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PhD 2023 days

PhD days 25/04/2023

CHARGED-PARTICLE PSEUDORAPIDITY DENSITY IN PROTON-PROTON COLLISIONS IN RUN 3

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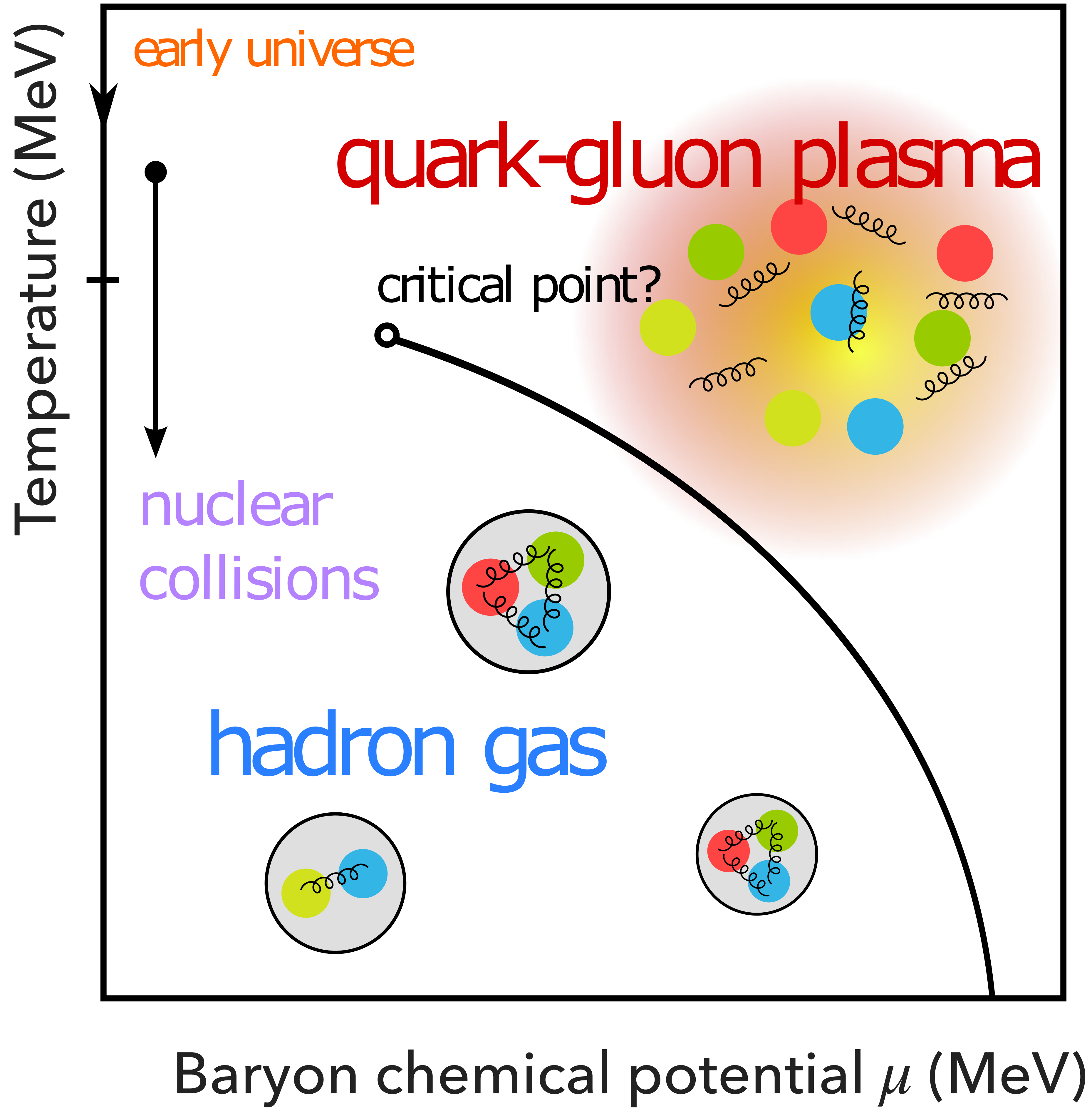
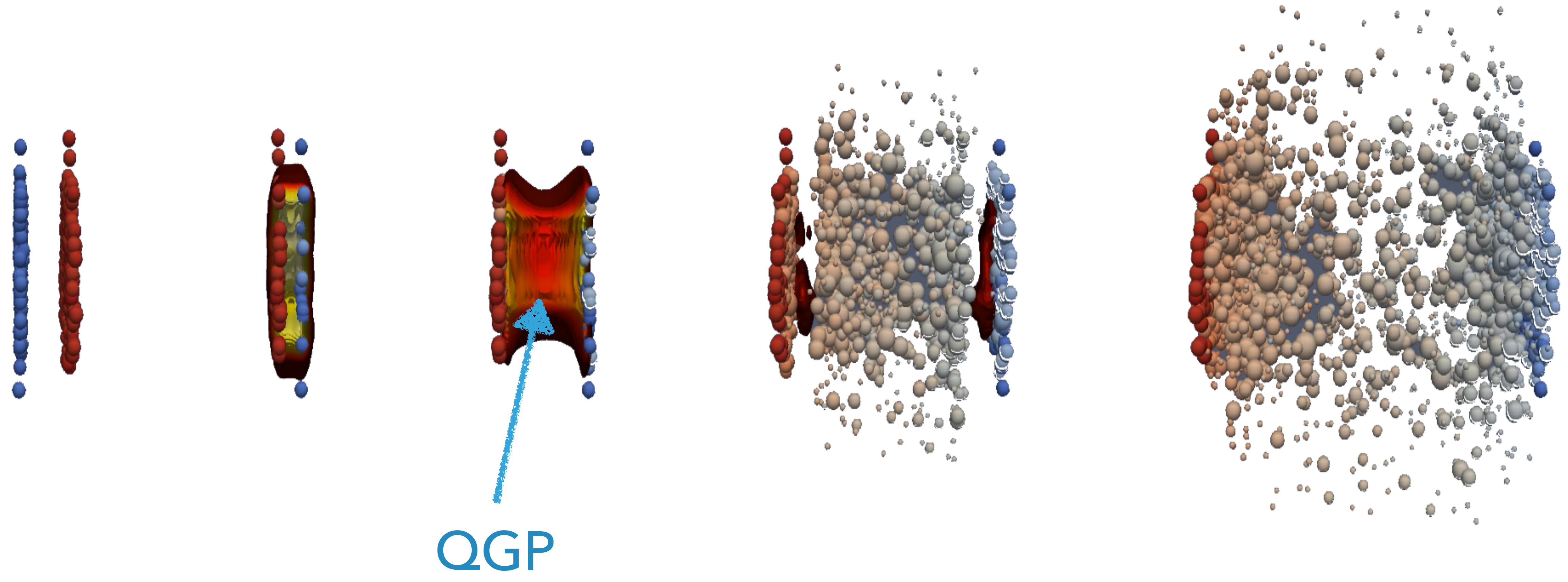
WHY ALICE ? TO STUDY QUARK GLUON PLASMA (QGP)



- QGP: state of matter were quarks and gluons are deconfined (not inside hadrons)
  - Early universe, core of neutron stars
  - Produced in high energy nuclear collisions (Pb-Pb)



HIGH ENERGY PHYSICS EXPERIMENTS AT THE LHC

- ALICE (A Large Ion Collider Experiment) is designed to study high energy QCD
- Broad field of research that encompasses **several analyses**: from proton-proton to Pb-Pb collisions

- Common strategy :
  - Take data
  - Study the detector response through Monte Carlo (MC) simulations
    - Generate (Physics models)
    - Propagate (Modeled interaction with detector)
    - Reconstruct (Same reconstruction algorithms as in data)
  - Correct data with simulation to derive physics results

Monte Carlo Simulation builds a model of possible results by using a probability distribution

VARIABLE AND SYSTEM COORDINATE DEFINITION

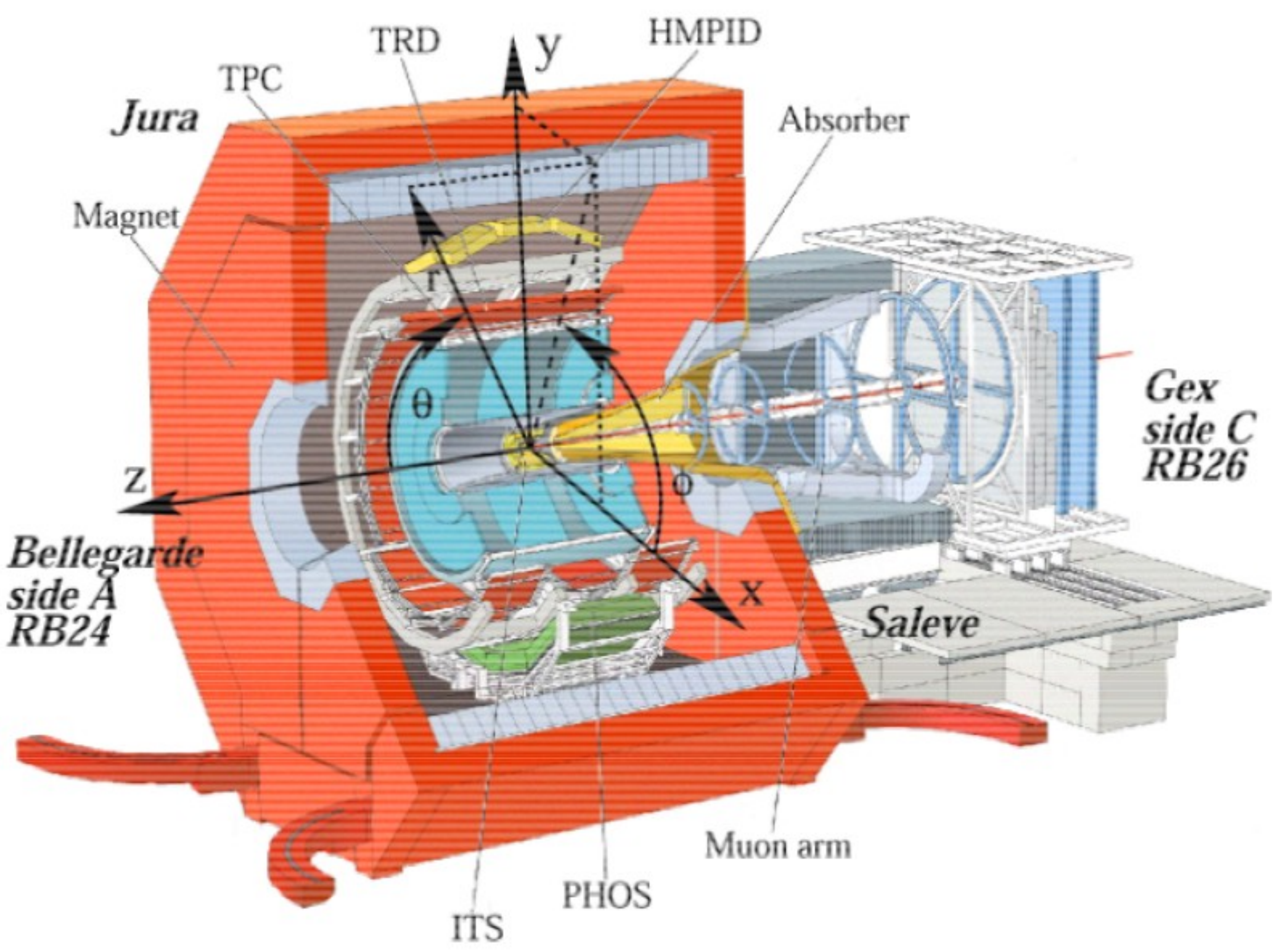
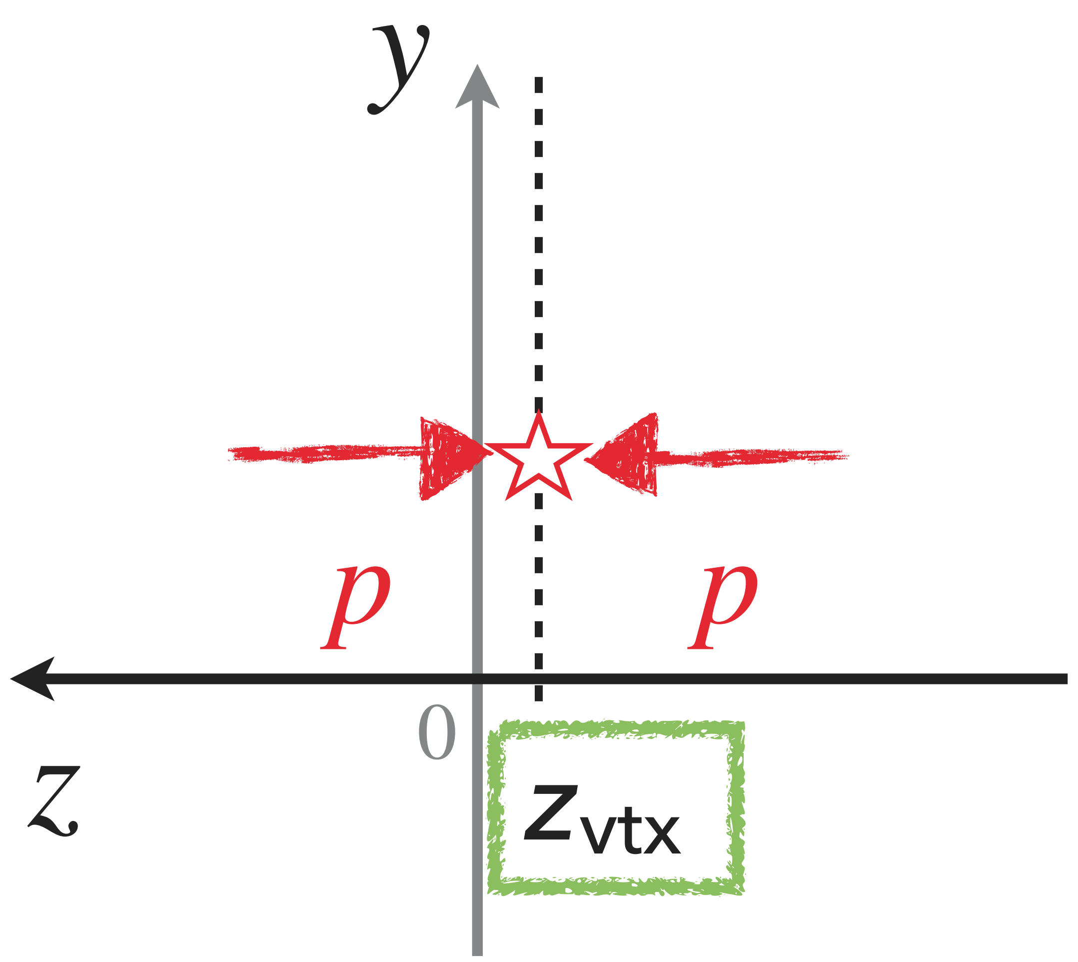
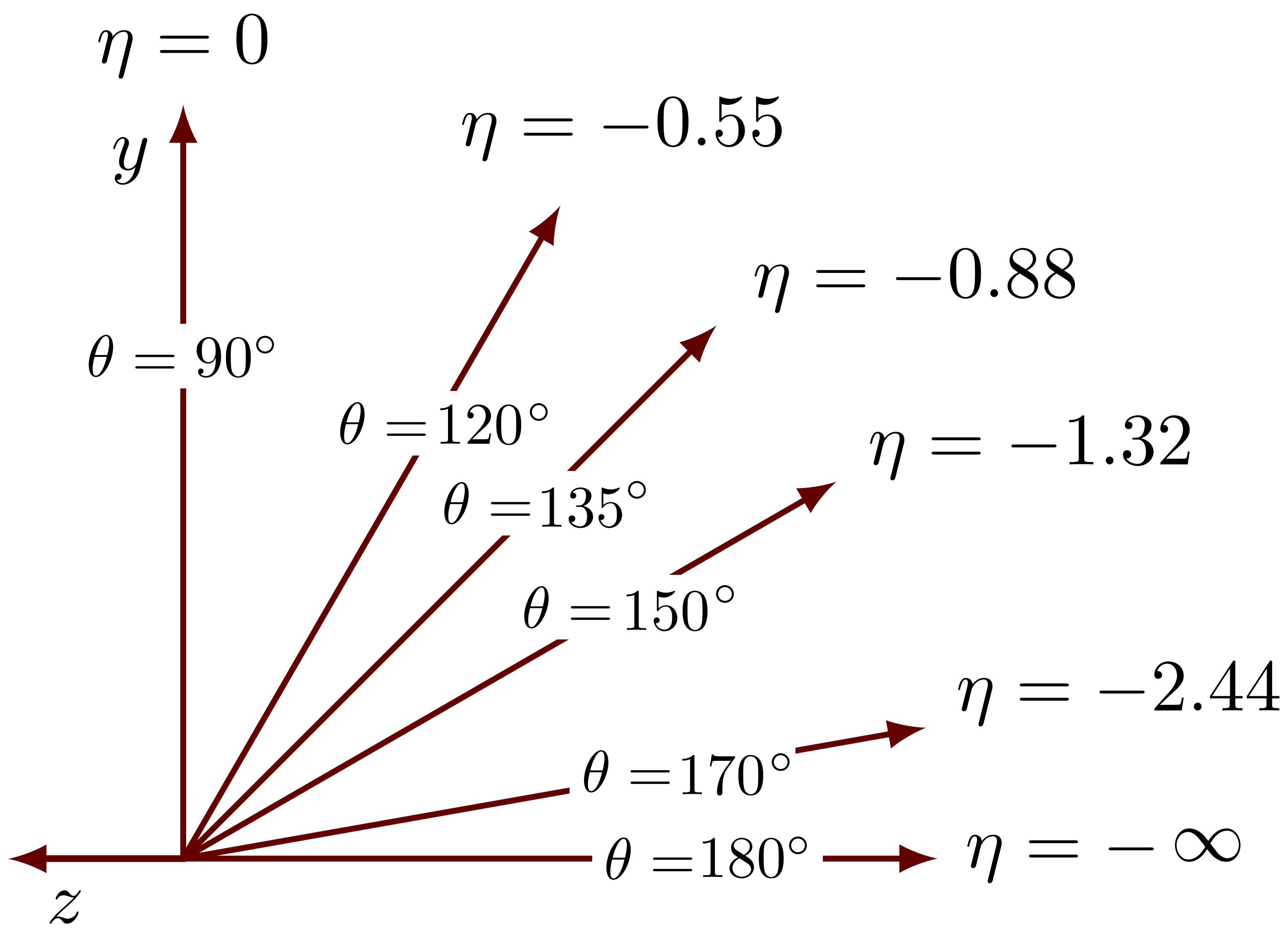


