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On behalf of the ALICE collaboration

IP2I Lyon

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

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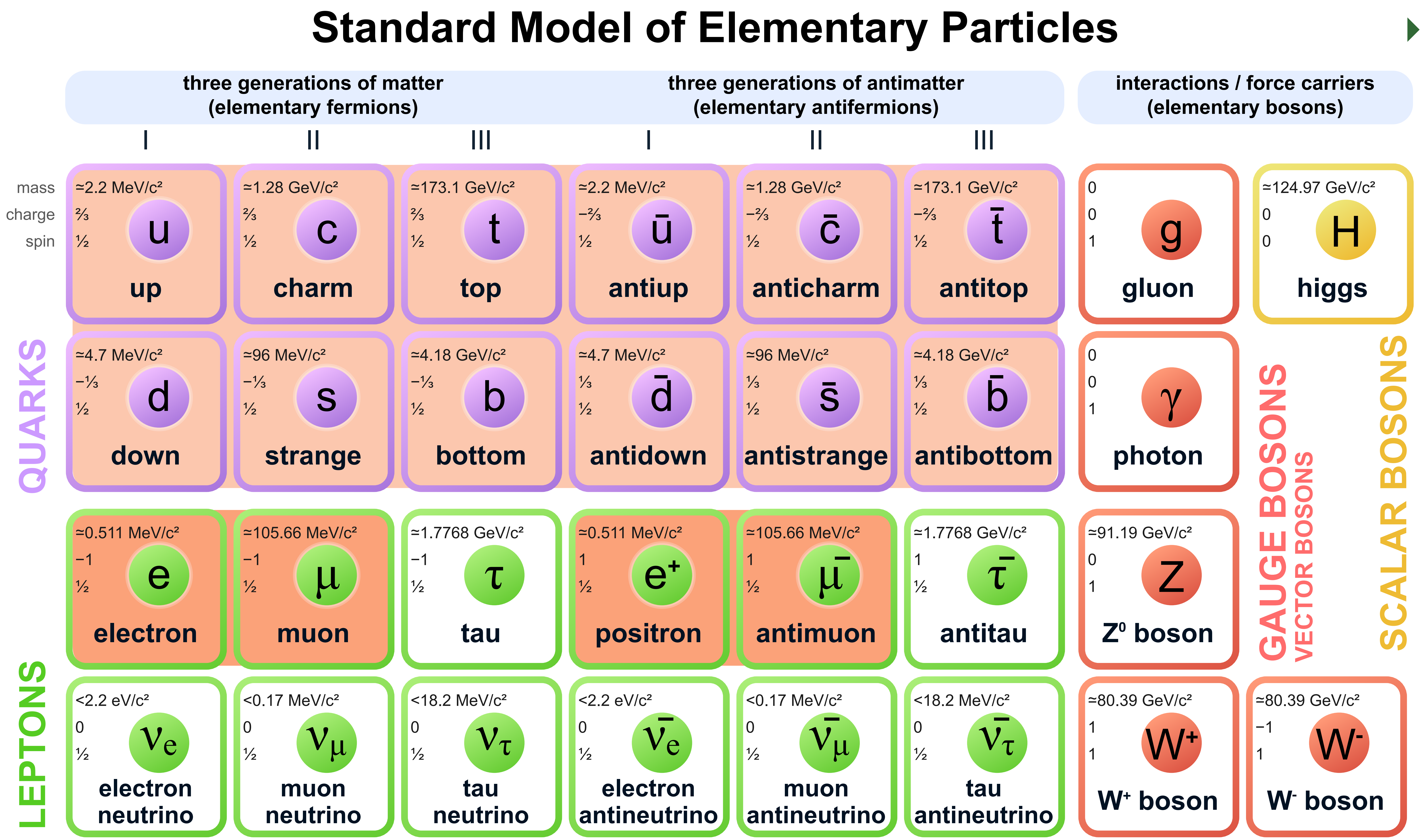
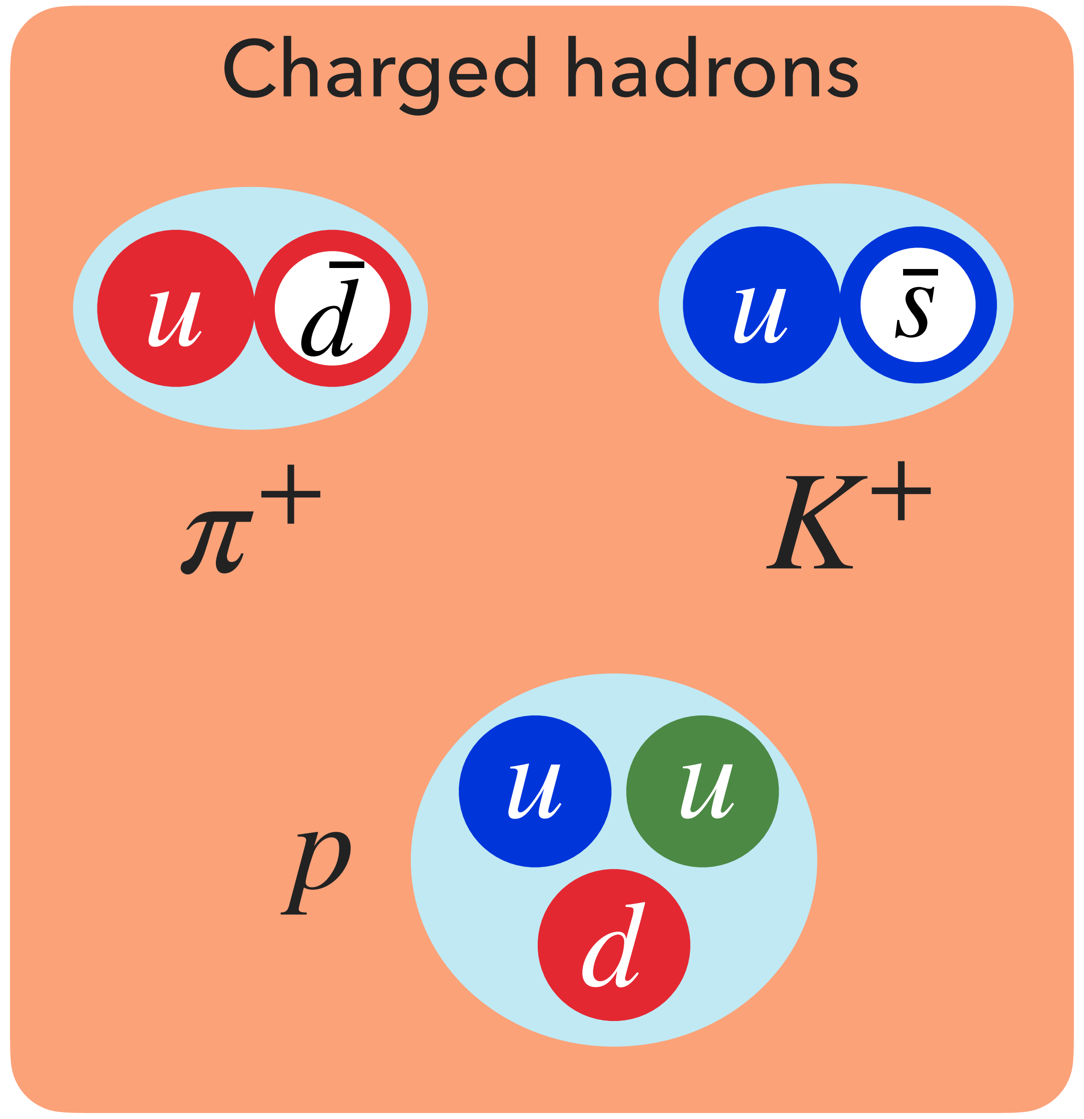
# STANDARD MODEL OF PARTICLES






- Primary particle : Particle with a mean proper lifetime $\tau > 1$ cm/c
  - produced directly in the interaction
  - from decays of particles with $\tau$ smaller than 1 cm/c excluding particles produced in interactions with material




