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ALICE

System size and energy dependence of resonance production measured with ALICE

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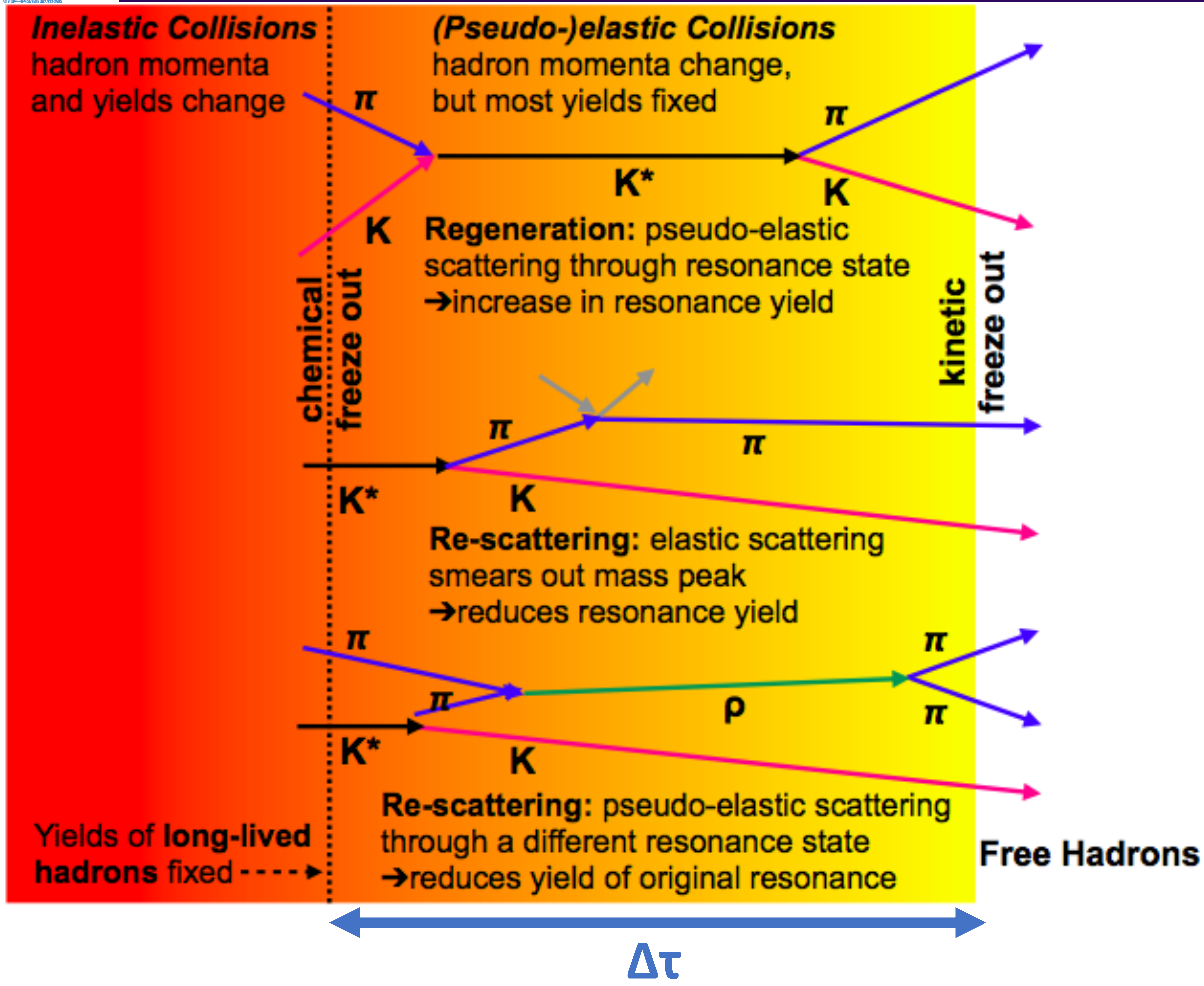
Outline

- Physics motivation
- The ALICE detector
- Resonances
  - p_T spectra in pp, p-Pb and heavy-ion collisions.
  - p_T integrated yields and $\langle p_T \rangle$.
  - Particle yield ratios.
  - Nuclear modification factors.
- Summary

NEW results in this presentation, are published at:

arXiv:2106.13113

Physics motivation



Good probes to verify the presence of **hadronic phase in nucleus - nucleus collisions** and study its properties.

They have **lifetimes comparable** with the **fireball lifetime**.

Regeneration and rescattering processes in hadronic phase affect resonance **yields** and transverse momentum (p_T) spectra shapes.

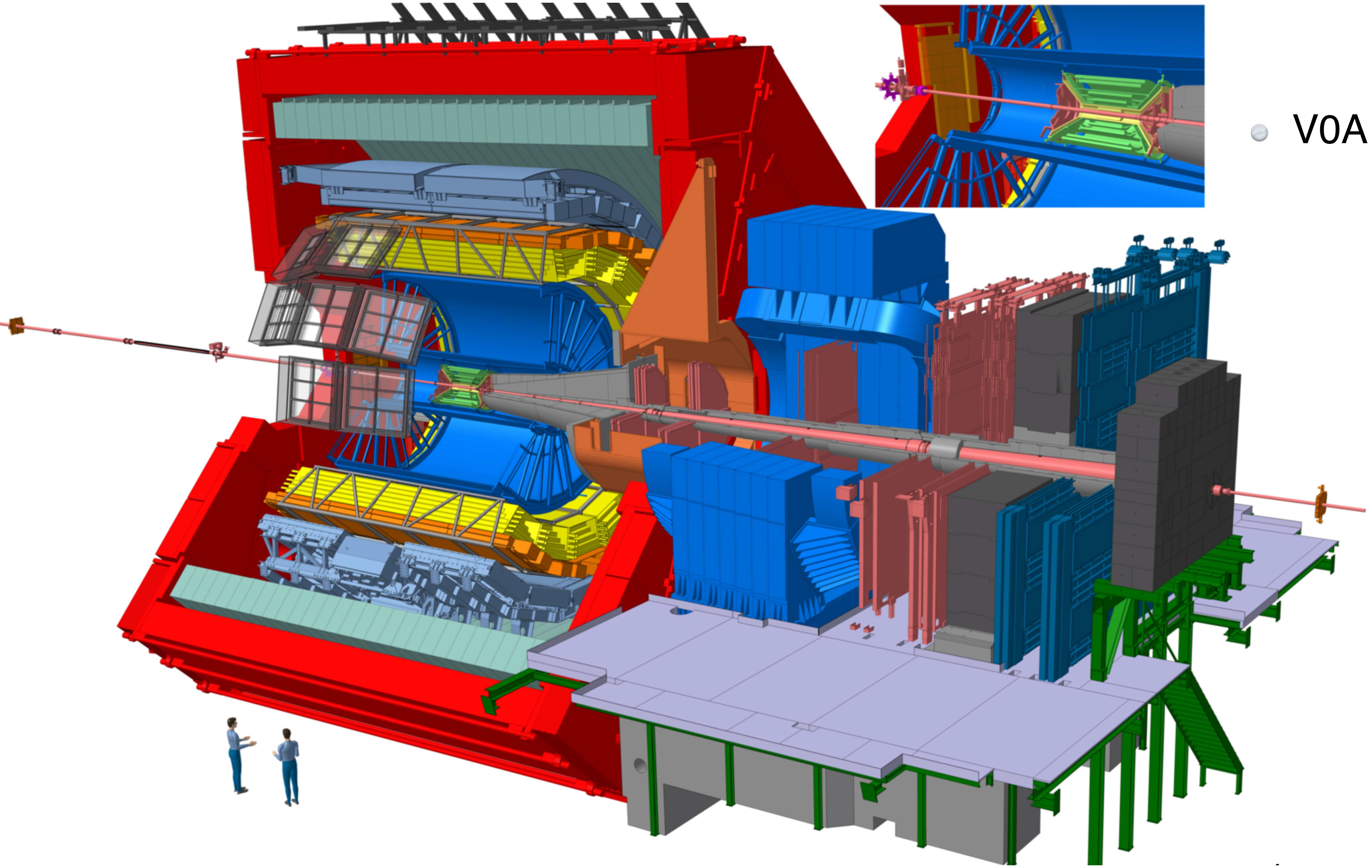
Physics motivation

Resonance	$\rho(770)^0$	$K^*(892)^\pm$	$K^*(892)^0$	$f_0(980)$	$\Sigma(1385)^\pm$	$\Xi(1820)^\pm$	$\Lambda(1520)$	$\Xi(1530)^0$	$\phi(1020)$
Quark composition	$\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$u\bar{s}, \bar{u}s$	$d\bar{s}, \bar{d}s$	unknown	uus, dds	uss	uds	uss	$s\bar{s}$
τ(fm/c)	1.3	3.6	4.2	large unc.	5-5.5	8.1	12.6	21.7	46.4
Decay	π π	K^0_S π	K π	$\pi^+\pi^-$	Λ π	Λ K	p K	Ξ π	K K
B.R.(%)	100	33.3	66.6	46	87	unknown	22.5	66.7	48.9

- Study the hadrochemistry of particle production.
- Study the in-medium energy loss via R_{AA}.
- Study of the higher mass resonances (Ξ(1820)) could potentially give information on chiral symmetry restoration.

The ALICE detector

- Inner Tracking System (ITS)
  - 6 layers of silicon detectors
  - Provide trigger, tracking, vertex, PID (dE/dx)



- Time Projection Chamber (TPC)
  - Gas-filled ionization detector
  - Tracking, vertex, PID (dE/dx)
- Time Of Flight (TOF)
  - PID through particle time of flight
- V0A and V0C
  - Trigger, centrality/multiplicity estimator

