Insight into Strangeness and Resonance Production from Small to Large System with ALICE at the LHC

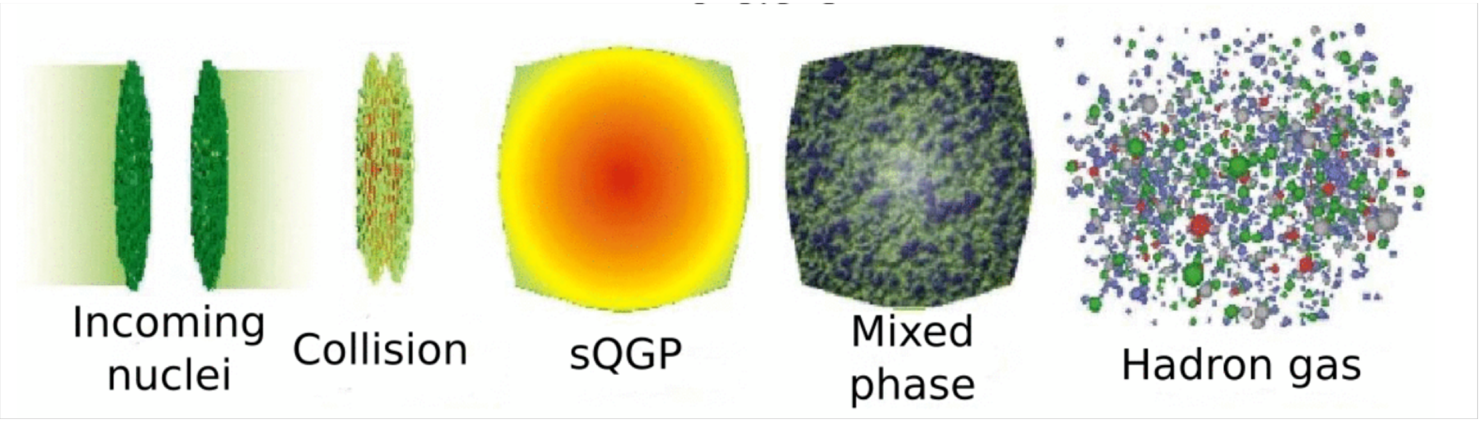
Arvind Khuntia

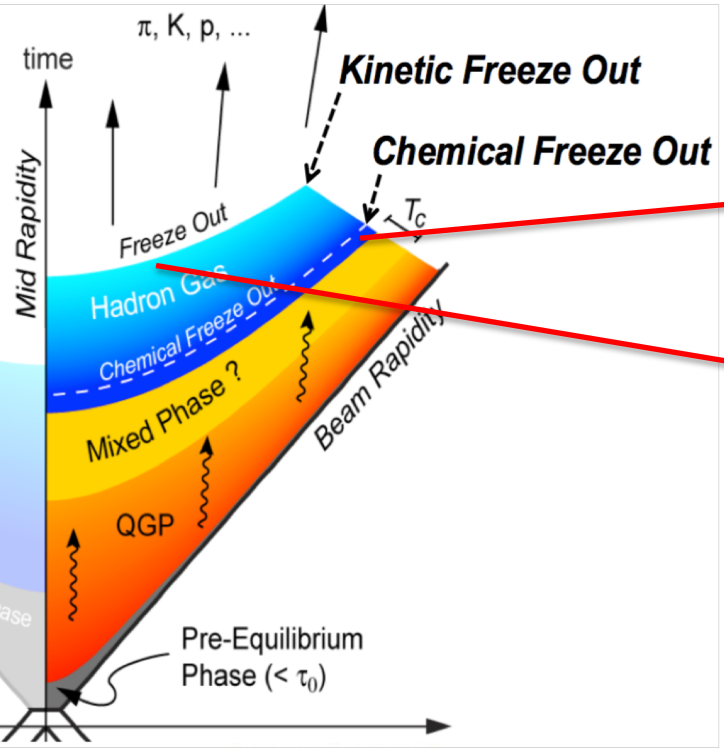
H. Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences

Outline:

- Motivation
- Transverse momentum spectra
- Mass ordering of mean-p_T
- Particle ratios
  - Energy dependence
  - Multiplicity dependence
- Strangeness enhancement in small systems
- Summary

Motivation





- **Chemical freeze out:**

The inelastic processes cease and the particle yields (and relative abundances) are fixed

- **Kinetic freeze out:**

The elastic processes cease and the particle p_T spectra are fixed

Hadronic phase

Resonance yields in heavy-ion collisions are defined by:

✓ resonance yields at chemical freeze-out

✓ hadronic processes between chemical and kinetic freeze-outs

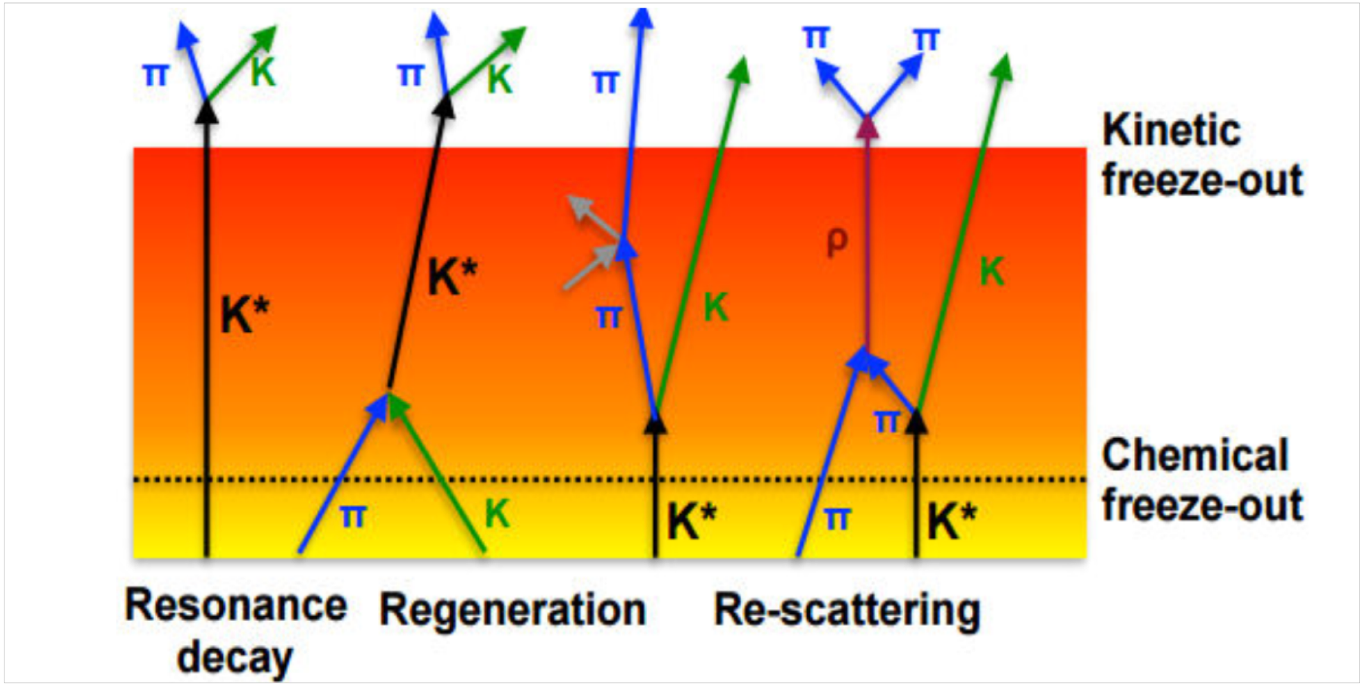
rescattering:

✓ daughter particles undergo elastic scattering or pseudo-elastic scattering through a different resonance

✓ parent particle is not reconstructed → **loss of signal**

regeneration:

✓ pseudo-elastic scattering of decay products ($K\pi \rightarrow K^{*0}$, $K^{+}K^{-} \rightarrow \phi$) → **increase of yields**



Hadronic phase

➢ **Effect of hadronic process depends on:**

- ✓ **lifetime of hadronic phase**
- ✓ **resonance lifetime**
- ✓ **scattering cross sections**

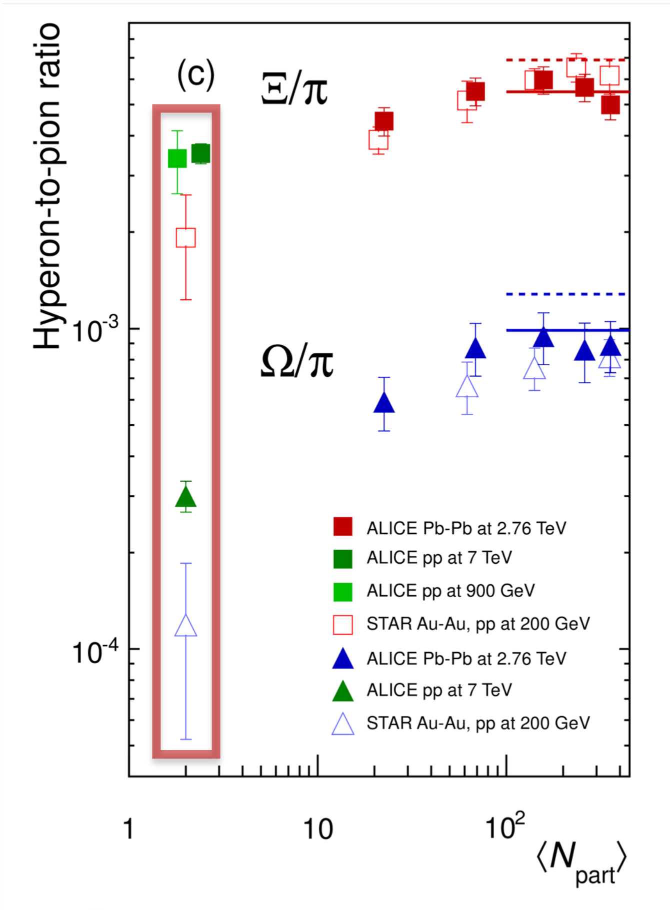
➢ Resonances with lifetimes comparable to that of the fireball are very promising tools to study properties of the hadronic phase

Particles	ρ^0	K^{*0}	ϕ	$\Lambda(1520)$	Ξ^{*0}
Mass (MeV/c^2)	770	896	1019	1520	1532
Width (MeV/c^2)	150	47.4	4.27	15.7	9.1
Mean Life-time (fm/c)	1.3	4.2	46.2	12.6	21.7
Decay	$\pi^+\pi^-$	πK	K^+K^-	K^-p	$\pi^+\Xi^-$
BR (%)	~100	66.6	48.9	22.5	66.7

Strangeness Enhancement: From pp to AA

- Enhanced production of strange particles in A-A w.r.t pp
  - ✓ **One of the first proposed signatures of QGP formation in A-A collisions**

