INSTITUTE OF EXPERIMENTAL AND APPLIED PHYSICS CTU IN PRAGUE

Visegrad Fund

ATLAS EXPERIMENT

ATLAS work in progress

Analysis of AFP ToF data from early LHC Run-3

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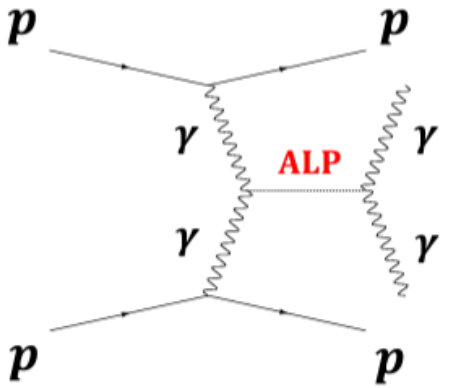
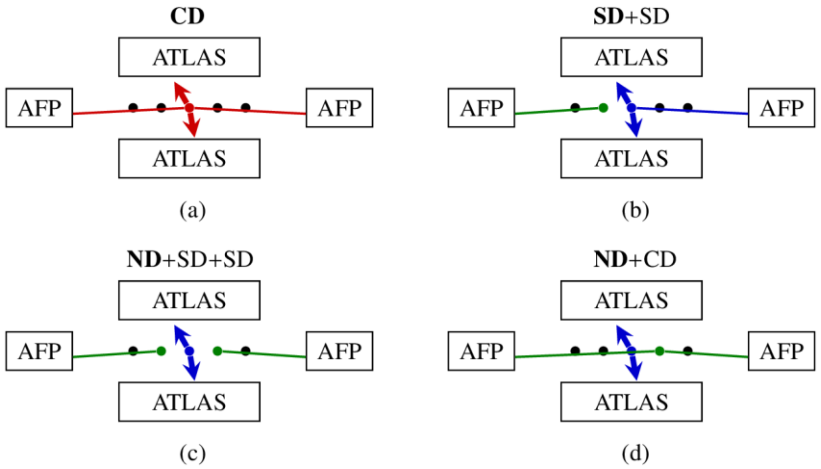
Theory and Experiment in High Energy Physics in Prague 2024

ALP motivation

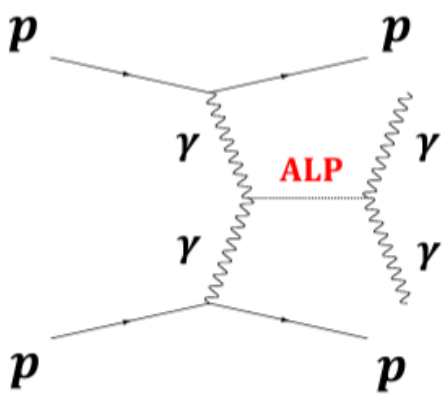
- Many extensions of the Standard Model use Axions and Axion-like particles (ALP), which are considered as candidates for particles that make up dark matter.
- Vertex position of di-photons are used as a criteria to separate di-photon events coming from the expected ALP signal from such events produced in background processes.
- The ToF detector will provide data to improve the vertex reconstruction.

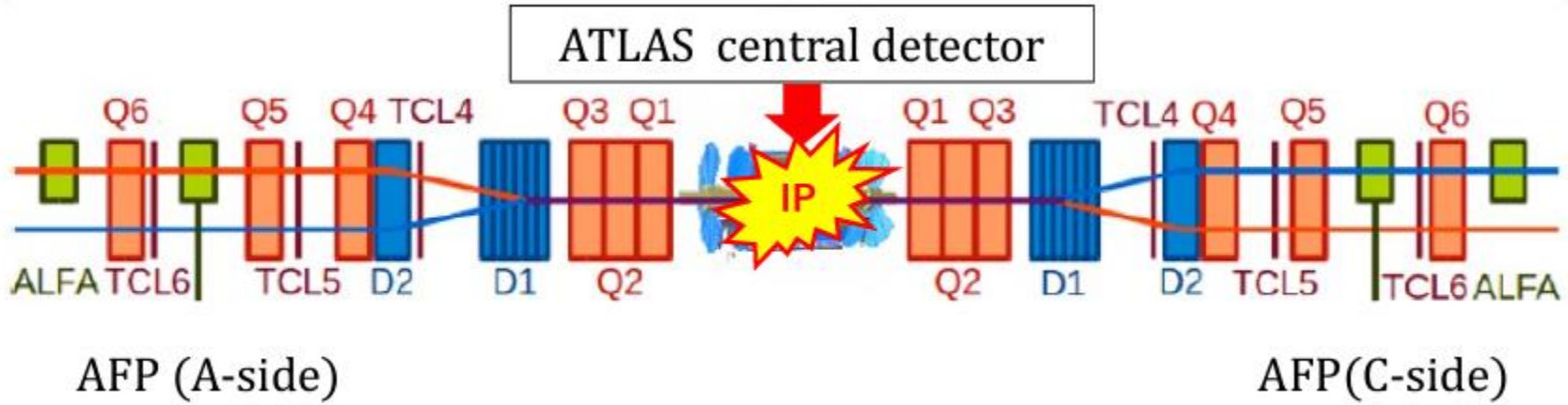




ATLAS Forward Proton (AFP) detector

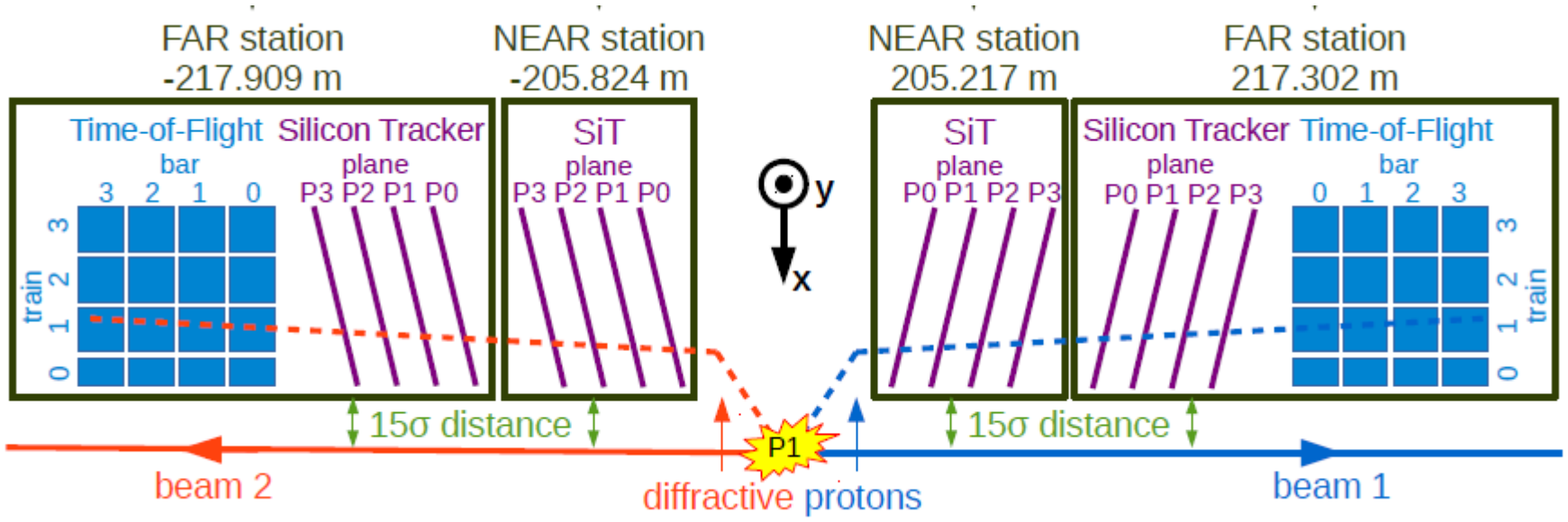
- ATLAS Forward Proton (AFP) detects protons undergoing small or zero angle scattering at the interaction point (IP), while losing energy through, for example, photon emission.
- Photons events from process of central exclusive di-photons production $pp \rightarrow p(\gamma\gamma)p$ are recorded with the ATLAS central detector.





