0.5% for $\phi_\eta^* < 0.5$ increasing to 0.8% at larger ϕ_η^* values.

The cross-section measurements have been compared to resummed QCD predictions combined with fixed-order perturbative QCD calculations. Calculations using ResBos provide the best descriptions of the data. However, they are unable to reproduce the detailed shape of the measured cross section to better than 4%.

The cross-section measurements have also been compared to predictions from different Monte Carlo generators interfaced to a parton shower algorithm. The best descriptions of the measured ϕ_η^* spectrum are provided by Sherpa and Powheg+Pythia8 Monte Carlo event generators. For ϕ_η^* values above 0.1, predictions from Sherpa are able to reproduce the data to within $\sim 2\%$. The low ϕ_η^* part of the spectrum is, however, described less accurately than by ResBos. Double differential measurements as a function of ϕ_η^* and y_Z provide valuable information for the tuning of MC generators. None of the tested predictions is able to reproduce the detailed shape of the measured cross section within the experimental

precision reached, which is typically lower by one order of magnitude than present theoretical uncertainties.

Open access

References

[1] G. Bozzi, et al., Phys. Lett. B 696 (2011) 207, arXiv:1007.2351 [hep-ph].
[2] S. Mantry, F. Petriello, Phys. Rev. D 84 (2011) 014030, arXiv:1011.0757 [hep-ph].
[3] T. Becher, M. Neubert, Eur. Phys. J. C 71 (2011) 1665, arXiv:1007.4005 [hep-ph].
[4] G. Bozzi, et al., Phys. Lett. B 564 (2003) 65, arXiv:hep-ph/0302104.
[5] G. Bozzi, et al., Nucl. Phys. B 737 (2006) 73, arXiv:hep-ph/0508068.
[6] D. de Florian, et al., JHEP 1111 (2011) 064, arXiv:1109.2109 [hep-ph].
[7] S. Berge, et al., Phys. Rev. D 72 (2005) 033015, arXiv:hep-ph/0410375.
[8] CDF Collaboration, T. Aaltonen, et al., Phys. Rev. Lett. 108 (2012) 151803, arXiv:1203.0275 [hep-ex].
[9] DØ Collaboration, V.M. Abazov, et al., Phys. Rev. Lett. 108 (2012) 151804, arXiv:1203.0293 [hep-ex].
[10] CDF Collaboration, T. Affolder, et al., Phys. Rev. Lett. 84 (2000) 845, arXiv:hep-ex/0001021.
[11] DØ Collaboration, B. Abbott, et al., Phys. Rev. Lett. 84 (2000) 2792, arXiv:hep-ex/9909020.
[12] DØ Collaboration, V.M. Abazov, et al., Phys. Rev. Lett. 100 (2008) 102002, arXiv:0712.0803 [hep-ex].
[13] DØ Collaboration, V.M. Abazov, et al., Phys. Lett. B 693 (2010) 522, arXiv:1006.0618 [hep-ex].
[14] CDF Collaboration, T. Aaltonen, et al., Phys. Rev. D 86 (2012) 052010, arXiv:1207.7138 [hep-ex].
[15] ATLAS Collaboration, Phys. Lett. B 705 (2011) 415, arXiv:1107.2381 [hep-ex].
[16] CMS Collaboration, Phys. Rev. D 85 (2012) 032002, arXiv:1110.4973 [hep-ex].
[17] ATLAS Collaboration, Phys. Rev. D 85 (2012) 012005, arXiv:1108.6308 [hep-ex].
[18] M. Boonekamp, M. Schott, JHEP 1011 (2010) 153, arXiv:1002.1850 [hep-ex].
[19] M. Vesterinen, T. Wyatt, Nucl. Instrum. Meth. A 602 (2009) 432, arXiv:0807.4956 [hep-ex].
[20] A. Banfi, et al., Eur. Phys. J. C 71 (2011) 1600, arXiv:1009.1580 [hep-ex].
[21] A. Banfi, M. Dasgupta, S. Marzani, Phys. Lett. B 701 (2011) 75, arXiv:1102.3594 [hep-ph].
[22] A. Banfi, et al., Phys. Lett. B 715 (2012) 152, arXiv:1205.4760 [hep-ph].
[23] DØ Collaboration, V.M. Abazov, et al., Phys. Rev. Lett. 106 (2011) 122001, arXiv:1010.0262 [hep-ex].
[24] K. Melnikov, F. Petriello, Phys. Rev. D 74 (2006) 114017, arXiv:hep-ph/0609070.
[25] R. Gavin, et al., Comput. Phys. Commun. 182 (2011) 2388, arXiv:1011.3540 [hep-ph].
[26] S. Catani, et al., Phys. Rev. Lett. 103 (2009) 082001, arXiv:0903.2120 [hep-ph].
[27] S. Catani, M. Grazzini, Phys. Rev. Lett. 98 (2007) 222002, arXiv:hep-ph/0703012.
[28] G. Ladinsky, C. Yuan, Phys. Rev. D 50 (1994) 4239, arXiv:hep-ph/9311341.
[29] C. Balazs, C. Yuan, Phys. Rev. D 56 (1997) 5558, arXiv:hep-ph/9704258.
[30] F. Landry, et al., Phys. Rev. D 67 (2003) 073016, arXiv:hep-ph/0212159.
[31] P.B. Arnold, M.H. Reno, Nucl. Phys. B 319 (1989) 37;
P.B. Arnold, M.H. Reno, Nucl. Phys. B 330 (1990) 284 (Erratum).
[32] F. Landry, et al., Phys. Rev. D 63 (2001) 013004, arXiv:hep-ph/9905391.
[33] J.M. Campbell, R.K. Ellis, Phys. Rev. D 65 (2002) 113007, arXiv:hep-ph/0202176.
[34] A. Banfi, et al., JHEP 1201 (2012) 044, arXiv:1110.4009 [hep-ph].
[35] T. Sjöstrand, S. Mrenna, P.Z. Skands, JHEP 0605 (2006) 026, arXiv:hep-ph/0603175.
[36] G. Corcella, et al., JHEP 0101 (2001) 010, arXiv:hep-ph/0011363.
[37] P. Nason, JHEP 0411 (2004) 040, arXiv:hep-ph/0409146.
[38] S. Frixione, P. Nason, C. Oleari, JHEP 0711 (2007) 070, arXiv:0709.2092 [hep-ph].
[39] S. Alioli, et al., JHEP 1006 (2010) 043, arXiv:1002.2581 [hep-ph].
[40] S. Alioli, et al., JHEP 0807 (2008) 060, arXiv:0805.4802 [hep-ph].
[41] S. Frixione, B.R. Webber, JHEP 0206 (2002) 029, arXiv:hep-ph/0204244.
[42] M.L. Mangano, et al., JHEP 0307 (2003) 001, arXiv:hep-ph/0206293.
[43] T. Gleisberg, et al., JHEP 0902 (2009) 007, arXiv:0811.4622 [hep-ph].
[44] S. Hoeche, et al., JHEP 0905 (2009) 053, arXiv:0903.1219 [hep-ph].
[45] F. Krauss, JHEP 0208 (2002) 015, arXiv:hep-ph/0205283.
[46] ATLAS Collaboration, JINST 3 (2008) S08003.
[47] H.-L. Lai, et al., Phys. Rev. D 82 (2010) 074024, arXiv:1007.2241 [hep-ph].
[48] ATLAS Collaboration, ATL-PHYS-PUB-2011-009, http://cdsweb.cern.ch/record/1363300.
[49] P. Golonka, Z. Wąs, Eur. Phys. J. C 45 (2006) 97, arXiv:hep-ph/0506026.
[50] D. Yennie, S. Frautschi, H. Suura, Ann. Phys. (NY) 13 (1961) 379.
[51] M. Schonherr, F. Krauss, JHEP 0812 (2008) 018, arXiv:0810.5071 [hep-ph].
[52] GEANT4 Collaboration, S. Agostinelli, et al., Nucl. Instrum. Meth. A 506 (2003) 250.
[53] ATLAS Collaboration, Eur. Phys. J. C 70 (2010) 823, arXiv:1005.4568 [physics.ins-det].
[54] ATLAS Collaboration, JHEP 1012 (2010) 060, arXiv:1010.2130 [hep-ex].
[55] R. Frühwirth, Comput. Phys. Commun. 100 (1997) 1.
[56] ATLAS Collaboration, ATLAS-CONF-2012-047, http://cdsweb.cern.ch/record/1449796.
[57] ATLAS Collaboration, Eur. Phys. J. C 72 (2012) 1909, arXiv:1110.3174 [hep-ex].
[58] ATLAS Collaboration, Phys. Rev. D 85 (2012) 072004, arXiv:1109.5141 [hep-ex].
[59] J.M. Campbell, R.K. Ellis, C. Williams, JHEP 1107 (2011) 018, arXiv:1105.0020 [hep-ph].
[60] Y. Li, F. Petriello, arXiv:1208.5967 [hep-ph].
[61] A.D. Martin, et al., Eur. Phys. J. C 39 (2005) 155, arXiv:hep-ph/0411040.
[62] G. D'Agostini, Nucl. Instrum. Meth. A 362 (1995) 487.
[63] A. Glazov, AIP Conf. Proc. 792 (2005) 237.
[64] H1 Collaboration, F.D. Aaron, et al., Eur. Phys. J. C 63 (2009) 625, arXiv:0904.0929 [hep-ex].
[65] H1 Collaboration, ZEUS Collaboration, F.D. Aaron, et al., JHEP 1001 (2010) 109, arXiv:0911.0884 [hep-ex].
[66] J. Pumplin, et al., JHEP 0207 (2002) 012, arXiv:hep-ph/0201195.
[67] A.D. Martin, et al., Eur. Phys. J. C 64 (2009) 653, arXiv:0905.3531 [hep-ph].

ATLAS Collaboration

G. Aad [48], T. Abajyan [21], B. Abbott [111], J. Abdallah [12], S. Abdel Khalek [115], A.A. Abdelalim [49], O. Abdinov [11], R. Aben [105], B. Abi [112], M. Abolins [88], O.S. AbouZeid [158], H. Abramowicz [153], H. Abreu [136], B.S. Acharya [164a,164b,a], L. Adamczyk [38], D.L. Adams [25], T.N. Addy [56], J. Adelman [176], S. Adomeit [98],

