CERN-LHCC-2014-024 ; TOTEM-TDR-002-ADD-1
11 November 2014

TOTEM-2014-005

Addendum to the TOTEM TDR: Timing Measurements in the Vertical Roman Pots of the TOTEM Experiment LHCC document CERN-LHCC-2014-020

including questions/answers from/to the referees

The TOTEM Collaboration

Abstract

This document details the answer to the questions and observation raised by the referees after the LHCC open presentation of the TOTEM Timing Upgrade TDR

CERN-LHCC-2014-024 / TOTEM-TDR-002-ADD-1
14/11/2014

Contents

Introduction: referees' document

This is the document containing the questions and comments made by the TOTEM referees to the TOTEM Timing Upgrade TDR [1] that were received by TOTEM on the 22nd of october 2014:

22 October 2014

LHCC referees' comments/questions on the TOTEM Timing Upgrade TDR: Timing measurements in the Vertical Roman Pots of the TOTEM experiment

U. Bassler, C. Cecchi, M.L. Mangano, P. Newman

We think this is an important step forwards for LHC proton tagging towards the use of timing for pile-up suppression, for which there are much more aggressive plans around. TOTEM has the best experience and track-record in the world for operating these detectors and we don't see any show-stoppers in the technical realisation. Nevertheless, the target resolution for the proposed diamond technology has not been achieved as yet. The summer test beams gave a time resolution of 200 ps/detector. This is a factor of 2 above the required resolution of 100ps/detector, which TOTEM expects to be achieved during the forthcoming October and November test beams.
If this does not happen, we would like TOTEM to address the following points:

1. Is there a back-up plan for the detector development? What are the implications of a lower resolution for the background suppression? For a standalone RP measurement, this likely scales linearly with the timing resolution; how much of this additional background can however be further suppressed by subsequent cuts (vertex matching with CMS tracks, T2 vetoes, etc)? Even in the case of an achieved resolution better than the 100ps goal, it would be useful to have more details on the scaling law of backgrounds w.r.t. timing resolution.

The discussion of the physics potential needs much more quantitative detail than what is currently available in Table 1 and Section 2. We understand that more material is available, and part of it was shown to us during the meeting at the September LHCC. But this must be documented and written up, possibly as an addendum to the TDR. Given that an important fraction of this physics programme relies on the role of the CMS detector and of an integrated trigger, this document should also discuss in more detail the impact of a realistic assessment of the CMS projected performance. More specifically, the following points could be clarified, particularly in the context of the requests for the 2015 runs:

2. It is not clear which parameter is used to define the optimal running conditions for 2015. Section 3.1 says that R=P(n>1)/P(n>0) should be kept below 5%. The following Sections, e.g. 4.1.3, use instead μ<5%,

which implies R<2.5% (from Table 3). This leads to an ambiguity of a factor of 2 in luminosity. Which one is right?

3. It would greatly help to show one case in full detail (e.g. f_o signal or χ_c spin as in Hubert's talk), but then the explanation for extrapolations to other cases should be clear. Some details of the analysis must be given, to understand to which extent this is fully optimized. For example, with a 20 MeV mass resolution, one could imagine performing a shape analysis of a signal 100 MeV wide, resulting in a better $S/\sqrt{B}$ discrimination than was obtained by the simple event counting in a 100 MeV window.
4. Concerning photoproduction of J/ψ: it seems unlikely that CMS can reconstruct the dimuon final state if the p_T is small, since 1.5 GeV muons don't reach the muon detectors. How does this impact the range of studies that are foreseen for this process?
5. The results of the sample analyses proposed above should be shown for various integrated luminosities and different mu conditions. We need to answer the following question: if a $10pb^{-1}$ run cannot be delivered, what is the minimum luminosity, and what are the most effective running conditions, that could deliver relevant physics results?
6. In Section 4.2.2, the document refers to both possibilities that TOTEM and CMS DAQ are fully integrated, or that they are not. What is the timescale for deciding which is the case? What would be the impact on physics analyses from the 2015 run in the latter case?

In relation to the physics programme with timing detectors:

7. Along the lines of previous requests, we would like to see explicit and complete examples of physics analyses and projected results for the $\mu = 0.5$ CEP / hard diffraction runs.
8. The TDR estimates 3% total background probability for double tags at $\mu = 0.5$ and $\beta^* =$90m. That doesn't sound too aggressive. Could it be pushed to a significantly larger number whilst remaining manageable? This sort of question is already discussed a bit e.g. in the Section 'pile-up rejection for hard CD dijets', but it would be good to see the corresponding studies described in more detail.
9. Section 2.2.3 describes the search for missing mass and momentum candidates. This part of the programme is one of the most luminosity-demanding. Are there explicit examples, in terms of discovery potential, or of exclusion limits, where the complementary role of these searches w.r.t. the usual BSM searches can be shown? Is the physics reach, at 100pb-1, sufficient to discover/exclude BSM scenarios that would have eluded other searches?

Other general questions:

10. All of the listed physics topics are double tagged. Is there also a prospect of a single tagged (single diffractive dissociation) programme?

11. What sort of ξ and t resolutions do you need / expect? Is it true that for most of the physics the proton tags are more important than the kinematic reconstruction?

12. We guess relative and absolute alignment between the different detectors is more important than the individual detector resolution ($\approx 10\mu$m in fig 5). Is the plan to do this in the same way as in Run 1? Does that require an elastic sample and do you expect to be able to get one? Maybe there are ways to do it relative to the CMS tracker using some well-chosen resonance?

13. Page 17 (Section "Reconstruction resolution") also suggests that the limiting factor may be the interaction point size (113 μm). How does this translate into a 0.6% ξ resolution or in the following text about very low ξ protons?

14. Figure 6 shows acceptance vs central diffractive mass for double-tagged events, assuming 10 sigma approach to the beam. We guess this also corresponds to the statement e.g. in the abstract that the acceptance covers all ξ for $|t| > 0.01 \mathrm{GeV}^2$, assuming some t slope? It would be interesting to know how that acceptance varies with the closest approach to the beam.

Costs and schedule: these sections are rather sketchy and poorly documented, they are hard to understand. In particular:

15. Does "allocated" in Table 7 mean that the funds have been already approved by the funding agencies? Is the whole cost of the project fully covered by the contributions listed in the table?

16. The schedule format makes it very hard to read. We understand that the timeline of several schedule items does not refer to the actual time required to complete them, but rather to time windows during which they can be achieved. More details should be given about the actual completion/installation needs of the various components. For example, what would be the impact of not having a full detector ready by September 2015? What are the tests envisaged after September, if a detector is installed? Do they require special runs or are they fully passive?

On the general comment by the referees on the physics potential

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than what is currently available in Table 1 and Section 2.  We understand
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possibly as an addendum to the TDR. ...
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Invited by the referees' comment reproduced above, we show here, as an example, the physics impact of our measurements in the search for glueballs. Another example of the physics potential of our experimental apparatus is given in the answer to Question n. 9 where we examine in detail the searches for missing mass.

Glueball candidates

Either the $f_0(1500)$ or the $f_0(1710)$ is in excess to the meson $SU(3)$ multiplet and both are resonances with mass, spin, parity, and decay channels compatible with glueball (e.g. suppressed gamma-gamma mode).

Unified lattice calculations from many authors [2, 3] now predict the 0^{++} glueball at 1.7 GeV within $\sim$ 100 MeV of overall (systematic and statistical) uncertainty favoring the $f_0(1710)$ candidate.

Formerly proposed mesons-glueball mixings [4, 5, 6] relied on wrong mass hierarchy (*uu*, *dd*, *gg*, *ss*) and have been obsoleted by current calculations [7, 8] based on the correct (*uu*, *dd*, *ss*, *gg*) mass hierarchy giving a glueball $\gtrsim 95\,\%$ purity at ~ 1.7 GeV.

The key open question

The WA102 experiment (and its predecessors) [4, 5, 6] disfavored the $f_0(1710)$ to be the glueball by reporting the anomaly that its decay in the kaons channel exceeded its decay in the pions channels they could observe, contrarily to the case of the $f_0(1500)$. This raised the problem of a higher coupling to the s-quark over the u,d-quarks unexpected for a glueball (although authors [9] noted a possible coupling to quark mass for pure gluonic states decay). Moreover the predicted decay mode into $\rho\rho$ has not been observed so far.

The observation by TOTEM+CMS of the decay $f_0(1710) \to \rho\rho$:

- would be the "first measurement" (to be included in the PDG),
- would change the branching ratio of the decay modes into kaon channels vs 'pionic' channels and therefore could renormalize the expected couplings to u,d-quarks vs s-quark in the glueball decay,
- would, in relation to the measurement of the decay to KK, bring additional knowledge about the coupling to quark masses.

