Visegrad Fund

Overview of the ATLAS Forward Proton detector

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Theory and Experiment
in High Energy Physics

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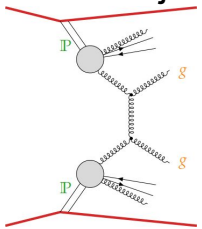
Physics Motivation

ATL-PHYS-SLIDE-2023-104

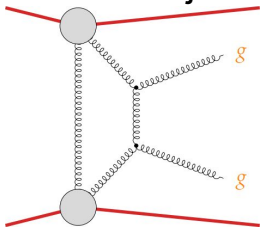
- Detection of events containing scattered intact protons
- Focused on low-cross section processes with high p_T objects in the final state
- Diverse physics program

Diffractive jets



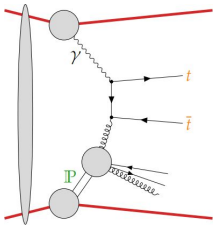
ATL-PHYS-PUB-2017-012

Exclusive jets



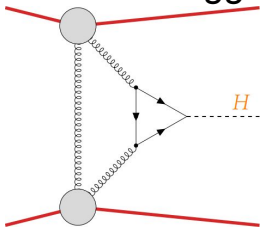
Trzebinski et al 1503.00699
Harland-Lang et al 1405.0018

Diffractive $t\bar{t}$



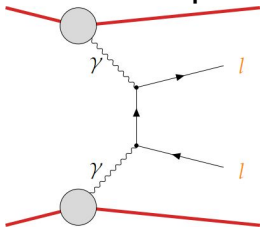
Goncalves et al 2007.04565
Howarth 2008.04249

Exclusive Higgs



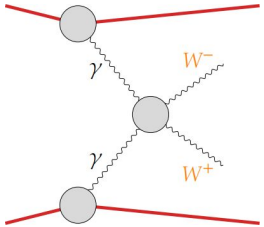
Cox et al 0709.3035
Heinemeyer et al 0708.3052

Exclusive Leptons



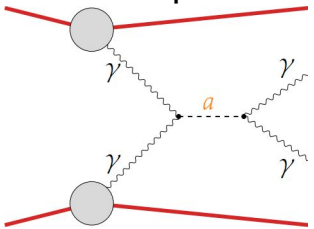
CMS 1803.04496
ATLAS 2009.14537

Exclusive W



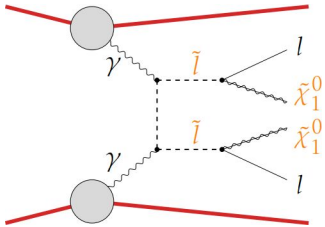
Tizchang, Etesami 2004.12203
Baldenegro et al 2009.08331

