

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 (dN/dy) and mean transverse momentum $\langle p_T \rangle$
 - - Particle ratios
 - - Rapidity asymmetry
 - - Nuclear modification factor
- ❖ Summary and Outlook

DAE HEP 2022
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- BEYOND THE STANDARD MODEL
- FORMAL THEORY
- FUTURE EXPERIMENTS AND DETECTOR DEVELOPMENT
- HEAVY IONS AND QCD
- HIGGS PHYSICS
- NEUTRINO PHYSICS
- QUARK AND LEPTON FLAVOUR PHYSICS
- SOCIETAL APPLICATIONS
- TOP QUARK AND EW PHYSICS

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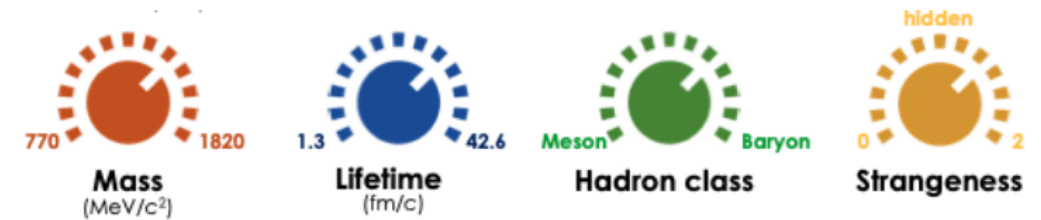
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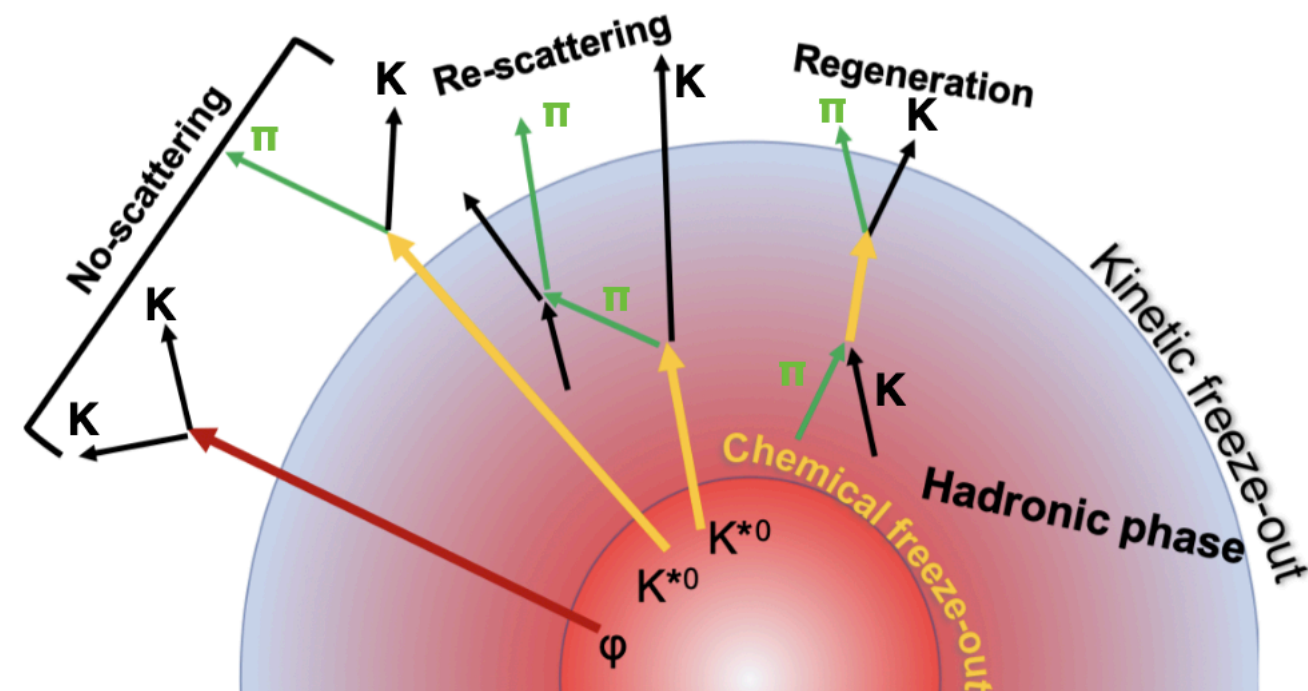
Why Resonances ?

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

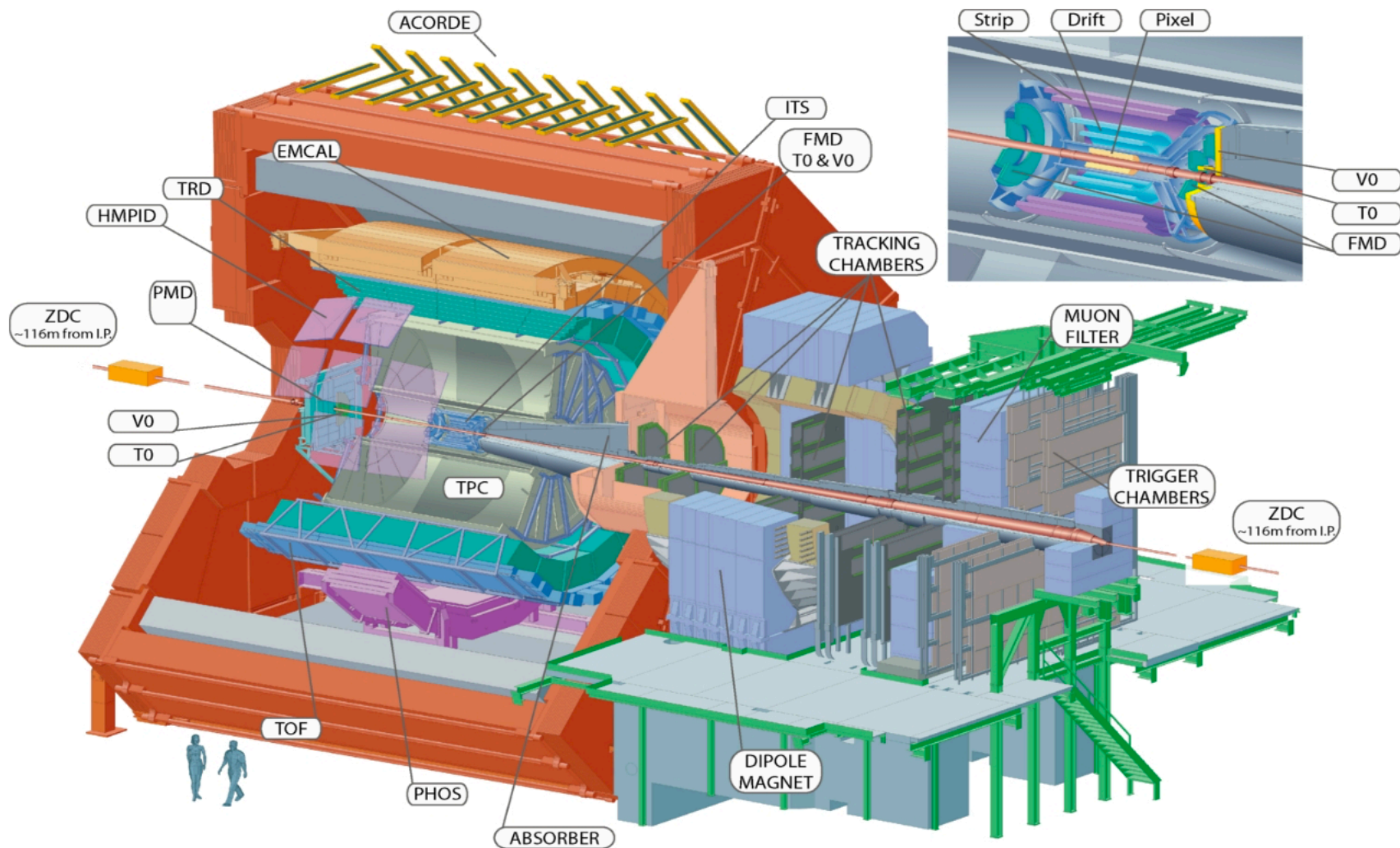


Hadronic phase : Duration between chemical and kinetic freeze-out



- ❖ 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): ($|\eta| < 0.9$)

