ALICE Highlights, Future, and Plans

Edmundo Garcia-Solis

for the ALICE Collaboration

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ALICE

Lake Louise Winter Institute 2024

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LHC schedule and ALICE

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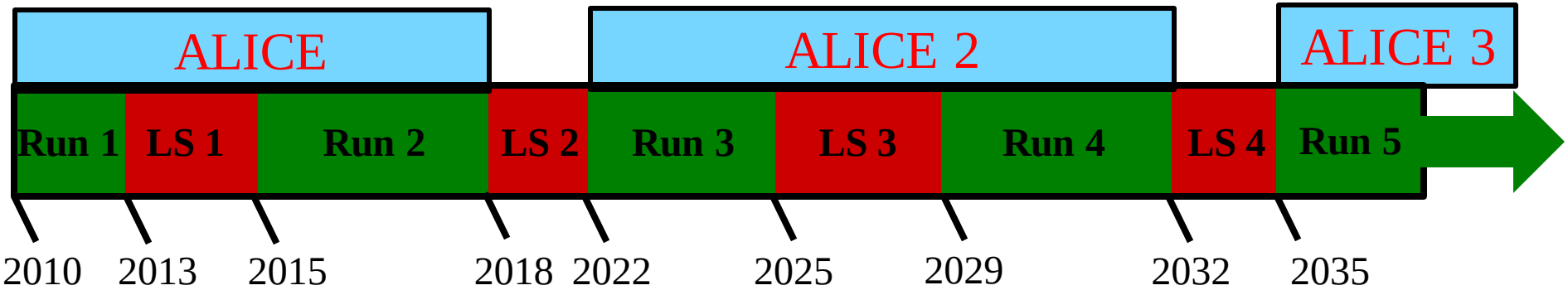
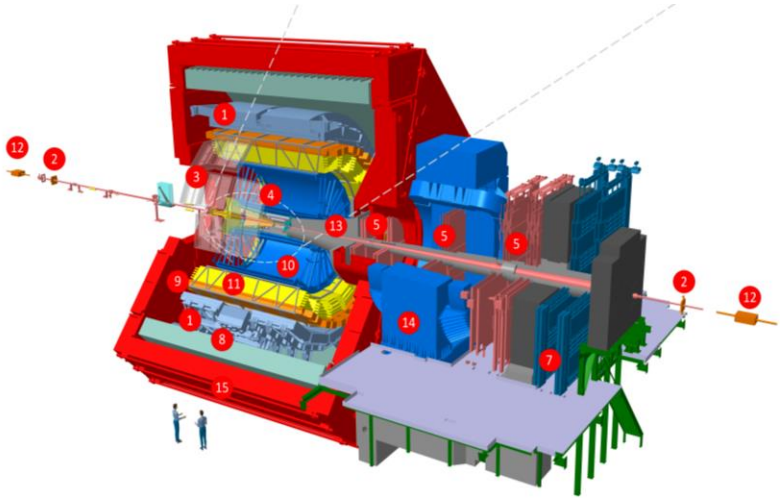
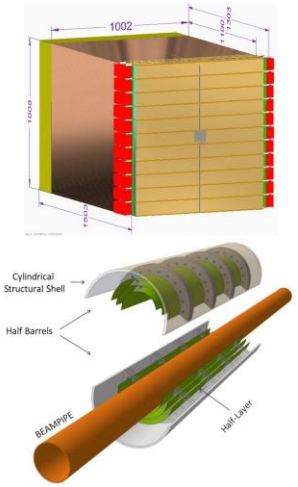


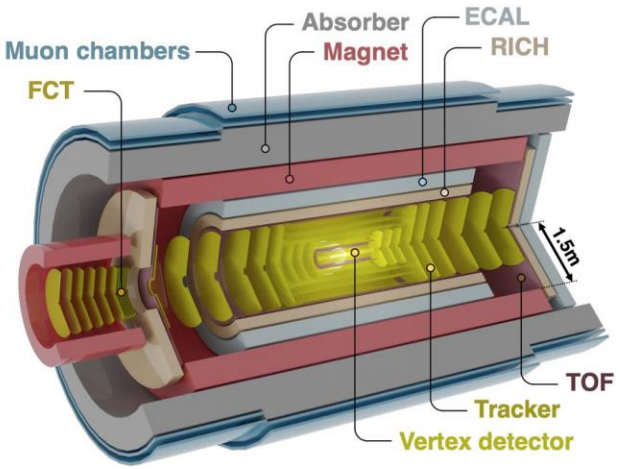
Run 3 ALICE 2



Run 4 FoCal and ITS3



Run 5 ALICE 3



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ALICE during Run 3

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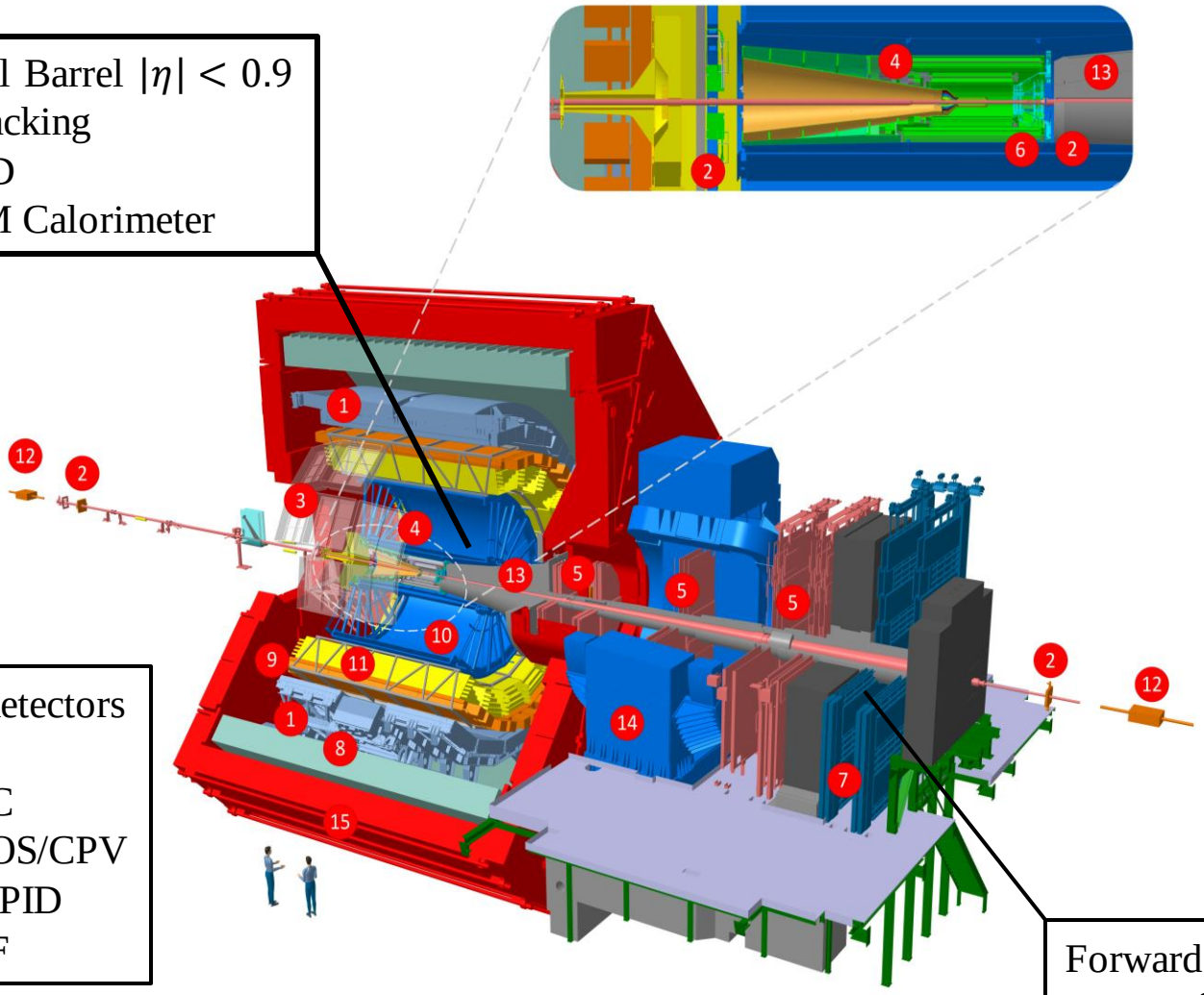
Central Barrel $|\eta| < 0.9$
- Tracking
- PID
- EM Calorimeter



Other detectors
- FIT
- ZDC
- PHOS/CPV
- HMPID
- TOF

Forward Muon Spectrometer
$2.5 < \eta < 4$

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Relativistic heavy ion collisions highlights

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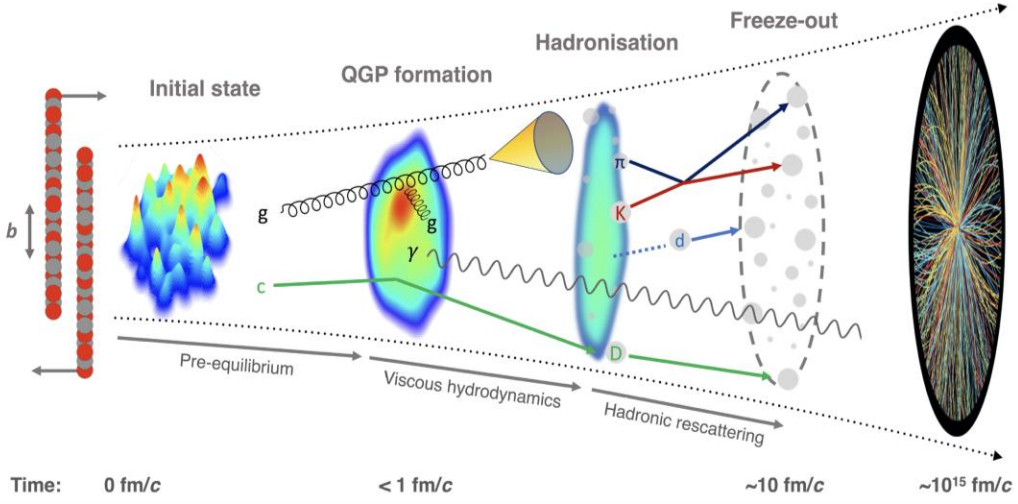
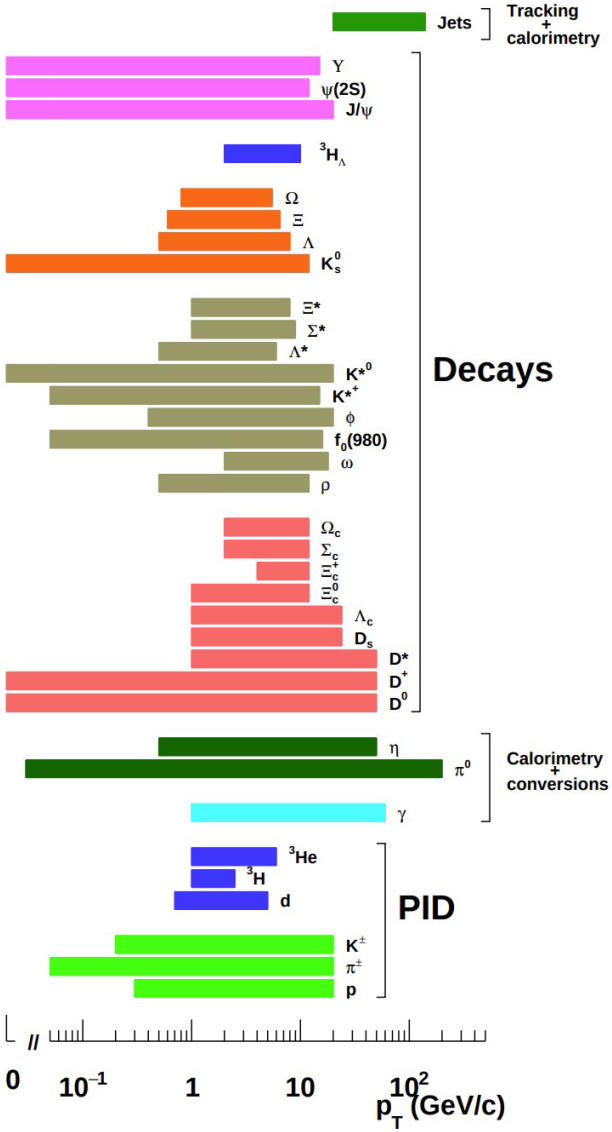
- Nature of the initial state of heavy-ion collisions
- Global properties of the Quark Gluon Plasma (QGP)
- Hydrodynamic and transport properties of the QGP
- Propagation of energetic hadrons in the QGP
- Hadronization of the QGP
- Deconfinement impact on the Quantum Chromo Dynamics (QCD) force
- Hadron-hadron interactions





