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Charged-particle pseudorapidity density in proton-proton collisions with ALICE MFT

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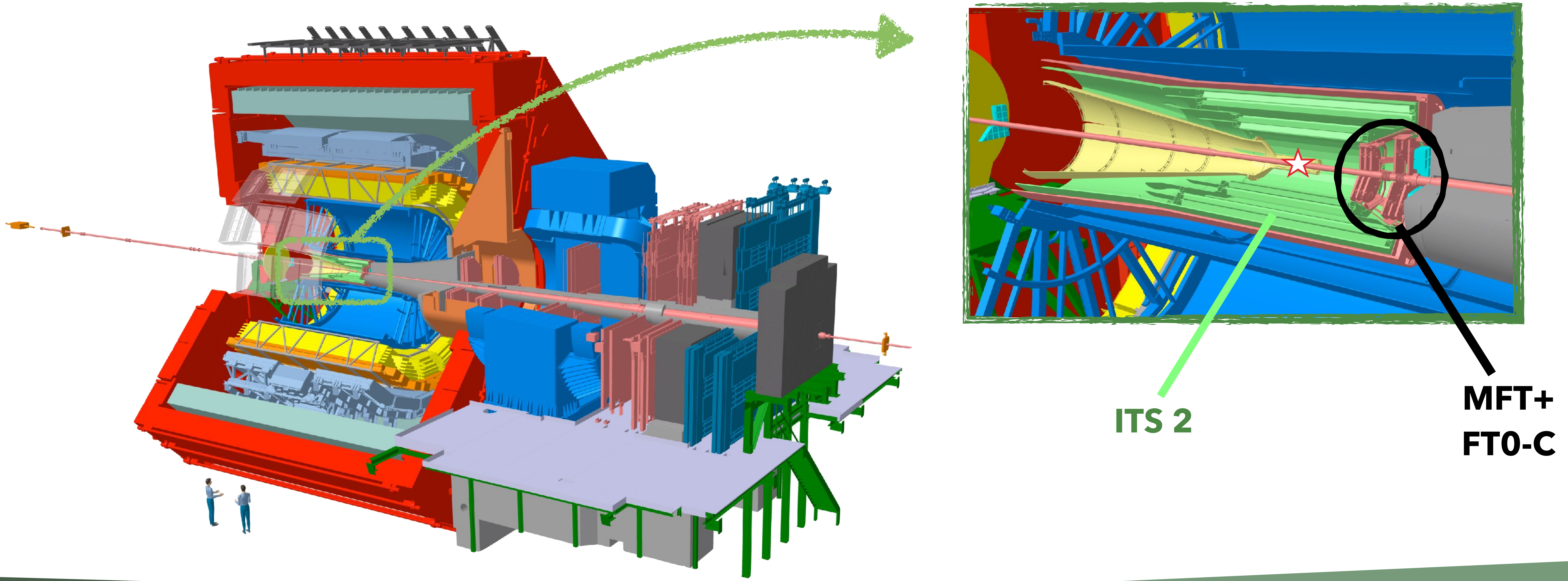
Outline

- The ALICE detector in run 3
  - Detector upgrades
  - The Muon Forward Tracker (MFT)
- Software developments: MFT time-alignment
- Charged particle pseudorapidity with MFT

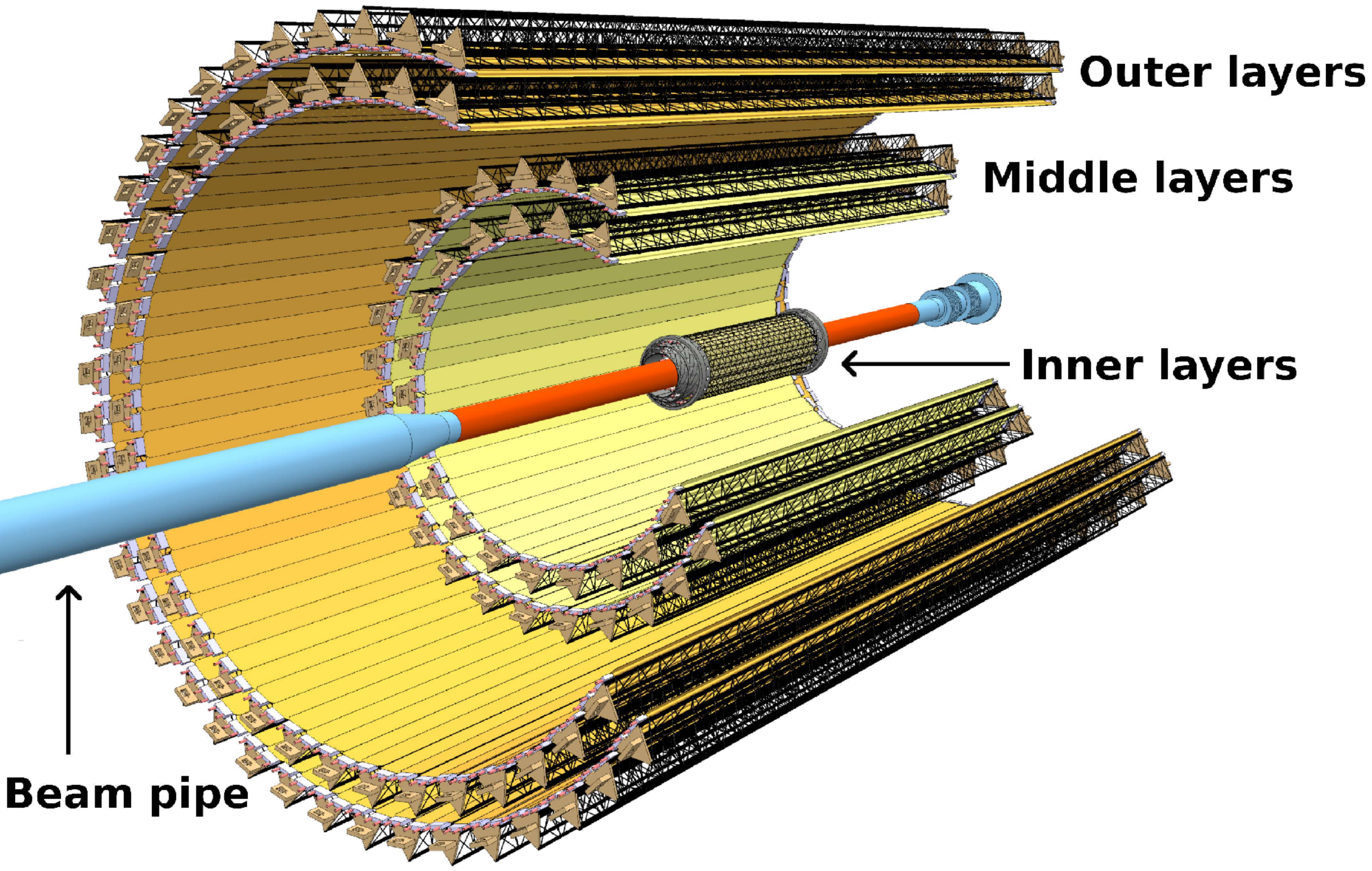
The ALICE DETECTOR in run 3

- ALICE in Run 3 : New sub-detectors and better performances
  - The Muon Forward Tracker (MFT) : a new sub-detector of ALICE
  - The Inner Tracking System (ITS2) : upgraded central barrel detector



The Inner Tracking System upgraded (ITS 2)

- ITS 2 goals :
  - Reconstruct the primary and secondary vertices → resolution : less than 25 μm
  - Track and identify charged particles at midrapidity with a low p_T cutoff (< 50 MeV)



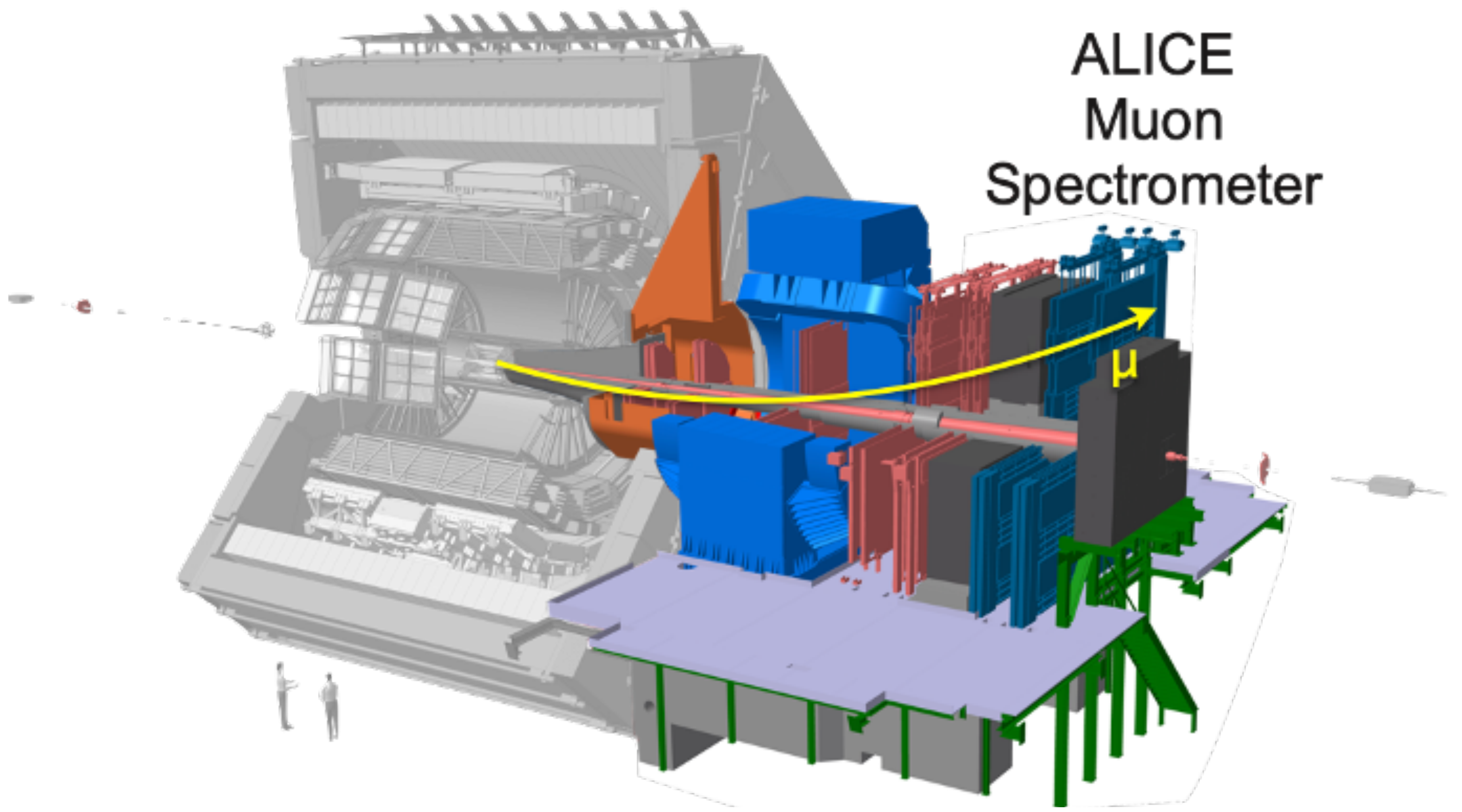
- Seven cylindrical detector layers (from R = 22 mm to R = 400 mm) with ALPIDE chips
  - CMOS* silicon pixel sensor
  - Spatial resolution: 5 μm
- η coverage [-1.2 ; 1.2]

* CMOS : Complementary Metal–Oxide–Semiconductor

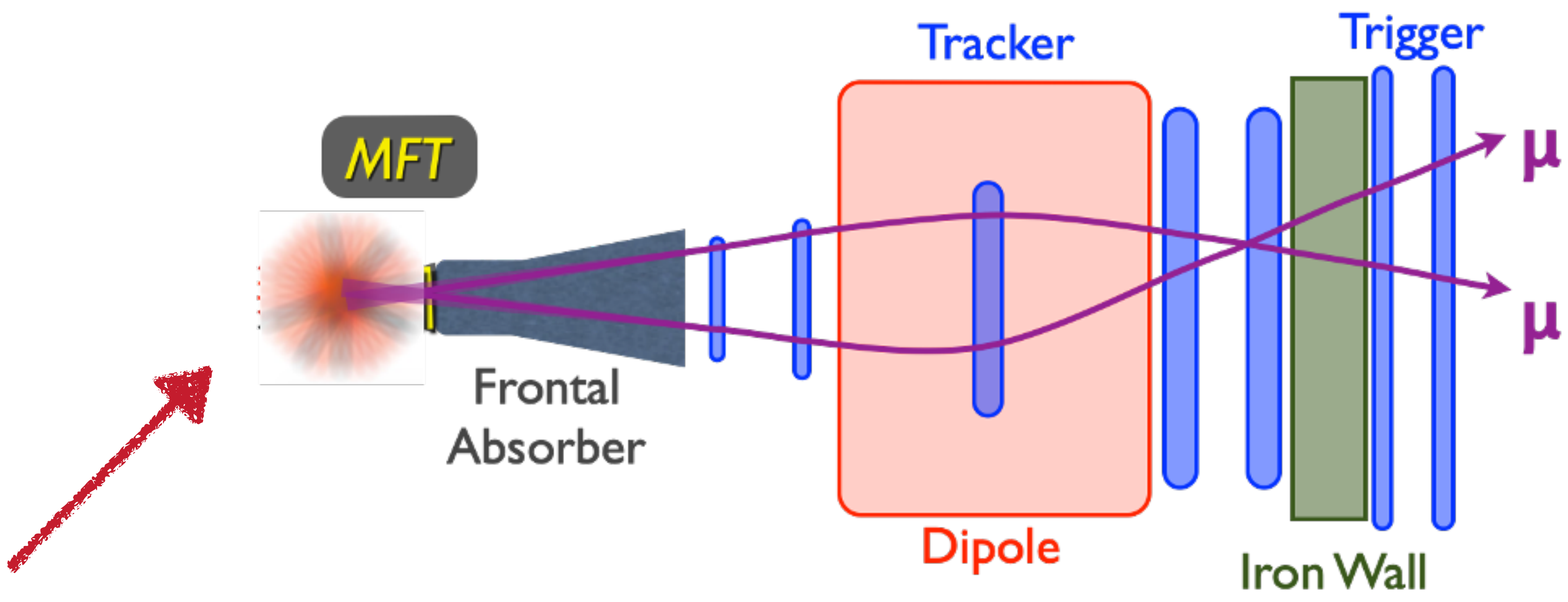
Limitations of the Muon Spectrometer

For more details on the muon spectrometer and muons, see Nicolas Bizé's talk

- Forward rapidity:
  - Detector: muon spectrometer
    - $-4 < \eta < -2.5$
  - Different region of the QGP
    - Complementary to central barrel