Mogette

# VARIABLES AND SYSTEM COORDINATE DEFINITION

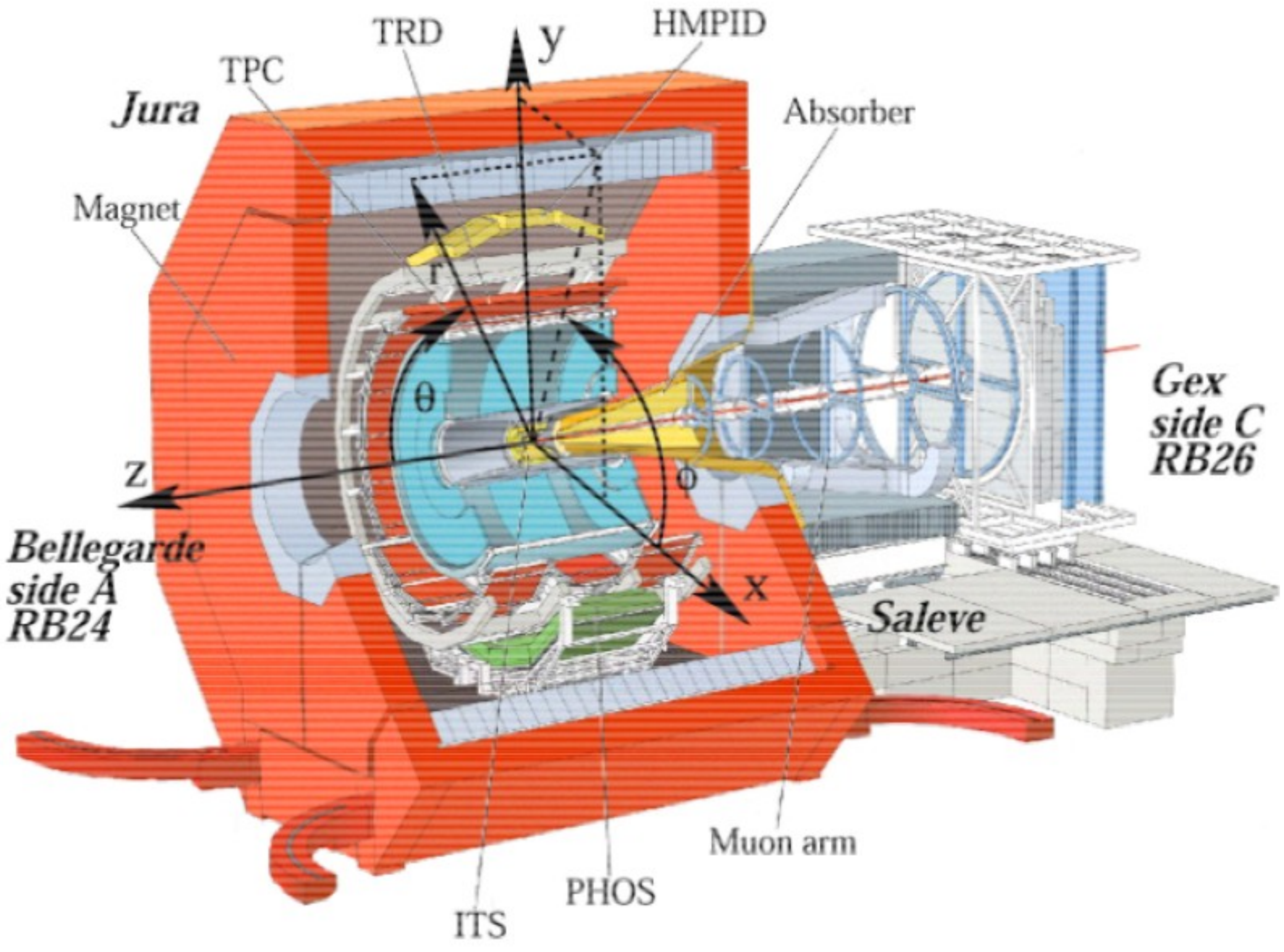
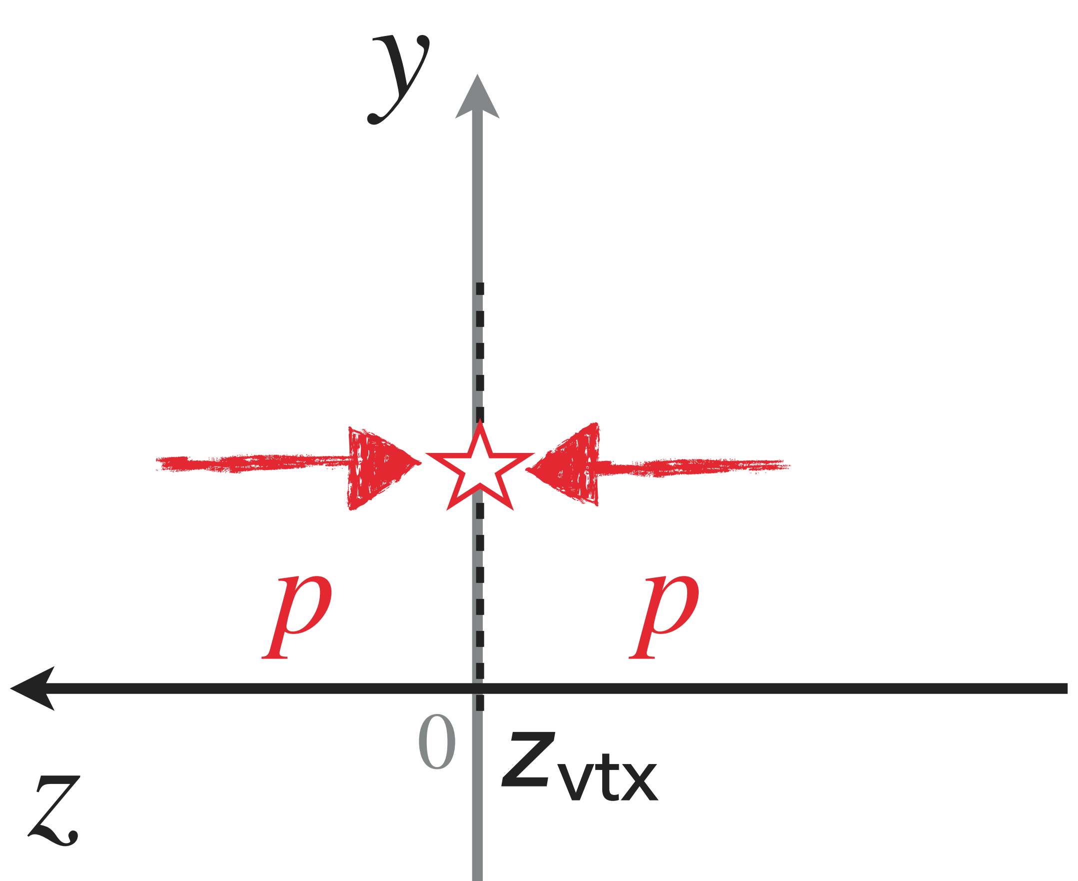
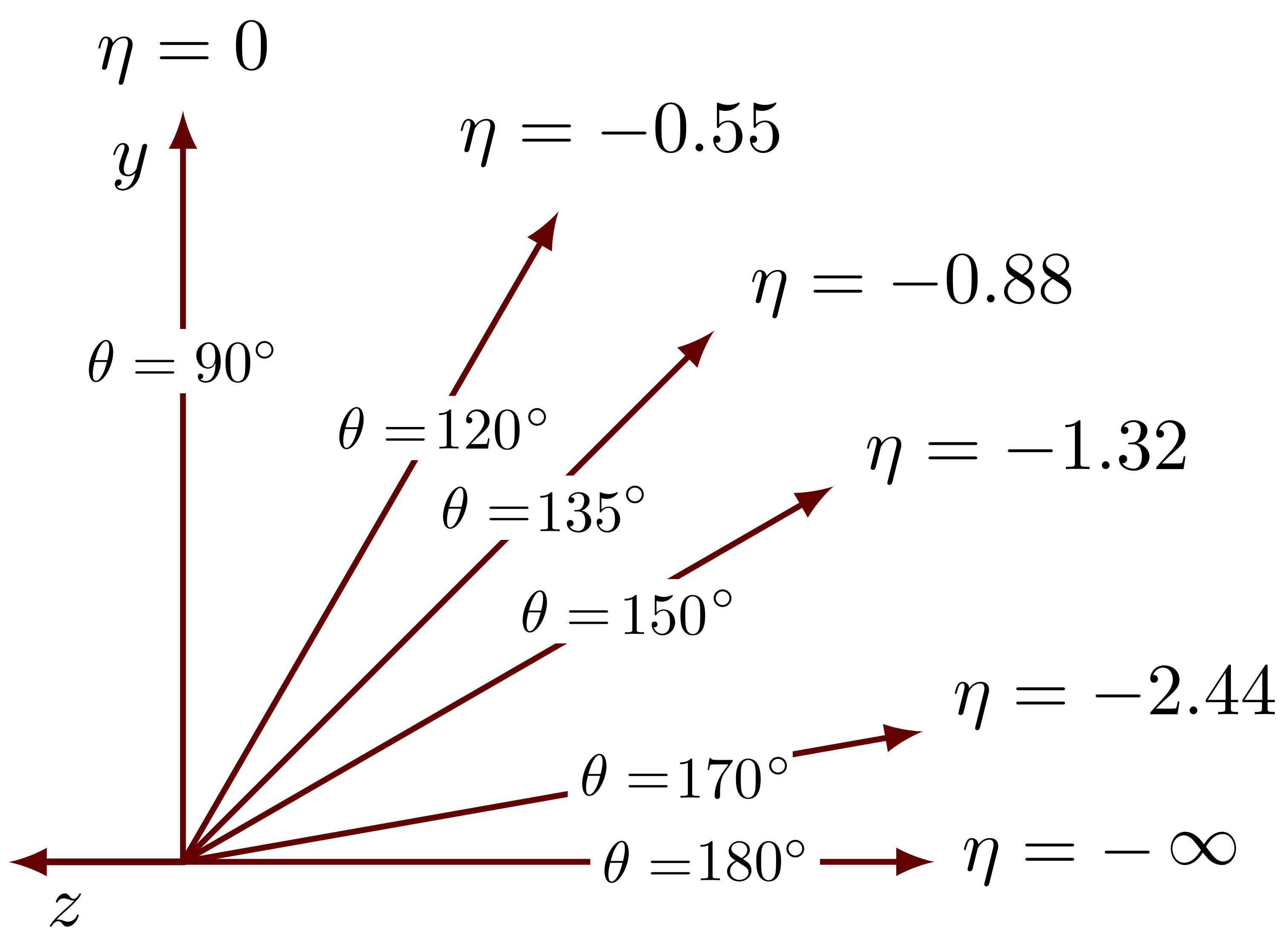



Fig1. Definition of the ALICE coordinate system axis, angles and detector sides.




One $z_{vtx}$ found = 1 collision




Pseudorapidity $\eta$

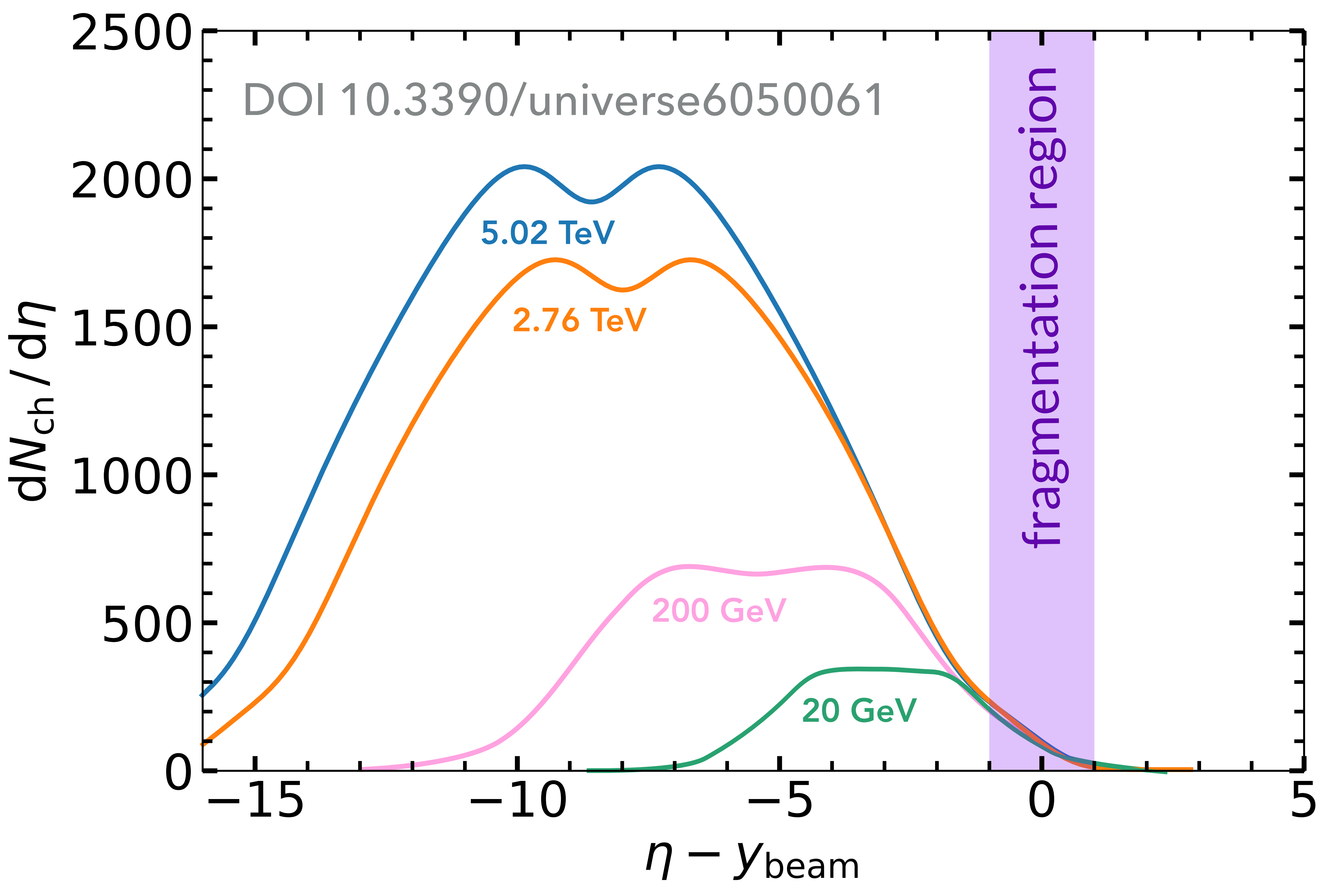
$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

# 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
- At **forward rapidity** → allows one to access the phenomena associated with particle production in the fragmentation region
  - Limiting fragmentation hypothesis

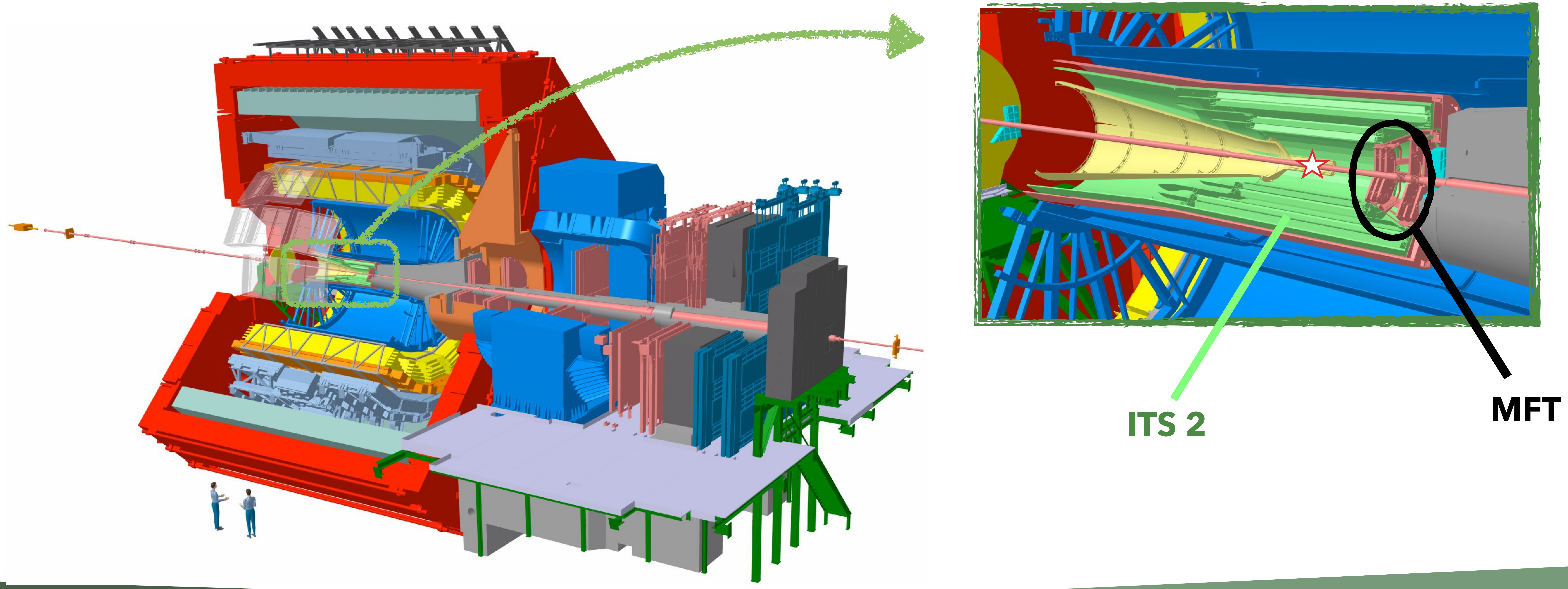
Charged-particle pseudorapidity density: number of primary charged **particles** per **collision** and unit of pseudorapidity