The ALICE experiment: A journey through QCD.
arXiv:2211.04384 [nucl-ex]

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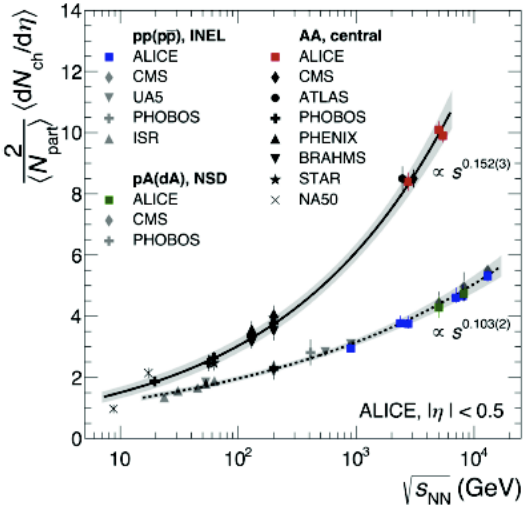
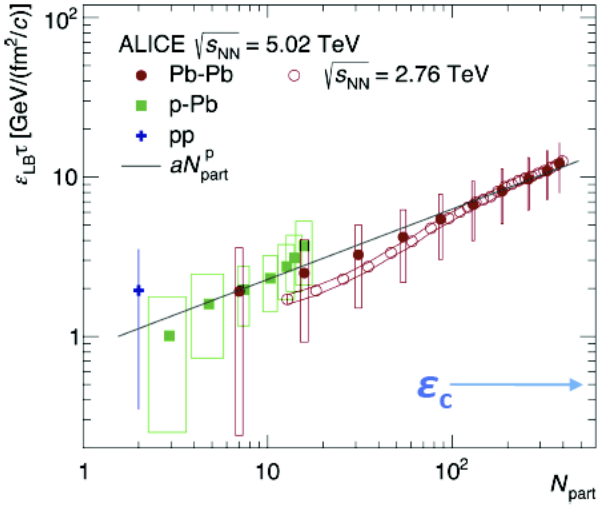
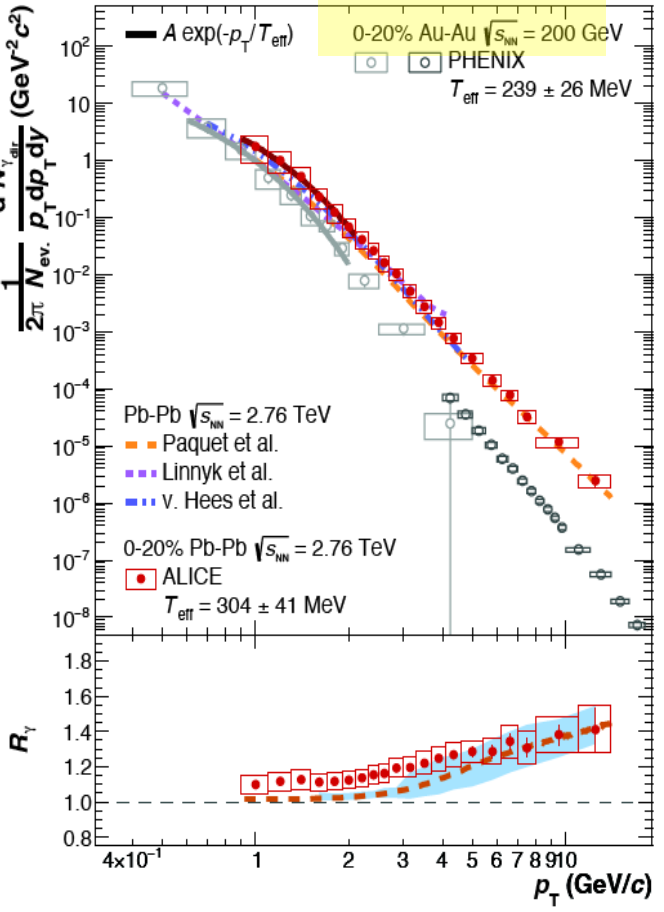
Global properties

arXiv:2211.04384 [nucl-ex]





Physics Letters B 754 (2016) 235–248



- Lattice QCD predicts
  $\varepsilon_c \approx 0.7$ MeV/fm^3 and $T_c \approx 150$ MeV
- Charged hadron production per nucleon is maximal in Pb-Pb at LHC
- Central Pb-Pb initial energy density is around thirty times larger than ε_c
- Photon effective temperature is twice T_c

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Hadronization properties

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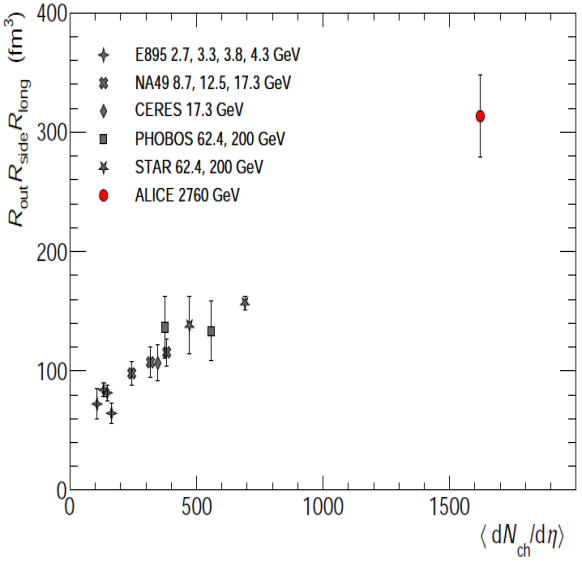
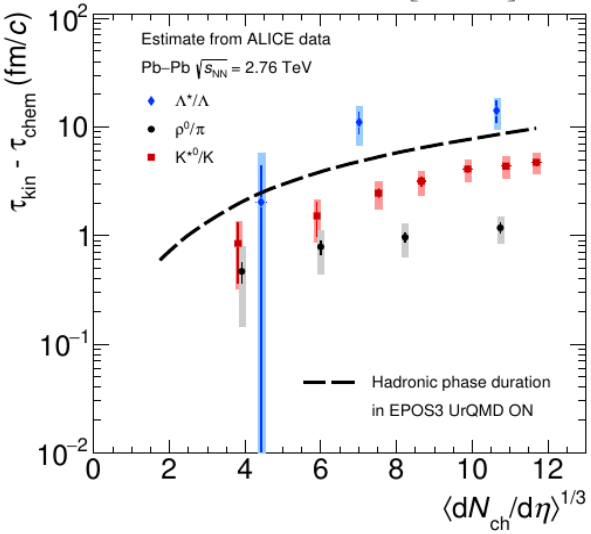
Physics Letters B 696 (2011) 328–337



arXiv:2211.04384 [nucl-ex]



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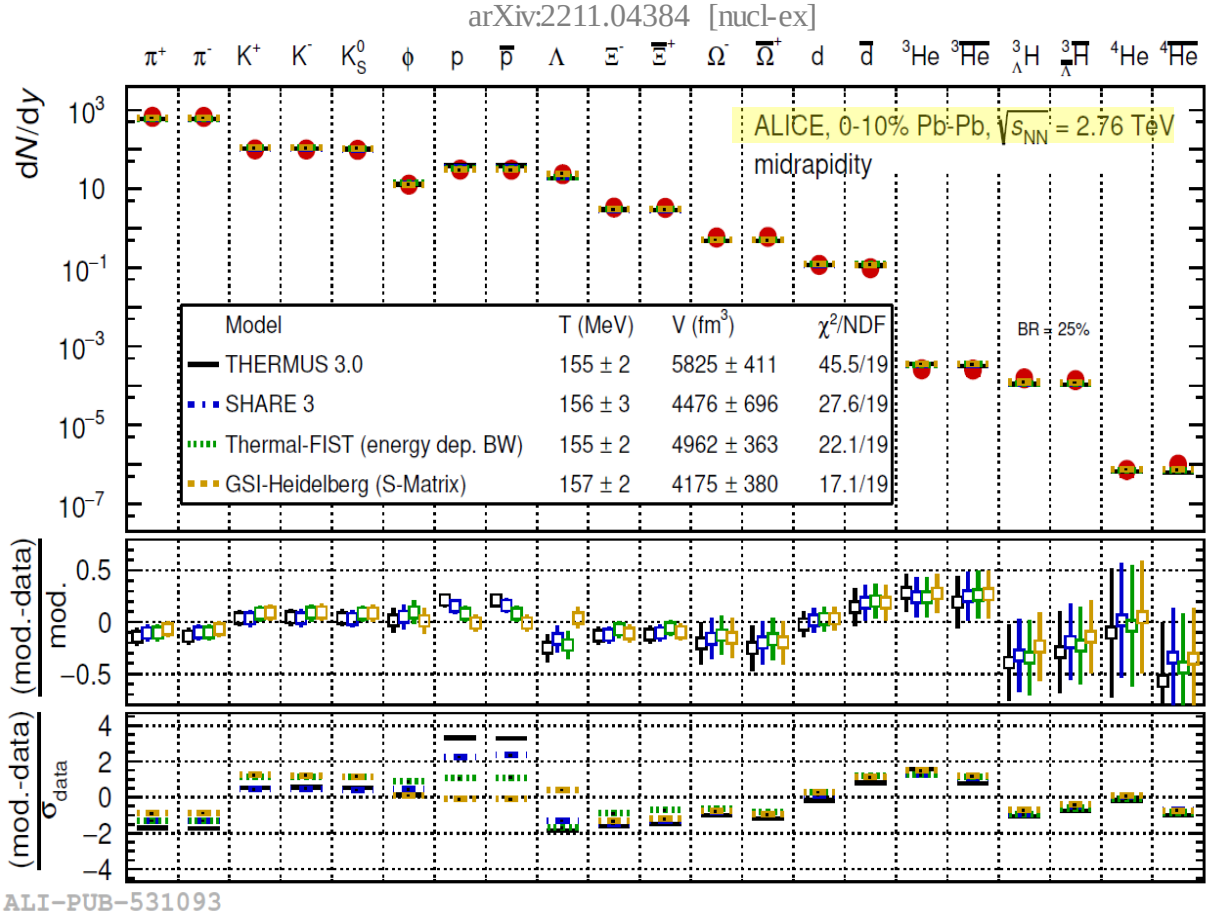

- Freeze-out volume and hadronic phase duration rise with multiplicity
- Particle yields described by statistical hadronization.
- Chemical equilibrium close to QGP transition temperature

