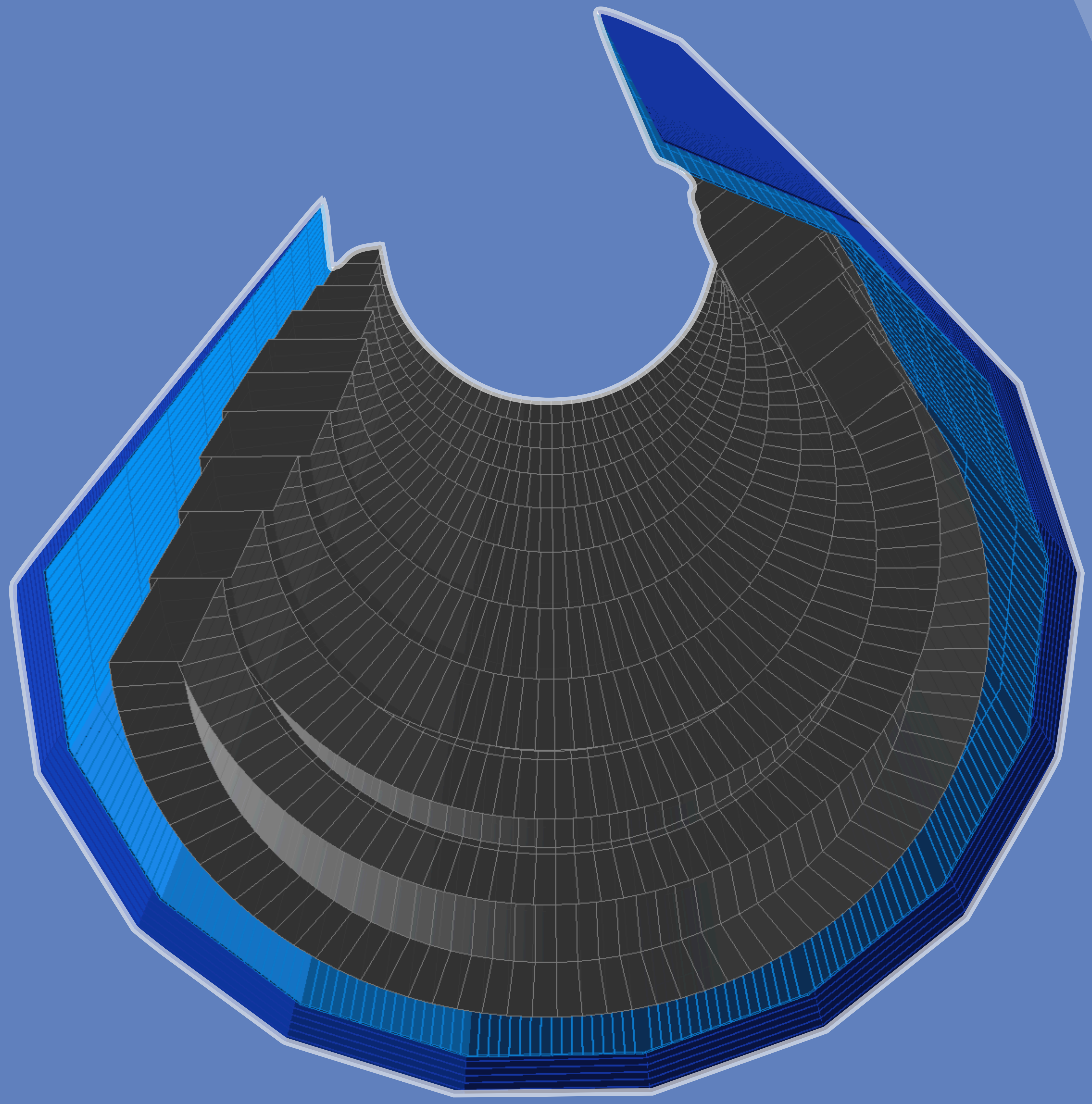


MID: a muon detector for the ALICE 3 upgrade project

Jesús Eduardo Muñoz Méndez
for the ALICE collaboration

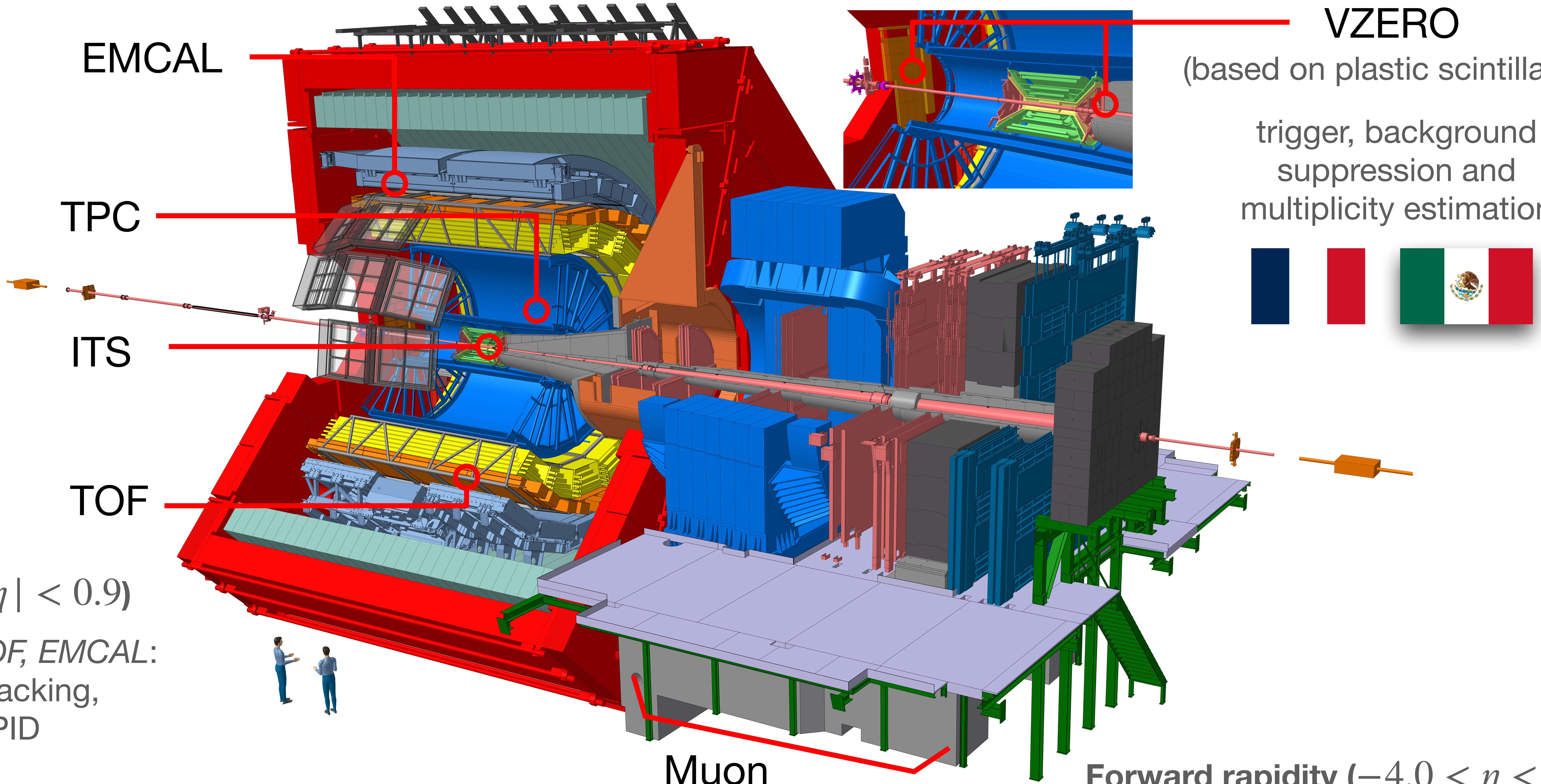
XV Latin American Symposium on High Energy Physics

4 November, 2024

Instituto de Ciencias Nucleares UNAM

ALICE

ALICE in Run 2



Midrapidity ($|\eta| < 0.9$)

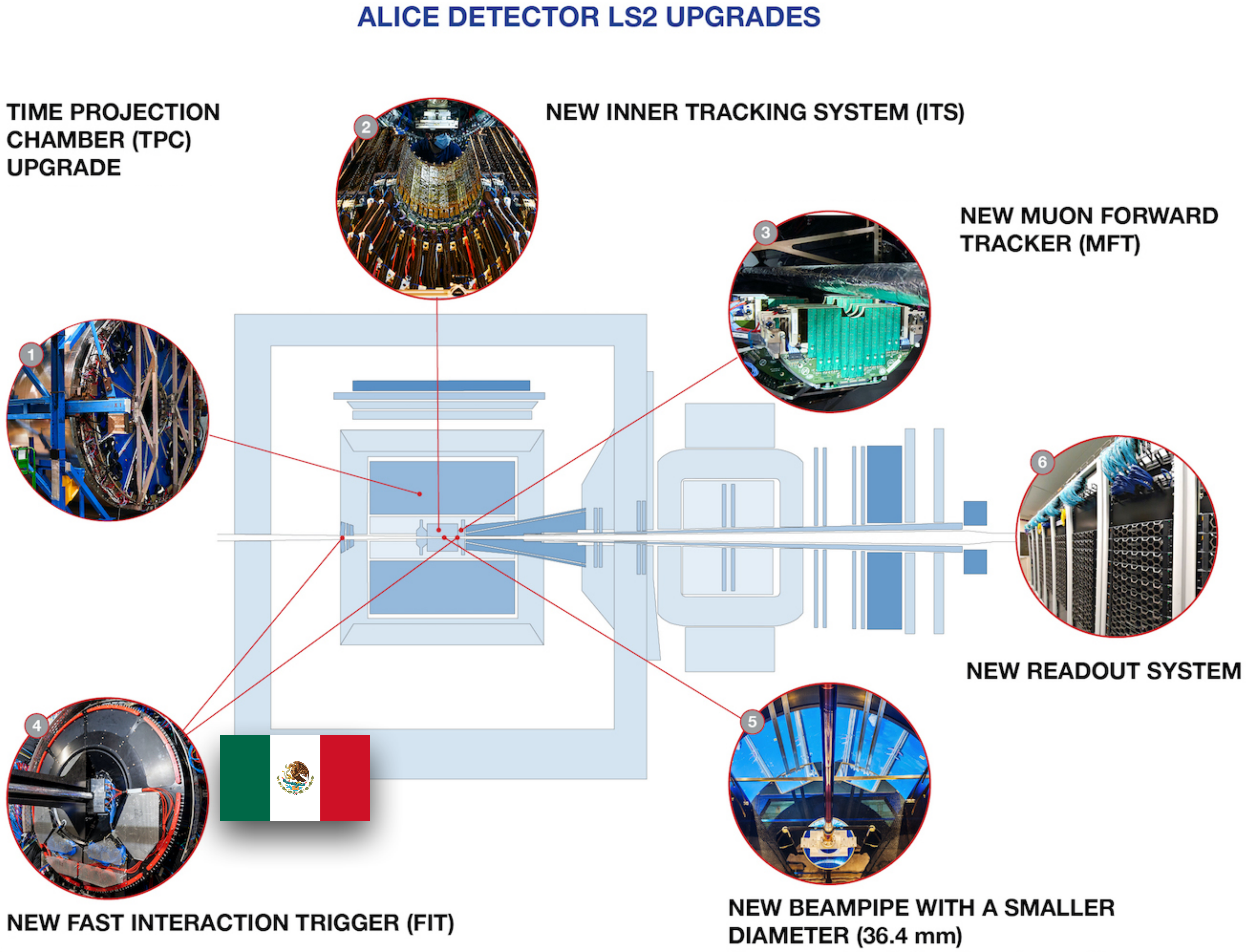
- *ITS, TPC, TOF, EMCAL*: Vertexing, Tracking, Multiplicity, PID

Forward rapidity ($-4.0 < \eta < -2.5$)

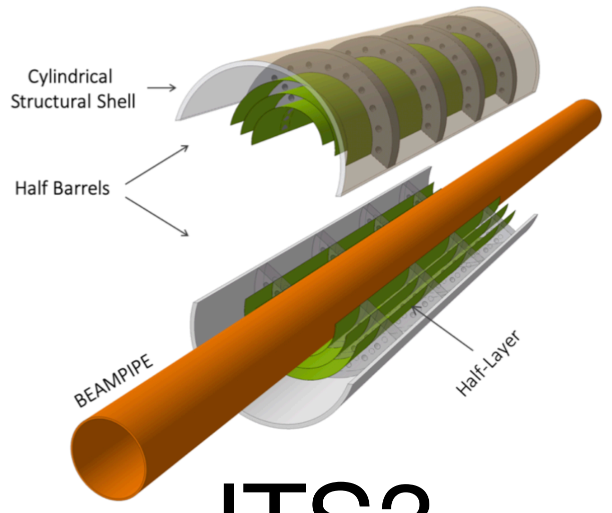
- $J/\psi \rightarrow \mu^+\mu^-$

ALICE in Run 3 and 4

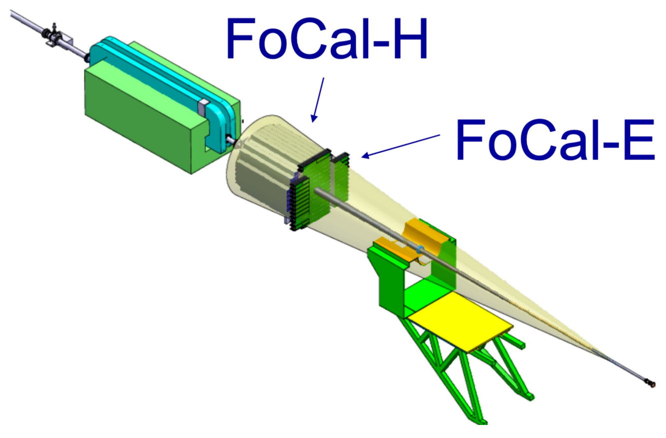
ALICE in current Run 3:



Upcoming upgrades for Run 4:



ITS3



FoCal

Several upgrades to the experiment have been done, and some are on the way..

Among the expected measurements during Runs 3 and 4 we have

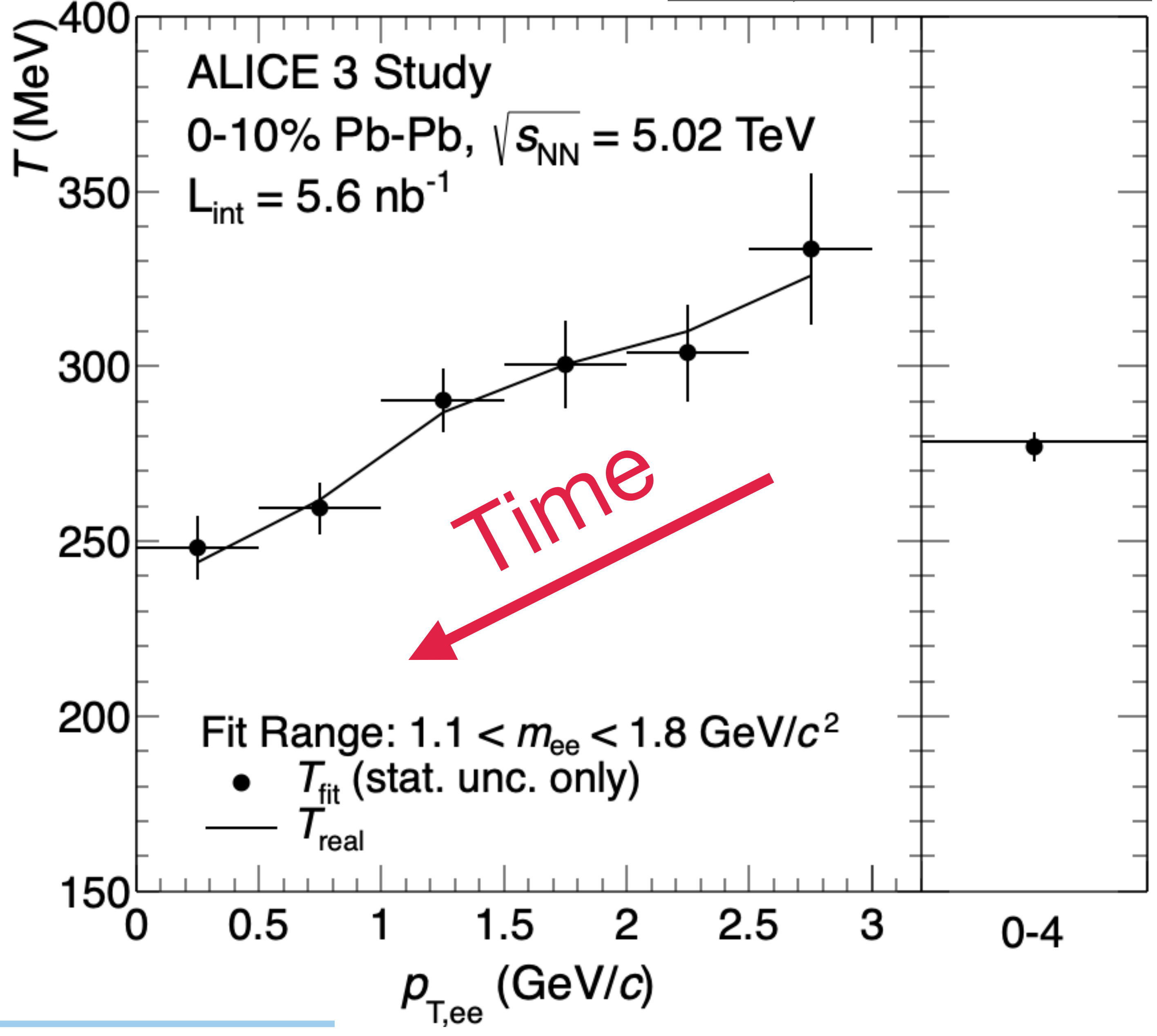
- Medium effects on single heavy-flavour hadrons
- Time averaged thermal QGP radiation
- Collective effects from small to large systems

