Experimental Overview: the Results of Heavy Flavours at LHC in QM 2018

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Outline

1. Introduction

2. Open Heavy Flavour in Nucleus-Nucleus Collisions

3. Quarkonia in Nucleus-Nucleus Collisions

4. Cold Nuclear Matter Effect in Heavy Flavours

5. Magnetic Vortical HQ Dynamics (theory)
The evolution of heavy flavours

→ Charm and beauty quarks are produced in hard scattering processes in the initial stages of the collisions.

→ They experience the full evolution of the system → sensitive probes of the properties of the Quark-Gluon Plasma.

→ Expected to lose energy while traversing the medium.

→ Collective expansion of the medium.

→ Hadronization: fragmentation vs coalescence.

→ Cold Nuclear Matter effect: modification of nPDF (shadowing) - Need reference measurements in pp and p-Pb collisions.
**Introduction**

**Nuclear modification factor :** $R_{AA}$

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

- **PbPb measurement**
- **pp reference**

Nuclear overlap function, encodes collision geometry

If $R_{AA}=1$ → no nuclear effects
If $R_{AA} \neq 1$ → nuclear effects

**Never forget:**

\[ \frac{dN_{AA}}{dp_T} \]

"vacuum" parton spectra
initial-state effects
parton interaction with the medium
(modified?) hadronization
hadronic phase
decay kinematics e.g. for leptons
Azimuthal anisotropy--elliptic flow: $V_2$

Initial spatial anisotropy
momentum anisotropy

$$\frac{dN}{d\varphi} = \frac{N_0}{2\pi} (1 + 2v_1 \cos(\varphi - \Psi_1) + 2v_2 \cos[2(\varphi - \Psi_2)] + \ldots)$$

$$v_n = \langle \cos(n[\varphi - \psi_n]) \rangle$$

Thermalization/collective motion
(at low $p_T$)

$V_2 > 0$

Path length dependence of energy loss
(at high $p_T$)
Quarkonium and heavy meson

Figure: P. Braun-Munzinger, J. Stachel, Nature 448 (2007) 302
Open Heavy Flavours in Nucleus-Nucleus Collisions
First measurement of non-prompt $D_0$ $R_{AA}$

$D_0$ from $b$ hadron

arXiv:1712.08959
Open Heavy Flavour in Nucleus-Nucleus Collisions

$R_{AA}$ in Xe-Xe collision

$R_{AA}$ of heavy-flavor electrons and muons in Xe-Xe collisions at 5.44 TeV
Flow of D0 in Xe-Xe collision

D0 meson V2 and V3 in PbPb Collisions and Comparison with Theoretical Models
$R_{AA}$ of $D$ meson at RHIC

- $R_{AA}$ of $B$ mesons estimated from the measured non-prompt $D^0$ fraction
Open Heavy Flavour in Nucleus-Nucleus Collisions

**V$_2$ of D meson at RHIC**

Charm quarks seem to acquire the same flow as light quarks!
Quarkonium in Nucleus-Nucleus Collisions
Quarkonia in Nucleus-Nucleus Collisions

**ATLAS**

Prompt $J/\psi$, $|y| < 2$

Cent. 40-80 %

Cent. 20-40 %

Cent. 0-10 %

**R_{AA}**

$Pb+Pb$, $\sqrt{s_{NN}}$ = 5.02 TeV, 0.42 nb$^{-1}$

$pp$, $\sqrt{s}$ = 5.02 TeV, 25 pb$^{-1}$

Correlated systematic uncer.

**CMS**

Hidden charm

Prompt $J/\psi$

$1.8 < |y| < 2.4$

$|y| < 2.4$

Open charm

$D^0$ HIN-16-001

$|y| < 1$

**Supplementary**

**PbPb 368 \mu b^{-1}, pp 28.0 pb^{-1} (5.02 TeV)**

Cent. 0-100%

**R_{AA}**

Non-prompt $J/\psi$, $|y| < 2$

$Pb+Pb$, $\sqrt{s_{NN}}$ = 5.02 TeV, 0.42 nb$^{-1}$

$pp$, $\sqrt{s}$ = 5.02 TeV, 25 pb$^{-1}$

Correlated systematic uncer.