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Flow

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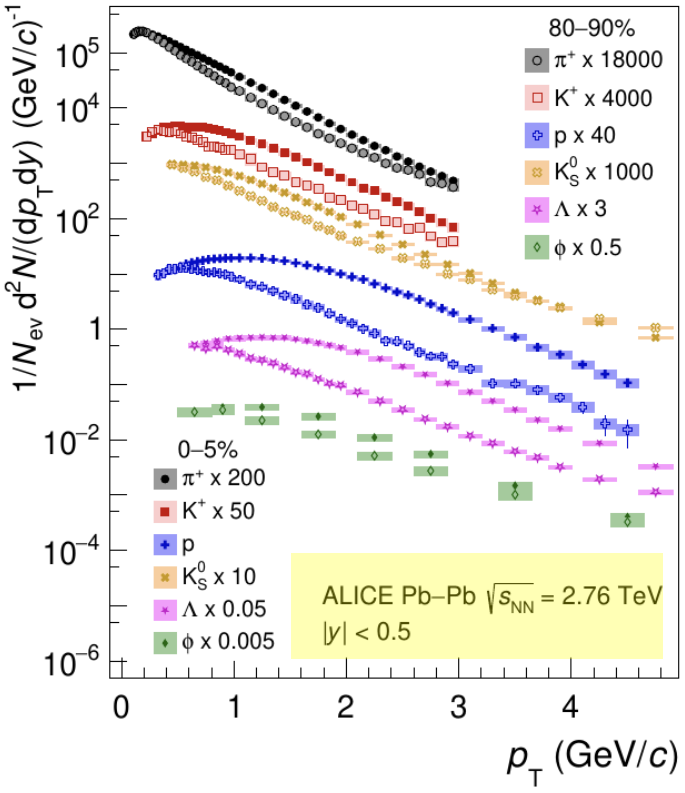
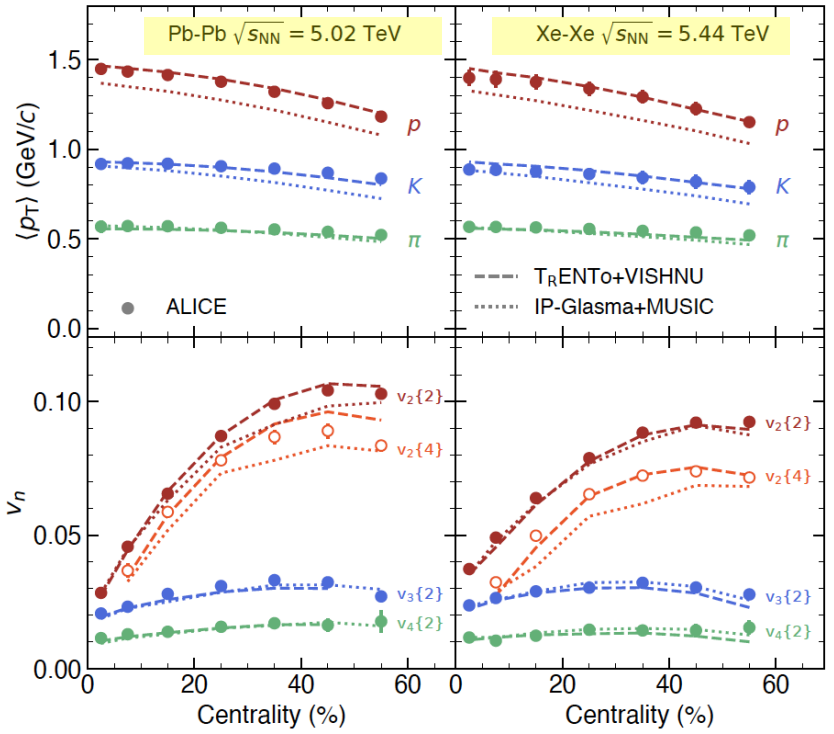
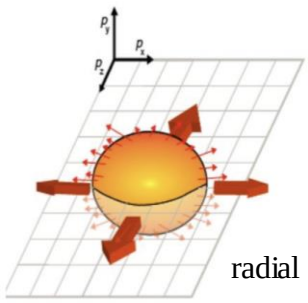
$$dN/d\phi = 1 + 2\,v_1 cos(\phi - \Psi_{RP}) + 2v_2 cos[2\,(\phi - \Psi_{RP})] + 2v_3 cos\,[3\,(\phi - \Psi_{RP})] + ...$$

arXiv:2211.04384 [nucl-ex]

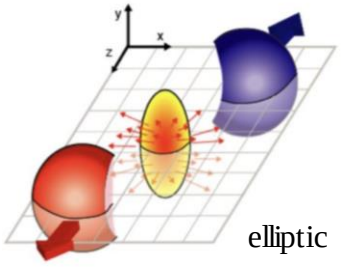




- Spectra shapes consistent with radial flow
- Observation of anisotropic flow (v_2)
- Radial and anisotropic expansion described by hydrodynamics



radial flow



elliptic flow

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Flow in small systems

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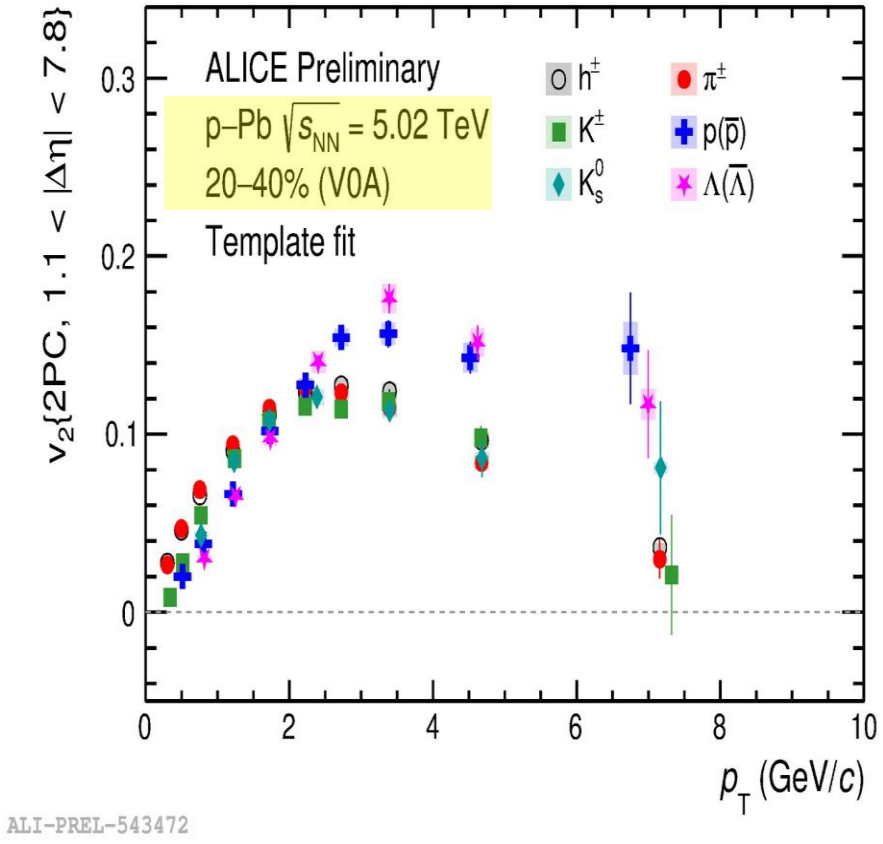
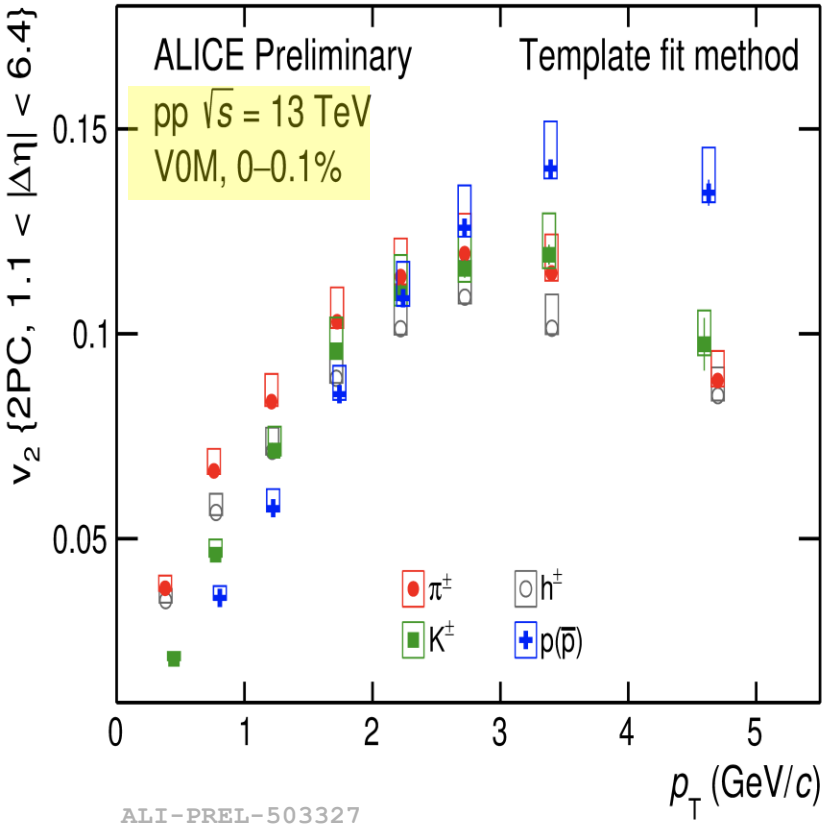
arXiv:2308.16590 [nucl-ex]





- Light and charmed hadrons exhibit anisotropic flow in small systems
- High multiplicity collisions of small systems resemble to QGP-like properties?

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Soft probes – Strangeness production

arXiv:2211.04384 [nucl-ex]

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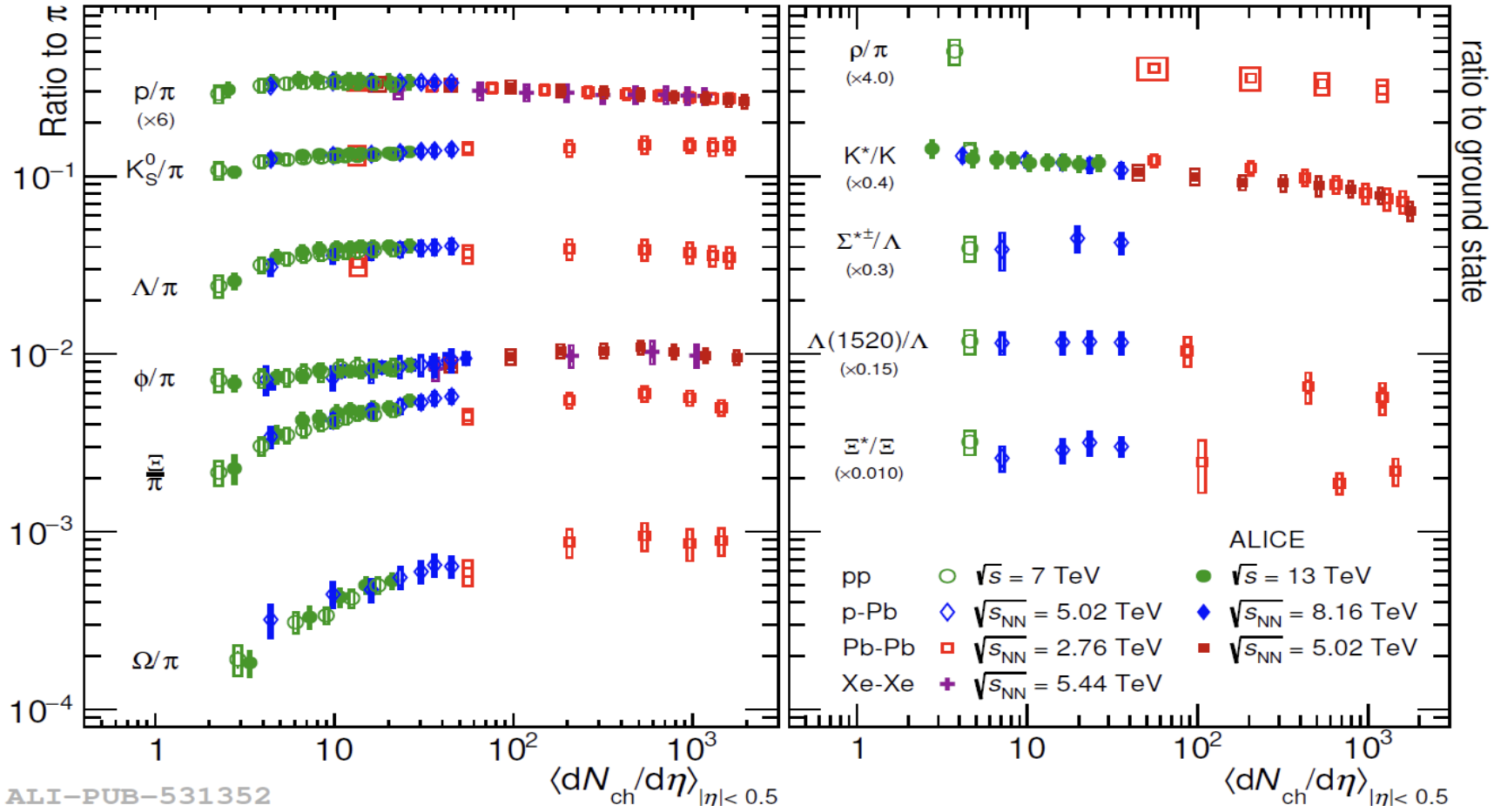

- Increase of yields of strange particles relative to pions with multiplicity
- Highest multiplicity ratios comparable with central Pb-Pb
- Thermalization of strangeness? QGP-related mechanisms?

