ALICE overview

Antonio Ortiz, for the ALICE Collaboration
(Instituto de Ciencias Nucleares, UNAM)

Outline

Instituto de Ciencias Nucleares UNAM

Introduction

ALICE upgrade for the LHC Run 3

ALICE performance during the LHC Run 3

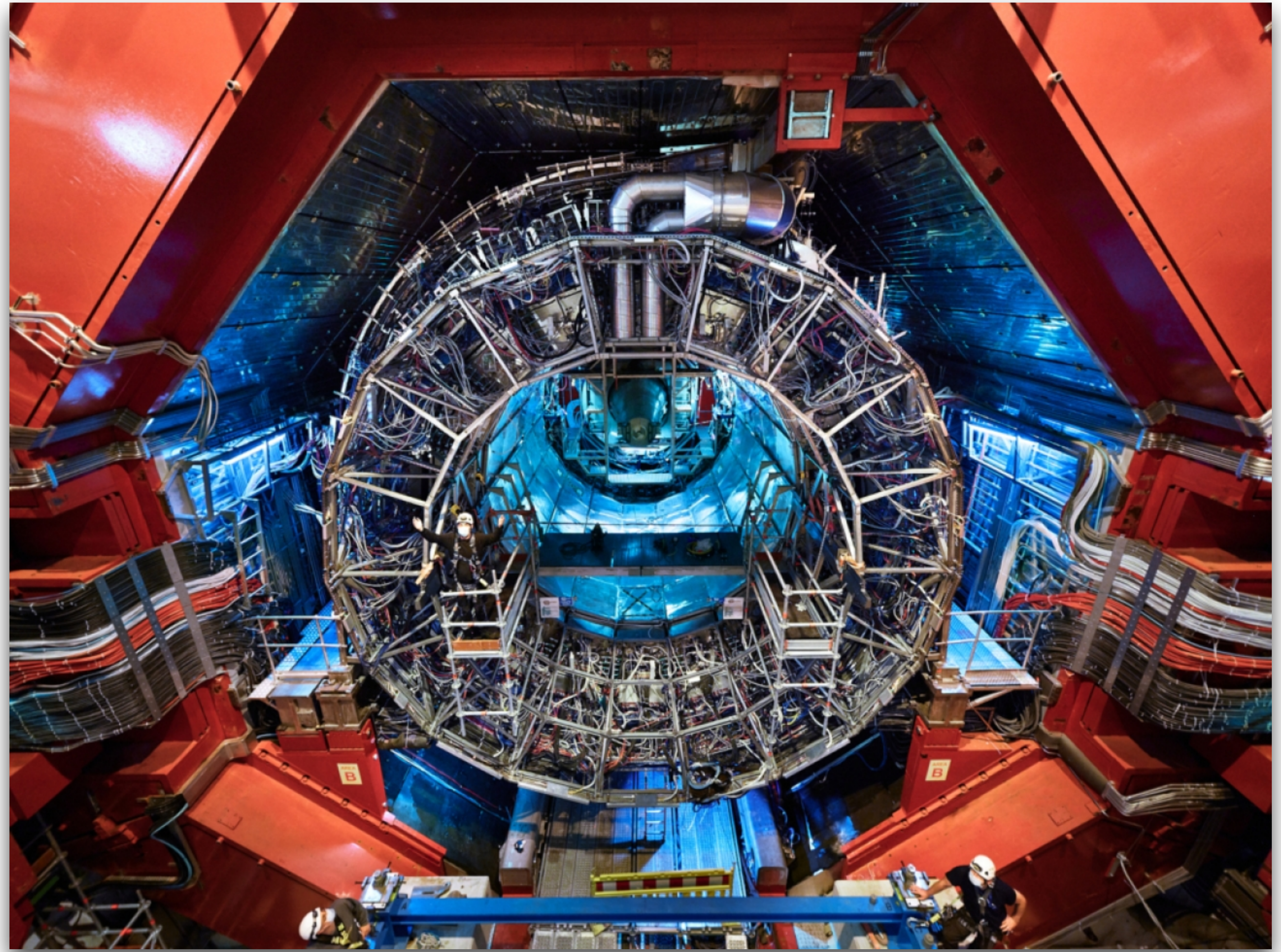
pp results (selected list)

Heavy-ion results (selected list)

Upgrades: LS3 and LS4 (ALICE 3)

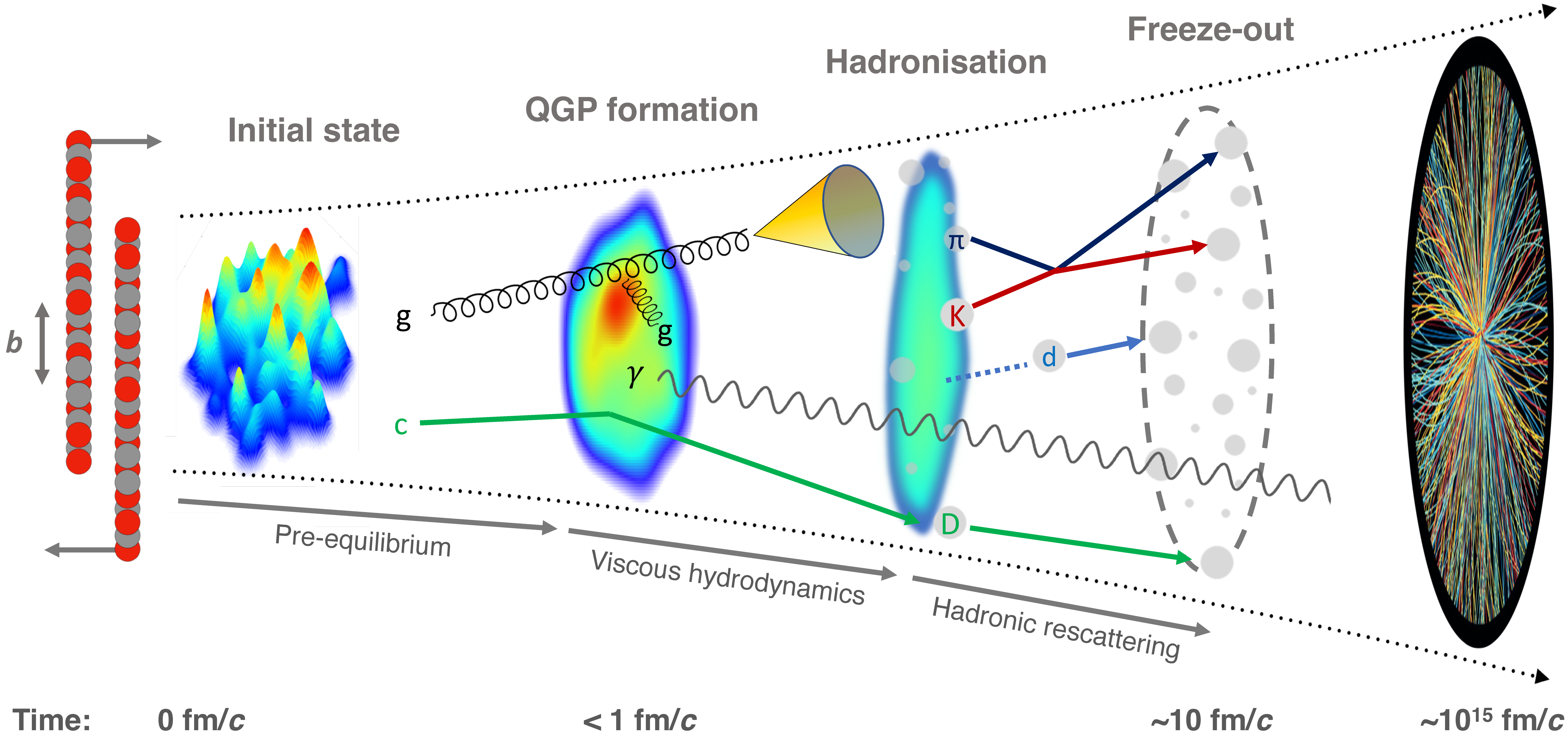
The MID subsystem

Summary



Heavy-ion collisions

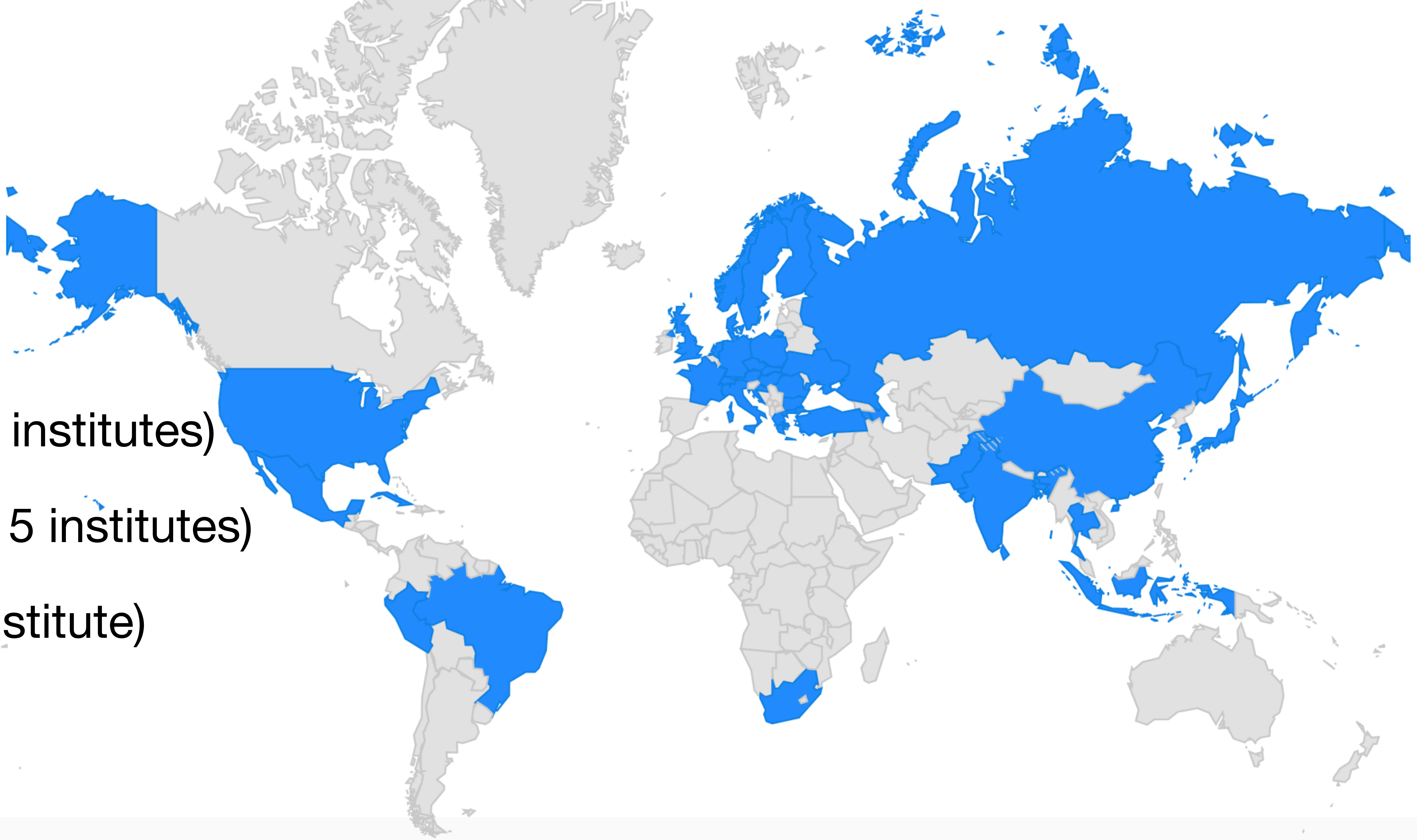
ALICE, EPJ C84 (2024) 813



ALI-PUB-528781

The ALICE Collaboration

40 countries, 171 institutes, 1967 members



Latin America:

Brazil (29 members, 4 institutes)

Mexico (52 members, 5 institutes)

Peru (3 members, 1 institute)

ALICE experiment at the LHC

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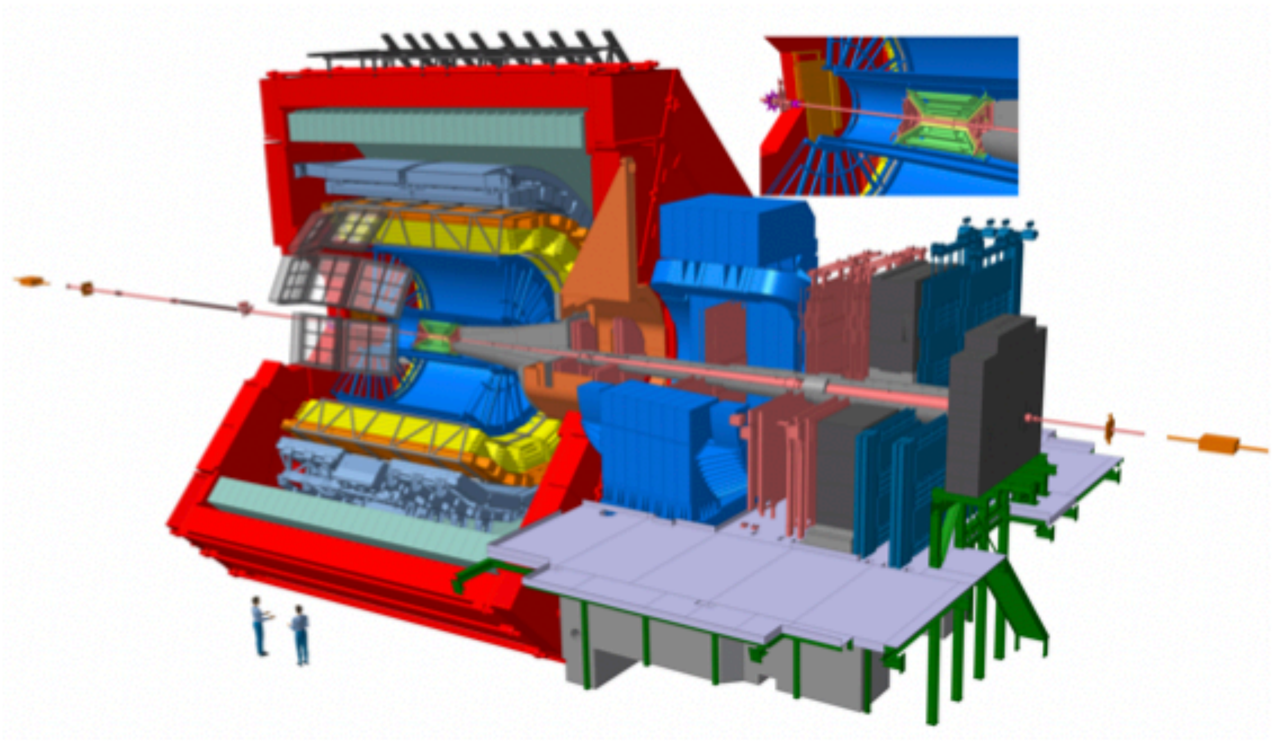
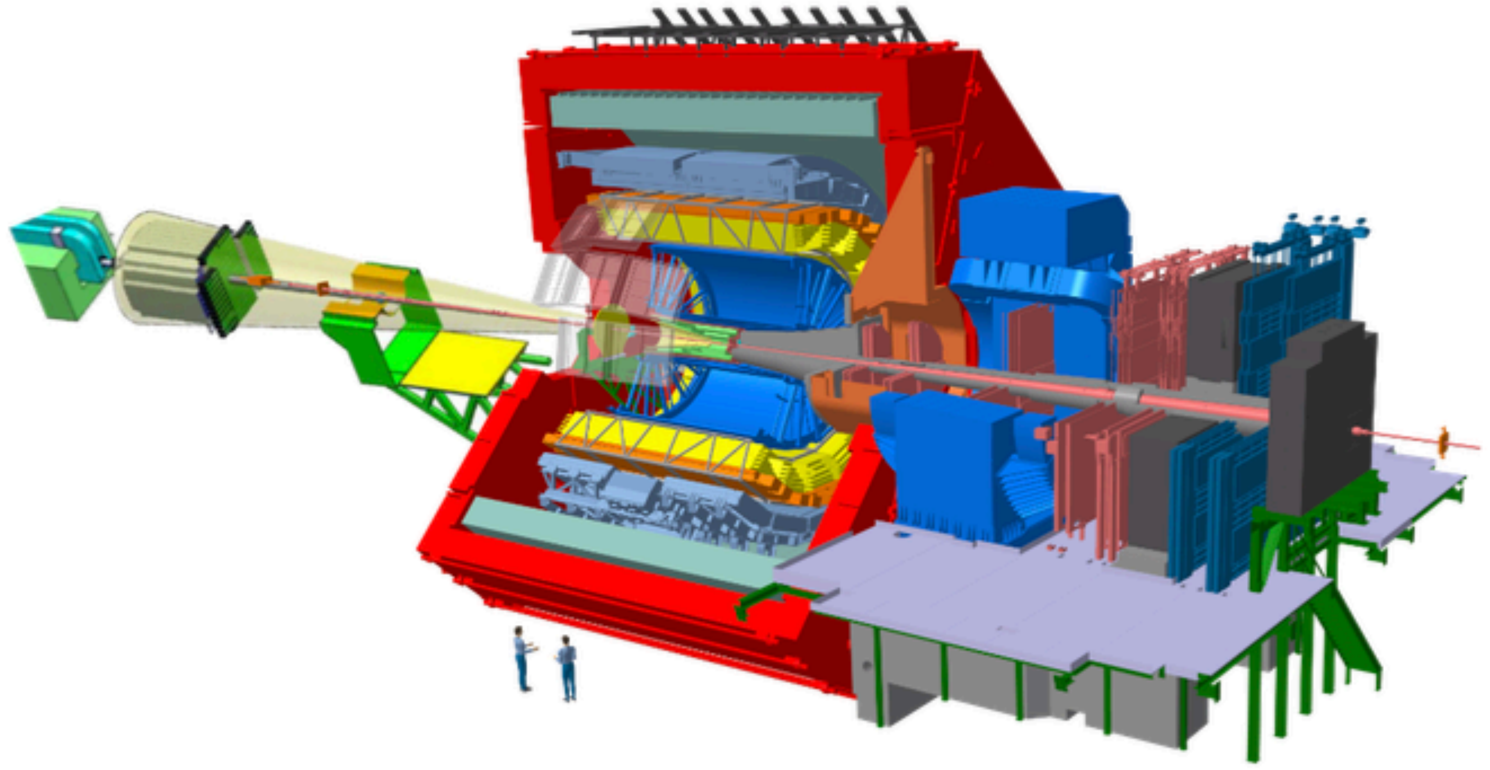
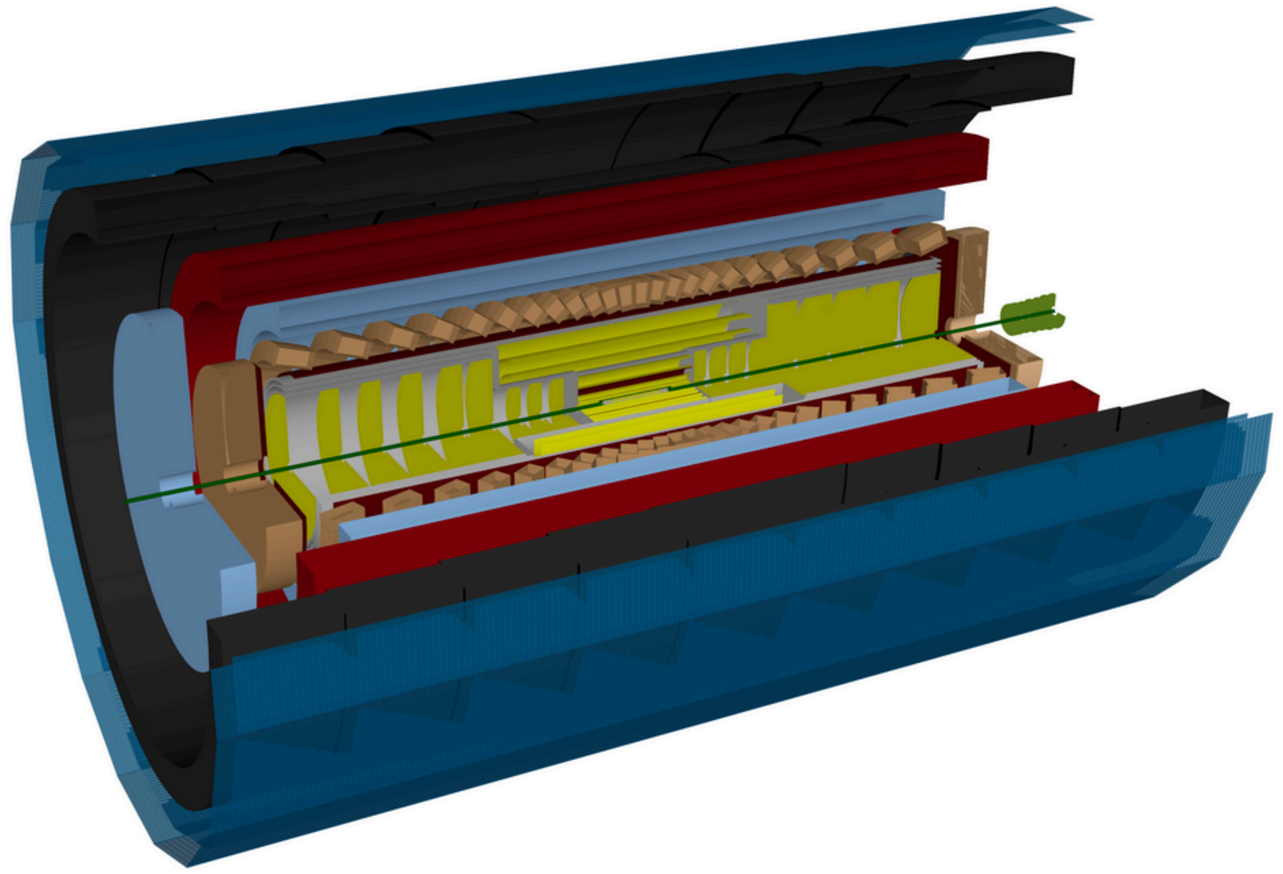
Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
pp, p-Pb, Pb-Pb	pp, p-Pb, Xe-Xe, Pb-Pb	pp, p-O, O-O, p-Pb, Pb-Pb	pp, p-Pb, Pb-Pb	pp, p-A?, A-A	pp, p-A?, A-A
2009-2013	2015-2018	2022-2026	2030-2033	(2036-—-)	(——2041)

ALICE 1 | ALICE 2 | ALICE 2.1 | ALICE 3





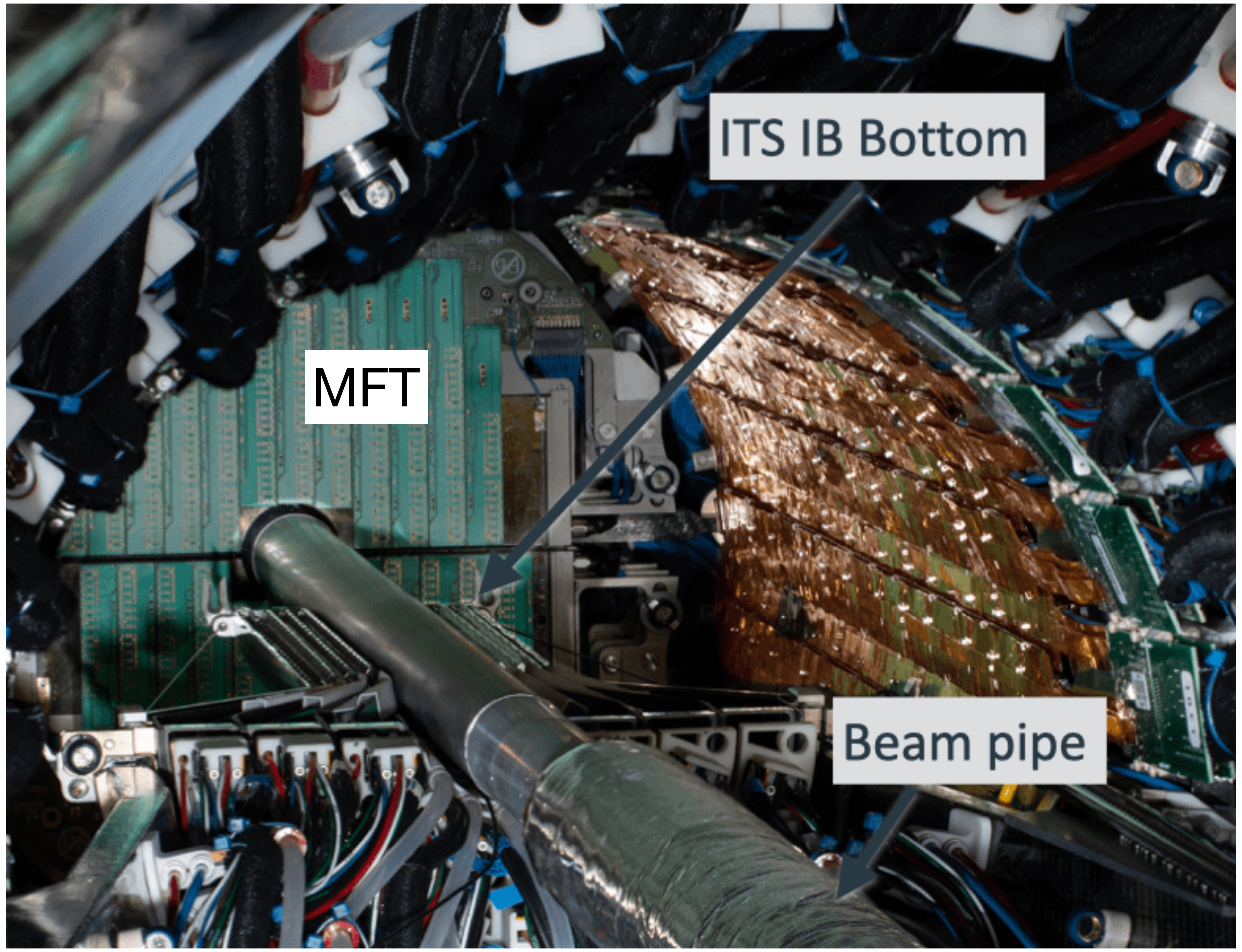


Major upgrade | Intermediate upgrade

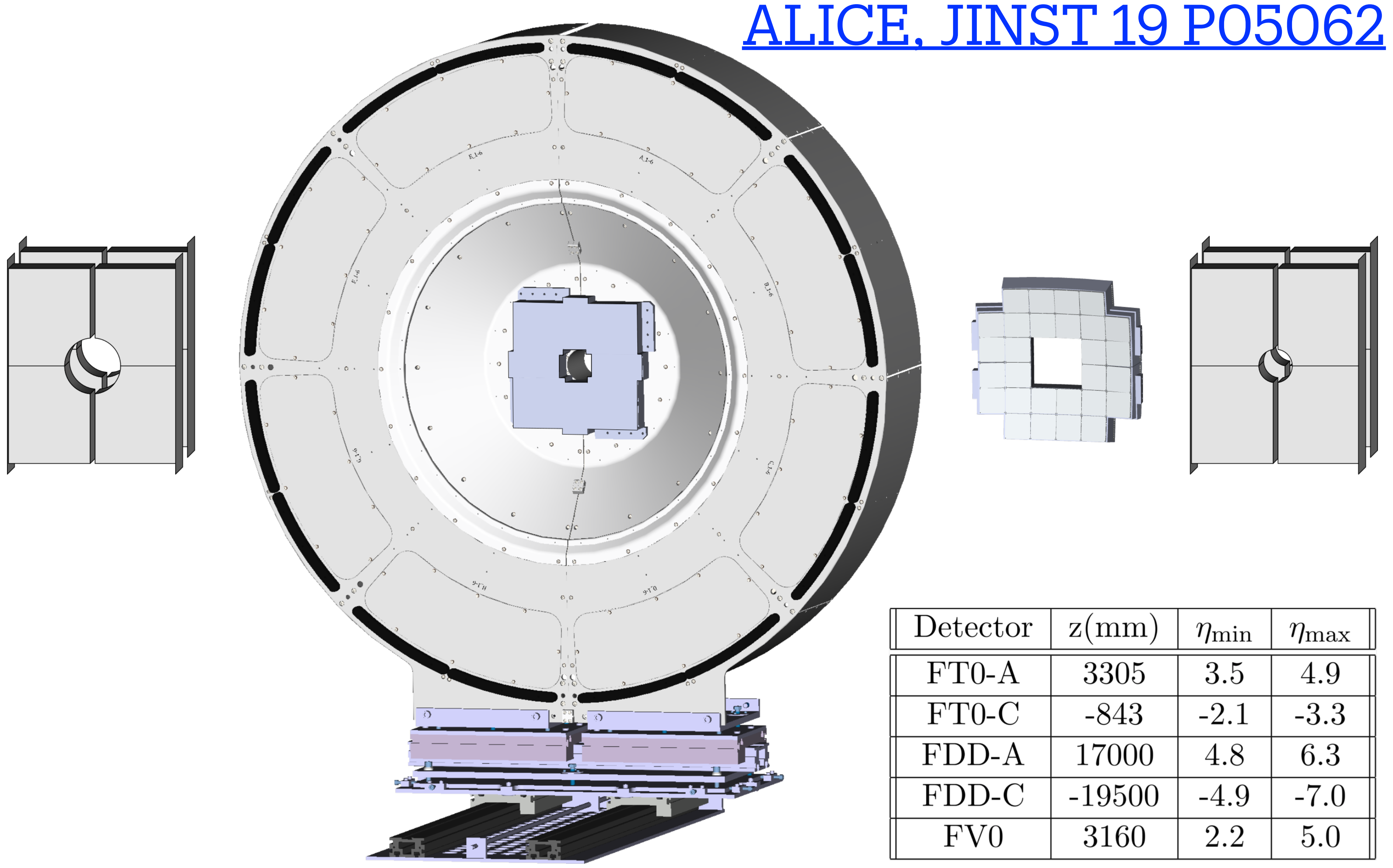
LS2 upgrade

Run 3
2022-2025

ALICE 2



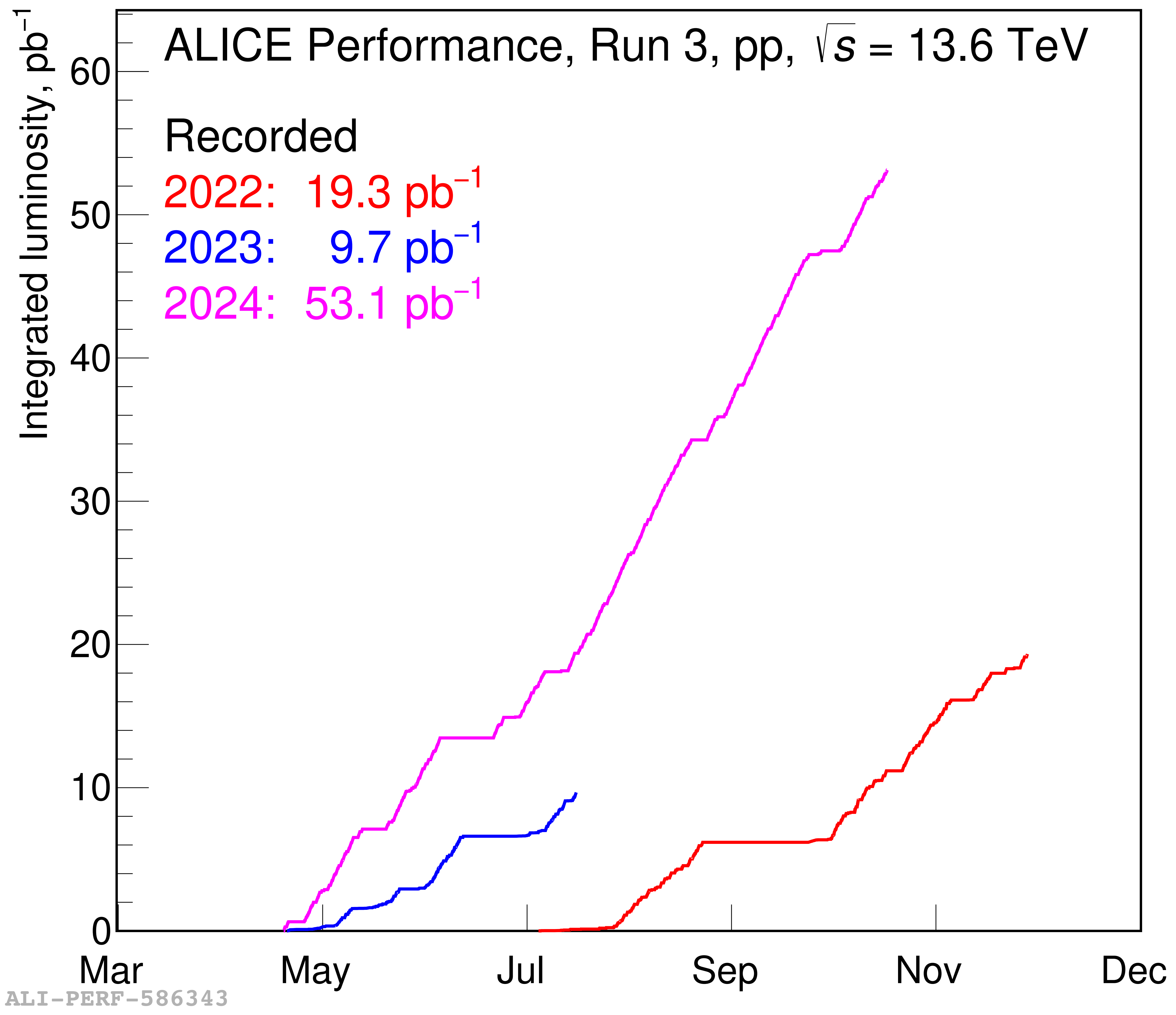
[ALICE, JINST 19 P05062]

