Recent ATLAS results on forward physics and diffraction

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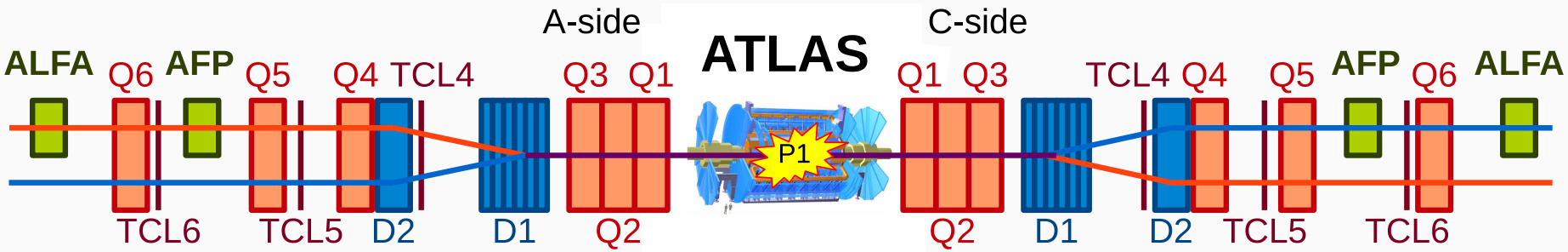
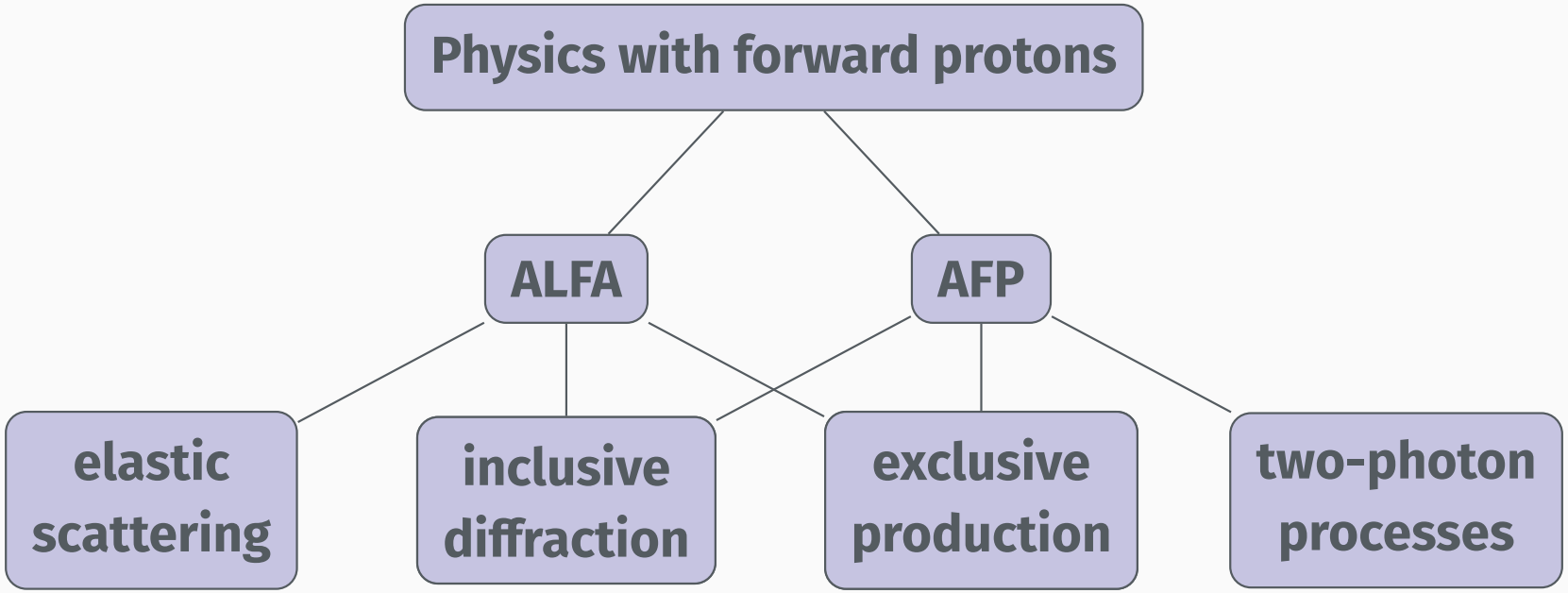
on behalf of the ATLAS Collaboration

ISMD 2022
51st International Symposium on Multiparticle Dynamics

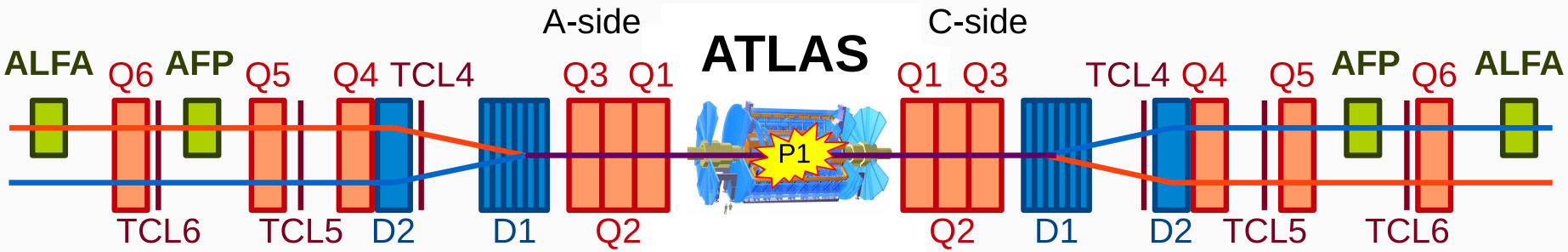
This work is supported in part by the Polish Ministry of Education and Science project no 2022/WK/08