Fig1. Definition of the ALICE coordinate system axis, angles and detector sides.

One *vertex* found = 1 collision





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

PHYSICS MOTIVATIONS: CHARGED-PARTICLE PSEUDORAPIDITY DENSITY

- Helps in understanding particle production mechanisms in high-energy hadronic collisions, from proton-proton to heavy-ion systems
  - QCD in the non-perturbative regime
  - Provides constraints on phenomenological models and event generators

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

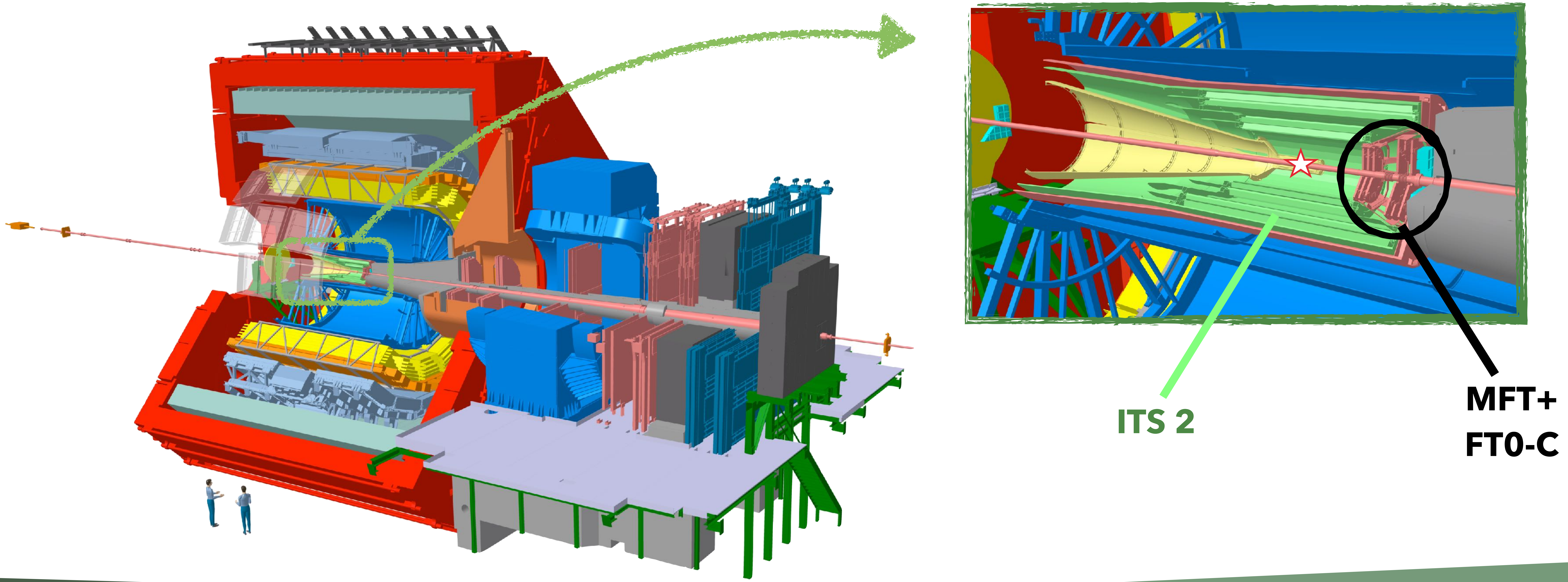
Primary particle: Particle with a mean proper lifetime τ > 1 cm/c excluding particles coming from weak decays of strange particles

- Straightforward analysis : allows to test the analysis framework

QCD = Quantum Chromo-Dynamics

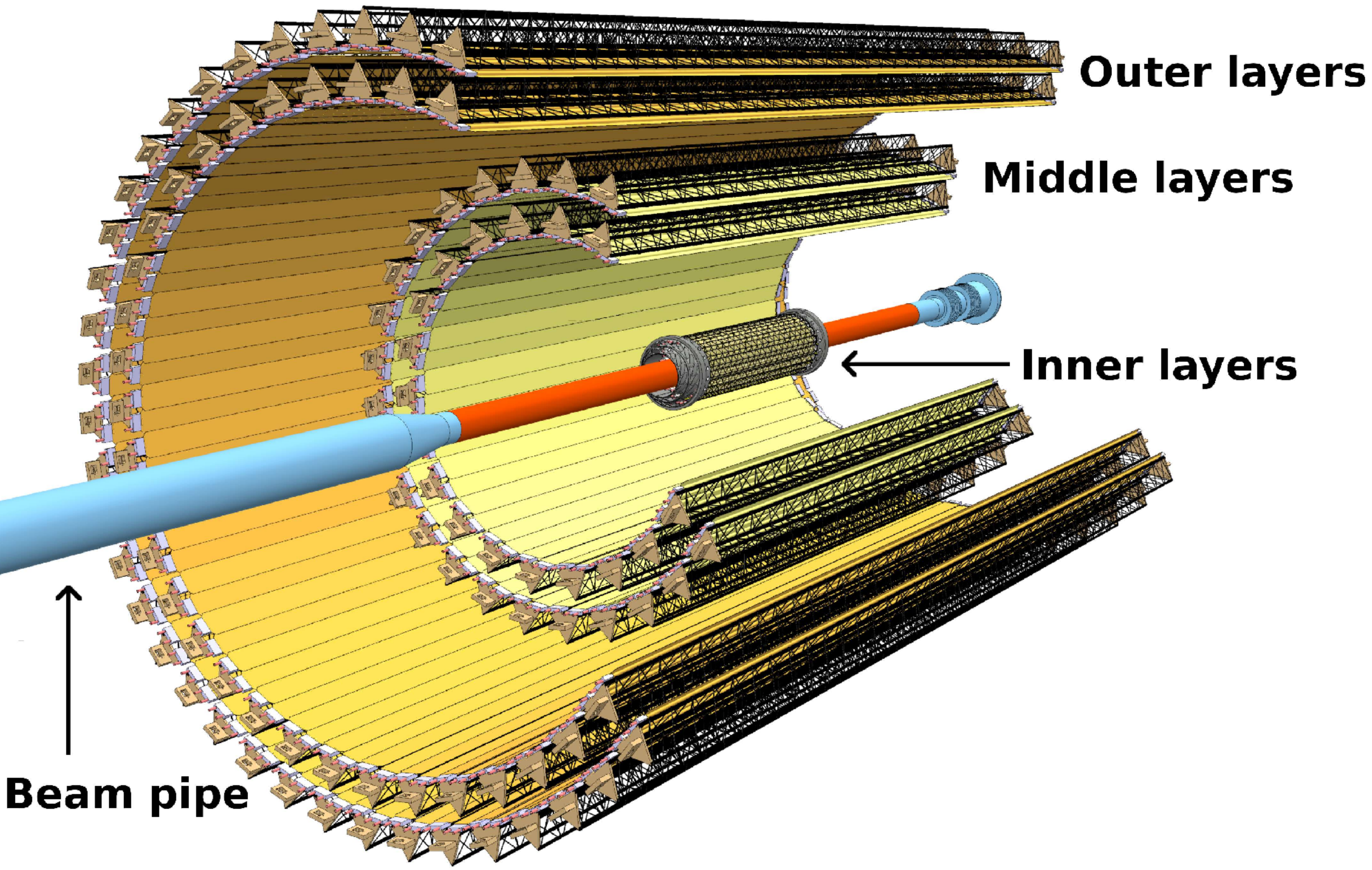
THE ALICE DETECTOR IN RUN 3

- 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)

