Physics Potential of the New ATLAS Forward Proton Detectors

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on behalf of
the ATLAS Collaboration

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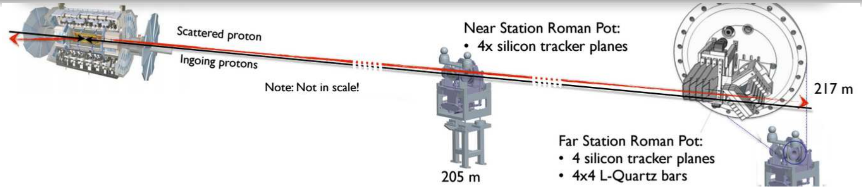
QCD challenges in pp, pA and AA collisions at high energies

Trento, 1st March 2017



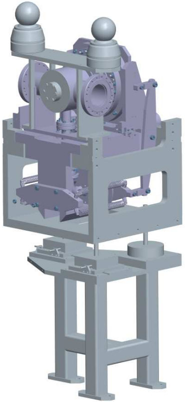
AFP TDR: CERN-LHCC-2015-009, ATLAS-TDR-024
ECR: LHC-XAFP-EC-0002, LHC-XAFP-EC-0003

Phase-1: AFP0+2 (2016)

- 2 horizontal Roman Pot stations at 205 (NEAR) and 217 m (FAR) on ATLAS C side – **installed!**
- study beam background in low and high intensity runs
- measure diffractive and exclusive events with one tag in a special low-μ runs (AFP triggers ATLAS)

Phase-2: AFP2+2 (2017+)

- 2 horizontal RPs on A side – **installed!**
- install time-of-flight detectors in far stations on both sides – new AFP trigger system
- measure double tagged diffractive and exclusive events
- deliver diffractive triggers to ATLAS during:
  - special (low pile-up) and
  - standard (high pile-up) runs



Installation:

- all four stations are installed in the LHC tunnel,
- cables, cooling and vacuum infrastructures are prepared,
- new sets of silicon trackers (SiT) are prepared to be installed in March,
- Time-of-Flight (ToF) detectors and electronics will be installed in March / April.

Commissioning:

- calibration of the AFP movement system in April,
- AFP Beam Interlock System tests in April / May,
- followed by the Beam Based Alignment and Loss Maps,
- Detector Control System – integration of arm A and ToF system,
- Trigger Data AcQuisition – new trigger system (ToF instead of SiT).

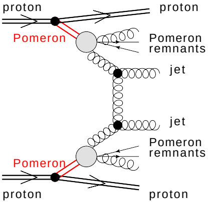
Data taking:

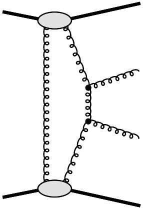
- take data at about 15 σ distance from the beam, using nominal optics ($\beta^* = 0.4$ m); low pile-up will be achieved by the beam separation,
- at least two special runs in 2017: $\mu \sim 0.01$ (integrated luminosity of about 100 nb^{-1}) and $\mu \sim 1$ (int. lumi. ~ 1 pb^{-1}),
- plan to collect ~ 10 pb^{-1} in several low luminosity runs in 2017 and 2018,
- **participate in all ATLAS physics runs.**

Physics Motivation

Special, low-μ runs

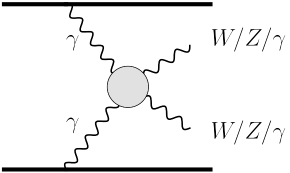
- diffractive physics:
  - soft diffraction (particle, gap, ξ spectra, *etc.*)
  - diffractive jets, jet-gap-jet, W, *etc.*
  - exclusive jets (low-p_T, single tagged)
- AFP can trigger ATLAS for presence of proton in:
  - one side (single difraction)
  - both sides (double Pomeron exch.)
- **special trigger menu based on AFP**
- as in 2016, we expect to have a few low-μ runs (bunch separation)
- we would like to have a majority of bandwidth on L1 and HLT dedicated to AFP items (min-bias stream)





