Overview of ATLAS forward proton detectors: status, performance and new physics results

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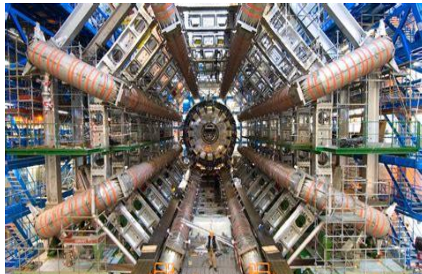
on behalf of ATLAS Forward Detectors

New Trends in High-Energy and Low-x Physics

3 September 2024

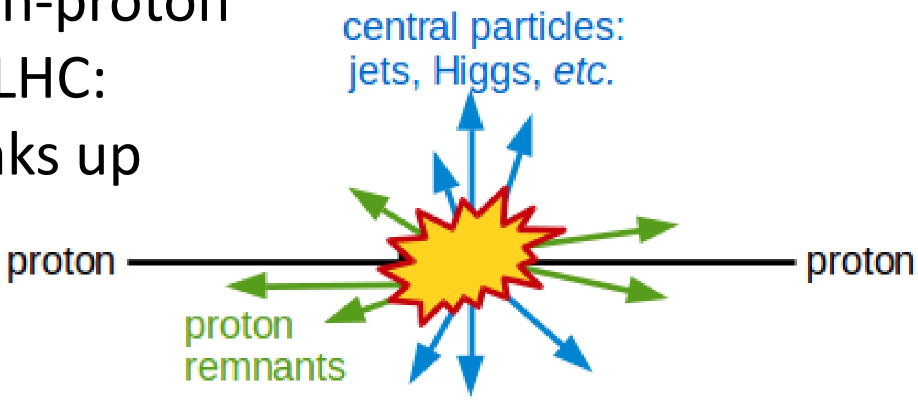


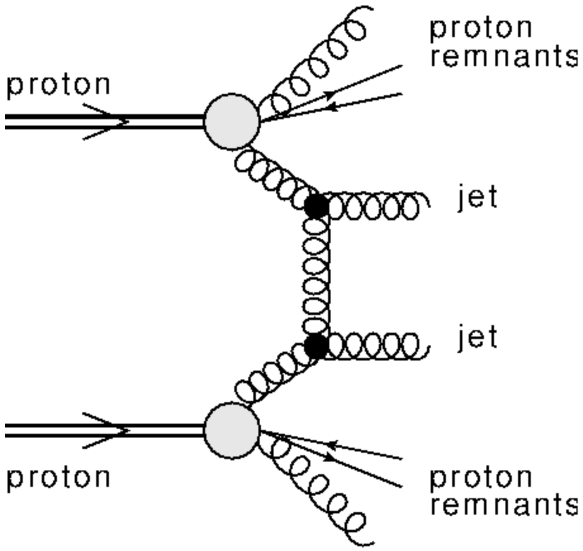
Outline

- Physics Motivation
- Absolute Luminosity For ATLAS (ALFA), 2011-2023 operation
- ATLAS Forward Proton Detectors (AFP), since 2016 (one-side), 2017 (double)
  - Silicon Tracker (SiT) and Time of Flight (ToF)
- Trigger
- Luminosity LHC Run-3
- Data quality, hit map, track map
- SiT correlation with central ATLAS Inner Detector tracker/Calorimeters
- Alignment
- ToF efficiency, vertex matching, performance
- Matching of proton energy loss with ATLAS central di-leptons/di-photons
- Conclusions
- Supplement: ToF resolution, New control system, Proton reconstruction

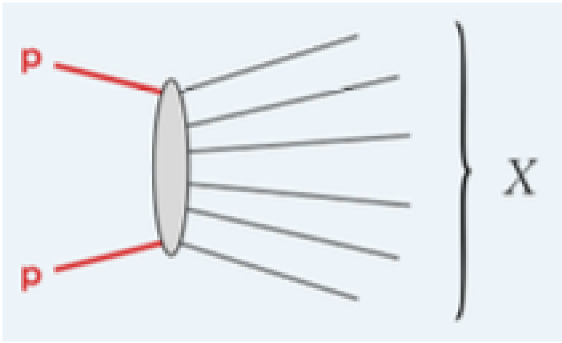
Collisions at LHC

- Usual proton-proton collision at LHC: proton breaks up



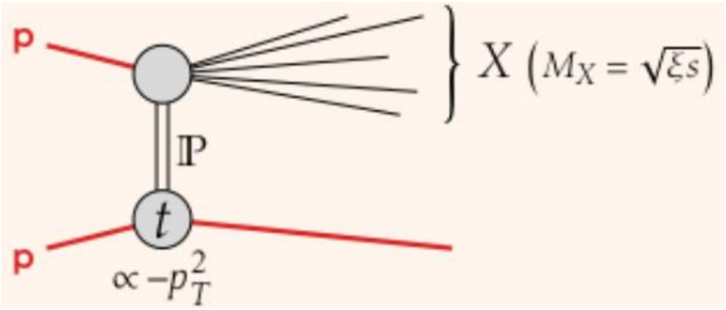


Non-diffractive

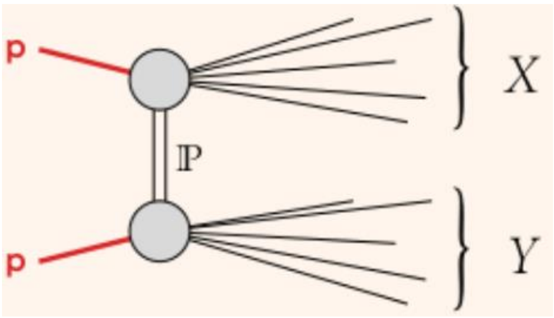


- Proton-proton interaction via photon (γ), electromagnetic force, or pomeron (P) exchange, strong force: proton can remain intact

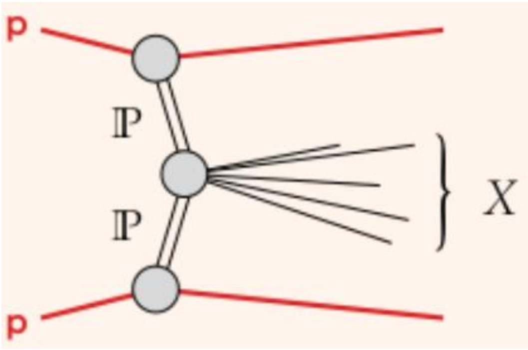
Single diffractive



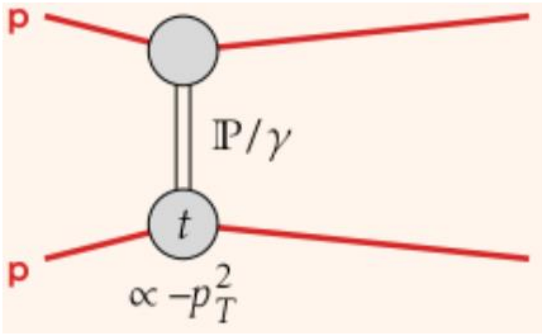
Double diffractive



Central diffractive

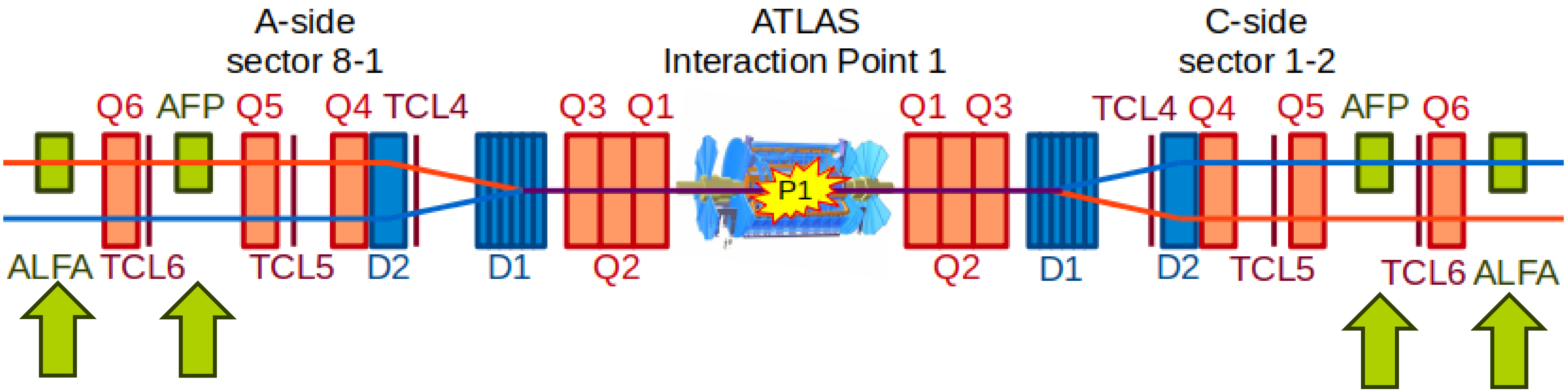


Elastic scattering

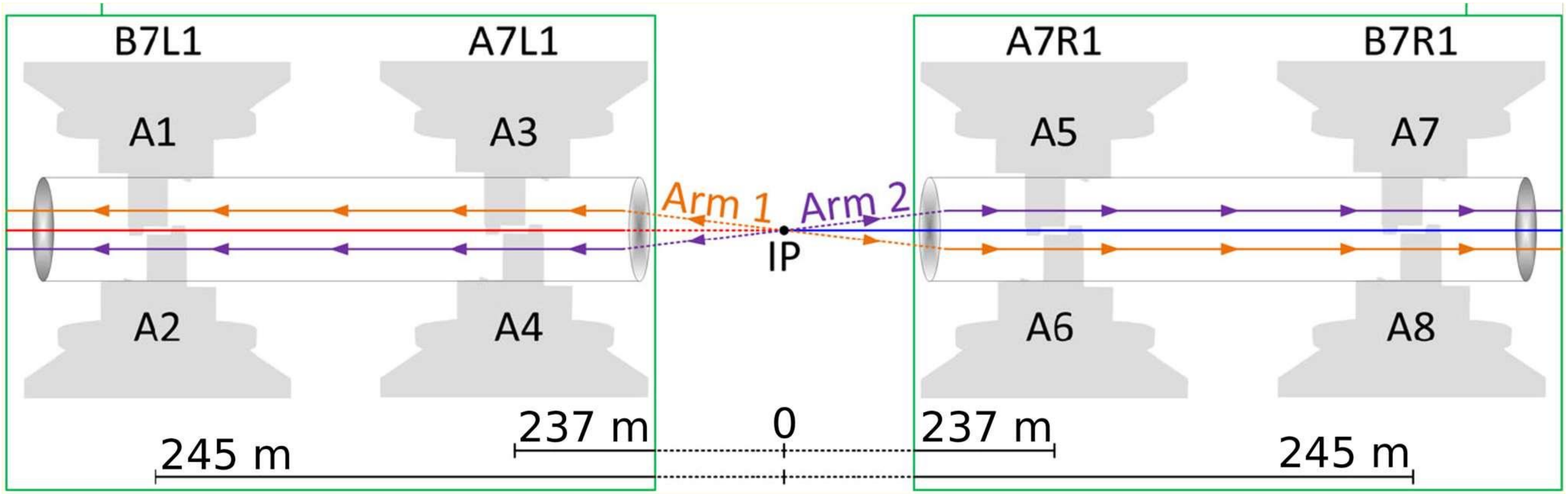


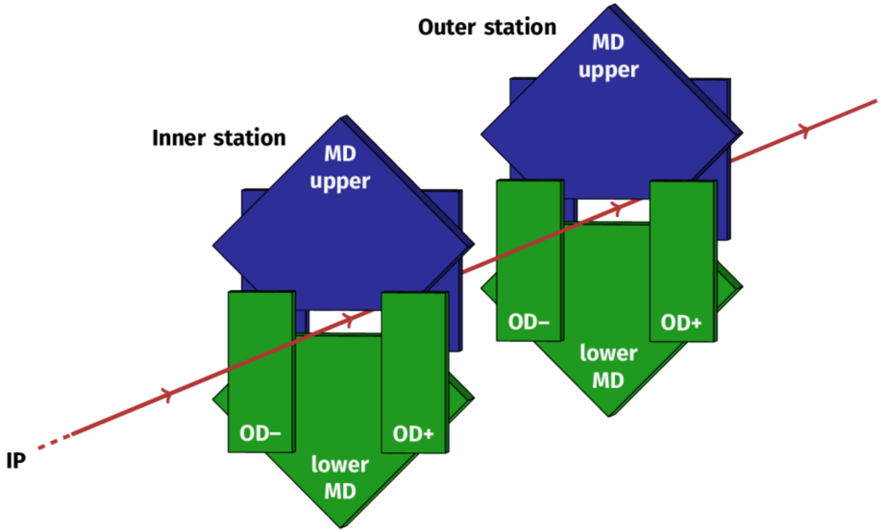
ATLAS Roman Pots

- Forward detectors - located in the LHC tunnel outside the ATLAS cavern
- Move close to the beam (1-3 mm) once “Stable Beams“ are declared
- Two detector systems
  - **Absolute Luminosity For ATLAS (ALFA)**, 237 m and 245 m ftom IP
  - **ATLAS Forward Proton (AFP)**, 205 m and 217 m from IP

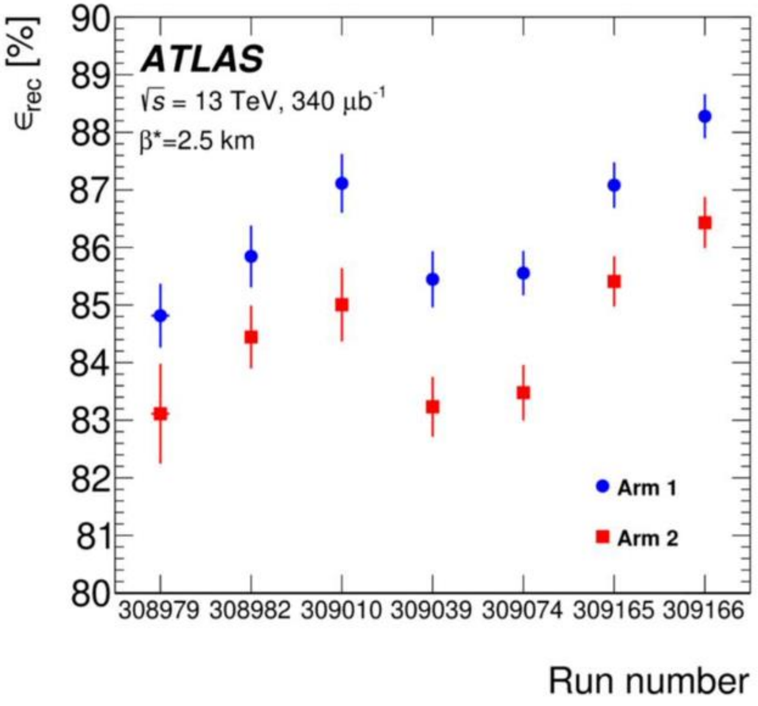


ALFA





- **Each station host two pots approaching the beam from top and bottom**
- **In each pot a set of 10 planes with 2x64 scinitillation fibres is mounted providing spatial resolution of 30 µm**
- **Trigger: presence of scattered protons**
- **Reconstruction efficiency: ~85%**
- **Tracking accuracy is dominated by the global vertical distance uncertainty (after alignment) of ±22 microns.**



ALFA Data-Taking

Year	β*	√s [TeV]	Comments
2011	90 m	7	elastics: NPB 889 (2014) excl. $\pi^+\pi^-$: EPJC 83 (2023) 627
2012	90 m	8	elastics: PLB 761 (2016) single diff.: JHEP 02 (2020) 042
2012	1 km	8	elastics dataset
2013	0.8 m	2.76	proton-lead dataset
2013	0.8 m	2.76	proton-proton reference dataset
2015	90	13	diffractive dataset
2016	2.5 km	13	elastics: EPJC 83 (2023) 441
2018	90 m	13	elastic (large *t*) and diff. datasets
2018	11 m	0.9	elastics (large *t*) dataset
2018	50/100m	0.9	elastics dataset
2023	3/6 km	13.6	elastics dataset

- ALFA running needed to measure pp→pp elastic cross sections down to low scattering angles θ. Outgoing protons at different θ were detected at different positions y at ALFA.
- ALFA did not run with high LHC luminosity because the detector is radiation-sensitive.
- Special beam conditions were required.

