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Understanding the hadronic phase with resonance studies with ALICE at LHC Energies

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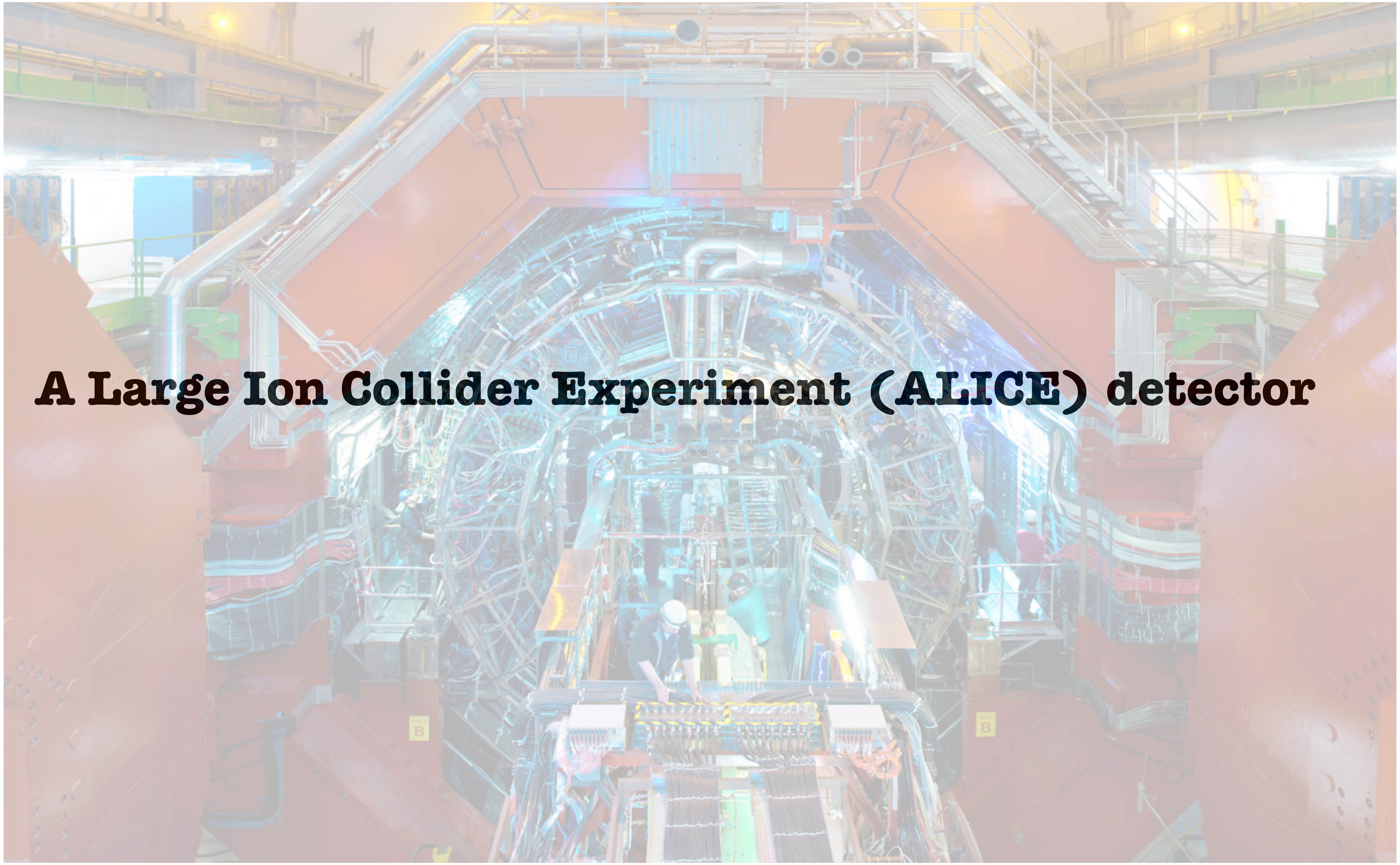
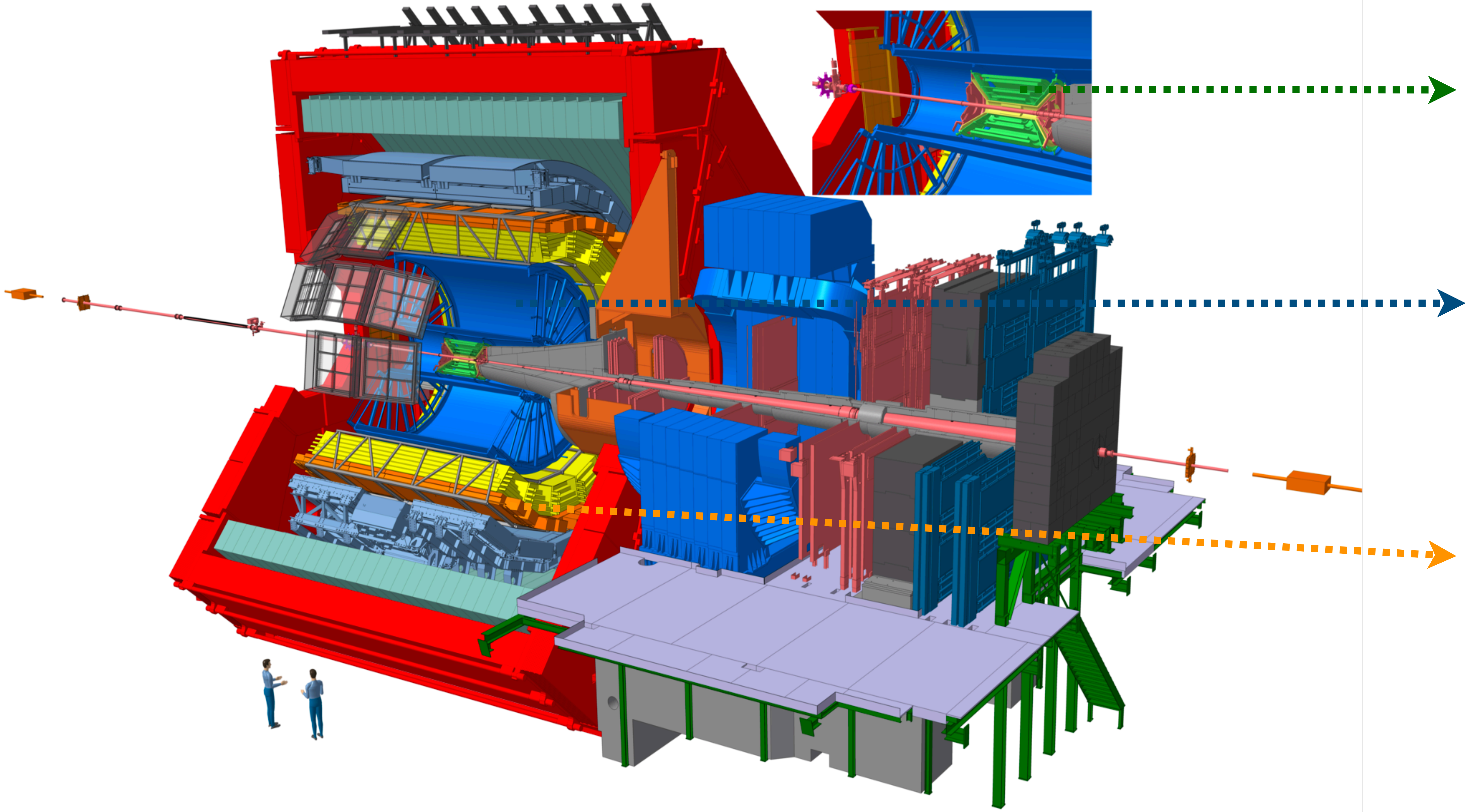
Outline

- Motivation
- Resonance reconstruction method
- Results
  - Transverse momentum spectra
  - p_T integrated yield
  - Mean traverse momentum
  - Resonance to stable particle ratio
- Summary

A Large Ion Collider Experiment (ALICE) detector



The ALICE detector in Run 2



A multipurpose detector at the LHC with excellent tracking and particle identification capability

Inner Tracking System (ITS)

- $|\eta| < 0.9$
- 6 layers of silicon detectors
- Particle identification & tracking

Time Projection Chamber (TPC)

- $|\eta| < 0.9$
- Gas-filled ionisation detector
- Particle identification & tracking

Time Of Flight (TOF)

- $|\eta| < 0.9$
- Multi-gap resistive plate chambers
- Particle identification & event timing

V0A & V0C

- V0A$(2.8 < \eta < 5.1)$, V0C$(-3.7 < \eta < -1.7)$
- Array of scintillators
- Trigger and multiplicity estimator

Motivation - Resonance as a probe of hadronic phase

Hadronic resonances are short-lived particles and their **lifetimes** are **comparable to** that of the **hadronic gas** created after the collisions.

Resonance production in small collisions systems (pp and p—Pb collisions)

- Serves as baseline for A—A collisions
- Study of collectivity in small collisions systems
- Role of cold nuclear effect

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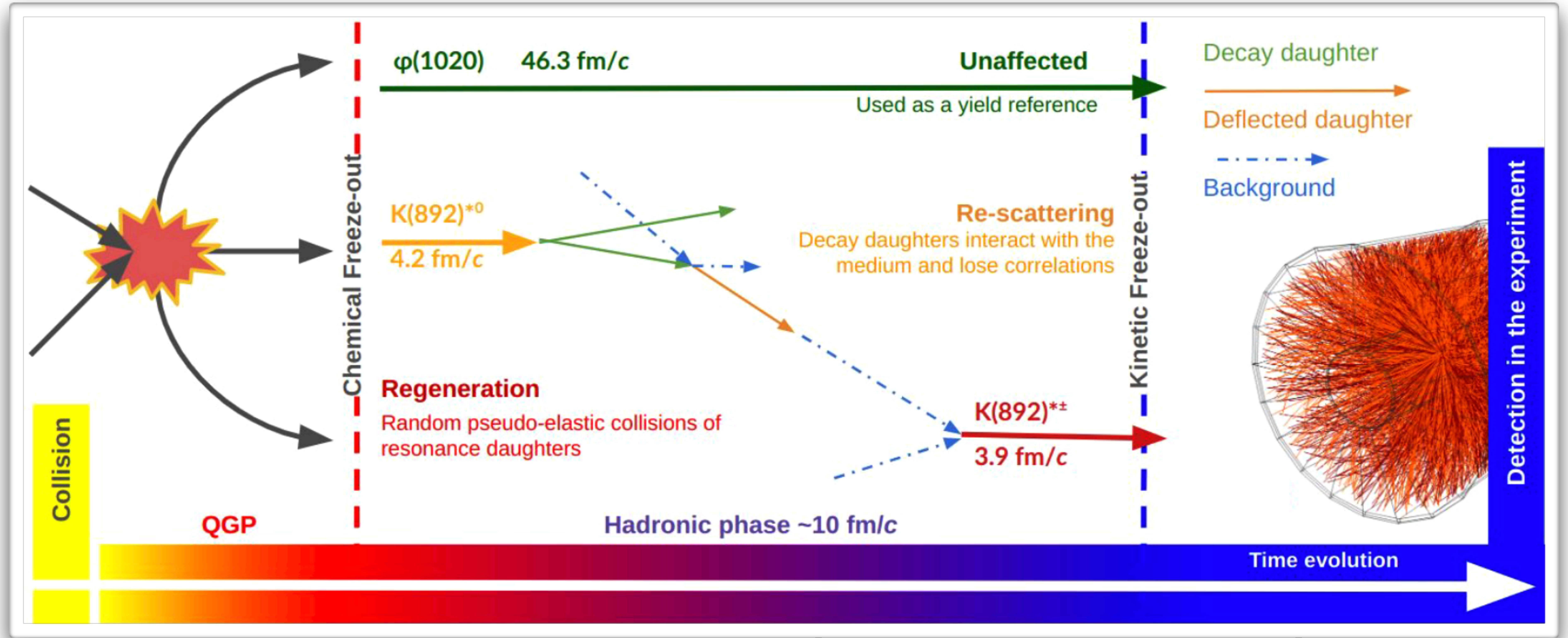
Resonance production in heavy-ion collisions (Pb—Pb collisions)

- **Study of rescattering and regeneration effect**
  - Yield ratios of resonance to longer-lived hadrons
  - Lifetime between chemical and kinetic freeze-out
- **In- medium energy loss**
  - Nuclear modification factor for resonance
- **Chiral symmetry restoration**
  - modification of width and mass

Medium effect on Resonance production



- **Regeneration :** Pseudo-elastic scattering through resonance state ⟶ increase in resonance yield
- **Rescattering :** elastic scattering smears out mass peak ⟶ reduction of the measured resonance yield

Most Hadron yields fixed
Momenta change

Hadron yields fixed
Momenta fixed

- **Rescattering** and **regeneration** processes in hadronic phase affect the resonance yield and shape of p_{T} spectra