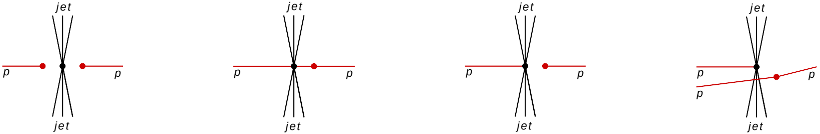
Standard, high-μ runs

- exclusive events (Pomeron and photon induced), new physics
- double tag can decrease the rates by factor 10 – 100 (depending on the mass of central system)
- in the case of jets a lower p_T threshold can be achieved (see *e.g.* ATL-PHYS-PUB-2015-003)
- in the case of new, heavy resonances or anomalous couplings the prescale can be reduced
- **AFP triggers (L1 and HLT) present in physics stream**
- for now, one unique item requested: the exclusive jet trigger

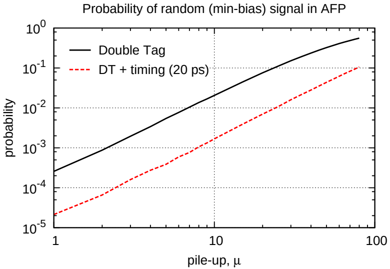


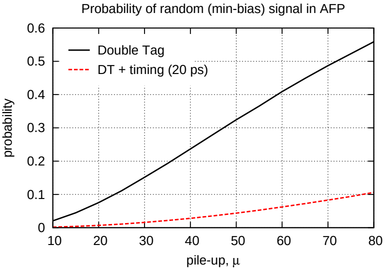
Usual background for the hard diffractive processes: a non-diffractive process + ,,soft'' protons from pile-up.

Example: backgrounds for the double Pomeron exchange jet production (2 jets + 2 protons from the same proton-proton interaction):

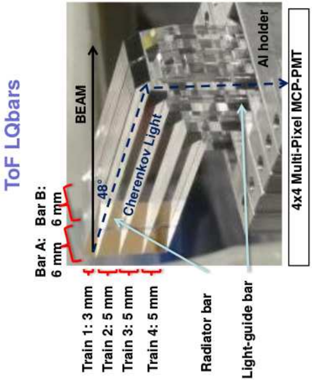


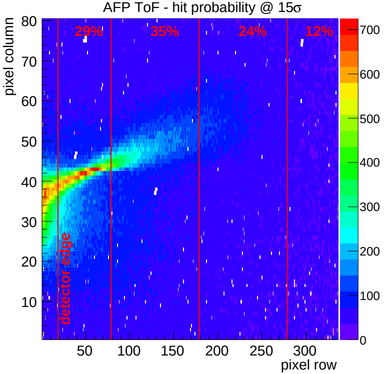
Amount of ,,soft'' protons strongly depends on pile-up:





Requirement of proton presence in both AFP arms (double tag) can significantly reduce such background.



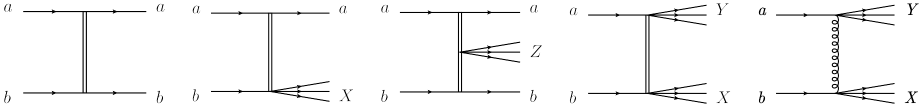


Trigger idea:

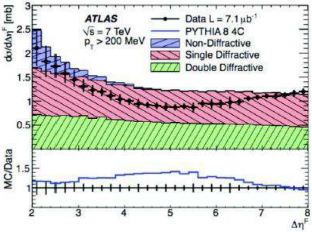
- use the second AFP trigger cable to specify which part of ToF triggered,
- for the exclusive jets we expect majority of events to be in the first train,
- in this way the rate on Level 1 can be reduced by a factor:
  - 2.5 when first two trains on each side are used,
  - 10 when only the first train on each side is used,
- this reduction is independent of the double proton tag requirement, *e.g.* for $\mu \sim 23$ a total reduction of factor 100 (10×10) can be expected.