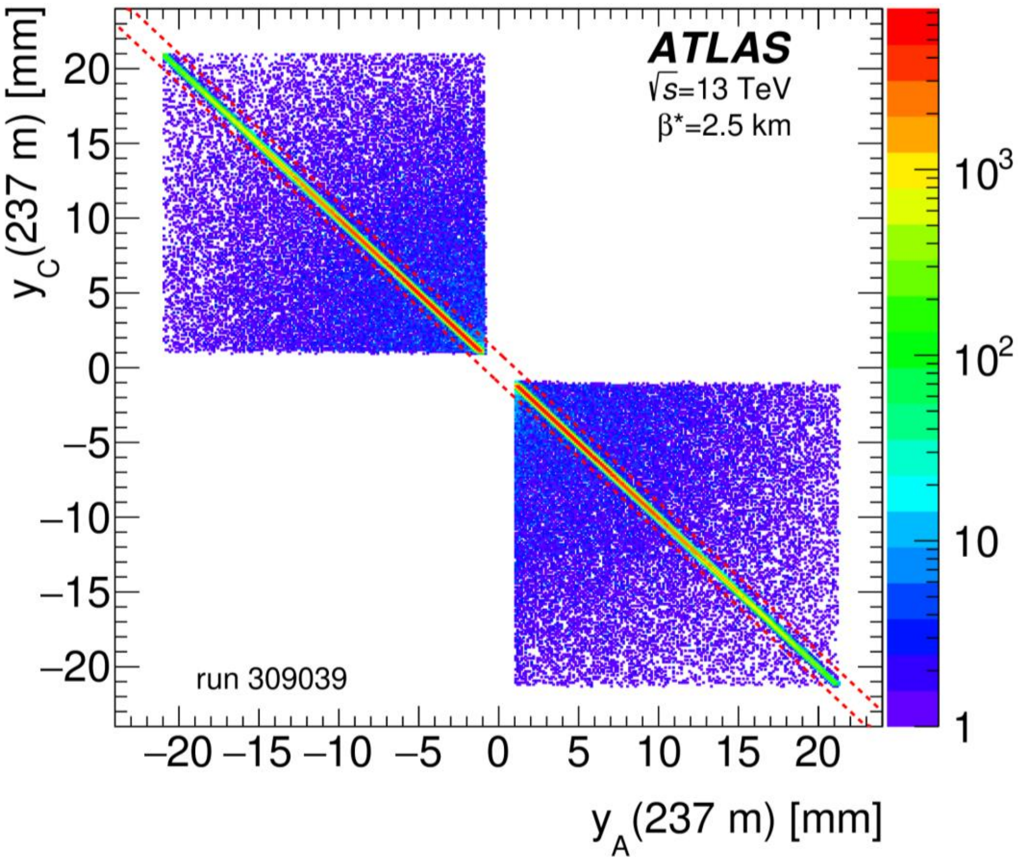
ALFA Results

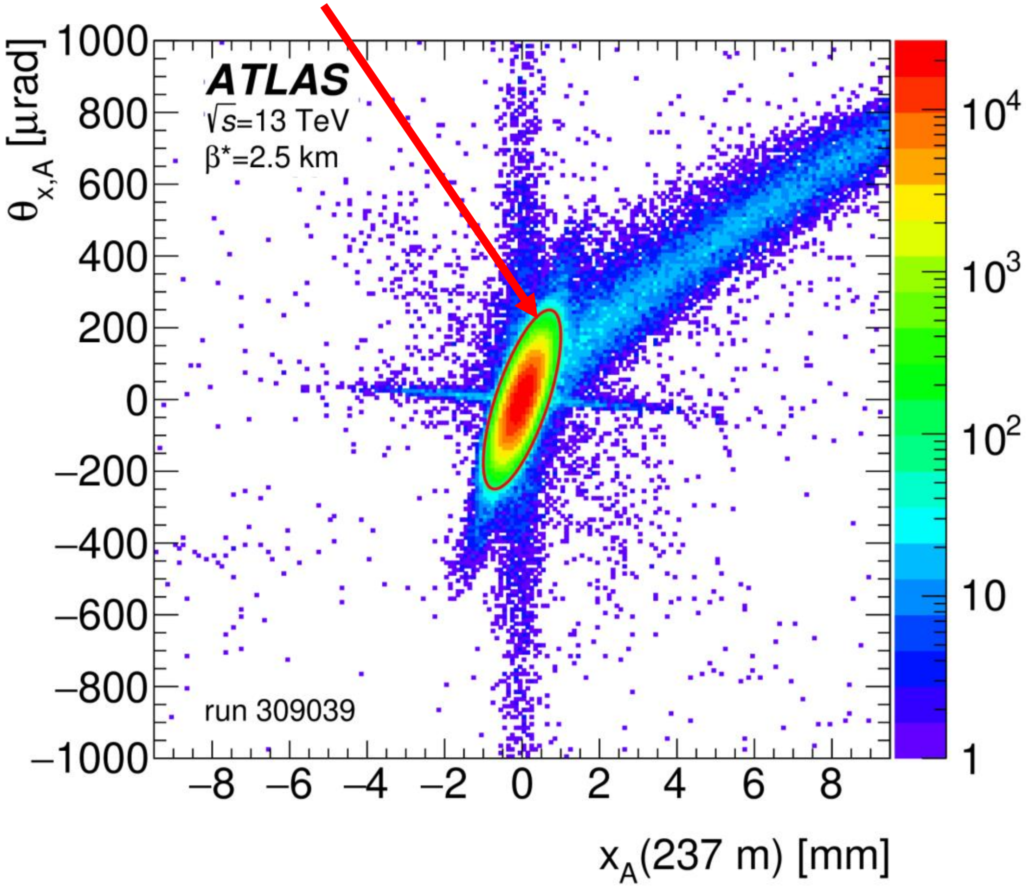
- Measurement of the total cross section from elastic scattering in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector, Nucl. Phys. B (2014) 486. σ_{tot} = 95.35 ± 1.36 mb
  One dedicated run at at β^* = 90 m, integrated luminosity 80 μb^{-1}
- Measurement of the total cross section from elastic scattering in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector, Phys. Lett. B 761 (2016) 158. σ_{tot} = 96.07 ± 0.92 mb
  One dedicated run at at β^* = 90 m, integrated luminosity 500 μb^{-1}
- Measurement of differential cross sections for single diffractive dissociation in $\sqrt{s}$ = 8 TeV pp collisions using the ATLAS ALFA spectrometer, JHEP 2020 (2020) 42.
  One dedicated run at at β^* = 90 m, integrated luminosity 500 μb^{-1}
- Measurement of the total cross-section and ρ-parameter from elastic scattering in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, Eur. Phys. J. C 83 (2023) 441.
  Seven dedicated runs at β^* = 2500 m, total integrated luminosity 340 μb^{-1}
- Measurement of exclusive pion pair production in proton–proton collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector. Eur. Phys. J. C 83 (2023) 627.
  One dedicated run at at β^* = 90 m, integrated luminosity 80 μb^{-1}.

Measurement of the total cross-section and ρ-parameter from elastic scattering in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, Eur. Phys. J. C 83 (2023) 441

Selection of elastic pp events in ALFA

- Quality cuts on the two proton tracks in the two ALFA stations
- Geometric acceptance cuts: Select back-to-back events, as indicated.
- Selection on x vs θ_x: Elastic events are within the ellipse.

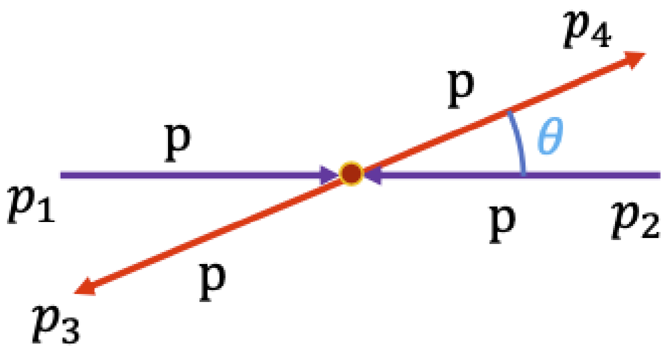


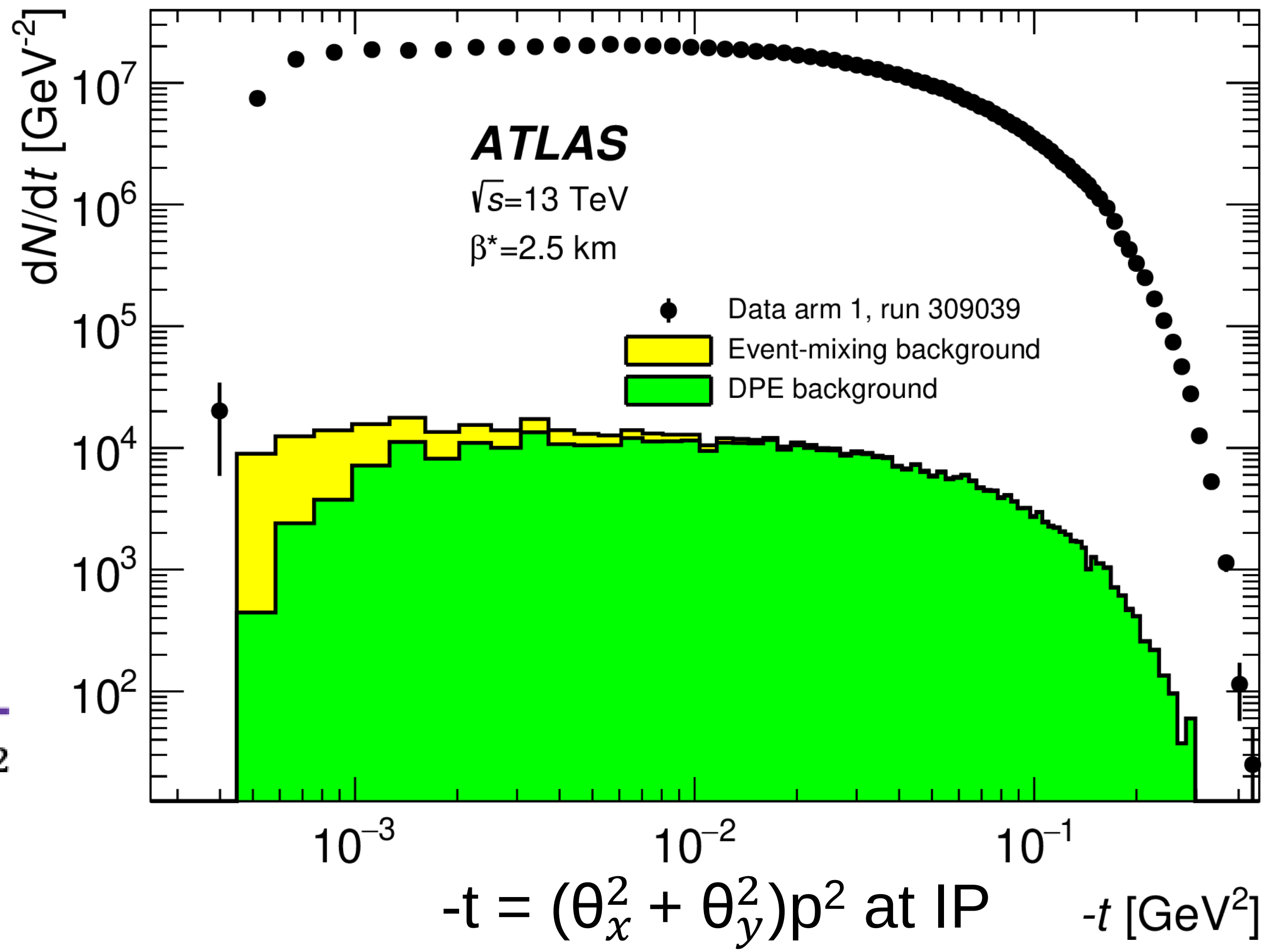


Background levels, Eur. Phys. J. C 83 (2023) 441

Sources of background:

- accidental halo+halo and halo+SD coincidences (data-driven, determined with an event-mixing method)
- central diffraction (MC simulation), double-Pomeron exchange (DPE), pp → pp + X





$-t = (\theta_x^2 + \theta_y^2)p^2$ at IP

Mandelstam variables, invariants

$s = (p_1 + p_2)^2$

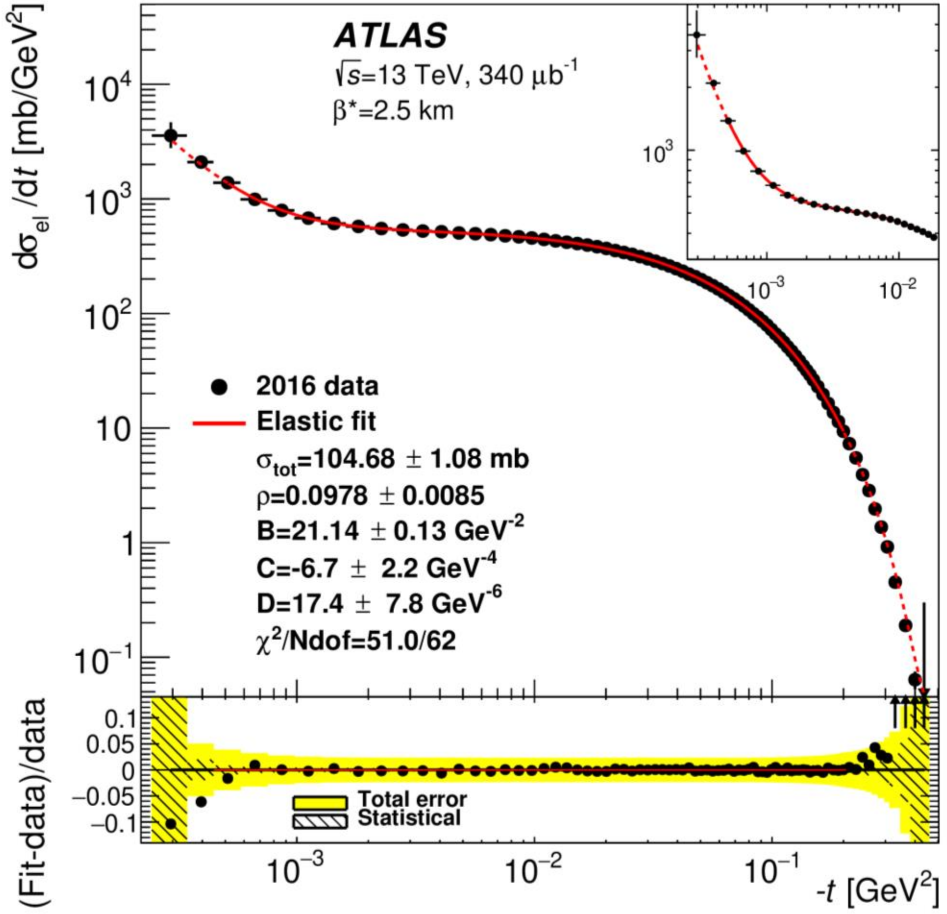
$t = (p_1 - p_4)^2 \cong -(p_0\theta)^2, |\vec{p_1}| = |\vec{p_2}| = |\vec{p_4}| = p_0$

Reconstruct t from beam optics and event kinematics using tracking of effective beam optics.

Evaluation of results, Eur. Phys. J. C 83 (2023) 441

$$\frac{d\sigma}{dt_i} = \frac{1}{\Delta t_i} \times \frac{\mathcal{M}^{-1}[N_i - B_i]}{A_i \times \epsilon_{\rm rec} \times \epsilon_{\rm trig} \times \epsilon_{\rm DAQ} \times L_{\rm int}}$$

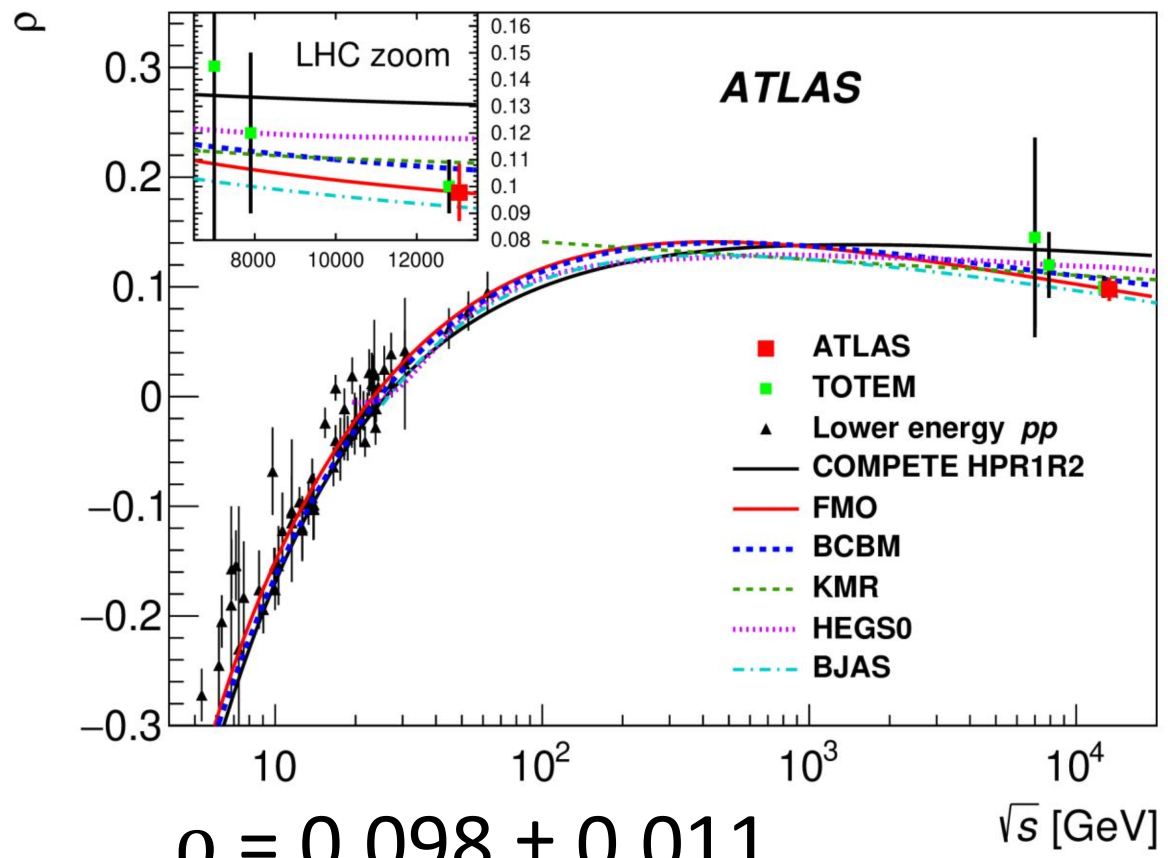
Δt_i is the bin width,
M^{-1} represents the unfolding procedure applied to the background-subtracted number of events $N_i - B_i$,
A_i is the acceptance,
ϵ_{rec} is the event reconstruction efficiency,
ϵ_{trig} is the trigger efficiency,
ϵ_{DAQ} is the dead-time correction and
L_{int} is the integrated luminosity used.
Fit: full BCD-model with validity up to $-t$ = 0.2 GeV^2

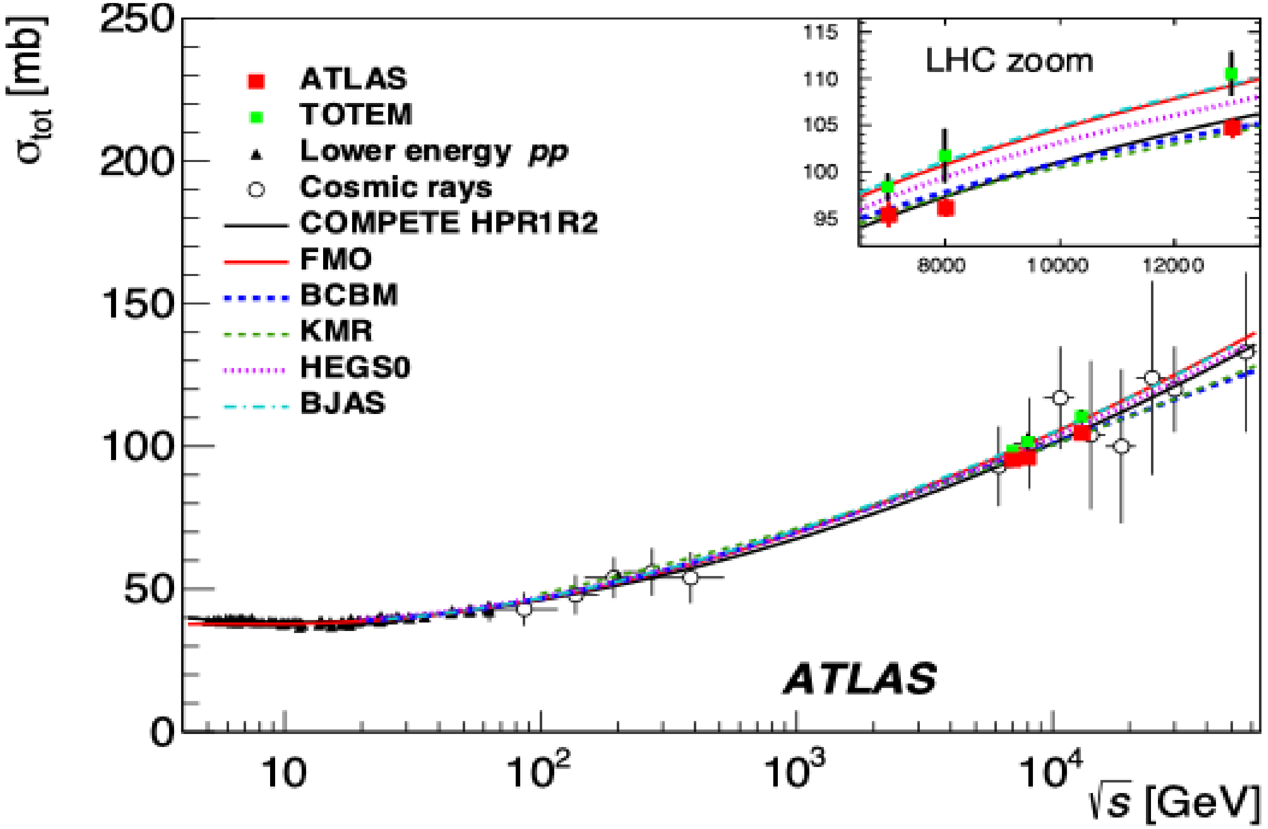


$$\begin{aligned}\frac{d\sigma}{dt} &= \frac{4\pi\alpha^2(\hbar c)^2}{|t|^2} \times G^4(t) \\ &- \sigma_{\rm tot} \times \frac{\alpha G^2(t)}{|t|}\left[\sin(\alpha\phi(t)) + \rho\cos(\alpha\phi(t))\right] \times e^{\frac{-B|t|-Ct^2-D|t|^3}{2}} \\ &+ \sigma_{\rm tot}^2 \frac{1+\rho^2}{16\pi(\hbar c)^2} \times e^{(-B|t|-Ct^2-D|t|^3)},\end{aligned}$$

Inelastic, elastic and total cross-section, Eur. Phys. J. C 83 (2023) 441

Elastic scattering is a low-p_T process, and a perturbative expansion cannot be applied. Therefore, σ_{tot} and the ρ-parameter cannot be calculated from first principles in QCD.