Axion-like particles



Baldenegro et al 1803.10835
ATLAS 2304.10953

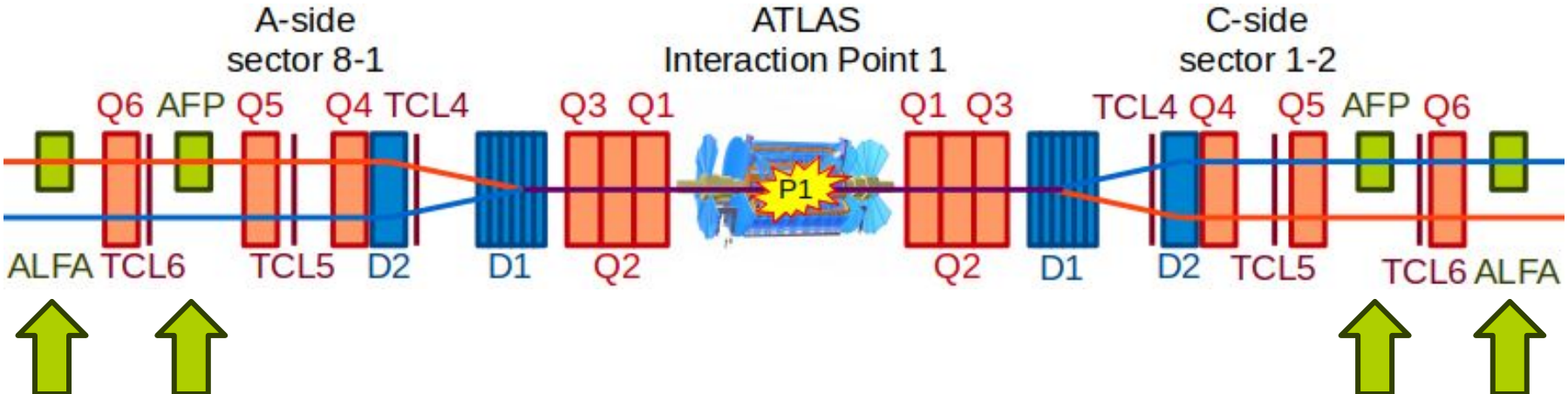
SUSY dark matter



Beresford & Liu 1811.06465
Harland-Lang et al 1812.04886

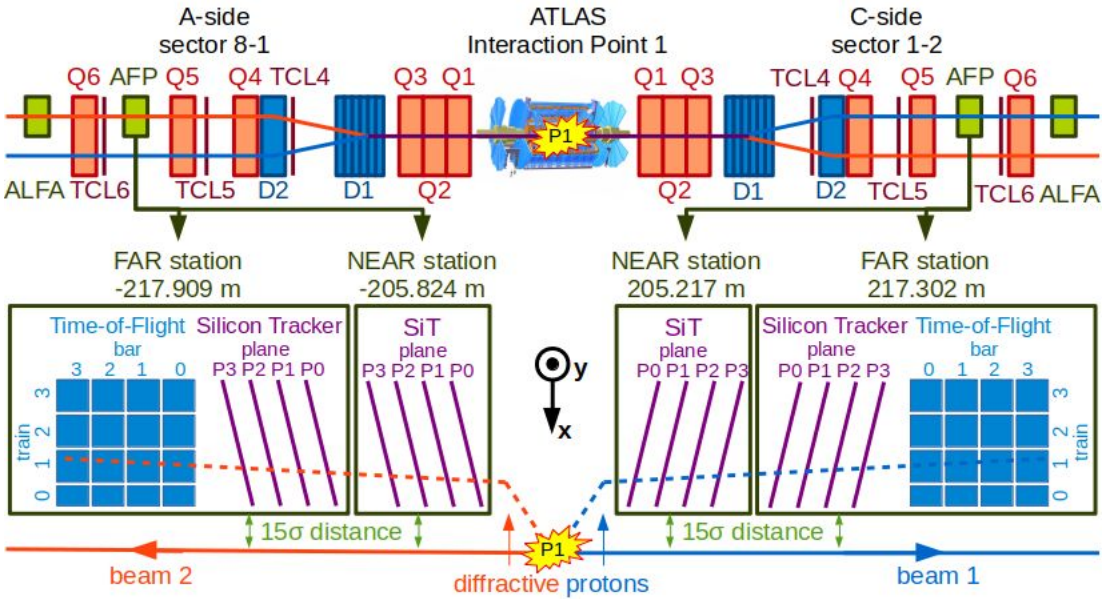
ATLAS Roman Pots

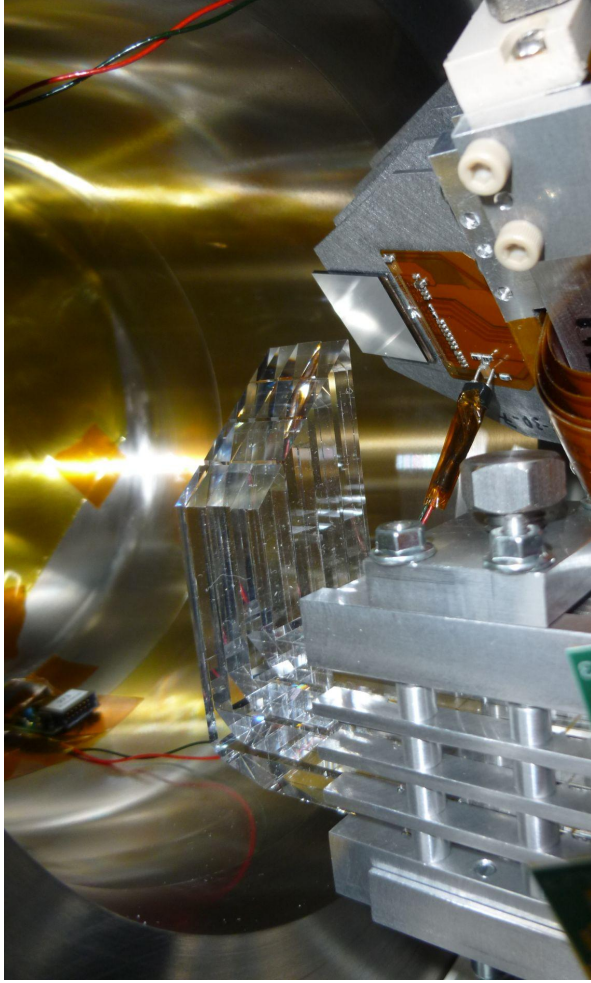
- Forward detectors - located in the LHC tunnel outside the ATLAS cavern
  - Around 210 meters from the ATLAS interaction point
