Hadronic resonance production with ALICE at the LHC

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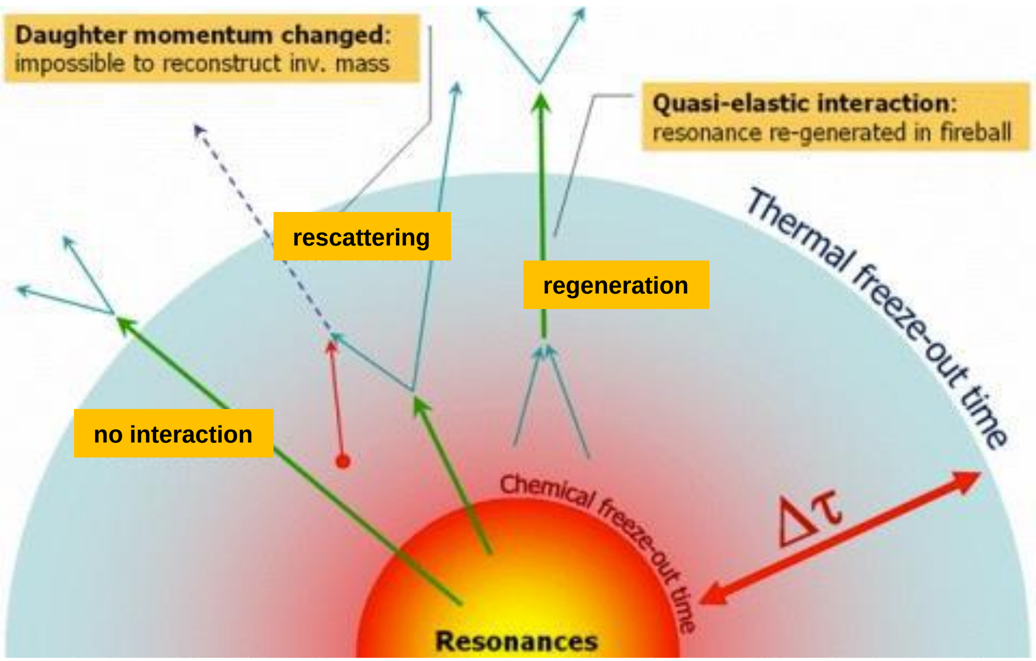
- Motivation
- ALICE detector
- Signal extraction
- p_T spectra
- Mean transverse momentum
- Yields
- Ratios to stable hadrons
- Nuclear modification factors
- Summary

Motivation

- **pp and p–Pb collisions:**
  - ✓ the baseline for heavy-ion collisions
  - ✓ system size dependence
  - ✓ role of cold nuclear matter
  - ✓ study of collectivity in small systems

Resonance	cτ (fm)	Decay	System @ energy (TeV)
$\rho(770)^0$	1.3	**$\pi\ \pi$**	pp/Pb–Pb @ 2.76
$K^*(892)^0$	4.2	**$K\ \pi$**	pp/p–Pb/Pb–Pb/Xe–Xe @ all energies
$K^*(892)^\pm$	4.2	**$K_S^0\ \pi$**	pp @ 5.02/8/13 Pb–Pb @ 5.02
f_0 (980)	~ 5	**$\pi\ \pi$**	pp/p–Pb @ 5.02
$\Sigma(1385)^\pm$	5-5.5	**$\Lambda\ \pi$**	pp@7 p–Pb /Pb–Pb @ 5.02
$\Lambda(1520)$	12.6	**p K**	pp @ 7 p–Pb @ 5.02 Pb–P b@ 2.76/5.02
$\Xi(1530)^0$	21.7	**$\Xi^-\ \pi$**	pp @ 7 p–P b@ 5.02 Pb–Pb @ 2.76
$\phi(1020)$	46.4	**K K**	pp/p–Pb/Pb–Pb/Xe–Xe @ all energies

- **AA collisions**:
  - ✓ in-medium energy loss
    - → nuclear modification factor for resonances
  - ✓ restoration of chiral symmetry
    - → modification of width, mass and branching ratio
  - ✓ regeneration and rescattering effects
    - → modification of yield and ratios to stable hadrons
    - → timescale between chemical and kinetic freeze-out

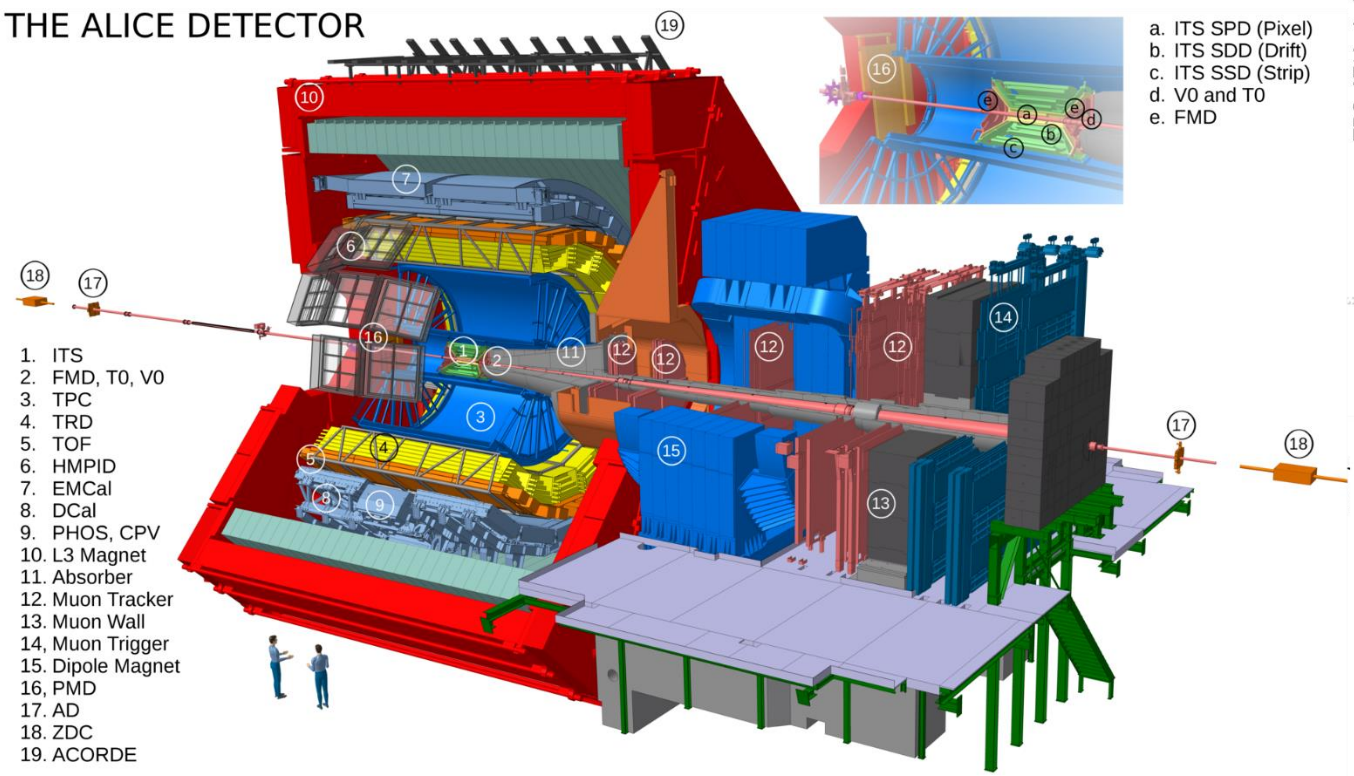


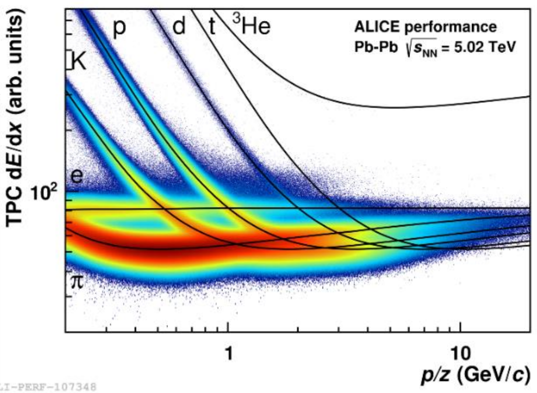
ALICE detector

V0 (scintillators):
→ triggering minimum bias collisions
→ centrality/multiplicity estimator

