Physics prospects with the ALFA and AFP detectors at ATLAS

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Outline

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- ALFA
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ALFA – principals and aim

- The main goal - absolute luminosity and total cross section measurement
- Elastically scattered protons under a small angle (several micro radians)
- Main Detector (MD)
  - 10 plates (U and V layer)
  - 64 squared fibers (0.5x0.5 mm, staggering), coated by aluminium
  - spatial resolution ~30 μm
  - a scintillating fiber tracker technology
- Overlap Detectors (OD)
  - 3 plates of 30 squared fibers
  - relative alignment by optics: 10 μm in horizontal (x,z) plane
  - 5 μm in vertical (y,z) plane
- Roman Pots technology, vertical moving system

From “ATLAS TDR 18, CERN/LHCC/2008-004” and “ATLAS-LUM-PROC-2013-001”
ALFA – physics aim

• The rate of elastic scattering is linked to the total interaction rate through the optical theorem

\[ \sigma_{tot} = 4\pi \Im \left[ f_{el}(t=0) \right] \]

• If \( p \) is the momentum of the scattered proton, then for small values of scattering angle (\( \theta \)) is obtained

\[ -t = (p\theta)^2 \]

• The rate of elastic scattering events at small \( t \) values is written as

\[
\left. \frac{dN}{dt} \right|_{t=0} = L\pi |f_C + f_N|^2 \approx \left| -\frac{2\alpha_{EM}}{|t|} + \frac{\sigma_{tot}}{4\pi} (i + \rho) \exp \left( \frac{-B|t|}{2} \right) \right|^2
\]

\( f_C \) corresponds to the Coulomb and \( f_N \) to the nuclear interaction amplitude, \( b \) ... nuclear slope, \( \rho \) ... a ratio of real to imaginary part of the elastic scattering amplitude

\[ \rho = \frac{\Re f_{el}}{\Im f_{el}} \bigg|_{t \to 0} \]
ALFA – physics

- High $\beta^*$ optic allow us to access low $t$ values for elastically scattered protons
- The elastic cross section as a function of $t$ spectrum for a possible set of parameters at LHC energies. An estimate of the expected $t$ value reachable at a given $\beta^*$ is plotted.

To achieve highest $\beta^* \sim 2625$ m optics (and fulfill ALFA physics programme) additional cables in the tunnel are needed; scheduled for the winter break 2015/16
ALFA – physics

- Reconstructed scattering angle correlation between left $(\theta^*_{xL}, \theta^*_{yL})$ and right side $(\theta^*_{xR}, \theta^*_{yR})$ for elastic candidates after background rejection cuts in the vertical (left plot) and in the horizontal plane (right plot)

Data taking from October 20th 2011, $\sqrt{s} = 7$ TeV, $\beta^* = 90$ m
- Beam intensities ~2.1E11 ppb, RP position at 6.5 $\sigma$ (~1.8 mm)
- About 800.000 clean elastic events

From ATLAS Detector public results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ForwardDetPublicResults
ALFA – physics

- Study of exclusive production in ATLAS
  - pp→pp π⁺π⁻ measurement possible, expected ~2000 events for L = 10^{27} cm^2 s⁻¹, 30 hour
  - it requires ALFA elastic AND trigger + low-pT tracking
  - so far only measurements were performed at = 62 & 63 GeV by ABCDHW Collaboration, ISR
  - other processes such as K+K- or p+p- can be studied

More theoretical studies in:


From ALFA detector and prospects for measurements, T. Sýkora, Results and prospects of FP at LHC, 12.02.2012
ALFA – data taking

- ATLAS Control Room
- Elastic track pattern in the detectors online histogramming
ALFA – data taking

**run#1: β* = 90 m, √s = 7 TeV, October 18-20, 2011**
- 2 bunches of 7E10 ppb plus 12 pilots
- data taking at 6.5 σ (~1.8 mm)
- optics measurements and data taking for distance calibration, background studies
- about 1.4 M elastic and 2 M diffractive triggers; 800.000 clean elastic events

**run#2: β* = 90 m, √s = 8 TeV, July 7, 2012**
- low intensity run with 3 bunches 1E+11 ppb, scraping at 4 σ (~2 hours)
- data taking at 6, 8, 9.5 σ
- about 3.6/65 million elastic/minimum bias triggers