- Move close to the beam (1-3 mm) once Stable Beams are declared
- Two detector systems
  - **ATLAS Forward Proton (AFP)**
  - Absolute Luminosity For ATLAS (ALFA) - not discussed in this talk



ATLAS Forward Proton (AFP)

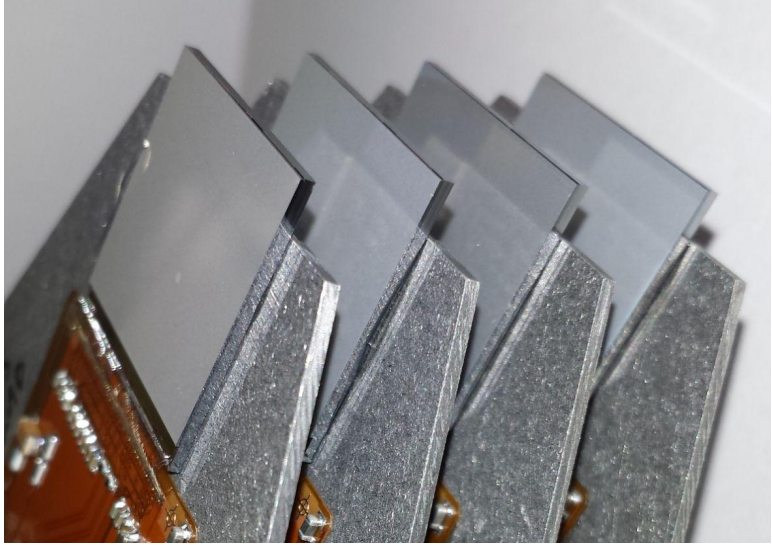
- Two stations on each side of ATLAS
- All stations host Silicon Tracker (SiT)
- Far stations host also Time-of-Flight (ToF) detector



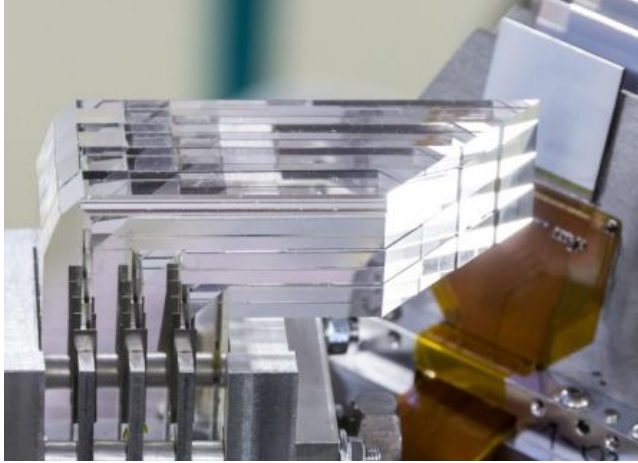


Silicon Tracker (SiT)

