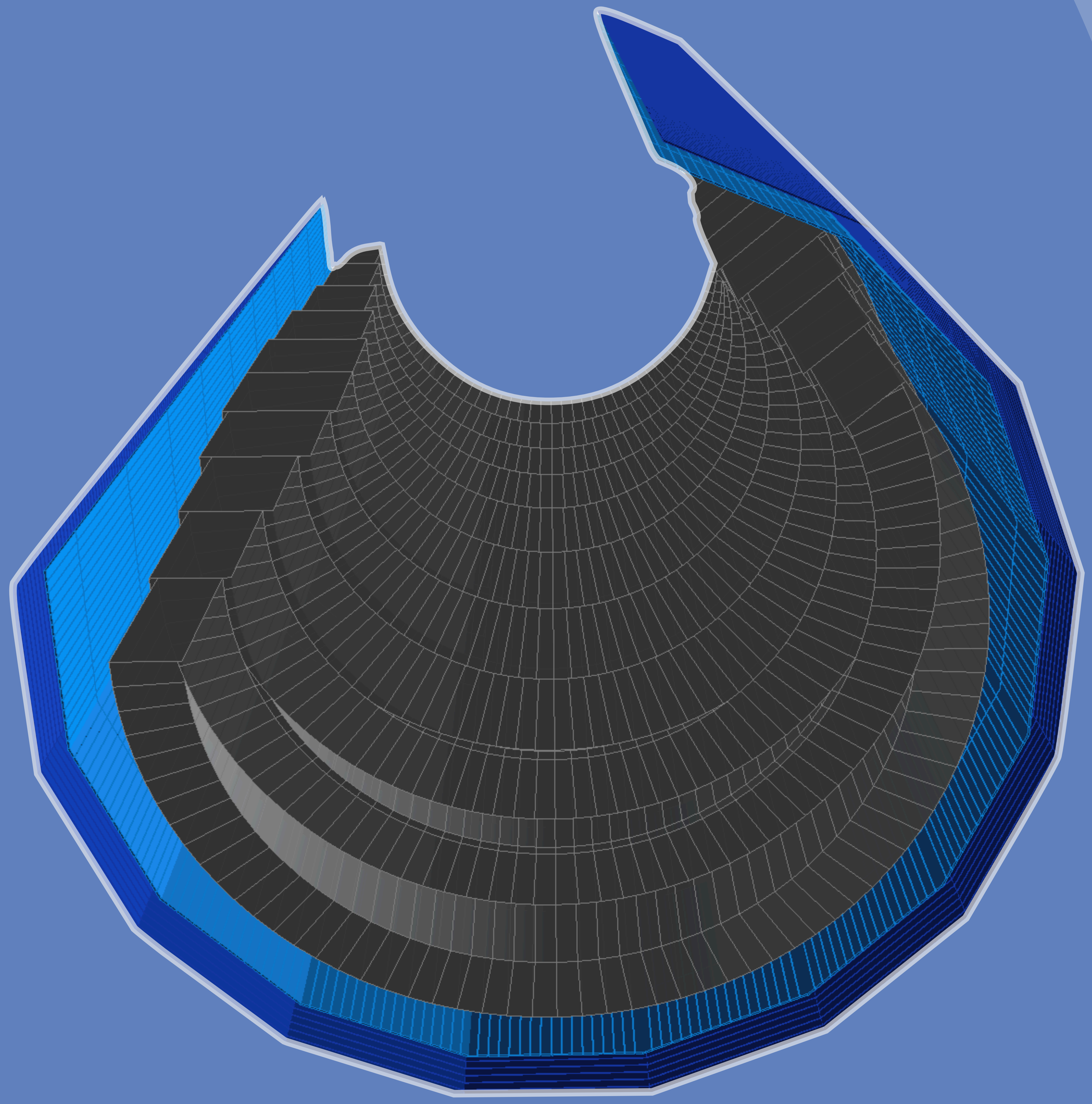


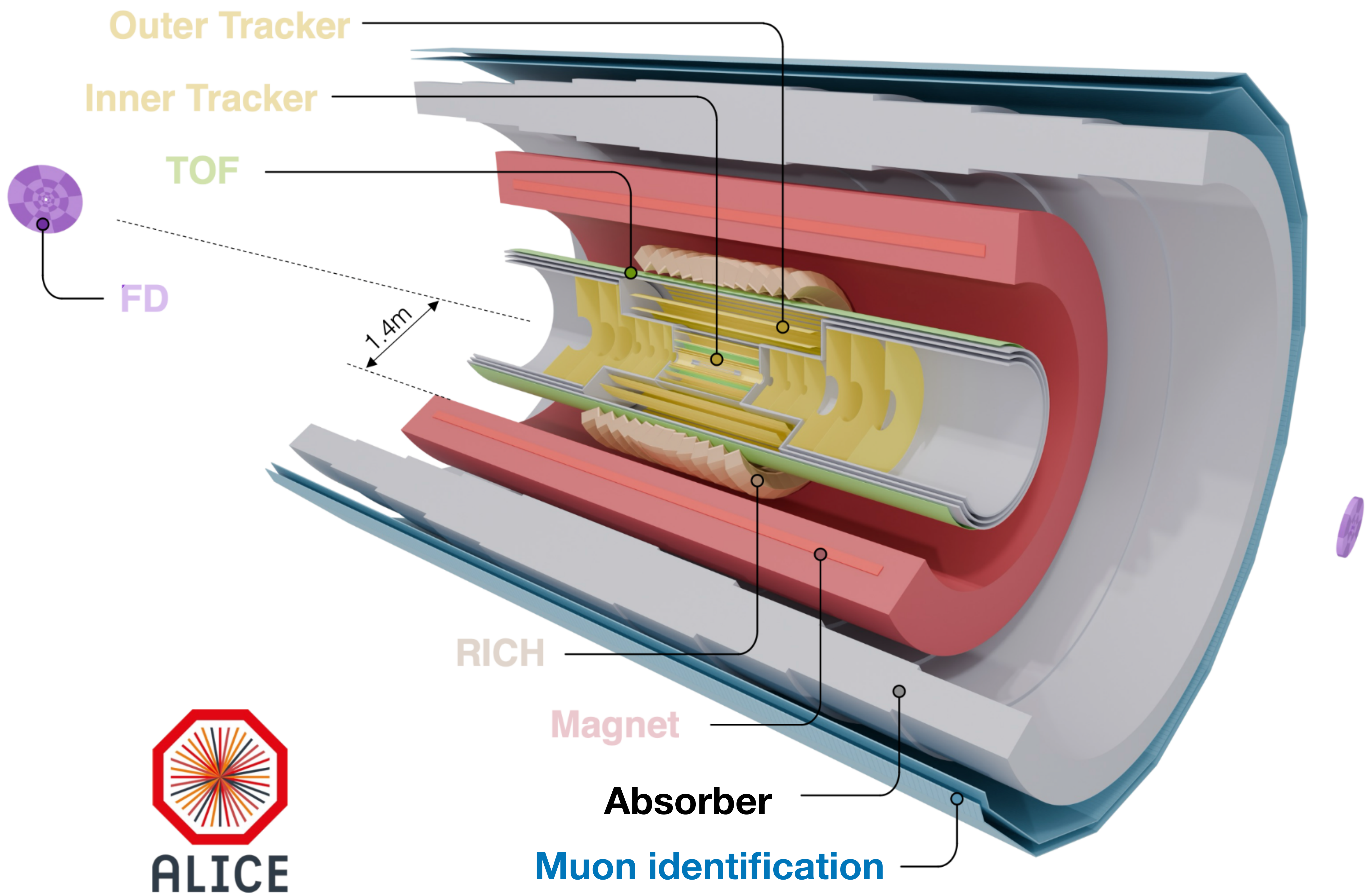
MID: a muon detector for the ALICE 3 upgrade project

Jesús Eduardo Muñoz Méndez

Reunión Anual de la División de Partículas y Campos
17 Jun, 2026

Instituto de Ciencias Nucleares UNAM

ALICE 3



ALICE 3 detector
layout v3b, CERN-LHCC-2025-002

ALICE 3 features:

Muon identification for charmonia and exotic hadrons

CMS and **ATLAS**:

μ identification down to $p_T \approx 3 - 4$ GeV/c

ALICE 3:

optimized to identify μ down to $p_T = 1.5$ GeV/c

vs

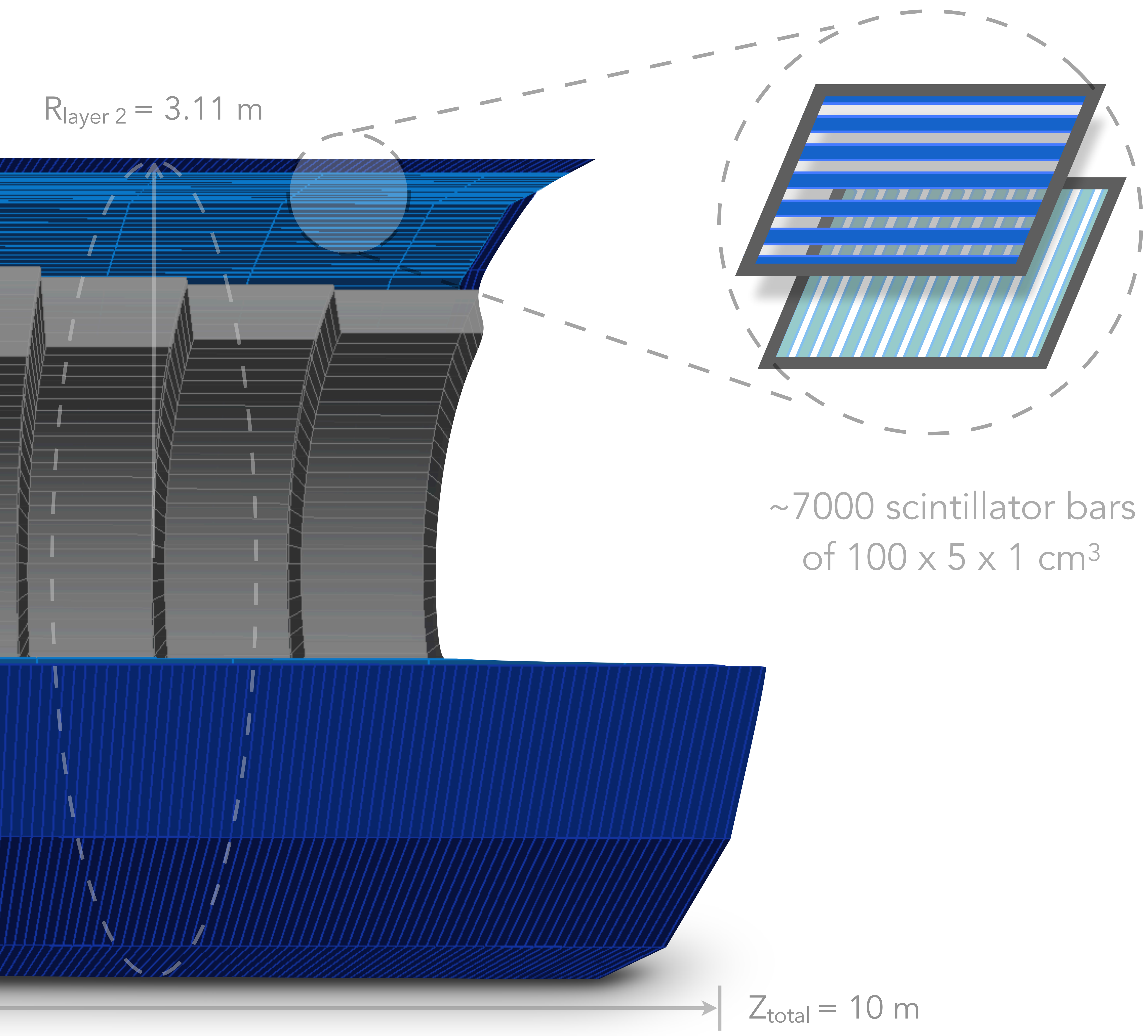
LHCb:

J/ψ at rest but only at forward rapidity

ALICE 3:

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

MID (plastic scintillator option)



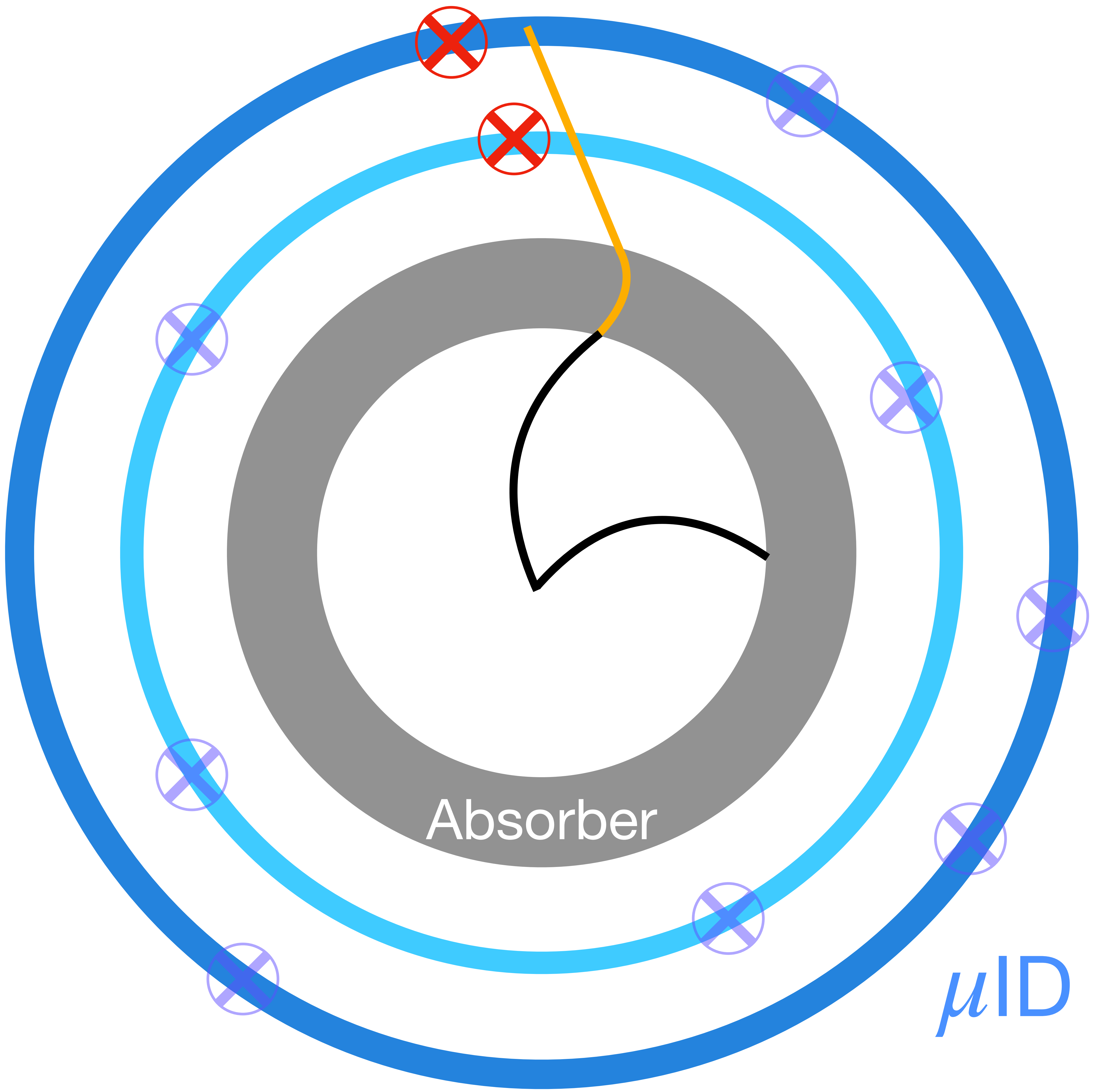
Baseline option:

Plastic scintillator bars 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)

	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

Muon tagging

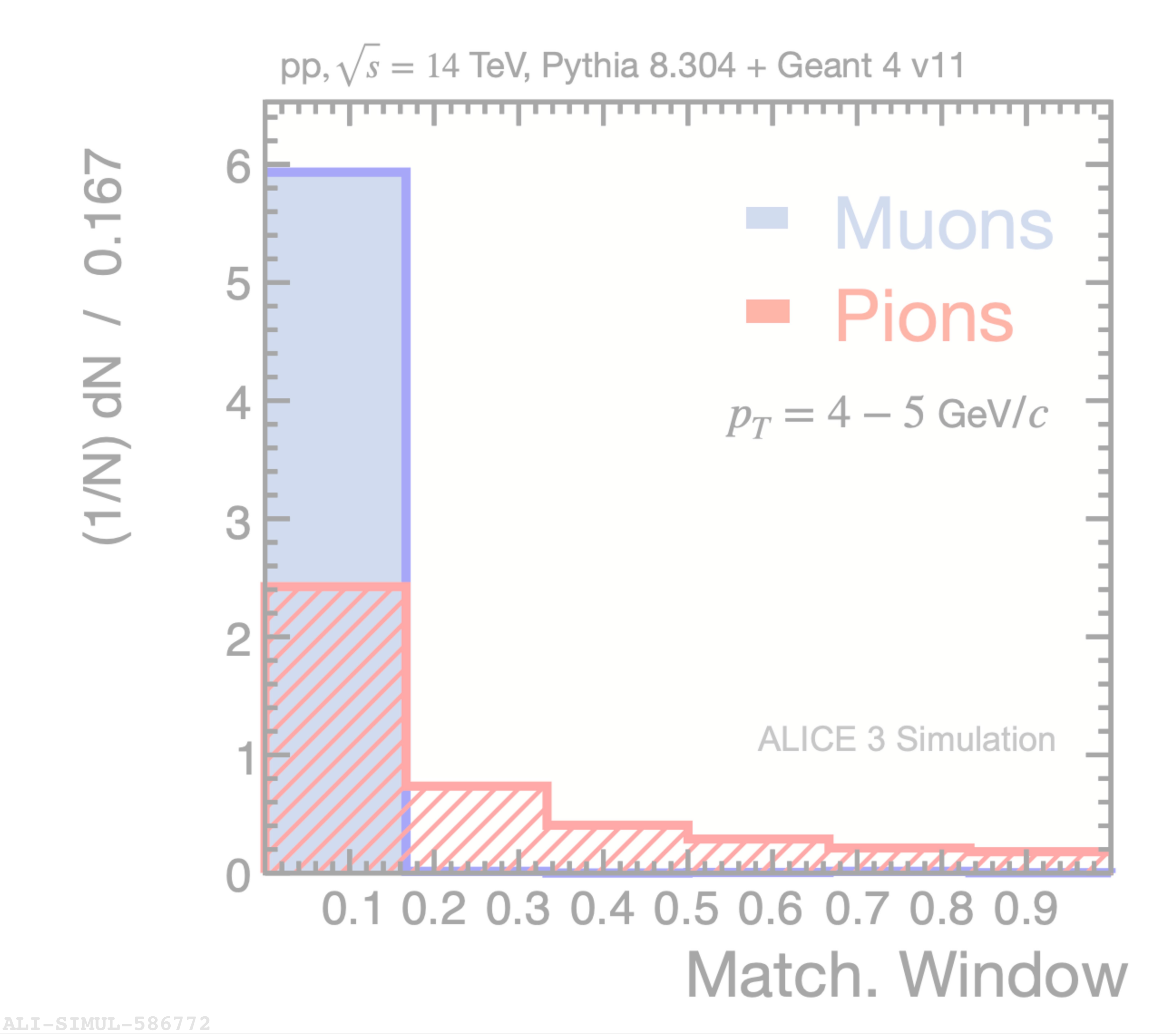


- Muon tagging is done by matching **activated bars** in the MID with tracks from the tracker
- All primary tracks are extrapolated to the MID
- Selection criteria are obtained via **boosted decision trees (BDT)**

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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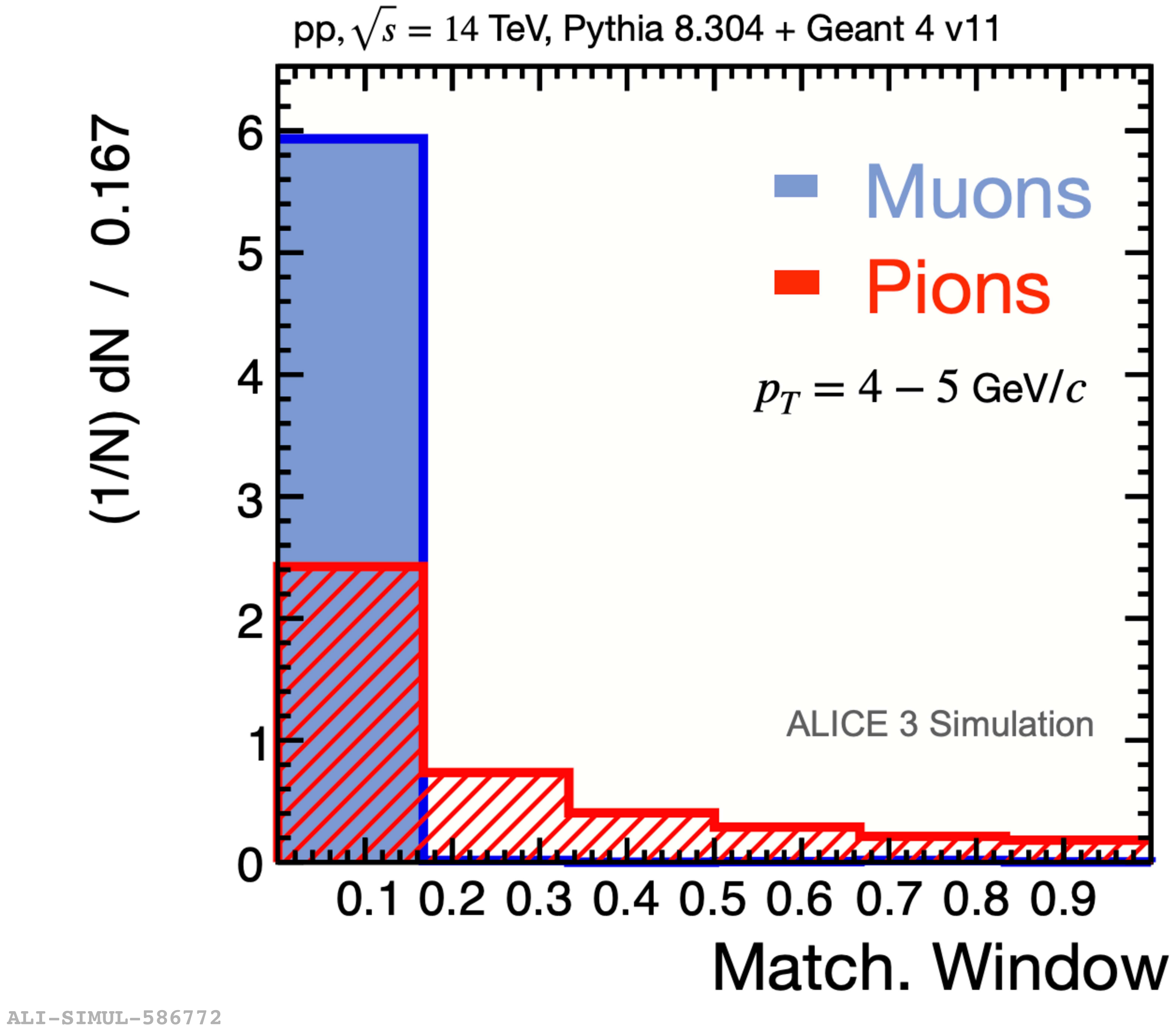