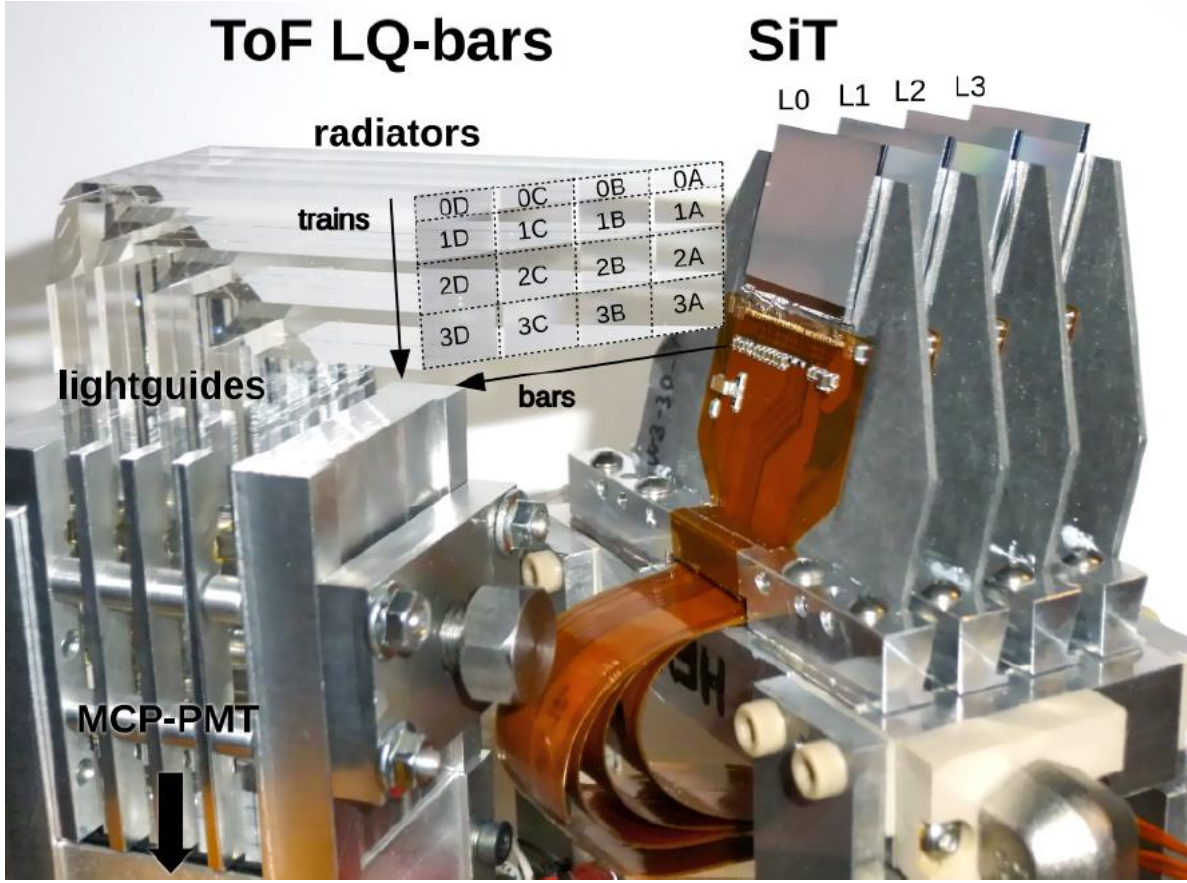
ATLAS Forward Proton (AFP) detector

- AFP consists of four stations: NEAR and FAR, on anticlockwise (A) and clockwise (C) sides.
- Each side of the AFP systems is referred to as an arm.
- For tracking the Silicon tracker (SiT) is used, which consists of four layers of silicon pixel detectors.
- FAR stations additionally equipped with the Time-of-Flight (ToF) detectors.



Time-of-Flight (ToF)

- Measurement of protons' time-of-arrival can be used for the reduction of background.
- The ToF detectors collect Cherenkov photons created in L-shaped fused silica bars, which are placed behind the tracker plates.
- Four bars are placed one after another to form a train. There are four trains on each side.
- Each cell (0A, 1B, etc.) is called “channel”.



[Forward Detectors Public Results]

ToF Efficiency

Method

- First sample: events passing main selection criteria and in addition it has to be inside a specific region of SiT
  - 4 numbers for each ToF train
- Second sample: defined for each ToF channel
  - 16 numbers for each ToF channel
- Final efficiency: the ratio of the number of events in the sample two (each channel) and number of events in the sample one (each train).

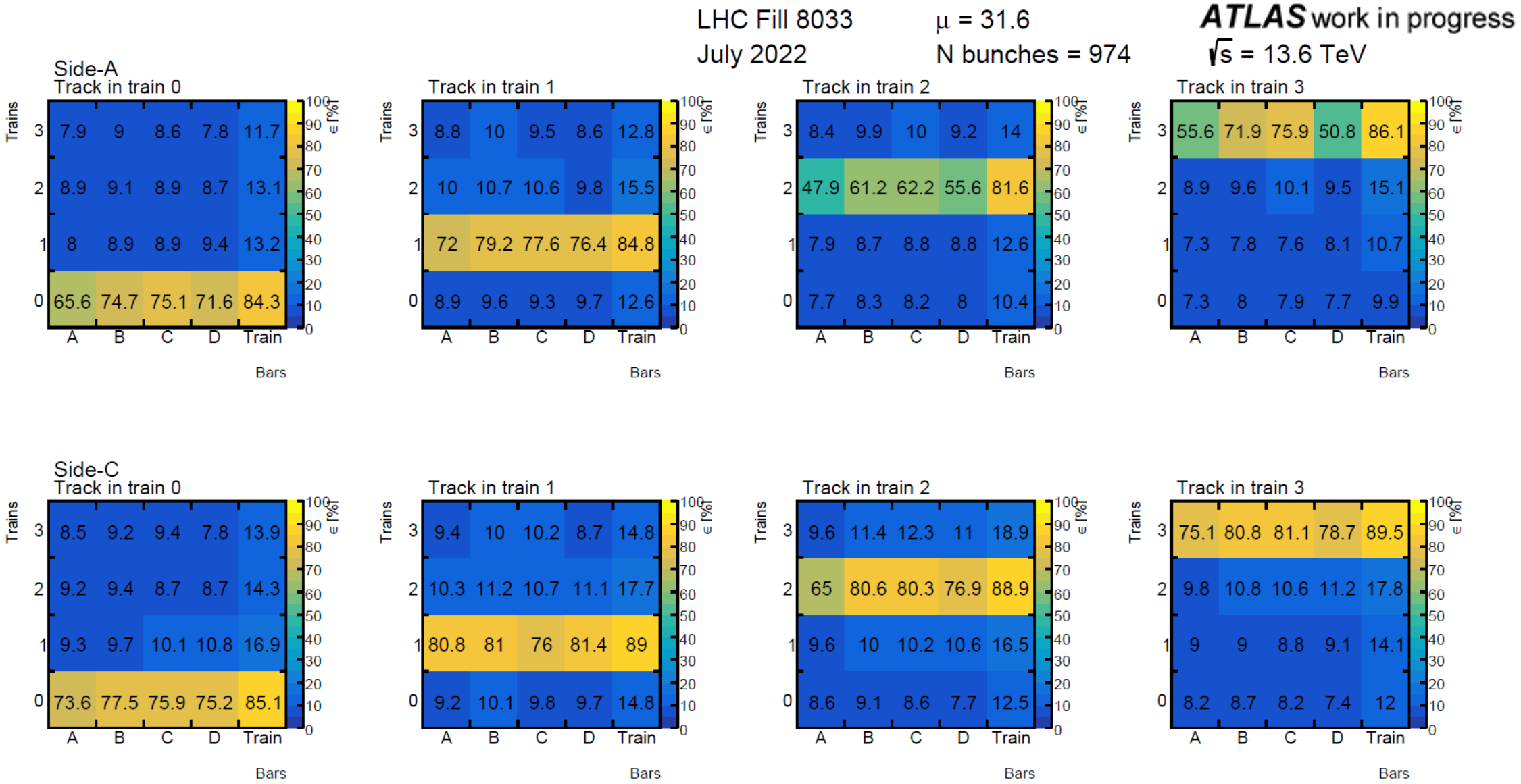
Following requirements were imposed on the data:

- One track in the SiT Far per event.
- One hit per channel in ToF per event.
- One active train in the ToF per event (ON/OFF)
  - ON – gives clean signal, but reduces statistics
  - Here only results without this extra requirement are shown

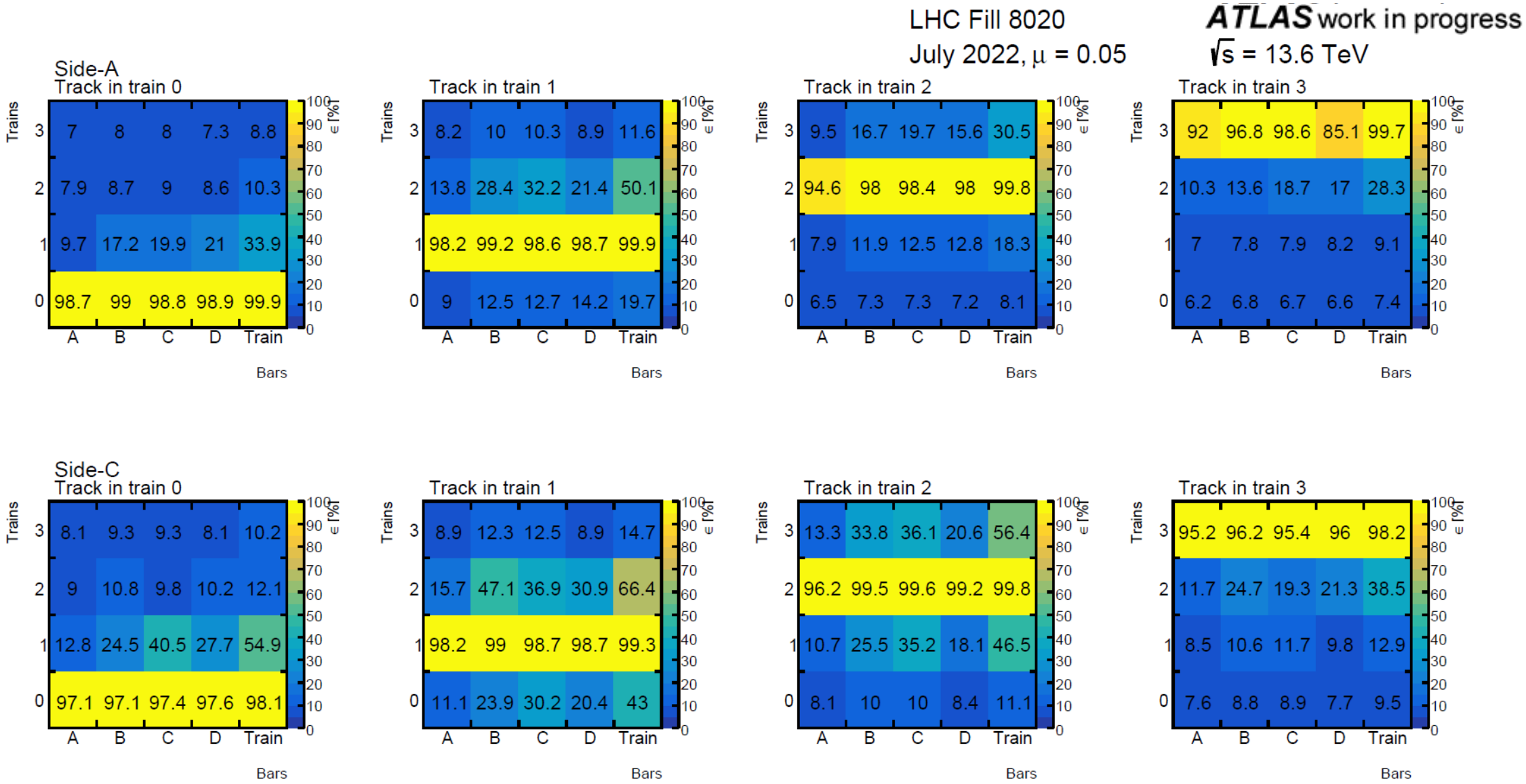
The regions for the x-value of the SiT, corresponding to the ToF train were defined experimentally for each side (A and C).

Train №	A-side (mm)	C-side (mm)
0	-4.9 to -2.0	-5.3 to -2.0
1	-8.0 to -5.0	-8.4 to -5.4
2	-13.0 to -8.1	-13.4 to -8.5
3	-15.0 to -13.1	-15.0 to -13.5

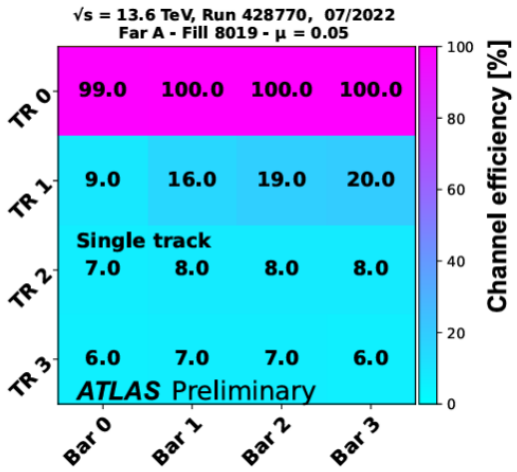
Efficiency (1 train req. OFF) track pointing

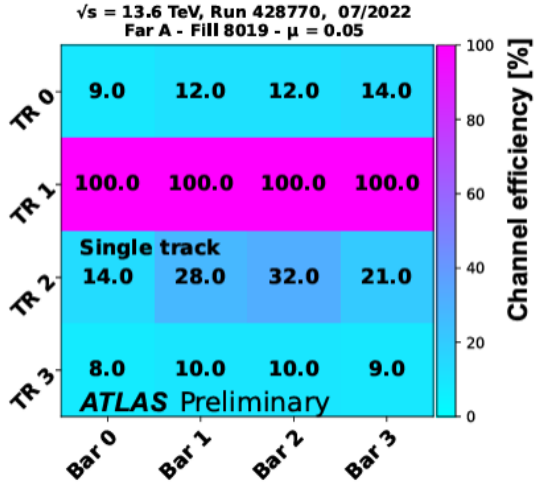


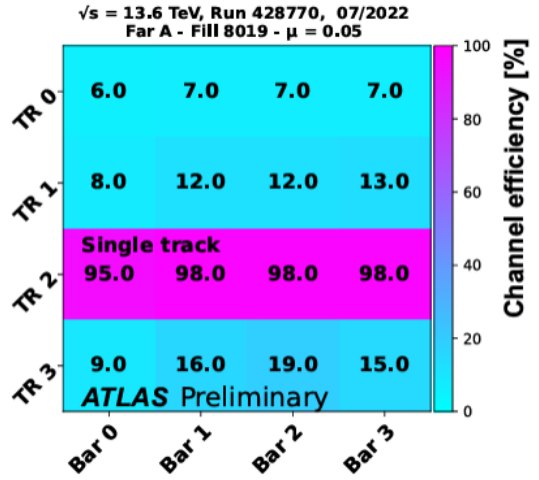
Efficiency (1 train req. OFF) track pointing

