Resonance production and hadronic phase in heavy-ion collisions with ALICE at the LHC

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Outline

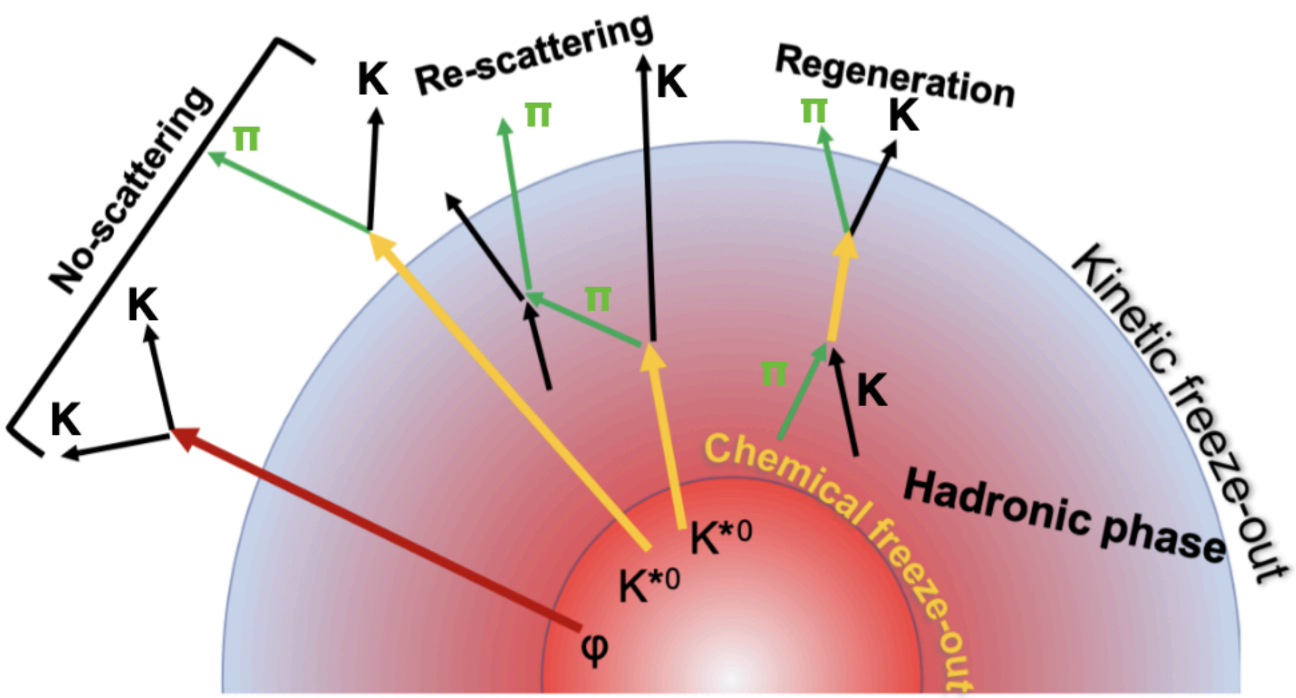
- ❖ Motivation
- ❖ Alice Detector
- ❖ Results :
  - - - p_T spectra
  - - - Integrated yield (d*N*/dy) and mean transverse momentum <p_T>
  - - - Particle ratios
  - - - Rapidity asymmetry
  - - - Nuclear modification factor
- ❖ Summary and Outlook

Why Resonances ?

Lifetime (fm/*c*): ρ^0 (1.3) < $K^{*\pm}$ (3.6) < K^{*0} (4.16) < $\Sigma^{*\pm}$ (5.0-5.5) < Λ^* (12.6) < Ξ^{*0} (21.7) < ϕ (46.2)

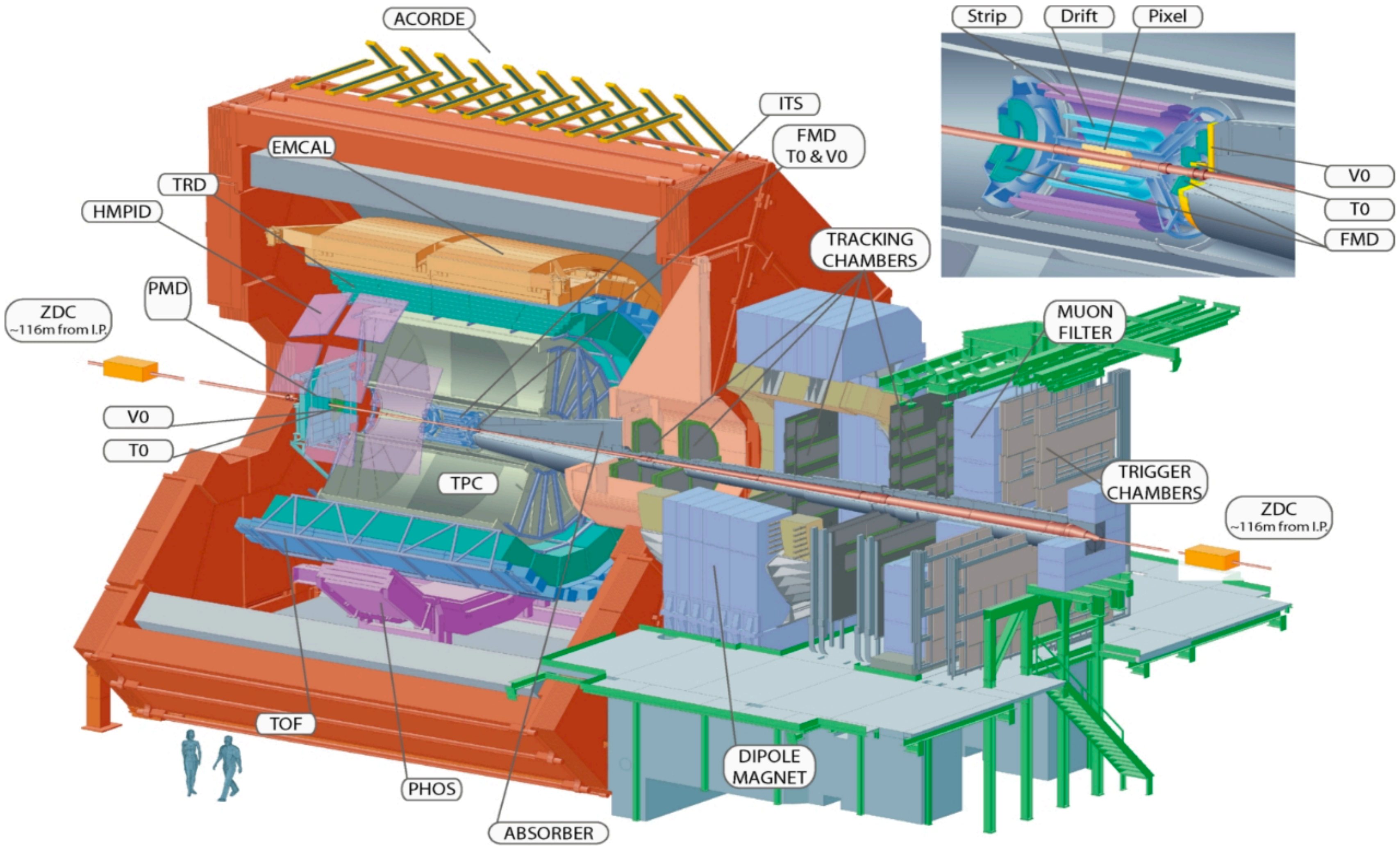
Resonances are short lived particles and decay by strong interaction

Hadronic phase : Duration between chemical and kinetic freeze-out



- ❖Information on the lifetime of hadronic phase
- ❖Modification of yield (re-scattering and regeneration effects)
- ❖Hadrochemistry of particle production
- ❖Study of in-medium energy loss