J. Rafelski and B. Müller, PRL 48, 1066 (1982)

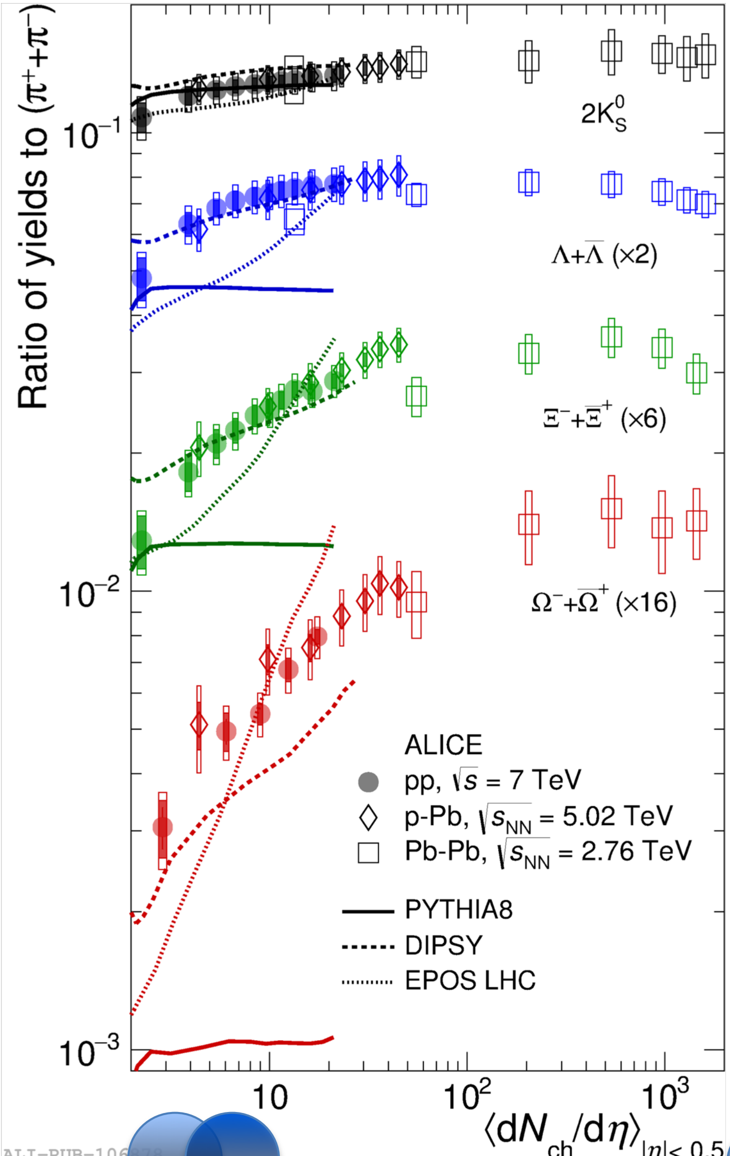


ALICE, PLB 728 (2014) 216-227

- ✓ Strangeness production increases from pp to A-A
- ✓ Strange hadron production relative to pion in pp collisions is larger at the LHC than at RHIC

Can we fill the gap between min. bias pp and Pb-Pb with high multiplicity pp and p-Pb events?

Strangeness Enhancement in Small Systems

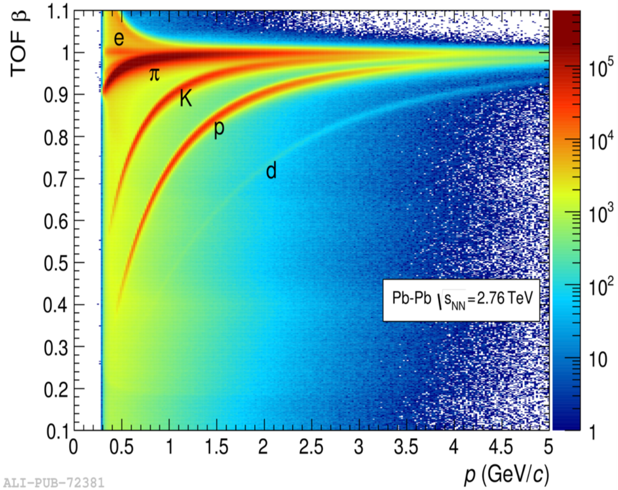


- Unprecedented statistics in pp/p-Pb collisions at the LHC allows us to study the multiplicity dependence of particle production
- A smooth evolution of these ratios from pp to Pb-Pb
- Enhancement of strangeness production is also observed in smaller systems from low to high-multiplicity.
- Strangeness production is independent of collision system and energy for a given multiplicity class

New multiplicity dependent results from pp at 13 TeV will provide more input to this picture

ALICE, Nature Physics 13 (2017) 535

ALICE

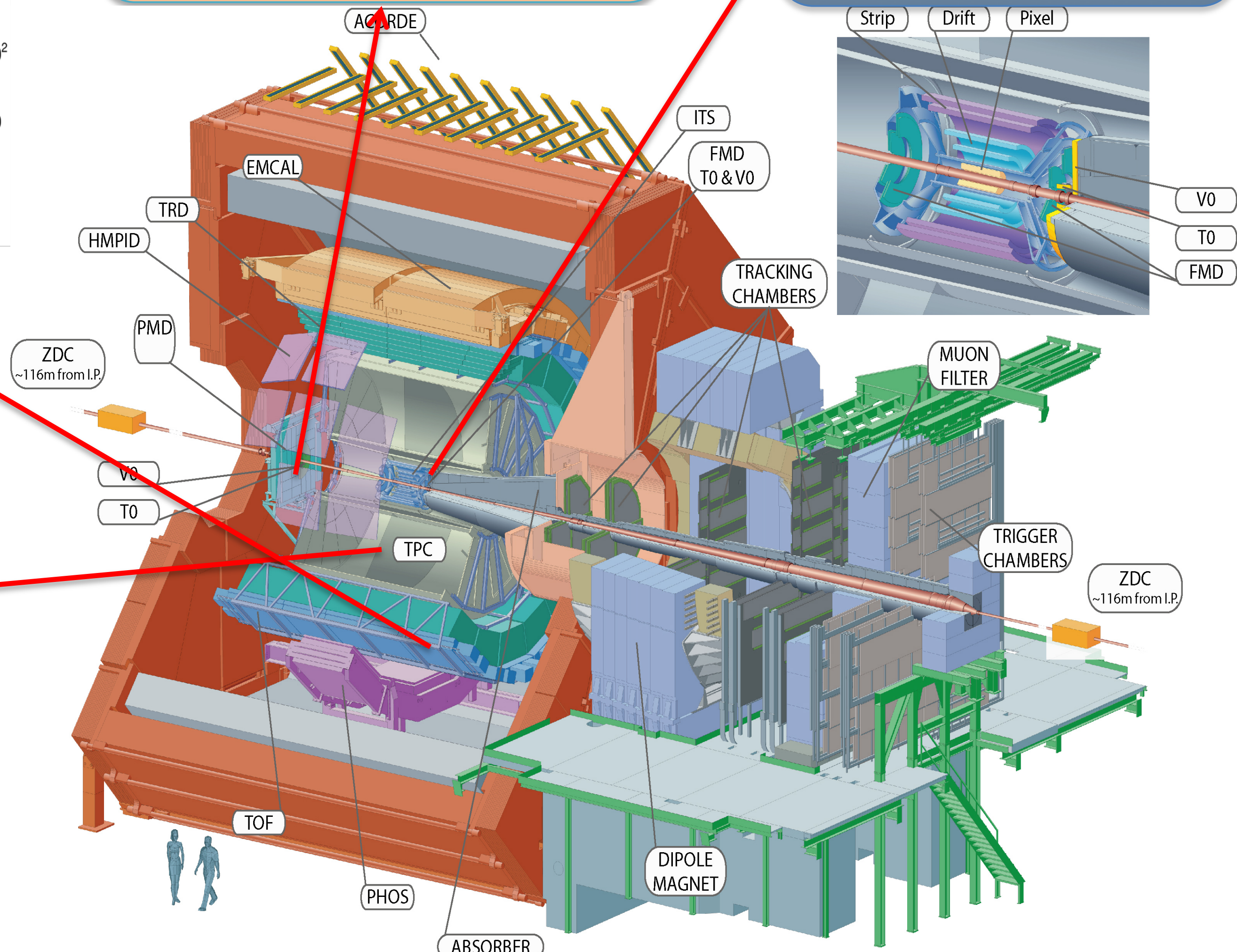


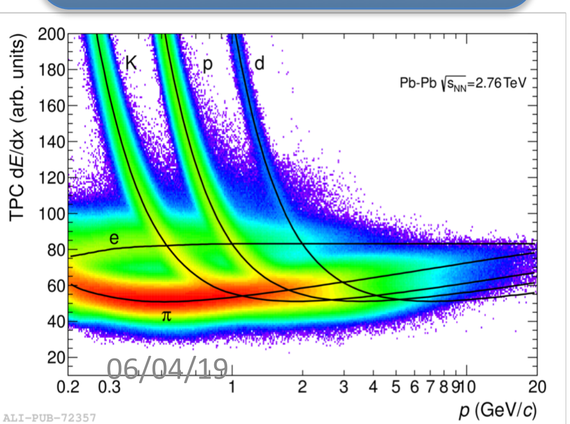
V0 (scintillators): centrality estimate through multiplicity in V0

