Production of hadronic resonances measured with ALICE at the LHC

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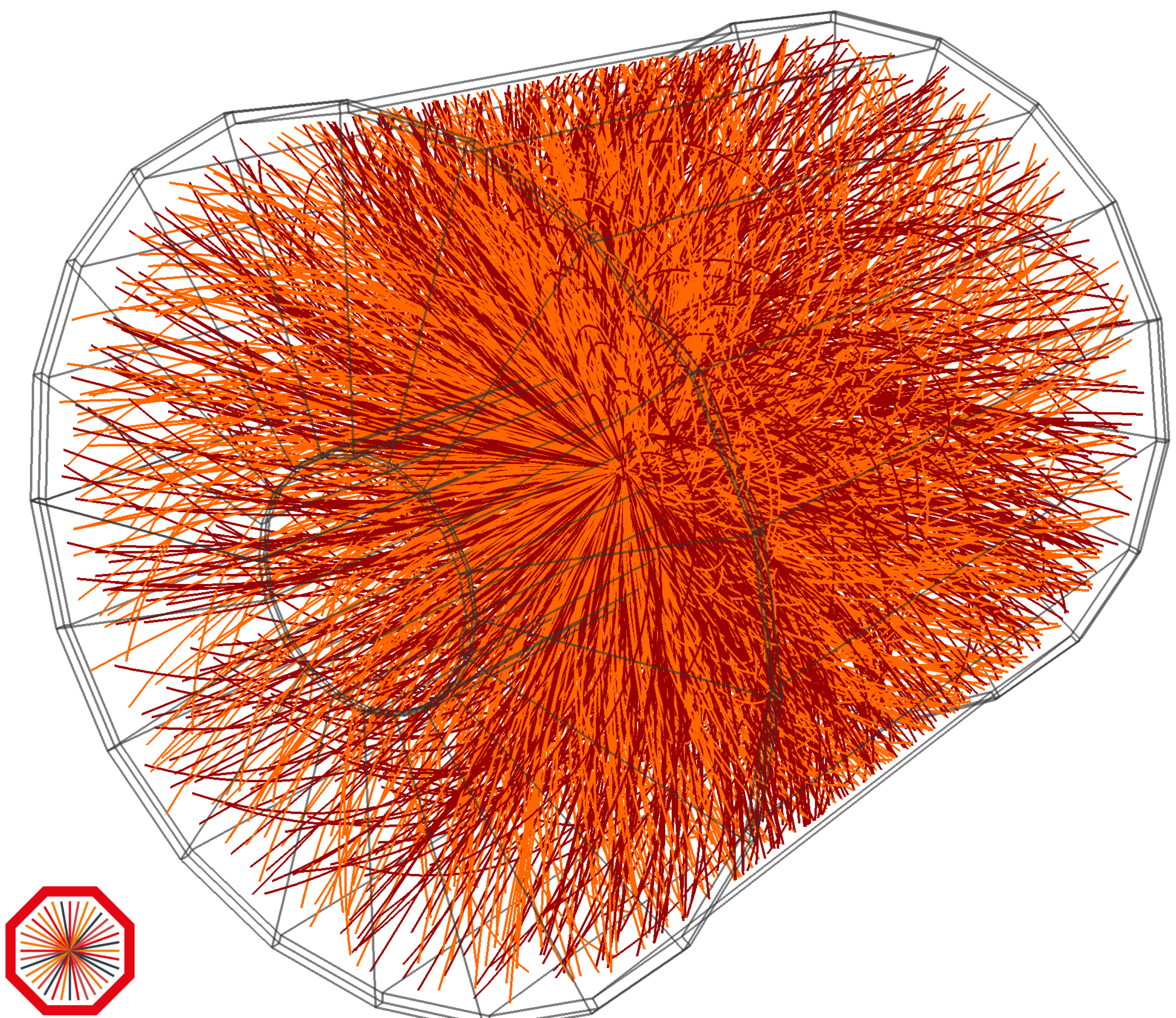
The 36th Winter Workshop on Nuclear Dynamics
1-7 March 2020

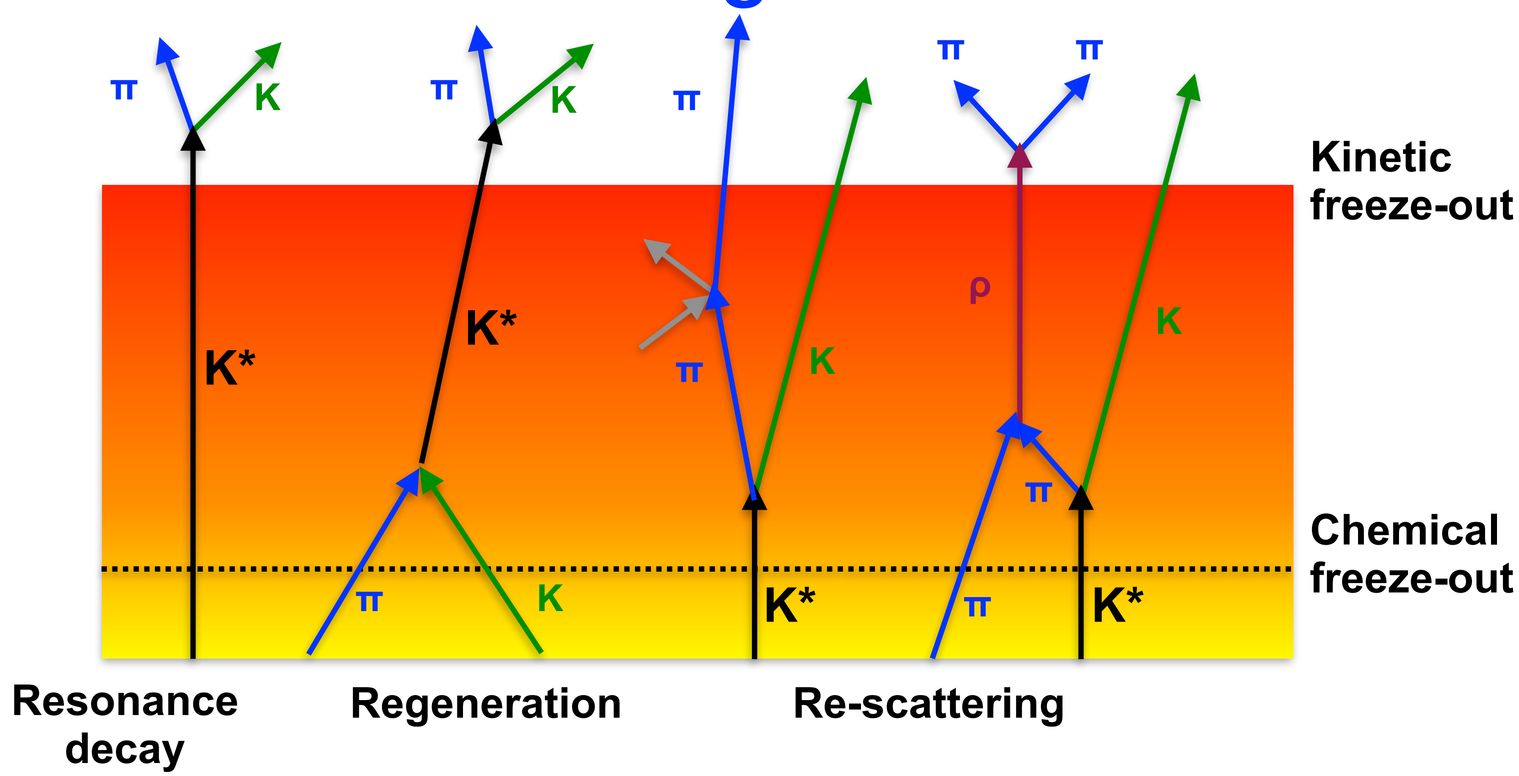
Outline

- Motivation
- ALICE detector
- Results in pp, p-Pb, Xe-Xe and Pb-Pb collisions
  - spectra
  - integrated yield and mean p_T
  - particle ratios
- Nuclear modification factors
- Reconstruction of Ξ(1820)
- Summary



Motivation

- Resonances have different **short lifetimes** similar to **Hadronic phase** - allows the study of properties of hadronic phase in terms of **regeneration and re-scattering** effects



Regeneration: pseudo-elastic scattering of decay products

→ ***Enhanced*** yield

Re-scattering: resonance decay products undergo elastic scattering or pseudo-elastic scattering through a different resonance state

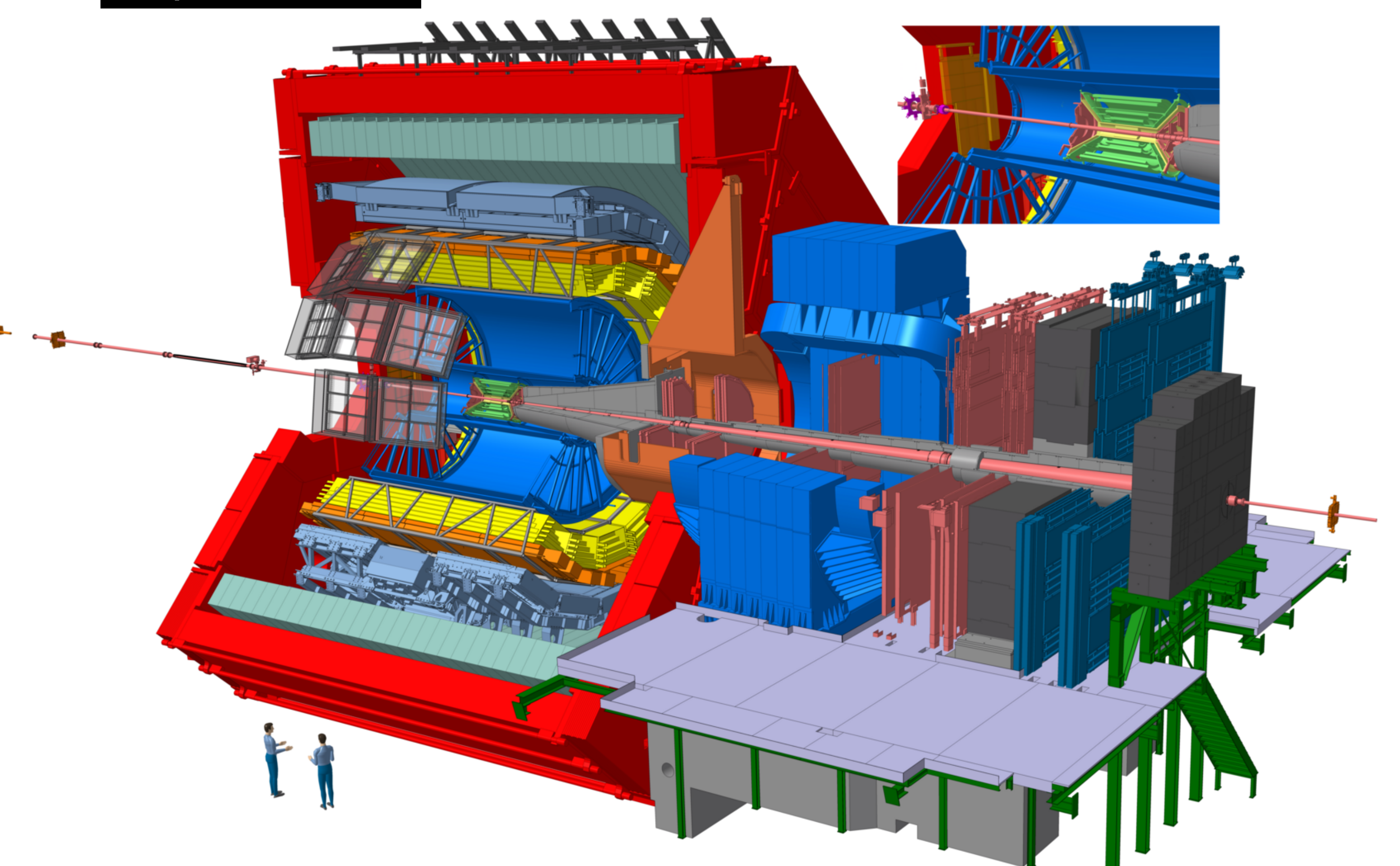
→ Not reconstructed through invariant mass

→ ***Reduced*** yield

Resonances in ALICE

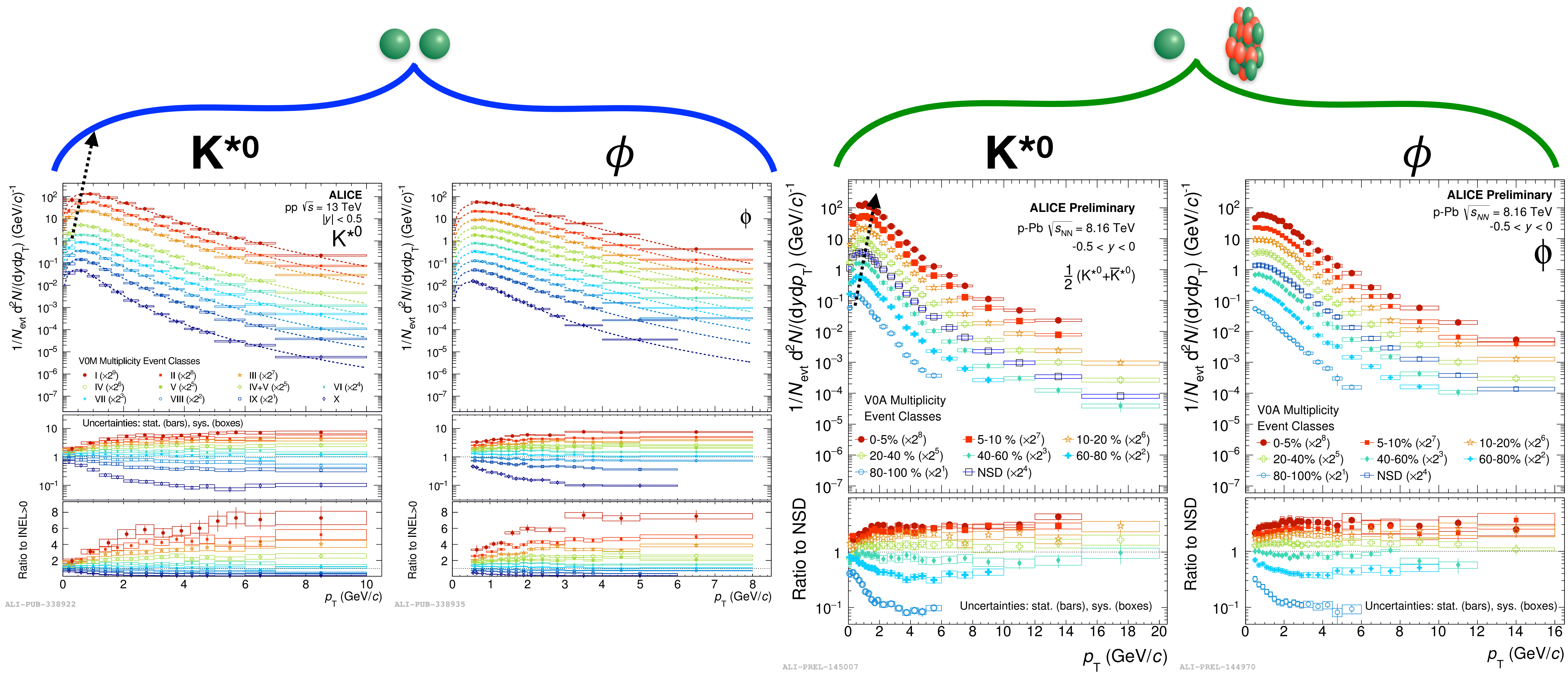
Resonance	τ(fm/c)	Decay	BR
$\rho(770)^0$	1.3	ππ	100
$K^*(892)^0$	4.2	Kπ	66.6
$\Sigma(1385)^\pm$	5.5	Λπ	87
$\Xi(1820)^\pm$	8.1	ΛK	unknown
$\Lambda(1520)$	12.6	pK	22.5
$\Xi(1530)^0$	21.7	Ξπ	66.7
$\phi(1020)$	46.4	KK	49.2

