Forward Physics with early ATLAS data

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The ATLAS forward detector system is presented. Following this, the forward physics measurements that are expected to be carried out with early ATLAS data are introduced and the relevant trigger and analysis strategies discussed.

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I. THE ATLAS FORWARD DETECTOR SYSTEM

ATLAS is a general multipurpose detector [1] designed to be able to measure a wide variety of physics processes at the LHC. ATLAS has a standard layout of sub-detectors; an Inner Detector ($|\eta| < 2.5$) for tracking purposes, electromagnetic calorimeters ($|\eta| < 3.2$) for measuring the energy of electrons and photons, hadronic calorimeters ($|\eta| < 4.9$) to measure the energy of mesons and baryons, and a muon spectrometer ($|\eta| < 2.7$). In addition, there are a number of other sub-detectors designed to measure (forward) particle production; these are the MBTS, LUCID, ZDC and ALFA.

The Minimum Bias Trigger Scintillators (MBTS) are located at $|z| = 3.6$ m and cover $2.1 < |\eta| < 3.8$ [2]. The MBTS is designed to trigger so-called *minimum bias events*, identifying particle production from inelastic collisions. Each side of the MBTS (positive and negative) are divided into 16 segments: two η-rings and eight ϕ-sections. The multiplicity of hit segments on each side will be available for the Level 1 (L1) trigger. The MBTS detector will only be available during the low luminosity phase of LHC operation, as it was not designed to have high radiation tolerance.

The LUCID detectors [3] are located 17 m from the interaction point, one on each side of ATLAS, and provide coverage of $5.6 < |\eta| < 6.0$ for charged particles. Each LUCID detector is a symmetric array of polished aluminium tubes that surround the beam-pipe. Each tube is 15 mm in diameter and filled with C_4 F_{10} gas, which results in Cerenkov emission from charged particles crossing the tube. The Cerenkov light is read out by photomultiplier tubes. The initial LUCID detector, available for early data taking, has L1 trigger capabilities but only limited azimuthal coverage. An upgrade to provide full azimuthal coverage is under study.

The Zero Degree Calorimeter (ZDC) [4] is located 140 m from the interaction point in the TAN region (target absorber for neutrals), where the single beam-pipe splits into two, and provides coverage of $|\eta| > 8.3$ for neutral particles. The ZDC consists of one electromagnetic and three hadronic tungsten/quartz calorimeters. Vertical quartz strips provide the energy measurements and horizontal quartz rods are used for coordinate readout. At LHC startup, when there are few bunches in the beam, the electromagnetic calorimeter is not installed and the space it would occupy is used by the LHCf experiment. After initial running, LHCf will be removed and the full ZDC installed.

The ALFA roman pot (RP) spectrometers are located 240 m from the interaction point [5]. Unlike other detectors, the RP spectrometers are not fixed relative to the beam. At injection, the ALFA detectors are in a withdrawn position far from the beam. After the protons have been injected and the beam has been stabilized, the detectors are moved to within 1.5 mm of the beam. Elastic and diffractive protons that have been deflected outside the beam envelope pass through arrays of scintillating fibre trackers (20×64 fibres in each array), which measure the position of the protons with respect to the beam. This allows the momentum and angle of each proton to be reconstructed by using the known LHC lattice. ALFA will only be used during special LHC runs at low luminosities with high β^* optics.

II. SOFT DIFFRACTION

Single diffraction is a low t-process in which a colour singlet (i.e. pomeron) is exchanged between the two protons and one of the protons breaks up into a dissociative system. There is a large rapidity gap between the outgoing proton and the dissociative system as a colour singlet object was exchanged. The cross section for soft single diffraction (SD) is expected to be of the order 10 mb at the LHC. There are two approaches that will be used to measure soft-SD at ATLAS.

The first approach will identify the dissociated system using the inner detector, calorimeters, LUCID and possibly the ZDC. The variable of interest is the fractional longitudinal momentum loss, ξ, given by

$$\xi = \frac{M_{\rm X}^2}{s} \tag{1}$$

where $M_{\rm X}$ is the invariant mass of the dissociative system and s is the centre-of-mass energy of the pp collision. It follows that the dissociated system for events with low-ξ will be contained only in the forward detectors, whereas high-ξ events will have activity in many areas of the central detector as well. The MBTS, LUCID and the ZDC will be required to trigger events across the full kinematic range. It has been estimated that a sample of one million events can be collected in two weeks given a luminosity of 10^{31} cm^{-2} s^{-1}.