- ❖ Primary vertex
- ❖ Tracking

TimeProjectionChamber (TPC): ($|\eta| < 0.9$)

- ❖ Tracking
- ❖ PID

Time-Of-Flight (TOF): ($|\eta| < 0.9$)

- ❖ PID

Forward detector (V0):
V0A ($2.8 < \eta < 5.1$) & V0C
($-3.7 < \eta < -1.7$)

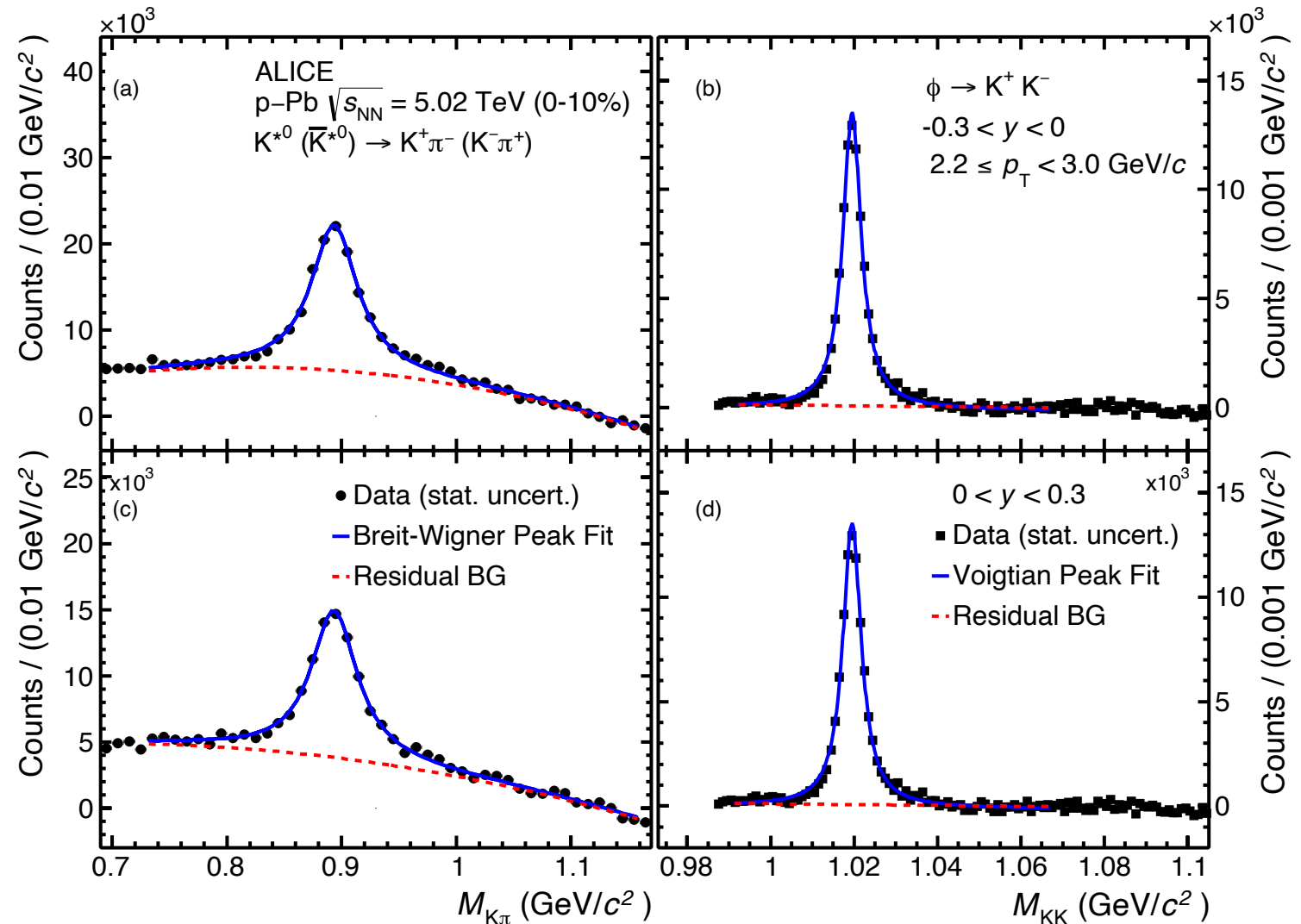
Multiplicity/centrality event classes definition

- ❖ In p–Pb (V0A) and in pp, Pb–Pb ($V0M = V0A + V0C$)

Resonance Reconstruction

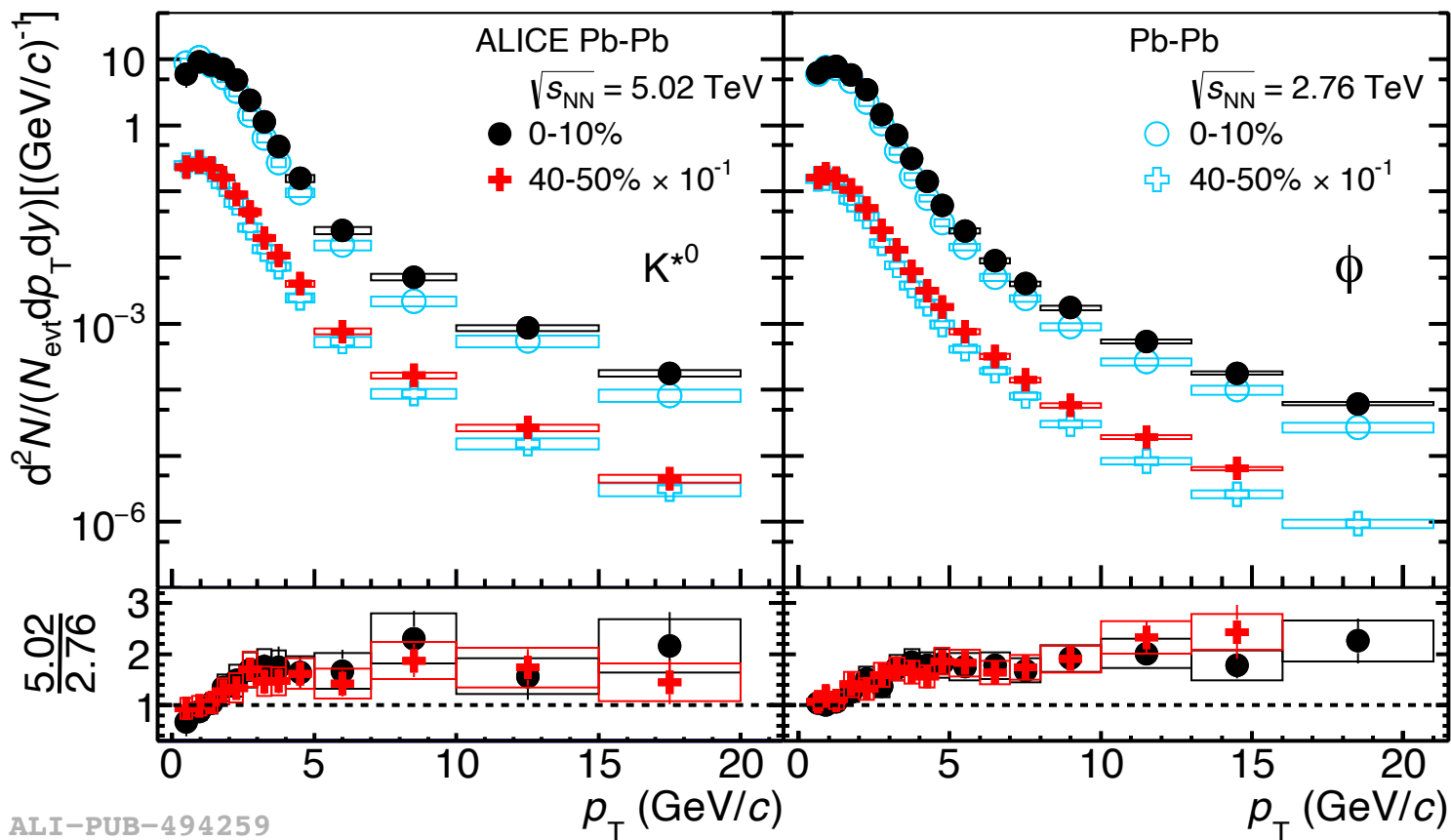
- ❖ Resonances are reconstructed from their decay daughter via the invariant mass technique
- ❖ Uncorrelated background is evaluated via event mixing or like-sign techniques and subtracted from the invariant mass distribution
- ❖ Residual background is modeled by a polynomial function
- ❖ Signal is fit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