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



- Inner Tracking System (**ITS**)
  - Silicon detectors
  - 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

p_T-spectra in pp and p-Pb collisions

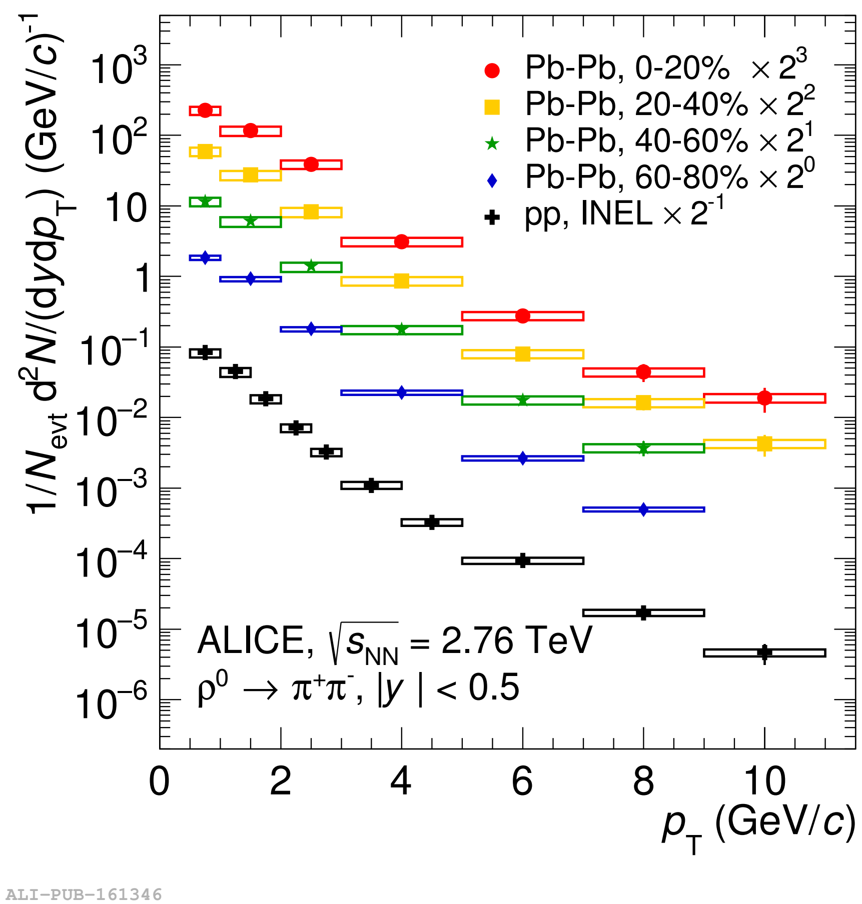


- Evolution of the spectral shape with increasing multiplicity for p_T<5 GeV/*c*
- The spectral shape is similar across multiplicity for p_T>5 GeV/*c*