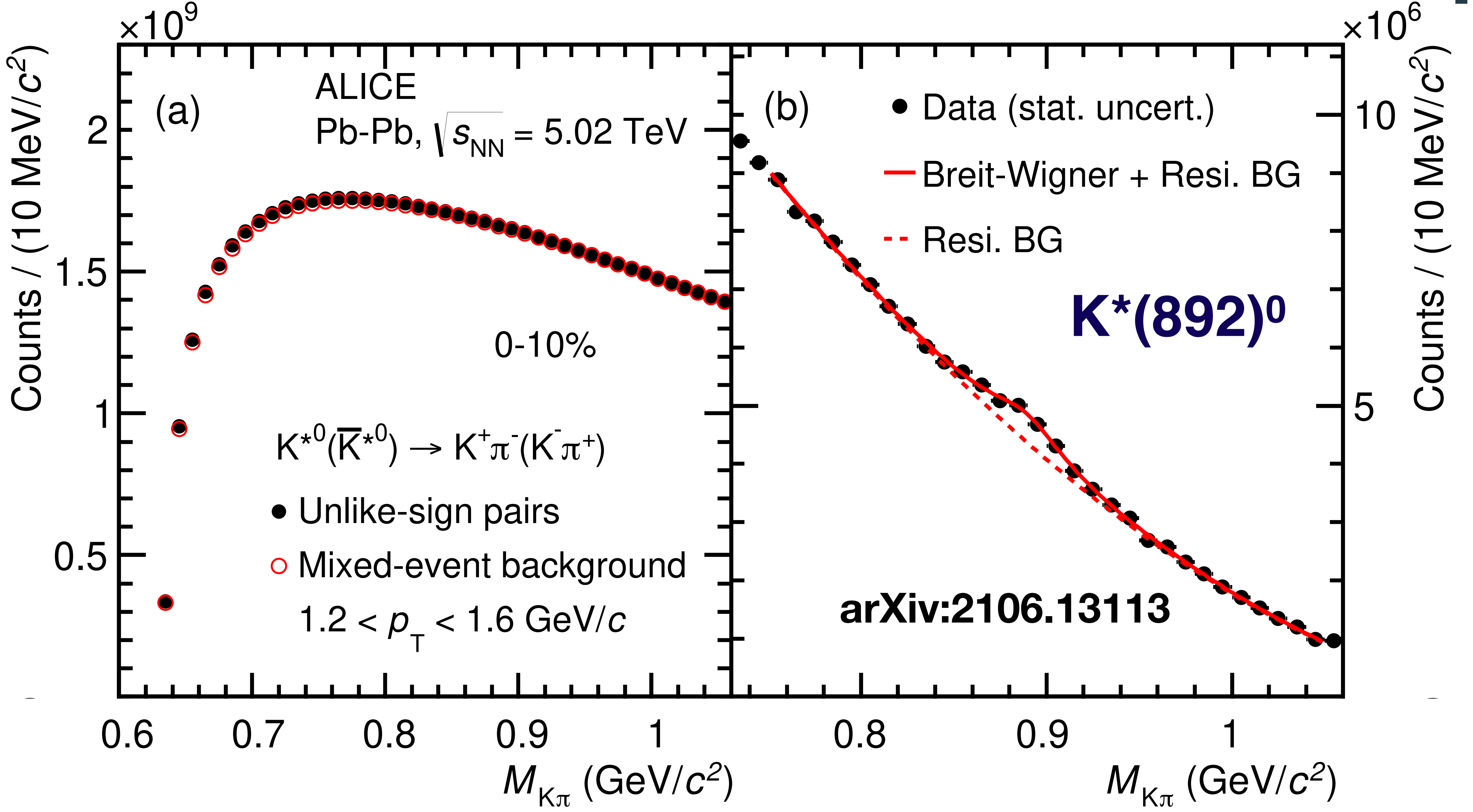
System	Year	$\sqrt{s_{NN}}$ (TeV)
Pb-Pb	2010 2011 2015 2018	2.76 2.76 5.02 5.02
Xe-Xe	2017	5.44
p-Pb	2013 2016	5.02 5.02, 8.16
pp	2009-2013 2015-2018	0.9, 2.76, 7 8, 13

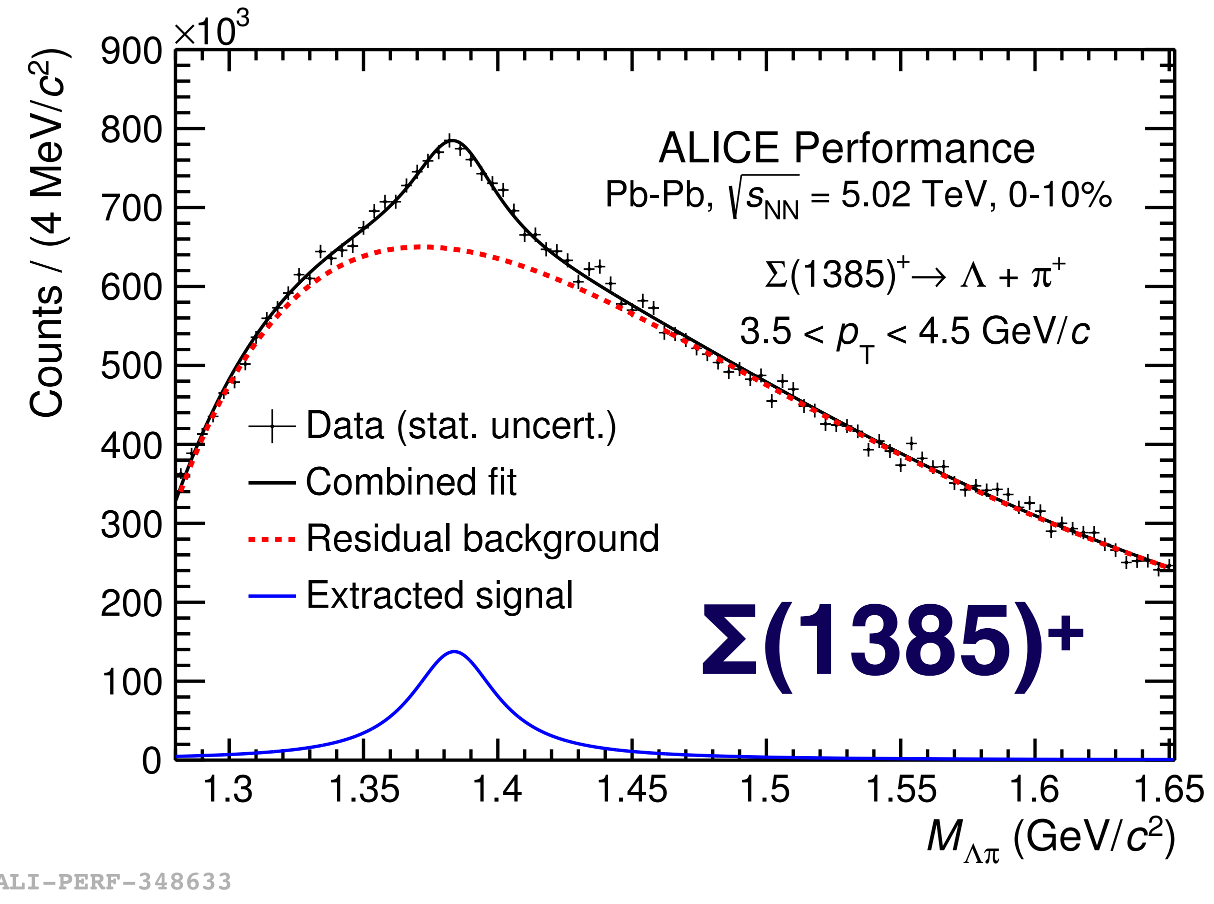
Resonance reconstruction - Analysis strategy

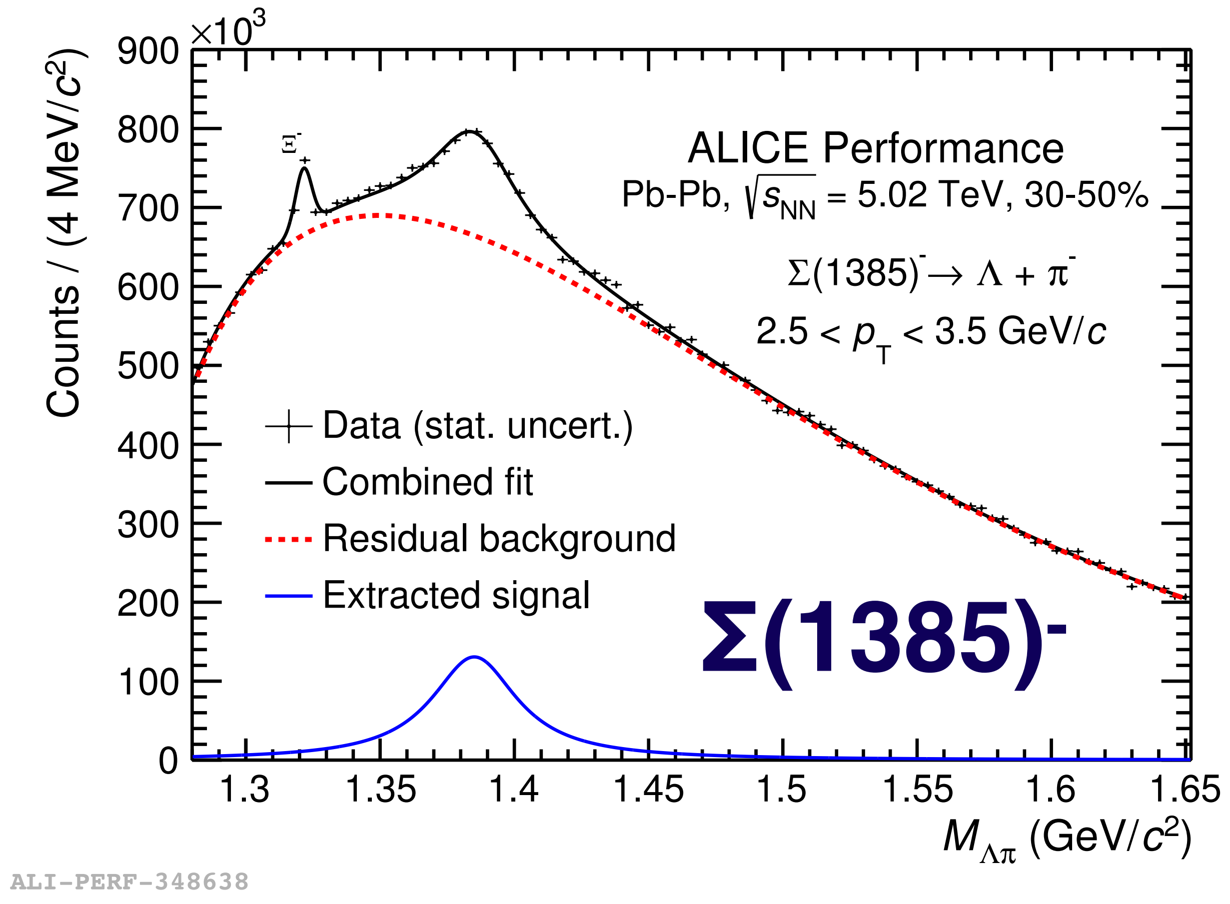
- Resonances are reconstructed via the **invariant mass** technique.

