QM QUARK MATTER KRAKÓW 2022

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Probing electromagnetic fields in uRHICs with heavy quarks and leptons from Z^0 decay

Yifeng Sun
sunyfphy@sjtu.edu.cn
Shanghai Jiao Tong University

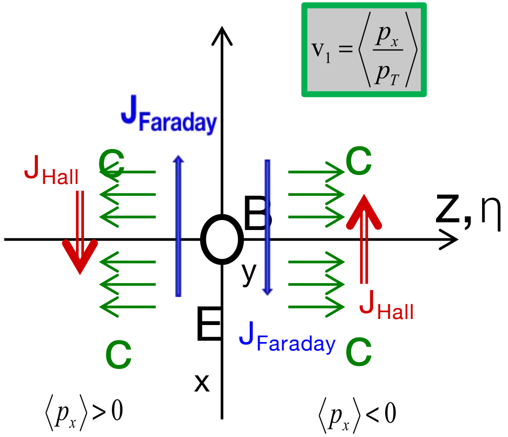
Collaborators:
S. Plumari, V. Greco and X.N. Wang

Refs： PLB 816, 136271 (2021); EPJP 136, 726 (2021); PLB 827, 136962 (2022)

Electromagnetic (e.m.) fields in uRHICs

- **Induces:** CME, CMW, Hyperons polarization splitting
- **Observables:** v_1 splitting of charged particles
- **Good Probes:** Heavy Quarks (HQs)

D.E. Kharzeev et al., NPA 803 (2008)
Y. Burnier et al., PRL 107 (2011), 052303
STAR, Nature 548 (2017), 62-65
U. Gursoy et al., PRC 89 (2014), 054905
S.K. Das et al., PLB 768 (2017), 260-264



❖ HQs best probe for v_1 induced by e.m. fields:

1. pQCD hard processes
2. negligible thermal production
3. $t_{form} \approx 0.08$ fm/c when B_y is ≈ its maximum and witness of all the QGP evolution
4. $\tau_{th}(c) \approx \tau_{QGP} >> \tau_{e.m}$ (keep more memory effects)

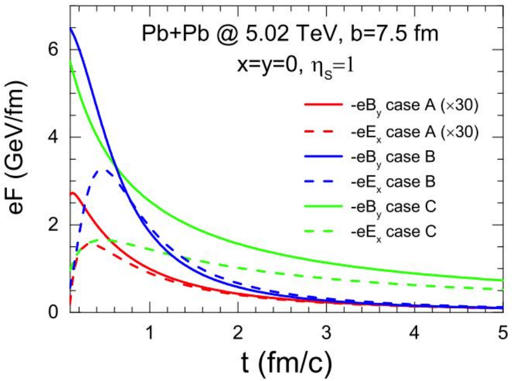
❖ Delicate balance between E and B

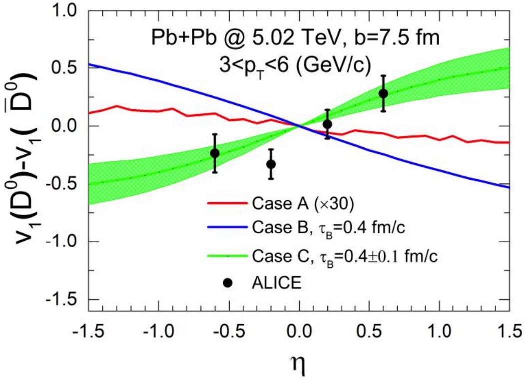
- ✓ E wins -> negative slope Δv_1 vs y_z between positively and negatively charged particles
- ✓ B wins -> positive slope Δv_1 vs y_z

