ATLAS Roman Pots
Present and Future Running

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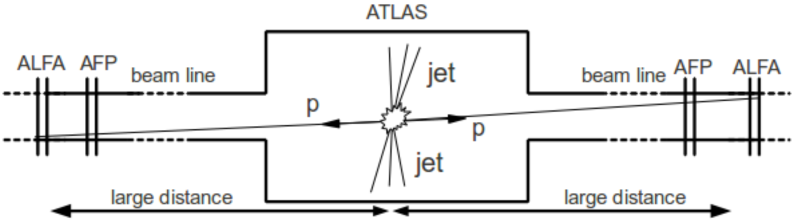
LHC Forward Physics meeting

CERN, 25th **October 2022**

Intact protons → natural diffractive signature → usually scattered at very small angles (μrad) → detectors must be located far from the Interaction Point.

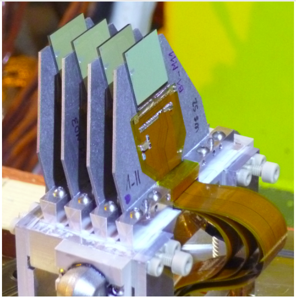


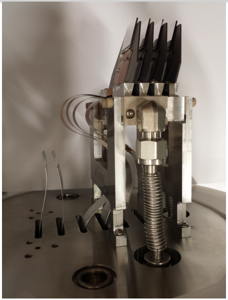
ALFA

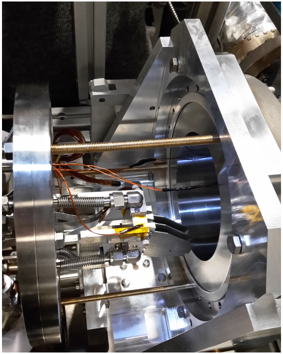
- **A**bsolute **L**uminosity **F**or **A**TLAS
- 240 m from ATLAS IP
- soft diffraction (elastic scattering)
- special runs (high β^* optics)
- vertically inserted Roman Pots
- tracking detectors, resolution: $\sigma_x = \sigma_y = 30\ \mu$m

AFP

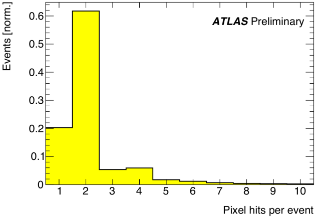
- **A**TLAS **F**orward **P**roton
- 210 m from ATLAS IP
- hard diffraction
- nominal runs (collision optics)
- horizontally inserted Roman Pots
- tracking detectors, resolution: $\sigma_x = 6\ \mu$m, $\sigma_y = 30\ \mu$m
- timing detectors, resolution: $\sigma_t \sim 25$ ps



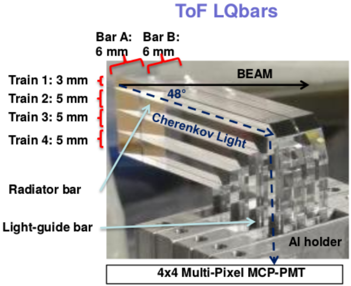


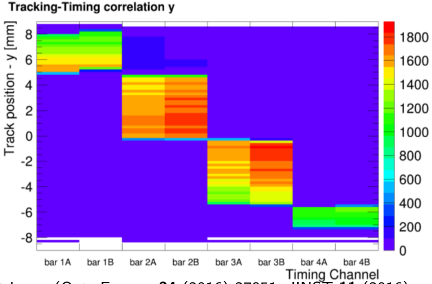


- Four detectors in each station.
- Technology: slim-edge 3D ATLAS IBL pixel sensors bonded with FE-I4 readout chips.
- Pixel size: $50x250\ \mu m^2$.
- Tilted by 14^0 to improve resolution in x.
- Resolution: $\sim 6\ \mu m$ in x and $\sim 30\ \mu m$ in y.
- Trigger: majority vote (2 out of 3; two chips in FAR station are paired and vote as one).
- **No major changes between Run 2 and Run 3 detector setups.**



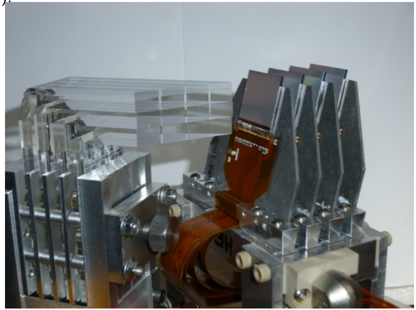
From JINST **11** (2016) P09005; JINST **12** (2017) C01086





Setup and performance shown above are from test-beam (Opt. Express **24** (2016) 27951, JINST **11** (2016) P09005).