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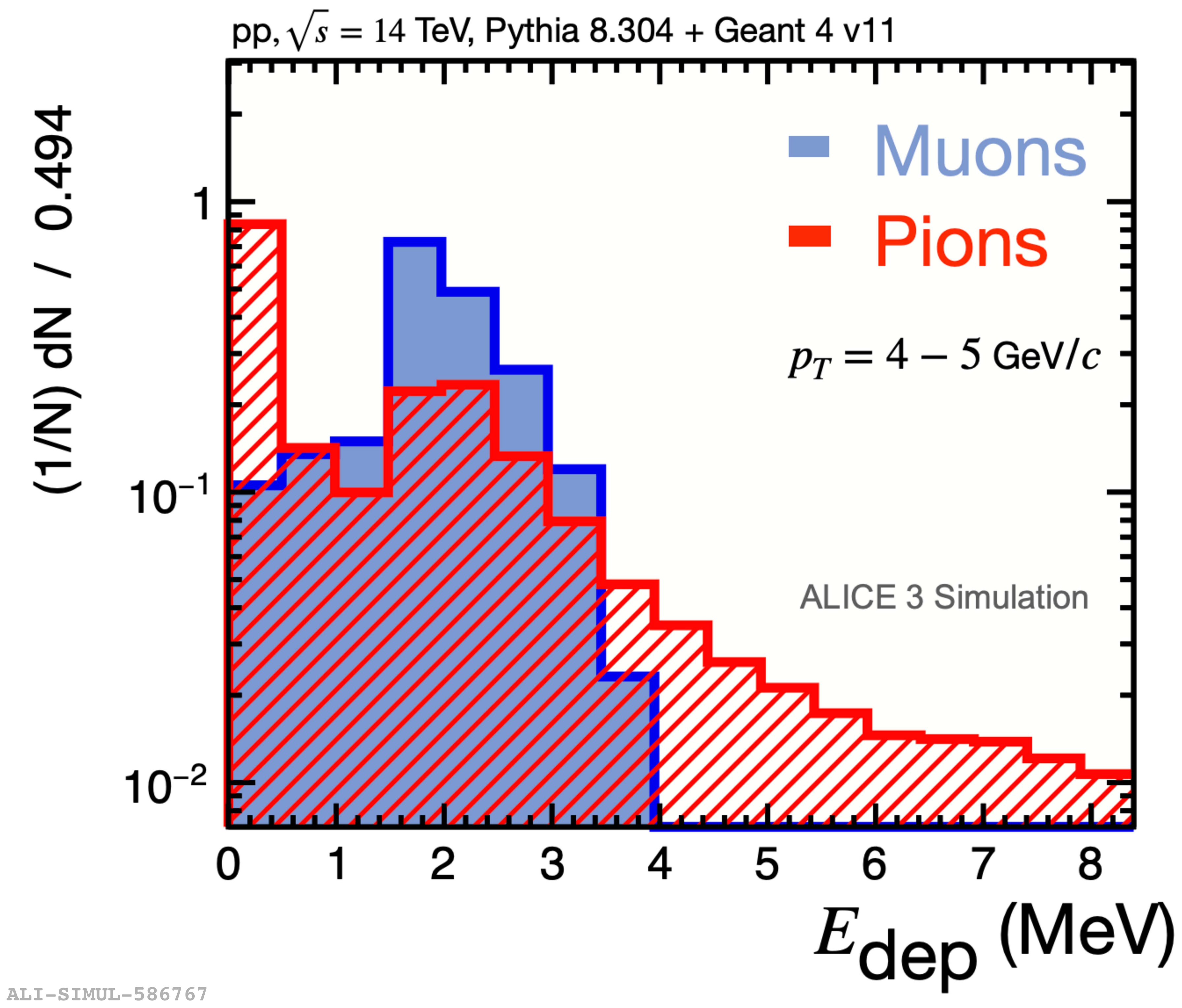

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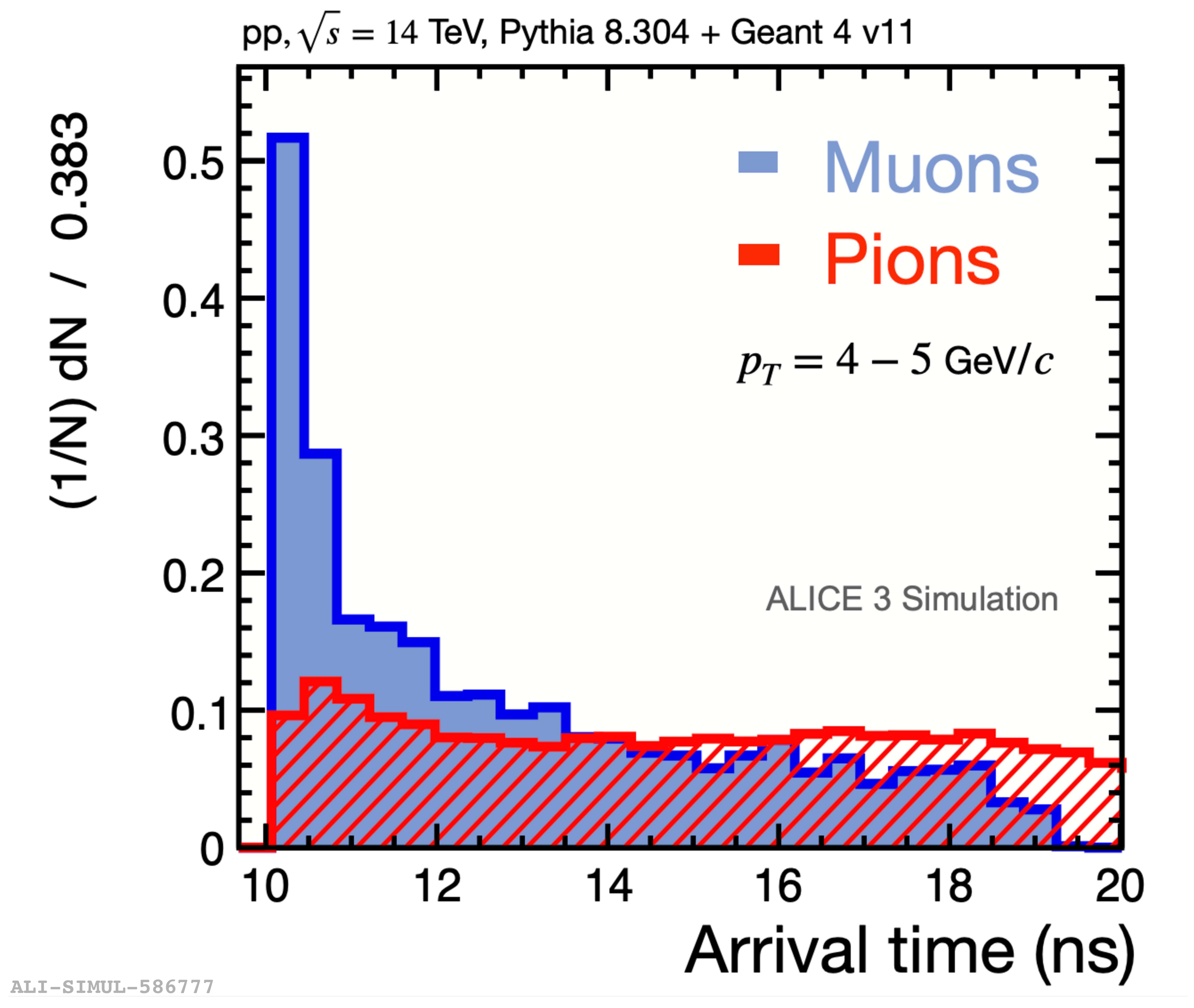
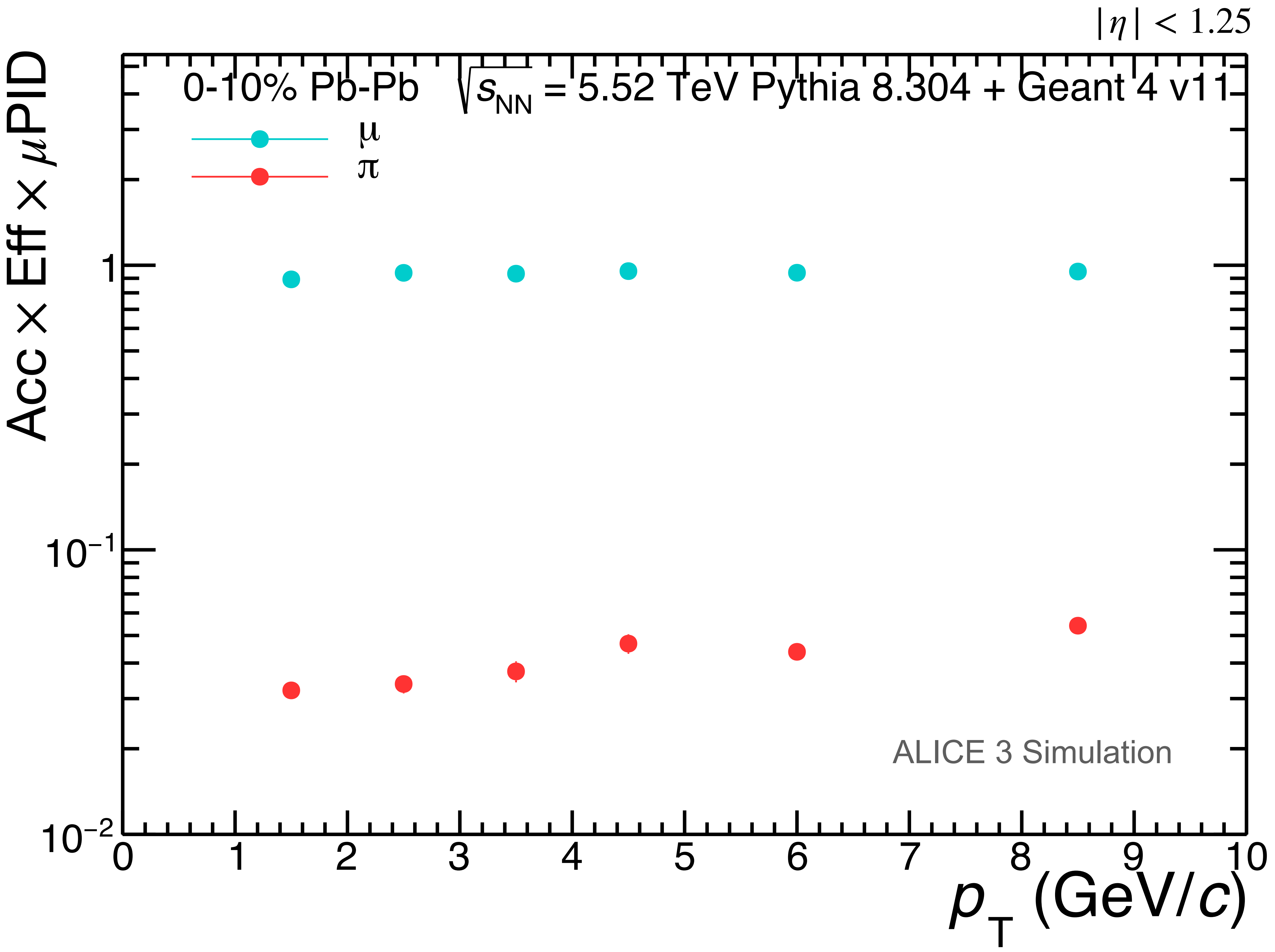
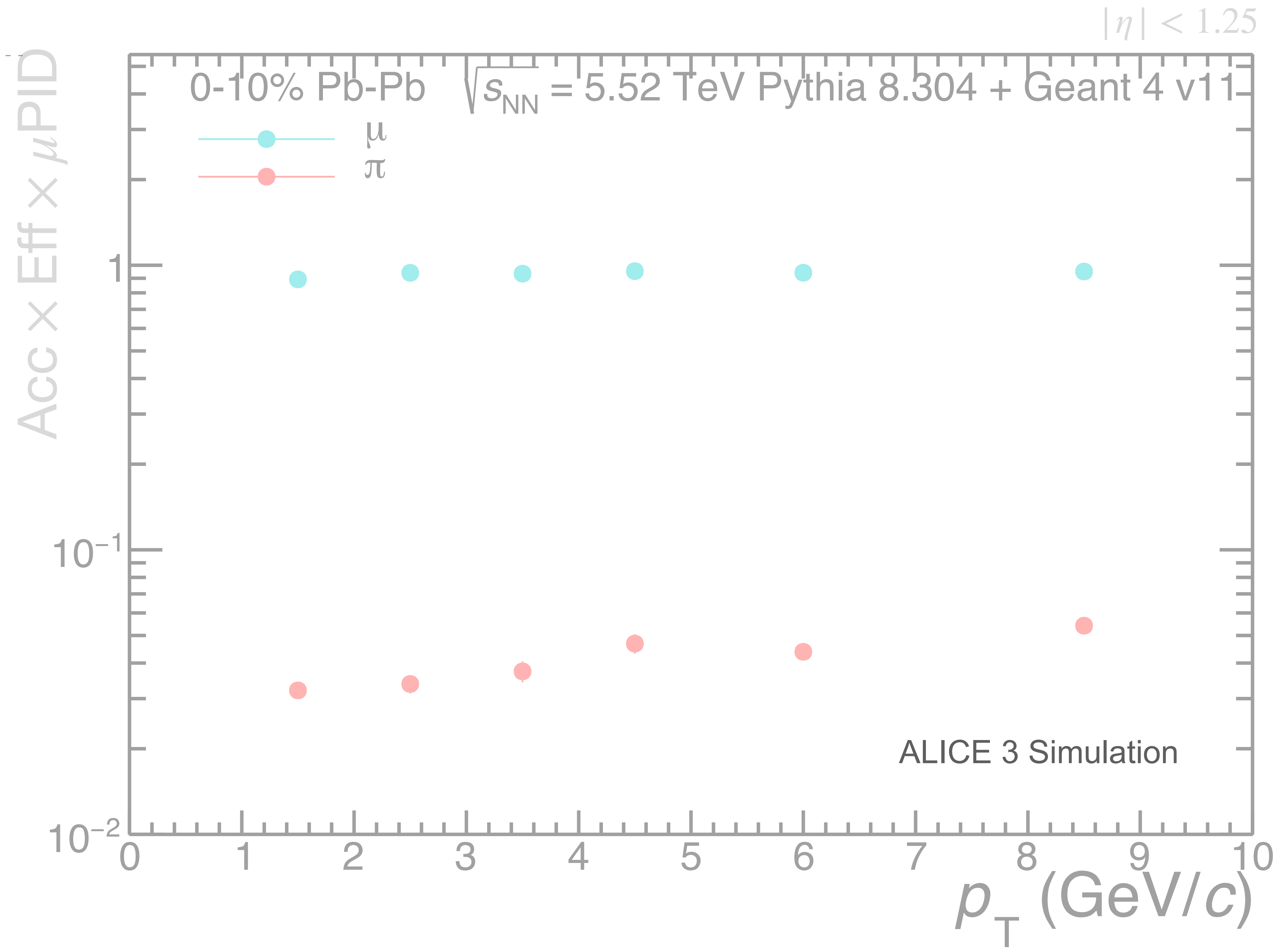


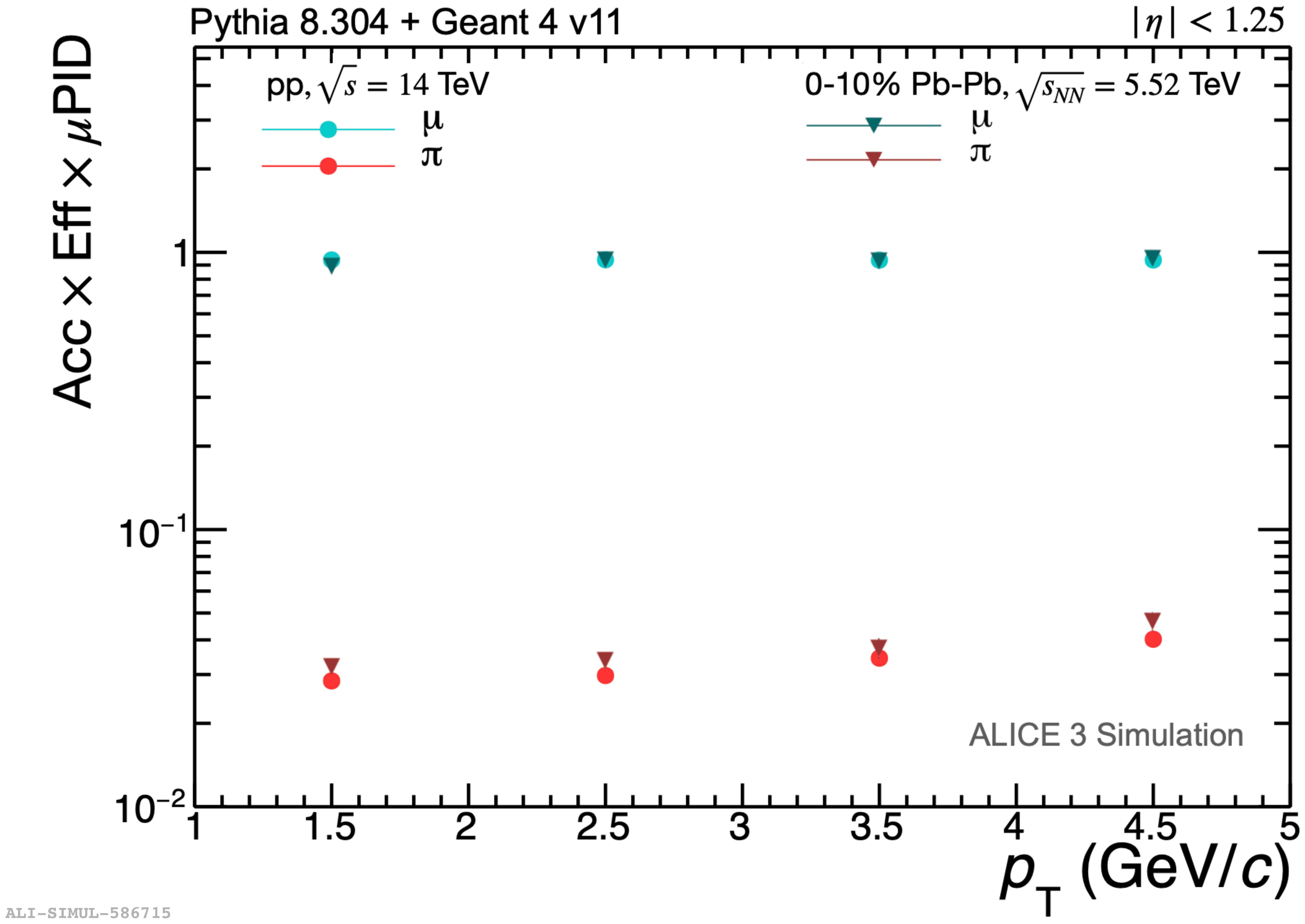
Pb-Pb and pp performance



- Muon efficiency around 94% for $p_{\mathrm{T}} > 1.5$ GeV/c
- Pion rejection at the level of 3-5%

