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Mini experimental review of low x physics and hard diffraction at the LHC

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Feasibility studies are presented on forward jet production at the LHC with the CMS detector, assuming an integrated luminosity of 1 pb^{-1}, together with studies of low-mass Drell Yan muon pair production with the LHCb detector. The potential sensitivity of the CMS and the LHCb experiments to the proton PDFs at low x is discussed. The feasibility of observing hard diffraction at the LHC with the first 10-100 pb^{-1} of data collected by the CMS detector is also summarized.

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1. Experimental Setup

1.1 Forward Instrumentation at CMS

The Compact Muon Solenoid (CMS) [1] is one of two general-purpose detectors located at the Large Hadron Collider (LHC) at CERN. The instrumentation around the CMS interaction point also features a full set of forward detectors, covering the kinematic region at small polar angles: the Forward Hadronic calorimeter (HF, with acceptance $3.0 <|\eta|< 5.0$) [2], the Centauro and Strange Object Research calorimeter (CASTOR , $-6.6 < \eta < -5.2$) [3] and the Zero Degree Calorimeter (ZDC, $|\eta|> 8.1$) calorimeter [4].

1.2 LHCb detector

The Large Hadron Collider beauty experiment (LHCb) [5], one of the four main detectors at the LHC, is primarily designed and built to make measurements of CP violation and rare B decays. It has been constructed as a forward single-arm spectrometer appropiate to the $b\bar{b}$ production topology at the LHC. The approximate coverage in terms of rapidity is $1.9 < \eta < 4.9$. In addition, LHCb can also make precise electroweak measurements at high rapidities.

2. Low x physics

The measurements in the forward direction will give information about the structure of the proton and its evolution at low values of Bjorken x . The relation between Bjorken x and the pseudorapidity of the system with hard scale Q and center of mass energy $\sqrt{s} = 14$ TeV is given by $x = \frac{Q}{\sqrt{s}} \mathrm{e}^{-\eta}$, which yields to a value of $x \sim 10^{-6}$ for $Q \leq 10$ GeV and $\eta = 6$ at the LHC energies. In the following, the potential of forward jet measurement and of forward Drell-Yan production to access the proton structure and evolution at low x is discussed.

2.1 Single inclusive jet measurement with CMS

The single inclusive jet measurement in HF with transverse momentum $p_T \sim 20-100$ GeV$/c$ will allow us to probe x values as low as $x \sim 10^{-5}$. The HF calorimeter offers excellent jet reconstruction capabilities. Forward jets in HF reach a p_T resolution of 18% at a $p_T \sim 20$ GeV$/c$ decreasing to 12% for a $p_T \sim 100$ GeV$/c$ [6]. The fractional differences between the p_T spectra of the reconstructed forward jet using the SISCone algorithm and fastNLO calculations based on CTEQ6.1M and MRST03 PDFs are shown in the Fig1. The error bars indicate the quadratic sum of the statistical and the energy resolution smearing uncertainties. The solid curves indicate the propagated uncertainty in the final jet spectrum due to the jet-energy scale error for an intermediate jet energy scale (10% decreasing to a constant 5% for $p_T > 50$ GeV$/c$). The uncertainties provided by the CTEQ6-set alone are shown by the thin yellow band. The single inclusive forward jet measurement can thus help constrain the low x proton PDF, if the jet energy scale uncertainty is controlled below the 5% level [6].

2.2 Low mass Drell -Yan production

The production of low mass Drell-Yan lepton pairs at forward rapidity at the LHC provides a unique opportunity to directly access low x quark densities in the proton. Due to its forward

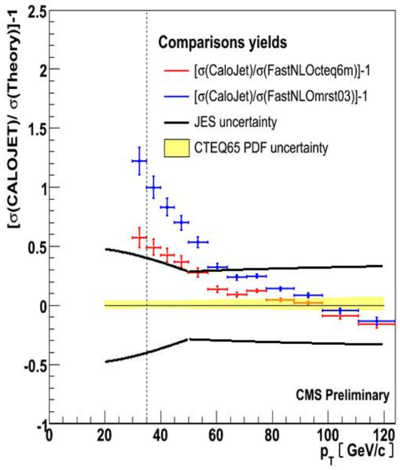

Figure 1: Percent differences between the reconstructed forward jet p_T spectrum and fastNLO calculations.