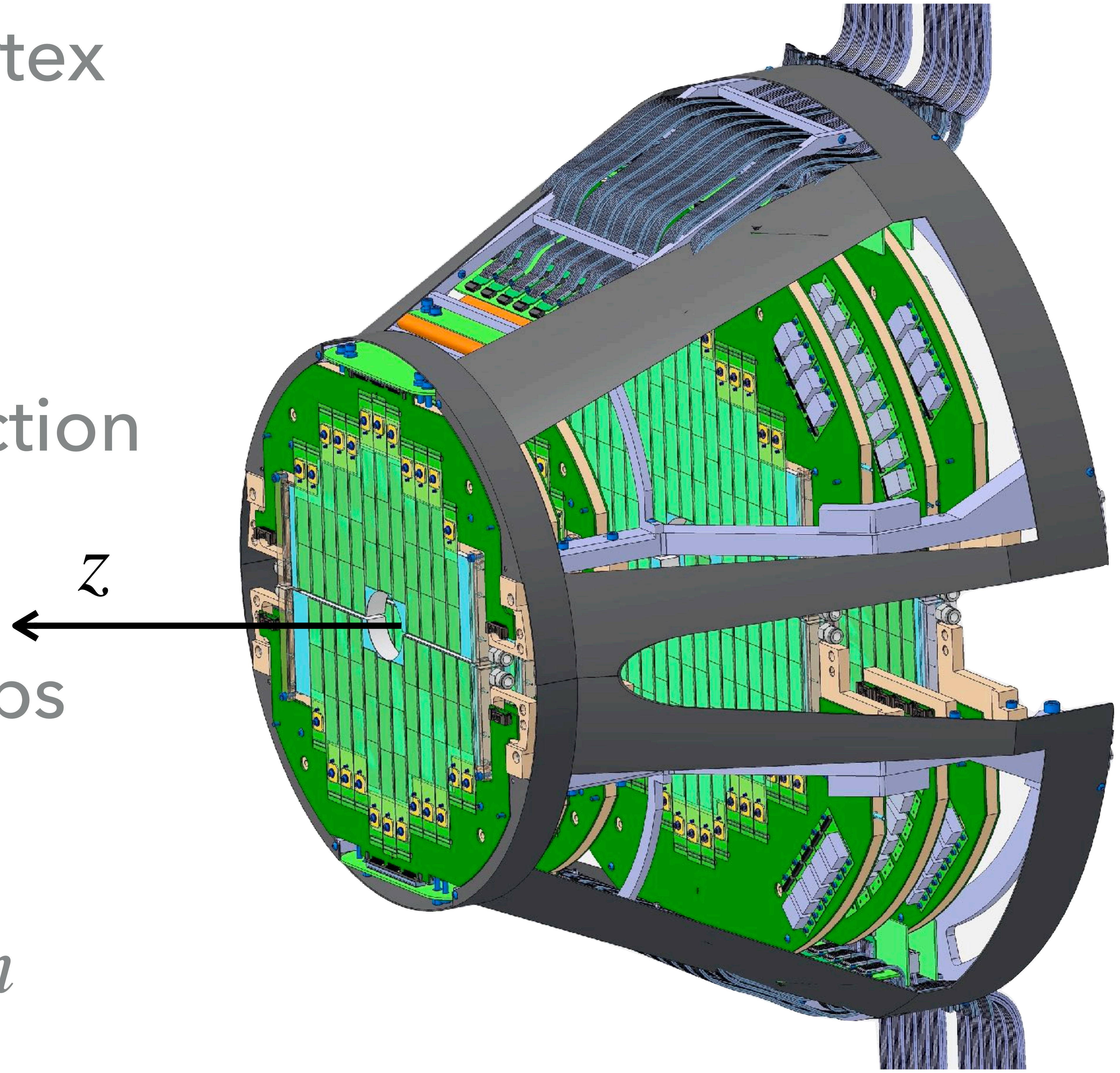


- Seven cylindrical detector layers (from R = 22 mm to R = 400 mm) with ALPIDE chips
  - CMOS* silicon pixel sensor
  - Spatial resolution: 5 μm
- η coverage [-1.2 ; 1.2]

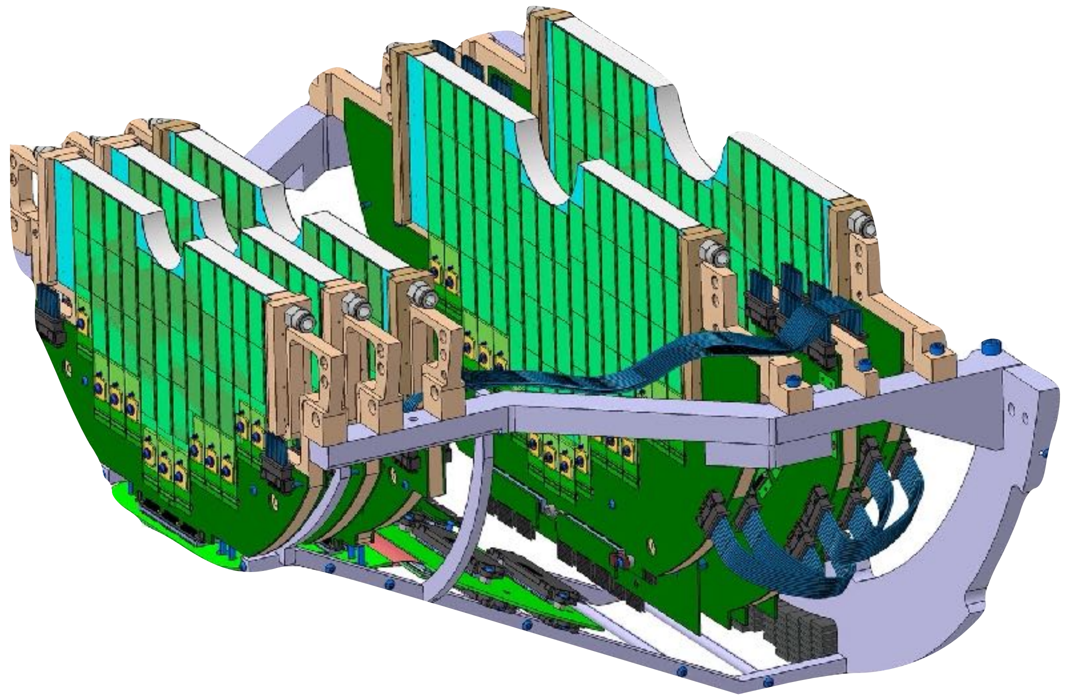
* CMOS : Complementary Metal–Oxide–Semiconductor

THE MUON FORWARD TRACKER (MFT)

- Installed in the ALICE cavern in 2020, new detector, a vertex tracker for the Muon Spectrometer
- 5 detection disks, 2 detection planes each
- Covered with ALPIDE chips (936)
  - Spatial resolution: 5 μm
- Time window: 5 μs



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



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

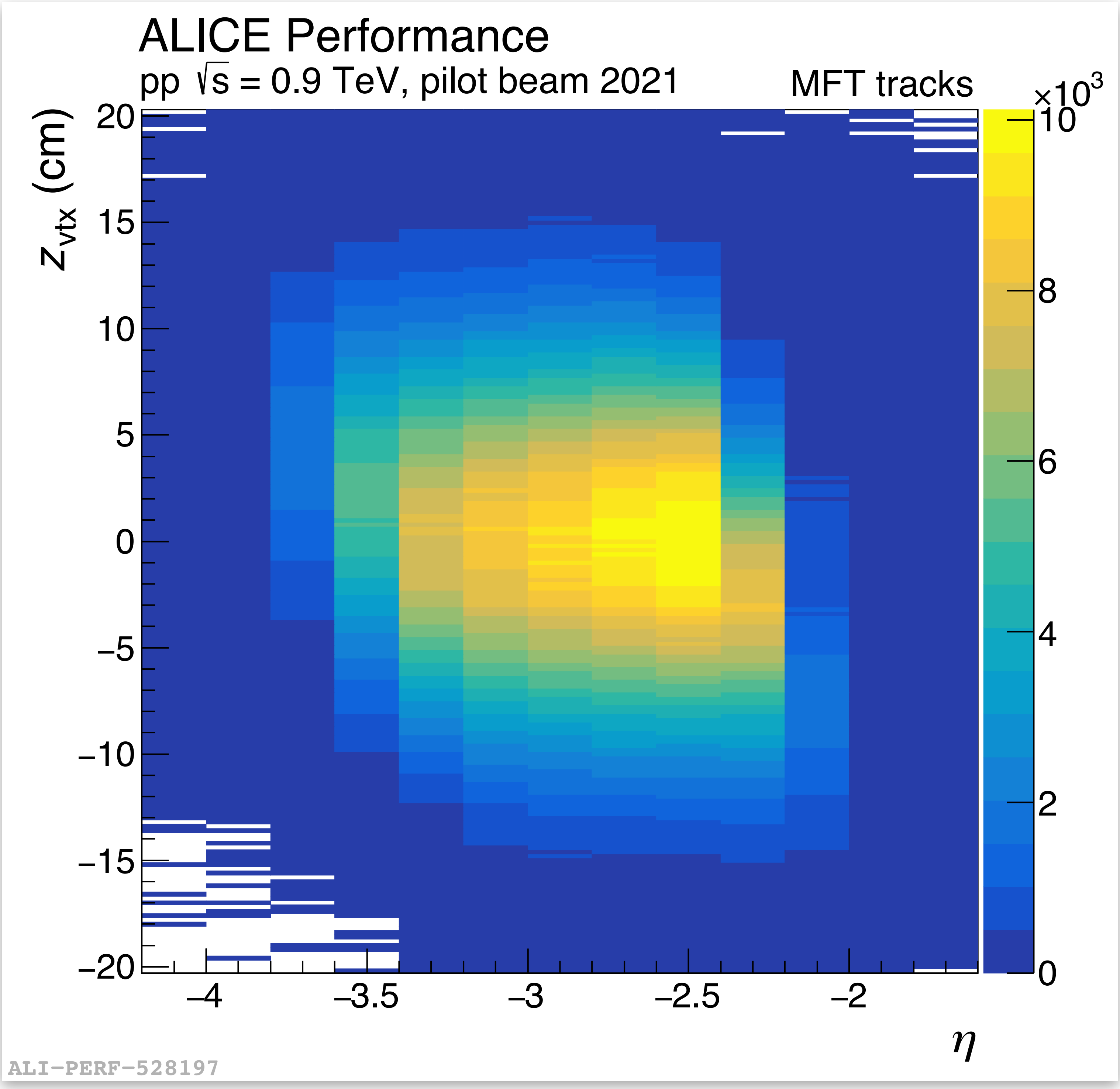
- Two observables to get the result:
  - Measured number of tracks in a (z_{vtx}, η) bin
  - Measured number of events (collisions) in a (N_{trk}, z_{vtx}) bin

CORRECTIONS NEEDED

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

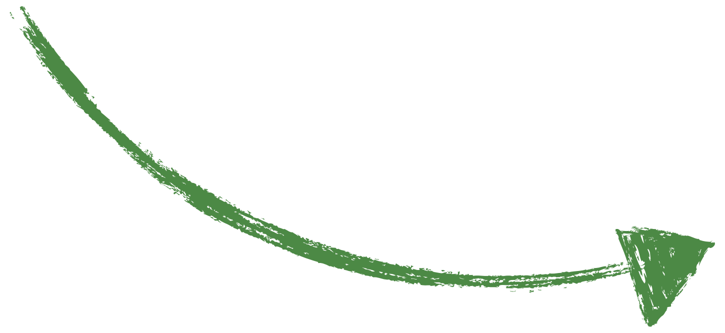
- 2 types of corrections computed with MC
  - Track-to-particle correction (difference between the number of reconstructed tracks and the number of primary charged particles) → Track level
  - Selection bias correction (corrects the difference between selected sample and generated one) → Track and event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

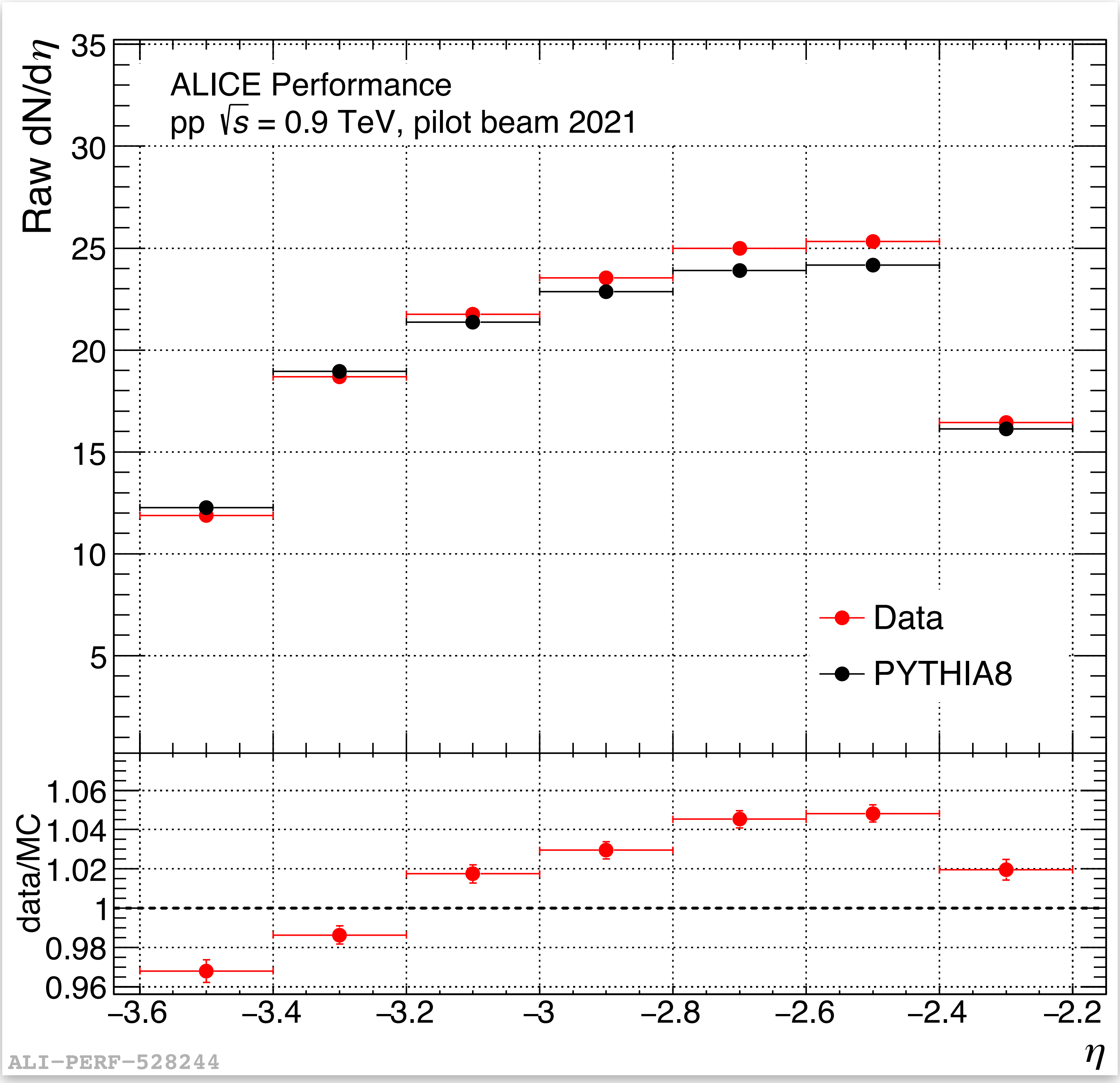
MFT PERFORMANCE



- 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 ?

