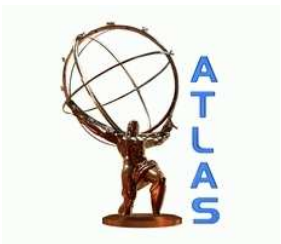
Prospects for Photon-Photon and Photon-Proton Measurements with Forward Proton Taggers in ATLAS

Maciej Trzebiński

on behalf of
the ATLAS Collaboration

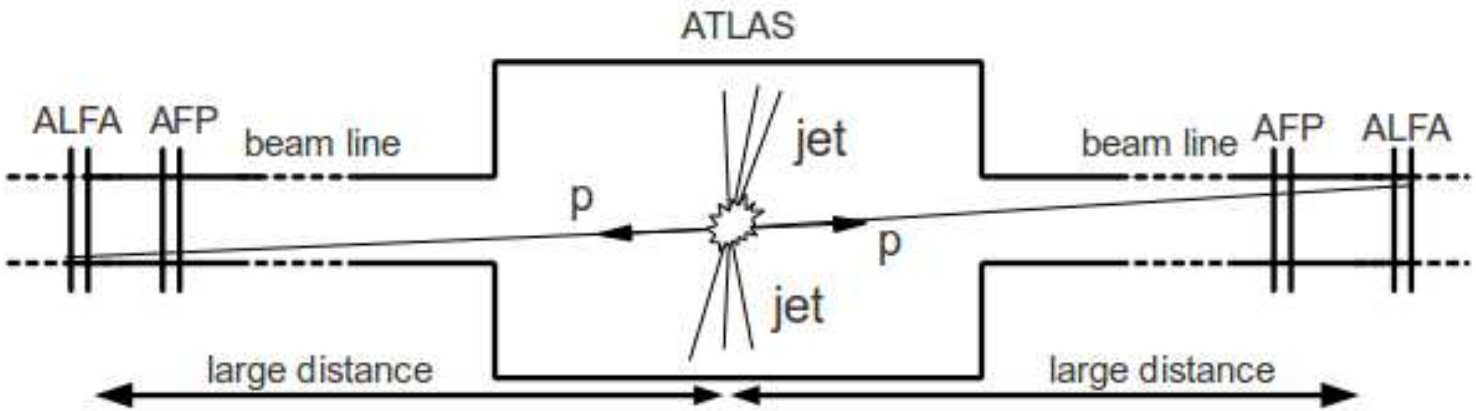


Institute of Nuclear Physics
Polish Academy of Sciences

Photon 2017 Conference

23rd May 2017

Signature: central system measured in ATLAS and one or both protons in forward detectors.