QCD = Quantum Chromo-Dynamics

# THE ALICE DETECTOR IN RUN 3

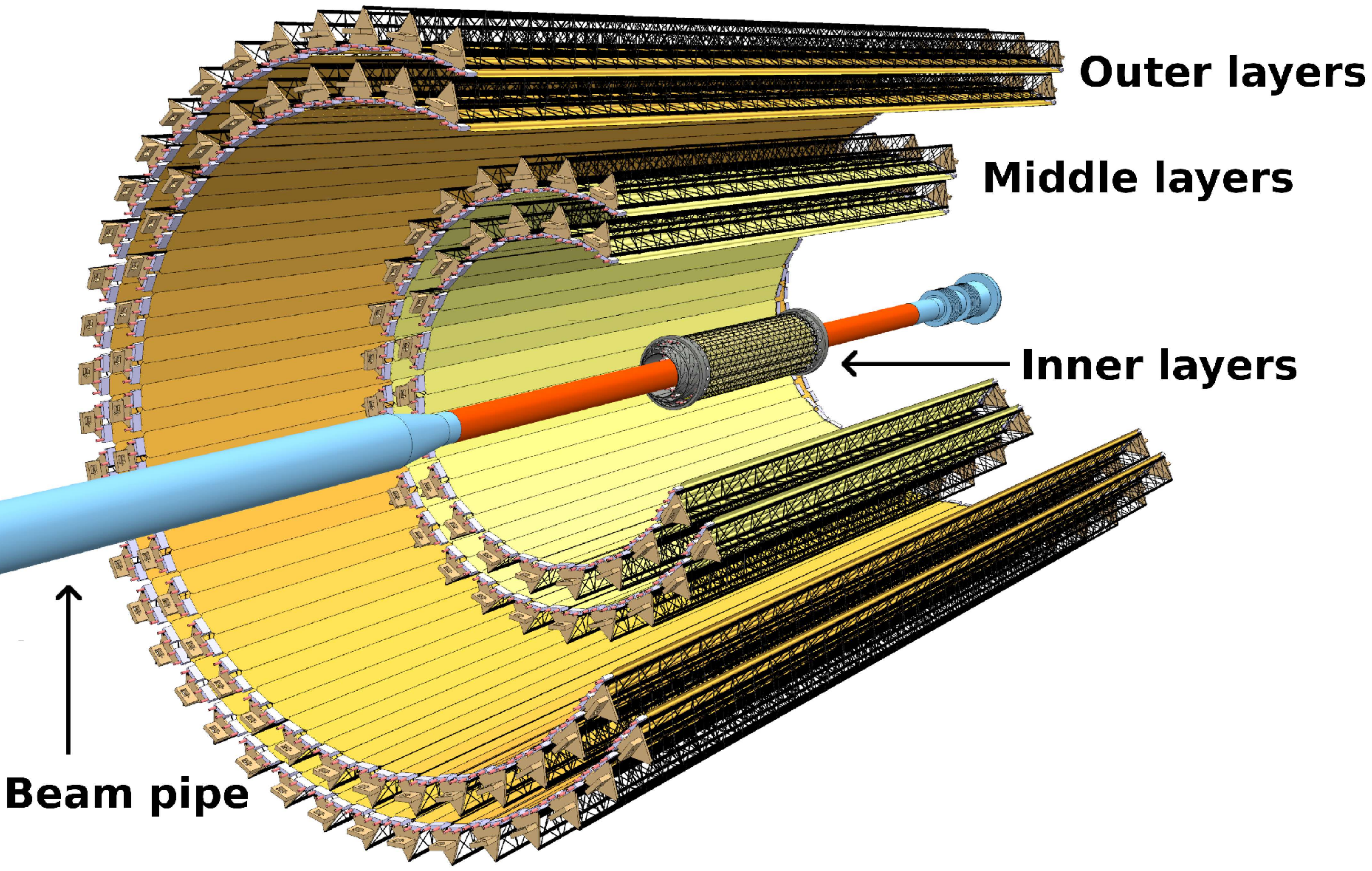
- ALICE in Run 3 : New sub-detectors and better performances
  - The Muon Forward Tracker (MFT) : a new sub-detector of ALICE
  - The Inner Tracking System (ITS2) : upgraded central barrel detector



# THE INNER TRACKING SYSTEM UPGRADED (ITS 2)



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



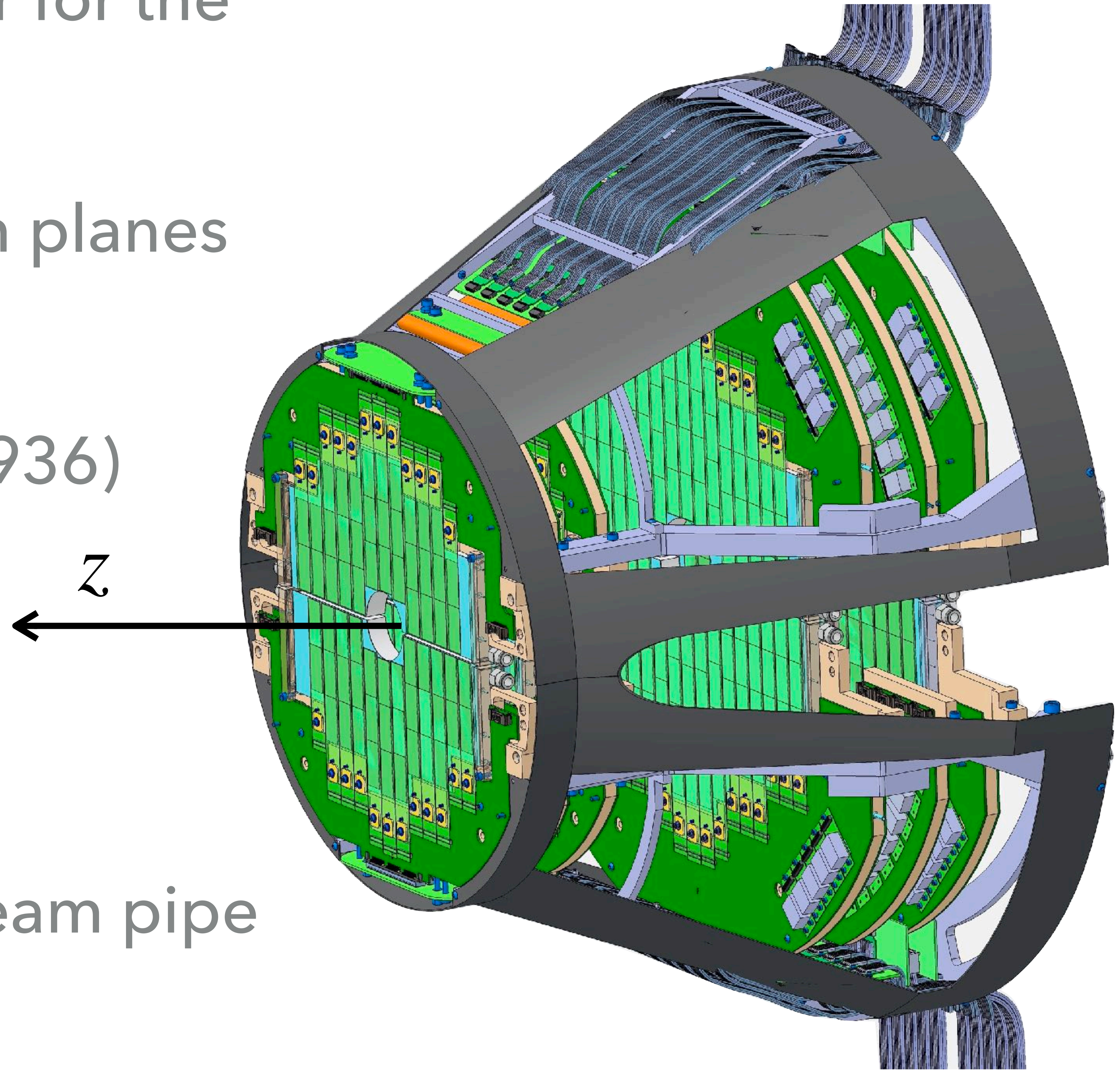

- Seven cylindrical detector layers (from $R$ = 22 mm to $R$ = 400 mm) with ALPIDE chips
  - CMOS* silicon pixel sensor
  - Space resolution: 5 $\mu m$
- $\eta$ coverage [-1.2 ; 1.2]

* CMOS : Complementary Metal–Oxide–Semiconductor

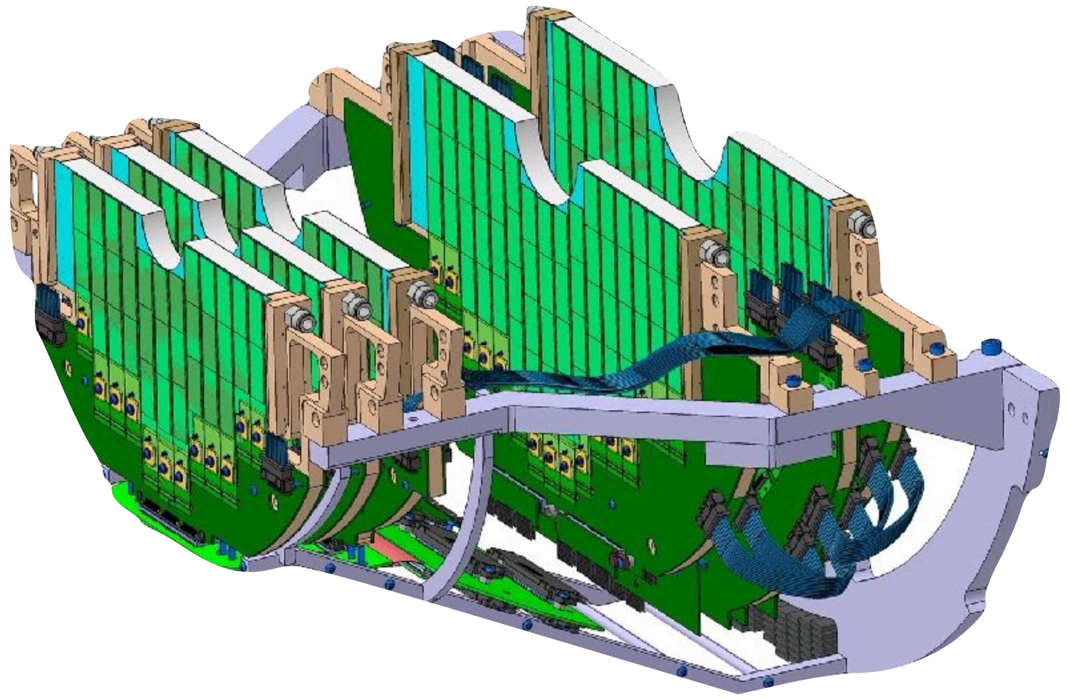
# THE MUON FORWARD TRACKER (MFT)



- 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)
  - Space resolution: 5 $\mu m$
- Time resolution: $4 - 15\ \mu s$
- Inner radius limited by the beam pipe
  - Nominal acceptance: -3.6 < $\eta$ < -2.5, full azimuth