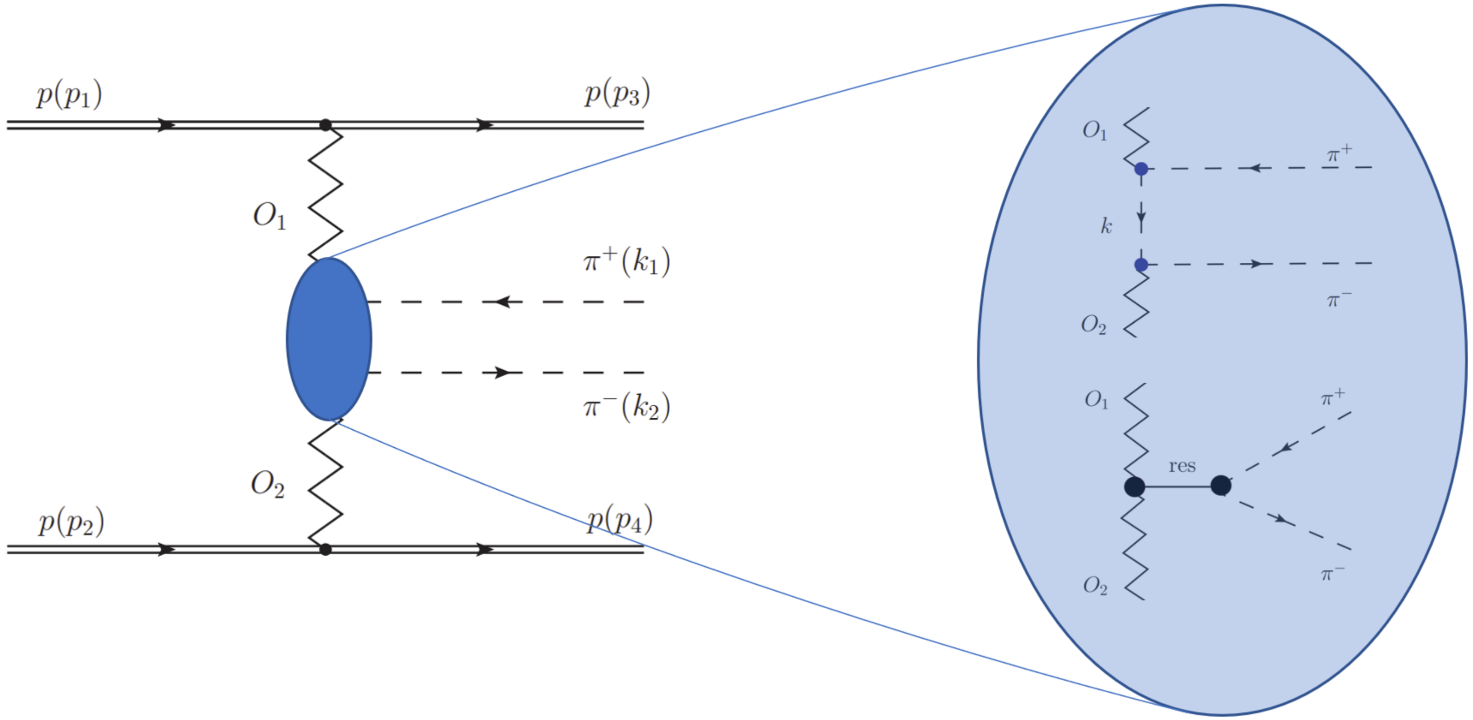


$\rho = 0.098 \pm 0.011$

(ρ-parameter defined as the ratio of the real part to the imaginary part of the elastic-scattering amplitude in the limit $t \to 0$)

$\sigma_{tot}(pp \to X) =$
104.68 ± 1.08 (exp.) ± 0.12 (th.) mb

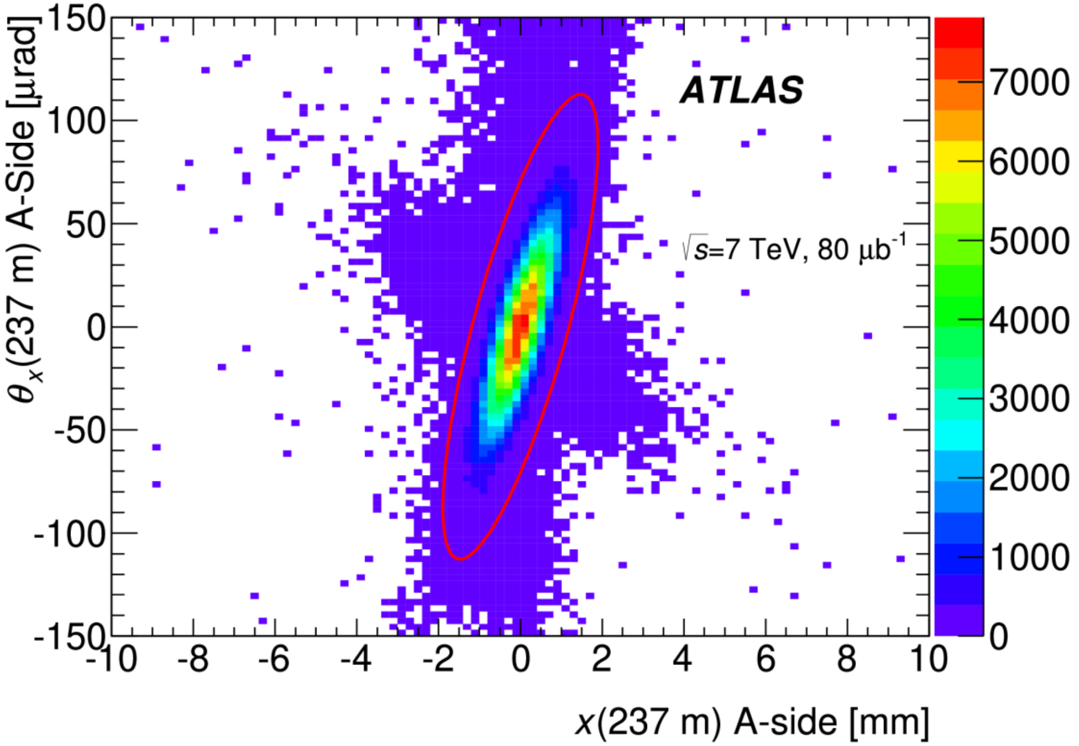
Measurement of exclusive pion pair production in proton-proton collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector, Eur. Phys. J. C 83 (2023) 627.

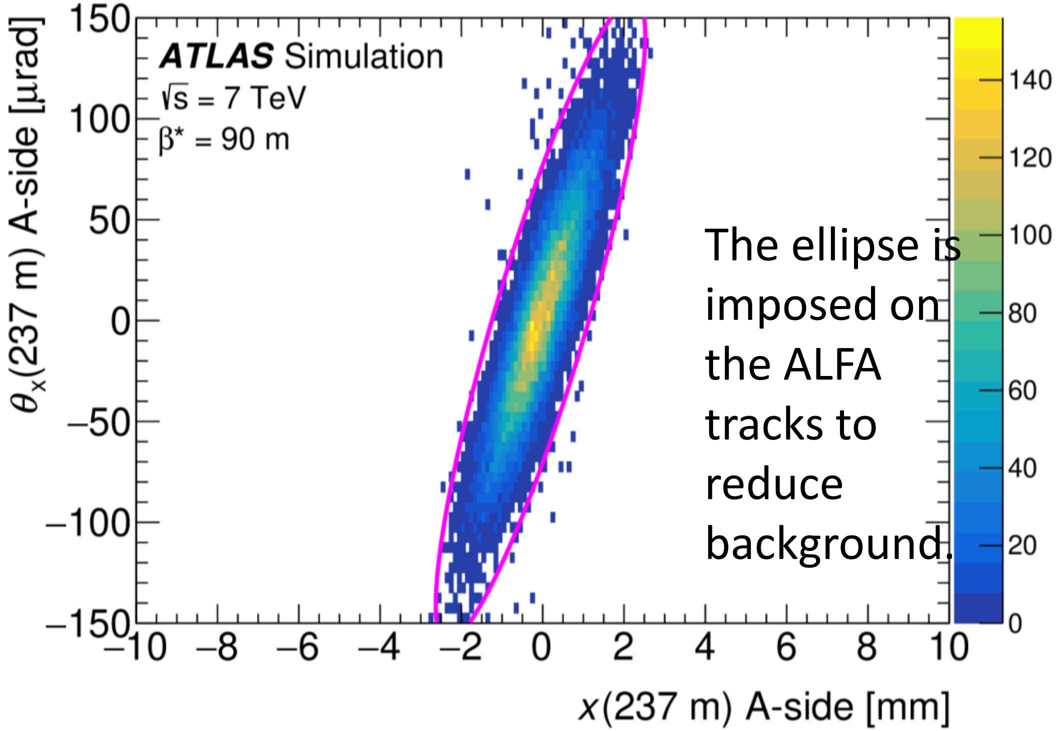


- **Trigger:** Elastic - ALFA coincidence of detectors in an elastic combination. Anti-elastic – signal in any ALFA detector, prescaled by 15
- **In ALFA detectors:** One good quality track on each side
- **In ATLAS Inner Detector:** Two oppositely charged tracks, taken as pions, $|\eta(\pi)| < 2.5$, $p_T(\pi) > 0.1$ GeV and quality requirements on the pion tracks

Further requirements, Eur. Phys. J. C 83 (2023) 627

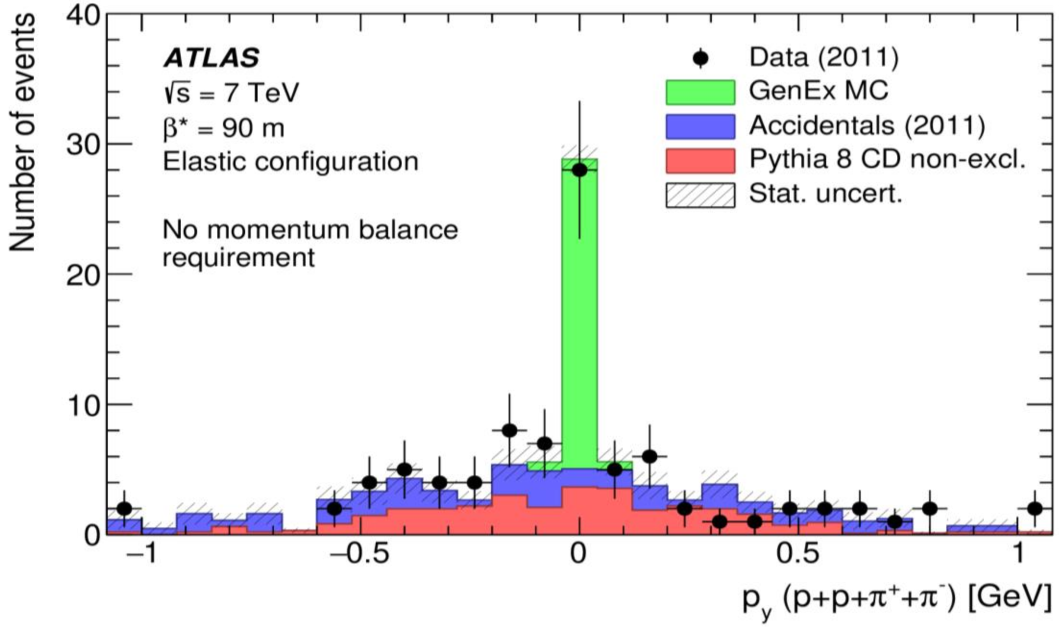
- **MBTS veto:** At most one hit in the combined inner MBTS scintillators (at z = ±3.6m, 2.1 < |η| < 3.8 , to remove diffractive-dissociative and non-diffractive events.
- **Overall momentum balance:** $pp\pi^+\pi^-$ momentum balance in x and in y consistent with zero (±3.5σ)
- **Track condition:** Track must have sufficient hits in MD layers, with limit on number of multiple hits in a layer

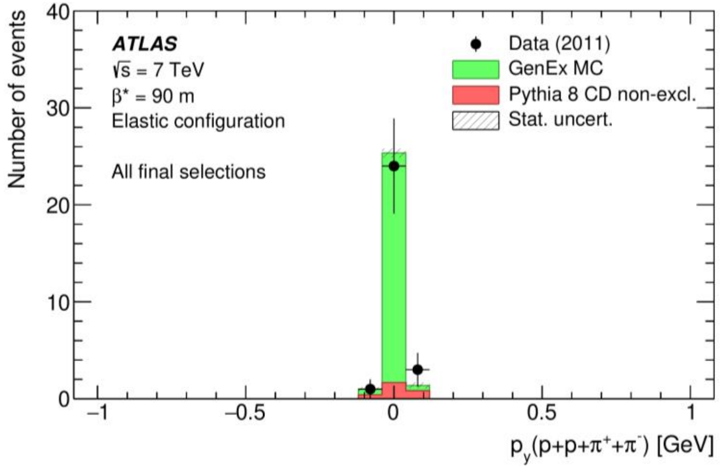




The ellipse is imposed on the ALFA tracks to reduce background.

Results, Eur. Phys. J. C 83 (2023) 627





- The cuts are very effective at removing background
- A cut on the MBTS counts was essential.
- Low statistics from this short run in 2011 at 7 TeV (4 hours at high β*, μ = 0.035).
- Feasibility of the measurement has been demonstrated.

