Study of resonances flow and production in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.36 TeV with ALICE

ATHIC 2025

Sarjeeta Gami, on behalf of the ALICE collaboration

National Institute of Science Education and Research (HBNI), Jatni, India

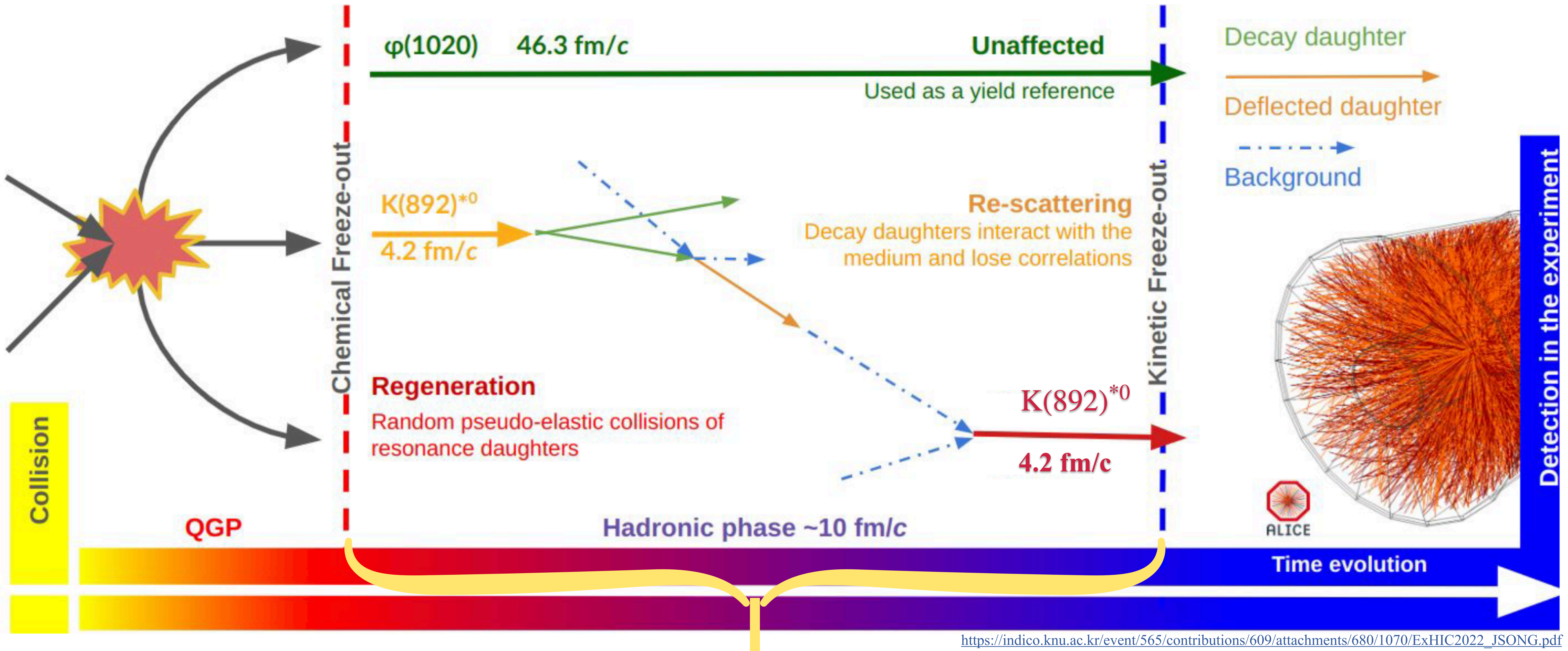
10th Asian Triangle Heavy-Ion Conference - ATHIC 2025

Outline

- Motivation
- ALICE detector
- Highlights from Run 2 results
- First look of Run 3 results
- Summary and outlook

Resonances as probes of the hadronic phase

- Resonances are short-lived particles that decay via the strong interaction
- Suitable to probe hadronic phase via regeneration and re-scattering effects



https://indico.knu.ac.kr/event/565/contributions/609/attachments/680/1070/ExHIC2022_JSONG.pdf

Aim is to investigate hadronic phase effects via measurement of resonances

momentum distribution and azimuthal anisotropy

Observable : Particle ratios (Ex : K^{*0}/K, ϕ/K, …)

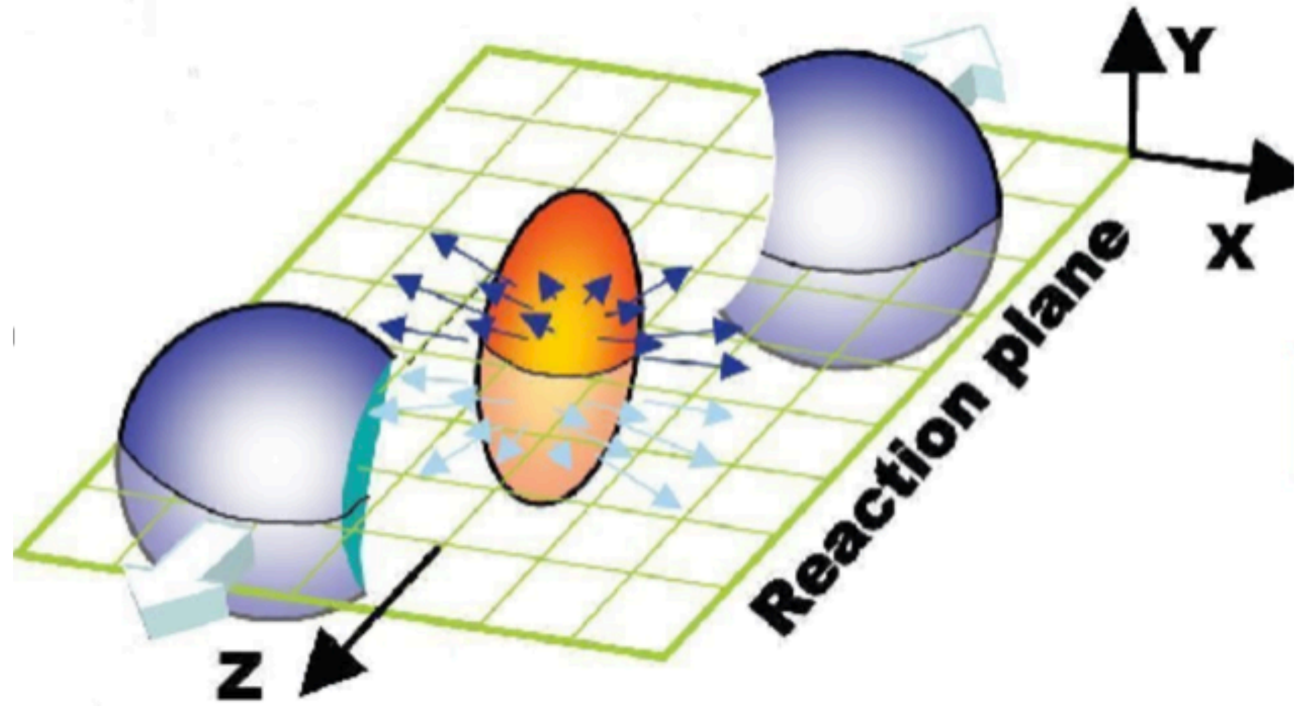
Observable : Resonance Flow (Ex : K^{*0}, ϕ, …)