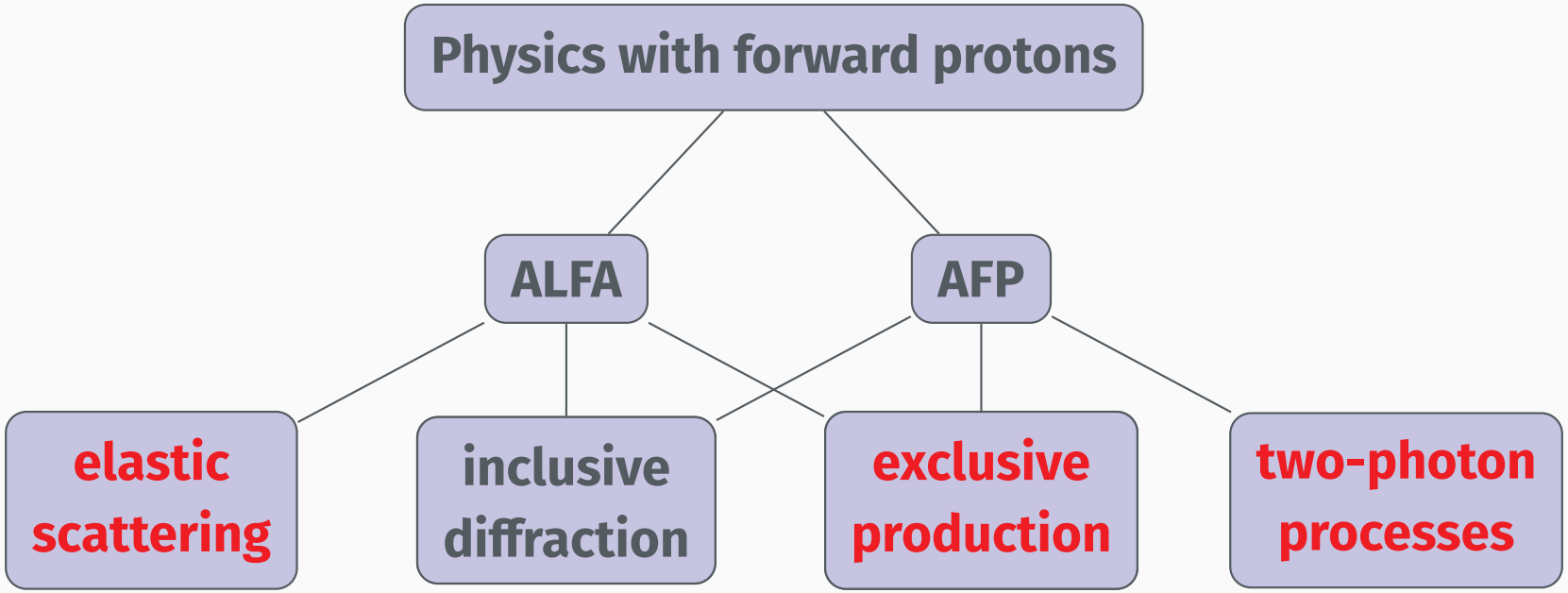
Forward detectors and physics





Forward detectors and physics





Topics covered in this talk

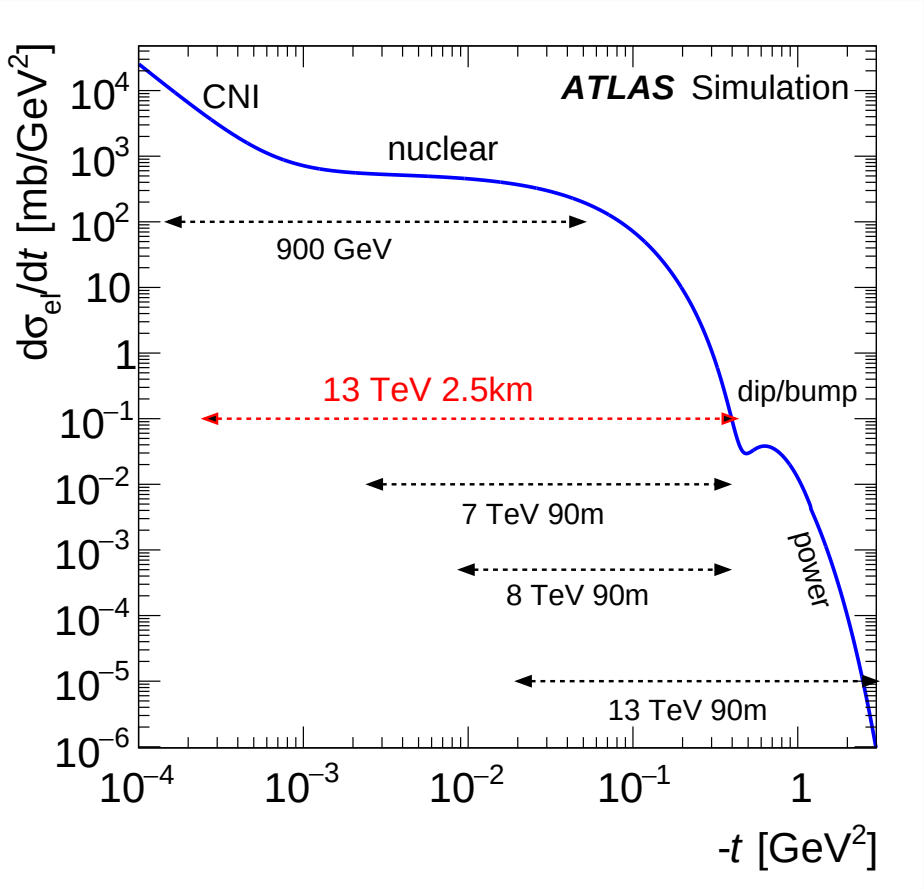
$pp \rightarrow pp$

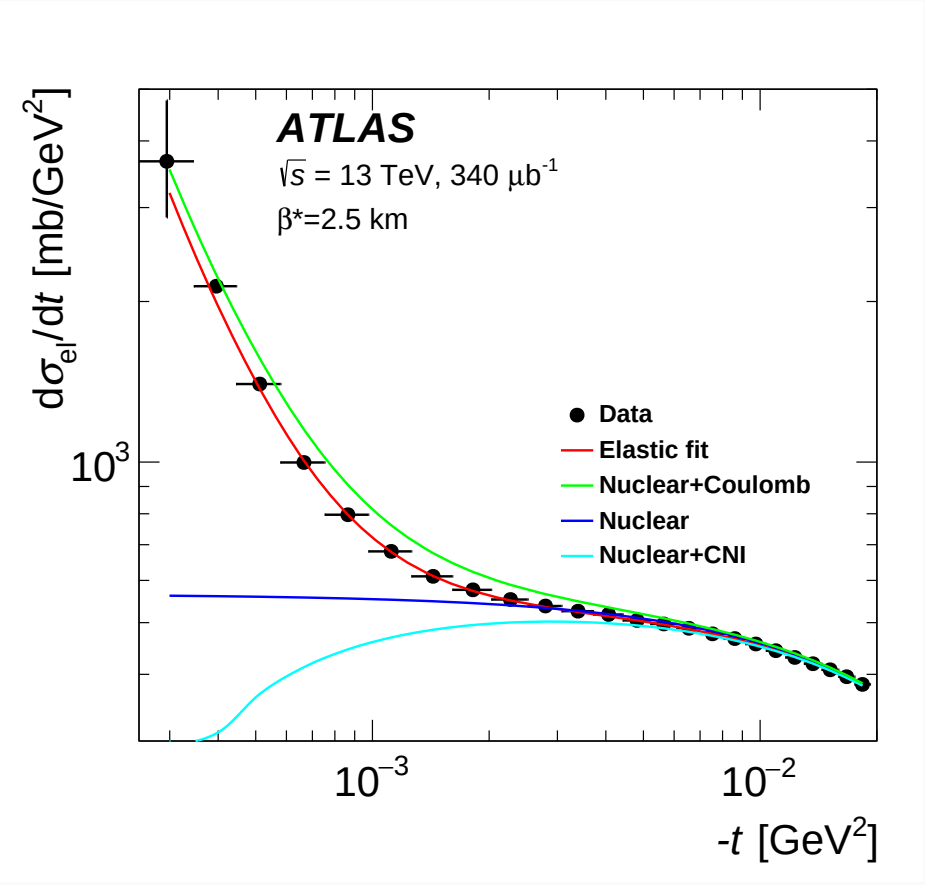
arXiv:2207.12246

https://atlas.cern/Updates/Physics-Briefing/ALFA-scattering

Mustafa's poster

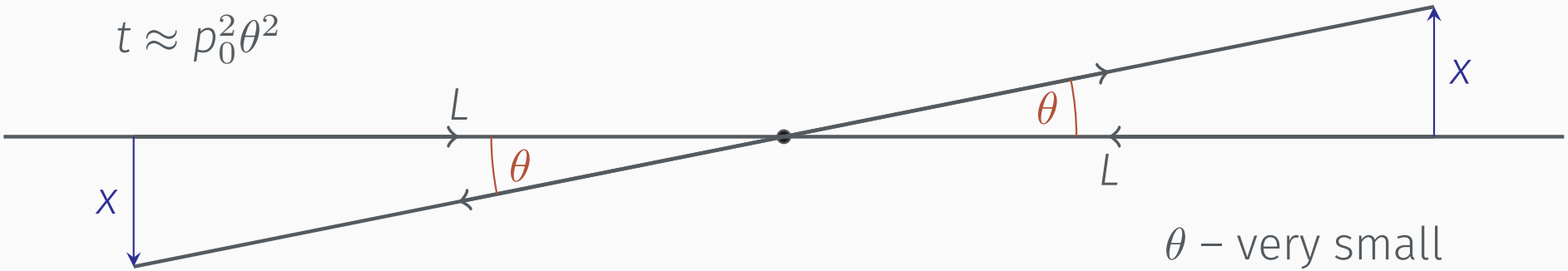
Mechanisms and experimental reach





- Dedicated $\beta^* = 2500$ m to access the CNI region
- Measurement in nuclear region to measure σ_{tot} (long-standing tension with TOTEM) and the nuclear slope parameter

Elastic scattering



No magnetic fields:

$$x = L\theta \qquad \theta_{\text{local}} = \theta$$

With magnetic fields

$$x = L_{\text{eff}}\theta \qquad \theta_{\text{local}} \propto \theta$$

Finite beam size:

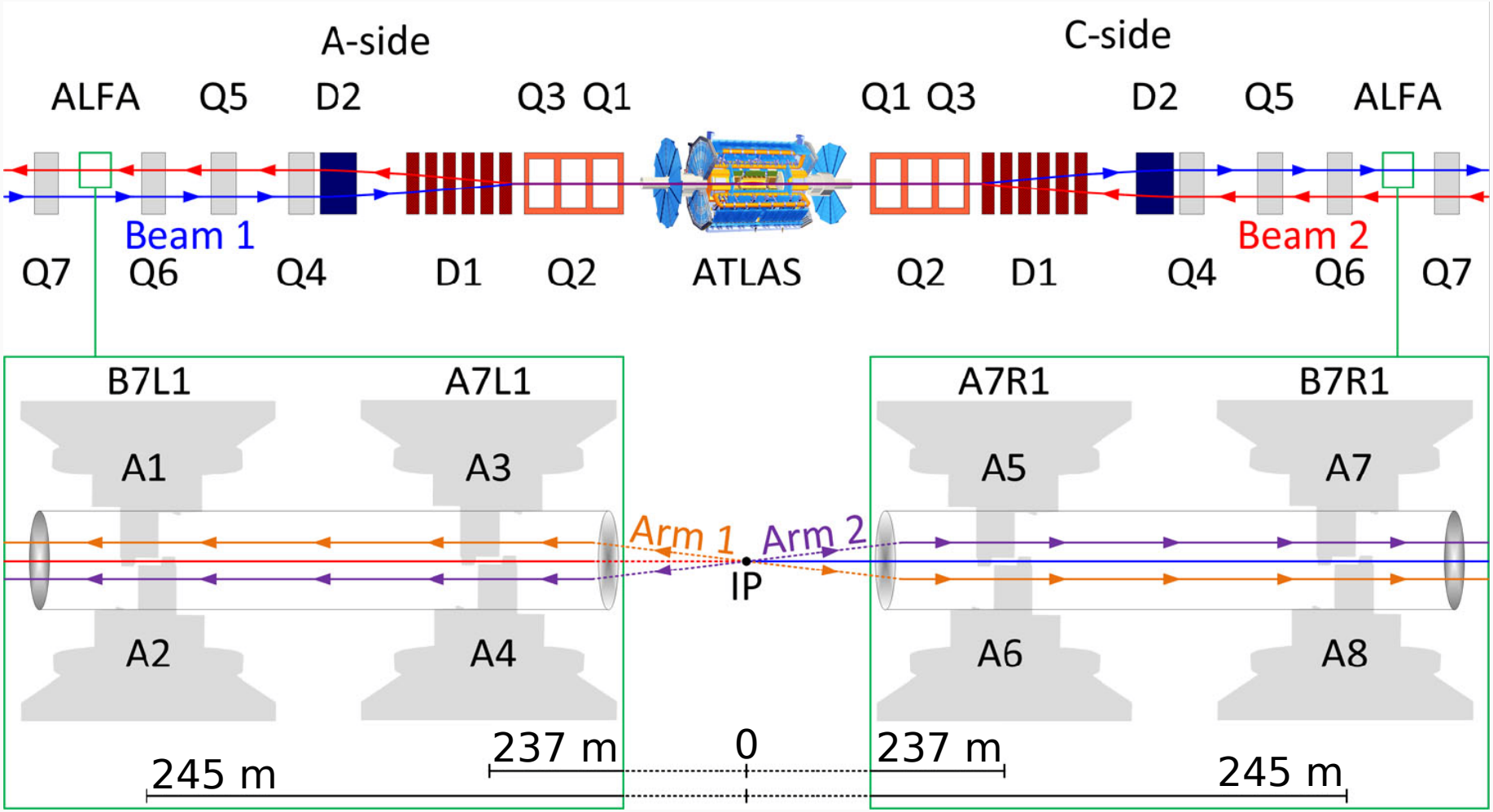
$$\begin{pmatrix} x \\ \theta_{\text{local}} \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \begin{pmatrix} x_0 \\ \theta \end{pmatrix}$$

