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National and Kapodistrian
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ALICE

# Hadronic resonance production measured by ALICE at the LHC

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National and Kapodistrian University of Athens
Physics Department

ICNFP2018

# Outline

- Introduction
- ALICE Detector and PID
- Resonance production in pp, p-Pb, Xe-Xe and Pb-Pb collisions:
  - signal extraction
  - transverse momentum spectra
  - particle ratios
  - strangeness production
  - nuclear modification factors
- Conclusions

# Introduction

ALICE is designed to study the physics of strongly interacting matter under extremely high temperature and energy density conditions to investigate the properties of the quark-gluon plasma (QGP)

The Experiment has collected data from:

- **pp collisions at $\sqrt{s}$ = 0.9, 2.76, 5.02, 7, 8, 13 TeV**
  - Test QCD inspired models
  - Provide reference for p-Pb and Pb-Pb data
- **p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02, 8.16 TeV**
  - Discriminate between initial (cold nuclear matter) and final state (QGP) effects
  - Provide reference for Pb-Pb data
- **Xe-Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV**
  - Study the colliding system size dependence
- **Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76, 5.02 TeV**
  - Study QGP properties and its evolution

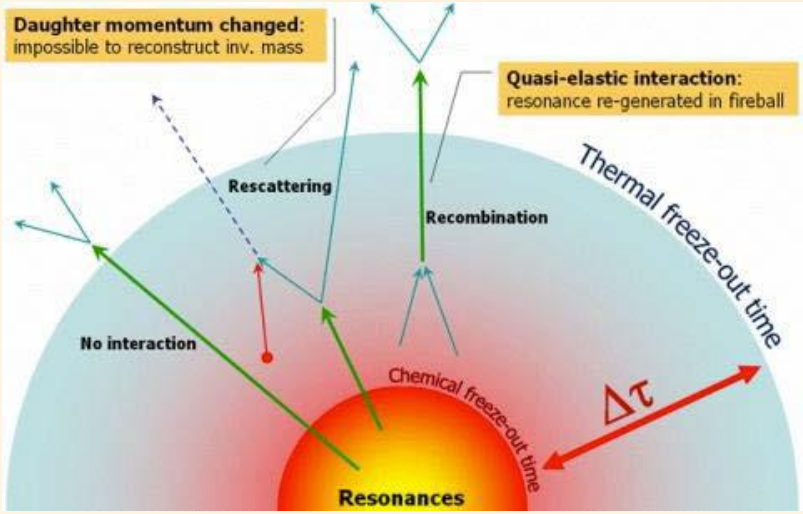
# Introduction

**Measuring short lived resonances in their hadronic decay channel in Pb-Pb collisions :**

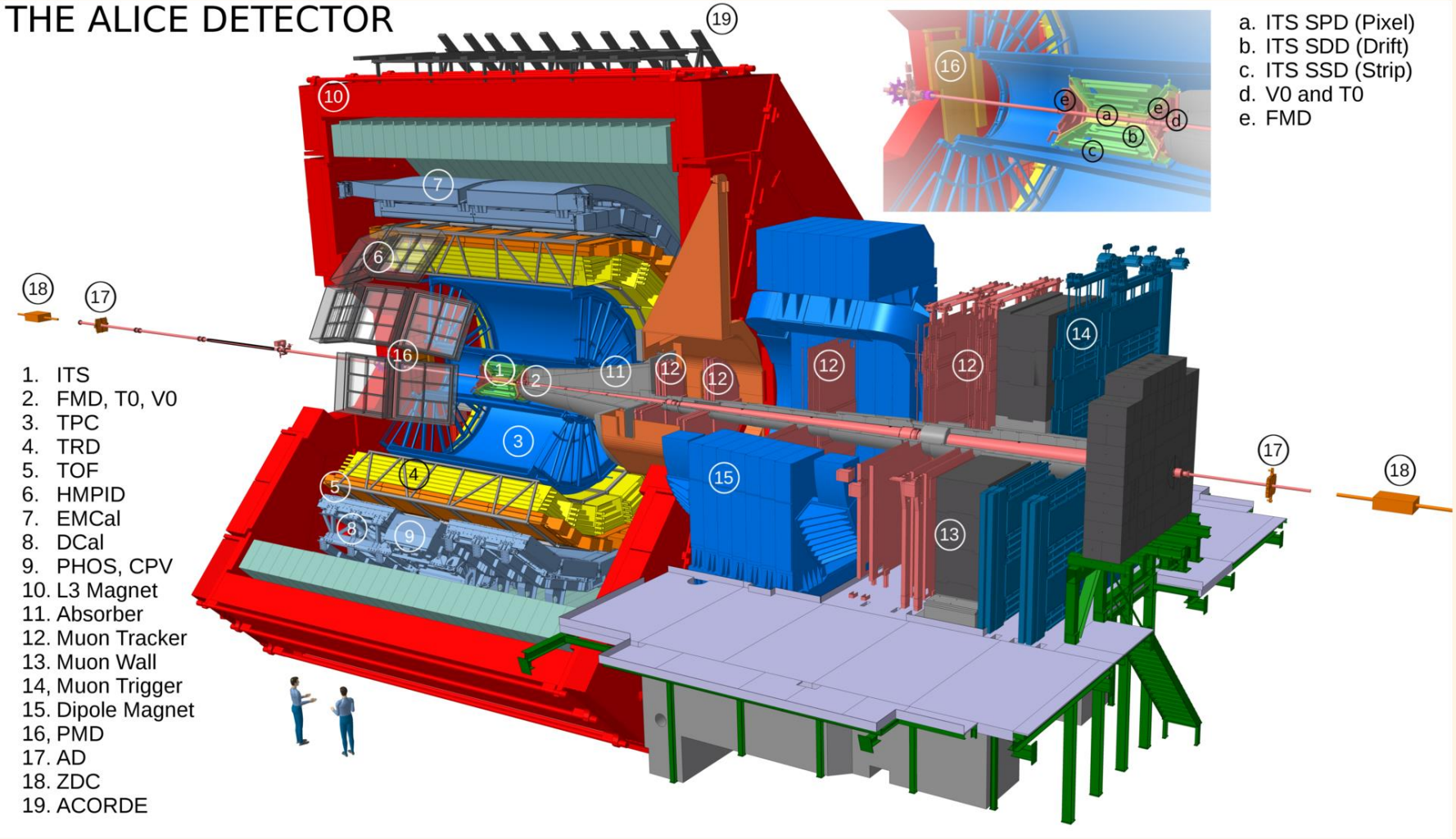
- in-medium energy loss → nuclear modification factors
- regeneration and re-scattering effects → modification of yield and particle ratios

**Lifetime(fm/c)**:

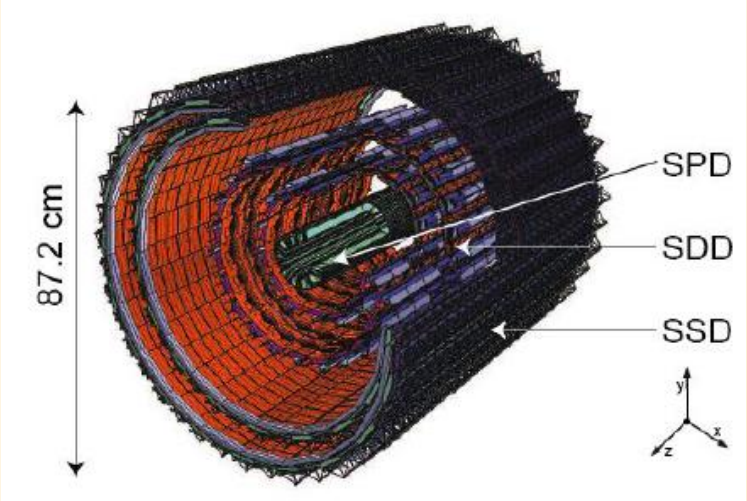
$\rho^0$ (1.3) < $K^*$(4.2) < $\Sigma^*$(5.5) < $\Lambda^*$(12.6) < $\Xi^*$(21.7) < $\phi$(46.2)