ITS (silicon): Tracking , Vertexing and PID at very low p_T

TOF: PID through particle time of flight

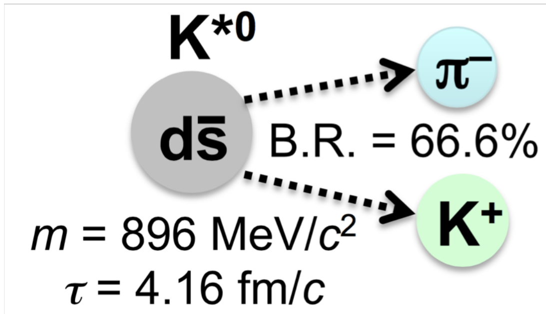
TPC: Tracking and PID through dE/dx

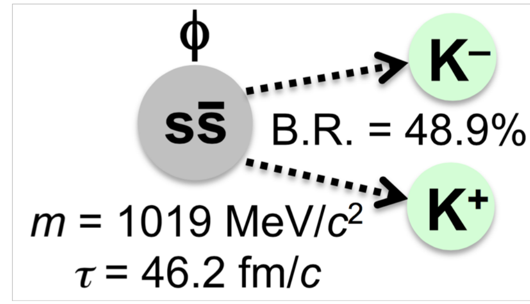


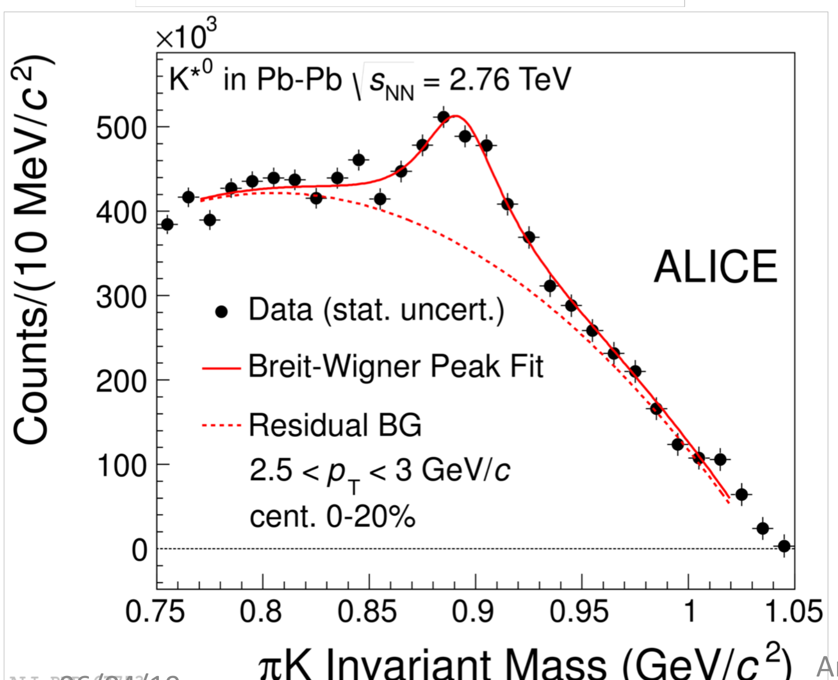


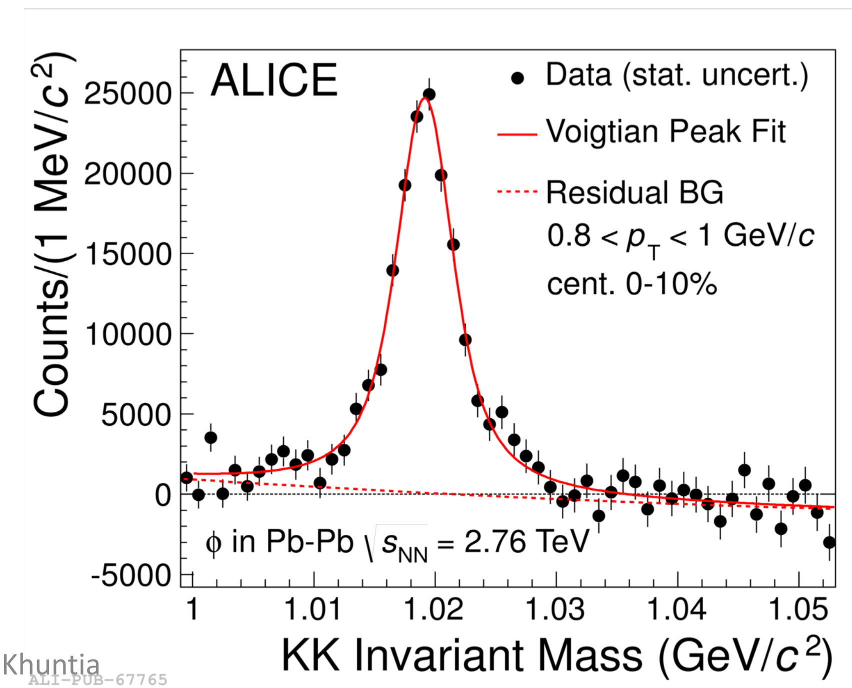
Invariant Mass Spectra (Mesons)

- Unlike-sign invariant mass distributions after subtraction of mixed-event or like-sign background Fitted with:
  - ✓ 2[nd] or 3[rd] order polynomial for residual background (jets, mis-reconstructed particles etc.)
  - ✓ **Breit-Wigner** or **Voigt** (convolution of Breit-Wigner with a Gaussian) function for signal

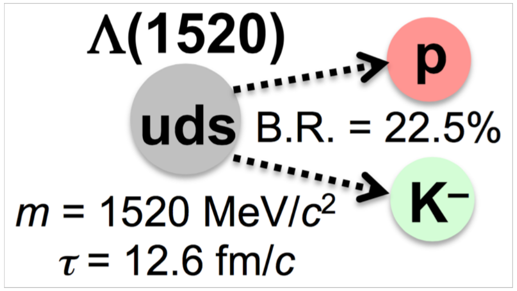


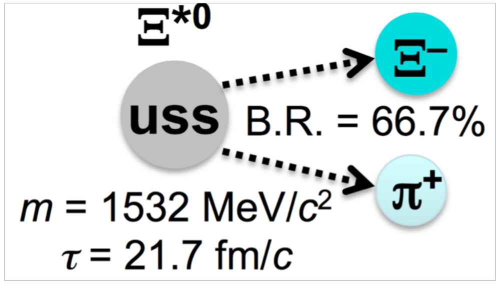


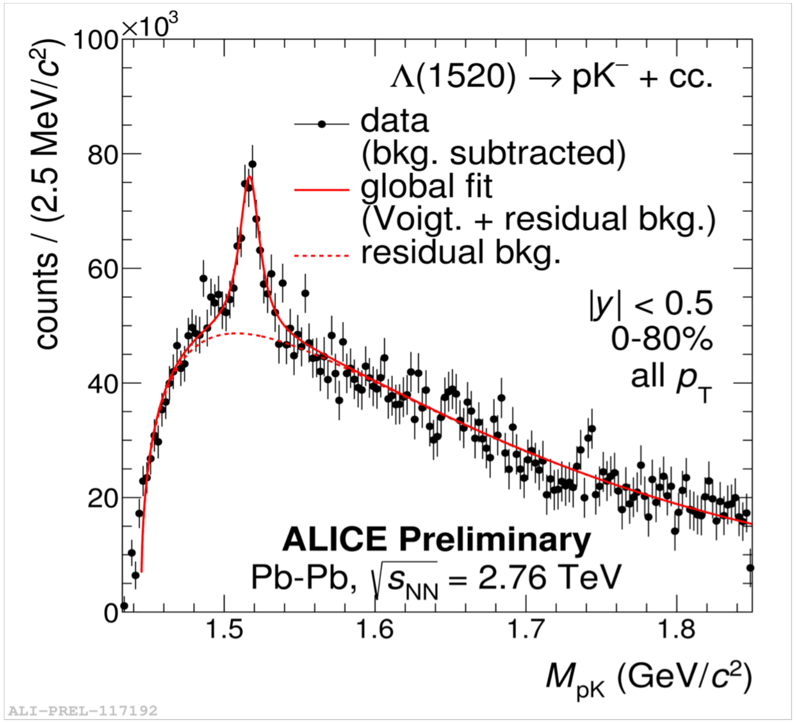


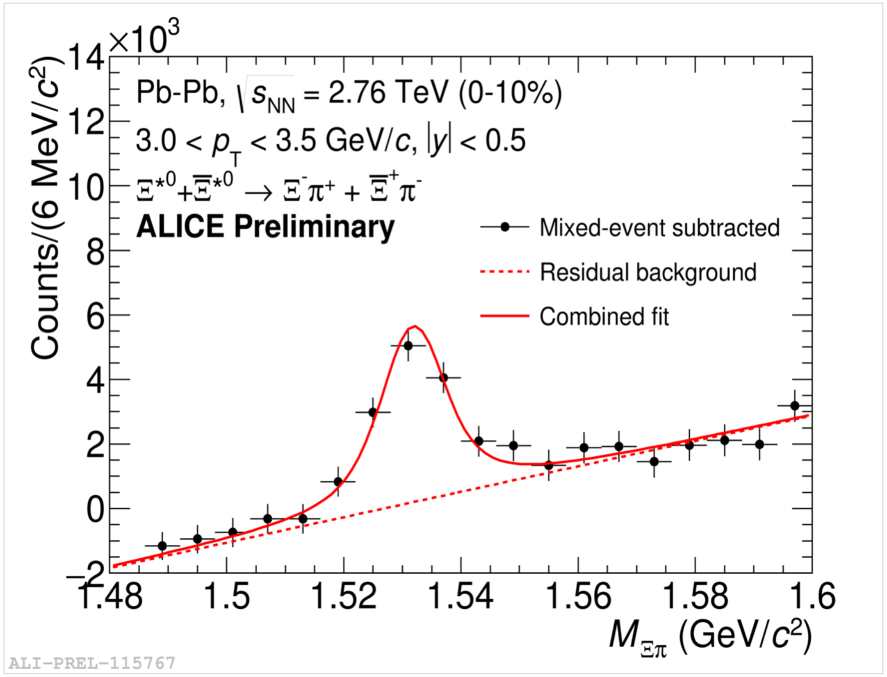


Invariant Mass Spectra (Baryons)