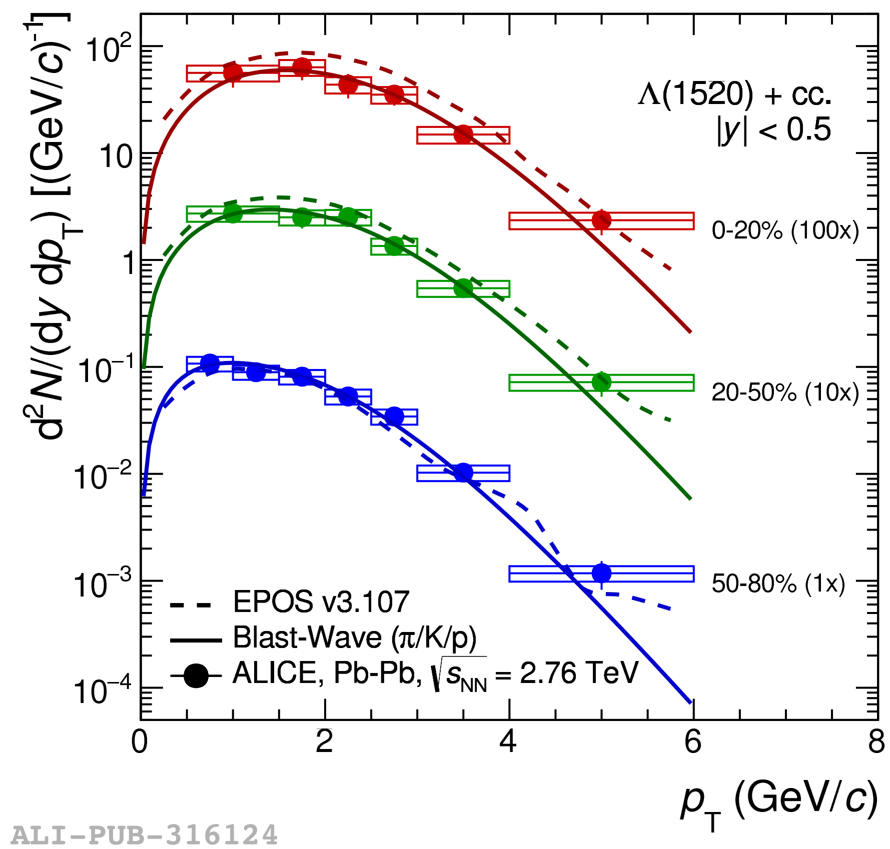
p_T-spectra in Pb-Pb collisions

ALICE

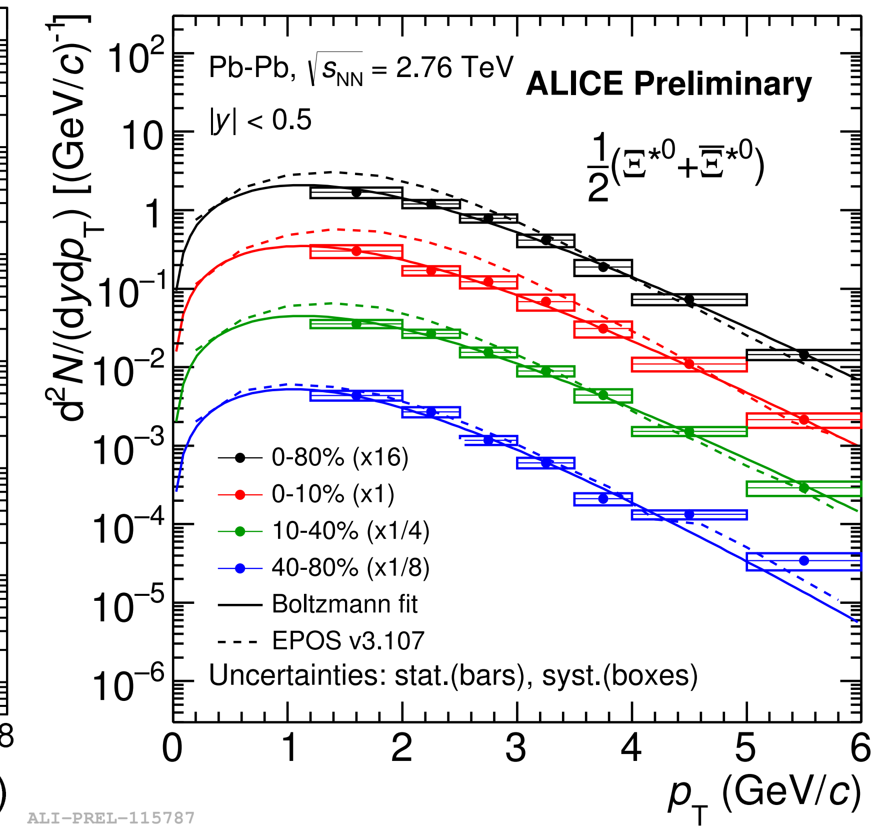
$\rho(770)^0$



$\Lambda(1520)$



$\Xi(1530)^0$

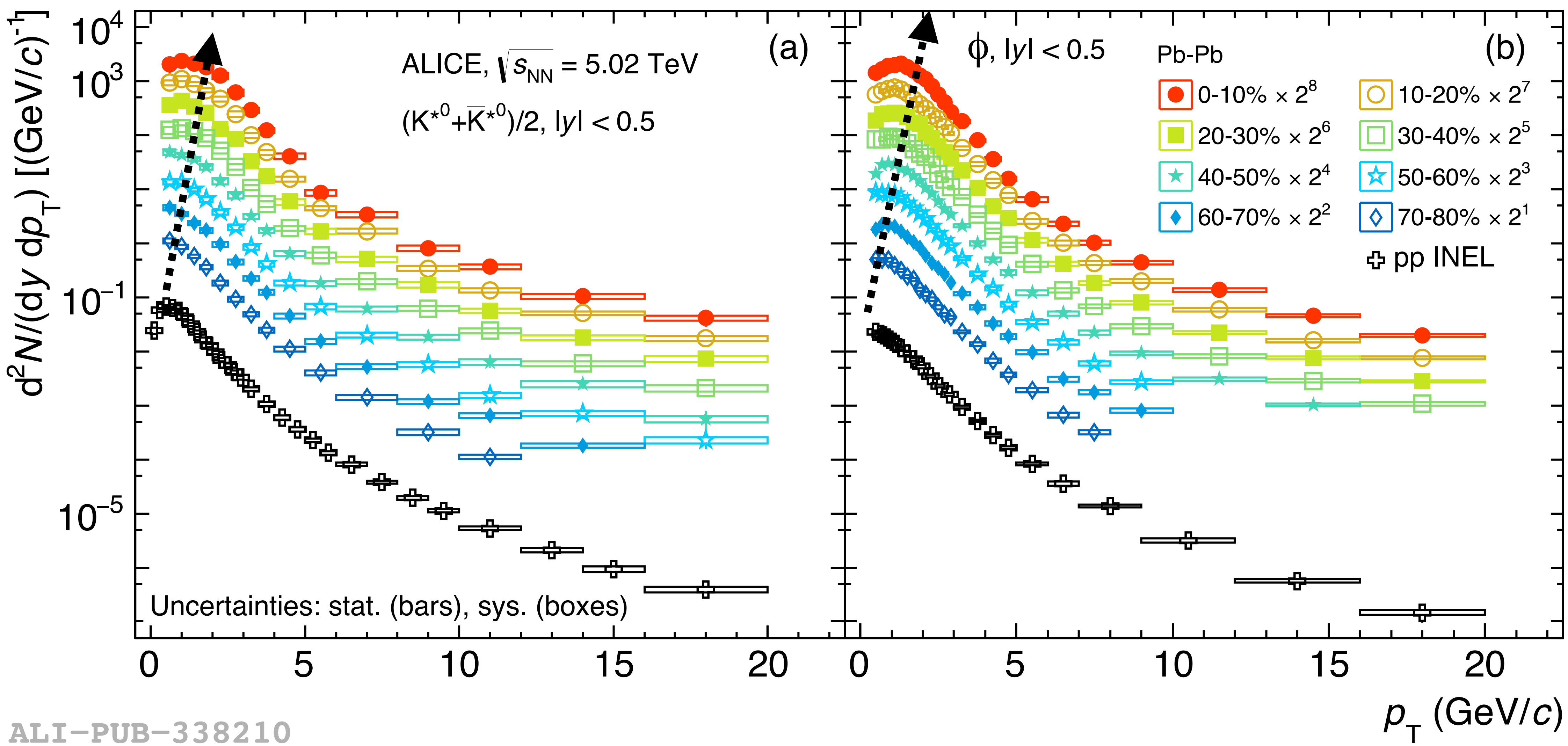


Phys.Rev. C99 (2019) 064901

Phys.Rev. C99 (2019) 024905

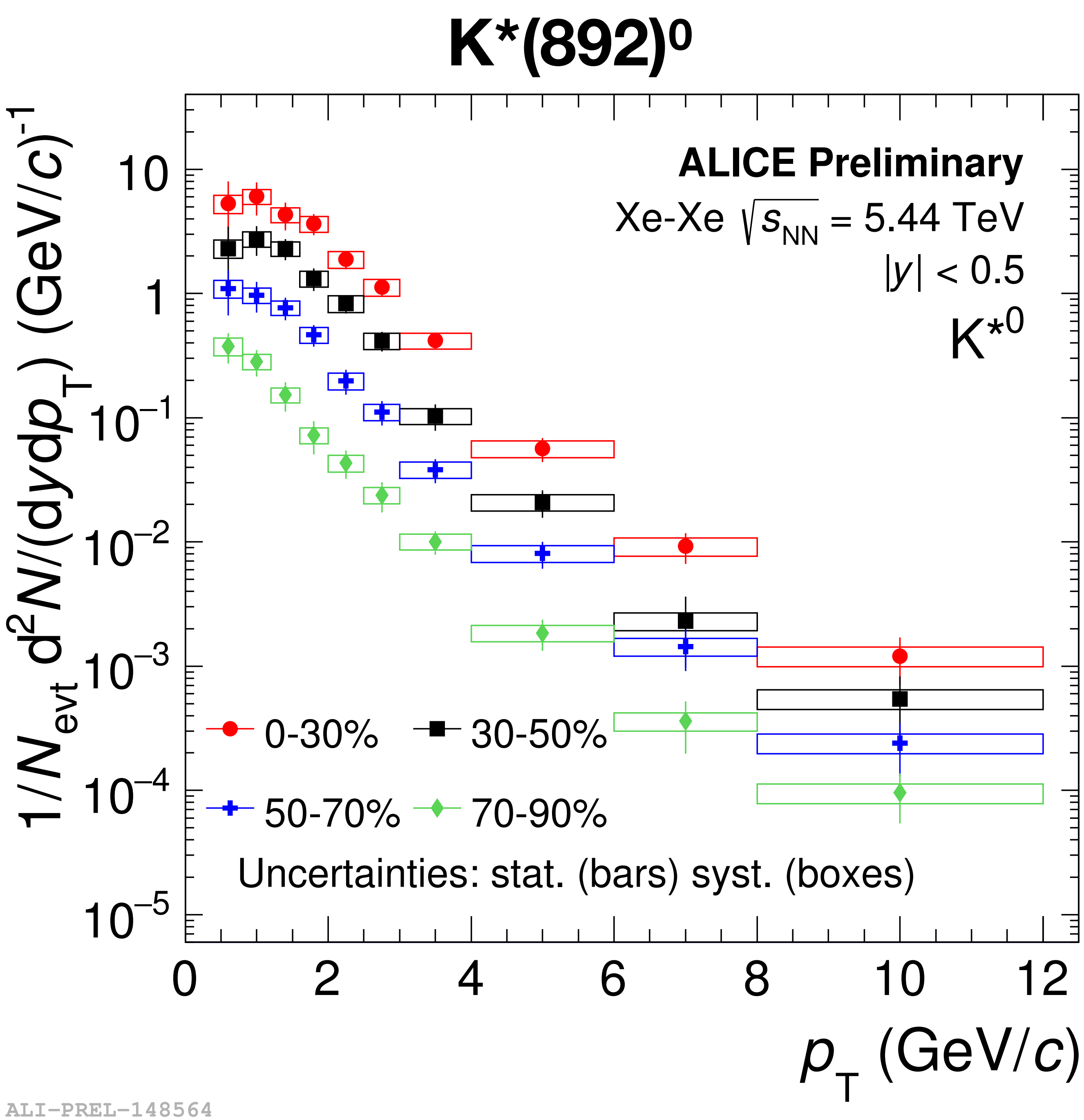
p_T-spectra in Pb-Pb collisions

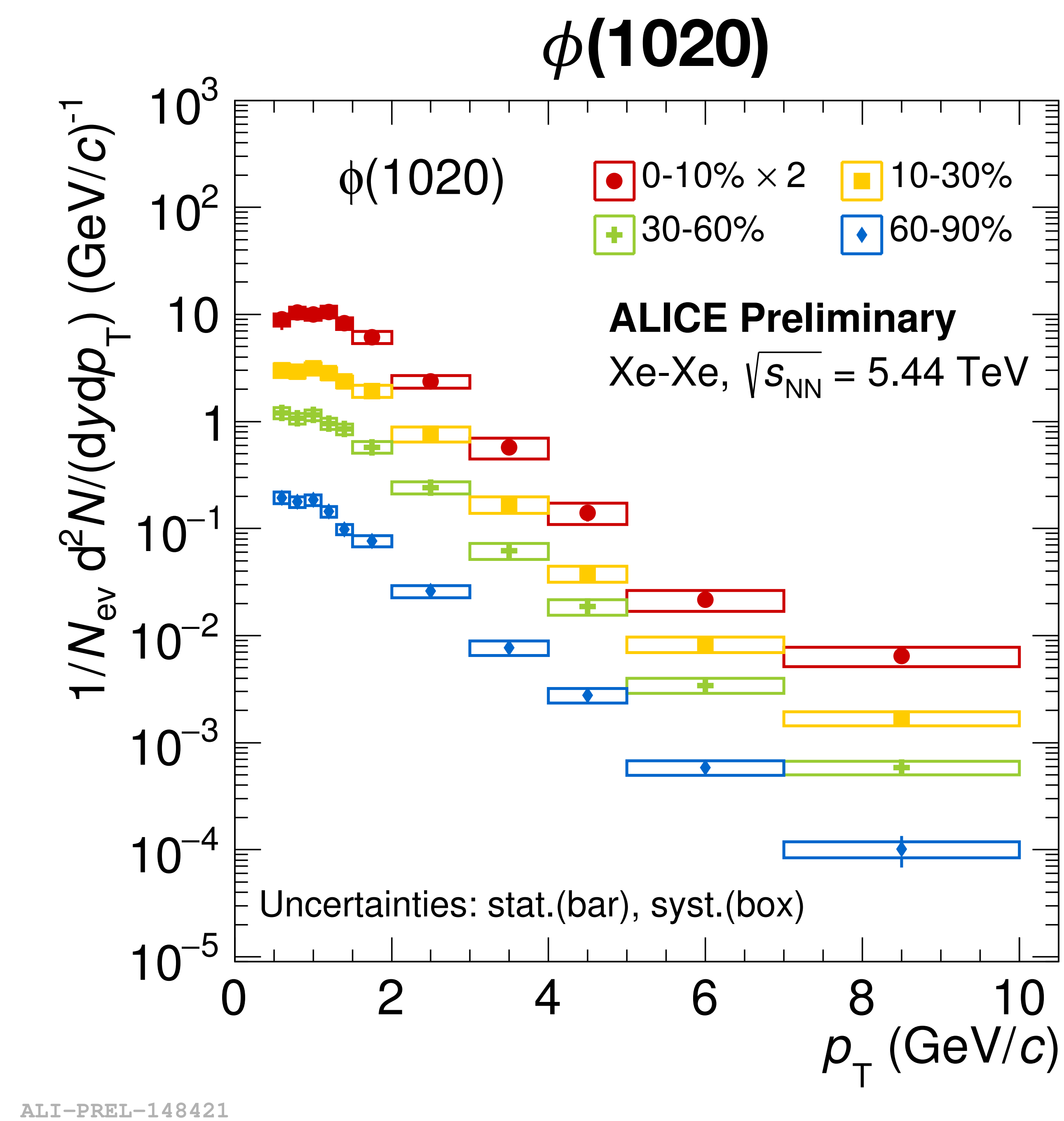
K*(892)^0 ϕ(1020)



- Hardening of particle spectra from peripheral to central collisions

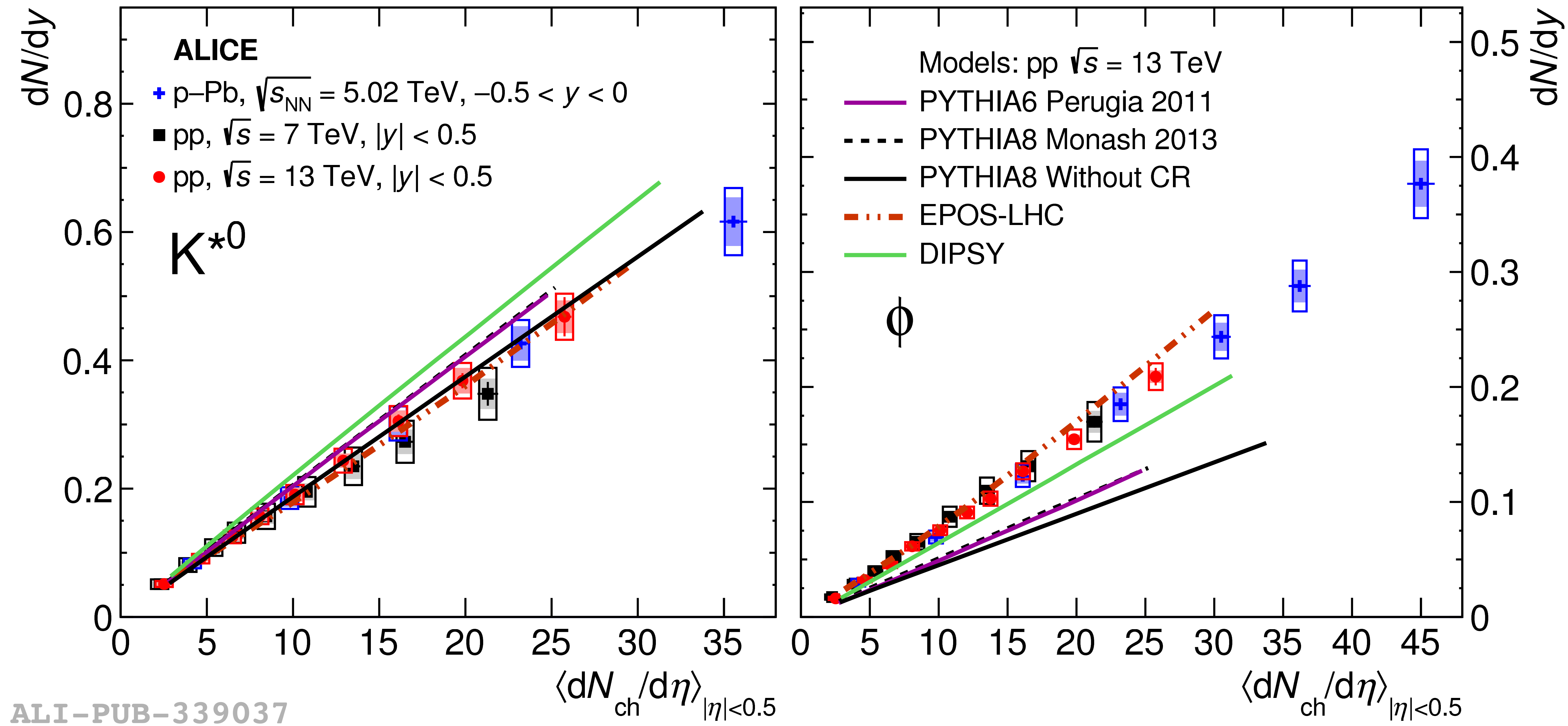
p_T-spectra in Xe-Xe collisions





- p_T-spectra measured in Xe-Xe collisions

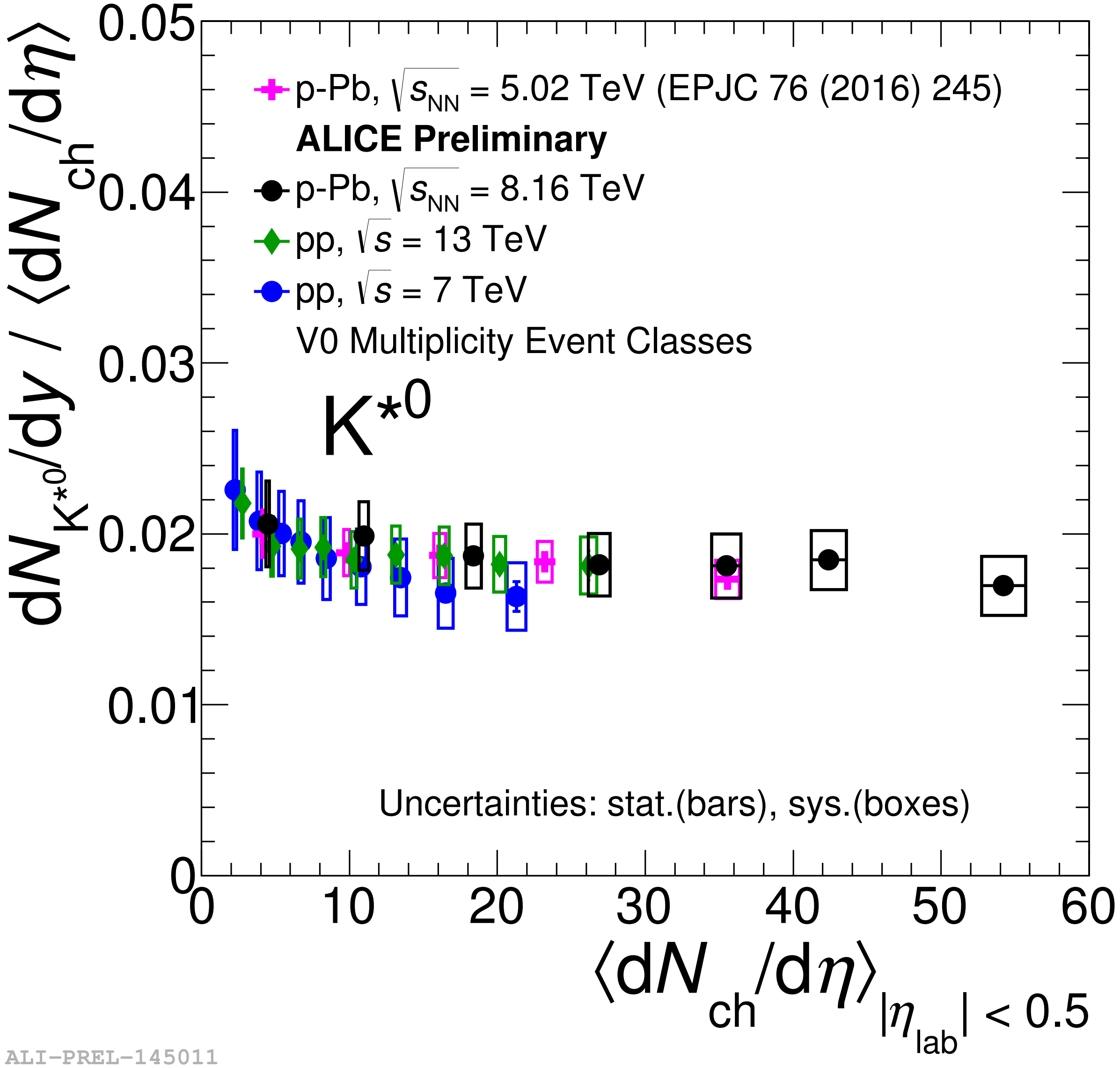
Integrated yield (dN/dy)

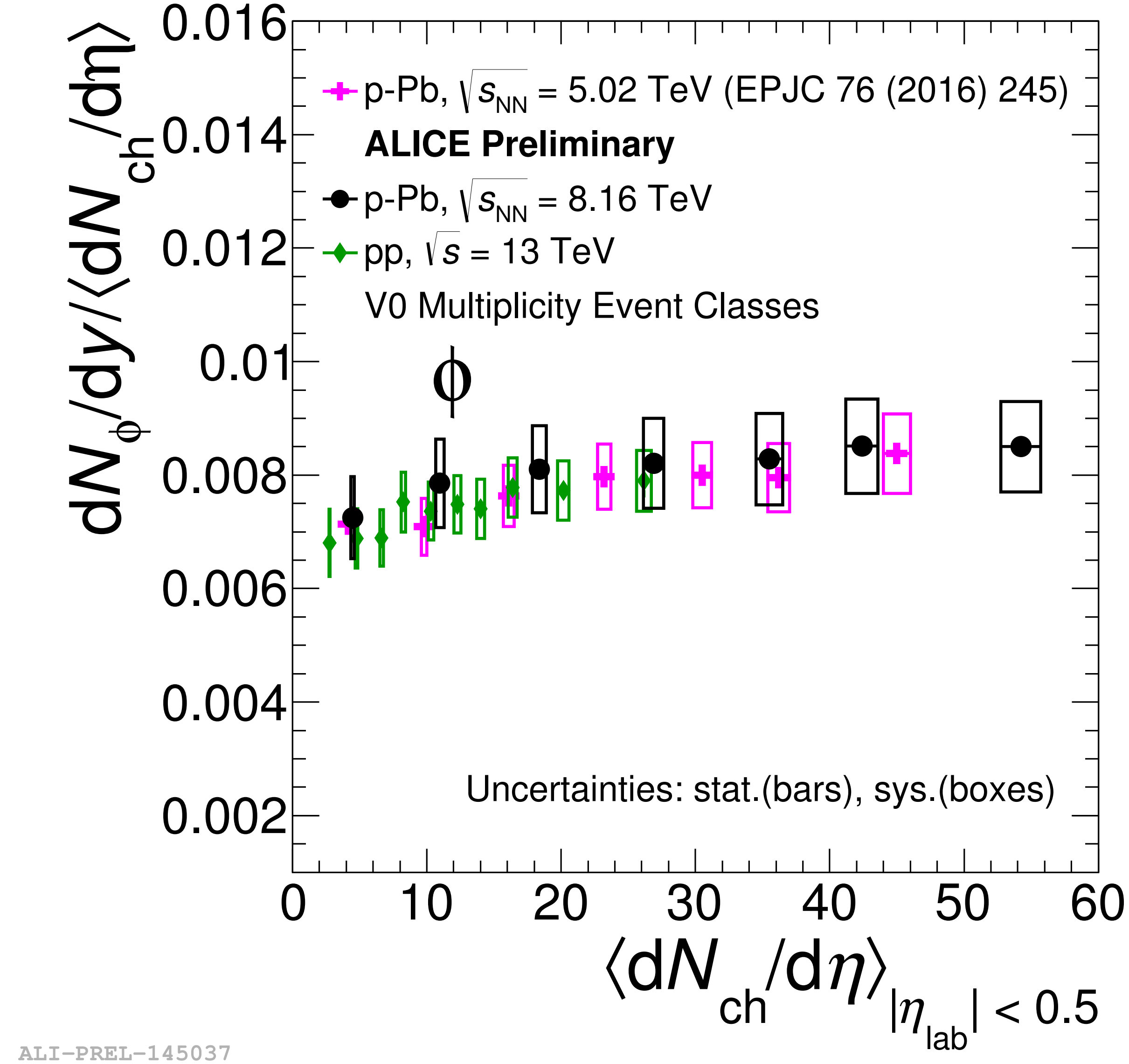


- dN/dy increases with multiplicity
- K^{*0}: described by EPOS-LHC and PYTHIA8 without color reconnection
- ϕ: slightly overestimated by EPOS-LHC and underestimated by PYTHIA tunes

