Overview of experimental results presented at MPI@LHC 2011

Arthur Moraes

University of Glasgow, School of Physics and Astronomy, G12 8QQ, Glasgow, UK

DOI: http://dx.doi.org/10.3204/DESY-PROC-2012-03/55

This report will present a brief overview of some of the exciting experimental results presented at the 3rd International Workshop on Multiple Partonic Interactions at the LHC - MPI@LHC 2011. The experimental results presented at the conference included some of the most recent measurements from the LHC experiments as well as results from Tevatron and HERA collaborations.

1 Introduction

The Large Hadron Collider (LHC) is successfully colliding particles at the energy frontier and will remain the prime international facility for high energy physics research for the next decades. The main purpose of LHC is the study of the fundamental laws of Nature at very high energies. Besides the search for the elusive Higgs boson, the last missing piece of the Standard Model (SM) of Particle Physics, the LHC is also investigating the existence of new particles and interactions.

Recent studies on Higgs and beyond the Standard Model (BSM) searches with LHC data have not yet produced conclusive evidence proving the existence of new physics. Nevertheless, these searches reveal a common feature in the attempt to separate candidate signals from the background: the complex structure of the underlying interactions produced alongside the candidate processes of interest.

Protons, and indeed all hadrons, are made of quarks and gluons, collectively known as partons. When protons collide at high energies, their partonic constituents may undergo head-on collisions. The higher the energy involved in a proton-proton collision, the greater is the probability that a parton from one of the incoming protons will scatter off a parton from the other proton. The record high energies in proton-proton collisions at the LHC lead to an increased probability that not only one but multiple parton-parton interactions may take place in each proton-proton collision. The production of rare signals at the LHC will typically be accompanied by and correlated to several parton-parton interactions taking place in the same proton-proton collision.

This underlying structure of partonic interactions present in hadronic interactions has not been fully understood yet and early LHC results have shown that simulation models cannot satisfactorily predict many of their features either. It is known, however, that multiple partonic interactions (MPI) account for much of the underlying event associated to the production of highly energetic particles as well as to the direct background in many searches for new physics.

The MPI are experiencing a growing popularity and are currently widely invoked to account for observations that would not be explained otherwise: the global properties of particle production in proton-proton collisions at the LHC, the cross sections for multiple heavy flavour production, the survival probability of large rapidity gaps in hard diffraction, etc. At the same time, the implementation of the MPI effects in the simulation models is quickly proceeding through an increasing level of sophistication and complexity that, in perspective, achieves deep general implications for the LHC physics.

Measuring the properties of multiple partonic interactions will be crucial to understand the challenging environment present in LHC collisions, hence the relevance of these studies and the discussion of their results in forums like the MPI@LHC workshop series.

This report will briefly review and introduce some of the experimental results presented at the 3rd International Workshop on Multiple Partonic Interactions at the LHC - MPI@LHC 2011, which took place at DESY, Hamburg. Further details on individual results, including technical details and extended discussion on the physics results, can be found in the contributions published in this proceedings.

2 Experimental results presented at MPI@LHC 2011

The global properties of high-energy proton-proton collisions are deeply correlated with the dynamics of multiple partonic interactions. The rise in the total proton-proton cross-section (σ_{tot}) as a function of the centre-of-mass energy ($\sqrt{s}$) can be associated with the rise in multiple partonic interactions. The TOTEM Collaboration presented their measurements of the total, elastic and inelastic proton-proton cross-sections at $\sqrt{s}$ = 7 TeV (fig. 1). They measured $\sigma_{tot}^{pp}(\sqrt{s}$ = 7 TeV) = 98.3 $\pm$ 0.2 (stat) $\pm$ 0.8 (syst) mb and $\sigma_{el}^{pp}(\sqrt{s}$ = 7 TeV) = 24.8 $\pm$ 0.2 (stat) $\pm$ 1.2 (syst) mb, from which they derived $\sigma_{inel}^{pp}(\sqrt{s}$ = 7 TeV) = σ_{tot} - σ_{el} = 73.5 $\pm$ 0.6 (stat) $\pm$ 1.8 (syst) mb. Their results confirm the expected rises in σ_{tot} and σ_{inel} with the centre-of-mass energy and further support models predicting an increase in the MPI activity at the LHC compared to previous hadron colliders.