Regeneration

- Pseudo-elastic scattering of decay products ➜ Enhanced yield

Re-scattering

- Elastic scattering or pseudo-elastic scattering of decay products
- Not reconstructed through invariant mass ➜ Reduced yield

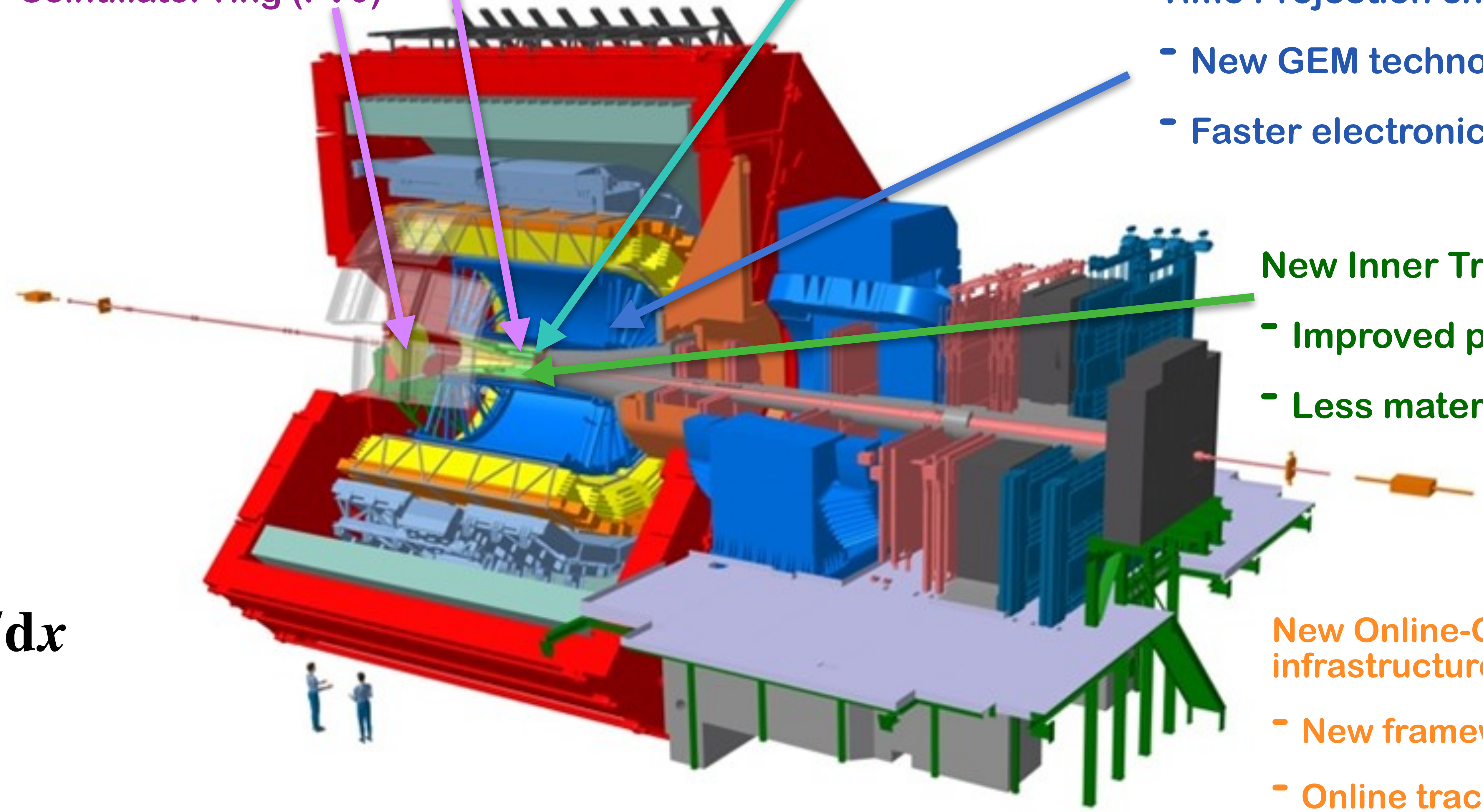


$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + \sum_{n=1}^{\infty} 2v_n \cos\left[n\left(\phi - \Psi_r\right)\right]\right)$$

$$v_n = \langle\langle \cos[n(\phi - \psi_r)] \rangle\rangle$$

ALICE detector

- Fast Interaction Trigger (FIT)
  - → Centrality/multiplicity estimation
- Inner Tracking System (ITS)
  - → Tracking of charge particles
  - → Reconstruction of vertices
- Time Projection Chamber (TPC)
  - → Momentum measurement
  - → Particle identification (PID) via $\mathrm{d}E/\mathrm{d}x$
  - → Tracking of charge particles
- Time Of Flight (TOF)
  - → Particle identification (PID) via time of flight



ALICE upgrades from Run 2 to Run 3

NIM A 958, 162116, (2020)

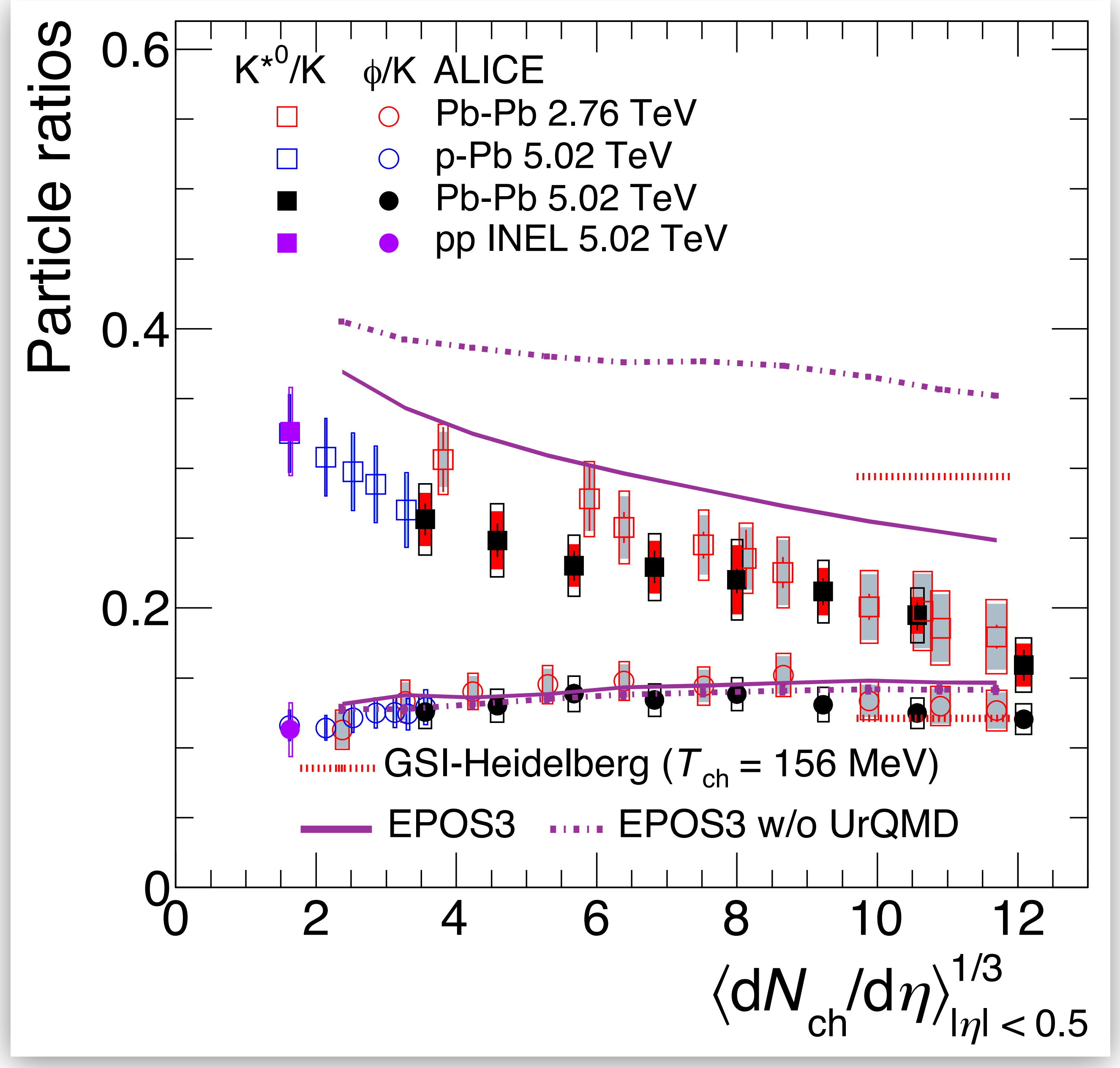
Interaction Rate for Pb – Pb Run 2 : 8 kHz ➔ Run 3 : 50 kHz