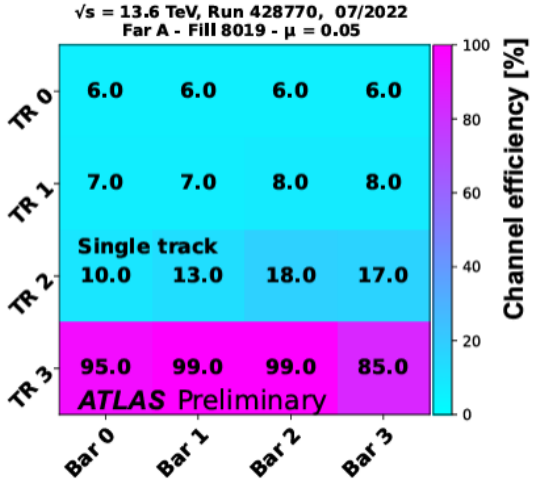


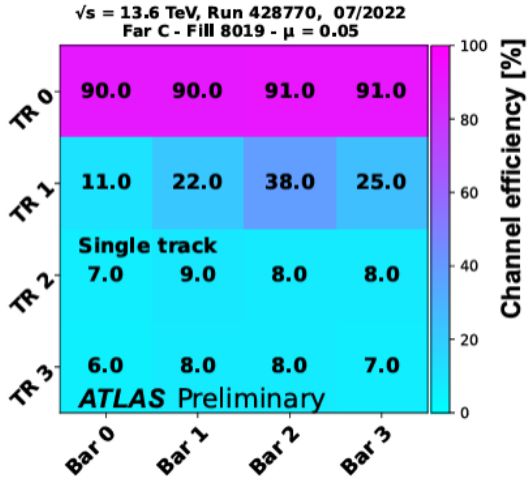
ToF Efficiency

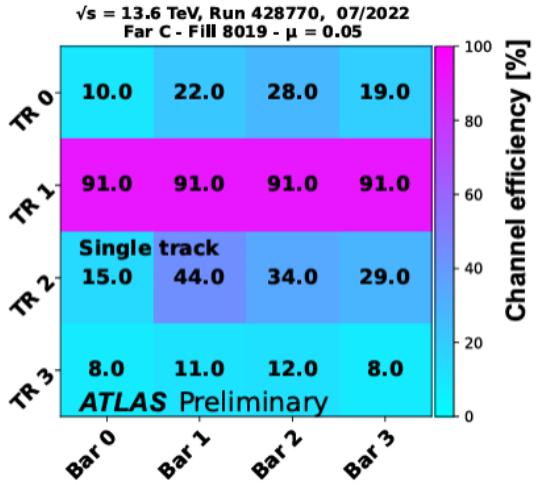


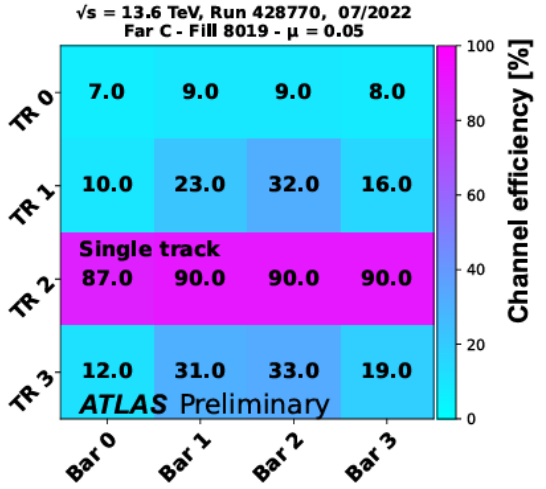


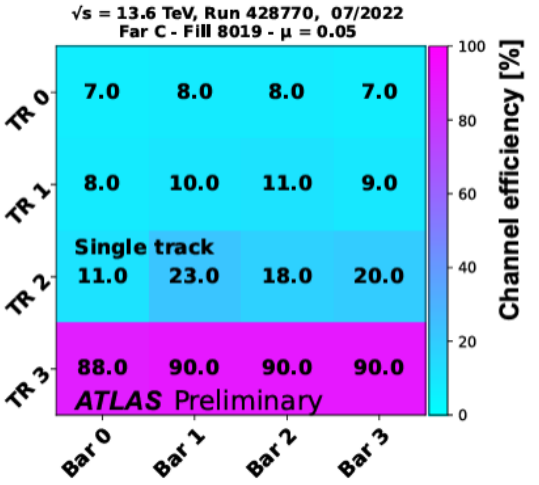












Another method, used by Daniel Ernani (Forward Detectors Public Results)

ToF Efficiency

Further analysis of ToF data in 2022 and 2024 years is ongoing.

The following dependencies were found:

- ToF efficiency is depended on number of interaction per munch crossing (μ)
- ToF efficiency is depended on a filling scheme of LHC (number of bunches)

Such dependencies are connected to constrains of electronics and are under investigation by the engineering ToF team.

New ways of improving the situation are being tested.

Di-proton ToF vertex reconstruction: time delays

- The time measured in one ToF channel is made up from several components, one of them is constant time delay, individual for each channel.
- Method, proposed by Karel Cerny: $z_{ToF} = \frac{c}{2}\,(t_C - t_A)$ value in its mean value copy the z-position of the luminous ATLAS beamspot.

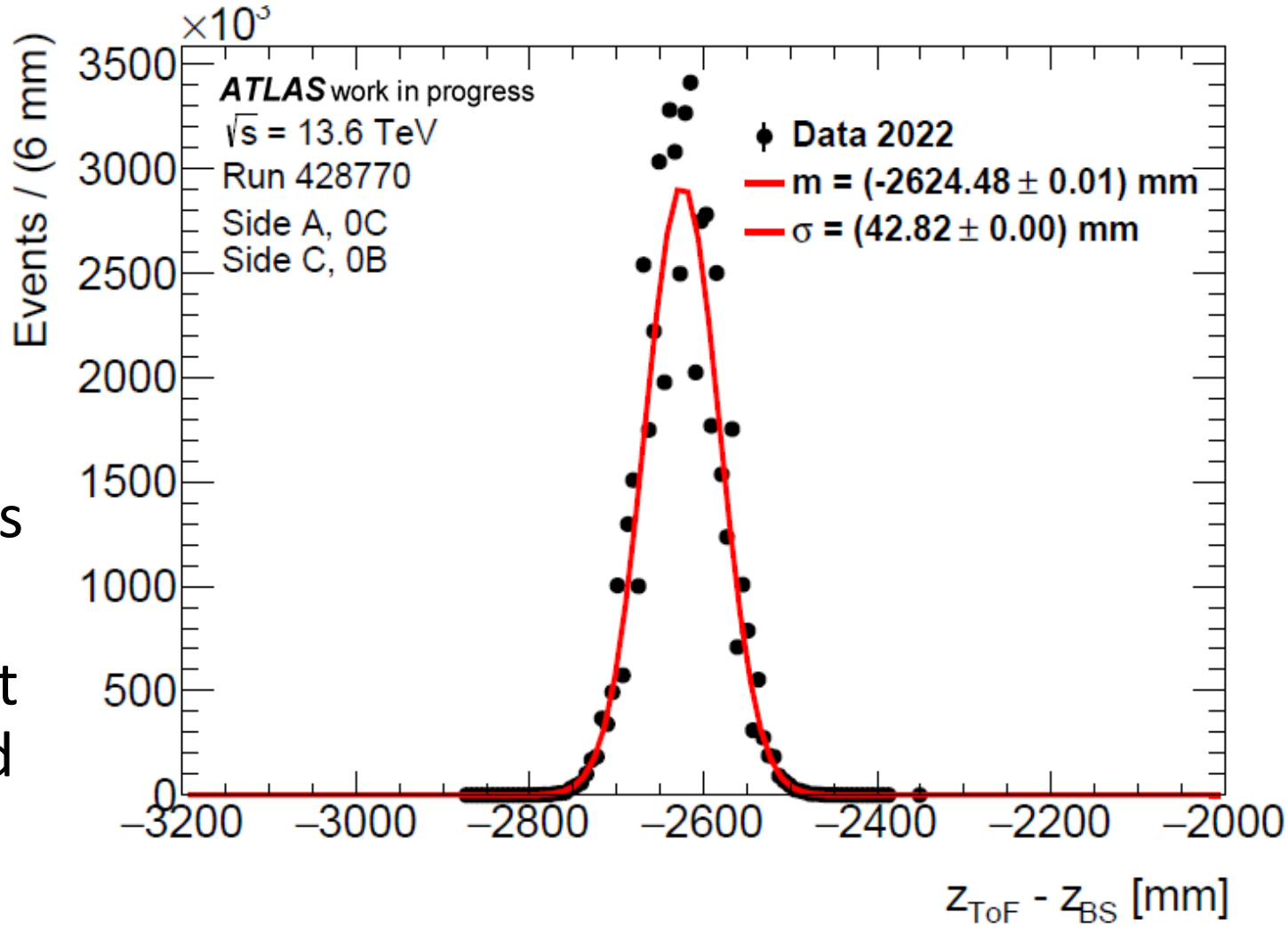
- Requirements on data:
  - One track in SiT per event
  - One active train in the ToF per event