Overview: Resonance production in ALICE

Resonance	Lifetime (fm/c)	Decay mode	Quark content
ρ^0	1.3	$\pi\pi$	$\frac{u\bar{u} + d\bar{d}}{2}$
$K^{*0}(892)$	4.2	$K\pi$	$d\bar{s}$
$K^{*\pm}(892)$	4.2	$K^0_s\pi$	$u\bar{s}, \bar{u}s$
$f_0(980)$	~ 5	$\pi\pi$	
$\Sigma(1385)$	5-5.5	$\Lambda\pi$	uus, dds
$\Lambda(1520)$	12.6	pK	uds
$\Xi^0(1530)$	21.7	$\Xi^-\pi$	dds
$\phi(1020)$	46.4	KK	$s\bar{s}$

Particle Data Group

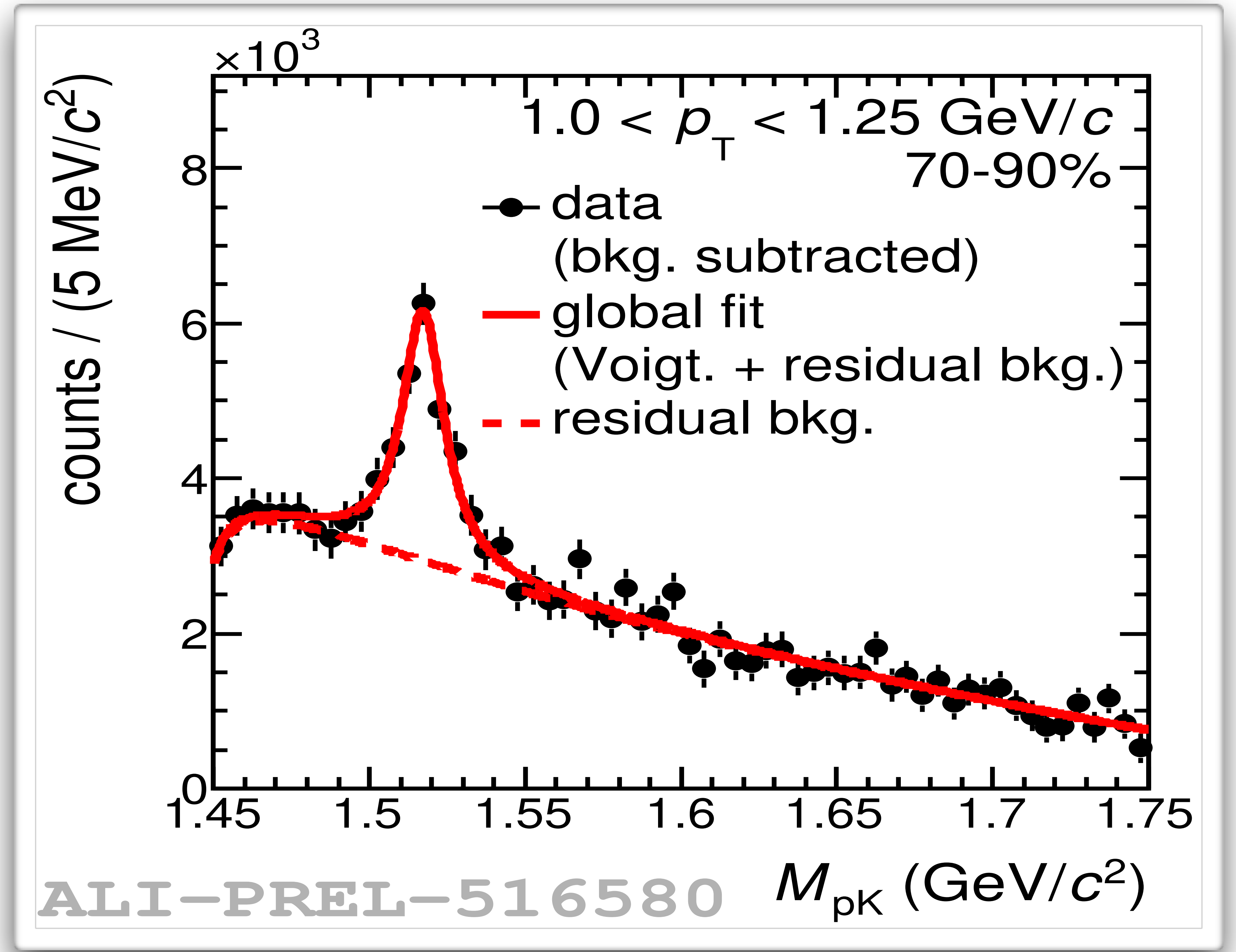
Resonance Reconstruction

- Resonances are reconstructed via the invariant mass technique. Uncorrelated background is calculated via event mixing.

$$M^2 = (E_1 + E_2)^2 - \|\mathbf{p}_1 + \mathbf{p}_2\|^2$$

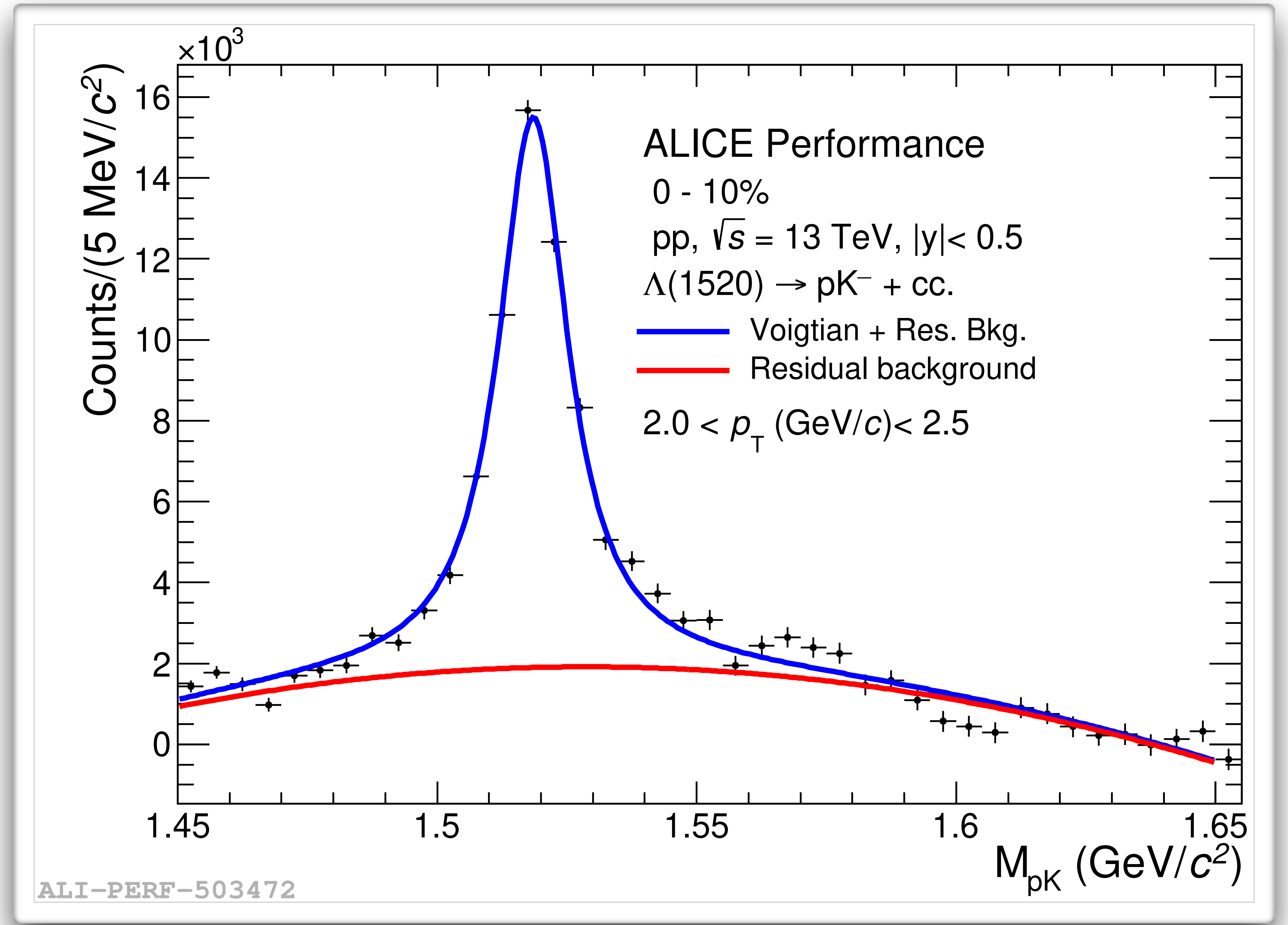
- After subtracting the event mixing background, the remaining distribution is fitted with a Voigtian (or Breit-Wigner) function to describe the signal and a polynomial for residual background.

Run2, Pb—Pb 5.02 TeV



Λ(1520)