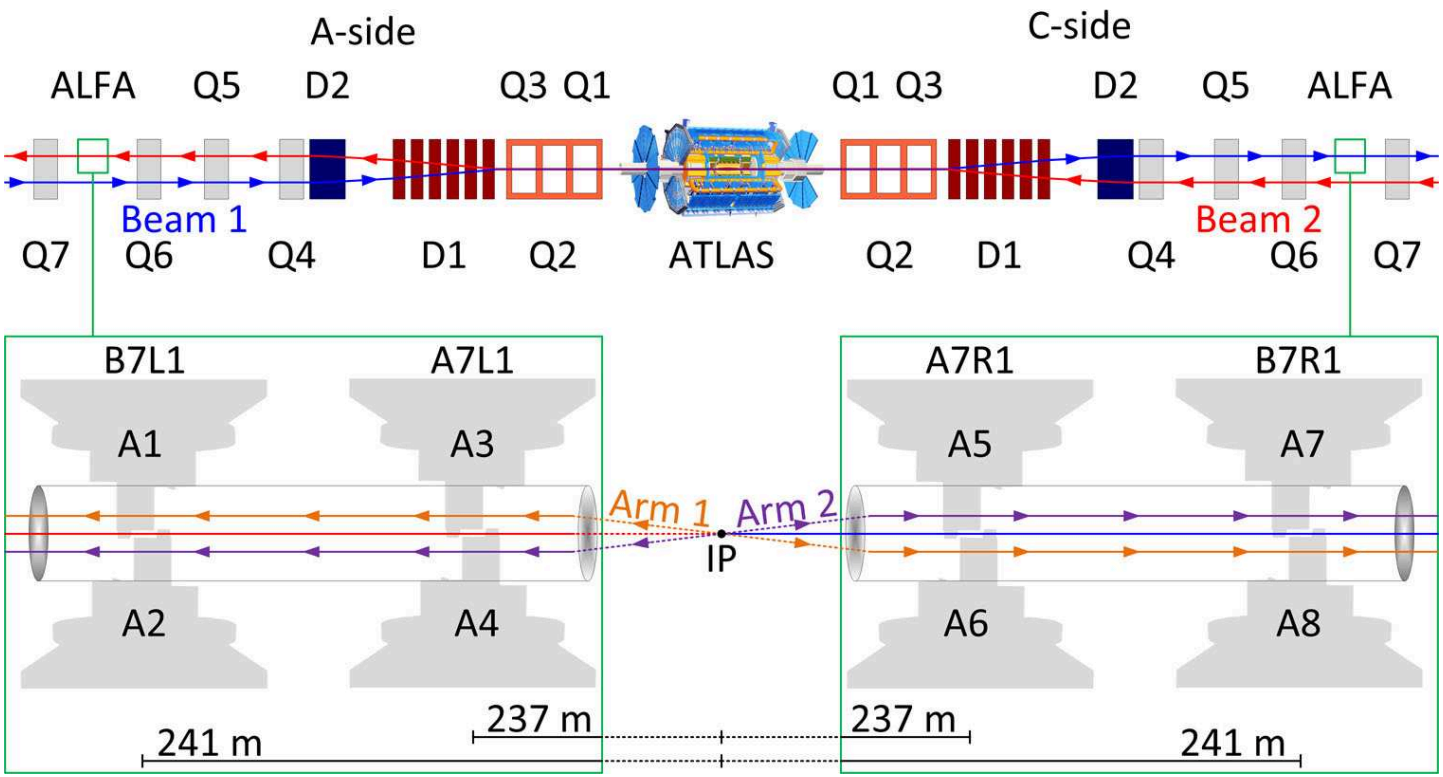
ALFA

- **A**bsolute **L**uminosity **F**or **A**TLAS
- vertically inserted Roman Pots
- 237 and 245 m from ATLAS IP
- soft diffraction (elastic scattering)
- special runs (high β^* optics)
- tracking detectors, resolution:
  $\sigma_x = \sigma_y = 30\ \mu$m

AFP

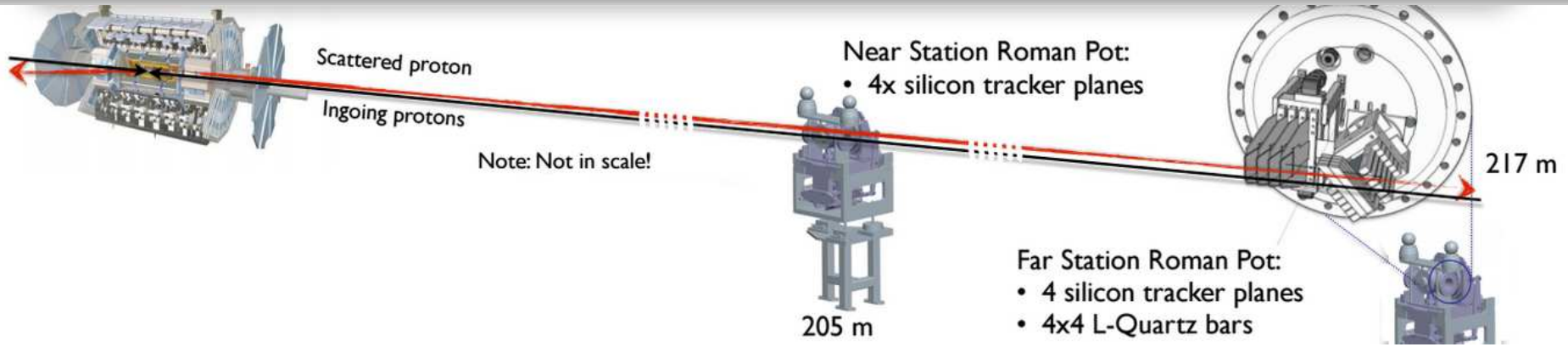
- **A**TLAS **F**orward **P**roton
- horizontally inserted Roman Pots
- 204 and 217 m from ATLAS IP
- hard diffraction
- nominal runs (collision optics)
- tracking detectors, resolution:
  $\sigma_x = 10\ \mu$m, $\sigma_y = 30\ \mu$m
- timing detectors, resolution:
  $\sigma_t \sim 20$ ps

ALFA Detector



- Near stations: 237 m from ATLAS Interaction Point (IP).
- Far stations: till 2014 – 241 m, after 2014 – 245 m from ATLAS IP.
- Each station contains:
  - four outer detectors (OD) for precise alignment,
  - two main detectors (MD):
    - 10 + 10 layers of 64 fibres,
    - UV geometry,
    - trigger.
- LHC magnets between ATLAS and ALFA: six quadrupoles (Q1 – Q6) and two dipoles (D1 and D2).
- More details in: JINST **11** (2016) P11013.