- Poor $p_T$ resolution because of low magnetic torque in the forward region



# HOW TO DERIVE THE CHARGED-PARTICLE PSEUDORAPIDITY DENSITY



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

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

# CORRECTIONS NEEDED



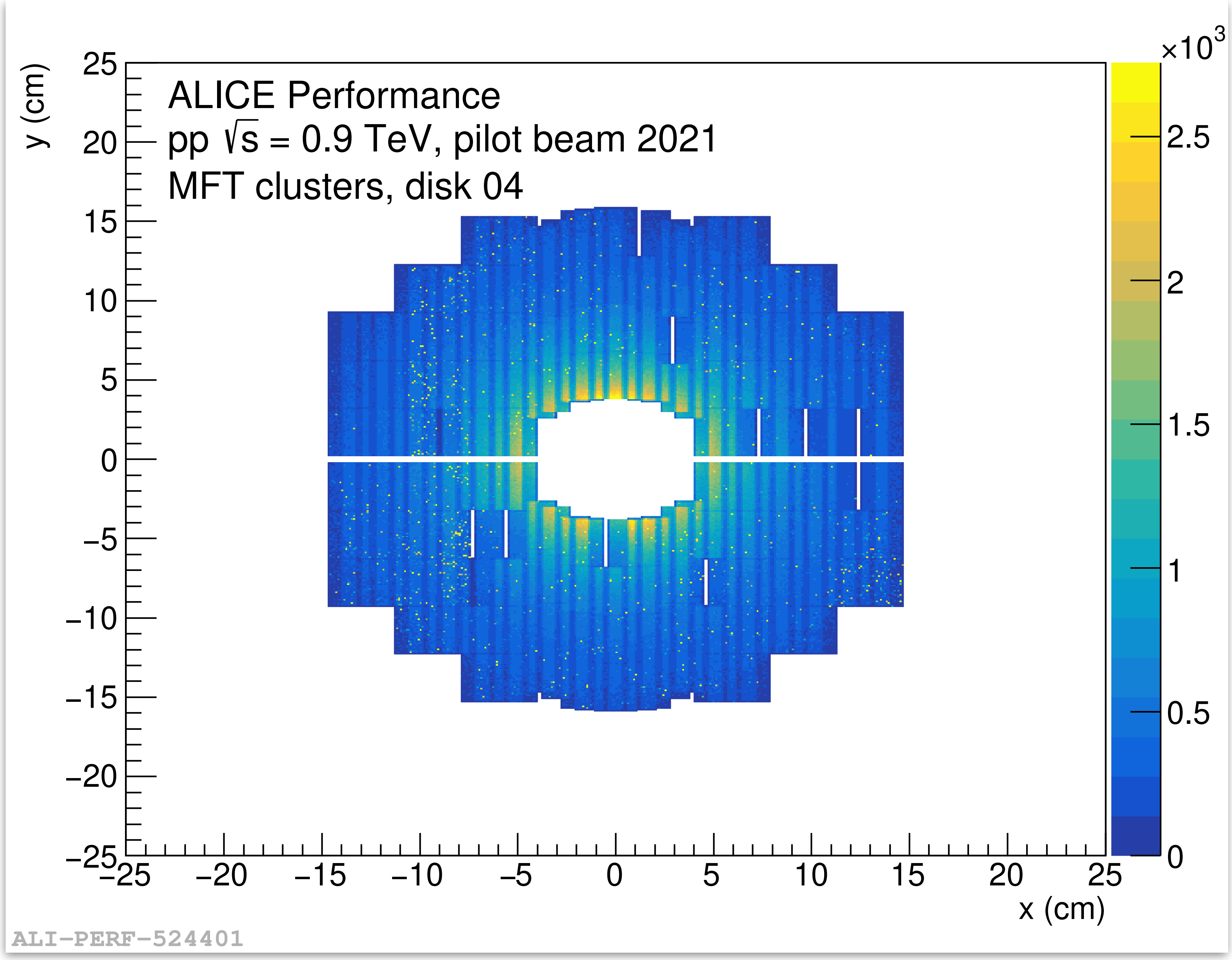
Charged-particle pseudorapidity density: number of primary charged **particles** per **collision** and unit of pseudorapidity

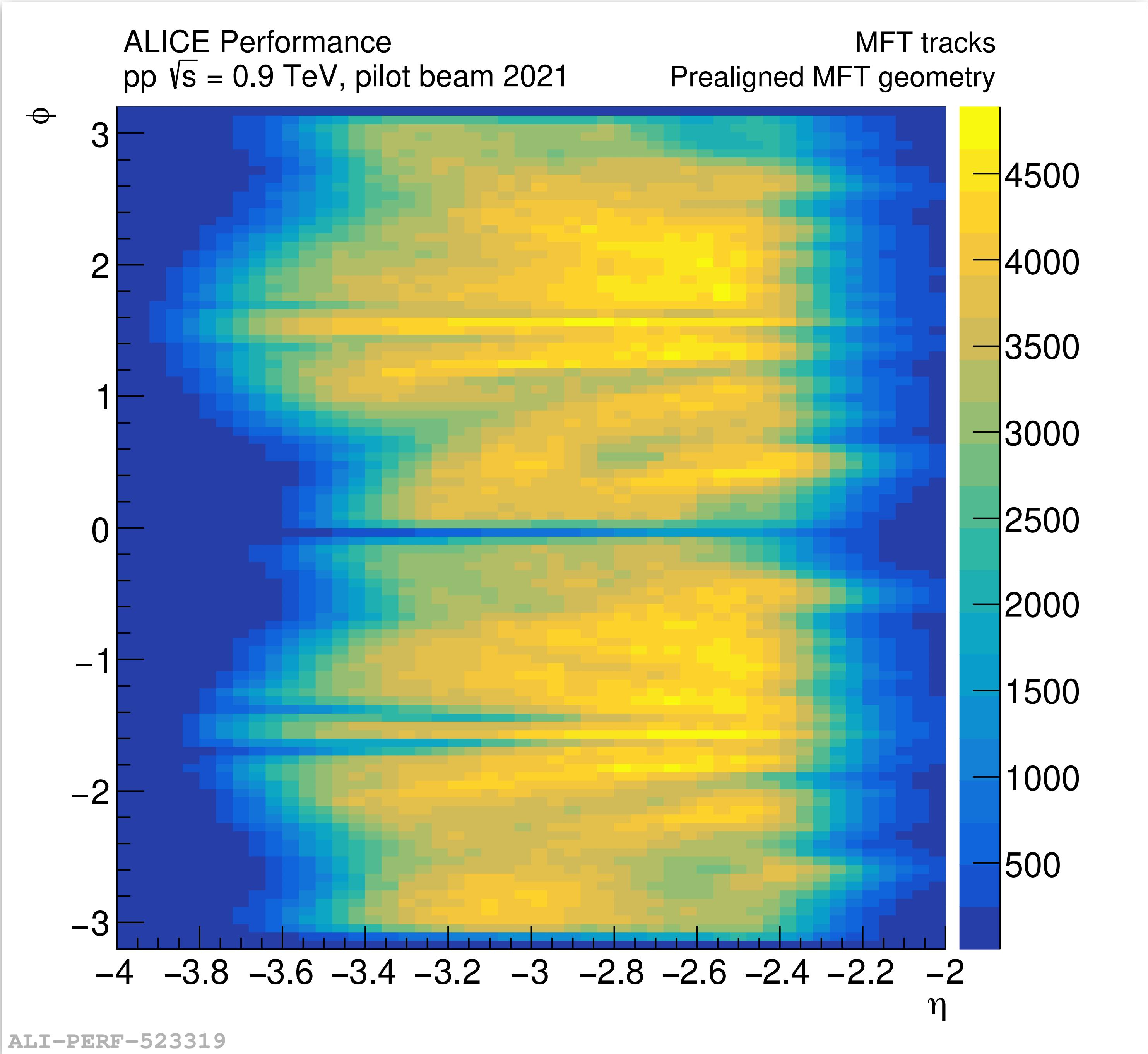
- 2 types of corrections computed with MC
  - Track-to-particle correction (difference between the number of reconstructed tracks and the number of primary charged particles) → Track level
  - Trigger bias correction (corrects the difference between triggered sample and generated one) → Track and event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

# MFT PERFORMANCE



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



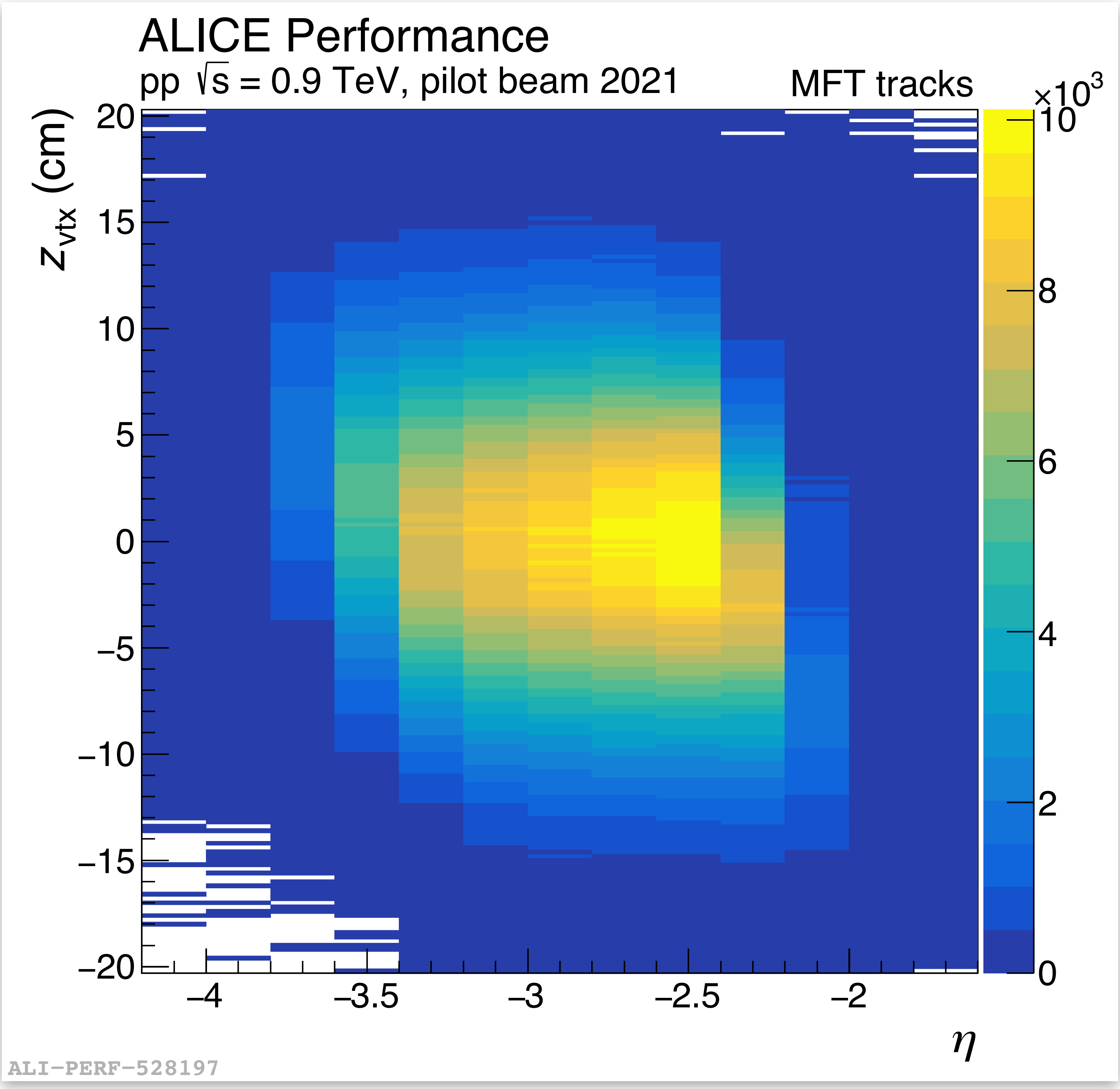




- (*x*,*y*) position of MFT clusters in the farthest disk from the interaction point
- Very few and small dead zones

