Hadronic Resonances Production with ALICE at the LHC

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The 18th International Conference on
Strangeness in Quark Matter (SQM 2019)
10-15 June 2019, Bari (Italy)

Outline

- Physics Motivation
- The ALICE detector
- p_{T} spectra in pp, p-Pb, Xe-Xe and Pb-Pb collisions
- Integrated yield and mean-p_{T}
- Particle ratios
- Nuclear Modification Factors
- Summary

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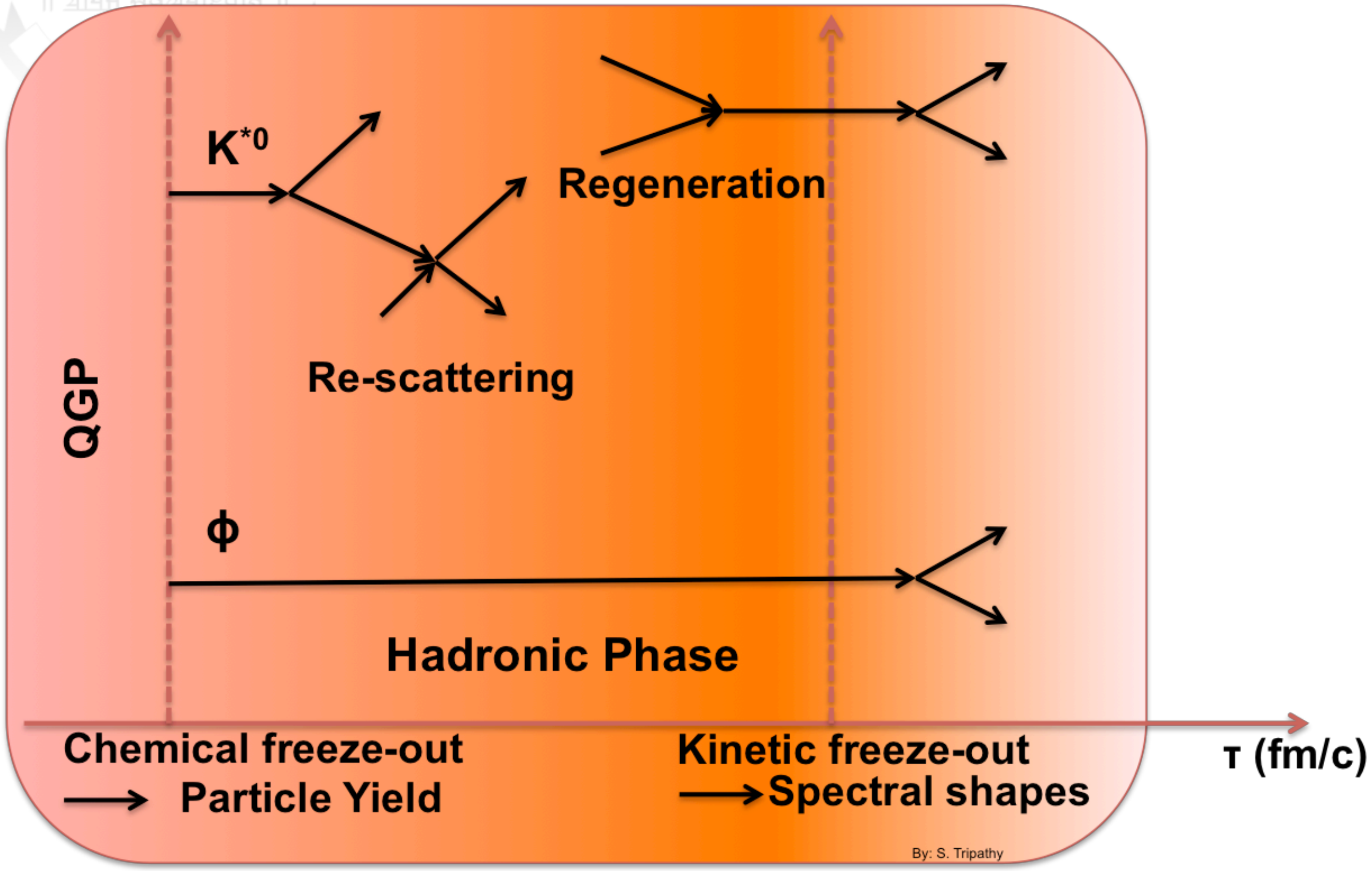
Why Resonances?

Short Lifetimes → Probing the hadronic phase

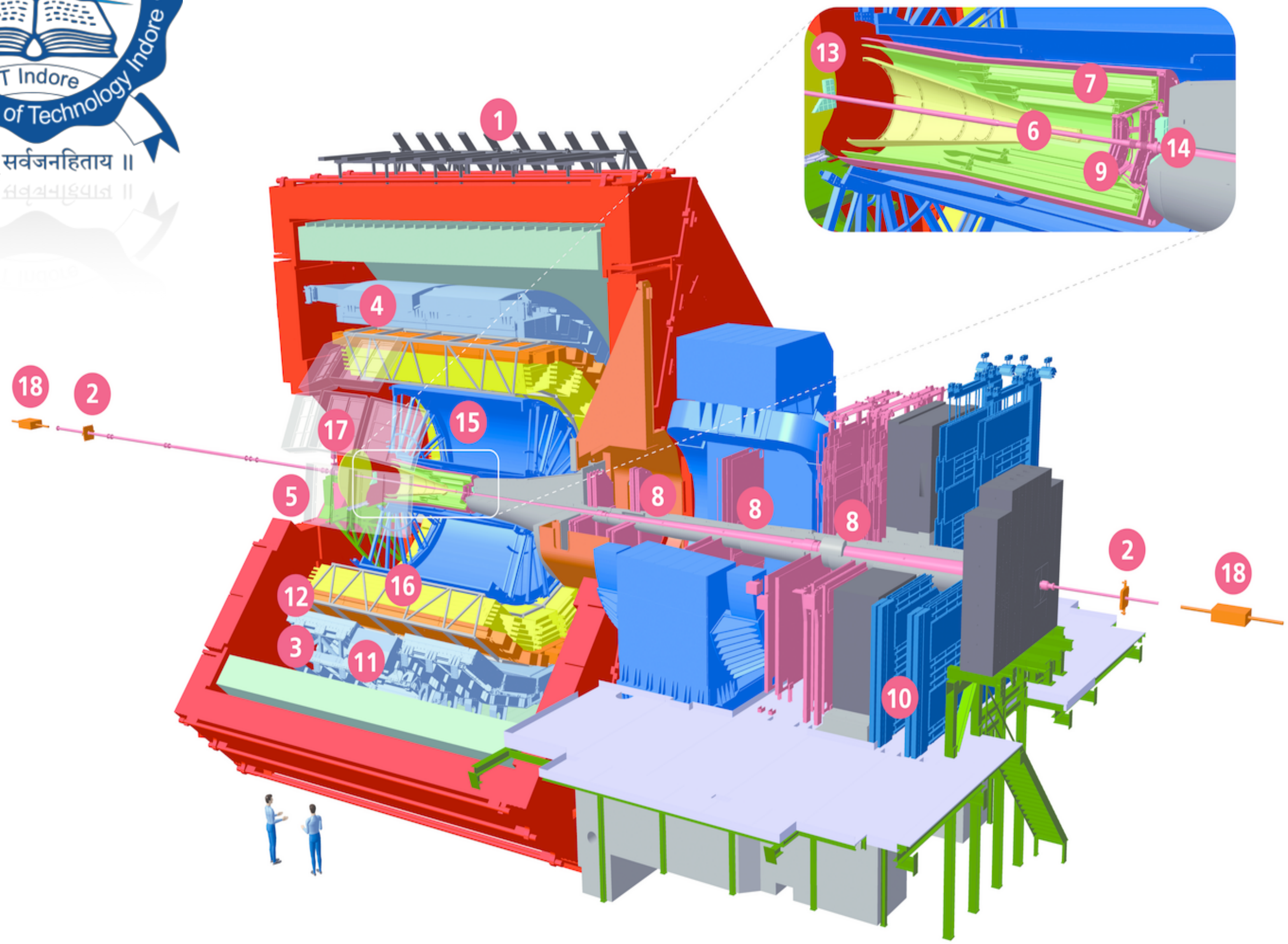


Resonance	τ (fm/c)	Decay	BR
$\rho(770)^0$	1.3	ππ	100
$K^*(892)^{0,\pm}$	4.2	Kπ	66.6
Σ(1385)	5.5	πΛ	87
Λ(1520)	12.6	pK	22.5
$\Xi^{*0}(1530)$	21.7	Ξπ	66.7
ϕ(1020)	46.4	KK	49.2

- **Regeneration:** Pseudo-elastic scattering through resonance state :- Enhancement of resonance yields
- **Re-scattering:** Decay products undergo elastic scattering or pseudo-elastic scattering through a different resonance :- Suppression of resonance yields

Is there any hadronic phase in high multiplicity pp and p-Pb collisions?

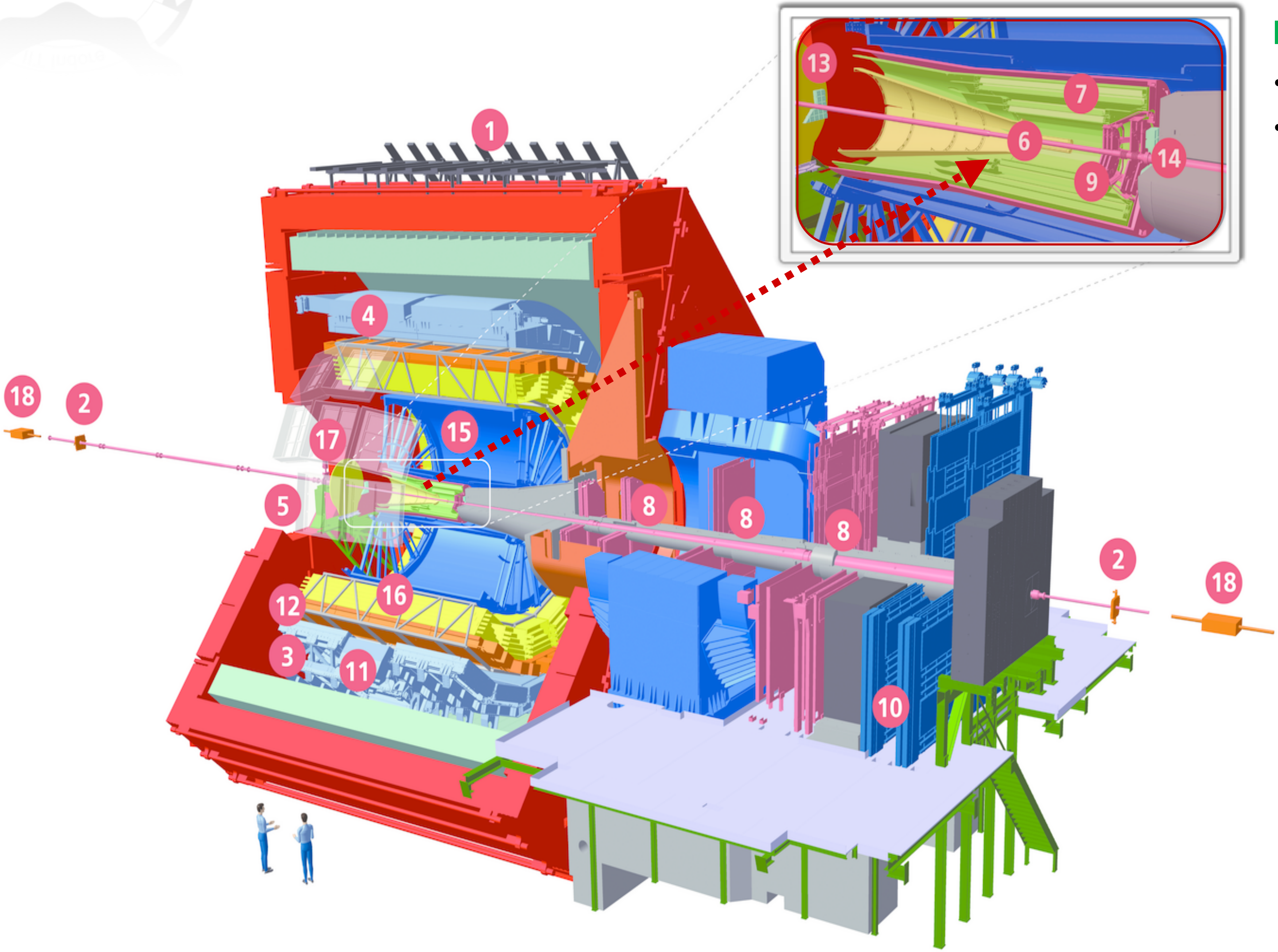
The ALICE Detector



1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter

Collision System	Pb-Pb	Xe-Xe	p-Pb	pp
Year(s)	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

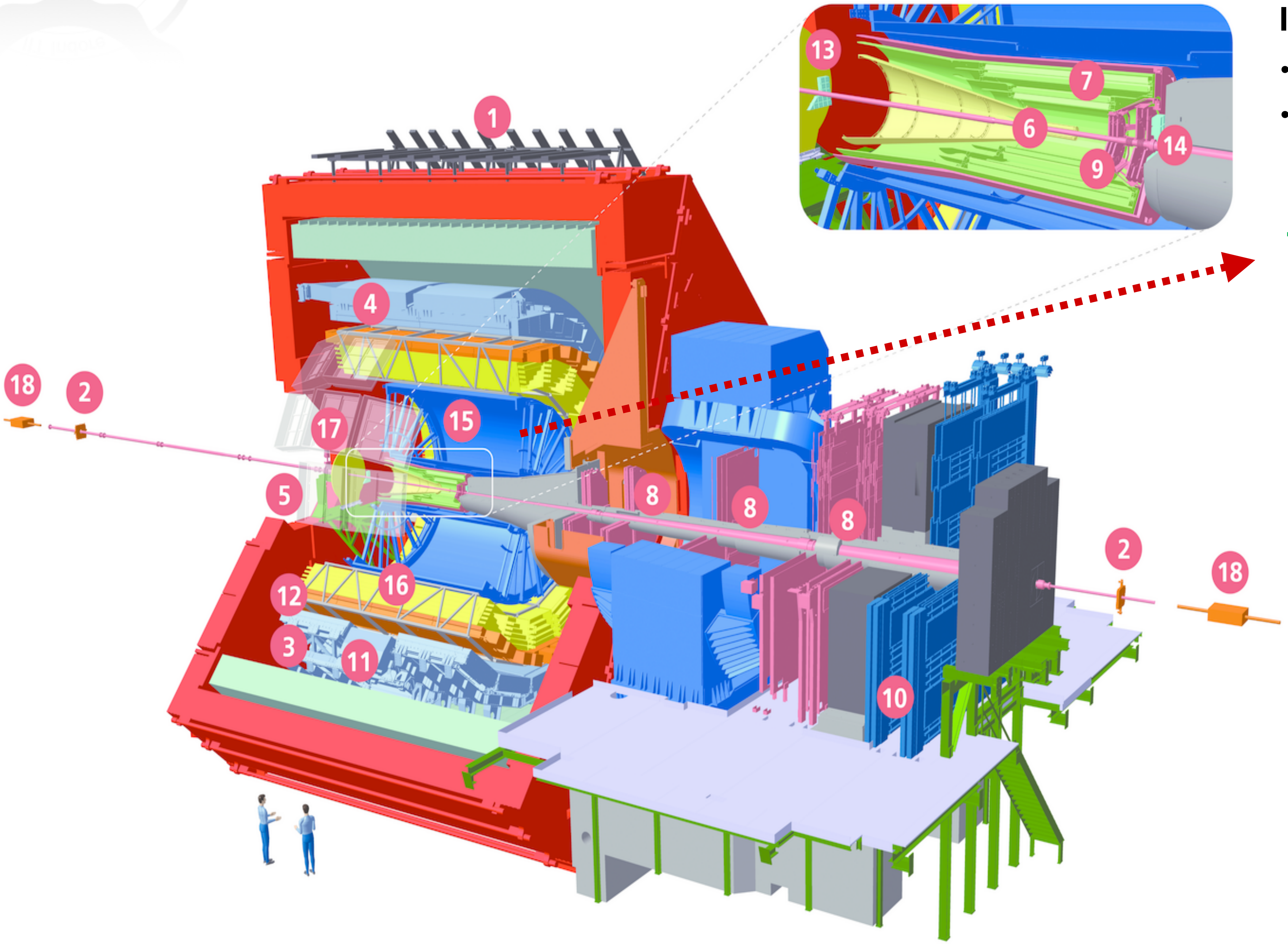
The ALICE Detector



ITS (Inner tracking System)