The second approach is to tag the outgoing proton and measure ξ directly using

$$\xi = 1 - \frac{|p'_{\mathrm{z}}|}{|p_{\mathrm{z}}|} \tag{2}$$

where p_{z} and p'_{z} are the longitudinal momenta of the incoming and outgoing protons respectively. This approach requires the ALFA RP detectors, which can only be used in special runs with high-β^* optics at a luminosity of 10^{27} cm^{-2} s^{-1}. ALFA will be able to measure the fractional momentum loss, with an accuracy between 8% (for $\xi \sim 0.01$) and 2% (for $\xi \sim 0.1$). The trigger will be provided by ALFA and it is expected that 1.2-1.8 million events will be retained with just 100 hrs of data taking [5]. The analysis will also make use of LUCID and the ZDC, which are used to tag the dissociative system to separate the events from elastic scattering.

In addition to soft single diffraction, it is expected that ATLAS will also be able to measure soft double diffraction, in which both protons form dissociative systems.

III. DIFFRACTIVE DI-JET PRODUCTION

ATLAS will be able to measure single diffractive di-jet production and di-jet production via double pomeron exchange. These processes, shown in Fig. 1 (a) and (b), will allow the study of diffractive parton density functions (dPDFs) and factorization breaking in diffractive events. Factorization breaking is the observation that the dPDFs obtained at HERA do not predict the correct cross section for diffractive events at hadron colliders [6] and is attributed to secondary scattering between spectator partons in the protons causing the proton to break up and the rapidity gap to be destroyed. Factorization breaking will be studied by measuring the ratio of single diffractive to non-diffractive di-jet events, R(SD/ND), and the ratio of double-pomeron exchange to single diffractive di-jet events, R(DPE/SD).

It is expected that a few thousand SD di-jet events, with jet transverse energy, $E_{\mathrm{T}} > 20$ GeV, will be available for analysis given 100 pb^{-1} of data. The number of events is restricted by the large prescale applied in the Level 1 (L1) trigger for low transverse energy jets and the current focus is to develop new trigger strategies capable of retaining more events. The new triggers may include information from LUCID and/or the MBTS (discussed futher in Sec. IV).

IV. CENTRAL EXCLUSIVE DI-JET PRODUCTION

Central exclusive di-jet production (CEP) is the process $pp \to p + jj + p$, where the '+' denotes a large rapidity gap from the outgoing protons, and is shown in Fig. 1 (c). CEP has received a great deal of attention in recent years due to the possibility of tagging the outgoing protons, using new forward proton detectors, in order to measure properties of the Higgs boson [7]. Although the CDF measurements of exclusive di-jets, photons and charmonium are in good agreement with the theoretical predications [8], there remains a factor of three uncertainty in the calculation of the Higgs cross section at 14 TeV. Exclusive di-jet production offers the opportunity to constrain this uncertainty at the LHC with early ATLAS data.

The analysis strategy is to define the exclusivity of an event using the di-jet mass fraction,

$$R_{\mathrm{jj}} = \frac{M_{\mathrm{jj}}}{M_{\mathrm{calo}}} \tag{3}$$

where M_{jj} is the invariant mass of the di-jets and M_{calo} in the mass of all energy deposits in the calorimeter. Typically, an exclusive event will have $R_{\mathrm{jj}} \sim 1$ and inclusive/diffractive events will have $R_{\mathrm{jj}} \ll 1$. However, the tail of the background distribution extends up to large R_{jj} values and the extraction of the exclusive signal will require a very good understanding of the background distributions.

Due to the large QCD cross sections, the standard low-E_{T} jet triggers will be heavily prescaled and will provide insufficient statistics to perform CEP measurements. Consequently, a new trigger was developed that, in addition to a jet with $E_{\mathrm{T}} > 18$ GeV, required an absence of hit segments on at least one side of the MBTS. Simulations show that this trigger has a 60% efficiency for signal events (with respect to the jet trigger alone) and provides a 10^4 rejection factor for standard QCD events. It is expected that a few hundred exclusive di-jet events will survive the final selection criteria for every 10 pb^{-1} of data.

In addition to exclusive studies, this trigger strategy can also be used to retain single diffractive di-jet events. Although the overall trigger efficiency for single diffractive events is approximately 10^{-2} (for this trigger), the majority of the events that are removed are at high-ξ. Thus, the trigger may allow a sample of low-ξ SD di-jet events to be analyzed, which could then be used to constrain the dPDFs in an interesting kinematic region.