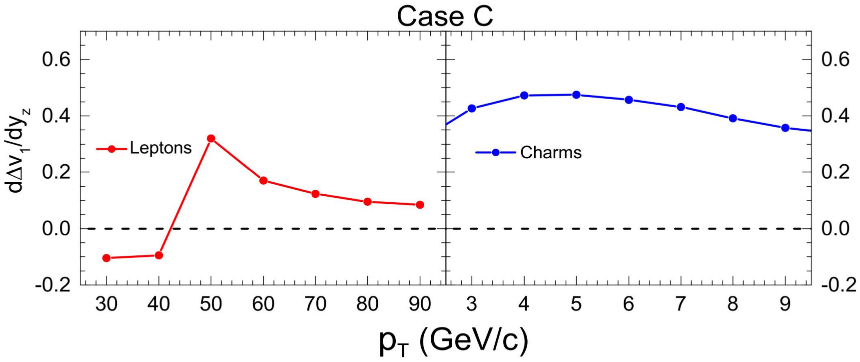
E.M. fields on HQs and leptons from Z^0 decay

- A slow decay e.m. fields (Case C) reproduces ALICE data
- V_1 splitting of leptons from Z^0 decay has a peculiar pattern
- Correlated measurement of c quarks and leptons from Z^0 decay a strong probe of e.m.

Sun&Plumari&Greco, PLB 816 (2021), 136271







Case A

- ✓ E-B fields like U. Gursoy et al., PRC 89 (2014), 054905
- ✓ Medium at t<0 + eq. medium σ_{el}=0.023 fm^{-1}

Case B and C

$$eB_y(x,y,\tau) = -B(\tau)\rho_B(x,y) \quad B(\tau) = eB_0/(1+(\tau/\tau_B)^a)$$

$$B(\tau) = eB_0/(1+\tau^2/\tau_B^2) \qquad B(\tau) = eB_0/(1+\tau/\tau_B)$$

- ✓ eB_0 fixed by the value t=0 in vaccum; a and τ_B can be tuned
- ✓ E_x is evaluated by the Faraday's Law $\nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$

❖ Why leptons from Z^0 decay

1. Clearer observables
2. Separable from other sources
3. $\tau_{decay}(Z^0)= \tau_{form}(charm)$=0.08 fm/c→ Strong correlation between $\Delta v_1(D^0,\bar{D}^0)$ and $\Delta v_1(l^+,l^-)$

Signatures of charge dependent flows by e.m. fields

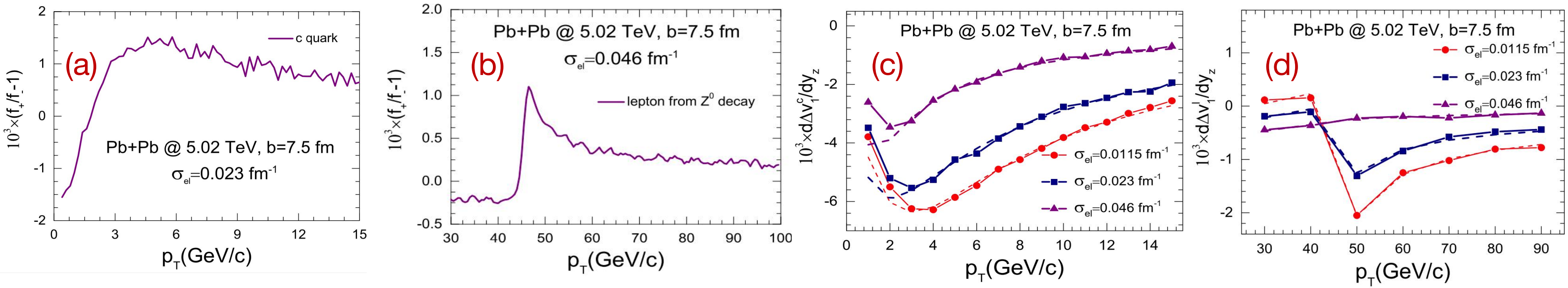
- E.M. fields modify charge dependent spectra and flows
- Can be described by simple forms