Run2, pp, 13 TeV

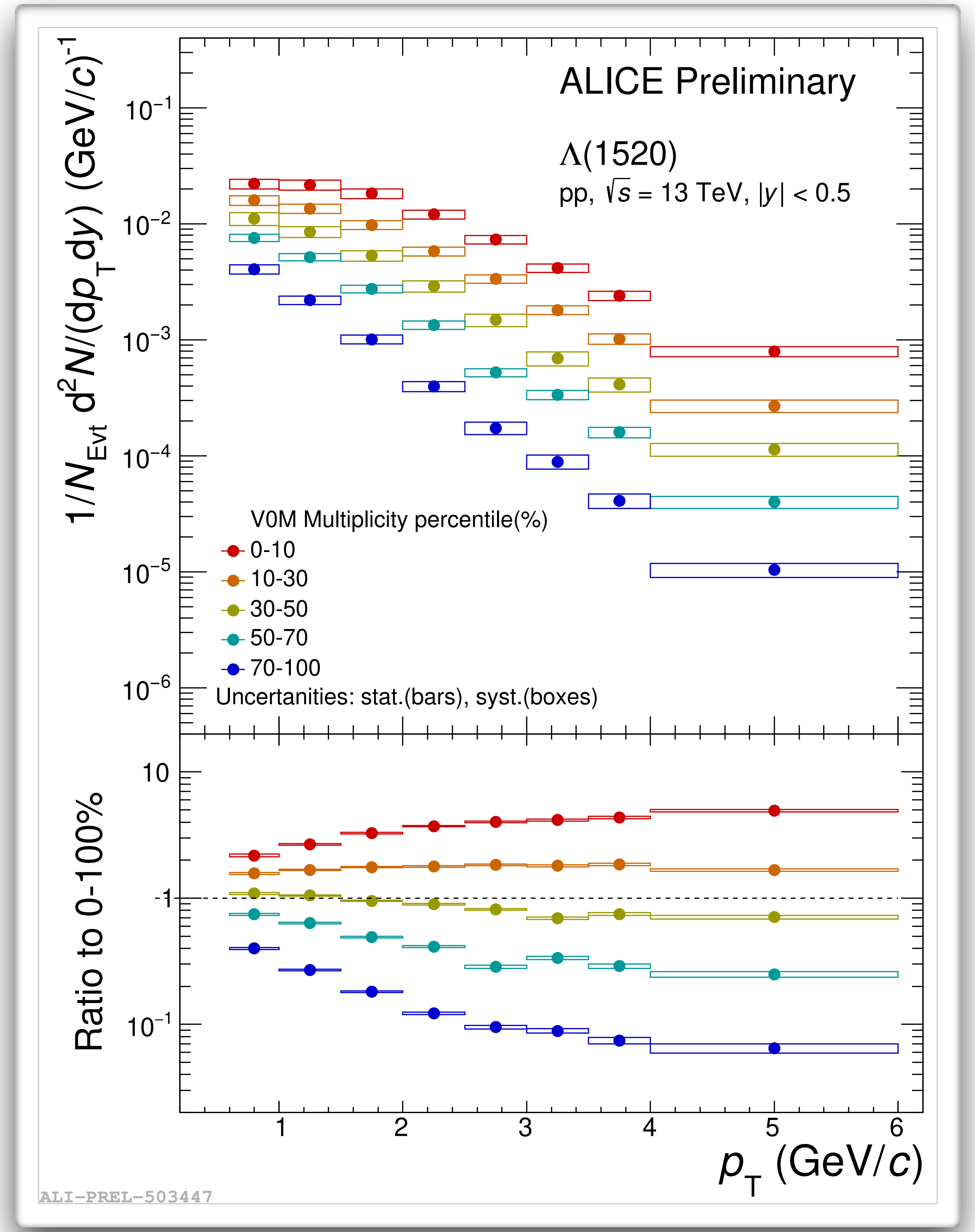


Results

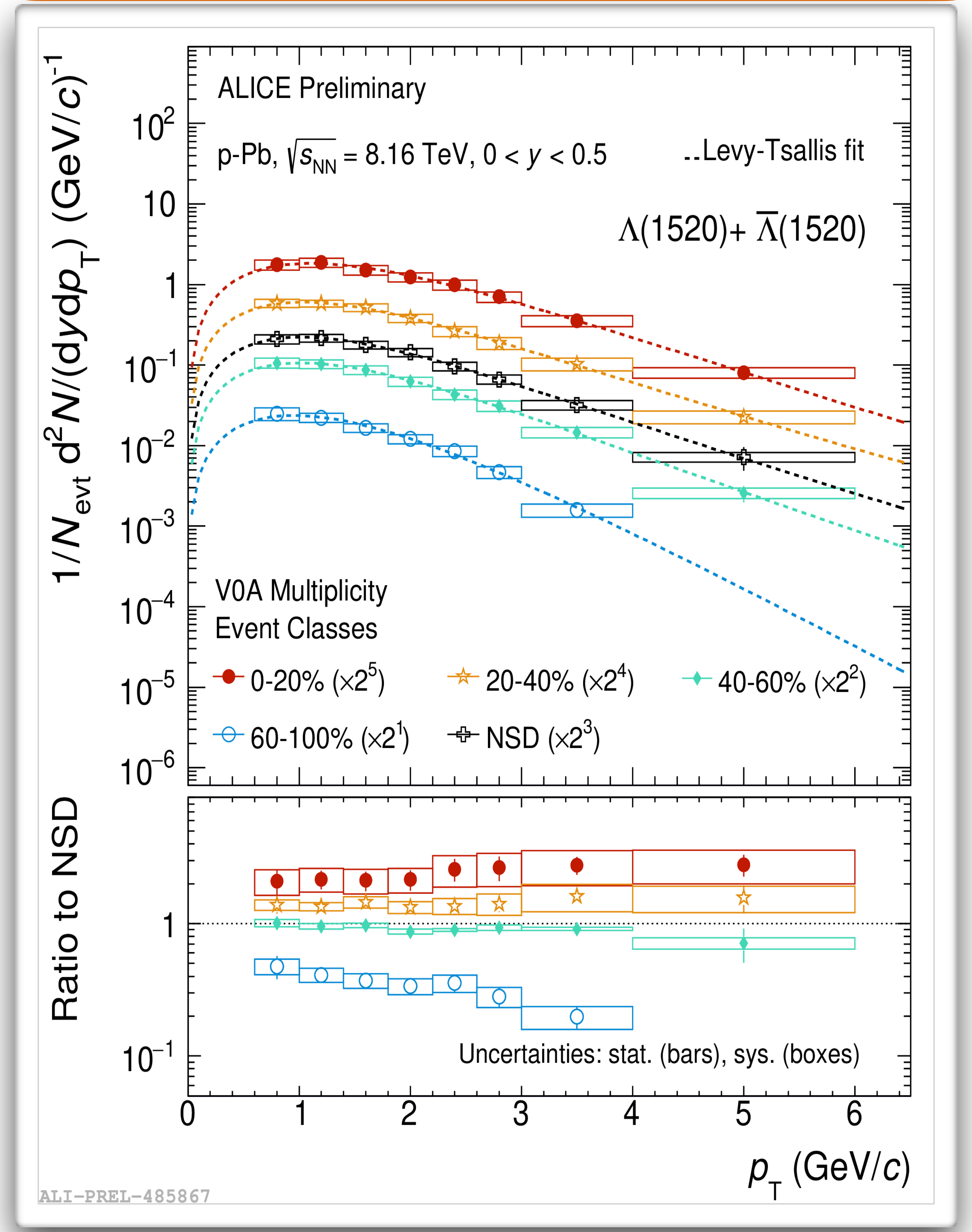
- **Transverse momentum spectra**
- p_{T} integrated yield
- Mean traverse momentum
- Resonance to stable particle ratio

Transverse Momentum (p_T) Spectra

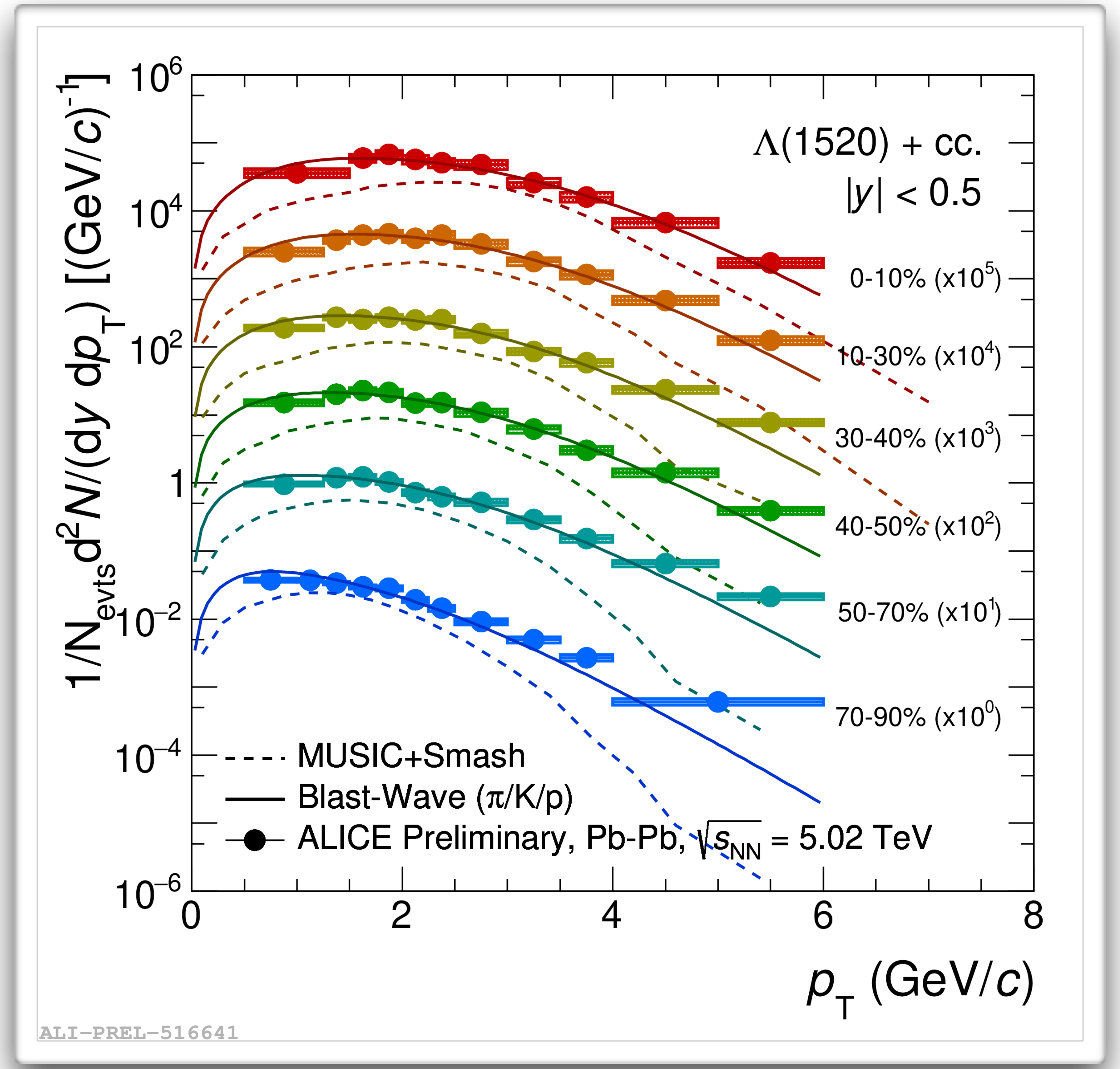
$\Lambda(1520)$, pp, $\sqrt{s} = 13$ TeV



$\Lambda(1520)$, p – Pb, $\sqrt{s_{NN}} = 5.02$ TeV



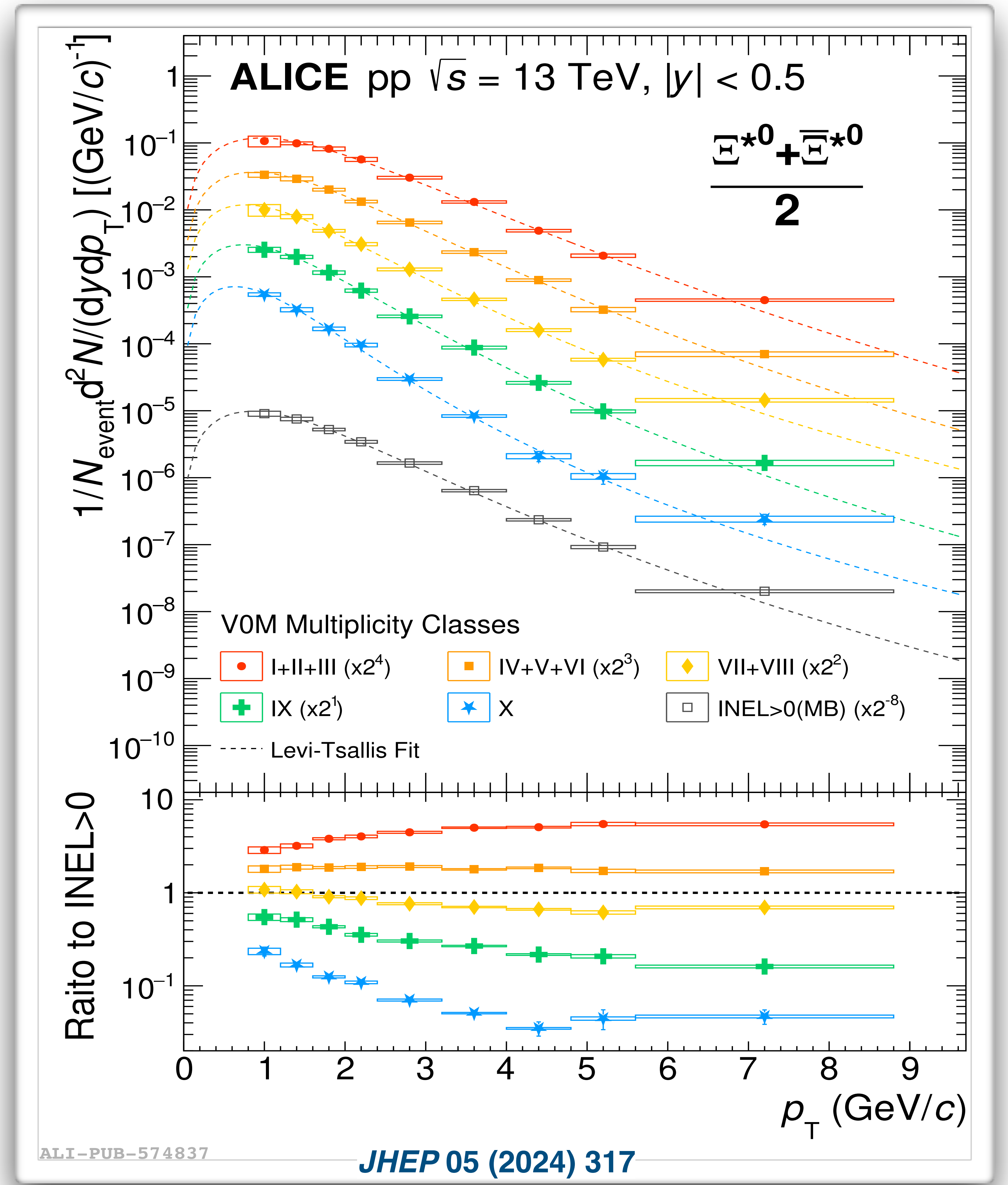
$\Lambda(1520)$, Pb – Pb, $\sqrt{s_{NN}} = 5.02$ TeV