Enhanced statistics and the highest center-of-mass energy in Run 3 provides the opportunity for precise measurements of resonance flow and production

Highlights from Run 2 : Exploring hadronic phase

Particle ratios

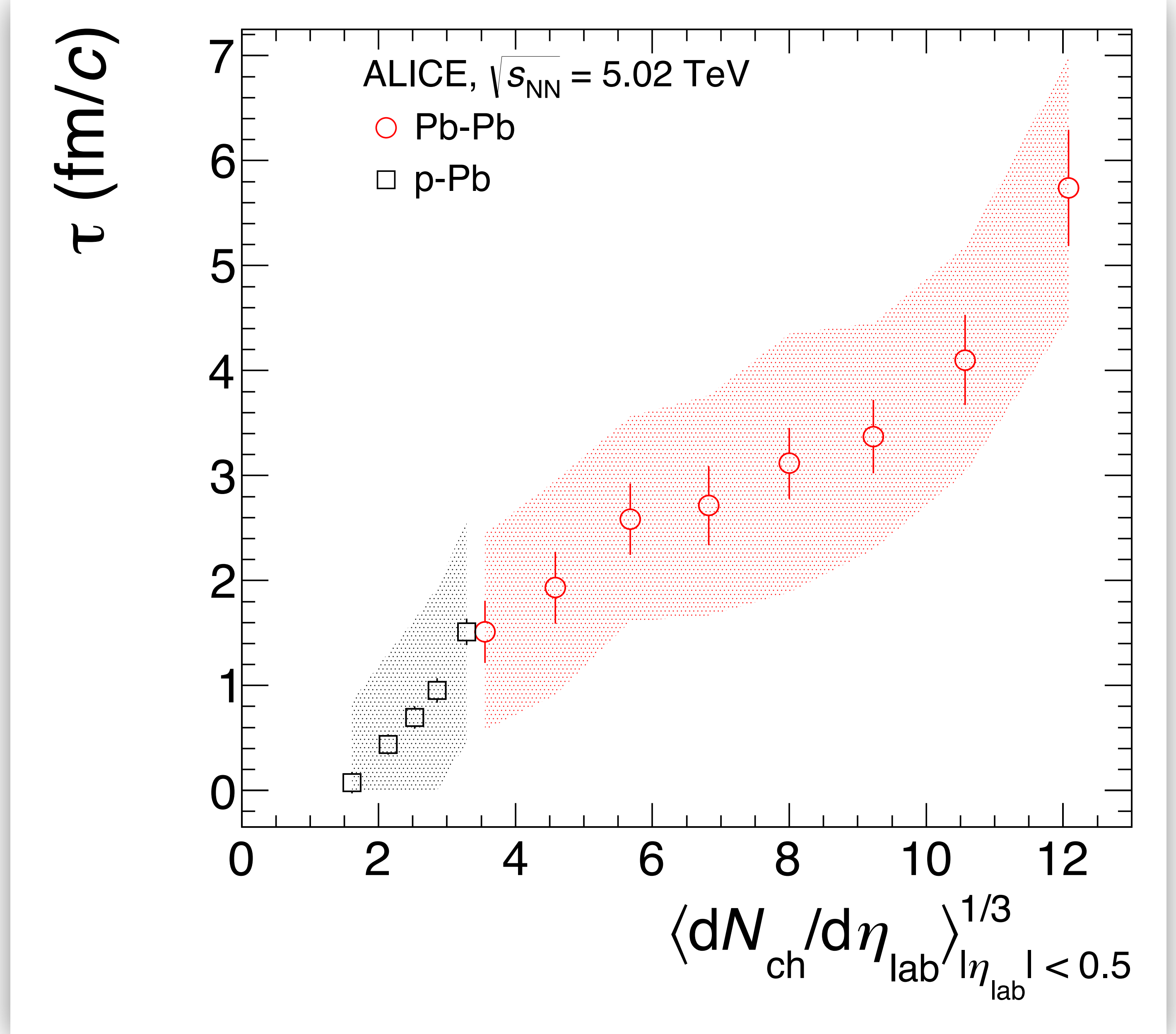
Phys. Lett. B 802, 135225, (2020)



- Suppression of K^{*0}/K in central heavy-ion collisions
- Indication of dominance of re-scattering of K^{*0} decay daughters over the regeneration effect
- No suppression of ϕ/K over wide centrality ranges
- EPOS3 with UrQMD (accounting for hadronic effects) reproduces the observed trend of the K^{*0}/K and ϕ/K ratios

Hadronic phase lifetime

Phys. Lett. B 802, 135225, (2020)