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Parton energy loss

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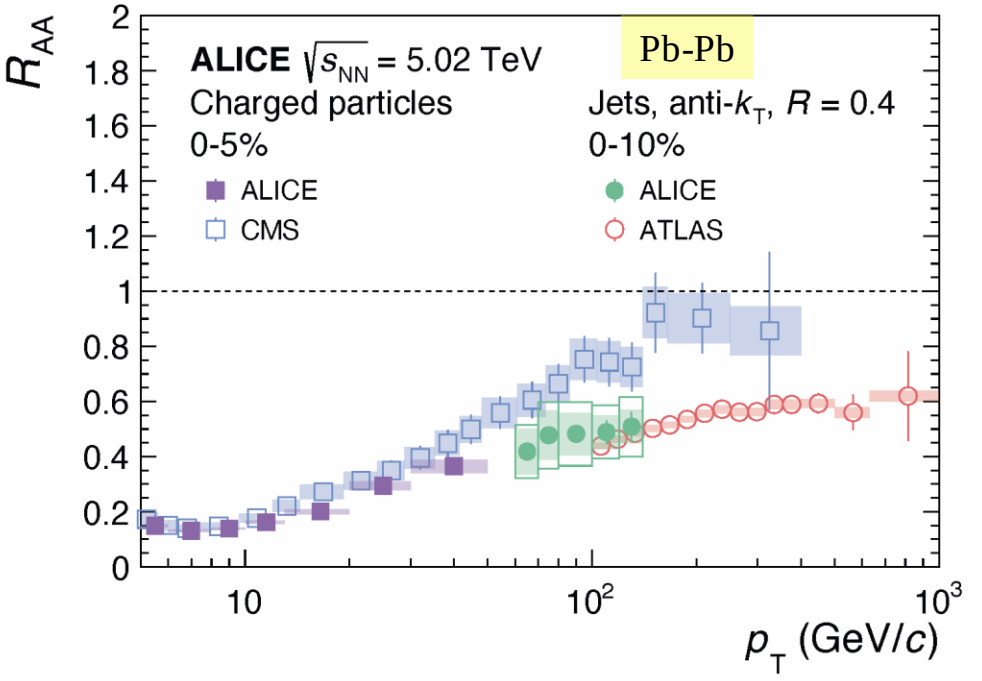
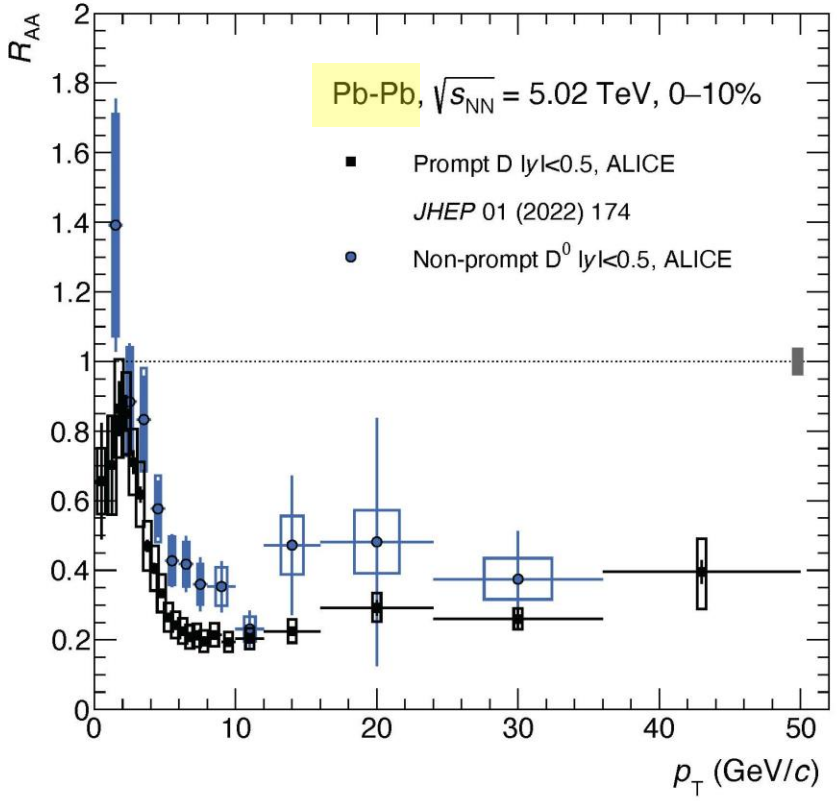
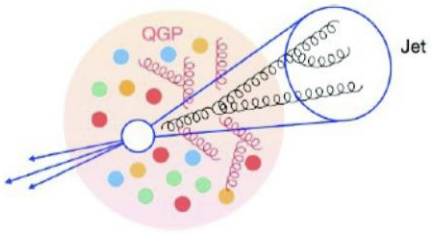
arXiv:2211.04384 [nucl-ex]



airXiv:2202.00815 [nucl-ex]





$$R_{AA} = \frac{\frac{1}{N_{event}} \frac{d^2N}{dp_{T,jet}d\eta_{jet}}\Big|_{AA}}{\langle T_{AA} \rangle \frac{d^2\sigma}{dp_{T,jet}d\eta_{jet}}\Big|_{pp}}$$

- Hard partons that shower into jets are produced early and interact with QGP
- Jet and high p_T hadron suppression observed over an extended range
- Process dominated by radiative emission $\Delta E_{loss} = 8 \pm 2$ GeV

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Parton energy loss in small systems

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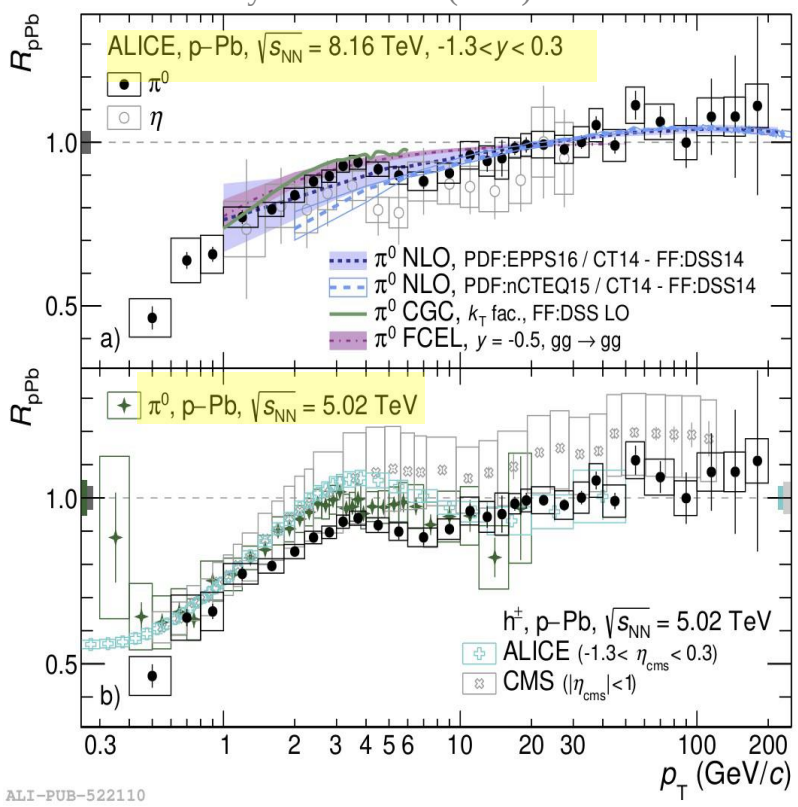
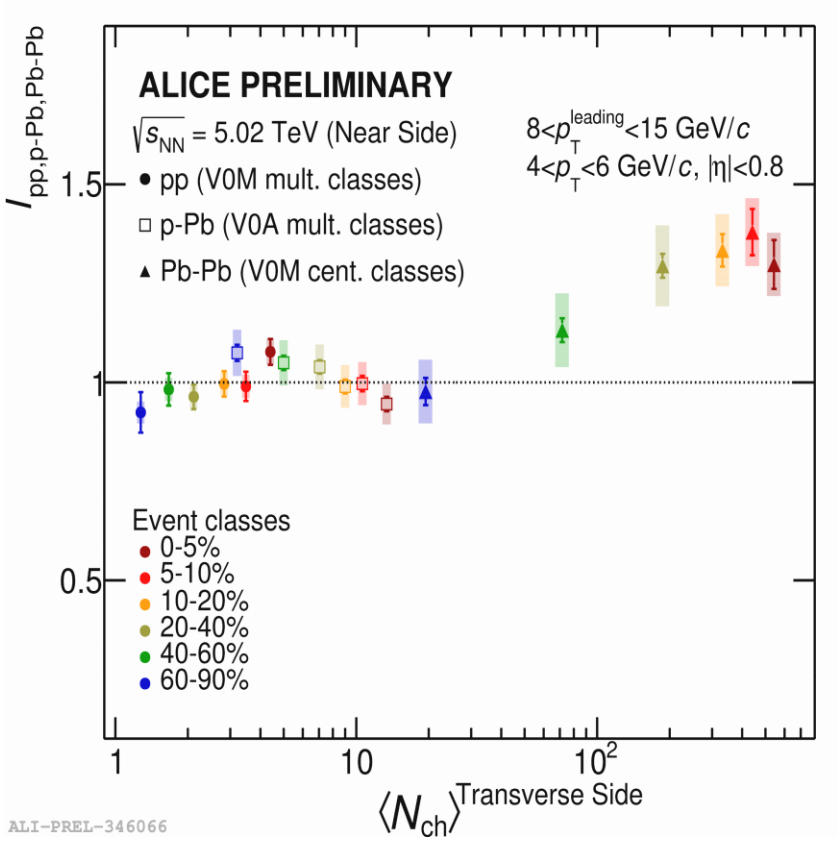
Phys. Lett. B 827 (2022) 136943





$$R_{\mathrm{pPb}} = \frac{1}{A_{\mathrm{Pb}}} \frac{\mathrm{d}^2\sigma_{\mathrm{pPb}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} \Big/ \frac{\mathrm{d}^2\sigma_{\mathrm{pp}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}$$

$$I_{\mathrm{pp,p-Pb,Pb-Pb}} = \frac{Y^{\mathrm{pp,p-Pb,Pb-Pb}} - Y_{\mathrm{TS}}^{\mathrm{pp,p-Pb,Pb-Pb}}}{Y^{\mathrm{pp\ min.bias}} - Y_{\mathrm{TS}}^{\mathrm{pp\ min.bias}}}$$

- There is no evidence of jet quenching for small systems
- Jet energy loss effects in p-Pb at least 20 times smaller than central Pb-Pb

