Heavy Flavour and Quarkonia Measurements from ALICE

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Utrecht University (The Netherlands)
Experimental setup

Collision system $\sqrt{s}$ or $\sqrt{s_{NN}}$ (TeV)

<table>
<thead>
<tr>
<th>System</th>
<th>Energy (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pp</td>
<td>2.76, 5.02, 7, 8, 13</td>
</tr>
<tr>
<td>p-Pb</td>
<td>5.02, 8.16</td>
</tr>
<tr>
<td>Pb-Pb</td>
<td>2.76, 5.02</td>
</tr>
<tr>
<td>Xe-Xe</td>
<td>5.44</td>
</tr>
</tbody>
</table>

Fully reconstructed $D$ and $\Lambda^{+}_{c}$

$D^{0} \rightarrow K^{-}\pi^{+}$, $D^{+} \rightarrow K^{-}\pi^{+}\pi^{+}$, $D^{*+} \rightarrow D^{0}\pi^{+}$

$D^{0}_{s} \rightarrow \phi\pi^{+} \rightarrow K^{-}K^{+}\pi^{+}$, $\Lambda^{+}_{c} \rightarrow \pi^{+}K^{-}p^{+}$

$\Lambda^{+}_{c} \rightarrow K_{0}^{s}\pi^{+}$

Quarkonia

$J/\psi \rightarrow \mu^{+}\mu^{-}$

$J/\psi \rightarrow e^{+}e^{-}$

$\Upsilon(1S, 2S, 3S) \rightarrow \mu^{+}\mu^{-}$

$\psi(2S) \rightarrow \mu^{+}\mu^{-}$

Semi-leptonic decays of open HF

$b, c \rightarrow e^{\pm}X$

$b, c \rightarrow \mu^{\pm}X$
Why charm and beauty?

**Heavy Quarks**
- High mass: produced in hard scatterings (short time scales)
- Propagate through the QGP interacting with its constituents

**Open heavy flavour**
- Hard fragmentation: carries large part of the c/b momentum
- Hadronization mechanisms

**Quarkonia**
- Sequential melting: can used as a thermometer
- Regeneration: Enhanced quarkonium production via (re)combination
• Reference for A-A collisions

• Test of pQCD-based calculations and production mechanisms
• Reference for A-A collisions

• Test of pQCD-based calculations and production mechanisms

• Reference for A-A collisions

• Address Cold Nuclear Matter (CNM) effects: Shadowing, $k_T$ broadening, CNM energy loss, ...

• Collective effects?

pp

p-Pb
• Reference for A-A collisions

• Test of pQCD-based calculations and production mechanisms

• Reference for A-A collisions

• Address Cold Nuclear Matter (CNM) effects: Shadowing, $k_T$ broadening, CNM energy loss, ...

• Collective effects?

Study the Quark-Gluon Plasma

• Energy loss

• Collective effects

• Hadronisation

• Debye screening
Study the production of HF particles across different systems

\[ R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T} \]

Ratios of different particles: understand fragmentation and hadronisation, constrain models, etc

Open and hidden heavy-flavour production
D-meson and $\Lambda^+_c$ production in pp

- Measurements for $D^0$, $D^+$, $D^{*+}$ and $D^+_s$ (2.76 TeV, 5.02 TeV, 7 TeV and 13 TeV) and $\Lambda^+_c$ (5.02 TeV and 7 TeV)

- D-meson $\frac{\sigma}{dydp_T}$ in agreement with different model predictions

2.76 TeV: JHEP 1207 (2012) 191
7 TeV: EPJC 77 (2017) 550

FONLL: JHEP 1210 (2012) 137

arXiv:1901.07979

ALICE FONLL Data 0.5 1

$\pm 2.1%$ lumi, $\pm 1.0%$ BR uncertainty not shown

D$^0@ 5.02$ TeV
D-meson and $\Lambda^+_c$ production in pp

- Measurements for $D^0$, $D^+$, $D^{*+}$ and $D^+_s$ (2.76 TeV, 5.02 TeV, 7 TeV and 13 TeV) and $\Lambda^+_c$ (5.02 TeV and 7 TeV)
- $D$-meson $\frac{d^2\sigma}{dy dp_T}$ in agreement with different model predictions
- $\Lambda^+_c$ $\frac{d^2\sigma}{dy dp_T}$ underestimated by pQCD calculations which describe D-meson production