- 6 layers of silicon detectors
- Trigger, tracking, vertex, PID (dE/dx)

The ALICE Detector



ITS (Inner tracking System)

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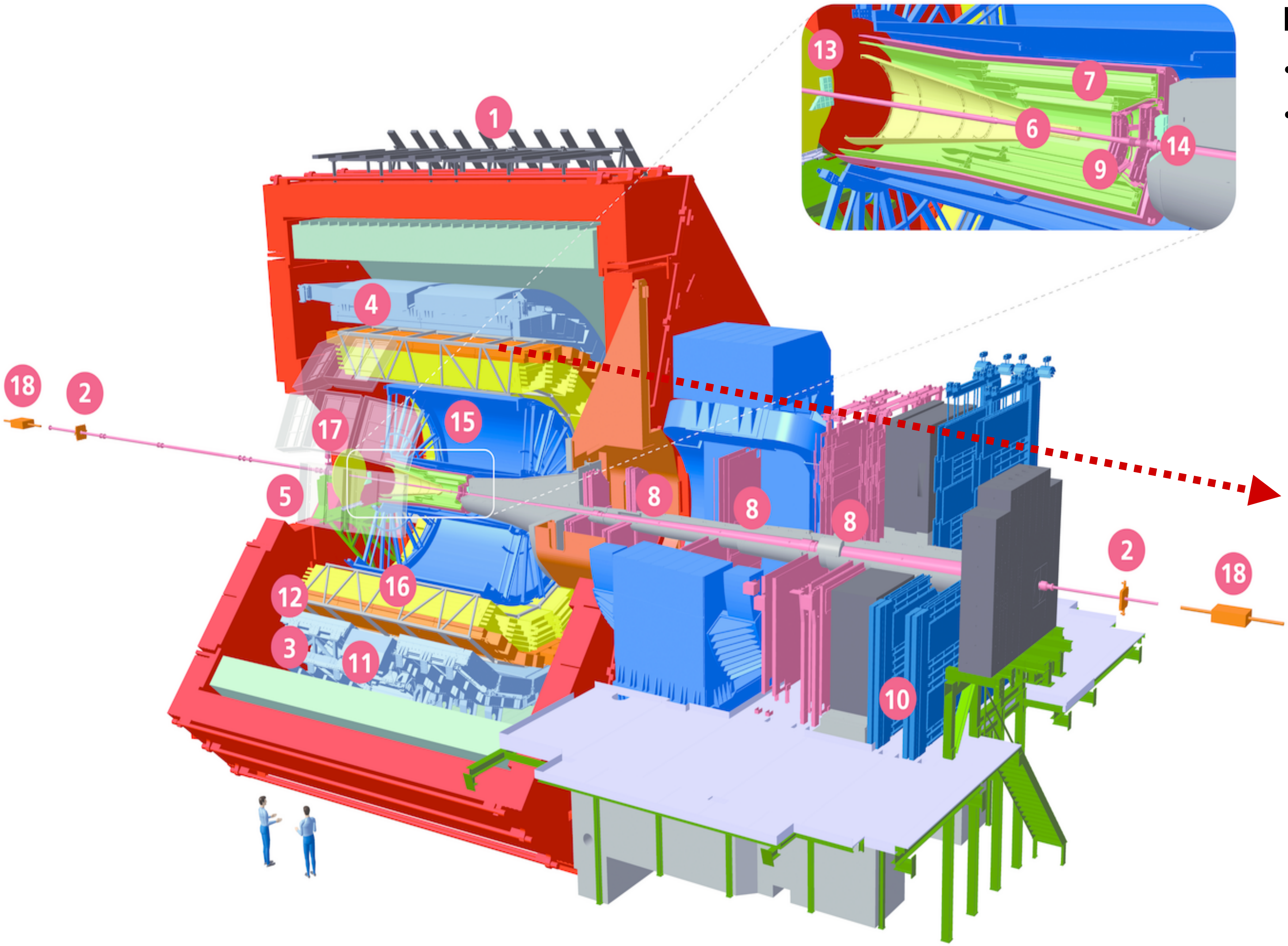
TPC (Time Projection Chamber)

- Gas-filled ionisation detector
- Tracking and PID

The ALICE Detector



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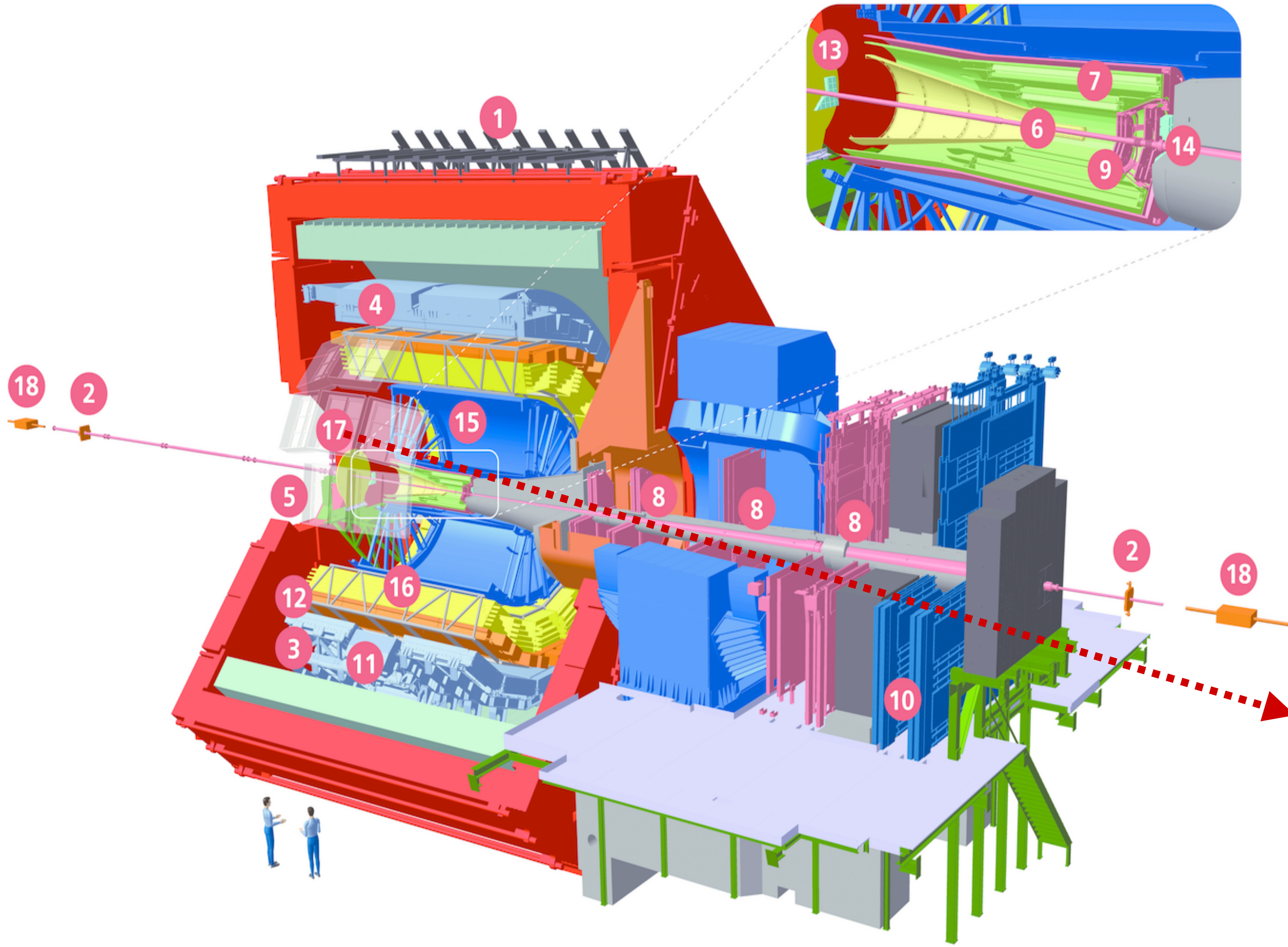
TOF (Time Of Flight)

- PID through particle time of flight

The ALICE Detector



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- 6 layers of silicon detectors
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TPC (Time Projection Chamber)

- Gas-filled ionisation detector
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TOF (Time Of Flight)

- PID through particle time of flight

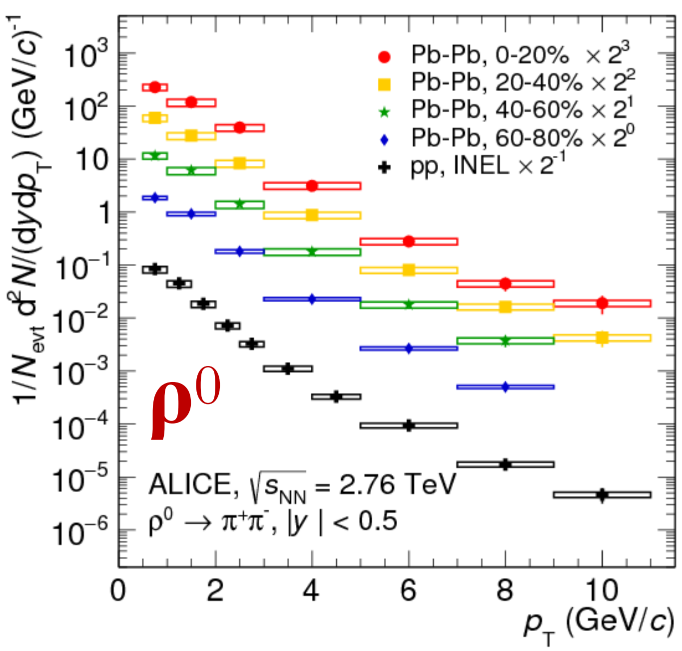
V0

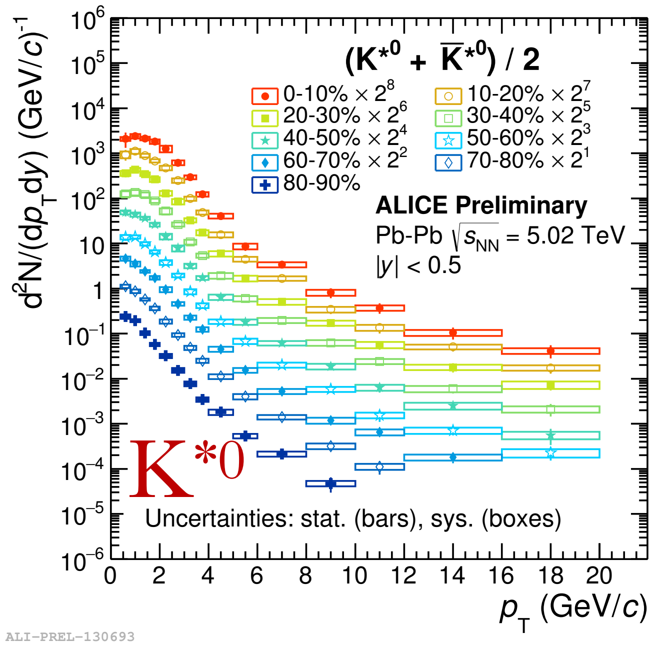
- Trigger
- Centrality/Multiplicity estimator

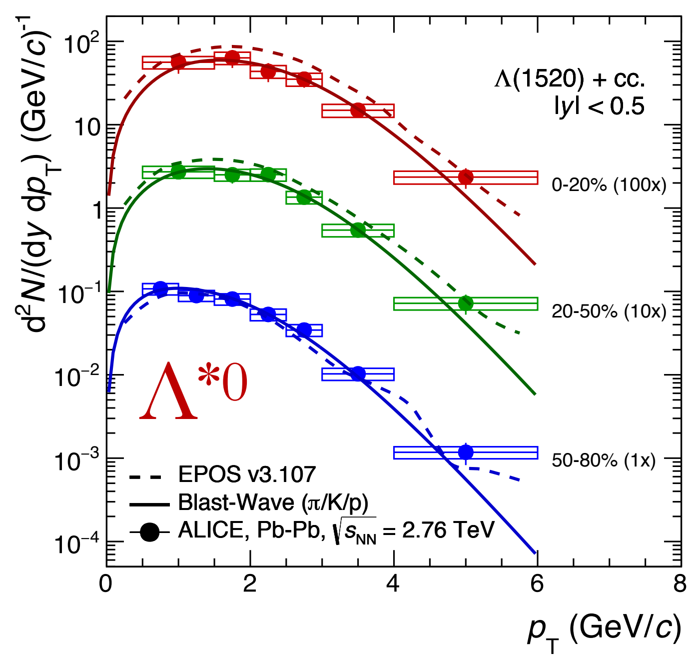
p_T spectra in Pb-Pb and Xe-Xe collisions

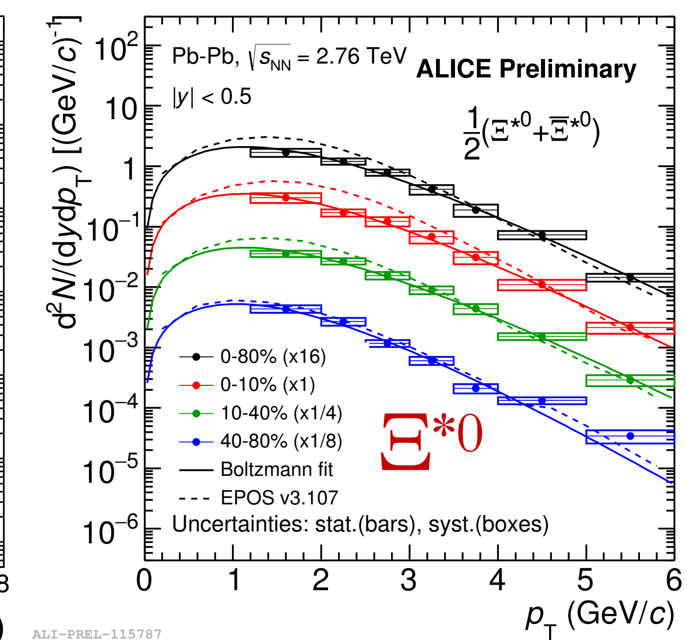
Resonances(Lifetime in fm/c):