The $f_0(1710)$ mass measurements (consistently pointing to a 1700–1710 MeV mean value within uncertainties) do not allow the PDG to do a reliable average due to the systematically shifted measurements by BELLE and BES. The currently most precise existing measurement gives 1701 MeV from ZEUS [10]. A high precision measurement at the LHC could put a decisive word on the $f_0(1710)$ mass.

The $f_0(1710)$ has been measured in the past as an f_2 by several experiments, although presently it has been consistently found to be an f_0 by modern experiments and the issue is considered solved [11]. However a thorough and redundant spin analysis is mandatory for any $f_0(1710)$ measurement to confirm the quantum numbers of the measured resonance as a glueball candidate, as well as to cross-calibrate with the mass measurement the purity of the event selection.

While for the $f_0(1500)$ the yields, decay channels and branching ratios have been extensively measured, the $f_0(1710)$ branching ratios are controversial in the literature, are largely unknown, and the main decay channels are just described as “seen” in the PDG. As already mentioned, allowed decay modes such as into $\rho\rho$ have never been observed. A systematic and quantitative study of the decay modes of the $f_0(1710)$ can be performed at the LHC via central diffractive exclusive production.

Experimental limitations of previous measurements

Former experiments (ISR, SPS, WestArea,...) did not have sensitivity to the $\rho\rho$ decay because of limited reach in invariant mass ($\lesssim 1.5\,\mathrm{GeV}$) and/or in the $4\,\pi$ final state.

The only experiment [12] which could analyse $4\,\pi$ final states searching for $\rho\rho$ decay of glueball candidates had the analysis faked by the old assumption that the $f(1710)$ was an f_2 (as wrongly measured by several previous experiments at that time and also reported by the PDG).

Attempts from modern experiments (FNAL, LHC, RHIC...) lacked either the purity due to the absence of proton-proton tagging or the mass resolution already on the two charged particles final states.

The previously assumed gluon-rich conditions for production diffractive processes, based on which relative yields for mesons and glueballs were estimated in the past, are today (after HERA) known to have been not pure in terms of gluonic exchange.

The unique characteristics of LHC+TOTEM+CMS

- LHC operates at $\sqrt{s}$ such that ~ 1–$10\,\mathrm{GeV}$ invariant masses can be produced diffractively with $\xi_{1,2} \sim 10^{-3}$–10^{-4} ensuring pure gluonic exchange conditions.
- TOTEM can measure and tag both protons emerging from central diffraction interactions.
- TOTEM+CMS can effectively select/cut with high purity (vertexing) on the required very low ξ range.
- CMS can reconstruct 4 charged particles in the tracker with an invariant mass resolution of 20–30 MeV : with sufficient statistics even the convolution effects of very close resonances can be deconvoluted directly in the data without model-dependent and multi-parameters-dependent partial-wave analyses.

Question & Answer n. 1

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1.  Is there a back-up plan for the detector development?  What are the
implications of a lower resolution for the background suppression?  For a
standalone RP measurement, this likely scales linearly with the timing
resolution; how much of this additional background can however be further
suppressed by subsequent cuts (vertex matching with CMS tracks, T2 vetoes,
etc)?  Even in the case of an achieved resolution better than the 100ps goal,
it would be useful to have more details on the scaling law of backgrounds
w.r.t.  timing resolution.
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The background suppression that can be obtained by cuts based on the reconstructed track parameters depends on the physics channel under study. As an example, in exclusive production studies an important background-suppression tool that can be added to timing detector cuts is to impose a balance between the P_T of the protons and that of the tracks in CMS. In fact in this case the information from timing detectors can be used to better understand the background and to reduce the analysis systematics. On the other hand in exclusive searches time information will allow to understand if events with non-balanced P_T are due to pile-up or are related to acceptance or threshold in the CMS detectors.

As benchmark to understand the implication of the timing detector resolution on the background suppression we use a sample of inclusive DPE: only events with one central reconstructed vertex are considered. The case corresponding to the baseline resolution of $\sigma_T = 50$ps ($|Z_{CMS} - Z_{protons}| < 2$ cm), results in an impurity of the selected events equal to 5%; if the resolution is $\sigma_T = 100\,ps$ ($|Z_{CMS} - Z_{protons}| < 4$ cm), the impurity increases to 8.5%. These results have to be compared to the case where no timing detectors are available and the only cut which can be used is the multiplicity of tracks in RPs. In this case the impurity is 22%. The selection efficiency in the three examples is the same.

The further request of T2 in veto is expected to improve the purity of the sample in most of the analysis channels. In the examples described above, if no timing detectors are available the impurity goes from 22% to 10%, while with timing detectors with baseline resolution the impurity goes from 5% to 1%. However, the efficiency of the T2-veto, as measured from data, is $\sim 50\%$, mainly due to the rapidity distribution of the DPE events. In addition to the large fraction of events excluded from the analysis, the T2-veto will also limit the study of the DPE process to topologies with small diffractive masses.

In conclusion: the deterioration of the timing detector resolution has a direct impact on the background suppression (almost linear) and the need of the timing measurement has been further demonstrated.

Question & Answer n. 2

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2.  It is not clear which parameter is used to define the optimal running
conditions for 2015.  Section 3.1 says that R=P(n>1)/P(n>0) should be kept
below 5%.  The following Sections, e.g.  4.1.3, use instead μ<5%, which
implies R<2.5% (from Table 3).  This leads to an ambiguity of a factor of
2 in luminosity.  Which one is right?
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The calculations in Section 4.1.3 were performed for $\mu = 0.05$, which was the pileup level of the data taken in 2012 at $\sqrt{s} = 8\,TeV$ and $\beta^* = 90\,\mathrm{m}$. Thus these evaluations, directly based on real data, can be considered with a high level of confidence. Estimations for other values of μ can be obtained by scaling.

Since for fixed β^*, normalised emittance and bunch population the pileup level scales linearly with the centre-of-mass energy, realistic values of μ at $\sqrt{s} = 13\,\mathrm{TeV}$ are indeed of the order of 10% (which is also the value given for 2015 in Table 1). The specific scenario elaborated in Section 3.1 for a typical bunch population of 7×10^{10} p/b and an emittance of $2\,\mu\mathrm{m\,rad}$ yields $\mu = 0.13$ which is still acceptable for the analysis. To obtain the different pileup background contributions for $\mu = 0.13$ instead of 0.05 of Section 4.1.3 , it is enough to scale the number of pileup events linearly with μ, i.e. to multiply by a factor 2.6.

To experimentally verify the background scaling with μ, it is planned to take data at several values of μ by varying the bunch population.

Question & Answer n. 3

3. It would greatly help to show one case in full detail (e.g. f_o signal or χ_c spin as in Hubert's talk), but then the explanation for extrapolations to other cases should be clear. Some details of the analysis must be given to understand to which extent this is fully optimized. For example, with a 20 MeV mass resolution, one could imagine performing a shape analysis of a signal 100 MeV wide, resulting in a better $S/\sqrt{B}$ discrimination than was obtained by the simple event counting in a 100 MeV window.

Sensitivity to the invariant mass

Preliminary analysis of the common CMS-TOTEM data reveals sensitivity to events showing possible decay of $f_0(1710) \to \rho\rho \to 4\pi$. Due to the limited amount of data, the $\mathbb{P}\,\mathbb{P} \to \rho\rho$ background was estimated with the DIME Monte Carlo [13] event generator for exclusive meson pair production via double Pomeron exchange. CMS tracker acceptance and resolution was modeled applying the $|\eta|$ and p_T acceptance and resolution as in the CMS Tracker TDR [14]. Since DIME's $\rho\rho$ cross-section uncertainty can reach a factor of 2, an upper limit was taken.

