Study of ATLAS Forward Proton TOF performances on Run 3 data

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From March 20th to August 4th

Outline of this presentation

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Theoretical basics

Cherenkov effect
Diffractive physics

Experimental basics

Time of flight detectors
Review of run 2
Upgrades for run 3

Methods exploited

Single channel efficiencies
Train efficiencies

Results

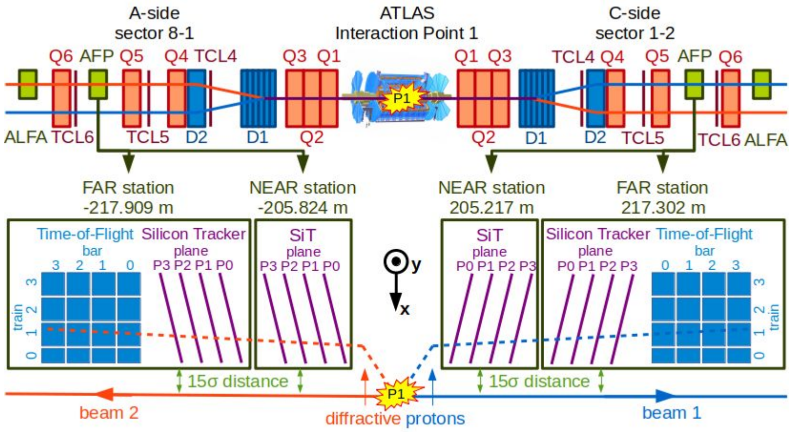
2022 results
2023 first results

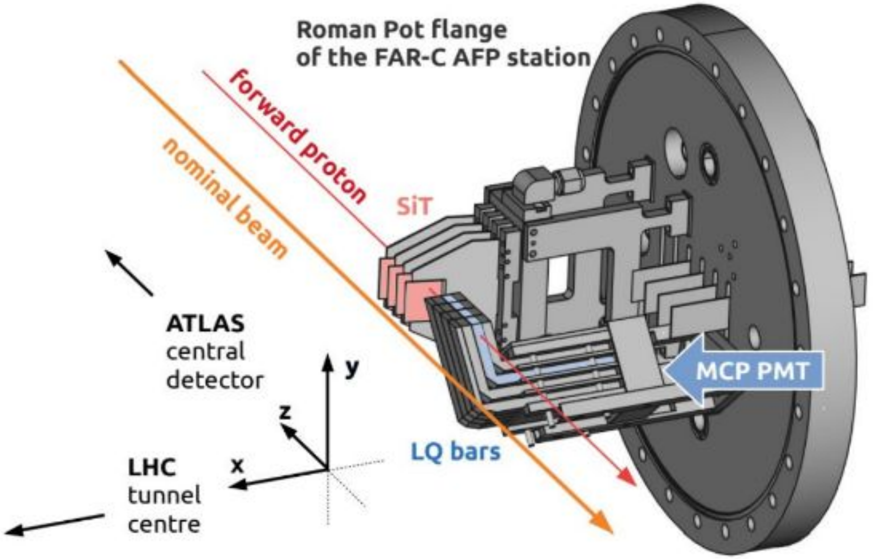
Conclusion

Introduction

ATLAS Forward Proton : generalities

- Was installed during run 2 but was able to take data in 2017 only before run 3





Courtesy of Karel Cerny

Theoretical basics

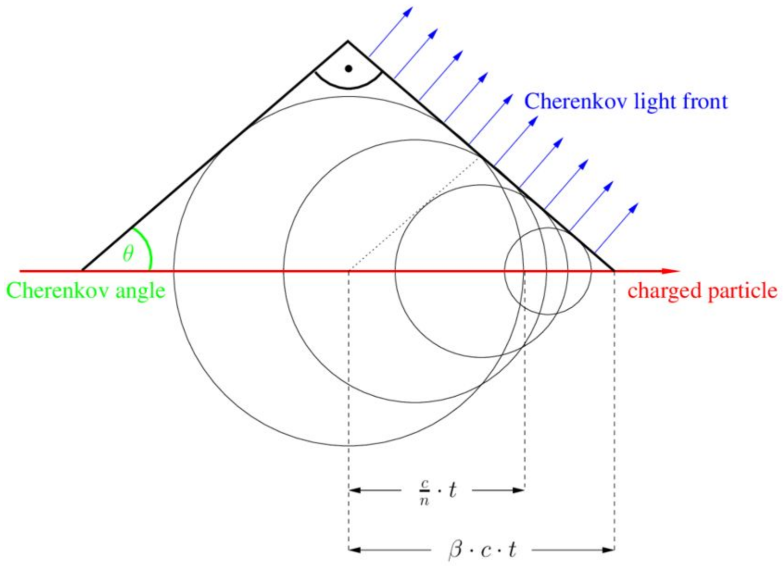
Cherenkov effect

- AFP ToF detectors are based on this effect

- Happens when charged particles travel faster Than light in a specific medium (but v < c)

- Characterized by a cone geometry with an angle θ such as :

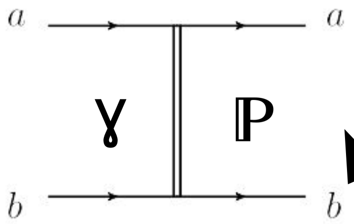
$$cos\theta = \frac{1}{\beta n}$$



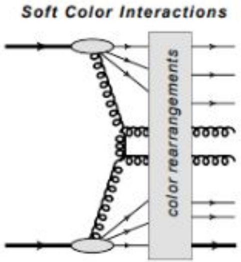
Theoretical basics

Diffractive physics 1/2

- Diffractive processes = processes where **no** quantum numbers are exchanged



- Quantum **Chromo**dynamics mediators are gluons which carry a color charge

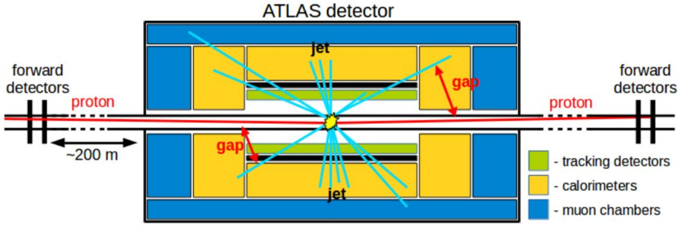


QCD “confinement” impose that all observable particles are colorless

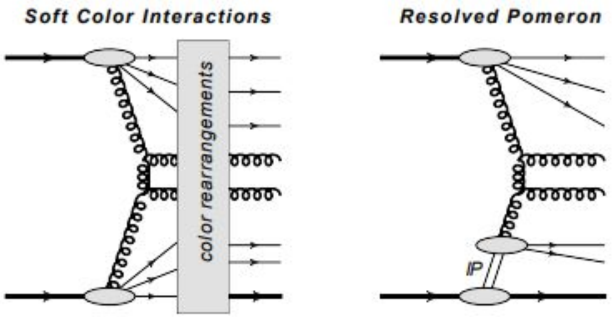
Diffractive processes in proton-proton via exchange of two gluons in singlet state or colorless “Pomeron”

Diffractive physics 2/2

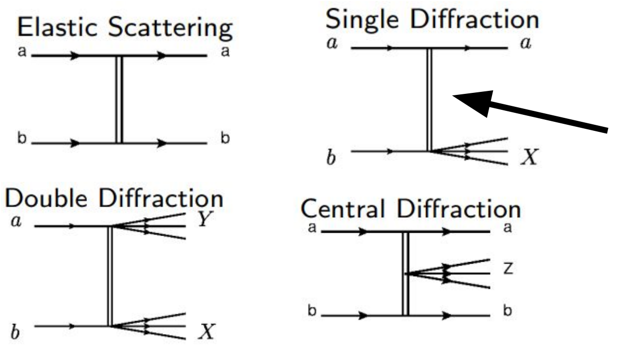
- Two experimental signatures : rapidity gaps and intact protons in the forward direction



Hard processes



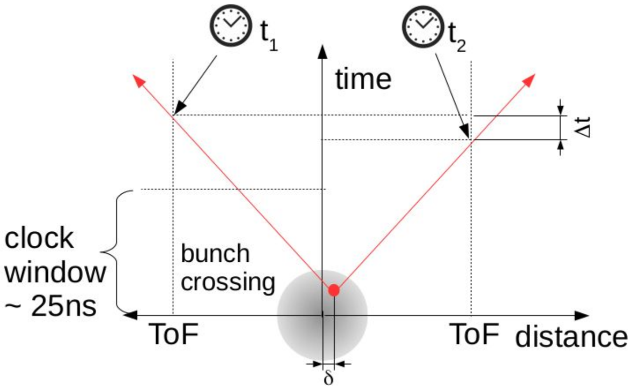
Soft processes



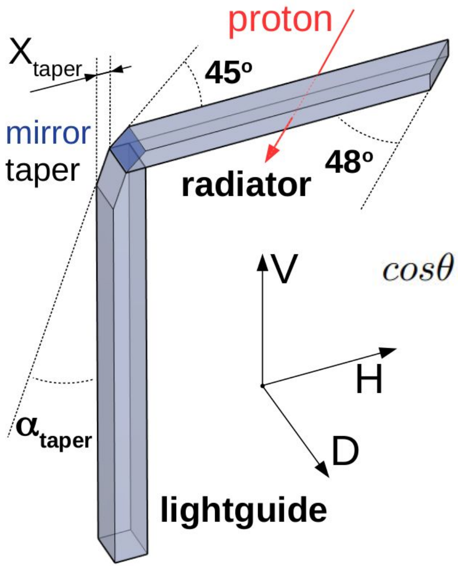
|| Pomeron (or ɣ in el. scat.)

ATLAS Forward Proton : time of flight detectors

- Very simple in principle, but need very strong precision in time resolution



$$\delta = \frac{c}{2}\Delta t$$



$$\cos\theta = \frac{1}{\beta n}$$

ATLAS Forward Proton : Review of run 2 performances

Expected specifications

- time resolution of **10 ps**
- efficiency **> 90%**
- radiation hard

Observed specifications

- time resolution **20 - 30 ps**
- efficiency of **8 - 9%**
- efficiency decreasing over time
→ degradation of photomultipliers
- efficiency of side A > side C

Experimental basics

ATLAS Forward Proton : upgrades during long shutdown 2

- Photomultipliers position changed, placed outside Roman pots

- Damaged photomultipliers replaced, LQ Bars replaced by glueless bars, many hardware updates…

- HPTDC **should** have been replaced by PicoTDC, but has not been !

