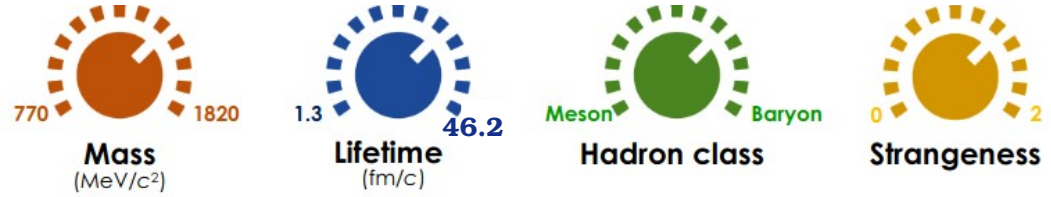

Exploring the hadronic phase of relativistic heavy-ion collisions with resonances in ALICE

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National Institute of Science Education and Research,
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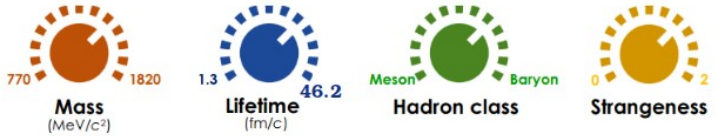
Why resonances ?

Lifetime (fm/*c*): ρ^0 (1.3) < $K^{*\pm}$ (4.0) < K^{*0} (4.16) < $\Sigma^{*\pm}$ (5.0-5.5) < Λ^* (12.6) < Ξ^{*0} (21.7) < ϕ(46.2)

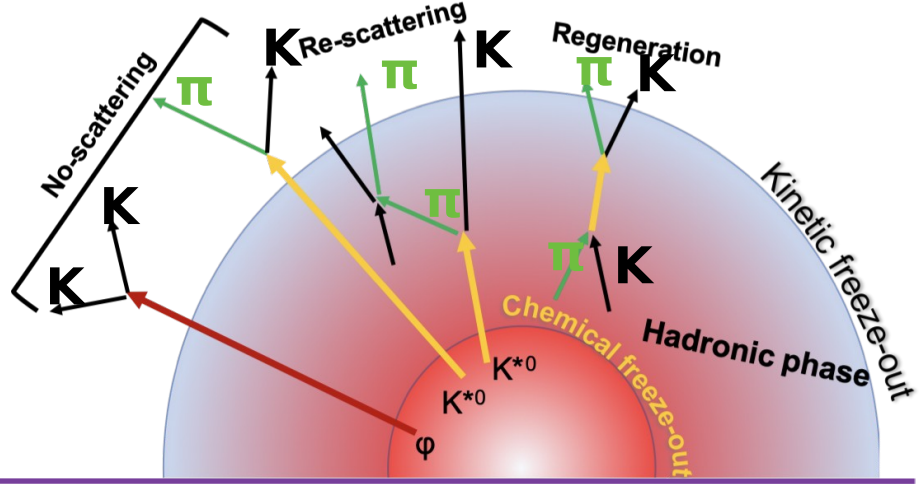


Short lifetimes

-- Lifetimes comparable to that of the hadron gas phase (~few fm/*c*)

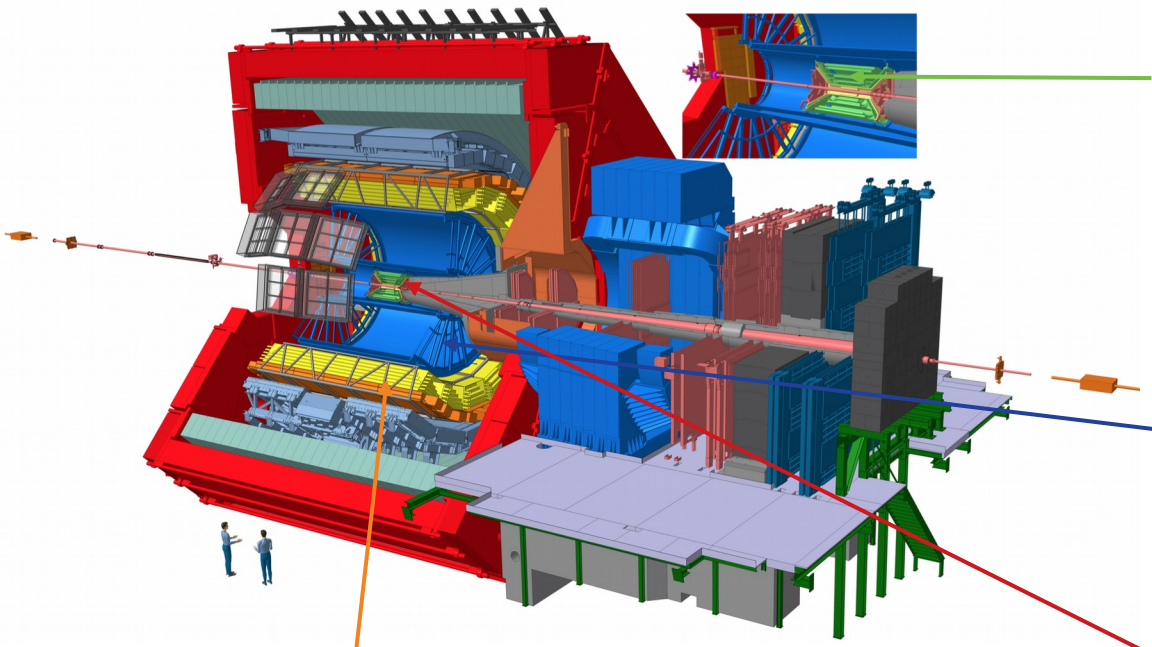
Modification of resonance yields

-- Rescattering and regeneration effects can be studied by measuring the ratios of resonance to stable hadron yields with the same quark content