$$(\theta, \varphi) \leftrightarrow (\theta_x, \theta_y)$$

$$\begin{pmatrix} x \\ \theta_{x,\text{local}} \end{pmatrix} = \begin{pmatrix} M_{11}^x & M_{12}^x \\ M_{21}^x & M_{22}^x \end{pmatrix} \begin{pmatrix} x_0 \\ \theta \end{pmatrix}$$

$$\begin{pmatrix} y \\ \theta_{y,\text{local}} \end{pmatrix} = \begin{pmatrix} M_{11}^y & M_{12}^y \\ M_{21}^y & M_{22}^y \end{pmatrix} \begin{pmatrix} y_0 \\ \theta \end{pmatrix}$$

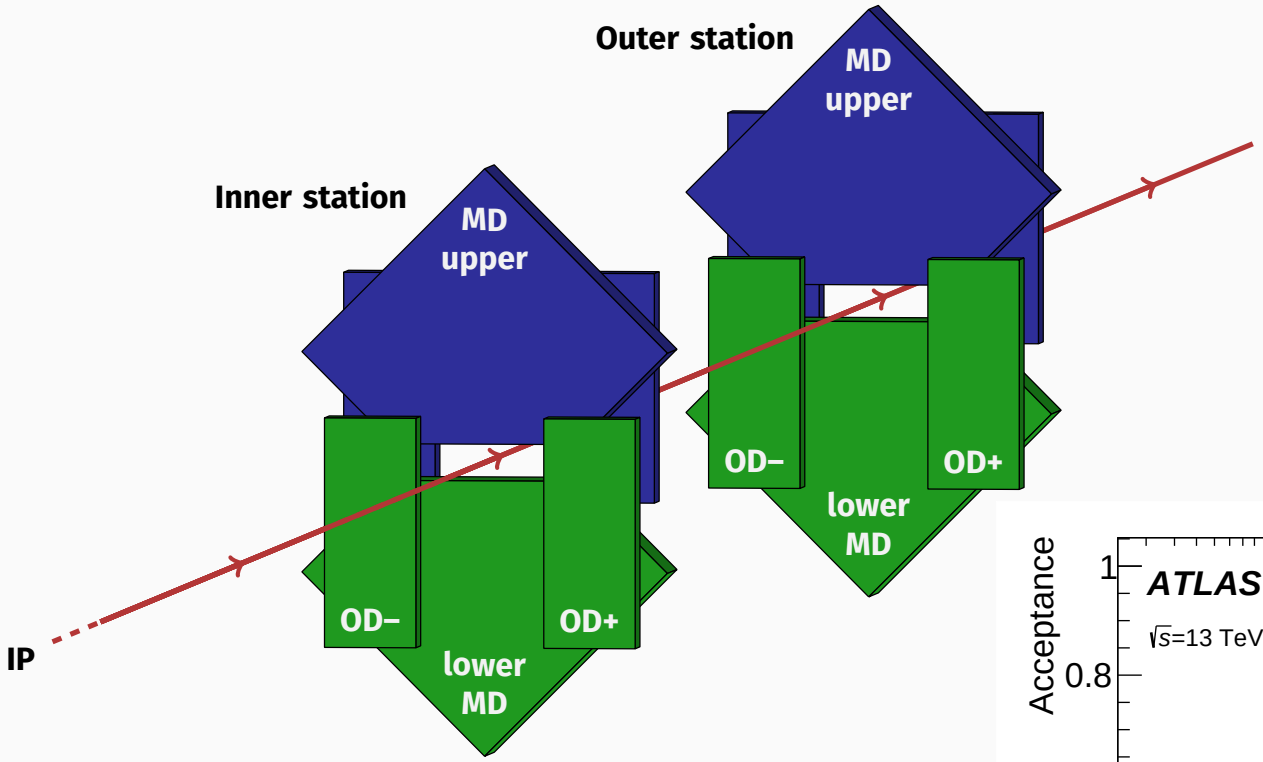
ALFA detectors



2 Roman pot stations on each side of IP

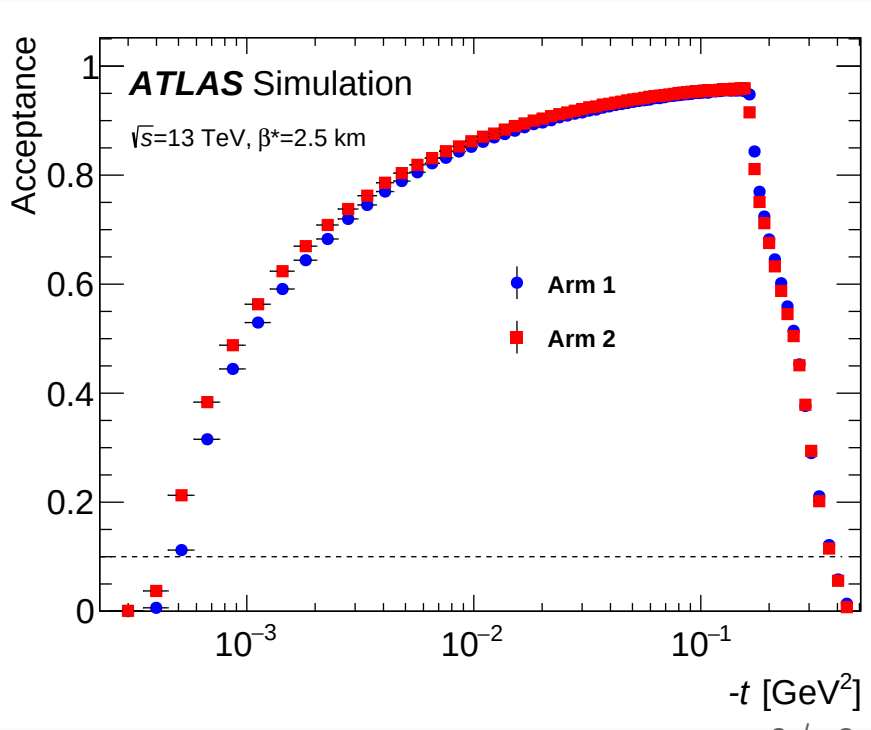
2 tracking detectors in each station

ALFA detectors



Main detectors (MDs)
