Access to small x Parton Density Functions at the LHC

Tara Shears, on behalf of the LHC collaborations.
University of Liverpool

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Abstract

Predictions for particle production at the LHC employ parton density functions extrapolated to lower x and higher Q^2 regions than have been tested experimentally. In these proceedings studies of low mass Drell-Yan, forward jet and J/ψ production, and their sensitivity to small x, are summarised. Features of the LHC experiments conducive to making these measurements are compared.

1 Introduction

The Large Hadron Collider (LHC) at CERN will operate at a centre of mass energy of $\sqrt{s} = 14$ TeV. Measurements made of particle production will access an unexplored kinematic region. Predicted cross-sections for such processes rely on assumptions for parton momentum fraction (x) extrapolated to untested regions.

The parton density functions (PDFs) that describe the momentum fraction carried by individual partons are based on measurements made at HERA, the Tevatron and fixed target experiments. These cover only a fraction of the x-Q^2 region accessed at the LHC (where Q^2 is the scale of the hard interaction). In order to describe LHC data the PDFs must be evolved up in Q^2 and down in x. Measurements taken at the LHC can therefore be used to test the DGLAP and BFKL evolution schemes used to achieve this.

These proceedings describe how certain measurements made at the LHC can probe the small x region of the proton. Smaller values of x are probed in measurements of low mass particle production, or forward (high rapidity) particle production. Section 2 describes the features of the LHC experiments relevant to these analyses. Section 3 summarises studies which have been carried out so far. Conclusions are given in section 4.

2 The LHC experiments

Four experiments, ALICE, ATLAS, CMS and LHCb, detect proton proton collisions at the LHC (heavy ion collisions will not be considered here). ATLAS and CMS have been designed to instrument as much of the solid angle around the collision point as possible, whereas the coverage of the ALICE and LHCb experiments is determined by sensitivity to heavy ion and heavy quark processes respectively. The pseudorapidity coverage of the major detector components of the four experiments is summarised in table 1.

3 Preliminary physics studies

Studies of low invariant mass Drell-Yan production, forward jet and forward particle production have been carried out by the experiments and will be presented in the following subsections. Note

Detector	ALICE	ATLAS	CMS	LHCb
Tracking	$-0.9 < \eta < 0.9$	$-2.5 < \eta < 2.5$	$-2.5 < \eta < 2.5$ $3.1 <\mid \eta \mid< 4.7$ $5.2 <\mid \eta \mid< 6.5$	$1.8 < \eta < 4.9$
EM calorimeters	$-0.9 < \eta < 0.9$	$-4.5 < \eta < 4.5$	$-6.5 < \eta < 6.5$	$1.8 < \eta < 4.9$
Had calorimeters	$\mid \eta \mid> 8.5$	$\mid \eta \mid< 4.5$, $\mid \eta \mid> 8.1$	$\mid \eta \mid< 6.5$	$1.8 < \eta < 4.9$
Muon chambers	$-4 < \eta < -2.5$	$\mid \eta \mid< 2.7$	$\mid \eta \mid< 2.5$	$1.8 < \eta < 4.9$
Counters	$-3.4 < \eta < 5$ $-6.1 < \eta < -5$ $\mid \eta \mid> 8.1$	$5 < \eta < 6.1$		
Triggers	$Pt(\mu) > 1(2)$ GeV	$Pt(\mu) > 4(10)$ GeV	$Pt(\mu) > 3.5$ GeV	$Pt(\mu) > 1$ GeV

Table 1: Pseudorapidity coverage of the main components of each LHC experiment: tracking; electromagnetic and hadronic calorimetry; muon chambers; particle counters; example transverse momentum (Pt) trigger thresholds for muons. For the last category, numbers in brackets refer to thresholds imposed during high luminosity running.

that these studies are preliminary and represent an incomplete survey of all measurements sensitive to small x. For example, measurements of forward W and Z boson production at LHCb [1], and exclusive upsilon production at CMS [2] will not be described here.

3.1 Low mass Drell Yan production

The ATLAS, CMS and LHCb collaborations have performed studies of low invariant mass Drell-Yan production.

ATLAS has studied $\gamma^* \rightarrow e^+e^-$ production, where the final state electrons lie within the pseudorapidity region $\mid \eta \mid< 2.5$ [3]. Events are triggered by requiring an electron candidate of at least 10 GeV transverse momentum within the angular acceptance. Candidates are reconstructed by requiring two oppositely charged electrons which both have transverse momentum exceeding 10 GeV within $\mid \eta \mid< 2.5$. In addition, the missing transverse energy of the event must not exceed 30 GeV. The selection efficiency depends on mass, and is about 1% for invariant masses around 8 GeV. Figure 1 shows the invariant mass spectrum of selected events, with background estimates overlaid. Note that the dijet background contains significant statistical uncertainty. Systematic errors have been investigated and are thought to be small. The largest, due to PDF uncertainty, arises from the acceptance correction. With 50 pb^{-1} of data analysed the statistical error of an inclusive cross-section measurement, for masses between 8 and 60 GeV, is about 7%, and values of x down to 10^{-4} can be probed.