$\Lambda^+_c$ @ 7 TeV

$D^0$ @ 5.02 TeV

2.76 TeV: JHEP 1207 (2012) 191
7 TeV: EPJC 77 (2017) 550


POWHEG: JHEP 0709 (2007) 126

FONLL: JHEP 1210 (2012) 137

arXiv:1901.07979
D-meson and $\Lambda_{+c}^+$ $R_{ppb}$

- $R_{ppb}$ is compatible with unity for both D mesons and $\Lambda_{+c}$

- Data does not favour a suppression larger than 10-20% for $5 < p_T < 12$ GeV/c

- Models qualitatively describe the results

$\Lambda_{+c}$

![Graph showing $R_{ppb}$ as a function of $p_T$ for D mesons and $\Lambda_{+c}$](ALI-PREL-311160)

D mesons

![Graph showing $R_{ppb}$ as a function of $p_T$ for ALICE preliminary data with $p$-Pb, $\sqrt{s_{NN}} = 5.02$ TeV, prompt D mesons, $-0.96 < y_{cms} < 0.04$](ALI-PREL-150504)

ALICE-PUBLIC-2017-008
D-meson and $\Lambda^+_c R_{AA}$

- $\Lambda^+_c$, $|y|<0.5$, 0–80%
- p–Pb reference from JHEP 04 (2018) 108
- Average $D^0$, $D^+$, $D^{*-}$, $|y|<0.5$, 0–10% (arXiv:1804.09083)
- $D^+_s$, $|y|<0.5$, 0–10% (arXiv:1804.09083)
- charged particles, $|y|<0.8$, 0–10% (arXiv:1802.09145)

ALICE

Pb–Pb, $\sqrt{s_{NN}} = 5.02$ TeV


$\Lambda^+_c$: PLB 793 (2019) 212
$[\Delta E(\pi) > \Delta E(D) \rightarrow] R_{AA}(\text{light}) < R_{AA}(D)$?

- $R_{AA}(D^{0,+,*+}) > R_{AA}(\text{ch. part.})$ for intervals with $3 < p_T < 8$ GeV/c (2$\sigma$) but similar at high $p_T$

\[ \Lambda^+_c, |y|<0.5, 0-80\%
\]
\[ p-\text{Pb reference from JHEP 04 (2018) 108}
\]
\[ \text{Average } D^0, D^+, D^{*-}, |y|<0.5, 0-10\% (\text{arXiv:1804.09083})
\]
\[ D^{0*}, |y|<0.5, 0-10\% (\text{arXiv:1804.09083})
\]
\[ \text{charged particles, } |y|<0.8, 0-10\% (\text{arXiv:1802.09145})
\]

ALICE

Pb–Pb, $\sqrt{s_{NN}} = 5.02$ TeV


$\Lambda^+_c$: PLB 793 (2019) 212
D-meson and $\Lambda^+ c R_{AA}$

\[ \Delta E(\pi) > \Delta E(D) \rightarrow] R_{AA}(\text{light}) < R_{AA}(D) ? \]

- $R_{AA}(D^{0,+,*+}) > R_{AA}($ch. part.$)$ for intervals with $3 < p_T < 8$ GeV/$c$ (2$\sigma$) but similar at high $p_T$

$R_{AA}($strange$) > R_{AA}($non strange$) ?$

- $R_{AA}(D^{+s}) > R_{AA}(D^{0,+,*+})$, but only 1$\sigma$ difference

\[ \Delta E(\pi) > \Delta E(D) \rightarrow] R_{AA}(\text{light}) < R_{AA}(D) ? \]

- $\Lambda^+, |y|<0.5, 0-80\%$
- $p$–$Pb$ reference from JHEP 04 (2018) 108
- Average $D^0$, $D^+$, $D^{*+}$, $|y|<0.5, 0-10\%$ (arXiv:1804.09083)
- $D^+_s$, $|y|<0.5, 0-10\%$ (arXiv:1804.09083)
- Charged particles, $|y|<0.8, 0-10\%$ (arXiv:1802.09145)