Pb-Pb and pp performance





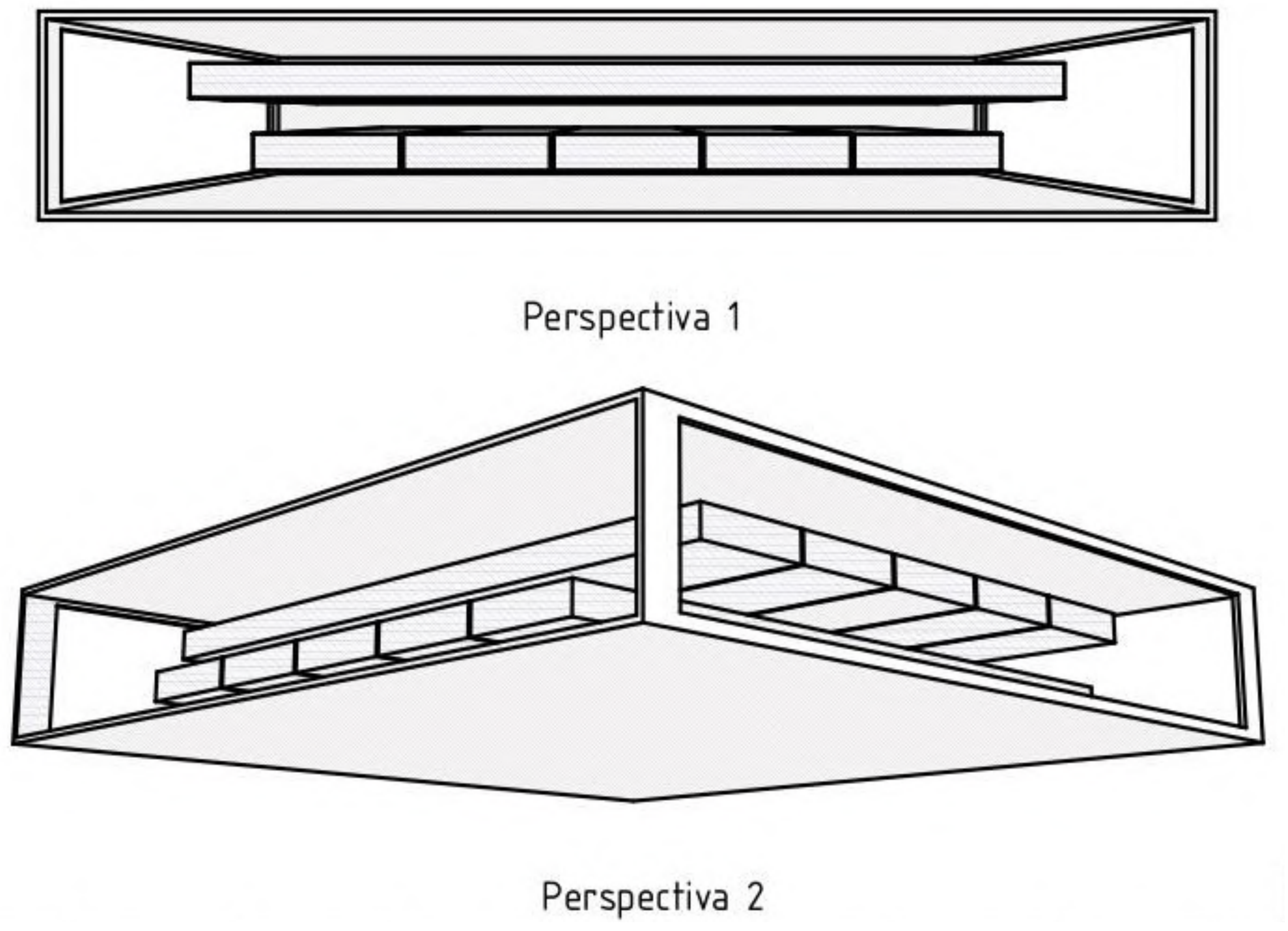
- Muon efficiency around 94% for $p_T > 1.5$ GeV/c
- Pion rejection at the level of 3-5%

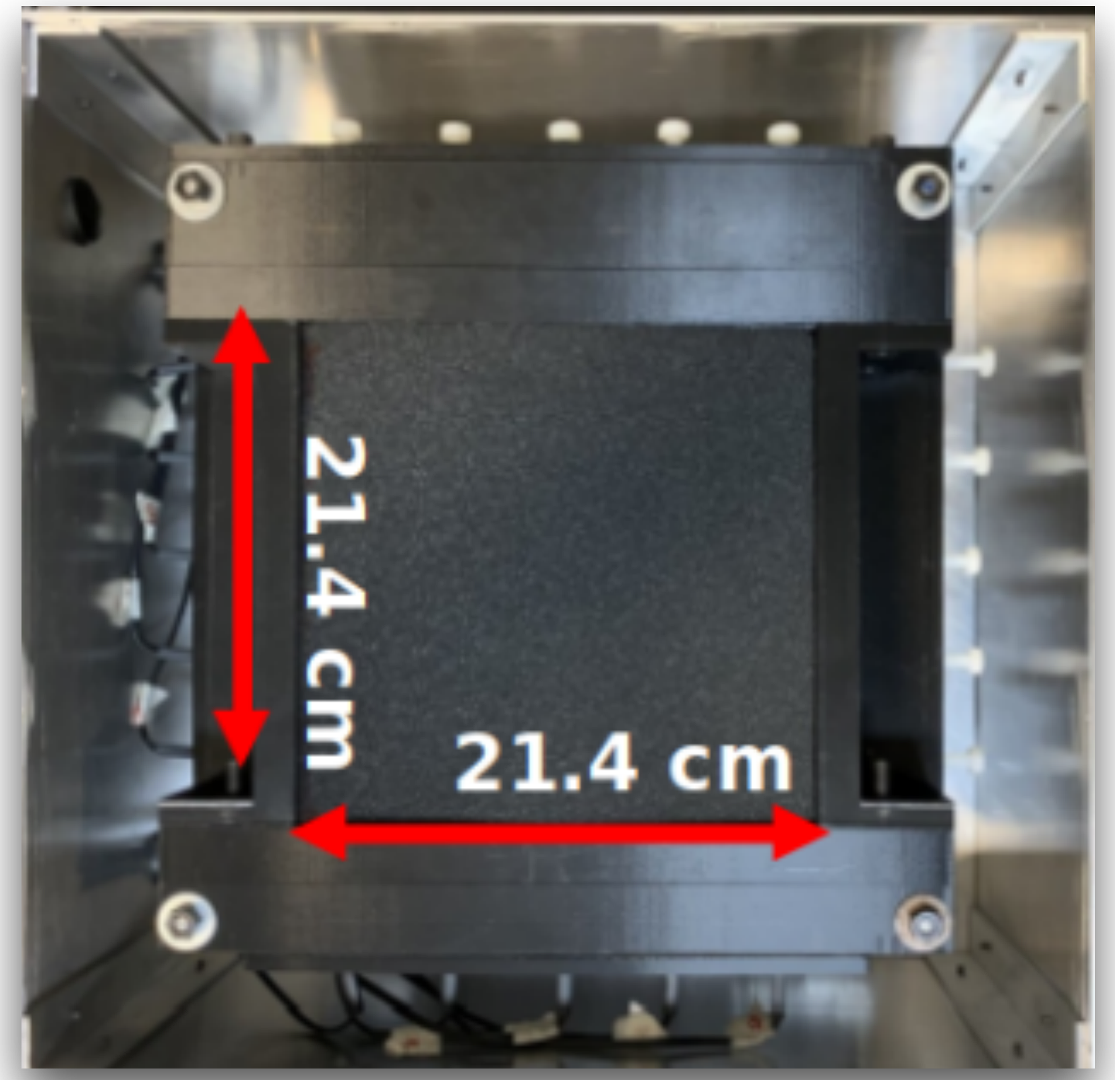
- Slightly above to the the pion rejection factor obtained in **pp simulations**

Test beam 2024

- A **small-size** prototype, based on plastic scintillators, has been tested

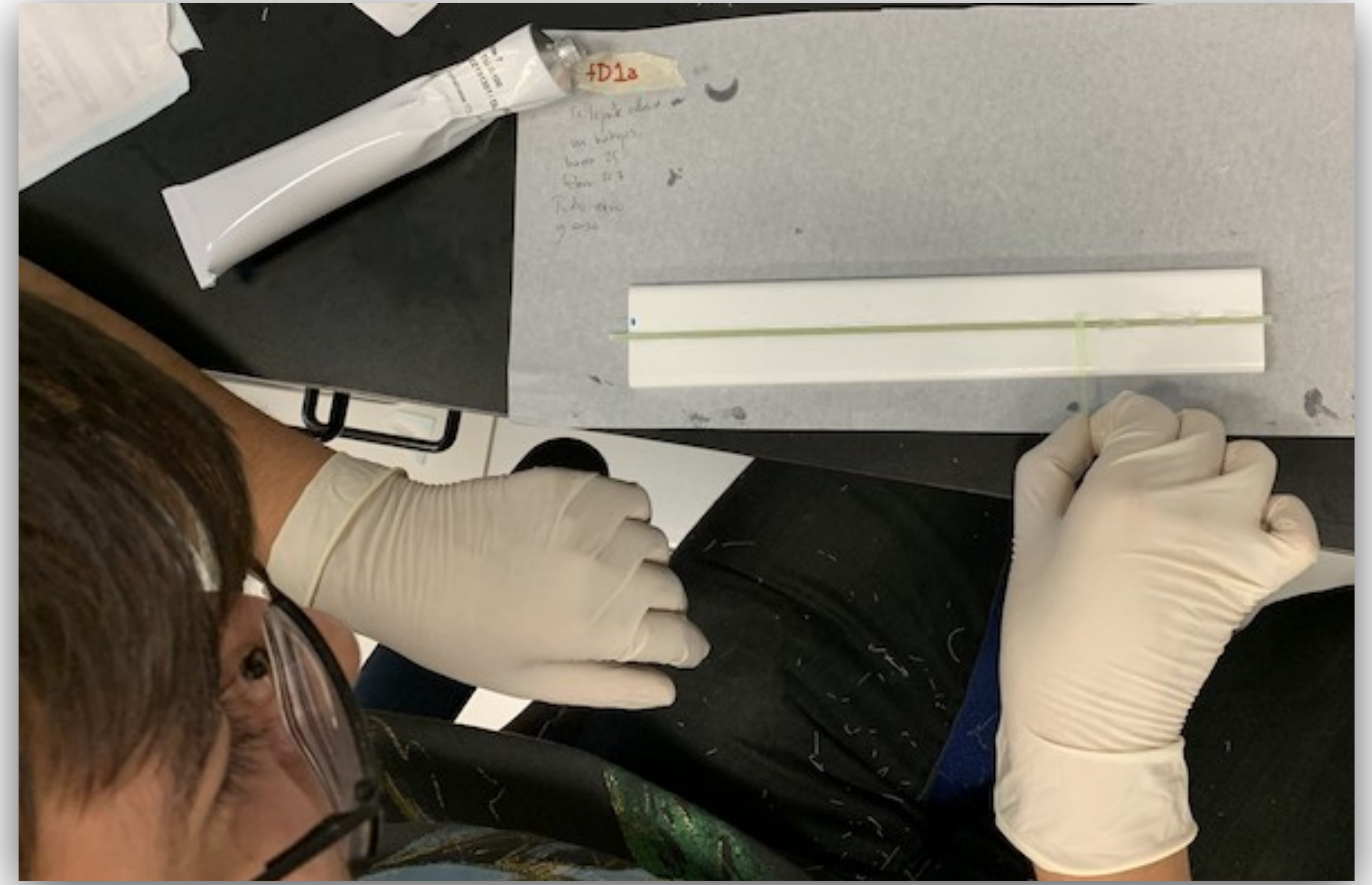
Figure by Antonio Paz (UANL)





Test beam 2024

- A **small-size** prototype, based on plastic scintillators, has been tested
- Constructed using FNAL-NICADD scintillators equipped with wavelength-shifting fibers and SiPM for readout



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- The performance of the prototype was done at CERN Proton Synchrotron

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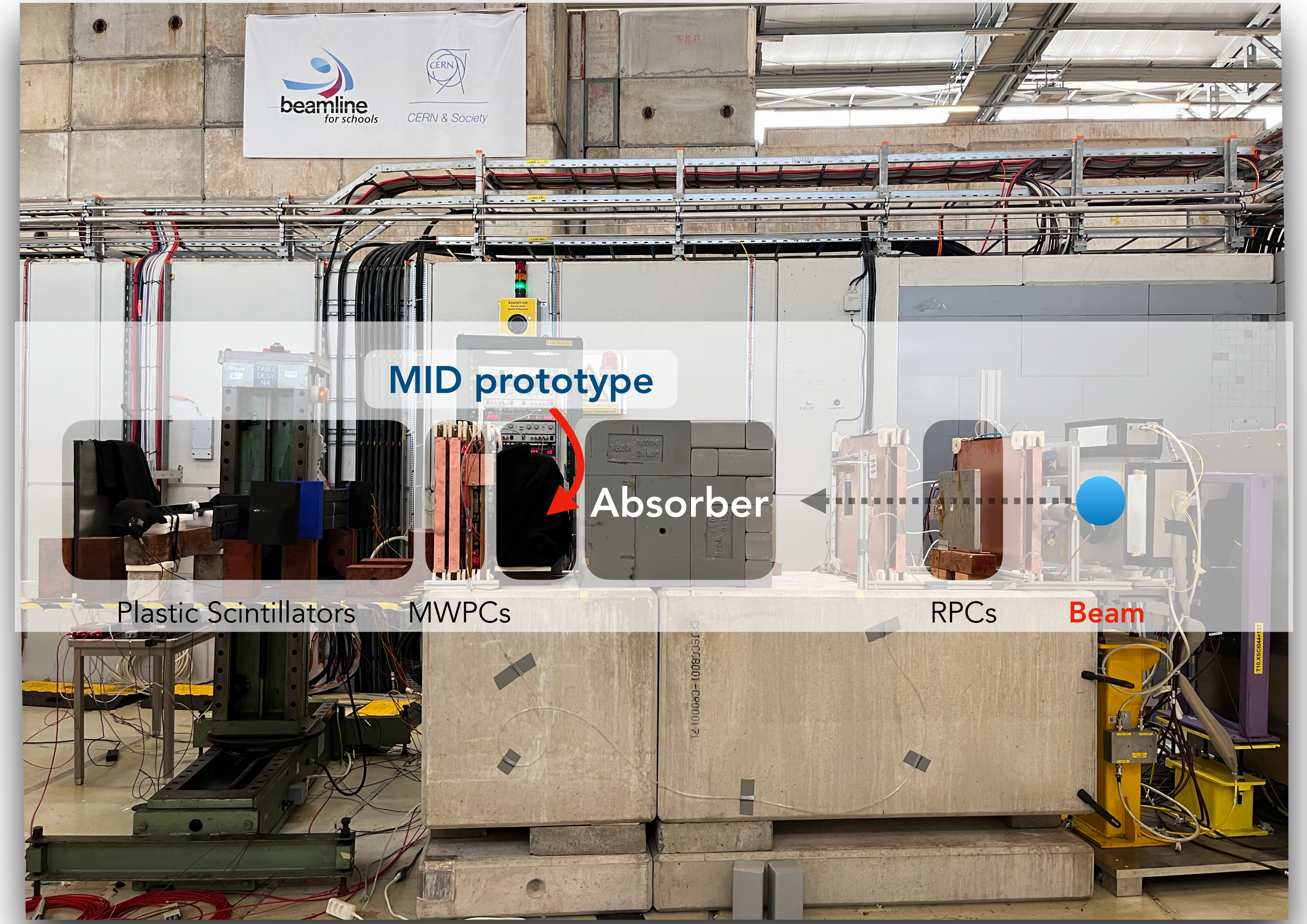
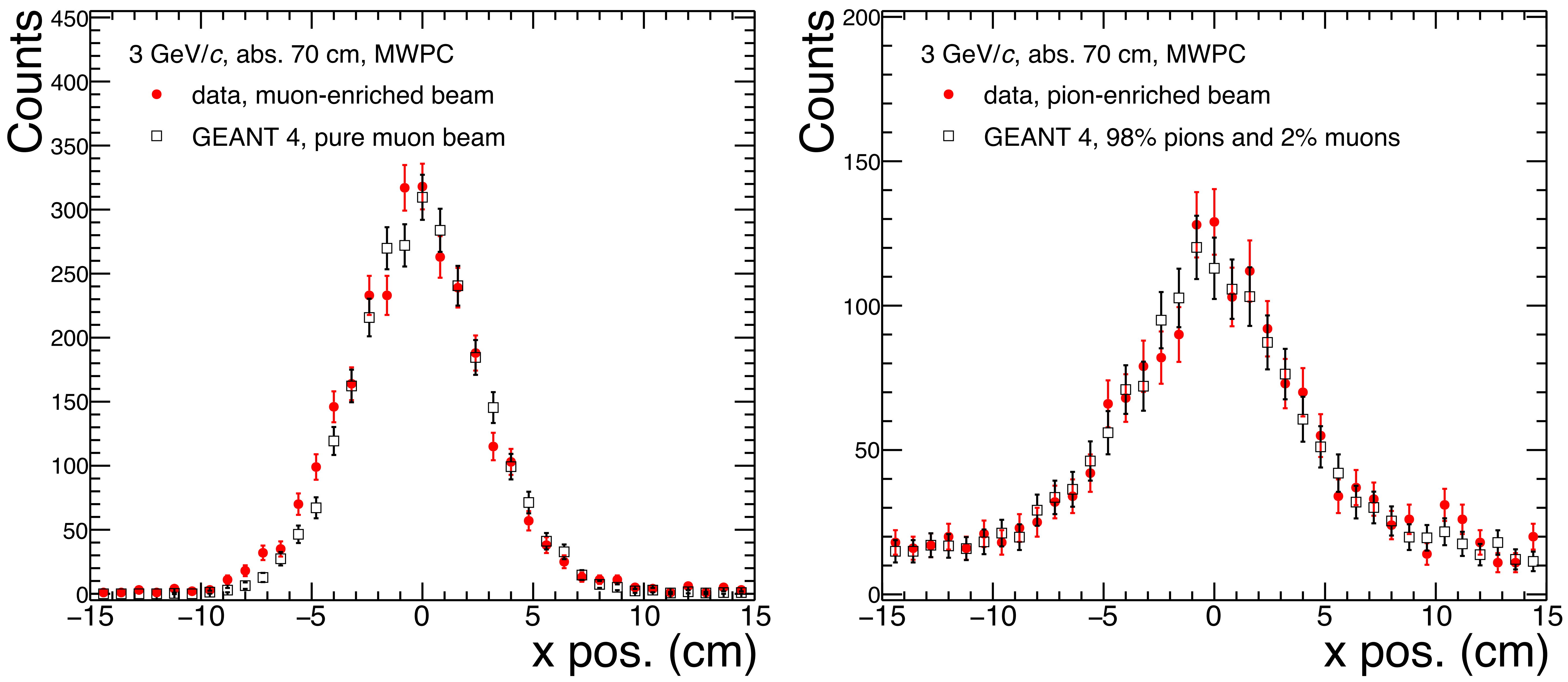


Test beam 2024

- **Results of the test beam have been [published]()**

- Analysis considering enriched pion-muon beams and different absorber lengths is reported

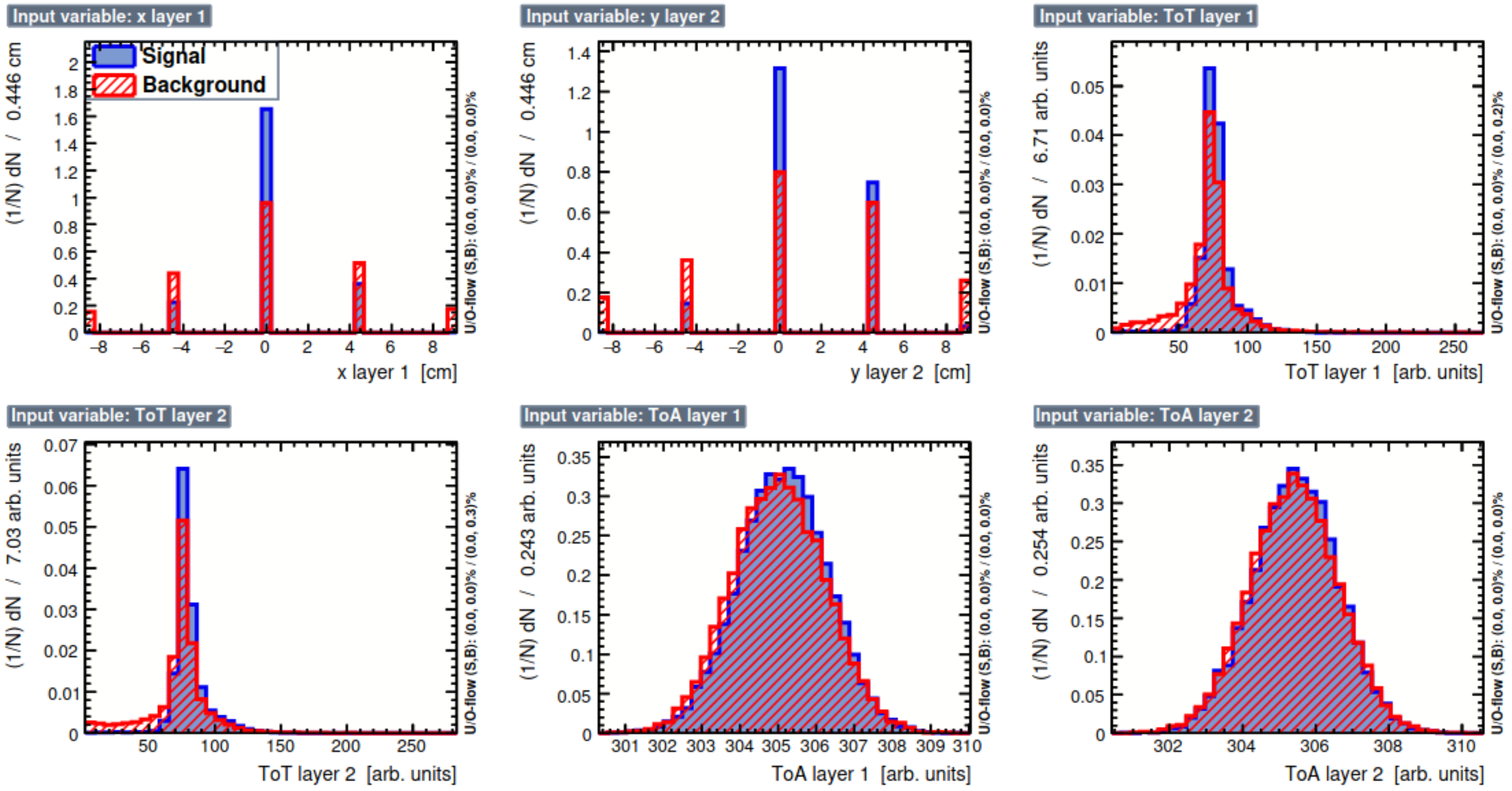
Jesús Méndez *et al* 2025 *JINST* **20** P09015



Test beam 2024

- **Results of the test beam have been [published]**
- Analysis considering enriched pion-muon beams and different absorber lengths is reported.
- The muon labeling algorithm, implemented traditionally and using machine learning, is compared to determine the best hadron suppression.

