DIFFRACTION AND LOW-x AT THE LHC*

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Opportunities for hard diffraction and low-x studies at the LHC are recalled. Such studies will need a central detector such as ATLAS or CMS, but equipped with forward detectors.

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1. Introduction

The LHC — expected to start in 2007 — will collide protons with a total Centre of Mass (CM) energy of 14 TeV, and will open up a new high energy frontier. Particular challenges are the high luminosity of the machine of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at the start-up, to $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for the nominal high luminosity mode, leading to event samples of 10–100 fb^{-1}/year. For the highest luminosity, it is expected that one bunch crossing will contain on average 23 (mostly soft) hadronic events overlaid.

Due to the high CM energy, parton distributions can in principle be explored for scaled parton momentum values x down to 10^{-7}. For diffractive events, *e.g.* events in which the proton beam loses 10% of the energy or less, the equivalent "Pomeron beams" have an energy of about 500 GeV. Such collisions allow to probe the structure of the Pomeron down to fractional momentum values, β, of less than 10^{-3}.

CMS [1] and ATLAS [2] are general purpose experiments with an acceptance of roughly $|\eta| < 3$ for tracking and $|\eta| < 5$ for calorimetry. The TOTEM [3] experiment will use the same interaction point (IP) as CMS and is designed to measure the total and elastic pp cross section at the highest energies and will use roman pots detectors to measure the low-t scattered protons, and detector for tagging inelastic events in the regions $3 < |\eta| < 5$ (T1) and $5 < |\eta| < 7$ (T2), as shown in Fig. 1. Both these TOTEM detectors around CMS offer an excellent opportunity for having an experiment which

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has almost full coverage of both the central and forward region, Recently a new study group was installed [4] that will analyse the physics case of combining the data of CMS and TOTEM, and try to optimise the detectors in the forward region.

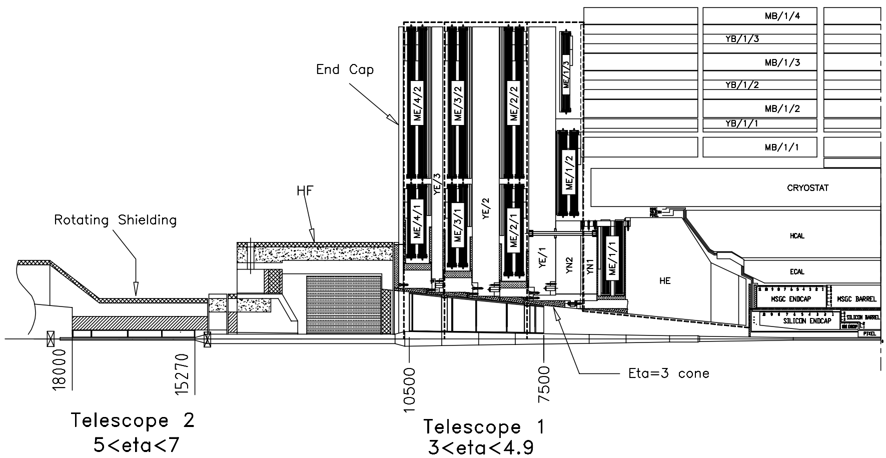

Fig. 1. Position of the inelastic event tagging detectors of TOTEM, T1 and T2, integrated with CMS.

2. Diffraction

Diffractive events can be selected by rapidity gap techniques or by detecting and measuring the non-dissociated proton. Overlap events will prevent to use the rapidity gap technique at the highest luminosities, but for a start-up luminosity of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ still in about 22% of the cases the bunch crossing will contain only one interaction. With good tagging of bunch crossings with a single collisions one could use these events for diffractive studies. At higher luminosities roman pots or microstations [5] will be imperative.

In its proposal, TOTEM plans to install three stations of roman pots on each beam side. Preliminary studies suggest additional locations, namely between 210 and 420 m from the IP. These are important for diffractive hard scattering studies, two-photon physics and for the detection of diffractive Higgs production. Combining CMS and TOTEM detectors will allow to study hard diffraction processes such as Single Pomeron Exchange (SPE) and Double Pomeron Exchange (DPE).