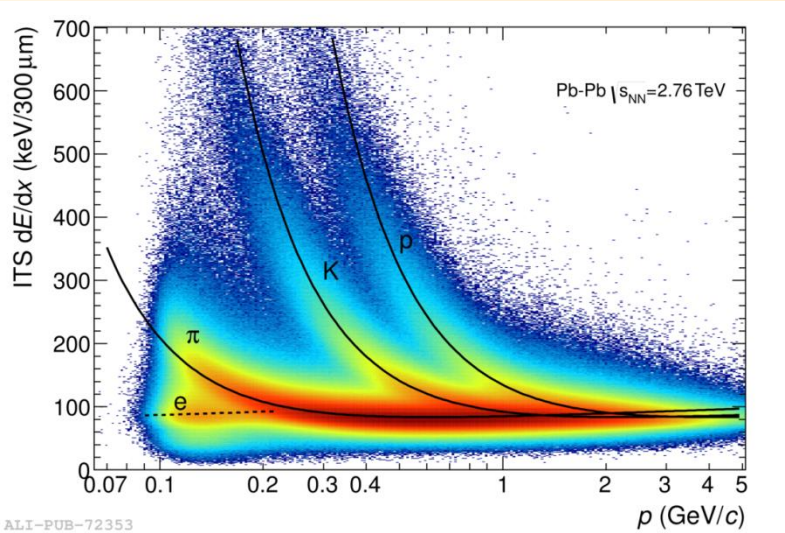


# ALICE Detector



# ITS



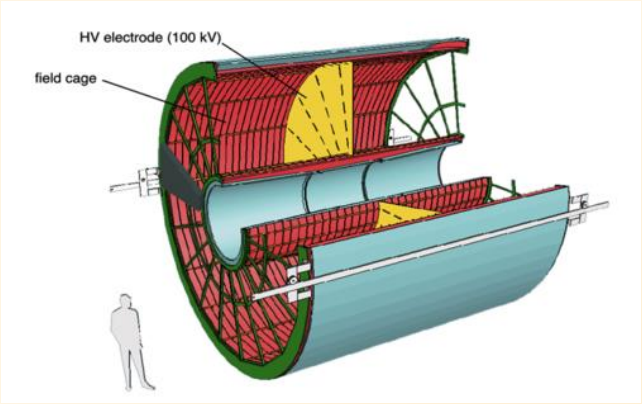

ALICE, Int. J. Mod. Phys. A29 (2014) 1430044

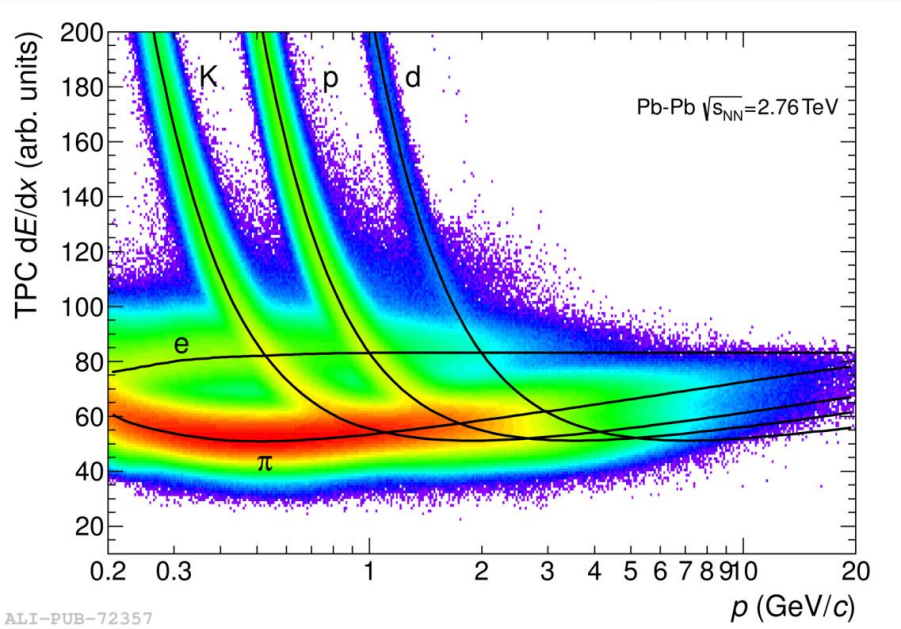
- Inner Tracking System:
  2 layers of Silicon Pixel Detector (SPD)
  2 layers of Silicon Drift Detector (SDD)
  2 layers of Silicon Strip Detector (SSD)

- Drift and Strip Detectors provide a measurement of the ionization energy loss

- PID to very low $p_T$:
  pions down to 100 MeV/c with stand-alone tracking

# TPC

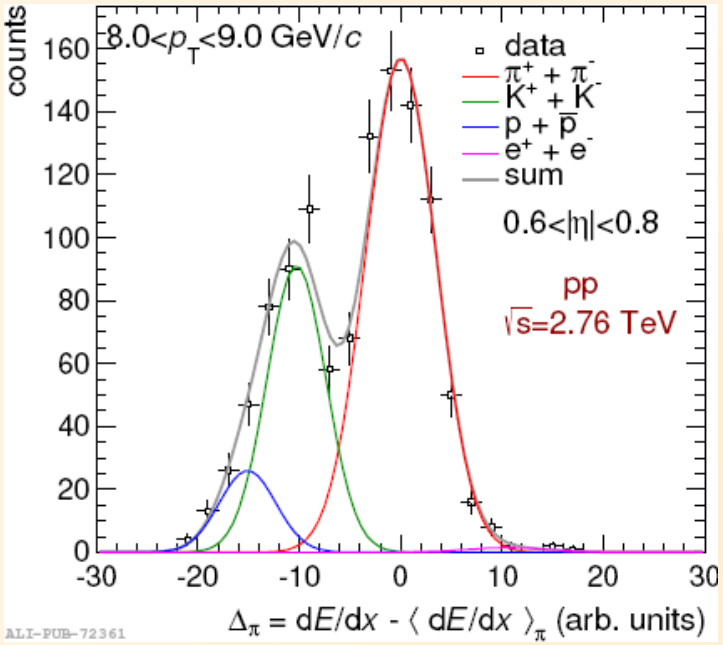


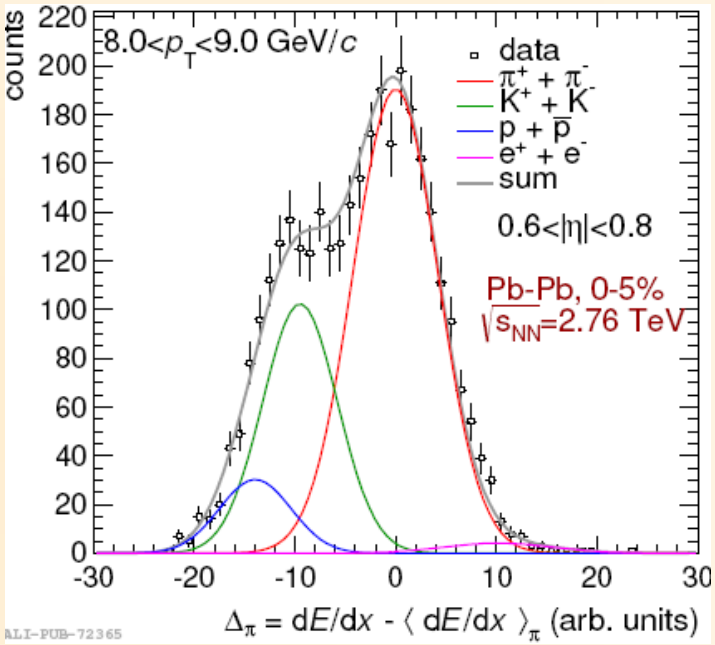




ALICE, Int. J. Mod. Phys. A29 (2014) 1430044

- PID via d$E$/d$x$ in gas – Ar/$CO_2$ (90:10) – up to 159 samples
- Truncated mean d$E$/d$x$ calculated and used for particle identification (PID) in a wide momentum range
- Largest π/K and K/p separation achieved at low $p$ (< 2.0 GeV/$c$)

# TPC

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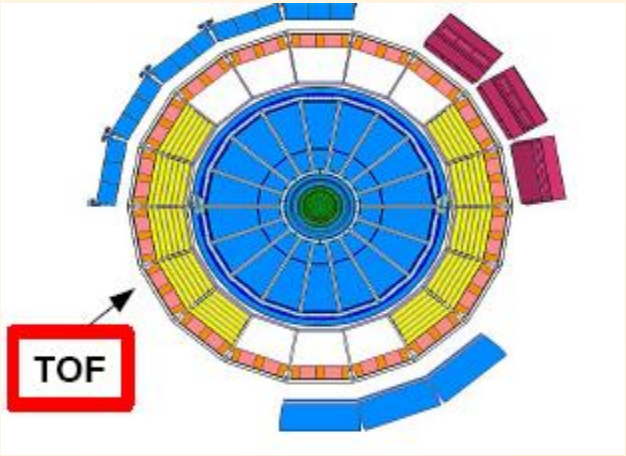
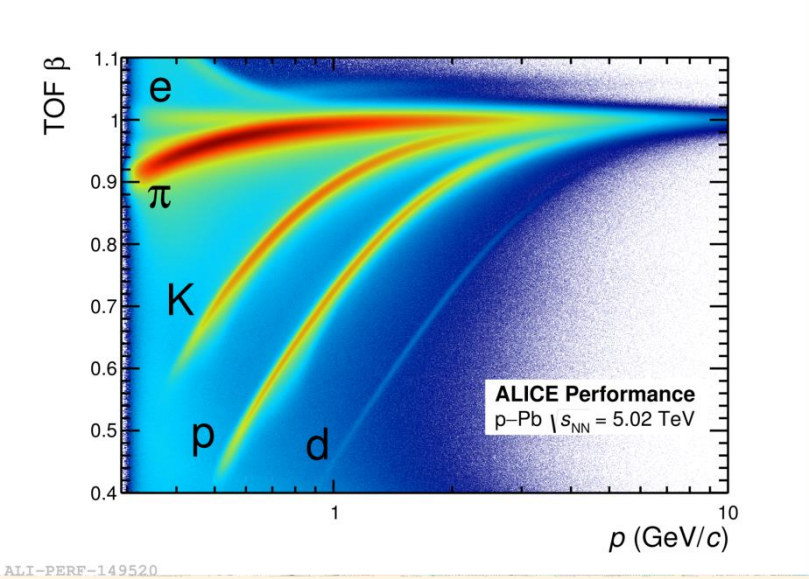
- At high $p_T$ : particles separated on a statistical basis via multi-Gaussian fits