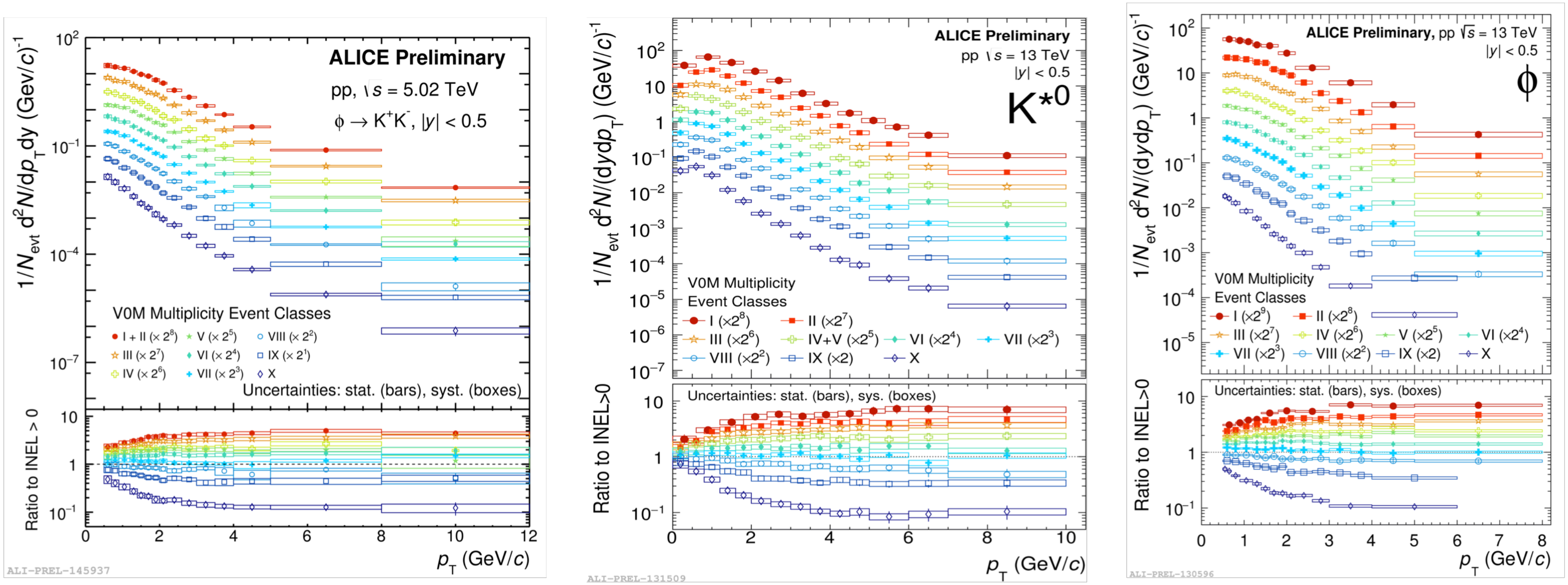








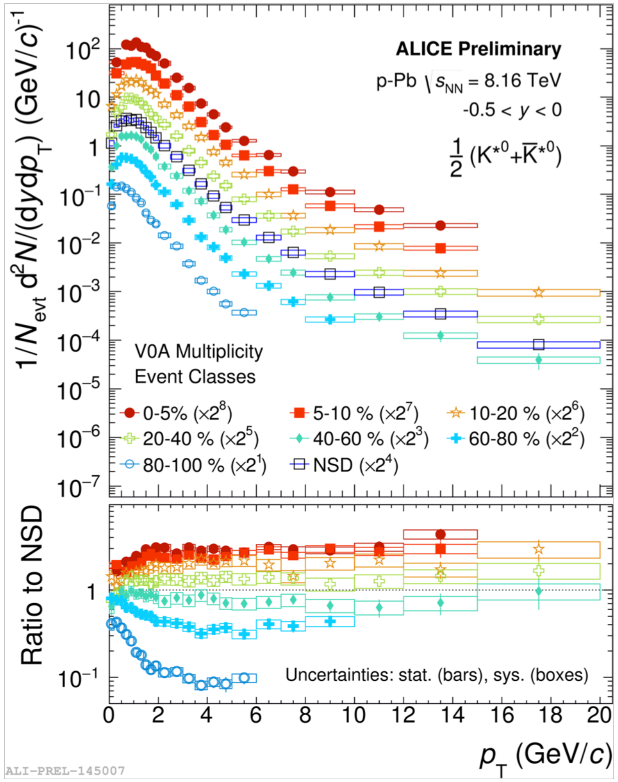
p_T-spectra in pp

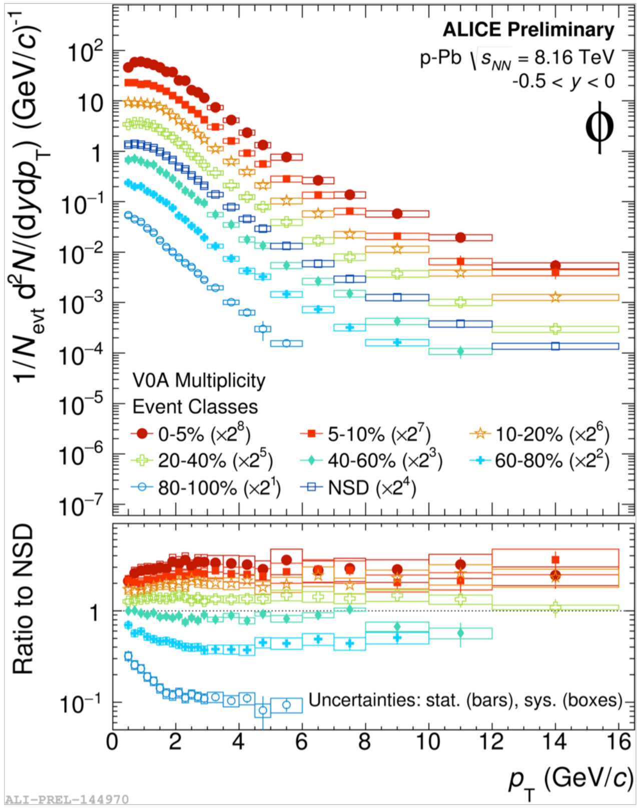


Run-II (new results): pp at 5.02 and 13 TeV

- 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
- Similar behavior observed for other light flavored particles

p_T-spectra in p-Pb

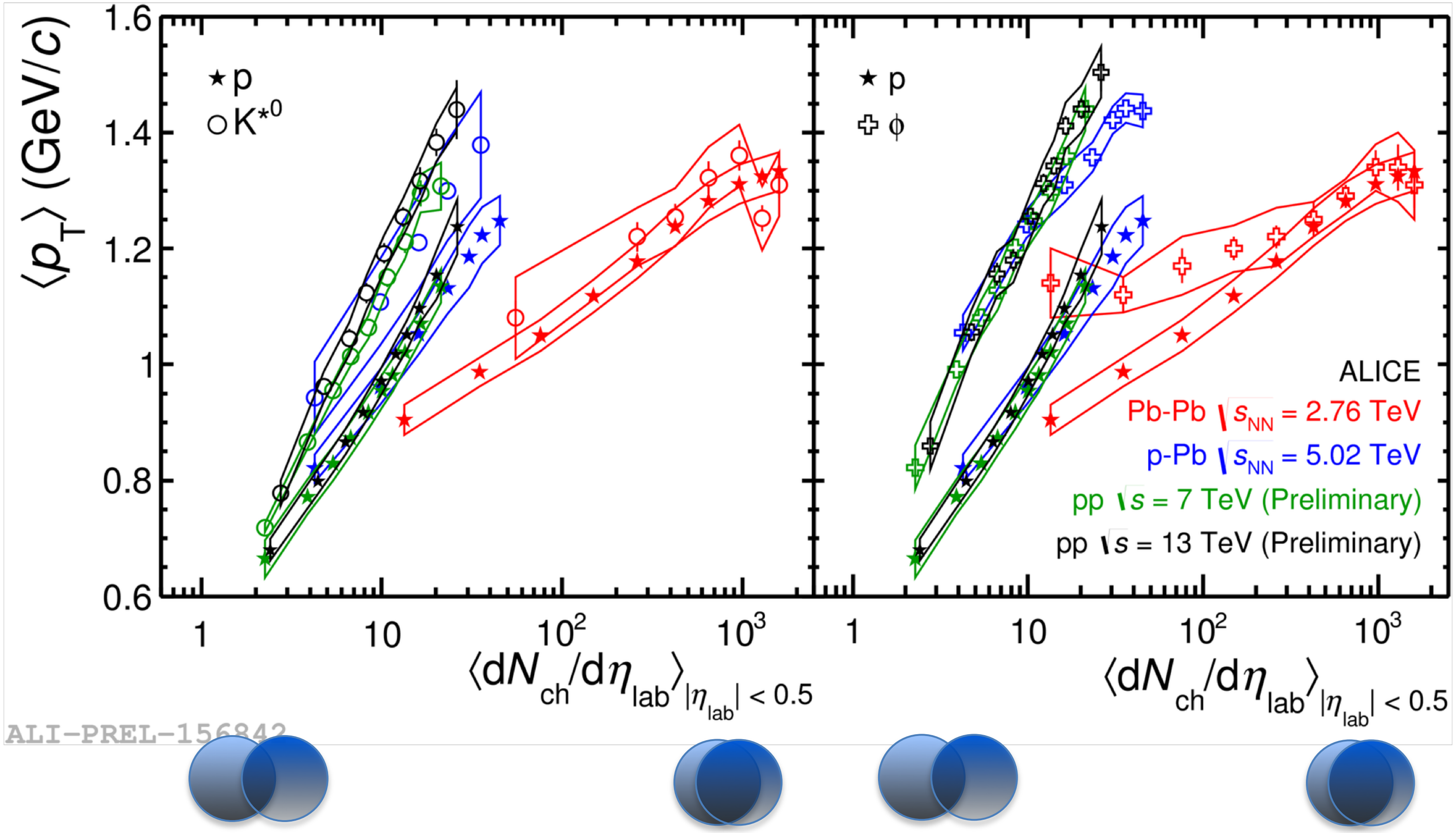




Run-II
(new results):
p-Pb at 8.16 TeV

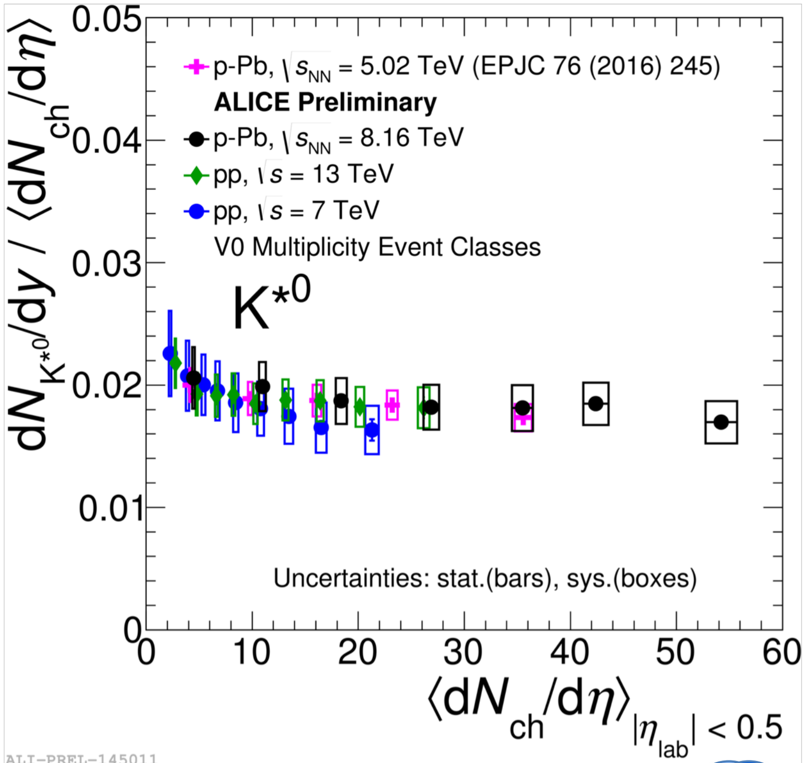
- Evolution of the spectral shape with increasing multiplicity for p_T < 5 GeV/c
- The spectral shape is similar across multiplicity for p_T > 5 GeV/c

