The Compact Muon Solenoid Experiment
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Forward and Low- x Physics Programme with CMS at the LHC

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Abstract

Forward physics with CMS at the LHC covers a wide range of physics subjects, including very low- x QCD, underlying event and multiple interaction characteristics, photon-mediated processes, diffraction in the presence of a hard scale and even MSSM Higgs discovery in central exclusive production. The status of the forward detector instrumentation of CMS, and the preparation of some example analyses of the first LHC data are discussed.

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Forward and Low- x Physics Programme with CMS at the LHC

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Forward physics with CMS at the LHC covers a wide range of physics subjects, including very low- x QCD, underlying event and multiple interaction characteristics, photon-mediated processes, diffraction in the presence of a hard scale and even MSSM Higgs discovery in central exclusive production. The status of the forward detector instrumentation of CMS, and the preparation of some example analyses of the first LHC data are discussed.

1 Forward instrumentation around IP5

Interaction point 5 (IP5) of the LHC is shared by the CMS and TOTEM experiments. Both collaborations plan the installation of several detectors to detect forward particles and energy deposits. The TOTEM collaboration in particular will install two tracking *telescopes*, T1 and T2, covering the pseudorapidity range $3.1 < |\eta| < 4.7$ and $5.2 < |\eta| < 6.5$, respectively, and *Roman Pot* detectors to detect forward protons at 147 m and 220 m from the interaction point. Physics analyses with TOTEM and CMS are discussed in [2]. In this contribution the emphasis lies on two forward calorimeters installed by the CMS collaboration: the CASTOR and Zero Degree Calorimeters.

1.1 The CASTOR calorimeter

CASTOR is a tungsten/quartz sandwich calorimeter located 14.37 m from the interaction point and extending the forward calorimetric coverage of CMS to the pseudo-rapidity region given by $5.2 < |\eta| < 6.6$. Its shape is an octagonal cylinder with inner radius 3.7 cm, outer radius 14 cm and a total depth of $10.5 \lambda_I$. Signal collection is based on the production of Čerenkov photons which are transmitted to photomultiplier tubes through aircore lightguides. To optimise the photon yield, the tungsten absorber and quartz plates are inclined by 45° w.r.t. the beam axis.

The calorimeter consists of an electromagnetic section of $20.12 X_0$ and a hadronic section of $10.3 \lambda_I$. It has a 16-fold segmentation in azimuth, a 14-fold (2 electromagnetic+12 hadronic) segmentation along the beam axis and no segmentation in pseudo-rapidity.

As of the time of writing, the CASTOR calorimeter was undergoing final tests in beam and installation of a single-sided partial detector within the CMS cavern was foreseen in July 2008.

Figure 1: The CASTOR calorimeter.

1.2 The Zero Degree Calorimeter

The CMS Zero Degree Calorimeter (ZDC) is located 140 m from the interaction point. Based on similar detection principles as the CASTOR calorimeter, it is again a tungsten/quartz sandwich calorimeter with electromagnetic ($19 X_0$) and hadronic ($5.6 \lambda_I$) sections. The electromagnetic section has a 5-fold horizontal segmentation to measure the angle of forward energy deposits, while the hadronic section has a 4-fold segmentation in depth. The ZDC has full acceptance for neutral particles produced at pseudorapidities $|\eta| > 8.4$ and is ready for the 2008 run of the LHC.

Figure 2: The Zero Degree Calorimeter.

2 The interest in forward physics

2.1 Proton-proton collisions at low- x

At low Bjorken- x , partons may undergo long parton showers before they meet to form the hard scattering subsystem. Forward particles can then be produced in two ways: (i) a collision between a low- x and a high- x parton will boost the hard scattering subsystem forward; (ii) a collision between two low- x partons will produce a central hard scattering system while forward jets may result from gluons radiated in the parton shower.

A large imbalance in Bjorken- x will result in a hard scattering subsystem X that is produced forward. X can be jets, Drell-Yan pairs, prompt photons, heavy quark pairs, etc. The relation between the Bjorken- x of the low- x parton and the pseudorapidity of the hard scattering system is given by $x = \frac{Q}{\sqrt{s}} e^{-\eta}$, which yields $x \geq 10^{-6}$ for $Q \geq 10$ GeV and $\eta = 6$ at the LHC. Figure 3 shows the kinematic plane of M vs. x for the production of forward Drell-Yan pairs with invariant mass M . CASTOR will be able to measure the energy deposits of Drell-Yan e^+e^- pairs with $M \lesssim 30$ GeV and $x < 10^{-5}$. In this kinematic region one expects large shadowing effects in the proton parton densities. One calculation using the PYTHIA Monte Carlo generator based on a *saturated* parton density function [3] yields a reduction by a factor 2 w.r.t. the prediction based on the CTEQ5L parametrisation [4].