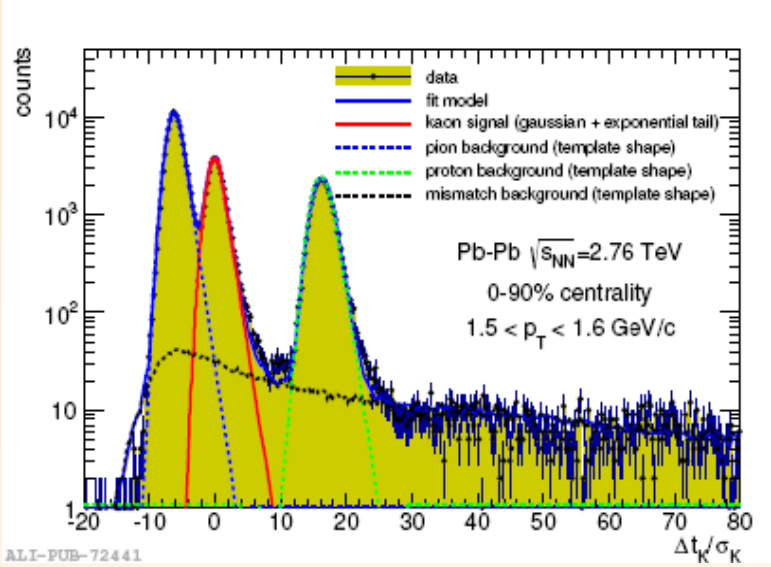
# TOF



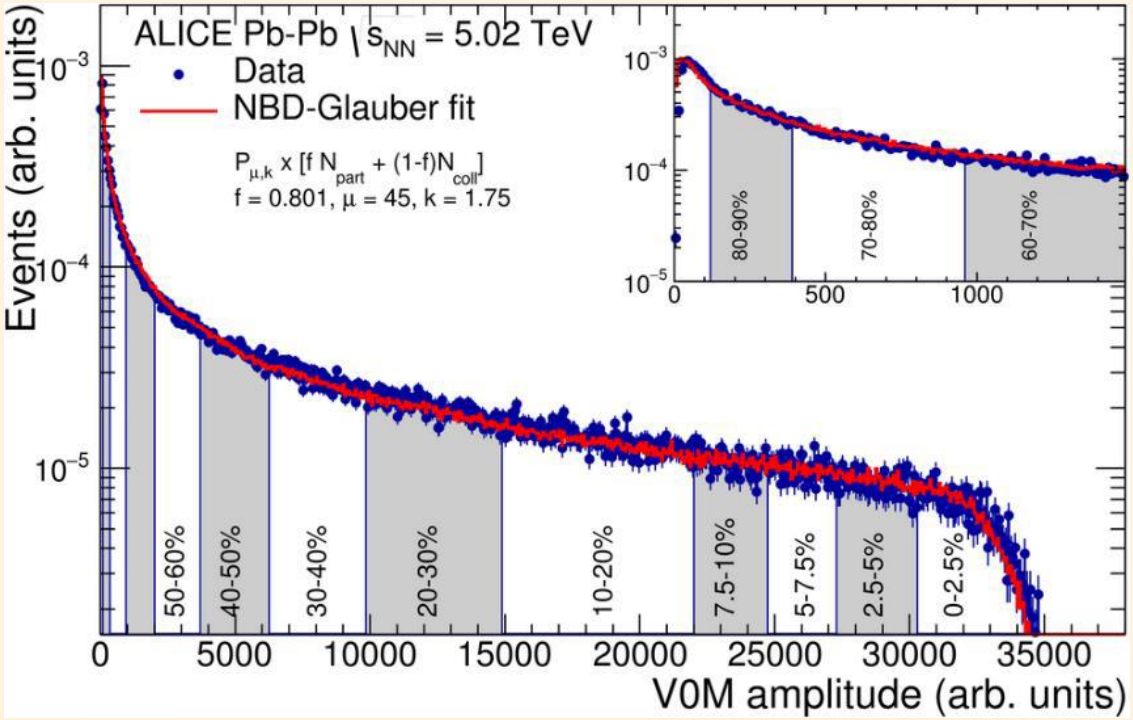

- Time - Of - Flight:
  Multigap Resistive Plate Chambers (MRPC)
  PID at intermediate momenta

- Resolution ~ 80 ps



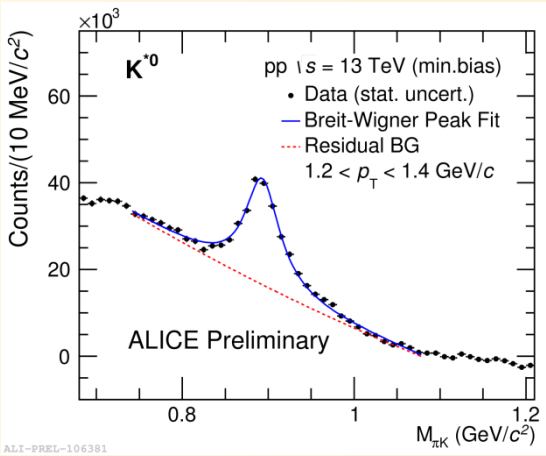
# Centrality Selection in Pb-Pb Collisions

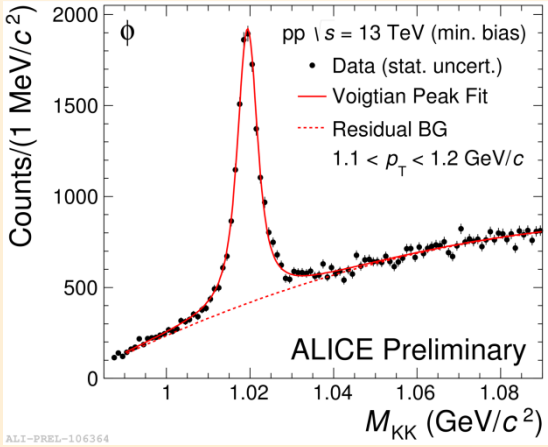


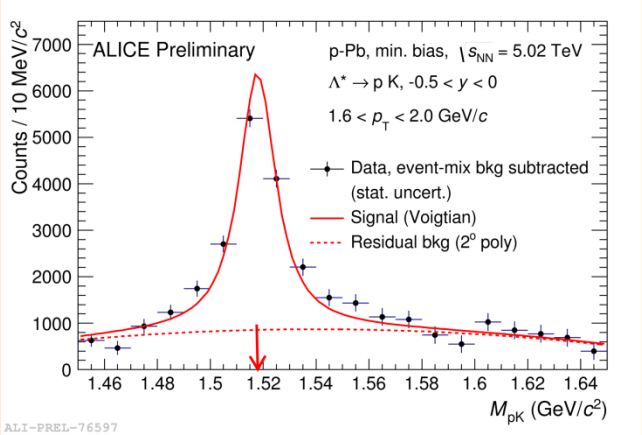

- Event centrality classes are defined based on the amplitude measured in the V0 scintillators placed at : 2.8<η<5.1 (V0A) and -3.7<η<-1.7 (V0C)
- Curve: Glauber model fit to the measurement

# pp, p-Pb and Xe-Xe Collisions

# Signal extraction

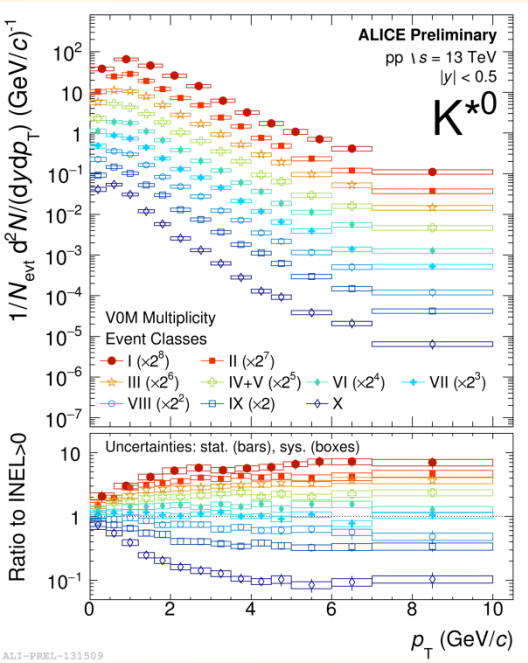


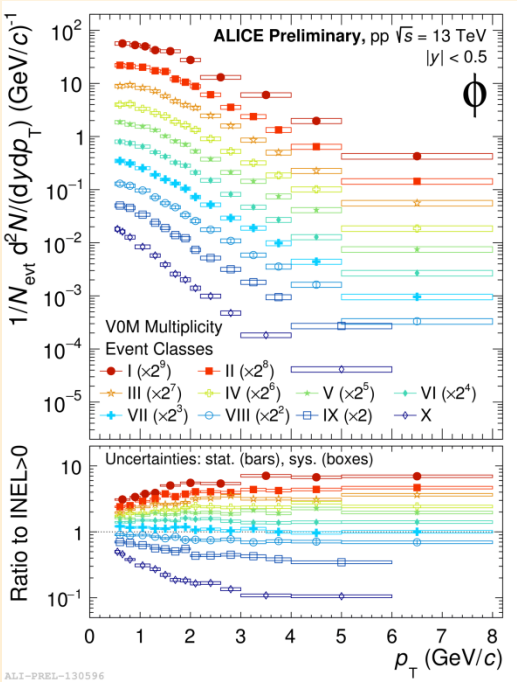



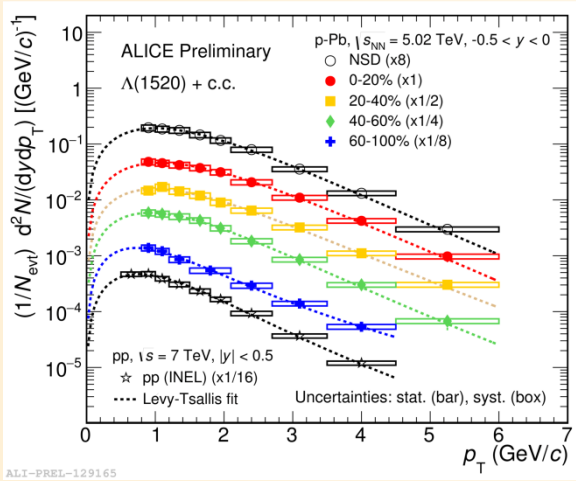




- Invariant-mass distribution of **K*0** and **ϕ** in pp @ √s = 13 TeV and **Λ*** in p-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV

# Transverse momentum spectra



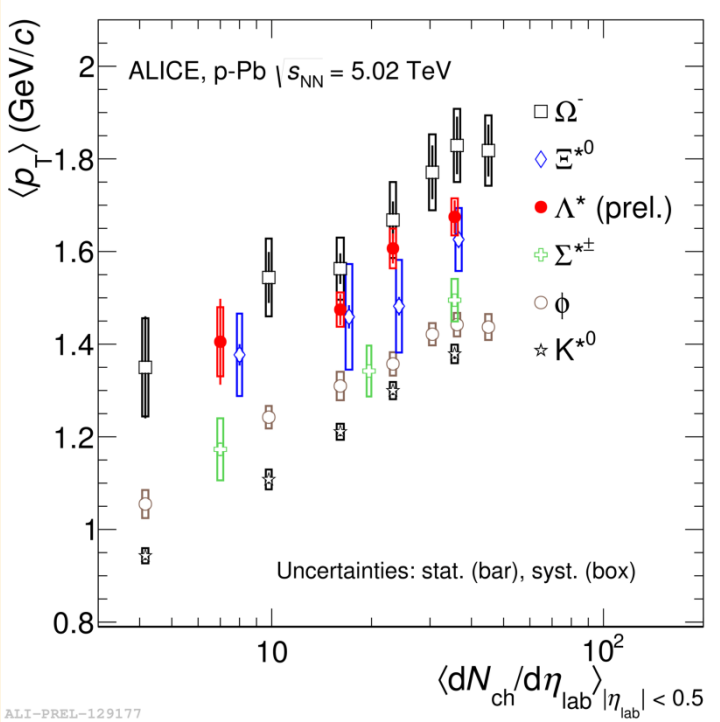



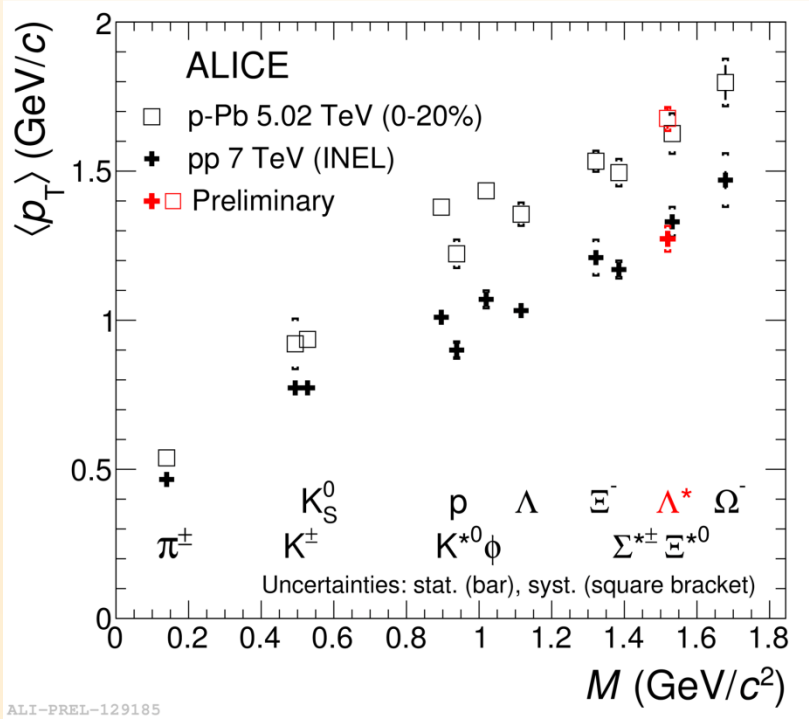




- Transverse momentum spectra of **K*⁰** and **ϕ** in pp @ √s = 13 TeV and **Λ*** in p-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV for different multiplicity /centrality classes

- Slope of the $p_T$ spectrum increases with increasing multiplicity/centrality

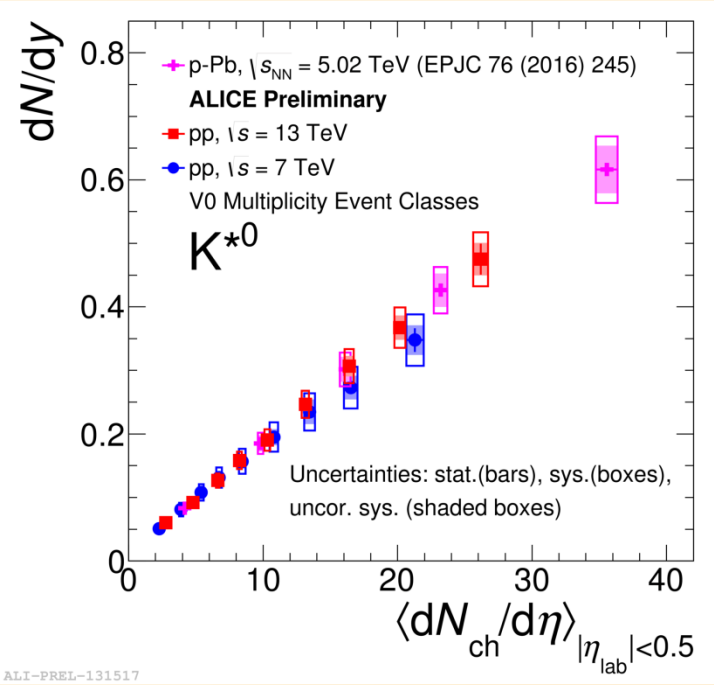
# Mean transverse momentum

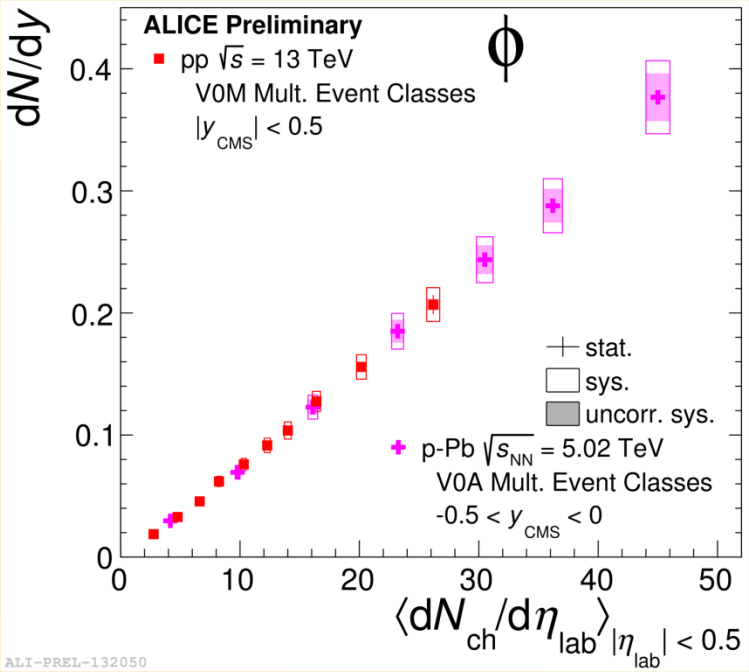



- $< p_T >$ increases from lowest to highest multiplicity events
- $< p_T >$ of **Λ*** and **Ξ*** are compatible due to similar mass
- In both systems $< p_T >$ increases with mass in a qualitatively similar way

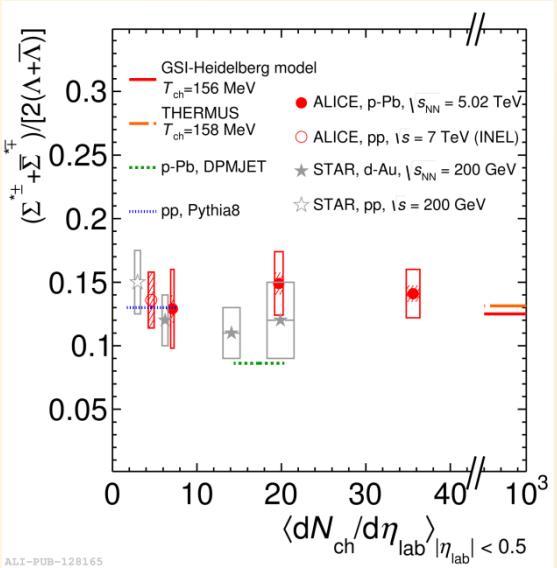
# Integrated yield vs. multiplicity

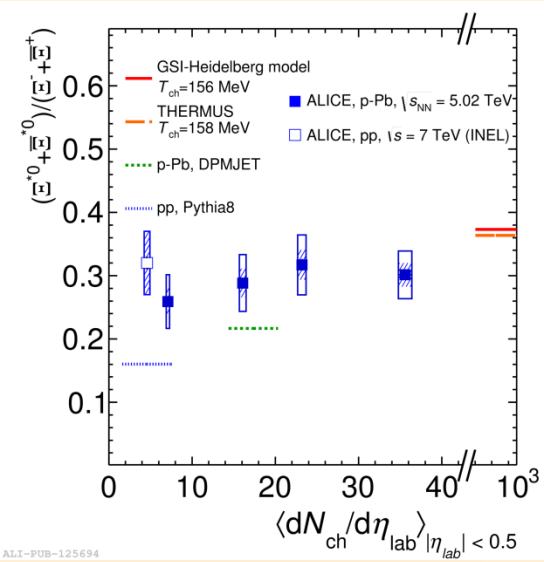


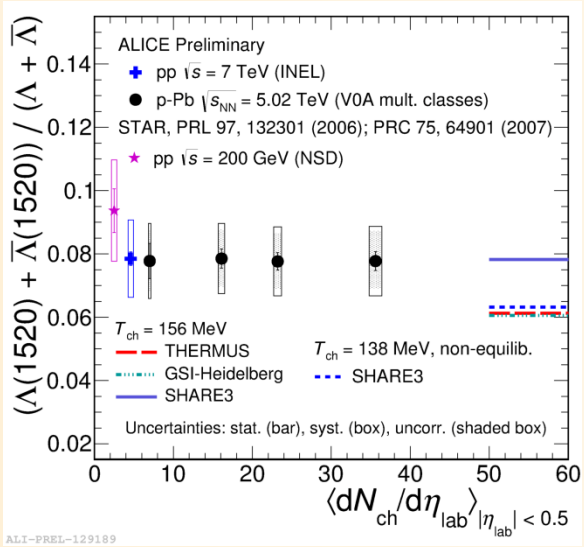




- Integrated yield increases with multiplicity
- All measurements consistent with each other and fall on a single line
- Particle production independent of colliding system, energy and driven by multiplicity