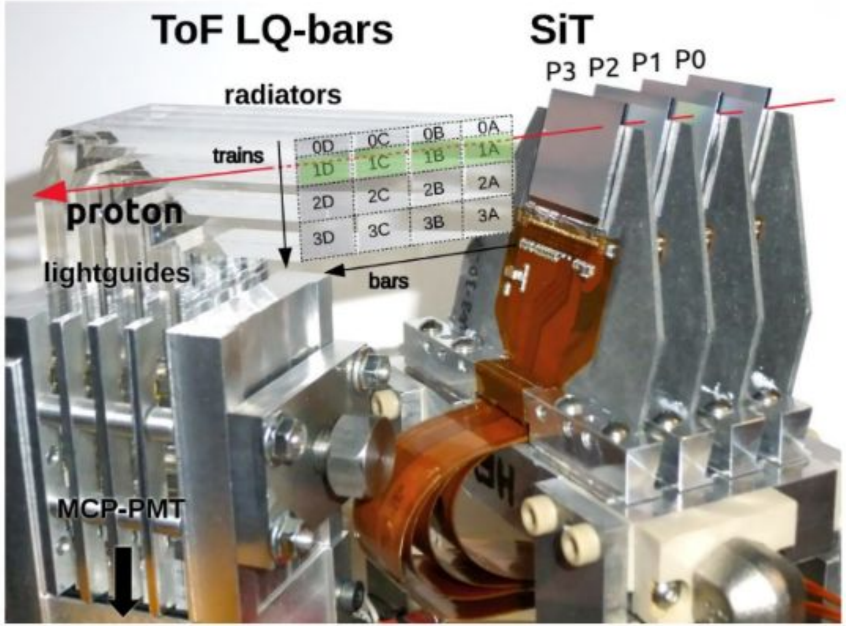
→ In the end, should be radiation hard now

Methods exploited

Single channel efficiencies : efficiency calculation

$$\varepsilon_{ijk} = \frac{N(bar - ij \mid track - k)}{N(track - k)}$$

N(bar-ij | track-k) : nb of events with a Track in SiT «**train k**» and also hits in ToF Channel i and train j
N (track-k) : nb of events with a track in SiT train k



Nota bene : j ≠ k which allows «strange» cases

Courtesy of Karel Cerny

Methods exploited

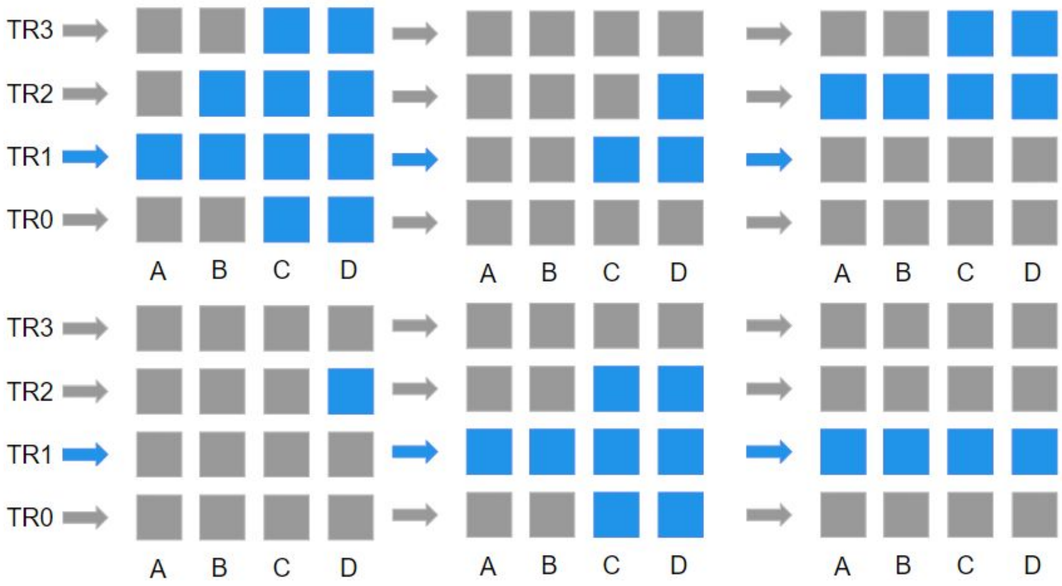
ToF efficiencies : any case

$$\varepsilon_{ijk} = \frac{N(bar - ij \mid track - k)}{N(track - k)}$$

- The most global case

- Application of previous equation with the only condition : **only 1** track in the SiT

- Allows to probe the performances of the ToF detectors on a detector level



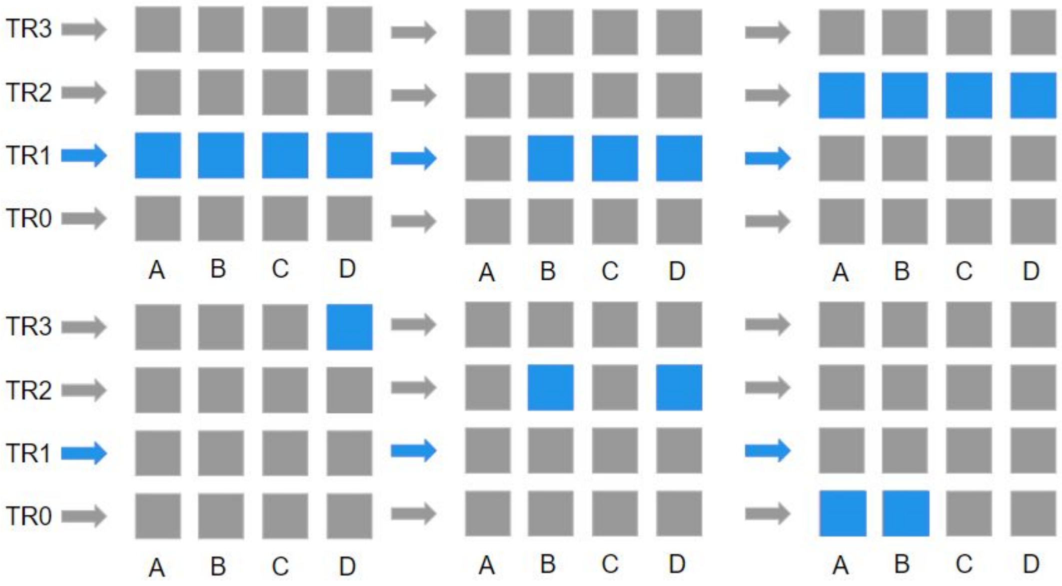
ToF efficiencies : clean case

$$\varepsilon_{ijk} = \frac{N(bar - ij \mid track - k)}{N(track - k)}$$

- Included in the «any» case calculation

- Two conditions : a single track in the SiT and events with ToF signals in a single ToF train -> **less stat.**

- Allows to probe the performances of the ToF detectors on a physics level



Methods exploited

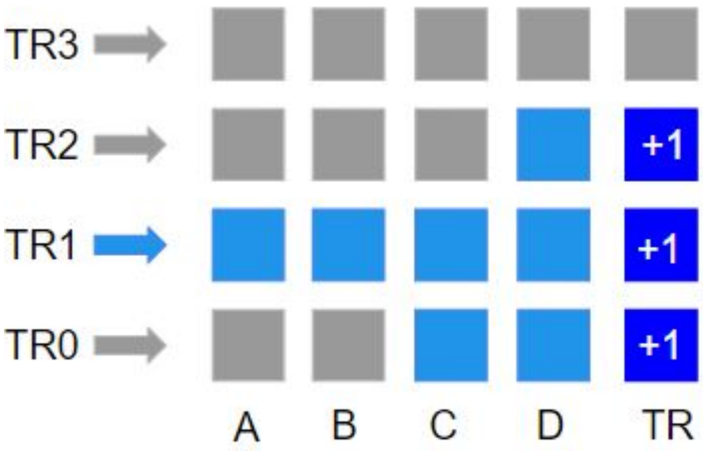
ToF efficiencies : train efficiencies

$$\varepsilon_{ijk} = \frac{N(bar - ij \mid track - k)}{N(track - k)}$$

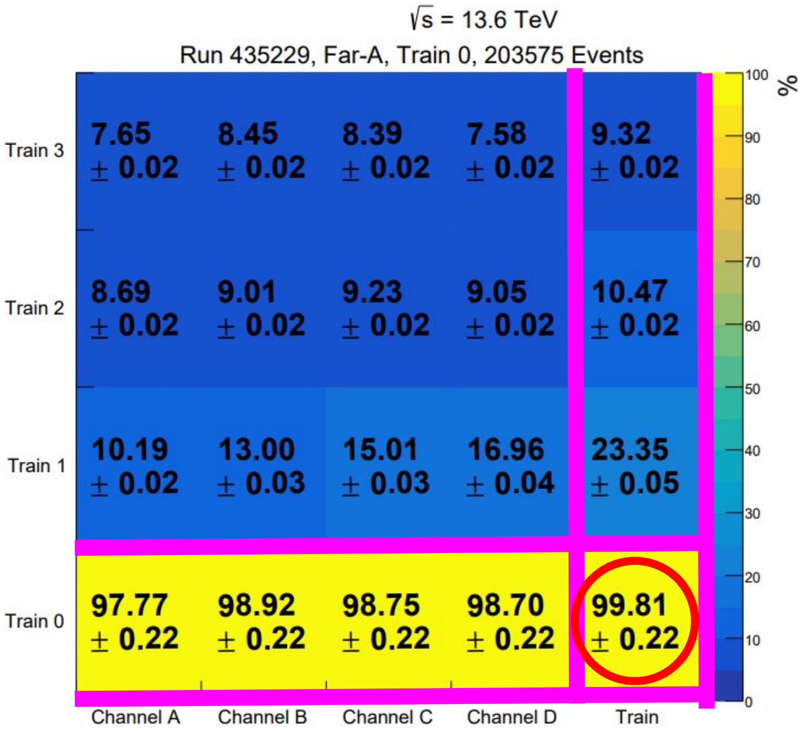
- Is calculated for both the «any» and the «clean» cases

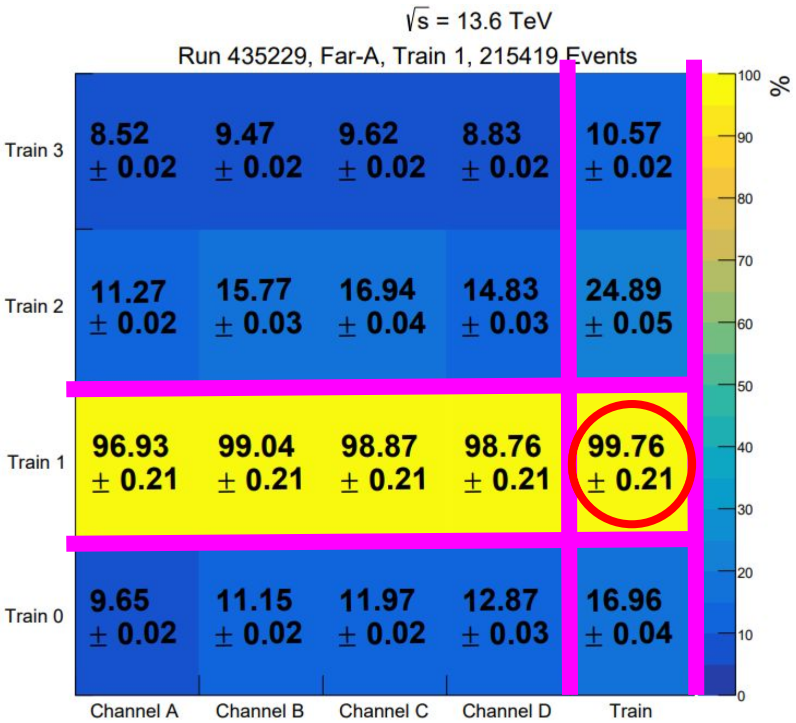
- A column is artificially added in the results plots → see next chapter

- Is used to plot the efficiency over time so we have only 4 points per run and per side



How to understand single channel efficiencies ?