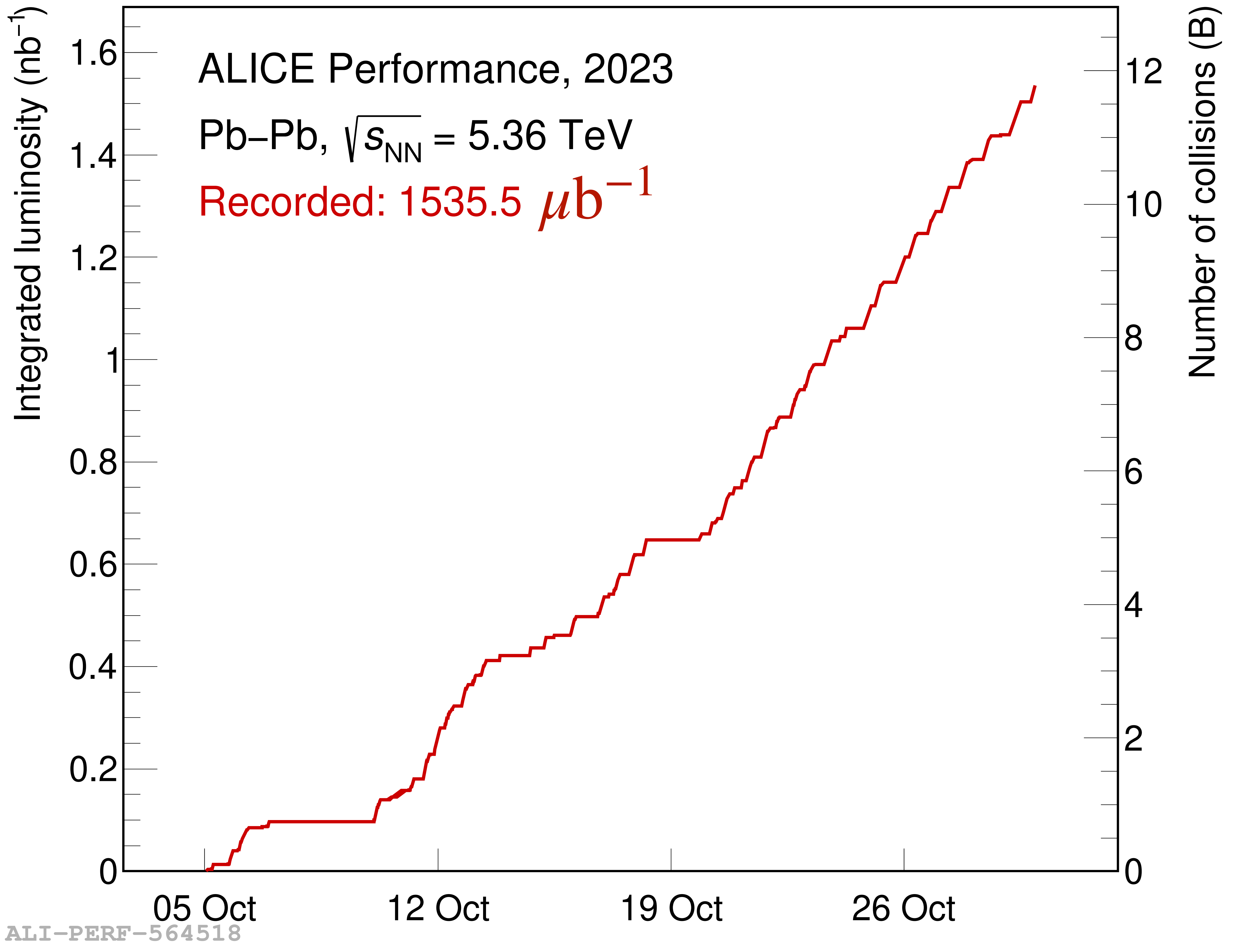


Detector	z(mm)	η_{min}	η_{max}
FT0-A	3305	3.5	4.9
FT0-C	-843	-2.1	-3.3
FDD-A	17000	4.8	6.3
FDD-C	-19500	-4.9	-7.0
FV0	3160	2.2	5.0

- New Fast Interaction Trigger
- Inner Tracking System (ITS2): full pixel layers
- New Muon Forward Tracker (MFT)
- continuous readout at high rate / Time Projection Chamber (GEM readout) / new event processing farm / Upgraded readout for most detectors

Run 3 data taking

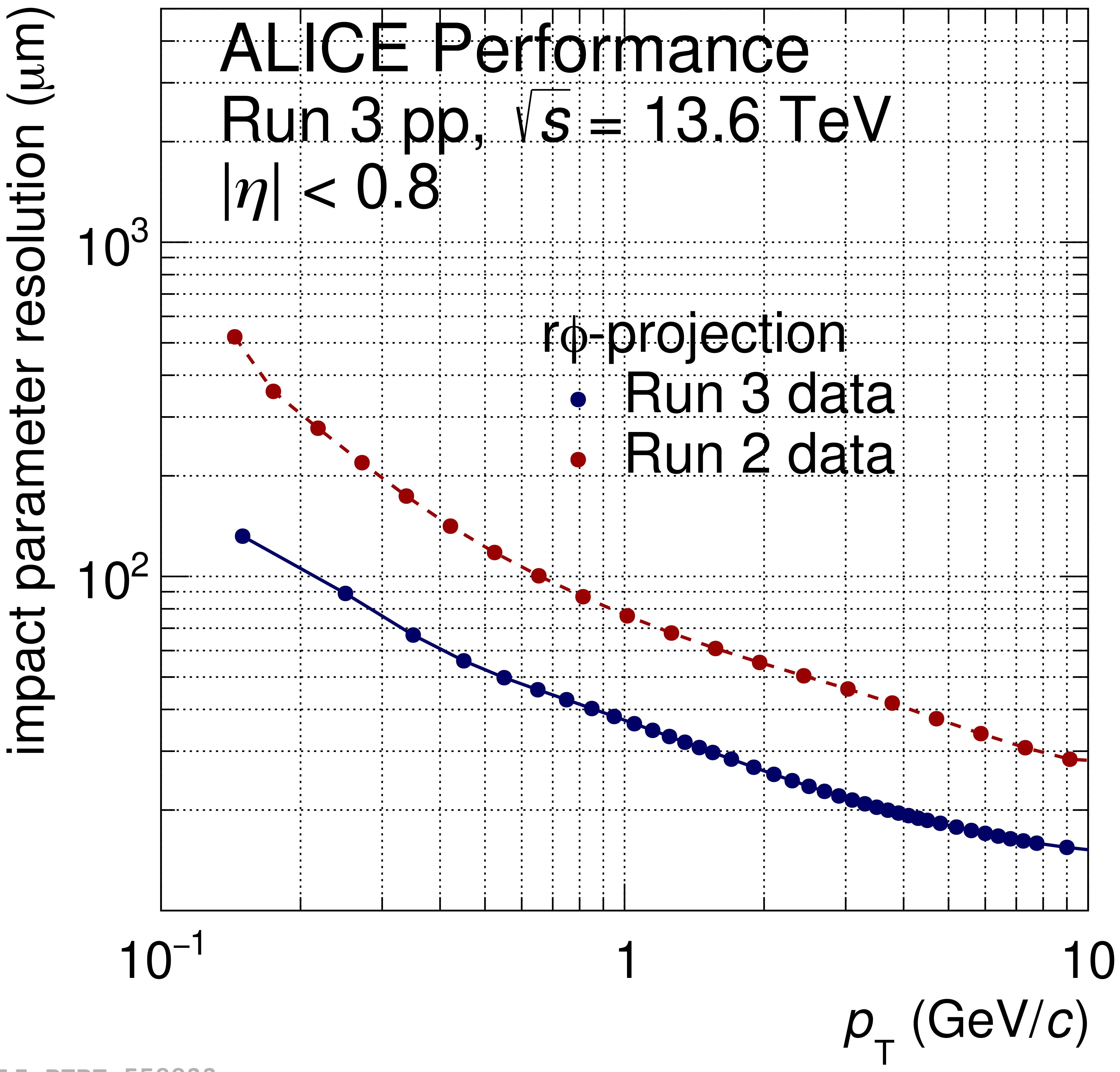


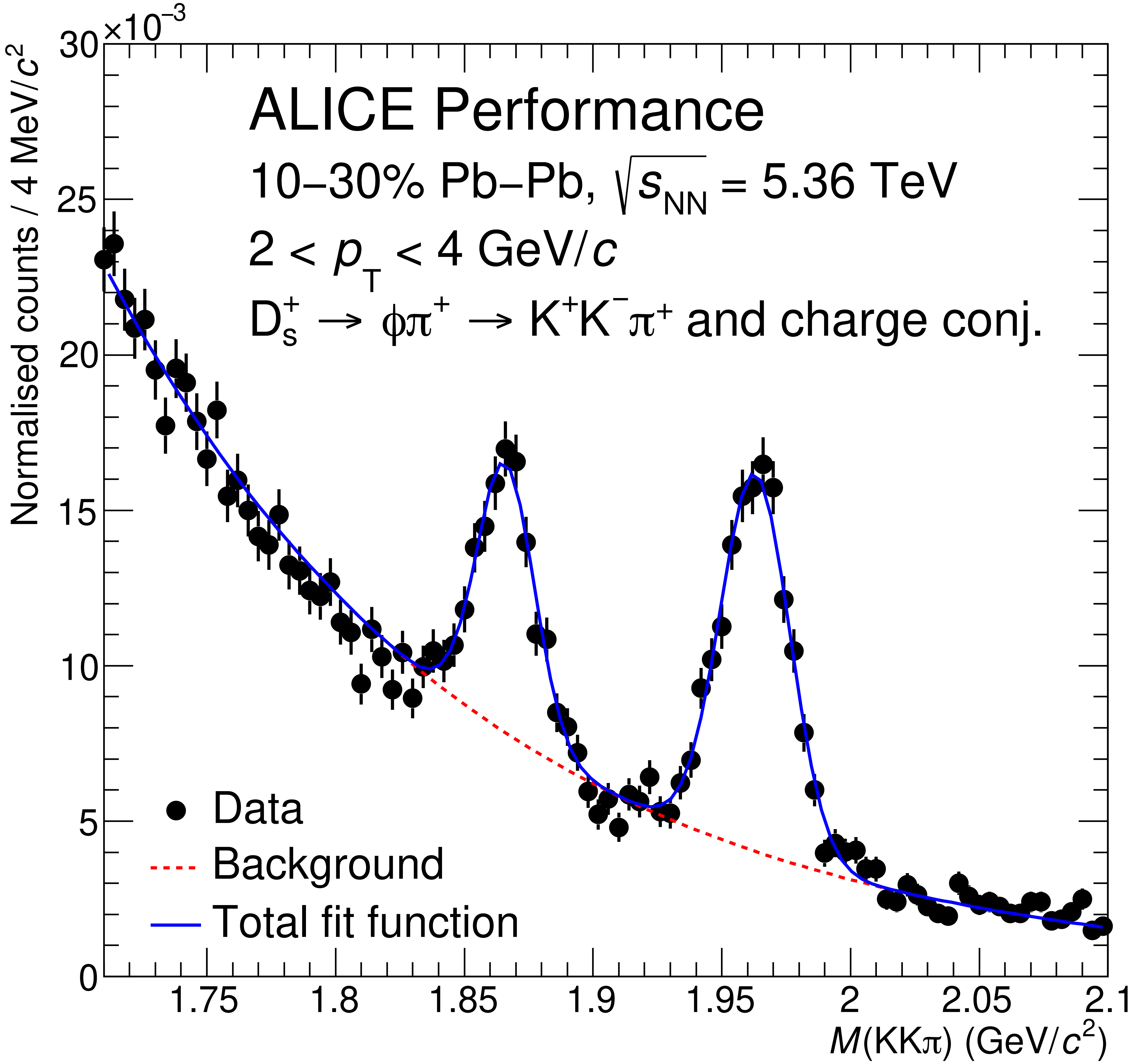


pp (2024): 53.1 pb^{-1}, efficiency: 95%

Heavy-ion run (2023): 1.6 nb^{-1},
≈ 11.5x10^9 minimum-bias collisions

Run-3 physics performance

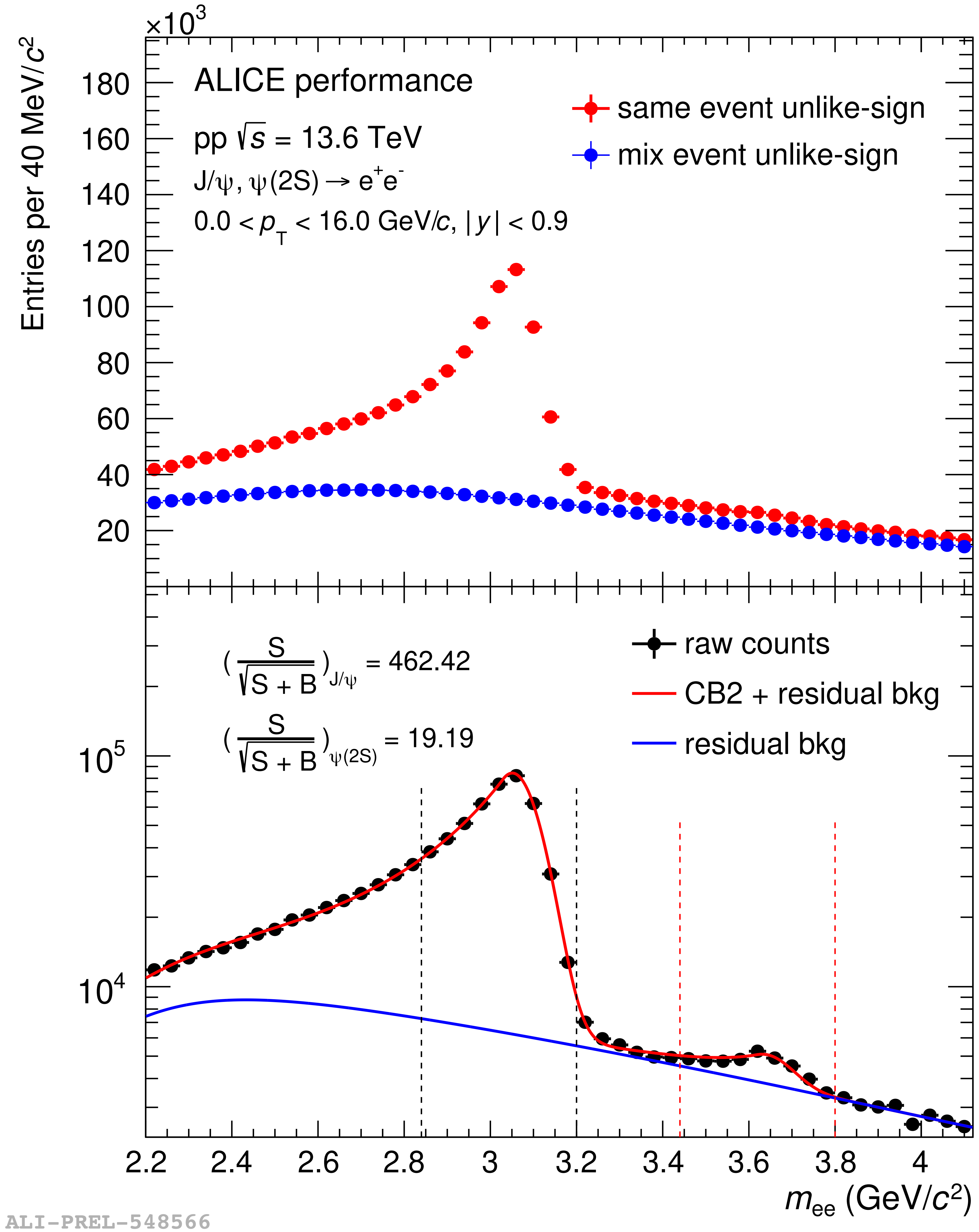




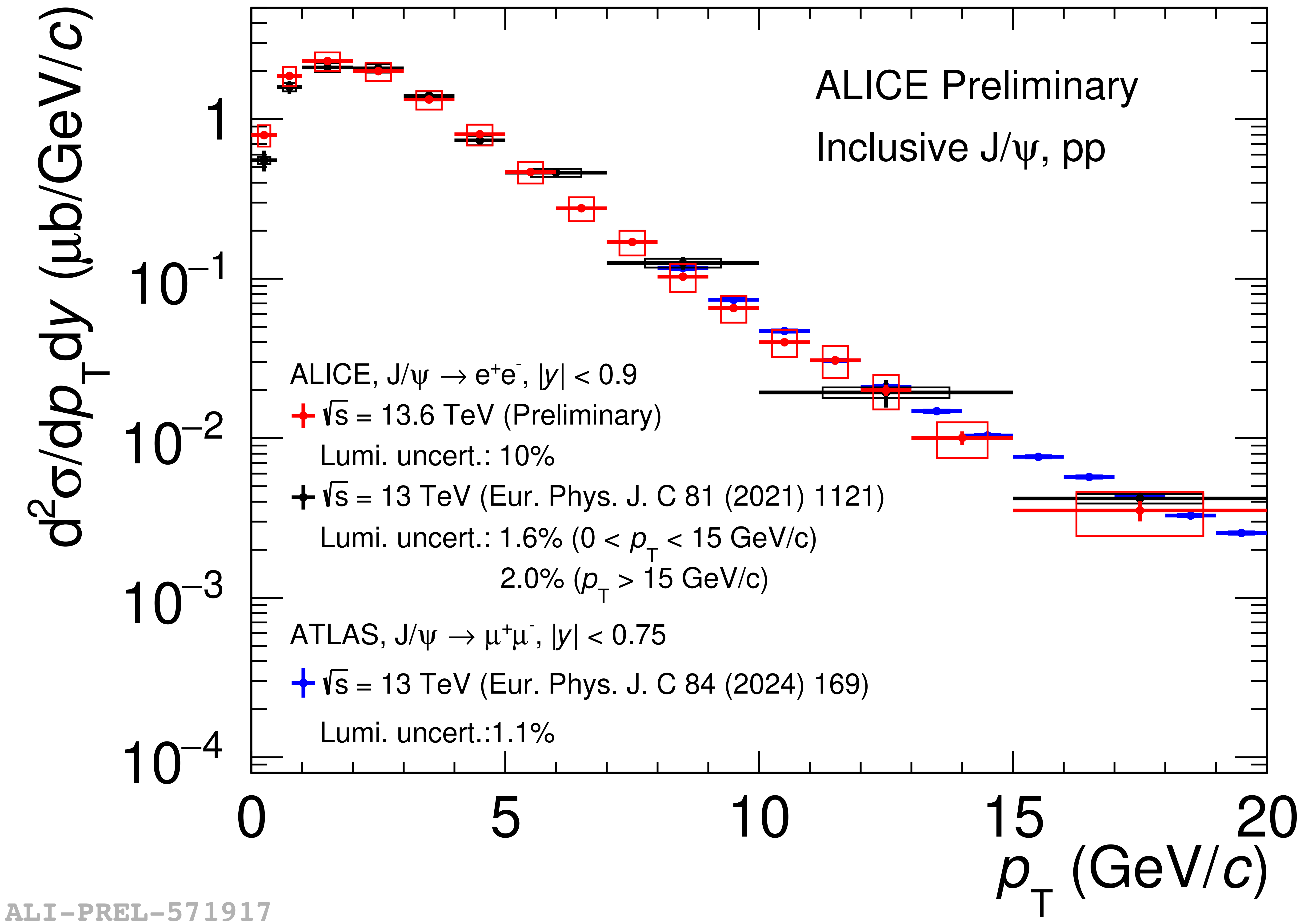
LS2 upgrades: improved pointing resolution and larger data samples

pp physics program

J/ψ production



ALI-PREL-548566

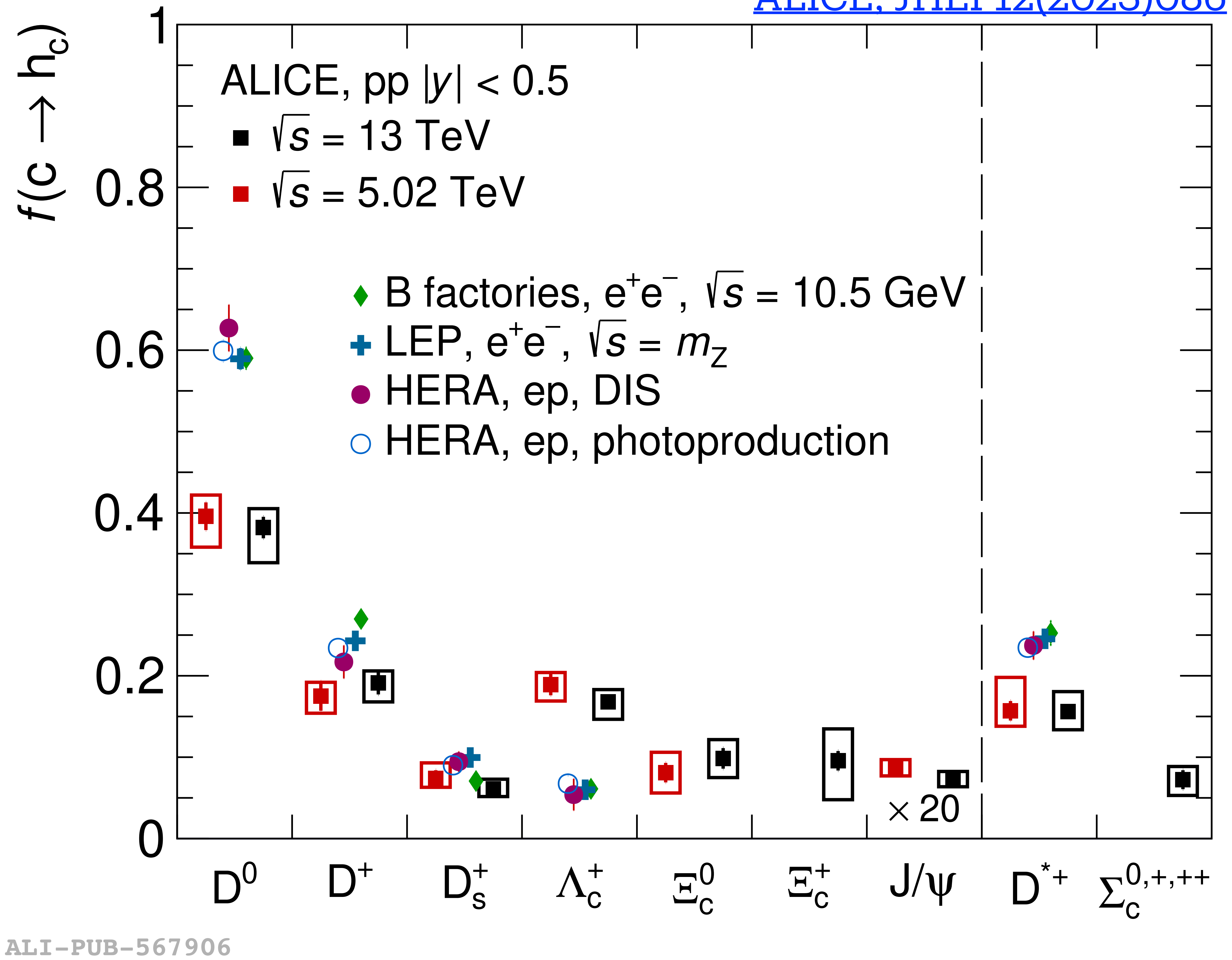


ALI-PREL-571917

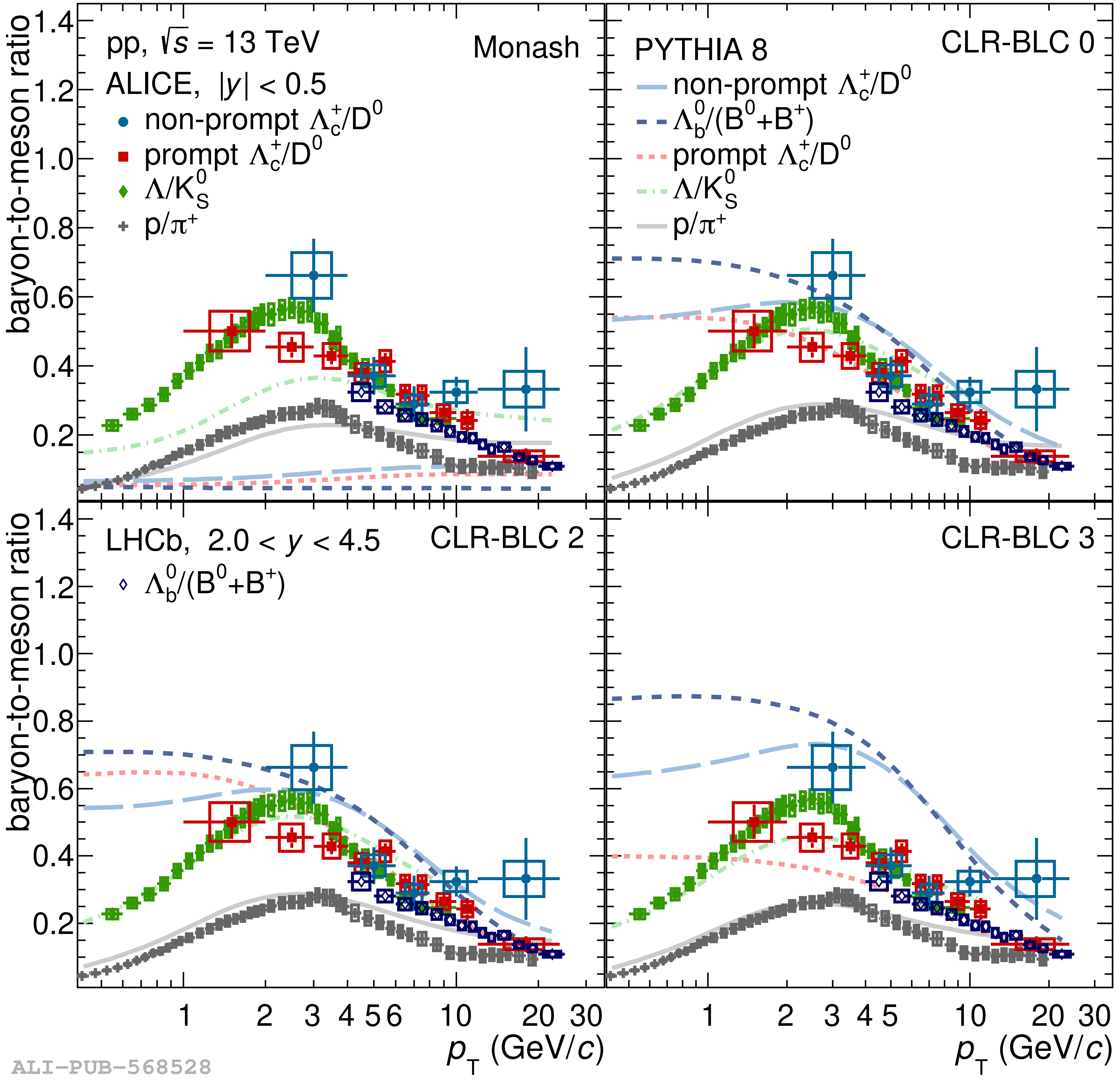
e⁺e⁻ decays: down to p_T = 0, excellent precision
Important input to quarkonia production models

Baryon to meson ratio: heavy quarks

[ALICE, JHEP12(2023)086](#)



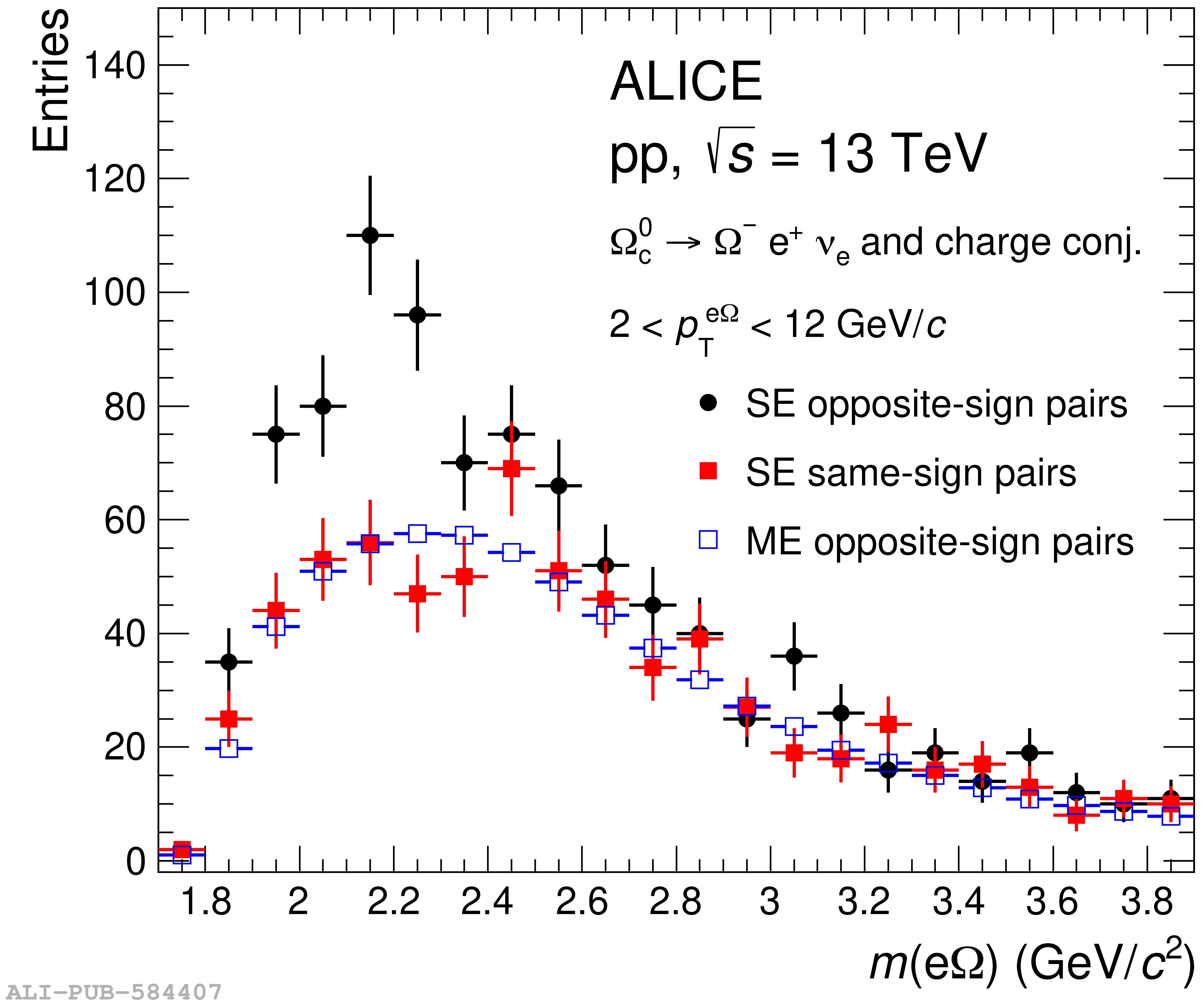
[ALICE, PRD 108, 112003 (2023)](#)

