Hadronic resonance production measured by ALICE at the LHC

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- Resonance production in pp, p-Pb, Xe-Xe and Pb-Pb collisions:
  - signal extraction
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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 $\rightarrow$ nuclear modification factors
- regeneration and re-scattering effects $\rightarrow$ 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

THE ALICE DETECTOR

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14. Muon Trigger
15. Dipole Magnet
16. PMD
17. AD
18. ZDC
19. ACORDE

a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD
**ITS**

- **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

- PID via $dE/dx$ in gas – Ar/CO$_2$ (90:10) – up to 159 samples
- Truncated mean $dE/dx$ calculated and used for particle identification (PID) in a wide momentum range
- Largest $\pi/K$ and $K/p$ separation achieved at low $p$ (< 2.0 GeV/$c$)
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 $\sim 80$ ps
Event centrality classes are defined based on the amplitude measured in the V0 scintillators placed at:

- $2.8 < \eta < 5.1$ (V0A)
- $-3.7 < \eta < -1.7$ (V0C)

Curve: Glauber model fit to the measurement
pp, p-Pb and Xe-Xe Collisions
Invariant-mass distribution of $K^*0$ and $\phi$ in pp @ $\sqrt{s} = 13$ TeV and $\Lambda^*$ in p-Pb @ $\sqrt{s_{NN}} = 5.02$ TeV
Transverse momentum spectra of $K^*$ and $\phi$ in pp @ $\sqrt{s} = 13$ TeV and $\Lambda^*$ 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 $\Lambda^*$ and $\Xi^*$ 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

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

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 $\phi$ in Pb-Pb @ $\sqrt{s_{NN}} = 5.02$ TeV and $\Xi^*$ in Pb-Pb @ $\sqrt{s_{NN}} = 2.76$ TeV
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
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 $\phi$ 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 $\rightarrow$ consistent with the re-scattering of daughters

- $\phi/K$ shows an almost constant behavior for all systems $\rightarrow$ re-scattering is not significant for $\phi$
Particle ratios

- $\rho^0/\pi$ 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

ALICE, arXiv: 1805.04365v1
Particle ratios

- $\Lambda^*/\Lambda$ shows clear suppression going from p-Pb and peripheral Pb-Pb to central Pb-Pb collisions $\rightarrow$ 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

- 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 $\phi$

- $K^{*0}$ 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 $K^*$ 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 $\phi$ 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.
Thank you!
Nuclear modification factor in Xe-Xe

- Nuclear Modification Factor of primary charged particles in Xe-Xe at $\sqrt{s_{NN}} = 5.44\,\text{TeV}$ consistent with the one in Pb-Pb at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$, compared at the same multiplicity.
Mean Transverse Momentum of identified hadrons measured in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV as a function of multiplicity