ALICE : A Large Ion Collider Experiment



Inner Tracking System(ITS): (|η| < 0.9)
- ❖ Primary vertex
- ❖ Tracking

TimeProjectionChamber (TPC): (|η| < 0.9)
- ❖ Tracking
- ❖ PID

Time-Of-Flight (TOF): (|η| < 0.9)
- ❖ PID

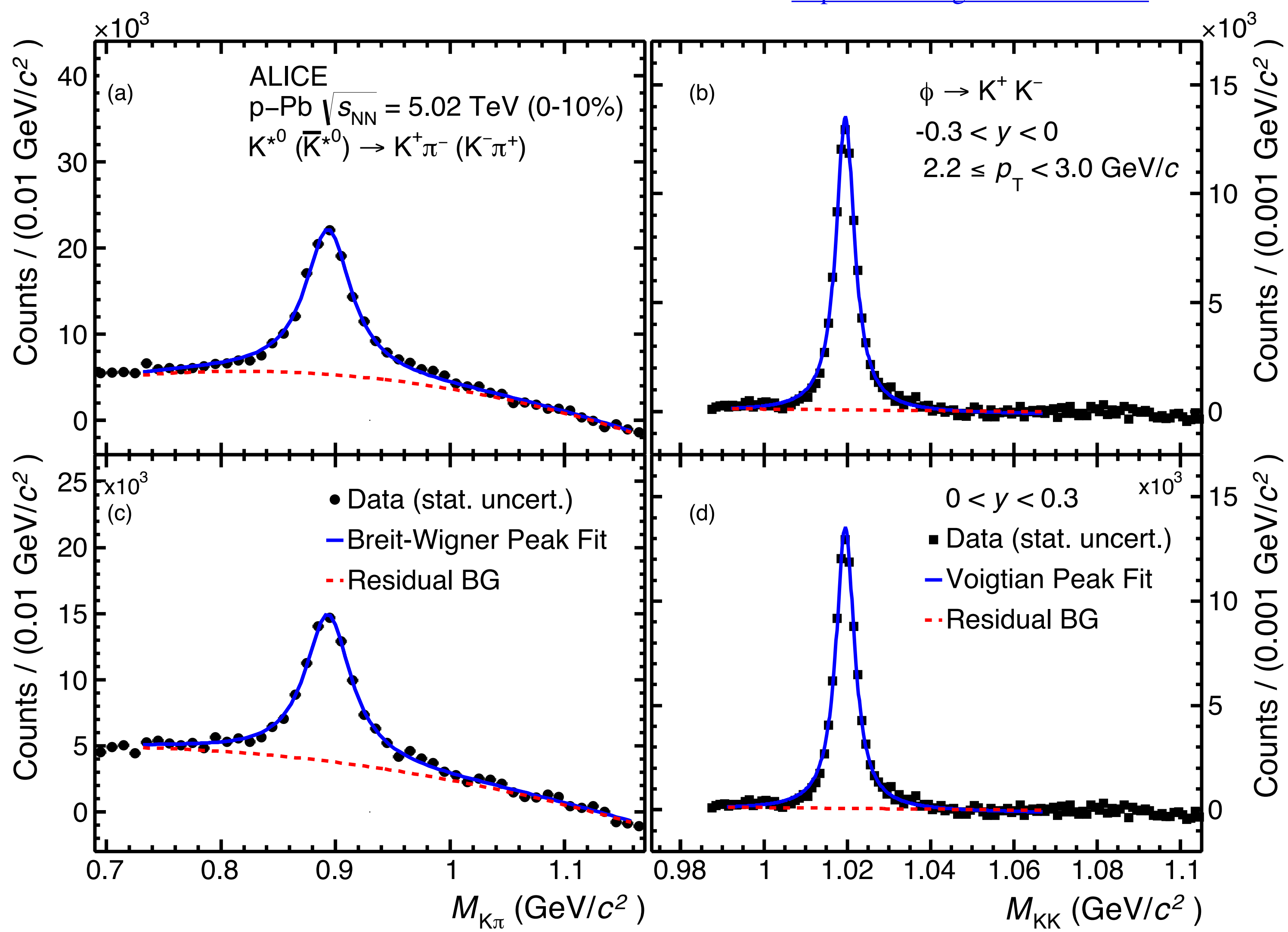
Forward detector (V0): V0A (2.8< η < 5.1) & V0C (-3.7< η < -1.7)

Multiplicity/centrality event classes definition
- ❖ In p—Pb (V0A) and in pp, Pb—Pb (V0M = V0A + V0C)

Resonance Reconstruction

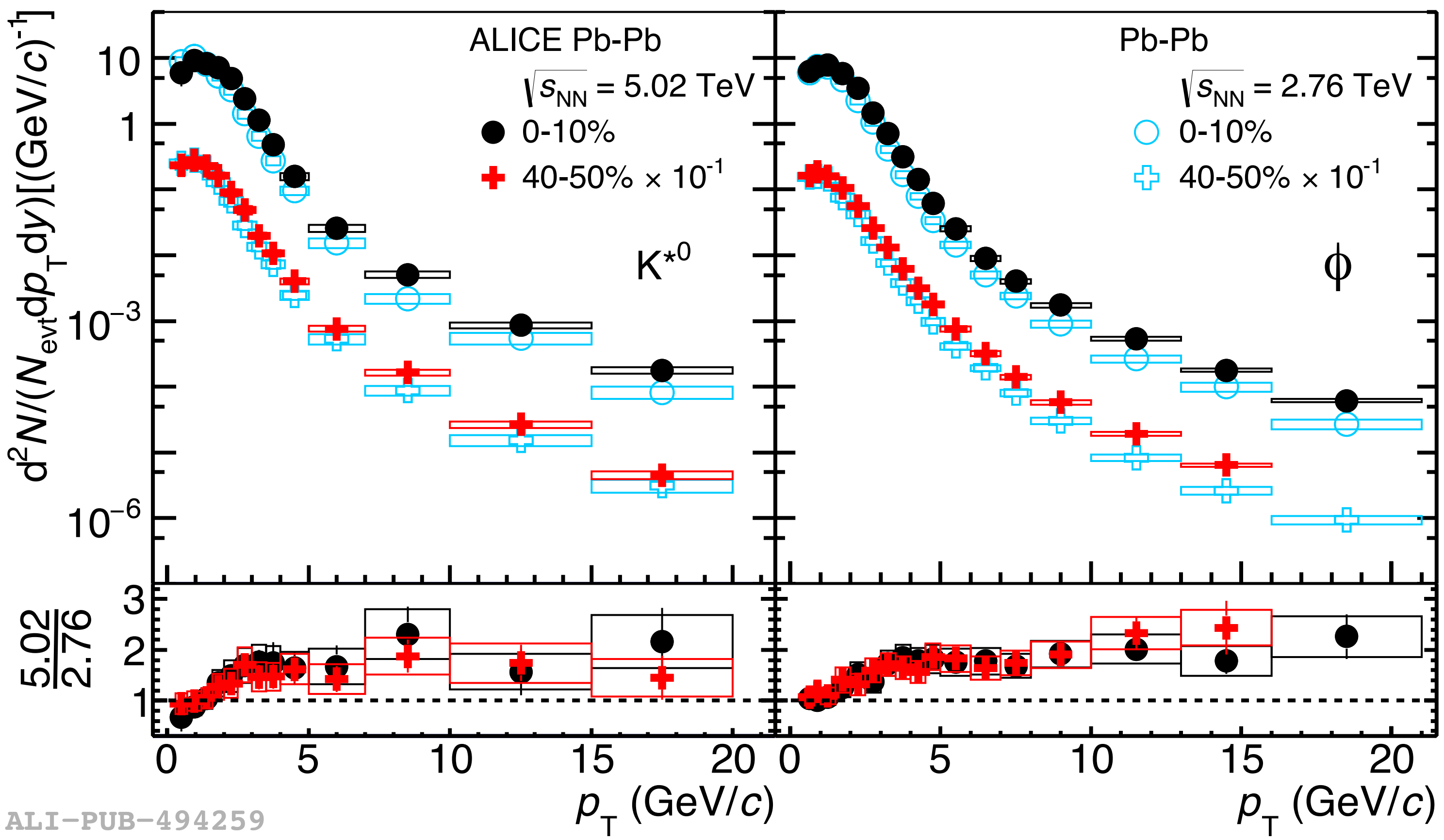
- ❖ Resonances are reconstructed from their decay daughter via the invariant mass technique
- ❖ Uncorrelated background is evaluated via event mixing or like-sign techniques and subtracted from the invariant mass distribution
- ❖ Residual background is modeled by a polynomial function
- ❖ Signal is fit with a Breit-Wigner or Voigtian function

