

Forward proton tagging in ATLAS

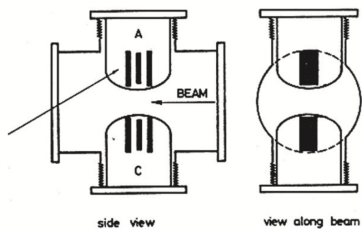
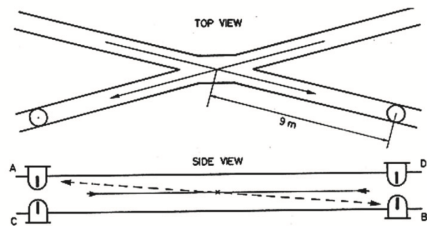
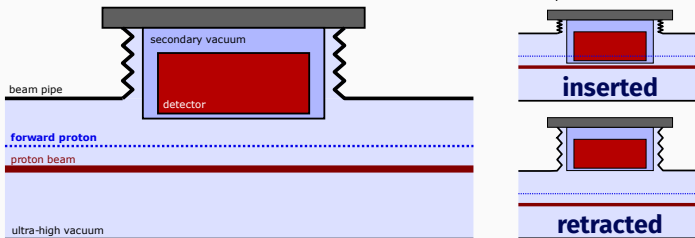
status of detectors and new physics results

Rafał Staszewski (IFJ PAN Cracow)

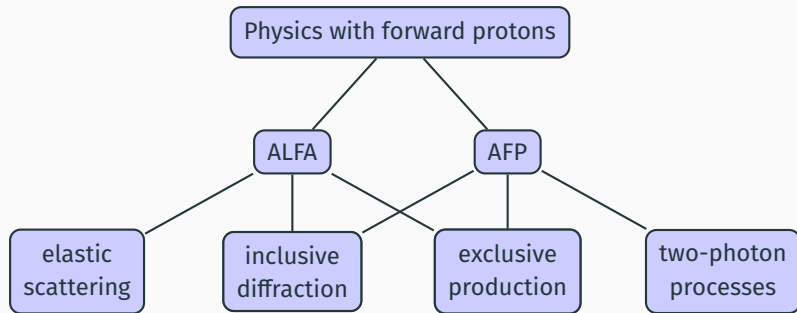
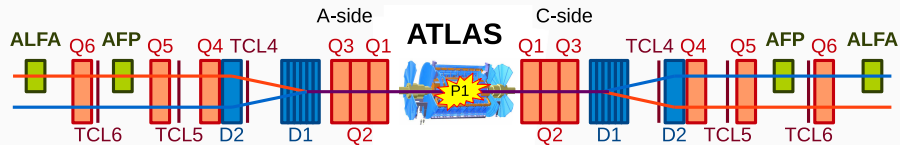
supported in part by Polish National Science Centre NCN project no 2021/42/E/ST2/00350

ISMD 2023, 21 – 26 August 2023, Gyöngyös, Hungary

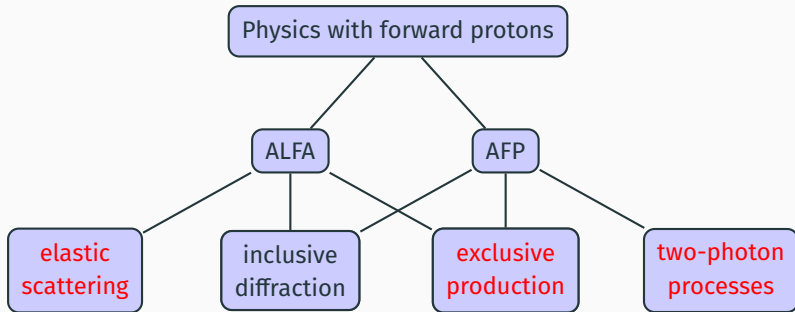
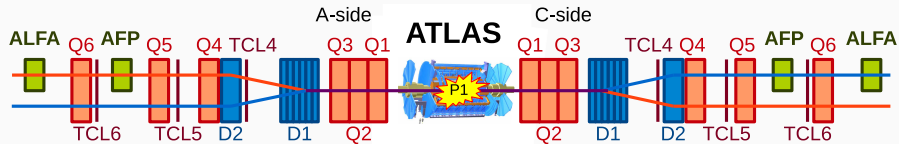
Roman pots