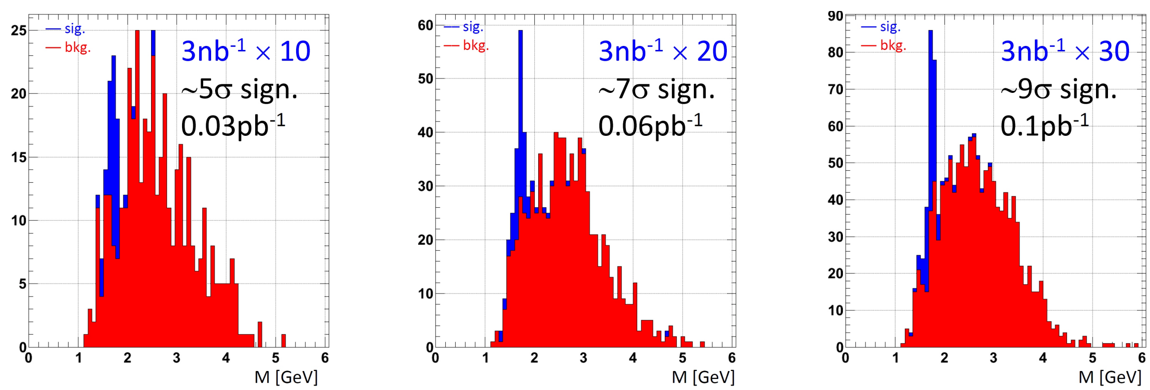

Figure 1: *Signal and background distributions for $f_0(1710) \to \rho\rho \to 4\pi$ with their local significance. Three different integrated luminosity scenarios are presented:* $0.03\,pb^{-1}$, $0.06\,pb^{-1}$ *and* $0.1\,pb^{-1}$ *together with the local peak significance.* $\mathbb{P}\,\mathbb{P} \to \rho\rho$ *background estimation is based on DIME [13].*

Figure 1 shows examples of generated signal and background distributions of $f_0(1710) \to \rho\rho \to 4\pi$ with their local significance, for three different integrated luminosity scenarios presented as a multiplicative factor of the currently available data. According to the simulation, at least $0.06\,\text{pb}^{-1}$ (or a factor of 20 of integrated luminosity increase) is required to observe the resonance. Clearly, the quoted local significance is further reduced by the 'look-elsewhere effect'. Similar integrated luminosity is needed for the measurement of

$f_0(1500) \to K^+K^-$ which should be present in the data sample. Since this decay channel is well measured, it is of particular interest for calibration purposes and to demonstrate the sensitivity and performance of the particle identification.

Decay characterization

The branching ratios of the f_0 and f_2 resonances may have severe implications in view of identifying the resonances as glueball candidates. The knowledge of the cross-section of $I\!P\,I\!P \to f_0(1710)$ as well as of the branching ratio to K^+K^- is limited: however, previous measurements [15, 16, 17, 18] demonstrated that such decay channel is dominantly seen. As simulations indicate that there is sensitivity of the detector for such a signal, the observation in the existing sample would be limited by the recorded luminosity: if the $\sigma \times BR$ is lower than $\sim$ 1 nb, then no events would be observed. As the branching ratios for low mass resonances may easily differ by an order of magnitude (e.g. for $f_0(1500)$ $\Gamma_{KK} = 9\,\%$, $\Gamma_{\eta\eta} = 5\,\%$ and $\Gamma_{4\pi} = 50\,\%$) and assuming a similar range for $f_0(1710)$, a factor of 10 of integrated luminosity would be required in order to see both K^+K^- and 4π decays modes. Combining this with the requirement described in the previous Subsection "Sensitivity to the invariant mass", the observations should be possible with 0.6–1 pb^{-1}, while these will become difficult with integrated luminosity equal or lower than $\sim 0.3\,\mathrm{pb}^{-1}$.

Spin analysis requirements

The estimate of the sample size requested for angular momentum analysis is based on the study of $I\!P\,I\!P \to f_J \to \rho\rho \to 2(\pi^+\pi^-)$ decay, which is of high importance for characterisation of low mass glueball candidates. The study was carried out with a Monte Carlo generator with a simplified detector acceptance model.

For simplicity no background was assumed. The selection rule of $J_z = 0$ for central diffractive system was applied, together with the assumption of the $\rho\rho$ angular momentum $L_{\rho\rho} = 0$. The amount of data taking requested from TOTEM should enable distinction between the $f_0 \to \rho\rho \to 2(\pi^+\pi^-)$ and the $f_2 \to \rho\rho \to 2(\pi^+\pi^-)$ reactions.

The amplitudes used to generate and fit the sample were expressed with spherical harmonics $|1\,m_1\rangle$ and $|1\,m_2\rangle$:

$$|J=0;J_z=0\rangle = \sum_{\substack{m_1+m_2=0\\ |m_{1,2}|\le 1}} \langle 1\,m_1;1\,m_2|00\rangle |1\,m_1\rangle|1\,m_2\rangle \qquad (1)$$

$$|J=2;J_z=0\rangle = \sum_{\substack{m_1+m_2=0\\ |m_{1,2}|\le 1}} \langle 1\,m_1;1\,m_2|20\rangle |1\,m_1\rangle|1\,m_2\rangle, \qquad (2)$$

where $\langle 1\,m_1;1\,m_2|00\rangle$ and $\langle 1\,m_1;1\,m_2|20\rangle$ are the Clebsch-Gordan coefficients for $J=0$ and $J=2$ respectively.

The spin J of the f_J resonance affects the angular distributions of the reaction products. This can be demonstrated with the marginal distributions of which the most indicatives are:

- the angular correlations between the leading protons,

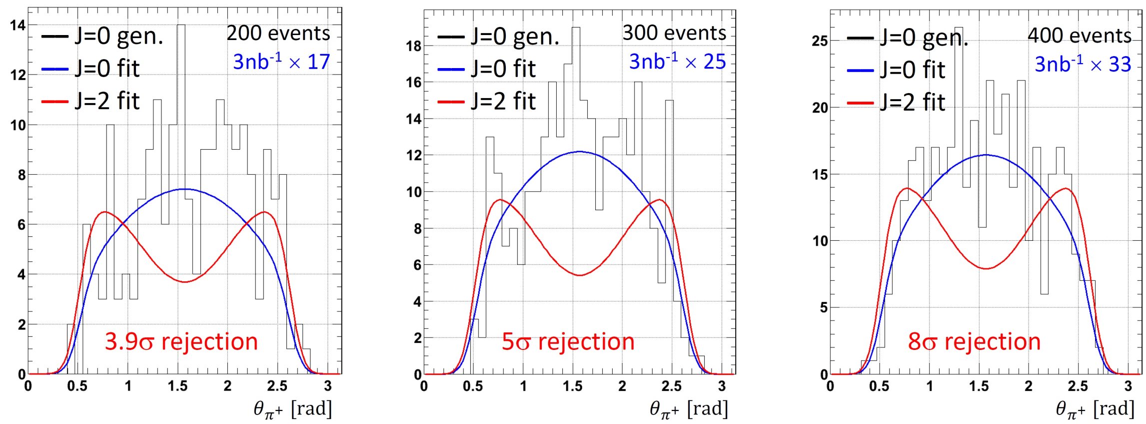

Figure 2: *Distribution of the polar angle θ_{π^+} of the pair of $\pi^+\pi^-$ from the ρ with $\eta > 0$, produced in the reaction $f_J \to \rho\rho \to 2(\pi^+\pi^-)$. The histograms represent the generated sample, and the blue curve is the fit to the simulated data for the theoretical prediction of $J = 0$. The red curve represents the fit with the assumption of $J = 2$. The left, central and right plots show results from samples of 200, 300 and 400 events, corresponding to the integrated luminosities of $3\,nb^{-1} \times 17$, $3\,nb^{-1} \times 25$ and $3\,nb^{-1} \times 33$ respectively.*

- $\rho \to \pi^+\pi^-$ angular distributions
- angular correlations between the 2 pairs of $\pi^+\pi^-$.

The integrated luminosity requirements for an ideal angular momentum study are illustrated in Figures 2, 3 and 4. Figure 2 shows the sensitivity of the spin J determination allowed by the distribution of the polar angle θ_{π^+} of the pair of $\pi^+\pi^-$ from the ρ with $\eta > 0$, produced in the reaction $f_J \to \rho\rho \to 2(\pi^+\pi^-)$. The rejection of a wrong $J = 2$ hypothesis is possible with at least 300 events, corresponding to an integrated luminosity 25 times higher than in the available CMS-TOTEM sample taken in 2012 (=75 nb^{-1}).

A similar integrated luminosity requirement is imposed by the spin determination from the azimuthal and polar angle difference ($\Delta\varphi_{\rho_1\rho_2}$, $\Delta\theta_{\rho_1\rho_2}$) between the $\pi^+\pi^-$ pairs, as illustrated in Figures 3 and 4. Similarly, at least about 300 events are required which would correspond to =75 nb^{-1}.

However, the considerations illustrated by Figures 2, 3 and 4 are not realistic, since they do not take into account the Central Diffraction background leading to 4π states from $I\!P\,I\!P \to \rho\rho$, $I\!P\,I\!P \to \rho\pi\pi$, $I\!P\,I\!P \to 4\pi$. Moreover, in the vicinity of the $f_0(1710)$ there are other resonances, such as the $f_2(1640)$ or $f_2(1810)$, which partially overlap in the invariant mass spectrum. The decay amplitude coupling constants of a given resonance may differ as a function of the invariant mass M.