for physics

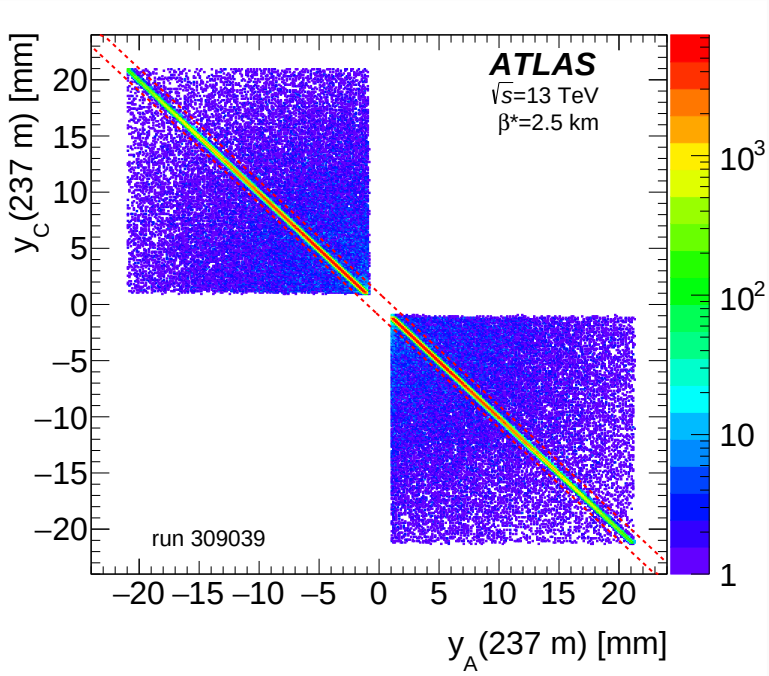
Overlap detectors (ODs)
for alignment

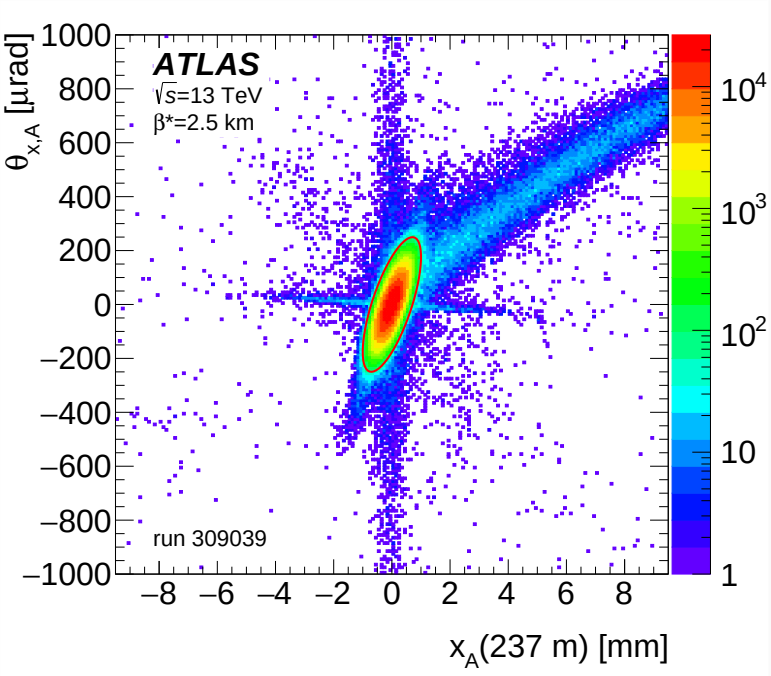


Detectors operate very closely to the beam (single millimetres)

Distance to the beam determines the lowest t

Event selection and background estimation



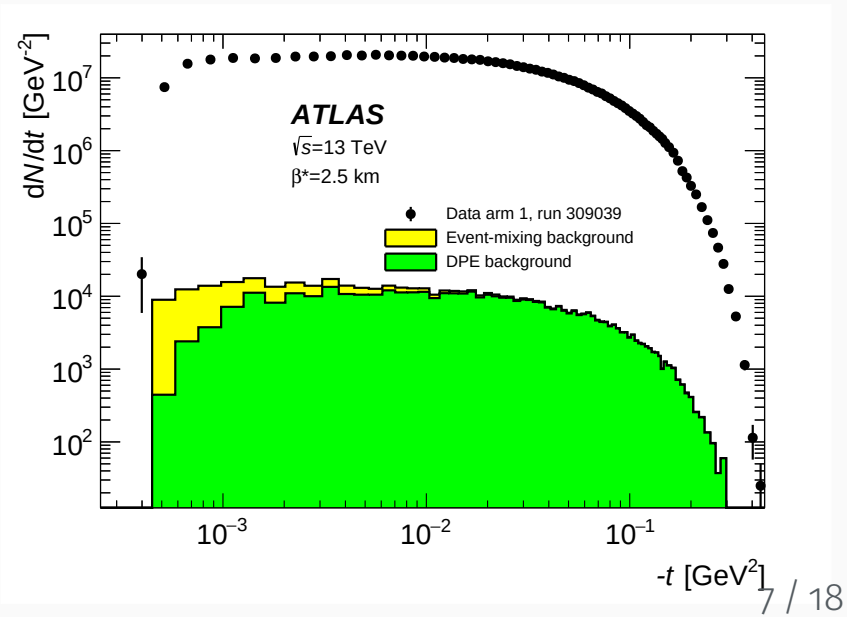


Event selection based on strong correlations present in elastic events

Background (normalized in control regions):

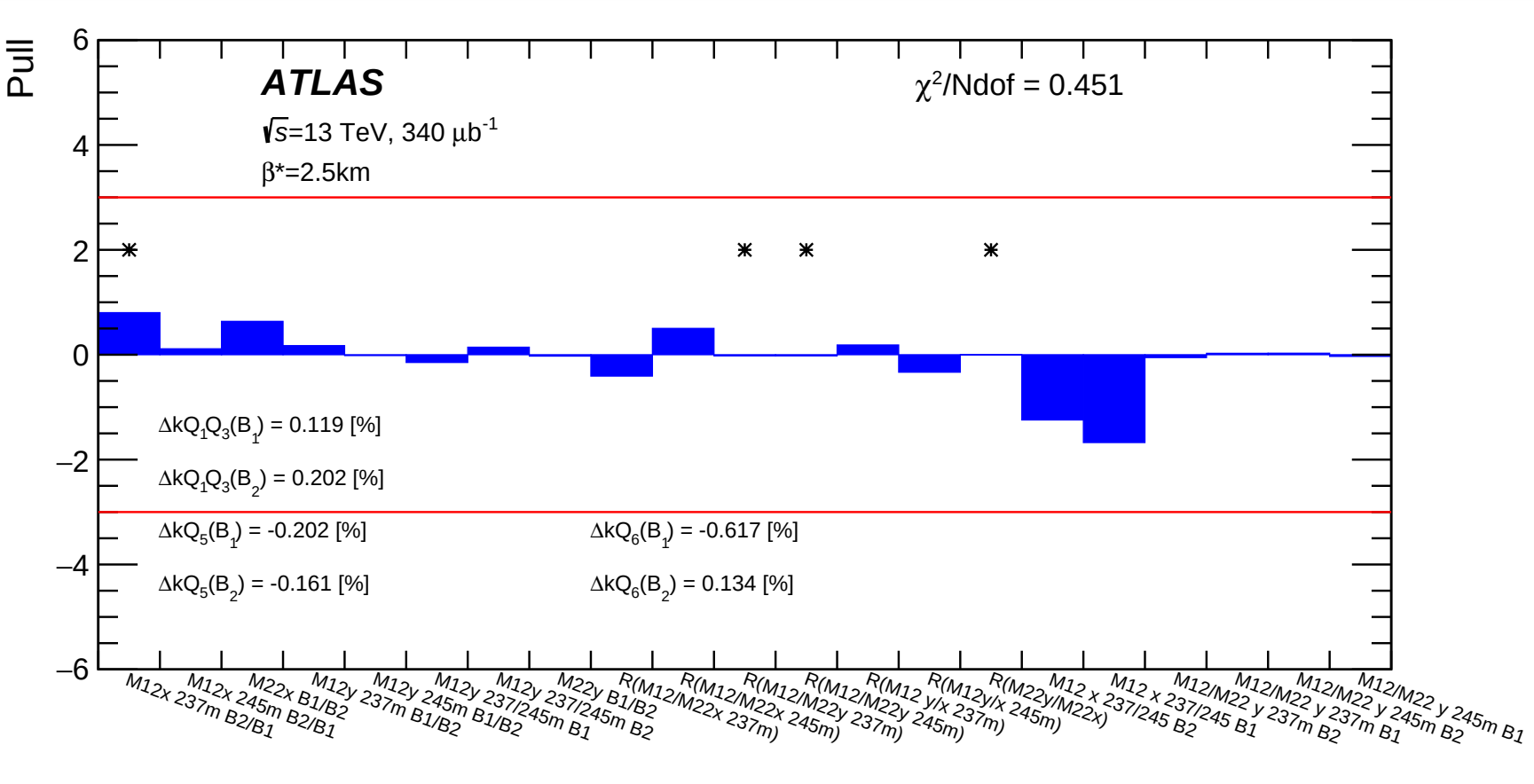
- accidental halo+halo and halo+SD coincidences (data-driven templates)
- central diffraction (MC simulation)

Relative uncertainty of 10 – 15%.