Forward detectors and physics

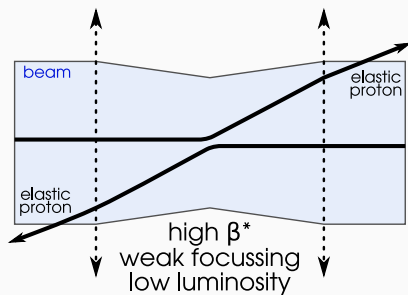
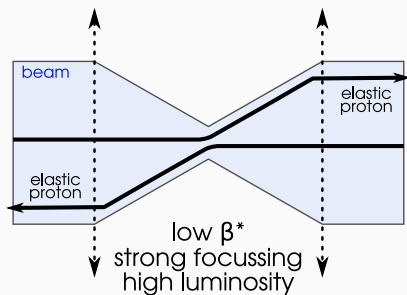


Forward detectors and physics



Topics covered in this talk

High- β^* optics



Typical values at LHC:

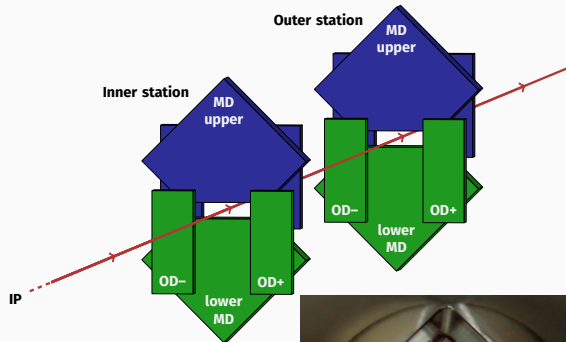
$$\beta^* < 1 \text{ m}$$

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

ALFA Detectors

$$pp \rightarrow pp$$

ALFA detectors

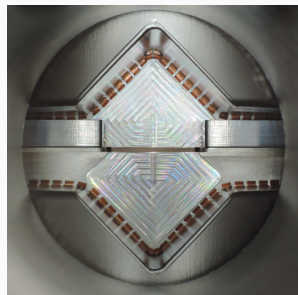
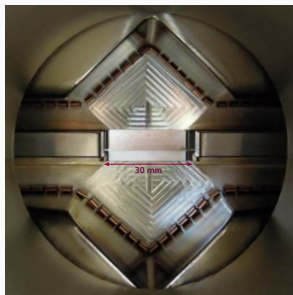


Main detectors (MDs)
for physics

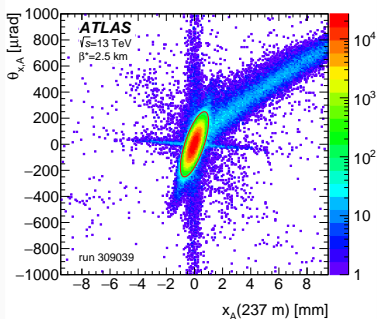
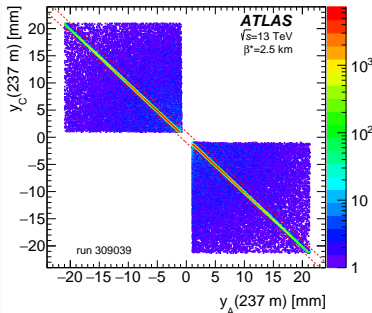
Overlap detectors (ODs)
for alignment

Detectors operate very
close to the beam

Distance to the beam
determines the lowest
scattering angles (lowest t)



Elastic event selection

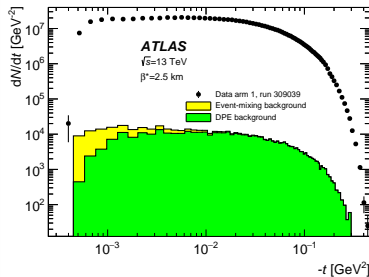


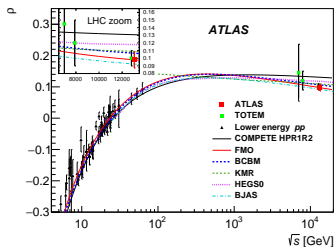
Event selection based on strong correlations present in elastic events

Background (normalized in control regions):

- accidental halo+halo and halo+SD coincidences (data-driven templates)
- central diffraction (MC simulation)

Relative uncertainty of 10 – 15%.