- 4x4 quartz bars oriented at the Cherenkov angle with respect to the beam trajectory.
- Light is directed to Photonis MCP-PMT.
- Expected resolution: $\sim$25 ps.
- Installed in both FAR stations.



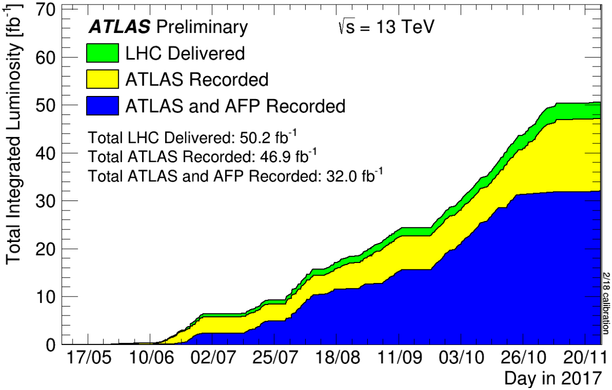
2016

- Conditions: $\sqrt{s} = 13$ TeV, $\beta^* = 0.4$ m
- Only two stations installed (ATLAS side C).
- Only single tagged events.
- Data taken during BBA:
  - two runs,
  - closer to the beam than during standard collisions,
  - very useful for alignment and optics studies.
- Data taken during special runs:
  - $\mu \sim 0.03$:
    - int. lumi.:$\sim$40 nb^{-1},
    - AFP triggers: $\sim$2 kHz stored,
    - main goal: soft diffraction.
  - $\mu \sim 0.3$:
    - int. lumi.:$\sim$500 nb^{-1},
    - AFP triggers: $\sim$2 kHz stored,
    - main goal: low-p_T jets.
- Data taken during standard runs:
  - AFP was inserted only when number of bunches was not greater than 600 (ramp-up).

2017

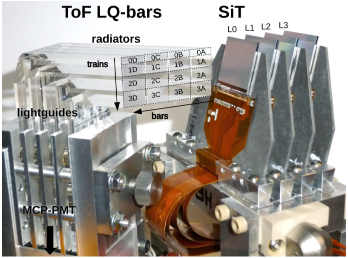
- $\sqrt{s} = 13$ TeV, $\beta^* = 0.3$ and 0.4 m
- Full system ready.
- Single and double tagged events.
- Data taken during BBA:
  - two runs.
- Data taken during special runs:
  - $\mu \sim 0.05$:
    - int. lumi.:$\sim$65 nb^{-1},
    - AFP triggers: $\sim$2 kHz stored,
    - main goal: soft diffraction.
  - $\mu \sim 1$:
    - int. lumi.:$\sim$640 nb^{-1},
    - AFP triggers: $\sim$2 kHz stored,
    - main goal: low-p_T jets.
  - $\mu \sim 2$:
    - int. lumi.:$\sim$150 pb^{-1},
    - AFP triggers: $\sim$300 Hz stored,
    - goals: medium-p_T jets, W/Z.
- Data taken during standard runs:
  - AFP was inserted on regular basis, usually few minutes after stable beams.

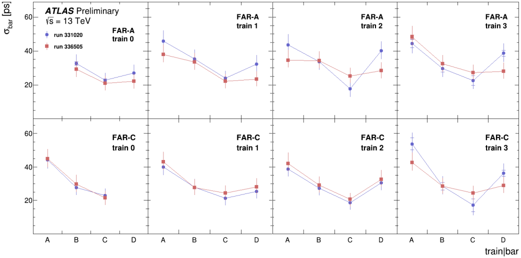
Data Collected in 2017

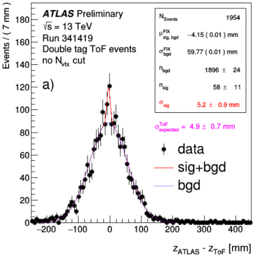


- This is only ATLAS and AFP recorded – there are no corrections due to efficiency of subsystems, *etc.*
- ToF trigger and detector were suffered very low efficiency → analysis should base on proton tagging rather than on ToF background reduction.