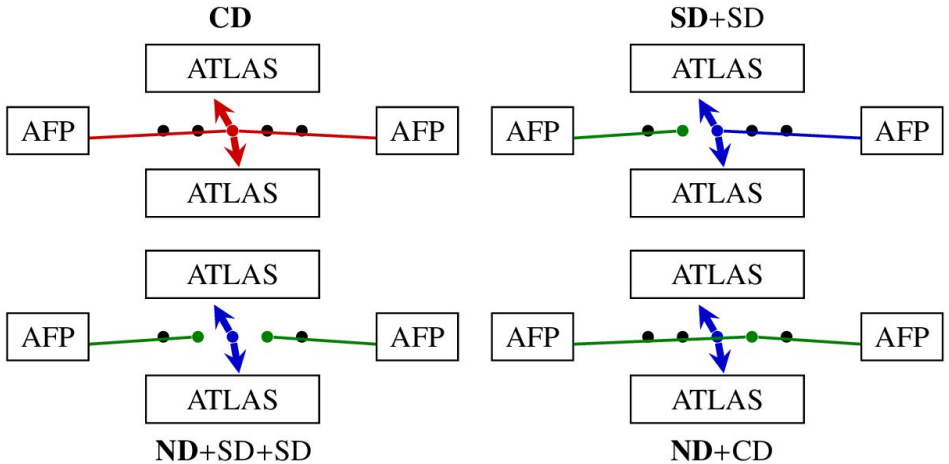
- Position measurement of scattered protons
  - Reconstruction of its kinematics
- 4 silicon pixel sensors
  - Spaced 9 mm apart
  - Each sensor 336x80 pixels
  - Pixel size 50x250 μm^2
  - Sensor size 16.8x20 mm^2
- Read out by FE-I4B chips
  - Same as ATLAS Pixel IBL
- 14° angle wrt. beam axis
  -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



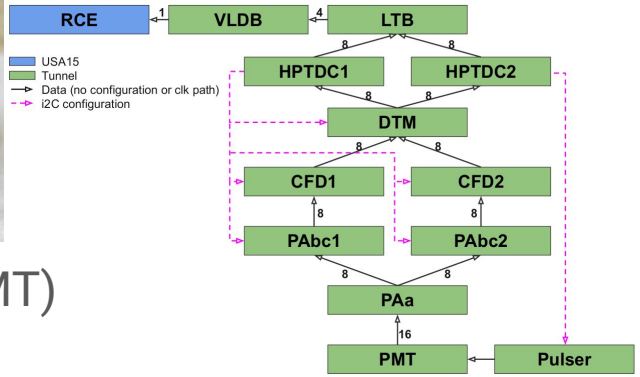
Time-of-Flight (ToF)



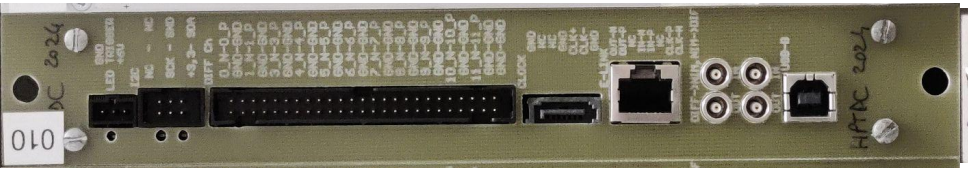
- Suppression of combinatorial background
- 16 quartz bars grouped in 4 trains
- Train/bar widths are 3 mm, 3 mm, 5 mm, 5.5 mm
- Passing proton emits Cherenkov radiation
- ToF bars shaped to direct the from the radiator to Photo-Multiplier