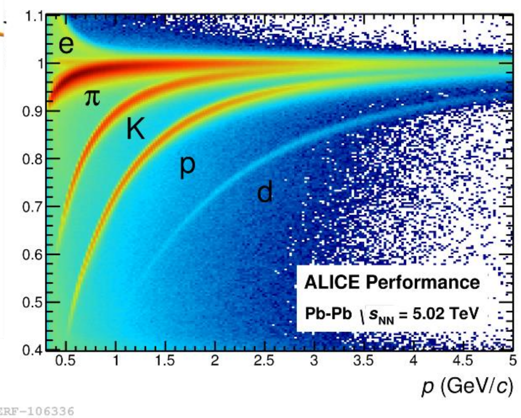
ITS: tracking and vertexing

TPC: tracking and PID through dE/dx





TOF: PID through particle time of flight

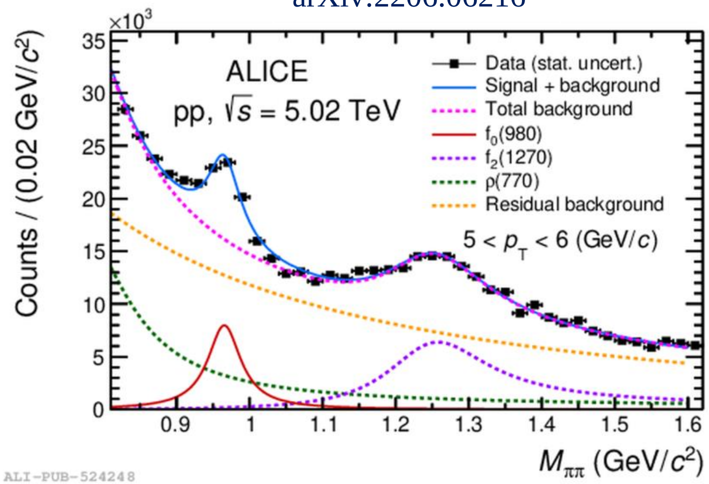


NEW

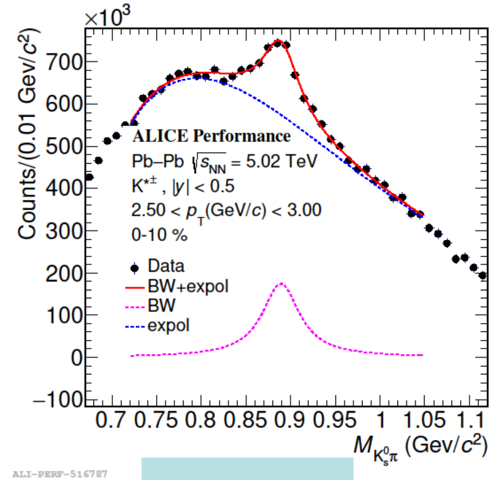
Signal extraction

$f_0(980)$

arXiv:2206.06216

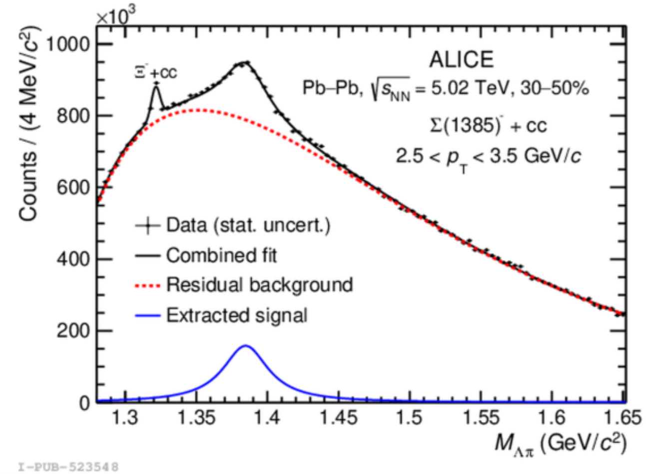


$K^*(892)^{\pm}$

