Energy and centrality dependence of resonance production with ALICE at the LHC

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Role of hadronic resonances

Several hadronic resonances studied via invariant-mass analysis with ALICE ($\rho^0$, $\phi$, $K^*$, $\Sigma^*$, $\Lambda^*$, $\Xi^*$) in all systems (pp, p-Pb, Pb-Pb and Xe-Xe) and at all energies from both Run I and Run II at LHC.

Focus today on:

- $\rho(770)^0 \rightarrow \pi^+ + \pi^- (c\tau = 1.3 \text{ fm})$
- $K^*(892)^0 \rightarrow \pi^+ + K^- (c\tau = 4.16 \text{ fm})$
- $\Lambda(1520) \rightarrow p + K^- (c\tau = 12.6 \text{ fm})$
- $\phi(1020) \rightarrow K^+ + K^- (c\tau = 46.2 \text{ fm})$

Resonances play an important role in the study of the bulk properties of the system created in the collision (e.g. production mechanisms, late hadronic stage of the collision).

arXiv:1805.04365
arXiv:1805.04361
Transverse momentum spectra

$\rho^0(770)$

$\Lambda(1520)$

$1/N_{\text{evt}} \frac{d^2N}{dy dp_T} (\text{GeV/c})^{-1}$

$\frac{d^2N}{dy dp_T} (\text{GeV/c})^{-1}$

ALICE, $\sqrt{s_{NN}} = 2.76$ TeV

$\rho^0 \rightarrow \pi^+\pi^-, |y| < 0.5$

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Transverse momentum spectra

**φ(1020)**

**K*⁰(892)**

**Xe-Xe**

**ALICE Preliminary**

Xe-Xe, \( \sqrt{s_{NN}} = 5.44 \) TeV

\(|y| < 0.5\)

K*⁰

\[\frac{1}{N_{\text{ev}} d^2N/d(\beta p_T)} (\text{GeV}/c)^{-1}\]

\[\frac{1}{N_{\text{ev}} d^2N/d(\beta p_T)} (\text{GeV}/c)^{-1}\]

**Uncertainties:** stat.(bar), syst.(box)
Mean transverse momenta provide first-order characterization of spectral shapes.

New data in Xe-Xe for identified hadrons suggest a consistent picture between Xe-Xe and Pb-Pb.

→ Hydrodynamics predicts only a weak dependence of the difference in $<p_T>$ between Xe-Xe and Pb-Pb ($O(3\%)$)
  
  [G. Giacalone et al., PRC 97, 034904 (2018)]

→ Mass scaling of $<p_T>$ observed in central Xe-Xe and Pb-Pb collisions.

Mass scaling is tested comparing p and φ ($m_p \sim m_\phi$)
Thermal fit

Statistical hadronization models describe hadron production assuming chemical equilibrium.

Also at 5.02 TeV, yields of light flavor hadrons are qualitatively well described over 7 orders of magnitude.

Deviation for short-lived $K^*^0$ resonance that suffers from rescattering in the late hadronic phase (excluded from fit).

THERMUS: Wheaton et al., Comput.Phys.Commun, 180 84
SHARE: Petran et al., arXiv:1310.5108
Chemistry is driven by charged particle multiplicity, i.e. the size of the system

Smooth evolution of particle chemistry from small to large systems as function of charged particle multiplicity

Increasing strangeness production with increasing multiplicity until saturation

Confirmed with new pp √s = 13 TeV and Xe-Xe data
Role of φ

Significantly increasing trend of φ-meson to pion ratio with increasing multiplicity

Pivotal role of the φ-meson in the understanding of strangeness production with thermal-statistical, core-corona, and MC models
Suppression of $K^*$

Re-scattering of the decay products and regeneration in the late hadronic stage of the collision

→ Modify the yields of reconstructed resonances
  

→ Effect depends on the lifetime of the resonance
Suppression of $\rho^0$

The $\rho^0/\pi$ ratio shows a suppression from pp to peripheral Pb–Pb and to central Pb–Pb collisions by about 40%.

The prediction of a grand-canonical thermal model with a chemical freeze-out temperature of 156 MeV is consistent with data only in peripheral collisions.

EPOS with UrQMD reproduces well the $\rho^0/\pi$ ratio

arXiv:1805.04365
A decrease of the $\Lambda(1520)/\Lambda$ yield ratio with increasing charged-particle multiplicity is observed from peripheral to central Pb–Pb collisions.

Evidence of suppression with a 3.1$\sigma$ confidence level

EPOS3 systematically overestimates the data but describes the trend of the suppression well.

$$\frac{[\Lambda(1520)/\Lambda]_{0-20\%}}{[\Lambda(1520)/\Lambda]_{50-80\%}} = 0.54 \pm 0.08 \text{ (stat)} \pm 0.12 \text{ (syst)}$$
Baryon-to-meson ratios are a powerful tool to test hydro behavior and the role of recombination at intermediate $p_T$.

Behaviour in Xe-Xe confirms observations in Pb-Pb at 5.02 TeV (ratios compared at similar multiplicity).

The flatness of the $p/\phi$ ratio explained by models with recombination [V. Greco et al., PRC 92 (2015) 054904].

Still an open point on whether recombination or flow determine the spectral shape at intermediate $p_T$. 
Centrality dependence of the nuclear modification factor

\[ R_{AA} = \frac{1}{\langle T_{AA} \rangle} \times \frac{(d^2N/dy\,dp_T)_{AA}}{(d^2\sigma/dy\,dp_T)_{pp}} \]

\( R_{AA} < 1 \) for all the centralities, strong suppression for the most central collisions.

Similar behaviour of K*\(^0\) and \(\phi\) to charged hadrons in all the centralities.
All light-flavoured hadrons ($\pi^\pm$, $K^\pm$, p) and $\rho$-meson are equally suppressed at $p_T > 8$ GeV/c by a factor of 4-5.

Suppression at high $p_T$ is not dependent on hadron properties (mass, quark content or baryon number).
Similar behaviour in 2.76 and 5.02 TeV Pb-Pb collisions
No significant energy dependence observed for $R_{AA}$
Energy dependence of the nuclear modification of $\phi$

Similar behaviour in 2.76 and 5.02 TeV Pb-Pb collisions

No significant energy dependence observed for $R_{AA}$
Nuclear modification in Xe-Xe

$R_{AA}$ in Pb-Pb at 5.02 TeV and Xe-Xe at 5.44 TeV are consistent within uncertainties once compared at the same multiplicity (and not just centrality percentile)
Conclusions

Role of resonances in the study of bulk properties

At similar multiplicity, no dependence with system nor energy

→ new Xe-Xe data follows trend observed in other systems

Suppression of $\rho^0$, $K^*$ and $\Lambda(1520)$ in most central collisions, while $\phi$ not suppressed

→ due to re-scattering in the late hadronic stage of the collision

→ qualitative description is obtained with EPOS+UrQMD
Nuclear modification factor of $K^*$ and $\phi$

ALICE Preliminary
Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV
$K^{*0}$ + $\bar{K}^{*0}$
$\phi$

$R_{AA}$ vs. $p_T$ (GeV/c) for different centrality classes:
- 0-10%
- 10-20%
- 20-30%
- 30-40%
- 40-50%
- 50-60%
- 60-70%
- 70-80%