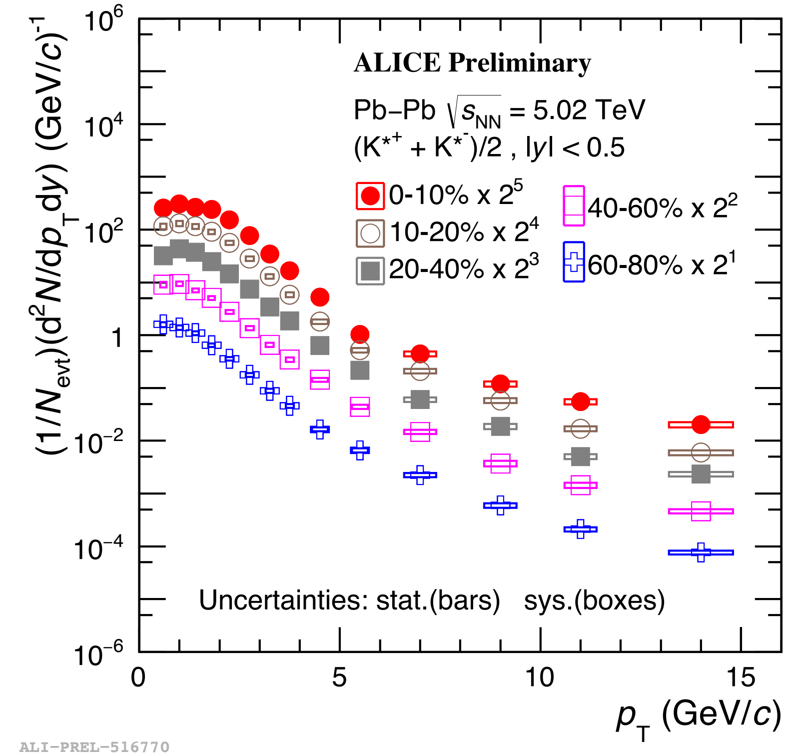
ALICE https://arxiv.org/abs/2204.10263

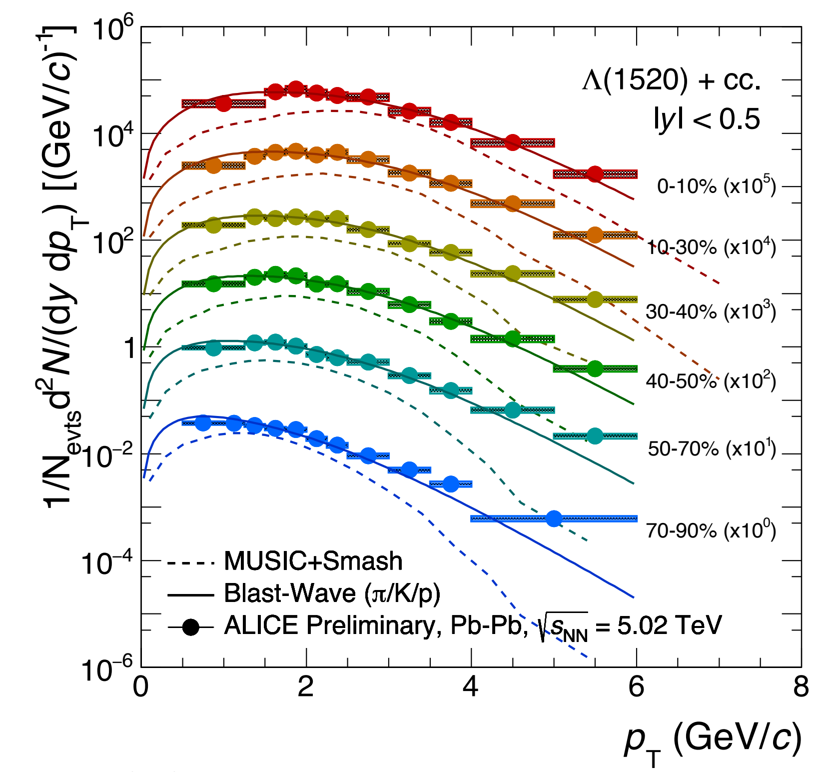


Transverse Momentum Spectra

ALICE Phys. Rev. C 106, 034907







- ❖ p_T spectra obtained in different multiplicity classes
- ❖ Hardening of the spectra with increasing multiplicity-> Caused by radial flow.

Rapidity dependence of p_T spectra

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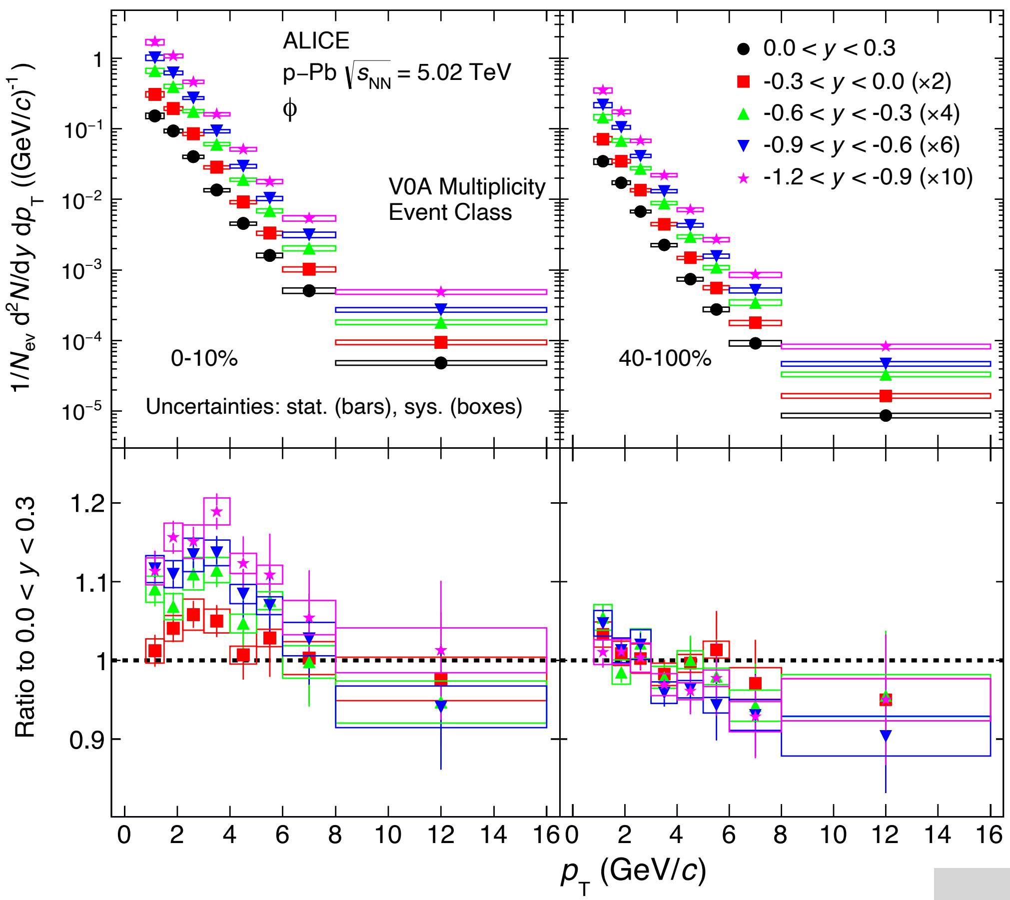
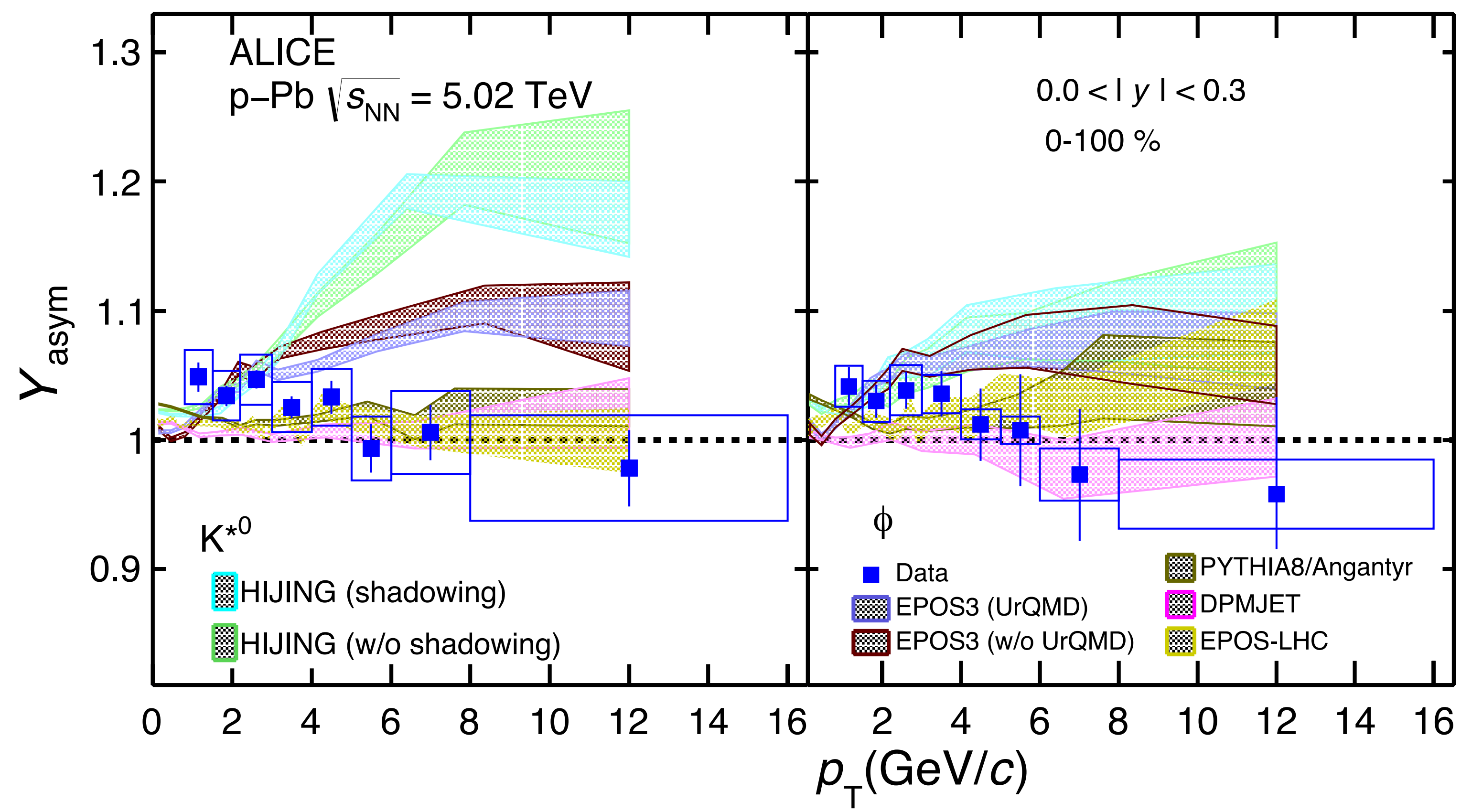
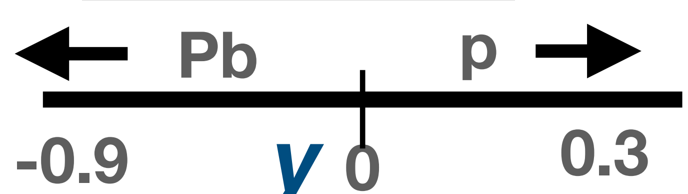