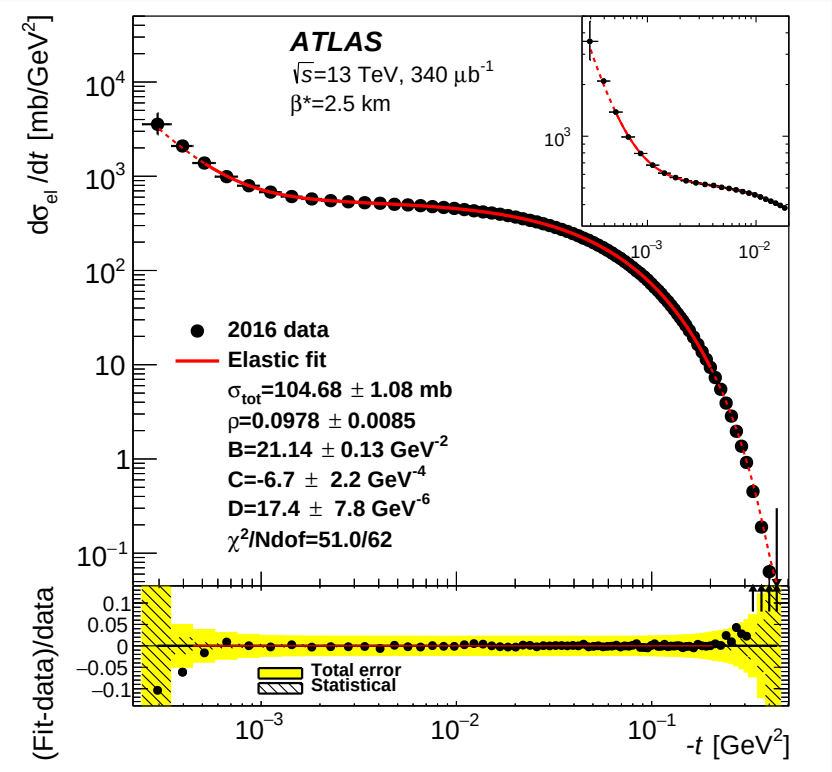


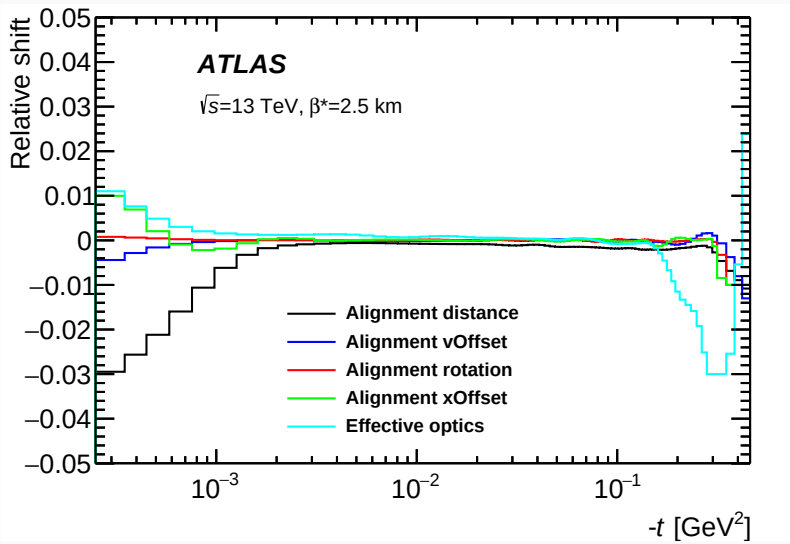
Data-driven methods

Many ingredients of the analysis are based on data exploiting strongly constrained elastic events: alignment, reconstruction efficiency, optics



Differential cross section





Systematic uncertainties evaluated as function of t

Main sources: alignment, luminosity, reconstruction efficiency

Fitted function:

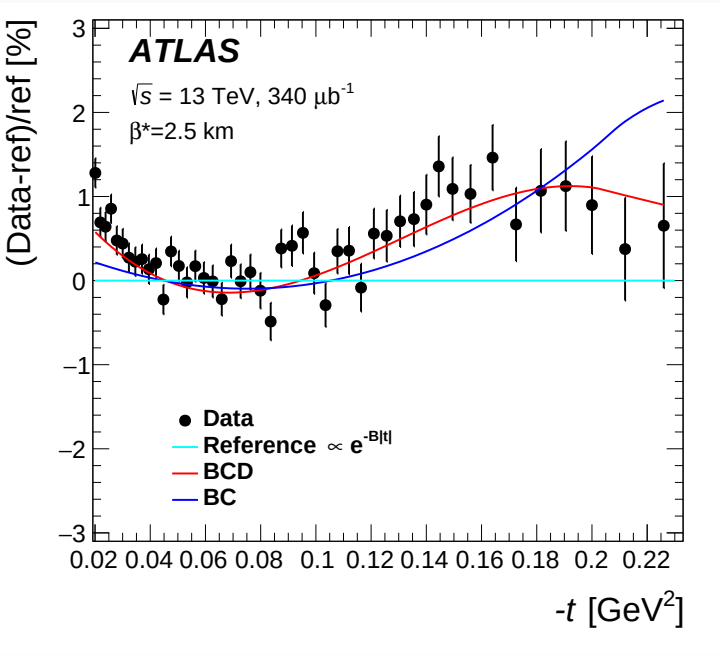
$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = \frac{1}{16\pi}\left|f_{\mathrm{N}}(t) + f_{\mathrm{C}}(t)\mathrm{e}^{\mathrm{i}\alpha\phi(t)}\right|^2$$

$$f_{\mathrm{C}}(t) = -8\pi\alpha\hbar c\frac{G^2(t)}{|t|}$$

$$f_{\mathrm{N}}(t) = (\rho + \mathrm{i})\,\frac{\sigma_{\mathrm{tot}}}{\hbar c}\mathrm{e}^{(-B|t| - C|t|^2 - D|t|^3)/2}$$

$$\rho = \frac{\mathrm{Re}\, f_{\mathrm{N}}(0)}{\mathrm{Im}\, f_{\mathrm{N}}(0)}$$

Results in nuclear region



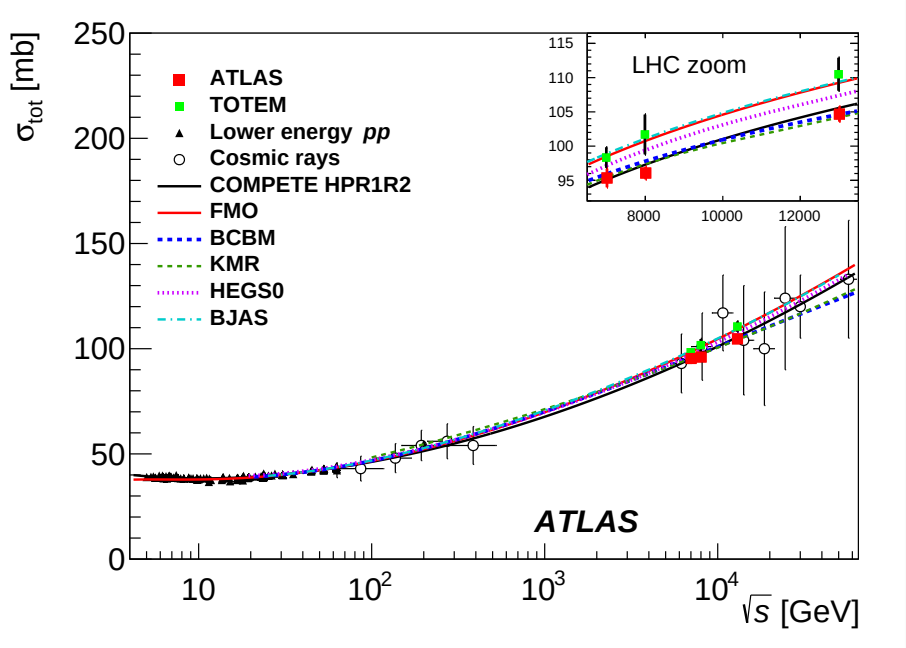
– Non-exponential shape of $d\sigma/dt$

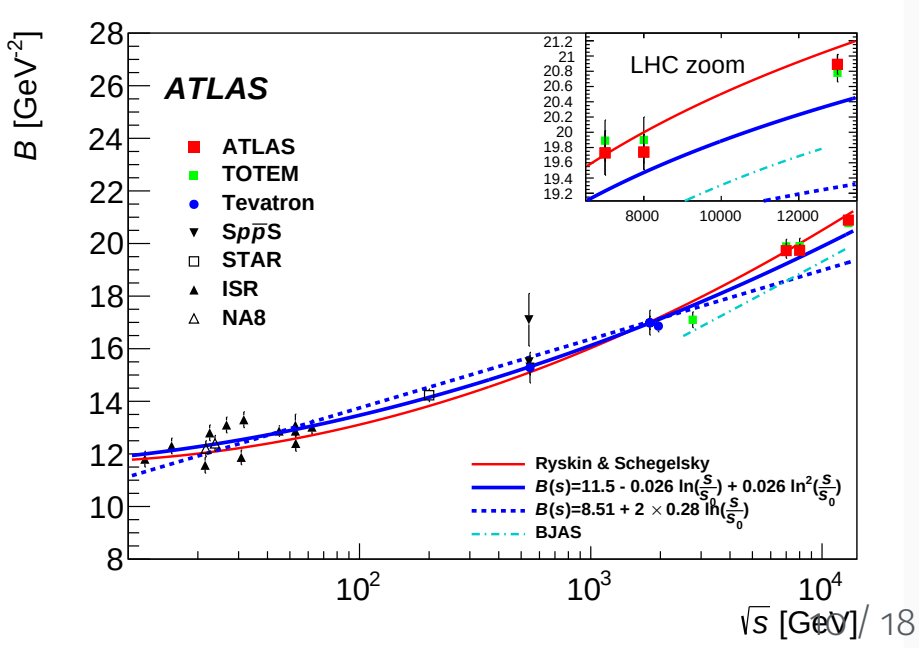
$$\sigma_{\text{tot}} = 104.68 \pm 0.22(\text{stat.}) \pm 1.06(\text{exp.}) \pm 0.12(\text{th.})$$