$\Lambda^+$: PLB 793 (2019) 212

D-meson and $\Lambda^+ c R_{AA}$

$$[\Delta E(\pi) > \Delta E(D) \rightarrow] R_{AA}(\text{light}) < R_{AA}(D) ?$$

- $R_{AA}(D^{0,+,*+}) > R_{AA}(\text{ch. part.})$ for intervals with $3 < p_T < 8$ GeV/c (2σ) but similar at high $p_T$

$R_{AA}(\text{strange}) > R_{AA}(\text{non strange}) ?$

- $R_{AA}(D^+) > R_{AA}(D^{0,+,*+})$, but only 1σ difference

Baryons vs mesons ?

- $R_{AA}(\Lambda^+ c) > R_{AA}(D^{0,+,*+})$ in 1.7σ (0-80%) Charmed-baryon production increased by hadronisation via coalescence?

\[ R_{AA} \]

\[ \text{p–Pb reference from JHEP 04 (2018) 108} \]

\[ \text{Average } D^0, D^+, D^{+,*}, |y|<0.5, 0–10\% \text{ (arXiv:1804.09083)} \]

\[ D^0, |y|<0.5, 0–10\% \text{ (arXiv:1804.09083)} \]

\[ \text{charged particles, } |y|<0.8, 0–10\% \text{ (arXiv:1802.09145)} \]

\[ \Lambda^+ c, |y|<0.5, 0–80\% \text{ (arXiv:1802.09145)} \]

\[ \text{ALICE} \]

\[ \text{Pb–Pb, } \sqrt{s_{NN}} = 5.02 \text{ TeV} \]

\[ \text{ΔE(π) > ΔE(D) → } \]

\[ R_{AA}(\text{light}) < R_{AA}(D) ? \]

\[ R_{AA}(D^{0,+,*+}) > R_{AA}(\text{ch. part.}) \text{ for intervals with } 3 < p_T < 8 \text{ GeV/c (2σ) but similar at high } p_T \]

\[ R_{AA}(\text{strange}) > R_{AA}(\text{non strange}) ? \]

\[ R_{AA}(D^+) > R_{AA}(D^{0,+,*+}) , \text{ but only 1σ difference} \]

\[ R_{AA}(\Lambda^+ c) > R_{AA}(D^{0,+,*+}) \text{ in 1.7σ (0-80%)} \]

\[ \text{Charmed-baryon production increased by hadronisation via coalescence?} \]
Heavy-quark transport

- Qualitative agreement between different models and data.
- Precise measurement provides constrains to models

Models: D-meson $R_{AA}$
• Qualitative agreement between different models and data.

• Precise measurement provides constrains to models

Models: D-meson $R_{AA}$

JHEP 2018 (2018) 174
$D^0$-tagged jets $R_{AA}$ and $R_{pPb}$

- $R_{pPb}$:
  - Compatible with unity within uncertainties

\[
R_{AA, \text{Pb-Pb} \ 0-20\% } (p-Pb \text{ data reference})
\]

\[
R_{p-Pb} (pp \text{ data reference})
\]
\textbf{D}^0\text{-tagged jets} $R_{AA}$ and $R_{pPb}$

- $R_{pPb}$:
  - Compatible with unity within uncertainties

- $R_{AA}$:
  - Strong suppression of D$^0$-tagged jets for $p_T > 5$ GeV/c
  - Similar suppression for D$^0$-tagged jets and D$^0$ mesons

\begin{itemize}
  \item D$^0$-tagged jets, $\sqrt{s_{NN}} = 5.02$ TeV, $p_{T,D^0} > 3$ GeV/c
  \item Charged jets, anti-$k_T$, $R = 0.3$, $|\eta_{\text{jet}}| < 0.6$
  \item $R_{AA}$, Pb-Pb 0-20\% (p-Pb data reference)
  \item $R_{pPb}$ (pp data reference)
\end{itemize}
$\Lambda^+_c/D_0$ ratios