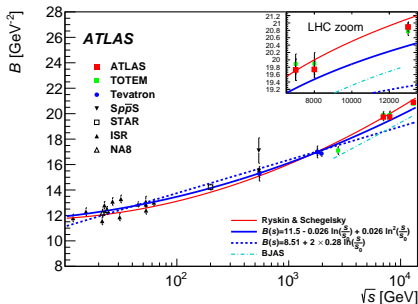
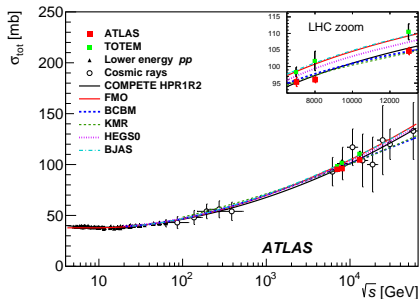




$$\rho = 0.0978 \pm 0.0043(\text{stat.}) \pm 0.0073(\text{exp.}) \pm 0.0064(\text{th.})$$

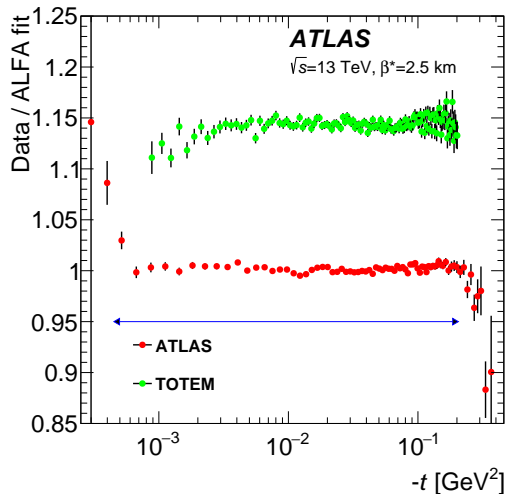
$$\sigma_{\text{tot}} = 104.68 \pm 0.22(\text{stat.}) \pm 1.06(\text{exp.}) \pm 0.12(\text{th.})$$

$$B = 21.14 \pm 0.07(\text{stat.}) \pm 0.11(\text{exp.}) \pm 0.01(\text{th.})$$



TOTEM vs ATLAS difference

Tension between ATLAS and TOTEM σ_{tot} (2.2σ)



atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2018-08/

Luminosity-independent (TOTEM)

$$\sigma_{\text{tot}} = \frac{16\pi}{1 + \rho^2} \frac{1}{N_{\text{el}} + N_{\text{inel}}} \left. \frac{dN_{\text{el}}}{dt} \right|_{t \rightarrow 0}$$

Requires correction for not measured small-mass diffraction

Luminosity-dependent (ATLAS)

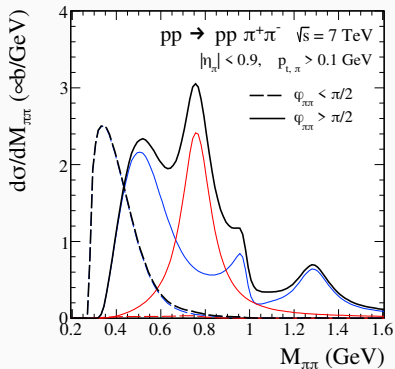
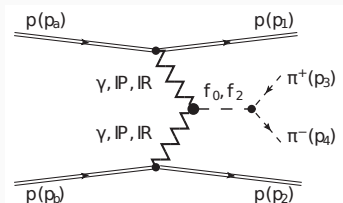
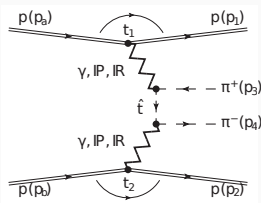
$$\sigma_{\text{tot}}^2 = \frac{16\pi}{1 + \rho^2} \frac{1}{L} \left. \frac{dN_{\text{el}}}{dt} \right|_{t \rightarrow 0}$$