Integrated yield (dN/dy)

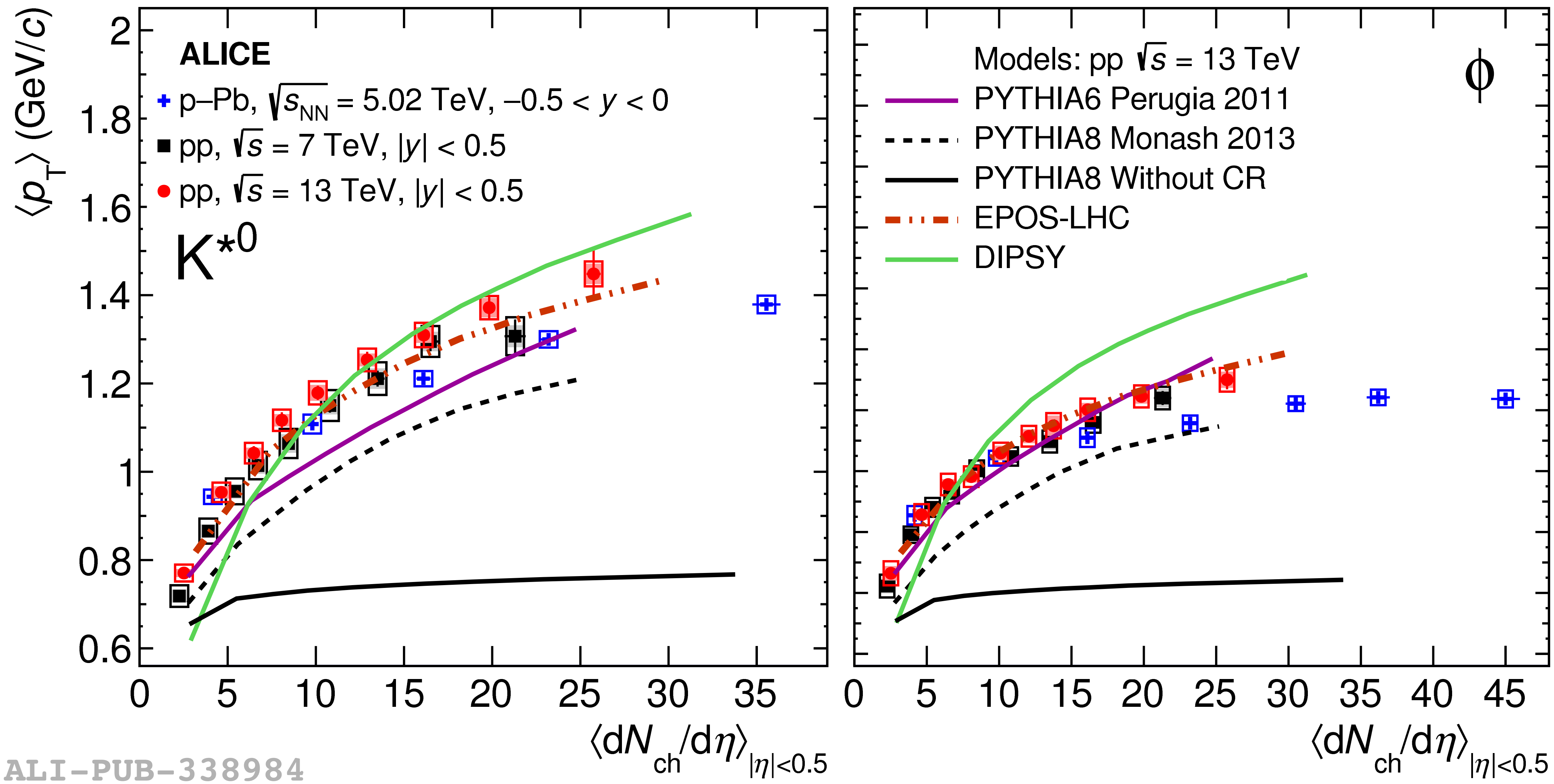
ALICE





- Integrated yield normalized to $\langle dN_{ch}/d\eta \rangle$ for K^{*0} and ϕ
  - independent of collision energy and systems for pp and p-Pb collisions

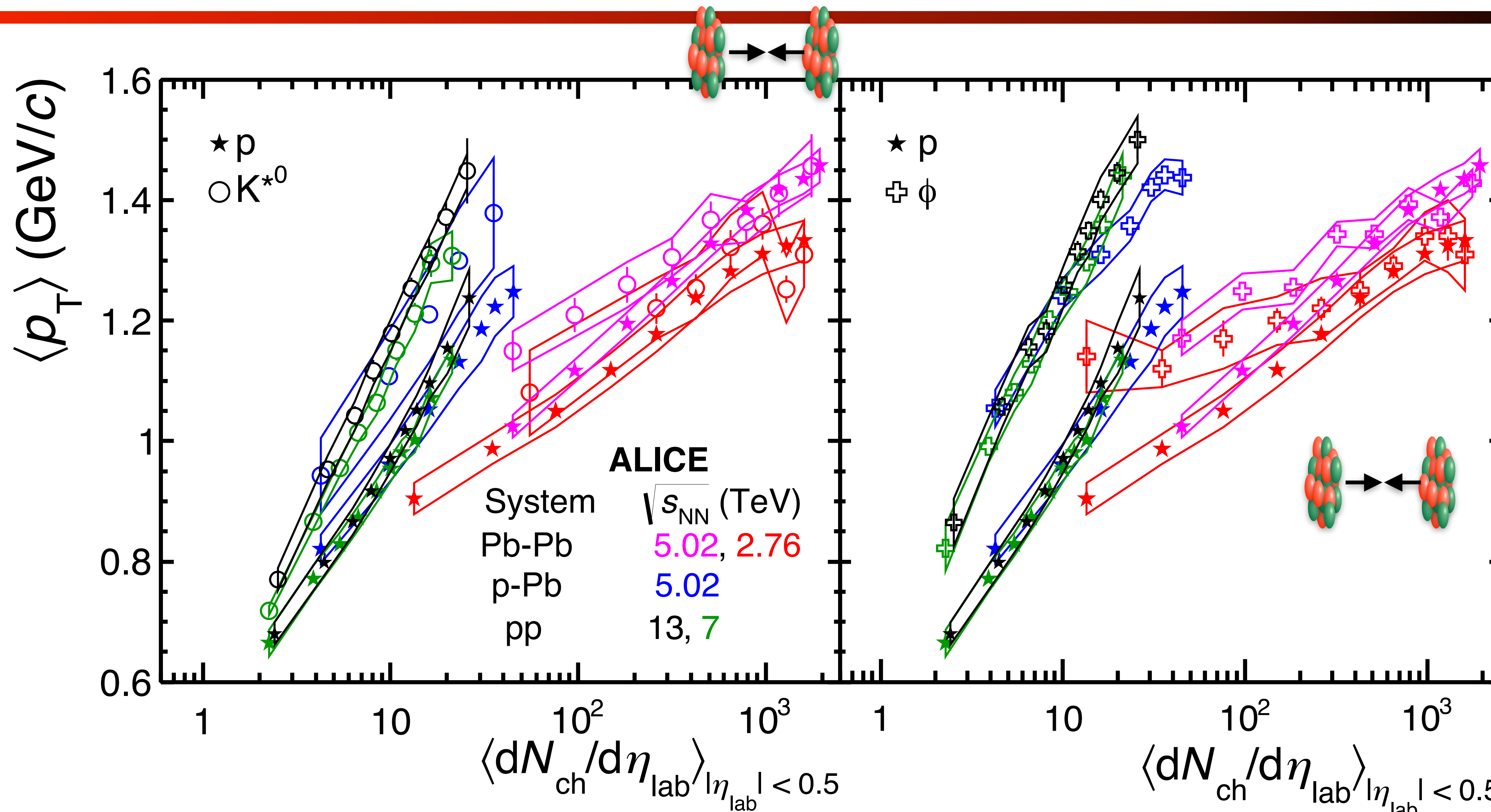
mean p_T



- ⟨p_T⟩ values in pp collisions at $\sqrt{s}$ = 7 TeV and 13 TeV follow approximately the same trend and rise faster as a function of ⟨dN_{ch}/dη⟩ than in p-Pb collisions

- ⟨p_T⟩ values predicted by EPOS-LHC are consistent with the measured values for ϕ, but slightly below values for K^{*0}

mean p_T

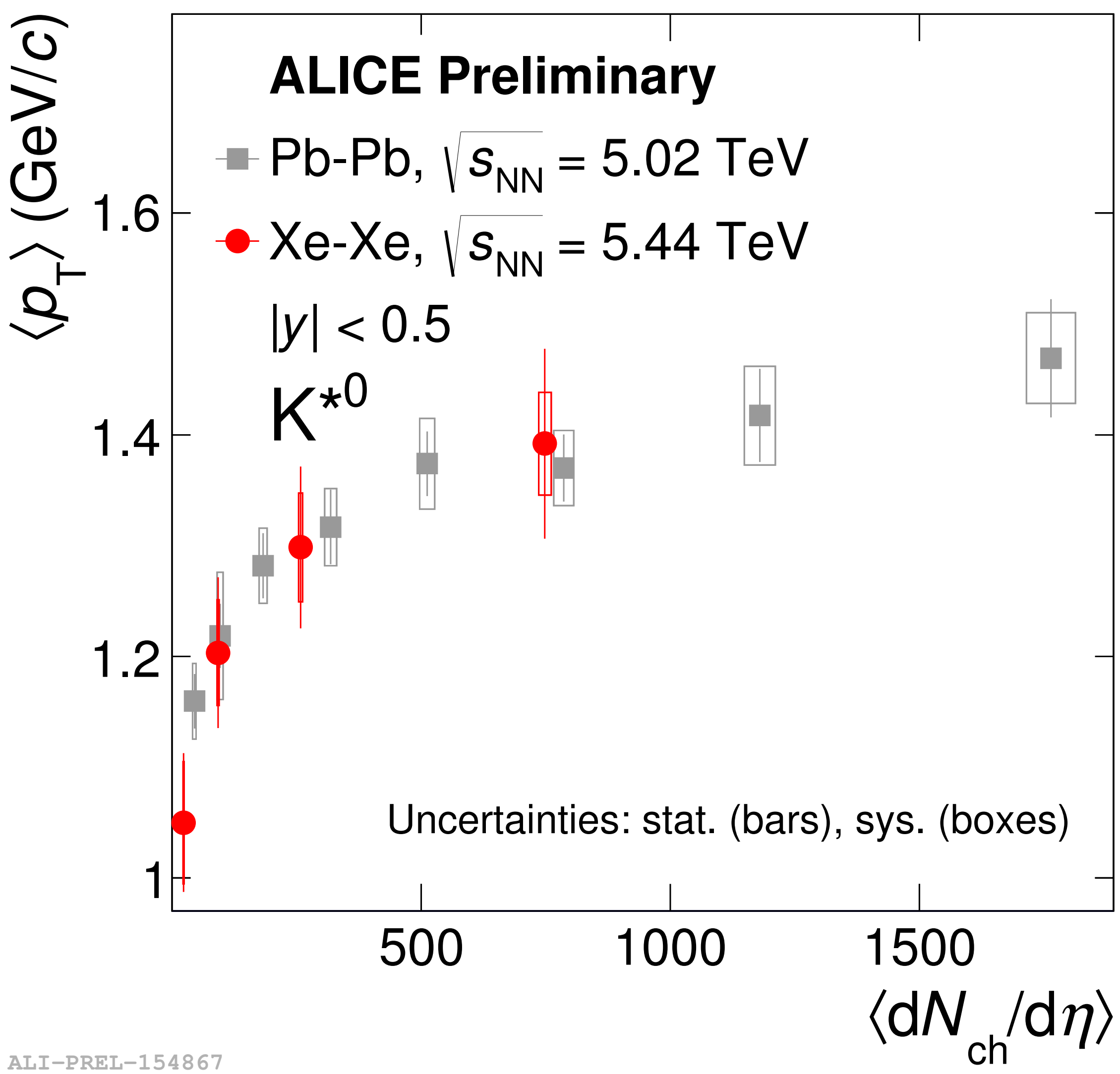


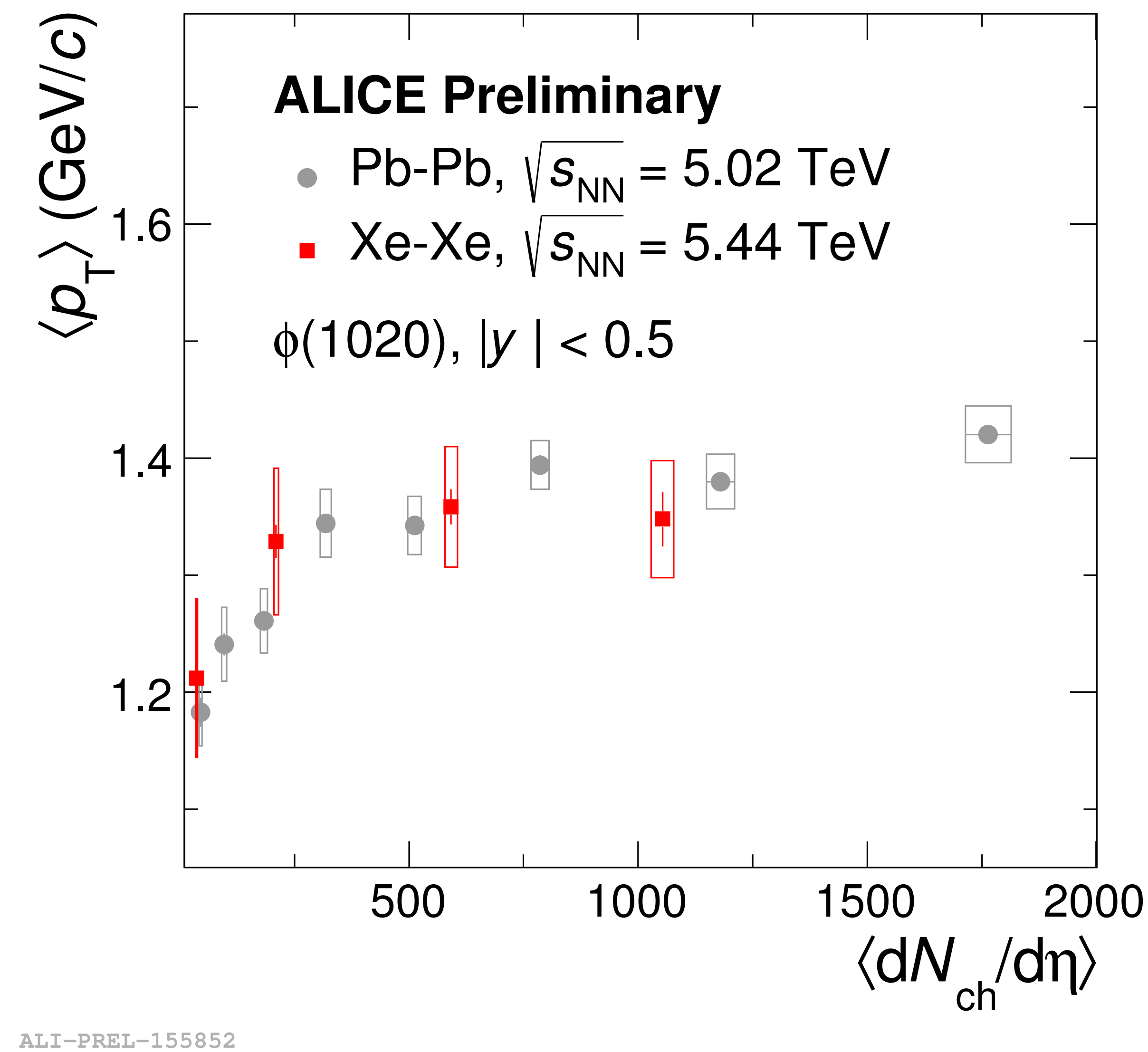
ALI-DER-339322

- In central Pb-Pb collisions
  - similar $\langle p_T \rangle$ for p, K^{*0} and ϕ have been observed
  - expected from hydrodynamics as they have similar masses