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

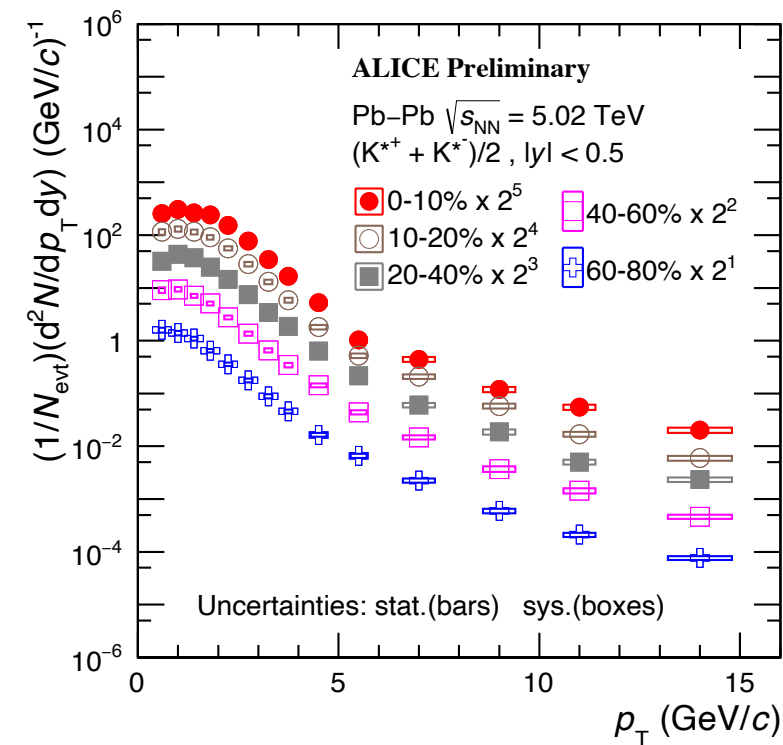


Transverse Momentum Spectra

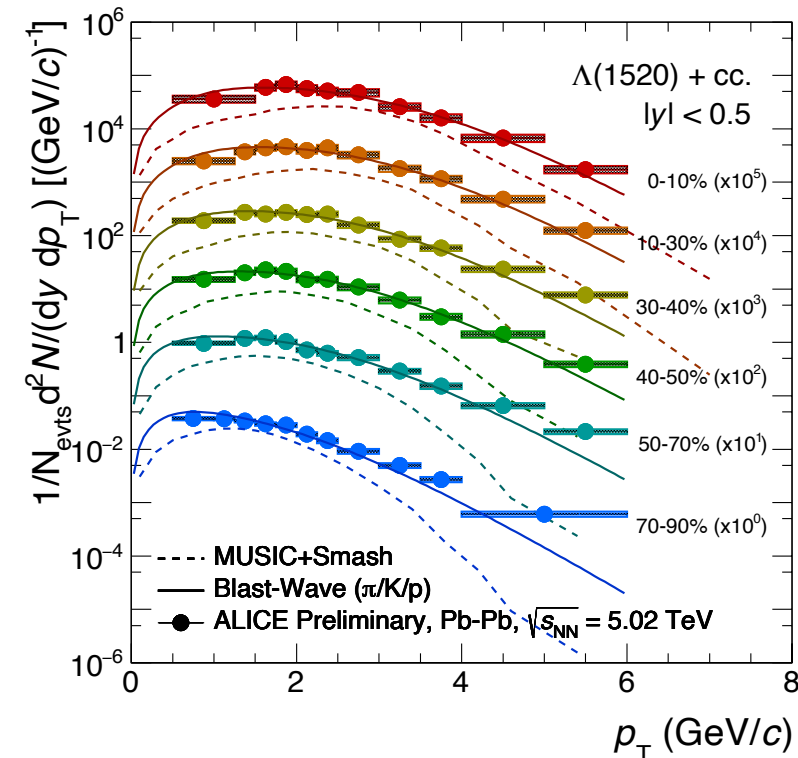
ALICE Phys. Rev. C 106, 034907



ALI-PUB-494259



ALI-PREL-516770

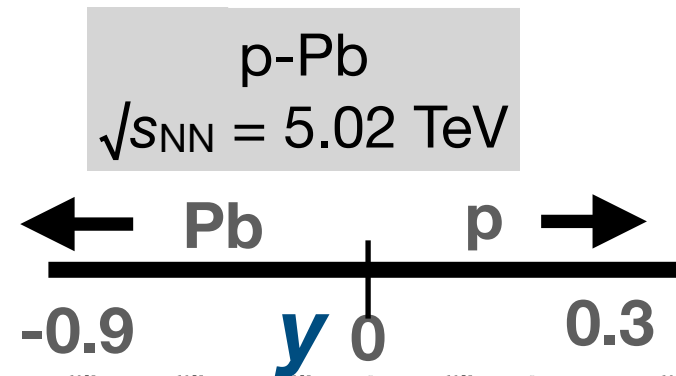
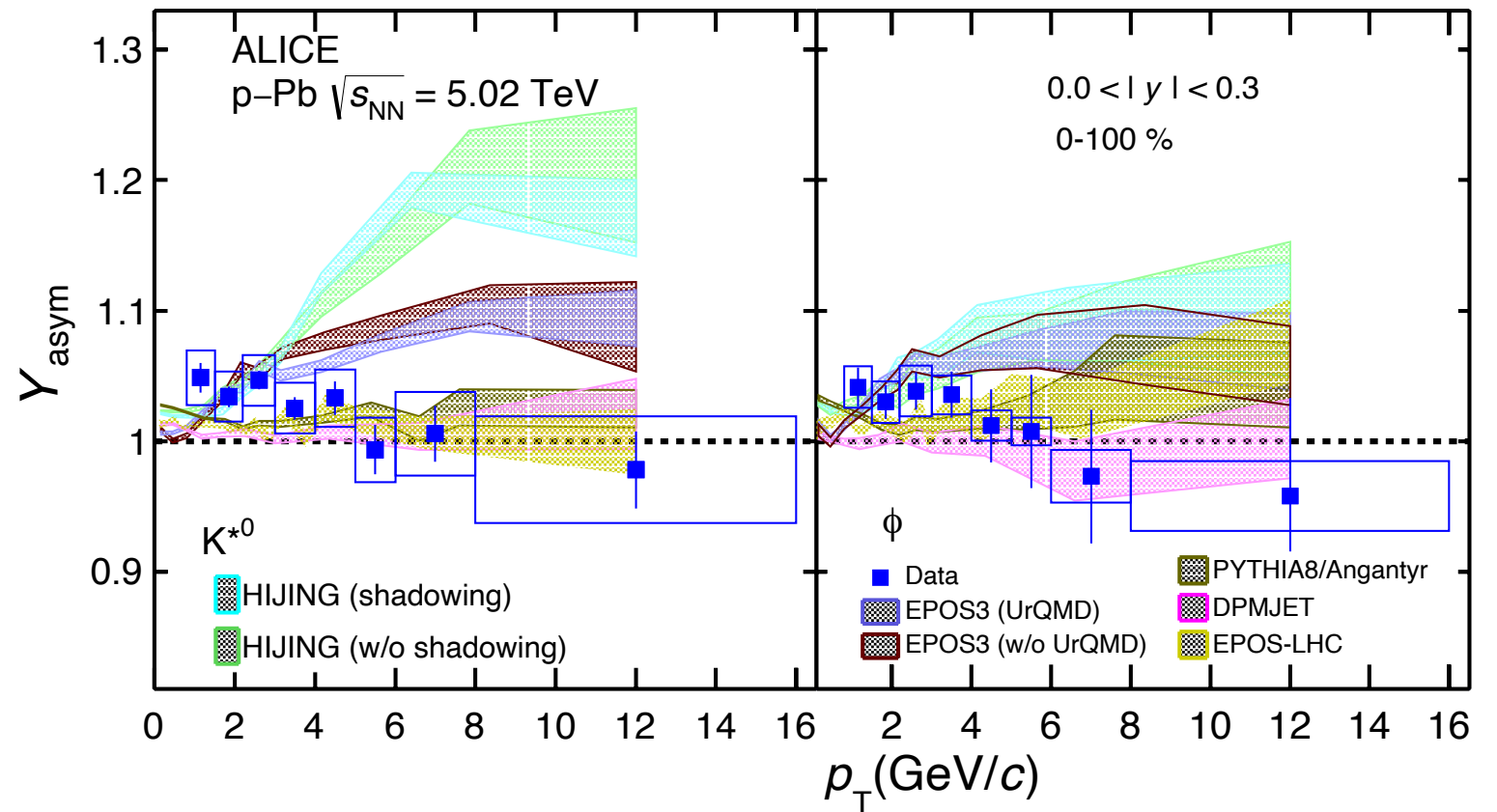
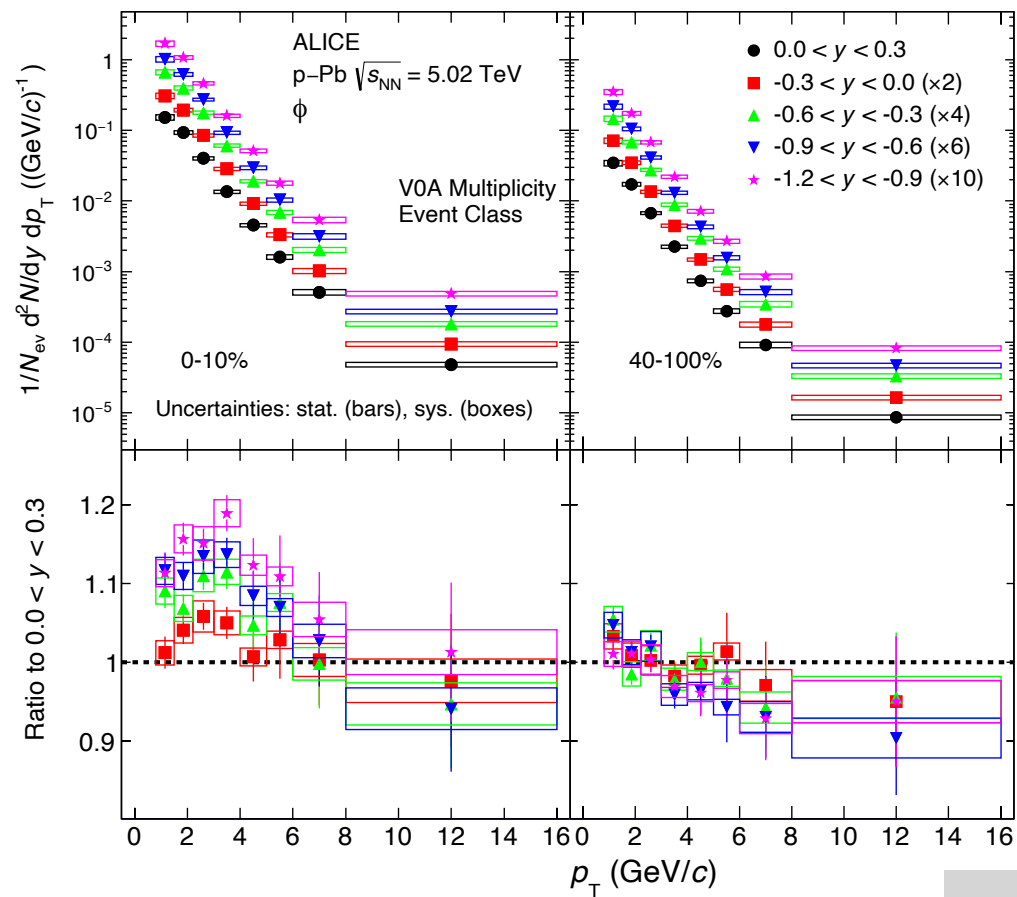