To demonstrate the sensitivity to the Pomeron structure the program POMWIG [6] was used to study di-jets in DPE events. The cuts applied are $0.001 < \xi < 0.1$ and $|t| < 1$ GeV^2, and $P_{\mathrm{T}}^{\mathrm{jet}} > 100$ GeV, with $\xi = E_{\mathrm{Pomeron}}/E_{\mathrm{beam}}$, inspired on preliminary calculations [7]. Both jets must be within the acceptance of $|\eta| < 5$. Cross sections and differential distributions for several different input parton distributions are calculated as function β, the fractional momentum of partons in the Pomeron, in Fig. 2. Different distributions for the partons in the Pomeron were used such as different fits from H1 (in LO: fits 4, 5 and 6; fit 4 has enforced no gluons at the starting scale of 4 GeV^2; fits 5 and 6 are different solutions with a rather large gluon content) and a simple soft ($(1-x)^5$) and hard $(x(1-x))$ parton distribution spectrum. For the calculations no factorisation breaking has been assumed. The kinematics is reconstructed from the jets and the scattered protons. Clearly prominent differences in shape are expected to be observed for the different parton distributions.

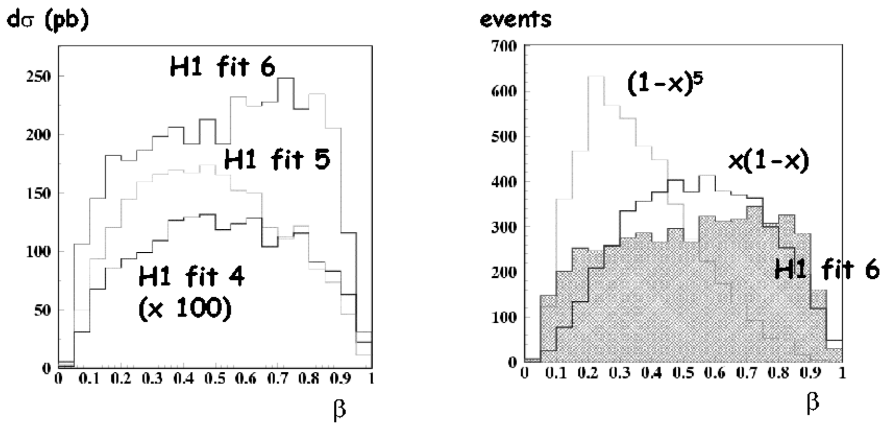

Fig. 2. β distributions calculated from di-jet events in DPE, for jets with $P_{\mathrm{T}}^{\mathrm{jet}} > 100$ GeV/c.

A recent development in the study of diffractive phenomena is the revival for the search of the Higgs particle in diffractive events. Most interestingly are the exclusive processes [8] $pp \to p + H + p$ which give a cross section about 3 fb. More details are given elsewhere in these proceedings [9].

3. Low-x

One of the most important results from HERA is the observed rise of the parton densities at small Bjorken-x. Have these data reached the region of parton saturation? In such a region one would expect to see a reduced growth of the partons due to parton recombination and shadowing mechanisms. A saturation region will be a new regime to study QCD where the parton densities are large but α_{s} is still small enough to perform perturbative calculations.

To establish unambiguously saturation smaller x values, beyond the reach of HERA, will be needed. The LHC kinematics (see [10, 11]) shows that values of $x = 10^{-7}$ can be reached. Information from pp collisions on parton distributions at the lowest possible x values can be provided via low mass Drell–Yan production, direct photon production and jet production. In case of hotspot formation, the effects should already become visible at larger x values.

Shadowing corrections have been estimated with GLR type of corrections to the standard parton evolution equations, using the results of from triple Pomeron vertex calculations [12]. These results are shown in Fig. 3, for different values of the saturation radius. Hence the effects could be very large: at $x = 10^{-6}$, and $Q^2 = 4$ GeV^2, the effect of shadowing is as large as a factor 2. For larger Q^2 values it is reduced to a 20–30% effect. Other estimates reach similar conclusions [13–15].

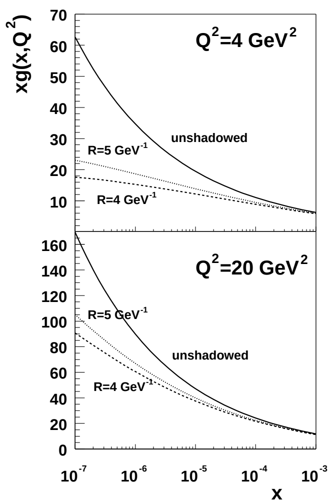

Fig. 3. Prediction for the gluon distribution at several scales, with and without saturation effects.