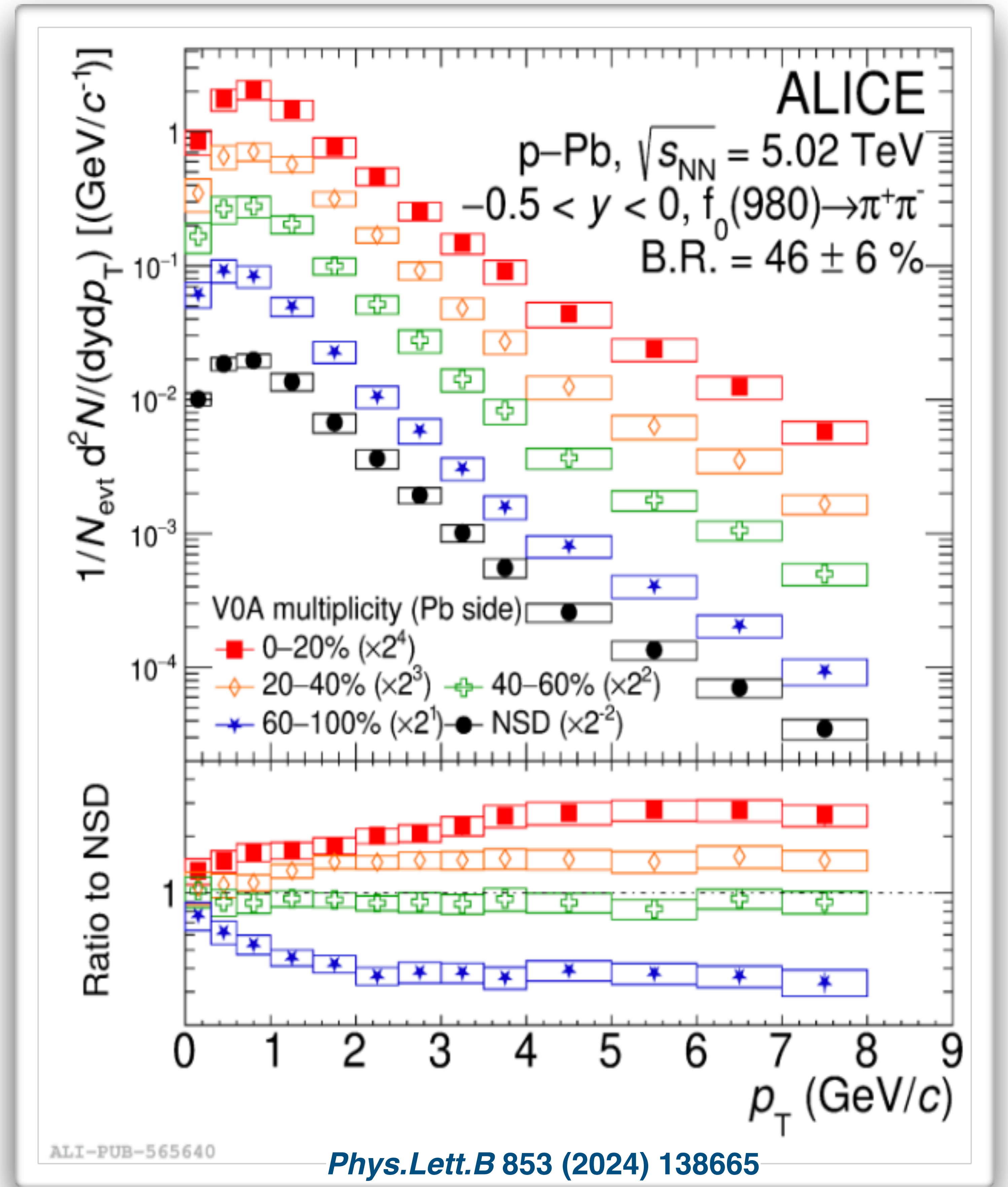
- Spectral shape changes and gets harder with increasing multiplicity, driven by stronger radial flow. (production of more high p_T particles in higher multiplicity classes)
- Changes in spectral shape primarily affect low p_T particles.

Transverse Momentum (p_T) Spectra

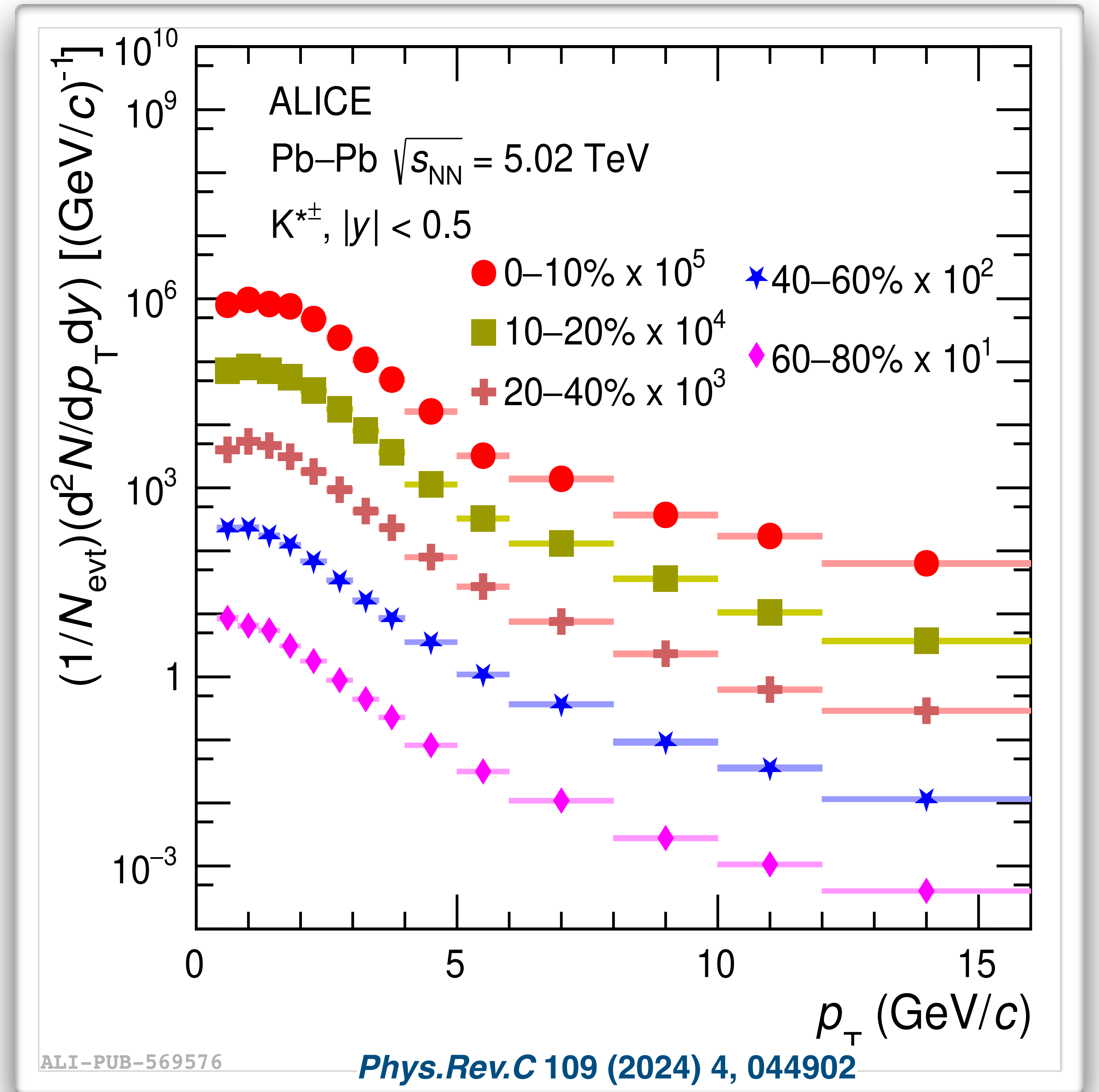
$\Xi(1530)$, pp, $\sqrt{s} = 13$ TeV



$f_0(980)$, p – Pb, $\sqrt{s_{NN}} = 5.02$ TeV



$K^{*\pm}(892)$, Pb – Pb, $\sqrt{s_{NN}} = 5.02$ TeV



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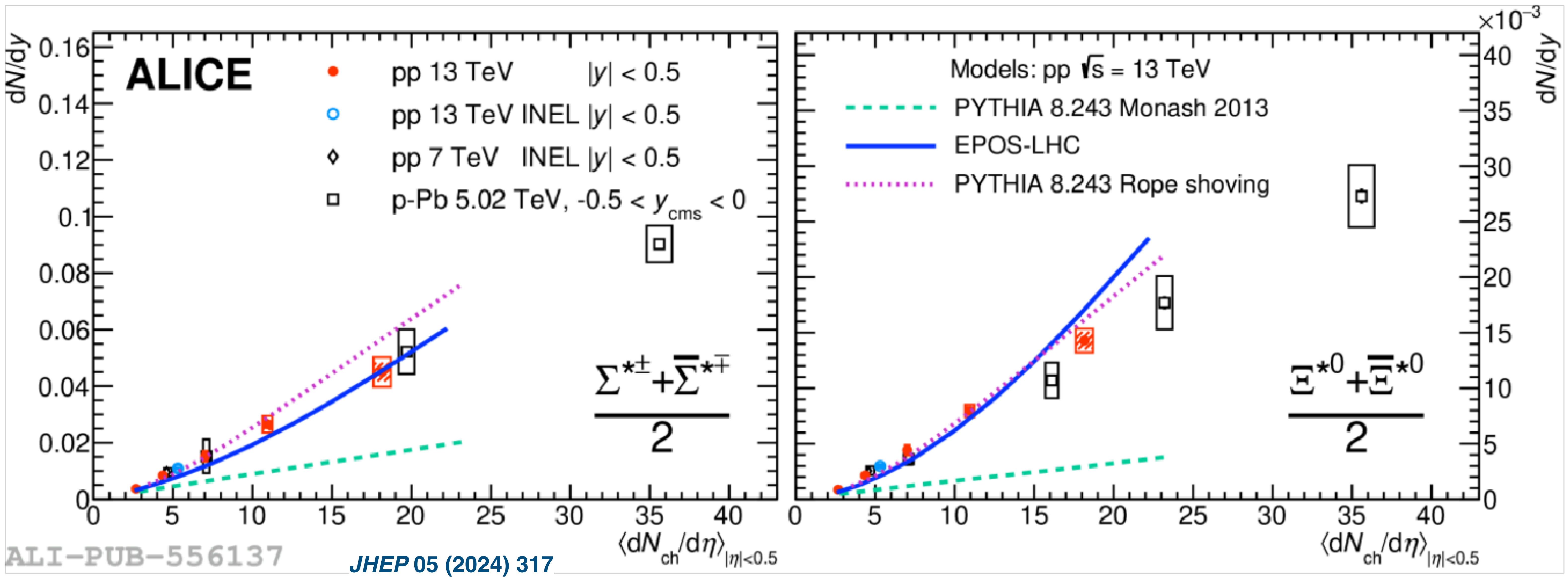
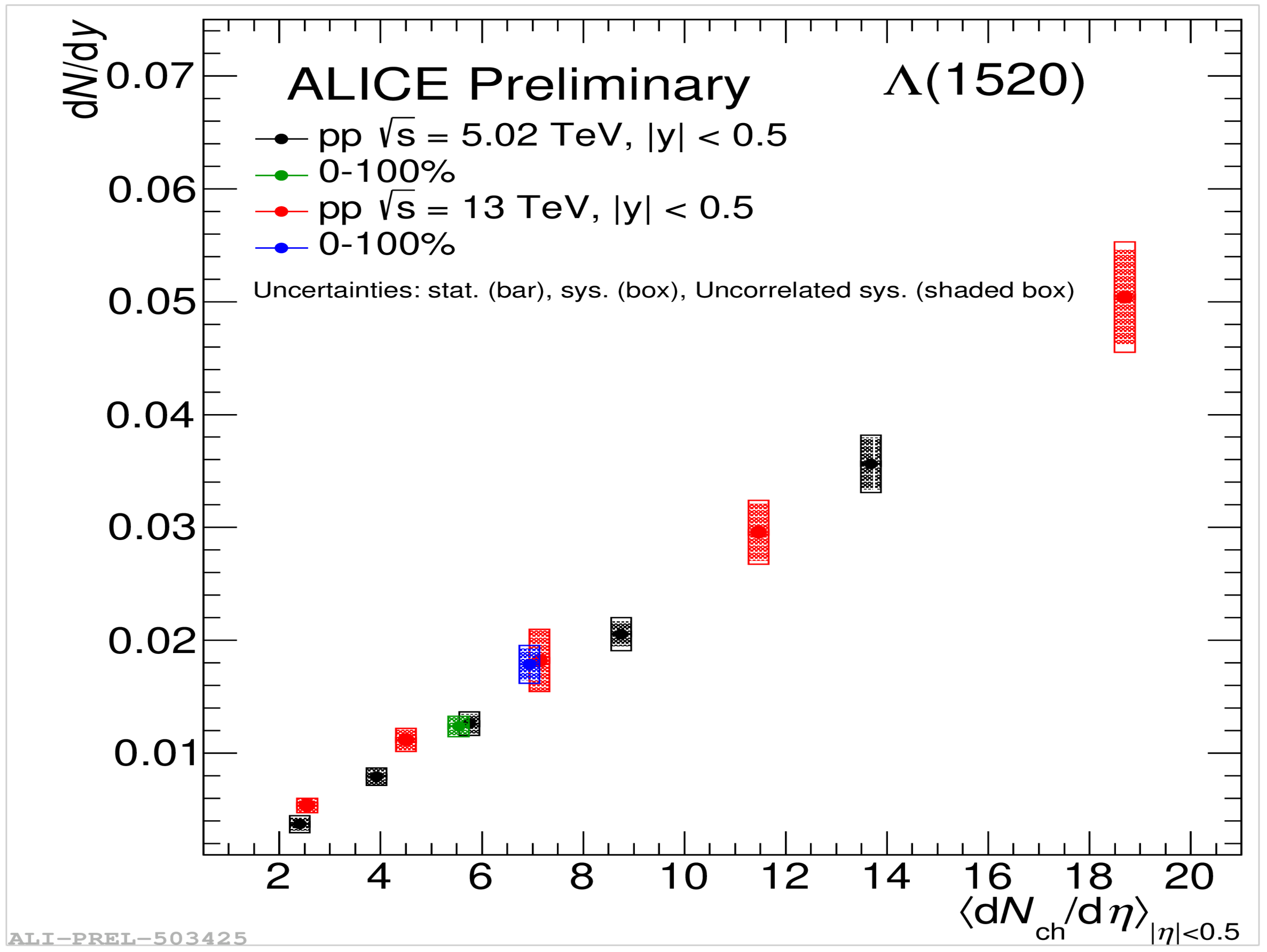
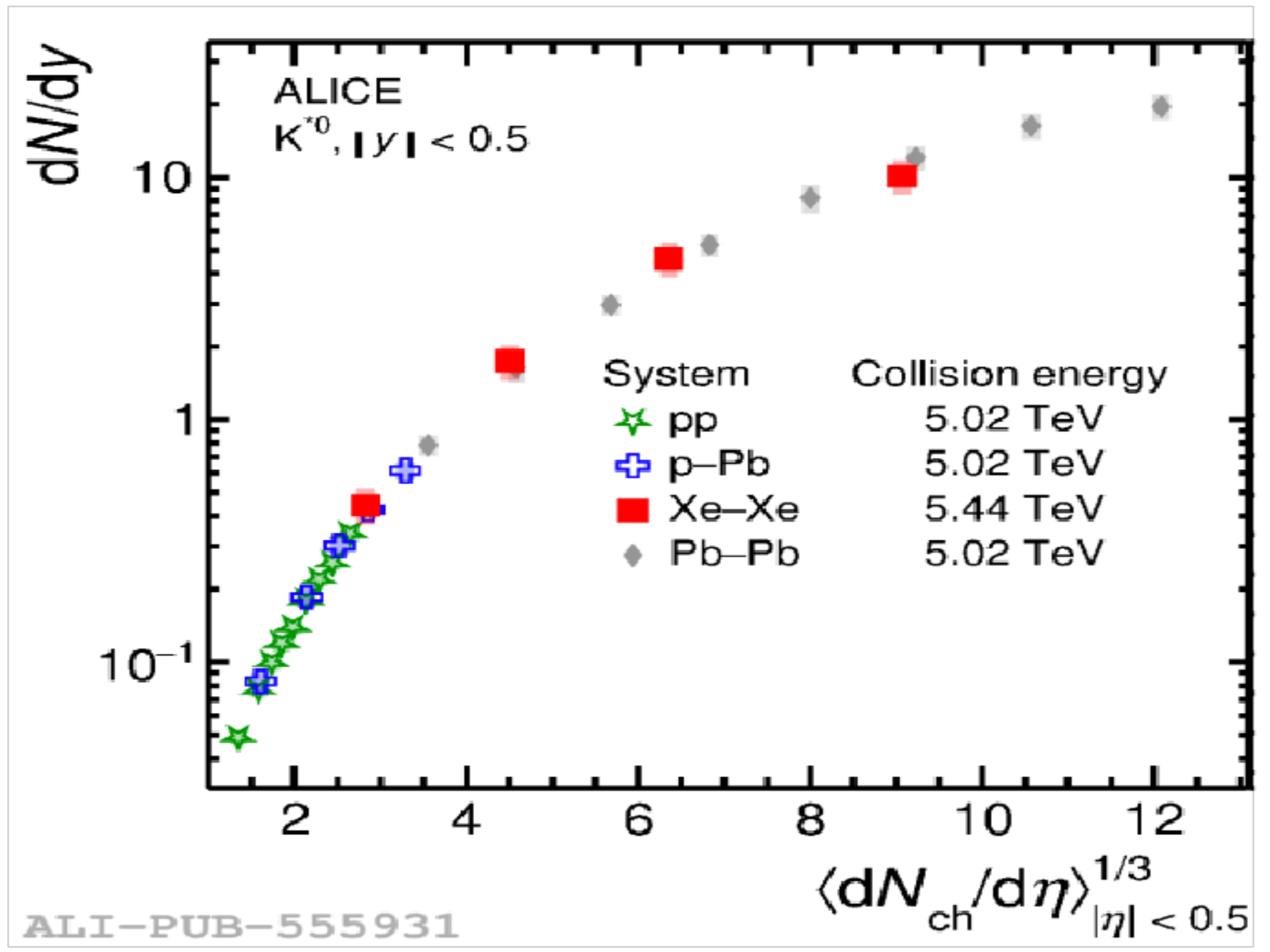
p_{T} integrated yield ($\mathrm{d}N/\mathrm{d}y$) vs. $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$







