Determine the magnitude of the magnetic field at freeze-out

Paper in preparation…

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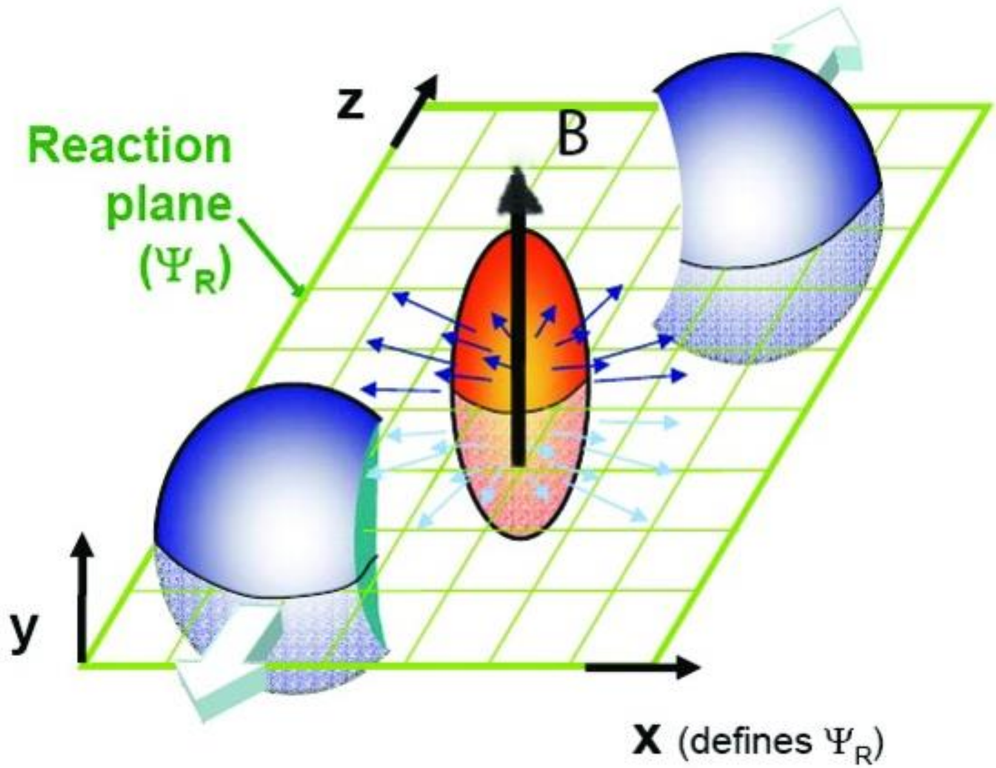
The 5th Workshop on Chirality, Vorticity and Magnetic Field in Heavy Ion Collisions