• Sensitive to hadronisation mechanisms

• $\Lambda^+_c/D_0$ higher than measured $e^+e^-$ and ep collisions at lower $\sqrt{s_{NN}}$ ($\Lambda^+_c/D_0 \sim 0.1-0.22$)

• $\Lambda^+_c/D_0$ similar in pp and p-Pb collisions

• Ratios in Pb-Pb collisions higher than in p-Pb collisions

• Ratios underestimated by models: PYTHIA8 calculations with enhanced colour reconnection mode is the closest to the measurement

\[
\left( \frac{\Lambda^+_c}{D_0} \right)_{Pb-Pb} = 1.07 \pm 0.20(\text{stat})^{+0.15}_{-0.14}(\text{syst})
\]

Pb-Pb: PLB 793 (2019) 212
HF decay leptons: $R_{AA}$

$\Delta E(D) > \Delta E(B) \rightarrow R_{AA}(D) < R_{AA}(B)$?

- Hint of a smaller suppression for beauty-decay electrons for $p_T < 6$ GeV/c
HF decay leptons: $R_{AA}$

$[\Delta E(D) > \Delta E(B) \rightarrow] R_{AA}(D) < R_{AA}(B)$?

- *Hint* of a smaller suppression for beauty-decay electrons for $p_T < 6$ GeV/c

- HF muons are heavily suppressed in central Pb-Pb collisions
- $R_{AA}$ grows from central to peripheral collisions
Charmonium production in pp

- Measurements of the J/ψ cross section at different energies and rapidities
• Measurements of the $J/\psi$ cross section at different energies and rapidities

• Good agreement with calculations from NRQCD calculations (prompt) + FONLL (non-prompt)
• Backward rapidity and mid rapidity: no significant suppression is observed
• Models in qualitative agreement

\[
J/\psi R_{pPb}
\]

ALICE, p–Pb \( \sqrt{s_{NN}} = 8.16 \text{ TeV} \)
- inclusive \( J/\psi \rightarrow e^+e^- \) (Preliminary)
- inclusive \( J/\psi \rightarrow \mu^+\mu^- \) (JHEP07(2018)160)

\( R_{pPb} \)

ALI–PREL–315007

JHEP 07 (2018) 160
J/ψ $R_{pPb}$

- Backward rapidity and mid rapidity: no significant suppression is observed
- Models in qualitative agreement
- Forward rapidity: suppression of the J/ψ yield for $p_T < 5$ GeV/c

![Graph showing $R_{pPb}$ vs. $p_T$ for different rapidities and center-of-mass energies.](image)
\( \psi(2S) \) and \( \Upsilon(1S, 2S) \) \( R_{pPb} \)

- \( R_{pPb}\psi(2S) < R_{pPb}\psi(2S) \) at backward rapidity

- Models with final-state effects reproduce the \( \psi(2S) R_{pPb} \) at backward rapidity
\( \psi(2S) \) and \( \Upsilon(1S, 2S) \) \( R_{pPb} \)

- \( R_{pPb} \psi(2S) < R_{pPb} \psi(2S) \) at backward rapidity

- Models with final-state effects reproduce the \( \psi(2S) \) \( R_{pPb} \) at backward rapidity

- \( R_{pPb} \Upsilon(2S) \) compatible with \( R_{pPb} \Upsilon(1S) \), but smaller for both backward and forward rapidities
$R_{AA}$ decreases with $<N_{\text{part}}>$ up to ~100. Change of ~10% w.r.t. 2.76 TeV.

$R_{AA}(\text{LHC}) > R_{AA}(\text{RHIC})$ for forward results.
$R_{AA}$ decreases with $<N_{\text{part}}> \text{ up to } \sim 100$. Change of $\sim 10\%$ w.r.t. 2.76 TeV.

$R_{AA}(\text{LHC}) > R_{AA}(\text{RHIC})$ for forward results.

$R_{AA}$ increases towards low $p_T$.

$R_{AA}$ decreases with increasing $y$.