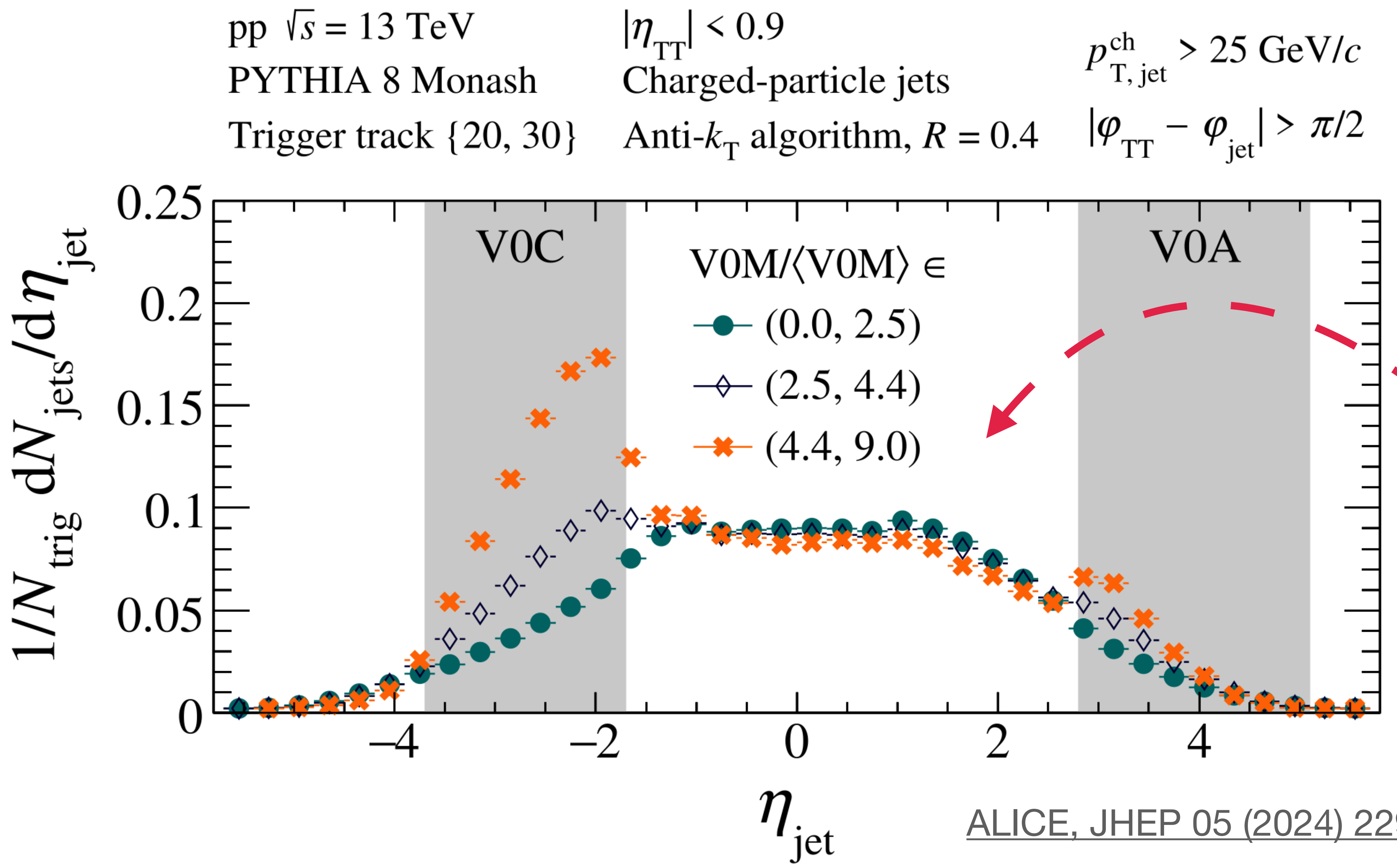
Nonetheless, some fundamental questions will still remain open…

Open questions after Run 4

- **More detailed evolution of the QGP through termal radiation**
- **Origin of QGP-like effects in small systems**
- **Formation and interaction of exotic hadronic states**
- **Transport and hadronization of heavy flavor hadrons in the medium:** azimuthal distributions, n-parton scattering dynamics, multi-charm baryons (Ξ_{cc}^{++} and Ω_{cc}^{+}), **suppression and recombination of charm and beauty quarks**

ALICE, arXiv:2211.02491





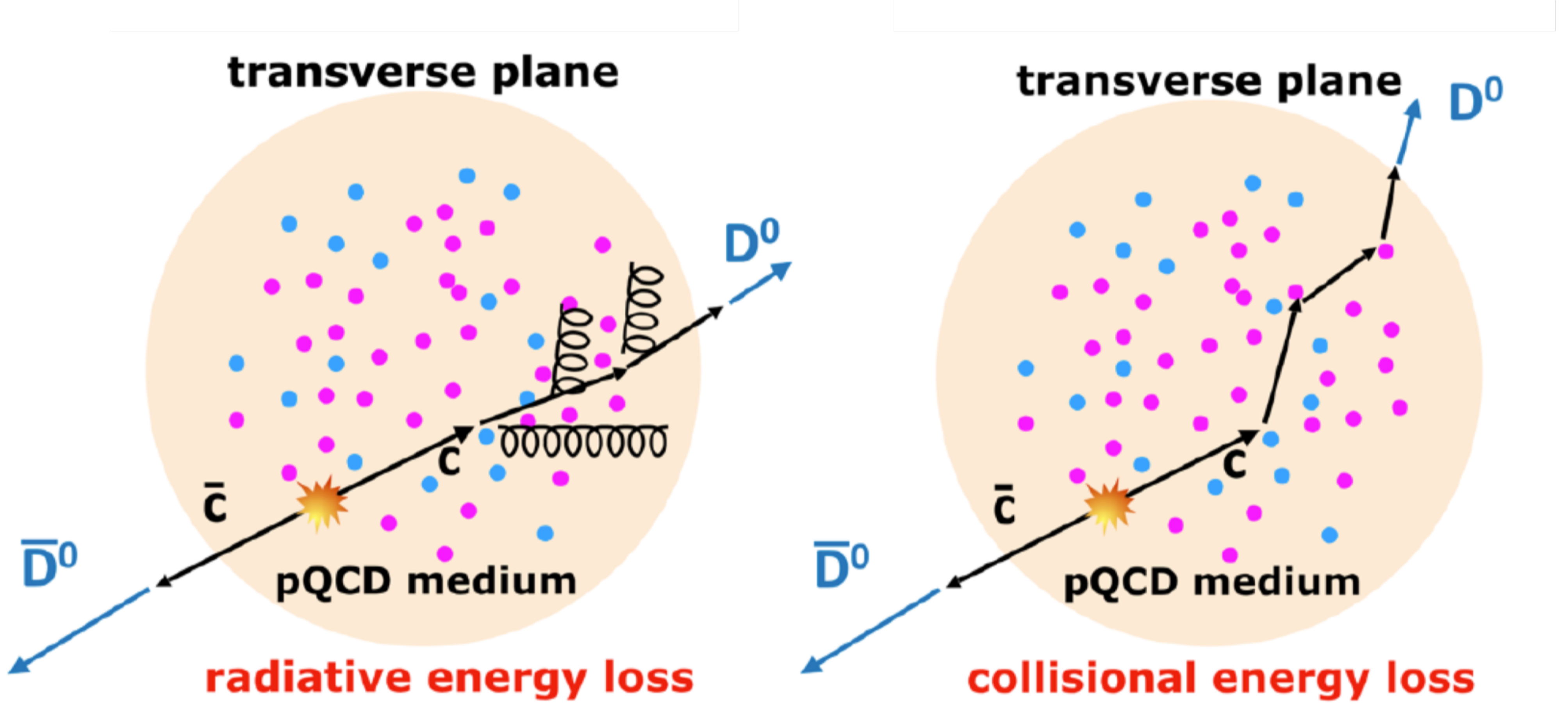
Bias toward local fluctuations

(see Paola Vargas talk: 8/11/24 12:15 h [QCD4])

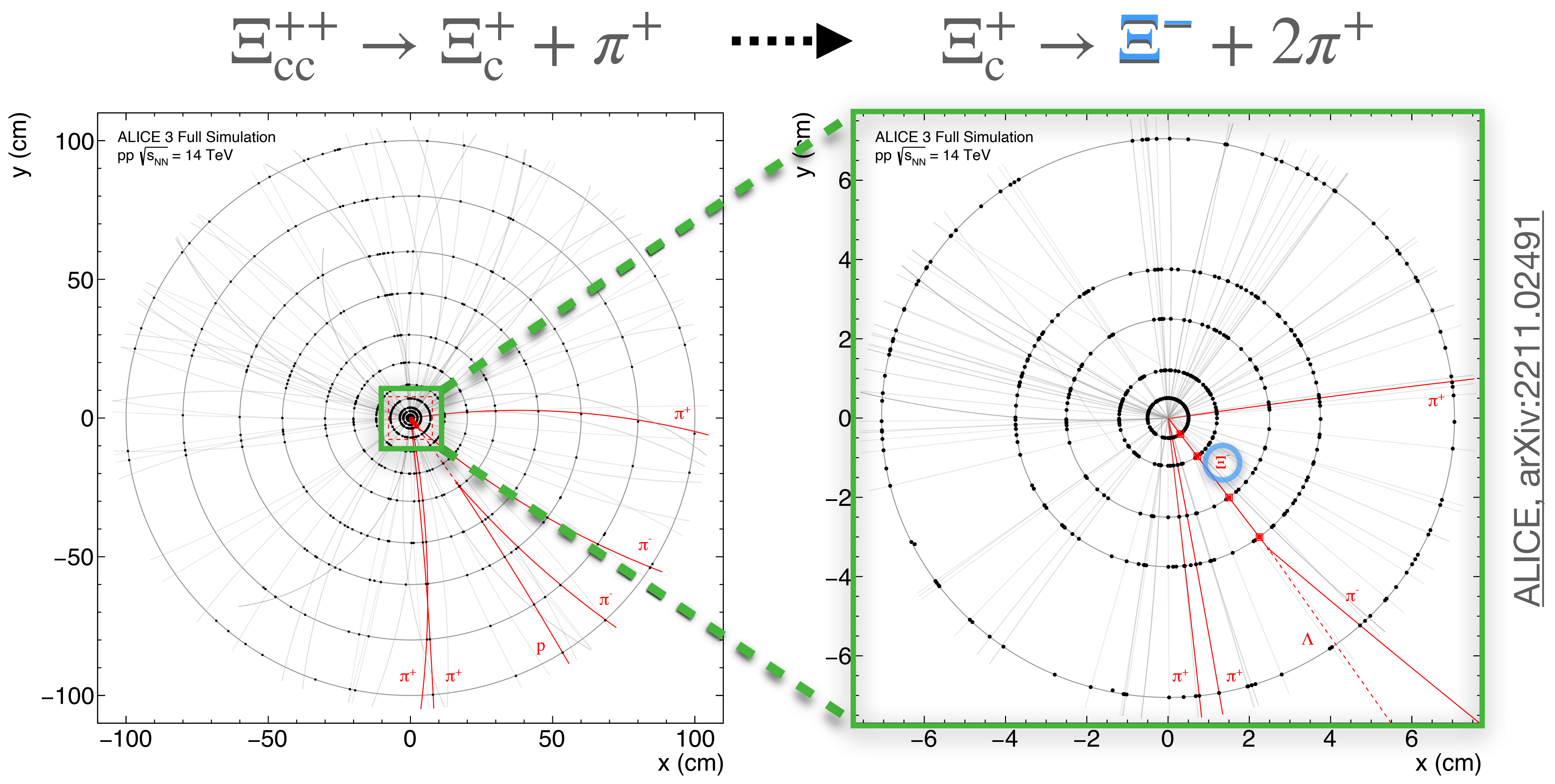
ALICE, JHEP 05 (2024) 229

Open questions after Run 4

- More detailed evolution of the QGP through termal radiation
- Origin of QGP-like effects in small systems
- **Formation and interaction of exotic hadronic states**
- **Transport and hadronization of heavy flavor hadrons in the medium:** azimuthal distributions, multi-charm baryons (Ξ_{cc}^{++} and Ω_{cc}^{+}), n-parton scattering dynamics, suppression and recombination of charm and beauty quarks



Higher purity and signal efficiency with a bigger acceptance is needed



Outstanding tracking resolution is required

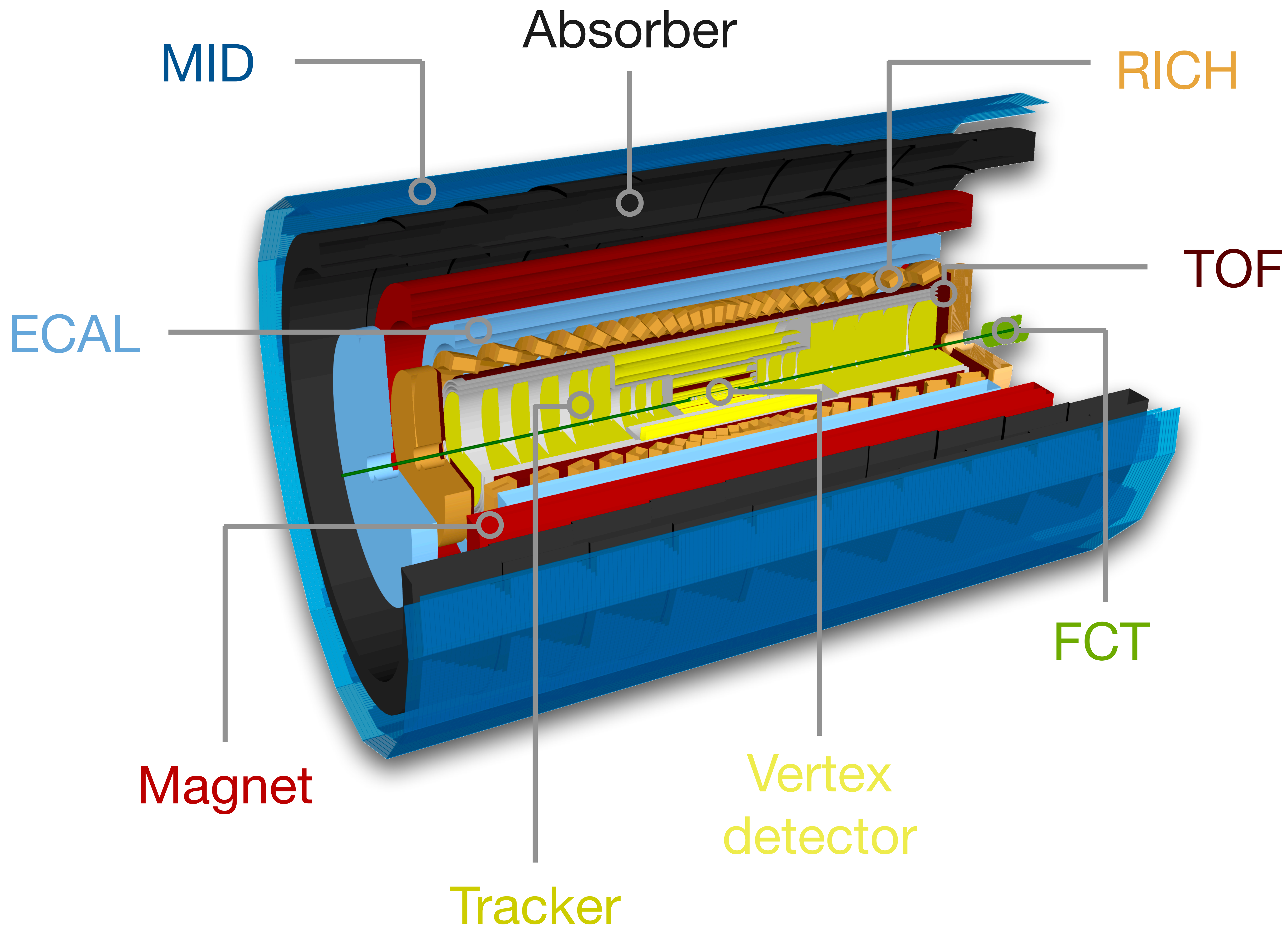
ALICE 3 : a next-generation heavy-ion experiment

ALICE, arXiv:2211.02491

To address these open questions, the ALICE collaboration has proposed an upgrade to the experiment with…

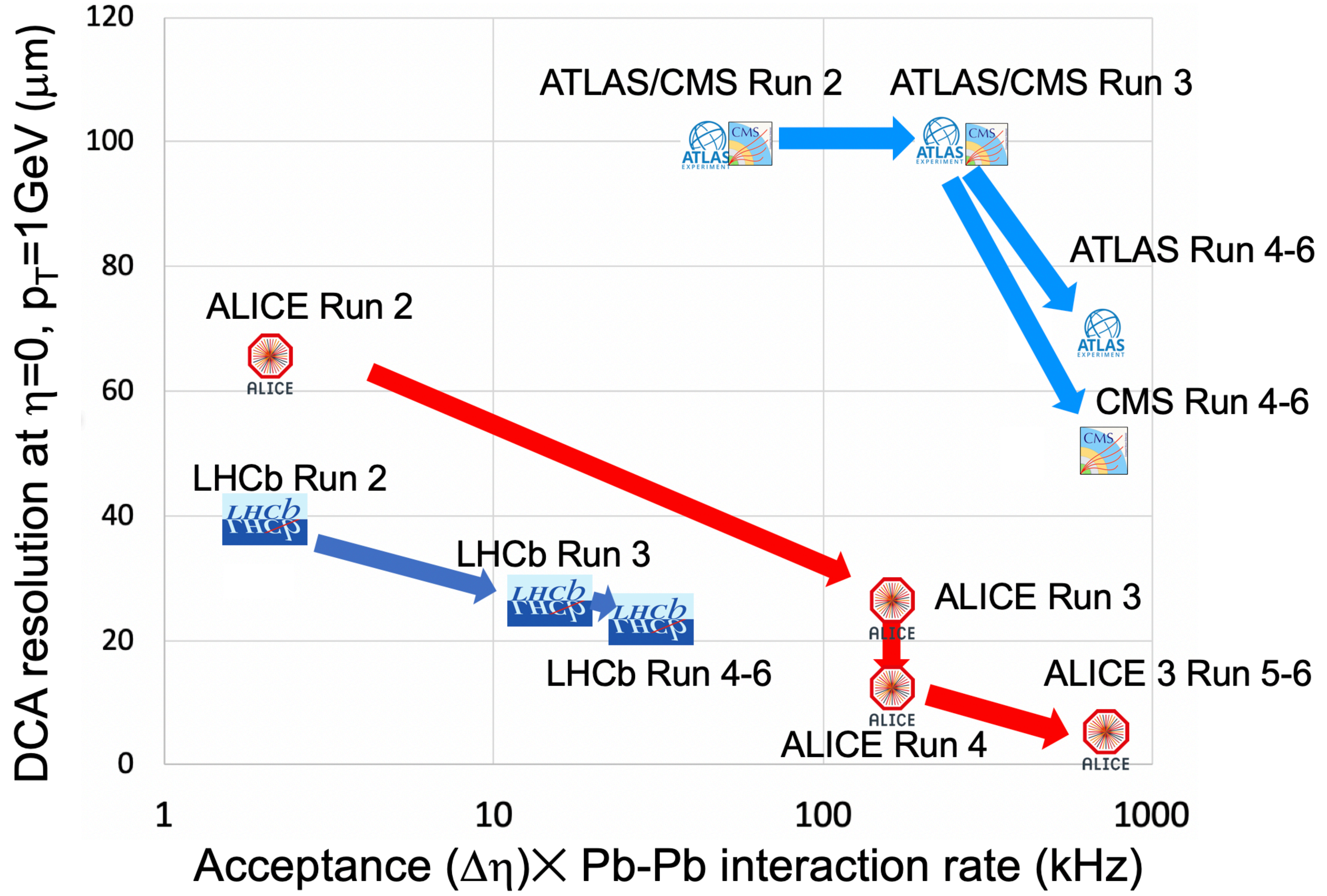
- excellent resolution
- tracking and PID over a greater acceptance: $|\eta| < 4$
- higher interaction and readout rate