ρ(1.3) < K^{*0}(4.2) < Σ^*(5.5) < Λ^*(12.6) < Ξ^{*0}(21.7) < ϕ(46.4)



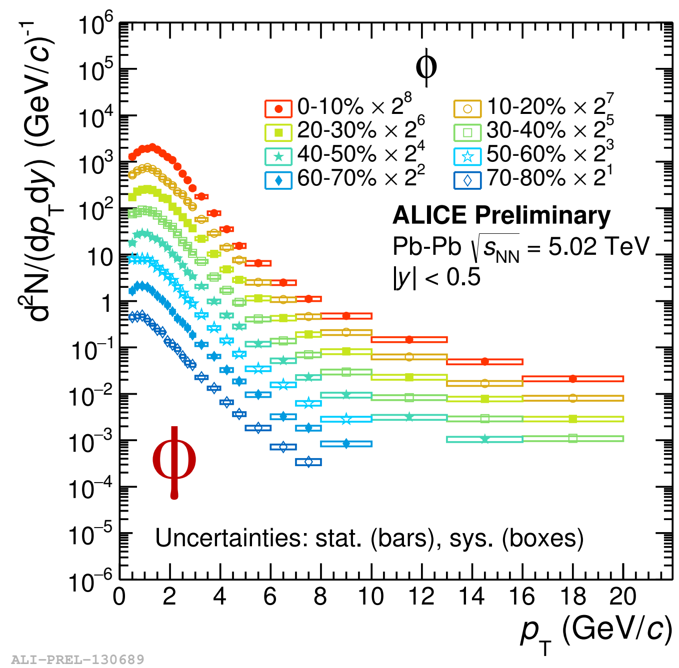


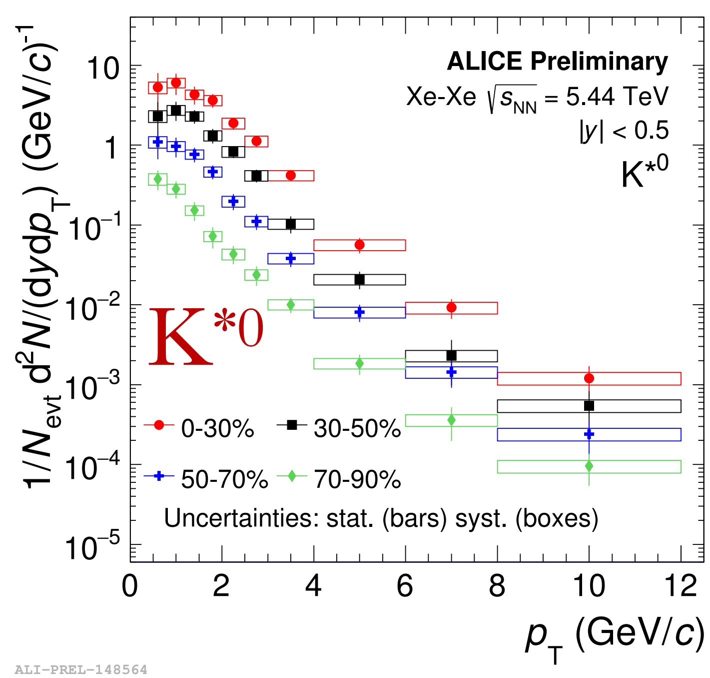


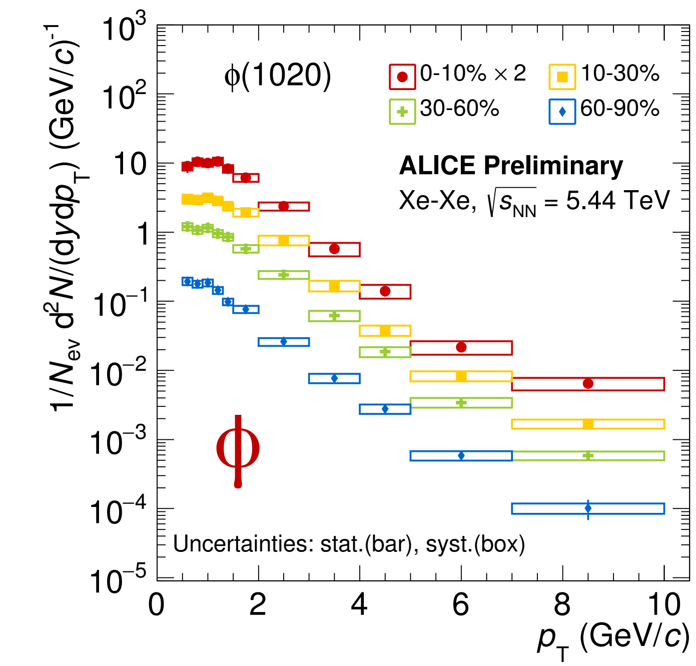


Phys. Rev. C 99, 064901 (2019)

Phys. Rev. C 99, 024905 (2019)







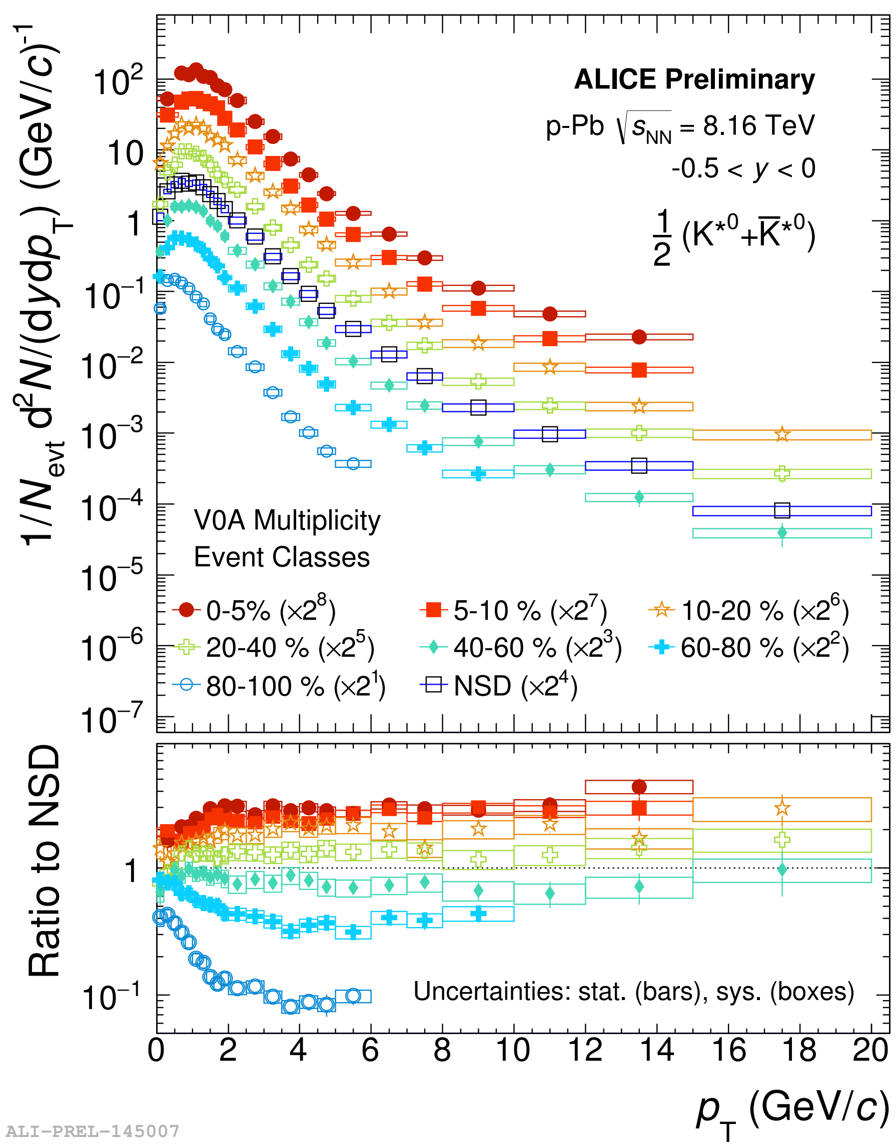
A wealth of measurements of resonances at the LHC are available to probe the hadronic phase

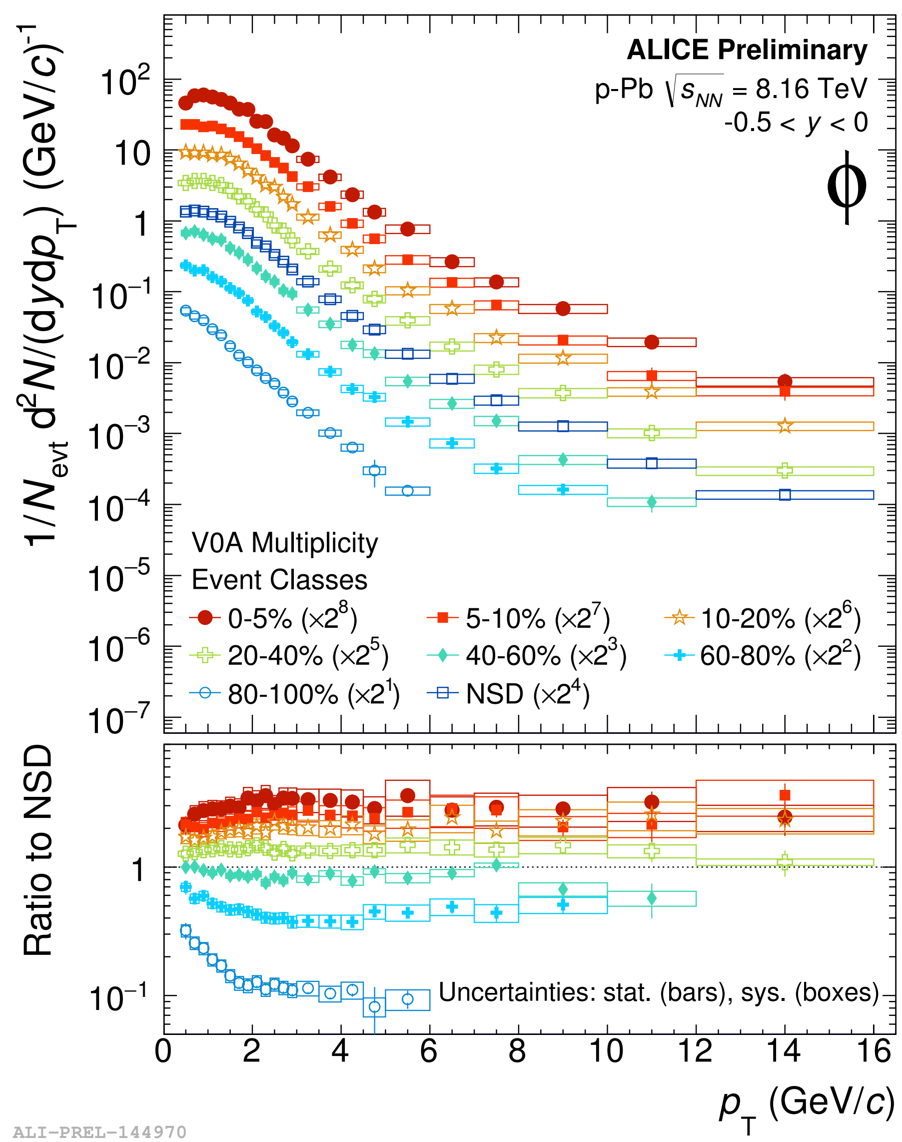
p_T spectra in p-Pb collisions

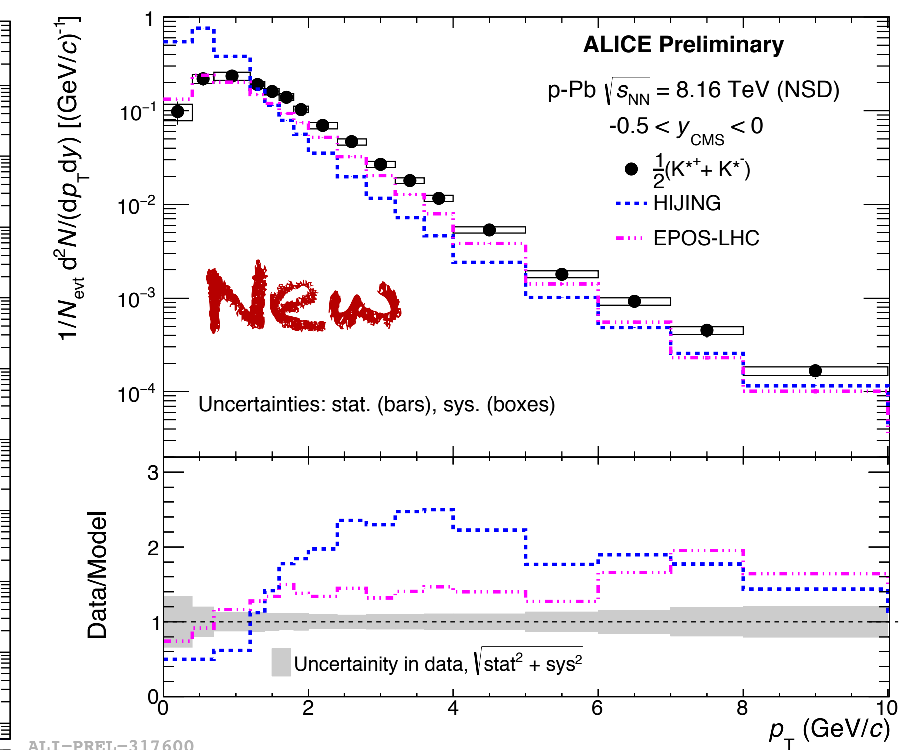
Resonances(Lifetime in fm/c):

$\rho(1.3) < K^{*0,\pm}(4.2) < \Sigma^{*}(5.5) < \Lambda^{*}(12.6) < \Xi^{*0}(21.7) < \phi(46.4)$

Poster by D. Mallick







- EPOS-LHC and HIJING underestimate the $K^{*\pm}$ production in p-Pb collisions at 8.16 TeV.

- Evolution of the spectral shapes with increasing multiplicity for $p_T < 5$ GeV/c.
- The spectral shapes remain similar across multiplicity for $p_T > 5$ GeV/c.