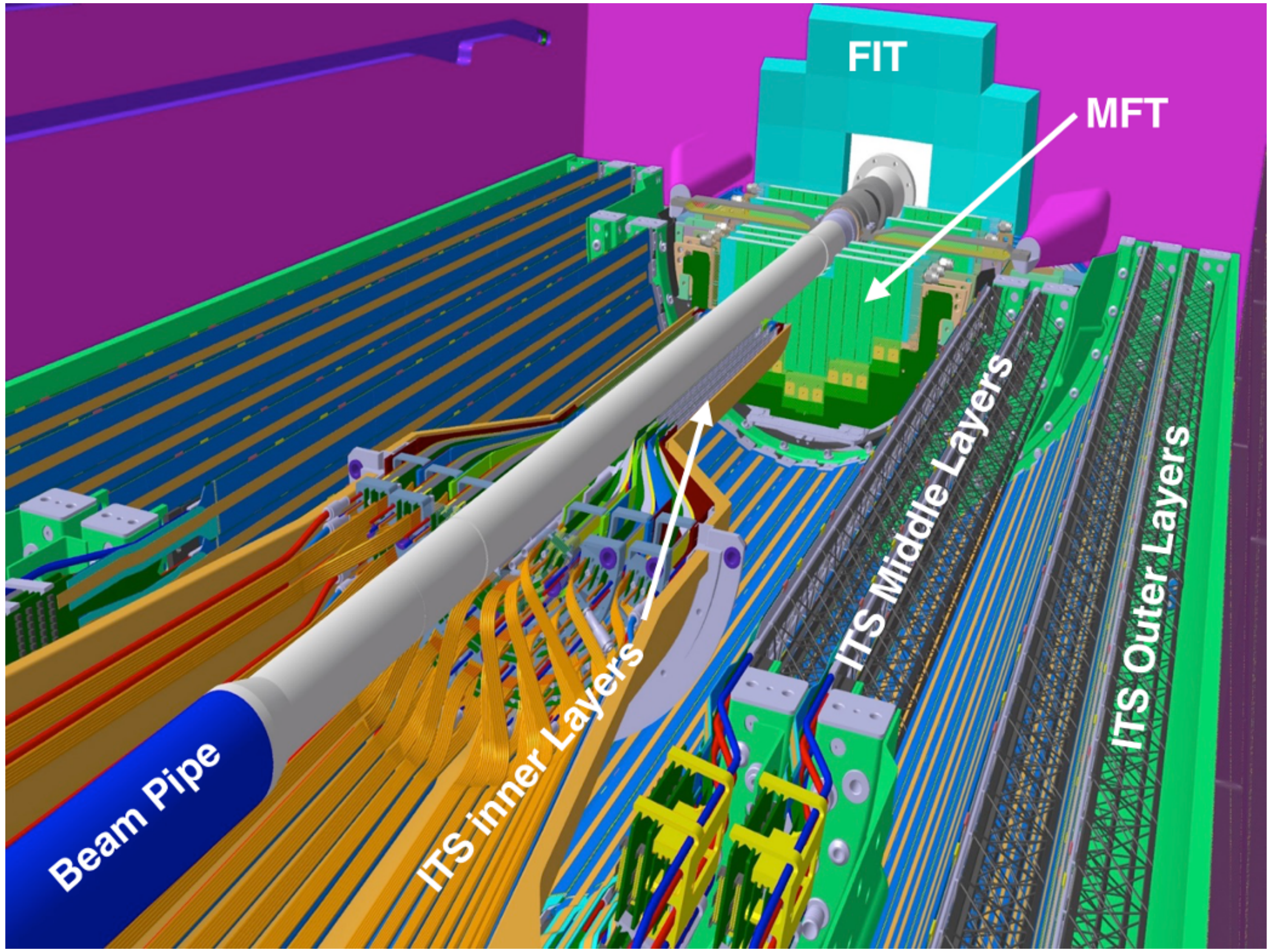


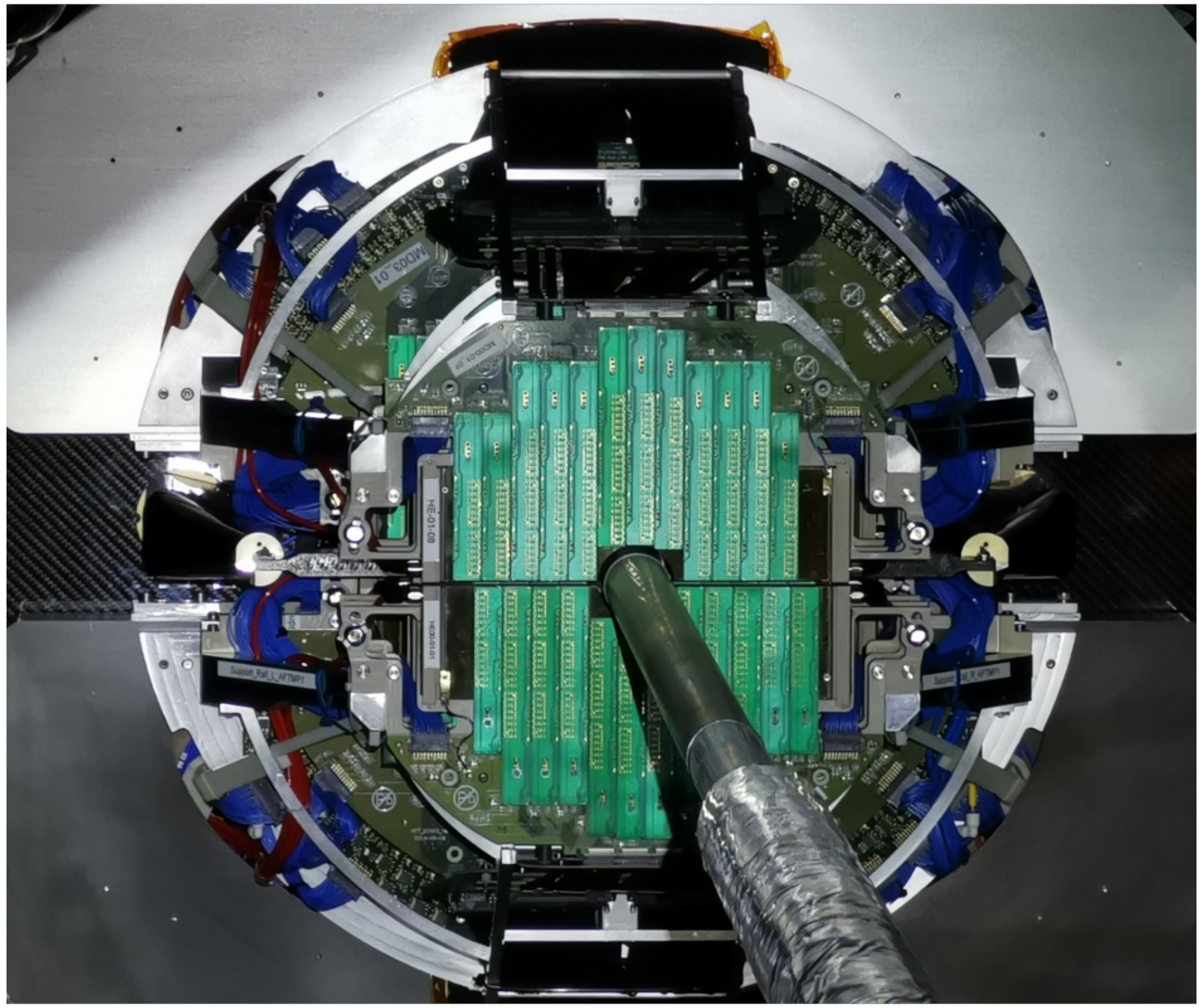
- Muon spectrometer in Run 1 & Run 2
  - Muon filter = Frontal absorber: poor spatial resolution around the interaction point
- Heavy flavor measurement
  - No charm/beauty separation
  - Hadronic background



Need of a high spatial resolution tracker in front of the muon absorber

MFT: The design –> The real detector

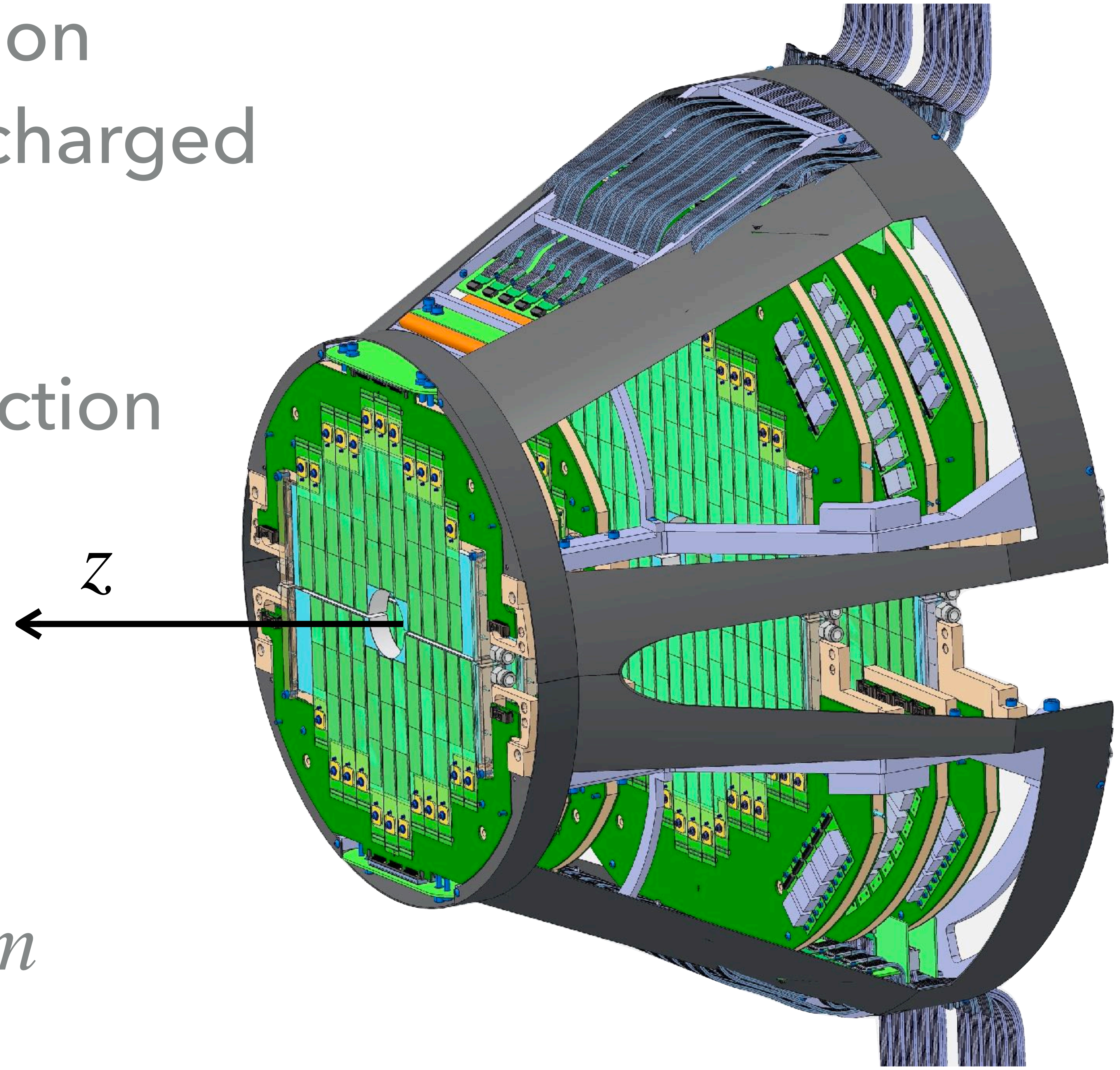




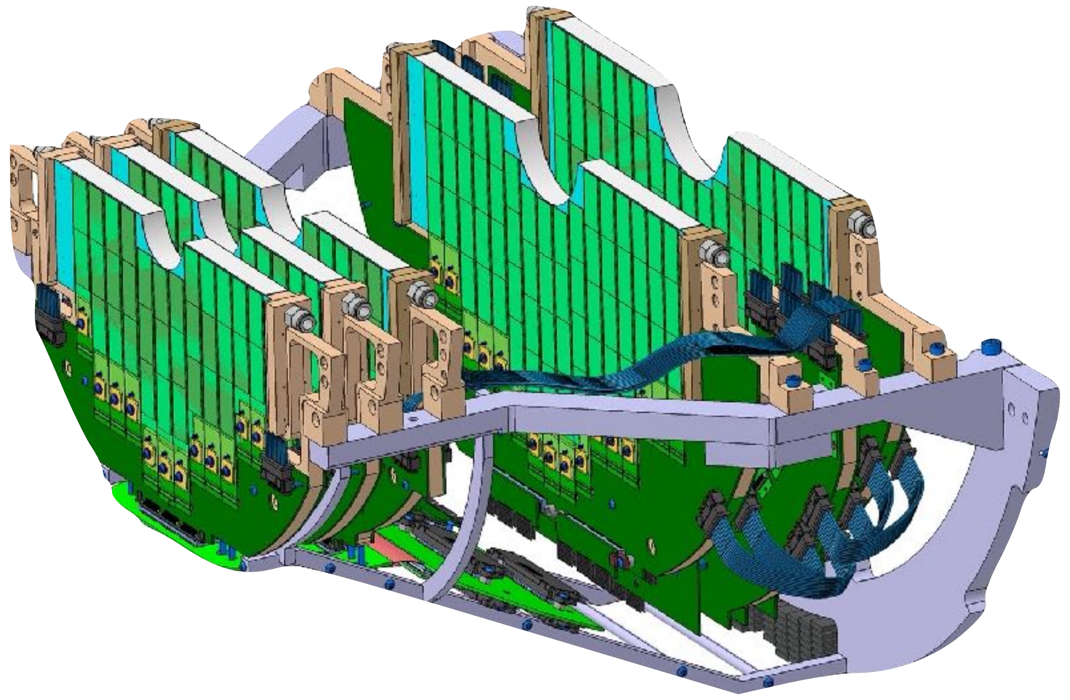
MFT : Muon Forward Tracker

The Muon Forward Tracker (MFT)

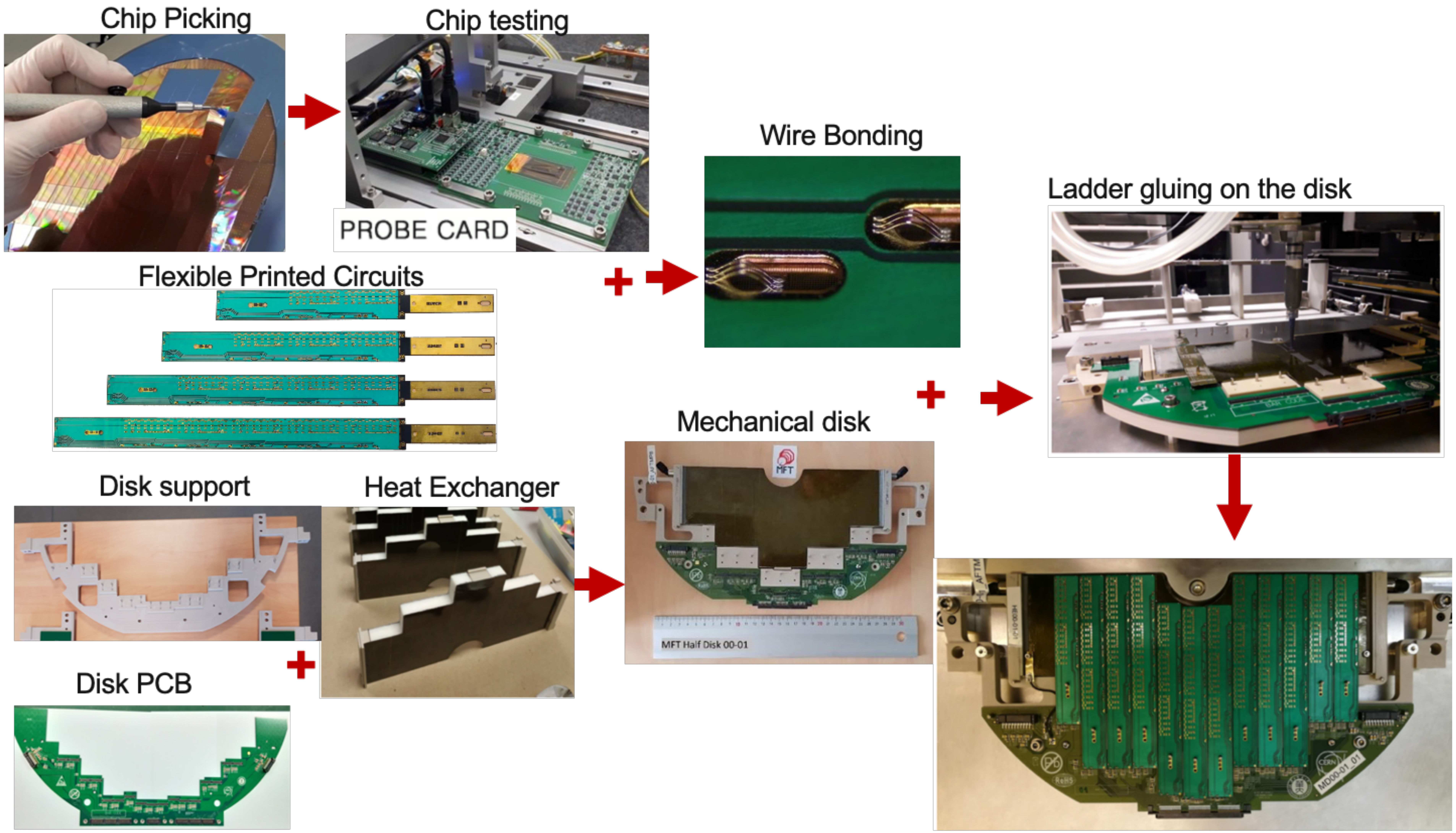
- Vertex tracker for the Muon Spectrometer, tracks all charged particles
- 5 detection disks, 2 detection planes each
- Covered with ALPIDE chips (936)
  - Spatial resolution: 5 μm
- Readout time window: 5 μs