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- ❖ p_T spectra obtained in different multiplicity classes
- ❖ Hardening of the spectra with increasing multiplicity \rightarrow Caused by radial flow.

Rapidity dependence of p_T spectra

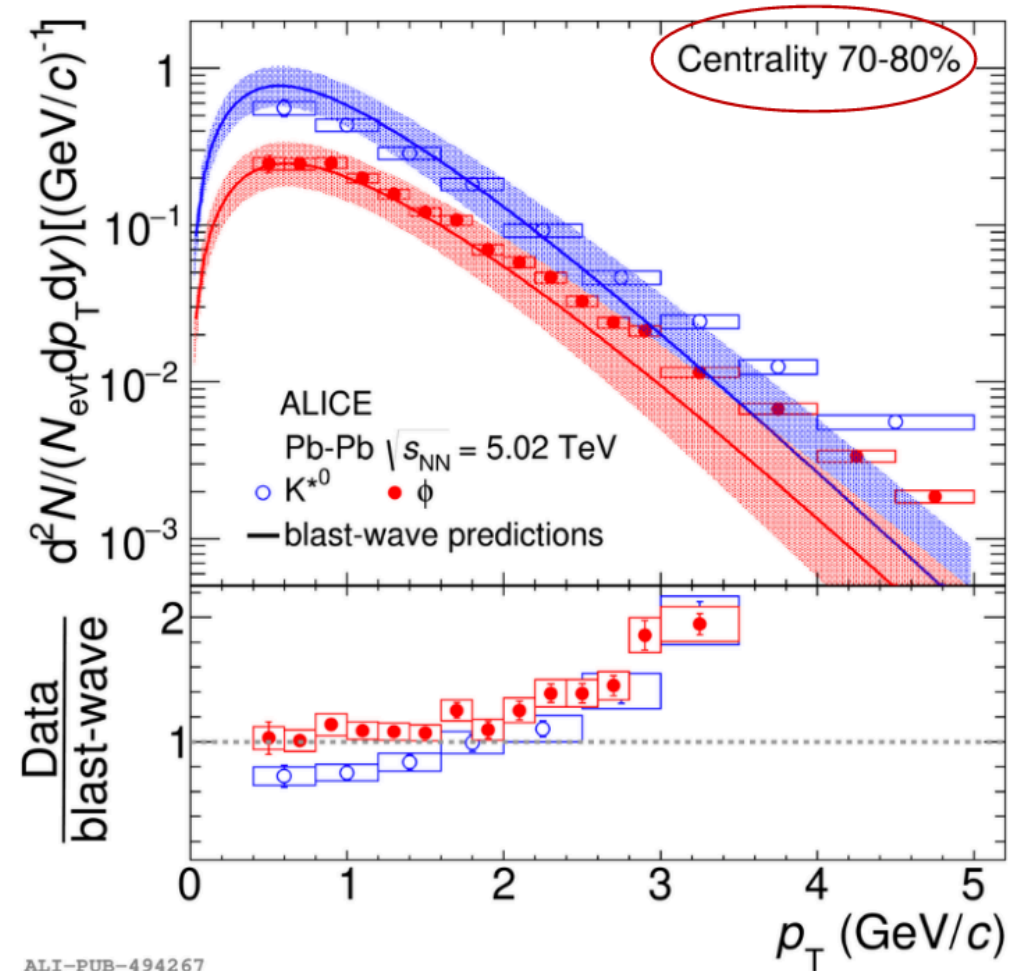
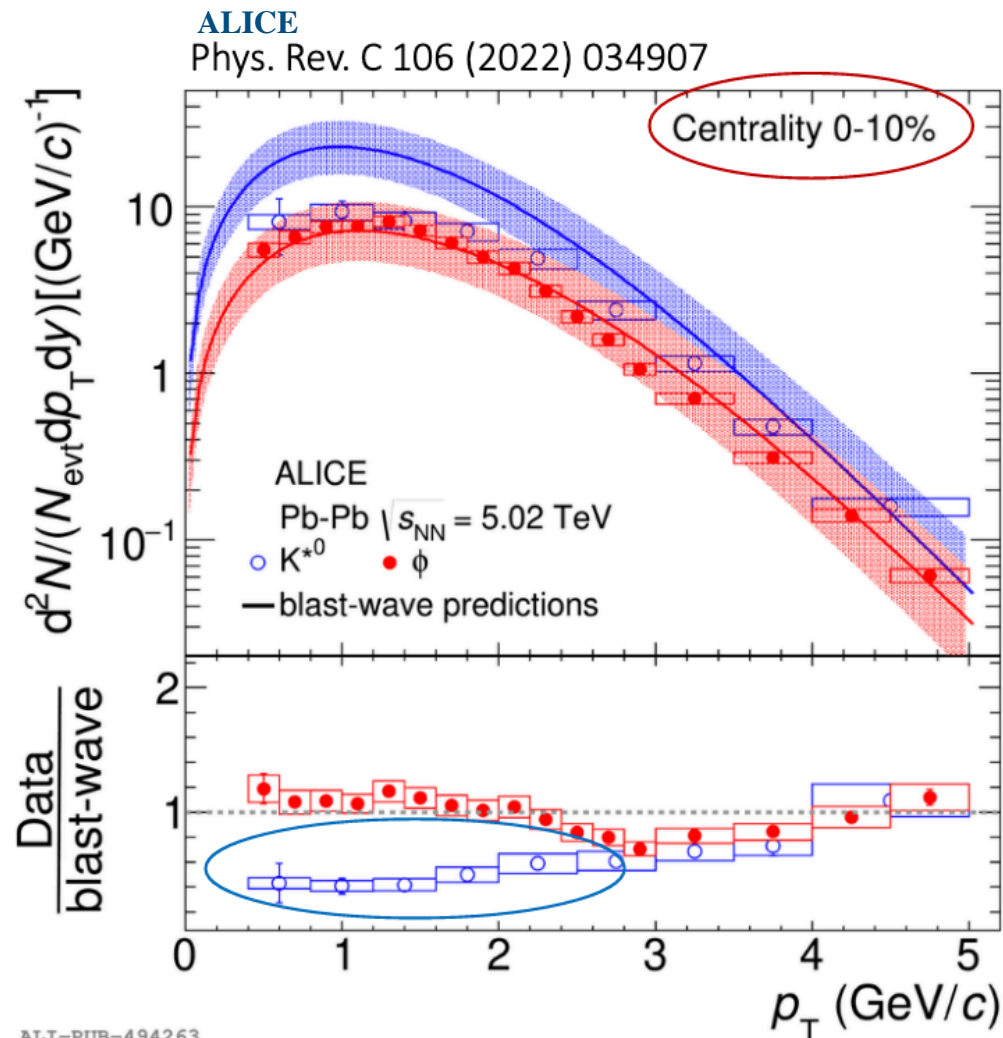
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$$y_{asym} = \frac{Yield_{FR}(p_T)}{Yield_{RR}(p_T)}$$