Source of uncertainty	Uncertainty [%] elastic	Uncertainty [%] anti-elastic
Trigger efficiency ϵ_{trig}	±0.1	±0.3
Background determination	±3.5	±3.5
Signal and background corrections:		
Beam energy	±0.1	±0.1
ID material	+4.8	+4.1
Veto on MBTS signal	±1.3	±2.0
ALFA single-track selection	±0.9	±0.9
ALFA reconstruction efficiency	±0.9	±0.8
ALFA geometry selection	±0.5	±0.5
Optics	±1.1	±1.0
Overall systematic uncertainty	+6.4 −4.2	+6.0 −4.4
Statistical uncertainty	±21.2	±61.6
Theoretical modelling	±2.8	±8.0
Luminosity	±1.2	±1.2

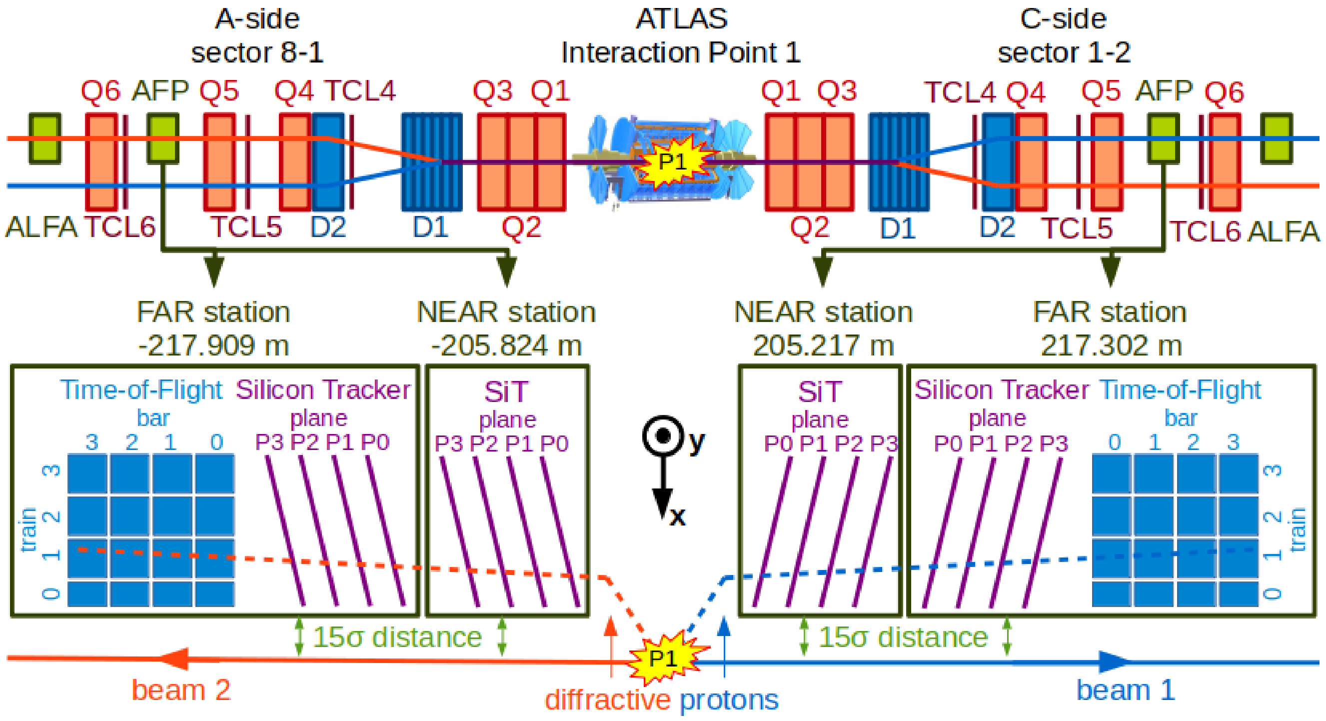
ALFA outlook

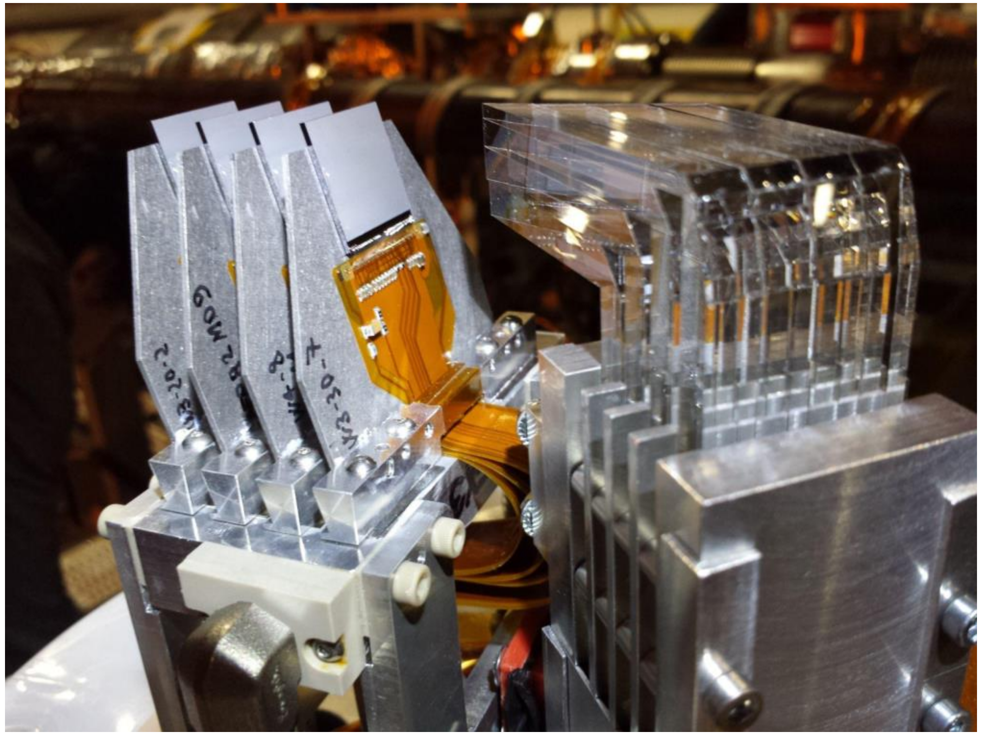
Future data analyses:

- Final run with ALFA completed in LHC Run-3 (2023) using $\beta^* = 3/6$ km. Improved ρ measurement for total cross section and parameters of elastic pp scattering.
- Exclusive pion pair analysis using Run-2 dataset:
  - resonance analysis
  - possible glueball search
  - possible search for other exclusive final states
- Data at 900 GeV (2018) $\beta^* = 50/100$ m for total cross section and ρ
- High-luminosity 0.5 nb^{-1} at 13 TeV, $\beta^* = 90$ m for study of dip/bump in t distribution.

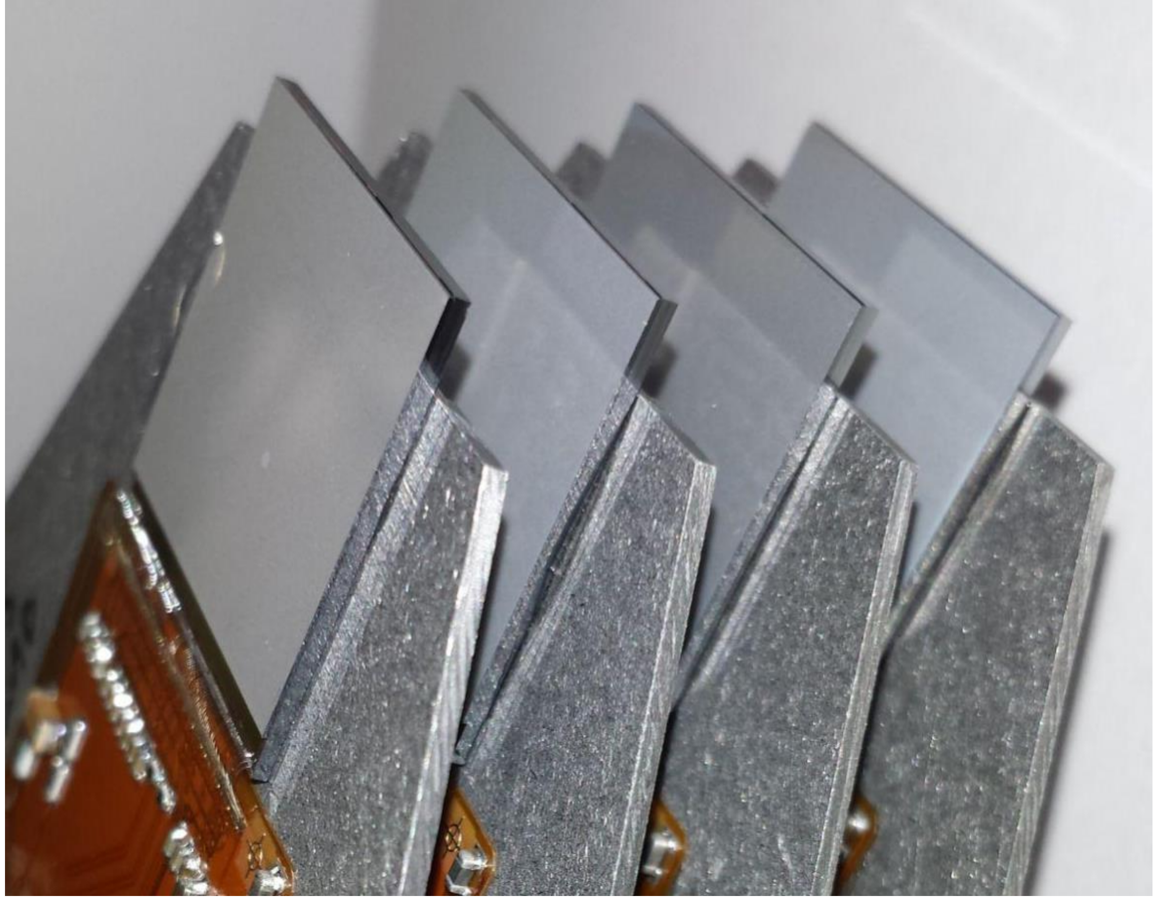
ATLAS Forward Proton (AFP) detector

- Two stations on each side of ATLAS
- All stations host Silicon Tracker (SiT)
- Far stations host also Time-of-Flight (ToF) detector





Silicon Tracker (SiT)

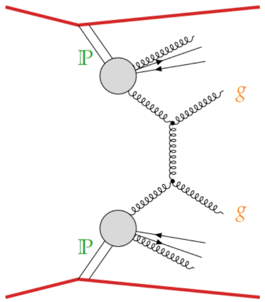


- Position measurement of scattered protons
  - Reconstruction of its kinematics
- 4 silicon pixel sensors
  - Spaced 9 mm apart
  - Each sensor 336x80 pixels
  - Pixel size 50x250 μm^2
  - Sensor size 16.8x20 mm^2
- Read out by FE-I4B chips
  - Same as ATLAS Pixel IBL
- 14° angle wrt. beam axis
  - To improve reconstruction resolution
    - ~6 μm in x and ~30 μm in y

Physics Motivation

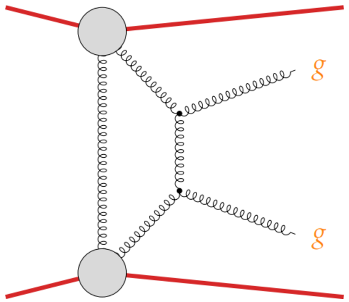
- Detection of events containing scattered intact protons
- Focused on low-cross section processes with high p_T objects

Diffractive jets



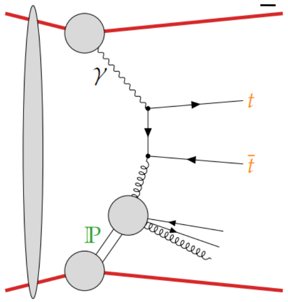
ATL-PHYS-PUB-2017-012

Exclusive jets



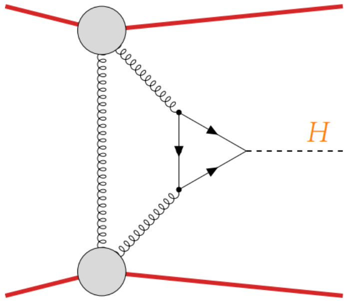
Trzebinski et al 1503.00699
Harland-Lang et al 1405.0018

Diffractive $t\bar{t}$



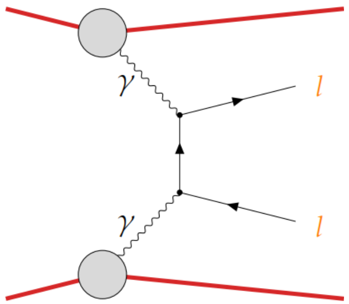
Goncalves et al 2007.04565
Howarth 2008.04249

Exclusive Higgs



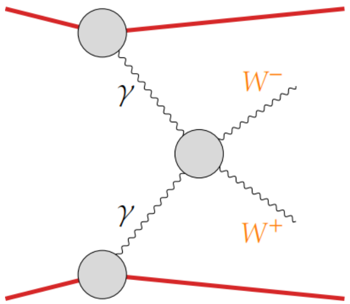
Cox et al 0709.3035
Heinemeyer et al 0708.3052

Exclusive Leptons



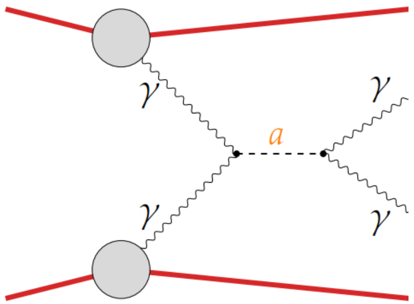
CMS 1803.04496
ATLAS 2009.14537

Exclusive W



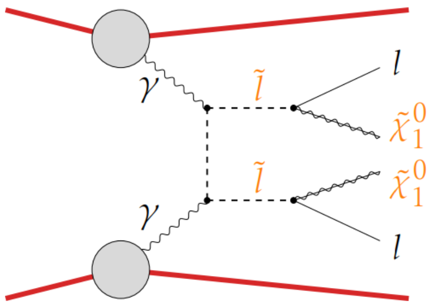
Tizchang, Etesami 2004.12203
Baldenegro et al 2009.08331

Axion-like particles



Harland-Lang & Tasevsky 2208.10526
ATLAS 2304.10953

SUSY dark matter



Beresford & Liu 1811.06465
Tasevsky et al 1812.04886

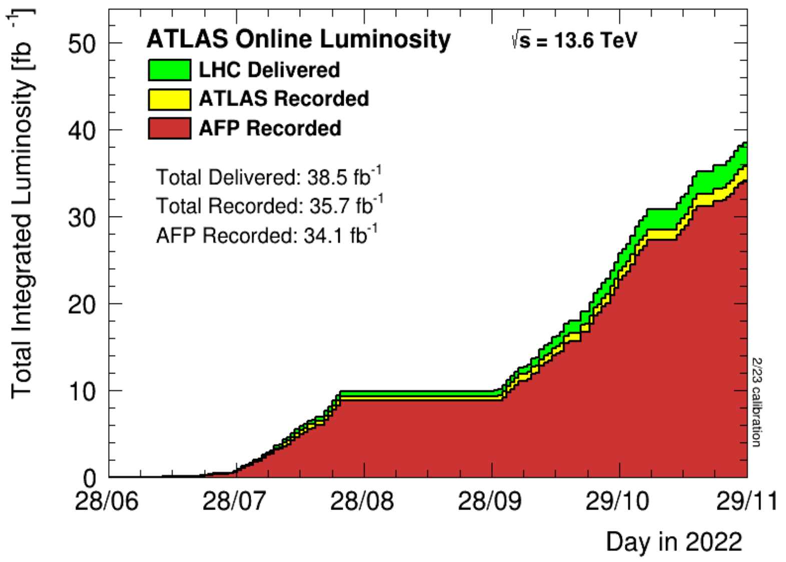
LHC Run-3 data-taking

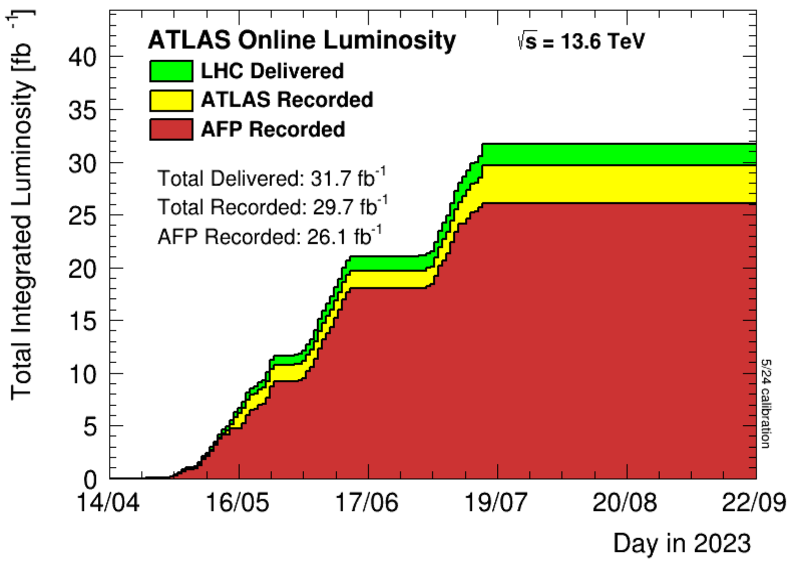
Total in LHC Run-3 so far:
AFP recorded: 84.4 fb^{-1}
89.7% wrt ATLAS recorded
83.8% wrt LHC delivered

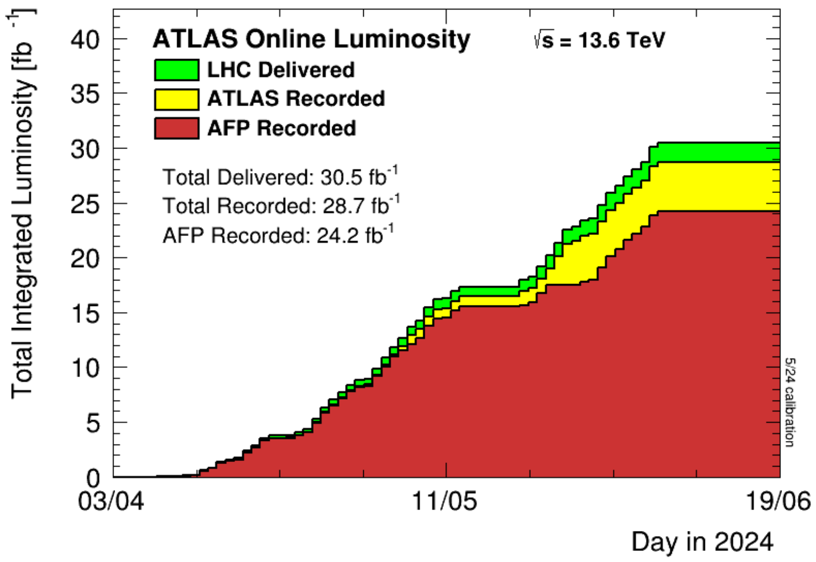
2022 at √s = 13.6 TeV
AFP recorded: 34.1 fb^{-1}
95.5% wrt. ATLAS recorded
88.6% wrt. LHC delivered

2023 at √s = 13.6 TeV
Recorded: 26.1 fb^{-1}
87.9% wrt. ATLAS recorded
82.3% wrt. LHC delivered

First half of 2024 at √s = 13.6 TeV
Recorded: 24.2 fb^{-1}
84.3% wrt. ATLAS recorded
79.3% wrt. LHC delivered







https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun3

Data Quality results

Fraction of good luminosity after Data Quality wrt. ATLAS:

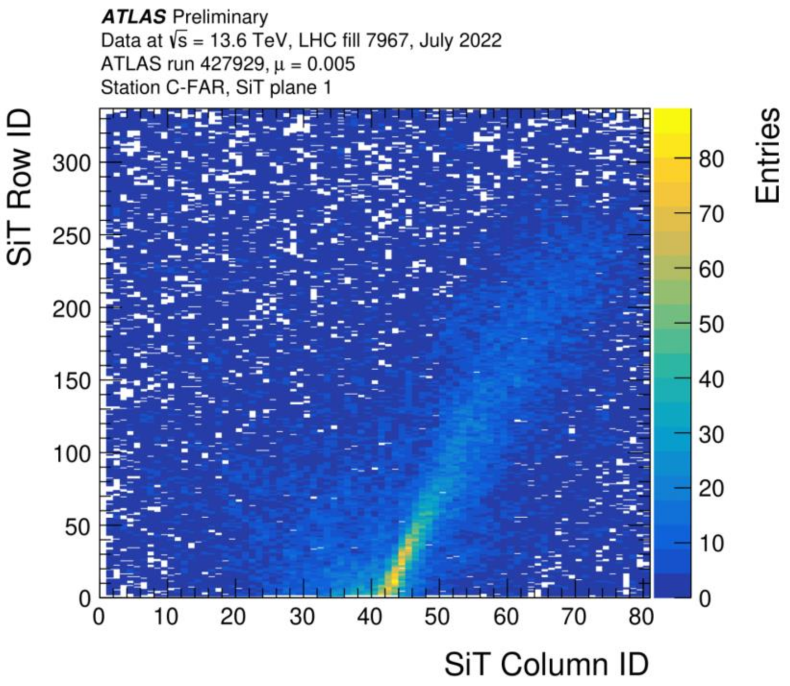
	2022*	2023** preliminary
All of AFP	83.4 %	76.4 %
Silicon Tracker only	92.5 %	81.4 %
A side Silicon Tracker only	96.8 %	84.5 %
C side Silicon Tracker only	93.7 %	82.1 %
Time-of-Flight only	83.6 %	77.7 %