ALICE detector

ALICE-PHO-SKE-2017-001



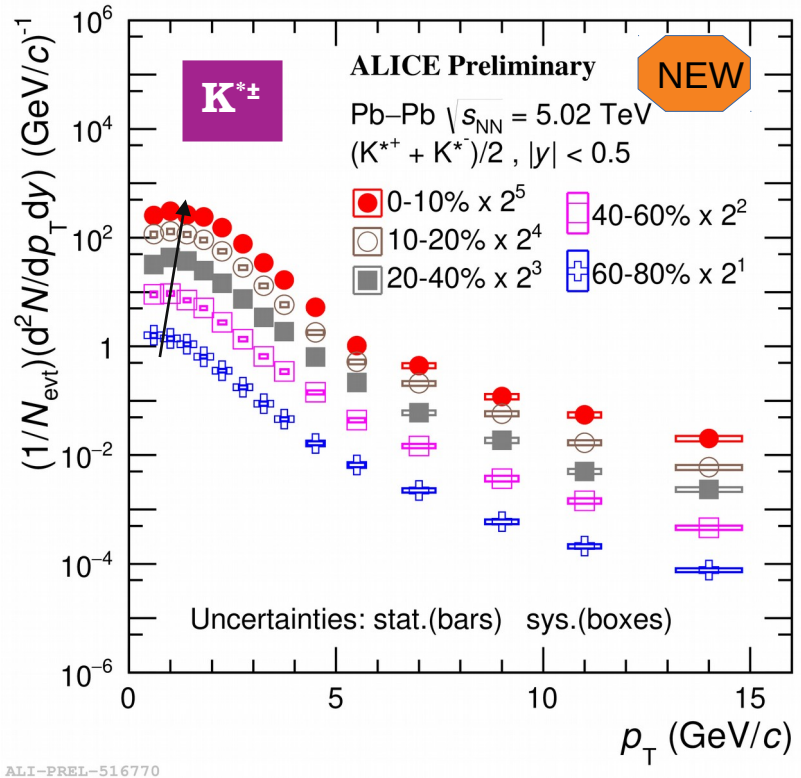
Inner Tracking System (ITS):
($|\eta| < 0.9$)
6 layers of silicon detectors
Tracking, vertex, Particle identification (PID)

Time Projection Chamber (TPC):
($|\eta| < 0.9$)
Main tracking device
PID (dE/dx in gas)

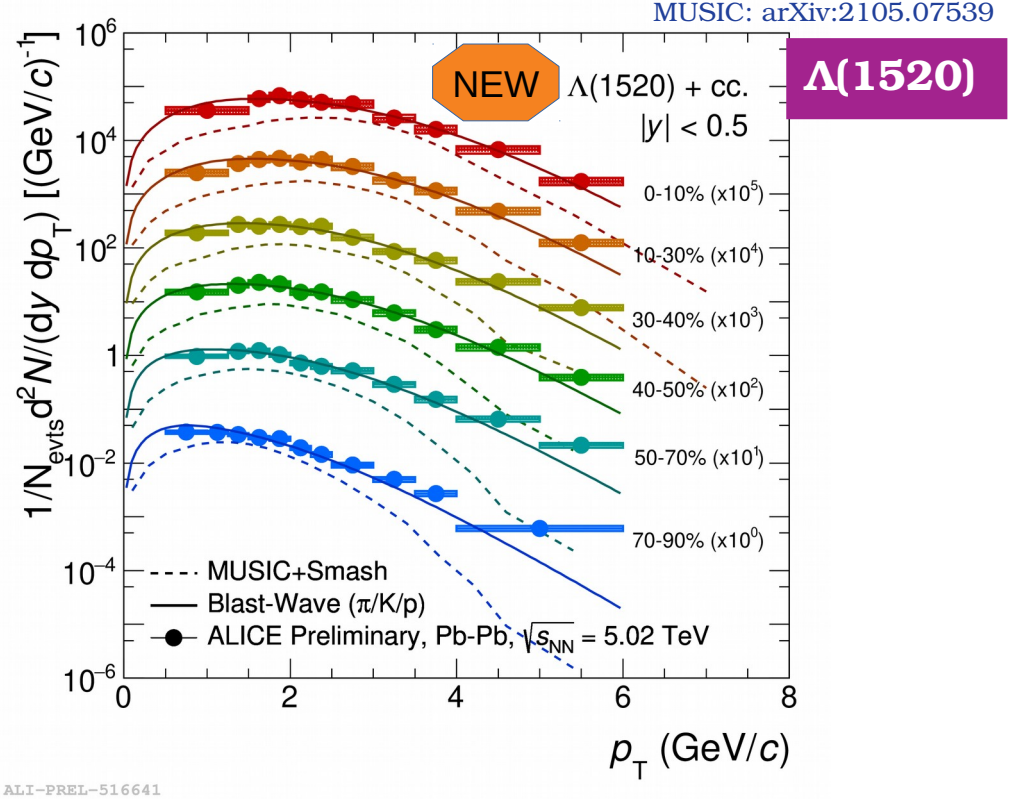
Forward detectors (V0):
V0A ($2.8 < \eta < 5.1$) &
V0C ($-3.7 < \eta < -1.7$)
Trigger, multiplicity/centrality estimator

Time-Of-Flight (TOF): ($|\eta| < 0.9$)
PID (time-of-flight measurement)

