Preparation for forward jet measurements in Atlas

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Abstract
The Atlas collaboration is defining the strategies for forward physics analyses with the first data. Most of the cross section at the LHC will involve production of particles in the forward direction, and the large rapidity coverage of Atlas allows the study of several interesting QCD channels, both in the framework of diffraction and for studies of underlying event and QCD evolution.

1 Introduction

1.1 Forward physics at the LHC

The first LHC data will mainly be used for commissioning and calibration, but even with small luminosity a large number of events with forward jets will be recorded. The LHC detectors aim at covering values of rapidity up to 5, much larger than CDF and D0, allow to say something new about forward physics. Still, most of the particles are produced in the rapidity regions above 5, so far uninstrumented. A vast program [1] is however under way to extend the coverage of both ATLAS and CMS detectors to rapidities of 10 or more, using the LHC dipoles as giant spectrometers to measure protons that remain intact after a diffractive interaction.

1.2 Forward jet production

Most of the LHC interactions will involve forward jets final states. In most of QCD events, jets are produced by fragmentation of coloured quarks and gluons, and also coloured objects are produced between the jets. So, in events with forward-backward jets, quite a strong hadronic activity is present in the forward region.

In some cases, final-state jets are produced through the exchange of colourless particles, like vector bosons, or gluons combining to form a colour-singlet state (often referred as a pomeron, or odderon depending on its parity quantum numbers). Exchange of colourless objects has a much smaller cross section than the exchange of coloured ones, but their characteristic signature is the presence of a rapidity gap, i.e. a zone of the detector with very little or absent hadronic activity. Not all events produced by the exchange of colour singlets will have a rapidity gap: initial and final state radiation will destroy the gap in the majority of the cases, and in the literature we usually define the gap survival fraction as the probability that a colour-singlet event will have a real rapidity gap. The interesting point is that this fraction is independent of the gap size, while for events with exchange of coloured objects, the presence of rapidity gaps is suppressed exponentially as a function of the gap size. Looking for large rapidity intervals between jets increases the likelihood of finding events with large gaps, hence the interest in looking for events with very forward and very backward jets.

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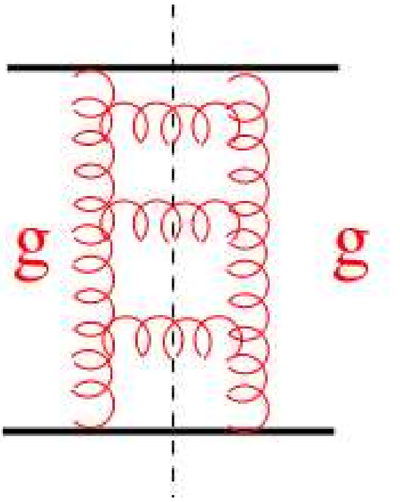

Fig. 1: A Feynman diagram showing a gluon ladder

1.3 QCD evolution

In most of the QCD calculations, the evolution from the hard scattering, usually calculated using a matrix element, and the soft scale, is done using the DGLAP [2] equation, where gluon splittings are ordered in k_T and x, and sums on $ln(Q^2)$. The BFKL equation [3] performs ordering in x (and random walk in k_T) and resummation in $ln 1/x$, therefore it is more suitable to describe low-x processes like forward-backward jets.

The resulting description is often depicted as a gluon ladder connecting quarks from the initial proton (see figure 1. When no gluon lines are emitted from the ladder, the gluon ladder behaves as a colour singlet, and these events will have a rapidity gap in the final state, i.e. a region of the detector with very little or absent hadronic activity.

2 Previous measurements on hard colour singlet

Events with two jets separated by rapidity gaps have already been measured at the Tevatron and at HERA, where events with pure colour singlet exchange (without initial- or final-state radiation) were measured to be about 1% of the total hadronic interactions. In particular a paper from D0 [4] studied the evolution of the fraction of events with a rapidity gap as a function of the $\Delta\eta$ between the two jets, up to a rapidity interval of 6, getting higher results to what expected from Herwig, that also incorporates the BFKL approach. It was suggested [5] that having a fixed value of α_S (as opposed to a running one) at the vertex between the pomeron and the quark does a better job in fitting the data, but more data are needed to solve this issue.

3 First predictions for the LHC

The extrapolation of the Tevatron measurements to the LHC energies is not obvious, but most of the present models foresee an increase of the survival factor (the probability that a rapidity gap event remains intact also after initial- and final-state radiation) at LHC energies. This increase is expected to be even larger for large gaps, and cross sections are such that a few pb^{-1} of data will be sufficient to have a measurement of the survival factor at the percent level, at least for values of $|\Delta\eta| < 8$. The analysis of rapidity gap events is not easy from the experimental point of view. To properly define a rapidity gap one should combine calorimeter clusters with Et above a certain threshold into mini-jets using the kt algorithm. Then the total transverse energy in the gap is summed up, and clusters coming from obvious pileup events are discarded. The analysis of these events in ATLAS is still ongoing, so the effect of background and pileup in "soiling" the gap is under study. Potentially, the fact that the fraction of rapidity gap events on the total of hedronic ones has to be independent on instantaneous luminosity (therefore on the amount of pileup) can be a very powerful tool to determine the efficiency of pileup corrections. One could in fact plot the fraction of gap events as a function of the instantaneous luminosity, expecting this fraction to be decreasing as effect of pileup. Applying pileup corrections, this slope is expected to reduce, and the amount of this reduction will provide a measurement of the efficiency of these corrections.