Jesús Méndez *et al* 2025 *JINST* **20** P09015



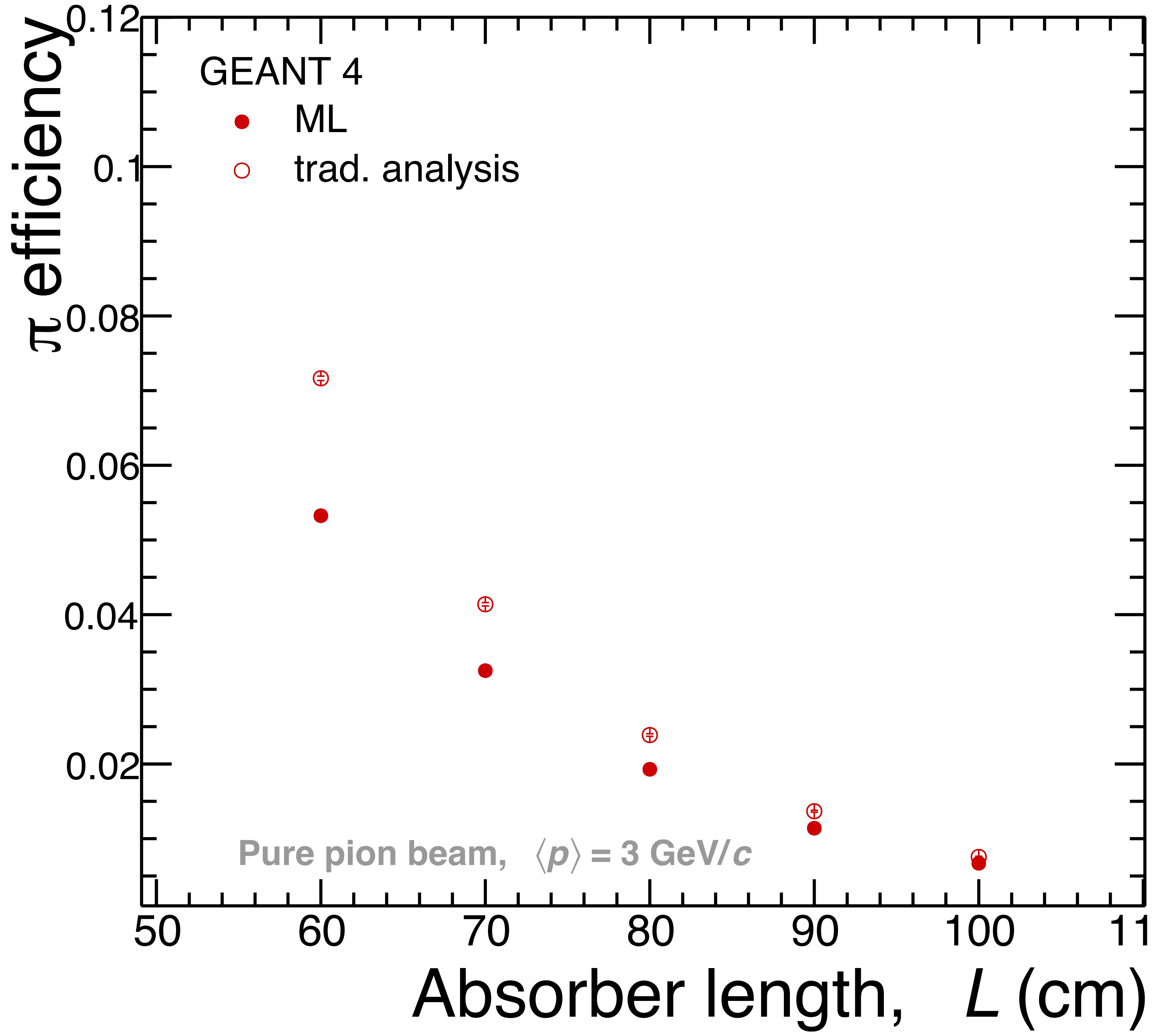
Results

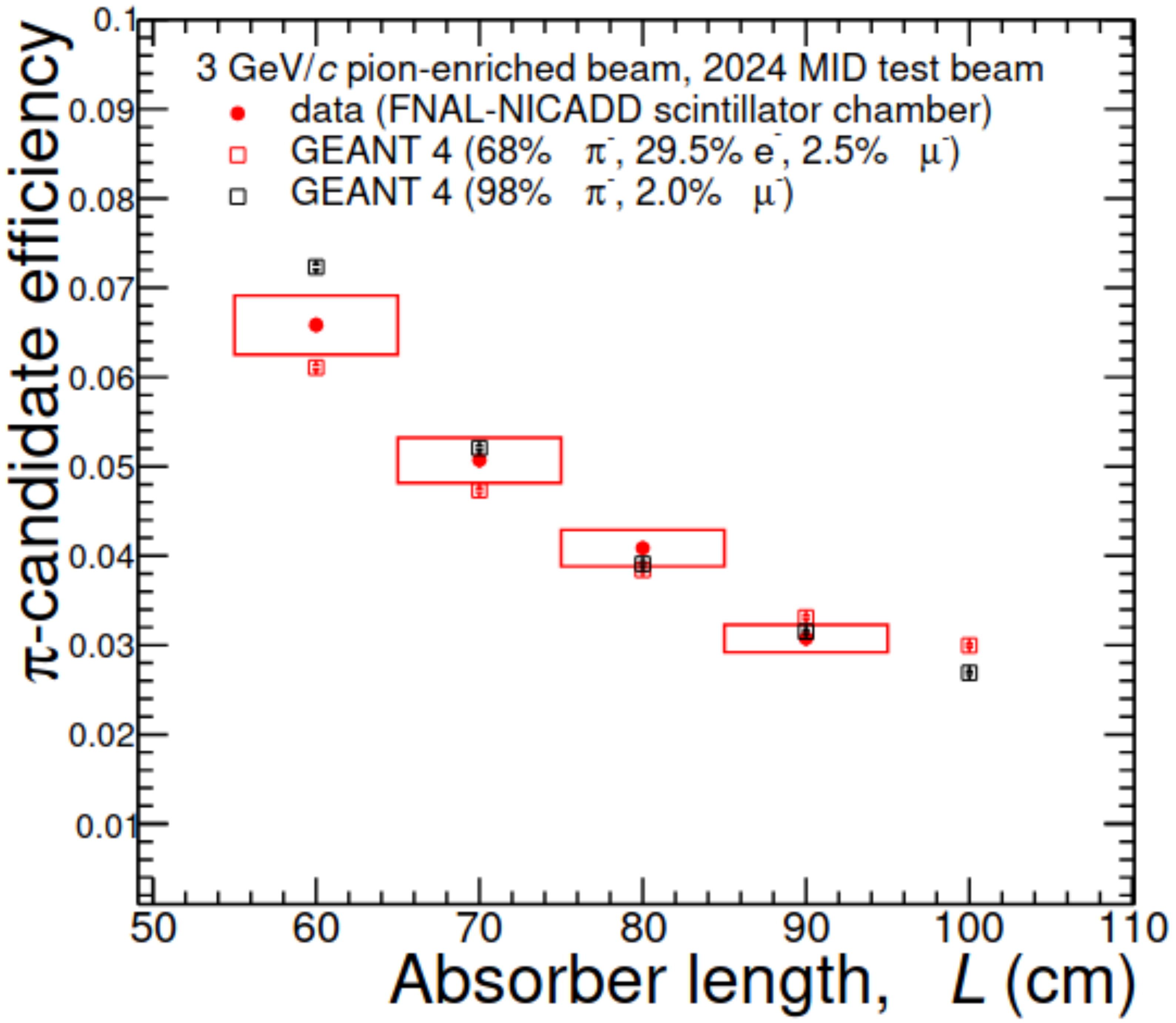
BDT analysis leads to ~15% improvement

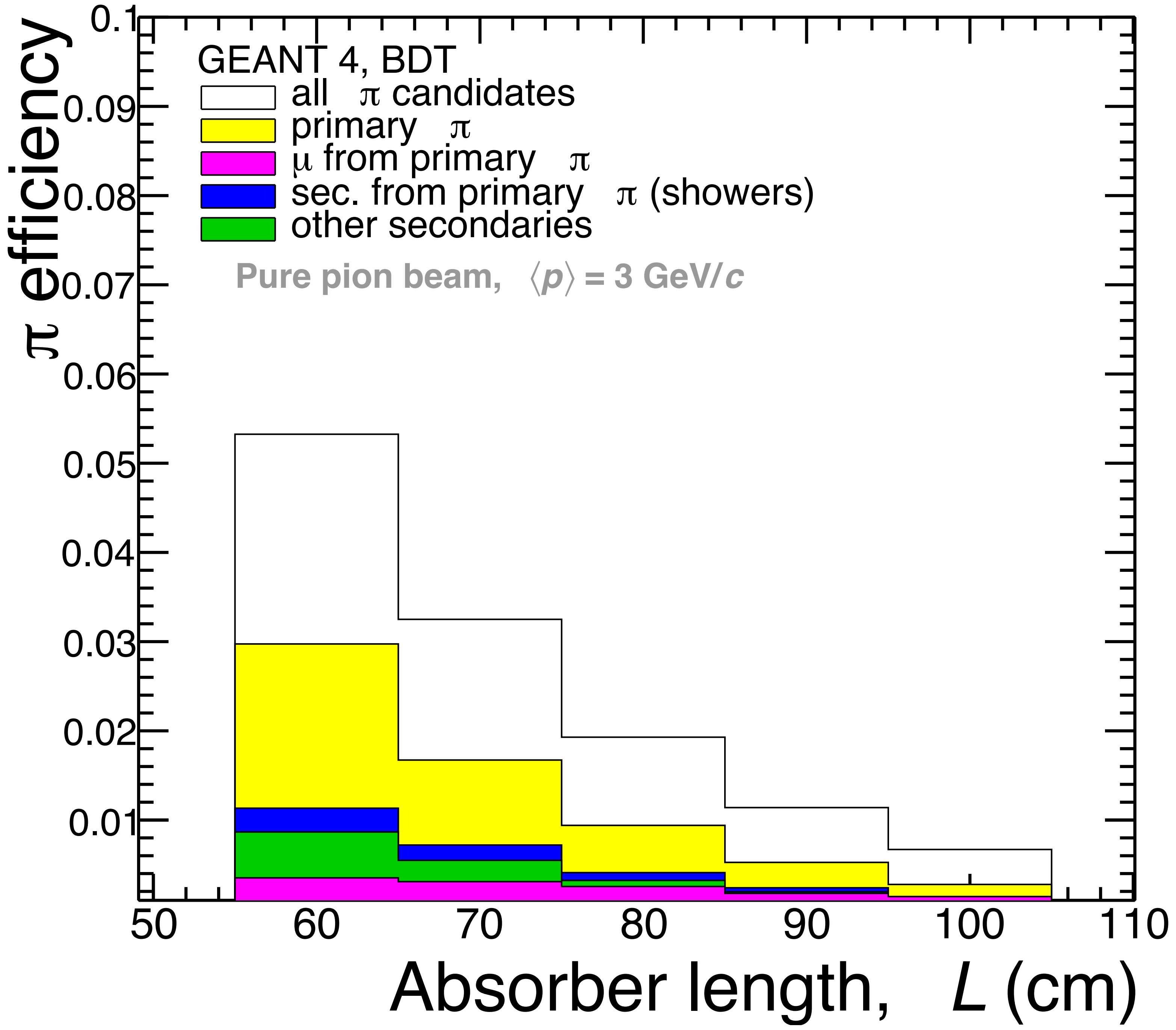
High beam contamination

Pure beam gives a ~3% pion efficiency

(compatible with MC simulations)



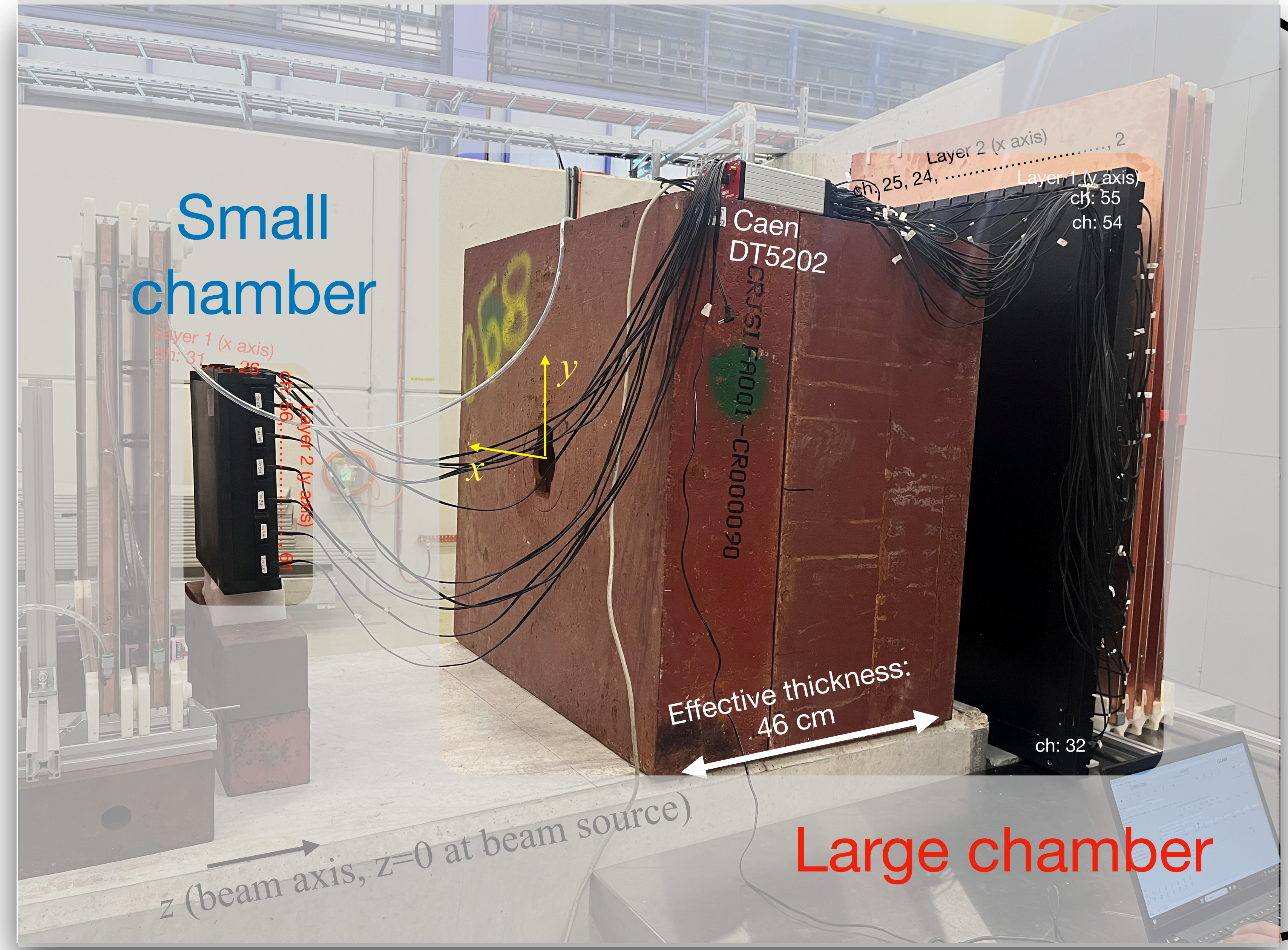




Jesús Méndez *et al* 2025 *JINST* **20** P09015

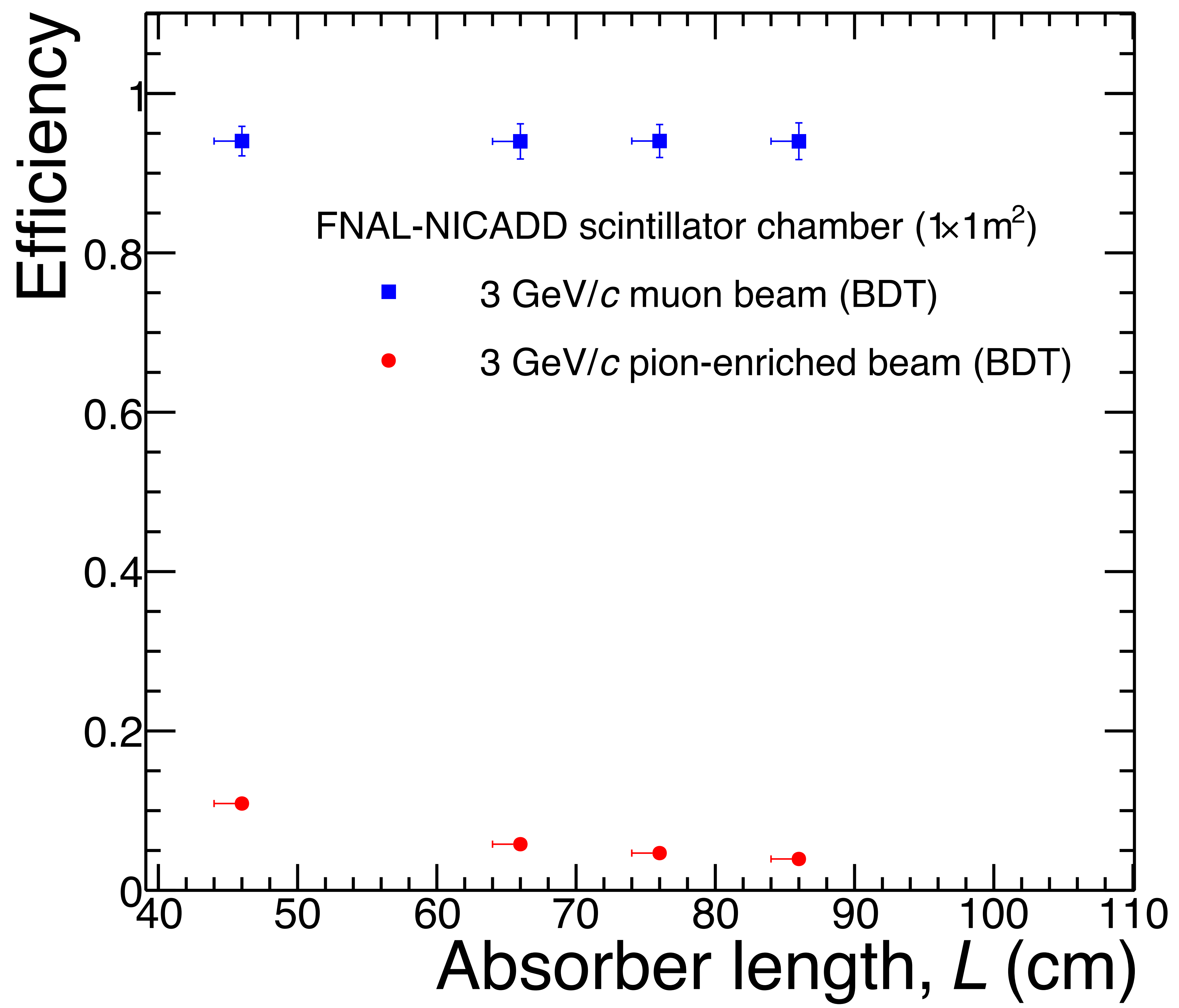
Test beam 2025

- A large chamber (bars of $100 \times 4 \times 1\ \text{cm}^3$) has been also tested
- A new mechanical framework of the chamber was included
- To remove electron contamination, a high-pressure threshold Cherenkov counter was used, providing a cleaner beam than in previous studies