- Nominal acceptance: $-3.6 < \eta < -2.5$, full azimuth
- Poor p_T resolution



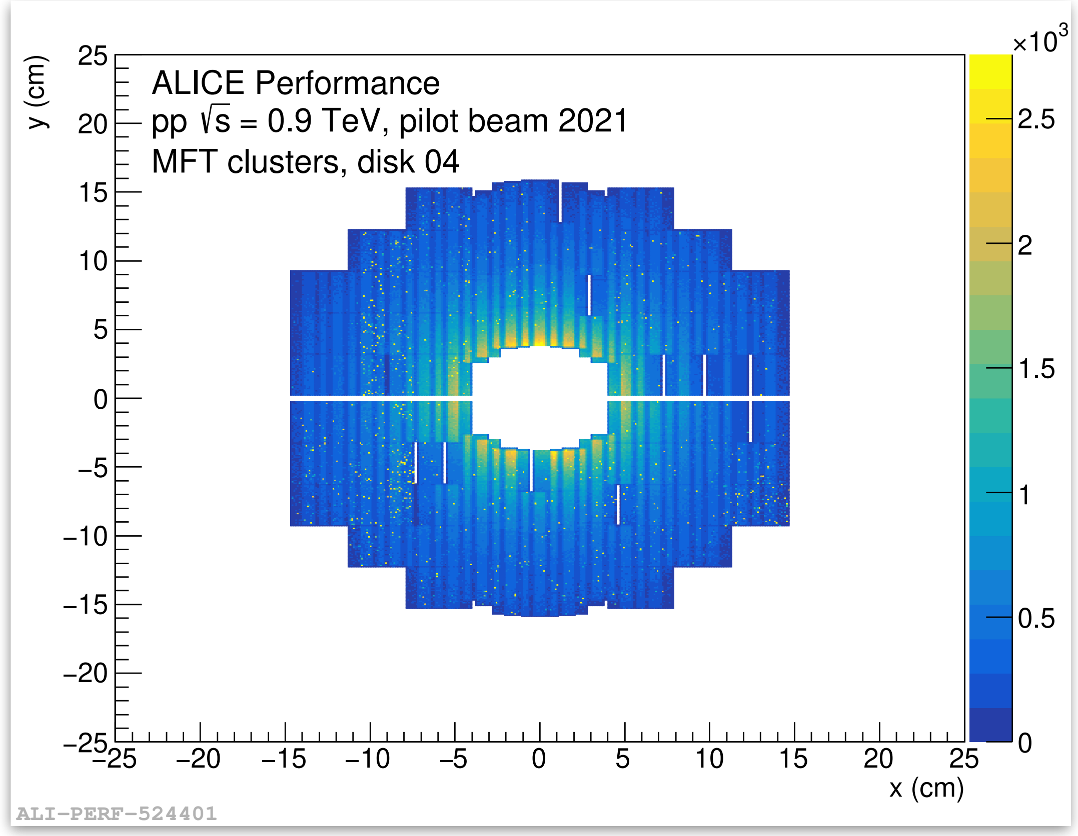
MFT disk production in a nutshell

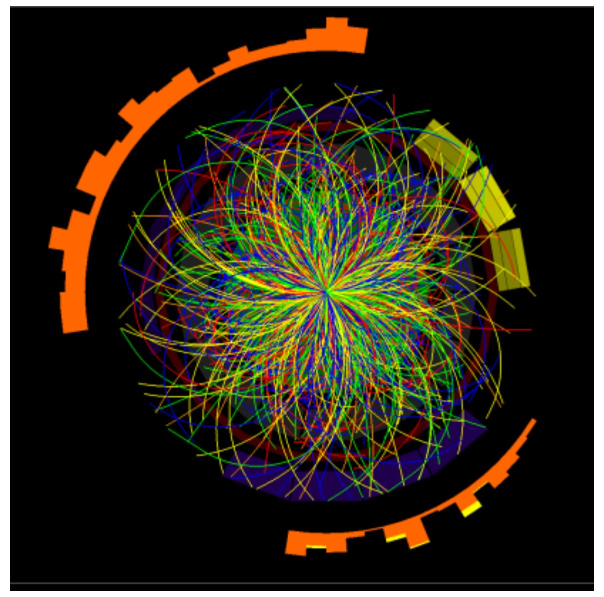


Credits: Stefano Panebianco

ALICE run 3 data taking: Timeline

- December 2020 — Installation of MFT in the ALICE cavern
- Commissioning
- September 2021
- October 2021 — First pp pilot beam
- 2022 — pp nominal & first PbPb pilot beam
- Sept. 2023 — PbPb collisions nominal conditions





MFT time alignment

- MFT is not a very fast detector
  - Readout window of 5 μs
- MFT tracks
  - matched with tracks from faster detectors in the muon spectrometer (for muons only)
  - associated to collisions that can be close in time
- The MFT readout window must be aligned with the global clock
  - FT0-C detector

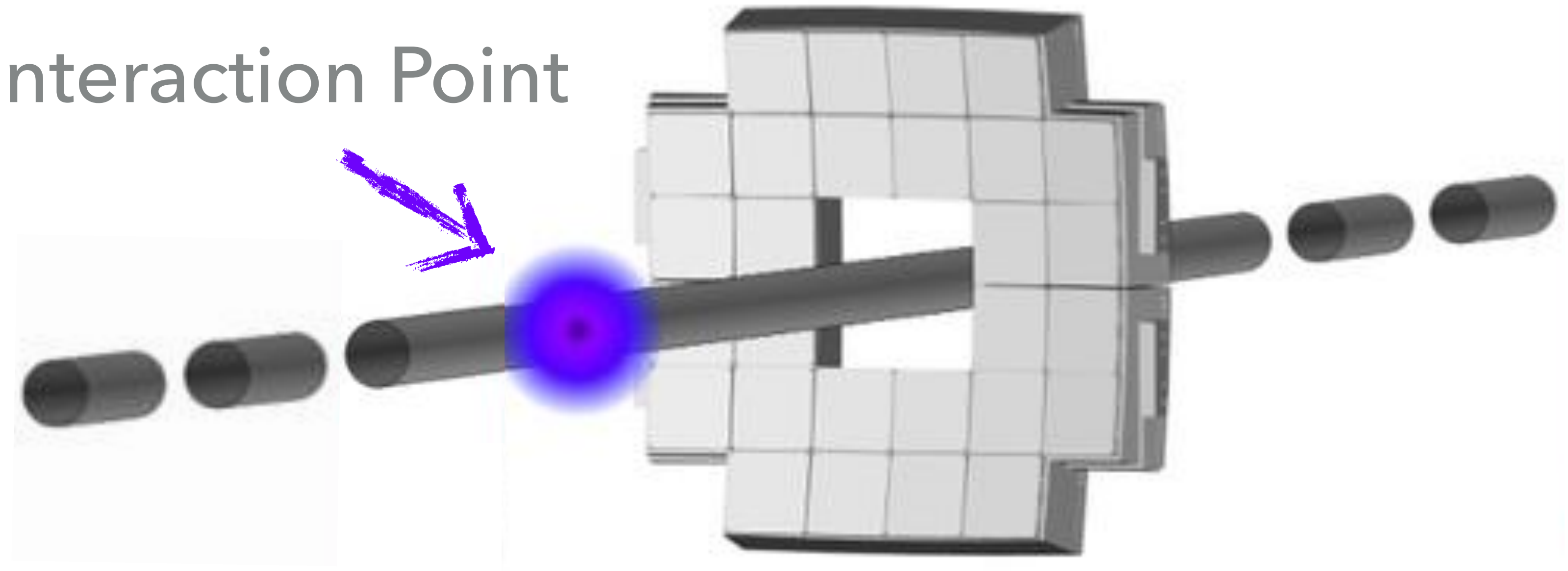
FT0-C characteristics

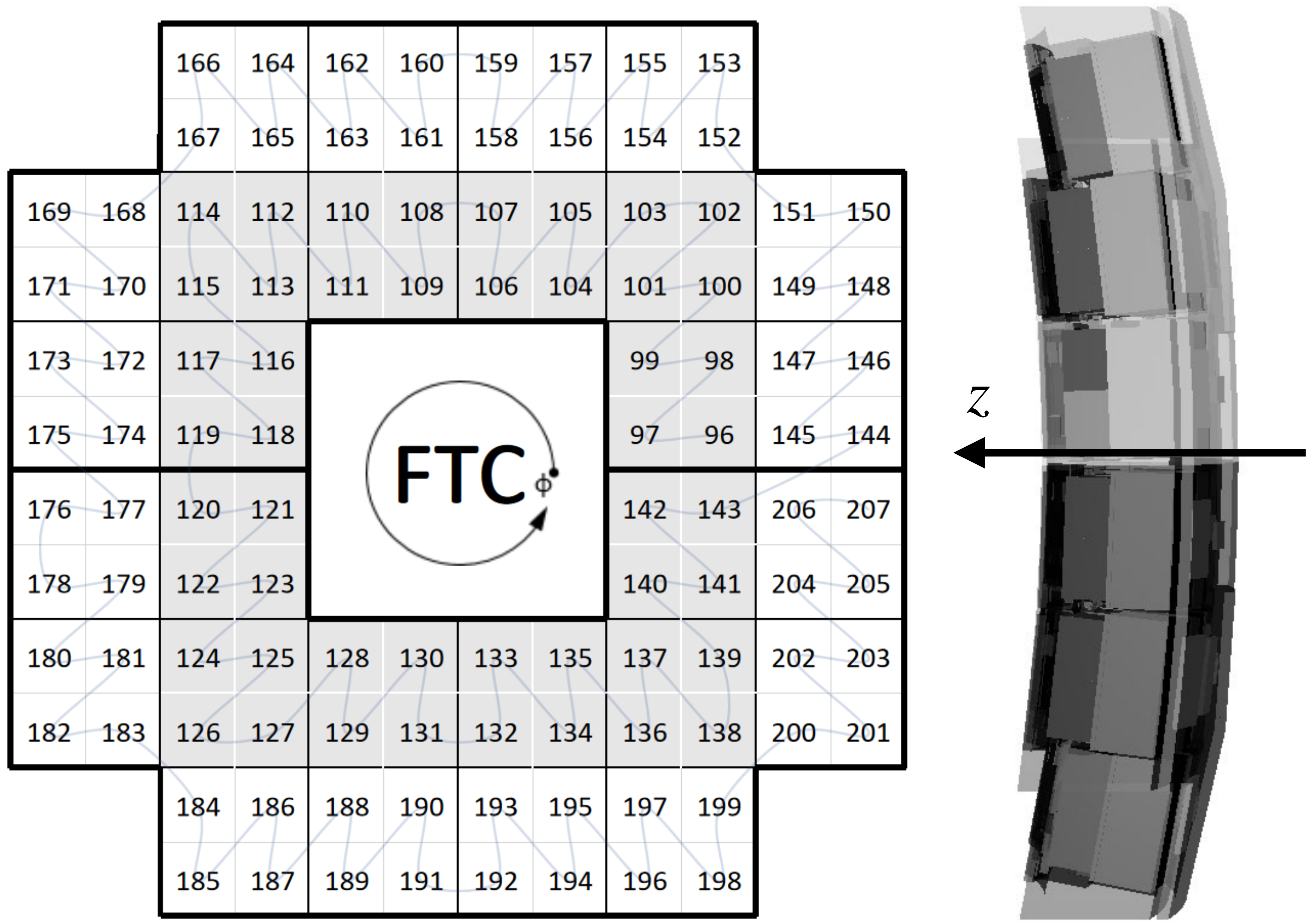
- The FT0-C: Quartz Cherenkov detector
  - Time precision ~50ps
  - 28 modules, each divided in 4 channels
  - Size of 1 channel : 26.5 x 26.5 mm

FT0-C

$-3.4 \leq \eta \leq -2.3$

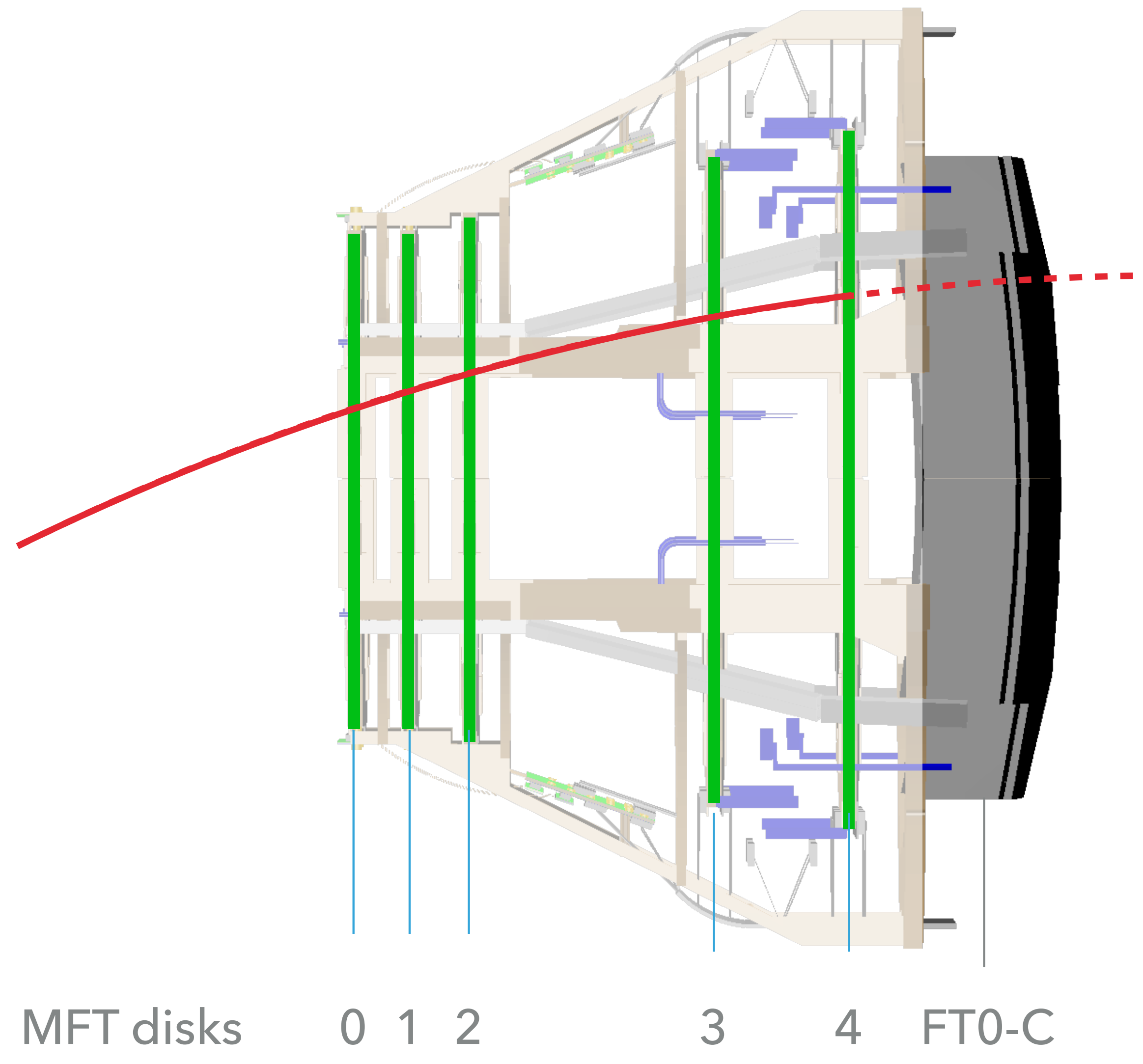
-0.8 m away from IP *



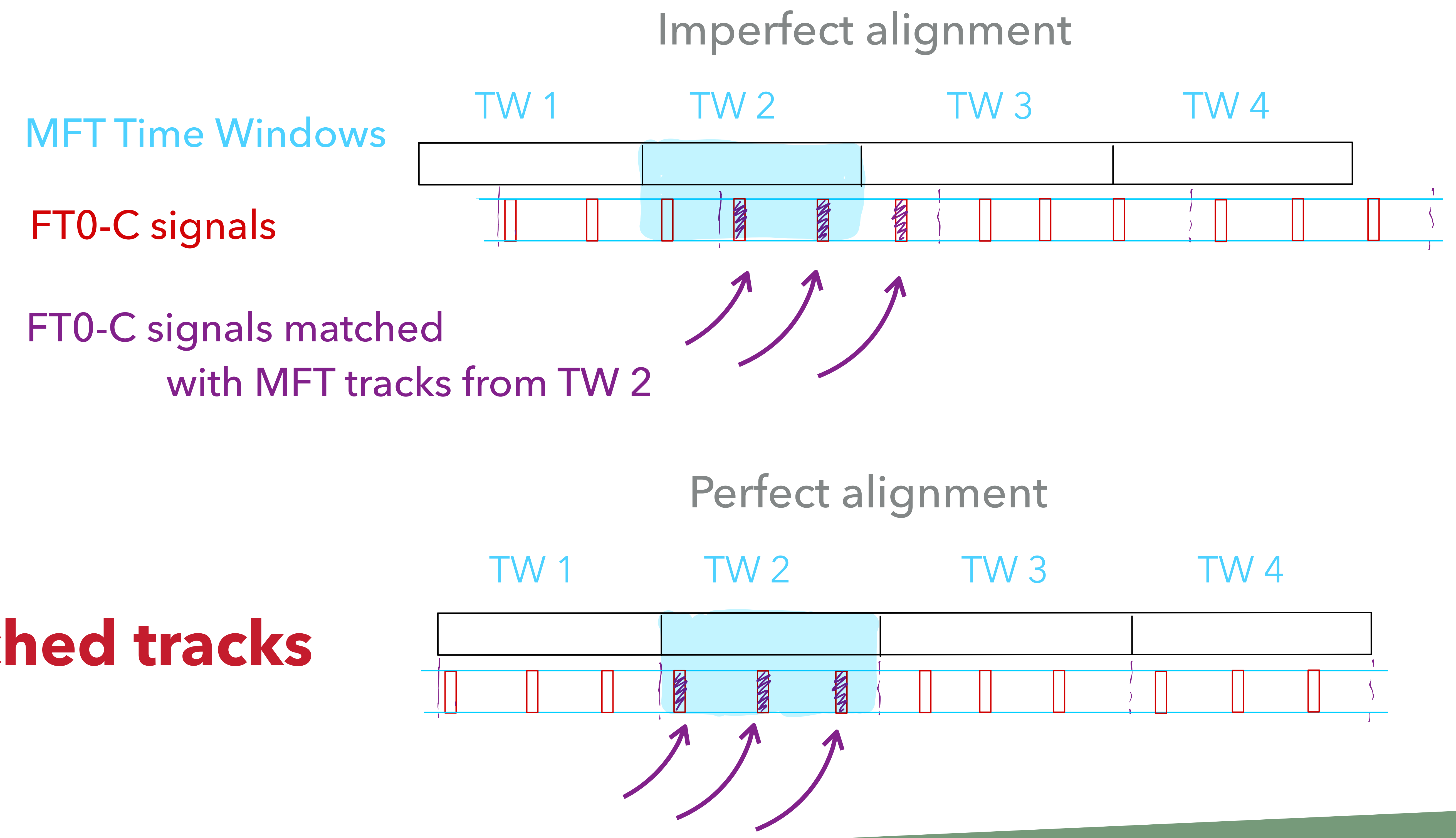


Time alignment procedure

- Extrapolate MFT tracks (helix) to the center of the FT0-C: if the extrapolated track falls into a fired FT0-C channel, **it's a match**
  - Only looking at FT0-C signal **within** the MFT readout time window



