Recent results on baryonic resonances in ALICE

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ALICE

HELLENIC REPUBLIC
National and Kapodistrian University of Athens
EST. 1837

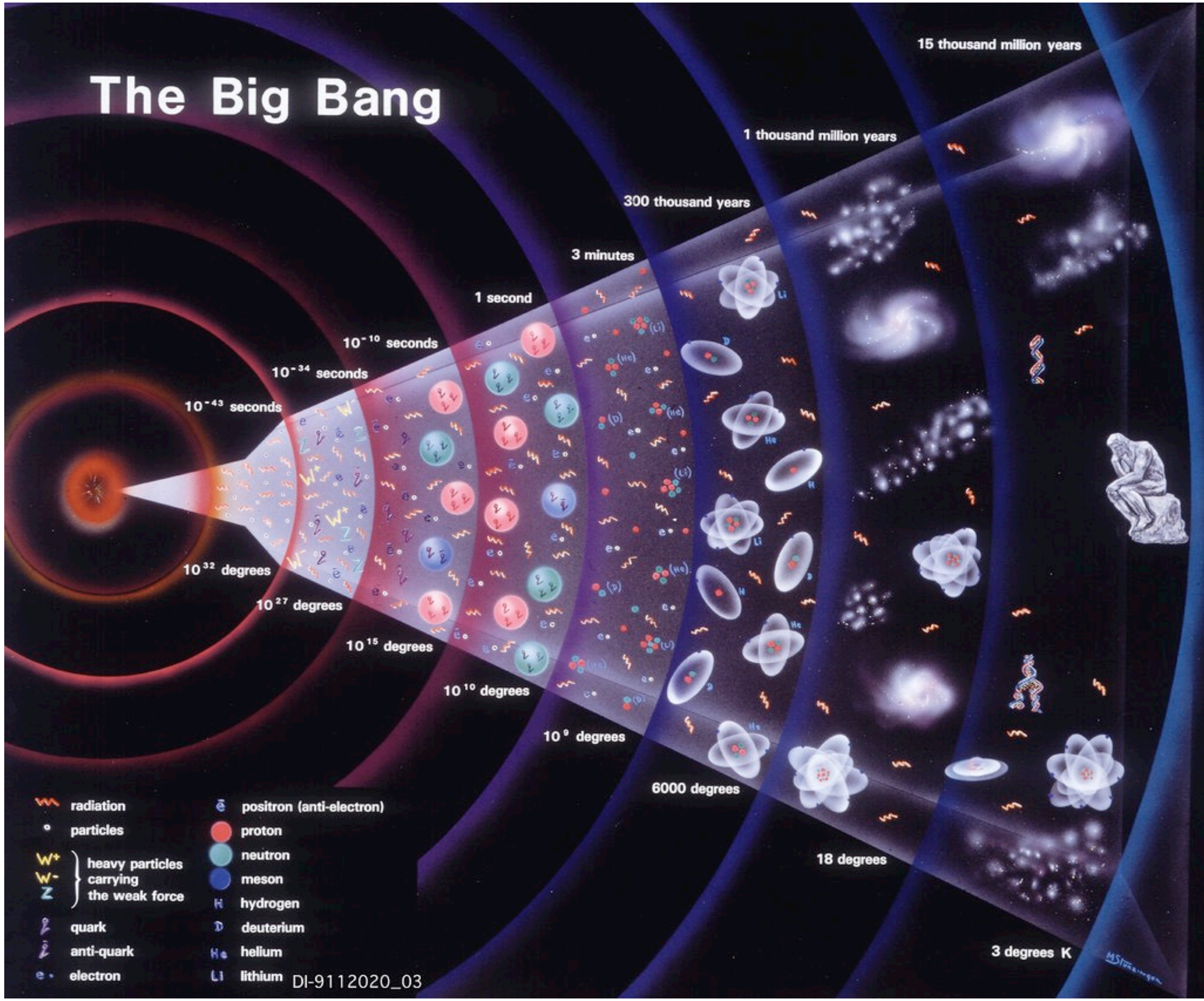
Physics Motivation

Results

Future

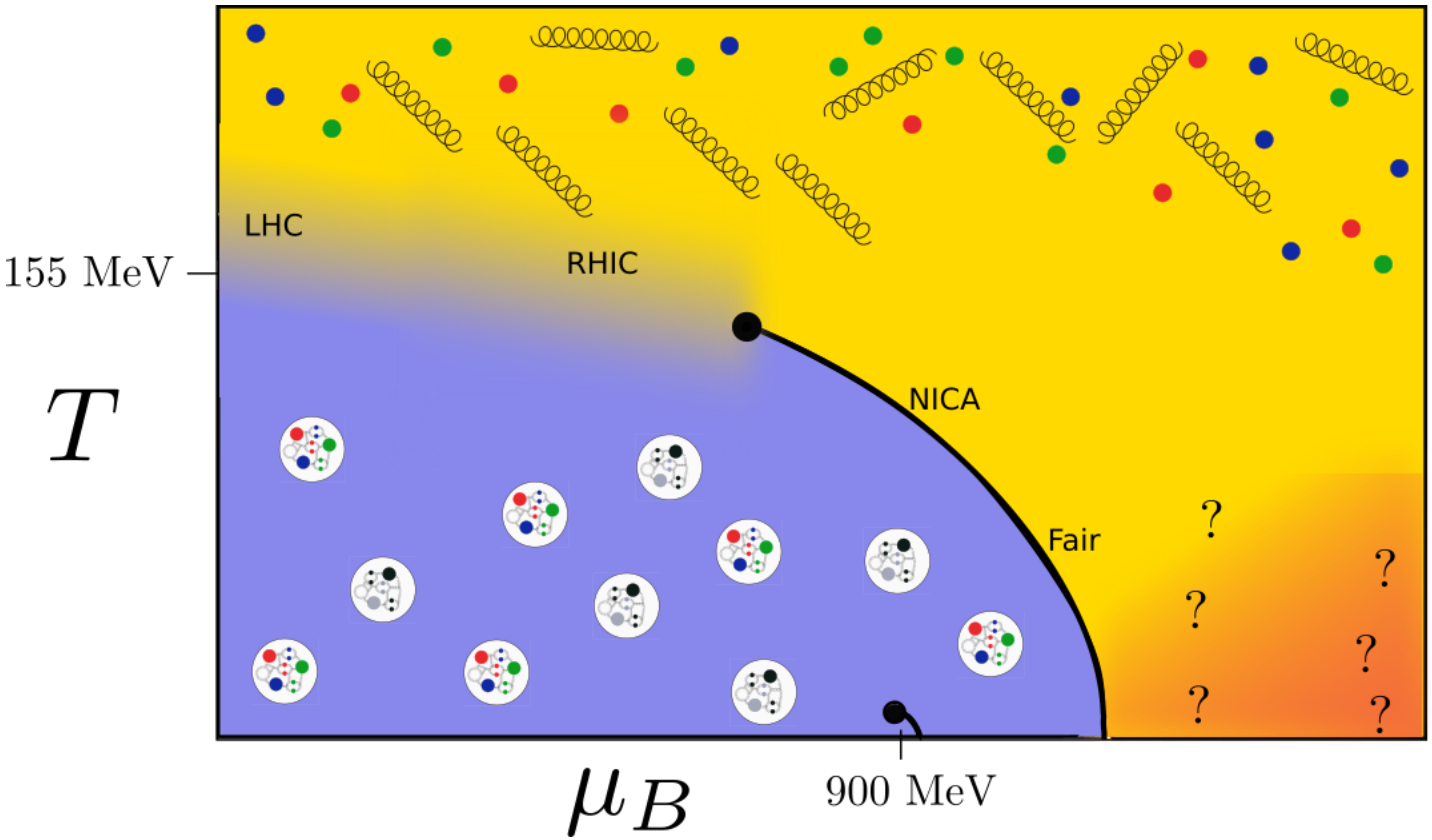
ALICE: A heavy-ion physics experiment

- **Study matter**
  - At energy densities like 10 μs after the Big Bang.
  - At temperatures 10^5 times larger than in the Sun core.
- **Study QCD**
  - Without confinement.
  - With quarks at their bare masses.
- **But also:**
  - Study QCD in the non-perturbative regime.

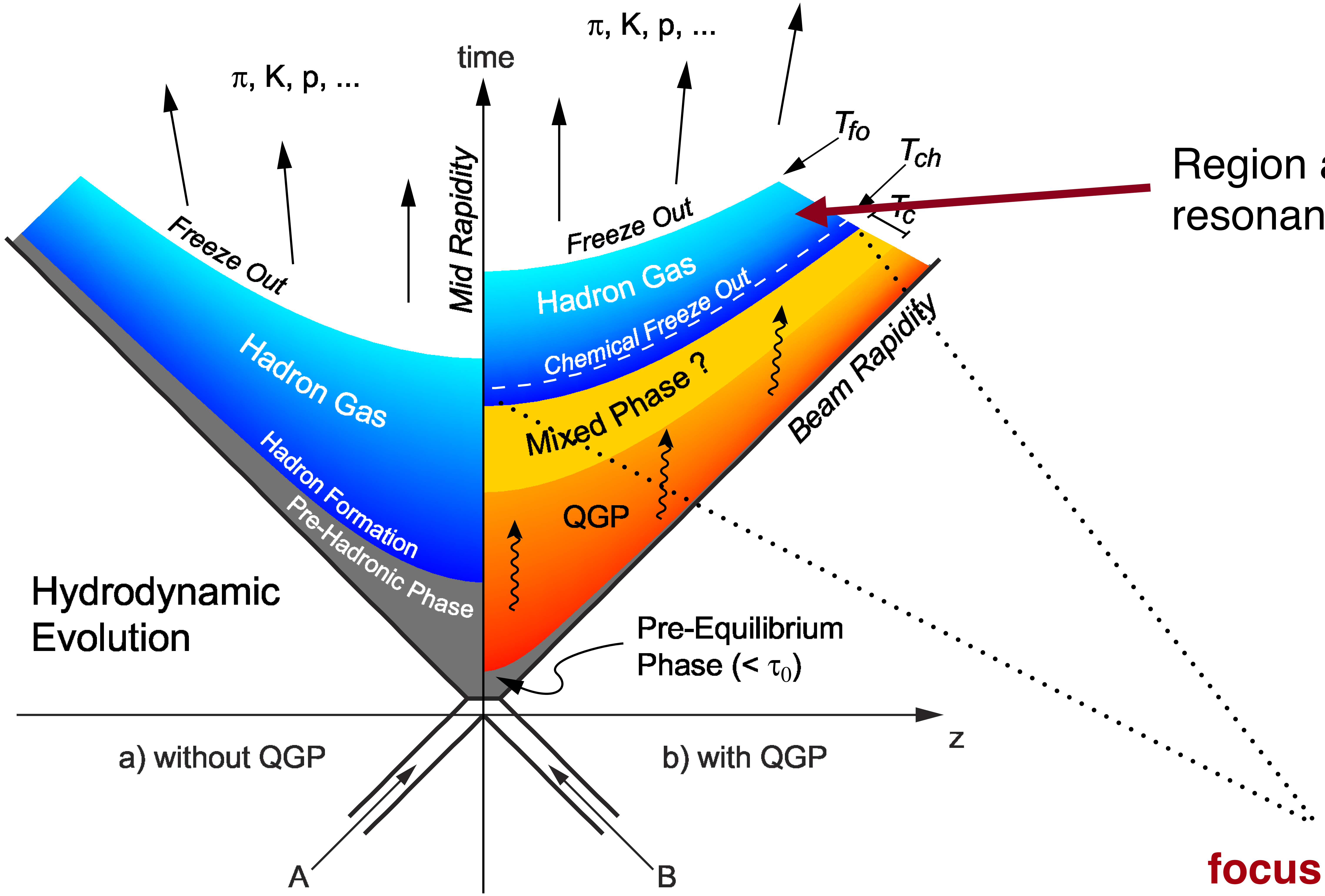


QCD Phase Diagram

arXiv:2010.15503v2



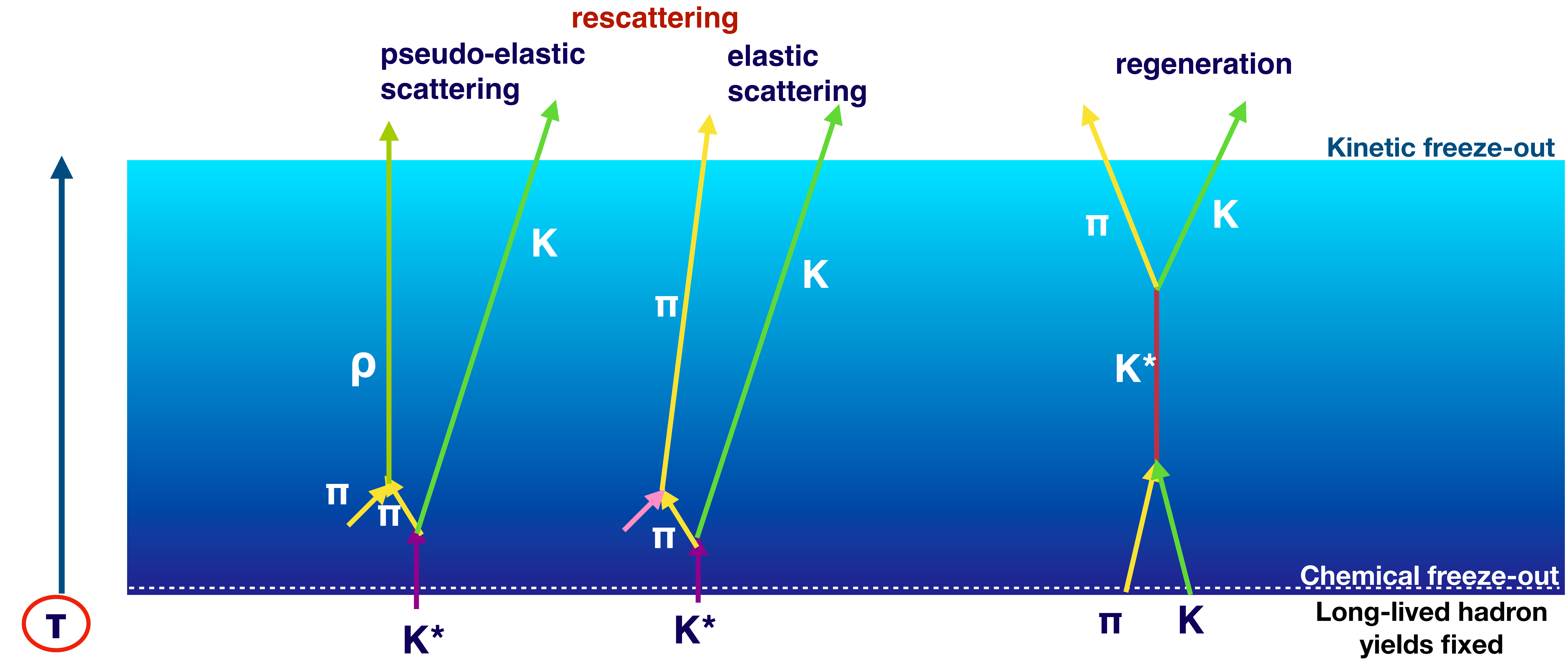
Heavy-ion collisions



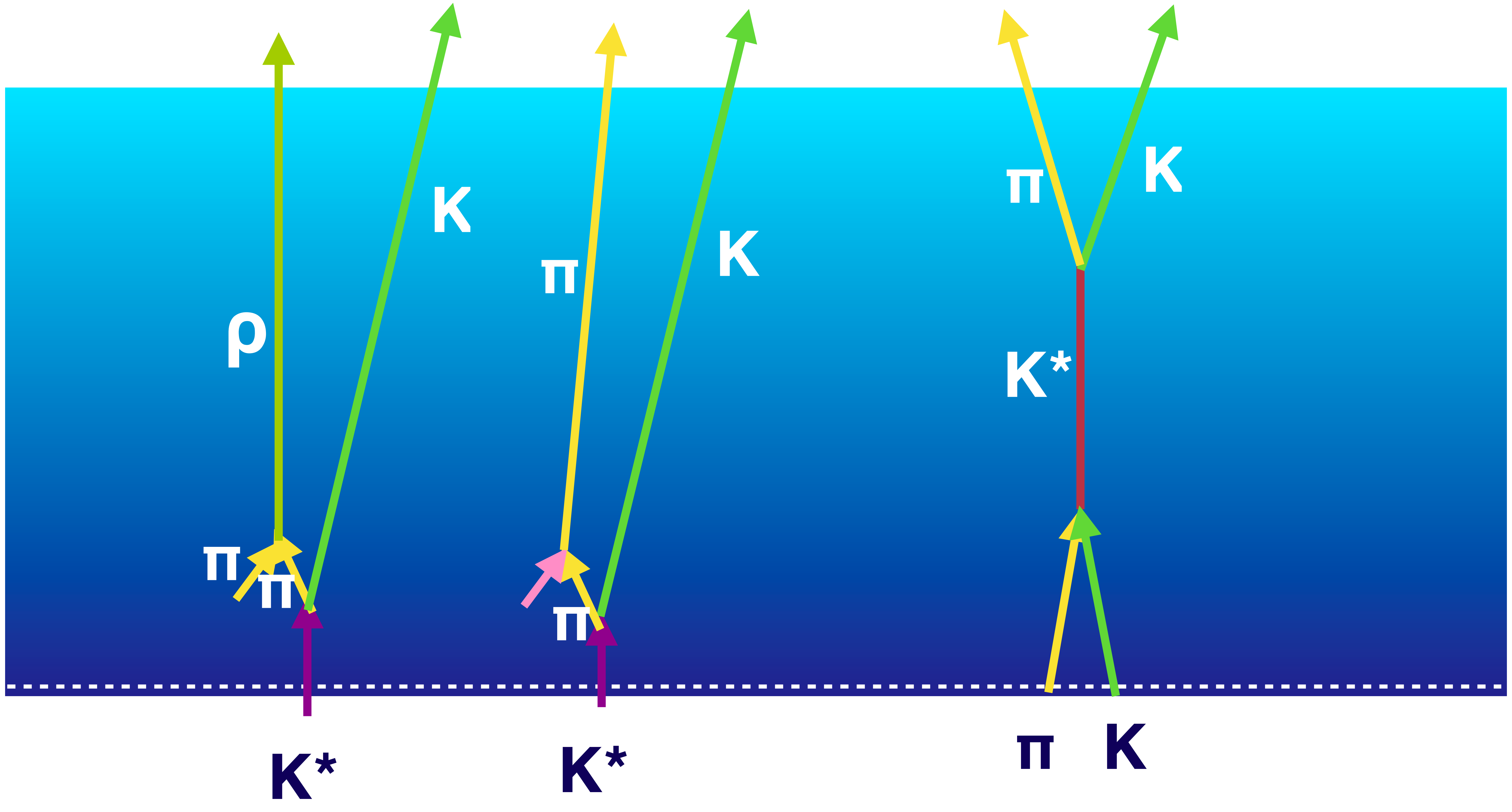
Region accessible through resonance measurements.

focus in this region

Resonance study



Resonance study



Good probes to verify the presence of **hadronic phase in nucleus - nucleus collisions** and study its properties.

They have **lifetimes comparable** with the **hadron-gas lifetime**.

Regeneration and rescattering processes in hadronic phase affect resonance **yields** and transverse momentum (p_T) spectra shapes.

Resonance properties

Resonance	$\rho(770)^0$	$K^*(892)^\pm$	$K^*(892)^0$	$f_0(980)$	$\Sigma(1385)^\pm$	$\Xi(1820)^\pm$	$\Lambda(1520)$	$\Xi(1530)^0$	$\phi(1020)$
Quark composition	$\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$u\bar{s}, \bar{u}s$	$d\bar{s}, \bar{d}s$	unknown	uus, dds	uss	uds	uss	$s\bar{s}$
τ(fm/c)	1.3	3.6	4.2	large unc.	5-5.5	8.1	12.6	21.7	46.4
Decay	$\pi\,\pi$	$K^0_S\,\pi$	$K\,\pi$	$\pi^+\pi^-$	$\Lambda\,\pi$	$\Lambda\,K$	$p\,K$	$\Xi\,\pi$	$K\,K$
B.R.(%)	100	33.3	66.6	46	87	unknown	22.5	66.7	48.9

- Study the hadrochemistry of particle production.
- Study the in-medium energy loss via R_{AA}.

