SQM2022

The 20th International Conference on Strangeness in Quark Matter
13-17 June 2022 Busan, Republic of Korea

Istituto Nazionale di Fisica Nucleare

ALICE

Rescattering effects on resonances production in small systems with ALICE at the LHC

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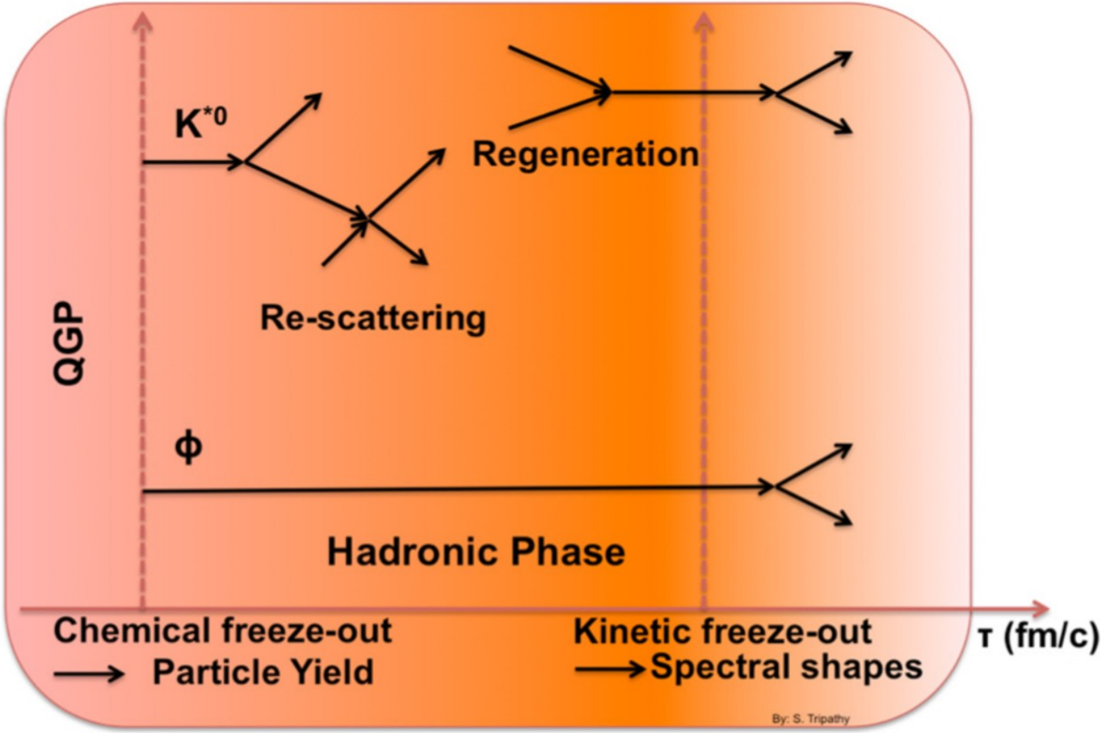
14 June 2022

Introduction

- **Hadronic resonances** → ideal probes to characterize heavy-ion collisions

- **Short lived** resonances: comparable to hadronic phase lifetime (~ 1-10 fm/*c*) → **sensitive** to **rescattering** and **regeneration**

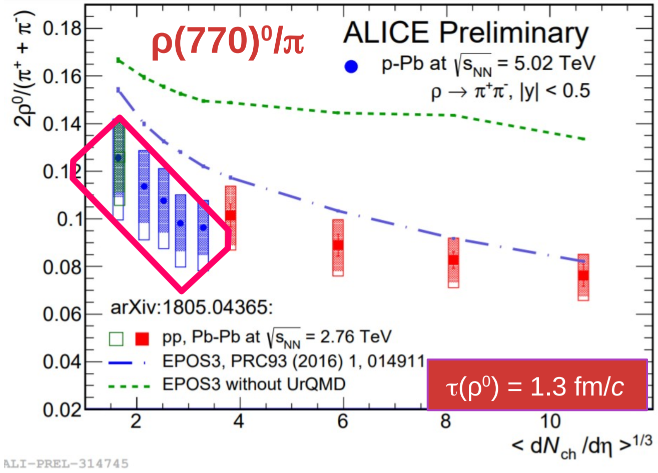


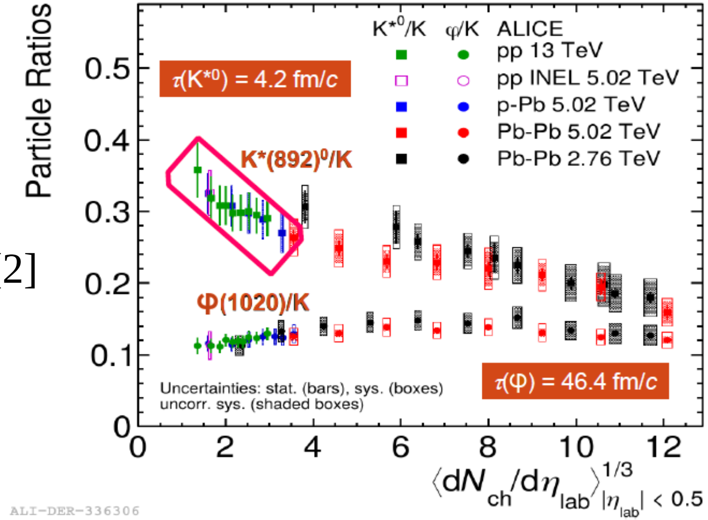
- **Small** collision systems (pp and p–Pb):
  - Used as a **baseline** for heavy-ion collisions
  - **Recent results** show some **typical** phenomena **of heavy-ion collisions**

Particle yield ratios in small systems

Resonance yields compared to ground-state hadrons with similar quark content (such as K^{*0}/K and ρ^0/π)

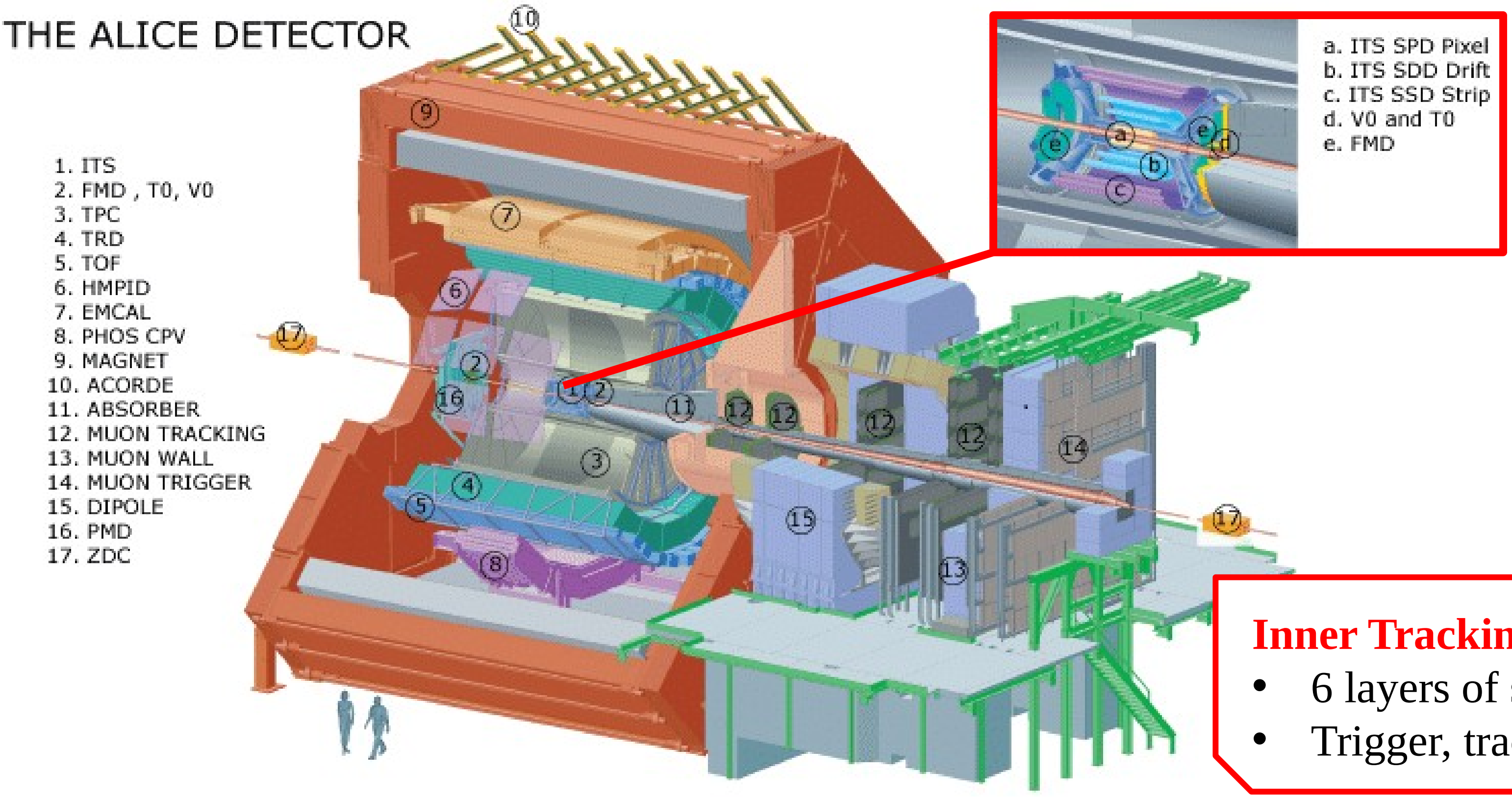
- Goal in heavy ion collisions: characterize the properties of the hadronic phase
- Same study in pp and p–Pb collisions → smooth trend across multiplicity
- Long-lived resonances (like φ) → no evidence of multiplicity evolution
- K^{*0} and ρ^0 → hint of decreasing trend
- Some QCD-inspired event generators, like PYTHIA 8 [1] and EPOS-LHC [2] can reproduce the suppression without a hadronic phase → colour reconnection and core/corona effects