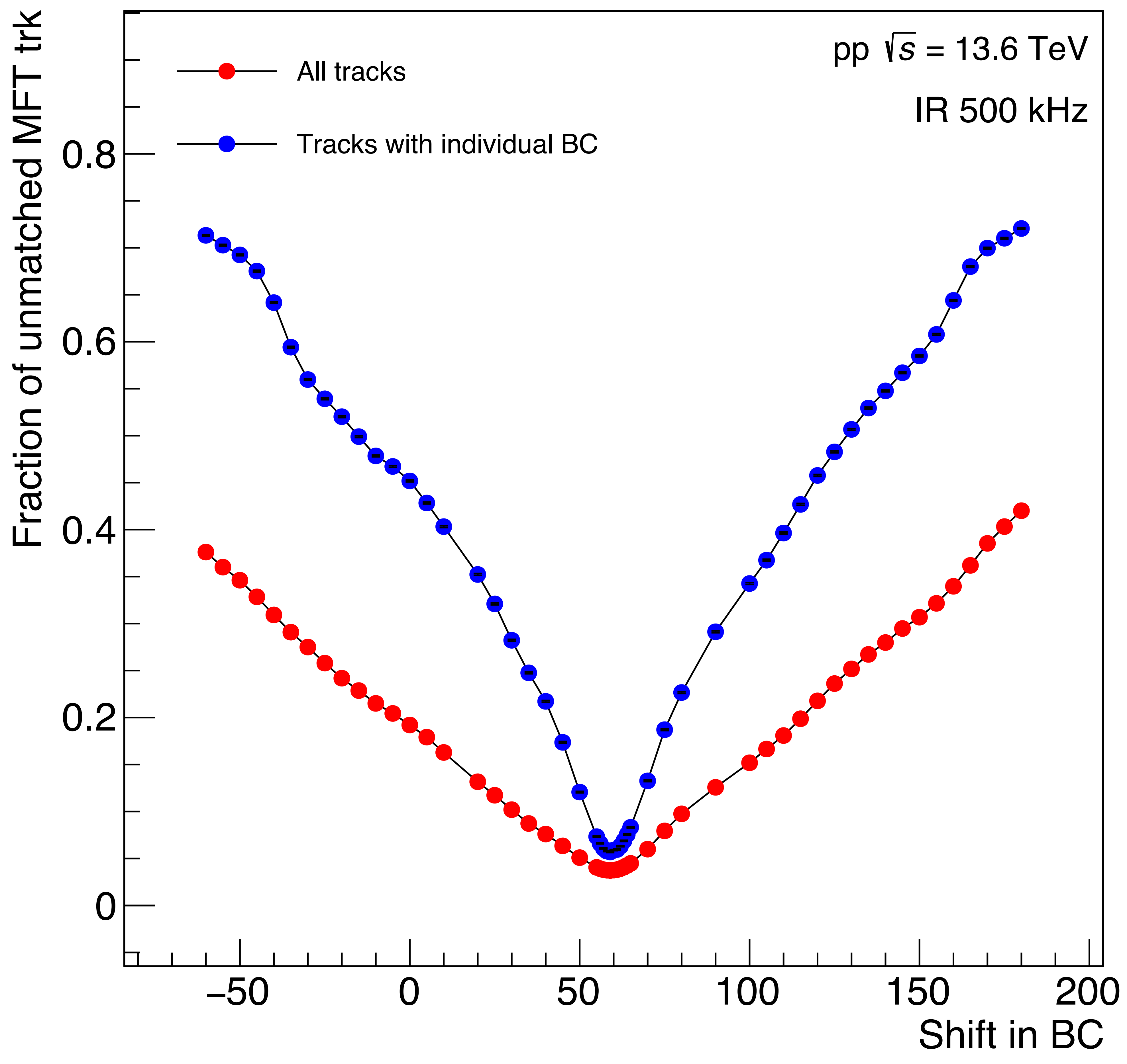
- Shift the MFT time window and count the number of matched and unmatched MFT tracks with FT0-C signals in that window



Time shift leading to a **minimum of unmatched tracks**
= time misalignment

Time alignment: Results

- Fraction of unmatched MFT tracks versus time shift in BC
  - For all MFT tracks (red)
  - For MFT tracks having only one collision within their time window (blue)
- Minimum at 60 BC = +1.5 μs



Time shift applied to the beginning of the MFT track time window

Time alignment: Conclusion

- A global time shift of +1.5 μs will be applied to **all** MFT time windows
  - More MFT tracks matched with muon tracks
  - Better track to vertex association

Charged-particle pseudorapidity density

Charged-particle pseudorapidity density: number of primary charged **particles** per **collision** and unit of pseudorapidity

Primary particle: Particle with a mean proper lifetime $\tau > 1$ cm/c excluding particles coming from weak decays of strange particles

- Helps in understanding particle production mechanisms in high-energy hadronic collisions, from proton-proton to heavy-ion systems
  - Provides constraints on phenomenological models and event generators
- Allows differential analyses: Yields as a function of charged-particle pseudorapidity density for instance

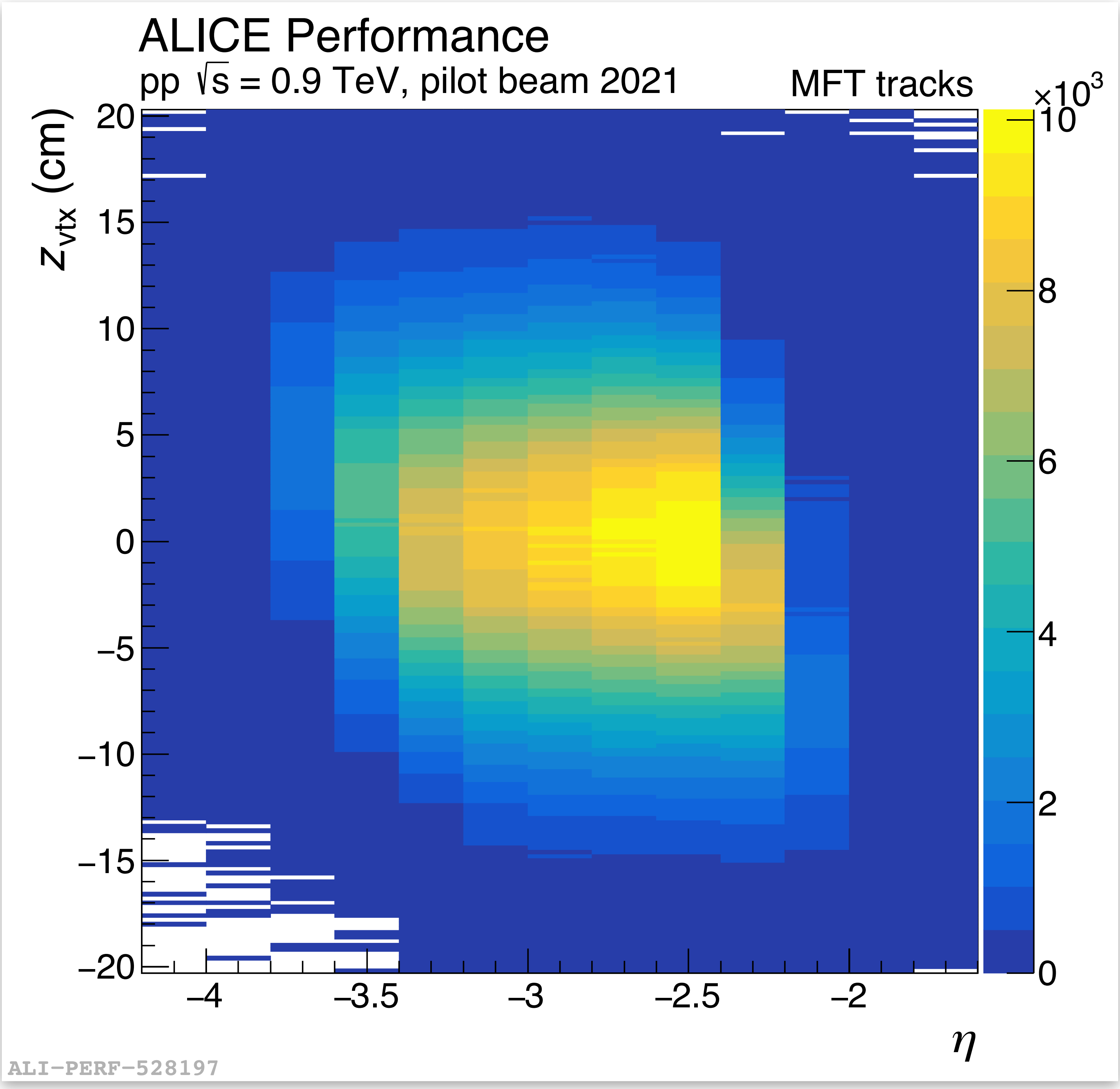
- Standard analysis needing only a limited statistics : allows to test the new analysis framework

Corrections needed

Charged-particle pseudorapidity density: number of primary charged **particles** per **collision** and unit of pseudorapidity

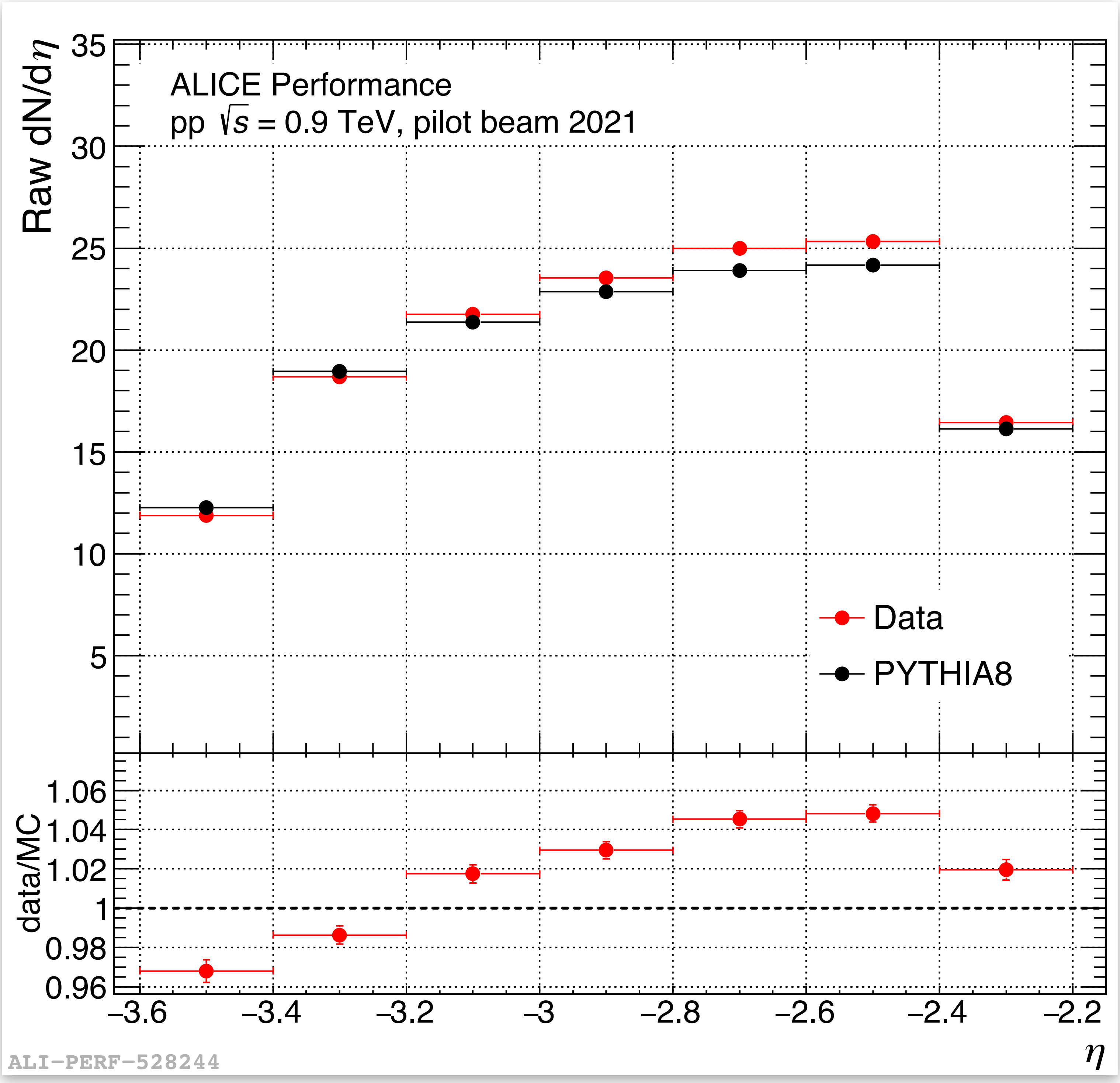
- 2 types of corrections computed with MC
  - Track-to-particle correction (difference between the number of reconstructed tracks and the number of primary charged particles) → Track level
  - Selection bias correction (corrects the difference between selected sample and generated one) → Track and event level

MFT performance and MC/data accuracy: at 900 GeV



- Measured number of tracks versus (z_{vtx}, η)

- Before correcting the measured number of tracks with the track-to-particle correction: consistency checks
  - Good agreement between reconstructed MC and data ?