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Quarkonia probes

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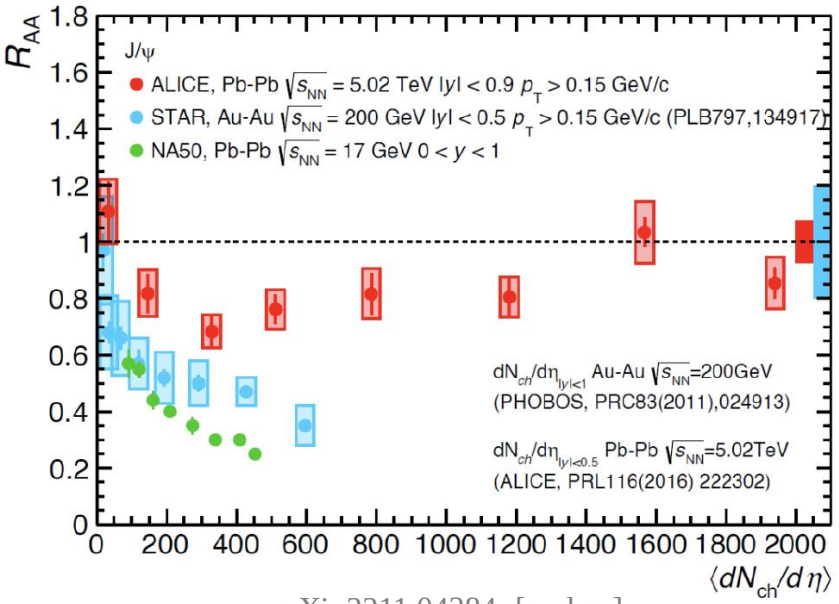
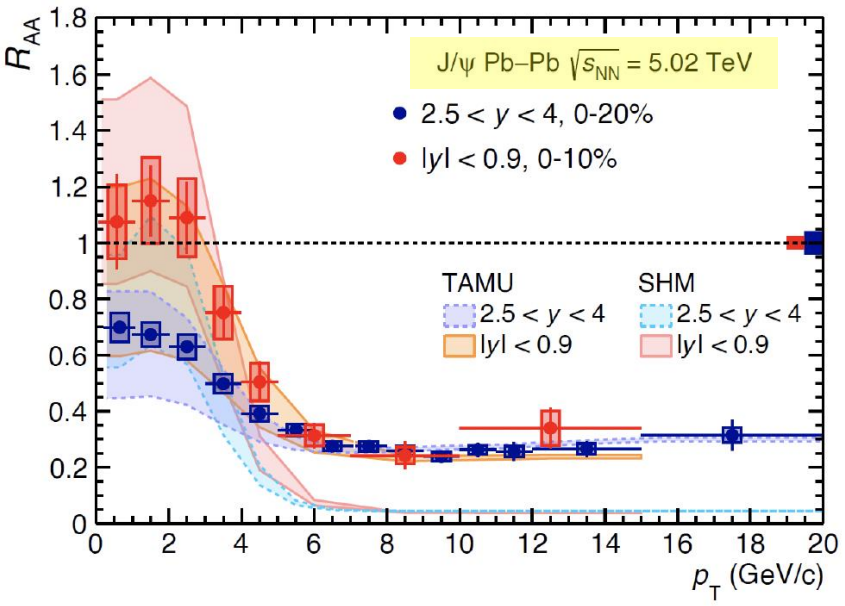
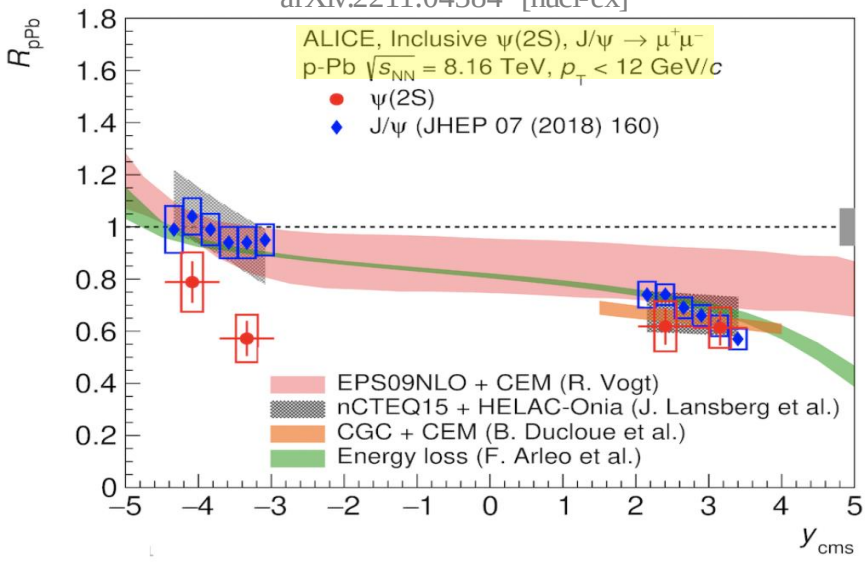
arXiv:2211.04384 [nucl-ex]





arXiv:2211.04384 [nucl-ex]



- Larger charm cross-section at LHC compared to RHIC/SPS, and mid-rapidity compared to forward maximize J/Ψ regeneration effects
- Deconfinement: charm quarks are free to move distances greater than hadronic size in QGP
- Small systems $\Psi(2S)$ suppressed, J/Ψ described using only initial state effects

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Nuclear synthesis

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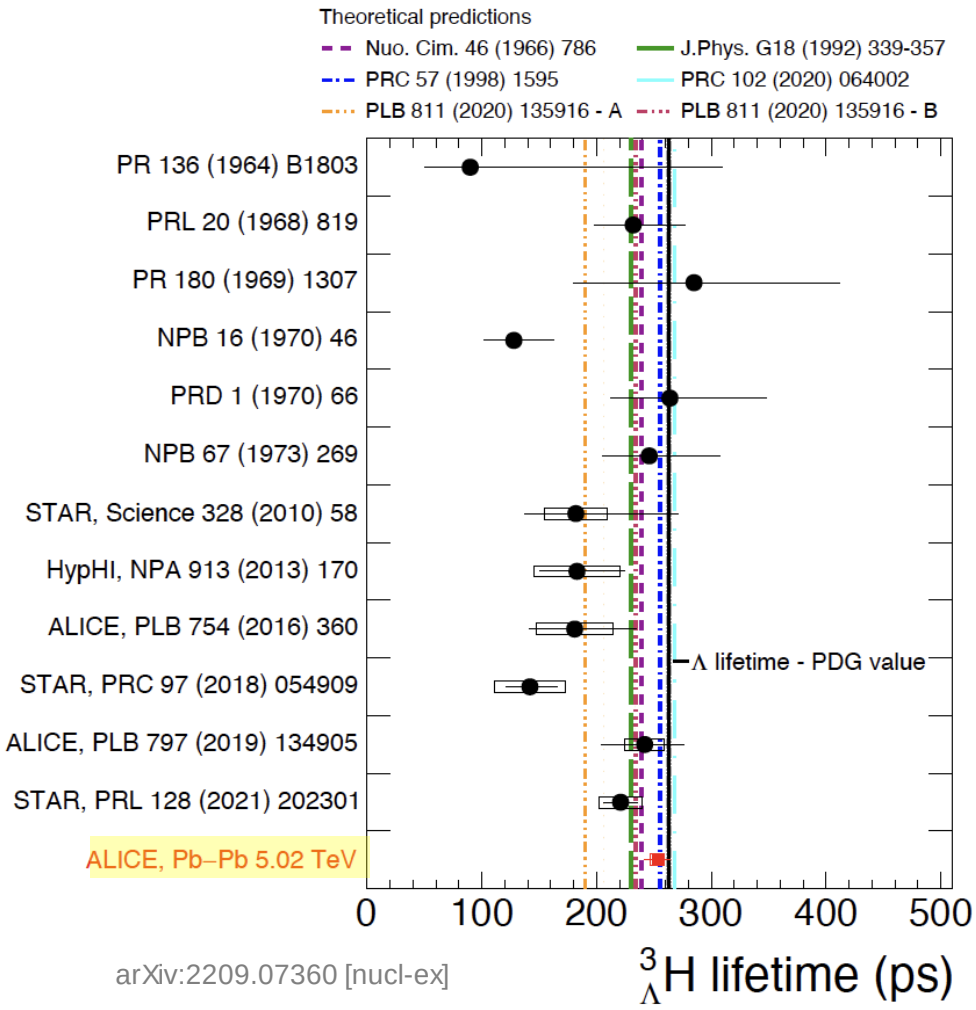
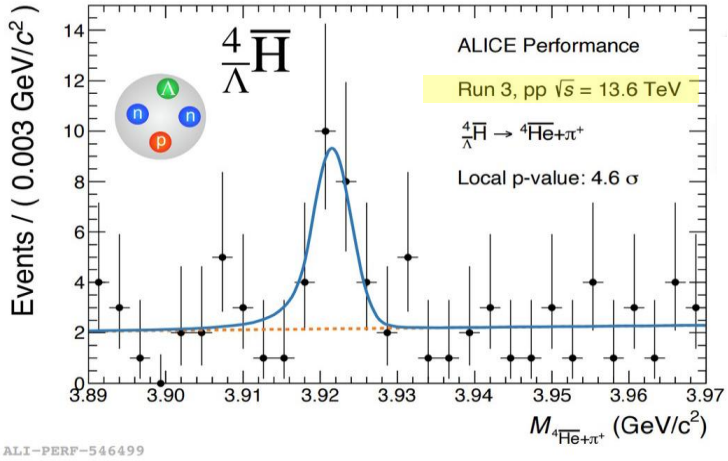
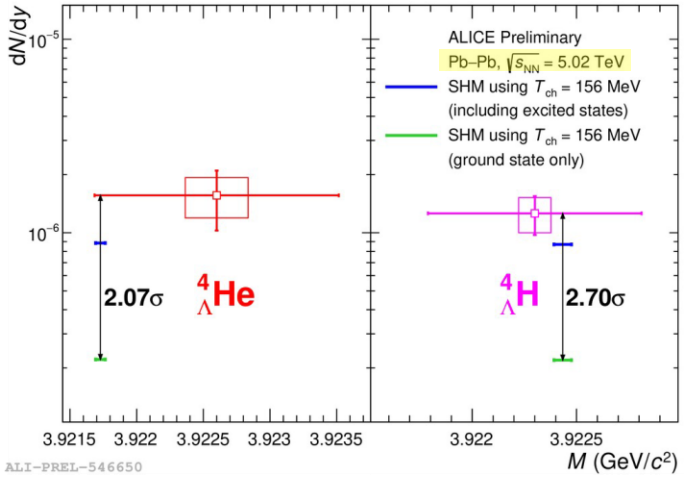


arXiv:2209.07360 [nucl-ex]



arXiv:2211.04384 [nucl-ex]



- Provided stringent constraints on lifetime and energy for hyper-nucleus

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Looking into the future

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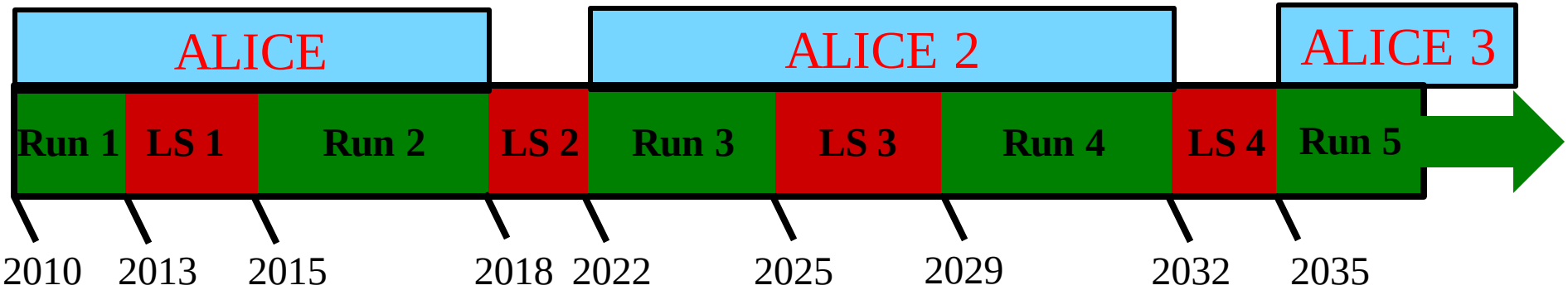
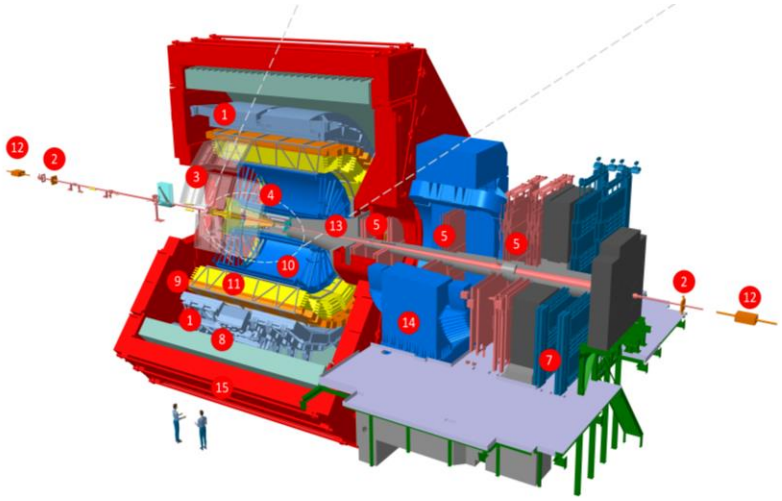
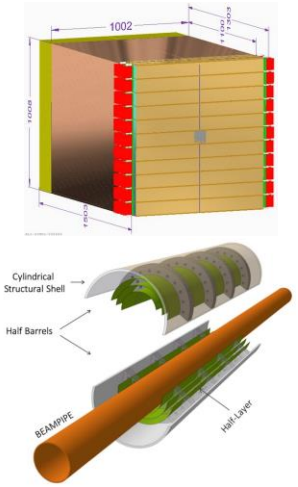