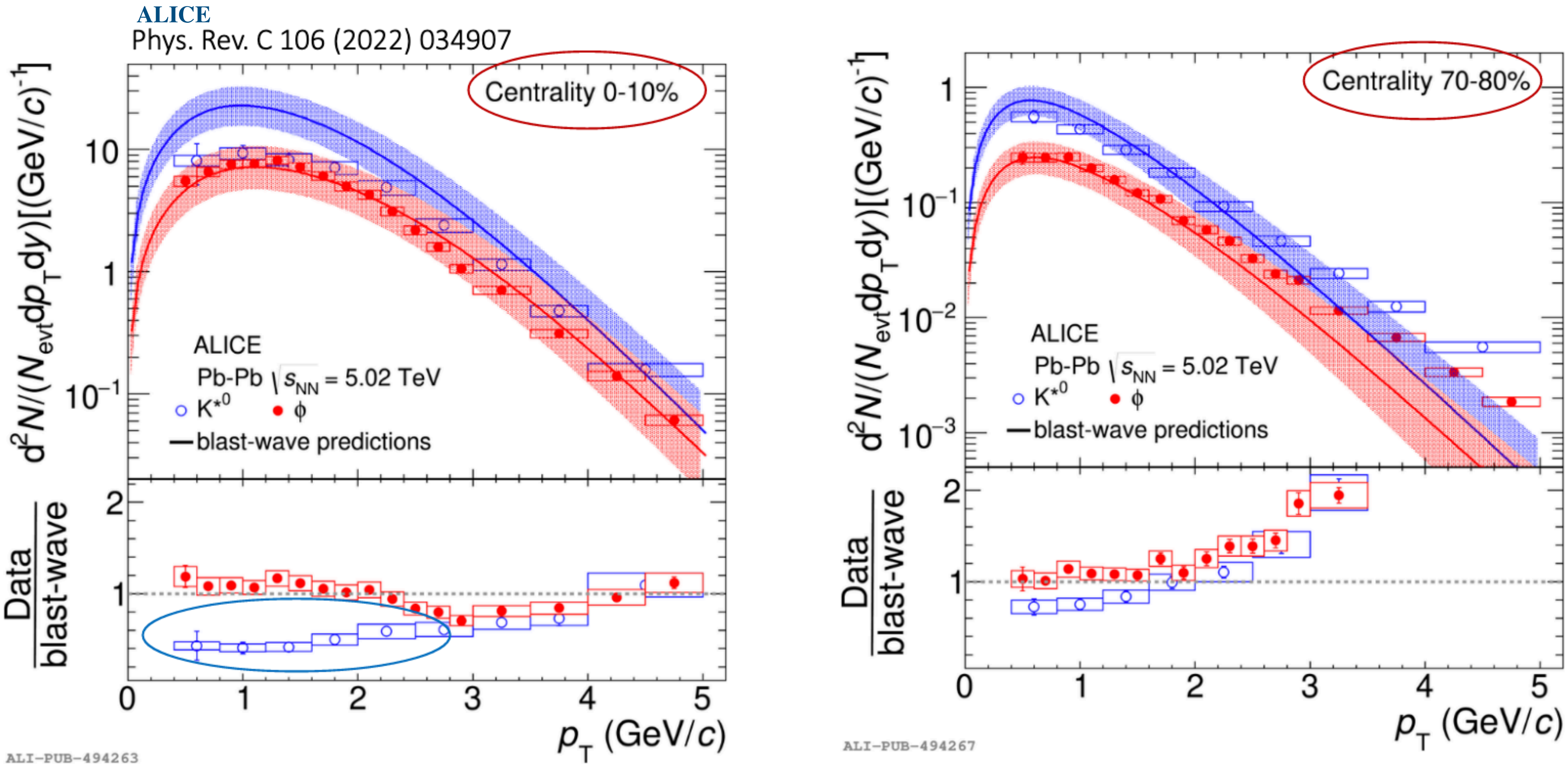
p-Pb
$\sqrt{s_{NN}}$ = 5.02 TeV



$$y_{asym} = \frac{Yield_{FR}(p_T)}{Yield_{BR}(p_T)}$$

- ❖ Rapidity yield asymmetry is observed at low p_T, asymmetry increases from low to high multiplicity classes.
- ❖ No significant rapidity dependence at high p_T for all multiplicity classes
- ❖ No model describes the data in the full measured p_T range.