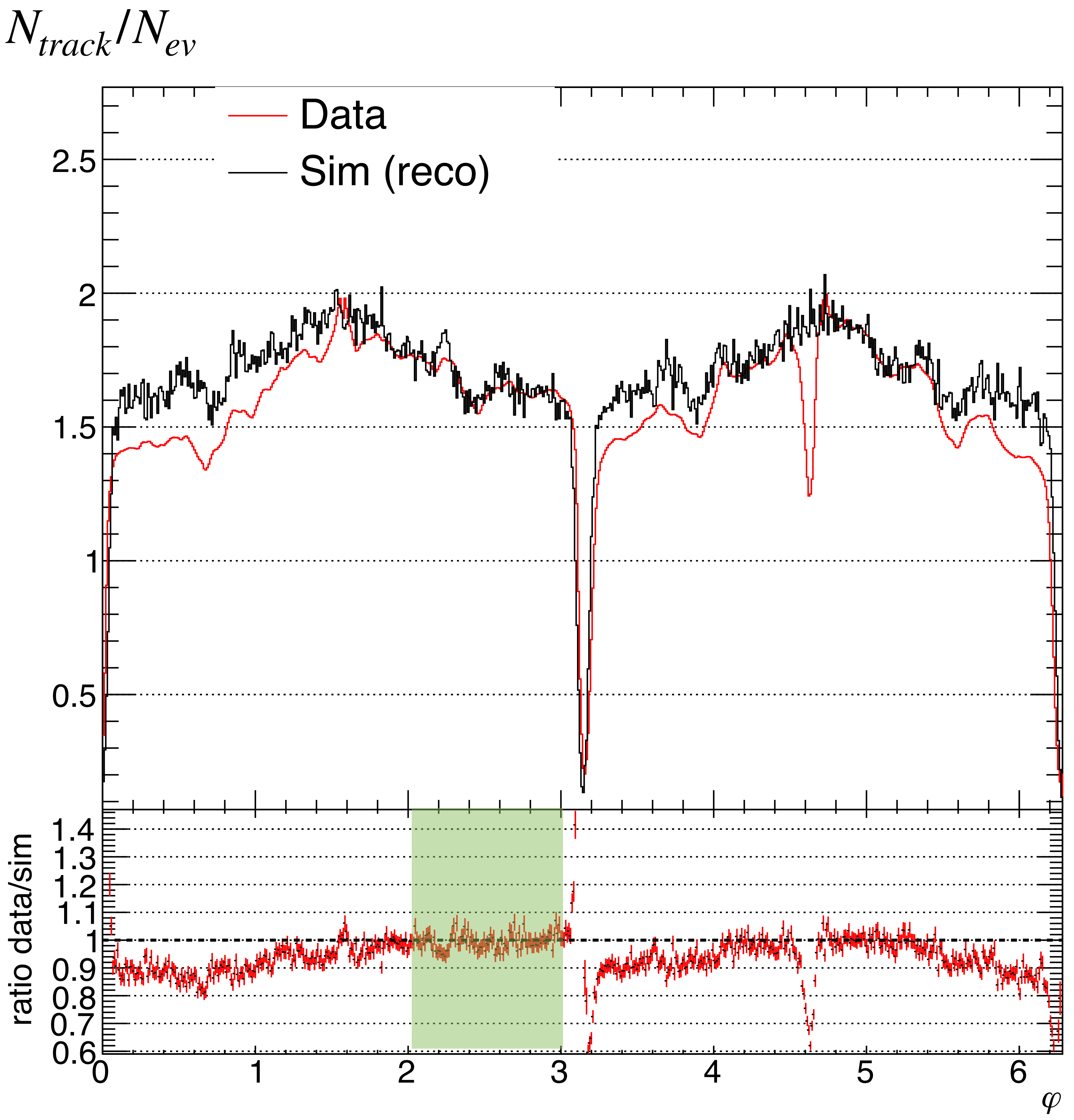
- Comparison of number of tracks versus η in simulation and data

Data and simulation are consistent within $\pm 5\ \%$

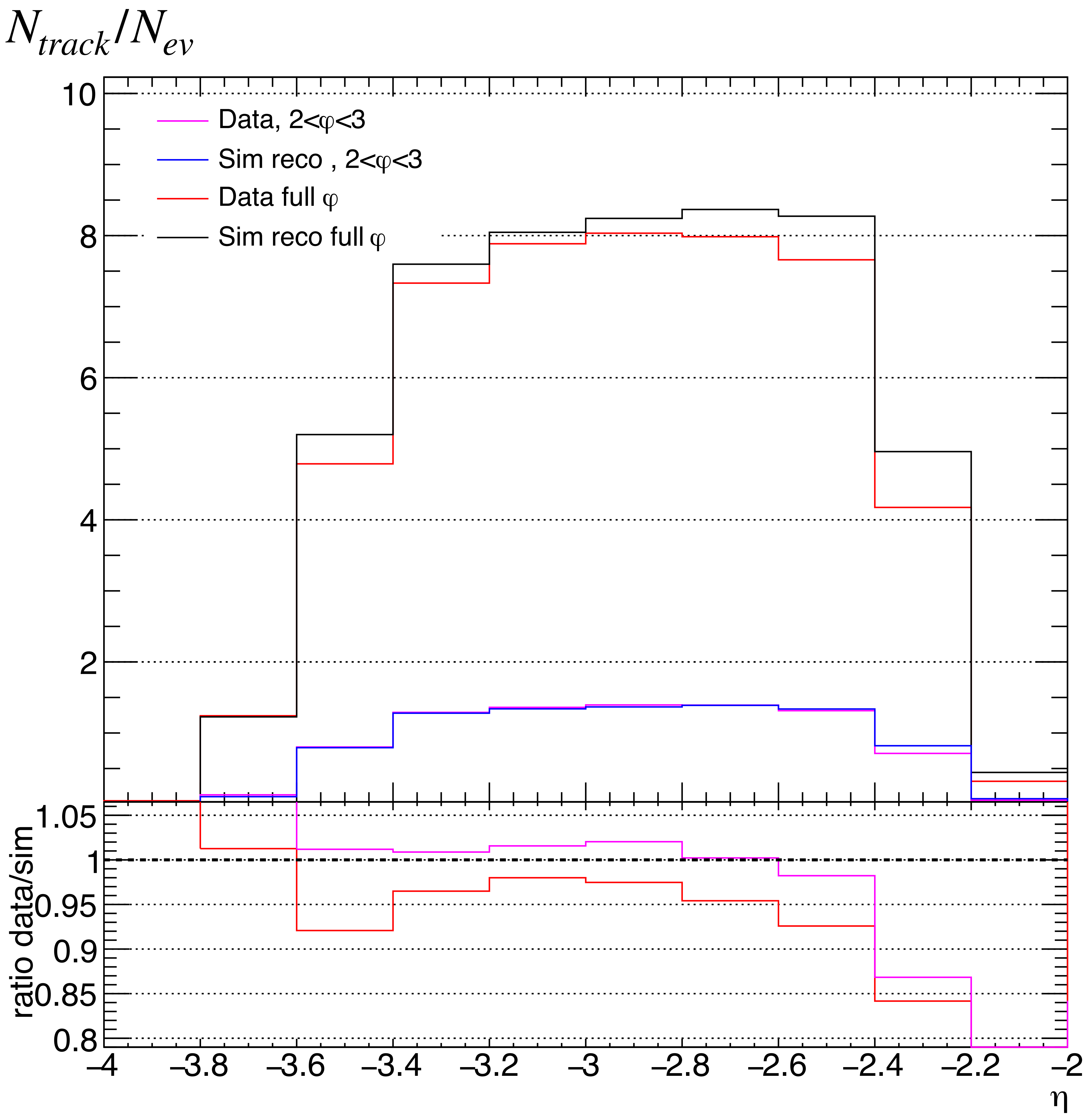
→ MC simulation can be used for correction

→ Systematic error would need to be reduced

MC/data accuracy at 13.6 TeV (WIP)



$2 < \varphi < 3$



Summary

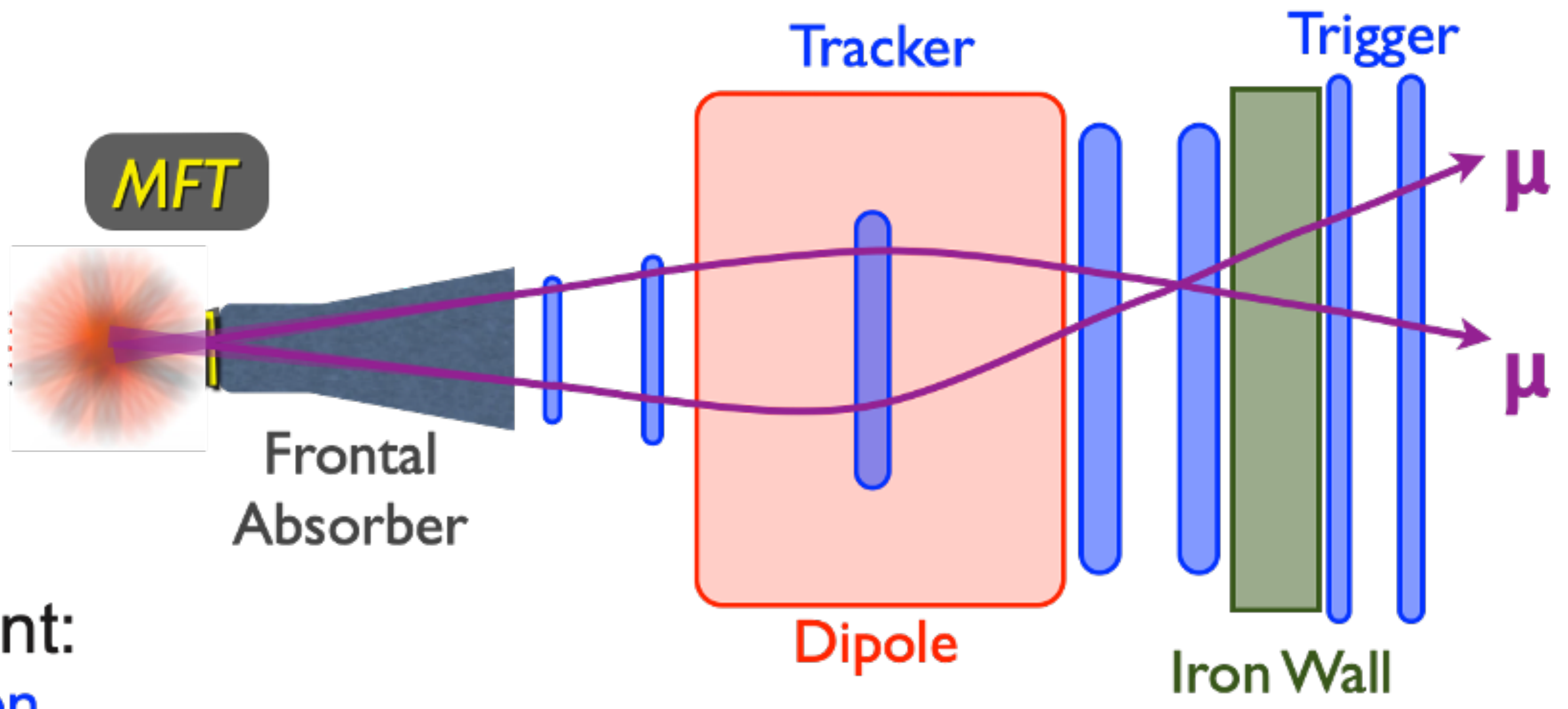
- MFT is a very well working detector, able to produce physics results such as charged particle pseudorapidity density but also allowing other nice future muon analysis by adding vertexing capabilities to the muon spectrometer
- The software part is making great progress, the time alignment is finalized
  - A bit more work needed in the tuning of MC simulations
- We are positive that the PbPb data will be very well reconstructed, and that the MC will be very good !
  - Stay tuned for future exciting results involving MFT

Thank you for your attention

BACKUP

Limitations of the Muon Spectrometer

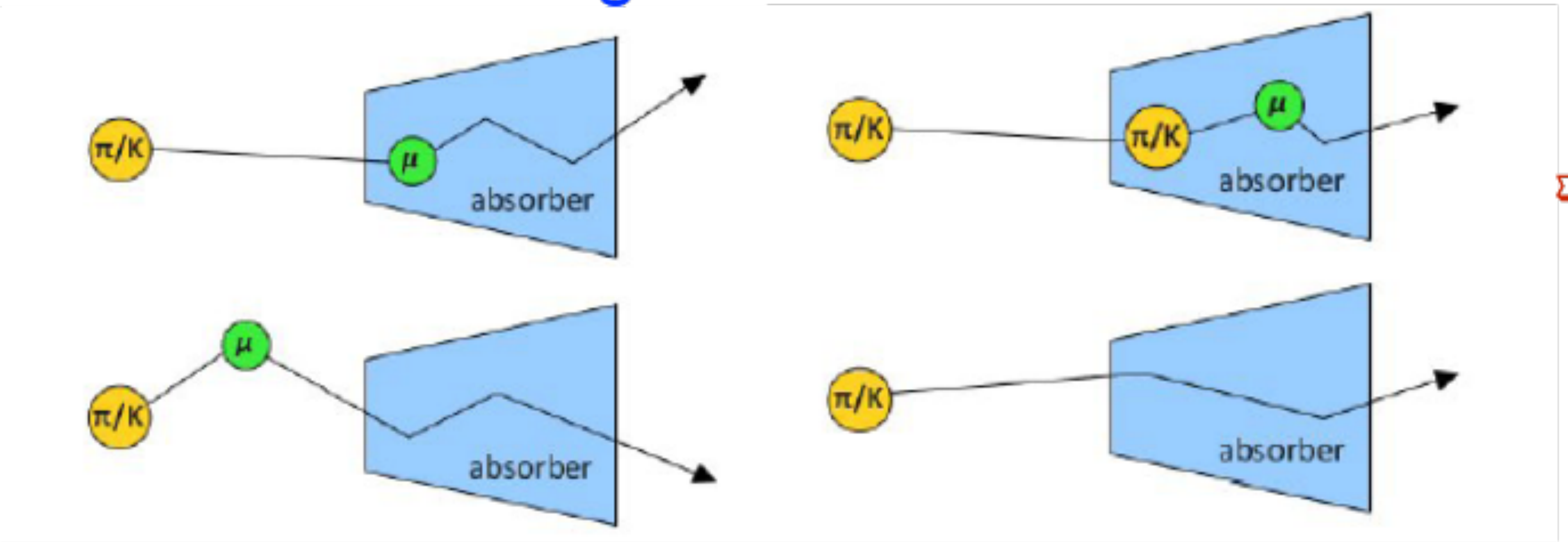
- Muon filter:
  - Frontal absorber: $10X_0$
  - Muons: p_{min} = 3-4GeV
  - ⇨ poor spatial resolution around the IP region



- Heavy flavour measurement:
  - No Charm/Beauty separation
    - on open heavy flavour
    - on J/ψ: B feed-down (est. ~20%)
    - Inclusive measurement only

	$\pi^{\pm}$	$K^{\pm}$	D^0	$D^{\pm}$	$B^{\pm}$	J/ψ
cτ (μm)	7.8×10^6	3.7×10^6	123	312	491	~ 0