ALICE 3



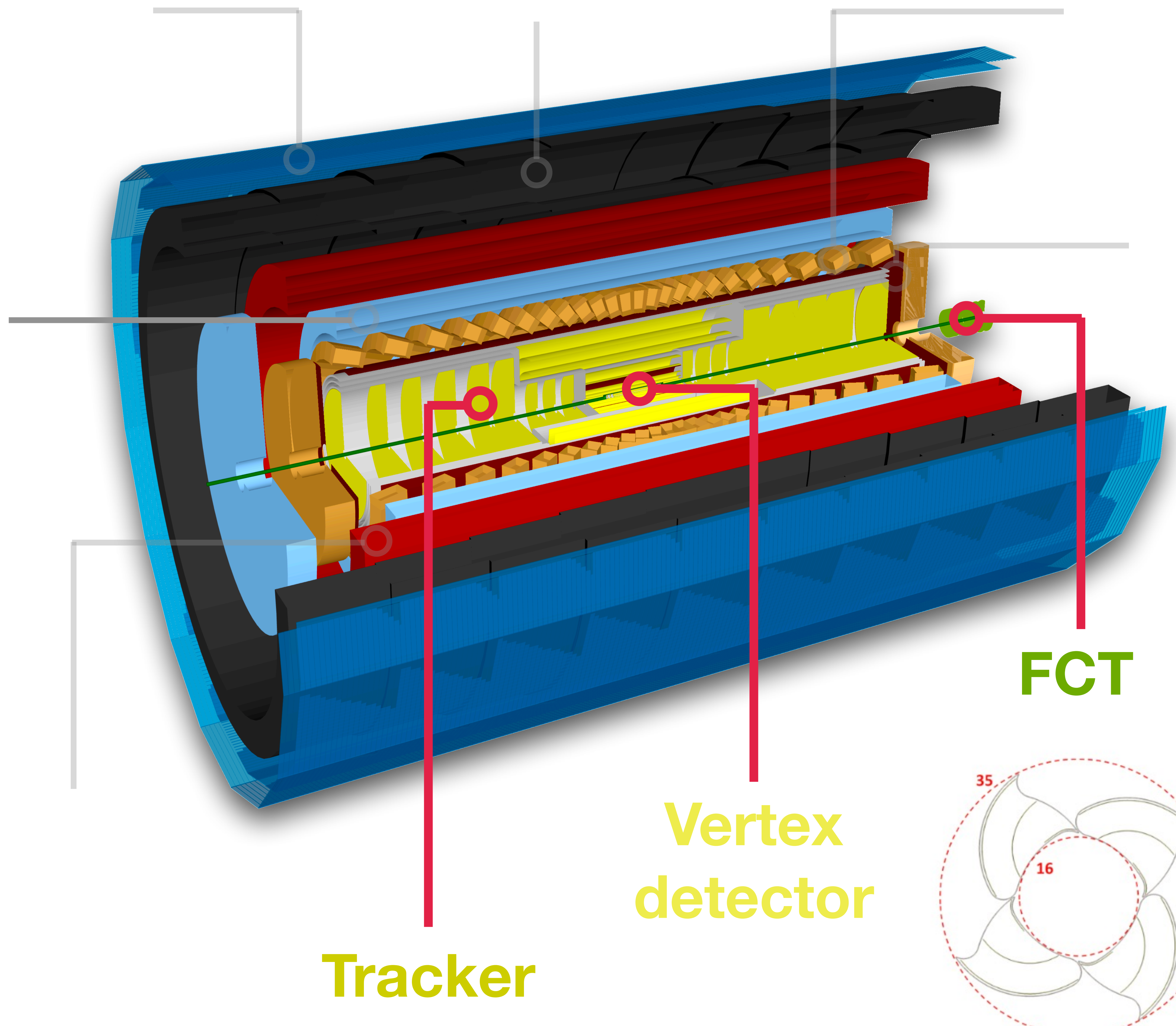
ALICE 3 features:

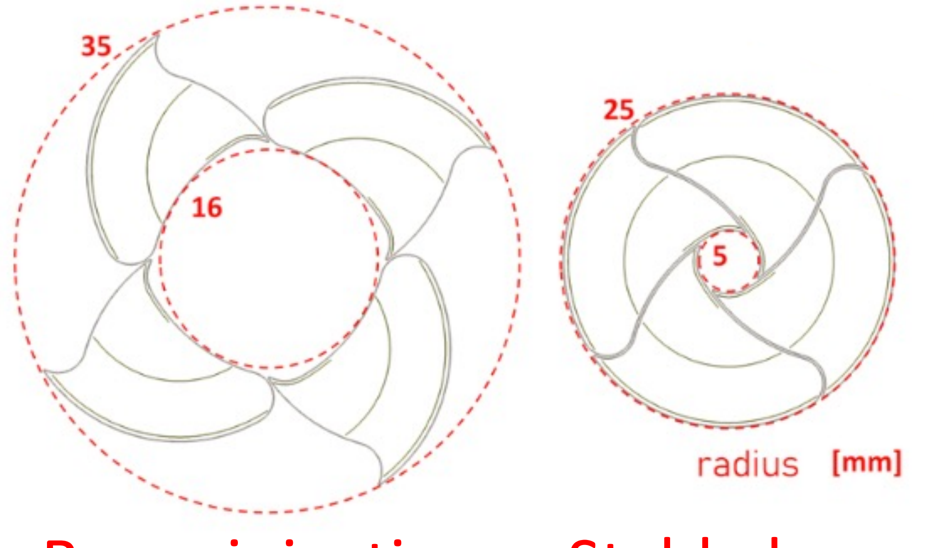
Overall, ALICE 3 will bring unique and unprecedented features to LHC, combining an excellent tracking and interaction rate



*For LHCb, $\eta = 3.5$

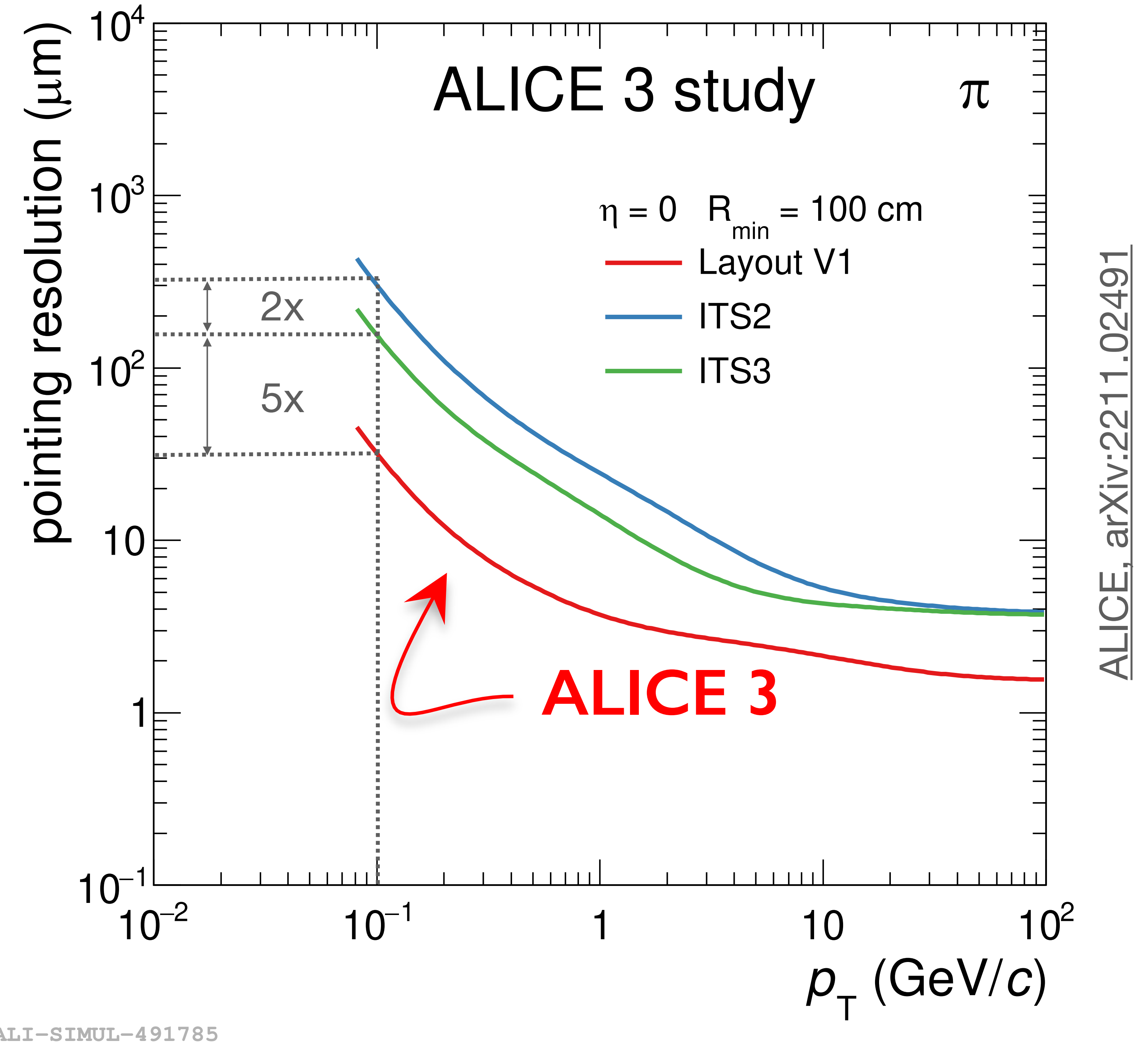
ALICE 3





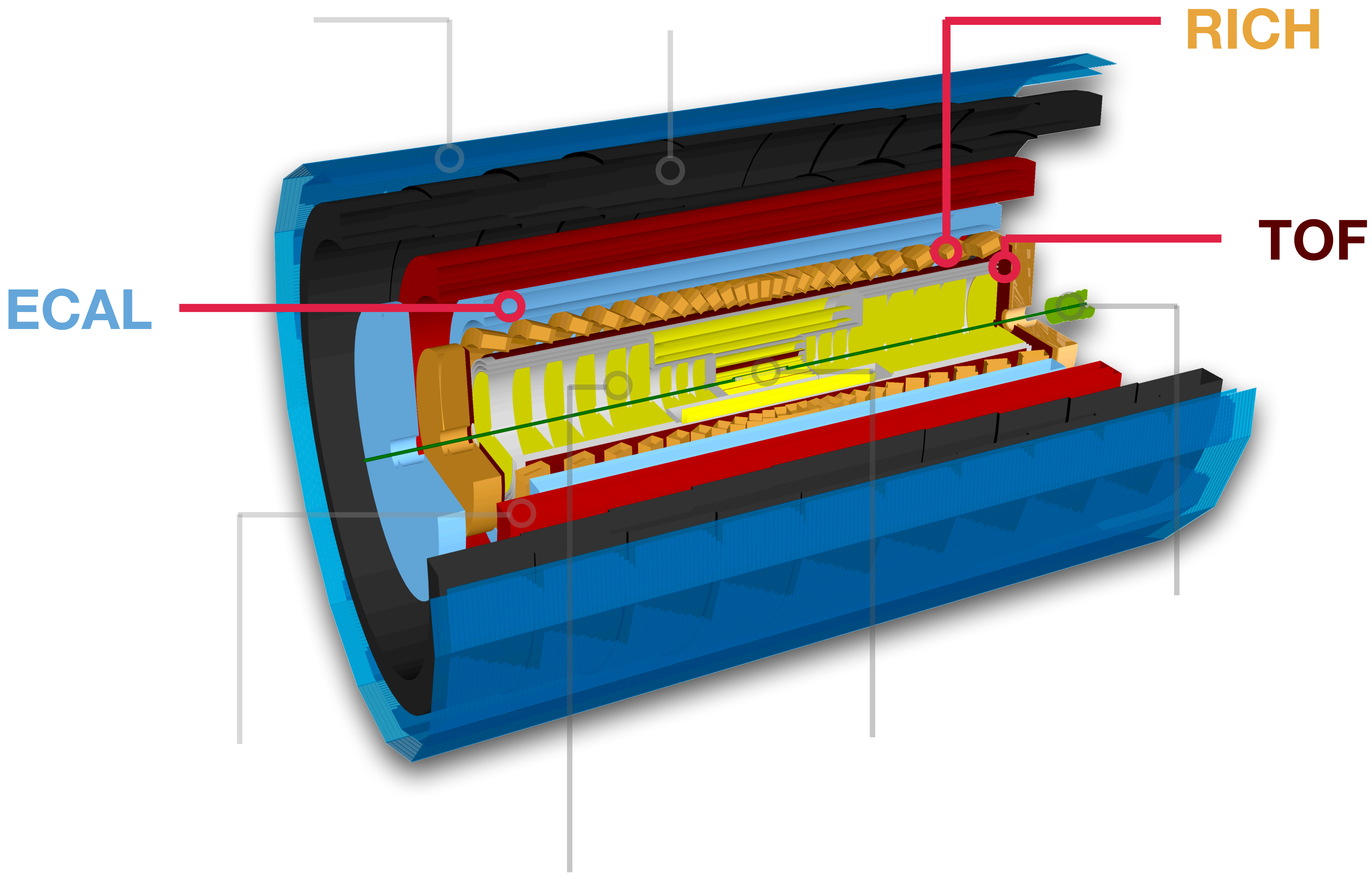
ALICE 3 features:

Silicon pixel tracker with a high resolution



and a retractable vertex detector that can close down to 5 mm

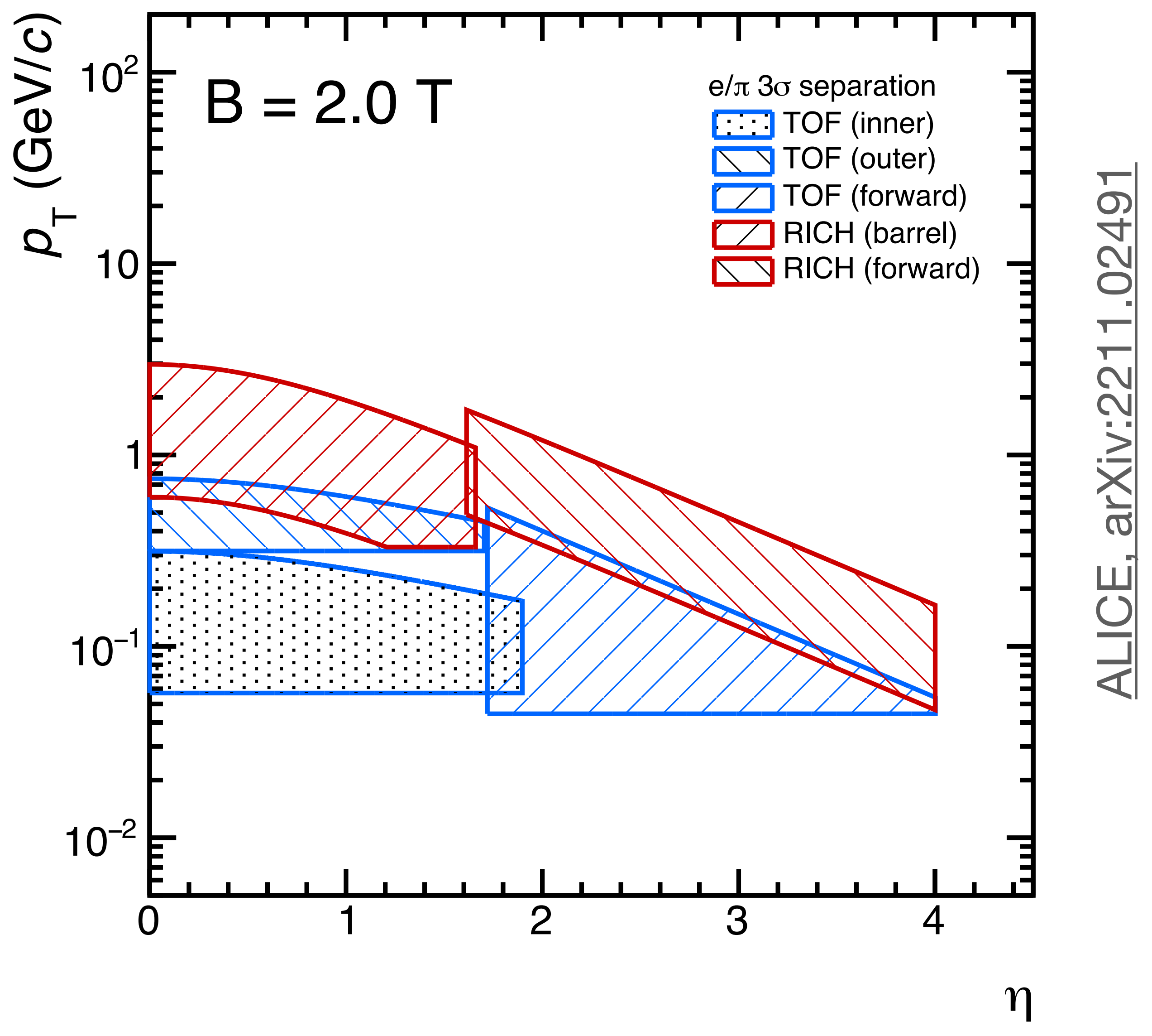
ALICE 3



ALICE 3 features:

$e/\pi/K/p$ and γ PID over large acceptance

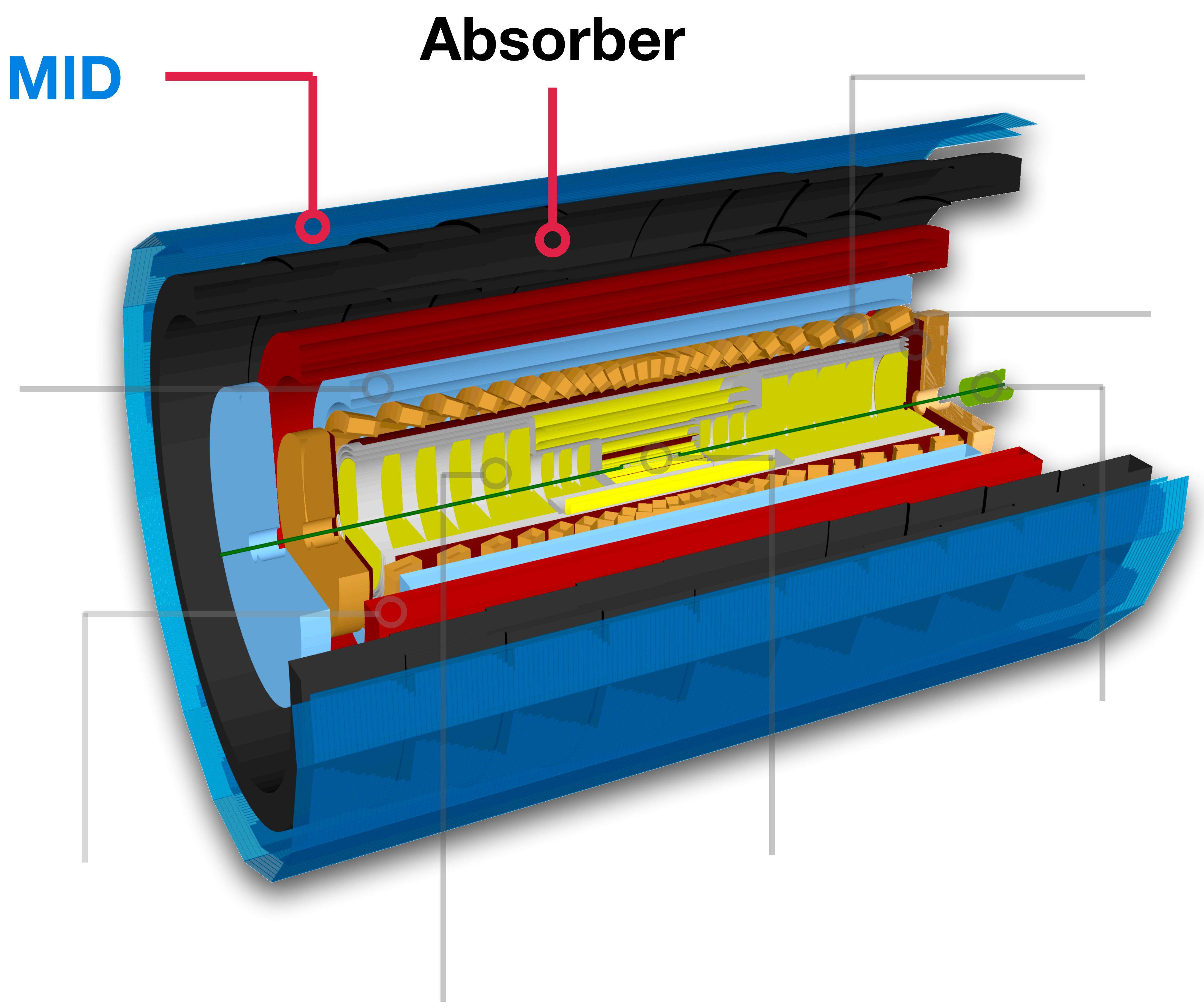
$$-4 < \eta < 4$$



ECAL: High-energy electrons and photon identification

- Barrel $\left(|\eta| < 1.5\right)$
- Endcap $\left(1.5 < \eta < 4\right)$

ALICE 3



ALICE 3 features:

Muon identification for charmonia and exotic hadrons

CMS and ATLAS:

μ identification down to $p_{\mathrm{T}} \approx 3 - 4$ GeV/c

ALICE 3:

optimized to identify μ down to $p_{\mathrm{T}} = 1.5$ GeV/c

vs

LHCb:

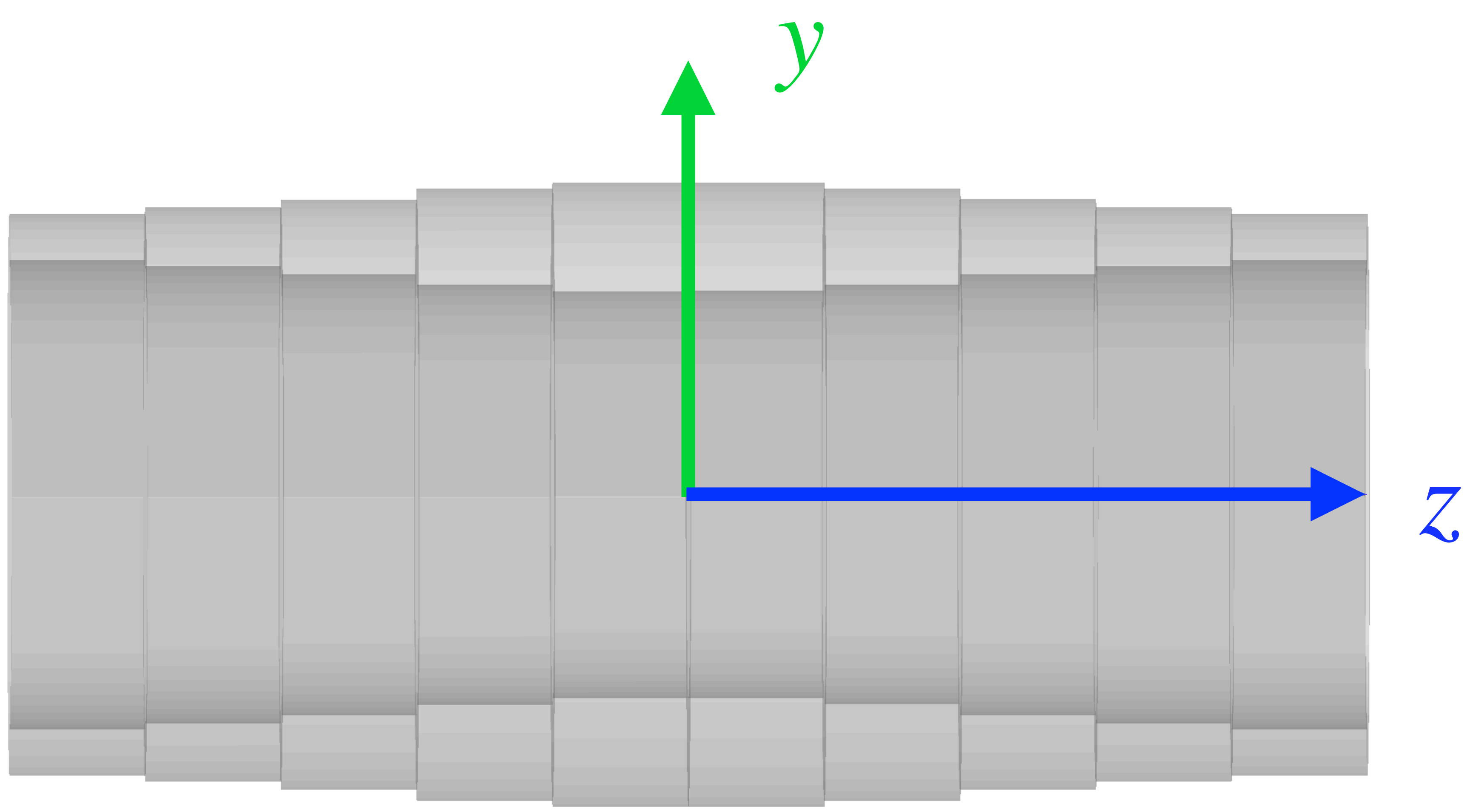
J/ψ at rest but only at forward rapidity

ALICE 3:

J/ψ at rest for a wider rapidity $|y| < 1.24$

ALICE 3 MID

The MID considers a magnetic iron ***absorber*** with varying thickness ⟹



~4 nuclear interaction lengths

- 10^{-2} hadron rejection factor
- Low charged particle fluence rate: ~4 Hz/cm^2
- Scattering within the absorber: ~5 cm for *p*=1.5 GeV/*c* (granularity of 5x5 cm^2 is enough for 1.5-5 GeV/*c*)

ALICE 3 MID

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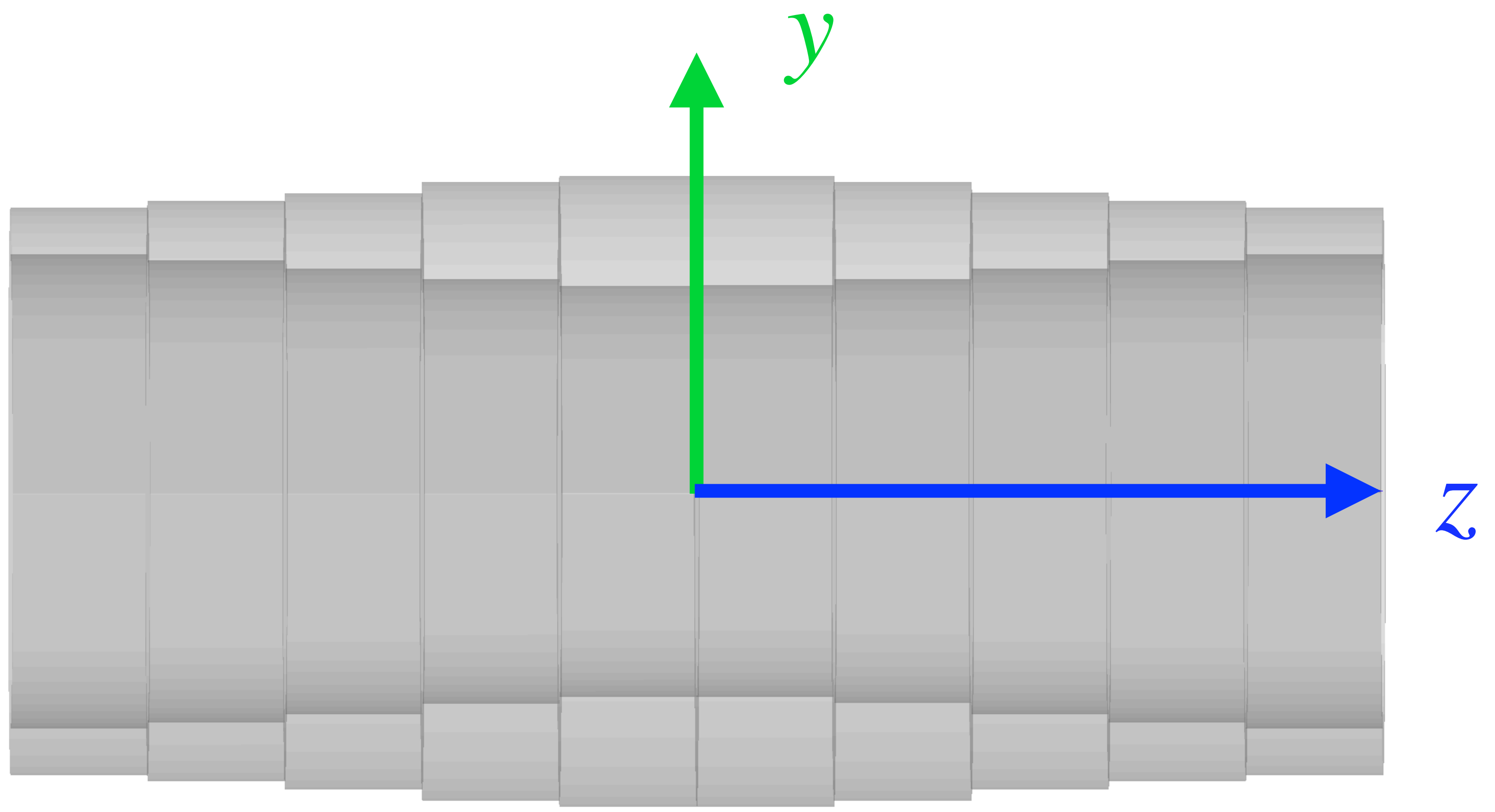

~4 nuclear interaction lengths

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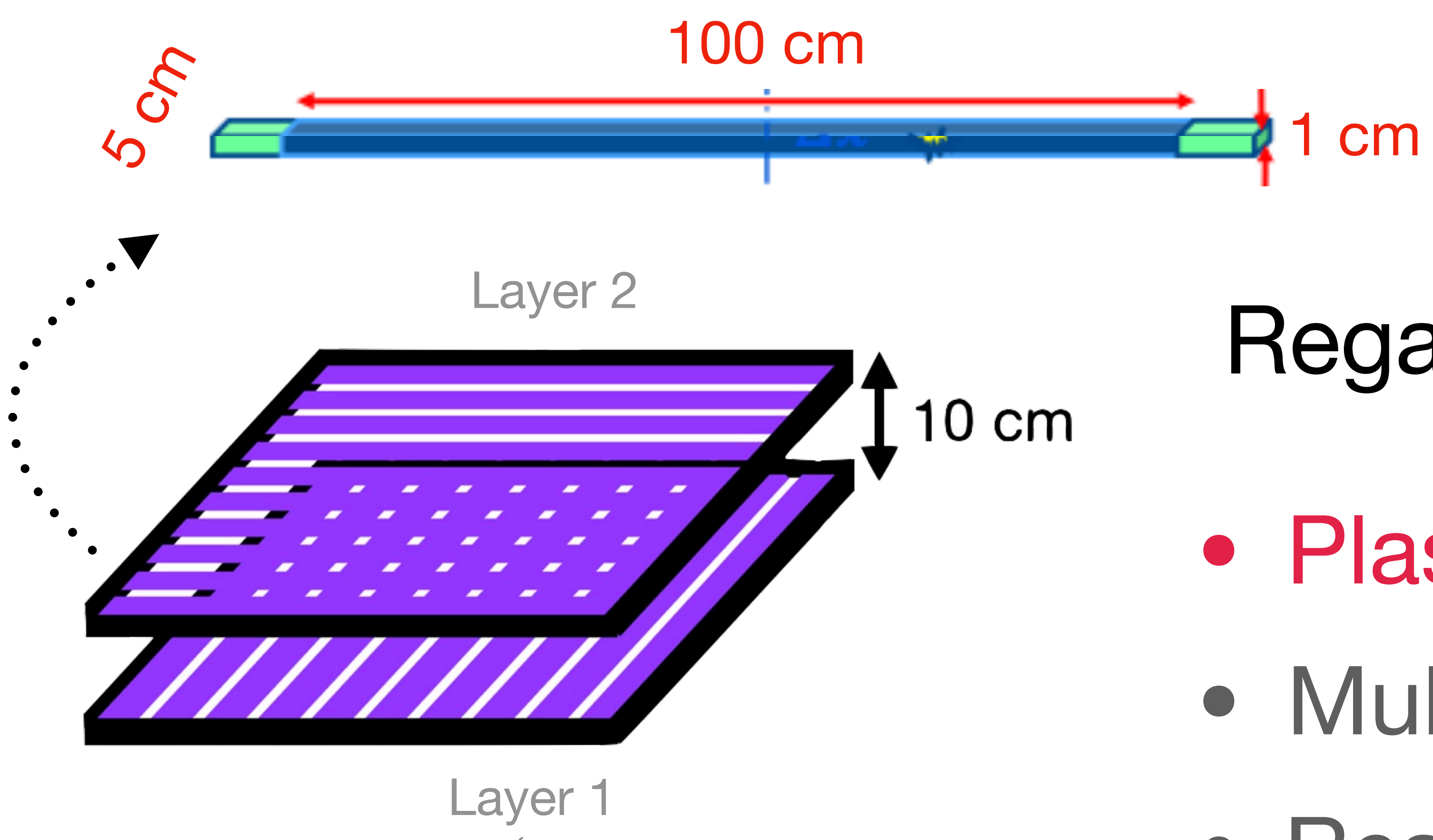

Regarding the muon chambers, there are some candidates

- Plastic scintillators and silicon photomultiplier (SiPM) for readout
- Multi-Wire Proportional Chambers (MWPCs)
- Resistive Plate Chambers (RPCs)

MID (plastic scintillator option)

Baseline option:

Low cost plastic scintillator bars (FNAL-NICADD) equipped with wave-length shifting fibers and SiPM

- **simplicity** (no need of gas mixture)
- **excellent timing resolution** (ns)
- **good performance on light-yield output** (around 40 photoelectrons)


JINST

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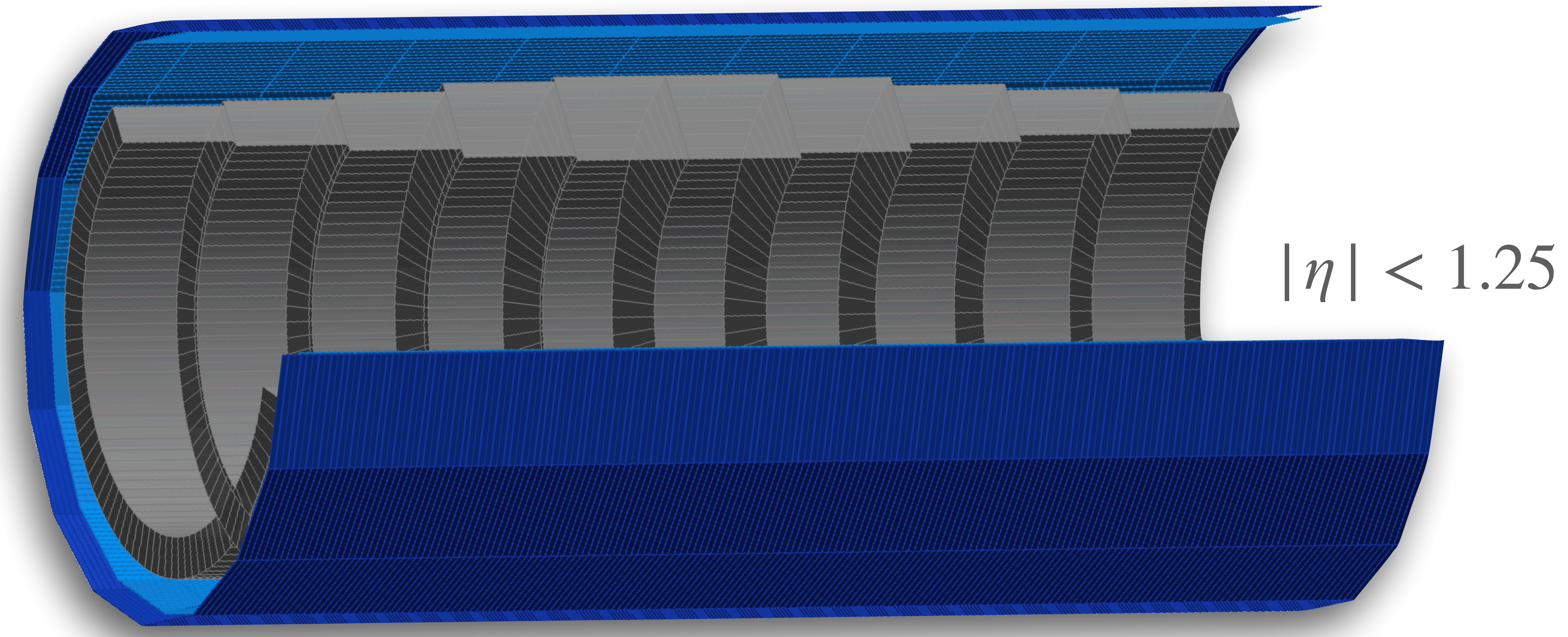
TECHNICAL REPORT

Characterisation of plastic scintillator paddles and lightweight MWPCs for the MID subsystem of ALICE 3

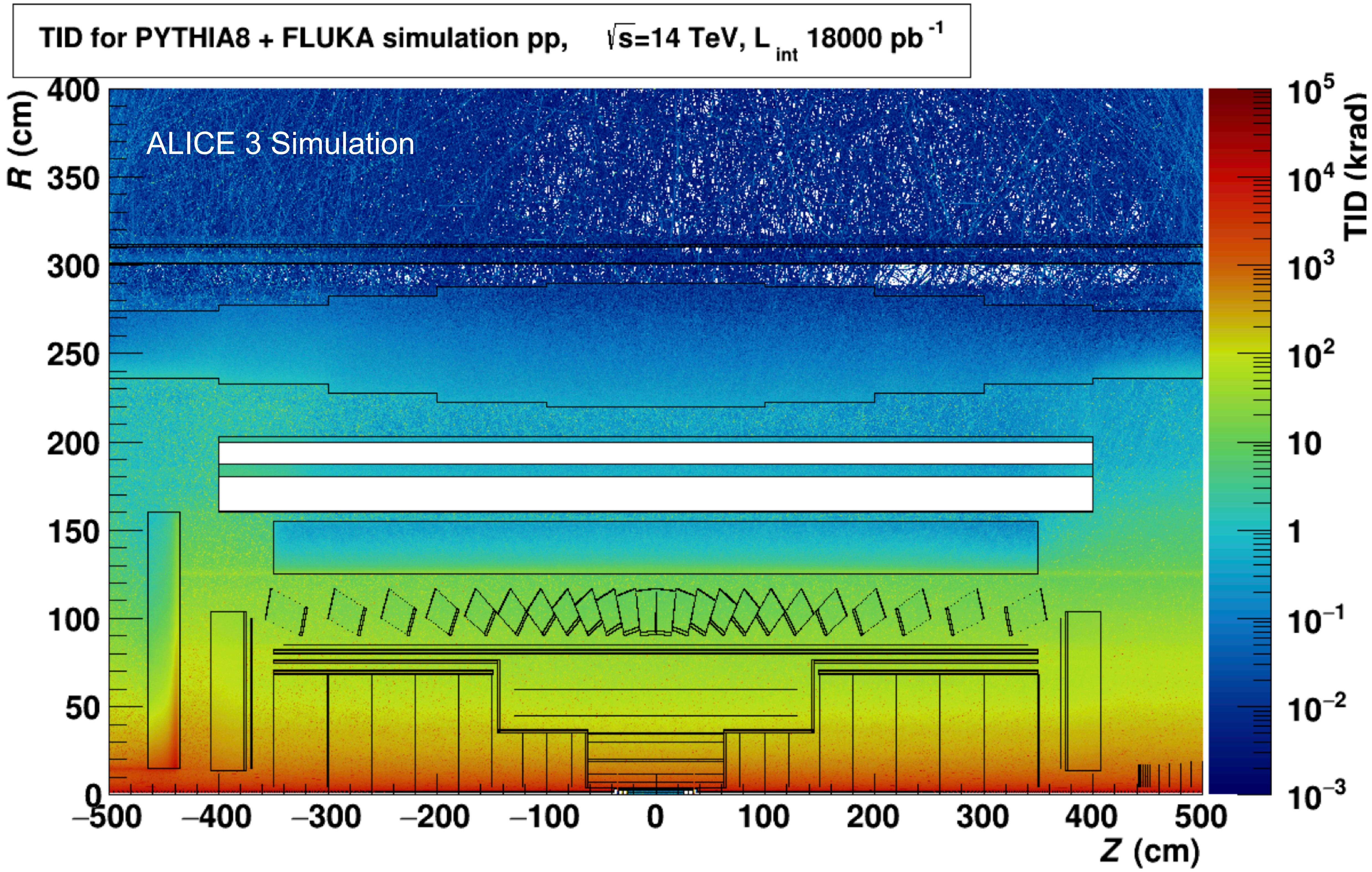
Ruben Alfaro,[a] Mauricio Alvarado Hernández,[b] Gyula Bencédi,[c] Juan Carlos Cabanillas Noris,[d] Marco Antonio Díaz Maldonado,[b] Carlos Duarte Galvan,[e] Arturo Fernández Téllez,[f] Gergely Gábor Barnaföldi,[c] Ádám Gera,[c] Varlen Grabsky,[a] Gergő Hamar,[c] Gerardo Herrera Corral,[g] Ildefonso León Monzón,[e] Josué Martínez García,[f] Mario Iván Martínez Hernandez,[f] Jesús Eduardo Muñoz Méndez,[b] Richárd Nagy,[c] Rafael Ángel Narcio Laveaga,[d] Antonio Ortiz,[b,*] Mario Rodríguez-Cahuantzi,[f] Solangel Rojas Torres,[h] Timea Szollosova,[h] Miguel Enrique Patiño Salazar,[b] Jared Pazarán García,[b] Hector David Regules Medel,[f] Guillermo Tejeda Muñoz,[f] Paola Vargas Torres,[b] Dezső Varga,[c] Róbert Vértesi,[c] Yael Antonio Vasquez Beltran,[f] Carlos Rafael Vázquez Villamar[b] and Irandheny Yoval Pozos[f]