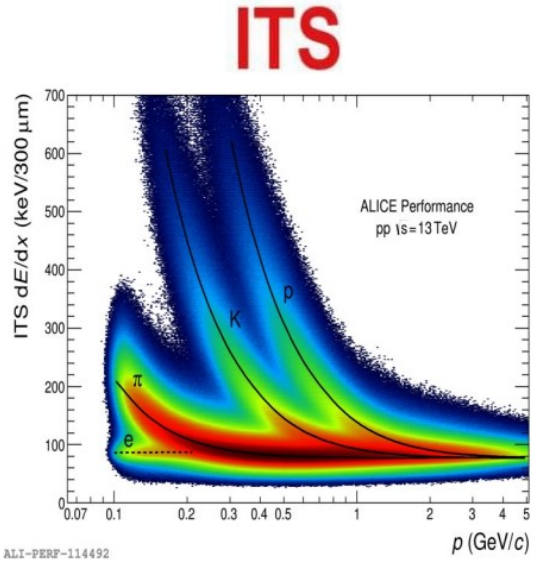




[1] *Phys. Rev. D 97, 036010 (2018)*
[2] *Phys. Rev. C 92, 034906 (2015)*

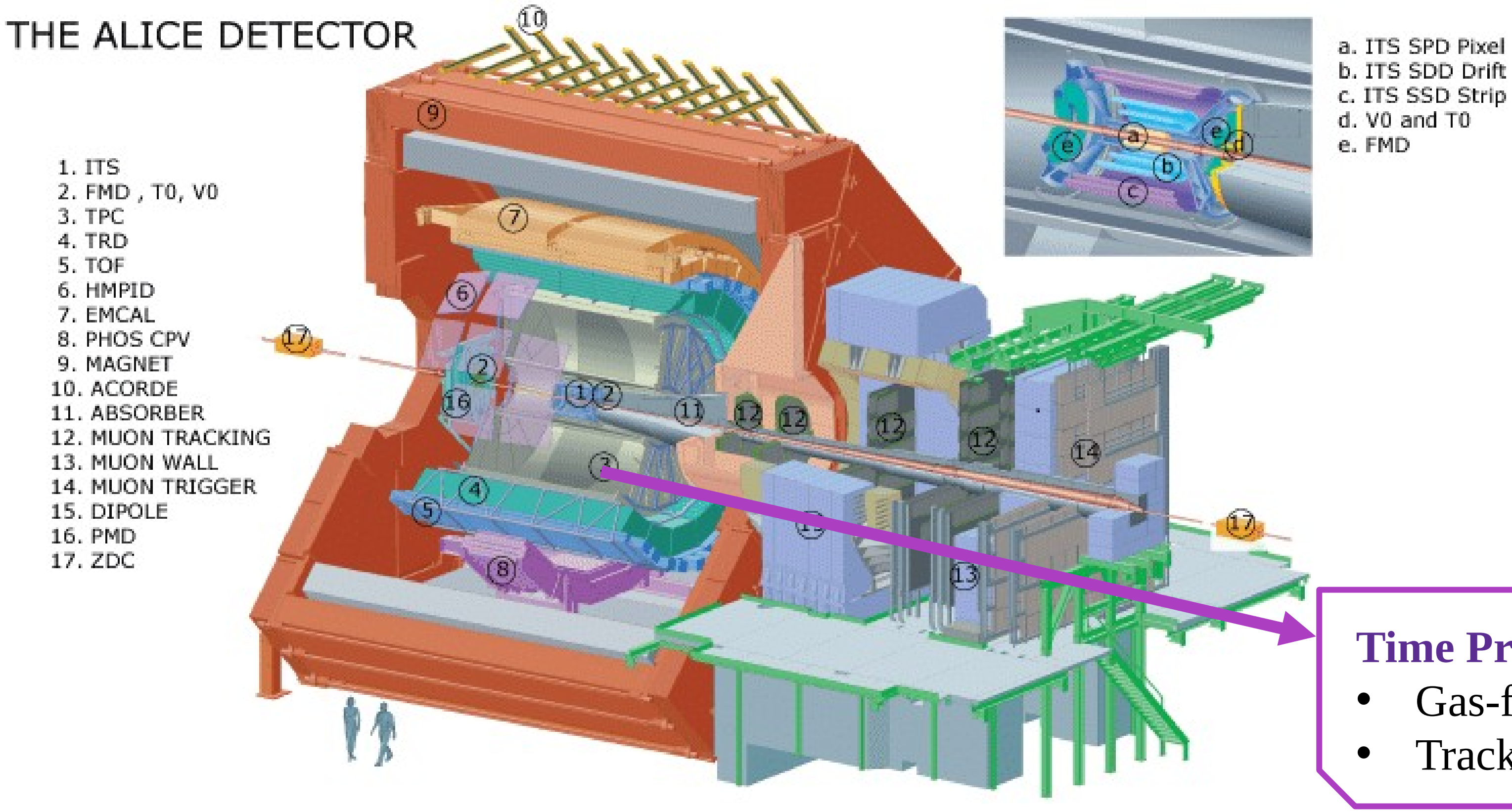
The ALICE detector:
Main sub-detectors for resonance reconstruction

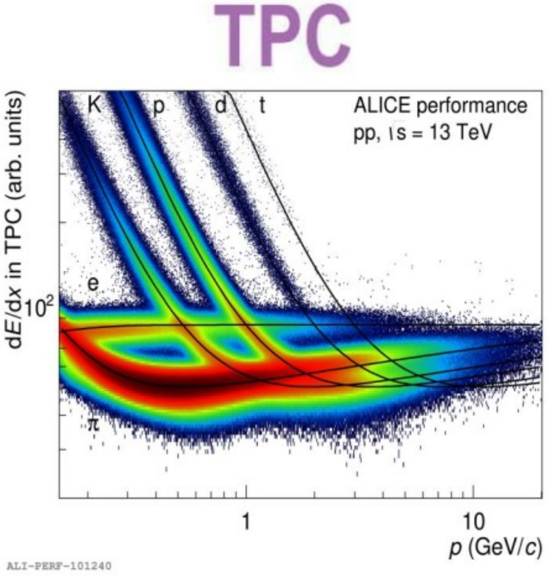




Inner Tracking System (ITS)
- 6 layers of silicon detectors
- Trigger, tracking, vertex, PID (dE/dx)

The ALICE detector:
Main sub-detectors for resonance reconstruction

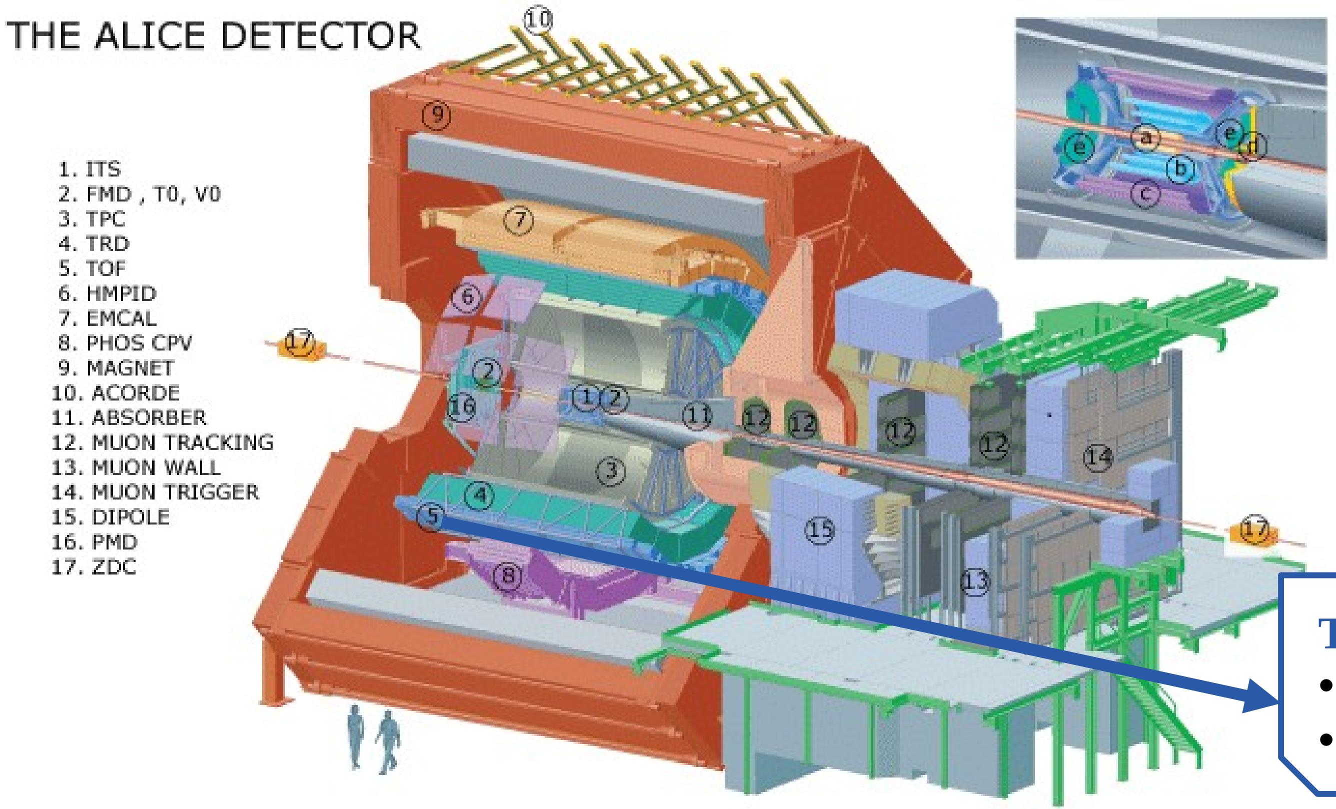




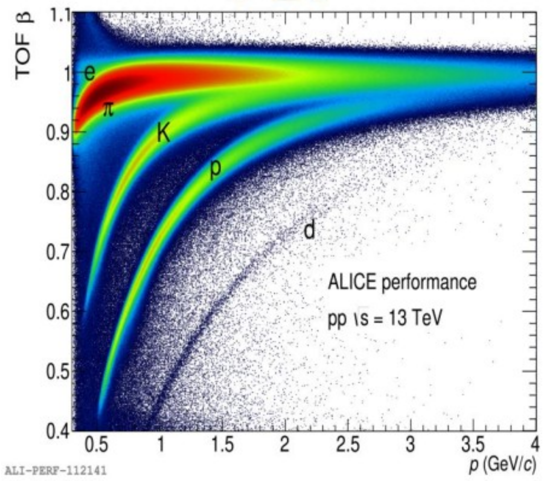
Time Projection Chamber (TPC)