$$M_{inv} = \sqrt{(E_1 + E_2)^2 - (\vec{p_1} + \vec{p_2})^2}$$

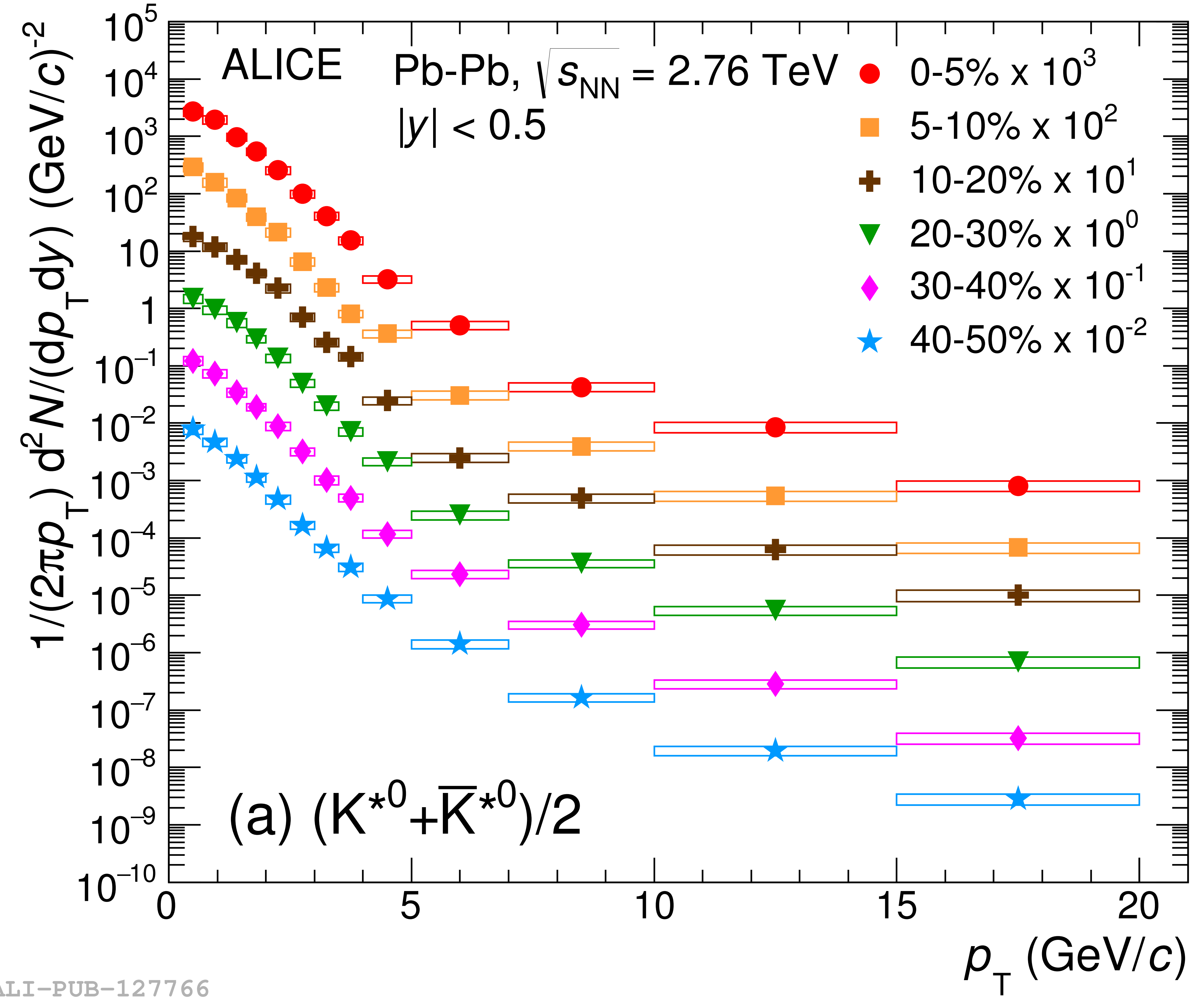
- **Uncorrelated background** is calculated via **event mixing or like-sign techniques**.
- **PID** from ITS, TPC, TOF for the **daughter tracks**.
- **Residual background**: Correlated pairs or misidentified decay products, usually modelled by a polynomial function.
- **Signal** : Fit the event-mixing (or like-sign) subtracted distribution with a Breit-Wigner or Voigtian function (signal function) and the polynomial background.
- Yields are calculated by integrating the signal function.