- Timespan between chemical and kinetic freeze-out is estimated by

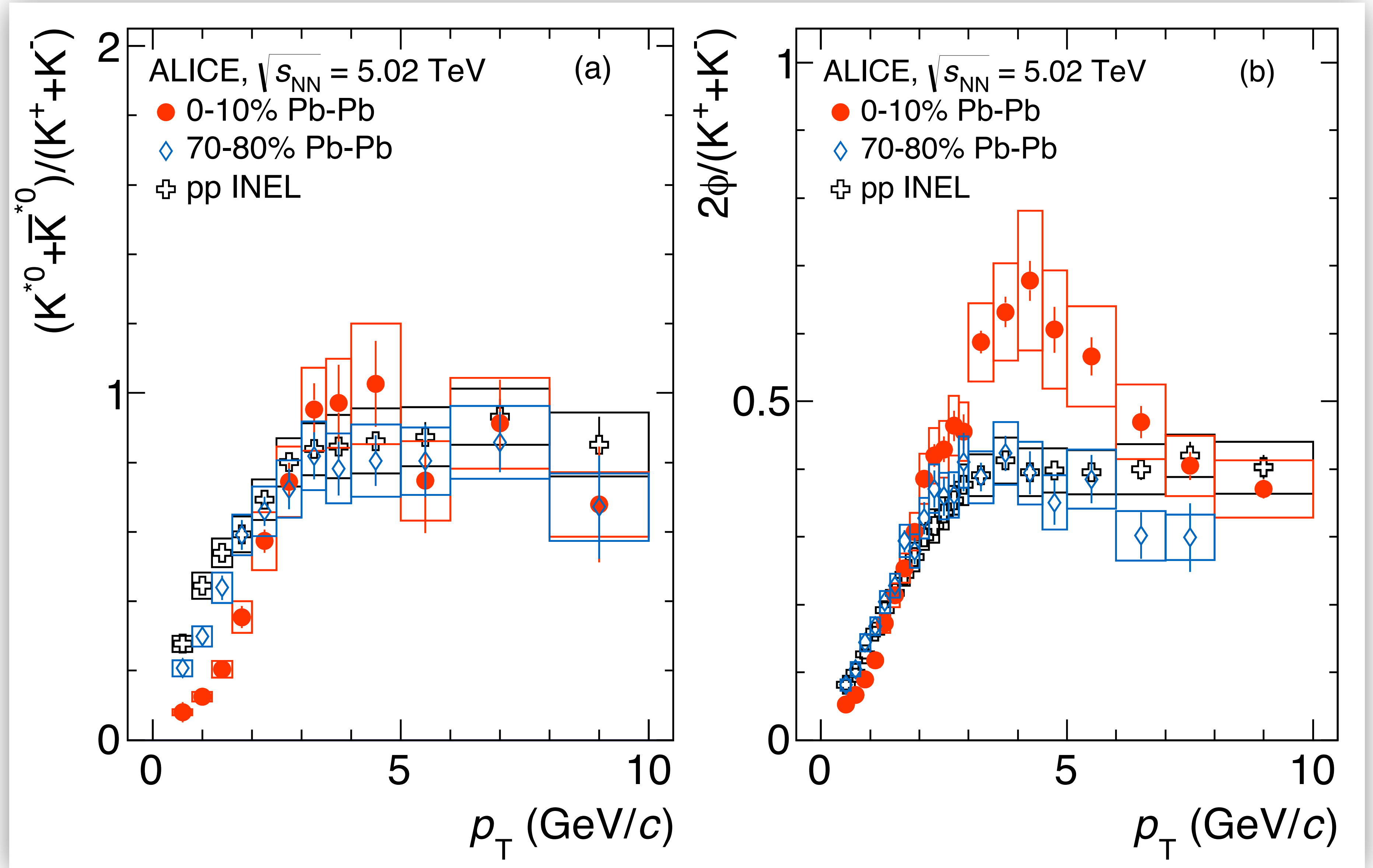
$$[K^{*0}/K]_{\text{kinetic (Pb-Pb)}} = [K^{*0}/K]_{\text{chemical (pp)}} \times e^{-\tau/\tau_{K^{*0}}}$$

- Lifetime of hadronic phase smoothly increases with multiplicity
- Lower limit of hadronic phase lifetime ~ 4-7 fm/c

Highlights from Run 2 : Hadronic phase observations

Differential yield ratios

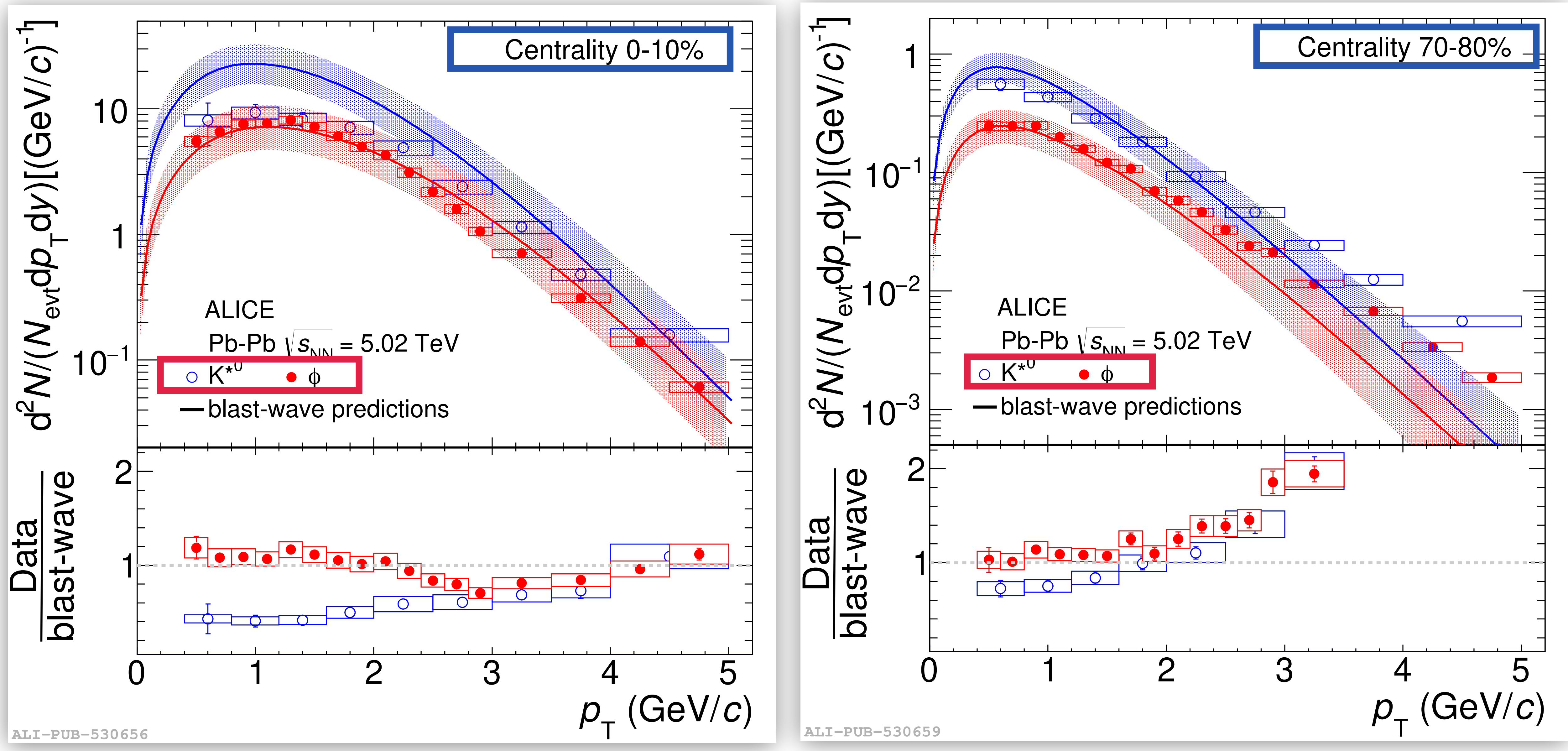
Phys. Lett. B 802, 135225, (2020)