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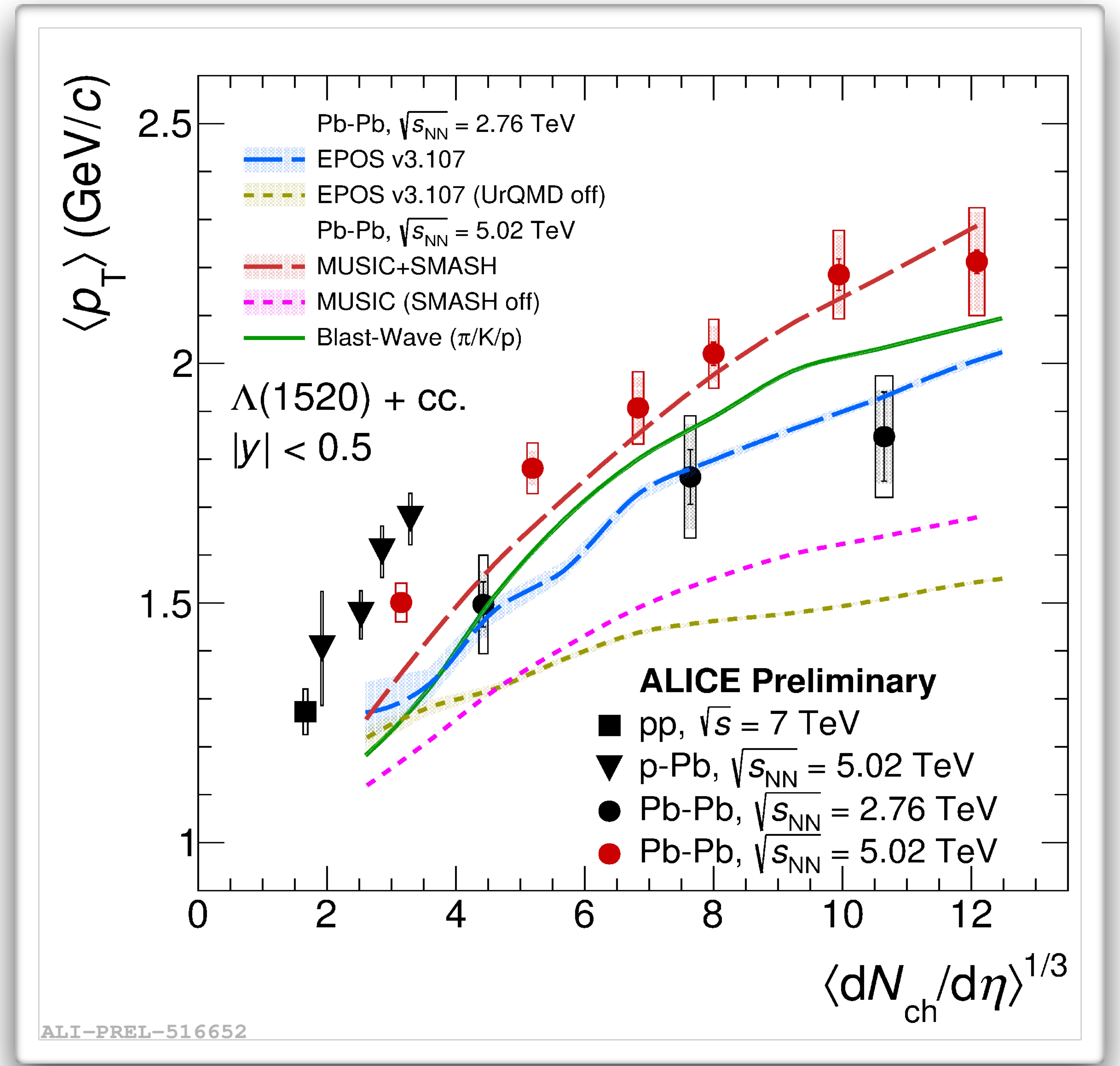
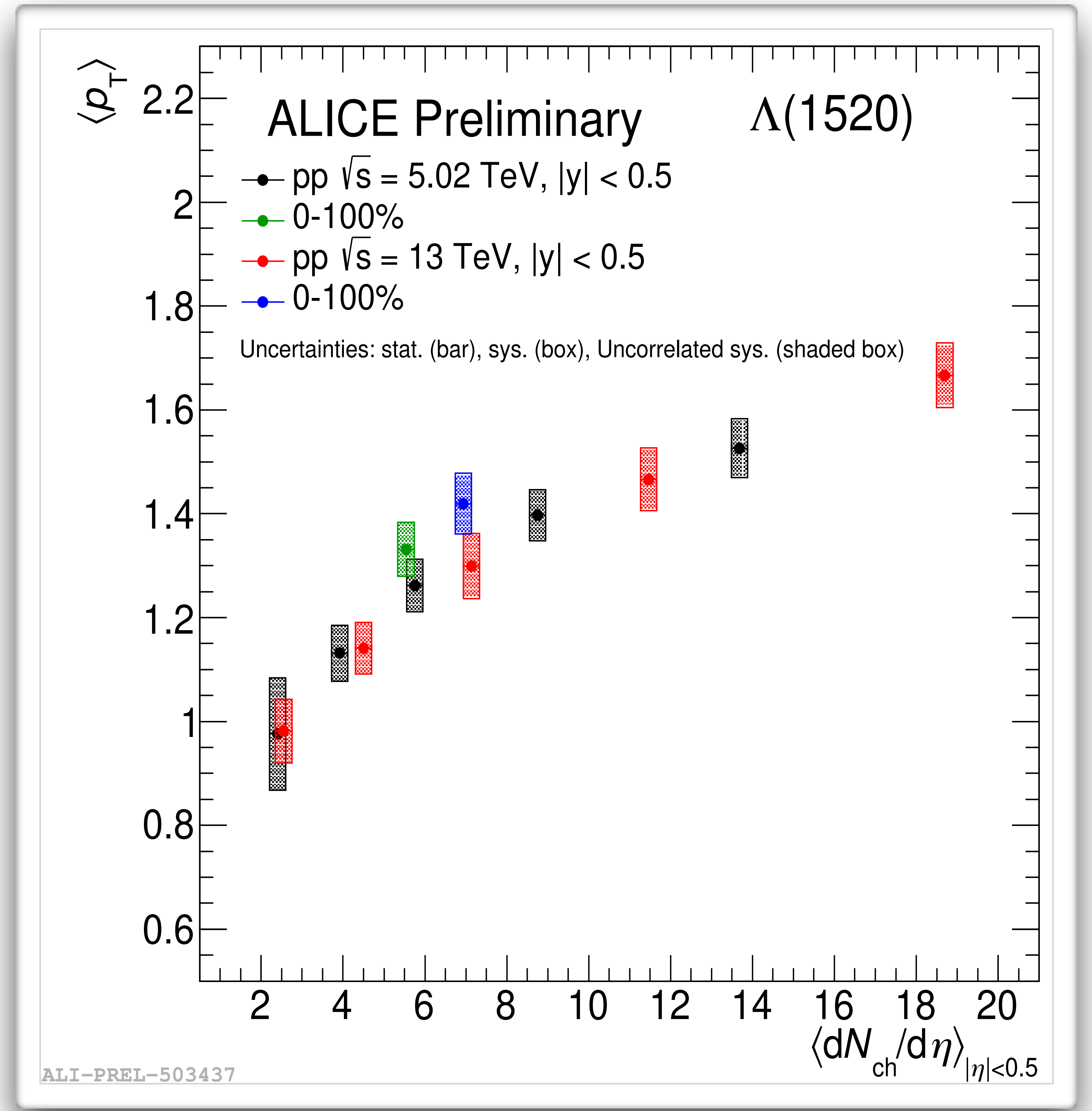
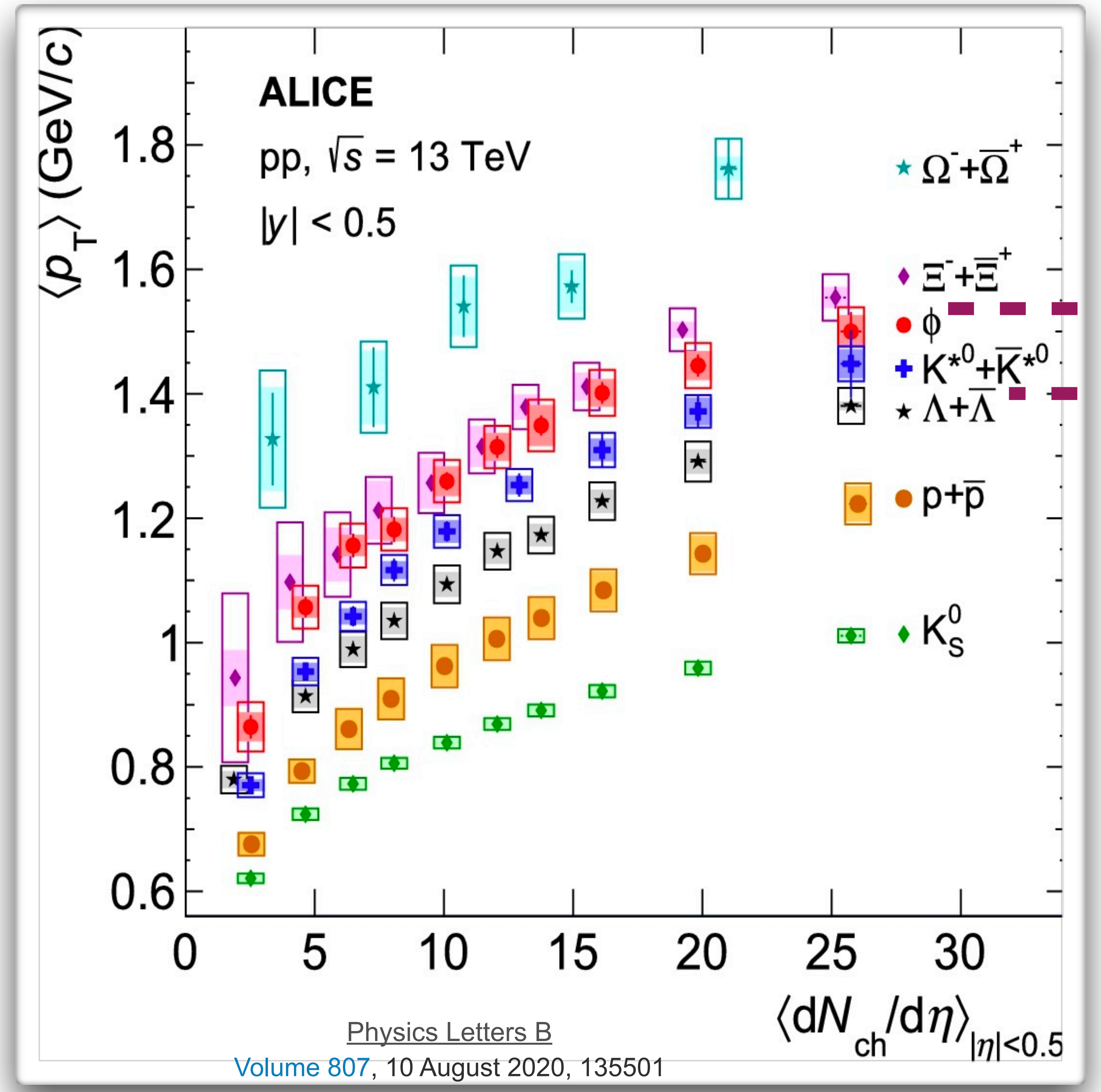
- The measured $\mathrm{d}N/\mathrm{d}y$ exhibit a linear increase with increasing $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$
- As observed for other hadron species, resonance production rate does not depend on the collision energy and size of colliding system → it is driven by the event multiplicity.

