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Forward physics at the ATLAS experiment

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Abstract. This contribution describes forward physics measurements possible to make with current ATLAS forward detectors including the upgrade project AFP. The aim of AFP is to tag very forward going protons at high luminosities.

Forward Detectors in ATLAS

The interest of forward physics is to study those processes in which particles are created at large rapidities. In the terms of pseudo-rapidity $\eta = -\ln[\tan(\theta/2)]$, where θ is the polar angle with respect to the beam, the ATLAS detector can be divided into a central detector, which consists of an inner tracking detector ($|\eta| < 2.5$), a muon spectrometer ($|\eta| < 2.7$) and a calorimeter system ($|\eta| < 4.9$), and forward detectors which cover rapidities above. At first, ATLAS will be equipped by three forward detectors: LUCID, ZDC and ALFA (LUCID and ZDC are already installed).

LUCID

LUCID is a Cerenkov detector composed of two modules located at 17 m on both sides of ATLAS. The detector provides pseudo-rapidity coverage $5.6 < |\eta| < 5.9$. The modules are composed of aluminum tubes that surround beam pipe and point toward the ATLAS interaction point. The mechanically polished tubes with a diameter of 15 mm are placed in a light-weight aluminum gas vessel and are filled with C_4F_{10} medium [1]. The detector is sensitive to charged particles with Cerenkov threshold of 10 MeV for electrons and 2.8 GeV for charged pions. The main purpose of LUCID is measurement of integrated luminosity and online monitoring of the instantaneous luminosity and beam conditions. One should note that LUCID will be the only detector that is dedicated to instantaneous luminosity monitoring. The principle of both integrated and instantaneous luminosity measurement is that the number of interactions in a bunch crossing is proportional to the number of particles detected in LUCID. At the beginning of LHC running, the calibration procedure will be based on LHC machine parameters. Later, LUCID will be calibrated mainly using the information from ALFA measurements (see bellow).

Zero Degree Calorimeter

Zero Degree Calorimeter (ZDC) is placed at 140 m from the IP. It is situated at TAN region (target absorber for neutrals), which is the point where the single beam pipe splits into two [2]. The calorimeter is able to measure neutral particles (the trajectory of charged particles is bended in the magnetic field in TAN region) at pseudo-rapidities $|\eta| > 8.3$. ZDC is a sampling calorimeter composed of tungsten alloy as absorber and quartz fibers which capture the Cerenkov light produced by shower of secondaries. Two types of quartz fibers are used: vertical quartz strips for energy measurement and horizontal quartz rods which provide position information. For Heavy Ion collisions, the ZDC plays a key role in determining the centrality of such collisions, which is strongly correlated to the number of very forward (spectator) neutrons. In p-p collisions, ZDC serves as an additional minimum bias trigger. The calorimeter is used for beam gas and beam halo suppression and it helps with beam tuning.

Both LUCID and ZDC can be used to tag diffractive processes. This class of processes is usually recognizable by the presence of so called rapidity gaps, regions devoid of hadronic activity. At low luminosity, ZDC and/or LUCID can serve as vetos to help identify rapidity gaps. At high luminosity, the rapidity gap method cannot be used to select diffractive events because particles from pile-up will fill in the gaps.

ALFA

ALFA (Absolute Luminosity for ATLAS) Roman Pots are situated at 240 m from the interaction point at both sides of the ATLAS. The Roman Pots system is able to move its scintillating fiber detectors close to beam [3]. At beginning of the run the ALFA detectors are in withdrawn position far from the beam. When the beam is stabilized the detectors are inserted to the measurement position. ALFA detectors are primarily intended for the measurement of the integrated luminosity and elastic cross section. The ALFA will collect data in special LHC run with high β^* optics. The precision of the luminosity measurement is expected to be $\sim 2-3\%$. Apart from the elastic processes, ALFA plans to study soft diffraction processes. However, such measurements are possible only at low luminosity. In diffractive processes one or both protons survive the collisions and are slightly deflected from the original direction. The intact proton then propagates through magnetic field of the LHC magnets and remains in beam pipe. Such proton can be detected in the Roman Pots. The cross section of the diffraction processes is described as a function of the fractional momentum lost ξ

$$\xi = \frac{|\mathbf{p}_i| - |\mathbf{p}|}{|\mathbf{p}_i|} \tag{1}$$

and the momentum transfer

$$t = (p_i - p)^2 \sim -p_T^2 \tag{2}$$

where p_i is four-momentum of incoming proton, p and p_T is four-momentum and transverse momentum of the scattered proton respectively. The variables ξ and t are computed from the proton momentum angle and position reconstructed in Roman Pots. The ALFA is able to measure ξ in interval 0.01 to 0.1 with accuracy of 8% to $\sim 2\%$ respectively.

AFP project

The AFP (ATLAS Forward Proton) is a project aiming to install forward detectors at 220 m (AFP220) and 420 m (AFP420) around ATLAS for measurement at high luminosities [4]. This section summarizes the physics interests, measurement principles and proposed technologies of the project.