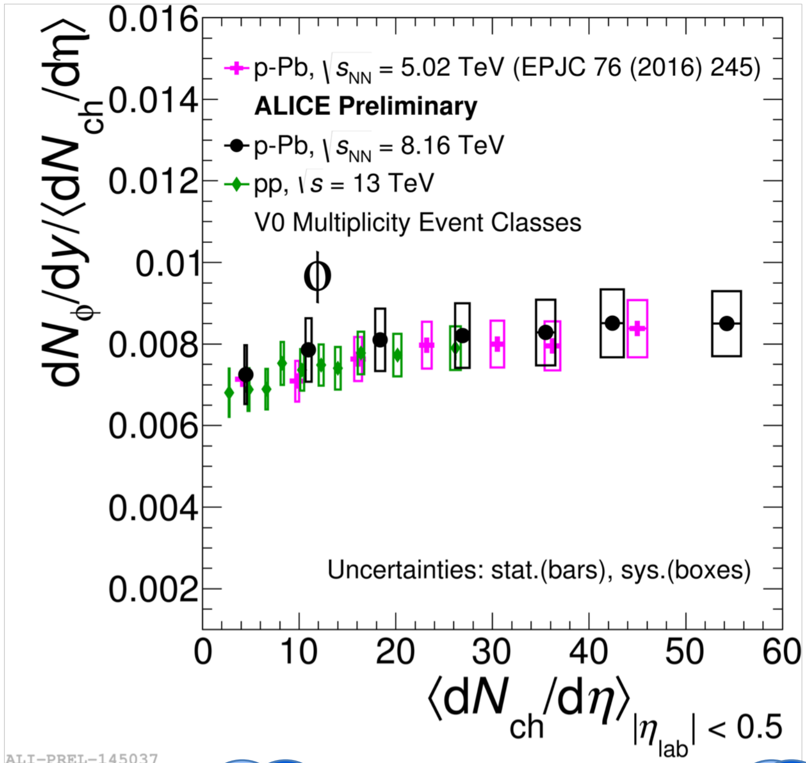
Mean-p_T (Mass Ordering)



- Mass ordering of <p_T> in central Pb-Pb → hydrodynamic behaviour
- Mass ordering breaks down for peripheral A–A, p–Pb and pp
- The increase of <p_T> with multiplicity is similar in pp
- Steeper increase of <p_T> with multiplicity in smaller systems

Particle yields: Multiplicity and √s Dependence

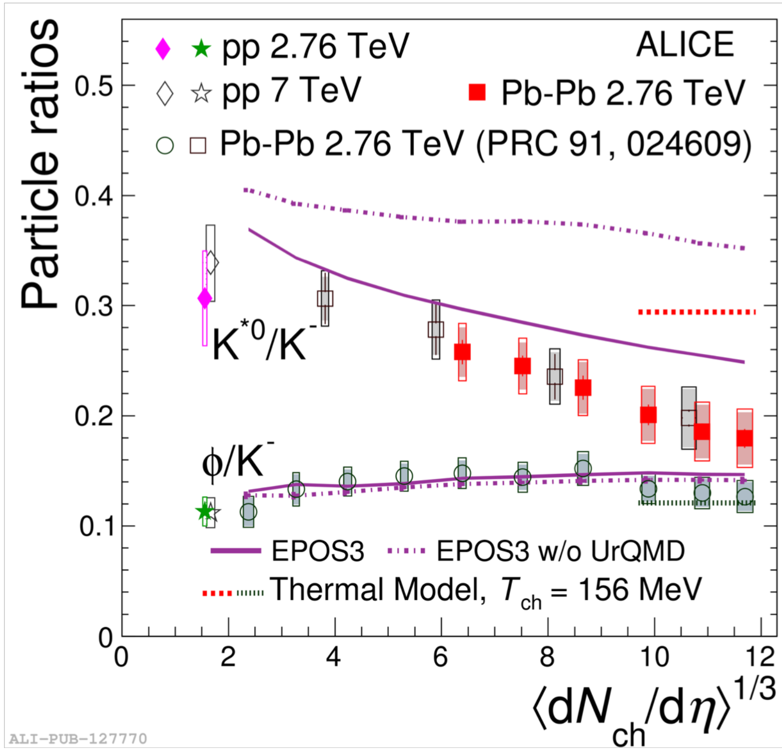


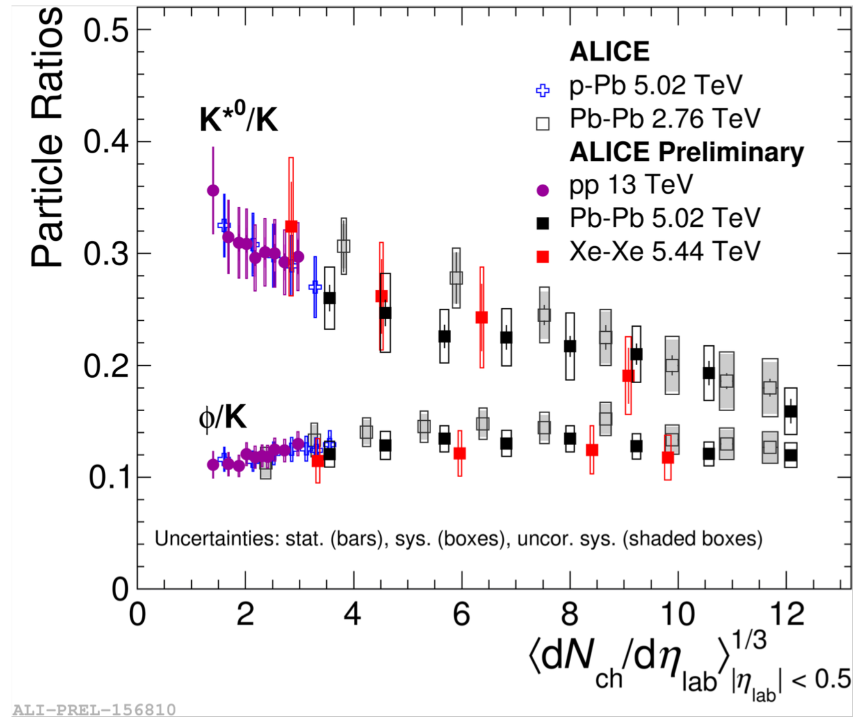


- Yields of K^{*0} and ϕ normalized to $<dN_{ch}/d\eta>$ is independent of collision systems and energy and lie on the same trend as a function of multiplicity

  → ***Event multiplicity drives particle production, irrespective of collision system and energy***

Multiplicity Dependence of Particle Ratios

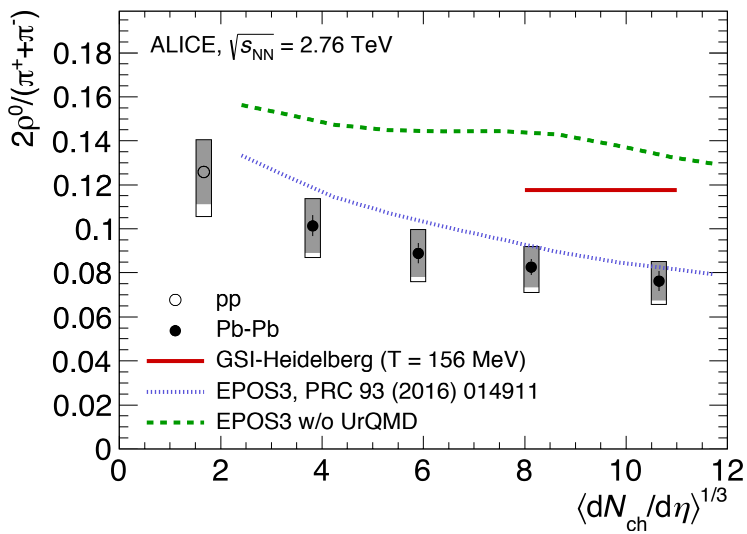




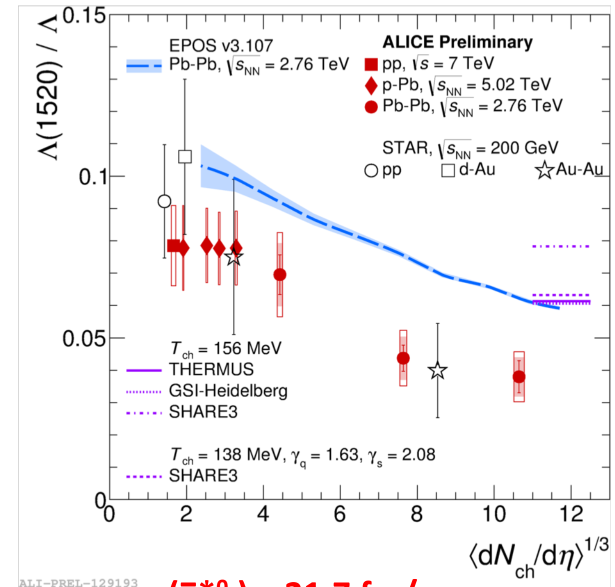
- **Suppression of K^{*0}** w.r.t. pp and thermal model values
  - ✓ Re-scattering of decay products in hadronic medium
  - ✓ Hint of K^{*0} suppression in high-multiplicity pp and p–Pb collisions
- **ϕ/K ratio is flat** as a function of multiplicity and agrees with thermal model prediction
  - ✓ lives longer, decays outside fireball
- Ratios do not depend on energy or collision system (same for p–Pb and Xe–Xe) for a given multiplicity class

