ATLAS Plans on Soft and Hard Diffraction at the Early LHC

Vojtěch Juránek[1]
on behalf of the ATLAS collaboration

[1]Institute of Physics, Academy of Sciences, Na Slovance 2, 182 21 Prague, Czech Republic

A brief review of ATLAS forward detector system is presented. Short review of forward physics measurements that are planned to be done with first ATLAS data are introduced. This includes several topics, mainly QCD processes, but also photon physics.

1 Forward Physics with First ATLAS Data

ATLAS first data will be taken at very low luminosity in very clean environment, where almost no additional $p-p$ scattering will be present. It expected that first data will be taken up in late 2009 or in beginning of 2010 at centre-of-mass energy of 7 TeV which will be increased to 10 TeV later on. Peak luminosity during this first data taking will be from $\mathcal{L} = 5 \cdot 10^{31}$ cm^{-2}s^{-1} to $\mathcal{L} = 2 \cdot 10^{32}$ cm^{-2}s^{-1}. At these luminosities the number of additional $p-p$ interactions will be small. Bunch spacing of 75 ns (expected during the first data taking) can lead up to 1.8 interactions per bunch crossing, which is still quite clean environment. Total integrated luminosity taken up during the first 100 days will be about 100 pb^{-1}, and about 200 pb^{-1} during the next 100 day of operation. With this amount of data a lot of forward physics measurements can be done. There are analysis that can be done with 10 pb^{-1} of data or less.

2 ATLAS Forward Detectors

ATLAS [1] is general purpose detector at the LHC designed to measure the broadest possible range of signals [2]. The main parts of the ATLAS detector are Inner Detector, electromagnetic and hadronic calorimeters, muon spectrometer and forward detectors. The Inner Detector covers pseudo-rapidity range up to $|\eta| < 2.5$, central electromagnetic and hadronic calorimeters up to $|\eta| < 3.2$ and forward calorimeters up to $|\eta| < 4.9$. The η coverage of muon spectrometer is up to $|\eta| < 2.7$.

To have good coverage in forward regions, there are MBTS and three additional smaller detectors: LUCID, ZDC and ALFA. Nearest forward detector is LUCID, which is ±17 m from the interaction point. ZDC is situated at ±140 m from interaction point and ALFA at ±240 m.

2.1 MBTS

MBTS stands for Minimum Bias Trigger Scintillators. MBTS is placed between inner detector and end-cap cryostats. It covers pseudo-rapidity in range $2.09 < |\eta| < 3.84$. MBTS consist of

16 wedges on each side, there are two rings in pseudo-rapidity and each ring has 8 azimuthal wedges. MBTS will be not active during whole lifetime of ATLAS. Because of heavy radiation, it is expected that MBTS will become increasingly inefficient after a few months of higher luminosity operation.

2.2 LUCID

LUCID (Luminosity measurement using Cerenkov Integrating Detector) is the main ATLAS on-line monitor for relative luminosity measurement. This measurement is done by detecting particles coming from inelastic scattering of the protons. One of the aims of LUCID is to reduce the uncertainty of relative luminosity measurement below 5%. LUCID is designed to count individual charged particles, because instantaneous luminosity measurement is based on the fact that the average number of interaction in bunch crossing is proportional to the number of particles detected in the detector. LUCID has also very good time resolution to be able to measure each individual bunch crossing. More over it has to be highly resistant to radiation.

The LUCID detectors are installed in the end-cap regions of the ATLAS detector. It consists of 20 aluminium tubes that surround the beam pipe in the distance of about 10 cm from the beam-line. The tubes point towards the interaction point. LUCID has good acceptance for minimum bias events and will be used for triggering of these events.

2.3 ZDC

ZDC (Zero Degree Calorimeter) is designed for measurements of forward neutrons in heavy-ion collisions. It is placed at 140 m on both sides of interaction point in Target Absorber Neutral (TAN) between the tubes at the point where LHC beam-pipe splits into two separate tubes. ZDC consists of 4 modules, one electromagnetic and three hadronic. It covers pseudo-rapidity $|\eta| > 8.3$. In the very early data taking period, the ZDC electromagnetic module will not be installed and its position is taken by the LHCf experiment [3].

ZDC can be also used for diffractive measurements during the start-up low luminosity runs (below 10^{33} cm^{-2}s^{-1}). The time resolution of ZDC is about 100 ps, so by requiring activity on both sides of ZDC, it can be also used for vertex determination with accuracy of about 3 cm in z direction. This can be used for excluding events like beam halo and beam gas. The only disadvantage for forward physics measurements is that ZDC can detect only neutral particles (n, γ). As soon as the luminosity of 10^{33} cm^{-2}s^{-1} will be reached, the ZDC modules will be removed for $p-p$ scattering and reinstalled only for heavy ions runs (in order to minimise radiation damage of ZDC).