AFP physics case

In processes with two intact protons, the precise measurement of fractional momentum losses ξ_1, ξ_2 can be used to determine the diffractive mass with a great accuracy. The precise measurement of the missing mass is provided by the following formula

$$M = \sqrt{s\xi_1\xi_2} \tag{3}$$

where $\sqrt{s} = 14$ TeV is the center of mass energy. Relation (3) is valid if $M \gg m_p$ and $t \gg m_p$, where m_p is proton mass. The acceptance for AFP220 and AFP420 is $0.01 < \xi < 0.2$ and $0.002 < \xi < 0.02$ respectively. This implies acceptance in mass of the centrally produced object spanning from 80 Gev up to masses beyond 1 TeV. The above technique opens up a possibility of searching for new physics in Central Exclusive Production (CEP) processes, such as Higgs boson production in the Standard Model, MSSM and NMSSM.

Another physics that can be probed using the proton taggers are the photon induced processes $pp \to p\gamma\gamma p \to pXp$, which have a final state topology similar to CEP. One of the interesting measurement is W-pair production which can provide constrains on the anomalous quartic gauge coupling $\gamma\gamma WW$ [5].

The AFP detectors will provide access to the unexplored low-x regime which offers new various tests and searches e.g.: tests of BFKL and CCFM equations, extrapolation of proton structure functions to lower-x, determination of parton saturation. A complete summary of the forward physics at the LHC with the proton taggers is described in [4].

Hamburg beam pipe

Because of the limited available space at 420 m, due to the cryogenic bypass, the traditional Roman Pot technique cannot be used for AFP420. Moreover to be able to detect the diffractive protons, the active detectors have to be placed between the beam pipes. Therefore it was decided to use Hamburg Movable Beam pipe in order to get detectors very close to the beam. Although AFP220 does not suffer with such difficulties it is reasonable to use the same technology for both AFP220 and AFP420 detectors. In Hamburg Movable Beam pipe the sensitive detectors are mounted directly on the beam pipe at two rectangular pockets. The ends of the moving beam pipe are connected to the fixed beam pipes by a set of bellows, allowing the displacement of the detectors between data taking and parked positions.

Both AFP220 and AFP420 are composed of two stations 8 m apart. Each station has two pockets, where one pocket is designed for silicon detectors and the other is allocated for fast timing detector.

Silicon detectors

In order to achieve a good acceptance in the mass of the centrally produced object at ∼100 GeV the detectors have to get very close to the beam. The detectors at 420 m will approach the beam down to 5 mm and the approach at 220 m should reach $2 - 3$ mm. Operating at such distances from the beam at high luminosity regime requires detectors designed to cope with high radiation. The other important requirement on the detectors is very good position resolution to achieve the desired resolution in mass. To obtain a mass resolution of the order of 1-2% for the 420+420 and 4-5% for the 420+220 configurations, the position and angular resolutions are required to be 10 μm and 1 μrad, respectively, for both the 420 and 220 stations.

The 3D silicon edgeless technology has been chosen to fulfill the above requirements. The 3D silicon sensors have rectangular pixels of 50 μm by 400 μm. The accuracy of measurement along the axis which is bound to fractional momentum loses, ξ, is privileged. The important property of the sensors is only 10 μm inactive edge which enables to get active area of the sensors very close to the beam. The regions of interest (i.e. where the bulk of diffractively scattered protons emerge far from the IP) are 25 mm×5 mm at 420 m and 20 mm×20 mm at 220 m from the IP.

Timing detectors

High precision time of flight (ToF) detectors will be used to obtain a large reduction in overlap backgrounds. The relative arrival time of the two protons will be measured (denoted E for East and W for West, $t = t_E - t_W$) . If one assumes that the protons come from the same interaction, the z-position of the event vertex can be calculated as $z_{pp} = \frac{1}{2}\delta t \times c$. The uncertainty on the measurement of z_{pp} is $\delta z_{pp} = \frac{c}{\sqrt{2}}\delta t$, where δt is the (r.m.s.) time resolution of the proton measurement. If δt of the order of 10 ps is achieved, the vertex resolution is then $\sim$2.1 mm. Such vertex resolution should suppress the background (already at level of L1 trigger) by factor 15 for $L = 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ or 20 for $L = 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [6].

Currently two technologies of TOF detectors are assumed: GasToF and QUARTIC. Both of them are based on the Cerenkov effect. In the former the light is produced in a gas radiator C_4F_8O, pressured at 1.3 bar. A thin concave mirror at the back reflects the light to a MCP-PMT. In QUARTIC quartz bars are used as radiators.

AFP trigger

Since the L1 trigger decision has to be made within 2.5 μs and the time needed for light to travel from the IP to the forward detector at 420 m and back is 2.8 μs the AFP420 cannot be included into ATLAS L1 trigger and only the AFP220 can provide a trigger signal. The AFP trigger detectors can trigger in a single-arm or double arm mode. In conjunction with other central detector triggers, the AFP220 can trigger on diffractive events (such as single diffractive and double pomeron exchange events). In order to trigger on events of desired missing mass, the AFP220 trigger ξ_1 information is combined with the assumed fixed final state mass M desired to be observed in the central detector, and only events with appropriate ξ_2 in AFP420 acceptance are kept. For High Level Triggers, information from both AFP220 and AFP420 can be used since the L2 latency is large.

Summary

The forward detectors (LUCID, ZDC, ALFA) in the ATLAS experiment are ready for luminosity and forward physics measurements at first low luminosity LHC phase. The AFP project will significantly extend the ATLAS physics program at high luminosities, especially in Higgs searches, BSM, diffraction, QCD and photon-induced processes. The AFP project has been reviewed by the ATLAS collaboration.

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