ATLAS Status Report

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on behalf of the ATLAS Forward Detector Group

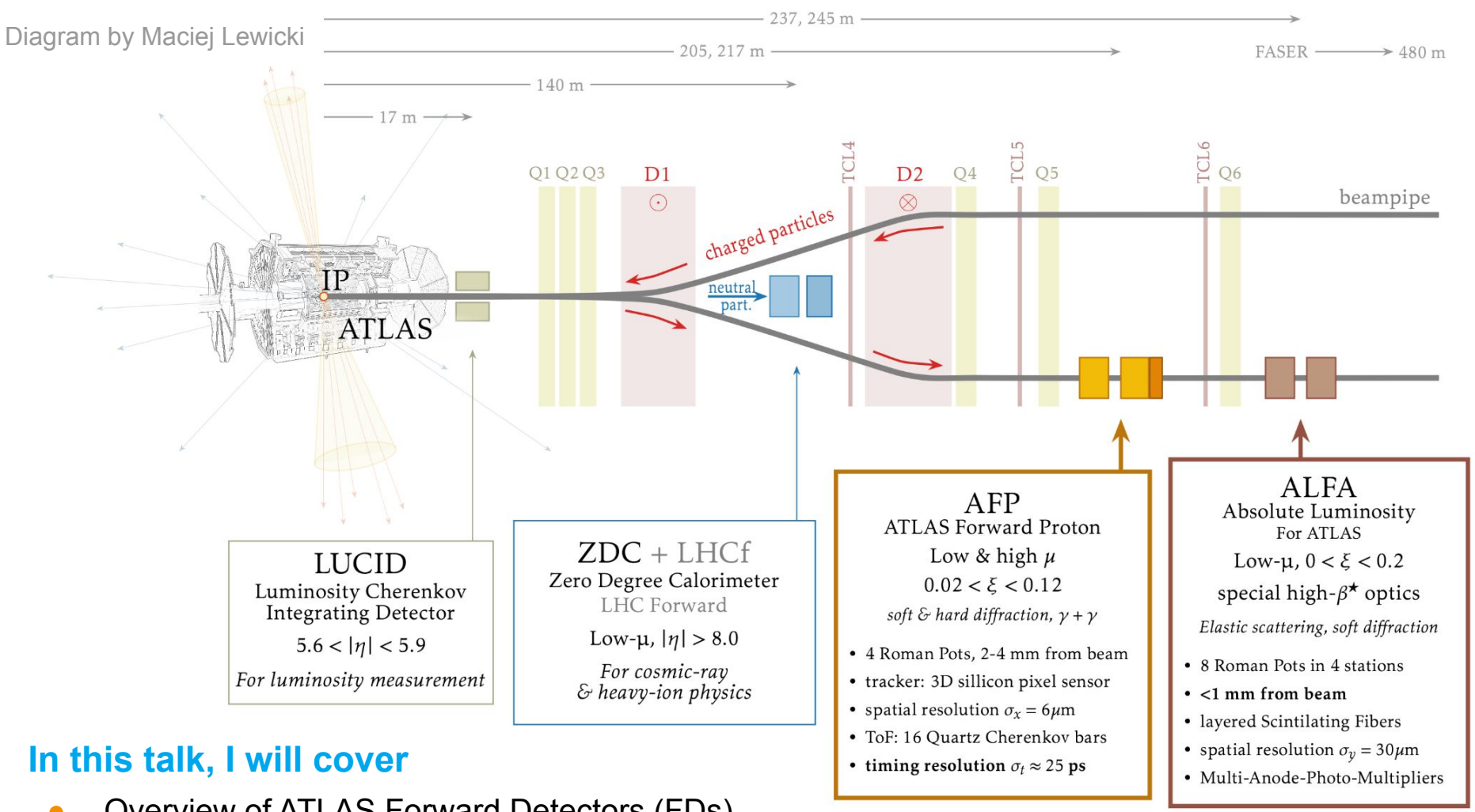
LHC FWD WG Meeting
Friday 15th March 2024

HELMHOLTZ

DESY.

ATLAS EXPERIMENT

ATLAS Forward Detectors

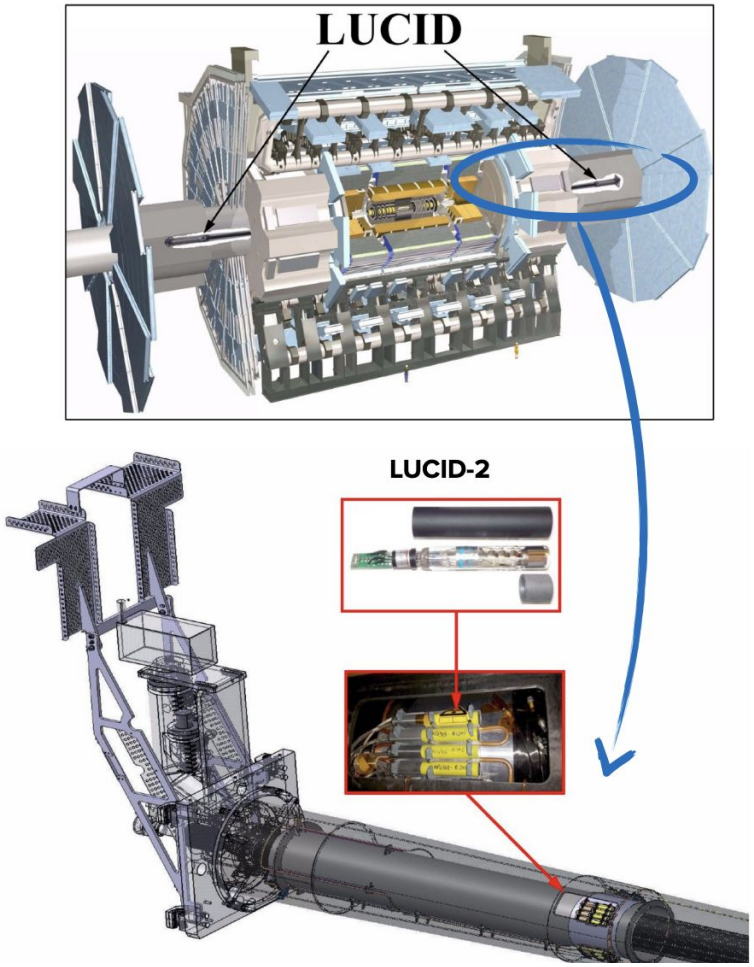


In this talk, I will cover

- Overview of ATLAS Forward Detectors (FDs)
- Status of ATLAS FDs
- Plans for 2024 data-taking and beyond