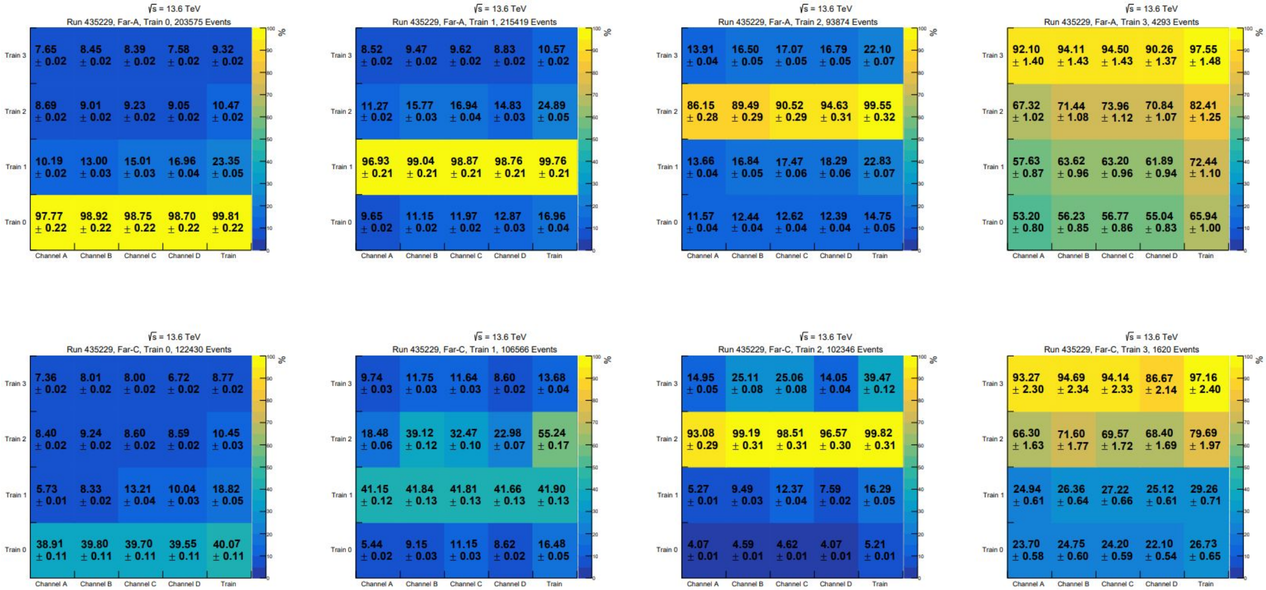
Magenta line are not present in the final result plots

2022 results : example of a low pile-up run in «any case»

- Eff. can reach >90%

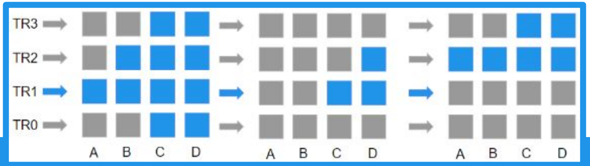
- Asymmetry between FAR-A and FAR-C

- Leakage in other trains is **NOT** negligible

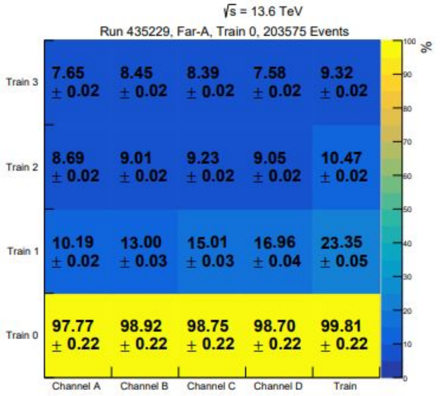


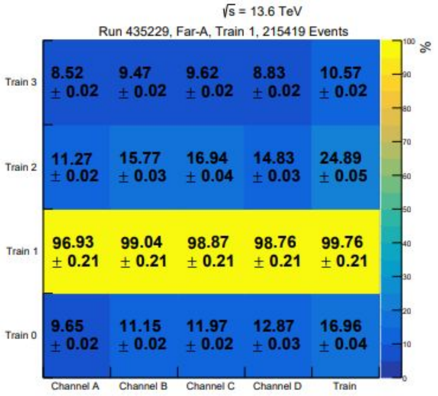
Run : 435229 (24 Sept. 2022), μ < 0.1, 18 096 933 events

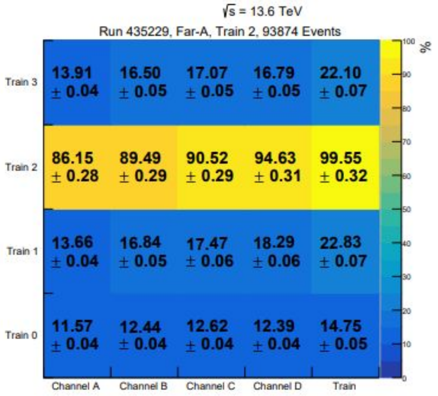
Topology :

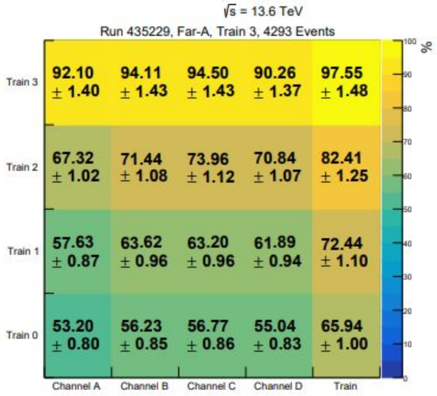


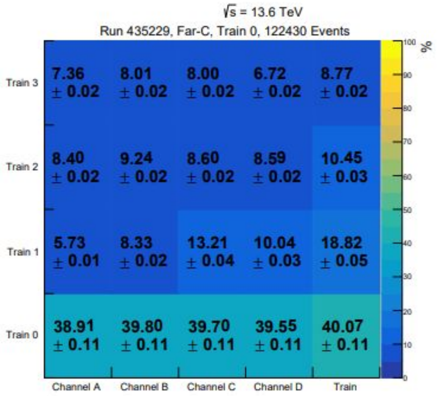
Results

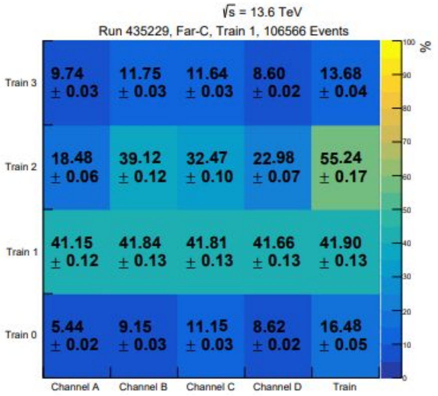

√s = 13.6 TeV
Run 435229, Far-A, Train 0, 203575 Events
Train 3: 7.65 ± 0.02, 8.45 ± 0.02, 8.39 ± 0.02, 7.58 ± 0.02, 9.32 ± 0.02
Train 2: 8.69 ± 0.02, 9.01 ± 0.02, 9.23 ± 0.02, 9.05 ± 0.02, 10.47 ± 0.02
Train 1: 10.19 ± 0.02, 13.00 ± 0.03, 15.01 ± 0.03, 16.96 ± 0.04, 23.35 ± 0.05
Train 0: 97.77 ± 0.22, 98.92 ± 0.22, 98.75 ± 0.22, 98.70 ± 0.22, 99.81 ± 0.22
Channel A, Channel B, Channel C, Channel D, Train
%

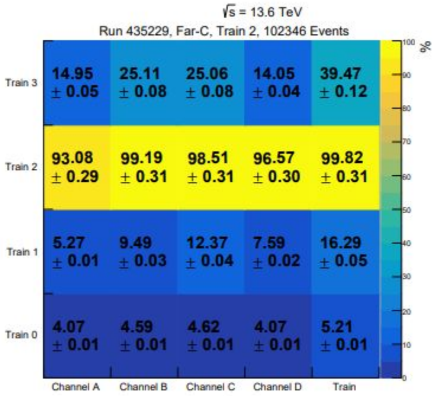

√s = 13.6 TeV
Run 435229, Far-A, Train 1, 215419 Events
Train 3: 8.52 ± 0.02, 9.47 ± 0.02, 9.62 ± 0.02, 8.83 ± 0.02, 10.57 ± 0.02
Train 2: 11.27 ± 0.02, 15.77 ± 0.03, 16.94 ± 0.04, 14.83 ± 0.03, 24.89 ± 0.05
Train 1: 96.93 ± 0.21, 99.04 ± 0.21, 98.87 ± 0.21, 98.76 ± 0.21, 99.76 ± 0.21
Train 0: 9.65 ± 0.02, 11.15 ± 0.02, 11.97 ± 0.02, 12.87 ± 0.03, 16.96 ± 0.04
Channel A, Channel B, Channel C, Channel D, Train
%

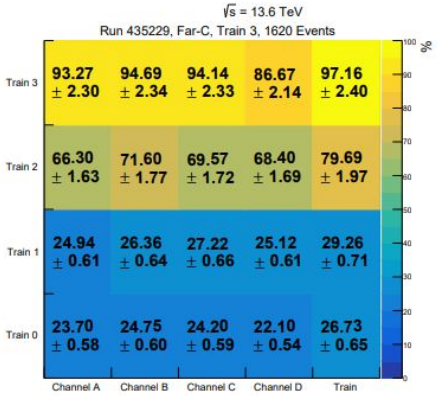

√s = 13.6 TeV
Run 435229, Far-A, Train 2, 93874 Events
Train 3: 13.91 ± 0.04, 16.50 ± 0.05, 17.07 ± 0.05, 16.79 ± 0.05, 22.10 ± 0.07
Train 2: 86.15 ± 0.28, 89.49 ± 0.29, 90.52 ± 0.29, 94.63 ± 0.31, 99.55 ± 0.32
Train 1: 13.66 ± 0.04, 16.84 ± 0.05, 17.47 ± 0.06, 18.29 ± 0.06, 22.83 ± 0.07
Train 0: 11.57 ± 0.04, 12.44 ± 0.04, 12.62 ± 0.04, 12.39 ± 0.04, 14.75 ± 0.05
Channel A, Channel B, Channel C, Channel D, Train
%


√s = 13.6 TeV
Run 435229, Far-A, Train 3, 4293 Events
Train 3: 92.10 ± 1.40, 94.11 ± 1.43, 94.50 ± 1.43, 90.26 ± 1.37, 97.55 ± 1.48
Train 2: 67.32 ± 1.02, 71.44 ± 1.08, 73.96 ± 1.12, 70.84 ± 1.07, 82.41 ± 1.25
Train 1: 57.63 ± 0.87, 63.62 ± 0.96, 63.20 ± 0.96, 61.89 ± 0.94, 72.44 ± 1.10
Train 0: 53.20 ± 0.80, 56.23 ± 0.85, 56.77 ± 0.86, 55.04 ± 0.83, 65.94 ± 1.00
Channel A, Channel B, Channel C, Channel D, Train
%


√s = 13.6 TeV
Run 435229, Far-C, Train 0, 122430 Events
Train 3: 7.36 ± 0.02, 8.01 ± 0.02, 8.00 ± 0.02, 6.72 ± 0.02, 8.77 ± 0.02
Train 2: 8.40 ± 0.02, 9.24 ± 0.02, 8.60 ± 0.02, 8.59 ± 0.02, 10.45 ± 0.03
Train 1: 5.73 ± 0.01, 8.33 ± 0.02, 13.21 ± 0.04, 10.04 ± 0.03, 18.82 ± 0.05
Train 0: 38.91 ± 0.11, 39.80 ± 0.11, 39.70 ± 0.11, 39.55 ± 0.11, 40.07 ± 0.11
Channel A, Channel B, Channel C, Channel D, Train
%