ATLAS Forward Proton Project



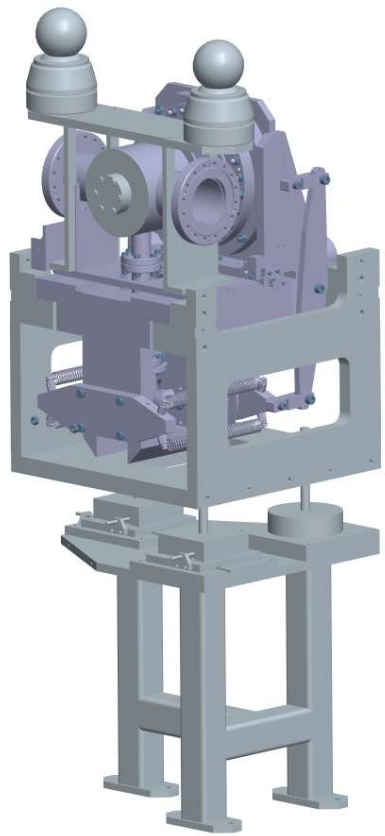
AFP TDR: CERN-LHCC-2015-009, ATLAS-TDR-024
ECR: LHC-XAFP-EC-0002, LHC-XAFP-EC-0003

Phase-1: **AFP0+2** (2016)

- 2 horizontal Roman Pot stations at 205 (NEAR) and 217 m (FAR) in 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+)