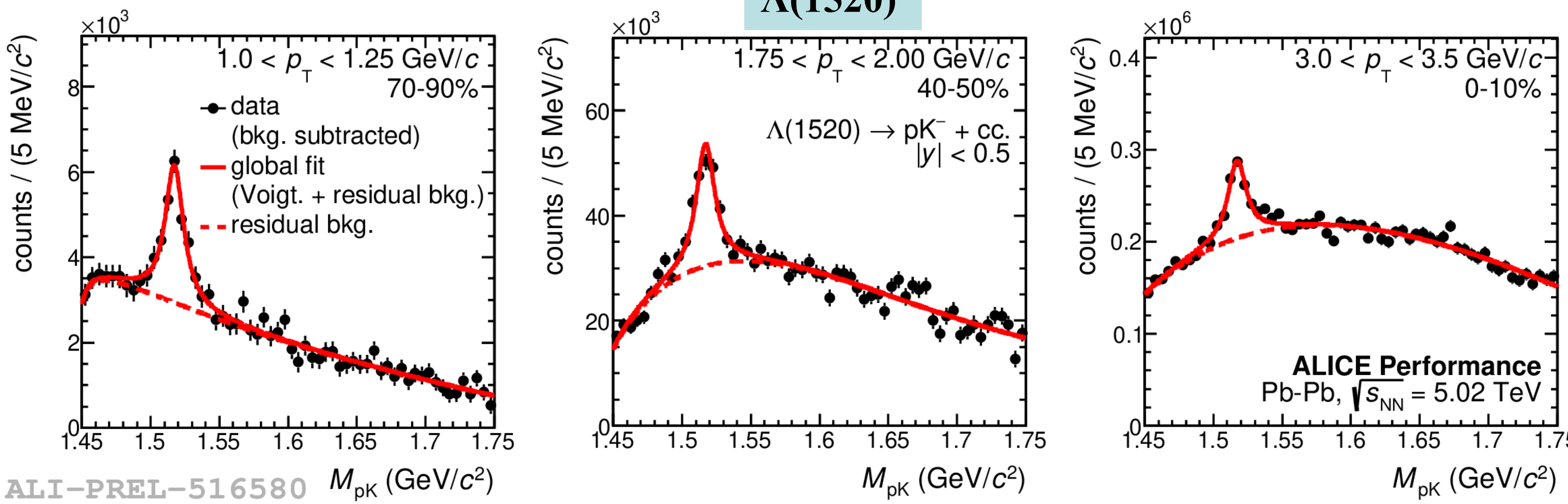


$\Sigma(1385)^-$

EPJ **C83** (2023) 351



$\Lambda(1520)$

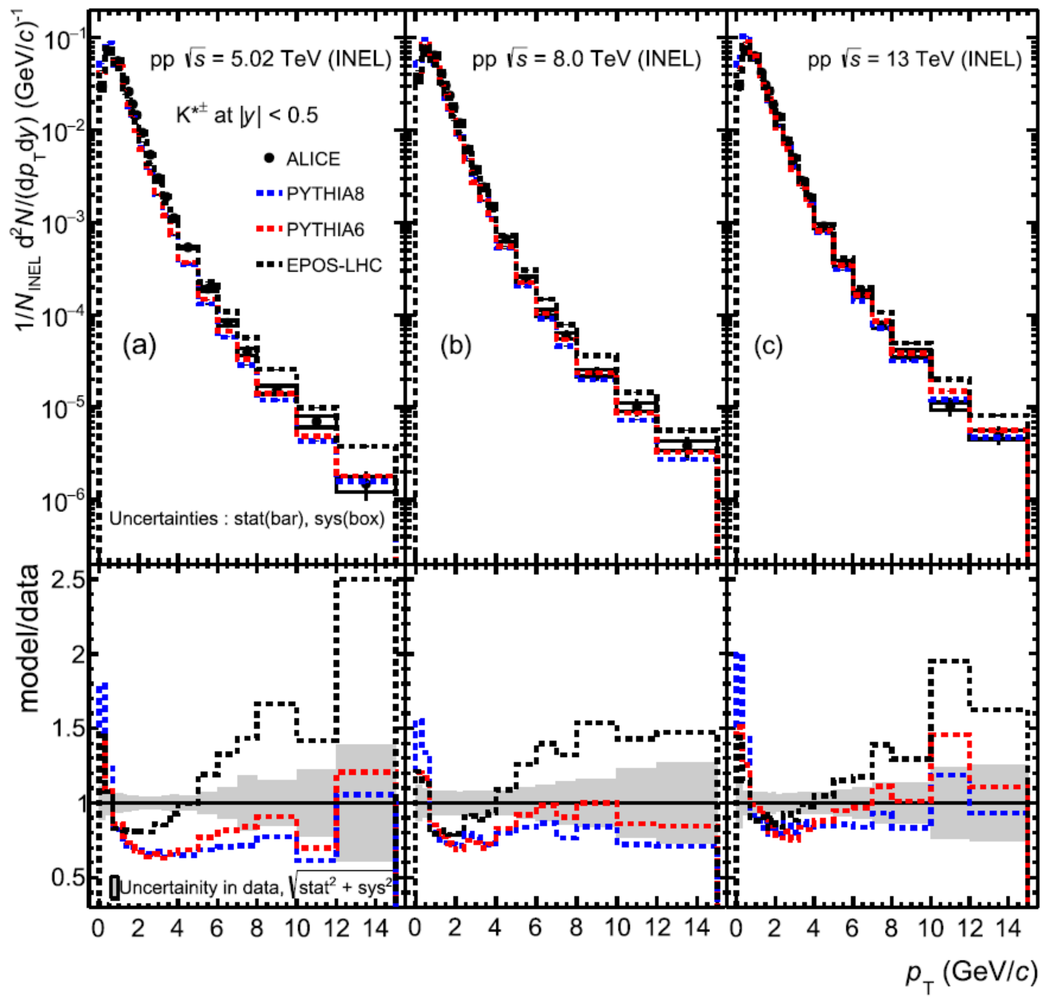


NEW

K*(892)$^{\pm}$

p_T spectra

PL **B828** (2022) 137013



Σ(1385)$^{-}$

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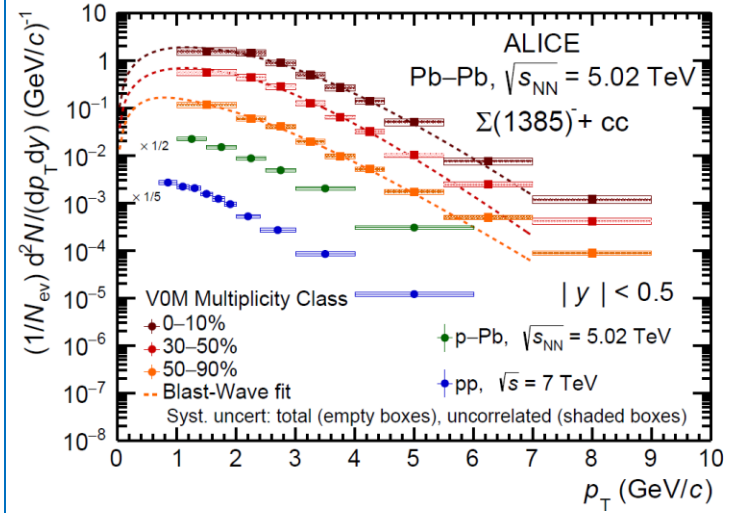
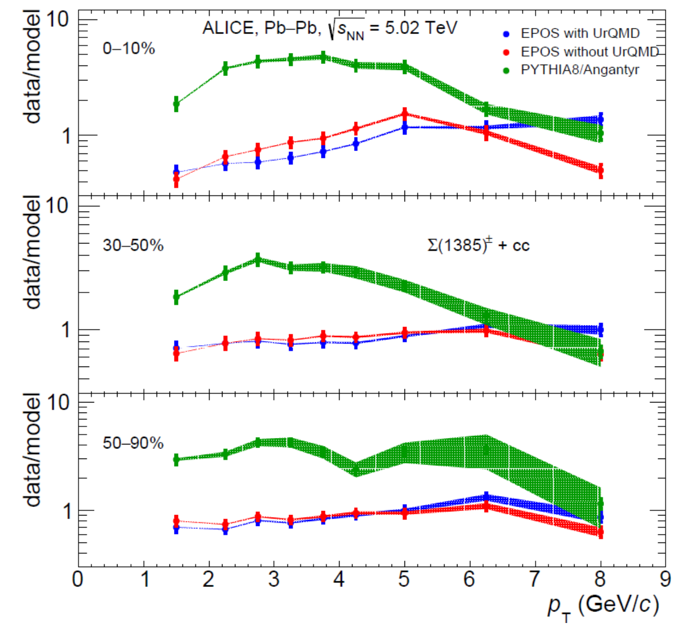