P. Adragna [75], T. Adye [129], S. Aefsky [23], J.A. Aguilar-Saavedra [124b,b], M. Agustoni [17], S.P. Ahlen [22], F. Ahles [48], A. Ahmad [148], M. Ahsan [41], G. Aielli [133a,133b], T.P.A. Åkesson [79], G. Akimoto [155], A.V. Akimov [94], M.A. Alam [76], J. Albert [169], S. Albrand [55], M. Aleksa [30], I.N. Aleksandrov [64], F. Alessandria [89a], C. Alexa [26a], G. Alexander [153], G. Alexandre [49], T. Alexopoulos [10], M. Alhroob [164a,164c], M. Aliev [16], G. Alimonti [89a], J. Alison [120], B.M.M. Allbrooke [18], L.J. Allison [71], P.P. Allport [73], S.E. Allwood-Spiers [53], J. Almond [82], A. Aloisio [102a,102b], R. Alon [172], A. Alonso [79], F. Alonso [70], A. Altheimer [35], B. Alvarez Gonzalez [88], M.G. Alviggi [102a,102b], K. Amako [65], C. Amelung [23], V.V. Ammosov [128,∗], S.P. Amor Dos Santos [124a], A. Amorim [124a,c], S. Amoroso [48], N. Amram [153], C. Anastopoulos [30], L.S. Ancu [17], N. Andari [115], T. Andeen [35], C.F. Anders [58b], G. Anders [58a], K.J. Anderson [31], A. Andreazza [89a,89b], V. Andrei [58a], M-L. Andrieux [55], X.S. Anduaga [70], S. Angelidakis [9], P. Anger [44], A. Angerami [35], F. Anghinolfi [30], A. Anisenkov [107], N. Anjos [124a], A. Annovi [47], A. Antonaki [9], M. Antonelli [47], A. Antonov [96], J. Antos [144b], F. Anulli [132a], M. Aoki [101], S. Aoun [83], L. Aperio Bella [5], R. Apolle [118,d], G. Arabidze [88], I. Aracena [143], Y. Arai [65], A.T.H. Arce [45], S. Arfaoui [148], J-F. Arguin [93], S. Argyropoulos [42], E. Arik [19a,∗], M. Arik [19a], A.J. Armbruster [87], O. Arnaez [81], V. Arnal [80], A. Artamonov [95], G. Artoni [132a,132b], D. Arutinov [21], S. Asai [155], S. Ask [28], B. Åsman [146a,146b], L. Asquith [6], K. Assamagan [25,e], A. Astbury [169], M. Atkinson [165], B. Aubert [5], E. Auge [115], K. Augsten [126], M. Aurousseau [145a], G. Avolio [30], D. Axen [168], G. Azuelos [93,f], Y. Azuma [155], M.A. Baak [30], G. Baccaglioni [89a], C. Bacci [134a,134b], A.M. Bach [15], H. Bachacou [136], K. Bachas [154], M. Backes [49], M. Backhaus [21], J. Backus Mayes [143], E. Badescu [26a], P. Bagnaia [132a,132b], Y. Bai [33a], D.C. Bailey [158], T. Bain [35], J.T. Baines [129], O.K. Baker [176], S. Baker [77], P. Balek [127], E. Banas [39], P. Banerjee [93], Sw. Banerjee [173], D. Banfi [30], A. Bangert [150], V. Bansal [169], H.S. Bansil [18], L. Barak [172], S.P. Baranov [94], T. Barber [48], E.L. Barberio [86], D. Barberis [50a,50b], M. Barbero [21], D.Y. Bardin [64], T. Barillari [99], M. Barisonzi [175], T. Barklow [143], N. Barlow [28], B.M. Barnett [129], R.M. Barnett [15], A. Baroncelli [134a], G. Barone [49], A.J. Barr [118], F. Barreiro [80], J. Barreiro Guimarães da Costa [57], R. Bartoldus [143], A.E. Barton [71], V. Bartsch [149], A. Basye [165], R.L. Bates [53], L. Batkova [144a], J.R. Batley [28], A. Battaglia [17], M. Battistin [30], F. Bauer [136], H.S. Bawa [143,g], S. Beale [98], T. Beau [78], P.H. Beauchemin [161], R. Beccherle [50a], P. Bechtle [21], H.P. Beck [17], K. Becker [175], S. Becker [98], M. Beckingham [138], K.H. Becks [175], A.J. Beddall [19c], A. Beddall [19c], S. Bedikian [176], V.A. Bednyakov [64], C.P. Bee [83], L.J. Beemster [105], M. Begel [25], S. Behar Harpaz [152], P.K. Behera [62], M. Beimforde [99], C. Belanger-Champagne [85], P.J. Bell [49], W.H. Bell [49], G. Bella [153], L. Bellagamba [20a], M. Bellomo [30], A. Belloni [57], O. Beloborodova [107,h], K. Belotskiy [96], O. Beltramello [30], O. Benary [153], D. Benchekroun [135a], K. Bendtz [146a,146b], N. Benekos [165], Y. Benhammou [153], E. Benhar Noccioli [49], J.A. Benitez Garcia [159b], D.P. Benjamin [45], M. Benoit [115], J.R. Bensinger [23], K. Benslama [130], S. Bentvelsen [105], D. Berge [30], E. Bergeaas Kuutmann [42], N. Berger [5], F. Berghaus [169], E. Berglund [105], J. Beringer [15], P. Bernat [77], R. Bernhard [48], C. Bernius [25], T. Berry [76], C. Bertella [83], A. Bertin [20a,20b], F. Bertolucci [122a,122b], M.I. Besana [89a,89b], G.J. Besjes [104], N. Besson [136], S. Bethke [99], W. Bhimji [46], R.M. Bianchi [30], L. Bianchini [23], M. Bianco [72a,72b], O. Biebel [98], S.P. Bieniek [77], K. Bierwagen [54], J. Biesiada [15], M. Biglietti [134a], H. Bilokon [47], M. Bindi [20a,20b], S. Binet [115], A. Bingul [19c], C. Bini [132a,132b], C. Biscarat [178], B. Bittner [99], C.W. Black [150], K.M. Black [22], R.E. Blair [6], J.-B. Blanchard [136], T. Blazek [144a], I. Bloch [42], C. Blocker [23], J. Blocki [39], W. Blum [81], U. Blumenschein [54], G.J. Bobbink [105], V.S. Bobrovnikov [107], S.S. Bocchetta [79], A. Bocci [45], C.R. Boddy [118], M. Boehler [48], J. Boek [175], T.T. Boek [175], N. Boelaert [36], J.A. Bogaerts [30], A. Bogdanchikov [107], A. Bogouch [90,∗], C. Bohm [146a], J. Bohm [125], V. Boisvert [76], T. Bold [38], V. Boldea [26a], N.M. Bolnet [136], M. Bomben [78], M. Bona [75], M. Boonekamp [136], S. Bordoni [78], C. Borer [17], A. Borisov [128], G. Borissov [71], I. Borjanovic [13a], M. Borri [82], S. Borroni [42], J. Bortfeldt [98], V. Bortolotto [134a,134b], K. Bos [105], D. Boscherini [20a], M. Bosman [12], H. Boterenbrood [105], J. Bouchami [93], J. Boudreau [123], E.V. Bouhova-Thacker [71], D. Boumediene [34], C. Bourdarios [115], N. Bousson [83], A. Boveia [31], J. Boyd [30], I.R. Boyko [64], I. Bozovic-Jelisavcic [13b], J. Bracinik [18], P. Branchini [134a], A. Brandt [8], G. Brandt [118], O. Brandt [54], U. Bratzler [156], B. Brau [84], J.E. Brau [114], H.M. Braun [175,∗], S.F. Brazzale [164a,164c], B. Brelier [158], J. Bremer [30], K. Brendlinger [120], R. Brenner [166], S. Bressler [172], T.M. Bristow [145b], D. Britton [53], F.M. Brochu [28], I. Brock [21], R. Brock [88], F. Broggi [89a], C. Bromberg [88], J. Bronner [99], G. Brooijmans [35], T. Brooks [76], W.K. Brooks [32b], G. Brown [82], P.A. Bruckman de Renstrom [39], D. Bruncko [144b], R. Bruneliere [48], S. Brunet [60], A. Bruni [20a], G. Bruni [20a], M. Bruschi [20a], L. Bryngemark [79], T. Buanes [14], Q. Buat [55], F. Bucci [49], J. Buchanan [118], P. Buchholz [141], R.M. Buckingham [118], A.G. Buckley [46], S.I. Buda [26a], I.A. Budagov [64], B. Budick [108], V. Büscher [81], L. Bugge [117], O. Bulekov [96], A.C. Bundock [73],

M. Bunse [43], T. Buran [117], H. Burckhart [30], S. Burdin [73], T. Burgess [14], S. Burke [129], E. Busato [34], P. Bussey [53], C.P. Buszello [166], B. Butler [143], J.M. Butler [22], C.M. Buttar [53], J.M. Butterworth [77], W. Buttinger [28], M. Byszewski [30], S. Cabrera Urbán [167], D. Caforio [20a,20b], O. Cakir [4a], P. Calafiura [15], G. Calderini [78], P. Calfayan [98], R. Calkins [106], L.P. Caloba [24a], R. Caloi [132a,132b], D. Calvet [34], S. Calvet [34], R. Camacho Toro [34], P. Camarri [133a,133b], D. Cameron [117], L.M. Caminada [15], R. Caminal Armadans [12], S. Campana [30], M. Campanelli [77], V. Canale [102a,102b], F. Canelli [31], A. Canepa [159a], J. Cantero [80], R. Cantrill [76], M.D.M. Capeans Garrido [30], I. Caprini [26a], M. Caprini [26a], D. Capriotti [99], M. Capua [37a,37b], R. Caputo [81], R. Cardarelli [133a], T. Carli [30], G. Carlino [102a], L. Carminati [89a,89b], S. Caron [104], E. Carquin [32b], G.D. Carrillo-Montoya [145b], A.A. Carter [75], J.R. Carter [28], J. Carvalho [124a,i], D. Casadei [108], M.P. Casado [12], M. Cascella [122a,122b], C. Caso [50a,50b,*], A.M. Castaneda Hernandez [173,j], E. Castaneda-Miranda [173], V. Castillo Gimenez [167], N.F. Castro [124a], G. Cataldi [72a], P. Catastini [57], A. Catinaccio [30], J.R. Catmore [30], A. Cattai [30], G. Cattani [133a,133b], S. Caughron [88], V. Cavaliere [165], P. Cavalleri [78], D. Cavalli [89a], M. Cavalli-Sforza [12], V. Cavasinni [122a,122b], F. Ceradini [134a,134b], A.S. Cerqueira [24b], A. Cerri [15], L. Cerrito [75], F. Cerutti [15], S.A. Cetin [19b], A. Chafaq [135a], D. Chakraborty [106], I. Chalupkova [127], K. Chan [3], P. Chang [165], B. Chapleau [85], J.D. Chapman [28], J.W. Chapman [87], D.G. Charlton [18], V. Chavda [82], C.A. Chavez Barajas [30], S. Cheatham [85], S. Chekanov [6], S.V. Chekulaev [159a], G.A. Chelkov [64], M.A. Chelstowska [104], C. Chen [63], H. Chen [25], S. Chen [33c], X. Chen [173], Y. Chen [35], Y. Cheng [31], A. Cheplakov [64], R. Cherkaoui El Moursli [135e], V. Chernyatin [25], E. Cheu [7], S.L. Cheung [158], L. Chevalier [136], G. Chiefari [102a,102b], L. Chikovani [51a,*], J.T. Childers [30], A. Chilingarov [71], G. Chiodini [72a], A.S. Chisholm [18], R.T. Chislett [77], A. Chitan [26a], M.V. Chizhov [64], G. Choudalakis [31], S. Chouridou [137], I.A. Christidi [77], A. Christov [48], D. Chromek-Burckhart [30], M.L. Chu [151], J. Chudoba [125], G. Ciapetti [132a,132b], A.K. Ciftci [4a], R. Ciftci [4a], D. Cinca [34], V. Cindro [74], A. Ciocio [15], M. Cirilli [87], P. Cirkovic [13b], Z.H. Citron [172], M. Citterio [89a], M. Ciubancan [26a], A. Clark [49], P.J. Clark [46], R.N. Clarke [15], W. Cleland [123], J.C. Clemens [83], B. Clement [55], C. Clement [146a,146b], Y. Coadou [83], M. Cobal [164a,164c], A. Coccaro [138], J. Cochran [63], L. Coffey [23], J.G. Cogan [143], J. Coggeshall [165], J. Colas [5], S. Cole [106], A.P. Colijn [105], N.J. Collins [18], C. Collins-Tooth [53], J. Collot [55], T. Colombo [119a,119b], G. Colon [84], G. Compostella [99], P. Conde Muiño [124a], E. Coniavitis [166], M.C. Conidi [12], S.M. Consonni [89a,89b], V. Consorti [48], S. Constantinescu [26a], C. Conta [119a,119b], G. Conti [57], F. Conventi [102a,k], M. Cooke [15], B.D. Cooper [77], A.M. Cooper-Sarkar [118], K. Copic [15], T. Cornelissen [175], M. Corradi [20a], F. Corriveau [85,l], A. Cortes-Gonzalez [165], G. Cortiana [99], G. Costa [89a], M.J. Costa [167], D. Costanzo [139], D. Côté [30], L. Courneyea [169], G. Cowan [76], B.E. Cox [82], K. Cranmer [108], F. Crescioli [78], M. Cristinziani [21], G. Crosetti [37a,37b], S. Crépé-Renaudin [55], C.-M. Cuciuc [26a], C. Cuenca Almenar [176], T. Cuhadar Donszelmann [139], J. Cummings [176], M. Curatolo [47], C.J. Curtis [18], C. Cuthbert [150], P. Cwetanski [60], H. Czirr [141], P. Czodrowski [44], Z. Czyczula [176], S. D'Auria [53], M. D'Onofrio [73], A. D'Orazio [132a,132b], M.J. Da Cunha Sargedas De Sousa [124a], C. Da Via [82], W. Dabrowski [38], A. Dafinca [118], T. Dai [87], F. Dallaire [93], C. Dallapiccola [84], M. Dam [36], M. Dameri [50a,50b], D.S. Damiani [137], H.O. Danielsson [30], V. Dao [104], G. Darbo [50a], G.L. Darlea [26b], J.A. Dassoulas [42], W. Davey [21], T. Davidek [127], N. Davidson [86], R. Davidson [71], E. Davies [118,d], M. Davies [93], O. Davignon [78], A.R. Davison [77], Y. Davygora [58a], E. Dawe [142], I. Dawson [139], R.K. Daya-Ishmukhametova [23], K. De [8], R. de Asmundis [102a], S. De Castro [20a,20b], S. De Cecco [78], J. de Graat [98], N. De Groot [104], P. de Jong [105], C. De La Taille [115], H. De la Torre [80], F. De Lorenzi [63], L. De Nooij [105], D. De Pedis [132a], A. De Salvo [132a], U. De Sanctis [164a,164c], A. De Santo [149], J.B. De Vivie De Regie [115], G. De Zorzi [132a,132b], W.J. Dearnaley [71], R. Debbe [25], C. Debenedetti [46], B. Dechenaux [55], D.V. Dedovich [64], J. Degenhardt [120], J. Del Peso [80], T. Del Prete [122a,122b], T. Delemontex [55], M. Deliyergiyev [74], A. Dell'Acqua [30], L. Dell'Asta [22], M. Della Pietra [102a,k], D. della Volpe [102a,102b], M. Delmastro [5], P.A. Delsart [55], C. Deluca [105], S. Demers [176], M. Demichev [64], B. Demirkoz [12,m], S.P. Denisov [128], D. Derendarz [39], J.E. Derkaoui [135d], F. Derue [78], P. Dervan [73], K. Desch [21], E. Devetak [148], P.O. Deviveiros [105], A. Dewhurst [129], B. DeWilde [148], S. Dhaliwal [158], R. Dhullipudi [25,n], A. Di Ciaccio [133a,133b], L. Di Ciaccio [5], C. Di Donato [102a,102b], A. Di Girolamo [30], B. Di Girolamo [30], S. Di Luise [134a,134b], A. Di Mattia [152], B. Di Micco [30], R. Di Nardo [47], A. Di Simone [133a,133b], R. Di Sipio [20a,20b], M.A. Diaz [32a], E.B. Diehl [87], J. Dietrich [42], T.A. Dietzsch [58a], S. Diglio [86], K. Dindar Yagci [40], J. Dingfelder [21], F. Dinut [26a], C. Dionisi [132a,132b], P. Dita [26a], S. Dita [26a], F. Dittus [30], F. Djama [83], T. Djobava [51b], M.A.B. do Vale [24c], A. Do Valle Wemans [124a,o], T.K.O. Doan [5], M. Dobbs [85], D. Dobos [30], E. Dobson [30,p], J. Dodd [35], C. Doglioni [49], T. Doherty [53], Y. Doi [65,*], J. Dolejsi [127],