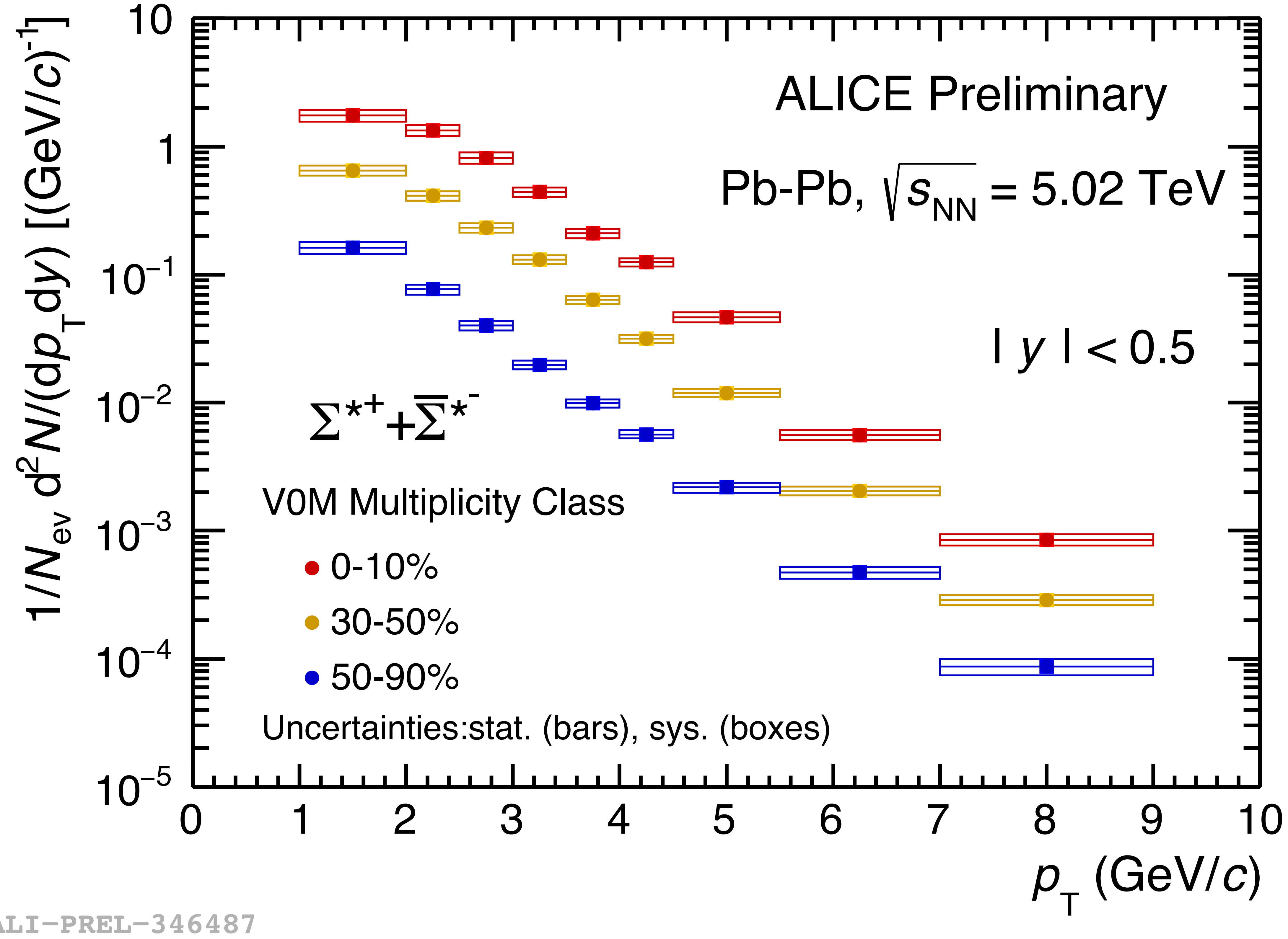


p_T spectra in heavy-ion collisions

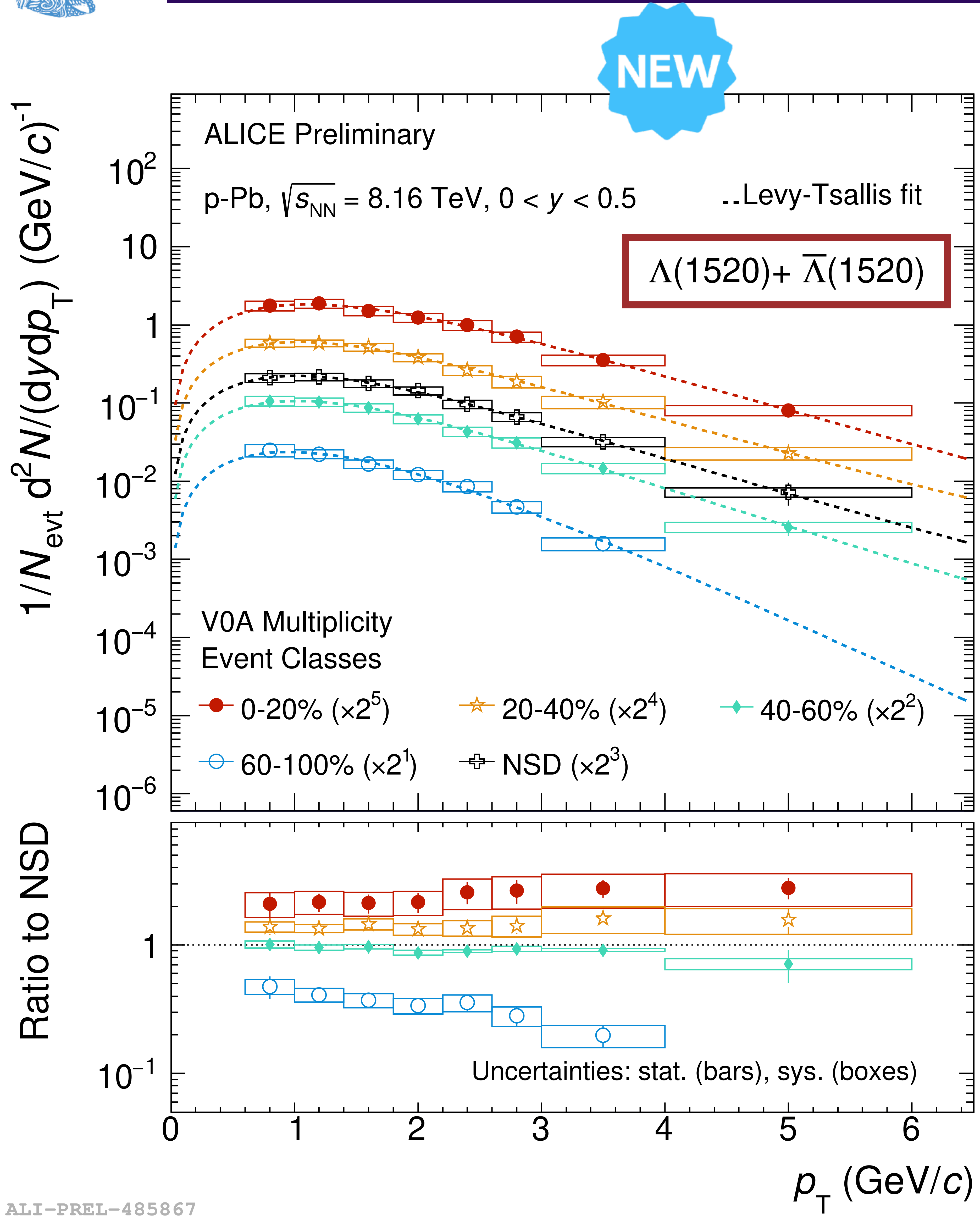


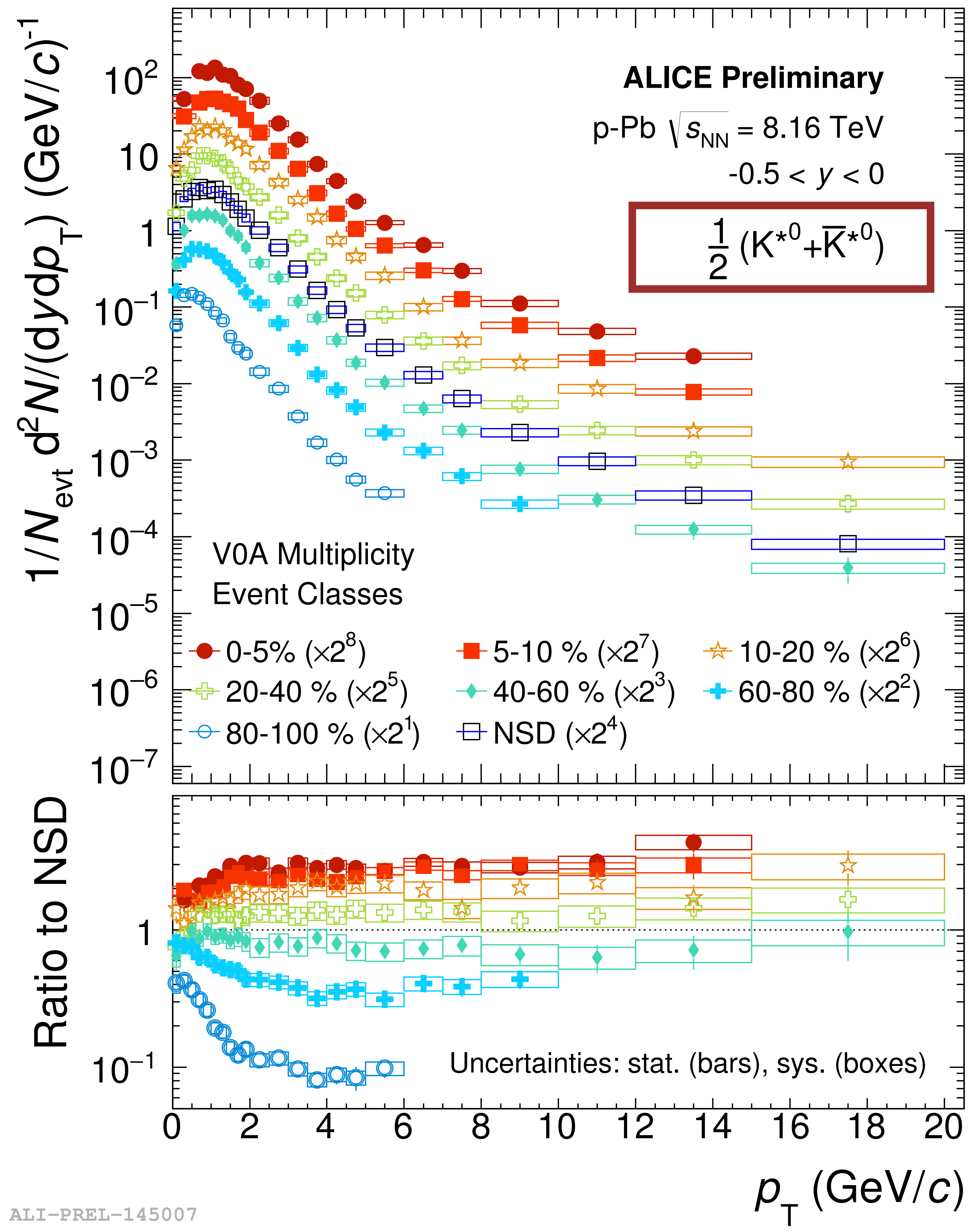
Phys. Rev. C 95 064606 (2017)

Hardening of the spectra with increasing multiplicity
→caused by radial flow.



p_T spectra in p-Pb collisions

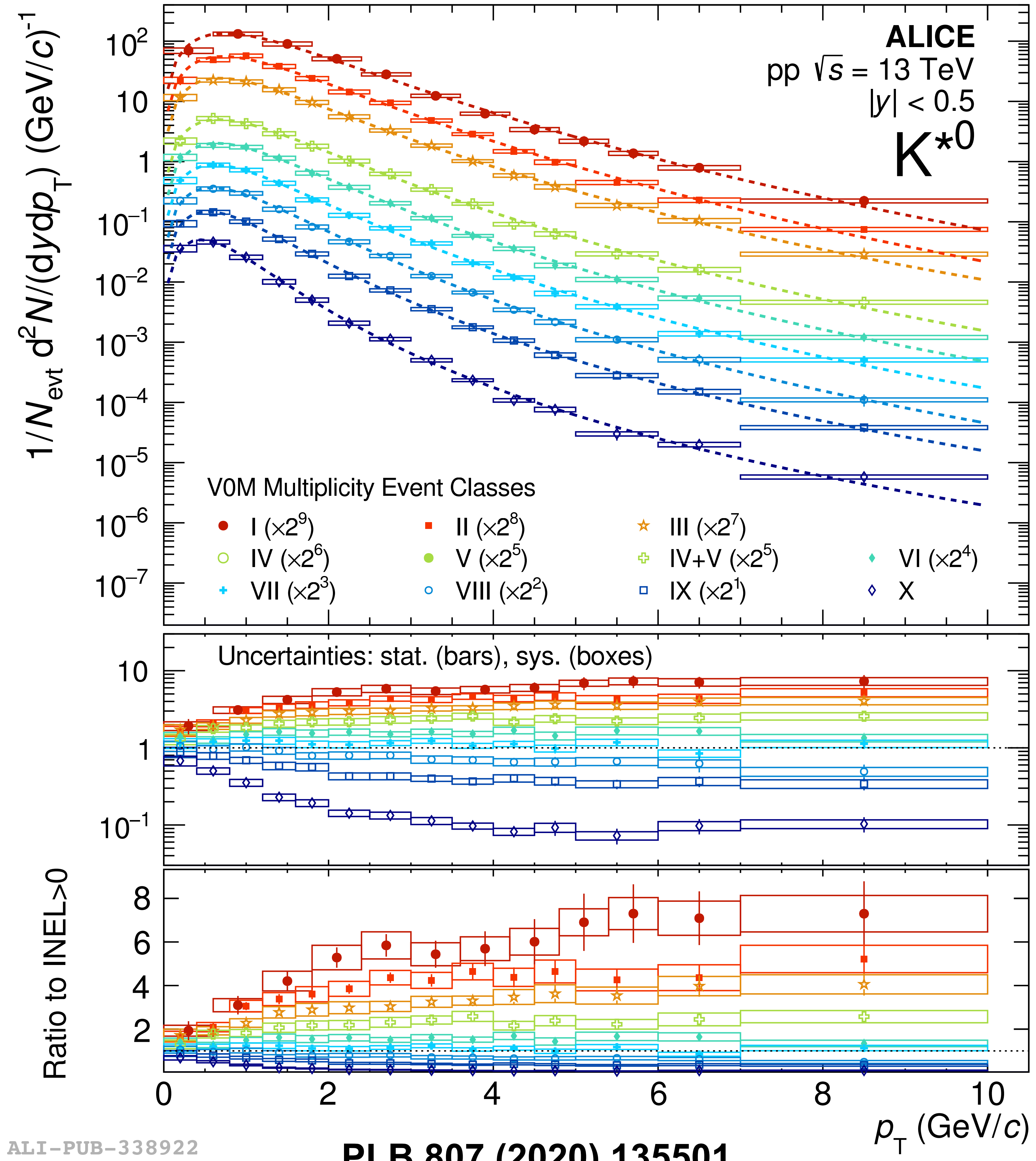




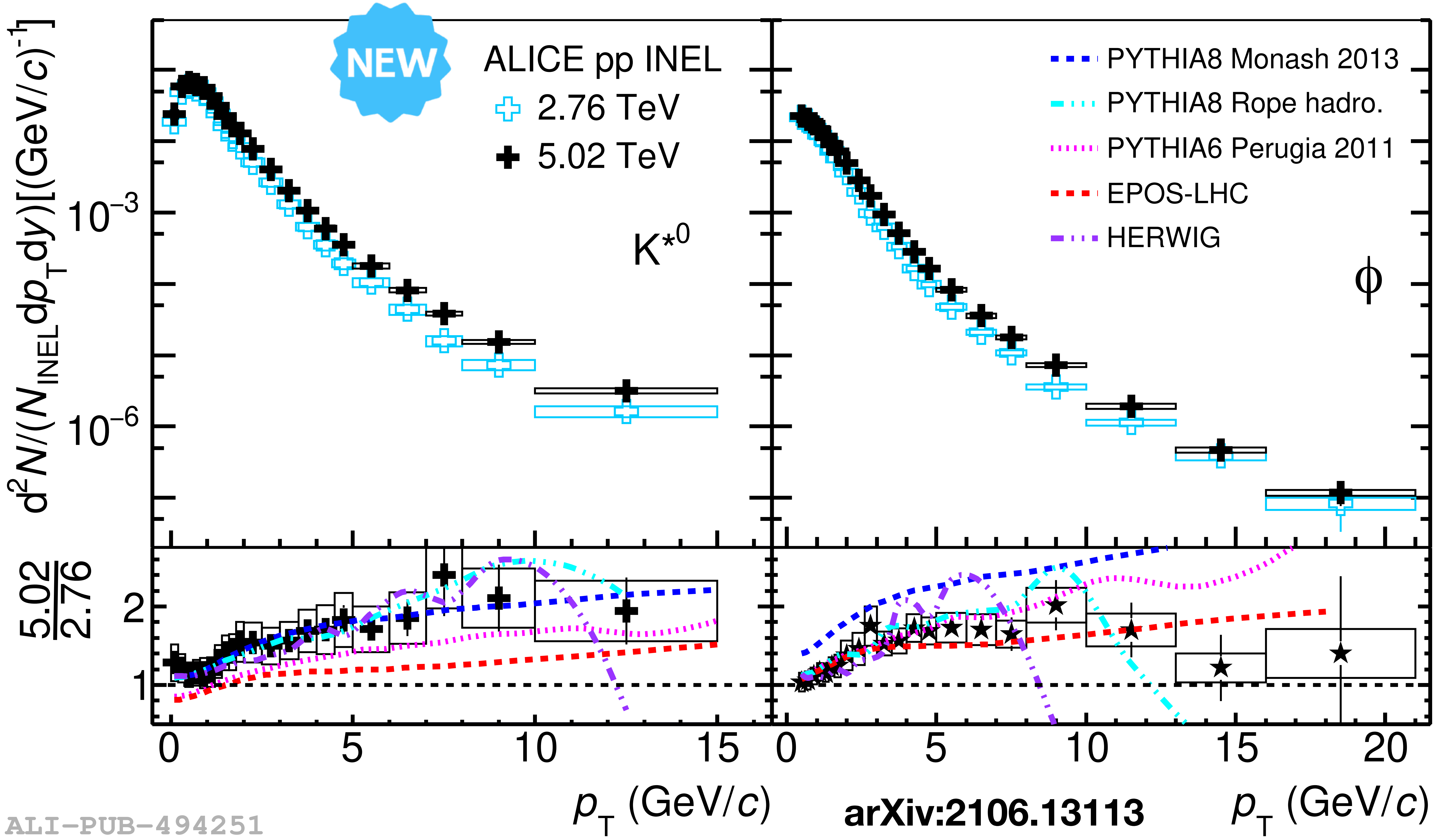
Qualitatively **similar observations** as for **heavy-ion collisions** regarding the **shapes**.