Disclaimer: I will be heavily biased towards AFP
List of acronyms used in this talk in backup :)

LUCID LUminosity measurement using Cherenkov Integrating Detector status

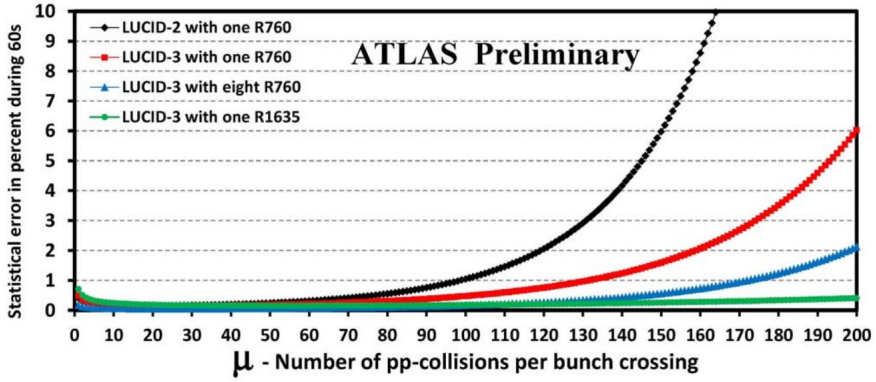


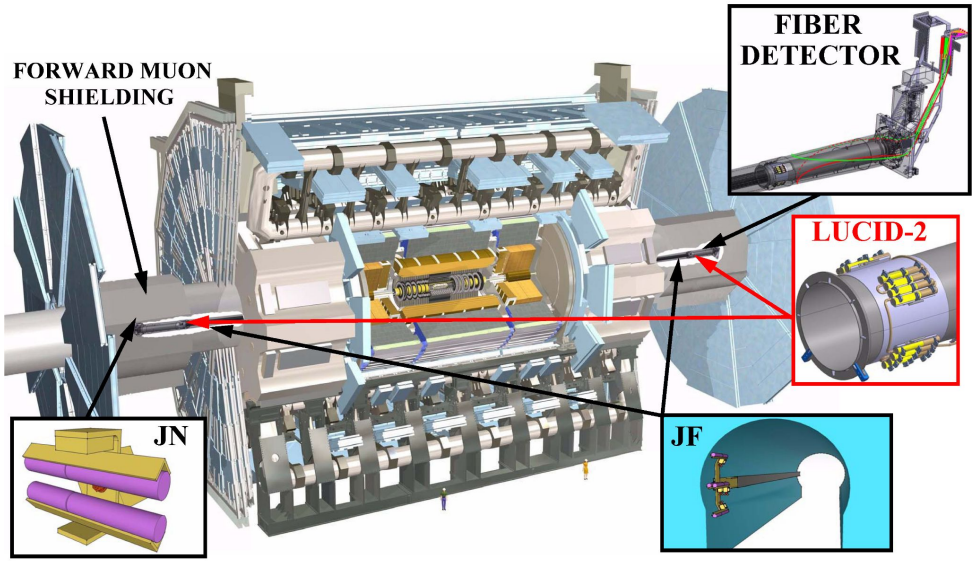
- ATLAS luminosity measurement strategy based on a redundancy of detectors with different technologies
- LUCID-2 provided both online and offline bunch-by-bunch luminosity to ATLAS in Run 2 in all beam-conditions, luminosity ranges and type of colliding particles
  - → 16 PMTs placed around the beam pipe at ±17 m from IP1
- 0.8% precision achieved in Run 2! [EPJC 83 (2023) 982]
  - → "ATLAS delivers most precise luminosity measurement at LHC" https://atlas.cern/updates/briefing/run2-luminosity

- LUCID-2 system continues to be used in Run 3

LUCID plans for 2024+

- LUCID-2 is not suitable for required precision at HL-LHC due to too large acceptance/particle flux on the detector
- New PMT prototypes (LUCID-3) being tested in Run 3 for implementation at HL-LHC
  - ➞ First data confirm lower acceptance and pile-up dependence of LUCID-3 compared to LUCID-2