R. Alfaro et. al., JINST 19 (2024) 04, T04006



	Absorber	MID layer 1	MID layer 2
Inner radius (m)	2.20	3.01	3.11
Outer radius (m)	2.90	3.02	3.12
Total length (m)	10	10	10.5
No. of sectors in z	9	10	10
No. of sectors in φ	1	16	16
Scintillator bar length (cm)	–	99.8	123.5
Scintillator bar width (cm)	–	5.0	5.0
Scintillator bar thickness (cm)	–	1.0	1.0

Radiation load studies for ALICE 3

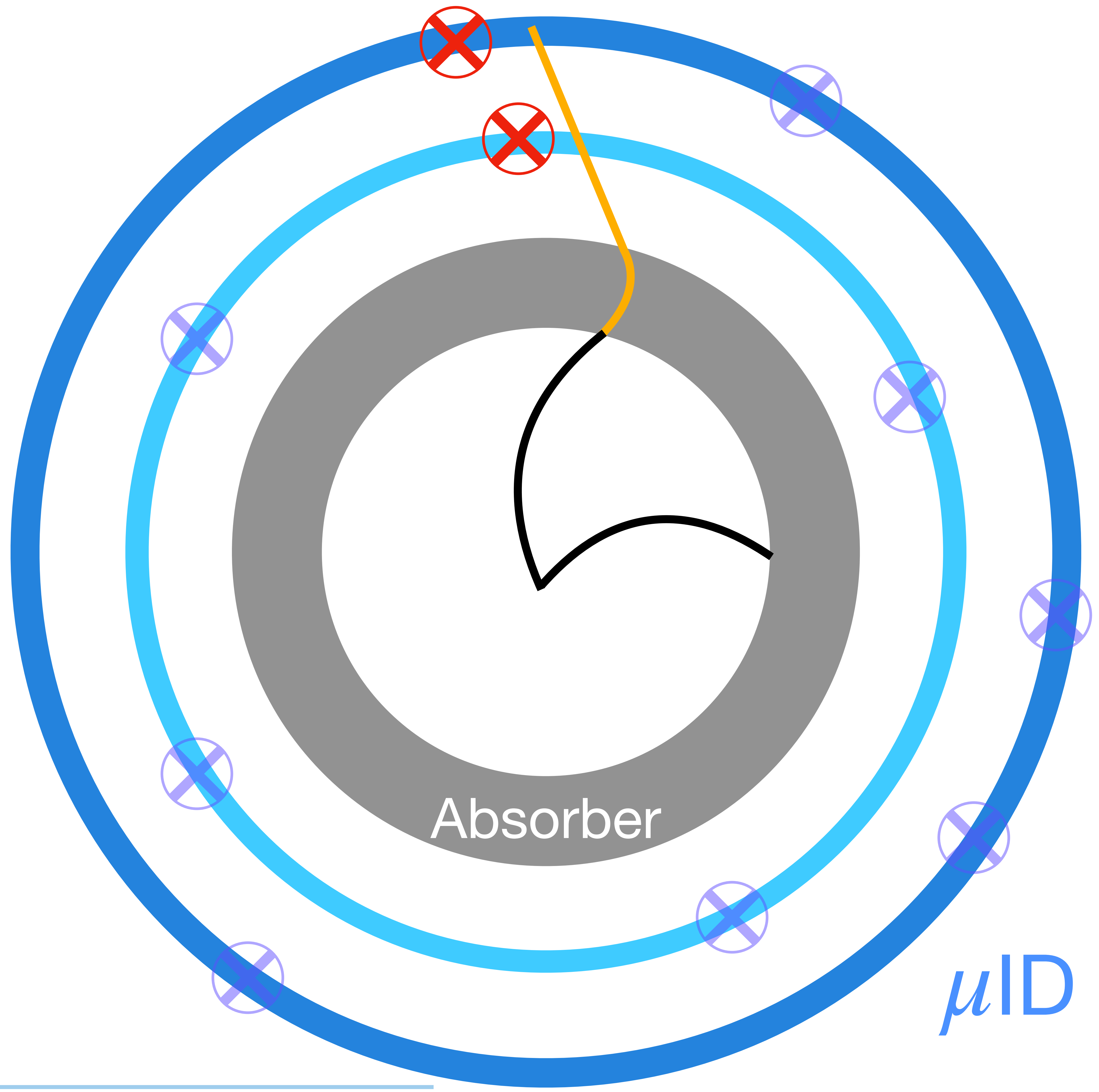


	pp	Pb-Pb
TID (rad)	54	0.94
NIEL (1 MeV neq/cm^2)	3.4 x 10^{10}	4.7 x 10^8

Table. *Radiation load in the MID* simulated with FLUKA for the Run 5+6 period

- **No significant decrease in light yield** due to the expected TID for baseline option scintillators [FERMILAB-PUB-05-344]
- **Our typical signals ~40 photoelectrons,** therefore single photoelectron detection with the SiPM is not required (impossible at 10^{11} MeV neq/ cm^2 at room temp.) [Nucl. Instrum. Meth. Phys. Res A, A 922 (2019)]

Muon tagging

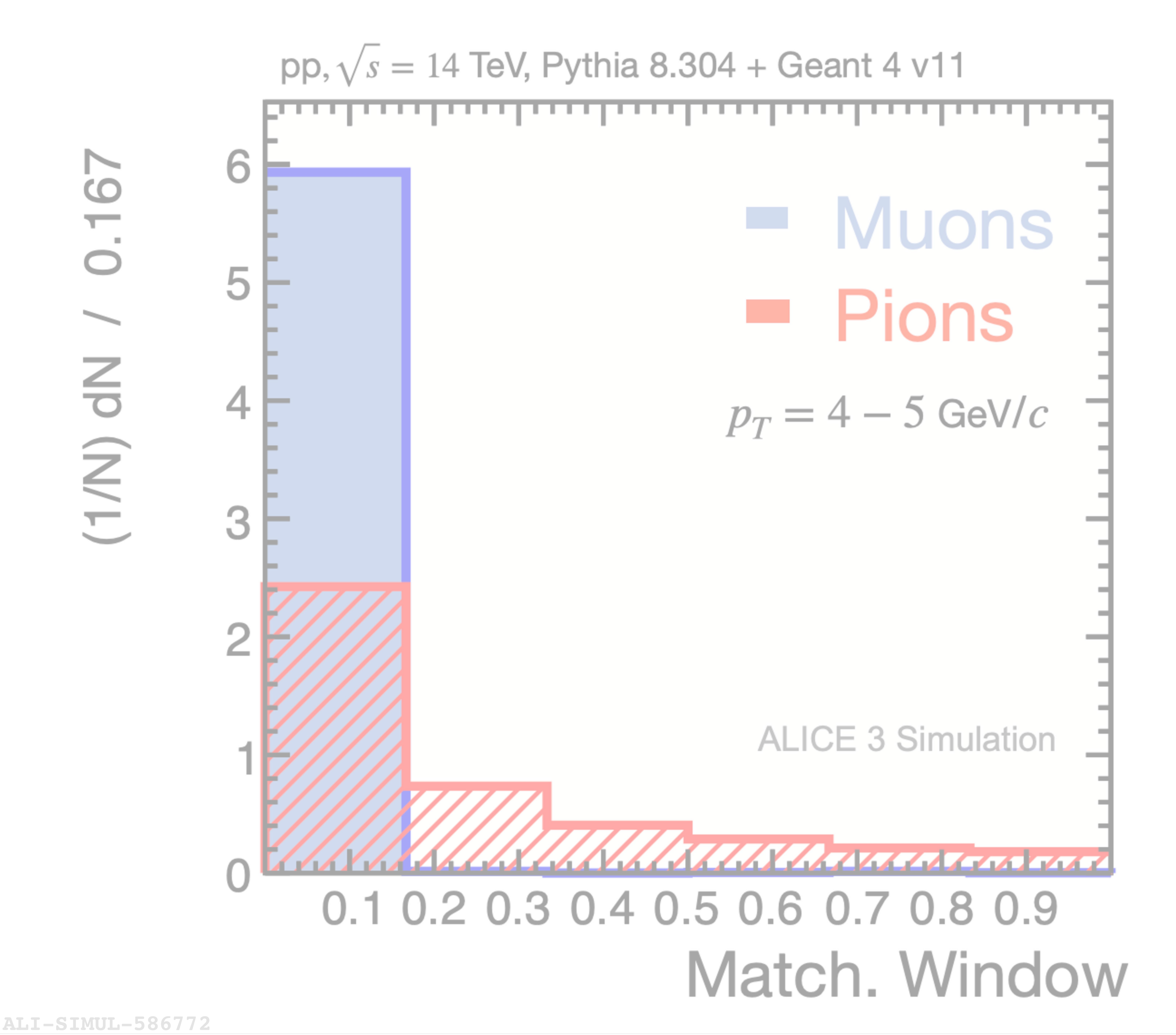


- Muon tagging is done by matching **activated bars** in the MID with tracks from the tracker
- All primary tracks are extrapolated to the MID
- Selection criteria are obtained via **boosted decision trees (BDT)**

BDT training

How to pick a set of variables for the training of the BDT?

- Momentum before the absorber
- **Matching window ($\Delta\eta, \Delta\phi$)**
- Number of bars activated around the extrapolation
- Highest **energy deposition** in the activated bars around to the extrapolation
- **Arrival time**



$$\mathrm{MW} = \sqrt{\Delta\eta^2 + \Delta\varphi^2} = \sqrt{(\eta^{\mathrm{extr.}} - \eta^{\mathrm{bar}})^2 + (\varphi^{\mathrm{extr.}} - \varphi^{\mathrm{bar}})^2}$$

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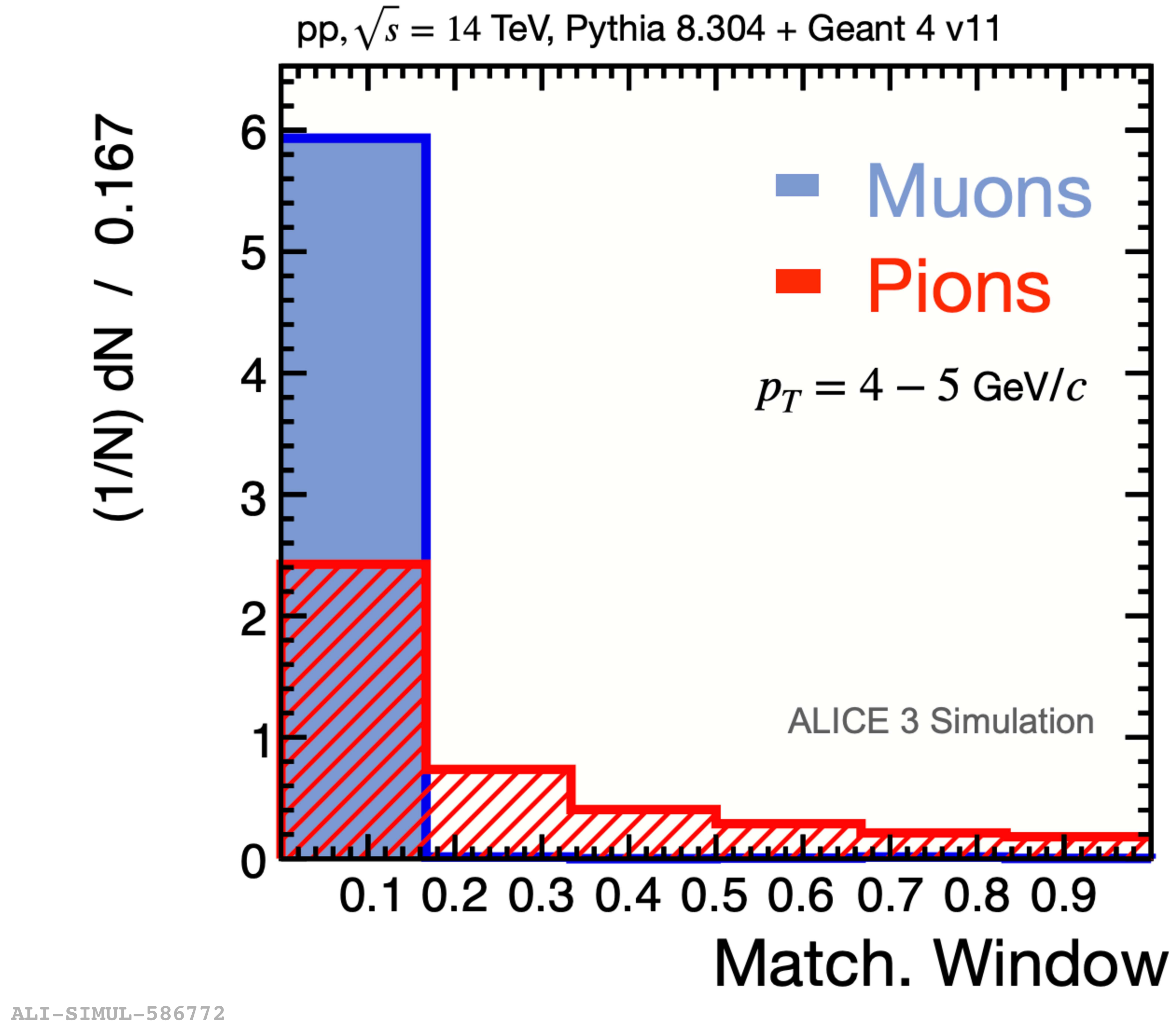

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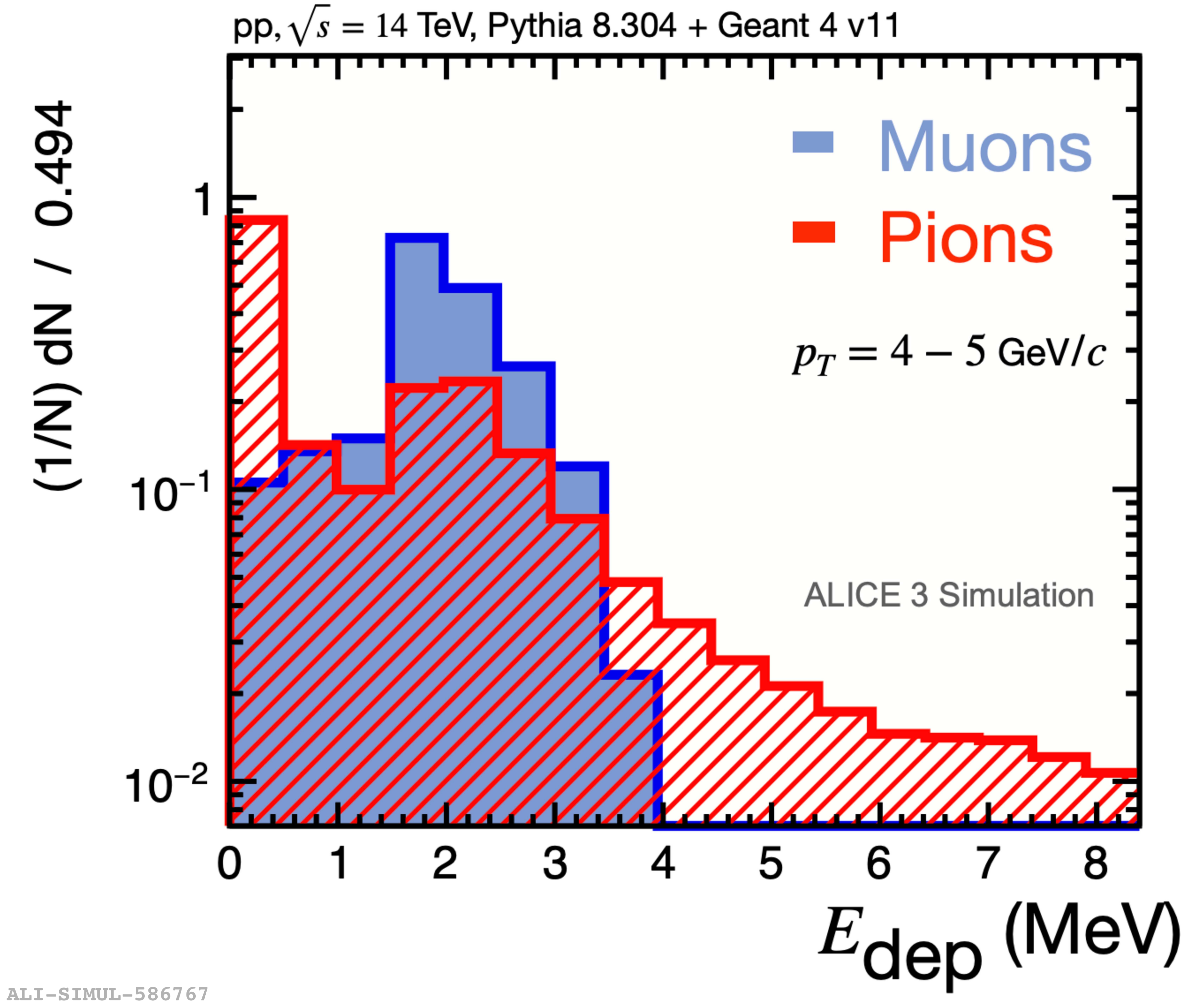