Finally the $\rho\rho$ angular momentum $L_{\rho\rho}$ needs to be properly determined. A realistic spin-parity analysis requires therefore a study of the angular amplitudes as a function of the invariant mass in a wider interval than the resonance width itself to make possible the deconvolution of the overlapping contributions coming from adjacent resonances and background. Similar

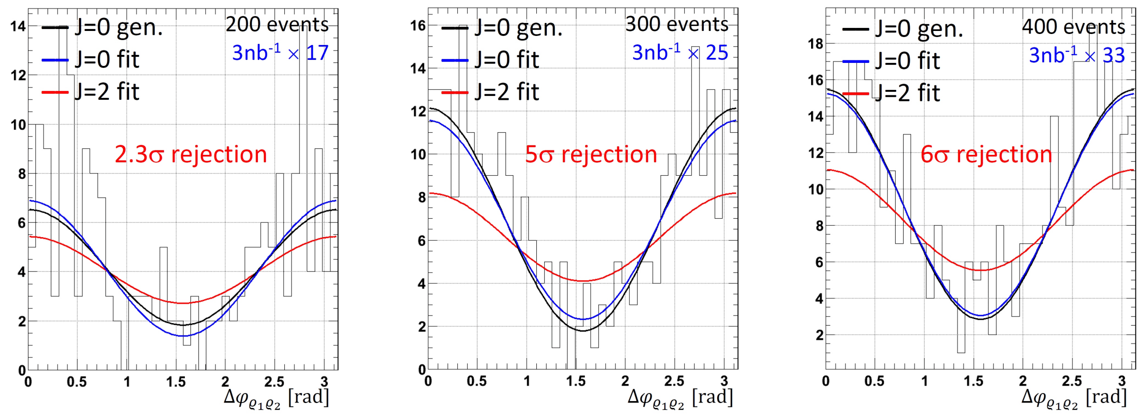

Figure 3: *Distribution of the azimuthal angle difference* $\Delta\varphi_{\rho_1\rho_2}$ *between the two* $\pi^+\pi^-$ *pairs in the reaction* $f_J \to \rho\rho \to 2(\pi^+\pi^-)$. *The histograms represent the generated sample according to the theoretical prediction for* $J = 0$ *indicated by the black curve. The blue curve is the fit to the simulated data for* $J = 0$. *The red curve represents the fit with the assumption of* $J = 2$. *The left, central and right plots show results from samples of 200, 300 and 400 events, corresponding to the integrated luminosities of* $3\,nb^{-1} \times 17$, $3\,nb^{-1} \times 25$ *and* $3\,nb^{-1} \times 33$ *respectively.*

approaches were already successfully employed in low mass resonance studies e.g. [17].

The spin-parity analysis therefore has to be performed in mass steps ΔM. The lowest step size ΔM is limited in our case by the mass reconstruction resolution $\sigma(M) \approx 30\,\text{MeV}$ determined by the CMS tracker p_T uncertainty. The largest possible step size could be a fraction of the resonance width but nevertheless should not exceed $\sim 40\,\text{MeV}$.

Assuming a uniform invariant mass distribution in the channel $I\!P\,I\!P \to \rho\rho$ over the range $1.3\,\text{GeV} < M < 4\,\text{GeV}$, at least 400 events per bin of width $\Delta M = 30\,\text{MeV}$ would be required to perform the spin-parity analysis. This would total to 36×10^3 events distributed over 90 bins. Assuming a visible cross-section of $I\!P\,I\!P \to \rho\rho$ of $\sim 4\,\text{nb}$, the required integrated luminosity would be $9\,\text{pb}^{-1}$, a factor 3000 larger than the existing data sample.

The requirements defined by the analysis can be slightly relaxed. With the bin size $\Delta M = 40\,\text{MeV}$ and an average number of 300 events per bin the integrated luminosity of about $5\,\text{pb}^{-1}$ will still make the study feasible. However, for $\leq 2\,\text{pb}^{-1}$ the spin-parity analysis is in principle unfeasible: the bin size becomes too large compared to the typical resonance width of 100 MeV and/or the number of events per bin becomes too low, contrary to the requirements illustrated in Figures 2, 3 and 4.

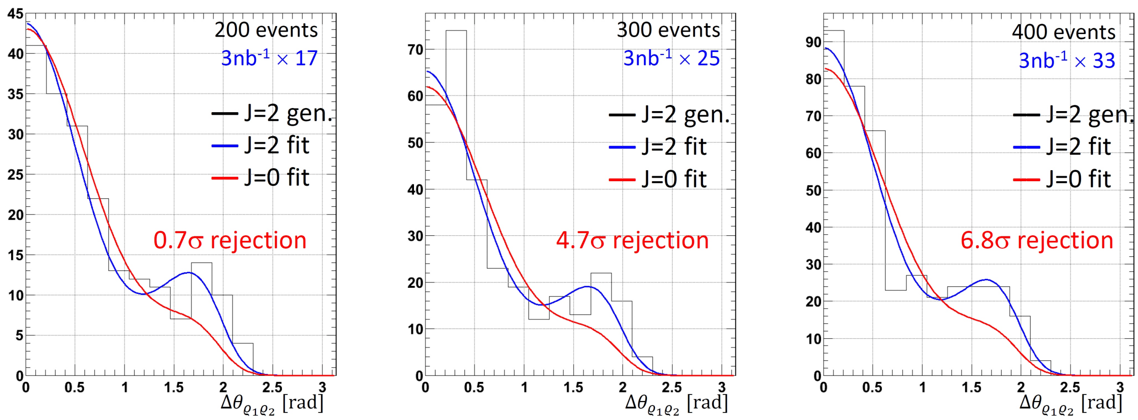

Figure 4: *Distribution of the polar angle difference $\Delta\theta_{\rho_1\rho_2}$ between the two $\pi^+\pi^-$ pairs in the reaction $f_J \to \rho\rho \to 2(\pi^+\pi^-)$. The histograms represent the generated sample and the blue curve the theoretical prediction for $J = 2$. The red line demonstrates the fit with the assumption of $J = 0$. The left, central and right plots show results from samples of 200, 300 and 400 events, corresponding to the integrated luminosities of $3\,nb^{-1} \times 17$, $3\,nb^{-1} \times 25$ and $3\,nb^{-1} \times 33$ respectively.*

Question & Answer n. 4

4. Concerning photoproduction of J/ψ: it seems unlikely that CMS can reconstruct the dimuon final state if the p_t is small, since 1.5 GeV muons don't reach the muon detectors. How does this impact the range of studies that are foreseen for this process?

The predicted cross-section of Superchic [19] for exclusive J/ψ($\rightarrow \mu^+\mu^-$) production at 13 TeV is about 5.35 nb. This agrees with the prediction of Starlight [20] within 10 %. Given the large cross-section and the small width of the J/ψ ($\ll$ resolution of mass reconstruction), exclusive J/ψ candidate events with sufficient purity can be selected in the double arm RP triggered data sample. An integrated luminosity of 5 pb^{-1} should contain O(10000) candidates if similar selections as in the glueball analysis without any particle identification requirement are used. This would enable important measurements of the azimuthal difference $\Delta\phi$ of the outgoing protons in exclusive J/ψ production as well as cross-section measurements for the process at higher p_T values for the produced J/ψ, where the proton diffractive dissociation background is large. These measurements would be complementary to the existing ALICE [21] and LHCb [22] measurements that fully rely on rapidity gaps and suffer from a large proton dissociation background. A precise determination of the J/ψ ! p_T spectrum at higher values of p_T may reveal deviations due to the Odderon, see Fig. 5.

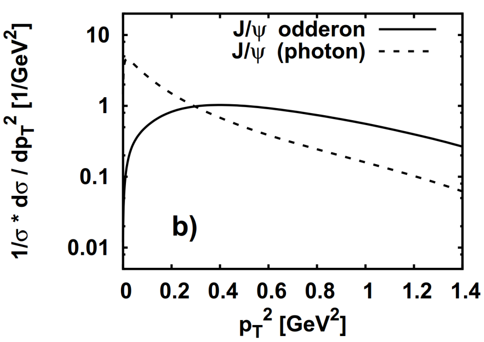

Figure 5: *The prediction of the normalized differential cross-section for exclusive J/ψ production at LHC through Odderon-Pomeron and photon-Pomeron fusion. From Ref. [23].*

It is correct that a large fraction of the muon produced in exclusive J/ψ events never reach the muon detectors (coverage $0 < |\eta| < 2.4$) but whenever the muon identification would be available, it would be used to enhance the purity of the selected sample. The exact muon tagging efficiency versus p_T and η can only be determined on the data itself but the efficiency estimates of the CMS inclusive J/ψ analysis on 2010 pp data [24] give an indication of what performances can be obtained. Based on those estimates, the efficiency of single muon identification increases with $|\eta|$ and p_T of the J/ψ and is about 40 % with a J/ψ $p_T \approx 1$ GeV for J/ψ's produced at an $|\eta| \approx 2$. The most favourable rapidity range is in the $1<|\eta|<2.4$ for the muon identification. Note however that the muon tagging contributes significantly at the p_Ts relevant for the search of effects due to the Odderon.