Results

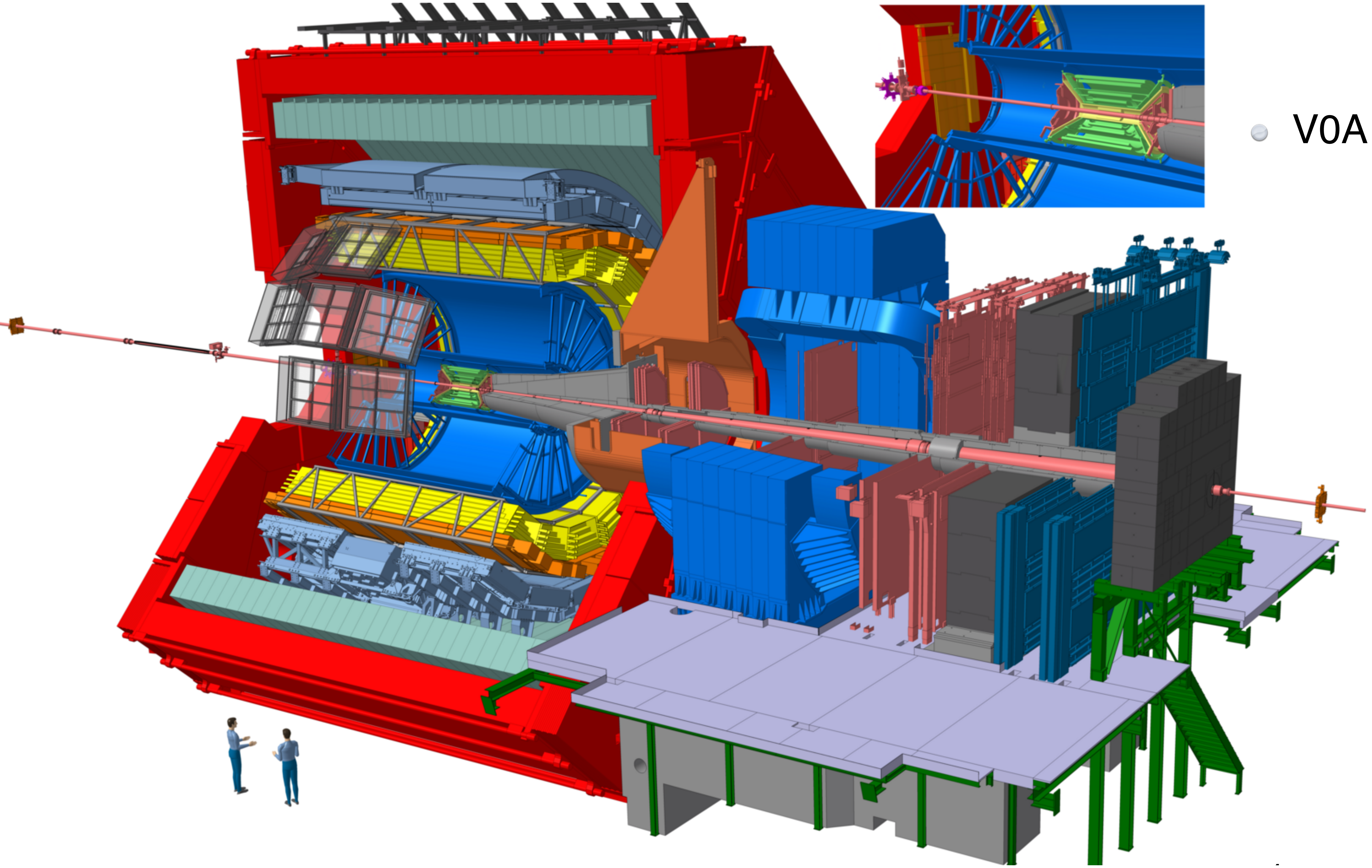
The ALICE detector

- Time Projection Chamber (TPC)
  - Gas-filled ionization detector
  - Tracking, vertex, PID (d*E*/d*x*)

- Inner Tracking System (ITS)
  - 6 layers of silicon detectors
  - Provide tracking, vertex

- Time Of Flight (TOF)
  - PID through particle time of flight

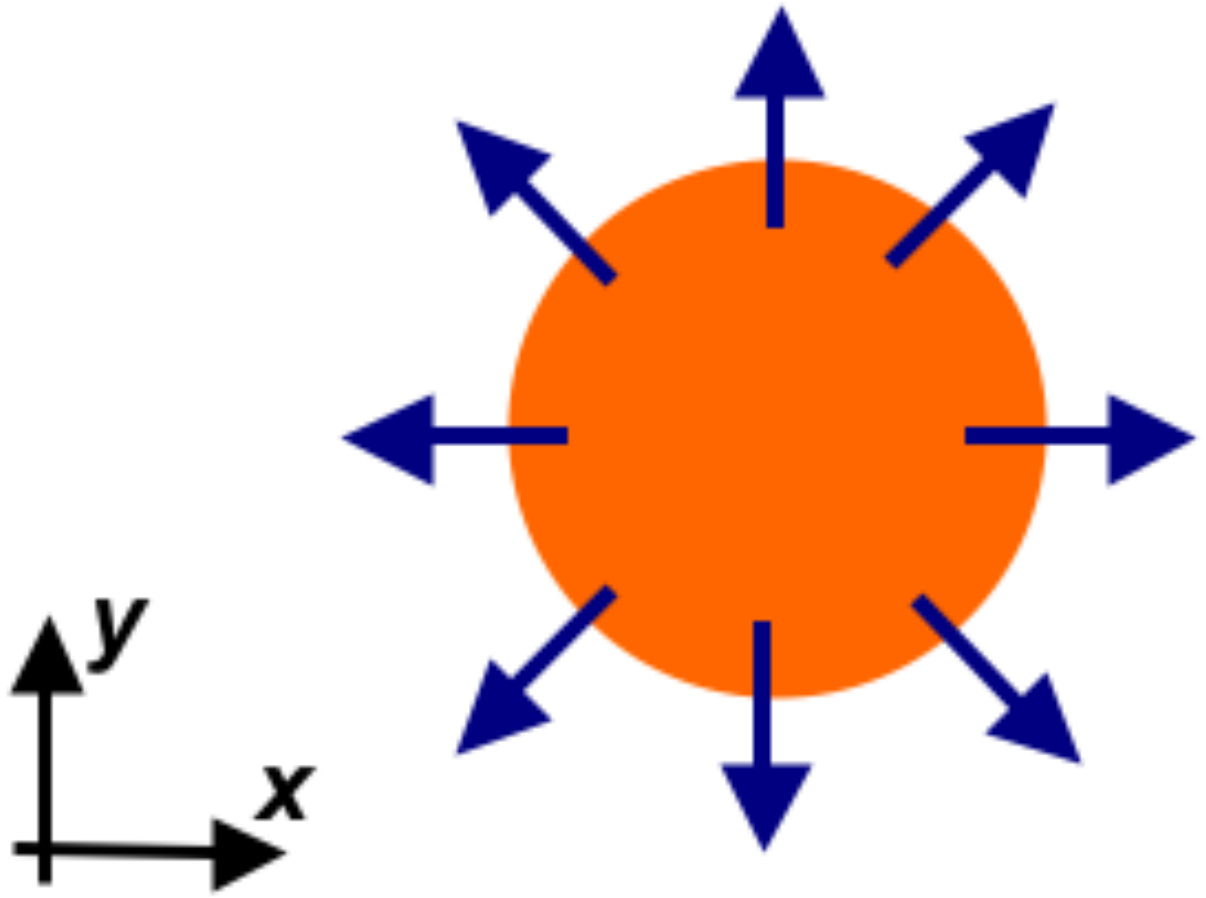
- V0A and V0C
  - Trigger, centrality/multiplicity estimator



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

Run 1 and Run 2

Radial flow



Radial flow: predicted by hydronamics in AA due to the higher energy density.

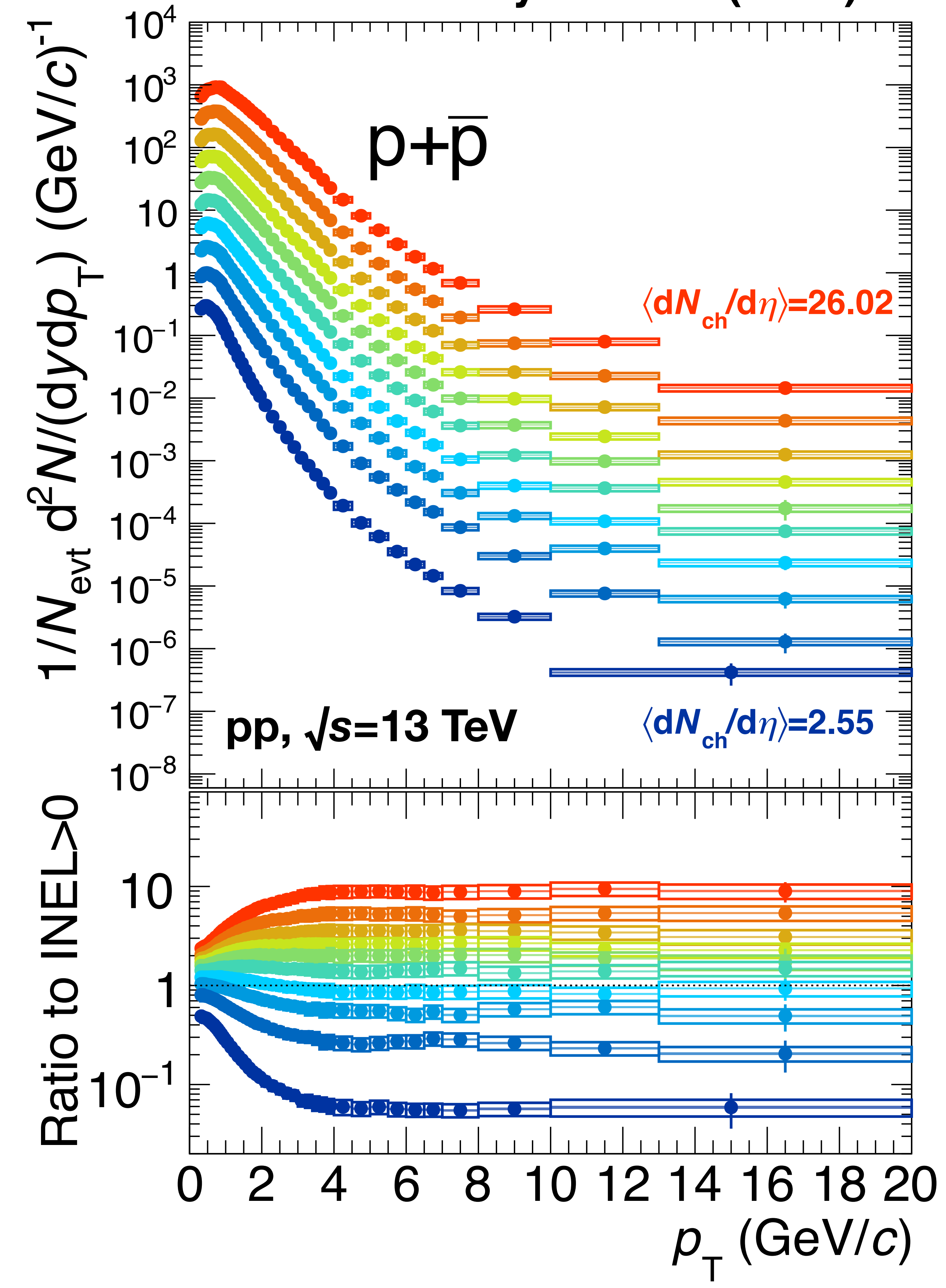
- The only type of collective flow in AA collisions with impact parameter b = 0.
- Affects the shape of particle spectra at low p_T.

p=mβγ

Common velocity field ***βγ*** fixed → **mass** dependence

Features of baryons - radial flow

Eur.Phys.J.C 80 (2020) 8



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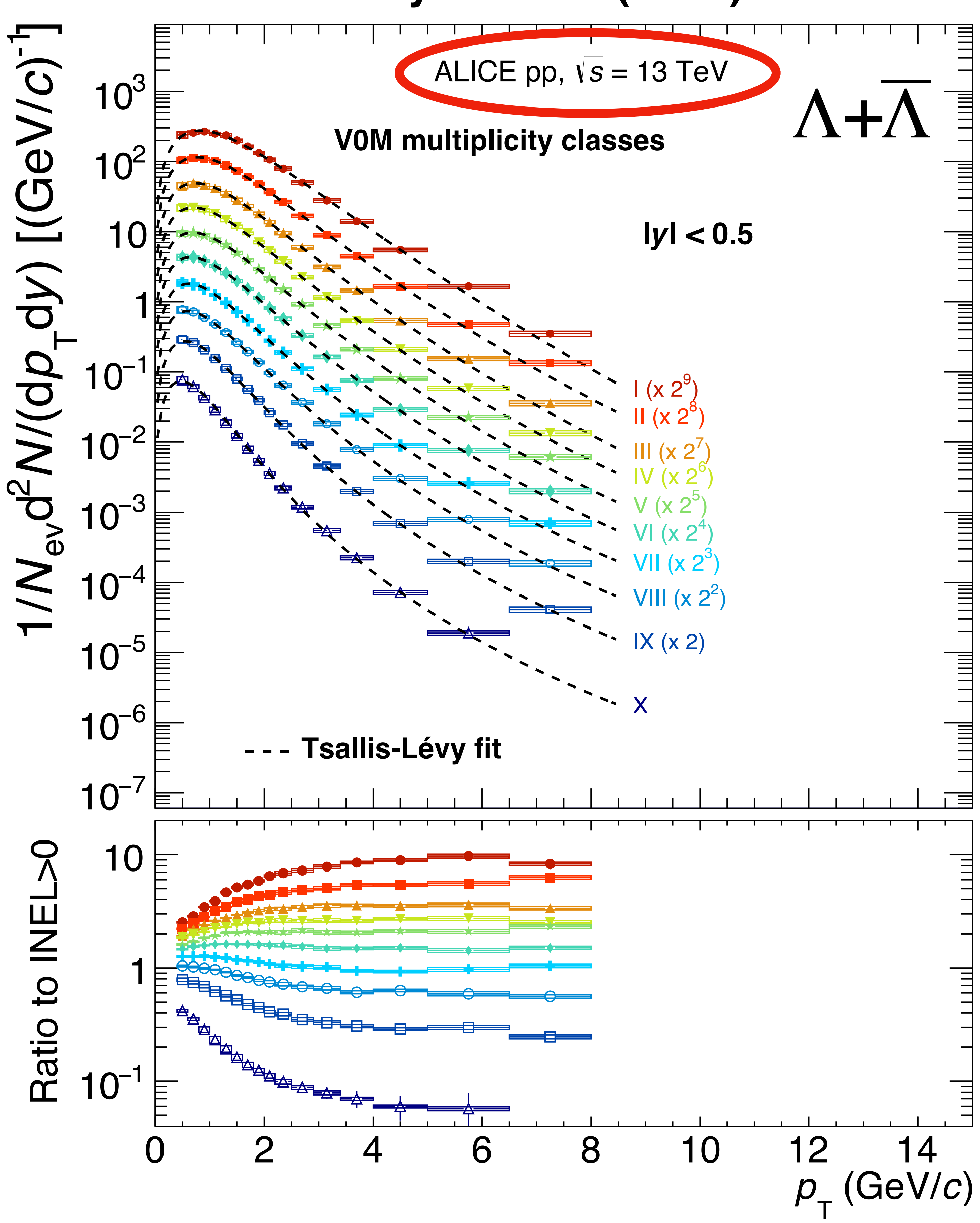


Present not only in Pb–Pb…

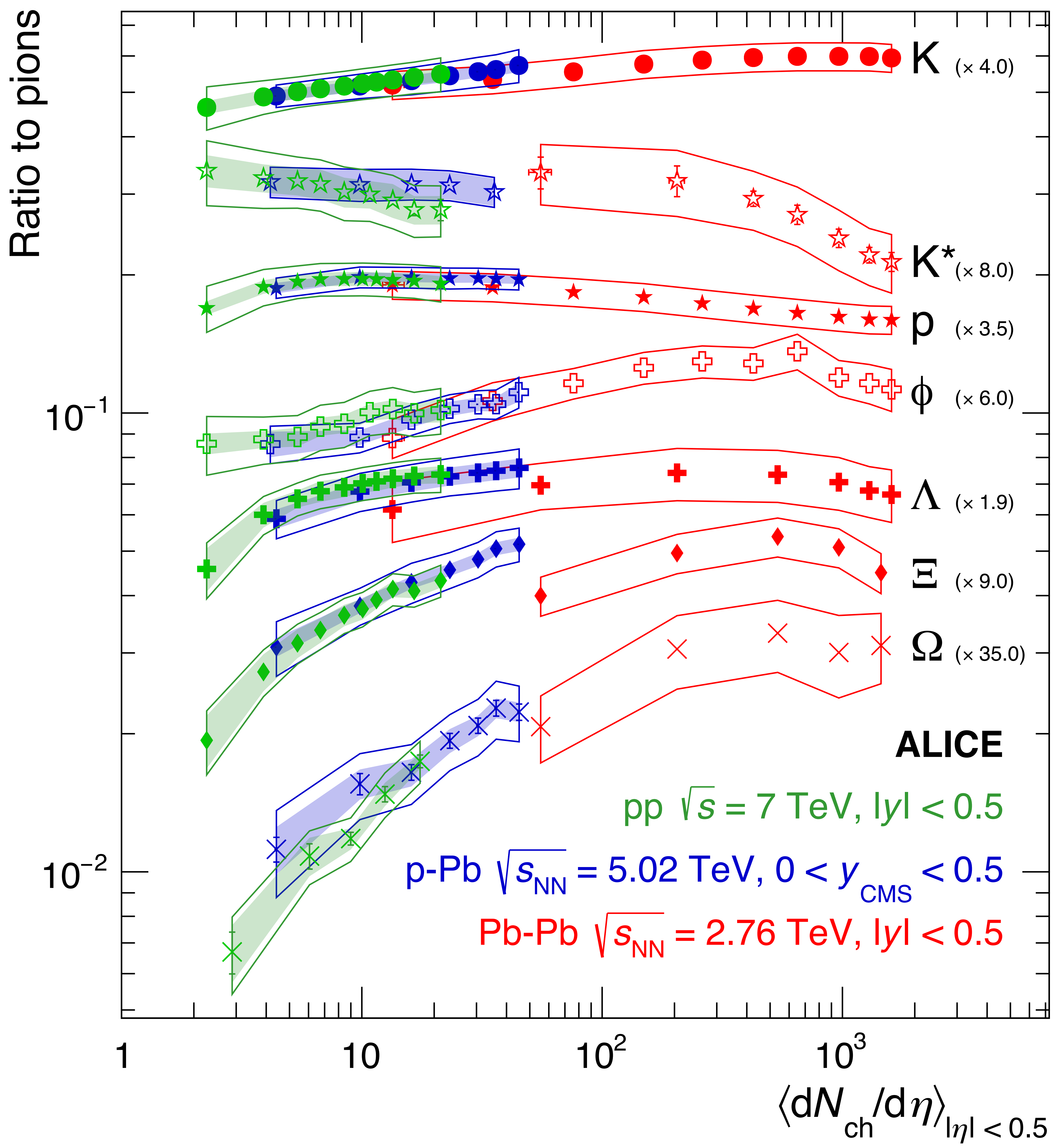
<u>pp collisions at $\sqrt{s}$ = 13 TeV:</u>

Hardening of the spectra with increasing multiplicity → **caused by radial flow**

Affects all produced hadrons

Strangeness enhancement

Phys.Rev.C 99 (2019) 2, 024906

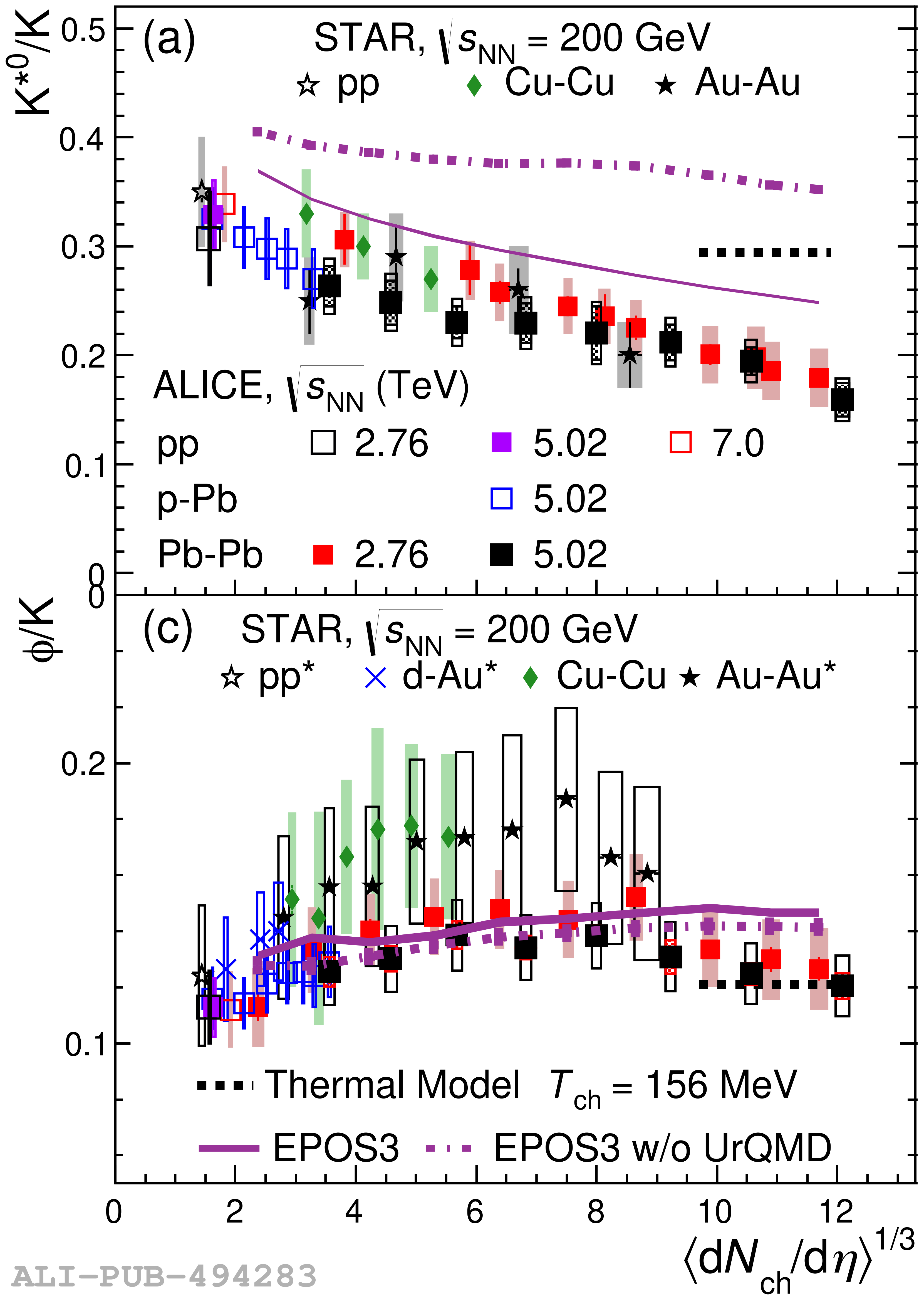


Yield ratio of hadrons and resonances with different strangeness content to pions:

- Ω(3s), are more enhanced than Ξ(2s)
- Ξ(2s), are more enhanced than Λ(1s) and K(1s)

Features of resonances - suppression at high multiplicities

Phys. Rev. C 106 (2002) 034907



NOT all of them though…

Ratio of K*/K (to cancel strangeness) shows gradual decrease with the system size→**effect of rescattering**

What drives this decrease?