The diffractive component of the inelastic cross-section was also discussed in several presentations at the workshop. Newman made an extensive review of diffraction and multiple partonic interactions.

Single and double diffraction are important components of the hadronic inelastic interactions. Among other applications, determining the exact fraction of diffraction is important for phenomenology models which rely on the non-diffractive inelastic cross-section to parameterize the rate of MPI in hadron collisions. Results from the ALICE Collaboration measured at different centre-of-mass energies were discussed and showed to agree with previous data from CERN SPS experiments as well as with a wide range of model predictions (see Newman's contribution).

The differential pseudorapidity (η) gap cross-section measurement made by ATLAS was also discussed by Newman (see fig. 2). Through this measurement one is able to study the impact of MPI and hadronisation fluctuations on small gaps (small $\Delta\eta^F$). There are considerable variations between Monte Carlo (MC) model predictions for small gap production which is associated with the fluctuations in predictions for the underlying event and MPI rates. The cross-section measurement for large gap values probes the single diffractive cross-section.

Multiplicity distributions were extensively discussed by all LHC collaborations (see, for example, contributions from Leyton, Bansal, Grosse-Oetringhaus and Volyansky). Similar conclusions regarding fluctuations in the prediction of multiplicity spectra can be obtained from

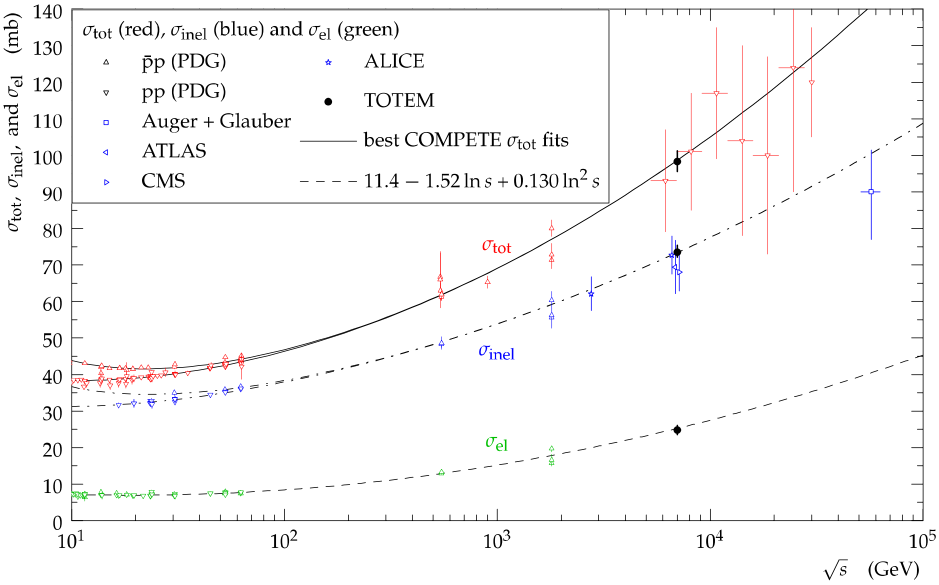
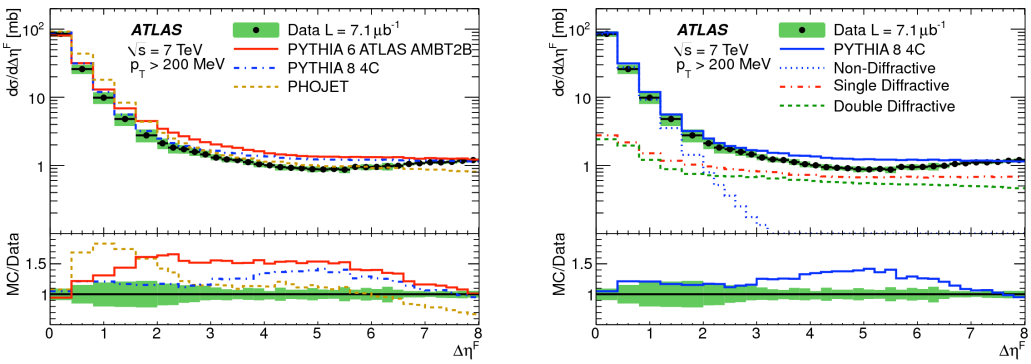


Figure 1: Total (σ_{tot}), inelastic (σ_{inel}) and elastic (σ_{el}) cross-section as a function of $\sqrt{s}$. Further details in contribution from Österberg in this proceedings.