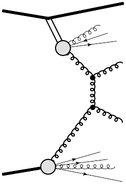
Minimum bias processes at the LHC

elastic scattering | single diffraction | central diffraction | double diffraction | non-diffractive interaction



- Gap measurement in ATLAS does not distinguish SD from DD.
- Possible with the forward proton tagging.
- High cross sections → low lumi needed → low pile-up possible.
- Properties of SD – central and forward.
- Central diffraction (DPE – double Pomeron exchange).

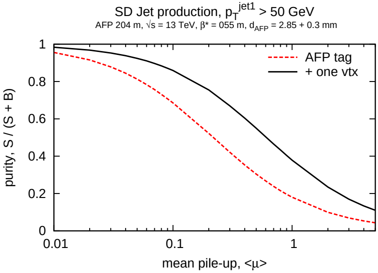


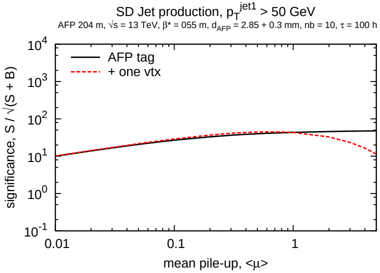


Motivation:

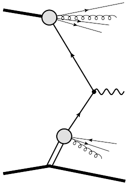
- measure cross section and gap survival probability,
- search for the presence of an additional contribution from Reggeon exchange,
- check Pomeron universality between *ep* and *pp* colliders.

Example: purity and statistical significance for AFP and $\beta^* = 0.55$ m.





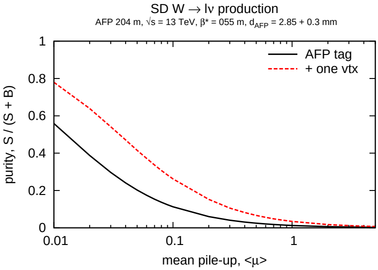
More details in: J. Phys. G: Nucl. Part. Phys. **43** (2016) 110201

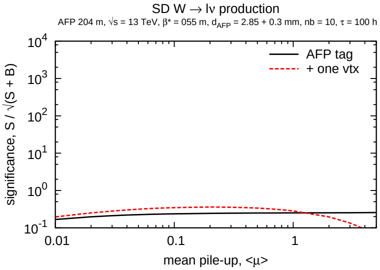


Motivation:

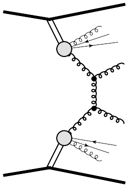
- measure cross section and gap survival probability,
- measure structure and flavour composition of Pomeron,
- search for the charge asymmetry.

Example: $W \to l\nu$ – purity and stat. significance for AFP and $\beta^* = 0.55$ m.



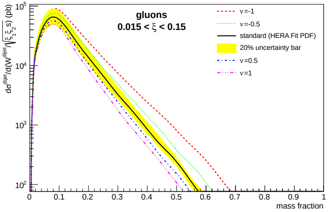


W asymmetry studies published in: Phys.Rev. D 84 (2011) 114006
More details in: J. Phys. G: Nucl. Part. Phys. **43** (2016) 110201

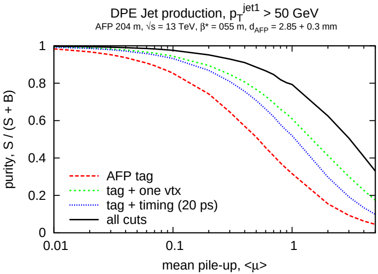


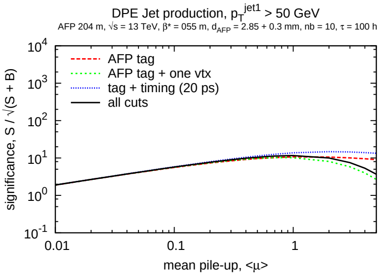
Motivation:

- measure cross section and gap survival probability,
- search for the presence of an additional contribution from Reggeon exchange,
- investigate gluon structure of the Pomeron.