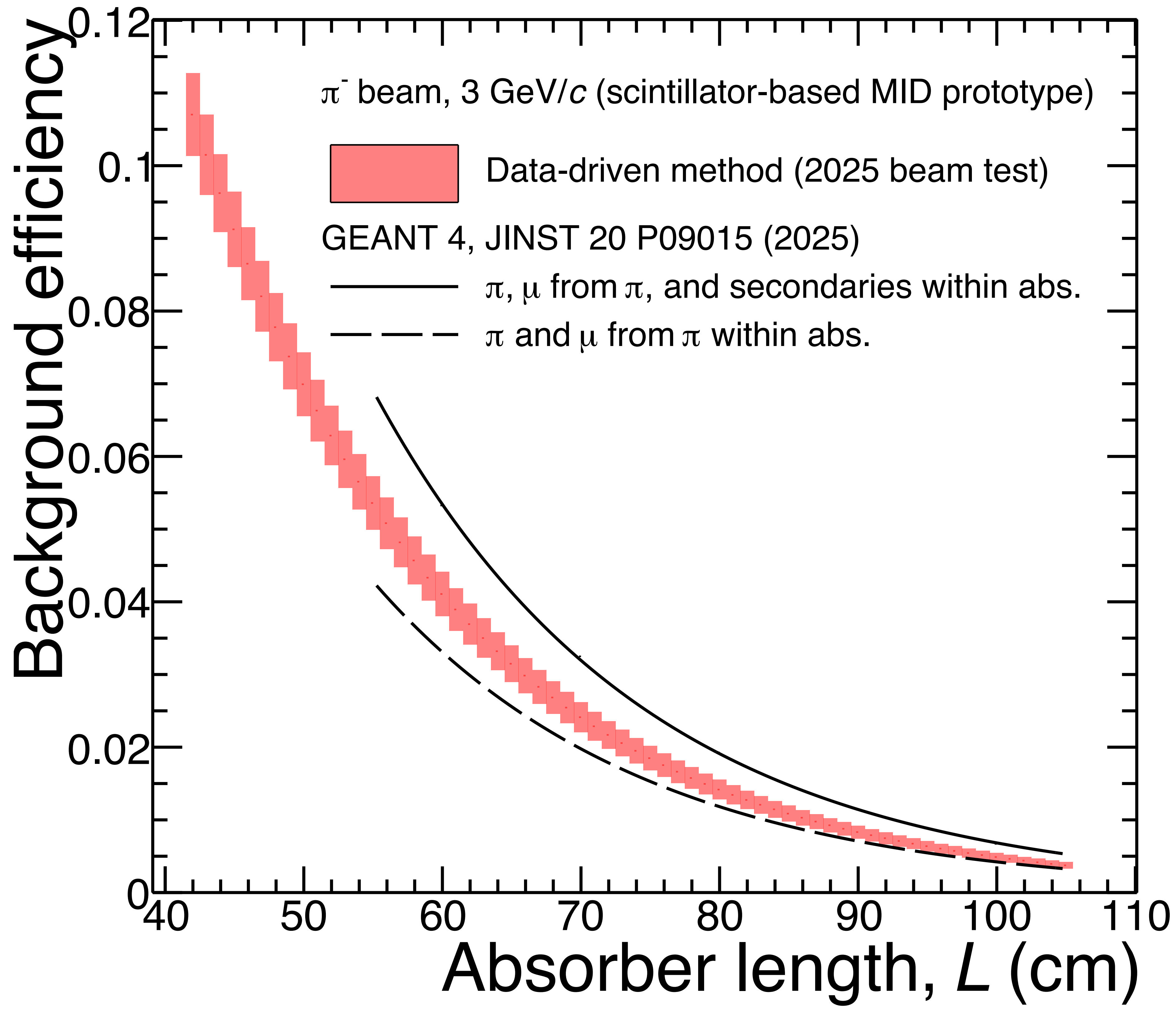


Results

Muon efficiency of 94% would be sufficient to give a fake-muon efficiency of 2.4% for a 70 cm-thick absorber

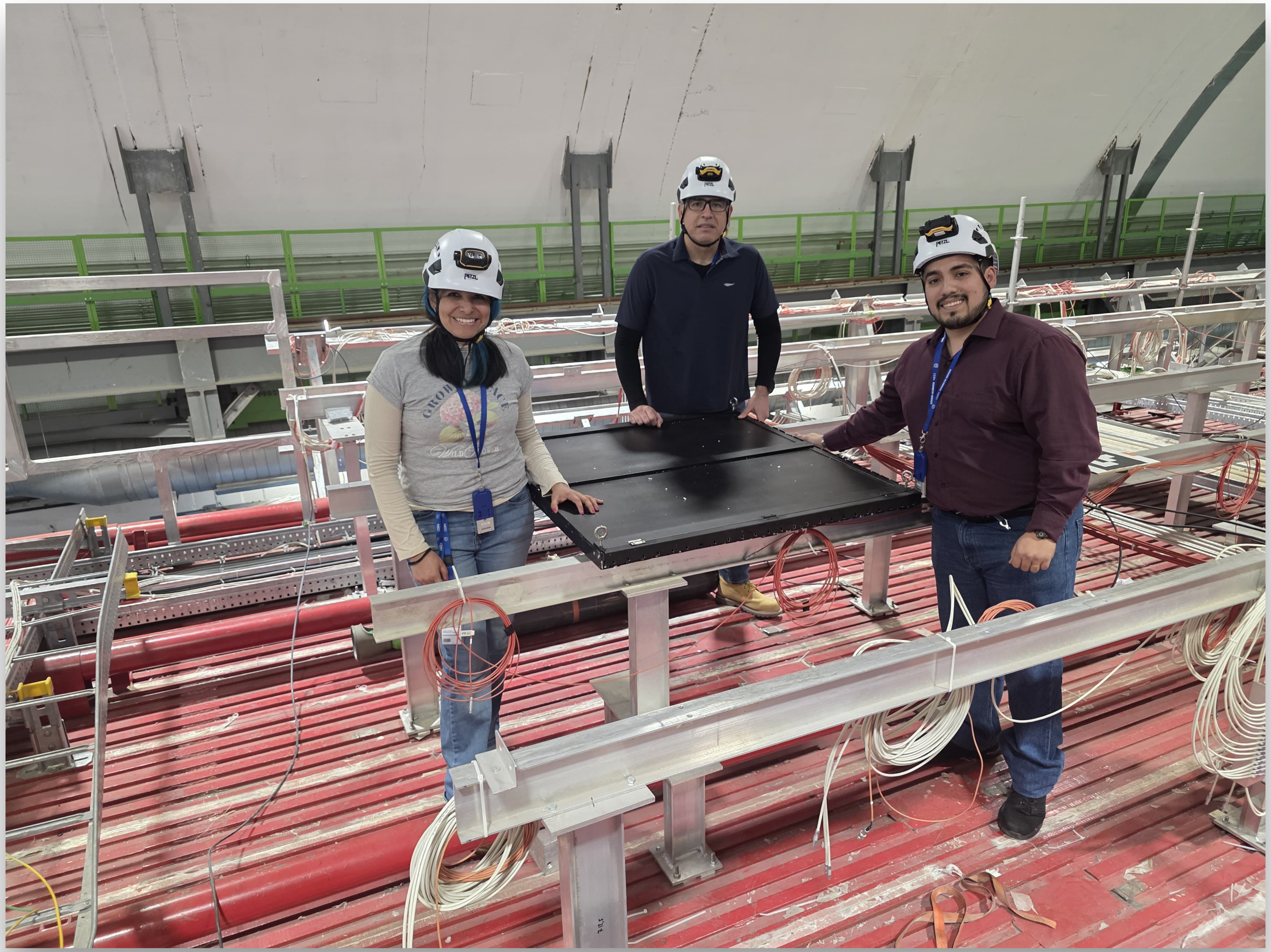


Background efficiency using the big prototype was able to further suppress the contribution from other secondaries



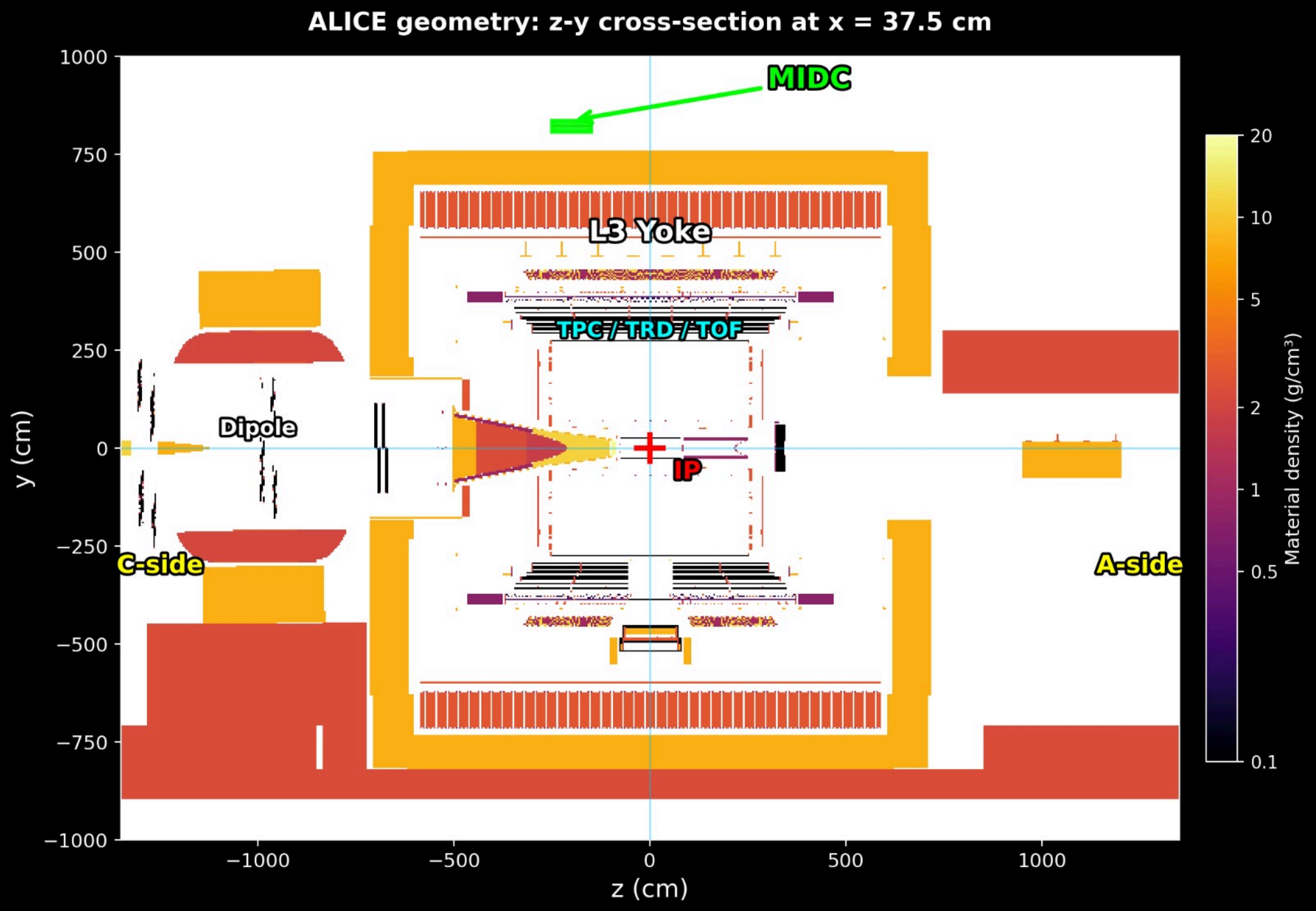
Ruben Alfaro Molina et al 2026 JINST 21 P05017

Test beam 2026



- Simulations of the MID prototype inside ALICE cavern are on their way
- A sensitive detector inside the current O^2 implementation of ALICE 2 has been added

Test beam simulations



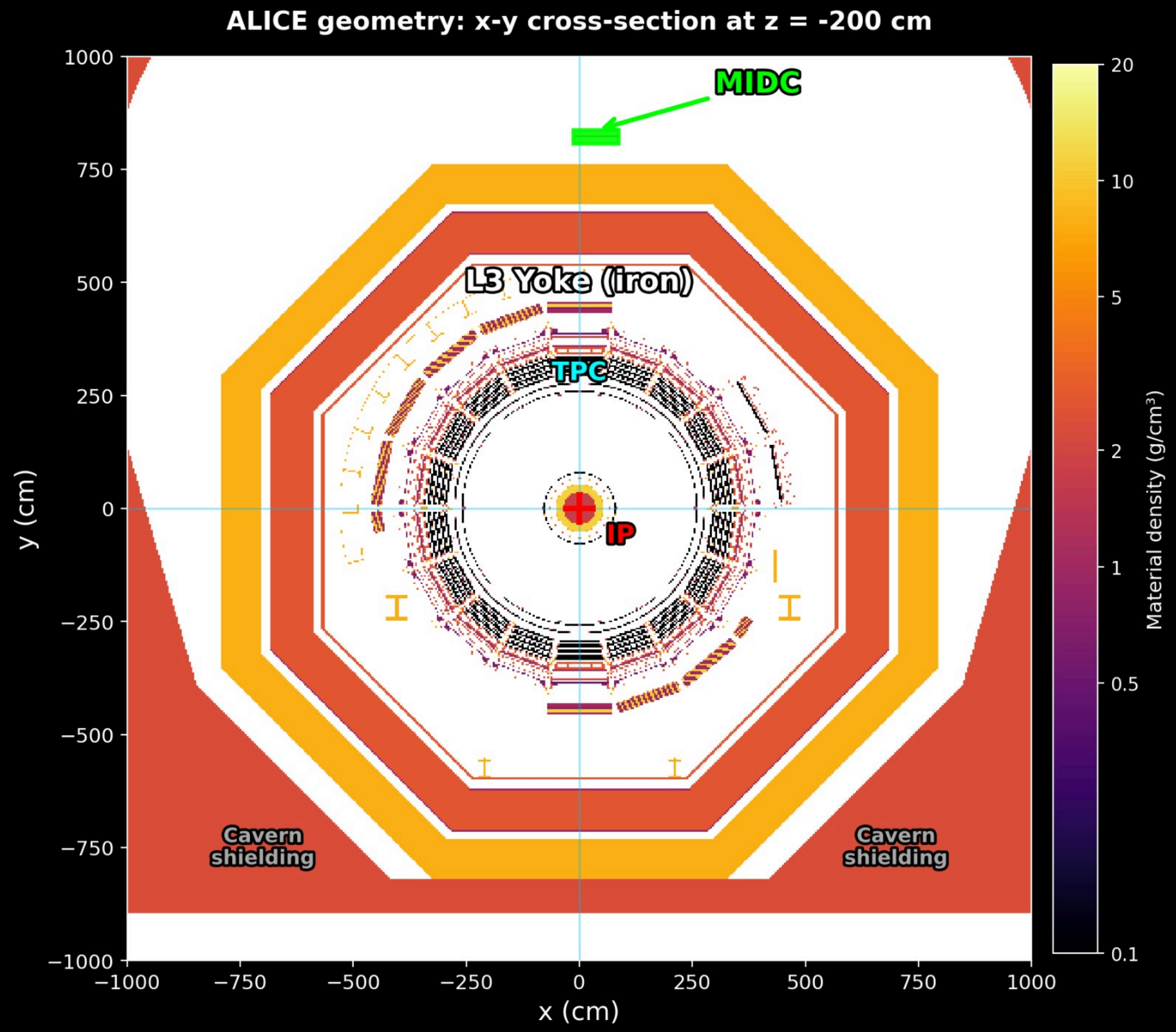
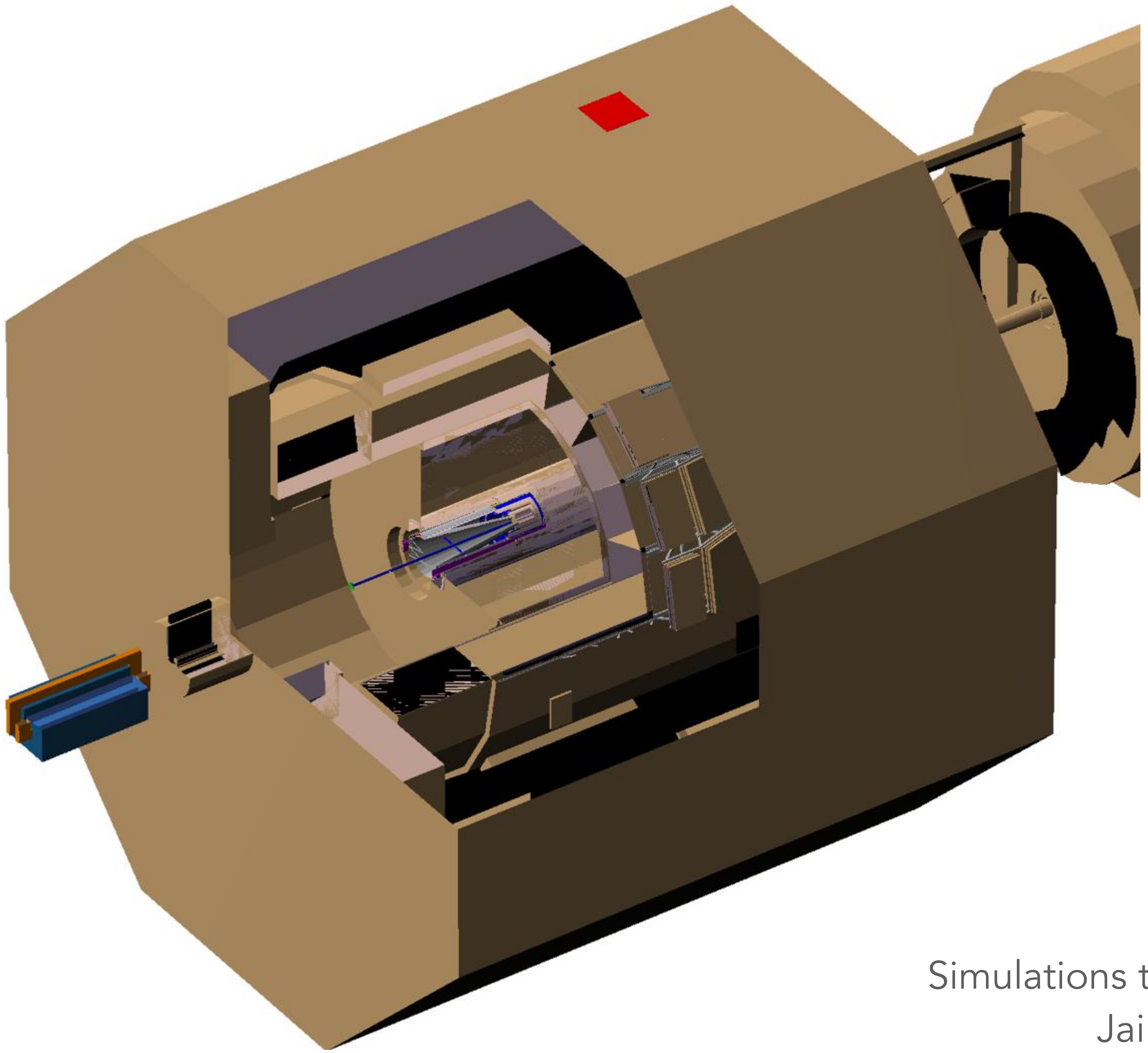
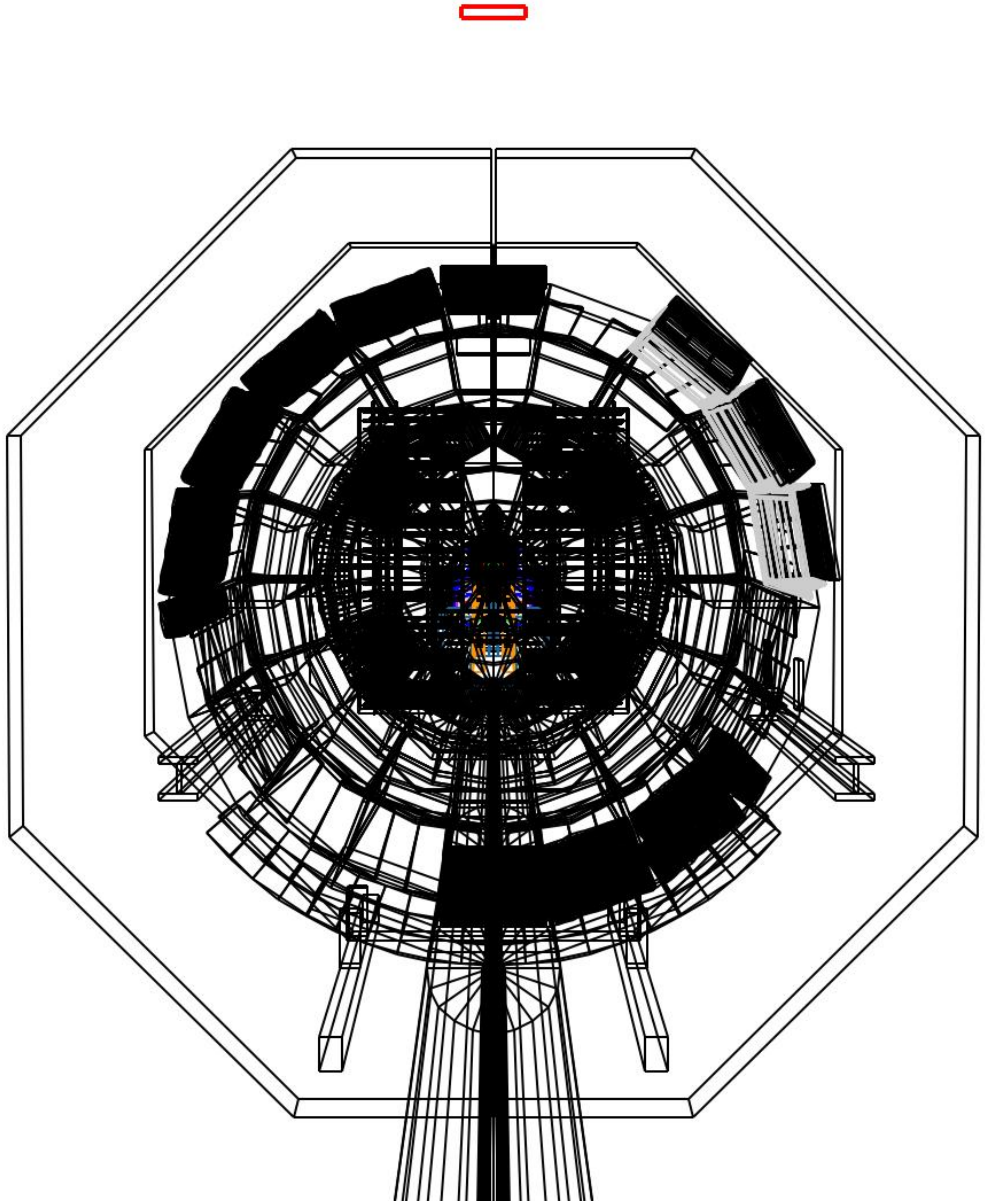


