Proceedings of the DIS'2004, Štrbské Pleso, Slovakia

# FORWARD PHYSICS WITH CMS

MAREK TAŠEVSKÝ
*Physics Department of the Antwerp University*
*Universiteitsplein 1, B-2610 Antwerp, Belgium*

The physics potential of the forward physics project at CMS is very rich. Some of the diffraction and low-$x$ physics channels are briefly discussed.

## 1 Introduction

Data from the proton-proton collisions which will be produced at the LHC at the highest-ever centre-of-mass energy, $\sqrt{s}$, of 14 TeV will provide information about unexplored phase space regions and new physics domains. The luminosity at startup, planned for the year 2007, is expected to be $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. In the high luminosity mode, it will reach values of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ leading to an integrated luminosity of 100 $\mathrm{fb}^{-1}$ per year. At these highest luminosities, it is expected to see on average 23 overlapping (mostly soft) hadronic interactions per bunch crossing.

The forward physics project includes the CMS [1], TOTEM [2] and CASTOR [3] detectors. The CMS detector is a general purpose detector with an acceptance of $|\eta| < 3$ for tracking and of $|\eta| < 5$ for calorimetry. The pseudorapidity is defined as $\eta = -\ln\tan(\theta/2)$ where $\theta$ is the polar angle of a particle with respect to the beam axis. The TOTEM experiment will use the same interaction point (IP) as CMS and is designed to measure the total and elastic pp cross sections, and the diffraction dissociation. It will use two telescopes to detect inelastic events, namely T1 with an acceptance of $3 < |\eta| < 5$ and T2 with an acceptance of $5.3 < |\eta| < 6.6$ (Fig. 1), and three Roman Pot (RP) stations, placed symmetrically (at 147, 180 and 215 m) from the IP to measure protons scattered under very small $\theta$ angles. The CASTOR calorimeter is designed to cover the same region as T2. A combination of these detectors thus provides the largest acceptance detector ever built at a hadron collider and enables a study of a large variety of processes in detail. The issue of a common usage of the TOTEM and CASTOR detectors an their integration into the CMS detector and trigger/DAQ system is being investigated in a common study group [4] established in 2002.

## 2 Diffraction

The selection of diffraction events is based on the presence of rapidity gaps and non-dissociated protons. At the highest luminosities, it is impossible to see any rapidity gaps due to overlap events and therefore, RP detectors are needed to detect the scattered protons. At startup, still about 20% of events will be of 'one-interaction-per-bunch-crossing' nature. The low luminosity mode will therefore be useful for precise soft diffraction measurements, such as those of different cross section compo-

© Institute of Experimental Physics SAS, Košice, Slovakia 

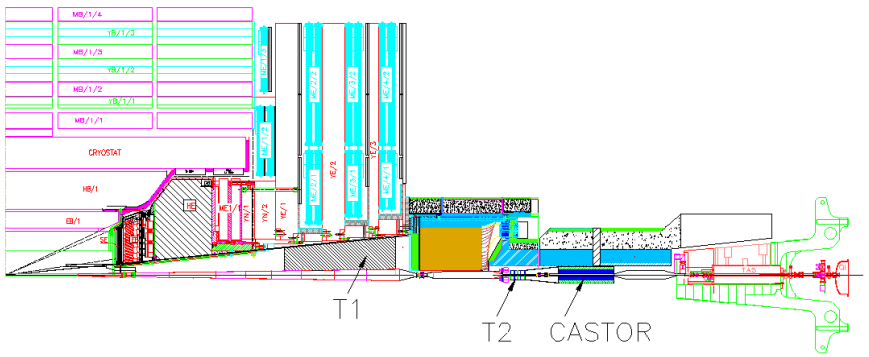


Figure 1. Positions of the T1 and T2 TOTEM telescopes and the CASTOR calorimeter, integrated into CMS.

nents (single and double dissociation, single and double pomeron exchange, ...). The combination of the central and RP detectors enables the measurement of the hard diffraction processes, such as single pomeron exchange (SPE) and double pomeron exchange (DPE). These types of processes are useful to study the pomeron structure and the dynamics of diffraction. The fractional momentum of the pomeron carried by a parton entering the hard interaction is given by $\beta = \Sigma_{\text{jets}} E_{\text{T}} e^{-\eta}/(\sqrt{s}\cdot\xi)$, where the jet characteristics are measured in CMS, while $\xi$, the proton momentum loss, is measured in the RPs. The dynamics of diffraction is investigated by studying the production of heavy particles, such as W and Z bosons, and heavy quarks.