Example: purity and statistical significance for AFP and $\beta^* = 0.55$ m.





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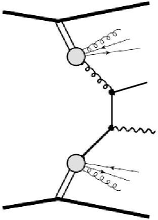
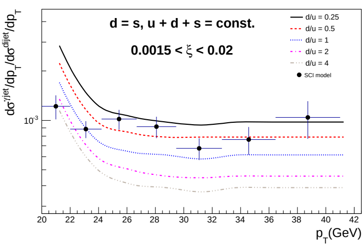
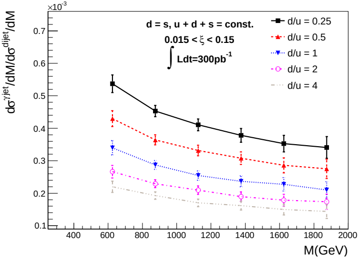


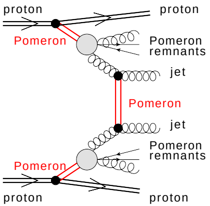
Motivation:

- measure cross section and gap survival probability,
- sensitive to the quark content in Pomeron (at HERA it was assumed that $u = d = s = \bar{u} = \bar{d} = \bar{s}$).



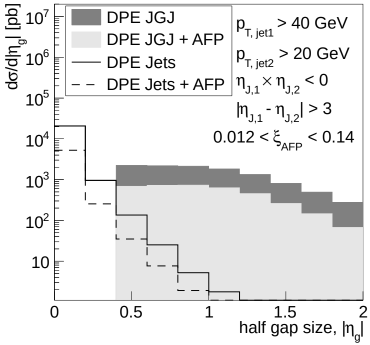


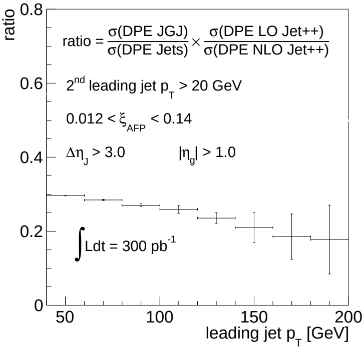
More details in: Phys.Rev. D 88 (2013) 7, 074029



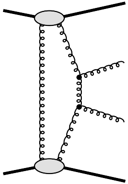
Motivation:

- measure cross section and gap survival probability,
- test the BFKL model.



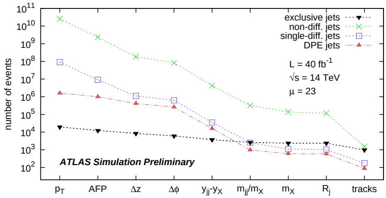


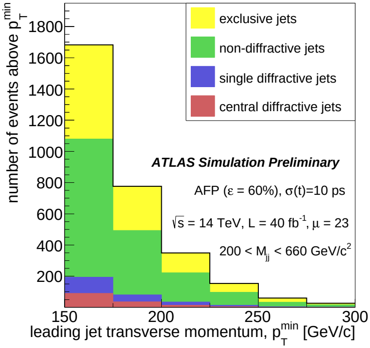
More details in: Phys.Rev. D 87 (2013) 3, 034010

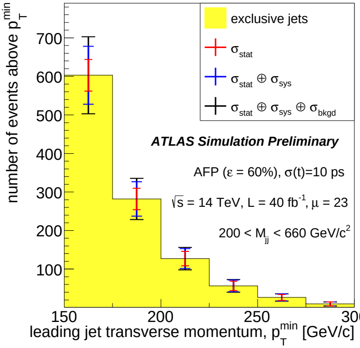


Motivation:

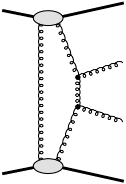
- cross section measurement for jets with $p_T > 150$ GeV,
- constrain other exclusive productions (*e.g.* Higgs).