Figure by Oscar Jair Miranda Ibarra

Test beam simulations





Simulations to be performed by Oscar Jair Miranda Ibarra

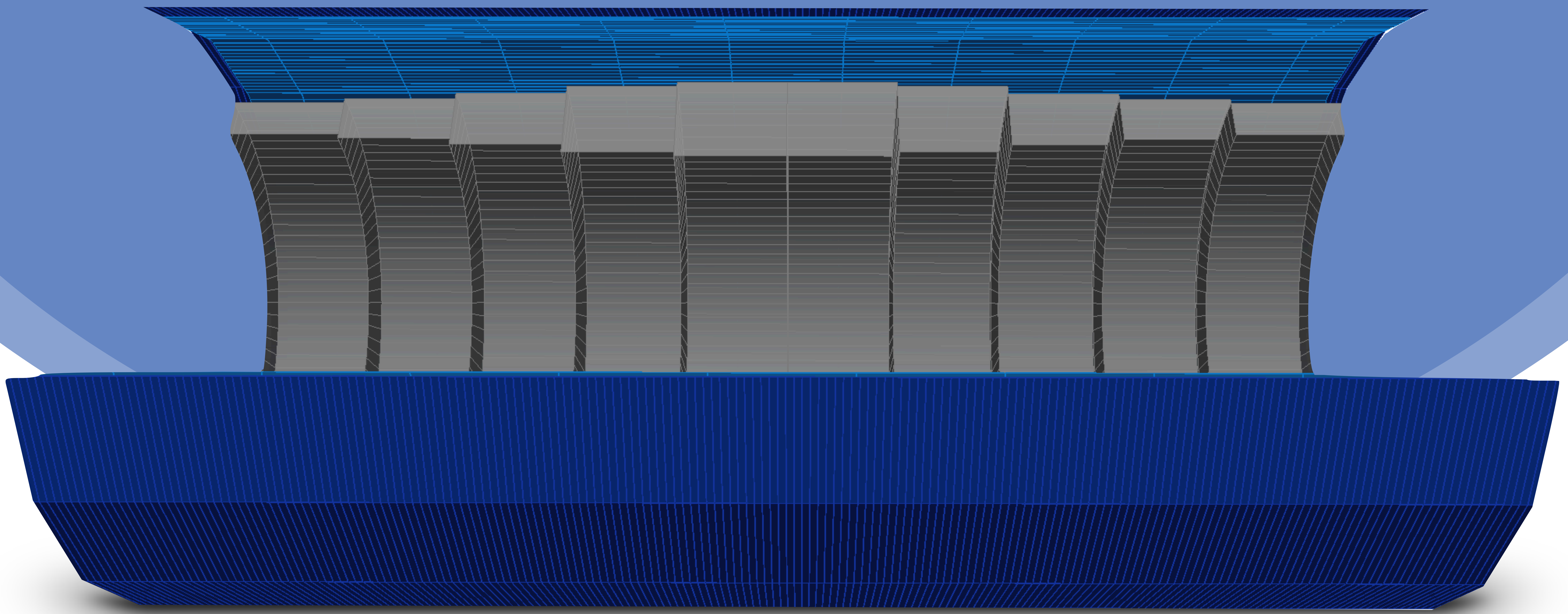
Summary

- **Simulations of the MID show a competitive performance in both pp and Pb-Pb simulations**
- **Muon tagging algorithm tested on prototypes show good performance**
- **Background rejection factor in a competitive value to fulfill physics program**
- **The expected radiation load does not represent a problem for plastic scintillators + SiPM**
- **MID front-end card being developed**
- **The preparation of the technical design report will be done in the next months**

Scintillators represent an excellent option for the MID

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

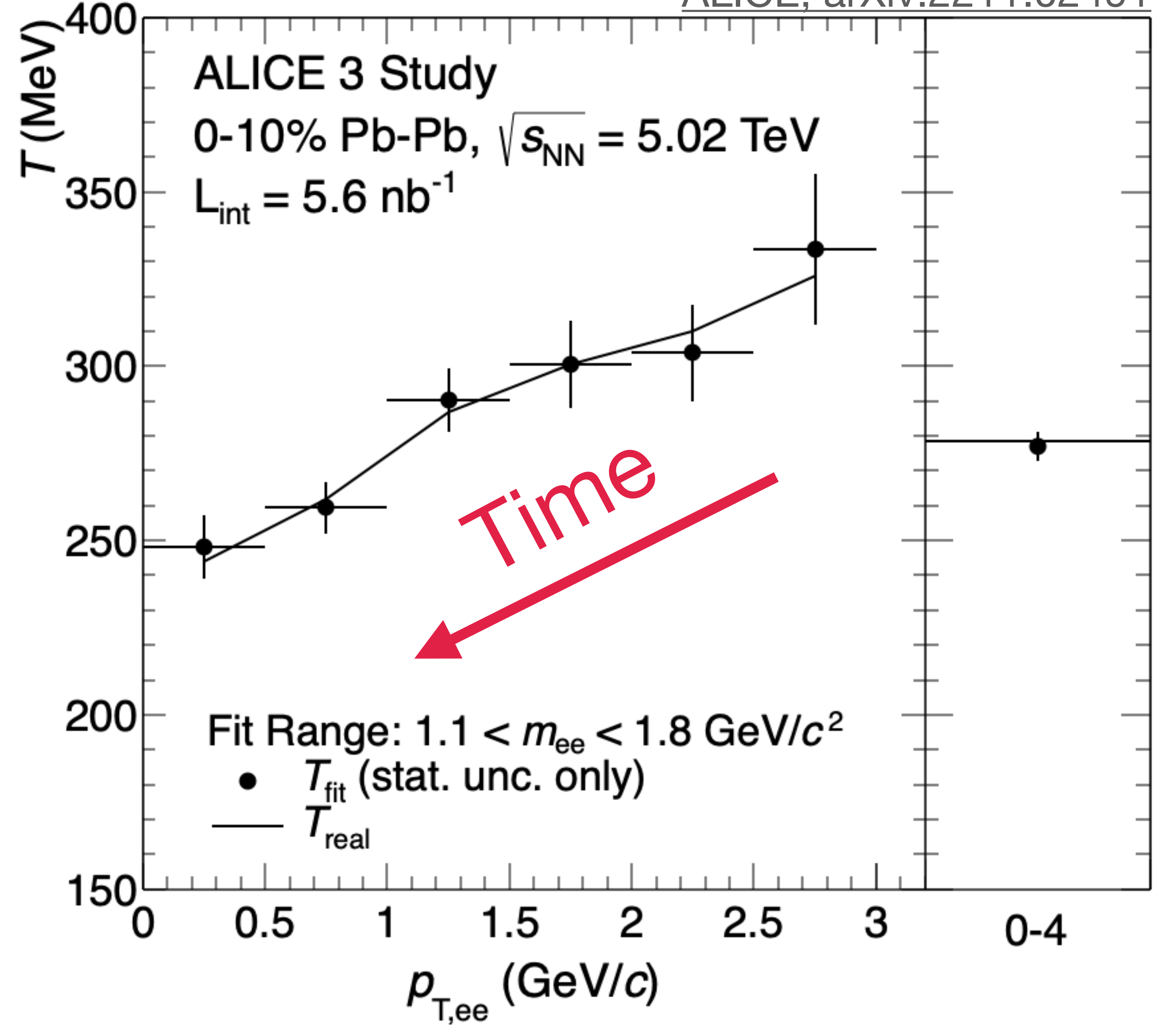
Thank you
for your attention!

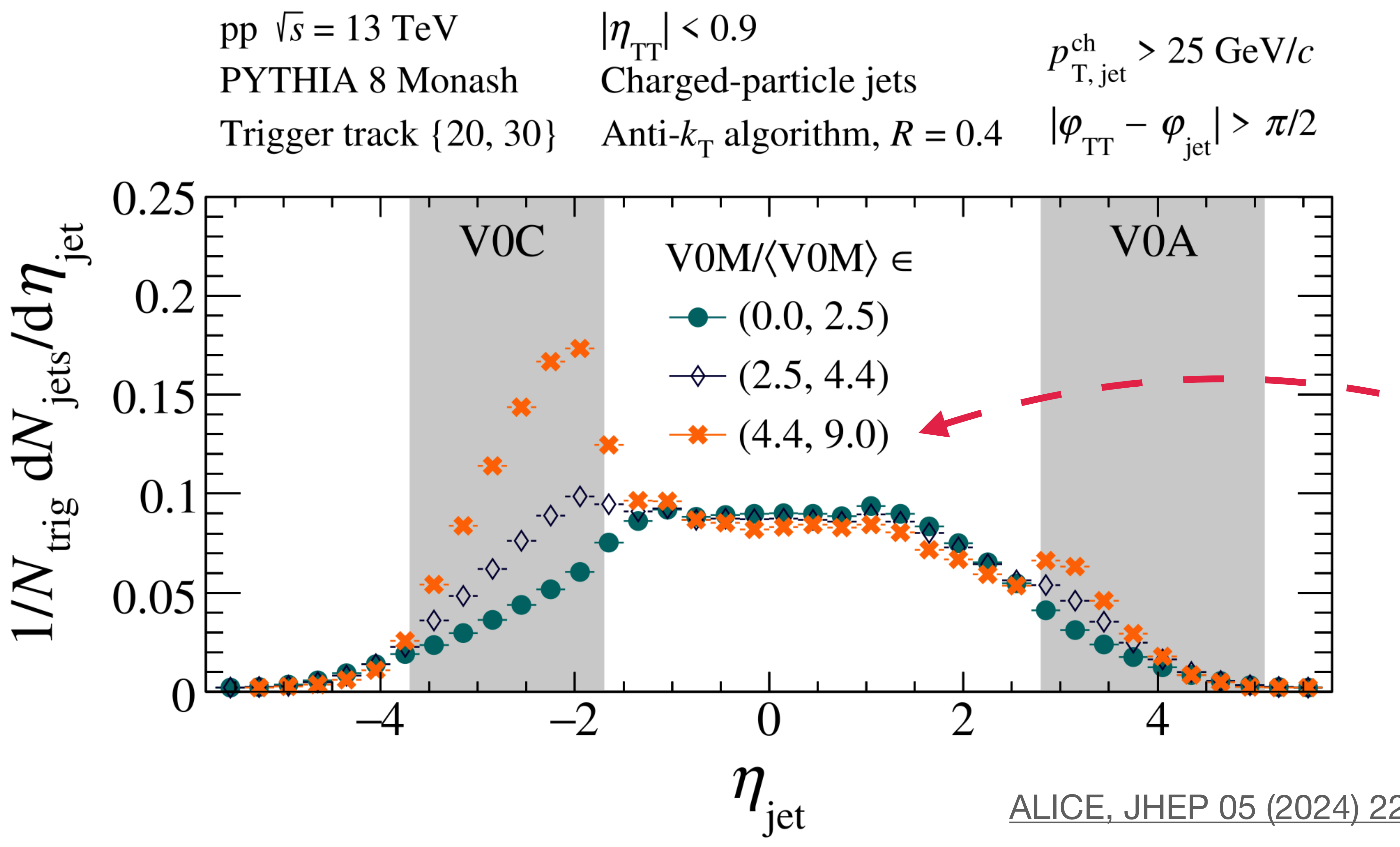


Open questions after Run 4

- **More detailed evolution of the QGP through termal radiation**
- **Evidences of QGP formation 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

ALICE, JHEP 05 (2024) 229

Open questions after Run 4

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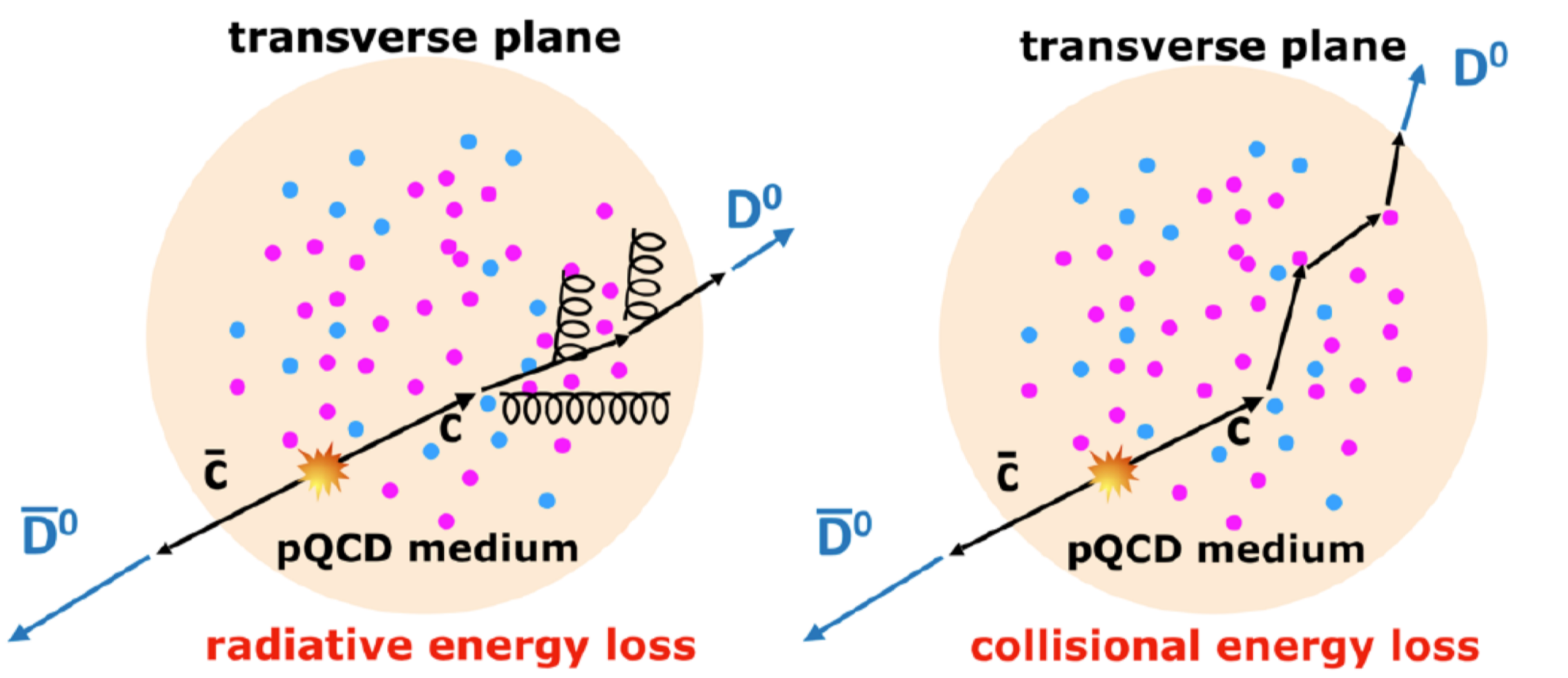
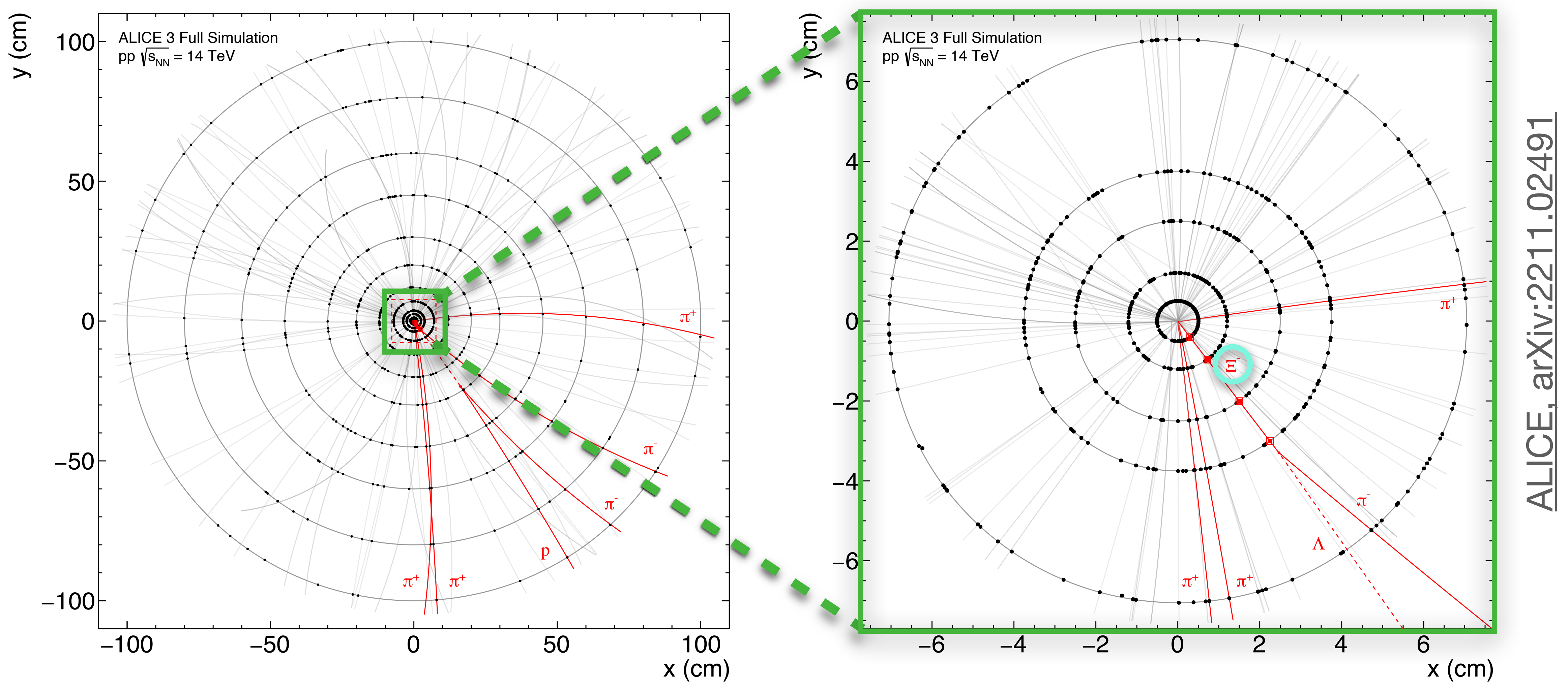


Higher purity and signal efficiency with a bigger acceptance is needed

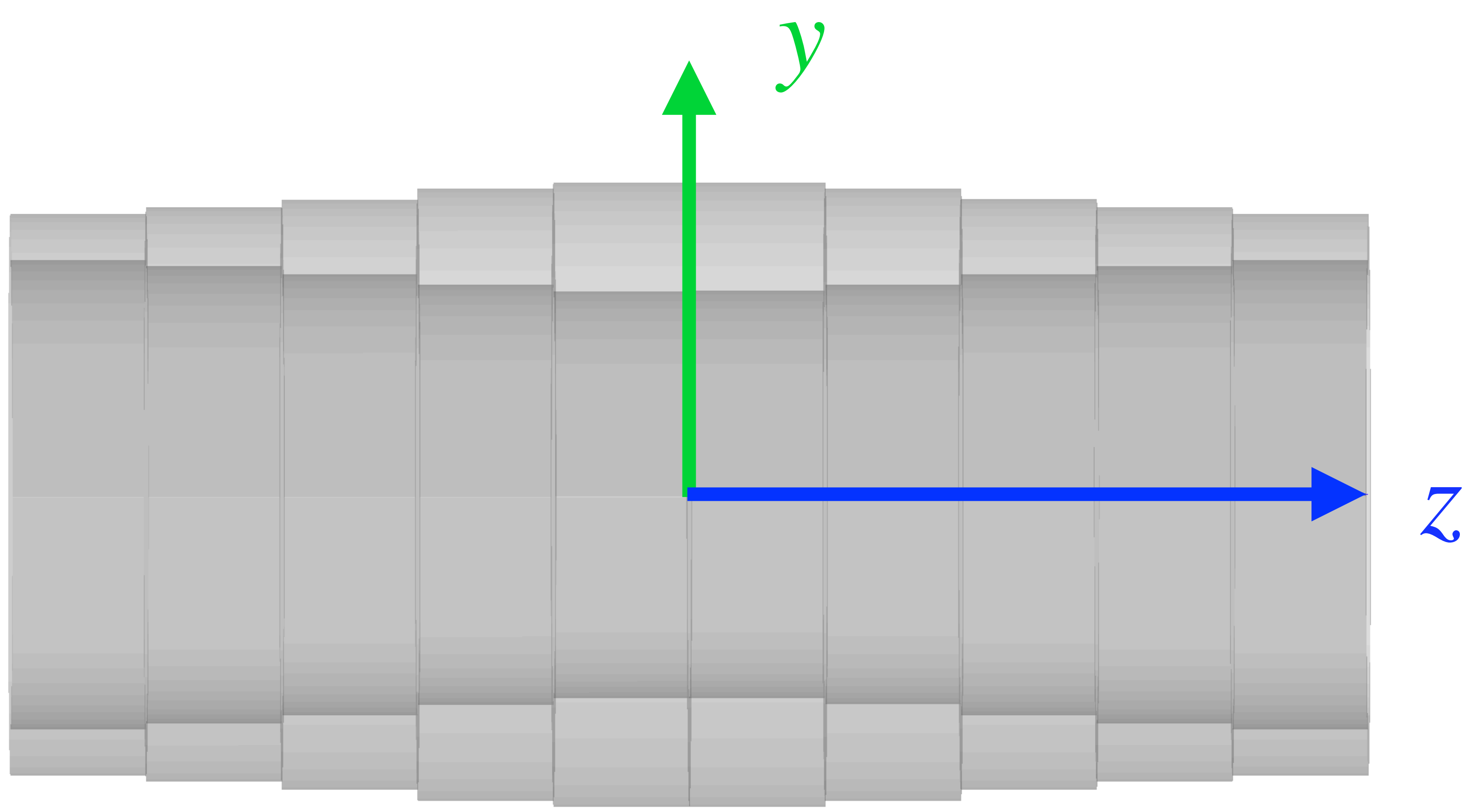
$\Xi_{cc}^{++} \rightarrow \Xi_c^+ + \pi^+$ $\Xi_c^+ \rightarrow \Xi^- + 2\pi^+$