- At low p_T, for central collisions K^{*0}/K ratio is more suppressed than ϕ/K ratio compared to peripheral (pp) collisions ➜ rescattering affects the low momentum particles
- At intermediate p_T, both ratios show enhancement for central collisions ➜ presence of larger radial flow in central collisions
- At high p_T, both ratios in central collisions are similar to peripheral (pp) collisions ➜ fragmentation is dominant hadron production mechanism

Transverse momentum spectra

Phys. Rev. C 106, 034907, (2022)

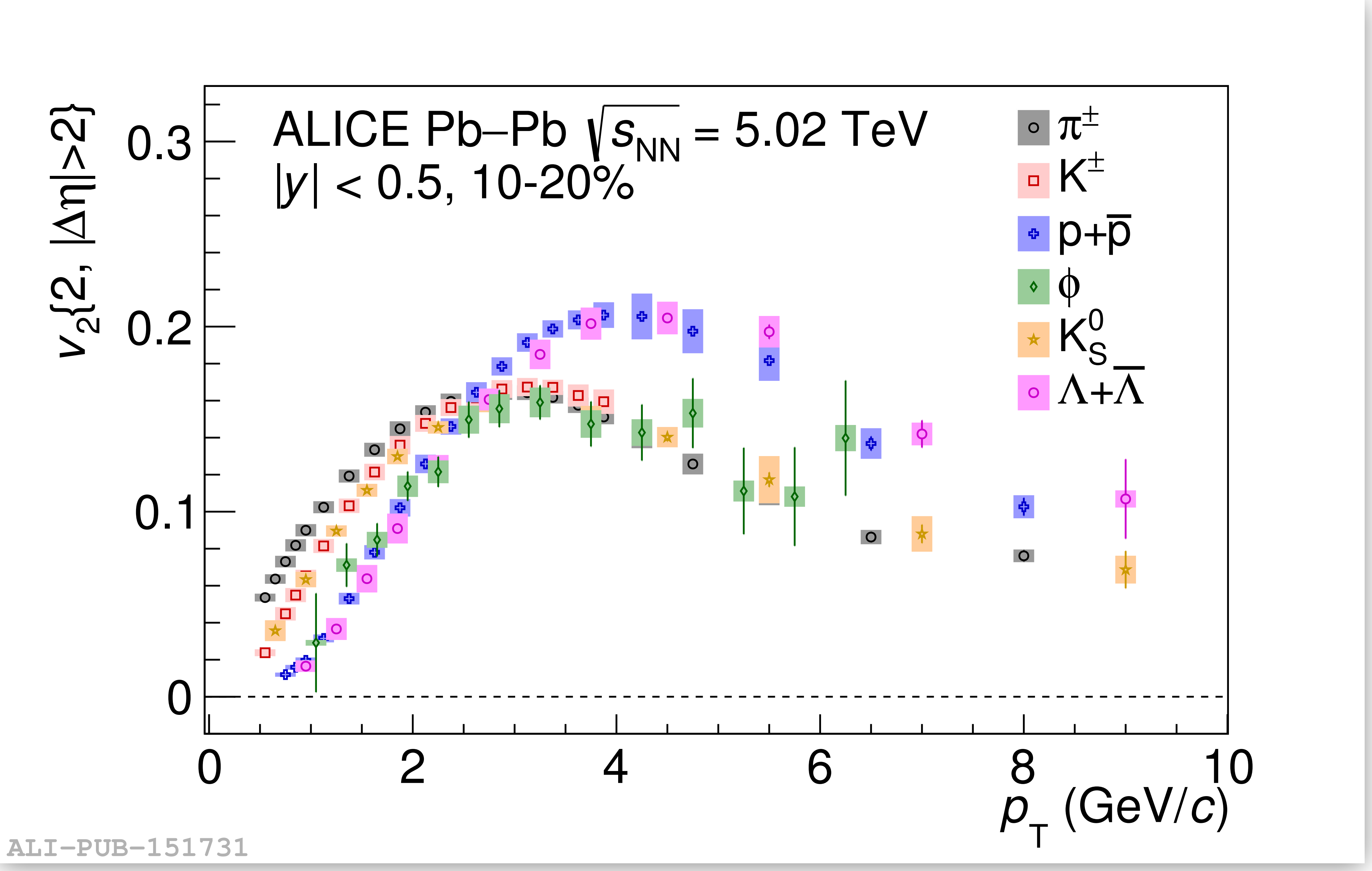


- p_T distributions of K^{*0} and ϕ with blast-wave model which does not include rescattering
- Blast-wave model predictions describe the p_T distribution of ϕ resonance at low p_T
- Suppression of yield of short-lived K^{*0} resonance relative to blast-wave prediction consistent with observation of dominance of rescattering effect