Mean transverse momentum ($\langle p_T \rangle$) vs. $dN_{ch}/d\eta$



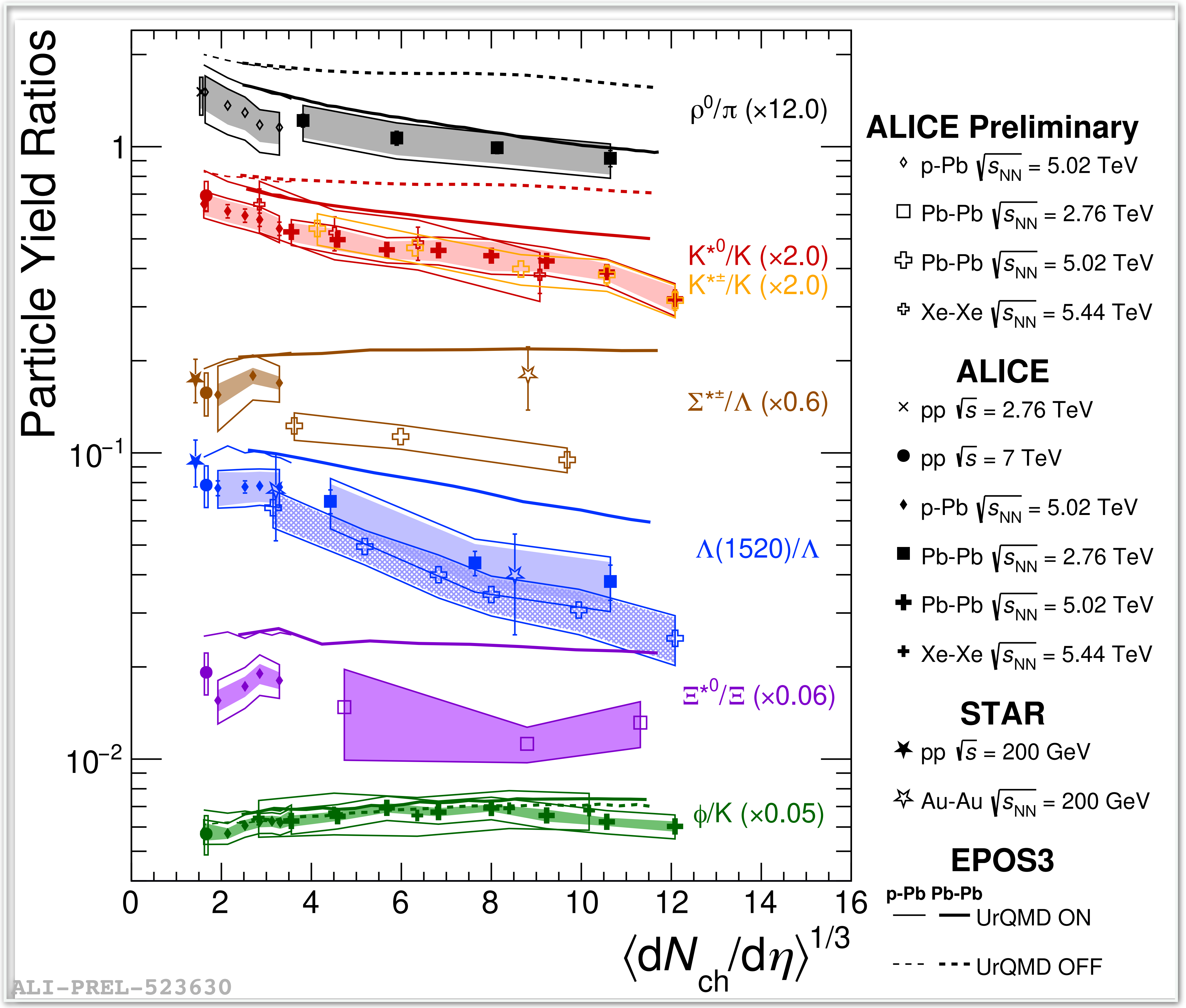




- An increasing trend of $\langle p_T \rangle$ from low to high multiplicity is observed for all measured particles.
- Steeper increase with multiplicity in small system i.e $\langle p_T \rangle$ is larger in small collision system compared to heavy-ion at similar charged particle multiplicity.
- Mass ordering of $\langle p_T \rangle$ is not observed for mesonic resonances.

Resonance to stable particle yield ratio

cτ (fm)
1.3
4.2
5.5
12.6
21.7
46.4



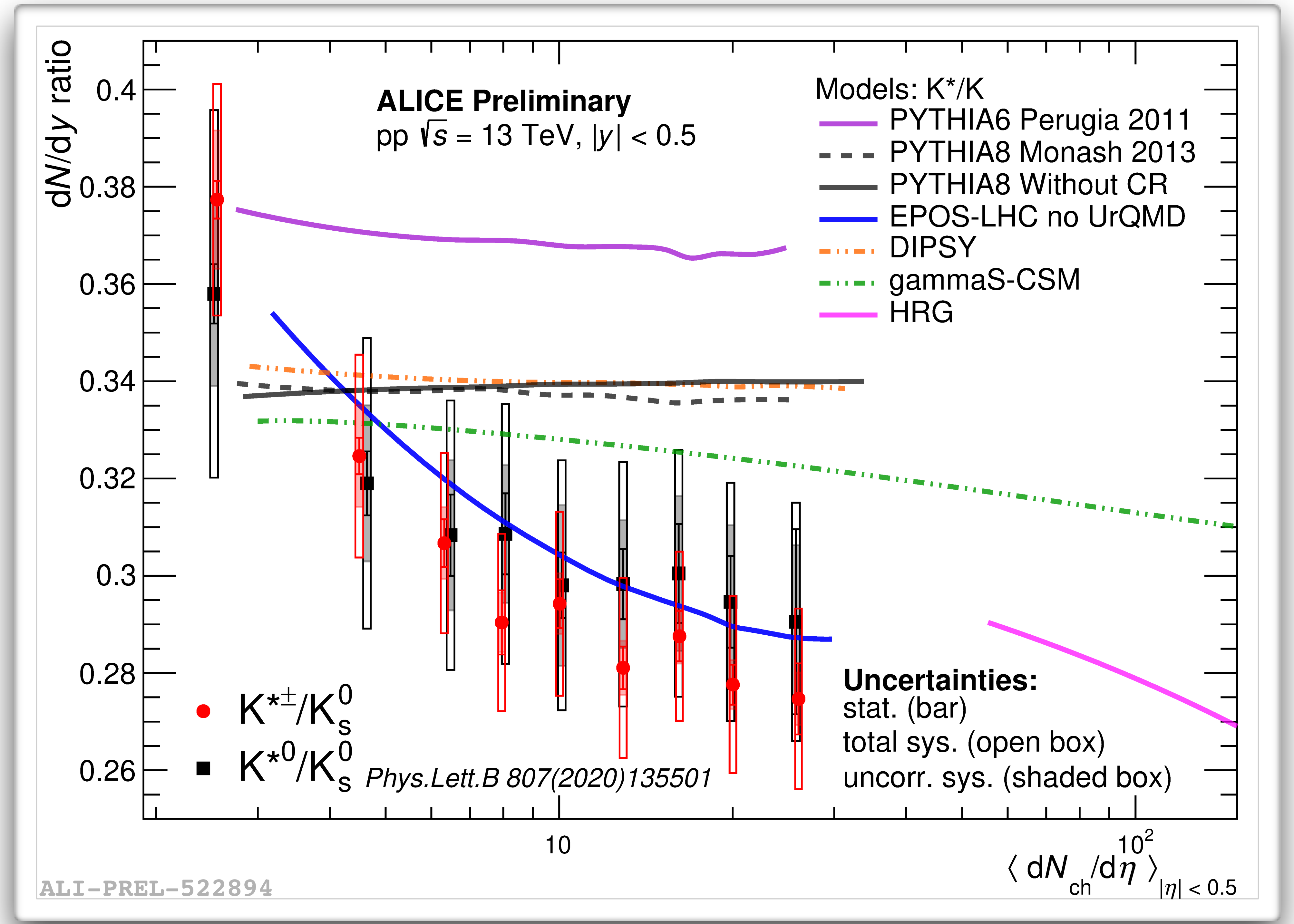
- **Strong suppression** of the yield ratio of short-lived resonances to the stable/ground state hadrons.
- **Weak/no suppression** for ratios involving **long-lived resonances.**
- **No energy dependence** of the production of resonance particles from RHIC to LHC.
- **Suppression** depends on the **interplay between rescattering** and **regeneration effects**, which depend on scattering cross-section of resonance decay daughters.

Suppressed | Not Suppressed

Resonance : Lifetime (fm/c) :	ρ^0 1.3	$K^{*0,\pm}$ ~ 4.0-4.16	$\Sigma^{*\pm}$ ~ 5.0-5.5	$\Lambda(1520)$ 12.6	Ξ^{*0} 21.7	ϕ 46.3

- In most cases **EPOS3 with UrQMD** describes the trend **qualitatively**, suggesting **rescattering** of decay products in hadronic phase.

Evidence of finite hadronic phase in pp and p–Pb?



$K^{*\pm}/K^0_s$, pp,13 TeV

- Suppression of $K^{*\pm}/K^0_s$ and K^{*}/K^0_s with increasing multiplicity in pp collisions (suppression at ~ 7σ level).