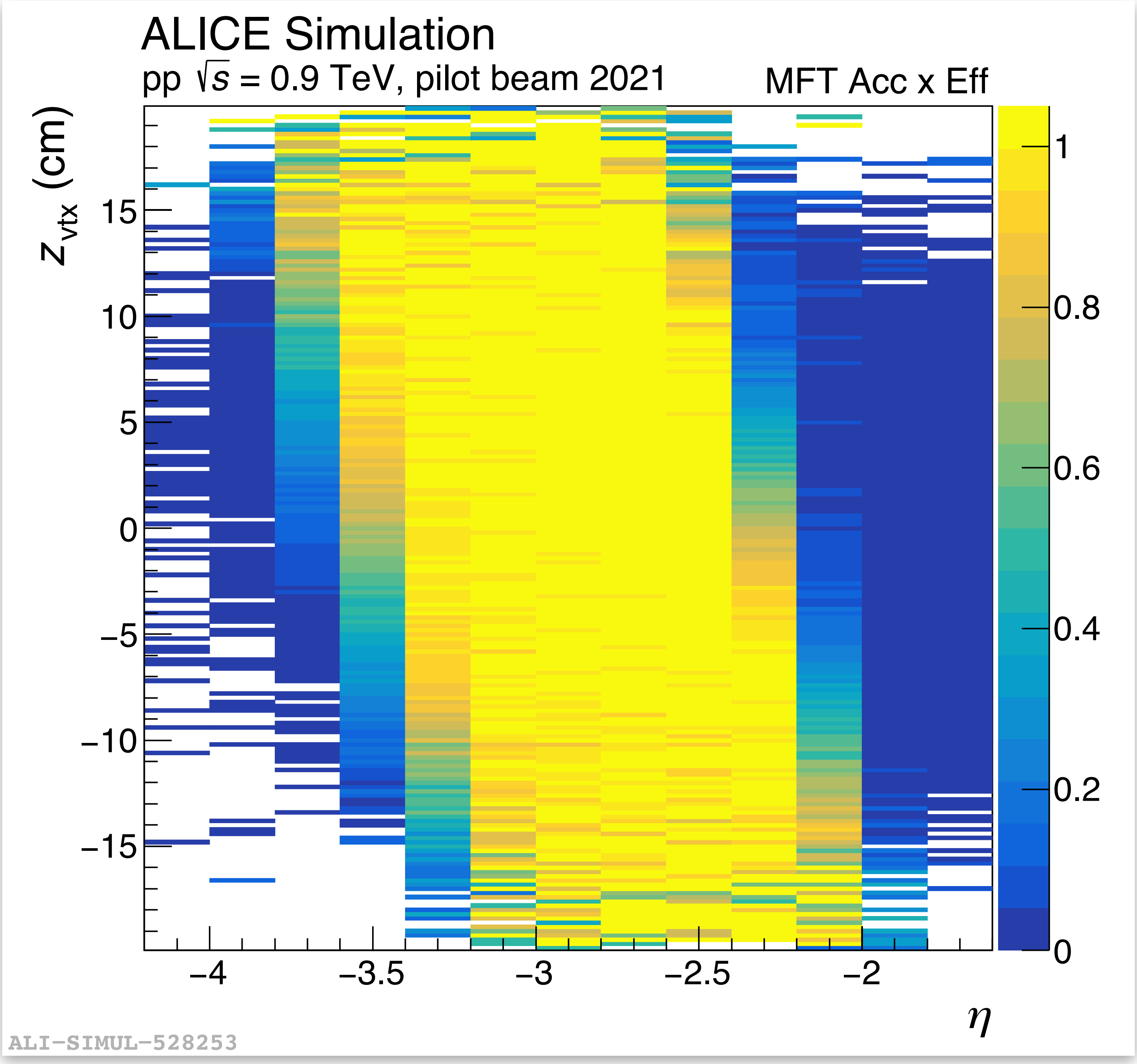




- Comparison of number of tracks versus η in simulation and data

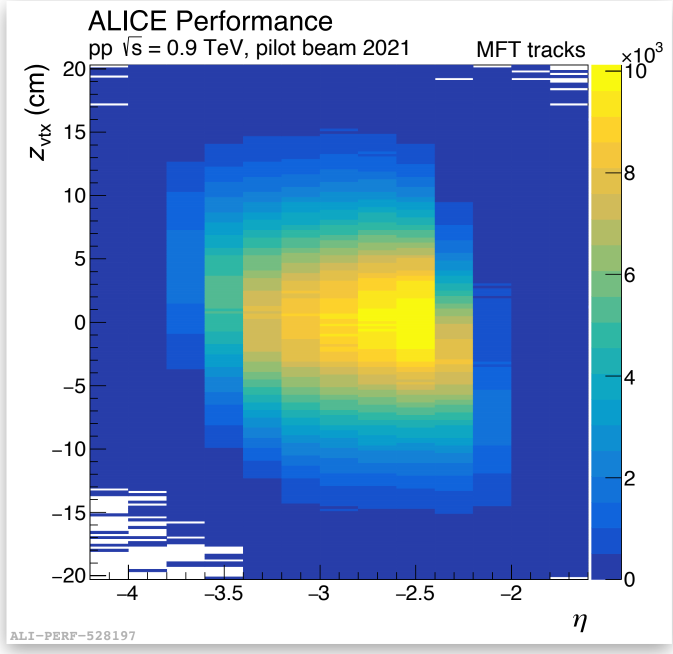
> Data and simulation are consistent within $\pm 5\ \%$
>
> → MC simulation can be used for correction
>
> → Systematic error would need to be reduced

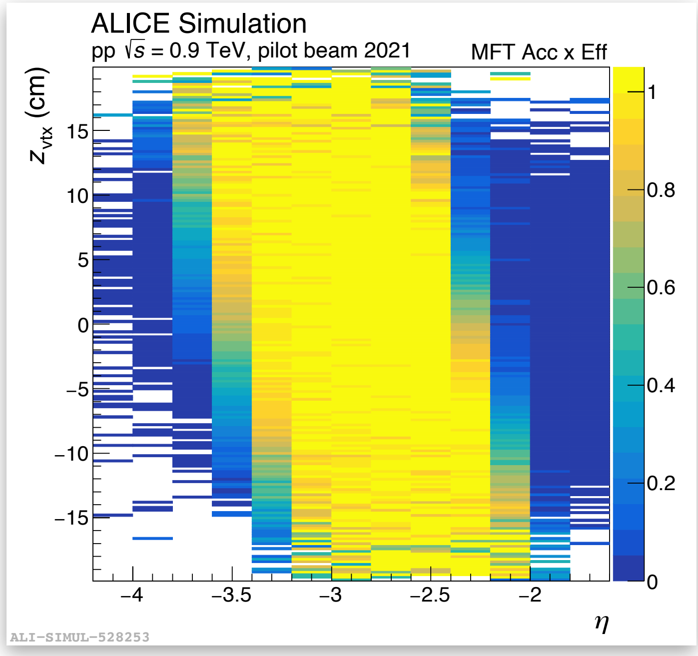
TRACK-TO-PARTICLE CORRECTION



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

$$\frac{N_{tr}^{rec}}{N_{part}^{gen}}$$



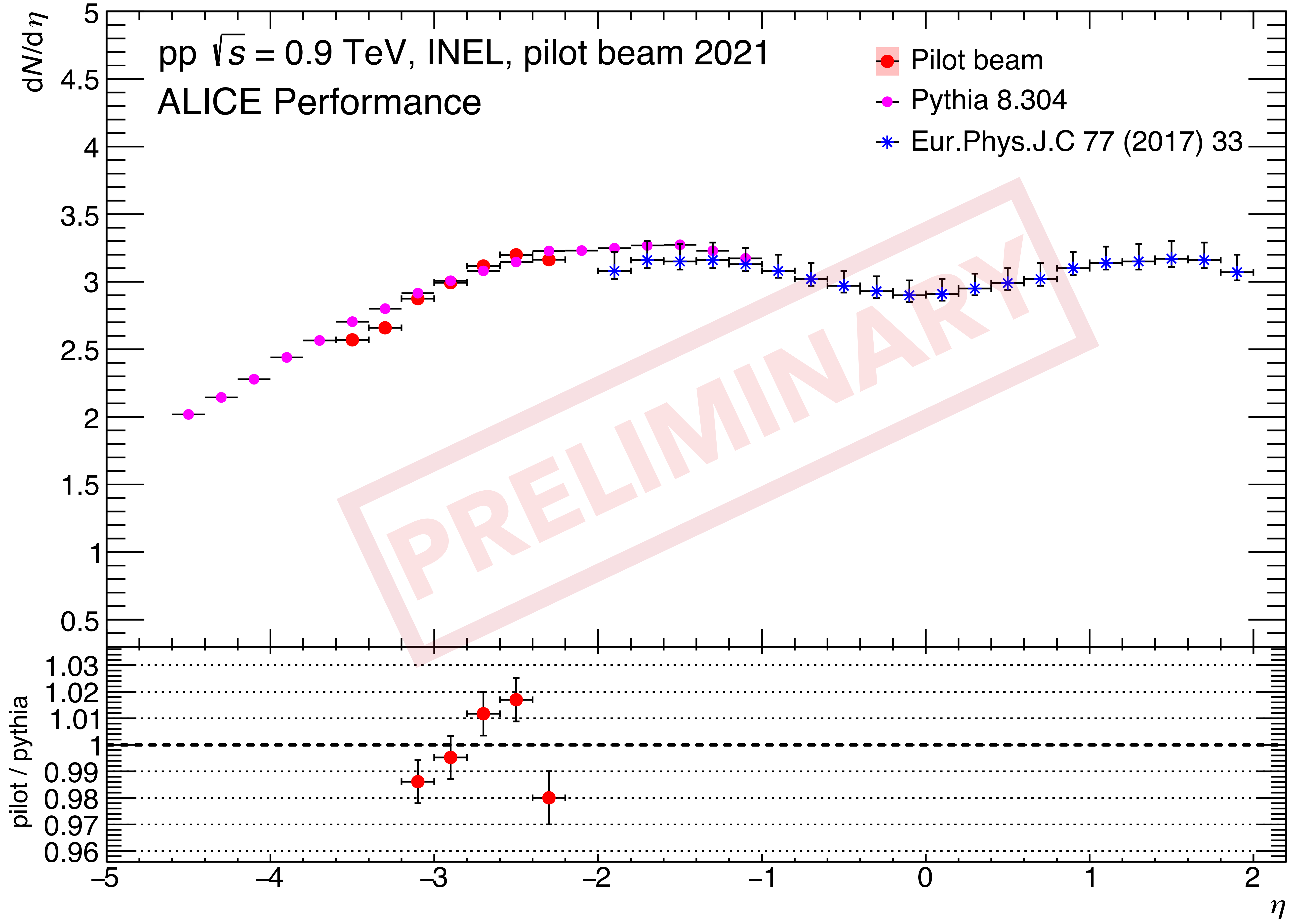


$$\frac{\quad}{\quad} = \frac{N^{meas}}{N^{rec}} \times N^{gen}$$

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

RESULTS WITH MFT

- $\frac{1}{N_{ev}}\frac{dN_{ch}}{d\eta}$ results at forward rapidity for the event class of all Inelastic collisions
- In red: result derived with the MFT
- Result compatible with the PYTHIA generated plot (pink)
- Analysis validated