- Performance analysis based on 2017 data (taken with $\mu \approx 2$): ATL-FWD-PUB-2021-002.
- Poor efficiency of few percent due to fast PMT degradation; effect not expected during Run 3 due to new PMTs.
- Very good timing resolution: 20 – 50 ps for single bar.
- Overall time resolution of each ToF detector:
  - 20 ± 4 ps for side A,
  - 26 ± 5 ps for side C,
  - note: systematic uncertainties dominate.







Glance on Analysis: Exclusive Di-lepton Measurement with AFP Tag

PHYSICAL REVIEW LETTERS **125,** 261801 (2020)

Observation and Measurement of Forward Proton Scattering in Association with Lepton Pairs Produced via the Photon Fusion Mechanism at ATLAS

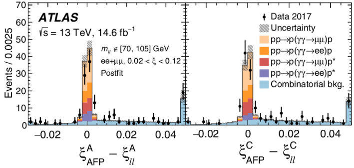
G. Aad *et al.*[*]
(ATLAS Collaboration)

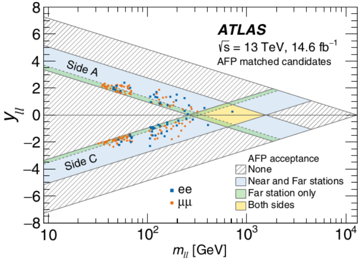
(Received 2 October 2020; revised 30 October 2020; accepted 23 November 2020; published 23 December 2020)

- Exclusive di-muons, $pp \to pl^- l^+ p$:
  - proton(s) measured in AFP,
  - leptons ($\mu^+\mu^-$ or e^+e^-) measured in ATLAS.
- 2017 data; $\sqrt{s} = 13$; $L = 14.6$ fb^{-1}.
- Powerful background rejection due to AFP:
  - proton tagging,
  - kinematics match: proton vs lepton system.
- 57 (123) candidates in the $ee + p$ ($\mu\mu + p$) final state.
- Background-only hypothesis rejected with a significance exceeding 5σ in each channel.
- Measured cross sections:

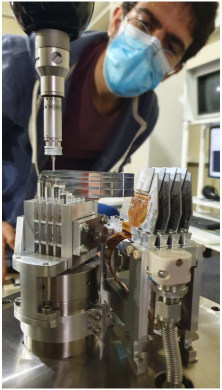
$$\sigma_{ee+p} = 11.0 \pm 2.6(\text{stat}) \pm 1.2(\text{syst}) \pm 0.3(\text{lumi}),$$

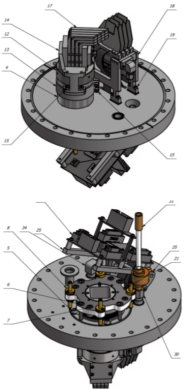
$$\sigma_{\mu\mu+p} = 7.2 \pm 1.6(\text{stat}) \pm 0.9(\text{syst}) \pm 0.2(\text{lumi}).$$





- Improvement in silicon detector cooling (new heat exchangers).
- Production of new tracking modules.
- New design of detector flange: Out-of-Vacuum solution for ToF detectors
- New trigger module: possibility to trigger on single train.
- New photo-multipliers: address inefficiency issues from Run2 data-taking.
- Above items were successfully tested at DESY in 2020.

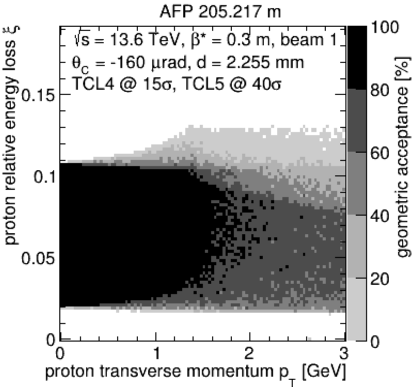




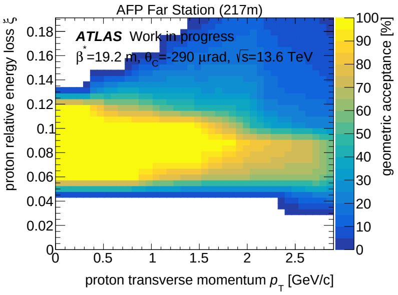
Both NEAR and FAR station have been successfully installed:

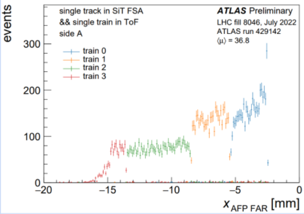
- laser survey (positioning wrt. LHC) done,
- interlock validation done → Roman pots qualified to be inserted to take data,
- SiT readout and trigger commissioned,
- ToF commissioning ongoing,
- successful data-taking during high- and low-μ runs in 2022.