Z. Dolezal [127], B.A. Dolgoshein [96,∗], T. Dohmae [155], M. Donadelli [24d], J. Donini [34], J. Dopke [30], A. Doria [102a], A. Dos Anjos [173], A. Dotti [122a,122b], M.T. Dova [70], A.D. Doxiadis [105], A.T. Doyle [53], N. Dressnandt [120], M. Dris [10], J. Dubbert [99], S. Dube [15], E. Dubreuil [34], E. Duchovni [172], G. Duckeck [98], D. Duda [175], A. Dudarev [30], F. Dudziak [63], M. Dührssen [30], I.P. Duerdoth [82], L. Duflot [115], M-A. Dufour [85], L. Duguid [76], M. Dunford [58a], H. Duran Yildiz [4a], R. Duxfield [139], M. Dwuznik [38], M. Düren [52], W.L. Ebenstein [45], J. Ebke [98], S. Eckweiler [81], W. Edson [2], C.A. Edwards [76], N.C. Edwards [53], W. Ehrenfeld [21], T. Eifert [143], G. Eigen [14], K. Einsweiler [15], E. Eisenhandler [75], T. Ekelof [166], M. El Kacimi [135c], M. Ellert [166], S. Elles [5], F. Ellinghaus [81], K. Ellis [75], N. Ellis [30], J. Elmsheuser [98], M. Elsing [30], D. Emeliyanov [129], R. Engelmann [148], A. Engl [98], B. Epp [61], J. Erdmann [176], A. Ereditato [17], D. Eriksson [146a], J. Ernst [2], M. Ernst [25], J. Ernwein [136], D. Errede [165], S. Errede [165], E. Ertel [81], M. Escalier [115], H. Esch [43], C. Escobar [123], X. Espinal Curull [12], B. Esposito [47], F. Etienne [83], A.I. Etienvre [136], E. Etzion [153], D. Evangelakou [54], H. Evans [60], L. Fabbri [20a,20b], C. Fabre [30], R.M. Fakhrutdinov [128], S. Falciano [132a], Y. Fang [33a], M. Fanti [89a,89b], A. Farbin [8], A. Farilla [134a], J. Farley [148], T. Farooque [158], S. Farrell [163], S.M. Farrington [170], P. Farthouat [30], F. Fassi [167], P. Fassnacht [30], D. Fassouliotis [9], B. Fatholahzadeh [158], A. Favareto [89a,89b], L. Fayard [115], P. Federic [144a], O.L. Fedin [121], W. Fedorko [168], M. Fehling-Kaschek [48], L. Feligioni [83], C. Feng [33d], E.J. Feng [6], A.B. Fenyuk [128], J. Ferencei [144b], W. Fernando [6], S. Ferrag [53], J. Ferrando [53], V. Ferrara [42], A. Ferrari [166], P. Ferrari [105], R. Ferrari [119a], D.E. Ferreira de Lima [53], A. Ferrer [167], D. Ferrere [49], C. Ferretti [87], A. Ferretto Parodi [50a,50b], M. Fiascaris [31], F. Fiedler [81], A. Filipčič [74], F. Filthaut [104], M. Fincke-Keeler [169], M.C.N. Fiolhais [124a,i], L. Fiorini [167], A. Firan [40], G. Fischer [42], M.J. Fisher [109], E.A. Fitzgerald [23], M. Flechl [48], I. Fleck [141], J. Fleckner [81], P. Fleischmann [174], S. Fleischmann [175], G. Fletcher [75], T. Flick [175], A. Floderus [79], L.R. Flores Castillo [173], A.C. Florez Bustos [159b], M.J. Flowerdew [99], T. Fonseca Martin [17], A. Formica [136], A. Forti [82], D. Fortin [159a], D. Fournier [115], A.J. Fowler [45], H. Fox [71], P. Francavilla [12], M. Franchini [20a,20b], S. Franchino [119a,119b], D. Francis [30], T. Frank [172], M. Franklin [57], S. Franz [30], M. Fraternali [119a,119b], S. Fratina [120], S.T. French [28], C. Friedrich [42], F. Friedrich [44], D. Froidevaux [30], J.A. Frost [28], C. Fukunaga [156], E. Fullana Torregrosa [127], B.G. Fulsom [143], J. Fuster [167], C. Gabaldon [30], O. Gabizon [172], S. Gadatsch [105], T. Gadfort [25], S. Gadomski [49], G. Gagliardi [50a,50b], P. Gagnon [60], C. Galea [98], B. Galhardo [124a], E.J. Gallas [118], V. Gallo [17], B.J. Gallop [129], P. Gallus [126], K.K. Gan [109], Y.S. Gao [143,g], A. Gaponenko [15], F. Garberson [176], M. Garcia-Sciveres [15], C. García [167], J.E. García Navarro [167], R.W. Gardner [31], N. Garelli [143], V. Garonne [30], C. Gatti [47], G. Gaudio [119a], B. Gaur [141], L. Gauthier [136], P. Gauzzi [132a,132b], I.L. Gavrilenko [94], C. Gay [168], G. Gaycken [21], E.N. Gazis [10], P. Ge [33d], Z. Gecse [168], C.N.P. Gee [129], D.A.A. Geerts [105], Ch. Geich-Gimbel [21], K. Gellerstedt [146a,146b], C. Gemme [50a], A. Gemmell [53], M.H. Genest [55], S. Gentile [132a,132b], M. George [54], S. George [76], D. Gerbaudo [12], P. Gerlach [175], A. Gershon [153], C. Geweniger [58a], H. Ghazlane [135b], N. Ghodbane [34], B. Giacobbe [20a], S. Giagu [132a,132b], V. Giangiobbe [12], F. Gianotti [30], B. Gibbard [25], A. Gibson [158], S.M. Gibson [30], M. Gilchriese [15], T.P.S. Gillam [28], D. Gillberg [30], A.R. Gillman [129], D.M. Gingrich [3,f], J. Ginzburg [153], N. Giokaris [9], M.P. Giordani [164c], R. Giordano [102a,102b], F.M. Giorgi [16], P. Giovannini [99], P.F. Giraud [136], D. Giugni [89a], M. Giunta [93], B.K. Gjelsten [117], L.K. Gladilin [97], C. Glasman [80], J. Glatzer [21], A. Glazov [42], G.L. Glonti [64], J.R. Goddard [75], J. Godfrey [142], J. Godlewski [30], M. Goebel [42], T. Göpfert [44], C. Goeringer [81], C. Gössling [43], S. Goldfarb [87], T. Golling [176], D. Golubkov [128], A. Gomes [124a,c], L.S. Gomez Fajardo [42], R. Gonçalo [76], J. Goncalves Pinto Firmino Da Costa [42], L. Gonella [21], S. González de la Hoz [167], G. Gonzalez Parra [12], M.L. Gonzalez Silva [27], S. Gonzalez-Sevilla [49], J.J. Goodson [148], L. Goossens [30], P.A. Gorbounov [95], H.A. Gordon [25], I. Gorelov [103], G. Gorfine [175], B. Gorini [30], E. Gorini [72a,72b], A. Gorišek [74], E. Gornicki [39], A.T. Goshaw [6], M. Gosselink [105], M.I. Gostkin [64], I. Gough Eschrich [163], M. Gouighri [135a], D. Goujdami [135c], M.P. Goulette [49], A.G. Goussiou [138], C. Goy [5], S. Gozpinar [23], I. Grabowska-Bold [38], P. Grafström [20a,20b], K-J. Grahn [42], E. Gramstad [117], F. Grancagnolo [72a], S. Grancagnolo [16], V. Grassi [148], V. Gratchev [121], H.M. Gray [30], J.A. Gray [148], E. Graziani [134a], O.G. Grebenyuk [121], T. Greenshaw [73], Z.D. Greenwood [25,n], K. Gregersen [36], I.M. Gregor [42], P. Grenier [143], J. Griffiths [8], N. Grigalashvili [64], A.A. Grillo [137], K. Grimm [71], S. Grinstein [12], Ph. Gris [34], Y.V. Grishkevich [97], J.-F. Grivaz [115], A. Grohsjean [42], E. Gross [172], J. Grosse-Knetter [54], J. Groth-Jensen [172], K. Grybel [141], D. Guest [176], C. Guicheney [34], E. Guido [50a,50b], T. Guillemin [115], S. Guindon [54], U. Gul [53], J. Gunther [125], B. Guo [158], J. Guo [35], P. Gutierrez [111], N. Guttman [153], O. Gutzwiller [173], C. Guyot [136], C. Gwenlan [118], C.B. Gwilliam [73], A. Haas [108], S. Haas [30], C. Haber [15], H.K. Hadavand [8], D.R. Hadley [18], P. Haefner [21], F. Hahn [30], Z. Hajduk [39], H. Hakobyan [177], D. Hall [118], G. Halladjian [62], K. Hamacher [175],