√s = 13.6 TeV
Run 435229, Far-C, Train 1, 106566 Events
Train 3: 9.74 ± 0.03, 11.75 ± 0.03, 11.64 ± 0.03, 8.60 ± 0.02, 13.68 ± 0.04
Train 2: 18.48 ± 0.06, 39.12 ± 0.12, 32.47 ± 0.10, 22.98 ± 0.07, 55.24 ± 0.17
Train 1: 41.15 ± 0.12, 41.84 ± 0.13, 41.81 ± 0.13, 41.66 ± 0.13, 41.90 ± 0.13
Train 0: 5.44 ± 0.02, 9.15 ± 0.03, 11.15 ± 0.03, 8.62 ± 0.02, 16.48 ± 0.05
Channel A, Channel B, Channel C, Channel D, Train
%


√s = 13.6 TeV
Run 435229, Far-C, Train 2, 102346 Events
Train 3: 14.95 ± 0.05, 25.11 ± 0.08, 25.06 ± 0.08, 14.05 ± 0.04, 39.47 ± 0.12
Train 2: 93.08 ± 0.29, 99.19 ± 0.31, 98.51 ± 0.31, 96.57 ± 0.30, 99.82 ± 0.31
Train 1: 5.27 ± 0.01, 9.49 ± 0.03, 12.37 ± 0.04, 7.59 ± 0.02, 16.29 ± 0.05
Train 0: 4.07 ± 0.01, 4.59 ± 0.01, 4.62 ± 0.01, 4.07 ± 0.01, 5.21 ± 0.01
Channel A, Channel B, Channel C, Channel D, Train
%


√s = 13.6 TeV
Run 435229, Far-C, Train 3, 1620 Events
Train 3: 93.27 ± 2.30, 94.69 ± 2.34, 94.14 ± 2.33, 86.67 ± 2.14, 97.16 ± 2.40
Train 2: 66.30 ± 1.63, 71.60 ± 1.77, 69.57 ± 1.72, 68.40 ± 1.69, 79.69 ± 1.97
Train 1: 24.94 ± 0.61, 26.36 ± 0.64, 27.22 ± 0.66, 25.12 ± 0.61, 29.26 ± 0.71
Train 0: 23.70 ± 0.58, 24.75 ± 0.60, 24.20 ± 0.59, 22.10 ± 0.54, 26.73 ± 0.65
Channel A, Channel B, Channel C, Channel D, Train
%

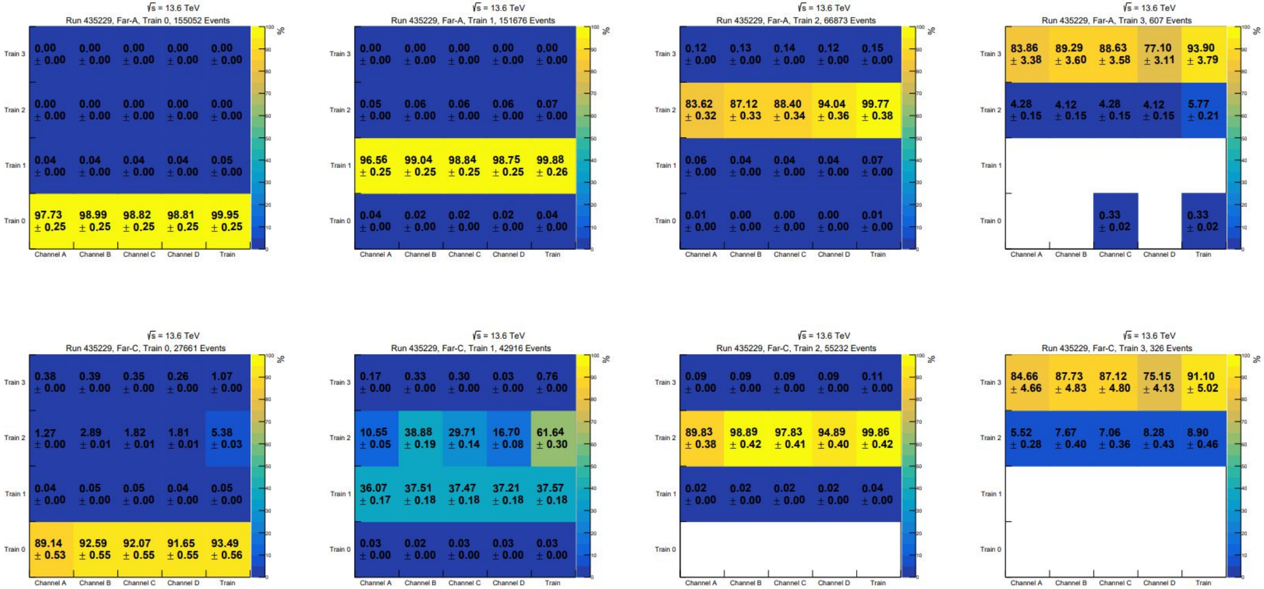
Results

2022 results : example of a low pile-up run in «clean case»

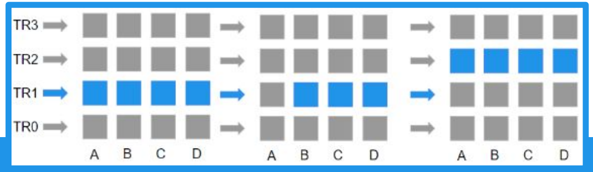
- Expected behavior :
pointed train eff. ↗
other trains eff. ↘

- Statistics loss up to **75%** in this run !

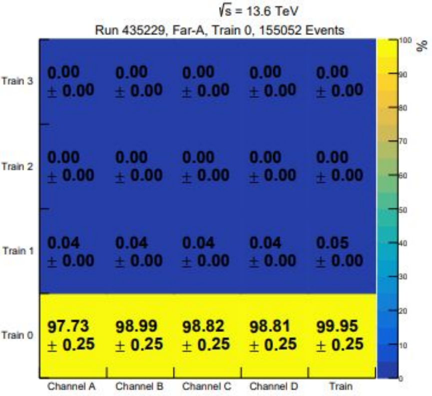
- Some channels completely lack of data

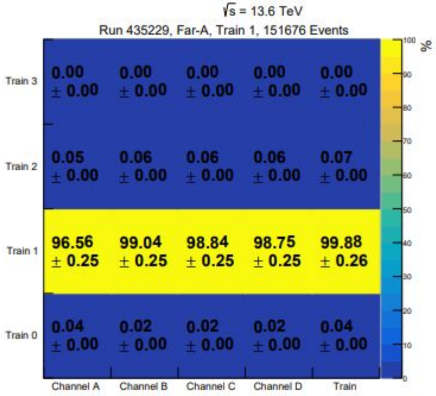


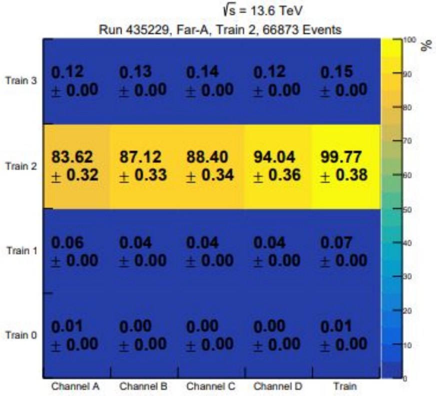
Run : 435229 (24 Sept. 2022), μ < 0.1, 18 096 933 events Topology :

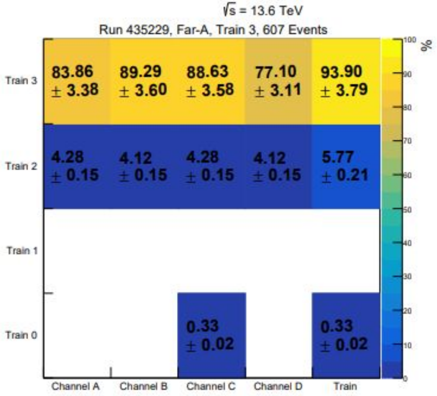


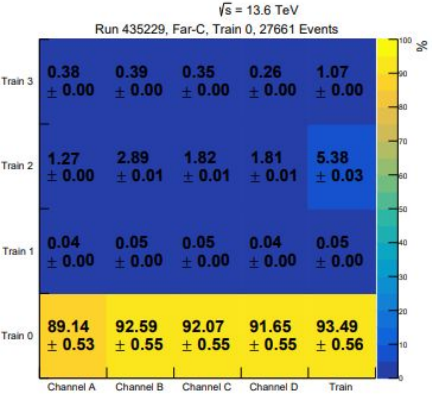
Results

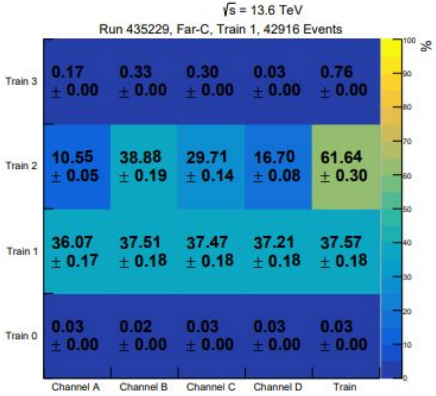

√s = 13.6 TeV
Run 435229, Far-A, Train 0, 155052 Events
Train 3: 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00
Train 2: 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00
Train 1: 0.04 ± 0.00 | 0.04 ± 0.00 | 0.04 ± 0.00 | 0.04 ± 0.00 | 0.05 ± 0.00
Train 0: 97.73 ± 0.25 | 98.99 ± 0.25 | 98.82 ± 0.25 | 98.81 ± 0.25 | 99.95 ± 0.25
Channel A
Channel B
Channel C
Channel D
Train
%

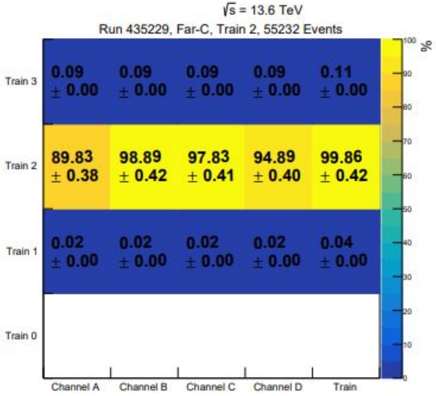

√s = 13.6 TeV
Run 435229, Far-A, Train 1, 151676 Events
Train 3: 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00
Train 2: 0.05 ± 0.00 | 0.06 ± 0.00 | 0.06 ± 0.00 | 0.06 ± 0.00 | 0.07 ± 0.00
Train 1: 96.56 ± 0.25 | 99.04 ± 0.25 | 98.84 ± 0.25 | 98.75 ± 0.25 | 99.88 ± 0.26
Train 0: 0.04 ± 0.00 | 0.02 ± 0.00 | 0.02 ± 0.00 | 0.02 ± 0.00 | 0.04 ± 0.00
Channel A
Channel B
Channel C
Channel D
Train
%