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

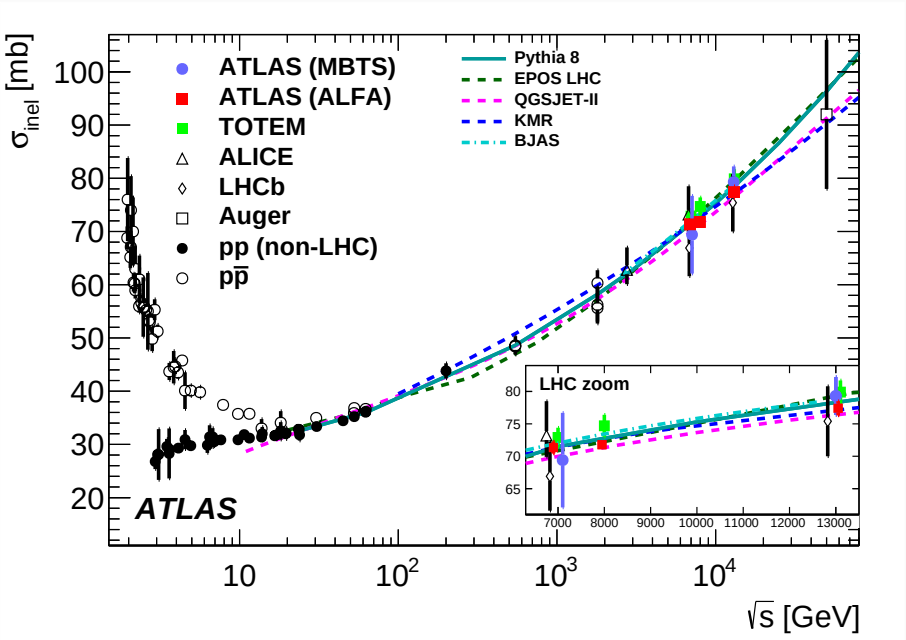
– Most precise σ_{tot} measurement

– Tension with TOTEM σ_{tot} results (2.2σ)

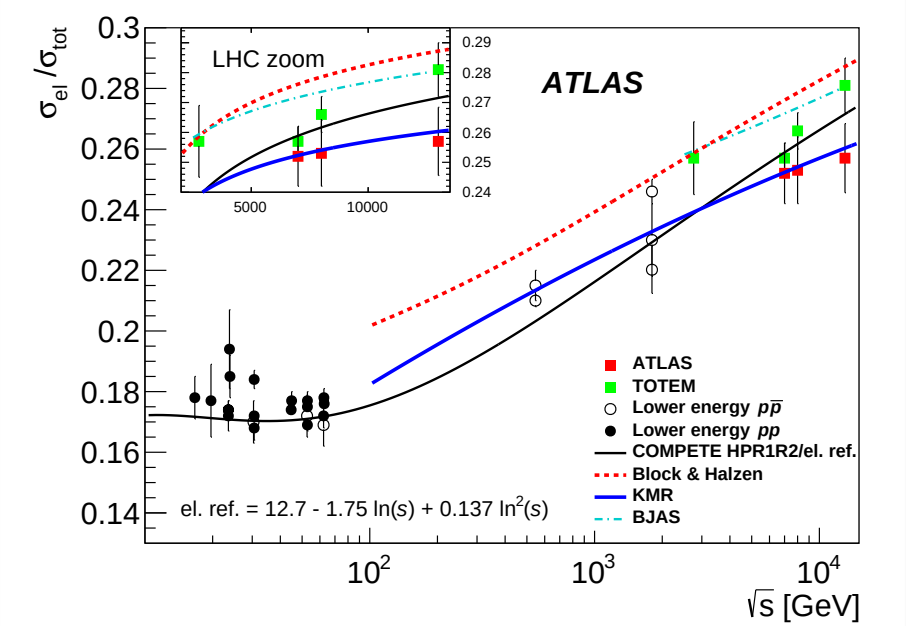




Derived quantities

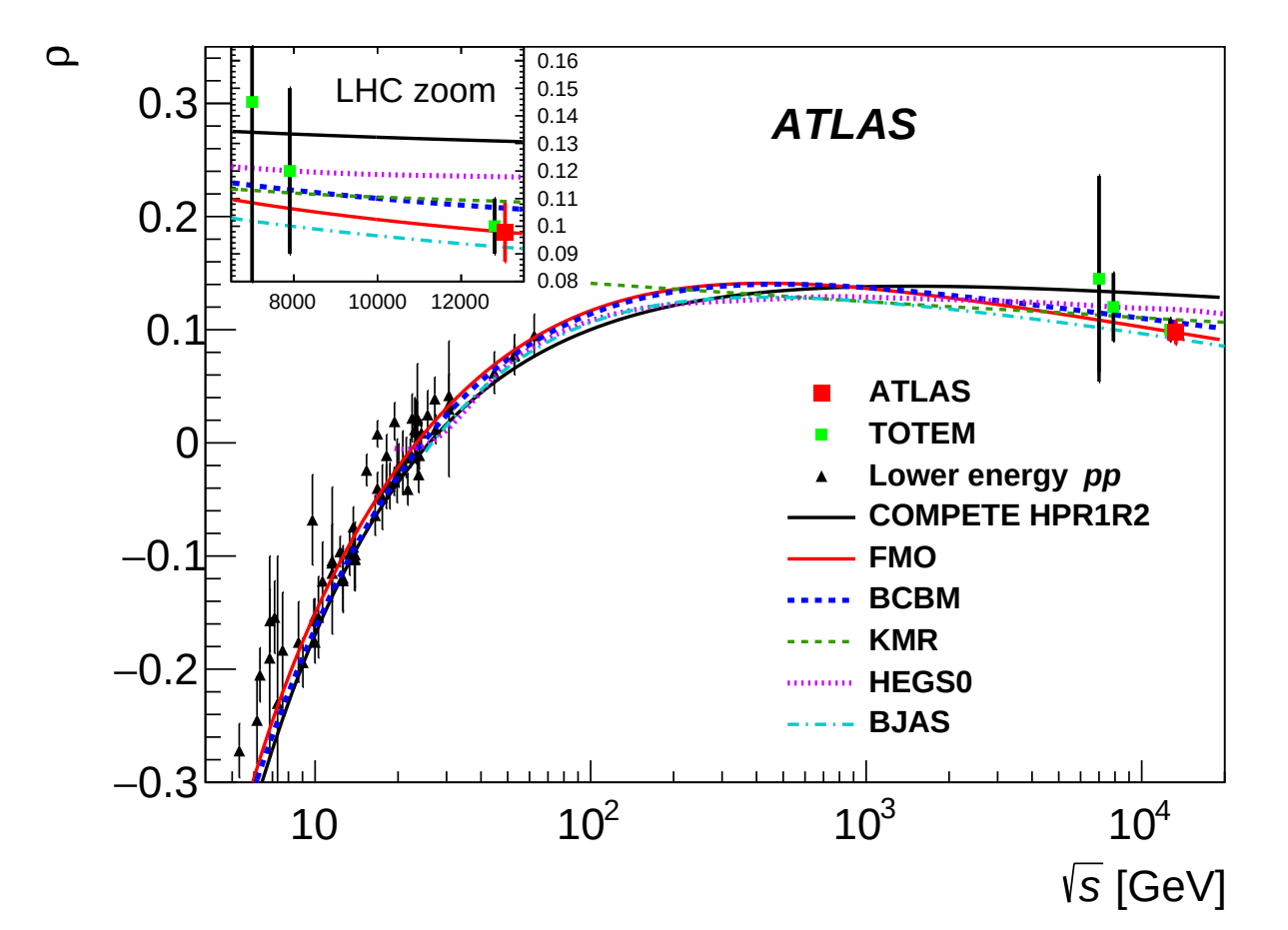


Total inelastic cross section in agreement with previous ATLAS measurements using MBTS detectors



Ratio of elastic to total cross section in tension with TOTEM's results

Results in interference region

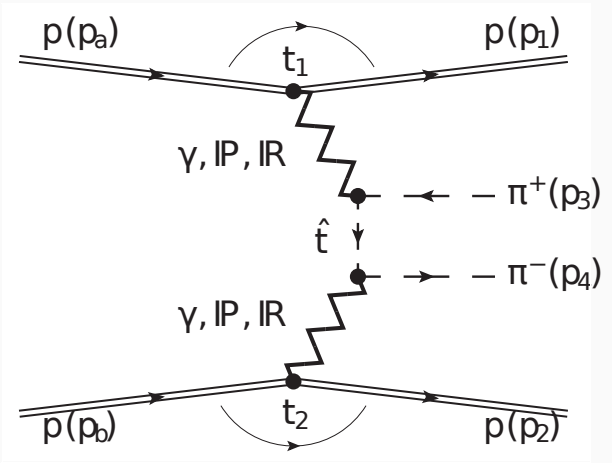


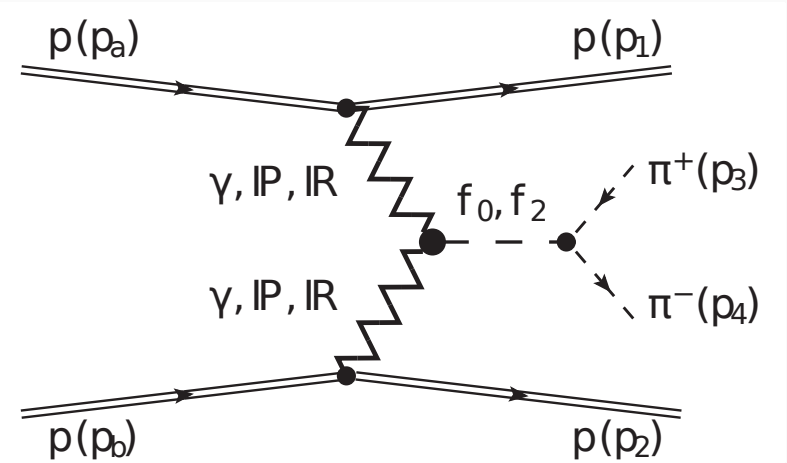
$$\rho = 0.0978 \pm 0.0043(\text{stat.}) \pm 0.0073(\text{exp.}) \pm 0.0064(\text{th.})$$