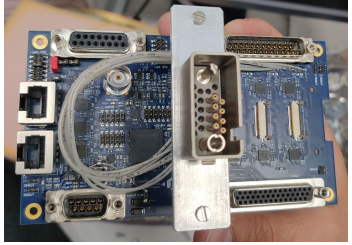
ToF chain

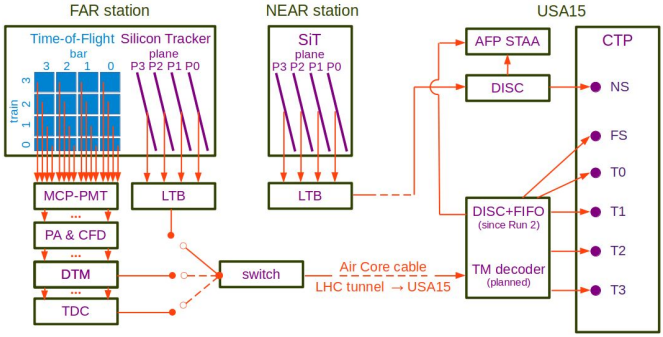


- Micro-Channel Plate Photo-Multiplier Tube (MCP-PMT)
- First stage pulse amplification (16x PAa)
- Second and third stage pulse amplification (2x PAbc)
- Signal normalization by Constant Fraction Discriminator (2x CFD)
- Signals filtered by Digital Trigger Module (DTM)
- Signal edges timestamped by High-Performance Time-to-Digital Converter
  - 2 TDC boards with 3 HPTDC chips each
  - In the future: 1 TDC board with 1 PicoTDC chip



Trigger



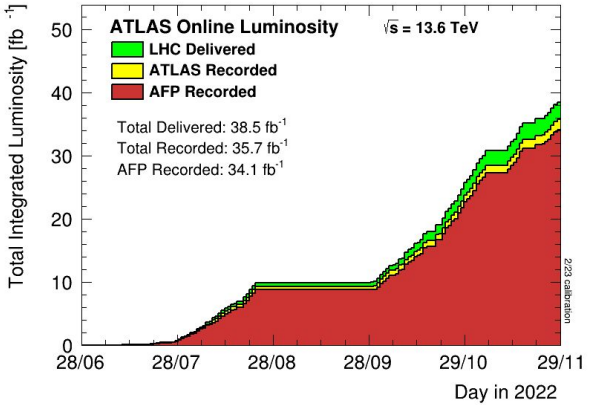


- SiT trigger signal sent by Local Trigger Board (LTB)
  - Standardly, requires signal from at least 3 planes
  - Can be reprogrammed to different logic
  - 400 ns deadtime
- ToF trigger signal sent by Digital Trigger Module (DTM) and Time-to-Digital Converter (TDC)
  - Requires signal from at least 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

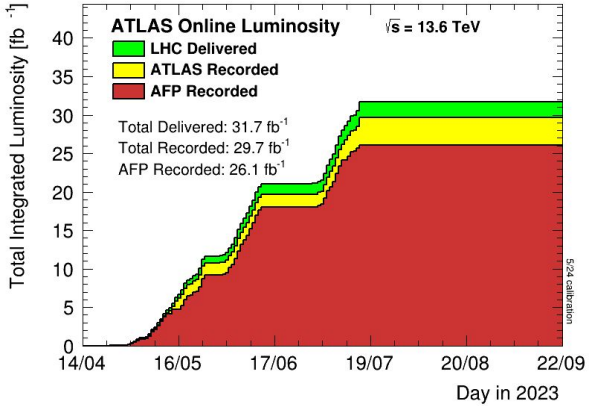
LHC Run-3 data-taking

Total in LHC Run-3 so far:
AFP recorded: 159.3 fb^{-1}
93.7 % wrt. ATLAS recorded
87.9 % wrt. LHC delivered