Multiplicity Dependence of Particle Ratios

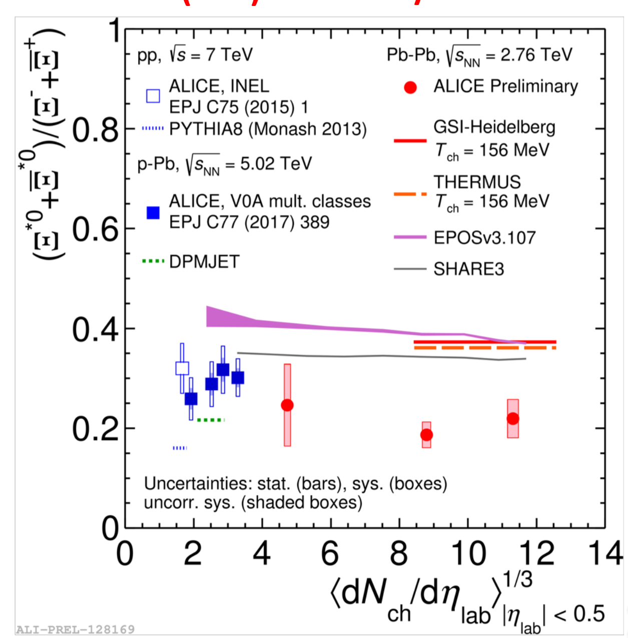
$\tau(\rho^0)$ = 1.3 fm/c



$\tau[\Lambda(1520)]$ = 12.6 fm/c



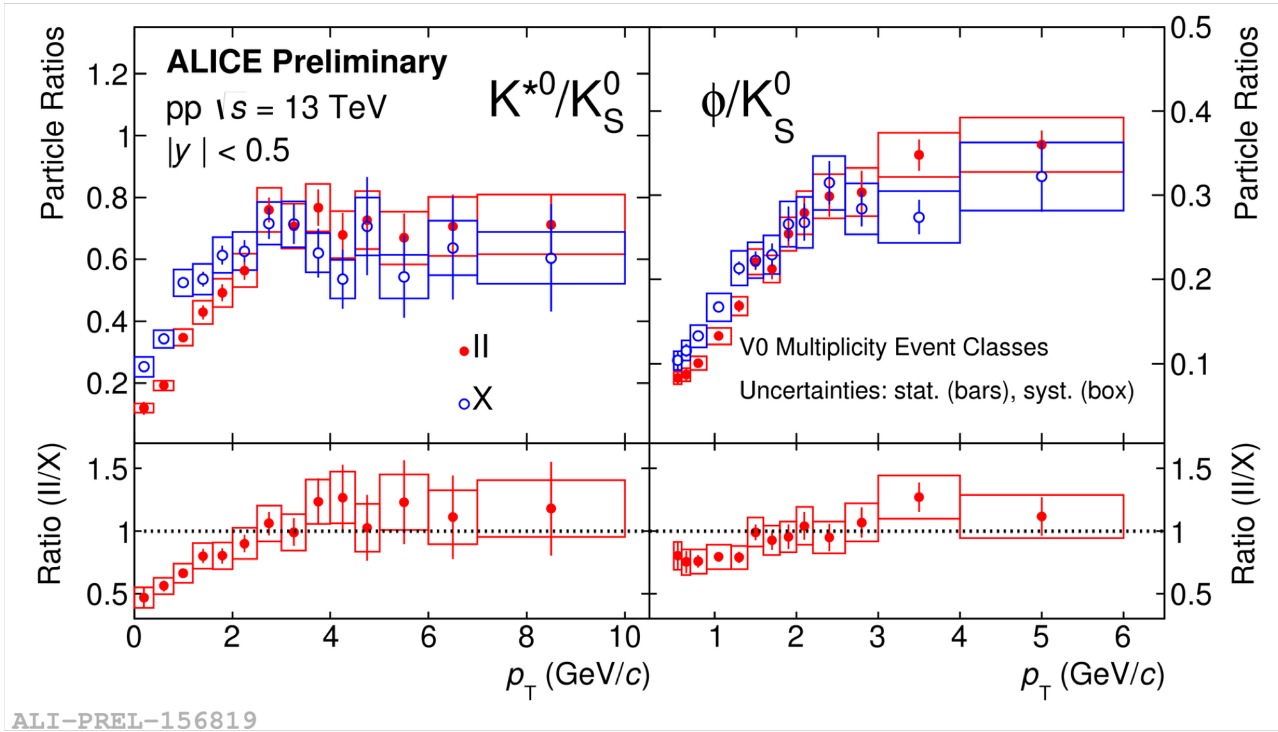
$\tau(\Xi^{*0})$ = 21.7 fm/c



- ρ^0 and Λ :
  - ✓ Flat in pp and p-Pb
  - ✓ Compatible with model prediction
  - ✓ **Suppression** in high multiplicity Pb-Pb collisions

- Ratios do not depend on energy (RHIC-->LHC)
- Possible weak suppression of Ξ^{*0} w.r.t. pp collisions
- Suppression trends qualitatively described by EPOS
  - ✓ Includes scattering effects modeled with UrQMD

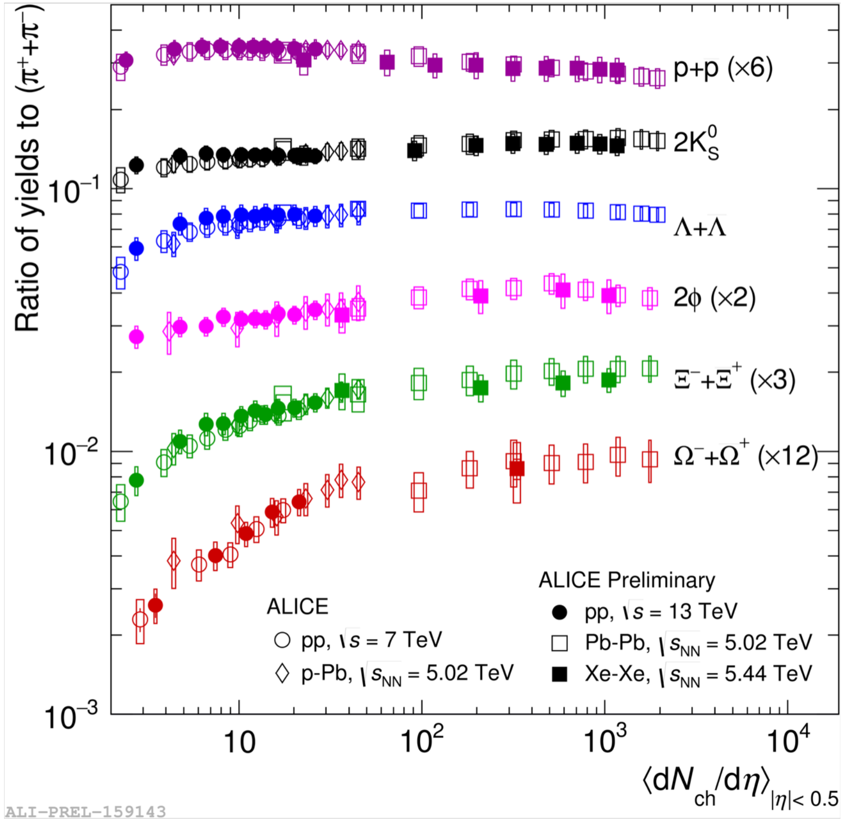
p_T-dependent Particle Yield Ratios in pp



New results pp at 13 TeV Run-II

- Both ratios increase at low p_T and saturate for p_T > 2 GeV/c
- Double ratios are consistent with unit for p_T> 2 GeV/c
- **K^{*0}/K_S^0 is more suppressed** compared to ϕ/K_S^0 for p_T < 2 GeV/c

Strangeness Production Relative to Pions



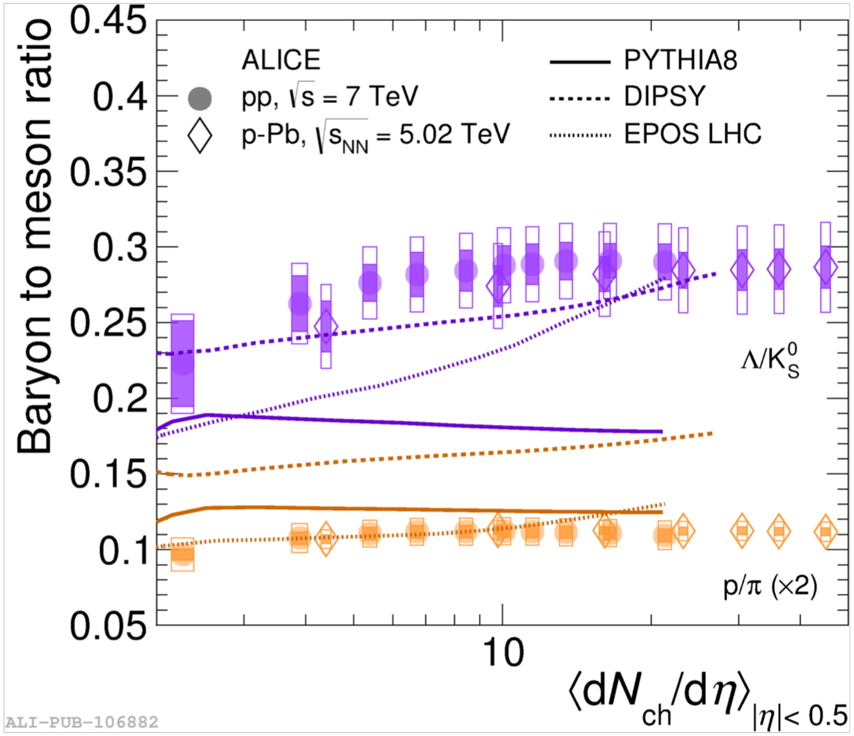
- pp 13 TeV results are in agreement with lower energy measurements
- Smooth evolution between pp, p-Pb and Pb-Pb
- Strangeness production is independent of the collision system and energy at similar multiplicity
- Ratios increase from low to high multiplicity in small systems and reach values similar to those observed in Pb-Pb collisions

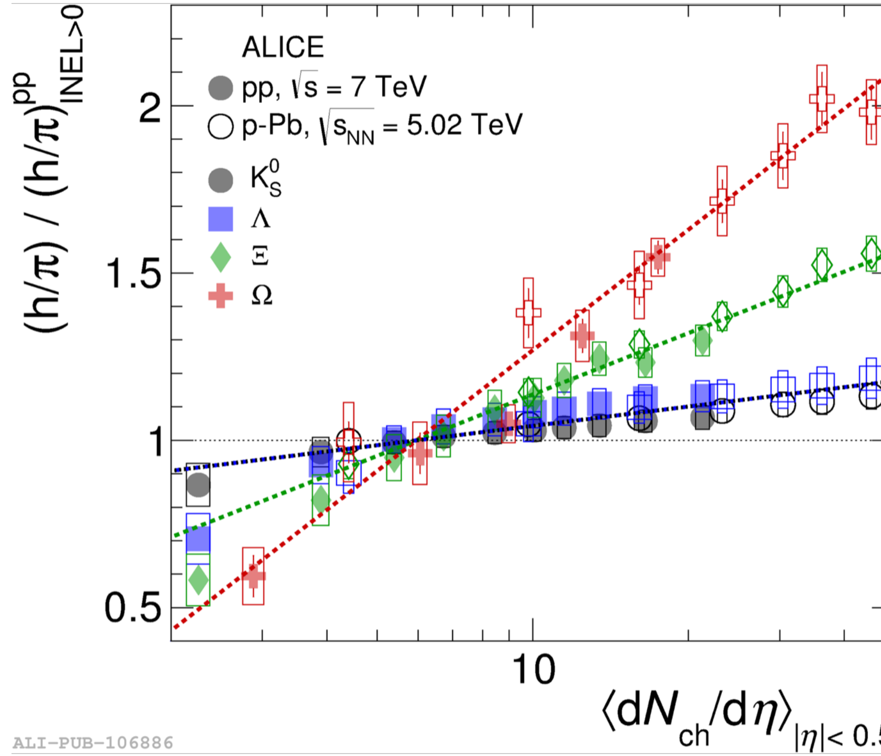
New results: pp at 13 TeV and Xe-Xe at 5.44 TeV

What is driving the strangeness enhancement in small systems?