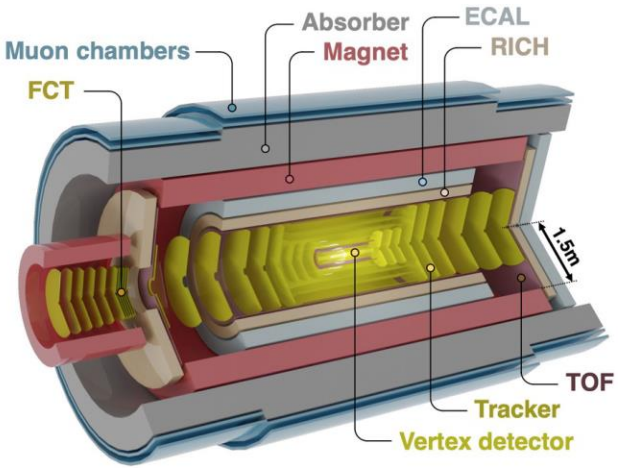
Run 3 ALICE 2



Run 4 FoCal and ITS 3



Run 5 ALICE 3



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ALICE upgrades - Run 4 - FoCal

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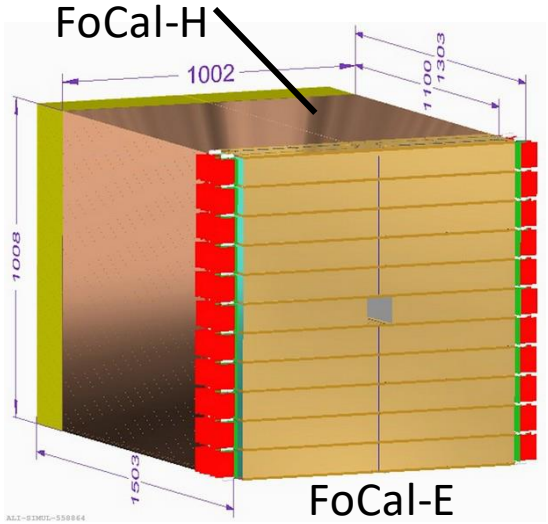
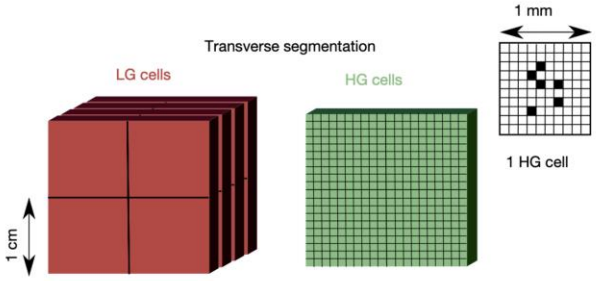
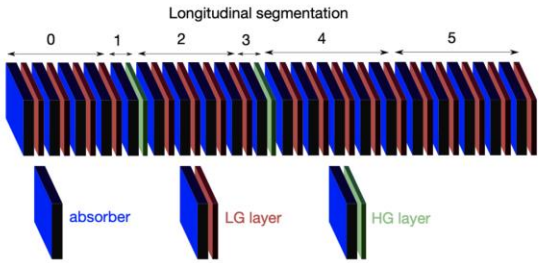
LoI: ALICE, LHCC-I-036 (2020)







FoCal-E (electromagnetic)

- High-granularity Si-W sampling combining 18 pad layers with silicon pads (1 cm^2) and two-pixel layers with digital readout (30 μm^2)
- Ability to "track" longitudinal component of the shower

FoCal-H (hadronic):

- Conventional metal-scintillator hadronic calorimeter
- Used to measure photon isolation, jet energy

Physics Capabilities

- Prompt photon production
- Hadron correlations
- Production of π^0, and vector mesons
- Jet measurements (e.g., di-jet production)
- Vector meson photo-production in Ultra-Peripheral Collisions (UPC)
- Physics case ALICE-PUBLIC-2023-001

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FoCal performance

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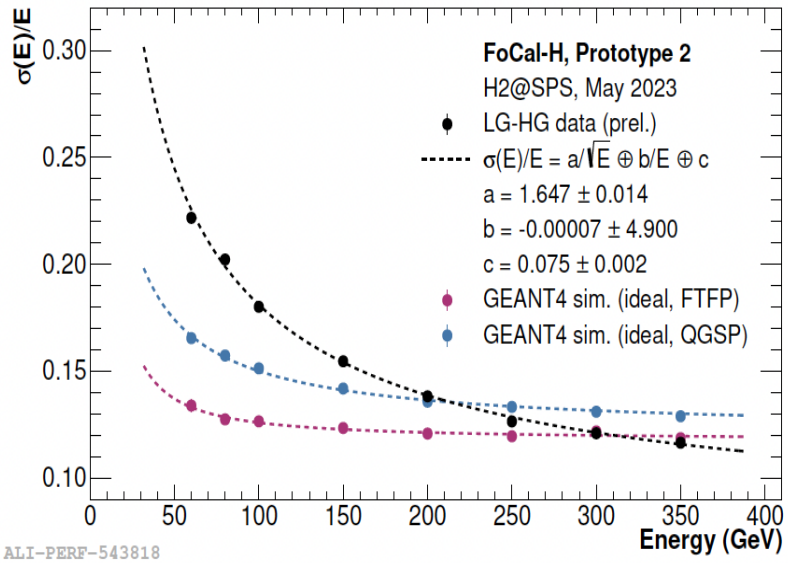
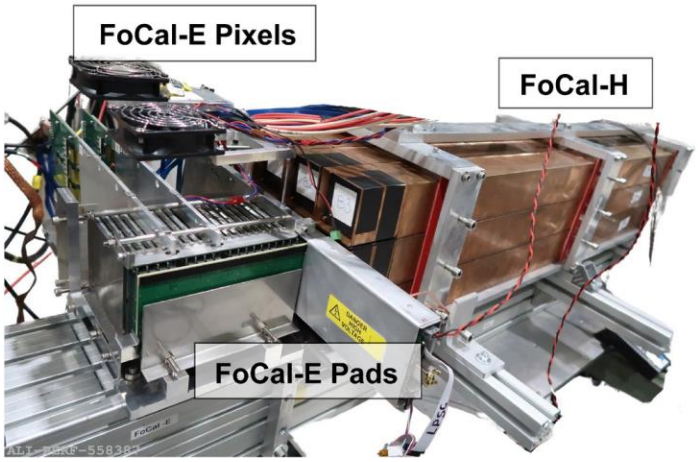
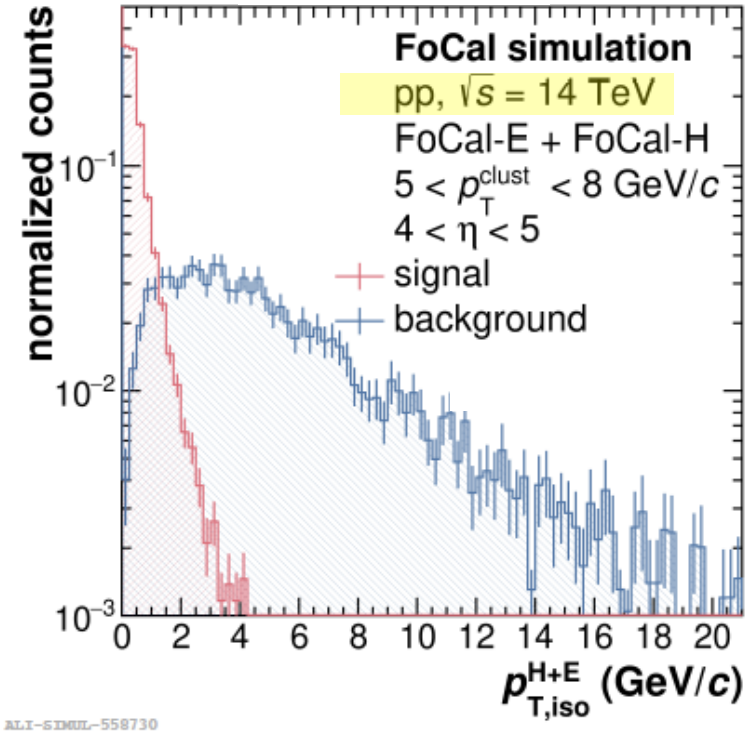




Isolated Photons



ALICE-PUBLIC-2023-004

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Run 4 – ITS 3

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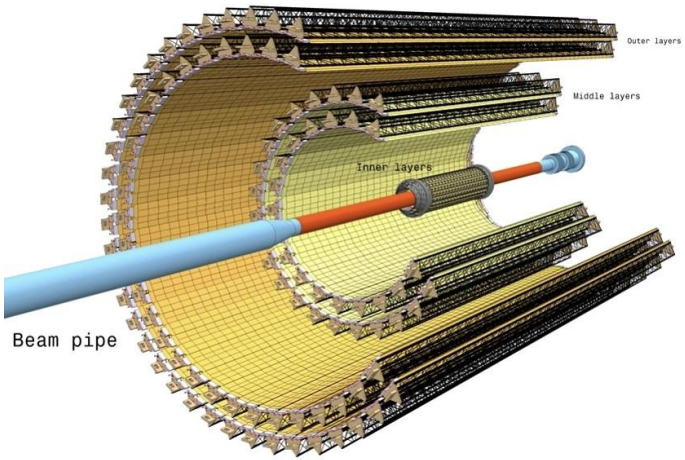
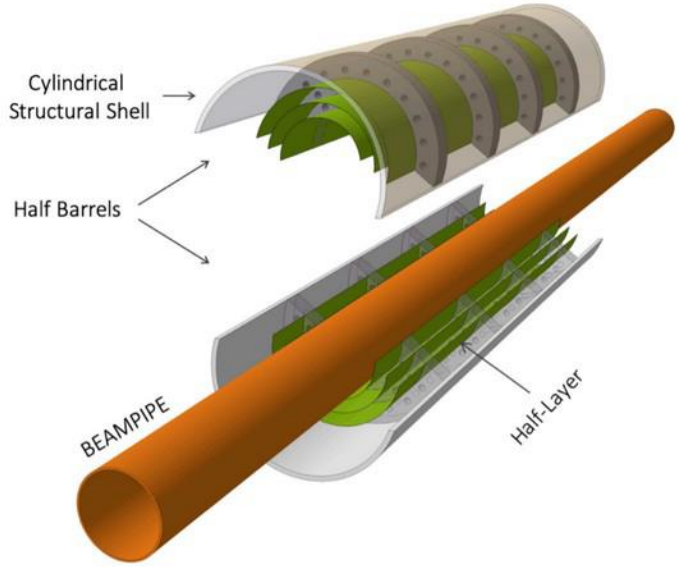


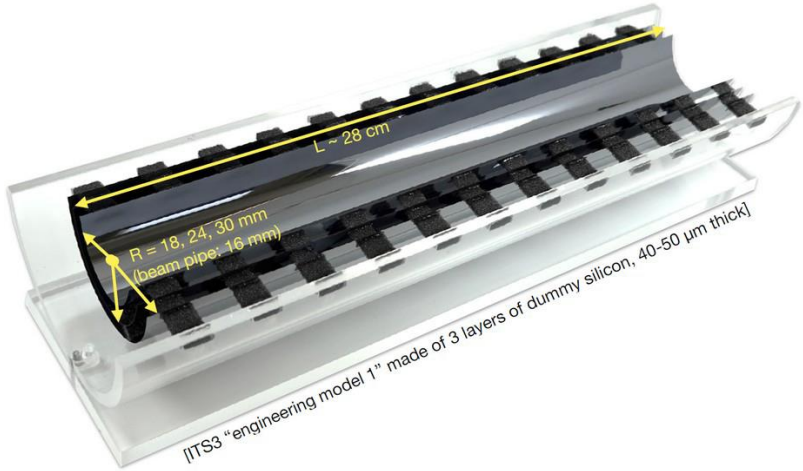


CERN-LHCC-2019-018 ; LHCC-I-034

- Replace the three innermost layers with new ultra-light, truly cylindrical layers
- Reduce material budget (from 0.35% to 0.05% X_0)
- Closer to the interaction point (23 to 18 mm)