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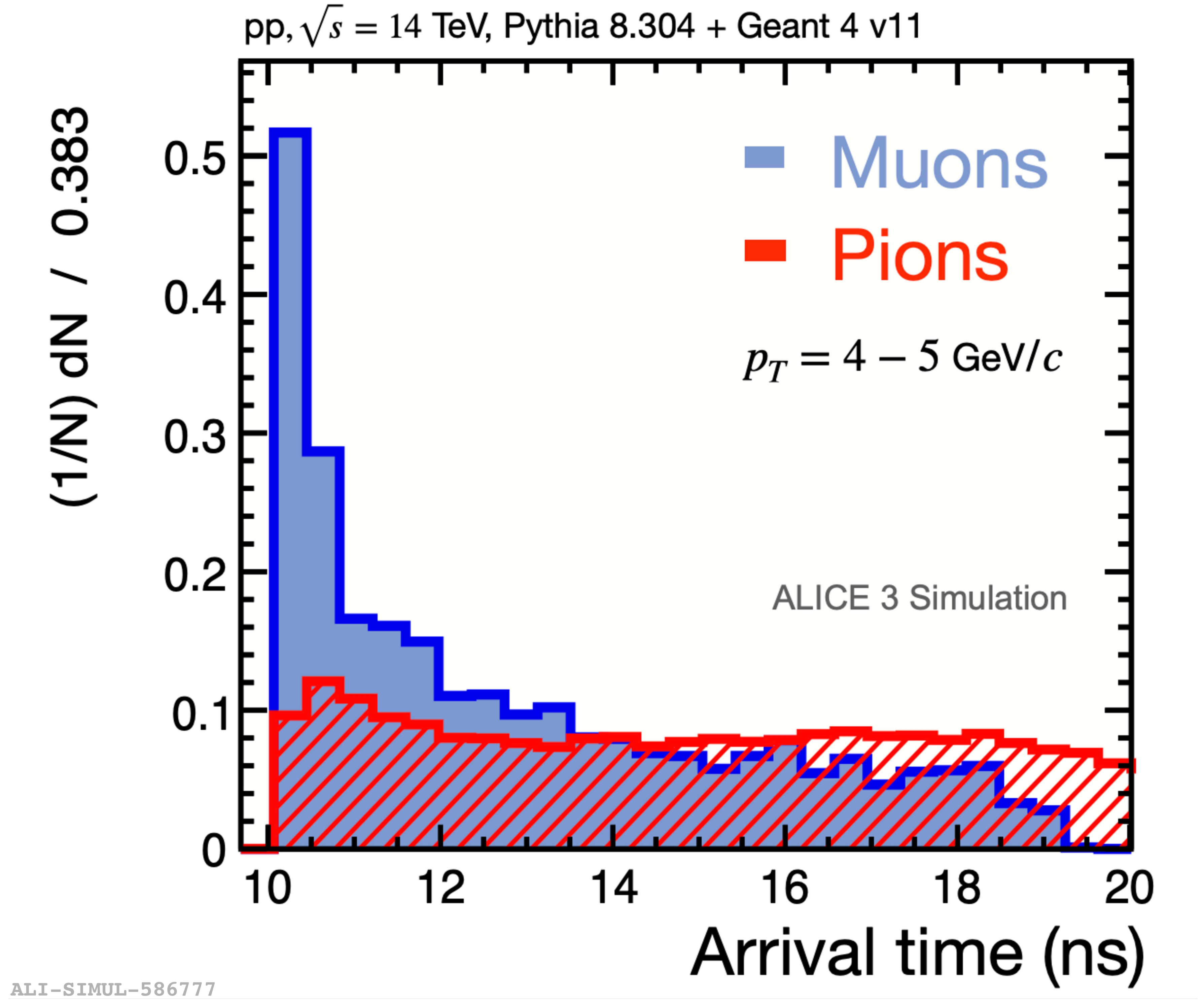
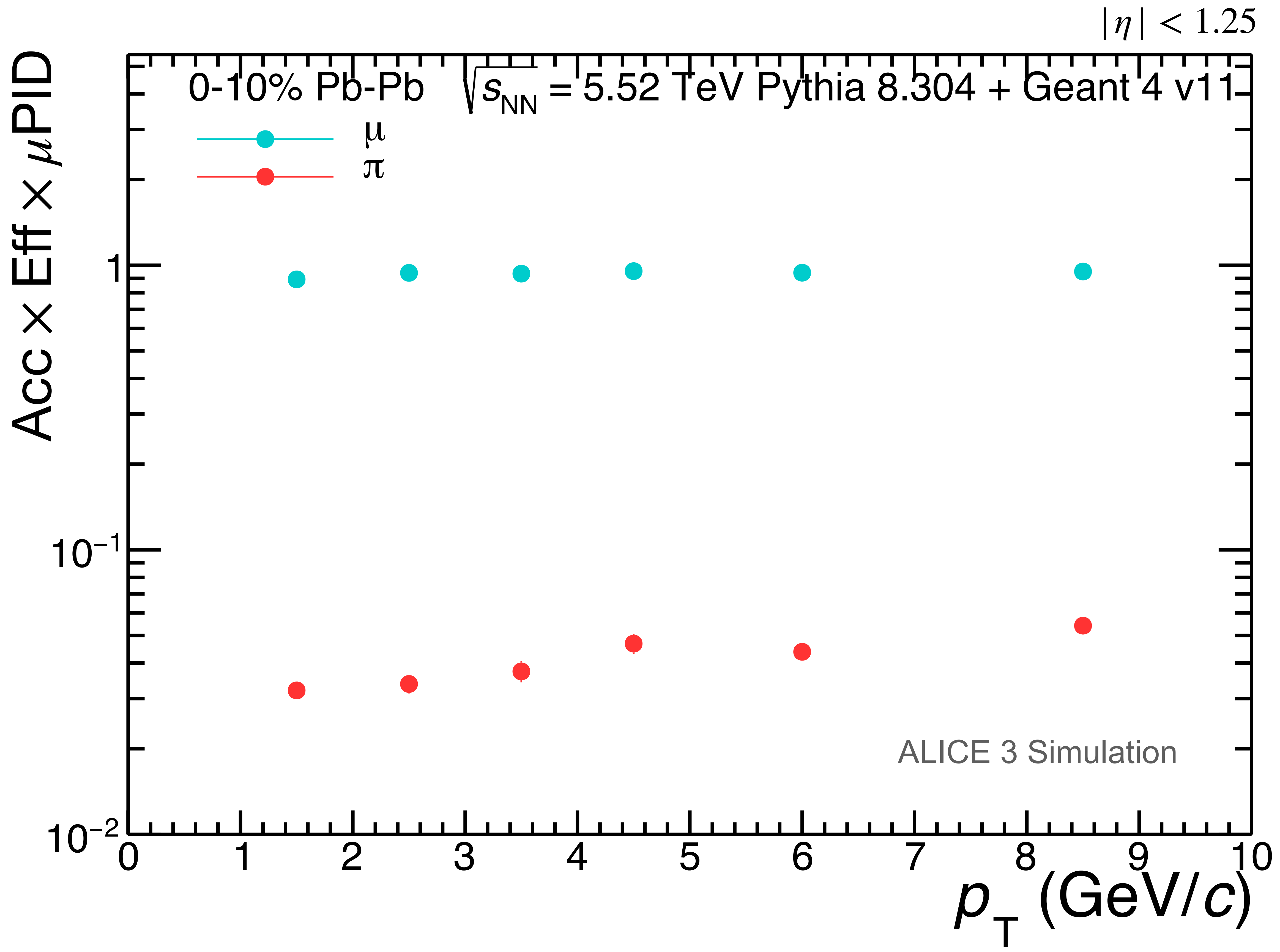
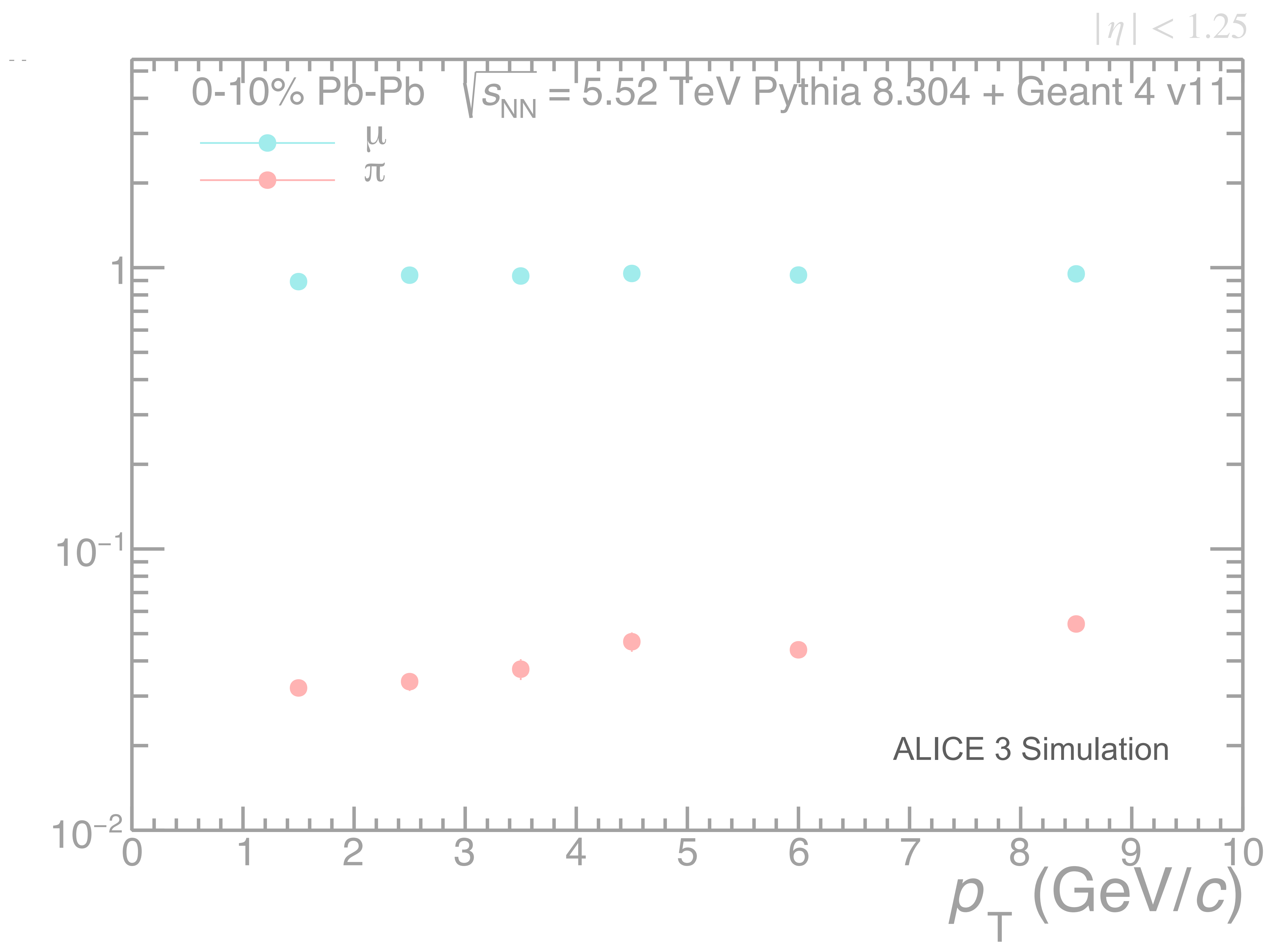


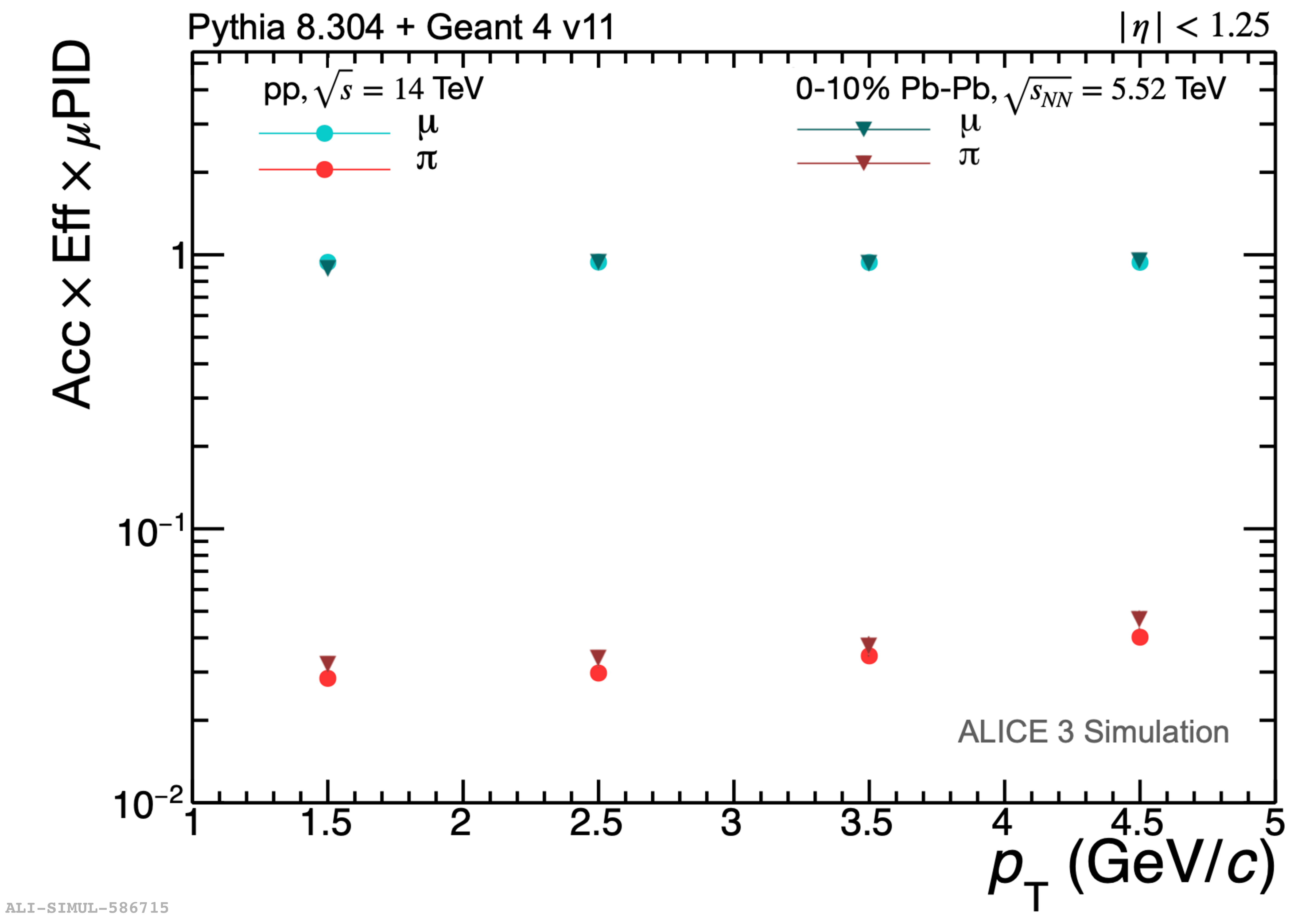
Pb-Pb and pp performance



- Muon efficiency around 94% for $p_T > 1.5$ GeV/c
- Pion rejection at the level of 3-5%

Pb-Pb and pp performance

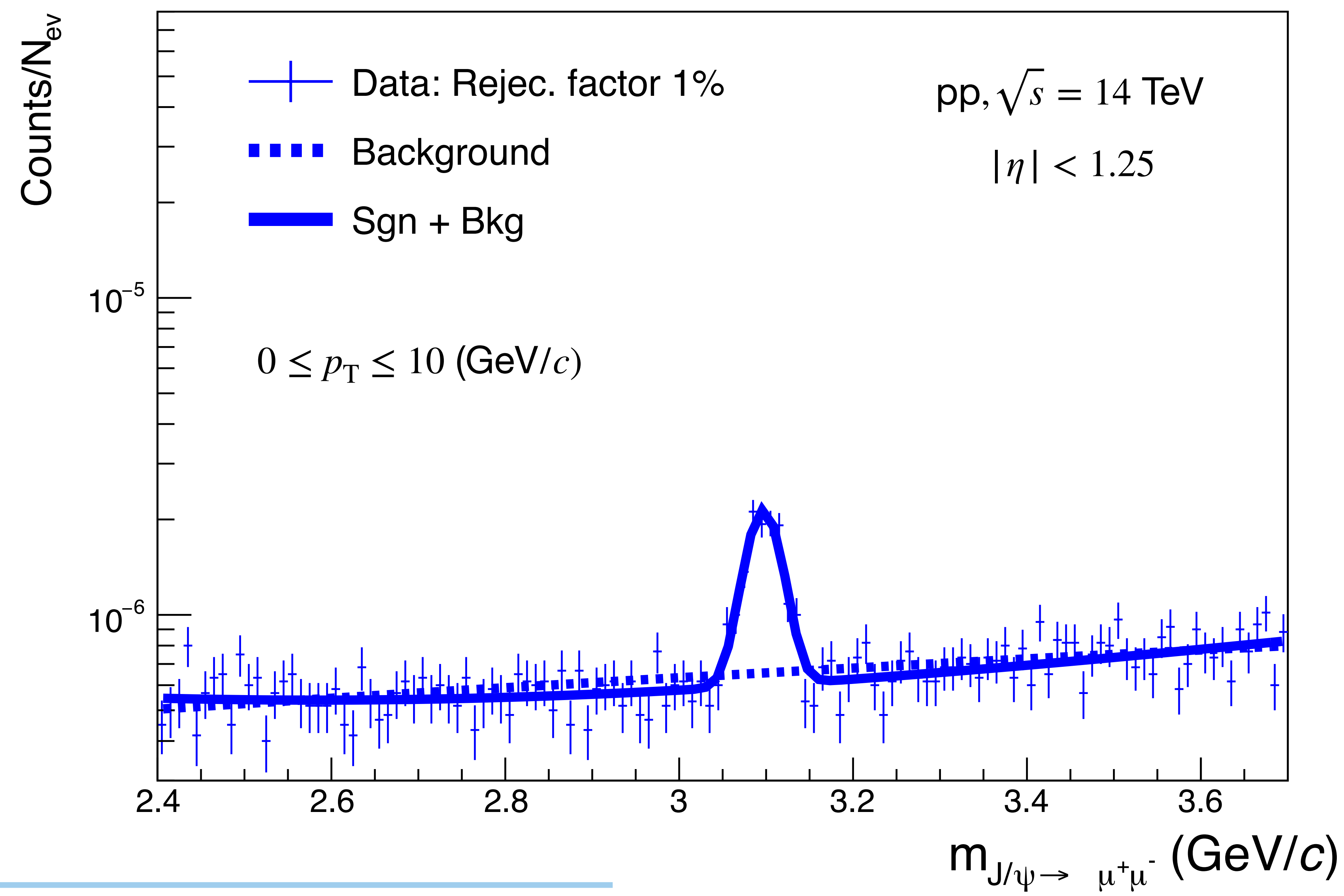




- Slightly above to the the pion rejection factor obtained in **pp simulations**

J/ψ reconstruction

The MID will allow the reconstruction of J/ψ down to $p_{\mathrm{T}} = 0$ via its dimuon decay channel



