Direct Flow of heavy mesons as unique probe of the initial E.M. fields in HICs

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Solve Maxwell Equations for point-like charges at fixed transverse coord. moving in +(-)z direction with velocity $\beta$.

\[
\begin{align*}
\nabla \cdot \vec{E} &= \delta(z' - \beta t)\delta(\vec{x}'_\perp - \vec{x}_\perp) \\
\nabla \cdot \vec{B} &= 0 \\
\nabla \times \vec{E} &= -\partial_t \vec{B} \\
\nabla \times \vec{B} &= (\partial_t + \sigma_{\text{el}})\vec{E} + e\beta \delta(z' - \beta t)\delta(\vec{x}'_\perp - \vec{x}_\perp)
\end{align*}
\]

Convolute with nuclear transverse density of spectators then sum forward(+) and backward(-)

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

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

$B \approx (m_{\pi})^2 \approx 10^{19}$ G

Gürsoy, Kharzeev, Rajagopal PRC89 (2014)
Electro-Magnetic field in HICs

\[ B \approx (m_\pi)^2 \approx 10^{19} \text{ G} \]

Gürsoy, Kharzeev, Rajagopal PRC89 (2014)

In light quark sector \( v_1 \approx 10^{-3} - 10^{-4} \) … but HQs have the right features.

\[ eB_{y,s} = -Z \int_{-\pi/2}^{\pi/2} d\phi' \int_{x_{\text{in}}(\phi')}^{x_{\text{out}}(\phi')} d\rho (x'_{\perp}) \times \left( eB_y^+(\tau, \eta, x_{\perp}, \pi - \phi) + eB_y^+(\tau, -\eta, x_{\perp}, \phi) \right) \\
\]

\[ eE_{x,s} = Z \int_{-\pi/2}^{\pi/2} d\phi' \int_{x_{\text{in}}(\phi')}^{x_{\text{out}}(\phi')} d\rho (x'_{\perp}) \times \left( -eE_x^+(\tau, \eta, x_{\perp}, \pi - \phi) + eE_x^+(\tau, -\eta, x_{\perp}, \phi) \right) \]
Main properties of HQs in QGP:

- $M_{\text{HQ}} \gg \Lambda_{\text{QCD}} \rightarrow$ HQ are produced in hard pQCD processes (decoupled from CME).

- $M_{\text{HQ}} \gg T \rightarrow$ thermal production of HQ is negligible (out-of-equilibrium).

- $\tau_{\text{eq}} \geq \tau_{QGP} \gg \tau_{f} \rightarrow$ probe the QGP evolution retaining the initial kick from E.M. field.

[S.K. Das, S. Plumari, S. Chatterjee, J. Alam, F. Scardina, V. Greco, PLB768 (2017)]
Boltzmann approach for HQ dynamics in QGP

\[
\begin{align*}
\left[ p_\mu \partial_\mu x + qF_{\mu\nu}(x)p^\nu \partial_\rho \right] f_{HQ} &= C_{22}[f_{HQ}]
\end{align*}
\]

Stress tensor \((E, B)\)

Collision Integral \(
\approx\text{Dissipative}\)

BM Eq. solved numerically

+ Hadronization: fragm. & coalescence

Good description of \(R_{AA}(p_T)\) and \(v_2(p_T)\) simultaneously

[Scardina, Das, Minissale, Plumari and Greco, PRC 96 (2017)]

[Plumari, Minissale, Das, Coci and Greco, EPJ C 78 (2018)]
[poster Minissale at QM18]
Boltzmann approach for HQ dynamics in QGP

\[
\left[ p_\mu \partial_\mu^\mu + q F_{\mu\nu}(x) p^\nu \partial_\mu^\mu \right] f_{HQ} = C_{22}[f_{HQ}]
\]

Maxwell tens. \((E,B)\)
Collision Integral \(\approx\) Dissipative

[Scardina, Das, Minissale, Plumari and Greco, PRC 96 (2017)]
[Plumari, Minissale, Das, Coci and Greco, EPJ C 78 (2018)]

Implement VORTICITY from initial angular momentum conservation

The angular momentum of the system constituted by the two nuclei is transferred to the plasma as a shear flow in the longitudinal direction.

In agreement with other models:
[Deng and Huang PRC93 (2016)]
[Jiang, Lin, Liao, PRC 94 (2016); PRC 95 (2017)]
RESULTS:
Smaller formation time and longer thermalization allow HQs to gain larger $v_1$ compared to light quarks.

CONCLUSIONS:
✧ $v_1$ is a powerful probe of the strong E.M. field created at initial stage of HICs.

[Das, Plumari, Chatterjee, Alam, Scardina and Greco, PLB768 (2017)]

✧ $v_1$ is very sensitive to the combined effect of vorticity + E.M. field.

➔ THEORY: dynamics, modelling

EXPERIMENTS: $v_1$ at RHIC and LHC
We follow the scheme in Fig. (1a).\cite{4}

Model (I): Electro-Magnetic Field

In this work we describe the propagation of HQs in the Quark-Gluon Plasma (QGP) and provide a consistent framework based on a relativistic Boltzmann transport approach\cite{5}. Our results indicate that $\eta_1$ is an excellent probe for investigating the strong E.M. field created at initial stage of HICs.

PRELIMINARY: While in this model we can also introduce an initial vorticity due to angular momentum conservation and study its effects on HQ dynamics coupled to E.M. field looking at possible effects on HQ direct flow $v_1$ at RHIC.\cite{7}

**References**

\[\text{[1]}\]\text{G. Coci, S. Plumari, L. Oliva, S. K. Daul and V. Greco}\text{, 2015.}

\[\text{[2]}\]\text{F. Scardina, S. K. Daul, V. Mitsoula, S. Plumari, V. Greco, PRC B107 (2013) no. 2 024911.}

\[\text{[3]}\]\text{V. K. Das, F. Scardina, S. Plumari, V. Greco, PoS (PHT) 2013, 084.}

\[\text{[4]}\]\text{V. Greco, D. Khurana, K. Rajagopal, PRC 89 (2014) no. 6 064906.}

\[\text{[5]}\]\text{W. Tucker, PRC 88 (2013) no. 2 024911.}


\[\text{[7]}\]\text{V. Cui, L. Oliva, S. Plumari and V. Greco, in preparation.}

**Link to poster:** [https://indico.cern.ch/event/656452/contributions/2871147/](https://indico.cern.ch/event/656452/contributions/2871147/)