$R_{AA(\text{forward})} < R_{AA(\text{mid})}$
• Qualitative agreement between different models and data.
- Qualitative agreement between different models and data.
- $R_{AA}$ increases towards low $p_T$: compatible with the regenerated $J/\psi$ scenario.
- Calculations need a more precise $d\sigma_{cc}/dy$ measurement to reduce uncertainties.

Models: $J/\psi$ $R_{AA}$
Strong suppression of $\Upsilon(1S, 2S)$ in central Pb-Pb.

\[
\frac{R_{\Upsilon(2S)}^{AA}}{R_{\Upsilon(1S)}^{AA}} = 0.28 \pm 0.12({\text{stat.}}) \pm 0.06({\text{syst.}})
\]

- $\Upsilon(2S)$ suppression w.r.t. $\Upsilon(1S)$
• Strong suppression of \( \Upsilon(1S, 2S) \) in central Pb-Pb.

• No multiplicity/ transverse momentum dependence

• Models qualitatively describe the results

\[
\frac{R_{\Upsilon(2S)}^{AA}}{R_{\Upsilon(1S)}^{AA}} = 0.28 \pm 0.12(\text{stat.}) \pm 0.06(\text{syst.})
\]

\( \Upsilon(2S) \) suppression w.r.t. \( \Upsilon(1S) \)
Dominant term in non-central A-A collisions: $v_2$ (elliptic flow)

$$\frac{dN}{d\phi} \propto 1 + 2 \sum_{n=1}^{+\infty} v_n \cos[n(\phi - \psi_n)]$$

Azimuthal Anisotropy ($v_n$)
Dominant term in non-central A-A collisions: $v_2$ (elliptic flow)

$$\frac{dN}{d\varphi} \propto 1 + 2 \sum_{n=1}^{+\infty} v_n \cos[n(\varphi - \psi_n)]$$

In Pb-Pb calculated using the angular differences w.r.t the event plane

$$v_2 = \langle \cos(\varphi_{part} - \Psi_{EP}) \rangle$$

In p-Pb calculated using two-particle correlations (with low multiplicity subtraction):

$$HM - LM = a_0 [1 + 2v_1 \cos(\Delta \varphi) + 2v_2 \cos(\Delta \varphi)]$$
• $v_2 > 0$ for $2 < p_T < 8$ GeV/c

• Low $p_T$: $v_2$ consistent with thermalisation of charm quarks and $J/\psi$ (re)generation

• High $p_T$: higher than predictions including path-length dependent energy loss
Inclusive $J/\psi$: $v_2$ and $v_3$ in Pb-Pb

- First observation of $J/\psi$ $v_3 > 0$ in Pb-Pb collisions (significance 3.7$\sigma$)
- Important to understand initial conditions

- $v_2 > 0$ for $2 < p_T < 8$ GeV/c
- Low $p_T$: $v_2$ consistent with thermalisation of charm quarks and $J/\psi$ (re)generation
- High $p_T$: higher than predictions including path-length dependent energy loss
First look at the $\Upsilon(1S) v_2$

Values are compatible with zero, but the uncertainties are large.

$\Upsilon(1S) v_2$ in Pb-Pb
- $D^0$, $D^+$ and $D^{**}$ $v_2 > 0$ for $p_T$ bin 2–10 GeV/$c$
- $D_s^+$ $v_2 > 0$ with $2.6\sigma$ significance for $p_T$ bin 2–8 GeV/$c$
- $v_2^D$ and $v_2^\pi$ have similar values.
  - Difference of $2\sigma$ for 2–4 GeV/$c$

\[ v_2 \{EP, |\Delta\eta|>0.9\} \]
- Prompt $D^0$, $D^+$, $D^{**}$ average $|y|<0.8$
- Prompt $D_s^+$ $|y|<0.8$
- $v_2\{2, |\Delta\eta|>2\}$
- $\pi^+$ $|y|<0.5$, arXiv:1805.04390

ALICE Pb–Pb, $\sqrt{s_{NN}} = 5.02$ TeV

D-meson $v_2$ in Pb–Pb

PRL 120 (2018) 102301
D-meson $v_2$ with ESE

\[ \langle q_2^2 \rangle \approx 1 + \langle (M - 1) \rangle \langle \delta v_2^2 \rangle \]