A wealth of measurements of resonances at the LHC are available

p_T spectra in pp collisions

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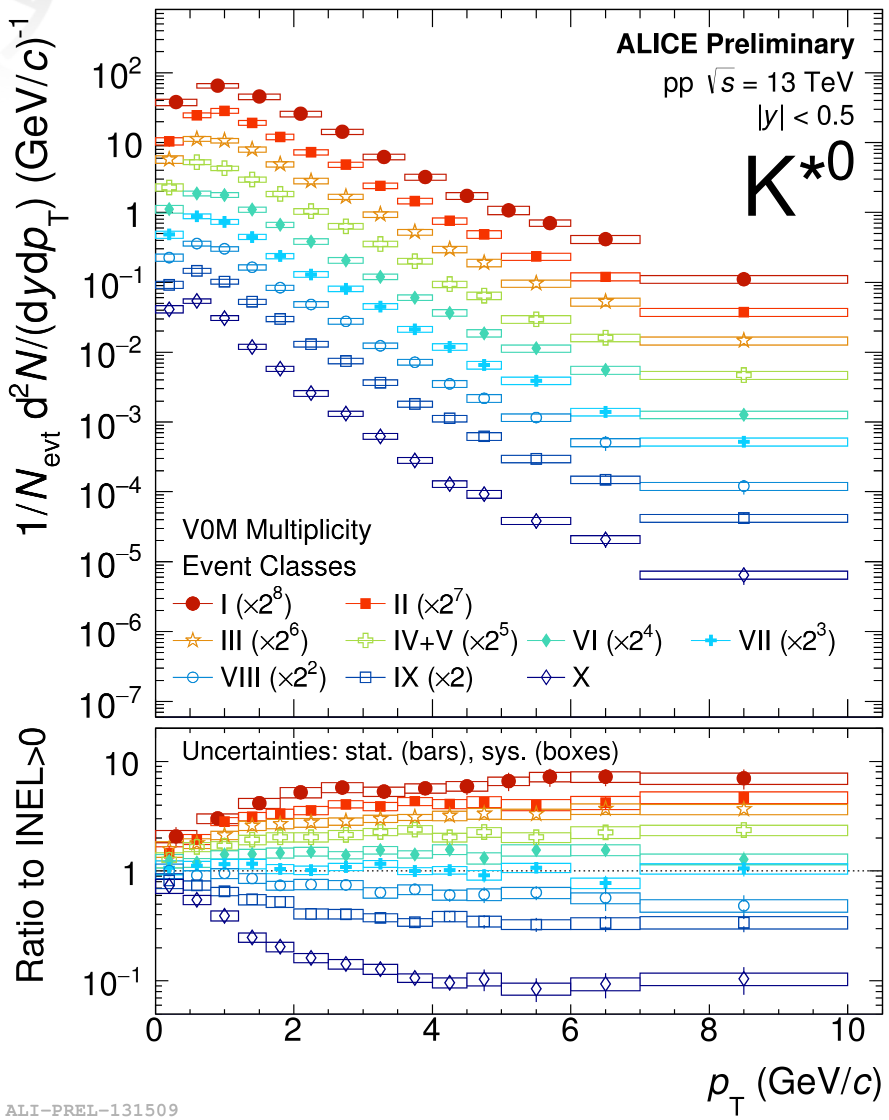
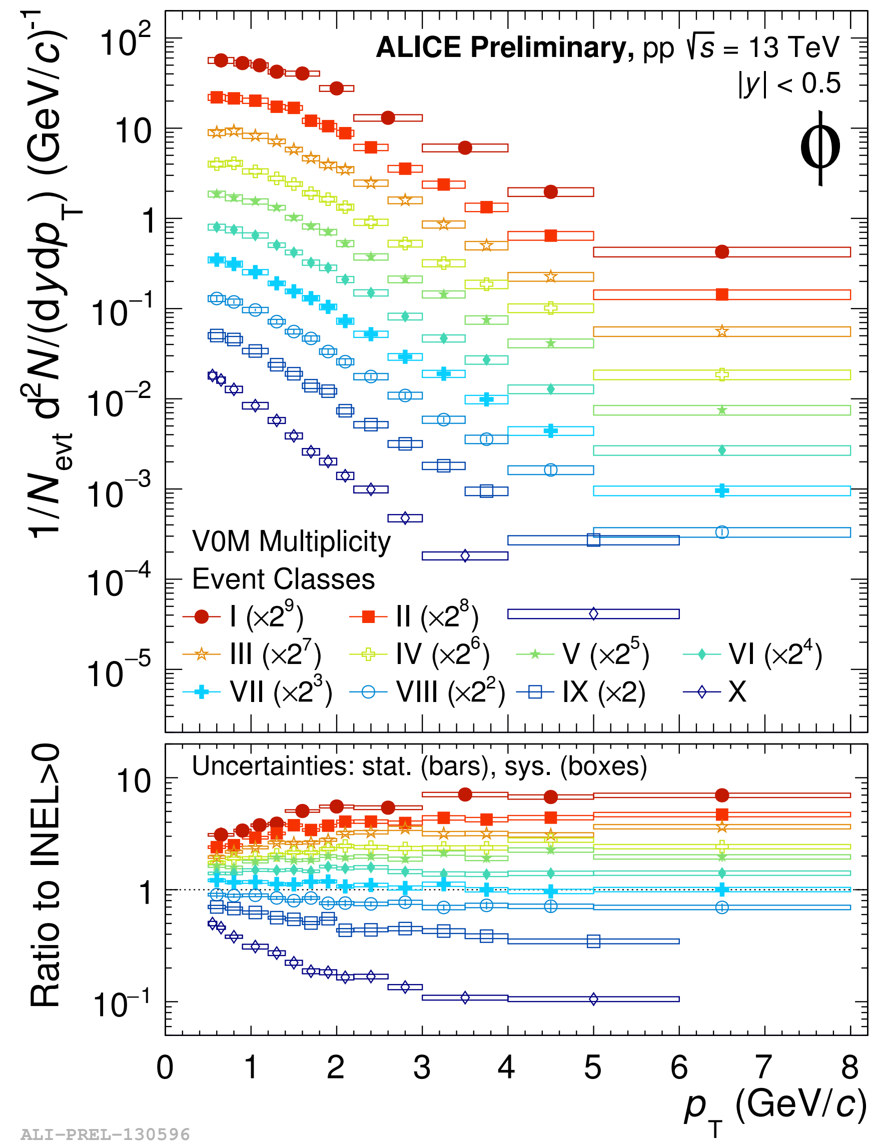




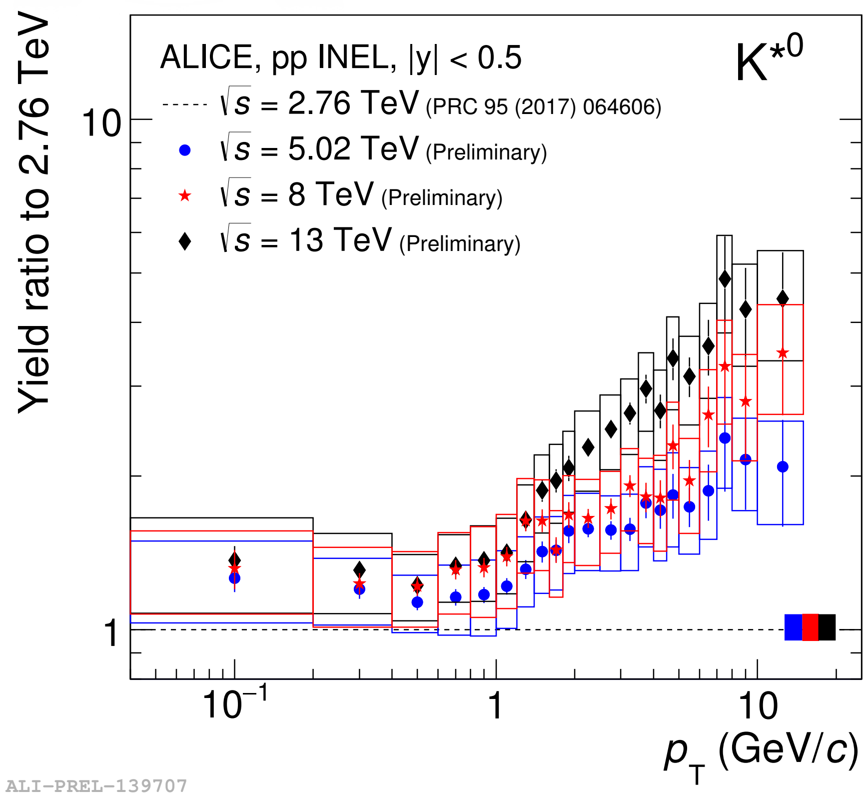
- Evolution of the spectral shapes with increasing multiplicity for $p_T < 5$ GeV/c.
- The spectral shapes remain similar across multiplicity for $p_T > 5$ GeV/c.
- Similar as seen in p-Pb collisions.

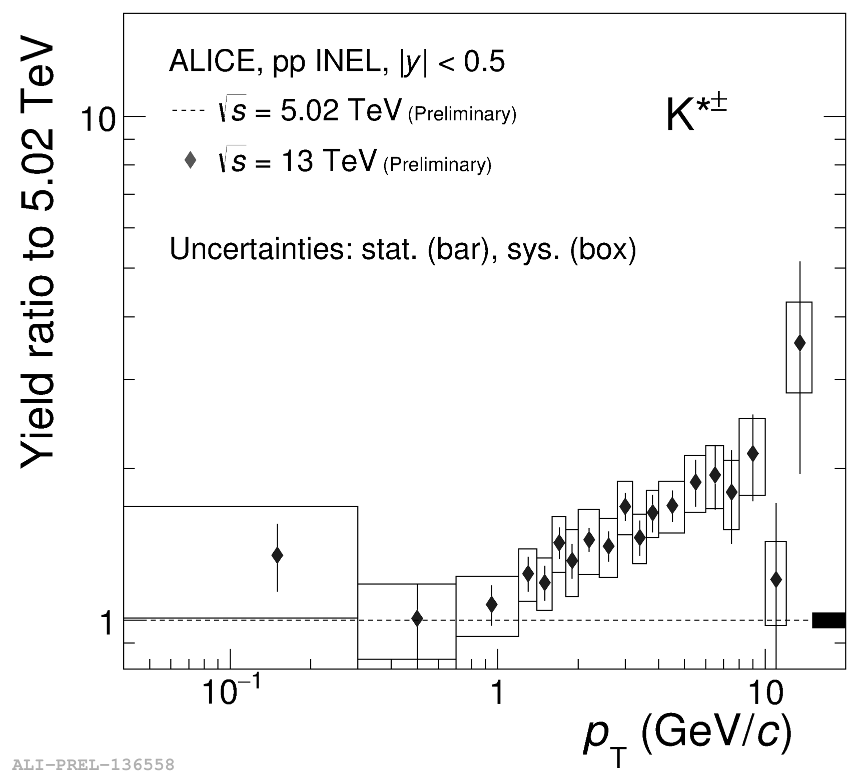
A wealth of measurements of resonances at the LHC are available

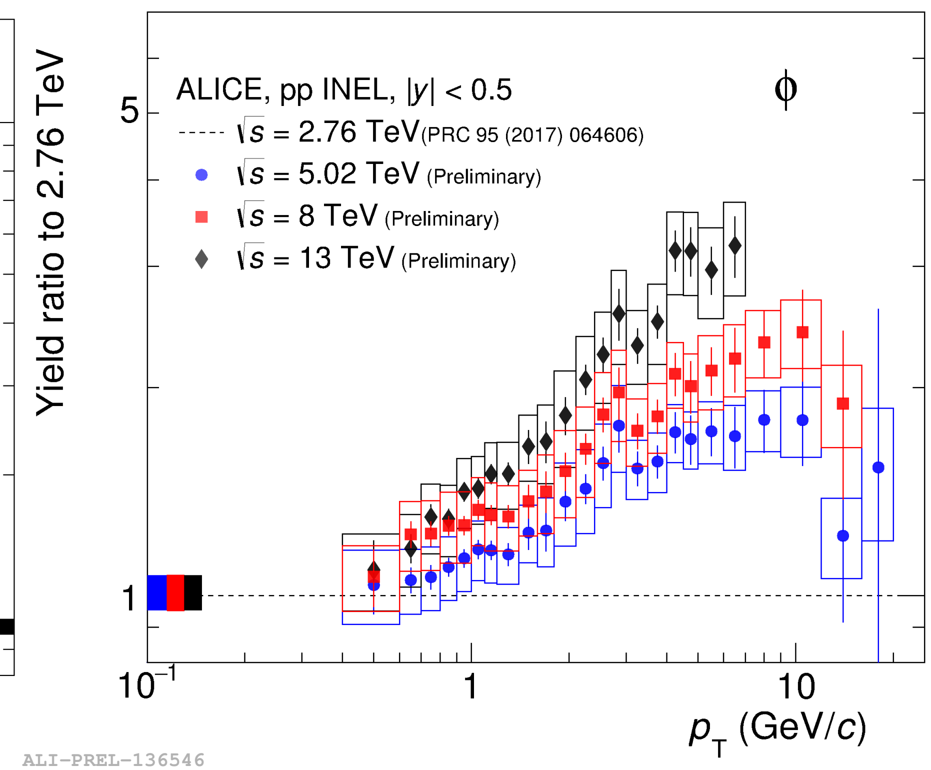
p_T spectra in minimum bias pp collisions

Resonances(Lifetime in fm/c):

$\rho(1.3) < K^{*0,\pm}(4.2) < \Sigma^*(5.5) < \Lambda^*(12.6) < \Xi^{*0}(21.7) < \phi(46.4)$





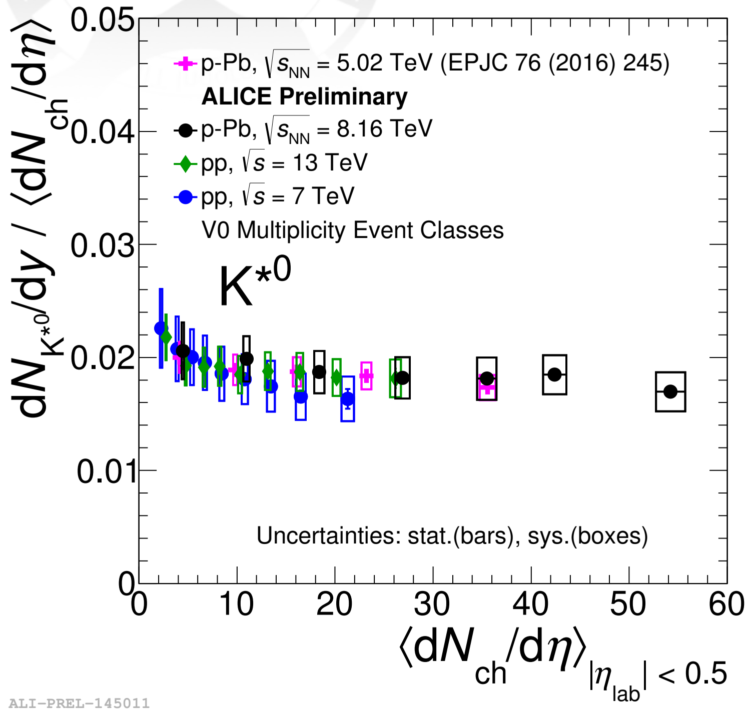


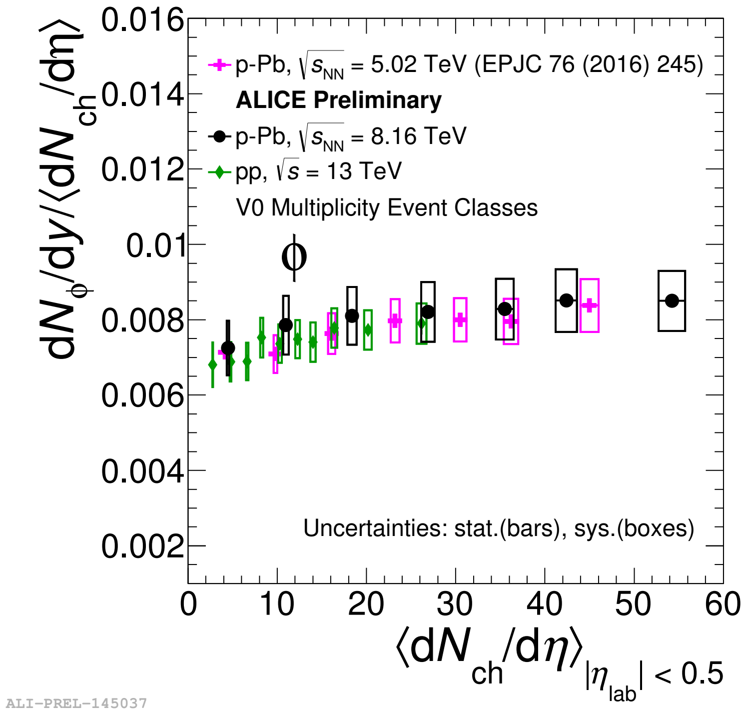
- Bulk production seems to be independent of collision energy.
- p_T spectra get harder with increasing collision energy.
- Behaviour is similar to other light flavoured hadrons.