- In small collision systems
  - $\langle p_T \rangle$ increases more steeply and similarity of p, K^{*0} and ϕ is broken

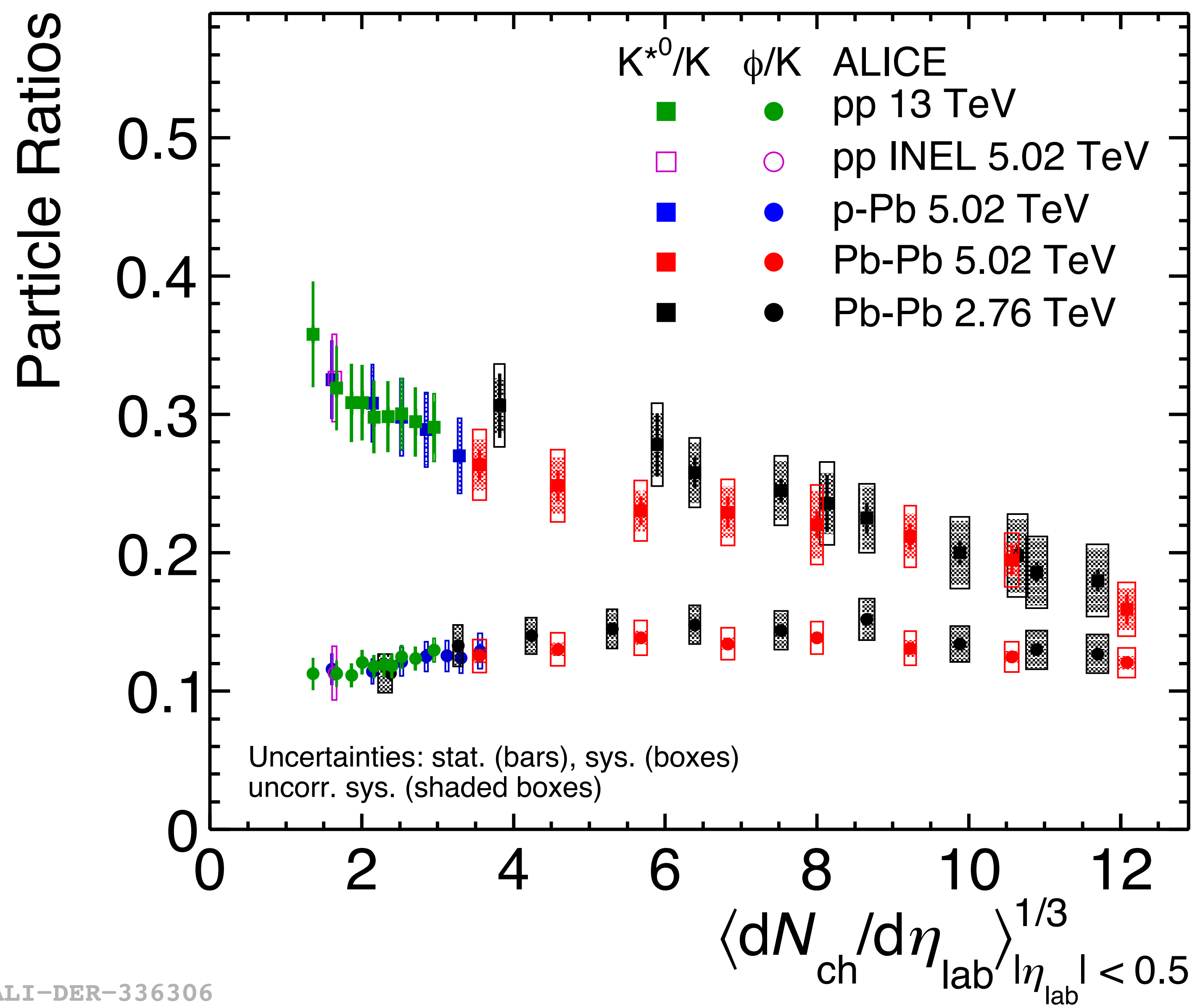
mean p_T





- $\langle p_T \rangle$ obtained from Pb-Pb and Xe-Xe collisions are in agreement with each other

Particle yield ratios



- Suppression of K^{*0}/K in central heavy-ion collisions w.r.t. peripheral Pb-Pb, p-Pb and pp collisions
  - suggests K^{*0} **re-scattering** is dominant over **regeneration**
- Hint of suppression in small systems at high multiplicity
  - hadronic phase also in small systems?
- No suppression of ϕ/K
  - due to larger ϕ lifetime

Lifetime(fm/c): ρ(1.3) < **K*0(4.2)** < Σ*(5.5) < Λ*(12.6) < Ξ*(21.7) < **ϕ(46.2)**

Resonance to long-lived particle ratios

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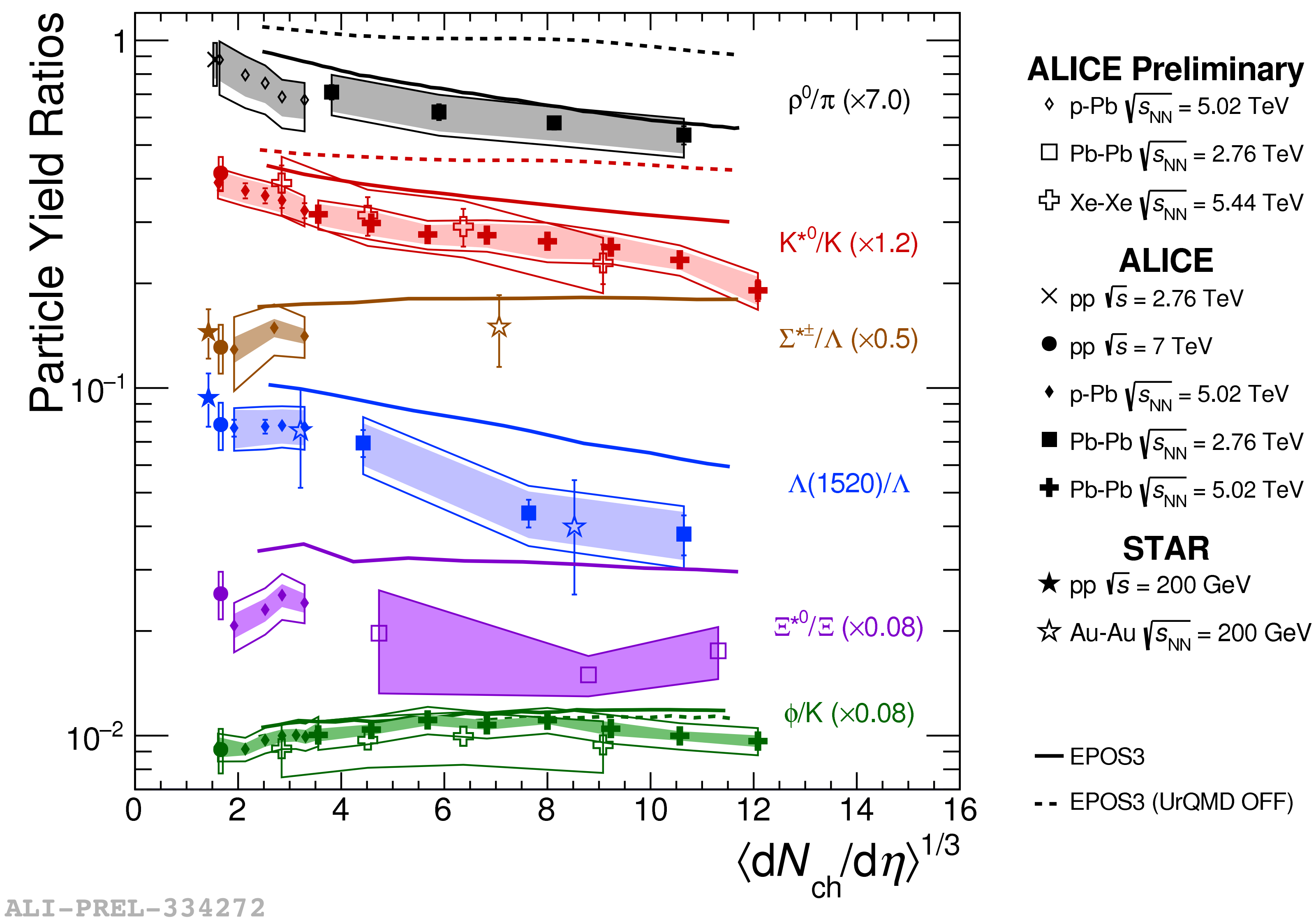


ρ^0/π, K^{*0}/K and Λ^*/Λ in Pb-Pb: suppression in central Pb-Pb collisions indicates dominance of re-scattering over regeneration for short lived resonances

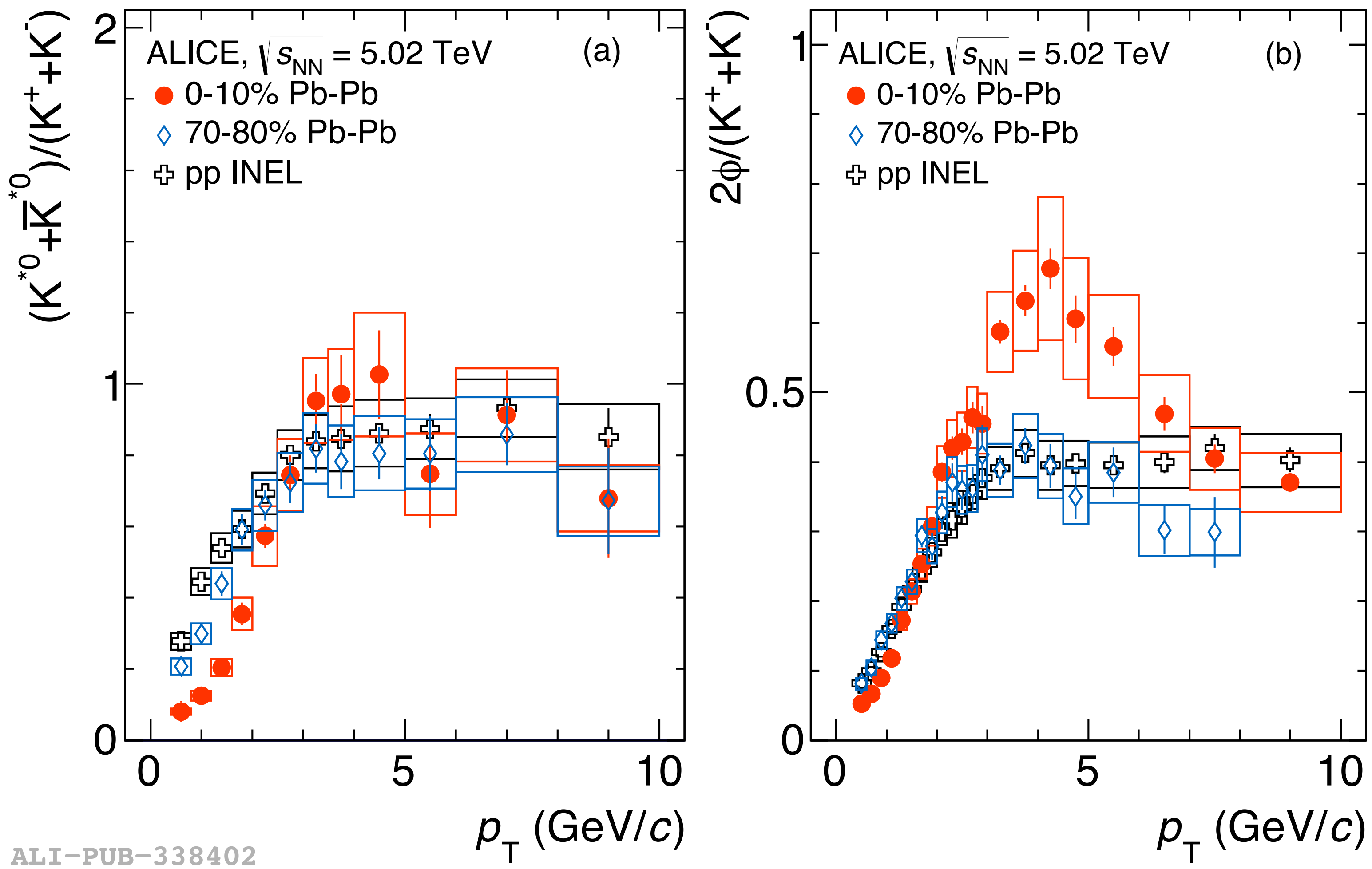
Σ^*/Λ and Λ^*/Λ: flat in small systems and no energy dependence from RHIC to LHC

Ξ^*/Ξ and ϕ/K: no significant centrality dependence across the different collision systems

In most cases EPOS3 with UrQMD describes the trend qualitatively

Lifetime(fm/c): **ρ(1.3)** < **K^{*0}(4.2)** < **Σ^*(5.5)** < **Λ^*(12.6)** < **Ξ^*(21.7)** < **ϕ(46.2)**