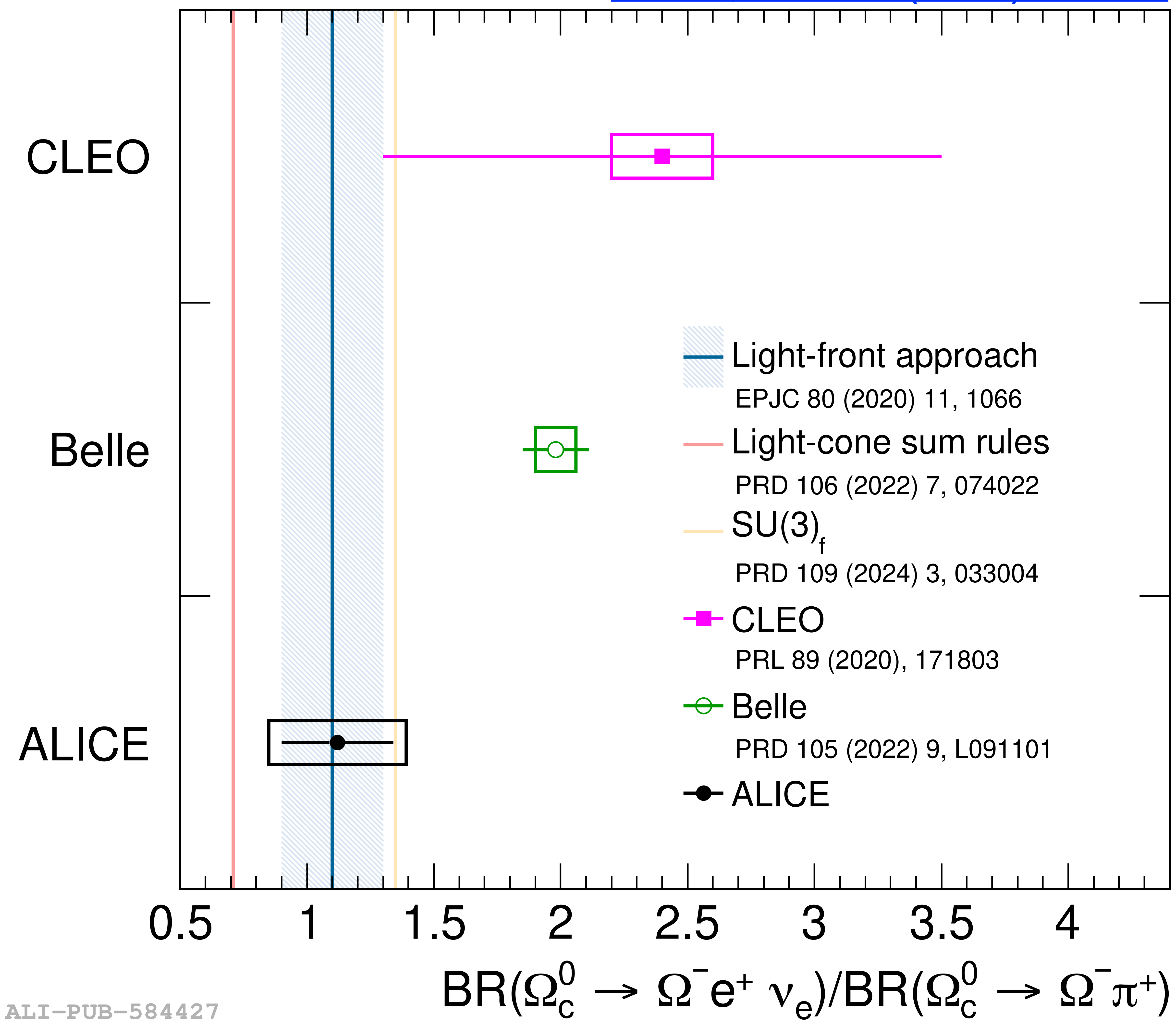


- Baryon production larger in pp than e^+e^-
- Baryon enhancement also present in beauty sector

Ω_c^0 branching ratios

ALICE, PRD 110 (2024) 032014

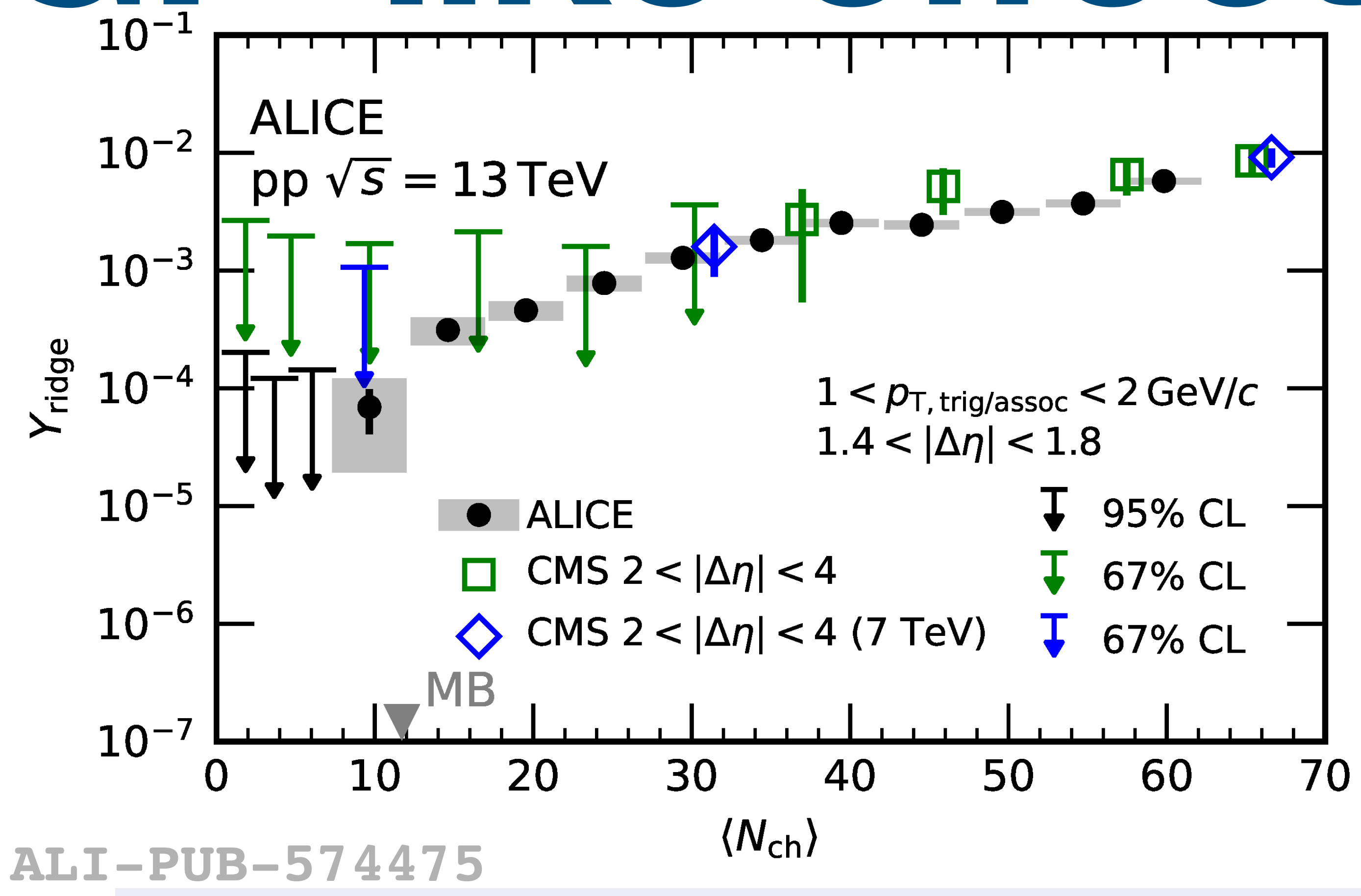




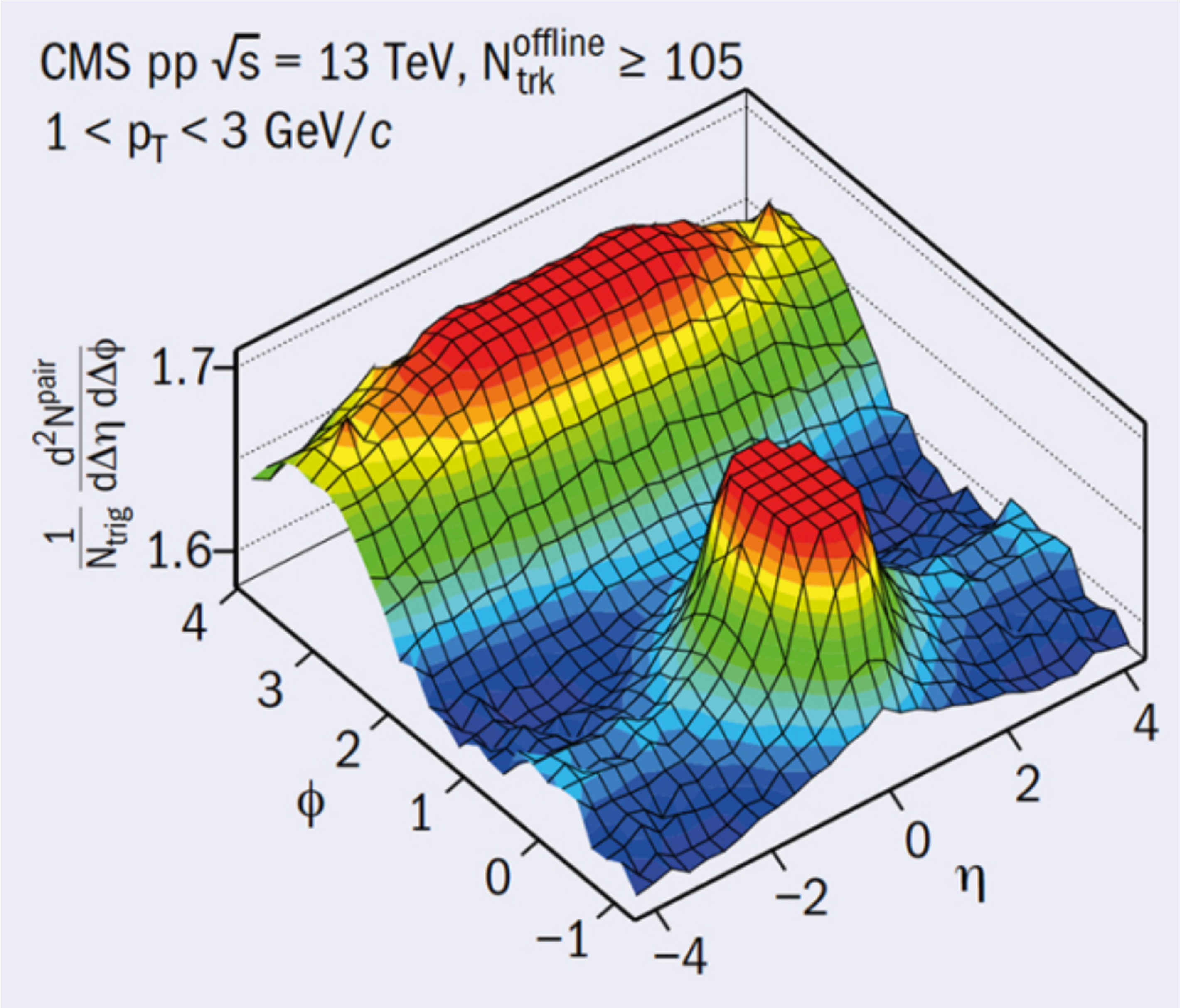
Charm baryon branching ratios: input to understanding charm baryon production

QGP-like effects in small systems

ALICE, PRL 132 (2024) 17, 172302



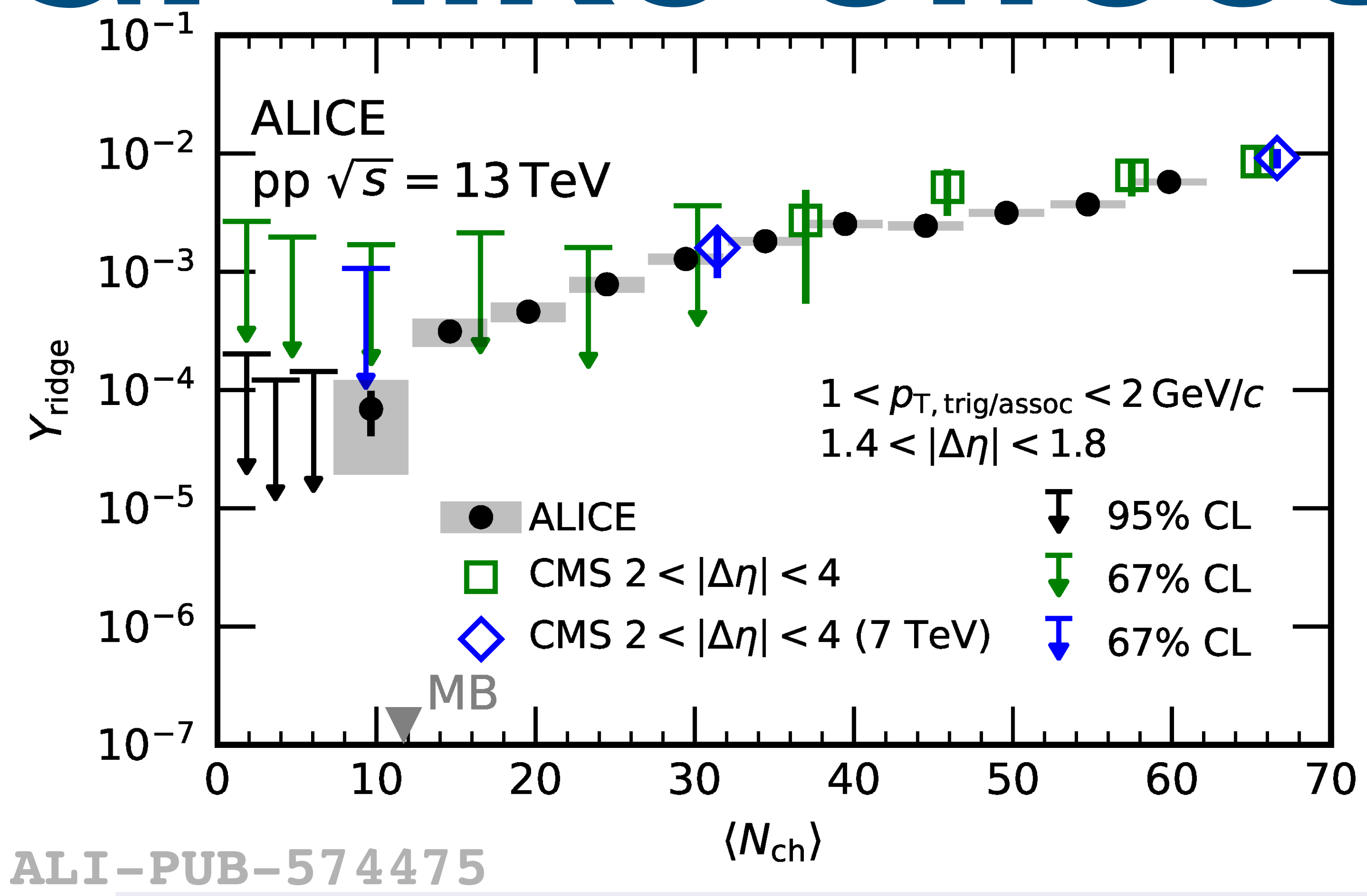
CMS, JHEP (2019) 1009:091



- Long range angular correlations in low- and high-multiplicity (HM) pp collisions

QGP-like effects in small systems

ALICE, PRL 132 (2024) 17, 172302



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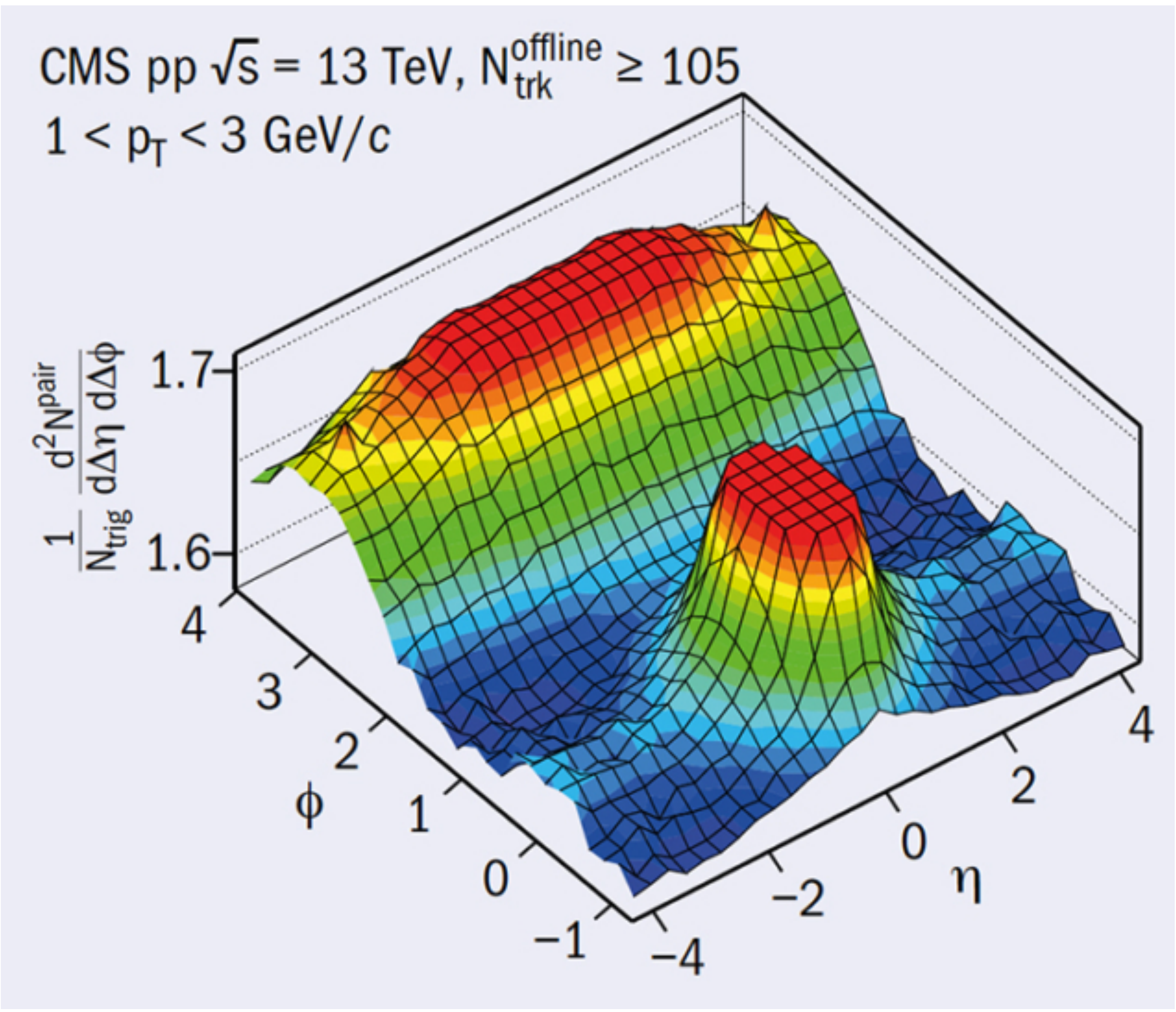
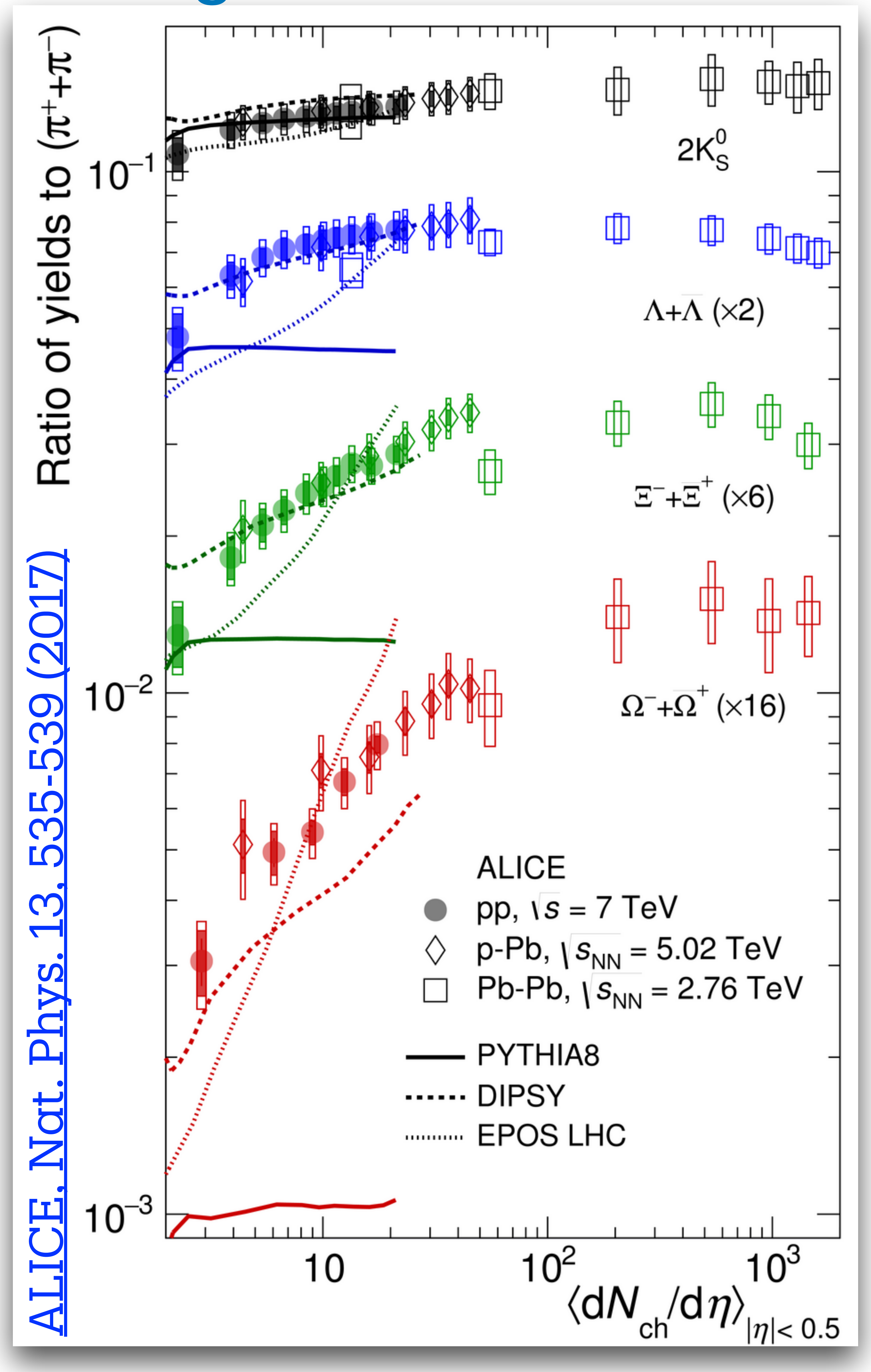


- Long range angular correlations in low- and high-multiplicity (HM) pp collisions

- Strangeness enhancement

ALICE, Nat. Phys. 13, 535-539 (2017)



QGP-like effects in small systems

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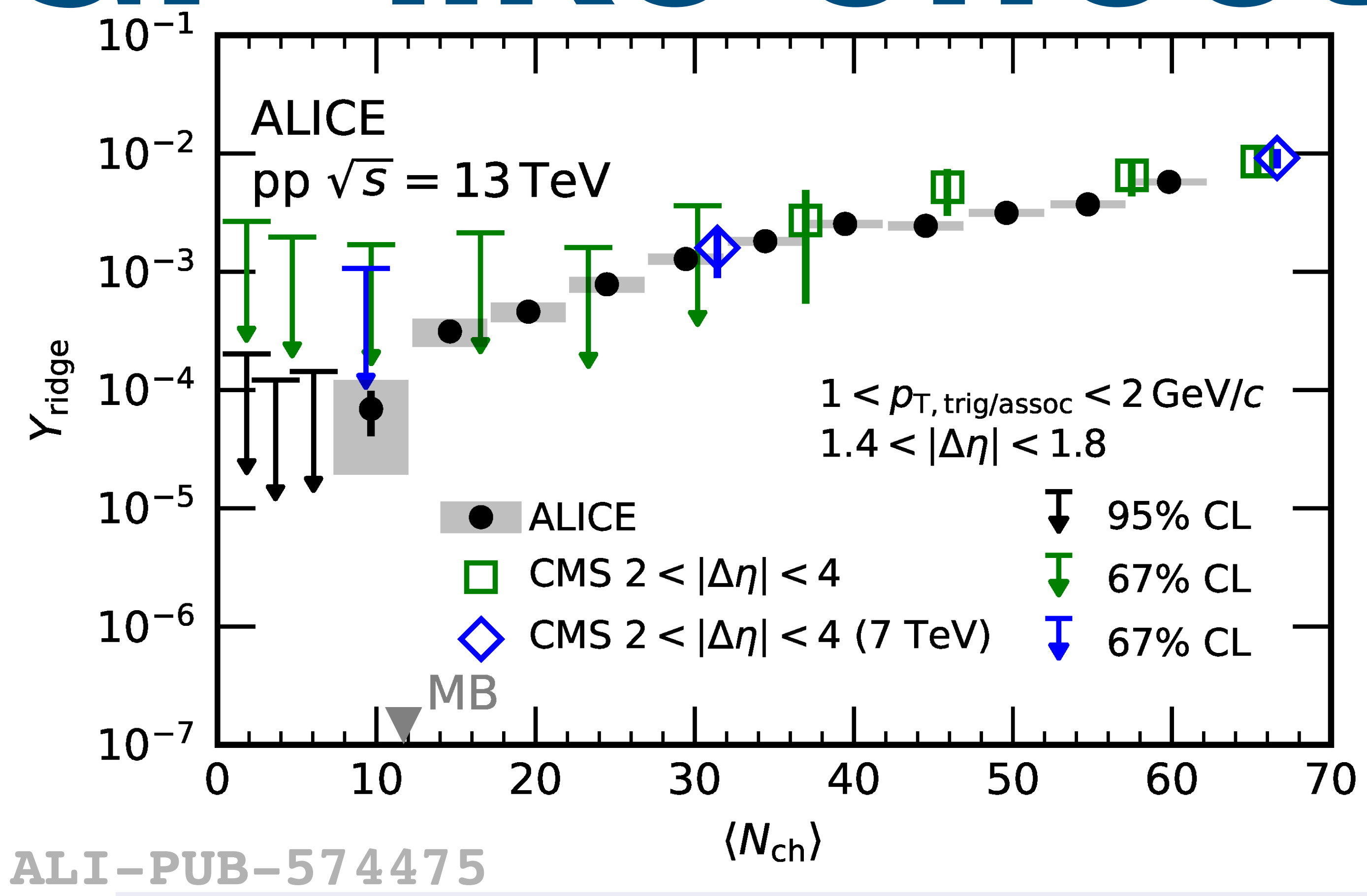
ALICE, PRL 132 (2024) 17, 172302



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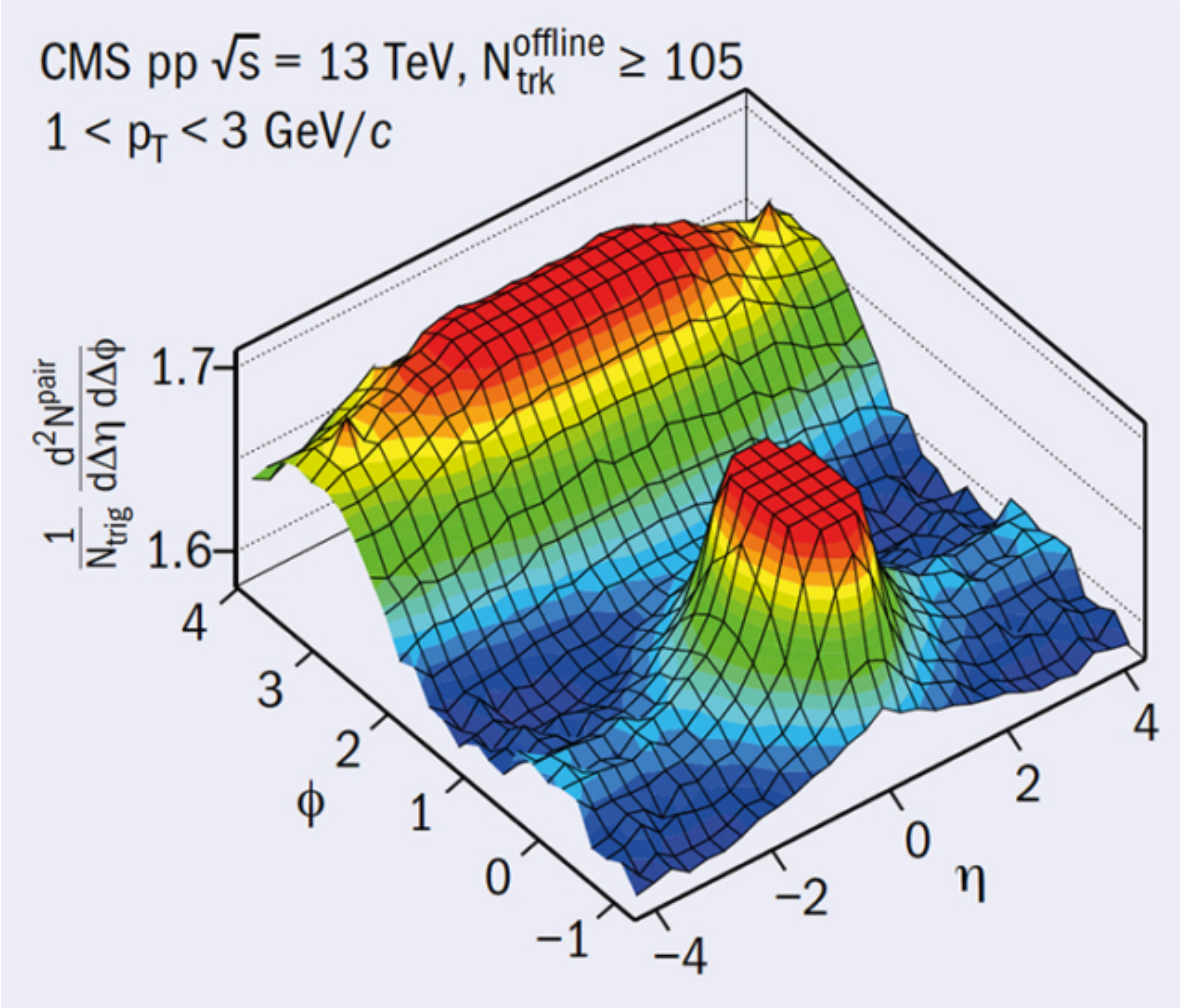