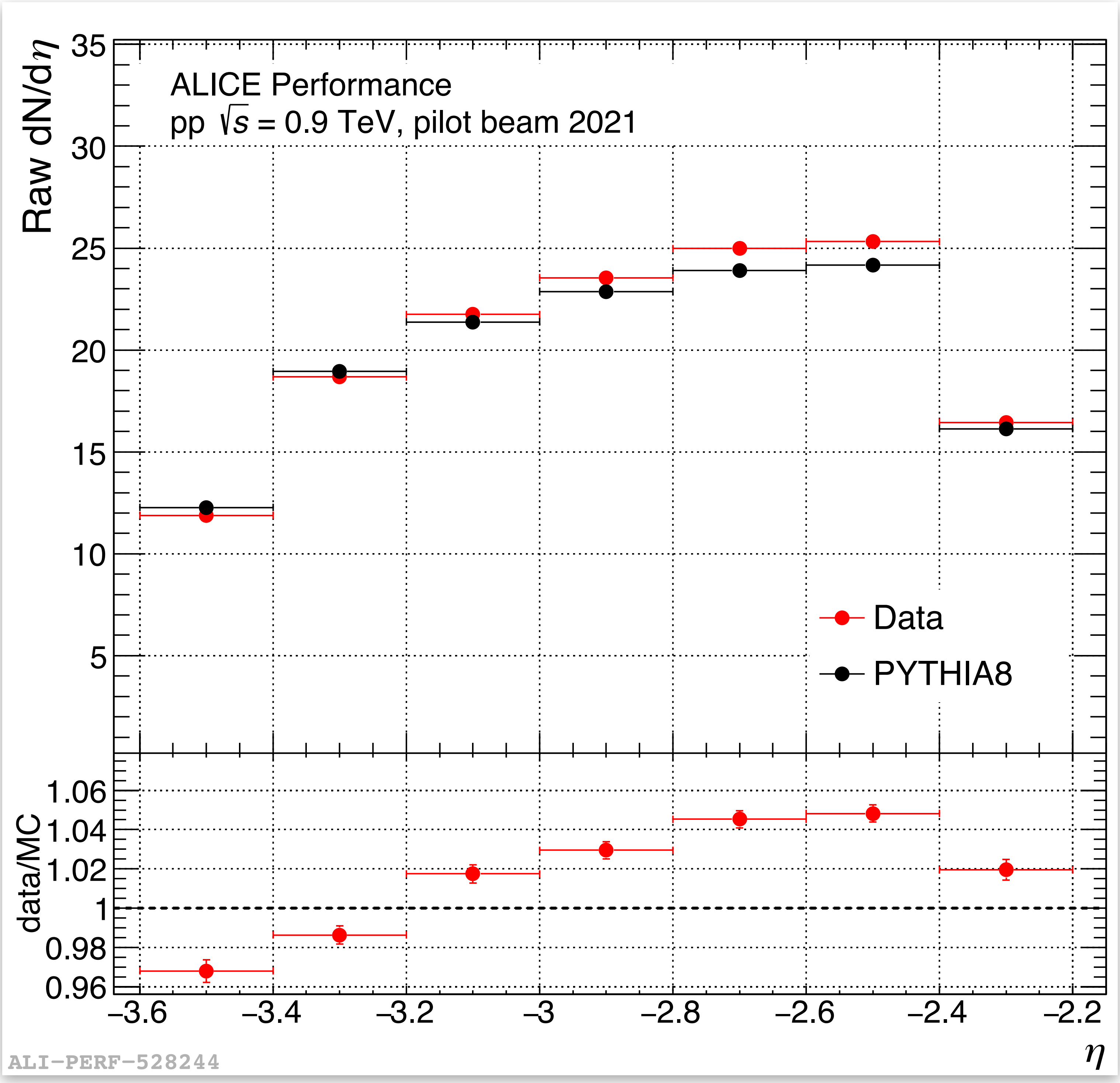
- $\eta$ and $\phi$ distribution of tracks as expected : full azimuth and -3.6 < $\eta$ < -2.5

# MFT PERFORMANCE






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




- Measured number of tracks versus $(z_{\mathrm{vtx}}, \eta)$

- Comparison of number of tracks versus $\eta$ in simulation and data

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

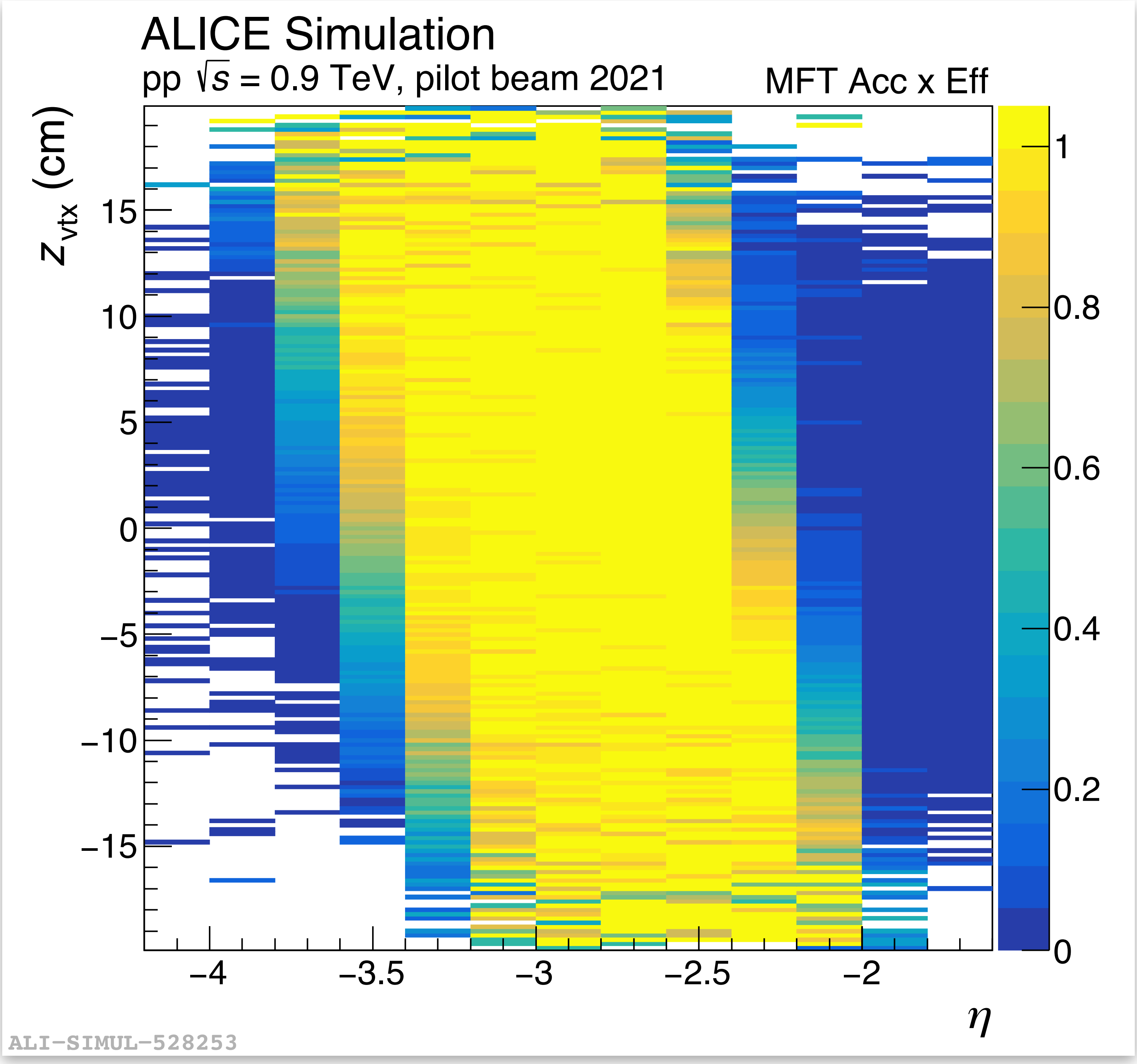
→ MC simulation can be used for correction

→ Systematic error would need to be reduced

MC = Monte Carlo

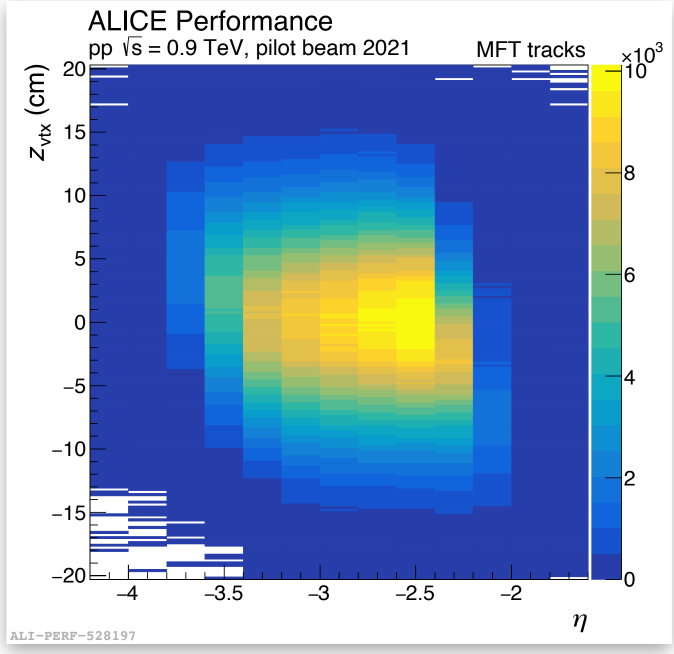
# TRACK-TO-PARTICLE CORRECTION

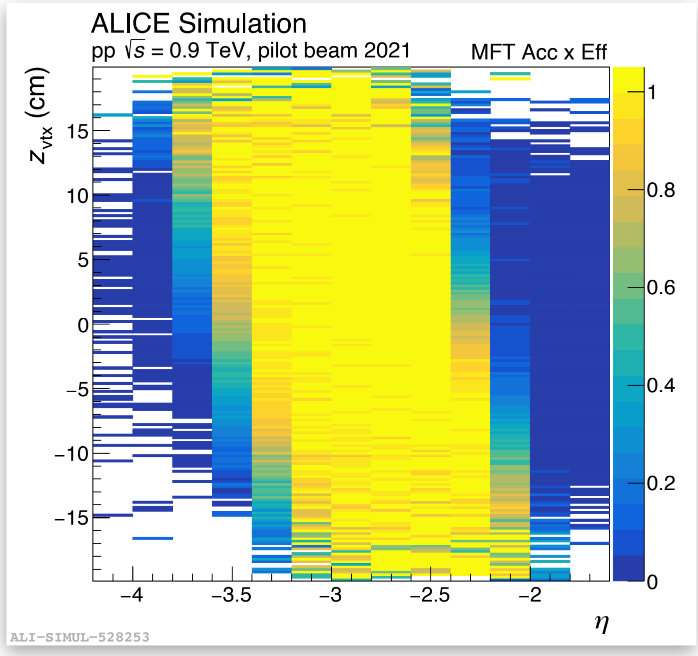





- Acceptance x Efficiency of the MFT
- Profile used for **track-to-particle** correction