Highlights from Run 2 : Resonance elliptic flow

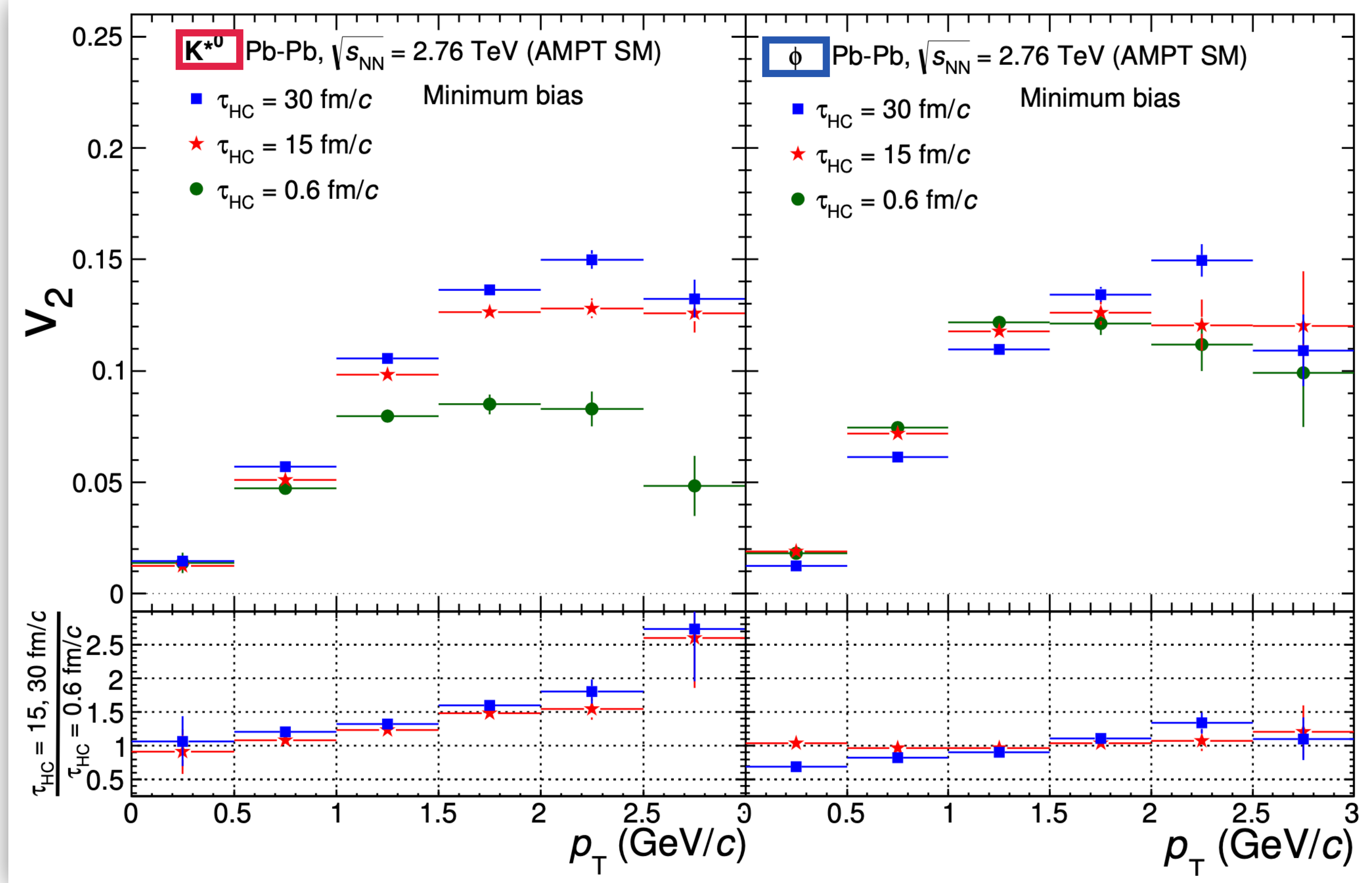
p_T – differential elliptic flow

JHEP09 (2018) 006



Effect of rescattering on flow from model

K. Nayak et al., DAE Symp.Nucl.Phys. 62 (2017) 962-963



- **Mass ordering** at lower p_T
- **Baryon meson crossing** at intermediate p_T
- **ϕ resonance scales with other mesons** at high p_T

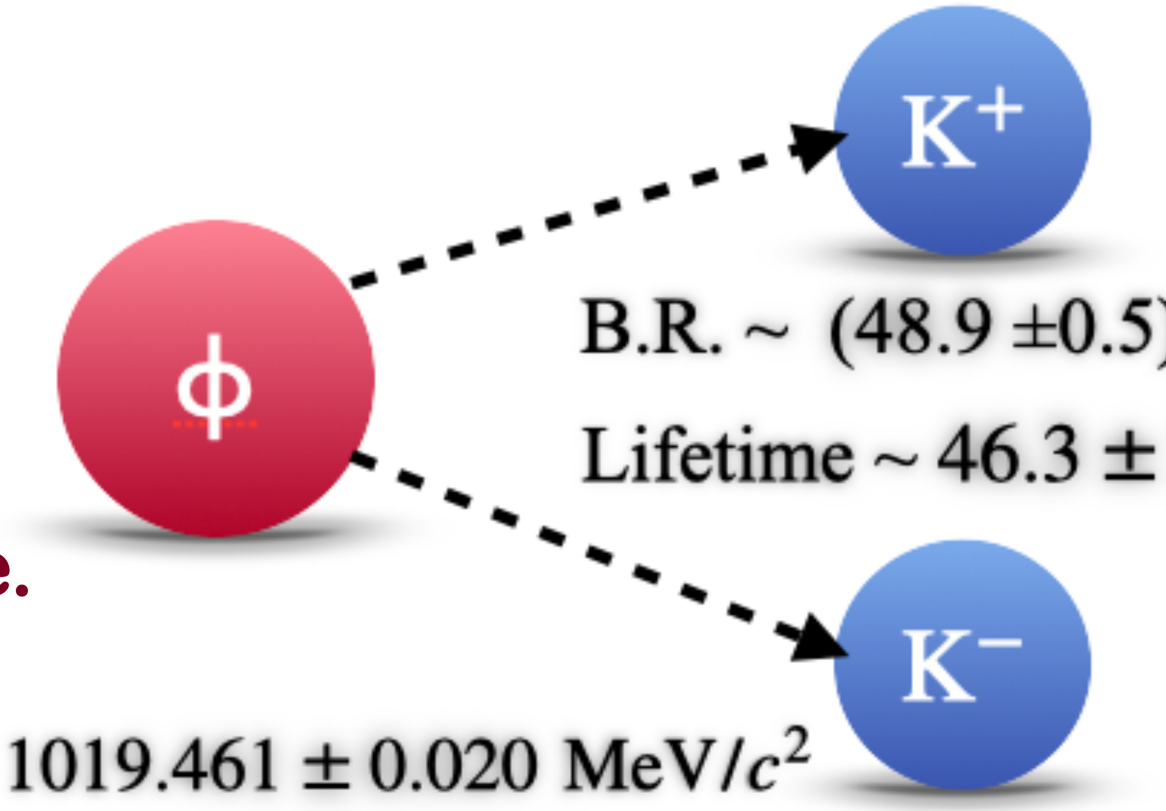
- Elliptic flow (v_2) of short-lived K^{*0} resonance is more affected by the hadronic phase interactions than longer-lived ϕ resonance suggested by AMPT model predictions

Measurement of resonances in Run 3

- Resonances are reconstructed using the invariant mass method.

$$M_{K^+K^-(\phi)} = \sqrt{(E_{K^+} + E_{K^-})^2 - (\vec{p}_{K^+} + \vec{p}_{K^-})^2}$$

- The shape of the uncorrelated background is estimated by the event-mixing technique.