# Strange resonance production



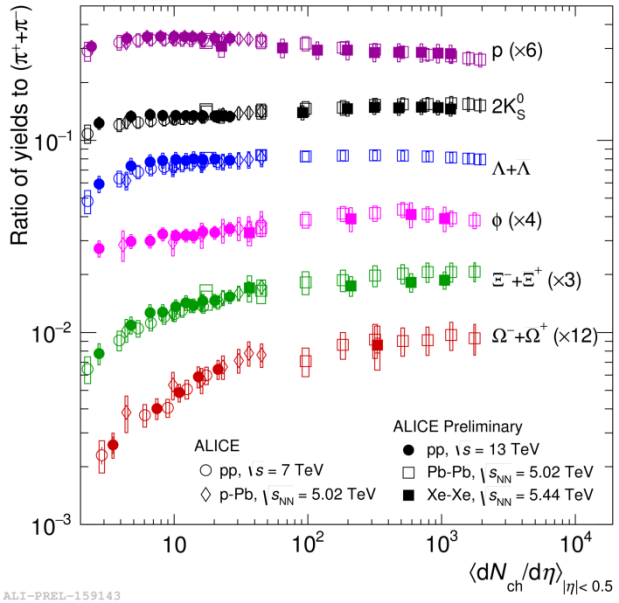



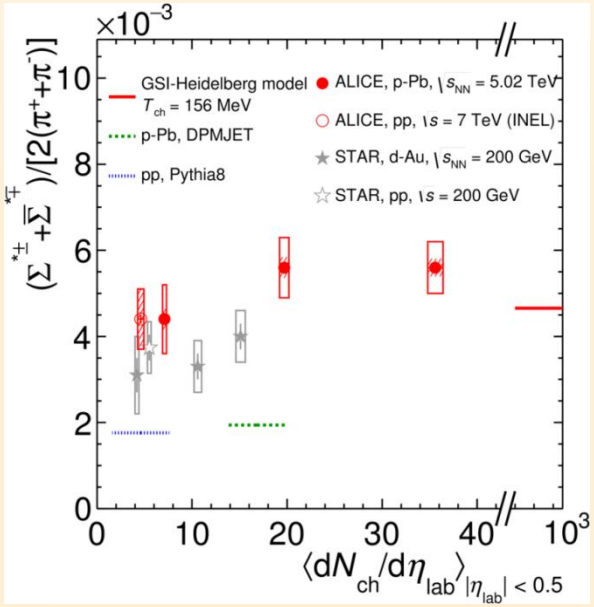



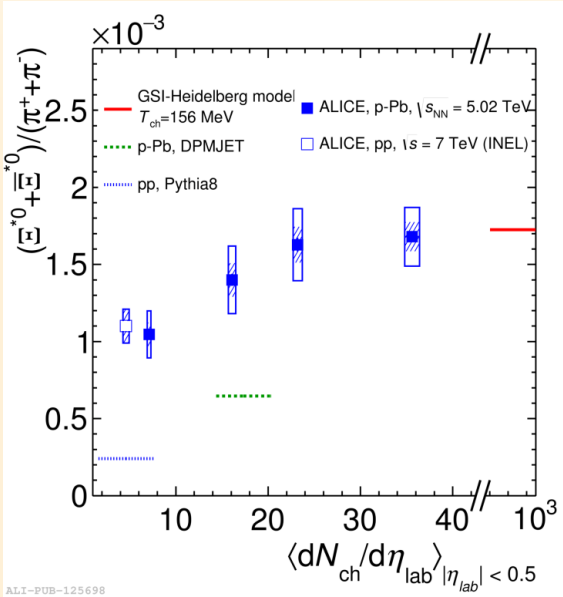

ALICE, Eur. Phys. J. C77 (2017) 389

- Ratio of resonance to stable particle with same strangeness content has no multiplicity dependence

# Strangeness production



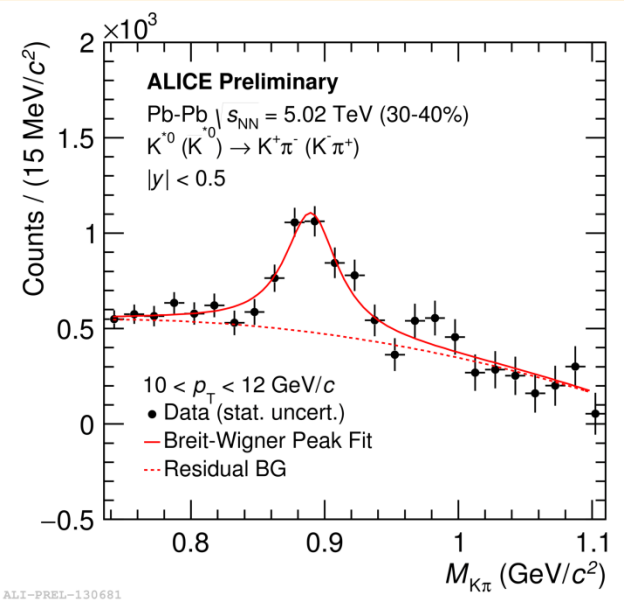



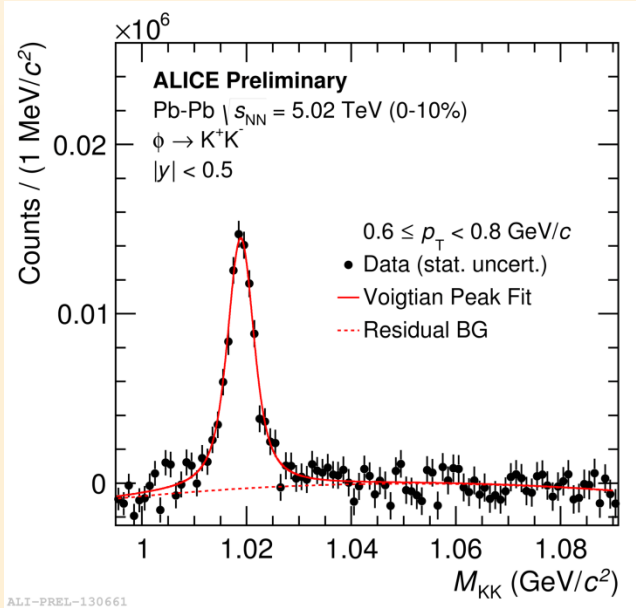

ALICE, Eur. Phys. J. C77 (2017) 389
ALICE, Nature Physics 13 (2017) 535

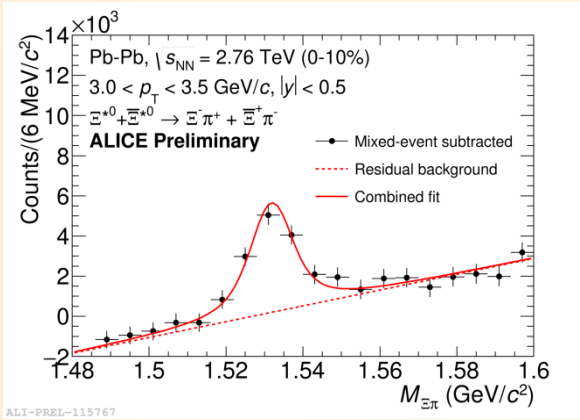
- First observation of enhanced production of strange particles in high-multiplicity pp collisions
- Increasing pattern depends only on strangeness content and not on particle mass: enhancement of higher mass resonances is the same as for the lower mass ground-state particle with the same strangeness content

# Pb-Pb Collisions

# Signal extraction

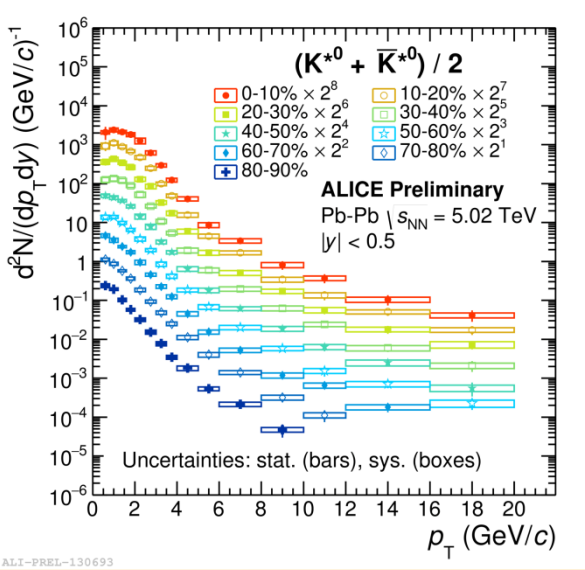


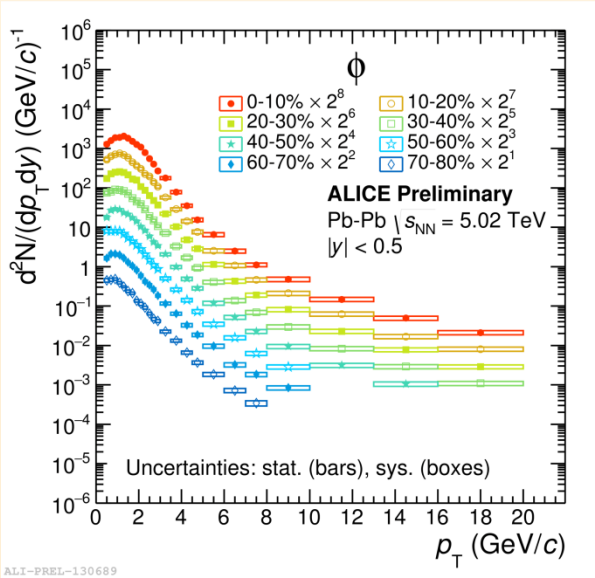



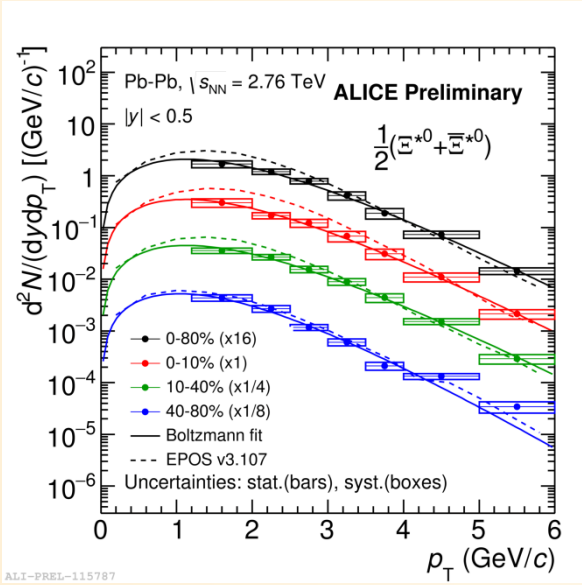




- Invariant-mass distribution of **$K^{*0}$** and **φ** in Pb-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV and **Ξ*** in Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV

# Transverse momentum spectra

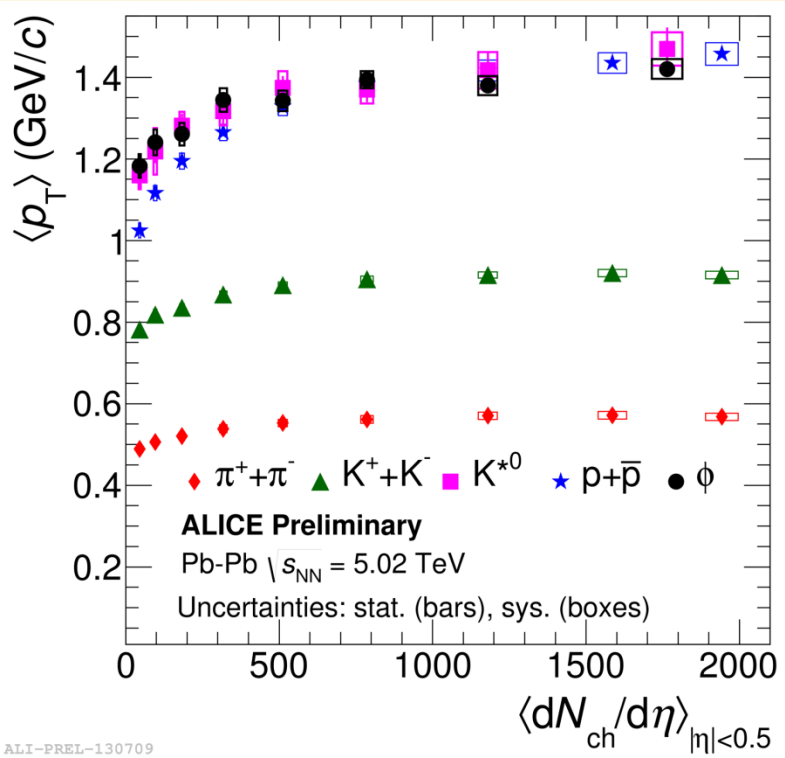


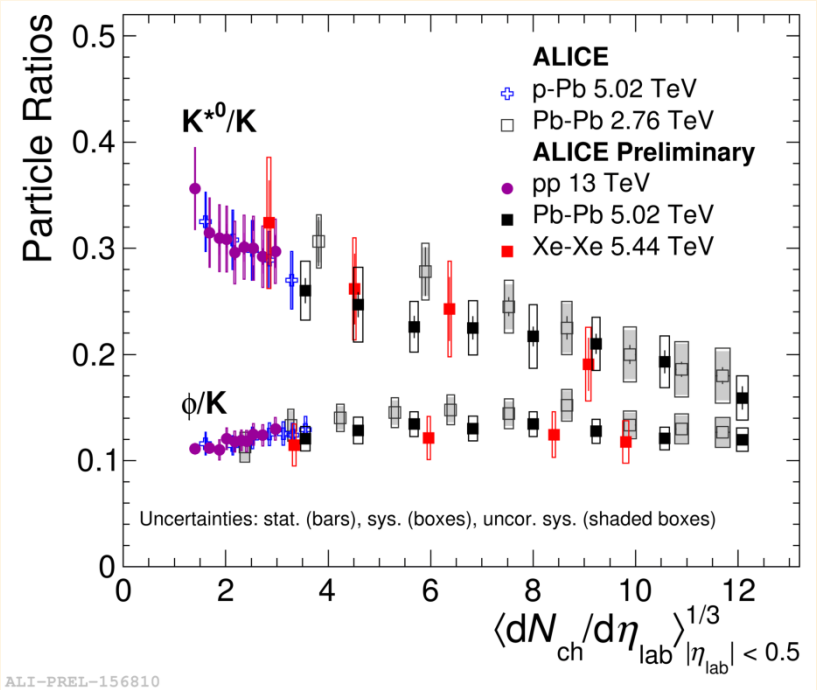

- Transverse momentum spectra of **$K^{*0}$** and **$\phi$** in Pb-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV and **$\Xi^*$** in Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV

# Mean transverse momentum



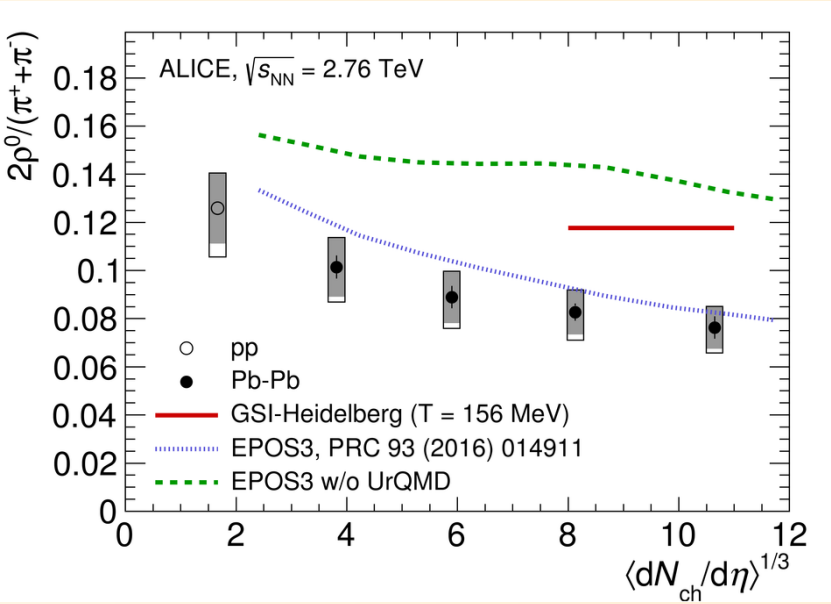

- All particles exhibit an increase in $< p_T >$ from peripheral to central Pb-Pb collisions
- In central collisions: $< p_T >$ values of the **$K^{*0}$**, **p** and **ϕ** are consistent with each other, as expected if spectral shape is dominated by radial flow

# Particle ratios




- **$K^{*0}/K$** shows clear suppression going from p-Pb and peripheral Pb-Pb to central Pb-Pb collisions → consistent with the re-scattering of daughters
- **$\phi/K$** shows an almost constant behavior for all systems → re-scattering is not significant for $\phi$