The Drell–Yan process $q\overline{q} \to \mu^+\mu^-$ or $q\overline{q} \to e^+e^-$ has a simple experimental characteristic. The $x_{1,2}$ values of the two incoming quarks relate to the invariant mass of the two muon system $M_{\mu\mu}$ as $x_1\, x_2\, s \simeq M^2_{\mu\mu}$, hence when one of the $x_{1,2}$ is large ($x > 0.1$), low-x can be probed with low mass Drell–Yan pairs. In order to reach small masses (small scales) and low-x, this will require to probe large values of pseudorapidity η. Hence the resulting muons will dominantly go in the very forward direction as illustrated in Fig. 4, made with the PYTHIA event generator [16], using MRST-LO parton distributions. Drell–Yan events were generated with a mass larger than 2 GeV.

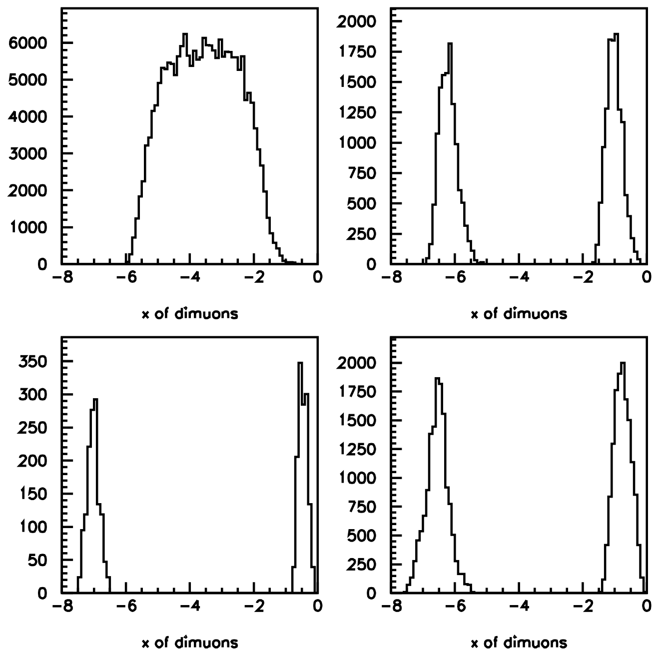

Fig. 4. Distribution of $\ln_{10}(x)$ for Drell–Yan production of muons for $M_{\mu\mu} > 4$ GeV^2 for different η regions of the two muons: (a) $0 < |\eta| < 5$, (b) $5 < |\eta| < 7$, (c) $7 < |\eta| < 9$, (d) $5.5 < |\eta| < 7.8$.

CMS and TOTEM are studying upgrades in the forward region to be able to measure high p_{T} leptons, photons and jets, by redesigning T2 mentioned above.

4. Other topics

Tagging two-photon production events offers a significant extension of the LHC physics programme. The effective luminosity of high-energy $\gamma\gamma$ collisions reaches 1% of the proton-proton luminosity and roman pots used for measuring very forward proton scattering should allow for a reliable extraction of interesting two-photon interactions. Particularly exciting is the possibility of detecting two-photon exclusive Higgs boson production at the LHC [17].

The physics program for two-photon physics at the LHC contains topics such as the two-photon total cross section, QCD in two photon physics, exclusive Higgs production, WW production and Susy particle production.

Finally, the LHC also offers the possibility to study processes at a lower centre of mass energy. Possible options [18] for lower energy runs at the LHC include running at 2 TeV with a maximum luminosity of $2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and 8 TeV with $3.3 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Topics to be studied [19] include to remeasure the total cross section at a CM energy of 2 TeV, to measure the production of Z bosons at 2 TeV and compare the pp and $p\overline{p}$ production rates (which are sensitive to the quark and anti-quark distributions in the proton), BFKL studies with dijets, the energy dependence of gap survival probabilities, inclusive jets *etc.*

5. Conclusions

Elastic, total and soft diffractive cross sections can be measured with TOTEM in low luminosity runs. Using the combination of CMS+TOTEM allows to study hard diffraction at the highest energies. Questions on the Pomeron structure and gap survival dynamics can be addressed. The LHC has the potential to reach the region in $x = 10^{-6}$–10^{-7}, but the CMS detector would need to be upgraded in the region $5 < |\eta| < 7$–8. A potentially interesting program for two-photon becomes accessible to the LHC, if proton taggers are available in the right location. It is possible to run the LHC at smaller energies, in the range of 2–14 TeV. This would allow for many studies related to QCD.

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