Outstanding tracking resolution is required

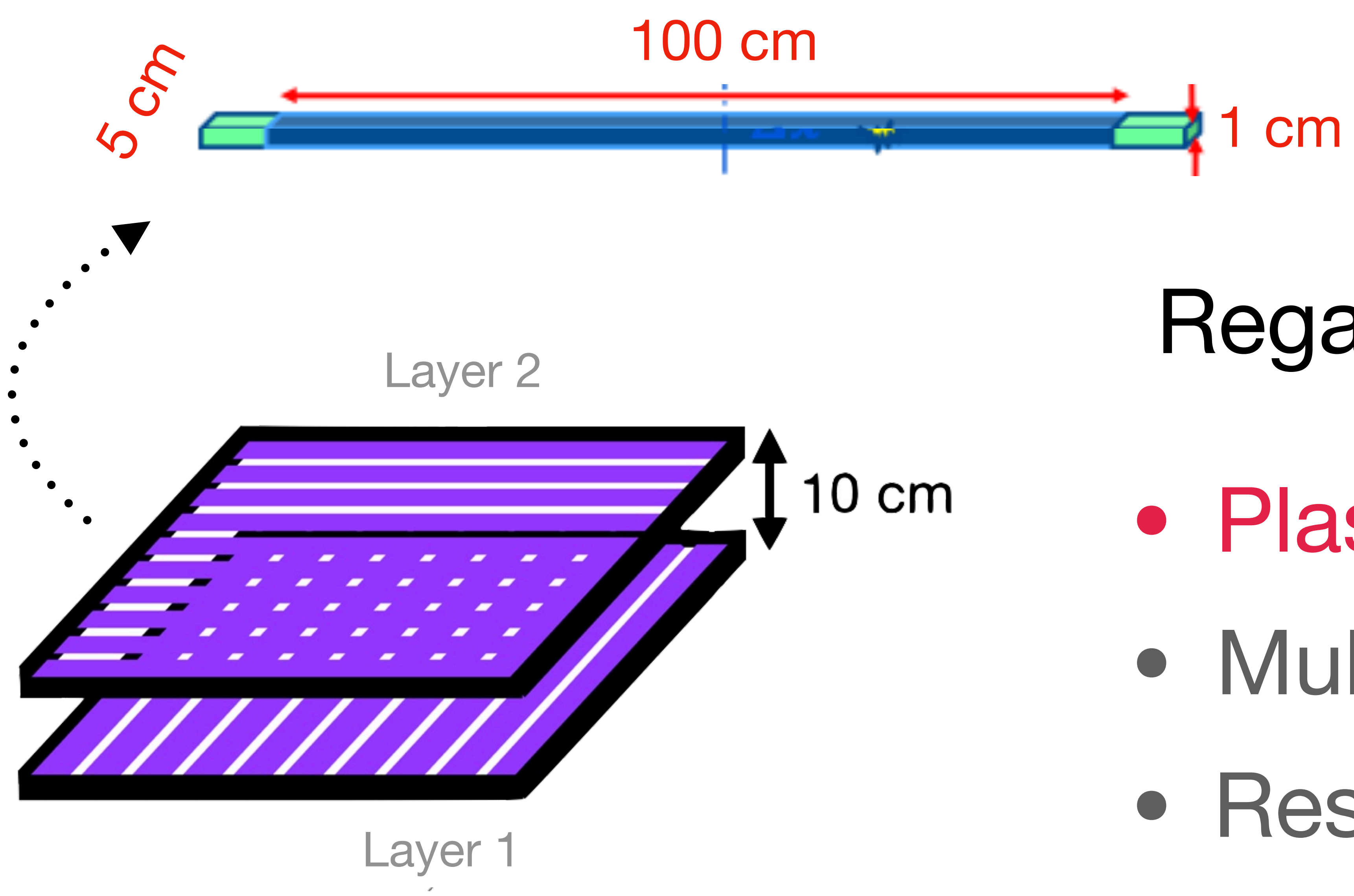
ALICE 3 MID

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)



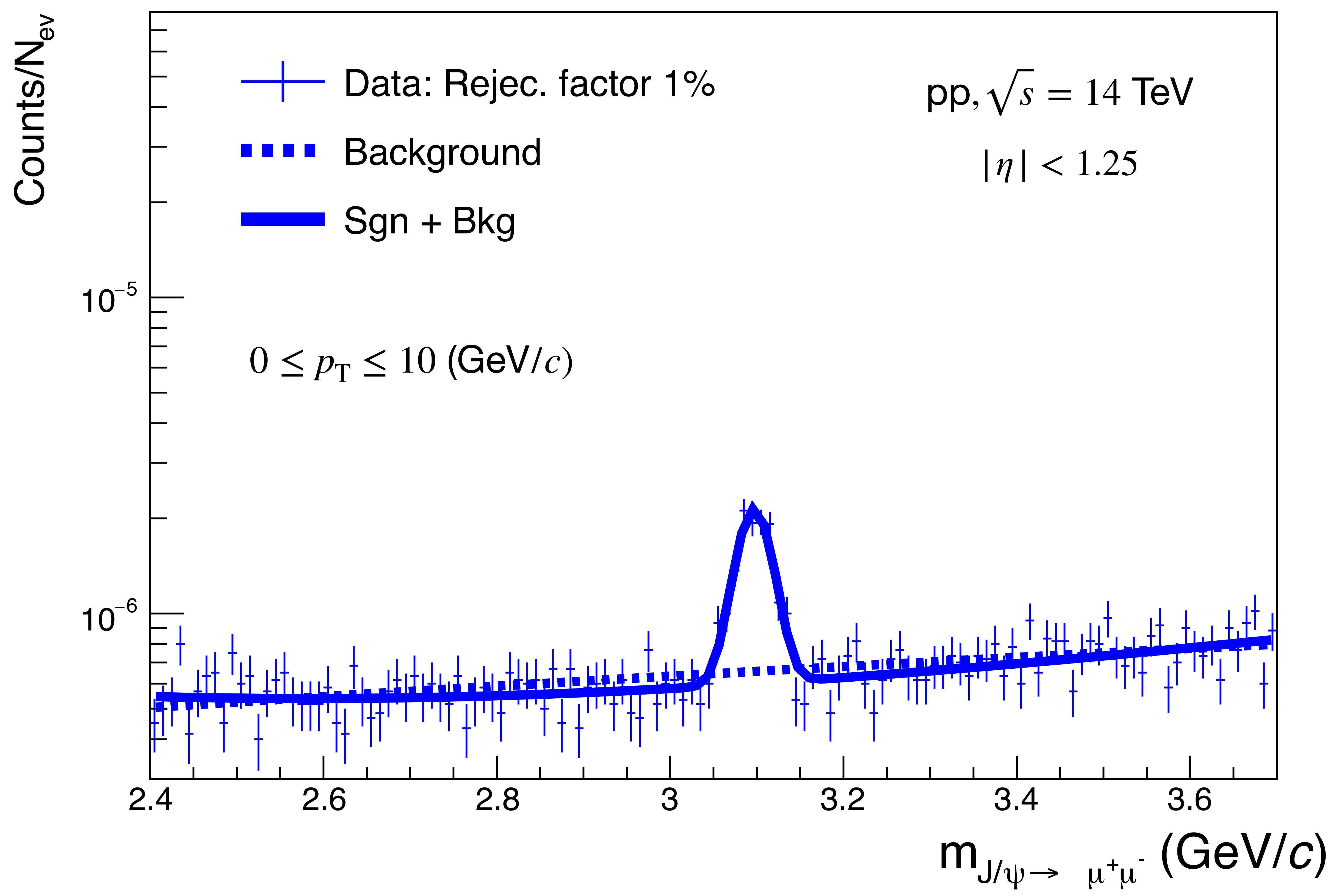
Regarding the muon chambers, there are some candidates

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

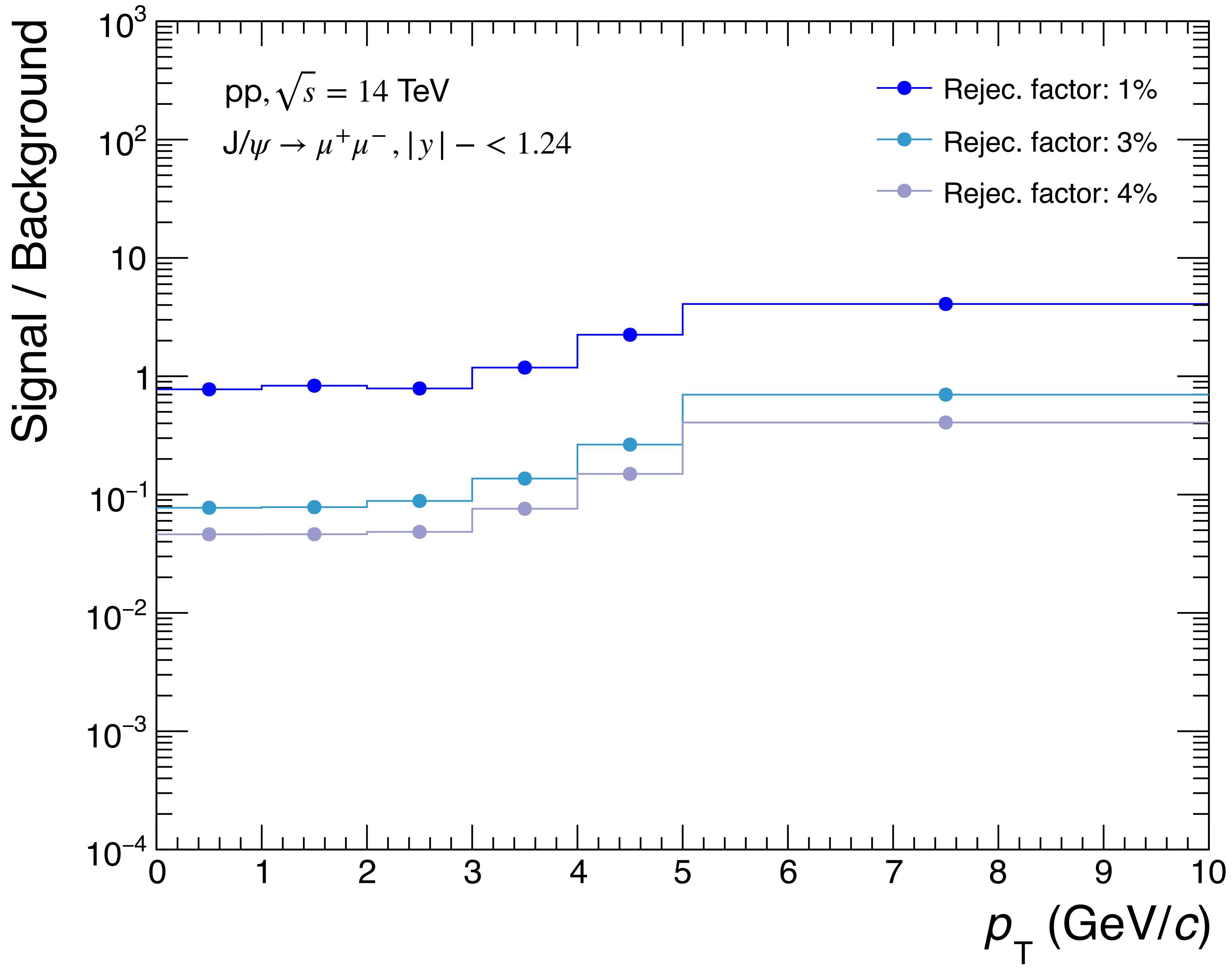
J/ψ reconstruction

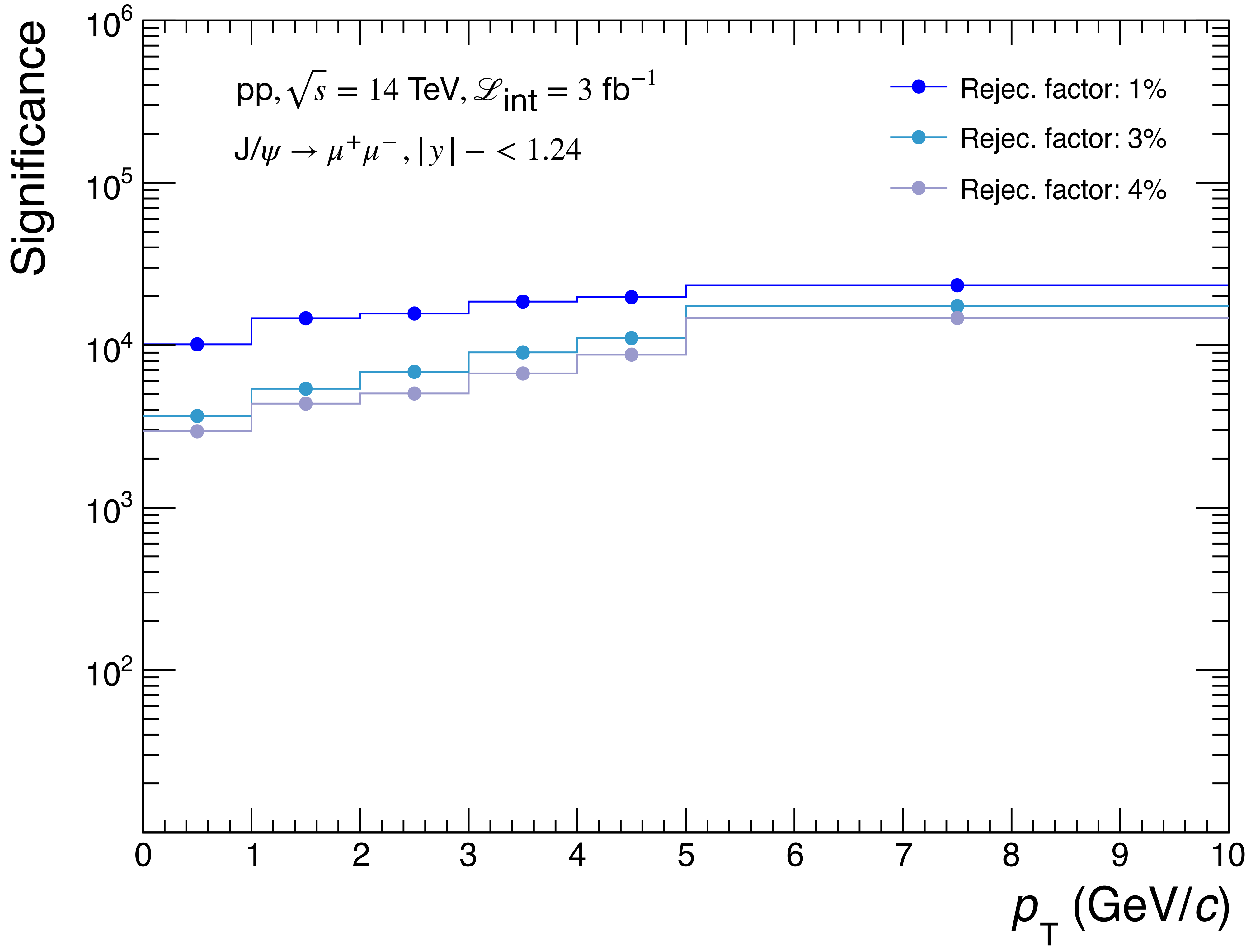
The MID will allow the reconstruction of J/ψ down to $p_{\mathrm{T}} = 0$ via its dimuon decay channel

Signal extracted from invariant mass distribution of the candidates, within a 3σ window around nominal J/ψ mass



J/ψ reconstruction (pp collisions)

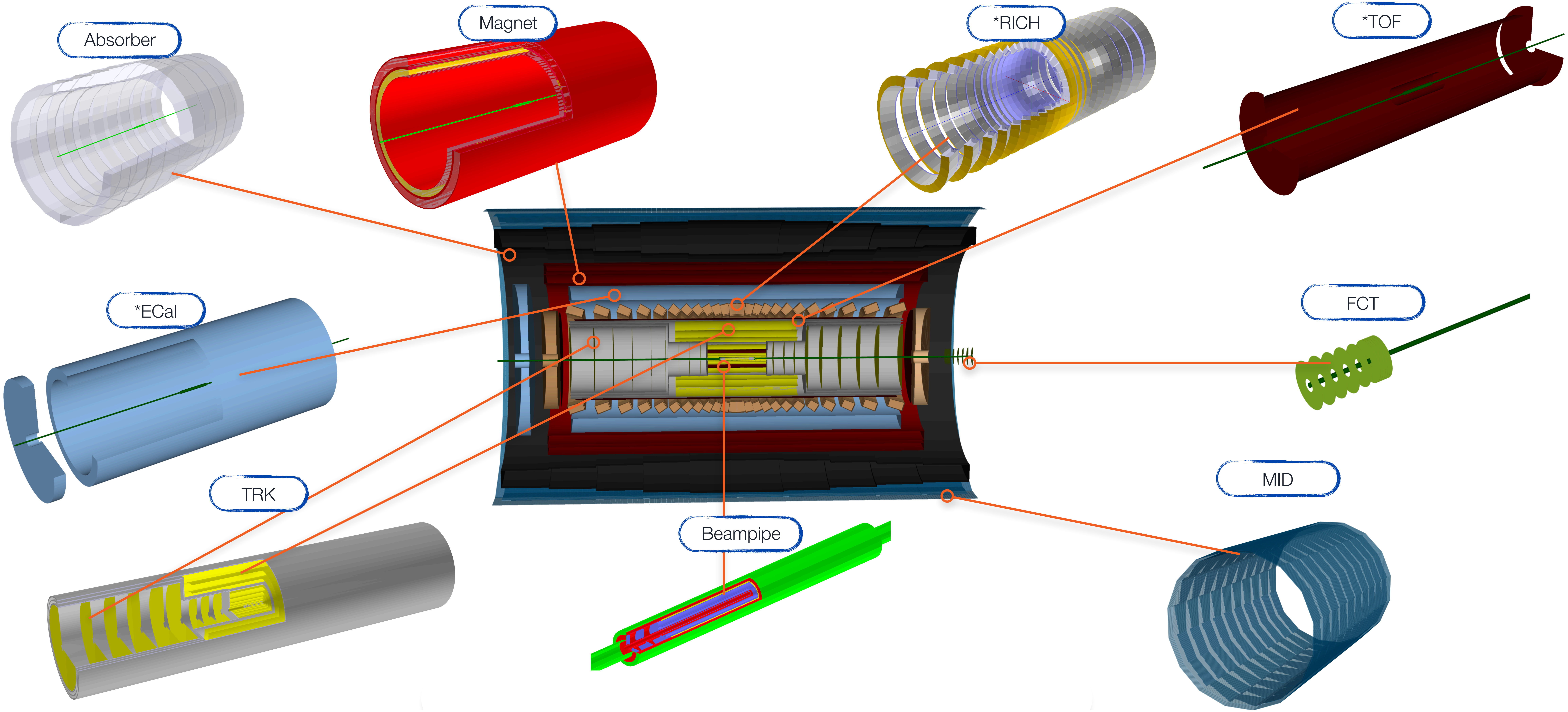




Even though the signal-to-background ratio varies with the **pion rejection factors**…

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

Status of the geometry in O^2



* Figures taken from M. Concas - ALICE 3 days, March 25-27, 2024

Status of the geometry in O^2

Instituto de Ciencias Nucleares UNAM

ALICE

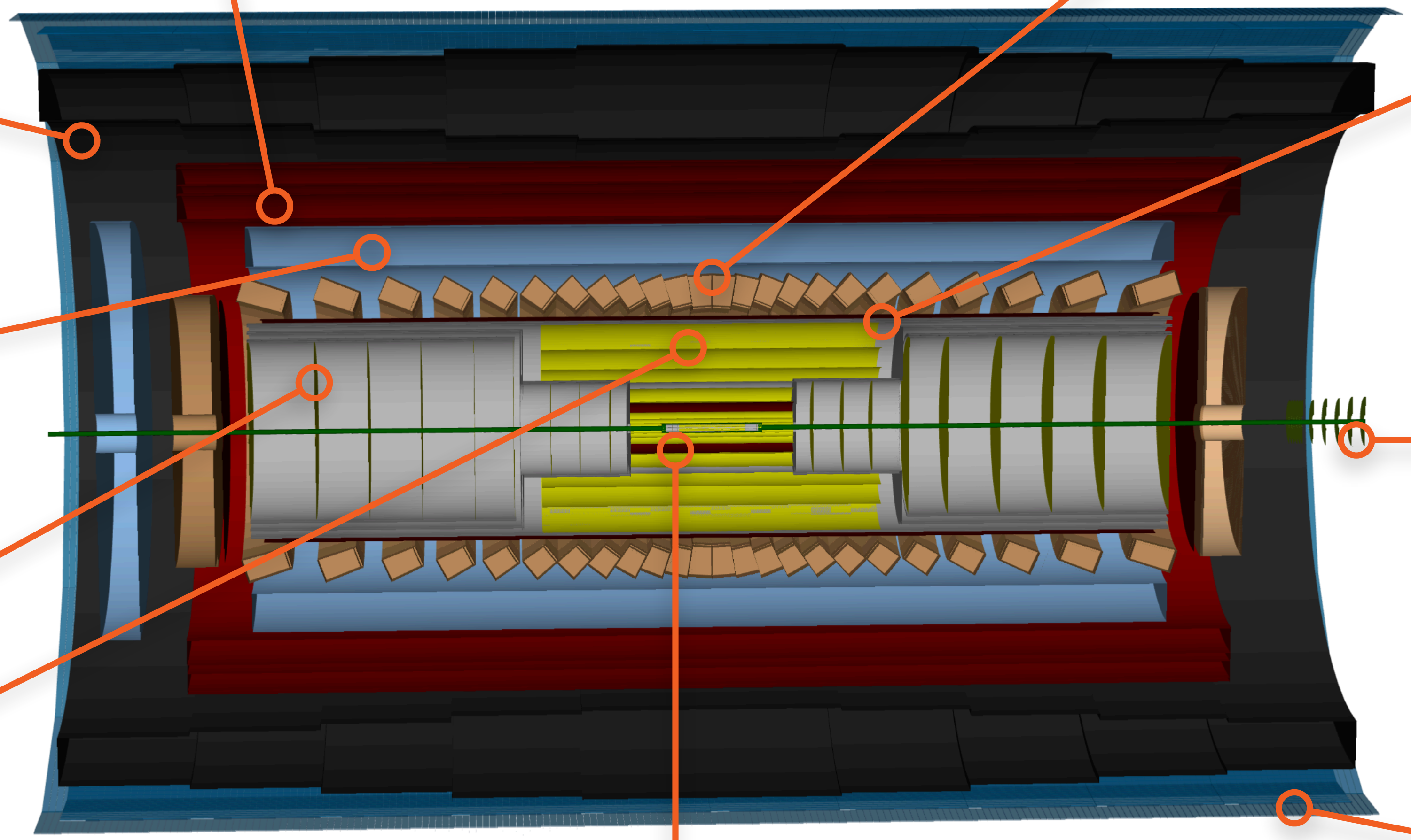
Absorber
- Passive iron blocks
- Exposes the same thickness vs η