- Slice events based on its shape.
- 20% large-$q_2^{TPC}$ -> ~40% more $v_2$
- 60% small-$q_2^{TPC}$ -> ~25% less $v_2$
- D mesons are sensitive to the light-quark collectivity and event-by-event fluctuations in initial conditions

\[ \langle M - 1 \rangle \langle \delta v_2^2 \rangle \]

Bulk $v_2$

\[ \langle (M - 1) \rangle \langle \delta v_2^2 \rangle \]

ALICE Pb–Pb, $\sqrt{s_{NN}} = 5.02$ TeV
Prompt $D^0$, $D^*$ average $|y|<0.8$

<table>
<thead>
<tr>
<th>Centrality 10–30%</th>
<th>Centrality 30–50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syst. from data</td>
<td>Syst. from B feed-down</td>
</tr>
</tbody>
</table>

60% small-$q_2^{TPC}$
20% large-$q_2^{TPC}$
unbiased

\[ \langle v_2^{(ESE-selected)} \rangle / \langle v_2 \rangle (\text{unbiased}) \]

\[ v_2 (\text{ESE-selected}) / v_2 (\text{unbiased}) \]

23 Henrique J C Zanoli
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arXiv:1809.09371


- $J/\psi v_2$ increases 35% in the high $q_2$ class (ratio: $1.35\pm0.14$) and decreases in the low $q_2$ class (ratio: $0.79\pm0.14$).

- Compatible with the expected variations of the eccentricity of the initial-state geometry within the uncertainties.

---

**J/ψ $v_2$ with ESE**

![Graph showing $v_2$ vs. $p_T$ for different $q_2$ classes.]

*arXiv:1811.12727*
\[ v_2 > 0 \] for \( 3 < p_T < 6 \text{ GeV/c} \) with a significance \( >5\sigma \) (backward+forward 5.02 and 8.16 TeV)

**J/\psi** and HF electron \( v_2 \) in p-Pb
• $v_2 > 0$ for $3 < p_T < 6$ GeV/c with a significance $>5\sigma$ (backward+forward 5.02 and 8.16 TeV)

$J/\psi$ and HF electron $v_2$ in p-Pb

• $v_2 > 0$ with a significance of more than $5\sigma$ for $1.5 < p_T < 4$ GeV/c.
• $v_2^{\text{HFe}} \equiv v_2^{\mu}$ and $v_2^{\text{HFe}} < v_2^{\text{ch. part.}}$. 
Summary

- Production: open and hidden HF production in pp, p-Pb and Pb-Pb.
  - $\Lambda^+_c/D^0$ in Pb-Pb higher than in p-Pb ($2\sigma$) and $R_{AA}(\Lambda^+_c) > R_{AA}(D^{0,+,*+})$ in $1.7\sigma$. Coalescence production?
  - Suppression of quarkonium states. Consistent with a (re)generation scenario.
• Production: open and hidden HF production in pp, p-Pb and Pb-Pb.
  • Suppression of open and hidden heavy flavour in Pb-Pb. Mass ordering? Mid-rapidity $R_{pPb}$ compatible with unity.
  • $\Lambda_c^+/D^0$ in Pb-Pb higher than in p-Pb (2$\sigma$) and $R_{AA}(\Lambda_c^+) > R_{AA}(D^{0,+,*+})$ in 1.7$\sigma$. Coalescence production?
  • Suppression of quarkonium states. Consistent with a (re)generation scenario.
• Azimuthal anisotropy: detailed study of open and hidden HF flow in Pb-Pb and p-Pb
  • Positive $v_2$ for open and hidden HF in Pb-Pb collisions. Charm quarks participate in the medium collective motion.
  • First measurement of the $J/\psi$ $v_3$. Information about the initial state.
• Event Shape Engineering studies for D mesons and $J/\psi$. HF $v_2$ sensitive to bulk $v_2$.
  • Positive $v_2$ for open and hidden HF in p-Pb collisions. Collective effects in p-Pb?
Backup
D-meson Ratios

- Sensitive to the fragmentation functions: universality of D-meson fragmentation functions

No significant $p_T$ dependence found

pp arXiv:1901.07979
D-meson Ratios

- Sensitive to the fragmentation functions: universality of D-meson fragmentation functions
- No difference between the pseudoscalar ($D^0, D^+, D^{+s}$) and vector ($D^{*+}$) in pp and p-Pb
- No difference between $D^{+s}/D^0$ ratios in pp and p-Pb. $D^{+s}/D^0$ higher in Pb-Pb, but compatible within uncertainties.