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



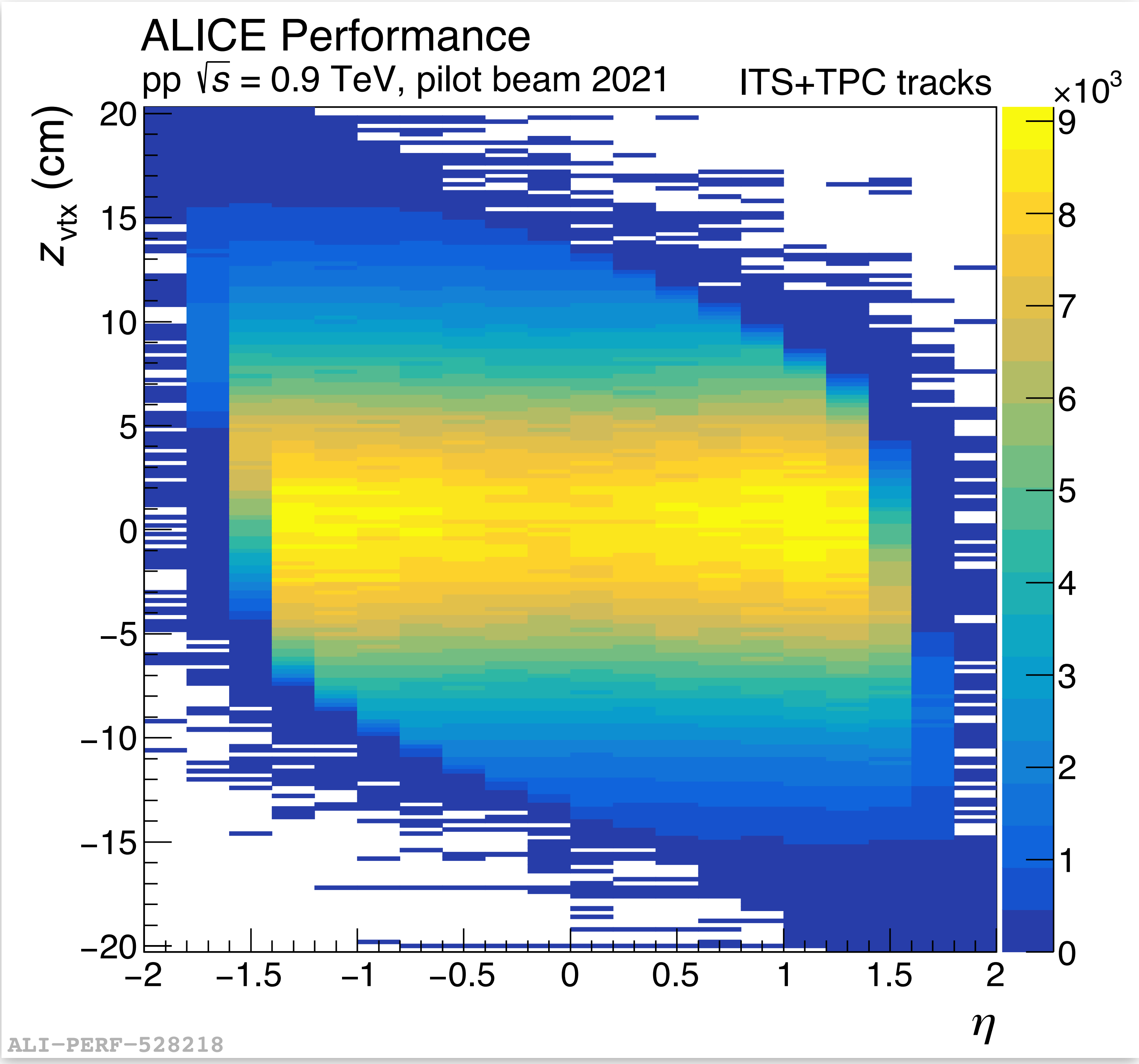



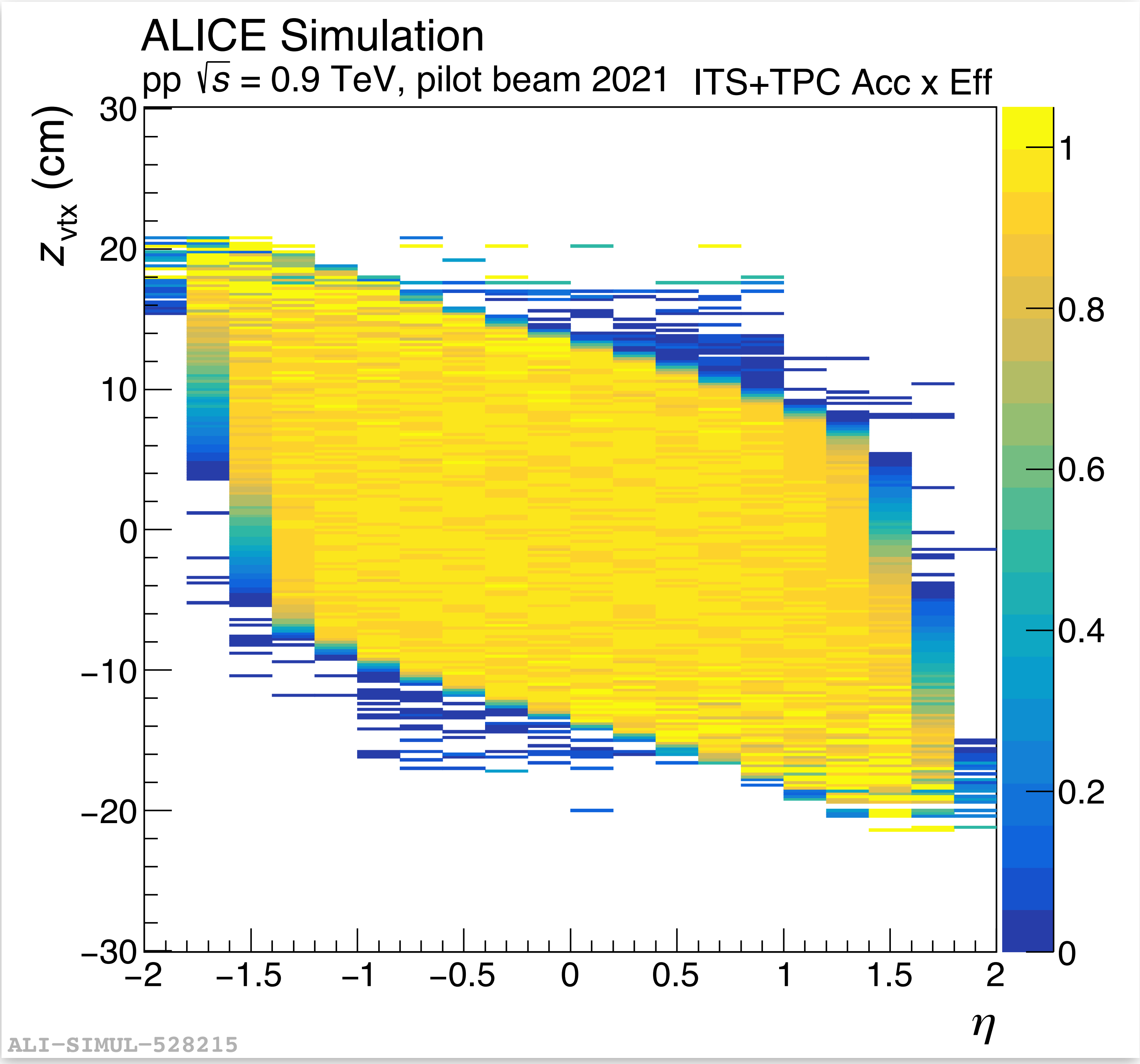

$$= \frac{N^{meas}}{N^{rec}} \times N^{gen}$$

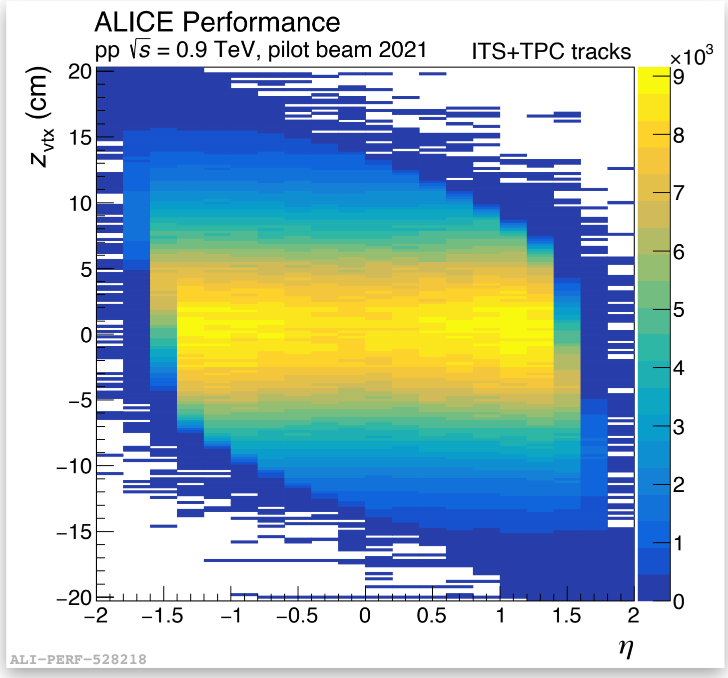
- Very high MFT Acc x Eff versus ($z_{vtx}$, $\eta$) in simulations
  - In the central $z_{vtx}$, $\eta$ region, AxE > 90%

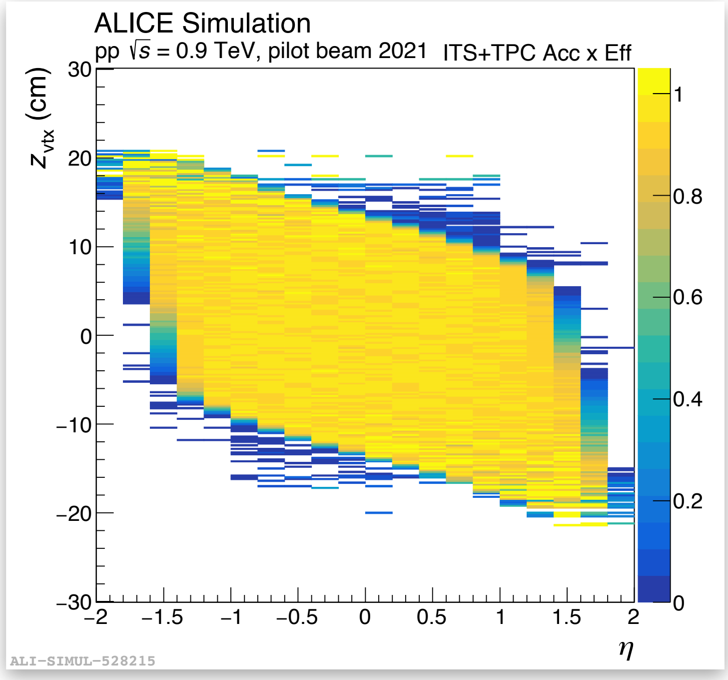
# PERFORMANCE PLOTS FOR THE CENTRAL TRACKS






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

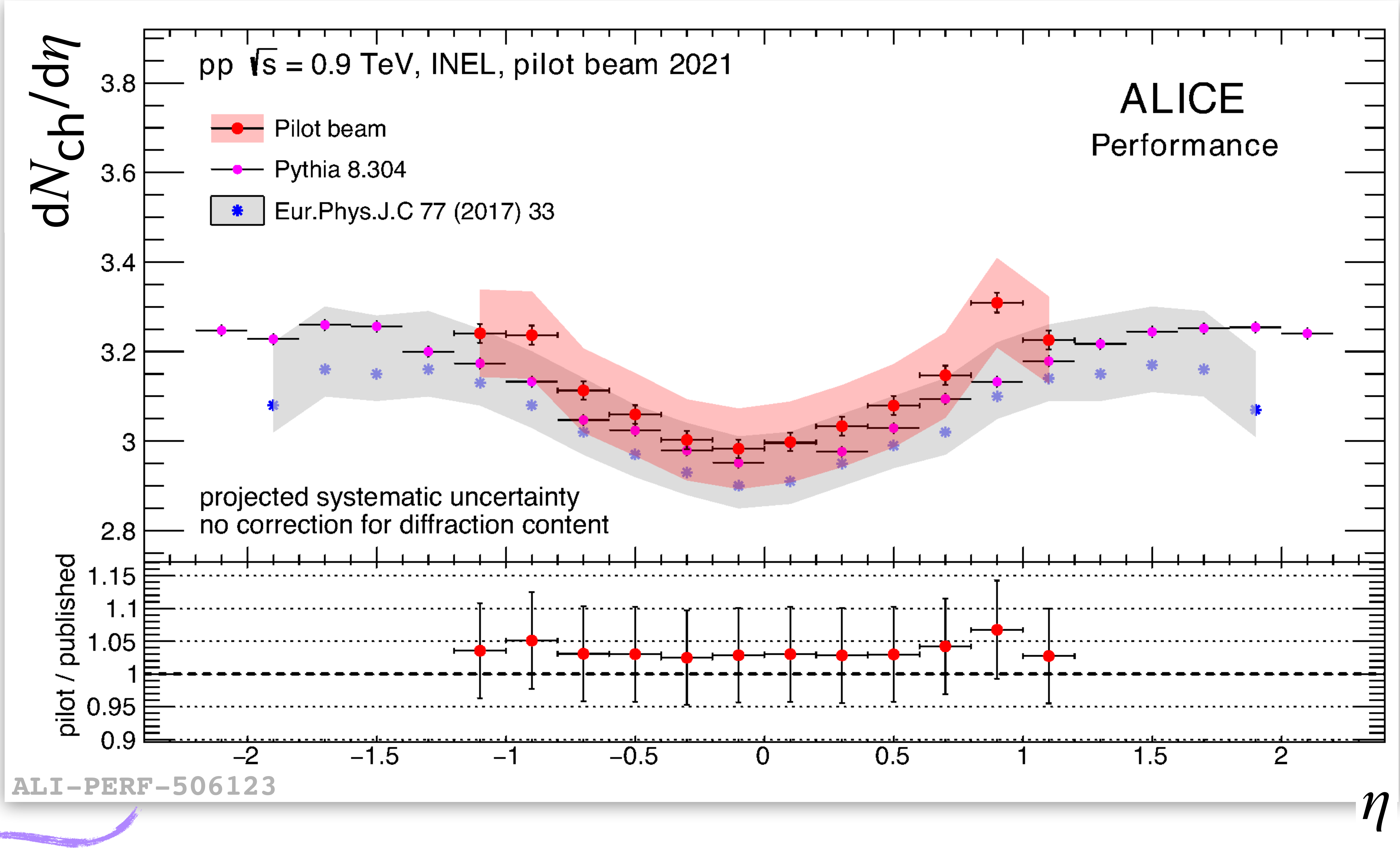
Very high Acc x Eff in the central region: good detector performance