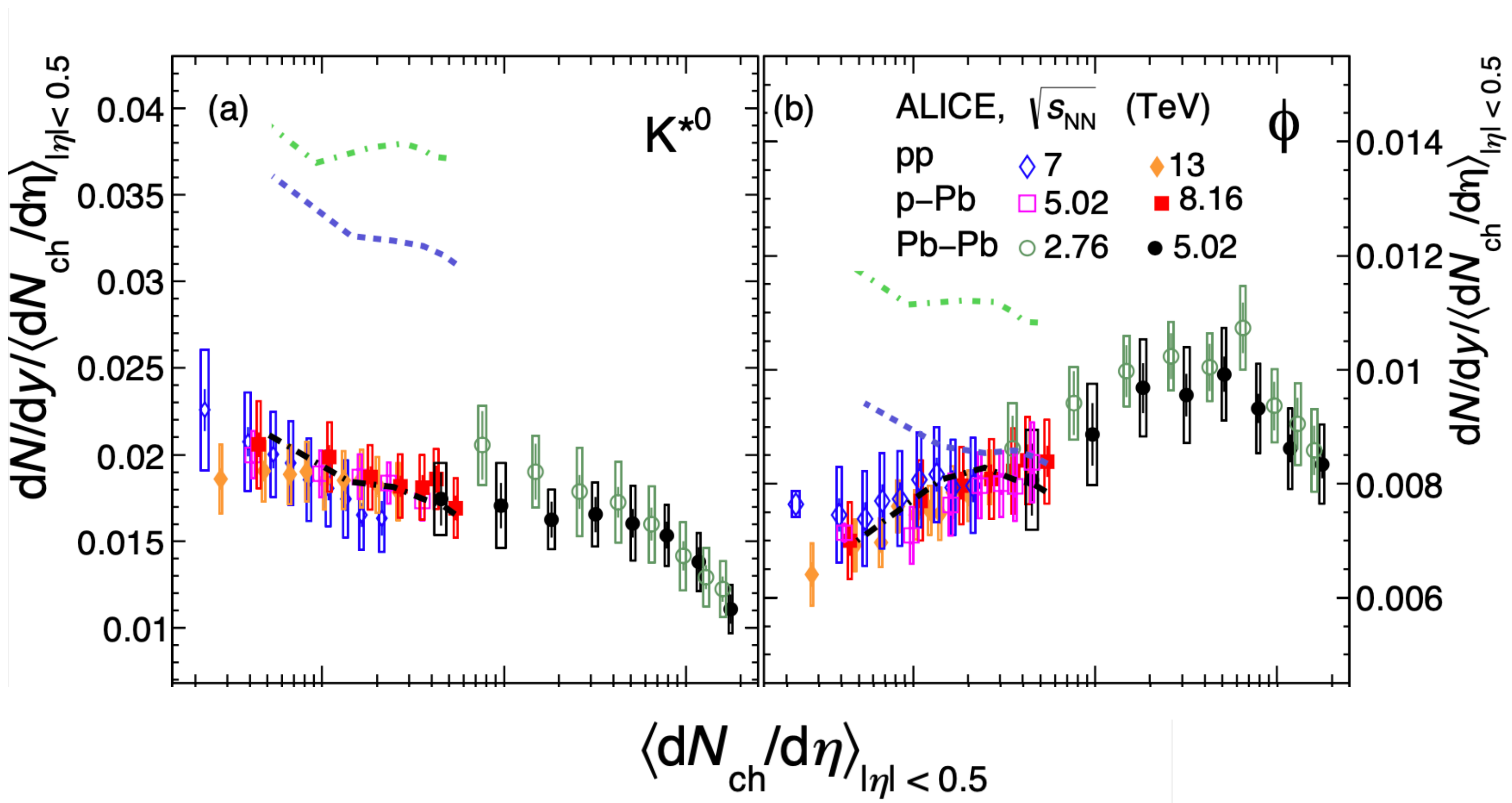
Comparison with blast wave model

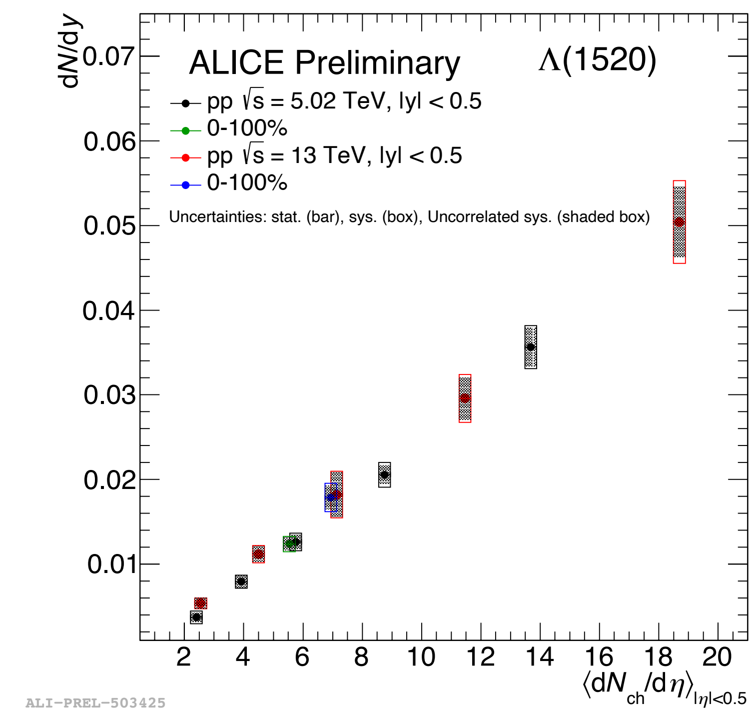


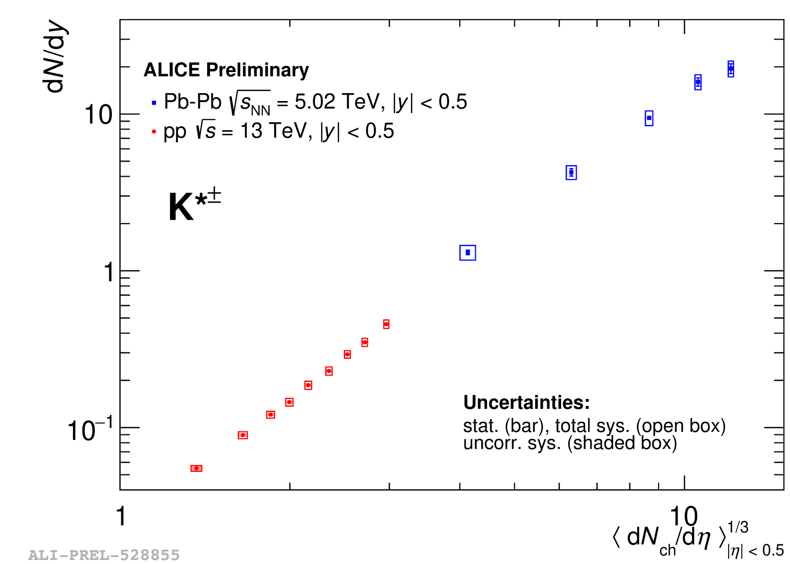
- ❖ Re-scattering and regeneration processes modify the yield of reconstructible resonances
- ❖ Effect more pronounced for central collisions where the duration of the hadronic phase is longer
- ❖ The effect is larger at low p_T

