D-meson nuclear modification factor in p-Pb and Pb-Pb collisions with ALICE

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Physics motivation

• heavy quarks are produced at the very initial stage of a nuclear collision and experience the whole evolution of the hot and dense QCD medium created

• expected modification of heavy-quark $p_T$ spectrum in nuclear collision w.r.t. pp collision
  ‣ in-medium energy loss (collisional and radiative)
  ‣ in-medium formation (recombination) and dissociation

• however initial state effect are present (PDFs modification in nuclei, $k_T$ broadening)

• the nuclear modification factor ($R_{AA}$) is an observable sensitive to these effects

\[
R_{AA}(p_T) = \frac{1}{N_{\text{coll}}} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}
\]

$N_{\text{coll}}$ = number of binary nucleon collisions

$R_{AA} \neq 1 \Rightarrow$ deviation from pp binary scaling

• comparing the nuclear modification factor of D mesons in pA and AA collisions help to disentangle initial from final-state effect

\[
R_{AA}(p_T) = \frac{1}{N_{\text{coll}}} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}
\]

\[
R_{pPb} = \frac{\left(\frac{d\sigma}{dp_T}\right)_{pPb}}{A \times \left(\frac{d\sigma}{dp_T}\right)_{pp}}
\]
ALICE apparatus

Detectors used in these analysis

- Inner Tracking System: Particle Identification + Tracking
- Time of Flight: Particle Identification
- V0 detector: Centrality estimator
- Time Projection Chamber: Particle Identification + Tracking
- Inner Tracking System: Vertexing + Tracking
Pb-Pb data sample

• 2011 Pb-Pb data sample at $\sqrt{s_{NN}} = 2.76$ TeV
• ~16 M events in the 0 - 7.5% centrality interval
• Centrality determination: ALICE makes use of different centrality estimators. In this analysis the VZERO-A amplitude is used.

VZERO (Scintillator hodoscopes) trigger, beam-BKG rejection

0-7.5%

most peripheral

most central
p-Pb data sample

- 2013 p-Pb data sample at $\sqrt{s_{\text{NN}}} = 5.02$ TeV
- ~100 M events collected with a minimum bias trigger
- $E_p = 4$ TeV, $E_{Pb} = (208) \times 1.58$ TeV, $\sqrt{s_{\text{NN}}} = 5.02$ TeV
- $\gamma_{\text{CMS}} = 0.465$ (in proton direction)
D meson reconstruction and selection

- D mesons are fully reconstructed in the following hadronic decay modes:
  - $D^0 \rightarrow K^- \pi^+$ (BR 3.88%, ct 123 μm)
  - $D^+ \rightarrow K^- \pi^+ \pi^+$ (BR 9.13%, ct 312 μm)
  - $D^*+ \rightarrow D^0 \pi^+$ (BR 68%, strong decay)

- Invariant mass analysis of fully reconstructed decay topologies displaced from the primary vertex.
- Selections on the reconstructed topological quantities of the D meson decay candidates are applied to reduce the combinatorial background.
- Further background rejection achieved exploiting the combined PID capabilities of TOF and TPC:
  - TOF: π/K separation up to 1.5/2 GeV/c
  - TPC: π/K separation up to 1 GeV/c
D-meson signal

Pb-Pb, 0-7.5 centrality class

- D-meson signal extracted from invariant mass fit
- D-meson raw yields corrected for acceptance and reconstruction efficiency
\[ R_{pPb} = \frac{\left( \frac{d\sigma}{dp_T} \right)_{pPb}}{A \times \left( \frac{d\sigma}{dp_T} \right)_{pp}} \]

\[ R_{AA}(p_T) = \frac{1}{N_{coll}} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T} \]

Needs a pp reference!

**pp runs @ LHC:**

- \( \sqrt{s} = 0.9 \text{ TeV} \)
- \( \sqrt{s} = 2.76 \text{ TeV} \)
- \( \sqrt{s} = 7 \text{ TeV} \)
- \( \sqrt{s} = 8 \text{ TeV} \)
\[ R_{p\text{Pb}} = \frac{\left( \frac{d\sigma}{dp_T} \right)_{p\text{Pb}}}{A \times \left( \frac{d\sigma}{dp_T} \right)_{pp}} \]

\[ R_{AA}(p_T) = \frac{1}{N_{\text{coll}}} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T} \]

\[ \sqrt{s} = 5.02 \text{ TeV} \]
\[ \sqrt{s} = 2.76 \text{ TeV} \]

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\[ \sqrt{s} = 8 \text{ TeV} \]

- given the higher statistics available in the 2010 $\sqrt{s} = 7$ TeV sample, an energy scaling from 7 to 2.76 TeV (5.02 for p-Pb) driven by theoretical (FONLL) predictions has been performed.

Energy scaling (FONLL)

7 TeV cross section (data)

2.76 TeV cross section (rescaled)
Results in Pb-Pb

\[ R_{AA}(p_T) = \frac{1}{N_{\text{coll}}} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T} \]

- Observed suppression (factor 3-5) for \( p_T > 5 \text{ GeV/c} \) in most central Pb-Pb collisions

- Comparison to theoretical models including different energy loss mechanisms, as well as in-medium recombination/dissociation

- **TAMU**: purely elastic energy loss in a hydrodynamically expanding medium [arXiv:1401.3817]
- **Djordjevic**: collisional + radiative with running coupling [arXiv:1307.4098]
- **Cao, Qin, Bass**: collisional + radiative energy loss, Langevin approach, recombination
- **WDHG**: collisional + radiative energy loss
- **MC@sHQ+EPOS**: collisional + radiative energy loss + hadronic bound states above \( T_c \), EPOS initial condition
- **Vitev**: collisional + radiative energy loss + in-medium dissociation
- **POWLANG**: collisional energy loss in Langevin evolution
- **BAMPS**: collisions / collisional+radiative
Results in p-Pb

\[ R_{pPb} = \frac{\left( \frac{d\sigma}{dp_T} \right)_{pPb}}{A \times \left( \frac{d\sigma}{dp_T} \right)_{pp}} \]

- average D-meson \( R_{pPb} \) compatible with unity within statistical and systematic uncertainties →
- **D-meson production in p–Pb collisions consistent with binary collision scaling of production in pp collisions**
- Predictions based on initial state effects only or cold nuclear matter energy loss are compatible with the results

- **Fujii Watanabe**: Color Glass Condensate (CGC) model
- **Mangano Nason Ricolfi**: perturbative QCD calculation with CTEQ6M+EPS09 parametrization of nuclear PDFs
- **Vitev**: cold nuclear matter energy loss, \( k_T \) broadening, nuclear shadowing

\[ \text{arXiv:1405.3452} \]

\[ \text{ALICE = 5.02 TeV} \]

\[ N N, s_p-Pb, ALICE-PUB-79415 \]
Conclusions

- $R_{pPb}$ consistent within uncertainties of about 15-20% with unity and compatible with calculations including gluon saturation

- suppression of D mesons observed in most central Pb–Pb collisions cannot be explained in terms of initial state effects but is due to strong final-state effects induced by hot partonic matter