1. **Mass ?**
2. **Baryon/meson effect ?**
3. **Strangeness content ?**

Strangeness enhancement: Baryon to Meson ratios





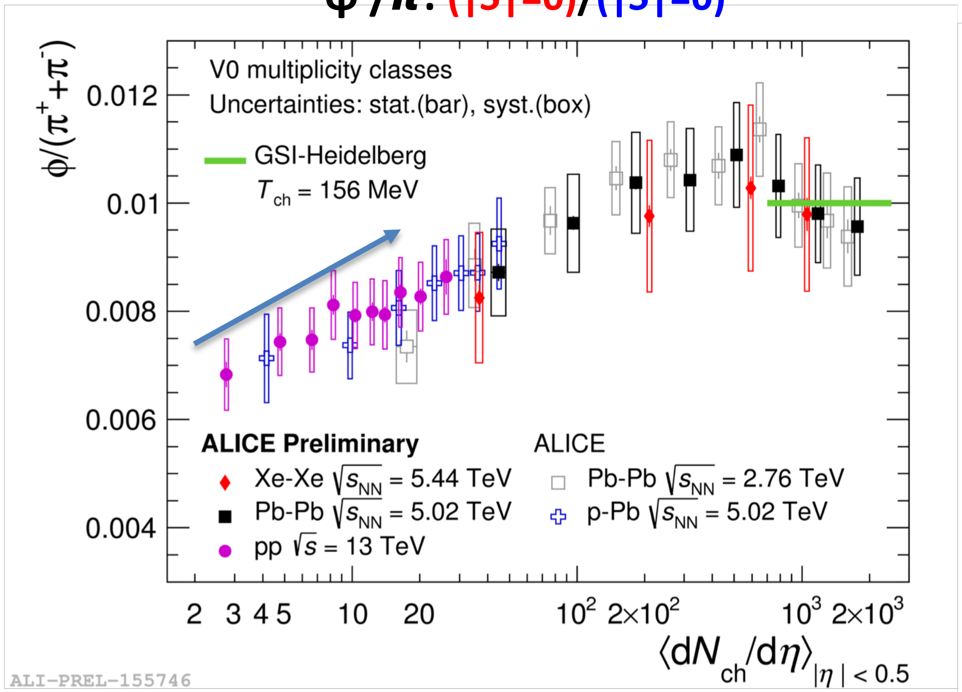
- Baryon-to-meson yield ratios for particle with large mass difference do not show enhancement as a function of charged particle multiplicity

- **Enhancement is due to strangeness content**

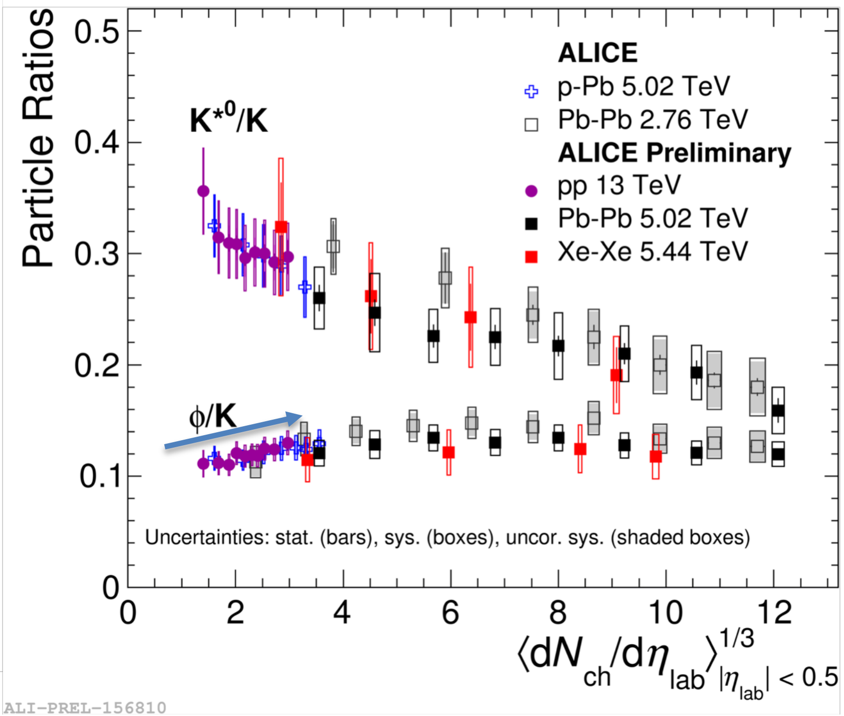
What about ϕ(ssbar)?

Effective Strangeness of ϕ -meson

ϕ /π: (|S|=0)/(|S|=0)



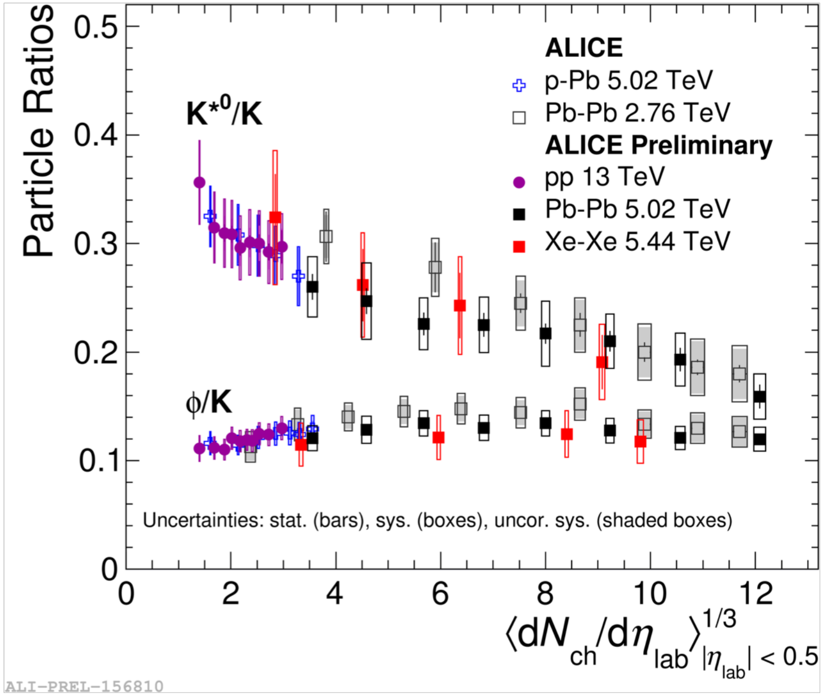
ϕ /K: (|S|=0)/(|S|=1)



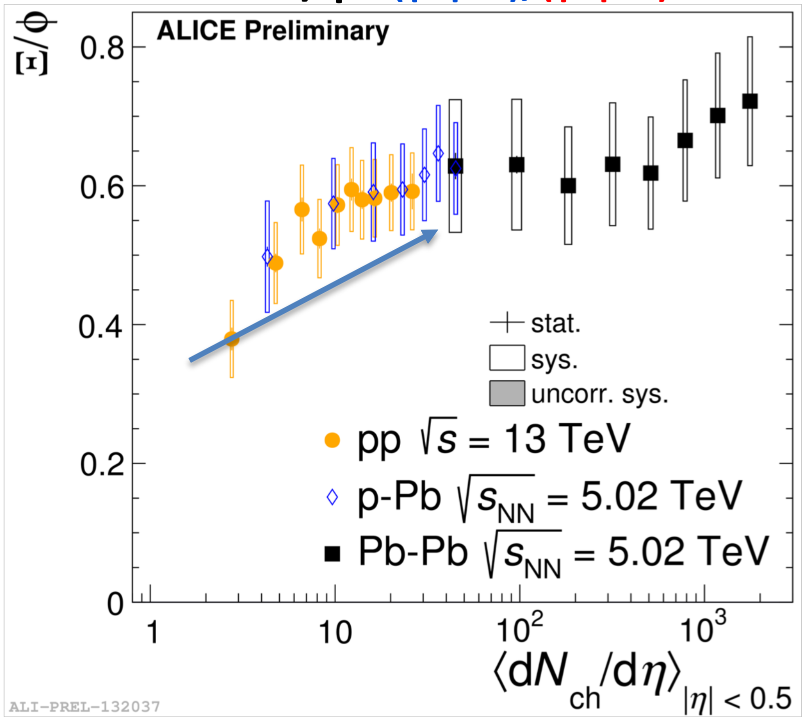
- ϕ(S=0) yield in agreement with thermal model expectation in central Pb-Pb collisions
- But increases for smaller systems as a function of multiplicity in contrast to the expectation from strangeness canonical suppression
- Flat or slightly increasing ϕ(S=0)/K(S=1) in pp → **S > 1**

Effective Strangeness of ϕ -meson

ϕ /K: (|S|=0)/(|S|=1)



Ξ /ϕ : (|S|=2)/(|S|=0)



- Flat Ξ^{*0}(S=2)/ϕ(S=0) for wide range of multiplicities → **S ~ 2**
- Slightly increasing in pp and p-Pb vs multiplicity → **S < 2**

✓ ***The ϕ-meson has effective strangeness of 1-2 units***

Summary

- **Particle spectra**
  - Evolution of the spectral shape with increasing multiplicity is similar to Pb-Pb
  - At low p_T , transverse momentum spectra harden with increasing multiplicity
- **Resonance to long-lived particle ratio in small collision systems**
  - Hint of multiplicity-dependent suppression of **K^{*0}** → **re-scattering?**
  - **ϕ, Λ* and Ξ^{*0}** constant vs multiplicity → **No re-scattering or regeneration**
- **Suppression of ρ^0 , K^{*0} and Λ resonances in central A–A**
  - Possible weak suppression of **Ξ^{*0}**
- **Enhancement of strange hadron production from low to high multiplicity pp and p-Pb**
  - Enhancement is due to **strangeness content – not due to mass or baryon-meson effect**
  - **The ϕ-meson** yields evolve similar to particles with open strangeness, even in small systems →**Effective strangeness of ϕ and production in small systems is still a puzzle** ?

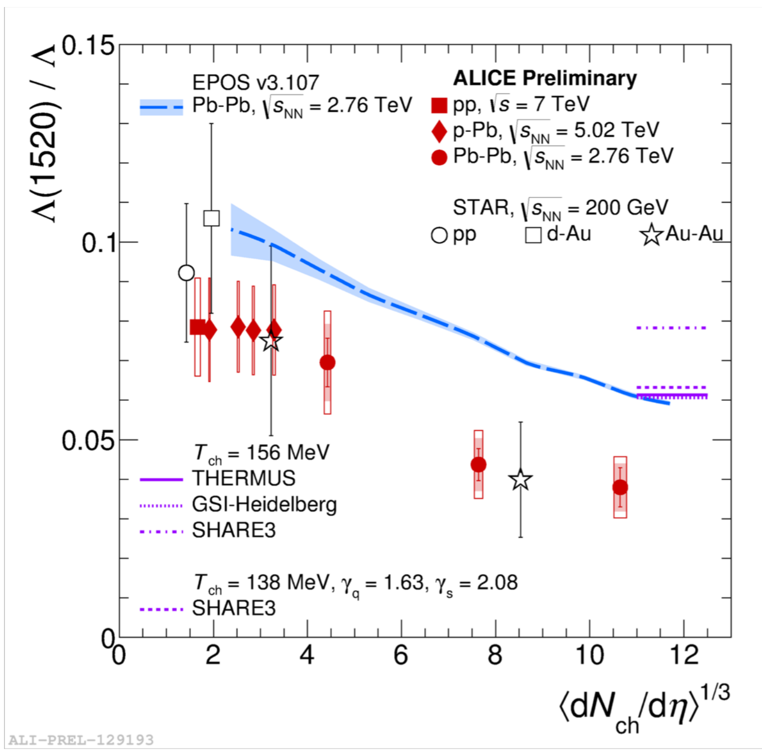
Thank you for your attention!