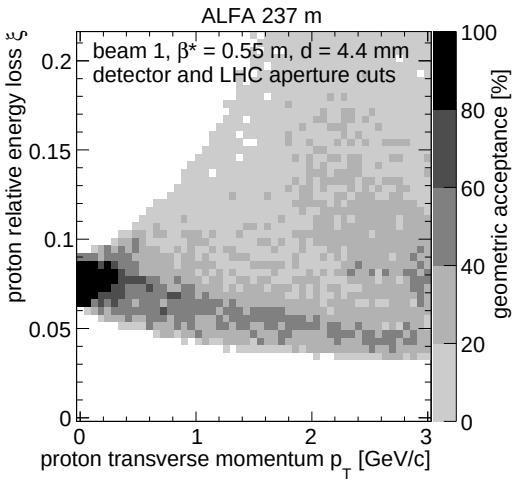
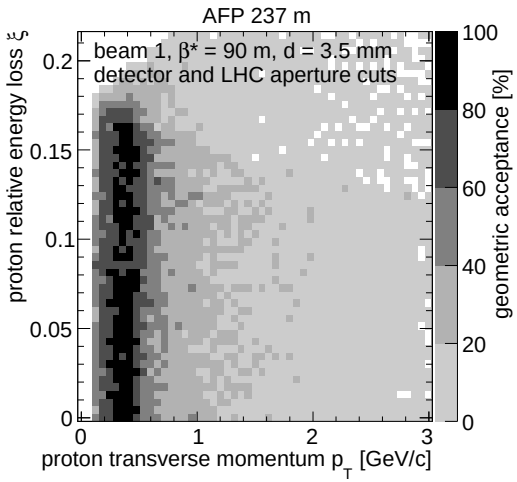
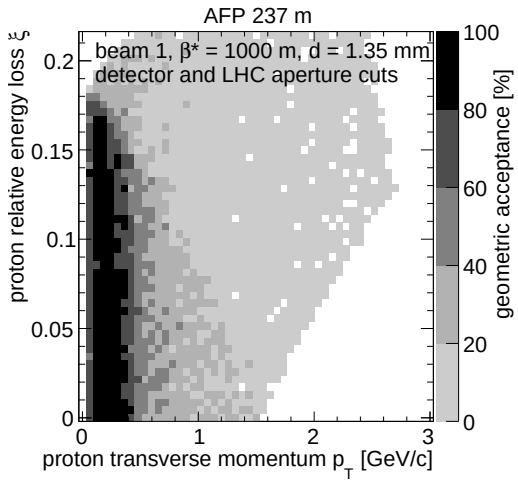
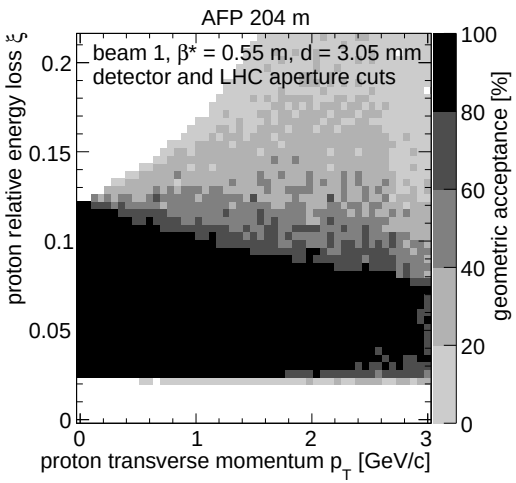
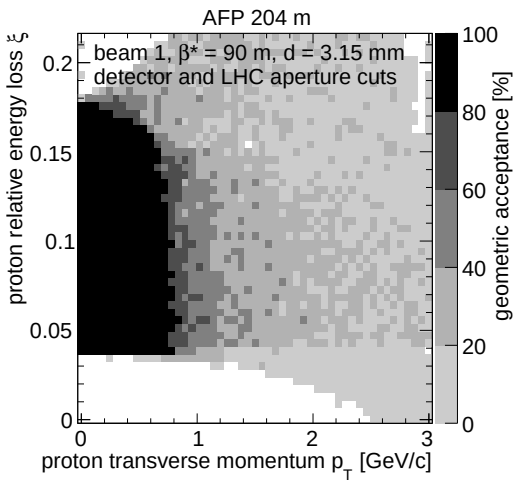
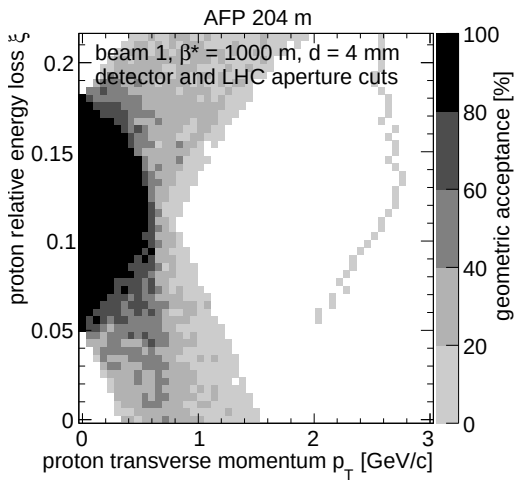
- 2 horizontal RPs on A side – installed!
- install time-of-flight detectors in far stations on both sides – new AFP trigger system
- measure double tagged diffractive and exclusive events
- deliver diffractive triggers to ATLAS during:
  - special (low pile-up) and
  - standard (high pile-up) runs



Geometric Acceptance

Ratio of the number of protons with a given relative energy loss (ξ) and transverse momentum (p_T) that crossed the active detector area to the total number of the scattered protons having ξ and p_T.

optics

	$\beta^* = 0.55$ m nominal (*collision*) distance: 15σ	$\beta^* = 90$ m special (*high-β^**) distance: 5σ	$\beta^* = 1000$ m special (*high-β^**) distance: 5σ
ALFA			
AFP			

TCL4 and TCL5 colimators are wide open!

Prospects of Photon-Photon and Photon-Proton Measurements

in ALFA

(low mass)

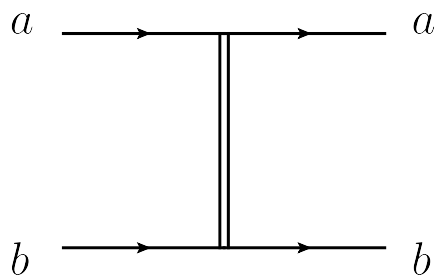
Total cross-section measurement via optical theorem

Total cross section is directly proportional to the imaginary part of the forward **elastic scattering** *amplitude extrapolated to* **zero momentum transfer**:

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

Elastic scattering:

- both protons stay intact,
- described by the four momentum transfer, t,
- protons are scattered at very small angles.