Collective flow-like effects in small collision systems.

p_T spectra in pp collisions



PLB 807 (2020) 135501



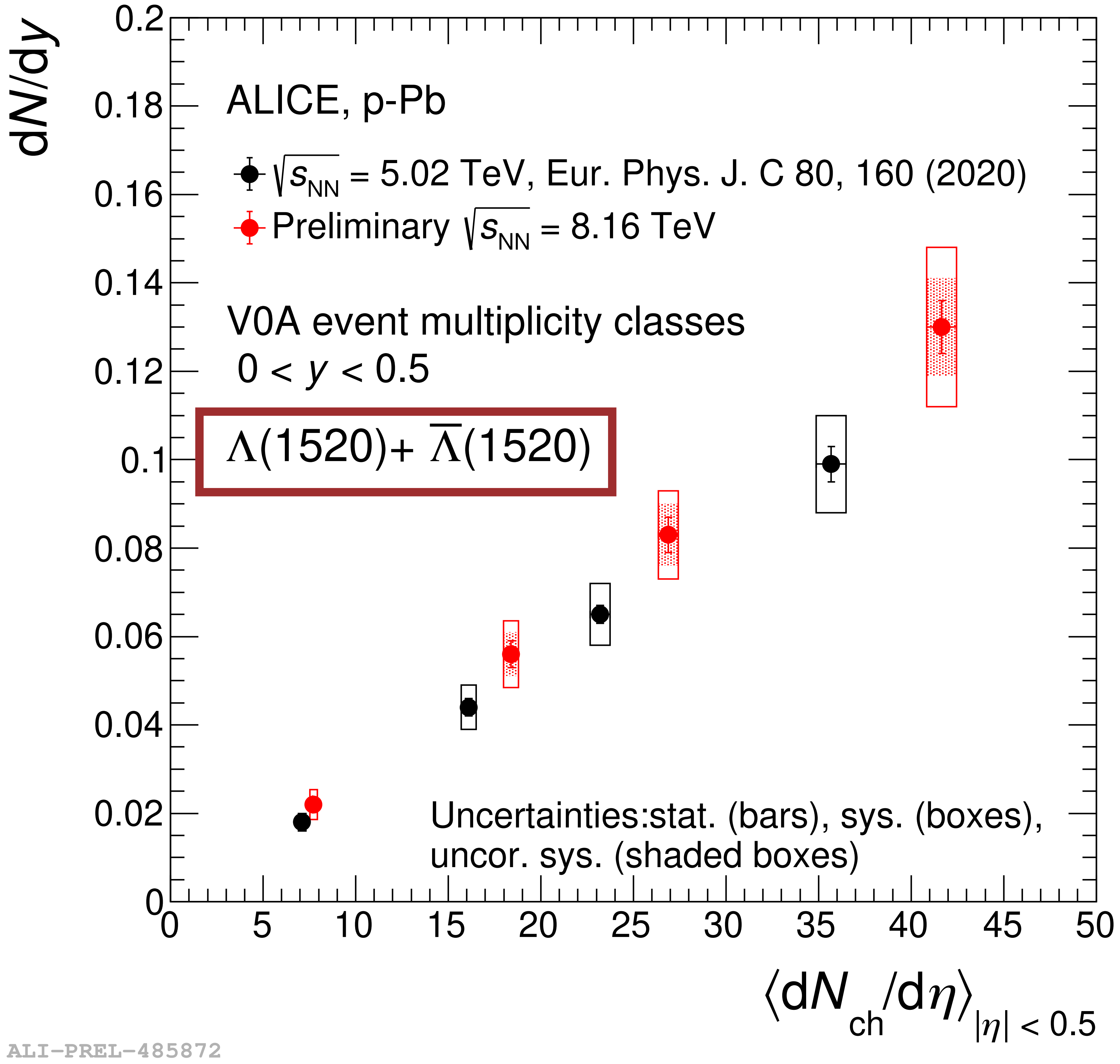
arXiv:2106.13113

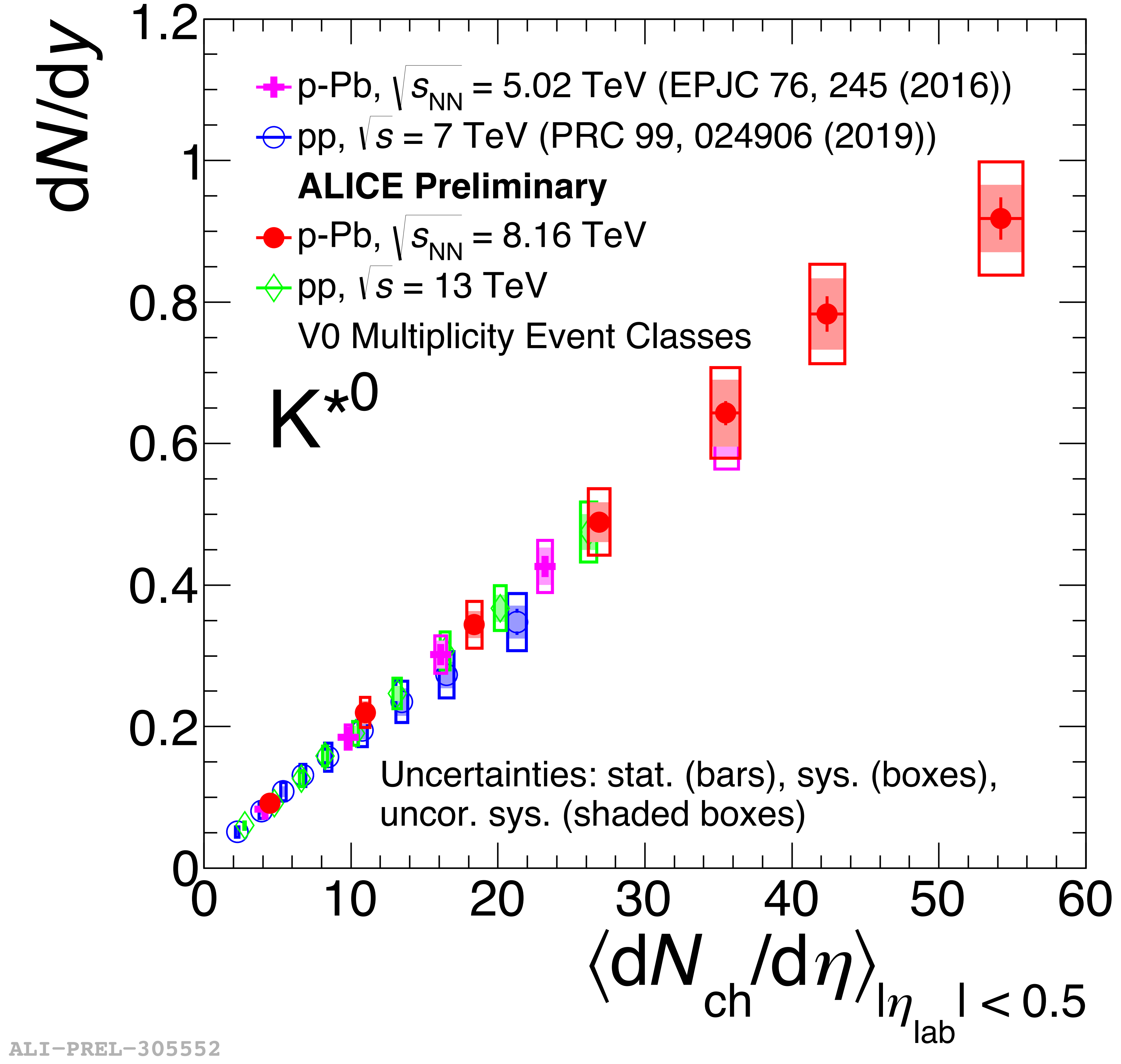
The **spectra shapes change with multiplicity** in the **same way** as for the **larger systems**.

Ratio between the two energies evolves with p_T.
Hint of **saturation at $p_T \sim 5$ GeV/c.**

Pythia tunes give good description except the Monash tune for the φ.
HERWIG describes the ratio for K* but φ only up to ~ 3 GeV/c.
EPOS-LHC underestimates K* but describes φ up to ~ 7-8 GeV/c.

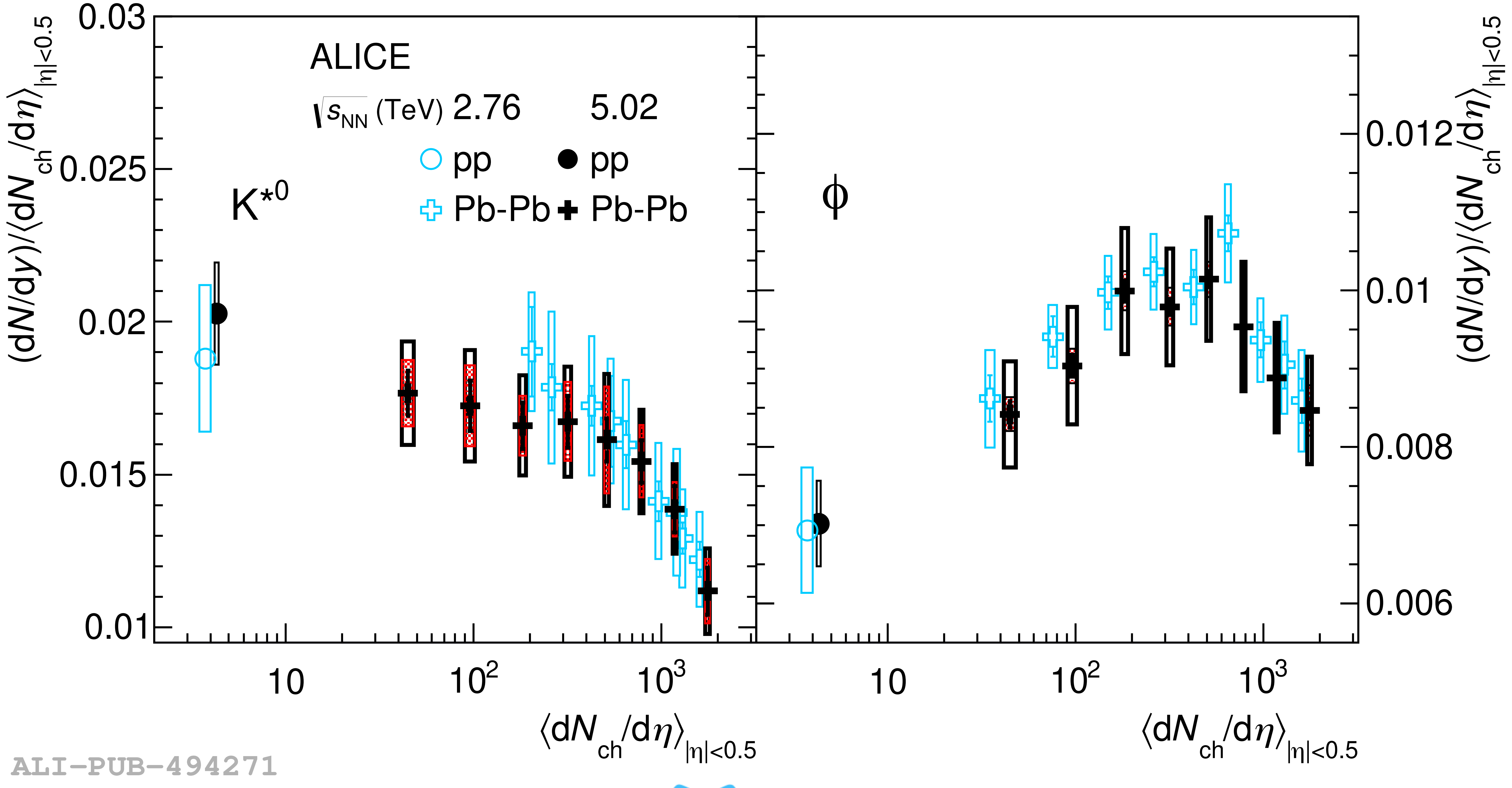
p_T integrated yields





In pp and p-Pb collisions there is a linear increase of d*N*/d*y* following a common trend for all resonances analysed, independent of the collision energy.

