

Adrien AURIOL, adrien.auriol@cern.ch December 14, 2021 Performance of AFP Detector during LHC Run 2 LHCFPWG - on behalf of ATLAS Forward Detector

AFP Overview (1)

Intro.

- 2 stations at $z \simeq 210$ m on each side of IP ("A-NEAR","A-FAR","C-NEAR","C-FAR")
- 4 planes of silicon tracking /stations
- FAR stations also have time-of-flight (ToF)



AFP Overview (2)





- Acceptance for protons losing $\simeq 2 12\%$ of their energy
- 32 fb⁻¹ recorded under high lumi. conditions in 2017
 - \Rightarrow Revolutionary dataset for tagged proton physics

Physics processes - examples

- Single proton diffractive dissociation
- Very large cross section ($\simeq 15\%$ of σ_{tot})
- Dominant source of proton in AFP (pile-up)

Large cross section

- Processes with two final state protons dominated by $\gamma\gamma$ scattering in ξ acceptance region
- Dileptons : Subject of recent AFP publication
- Important calibration tool due to exclusivity

Low cross section

Longer-term AFP program is mainly rare and exotic $W^{W/Z/\gamma}$ processes with $\gamma\gamma$ initial state and two tagged final $W_{W/Z/\gamma}$ state protons

Low cross section / Exotic

Intro.

ToF Performance





- Time resolutions at 30 ps level for single channels (\simeq 20 ps when integrated over train)
- Corresponding vertex resolution $\simeq 6 \pm 1$ mm
- Poor efficiencies in first AFP runs (PMTs degraded fast)
 - □ 1-9 % single channel
 - 5-10 % per 4-bar train
- Issues addressed promising perspectives for Run 3 and beyond

SiT - Single pixel / Plane efficiencies

- 14° angle to vertical results in two pixel hits per plane in most cases
- \blacksquare Single plane efficiencies \simeq 98% for bias voltage \gtrsim 20 V
- In situ, some evidence for ageing. Efficiency drops at low bias voltage for regions of planes with highest occupancy (closest to beam)
- Multiple algorithms and techniques developed to identify dead, low efficiency and noisy pixels
- Can be carried forward to Run 3 on-line / off-line monitoring



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SiT - Local alignment

Local alignment of each plane within a station was determined using redundancy with respect to other planes.

- Form residuals on each plane relative to reconstructed tracks
- Correct for shifts in x and y direction and rotation about z axis
- Iterate I

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Aligned to better than 10 μ m within a Roman pot station



Global alignment (1)

- Alignment of stations relative to one another exploits redundancy in kinemactics in exclusive diLepton data
- ξ (and equivalently x coordinate in AFP) can be predicted from the leptons

$$\xi^\pm_{\mu\mu}=rac{m_{\mu\mu}}{\sqrt{s}}e^{y_{\mu\mu}}$$
 ; $\xi_{
m AFP}=1{-}rac{E'_
ho}{E_
ho}$

 Small background well modelled by event mixing





Global alignment precision uncertainty currently quoted as $\frac{300 \ \mu m}{\mu m}$ but better uncertainty seems achievable.



Reconstructed proton signal



- Characteristic diffractive signal (dominantly single dissociation $pp \rightarrow pX$)
- Trigger rate (2 out of 3 coincidence of selected SiT planes) follows pile-up rate in special runs (*i.e* beam-induced background is small)
- Occupancy ~ 0.02 reconstructed track segments / pot station / pp collision



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From tag and probe (*eg.* NEAR vs FAR station) $\Rightarrow \simeq 99\%$ in NEAR station, $\simeq 95\%$ in FAR stations (showering)



From special low- μ runs, some evidence for ageing in region nearest to beam.

Showering in SiT planes and pot walls



- Evidence for modest level of showering in material of SiT planes (long non-Poisson tail, growing with distance from track start)
- Showering also takes place in pot windows
- Largest contribution to inefficiencies

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First High Lumi AFP publication (15 fb⁻¹)



diLepton signal observation based on redundancy in kinematics (proton energy loss ξ measured with AFP and central detector)

Resolution on $\xi \simeq 10\%$: contributions from intrinsic detector resolution and (at lowest ξ) multiple scattering



- 57 (123) candidates observed in the $ee + p (\mu \mu + p)$ final state
- Highest-mass *ee* candidate has m_{ℓℓ} = 717 GeV and y_{ℓℓ} = 0.252

First High Lumi AFP publication (15 fb⁻¹)

October 1, 2020

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN



Observation and measurement of forward proton scattering in association with lepton pairs produced via the photon fusion mechanism at ATLAS

The ATLAS Collaboration

The observation of forward proton scattering in association with lepton pairs ($e^+e^- + p$ or $\mu^{+}\mu^{-} + p$) produced via photon fusion is presented. The scattered proton is detected by the ATLAS Forward Proton spectrometer while the leptons are reconstructed by the central ATLAS detector. Proton-proton collision data recorded in 2017 at a center-of-mass energy of $\sqrt{s} = 13$ TeV are analyzed, corresponding to an integrated luminosity of 14.6 fb⁻¹. A total of 57 (123) candidates in the $ee + p(\mu\mu + p)$ final state are selected, allowing the background-only hypothesis to be rejected with a significance exceeding five standard deviations in each channel Proton-tagging techniques are introduced for cross-section measurements in the fiducial detector acceptance, corresponding to $\sigma_{exc.n} = 11.0 \pm 2.6 \text{ (stat.)} \pm 1.2 \text{ (syst.)} \pm 0.3 \text{ (lumi.)} \text{ fb}$ and $\sigma_{unt,n} = 7.2 \pm 1.6 \, (stat.) \pm 0.9 \, (syst.) \pm 0.2 \, (lumi.)$ fb in the dielectron and dimuon channel, respectively.

$\sigma_{\rm Herwig+Lpair} \times S_{\rm surv}$	$\sigma_{ee+p}^{\mathrm{fid.}}$ [fb]	$\sigma^{\rm fid.}_{\mu\mu+p}$ [fb]
$S_{\text{surv}} = 1$ S_{surv} using Refs. [30, 31]	15.5 ± 1.2 10.9 ± 0.8	13.5 ± 1.1 9.4 ± 0.7
SuperChic 4 [94]	12.2 ± 0.9	10.4 ± 0.7
Measurement	11.0 ± 2.9	7.2 ± 1.8

First LHC measurement of a proton tagged $\gamma\gamma$ cross section !

These measurements are sensible about S_{surv}

- Global alignment systematic (dominant on ξ measurement at low ξ)
 - Robustness / systematic checks with muon-based method
 - Include beam-spot position changes in calculations
 - Include Roman pot thermal expansion data in calculations



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- Beam optics systematic (dominant at high ξ)
 - Investigate sensitivity to varying magnet strengths
 - □ "Effective optics" from data (test assumption on correlation between x position and ξ in $\Delta \xi$ distributions)
- Improving simulation tool
 - $\hfill\square$ Tuning ξ resolution parameter using diLepton $\Delta\xi$ data
 - Implementing pile-up
- Extend ξ range for 2-station events and use FAR station only events

AFP Lumi Monitoring (2018 Data study)





- Precision based on counting AFP tracks is at 1% level relative to LUCID
- Statistics could be improved by combining stations
- Possible use in Run 3 ?

Summary

- We reached a complete first understanding of 2017 data
- Further optimisations ongoing
 - □ Understanding of systematics (global alignment, beam optics)
 - Improving simulation
- More publications still to come
 - Performances of SiT
 - Performances of ToF
 - Physics publications
- Promising for future (Run 3, Run 4...)