Transverse momentum spectra



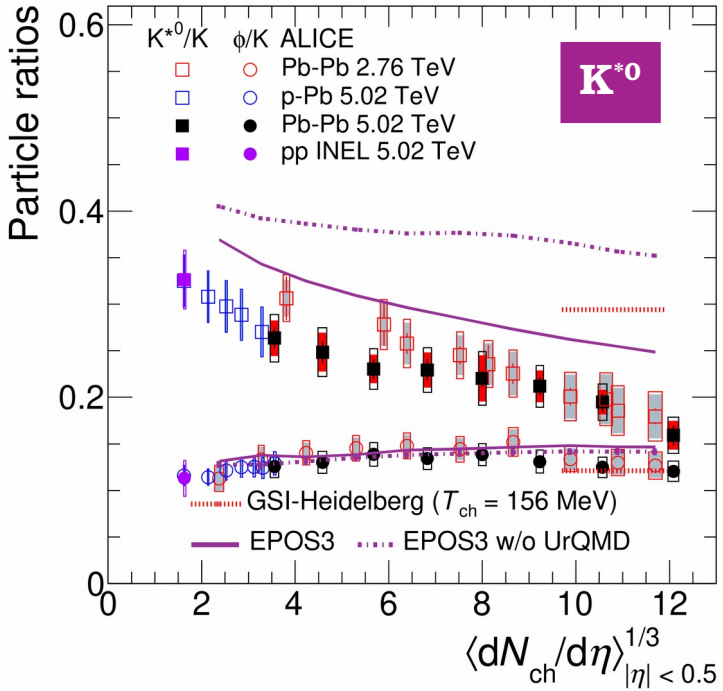
MUSIC: arXiv:2105.07539

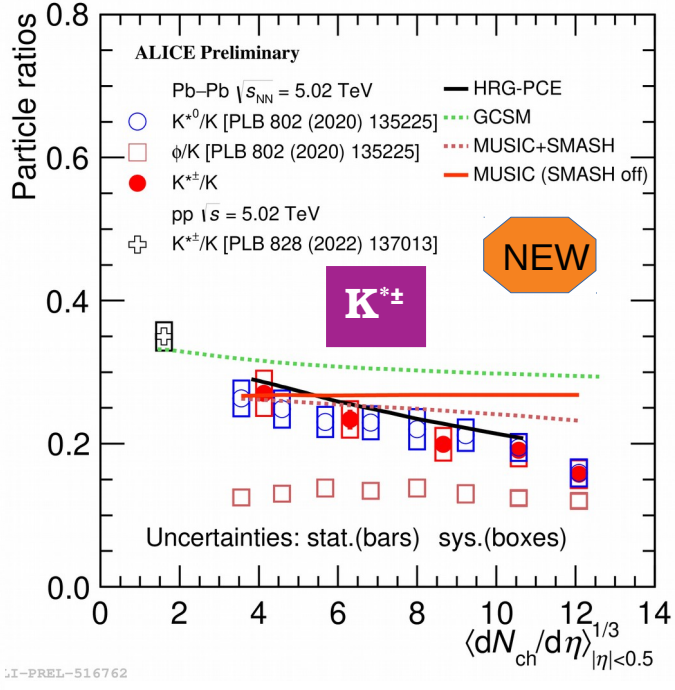


- Shape of p_T spectra and slope changes with centrality
- Position of the maximum shifts to higher values with increasing multiplicity/centrality

Particle ratios: $K^{*0,+-}/K$ and ϕ/K

$\tau(K^{*\pm}) = 4$ fm/c | $\tau(K^{*0}) = 4.16$ fm/c | $\tau(\phi) = 46.2$ fm/c





Suppression of yield ratio $K^{*0,+-}/K$

- $K^{*0,+-}/K$ ratio decreases with increasing system size
- Values are below the statistical model predictions in central Pb-Pb collisions
  -> **Rescattering** dominates over **regeneration**
- In contrast, ϕ/K constant across multiplicities and consistent with statistical model predictions

Models with rescattering effect (EPOS with UrQMD and HRG-PCE) qualitatively describe the measurements

A. Rosano, talk-14/06/2022

P. Das, Poster Session 14/06/2022

$\langle dN_{ch}/d\eta \rangle^{1/3}$: Proxy for system size

p_T-differential particle ratios

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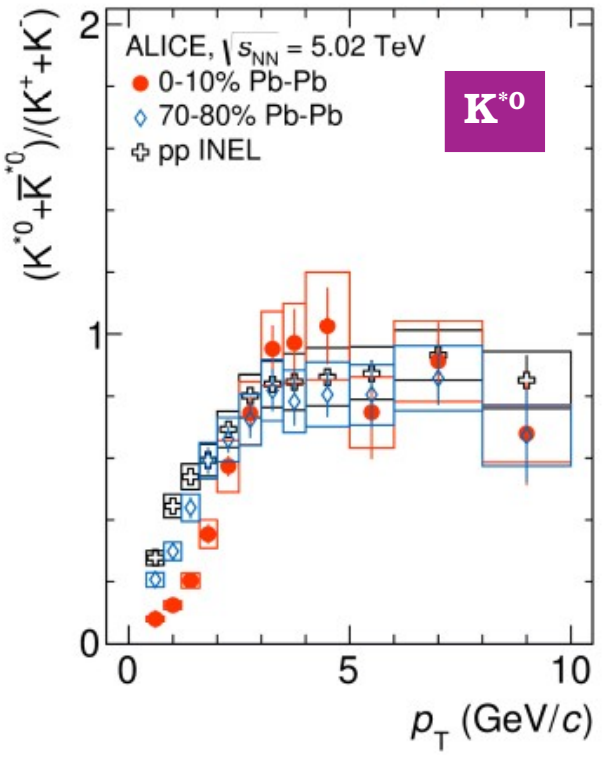
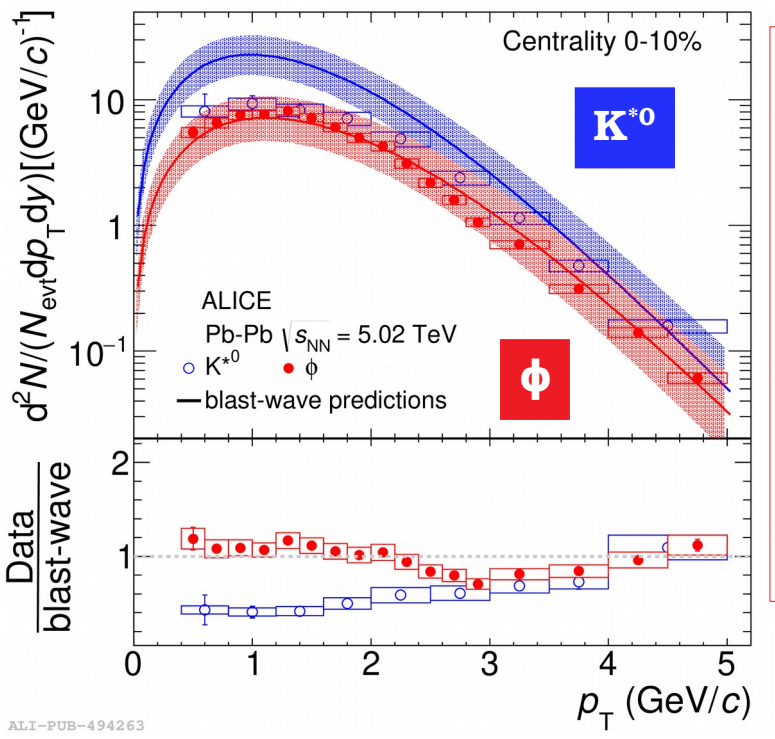