The DPE processes with a Higgs boson in the final state are of particular interest. A recent calculation [5] for the DPE exclusive production of a 120 GeV/$c^2$ Higgs boson, pp$\rightarrow$ pHp, gives a cross section of about 3 fb, while that for the DPE inclusive production could be as large as 50–200 fb. The exclusive Higgs boson production (the energy of the pomerons entirely goes into the production of the Higgs boson, i.e. $\beta = 1$) has the advantage of the spin selection rule $J_Z = 0$ [6] which suppresses LO QCD background - $\mathrm{b\bar{b}}$ production- allowing the $\mathrm{H} \rightarrow \mathrm{b\bar{b}}$ decay to be observed in the central detector. Another advantage is a precise Higgs boson mass determination by exploiting the missing mass method, $M_{\text{H}}^2 = (p_1 + p_2 - p_3 - p_4)^2$, where $p_1, p_2$ are the four-momenta of the beam protons and $p_3, p_4$ those of the scattered protons measured in RPs. First studies show that a mass resolution of 2–3% can be achieved [7]. In Fig. 2 the Higgs boson mass acceptance is shown for various combinations of RP stations. A nice agreement is seen between the results of a study of the RPs' response [7] and those of a fast simulation program of CMS in which the former results were used as input together with the EDDE [8] event generator. It turns out that the most distant RP station of those designed by TOTEM so far (at 215 m) does not suffice to detect a Higgs boson with a mass around 120 GeV/$c^2$. For that purpose, an additional RP station further away from the IP would be needed. Two positions were considered in [7], namely 308 and 420 m. The combination of the 215 m and 420 m RP stations gives a 40% acceptance for $m_{\text{H}} = 120$ GeV/$c^2$. Anything behind 215 m would, however, be in the

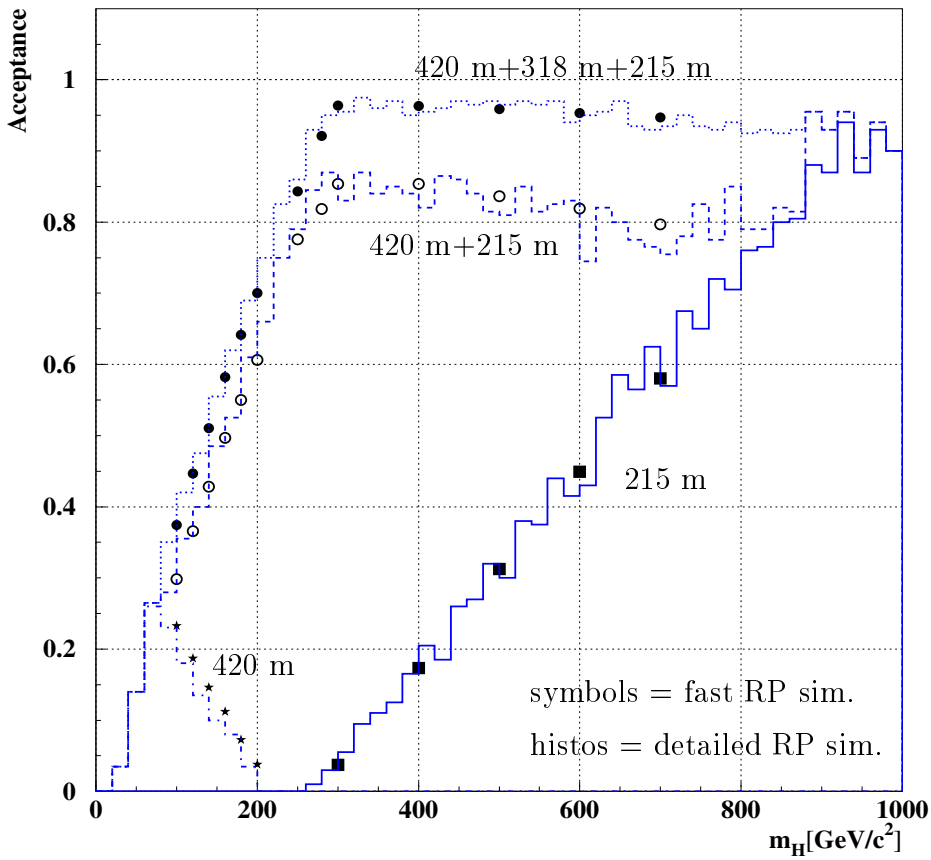


Figure 2. Acceptance of various Roman Pot combinations as a function of the Higgs boson mass. The histograms represent the results of Helsinki group study [7] and the symbols represent the results of the CMS fast simulation using the EDDE [8] event generator.

so called "cold region", which means difficulties in controlling and maintaining the stations. Furthermore, signals from these distant stations would arrive too late to the central trigger to be included in its first level. These issues are now intensively studied in the common CMS/TOTEM working group.

## 3 The low-$x$ programme

Data from HERA convincingly show a rise of the proton parton density function (PDF) for $x$ down to $10^{-4}$. The PDF behaviour at even smaller $x$ is a subject of intensive discussions. An important question is whether the PDF has reached a region of saturation. In such a region, effects such as parton recombination and shadowing corrections would suppress the growth of the PDF. At LHC, $x$ values down to $10^{-7}$ can be reached [9]. Processes suitable to extract the very low-$x$ region

of the PDF are the production of low-mass Drell-Yan lepton pair, prompt photons, W and dijets. The experimental signature of the Drell-Yan events consists of a low-mass lepton pair going very forward. The parton $x_1$ and $x_2$ values and the invariant mass of the dimuon system, $M_{\mu\mu}$, are connected by the relation $M^2_{\mu\mu} \sim x_1 x_2 s$. Hence, e.g. $x_1$ can be probed at very small values if $M_{\mu\mu}$ is kept small and $x_2$ large ($x_2 > 0.1$). It has been shown [10] that such a lepton pair predominantly goes in the very forward direction. Very-forward high $p_T$ leptons, photons and jets are expected to be well measured in the CASTOR calorimeter.