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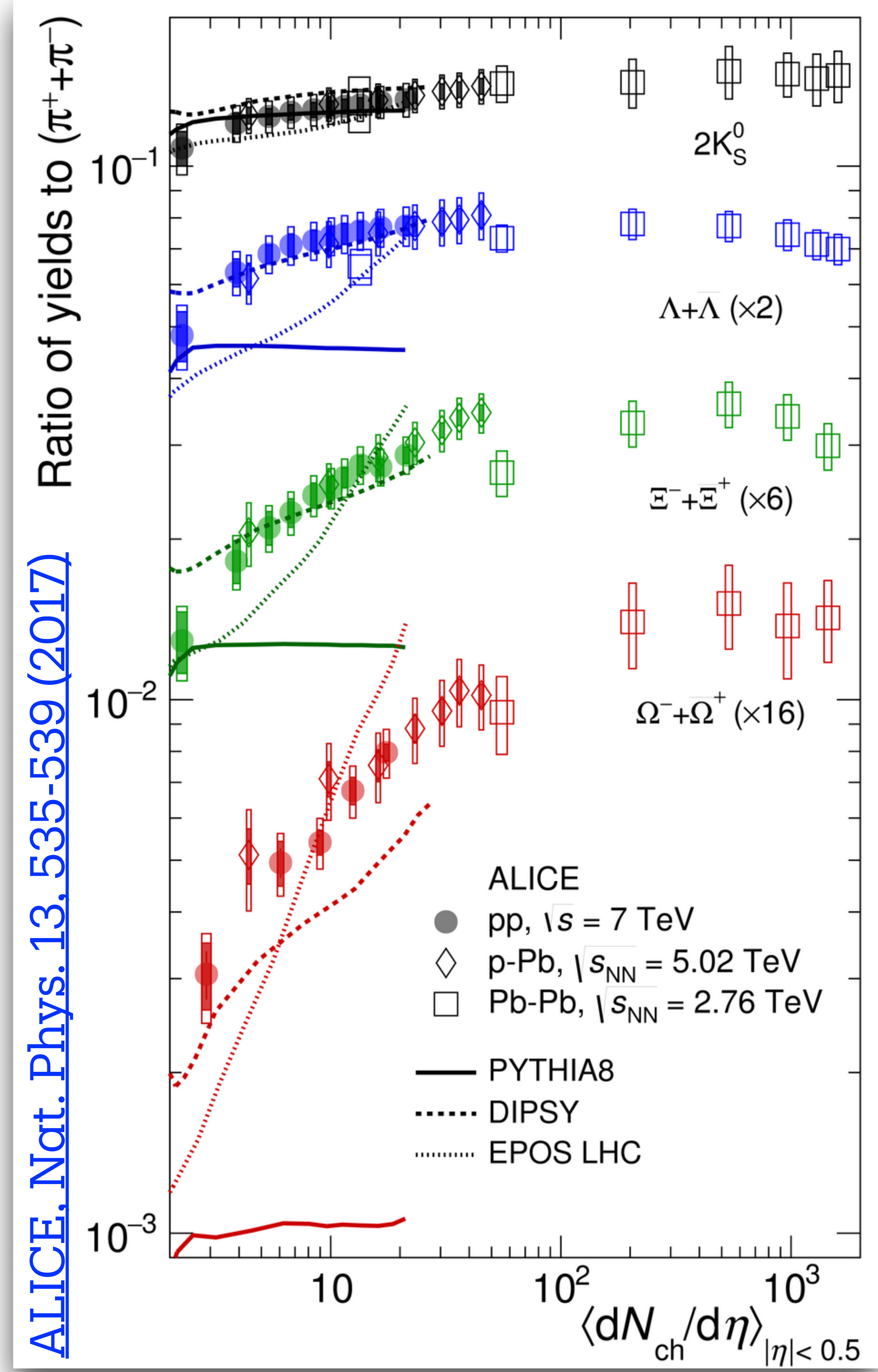
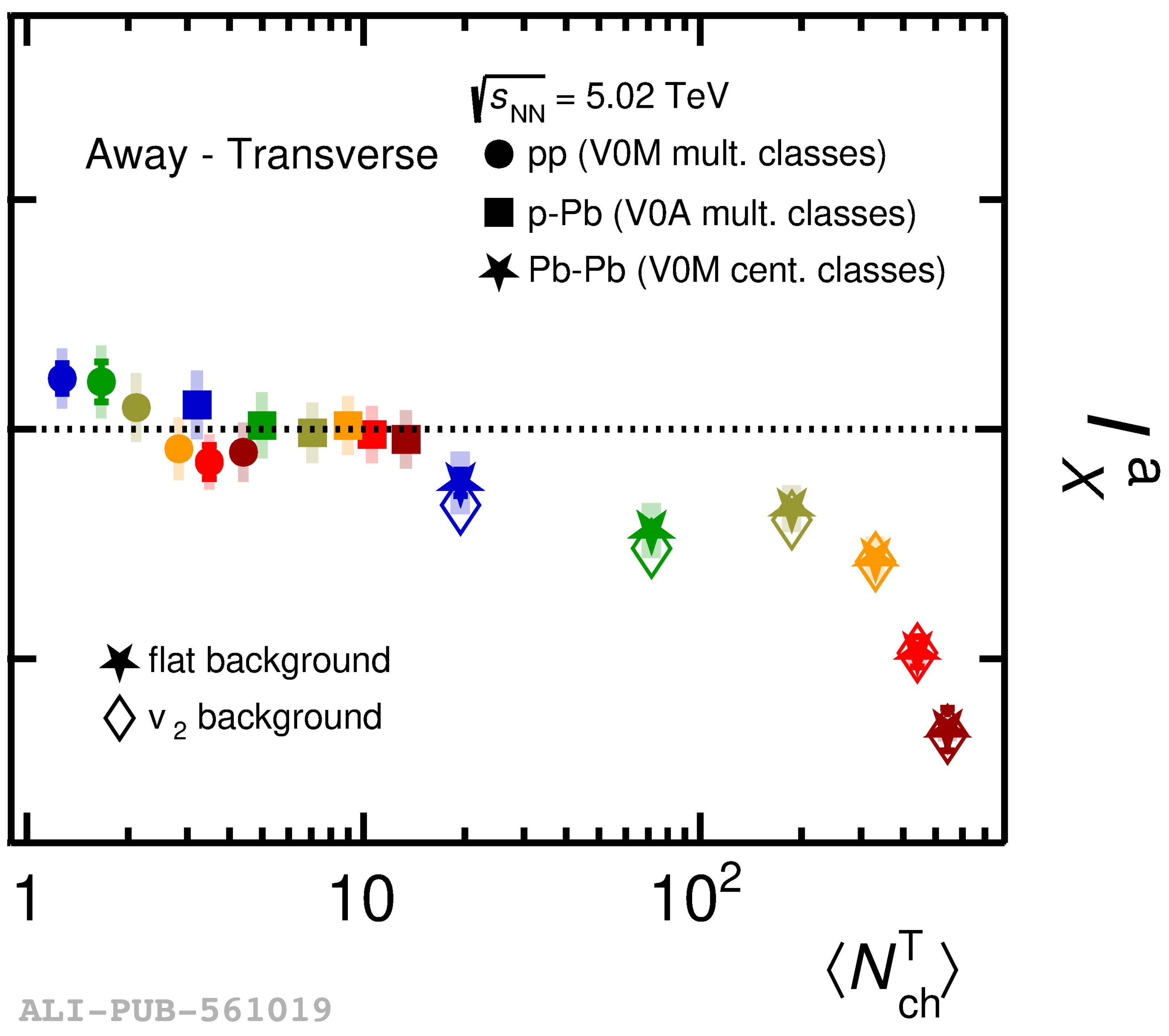


$$8 < p_{\mathrm{T}}^{\mathrm{trig}} < 15\,\mathrm{GeV}/c$$

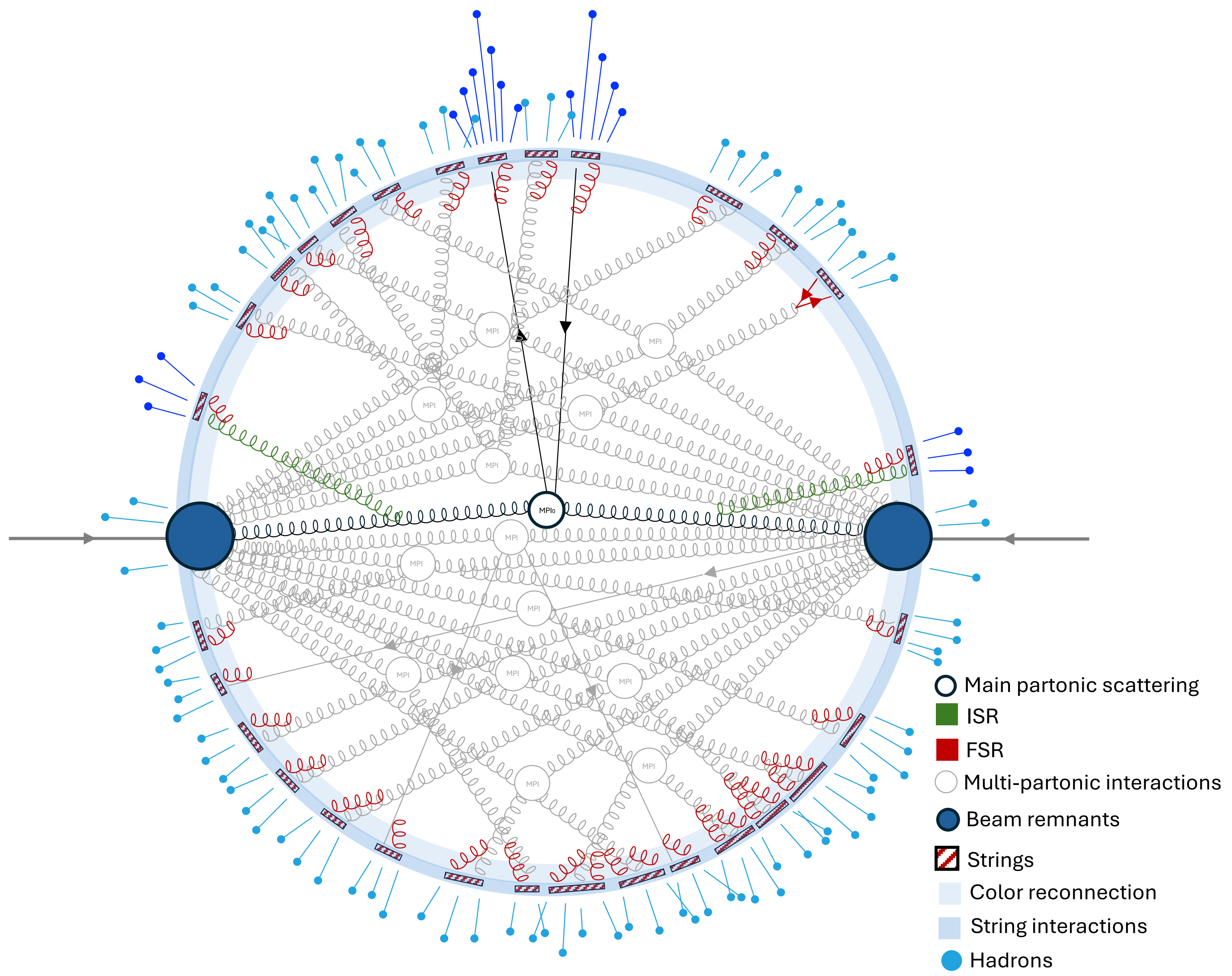
- Jet quenching?

ALICE, PLB 843 (2022) 137649



- pp and p-Pb collisions: small effect is driven by a bias (search is ongoing)

Bias due to local mult. fluctuations



- Multiparton interactions (MPI): more than one parton-parton scattering occurring in the same pp collision. Color reconnection (CR) produce collective-like effects

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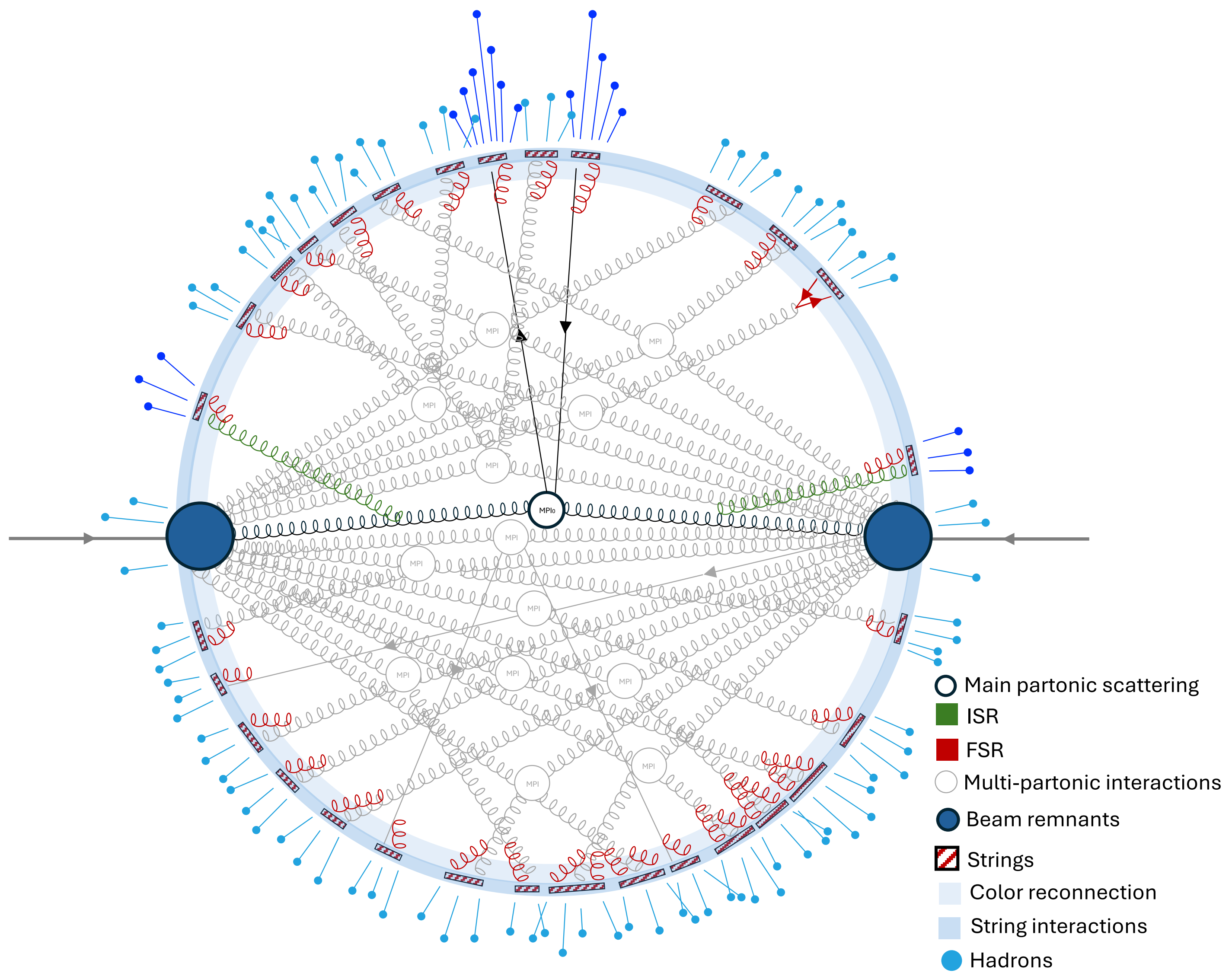
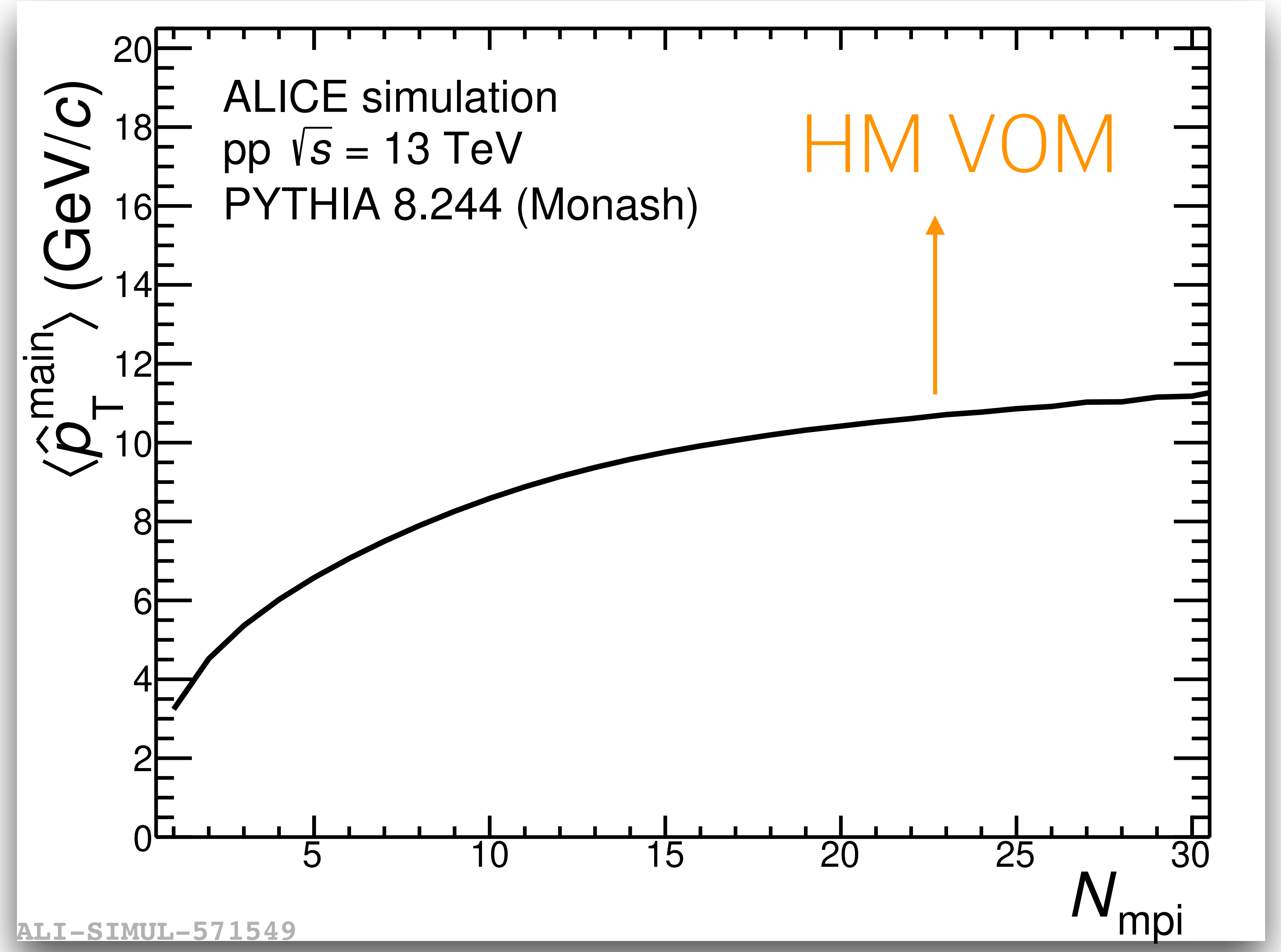


- The more central the pp collision, the higher the probability to find a high-p_T parton ($\hat{p}_T^{\text{main}}$)



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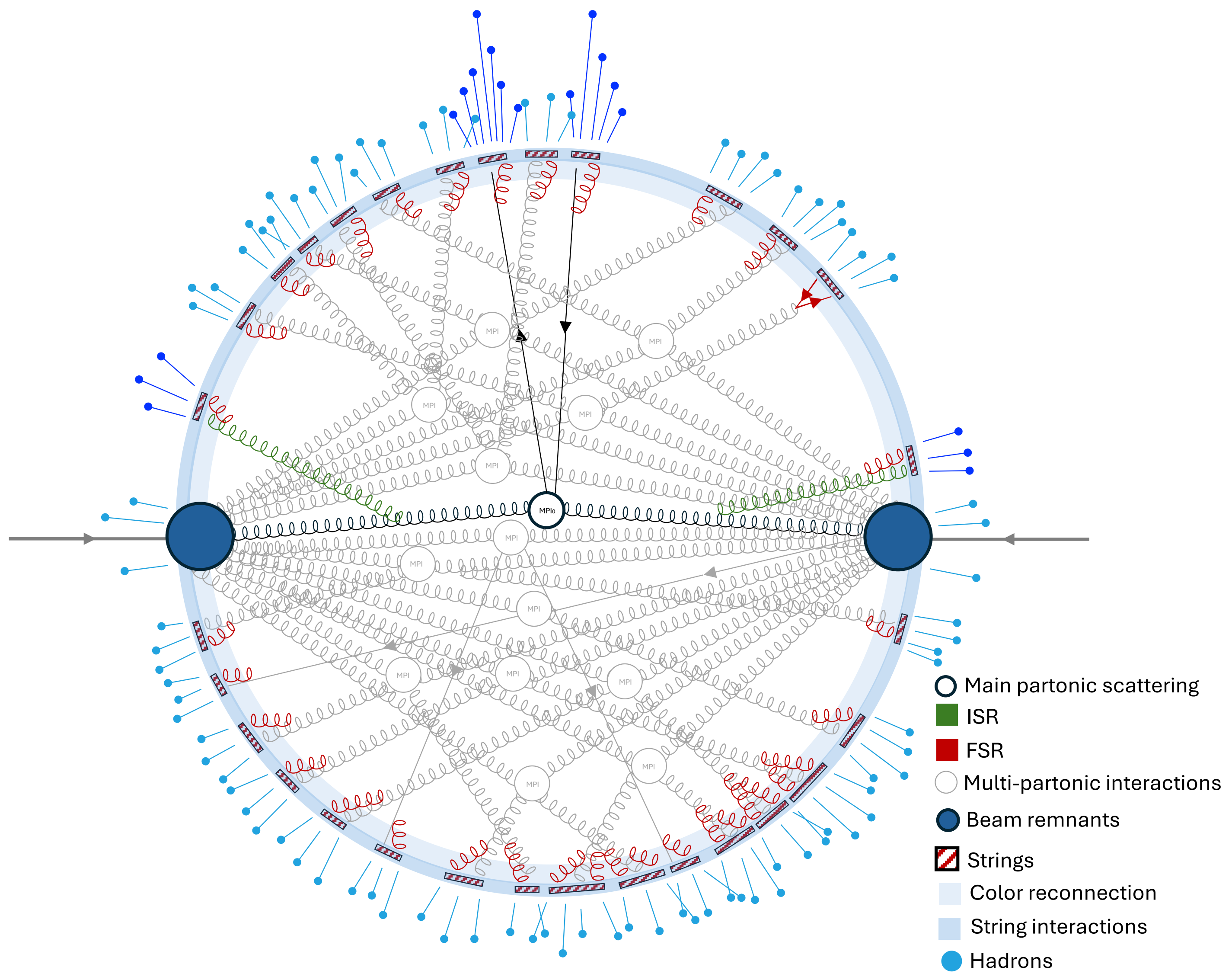

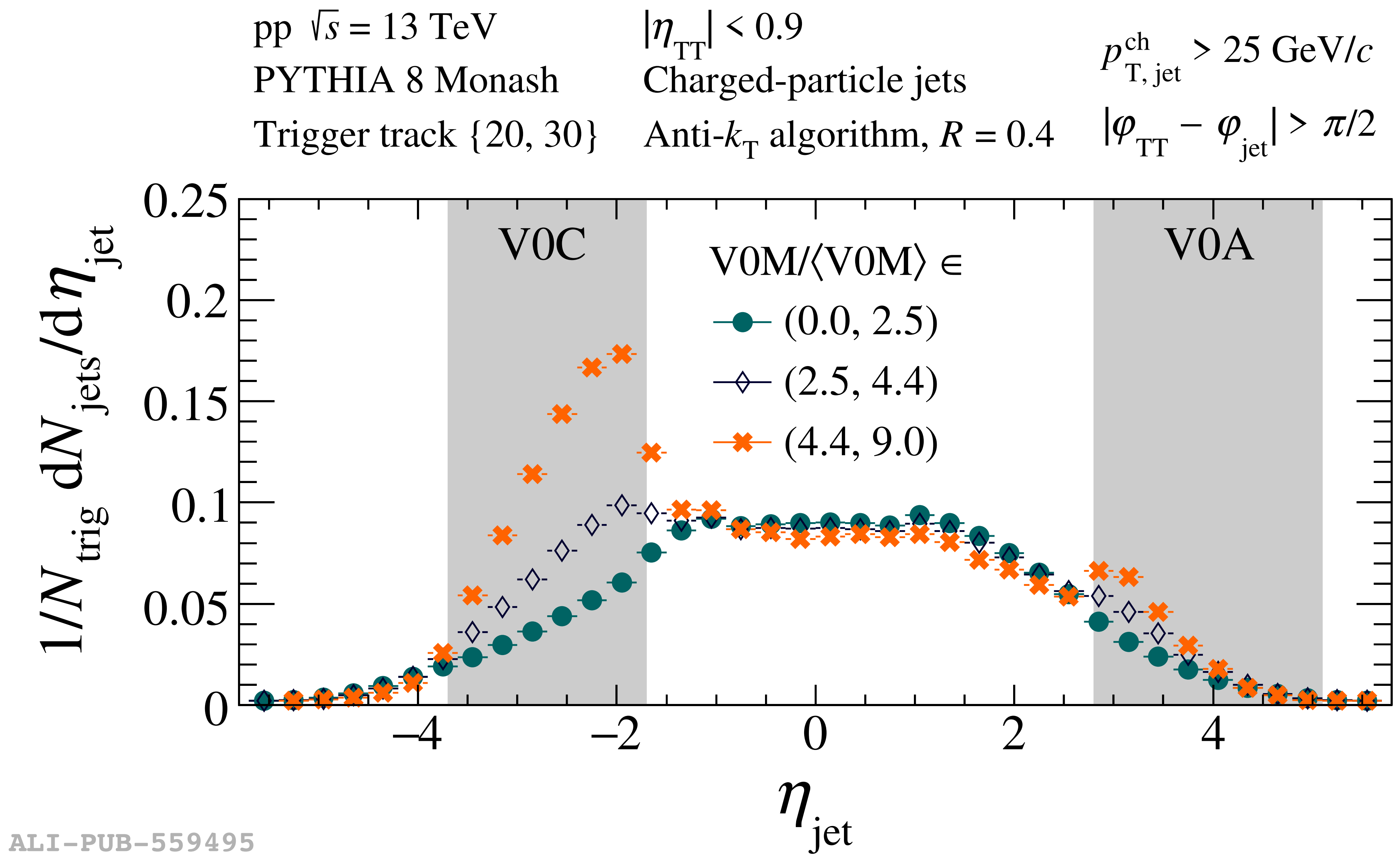

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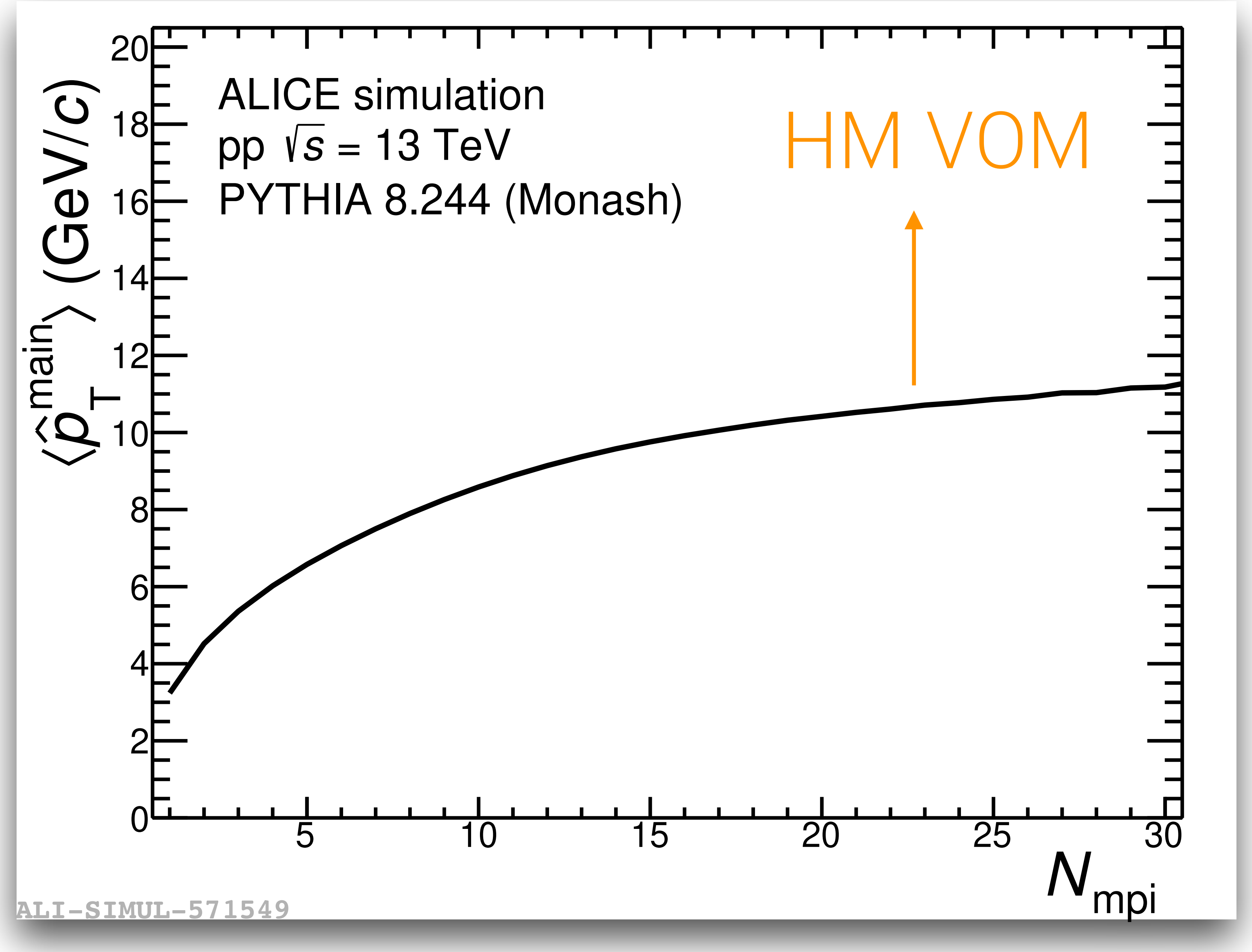


- The high-V0M multiplicity class selects pp collisions with jets in the forward detector

ALICE, JHEP 05 (2024) 229

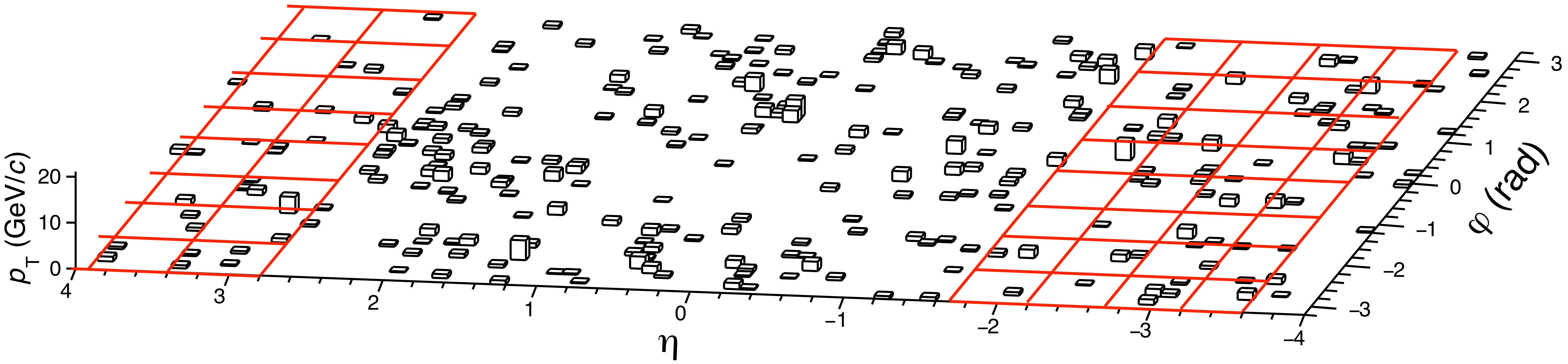
Flattenicity

- Event-by-event selection based on the relative standard deviation of the multiplicity measured in the 64 V0 channels, $N^{(\mathrm{ch.}\,i)}$

$$\rho = \sqrt{\sum_{i}^{64}\left(N^{(\mathrm{ch}.i)} - \langle N^{(\mathrm{ch})}\rangle\right)^2/64^2} \Big/ \langle N^{(\mathrm{ch})}\rangle$$

[A. Ortiz et al., PRD 107 (2023) 7, 076012]

PYTHIA 8.303 (Monash 2013), pp $\sqrt{s}$ = 13 TeV, N_{mpi}=24



Small local $N^{(\mathrm{ch.}\,i)}$ fluctuations in the V0 acceptance: small flattenicity values

- "isotropic" distribution of particles in the V0 acceptance (large multiplicities)

p_T spectra as a function of flattenicity

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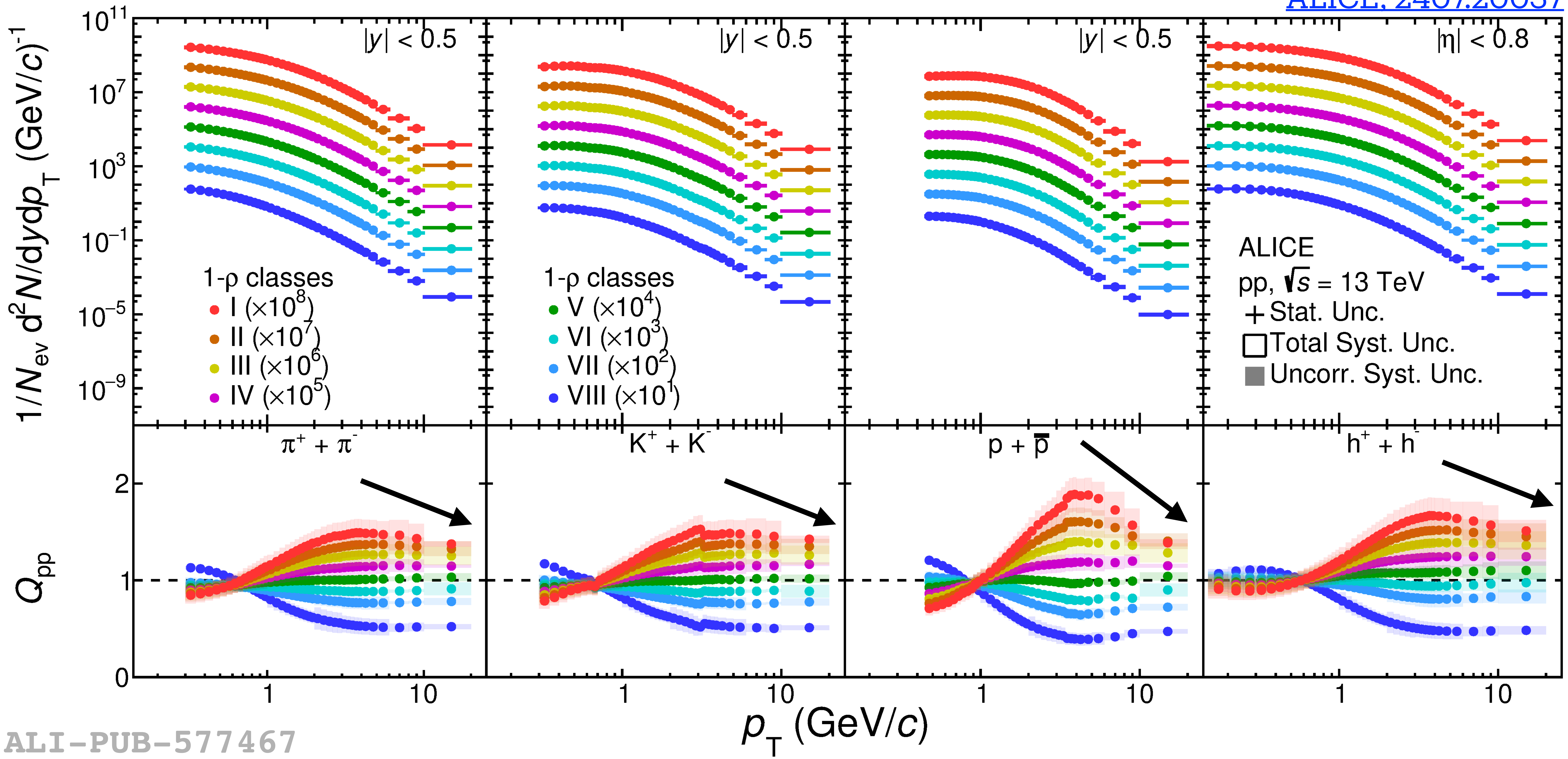
ALICE, 2407.20037