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

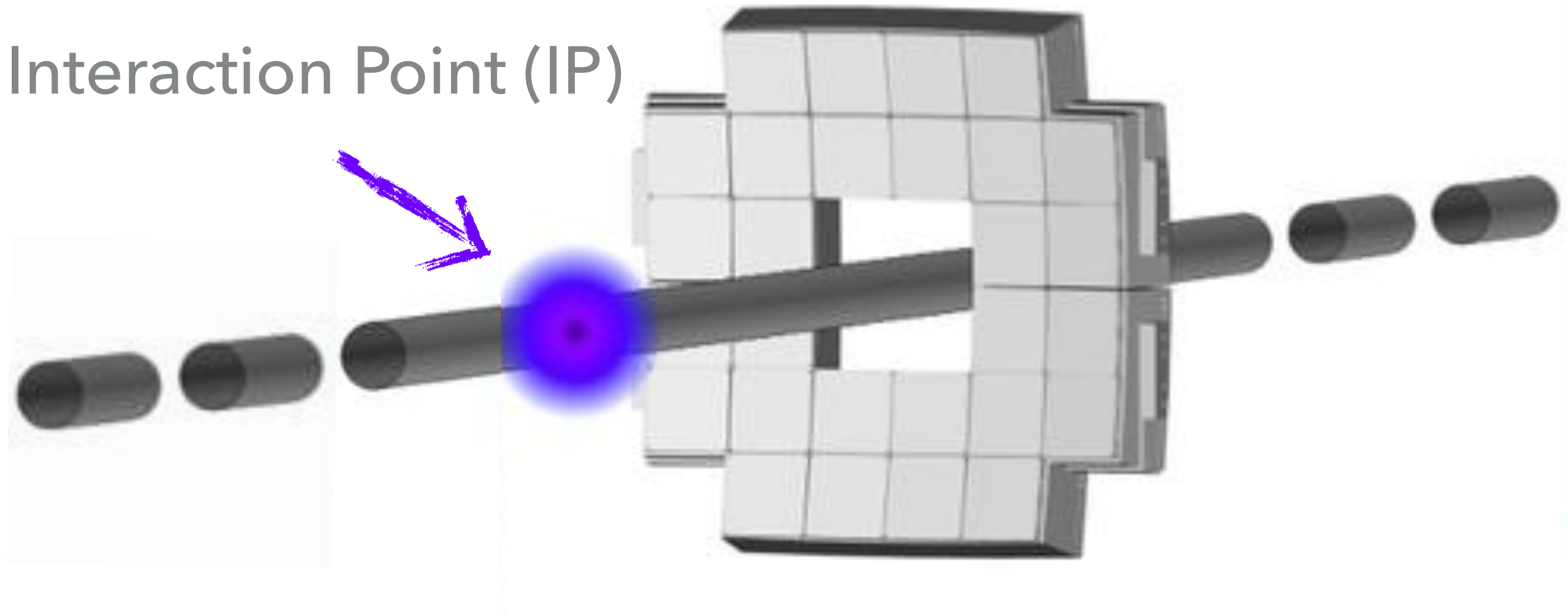
PLANS TO REDUCE THE TRACK AMBIGUITY

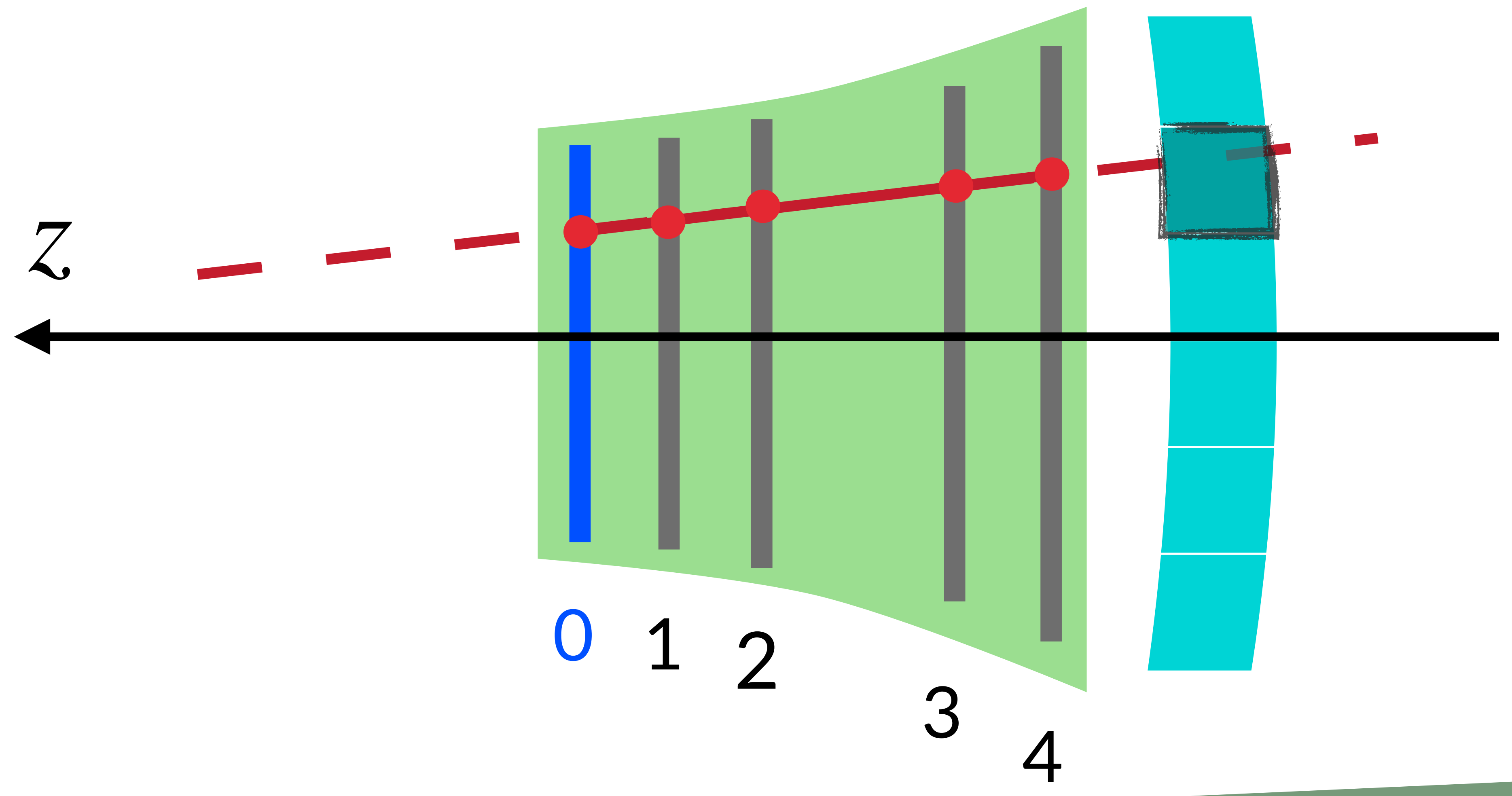
- MFT time resolution: 5 μs
    - Nominal MFT acceptance: -3.6 < η < -2.5, full azimuth
- Matching with FT0-C
    - Precision of FT0-C: ~50ps < 1 BC
- Matching should be quite easy since the detectors are very close to one another

FT0-C Cherenkov detector

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

-0.8 m away from IP *





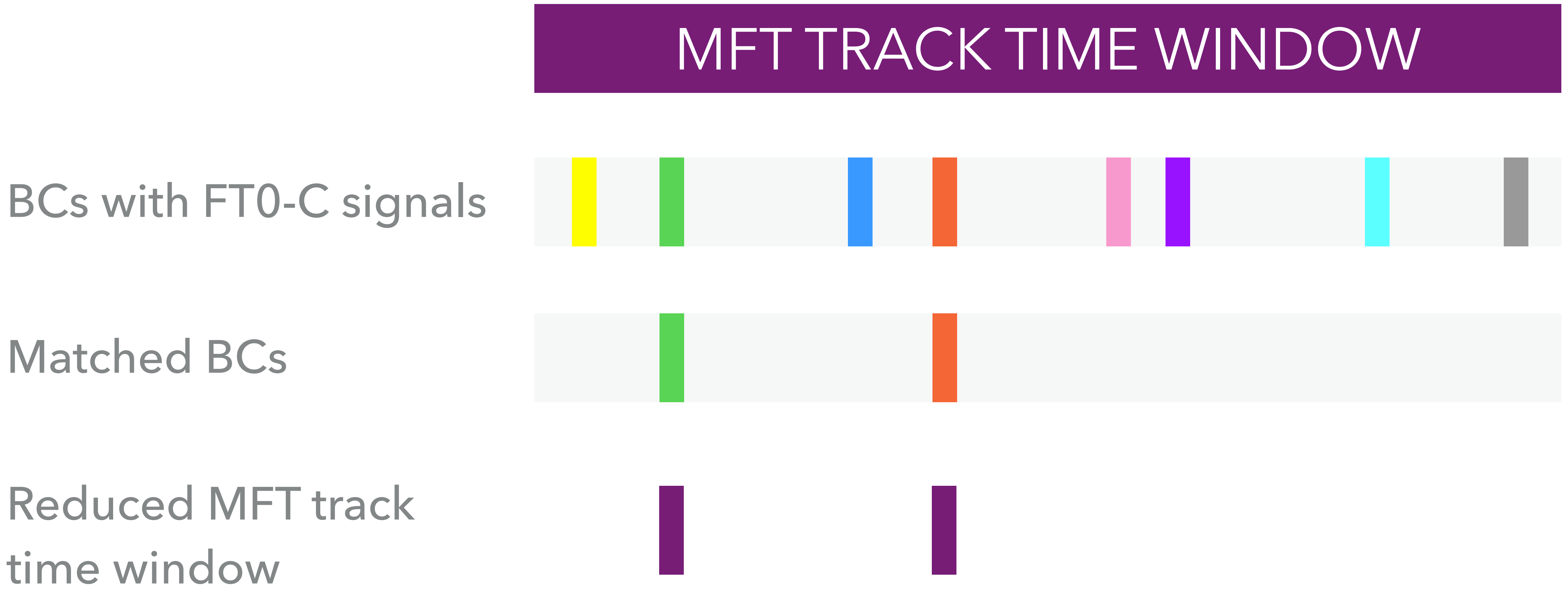
1 BC = 25 ns

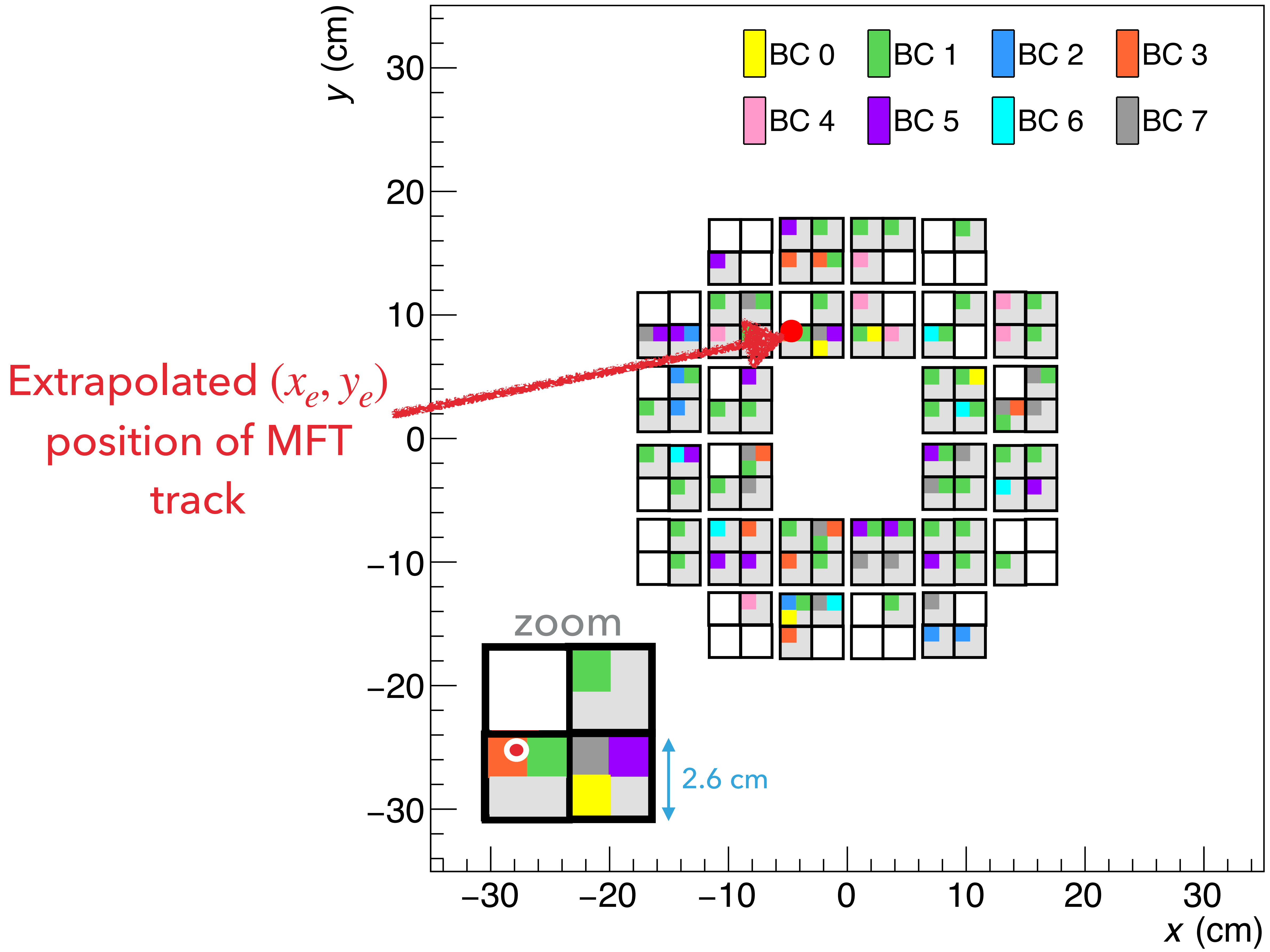
* IP = Interaction Point

https://alice-collaboration.web.cern.ch/menu_proj_items/FIT

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





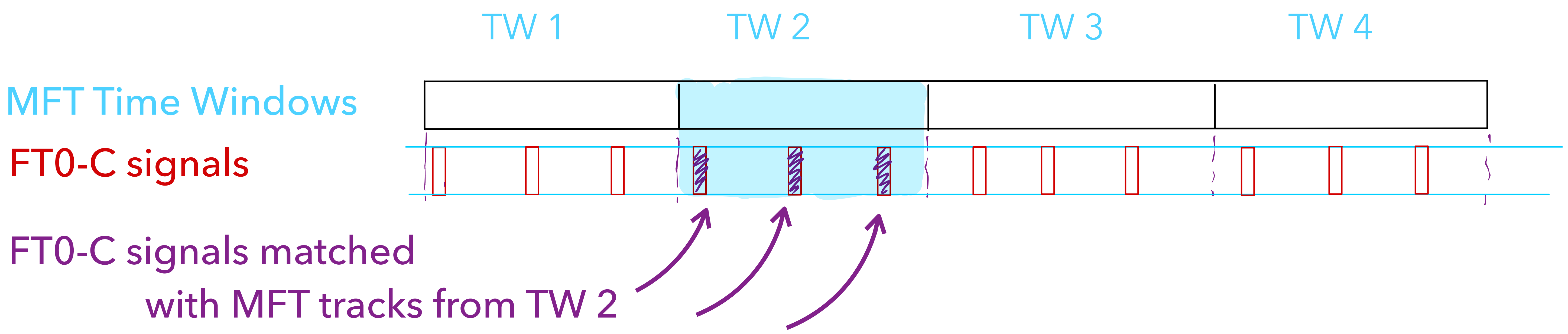
- But : this is in an ideal case

BC = Bunch Crossing = 25 ns

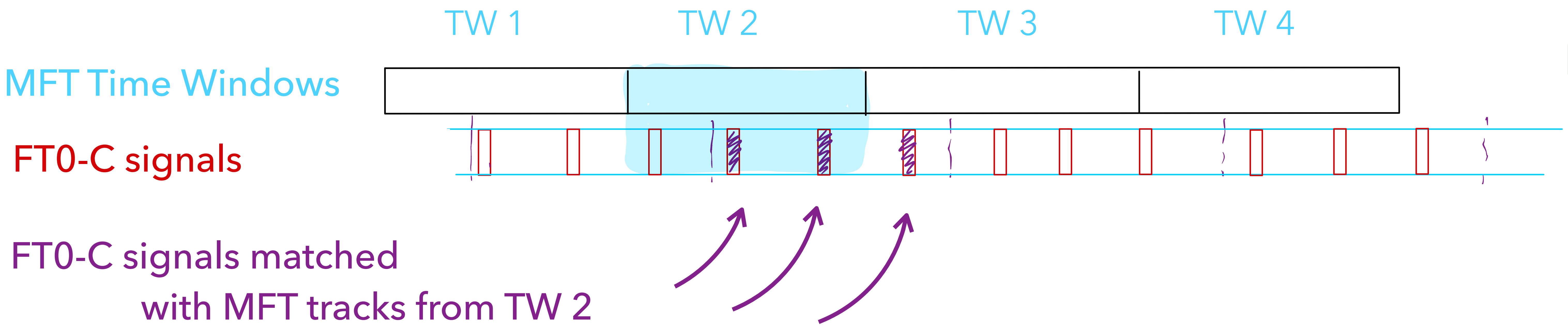
DETECTOR TIME ALIGNMENT

- The MFT time precision is bad: means that it is not aligned in time with the FT0-C
- Need to align the 2 detectors in time