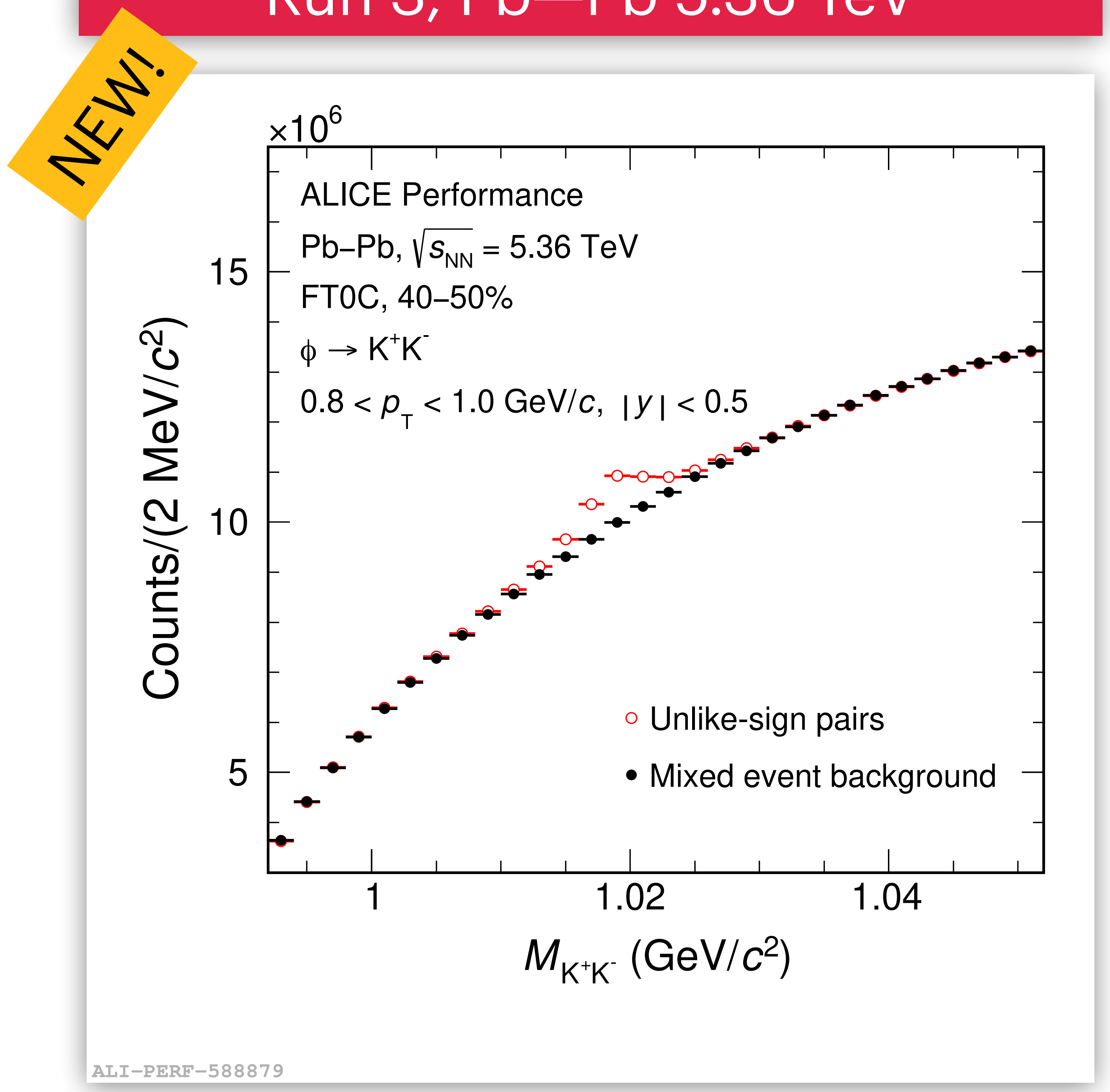
B.R. ~ (48.9 ±0.5)%

Lifetime ~ 46.3 ± 2.08 fm/c

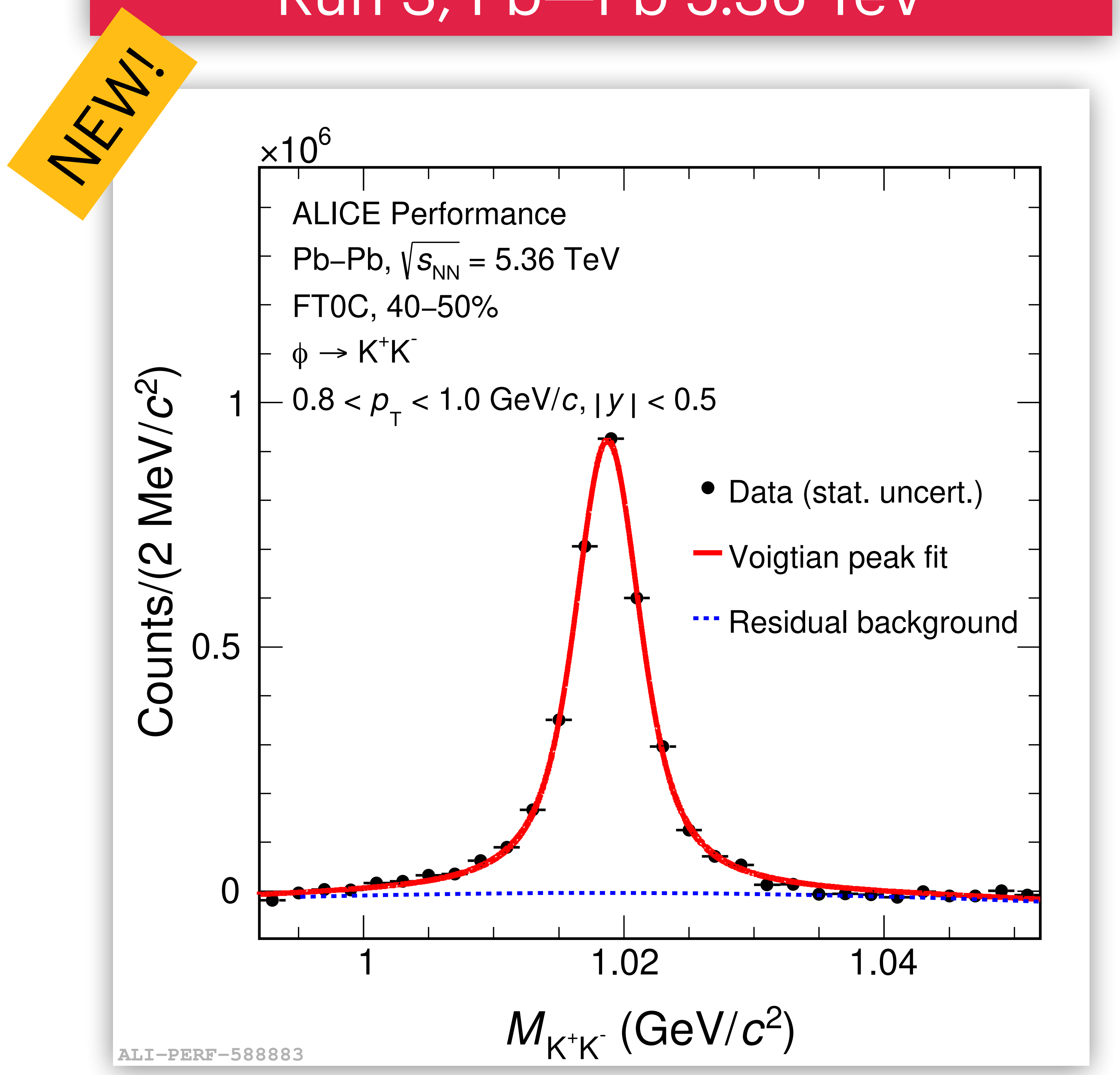
$M = 1019.461 \pm 0.020$ MeV/c^2

$\Gamma = 4.26 \pm 0.04$ MeV/c^2

Run 3, Pb—Pb 5.36 TeV



Run 3, Pb—Pb 5.36 TeV



- Signal is fitted with Voigtian function and residual background is fitted with second order polynomial.
- Raw yields are calculated by integrating the fitting function for different p_T intervals and different centrality classes.

Elliptic flow calculation in Run 3

- Elliptic flow $(v_2) = \langle\langle \cos[2(\phi - \psi_{RP})] \rangle\rangle$
- Event plane angle (ψ_2) is calculated from event flow vector (Q) and Q is calculated using FT0C detector.

$$\psi_2 = \frac{1}{2}\tan^{-1}\left(\frac{Q_y}{Q_x}\right) \qquad Q_x = \sum_i w_i \cos(2\phi_i) \qquad Q_y = \sum_i w_i \sin(2\phi_i)$$

where the sum runs over the 112 channels i of the FT0C detector

w_i : amplitude of the i^{th} cannel of FIT detector

ϕ_i : position of the i^{th} cannel of FIT detector

- v_2 is calculated by Invariant mass fit method.