Introduction

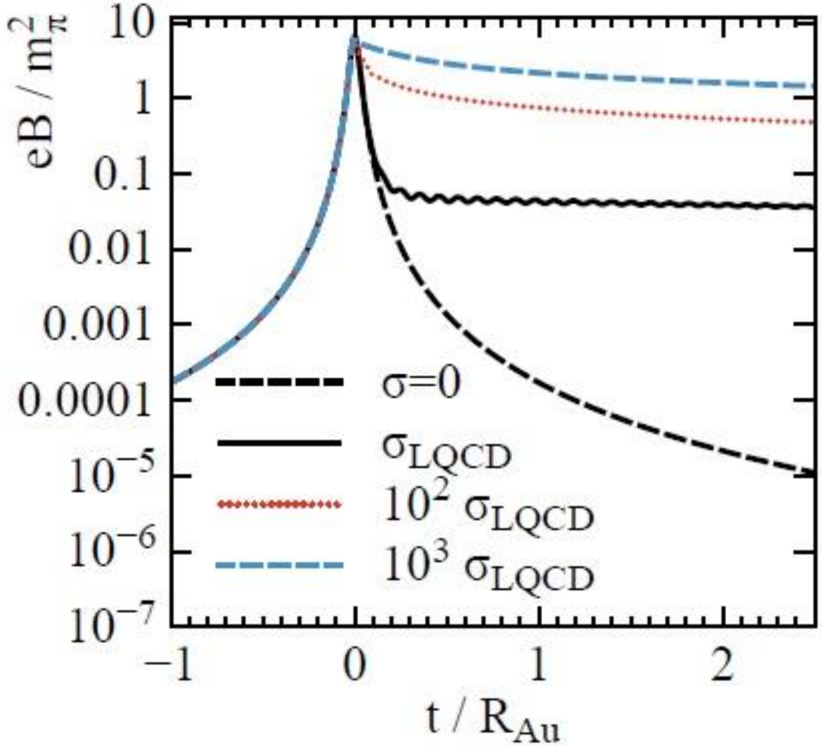


Question：

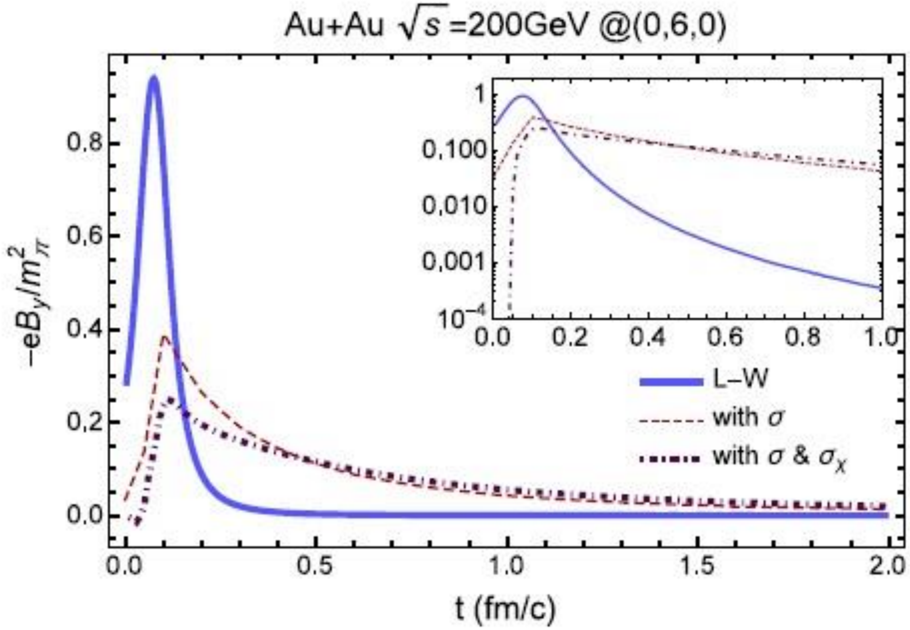
How does the magnetic field evolve?

How large the magnitude of the magnetic field remains at freeze-out?