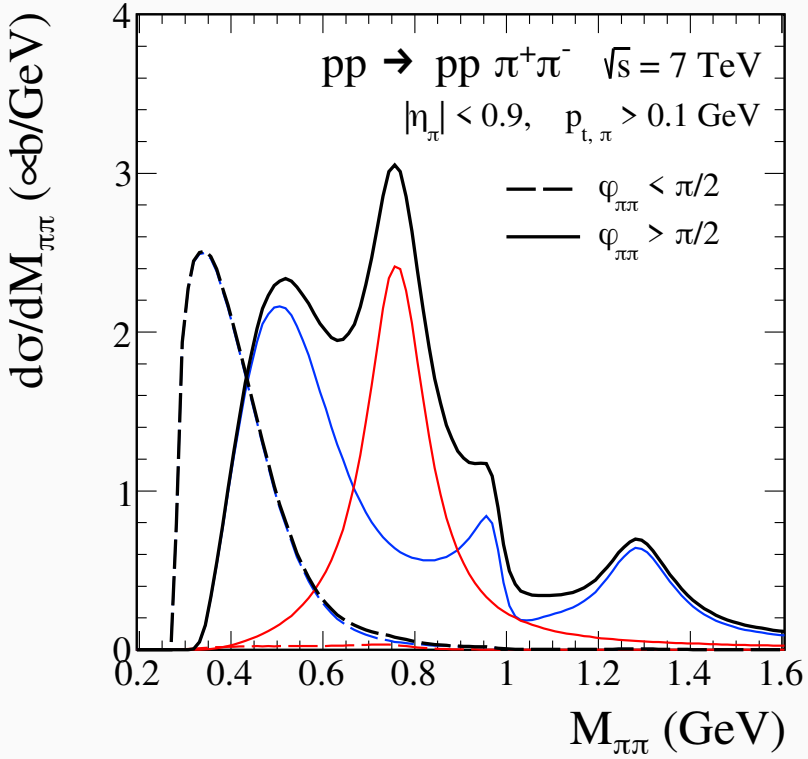
Result incompatible with COMPETE (community-standard semi-empirical fits) indicating Odderon exchange or a slowdown of σ_{tot} rise at high $\sqrt{s}$.

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

Exclusive pion pair production







Interesting and complex mechanism

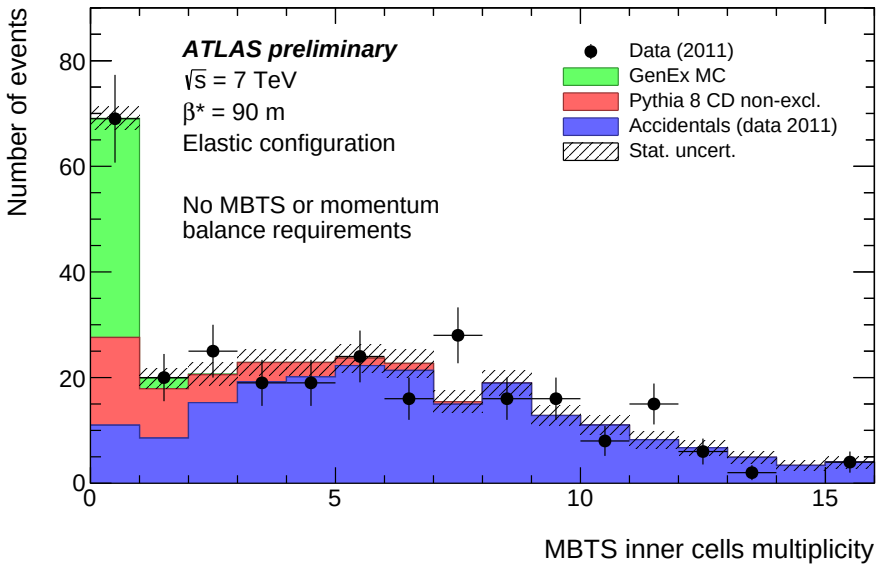
Non-trivial interplay of continuous and resonant production

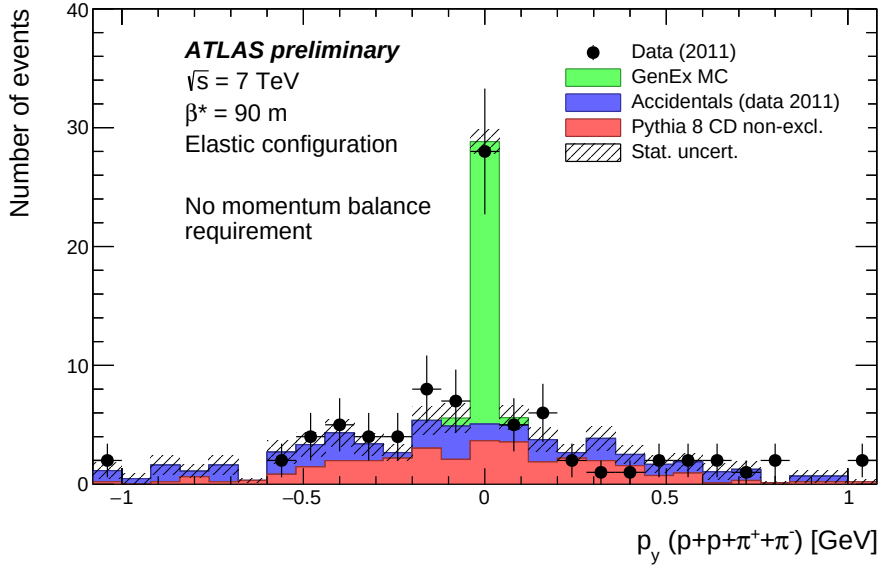
Plot and diagrams from
P. Lebiedowicz et al., Phys.Rev.D 93 (2016) 5, 054015.

Event selection

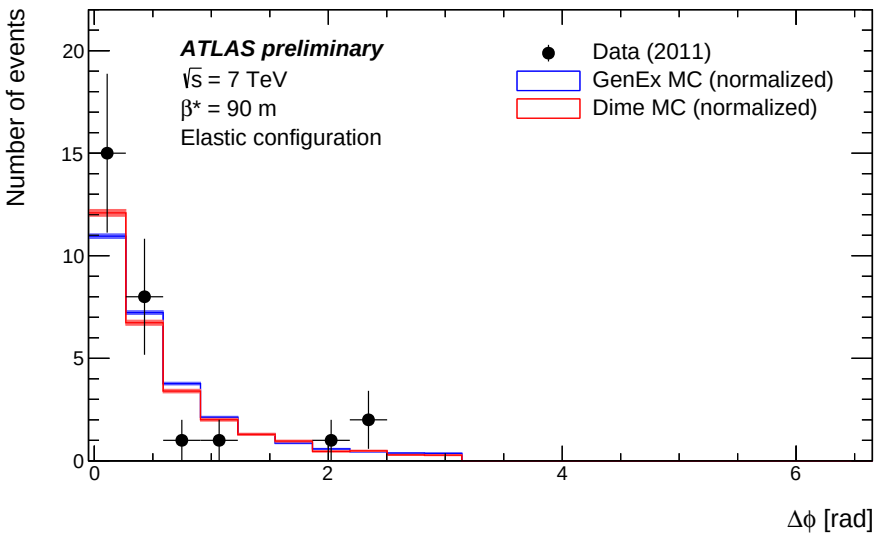
Selection of exclusive events:

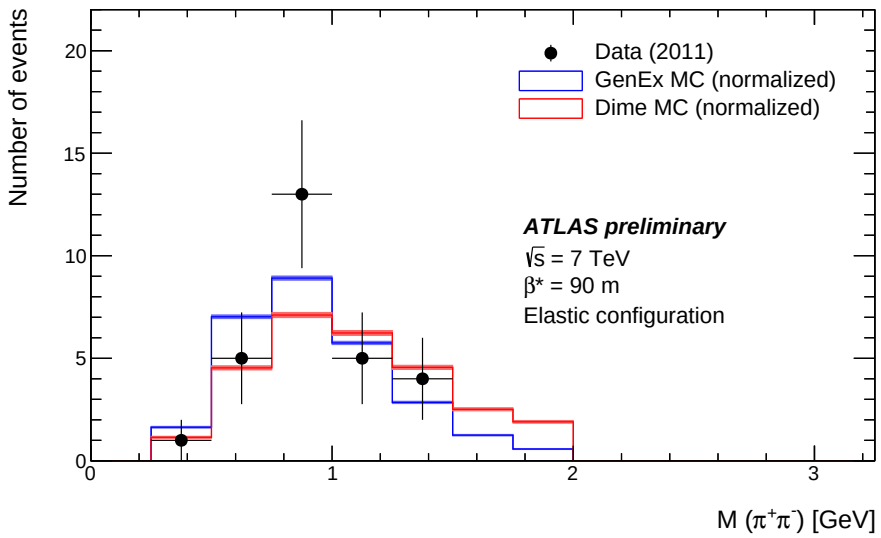
- forward protons detected in ALFA
- opposite-charged pions detected in the central ATLAS detector
- vetoing activity in Minimum Bias Trigger Scintillator (MBTS)
- exclusivity enforced by looking at p_T balance in the event