Physics capabilities

- Improve vertexing performance and reduced backgrounds for heavy-flavour signals and low-mass dielectrons



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ITS 3 performance

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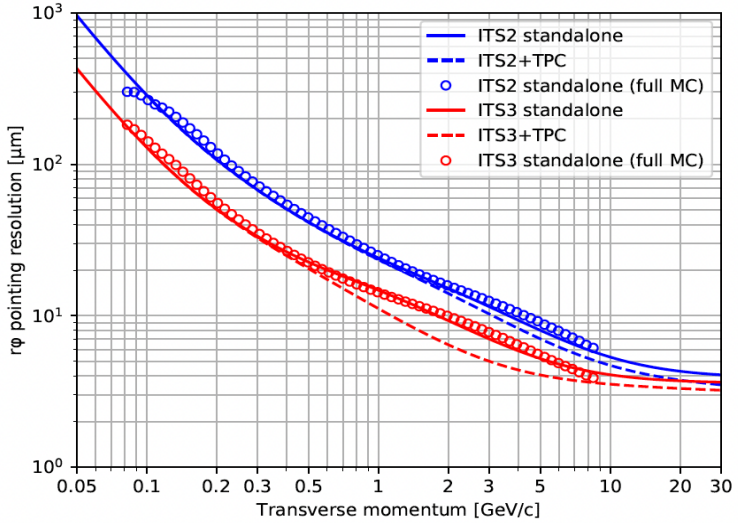
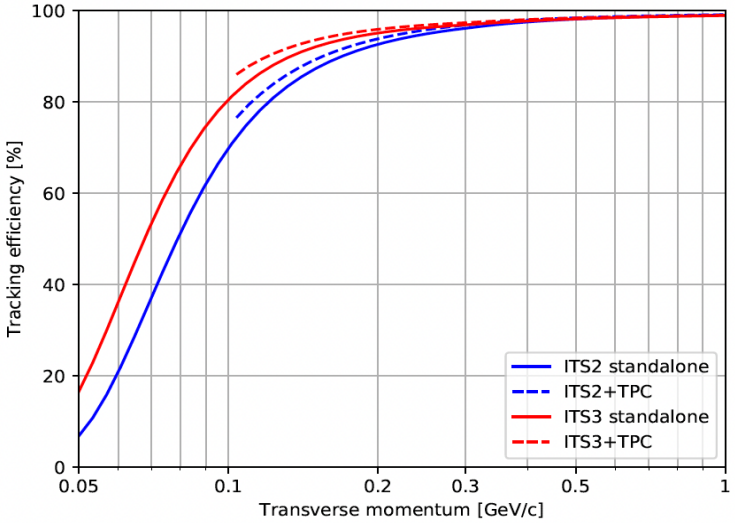
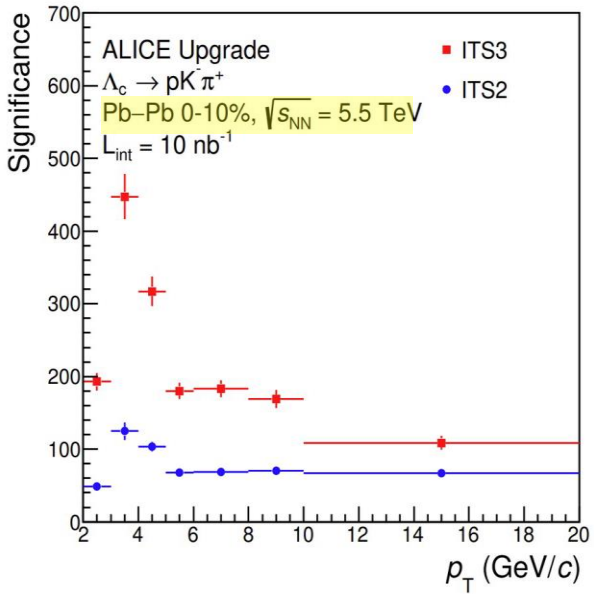
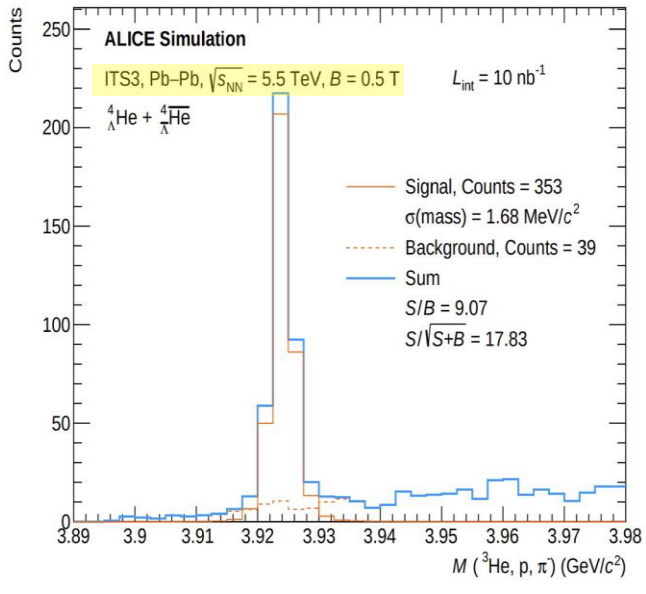
CERN-LHCC-2019-018





ALICE-PUBLIC-2023-002





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ALICE 3 - Run 5

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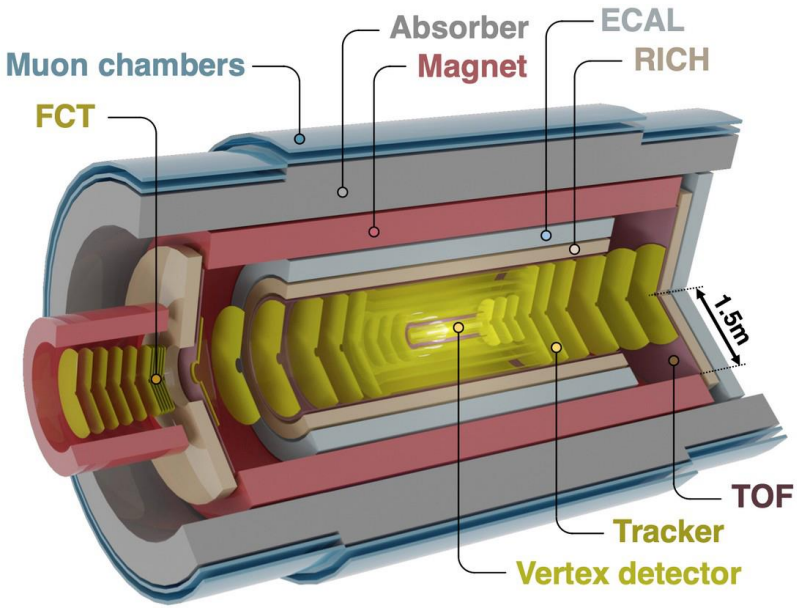
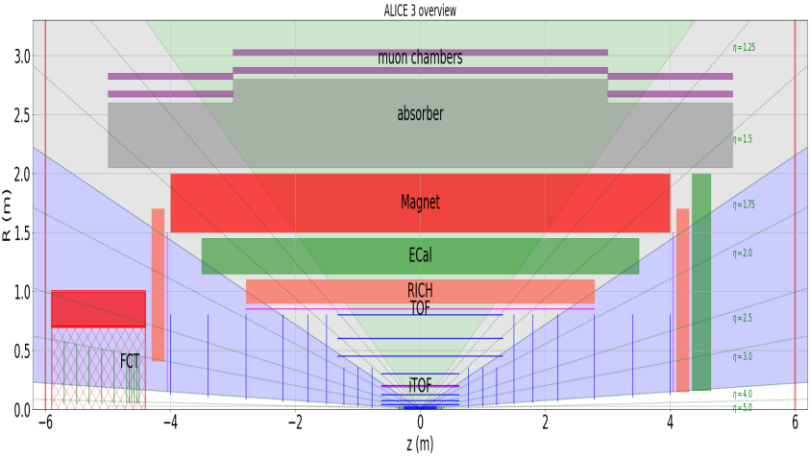
CERN-LHCC-2022-009





- Compact all-silicon tracker with high-resolution retractable vertex detector
- Superconducting magnet system
- PID over large acceptance: muons, electrons, hadrons, photons
- Forward conversion tracker
- Fast read-out and online processing
- Large-area ECal for photons and jets

Physics capabilities

- Charm and beauty hadronization in the QGP
- Multi-charm hadrons and quarkonia
- Thermal radiation and chiral symmetry restoration
- Dileptons, photons, vector mesons
- Light (hyper)nuclei and searches for charmed hyper nuclei
- Ultra-soft photons
- BSM searches

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ALICE 3 - Performance

ALICE

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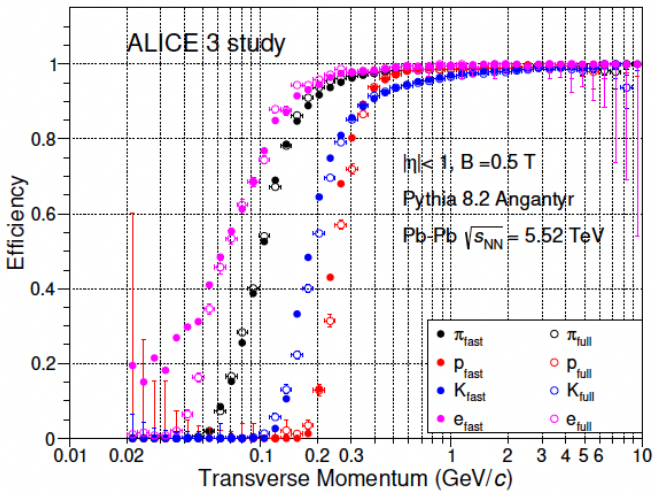