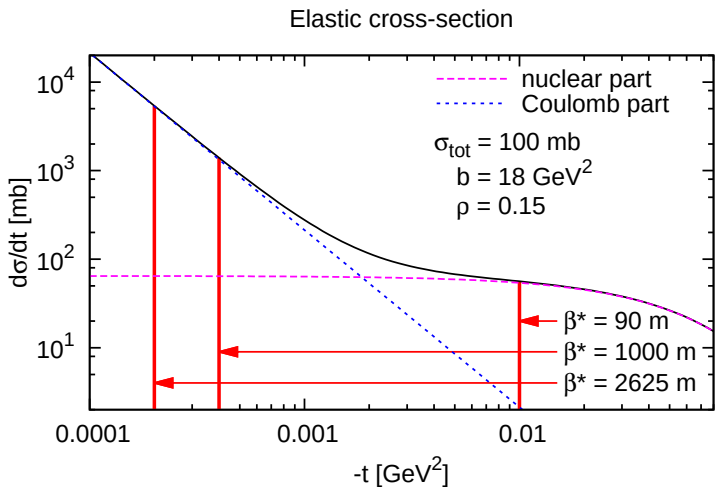


$$\left.\frac{dN}{dt}\right|_{t=0} = L\pi|f_C + f_N|^2 \approx$$

$$\approx L\pi \left| -\frac{2\alpha_{EM}}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)\exp\left(\frac{-b|t|}{2}\right)\right|^2$$

red – Coulomb part, blue – nucl. part

$$\rho = \left.\frac{Re\ f_{el}}{Im\ f_{el}}\right|_{t\to 0}$$

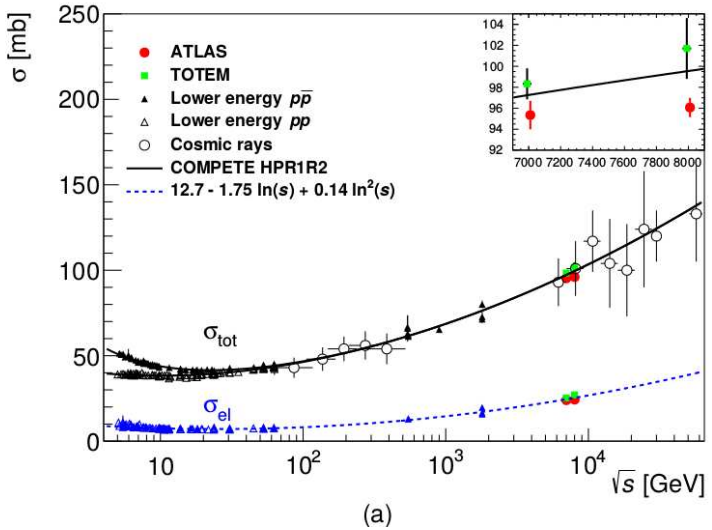


ALFA took data at: 7 TeV with $\beta^* = 90$ m, 8 TeV with $\beta^* = 90$ m, 8 TeV with $\beta^* = 1000$ m, 13 TeV with $\beta^* = 2500$ m.

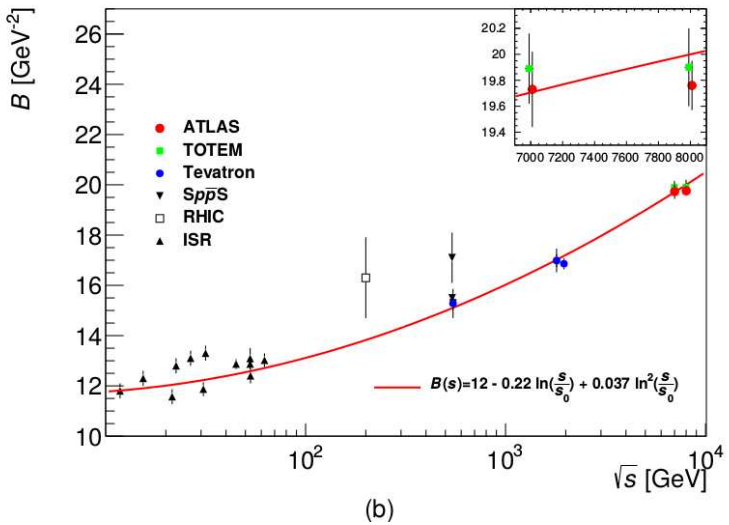
Plans (not approved yet): take data at 14 TeV ($\beta^* = 2.5$ km) and 450 GeV or 1 TeV.