Di-proton ToF vertex reconstruction: time delays

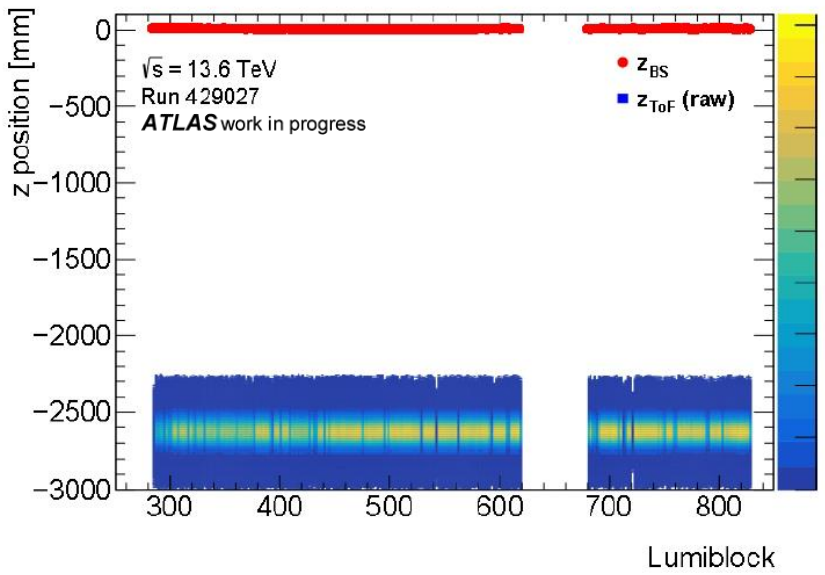
Channel delays and ToF positions are absorbed into correction factors “D”

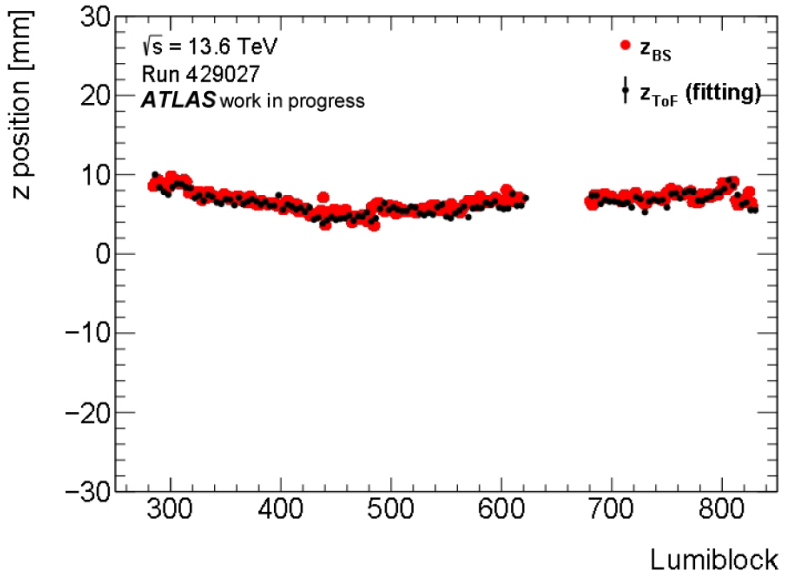
$$< \sum_{LB} z_{\mathrm{ToF}}^{(ij)} - z_{\mathrm{BS}} >= D_C^j - D_A^i$$

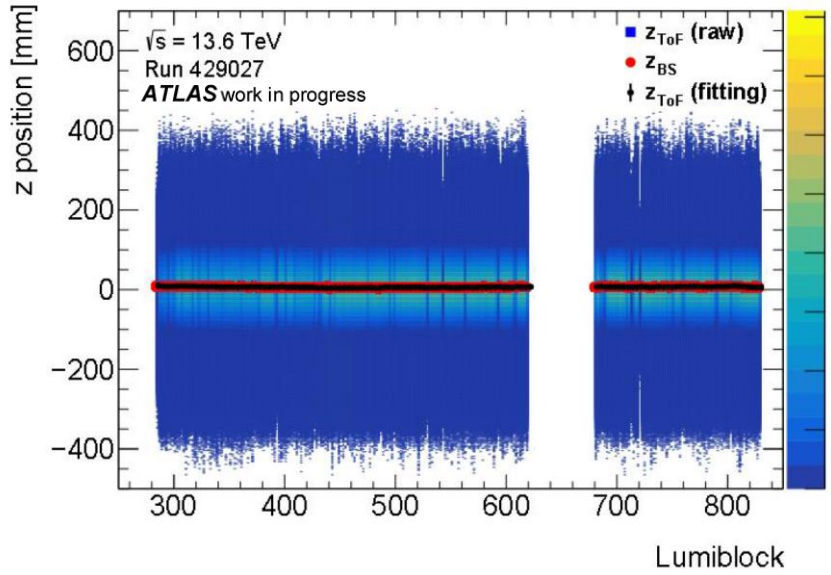
- ToF z-position is obtained within one lumiblock, using mixed events technique.
- Using chi-squared minimization fit 32 correction factors are obtained from 256 time delays.