V. FORWARD JETS

There are a number of signatures involving widely separated jets that can be measured with early ATLAS data. The processes of interest are $2 \to 2$ partonic scatters mediated by t-channel colour octet or colour singlet exchange.

An inclusive measurement of interest is the azimuthal de-correlation of di-jets, the size of which is dependent on the pseudo-rapidity separation of the jets . The theoretical predictions of the azimuthal de-correlation is dependent on the framework used to make the prediction, namely fixed order (NLO), parton shower and BFKL. It is expected that LHC measurements will be sensitive to BFKL effects[9].

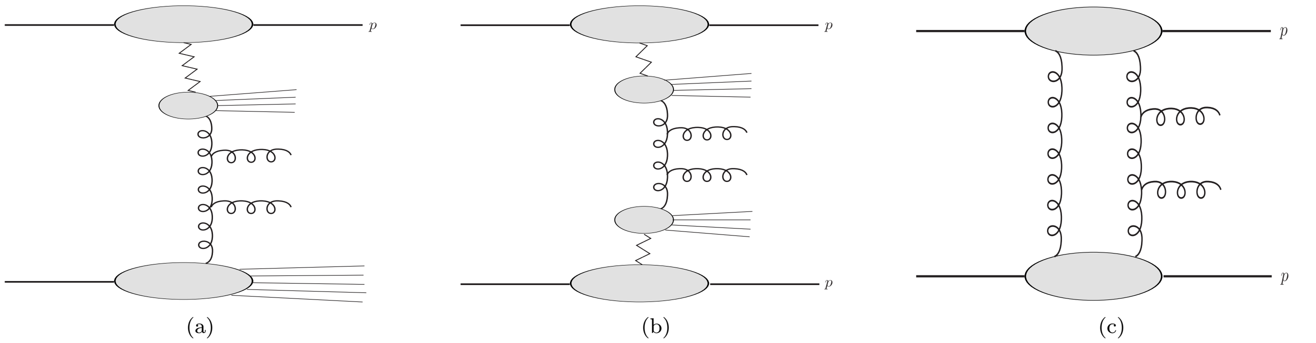

FIG. 1: Single diffractive di-jet production (a), di-jet production via double pomeron exchange (b) and central exclusive di-jet production (c). In (a) and (b), the 'zig-zag' line represents colour singlet (pomeron) exchange and there will be rapidity gap between the intact proton and the pomeron remnants. In (c), the di-jets are produced *exclusively*, implying no hadronic activity outside of the di-jet system.

It is also useful to split the di-jet samples into gap and non-gap components. This is achieved by vetoing on radiation between the jets. Experimentally, we introduce a veto-scale which defines the maximum transverse energy that can be deposited between the jets in a gap event. It is then useful to study the fraction of gap-events as a function of the pseudo-rapidity separation of the jets, $\Delta\eta$. For large separation, $\Delta\eta \sim 6$, the gap events are predominantly due to colour singlet exchange. A prediction of BFKL [10] is that the fraction of events with little activity between the jets should rise with the separation of the jets, $\Delta\eta$, and was extensively searched for at the Tevatron and HERA [11]. The rise of the gap-fraction was not observed at the Tevatron, for example, because the centre-of-mass energy was too small; it was shown in [12] that the rapidly falling PDFs at high x tempered the rise and meant that a large enough sample of events with large jet separations could not be obtained (because $\Delta\eta = \ln(\hat{\mathrm{s}}/\hat{\mathrm{t}})$). An improved measurement should be possible at the LHC due to the increased centre-of-mass energy. In principle, ATLAS should be able to measure the gap-fraction up to $\Delta\eta \sim 9, 9.5$ with approximately 10 pb^{-1} of data. The events are retained for analysis by using a forward di-jet ($|\eta_{\mathrm{jet}}| > 3.2$) trigger with $E_{\mathrm{T}} > 18$ GeV.

Finally, for smaller pseudo-rapidity separations ($\Delta\eta \sim 4$), it is interesting to study the fraction of gap events as a function of $\ln(\mathrm{Q}/\mathrm{Q}_0)$, where Q is the transverse energy of the jets. In this region, the gap events also arise from single gluon (colour octet) exchange. This observable is sensitive to QCD effects such as wide angle soft gluon radiation [13, 14]. Preliminary studies indicate that these measurements should be achievable with less than 100 pb^{-1} of data using standard jet triggers.

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