p_T integrated yields



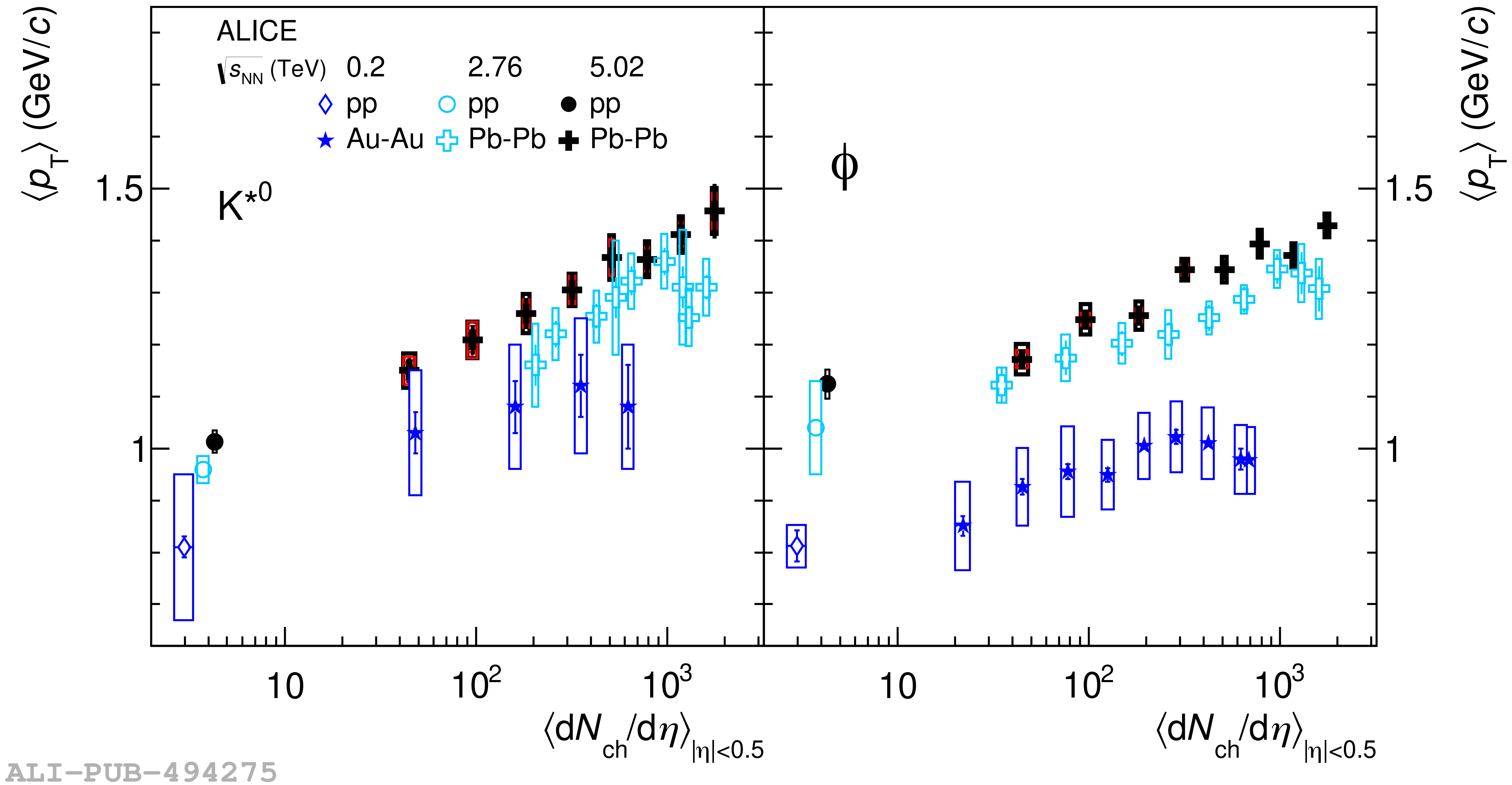
NEW

arXiv:2106.13113

d*N*/dy, scaled by the average charged particle multiplicity measured at midrapidity.

The dependence on ⟨dNch/dη⟩$_{|\eta|<0.5}$ is found to be the **same regardless of the beam energy.**

Mean transverse momentum



ALI-PUB-494275

NEW

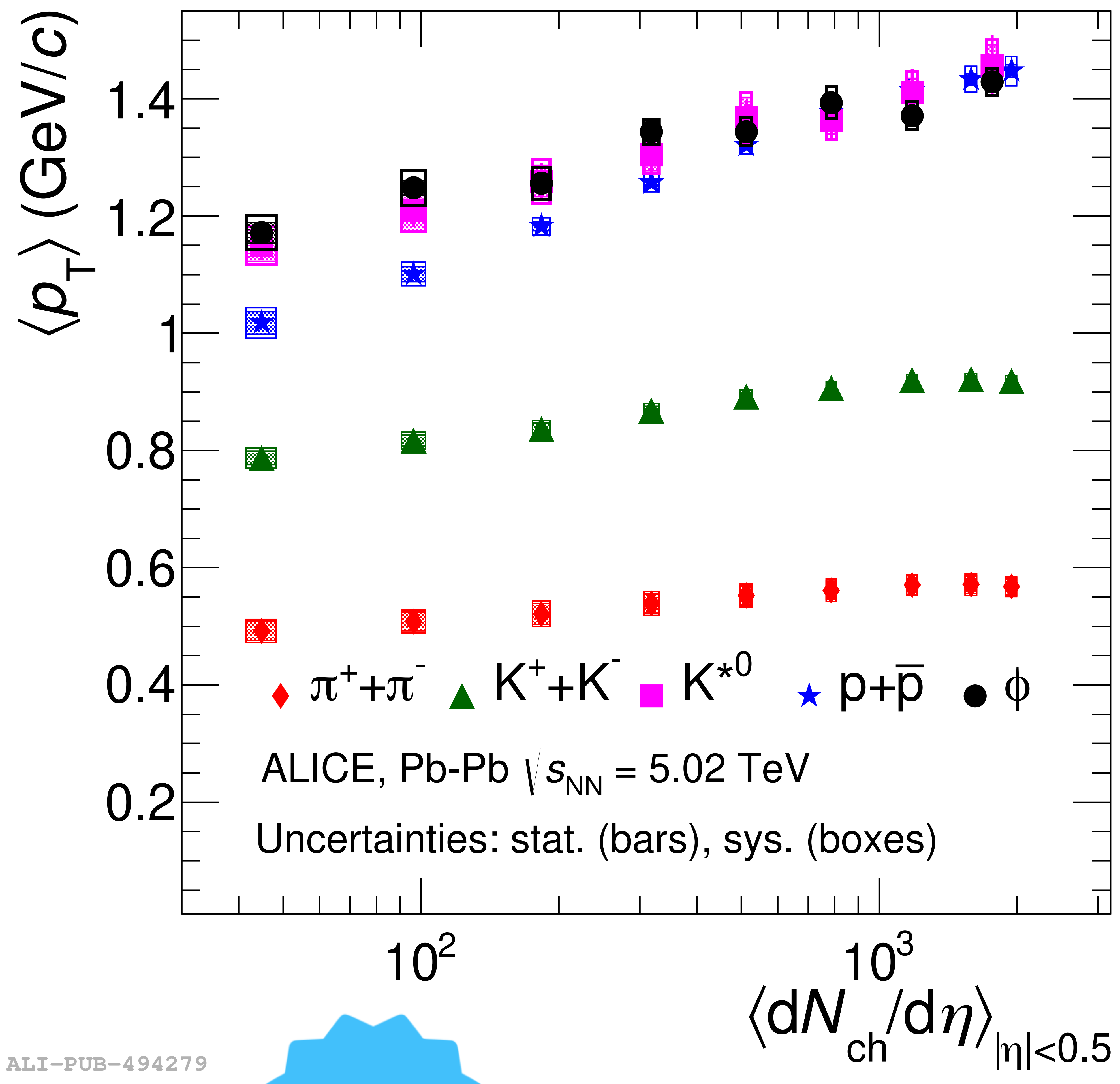
arXiv:2106.13113

The $\langle p_T \rangle$ values increase with charged particle multiplicity.

The $\langle p_T \rangle$ of K^{*0} and ϕ mesons (which have similar masses) are similar for events with the same $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$ in Pb–Pb collisions → Consistent with the picture of a growing contribution of radial flow with increasing $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$

The $\langle p_T \rangle$ values are larger for higher energy collisions at similar values of $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$.

Mean transverse momentum



NEW

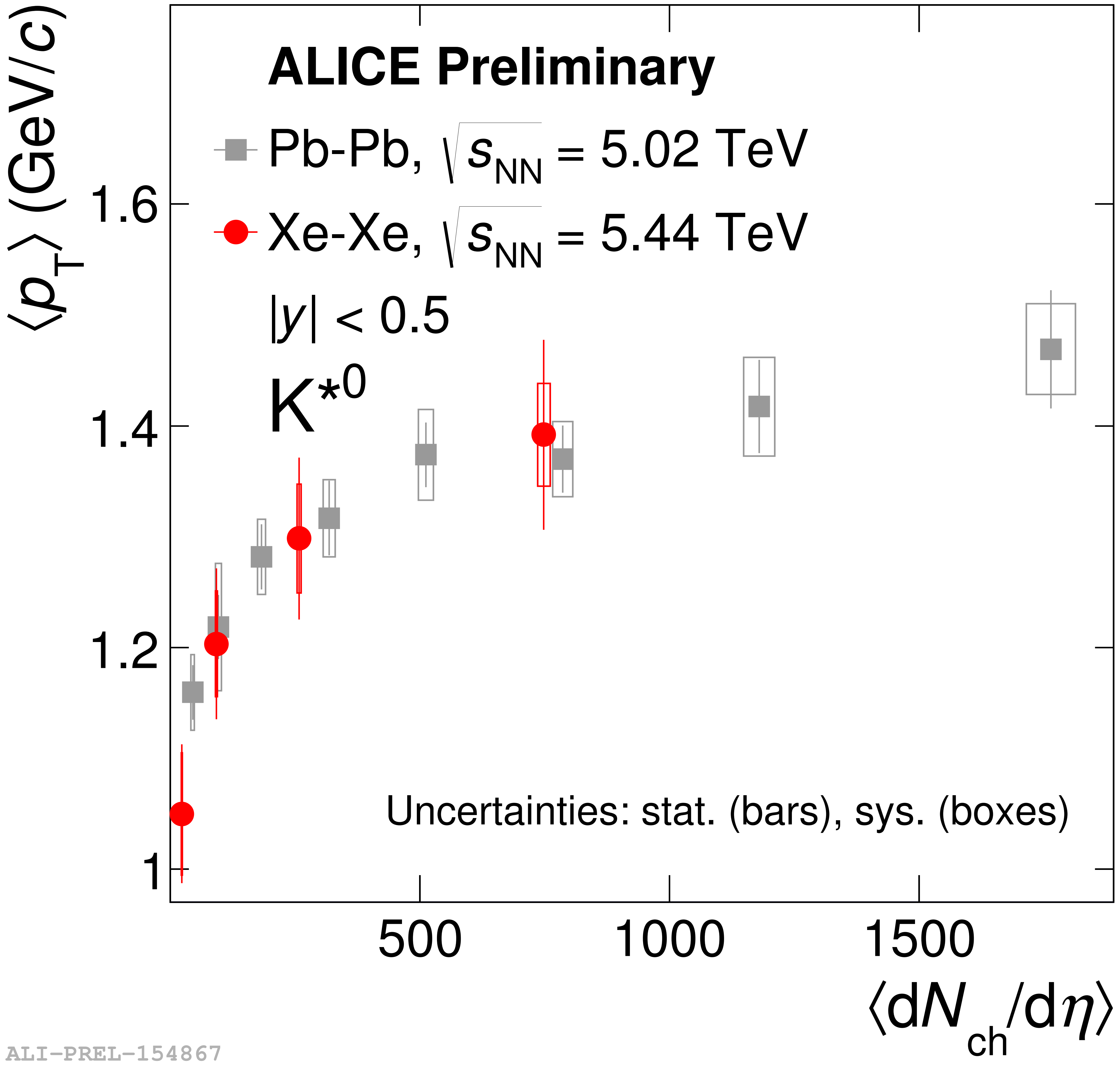
arXiv:2106.13113

Steeper rise of $\langle p_T \rangle$ for the heavier particles.