100

$R_{AA}$

$R_{AA}$

$p_T$ [GeV]

$p_T$ [GeV/c]

arXiv:1712.08959

RAA of $J/\psi$ in PbPb at 5.02TeV

arXiv:1805.04077
Transport models predict a slightly stronger suppression in Xe-Xe collisions, counterbalanced by a larger recombination effect.
Quarkonia in Nucleus-Nucleus Collisions

Elliptic flow $V_2$

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ATLAS Preliminary

- ATLAS, Prompt J/ψ, 5.02 TeV, |y| < 2, 0 - 60%
- ATLAS, Non-prompt J/ψ, 5.02 TeV, |y| < 2, 0 - 60%
- ALICE, Inclusive J/ψ, 5.02 TeV, 2.5 < |y| < 4, 20 - 40%
- CMS, Prompt J/ψ, 2.76 TeV, 1.6 < |y| < 2.4, 10 - 60%
- CMS, Prompt J/ψ, 2.76 TeV, |y| < 2.4, 10 - 60%
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HION-2017-05

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ALICE Pb-Pb, √sNN = 5.02 TeV

global syst. ± 1%
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ALICE Collaboration PRL 119 (2017) 242301
ALICE Collaboration PRL 120 (2018) 102301
Theoretical description for $V_2$

- forward and mid-rapidity results agree within uncertainties
- at low $p_T$ models including regeneration agree with the data
- at high $p_T$ the elliptic flow is underestimated by the models
Cold Nuclear Matter Effects in Heavy Flavours
Cold Nuclear Matter Effect in Heavy Flavours

ALICE Preliminary

$R_{pPb}$
p-Pb, $\sqrt{s}_{NN} = 5.02$ TeV
Prompt $D^0$, $-0.96 < y_{cm} < 0.04$

PbPb 368 $\mu$b$^{-1}$, pp 28.0 pb$^{-1}$ (5.02 TeV)

CMS Supplementary

$R_{AA}$
Hidden charm
Prompt $J/\psi$
- $1.8 < |y| < 2.4$
- $|y| < 2.4$
Open charm
- $D^0$
- HIN-16-001
- $|y| < 1$

Cent. 0-100%

ALICE_PUBLIC-2018-006
arXiv:1712.08959
Cold Nuclear Matter Effect in Heavy Flavours

- $v_2^{D^0} < v_2^{\text{light hadrons}}$
- Charm quarks does not couple to the system as strongly as the light flavor quarks
- $D^0 v_2^{pPb} < v_2^{pPbPb}$ for a given $p_T$

arXiv: 1804.09767
Magnetic Vortical HQ Dynamics

Talk by S. Plumari
Magnetic vortical HQ dynamics

- **Intense magnetic field** $B$: created on Earth $\approx 10^7$ Gauss in Neutron Star $\approx 10^{13}$ Gauss in uRHIC $\approx 10^{19}$ Gauss $\approx 10 m_\pi^2$

A. Bzdak, V. Skokov, PLB 710 (2012) 171-174
Magnetic Vortical HQ Dynamics

\[ \langle p_x \rangle > 0 \]

\[ \langle p_x \rangle < 0 \]

\[ F_{\text{ext}} = qE + \frac{q}{E_p} (p \times B) \]

\[ \nu_1 = \left\langle \frac{p_x}{p_T} \right\rangle \neq 0 \]
Magnetic Vortical HQ Dynamics

Solve the Maxwell eq.s by starting with a point-like charge at the $x_T$ in the transverse plane and moving in the $+z$ direction with velocity $\beta$.

\[
\begin{align*}
\nabla \cdot E &= e \delta(z - \beta t) \delta(x - x_T) \\
\nabla \cdot B &= 0 \\
\n\nabla \times E &= -\frac{\partial B}{\partial t} \\
\n\nabla \times B &= \frac{\partial E}{\partial t} + \sigma_{el} E + e\beta \delta(z - \beta t) \delta(x - x_T)
\end{align*}
\]

Fold them with the nuclear transverse density profile of the spectator nuclei and sum forward (+) and backward (-)

\[
e B_{y,s} = -Z \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} d\phi' \int_{x_{in}(\phi')}^{x_{out}(\phi')} dx'_x dx'_y \rho_-(x'_\perp) \\
\times \left( eB_y^+(\tau, \eta, x_\perp, \pi - \phi) + eB_y^+(\tau, -\eta, x_\perp, \phi) \right),
\]

\[
e E_{x,s} = Z \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} d\phi' \int_{x_{in}(\phi')}^{x_{out}(\phi')} dx'_x dx'_y \rho_-(x'_\perp) \\
\times \left( -eE_x^+(\tau, \eta, x_\perp, \pi - \phi) + eE_x^+(\tau, -\eta, x_\perp, \phi) \right),
\]

RHIC: Au+Au @ 200 GeV, $b=7.5$ fm
For light quarks was predicted $v_1 \approx 10^{-3} - 10^{-4}$

For charm quarks due to early production we find a sizeable $v_1$ with the same E-B evolution
Thank you!