Integrated Yield

ALICE http://arxiv.org/abs/2110.10042

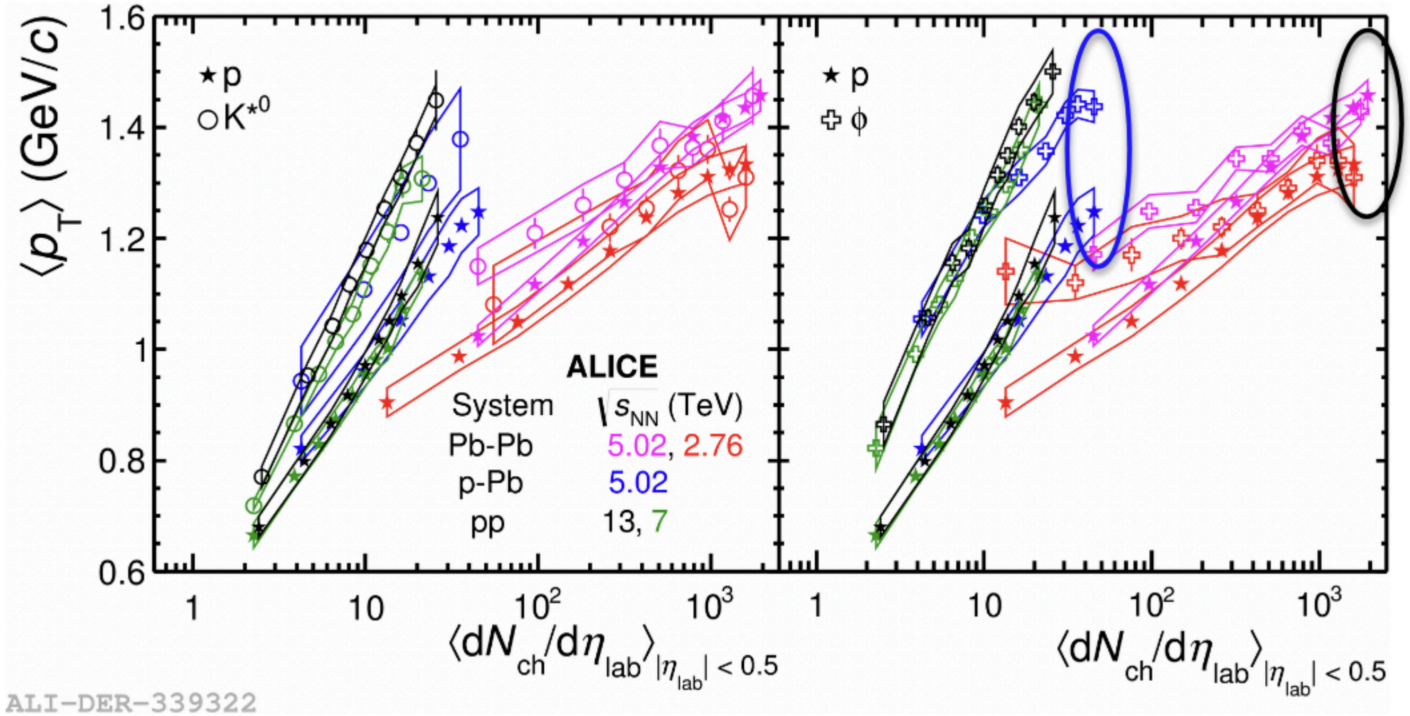


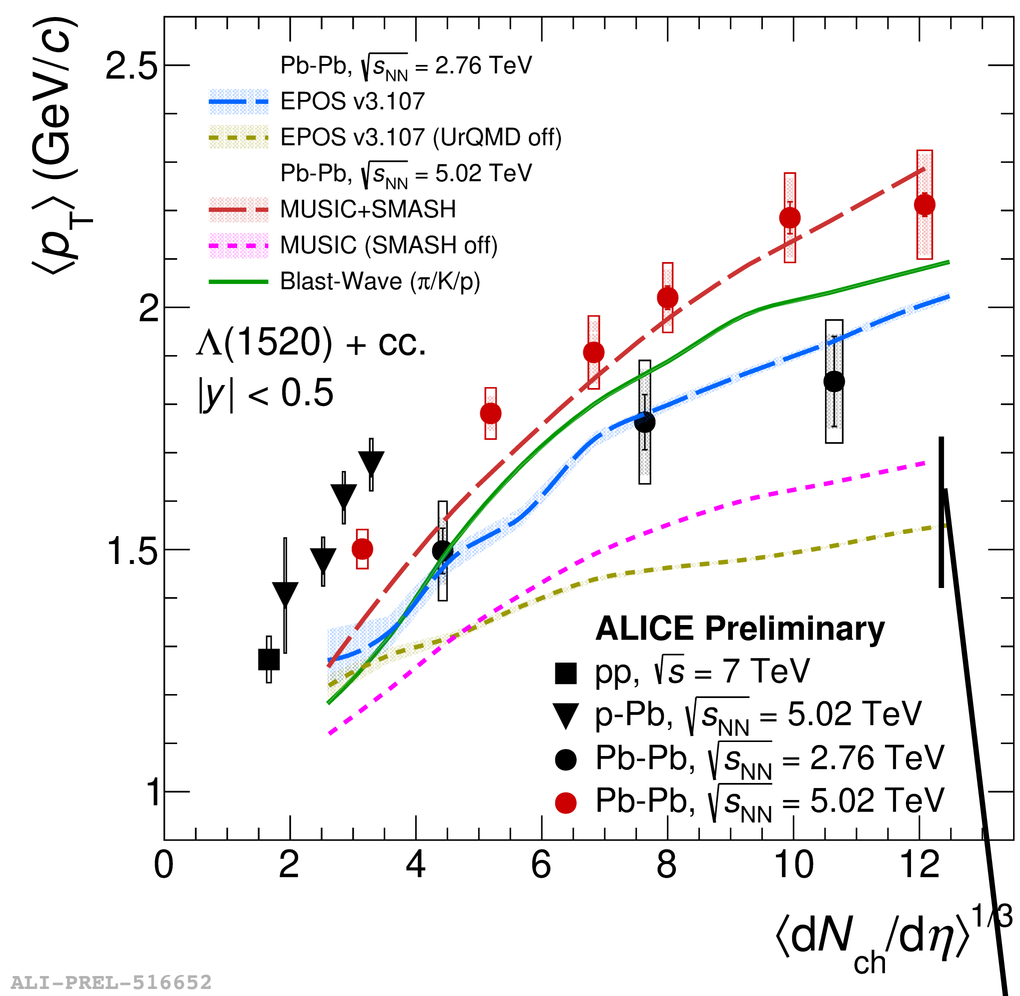




Particle production depends on the multiplicity and does not depend on the collision system or the centre-of-mass energy → Suggest a common particle production mechanism for all systems and energy.

Mean Transverse Momentum





- ❖ Central Pb—Pb collisions: Mass ordering
- ❖ Peripheral Pb-Pb and small collisions (pp and p-Pb) : $\langle p_T \rangle_\phi \sim \langle p_T \rangle_{K^{*0}} > \langle p_T \rangle_p$ Mass ordering breaks down
- ❖ Small collisions (pp and p—Pb) ➔ $\langle p_T \rangle$ rise faster than Pb—Pb with multiplicity

❖ Models that do not include a hadronic afterburner do not reproduce the data

Resonances to long lived particle ratios

Lifetime (fm/c): ρ^0 (1.3) < $K^{*\pm}$ (3.6) < K^{*0} (4.16) < $\Sigma^{*\pm}$ (5.0-5.5) < Λ^* (12.6) < Ξ^{*0} (21.7) < ϕ (46.2)

Pb—Pb Collisions :