Question & Answer n. 5

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5.  The results of the sample analyses proposed above should be shown for
various integrated luminosities and different mu conditions.  We need to
answer the following question:  if a 10pb^-1 run cannot be delivered, what
is the minimum luminosity, and what are the most effective running condi-
tions, that could deliver relevant physics results?
```

As shown above, an integrated luminosity of $4-5\,\mathrm{pb}^{-1}$ at $\beta^* = 90\,\mathrm{m}$ is needed as a minimum in 2015 to perform the described physics programme. Assuming standard machine parameters for the 90 m runs (702 bunches and a normalised emittance of $2\,\mu$m rad), the only free parameter is the bunch population ($0.4-1.5\times10^{11}$ protons/bunch) which determines the luminosity and hence μ. However, the integrated luminosity depends critically on the running scenario. With a proton density of 0.7×10^{11} per bunch (corresponding to $\mu = 0.13$), the set-up time should, on average, not exceed 10 hours per run resulting in 14 hours running time per day. With identical beam conditions over 7 days and no interruptions, an integrated luminosity of $4.2\,\mathrm{pb}^{-1}$ can be accumulated assuming a luminosity lifetime of more than 20 hours, which the previous 90 m run in 2012 demonstrated to be realistic. To adapt to the different physics objectives and to s! tudy the impact of pileup, it is important that also a run with higher pile-up (e.g. $\mu = 0.34$ for nominal bunches, 1.15×10^{11} p/b) and one with lower pileup (e.g. $\mu = 0.065$ for 0.5×10^{11} p/b) be taken. In summary, dedicated TOTEM-CMS runs over 7 days with an optimised running scenario can deliver the required integrated luminosity.

Question & Answer n. 6

```
6.  In Section 4.2.2, the document refers to both possibilities that
TOTEM and CMS DAQ are fully integrated, or that they are not.  What is
the timescale for deciding which is the case?  What would be the impact
on physics analyses from the 2015 run in the latter case?
```

The TOTEM and CMS DAQs are independent. Also when the TOTEM DAQ will be connected to the CMS one, the standalone DAQ can be used by simply modifying the configuration of the read-out firmware, thus allowing at any moment the full control of the choice of the DAQ system to be used. In this way no constraint on the physics program will come from the DAQ.

In the TOTEM architecture design the opto receiver card houses a mezzanine with the CMS interface while already being interfaced to a host board, hence the TOTEM DAQ may acquire data from the host board interface, and simultaneously the CMS DAQ from the mezzanine interface.

The actual TOTEM DAQ firmware already support integration with the CMS DAQ system and has been tested using laboratory bench test equipment. After the commissioning of the CMS DAQ2 system TOTEM will test the integration with the new CMS hardware.

Furthermore the TOTEM DAQ system will have no impact on the 2015 running scenario, since the consolidated TOTEM DAQ system can already fulfill of the requirements of the physics program foreseen for the special runs of 2015. Section 4.2.2 of the Timing Upgrade TDR describes running scenarios related to the upgrade of the experiment with timing detectors, which is not related with the standard running scenario proposed for the 2015.

Question & Answer n. 7

7. Along the lines of previous requests, we would like to see explicit and complete examples of physics analyses and projected results for the $\mu = 0.5$ CEP / hard diffraction runs.

Central exclusive dijets production at $\sqrt{s} = 13\,\text{TeV}$ has been studied in detail with MC simulations [25, 26] by the CMS and TOTEM collaborations. Furthermore, an analysis has also been performed on the data sample available from Run I (see the TOTEM Timing Upgrade TDR, Figure 2). These studies are complementary as they address specific problems for different running conditions. In order to assess the visible cross section for exclusive dijets events in low pileup runs at $\beta^* = 90m$ (μ ~1), the performance of the CMS central detector in reconstructing and selecting low-pT dijets events has been studied, together with the double arm proton detection [25].

For the cases with much higher pileup conditions of $\mu = 25\,\text{and}\,50$ the full analysis has been performed, including the study of the physics backgrounds [26].

The preliminary analysis of the available data at $\sqrt{s} = 8\,\text{TeV}$ (β^*=90m, μ 0.05) gave valid inputs for the 2015 runs, confirming the methods for the pile-up reduction, as described in the the TOTEM Timing Upgrade TDR (page 21). A hard CD dijet event with two large p_T jets can be mimicked by various pile-up backgrounds. As an example, an overlap of two Single Diffractive events can be eliminated by a vertex cut ($\Delta x_0 > 40\mu$m) and elastic scattering events with a cut in the difference of the vertical position in the two arms ($\Delta y > 50\mu$m). Soft DPE events overlapping with a QCD-dijet events are the most dangerous background. Several techniques have been developed and once that the topology observed in CMS agrees with the proton parameters measured in the RP, most of these background events are eliminated.

Similar techniques have been applied to the simulated samples at higher energy. Figure 10 in [25] shows as an example the fraction M_{jj}/M_X, whereM_{jj} is the mass calculated from the dijets system and M_X is the mass of the central system calculated either from the momentum loss of the protons or from the particle flow in the central detector: events populating the region around $M_{jj}/M_X \approx 1$ are exclusive. T2 telescopes in veto as well as the timing detectors are powerful handles to further reduce pileup and backgrounds.

In [26] it has been demonstrated that the key handles to disentangle inclusive dijets production from CEP are: cuts on dijet mass fraction (M_{jj}/M_X >0.7), rapidity difference between jets and protons and number of tracks outside the jet system.

In conclusion, the detailed Monte-Carlo studies demonstrate the adequate performance of the central detector, even at highest energy and luminosity. In addition, the experience from the 2012 runs lets us believe that the backgrounds in the 2015 runs can be understood well and the relevant physics can be extracted with a reasonable statistics.

Question & Answer n. 8

8. The TDR estimates 3% total background probability for double tags at μ = 0.5 and β^* =90m. That doesn't sound too aggressive. Could it be pushed to a significantly larger number whilst remaining manageable? This sort of question is already discussed a bit e.g. in the Section 'pile-up rejection for hard CD dijets', but it would be good to see the corresponding studies described in more detail.

The estimate quoted in the TOTEM Timing Upgrade TDR refers to the beam-background probability per bunch crossing and was defined as the probability to produce a proton in the RP acceptance.

In the TOTEM Timing Upgrade TDR we have studied a case with $\mu = 0.5$, which is close to the maximum pileup probability that the machine can provide with the $\beta^* = 90$ m optics ($\mu \propto 1/\beta^*$). A value of $\mu = 0.59$ is reached with the maximum expected bunch population of 1.5×10^{11} p/b and a realistic normalised emittance of $2\,\mu$m rad.

Of course the presence of timing detectors becomes more and more effective as the pileup probability increases. The beam background estimation was necessary for a proper optimization of the timing detector design, as explained in Section 4.2.1 of the TOTEM Timing Upgrade TDR. Moreover the purpose of the TDR estimate was to add the contribution of the beam-related background to the background from the physics interactions, in the study of the DPE selection purity (see as an example Question 1). In this case, the physics background is found to be the dominant one once the cuts for the DPE selection are introduced.

The beam-related background has two components: the "collision debris" and the "beam halo" background. The "collision debris" contains particles from showers generated in the vacuum pipe aperture limitations that eventually produce a signal in the RPs. This fraction of the background scales with μ as the number of vertices generated in the bunch crossing. The "beam halo" contribution instead is due to beam protons traveling far from the central beam orbit that hit the RPs; this contribution is expected to scale with the two beam currents ($\approx \sqrt{\mu}$). The background rate, assumed to scale with $\sqrt{\mu}$ is 2-3% per BX, for each vertical RP at μ =0.5. The beam-beam background has been estimated by selecting events with tracks in both arms of T2: in this subsample the probability to have at least a cluster in the RPs for events without elastic candidates was found to be 1.5%. In this estimate the contribution of the high-mass diffraction is already subtracted (about 0.5%).

In conclusion the beam-halo and beam-beam background probability is estimated for a scenario with high-β^* and μ =0.5 and is about 3% per BX.

Question & Answer n. 9