2.4 ALFA

ALFA (Absolute Luminosity For ATLAS) is dedicated to measurements of absolute luminosity using Roman Pot detectors. This will be done by measurements of $p-p$ elastic scattering. Protons scatter through very small angles in this reaction, so the detector has to be placed far from the interaction point and very close to the beam. Moreover for this measurement special runs (high β^* optics and reduced beam emittance) are required. ALFA roman pots will be able to come as close to the beam as 1 mm. There will be two roman pots on each side. The distance between these two pots is 4 m. ALFA is not yet installed and will not be used during 2009/2010.

2.5 Forward Detectors Used in Early Data

The majority of the physics studies that are presented in the following sections make use of the ATLAS central detectors and then propose to use the forward detectors as either a trigger or to measure the properties of the diffractive events in early ATLAS data. The MBTS is used to trigger both minimum bias and diffractive events and can be used to impose a rapidity gap (i.e. particle veto) in the regions $2.1 < |\eta| < 3.8$. In addition to MBTS, LUCID and the ZDC will be used to trigger events. In principle, both LUCID and the ZDC can also be used to define rapidity gaps in the very forward region in order to select central exclusive events (Sec. 5) and single diffractive (Sec. 6). This possibility is currently being investigated using the ATLAS simulation.

3 Soft Single Diffraction

Soft single diffraction is a low t-process (t being standard Mandelstam variable), where colour singlet is exchanged in t channel between two protons and one of the protons breaks up into a dissociative system. A similar process is soft double diffraction, but in this process both protons breaks up into dissociative system. As the exchanged object is colour singlet, there is a large rapidity gap between intact proton and dissociative system (or between dissociative systems in case of double diffraction). Expected cross sections at LHC are about 12 mb in case of soft single diffraction and about 7 mb in case of soft double diffraction.

Soft single diffraction can be measured by ALFA by tagging the outgoing proton, but it can be measured also with the more central detectors by imposing a pseudo-rapidity gap in the forward regions. With such high cross section, only about two weeks of data taking at lowest luminosity (10^{31} cm^{-2}s^{-1}) is required by this analysis (it is expected to collect sample of about one million events in two weeks at luminosity of 10^{31} cm^{-2}s^{-1}). The measurement of soft single diffraction at ATLAS will be focused on the diffractive mass distribution, M_X, and the fractional energy loss of proton, $\xi = \frac{M_X}{\sqrt{s}}$. ATLAS will cover several orders in magnitude in ξ. MBTS, LUCID and ZDC will be used as triggers.

When installed, ALFA will be able to measure directly proton momentum loss ξ during the special runs with high-β^* optics and luminosity of 10^{27} cm^{-2}s^{-1}.

4 BFLK Jet Evolution and Colour Singlet Exchange

ATLAS has potential to measure a lot of interesting observables inspired by BFKL. A process of interest is QCD $2 \rightarrow 2$ scattering mediated by t-channel exchange. It is interesting to study jet evolution and compare the results with DQLAP and BFKL predictions. In particular, interesting process is t-channel colour singlet exchange, as possible candidate for colour singlet exchange is BFKL pomeron [4].

BFKL predicts different shower evolution to DGLAP. In BFKL gluon splitting is not ordered in E_T, which can lead to final state with jets in central region with similar E_T to those in forward regions. BFKL also predicts larger decorrelation than DGLAP in $\Delta\Phi(= \pi - \phi_{jet1} + \phi_{jet2})$ between the jets, see e.g. [5, 6]. This azimuthal decorrelation increases[1] with pseudo-rapidity separation of jets, $\Delta\eta$.

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[1] This effect is dominant in leading log approximation. In NLL the decorrelation decrease and becomes similar to the DGLAP predictions [7]

Another interesting observable is so called gap fraction - a fraction of events containing no or small radiation in the centre of the detector, i.g. with large central rapidity gap. This observable has been previously measured at HERA [8, 9] and Tevatron [10, 11]. However, at the Tevatron the gap fraction was not observed as, for example, the centre-of-mass energy was too small. The fraction of events with suppressed activity in central region should rise with rapidity gap between jets. The separation of jets in pseudo-rapidity increases with centre-of-mass energy as $\Delta\eta \simeq \ln \frac{x_1 x_2 s}{Q_1 Q_2}$, where $Q_i \approx E_{T,i}$. This means that situation at LHC will be improved with comparison with Tevatron and it is expected that a sufficiently large statistics sample of events with gaps can be collected. The signature of the process will be two jets in forward calorimeter, one jet in each forward calorimeter, and gap in central calorimeter. The 2FJ18 trigger will be used to trigger the events - trigger on two jets in FCAL with E_T >18 GeV.