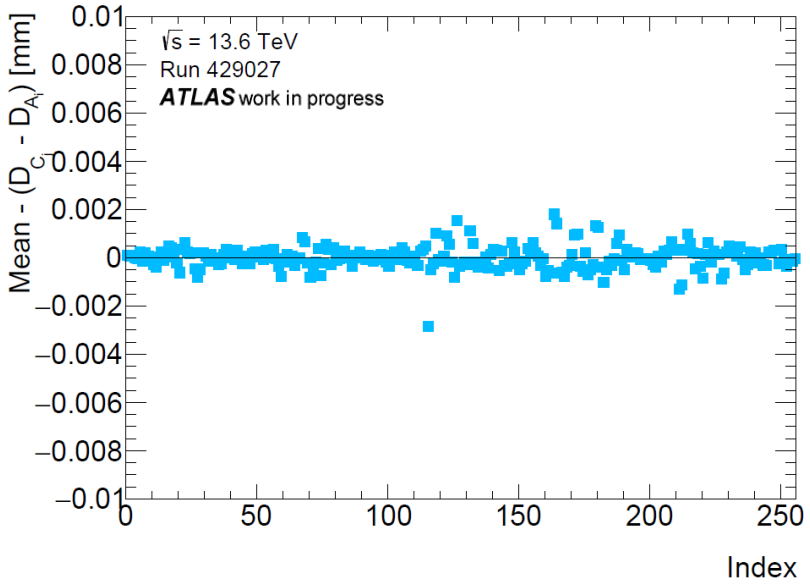


Run 429027 (μ = 31.6) Before/after

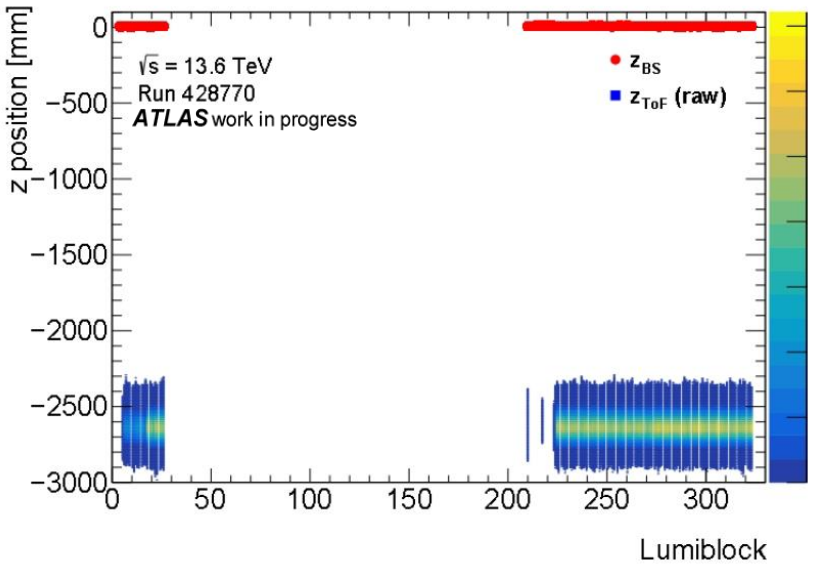


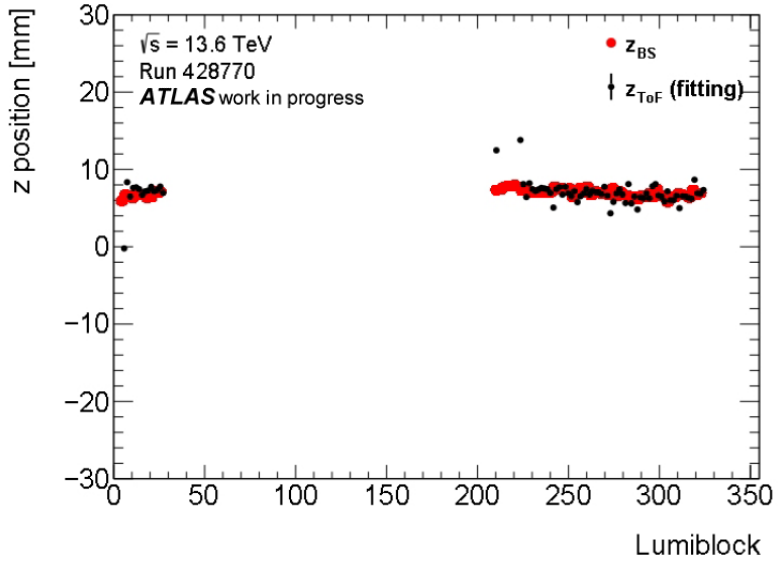


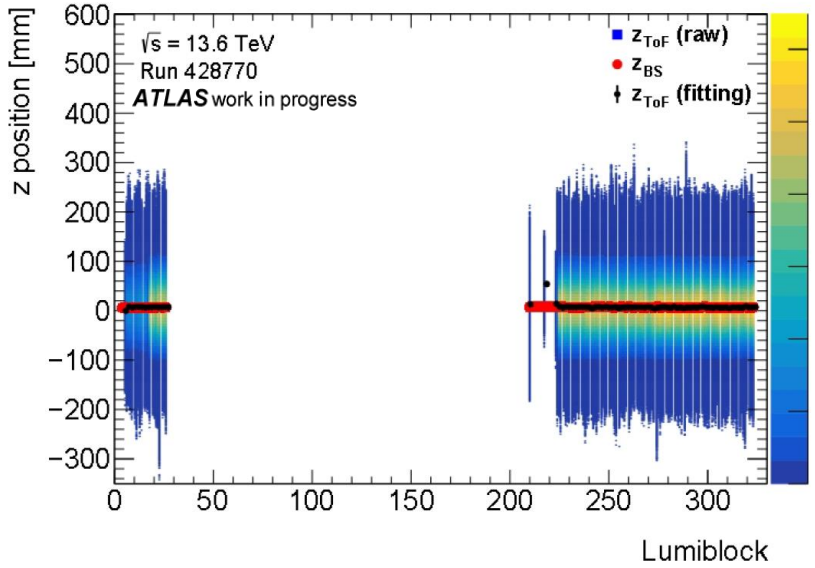


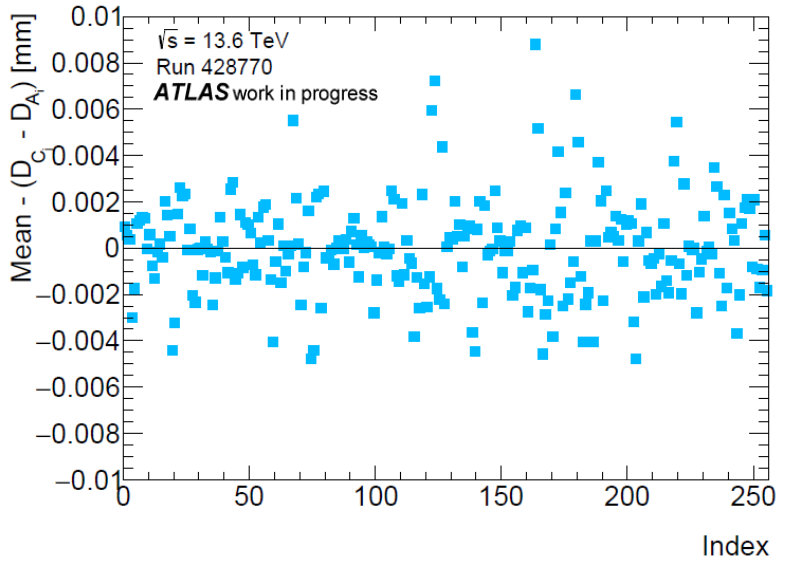


Run 428770 (μ = 0.05) Before/after



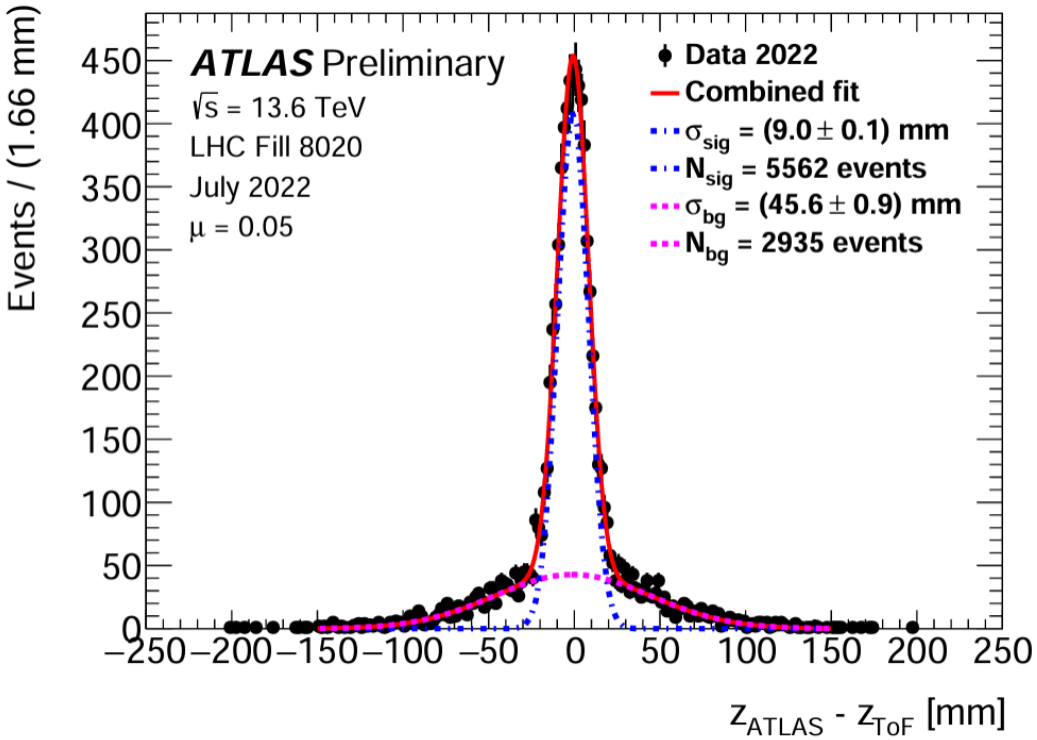




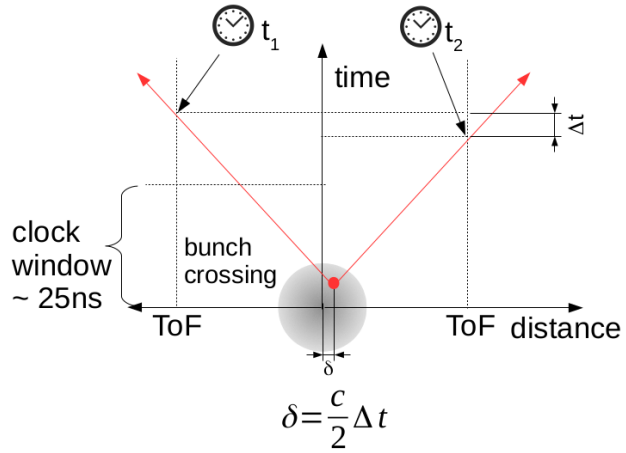


Di-proton ToF vertex reconstruction: vertex matching

- The ToF detector reconstructs the primary vertex in the case of finding two leading protons under the proper conditions. However, it can reconstruct fake vertices caused by a fake double-tag of two leading protons from two unrelated interactions in the same event.



- If z_{ToF} happens to be measured from protons that truly are coming from the primary ATLAS vertex, a narrow peak is observed in the otherwise wide $z_{\mathrm{ATLAS}} - z_{\mathrm{ToF}}$ distribution.