arXiv:2106.13113

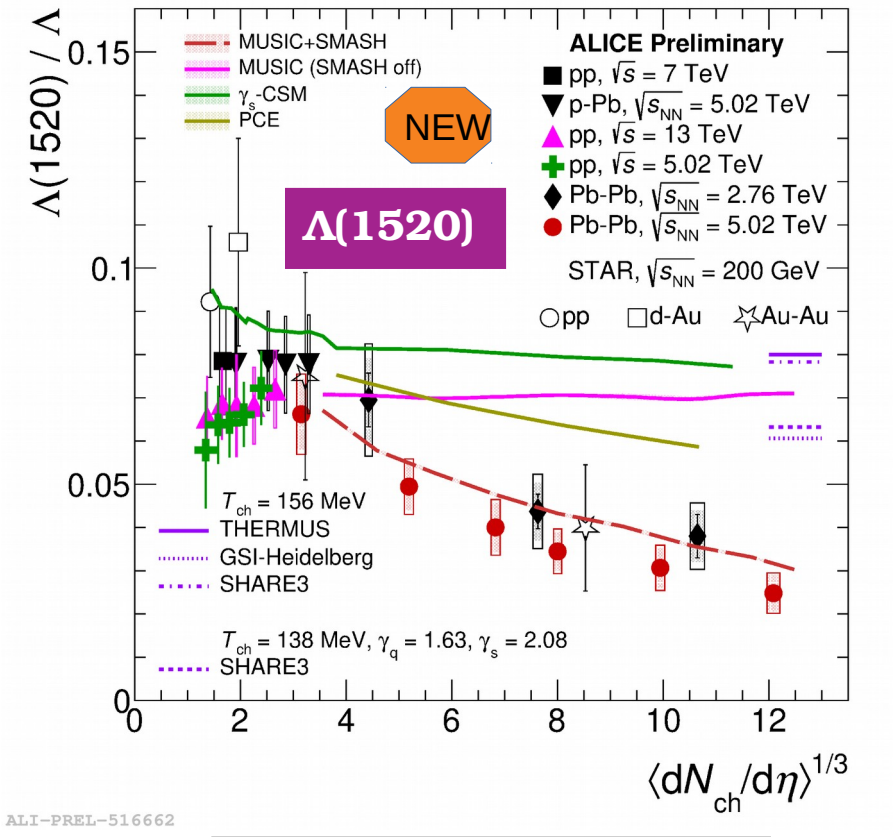


- A suppression of K^{*0} in central Pb-Pb collisions for low p_T (< 3 GeV/c)
- ϕ : No suppression
- Blast-wave model : No rescattering effect

- **Suppression** at low transverse momentum in **central Pb-Pb collisions**
  -> Rescattering effects play a role at low p_T

Particle ratio : Λ(1520)/Λ

S. Padhan, Poster Session 14/06/2022



MUSIC: arXiv:2105.07539
PCE: Phys.Rev.C 102 (2020) 2, 024909
CSM: Phys.Rev.C 100 (2019) 5, 054906

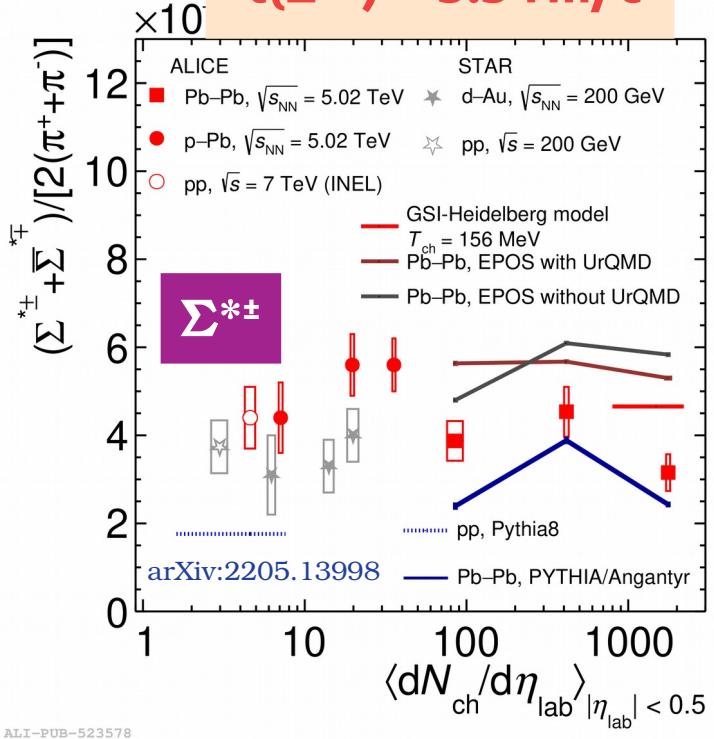
τ(Λ(1520)) =12.6 fm/c

Suppression of Λ(1520)/Λ yield ratio in Pb-Pb collisions

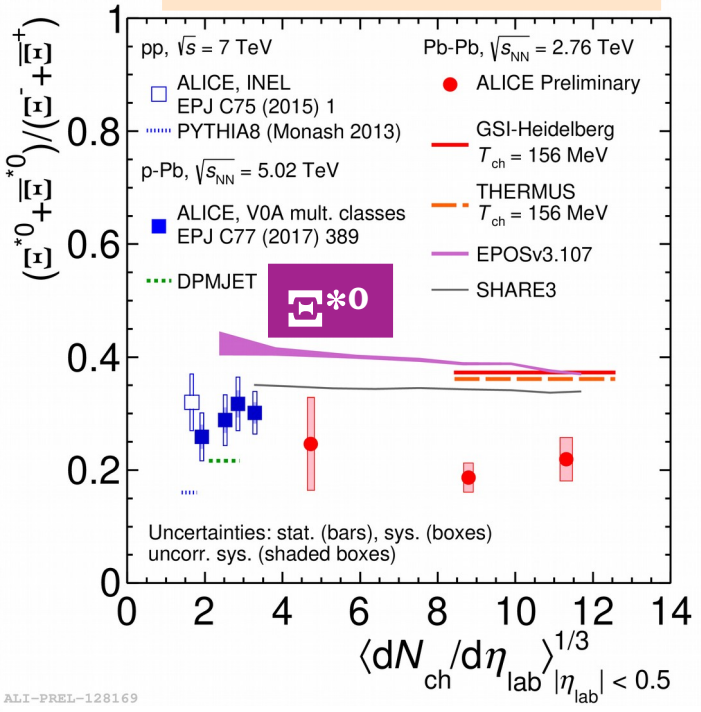
- Λ(1520)/Λ ratio decreases with increasing multiplicity
- Λ(1520) lifetime is a factor 3 longer than $K^{*0,\pm}$, but it is more suppressed
  -> It depends on the interplay between rescattering and regeneration and the mean free path of the resonance in the hadron gas
- MUSIC with hadronic phase afterburner (SMASH) qualitatively reproduces trend of the measurements

Particle ratios: $\Sigma^{*\pm}$ and Ξ^{*0}

$\tau(\Sigma^{*\pm}) \sim 5.5$ fm/c



$\tau(\Xi^{*0}) = 21.7$ fm/c



No significant suppression of yield ratio (Ξ^{*0})