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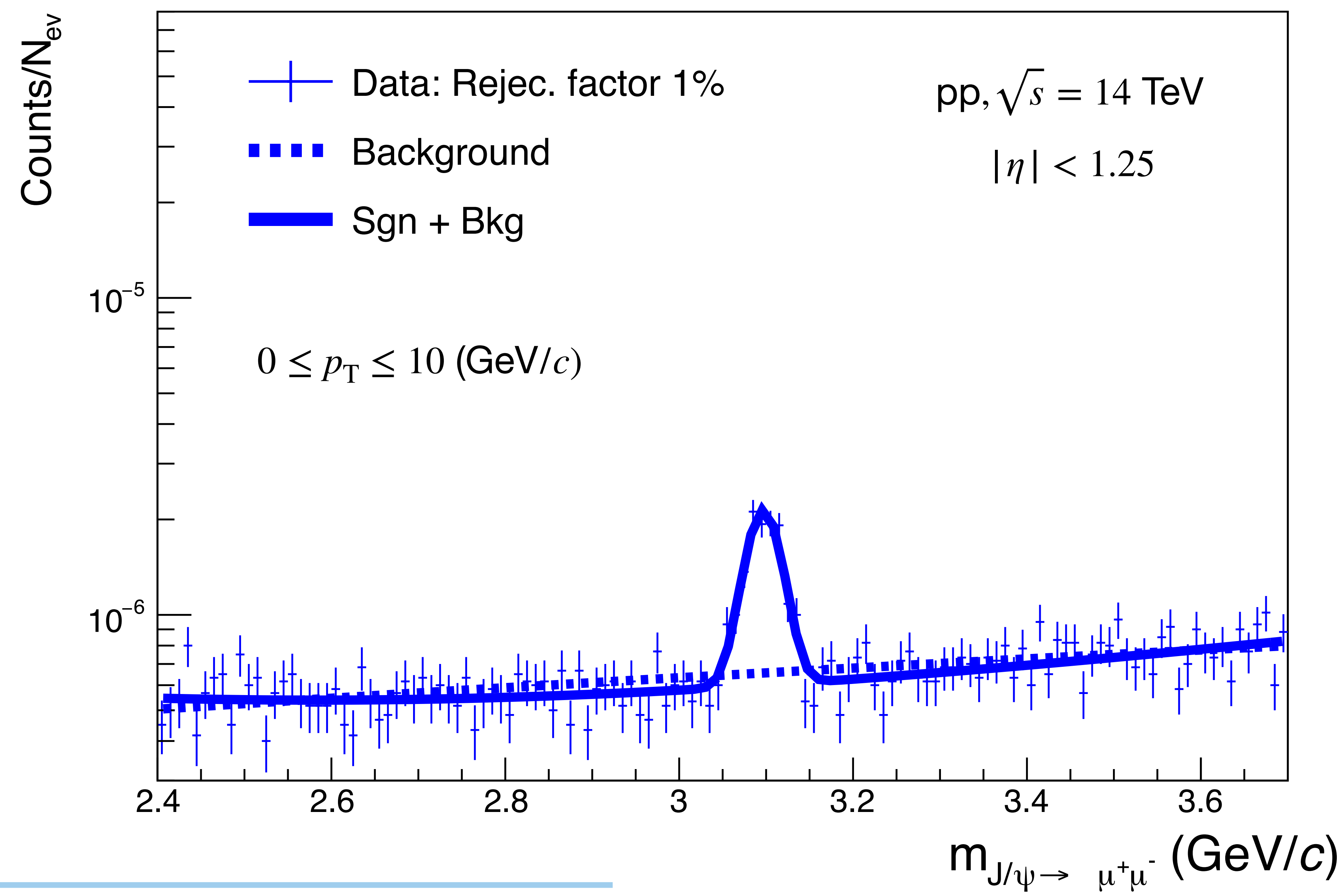
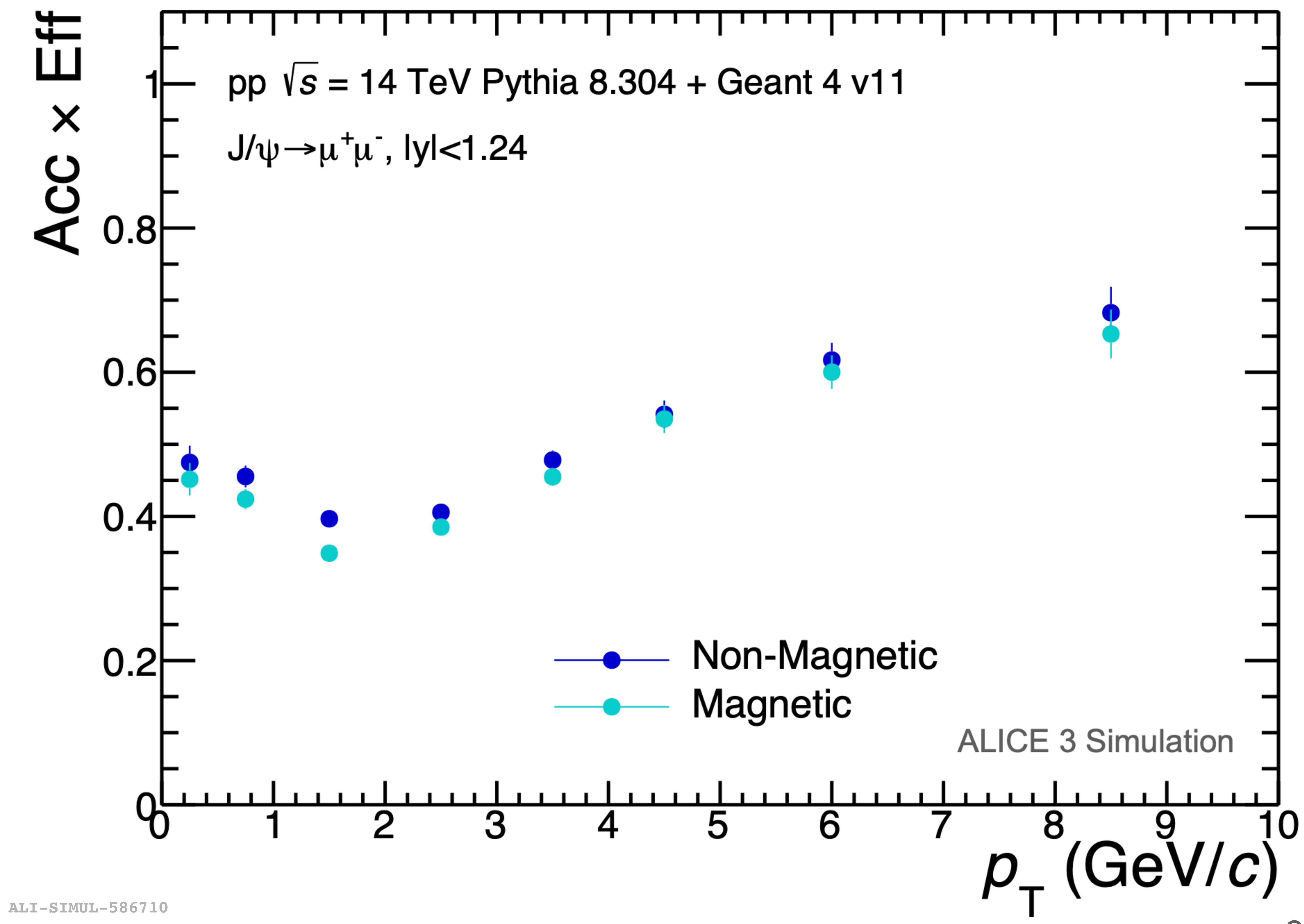


Reconstruction efficiency is **weakly affected** by the choice of the absorber



J/ψ reconstruction

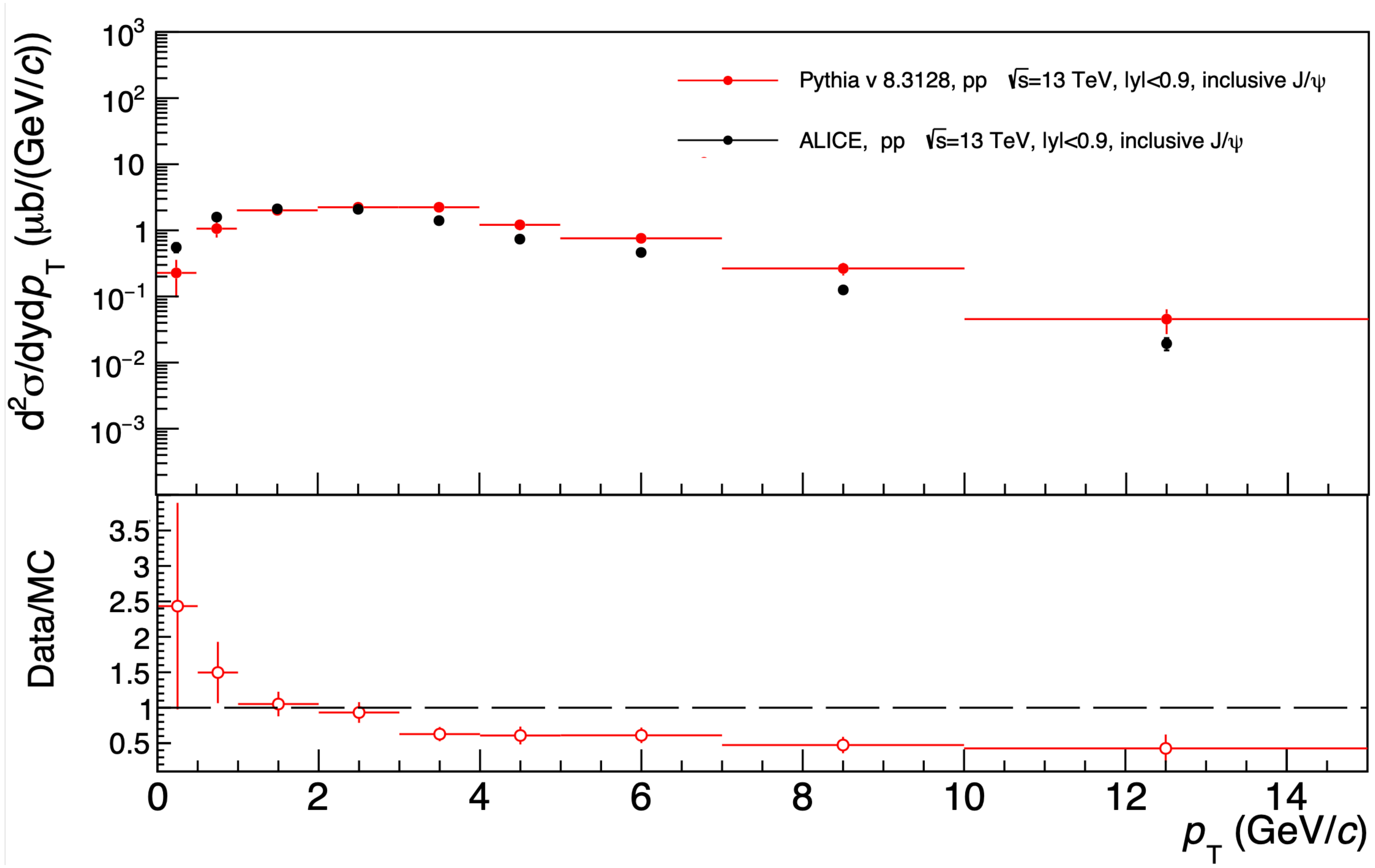


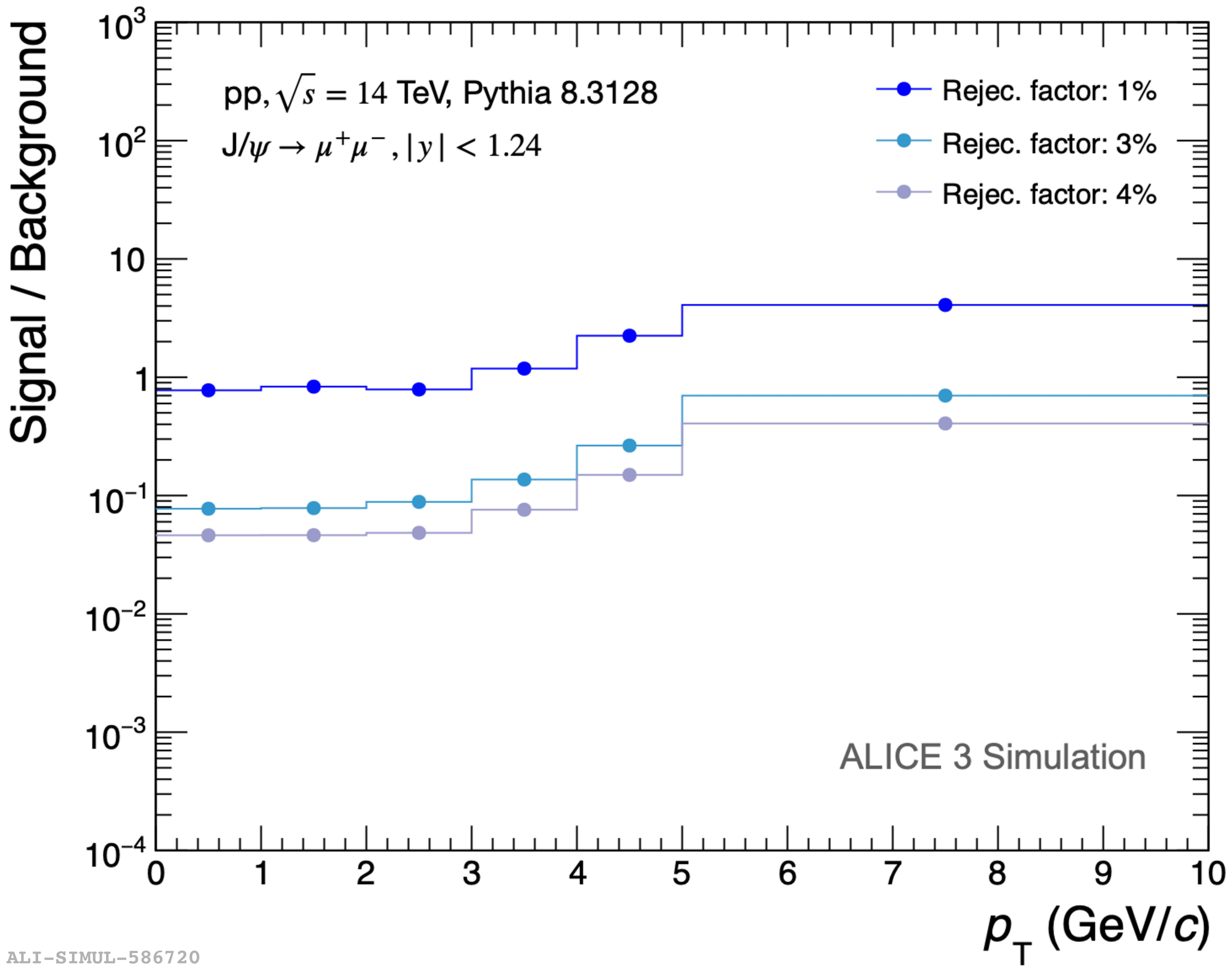
Fig. Inclusive J/ψ production cross section at midrapidity in pp collisions. Data taken from [ALICE, Eur. Phys. J. C 81, 1121 (2021)]

Disclaimer:

In the following results, PYTHIA's cross section needs to be corrected in order to match experimental measurements of J/ψ.

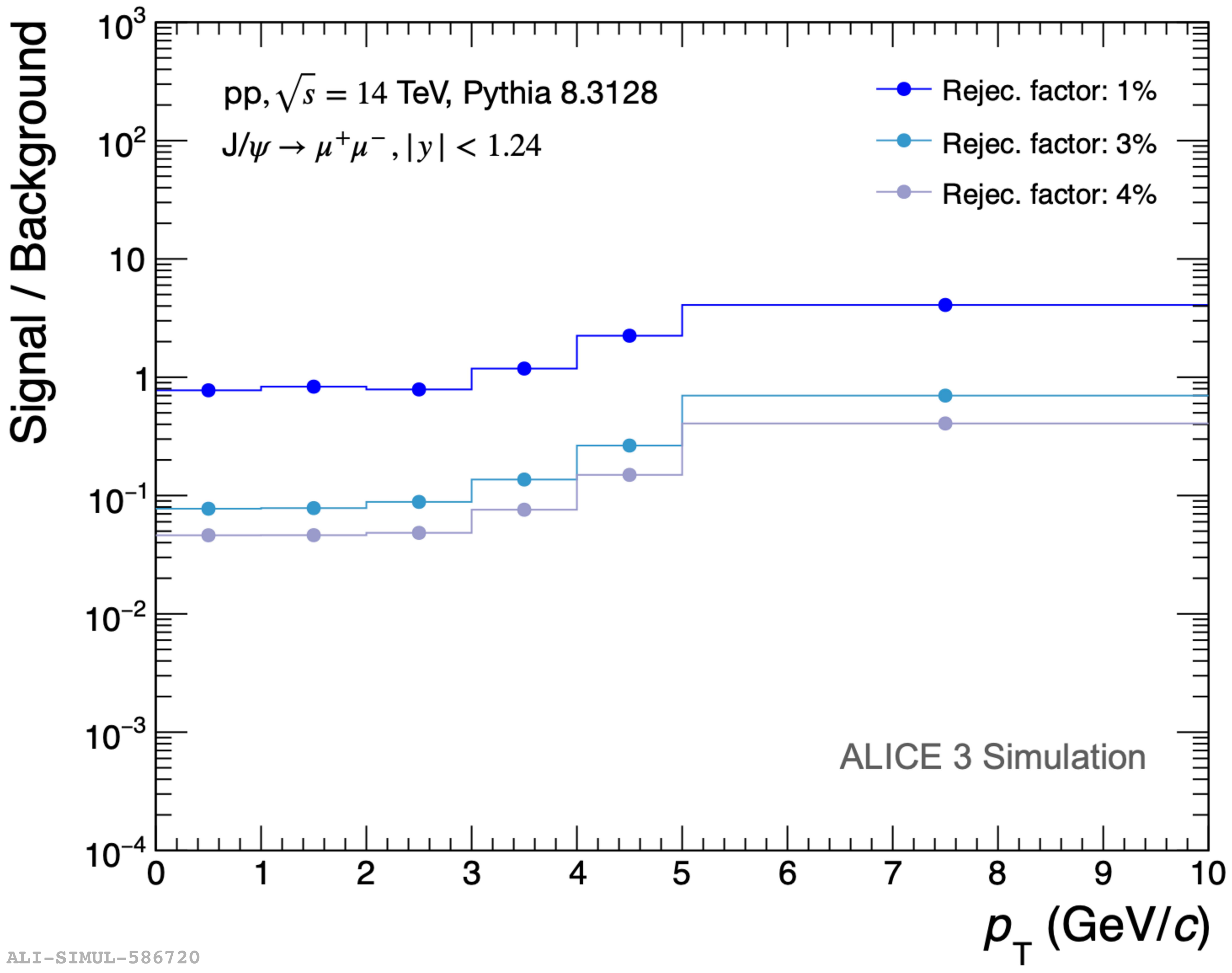
Nonetheless, we still can make some remarks without this correction…

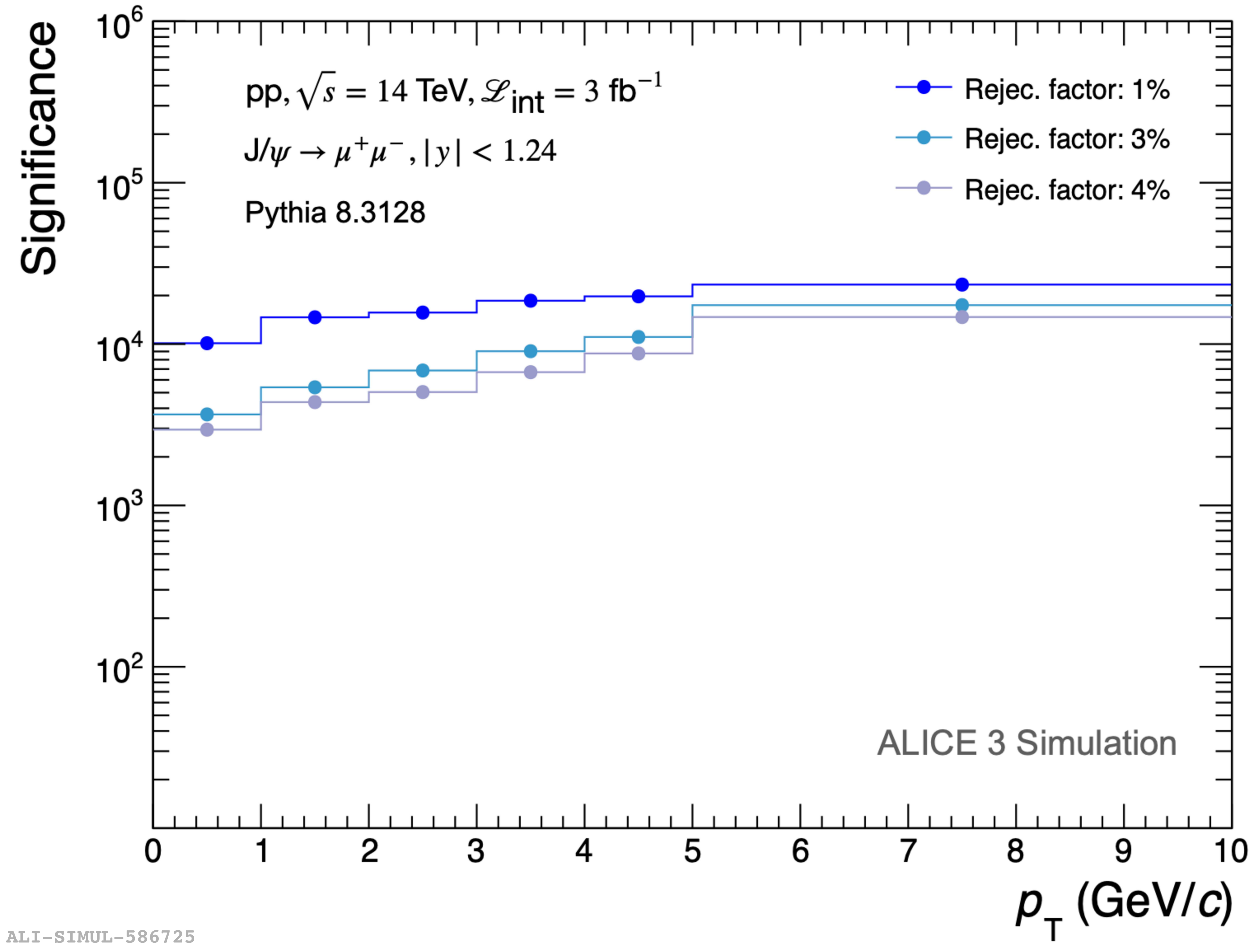
J/ψ reconstruction (pp collisions)