- Gas-filled ionization detector
- Tracking, vertex, PID (dE/dx)

The ALICE detector:
Main sub-detectors for resonance reconstruction



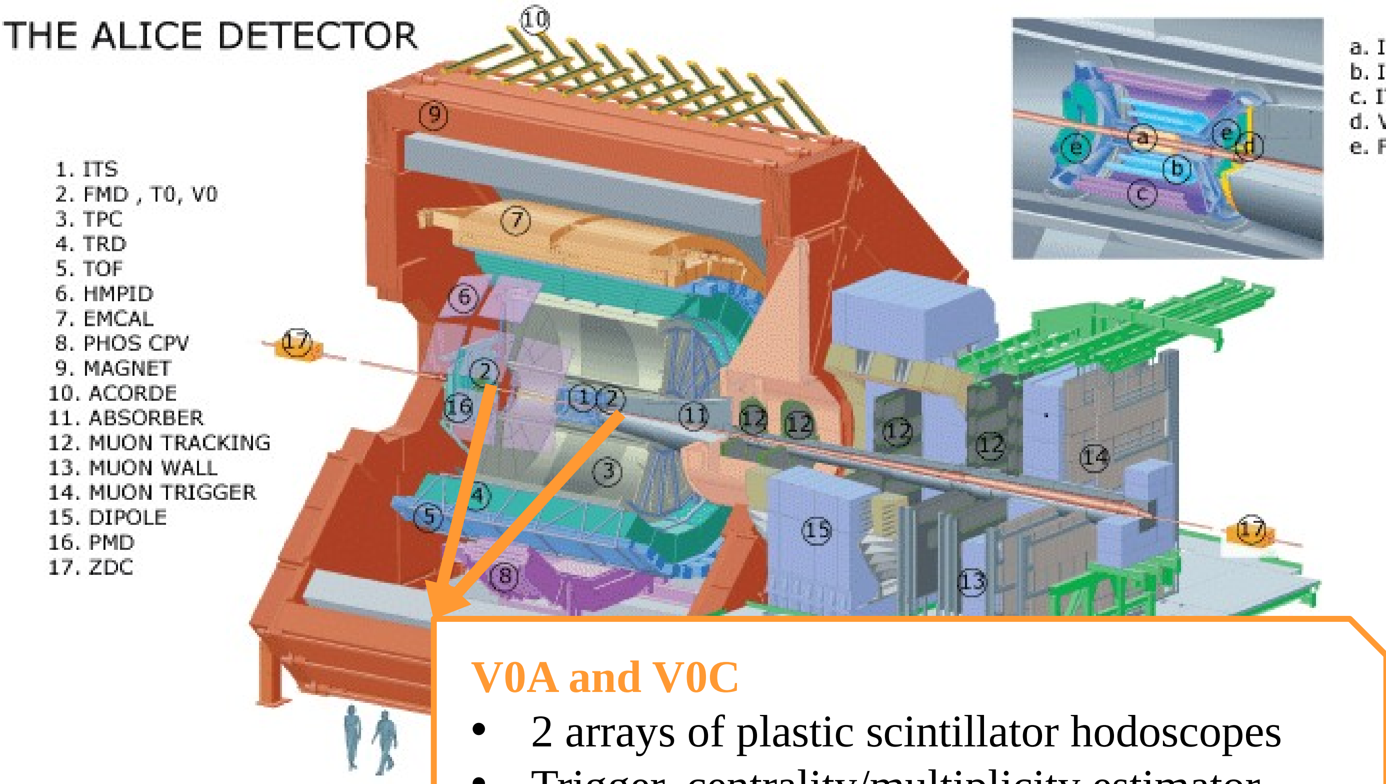
TOF

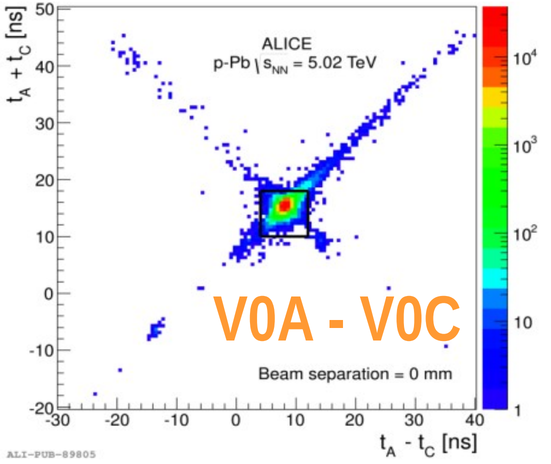


Time Of Flight (TOF)

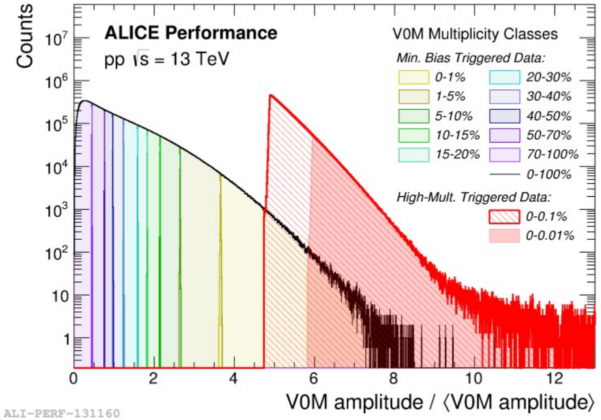
- Multi-gap Resistive Plate Chamber
- PID through particle time of flight

The ALICE detector:
Main sub-detectors for resonance reconstruction





The ALICE collaboration 2014 JINST 9 P11003

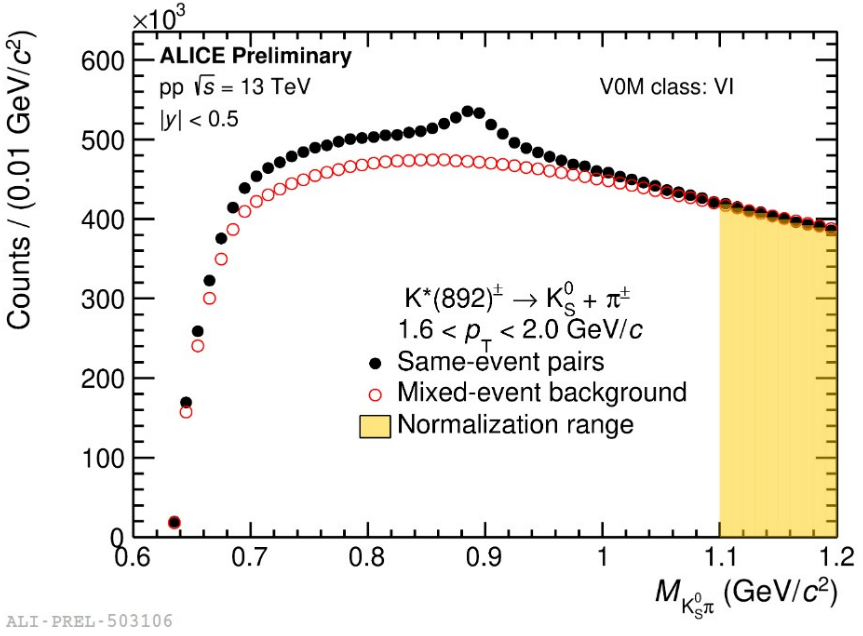


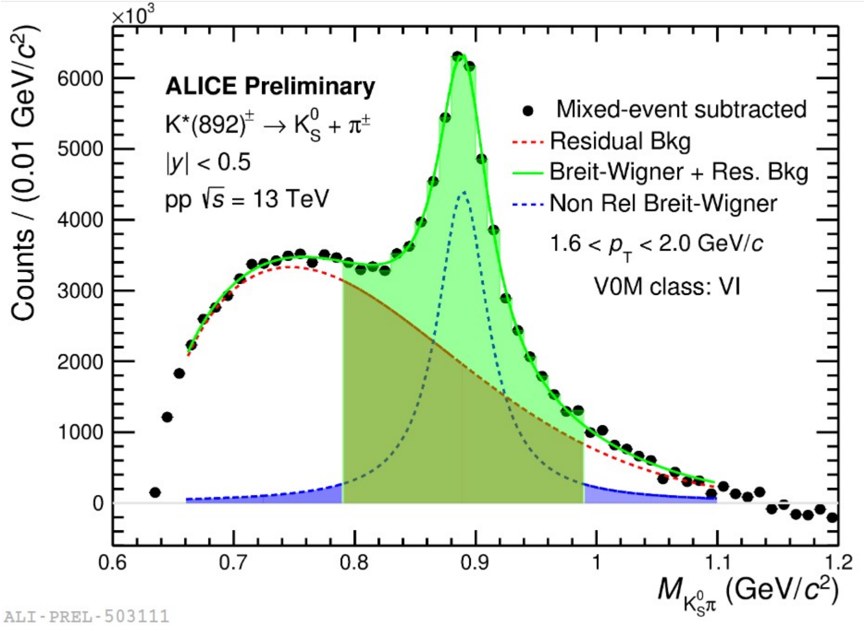
V0A and V0C

- 2 arrays of plastic scintillator hodoscopes
- Trigger, centrality/multiplicity estimator