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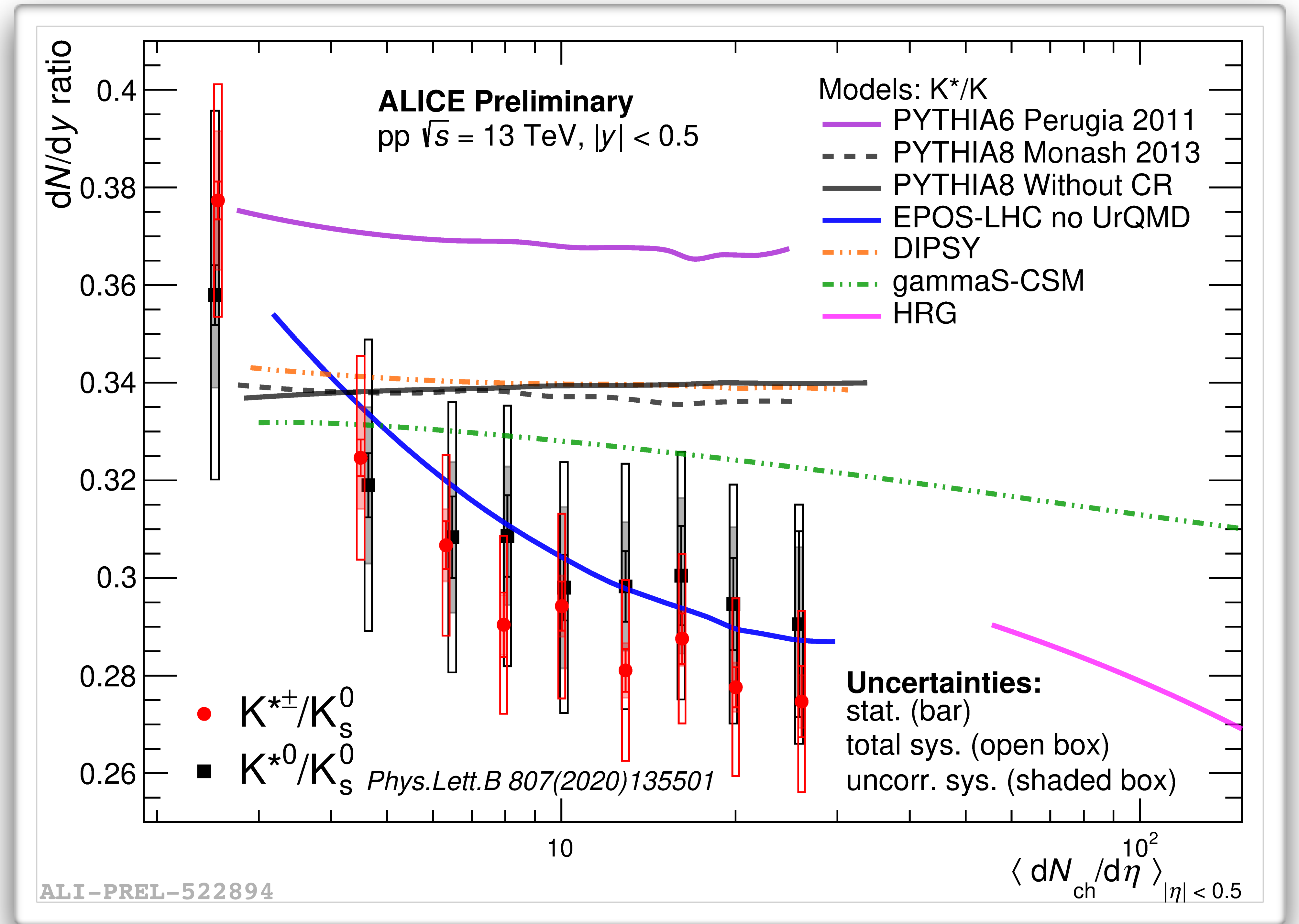

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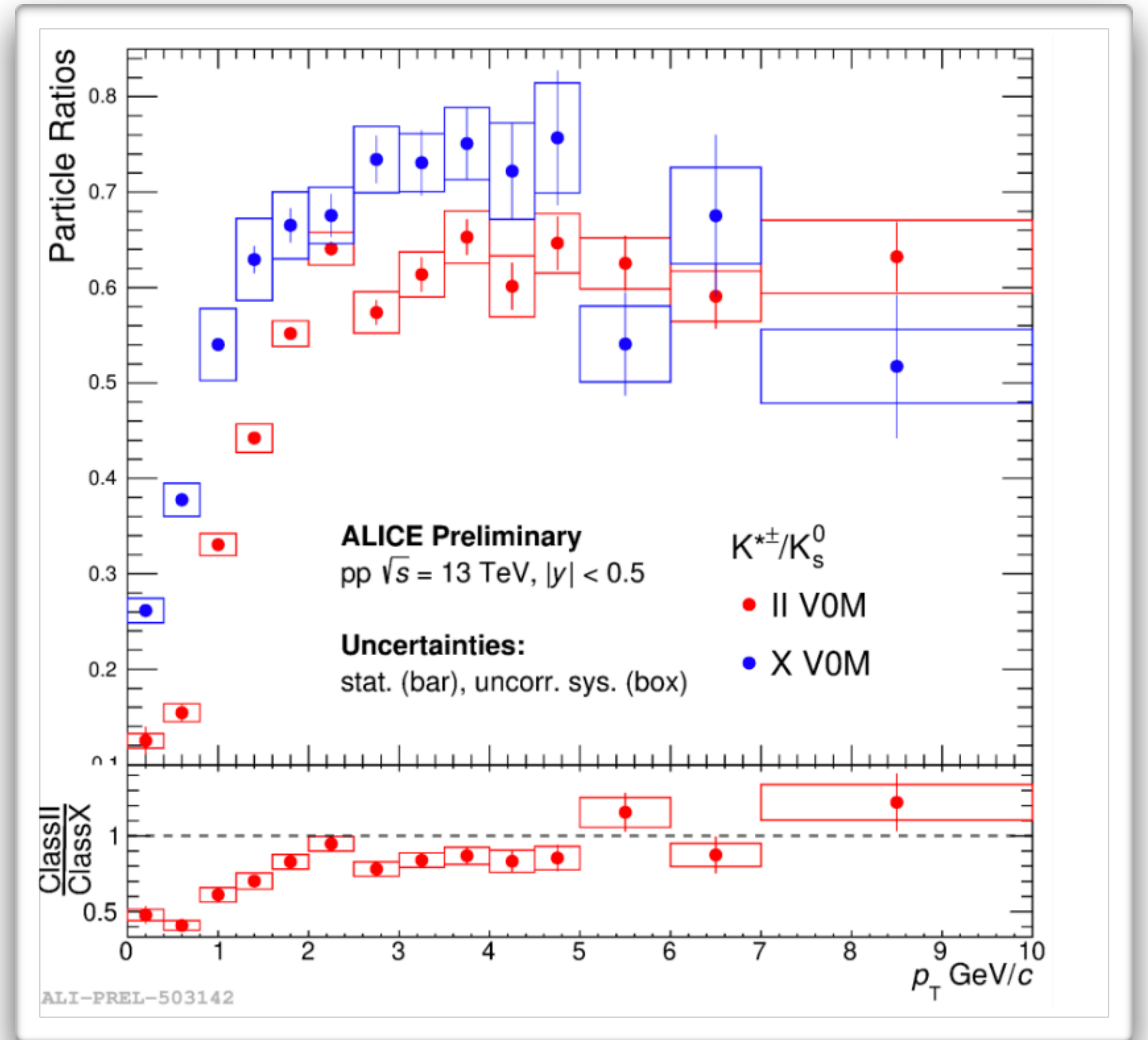
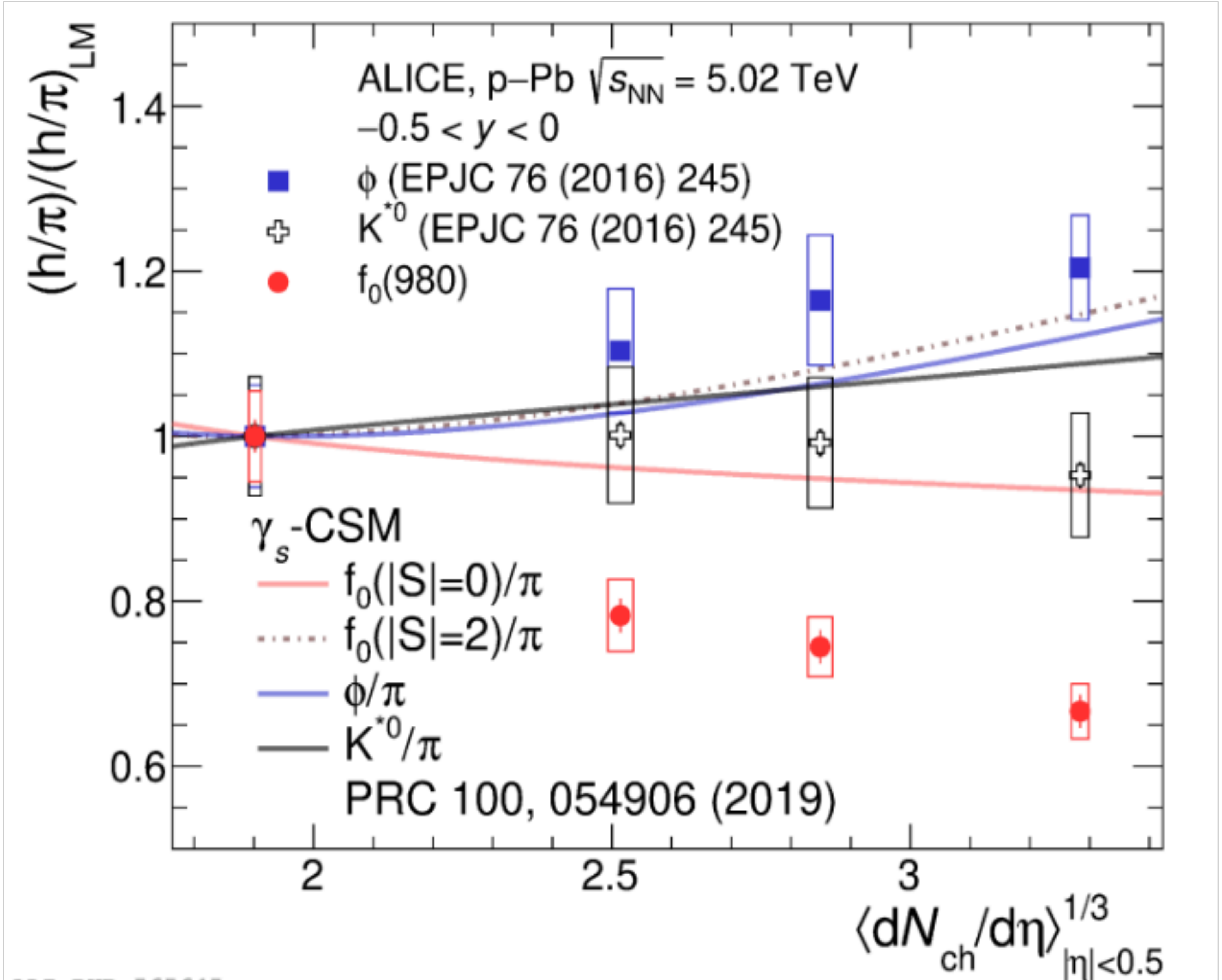


- Suppression of $K^{*\pm}/K^0_s$ and K^*/K^0_s with increasing multiplicity in pp collisions (suppression at ~ 7σ level).
- $K^{*\pm}/K^0_s$ ratio is suppressed at low p_T in high-multiplicity pp collisions compared to the low-multiplicity
- In AA collisions the stronger suppression of ratio at low p_T is interpreted as a signature for rescattering effects.
- Hint of a (short-lived) hadronic phase in pp collisions?

Evidence of finite hadronic phase in pp and p–Pb?

$f_0(980)$, p – Pb, @5.02 TeV



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- ϕ/π: is consistent with γ_s-CSM (no rescattering).