CMS has studied the same production channel in the forward rapidity region ($5.2 <\mid \eta \mid< 6.5$) [4]. Events are triggered by requiring a large electromagnetic ($>$ 300 GeV) and small hadronic ($<$ 5 GeV) energy deposit in the calorimeter, and at least one charged track found by the TOTEM tracking stations. Candidate events must also satisfy a minimum invariant mass cut m(ee)$>$ 4 GeV. Studies are preliminary - no backgrounds or systematic error have yet been considered. Figure 1 shows the values of x probed as a function of differential cross-section, for predictions using PDFs which include an estimate of saturation (EHKQ6) and which do not (CTEQ5L). Values of x approaching 10^{-6} can be probed. The measurement is sensitive to the saturation effects included in the PDF set tested.

LHCb has studied the production of $\gamma^* \rightarrow \mu^+\mu^-$ events inside the experimental acceptance of $1.8 < \eta < 4.9$ [1]. Events can be triggered by requiring two muon candidates, of summed transverse momentum exceeding 1.6 GeV. This requirement is 70% efficient for invariant masses m($\mu\mu$) >8 GeV. Candidate events are then chosen by requiring that both muons have low impact parameter and a high degree of isolation. These requirements are combined in a likelihood. Backgrounds from bottom and charm semi-leptonic decays, and kaons and pions misidentified as muons, have been considered. Figure 1 illustrates the likelihood shapes for these different contributions, shown as a function of differential cross-section. A full evaluation of systematic error is ongoing. Purities of 70% are thought to be achievable at invariant masses of 8-10 GeV, which would probe values of x approaching 10^{-6}. The statistical error is estimated at 1% if $100pb^{-1}$ of data are analysed.