(a) (b)

Figure 2: Inelastic cross section differential in forward gap size $\Delta\eta^F$ for particles with $p_T >$ 200 MeV. The shaded bands represent the total uncertainties. The full lines in (a) show the predictions of PHOJET and versions of PYTHIA 6 and PYTHIA 8. The dashed lines in (b) represent the contributions of the non-diffractive (ND), single diffractive (SD) and double diffractive (DD) components according to PYTHIA 8.

these studies: phenomenology models employing MPI cannot adequately describe very low multiplicity events, typically dominated by soft particles (low p_T particles) and highly influenced by diffractive interactions nor the high multiplicity tails of multiplicity distributions, usually associated to events containing hard particles (high p_T particles) and (semi-) hard multiple partonic interactions.

New results on particle correlations as well as attempts to model these observables have been presented at the workshop. These studies further extend the reach of physics effects one can investigate in order to assess the impact of MPI in different regions of the phase-space. Measurement of two-particle angular correlations (see fig. 3) and on the azimuthal ordering of charged hadrons (fig. 4) reveal interesting features which current phenomenology models still cannot describe properly.

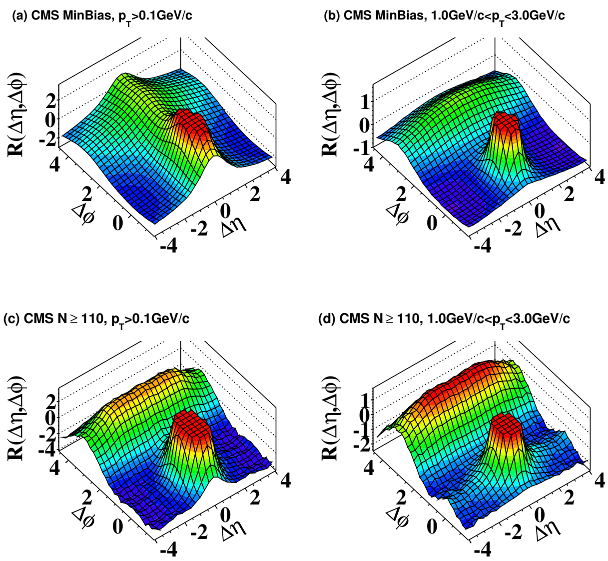
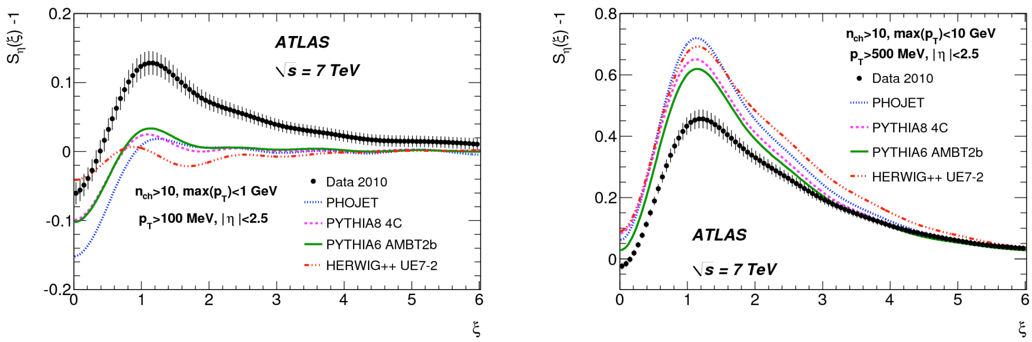


Figure 3: Two-particle angular correlations measured for various kinematic selection cuts for proton-proton collisions at $\sqrt{s} = 7$ TeV by the CMS collaboration. These measurements have inspired modifications in the implementation of MPI in some MC models. Further details in contribution from Basal and Alderweireldt in this proceedings.

The underlying event (UE) was also object of several presentations. The ALICE collaboration, amongst various interesting results, showed measurements for the transverse sphericity which indicate that data events are more spherical than MC, particularly for selection cuts focused on high multiplicity events. This suggests there is a higher MPI activity in data than what is currently generated in MC simulations (see contribution from Grosse-Oetringhaus in this proceedings). Comparisons between the rise in charged particle densities for minimum bias and underlying event as a function of the centre-of-mass energy were also presented by ALICE and highlight the crucial role played by MPI in these two classes of measurements (fig. 5): the rise in charged particle density in the UE is steeper that that seen in minimum bias indicating that MPI activity is higher in the former compared to the latter. ATLAS and CMS report similar results.