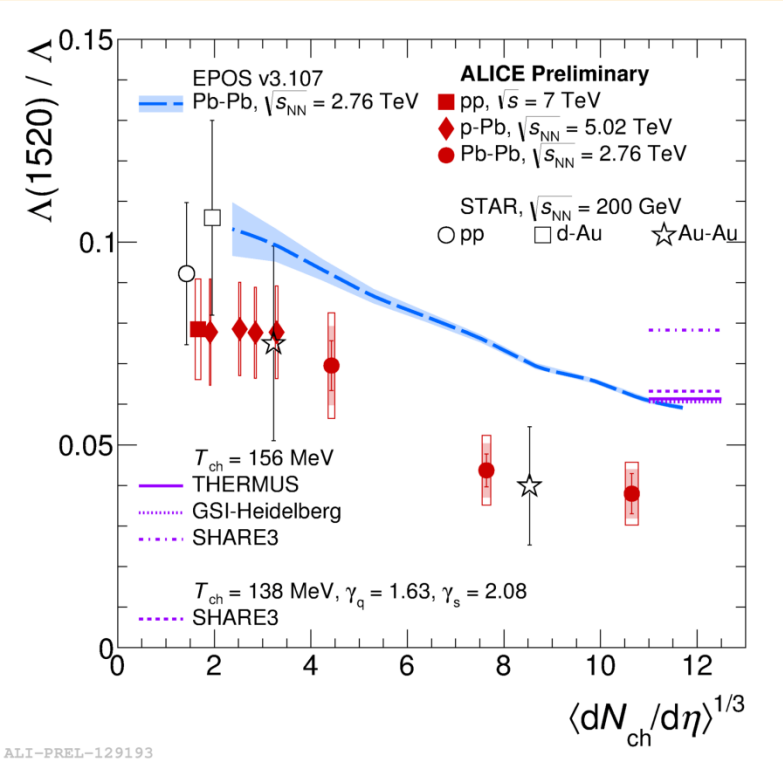
# Particle ratios




ALICE, arXiv: 1805.04365v1

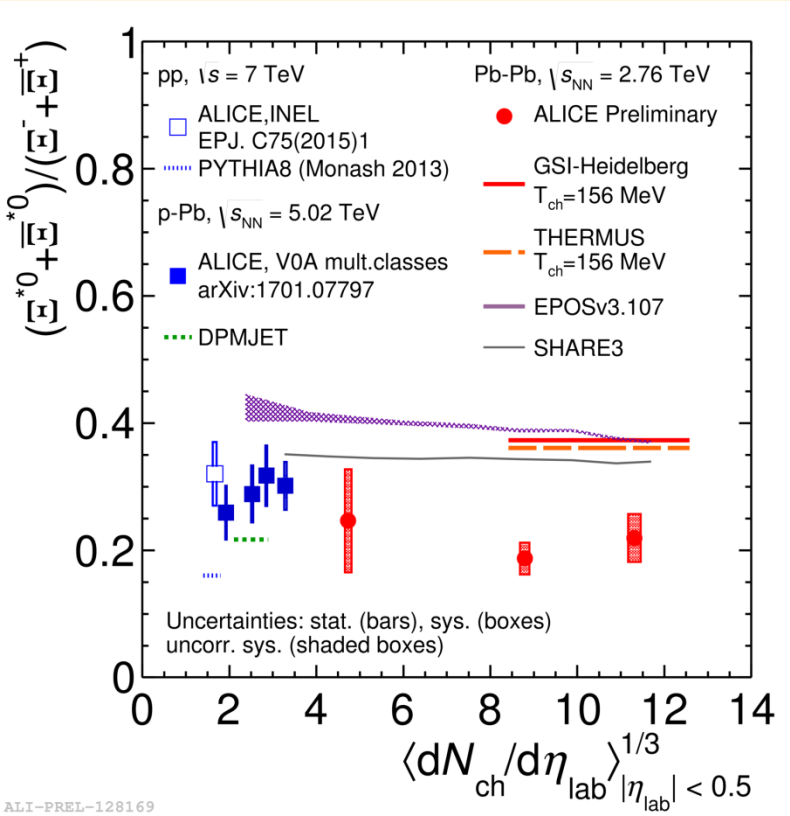
- **$\rho^0/\pi$** shows clear suppression going from pp and peripheral Pb-Pb to central Pb-Pb collisions → consistent with the re-scattering of daughters
- EPOS3 with URQMD reproduces the trend of the suppression
- Thermal model overestimates the ratio

# Particle ratios



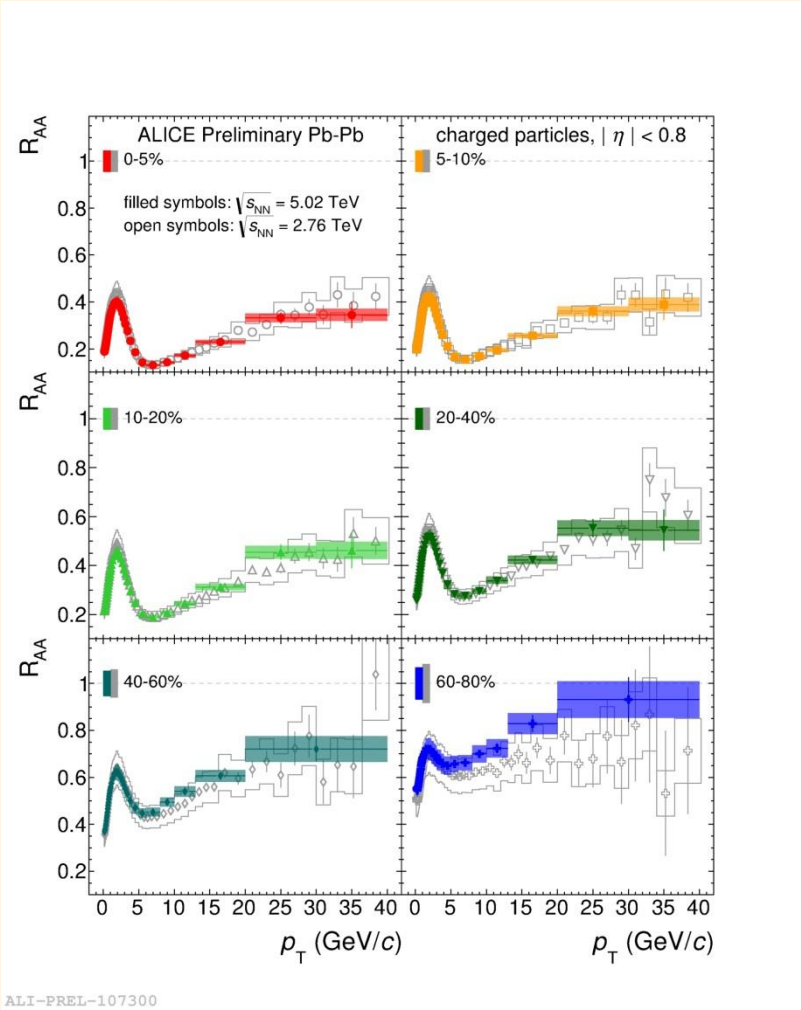

- **Λ*/Λ** shows clear suppression going from p-Pb and peripheral Pb-Pb to central Pb-Pb collisions → consistent with the re-scattering of daughters
- The ratio follows STAR trend with higher multiplicity and better accuracy
- Thermal models overestimate the ratio

# Particle ratios




- $\Xi^*/\Xi^0$ shows hint of suppression in central Pb-Pb collisions w.r.t pp and p-Pb, but systematics need to be improved in peripheral Pb-Pb collisions
- Thermal models overestimate the ratio

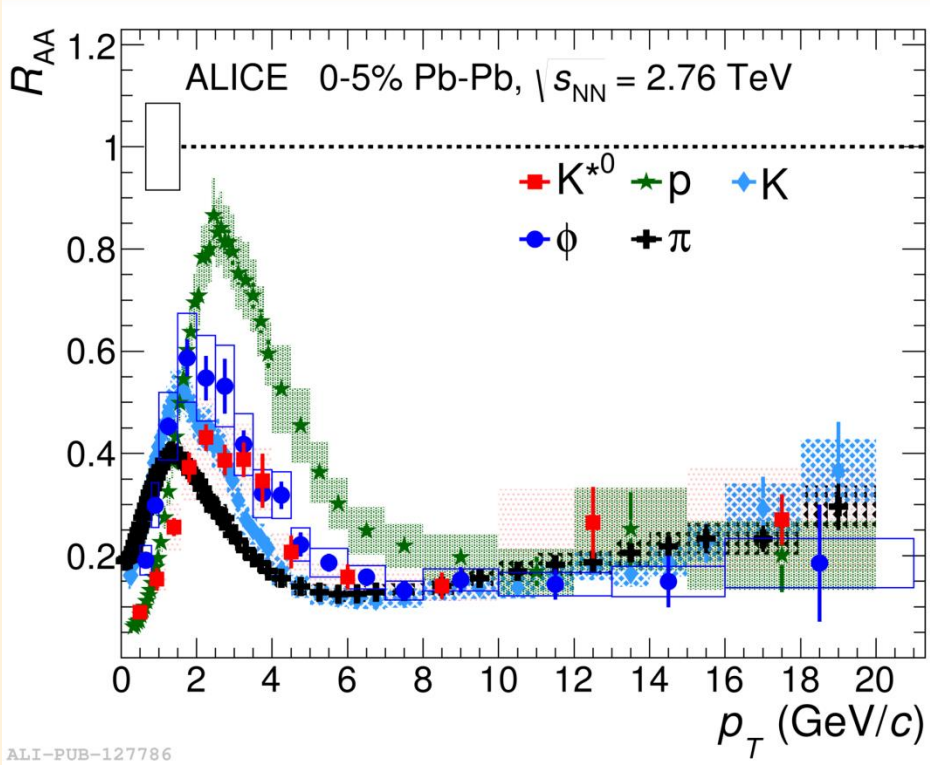
# Nuclear Modification Factor of Inclusive Charged Particles




$$R_{AA}(p_T) = \frac{d^2N_{ch}^{AA}/d\eta\, dp_T}{\langle T_{AA}\rangle\, d^2\sigma_{ch}^{pp}/d\eta\, dp_T}$$

- Suppression for all centrality intervals
- Larger suppression for more central events
- Minimum at around $p_T$ = 6 GeV/$c$
- Suppression of high-$p_T$ particles strongly depends on event centrality
- No significant evolution with collision energy is measured

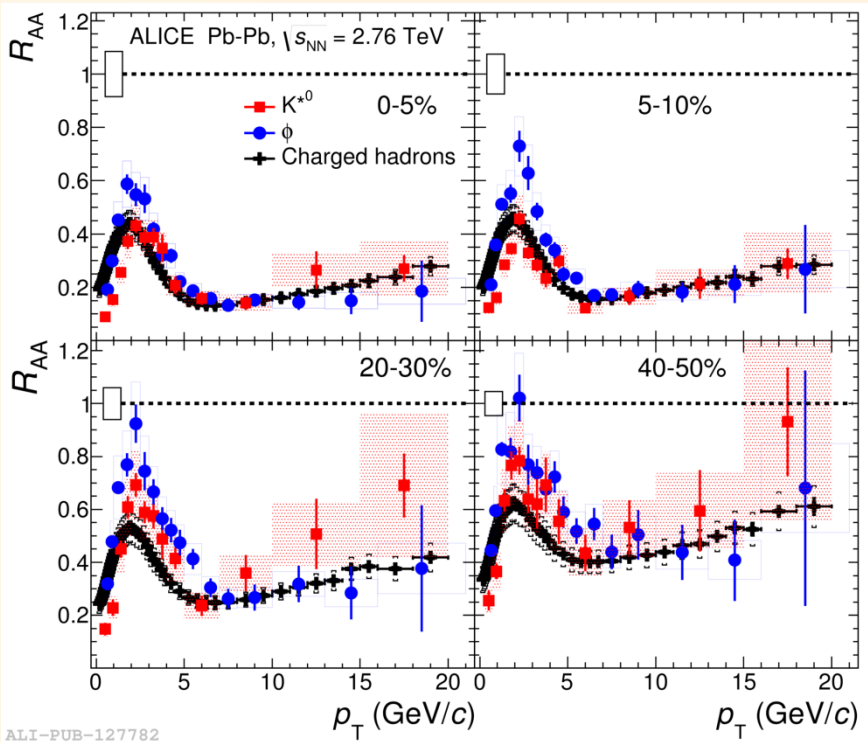
# Nuclear modification of $K^{*0}$ and $\phi$