4 Beyond gaps, Müller-Navelet jets

The gluon ladder does not only predict an increase of events with large rapidity gaps. In case the gluon ladder also has additional external gluon lines, gluon jets will be emitted in the central part of the detector, between the two main jets. This emission will result in interesting QCD radiation patterns, and this additional radiation will spoil the back-to back nature of the two leading jets. The de-correlation of the azimuthal angle between the two leading jets is expected to be one of the first measurements with LHC data, since it does not require too detailed energy calibration. These de-correlation effects should be already visible for values of $\Delta\eta$ accessible in the LHC experiments, as discussed in [6].

So far, BFKL has been approximated in MonteCarlo by a Colour Dipole Model (CDM) [7], available since years in ARIADNE [8], widely used at HERA.

A third approach to QCD evolution, the CCFM equation [9] is based on kt factorisation, angular ordering (instead of kt as for DGLAP), and is a good approximation of the DGLAP approach at high-Q^2 and of BFKL for low x. This equation is currently implemented in the CASCADE [10] code. Comparison of CDM and CCFM approaches to HERA data did not give conclusive results, that could on the other hand be obtained from a few days of LHC running. For instance, the cross section for dijet events separated by $\Delta\eta$ of at least 2 is of the order of the μbarn. A recent advance has been the availability of a MonteCarlo code implementing the BFKL formalism [11], even if a proper comparison with data would require interface with hadronisation, not yet available.

5 More diffractive topologies

So far we have considered events with forward-backward jets, with or without a rapidity gap in the middle. There are however many more diffractive topologies presently under study for the first period of data-taking in ATLAS. The most studied are single diffraction, where one proton remains intact (and undetected), and a rapidity gap is present on the same side of the detector. Another interesting topology is the Central Exclusive Production (CEP), where the exchange of two colour singlets lead to a final state where both protons stay intact, and two rapidity gaps are present, in the forward and backward region of the detector. The central activity is present in the form of dijets or exclusive final states. All energy lost by the protons goes in the mass of the central system, and a precision measurement of their momentum would allow high precision in the determination of the mass of the central system. A detailed discussion of the detector upgrades ATLAS (and CMS) are planning to install for the determination of the proton momentum loss will be discussed in the next session.

Lacking, at least for the first phase, a dedicated proton tagger, the main problem to observe CEP with the first LHC data is a valid trigger strategy. The observable system is quite soft, and the production of jets, dominated by QCD, will be heavily prescaled at trigger level. Requiring the presence of rapidity gaps at L1 trigger level is possible in ATLAS using a detector designed to trigger on minimum-bias events at low luminosity, the Minimum- Bias Trigger Scintillators (MBTS). They are a set of 32 scintillators, arranged in two wheels, each covering the rapidity region between 2 and 4. The aim of this detector is to provide a fast and simple trigger for minimum bias events, and due to radiation damage it will have to be removed after a few years of data taking. In this case, since we are looking at rapidity gaps, the MBTS are used as a veto, to select events where no particles are present in a given rapidity region. It was shown that a veto on both sides of the MBTS can reduce the QCD rate by a factor 10000, while keeping the efficiency to CEP of around 65%. In realistic data-taking conditions, the MBTS rate is expected to be higher, due to the more radioactive environment, so realistically both rejection factor and efficiency are expected to be smaller than these simulated figures.

The distribution of the energy lost by the incoming protons (therefore, the mass of the central system) is on average much smaller than 10^{-2} for diffractive events, while typical values for non-diffractive interactions are in the 0.1-0.5 range. If no dedicated proton detector is present, we can estimate the resolution on this variable of the order of 10%, only using the information from the central calorimeters. Such a resolution is inadequate to distinguish a narrow resonance from a much larger background (as it would be the case for a diffractively-produced Higgs boson), and due to the steeply falling behaviour of this distribution, also leads to a shift in the measured mean value. In order to make a precise measurement of CEP processes, it is necessary to equip the LHC detectors of high-precision proton taggers, like those proposed to both ATLAS and CMS by the FP420 collaboration [1].