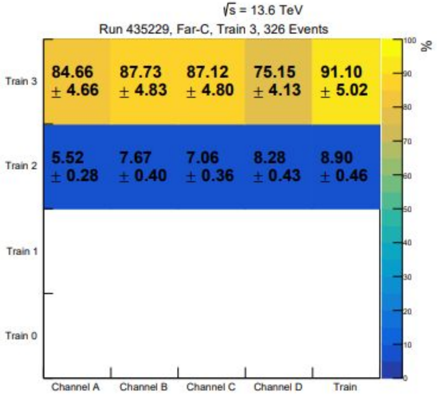

√s = 13.6 TeV
Run 435229, Far-A, Train 2, 66873 Events
Train 3: 0.12 ± 0.00 | 0.13 ± 0.00 | 0.14 ± 0.00 | 0.12 ± 0.00 | 0.15 ± 0.00
Train 2: 83.62 ± 0.32 | 87.12 ± 0.33 | 88.40 ± 0.34 | 94.04 ± 0.36 | 99.77 ± 0.38
Train 1: 0.06 ± 0.00 | 0.04 ± 0.00 | 0.04 ± 0.00 | 0.04 ± 0.00 | 0.07 ± 0.00
Train 0: 0.01 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.01 ± 0.00
Channel A
Channel B
Channel C
Channel D
Train
%


√s = 13.6 TeV
Run 435229, Far-A, Train 3, 607 Events
Train 3: 83.86 ± 3.38 | 89.29 ± 3.60 | 88.63 ± 3.58 | 77.10 ± 3.11 | 93.90 ± 3.79
Train 2: 4.28 ± 0.15 | 4.12 ± 0.15 | 4.28 ± 0.15 | 4.12 ± 0.15 | 5.77 ± 0.21
Train 1
Train 0: 0.33 ± 0.02 (Channel C) | 0.33 ± 0.02 (Train)
Channel A
Channel B
Channel C
Channel D
Train
%


√s = 13.6 TeV
Run 435229, Far-C, Train 0, 27661 Events
Train 3: 0.38 ± 0.00 | 0.39 ± 0.00 | 0.35 ± 0.00 | 0.26 ± 0.00 | 1.07 ± 0.00
Train 2: 1.27 ± 0.00 | 2.89 ± 0.01 | 1.82 ± 0.01 | 1.81 ± 0.01 | 5.38 ± 0.03
Train 1: 0.04 ± 0.00 | 0.05 ± 0.00 | 0.05 ± 0.00 | 0.04 ± 0.00 | 0.05 ± 0.00
Train 0: 89.14 ± 0.53 | 92.59 ± 0.55 | 92.07 ± 0.55 | 91.65 ± 0.55 | 93.49 ± 0.56
Channel A
Channel B
Channel C
Channel D
Train
%


√s = 13.6 TeV
Run 435229, Far-C, Train 1, 42916 Events
Train 3: 0.17 ± 0.00 | 0.33 ± 0.00 | 0.30 ± 0.00 | 0.03 ± 0.00 | 0.76 ± 0.00
Train 2: 10.55 ± 0.05 | 38.88 ± 0.19 | 29.71 ± 0.14 | 16.70 ± 0.08 | 61.64 ± 0.30
Train 1: 36.07 ± 0.17 | 37.51 ± 0.18 | 37.47 ± 0.18 | 37.21 ± 0.18 | 37.57 ± 0.18
Train 0: 0.03 ± 0.00 | 0.02 ± 0.00 | 0.03 ± 0.00 | 0.03 ± 0.00 | 0.03 ± 0.00
Channel A
Channel B
Channel C
Channel D
Train
%


√s = 13.6 TeV
Run 435229, Far-C, Train 2, 55232 Events
Train 3: 0.09 ± 0.00 | 0.09 ± 0.00 | 0.09 ± 0.00 | 0.09 ± 0.00 | 0.11 ± 0.00
Train 2: 89.83 ± 0.38 | 98.89 ± 0.42 | 97.83 ± 0.41 | 94.89 ± 0.40 | 99.86 ± 0.42
Train 1: 0.02 ± 0.00 | 0.02 ± 0.00 | 0.02 ± 0.00 | 0.02 ± 0.00 | 0.04 ± 0.00
Train 0
Channel A
Channel B
Channel C
Channel D
Train
%


√s = 13.6 TeV
Run 435229, Far-C, Train 3, 326 Events
Train 3: 84.66 ± 4.66 | 87.73 ± 4.83 | 87.12 ± 4.80 | 75.15 ± 4.13 | 91.10 ± 5.02
Train 2: 5.52 ± 0.28 | 7.67 ± 0.40 | 7.06 ± 0.36 | 8.28 ± 0.43 | 8.90 ± 0.46
Train 1
Train 0
Channel A
Channel B
Channel C
Channel D
Train
%

Results

2022 results : efficiency over time

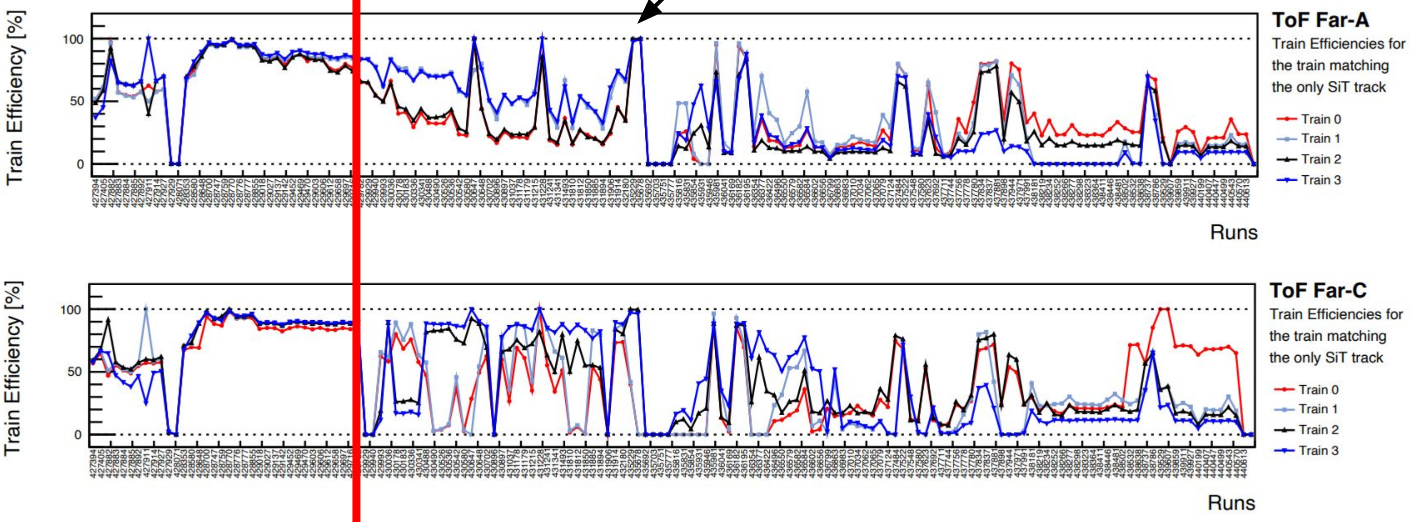
Graph updated compared to report

- Great efficiencies up to the end of July

- Not taking in account pile-up

End of july

Studied run is here



156 runs from July 5th 2022 to November 27th 2022

Results

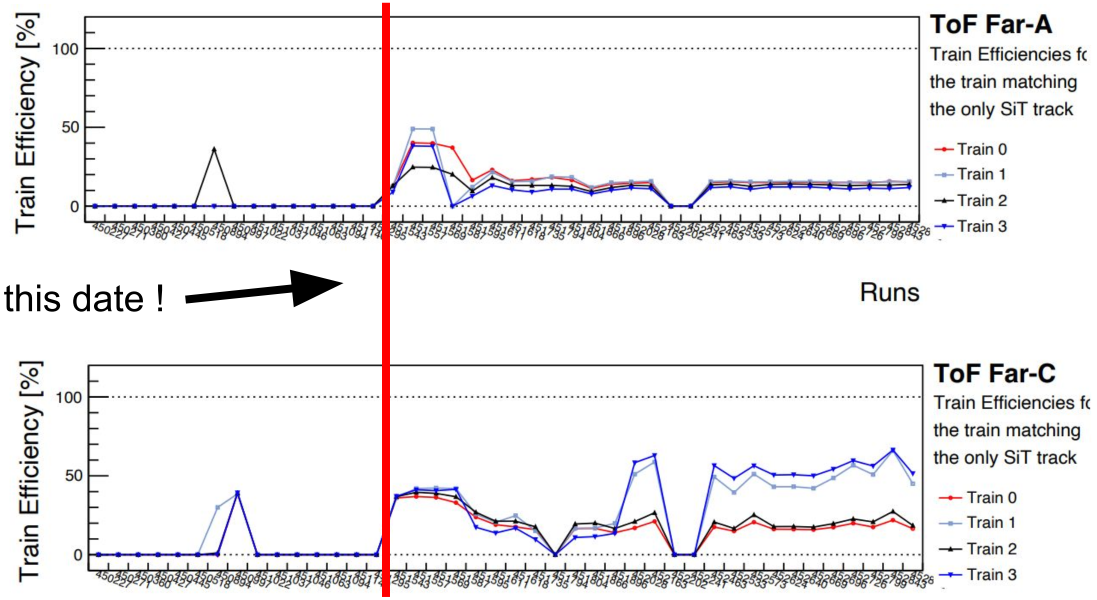
2023 results : efficiency over time

Graph updated compared to report

- Scary beginning, but seems like it can be fixed at a later stage of the year

- 1 week delay between run and AOD data available after reconstruction

HPTDC last touched at this date !



44 runs from April 21th 2023 to May 25th 2023

Conclusion

Preliminary conclusion of run 3 performances

- Great efficiencies **CAN** be achieved with the time of flight detectors

- However the great performances were not maintained over the year
→ Seems like it is a matter of hardware settings

- A dedicated run at low pile-up will happen next week at the LHC, the AFP group will take this run as an opportunity to probe the problems of the ToF detectors !

- If the good performances in time resolution are confirmed in run 3, the ToF detectors could be able to have really great performances to study physics of interest

Conclusion

What's next ?

Concerning the efficiencies :

- Unification/documentation of the analysis code
- Efficiency vs pile-up study
- Investigating multiple hits

After the work on efficiencies is finished :

- Time resolution determination

Thank you for your attention !