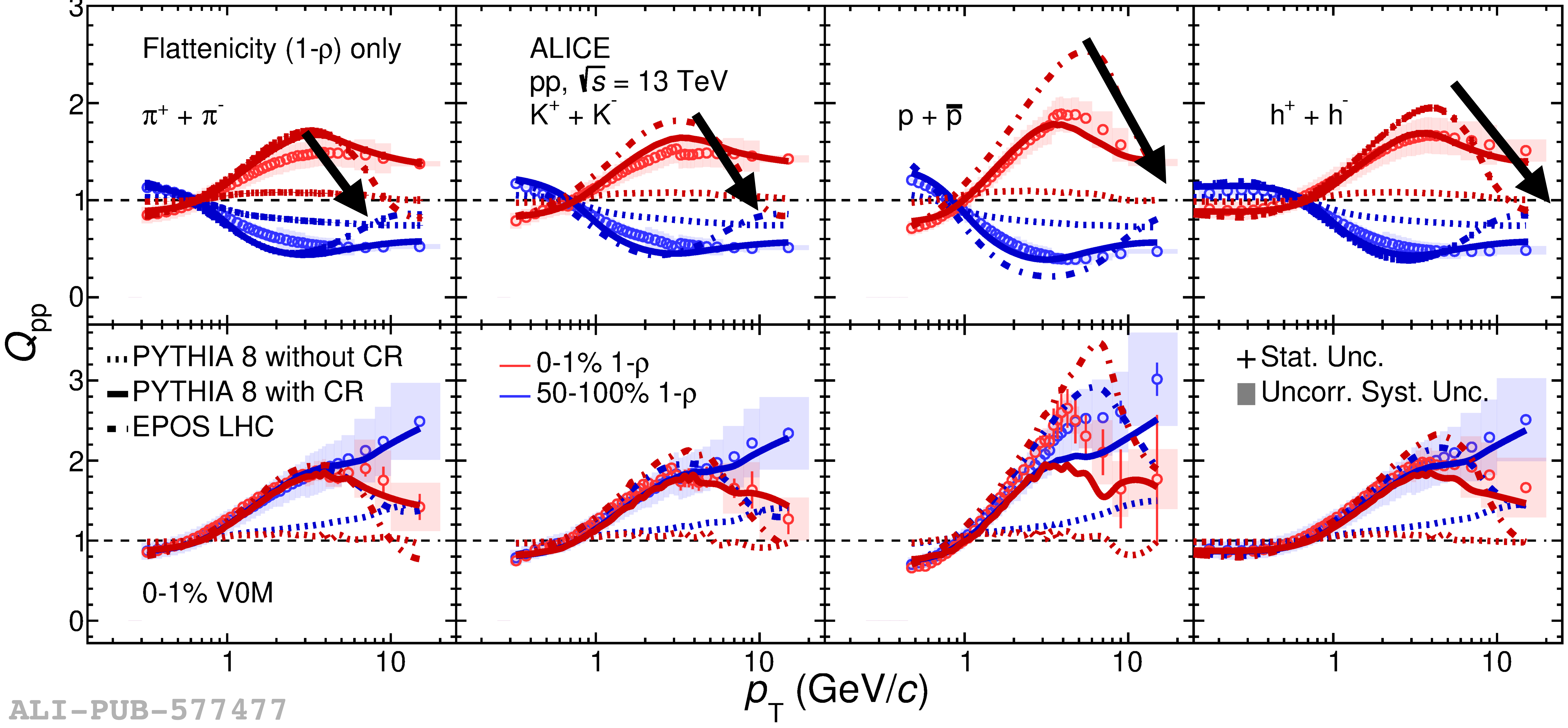
$$Q_{pp} = \frac{\left.\frac{1}{N_{ev}}\frac{dN_{ch}}{dp_T}\frac{1}{\langle N_{ch}\rangle}\right|_{HM}}{\left.\frac{1}{N_{ev}}\frac{dN_{ch}}{dp_T}\frac{1}{\langle N_{ch}\rangle}\right|_{MB}}$$

- Intermediate p_T: a bump structure is developed with increasing multiplicity
- High p_T: Q_{pp} seems to approach to the vicinity of one

Flattenicity: data vs models

See Paola Vargas talk: 8/11/24 12:15 h (QCD4)

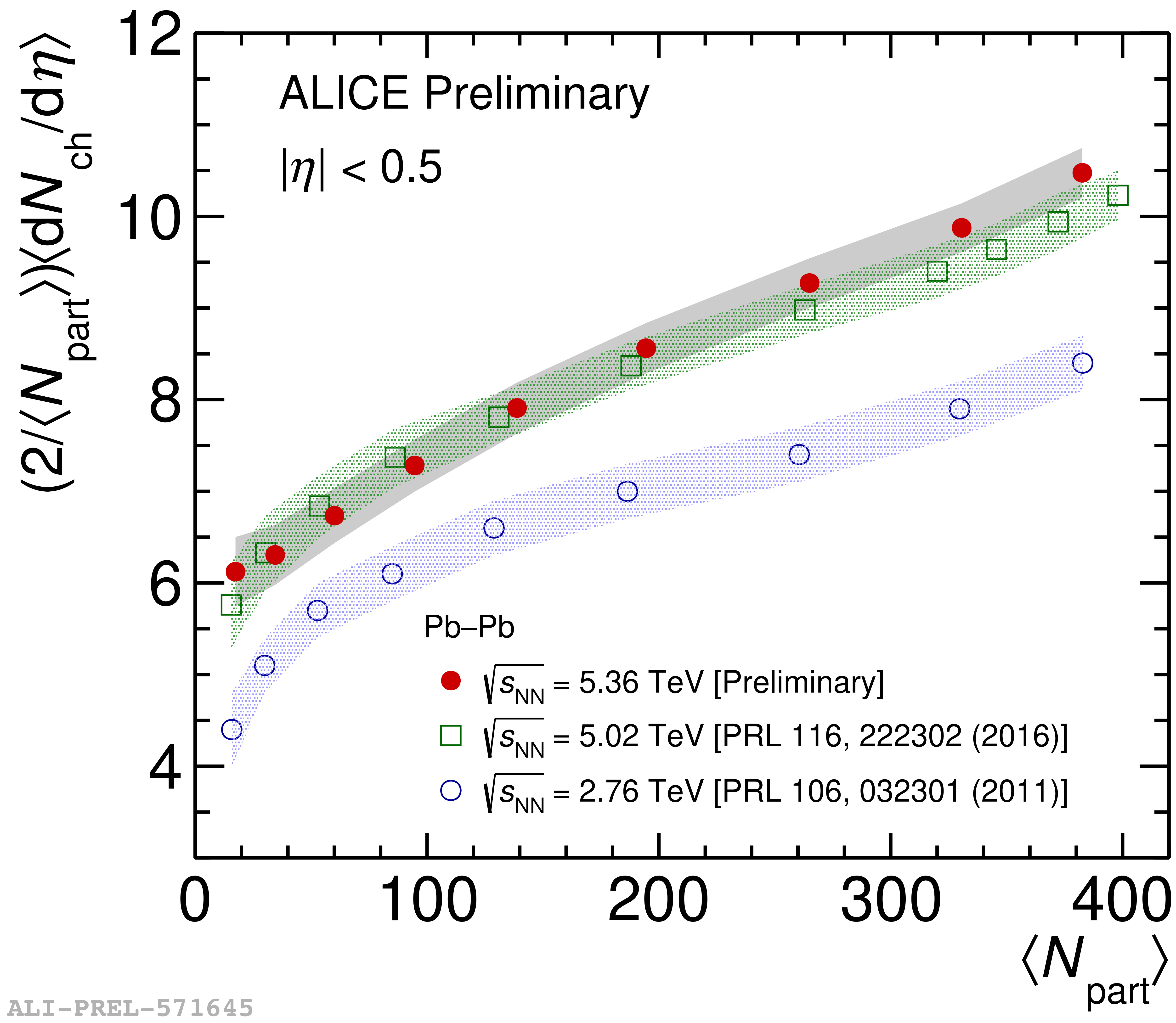
ALICE, 2407.20037

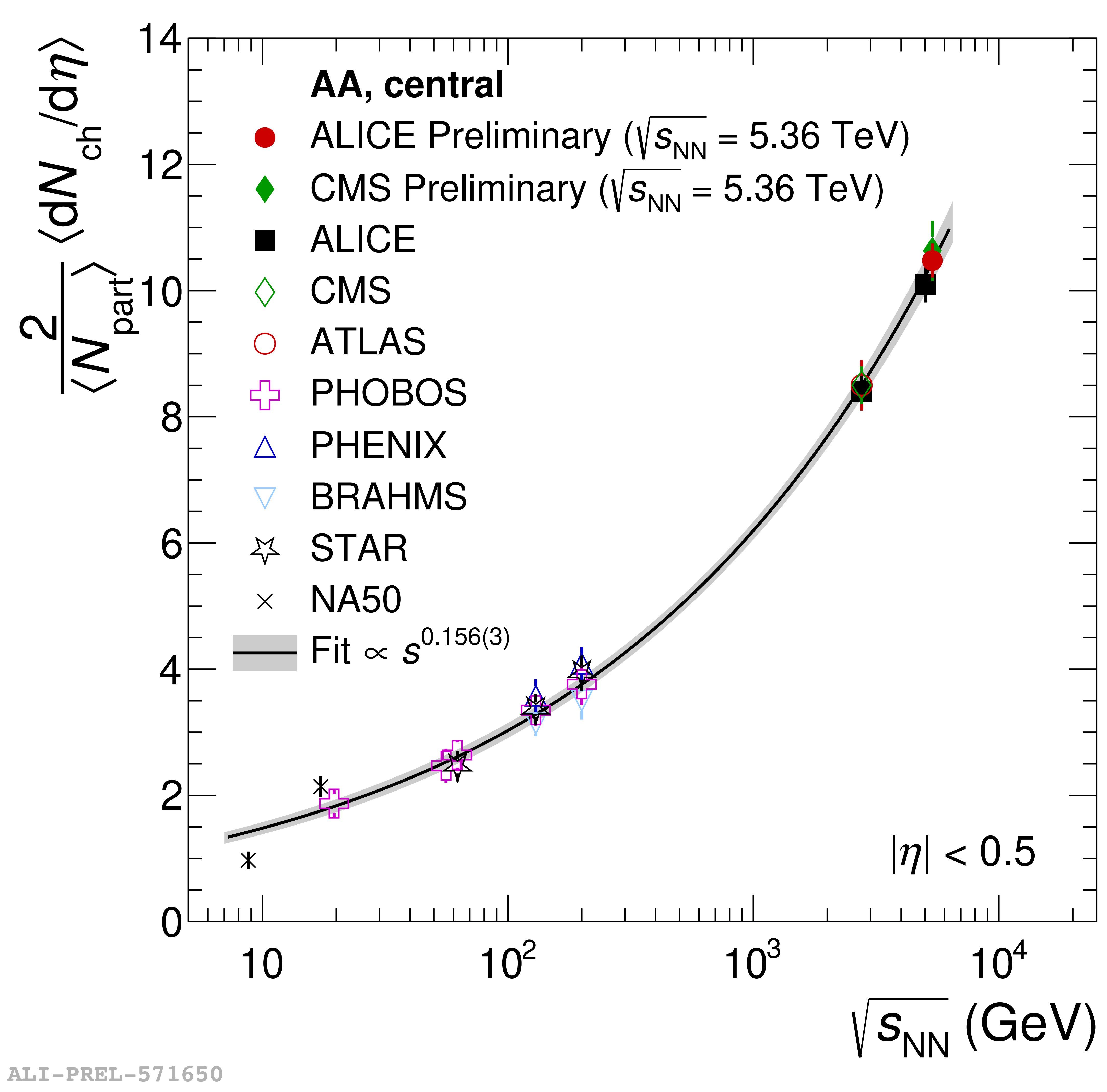


- Epos LHC does not describe data, PYTHIA w/o CR, flat Qpp

Pb-Pb physics program

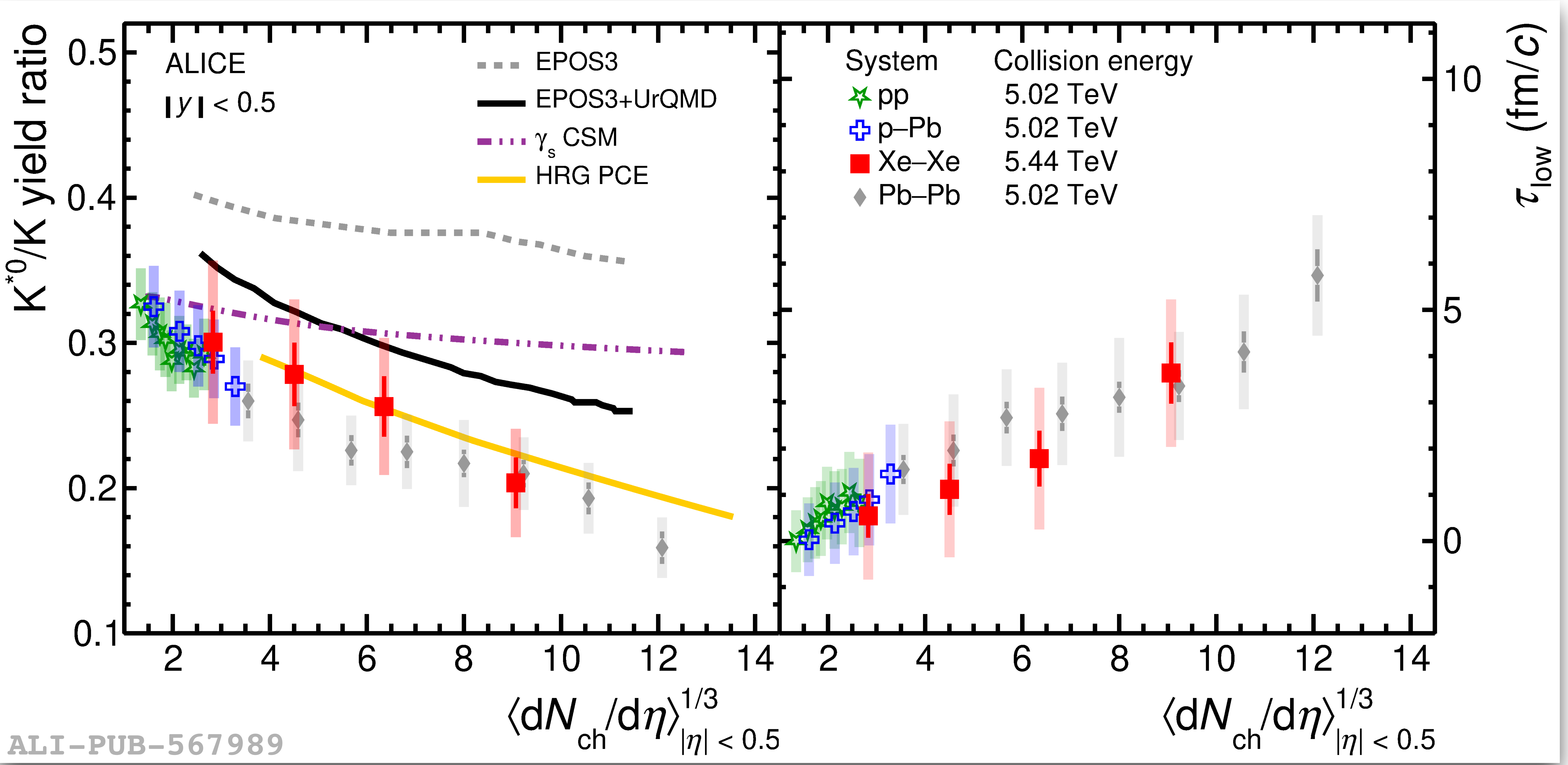
Multiplicity: Run 3 Pb-Pb collisions





- Multiplicity measured using tracks (TPC, ITS)
- Results in line with extrapolation from lower energies

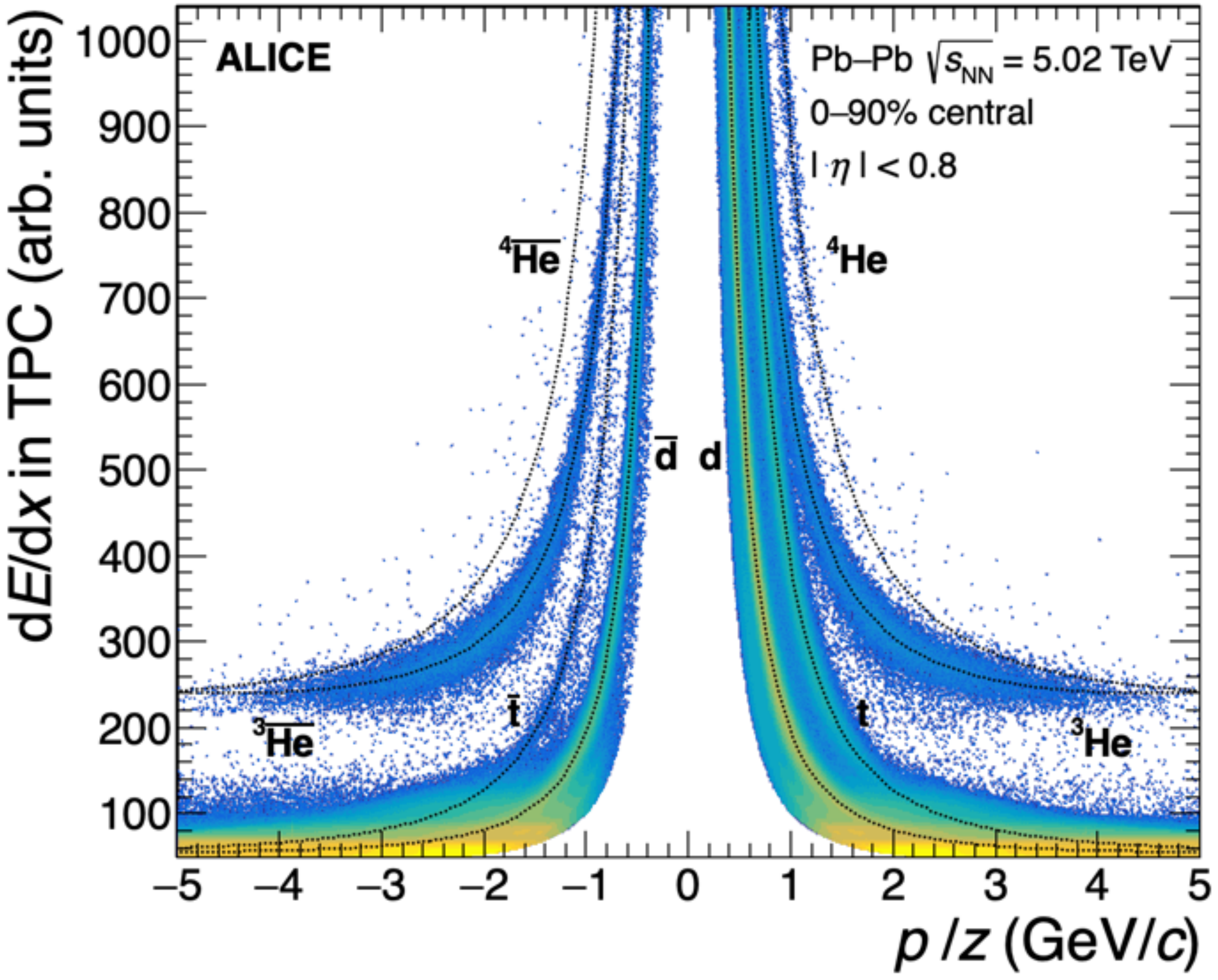
Hadronic phase: resonance production



- Scattering of decay daughters of short-lived resonances reduces apparent yield
- K*/K ratio decreases with centrality: duration of hadronic phase increases with centrality $K^*/K^0{}_{\text{kin}} = K^*/K^0{}_{\text{chem}} \times e^{-\tau/\tau_{K^*}}$

Light nuclei

ALICE, PRC 107, 064904



Light nuclei

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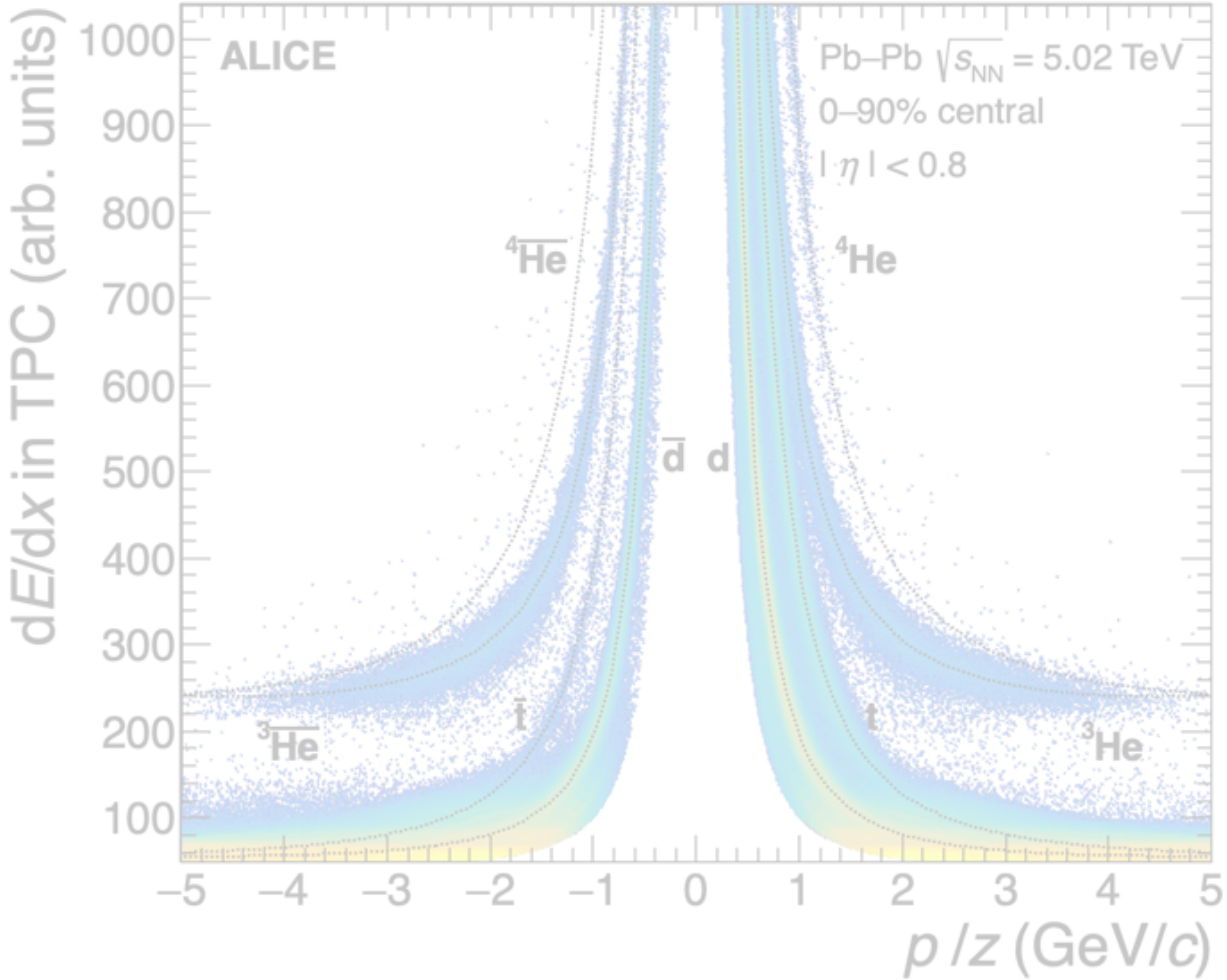
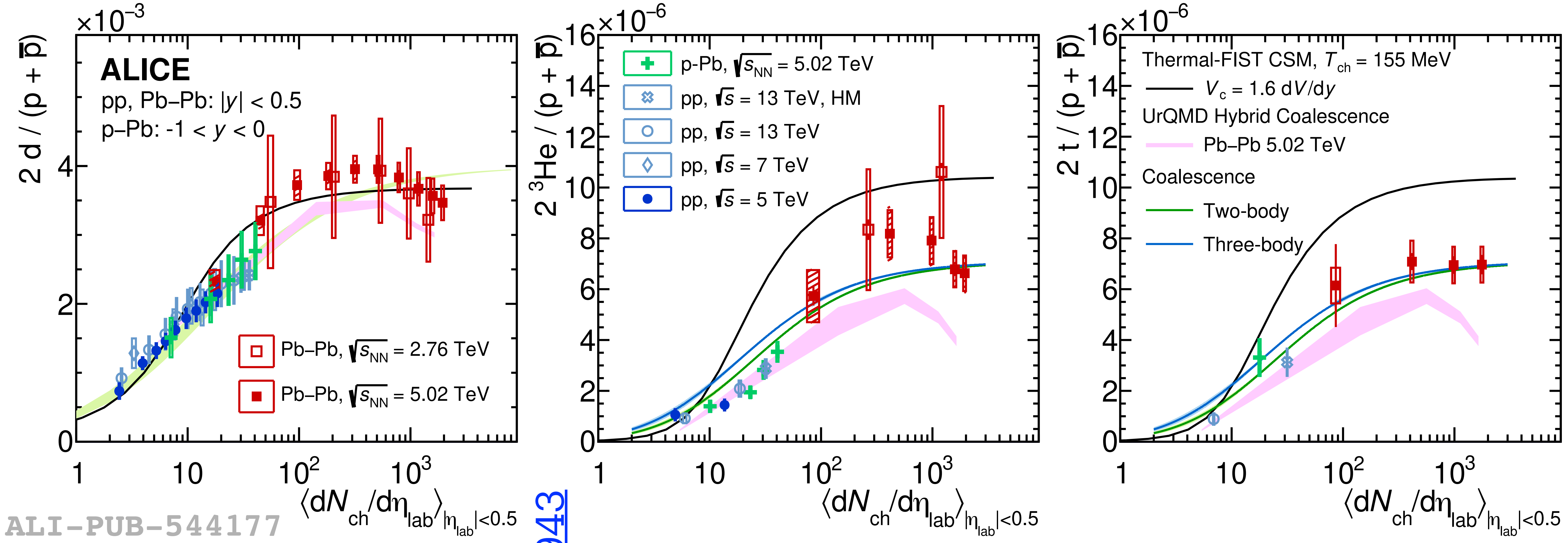
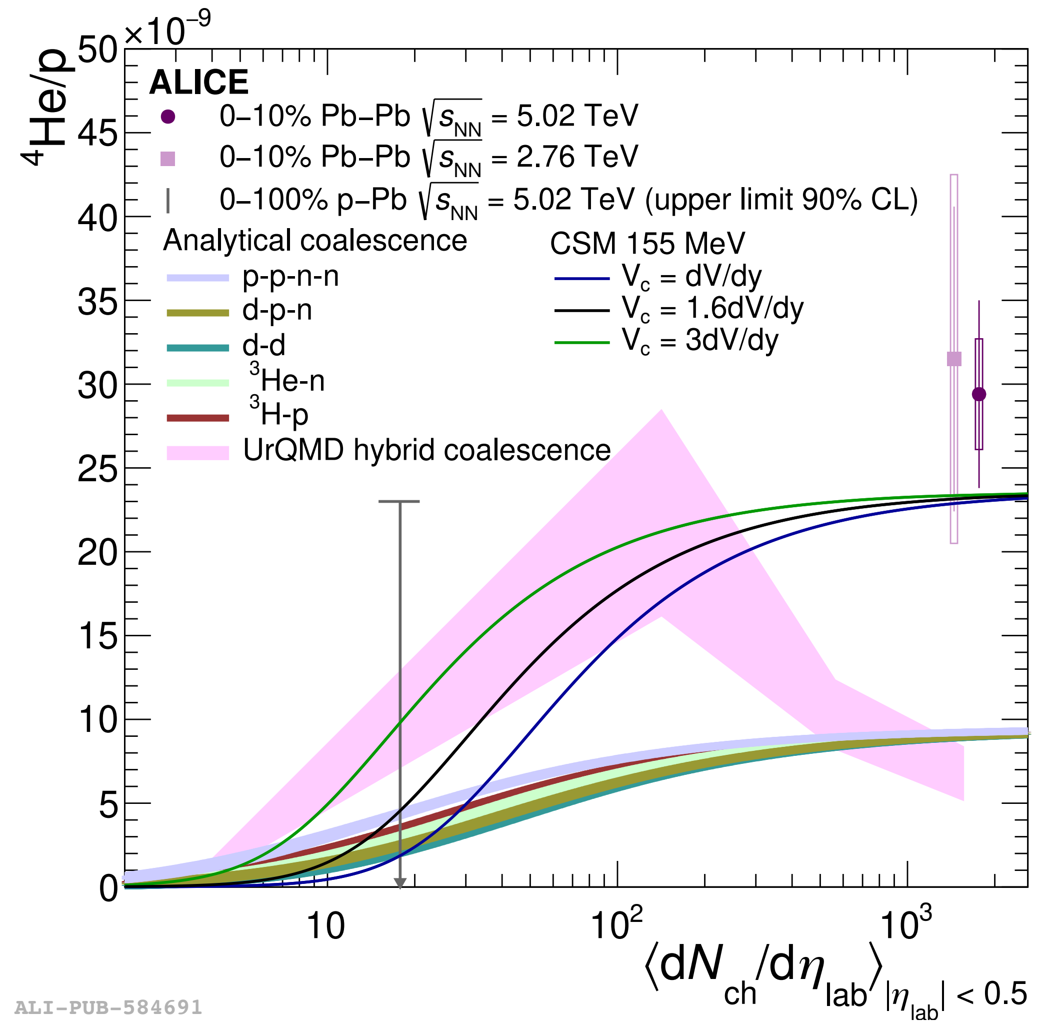


Binding energy O(10 MeV): dissociation in rescattering phase + formation via coalescence of baryons