Magnet
- Passive cryostat filled with vacuum
- Cu/NbTi intermediate layer for the coils

***RICH**
- Projective geometry |η|<2
- Layout configurable via CLI

***TOF**
- Barrel and Fwd silicon layers
- Sensitive (produces hits)

***ECal**
- Barrel and forward
- For material budget



FCT
- Sensitive (produces hits)
- Layers can be interleaved with converter disks

TRK
- Sensitive barrel and fwd silicon layers
- Services for powering/data
- IRIS cold plate and vacuum vessel service

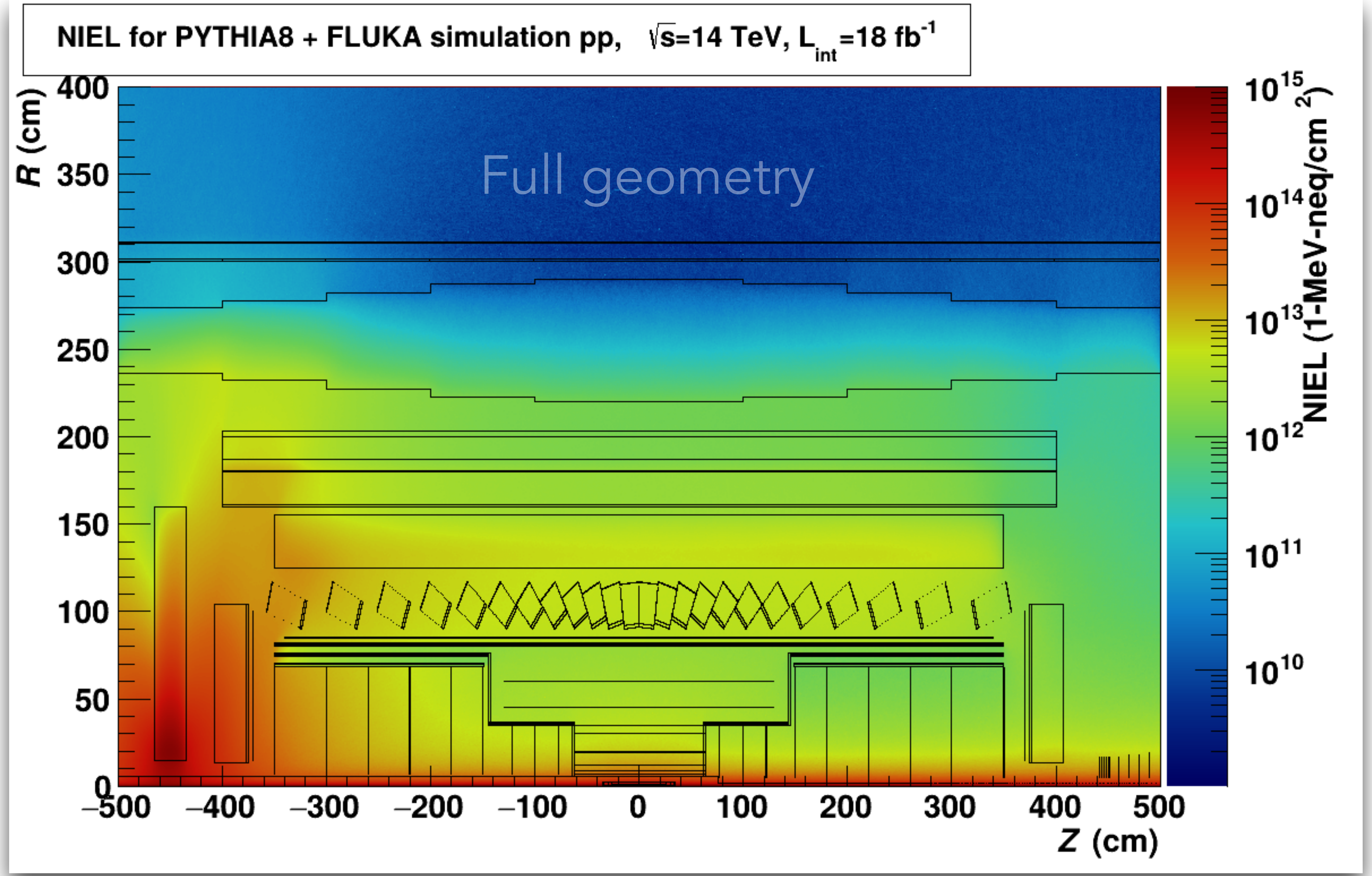
Beampipe
- Vacuum vessel to host IRIS

MID
- Polystyrene version
- Two layers with granular composition
- Modular structure: layer -> module -> bars

A custom magnetic field can be implemented

* Figures taken from M. Concas - ALICE 3 days, March 25-27, 2024

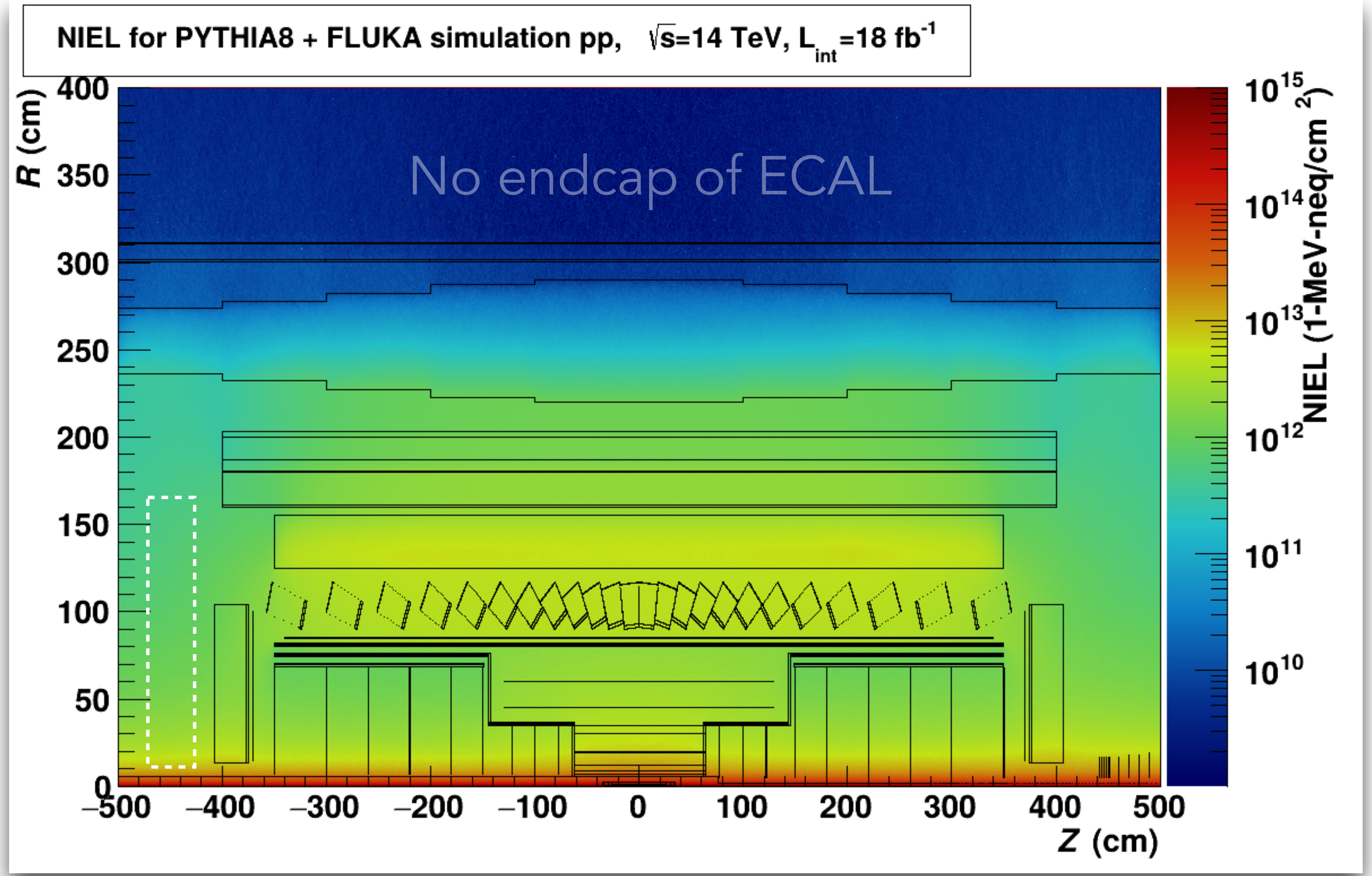
Layouts



pp and Pb-Pb simulations for different layouts

1. Full geometry
2. No endcap of ECAL
3. No ECAL (w/o radii reduction)
4. No ECAL (w radii reduction)

Layouts



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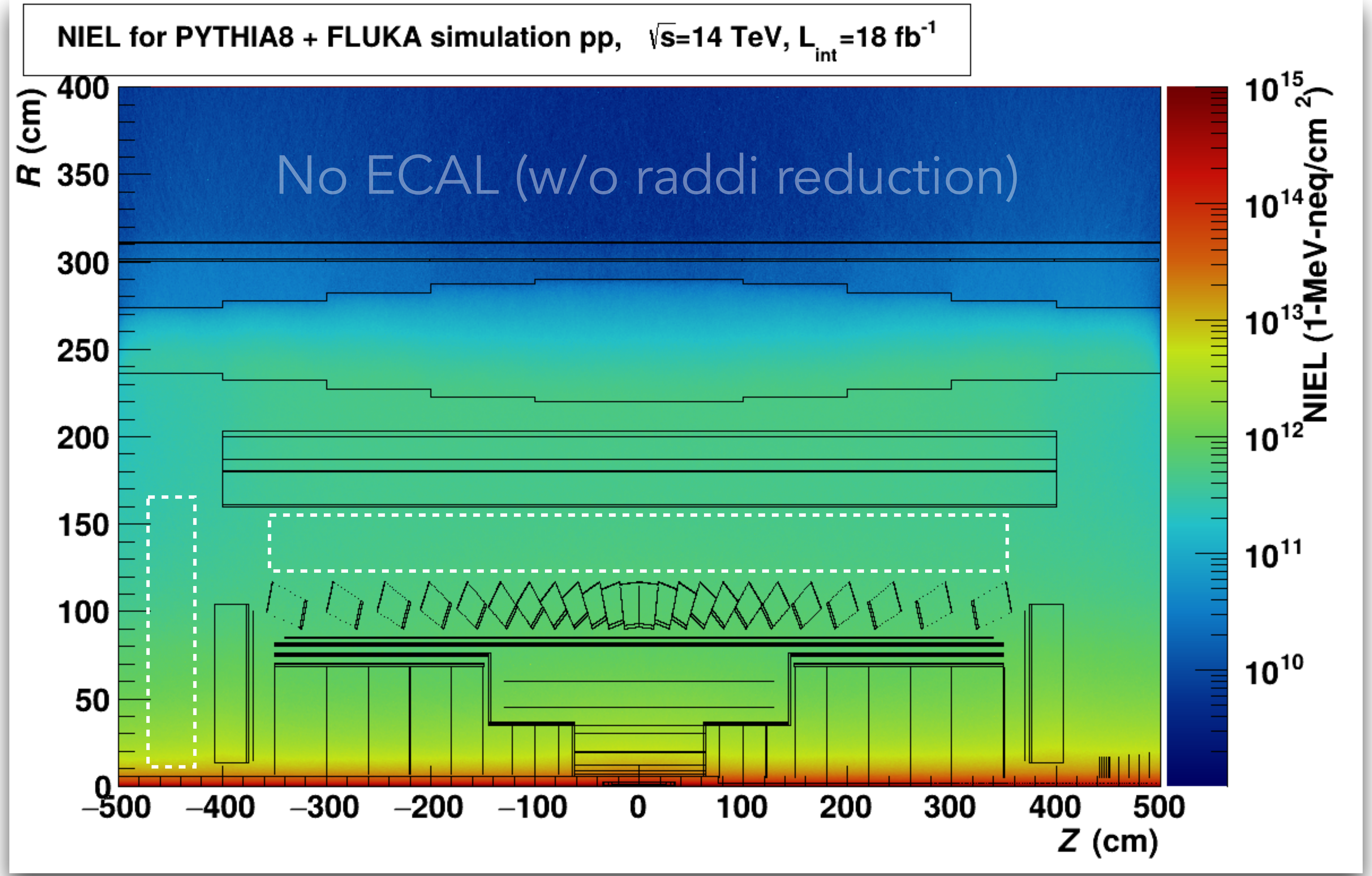

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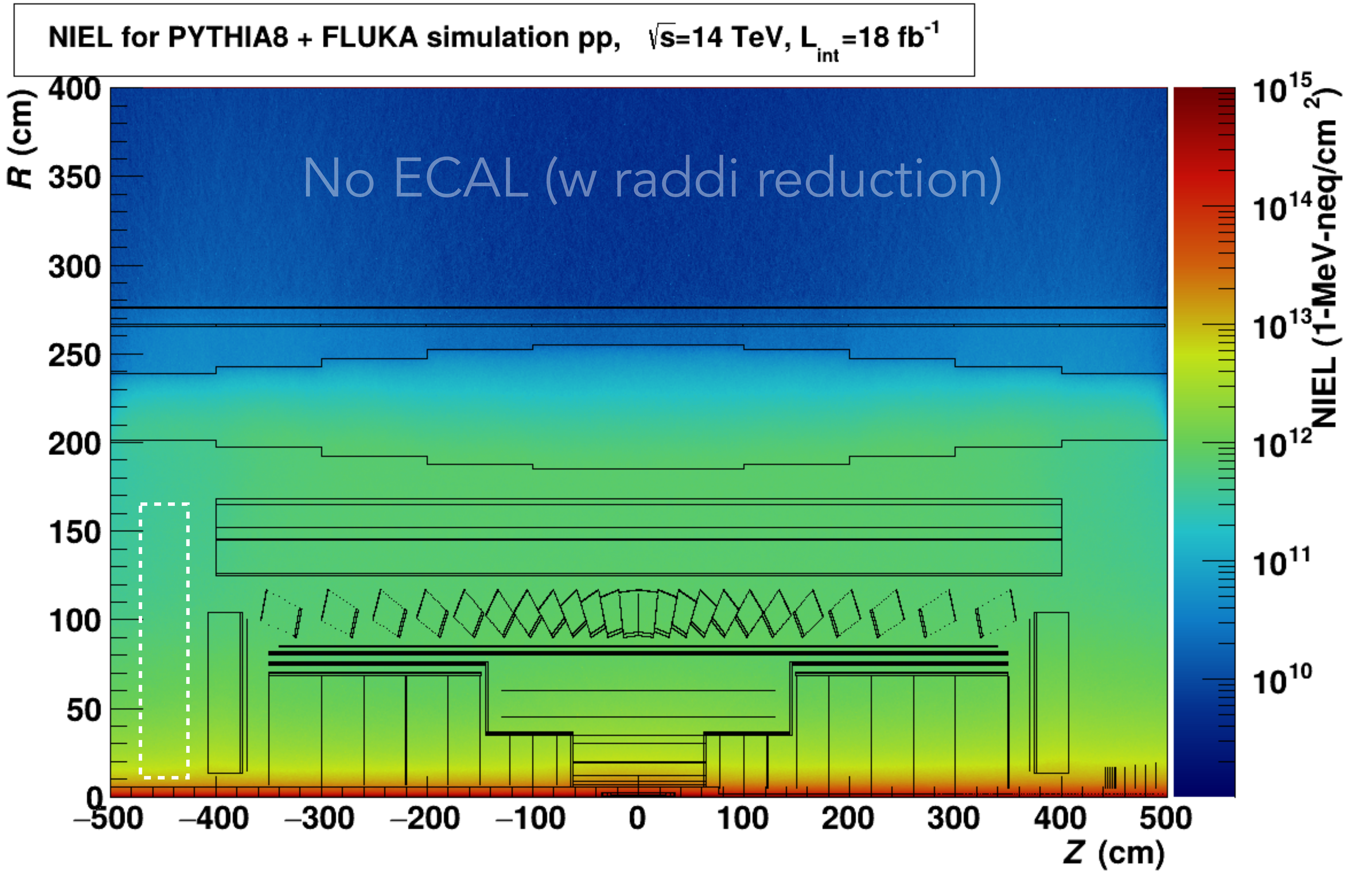
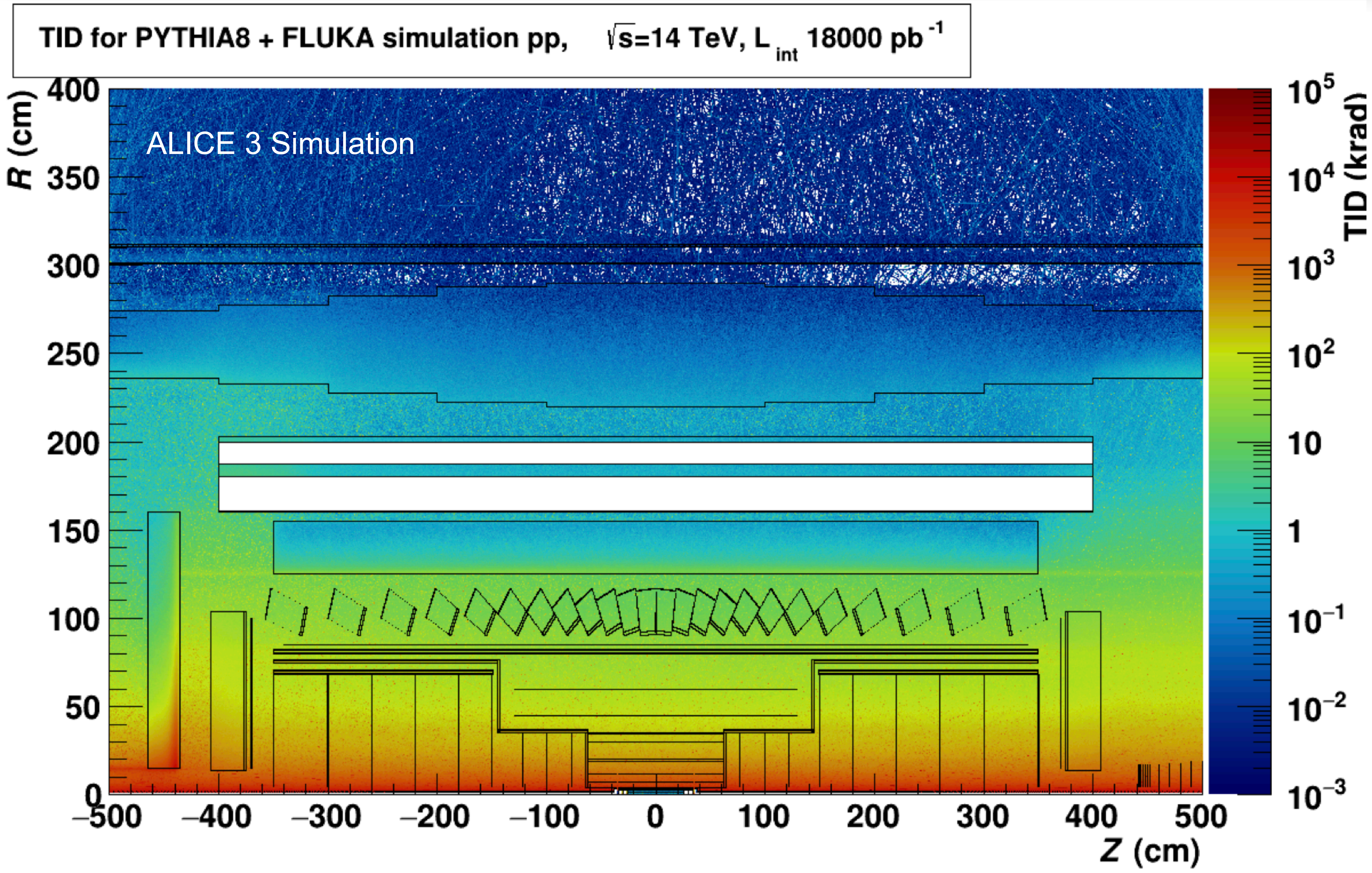


pp and Pb-Pb simulations for different layouts

1. Full geometry
2. No endcap of ECAL
3. No ECAL (w/o radii reduction)
4. No ECAL (w radii reduction)

both average and maximum values for each subdetector region

Radiation load in the MID region



	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)]