Integrated yield and mean-p_T

Resonances(Lifetime in fm/c):

$\rho(1.3) < K^{*0}(4.2) < \Sigma^{*}(5.5) < \Lambda^{*}(12.6) < \Xi^{*0}(21.7) < \phi(46.4)$





- Integrated yield normalised to $<dN_{ch}/d\eta>$ for K^{*0} and ϕ seem to be independent of collision energies and colliding systems for pp and p-Pb collisions.
- Event multiplicity drives the particle production irrespective of collision energies and colliding system.

Integrated yield and mean-p_T

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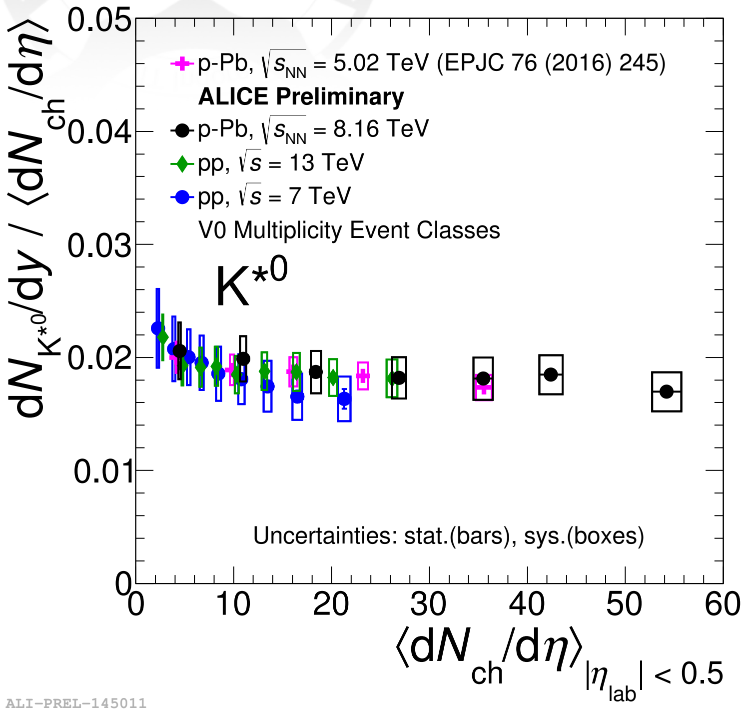
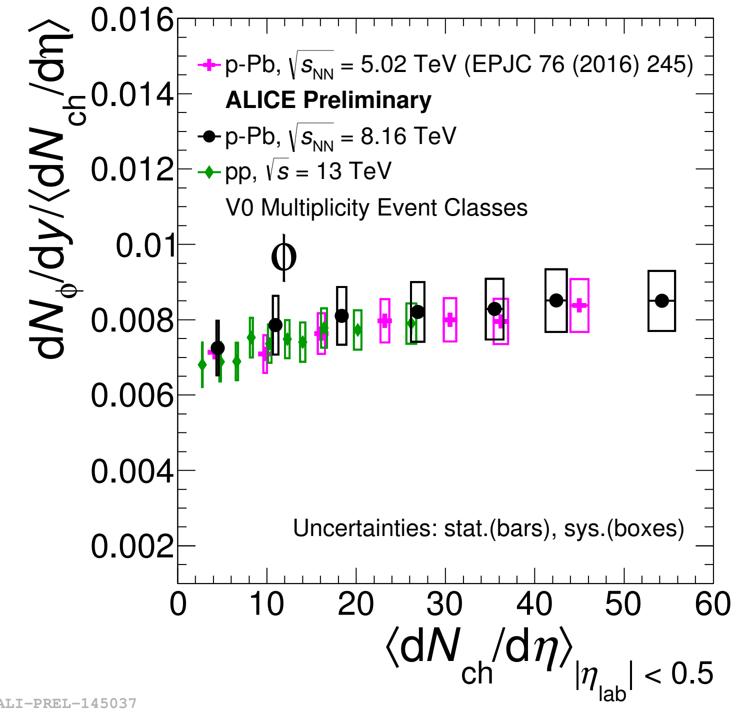
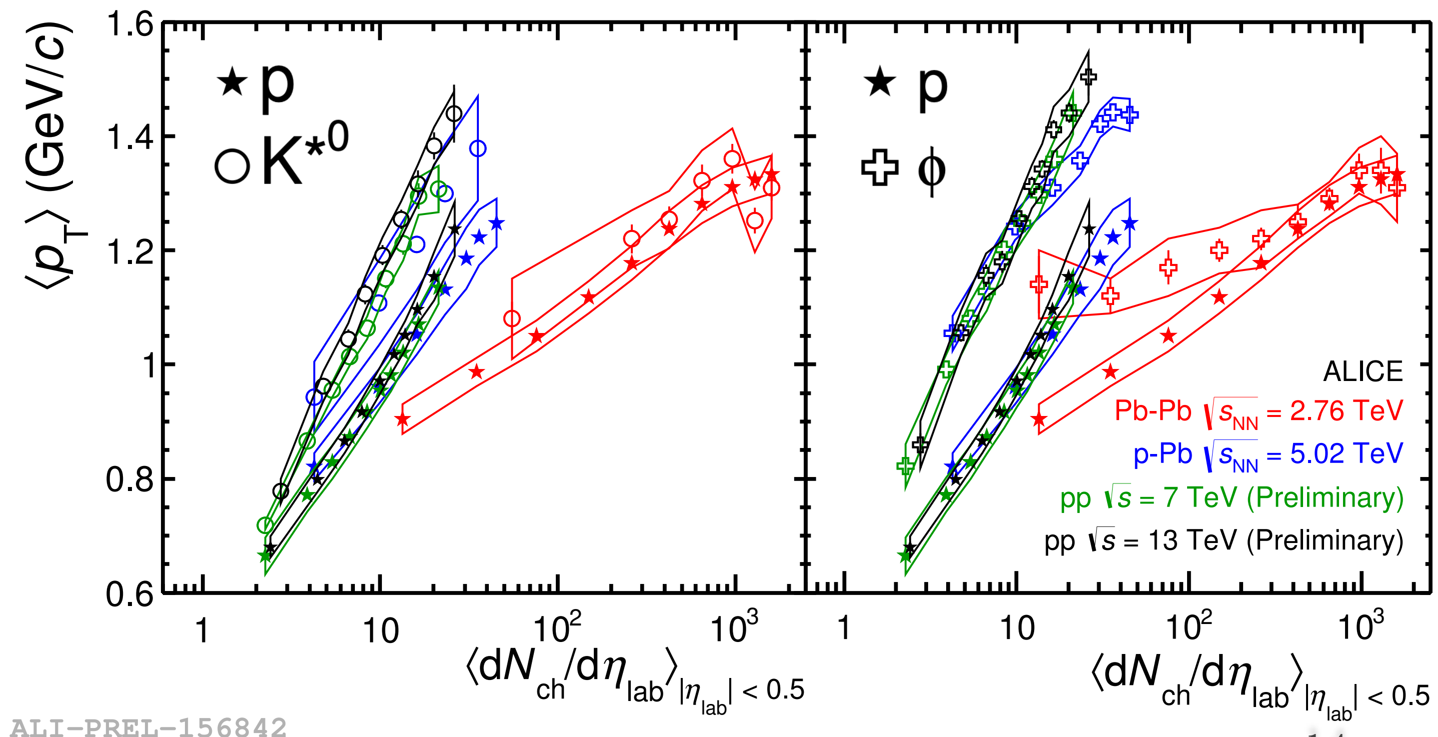




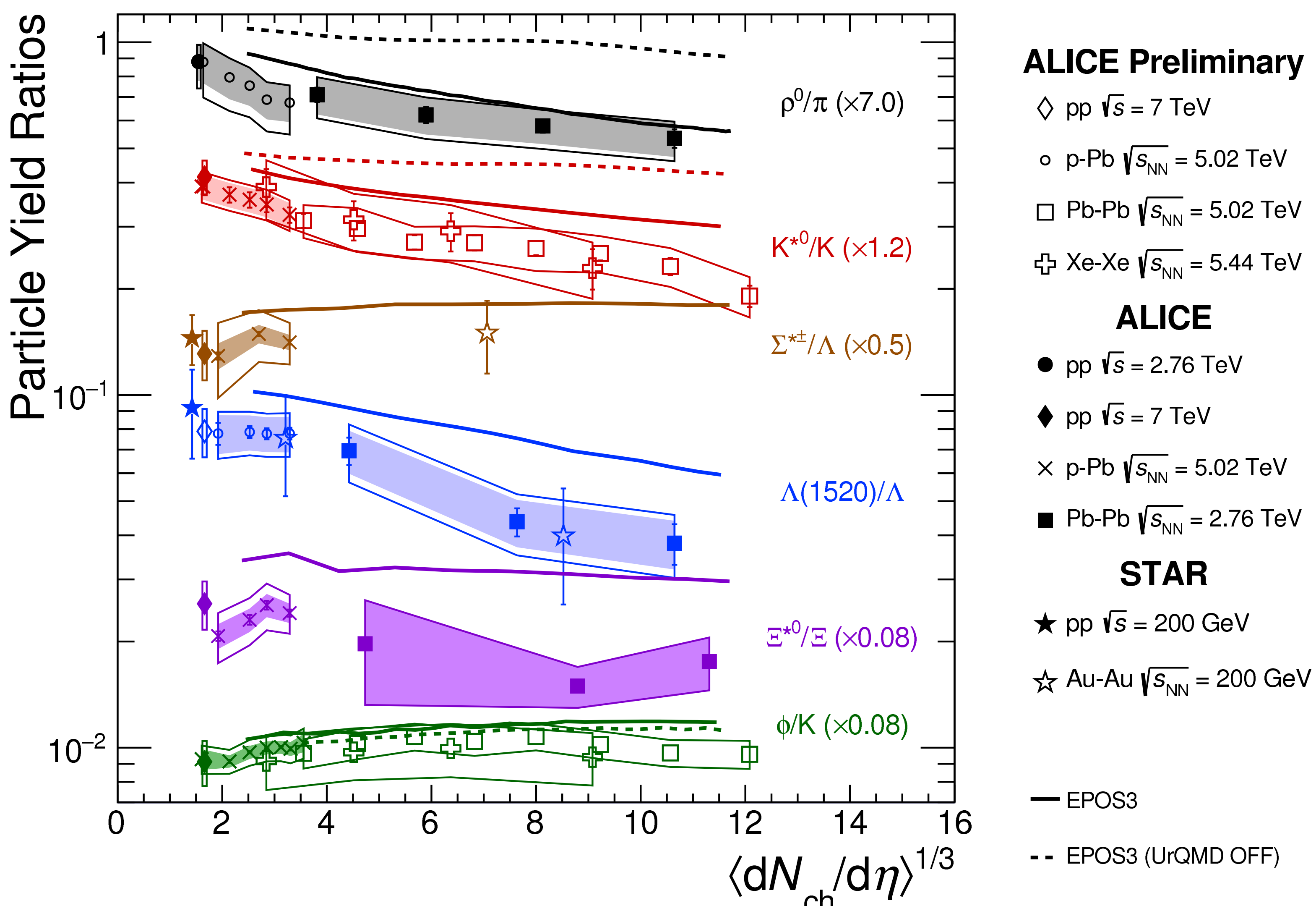


- Integrated yield normalised to $<dN_{ch}/d\eta>$ for K^{*0} and ϕ seem to be independent of collision energies and colliding systems for pp and p-Pb collisions.
- Event multiplicity drives the particle production irrespective of collision energies and colliding system.
- Similar $<p_T>$ for protons, K^{*0} and ϕ in central Pb-Pb collisions ⟶ expected from hydrodynamics as they have similar masses.
- Mass ordering is violated for peripheral Pb-Pb collisions.
- Steeper increase of $<p_T>$ with multiplicity in small systems.

Resonance to long-lived particle ratio

Resonances(Lifetime in fm/c):

$\rho(1.3) < K^{*0}(4.2) < \Sigma^{*}(5.5) < \Lambda^{*}(12.6) < \Xi^{*0}(21.7) < \phi(46.4)$



ALI-PREL-316435

$<dN_{ch}/d\eta>^{1/3}$: Proxy for system size
(Phys. Lett.B **696** (2011) 328–337)

ρ/π, K^{*0}/K and $\Lambda(1520)/\Lambda$ in Pb-Pb:

- Significant suppression of yield with increasing charged particle multiplicity indicates dominance of re-scattering over regeneration

Σ^{*}/Λ and $\Lambda(1520)/\Lambda$ in small systems:

- Independent of charged-particle multiplicity indicates no re-scattering or regeneration

Ξ^{*0}/Ξ and ϕ/K:

- Independent of system size irrespective of colliding systems indicate no re-scattering or regeneration

In most cases EPOS3 explains the trend qualitatively

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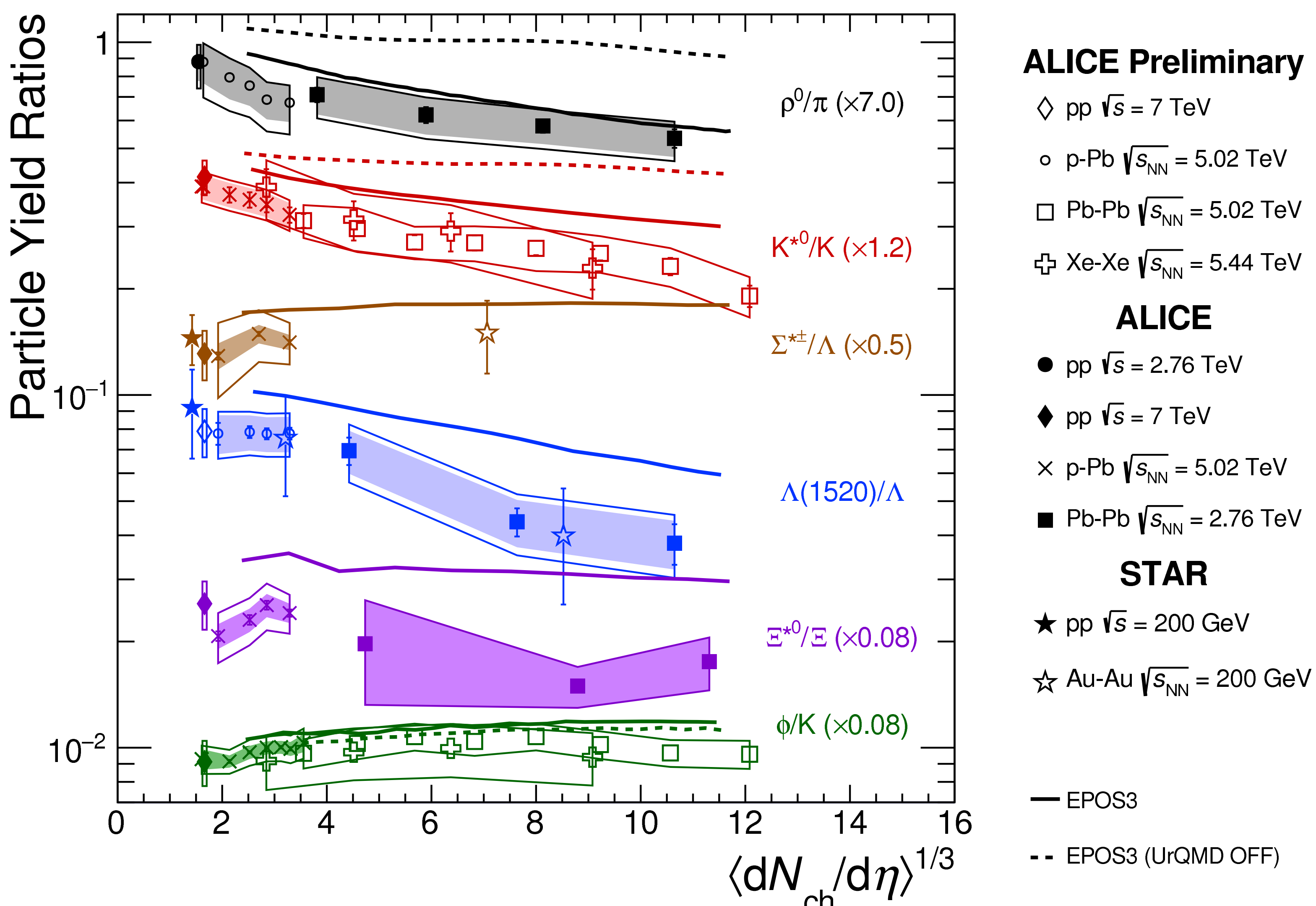