Total and Elastic Cross-Section: 7 and 8 TeV Results

total and elastic cross-section



nuclear slope



Total cross-section:

$\sigma_{tot}^{ALFA}(7\,TeV) = 95.35 \pm 0.38\ (\text{stat.}) \pm 1.25\ (\text{exp.}) \pm 0.37\ (\text{extr.})\ \text{mb}$

$\sigma_{tot}^{ALFA}(8\,TeV) = 96.07 \pm 0.18\ (\text{stat.}) \pm 0.85\ (\text{exp.}) \pm 0.31\ (\text{extr.})\ \text{mb}$

Nuclear slope:

$B^{ALFA}(7\,TeV) = 19.73 \pm 0.14\ (\text{stat.}) \pm 0.26\ (\text{syst.})\ \text{GeV}^{-2}$

$B^{ALFA}(8\,TeV) = 19.74 \pm 0.05\ (\text{stat.}) \pm 0.23\ (\text{syst.})\ \text{GeV}^{-2}$

Elastic cross-section:

$\sigma_{el}^{ALFA}(7\,TeV) = 24.00 \pm 0.19\ (\text{stat.}) \pm 0.57\ (\text{syst.})\ \text{mb}$

$\sigma_{el}^{ALFA}(8\,TeV) = 24.33 \pm 0.04\ (\text{stat.}) \pm 0.39\ (\text{syst.})\ \text{mb}$

Inelastic cross-section:

$\sigma_{inel}^{ALFA}(7\,TeV) = 71.34 \pm 0.36\ (\text{stat.}) \pm 0.83\ (\text{syst.})\ \text{mb}$

$\sigma_{inel}^{ALFA}(8\,TeV) = 71.73 \pm 0.15\ (\text{stat.}) \pm 0.69\ (\text{syst.})\ \text{mb}$

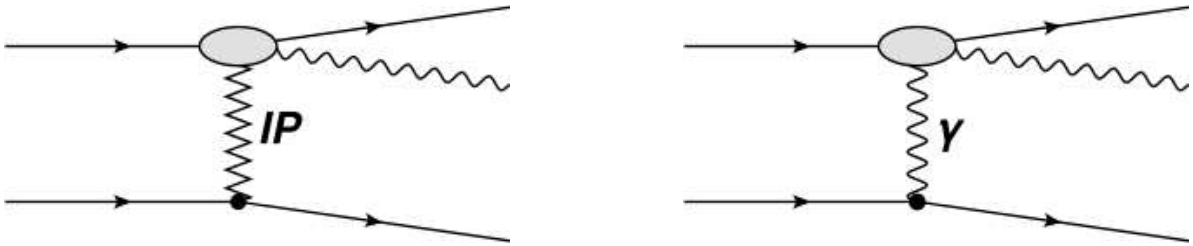
More details in:

Nucl. Phys. B **889** (2014) 486 (7 TeV)

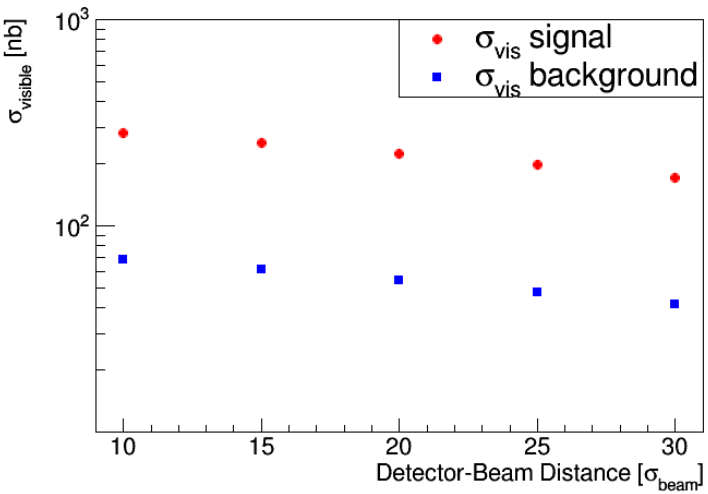
Phys. Lett. B **761** (2016) 158 (8 TeV)

Results from data taken at 8 TeV with $\beta^* = 1000$ m and 13 TeV with $\beta^* = 2500$ m (CNI and (potentially) Coulomb regions) are on the way. Stay tuned!

Diffractive Bremsstrahlung



- Pomeron or photon induced process.
- Production described by models of *e.g.*:
  - Khoze-Lamsa-Orava-Ryskin, JINST **6** (2011) P01005,
  - Lebiedowicz-Szczurek, Phys. Rev. D **87** (2013) 114013.
- Implemented in *e.g.* GenEx MC generator (arXiv:1411.6035).
- Measurement idea:
  - measure protons in ALFA and photon in ZDC,
  - described in: [1] Eur. Phys. J. C **77** (2017) 216.