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S. Donnachie et al. Pomeron Physics and QCD. Cambridge Monographs on Particle Physics, Nuclear Physics and Cosmology. Cambridge University Press, 2002. isbn : 9780521780391. url : https://books.google.ch/books?id=f-VzngEACAAJ

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Staszewski Rafal. « Study of Diffraction with the ATLAS detector at the LHC ». presented 24 Sep 2012. 2012. url : https://cds.cern.ch/record/1504372

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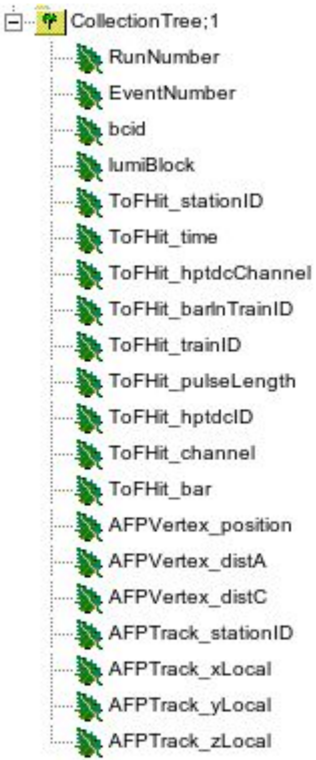
Back up

Ntuples creation

Previous format
«**vector** like»



- unclear

- more needy in storage place

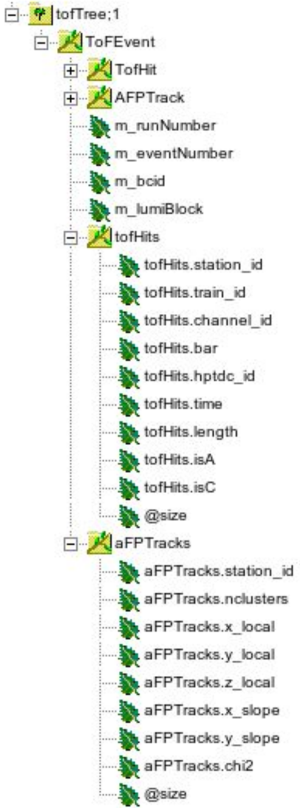
- error prone due to the many indices

New format
«**object** like»

- way clearer, easier to code with

- translate how is the data taken

→ ~200 runs processed this way



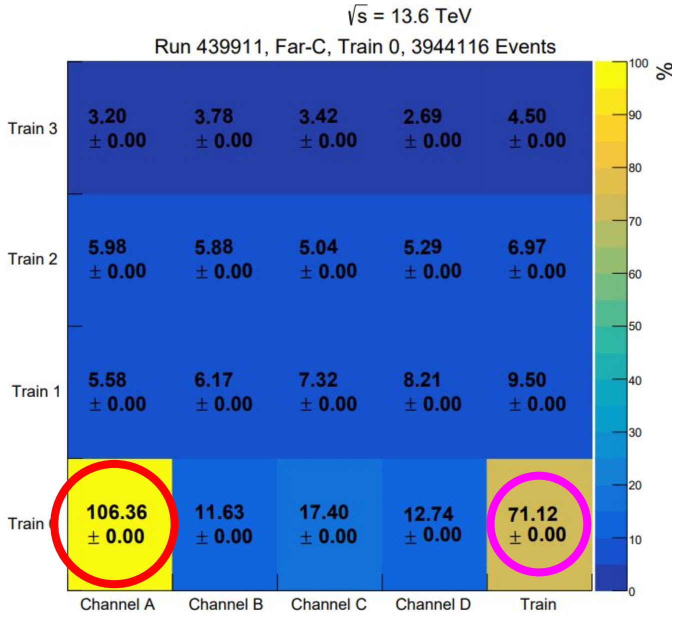
Back-up

Number of runs and integrated luminosity

	Number of Runs	Integrated Luminosity
2022	156	36.1 fb^{-1}
2023	42	11.7 fb^{-1}

2022 runs correspond to around 220 Gb of data
2023 runs correspond to around 90 Gb of data

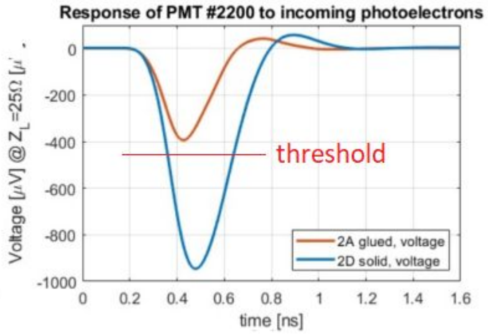
2022 results : anomalies detected



- Anomalies have been detected in <10 runs / 150
→ Mainly during the latest runs of 2022

- The only possibility for this to happen according to the code is **multi-hits** in a single channel during the **same** event !

- Problem coming from the CDF of PMT ?



Graph updated compared to report

Back-up

Silicon tracker Region of Interest

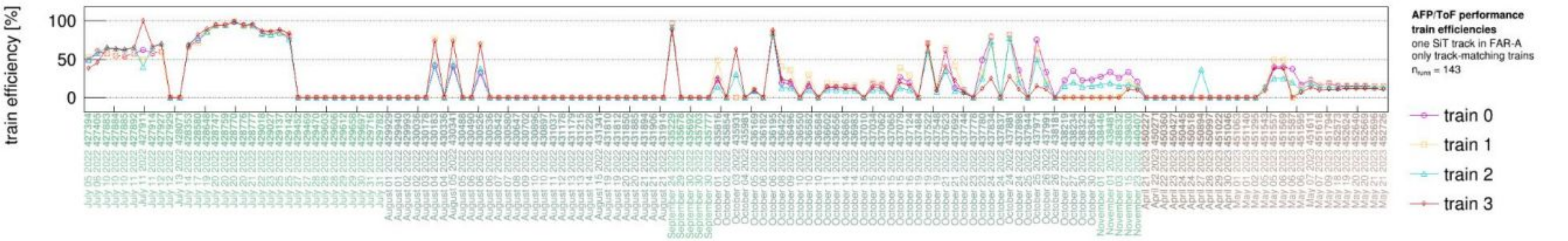
- Silicon tracker do not possess physical trains like the ToF detectors do.

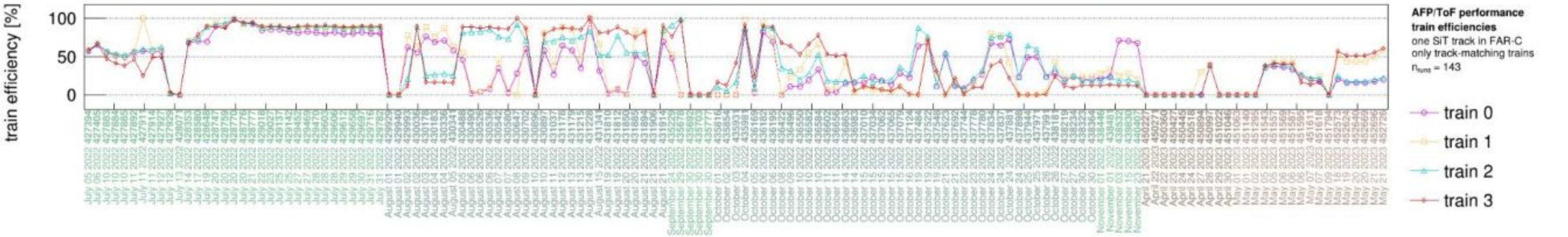
- To determine the SiT trains ROI, they look at the x-coordinate of tracks when a signal was detected in the concerned ToF train. (With the condition : an unique track in the silicon tracker)

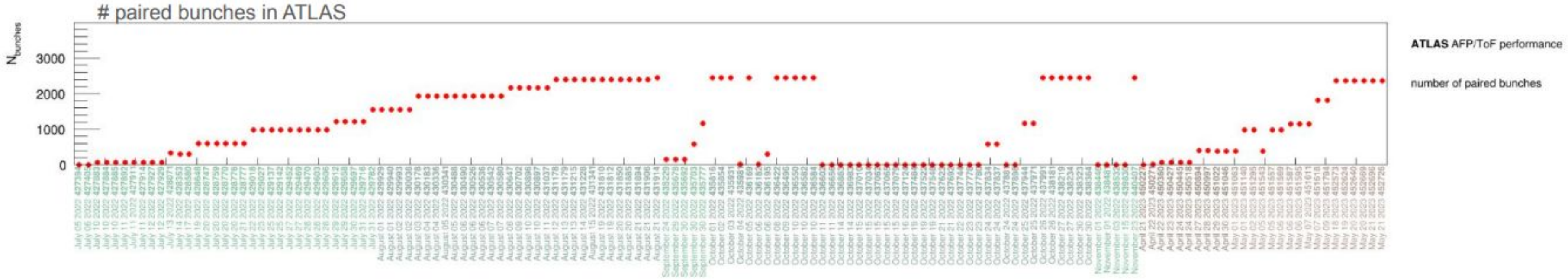
- They then look at the distribution of the track x-coordinate and make bounds between the x-coordinates where there are the most events.

- A side and C side have different region of interest !

Back-up


train efficiency [%]
100
50
0
AFP/ToF performance
train efficiencies
one SiT track in FAR-A
only track-matching trains
n_{runs} = 143
train 0
train 1
train 2
train 3


train efficiency [%]
100
50
0
AFP/ToF performance
train efficiencies
one SiT track in FAR-C
only track-matching trains
n_{runs} = 143
train 0
train 1
train 2
train 3


paired bunches in ATLAS
$N_{bunches}$
3000
2000
1000
0
ATLAS AFP/ToF performance
number of paired bunches

Theoretical basics

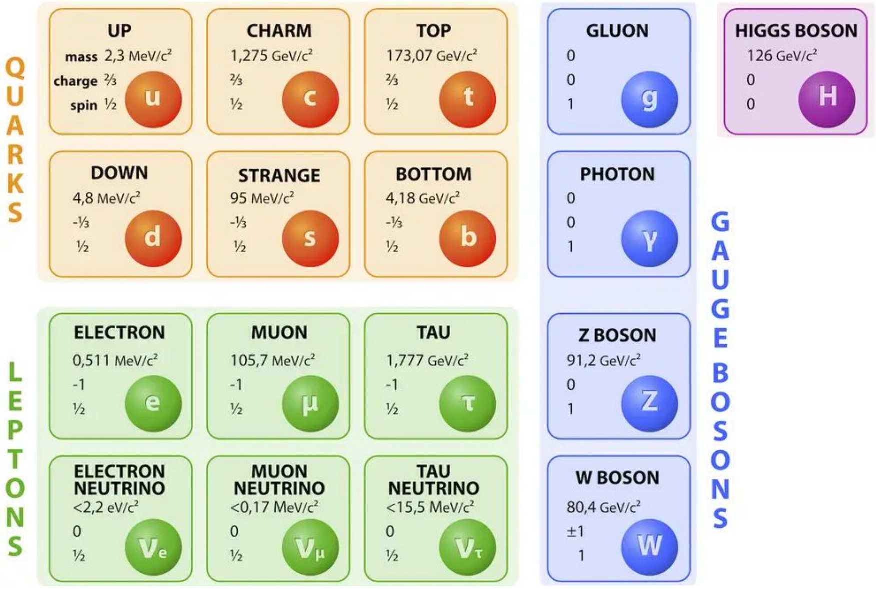
Standard Model of particle physics

- Describes **3 out the 4** fundamental interactions of our universe

- Interactions carried by integer spin particles called «**bosons**»

- Matter described by half-integer spin particles called «**fermions**»

- Is fallible and is **NOT** the final picture !