Dynamical evolution

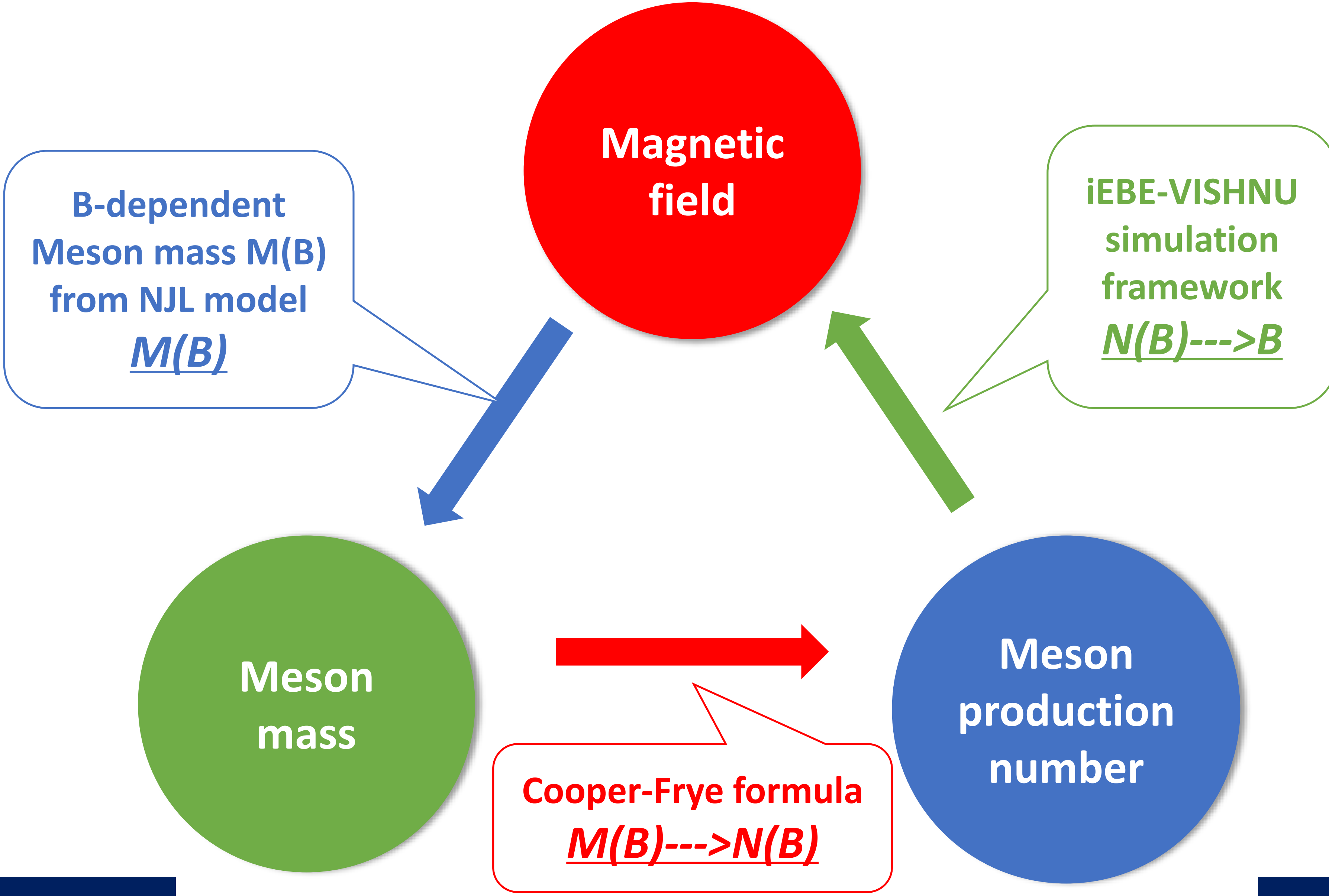


L. McLerran, V. Skokov 1305.0774



Hui Li, Xin-li Sheng, and Qun Wang 1602.02223

Motivation


Magnetic field
B-dependent Meson mass M(B) from NJL model
M(B)
iEBE-VISHNU simulation framework
N(B)--->B
Meson mass
Meson production number
Cooper-Frye formula
M(B)--->N(B)

NJL model

Lagrangian density of NJL model

$$
\begin{aligned}
\mathcal{L} \quad = \quad & \bar{\psi}(i\gamma^{\mu}D_{\mu} - m_0)\psi + G_S[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma^5\vec{\tau}\psi)^2] \\
& - G_V[(\bar{\psi}\gamma^{\mu}\tau^a\psi)^2 + (\bar{\psi}\gamma^{\mu}\gamma^5\tau^a\psi)^2] \\
& + \frac{1}{4}F_{\mu\nu}F^{\mu\nu},
\end{aligned}
$$

Where $D_{\mu} = \partial_{\mu} - iq_f A_{\mu}^{ext}$

$F_{\mu\nu} = \partial_{\mu}A_{\nu}^{ext} - \partial_{\nu}A_{\mu}^{ext}$, $A_{\mu}^{ext} = \{0, 0, Bz, 0\}$

Meson in NJL Model

Define meson fields

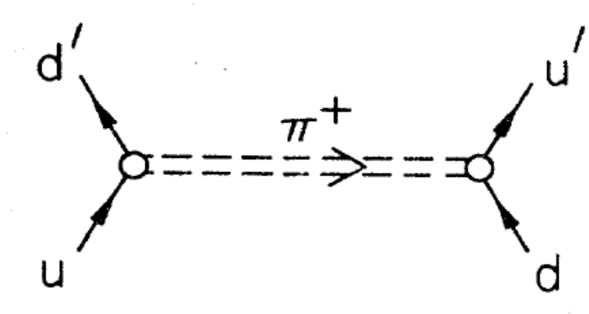
$$\sigma(x) = -2G_S\bar{\psi}(x)\psi(x), \quad \vec{\pi}(x) = -2G_S\bar{\psi}(x)i\gamma^5\vec{\tau}\psi(x)$$

$$V_\mu^a(x) = -2G_V\bar{\psi}(x)\gamma_\mu\tau^a\psi(x), \quad A_\mu^a(x) = -2G_V\bar{\psi}(x)\gamma_\mu\gamma^5\tau^a\vec{\tau}\psi(x)$$