5 Central Exclusive Di-Jet Production

Central exclusive di-jet production (CEP) is defined as $pp \to p \oplus jj \oplus p$, where all the proton energy lost during the interaction is used in production of di-jet system, jj. Symbol $\oplus$ denotes rapidity gap. CEP processes were measured by CDF and are in good agreement with theoretical predictions [12]. However, there are still large uncertainties in theoretical calculations. The main aim of this measurement is to measure cross section as function of E_T to constraint the uncertainty of theoretical models (namely KMR model [13], by factor of 2-3) and understand CEP di-jet production as a background for other interesting processes like CEP production of Higgs boson. Possible strategy will be measurement of di-jet mass fraction

$$R_{jj} = \frac{M_{jj}}{M_{calo}} \simeq \sqrt{\frac{x_1 x_2}{\xi_1 \xi_2}}, \tag{1}$$

where M_{jj} is invariant mass of di-jet system, M_{calo} is the mass of all energy deposit in the calorimeter and

$$x_{1,2} = \frac{1}{\sqrt{s}} \sum_{jets} E_T^i \exp(\pm\eta_i) \tag{2}$$

$$\xi_{1,2} = \frac{1}{\sqrt{s}} \sum_{clus} E_T^i \exp(\pm\eta_i). \tag{3}$$

R_{jj} should be near unity for CEP di-jet, while $R_{jj} \ll 1$ for inclusive and diffactive events.

The trigger strategy is to require a jet with $E_T > 10$ GeV and a veto on at least one side of MBTS trigger (L1_J10_MV). The trigger is expected to be run unprescaled at luminosity around 10^{31} cm^{-2}s^{-1}. It is expected to collect a few hundred exclusive di-jet events in 10 pb^{-1} of data.

6 Diffractive Di-Jet Production

Diffractive di-jet production is a process where one proton (single diffraction, SD) or both protons (double pomeron exchange, DPE) remains intact and remnant from exchanged particles (pomerons) are present. This means that not all energy of exchanged objects is used to create central object as in case of exclusive production and also rapidity gaps are smaller because of presence of pomeron remnants. These types of processes were measured at HERA [14, 15] and Tevatron [16, 17], where factorisation breaking were observed in comparison with HERA results.

The aim of this analysis is to measure ratio of di-jet production in hard single diffraction (SD) to non-diffractive di-jet production and ratio of double pomeron exchange (DPE) di-jet production to SD di-jet production. From these measurements, conclusions about gap survival probability at LHC energies can be made and theoretical uncertainties can be reduced. Also diffractive structure functions can be determined from relation

$$\frac{\sigma(SD_{jj})}{\sigma(ND_{jj})} = \frac{F^D_{jj}(x)}{F_{jj}(x)}. \tag{4}$$

POMWIG Monte Carlo [18] predicts SD di-jet production cross section of about 3 μb for LHC energies with gap survival probability equal to 0.075, $E_T^{jet} > 17$ GeV and $\xi < 0.1$. The cross section is quite large, but unfortunately the triggering SD events is quite problematic at ATLAS. Low E_T jet trigger (J_18) is heavily prescaled (the considered prescale is 6000) and forward detectors are not very helpful - MBTS veto passes only very small amount of signal (only events with very small ξ, where rapidity gap is very large). A LUCID veto passes almost all signal, but also a lot of background (non-diffractive di-jets, about 70%), which again require heavy prescaling. ZDC could be very helpful as most of the events which pass veto in ZDC have rapidity gaps in the forward regions. Trigger design for diffractive di-jets is still in progress.

7 Photon Physics

Another interesting topics is photon induced forward physics processes, especially photon induced CEP WW, CEP Υ production and CEP di-lepton production. CEP WW is interesting process itself, but it attracts attention also for another reason: using this process allows studying anomalous triple WWγ and quartic WW$\gamma\gamma$ gauge coupling. It has be shown [19], that LHC is more sensitive to quartic anomalous coupling than to anomalous triple gauge coupling. It is expected that about 100 pb^{-1} amount of data will be sufficient to observe CEP WW and significantly improve conclusion about WW$\gamma\gamma$ anomalous coupling. Details about measurements of this process can be found in [19] and [20].

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