Perfect alignment



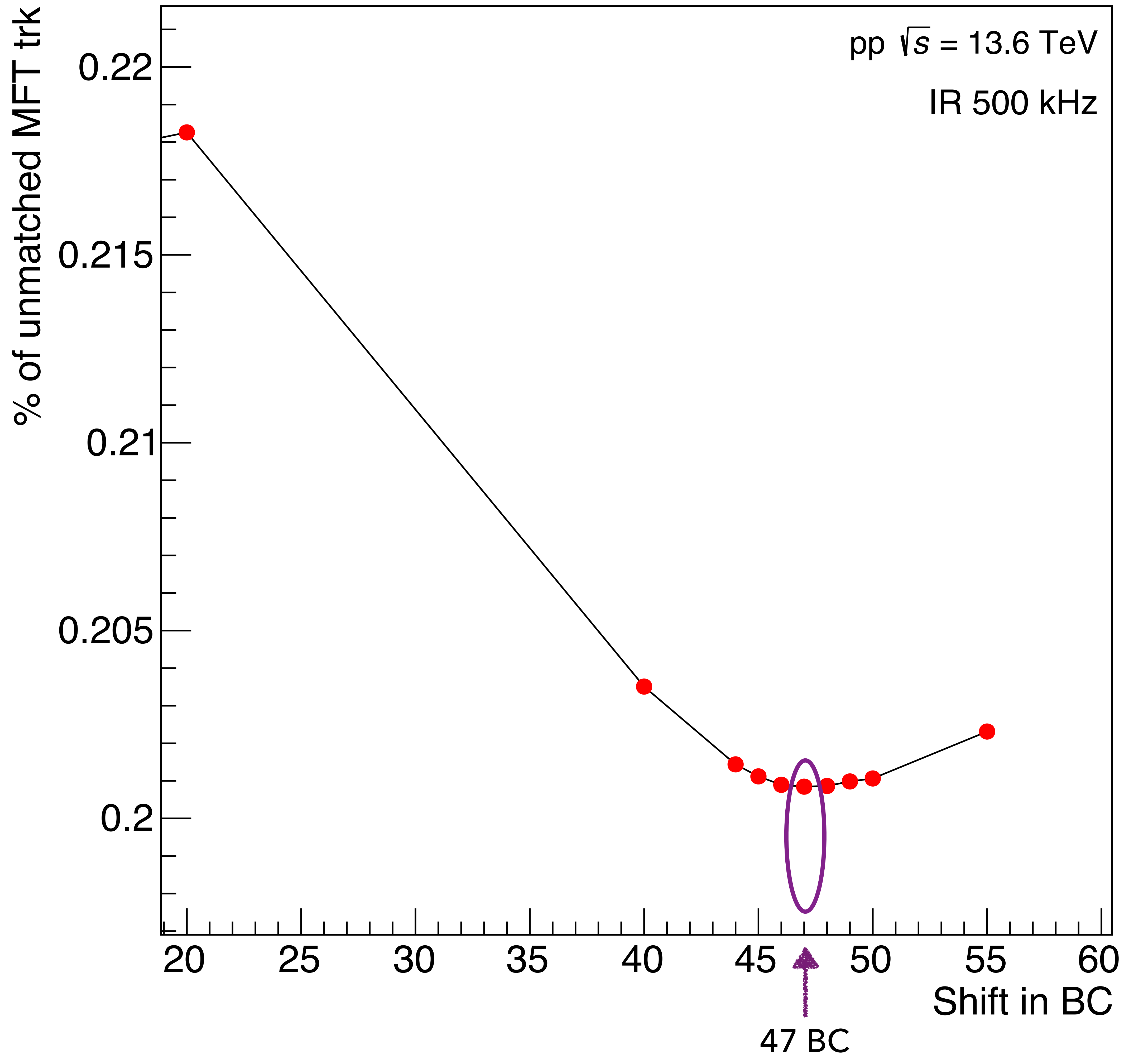
Imperfect alignment



- Idea: shift the MFT time window by a few BC (25ns) in the analysis
- When the number of matched MFT tracks is the highest => Time aligned
- In practice find the BC shift for which the fraction of **un**matched MFT tracks is the lowest

DETECTOR TIME ALIGNMENT

- Results of the fraction of unmatched tracks versus the time shift
- Minimum for a shift of 47 BC = 1.175 μs
- Next step : See how much the matching with FT0-C reduces the number of ambiguous MFT tracks



SUMMARY AND OUTLOOK

- MFT is fully functional, producing promising performance plots: ready for physics results
  - Still waiting for MC simulations tailored to other datasets (pp 13.6 TeV and PbPb)

- Future developments:
  - Evaluate uncertainty contributions
  - Check that the time shift between MFT and FT0-C is consistent on different datasets
  - Reduce the track ambiguity for higher IR productions
    - See how much the matching MFT - FT0-C reduces the fraction of ambiguous track