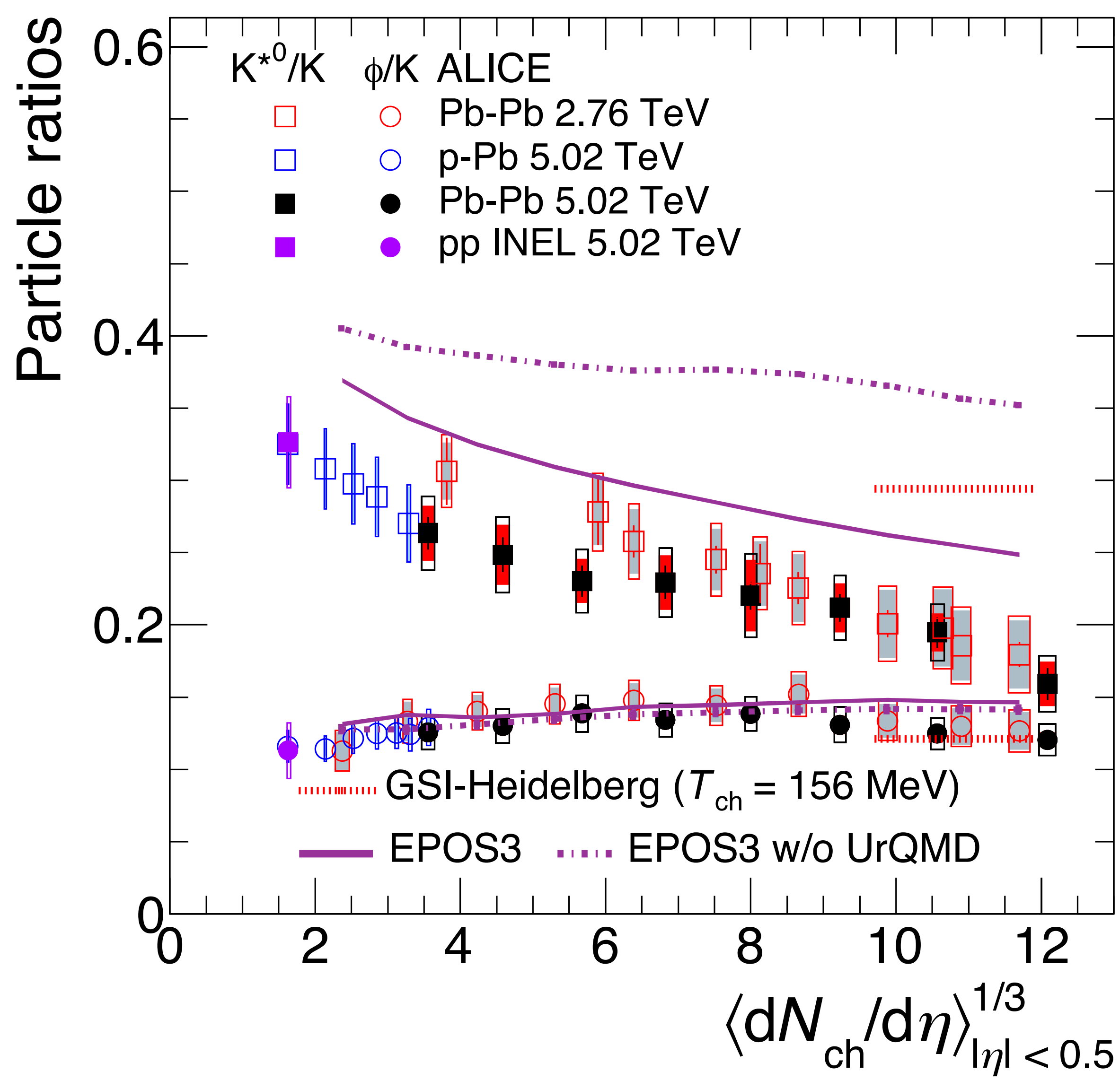
- - Suppression of the yield of K^{*0}/K in central Pb—Pb collisions in comparison to peripheral Pb—Pb collisions, pp collisions, and statistical thermal model predictions
  -> Suggests that re-scattering is dominant over regeneration

- - ϕ/K not suppressed
  -> Re-scattering effects not significant for longer lived particles

Small systems:

- - The yield of K^{*0}/K shows a hint (~2σ level) of decreasing trend with multiplicity in pp and p–Pb collisions: - Hadronic phase can form in pp collisions: critical density reached because of partons multiple scattering

ALICE PLB 802 (2020) 135225



Nuclear modification factors (R_{AA} or R_{pPb})

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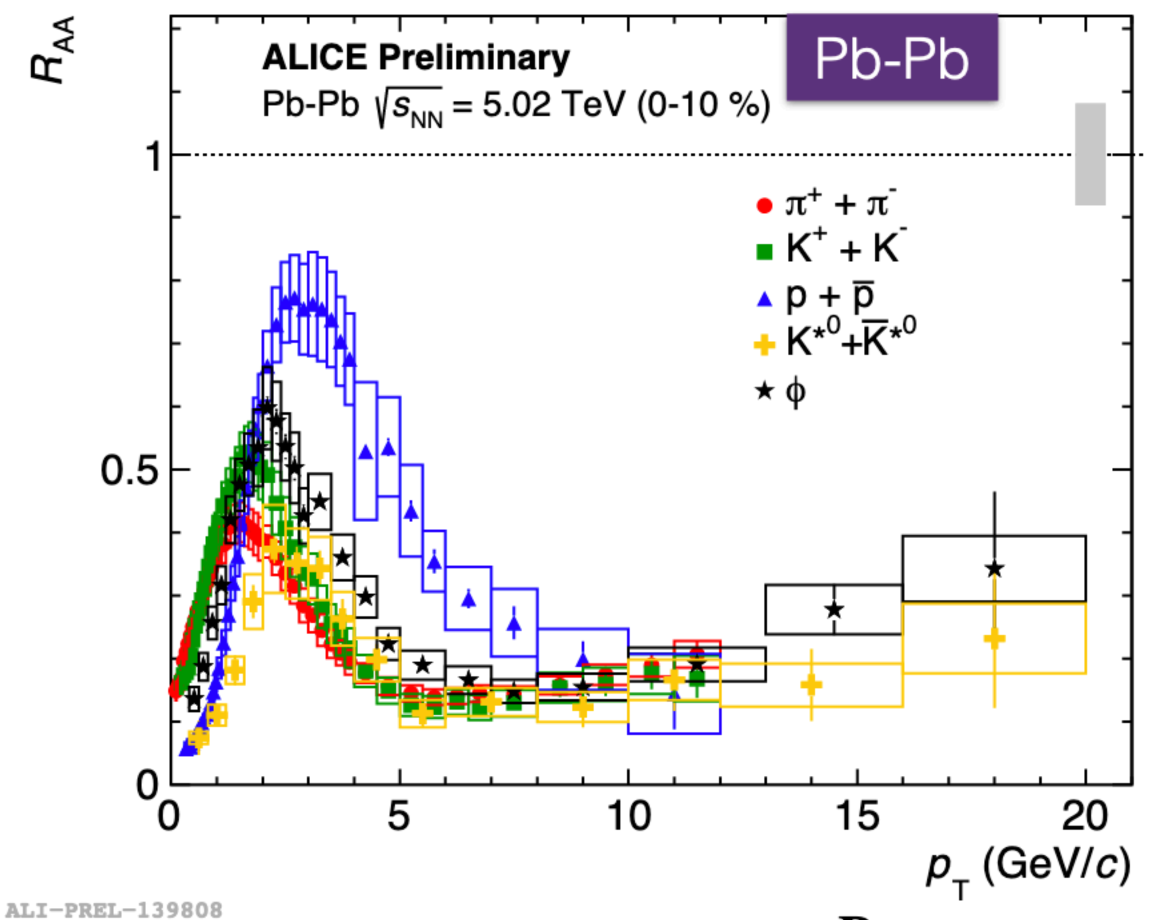