  - Hadronic background



⇨ Need of a high spatial resolution tracker in front of the muon absorber

VARIABLE AND SYSTEM COORDINATE DEFINITION

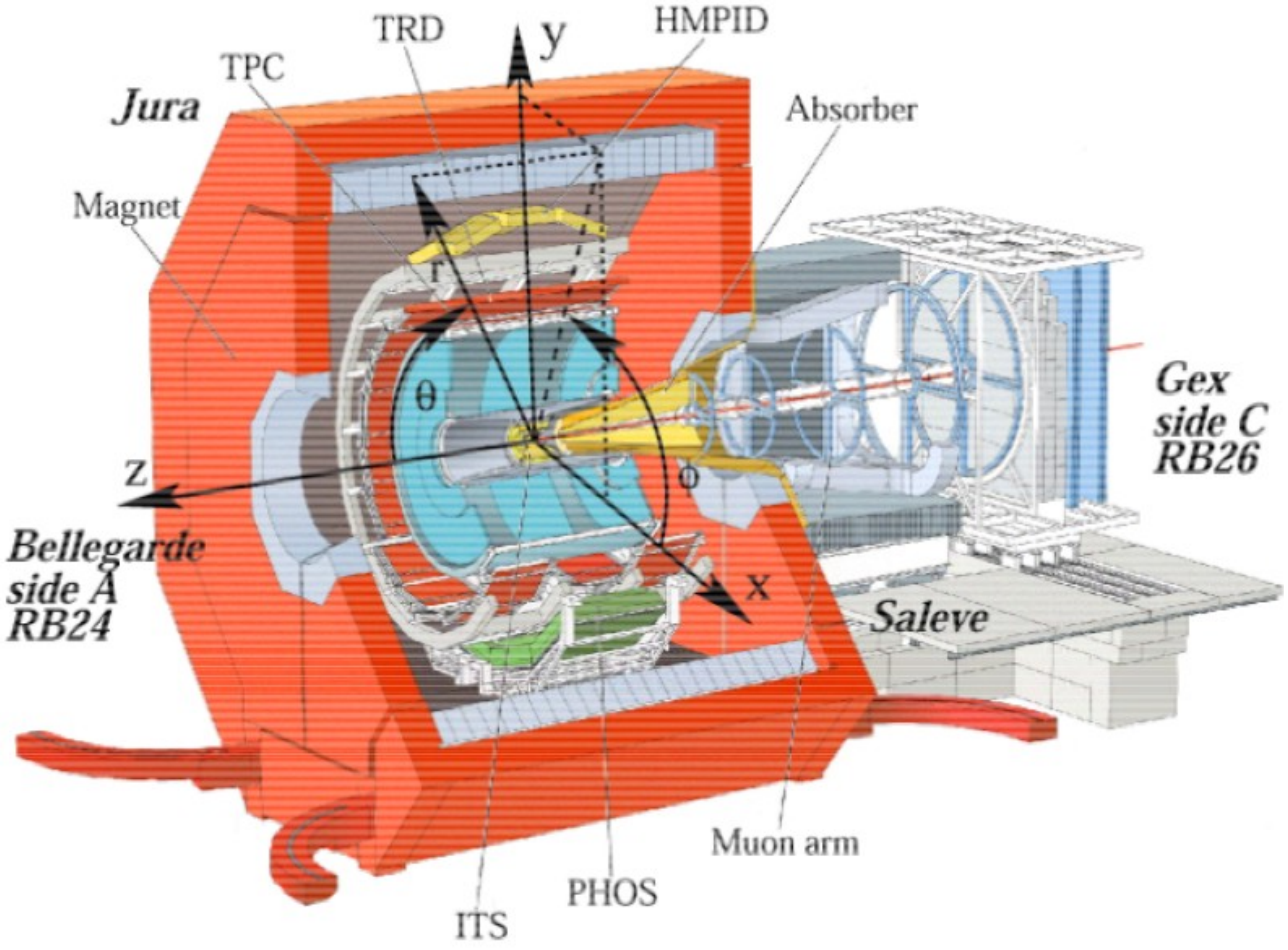
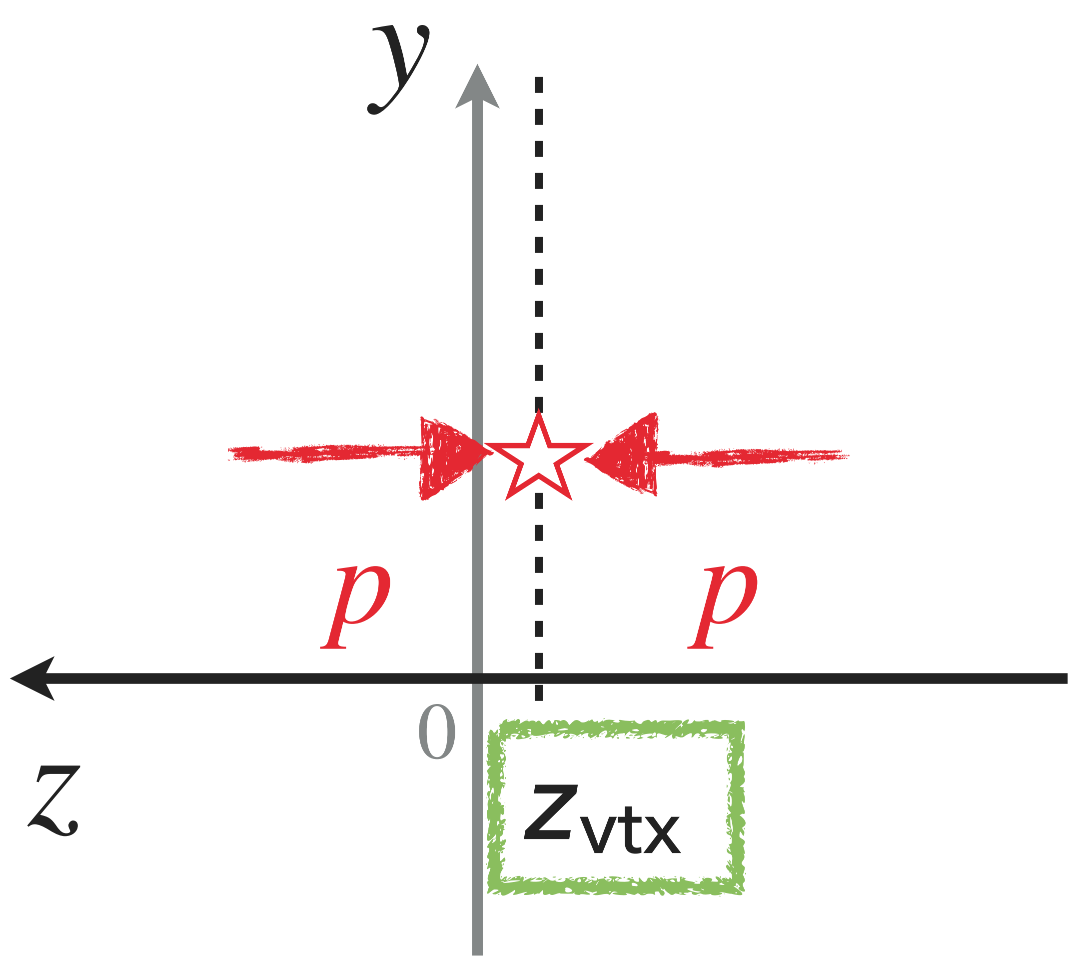
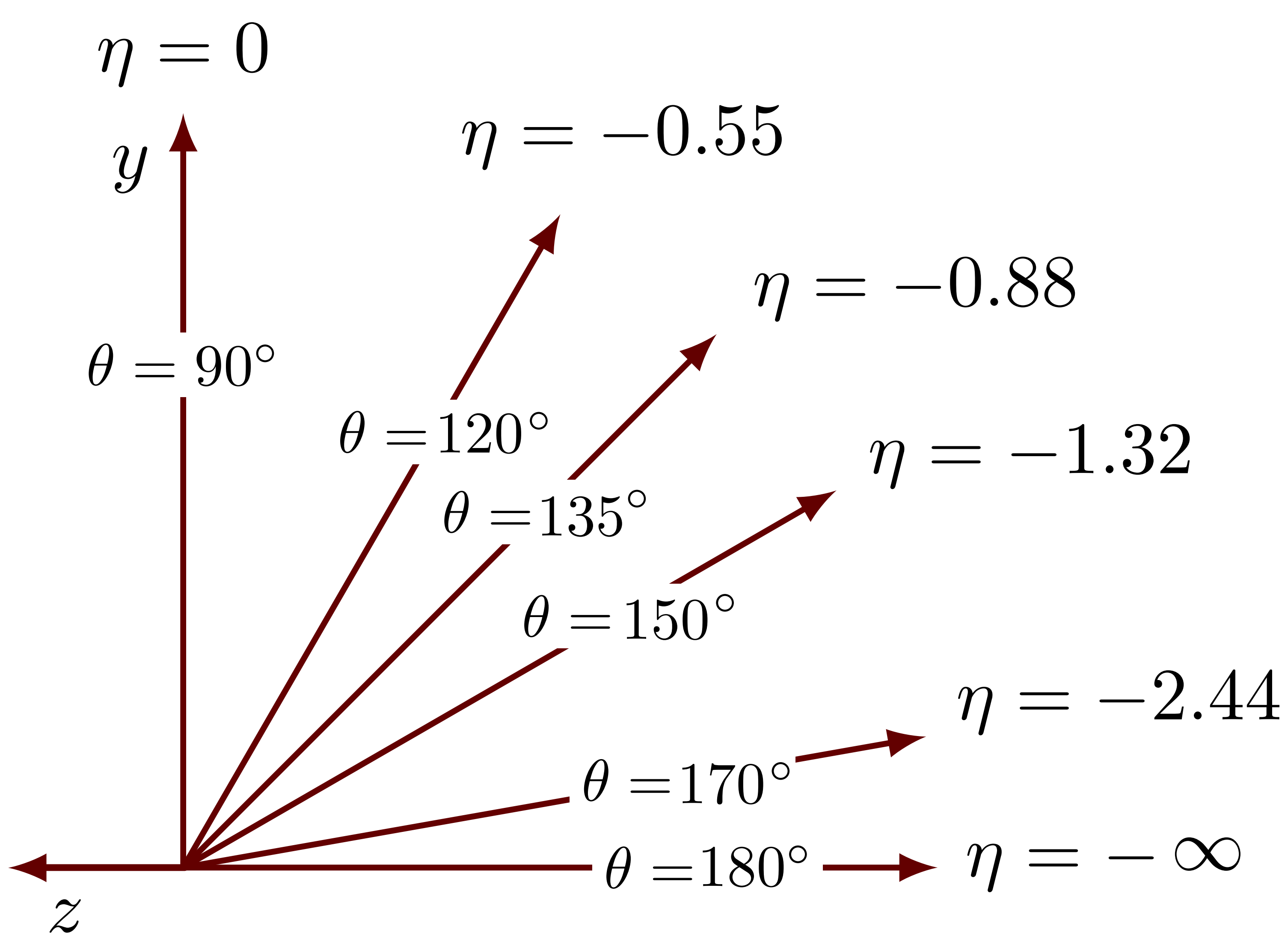


Fig1. Definition of the ALICE coordinate system axis, angles and detector sides.

One *vertex* found = 1 collision



z_{vtx}



Pseudorapidity η

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

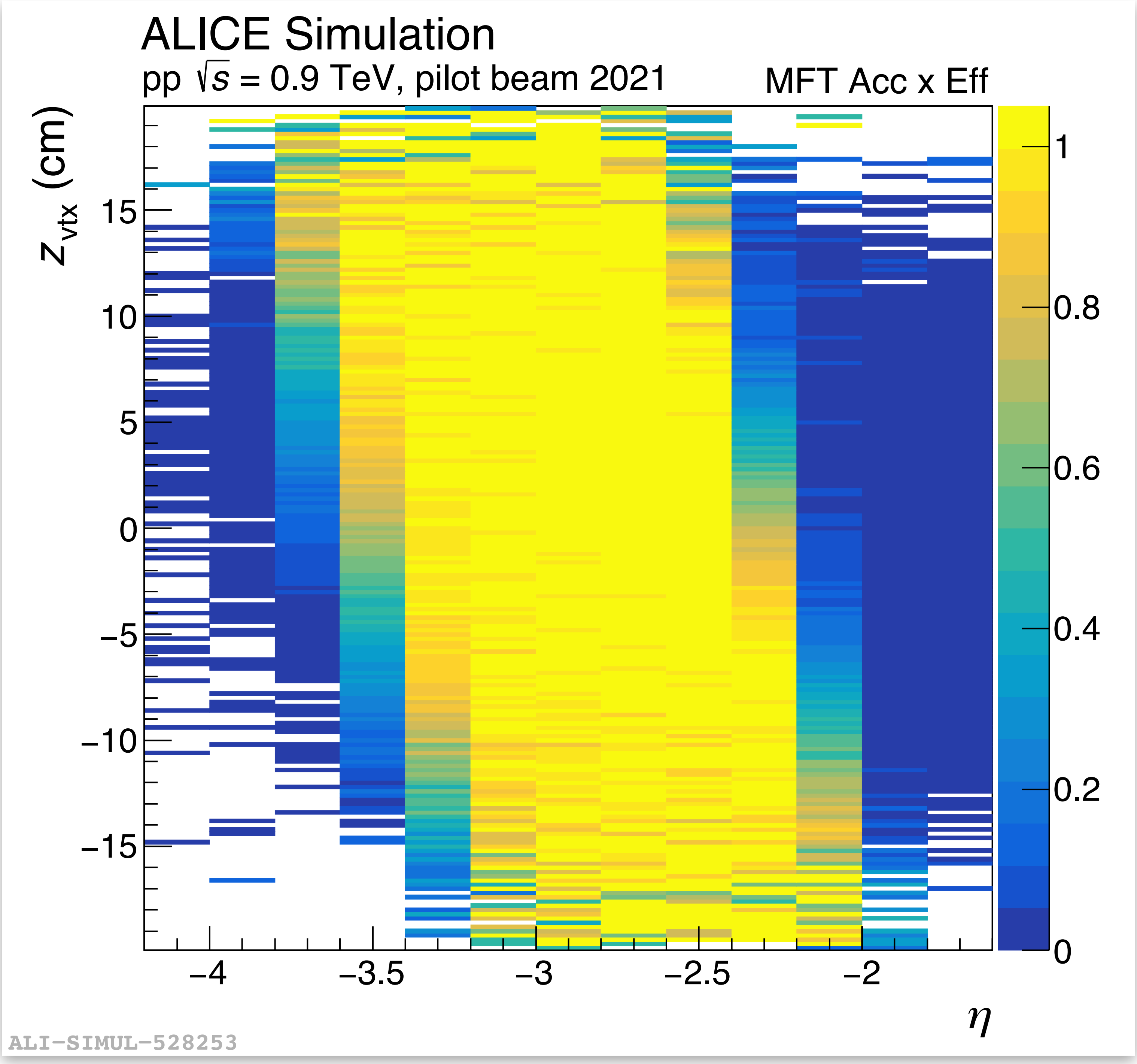
Transverse momentum p_T
Projection of the momentum on the transverse (Oxy) plane

HOW TO DERIVE THE CHARGED-PARTICLE PSEUDORAPIDITY DENSITY

- Charged-particle pseudorapidity density: $\frac{1}{N_{ev}}\frac{dN_{ch}}{d\eta}$ number of primary charged particles per collision and unit of pseudorapidity

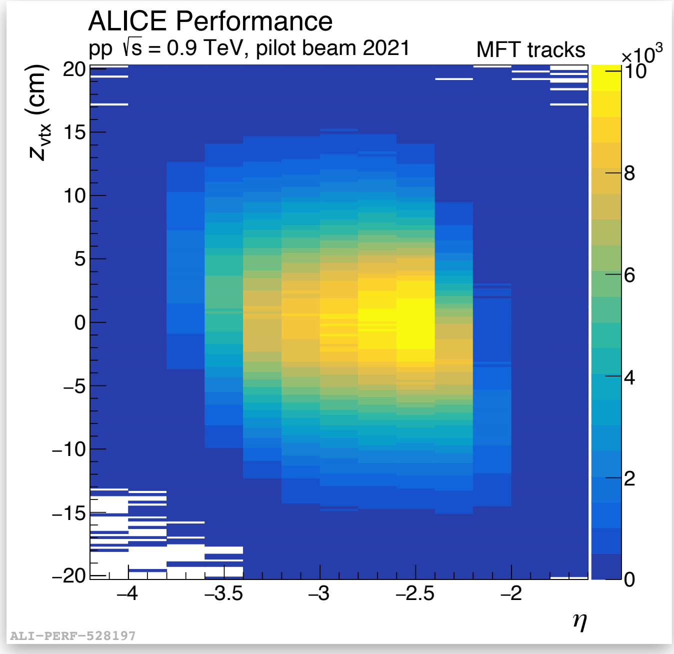
- Two observables to get the result:
  - Measured number of tracks in a (z_{vtx}, η) bin
  - Measured number of events (collisions) in a (N_{trk}, z_{vtx}) bin

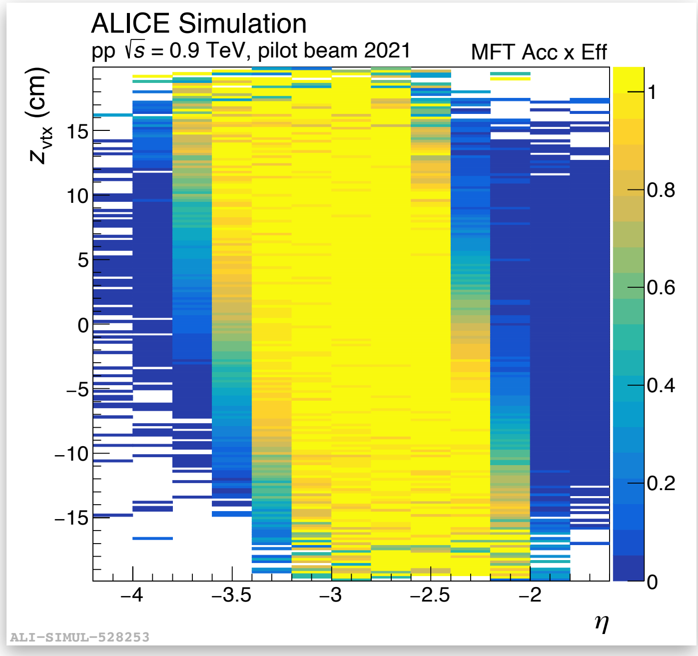
TRACK-TO-PARTICLE CORRECTION



- Acceptance x Efficiency of the MFT
- Profile used for **track-to-particle** correction

$$\frac{N^{rec}_{tr}}{N^{gen}_{part}}$$





$$= \frac{N^{meas}}{N^{rec}} \times N^{gen}$$

- Very high MFT Acc x Eff versus (z_{vtx}, η) in simulations
  - In the central z_{vtx}, η region, AxE > 90%

UNCERTAINTY SOURCES

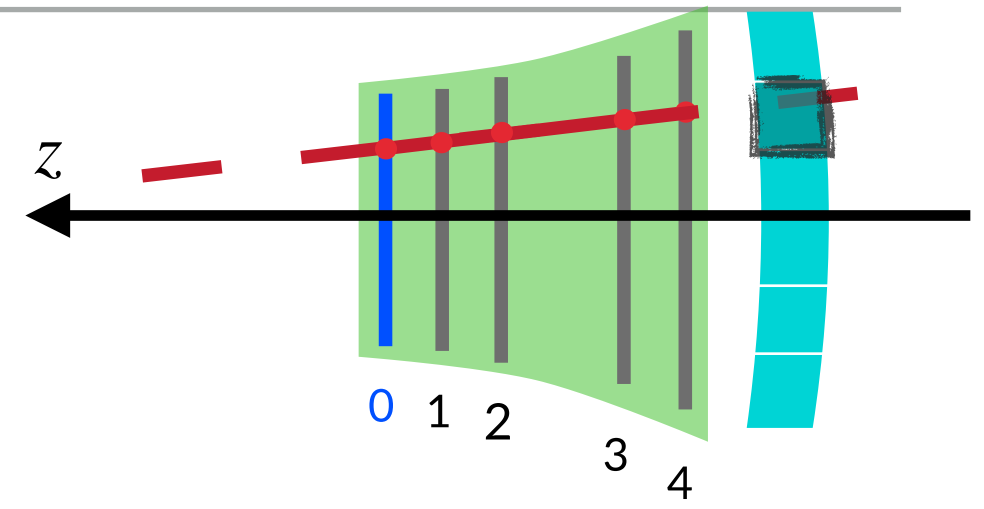
- Main uncertainty sources:
  - Model dependence (PYTHIA)
  - Ambiguous tracks (a track compatible with more than 1 collision is called *ambiguous*)