- ❖ 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.

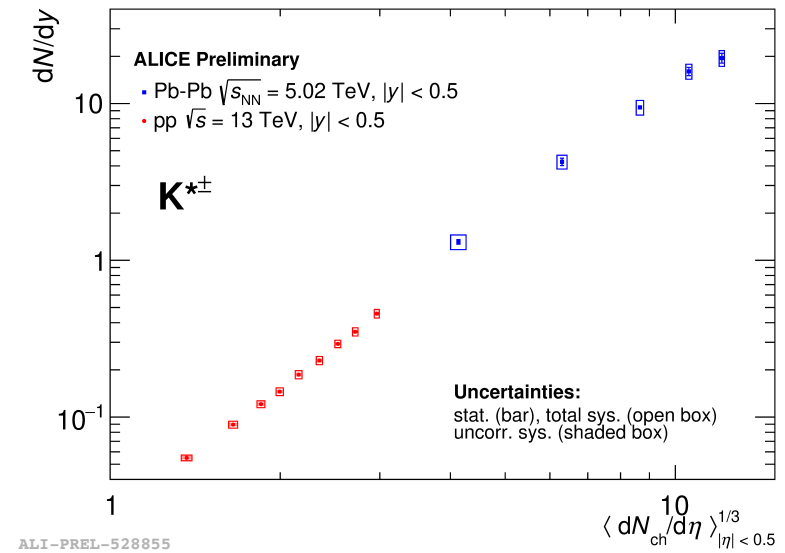
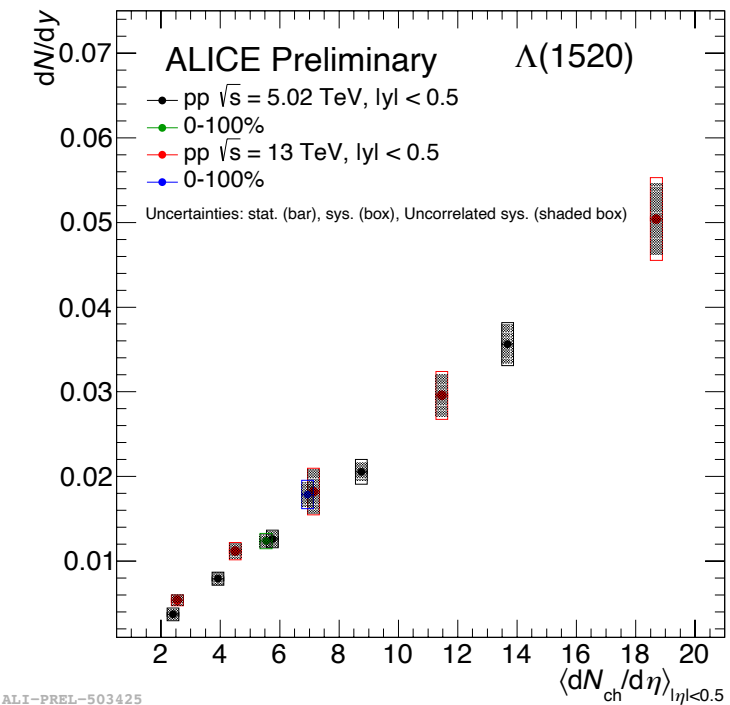
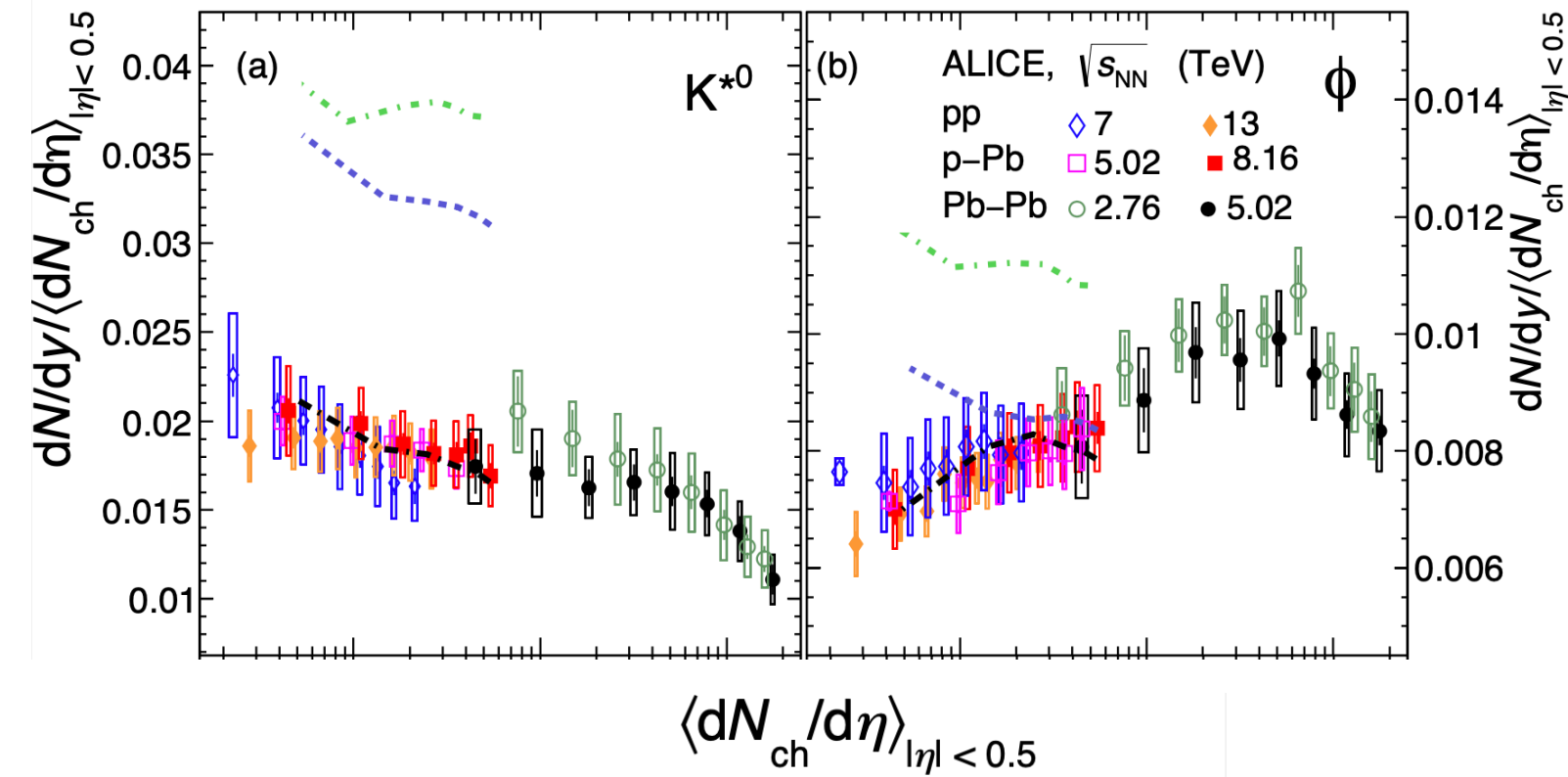
Comparison with blast wave model