Mean-field approximation

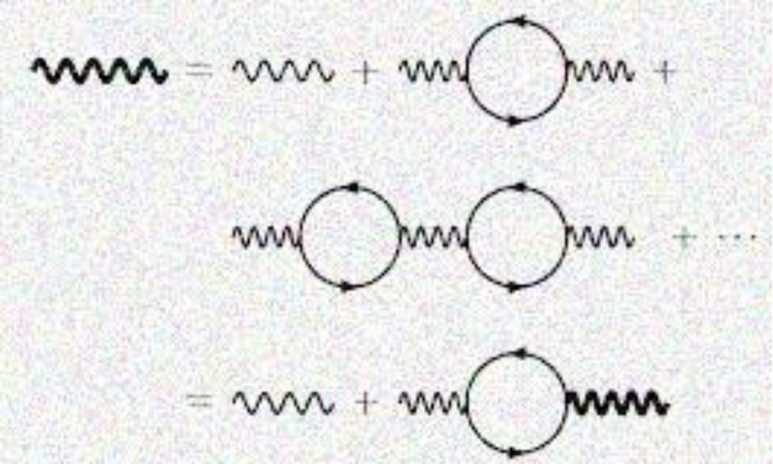
$$\mathcal{L} = \bar{\psi}(i\gamma^\mu D_\mu - m_0)\psi - \bar{\psi}(\sigma - i\gamma^5\vec{\tau}\cdot\vec{\pi})\psi - \frac{\sigma^2+\vec{\pi}^2}{4G_S} - \frac{V_\mu^a V^{a\mu} + A_\mu^a A^{a\mu}}{4G_V} - \frac{B^2}{2}$$

Meson mass in NJL model



[1408.1318, Hao Liu, Lang Yu, Mei Huang]
[1507.05809, Lang Yu, Hao Liu, Mei Huang]

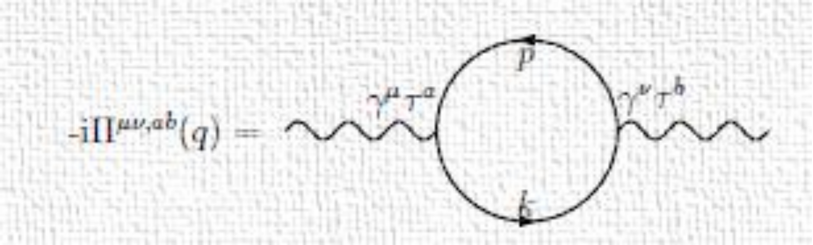
Full propagator in random phase approximation



Schwinger-Dyson equation

$$[-iD^{\mu\nu}_{ab}] = [-2iG_V\delta_{ab}g^{\mu\nu}] + [-2iG_V\delta_{ac}g^{\mu\lambda}]\,[-i\Pi_{\lambda\sigma,cd}]\,[-iD^{\sigma\nu}_{db}]$$

