IL NUOVO CIMENTO Vol. 32 C, N. 3-4 Maggio-Agosto 2009
DOI 10.1393/ncc/i2009-10463-y

Colloquia: IFAE 2009

Forward and diffractive physics at CMS

M. M. Obertino on behalf of the CMS Collaboration

Università del Piemonte Orientale - I-28100 Novara, Italy
INFN, Sezione di Torino - I-10125 Torino, Italy

(ricevuto il 19 Settembre 2009; pubblicato online il 20 Novembre 2009)

Summary. — A rich program of forward physics, including very low-x QCD dynamics, diffraction in the presence of a hard scale and photon-mediated processes, is being studied by the CMS Collaboration, taking advantage of the forward detector instrumentation around the CMS interaction point. We describe here the analyses planned for the first LHC data-taking period, when the istantaneous luminosity will be low (10^{29}–$10^{32}\,\mathrm{cm^{-2}\,s^{-1}}$) and the pile-up negligible. A centre-of-mass energy of 14 TeV is assumed.

PACS 13.85.-t – Hadron-induced high- and super-high-energy interactions (energy > 10 GeV).

1. – Introduction

Forward physics at the LHC covers a wide range of physics subjects whose defining characteristics are provided by particles produced at small polar angles θ and hence at large pseudo-rapidities η. The CMS detector [1] provides a wide η coverage in the forward region by means of the HF and CASTOR calorimeters. The first one is made of steel absorbers and radiation-hard quartz fibers for the fast collection of Cherenkov light and covers the regions $3 \leq |\eta| \leq 5$. The second one is a sampling calorimeter with tungsten plates as absorbers and fused silica quartz plates as active medium; it is currently installed only on one side of the interaction point and extends the CMS forward hermeticity to $-6.6 < \eta < -5.2$.

In the following we present a few selected studies on very low-x QCD dynamics, diffraction in the presence of a hard scale and photon-mediated processes; the analyses described will be carried out on the first LHC data characterized by negligible pile-up.

2. – Low-x physics

At the LHC the minimum accessible Bjorken-x decreases by a factor ~ 10 every two units of rapidity and values as low as $\sim 10^{-6}$ can be reached if the CASTOR calorimeter is used. This allows to study the proton's parton structure and the QCD parton evolution

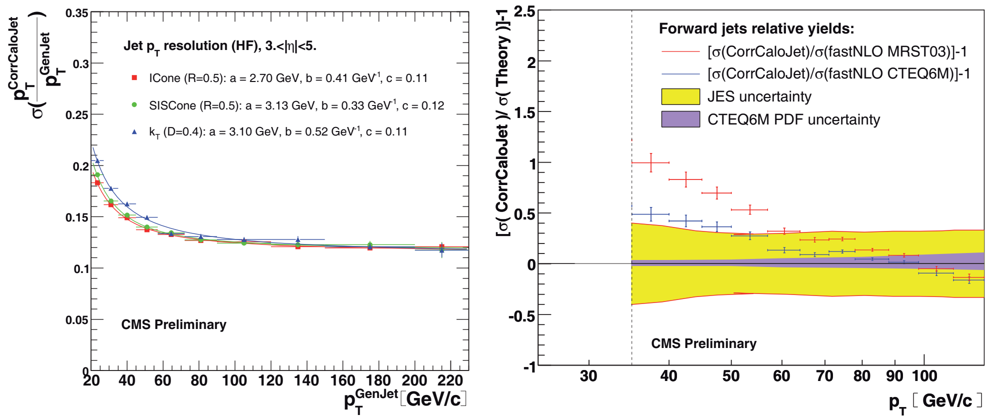

Fig. 1. – Left: p_T resolution *vs.* p_T in HF for different jet algorithms. Right: percentage differences between the reconstructed forward jet p_T spectrum and the fast NLO predictions for two PDFs. The error bars include the statistical and the energy resolution smearing error.

dynamics in a Q^2-x region not covered by previous experiments. In particular, forward jet measurements are a useful tool to constrain the proton parton distribution functions (PDFs) at low x and study the possible onset of the BFKL evolution.