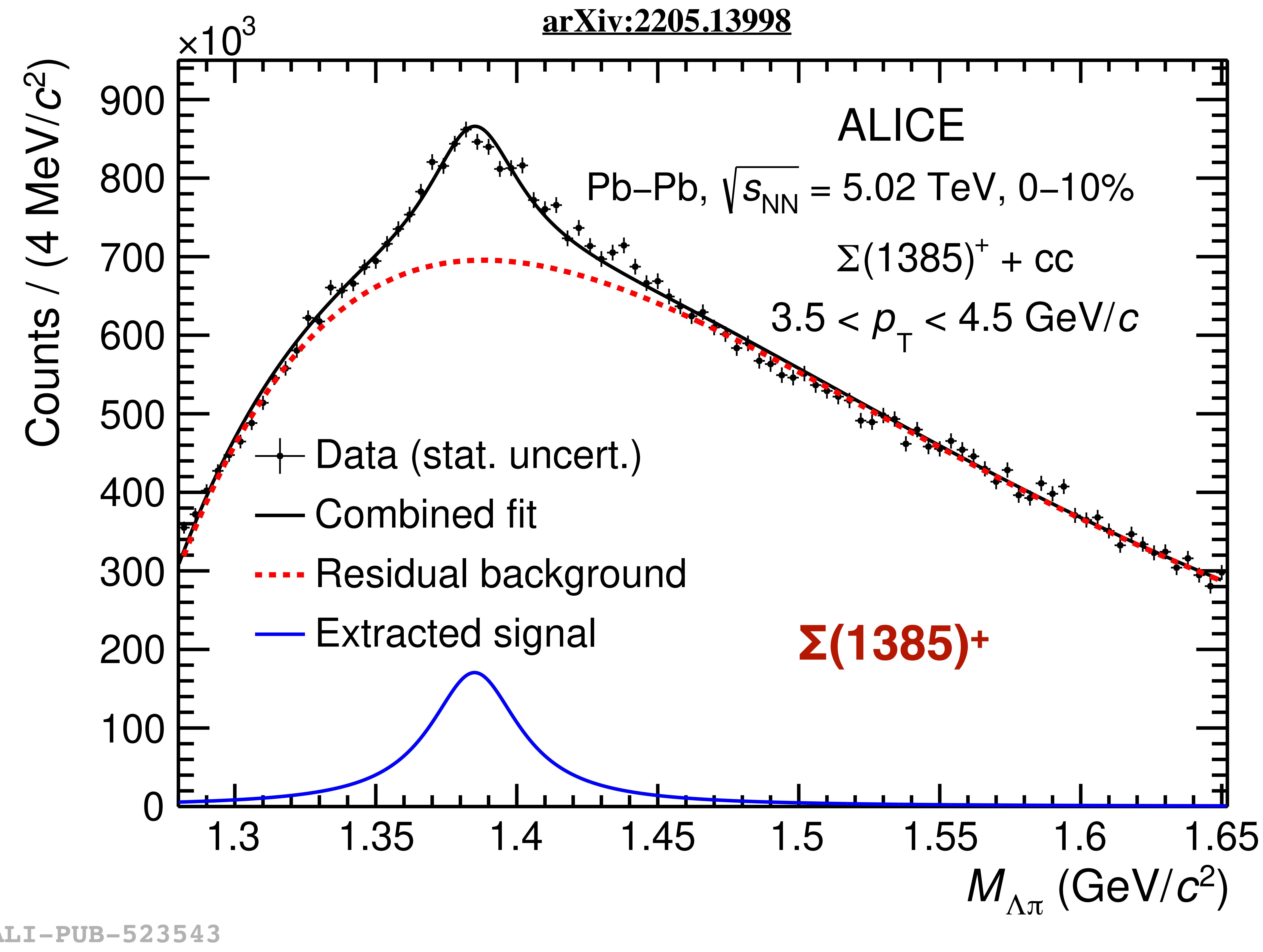
- the **lifetime of the resonance**
- the **cross sections for rescattering and regeneration** processes
- the **time duration** of the **hadronic phase**

Resonance reconstruction - Analysis strategy

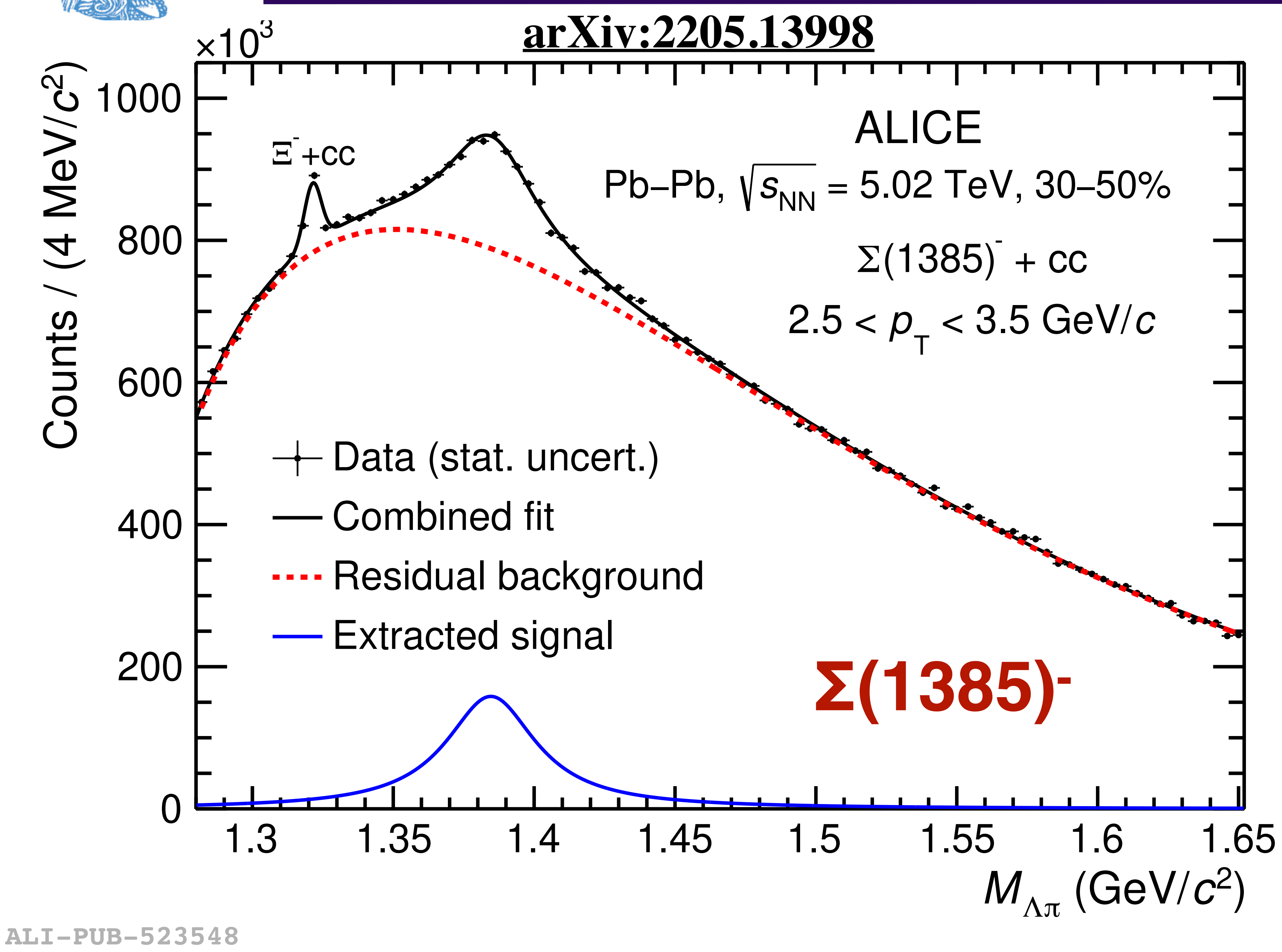
- Resonances are reconstructed via the **invariant mass** technique

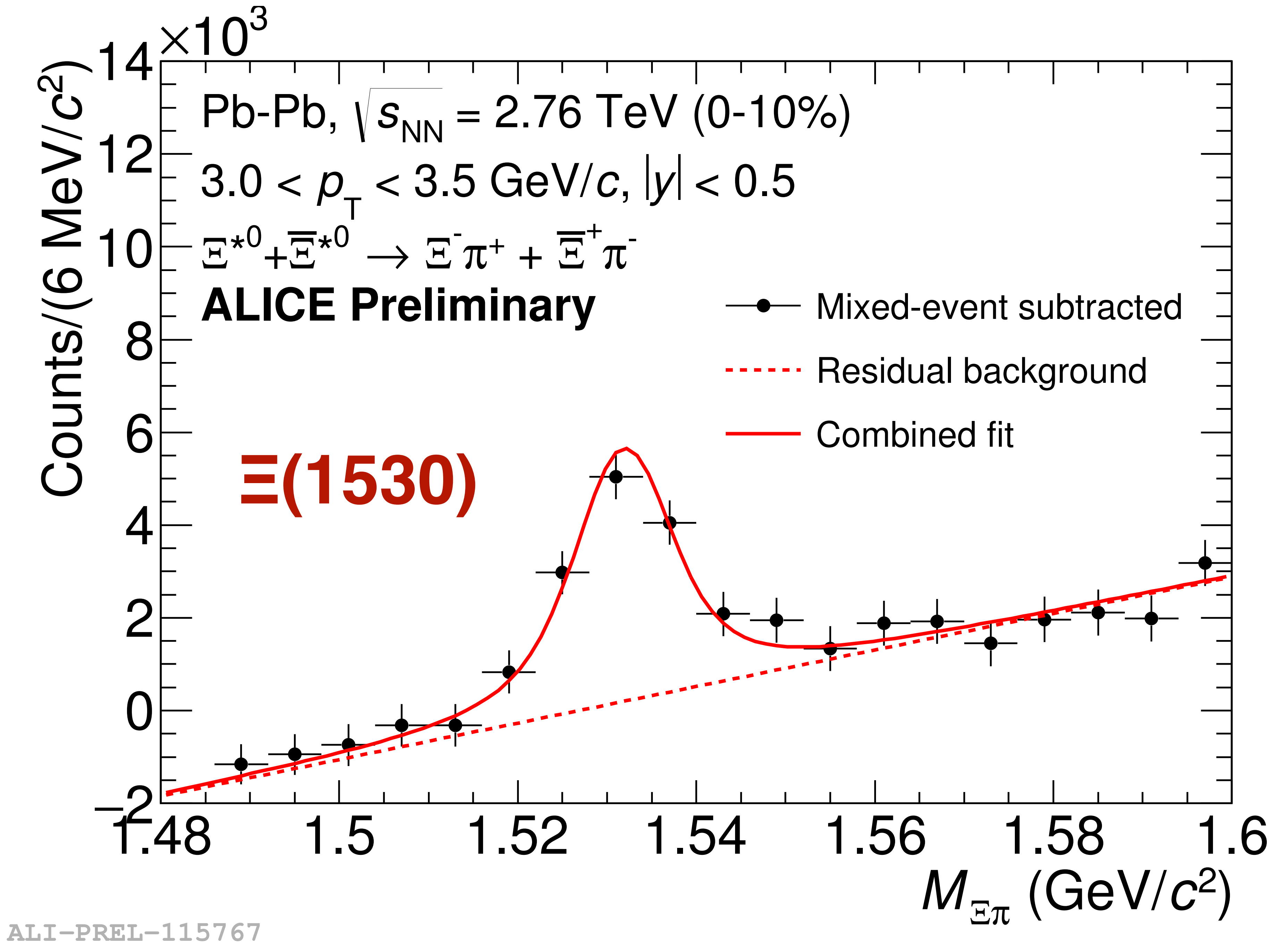
$$M_{inv} = \sqrt{(E_1 + E_2)^2 - (\vec{p_1} + \vec{p_2})^2}$$

- **Uncorrelated background** is calculated via **event mixing** or **like-sign** techniques
- **PID** from TPC, TOF for the **daughter tracks**
- **Residual background**: Correlated pairs or misidentified decay products, usually modelled by a polynomial function
- **Signal** : Fit the event-mixing (or like-sign) subtracted distribution with a Breit-Wigner or Voigtian function (signal function) and the polynomial background
- Yields are calculated by integrating the signal function