6 Forward detectors at the LHC

Both LHC general-purpose detectors will be equipped by detectors in the forward region, extending far beyond the coverage of the calorimeters of about 5. In Atlas, the luminosity monitor Lucid, based on detection of Cerenkov light, will cover (even if with limited azimuthal coverage for the first period) a rapidity region down to 6.2, while a zero-degree calorimeter, located at about 150 meters from the interaction point, will measure neutral particles emitted almost parallel to the beam direction. None of these detectors will be however incapable of tagging or measuring the momentum of protons scattered off diffractive events. Since measuring them is quite important, and can be done in an elegant way using the LHC optics as a giant spectrometer, a group of physicists, most of whom from the fp420 collaboration [1], is proposing to install two detectors at 220 and 420 meters from the Atlas interaction point. The goal is to measure with high precision the position of the protons diffracted from the beam (and from that their momentum, using the LHC dipoles as a giant spectrometer), as well as their time of flight, in order to distinguish particles coming from different vertexes in a high-pileup situation.

The stringent radiation hardness and speed requirements of the position detectors required the development of a new technology. 3D silicon detectors (see figure 3), the result of a long R&D work, have several advantages with respect to the planar geometry: they work with a smaller depletion voltage, are more radiation hard and are faster since the drift is shorter. They can operate at few mm from the beam line, in both the 220 and 420 meter location. The requirements on the timing detectors are also very stringent. The problem comes from the fact that at high-pileup conditions a Central Exclusive Production event can be perfectly faked by the overlap of a soft-QCD production event plus two single-diffractive interactions. The only way to separate them is due to the fact that these overlapping events come from different vertexes, so if the vertex position can be determined with a resolution of 2-3 mm, a sufficient background rejection can be obtained. While such a resolution is easy to reach using tracks for the central system, the only way to have good vertex resolution for the forward protons is to have a very precise (10 ps resolution) time of flight detector. So far, two technologies have been proposed, a gas tube with a mirror at the end to detect Cerenkov light, and an array of quartz detectors, that also can focus Cerenkov light into a multi-channel plate photomultiplier. So far, test-beam results indicate that a resolution of 10-20 ps can be obtained by the gas approach, while 20-30 ps can be reached by the gas detector, that on the other hand has a higher light yield and can be spatially segmented. R&D for timing detectors is still going on, and maybe a combination of the two technology can offer the advantages of both. To see how timing resolution can be important for the whole project, figures 2 show the expected peak of a possible MSSM Higgs boson A (m_A = 120 GeV, tanβ=40, $\sigma(h \rightarrow bb)$ = 17.9 fb) with time resolutions of 10 and 5 ps.

6.1 Conclusions

Diffractive and forward physics, due to their large cross-section and need for a low-pileup environment, will play a large role in the LHC startup. The main research topics will be:

- the study of forward jets, both with and without rapidity gaps. The first analysis will measure the soft survival factor, and help understanding forward jets and rapidity gaps, while the second will discriminate between different QCD evolution schemes. These studies will require a few tens of pb^{-1} of data
- single diffraction, with one undetected proton and a matching rapidity gap, will provide complementary measurements on the interface between the jets and the gap. Its study will require a few hundreds of pb^{-1}.
- Central exclusive production, with two rapidity gaps and a soft central system, will also

help understanding diffractive PDF's, Sudakov suppression factors, and discriminate among theoretical models. A few hundreds of pb^{-1} are needed for a complete study of these events

For the future, ATLAS is planning to install a four-station proton tagger station to measure the momentum loss of the forward protons, therefore the mass of the central system, and the accurate time of flight, to distinguish genuine diffractive events from pileup background. Installation of these detectors, still under approval, is foreseen by 2013-2014.

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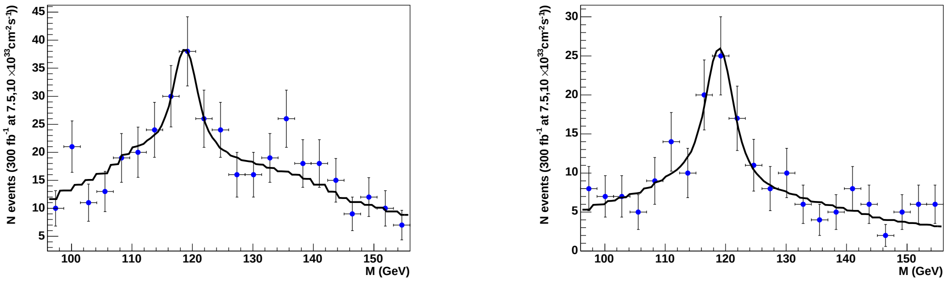

Fig. 2: The reconstructed mass of the SM Higgs boson A for a time resolution of 10 ps (left) and 5 ps (right)

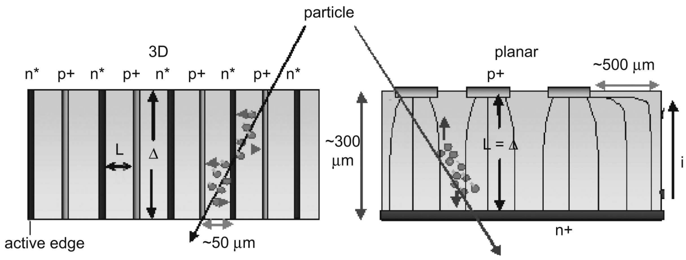

Fig. 3: A comparison between 3D silicon (left) and planar geometry (right)