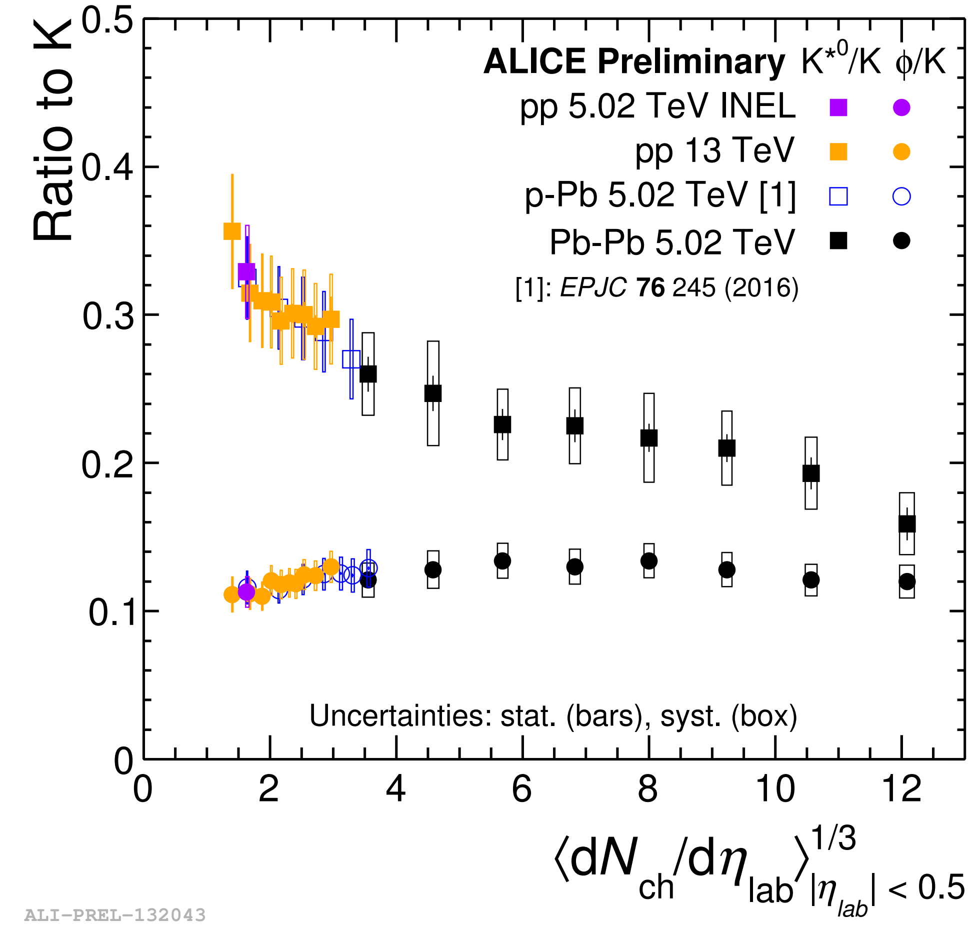

$<dN_{ch}/d\eta>^{1/3}$: Proxy for system size
(Phys. Lett.B **696** (2011) 328–337)

K^{*0}/K and ϕ/K in pp and p-Pb:
- Hint of suppression of K^{*0}/K ratio compared to ϕ/K.

Is re-scattering possible in pp and p-Pb collisions?

Relative strangeness production

Resonances(Lifetime in fm/c):

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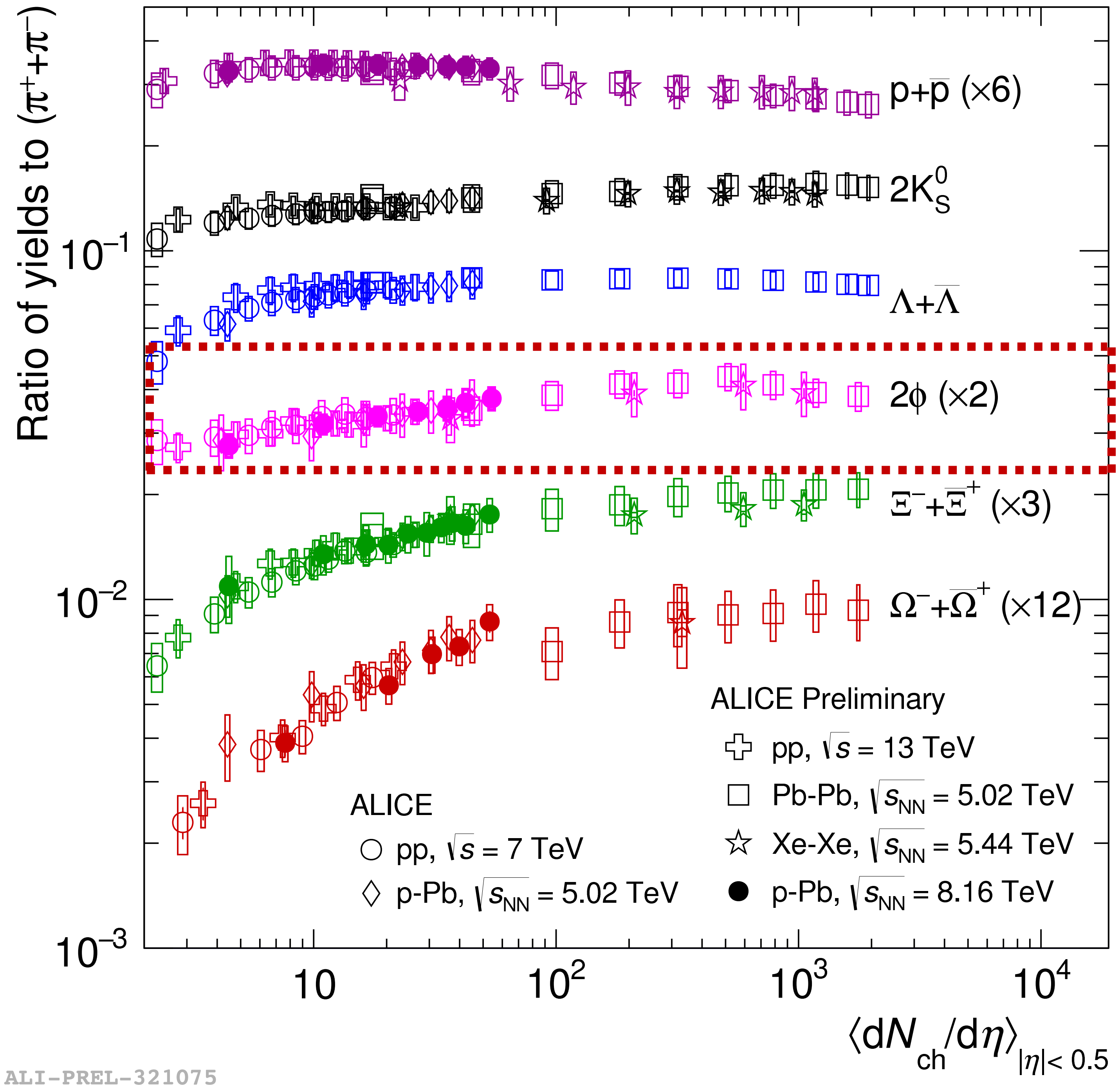


$\phi/\boldsymbol{\pi}$ (|S|=0/|S|=0):

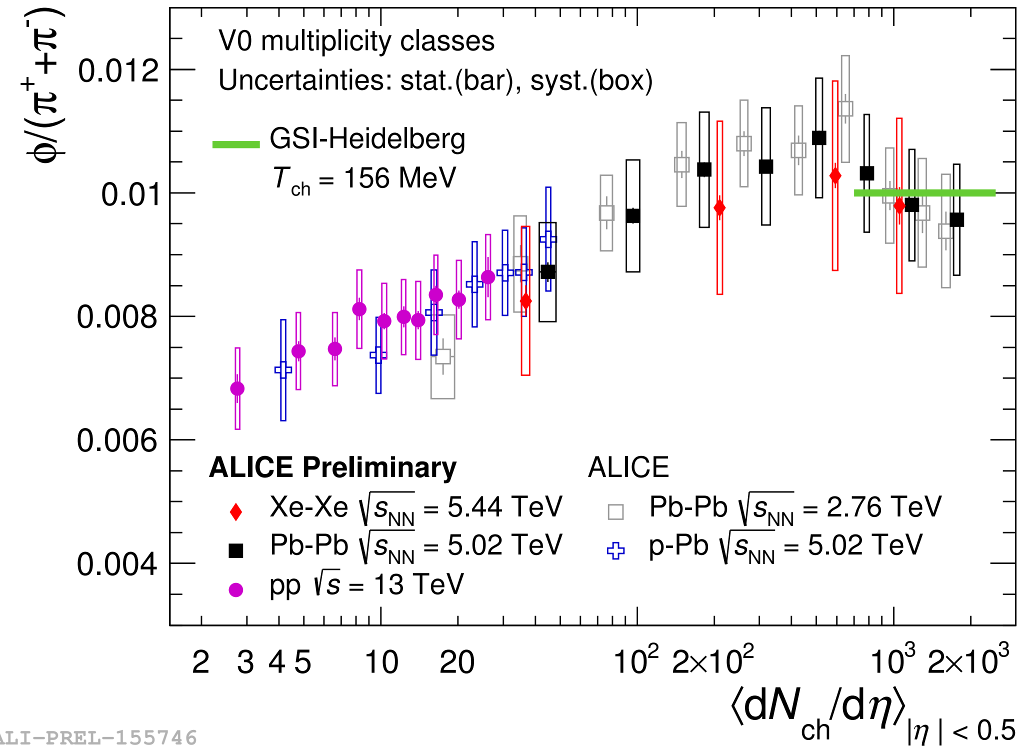
- No sign of energy dependence
- Hint of increase in small collision systems.
- Does ϕ behave as non-strange or double-strange particle?

Poster by S. Tripathy

Hidden and Open Strangeness

Resonances(Lifetime in fm/c):

$\boldsymbol{\rho}(1.3) < K^{*0}(4.2) < \Sigma^{*}(5.5) < \Lambda^{*}(12.6) < \Xi^{*0}(21.7) < \phi(46.4)$



ALI-PREL-155746

$\phi/\boldsymbol{\pi}$ (|S|=0/|S|=0):

- Large systems: Consistent with the predictions from thermal model
- Small systems: increase with multiplicity, in contrast to the canonical suppression of strangeness