No significant $p_T$ dependence found

pp arXiv:1901.07979
D$^0$ jets

ALICE Preliminary

**29**

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HF decay leptons: $R_{AA}$

Models with mass dependent energy loss provide a good description.
Beauty electron $R_{AA}$

**Figure:**

- **ALICE Preliminary**
  - $b \to c \to e$
  - $2\pi \frac{d^2N}{dp_T^2}(GeV/c)^2$
  - $0-10\%$ Pb-Pb, $\sqrt{s_{NN}} = 5.02$ TeV
  - $2.25 < p_T < 2.50$ GeV/c
  - $|y| < 0.8$
  - $\eta_{TPC-TOE eID}$, $|\eta_{TPC-EMCal eID}| < 0.6$

- **Graph:**
  - Data
  - Dalitz
  - Conversion
  - Fit
  - $c \to e$
  - $b (\to c) \to e$

- **Legend:**
  - $\pm 3\%$ norm. unc. on $\langle T_{AA} \rangle$
  - Not shown

- **Notes:**
  - $\pm 3.5\%$ norm. unc. on $\sqrt{s}$-scaled data not shown

**ALI-PREL-308460**
Baryon/Meson ratios vs models

Catalina: EPJC 78 (4) (2018) 348
Shao-Song: PRC 97 (6) (2018) 064915

Results described by model calculations including only coalescence

ALICE Preliminary

$\Lambda^+ / D^0$ vs $p_T$ (GeV/c)

- $\sqrt{s} = 5.02$ TeV, $|y| < 0.5$
- $\sqrt{s} = 7$ TeV, $|y| < 0.5$

Data (JHEP 04 (2018) 108)
- PYTHIA8 Monash
- PYTHIA8 gg, $Q_T > 2$, Mode0
- PYTHIA8 SoRQCD, Mode0
- DIPSY (ropes)
- HERWIG7

Results described by model calculations including only coalescence

- PYTHIA8 Monash
- PYTHIA8 Mode0
- DIPSY
- HERWIG7

ALI−DER−314630

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Inclusive $J/\psi$: $v_2$ calculation (Pb-Pb)

(a) ALICE
- Inclusive $J/\psi \rightarrow \mu^+\mu^-$
- $2.5 < y < 4$, $2 < p_T < 4$ GeV/c
- $L_{int} = 225 \mu b$^(-1)

(b) Opposite-sign pairs
- Fit total
- Fit signal
- Fit background

(c) ALICE
- Inclusive $J/\psi \rightarrow e^+e^-$
- $|y| < 0.9$, $2 < p_T < 6$ GeV/c
- $L_{int} = 13 \mu b$^(-1)

(d) Opposite-sign pairs
- Mixed event pairs
- MC signal shape

Counts

Opposite-sign pairs
Fit total
Fit signal
Fit background

ALI-PUB-138829
Inclusive muon $v_2$ in p-Pb

- Dominated by muons from open heavy in the ranged studied
- Calculated using cumulants
- Non-flow contributions subtracted using pp collisions
- Positive $v_2$ measured.