ALICE, Phys. Rev. C 95 (2017) 06460

- **$K^{*0}$** and **$\phi$** show similar behaviour as light-flavoured hadrons at $p_T$ > 8 GeV/$c$ and are equally suppressed by a factor 4-5

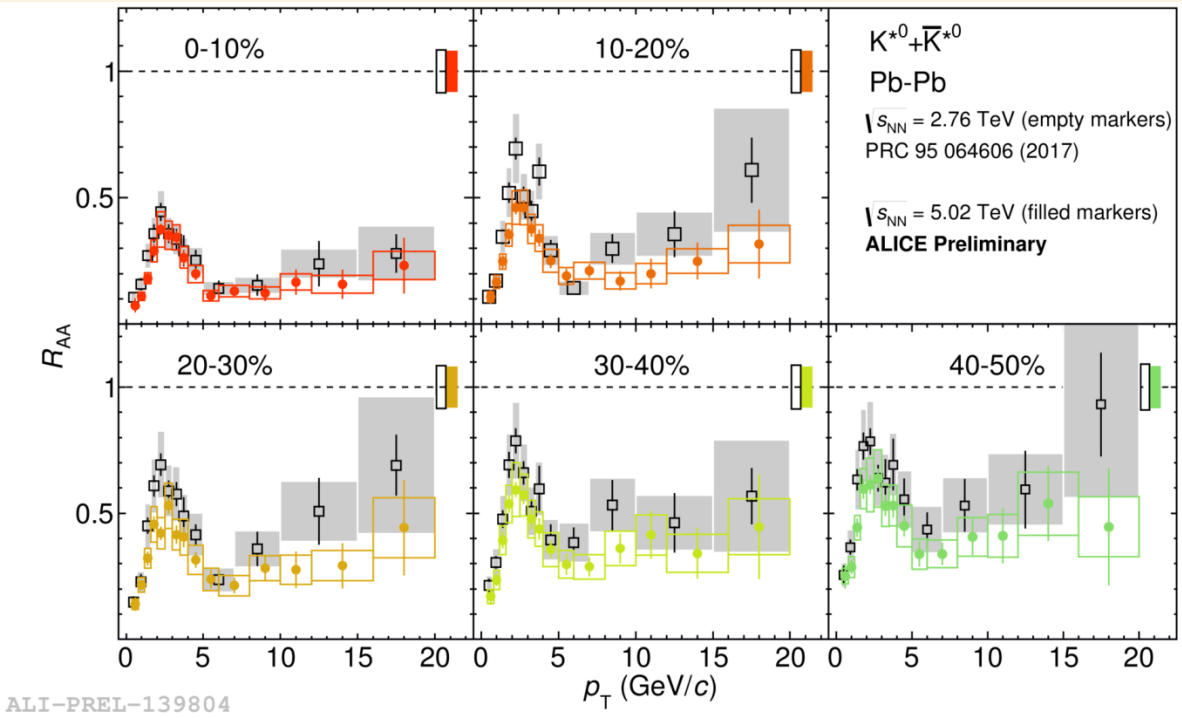
# Centrality dependence of $R_{AA}$




- Nuclear modification factor of **$K^{*0}$** and **$\phi$** shows similar behaviour to the one of charged hadrons in all centralities
- A strong suppression is observed for the most central collisions

ALICE, Phys. Rev. C 95 (2017) 064606

# Energy dependence of $R_{AA}$




- Nuclear modification factor of **$K^{*0}$** shows no significant energy dependence

# Conclusions

- ALICE has measured the production of hadronic resonances in pp, p-Pb, Xe-Xe and Pb-Pb collisions
- In central Pb-Pb collisions the mean $p_T$ values of **$K^{*0}$ , p** and **ϕ** are consistent with each other, as expected if spectral shape is dominated by radial flow
- From the $p_T$-integrated yield-ratios to long lived particles, indication of re-scattering effect for the short-lived resonances has been observed in heavy ion collisions

# Conclusions

- Strangeness enhancement has been studied with resonances. In small systems strangeness enhancement as function of multiplicity is found to be driven by strangeness content
- Strong suppression of high-$p_T$ resonances is observed in central Pb-Pb collisions
- Nuclear modification factor has no significant evolution with the collision energy

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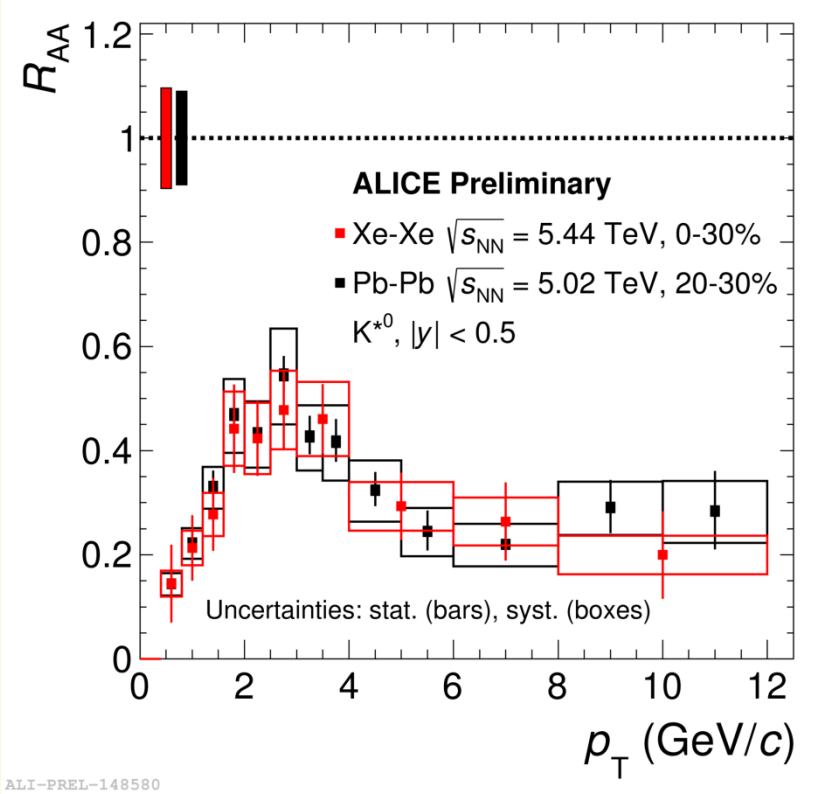
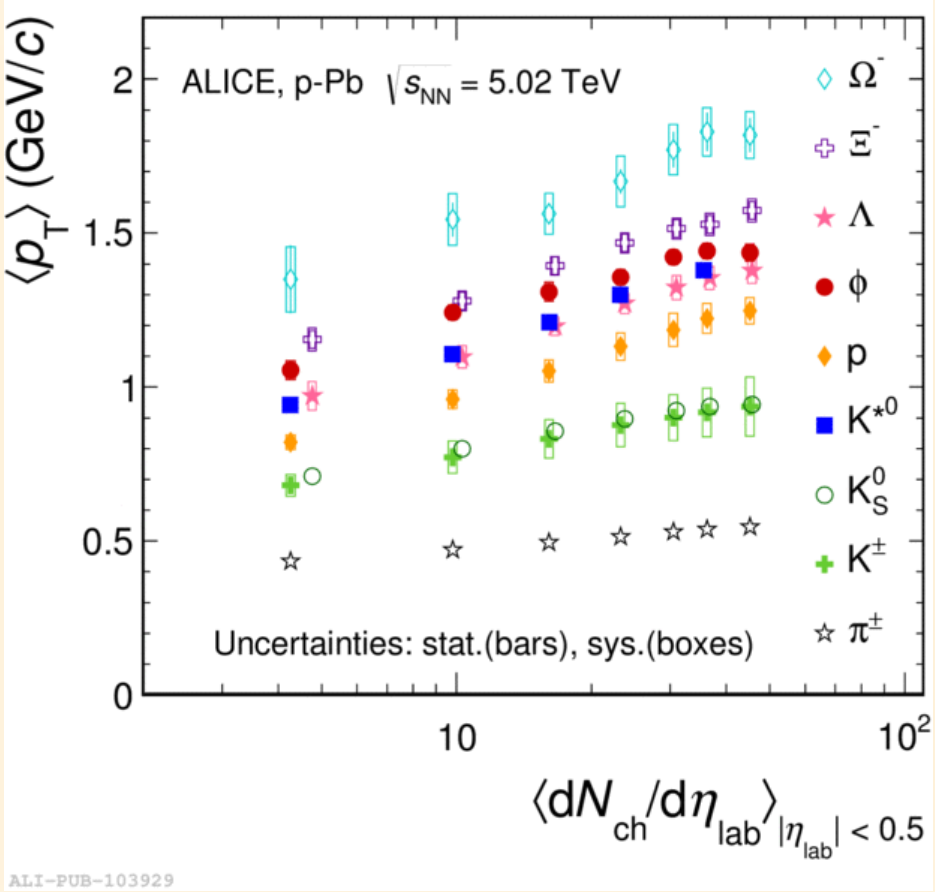
# Thank you!

# Nuclear modification factor in Xe-Xe




- Nuclear Modification Factor of primary charged particles in Xe-Xe at $\sqrt{s_{NN}}$ = 5.44TeV consistent with the one in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV, compared at the same multiplicity

# Multiplicity Dependence of < $p_T$ >




- Mean Transverse Momentum of identified hadrons measured in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV as a function of multiplicity