Knutsson presented an overview of several H1 and ZEUS measurements which investigate



(a) (b)

Figure 4: Spectral analysis of correlations between the longitudinal and transverse components of charged hadrons. Power spectrum S_η for the azimuthal ordering of charged hadrons measured by ATLAS for two selection cuts: (a) low-p_T enriched and (b) low-p_T depleted sample. Further details in contribution from Leyton in this proceedings.

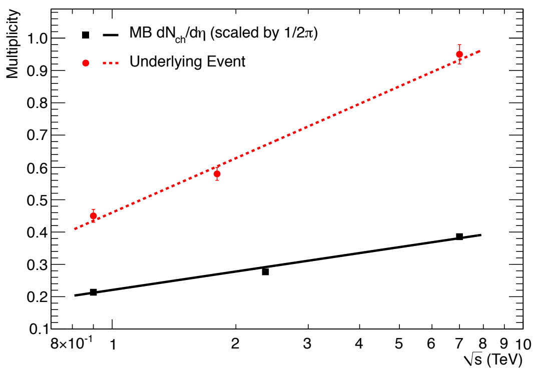


Figure 5: Comparison of number density in the plateau of the transverse region and $\mathrm{dN}_{ch}/\mathrm{d}\eta$ in minimum bias events (scaled by $1/2\pi$). Both are for charged particles with $p_T > 0.5$ GeV. Further details in contribution from Grosse-Oetringhaus in this proceedings.

the role of MPI in electron (or positron)-proton collisions at HERA. Recent studies on charged particle distributions and mini-jet production in photoproduction events were discussed and highlight, yet again, the relevance of MPI in the interpretation of their results. For example, fig. 6 shows the charged particle flow in photoproduction measured by H1. It is clear from the comparison between data and MC predictions that an adequate description of the data requires the inclusion of MPI in the MC models.

The D0 collaboration reported on their direct measurements of multiple partonic interactions which included results for double-parton scattering (DPS) as well as triple-parton scattering (TPS). Golanov presented their results for the measured fractions of DPS and TPS events which

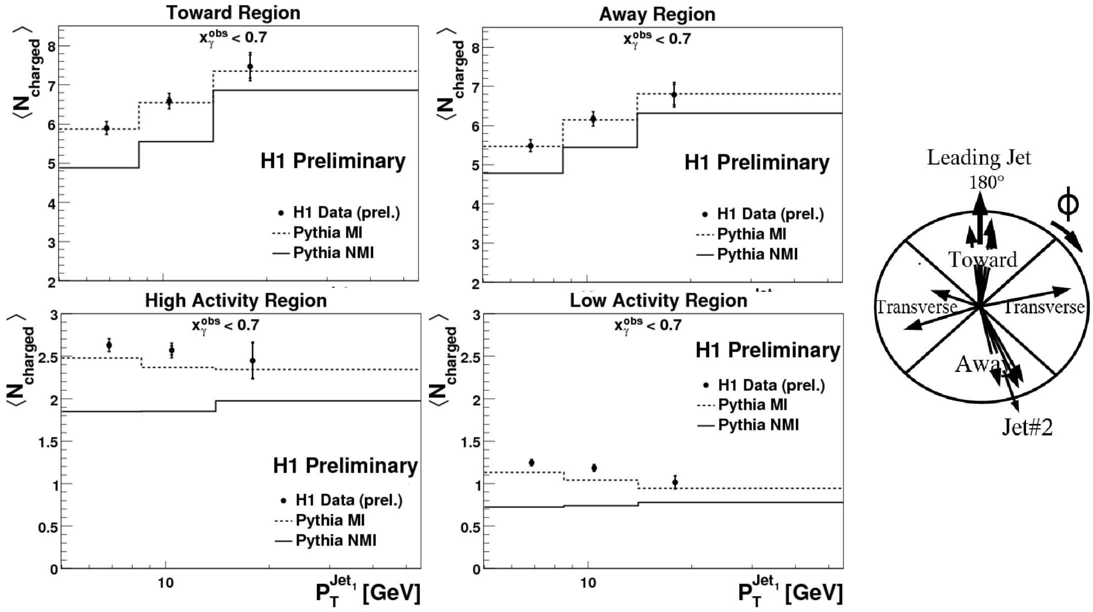


Figure 6: Charged particle flow in photoproduction: comparison between data and MC for various angular regions. Further details in contribution from Knutsson in this proceedings.