EPOS: PR **C93** (2016) 014911
PYTHIA8/Angantyr :
JHEP 10 (2018) 134,

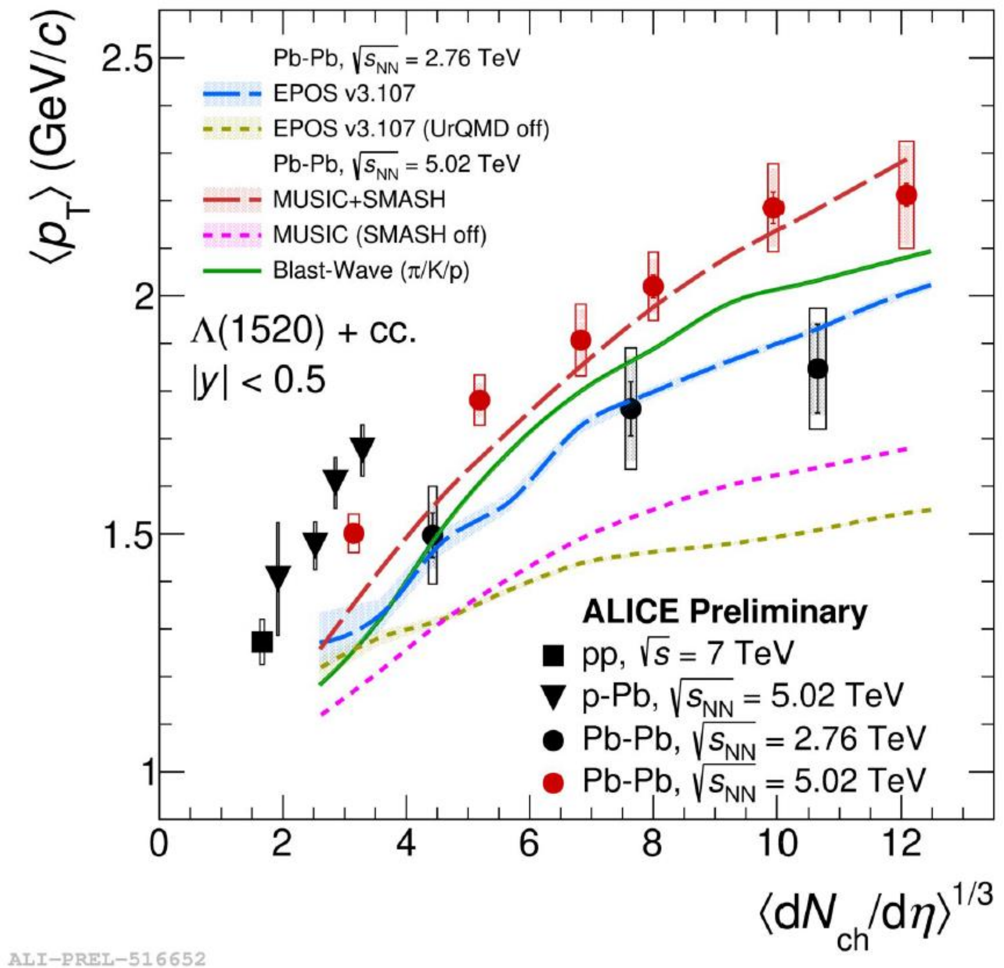
models do not fully describe data

NEW

‹ p_T › vs. $dN_{ch}/d\eta$

Λ(1520)

Pb–Pb@5.02 TeV



‹ p_T › rises with increasing multiplicity

models with rescattering effects (EPOS+UrQMD, MUSIC+SMASH) reproduce data

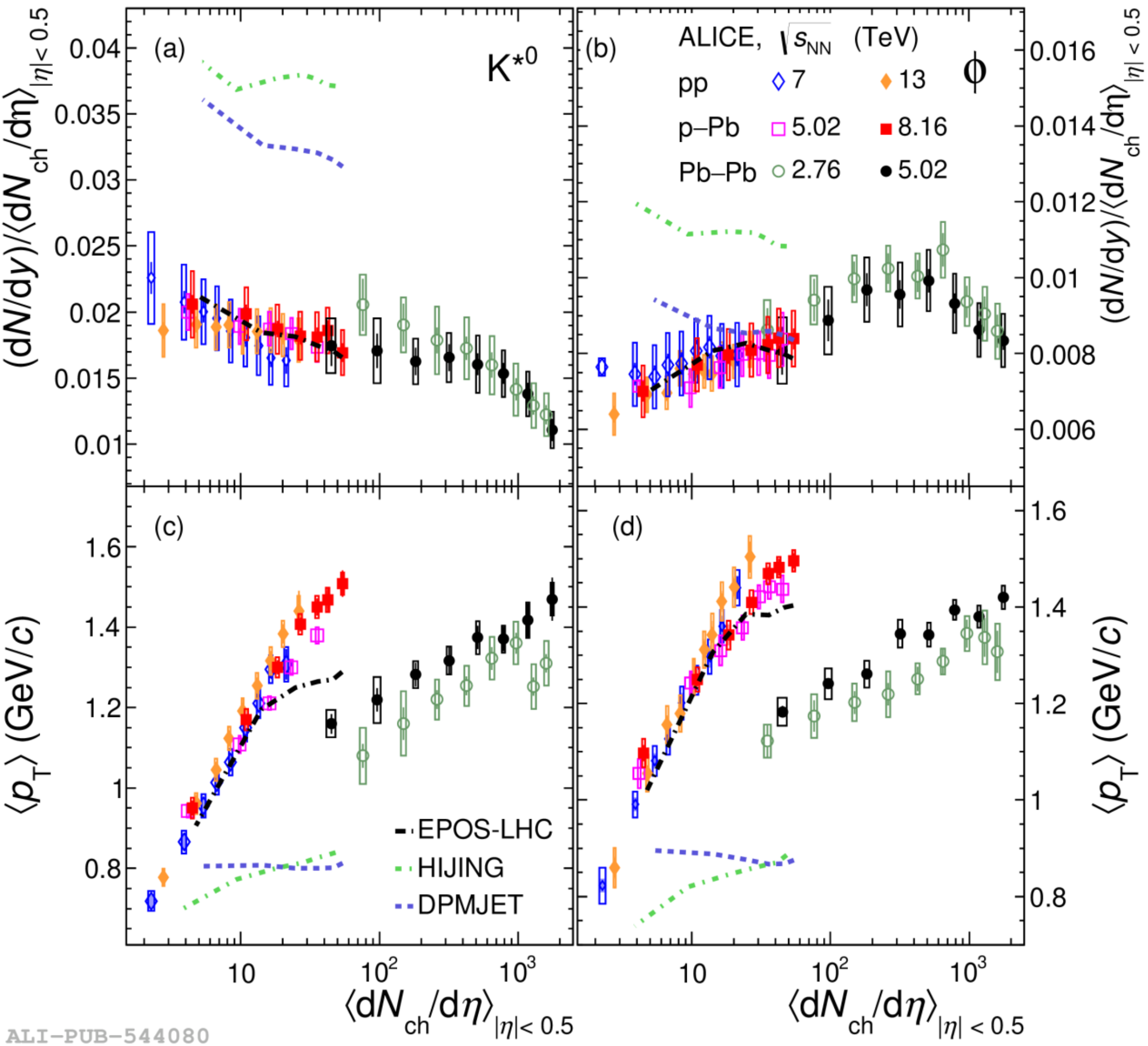
models without hadronic afterburner underestimate the measurements

MUSIC:arXiv:2105.07539

NEW

yields, ‹ p_T › vs. $dN_{ch}/d\eta$

K*(892)⁰ PR C107 (2023) 055201 **ϕ(1020)**



yields:
- independent of collision system and energy
- appear to be driven by event multiplicity

pp, p–Pb:
steeper increase with multiplicity can be understood as the effect of color reconnection between strings produced in multi-parton interactions, PL B727 (2013) 371