# 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 ones 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

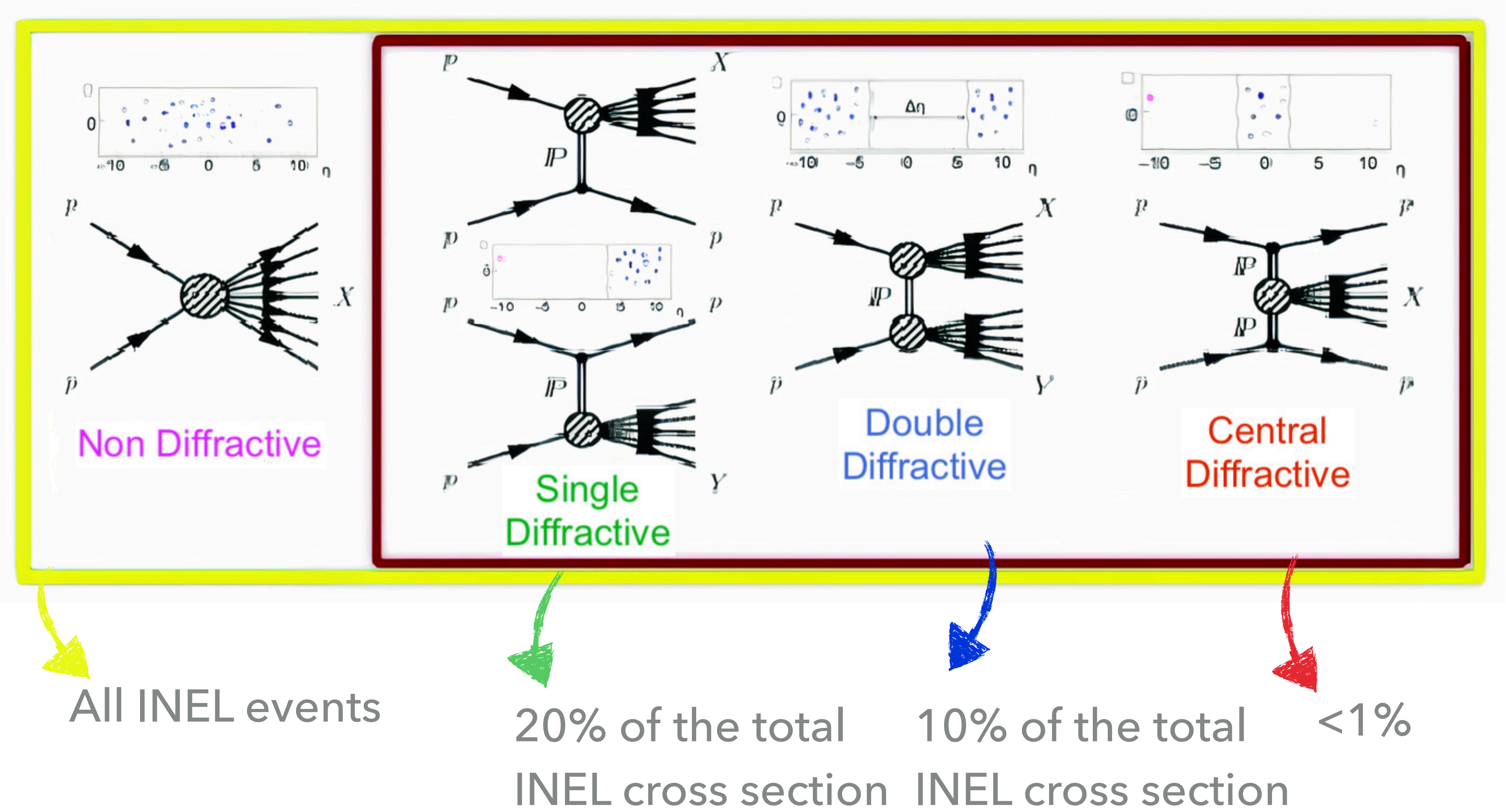
Study made by Anton Alkin



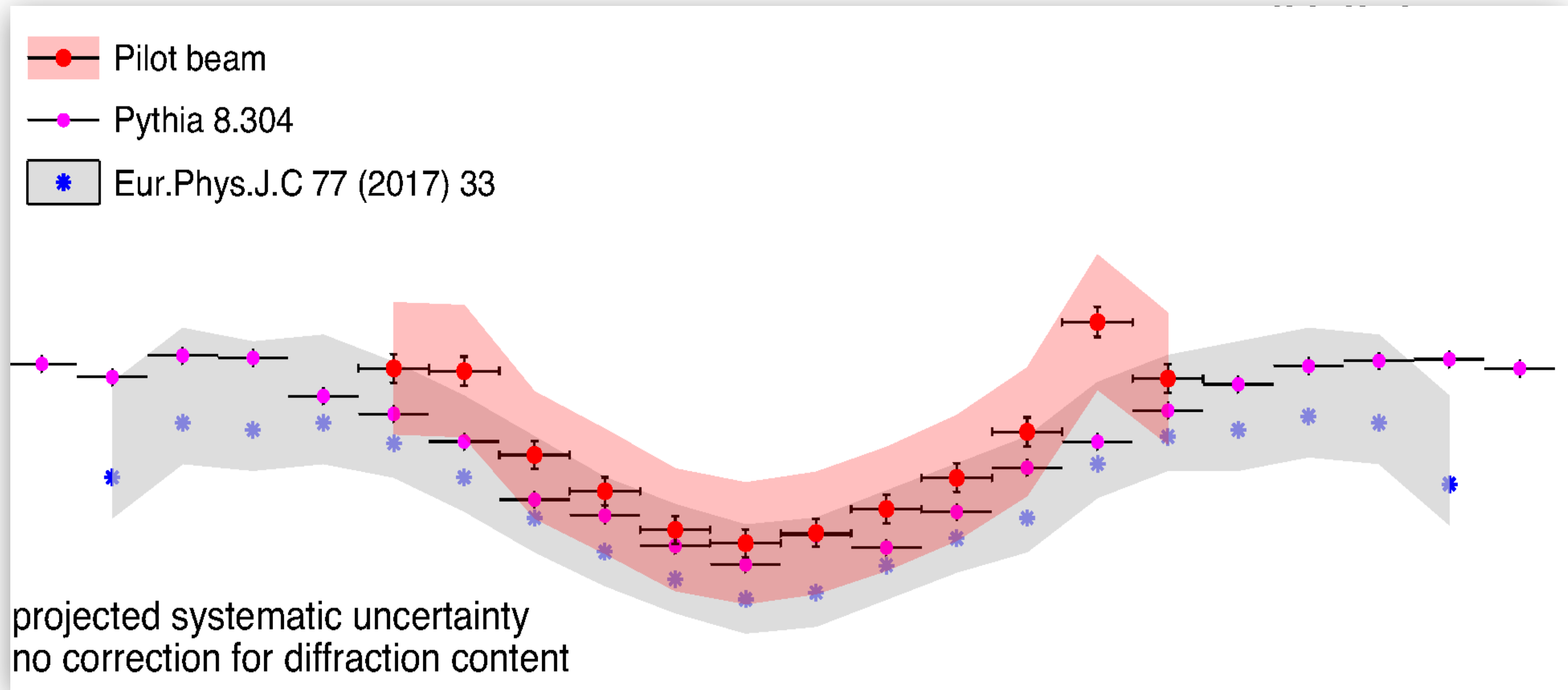

Expected MFT results

# 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 they produce no tracks in the midrapidity region
  - Not enough events seen in data + Not enough events generated by PYTHIA + Not enough events reconstructed in simulation




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



# UNCERTAINTY SOURCES

- Uncertainty sources:
  - Uncertainty of the diffraction tuning
  - Model dependence
  - Extrapolation to $p_T = 0$ (the distribution of tracks is unknown at low $p_T$)
  - 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 : $4 - 15\ \mu s$
  - At an interaction rate of 500 kHz it means 1 collision every 2 $\mu s$
  - Each MFT track would then be compatible in time with $2 - 7.5$ collisions in average
- More ambiguous tracks with higher IR
- Can quickly become an issue

IR = Interaction Rate

# SUMMARY AND OUTLOOK



- MFT is fully functional, producing promising performance plots: ready for physics results
- Midrapidity results compatible with previously published ones
    - Validation of new ITS data

- Future developments:
    - Evaluate uncertainty contributions
    - Reduce the track ambiguity for higher IR productions
    - Finalize the tuning of MC simulation including diffraction
    - Reduce systematic uncertainty

IR = Interaction Rate

# Thank you for your attention

# SOURCES




- ALICE definition of primary particles https://cds.cern.ch/record/2270008/files/cds.pdf
- Wolschin G. Aspects of Relativistic Heavy-Ion Collisions. *Universe*. 2020; 6(5):61. https://doi.org/10.3390/universe6050061
- *Measurement of the Charged-Particle Multiplicity in Proton–Proton Collisions with the ALICE Detector*, Jean Fiete Grosse-Oetringhaus, 2009
- J. Adam et al. (ALICE), "Charged-particle multiplicities in proton–proton collisions at $\sqrt{s}$ = 0.9 to 8 TeV", Eur. Phys. J. C 77, 33 (2017) 10.1140/epjc/s10052-016-4571-1, arXiv:1509.07541 [nucl-ex].
- A. Alkin and B. Kim, Analysis note: "*Charged particle multiplicity and pseudorapidity densitymeasurements in pp collisions from $\sqrt{s}$ = 0.9 to 8 TeV*", using improved track counting algorithms, tech. rep. (ALICE-ANA-2015-2432, 2017).

# ABBREVIATIONS



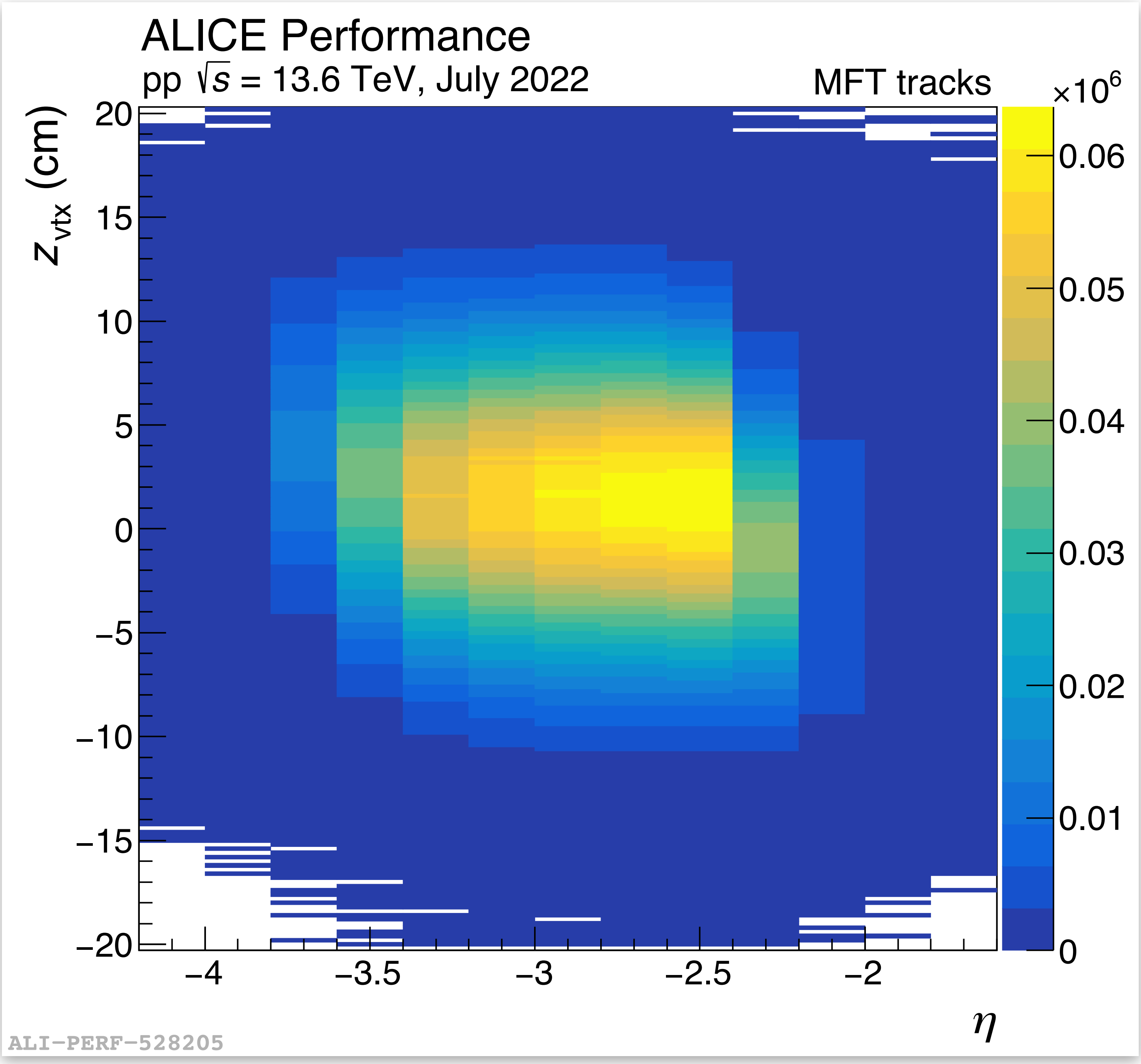
- QCD: Quantum Chromo Dynamics
- ALICE: A Large Ion Collider Experiment
- MFT: Muon Forward Tracker
- ITS: Inner Tracking System
- MC: Monte Carlo
- CMOS: Complementary Metal–Oxide–Semiconductor
- Acc x Eff, AxE: Acceptance x Efficiency
- IR: Interaction Rate
- TPC: Time Projection Chamber
- FIT: Fast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