P. Hamal [113], K. Hamano [86], M. Hamer [54], A. Hamilton [145b,q], S. Hamilton [161], L. Han [33b], K. Hanagaki [116], K. Hanawa [160], M. Hance [15], C. Handel [81], P. Hanke [58a], J.R. Hansen [36], J.B. Hansen [36], J.D. Hansen [36], P.H. Hansen [36], P. Hansson [143], K. Hara [160], T. Harenberg [175], S. Harkusha [90], D. Harper [87], R.D. Harrington [46], O.M. Harris [138], J. Hartert [48], F. Hartjes [105], T. Haruyama [65], A. Harvey [56], S. Hasegawa [101], Y. Hasegawa [140], S. Hassani [136], S. Haug [17], M. Hauschild [30], R. Hauser [88], M. Havranek [21], C.M. Hawkes [18], R.J. Hawkings [30], A.D. Hawkins [79], T. Hayakawa [66], T. Hayashi [160], D. Hayden [76], C.P. Hays [118], H.S. Hayward [73], S.J. Haywood [129], S.J. Head [18], V. Hedberg [79], L. Heelan [8], S. Heim [120], B. Heinemann [15], S. Heisterkamp [36], L. Helary [22], C. Heller [98], M. Heller [30], S. Hellman [146a,146b], D. Hellmich [21], C. Helsens [12], R.C.W. Henderson [71], M. Henke [58a], A. Henrichs [176], A.M. Henriques Correia [30], S. Henrot-Versille [115], C. Hensel [54], C.M. Hernandez [8], Y. Hernández Jiménez [167], R. Herrberg [16], G. Herten [48], R. Hertenberger [98], L. Hervas [30], G.G. Hesketh [77], N.P. Hessey [105], R. Hickling [75], E. Higón-Rodriguez [167], J.C. Hill [28], K.H. Hiller [42], S. Hillert [21], S.J. Hillier [18], I. Hinchliffe [15], E. Hines [120], M. Hirose [116], F. Hirsch [43], D. Hirschbuehl [175], J. Hobbs [148], N. Hod [153], M.C. Hodgkinson [139], P. Hodgson [139], A. Hoecker [30], M.R. Hoeferkamp [103], J. Hoffman [40], D. Hoffmann [83], M. Hohlfeld [81], M. Holder [141], S.O. Holmgren [146a], T. Holy [126], J.L. Holzbauer [88], T.M. Hong [120], L. Hooft van Huysduynen [108], S. Horner [48], J-Y. Hostachy [55], S. Hou [151], A. Hoummada [135a], J. Howard [118], J. Howarth [82], I. Hristova [16], J. Hrivnac [115], T. Hryn'ova [5], P.J. Hsu [81], S.-C. Hsu [138], D. Hu [35], Z. Hubacek [30], F. Hubaut [83], F. Huegging [21], A. Huettmann [42], T.B. Huffman [118], E.W. Hughes [35], G. Hughes [71], M. Huhtinen [30], M. Hurwitz [15], N. Huseynov [64,r], J. Huston [88], J. Huth [57], G. Iacobucci [49], G. Iakovidis [10], M. Ibbotson [82], I. Ibragimov [141], L. Iconomidou-Fayard [115], J. Idarraga [115], P. Iengo [102a], O. Igonkina [105], Y. Ikegami [65], M. Ikeno [65], D. Iliadis [154], N. Ilic [158], T. Ince [99], P. Ioannou [9], M. Iodice [134a], K. Iordanidou [9], V. Ippolito [132a,132b], A. Irles Quiles [167], C. Isaksson [166], M. Ishino [67], M. Ishitsuka [157], R. Ishmukhametov [109], C. Issever [118], S. Istin [19a], A.V. Ivashin [128], W. Iwanski [39], H. Iwasaki [65], J.M. Izen [41], V. Izzo [102a], B. Jackson [120], J.N. Jackson [73], P. Jackson [1], M.R. Jaekel [30], V. Jain [2], K. Jakobs [48], S. Jakobsen [36], T. Jakoubek [125], J. Jakubek [126], D.O. Jamin [151], D.K. Jana [111], E. Jansen [77], H. Jansen [30], J. Janssen [21], A. Jantsch [99], M. Janus [48], R.C. Jared [173], G. Jarlskog [79], L. Jeanty [57], I. Jen-La Plante [31], G.-Y. Jeng [150], D. Jennens [86], P. Jenni [30], A.E. Loevschall-Jensen [36], P. Jež [36], S. Jézéquel [5], M.K. Jha [20a], H. Ji [173], W. Ji [81], J. Jia [148], Y. Jiang [33b], M. Jimenez Belenguer [42], S. Jin [33a], O. Jinnouchi [157], M.D. Joergensen [36], D. Joffe [40], M. Johansen [146a,146b], K.E. Johansson [146a], P. Johansson [139], S. Johnert [42], K.A. Johns [7], K. Jon-And [146a,146b], G. Jones [170], R.W.L. Jones [71], T.J. Jones [73], C. Joram [30], P.M. Jorge [124a], K.D. Joshi [82], J. Jovicevic [147], T. Jovin [13b], X. Ju [173], C.A. Jung [43], R.M. Jungst [30], V. Juranek [125], P. Jussel [61], A. Juste Rozas [12], S. Kabana [17], M. Kaci [167], A. Kaczmarska [39], P. Kadlecik [36], M. Kado [115], H. Kagan [109], M. Kagan [57], E. Kajomovitz [152], S. Kalinin [175], L.V. Kalinovskaya [64], S. Kama [40], N. Kanaya [155], M. Kaneda [30], S. Kaneti [28], T. Kanno [157], V.A. Kantserov [96], J. Kanzaki [65], B. Kaplan [108], A. Kapliy [31], D. Kar [53], M. Karagounis [21], K. Karakostas [10], M. Karnevskiy [58b], V. Kartvelishvili [71], A.N. Karyukhin [128], L. Kashif [173], G. Kasieczka [58b], R.D. Kass [109], A. Kastanas [14], M. Kataoka [5], Y. Kataoka [155], J. Katzy [42], V. Kaushik [7], K. Kawagoe [69], T. Kawamoto [155], G. Kawamura [81], S. Kazama [155], V.F. Kazanin [107], M.Y. Kazarinov [64], R. Keeler [169], P.T. Keener [120], R. Kehoe [40], M. Keil [54], G.D. Kekelidze [64], J.S. Keller [138], M. Kenyon [53], H. Keoshkerian [5], O. Kepka [125], N. Kerschen [30], B.P. Kerševan [74], S. Kersten [175], K. Kessoku [155], J. Keung [158], F. Khalil-zada [11], H. Khandanyan [146a,146b], A. Khanov [112], D. Kharchenko [64], A. Khodinov [96], A. Khomich [58a], T.J. Khoo [28], G. Khoriauli [21], A. Khoroshilov [175], V. Khovanskiy [95], E. Khramov [64], J. Khubua [51b], H. Kim [146a,146b], S.H. Kim [160], N. Kimura [171], O. Kind [16], B.T. King [73], M. King [66], R.S.B. King [118], J. Kirk [129], A.E. Kiryunin [99], T. Kishimoto [66], D. Kisielewska [38], T. Kitamura [66], T. Kittelmann [123], K. Kiuchi [160], E. Kladiva [144b], M. Klein [73], U. Klein [73], K. Kleinknecht [81], M. Klemetti [85], A. Klier [172], P. Klimek [146a,146b], A. Klimentov [25], R. Klingenberg [43], J.A. Klinger [82], E.B. Klinkby [36], T. Klioutchnikova [30], P.F. Klok [104], S. Klous [105], E.-E. Kluge [58a], T. Kluge [73], P. Kluit [105], S. Kluth [99], E. Kneringer [61], E.B.F.G. Knoops [83], A. Knue [54], B.R. Ko [45], T. Kobayashi [155], M. Kobel [44], M. Kocian [143], P. Kodys [127], K. Köneke [30], A.C. König [104], S. Koenig [81], L. Köpke [81], F. Koetsveld [104], P. Koevesarki [21], T. Koffas [29], E. Koffeman [105], L.A. Kogan [118], S. Kohlmann [175], F. Kohn [54], Z. Kohout [126], T. Kohriki [65], T. Koi [143], G.M. Kolachev [107,*], H. Kolanoski [16], V. Kolesnikov [64], I. Koletsou [89a], J. Koll [88], A.A. Komar [94], Y. Komori [155], T. Kondo [65], T. Kono [42,s], A.I. Kononov [48], R. Konoplich [108,t], N. Konstantinidis [77], R. Kopeliansky [152], S. Koperny [38], A.K. Kopp [48], K. Korcyl [39], K. Kordas [154], A. Korn [118], A. Korol [107], I. Korolkov [12], E.V. Korolkova [139], V.A. Korotkov [128],

O. Kortner [99], S. Kortner [99], V.V. Kostyukhin [21], S. Kotov [99], V.M. Kotov [64], A. Kotwal [45], C. Kourkoumelis [9], V. Kouskoura [154], A. Koutsman [159a], R. Kowalewski [169], T.Z. Kowalski [38], W. Kozanecki [136], A.S. Kozhin [128], V. Kral [126], V.A. Kramarenko [97], G. Kramberger [74], M.W. Krasny [78], A. Krasznahorkay [108], J.K. Kraus [21], A. Kravchenko [25], S. Kreiss [108], F. Krejci [126], J. Kretzschmar [73], K. Kreutzfeldt [52], N. Krieger [54], P. Krieger [158], K. Kroeninger [54], H. Kroha [99], J. Kroll [120], J. Kroseberg [21], J. Krstic [13a], U. Kruchonak [64], H. Krüger [21], T. Kruker [17], N. Krumnack [63], Z.V. Krumshteyn [64], M.K. Kruse [45], T. Kubota [86], S. Kuday [4a], S. Kuehn [48], A. Kugel [58c], T. Kuhl [42], V. Kukhtin [64], Y. Kulchitsky [90], S. Kuleshov [32b], M. Kuna [78], J. Kunkle [120], A. Kupco [125], H. Kurashige [66], M. Kurata [160], Y.A. Kurochkin [90], V. Kus [125], E.S. Kuwertz [147], M. Kuze [157], J. Kvita [142], R. Kwee [16], A. La Rosa [49], L. La Rotonda [37a,37b], L. Labarga [80], S. Lablak [135a], C. Lacasta [167], F. Lacava [132a,132b], J. Lacey [29], H. Lacker [16], D. Lacour [78], V.R. Lacuesta [167], E. Ladygin [64], R. Lafaye [5], B. Laforge [78], T. Lagouri [176], S. Lai [48], E. Laisne [55], L. Lambourne [77], C.L. Lampen [7], W. Lampl [7], E. Lancon [136], U. Landgraf [48], M.P.J. Landon [75], V.S. Lang [58a], C. Lange [42], A.J. Lankford [163], F. Lanni [25], K. Lantzsch [30], A. Lanza [119a], S. Laplace [78], C. Lapoire [21], J.F. Laporte [136], T. Lari [89a], A. Larner [118], M. Lassnig [30], P. Laurelli [47], V. Lavorini [37a,37b], W. Lavrijsen [15], P. Laycock [73], O. Le Dortz [78], E. Le Guirriec [83], E. Le Menedeu [12], T. LeCompte [6], F. Ledroit-Guillon [55], H. Lee [105], J.S.H. Lee [116], S.C. Lee [151], L. Lee [176], M. Lefebvre [169], M. Legendre [136], F. Legger [98], C. Leggett [15], M. Lehmacher [21], G. Lehmann Miotto [30], A.G. Leister [176], M.A.L. Leite [24d], R. Leitner [127], D. Lellouch [172], B. Lemmer [54], V. Lendermann [58a], K.J.C. Leney [145b], T. Lenz [105], G. Lenzen [175], B. Lenzi [30], K. Leonhardt [44], S. Leontsinis [10], F. Lepold [58a], C. Leroy [93], J-R. Lessard [169], C.G. Lester [28], C.M. Lester [120], J. Levêque [5], D. Levin [87], L.J. Levinson [172], A. Lewis [118], G.H. Lewis [108], A.M. Leyko [21], M. Leyton [16], B. Li [33b], B. Li [83], H. Li [148], H.L. Li [31], S. Li [33b,u], X. Li [87], Z. Liang [118,v], H. Liao [34], B. Liberti [133a], P. Lichard [30], K. Lie [165], W. Liebig [14], C. Limbach [21], A. Limosani [86], M. Limper [62], S.C. Lin [151,w], F. Linde [105], J.T. Linnemann [88], E. Lipeles [120], A. Lipniacka [14], T.M. Liss [165], D. Lissauer [25], A. Lister [49], A.M. Litke [137], D. Liu [151], J.B. Liu [33b], L. Liu [87], M. Liu [33b], Y. Liu [33b], M. Livan [119a,119b], S.S.A. Livermore [118], A. Lleres [55], J. Llorente Merino [80], S.L. Lloyd [75], E. Lobodzinska [42], P. Loch [7], W.S. Lockman [137], T. Loddenkoetter [21], F.K. Loebinger [82], A. Loginov [176], C.W. Loh [168], T. Lohse [16], K. Lohwasser [48], M. Lokajicek [125], V.P. Lombardo [5], R.E. Long [71], L. Lopes [124a], D. Lopez Mateos [57], J. Lorenz [98], N. Lorenzo Martinez [115], M. Losada [162], P. Loscutoff [15], F. Lo Sterzo [132a,132b], M.J. Losty [159a,*], X. Lou [41], A. Lounis [115], K.F. Loureiro [162], J. Love [6], P.A. Love [71], A.J. Lowe [143,g], F. Lu [33a], H.J. Lubatti [138], C. Luci [132a,132b], A. Lucotte [55], D. Ludwig [42], I. Ludwig [48], J. Ludwig [48], F. Luehring [60], G. Luijckx [105], W. Lukas [61], L. Luminari [132a], E. Lund [117], B. Lund-Jensen [147], B. Lundberg [79], J. Lundberg [146a,146b], O. Lundberg [146a,146b], J. Lundquist [36], M. Lungwitz [81], D. Lynn [25], E. Lytken [79], H. Ma [25], L.L. Ma [173], G. Maccarrone [47], A. Macchiolo [99], B. Maček [74], J. Machado Miguens [124a], D. Macina [30], R. Mackeprang [36], R.J. Madaras [15], H.J. Maddocks [71], W.F. Mader [44], T. Maeno [25], P. Mättig [175], S. Mättig [42], L. Magnoni [163], E. Magradze [54], K. Mahboubi [48], J. Mahlstedt [105], S. Mahmoud [73], G. Mahout [18], C. Maiani [136], C. Maidantchik [24a], A. Maio [124a,c], S. Majewski [25], Y. Makida [65], N. Makovec [115], P. Mal [136], B. Malaescu [78], Pa. Malecki [39], P. Malecki [39], V.P. Maleev [121], F. Malek [55], U. Mallik [62], D. Malon [6], C. Malone [143], S. Maltezos [10], V. Malyshev [107], S. Malyukov [30], J. Mamuzic [13b], A. Manabe [65], L. Mandelli [89a], I. Mandić [74], R. Mandrysch [62], J. Maneira [124a], A. Manfredini [99], L. Manhaes de Andrade Filho [24b], J.A. Manjarres Ramos [136], A. Mann [98], P.M. Manning [137], A. Manousakis-Katsikakis [9], B. Mansoulie [136], R. Mantifel [85], A. Mapelli [30], L. Mapelli [30], L. March [167], J.F. Marchand [29], F. Marchese [133a,133b], G. Marchiori [78], M. Marcisovsky [125], C.P. Marino [169], F. Marroquim [24a], Z. Marshall [30], L.F. Marti [17], S. Marti-Garcia [167], B. Martin [30], B. Martin [88], J.P. Martin [93], T.A. Martin [18], V.J. Martin [46], B. Martin dit Latour [49], S. Martin-Haugh [149], H. Martinez [136], M. Martinez [12], V. Martinez Outschoorn [57], A.C. Martyniuk [169], M. Marx [82], F. Marzano [132a], A. Marzin [111], L. Masetti [81], T. Mashimo [155], R. Mashinistov [94], J. Masik [82], A.L. Maslennikov [107], I. Massa [20a,20b], G. Massaro [105], N. Massol [5], P. Mastrandrea [148], A. Mastroberardino [37a,37b], T. Masubuchi [155], H. Matsunaga [155], T. Matsushita [66], C. Mattravers [118,d], J. Maurer [83], S.J. Maxfield [73], D.A. Maximov [107,h], R. Mazini [151], M. Mazur [21], L. Mazzaferro [133a,133b], M. Mazzanti [89a], J. Mc Donald [85], S.P. Mc Kee [87], A. McCarn [165], R.L. McCarthy [148], T.G. McCarthy [29], N.A. McCubbin [129], K.W. McFarlane [56,*], J.A. Mcfayden [139], G. Mchedlidze [51b], T. Mclaughlan [18], S.J. McMahon [129], R.A. McPherson [169,l], A. Meade [84], J. Mechnich [105], M. Mechtel [175], M. Medinnis [42], S. Meehan [31], R. Meera-Lebbai [111], T. Meguro [116], S. Mehlhase [36], A. Mehta [73], K. Meier [58a], B. Meirose [79], C. Melachrinos [31], B.R. Mellado Garcia [173], F. Meloni [89a,89b],