$K^{*\pm}/K$ vs. $dN_{ch}/d\eta$

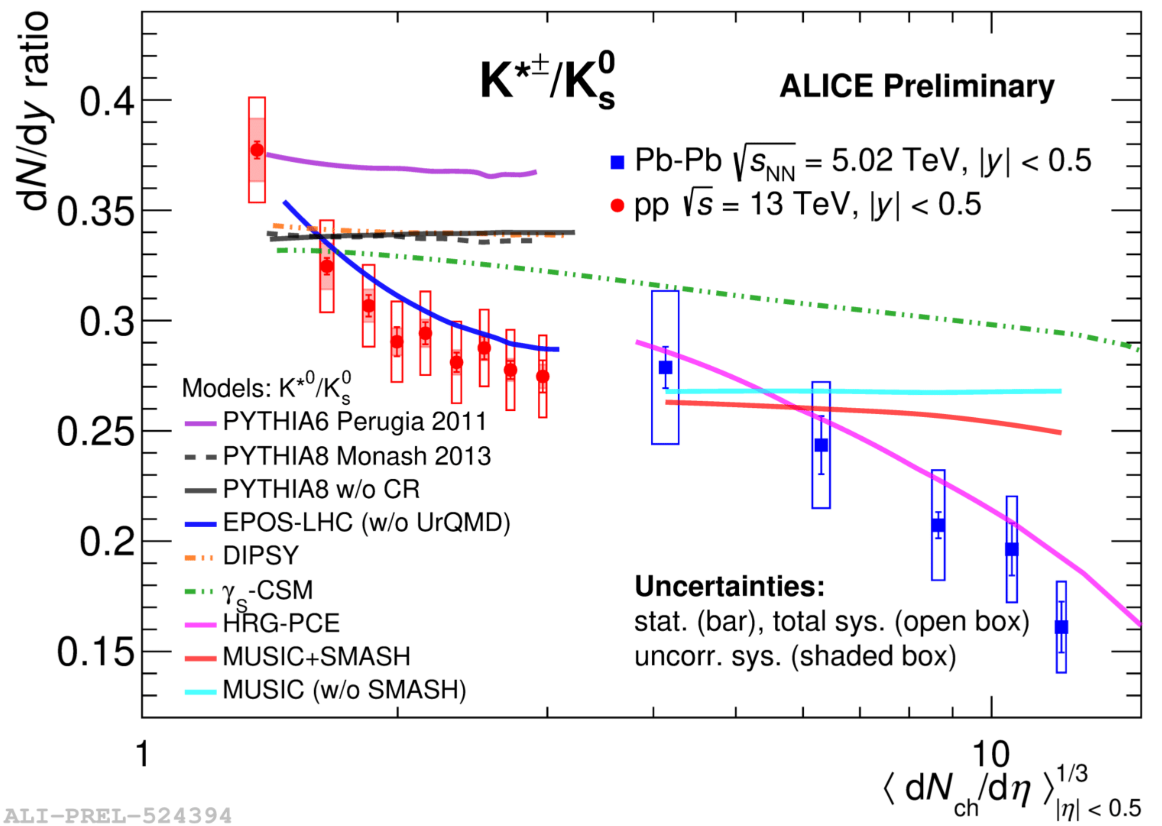
NEW

$\tau(K^*)$ = 4.2 fm/c

$K^{*\pm}/K$ shows a ~55% suppression
- going from peripheral Pb–Pb collisions to most central Pb–Pb
→ consistent with the rescattering of the daughters as the dominant effect
- models with rescaterring effect (MUSIC+SMASH and HRG-PCE) qualitatively describe the data

- pp: hint of decrease

- $K^{*\pm}$ measurement is consistent with previous results for K^{*0}



HRG-PCE: PRC102(2020)024909
γ_s-CSM: PRC100(2019)054906

Λ^*/Λ vs. $dN_{ch}/d\eta$

NEW(pp@5.02,13 Pb–Pb@5.02 TeV)

- **Λ*/Λ** shows a ~ 70% suppression
  - going from peripheral Pb–Pb collisions to most central Pb–Pb

  → consistent with the rescattering of the daughters as the dominant effect

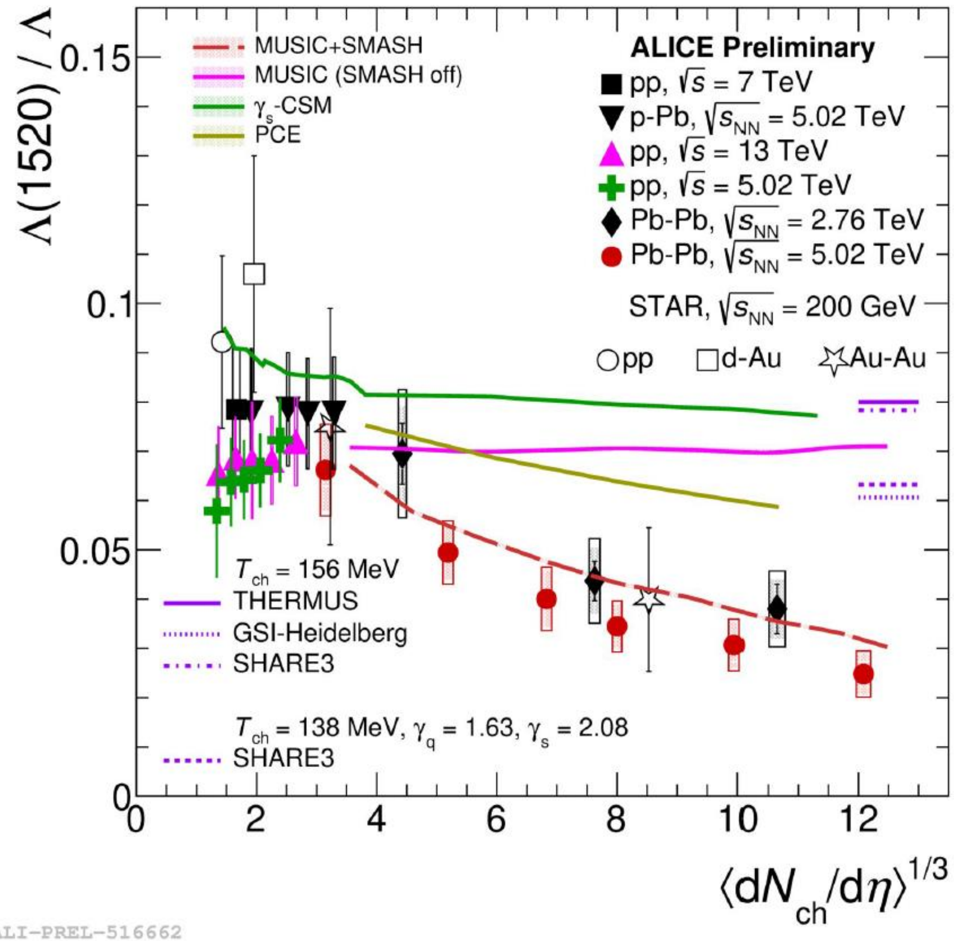
  it is larger than ~ 55% for $K^{*\pm}$ although $\tau(\Lambda^*) = 3\ \tau(K^*)$
  - follows Pb–Pb@2.76 TeV (PR **C99** (2019) 02490) suppression trend
  - confirms the trend seen by STAR at 200 GeV

•MUSIC-SMASH:
  - reproduce the multiplicity suppression trend

•thermal models
  - all overestimate the ratio in central Pb-Pb collisions

- pp: no suppression is observed

τ(Λ*) = 12.6 fm/*c*



PCE: PRC102(2020)024909
THERMUS: Comput. Phys. Commun. **180** (2009) 84
GSI-Heidelberg: PL **B673** (2009) 142
SHARE3: Comput. Phys. Commun. **185** (20014) 2056
STAR data: PR **C78** (2008) 044906

