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Forward Physics and Luminosity Measurement with the ATLAS Detector

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1. Introduction (Rijssenbeek, all)

We describe the exciting possibilities for Forward Physics, i.e. soft and hard diffraction physics, with the ATLAS detector, at the very high energy frontier. As will be shown, in forward physics processes at the LHC energies, very massive diffractive systems can be produced, both in single-Pomeron exchange, as well as centrally produced objects in double-Pomeron exchange processes. In this, we have used the Pomeron as representing a still poorly understood system of QCD gluons, which we may expect to understand better at the hard scales accessible at the LHC: in contrast to the ISR, the mass and momentum transfer scales reachable at the LHC may make a perturbative QCD treatment possible.

As direct benefit to the ATLAS community, the absolute measurement of the total elastic cross sections with a very large beta* tune of the LHC machine allows a direct measurement of the LHC luminosity at the ATLAS IP with high precision. The transfer of the luminosity calibration is done by means of, among others, a dedicated forward detector.

To start, we describe in detail the interests and methods for precision measurement of elastic scattering and the absolute measurement of the total pp cross section, using the normalization based on the Coulomb scattering cross section. The details of the cross section in the neighborhood of the "dip" region ($-t \sim 0.5$ GeV^2) may give insight in the various types of gluonic exchange amplitudes that contribute to the Pomeron. We discuss the determination of luminosity and techniques for luminosity monitoring using dedicated detectors and physics processes.

We discuss the physics interest of single and double diffraction, which are the evolution of the elastic hadronic scattering process into the large momentum transfer (t) regime. We describe the reach in terms of diffractive mass and momentum transfer. We follow with a discussion of the Double Pomeron Exchange process, a process that is thought to be responsible for the "rapidity gap" event signatures observed at HERA and the TeVatron. This process has received much attention lately because of the possibility for production of massive bosonic colorless objects in the central rapidity region, and as such may provide a clean and alternative production signature of the Higgs boson, irrespective of its decay mode.

In the part 2 of this note, we discuss the detectors proposed to access the physics described above. We start with a so-called baseline configuration, which we think is the minimum configuration needed to do most of the physics, and follow with a discussion of detector extensions that are more demanding in terms of construction complexity and costs.

In part 3 of this note we summarize the projected costs and responsibilities for two detector scenarios, and discuss a possible construction and installation scenario. We detail the steps that need to be taken for the proposal to turn into reality.

This note is intended to be an evolving Statement of Interest and Proposal from the authors; it will evolve into a full TDR if the ATLAS collaboration is supportive of this proposal.

2. Elastic Scattering and Total Cross Section (Haguenauer)

Short history of elastic scattering measurements at ISR, SppS, Tevatron, RHIC. Cosmic Ray data.

2.1. Elastic Scattering and Total Cross Section

Discussion of elastic scattering: the shape of the hadronic amplitude; the rise of the total (and elastic) cross section with log(s) and its corresponding picture of the proton. Comparison of pp and antiproton-proton data.

2.2. The Medium and Large |*t*| Region

The region of the dip in the forward scattering amplitude at $-t \approx 0.5$ GeV^2, and further recurrences. Theoretical/phenomenological models (Pomeron, odderon) and the need for more precision data. Testability of perturbative QCD with large $|t|$ data.

3. Luminosity Determination

Short overview of methods for luminosity determination, including the use of physics processes.

3.1. Absolute Luminosity by Coulomb Normalization

Short discussion on $\beta^* = 3500$ m tune, minimum obtainable $|t|$. Maximum $|t|$. Discuss the necessity to have efficient detection down to $\Delta x = k\sigma$, k = 10-15. Typical Luminosity and running times.

3.2. Luminosity Monitoring (Pinfold/Saclay)

Requirements for monitoring. Need for per-bunch measurements. Description of various methods; need for dedicated detector. Discuss eta range and large non-interaction backgrounds: LUCID principles.

Other methods: well calculable, efficient and stable (QED/QCD) physics processes.