Poster by S. Tripathy

Hidden and Open Strangeness

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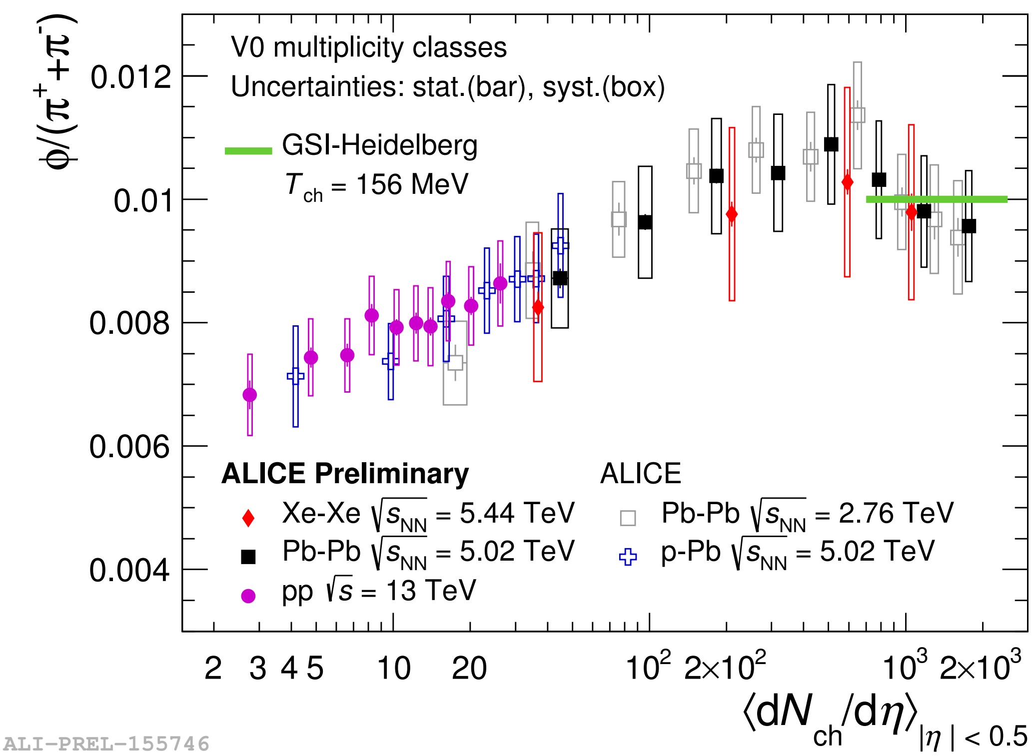
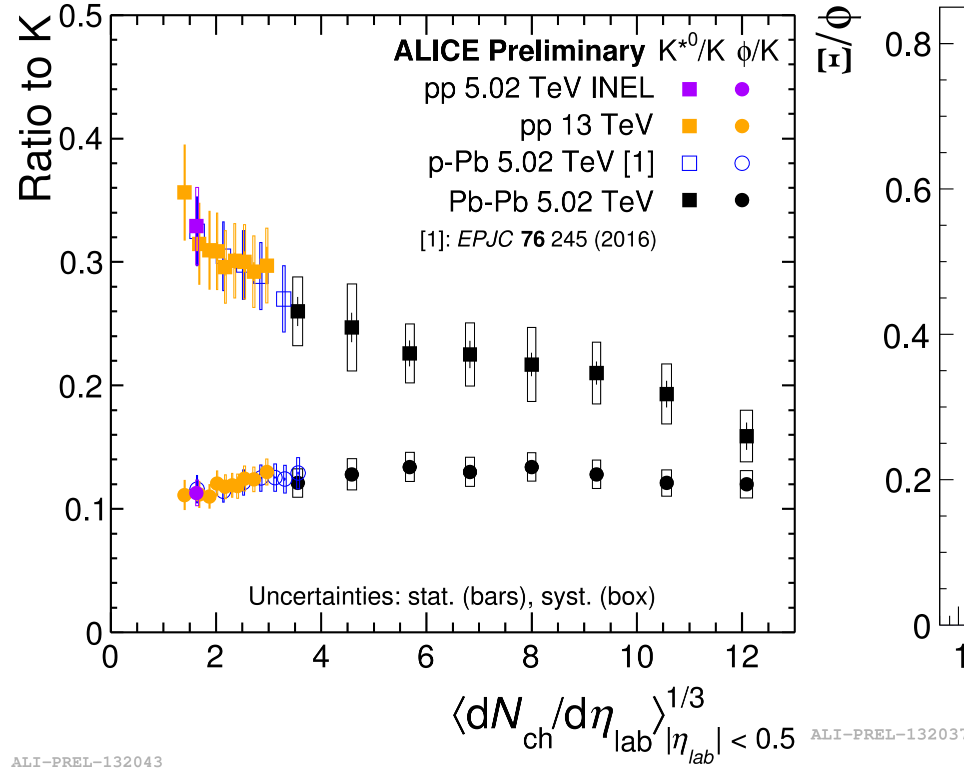
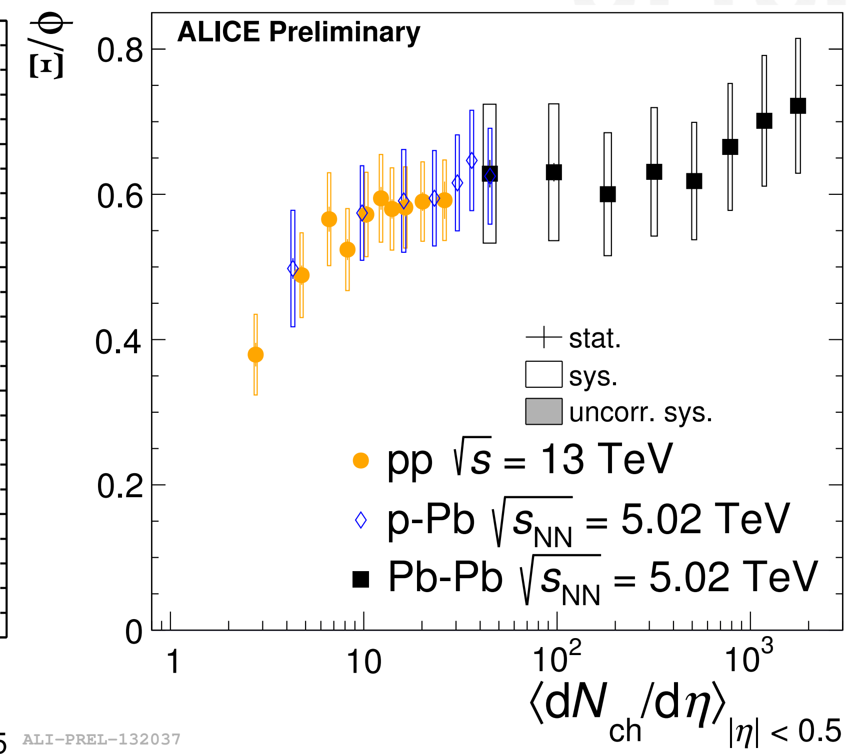






ϕ/π (|S|=0/|S|=0):

- Large systems: Consistent with the predictions from thermal model
- Small systems: increase with multiplicity, in contrast to the canonical suppression of strangeness

ϕ/K (|S|=0/|S|=1) and Ξ/ϕ (|S|=2/|S|=0):

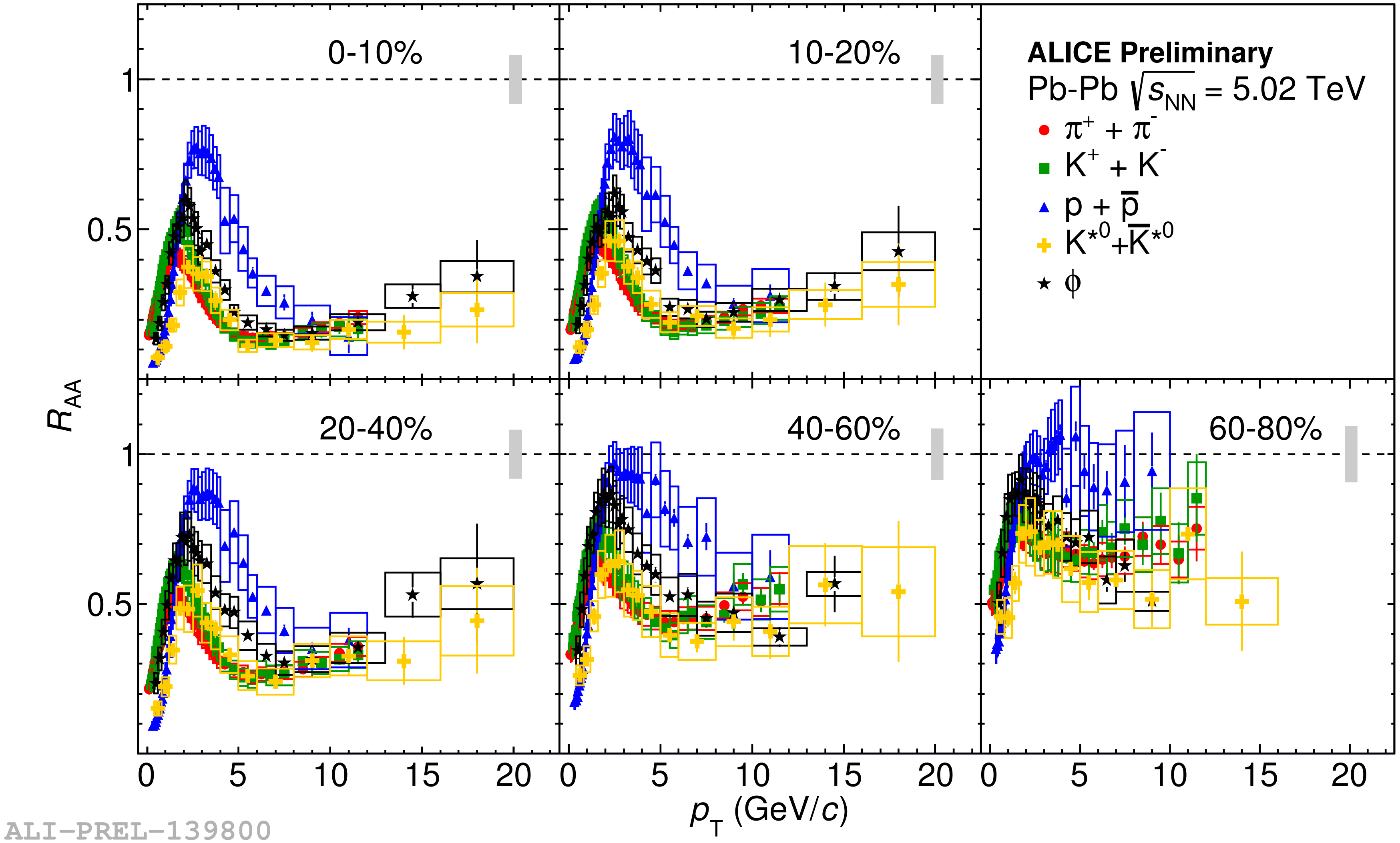
- Fairly flat or slight increase across wide multiplicity ranges

ϕ behaves like a particle with strangeness 1 or 2 units

ϕ behaving as if it has 1-2 units of open strangeness may be consistent with expectation from rope-hadronization models (e.g. DIPSY).

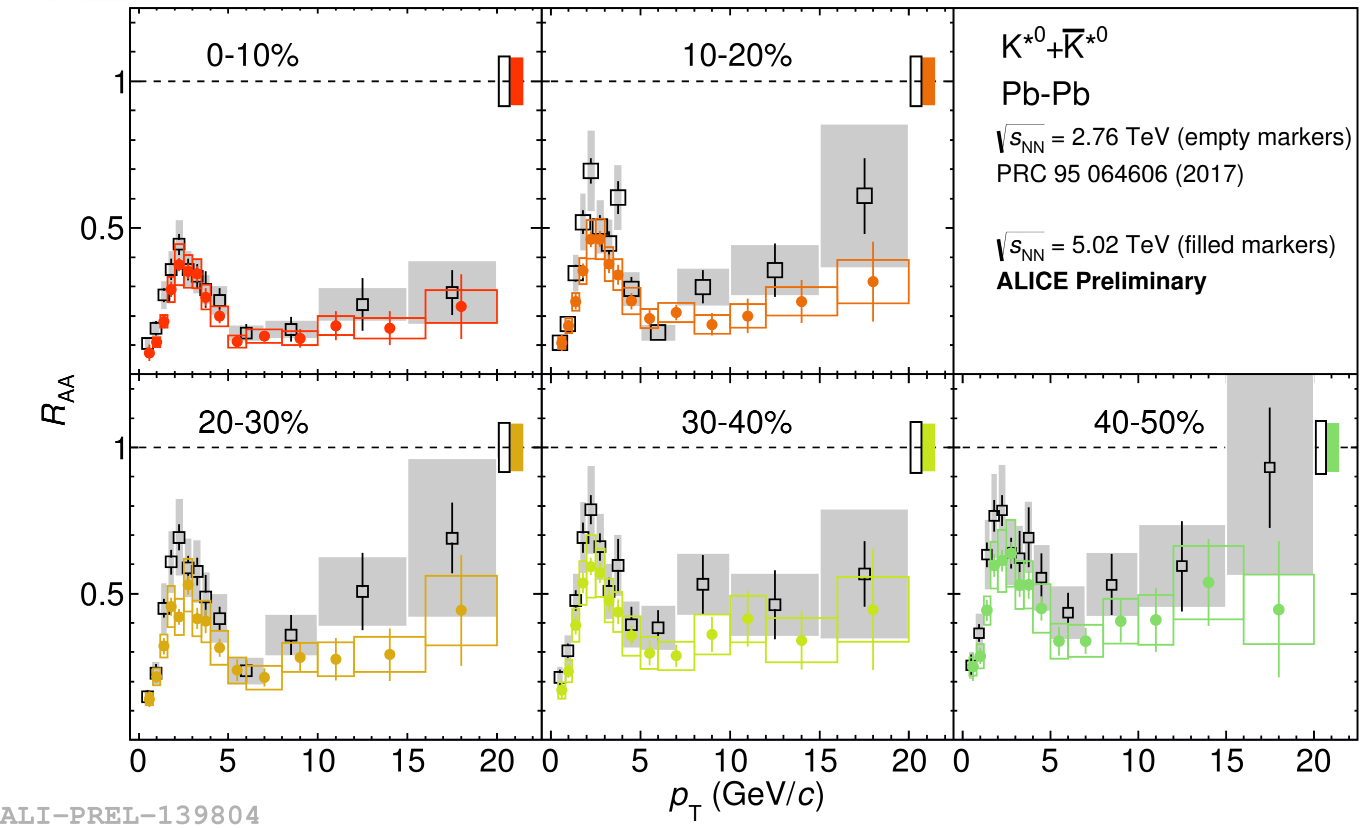
Poster by S. Tripathy

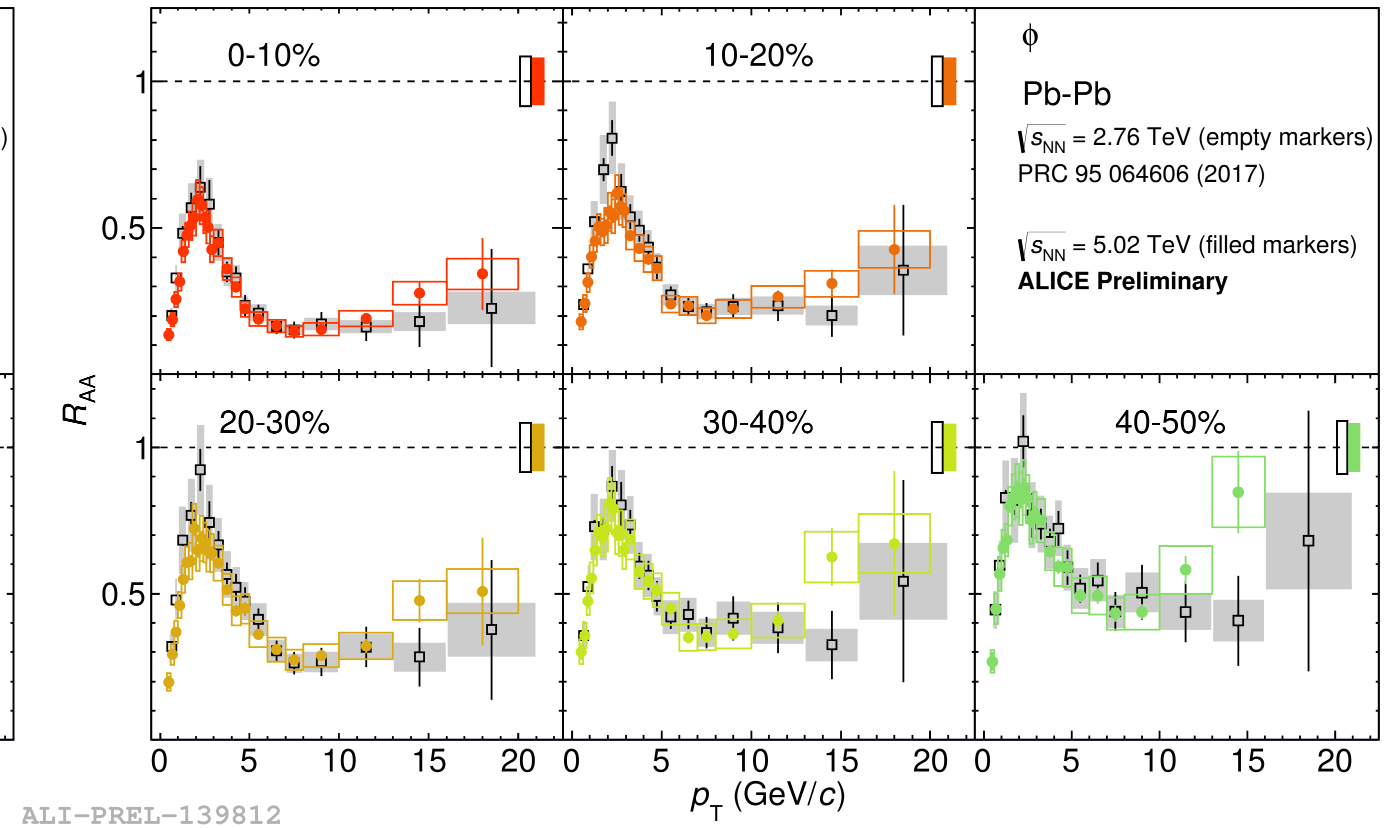
Nuclear Modification Factor (R_{AA})



- R_{AA} above $p_T \simeq 8$ GeV/c is same for all light flavoured hadrons :- No flavour dependence (u, d, s) of Parton energy loss
- Mass ordering of R_{AA} is observed at intermediate-p_T :- Indicate radial flow effect
- Proton R_{AA} is higher compared to ϕ R_{AA} :- May be due to Baryon-meson effect