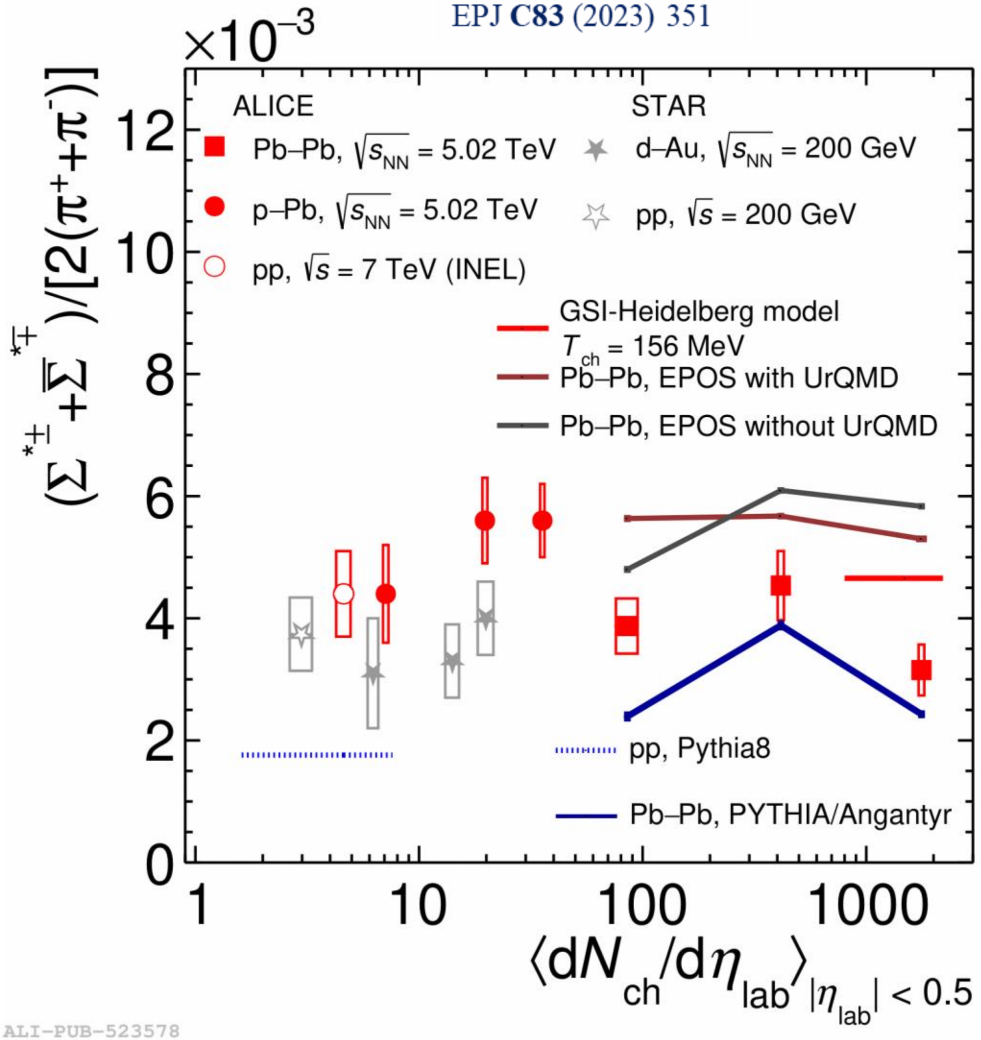
Σ^*/π vs. $dN_{ch}/d\eta$

NEW

$\tau(\Sigma^*)$ = 5-5.5 fm/c

- **Σ^*/π:** no particular trend with multiplicity is observed given the uncertainties hint of some suppression at the highest multiplicity → future higher precision measurements
- EPOS with UrQMD:
  - reproduce qualitatively
  - overestimates the data
- thermal model
  - overestimates the ratio in central Pb–Pb collisions
- pp/p–Pb: close to the STAR pp/d–Au data

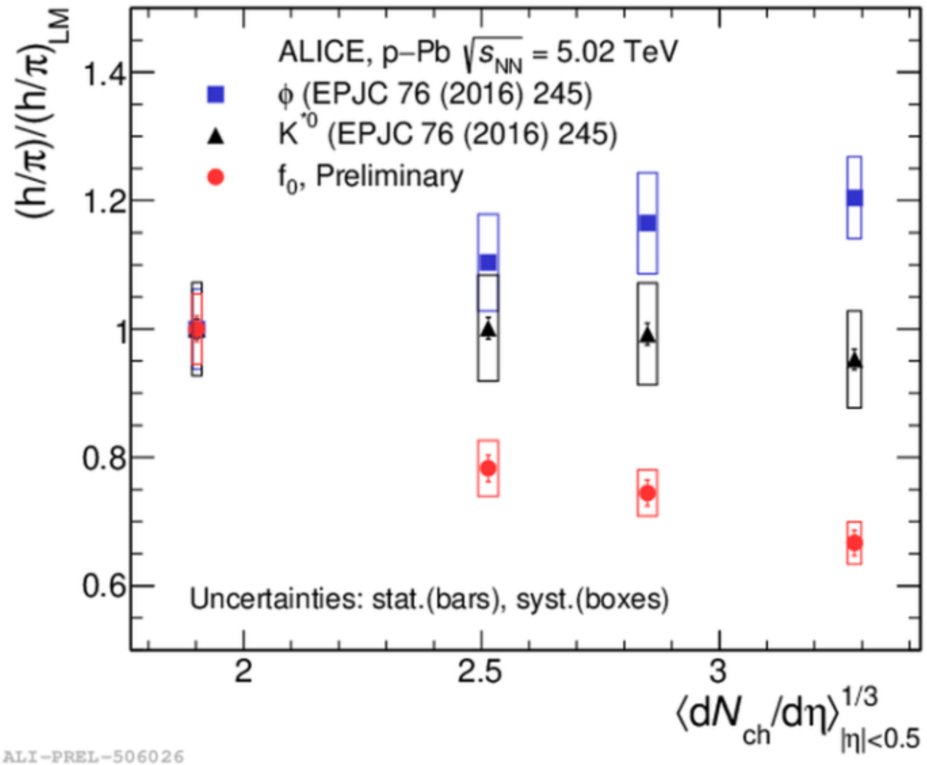
EPJ **C83** (2023) 351



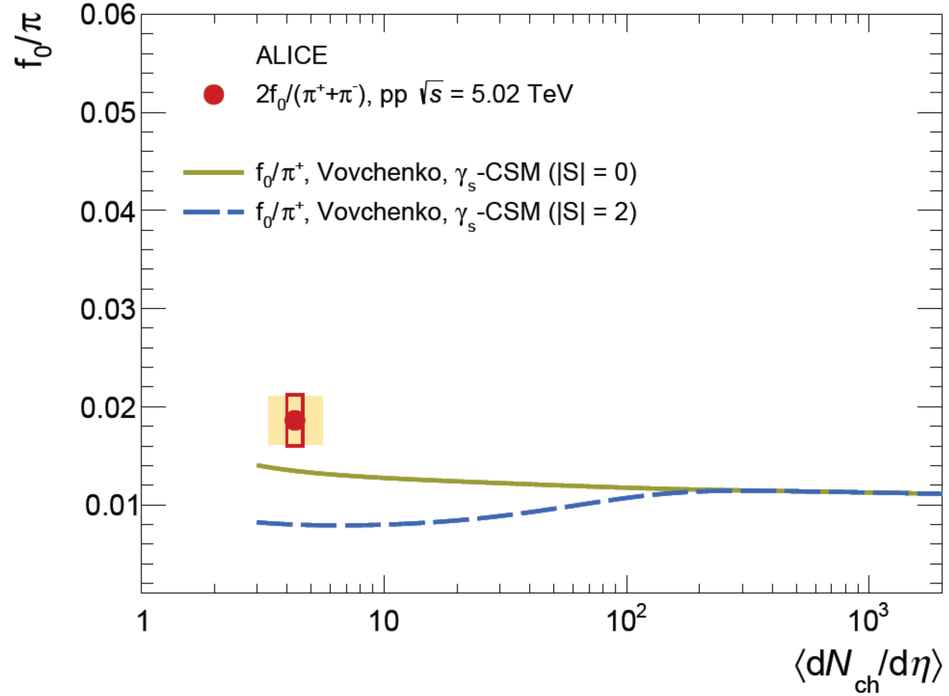
NEW f_0/π vs. $dN_{ch}/d\eta$, vs. p_T

$\tau(f_0)$ = ~5 fm/c

quark structure of f_0 is still unknown.
possible configurations: qqbar, (qq)(qbar qbar), hadronic molecules, …