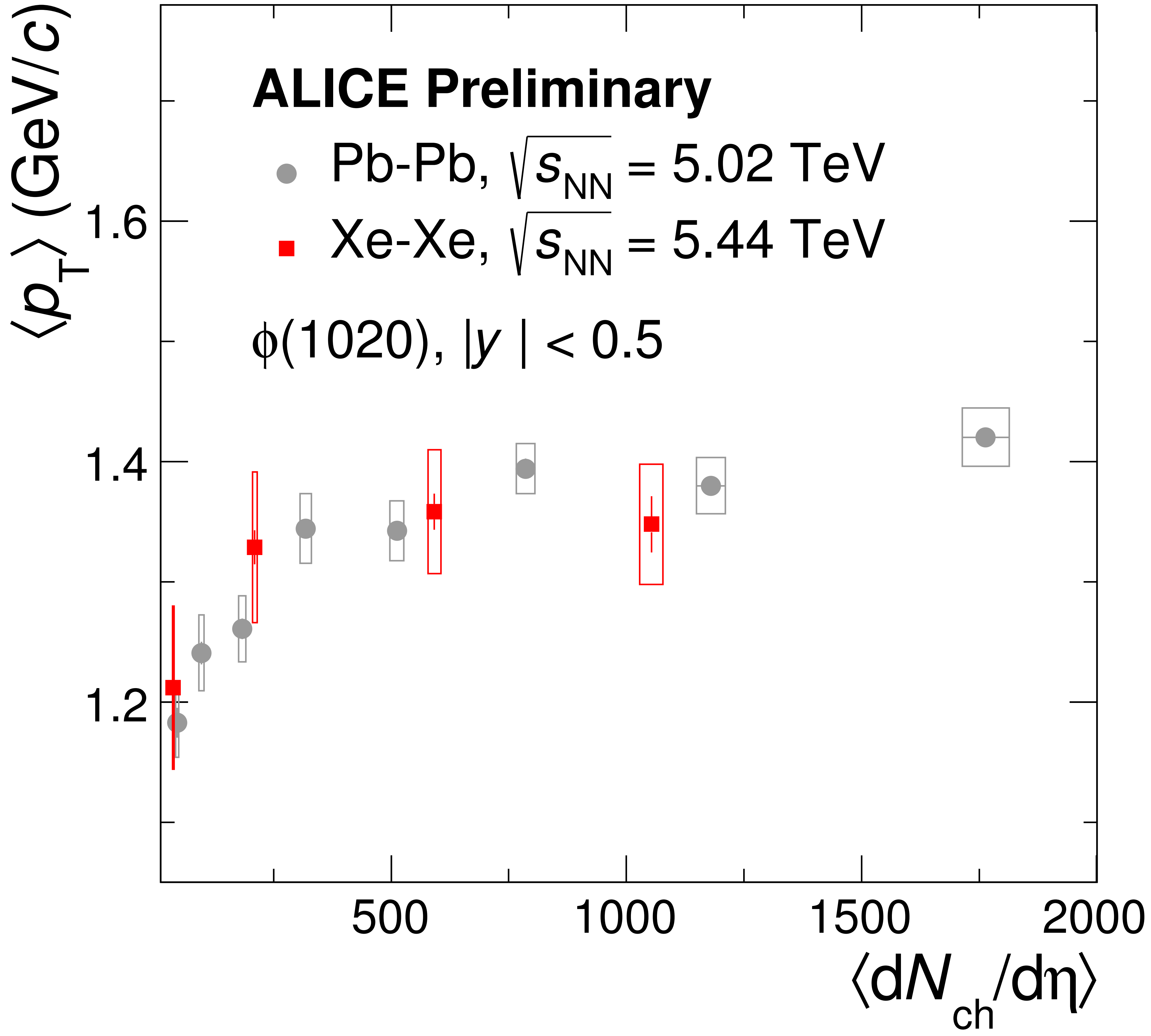
K*, p and **ϕ** (they have similar masses):

- At the higher multiplicities have similar $\langle p_T \rangle$ within the uncertainties.
- At lower multiplicities mass scaling is breaking.

Mean transverse momentum



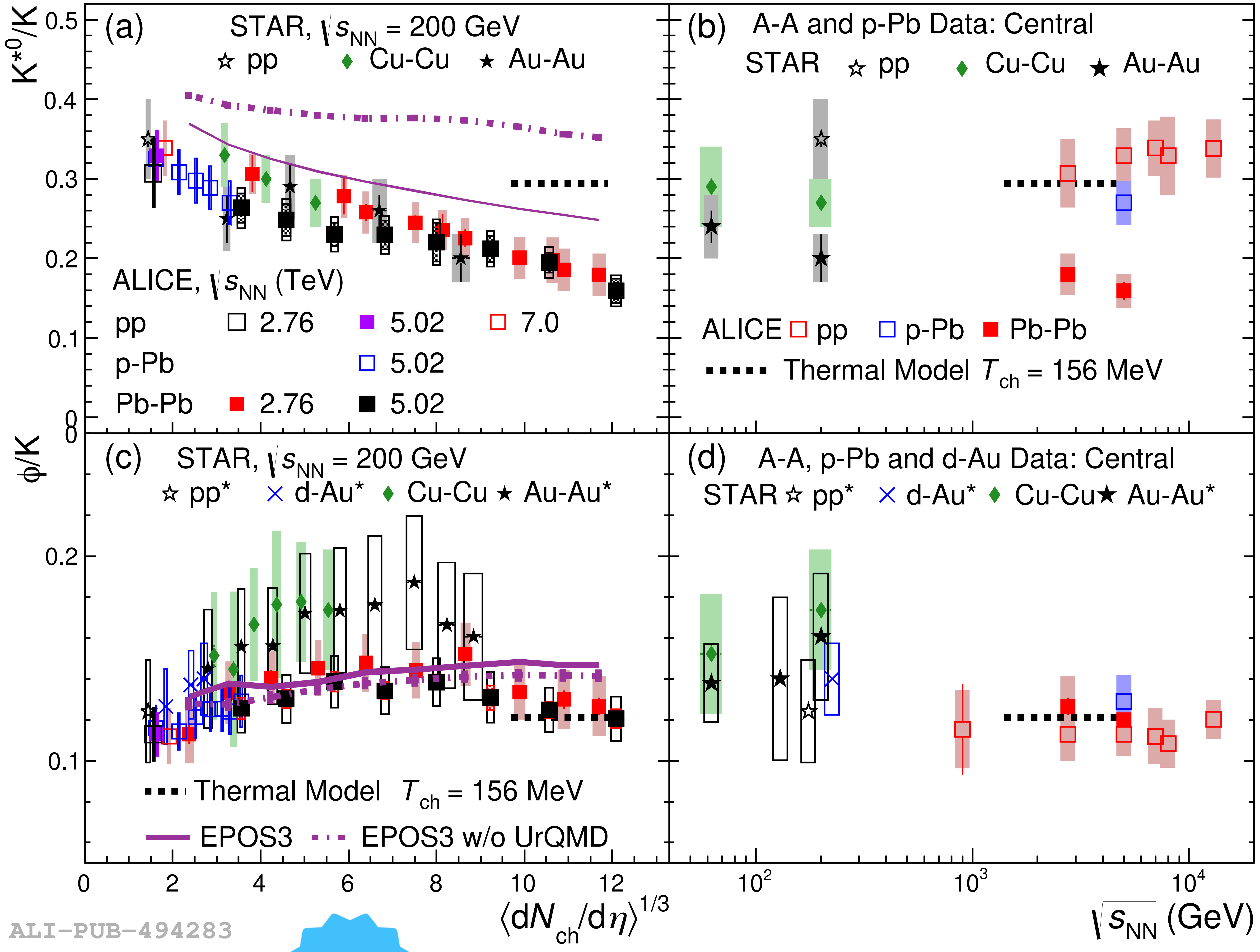
ALI-PREL-154867



ALI-PREL-155852

Similar evolution of $\langle p_T \rangle$ in **Pb-Pb** and **Xe-Xe** collisions. For the same particle $\langle p_T \rangle$ is driven by the multiplicity.

Particle yield ratios



NEW

arXiv:2106.13113

K*/K:

Gradual decrease with the system size→effect of rescattering.
Lower values for Au-Au and Pb-Pb central collisions in all centre-of-mass energies.

ϕ/K:

approximately constant with the **system size (due to the larger lifetime)** and **centre-of-mass energies.**

- The **thermal** model predictions **without rescattering** effects agree with the ϕ/K and the K*/K in **small** systems, **but**

  K*/K in **central Pb-Pb** collisions is **not described**.

- **EPOS3 with UrQMD afterburner** (Phys. Rev. C 93 (2016) 014911) describes better the two ratios.

Particle yield ratios

cτ (fm)