L. Mendoza Navas [162], Z. Meng [151,x], A. Mengarelli [20a,20b], S. Menke [99], E. Meoni [161], K.M. Mercurio [57], P. Mermod [49], L. Merola [102a,102b], C. Meroni [89a], F.S. Merritt [31], H. Merritt [109], A. Messina [30,y], J. Metcalfe [25], A.S. Mete [163], C. Meyer [81], C. Meyer [31], J-P. Meyer [136], J. Meyer [174], J. Meyer [54], S. Michal [30], L. Micu [26a], R.P. Middleton [129], S. Migas [73], L. Mijović [136], G. Mikenberg [172], M. Mikestikova [125], M. Mikuž [74], D.W. Miller [31], R.J. Miller [88], W.J. Mills [168], C. Mills [57], A. Milov [172], D.A. Milstead [146a,146b], D. Milstein [172], A.A. Minaenko [128], M. Miñano Moya [167], I.A. Minashvili [64], A.I. Mincer [108], B. Mindur [38], M. Mineev [64], Y. Ming [173], L.M. Mir [12], G. Mirabelli [132a], J. Mitrevski [137], V.A. Mitsou [167], S. Mitsui [65], P.S. Miyagawa [139], J.U. Mjörnmark [79], T. Moa [146a,146b], V. Moeller [28], K. Mönig [42], N. Möser [21], S. Mohapatra [148], W. Mohr [48], R. Moles-Valls [167], A. Molfetas [30], J. Monk [77], E. Monnier [83], J. Montejo Berlingen [12], F. Monticelli [70], S. Monzani [20a,20b], R.W. Moore [3], G.F. Moorhead [86], C. Mora Herrera [49], A. Moraes [53], N. Morange [136], J. Morel [54], G. Morello [37a,37b], D. Moreno [81], M. Moreno Llácer [167], P. Morettini [50a], M. Morgenstern [44], M. Morii [57], A.K. Morley [30], G. Mornacchi [30], J.D. Morris [75], L. Morvaj [101], H.G. Moser [99], M. Mosidze [51b], J. Moss [109], R. Mount [143], E. Mountricha [10,z], S.V. Mouraviev [94,*], E.J.W. Moyse [84], F. Mueller [58a], J. Mueller [123], K. Mueller [21], T.A. Müller [98], T. Mueller [81], D. Muenstermann [30], Y. Munwes [153], W.J. Murray [129], I. Mussche [105], E. Musto [152], A.G. Myagkov [128], M. Myska [125], O. Nackenhorst [54], J. Nadal [12], K. Nagai [160], R. Nagai [157], Y. Nagai [83], K. Nagano [65], A. Nagarkar [109], Y. Nagasaka [59], M. Nagel [99], A.M. Nairz [30], Y. Nakahama [30], K. Nakamura [65], T. Nakamura [155], I. Nakano [110], G. Nanava [21], A. Napier [161], R. Narayan [58b], M. Nash [77,d], T. Nattermann [21], T. Naumann [42], G. Navarro [162], H.A. Neal [87], P.Yu. Nechaeva [94], T.J. Neep [82], A. Negri [119a,119b], G. Negri [30], M. Negrini [20a], S. Nektarijevic [49], A. Nelson [163], T.K. Nelson [143], S. Nemecek [125], P. Nemethy [108], A.A. Nepomuceno [24a], M. Nessi [30,aa], M.S. Neubauer [165], M. Neumann [175], A. Neusiedl [81], R.M. Neves [108], P. Nevski [25], F.M. Newcomer [120], P.R. Newman [18], V. Nguyen Thi Hong [136], R.B. Nickerson [118], R. Nicolaidou [136], B. Nicquevert [30], F. Niedercorn [115], J. Nielsen [137], N. Nikiforou [35], A. Nikiforov [16], V. Nikolaenko [128], I. Nikolic-Audit [78], K. Nikolics [49], K. Nikolopoulos [18], H. Nilsen [48], P. Nilsson [8], Y. Ninomiya [155], A. Nisati [132a], R. Nisius [99], T. Nobe [157], L. Nodulman [6], M. Nomachi [116], I. Nomidis [154], S. Norberg [111], M. Nordberg [30], J. Novakova [127], M. Nozaki [65], L. Nozka [113], A.-E. Nuncio-Quiroz [21], G. Nunes Hanninger [86], T. Nunnemann [98], E. Nurse [77], B.J. O'Brien [46], D.C. O'Neil [142], V. O'Shea [53], L.B. Oakes [98], F.G. Oakham [29,f], H. Oberlack [99], J. Ocariz [78], A. Ochi [66], S. Oda [69], S. Odaka [65], J. Odier [83], H. Ogren [60], A. Oh [82], S.H. Oh [45], C.C. Ohm [30], T. Ohshima [101], W. Okamura [116], H. Okawa [25], Y. Okumura [31], T. Okuyama [155], A. Olariu [26a], A.G. Olchevski [64], S.A. Olivares Pino [32a], M. Oliveira [124a,i], D. Oliveira Damazio [25], E. Oliver Garcia [167], D. Olivito [120], A. Olszewski [39], J. Olszowska [39], A. Onofre [124a,ab], P.U.E. Onyisi [31,ac], C.J. Oram [159a], M.J. Oreglia [31], Y. Oren [153], D. Orestano [134a,134b], N. Orlando [72a,72b], C. Oropeza Barrera [53], R.S. Orr [158], B. Osculati [50a,50b], R. Ospanov [120], C. Osuna [12], G. Otero y Garzon [27], J.P. Ottersbach [105], M. Ouchrif [135d], E.A. Ouellette [169], F. Ould-Saada [117], A. Ouraou [136], Q. Ouyang [33a], A. Ovcharova [15], M. Owen [82], S. Owen [139], V.E. Ozcan [19a], N. Ozturk [8], A. Pacheco Pages [12], C. Padilla Aranda [12], S. Pagan Griso [15], E. Paganis [139], C. Pahl [99], F. Paige [25], P. Pais [84], K. Pajchel [117], G. Palacino [159b], C.P. Paleari [7], S. Palestini [30], D. Pallin [34], A. Palma [124a], J.D. Palmer [18], Y.B. Pan [173], E. Panagiotopoulou [10], J.G. Panduro Vazquez [76], P. Pani [105], N. Panikashvili [87], S. Panitkin [25], D. Pantea [26a], A. Papadelis [146a], Th.D. Papadopoulou [10], A. Paramonov [6], D. Paredes Hernandez [34], W. Park [25,ad], M.A. Parker [28], F. Parodi [50a,50b], J.A. Parsons [35], U. Parzefall [48], S. Pashapour [54], E. Pasqualucci [132a], S. Passaggio [50a], A. Passeri [134a], F. Pastore [134a,134b,*], Fr. Pastore [76], G. Pásztor [49,ae], S. Pataraia [175], N. Patel [150], J.R. Pater [82], S. Patricelli [102a,102b], T. Pauly [30], S. Pedraza Lopez [167], M.I. Pedraza Morales [173], S.V. Peleganchuk [107], D. Pelikan [166], H. Peng [33b], B. Penning [31], A. Penson [35], J. Penwell [60], M. Perantoni [24a], K. Perez [35,af], T. Perez Cavalcanti [42], E. Perez Codina [159a], M.T. Pérez García-Estañ [167], V. Perez Reale [35], L. Perini [89a,89b], H. Pernegger [30], R. Perrino [72a], P. Perrodo [5], V.D. Peshekhonov [64], K. Peters [30], B.A. Petersen [30], J. Petersen [30], T.C. Petersen [36], E. Petit [5], A. Petridis [154], C. Petridou [154], E. Petrolo [132a], F. Petrucci [134a,134b], D. Petschull [42], M. Petteni [142], R. Pezoa [32b], A. Phan [86], P.W. Phillips [129], G. Piacquadio [30], A. Picazio [49], E. Piccaro [75], M. Piccinini [20a,20b], S.M. Piec [42], R. Piegaia [27], D.T. Pignotti [109], J.E. Pilcher [31], A.D. Pilkington [82], J. Pina [124a,c], M. Pinamonti [164a,164c], A. Pinder [118], J.L. Pinfold [3], A. Pingel [36], B. Pinto [124a], C. Pizio [89a,89b], M.-A. Pleier [25], E. Plotnikova [64], A. Poblaguev [25], S. Poddar [58a], F. Podlyski [34], L. Poggioli [115], D. Pohl [21], M. Pohl [49], G. Polesello [119a], A. Policicchio [37a,37b], R. Polifka [158], A. Polini [20a], J. Poll [75], V. Polychronakos [25], D. Pomeroy [23], K. Pommès [30], L. Pontecorvo [132a],