arXiv:2206.06216



ϕ/π: strangeness enhancement
K^{*0}/π: competition strangeness enhancement and rescattering effect
f_0/π: rescattering is the dominant effect

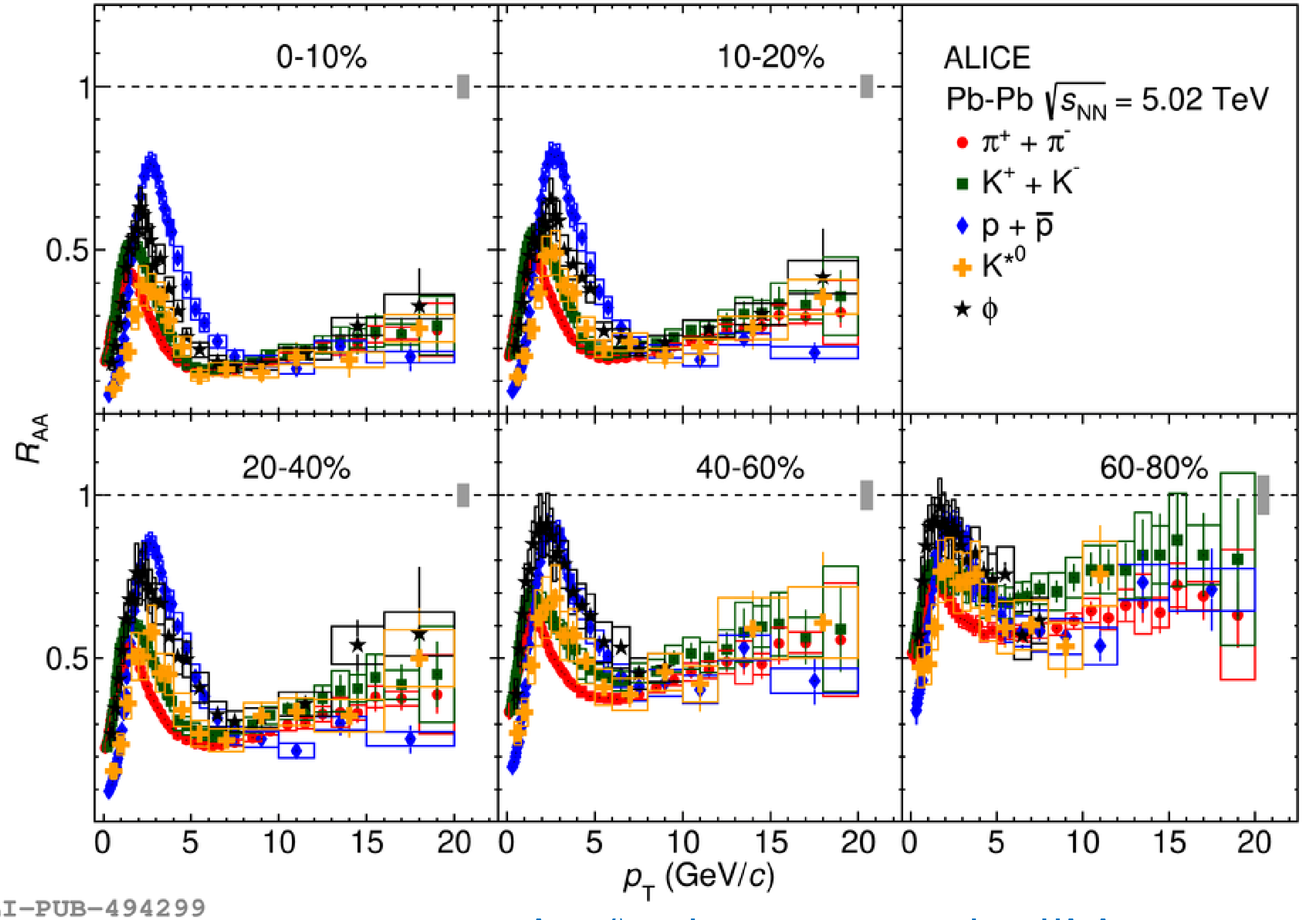
γ_s-CSM prediction for the $f_0(980)$ assuming net strangeness equal to zero is consistent with the data within 1.9σ

Nuclear modification factor R_{AA} – centrality dependence

NEW

PR **C106** (2022) 034907

Pb–Pb@5.02 ATeV | **K*(892)^0** | **ϕ(1020)**



strong suppression for the most central collisions
behaviour similar to charged hadrons