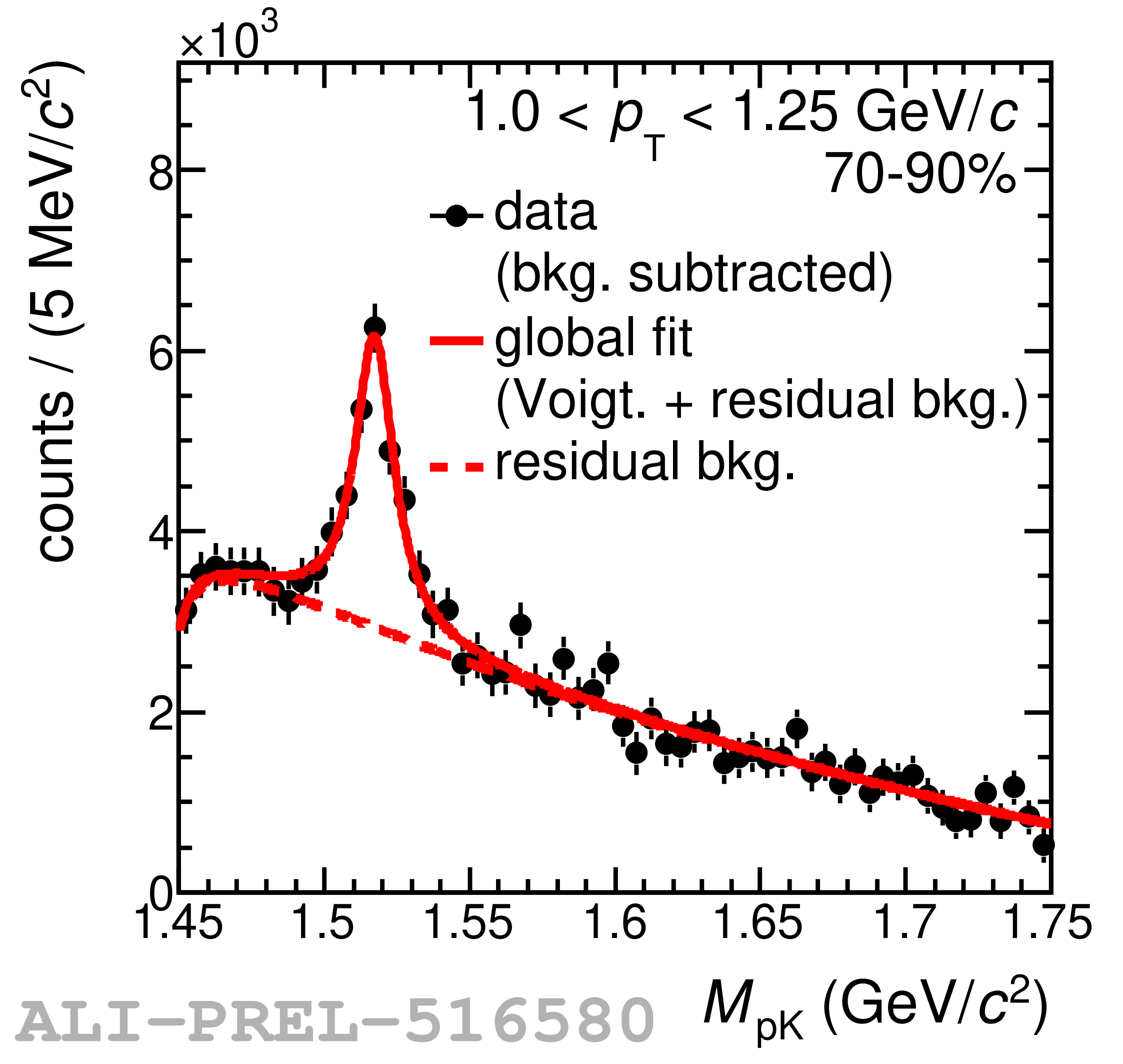
Baryonic resonances measured by ALICE

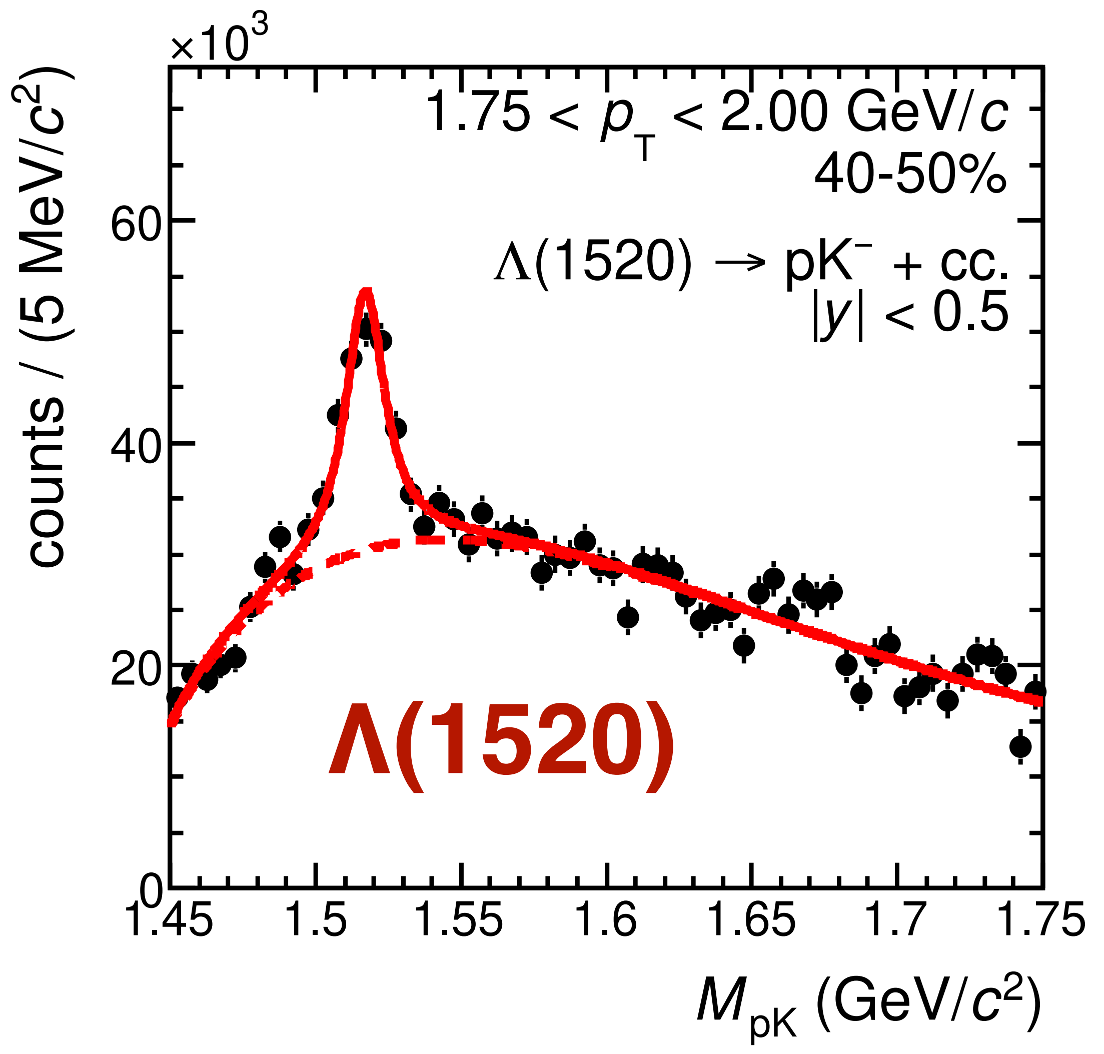


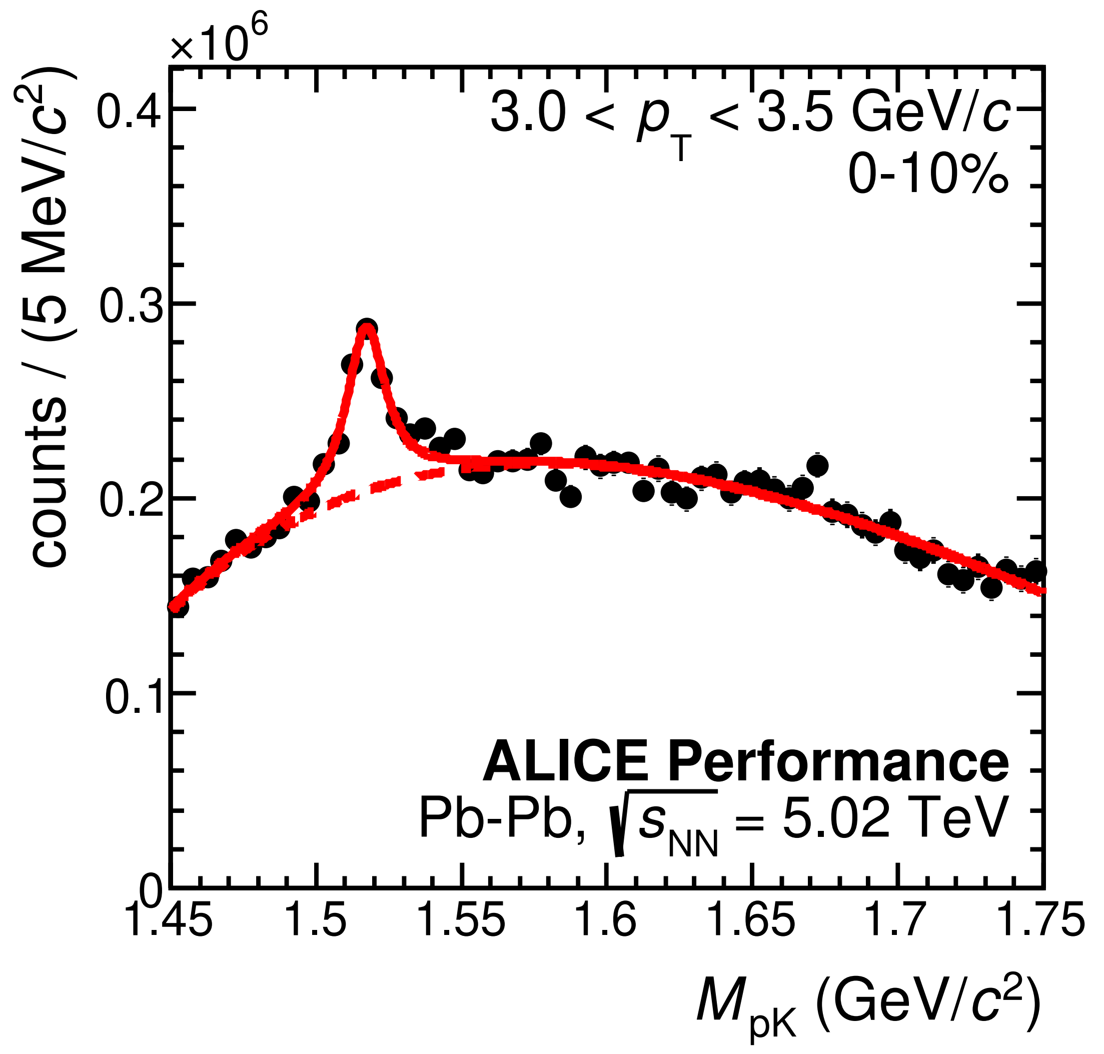


ALICE has measured **mesonic and baryonic** resonances in **all systems** and **energies**

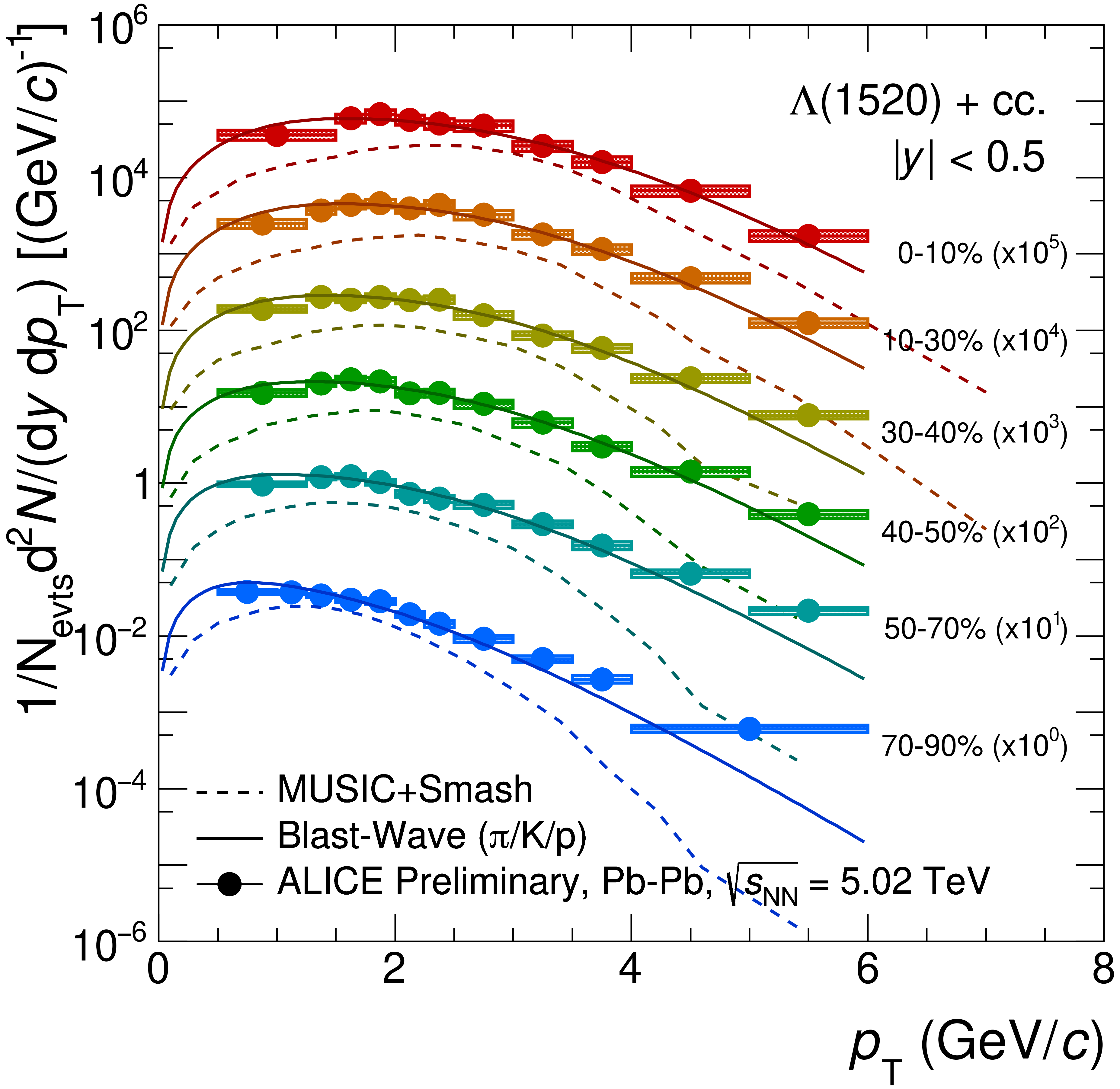
Here, selected results from **Pb–Pb** collisions at **$\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV**







Baryonic resonances p_T spectra



ALI-PREL-516641

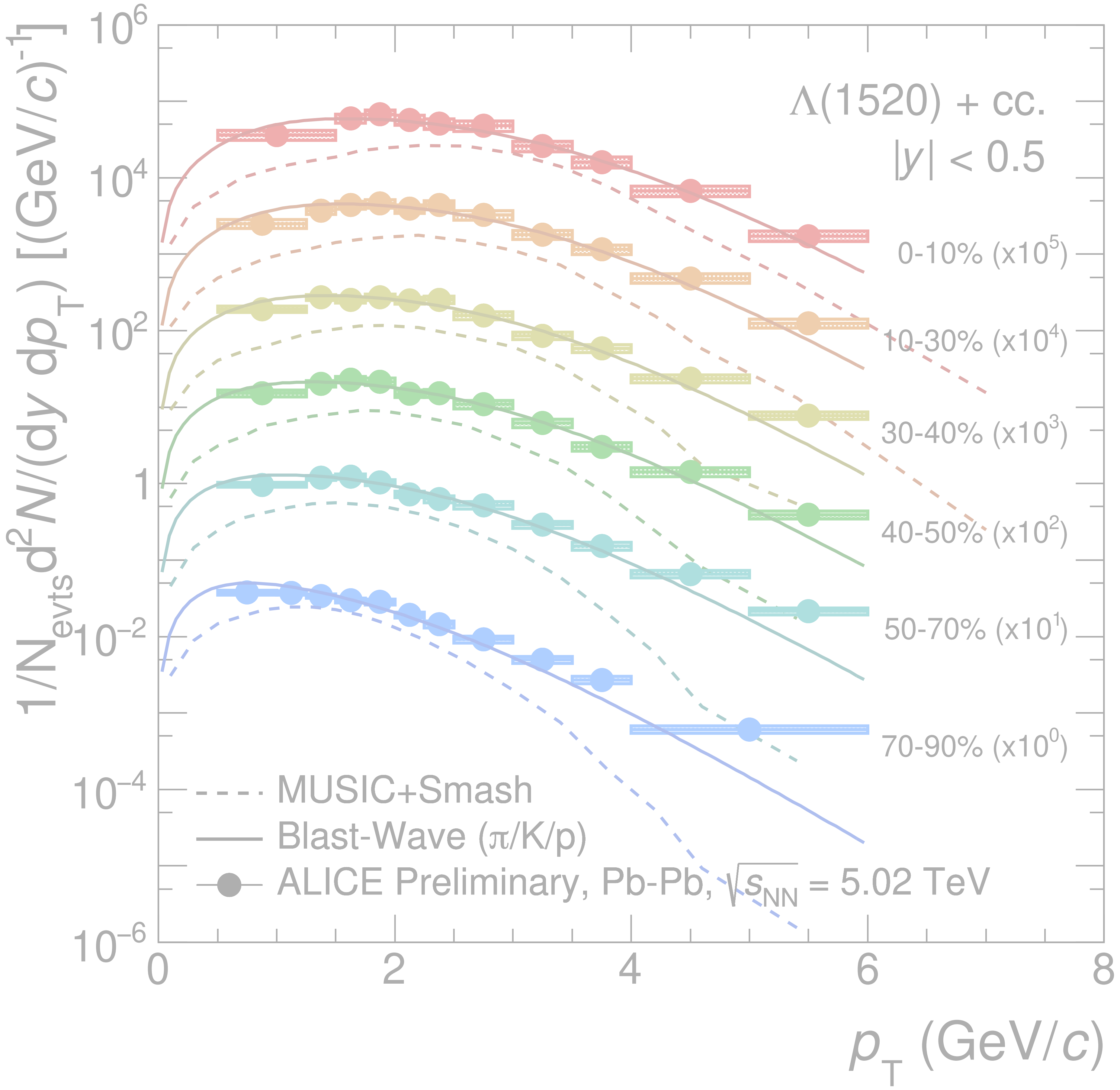
Λ(1520) in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

Measured **p_T spectra in different centrality** classes are compared with **Blast-Wave and MUSIC hydrodynamic** models with **SMASH afterburner**

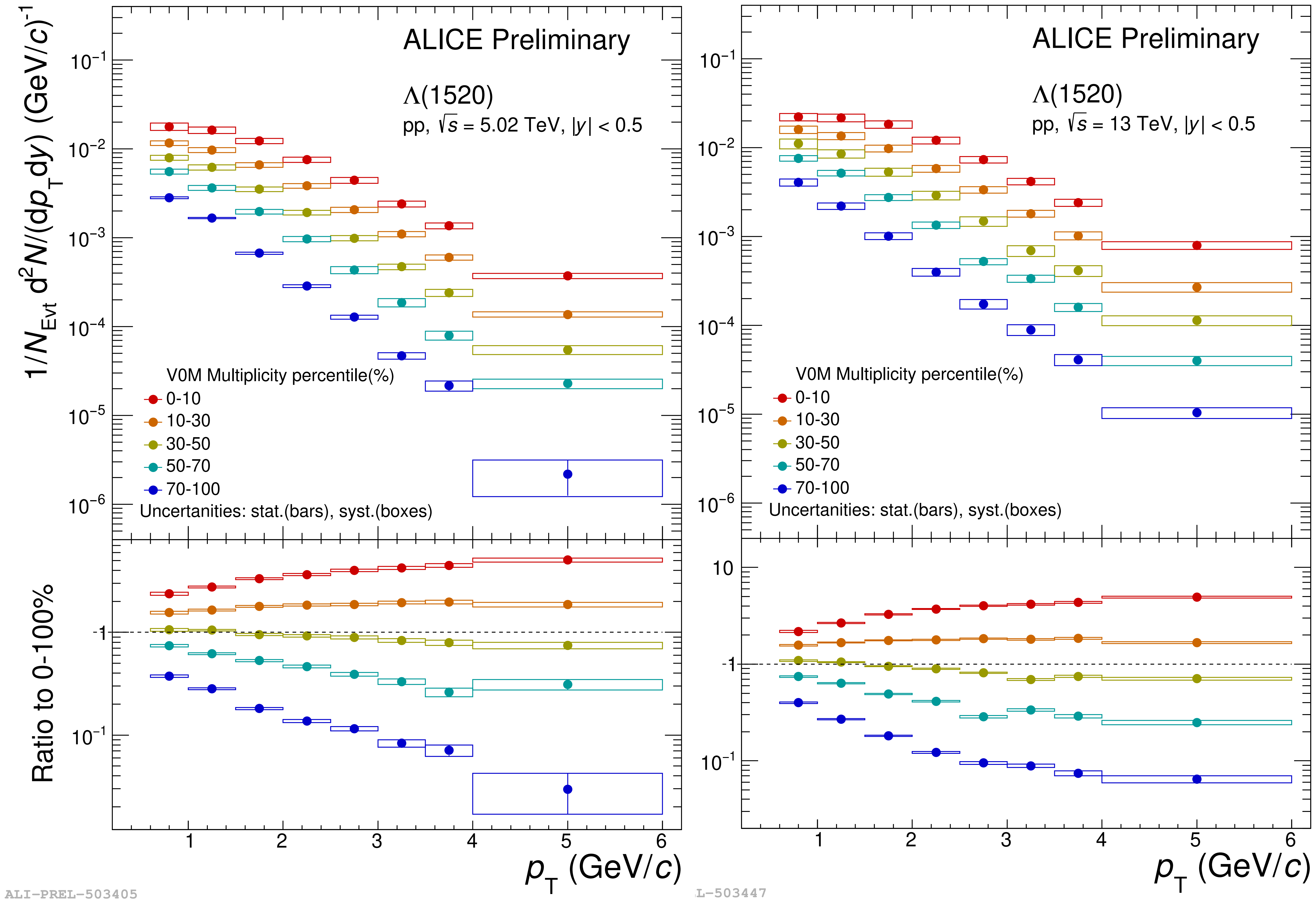
Blast-Wave: good description of the data
MUSIC with SMASH: underestimates the data

Hardening of the spectra **with increasing multiplicity → radial flow**

Baryonic resonances p_T spectra



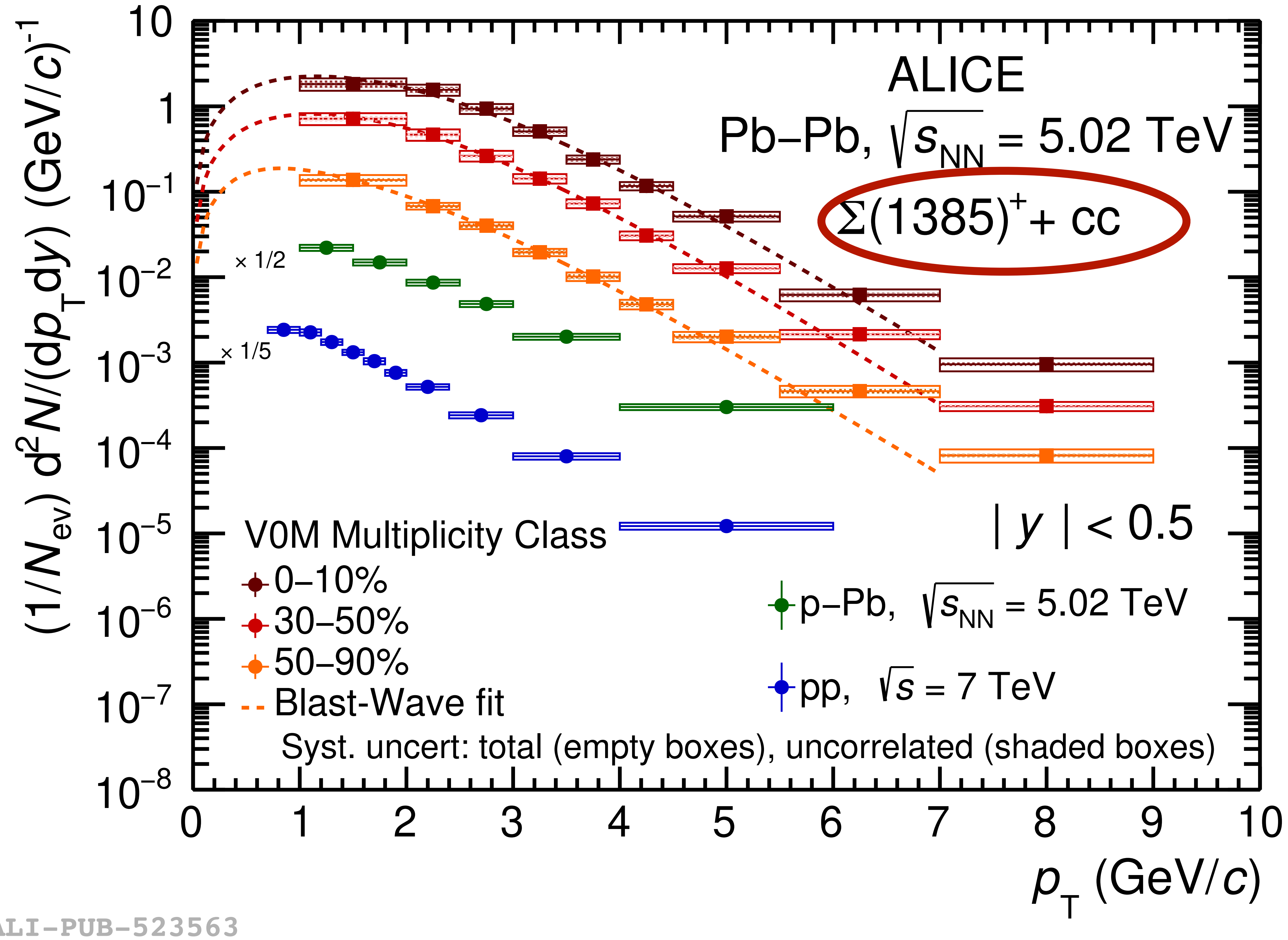
pp collisions at $\sqrt{s}$ = 5.02 and 13 TeV