The effect of shadowing corrections for different saturation radii is shown in Fig. 3. The shadowing corrections were estimated with GLR type of corrections to the standard evolution equations, using the results from triple pomeron vertex calculations [11]. The effect turns out to be sizeable (a factor of two) for $x = 10^{-6}$ at $Q^2 = 4$ GeV$^2$ and is reduced for $Q^2 = 20$ GeV$^2$ to values of 20–30%.

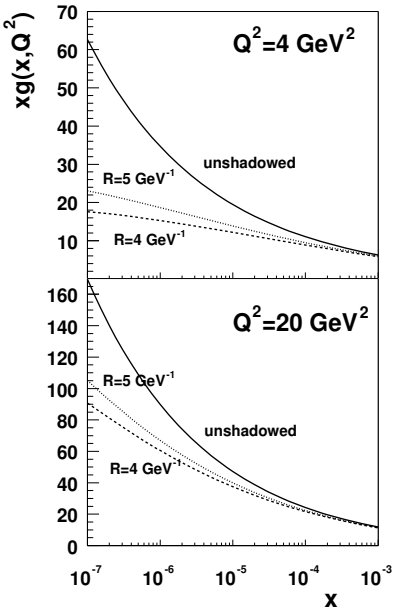


Figure 3. Predictions for the gluon PDF for two hard scales $Q^2$, with and without shadowing corrections. The shadowing corrections are shown for two saturation radii $R$.

## 4 Other topics

Other physics chapters included in the forward physics project are as follows [12].

**Two-Photon Physics**: The effective luminosity of high-energy $\gamma\gamma$ collisions reaches 1% of the pp luminosity and RP stations should allow a reliable detection of scattered protons, hence of $\gamma\gamma$ events. Possible measurements are the total $\gamma\gamma$ cross section, comparisons with QCD predictions, exclusive Higgs boson pro-

duction and Supersymmetry particle production [13].

**Cosmic rays**: Programs used to reconstruct the incident particle energy and type show large uncertainties, in particular in the forward direction. Therefore, there is a considerable interest from the cosmic rays community to see measurements of the particle and energy flow at large rapidities in pp and pA interactions [14].

**Luminosity**: In the QED processes $pp \to ppe^+e^-$, the produced electrons point dominantly to the region $5 < |\eta| < 8$, which is in the T2/CASTOR acceptance. Calculations can be controlled to a precision of 1%. This channel is therefore promising for an absolute luminosity measurement.

## 5 Acknowledgements

I would like to thank Patrick Janot for a careful reading of the manuscript. The work was supported by Interuniversity Attraction Poles Programme - Belgian Science Policy.

## References

1. CMS Coll., *The Compact Muon Solenoid, Technical Proposal*, CERN-LHCC-1994-038.
2. TOTEM Coll., *TOTEM Technical Design Report*, CERN-LHCC-2004-022.
3. A.L.S. Angelis *et al.*, Nuovo Cim. **24C** (2001) 755;
   A. Panagiotou, *Progress with CASTOR*, talk at CMS/TOTEM meeting on Diffraction, CERN, 12.12.2003.
4. Agendas of CMS/TOTEM meetings on Diffraction,
   http://agenda.cern.ch/displayLevel.php?fid=28.
5. A. De Roeck *et al.*, Eur. Phys. J. **C25** (2002) 391.
6. V.A. Khoze, A.D. Martin and M.G. Ryskin, *Higgs or Dijet Production in Double Rapidity Gap Events*, hep-ph/0006005.
7. J. Kalliopuska *et al.*, HIP-2003-11/EXP.
8. V.A. Petrov and R.A. Ryutin, *Exclusive Double Diffractive Events: Menu for LHC*, hep-ph/0403189; *Exclusive Double Diffractive Higgs Boson Production at LHC*, hep-ph/0311024.
9. A.D. Martin *et al.*, Eur. Phys. J. **C14** (2000) 133.
10. A. De Roeck, Acta Phys.Polon. **B33** (2002) 3591.
11. M. Kimber, J. Kwieciński, A.D. Martin, Phys. Lett. **B508** (2001) 58.
12. CMS Coll., *Expression of Interest*, CERN-LHCC-2004-003/G-068.
13. K. Piotrzkowski, Phys. Rept. **D63** (2001) 071502;
    *High-Energy Two Photon Interactions at the LHC*, hep-ex/0201027.
14. R. Engel and H. Rebel, Acta Phys.Polon. **B35** (2004) 321;
    S. Heck, M. Risse and J. Knapp, *Comparison of Hadronic Interaction Models at Auger Energies*, astro-ph/0210392.