B.G. Pope [88], G.A. Popeneciu [26a], D.S. Popovic [13a], A. Poppleton [30], X. Portell Bueso [30], G.E. Pospelov [99],
S. Pospisil [126], I.N. Potrap [99], C.J. Potter [149], C.T. Potter [114], G. Poulard [30], J. Poveda [60], V. Pozdnyakov [64],
R. Prabhu [77], P. Pralavorio [83], A. Pranko [15], S. Prasad [30], R. Pravahan [25], S. Prell [63], K. Pretzl [17], D. Price [60],
J. Price [73], L.E. Price [6], D. Prieur [123], M. Primavera [72a], K. Prokofiev [108], F. Prokoshin [32b], S. Protopopescu [25],
J. Proudfoot [6], X. Prudent [44], M. Przybycien [38], H. Przysiezniak [5], S. Psoroulas [21], E. Ptacek [114],
E. Pueschel [84], D. Puldon [148], J. Purdham [87], M. Purohit [25,ad], P. Puzo [115], Y. Pylypchenko [62], J. Qian [87],
A. Quadt [54], D.R. Quarrie [15], W.B. Quayle [173], M. Raas [104], V. Radeka [25], V. Radescu [42], P. Radloff [114],
F. Ragusa [89a,89b], G. Rahal [178], A.M. Rahimi [109], D. Rahm [25], S. Rajagopalan [25], M. Rammensee [48],
M. Rammes [141], A.S. Randle-Conde [40], K. Randrianarivony [29], K. Rao [163], F. Rauscher [98], T.C. Rave [48],
M. Raymond [30], A.L. Read [117], D.M. Rebuzzi [119a,119b], A. Redelbach [174], G. Redlinger [25], R. Reece [120],
K. Reeves [41], A. Reinsch [114], I. Reisinger [43], C. Rembser [30], Z.L. Ren [151], A. Renaud [115], M. Rescigno [132a],
S. Resconi [89a], B. Resende [136], P. Reznicek [98], R. Rezvani [158], R. Richter [99], E. Richter-Was [5,ag], M. Ridel [78],
M. Rijssenbeek [148], A. Rimoldi [119a,119b], L. Rinaldi [20a], R.R. Rios [40], E. Ritsch [61], I. Riu [12],
G. Rivoltella [89a,89b], F. Rizatdinova [112], E. Rizvi [75], S.H. Robertson [85,l], A. Robichaud-Veronneau [118],
D. Robinson [28], J.E.M. Robinson [82], A. Robson [53], J.G. Rocha de Lima [106], C. Roda [122a,122b],
D. Roda Dos Santos [30], A. Roe [54], S. Roe [30], O. Røhne [117], S. Rolli [161], A. Romaniouk [96], M. Romano [20a,20b],
G. Romeo [27], E. Romero Adam [167], N. Rompotis [138], L. Roos [78], E. Ros [167], S. Rosati [132a], K. Rosbach [49],
A. Rose [149], M. Rose [76], G.A. Rosenbaum [158], P.L. Rosendahl [14], O. Rosenthal [141], L. Rosselet [49],
V. Rossetti [12], E. Rossi [132a,132b], L.P. Rossi [50a], M. Rotaru [26a], I. Roth [172], J. Rothberg [138], D. Rousseau [115],
C.R. Royon [136], A. Rozanov [83], Y. Rozen [152], X. Ruan [33a,ah], F. Rubbo [12], I. Rubinskiy [42], N. Ruckstuhl [105],
V.I. Rud [97], C. Rudolph [44], F. Rühr [7], A. Ruiz-Martinez [63], L. Rumyantsev [64], Z. Rurikova [48],
N.A. Rusakovich [64], A. Ruschke [98], J.P. Rutherfoord [7], N. Ruthmann [48], P. Ruzicka [125], Y.F. Ryabov [121],
M. Rybar [127], G. Rybkin [115], N.C. Ryder [118], A.F. Saavedra [150], I. Sadeh [153], H.F-W. Sadrozinski [137],
R. Sadykov [64], F. Safai Tehrani [132a], H. Sakamoto [155], G. Salamanna [75], A. Salamon [133a], M. Saleem [111],
D. Salek [30], D. Salihagic [99], A. Salnikov [143], J. Salt [167], B.M. Salvachua Ferrando [6], D. Salvatore [37a,37b],
F. Salvatore [149], A. Salvucci [104], A. Salzburger [30], D. Sampsonidis [154], B.H. Samset [117], A. Sanchez [102a,102b],
V. Sanchez Martinez [167], H. Sandaker [14], H.G. Sander [81], M.P. Sanders [98], M. Sandhoff [175], T. Sandoval [28],
C. Sandoval [162], R. Sandstroem [99], D.P.C. Sankey [129], A. Sansoni [47], C. Santamarina Rios [85], C. Santoni [34],
R. Santonico [133a,133b], H. Santos [124a], I. Santoyo Castillo [149], J.G. Saraiva [124a], T. Sarangi [173],
E. Sarkisyan-Grinbaum [8], B. Sarrazin [21], F. Sarri [122a,122b], G. Sartisohn [175], O. Sasaki [65], Y. Sasaki [155],
N. Sasao [67], I. Satsounkevitch [90], G. Sauvage [5,*], E. Sauvan [5], J.B. Sauvan [115], P. Savard [158,f], V. Savinov [123],
D.O. Savu [30], L. Sawyer [25,n], D.H. Saxon [53], J. Saxon [120], C. Sbarra [20a], A. Sbrizzi [20a,20b], D.A. Scannicchio [163],
M. Scarcella [150], J. Schaarschmidt [115], P. Schacht [99], D. Schaefer [120], U. Schäfer [81], A. Schaelicke [46],
S. Schaepe [21], S. Schaetzel [58b], A.C. Schaffer [115], D. Schaile [98], R.D. Schamberger [148], V. Scharf [58a],
V.A. Schegelsky [121], D. Scheirich [87], M. Schernau [163], M.I. Scherzer [35], C. Schiavi [50a,50b], J. Schieck [98],
M. Schioppa [37a,37b], S. Schlenker [30], E. Schmidt [48], K. Schmieden [21], C. Schmitt [81], S. Schmitt [58b],
B. Schneider [17], Y.J. Schnellbach [73], U. Schnoor [44], L. Schoeffel [136], A. Schoening [58b], A.L.S. Schorlemmer [54],
M. Schott [30], D. Schouten [159a], J. Schovancova [125], M. Schram [85], C. Schroeder [81], N. Schroer [58c],
M.J. Schultens [21], J. Schultes [175], H.-C. Schultz-Coulon [58a], H. Schulz [16], M. Schumacher [48],
B.A. Schumm [137], Ph. Schune [136], A. Schwartzman [143], Ph. Schwegler [99], Ph. Schwemling [78],
R. Schwienhorst [88], J. Schwindling [136], T. Schwindt [21], M. Schwoerer [5], F.G. Sciacca [17], E. Scifo [115],
G. Sciolla [23], W.G. Scott [129], J. Searcy [114], G. Sedov [42], E. Sedykh [121], S.C. Seidel [103], A. Seiden [137],
F. Seifert [44], J.M. Seixas [24a], G. Sekhniaidze [102a], S.J. Sekula [40], K.E. Selbach [46], D.M. Seliverstov [121],
B. Sellden [146a], G. Sellers [73], M. Seman [144b], N. Semprini-Cesari [20a,20b], C. Serfon [30], L. Serin [115],
L. Serkin [54], T. Serre [83], R. Seuster [159a], H. Severini [111], A. Sfyrla [30], E. Shabalina [54], M. Shamim [114],
L.Y. Shan [33a], J.T. Shank [22], Q.T. Shao [86], M. Shapiro [15], P.B. Shatalov [95], K. Shaw [164a,164c], D. Sherman [176],
P. Sherwood [77], S. Shimizu [101], M. Shimojima [100], T. Shin [56], M. Shiyakova [64], A. Shmeleva [94],
M.J. Shochet [31], D. Short [118], S. Shrestha [63], E. Shulga [96], M.A. Shupe [7], P. Sicho [125], A. Sidoti [132a],
F. Siegert [48], Dj. Sijacki [13a], O. Silbert [172], J. Silva [124a], Y. Silver [153], D. Silverstein [143], S.B. Silverstein [146a],
V. Simak [126], O. Simard [136], Lj. Simic [13a], S. Simion [115], E. Simioni [81], B. Simmons [77], R. Simoniello [89a,89b],
M. Simonyan [36], P. Sinervo [158], N.B. Sinev [114], V. Sipica [141], G. Siragusa [174], A. Sircar [25], A.N. Sisakyan [64,*],
S.Yu. Sivoklokov [97], J. Sjölin [146a,146b], T.B. Sjursen [14], L.A. Skinnari [15], H.P. Skottowe [57], K. Skovpen [107],