Requires a dedicated luminosity measurement

ALFA Detectors

$$pp \rightarrow p\pi^+\pi^-p$$

Exclusive pion pair production



Interesting and complex mechanism

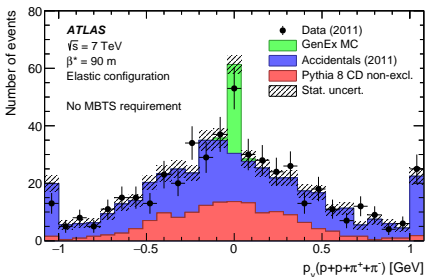
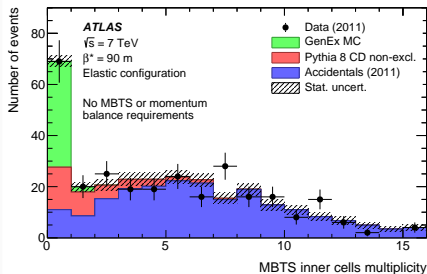
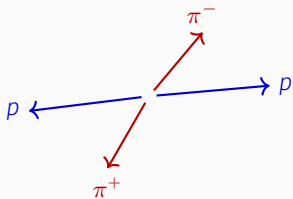
Non-trivial interplay of continuous and resonant production

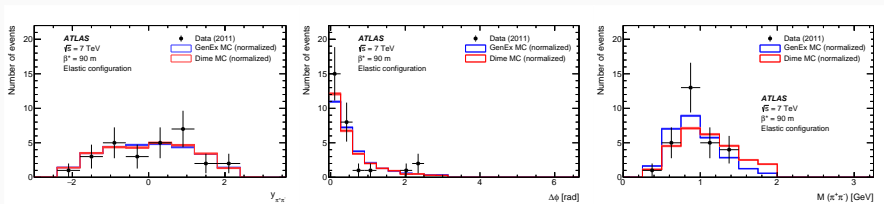
Theoretical predictions and diagrams from
 P. Lebiedowicz et al., Phys.Rev.D 93 (2016) 5, 054015.

Exclusive event selection

Selection of exclusive events:

- forward protons detected in ALFA
- opposite-charged pions detected in the central ATLAS detector
- vetoing activity in Minimum Bias Trigger Scintillator (MBTS)
- Exclusivity enforced by looking at p_T balance in the event





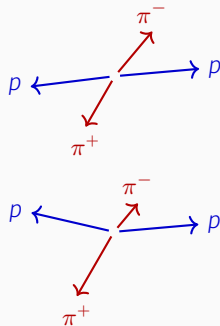
First exclusive $\pi^+\pi^-$ measurement with proton tagging at LHC!

- elastic pp configuration

$$\sigma = 4.8 \pm 1.0(\text{stat})_{-0.2}^{+0.3}(\text{syst}) \pm 0.1(\text{lumi}) \pm 0.1(\text{model}) \mu\text{b}$$

- anti-elastic pp configuration

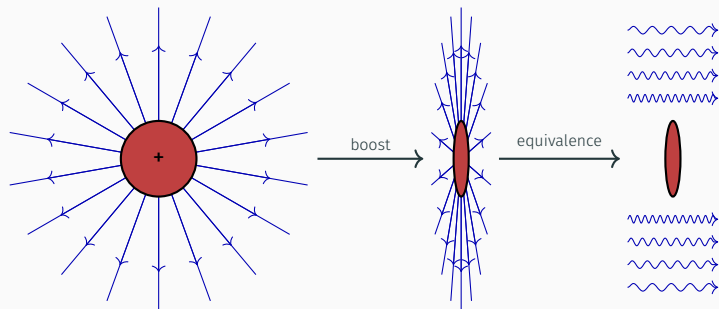
$$\sigma = 9 \pm 6(\text{stat}) \pm 1(\text{syst}) \pm 1(\text{lumi}) \pm 1(\text{model}) \mu\text{b}$$