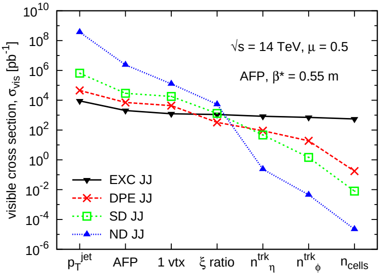


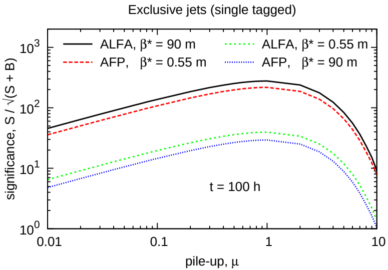
More details in: ATL-PHYS-PUB-2015-003



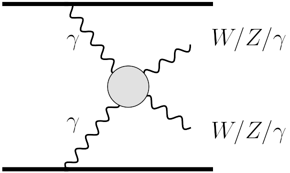
Motivation:

- cross section measurement for low p_T jets,
- constrain other exclusive productions (*e.g.* Higgs).





More details in: Eur. Phys. J. C **75** (2015) 320 and Acta Phys. Pol. B **47** (2016) 1745



- Quartic Gauge Couplings – testing BSM models.
- Constrained kinematics → low background.
- Reaching limits predicted by string theory and grand unification models (10^{-14} – 10^{-13} for $\gamma\gamma\gamma\gamma$).

$\gamma\gamma WW$ and $\gamma\gamma ZZ$

Coupling	OPAL limits [GeV2]	Sensitivity for 200 fb1 5σ	95% CL
a_0^W/Λ^2	[-0.020, 0.020]	$2.7 \cdot 10^{-6}$	$1.4 \cdot 10^{-6}$
a_C^W/Λ^2	[-0.052, 0.037]	$9.6 \cdot 10^{-6}$	$5.2 \cdot 10^{-6}$
a_0^Z/Λ^2	[-0.007, 0.023]	$5.5 \cdot 10^{-6}$	$2.5 \cdot 10^{-6}$
a_C^Z/Λ^2	[-0.029, 0.029]	$2.0 \cdot 10^{-5}$	$9.2 \cdot 10^{-6}$

$\gamma\gamma\gamma\gamma$

Coupling (GeV^{-4})	1 conv. γ 5σ	1 conv. γ 95% CL	all 95% CL
ζ_1 f.f.	$1 \cdot 10^{-13}$	$7 \cdot 10^{-14}$	$4 \cdot 10^{-14}$
ζ_1 no f.f.	$3 \cdot 10^{-14}$	$2 \cdot 10^{-14}$	$1 \cdot 10^{-14}$
ζ_2 f.f.	$3 \cdot 10^{-13}$	$1.5 \cdot 10^{-13}$	$8 \cdot 10^{-14}$
ζ_2 no f.f.	$7 \cdot 10^{-14}$	$2 \cdot 10^{-14}$	$2 \cdot 10^{-14}$

Summary

- All AFP stations are installed in the LHC tunnel. New sets of silicon trackers, Time-of-Flight detectors and electronics will be installed in March / April.
- After commissioning phase in April / May, AFP will take data during:
  - dedicated, low-μ runs (~ 100 nb^{-1} at $\mu \sim 0.01$ and ~ 10 pb^{-1} $\mu \sim 1$),
  - all standard, high-μ runs.
- In all cases AFP will deliver triggers to ATLAS.

- **Various data taking strategies:**
  - very low pile-up ($\mu \sim 0.05$): measure properties of soft diffraction,
  - low pile-up ($\mu \sim 1$): measure properties of hard diffraction: SD JJ, SD JGJ, SD W, SD Z, DPE JJ, DPE JGJ, DPE γ+jet, exclusive jets (single tag),
  - high pile-up ($\mu \sim 50$): measure exclusive production and discovery physics: exclusive jets, anomalous couplings: $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$.

The work of M.T. is supported in part by Polish Ministry of Science and Higher Education under the Mobility Plus programme (1285/MOB/IV/2015/0).