Physics prospects and technical status of ATLAS Forward proton detectors

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On behalf of the ATLAS collaboration
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outline

• Diffractive physics concepts & experimental approach at ATLAS
• Why proton tagging ?
• The AFP detector
• 2016: single-arm configuration (AFP 0+2)
  • Physics program
  • Gaining experience and first data
• The present: double-arm configuration (AFP 2+2)
  • Present status of installation
  • Physics program
Soft processes

• Hard interactions are relatively well understood but represent a small fraction of the total cross section
• Soft processes are poorly known because of non-perturbative nature
• In general they are hardly calculable and experimental input is needed
  • See for example total proton-proton cross section
• Important in pp interactions to understand «underlying event», soft interactions accompanying hard processes
• At LHC, due to multiple interactions per BX (pile-up up to 50 so far), hard process superimposed to several different soft interactions
• Understanding of soft processes valuable in several different areas (for example cosmic rays physics)
Soft diffraction

- Mediated by strongly interacting color-less Pomeron => intact proton(s) in contrast to non-diffractive processes

- Typical experimental signature for diffraction are (central) rapidity gaps, but effectiveness depends on purity, pile-up, gap-survival in ND interactions

- Forward protons present in most of diffractive processes and detection represent clear clear signature
Hard diffraction

- Hard diffraction mediated either by exchange of a Pomeron with partonic structure or by final state exchange of soft gluons
  - Can these models be discriminated?

- Rapidity gaps still present but can be spoiled by additional soft interactions
- Proton tag crucial in addition to measurement in the central detector
- Jets, Vector-bosons, Photons+Jets, can be produced diffractively, depending on the interacting partons
ATLAS diffractive studies w/o proton tag

**Rapidity-gap cross section measurement**

Studies ND gap-survival and SD+DD
MC does not fully explain data
**Proton tag helpful to distinguish SD from DD**


**Inelastic cross-section measurement using rapidity gap**

Good agreement with models and other measurements, but large systematics

*Phys. Rev. Lett. 117 (2016) 182002*

**Hard diffractive di-jet production with Rapidity-gaps**

Studies ND gap-survival and SD+DD
Components. Good description from MC

ALFA-ATLAS measurements with proton tag

- Elastic, total and inelastic cross sections at $\sqrt{s} = 7$ & $8$ TeV with the ALFA detector
- ALFA measures forward protons with detectors housed in vertical Roman Pots at 237-245 meters from IP
- Elastically scattered protons measured down to Mandelstam $t \sim -0.01$ GeV$^2$
- Optical theorem used to derive $\sigma_{\text{tot}}$
- Ongoing measurement at $\sqrt{s} = 13$ TeV

Nuclear Physics B 761 (2014) 486
Why a new forward proton detector?

• ALFA is optimized for elastic scattering measurement at very low momentum transfer
  • Needs to measure small proton fractional momentum loss ($\xi \sim 0$) and small $P_T$
  • Acceptance depends on LHC optics: $\xi \sim 0$ reached in high-$\beta^*$ (low focusing) mode. In standard optics acceptance not optimal for diffractive studies => need to access lower $\xi$ in standard optics calls for new forward proton detectors

Low-$t$ region of Interest for elastic Scattering and $\sigma_{tot}$ measurement

$0.06 < \xi < 0.12$

$\beta^* = 0.55 \text{ m}$

$\beta^* = 90 \text{ m}$

$\beta^* = 1000 \text{ m}$
The ATLAS forward protons detector (AFP)

- 2 stations at 205 and 217 m from IP on both sides
- Housed in horizontal Roman Pots
- Near stations house 3D pixel tracking detectors
- Far stations also have time-of-flight counters
- Pixels tag and measure momentum and emission angle of forward protons
- Time-of-flight to identify origin of protons in longitudinal direction

CERN-LHCC-2015-009 ; ATLAS-TDR-024
The tracking detectors

- Together with LHC magnets measure momentum of forward scattered protons
- Resolution of \(~15\ \mu m\) needed
- To maximize approach to the beam (2-3 mm) inactive area <200 \(\mu m\)
- Radiation hardness crucial
- In each station 4 pixel layers of 336x80 pixels (50x250\(\mu m^2\))
- 3D pixel sensors derived from ATLAS IBL (rad-hard)
- \(14^\circ\) with respect to the horizontal direction

*JINST* 11 (2016) P09005
The time of flight counters

- Determination of longitudinal origin of scattered protons
- Crucial to reject background at high pile-up and associate proton origin to vertex by ATLAS
  - $\sigma_t = 10$ ps $\Rightarrow \sigma_z = 2.1$ mm
  - $\epsilon > 90\%$, high granularity for multiple protons
  - High rate and fast trigger signal
  - 4x4 Quartz Lbars
  - Cherenkov light read-out by Microchannel-Plate PMTs