Figure 3: Kinematic plane of invariant mass M vs. x for Drell-Yan pairs at generator level. The full line gives the kinematic limit $M_{max} = \sqrt{x_2 s}$, while the dashed lines show the acceptance limits $M = x_2 \sqrt{s} e^y$, $y \in [5.2, 6.6]$ of the CASTOR calorimeter. Green/light grey (blue/dark grey) dots indicate Drell-Yan pairs where at least one (both) electron(s) are within the CASTOR acceptance.

When both partons involved in the hard scattering have similar, low x , a dijet system will be produced centrally in the detector. Forward jets may then result from parton showers. BFKL-like QCD evolution will result in a larger cross section for high energy forward jets, as can be seen in Figure 4. Also jet-gap-jet or Mueller-Navelet jet topologies are particularly sensitive to different approaches for QCD evolution.

2.2 Diffraction

In diffractive pp interactions, one or both protons survive the interaction, possibly yielding hard jets, heavy quarks, etc. Diffraction, including soft diffraction, makes up 25% of the total cross section and provides a tool to study (perturbative) QCD and the structure of hadrons through the measurement of the cross section for diffractive jet, Z , W or heavy quark production and the rapidity gap survival probability. The latter is related to multiple partonic interactions and soft rescattering effects. One interesting diffractive channel is the central exclusive production of Higgs bosons - a particularly clean channel for the study or discovery of standard model or MSSM Higgs boson [7].

One of the analyses being prepared in detail by the CMS collaboration concerns the single diffractive production of W bosons [8]. This process is sensitive to the quark component of the diffractive parton density function and to the rapidity gap survival probability. Diffractive processes will be selected by rejecting forward activity in the HF and CASTOR calorimeters. The use of CASTOR in particular yields a much better rejection of non-diffractive processes, while the ZDC can be exploited to reduce the diffractive dissociation.

2.3 Exclusive dilepton production

Exclusive dilepton production, $pp \rightarrow pp l^+ l^-$, through double photon exchange, is a nearly pure QED process and can therefore be used for luminosity monitoring with a precision of down to 4%. The measurement of this process can also help in the study of lepton identification in the main CMS detector and for the calibration of forward proton detectors.

The CMS collaboration prepares the measurement of exclusive dilepton production based on the detection of centrally produced e^+e^- or $\mu^+\mu^-$ pairs [9]. The main uncertainty in this analysis will be due to the inelastic background where one of the protons dissociates. Again, the use of CASTOR and ZDC can greatly reduce this background.

The p_T threshold used for the detection of muon pairs is low enough to allow the reconstruction of the Υ mass peaks. Here, the Υ is produced in diffractive photoproduction processes. The analysis of the process therefore allows to constrain the gluon distribution in

Figure 4: Distribution of generator-level jet energy in CASTOR for events with hard central dijets ($p_T > 60$ GeV and $|\eta| < 3$) as obtained from a PYTHIA simulation using the standard DGLAP evolution [5] (dashed line) and the colour dipole model implemented in ARIADNE [6] (full line).

the proton at low x and to study diffractive and QCD models. A preliminary CMS analysis shows that the resolution is good enough to resolve different Υ resonances and to extract the exponential slope parameter b from the p_T spectrum.

Figure 5: (left) Invariant mass spectrum for diffractive Υ photoproduction $pp \rightarrow pp\Upsilon$, $\Upsilon \rightarrow \mu^+\mu^-$; (right) p_T^{Υ} distribution.

3 Conclusion

Forward physics in pp collisions covers many subjects ranging from low- x QCD and diffraction to $\gamma\gamma$ interactions. For all these subjects forward detectors are mandatory, or greatly enhance the possibilities, for data analysis with the CMS detector. Several subdetectors (CASTOR, ZDC) are therefore being installed. Together with the TOTEM detectors, CMS will have a kinematic coverage that is unprecedented at hadron colliders.

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References

- [1] Slides: <http://indico.cern.ch/contributionDisplay.py?contribId=58&sessionId=29&confId=24657>
- [2] CMS Coll., TOTEM Coll., CERN-LHCC-2006-039/G-14 (2006).
- [3] A. Dainese et al., Small- x effects in heavy quark production, proceedings of the HERA and the LHC workshop, March 2004 - March 2005;
K. J. Eskola et al., Nucl. Phys. **B660** 211 (2003).
- [4] H. L. Lai et al., *Global QCD analysis of parton structure of the nucleon: CTEQ5 parton distributions*, Eur. Phys. J. **C12** 375–392 (2000).
- [5] T. Sjöstrand, S. Mrenna and P. Skands, *PYTHIA 6.4 physics and manual*, JHEP **05** 026 (2006).
- [6] L. Lönnblad, *ARIADNE version 4.12 program and manual*, Comput. Phys. Commun. **71** 15 (1992).
- [7] B. Cox, *Status of the FP420 project and potential for diffractive Higgs at the LHC*, these proceedings.
- [8] A. V. Pereira, *Single diffractive W production with CMS*, CMS PAS DIF-07-001 and these proceedings.
- [9] S. Ovyn, *Exclusive dilepton and Upsilon production with CMS*, CMS PAS DIF-07-002 and these proceedings.