1.3

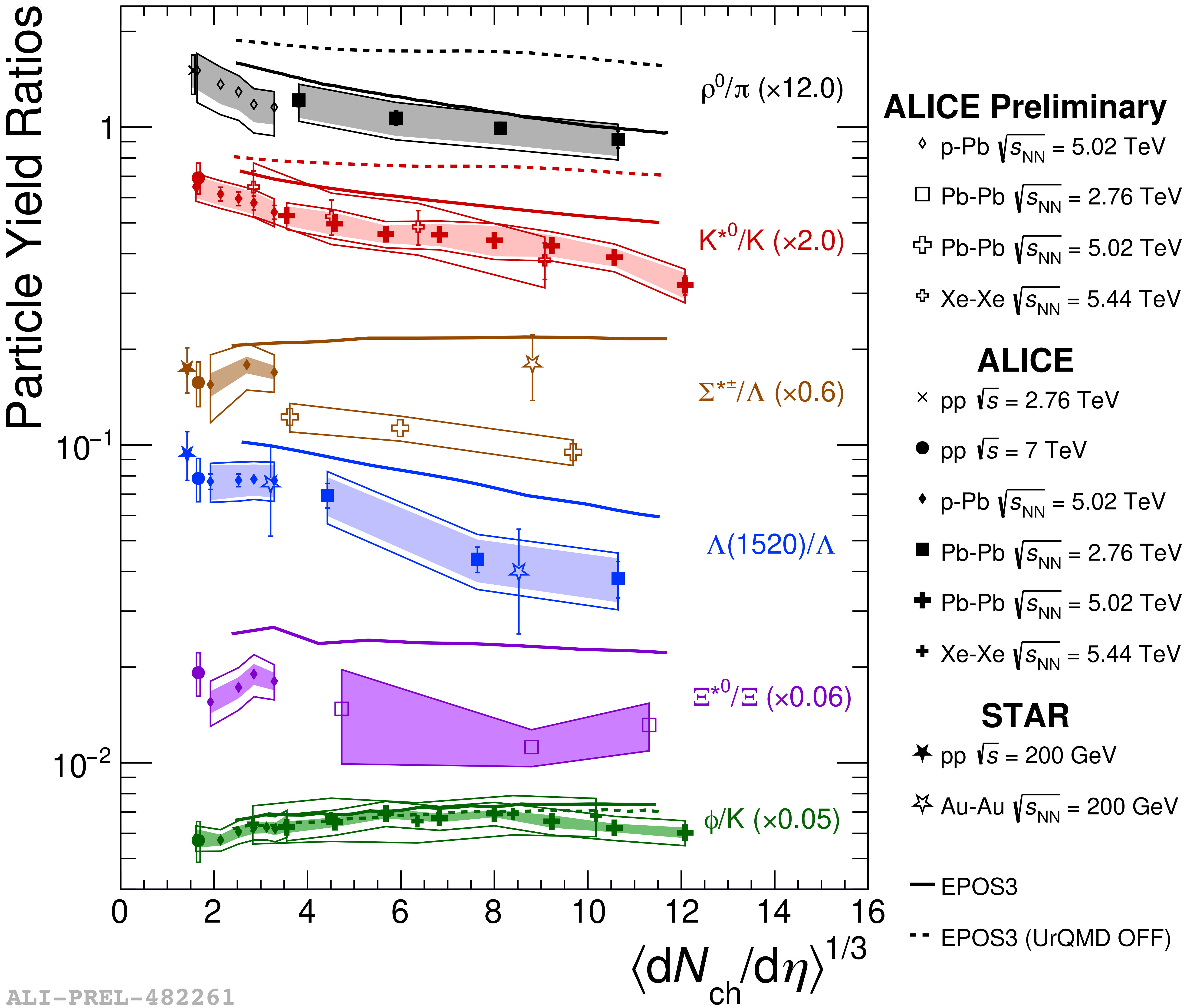
4.2

5.5

12.6

21.7

46.4



ALI-PREL-482261

All particle ratios evolve smoothly with system size for the measured systems and energies.

Short-lived resonances like ρ^0, K^{*0}, $\Sigma^{*\pm}$ Λ^* are affected by re-scattering in the hadronic phase.

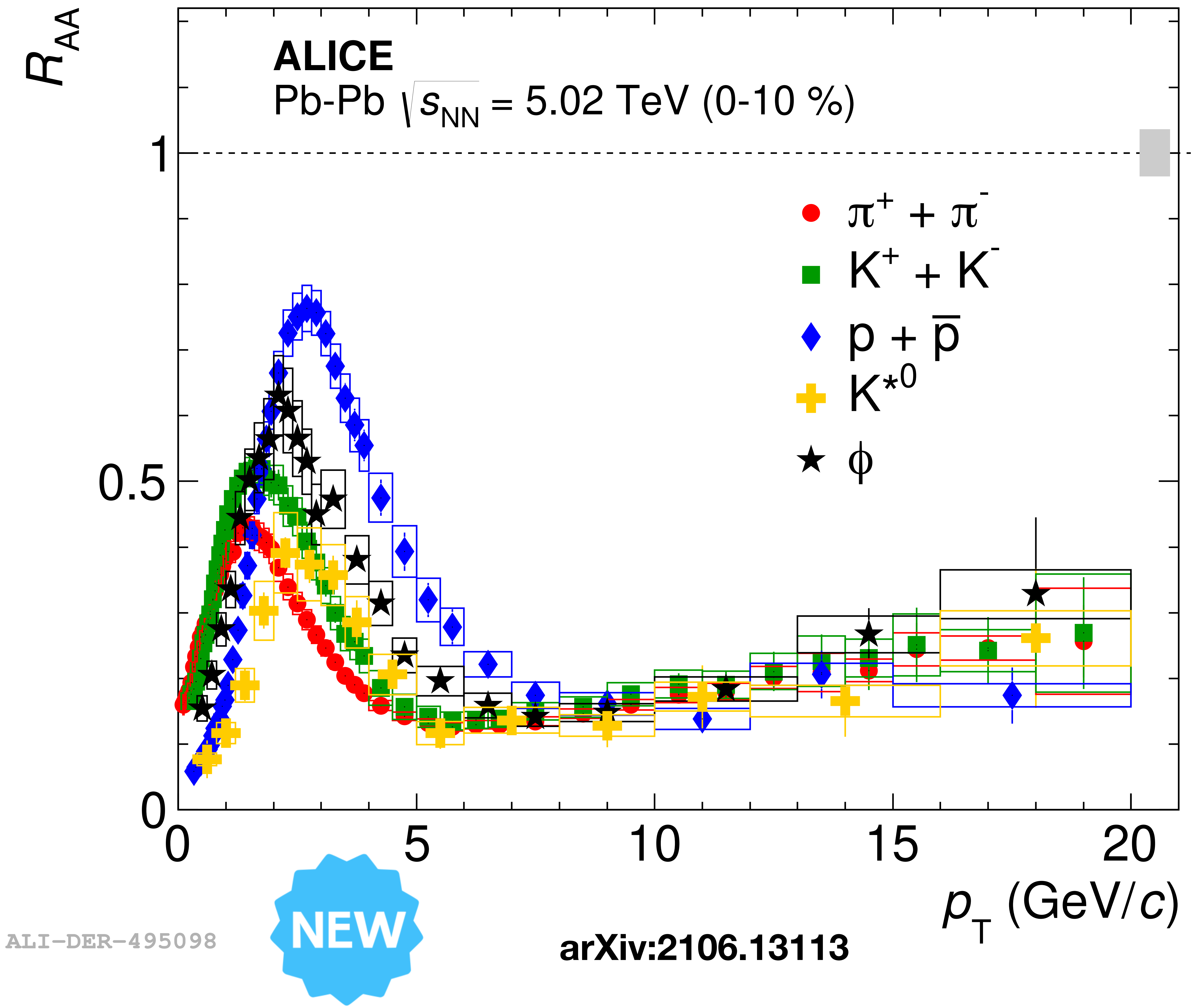
Ξ^* production is rather independent of the system size.

ϕ is not suppressed as it decays after the kinetic freeze-out.

EPOS with UrQMD qualitatively describes the trends, **except** for $\Sigma^{*\pm}/\Lambda$.

Short-lived resonances are used to measure the hadronic phase lifetime: 4-7 fm/c (PLB 802 (2020) 135225) in the most central collisions, in agreement with femtoscopic measurements.

Nuclear modification factors (R_{AA})



arXiv:2106.13113

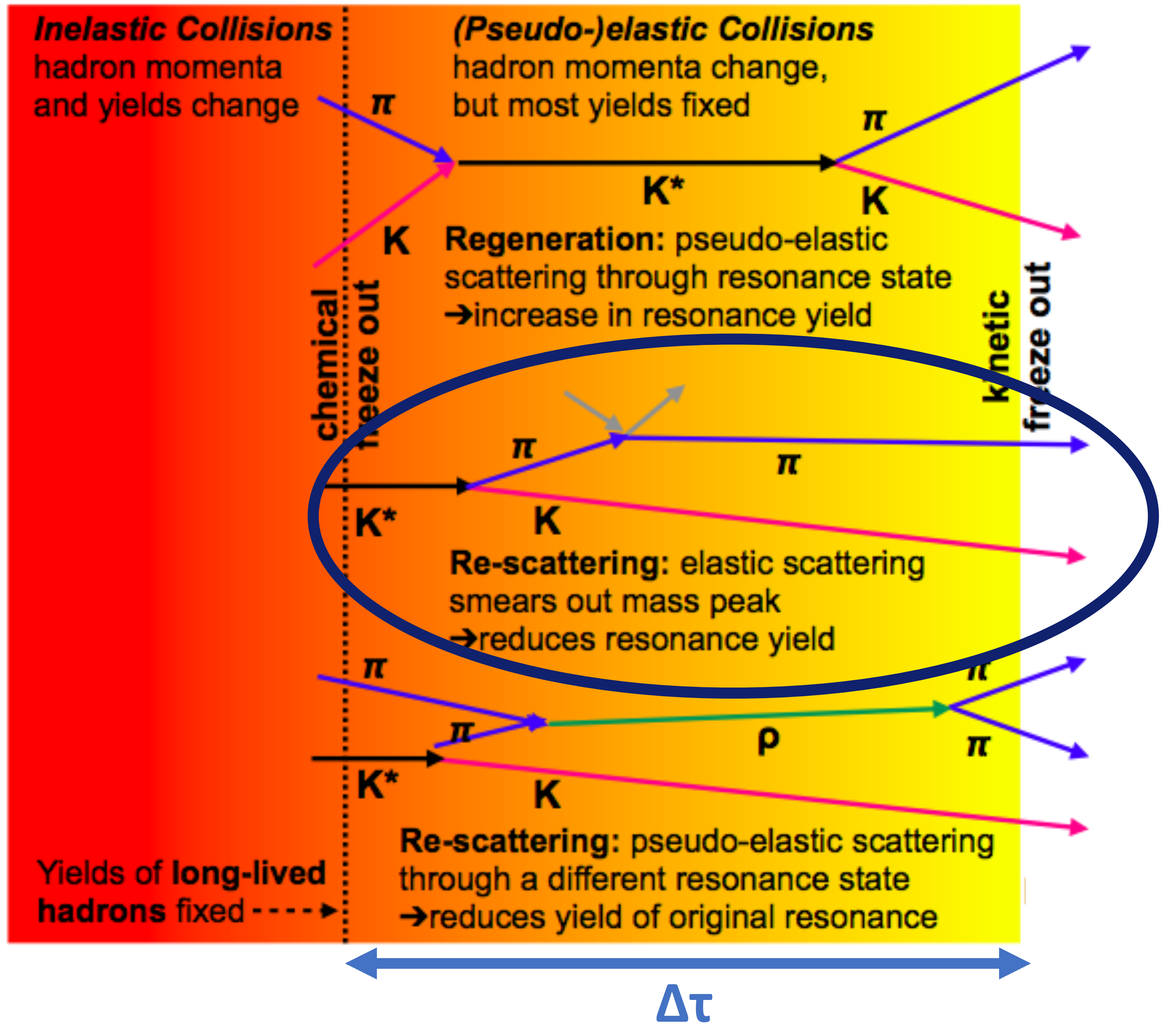
$$R_{AA}(p_T) = \frac{\mathrm{Yield}_{AA}(p_T)}{\mathrm{Yield}_{pp}(p_T) \times < N_{coll} >}$$

$p_T < 2$ GeV/c:
K* R_{AA} values are **the smallest → Effect of re-scattering.**

$2 < p_T < 8$ GeV/c:
- hadron mass dependence for mesons.
- Protons have the highest values of R_{AA}→ baryon-meson ordering.

$p_T > 8$ GeV/c: similar R_{AA} values for all **hadron species** within the uncertainties → the relative particle composition at high p_T remains the same as in vacuum.

Summary



Results from resonance reconstruction in **pp, p-Pb and Pb-Pb collisions at various centre-of-mass energies show:**

- **No dependence of resonance production on the collision energy and system. It is driven by the charged particle multiplicity.**

- **Rescattering is the dominant process in the hadronic phase for short-lived resonances ($c\tau < \sim 15$ fm/c).**