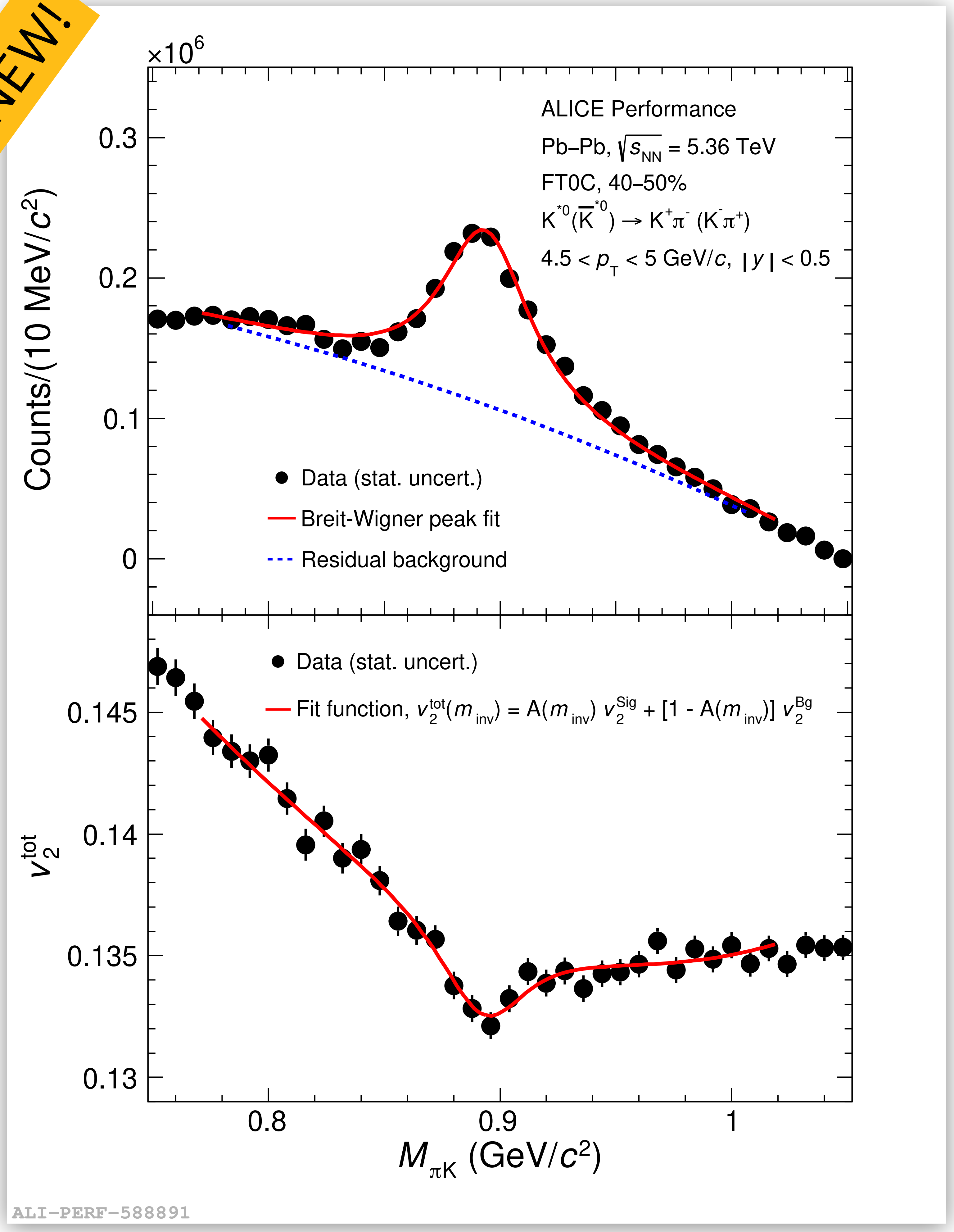
$$v_2^{tot}(m_{inv}) = A(m_{inv})\, v_2^{Sig} + \left[1 - A(m_{inv})\right] v_2^{Bg}$$

$$A(m_{inv}) = N^{Sig}(m_{inv}) / N^{Sig+Bg}(m_{inv})$$

- By simultaneous fit of invariant mass and total v_2 distribution, elliptic flow of K^{*0} is calculated for the first time in ALICE

Run 3, Pb—Pb 5.36 TeV

NEW!



Stay tuned for more Run 3 results…

Summary & Goals in Run 3

Summary

- Run 2 observations show the suppression of short-lived K^{*0} resonances but no suppression for longer-lived ϕ resonance suggests evidence for dominance of the re-scattering over the regeneration effect.
- Presented ϕ resonance signal in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.36 TeV, using 2 billion events from the latest Run 3 data.
- Reported first look of elliptic flow (v_2) signal of K^{*0} resonance for the first time using Run 3 Pb–Pb data at $\sqrt{s_{NN}}$ = 5.36 TeV.

Goals

- Transverse momentum (p_T) spectra, p_T integrated yield, $\langle p_T \rangle$ and particle ratios will be calculated to get insights into the hadronic phase.
- Centrality and p_T dependence of K^{*0} and ϕ elliptic flow will be studied and compared with other hadrons to explore the impact of final-state interactions on resonance flow.
- Various model studies will be performed.

Thank You

Back up slides

Lifetime of hadronic phase

$$[\mathrm{K}^{*0}/\mathrm{K}]_{\text{kinetic (Pb–Pb)}} = [\mathrm{K}^{*0}/\mathrm{K}]_{\text{chemical (pp)}} \times e^{-\tau/\tau_{\mathrm{K}^{*0}}}$$

- Here $\tau_{\mathrm{K}^{*0}}$ is taken as 4.16 fm/c ignoring any medium modification
- Assumption that all K* that decay before kinetic freeze-out are lost due to rescattering effects and there is no regeneration effect between kinetic and chemical freeze-out
- All assumptions leads to lower limit for timespan of hadronic phase.
- τ boosted by a Lorentz factor (~ 1.65 for p–Pb collisions and 1.75 forPb–Pb collision) as a function of ⟨dN_ch/dη⟩, Neglecting higher order terms, the Lorentz factor is estimated as $\sqrt{1+(\langle p_{\mathrm{T}}\rangle/mc)^2}$, Here m is the rest mass of the resonance and ⟨pT⟩ is used asan approximation for p for the measurements at midrapidity.
- decrease in the kinetic freeze-out temperature from peripheral to central collisions.

p_T dependence of rescattering

- Ratio of resonance yields relative to the ones of kaons and pions can shed light on the shapes of the pT distributions of mesons with different mass and quark content.
- resonances experience a larger radial flow effect.
- blast-wave model using parameters obtained from the combined fit to $\pi^{\pm}$, $K^{\pm}$, and $p(\bar{p})$ spectra.
- blast-wave function is a three parameter simplified hydrodynamic model, which assumes that the emitted particles are locally thermalized in a uniform-density source at a kinetic freezeout temperature Tkin and move with a common collective transverse radial flow velocity field.

$$\frac{1}{p_{\mathrm{T}}}\frac{dN}{dp_{\mathrm{T}}} \propto \int_0^R r\, dr\, m_{\mathrm{T}}\, I_0\left(\frac{p_{\mathrm{T}}\sinh\rho}{T_{\mathrm{kin}}}\right)K_1\left(\frac{m_{\mathrm{T}}\cosh\rho}{T_{\mathrm{kin}}}\right)$$

- The expected distributions are normalized so that their integrals are equal to the measured yield of charged kaons