Opt Express. 2016 Nov 28;24(24) 27951
2016 data taking: AFP 0+2

- One single arm installed with 2 stations at nominal positions (AFP 0+2)
- tracking detectors in both stations. No TOF
- LHC qualification, DAQ and Trigger integration with ATLAS
- ~10 h acquisition (L~0.5 pb\(^{-1}\)) at low pile-up (\(\mu < 0.3\))
  - Usable for physics measurements
- ~15 h acquisition (L~2 pb\(^{-1}\)) at high luminosity (max \(\mu \sim 35\) & 3->600 bunches)
  - Mainly aimed to study background and beam environment
- Data analysis started: what can be studied?
Physics program available to AFP 0+2

<table>
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<tr>
<th>Analysis</th>
<th>Motivation</th>
<th>$\int L dt$ [pb$^{-1}$]</th>
<th>Optimal $\mu$</th>
</tr>
</thead>
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<tr>
<td>Soft Single Diffraction with AFP0+2</td>
<td>$d\sigma/dt$, $d\sigma/d\xi$, $t$-Slope vs. $\xi$, $dN^\pm/dp_T$ vs. $t$ and $\xi$</td>
<td>1</td>
<td>$\mu \sim 0.01$</td>
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<tr>
<td>Single Diffractive jet Production [21]</td>
<td>gap survival probability, Pomeron structure</td>
<td>10 – 100</td>
<td>$\mu \sim 1$</td>
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<tr>
<td>Single Diffractive jet-gap-jet Production [22, 23, 24]</td>
<td>$\sigma$, central gap distribution, Jet $p_T$ vs. $t$, $\xi$, and $\beta$</td>
<td>1 – 100</td>
<td>$\mu \sim 1$</td>
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<tr>
<td>Single Diffractive Production of $\gamma$ + jet [25]</td>
<td>$\sigma$, rapidity gap, Jet structure and $p_T$, Photon $p_T$, event shape (MPI); vs. $t$, $\xi$, and $\beta$</td>
<td>10 – 100</td>
<td>$\mu \sim 1$</td>
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<td>Single Diffractive $Z$ Production</td>
<td>$\sigma$, rapidity gap, charge-asymmetry; vs. $t$, $\xi$, and $\beta$</td>
<td>10 – 100</td>
<td>$\mu \sim 1$</td>
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<tr>
<td>Single Diffractive $W$ Production</td>
<td>$\sigma$, rapidity gap; vs. $t$, $\xi$, and $\beta$</td>
<td>10 – 100</td>
<td>$\mu \sim 1$</td>
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First experience with data: alignment

- Pots inserted to $5\sigma$ from beam + 400 $\mu$m: absolute position measured with beam-based alignment
- Good correlation between tracker planes => mainly single tracks parallel to beam
- Data taking at low $\mu$ at $20\sigma_{\text{beam}}$ + inactive area ($\xi>0.035$)
First experience with data at high pile-up

- Data-taking at high pile-up (<26), 300 bunches and AFP distance $20\sigma_{\text{beam}}$: background, AFP performance, trigger rate
- 2 hits/track observed as expected due to $14^\circ$ tilt of sensors
- Good correlation between tracker planes and clearly visible diffracted protons
- Trigger rates compatible with simulation in wide pile-up range
2016-2017 winter shutdown: AFP 2+2

- Installed second AFP arm
  - All stations with 4 layers of silicon sensors
  - Far stations also include time-of-flight counters
  - All detectors operational
  - Beam-based alignment done
  - Ready to take data (both in special and normal runs)!
AFP 2+2 physics program (I)

- Central Exclusive dijet-Production

- Central Diffractive (DPE) jet and $\gamma$+jet production
  - Double p-tag & vertex lead to excellent purity
AFP 2+2 physics program: photon induced processes

• $\gamma\gamma \rightarrow \mu\mu$
  • But too low $\sigma$ for double-tag
  • Also helpful for alignment

• Anomalous Quartic Couplings
  • very low $\sigma$ ($\sim$fb)
  • AFP mass resolution from proton momentum measurement
    $\sim$2-4%
  • Match with measurement from ATLAS central detector
  • Present limits can be improved by factor up to 2
Conclusions

• Diffractive processes have large cross section at LHC and are poorly known

• Proton(s) tag is an highly efficient diffractive signature. AFP designed to this goal and is complementary in many aspects with ALFA

• Single-arm configuration (AFP 0+2) installed and took data in 2016
  • Successful installation and smooth operation. First data available at low mu for single diffractive measurements. Proven to work also at high pile-up

• Full detector installed in 2016-17 winter shutdown, with time-of-flight counters for proton-vertex identification.

• Wide physics program exploiting double proton-tag accessible !

• First analysis ongoing: physics results soon !
Thanks for the invitation to this interesting conference in such a beautiful Region!

«Se Parigi avesse lu mere, sarebbe una piccola Beri»

(if Paris was by the sea, it would be as a little Bari)