- ❖ 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

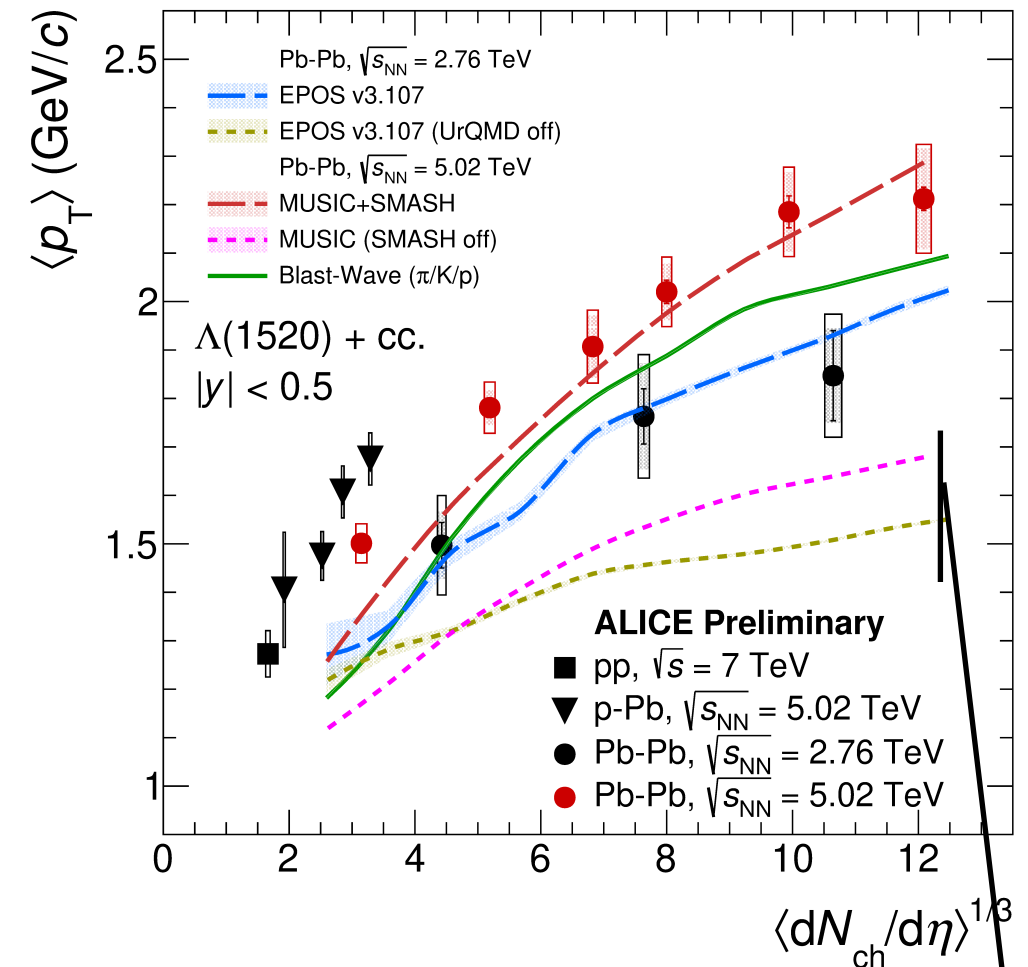
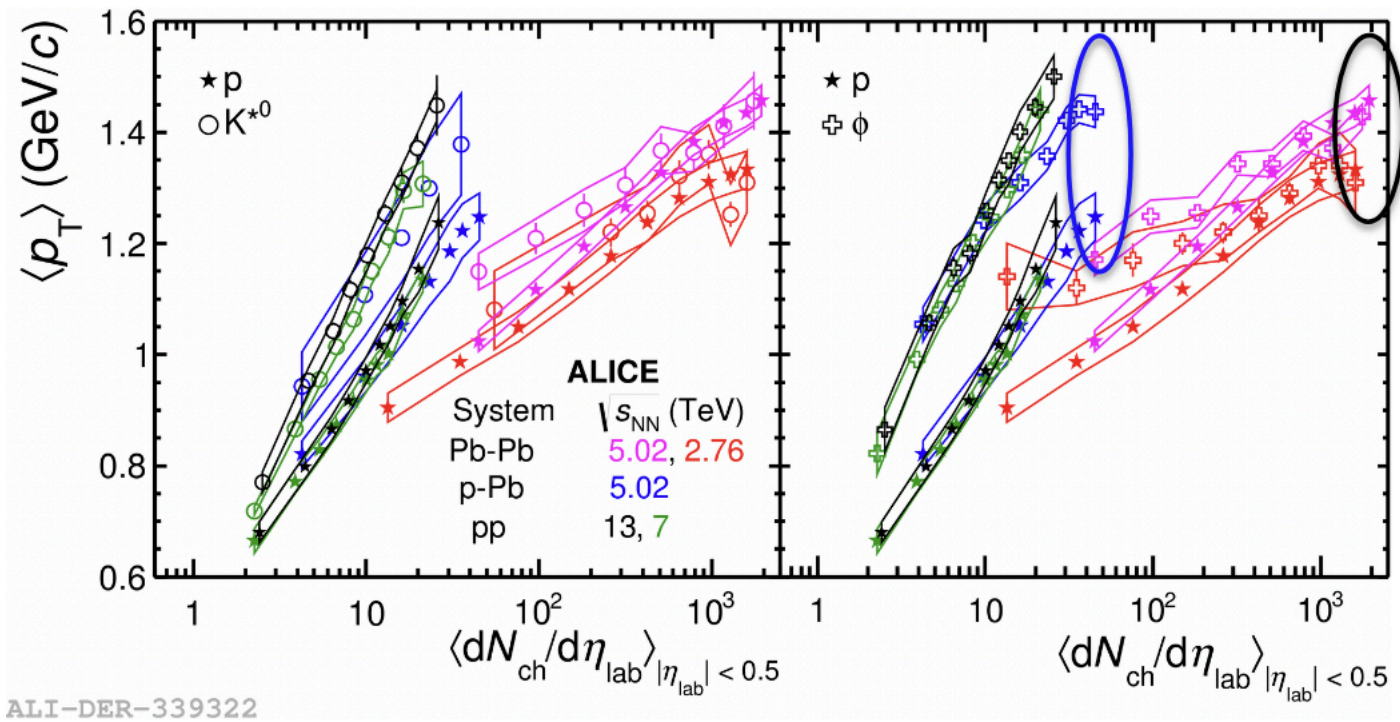
Integrated Yield