THE AMBIGUOUS TRACK ISSUE

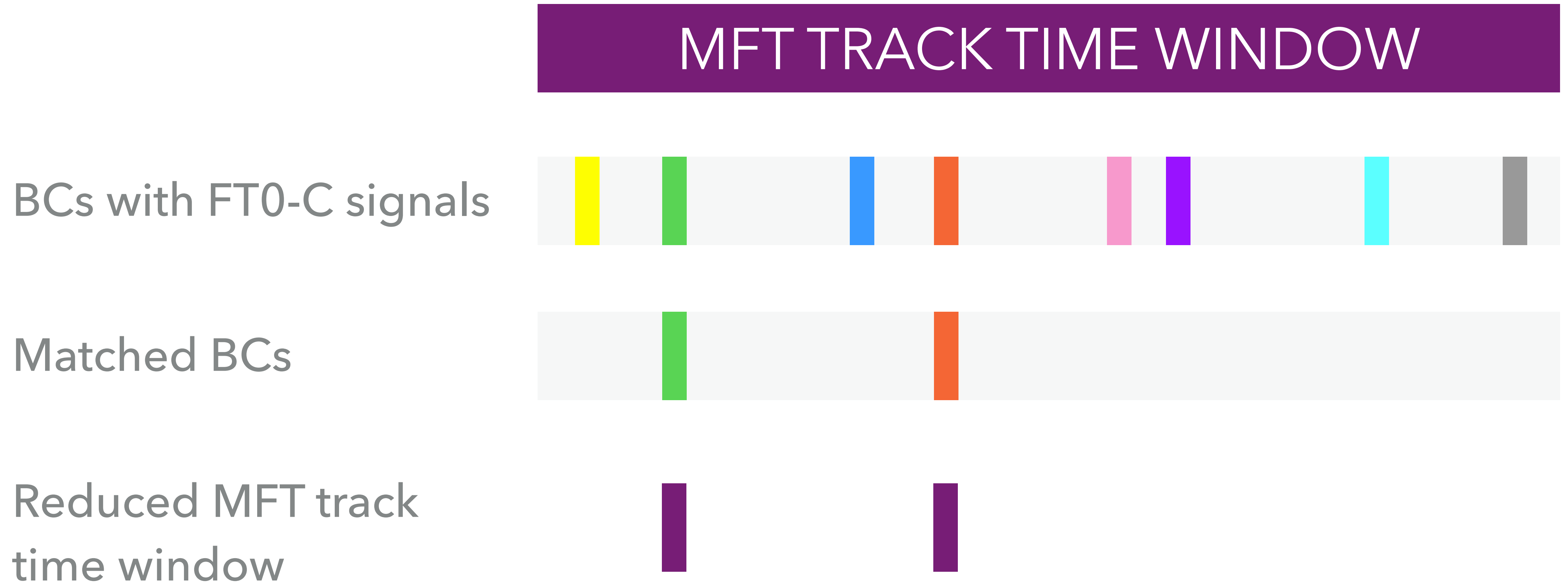
- In Run 3 : continuous readout (no trigger), everything is read
- MFT time resolution : $5\ \mu s$
  - At an interaction rate of 500 kHz it means 1 collision every 2 μs
  - Each MFT track would then be compatible in time with 2.5 collisions in average
- More ambiguous tracks with higher IR
- Can quickly become an issue

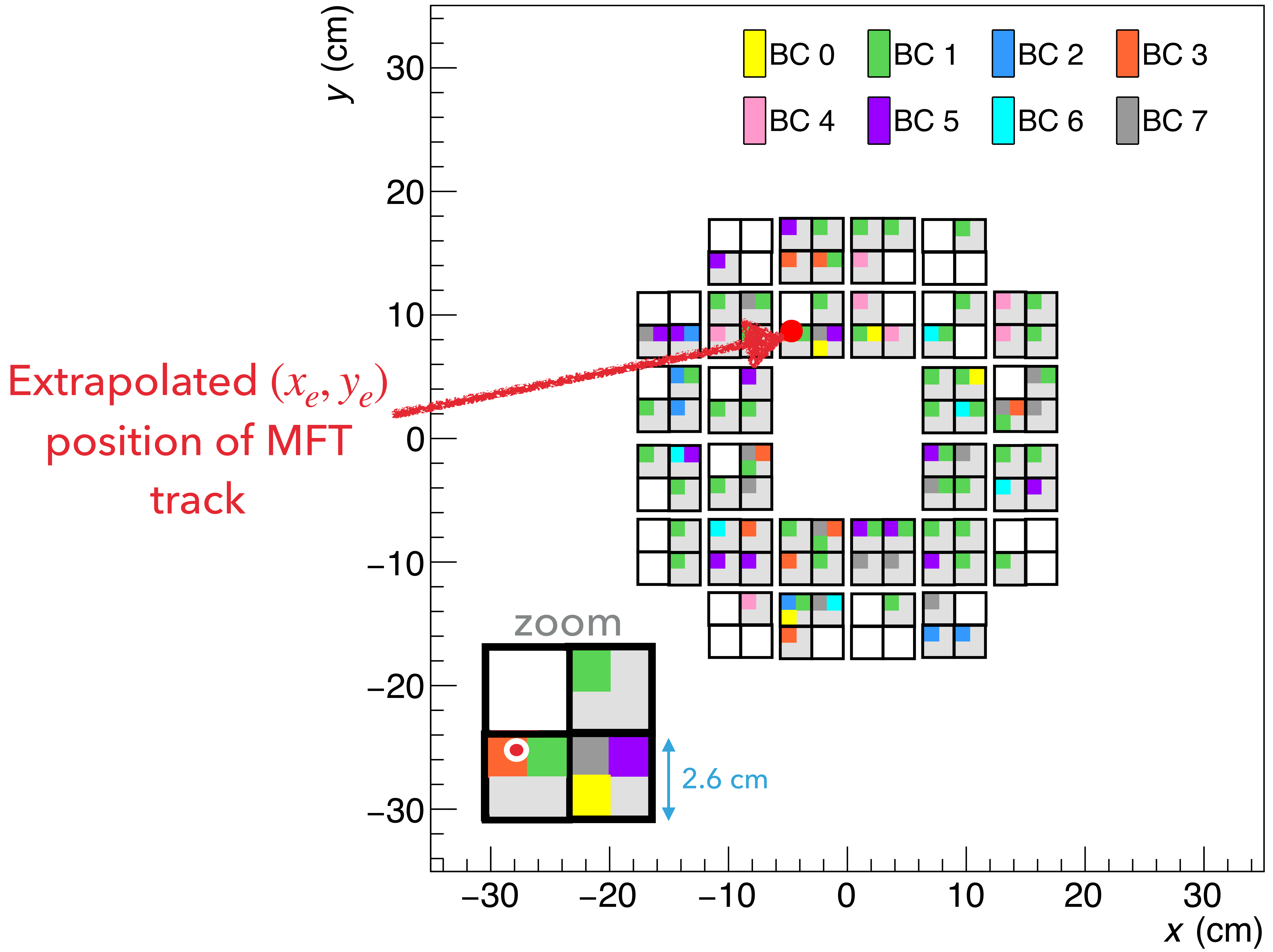
IR = Interaction Rate

MATCHING PROCEDURE



- Extrapolation of the MFT track to the mean z position of FT0-C: -82.6 cm, using an helix
- If (x_e, y_e) falls into a fired FT0-C channel: it's a match





- But : this is in an ideal case

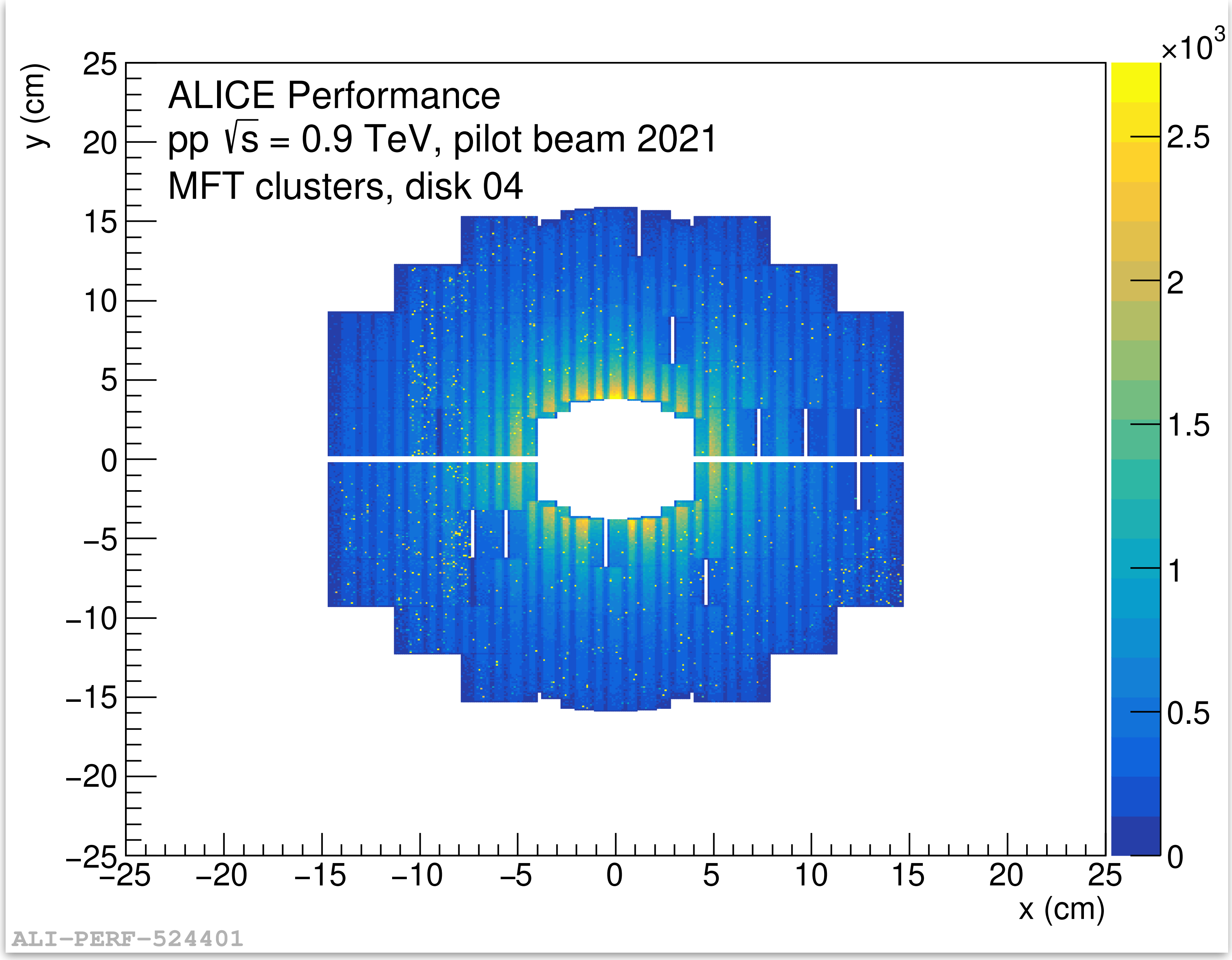
BC = Bunch Crossing = 25 ns

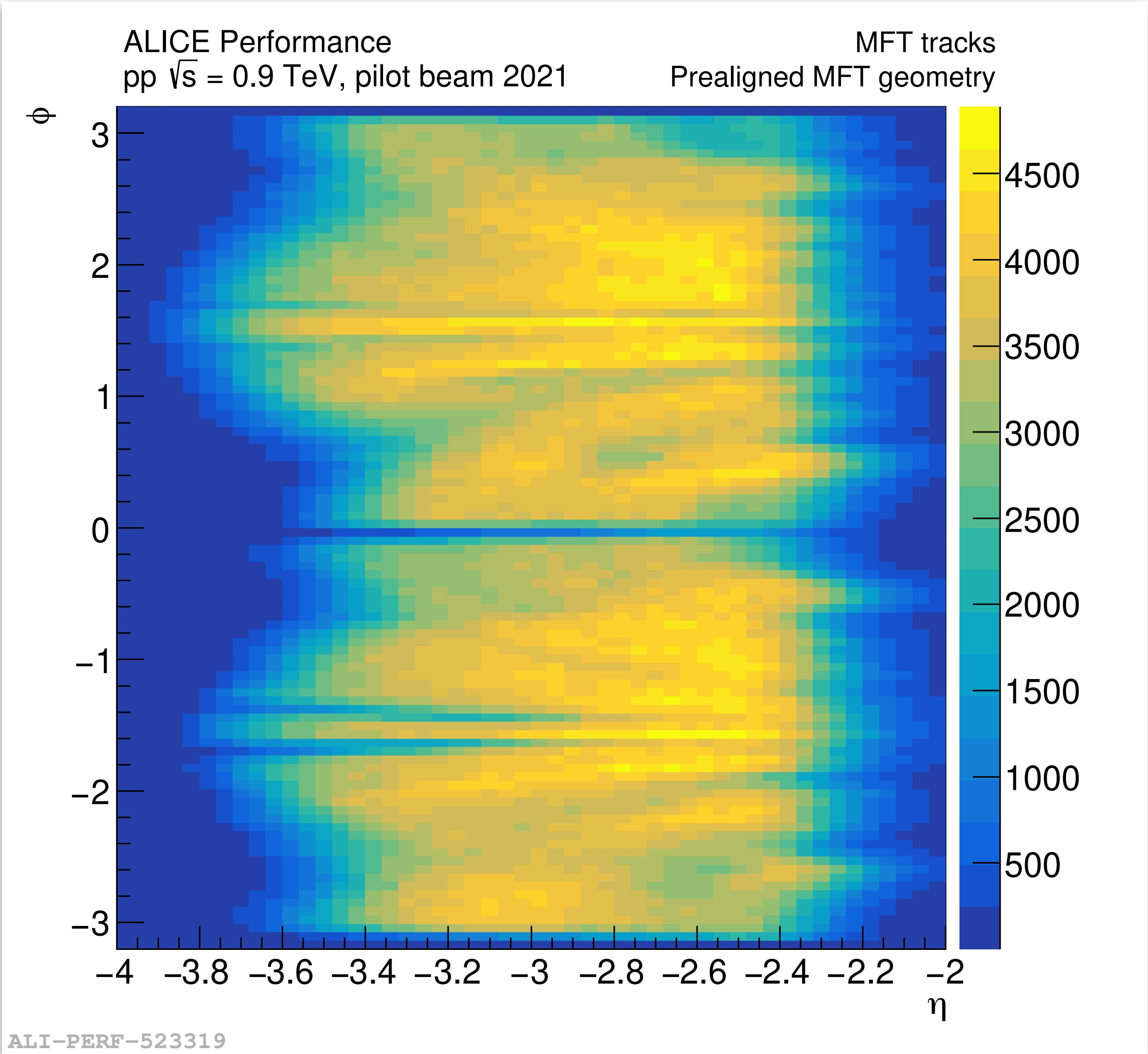
ABBREVIATIONS

- QCD: Quantum Chromo Dynamics
- ALICE: A Large Ion Collider Experiment
- MFT: Muon Forward Tracker
- ITS: Inner Tracking System
- MC: Monte Carlo
- CMOS: Complementary Metal–Oxide–Semiconductor
- Acc x Eff, AxE: Acceptance x Efficiency
- IR: Interaction Rate
- TPC: Time Projection Chamber
- FIT: Fast Interaction Trigger
- DCA: Distance of Closest Approach

MFT PERFORMANCE

- Pilot beam : short proton-proton run at center-of-mass energy of $\sqrt{s}$ = 900 GeV, October 2021, at an interaction rate of 2 kHz