Nuclear Modification Factor (R_{AA})



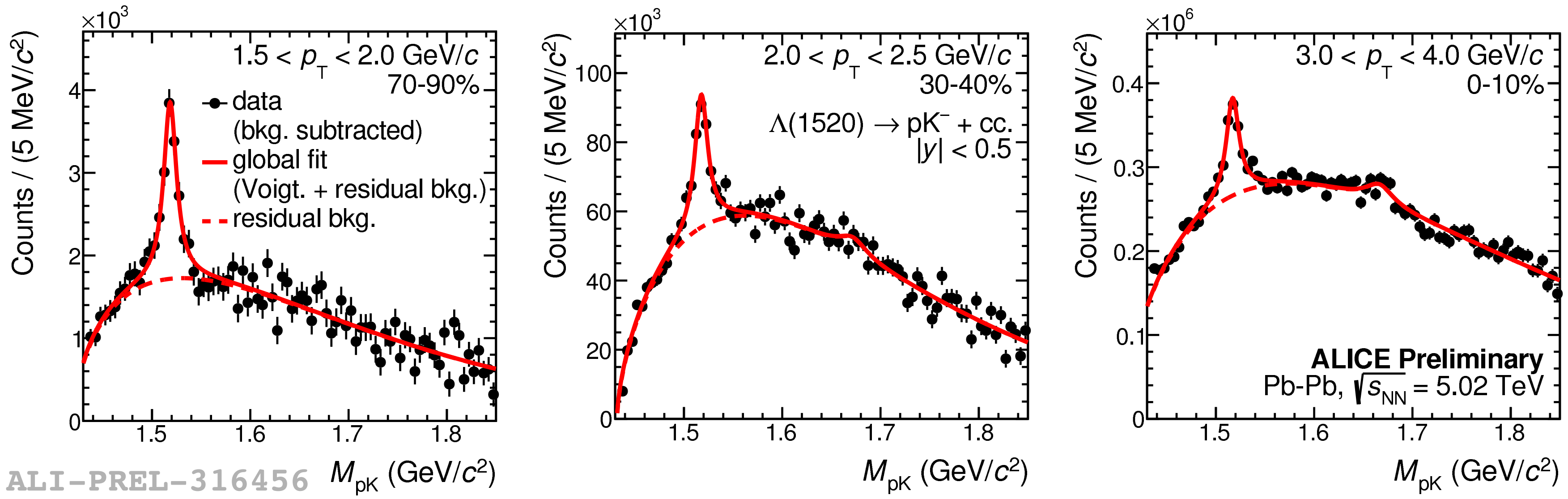


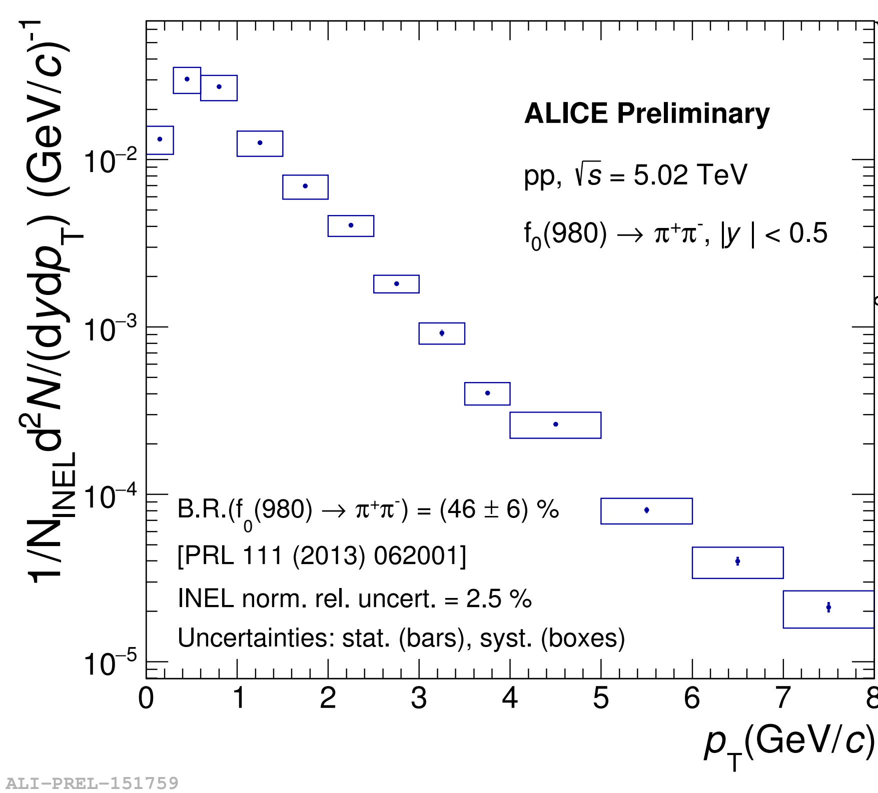
- R_{AA} does not show any energy dependence from Pb-Pb collisions at 2.76 TeV to 5.02 TeV
- Parton energy loss effect is similar

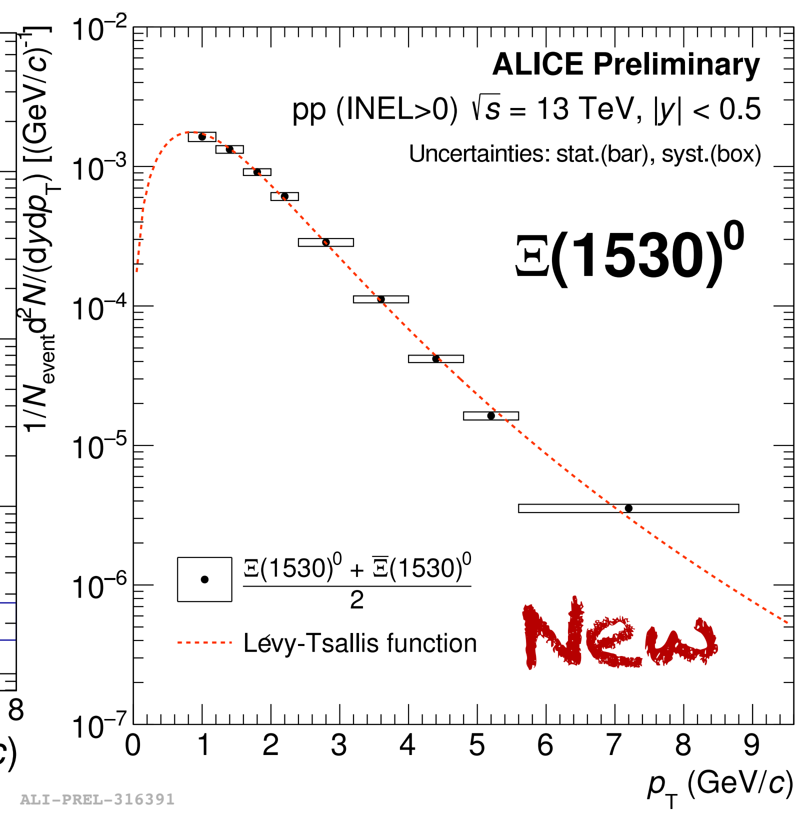
Other latest results

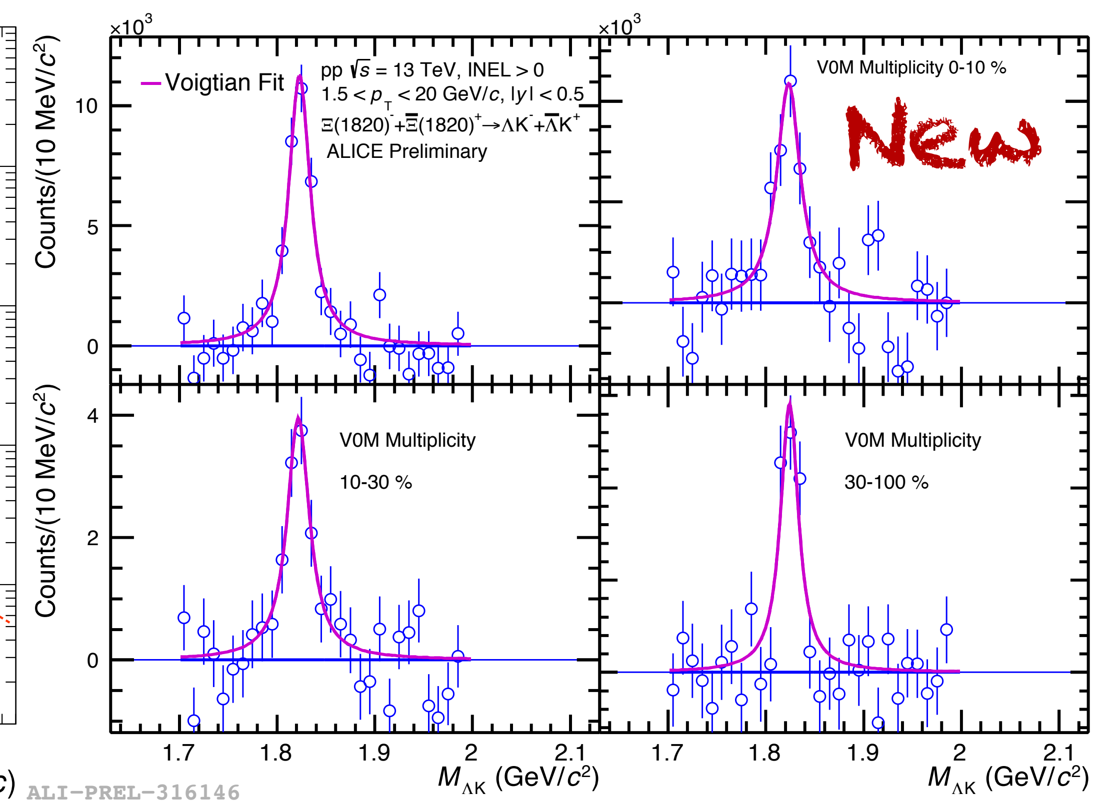
Λ(1520) production in Pb-Pb collisions (Poster by N. Agrawal)

New









$f_0(980)$ production in pp collisions at 5.02 TeV (Poster by F. Bellini)

Ξ(1530) production in pp collisions at 13 TeV (Poster by Bong-Hwi Lim)

Ξ(1820) production in pp collisions at 13 TeV (Poster by C. J. Myers)

Summary

- ALICE has measured several resonances having different lifetimes in different collision energies and colliding systems.
- Event multiplicity drives the particle production irrespective of collision energies and colliding system at the LHC energies.
- Suppression of ρ, K^{*0} and $\Lambda(1520)$ is observed in most central collisions compared to small collision systems, no suppression of ϕ.
- Hint of suppression for ρ and K^{*0} in high multiplicity pp and p-Pb collisions.
- ϕ behaves like a particle with strangeness 1 or 2 units.

Thank you for your attention

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Back-up

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p_T-differential yield ratio in pp

Resonances(Lifetime in fm/c):

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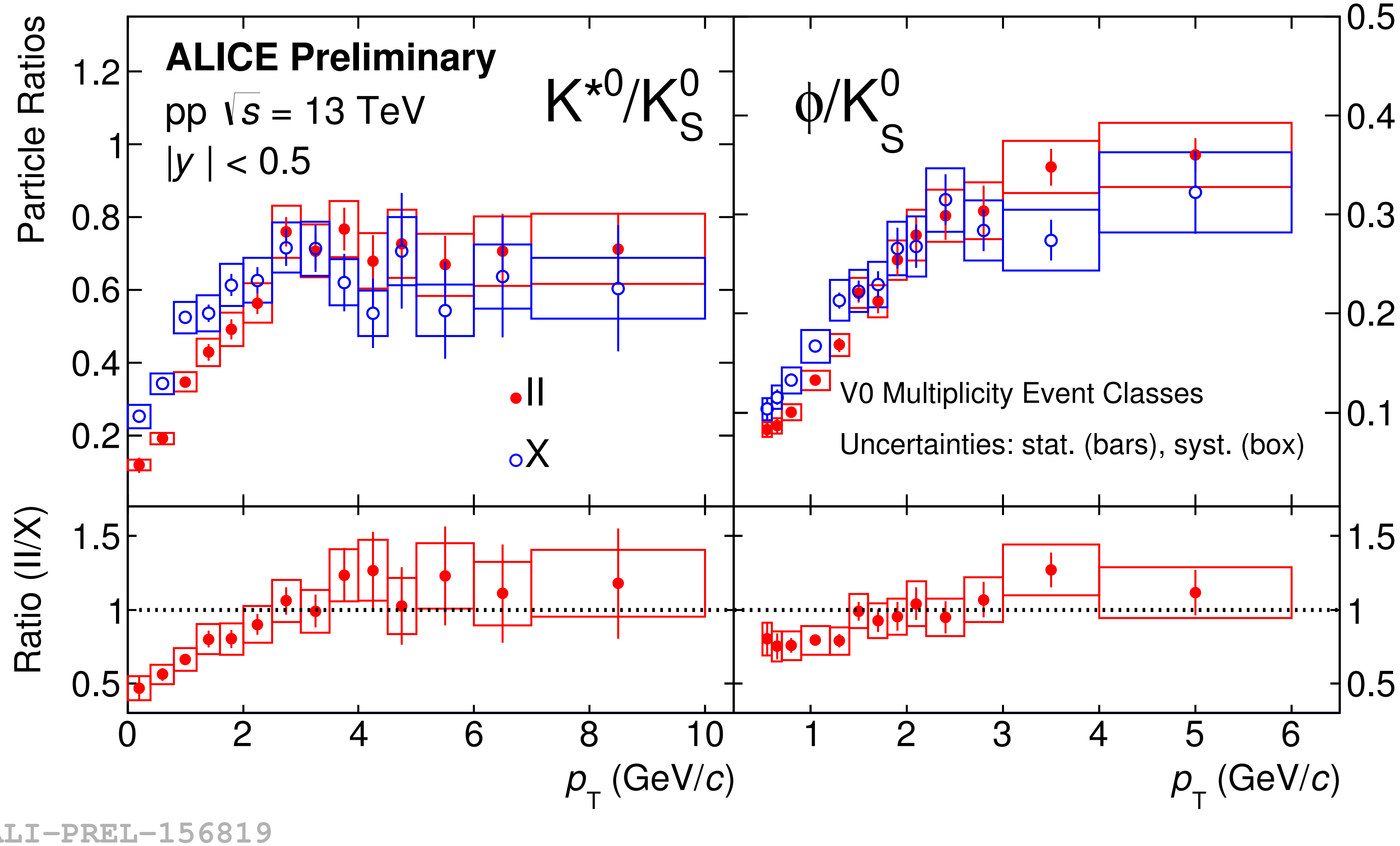

- Both K^{*0}/K$_S^0$ and ϕ/K$_S^0$ increase with p_T and saturate for p_T > 2 GeV/c.
- Double ratios (II/X) are consistent with unity for p_T > 2 GeV/c.
- K^{*0}/K$_S^0$ is more suppressed compared to ϕ/K$_S^0$ for p_T > 2 GeV/c.

II: High multiplicity event ($dN_{ch}/d\eta \sim 20$)
X: Low multiplicity event ($dN_{ch}/d\eta \sim 2.4$)

Do we observe re-scattering of K^{*0} in high multiplicity pp collisions?