ALICE, PLB 858 (2024) 138943



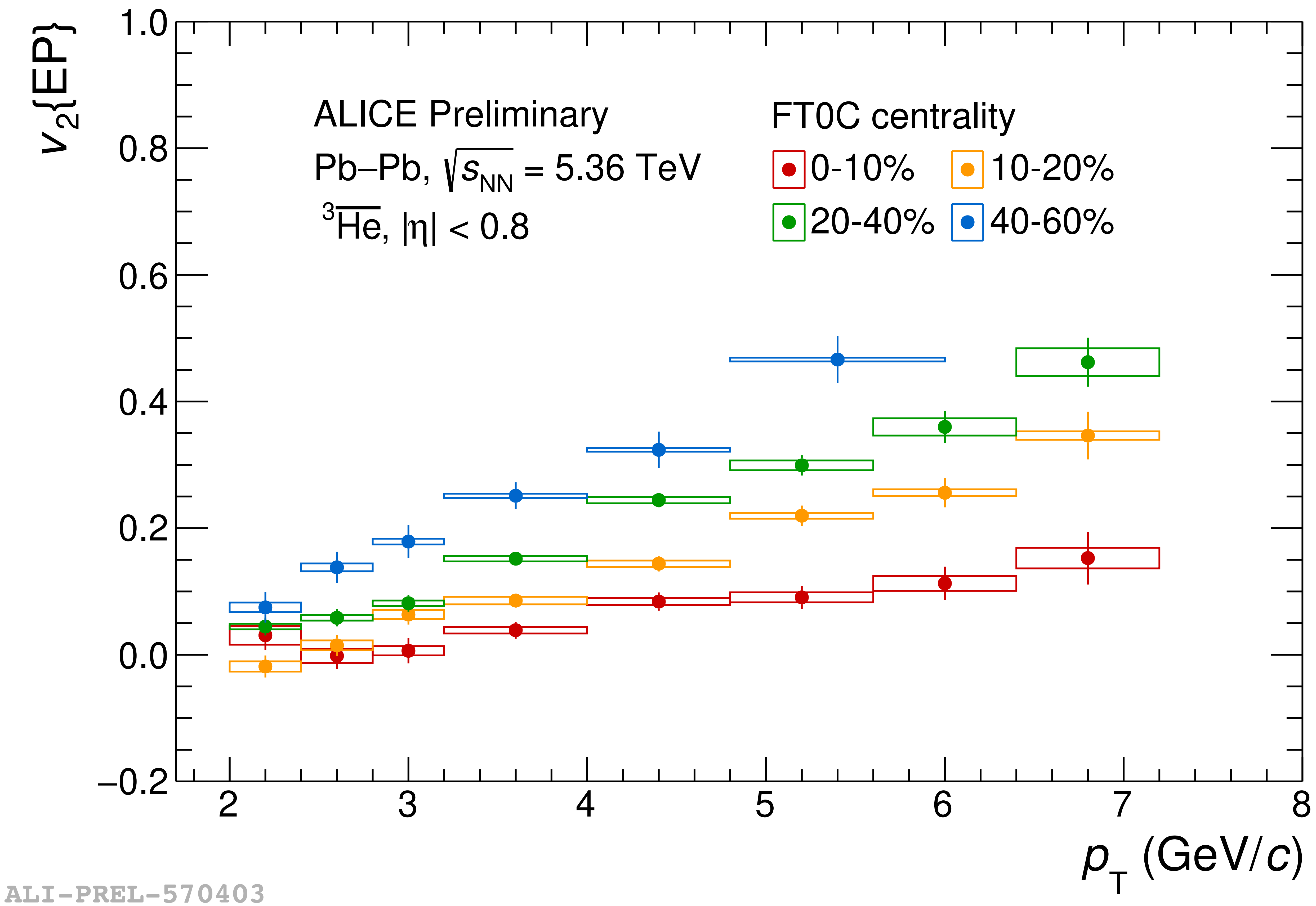
A=2: deuteron, limited sensitivity

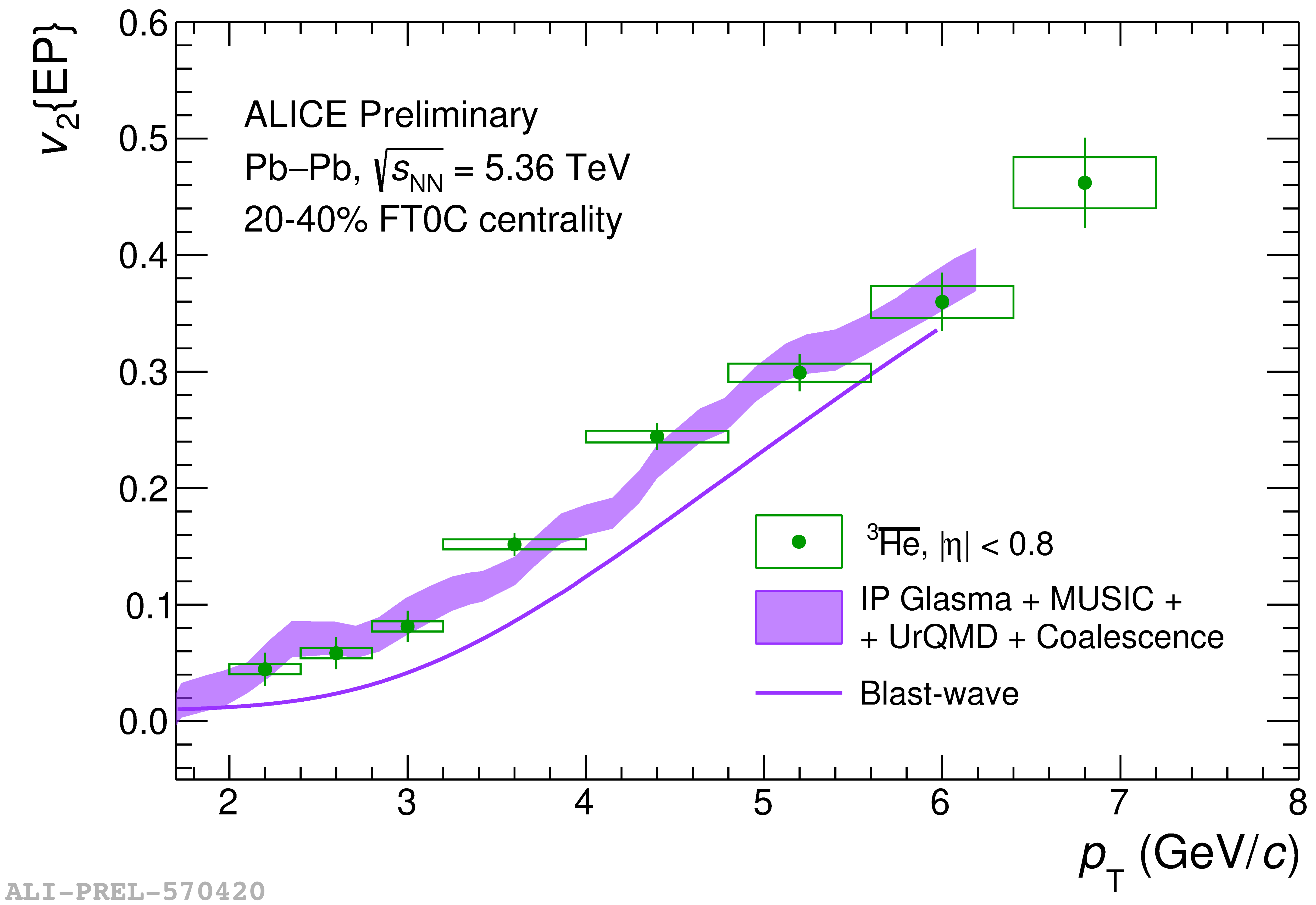
A=3: ^{3}He, t, favour coalescence models

A=4: ^{4}He, result favours thermal model

(new round of theory calculations is needed here on the coalescence side)

$^{3}\overline{\mathrm{He}}$ elliptic flow





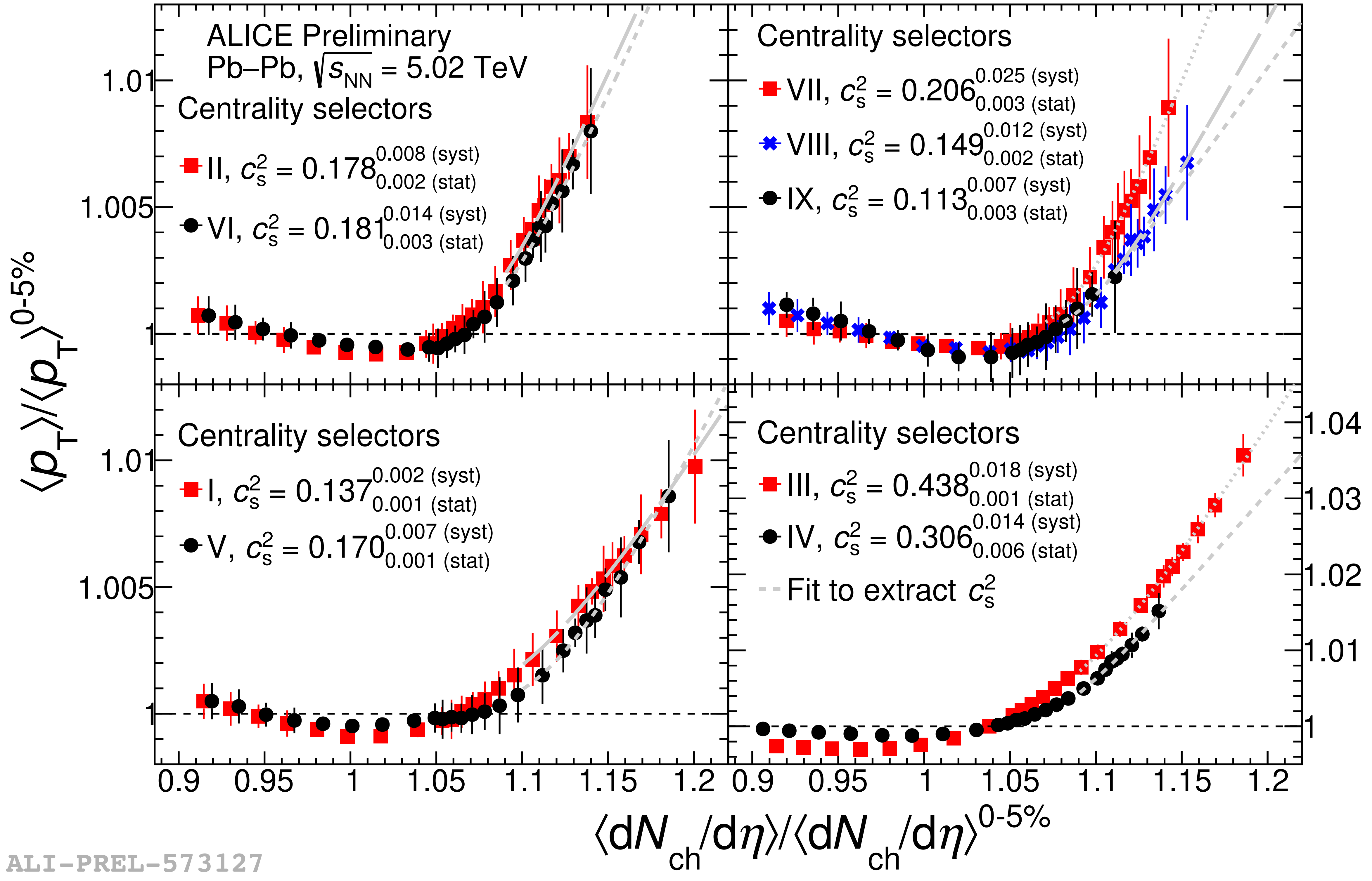
- v_2 sensitive to geometry: largest for semicentral Pb-Pb collisions small in central Pb-Pb collisions
- Coalescence model describes better the data than “thermal freeze out model”

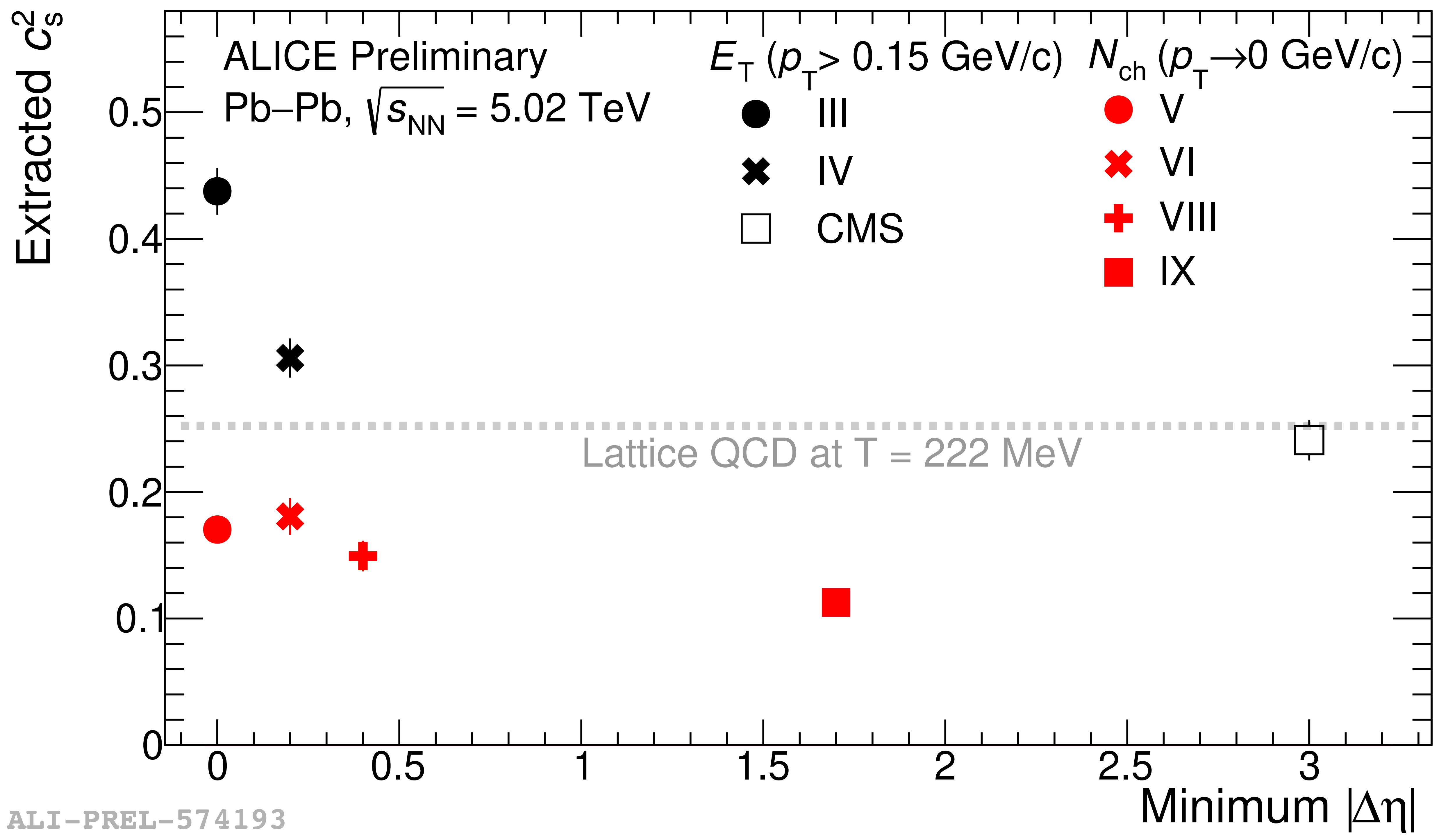
Speed of sound?

“Ultra-central events increase entropy at constant volume -> measure speed of sound”

$$c_s^2 = \frac{d \ln\langle p_T \rangle}{d \ln N_{ch}}$$

explored by CMS: arXiv: RPP 87 (2024) 077801, ATLAS: ATLAS-CONF-2023-061





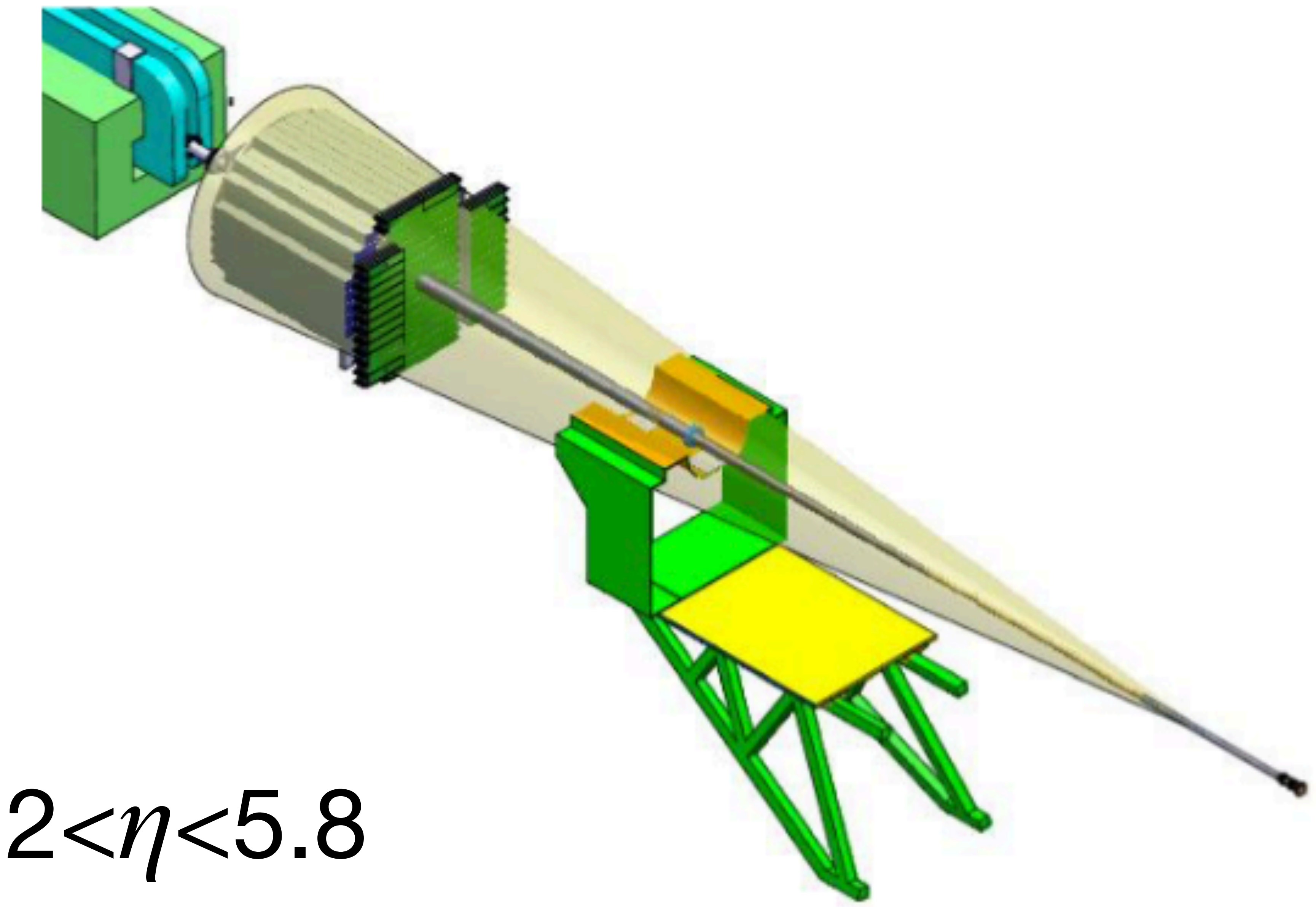
- Slope depends on centrality estimator: E_T-based selection give larger c_s than multiplicity-based estimator

See Omar Vázquez talk: 8/11/24 11:35 h (QCD4)

LS3 upgrades

FoCal

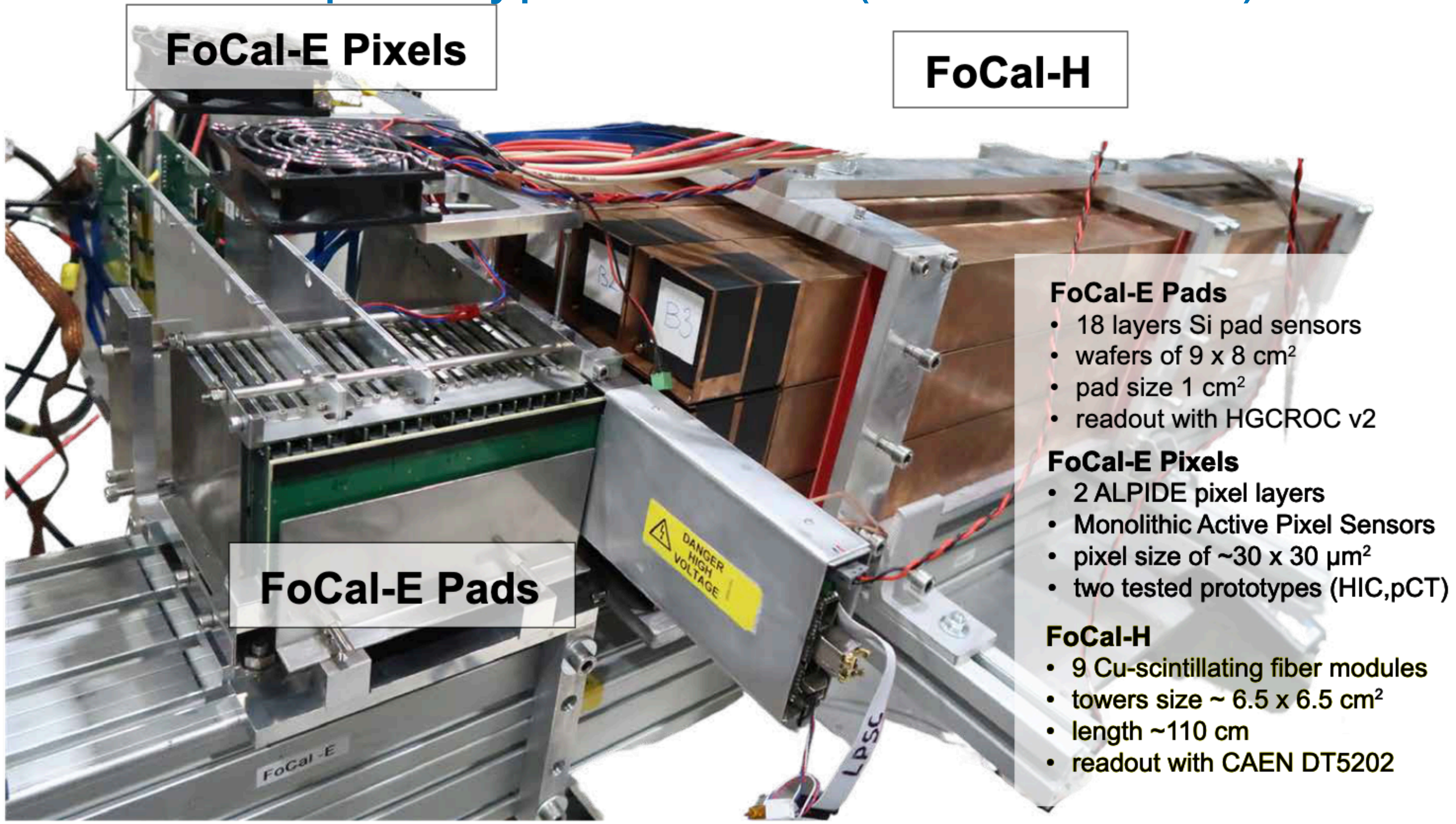
Goal: determine small-x gluon density in the nucleus by measuring forward production of isolated direct photons, π^0, jets



$3.2<\eta<5.8$

- Highly granular Si+W electromagnetic calorimeter (FoCal-E)
- Cu+scintillating-fiber hadronic calorimeter (FoCal-H)

Final prototype of FoCal (tested at SPS)

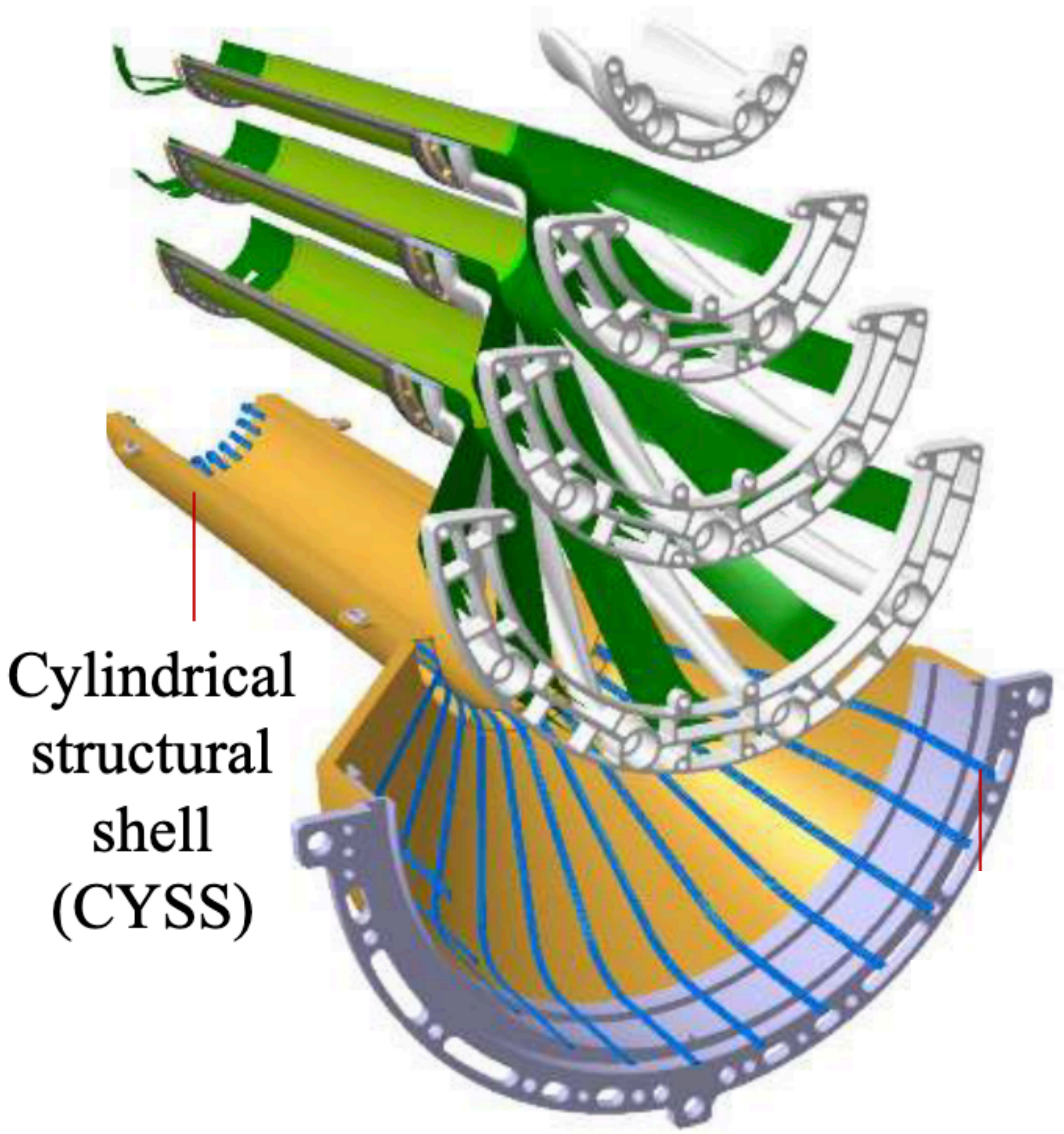


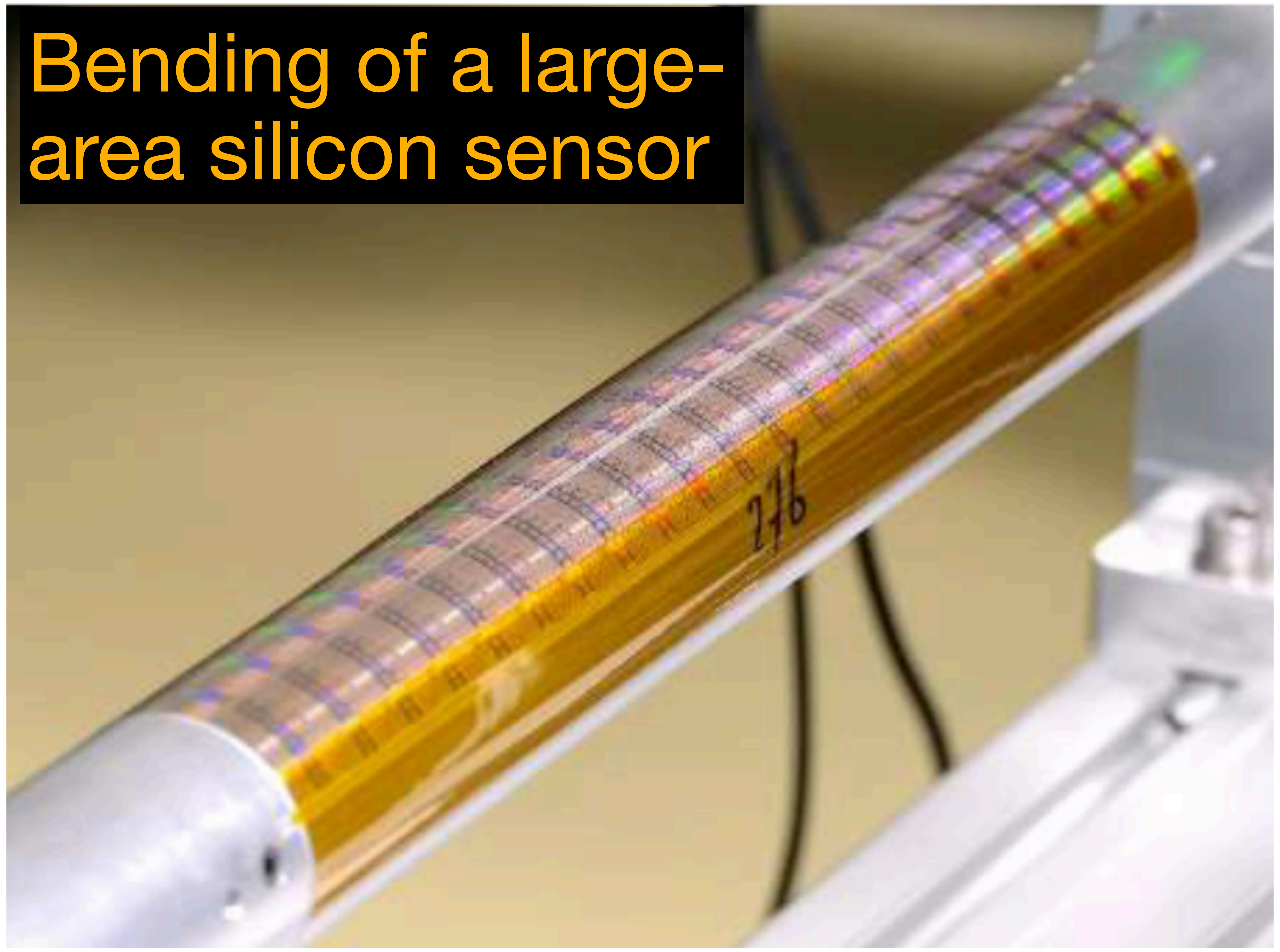
TDR approved CERN-LHCC-2024-004, ALICE-TDR-022

ITS3

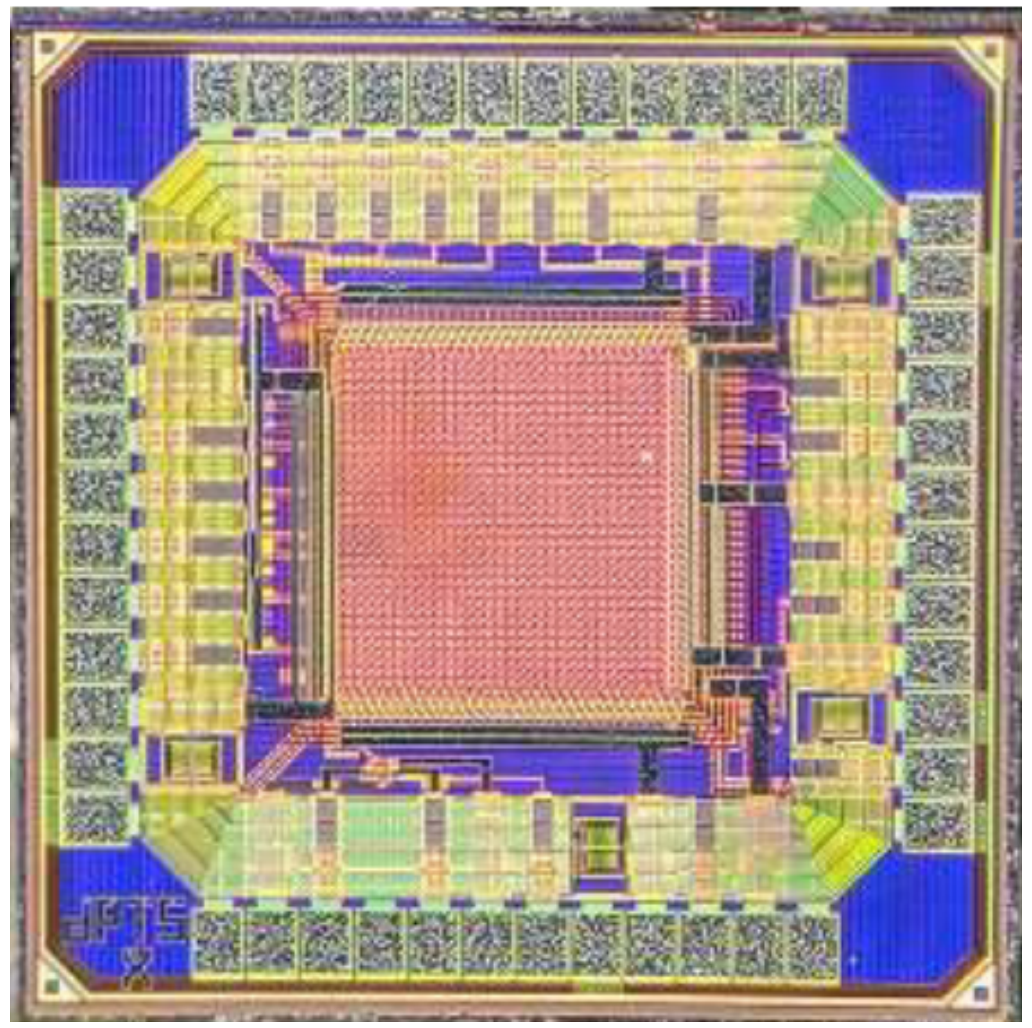
ITS3: replace the 3 inner-most vertexing layers of ALICE with ultra-light tracking layers (0.07% X_0 per layer)