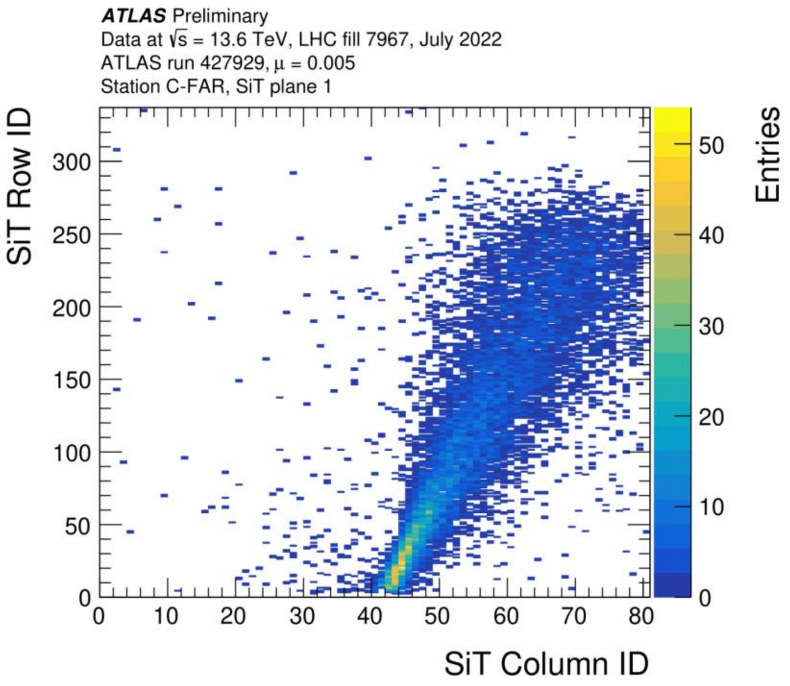
*based on Good Run List for analyses relying on jet, met or b-jet triggers (data22_13p6TeV.periodAllYear_DetStatus-v109-pro28-04_MERGED_PHYS_StandardGRL_All_Good_25ns)

**based on Good Run List for analyses relying on jet triggers at L1 or HLT (data23_13p6TeV.periodAllYear_DetStatus-v110-pro31-06_MERGED_PHYS_StandardGRL_All_Good_25ns)

SiT Hit Map

- First 1.5 M events of run 427929 (LBs 200-206)
- Top: Raw distribution of hits in a single SiT plane
- Bottom: Effect of signal cleaning
  - Single track reconstructed per station
  - Single cluster reconstructed per plane
  - Only 1 or 2 hits recorded per plane
- “Diffractive pattern”
  - Caused by settings of LHC magnet between ATLAS interaction point and AFP detectors

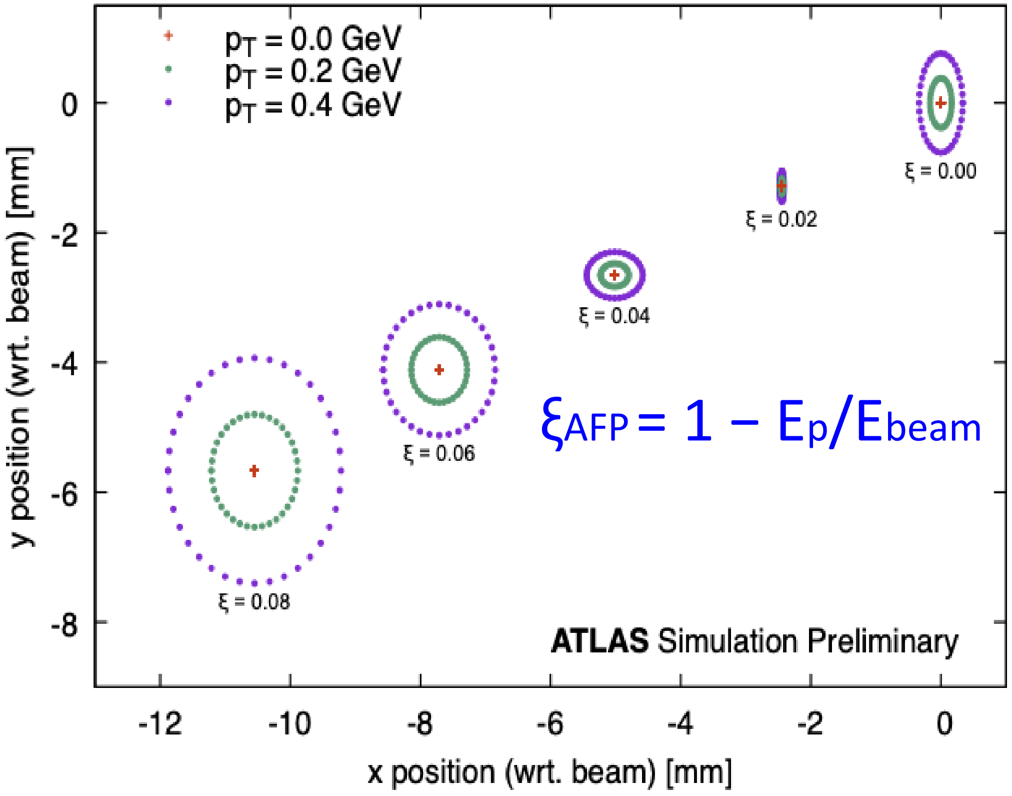




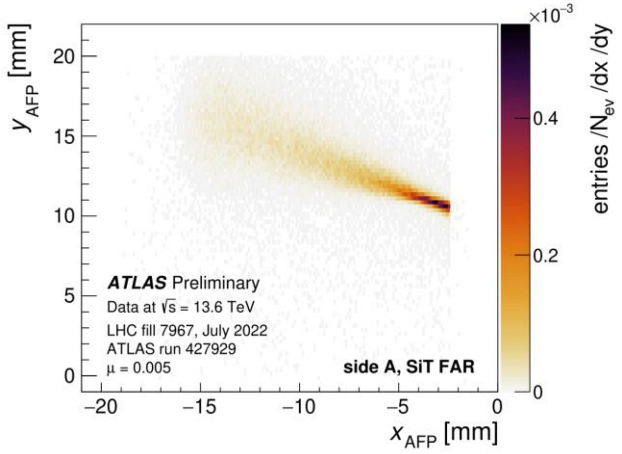
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ForwardDetPublicResults

SiT Track Map

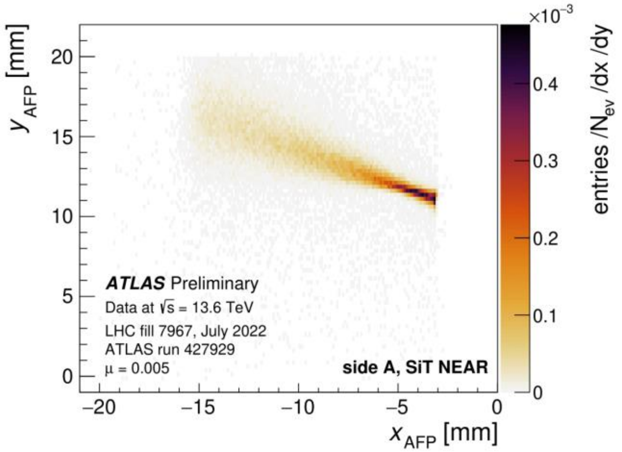
- Distribution of reconstructed tracks
- Center of beam pipe at (0, 10 mm)
- Selection:
  - Events triggered by Minimum-Bias Trigger Scintillators (MBTS)
  - Reconstructed primary vertex
  - Single track in each station on a given side
- Expected relation of scattered proton's x-position in SiT to energy lost ξ_{AFP} in the interaction due to LHC magnetic field



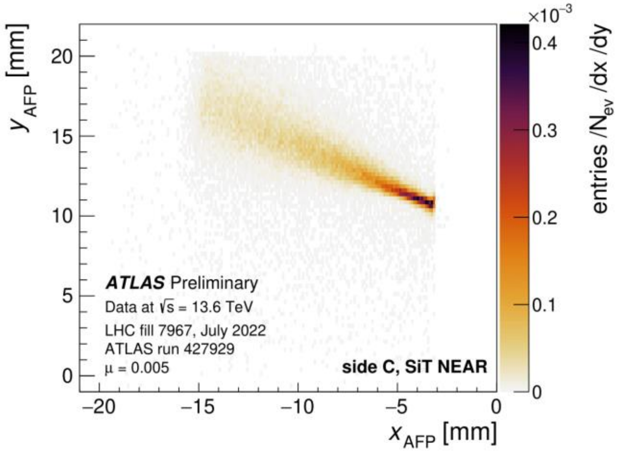
Side A, Far



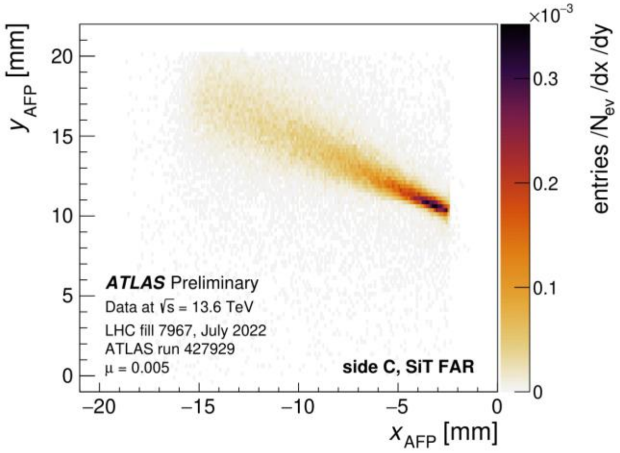
Side A, Near



Side C Near



Side C, Far

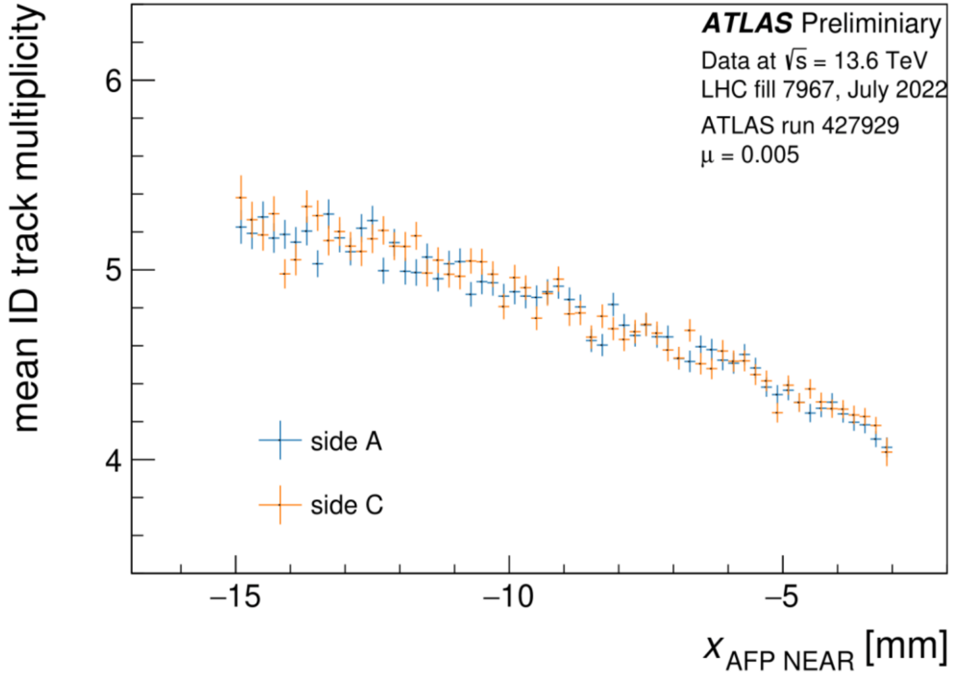


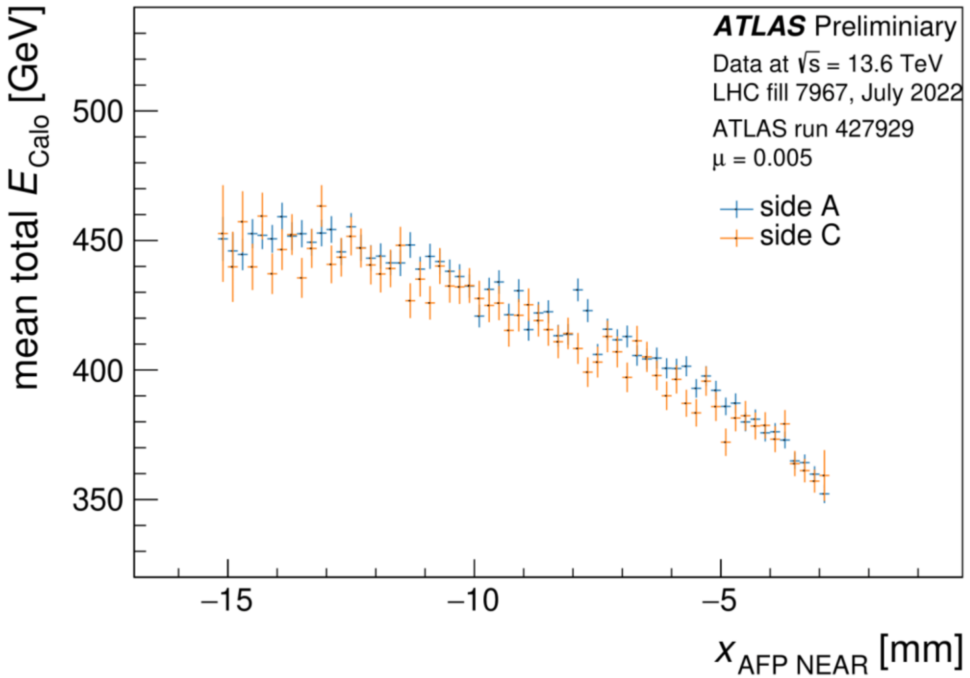
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ForwardDetPublicResults

Correlation to ATLAS central

- Correlation of track x-position to charged track multiplicity of the Inner Detector (ID)
- Selection:
  - Single AFP track in each station on given side
  - ID track $p_T > 500$ MeV
  - ID track $|\eta| < 2.5$
  - Reconstructed primary vertex

- Correlation of track x-position to total energy measured by ATLAS Calorimeters
- Selection:
  - Only one AFP track in each station on given side
  - Reconstructed primary vertex

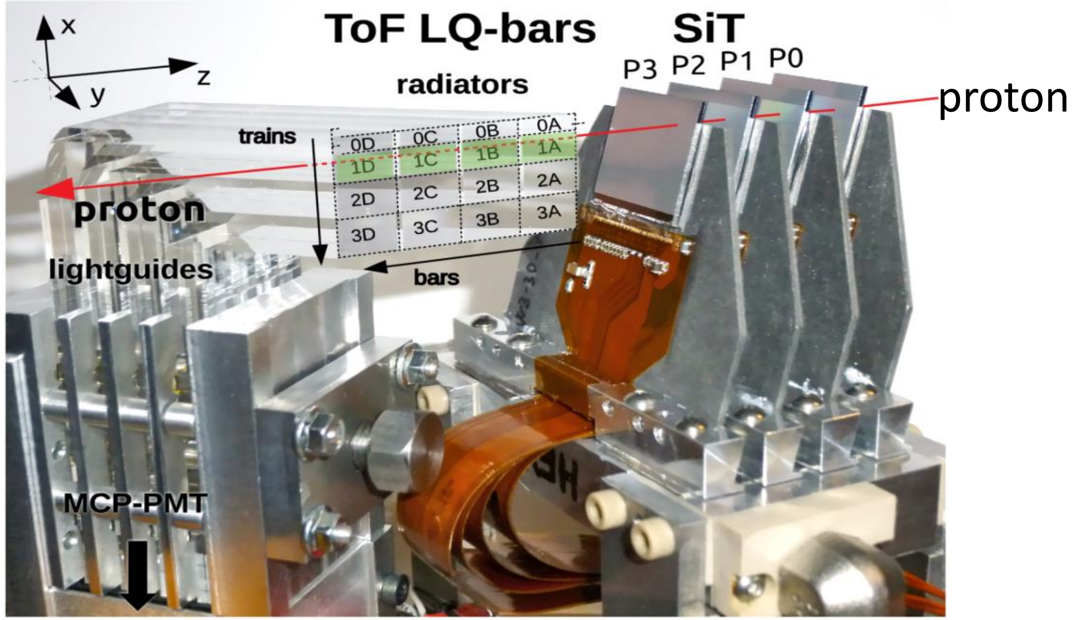




https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ForwardDetPublicResults

ToF-SiT alignment

- Correlation of SiT track x-position to ToF train signal
- Selection:
  - Single SiT track in the station
  - Single ToF train signal in the station