Low-β^* Runs

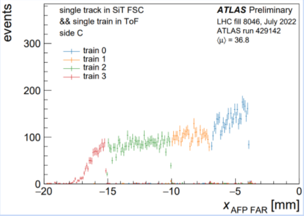


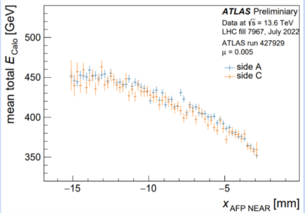
LHCf Runs



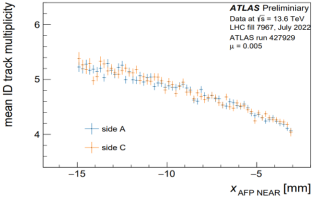


The x position of the track reconstructed in AFP SiT (FAR station) in events in which a single-train signal in ToF detector was observed for side A (left plot) and side C (right plot). The differences in the $x_{\mathrm{AFP\ FAR}}$ between sides are due to global alignment corrections not being applied).

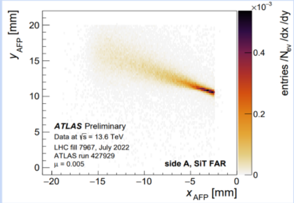




Correlation between the x position of reconstructed tracks in AFP NEAR stations and the total energy measured by the ATLAS Calorimeters for side A and C.

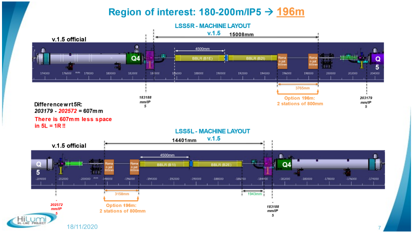


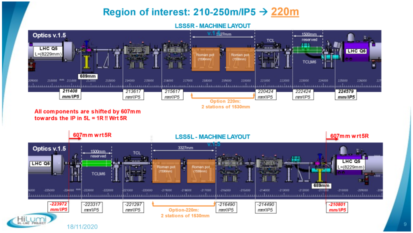
Correlation between the x position of reconstructed tracks in AFP NEAR stations and the charged track multiplicity in the ATLAS Inner Detector for Side A and C.

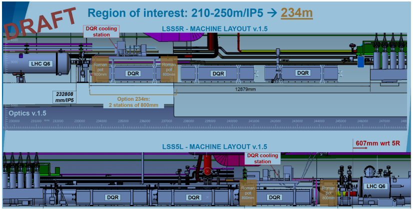


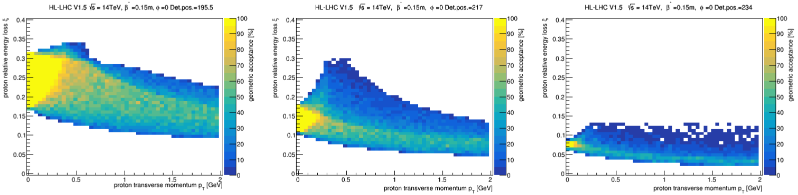
Positions of tracks reconstructed in AFP. Coordinate system: center of the beampipe at (x, y) = (0, 10 mm)

- According to HL-LHC machine layout only few locations are possible:
  - RP1A at 195.5 m
  - RP1B at 198.0 m
  - RP2A at 217.0 m
  - RP2B at 219.5 m
  - RP3A at 234.0 m
  - RP3B at 237.0 m
  - RP3C at 245.0 m
- Collimators are also relocated:
  - TCLPX4 at 136 m
  - TCL5 at 199 m
  - TCL6 at 221 m
- Studies were done using newest available HL-LHC optics.
- Assumption:
  - $\sqrt{s}$ = 14 TeV, β^* = 15 cm,
  - crossing angle of 250 μrad with phase: ϕ = 0,
  - emittance ε = 2.5 μm·rad.