P. Skubic [111], M. Slater [18], T. Slavicek [126], K. Sliwa [161], V. Smakhtin [172], B.H. Smart [46], L. Smestad [117], S.Yu. Smirnov [96], Y. Smirnov [96], L.N. Smirnova [97,ai], O. Smirnova [79], B.C. Smith [57], K.M. Smith [53], M. Smizanska [71], K. Smolek [126], A.A. Snesarev [94], S.W. Snow [82], J. Snow [111], S. Snyder [25], R. Sobie [169,l], J. Sodomka [126], A. Soffer [153], C.A. Solans [30], M. Solar [126], J. Solc [126], E.Yu. Soldatov [96], U. Soldevila [167], E. Solfaroli Camillocci [132a,132b], A.A. Solodkov [128], O.V. Solovyanov [128], V. Solovyev [121], N. Soni [1], A. Sood [15], V. Sopko [126], B. Sopko [126], M. Sosebee [8], R. Soualah [164a,164c], P. Soueid [93], A. Soukharev [107], D. South [42], S. Spagnolo [72a,72b], F. Spanò [76], R. Spighi [20a], G. Spigo [30], R. Spiwoks [30], M. Spousta [127,aj], T. Spreitzer [158], B. Spurlock [8], R.D. St. Denis [53], J. Stahlman [120], R. Stamen [58a], E. Stanecka [39], R.W. Stanek [6], C. Stanescu [134a], M. Stanescu-Bellu [42], M.M. Stanitzki [42], S. Stapnes [117], E.A. Starchenko [128], J. Stark [55], P. Staroba [125], P. Starovoitov [42], R. Staszewski [39], A. Staude [98], P. Stavina [144a,*], G. Steele [53], P. Steinbach [44], P. Steinberg [25], I. Stekl [126], B. Stelzer [142], H.J. Stelzer [88], O. Stelzer-Chilton [159a], H. Stenzel [52], S. Stern [99], G.A. Stewart [30], J.A. Stillings [21], M.C. Stockton [85], M. Stoebe [85], K. Stoerig [48], G. Stoicea [26a], S. Stonjek [99], P. Strachota [127], A.R. Stradling [8], A. Straessner [44], J. Strandberg [147], S. Strandberg [146a,146b], A. Strandlie [117], M. Strang [109], E. Strauss [143], M. Strauss [111], P. Strizenec [144b], R. Ströhmer [174], D.M. Strom [114], J.A. Strong [76,*], R. Stroynowski [40], B. Stugu [14], I. Stumer [25,*], J. Stupak [148], P. Sturm [175], N.A. Styles [42], D.A. Soh [151,v], D. Su [143], HS. Subramania [3], R. Subramaniam [25], A. Succurro [12], Y. Sugaya [116], C. Suhr [106], M. Suk [127], V.V. Sulin [94], S. Sultansoy [4d], T. Sumida [67], X. Sun [55], J.E. Sundermann [48], K. Suruliz [139], G. Susinno [37a,37b], M.R. Sutton [149], Y. Suzuki [65], Y. Suzuki [66], M. Svatos [125], S. Swedish [168], I. Sykora [144a], T. Sykora [127], J. Sánchez [167], D. Ta [105], K. Tackmann [42], A. Taffard [163], R. Tafirout [159a], N. Taiblum [153], Y. Takahashi [101], H. Takai [25], R. Takashima [68], H. Takeda [66], T. Takeshita [140], Y. Takubo [65], M. Talby [83], A. Talyshev [107,h], M.C. Tamsett [25], K.G. Tan [86], J. Tanaka [155], R. Tanaka [115], S. Tanaka [131], S. Tanaka [65], A.J. Tanasijczuk [142], K. Tani [66], N. Tannoury [83], S. Tapprogge [81], D. Tardif [158], S. Tarem [152], F. Tarrade [29], G.F. Tartarelli [89a], P. Tas [127], M. Tasevsky [125], E. Tassi [37a,37b], Y. Tayalati [135d], C. Taylor [77], F.E. Taylor [92], G.N. Taylor [86], W. Taylor [159b], M. Teinturier [115], F.A. Teischinger [30], M. Teixeira Dias Castanheira [75], P. Teixeira-Dias [76], K.K. Temming [48], H. Ten Kate [30], P.K. Teng [151], S. Terada [65], K. Terashi [155], J. Terron [80], M. Testa [47], R.J. Teuscher [158,l], J. Therhaag [21], T. Theveneaux-Pelzer [78], S. Thoma [48], J.P. Thomas [18], E.N. Thompson [35], P.D. Thompson [18], P.D. Thompson [158], A.S. Thompson [53], L.A. Thomsen [36], E. Thomson [120], M. Thomson [28], W.M. Thong [86], R.P. Thun [87], F. Tian [35], M.J. Tibbetts [15], T. Tic [125], V.O. Tikhomirov [94], Y.A. Tikhonov [107,h], S. Timoshenko [96], E. Tiouchichine [83], P. Tipton [176], S. Tisserant [83], T. Todorov [5], S. Todorova-Nova [161], B. Toggerson [163], J. Tojo [69], S. Tokár [144a], K. Tokushuku [65], K. Tollefson [88], M. Tomoto [101], L. Tompkins [31], K. Toms [103], A. Tonoyan [14], C. Topfel [17], N.D. Topilin [64], E. Torrence [114], H. Torres [78], E. Torró Pastor [167], J. Toth [83,ae], F. Touchard [83], D.R. Tovey [139], T. Trefzger [174], L. Tremblet [30], A. Tricoli [30], I.M. Trigger [159a], S. Trincaz-Duvoid [78], M.F. Tripiana [70], N. Triplett [25], W. Trischuk [158], B. Trocmé [55], C. Troncon [89a], M. Trottier-McDonald [142], P. True [88], M. Trzebinski [39], A. Trzupek [39], C. Tsarouchas [30], J.C-L. Tseng [118], M. Tsiakiris [105], P.V. Tsiareshka [90], D. Tsionou [5,ak], G. Tsipolitis [10], S. Tsiskaridze [12], V. Tsiskaridze [48], E.G. Tskhadadze [51a], I.I. Tsukerman [95], V. Tsulaia [15], J.-W. Tsung [21], S. Tsuno [65], D. Tsybychev [148], A. Tua [139], A. Tudorache [26a], V. Tudorache [26a], J.M. Tuggle [31], M. Turala [39], D. Turecek [126], I. Turk Cakir [4e], R. Turra [89a,89b], P.M. Tuts [35], A. Tykhonov [74], M. Tylmad [146a,146b], M. Tyndel [129], G. Tzanakos [9], K. Uchida [21], I. Ueda [155], R. Ueno [29], M. Ughetto [83], M. Ugland [14], M. Uhlenbrock [21], F. Ukegawa [160], G. Unal [30], A. Undrus [25], G. Unel [163], Y. Unno [65], D. Urbaniec [35], P. Urquijo [21], G. Usai [8], L. Vacavant [83], V. Vacek [126], B. Vachon [85], S. Vahsen [15], S. Valentinetti [20a,20b], A. Valero [167], L. Valery [34], S. Valkar [127], E. Valladolid Gallego [167], S. Vallecorsa [152], J.A. Valls Ferrer [167], R. Van Berg [120], P.C. Van Der Deijl [105], R. van der Geer [105], H. van der Graaf [105], R. Van Der Leeuw [105], E. van der Poel [105], D. van der Ster [30], N. van Eldik [30], P. van Gemmeren [6], J. Van Nieuwkoop [142], I. van Vulpen [105], M. Vanadia [99], W. Vandelli [30], A. Vaniachine [6], P. Vankov [42], F. Vannucci [78], R. Vari [132a], E.W. Varnes [7], T. Varol [84], D. Varouchas [15], A. Vartapetian [8], K.E. Varvell [150], V.I. Vassilakopoulos [56], F. Vazeille [34], T. Vazquez Schroeder [54], G. Vegni [89a,89b], J.J. Veillet [115], F. Veloso [124a], R. Veness [30], S. Veneziano [132a], A. Ventura [72a,72b], D. Ventura [84], M. Venturi [48], N. Venturi [158], V. Vercesi [119a], M. Verducci [138], W. Verkerke [105], J.C. Vermeulen [105], A. Vest [44], M.C. Vetterli [142,f], I. Vichou [165], T. Vickey [145b,al], O.E. Vickey Boeriu [145b], G.H.A. Viehhauser [118], S. Viel [168], M. Villa [20a,20b], M. Villaplana Perez [167], E. Vilucchi [47], M.G. Vincter [29], E. Vinek [30], V.B. Vinogradov [64], M. Virchaux [136,*], J. Virzi [15], O. Vitells [172], M. Viti [42], I. Vivarelli [48], F. Vives Vaque [3], S. Vlachos [10],

D. Vladoiu [98], M. Vlasak [126], A. Vogel [21], P. Vokac [126], G. Volpi [47], M. Volpi [86], G. Volpini [89a],
H. von der Schmitt [99], H. von Radziewski [48], E. von Toerne [21], V. Vorobel [127], V. Vorwerk [12], M. Vos [167],
R. Voss [30], J.H. Vossebeld [73], N. Vranjes [136], M. Vranjes Milosavljevic [105], V. Vrba [125], M. Vreeswijk [105],
T. Vu Anh [48], R. Vuillermet [30], I. Vukotic [31], W. Wagner [175], P. Wagner [21], H. Wahlen [175], S. Wahrmund [44],
J. Wakabayashi [101], S. Walch [87], J. Walder [71], R. Walker [98], W. Walkowiak [141], R. Wall [176], P. Waller [73],
B. Walsh [176], C. Wang [45], H. Wang [173], H. Wang [40], J. Wang [151], J. Wang [33a], R. Wang [103], S.M. Wang [151],
T. Wang [21], A. Warburton [85], C.P. Ward [28], D.R. Wardrope [77], M. Warsinsky [48], A. Washbrook [46],
C. Wasicki [42], I. Watanabe [66], P.M. Watkins [18], A.T. Watson [18], I.J. Watson [150], M.F. Watson [18], G. Watts [138],
S. Watts [82], A.T. Waugh [150], B.M. Waugh [77], M.S. Weber [17], J.S. Webster [31], A.R. Weidberg [118], P. Weigell [99],
J. Weingarten [54], C. Weiser [48], P.S. Wells [30], T. Wenaus [25], D. Wendland [16], Z. Weng [151,v], T. Wengler [30],
S. Wenig [30], N. Wermes [21], M. Werner [48], P. Werner [30], M. Werth [163], M. Wessels [58a], J. Wetter [161],
C. Weydert [55], K. Whalen [29], A. White [8], M.J. White [86], S. White [122a,122b], S.R. Whitehead [118],
D. Whiteson [163], D. Whittington [60], D. Wicke [175], F.J. Wickens [129], W. Wiedenmann [173], M. Wielers [129],
P. Wienemann [21], C. Wiglesworth [75], L.A.M. Wiik-Fuchs [21], P.A. Wijeratne [77], A. Wildauer [99],
M.A. Wildt [42,s], I. Wilhelm [127], H.G. Wilkens [30], J.Z. Will [98], E. Williams [35], H.H. Williams [120],
S. Williams [28], W. Willis [35], S. Willocq [84], J.A. Wilson [18], M.G. Wilson [143], A. Wilson [87], I. Wingerter-Seez [5],
S. Winkelmann [48], F. Winklmeier [30], M. Wittgen [143], S.J. Wollstadt [81], M.W. Wolter [39], H. Wolters [124a,i],
W.C. Wong [41], G. Wooden [87], B.K. Wosiek [39], J. Wotschack [30], M.J. Woudstra [82], K.W. Wozniak [39],
K. Wraight [53], M. Wright [53], B. Wrona [73], S.L. Wu [173], X. Wu [49], Y. Wu [33b,am], E. Wulf [35], B.M. Wynne [46],
S. Xella [36], M. Xiao [136], S. Xie [48], C. Xu [33b,z], D. Xu [33a], L. Xu [33b], B. Yabsley [150], S. Yacoob [145a,an],
M. Yamada [65], H. Yamaguchi [155], A. Yamamoto [65], K. Yamamoto [63], S. Yamamoto [155], T. Yamamura [155],
T. Yamanaka [155], K. Yamauchi [101], T. Yamazaki [155], Y. Yamazaki [66], Z. Yan [22], H. Yang [33e], H. Yang [173],
U.K. Yang [82], Y. Yang [109], Z. Yang [146a,146b], S. Yanush [91], L. Yao [33a], Y. Yasu [65], E. Yatsenko [42], J. Ye [40],
S. Ye [25], A.L. Yen [57], M. Yilmaz [4c], R. Yoosoofmiya [123], K. Yorita [171], R. Yoshida [6], K. Yoshihara [155],
C. Young [143], C.J. Young [118], S. Youssef [22], D. Yu [25], D.R. Yu [15], J. Yu [8], J. Yu [112], L. Yuan [66], A. Yurkewicz [106],
B. Zabinski [39], R. Zaidan [62], A.M. Zaitsev [128], L. Zanello [132a,132b], D. Zanzi [99], A. Zaytsev [25], C. Zeitnitz [175],
M. Zeman [126], A. Zemla [39], O. Zenin [128], T. Ženiš [144a], Z. Zinonos [122a,122b], D. Zerwas [115],
G. Zevi della Porta [57], D. Zhang [87], H. Zhang [88], J. Zhang [6], X. Zhang [33d], Z. Zhang [115], L. Zhao [108],
Z. Zhao [33b], A. Zhemchugov [64], J. Zhong [118], B. Zhou [87], N. Zhou [163], Y. Zhou [151], C.G. Zhu [33d], H. Zhu [42],
J. Zhu [87], Y. Zhu [33b], X. Zhuang [98], V. Zhuravlov [99], A. Zibell [98], D. Zieminska [60], N.I. Zimin [64],
R. Zimmermann [21], S. Zimmermann [21], S. Zimmermann [48], M. Ziolkowski [141], R. Zitoun [5], L. Živković [35],
V.V. Zmouchko [128,*], G. Zobernig [173], A. Zoccoli [20a,20b], M. zur Nedden [16], V. Zutshi [106], L. Zwalinski [30]

[1] *School of Chemistry and Physics, University of Adelaide, Adelaide, Australia*
[2] *Physics Department, SUNY Albany, Albany, NY, United States*
[3] *Department of Physics, University of Alberta, Edmonton, AB, Canada*
[4] [(a)] *Department of Physics, Ankara University, Ankara;* [(b)] *Department of Physics, Dumlupinar University, Kutahya;* [(c)] *Department of Physics, Gazi University, Ankara;* [(d)] *Division of Physics, TOBB University of Economics and Technology, Ankara;* [(e)] *Turkish Atomic Energy Authority, Ankara, Turkey*
[5] *LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France*
[6] *High Energy Physics Division, Argonne National Laboratory, Argonne, IL, United States*
[7] *Department of Physics, University of Arizona, Tucson, AZ, United States*
[8] *Department of Physics, The University of Texas at Arlington, Arlington, TX, United States*
[9] *Physics Department, University of Athens, Athens, Greece*
[10] *Physics Department, National Technical University of Athens, Zografou, Greece*
[11] *Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
[12] *Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain*
[13] [(a)] *Institute of Physics, University of Belgrade, Belgrade;* [(b)] *Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia*
[14] *Department for Physics and Technology, University of Bergen, Bergen, Norway*
[15] *Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, CA, United States*
[16] *Department of Physics, Humboldt University, Berlin, Germany*
[17] *Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
[18] *School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
[19] [(a)] *Department of Physics, Bogazici University, Istanbul;* [(b)] *Division of Physics, Dogus University, Istanbul;* [(c)] *Department of Physics Engineering, Gaziantep University, Gaziantep;* [(d)] *Department of Physics, Istanbul Technical University, Istanbul, Turkey*
[20] [(a)] *INFN Sezione di Bologna;* [(b)] *Dipartimento di Fisica, Università di Bologna, Bologna, Italy*
[21] *Physikalisches Institut, University of Bonn, Bonn, Germany*
[22] *Department of Physics, Boston University, Boston, MA, United States*
[23] *Department of Physics, Brandeis University, Waltham, MA, United States*
[24] [(a)] *Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro;* [(b)] *Federal University of Juiz de Fora (UFJF), Juiz de Fora;* [(c)] *Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei;* [(d)] *Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil*
[25] *Physics Department, Brookhaven National Laboratory, Upton, NY, United States*
[26] [(a)] *National Institute of Physics and Nuclear Engineering, Bucharest;* [(b)] *University Politehnica Bucharest, Bucharest;* [(c)] *West University in Timisoara, Timisoara, Romania*
[27] *Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina*