```
9.  Section 2.2.3 describes the search for missing mass and momentum can-
didates.  This part of the programme is one of the most luminosity-demand-
ing.  Are there explicit examples, in terms of discovery potential, or of
exclusion limits, where the complementary role of these searches w.r.t.
the usual BSM searches can be shown?  Is the physics reach, at 100pb^-1,
sufficient to discover/exclude BSM scenarios that would have eluded other
searches?
```

In special runs at 90 m TOTEM+CMS have extremely powerful capabilities to measure directly missing mass under stringent constraints.

From the experimental point of view, the two main limitations affecting other experiments are: *a*) the modelling of the energy escaping in the forward direction for the inclusive missing mass searches, and *b*) the necessity to trigger on single gluon Bremsstrahlung (in a high pile-up environment) for the exclusive missing mass searches.

We will describe in the following the key advantages of the TOTEM+CMS combination.

With the 90 m β^* optics, TOTEM+CMS have the capability to measure ξ of $\approx 1\%$ with sensitivity (zero-discrimination) at $\approx 95\%$ C.L., and the safety to always discriminate pile-up events for $\mu \lesssim 0.5$, moving the focus of the physics search to the $\sim 100\,\mathrm{GeV}$ mass range.

Therefore, on the one hand TOTEM+CMS can turn the LHC into a gluon-gluon collider, a LEP-like machine with a superior $\sqrt{s}$ and specific quantum numbers, having the needed redundancy on the invariant mass measurement; but in addition, the TOTEM measurement of both protons ξ can selectively allow to restrict the event search to the rapidity ranges where the energy flow in CMS is not forbidden by the predicted kinematic forward gaps (and where CMS is perfectly instrumented): this advantage derives exclusively from the (basically unprecedented) possibility to tag and measure directly both protons. Moreover, the case of exclusive missing mass production, e.g. a pair of BSM undetected particles, becomes just a special case with:

a) the entire CMS detector and the TOTEM forward telescopes empty, *b*) the rapidity regions non-instrumented being forbidden by forward gaps (e.g. for neutrals in the very forward direction), *c*) two non-elastic protons measured in the RPs produced by a CD interaction.

The 100 GeV scale of the sensitivity also protects from low energy flow leaks and detector thresholds limitations, and allows as well the modelling of the kinematic background due to baryonic resonances forward production like N^* (for which the ZDC could allow direct calibration).

The measurement of the invariant mass by the protons ξ measured by the TOTEM RPs allows a direct probe on the inclusive production cross-section of the missing mass generating mechanism, independently from whether its evolution to the final states is detected or not in the CMS central detectors.

Squark $\tilde{q} - \tilde{\bar{q}}$ pair production with the $\tilde{q} \to q + \tilde{\chi}_1^0$ decay channel seems ideal given the inclusive pp cross-section of $\sim$1000 pb at 13 TeV for $\tilde{q}$ masses of just a few hundreds GeV, assuming large gluino masses [27]. In this case, the neutralino $\tilde{\chi}_1^0$ is assumed to be a weakly interacting stable particle.

This would allow still for a sizable squark cross-section in the central diffractive channel. The DPE dijet cross-section prediction from POMWIG is $\sim$3 pb for jets with $p_T > 200$ GeV at $\sqrt{s}$ = 13 TeV. Albeit some kinematical factor due to the large squark mass, the production cross-section for squarks should be similar to jet cross-section at same p_T as the squark mass. Assuming a factor 3 uncertainty on the POMWIG cross-section, we obtain a 1-10 pb range for the cross-section for a 200 GeV squark. Since $\sim$50 % are visible in the TOTEM-CMS acceptance, an integrated luminosity of $\sim$100 pb^{-1} could yield $\sim$50-500 events with missing energy corresponding to the two neutralinos.

Therefore the TOTEM+CMS experimental technique described above could allow checking the current exclusion limits on the $\tilde{q}-\tilde{\chi}_1^0$ range without tight cuts on the momentum of the jets thus extending the kinematic limits [28], and allowing to explore the $\tilde{q}-\tilde{\chi}_1^0 \leq 40$ GeV range, currently not excluded [28].

The hypothesis of close $\tilde{q}$ and $\tilde{\chi}_1^0$ masses is particularly relevant for the $\tilde{t}$ given the cosmological implications [29] and for $\tilde{t}$ masses above $\sim$250 GeV the decay $\tilde{t} \rightarrow c+\tilde{\chi}_1^0$ is currently not excluded [30].The gluino-gluino production channel could offer options of the same order of magnitude as $\tilde{q}-\bar{\tilde{q}}$ in terms of cross-section (for gluino masses of just a few hundreds GeV and large $\tilde{q}$ masses) [27].

The pure neutralino pair-production from gluon-gluon fusion ($\sim$0.1 pb or less [31]) would result in a too low yield in the central diffractive channel (unless it would favour particular momentum correlations in DPE): it would however be an exceptionally clean channel for the CT-PPS.

In summary, the combination of the largest ever $\sqrt{s}$, the specificity of the gluon-gluon channel, the sensitivity to the missing mass mechanism in terms of production cross-section, the capability to trigger directly on exclusive missing mass, and the natural performance of the experimental apparatus for a few 100 GeV invariant mass range, makes the TOTEM+CMS combination at LHC attractive to explore missing-mass physics.

Question & Answer n. 10