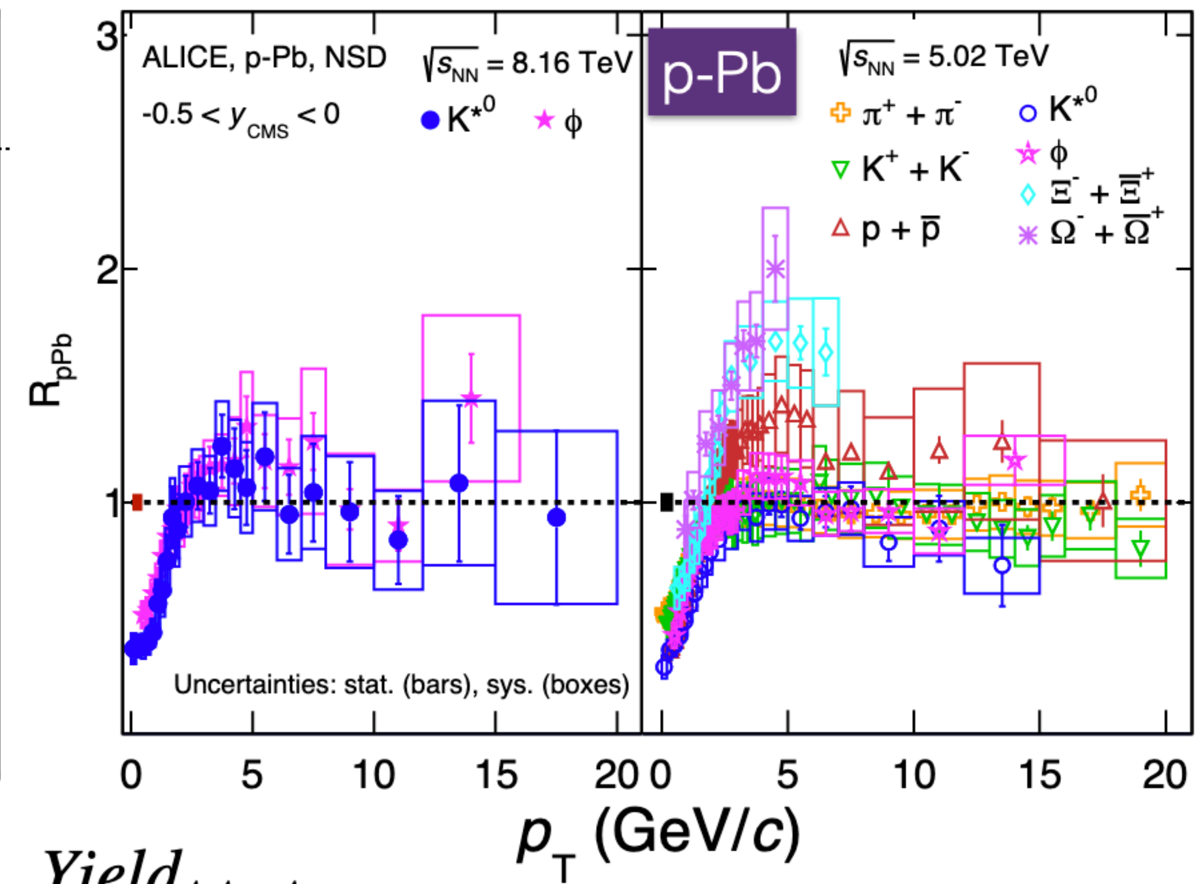

$$R_{AA,pA} = \frac{Yield_{AA,pA}}{\langle N_{coll} \rangle \times Yield_{pp}}$$

High- p_T (> 8 GeV/c):
- - R_{AA}< 1, suppression (presence of in medium effects)
- - Light-flavoured hadrons consistent with each other at p_T > 8 GeV/c -> No flavour (u,d,s) dependence

High- p_T (> 6 GeV/c):
- - R_{pPb}= 1, no suppression (absence of nuclear effects)
- - Light-flavoured hadrons consistent with each other at p_T > 6 GeV/c -> No flavour (u, d, s) dependence

Nuclear modification factors (Q_{CP})

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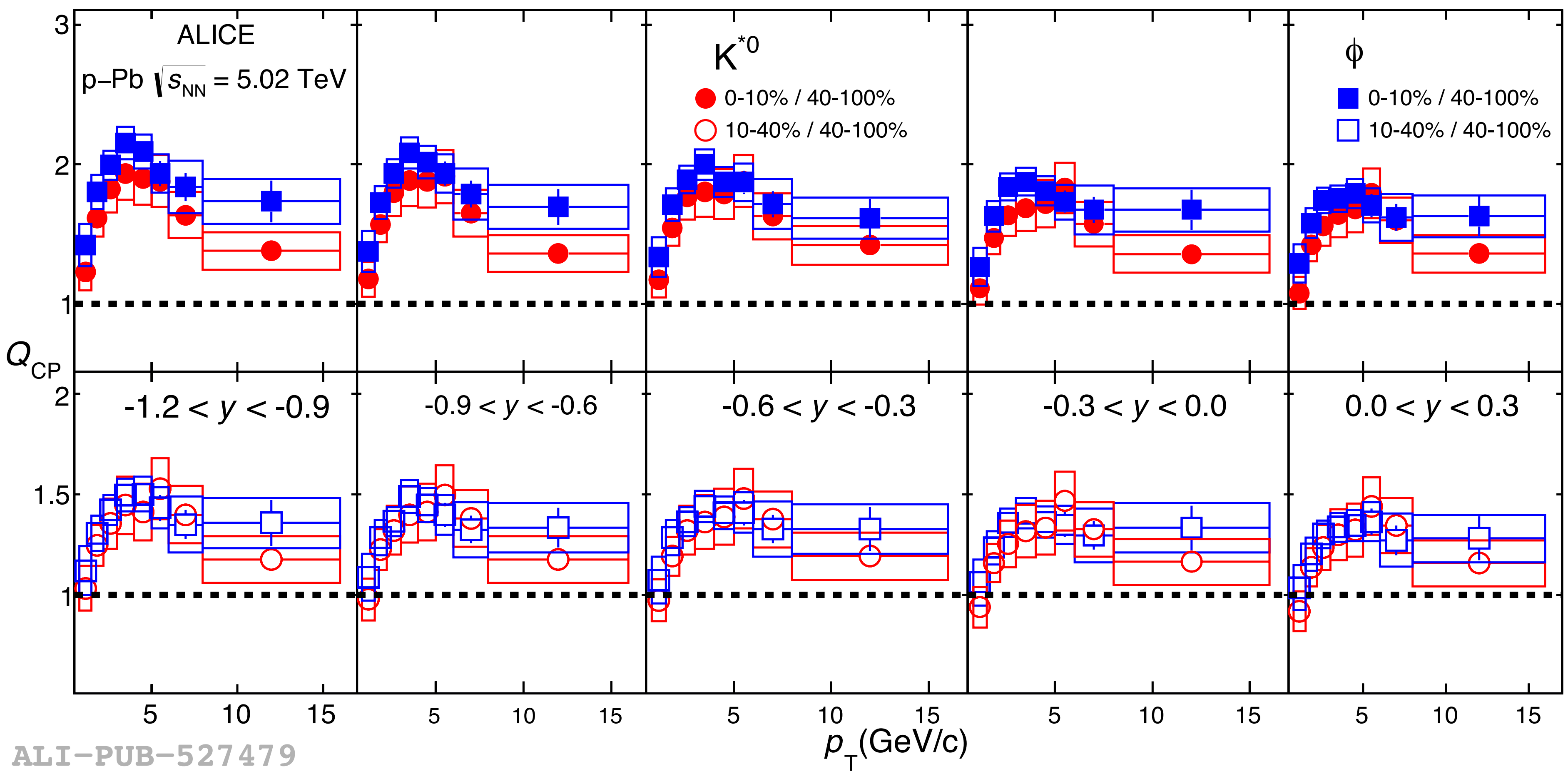

$$Q_{CP}(p_T) = \frac{\mathrm{d^2N/dp_Tdy_{HM}}(<\mathrm{N_{coll}}>)_{\mathrm{HM}}}{\mathrm{d^2N/dp_Tdy_{HM}}(<\mathrm{N_{coll}}>)_{\mathrm{LM}}}$$

❖ At intermediate p_T, Q_{CP} increases with rapidity, Cronin-like multiple scattering effects are more pronounced in high multiplicity classes.

❖ Nuclear effects are more prominent at higher rapidity and for high multiplicity classes

Summary

❖ **p_T spectra**

- The shapes of p_T spectra are different for different multiplicity classes ($p_T < 5.0$ GeV/c), spectra become harder with increasing multiplicity

❖ **Yields (dN/dy)**

- pp, p—Pb, Pb—Pb: Independent of colliding system, energy and driven by multiplicity

❖ **Mean p_T ($\langle p_T \rangle$)**

- In central Pb—Pb: Mass ordering as expected from hydrodynamics
- pp, p—Pb collisions: Mass ordering violated

❖ **Particle ratios**

- The yield ratio of K^{*0}/K decreases for central Pb—Pb collisions in comparison to peripheral Pb—Pb collisions, pp, p—Pb collisions and statistical-model predictions -> Re-scattering dominates over regeneration
- Hyperon production increases from low to high multiplicity in pp and p—Pb collisions

❖ **Rapidity Asymmetry:** Y_{asym} is observed at low p_T and high multiplicity classes

❖ **Nuclear Modification Factor:** At high p_T, R_{AA} of light flavour hadrons show suppression, whereas R_{pPb} is consistent with unity -> Presence of in-medium effects in Pb—Pb collisions

- Nuclear modification factors of light flavour hadrons are consistent with each other within uncertainties -> No flavour or species dependence

❖ Q_{CP} shows Cronin-like effects at intermediate p_T and it is more prominent for the rapidity interval $-1.2 < y < -0.9$ and highest multiplicity class.

Thank you