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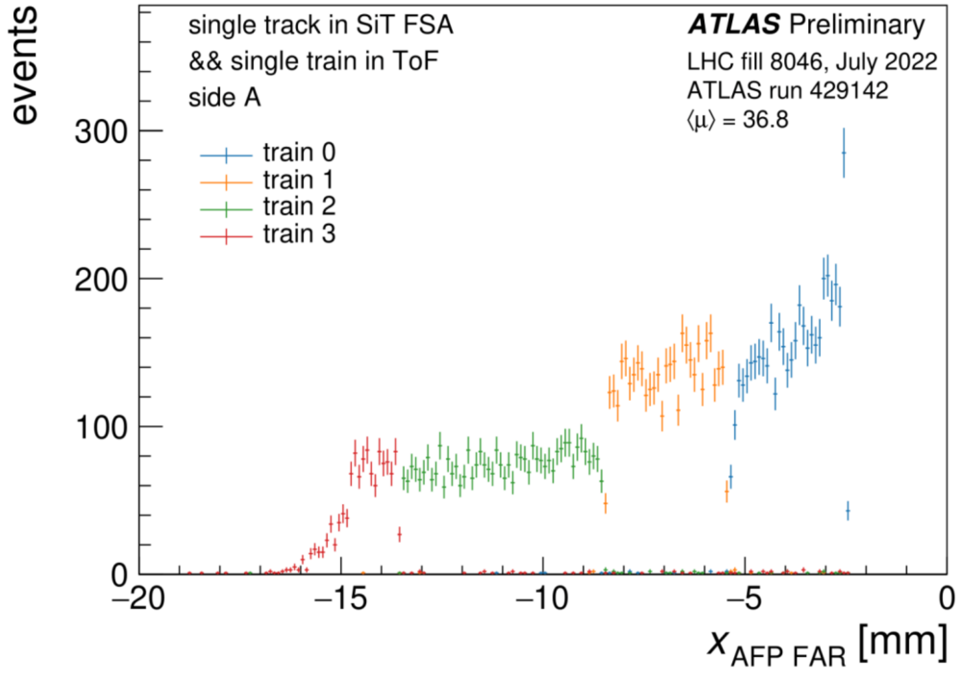
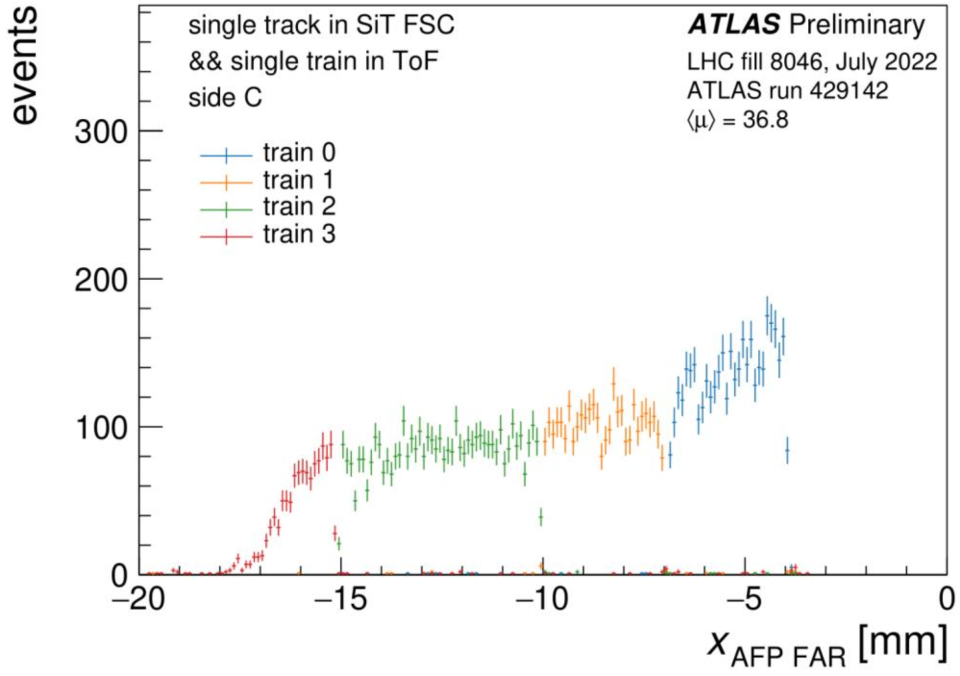
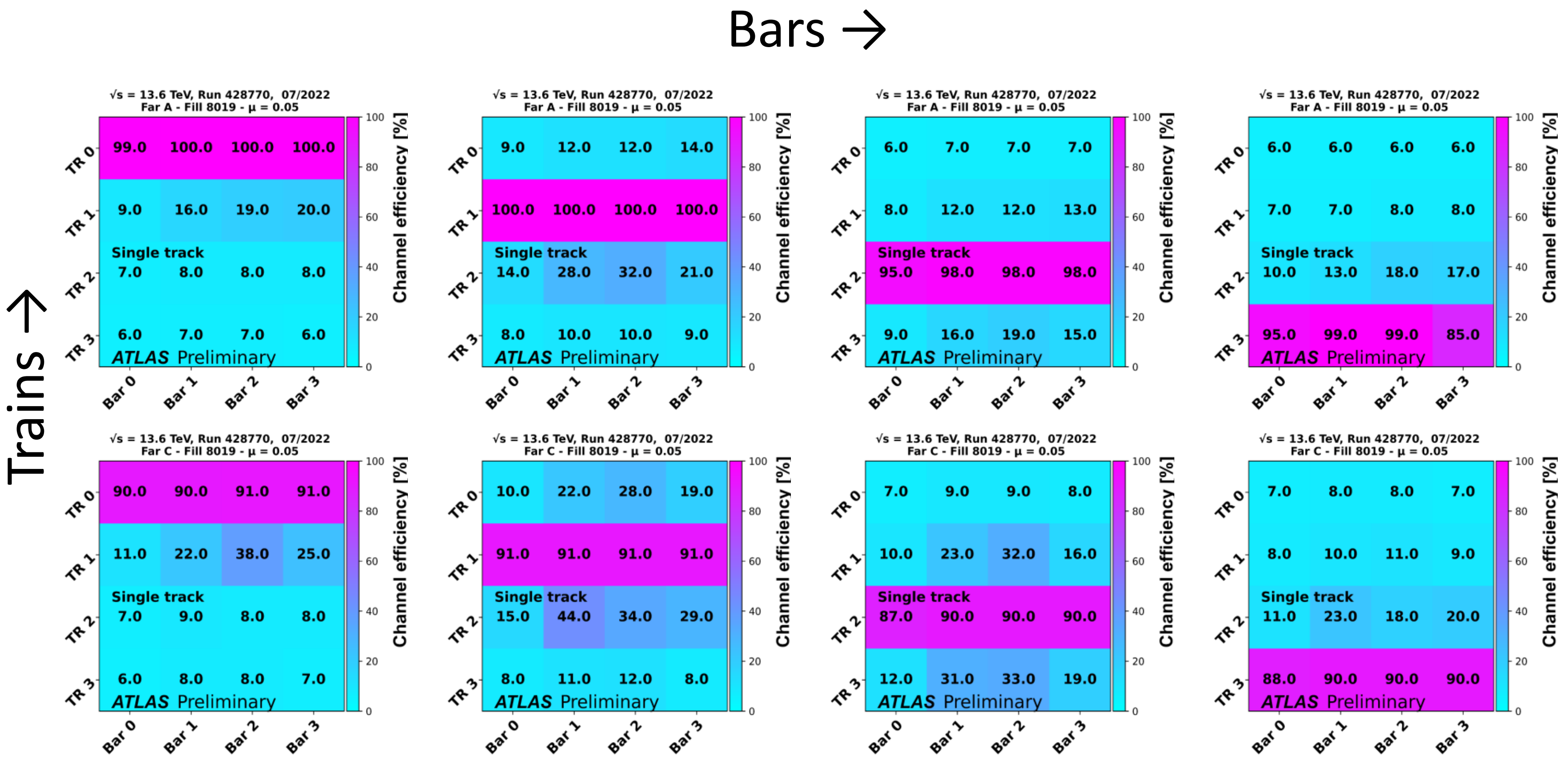




ToF Efficiency

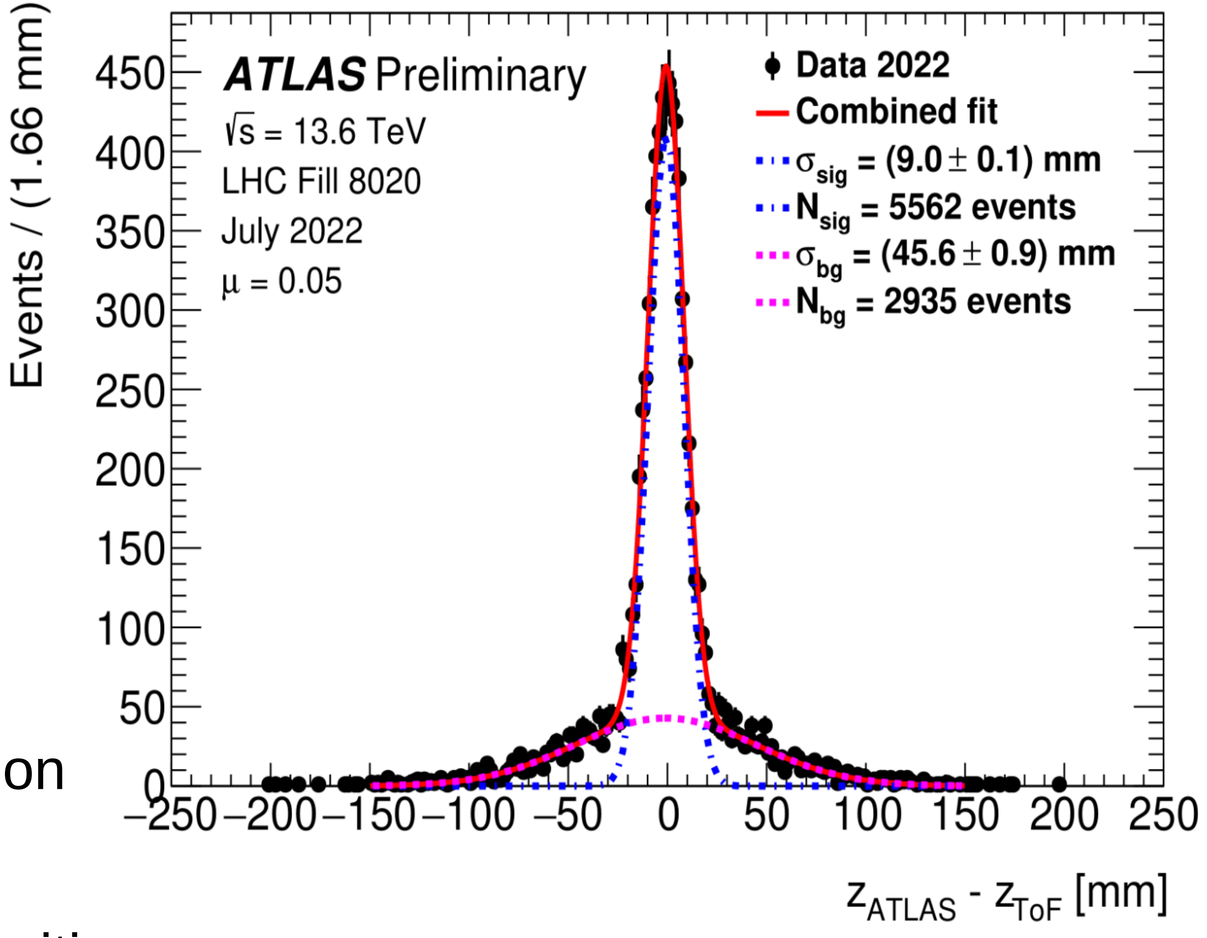
- Probability of observing a hit in the ToF detector during the **low-μ run** in July 2022
- Tag and Probe method
- Tagged by SiT
- Single track only
- Selection:
  Single SiT track
  in the station
- High hit probability in expected trains



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ForwardDetPublicResults

ToF Vertex Matching

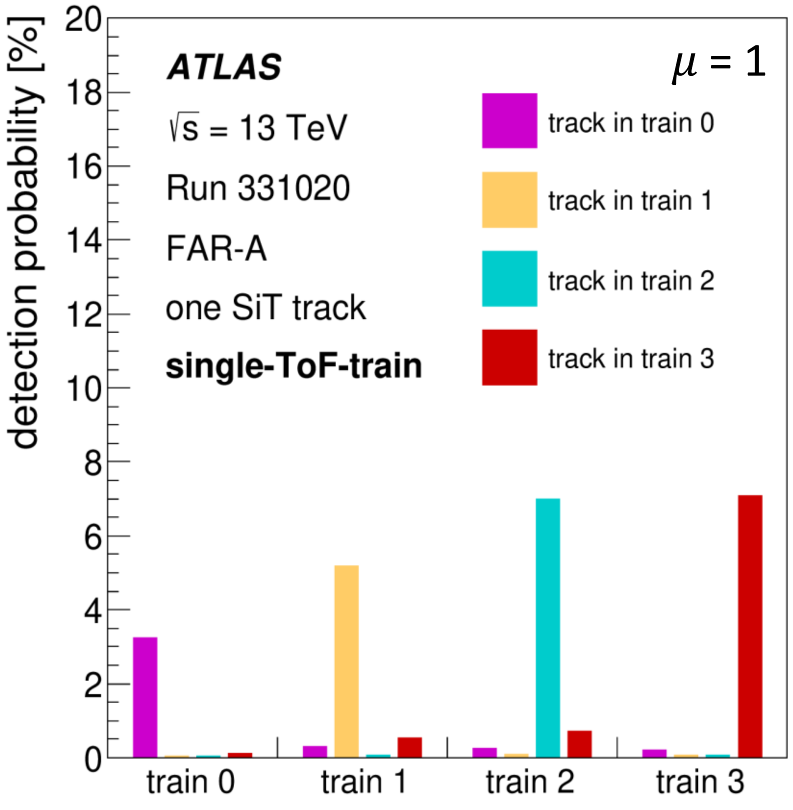
- Difference between longitudinal vertex position measured with AFP ToF and ATLAS Inner Detector (ID) measured during μ=0.05 run taken in July 2022
- Resolution 9.0 ± 0.1 mm (30 ps)
- Small initial background contribution wrt signal
  - Low pile-up data-taking conditions
- Visible advantage of use of ToF information
  - Much smaller difference in vertex position in case of signal
- Selection:
  - Primary vertex in ATLAS ID
  - Single AFP ToF train signal in each far station
  - Maximum of one hit in each ToF channel
  - Single track in AFP SiT in each far station
  - SiT track position matching the ToF train position

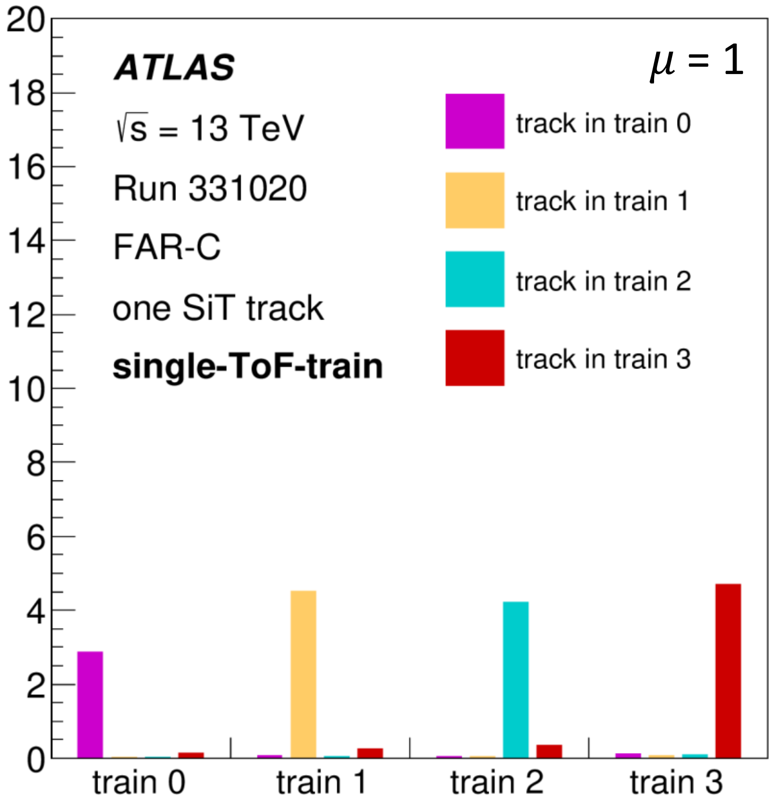


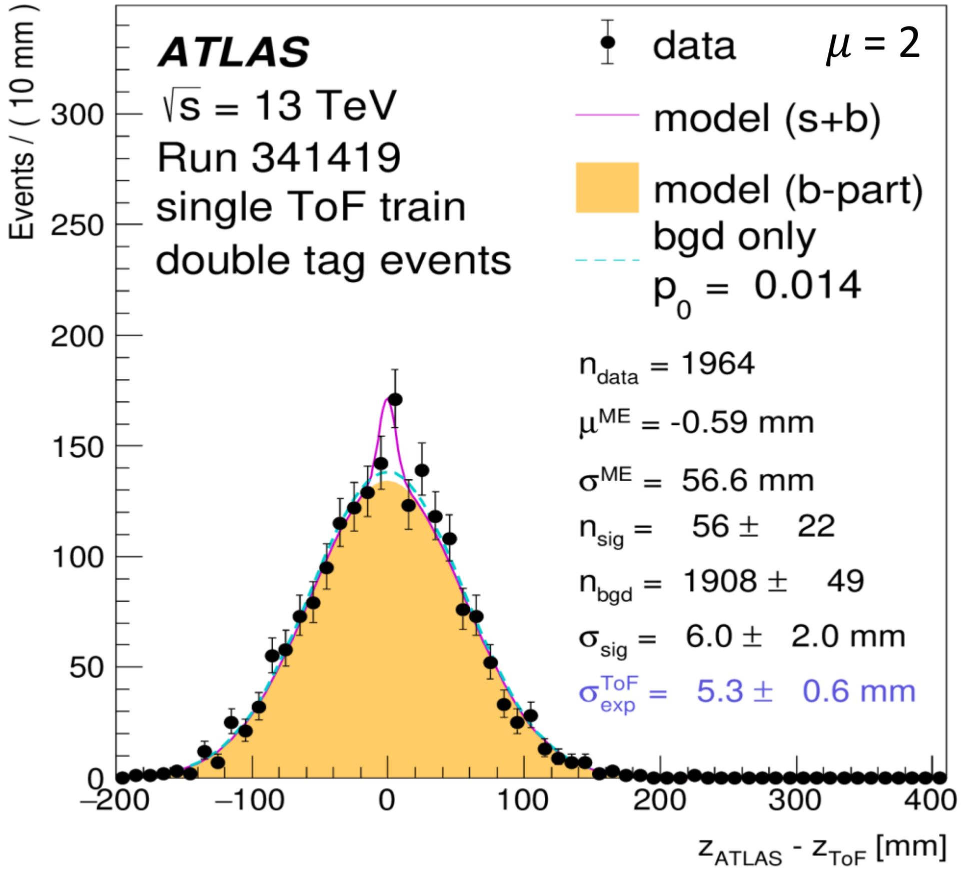
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ForwardDetPublicResults

ToF Performance in LHC Run-2, JINST 19 (2024) P05054

- Full-train efficiency of ~4-6 %
- While low efficiencies are observed, of the order of a few percent, the resolutions of the two ToF detectors measured individually are 21 ps and 28 ps
- Resolution of 6.0 ± 2.0 mm