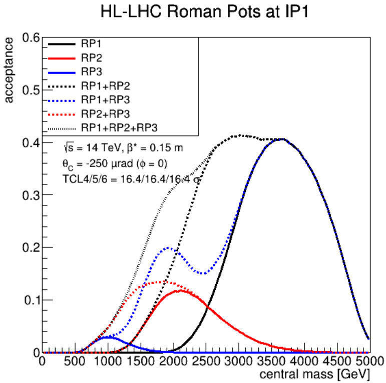






- Proton relative energy loss: $\xi = 1 - \frac{E_{proton}}{E_{beam}}$.
- High-ξ limit on acceptance is due to beampipe elements and TCL collimators between collision point and Roman pot.
- Low-ξ limit is due to detector-beam distance, which depends on settings of collimators ("hierarchy"; machine protection rules).
- Yellow area corresponds to $> 90\%$ of proton tag chance.
- Scattered protons usually (distribution is process-dependent) have p_T around 0.2 GeV.
- Left: detectors located around 195 m: $0.17 \lesssim \xi \lesssim 0.31$.
- Center: detectors located around 217 m: $0.1 \lesssim \xi \lesssim 0.19$.
- Right: detectors located around 234 m: $0.06 \lesssim \xi \lesssim 0.09$.

- Acceptance in ξ translates into the acceptance in mass (note: process dependent as integral sensitive to p_T).
- Figure: mass acceptance of all pots and all pots combinations for the case of horizontal crossing angle (ϕ=0):
  - "RP1" indicates that both the protons are tagged at the pot RP1A and RP1B (similarly for RP2 and RP3),
  - "RP1+RP2" means both protons are tagged at any two of the four pot locations RP1A, RP1B, RP2A and RP2B (similarly "RP1+RP3" and "RP2+RP3"),
  - "RP1+RP2+RP3" indicates that protons are tagged at any two stations on each side.



- I was asked to 'squeeze' physics case and focus on other topics in this presentation.
- For the real overview, please take a look at Physics opportunities of ATLAS Forward Proton at the High-Luminosity LHC [47 pages, on CDS]:
  - detailed ATLAS simulations:
    - WW (fully leptonic) + EFT study, WW (semi-leptonic), ZZ,
    - various ξ ranges; ToF of 10 and 20 ps,
  - based on ongoing Run 2 analyses: ALP searches ($0.035 < \xi < 0.08$; single-tag),
  - phenomenological studies:
    - semi-exclusive $t\bar{t}$: $0.015 < \xi < 0.15$, 10ps,
    - DM searches: $0.015 < \xi < 0.15$, 10ps,
    - exclusive Higgs in SM and BSM: $0.002 < \xi < 0.20$ (420 station considered), 10ps,
    - exclusive dijets: $0.02 < \xi < 0.12$, 10 ps.
- AFP is an asset to the ATLAS physics programme by providing additional handles for kinematic reconstruction and background rejection.
- From detailed simulations for single-tag AFP + ITk + HGTD configurations:
  - comparable significances observed to those based on central detector only,
  - higher S/B $\rightarrow$ may indicate lower background modelling uncertainties.
- RP1 + RP3 is optimum if only eight stations can be installed.

ATLAS Decision

An *Initial Design Report for ATLAS Forward Proton Detectors at the High-Luminosity LHC* was sent to a Review Panel called by the ATLAS Upgrade Coordinator on 22 Sep 2022:

- The main review meeting took place on 26/27 September.
- The Review Panel report with recommendations was issued on 10 October: **the main recommendation to ATLAS is not to approve the development of an AFP upgrade program for HL-LHC for Run 4, but to reserve the space for possible Run 5 or beyond projects if this is possible for the machine w/o constraints or additional cost**.
- The USC endorsed the Review Panel report and its recommendations at its meeting on 13 October 2022.
- The Executive Board approved the Review Panel report and its recommendations at its meeting on 17 October 2022.
- The result has been reported to and accepted by the HL-LHC Coordination Group (HLCG) on 18 October 2022.

- AFP was upgraded during LS2:
  - production of new tracking modules,
  - new design of detector flange: Out-of-Vacuum solution for ToF detectors,
  - new photo-multipliers: address inefficiency issues from Run2 data-taking,
- High and low-μ datasets collected in 2016 (one arm), 2017 and 2022:
  - performance studies close to be finalized,
  - analyses ongoing.
- No Roman Pots in ATLAS during Run 4.