Signal extraction

- **Resonance yield extraction** from invariant mass distribution of the decay daughters identified with TPC/TOF and topological selection criteria
- Uncorrelated background calculated via event mixing technique or like-sign pair method
- Remaining distribution fitted with a Breit-Wigner (signal) + polynomial (residual background)





p_T distributions versus event multiplicity: K*(892)$^{\pm}$

pp at $\sqrt{s}$ = 13 TeV

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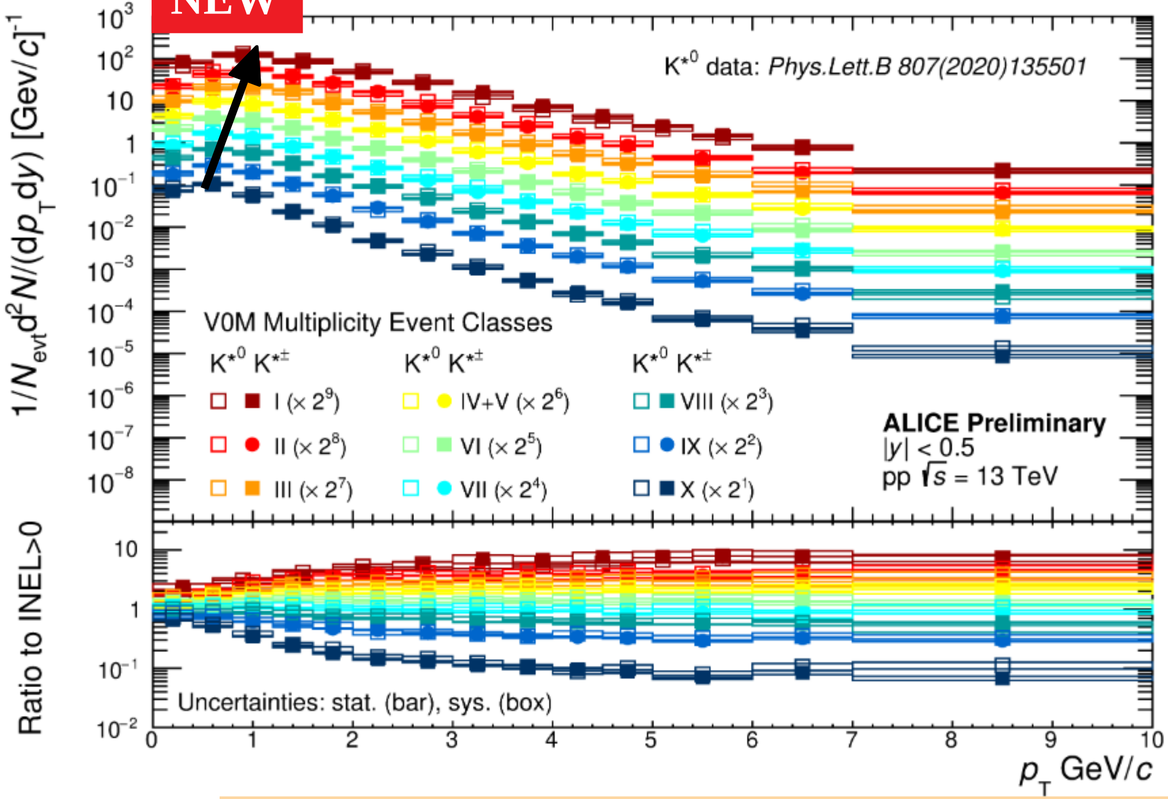


ALI-PREL-503116

Antonina Rosano, Poster Session: Resonances and Hyper-nuclei

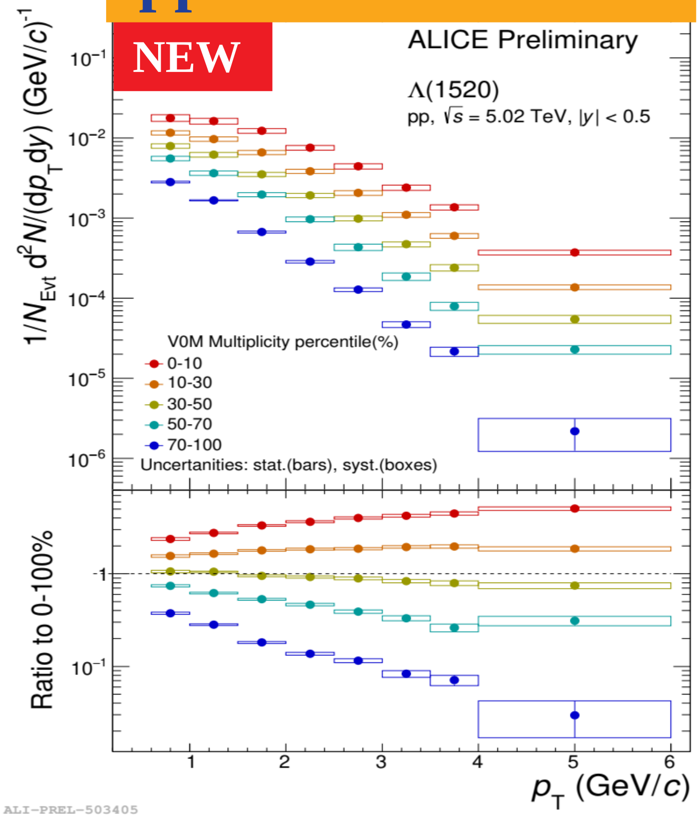
- Good agreement between K*$^{\pm}$ and K*^{0} results (isospin symmetry)
- Hardening of p_T spectra and maximum shifts with increasing multiplicity → flow-like effects

LOWER PANEL

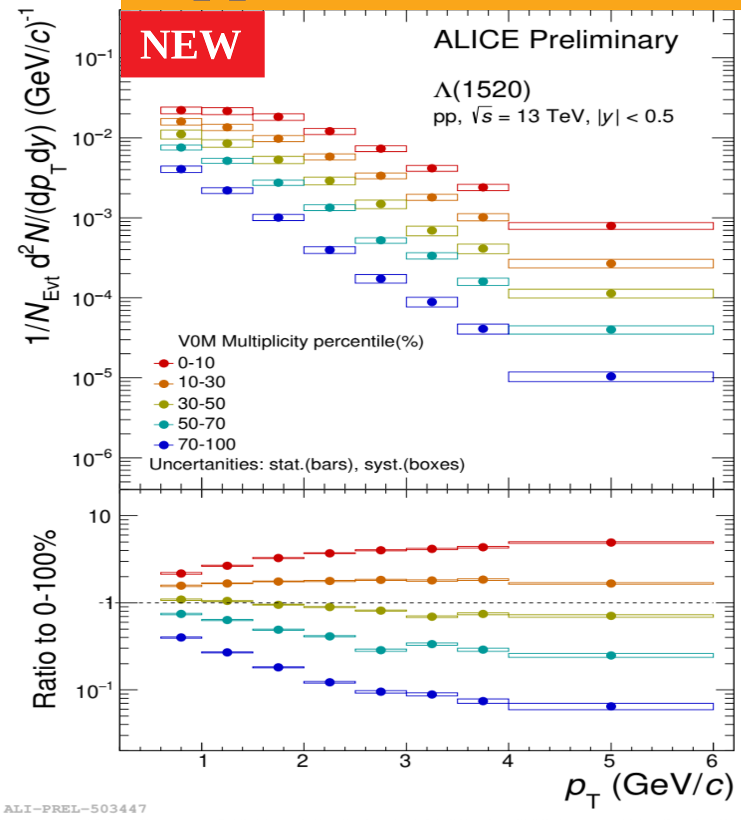
- Mean p_T increasing with multiplicity
- The process causing spectra variation is dominant at low p_T

p_T distributions versus event multiplicity: Λ(1520)

pp at √*s* = 5.02 TeV



pp at √*s* = 13 TeV

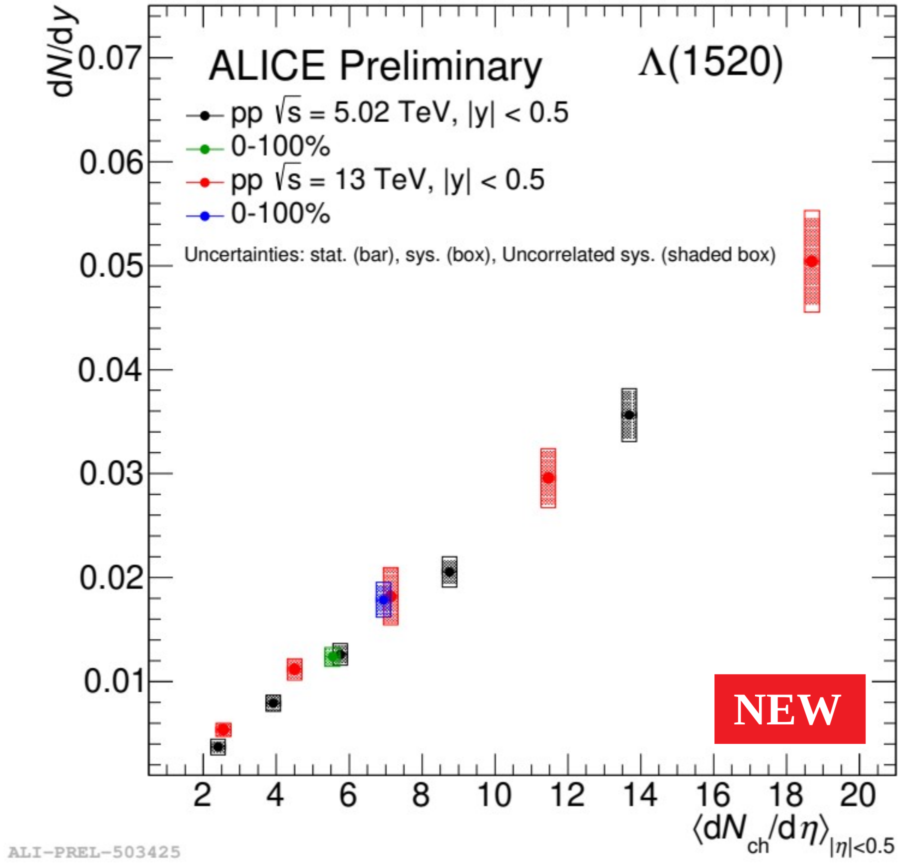


Λ(1520): same trend as $K^{*\pm}$

- The spectral shape changes with multiplicity class
- p_T distributions get harder with increasing event multiplicity