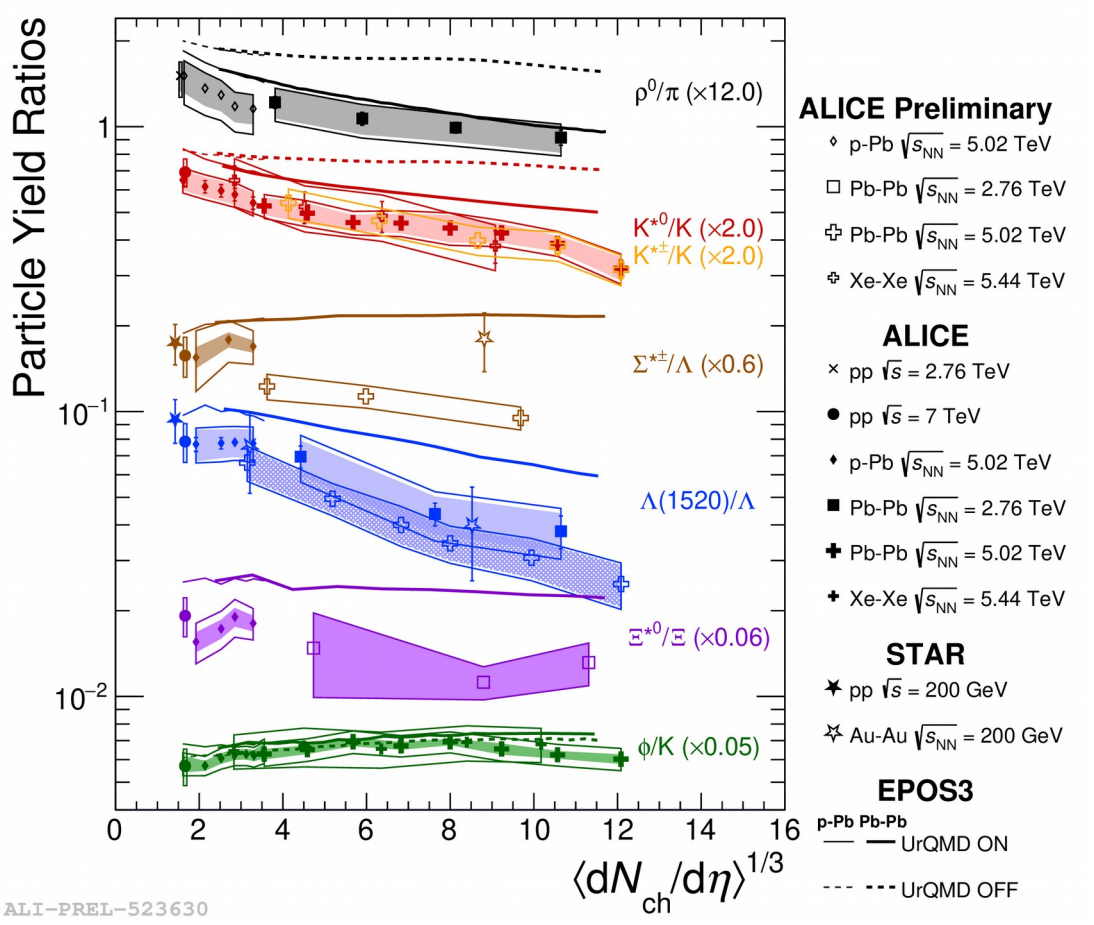
- Values are lower than the thermal model and EPOS with an hadronic phase afterburner (UrQMD).
- Values in central Pb-Pb collisions are lower than pp, p-Pb collisions

Suppression of yield ratio in Pb-Pb collisions ($\Sigma^{*\pm}$)

- Flat in pp, p-Pb
- EPOS with an hadronic phase afterburner (UrQMD) overestimates the measurements

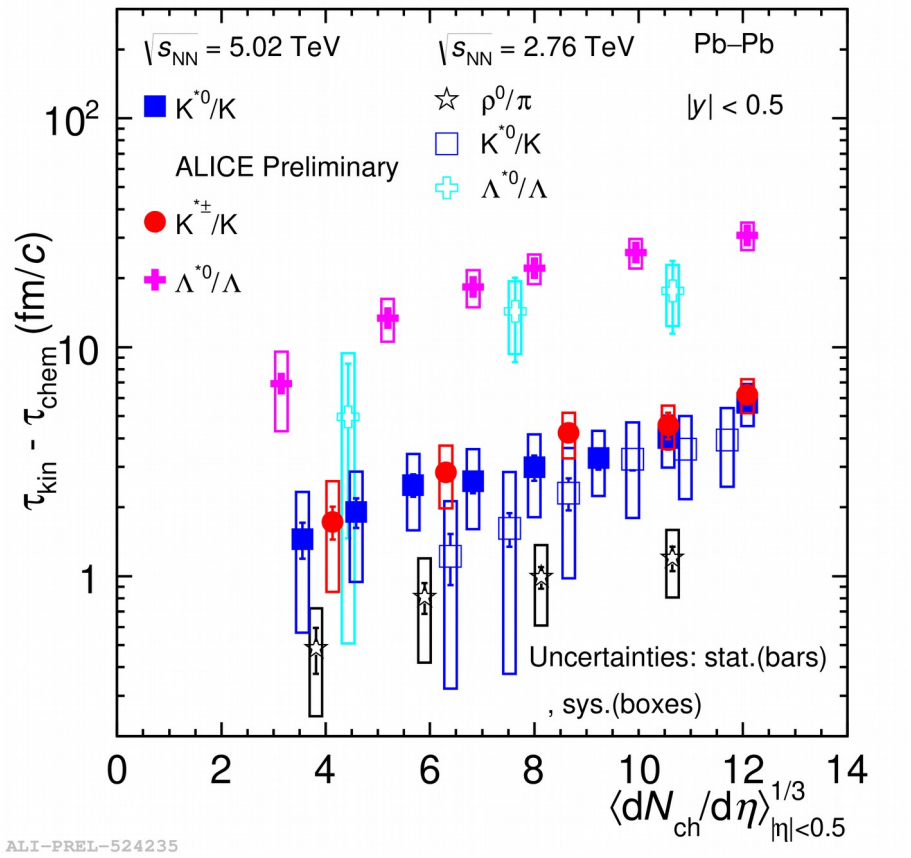
Overview: resonance yield ratios

Lifetime (fm/c): ρ^0 (1.3) < $K^{*\pm}$ (4.0) < K^{*0} (4.16) < $\Sigma^{*\pm}$ (5.0-5.5) < Λ^* (12.6) < Ξ^{*0} (21.7) < ϕ(46.2)



