D meson nuclear modification factors in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV measured with the ALICE detector

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on behalf of the ALICE collaboration

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Disagreement STAR-PHENIX factor 2 in cross section measurement. Data in agreement with binary scaling - negligible initial state nuclear effects.

Charm with non-photonic electrons. High suppression of charm, at the level of light quark. Predictions contradicted!
Heavy quarks produced at the early stage of the collision (large mass requires high $Q^2$)

Heavy quarks are expected to lose less energy than light quarks and gluons due to color-charge and dead cone effect $\rightarrow$ higher penetrating power into QCD medium.


What about charm strange hadrons ($D_s$)? If in-medium hadronization dominant mechanism of charm hadron formation at low $p_T$ $\rightarrow$ strange charm hadrons largely enhanced.


$E_{\text{loss}}(\text{light}) > E_{\text{loss}}(D) > E_{\text{loss}}(B)$

$\rightarrow$ Allow testing of pQCD models of quark energy loss.
$\rightarrow$ Good probes of the QCD medium.
Data sample

OR between central and minimum bias trigger, based on ITS pixel and VZERO scintillators.

Centrality
- Determined via geometrical Glauber model fit of the VZERO amplitude.

<table>
<thead>
<tr>
<th>System</th>
<th>c.m.s energy (TeV)</th>
<th>events analyzed</th>
</tr>
</thead>
<tbody>
<tr>
<td>pp</td>
<td>7</td>
<td>~3.16×10^8</td>
</tr>
<tr>
<td>pp</td>
<td>2.76</td>
<td>~6.8×10^7</td>
</tr>
<tr>
<td>Pb-Pb</td>
<td>2.76</td>
<td>~3.0×10^6 (0-20%)</td>
</tr>
<tr>
<td>Pb-Pb</td>
<td>2.76</td>
<td>~1.6×10^7 (0-7.5%)</td>
</tr>
</tbody>
</table>
D mesons via hadronic decays

- Fully reconstructed D mesons in hadronic decay channels.

- In this talk:
  \[ D^0 \rightarrow K^- \pi^+ \]
  \[ D^+ \rightarrow K^- \pi^+ \pi^+ \]
  \[ D^{*+} \rightarrow D^0 \pi^+ \rightarrow K^- \pi^+ \pi^+ \]
  \[ D^+_s \rightarrow \phi \pi^+ \rightarrow K^+ K^- \pi^+ \]

- Additional information on \( D^+_s \) and \( D^+ \) in:
  - \( D^+_s \) talk by Gian Michele Innocenti
  - \( D^+ \) poster by Riccardo Russo
D meson reconstruction

- Topology of the decay resolved via the reconstruction of the secondary vertex.
- Combinatorial background reduced via topological selections.
- PID using TOF and TPC to further suppress background.
- Invariant mass analysis.

\[ D^0 \rightarrow K^- \pi^+ \]

Impact parameters \(\sim 100 \mu m\)

Similar strategy for all D mesons both in pp and Pb-Pb collisions.
D meson cross sections in pp at $\sqrt{s} = 7$ TeV

- $D^0$, $D^+$ and $D^{*+}$ cross section at $\sqrt{s}=7$ TeV, $|y|<0.5$

- Large $p_T$ coverage [1,24] GeV/c and well described by pQCD predictions.


Scaling to 2.76 TeV and extrapolation to high $p_T$

- pp reference defined by scaling the 7 TeV measurement to 2.76 TeV
  - FONLL predictions at 7 and 2.76 TeV used for the scaling
  - Scaling uncertainty from $\sim 50\%$ ($p_T=1$ GeV/c) to $\sim 5\%$ (high $p_T$)
- Direct measurement with short run at 2.76 TeV to validate the reference.

**Data at 2.76 TeV**

**Scaling from 7 TeV**

**Data/scaled**

At high $p_T$ (>16 GeV/c for $D^0$ and >24 GeV/c for $D^{*+}$ and $D^+$) reference extrapolated using the ratio data/theory ($\rightarrow$ rely on FONLL $p_T$ shape)
Scaling to 2.76 TeV and extrapolation to high $p_T$

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What about RHIC results

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D mesons in Pb-Pb
In 2010 the first measurement of $D^0$, $D^+$ and $D^{*+}$ meson $R_{AA}$ using $\sim 3 \times 10^6$ events. Similar suppression for all the meson species.

$R_{AA}(p_T)$ shows a tendency to increase at low $p_T$ in the 20% most central class.

Large suppression in the 10% most central class.
D⁰, D⁺ and D*⁺ invariant mass in 2011 data 0-7.5%

- ~16×10⁶ Pb-Pb events in the centrality class 0-7.5%
- Significance > 30 (D⁰) and >11 (D*⁺ and D⁺)

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D meson signal in $p_T$ bins (0-7.5%)

D mesons cover a $p_T$ range from 1 to 36 GeV/c with 10 $p_T$ bins.

Note: here as example the first 8 bins D$^0$ and last 2 bins D*$^+$. 