Sun&Greco &Plumari, EPJP 136 (2021), 726

$$
\begin{aligned}
f' &= f - \{\frac{\partial f(a_1+b_1)}{\partial p_T} + f(-\frac{p_T}{m_T^2}\frac{\partial (a_1+b_1)\tanh y_z}{\partial y_z} \\
&+ \frac{a_1+b_1}{p_T} + \frac{2}{m_T}\frac{\partial c_0/\cosh y_z}{\partial y_z})\} \\
&- \{-f\frac{p_T}{m_T^2}\frac{\partial (a_0+b_0)\tanh y_z}{\partial y_z} + \frac{\partial (a_0+b_0) f}{\partial p_T}\}\cos\phi \\
&- \sum_{n=1}\{\frac{\partial f(a_{n+1}+b_{n+1}+a_{n-1}-b_{n-1})}{\partial p_T} \\
&+ f[\frac{(n+1)(a_{n+1}+b_{n+1})-(n-1)(a_{n-1}-b_{n-1})}{p_T} \\
&- \frac{p_T}{m_T^2}\frac{\partial \tanh y_z (a_{n+1}+b_{n+1}+a_{n-1}-b_{n-1})}{\partial y_z} \\
&+ \frac{2}{m_T}\frac{\partial c_n/\cosh y_z}{\partial y_z}]\}\cos n\phi. \qquad (7)
\end{aligned}
$$

❖ From the p_T dependence of $d\Delta v_1/dy$ of leptons and charm quarks

- ✓ α ratio for Case A with σ_{el}=0.0115, 0.023 fm^{-1} are 8.7 MeV/6.3 MeV=1.4 and 4.7 MeV/3.6 MeV=1.3
- ✓ for Case C is 1.5 GeV/0.75 GeV=2
- ✓ close to charge ratio 1.5 for different e.m. fields: 100 times



$$f'|_{y_z=0} = f\left[1-(a_1+b_1)\frac{\partial \ln f}{\partial p_T} - \frac{2}{p_T}\frac{\partial c_0}{\partial y_z}\right]|_{y_z=0}$$