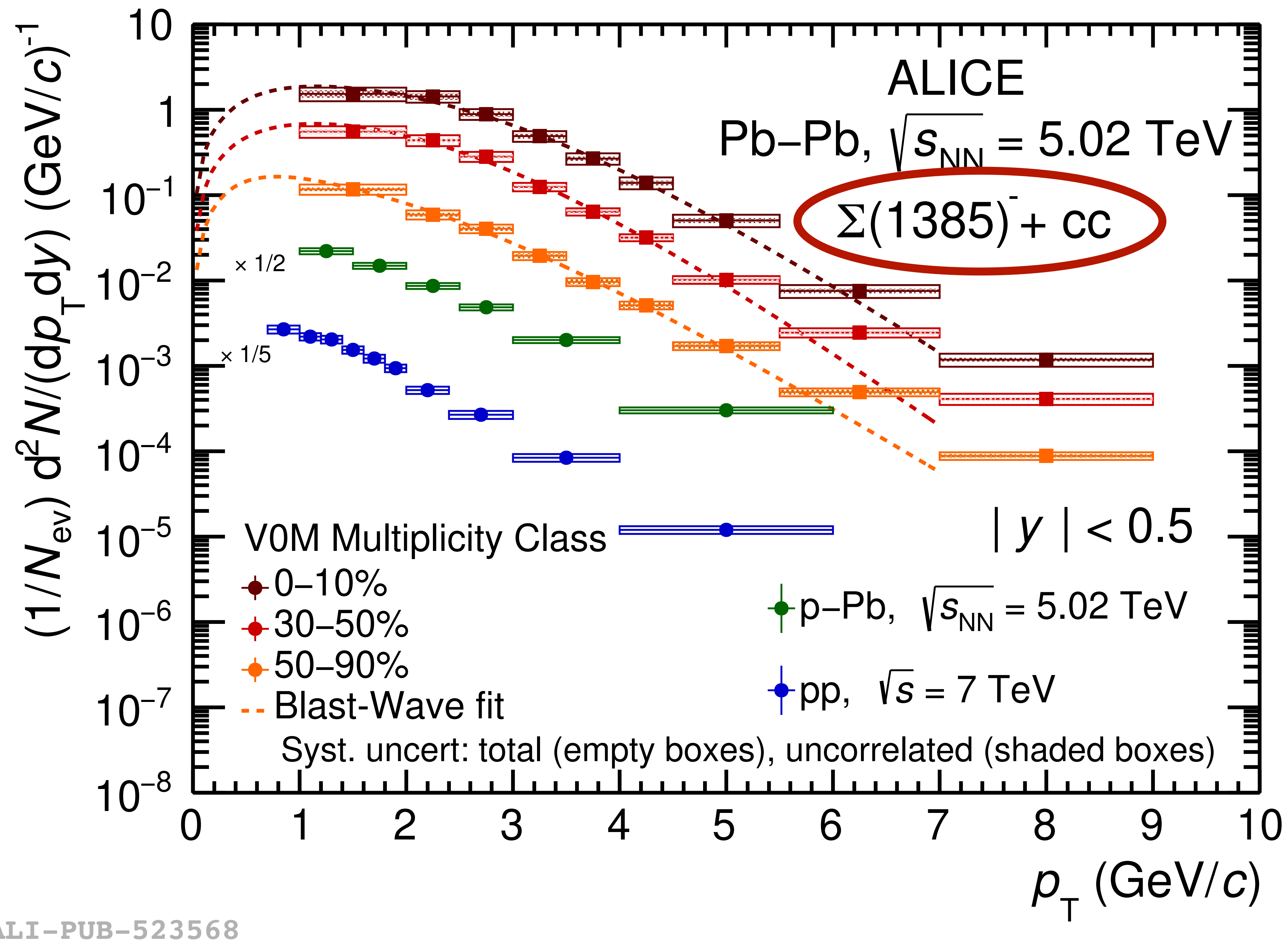
Qualitatively similar observations as for heavy-ion collisions regarding the shapes.
Collective flow-like effects in small collision systems

Baryonic resonances p_T spectra

arXiv:2205.13998



ALI-PUB-523563



ALI-PUB-523568

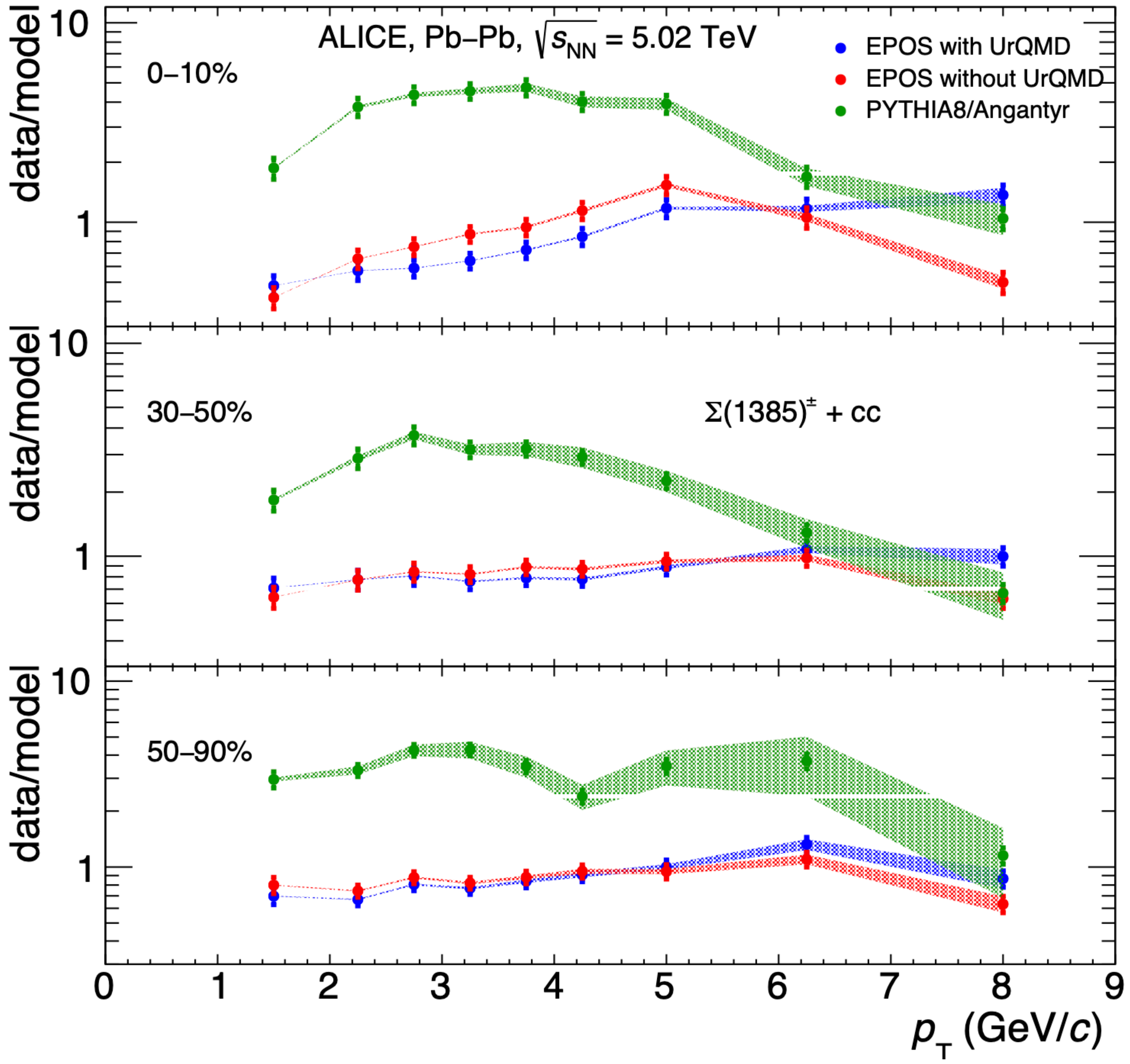
First measurement of Σ(1385)$^{\pm}$ in Pb–Pb collisions

Similar lifetime with K* that is suppressed in central Pb–Pb collisions

Resonances exhibit **radial flow**

Baryonic resonances p_T spectra

arXiv:2205.13998



ALI-PUB-523573

EPOS3:

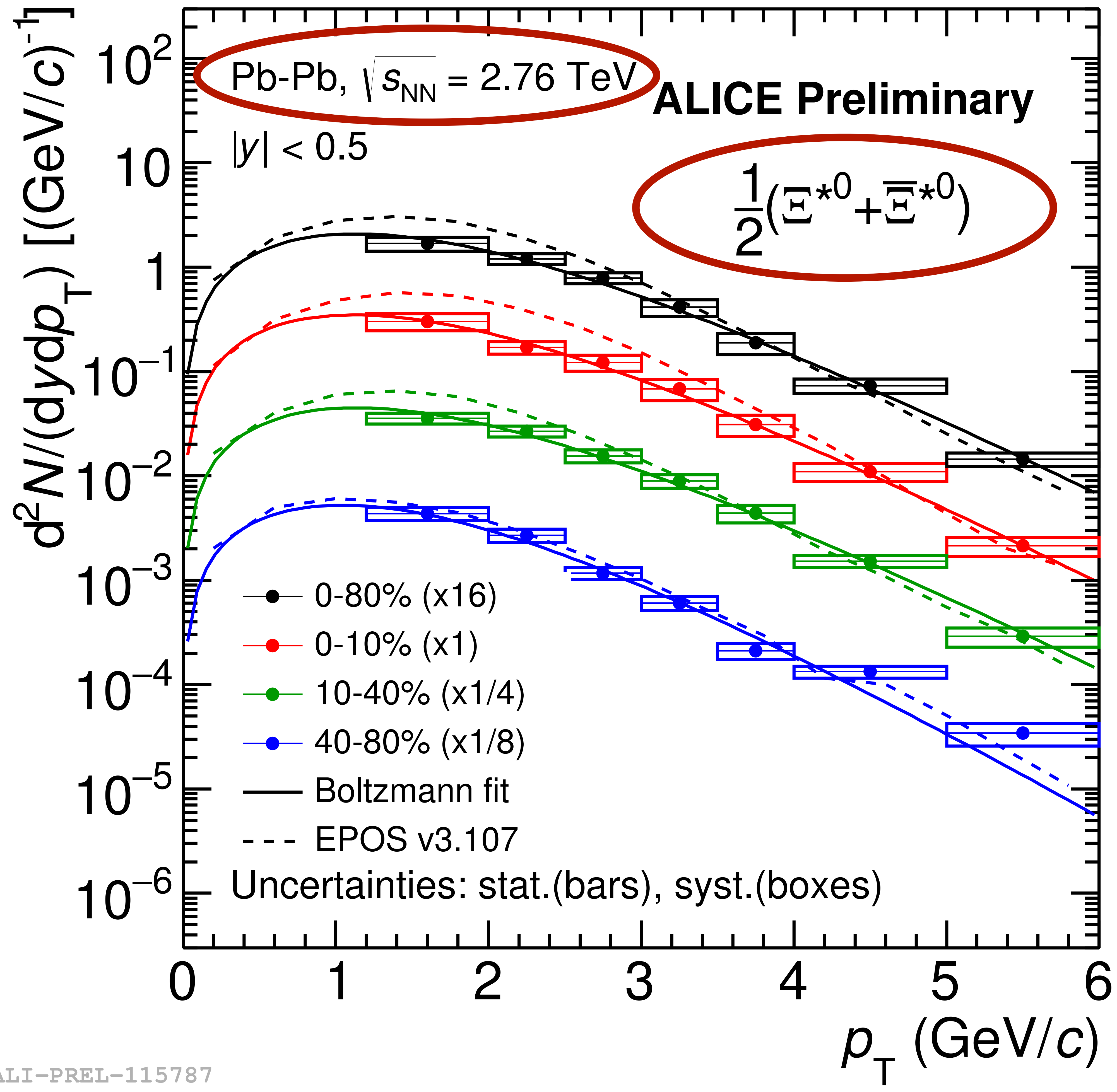
Semicentral and peripheral collisions:
No significant difference is observed between the calculation with the UrQMD afterburner and without it. Data are described within 20-30%

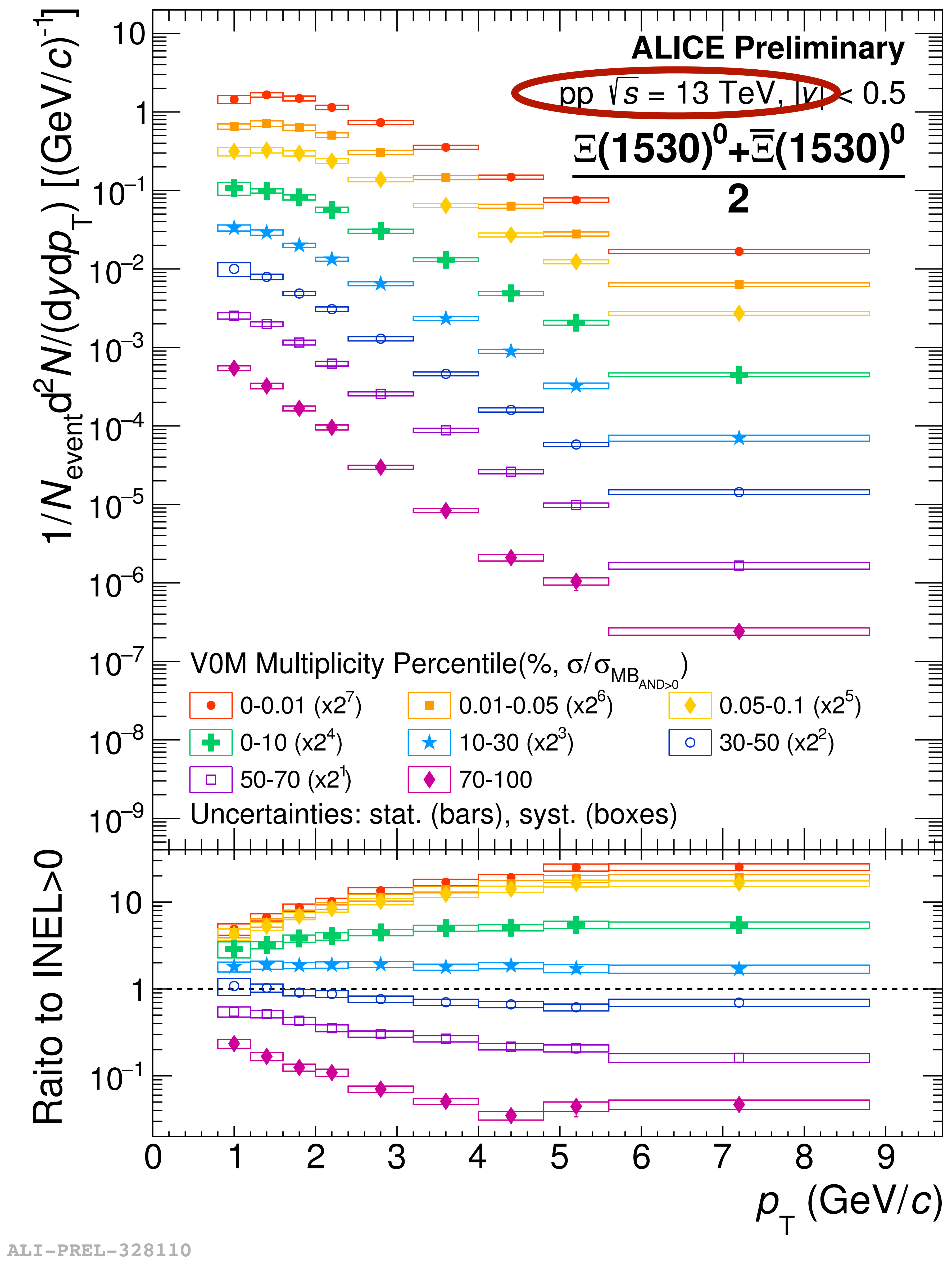
The Σ(1385)$^{\pm}$ production is overestimated by ~ 60% in most central collisions and p_T < 5 GeV/c

PYTHIA8/Angantyr:

Semicentral and peripheral collisions:
The Σ(1385)$^{\pm}$ production is underestimated by a factor 3 to 4 up to p_T ~ 6–7 GeV/c

Baryonic resonances p_T spectra



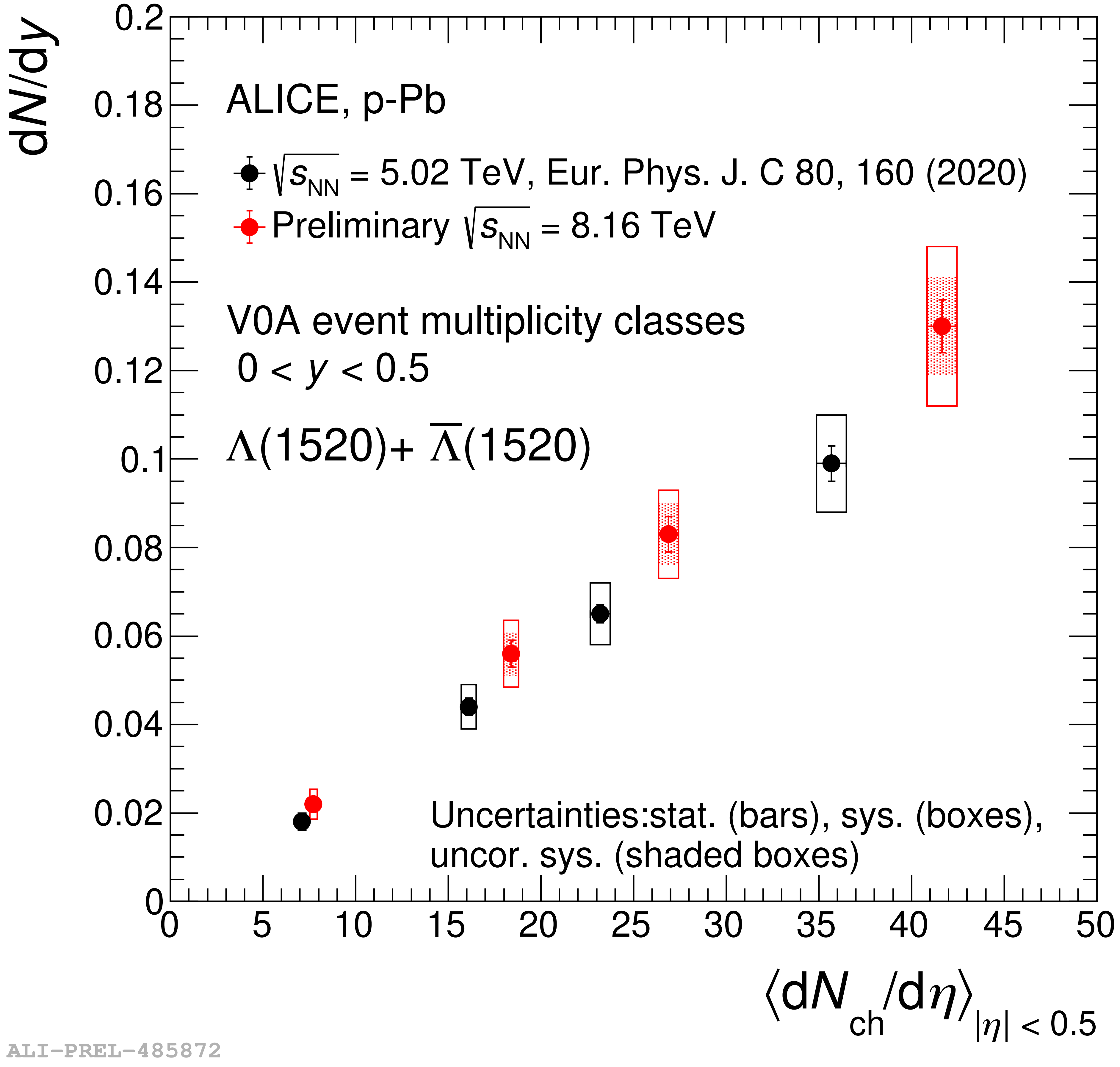


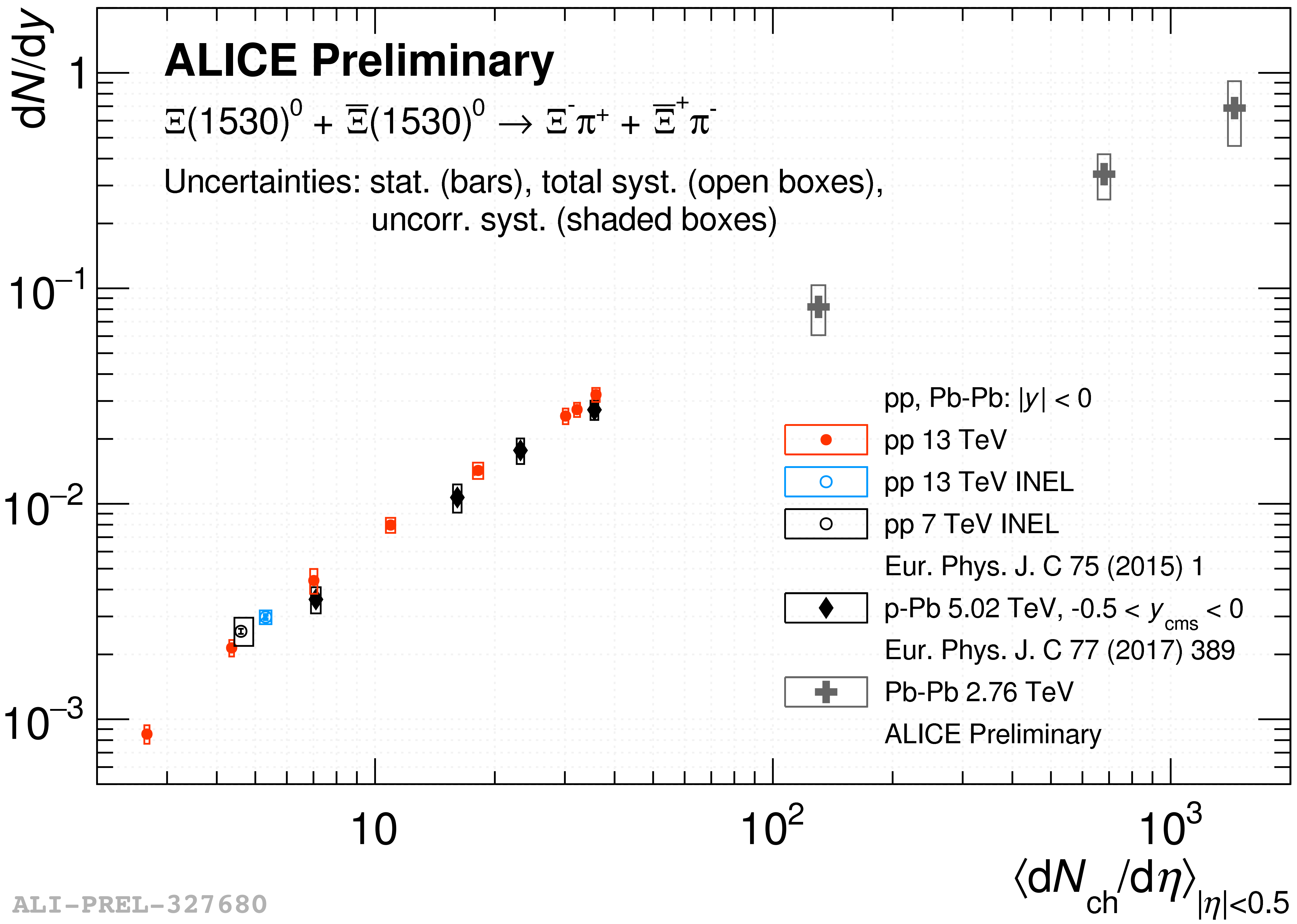
Ξ(1530)* is the third baryonic resonance measured in ALICE Run 1 and Run 2 data