AFP Detectors

$$\gamma\gamma \rightarrow ll$$

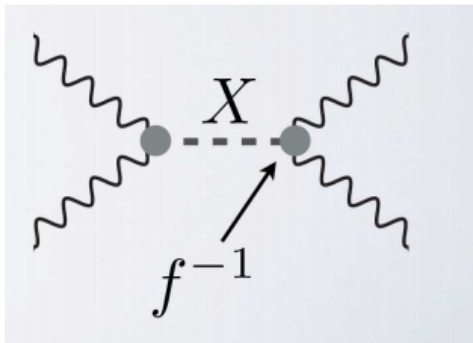
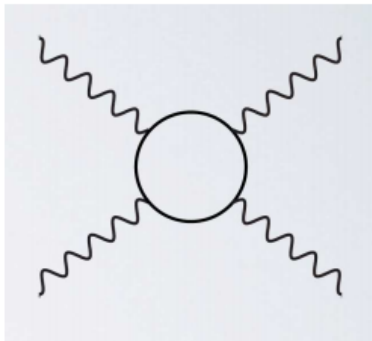
Photon-photon interactions



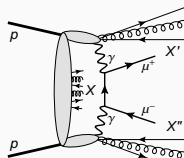
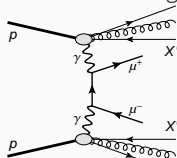
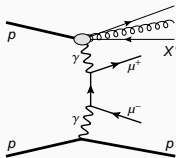
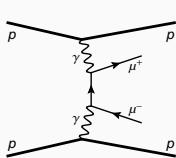
Large flux of high-energy photons allows studies of $\gamma\gamma$ interactions

Photon-photon interactions

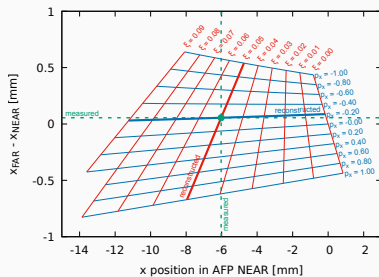
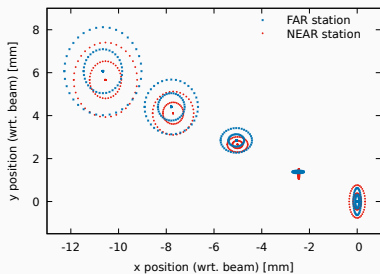
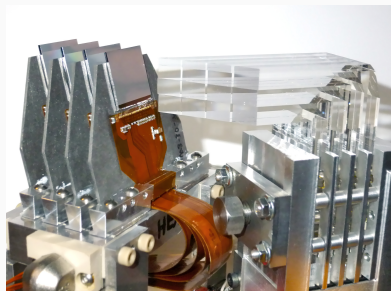
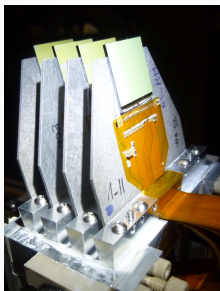
EWK motivation – possible new particles:



QCD motivation – proton dissociation and additional exchanges:

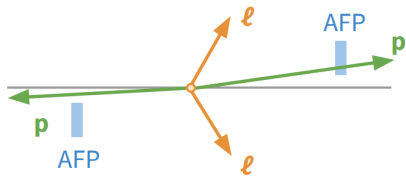


AFP detectors and proton reconstruction



Kinematic matching

Signal:



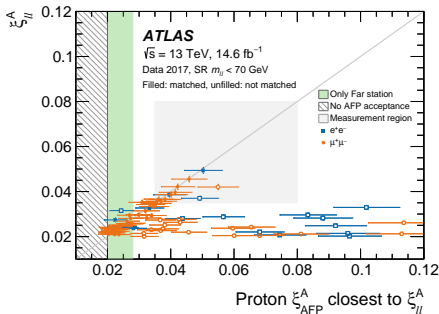
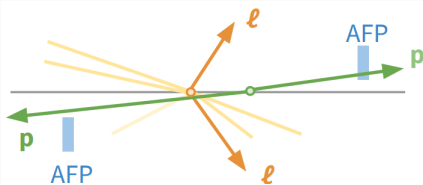
- ξ – fraction of proton energy carried by the photon
- ξ from proton measurement

$$\xi = 1 - E_p/E_{\text{beam}}$$

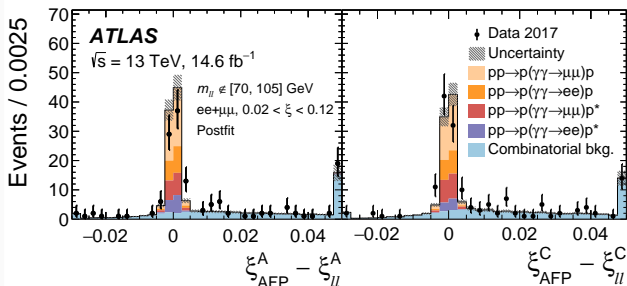
- ξ from ll system

$$\xi_{\pm} = \frac{M_{ll}}{\sqrt{s}} \cdot e^{\pm y_{ll}}$$

Background:



First measurement of exclusive dileptons with proton tagging! Demonstrating performance of proton tagging in standard LHC running.



	$\sigma_{ee+p}^{\text{fid.}} [\text{fb}]$	$\sigma_{\mu\mu+p}^{\text{fid.}} [\text{fb}]$
Measurement	11.0 ± 2.9	7.2 ± 1.8

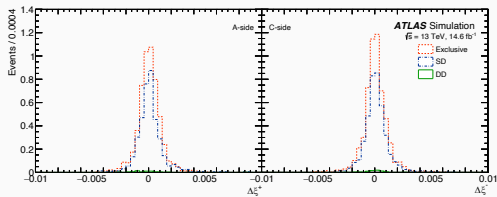
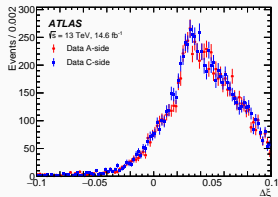
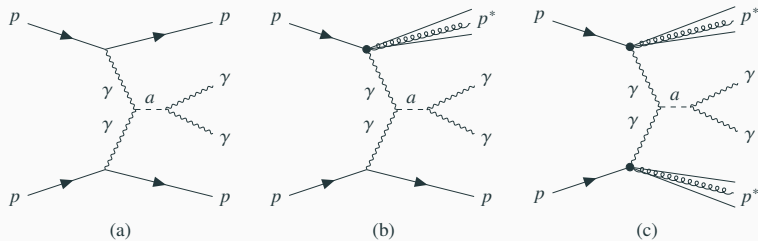
SUPERCHIC 4 predictions