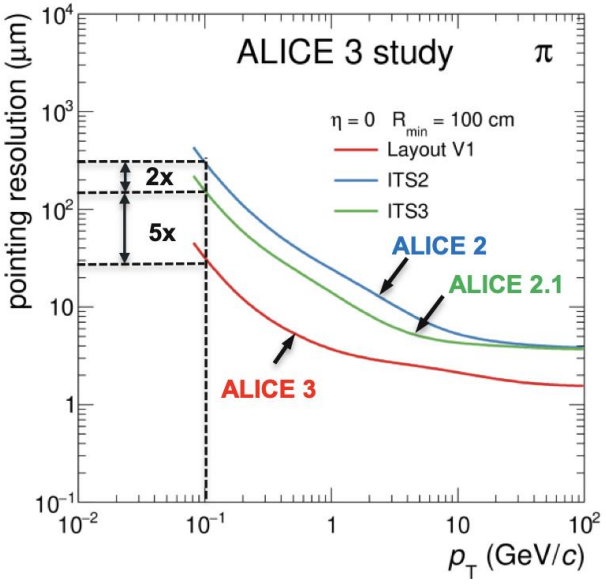

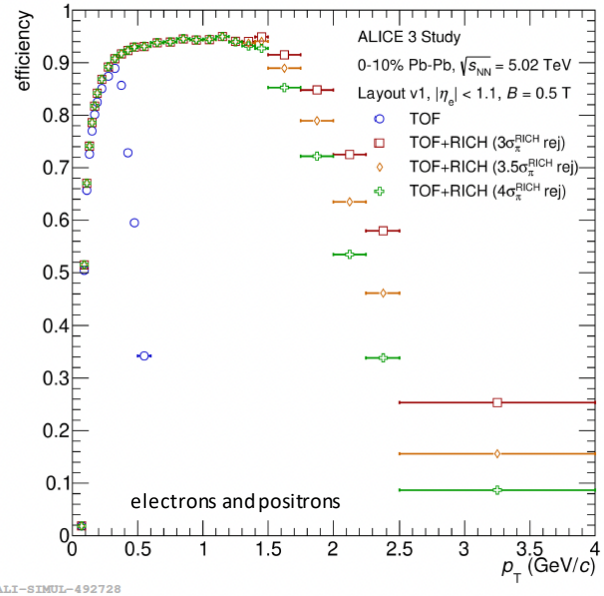

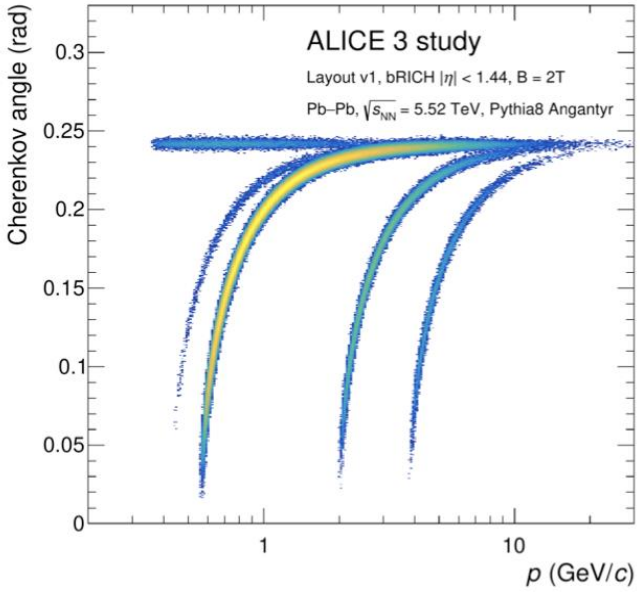

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ALICE 3 performance

ALICE

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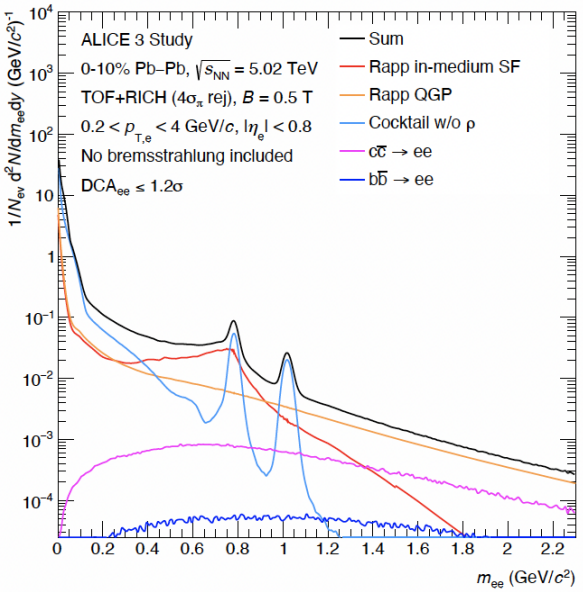

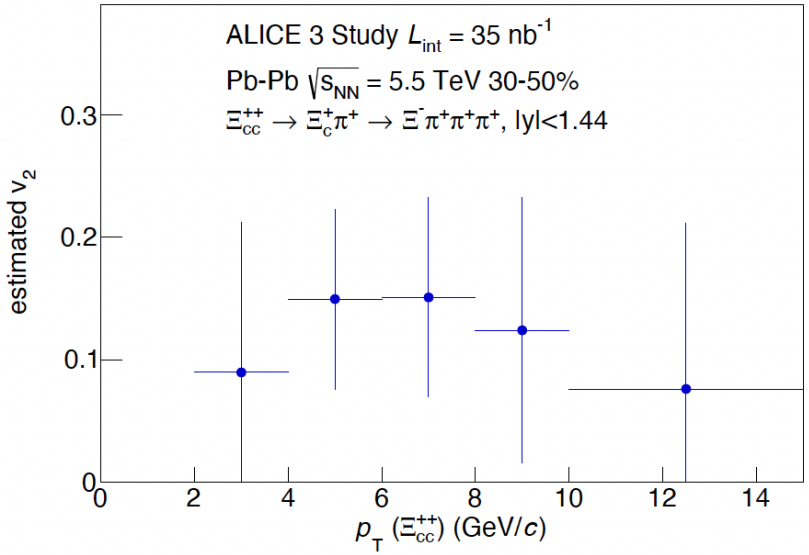

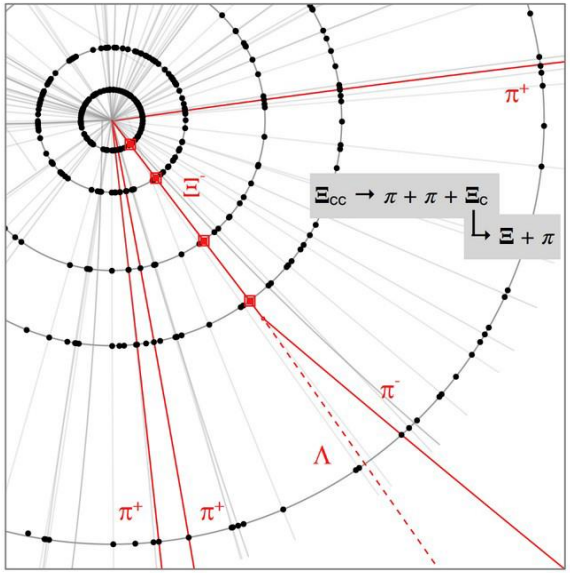

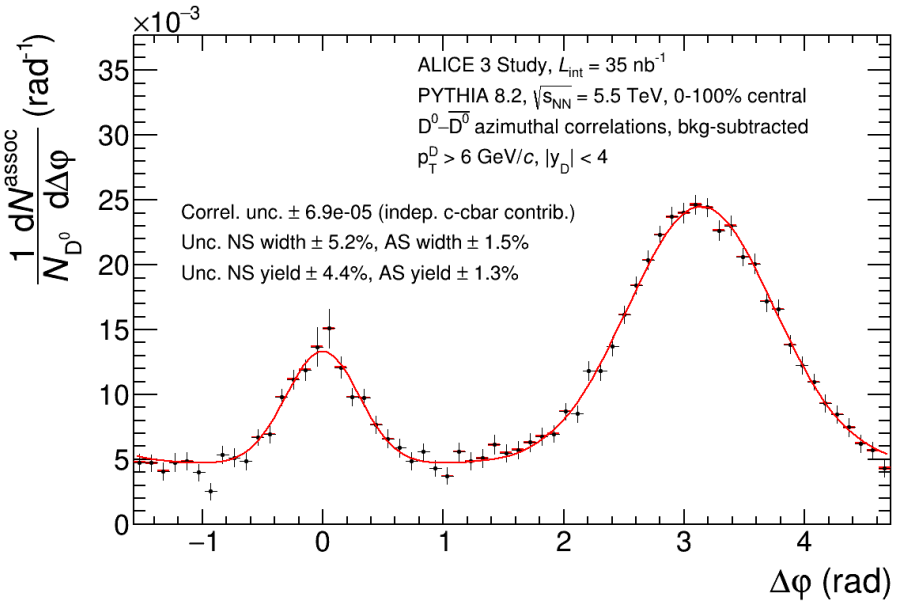

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Final notes

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- ALICE has engaged in a strong program of measurements
- Run 3 results are on going
- ALICE will be strategically prepared to address the physics observables of the Quark Gluon plasma phase available after the LHC upgrades

For Chicago State University, this material is based upon work supported by the National Science Foundation under grant NSF-PHY-2208883

NSF

Backup

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Probing initial state

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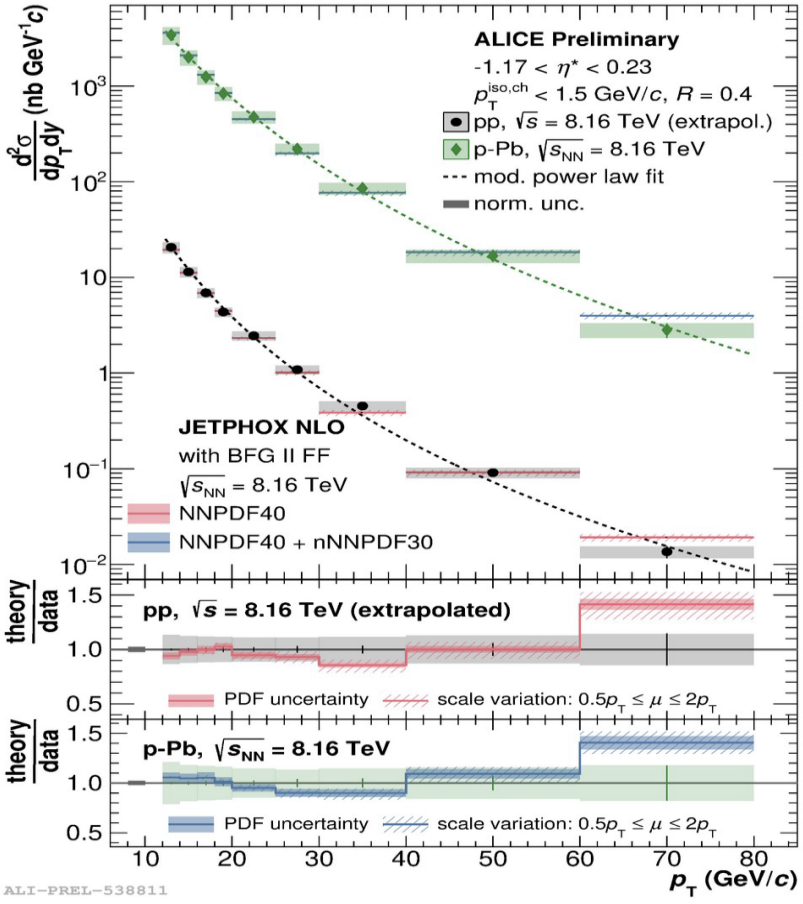

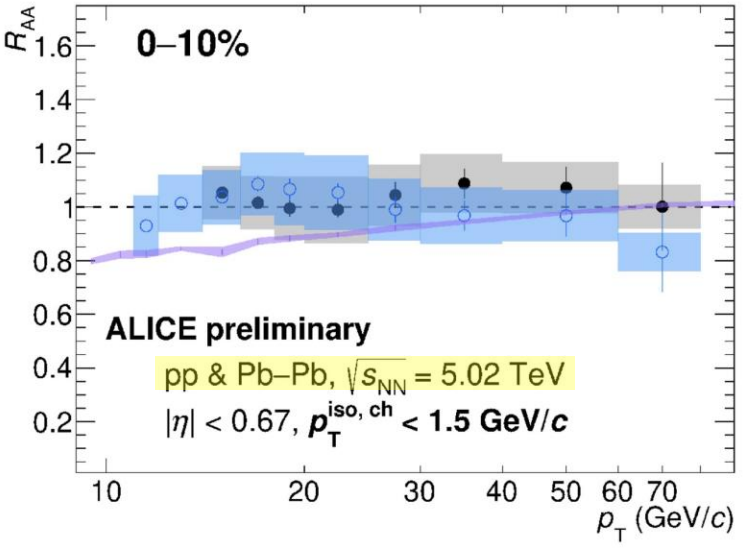

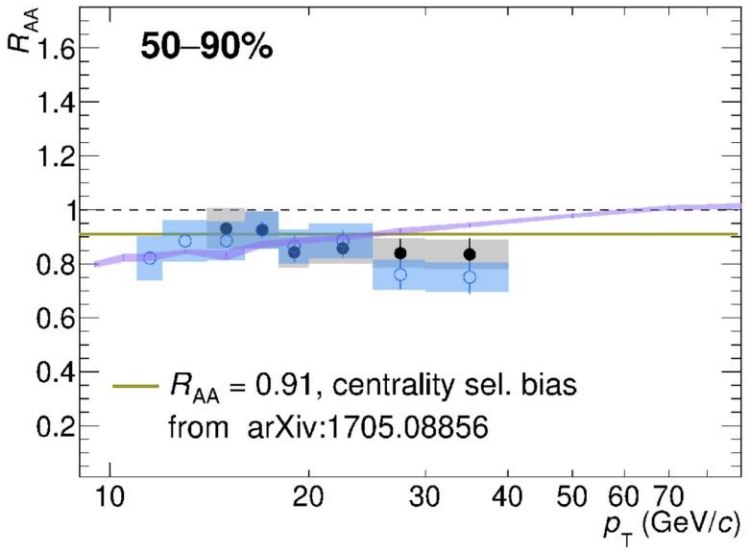

$$R_{AA} = \frac{dN^{AA}/dp_T}{\langle N_{coll} \rangle dN^{pp}/dp_T}$$

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Effects of hard probes in small systems

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arXiv:2211.04384 [nucl-ex]