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 \rightarrow 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

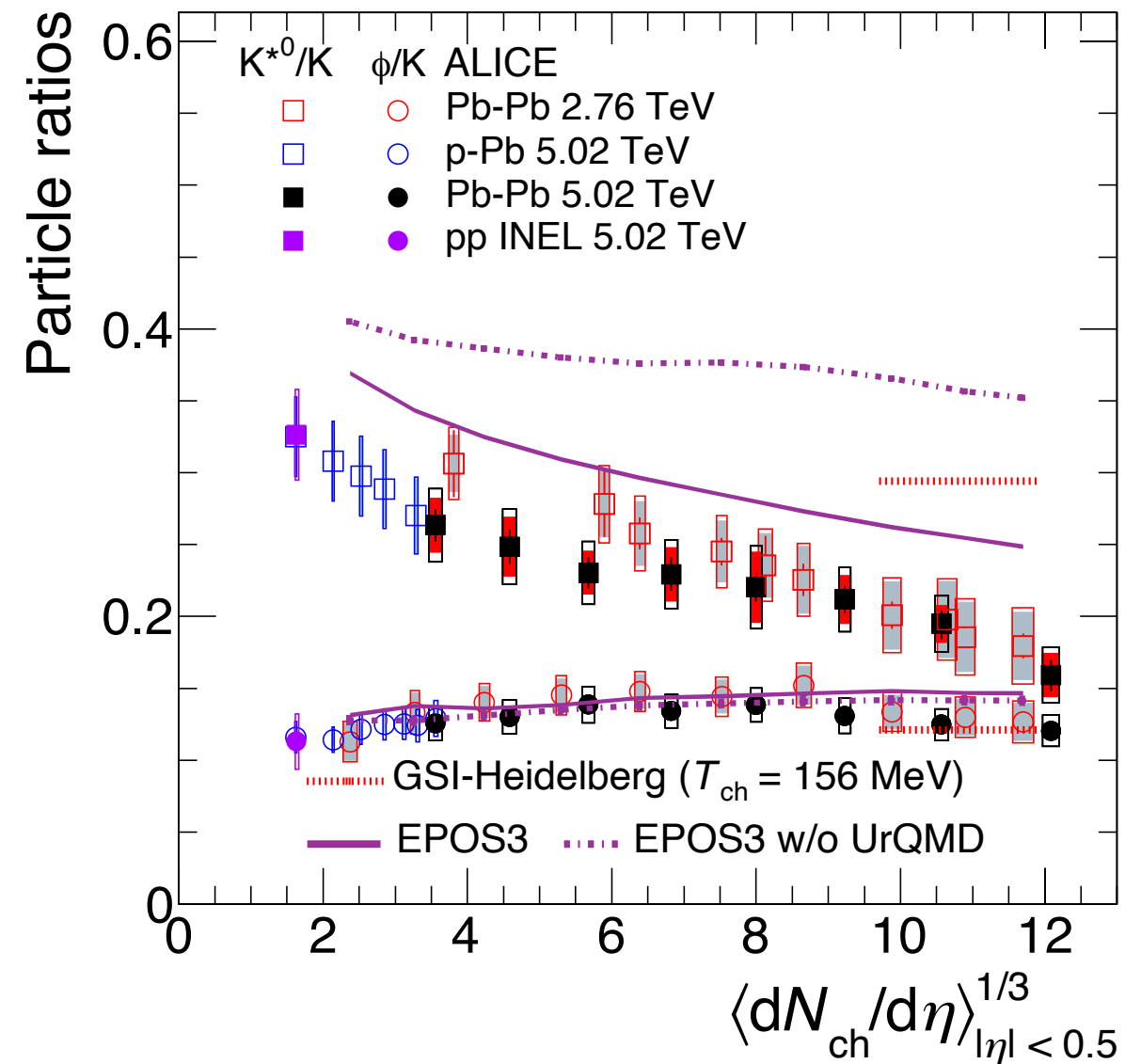
- - ϕ/K not suppressed

- > **Re-scattering effects not significant for longer lived particles**

Small systems:

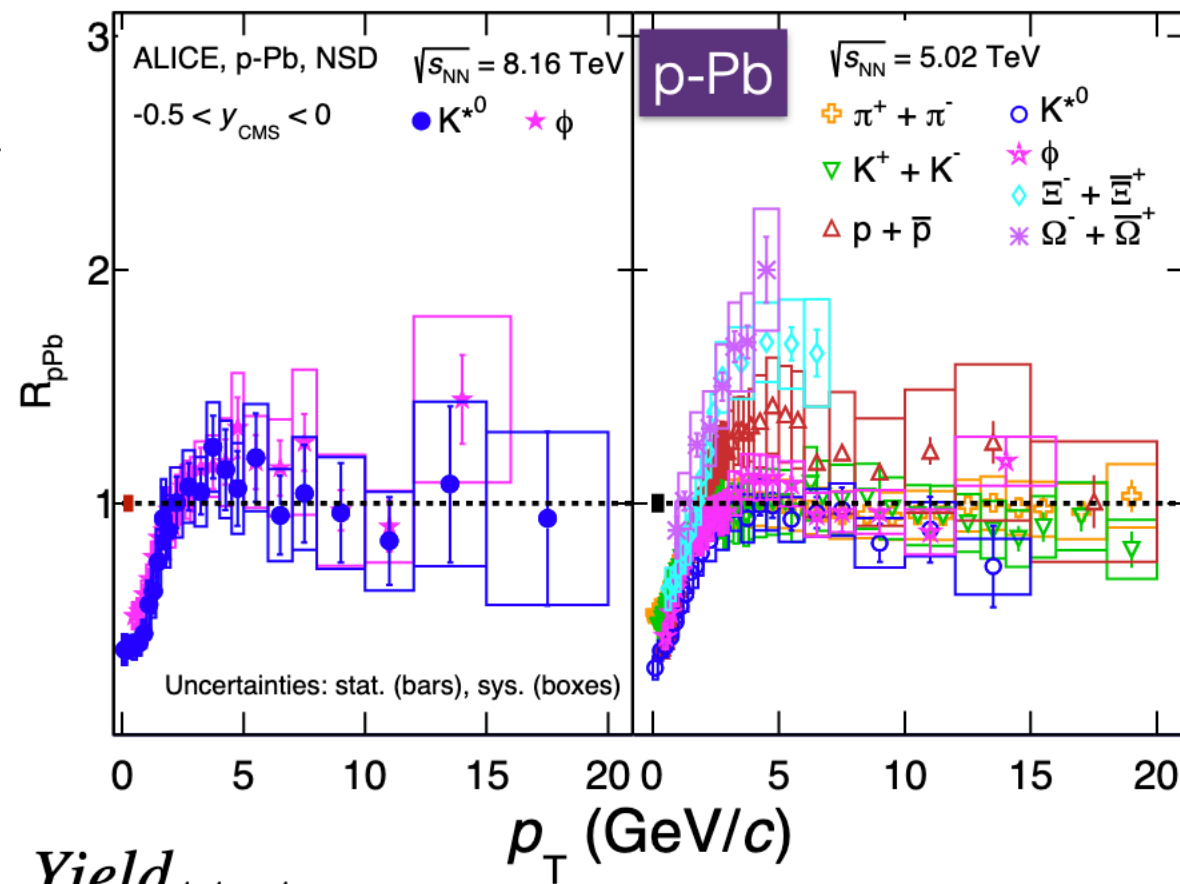
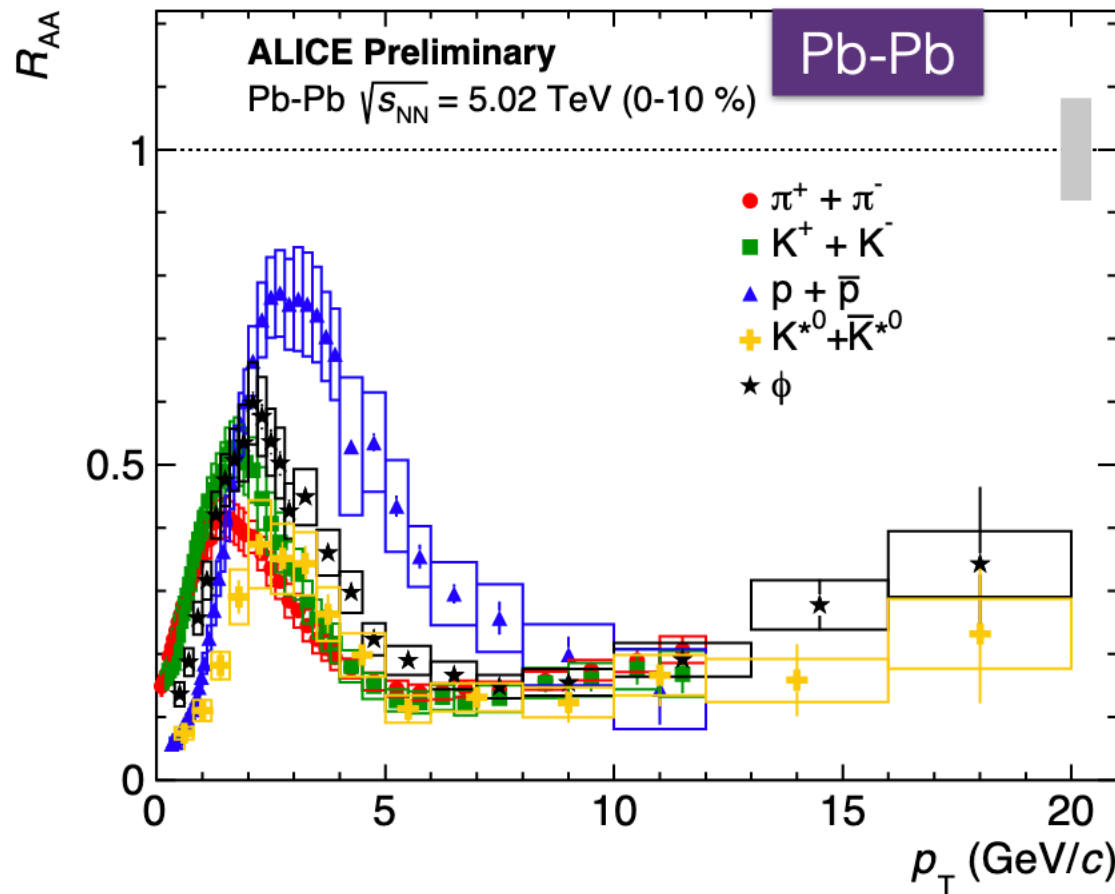
- - The yield of K^{*0}/K shows a hint ($\sim 2\sigma$ level) of decreasing trend with multiplicity in **pp and p—Pb** collisions: - Hadronic phase can form in pp collisions: critical density reached because of partons multiple scattering

ALICE [PLB 802 \(2020\) 135225](#)



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

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



ALI-PREL-139808

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

High- p_T (> 8 GeV/c):

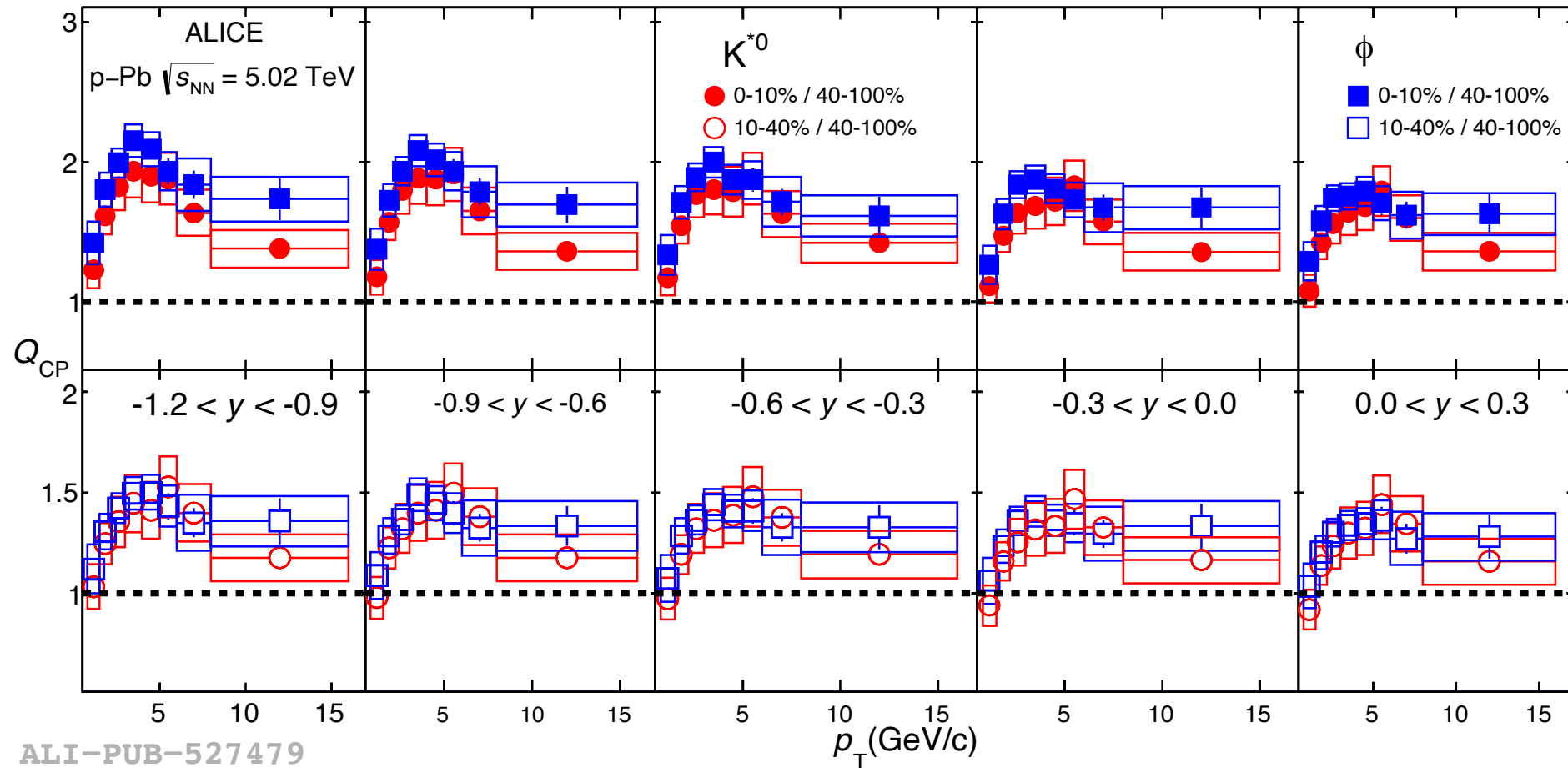
- $R_{AA} < 1$, **suppression** (presence of in medium effects)
- Light-flavoured hadrons consistent with each other at $p_T > 8$ GeV/c -> **No flavour (u,d,s) dependence**

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})

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



$$Q_{CP}(p_T) = \frac{d^2N/dp_T dy_{HM}(\langle N_{coll} \rangle)_{HM}}{d^2N/dp_T dy_{HM}(\langle N_{coll} \rangle)_{LM}}$$

- ❖ 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