Results





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

– elastic *pp* configuration

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

– anti-elastic *pp* configuration

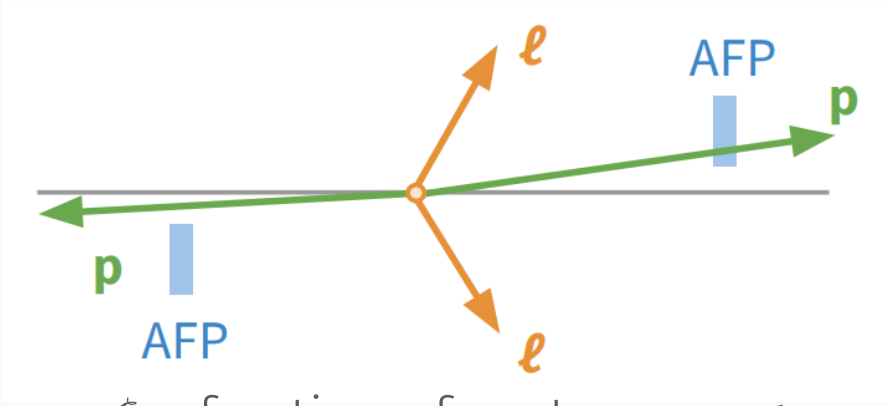
$$\sigma = 9 \pm 6(\text{stat}) \pm 1(\text{syst}) \pm 1(\text{lumi}) \pm 1(\text{model})\ \mu\text{b}$$

$\gamma\gamma \to ll$

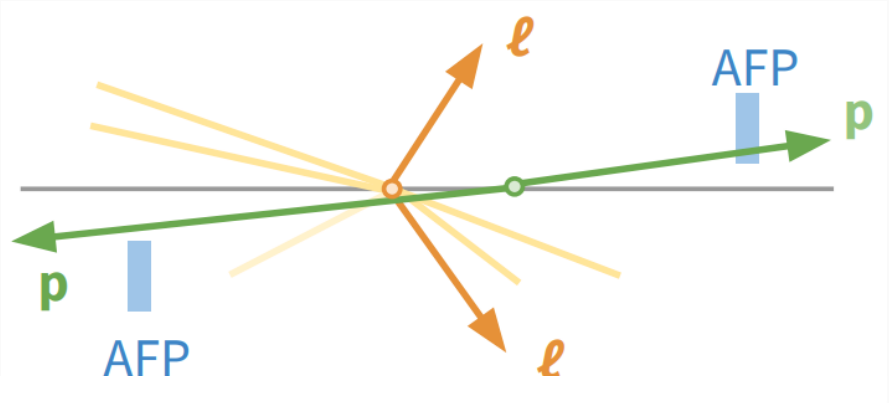
PRL 125 (2020) 261801

Analysis strategy

Signal:



Background:

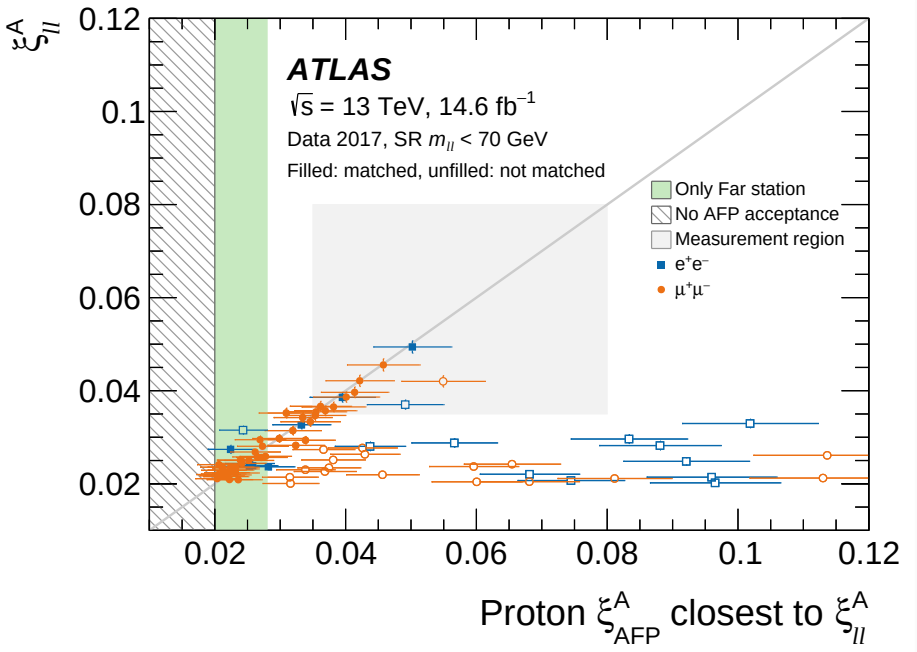


- ξ – fraction of proton energy carried by the photon
- ξ from proton measurement

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

- ξ from $l\bar{l}$ system

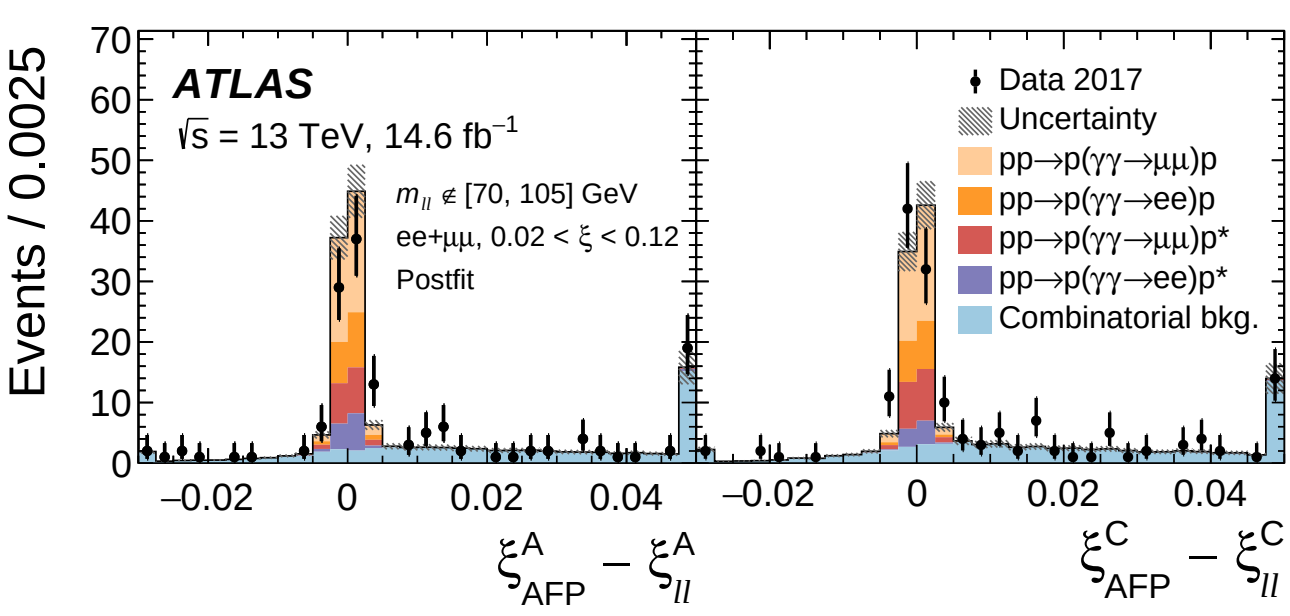
$$\xi_{\pm} = \frac{M_{l\bar{l}}}{\sqrt{s}} \cdot e^{\pm y_{l\bar{l}}}$$



First measurement of exclusive dileptons with proton tagging!

Demonstrating performance of proton tagging in standard LHC running.

Kinematic matching and measurements



	$\sigma^{\text{fid.}}_{ee+p}$ [fb]	$\sigma^{\text{fid.}}_{\mu\mu+p}$ [fb]
Measurement	$\mathbf{11.0 \pm 2.9}$	$\mathbf{7.2 \pm 1.8}$
SuperChic 4 predictions		
Exclusive + single-dissociative	$\mathbf{12.2 \pm 0.9}$	$\mathbf{10.4 \pm 0.7}$
Exclusive	8.6 ± 0.6	7.3 ± 0.5
Single-dissociative	3.6 ± 0.6	3.1 ± 0.5

Summary

Summary

Interesting diffractive and photon-induced physics done in ATLAS

Important role of proton detectors: ALFA and AFP

Two new important results:
elastic scattering at 13 TeV and exclusive $\pi^+\pi^-$