- Yield ratios show **suppression** for resonances with lifetimes up to ~13 fm/c
- **EPOS with UrQMD** qualitatively describes trend of measurements
  -> Suggesting rescattering of decay products in hadronic phase
- Smooth transition from pp to A-A
  -> **Multiplicity (system size)** controls resonance production

Extract lifetime of hadronic phase



- Estimation of lower limit of the timespan between chemical and kinetic freeze-out by exponential law.
- Assumptions:
  i) Negligible regeneration
  ii) Simultaneous freeze-out occurs for all particles

$$r_{\mathrm{kin}} = r_{\mathrm{chem}} \times \exp(-(\tau_{\mathrm{kin}} - \tau_{\mathrm{chem}})/\tau_{\mathrm{res}})$$

r_{kin} = measured yield ratios in Pb-Pb collisions

r_{chem} = measured yield ratios in pp collisions

τ_{res} = lifetime of resonance

$$\frac{\rho}{\pi} < \frac{K^{*0,\pm}}{K} < \frac{\Lambda^*}{\Lambda}$$

Lifetime of hadronic phase smoothly increases with multiplicity

Summary

- **ALICE** has measured a rich set of resonance particles with varying lifetime, quark content and mass in various collision systems and energies

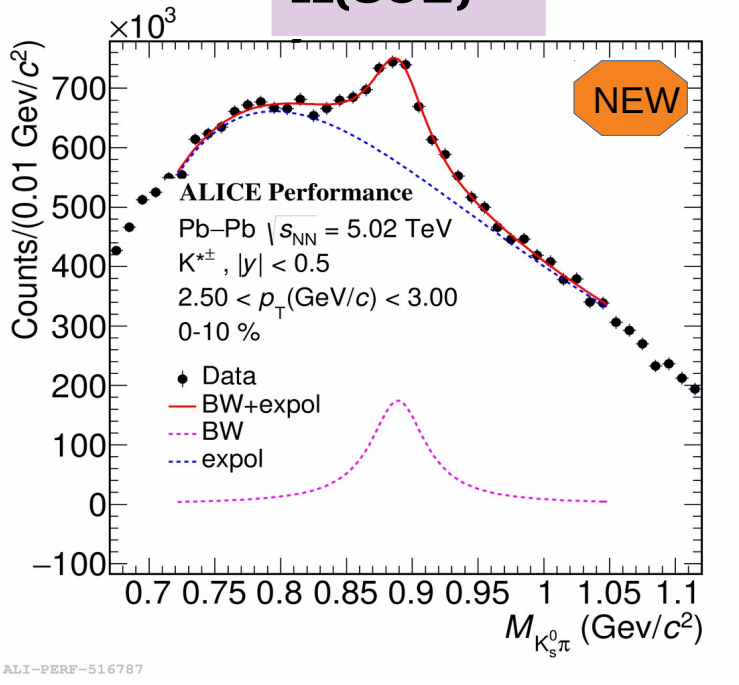
	Suppressed				Not suppressed	
Resonance :	ρ^0	$K^{*0,\pm}$	$\Sigma^{*\pm}$	$\Lambda(1520)$	Ξ^{*0}	ϕ
Lifetime (fm/c) :	1.3	~ 4.0-4.16	~ 5.0-5.5	12.6	21.7	46.3

- **Rescattering effects** dominant over **regeneration for short-lived resonances**
- **Rescattering effects** dominant at **low p_T**
- The estimated time of **the hadronic phase** increases with **multiplicity**

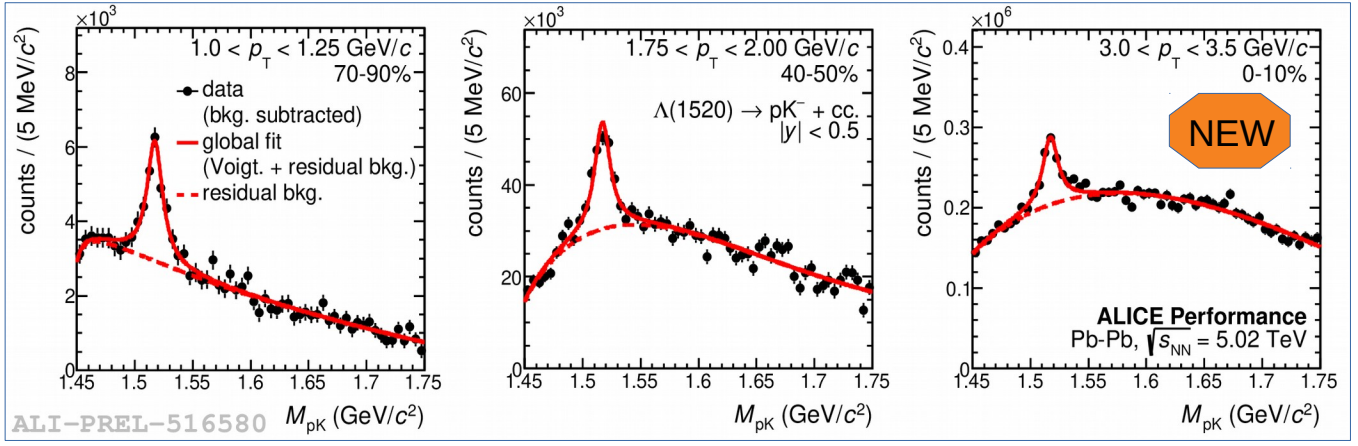
Back up

Resonance signal

K(892)*+



Λ(1520)