Sonali Padhan, Poster Session: Resonances and Hyper-nuclei

Integrated yield versus event multiplicity: Λ(1520)



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

- d*N*/dy spectra exhibit a linear increase with increasing $\langle dN_{ch}/d\eta \rangle$

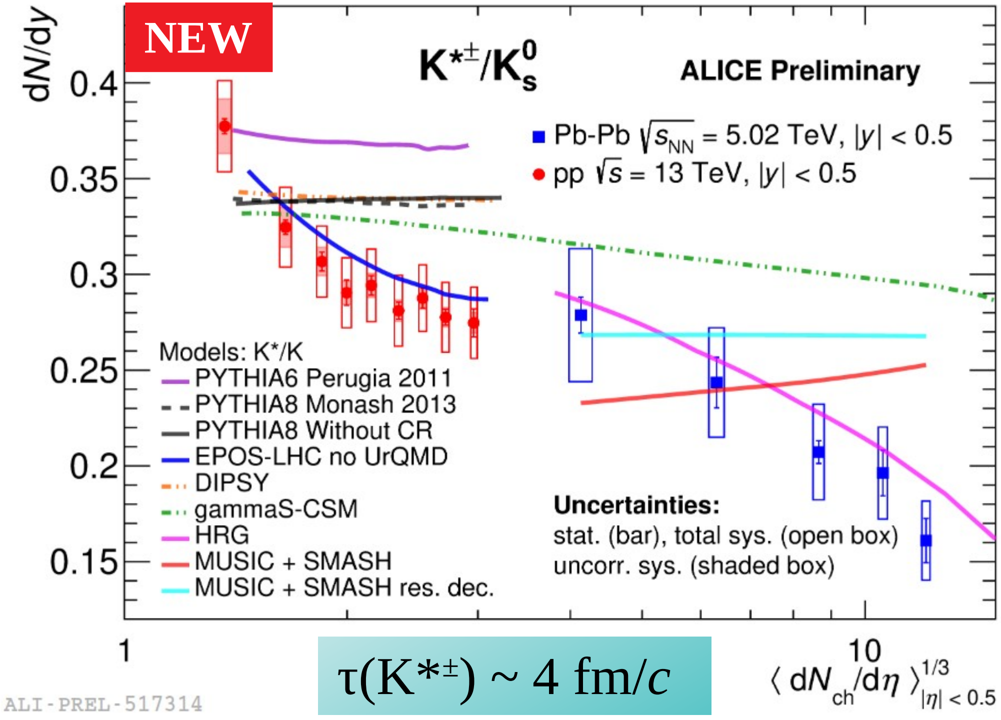
As observed for other hadron species, resonance production rate does not depend on collision energy → it is driven by the event multiplicity

Sonali Padhan, Poster Session: Resonances and Hyper-nuclei

$K^*(892)^{\pm}/K^0_S$ ratio versus event multiplicity

Antonina Rosano, Poster Session: Resonances and Hyper-nuclei

Prottay Das, Poster Session: Resonances and Hyper-nuclei



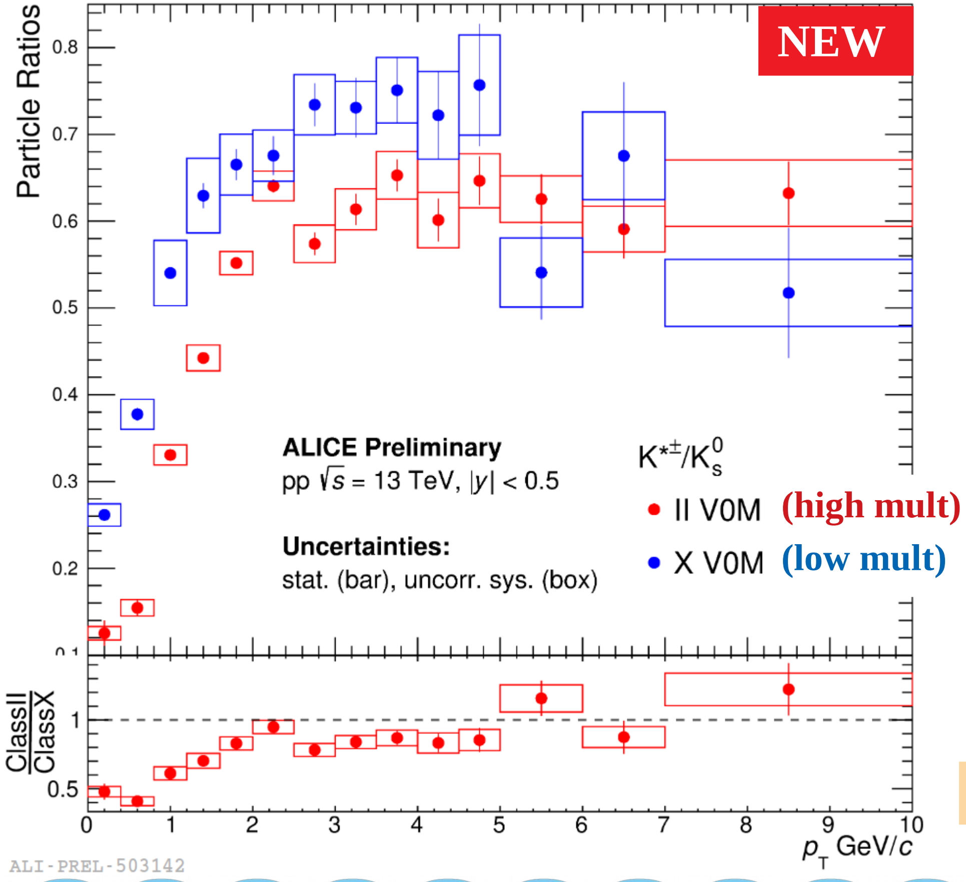
$\tau(K^{*\pm}) \sim 4$ fm/c

Model predictions are computed for K^{*0} measurements

- Suppression of $K^{*\pm}/K^0_S$ with increasing multiplicity in pp and Pb–Pb collisions
- $K^{*\pm}$ analysis in **pp @ 13 TeV** confirms, with lower systematic uncertainties, suppression observed for K^{*0} [3]
- **EPOS-LHC** for pp and **HRG** in Partial Chemical Equilibrium [4] for Pb–Pb collisions: best description
- EPOS-LHC: same treatment for pp, p–A, and A–A systems → two regions: core (high density) and corona (low density)
- Core can form in pp collisions: critical density reached because of partons multiple scattering

[3] Phys.Lett.B 807 (2020) 135501, 2020
[4] Phys. Rev. C 102, 024909 (2020)

$K^{*\pm}/K^0_S$ ratio for low and high multiplicity classes



pp at $\sqrt{s}$ = 13 TeV

- Important $K^{*\pm}/K^0_S$ **suppression** for p_T < 2.5 GeV/c (low p_T)
- Results consistent with those obtained for K^{*0}
- Stronger suppression at low p_T interpreted in A–A collisions as a signature for rescattering effects:
  - ➔ **hint** of a (short-lived) **hadronic phase** in pp collisions?

Antonina Rosano, Poster Session: Resonances and Hyper-nuclei

Λ*/Λ ratio versus event multiplicity

τ(Λ*) ~ 13 fm/*c*

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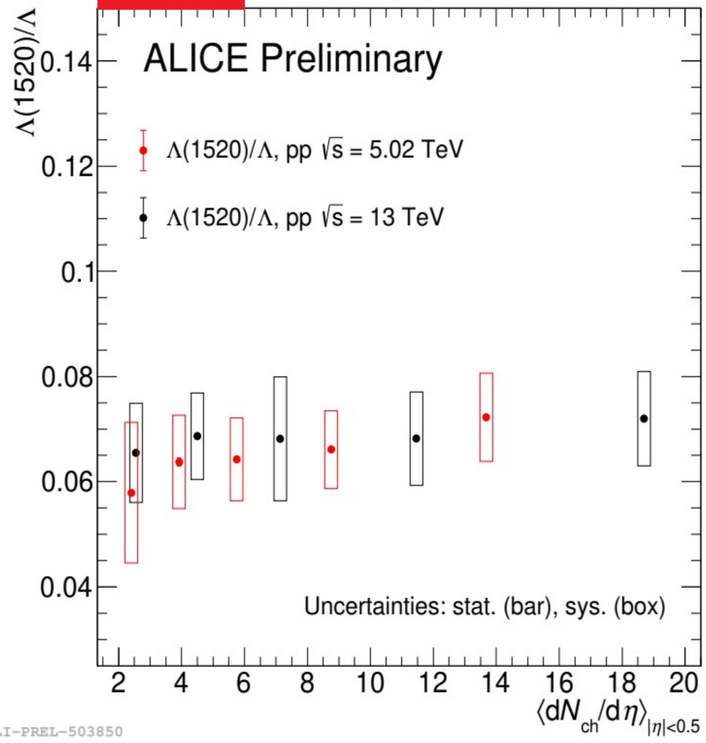