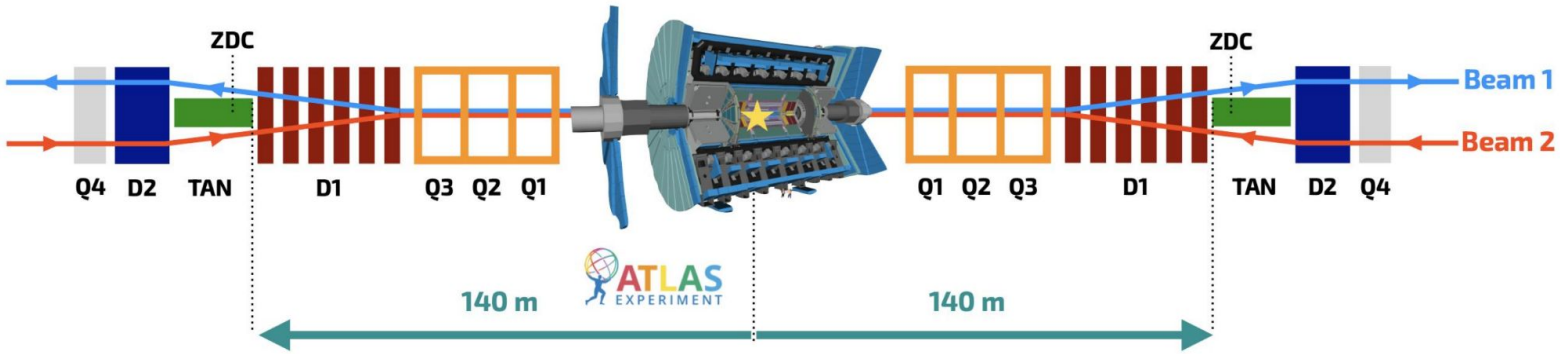




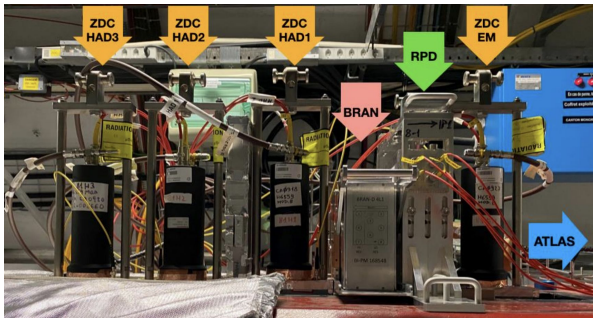
- New fiber detectors also being tested
  - ➞ Alternative approach that uses charge instead of hits
  - ➞ Intrinsically linear with luminosity
  - ➞ Approach not yet validated with data - will be a key input from Run 3 experience

ZDC Zero Degree Calorimeter status

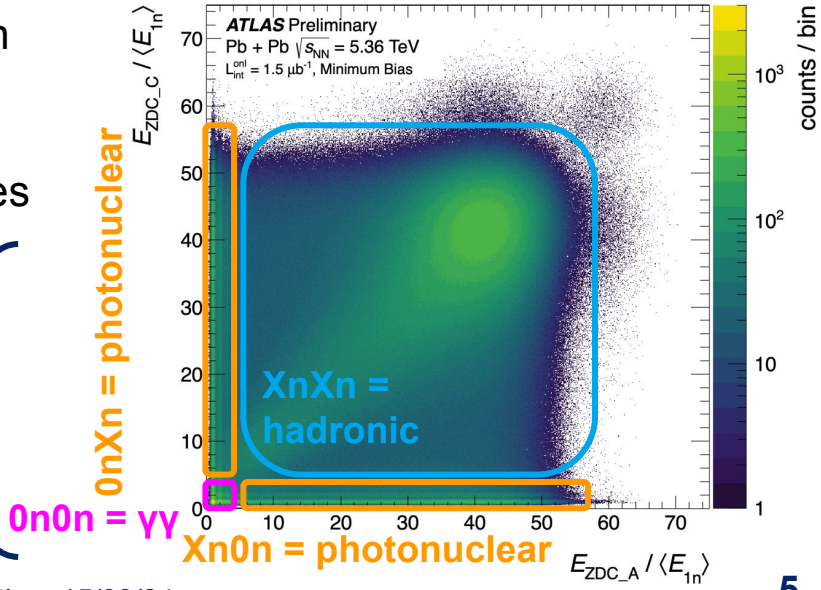
- **ZDC** = Tungsten fused silica calorimeters located at ± 140 m from IP1 to detect forward spectator neutrons in **Heavy Ion collisions**
- New Reaction Plane Detector (**RPD**) samples 2D transverse shower profile



- Run 3 performance shows good neutron resolution
- RPD data analysis shows some differences in the two sides, possibly from different sized EM modules

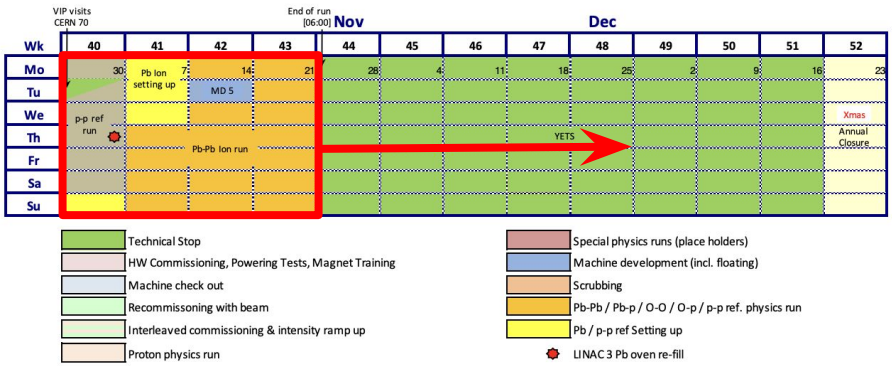


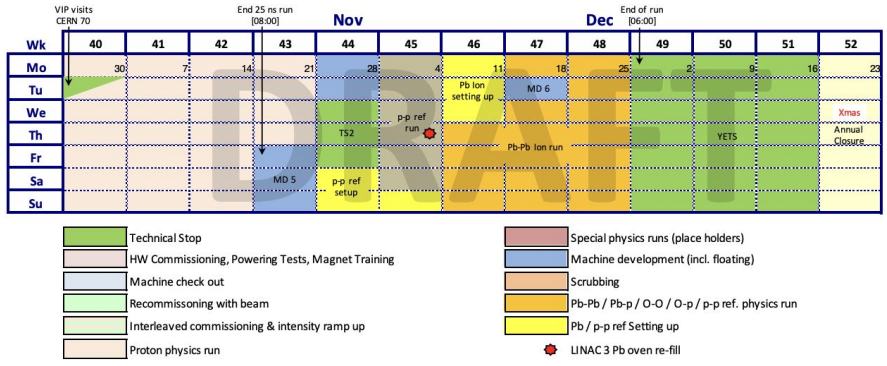
Different forward neutron topologies can give information on class of physics process