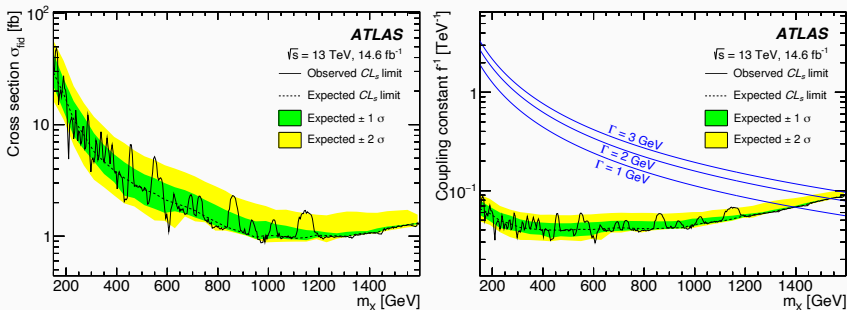
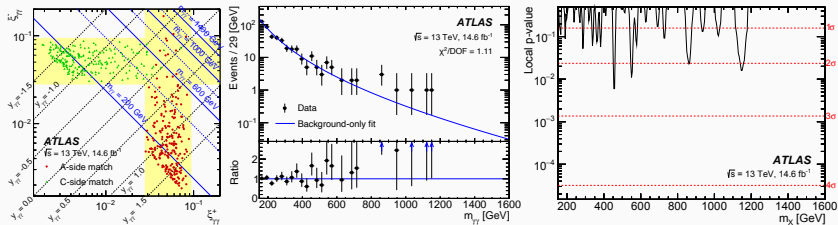
Exclusive + single-dissociative	12.2 ± 0.9	10.4 ± 0.7
Exclusive	8.6 ± 0.6	7.3 ± 0.5
Single-dissociative	3.6 ± 0.6	3.1 ± 0.5

AFP Detectors

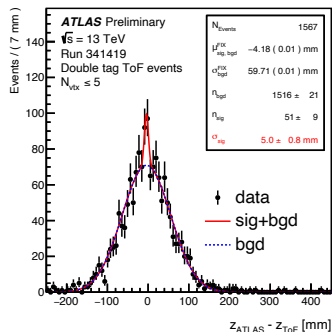
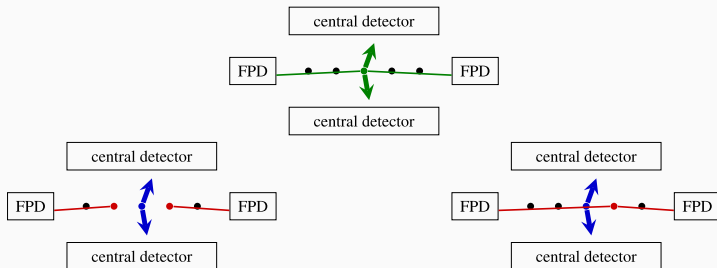
$\gamma\gamma \rightarrow \gamma\gamma$ (ALP search)

ALP search in $\gamma\gamma \rightarrow \gamma\gamma$

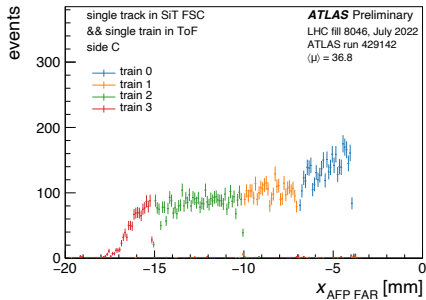
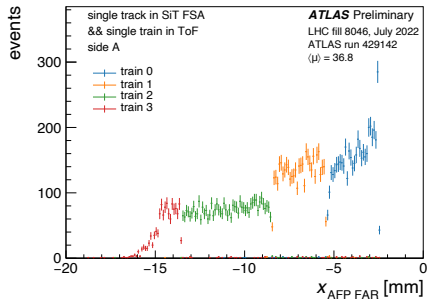
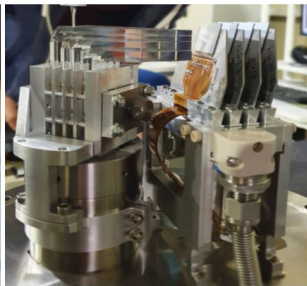
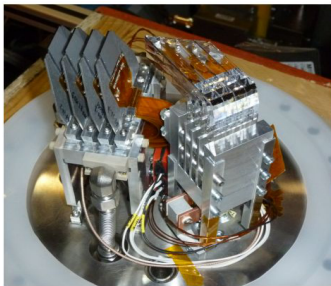




AFP ToF – vertex matching



AFP in Run 3



Summary

ATLAS pursues interesting physics using forward proton tagging

Interesting recent results on elastic scattering, central exclusive production and photon-induced processes

ALFA attempting to collect data with highest- β^* special optics

AFP already collected more data in Run 3 than in Run 2