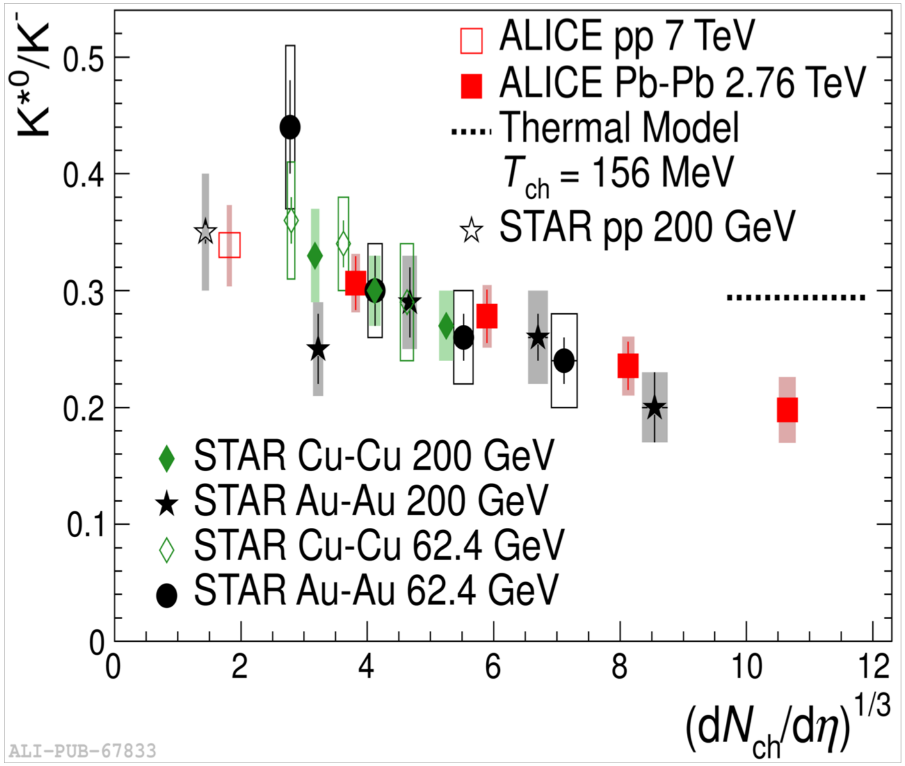
Supporting material

Comparison to RHIC Energies

- No significant evolution of particle ratios of K^{*0} or $\Lambda(1520)$ from RHIC to LHC [1]

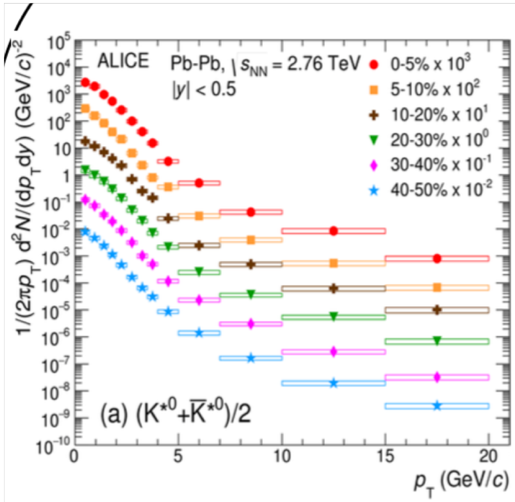
- For a given system size, observations are very similar at RHIC and at LHC

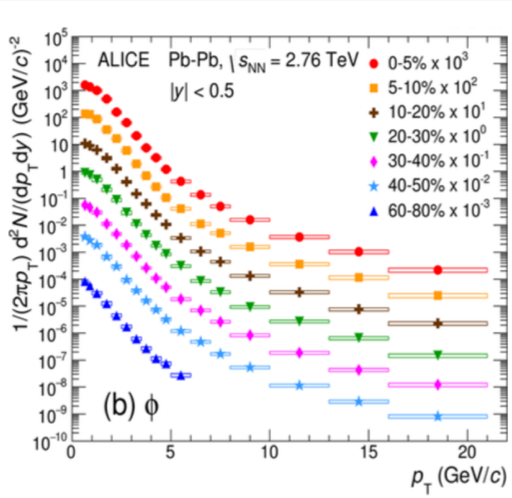


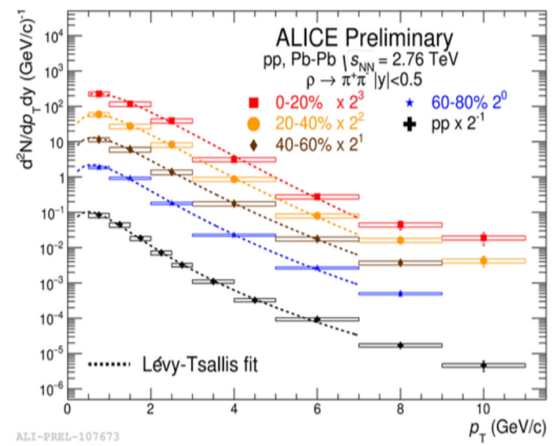


[1] Phys. Rev. C 91, 024609 (2015)

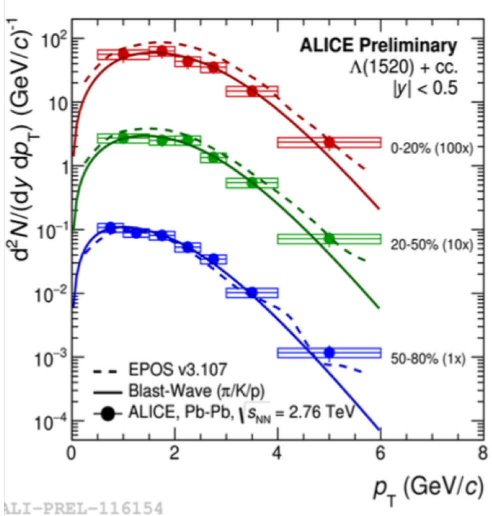
p_T Spectra

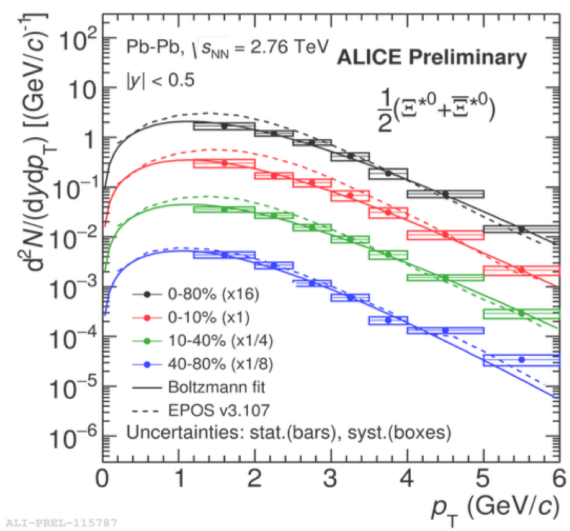






[arXiv:1702.00555](https://arxiv.org/abs/1702.00555)





Signal: Unlike-sign pairs from the same event

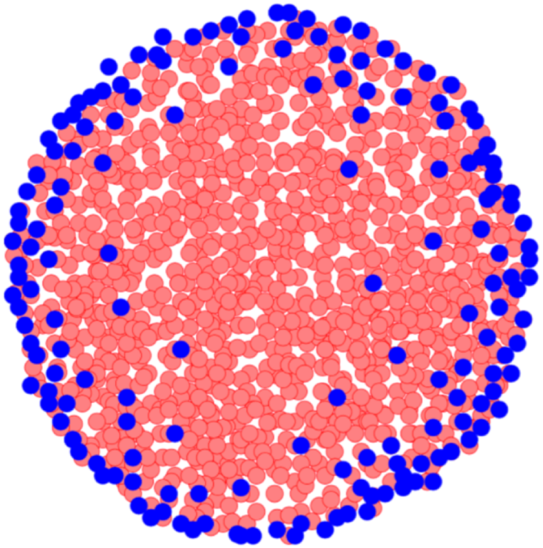
Background: Like-sign pairs from the same event and unlike-sign pairs from the mixed events

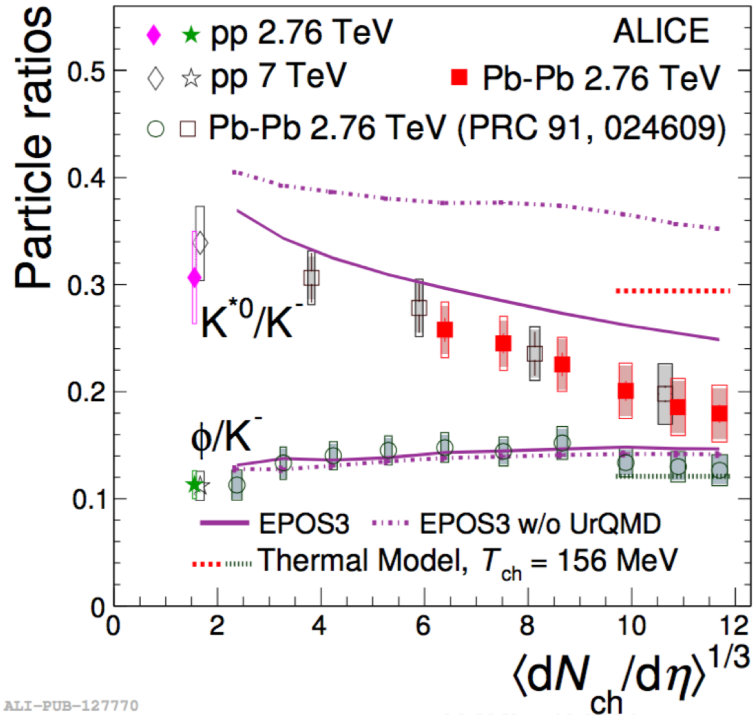
Peak Fit Function:

1. Breit-Wigner (BW)
2. Voigtian Function (Convolution of BW and Gaussian)

EPOS

- EPOS: describes pp, p–A, and A–A collisions with common framework
  - Collision divided into a core (QGP) and a corona of jets
  - Core evolves hydrodynamically
  - Hadronic phase with re-scattering and regeneration (UrQMD)
  - Possible to turn off UrQMD to test importance of scattering processes





EPOS: *Phys. Rev. C* **93** 014911 (2016)
UrQMD: *Prog. Part. Nucl. Phys.* **41** 255 (1998)
J. Phys. G **25** 1859 (1999)