- Improved pointing resolution for heavy flavour reconstruction
- Di-lepton measurements





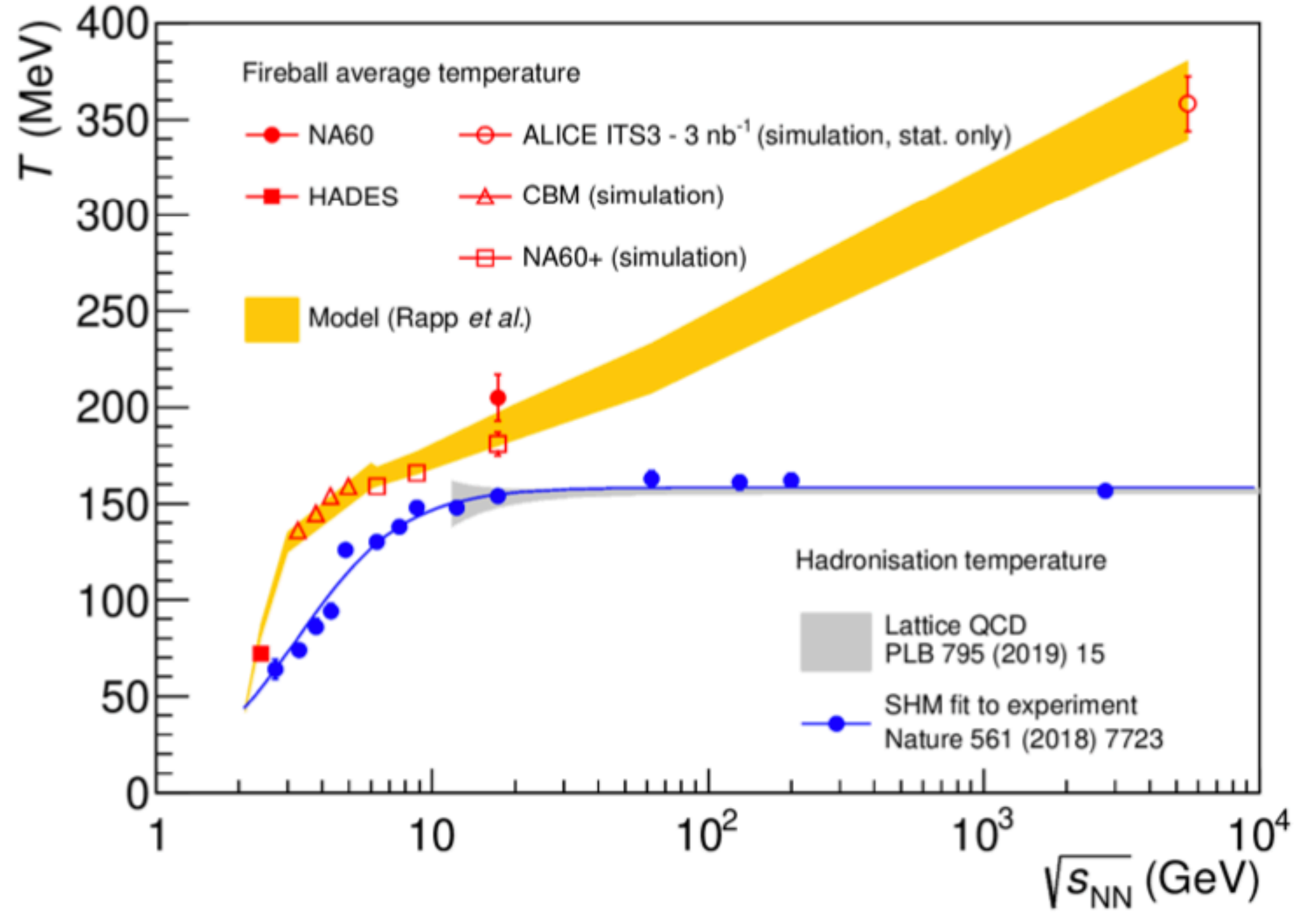
Digital pixel test structure



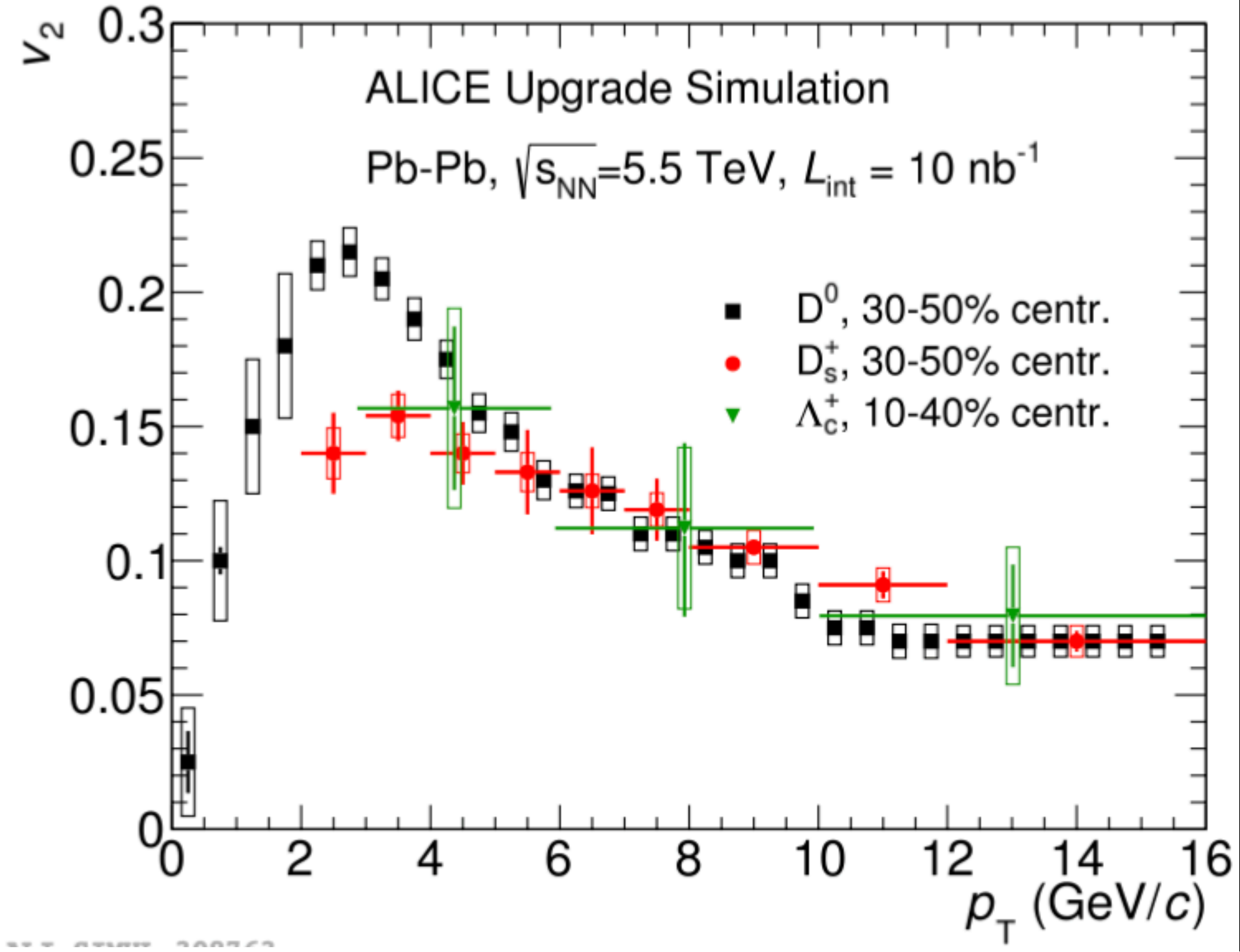
TDR approved [CERN-LHCC-2024-003 ; ALICE-TDR-021]

Questions to be addressed in Runs 3 & 4

Runs 3 and 4



Time-averaged thermal radiation from QGP



Medium effects and hadrochemistry of single charm

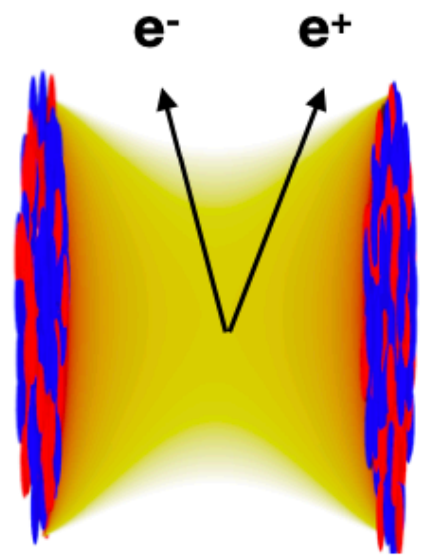
- What is the nature of interactions between highly energetic quarks and gluons and the quark-gluon plasma?
- To what extent do quarks of different mass reach thermal equilibrium?
- How do quarks and gluons transition to hadrons as the quark-gluon plasma cools down?
- What are the mechanisms for the restoration of chiral symmetry in the quark-gluon plasma?

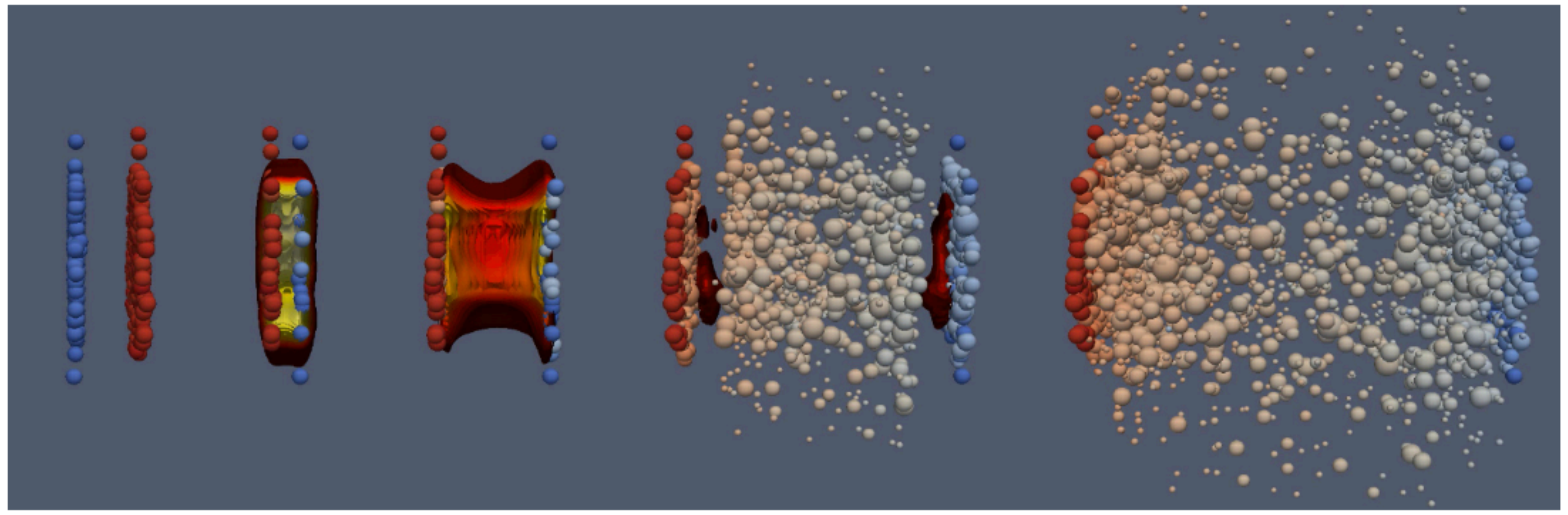
Upgrades beyond LS4

Measurements beyond Run 4

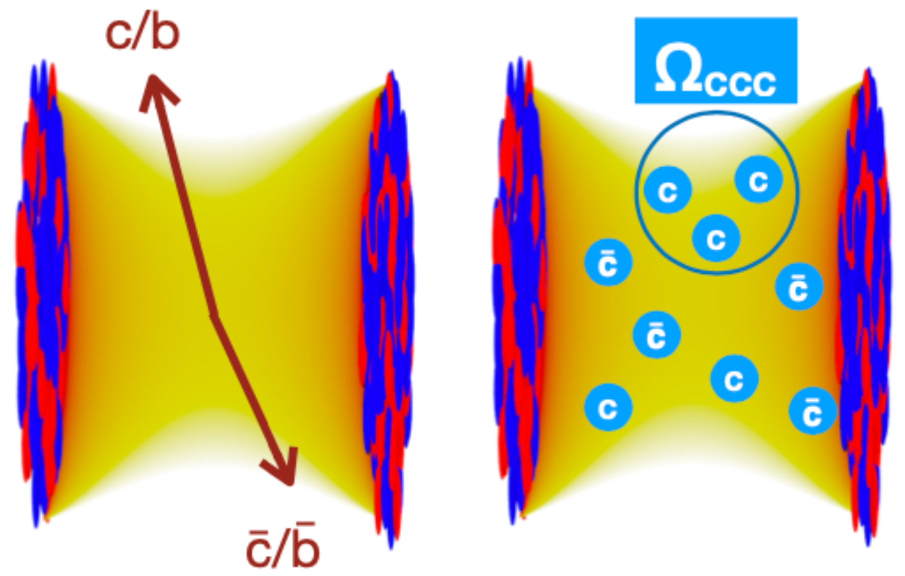
Further progress relies on

- Precision measurements of dileptons
  - evolution of the QGP / mechanisms of chiral symmetry restoration in the QGP

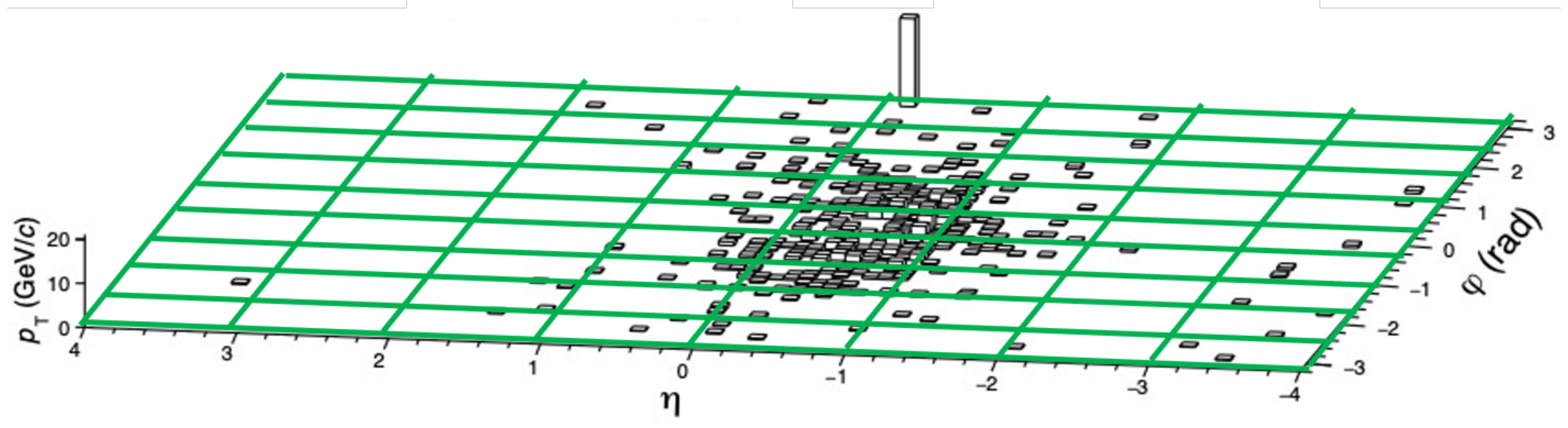




- Systematic measurements of (multi-)heavy-flavoured hadrons
  - transport properties in the QGP / mechanisms of hadronisation from the QGP



- Collectivity in small systems
  - ALICE 3 would open an unique opportunity to fully understand the origin of collectivity in small systems



Probes

- Heavy-flavour hadrons ($p_{\mathrm{T}} \to 0$, wide η range)
  - vertexing, tracking, hadron ID
- Dileptons ($p_{\mathrm{T}} \approx 0.1 - 3$ GeV/c, $M_{ee} \approx 0.1 - 4$ GeV/c^2)
  - vertexing, tracking, lepton ID
- Photons ($0.1 - 50$ GeV/c, wide η range)
  - electromagnetic calorimetry
- Quarkonia and Exotica ($p_{\mathrm{T}} \to 0$)
  - muon ID
- Jets
  - tracking and calorimetry, hadron ID

Qualitative steps needed in detector performance and statistics
→
next-generation heavy-ion experiment

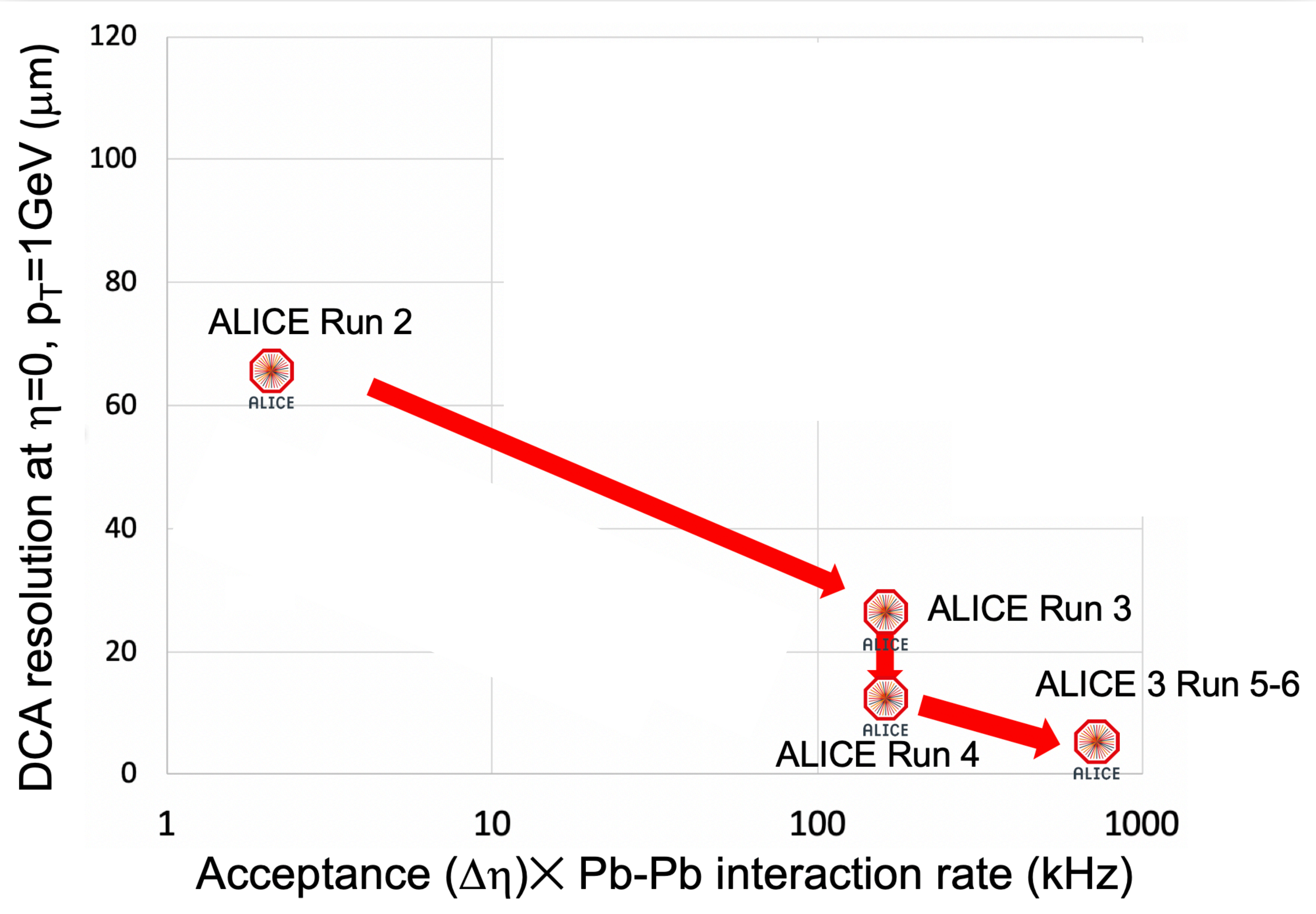
Detector requirements (LoI)

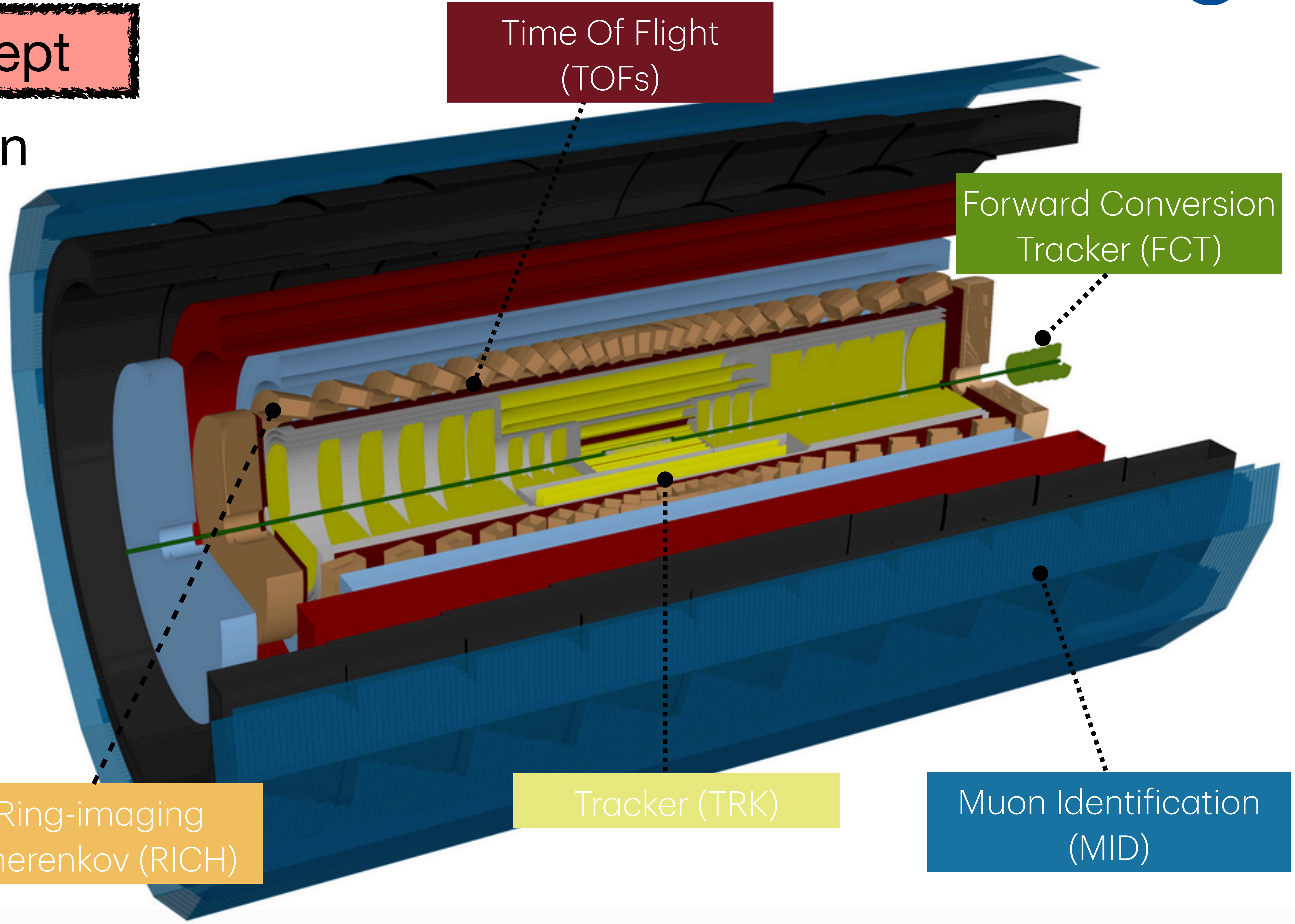
Component	Observables	Barrel ($\lvert\eta\rvert < 1.75$)	Forward ($1.75 < \lvert\eta\rvert < 4$)	Detectors
Vertexing	(Multi-) charm baryons, dielectrons	Best possible DCA resolution, $\sigma_{\mathrm{DCA}} \approx 1\,\mu$m at $p_{\mathrm{T}} = 200$ MeV/c, $\eta = 0$	Best possible DCA resolution, $\sigma_{\mathrm{DCA}} \approx 30\,\mu$m at $p_{\mathrm{T}} = 200$ MeV/c, $\eta = 3$	Retractable Si-pixel tracker: $\sigma_{\mathrm{pos}} \approx 2.5\,\mu$m, $R_{\mathrm{in}} \approx 5$ mm, $X/X_0 \approx 0.1\,\%$ for the first layer
Tracking	(Multi-) charm baryons, dielectrons, photons …	$\sigma_{p_{\mathrm{T}}}/p_{\mathrm{T}} \approx 1-2\,\%$		Silicon pixel tracker: $\sigma_{\mathrm{pos}} \approx 10\,\mu$m, $R_{\mathrm{out}} \approx 80$ cm, $L \approx \pm 4$ m, $X/X_0 \approx 1\,\%$ per layer
Hadron ID	(Multi-) charm baryons	$\pi/\mathrm{K}/\mathrm{p}$ separation up to a few GeV/c		Time of flight: $\sigma_{\mathrm{tof}} \approx 20$ ps RICH: $n \approx 1.006-1.030$, $\sigma_\theta \approx 1.5$ rad
Electron ID	Dielectrons, quarkonia, $\chi_{\mathrm{c1}}(3872)$	Pion rejection by 1000x top to 2-3 GeV/c		Time of flight: $\sigma_{\mathrm{tof}} \approx 20$ ps RICH: $n \approx 1.006-1.030$, $\sigma_\theta \approx 1.5$ rad
Muon ID	Quarkonia, $\chi_{\mathrm{c1}}(3872)$	Reconstruction of J/ψ at rest, i.e. muons from $p_{\mathrm{T}} \approx 1.5$ GeV/c at $\eta = 0$		Steel absorber: $L \approx 70$ cm muon chambers (scintillators, RPCs or MWPC)

ALICE 3

Novel and innovative detector concept

- Compact and lightweight all-silicon tracker
- Retractable vertex detector
- Particle identification systems
- Large acceptance

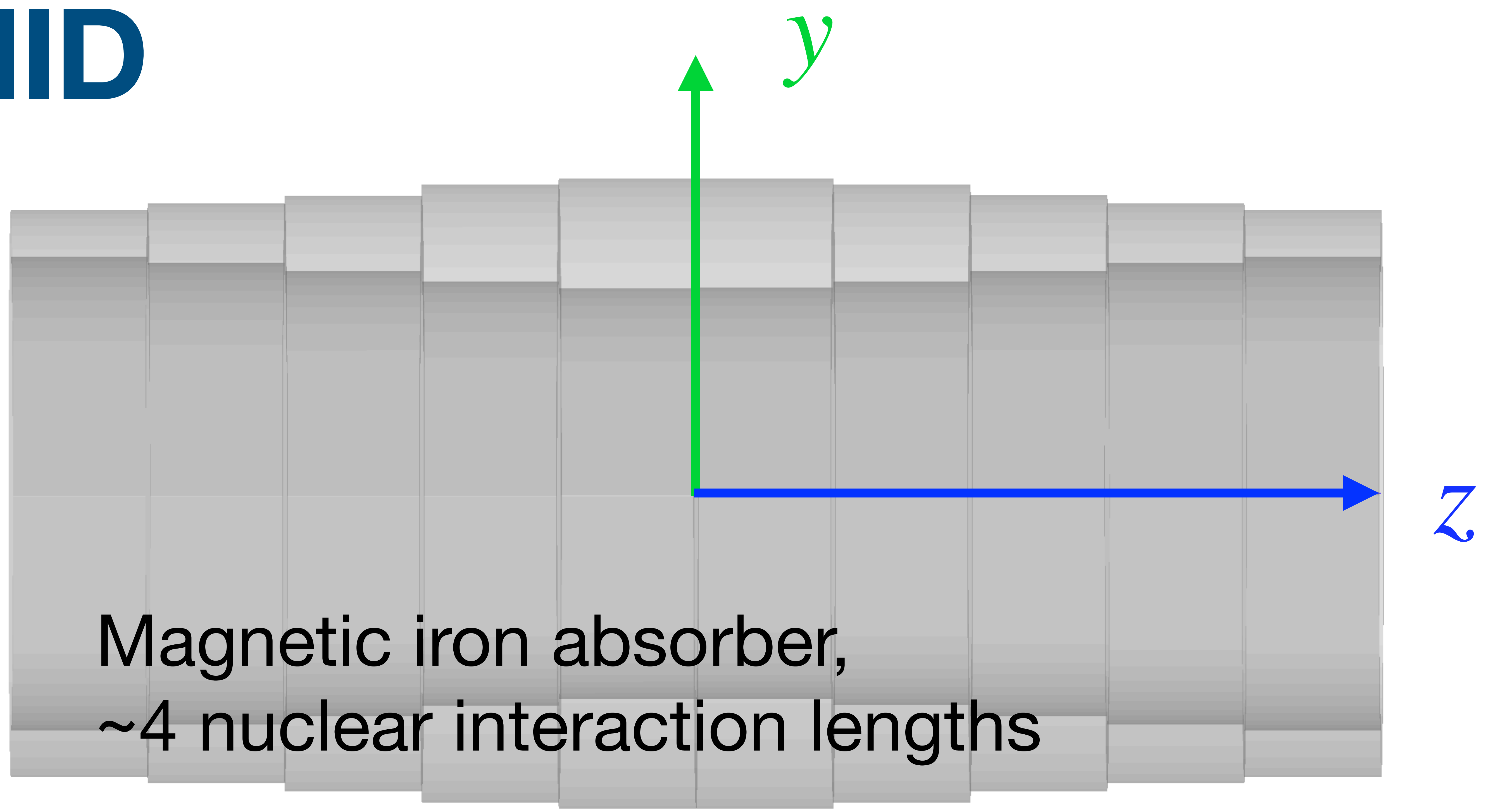




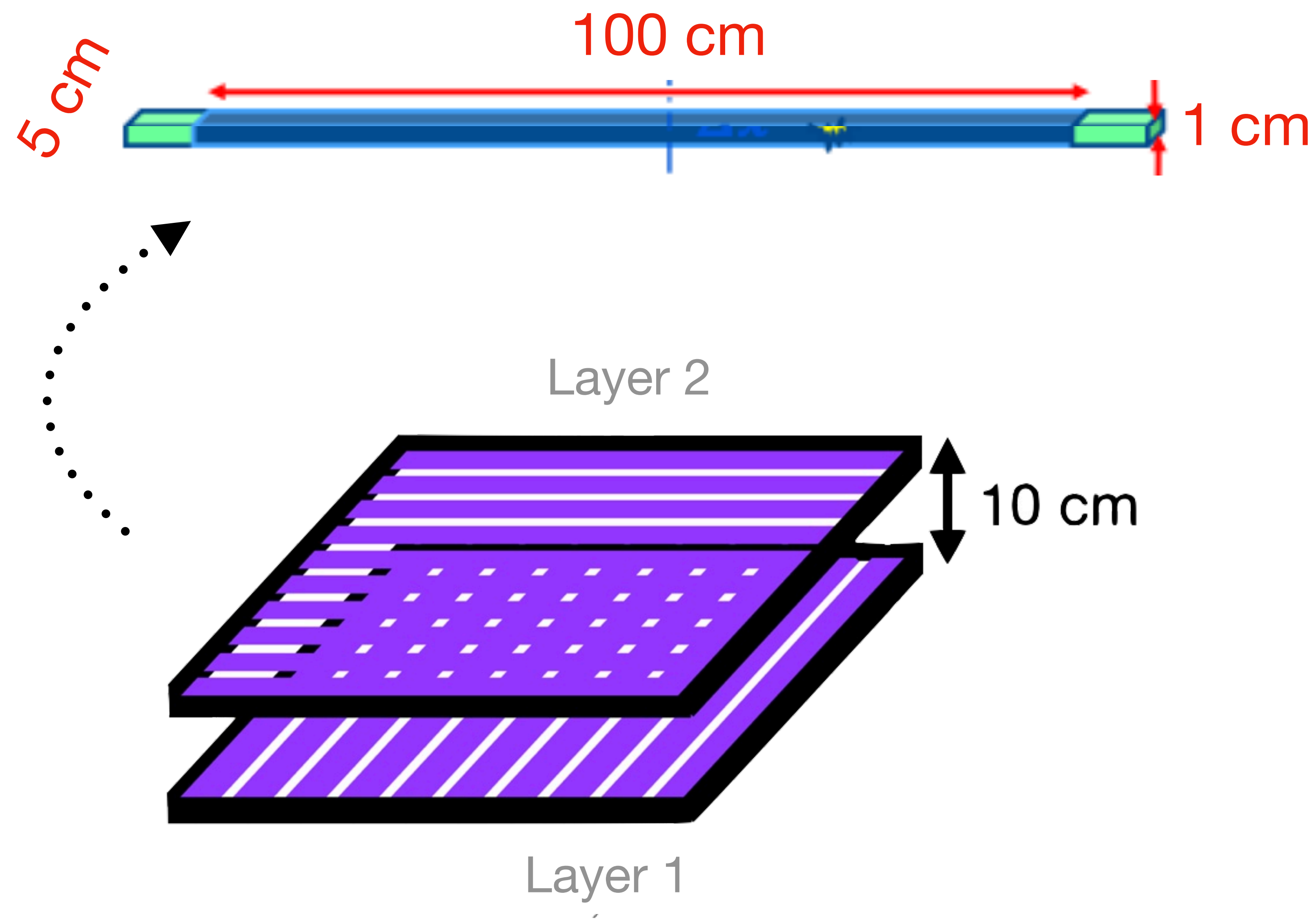
- Superconducting magnet system / Continuous read-out and online processing