Back-up

Ssdd

Text

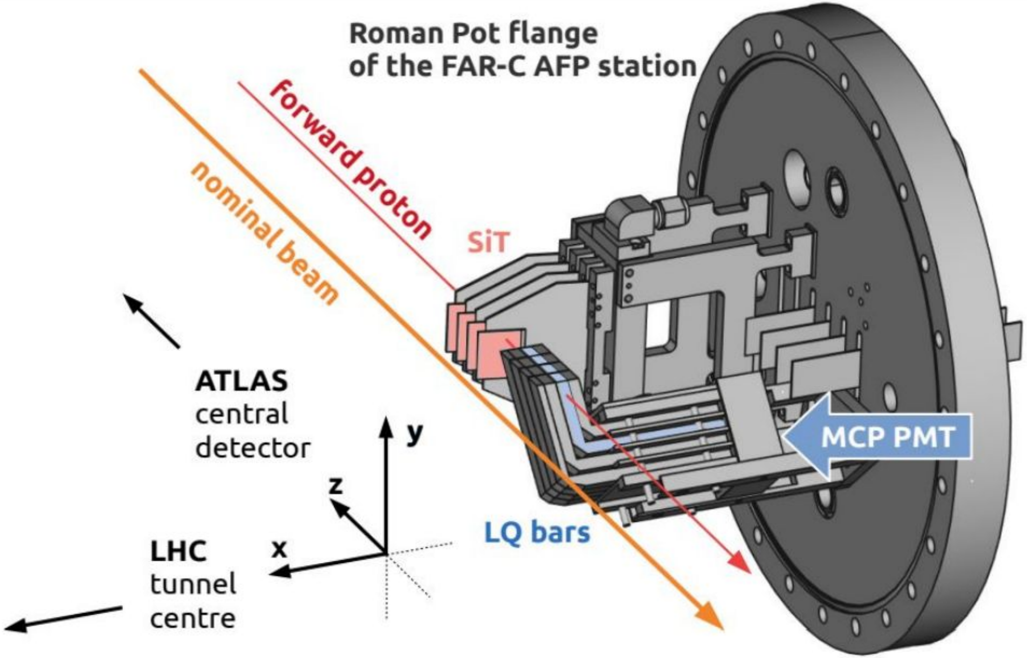


Figure 2: Schematic view of a leading proton detection in the SiT and ToF detector of the FAR-C station. The LQ bars traversed by the leading proton are highlighted by blue colour.

Back-up

Ssdd

Text

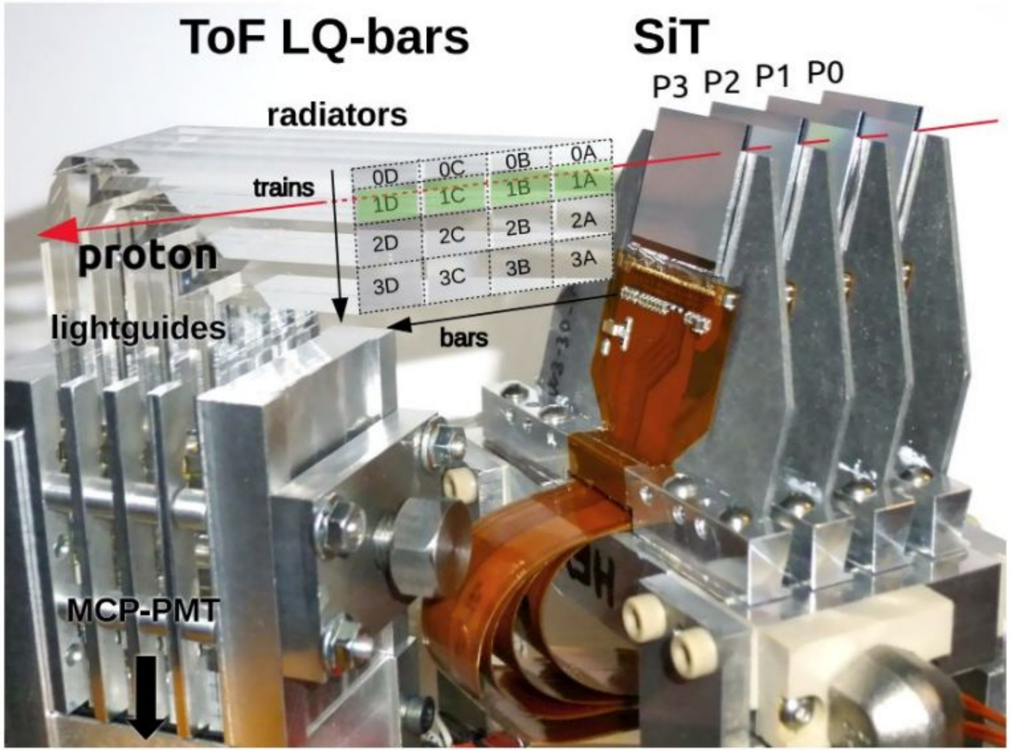
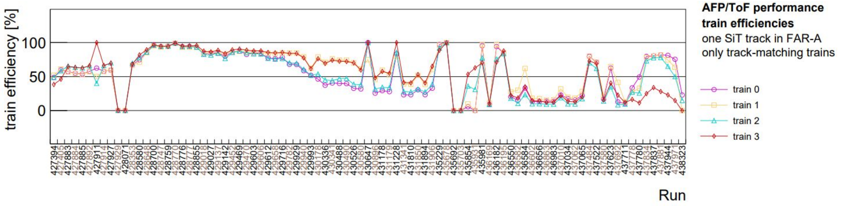
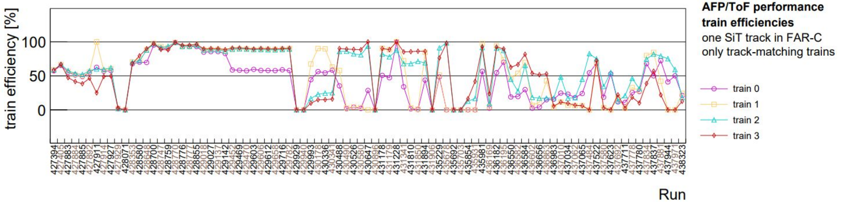


Figure 3: Photo of the assembled AFP detector composed of the Silicon tracker (SiT) and the Time-of-flight detector (ToF) with leading proton trajectory indicated with an oriented red line. The segmentation of the ToF to trains and

Results

2022 results : efficiency over time





Update results

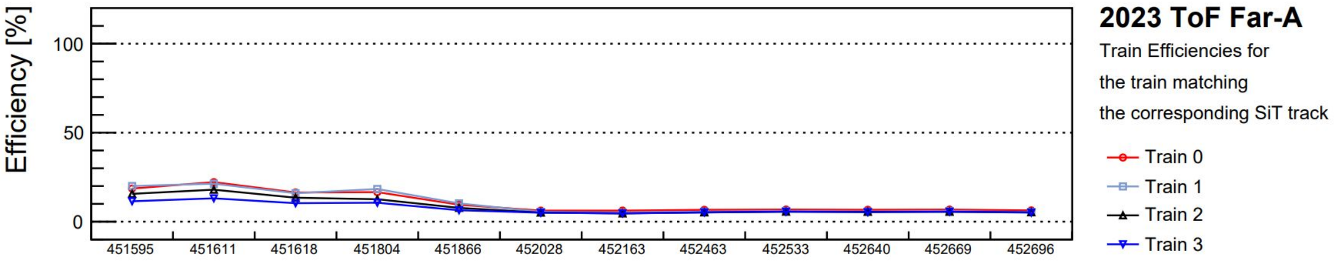
ARP General Meeting last week
-> we got to talk about the results, we are no
With experts
-> a special low mu run in two weeks will hap
it will be an opportunity to probe the issues

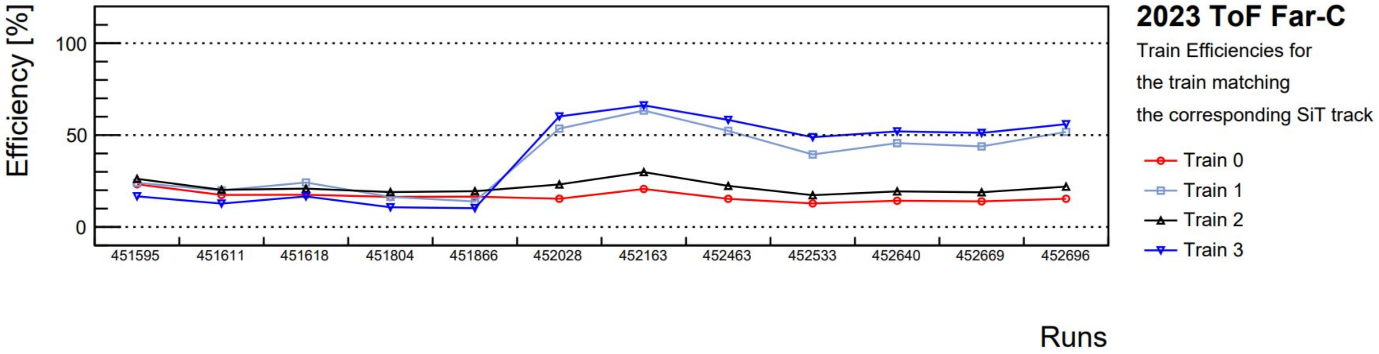
Point to the moment when TDC starting having problem!!!