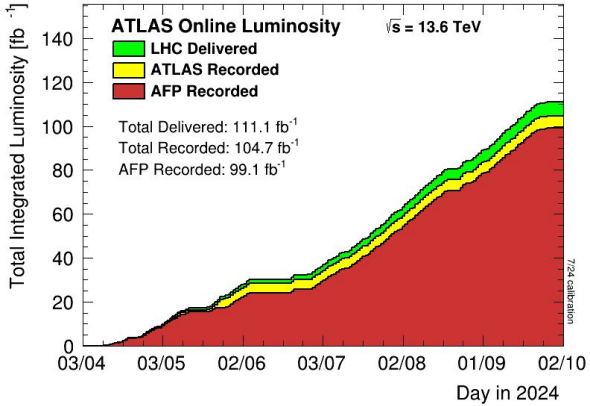
2022 at $\sqrt{s}$=13.6 TeV
AFP recorded: 34.1 fb^{-1}
95.5 % wrt. ATLAS recorded
88.6 % wrt. LHC delivered



2023 at $\sqrt{s}$=13.6 TeV
AFP recorded: 26.1 fb^{-1}
87.9 % wrt. ATLAS recorded
82.3 % wrt. LHC delivered



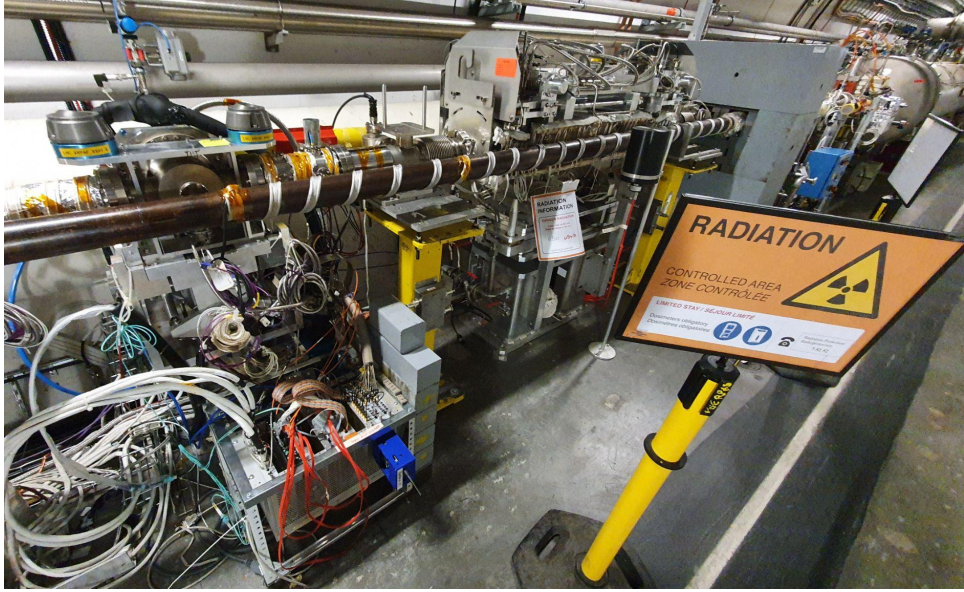
2024 (so far) at $\sqrt{s}$=13.6 TeV
AFP recorded: 99.1 fb^{-1}
94.7 % wrt. ATLAS recorded
89.2 % wrt. LHC delivered