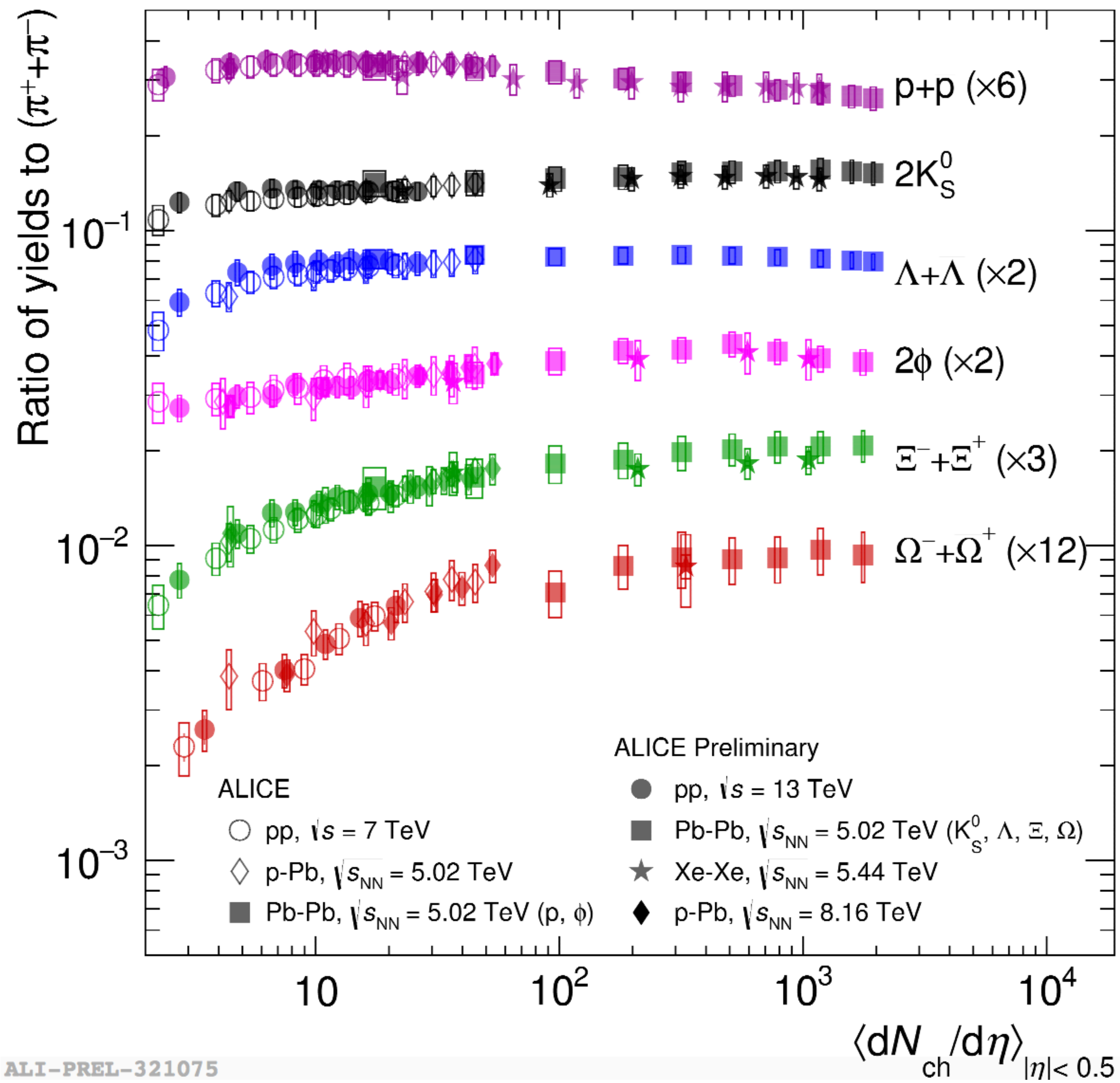
p_T-differential yield ratios



- At low p_T, K^{*0}/K for central collisions are lower than peripheral (pp) collisions whereas ϕ/K are comparable within the uncertainties
  - K^{*0} yields are suppressed due to re-scattering in the hadronic phase
  - most effect on low momentum particles

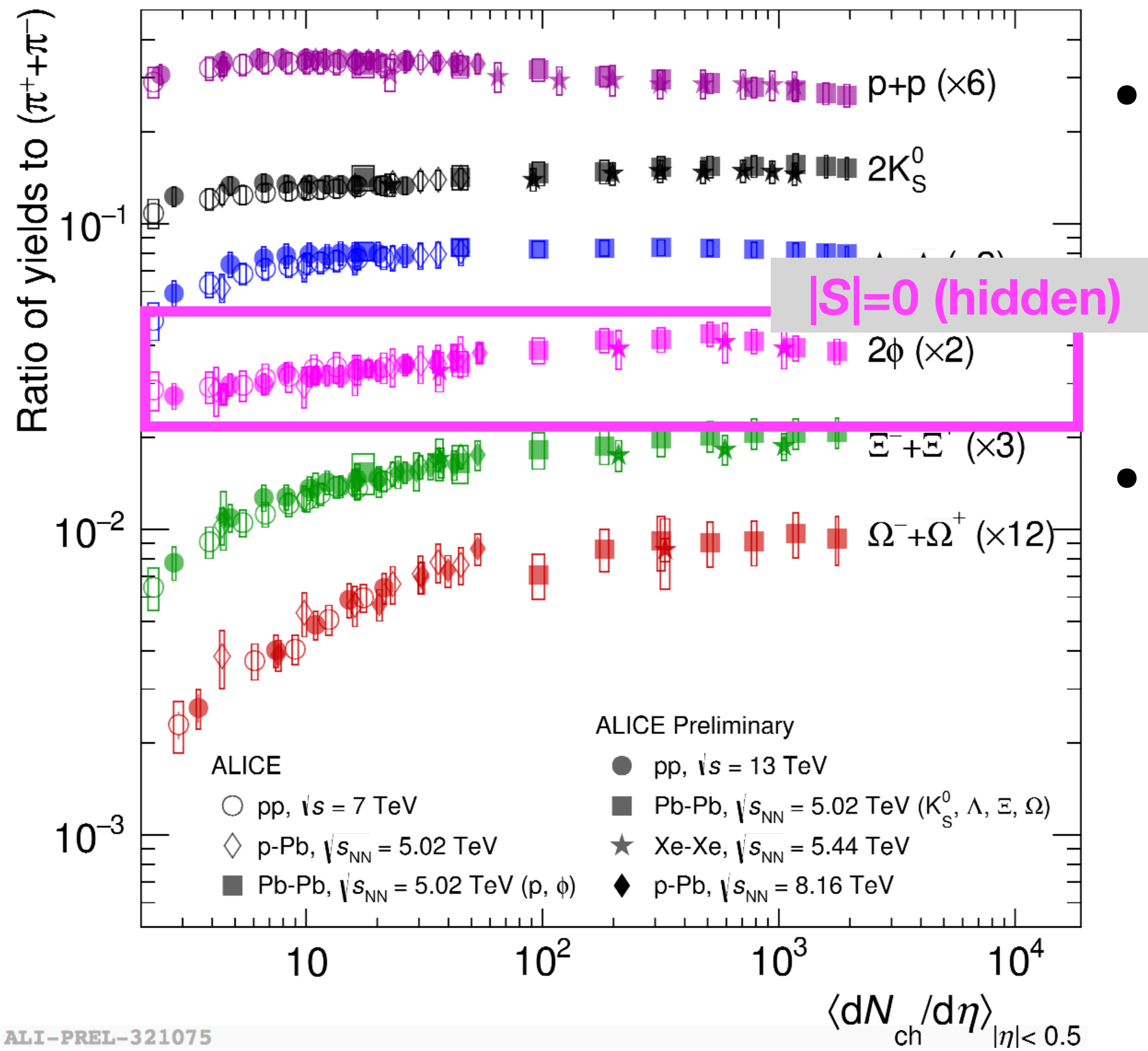
- At intermediate p_T, ratios show greater enhancement for central Pb-Pb collisions than peripheral and pp collisions

Strangeness production



- Smooth evolution vs. multiplicity in pp, p-Pb, Xe-Xe and Pb-Pb collisions from different energies
- Strangeness enhancement increases with strangeness content

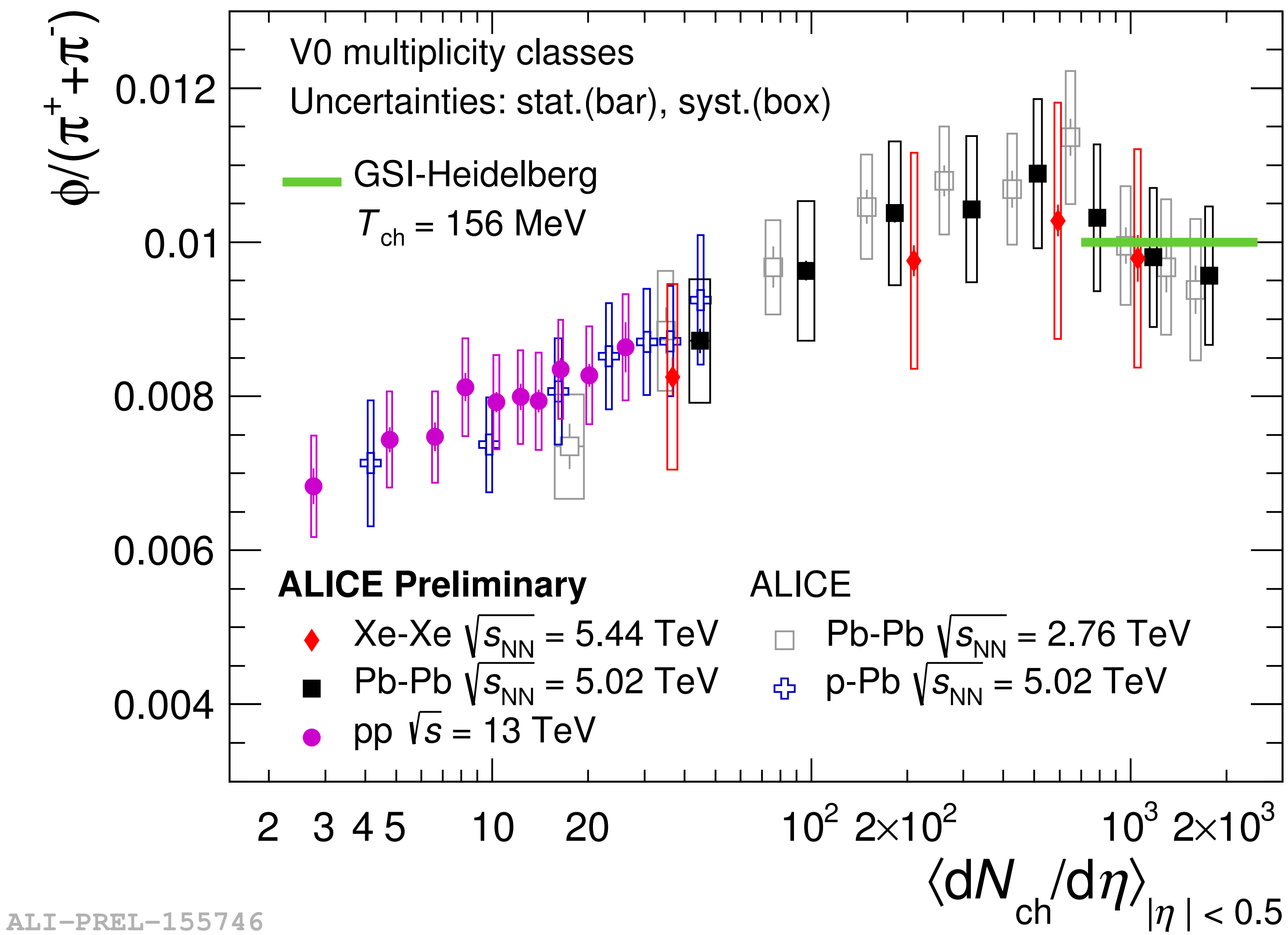
Strangeness production



- Smooth evolution vs. multiplicity in pp, p-Pb, Xe-Xe and Pb-Pb collisions from different energies
- Strangeness enhancement increases with strangeness content

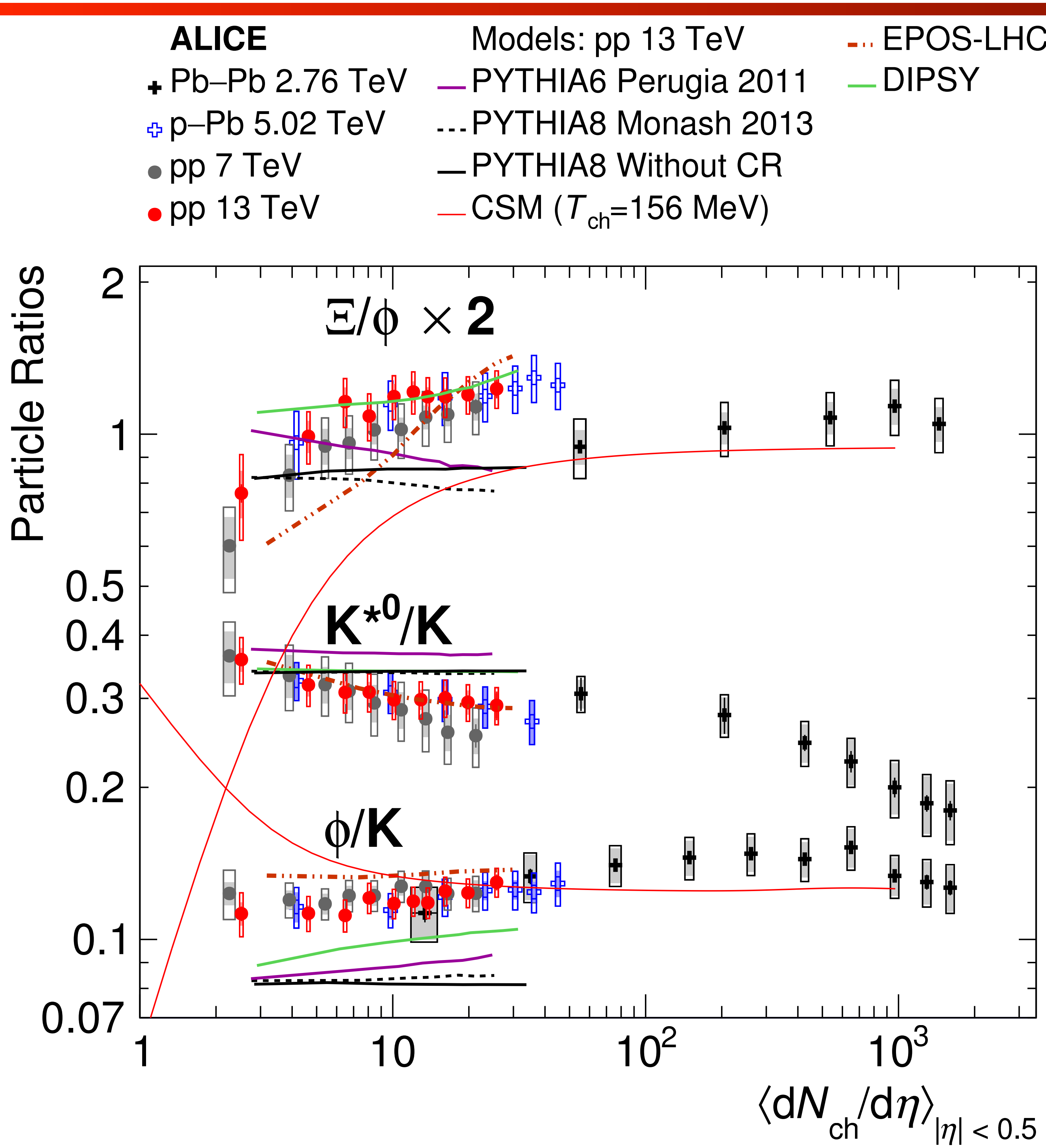
Does ϕ behave as a non-strange or double strange particle?