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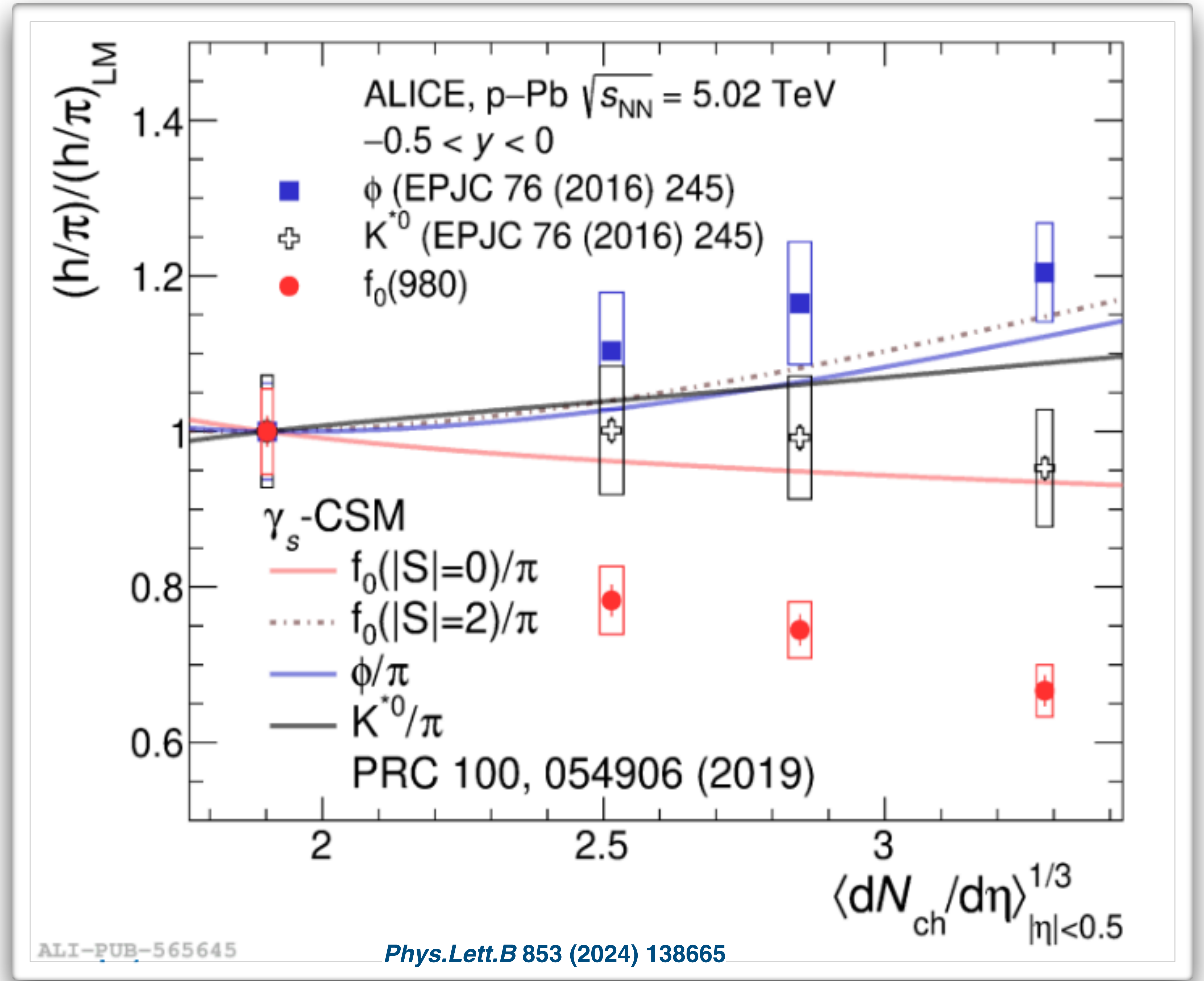
$f_0(980)$, p – Pb, @5.02 TeV



- ϕ/π: is consistent with γ_s-CSM (no rescattering).
- K^{*0}/π : independent of multiplicity due to competing effect between rescattering and strangeness enhancement but model shows a small hint of enhancement probably due to the strangeness content of K^{*0}.

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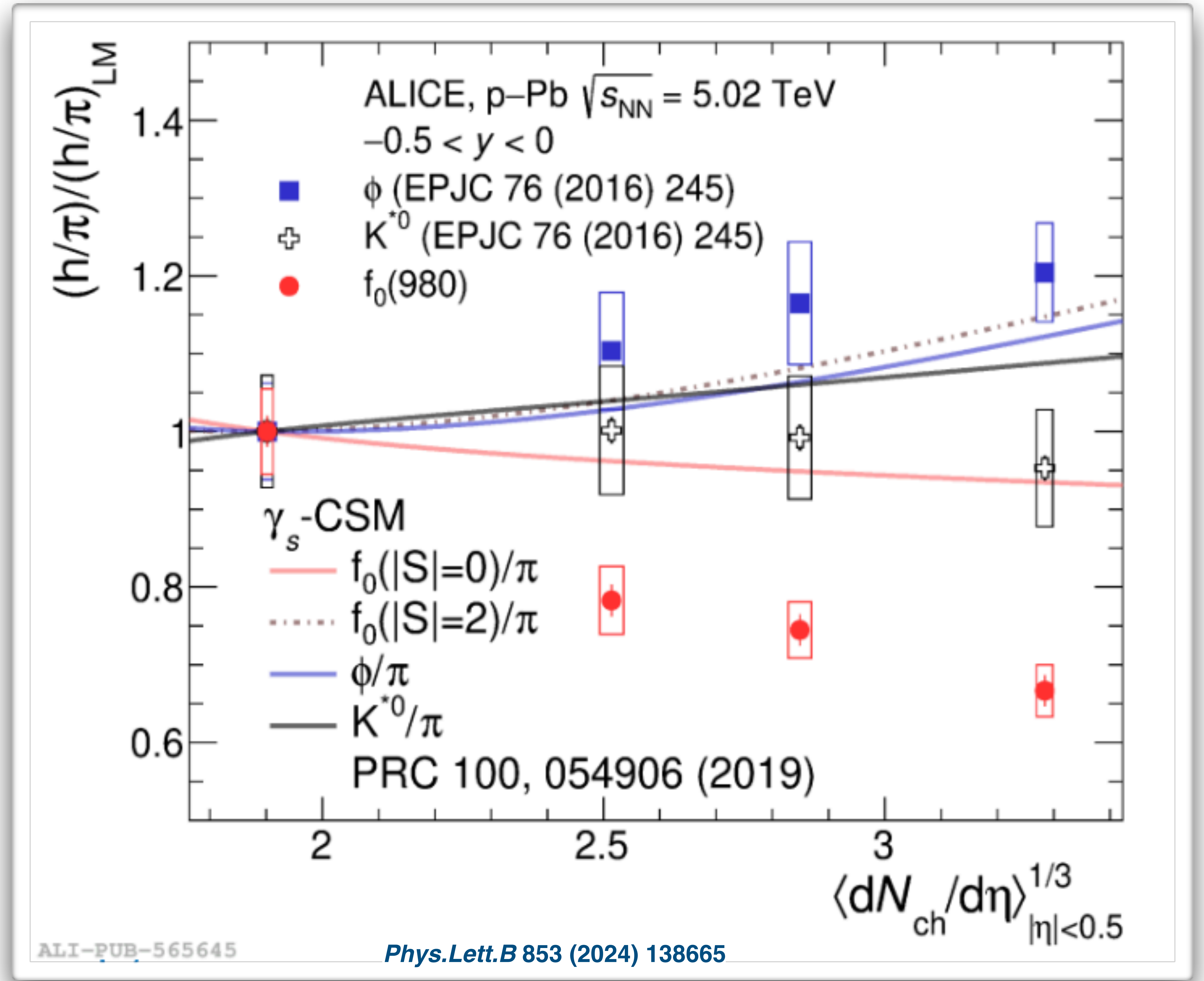
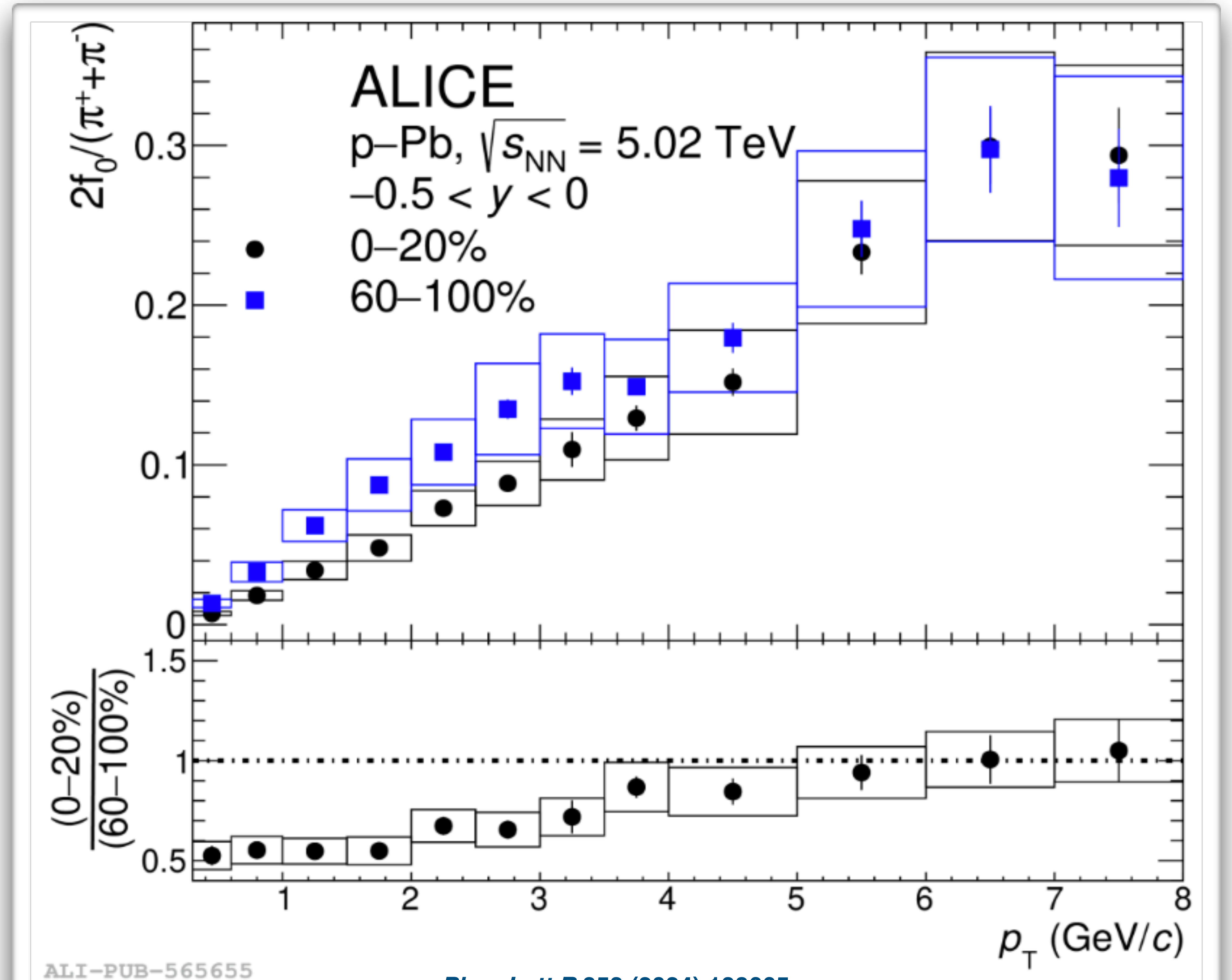


Phys.Lett.B 853 (2024) 138665

- ϕ/π: is consistent with γ_s-CSM (no rescattering).
- K^{*0}/π : independent of multiplicity due to competing effect between rescattering and strangeness enhancement but model shows a small hint of enhancement probably due to the strangeness content of K^{*0}.
- f_0/π : Significant suppression observed and is due to rescattering dominant at low p_T.
    - γ_s-CSM (no rescattering effects): qualitatively describe the decreasing trend observed in data but quantitatively underestimate the **suppression indicating the presence of final state hadronic interaction in data.**

Evidence of finite hadronic phase in pp and p–Pb?

f_0/π, p – Pb, @5.02 TeV



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- Suppression of f_0/π ratio at low p_T : f_0/π is lower in HM (0-20%) than LM (60-100%) at low p_T.
- Suppression attributed to rescattering effects in Pb—Pb collisions.
- **This might indicate the existence of a finite hadronic phase in p—Pb collisions?**

Summary

- Resonances play important role in understanding the in medium phenomena like rescattering and regeneration.
- Hardening of p_{T} spectra is observed from low to higher multiplicity classes suggests stronger radial flow in higher multiplicity classes.
- p_{T} integrated yield and $\langle p_{\mathrm{T}} \rangle$ increases with increasing multiplicity reflects enhanced particle production in higher multiplicity classes.
- Yield for similar multiplicity is independent of collisions system and energy.
- $\langle p_{\mathrm{T}} \rangle$ at similar multiplicity class is $\langle p_{\mathrm{T}} \rangle(\mathrm{pp}) > \langle p_{\mathrm{T}} \rangle(\mathrm{p-Pb}) > \langle p_{\mathrm{T}} \rangle(\mathrm{Xe-Xe}) \sim \langle p_{\mathrm{T}} \rangle(\mathrm{Pb-Pb})$.

Summary

- Suppression in yield ratio of $K^{*\pm}/K^0_S$, K^{*0}/K^0_S, and $\Lambda(1520)/\Lambda$ ratio is observed for central Pb—Pb collisions due to re-scattering effect.
- Suppression of yield ratio for short-lived resonances such as K^{*0}/K^0_S at low p_T in high-multiplicity pp collisions compared to low-multiplicity collisions might provides evidence for hadronic phase effects.
- No such suppression is observed for ϕ/K (both pp and Pb—Pb) and $\Lambda(1520)/\Lambda$ (pp and p—Pb) in small collisions systems.
- Suppression in yield ratio might suggest potential existence of finite hadronic phase in small systems.
- **Stay tuned for more exciting results with large statistics Run 3 data.**

Thank you
for your kind attention!!