[Graphs showing data on D meson signal in different $p_T$ bins with invariant mass distributions.]
Invarian mass analysis in the $p_T$ range [4,12] GeV/c, centrality class 0-7.5%

PID selection ensures large background reduction to the presence of two kaons in the final state.
D mesons efficiencies

Corrections from MC

- HIJING+Pythia (D meson enriched)
- Full description of detector status
- Detailed analysis of the systematic error sources (MC $p_T$ shape, PID, cut variation and yield extraction, particle-antiparticle ....)

Efficiencies up to 20% at high $p_T$. 
Subtraction of secondary D from B needed to compute prompt D-meson $R_{AA}$

✓ Rely on FONLL predictions as done for D meson cross section in pp at $\sqrt{s}=7$ TeV and 2.76 TeV

✓ Hypothesis on $R_{AA}$ of D from B mesons

$$N_{\text{theory, uncorrected}}^{D \text{ from } B} = \Delta p_t \times \epsilon_{D \text{ from } B} \times \frac{dN_{\text{theory}}^{D \text{ from } B}}{dp_t}$$

$$\frac{dN_{\text{D from B}}^{D \text{ from B}}}{dp_t} = R_{AA}^D \times T_{AA} \times \frac{d\sigma_{pp, \text{theory}}^{D \text{ from B}}}{dp_t}$$

$R_{AA}^{\text{D from B}}/R_{AA}^{\text{prompt D}}$ ranges from 0.3 to 3.0

✓ Data driven method in development:

fit the impact parameter of D to measure the prompt charm fraction
D meson $dN/dp_T$ in pp and Pb-Pb (0-7.5%)

- **pp data** from $\sqrt{s}=7$ TeV scaled to 2.76 TeV and multiplied by $<T_{AA}>$.

- **Pb-Pb data** show large suppression at high $p_T$. 

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17/8/2012

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D meson nuclear modification factor

\[ R_{AA}^D(p_T) = \frac{dN_{AA}^D / dp_T}{\langle T_{AA} \rangle \times d\sigma_{pp}^D / dp_T} \]

- **D**\(^0\), **D**\(^+\) and **D**\(*^+\) **R**\(_{AA}\) measured in the range \([1,36]\) GeV/\(c\) with 2011 data. Compatible within uncertainties.
- Suppression up to a factor 5 for **D**\(^0\), **D**\(^+\) and **D**\(*^+\) at \(p_T\sim10\) GeV/\(c\).
- First measurement of **D**\(_s^+\) **R**\(_{AA}\), data not conclusive on comparison with other mesons.

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Comparison of the 2010 and 2011 results. Hint of a larger suppression going to more central events, but compatible within uncertainties.

At low $p_T$ indication of a $R_{AA}<1$

At high $p_T$ data are consistent both with a rising and flat shape

pPb run beginning of 2013 to study the shadowing effect.
Comparison with models

Radiative energy loss supplemented with in-medium D meson dissociation and radiative plus collisional energy loss in the WHDG and BDMPS-ASW implementations describe reasonably well our average $R_{AA}$.

![Graph showing comparison with models](image)

**References**

Conclusions

- D meson $R_{AA}$ measured in 0-7.5% centrality with 2011 data sample. $p_T$ reach extended with respect to the 2010 analysis. Now [1,36] GeV/c Large suppression, factor of 5 at about $p_T = 10$ GeV/c for $D^0$, $D^+$ and $D^{*+}$

- First measurement of $D^{+s} R_{AA}$: intriguing result, in view of future LHC Pb-Pb runs.
  - $D^{+s}$ talk by Gian Michele Innocenti
  - Upgrade of ALICE: talk by Roy Lemmon

- Comparison of the average $D^0$, $D^{*+}$ and $D^+ R_{AA}$ with 2011 and 2010 data shows a hint of larger suppression for $p_T > 5$ GeV/c with 2011 data consistent with the change in centrality from 0-20% to 0-7.5%
Backup

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Proton-proton D mesons ratio and $\Gamma_{s}$

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Ratio of D mesons versus pt. FONLL, GM-VFNS and Pythia are also shown

Strangeness suppression factor as measured by ALICE and compared with other experiments.

arXiv:1208.1948

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D^+_s cross section in pp at \sqrt{s} = 7\,\text{TeV} in the p_T range [2, 12]\,\text{GeV/c}.

Well described by pQCD prediction.

D$^+$ mass plots

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EPS2009 - Krakow

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03/12/09 - Pavia

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Systematic errors

\( \sqrt{s_{NN}} = 2.76 \text{ TeV}, 16 \times 10^6 \text{ events} \)

Centrality 0-7.5 %

\( D^+ \rightarrow K^+ \pi^+ \pi^- \)

\( D^+_s \)

Relative Error

\( \Delta p_T (\text{GeV/c}) \)

Total (excl. norm.)

Normalization (4.8%)

Tracking efficiency

Branching ratio

Yield extraction

Cuts efficiency

PID efficiency

MC \( p_T \) shape

26/07/2012

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R_{AA} of D^0, D^+, D^{*+} and D^{+}_{s}