```
10.  All of the listed physics topics are double tagged.  Is there also a
prospect of a single tagged (single diffractive dissociation) programme?
```

Yes, as briefly mentioned in the last sentence of Section 2.1 of the TOTEM Timing Upgrade TDR, several single diffractive (SD) processes can be studied running at $\beta^* = 90$ m with proton tags like SD dijet, J/ψ, W and Z production. The visible cross-sections at 13 TeV has been estimated to be about 330, 37 and 3.4 pb for SD J/ψ ($\rightarrow \mu^+\mu^-$ only), W ($\rightarrow \mu\nu_\mu$ or $e\nu_e$) and Z ($\rightarrow \mu^+\mu^-$ or e^+e^-), respectively, assuming a constant rapidity gap survival probability, $< S^2 >$, of 10 %. More details can be found in reference [25].

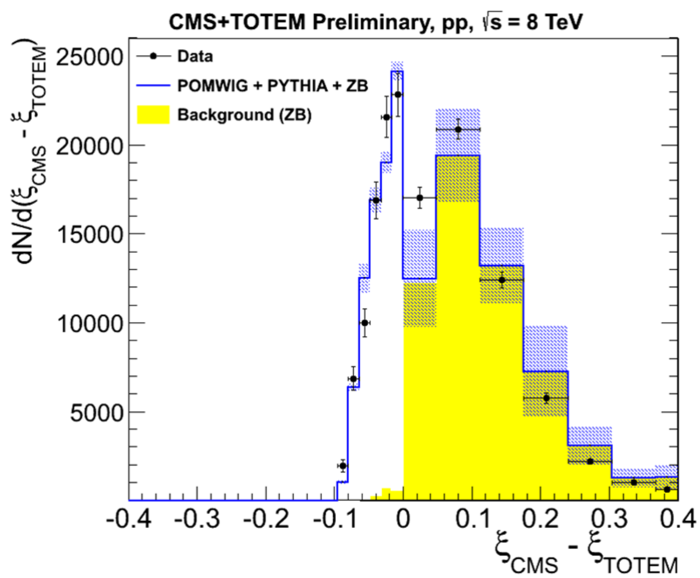

Figure 6: *Distribution of the difference between the longitudinal momentum loss of the proton in single diffractive dijet production at LHC, pp $\rightarrow$ pjjX, reconstructed with CMS (ξ_{CMS}) and that reconstructed with TOTEM (ξ_{TOTEM}). The data points (full circles) are compared to a mixture of Monte Carlo (MC) and zero bias (ZB) data events. The MC sample consists of POMWIG events for the single diffractive (SD) signal, scaled down to account for the rapidity gap survival probability, and PYTHIA6 tune Z2* events for the non diffractive (ND) background. Pileup events were not simulated in the MC, but are included in the ZB data. To provide an estimate of the beam halo and soft pileup backgrounds, each MC event was associated to an event taken randomly from the ZB sample. The mixture MC+ZB was passed through the selection procedure. An event with the proton measured in TOTEM roman pots contributed to the white histogram if it originated from the MC sam! ple, or to the yellow histogram if it originated from the ZB sample. The requirement $\xi_{\text{CMS}} - \xi_{\text{TOTEM}} < 0$ selects the signal events and rejects the kinematically forbidden region populated by the background events. The remaining contamination of background was estimated to be $\sim$ 4 %.*

For SD dijets the visible cross-section is O(10 nb). For example in the dijet triggered sample available from the 8 TeV run of 2012, there are more than 1000 proton tagged SD dijet candidates
($E_{\mathrm{T,jet}} > 30\,\mathrm{GeV}$) with an estimated background fraction of about 4 %. With 5–10 pb^{-1} of integrated luminosity with β^* = 90 m at least SD dijet, J/ψ and W production can be studied in detail. For each process one could determine the dependence of $< S^2 >$ versus different kinematic variables like e.g. x, the fractional of the proton momentum carried by the exchanged Pomeron. For SD Z production, one most likely needs a luminosity of O(100 pb^{-1}) to obtain a sufficient number of events.

The SD programme relies on CMS dijet and lepton triggers, the single proton rate in the RPs being too high to be of any use at trigger level; since the SD analyses don't benefit from timing detector information, the study of these channels was only briefly mentioned in the physics motivation of the TOTEM Timing Upgrade TDR. Note also that the $\xi_{CMS} - \xi_{TOTEM}$ variable can be used to effectively remove the pileup background, as shown in Figure 6 for the SD dijet analysis on the available 8 TeV data set, as long as $\mu \lesssim 1$. The remaining background can be well modeled by mixing protons from zero-bias events with non-diffractive MC events.

Question & Answer n. 11

`11. What sort of` ξ `and` t `resolutions do you need / expect? Is it true that for most of the physics the proton tags are more important than the kinematic reconstruction?`

The availability of proton tags is always decisive as they provide a direct signature of Central Diffraction. Preliminary data analysis at 8 TeV shows extremely enhanced purity and resolution in the invariant mass spectrum compared to experiments using only rapidity gaps. Moreover, proton reconstruction in the RP has high p_T resolution: in the vertical plane is limited by the beam divergence only: for runs at $\sqrt{s} = 13\,\mathrm{TeV}$, $\sigma(p_{T,y}) \approx 14\,\mathrm{MeV}$. In the horizontal plane a common CMS-TOTEM reconstruction allows to reach $\sigma(p_{T,x}) \approx 40\,\mathrm{MeV}$. As it has been extensively shown in the TOTEM Timing Upgrade TDR, this allows to verify the exclusivity of the event.

The ξ reconstruction is primarily limited by the IP5 transverse beam size and the dispersion value at RPs. A resolution of $\sigma(\xi) \approx 0.006$ should be attainable.

Question & Answer n. 12

12. We guess relative and absolute alignment between the different detectors is more important than the individual detector resolution ($\approx 10\mu$m in fig 5). Is the plan to do this in the same way as in Run 1? Does that require an elastic sample and do you expect to be able to get one? Maybe there are ways to do it relative to the CMS tracker using some well-chosen resonance?

A fundamental difference between alignment- and resolution-induced uncertainties lies in the fact that the former correspond to systematic shifts whereas the latter only produce a smearing. Quantitatively, for $\beta^* = 90\,$m the vertical and horizontal alignment uncertainties amount to several tens of μm and $5-10\,\mu$m, respectively.

The Roman Pot alignment strategy of Run 1 [32] proved to be very successful, and no changes are foreseen. The alignment of the vertical (top-bottom) detector pairs relative to the beam centre is indeed based on elastic data samples. The relative distances and tilts between the top and bottom detectors will be provided by particles traversing the overlap regions with the horizontal detectors. For this purpose, the horizontal RPs will be occasionally inserted for short periods of time.

Given that for all diffractive physics at $\beta^* = 90\,$m the vertical pots are used, elastic events (which are also detected entirely by the vertical detectors) can be collected abundantly at each insertion. Furthermore, to preserve full acceptance for diffractive events and to control the effectiveness and purity of the background cuts, no elastic veto will be applied at trigger level.

The RP alignment with respect to CMS is guaranteed since both are aligned with respect to the same beam.

Question & Answer n. 13

13. Page 17 (Section ''Reconstruction resolution'') also suggests that the limiting factor may be the interaction point size (113 μm). How does this translate into a 0.6% ξ resolution or in the following text about very low xi protons?

The optics transfer function translates the transverse position of the interaction point by amplifying the transverse position at the RP via the magnification parameter $v_{x,RP} = 1.9$. The ξ-value is reconstructed mainly from the horizontal proton displacement at the RP.

In this way the IP5 vertex uncertainty is translated into the ξ uncertainty via the approximate formula (L_x=0):

$$\sigma(\xi) \approx \frac{\sigma(x^*)\, v_{x,\mathrm{RP}}}{D_{\mathrm{RP}}} = \frac{113\mu\mathrm{m} \cdot 1.9}{4\,\mathrm{cm}} = 0.5\,\%$$

The ultimate numerical values have been computed with a full Monte Carlo simulation.

Question & Answer n. 14

`14. Figure 6 shows acceptance vs central diffractive mass for double-tagged events, assuming 10 sigma approach to the beam. We guess this also corresponds to the statement e.g. in the abstract that the acceptance covers all` ξ `for` $|t| > 0.01\text{GeV}^2$`, assuming some` t `slope? It would be interesting to know how that acceptance varies with the closest approach to the beam.`

For diffractively scattered protons the RP acceptance in (t,ξ) with optics β^*=90m depends mainly from $|t|$ and it is almost ξ independent as shown for $\sqrt{s}$= 8 TeV in Figure 7 .

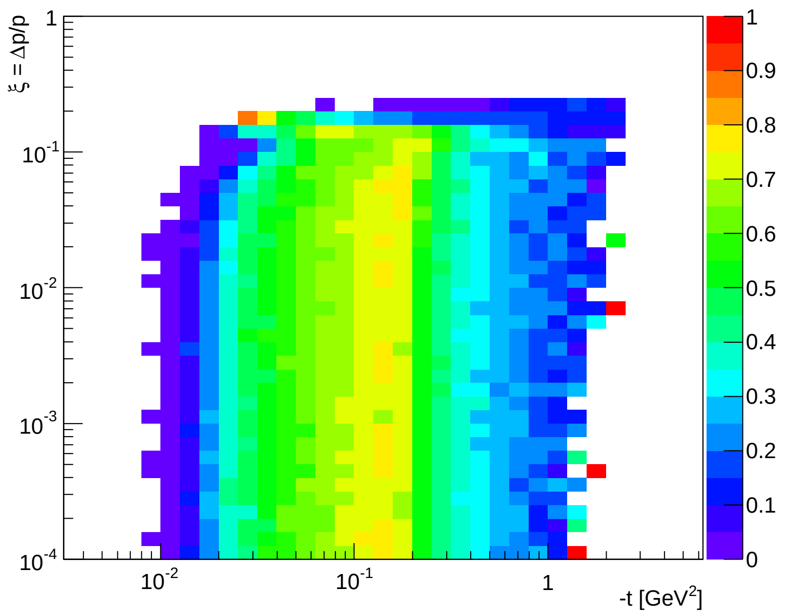

Figure 7: *Acceptance at* $\sqrt{8}$ *TeV of the RP 220-F (vertical) for diffractive protons at* $\beta^* = 90\,m$ *in* t *and* ξ*. (From the TOTEM Collaboration, Upgrade Proposal [25]).*

The minimum observable $|t|_{min}$ depends on the distance of the RPs from the beam centre:

$$|t|_{min} = \frac{p^2(n\sigma_y + \delta)^2}{L_y(\xi)^2} \tag{3}$$

where δ=0.5 mm accounts for the distance of the silicon edge from the bottom of the pot and σ_y is the vertical beam size at the RP location.

The $|t|$-value at 50% of the acceptance as a function of the distance from the beam centre is shown in Figure 8, for $\sqrt{s}$= 13 TeV and assuming a normalized emittance ε_N=2.5 μrad·m.

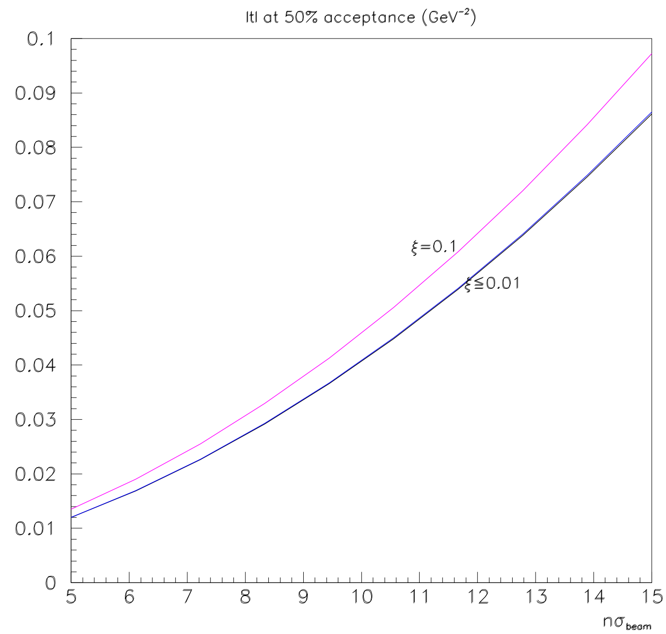

Figure 8: $|t|$*-value at 50% of the acceptance as a function of the distance from the beam centre, expressed as multiples of the transverse beam size* σ.

The mass acceptance reproduced in Figure 6 of the TOTEM Timing Upgrade TDR is calculated assuming a t-spectrum of $\exp(-10t)$ and a detector distance of 10σ. Increasing the RP distance by 50% to $15\,\sigma$ would result in a loss of $\sim$25% of detected events (see Figure 8).

Question & Answer n. 15

`15. Does ‘‘allocated’’ in Table 7 mean that the funds have been already approved by the funding agencies? Is the whole cost of the project fully covered by the contributions listed in the table?`

The total cost of the upgrade is calculated as the sum of allocated and committed resources and expenditures. In this context, allocated stands for “requested according to a temporal spending profile already discussed with the funding agencies”, committed stands for approved by funding agencies and marked for the specific item. The amount of resources listed in the allocated column will therefore seem to gradually diminish over time, when they will migrate from allocated to committed and eventually to the expenditures column.

Question & Answer n. 16