ZDC plans for 2024+

- Preparations underway to operate ZDC+RPD with ATLAS, taken calibration data
- Steady progress on ZDC offline data analysis and TDAQ preparations for 2024
- Studying effects of BRAN (**B**eam **RA**te of **N**eutrals) → energy lost between EM and hadronic modules
  - → Possibility to move BRAN detector downstream of ZDC has been discussed, would improve ZDC energy resolution
- Possible extension of LHC 2024 schedule by 5 weeks, resulting in shifted HI run:

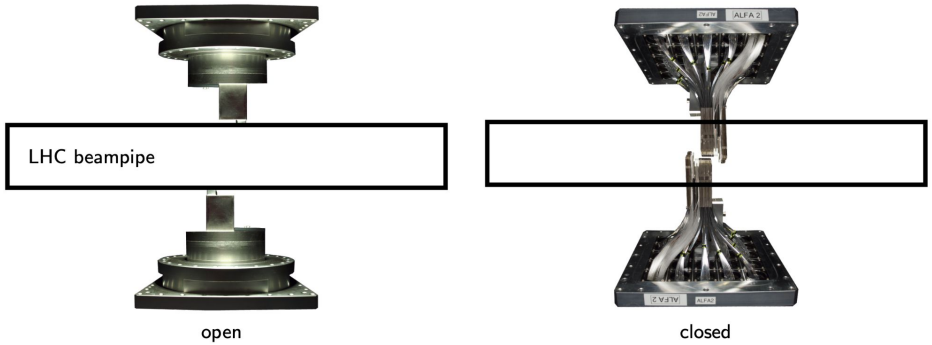




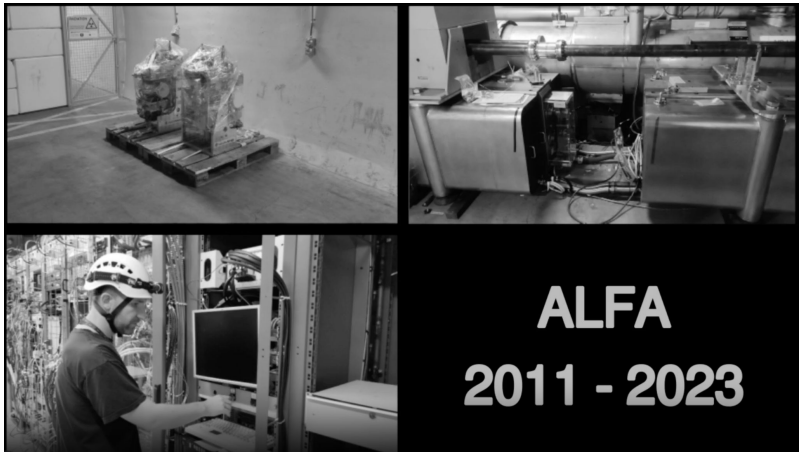
- A HL-ZDC upgrade is essential for the ATLAS Heavy Ion program in Run 4 and beyond
  - → joint project between ATLAS and CMS to tackle common challenges
  - → Brand-new detectors need to be built to fit size constraints + with radiation hard materials

ALFA Absolute Luminosity For ATLAS status

- Two stations at each ATLAS side, 240 m from IP1.
- Scintillating fibres – position measurement with precision of ~30 μm,
- Roman Pot (RP) technology – detectors can move in vertical (y) direction



TOTAL in-beam time: 87h50
TOTAL acquired luminosity: 0.32893 nb^{-1}

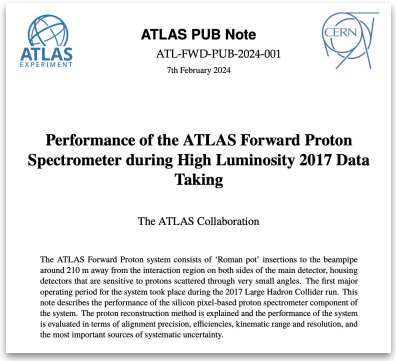


- In 2023, ALFA successfully finished its data-taking programme!
- Initial focus to measure properties of elastic scattering was extended to measure diffractive events
  - → lots of interesting data-sets to be analysed!
  - → There is also a unique, never analysed proton-lead dataset

PHYSICS HIGHLIGHTS:
Exclusive pion pair production in pp collisions at √s = 7 TeV [EPJC 83, 627 (2023)]
Total cross section and ρ-parameter from elastic scattering in pp collisions at √s = 13 TeV [EPJC 83, 441 (2023)]

AFP ATLAS Forward Proton status

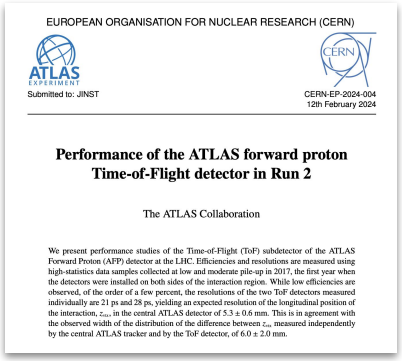
- AFP was a new detector in Run 2
  - → Four stations ~200 m from IP1
  - → RP technology – detectors can move in horizontal (x) direction
  - → Documentation for both SiT and ToF performance now public!


ATLAS PUB Note
ATL-FWD-PUB-2024-001
7th February 2024

Performance of the ATLAS Forward Proton Spectrometer during High Luminosity 2017 Data Taking

The ATLAS Collaboration

The ATLAS Forward Proton system consists of 'Roman pot' insertions to the beampipe around 210 m away from the interaction region on both sides of the main detector, housing detectors that are sensitive to protons scattered through very small angles. The first major operating period for the system took place during the 2017 Large Hadron Collider run. This note describes the performance of the silicon pixel-based proton spectrometer component of the system. The proton reconstruction method is explained and the performance of the system is evaluated in terms of alignment precision, efficiencies, kinematic range and resolution, and the most important sources of systematic uncertainty.


EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

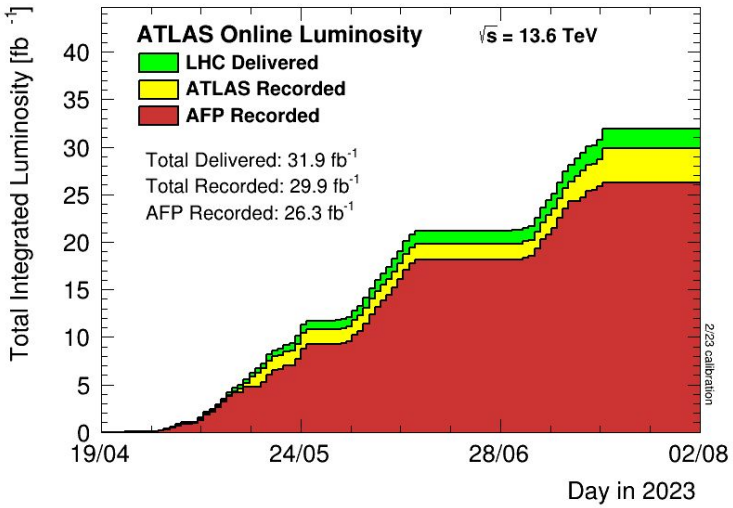
Submitted to: JINST

CERN-EP-2024-004
12th February 2024

Performance of the ATLAS forward proton Time-of-Flight detector in Run 2

The ATLAS Collaboration

We present performance studies of the Time-of-Flight (ToF) subdetector of the ATLAS Forward Proton (AFP) detector at the LHC. Efficiencies and resolutions are measured using high-statistics data samples collected at low and moderate pile-up in 2017, the first year when the detectors were installed on both sides of the interaction region. 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, yielding an expected resolution of the longitudinal position of the interaction, z_{vtx}, in the central ATLAS detector of 5.3 ± 0.6 mm. This is in agreement with the observed width of the distribution of the difference between z_{vtx} measured independently by the central ATLAS tracker and by the ToF detector, of 6.0 ± 2.0 mm.

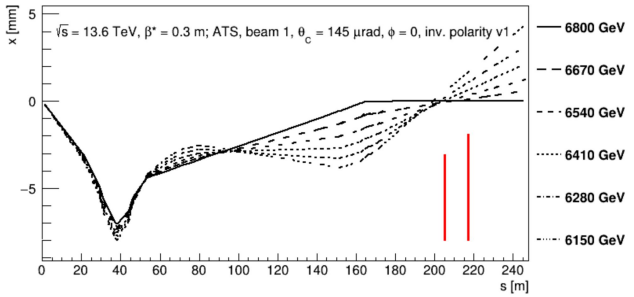


- Lots of lessons learned from Run 2, improved operation and understanding of performance in Run 3
  - → Dataset available to analysis more than doubled with 2022 alone!
  - → ToF remains challenging but significant amount of work going into both operation and performance of ToF detectors

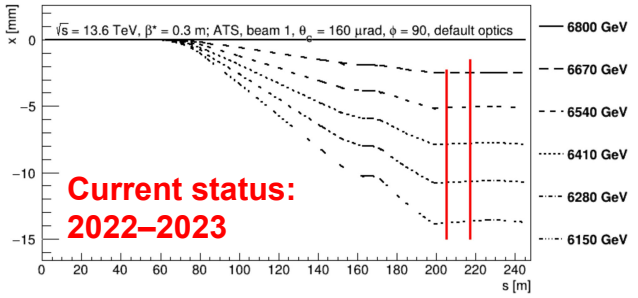
- Questions about the future of AFP in Run 3 related to inner triplet radiation mitigation strategies (more on next slides)

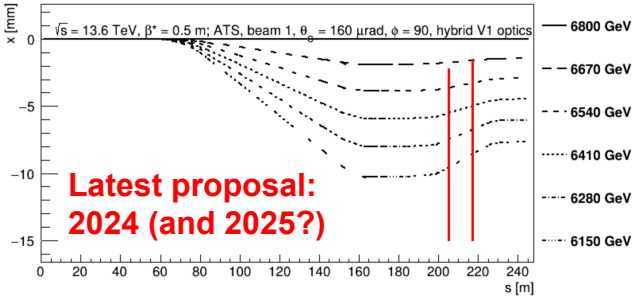
Impact of LHC optics on AFP acceptance

- The acceptance of AFP is heavily dependent on the optics settings of the LHC
- Worries about total radiation dose received by inner triplet by end of LHC lifetime
  - ➞ Several mitigation strategies considered, involving reversing magnet polarity and changing IP crossing planes to move locations of highest dose
- Original proposals resulted in zero acceptance for AFP!!



- Lots of back and forth with magnet experts (S. Fartoukh) to find a suitable solution
  - ➞ In December the option to invert the polarity while keeping vertical crossing angle was presented
  - ➞ After a few iterations, V1 was prepared: comparable to default optics at low-ξ, worse acceptance at high-ξ. Proton resolution will be impacted.





AFP plans in 2024

- New SiT modules, new RP heat-sink, new and refurbished readout electronics
- AFP will run with a legacy ToF system (HPTDC) in 2024
  - → Decision on changing to picoTDC will be taken after production and successful testbeam (planned for ~August)