Strangeness enhancement: ϕ



- ϕ/π (|S|=0)/(|S|=0)
  - large systems: described by thermal model
  - small systems: increase with multiplicity

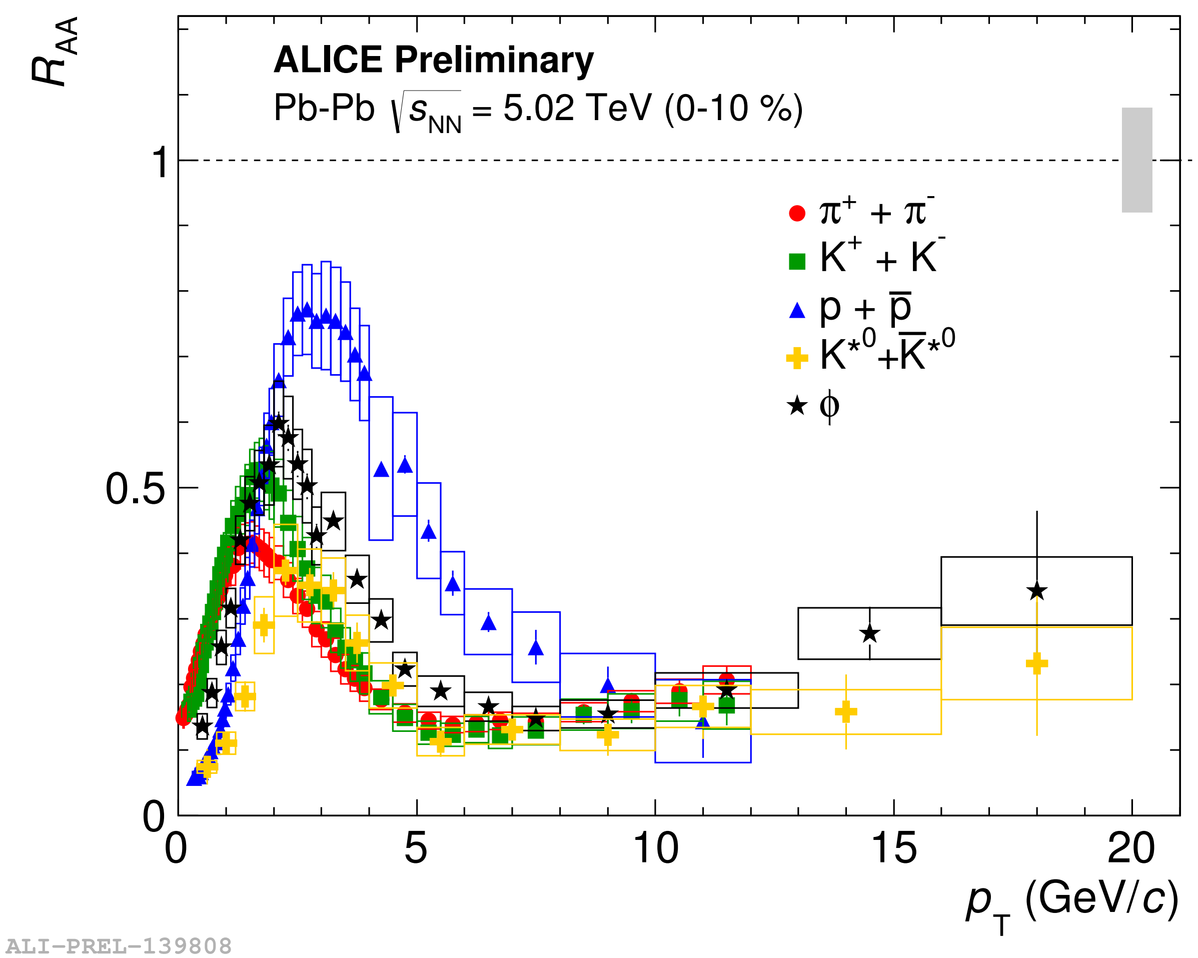
Strangeness enhancement: ϕ

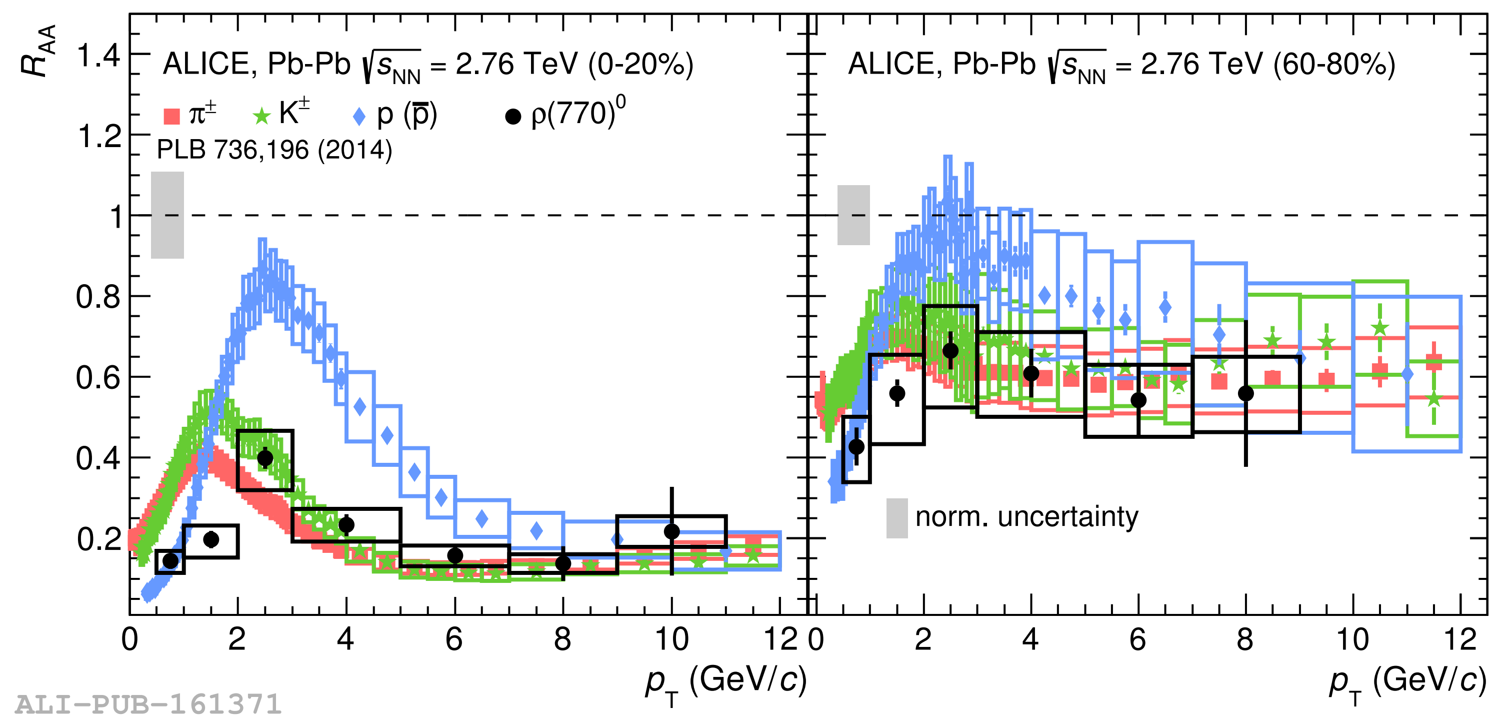


- ϕ/K (|S|=0)/(|S|=1)
  - flat or slightly increasing at lowest multiplicities
  - suggest ϕ behaves like a S ≧ 1 particle
- Ξ/ϕ (|S|=2)/(|S|=0)
  - increase for low multiplicity collisions
  - fairly flat across wide multiplicity range
- The ϕ has "effective strangeness" of 1-2 units

Nuclear modification factor (R_{AA}, R_{pPb})

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





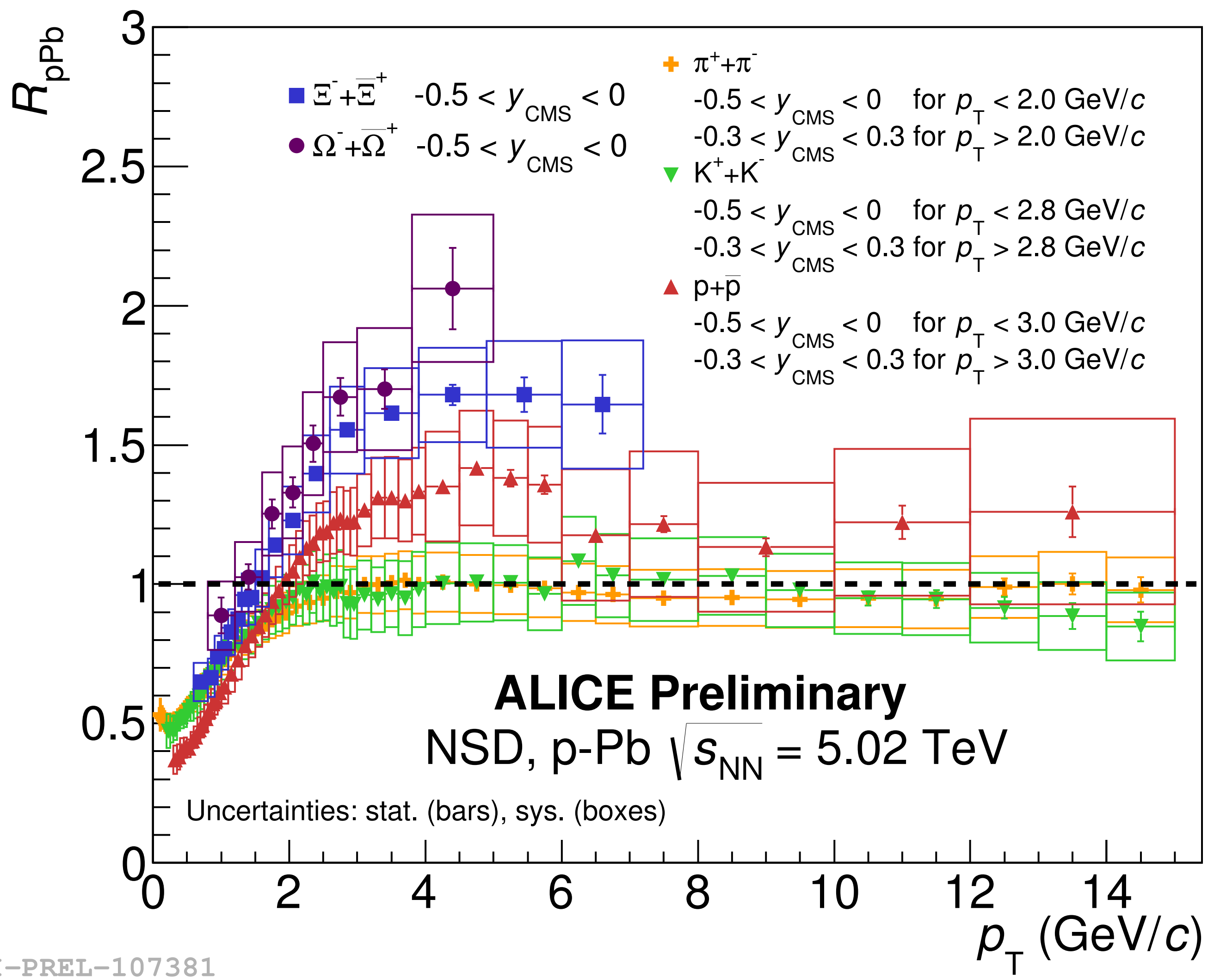
Intermediate-p_T (2 < p_T < 8 GeV/c)

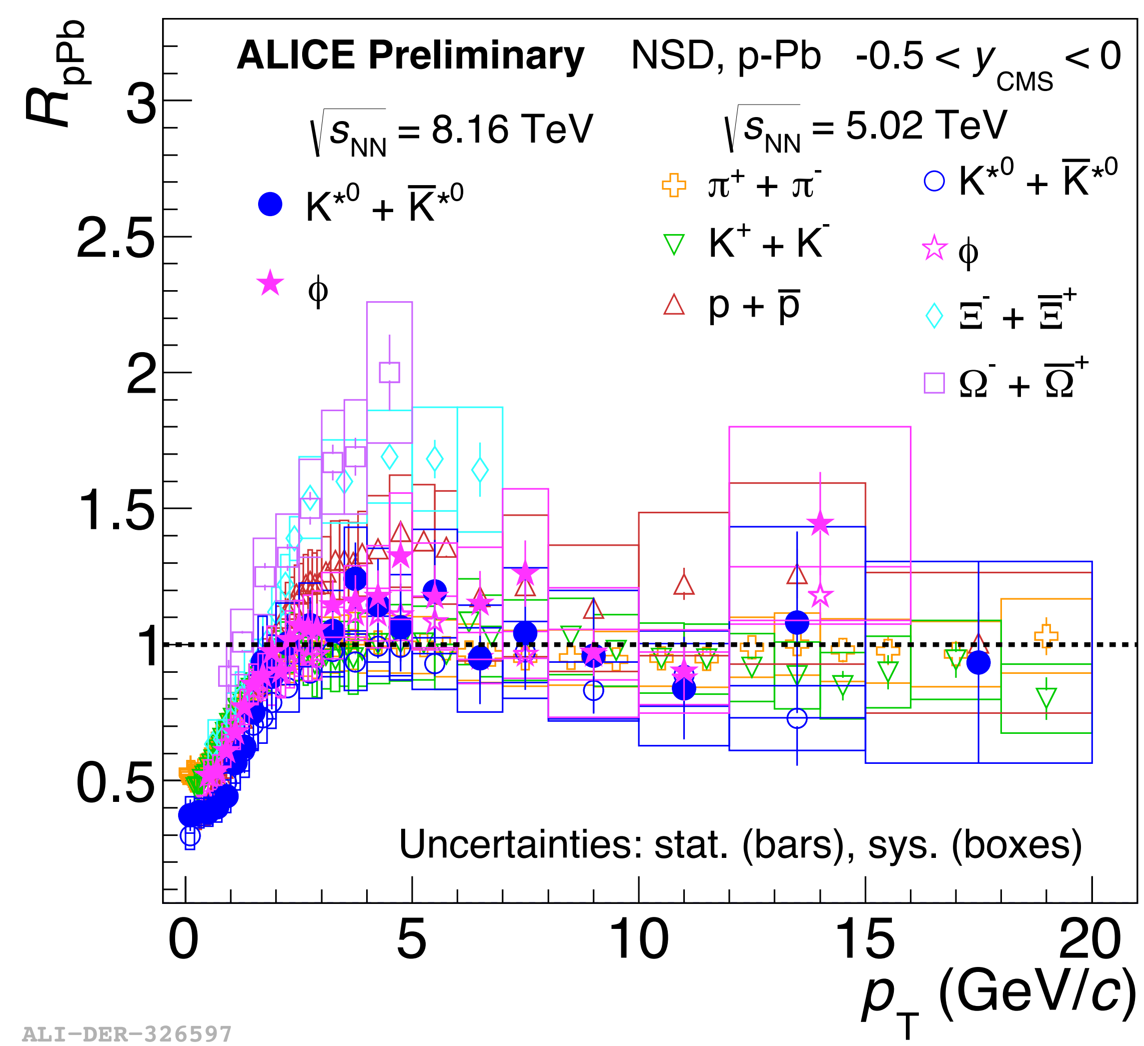
- hint of **mass ordering** among mesons
- higher R_{AA} values for proton (might be due to baryon-meson effect)

High-p_T (>8 GeV/c)

- similar **suppression** for different light flavor hadrons
- No flavor (u,d,s) dependence

Nuclear modification factor (R_{AA}, R_{pPb})