Results

2023 results : efficiency over time

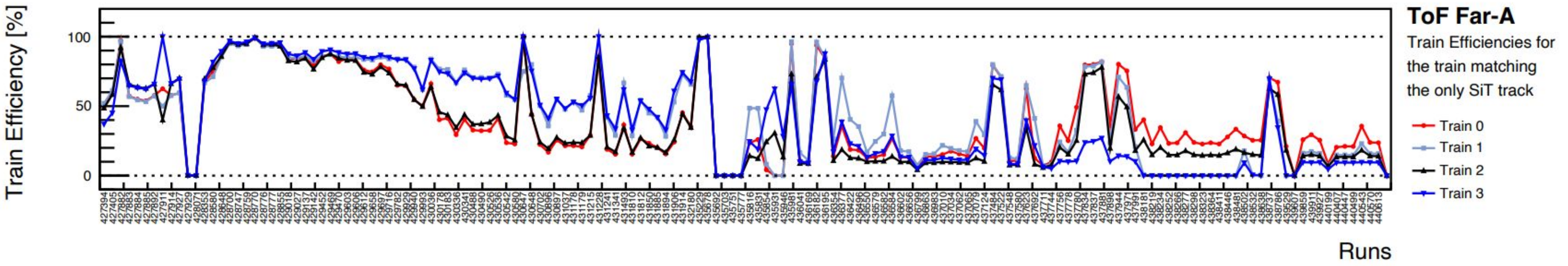
Text

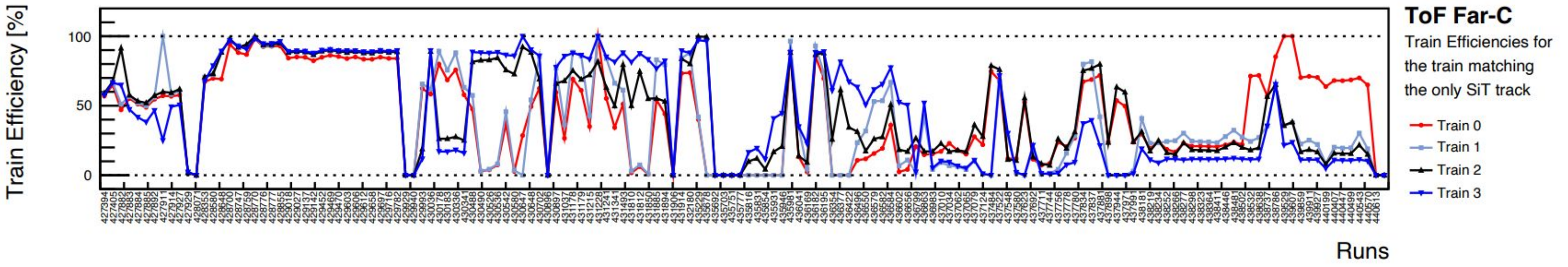




Ssdd

Text





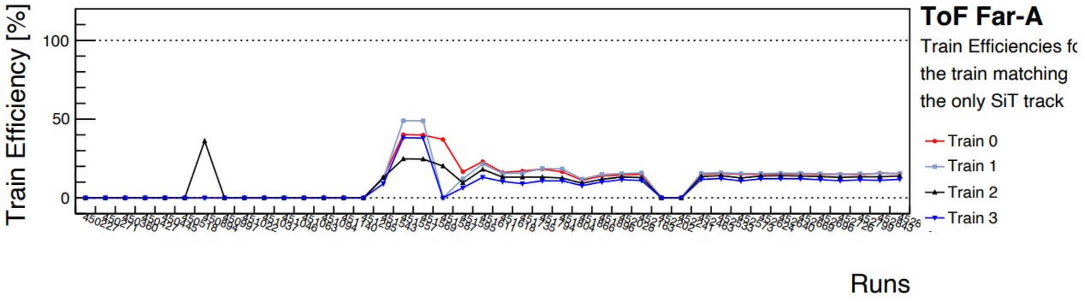
156 runs from 5 Jul 2022 ~ 27 Nov 2022

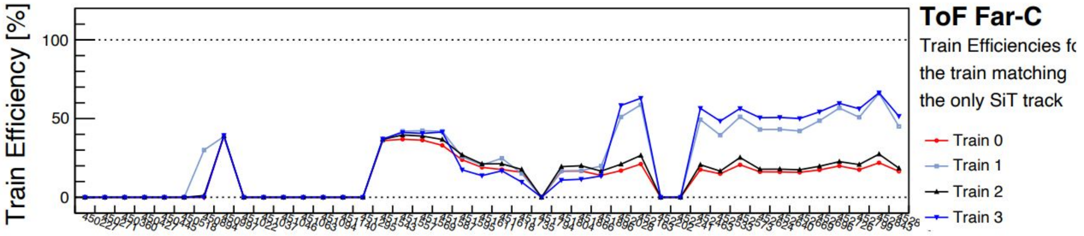
Back-up

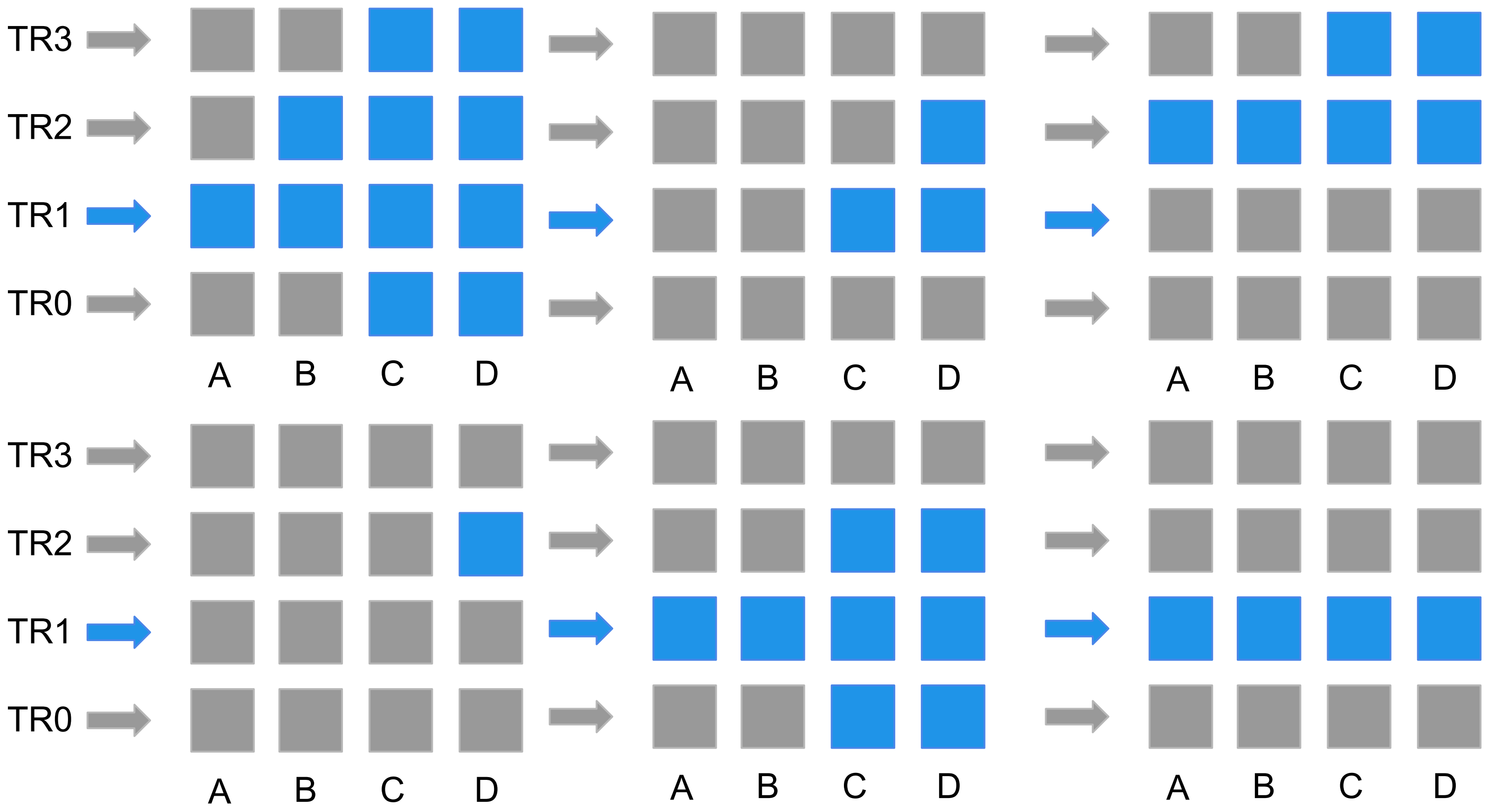
Ssdd

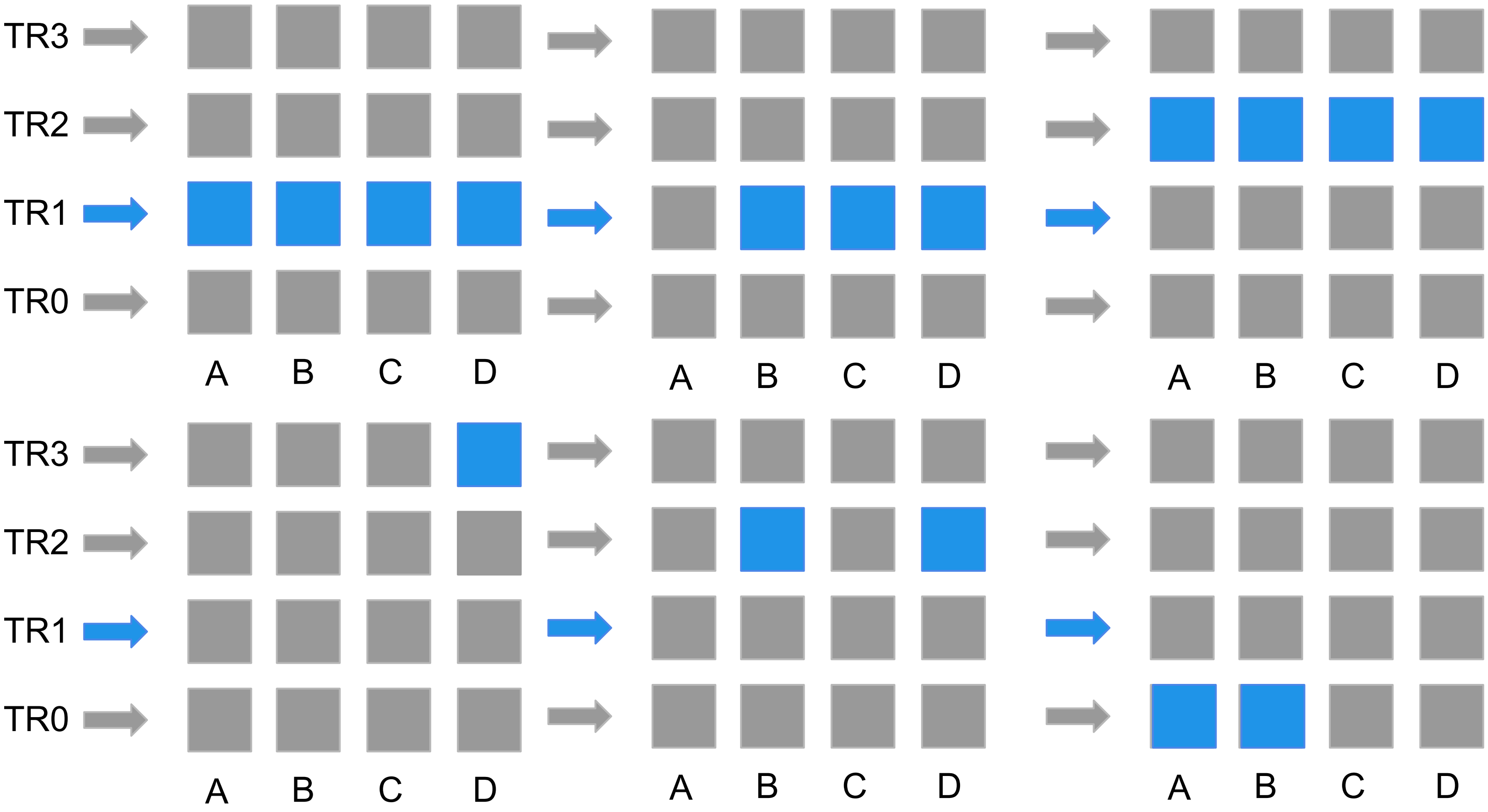
44 runs from 21 Apr 2023 ~ 25 May 2023

Text






TR3
TR2
TR1
TR0
A B C D
A B C D
A B C D
TR3
TR2
TR1
TR0
A B C D
A B C D
A B C D



TR3
TR2
TR1
TR0
A
B
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D
A
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C
D
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TR3
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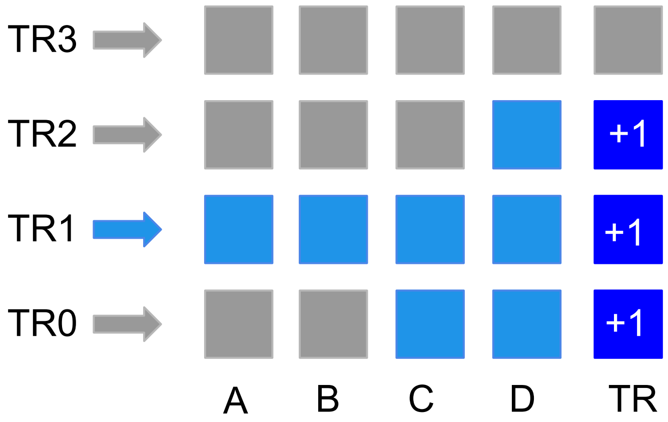
D
A
B
C
D


TR3
TR2
TR1
TR0
+1
+1
+1
A
B
C
D
TR

Main title

Sub-title

Text