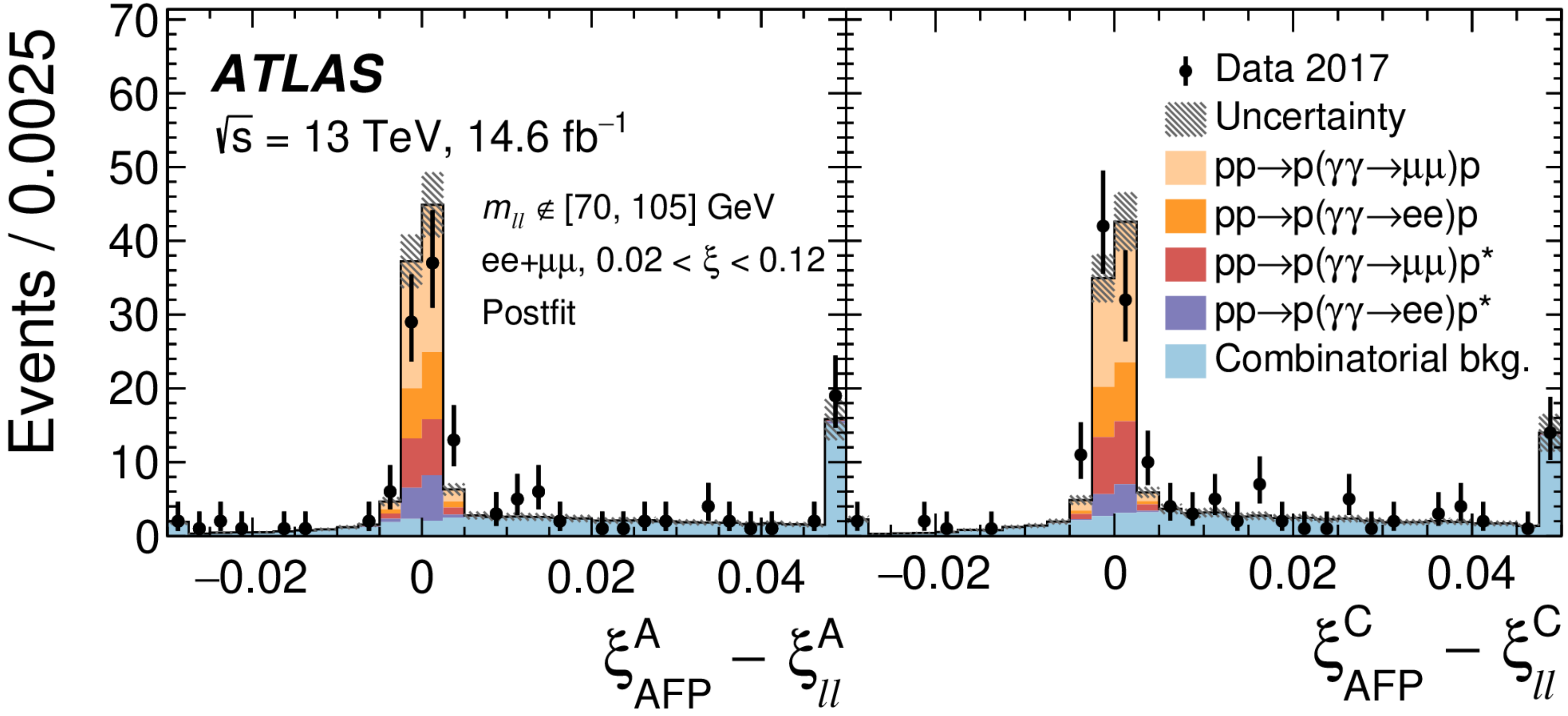
AFP Results

- **Proton tagging with the one arm AFP detector** ATL-PHYS-PUB-2017-012 (2017)
- **Observation and measurement of forward proton scattering in association with lepton pairs produced via the photon fusion mechanism at ATLAS,** Phys. Rev. Lett. 125 (2020) 261801
- **Performance of ATLAS Forward Proton Time-of-Flight Detector 2017,** ATL-FWD-PUB-2021-002 (2021)
- **Search for an axion-like particle with forward proton scattering in association with photon pairs at ATLAS,** JHEP 2307 (2023) 234
- **Performance of the ATLAS Forward Proton Spectrometer during High Luminosity 2017 Data Taking,** ATL-FWD-PUB-2024-001 (2024)
- **Performance of the ATLAS forward proton Time-of-Flight detector in LHC Run-2,** JINST 19 (2024) P05054

Matching of lepton pair and proton kinematics $\xi_{\ell\ell}$, ξ_{AFP}
PRL 125 (2020) 261801, 14.6 fb^{-1}

- Photon-induced di-lepton production with forward proton tag at 13 TeV
- AFP detection range $0.02 < \xi < 0.12$
- Signal and combinatorial background processes
- p* dissociated proton

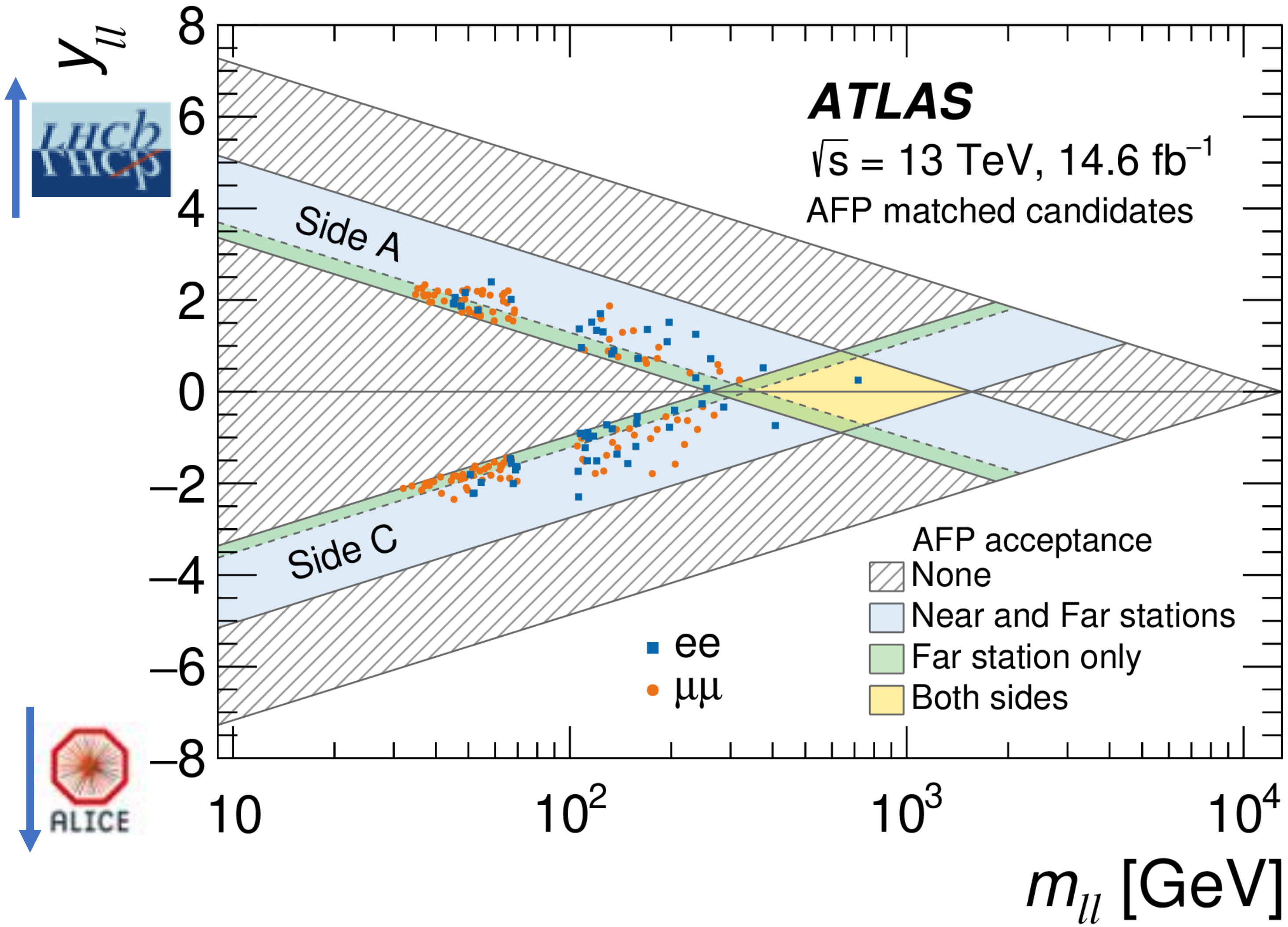
$c_{\ell\ell} = (m_{\ell\ell}/\sqrt{s})e^{\pm y_{ll}}$, $\xi_{AFP} = 1 - E_p/E_{beam}$



Di-lepton events: rapidity $y_{\ell\ell}$ versus $m_{\ell\ell}$ plane

PRL 125 (2020) 261801, 14.6 fb^{-1}

- Event selection and kinematic matching $|\xi_{AFP} - \xi_{\ell\ell}| < 0.005$ on at least one side
- Shaded (hatched) areas denote the acceptance (no acceptance) for the AFP stations
- Areas neither shaded nor hatched correspond to $\xi \notin [0, 1]$



Matching of photon pair and proton kinematics $\xi_{\gamma\gamma}$, ξ_{AFP}

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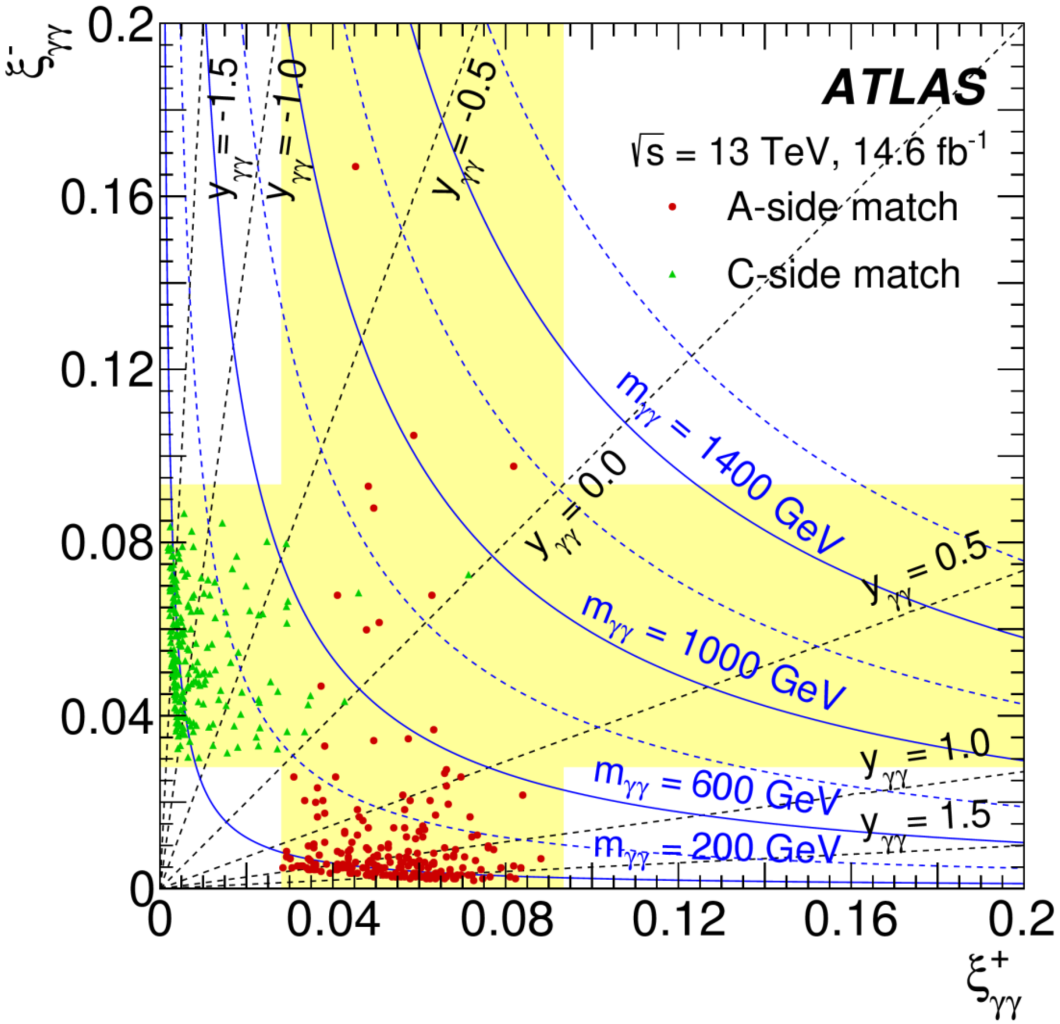
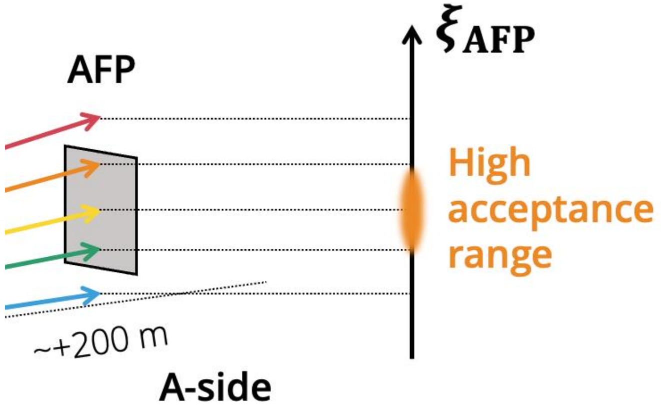
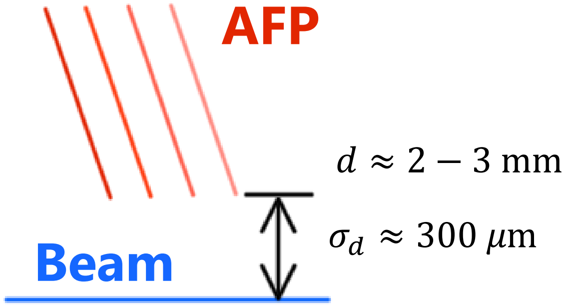




Dominant systematic uncertainty:
AFP global alignment



$$|\Delta\xi| \equiv |\xi_{AFP} - \xi_{\gamma\gamma}| < 0.004 + 0.1\xi_{\gamma\gamma}$$

2017 data: 441 events single matching, no double matching.

AFP key physics results: $\gamma\gamma \to \ell\ell$ and $\gamma\gamma \to \gamma\gamma$

Measurement of $\gamma\gamma \to \ell\ell$:

PRL 125 (2020) 261801, 14.6 fb^{-1}.

- 57 (123) candidates e^+e^-+p ($\mu^+\mu^-$+p)
- Background-only hypothesis rejected with a significance >5σ in each channel
- Cross-section measurements in the fiducial detector acceptance $\xi \in$[0.035; 0.08]

σ(ee+p)=11.0 $\pm$2.6 (st) $\pm$1.2 (sy) $\pm$0.3 (lumi) fb

$\sigma(\mu\mu$+p)=7.2 $\pm$1.6 (st) $\pm$0.9 (sy) $\pm$0.2 (lumi) fb

- Comparison with proton soft survival (no additional soft re-scattering) models: including soft survival probability improves the agreement with data.