The capabilities of the HF calorimeter to carry out precise jet measurements were studied with fully simulated and reconstructed QCD jet events generated with PYTHIA [2] in the range $p_T = 20$–$200\,\mathrm{GeV}/c$ [3]. As shown in fig. 1 left panel, a p_T resolution of about 20% at $40\,\mathrm{GeV}/c$, decreasing to 10% above $100\,\mathrm{GeV}/c$, was found. The expected jet p_T spectrum in HF for p-p collisions at 14 TeV was also studied. The measured spectrum, corresponding to an integrated luminosity of $1\,\mathrm{pb}^{-1}$, is compared to the fast NLO predictions for two different PDFs (MRST03 and CTEQ6.1M) in fig. 1 right panel. The jet spectra corresponding to the two PDFs are similar at high p_T while they differ by as much as $\mathcal{O}(60\%)$ below $\sim 60\,\mathrm{GeV}/c$. The study indicates that if the jet energy scale (main soure of systematic uncertainty) is known at the level of 5% or below and the PDF uncertainties are indeed as large as the differences between MRST03 and CTEQ6.1M, the CMS forward jet measurements could help constraining the PDFs in global-fit analyses.

Moving from HF to CASTOR and measuring the jet spectrum in the region $-6.6 \leq \eta \leq -5.2$, it is possible to distinguish among different QCD parton evolution models. Monte Carlo generator studies, in fact, indicate that an excess of high-energy forward jets in CASTOR would be a clear sign of BFKL evolution, where no ordering in transverse momentum is assumed, leading to hard partons produced at the beginning of the cascade close to the proton, *i.e.* in the forward direction.

3. – Diffraction with hard scale

A substantial fraction of pp interactions consists of diffractive reactions, $pp \to pXp$ or $pp \to pX$, in which the incoming proton(s) emerge from the interaction intact, or excited into a low-mass state, with an energy loss within a few per cent. Diffractive events are characterised by the exchange of a color singlet object with vacuum quantum numbers. The absence of colour flow between the proton(s) and the system X results in the topological signature of these events, *i.e.* large gap(s) in the rapidity distribution of the final state (large rapidity gap, LRG).

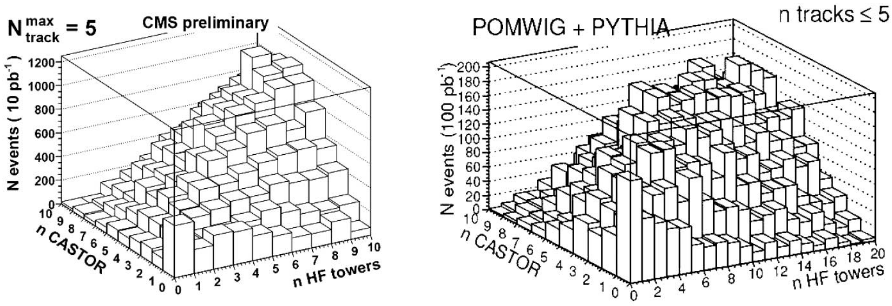

Fig. 2. – Two-dimensional multiplicity (HF *vs.* CASTOR) for the SD dijet (left panel) and W (right panel) analyses.

Diffractive reactions are predominantly soft but can also occur in the presence of a hard scale, as observed at UA8, HERA and Tevatron. The hard scale may be provided by jets, heavy quarks or the W or Z boson mass and allows perturbative QCD (pQCD) to be used. Cross-sections can then be factorized into a partonic cross-section, which describes the hard scattering and is calculable in pQCD, times a diffractive parton distribution function (dPDF), which can be interpreted as the proton PDF under the condition that the proton remains intact. Diffractive processes are thus additional tools to study the structure of the proton. In hadron-hadron collisions factorization is broken by rescattering between spectator partons, which fill the LRG. The resulting suppression of the diffractive cross-section is quantified by the rapidity gap survival probability, S^2, which is an important ingredient to be measured at the beginning of the LHC data taking.

Three preliminary studies have been performed by the CMS Collaboration to demonstrate the feasibility of measuring hard diffraction with the early LHC data by means of single diffractive (SD) dijet and W productions and the Υ photoproduction. A center-of-mass energy of 14 TeV and a zero pile-up scenario, which allows a rapidity gap based selection, were assumed. All Monte Carlo samples were processed through detector simulation, trigger emulation, and reconstruction, except for what concerns CASTOR for which generator level information were used.

3˙1. *Single diffractive W and dijet production.* – The studies of SD W and dijet production ($pp \to pX$, with X including a W or a dijet system) carried out by the CMS Collaboration are reported in [4] and [5], respectively. The single diffractive signals were simulated with the POMWIG Monte Carlo generator [6], assuming $S^2 = 5\%$. Non-diffractive events were simulated with PYTHIA [2] or MADGRAPH [7]. The W was studied in the $\mu\nu$ decay channel.