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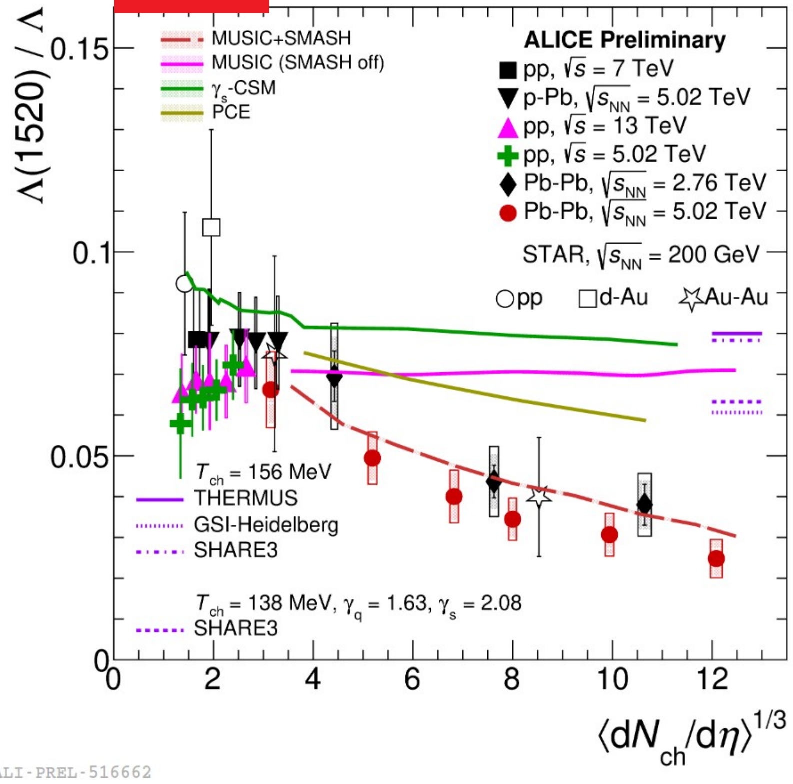
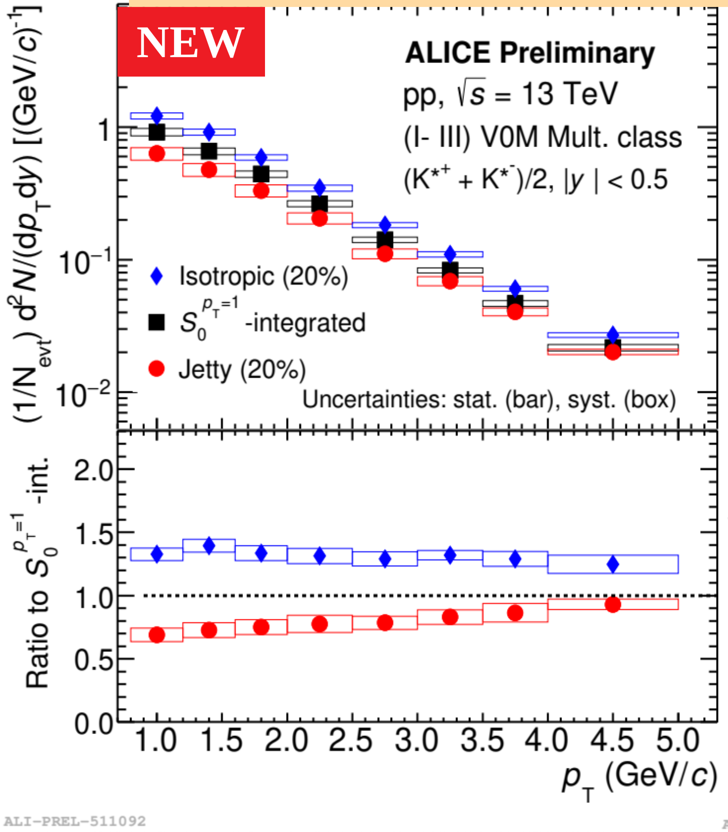


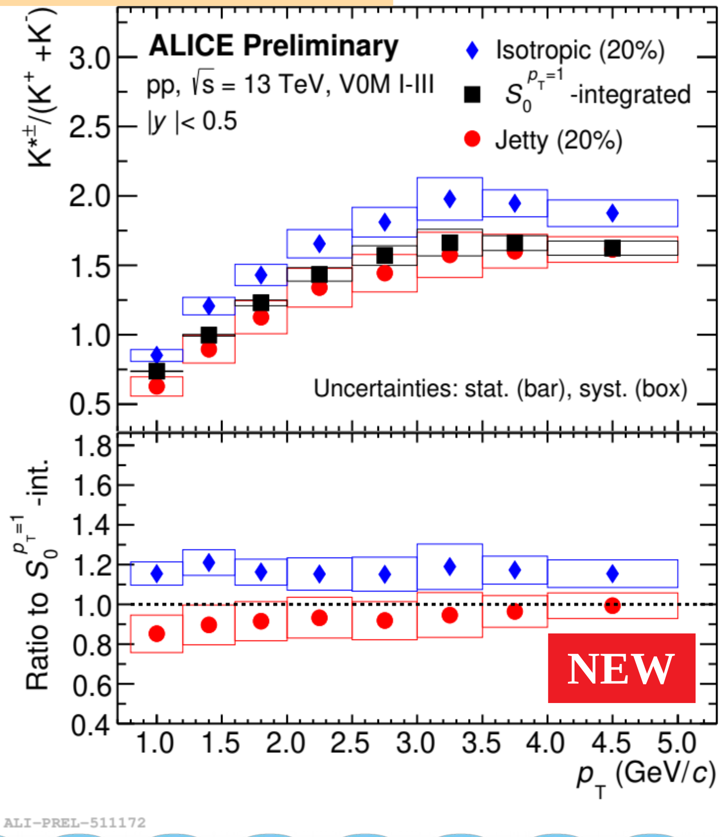
- No suppression for Λ*/Λ in pp and p–Pb collisions
- Suppression of Λ*/Λ in most central Pb–Pb collisions with respect to smaller systems and peripheral Pb–Pb
- Λ*/Λ is more suppressed w.r.t K*/K although τ(Λ*) > τ(K*)

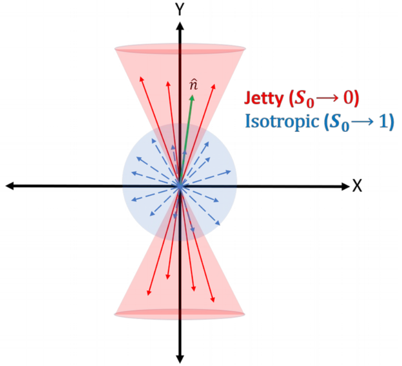
Sonali Padhan, Poster Session: Resonances and Hyper-nuclei

Transverse spherocity: K*(892)± in pp at √s = 13 TeV

Suman Deb, Poster Session: Resonances and Hyper-nuclei







p_T spectra for several spheoricity classes measured for high multiplicity events

- Dominance of isotropic events seems to decrease with increasing p_T, where jetty events take over
- $K^{*\pm}/K^{\pm}$ ratio: hint of spherocity dependence at low p_T

Measurement of ϕ meson pair in pp at √s = 7 TeV

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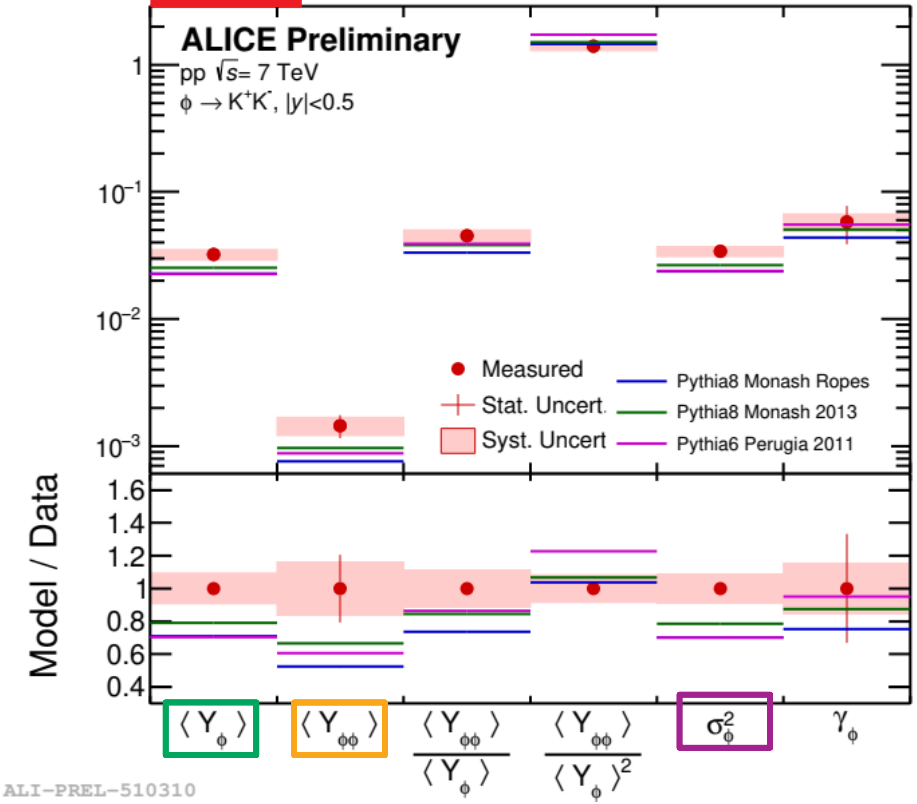


Strangeness enhancement in **small systems**:
study of double φ production in pp at √s = 7 TeV

- Inclusive ϕ meson production: $\langle Y_\Phi \rangle$

In terms of statistical properties:

$\mu = \langle Y_\phi \rangle$ Average yield of produced ϕ meson

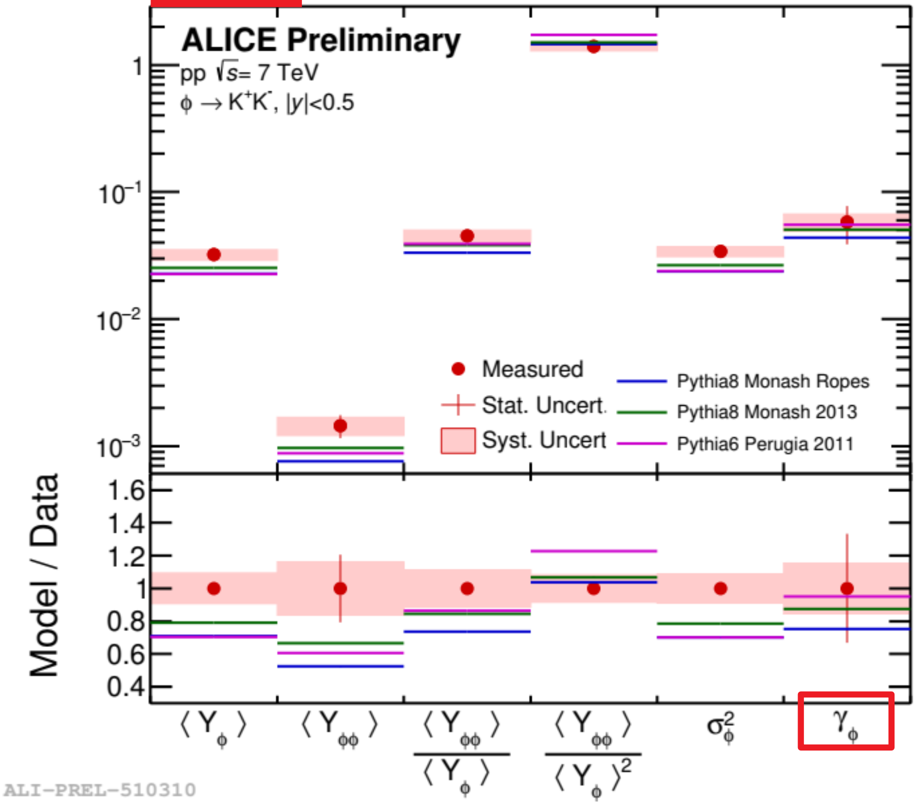
$\sigma^2 = \langle Y_\phi^2 \rangle - \langle Y_\phi \rangle^2$ Variance of produced ϕ mesons

- $\langle Y_\Phi \rangle^2$ directly measured, $\langle Y_\Phi{}^2 \rangle$ can be obtained through the ϕ meson pair production: $\langle Y_{\Phi\Phi} \rangle$

$$\langle Y_\phi^2 \rangle = 2\langle Y_{\phi\phi} \rangle + \langle Y_\phi \rangle \Rightarrow \sigma^2 = \left(2\langle Y_{\phi\phi} \rangle + \langle Y_\phi \rangle\right) - \langle Y_\phi \rangle^2$$

Measurement of ϕ meson pair in pp at √s = 7 TeV

NEW



Strangeness enhancement in **small systems:**
study of double φ production in pp at √s = 7 TeV

- **New way to characterise production:**

$$\gamma_\phi = \frac{\sigma^2}{\mu} - 1 = \frac{2\langle Y_{\phi\phi}\rangle}{\langle Y_\phi\rangle} - \langle Y_\phi\rangle$$

- γ_Φ describes the accordance with a poissonian behaviour of the production statistics:
  - If $\gamma_\Phi = 0$, **purely statistical** with a Poissonian distribution
  - If $\gamma_\Phi \neq 0$, production **enhanced** or **suppressed**

- Results:
  - $\gamma_\Phi > 0$: **non-statistical** and **enhanced**
  - PYTHIA models underestimate $\langle Y_\Phi\rangle$, $\langle Y_{\Phi\Phi}\rangle$ while γ_Φ is described quantitively

Summary

- **Small collision systems**: from benchmark measurements to results with a trend similar to Pb–Pb collisions

- **New measurements of K*(892)$^{\pm}$** consistent with the result obtained for K*(892)^{0}
  - K*$^{\pm}$/K^{0}_{S} ratio suppressed in high multiplicity pp collisions → rescattering effects or mini-plasma formation (core) in small systems too?
  - Ratio of K*$^{\pm}$/K$^{\pm}$ p_{T} spectra: hint of spherocity dependence

- **New measurements of Λ(1520)**
  - Λ(1520)/Λ ratio suppressed in central Pb–Pb collisions. No suppression in pp and p–Pb collisions

- **ϕ meson pair production**
  - Strangeness production in pp collisions: deviations from a Poissonian distribution

Thank you for your attention

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Backup

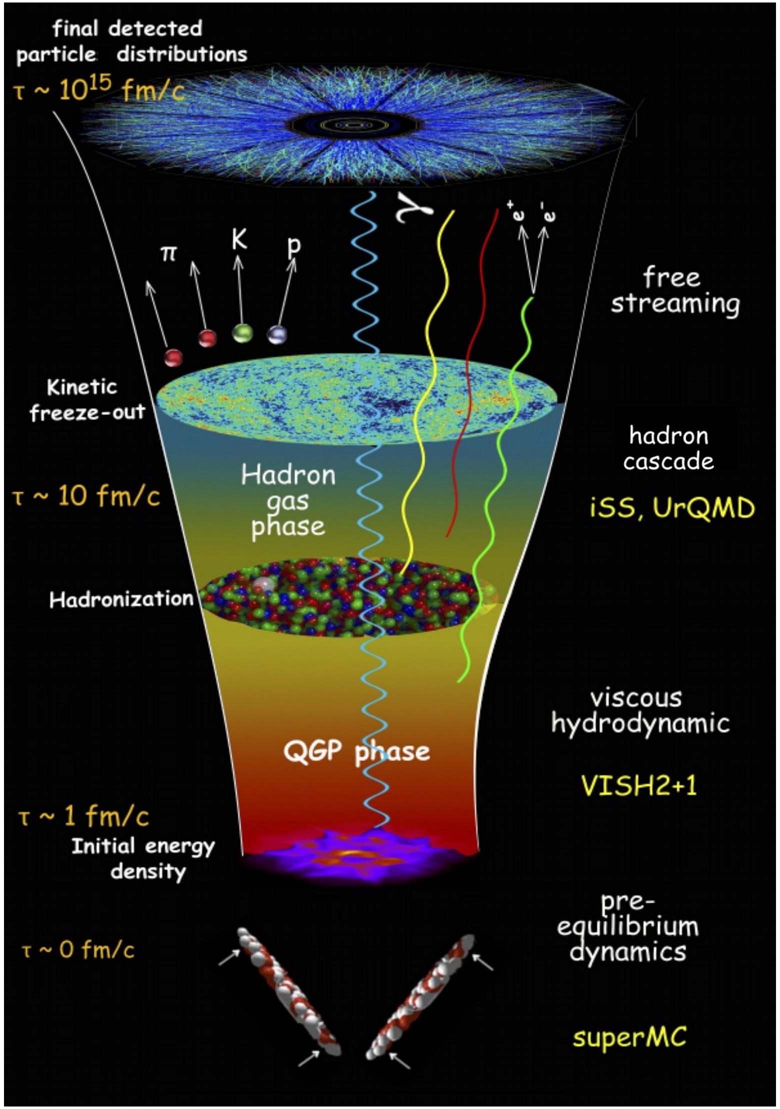
Introduction

- Hadronic resonances are the perfect probes to characterize the system formed in heavy-ion collisions at ultrarelativistic energies

- If the critical condition of temperature and energy density are satysfied (T_C ~170 MeV and ε_C ~1 GeV/fm^3), system evolves following several stages: Pre-equilibrium → QGP → Hadronization → Chemical freeze-out → Kinetic freeze-out

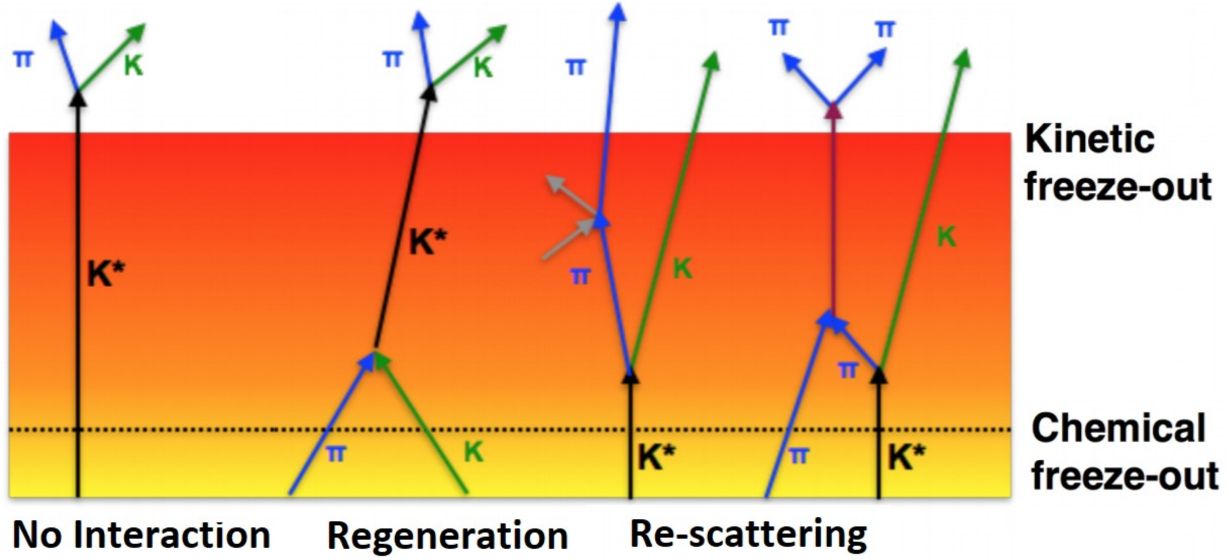
- In particular the phase between chemical and kinetic freeze-out is known as **hadronic phase**

- Small collision systems (pp and p–Pb):
  - ➢ Used as a baseline for heavy-ion collisions
  - ➢ Recent results on resonance production show the onset of phenomena typical of heavy-ion collisions, like collective behaviour and suppression of the yield ratios of resonances to stable particles



Hadronic phase

Resonances with a lifetime comparable to the one of the hadronic phase are particularly interesting because they may be sensitive to the competing **rescattering** and **regeneration** effects



Regeneration: a given resonance can be regenerated as a consequence of pseudo-elastic collisions of the particles medium → signal gain: yield enhancement.