[28] *Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
[29] *Department of Physics, Carleton University, Ottawa, ON, Canada*
[30] *CERN, Geneva, Switzerland*
[31] *Enrico Fermi Institute, University of Chicago, Chicago, IL, United States*
[32] [a] *Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;* [b] *Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
[33] [a] *Institute of High Energy Physics, Chinese Academy of Sciences, Beijing;* [b] *Department of Modern Physics, University of Science and Technology of China, Anhui;* [c] *Department of Physics, Nanjing University, Jiangsu;* [d] *School of Physics, Shandong University, Shandong;* [e] *Physics Department, Shanghai Jiao Tong University, Shanghai, China*
[34] *Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France*
[35] *Nevis Laboratory, Columbia University, Irvington, NY, United States*
[36] *Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark*
[37] [a] *INFN Gruppo Collegato di Cosenza;* [b] *Dipartimento di Fisica, Università della Calabria, Arcavata di Rende, Italy*
[38] *AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*
[39] *The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland*
[40] *Physics Department, Southern Methodist University, Dallas, TX, United States*
[41] *Physics Department, University of Texas at Dallas, Richardson, TX, United States*
[42] *DESY, Hamburg and Zeuthen, Germany*
[43] *Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany*
[44] *Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany*
[45] *Department of Physics, Duke University, Durham, NC, United States*
[46] *SUPA – School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
[47] *INFN Laboratori Nazionali di Frascati, Frascati, Italy*
[48] *Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany*
[49] *Section de Physique, Université de Genève, Geneva, Switzerland*
[50] [a] *INFN Sezione di Genova;* [b] *Dipartimento di Fisica, Università di Genova, Genova, Italy*
[51] [a] *E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi;* [b] *High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
[52] *II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
[53] *SUPA – School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
[54] *II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany*
[55] *Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble, France*
[56] *Department of Physics, Hampton University, Hampton, VA, United States*
[57] *Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA, United States*
[58] [a] *Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;* [b] *Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg;* [c] *ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany*
[59] *Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan*
[60] *Department of Physics, Indiana University, Bloomington, IN, United States*
[61] *Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*
[62] *University of Iowa, Iowa City, IA, United States*
[63] *Department of Physics and Astronomy, Iowa State University, Ames, IA, United States*
[64] *Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia*
[65] *KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
[66] *Graduate School of Science, Kobe University, Kobe, Japan*
[67] *Faculty of Science, Kyoto University, Kyoto, Japan*
[68] *Kyoto University of Education, Kyoto, Japan*
[69] *Department of Physics, Kyushu University, Fukuoka, Japan*
[70] *Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
[71] *Physics Department, Lancaster University, Lancaster, United Kingdom*
[72] [a] *INFN Sezione di Lecce;* [b] *Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*
[73] *Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
[74] *Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia*
[75] *School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
[76] *Department of Physics, Royal Holloway University of London, Surrey, United Kingdom*
[77] *Department of Physics and Astronomy, University College London, London, United Kingdom*
[78] *Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France*
[79] *Fysiska institutionen, Lunds universitet, Lund, Sweden*
[80] *Departamento de Fisica Teorica C-15, Universidad Autonoma de Madrid, Madrid, Spain*
[81] *Institut für Physik, Universität Mainz, Mainz, Germany*
[82] *School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
[83] *CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France*
[84] *Department of Physics, University of Massachusetts, Amherst, MA, United States*
[85] *Department of Physics, McGill University, Montreal, QC, Canada*
[86] *School of Physics, University of Melbourne, Victoria, Australia*
[87] *Department of Physics, The University of Michigan, Ann Arbor, MI, United States*
[88] *Department of Physics and Astronomy, Michigan State University, East Lansing, MI, United States*
[89] [a] *INFN Sezione di Milano;* [b] *Dipartimento di Fisica, Università di Milano, Milano, Italy*
[90] *B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus*
[91] *National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Belarus*
[92] *Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, United States*
[93] *Group of Particle Physics, University of Montreal, Montreal, QC, Canada*
[94] *P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia*
[95] *Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia*
[96] *Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia*
[97] *D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*
[98] *Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
[99] *Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
[100] *Nagasaki Institute of Applied Science, Nagasaki, Japan*
[101] *Graduate School of Science and Kobayashi–Maskawa Institute, Nagoya University, Nagoya, Japan*
[102] [a] *INFN Sezione di Napoli;* [b] *Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy*
[103] *Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States*
[104] *Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*

[105] *Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
[106] *Department of Physics, Northern Illinois University, DeKalb, IL, United States*
[107] *Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia*
[108] *Department of Physics, New York University, New York, NY, United States*
[109] *Ohio State University, Columbus, OH, United States*
[110] *Faculty of Science, Okayama University, Okayama, Japan*
[111] *Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, United States*
[112] *Department of Physics, Oklahoma State University, Stillwater, OK, United States*
[113] *Palacký University, RCPTM, Olomouc, Czech Republic*
[114] *Center for High Energy Physics, University of Oregon, Eugene, OR, United States*
[115] *LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France*
[116] *Graduate School of Science, Osaka University, Osaka, Japan*
[117] *Department of Physics, University of Oslo, Oslo, Norway*
[118] *Department of Physics, Oxford University, Oxford, United Kingdom*
[119] [(a)] *INFN Sezione di Pavia;* [(b)] *Dipartimento di Fisica, Università di Pavia, Pavia, Italy*
[120] *Department of Physics, University of Pennsylvania, Philadelphia, PA, United States*
[121] *Petersburg Nuclear Physics Institute, Gatchina, Russia*
[122] [(a)] *INFN Sezione di Pisa;* [(b)] *Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*
[123] *Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA, United States*
[124] [(a)] *Laboratorio de Instrumentacao e Fisica Experimental de Particulas – LIP, Lisboa, Portugal;* [(b)] *Departamento de Fisica Teorica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain*
[125] *Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic*
[126] *Czech Technical University in Prague, Praha, Czech Republic*
[127] *Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic*
[128] *State Research Center Institute for High Energy Physics, Protvino, Russia*
[129] *Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
[130] *Physics Department, University of Regina, Regina, SK, Canada*
[131] *Ritsumeikan University, Kusatsu, Shiga, Japan*
[132] [(a)] *INFN Sezione di Roma I;* [(b)] *Dipartimento di Fisica, Università La Sapienza, Roma, Italy*
[133] [(a)] *INFN Sezione di Roma Tor Vergata;* [(b)] *Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*
[134] [(a)] *INFN Sezione di Roma Tre;* [(b)] *Dipartimento di Fisica, Università Roma Tre, Roma, Italy*
[135] [(a)] *Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies – Université Hassan II, Casablanca;* [(b)] *Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat;* [(c)] *Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA, Marrakech;* [(d)] *Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda;* [(e)] *Faculté des sciences, Université Mohammed V-Agdal, Rabat, Morocco*
[136] *DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France*
[137] *Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, CA, United States*
[138] *Department of Physics, University of Washington, Seattle, WA, United States*
[139] *Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
[140] *Department of Physics, Shinshu University, Nagano, Japan*
[141] *Fachbereich Physik, Universität Siegen, Siegen, Germany*
[142] *Department of Physics, Simon Fraser University, Burnaby, BC, Canada*
[143] *SLAC National Accelerator Laboratory, Stanford, CA, United States*
[144] [(a)] *Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava;* [(b)] *Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
[145] [(a)] *Department of Physics, University of Johannesburg, Johannesburg;* [(b)] *School of Physics, University of the Witwatsrand, Johannesburg, South Africa*
[146] [(a)] *Department of Physics, Stockholm University;* [(b)] *The Oskar Klein Centre, Stockholm, Sweden*
[147] *Physics Department, Royal Institute of Technology, Stockholm, Sweden*
[148] *Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook, NY, United States*
[149] *Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
[150] *School of Physics, University of Sydney, Sydney, Australia*
[151] *Institute of Physics, Academia Sinica, Taipei, Taiwan*
[152] *Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel*
[153] *Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
[154] *Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
[155] *International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan*
[156] *Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*
[157] *Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
[158] *Department of Physics, University of Toronto, Toronto, ON, Canada*
[159] [(a)] *TRIUMF, Vancouver, BC;* [(b)] *Department of Physics and Astronomy, York University, Toronto, ON, Canada*
[160] *Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
[161] *Department of Physics and Astronomy, Tufts University, Medford, MA, United States*
[162] *Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia*
[163] *Department of Physics and Astronomy, University of California Irvine, Irvine, CA, United States*
[164] [(a)] *INFN Gruppo Collegato di Udine;* [(b)] *ICTP, Trieste;* [(c)] *Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy*
[165] *Department of Physics, University of Illinois, Urbana, IL, United States*
[166] *Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
[167] *Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain*
[168] *Department of Physics, University of British Columbia, Vancouver, BC, Canada*
[169] *Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada*
[170] *Department of Physics, University of Warwick, Coventry, United Kingdom*
[171] *Waseda University, Tokyo, Japan*
[172] *Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel*
[173] *Department of Physics, University of Wisconsin, Madison, WI, United States*
[174] *Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany*
[175] *Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
[176] *Department of Physics, Yale University, New Haven, CT, United States*
[177] *Yerevan Physics Institute, Yerevan, Armenia*
[178] *Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*

[a] Also at Department of Physics, King's College London, London, United Kingdom.
[b] Also at Laboratorio de Instrumentacao e Fisica Experimental de Particulas – LIP, Lisboa, Portugal.
[c] Also at Faculdade de Ciencias and CFNUL, Universidade de Lisboa, Lisboa, Portugal.
[d] Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom.
[e] Also at Department of Physics, University of Johannesburg, Johannesburg, South Africa.
[f] Also at TRIUMF, Vancouver, BC, Canada.
[g] Also at Department of Physics, California State University, Fresno, CA, United States.
[h] Also at Novosibirsk State University, Novosibirsk, Russia.
[i] Also at Department of Physics, University of Coimbra, Coimbra, Portugal.
[j] Also at Department of Physics, UASLP, San Luis Potosi, Mexico.
[k] Also at Università di Napoli Parthenope, Napoli, Italy.
[l] Also at Institute of Particle Physics (IPP), Canada.
[m] Also at Department of Physics, Middle East Technical University, Ankara, Turkey.
[n] Also at Louisiana Tech University, Ruston, LA, United States.
[o] Also at Departamento de Fisica and CEFITEC of Faculdade de Ciencias e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal.
[p] Also at Department of Physics and Astronomy, University College London, London, United Kingdom.
[q] Also at Department of Physics, University of Cape Town, Cape Town, South Africa.
[r] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
[s] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
[t] Also at Manhattan College, New York, NY, United States.
[u] Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.
[v] Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China.
[w] Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.
[x] Also at School of Physics, Shandong University, Shandong, China.
[y] Also at Dipartimento di Fisica, Università La Sapienza, Roma, Italy.
[z] Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France.
[aa] Also at Section de Physique, Université de Genève, Geneva, Switzerland.
[ab] Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal.
[ac] Also at Department of Physics, The University of Texas at Austin, Austin, TX, United States.
[ad] Also at Department of Physics and Astronomy, University of South Carolina, Columbia, SC, United States.
[ae] Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
[af] Also at California Institute of Technology, Pasadena, CA, United States.
[ag] Also at Institute of Physics, Jagiellonian University, Krakow, Poland.
[ah] Also at LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France.
[ai] Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia.
[aj] Also at Nevis Laboratory, Columbia University, Irvington, NY, United States.
[ak] Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom.
[al] Also at Department of Physics, Oxford University, Oxford, United Kingdom.
[am] Also at Department of Physics, The University of Michigan, Ann Arbor, MI, United States.
[an] Also at Discipline of Physics, University of KwaZulu-Natal, Durban, South Africa.
[*] Deceased.