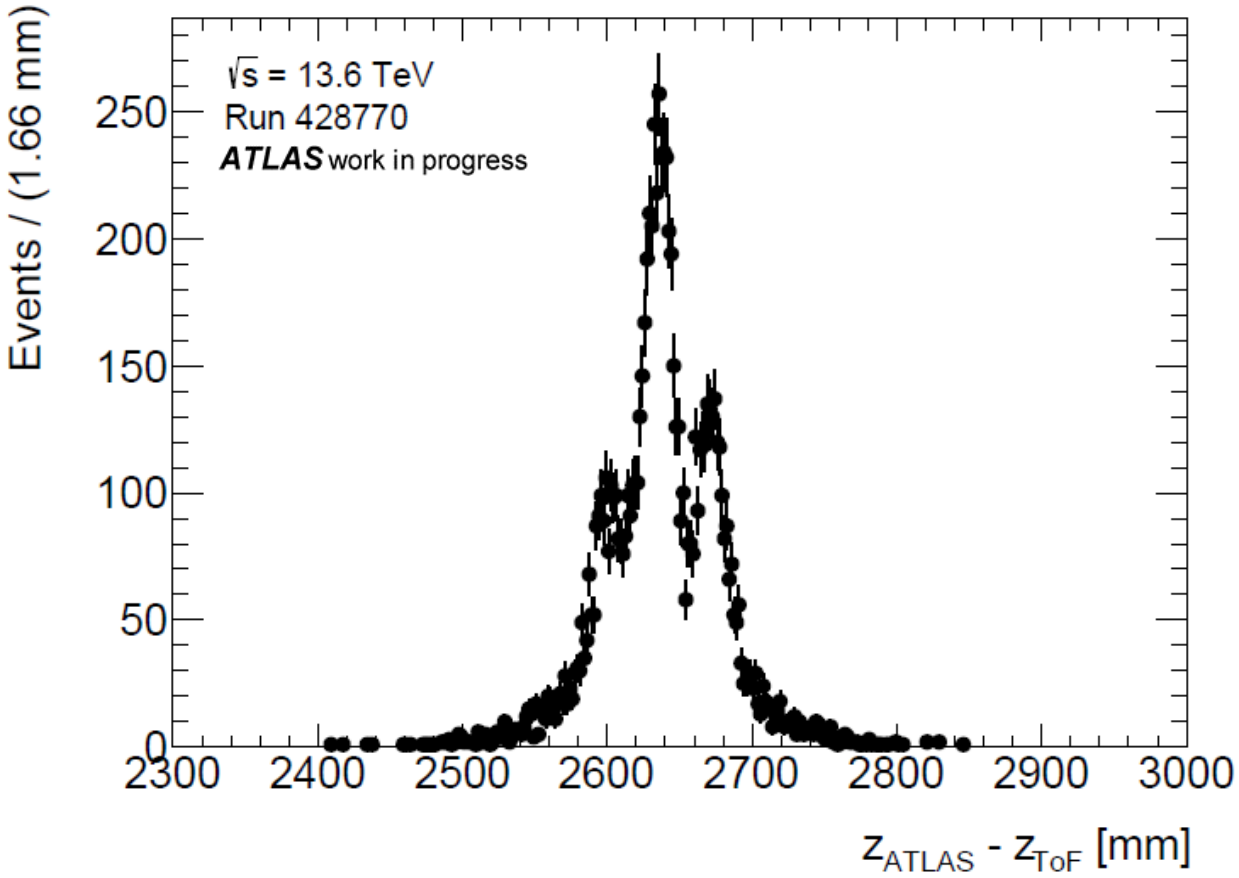


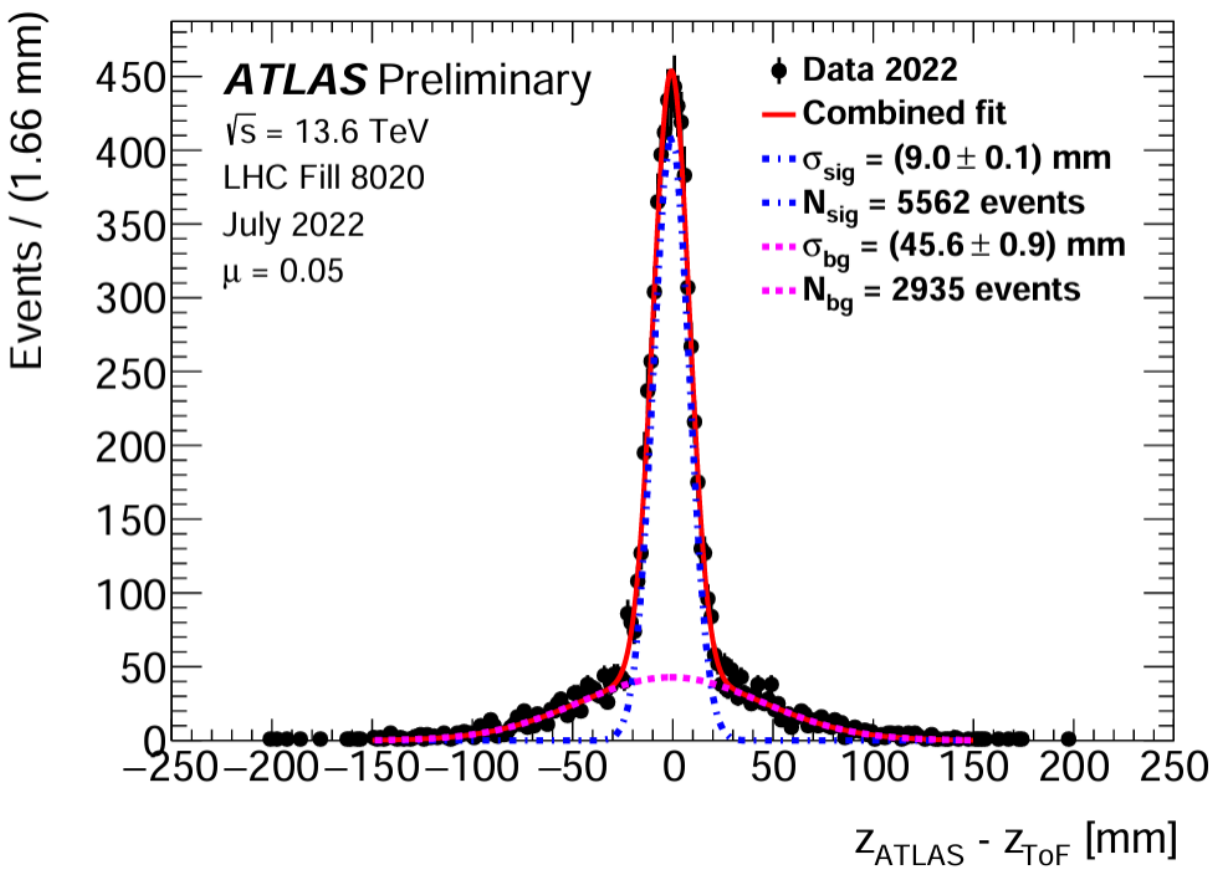
- Resolution σ = 9 mm ≈ 42.45 ps

[Forward Detectors Public Results]

Di-proton ToF vertex reconstruction: vertex matching

Comparison before\after calibration on time delays





Summary and outlook

Summary:

- ToF efficiency study with Run-3 data.
- Di-proton ToF vertex reconstruction:
  ToF calibration and using Run-3 data.
  Obtained resolution near 40 ps.