vary as a function of the second leading jet p_T (p_T^{jet2}). The DPS fraction in $\gamma+2$ jets was 11.6% for events with 15 GeV< p_T^{jet2} < 20 GeV and drops to 2.2% for 25 GeV < p_T^{jet2} < 30 GeV. The TPS fraction in $\gamma + 3$ jets, which was determined for the first time, was 5.5% for events with 15 GeV< p_T^{jet2} < 20 GeV and drops to 0.9% for 25 GeV < p_T^{jet2} < 30 GeV. The measured effective cross-section (σ_{eff}) was $\sigma_{eff} = 16.4 \pm 0.3(\text{stat}) \pm 2.3(\text{syst})$ mb, which is comparable to a similar measurement done by the CDF collaboration.

The first result on direct measurement of DPS at the LHC was presented by the ATLAS collaboration. Investigating W+2 jet event topologies from proton-proton collisions at $\sqrt{s}$=7 TeV they were able to measure the fraction of DPS in their sample (f_{DPS}) as well as σ_{eff}. Dobson reported the following results: $f_{DPS} = 0.16 \pm 0.01(\text{stat}) \pm 0.03(\text{syst})$ and $\sigma_{eff} = 11 \pm 1(\text{stat}) \pm 3(\text{syst})$ mb.

3 Outlook

Measurements exploring several aspects of multiple partonic interactions were discussed at the 3rd International Workshop on Multiple Partonic Interactions at the LHC - MPI@LHC 2011. These results add to the growing body of evidence showing the impact of MPI on the QCD dynamics in high-energy collisions involving partonic initial states. Many of these results also challenge our current phenomenology used to describe the complex nature of QCD interactions at the LHC.

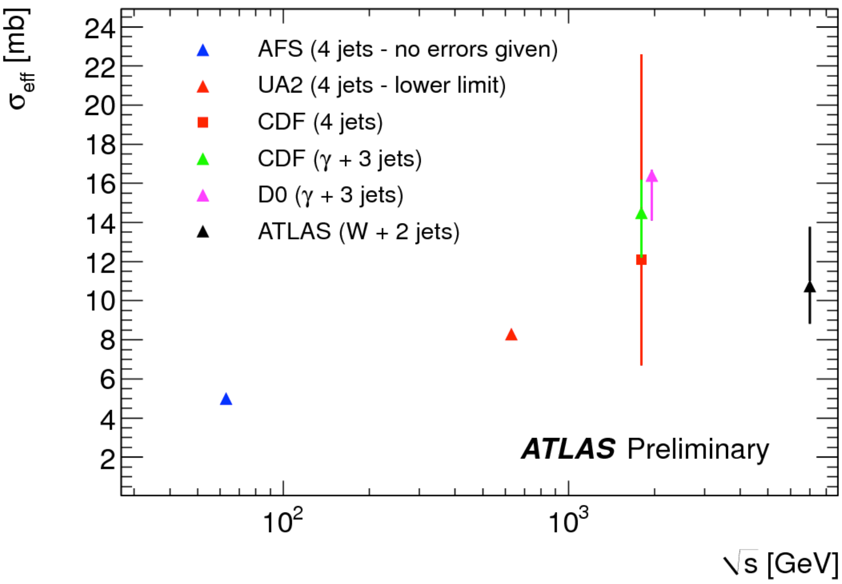


Figure 7: The centre-of-mass $\sqrt{s}$ dependence of σ_{eff} extracted in different processes in different experiments, for an energy range between 63 GeV and 7 TeV. Further details in contribution from Dobson in this proceedings.

The future outlook for the continuation of these discussions looks very exciting and will certainly rely on new results expected to be published by the LHC collaborations in the coming months. These will include further measurements on correlations in particle production in inelastic events, underlying event measurements in different systems and with new observables (Drell-Yan and jet area studies, for example) and direct measurements of MPI processes.