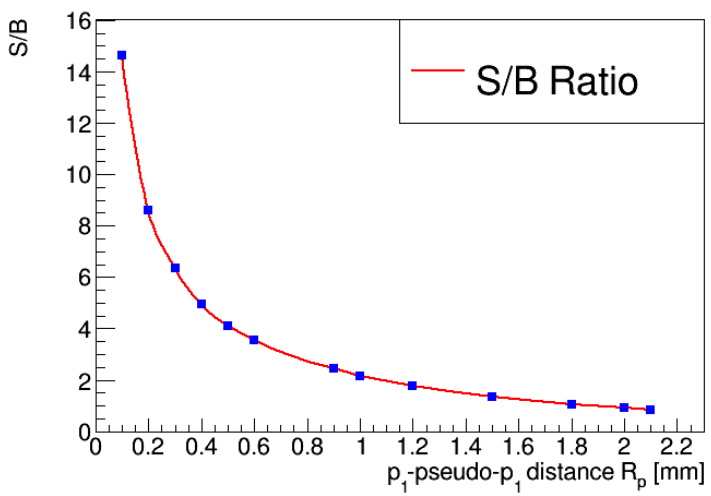
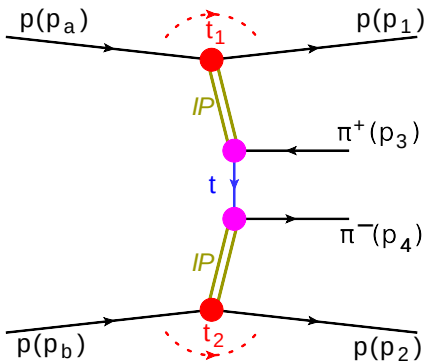
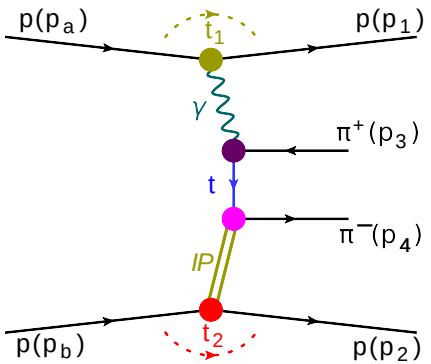


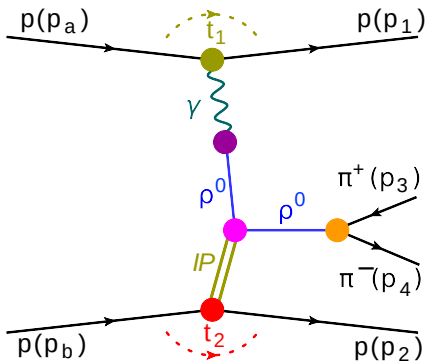
Fig. Predictions for ATLAS. **Left***: visible cross-sections for signal and background as a function of beam-detector distance.* **Right***: signal to background ratio. From [1].*

Exclusive Pion Pair Production

Dominant diagram: Pomeron induced continuum (right).
However, photon induced continuum (centre) with ρ^0 photoproduction (right) on top of it are also possible.







- Theoretical model:
  Lebiedowicz-Nachtmann-Szczurek,
  [1] Phys. Rev. D **91** (2015) 074023.
- Processes will be added to GenEx MC generator.
- Feasibility studies of the ρ^0 photoproduction for ATLAS to be done.
- Exclusive pion measurements at 7 and 8 TeV with ALFA@ATLAS are under way.