4. Soft Diffraction: Single and Double Diffraction Dissociation (Tapprogge)

Physics Interest: extension of elastic scattering into the inelastic regime; production of massive/energetic systems with the quantum numbers of the nucleon (for Pomeron exchange). At LHC (high energy, high luminosity) very massive systems are reachable. Study the central rapidity gap: is it "clean"? Comparison with UA4 and other experiments; comparison with perturbative QCD calculations of diffraction.

Coverage needed in terms of angle (θ) and momentum loss $\xi = 1 - x$.

5. Hard Central Diffraction (Boonekamp)

Definition of Hard Central Diffraction and Rapidity Gaps. Recent interest and data (HERA, TeVatron). Models and predictions. Reach at LHC.

Leading proton measurement reach needed; importance of rapidity gap measurement. Coverage needed for good measurements.

6. Detectors for Forward Physics and Luminosity Measurement

In this section the various detectors needed to do the physics measurements described above, are discussed. Some of the detectors (several roman pot stations, LUCID) are, in our opinion, essential for forward physics and measurement of luminosity, while some others need further detailed evaluation before making a final judgment.

We start off by a description of the LHC lattice in the vicinity of the ATLAS IP (IP1), in order to illustrate the various possible locations for detectors, both for the special very large $\beta^* = 3500$ m tune, as well as for the standard tune with $\beta^* = 0.5$ m. We then describe the various detectors for Luminosity measurement and monitoring, followed by the small-angle roman pot detectors intended for forward diffraction measurements. We finish this section with a discussion of an optional instrumentation of the TAS radiation shield (at $z \approx 20$ m) for a rough calorimetric measurement of particles at pseudorapidities beyond the FCAL coverage.

6.1. The LHC Lattice at ATLAS (Faus-Golfe)

Description of the LHC lattice in various close-ups: $0<|z|<25$ m, $0<|z|<450$ m (overview), $140<|z|<250$ m, $250<|z|<450$ m. Description of Q4 mods for large beta; changes in the lattice since last year (?), difficulty of the z = 450 m location, ect...

Coverage in *x* and/or *y* at the various locations.

6.2. Roman Pot Detectors for Elastic Scattering and Luminosity Measurement (Velasco)

Description of roman pot principle: earlier uses at UA4, TeVatron. Microstations in earlier proposal, and why we think we can/should be more conservative in design. Absolute necessity to have the opposing detector planes overlap in coverage for internal x/y scale calibration with events. Newest plans for small pots. Possible detectors: scintillators, Si pixels; comparisons, (dis)advantages, coverage, etc…

6.3. Roman Pot Detectors for Diffraction and Forward Proton Measurement (Brandt)

Absolute necessity to have the opposing detector planes overlap in coverage for internal x/y scale calibration with events. Requirements for detectors for measurement of single and double diffraction dissociation (e.g. collimated tracks per event). Possible detectors: Si pixels, scintillators; comparisons, (dis)advantages, coverage, etc…

6.4. LUCID (Pinfold)

Describe LUCID principles, location, and shortly: construction, prototyping, CDF results, LUCID simulation results.

In Appendix: full technical description of LUCID, simulation details, etc.

6.5. TAN Instrumentation (Turner)

Describe principles of the Thin-Gap ionization detector, location, linearity results, backgrounds, test results, etc. More in dedicated Apendix.

6.6. TAS Instrumentation (Turner/Rijssenbeek)

As a more tentative option, we describe instrumentation of the TAS collimator, which is located inside the low beta quadrupole shielding cone. We propose to instrument the transverse gaps in the TAS shield with thin-gap ionization chambers, with cathode pad readout. However, because of the very restricted space, and in order not to compromise in any way the functionality of the TAS, this option will be thoroughly studied in terms of physics yield before making this option a formal part of this proposal. The option is raised here, to make the ATLAS and LHC community aware of our intent to study this option in detail and to not foreclose the TAS instrumentation possibility by irreversible construction decisions at this point in time.

7. APPENDIX

7.1. LUCID (Pinfold)

In Appendix: full technical description of LUCID, simulation details, etc.

7.2. TGI (Turner)

Describe technical details of the Thin-Gap ionization detector, location, linearity results, backgrounds, design, construction, prototyping, test results, etc.