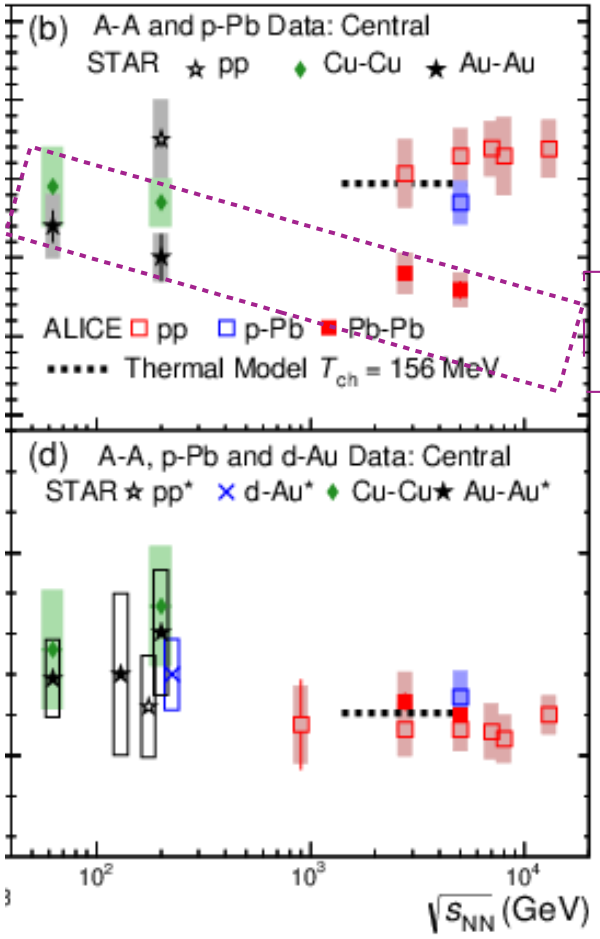


Energy and system size dependence

K^{*0}/K

ϕ/K

arXiv:2106.13113



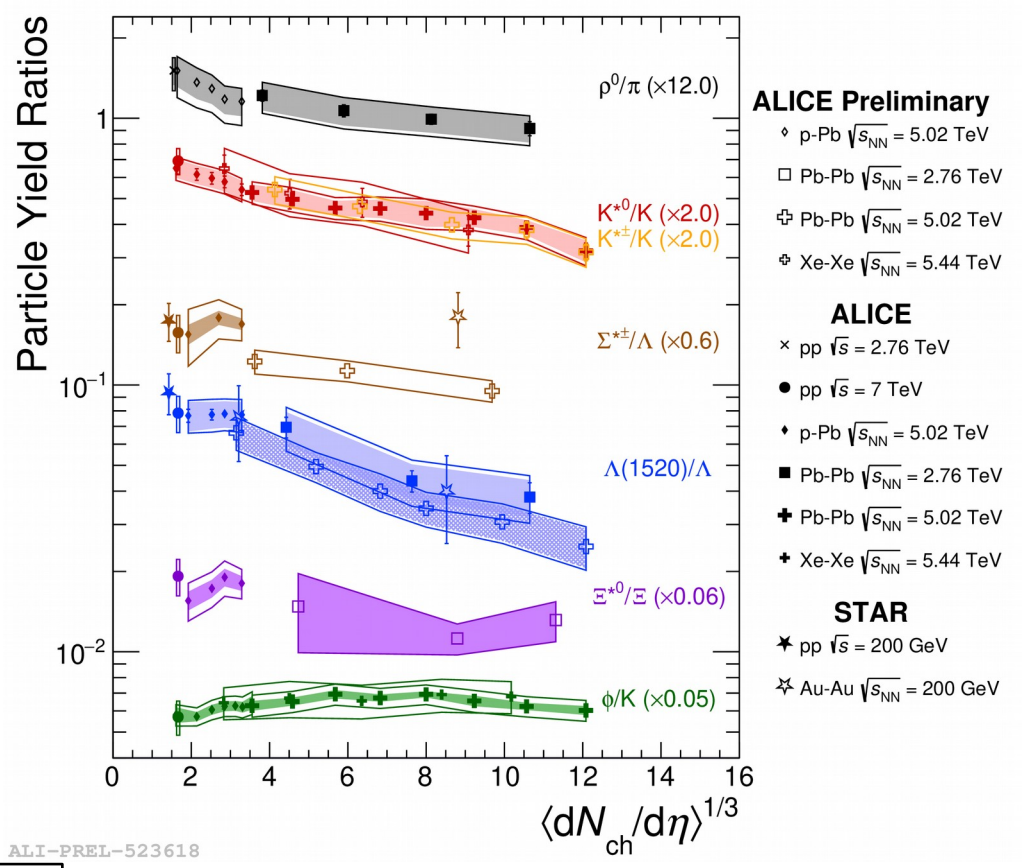
Heavy-ion collisions

K*0/K : Central heavy-ion collisions:
Small decrease with collision energy and weak dependence on system size

ϕ/K :
No energy and system size dependene

Overview: resonances in ALICE

Lifetime (fm/c): ρ^0 (1.3) < $K^{*\pm}$ (4.0) < K^{*0} (4.16) < $\Sigma^{*\pm}$ (5.0-5.5) < Λ^*(12.6) < Ξ^{*0} (21.7) < ϕ(46.2)



- Yield ratios show **suppression**

  for resonances up to the lifetime ~13 fm/c
- $\Lambda(1520)$ is suppressed more than $K^{*0,\pm}$, even though its lifetime 3 times higher than $K^{*0,\pm}$

  ->Supperssion of resonance yields depend on **interplay between rescattering and regeneration effect, and mean free path** of resonance in the hadron gas
- Smooth transition from pp to AA