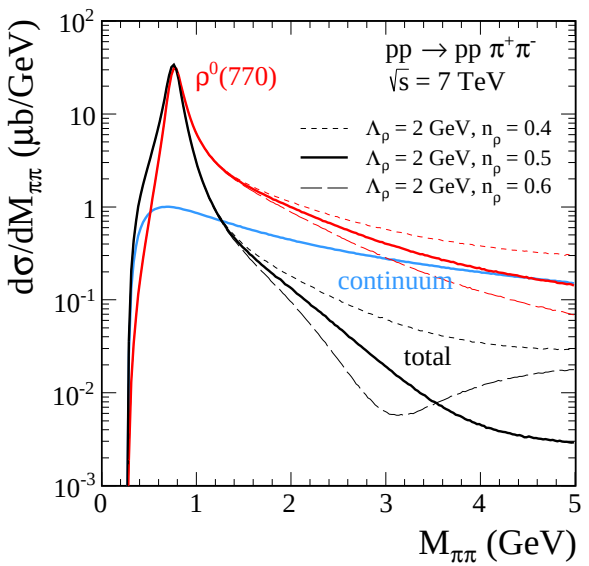


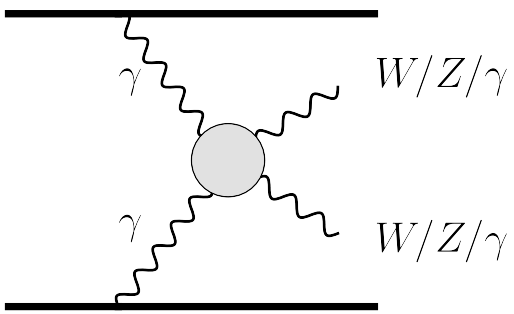
Fig. Two-pion invariant mass distributions at $\sqrt{s} = 7$ TeV. No ATLAS selection applied. From [1].

Prospects of Photon-Photon and Photon-Proton Measurements

in AFP

(medium and high mass)

Anomalous Gauge Couplings: W, Z and Photon Pairs



Motivation:

- measurement of W and Z boson pair production via the exchange of two photons allows to perform a stringent test of the electroweak symmetry breaking,
- tag in AFP results in gain in sensitivity of about two orders of magnitude over a standard ATLAS analysis.

$\gamma\gamma WW$ 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]	$2.0 \cdot 10^{-5}$	$9.2 \cdot 10^{-6}$

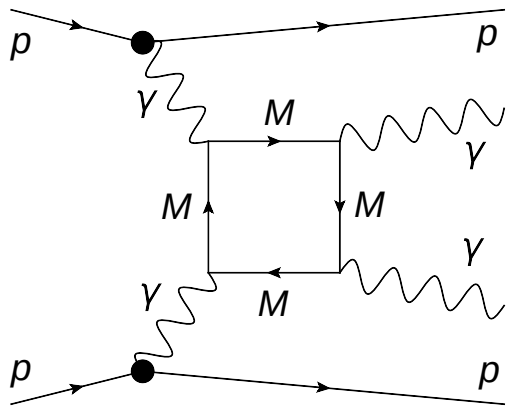
$\gamma\gamma\gamma\gamma$

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.	$7 \cdot 10^{-14}$	$2 \cdot 10^{-14}$	$2 \cdot 10^{-14}$

Details can be found in:

- Phys. Rev. D **78** (2008) 073005,
- Phys. Rev. D **81** (2010) 074003.

- **Main idea:** production of objects in which background can be extremely reduced by kinematic constraints coming from AFP proton measurements (high mass).
- Production of magnetic monopoles:



- Invisible objects: central system escape (or is not measurable) ATLAS, but scattered protons can be measured in AFP.
- SUSY sparticle production: precise mass and quantum numbers measurement.
- Any production of new objects (with mass up to 2 TeV) *via* photon or gluon exchanges.

Summary

- Intact protons → natural diffractive signature → usually scattered at very small angles (μrad) → detectors must be located far form the IP.
- Two forward detectors systems in ATLAS:
  - ALFA – vertical RPs located 240 m from IP1 (low mass acceptance; soft diffraction),
  - AFP – horizontal RPs located 210 m from IP1 (medium and high mass acceptance; hard diffraction).

- **ALFA successfully took data at**: 7 TeV with $\beta^* = 90$ m, 8 TeV with $\beta^* = 90$ m, 8 TeV with $\beta^* = 1000$ m, 13 TeV with $\beta^* = 2500$ m.
- Properties of elastic scattering were measured for both runs with $\beta^* = 90$ m. Results from data taken at 8 TeV with $\beta^* = 1000$ m and 13 TeV with $\beta^* = 2500$ m (CNI and (potentially) Coulomb regions) are on the way.
- When ALFA is used together with ZDC, it would be possible to measure diffractive bremsstrahlung.
- It should be also possible to measure photon induced contribution of exclusive pion production continuum with ρ^0 photoproduction on top of it.

- **AFP took data** in two special low luminosity runs **in 2016** (with detectors on one side). From 2017 AFP is fully equipped **and will take data with proton tag on both sides during special and standard LHC runs**.
- AFP plan to measure Anomalous Gauge Couplings (W, Z and Photon Pairs). A gain in sensitivity of about two orders of magnitude over a standard analysis is expected.
- In principle one can try to search for any production of new object produced *via* photon or gluon exchanges (magnetic monopoles, inivisible particles, ...). Proton measurement can be used for significant background reduction.

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