![Graph showing $v_2$ distribution with p-Pb at $\sqrt{s_{NN}} = 8.16$ TeV and CMS $y$, $2.03 < y_{CMS} < 3.53$.](ALICE-PREL-308092)
Inclusive $J/\psi$: $v_2$ and $v_3$

- $v_2 > 0$ for $2 < p_T < 8$ GeV/$c$ for 3 centrality classes studied.
- Comparison to D mesons is not straightforward, but values are of the same magnitude.
**D-meson $v_2$**

\[ D^0 \rightarrow K\pi^+ \text{ and charge conj.} \]

**Counts / (5 MeV/c^2)**

<table>
<thead>
<tr>
<th>$M_{K\pi}$ (GeV/c^2)</th>
<th>In-plane</th>
<th>Out-of-plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.75</td>
<td>2 &lt; $p_T$ &lt; 3 GeV/c</td>
<td></td>
</tr>
<tr>
<td>1.85</td>
<td>30-50% Pb-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV</td>
<td></td>
</tr>
</tbody>
</table>

\[ D^+ \rightarrow K^{+}\pi^+\pi^+ \text{ and charge conj.} \]

**Counts / (19 MeV/c^2)**

<table>
<thead>
<tr>
<th>$M_{K\pi\pi}$ (GeV/c^2)</th>
<th>In-plane</th>
<th>Out-of-plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.75</td>
<td>10 &lt; $p_T$ &lt; 12 GeV/c</td>
<td></td>
</tr>
<tr>
<td>1.85</td>
<td>30-50% Pb-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV</td>
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</tr>
</tbody>
</table>

ALICE Preliminary

ALI-PREL-120925

ALI-PREL-120933
Charmonium production in pp

- 13 TeV significantly extend the $p_T$ range
- Spectra is harder for increasing energy
Charmonium production in pp

- 13 TeV significantly extend the $p_T$ range
- Spectra is harder for increasing energy
- $\psi(2S)/(J/\psi)$ ratios show no energy dependence

\[ \frac{\sigma(\psi(2S))}{\sigma(J/\psi)} \text{ as a function of } p_T \]

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D-meson $v_2$

Per meson $v_2$

$30-50\%$ Pb–Pb, $\sqrt{s_{NN}} = 5.02$ TeV

$|y|<0.8$

Prompt $D^0$

Prompt $D^*$

Prompt $D^{**}$

Prompt $D^*_s$

$D^0$, $D^*$, $D^{**}$ average, $|y|<0.8$

$D^0$, $D^*$, $D^{**}$ average, $|y|<0.8$

Syst. from data

Syst. from B feed-down

$|y|<0.8$

$|y|<0.8$

Model comparison

$30-50\%$ Pb–Pb, $\sqrt{s_{NN}} = 5.02$ TeV

$|y|<0.8$

$30-50\%$ Pb–Pb, $\sqrt{s_{NN}} = 2.76$ TeV

$|y|<0.8$

$|y|<0.8$

$2.76$ TeV vs $5.02$ TeV

ALICE
How does the c quark couples with the bulk of light quarks?

Selecting events with different eccentricity

$$\langle q_2^2 \rangle \approx 1 + \langle (M - 1) \rangle \langle v_2^2 + \delta_2 \rangle$$
D-meson $v_2$ with Event Shape Engineering

Selection in $q_2$ TPC

Results for V0A:
Reduced selectivity in $q_2$
Event-shape engineering (ESE) with the reduced flow vector:

\[ q_2 = \left| Q_2 \right| / \sqrt{M} \]

\[ \langle q_2^2 \rangle \approx 1 + \langle (M - 1) \rangle \langle v_2^2 + \delta_2 \rangle \]

Study one observable in classes of events corresponding to the same centrality, but different eccentricity

High \( q_2 \)
- More Elliptical interaction area

Low \( q_2 \)
- More circular interaction area

\[ Q_n = \sum_{j=1}^{M} e^{i\phi_j} \]

How does the c quark couples with the bulk of light quarks?
HFe $v_2$ in p-Pb

- Correlation obtained for high- and low-multiplicity events

- Jet subtraction: low multiplicity correlations used to remove most of short-range correlations
$\nu_2$ in $p$-$Pb$

- $\nu_2$ compatible with zero for $p_T < 3$ GeV/c

- $\nu_2 > 0$ for $3 < p_T < 6$ GeV/c with a significance $> 5\sigma$ when combining backward and forward results at the two energies (5.02 and 8.16 TeV)

- Similar to the one obtained in $Pb$-$Pb$

$PLB$ 880 (2018) 7