Longer lifetime than Λ(1520) and $\Sigma(1385)^{\pm}$

Resonances exhibit **radial flow**

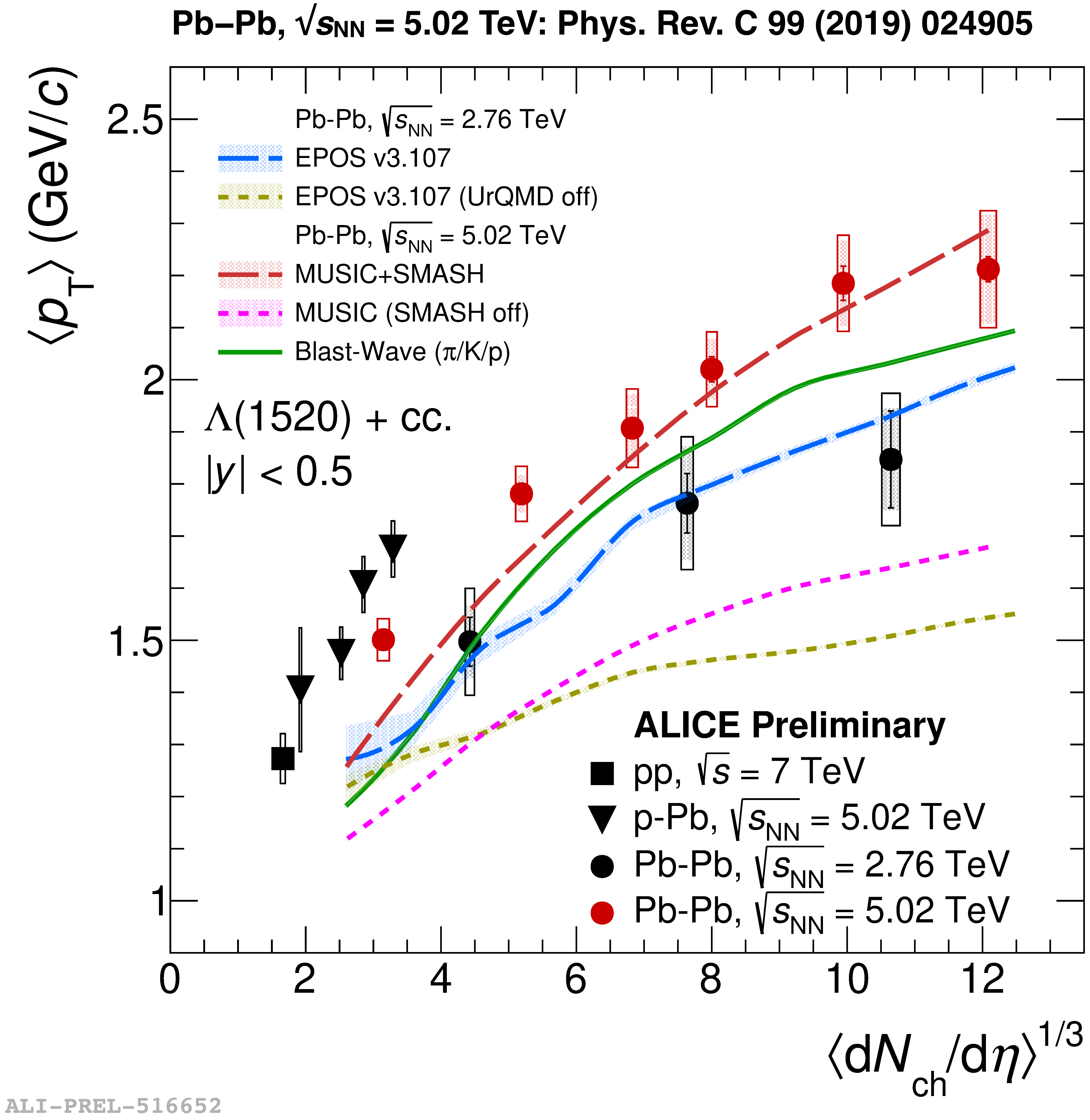
Integrated yields





Resonance **production is driven by the multiplicity** - doesn't depend on the system size or the centre-of-mass energy

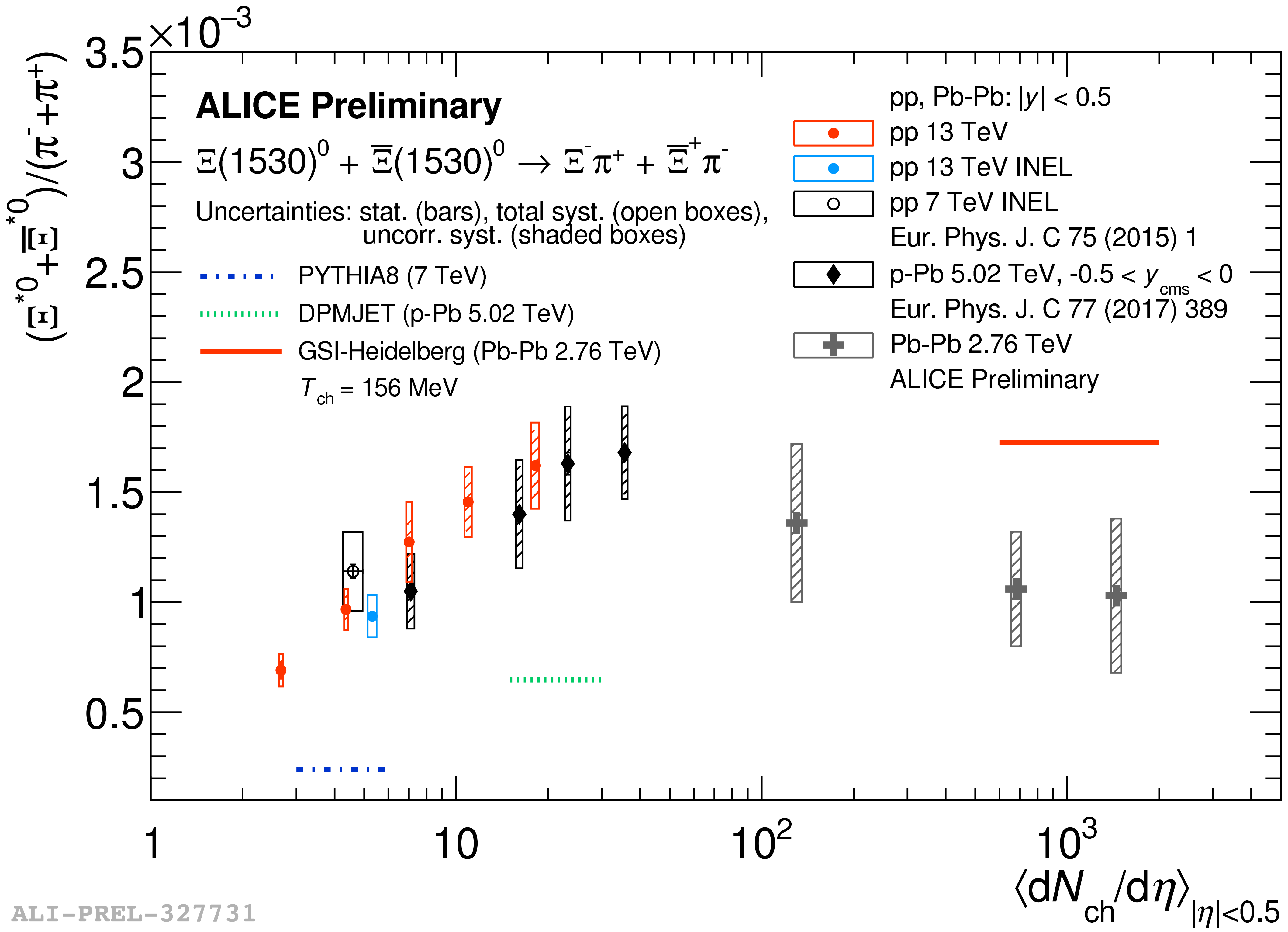
Mean transverse momentum

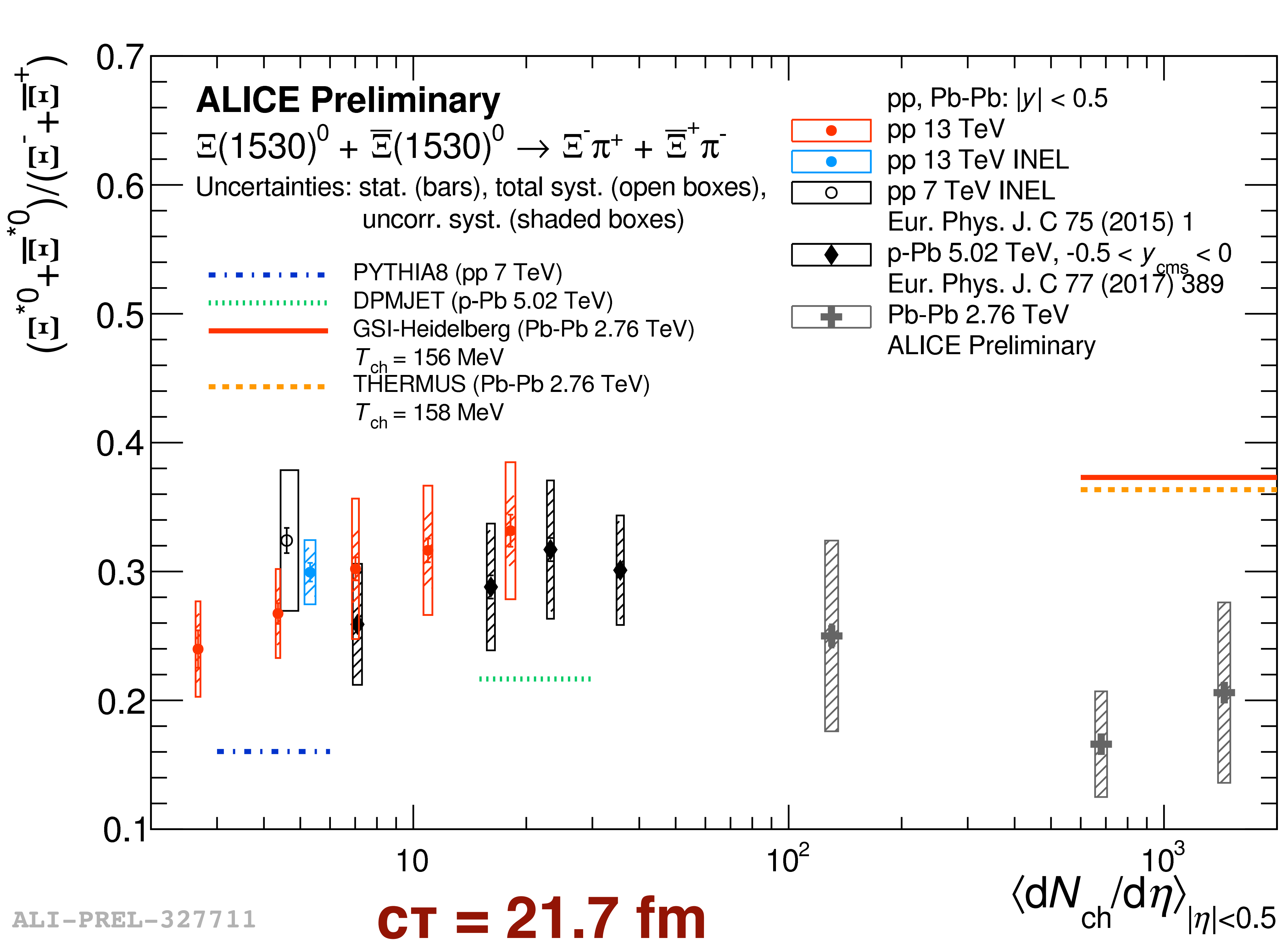


$\langle p_T \rangle$ values increase with increasing multiplicity and are higher for the higher centre-of-mass energy

Models that do not include a hadronic afterburner do not reproduce the data

Particle ratios

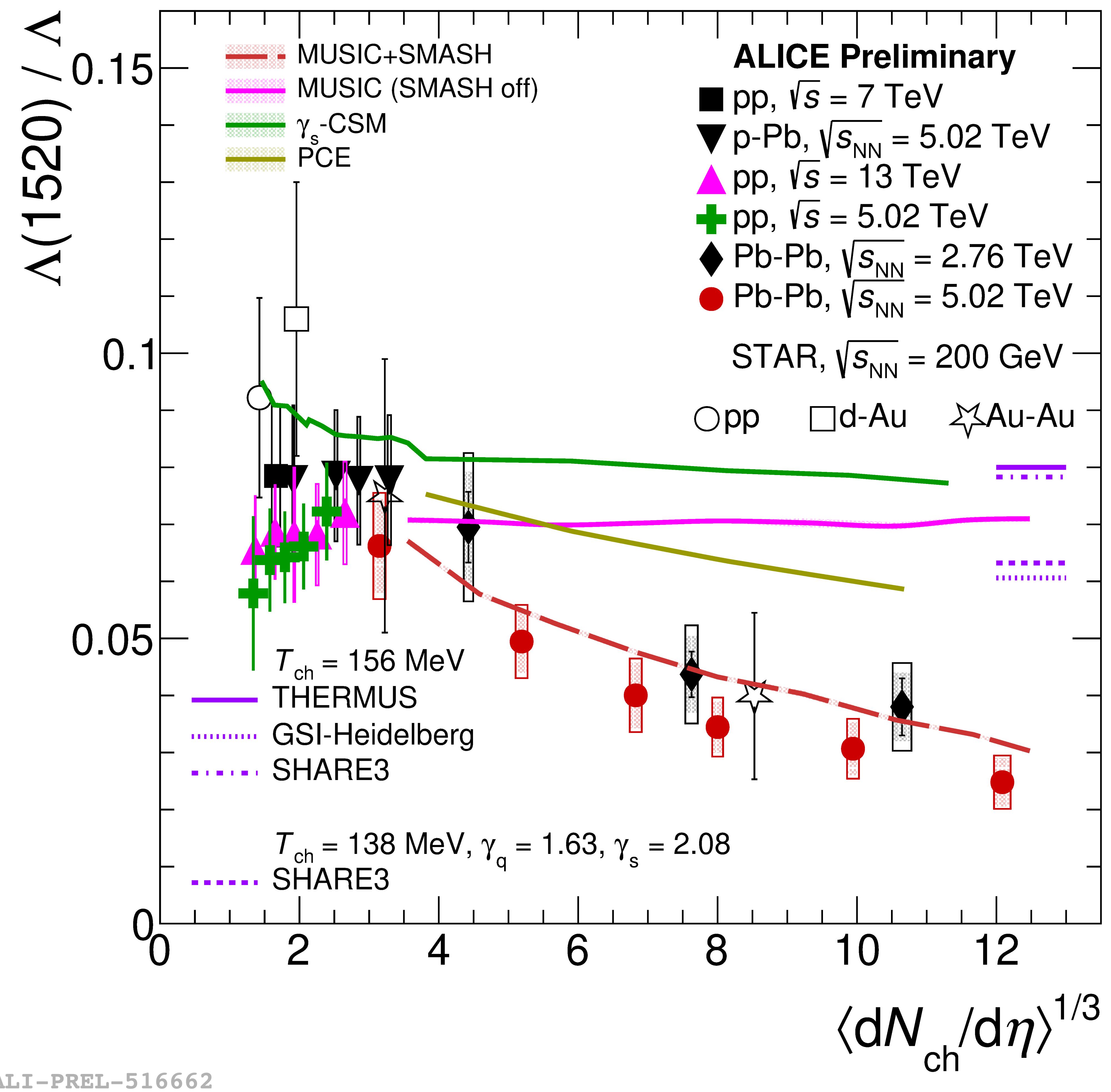




cτ = 21.7 fm

Ξ(1530)/π increases in small systems as expected, and Ξ(1530)/Ξ is rather flat (strangeness canceled). Some **trend** is seen **in larger systems** → need more precise measurements

Particle ratios



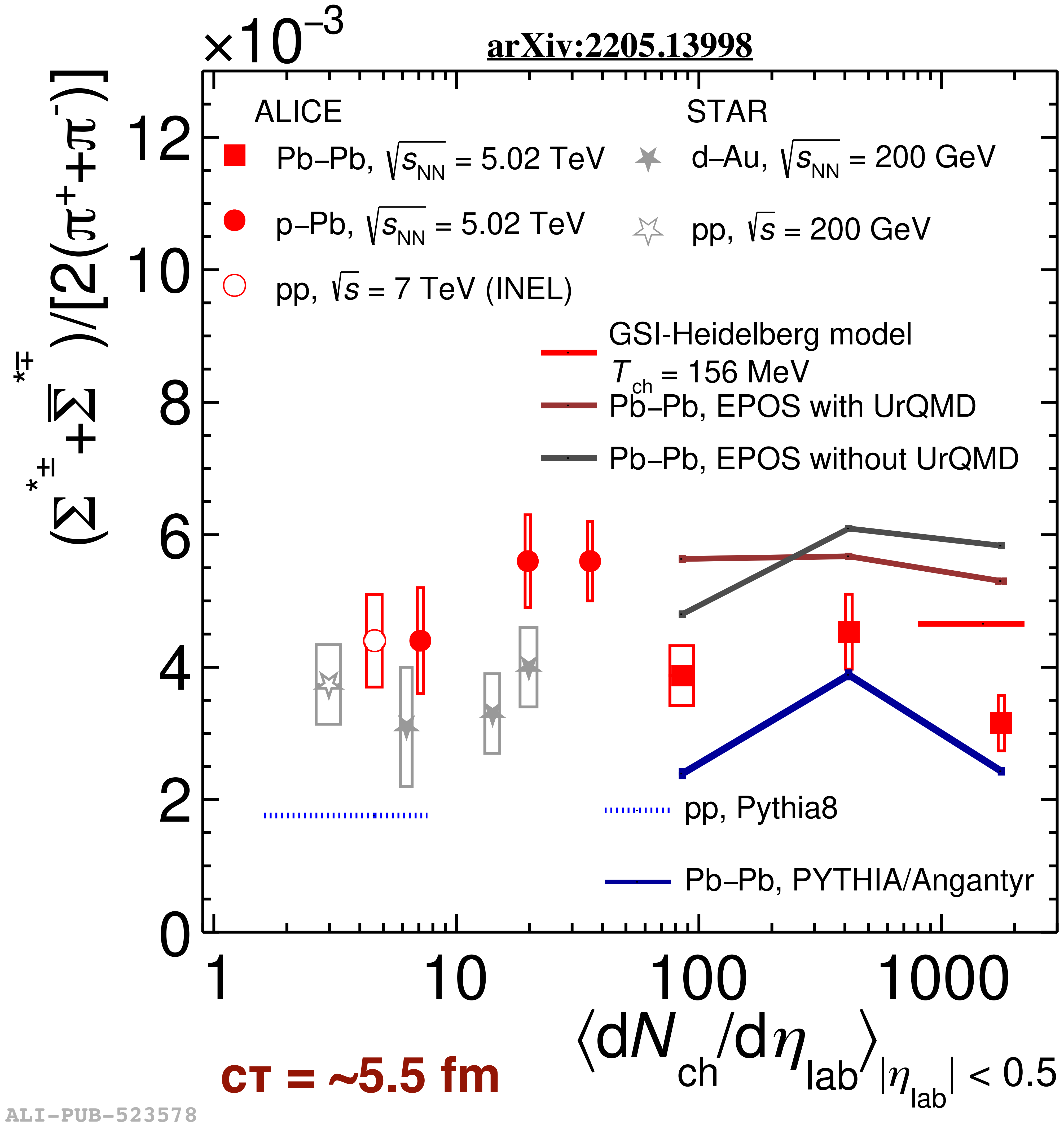
cτ = 12.6 fm

Gradual decrease of the p_T-integrated Λ(1520)/Λ yield ratio from peripheral to central Pb–Pb collisions