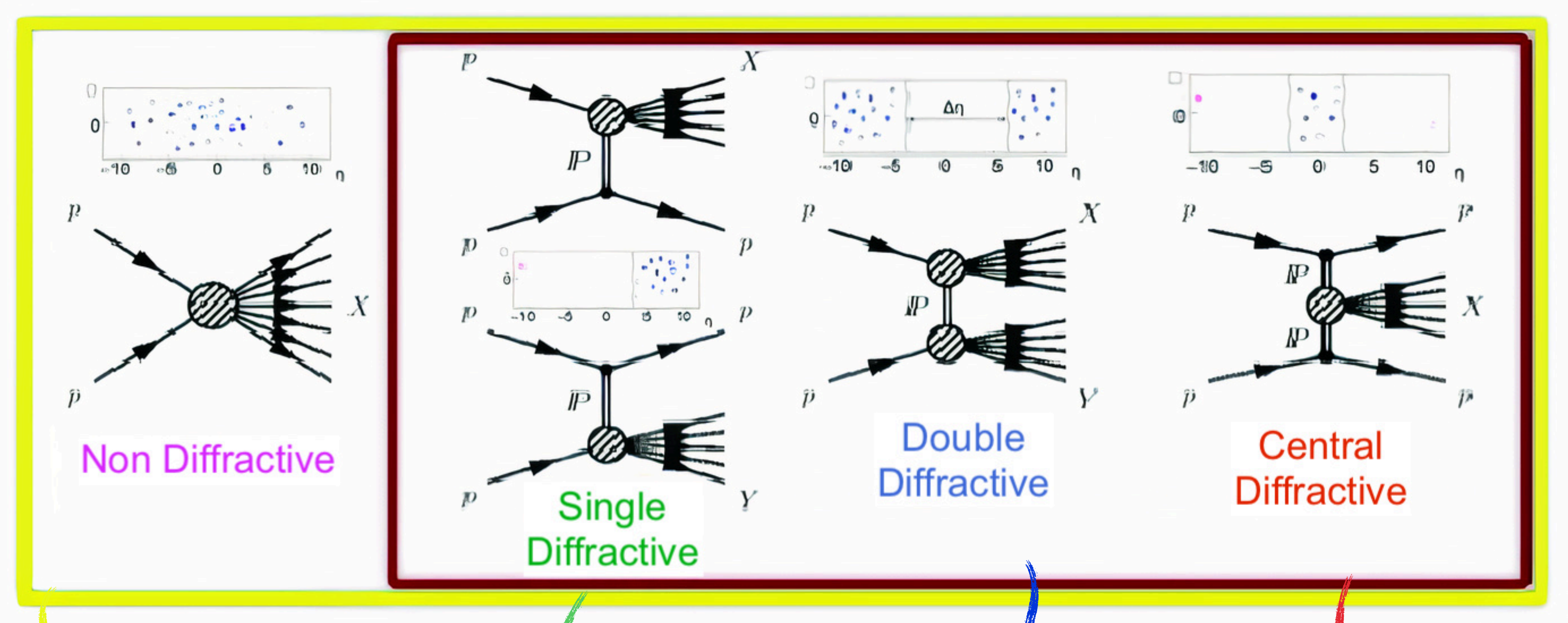


- (x,y) position of MFT clusters in the farthest disk from the interaction point
- Very few and small dead zones

- η and ϕ distribution of tracks as expected : full azimuth and -3.6 < η < -2.5

ADDITIONAL CORRECTION : DIFFRACTION TUNING

- Diffraction tuning:
  - MC simulations (PYTHIA) fail to reproduce the number of diffractive events, need a tuned MC for correction
- Single Diffractive and Double Diffractive events are very rarely reconstructed because there produce no tracks in the midrapidity regions
  - Not enough events seen in data + Not enough events generated by PYTHIA + Not enough events reconstructed in simulation



All INEL events

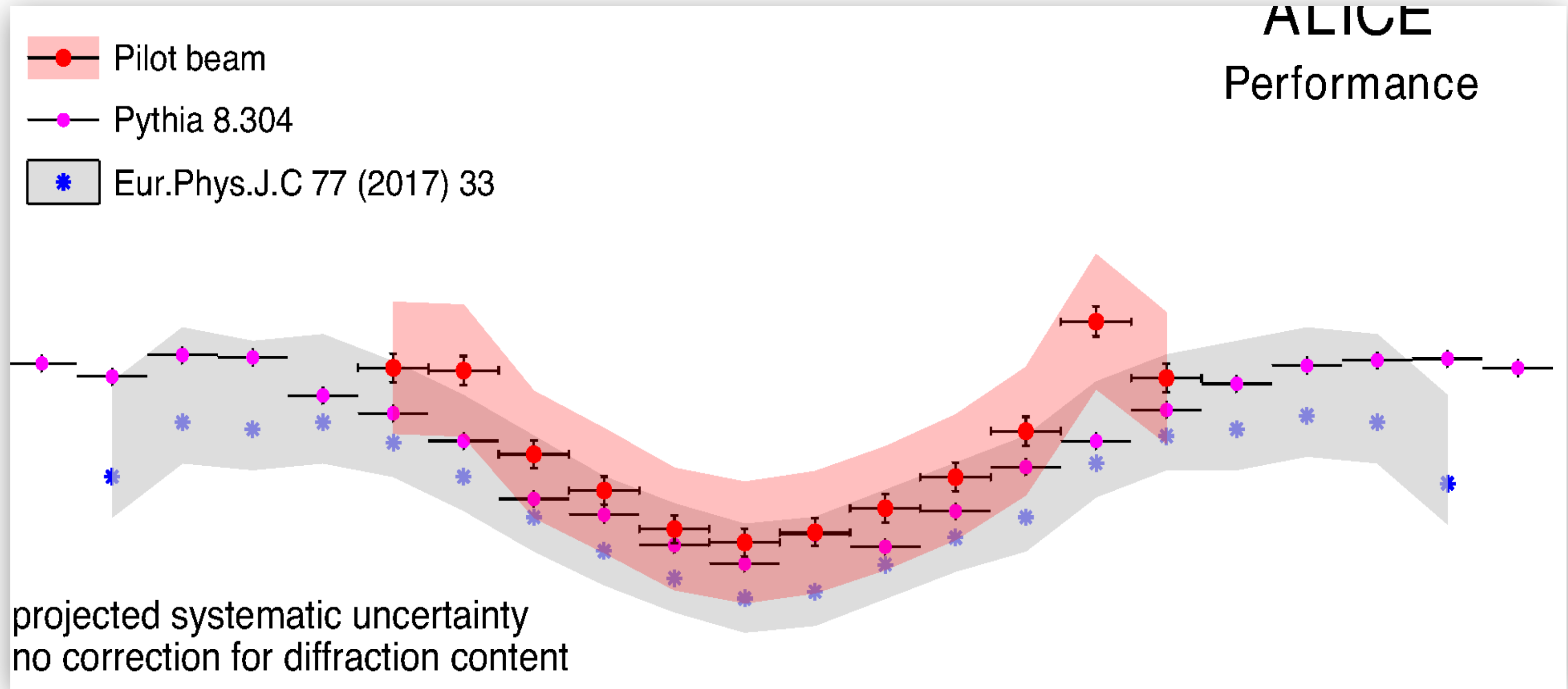
20% of the total INEL cross section

10% of the total INEL cross section

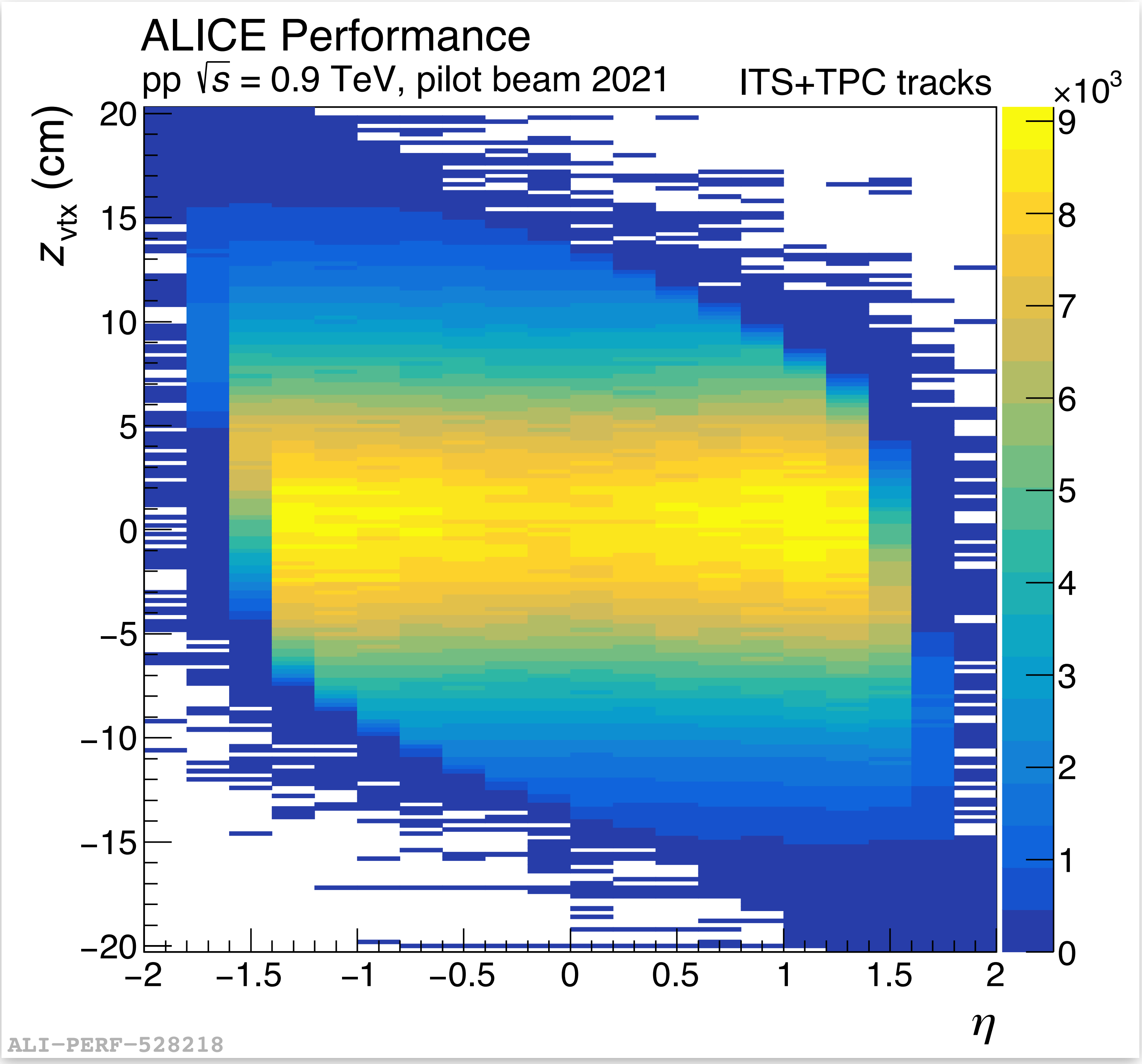
<1%

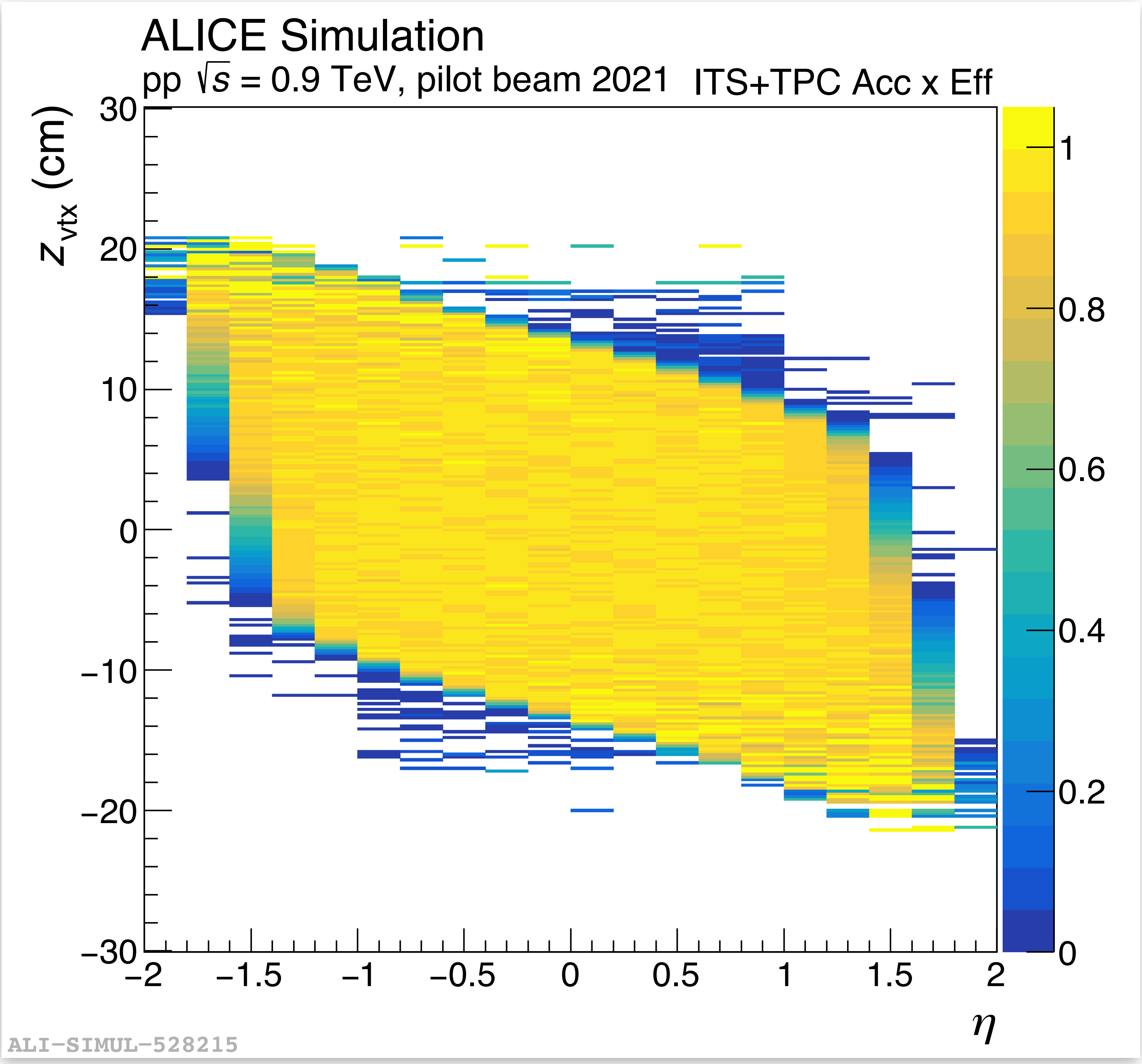
$$\frac{1}{N_{ev}}\frac{dN_{ch}}{d\eta} \text{ with } N_{ev}$$

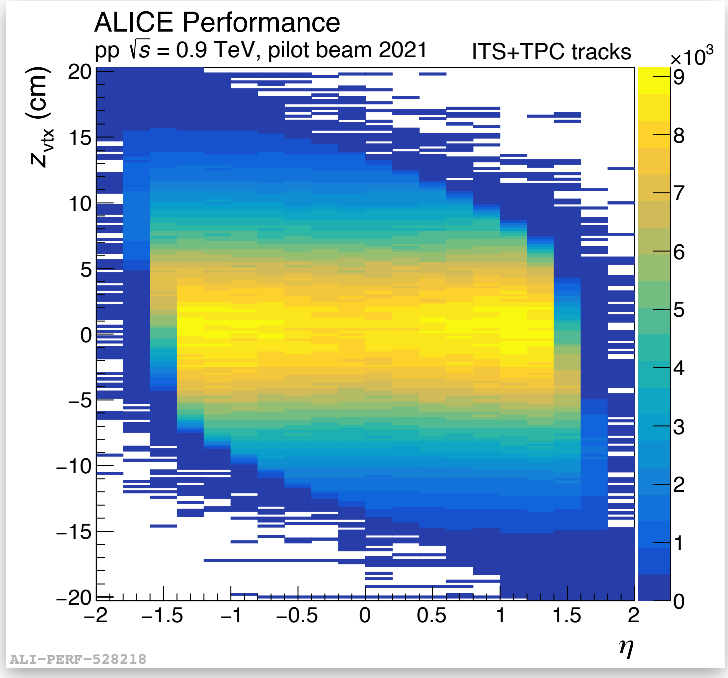
underestimated

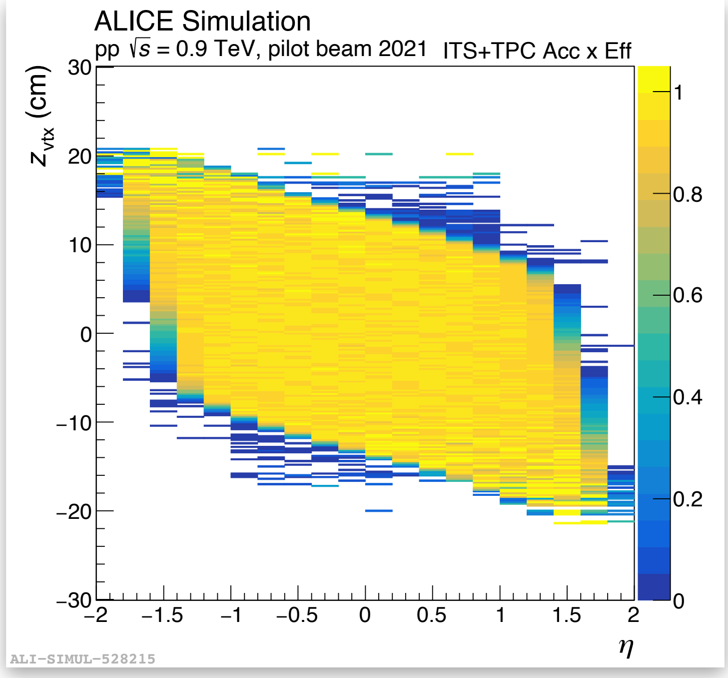


PERFORMANCE PLOTS FOR THE CENTRAL TRACKS









- Measured number of tracks versus (z_{vtx}, η)
- ITS+TPC Acc x Eff: profile used for track-to-particle correction

Very high Acc x Eff in the central region: good detector performance