```
16.  The schedule format makes it very hard to read.  We understand that
the timeline of several schedule items does not refer to the actual time
required to complete them, but rather to time windows during which they can
be achieved.  More details should be given about the actual completion installation
needs of the various components.  For example, what would be the impact of
not having a full detector ready by September 2015?  What are the tests envisaged
after September, if a detector is installed?  Do they require special runs
or are they fully passive?
```

To completely define the design of the detectors to be installed in the LHC TOTEM has performed specific measurements of the realistic parameters of the detector chain from the sensor to the the electronics and the DAQ. Test beam studies in the last months were focused on the optimization of the signal to noise ratio versus rise time of the input signal of the preamplifier. Both parameters work in opposition: lowering the bandwidth to reduce the noise consequently generates signals with larger rise time and the signal to noise increases. The limiting parameter of the test setup used so far was an increased input capacitance due to a connector needed between the prototype detector and its preamplifier. A prototype of the hybrid circuit with the preamplifier bonded directly to the diamond pixel is now available. It profits of the experience of the GSI HADES group on diamond detectors and also incorporates the requirements (geometry) of the TOTEM final design.

Preliminary results on a test beam indicate that the goal of 100 ps timing resolution can be reached with this setup.

In parallel (on another beam line) TOTEM is collaborating with the AFP group to test the Sampic chip to characterize the digitzing part of the R/O. The design of the final hybrid will follow and production is foreseen to start next spring. More tests are planned for 2015 as soon as beams will be available in the North Area.

The installation schedule foresees to install a first detector in the LHC in September 2015. The others may be installed in successive technical stops as soon as they will be available. The first Detector installed in the LHC will be used to test the full readout chain in the tunnel including the clock distribution. R/O boards specific to this TOTEM installation are under development with FPGA's of space grade quality: each board will house 3 Sampic mezzanines and the Clock Control Unit Mezzanine (CCUM) control ring controller. The motherboard being designed complies with the rules to interface to CMS and incorporates the existing controller of the Sampic system. This motherboard will replace for the timing detectors the VFAT motherboard and is designed such as that the impact on the existing TOTEM DAQ/Trigger will be minimal.

Already the first few timing planes, one for each arm, can be tested during LHC high intensity beam operation with the RP still in the garage position, detecting particles from the beam halo and the beam debris which have the same specific timing of the passage of the bunch. The tests foreseen are also to study the correlations between tracks in the silicon tracking detectors and the time associated to each hit in the diamonds. A full commissioning of the readout chain can be performed with this reduced setup. These tests in the LHC are programmed for the last quarter of 2015 and may last until the winter shutdown: they will allow to study in detail the performance of the new system in its final environment. If any unforeseen problem is identified, it may be solved and corrections can still be be applied to the full detectors during their production which will start in the last quarter of 2015. In any case a delay in the installation of the first test planes will reflect only weakly on the final system installation, leaving only less time for the tests in situ. The production of the four final detector packages (“Champignons”) to equip the four vertical pots, and that contain 4 timing detector layers each, may extend to the early part of 2016 before the Totem special run.

By the end of the 2015–2016 winter Technical Stop all the infrastructure needed for the new system will be fully installed in the LHC tunnel and tested. The actual installation of each “Champignon” in the pots requires a very short time and will be performed during the LHC regularly programmed technical stops.

A detailed timetable is reproduced in Figure 9.

ID	Task Mode	Task Name	Start	Finish
1		**R&D**	**Mon 03/11/14**	**Sat 28/11/15**
2		**hybrid**	**Mon 03/11/14**	**Fri 27/11/15**
3		construction of first test prototype	Mon 03/11/14	Thu 13/11/14
4		tests on beam	Mon 10/11/14	Mon 15/12/14
5		hybrid final design	Tue 06/01/15	Mon 30/03/15
6		Hybrid final production	Wed 01/04/15	Fri 27/11/15
7		**detectors**	**Mon 03/11/14**	**Mon 30/03/15**
8		first sensor test with geometry	Mon 03/11/14	Fri 19/12/14
9		TDC/Sampic tests	Mon 03/11/14	Mon 30/03/15
10		**Procurement & Construction**	**Fri 30/01/15**	**Fri 10/06/16**
11		sensors' procurement	Fri 30/01/15	Tue 05/04/16
15		final `detector assembly` (single plane)	Tue 03/02/15	Thu 05/05/16
13		Motherboard including SAMPIC	Wed 18/03/15	Tue 01/09/15
12		SAMPIC procuremet	Thu 02/04/15	Mon 11/04/16
14		test detector assemblies on beam	Mon 27/04/15	Wed 16/12/15
16		detector protoypes for first tests in LHC	Tue 04/08/15	Tue 15/12/15
17		Champignons construction	Mon 02/11/15	Fri 10/06/16
18		**DAQ**	Wed 15/07/15	Wed 16/03/16
19		**Clock Distribution**	Tue 06/01/15	Sat 29/08/15
20		**Trigger**	Thu 20/08/15	Wed 17/08/16
21		**Installation of "champignons" in LHC**	Mon 04/01/16	Fri 17/06/16
22		**Physics special run (beta 90 m)**	Thu 25/08/16	Fri 02/09/16

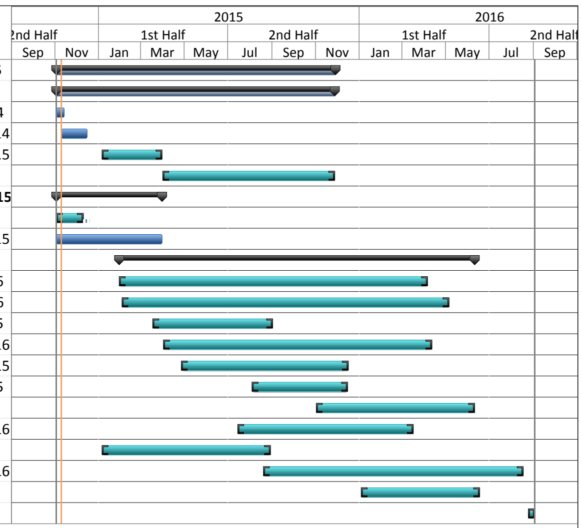

Figure 9: *Updated R&D and Construction schedule. (see the text for further explnations)*

Conclusions

The TOTEM experiment has measured elastic [33], total [34, 35, 36, 37] and diffractive dissociation [38] cross sections at energies so far explored during the LHC running. TOTEM has also measured together with the CMS experiment [39] "diffractive dissociation, including single, double and central diffraction topologies using the forward inelastic detectors in combination with one of the large LHC detectors", as originally proposed at the time of the TOTEM TDR [40].

While the measurement of the total cross-section and the elastic scattering were performed using only the TOTEM detectors, the CMS/TOTEM experiment with an unprecedented particle coverage over 15 units of rapidity that extends further down to production angles of a few micro-radians for the measurement of very forward protons offers the prospect of more detailed studies of diffractive events.

The future physics programme of TOTEM includes the physics cases and analysis channels outlined in the TOTEM Timing Upgrade TDR, which exploit the LHC as a pure gluon-gluon collider in particular via central diffractive production. The relevant analysis channels have already been explored and tested with the data available from July's 2012 runs. The required statistics and consequent integrated luminosity for 2015 and 2016 are derived from the extrapolation of the current data analyses, where the physics observables and results were extracted from the data taken with $\beta^* = 90\,\mathrm{m}$ on July 2012.

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