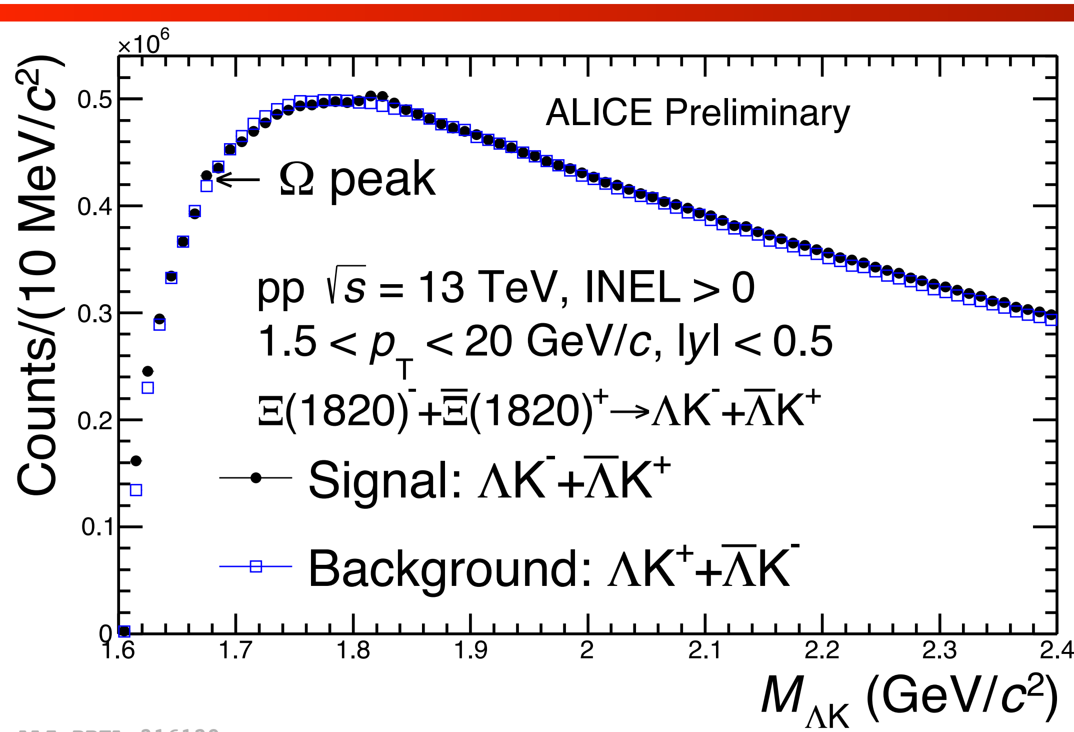
Intermediate-p_T ($2 < p_T < 8$ GeV/c)

- **mass dependent** for strange baryons

High-p_T (>8 GeV/c)

- **no suppression** for different light flavor hadrons
- No flavor (u,d,s) dependence

Reconstruction of Ξ(1820)



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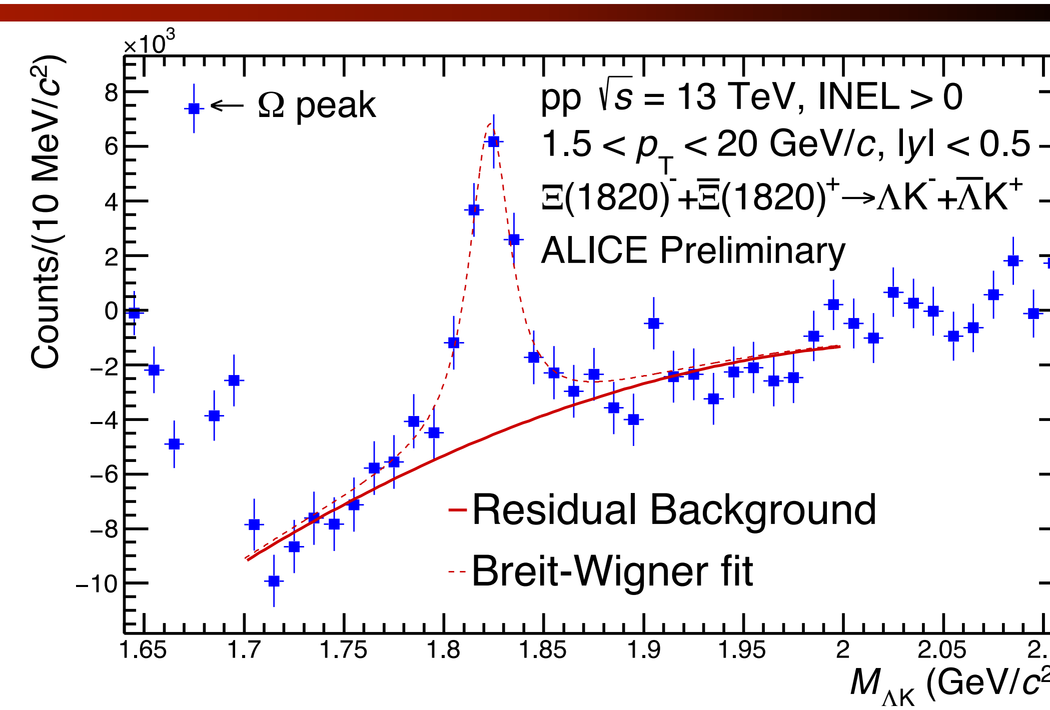

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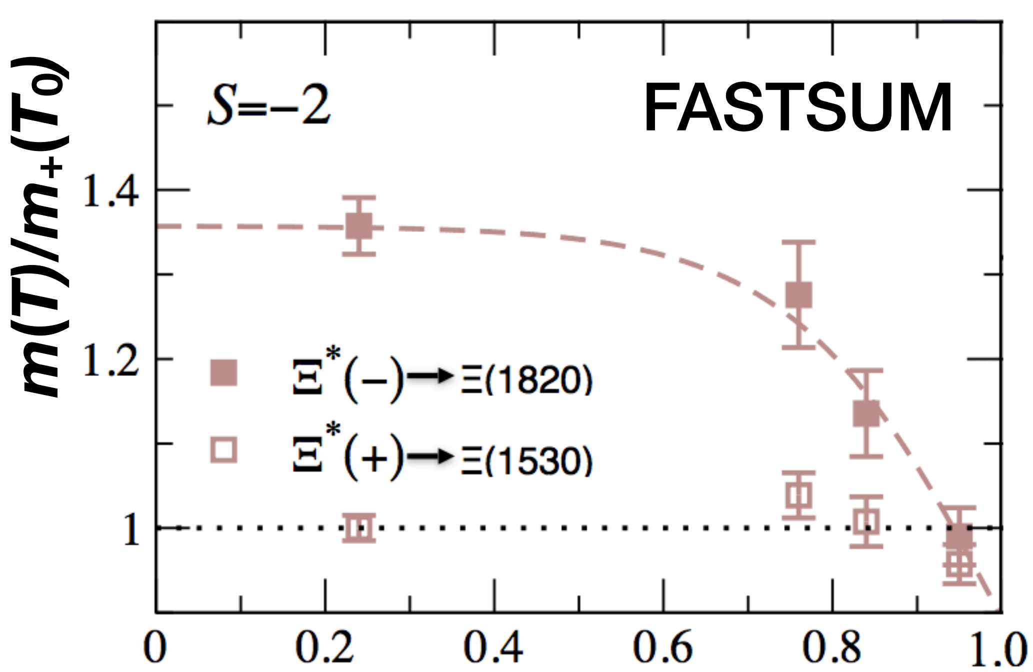

G. Aarts *et al.*, Arxiv: 1710.00566v1

- First measurement of Ξ(1820) from a collider experiment
- Calculation from FASTSUM Collaboration shows potential parity doubling
  - signature of chiral symmetry restoration in heavy-ion collisions
  - expected signal: mass shift, width broadening or change in yield ratio between Ξ(1820) and Ξ(1530)

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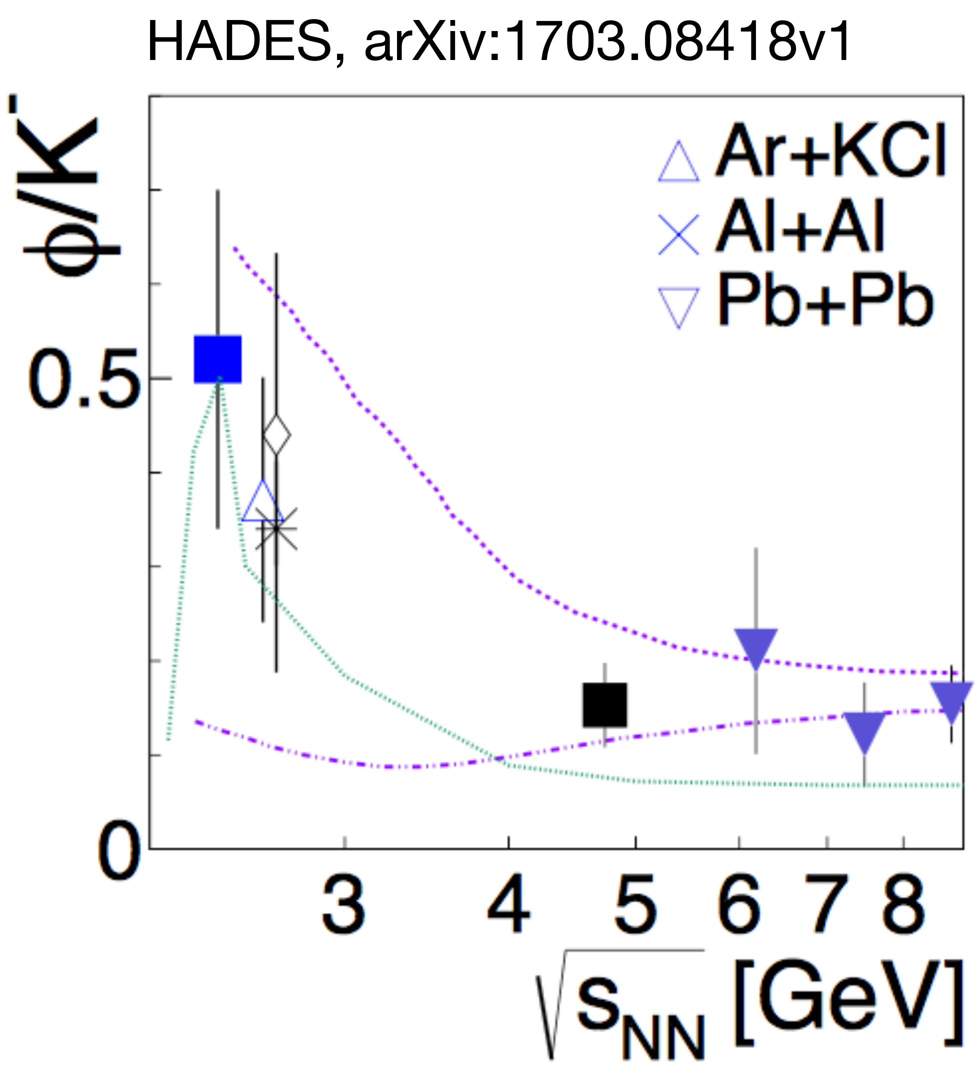
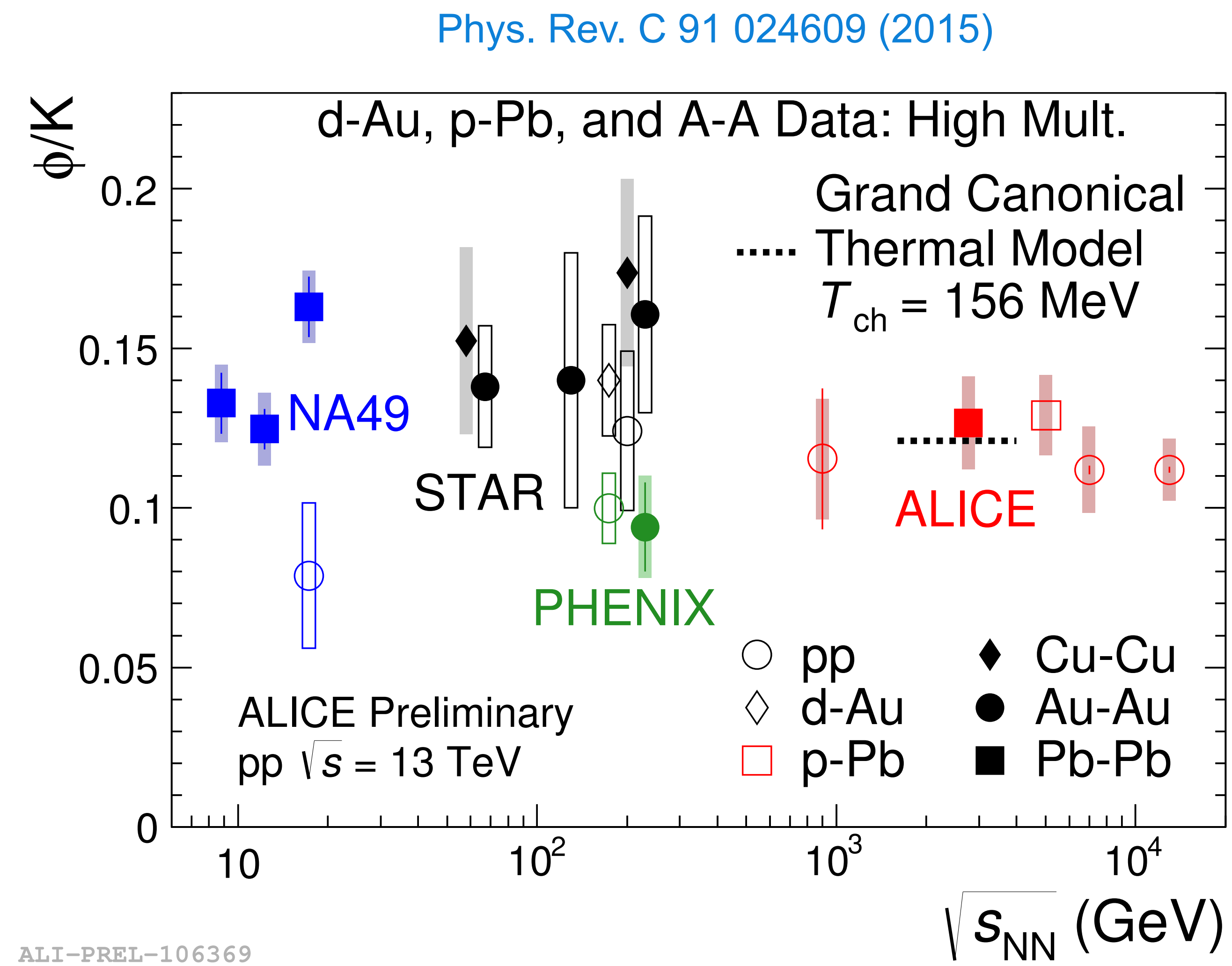
Conclusion

- **ALICE** has a measured comprehensive set of resonance particles
- **mean p_T**: steeper increase in small systems and similar $\langle p_T \rangle$ for p, K^{*0} and ϕ in central Pb-Pb collisions
- **Normalized integrated yield**: independent of collision energy and systems for pp and p-Pb collisions
- **Particle yield ratios**:
  - suppression of short-lived resonances, ρ^0, K^{*0}, Λ^* , has been observed in most central collisions w.r.t. small collision systems
  - no suppression observed for the longer-lived resonances, ϕ
- **Hidden strange particle**: ϕ has effective strangeness 1-2 units
- **Nuclear modification factor**: at high p_T suppression for Pb-Pb, no suppression in p-Pb collisions
- **Reconstruction of Ξ(1820)**: first measurement and clear signal

Backup

Energy dependence: ϕ/K





- Flat behavior in wide range of energy (~10-10^4 GeV)
- Increase for low energies due to canonical suppression
  - reproduced by statistical model calculation with strangeness correlation radius parameter R_c = 2.2fm