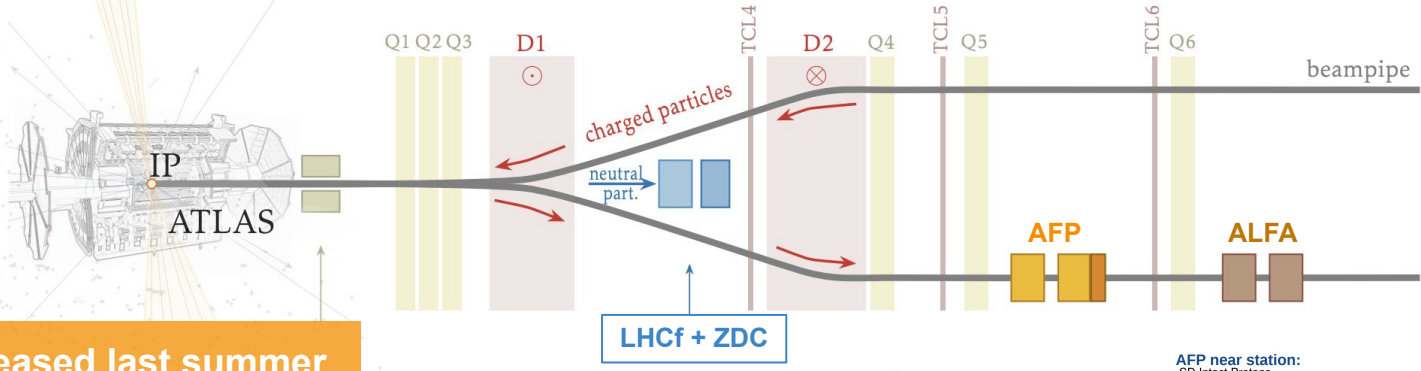
- **AFP will participate in all standard high-μ runs**
  - → Expect proton resolution to be slightly worse than 2023 due to change in LHC optics

- Discussions with ATLAS to request **one special physics run for 2024**
  - → Medium-μ (10→5→2→1→0.2) during the post-TS1 short ramp-up period
  - → Assumption is that ToF will be fully efficient
- AFP also plans to take part in low-μ runs requested by other systems
  - → 900 GeV partial insertion, BBA, pp reference run

AFP plans for 2025+

- AFP plans for 2025 depend on outcome of inner triplet radiation dose mitigation strategies put in place this year
  - → If triplet polarity switch in 2024 means there is **no crossing plane change in 2025**, AFP expects to take part in all standard high-μ runs
  - → If there is a change in crossing plane (V→H at IP1), AFP has no acceptance
    - In this case, will only partake in special runs
- AFP would like to participate in both **proton-oxygen** and **oxygen-oxygen** runs planned for 2025
  - → Insertion on both proton and oxygen side should be possible
  - → Will require additional beam based alignment
- No AFP in Run 4 (HL-LHC, expected 2029) due to limited acceptance

New in Run 3: Combined AFP+LHCf+ZDC

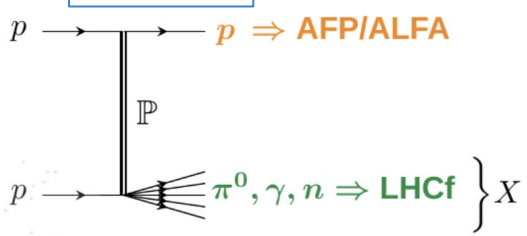


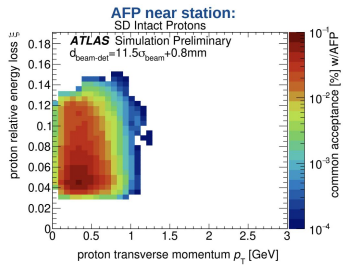
Feasibility PUB note released last summer

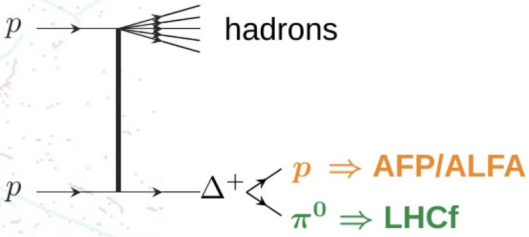
AIM: Provide input to cosmic ray background modelling (soft-QCD)

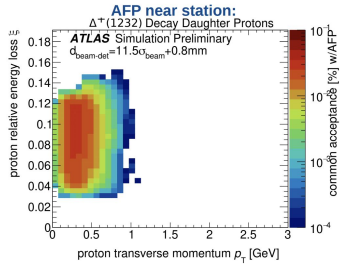
- Large differences in generator predictions:
  - ➞ Position of shower maximum
  - ➞ Particle multiplicities
  - ➞ Insufficient tuning data
- Proton excited states in diffractive regime not been measured at the LHC before
- LHCf Calorimeters
  - ➞ Neutral particles (γ, $\pi^0 \rightarrow \gamma\gamma$, n) at $|\eta| > 8.4$
  - ➞ Special runs with $\mu_{max} = 0.05$

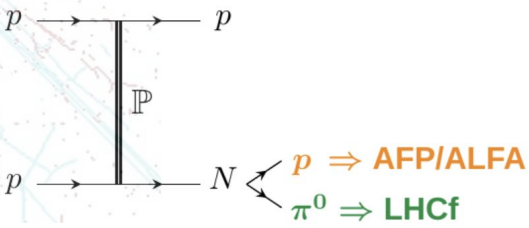
Analysis of 2022 LHCf special run ongoing

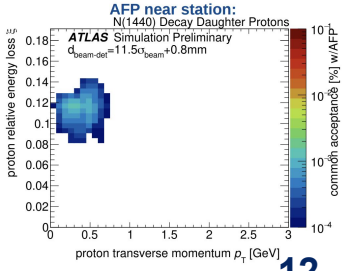












Summary

- ATLAS Forward Detectors continue to take data
- **LUCID** and **ZDC** preparing for HL-LHC upgrades
- **ALFA** concluded its data-taking campaign last year
  - → Lack of personpower means many datasets have not been touched!
- **AFP** continues to take data in both high-μ and special runs in Run 3
- Near-term future of AFP high-μ data-taking depends on LHC optics configurations
  - → Switch to horizontal crossing plane at IP1 results in zero acceptance for AFP
  - → Will participate in special runs (with vertical crossing plane) regardless
- New synergies between forward systems (AFP+ZDC+LHCf)
  - → ATLAS FDs plan to be involved in both pO and OO special runs in 2025

For public results relating to ATLAS FD performance, see
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ForwardDetPublicResults