Diffractive events have, on average, lower multiplicity than the non-diffractive ones both in the central region and in the hemisphere which contains the scattered proton, the so-called *rapidity gap side*. Signal event candidates were therefore selected on the basis of the multiplicity distribution in the central tracker and in the forward calorimeters (HF and CASTOR). Figure 2 shows the number of towers with activity above noise level in HF *versus* in CASTOR for events with track multiplicity in the central tracker ≤ 5. The number of events is normalized to an integrated luminosity for single interactions of $10\,\text{pb}^{-1}$ and $100\,\text{pb}^{-1}$ for the dijet and the W channel, respectively. A simple way to isolate a sample of signal events from these plots is to use the zero-multiplicity bins, where diffractive events cluster and the non-diffractive background is small. Our studies show that when an effective integrated luminosity for single interactions of $10\,\mathrm{pb}^{-1}$ becomes available, single diffractive dijet production can be observed with $\mathcal{O}(300)$ signal events. Once an integrated luminosity of $100\,\mathrm{pb}^{-1}$ is reached, also the SD-W channel becomes visible, with $\mathcal{O}(100)$ events expected. The simple measurement of event yields may also give early information on the rapidity gap survival probability.

3·2. *Exclusive* Υ *photoproduction.* – The Υ mesons can be exclusively produced through the reaction $pp \to p\Upsilon p \to p(l^+l^-)p$, in which one of the protons radiates a quasi-real photon that interacts, via colour-singlet exchange, with the other proton. This reaction has been studied at HERA, and can be investigated at CMS with the Υ decaying in the $\mu^+\mu^-$ channel [8]. Assuming the STARLIGHT Monte Carlo [9] cross-section prediction, the $1S$, $2S$ and $3S$ resonances will be clearly visible in the $\mu^+\mu^-$ invariant mass spectrum with $100\,\mathrm{pb}^{-1}$ of single interaction data. The LHC measurements would extend the accessible range in $W_{\gamma p}$ (γp center-of-mass energy) for $\sigma(\gamma p \to \Upsilon(1S)p)$ by approximately a factor three with respect to HERA. A study of the t dependence of the cross-section in these events is also possible using the p_T^2 distribution of the Υ as an estimator of the true t distribution. This dependence is sensitive to the two-dimensional gluon distribution of the proton and would give access to its generalized parton distribution functions (GPDs). Finally, the rapidity gap survival probability for this process is expected to be close to unity [10]. The yield of exclusive Υ photoproduction should thus be essentially unsuppressed and can be used to further constrain the understanding of the rapidity gap survival probability.

4. – Photon-mediated processes

Dimuon and dielectron final states with no significant additional activity in the CMS detector can be produced in gamma-mediated processes at the LHC. The protons radiating the photons often survive the collision intact and the resulting events, $pp \to p(\gamma\gamma)p \to p(l^+l^-)p$, exhibit the same topology as the diffractive ones. A study carried out by the CMS Collaboration with full detector simulation and reconstruction assuming an early data-taking scenario with no pile-up events [8] shows that $\mathcal{O}(700)$ $\mu^+\mu^-$ events and $\mathcal{O}(70)$ e^+e^- events can be obtained in $100\,\mathrm{pb}^{-1}$ of data. The events were selected by requiring exclusivity conditions in central detectors and no activity above noise level in forward ones. Using the very precisely known QED cross-section of these processes, an absolute luminosity measurement with a 4% precision can be performed with these events.

REFERENCES

[1] CMS Collaboration, *JINST*, **3** (2008) S08004.
[2] Sjostrand T., Mrenna S. and Skands P., *JHEP*, **0605** (2006) 026.
[3] Cerci S. and d'Enterria D. (CMS Collaboration), *AIP Conf. Proc.*, **1105** (2009) 28.
[4] CMS Collaboration, CMS PAS-DIF-07-002 (2008).
[5] CMS Collaboration, CMS PAS-FWD-08-002 (2008).
[6] Cox B. E. and Forshaw J. R., *Comput. Phys. Commun.*, **144** (2002) 104.
[7] Alwall J. *et al.*, *JHEP*, **0709** (2007) 028.
[8] CMS Collaboration, CMS PAS DIF-07-001 (2007).
[9] Klain S. R. and Nystrand J., *Phys. Rev. Lett.*, **92** (2004) 142003.
[10] Ryskin M. G., private communication (2008).