Re-scattering: resonance decay daughters interact with other particles of the hadronic medium → signal loss: yield suppression.

Long-lived resonances, like Ξ(1530) and φ(1020), decaying outside the hadronic medium do not undergo any such processes

Main resonances studied by ALICE

Yields at kinetic freeze-out depend on:

- Resonance and hadronic phase lifetime
- Yields at the chemical freeze-out
- Scattering cross sections of decay products

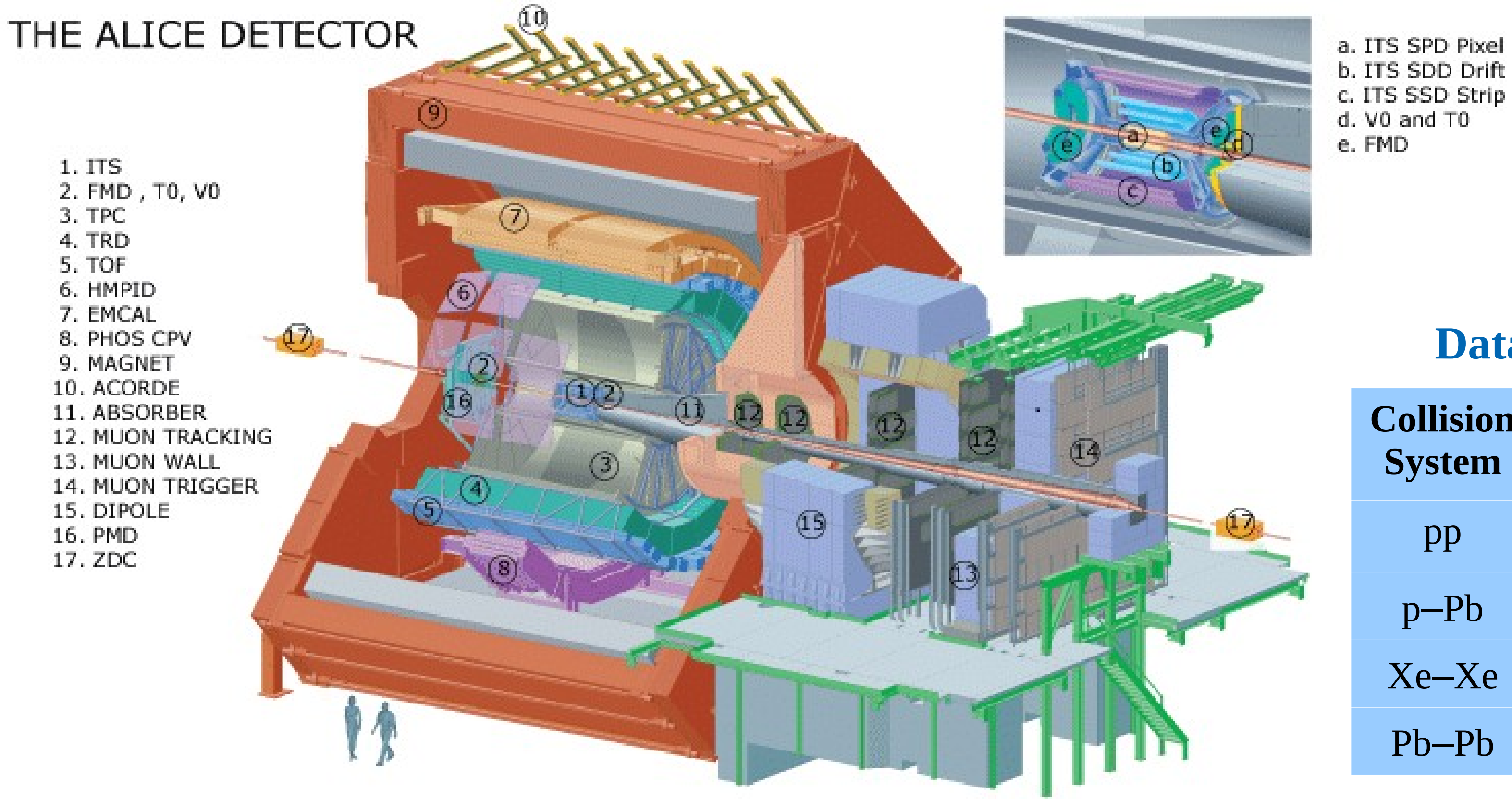
Resonance yields encode the effects of interaction during the hadronic phase!

Lifetime →

Resonance	ρ(770)⁰	K*(892)±	K*(892)⁰	f₀(990)	Σ(1385)±	Ξ(1820)±	Λ(1520)	Ξ(1530)⁰	φ(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	dss	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	ππ	K^0_s π	K π	$\pi^+\pi^-$	Λ π	Λ K	p K	Ξ π	K K
B.R.(%)	100	33.3	66.6	46	87	unknown	22.5	66.7	48.9

Fireball lifetime: $\tau \sim$ 10 fm/c at LHC energies

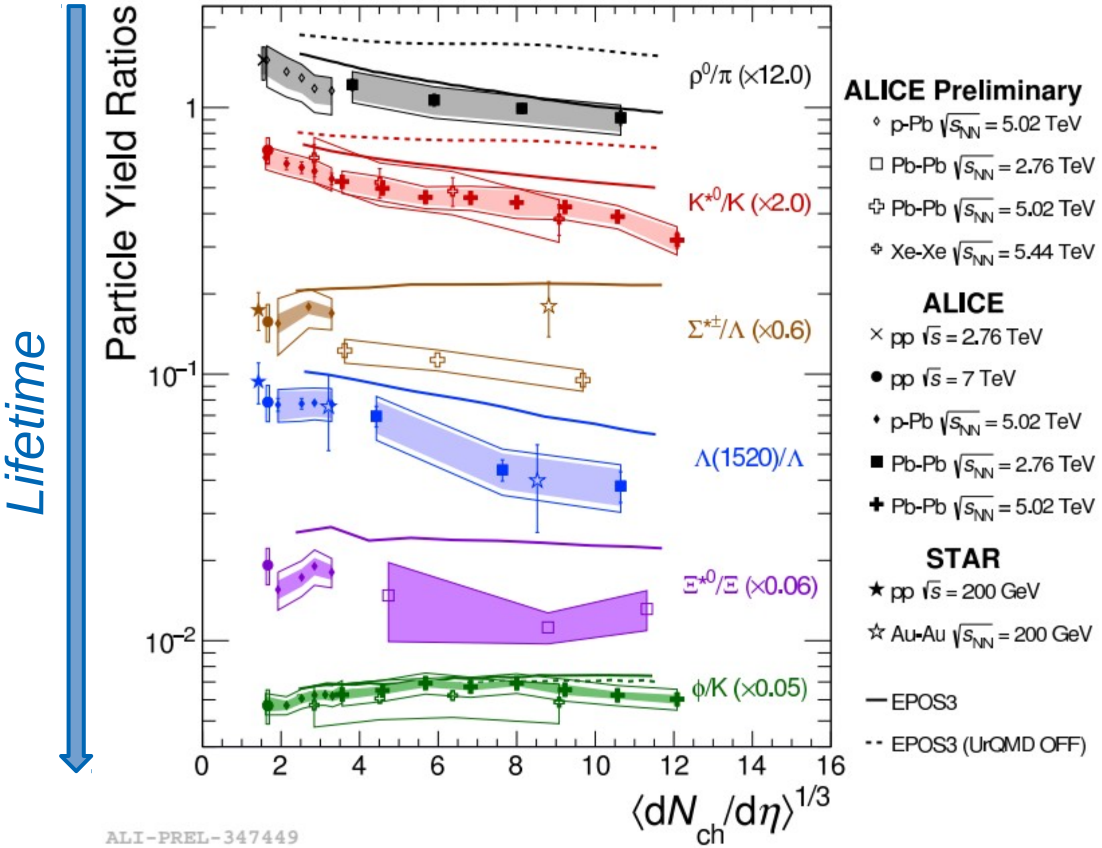
The ALICE detector



Data colected from:

Collision System	$\sqrt{s_{NN}}$ (TeV)
pp	0.9, 2.76, 5.02, 7, 8,13
p–Pb	5.02, 8.16
Xe–Xe	5.44
Pb–Pb	2.76, 5.02

Overview on resonance production



Small collision systems (pp, p–Pb):

- **ϕ/K $\Sigma^{*\pm}/\Lambda$ $\Lambda(1520)/\Lambda$**, and **Ξ^{*0}/Ξ** ratios are independent on charged particle multiplicity
- **ρ^0/π, K^{*0}/K** → hint of suppression (possible re-scattering effect)

Heavy-ion collision systems (Pb–Pb, Xe–Xe):

- **ρ^0/π, K^{*0}/K, $\Sigma^{*\pm}/\Lambda$**,and **$\Lambda(1520)/\Lambda$** ratios are suppressed with respect to pp, p–Pb and peripheral Pb–Pb: dominance of re-scattering compared to regeneration
- **ϕ/K**, and **Ξ^{*0}/Ξ** no suppression: larger lifetime → decay outside the medium

New results for $K^*(892)^{\pm}$, $\Lambda(1520)$, and $\phi(1020)$ will be shown here