Even though the signal-to-background ratio varies with the **pion rejection factors**…

J/ψ reconstruction (pp collisions)





Even though the signal-to-background ratio varies with the **pion rejection factors**…

…the **significance is less affected**, ensuring reliable detection of the signal across different conditions

Summary

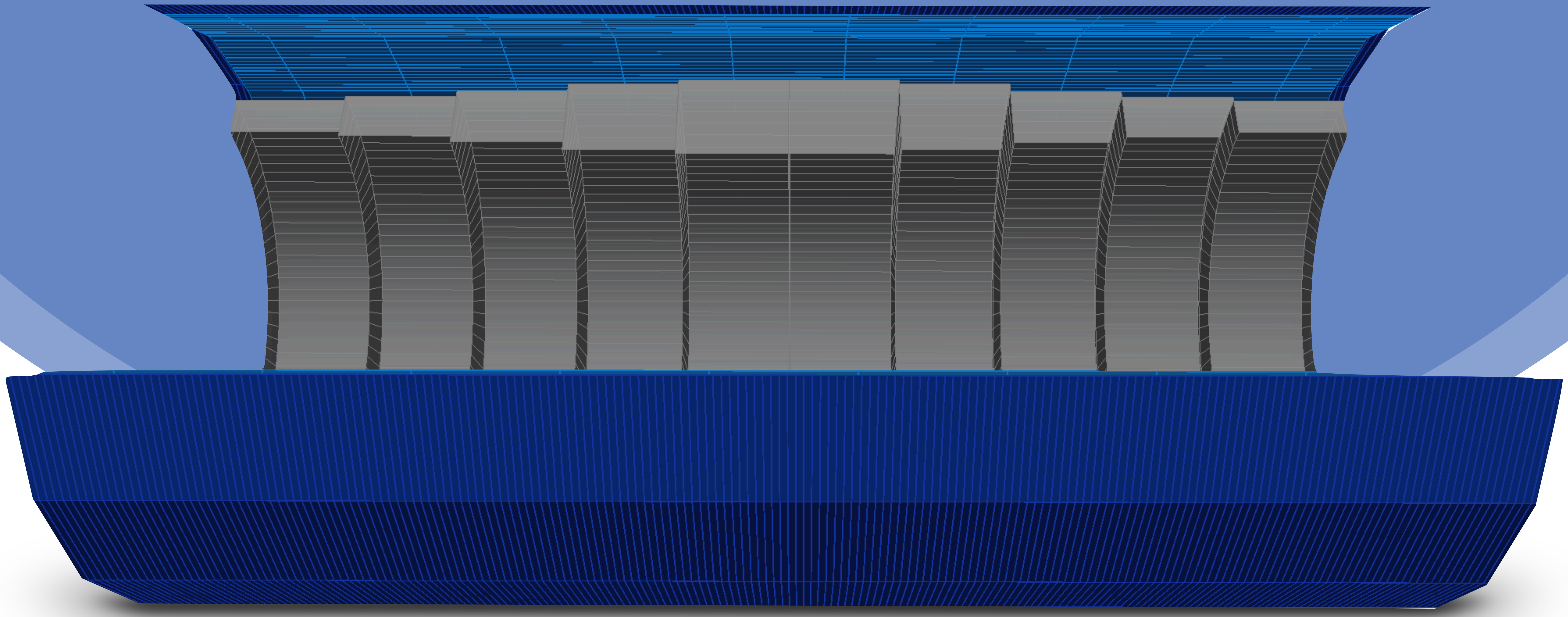
ALICE 3 will provide access to further understand the hottest- and longest-lived QGP available in any laboratory, with the MID playing an important role in this exploration

- **Simulations of the MID show a competitive performance in both pp and Pb-Pb simulations**
- **Significance results suggest that detecting reliable signals under varying pion rejection factors is plausible**
- **The expected radiation load does not represent a problem for plastic scintillators + SiPM**
- **Results on a first prototype of the MID are on their way** *(see Antonio Paz talk: 05/11/24, 19:15 [QCD2])*

Scintillators represent an excellent candidate for the MID

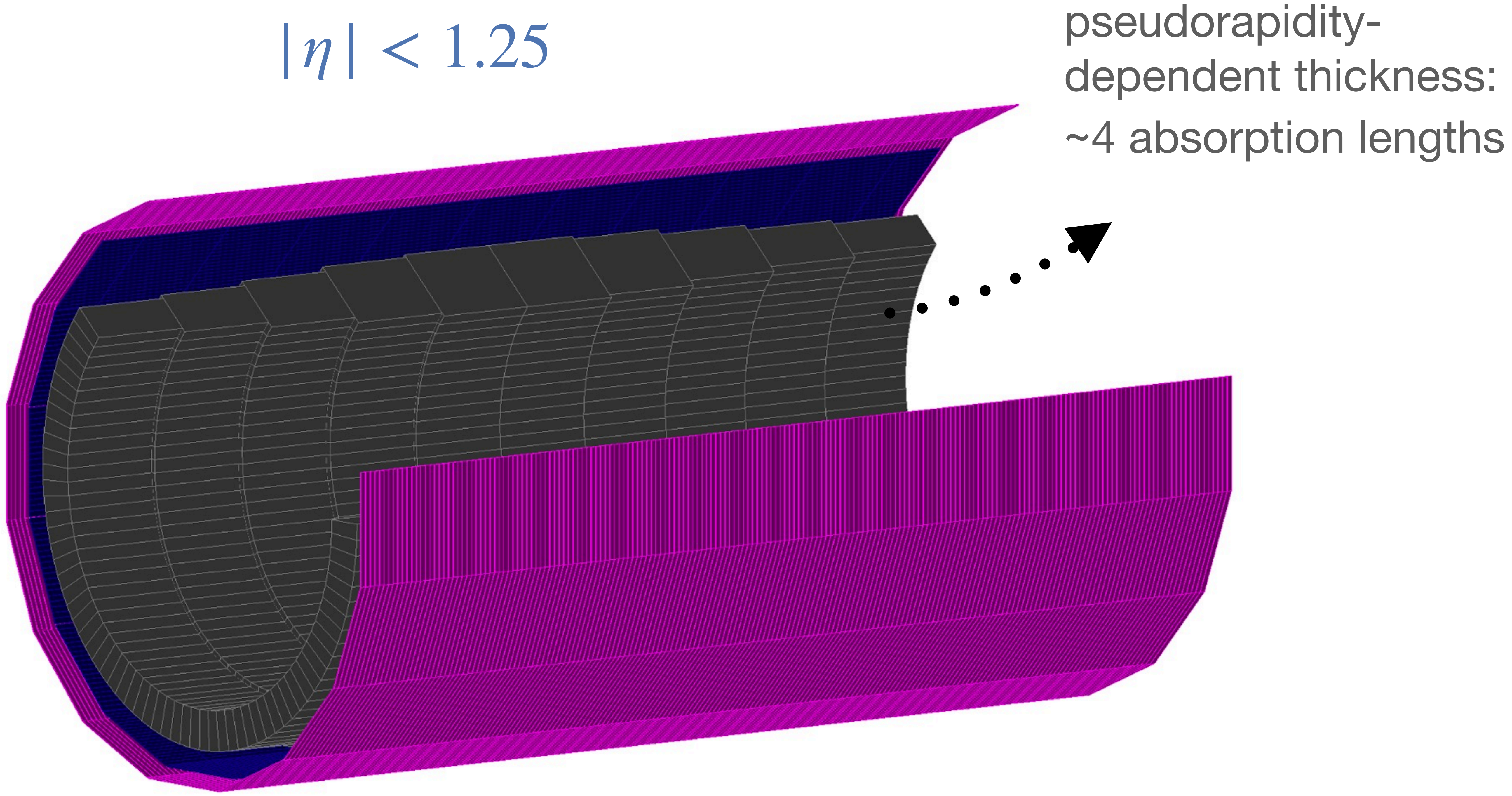
(very simple, robust, cheap, excellent timing performance)

Thank you
for your attention!



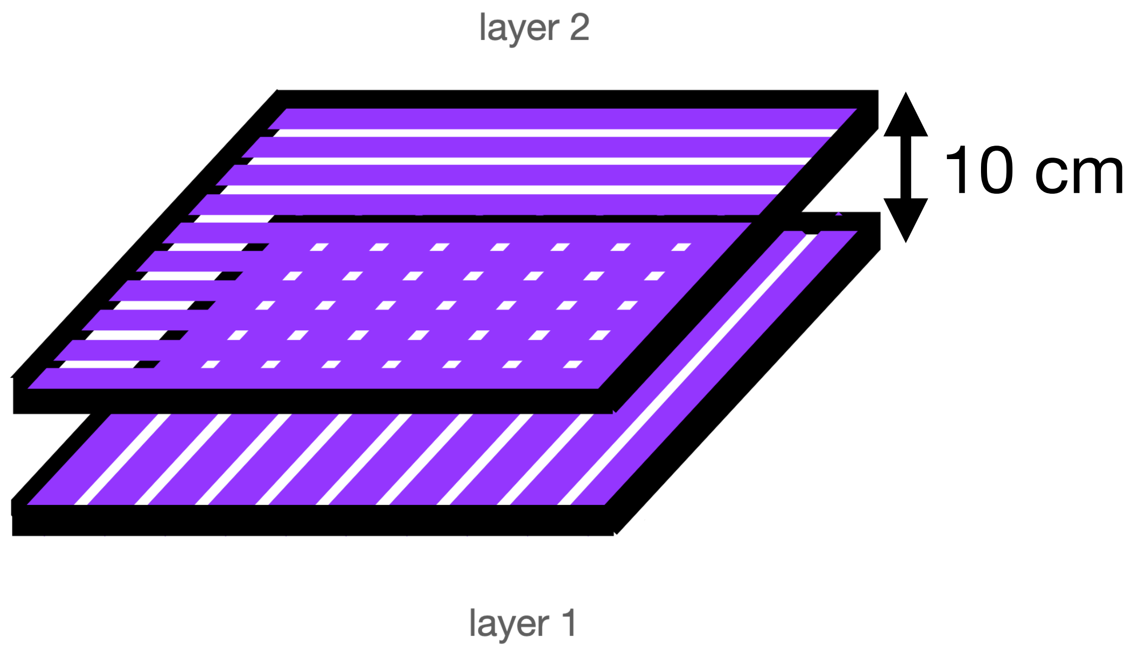
Backup

MID specifications



	Absorber	MID layer 1	MID layer 2
Inner radius (m)	220	301	311
Outer radius (m)	290	302	312
z range (m)	10	10	10.5
No. sectors in z	9	10	10
No. sectors in φ	1	16	16
Scint. bar length (cm)		99.8	123.5
Scint. bar width (cm)		5.0	5.0
Scint. bar thickness (cm)		1.0	1.0

No. of bars
4048 in layer 1
3200 in layer 2

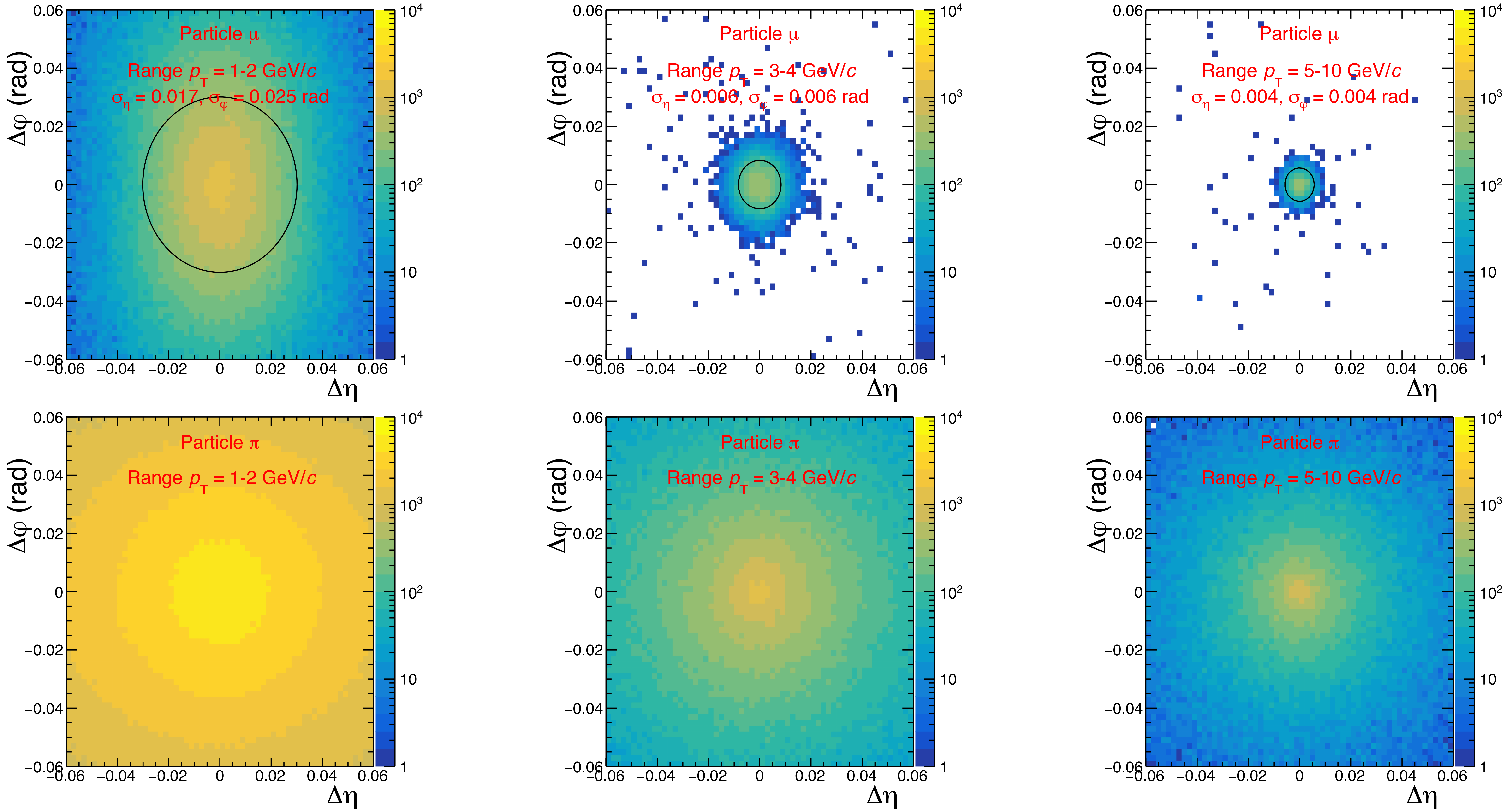


One of the proposals for the MID are **plastic scintillators equipped with wavelength-shifting fiber and SiPM for readout**

Matching window ($\Delta\eta$, $\Delta\phi$)

$\mu \rightarrow$

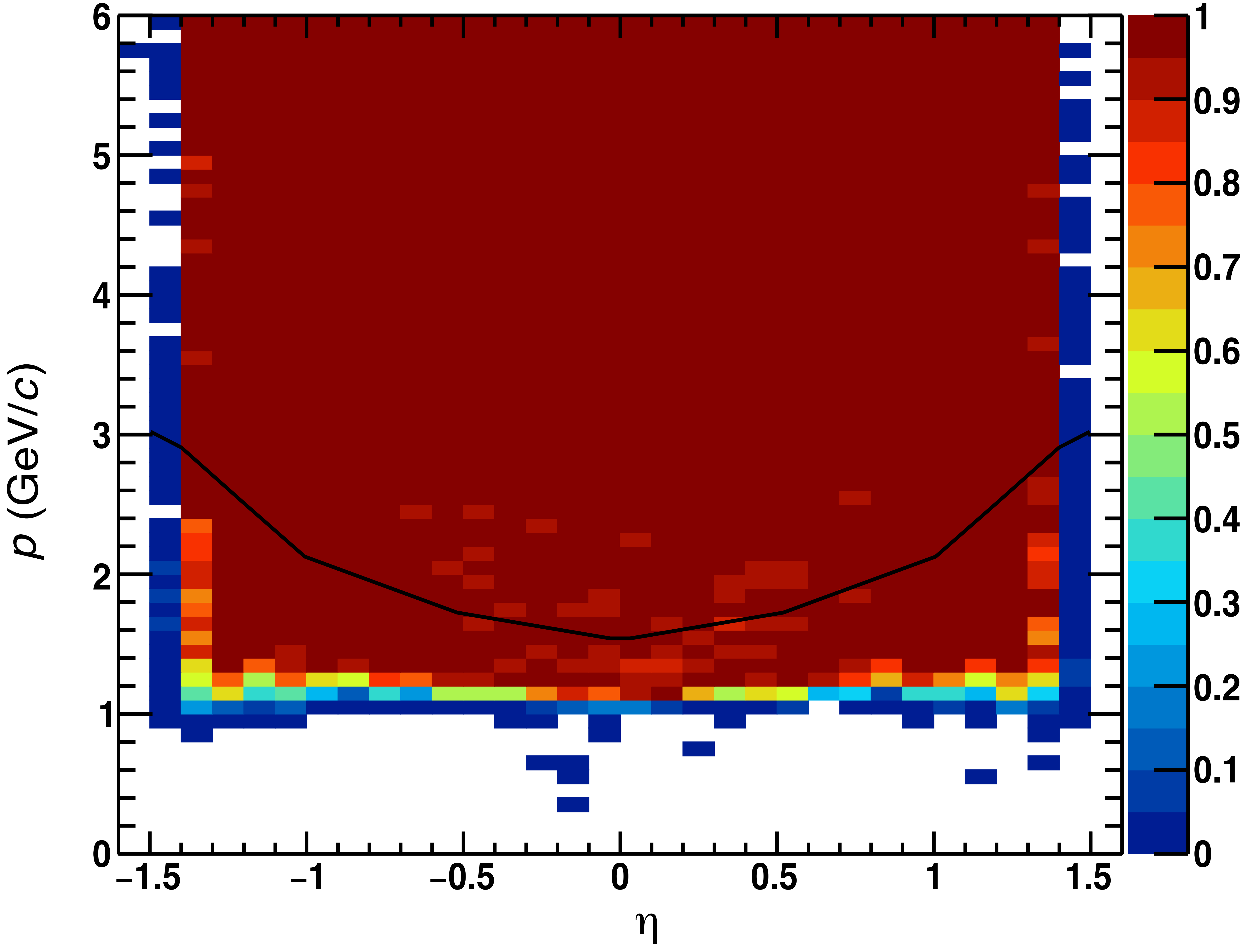
$\pi \rightarrow$



$$\Delta\phi = \phi^{\text{extr.}} - \phi^{\text{bar}}$$
$$\Delta\eta = \eta^{\text{extr.}} - \eta^{\text{bar}}$$

The **muon candidates** are those within the MW: $R = \sqrt{\sigma^2_{\Delta\eta} + \sigma^2_{\Delta\phi}}$

Single muon acceptance vs p and pseudorapidity



Solid black line:

approximate minimum momentum to have non-zero J/ψ acceptance down to

$p_{\mathrm{T}} = 0$ and $|y| < 1.5$

(Calculation by Antonio Uras)

Optimization of the absorber leads to good acceptance for J/ψ