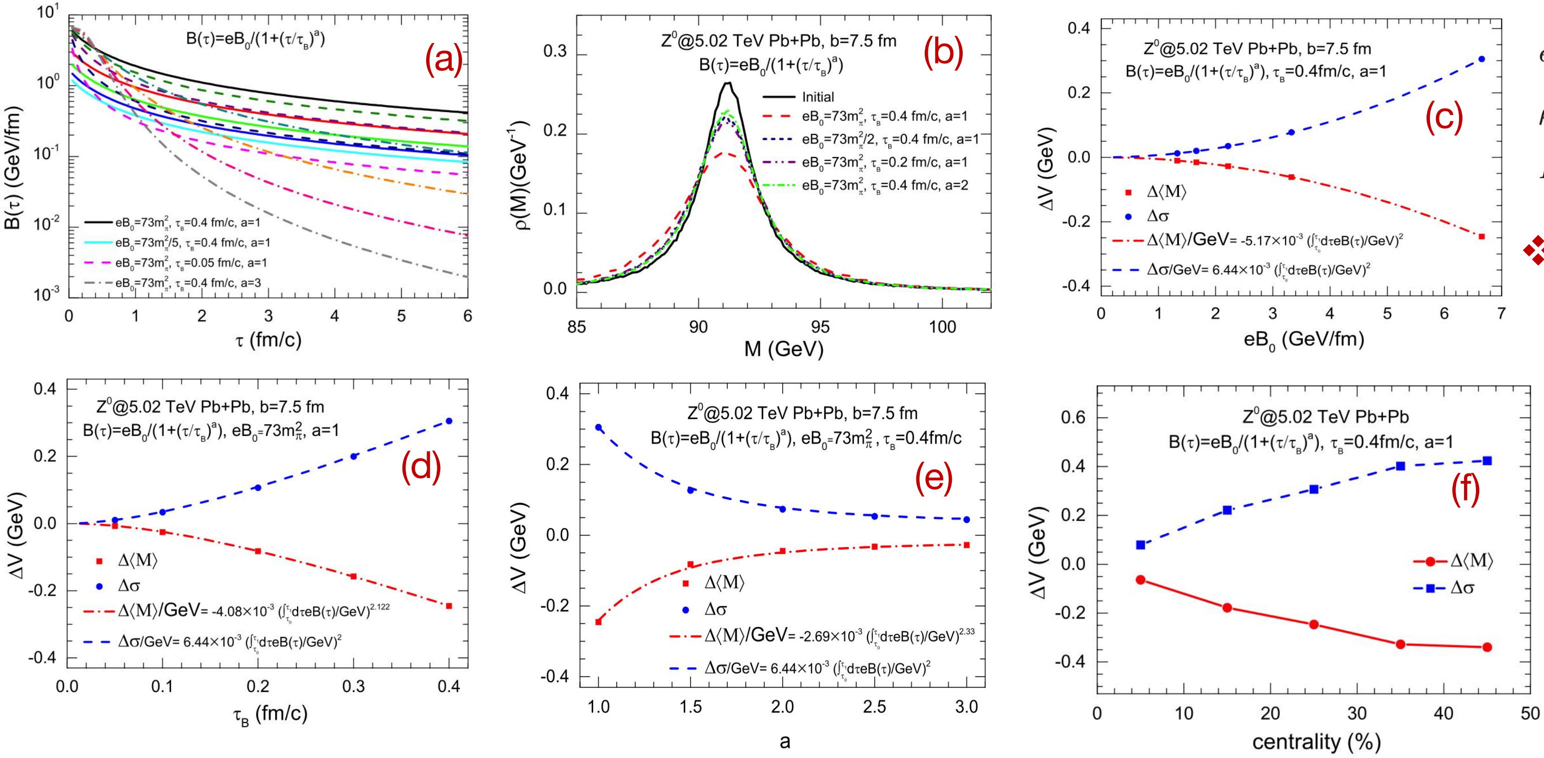
$$
\begin{aligned}
\frac{d\Delta v_1^c}{dy_z}|_{y_z=0} &= \frac{d\Delta a_0}{dy_z}|_{y_z=0}\left(-\frac{\partial \ln f_c}{\partial p_T}+\frac{2p_T}{m_T^2}\right) - \frac{1}{m_T}\left(\frac{d^2 c_1}{dy_z^2}-c_1\right) \\
&= -\alpha\frac{\partial \ln f_c}{\partial p_T} + (2\alpha-\beta)\frac{p_T}{m_T^2}
\end{aligned}
$$

$$
\begin{aligned}
\frac{d\Delta a_0}{dy_z}|_{y_z=0} &= |q|K\left[\tau_1 g(\tau_1,0)-\tau_0 g(\tau_0,0)\right] \\
&\simeq -|q|K\ \left[\tau_1 B_y(\tau_1,0)-\tau_0 B_y(\tau_0,0)\right]
\end{aligned}
$$

E.m. fields on Z^0 leptonic invariant mass

- ❑ E.M. fields decreases Z^0 leptonic invariants and increase width
- ❑ Changes of Z^0 leptonic invariant mass and its width
  - ✓ Depends on the integral of B_y quadratically (approximate)

Sun&Greco&Wang, PLB 827, 136962 (2022)



$$eB_y(x,y,\tau) = -B(\tau)\rho_B(x,y)$$
$$\rho_B(x,y) = \exp[-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2}]$$
$$B(\tau) = eB_0/(1+(\tau/\tau_B)^a),$$

❖ Small effect of lepton-quarks scattering

$$\Delta\langle M\rangle = -1.9 \text{ MeV}$$
$$\Delta\sigma \leq 0.2 \text{ MeV}$$