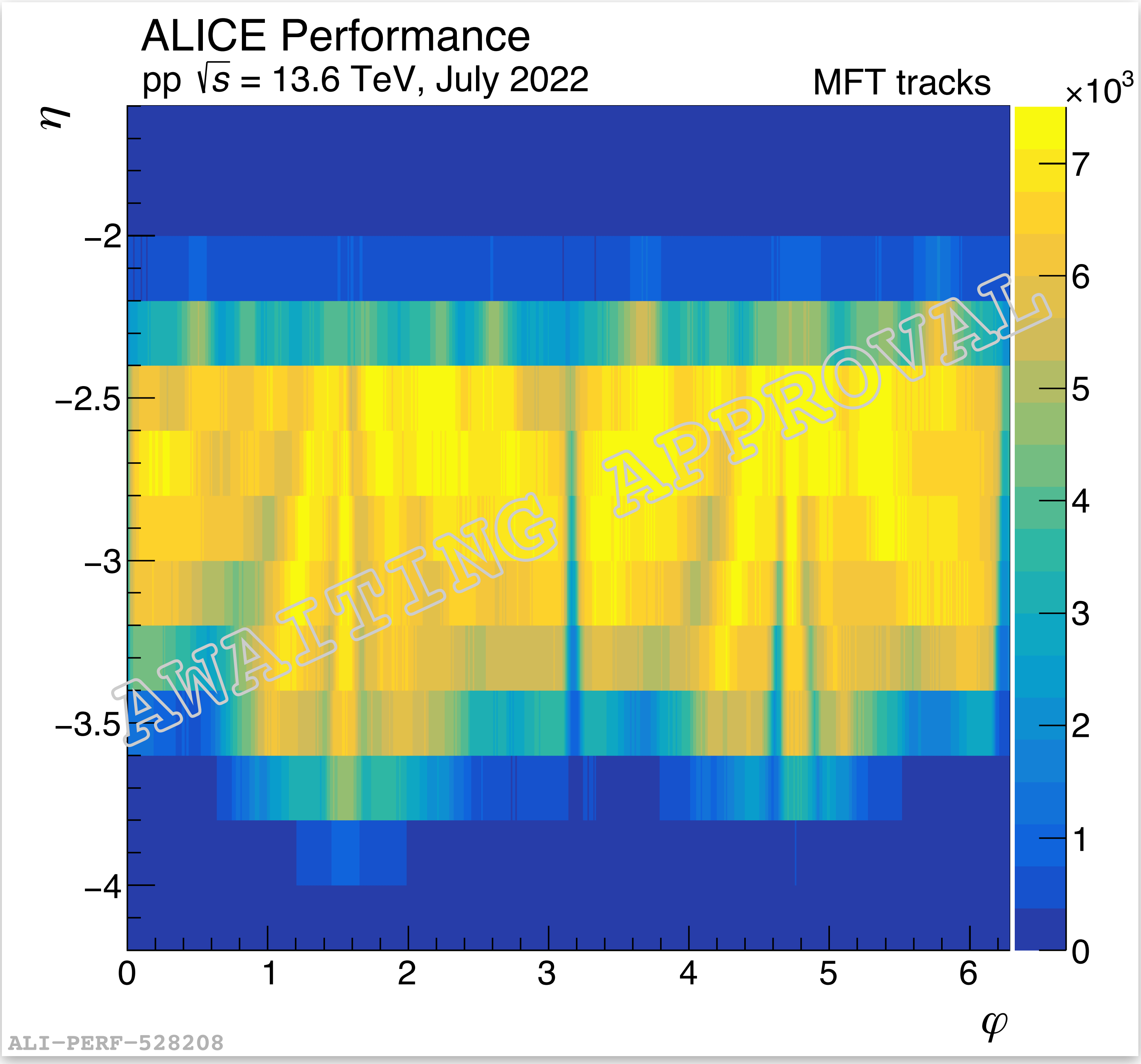
# BACKUP

# RUN 3 AT 13.6 TEV



- Conventional Run 3 data taking started in July 2022




- No MC simulation available with the same conditions: No correction profile available

# PLANS TO REDUCE THE TRACK AMBIGUITY

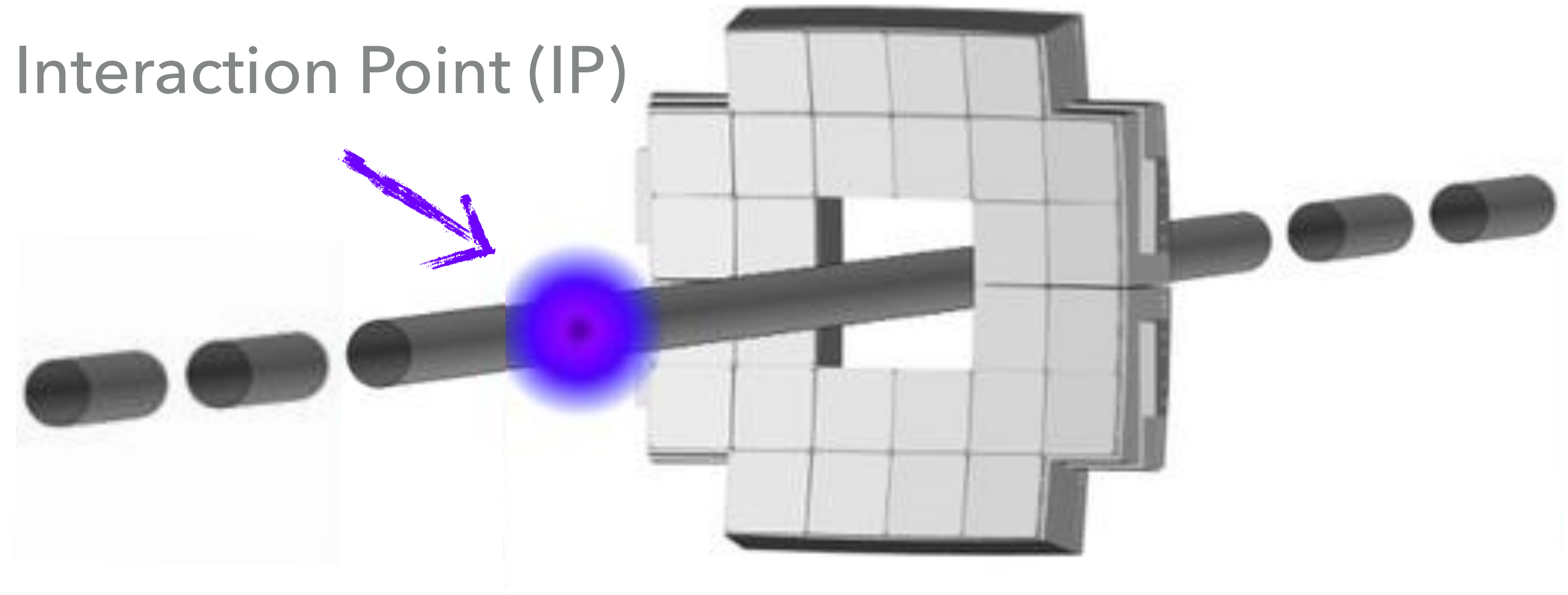


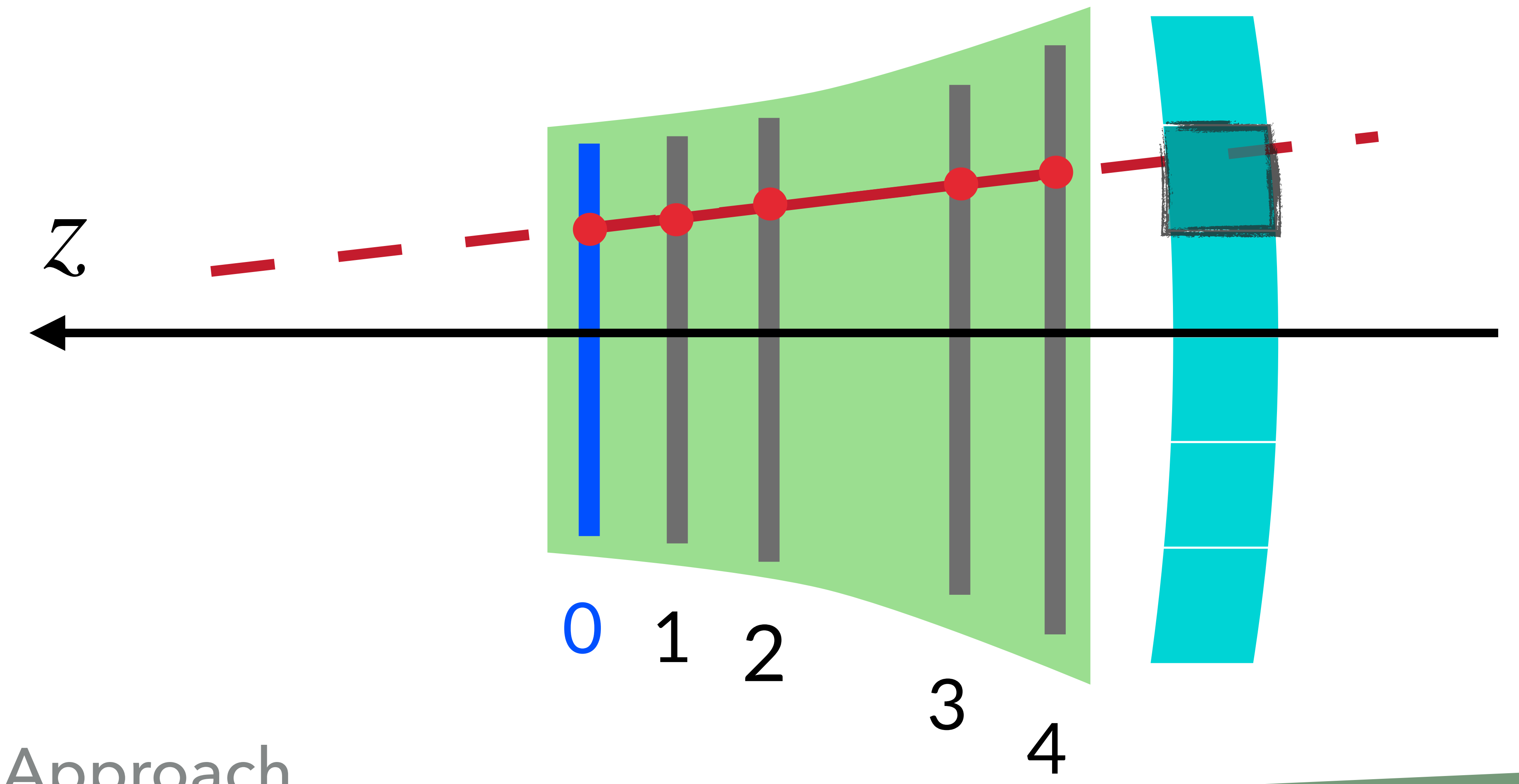
- Match the track with the *best collision* by computing the transverse DCA
- Matching with FIT (Fast Interaction Trigger)
  - Precision of FT0-C: 25ns
  - FT0-C : 28 modules (very poor spatial resolution)

**FT0-C Cherenkov detector**

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

-0.8 m away from IP




* DCA = Distance of Closest Approach

# FULL FIT DETECTOR