IR = Interaction Rate

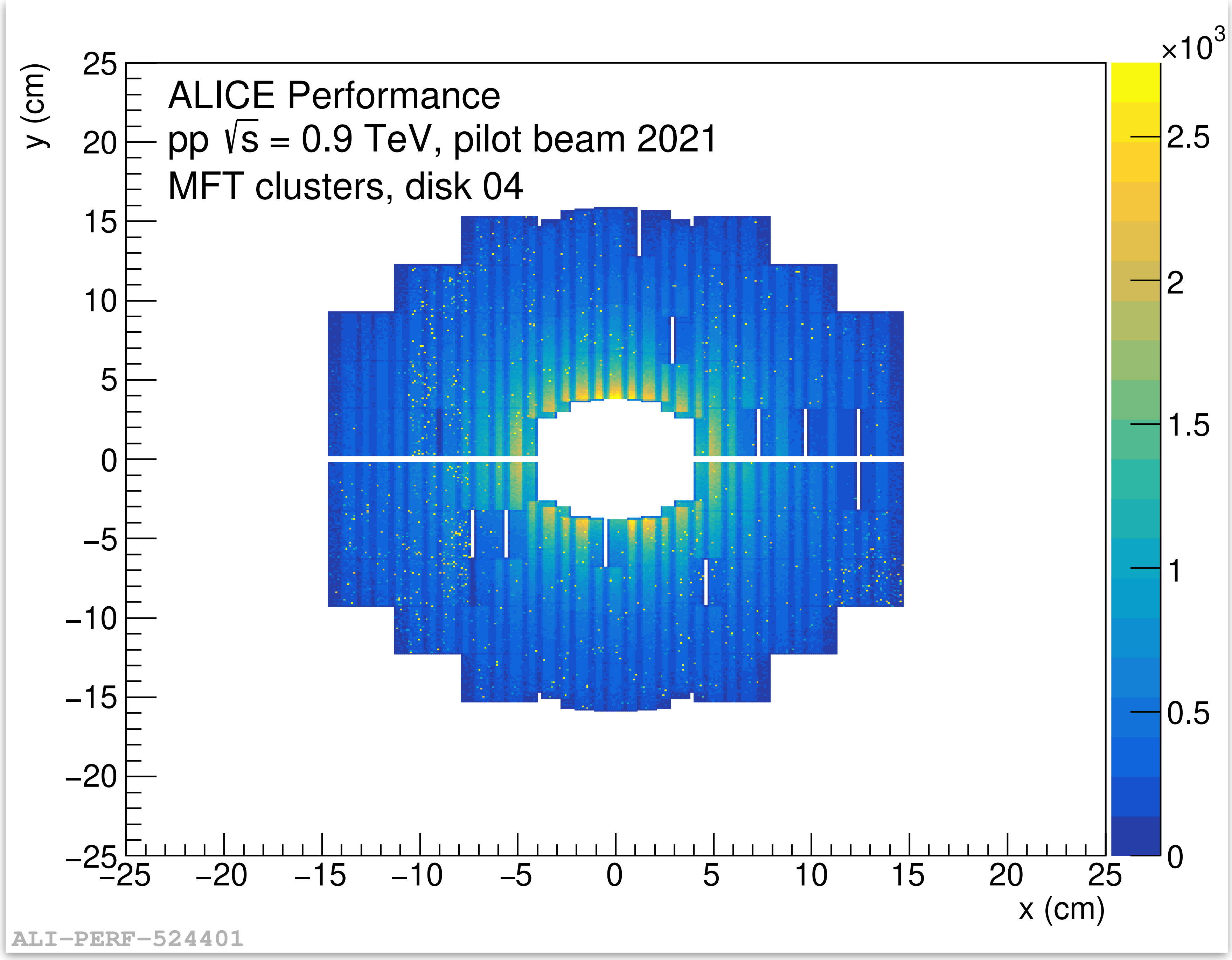
Thank you for your attention

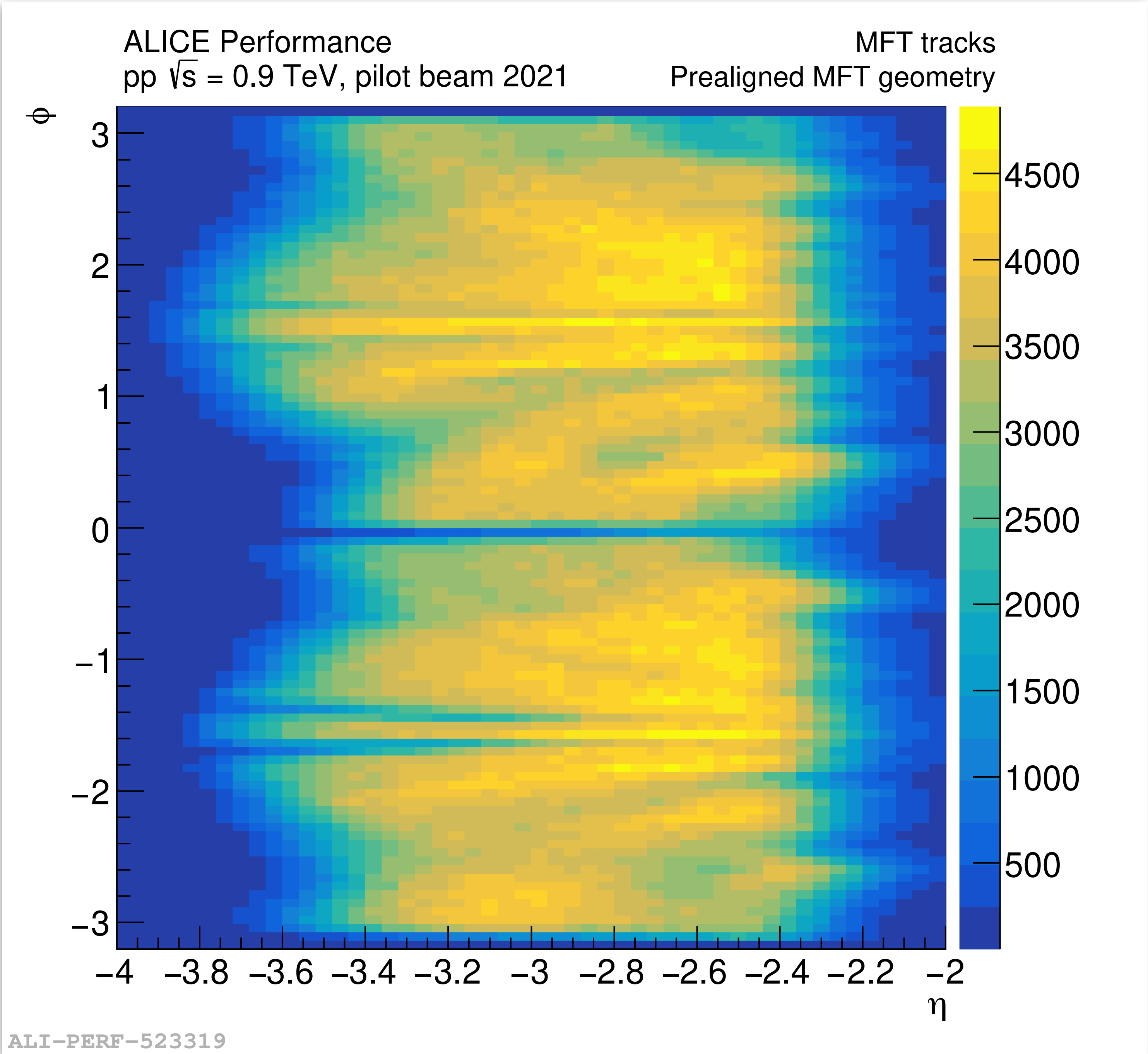
ABBREVIATIONS

- 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



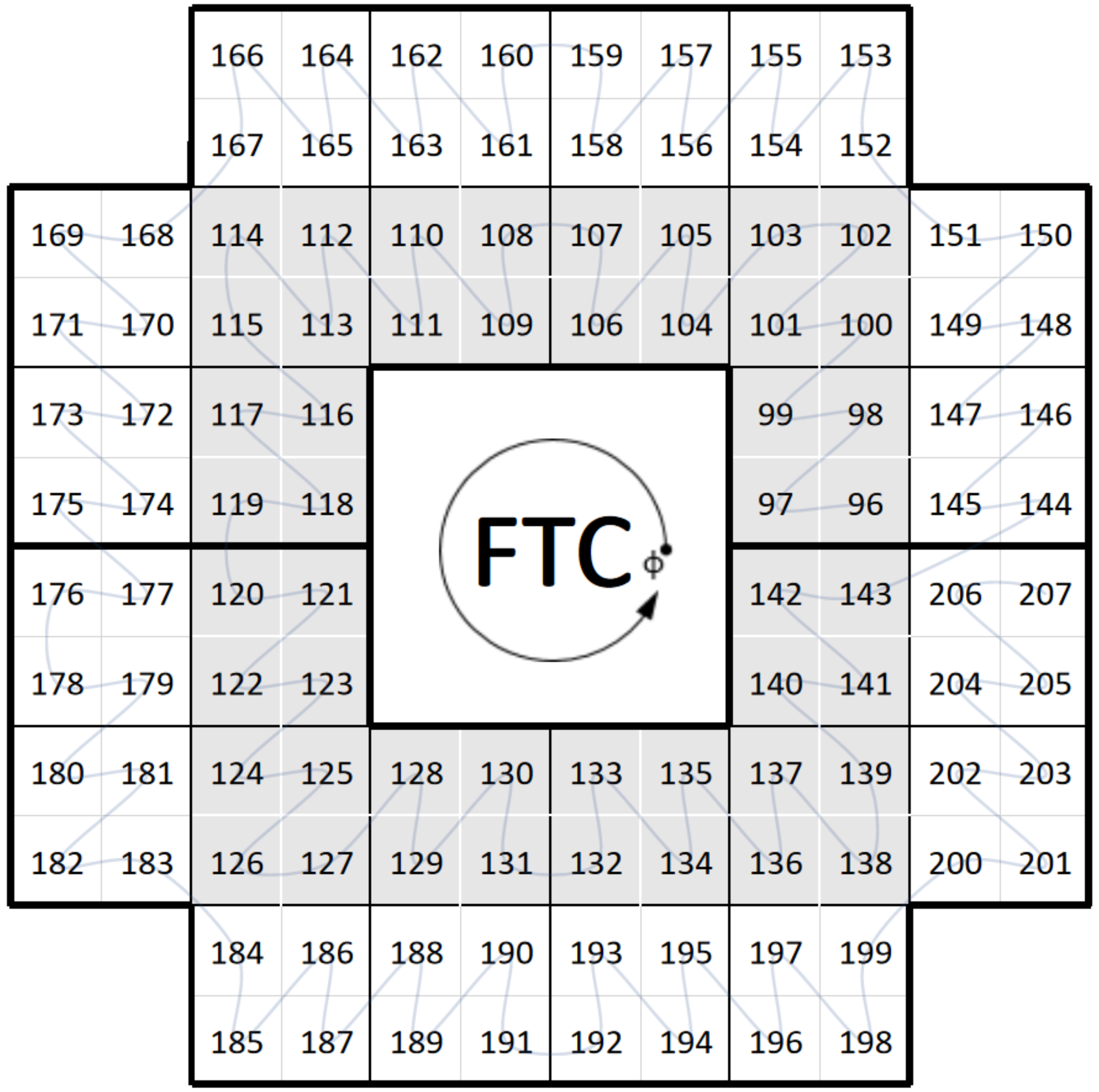


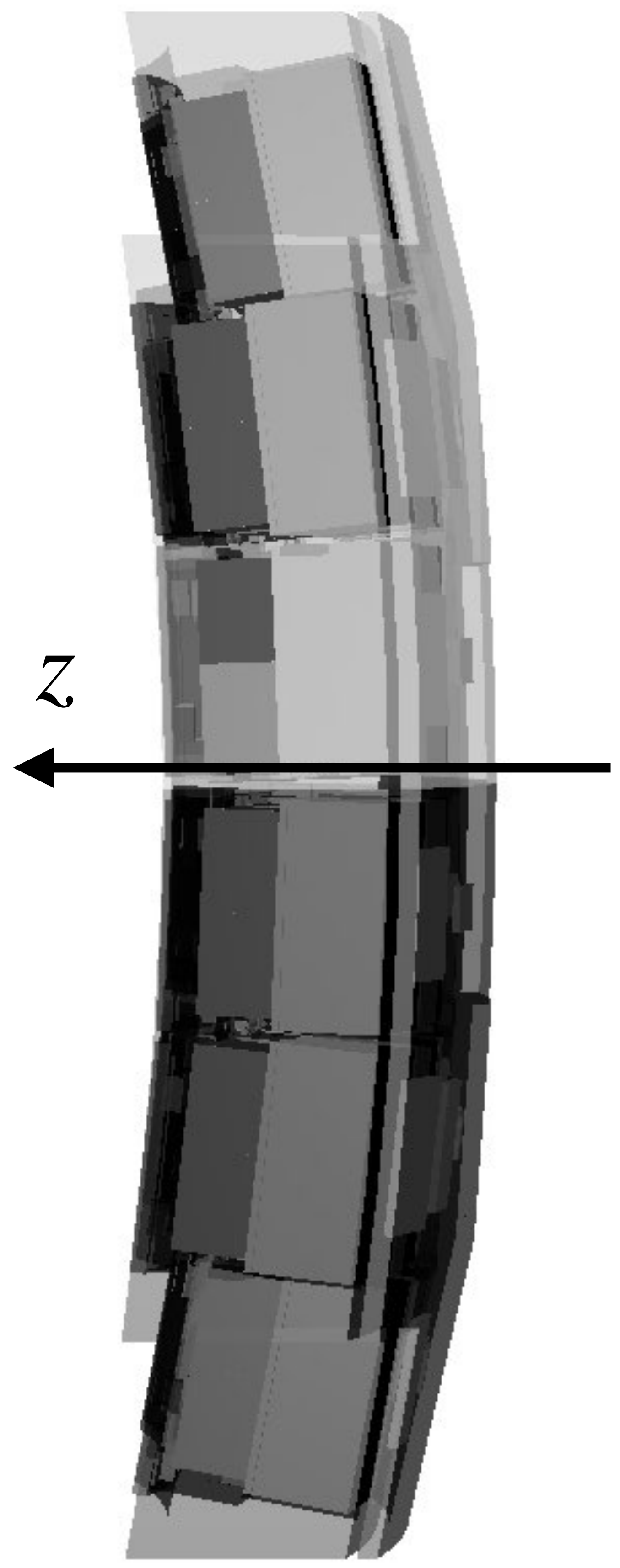
- (*x*,*y*) position of MFT clusters in the farthest disk from the interaction point
- Very few and small dead zones

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

FTO-C specifications

- 28 modules, each divided in 4 channels
- Size of 1 channel : 26.5 x 26.5 mm
- Curvature: z position of the center of channels vary in $[-83.4, -81.5]$ cm

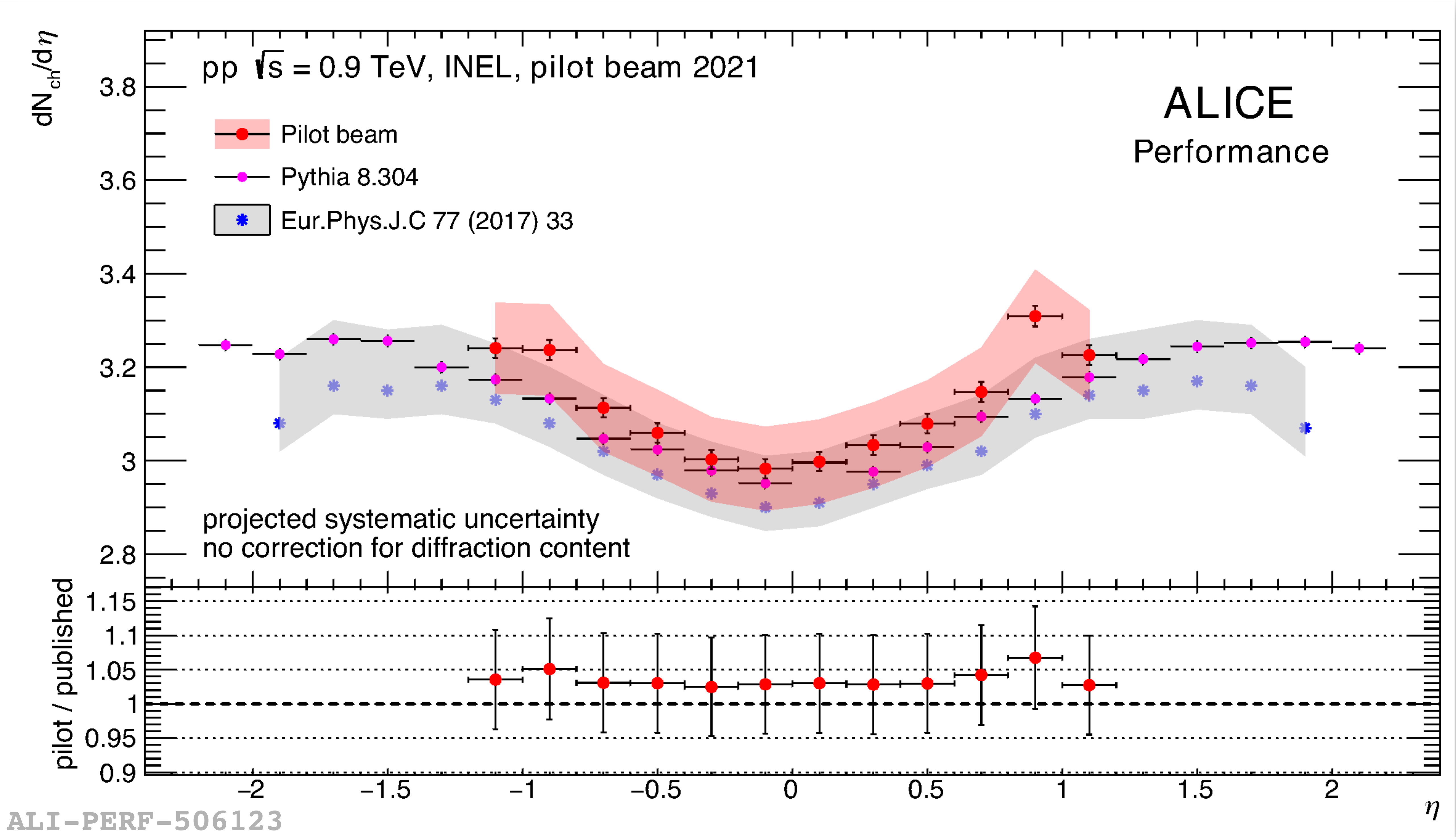




RESULTS AT MIDRAPIDITY

- $\frac{1}{N_{ev}} \frac{dN_{ch}}{d\eta}$ results at midrapidity for the INEL event class (all Inelastic collisions)
- Results compatible with previously published one on run2 data
  - Small shift due to the lack of diffraction correction in Run3 MC simulations
- The full measurement including the MFT points is expected in the coming months