Backup

List of acronyms

AFP = **A**TLAS **F**orward **P**roton

ALFA = **A**bsolute **L**uminosity **F**or **A**TLAS

ATLAS = **A** **T**oroidal **L**HC **A**pparatu**S**

BBA = **B**eam **B**ased **A**lignment

BRAN = **B**eam **RA**te of **N**eutrals

FD = **F**orward **D**etector

HI = **H**eavy **I**on

HL-LHC = **H**igh-**L**uminosity **LHC**

IP = **I**nteraction **P**oint

LHC = **L**arge **H**adron **C**ollider

LHCf = **LHC f**orward

LUCID = **LU**minosity measurement using **C**herenkov **I**ntegrating **D**etector

PMT = PhotoMultiplier Tube

TAN = Target Absorber for Neutrals

(**HP**)**TDC** = (**H**igh-**P**erformance) **T**ime to **D**igital **C**onverter

RP = **R**oman **P**ot

RPD = **R**eaction **P**lane **D**etector

SiT = **Si**licon **T**racking

ToF = **T**ime **o**f **F**light

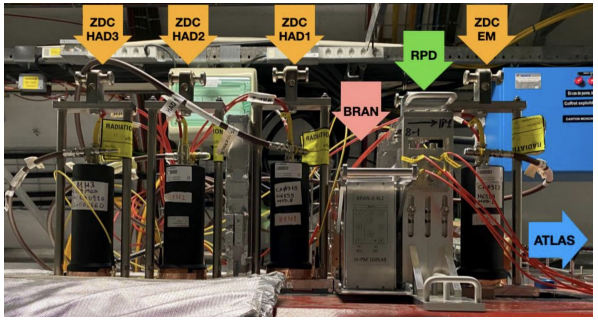
ZDC = **Z**ero **D**egree **C**alorimeter

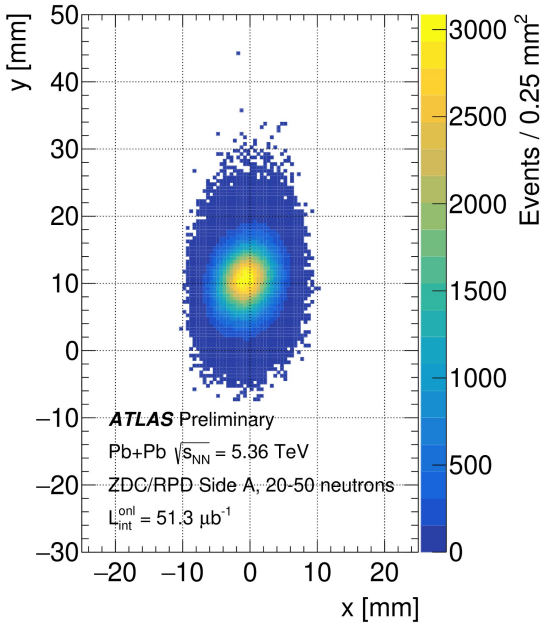
ATLAS luminosity detectors and algorithms

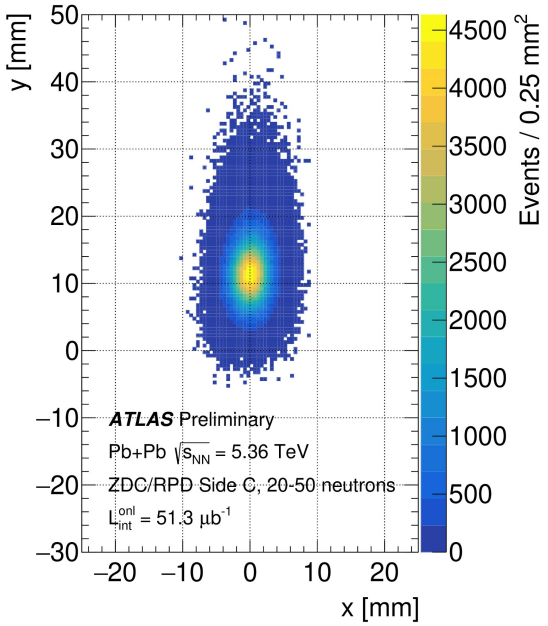
- Primary bunch-by-bunch luminosity measurement provided by LUCID
- Complemented by bunch-by-bunch measurements from
  - → ATLAS beam conditions monitor (BCM) diamond detectors
  - → Offline measurements of the track multiplicity in randomly selected colliding-bunch crossings (track counting)
- ATLAS calorimeters provide bunch-integrated measurements based on quantities proportional to instantaneous luminosity
  - → Liquid-argon (LAr) gap currents in the case of the endcap electromagnetic and forward calorimeters
  - → Photomultiplier currents from the scintillator-tile hadronic calorimeter

RPD side differences

- RPD data analysis shows some differences in the two sides, possibly from different sized EM modules

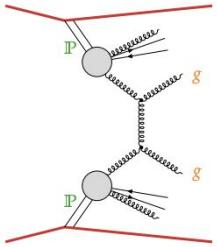






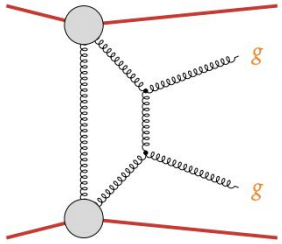
Distributions of the horizontal (x) and vertical (y) positions of the centroids of the showers measured in the RPD for events having between 20 and 50 neutrons in the ZDC. The centroids are obtained using online data. The elongation and shift in the vertical direction results from the light collection method and will be corrected in offline analysis.