Limit on $\gamma\gamma \to \gamma\gamma$

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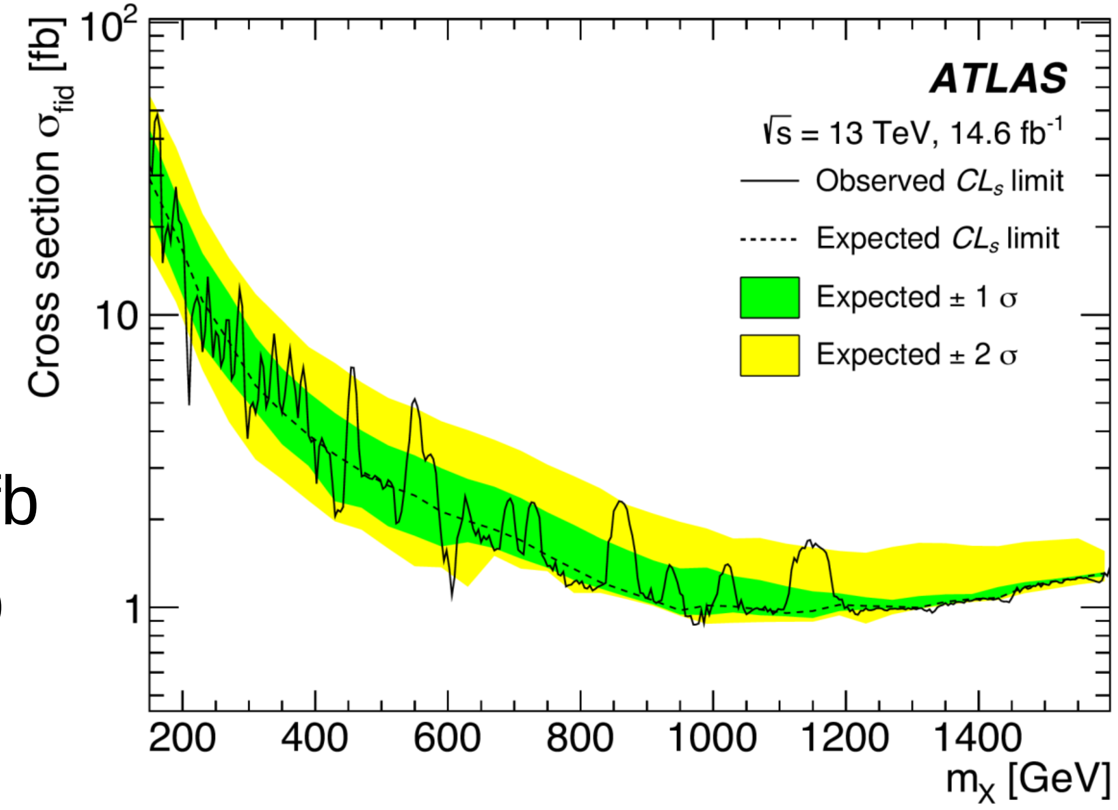
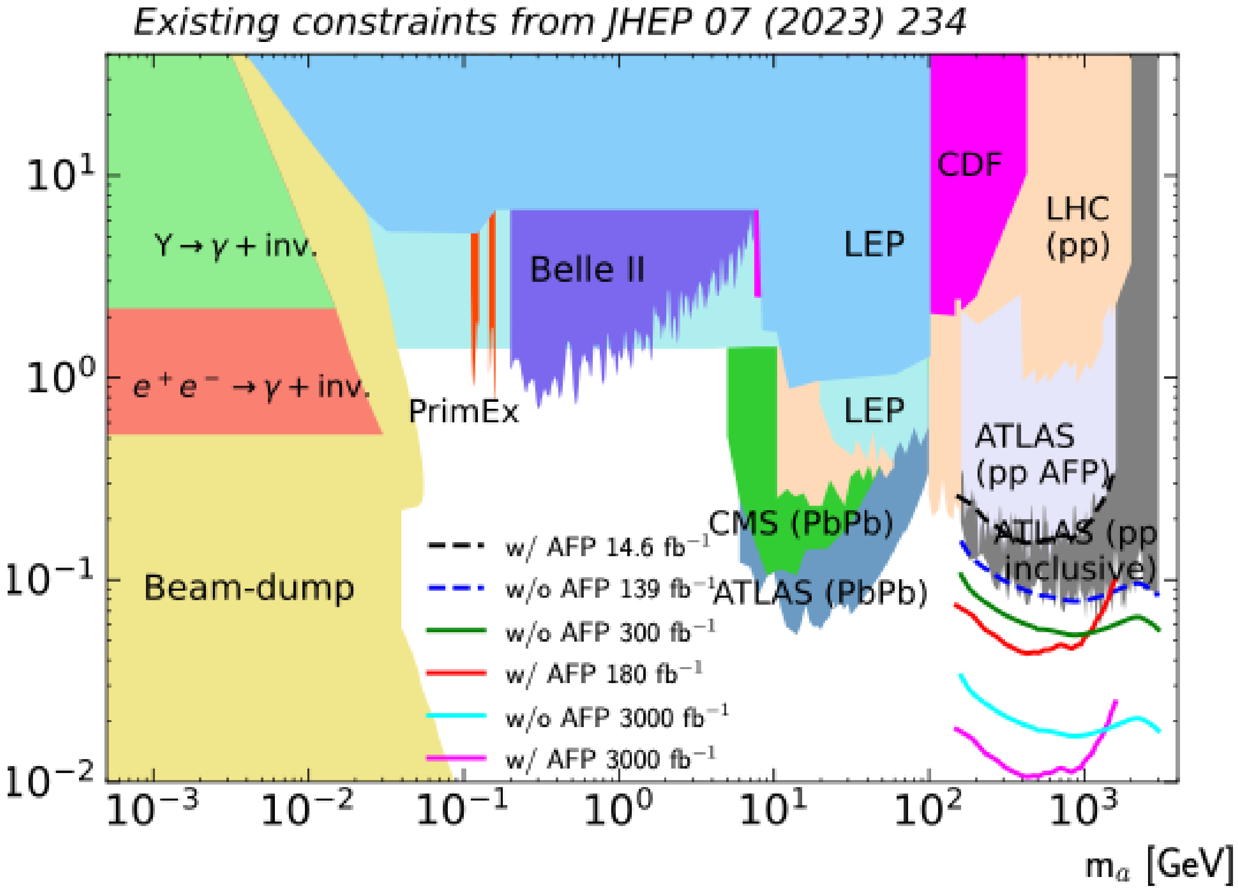
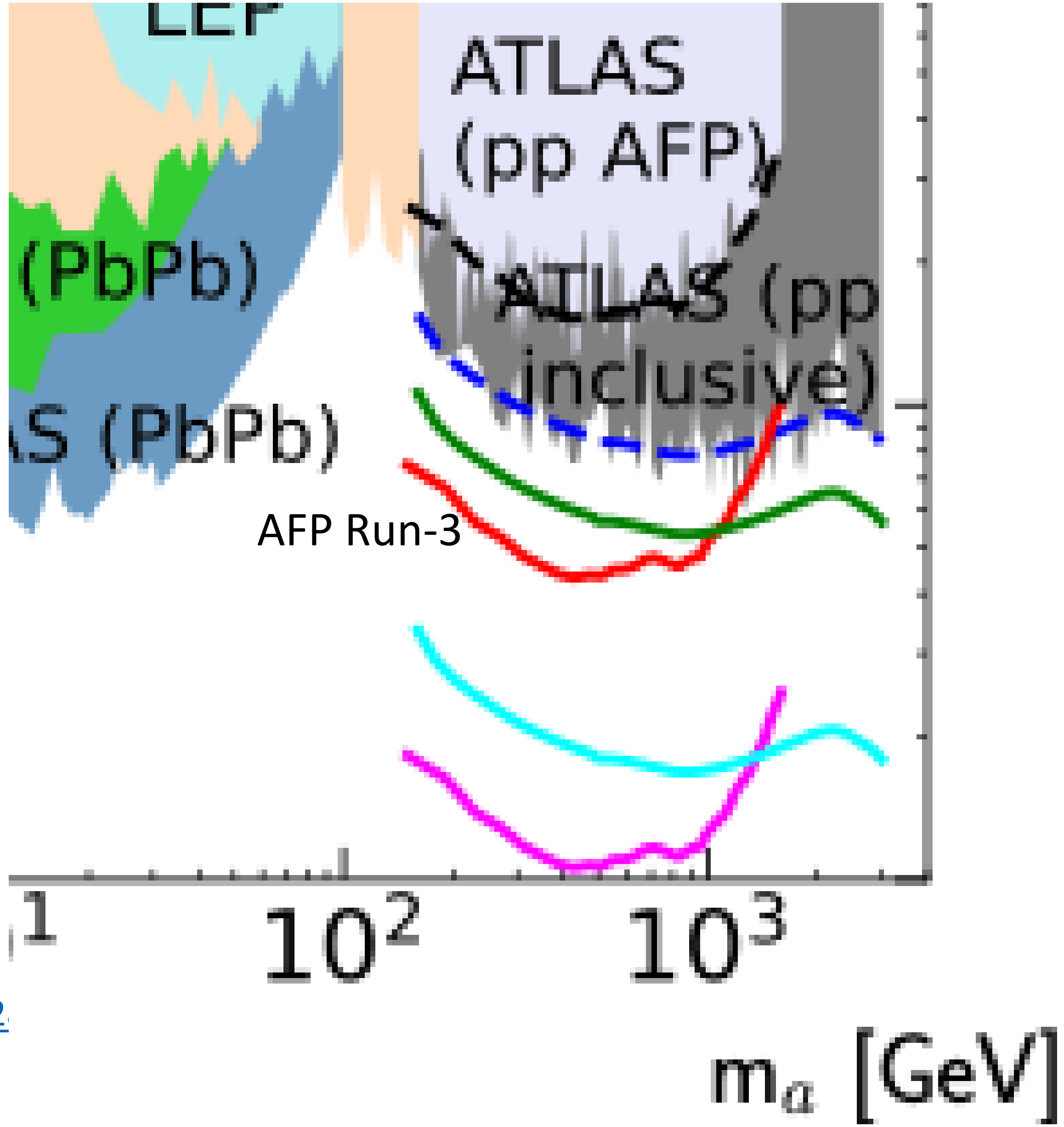


Comparison with previous $\gamma\gamma \rightarrow \gamma\gamma$ results and extrapolation (separating systematic and statistical uncertainties)

ALP-photon coupling ($1/\Lambda_a = 4/f$)





https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2019-2

https://cds.cern.ch/record/2890623

Conclusions and Outlook

- Physics programme with ALFA and AFP enhancement of ATLAS measurement capabilities
- High performance of ALFA and AFP-SiT detectors
- Good efficiency and time reconstruction resolution of AFP-ToF detectors in low-μ campaigns
- AFP efficient recorded data during high-μ campaigns as well as during special, low-μ runs
- Recent ALFA and AFP publications:
  - Measurement of exclusive pion pair production in proton-proton collisions at $\sqrt{s}$ = 7 TeV
  - Measurement of total cross-section from elastic scattering in pp collisions at $\sqrt{s}$ = 13 TeV
  - Observation of forward proton scattering in association with lepton pairs in photon fusion
  - Axion-Like-Particle with AFP search
  - AFP ToF Performance in LHC Run-2

Outlook:

- Large additional ALFA and AFP data sets being analysed
- LHC Run-3: AFP detector continues data-taking

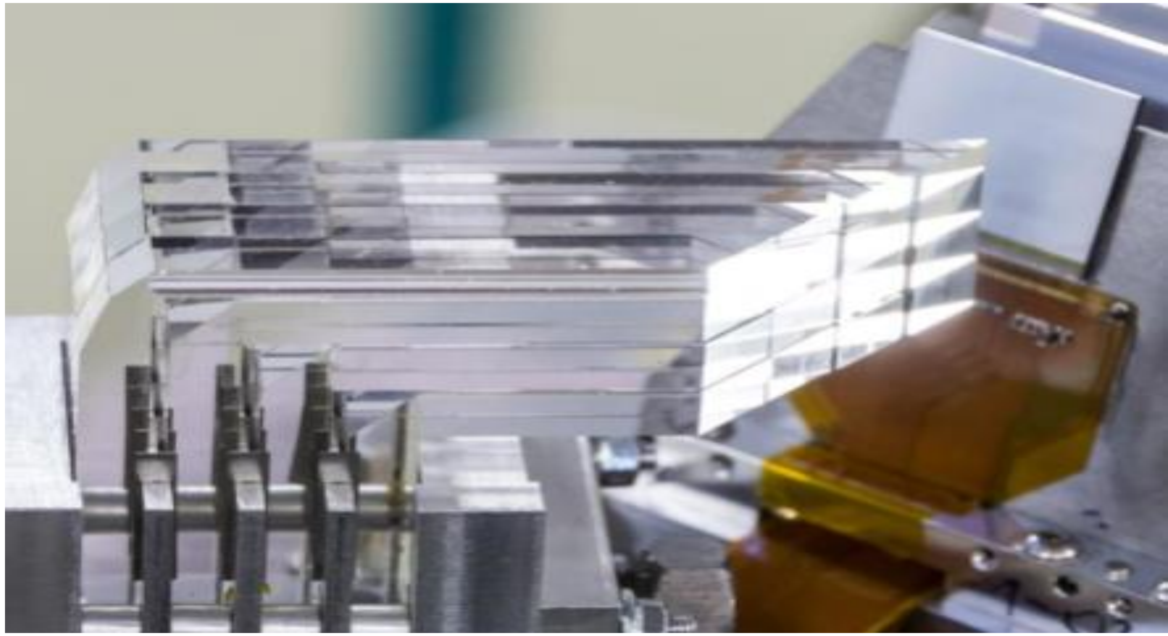
Thank you for your attention

Supplement

Trigger

- SiT trigger signal sent by Local Trigger Board (LTB)
  - Standardly, requires signal from at least 3 planes
  - Can be reprogrammed to different logic
  - 400 ns deadtime
- ToF trigger signal sent by Digital Trigger Module (DTM) and Time-to-Digital Converter (TDC)
  - Requires signal from at least N bars in a train
- Far stations can trigger either on SiT or ToF
- Passed to ATLAS cavern (USA15) by ultra-fast Air Core cables
  - To arrive in time to trigger the "central" detector
- Far station signal connected to 5 Central Trigger Processor (CTP) inputs
  - 1 SiT and 1 for each ToF train
- Different latency for SiT and ToF triggers
  - Dedicated timing-in campaigns

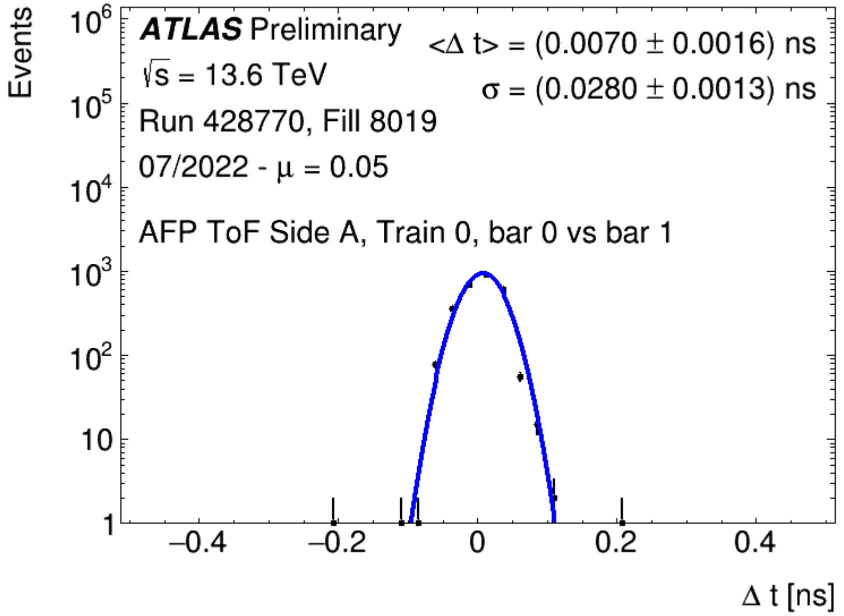
Time-of-Flight (ToF)

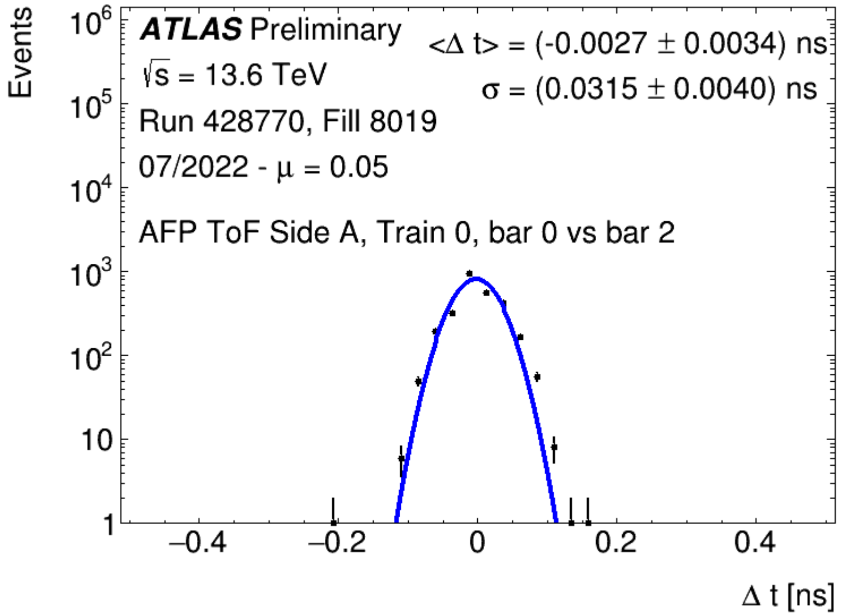


- Suppression of combinatorial background
- 16 quartz bars grouped in 4 trains
- Train/bar widths are
  3 mm, 3 mm, 5 mm, 5.5 mm
- Directing light to Micro-Channel Plate Photo-Multiplier Tube (MCP-PMT)
- Amplified by 3-stages of Pulse Amplifiers (PAa and PAbc)
- Processed by Constant Fraction Discriminator (CFD)
- Passed through Digital Trigger Module (DTM)
- Processed by High-Performance Time-to-Digital Converter (HPTDC)
- Double PAbc, CFD, and HPTDC; each for 2 trains

ToF Resolution Indication

- Time difference between two channels of the same ToF train
- Selection:
  - Single SiT track in the station
  - SiT track pointing to the given ToF train
  - Single ToF train signal in the station





https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ForwardDetPublicResults

New control systems in LHC Run-3

Data Quality

- Evaluate usability for physics analysis
  - AFP participating in data-taking
  - AFP in physics position
  - Enough SiT planes working
  - All ToF parts working

Improved online monitoring

- Lots of new histograms
- Increased statistics

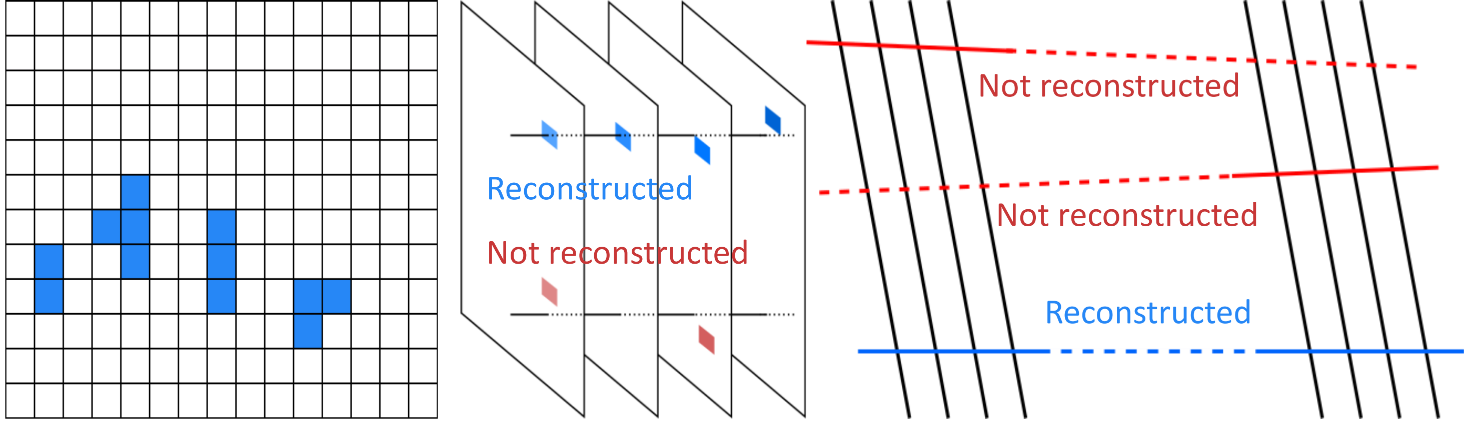
Automatic Recovery

- Reconfiguration of modules
- Scheduling of next reconfiguration attempts after failed attempt
- Optional power-cycle after several failed attempts

Mattermost Bot

- Sending messages about AFP state
- Sending warnings about issues which need to be acted on

“Proton” Reconstruction



- Starting with SiT and ToF hits
- SiT cluster reconstruction by grouping of adjacent SiT hits
- SiT track reconstruction using Kalman Filter with clusters on the input
- Proton reconstruction by combining SiT tracks from Near and Far stations
  - Knowledge of the LHC magnetic field, the proton position, and the elevation angle allows for reconstruction of the proton kinematics (energy and momentum)
- ToF track reconstruction by grouping ToF hits in a single train
- Vertex reconstruction by combining reconstructed protons and ToF tracks from each side