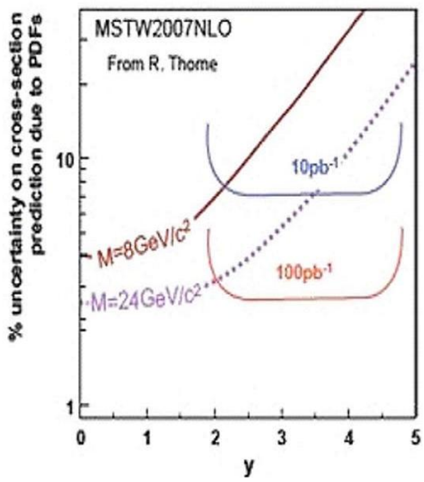

Figure 2: Uncertainty on Drell-Yan cross-section predictions at the LHC due to the PDFs .

geometry, LHCb will be capable of triggering on low transverse momentum objects. In particular LHCb will provide a measurement of the differential cross-section for the Drell-Yan process $q\bar{q} \rightarrow \gamma^{\star} \rightarrow \mu^{+}\mu^{-}$. LHCb will be able to trigger and reconstruct events for dimuon invariant masses as low as 2.5 GeV$/c^2$. For masses above 20 GeV$/c^2$ the trigger efficiency is expected to be 97% and it decreases to 62% for masses of 2.5 GeV$/c^2$ [7]. The comparison between the uncertainty on the Drell-Yan cross section prediction at the LHC due to the uncertainty on the PDFs as a function of rapidity for two diferent dimuon invariant masses [8] and the expected experimental statistical precision using 10 pb^{-1} and 100 pb^{-1}of LHCb data is shown in Fig.2. Measuring the total and differential cross section of the Drell -Yan process for a large range of invariant masses can improve the estimate of the PDFs.

3. Hard diffraction with CMS

Diffractive events are characterised by a large gap in the rapidity distribution of final-state hadrons. Many aspects of diffraction in electron-proton collisions are well understood in QCD when a hard scale is present, which can be provided by jets, heavy quarks, W or Z bosons. In that case the cross section is factorized into a partonic cross section, which describes the hard scattering and is calculable in pQCD and the diffractive parton distribution function (dPDF). Diffractive processes are thus additional tools to study the structure of the proton. In diffractive hadron-hadron scattering, factorization is broken by the rescattering between spectator particles which fill the rapidity gap. To quantify these effects, the so called rapidity gap survival probability $\langle S^2 \rangle$, was introduced and can be measured by means of the ratio of diffractive to inclusive processes with the same hard scale. Preliminary studies were performed by the CMS Collaboration which demonstrate the feasibility of measuring hard diffraction with the first 10 - 100 pb^{-1} of integrated luminosity and no event pile-up which allows a rapidity gap based selection. Two experimental scenarios are considered for these studies. In the first, no forward detectors beyond the forward calorimeter HF are assumed. In the second, additional coverage is assumed by means of the CASTOR calorimeter. Two processes have been studied in detail [9] [10]: single diffractive dijet (SD) production, sensitive to the dPDF gluon content and single diffractive $W \to \mu\nu$ production, mainly sensitive to the dPDF quark content. The diffractive selection is based on hadronic activity measured in forward calorimeters HF and CASTOR and the particle multiplicity detected in the central tracker. Requiring no activity above noise level in HF and CASTOR and assuming a value of $\langle S^2 \rangle = 5\%$, for SD W production, O(100) events per 100 pb^{-1} are expected with a signal to background ratio up to ~ 20 [9]. For SD dijet production O(300) events per 10 pb^{-1} are expected with a signal to background ratio up to ~ 30 [10].

4. Conclusion

Significant improvement of the knowledge of the gluon PDF at low x can be achieved with the CMS and LHCb measurements. CMS has studied the feasibility of observing single diffractive W and single diffractive dijets with 10-100 pb^{-1} of data. The single inclusive forward jet measurement in the range $p_T \sim 35-40$ GeV$/c$ can discriminate between the MRST03 and CTEQ6 PDFs, if the jet energy scale is controlled below 5%. At LHCb due to the angular acceptance and the low trigger thresholds it will be possible to access low x down to 10^{-6} and low mass events ($M_{\mu^+\mu^-} >$ 2.5 GeV).

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