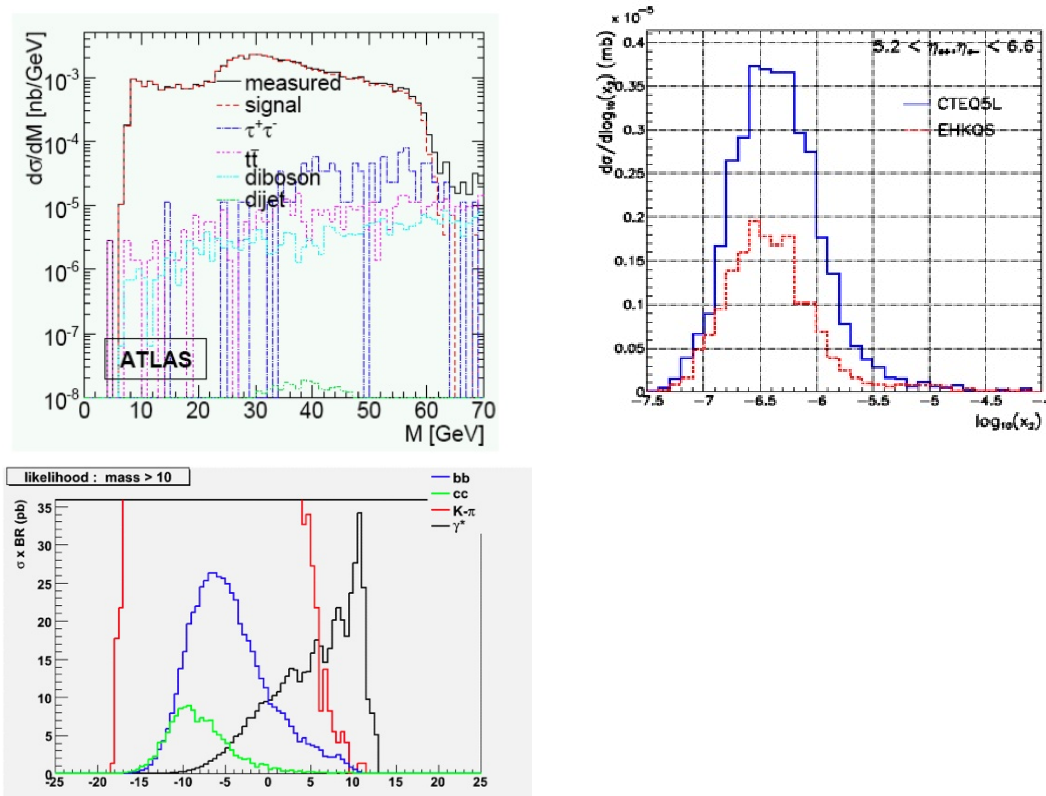

Fig. 1: (Top left) Invariant mass of $\gamma^* \rightarrow e^+e^-$ events analysed at ATLAS. Background contributions are shown by the coloured lines. (Top right) Range of x probed in forward $\gamma^* \rightarrow e^+e^-$ production with the CMS detector. Two theoretical predictions are shown: EHK6, which includes a treatment of saturation; CTEQ5, which does not. (Bottom left) Selection likelihood shapes for signal and major backgrounds for $\gamma^* \rightarrow \mu^+\mu^-$ with the LHCb experiment.

3.2 Forward jet production

CMS have studied jet production in the region $3 <\mid \eta \mid< 5$ [4]. Events can be triggered by requiring a transverse energy deposit exceeding 10 GeV in the HF calorimeter. Jets are defined using a cone algorithm, with radius R= $\sqrt{\Delta\phi^2 + \Delta\eta^2} = 0.5$. A candidate jet must have transverse energy exceeding 20 GeV. Figure 2 shows that values of x can be probed down to 10^{-5}. However, this measurement requires careful systematic error evaluation. Studies indicate that, unlike measurements of Drell-Yan production, accuracy is limited by the uncertainty in jet energy correction, which could contribute up to 30% systematic error in low transverse energy jets, where the smallest x is probed.

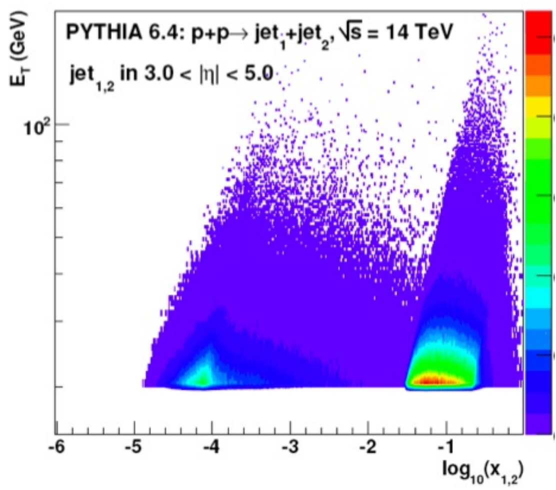

Fig. 2: Range of x probed in forward jet production with CMS, shown as a function of the transverse energy of the jet.

3.3 Forward J/ψ production

The ALICE experiment can probe small x through measurements of forward muon production. Figure 3 shows the region of x accessible when J/ψ production is measured within the confines of the ALICE muon detector. No studies have yet been performed, but the figure suggests it may be possible to probe values of x approaching 10^{-6}.

4 Conclusions

Measurements made of low invariant mass particle production at the LHC, particularly at forward rapidities, probe the small x region of the proton. These measurements can be used to test the evolution of the parton density functions to small x. Studies carried out by the LHC experiments indicate that it may be possible to probe values of x down to 10^{-6}.

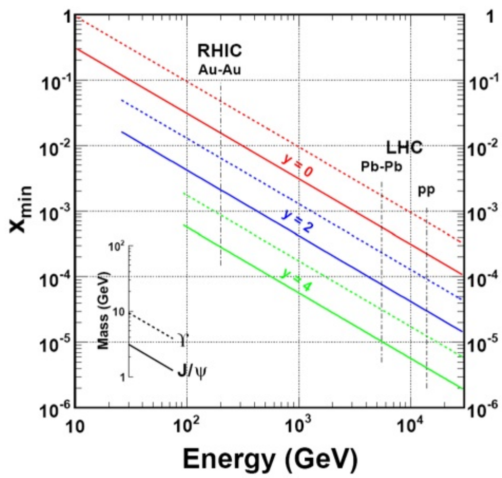

Fig. 3: Range of x probed in Υ (dotted line) and J/ψ (solid line) production with the ALICE experiment, shown for data taken at different centre-of-mass energies. Values of x probed at rapidities of 0, 2 and 4 are shown by the red, blue and green lines.

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References

[1] R. McNulty,"Potential PDF sensitivity at LHCb", Proceedingsof the XVI International Workshop on Deep-Inelastic Scattering and Related Topics, April 7-11, 2008 London, England **doi:10.3360/dis.2008.29**.

[2] The CMS collaboration, **CMS PAS DIF-07-001** (2008).

[3] The ATLAS collaboration, **ATL-COM-2008-064** (2008).

[4] The CMS collaboration, **CERN/LHCC 2006-039/G-124**, (2006).