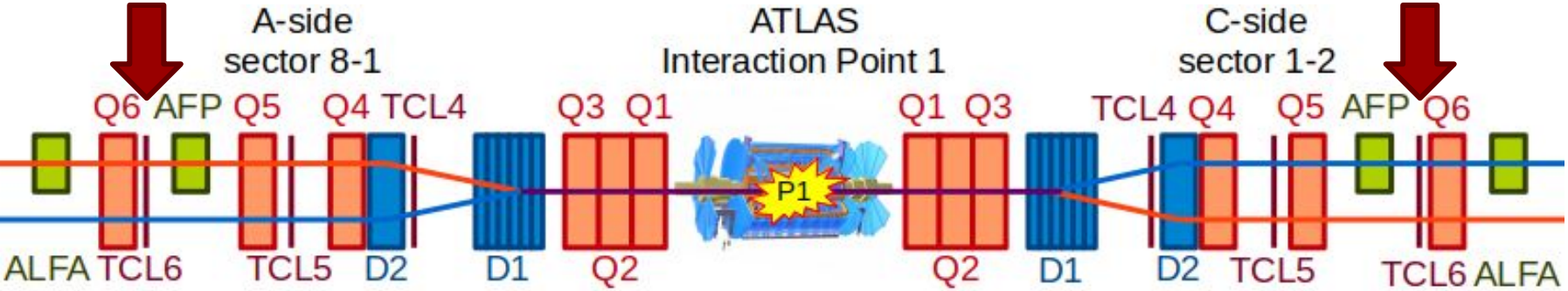


https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun3

Challenges

- Damage from harsh radiation environment
- Far stations 1 meter from collimators
- Problematic replacement of modules
  - Custom-made hardware
  - Rare tunnel access
  - High radiation dosage





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)

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

Automatic Recovery

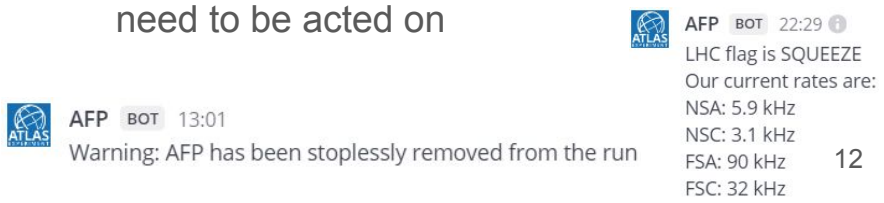
- Reconfiguration of modules
- Scheduling of next reconfiguration attempts after failed attempt
- Optional power-cycle after several failed attempts

Improved online monitoring

- Lots of new histograms
- Increased statistics

Mattermost Bot

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

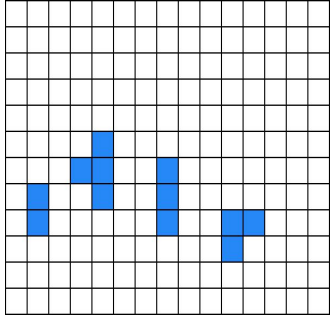


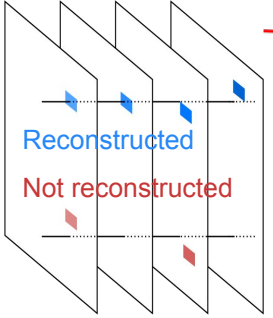
Summary

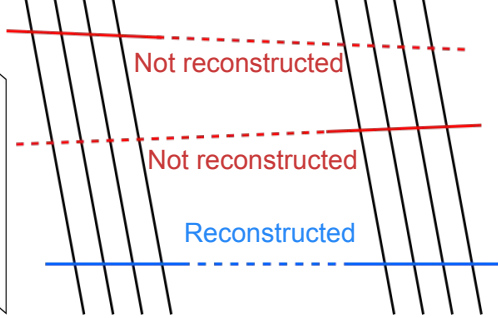
- Diverse physics programme possible with AFP
- Efficient data-taking during the high-μ campaigns as well as during special, low-μ runs:
  - AFP team bigger and younger than in Run-2
  - Continued work to improve data-taking efficiency
  - Data analyses ongoing
- Two analyses published, more is expected in the near future:
  - Diphoton resonance search with AFP tag, JHEP 07 (2023) 234 (2009.14537)
  - Observation of forward proton scattering in association with lepton pairs produced in photon fusion, Phys. Rev. Lett. 125 (2020) 261801 (2304.10953)
- AFP ToF Performance in LHC Run-2, JINST 19 (2024) P05054
- Following talks:
  - Viktoriia Lysenko: Analysis of AFP ToF data from early LHC Run-3 (Wed 16:45)
  - Maciej Piotr Lewicki: Hard diffraction in ATLAS (Thu 9:45)
  - Marek Taševský: Searches for QCD instantons with forward proton tagging (Thu 11:00)
  - Karel Černý: The ATLAS Forward Proton Time-of-Flight Detector System (Thu 11:30)

Backup

“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