MID subsystem

MID



- 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)

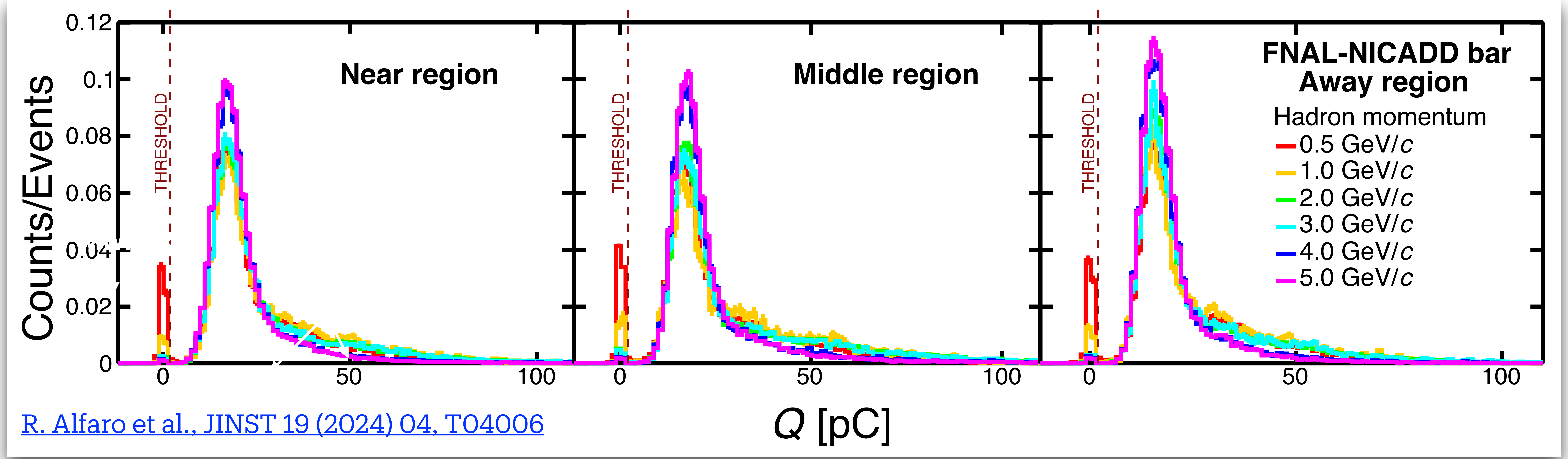


Candidates for the MID chambers

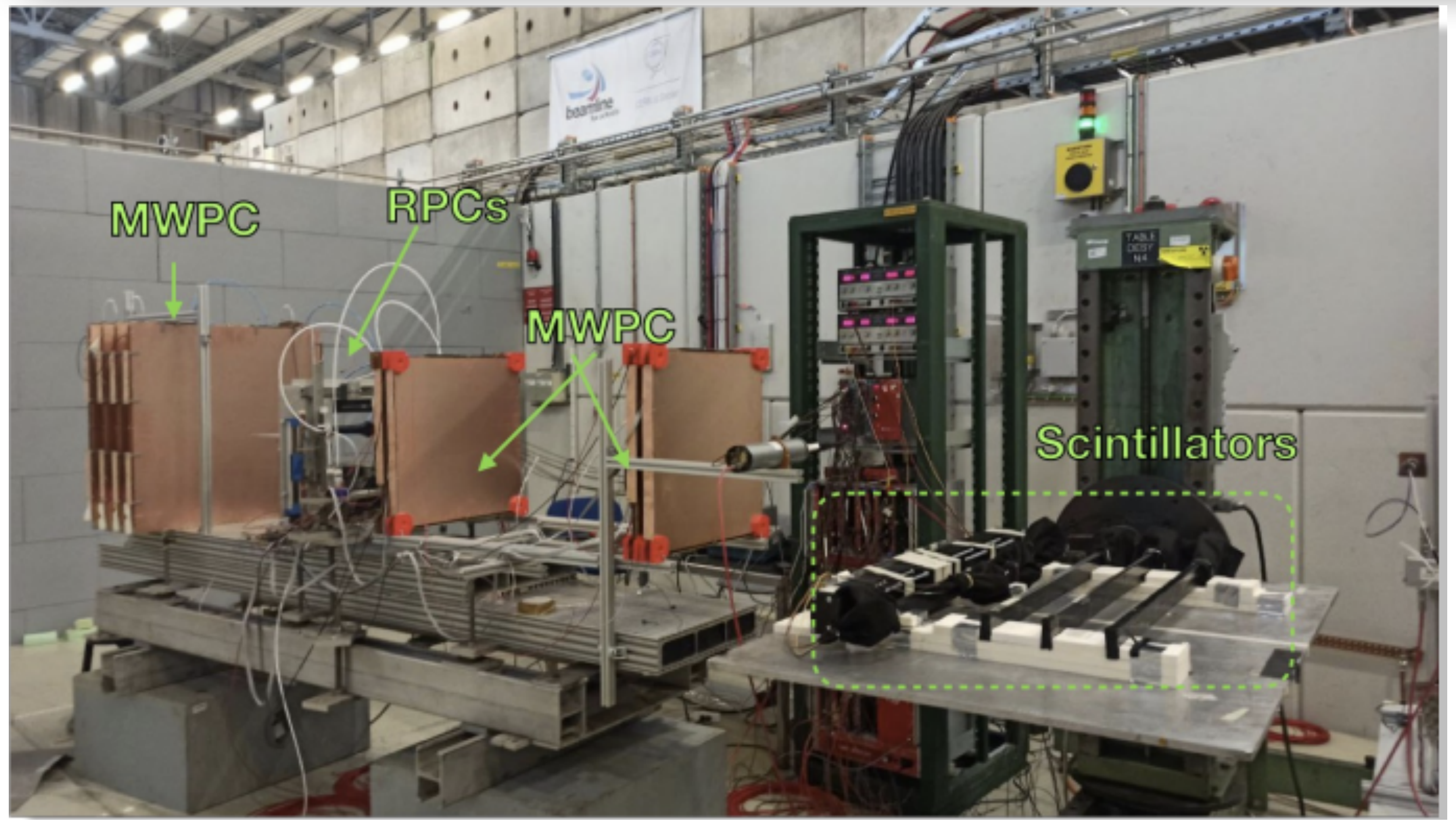
- Plastic scintillators and silicon photomultiplier (SiPM) for readout
- Multi-Wire Proportional Chambers (MWPCs)
- Resistive Plate Chambers (RPCs)

Physics performance studies, see Jesús Muñoz talk: 4/11/24 19:15 h (QCD1)

Test beam results (2023)



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



- Low-cost plastic scintillator equipped with WLS fiber: high and uniform efficiency along the bar (1 m length)
- Excellent separation between signal and pedestal. About 40 p.e. are measured for MIP (insensitive to dark count rate)

Test beam (2024)

Instituto de Ciencias Nucleares UNAM

See Antonio Paz talk: 5/11/24 19:15 h (QCD2)

Summary

- Successful LS2 upgrades - high data taking efficiency in 2024
- pp and heavy-ion physics programs: several new results using Run 3 data
- LS3 upgrades (FoCal and ITS3) moving towards detector construction
- ALICE 3 preparation, progressing well

Backup

Time evolution & chiral symmetry

Understand time evolution and mechanisms of chiral symmetry restoration:

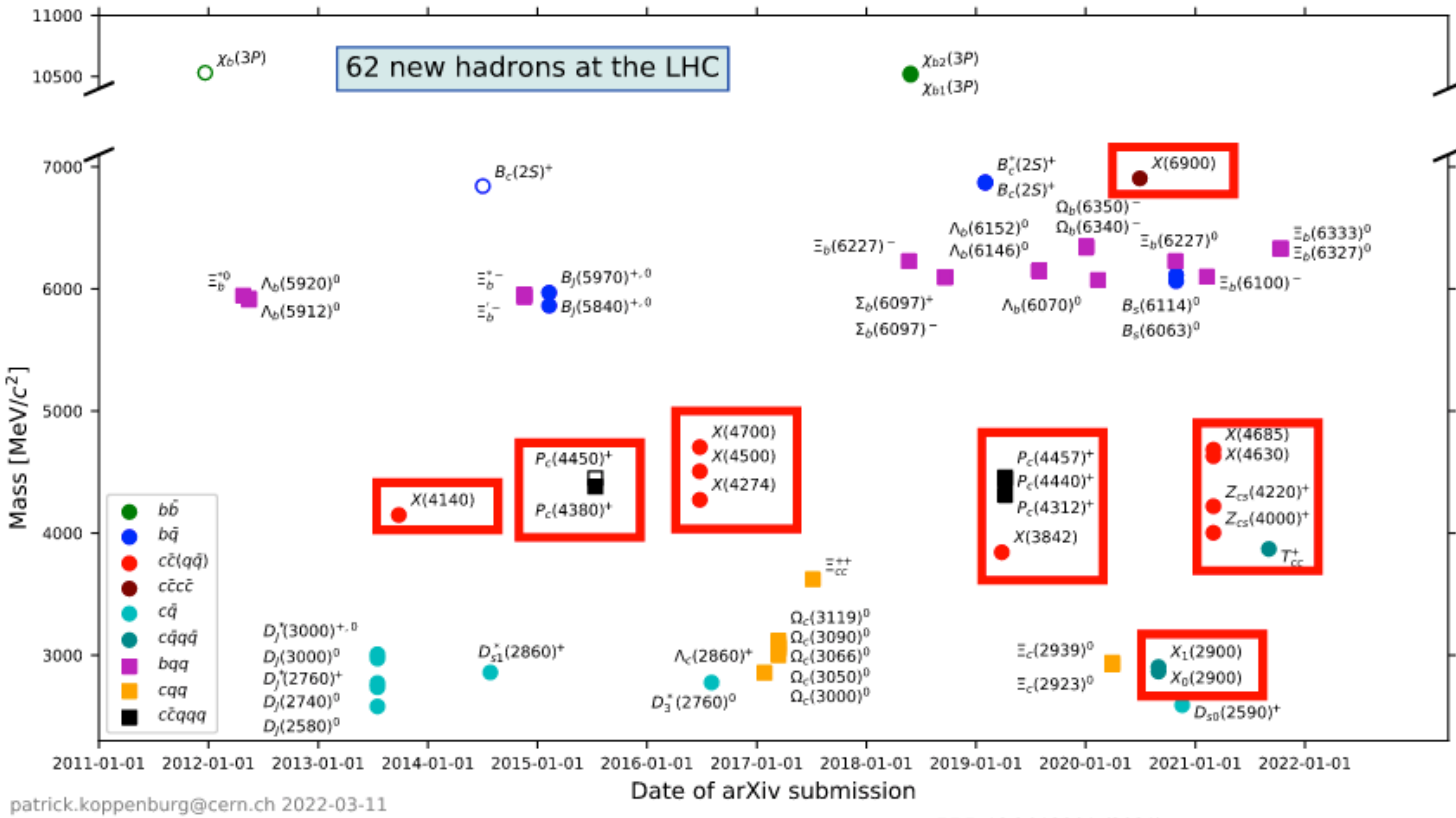
- high-precision measurements of dileptons, also multi-differentially
- further reduced material; excellent heavy-flavour rejection

* SF: Spectral Function

Without ρ-a1 mixing→ dip in thermal spectrum

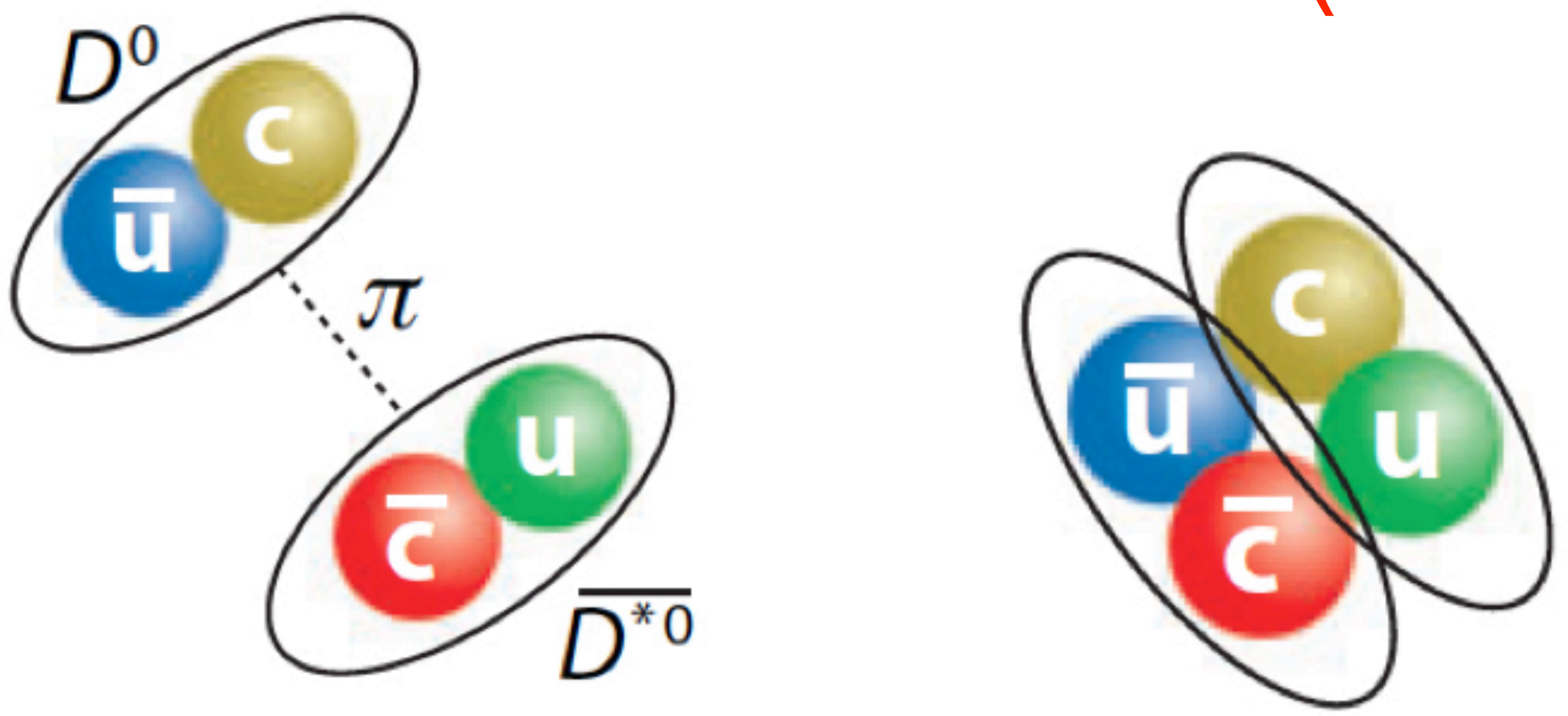
Exotic hadrons

$X(3872) \rightarrow J/\psi + \pi^{+}\pi^{-}$



X(3872)

¿



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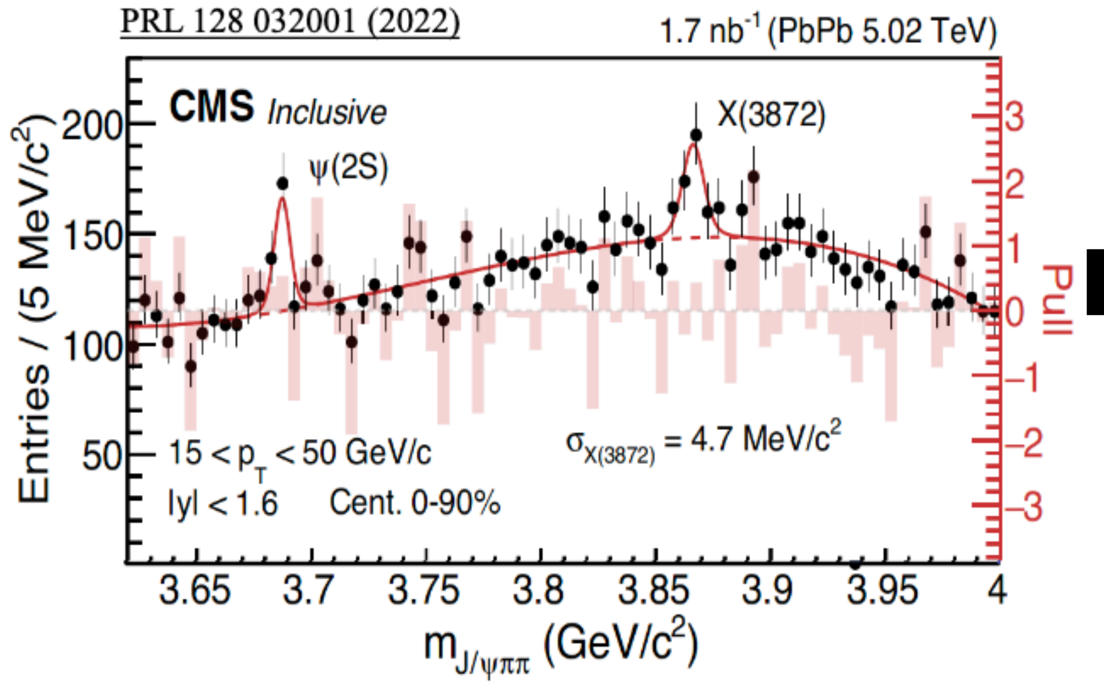
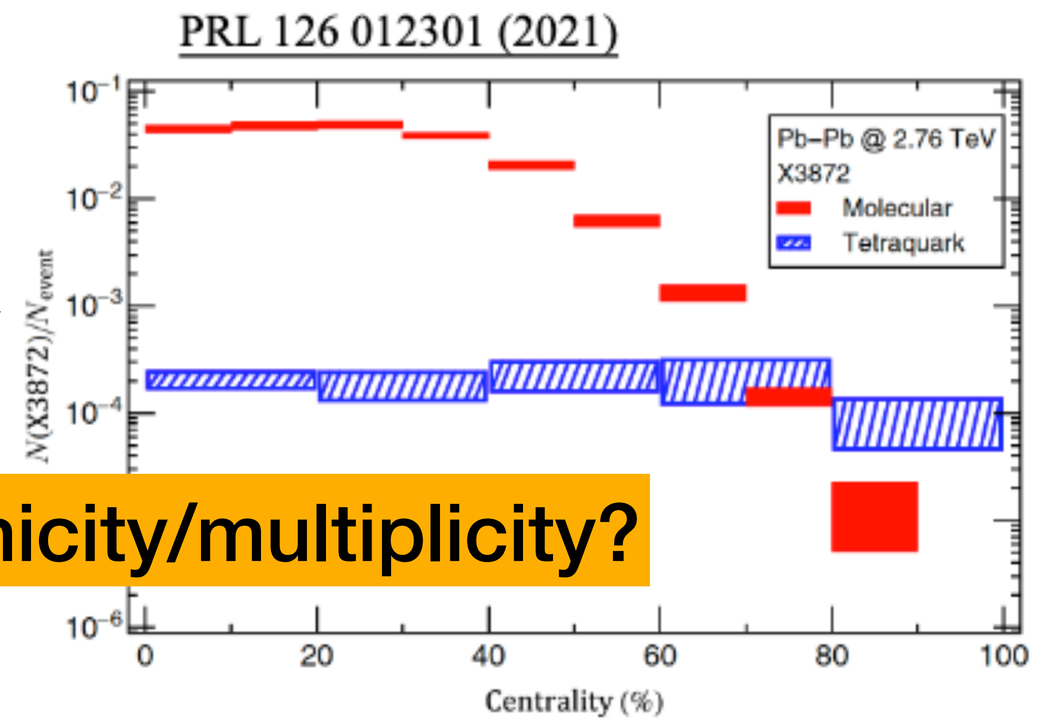
D^0–$\overline{D}^{*0}$ **"molecule"** **Diquark–diantiquark**



pp vs flatenicity/multiplicity?

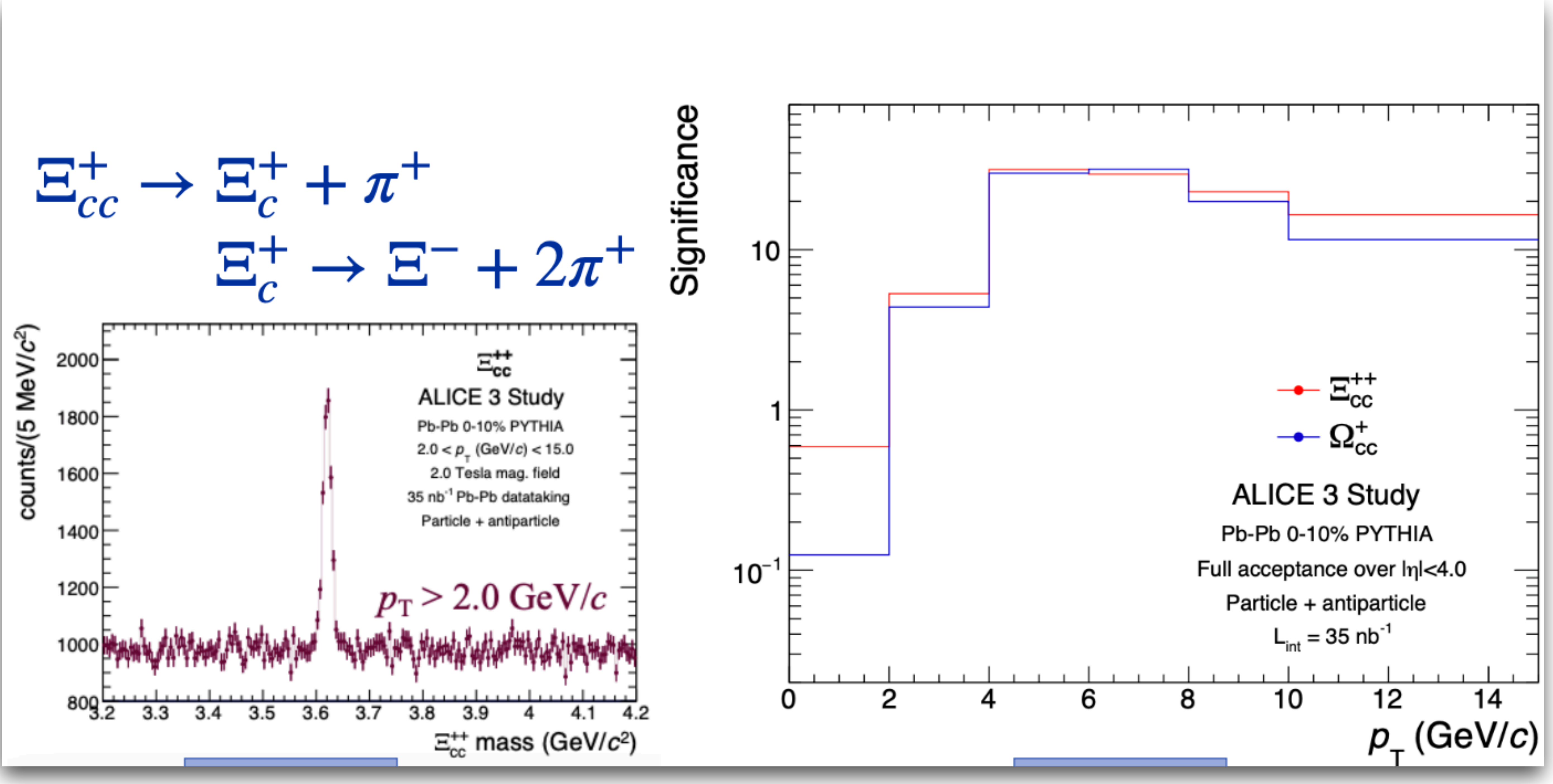


ALICE 3 muonID: muons down to low p_{T} (~1.5 GeV/c at $\eta = 0$) ->unique p_{T} reach to study the formation and dissociation of e.g. X(3872) in HIC at thermal momentum scales.

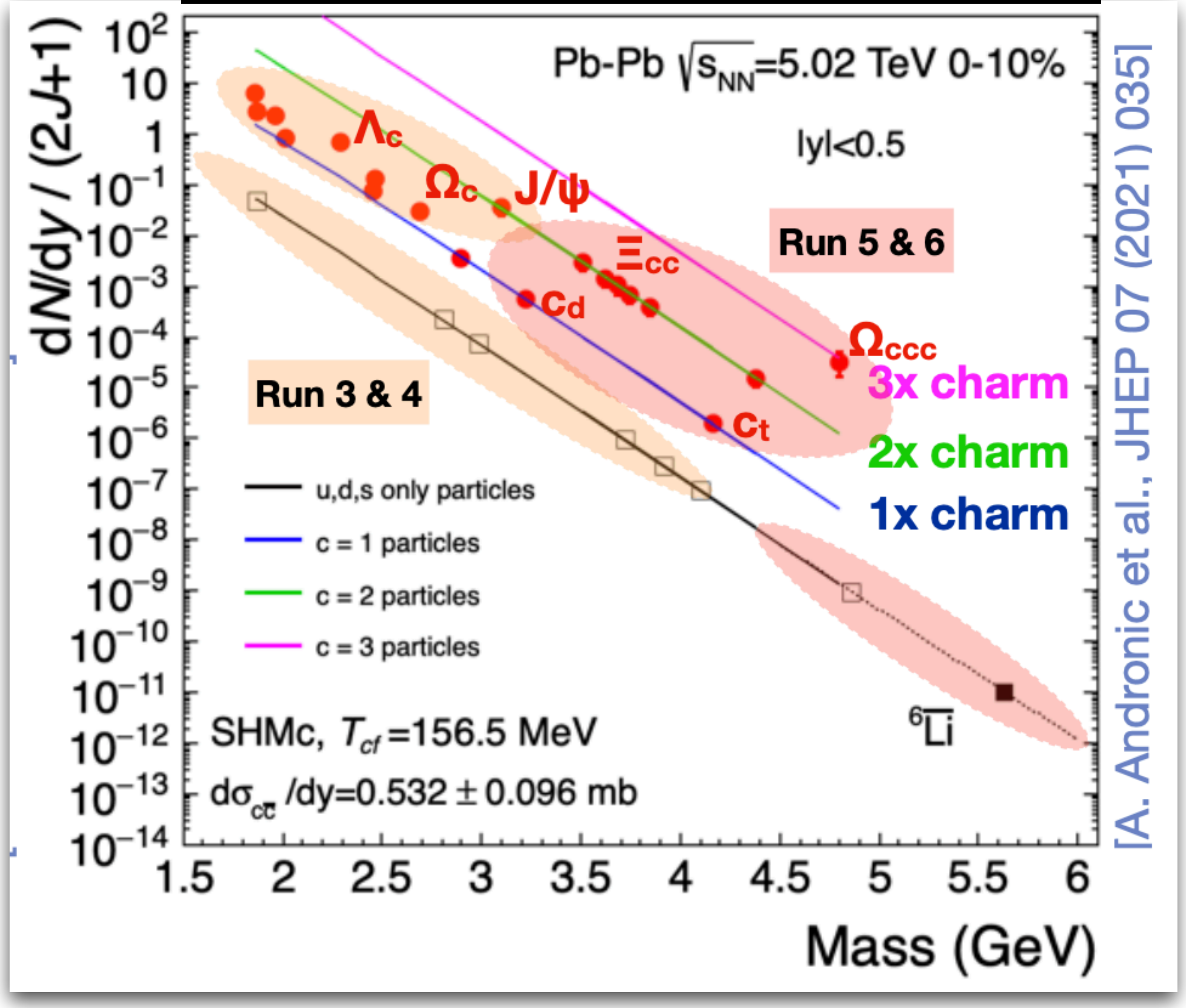
CMS: $p_{\mathrm{T}} > 10$ GeV/c.

Expected enhancement of multi-charm states provides high sensitivity to equilibration

- Systematic measurement of hadron yields
- Luminosity, acceptance, vertexing, PID, strangeness tracking



Hadron yields in statistical hadronisation model



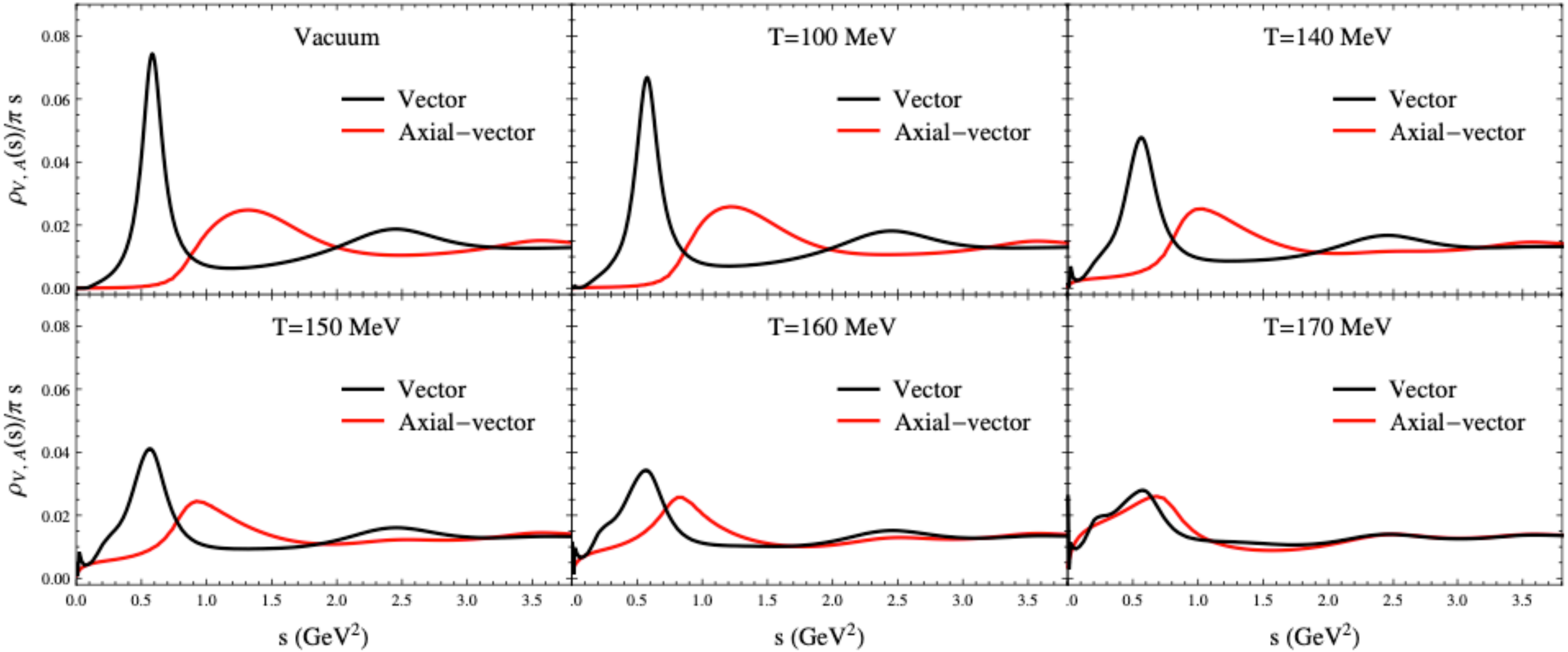


Figure 5: Temperature evolution of vector and axial-vector spectral functions (non-linear realization) [132].