Thermal models **overestimate** the data

MUSIC with SMASH afterburner **reproduces** the trend observed in data

Particle ratios



cτ = ~5.5 fm

ALI-PUB-523578

Within the uncertainties, **no particular trend with multiplicity is observed**

Evidence of suppression with respect to the grand canonical thermal model is observed in central collisions

EPOS3 with UrQMD qualitatively describes the data but **overestimates** the yield in all collision centralities

Future higher precision measurements are needed to clarify whether there is a suppression with respect to pp or peripheral Pb–Pb collisions

Particle ratios

cτ (fm)

1.3

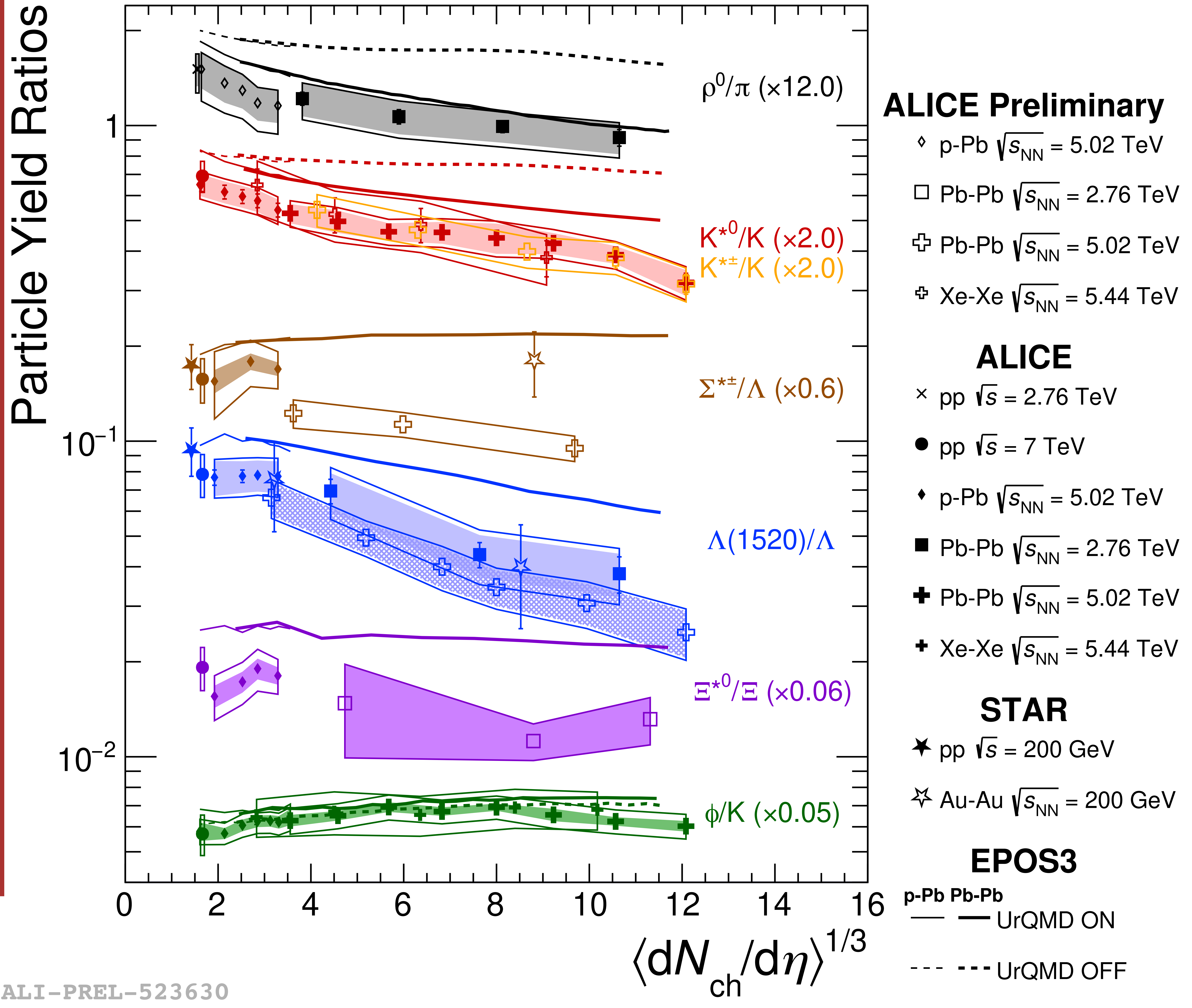
4.2

5.5

12.6

21.7

46.4



ALI-PREL-523630

Ξ(1530) and ϕ that live longer show **a flat behaviour with system size** within the uncertainties

However, it seems that **Λ(1520)** is **more suppressed** than the **K*** that has a shorter lifetime

The **observations** result from the **interplay of various parameters. Regeneration** may play a more important role in K* than in Λ(1520)

Nuclear modification factors (R_{AA})

p_T distribution in AA collisions

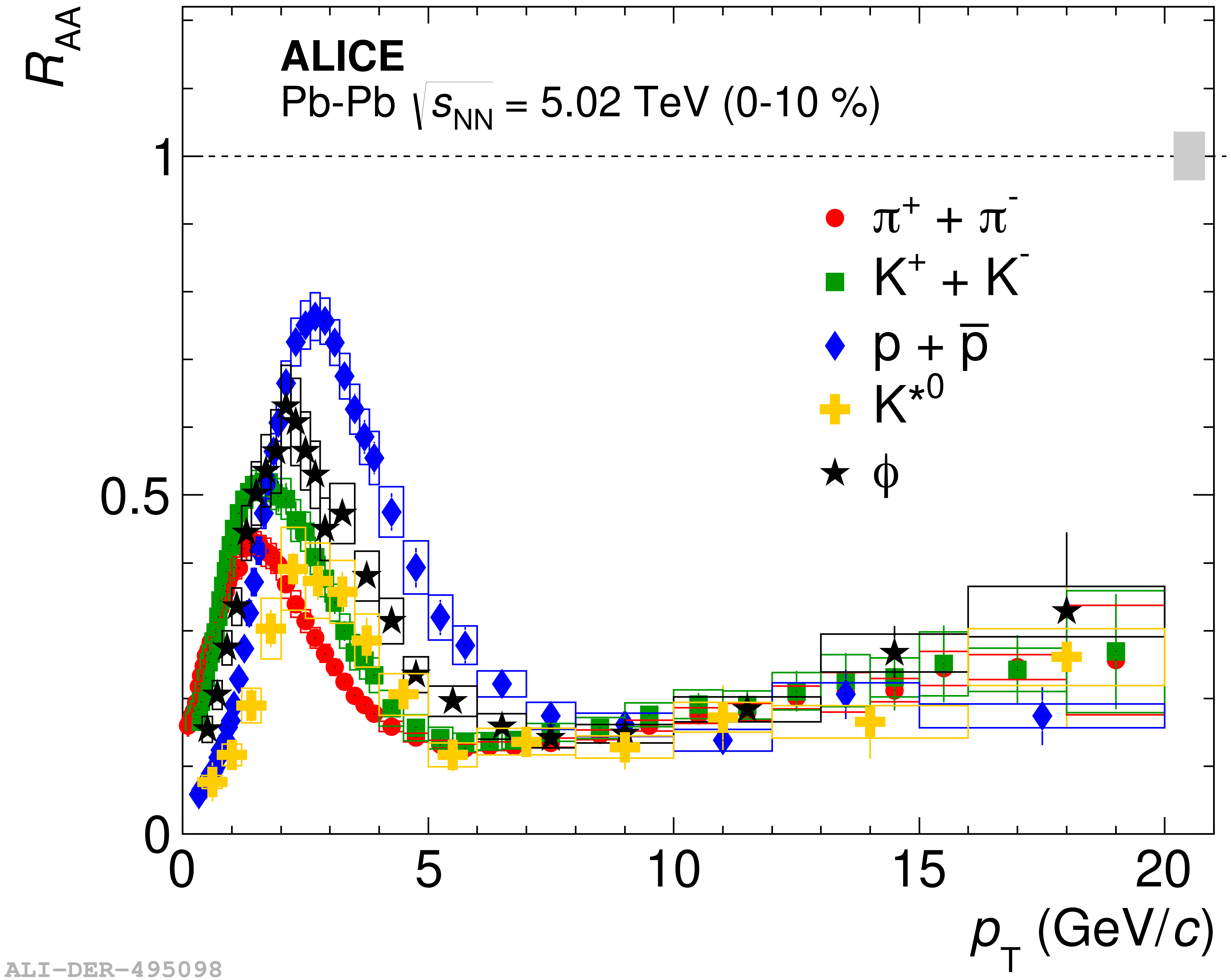
$$R_{AA} = \frac{dN_{AA}/dp_T}{\langle N_{coll} \rangle dN_{pp}/dp_T}$$

Number of binary collisions, N_{coll}.

p_T distribution in pp collisions

Nuclear modification factors (R_{AA})

Another way to explore rescattering….



ALI-DER-495098

p_T < 2 GeV/c:
K* R_{AA} values are **the smallest → effect of rescattering**
Rescattering affects the resonances in this p_T region

2 < p_T < 8 GeV/c:
- hadron mass dependence for mesons.
- Protons have the highest values of R_{AA} → baryon-meson ordering

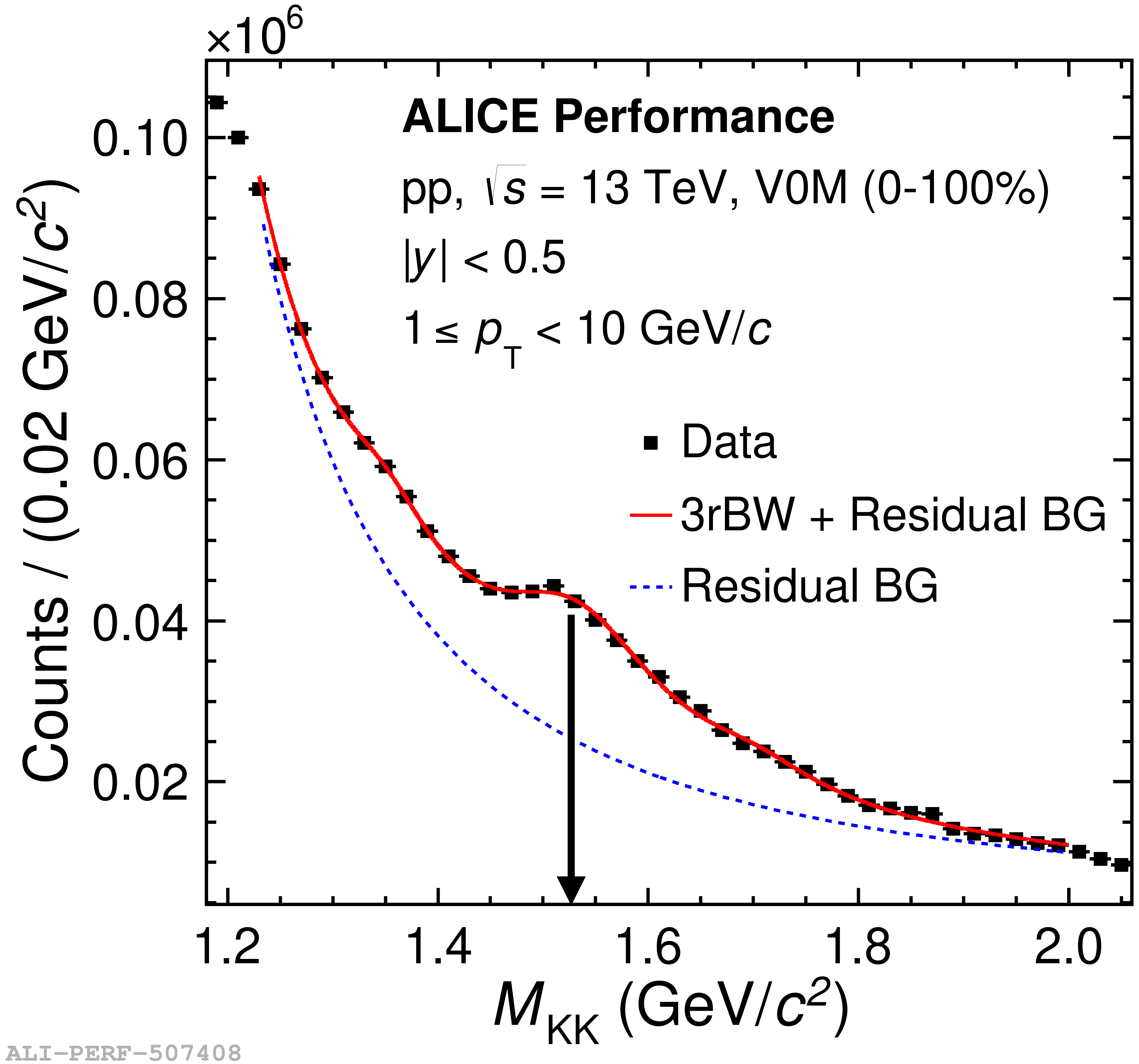
p_T > 8 GeV/c: **similar R_{AA} values** for all **hadron species** within the uncertainties → the relative particle composition at high p_T remains the same as in vacuum

Similar plots are needed for baryonic resonances

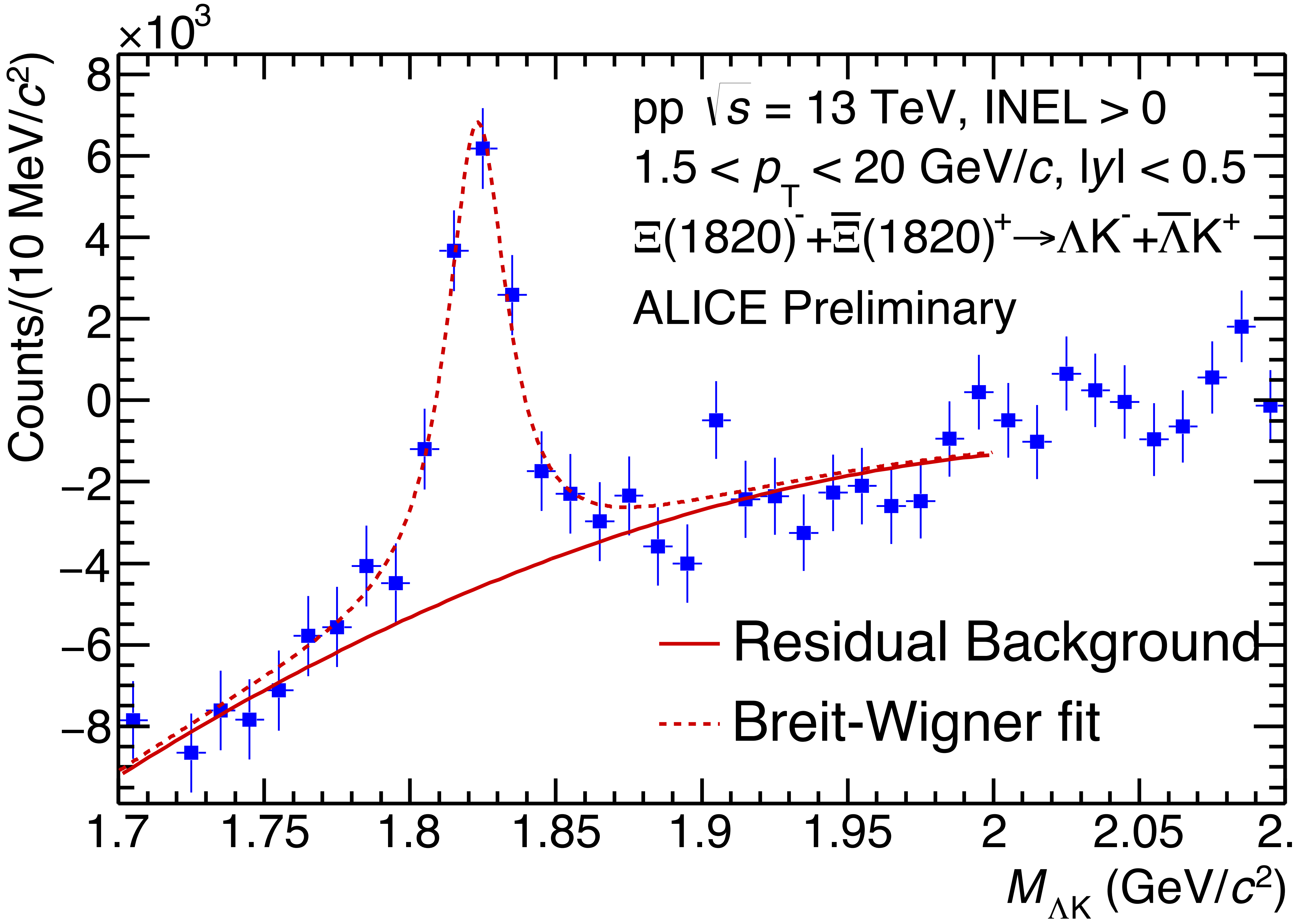
Future

Look at the invariant mass distributions of **KK** pairs

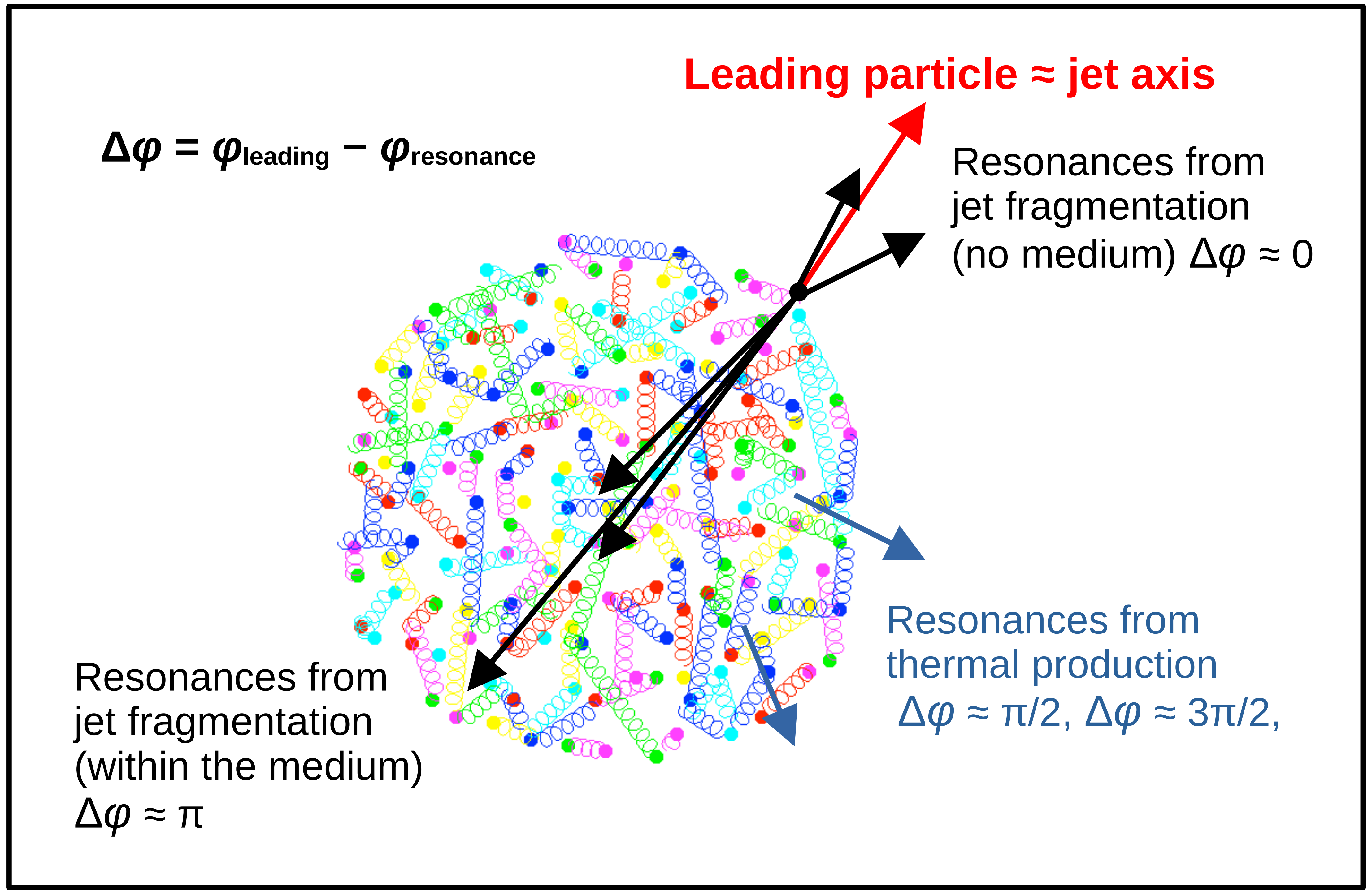
Prominent signal peak is seen for **f_2(1525)**