  -> **Multiplicity (system size)** controls resonance production

Overview: hadronic phase lifetime

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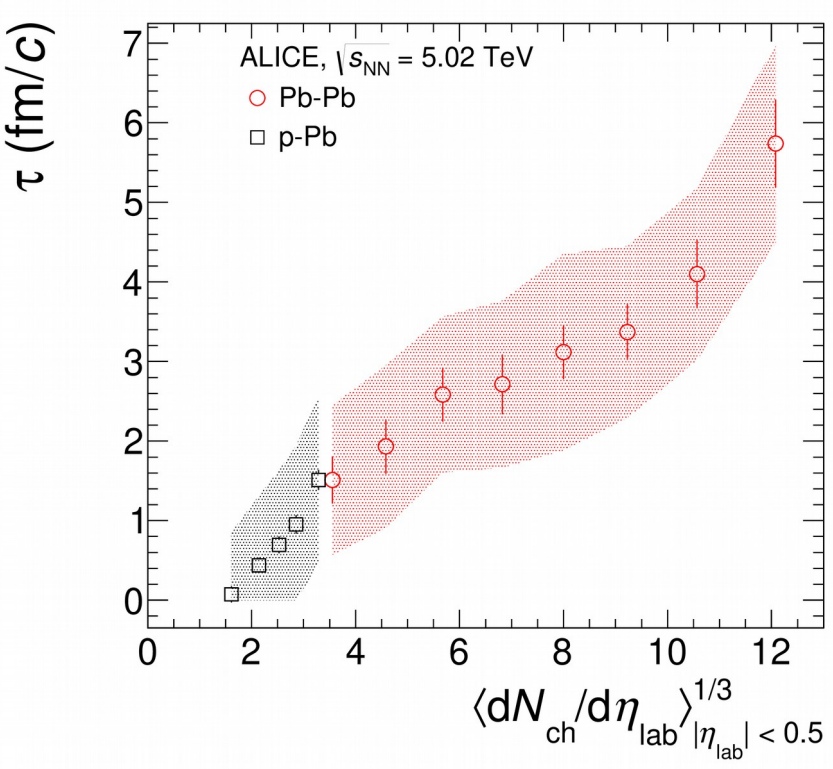
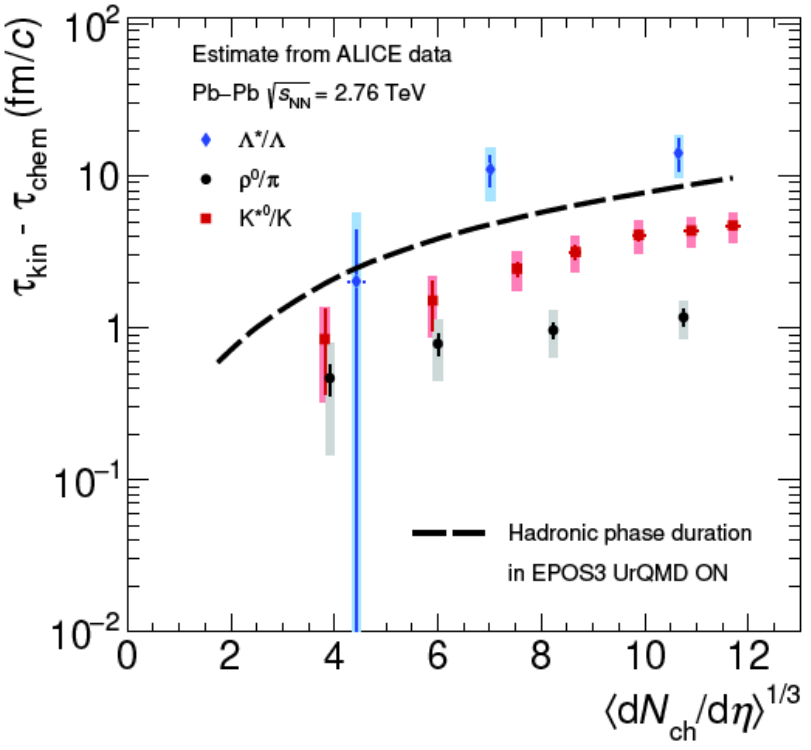


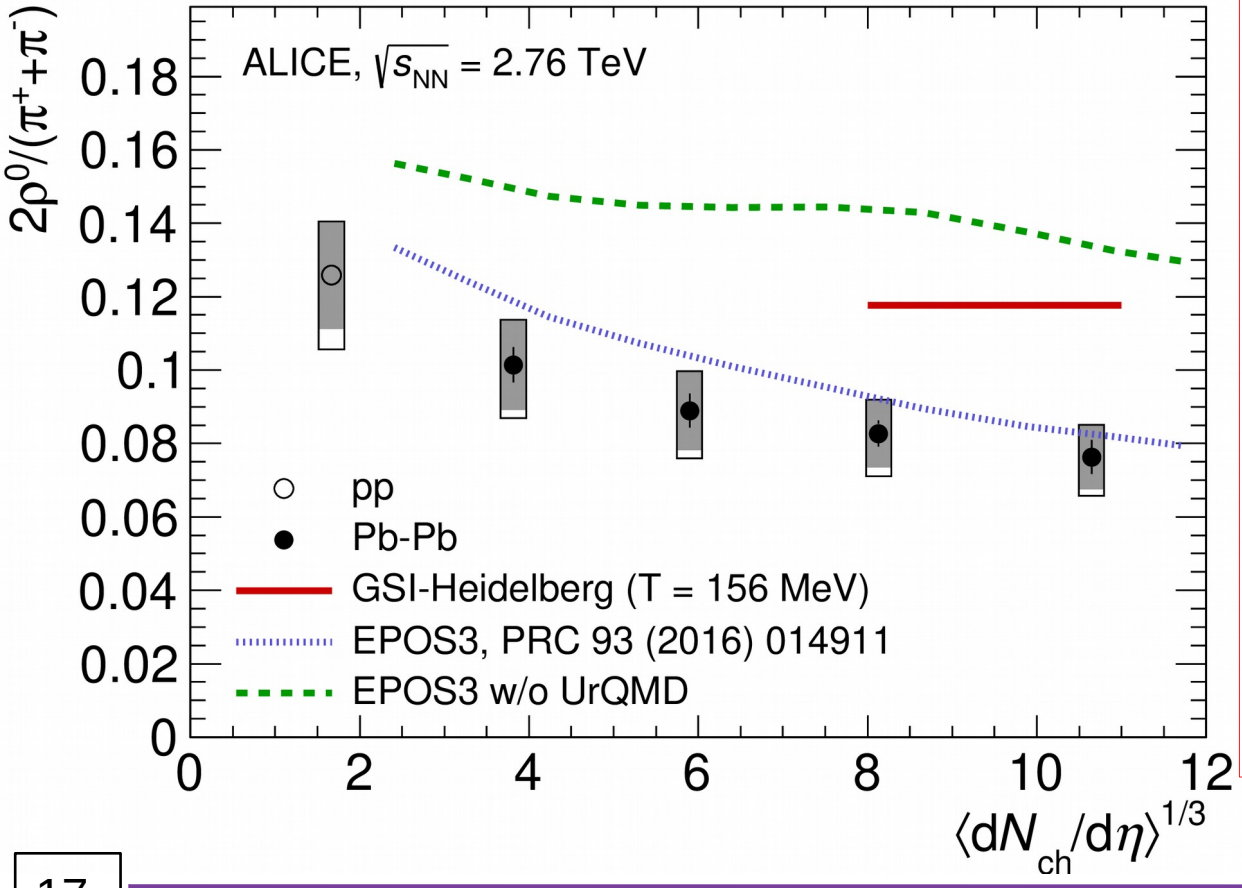
ALICE review draft: https://alice-publications.web.cern.ch/node/7780



A smooth increase of τ (fm/c) with system size and also lifetime of resonances

Particle ratio: ρ^0/π

Phys. Rev. C 99, 064901 (2019)



Suppression of ρ^0/π yield ratio in Pb-Pb collisions

- ρ^0/π ratio decreases with system size
- Value in central Pb-Pb collisions is lower than peripheral Pb-Pb collisions and statistical model predictions

EPOS3 with UrQMD

- Overestimates the data

  Qualitatively reproduces the trend of the suppression

$\langle dN_{ch}/d\eta \rangle^{1/3}$: Proxy for system size