NEW

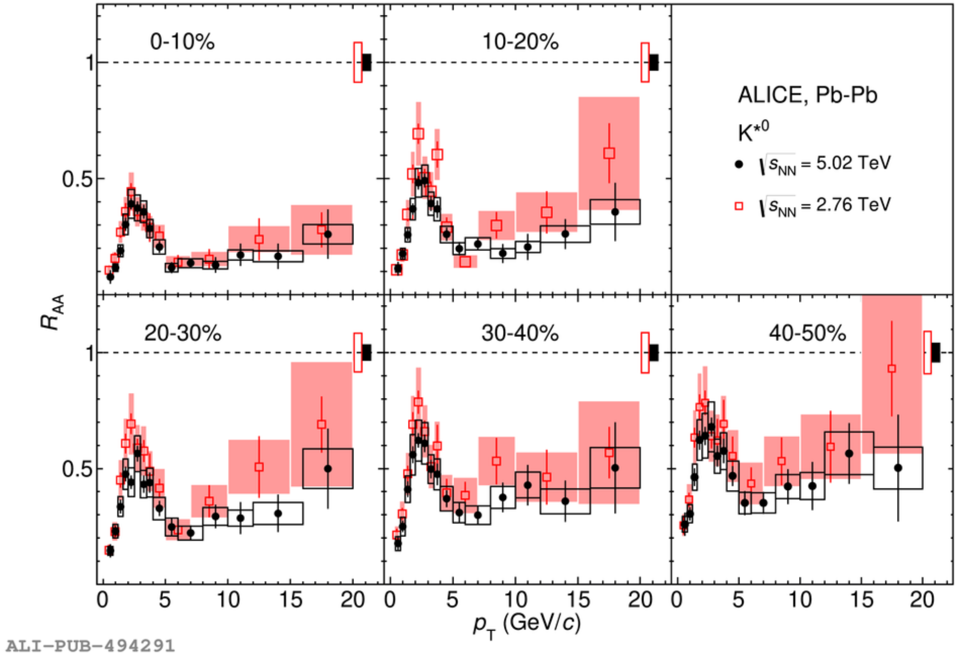
R_{AA} – energy dependence

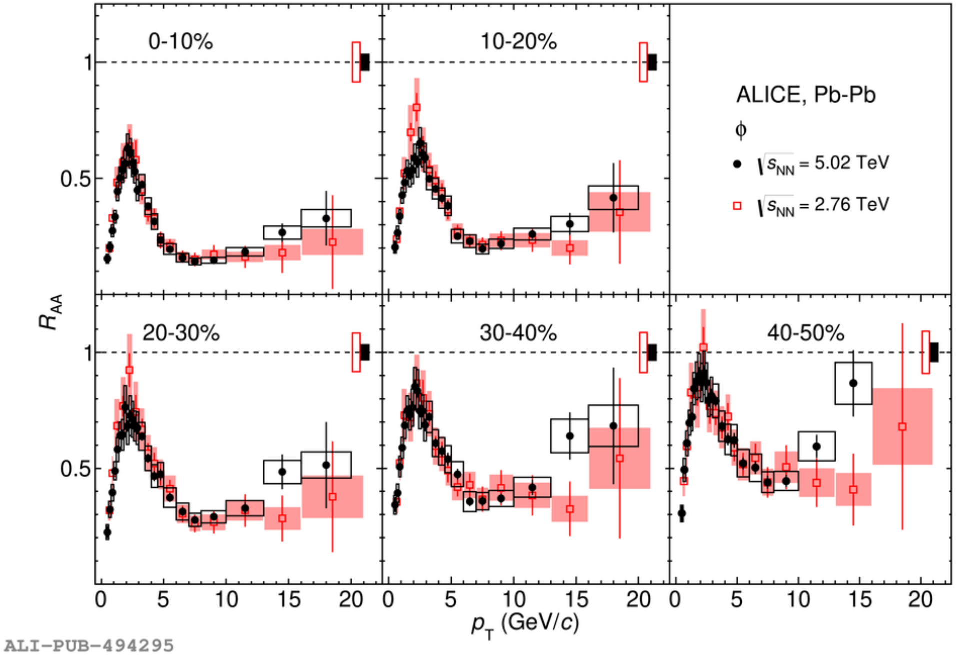
PR **C106** (2022) 034907

Pb–Pb
2.76 TeV (empty markers)
5.02 TeV (filled markers)

K*(892)^0

ϕ(1020)





no significant energy dependence

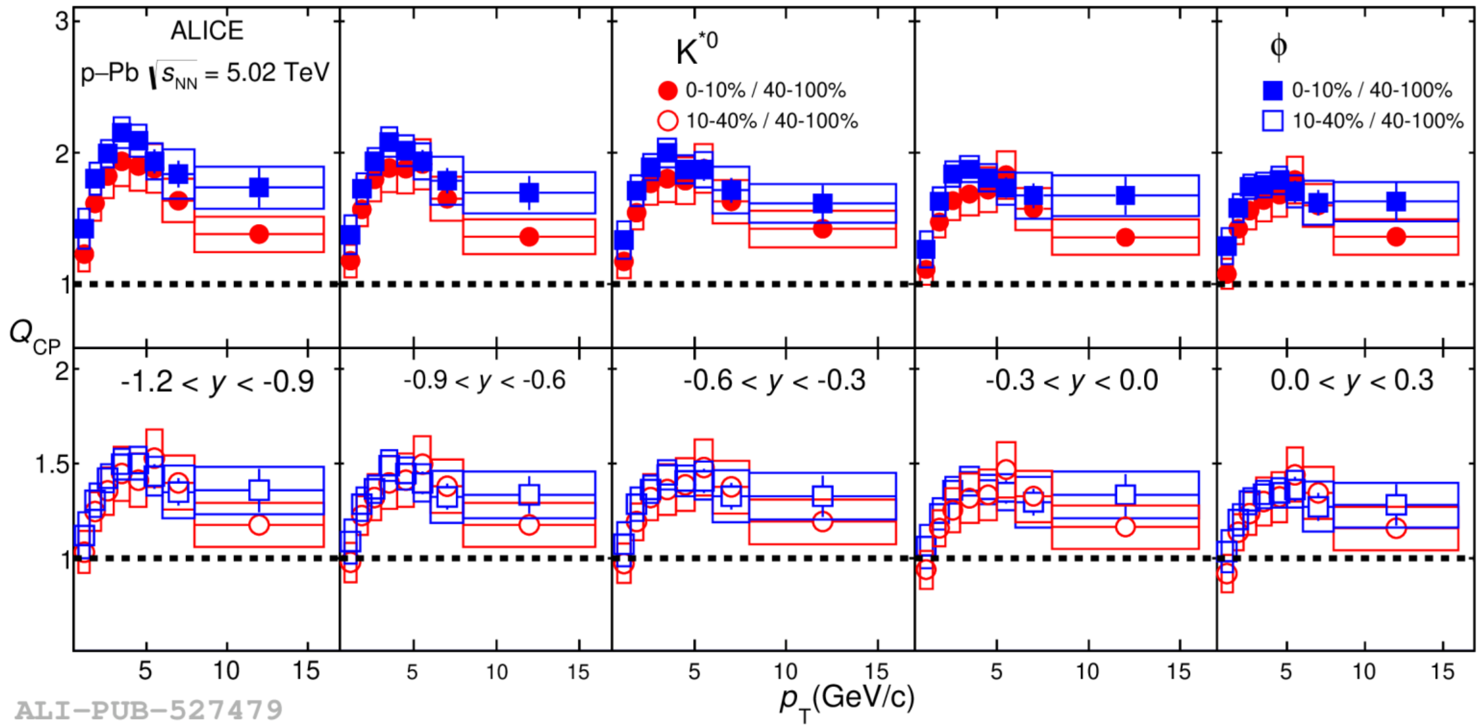
Nuclear modification factor Q_{CP} – multiplicity and rapidity dependence

$$Q_{CP}(p_T) = \left.\frac{\frac{d^2N}{dp_T dy}}{\langle N_{coll}\rangle}\right|_{HM} \Bigg/ \left.\frac{\frac{d^2N}{dp_T dy}}{\langle N_{coll}\rangle}\right|_{LM}$$

NEW

EPJ **C83** (2023) 540

K*(892)^0 | **p–Pb@5.02 ATeV** | **φ(1020)**



- a bump, with a maximum around p_T =3 GeV/c, suggestive of the Cronin effect
- more pronounced for large negative rapidities (in the Pb-going direction) and for more central (higher multiplicity) collisions

Summary

Yields:

independent of collision system and energy
appear to be driven by event multiplicity

Particle yield ratios (with previous results):

Pb–Pb: resonance suppression

resonance	ρ^0	K*	$\Sigma^{*\pm}$	Λ^*	Ξ^{*0}	ϕ
lifetime (fm/*c*)	1.3	4.2	5-5.5	12.6	21.7	46.4
suppression	**yes**	**yes**	**?**	**yes**	**no**	**no**

qualitatively described by model with rescattering

pp, p–Pb: resonance suppression

K* and f_0 – yes, Λ^* - no

R_{AA} **:**

Pb–Pb: no significant energy dependence

Q_{CP} **:**

p–Pb: Cronin-like enhancement is more pronounced for large negative rapidities (in the Pb-going direction) and for more central (higher multiplicity) collisions.