**run#3, β* = 90 m, √s = 8 TeV, July 14, 2012**
- high intensity run with 108 bunches of 0.9E+11 ppb
- data taking at 9.5 σ
- elastic triggers from 3 bunches only (3 hours), diffractive triggers from all bunches (5 hours)
- about 6.5/284/12 millions of elastic/minimum bias/diffractive triggers useful

**run#4: β* = 1 km, √s = 8 TeV, October 24-25, 2012**
- data taking at 3 σ (bellow 1 mm, ~6 hours)
- total of 33M elastic and many diffractive triggers
- about 300k events for elastic and total cross section

**p+Pb runs: January/February 2013**
- data taking at 20 σ (~4.5 mm) on the proton side
AFP
AFP – principals and aim

- A successor of ALFA and foreseen for forward / diffractive physics at highest LHC intensities

- The goal of the AFP (ATLAS Forward Proton) - to measure exclusive physics processes and anomalous coupling

- To detect intact protons from hard interaction, scattered at very small angles

- Position: ±204 m and ±212 m from the ATLAS IP

- Designed to operate with high pile up

- Allows to run with standard high luminosity runs, contrary to ALFA
AFP – Tracking Detectors

- The main purpose: a measurement of the trajectory of beam collision deflected protons coming from the ATLAS IP
- 3D Si pixel detector - a technology also used for IBL
- Two stations: ±204 m, ±212 m
- Current status: a spatial resolution ~10 μm in horizontal plane, ~30 μm in vertical plane, ~1 μrad angular
AFP – Timing Detector

- Precise time of flight measurement using Quartic timing detector
- Purpose - pileup background rejection / signal confirmation
- 10 ps or better resolution for nominal luminosity and $\mu \sim 50$ interactions

- To achieve required time resolution:
  - 4x8 (6x6 mm$^2$) quartz bars, 8-12 cm long $\rightarrow$ 8 measurements per detector with 30-40 ps resolution each

- Another solution: diamond timing detector (in RND)
AFP – physics

Studies:
- exclusive physics processes – (eg. jets, γγ, W/Z)
- Anomalous gauge coupling studies (γγWW, γγZZ, γγγγ)
- SUSY; magnetic monopoles
- Any production of new objects (with mass up to 2 TeV) via photon or gluon exchanges: Kaluza-Klein resonances, black holes, etc.

More details in:
- ATLAS Letter of Intent Phase-I Upgrade (CERN LHCC-2011-012, LHCC-I-020)
- Physics Cases within the AFP project (ATL-COM-PHYS-2012-775)
- AFP physics topics (ATL-COM-PHYS-2013-390)
Summary & Future prospects

**ALFA**

- successful data taking with $\beta^* = 90\text{m}$ and $\beta^* = 1\text{km}$ optics
- promising results from $\beta^* = 90\text{m}$ data taking, analysis with $\beta^* = 1\text{km}$ ongoing
- better understanding of the LHC optics for special high $\beta^*$ runs still in process
- increase the distance between neighboring stations for better angular resolution
- to achieve highest $\beta^* \sim 2625\text{ m}$ optics (and fulfill ALFA physics programme) additional cables in the tunnel are needed; scheduled for the winter break 2015/16

**AFP**

- 3D Si Tracking Detector – a technology coming from IBL
- Timing Detector
  - 10 ps Quartic TD development is ongoing
  - Diamond TD in RND
- Full simulation and integration is ongoing
Silicon detector with simulated photon tracks (yellow lines)

Timing Detector with simulated photon tracks (yellow lines)

Silicon detector with simulated hits (yellow dots)
back up
ALFA – optics

• The ALFA aim is to determine $\theta^*$ angle at ATLAS IP via the optics

$$\theta^*_y = \frac{y}{L_{y\text{eff}}}$$

where $L_{y\text{eff}} = L_{y\text{eff}}(\beta, \beta^*, \psi)$ is effective arm in $y$ axis, $\beta$ is betatron function, $\psi$ is phase

• parallel-to-point focusing – all protons with the same $p_y$ are focused in one point at ALFA station ($y$)
  - phase advance $\psi = \pi/2$

• t-spectrum can be described by superposition of nuclear and Coulomb scattering ($t \equiv -(p-p')^2$ – Mandelstam variable)

From “ATLAS TDR 18, CERN/LHCC/2008-004”
ALFA detector and prospects for measurements, T. Sýkora, Results and prospects of FP at LHC, 12.02.2012