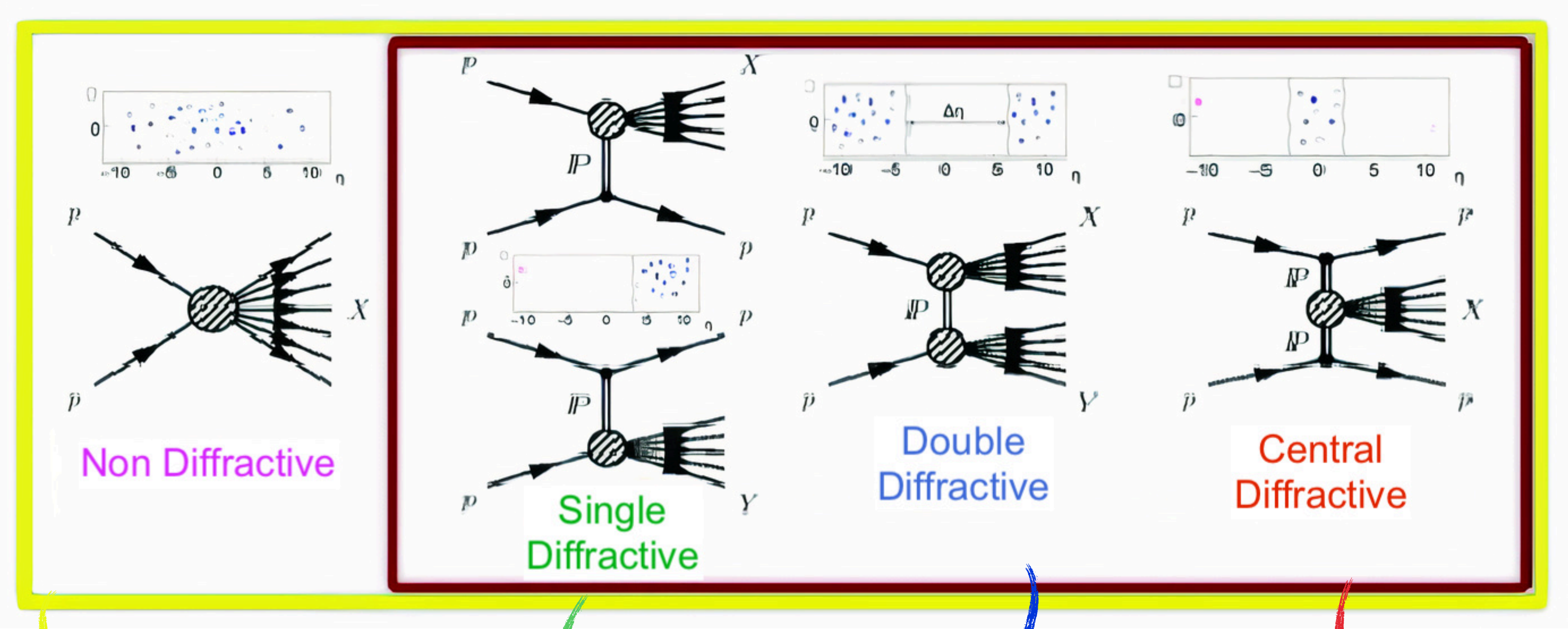
Study made by Anton Alkin



Expected MFT results

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

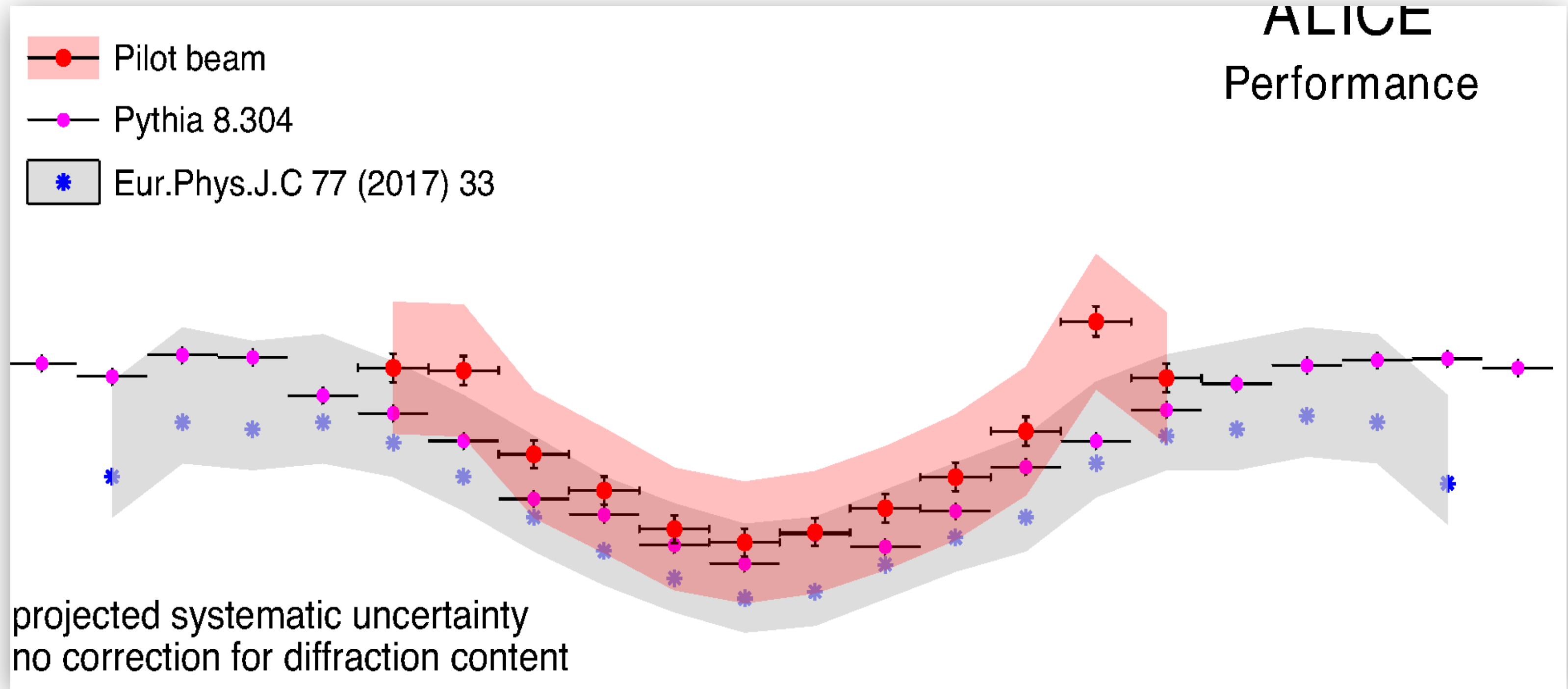
20% of the total INEL cross section

10% of the total INEL cross section

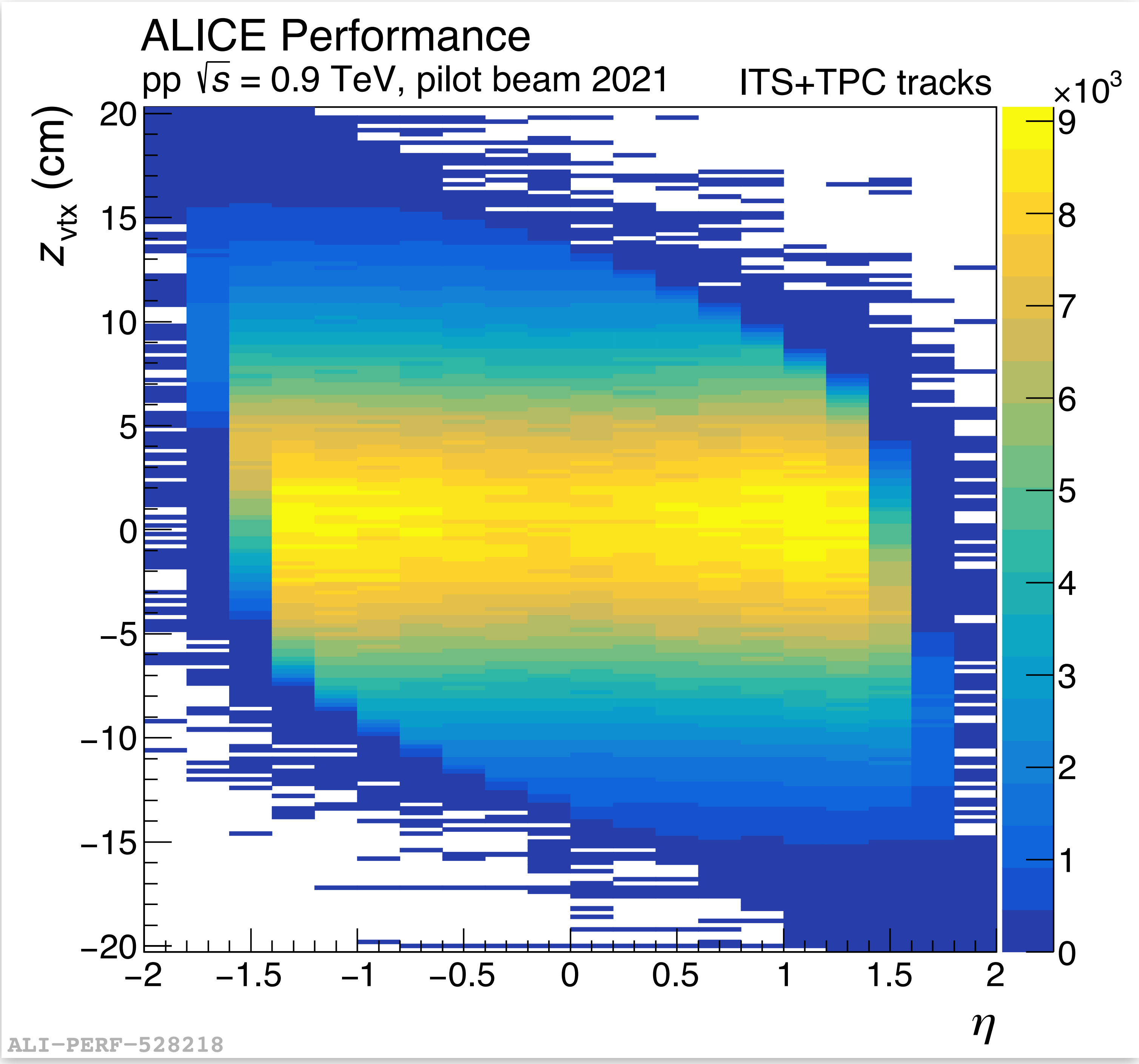
<1%

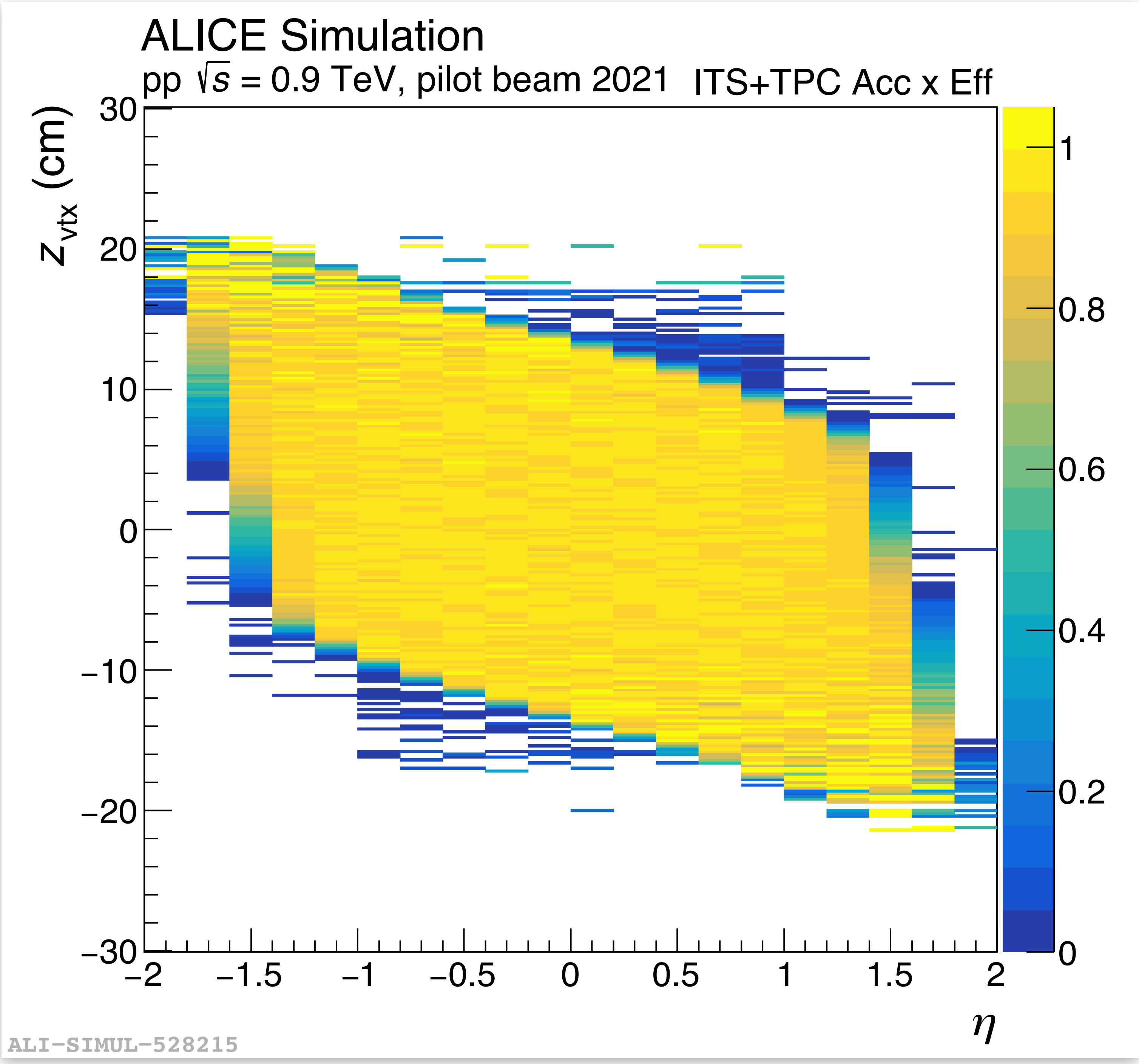
$$\frac{1}{N_{ev}}\frac{dN_{ch}}{d\eta} \text{ with } N_{ev}$$

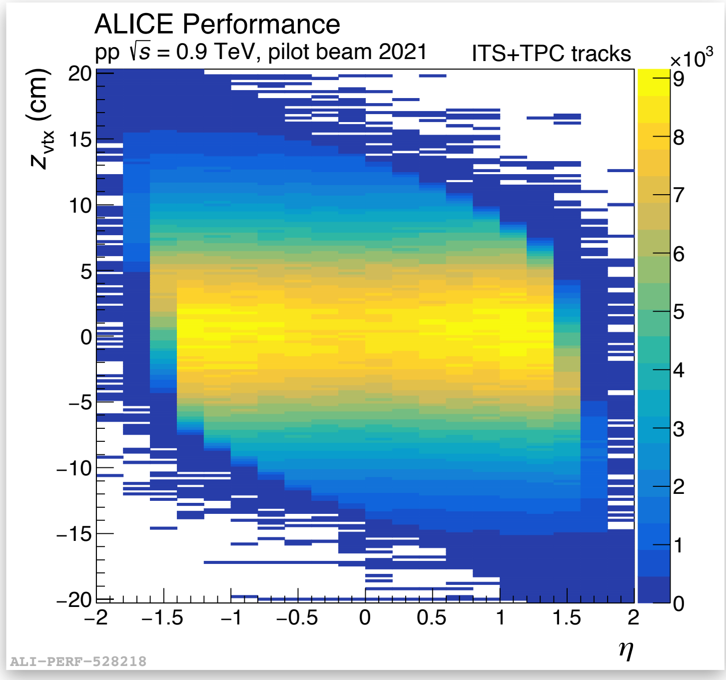
underestimated

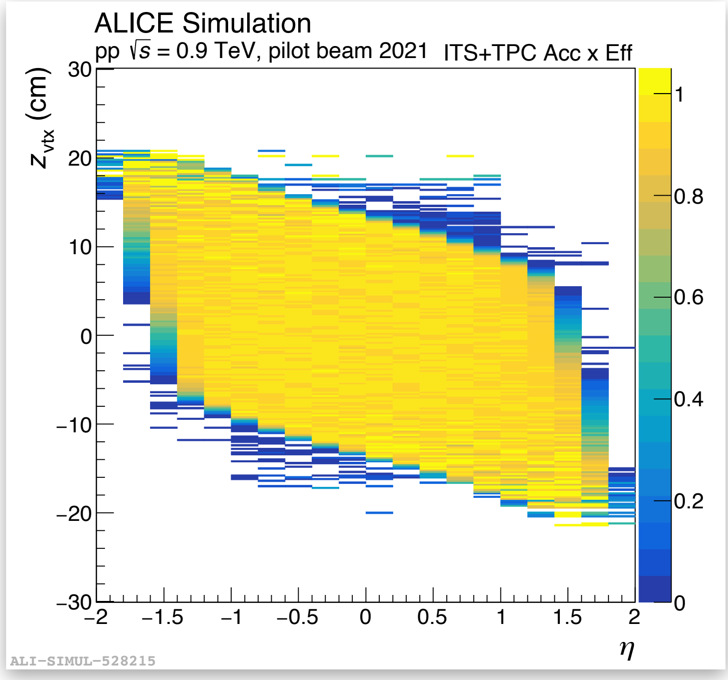


PERFORMANCE PLOTS FOR THE CENTRAL TRACKS









- 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