Ξ(1820)



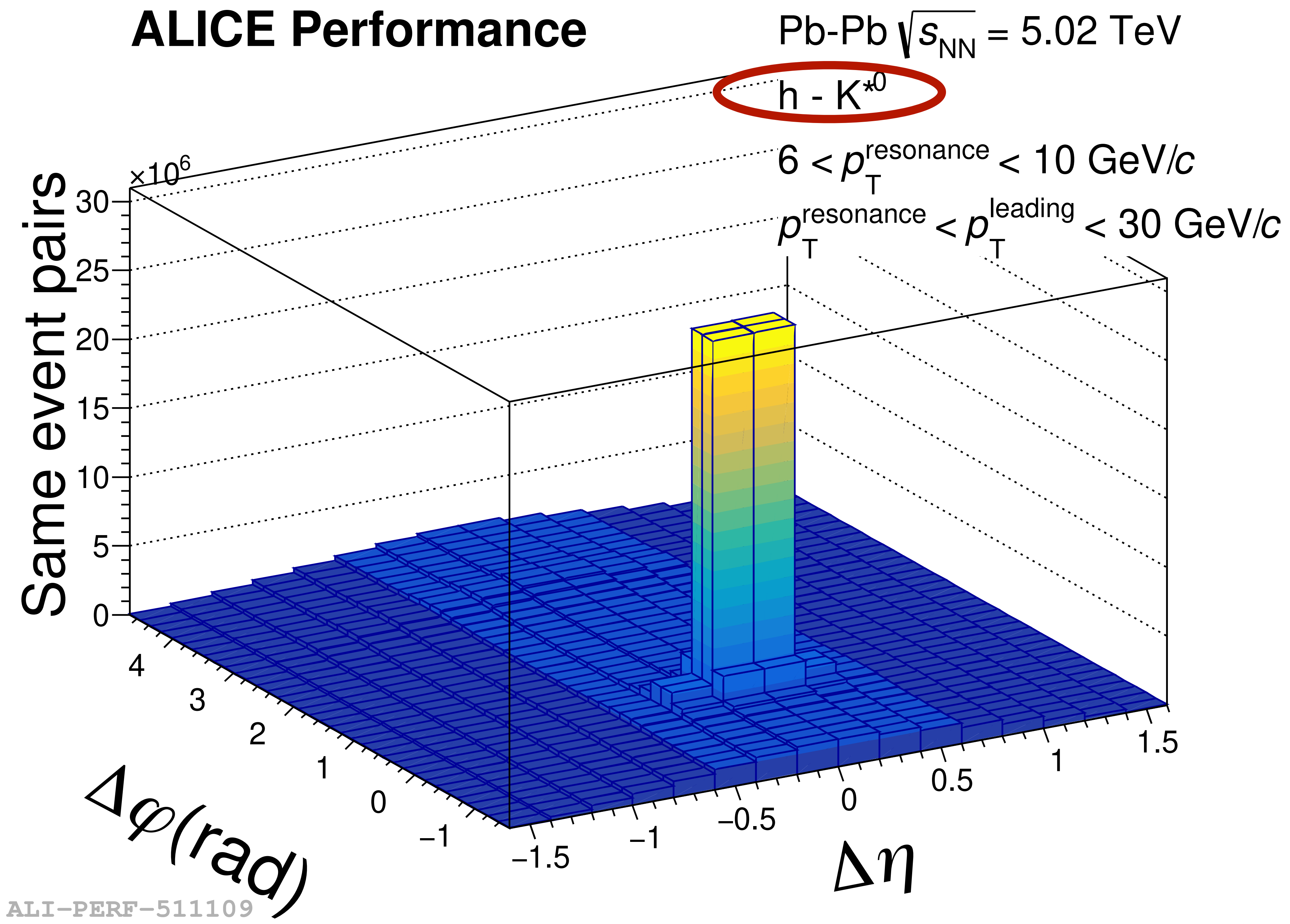
Angular hadron-resonance correlations



The study of the resonance production yield and properties can probe the partonic phase created after the collisions **(Physics Letters B 669 (2008) 92 - 97)**

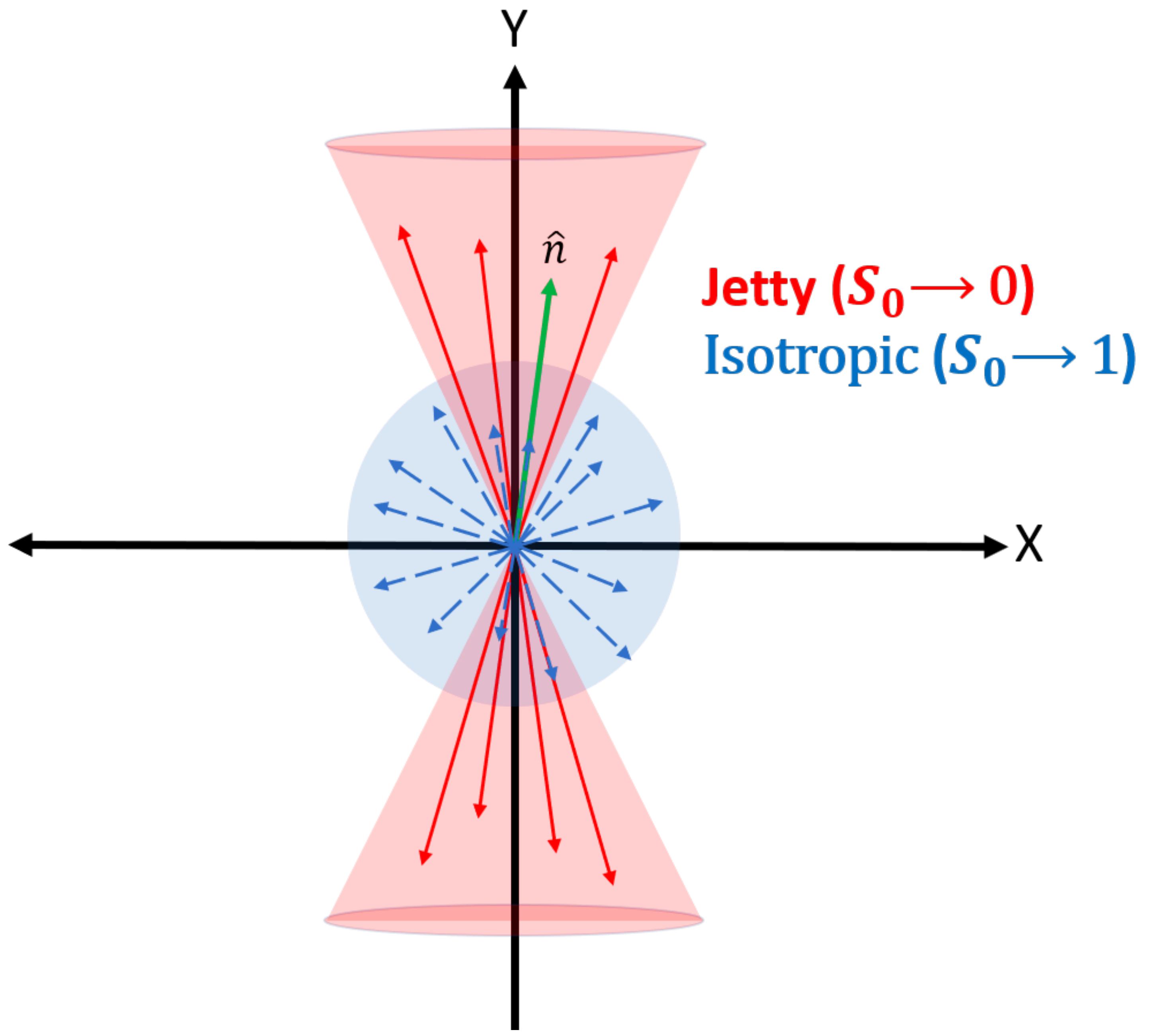
High p_T resonances can probe this phase if they are created early by jet fragmentation

Hadron-resonance angular correlations could serve to select resonances coming from the jet or out-of-jet region

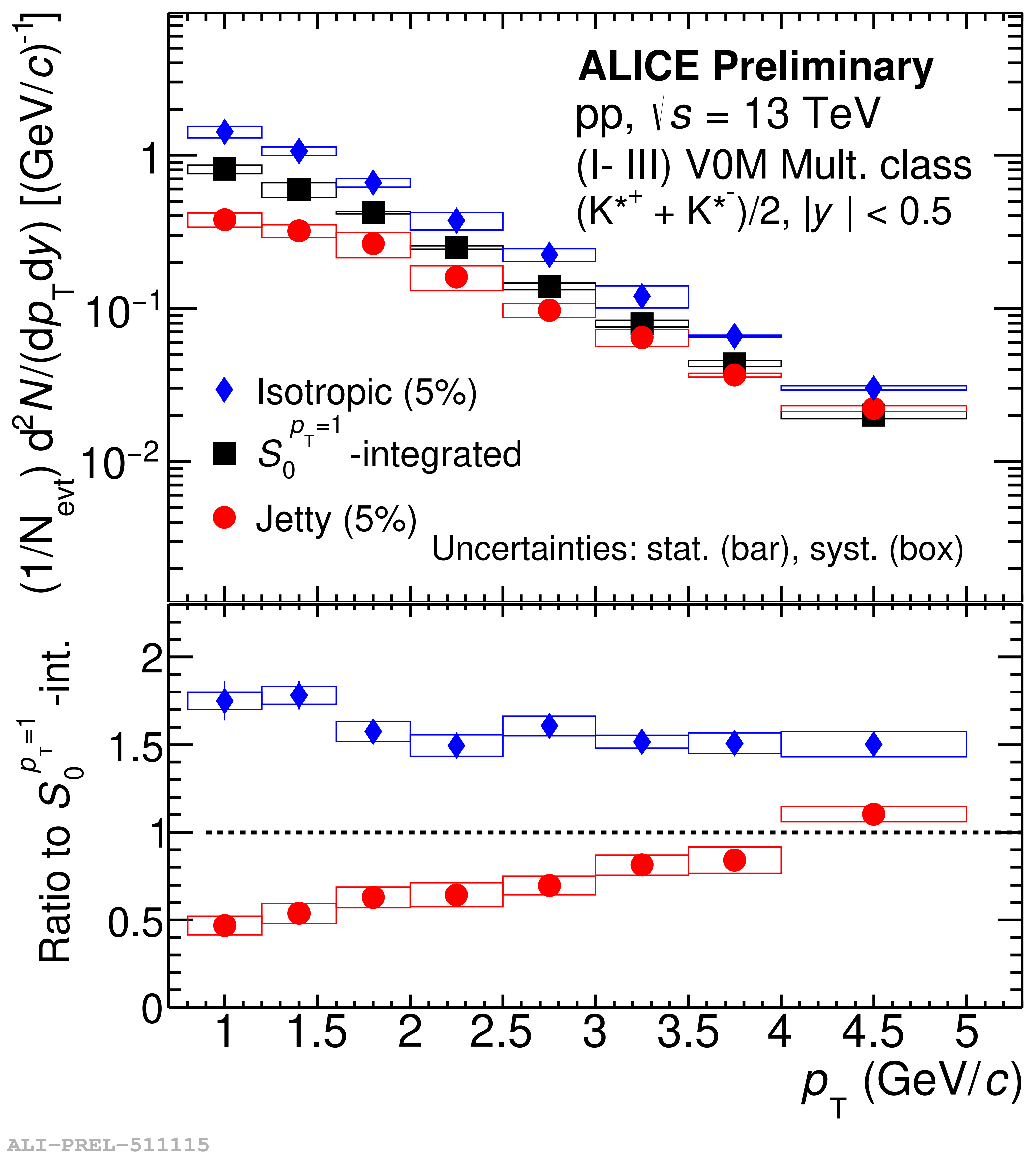


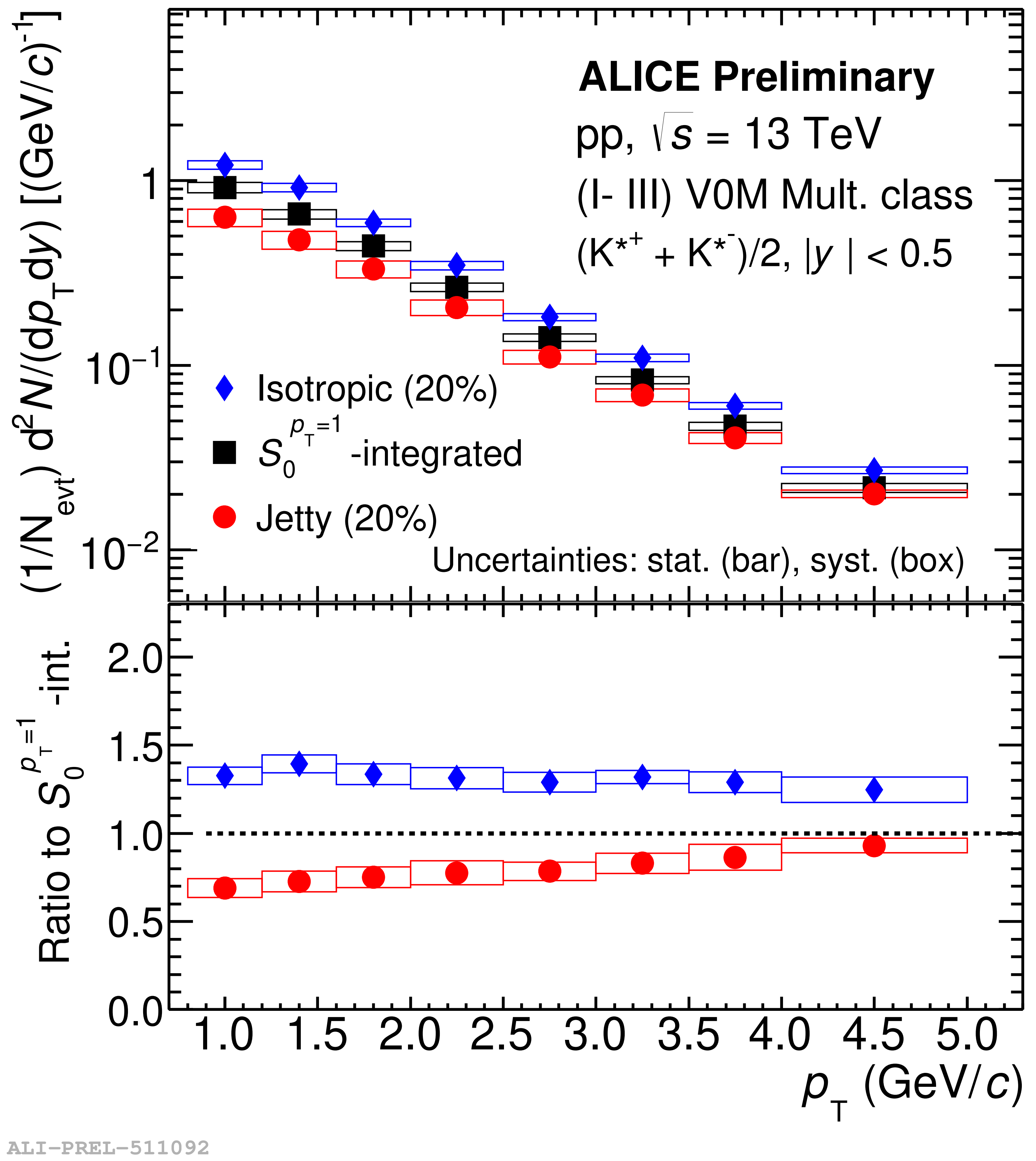
- resonances from jet region: $|\Delta\eta| < 0.6$
- the resonances out of jet region: $|\Delta\eta| > 0.6$

Transverse spherocity



Event shape observable, **sensitive to hard (S_0→0) and soft processes (S_0→1)**. It can be used to distinguish isotropic (dominated by soft QCD) and jetty (dominated by hard QCD) pp collisions



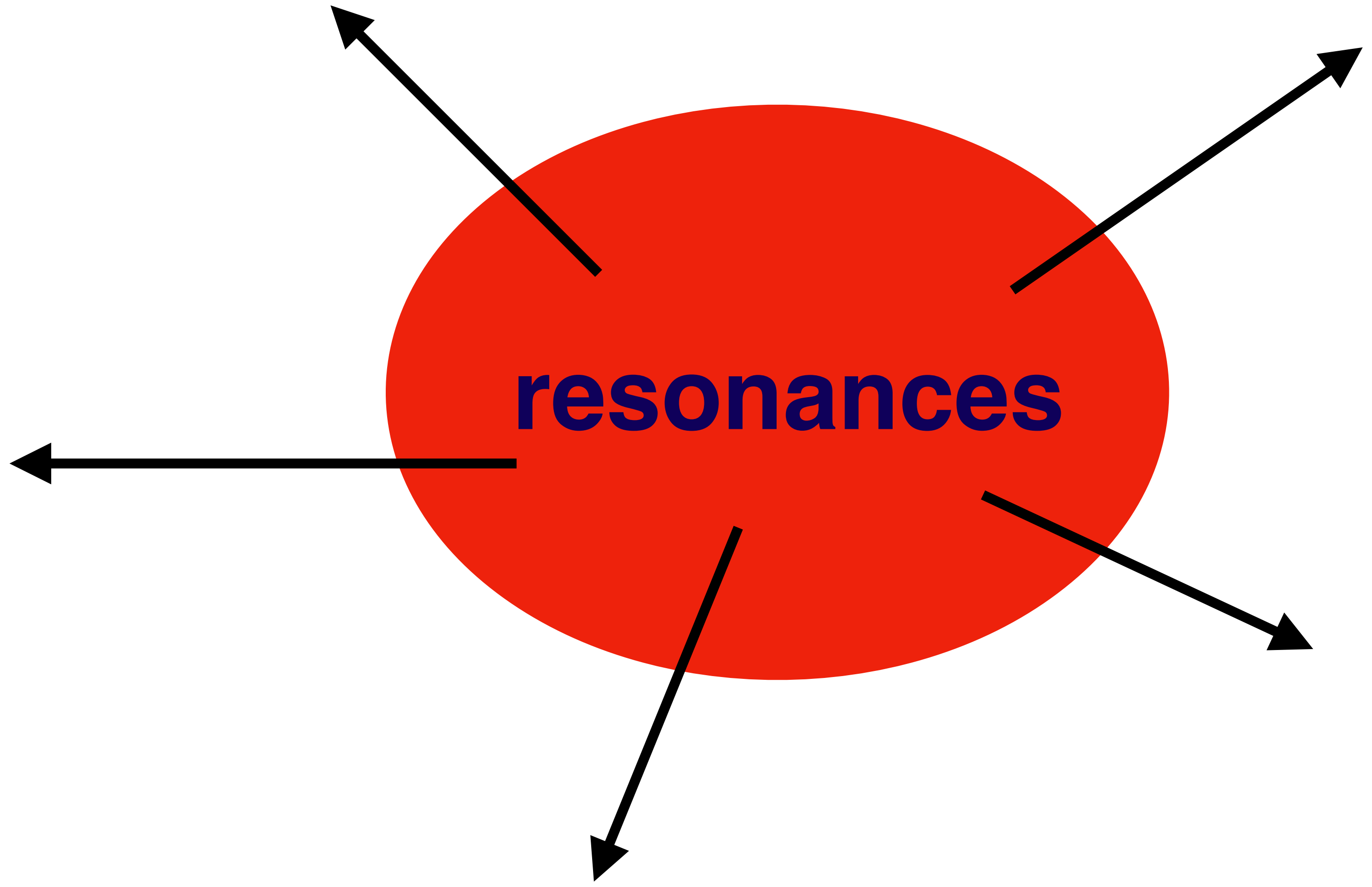


K*± measured in spherocity classes, in high multiplicity pp events at $\sqrt{s}$ = 13 TeV

Summary

- **Resonance** production is **independent** of the collision **energy** and **system** and it is **driven** by the event **multiplicity**

- **ρ^0, K^{*0}, $\Sigma^{*\pm}$, Λ^* are suppressed** in **most central** collisions with respect to small collisions systems.
  ϕ with τ = 46.4 fm/c is **not suppressed**



- More **precise results** in the future and **multi-differential** analyses

- **Rescattering** is the **dominant** process in the hadronic phase for **short-lived** resonances ($\tau < \sim$15 fm/c)

- **Higher mass** resonances are being explored

Models

MUSIC:arXiv:2105.07539
EPOS3: Phys. Rept. 350 (2001) 93–289, arXiv:hep-ph/0007198.
Phys. Rev. C 82 (2010) 044904, arXiv:1004.0805[nucl-th]
Phys. Rev. C 89 (2014) 064903, arXiv:1312.1233 [nucl-th]
PYTHIA8/Angantyr: JHEP 10 (2018) 134, arXiv:1806.10820 [hep-ph]
SHM: Nature 561 (2018) 321–330, arXiv:1710.09425[nucl-th]