AFP physics motivation



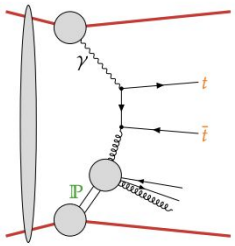
Diffractive jets

ATL-PHYS-PUB-2017-012



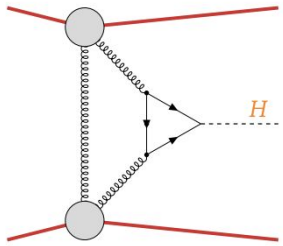
Exclusive jets

Trzebinski et al 1503.00699
Harland-Lang et al 1405.0018



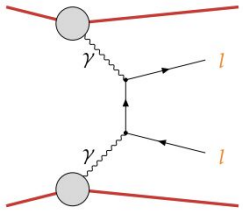
Top quarks

Goncalves et al 2007.04565
Howarth 2008.04249



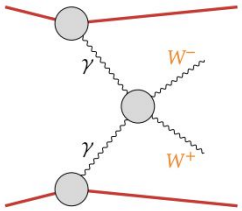
Higgs boson

Cox et al 0709.3035
Heinemeyer et al 0708.3052



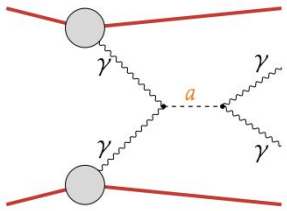
Leptons

CMS 1803.04496
ATLAS 2009.14537



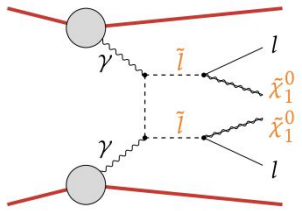
W bosons

Tizchang, Etesami 2004.12203
Baldenegro et al 2009.08331



Axion-like particles

Harland-Lang & Tasevsky 2208.10526
Baldenegro et al 1803.10835



SUSY dark matter

Beresford & Liu 1811.06465
Harland-Lang et al 1812.04886

Types of processes which allow protons to remain intact:

- **Diffraction** via pomeron exchange
- Exclusive **photon-photon fusion**

– **discrimination tool** for models:

- **QCD – hard and non-perturbative,**
- **probing electroweak scale,**
- **physics beyond SM.**

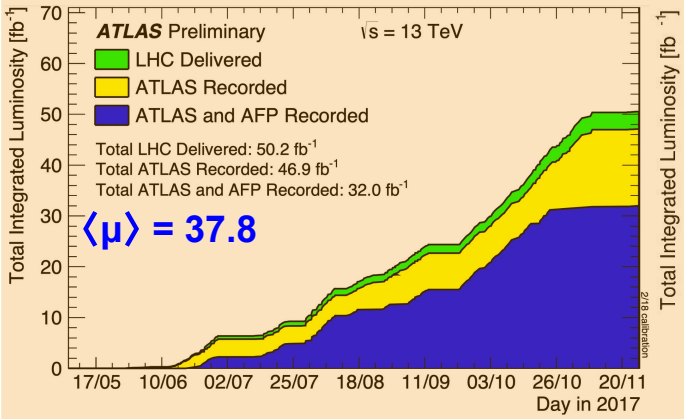
Natural ways to seek for diffraction

- rapidity gaps,
- **forward protons**

AFP available data

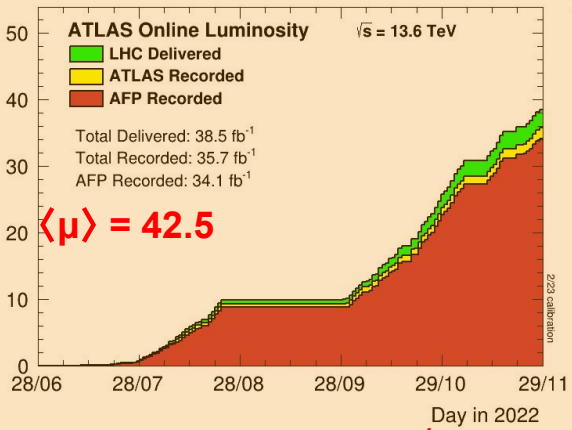
STANDARD RUNS

2017



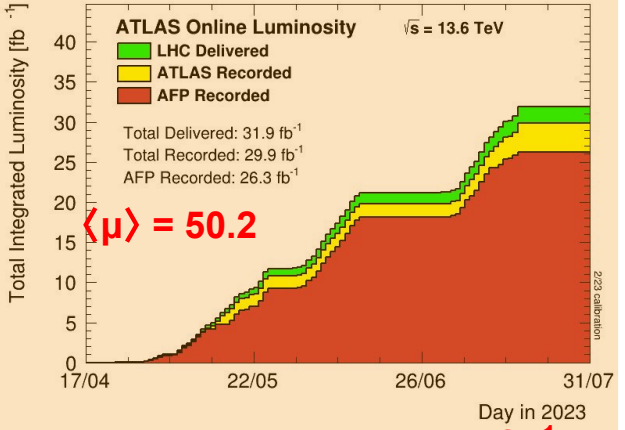
- AFP recorded **32.0 fb^{-1}**
- After ATLAS+AFP GRL = **14.6 fb^{-1}**

2022



- AFP recorded **34.1 fb^{-1}**
- After ATLAS+AFP GRL ≈ **25–30 fb^{-1}**

2023



- AFP recorded **26.3 fb^{-1}** as of the end of July

PHYSICS MOTIVATION: photon-induced processes, central exclusive diffraction

SPECIAL RUNS

2017

- $0.03 \lesssim \mu \lesssim 0.05$ = 100 nb^{-1}
- $0.3 \lesssim \mu \lesssim 1$ = 1.15 pb^{-1}
- $\mu \approx 2$ = 150 pb^{-1}

2022

- $\mu \approx 0.005$ = 0.4 nb^{-1}
- $\mu \approx 0.05$ = 35 nb^{-1}
- $\mu \approx 0.02$–1.0 = 170 nb^{-1}

2023

- $\mu \approx 0.05$ = 61 nb^{-1}
- $\mu \approx 0.2$ = 29 nb^{-1}
- $\mu \approx 1$ = 175 nb^{-1}

PHYSICS MOTIVATION: single-diffractive production, pomeron structure, rapidity gaps