Outlook:

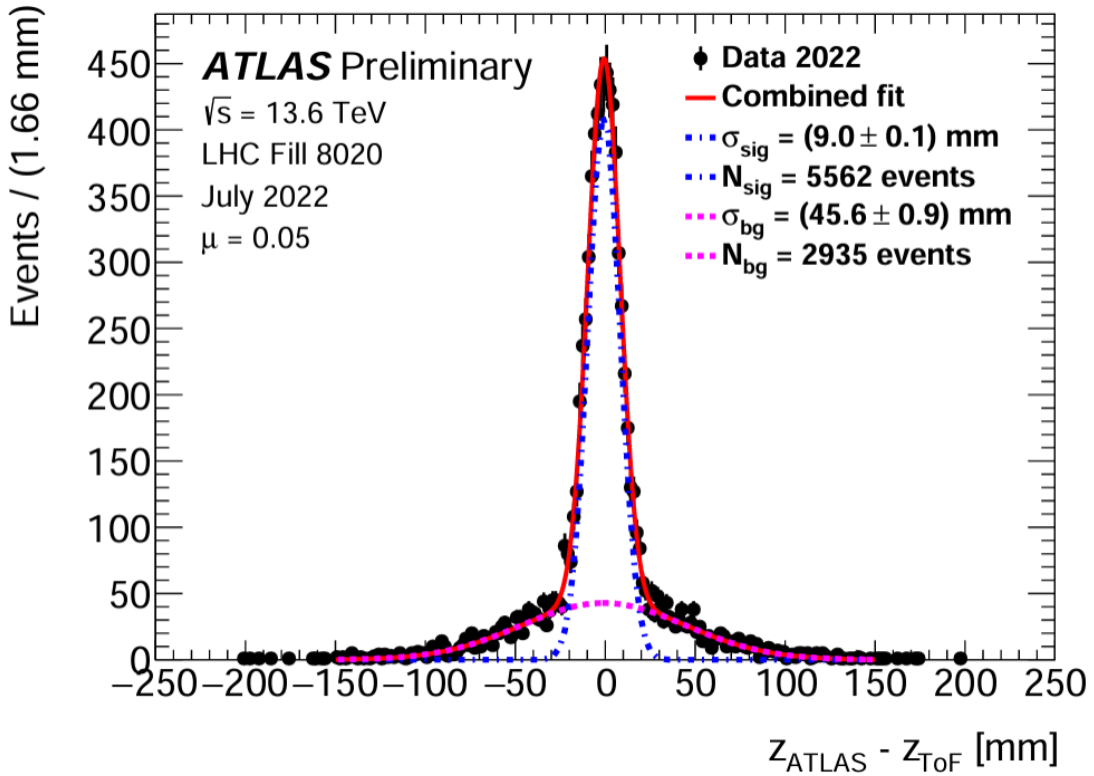
- Analysis of 2024-2025 data
- Study of Run-3 ToF data on ALP sensitivity

Backup

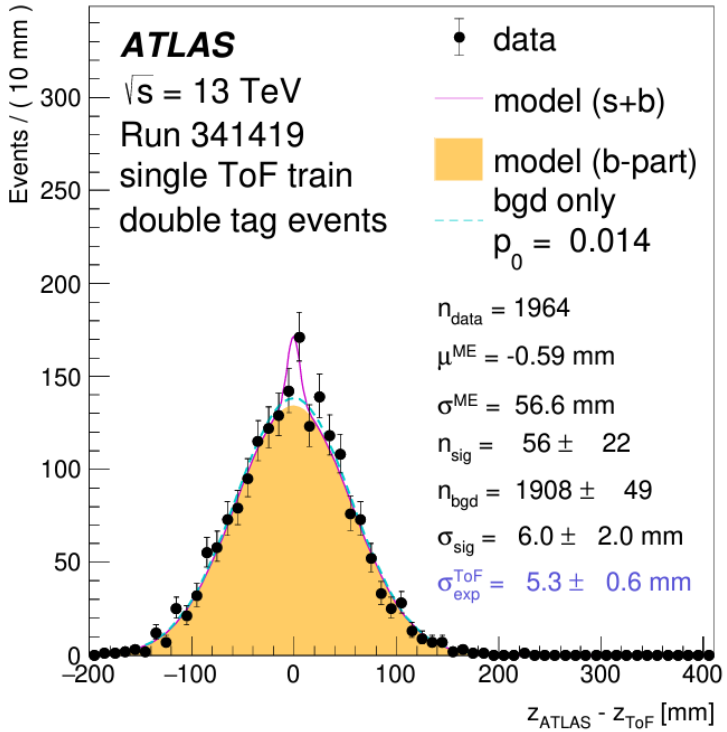
Di-proton ToF vertex reconstruction: vertex matching for low- μ run

Comparison with data from 2017: In data from 2022 the signal is much better visible

Width in 2022 measured was 8.8 m, in 2017 with lower statistic – 5.2 mm.



2022



Karel Cerny 2017

arXiv:2402.06438