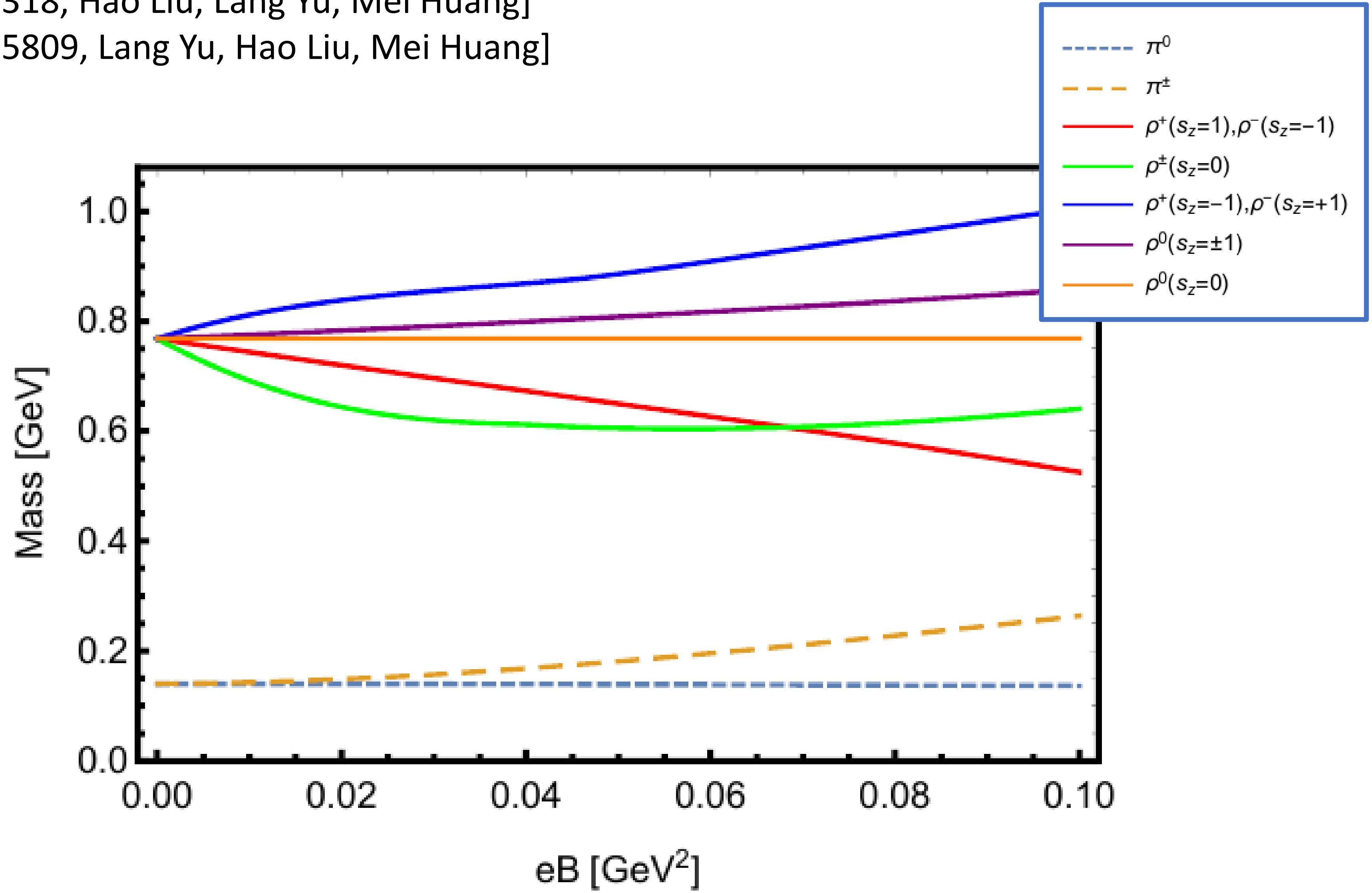
One-loop polarization function



$$D(q^2) = \frac{2G}{1+2G\Pi(q^2)}, \qquad 1+2G\Pi(q^2)=0$$

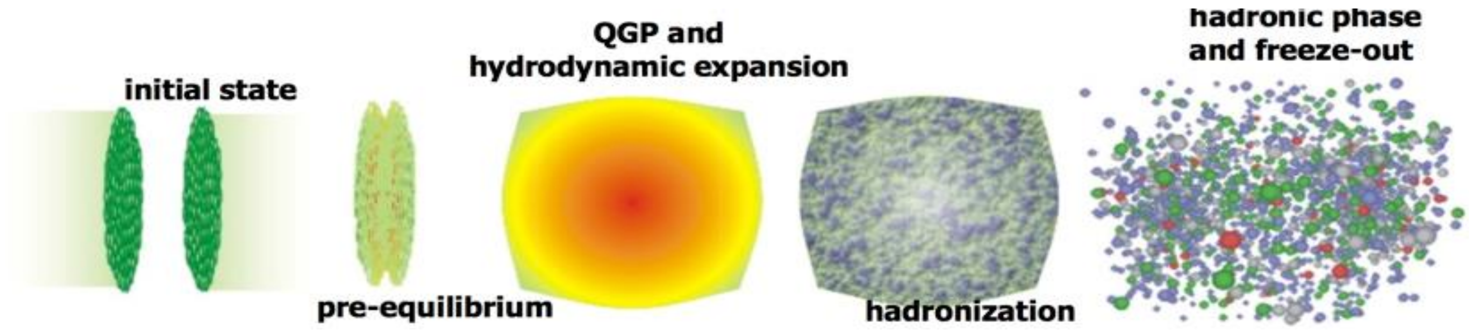
Meson mass and magnetic field

[1408.1318, Hao Liu, Lang Yu, Mei Huang]
[1507.05809, Lang Yu, Hao Liu, Mei Huang]



Evolution: Hydro->freeze-out->decay

1、 Dynamical evolution of energy-momentum:



2、 Chemical freeze-out. Cooper-Frye formula: [F. Cooper, G. Frye, 1974]

$$\frac{dN}{dy p_T dp_T d\phi} = \frac{g_i}{(2\pi)^3} \int_\Sigma p^\mu d\sigma_\mu \left[f_0 + f_0(1 \mp f_0) \frac{p^\mu p^\nu \pi_{\mu\nu}}{2T^2(e+P)} \right]$$

where $f_0 = \frac{1}{\exp{(p \cdot V)/T} \pm 1}$

$$N \sim f(m)$$

B dependent mass

3、 Hadron resonance decay:

$$\rho^\pm \to \pi^\pm + \pi^0, \rho^0 \to \pi^+ + \pi^-$$

Measurement of production number

IEBE-VISHNU

Collision condition:

Au-Au collision, 200GeV, 30%-40% centrality

Assumptions:

1、 only pion and rho are considered;

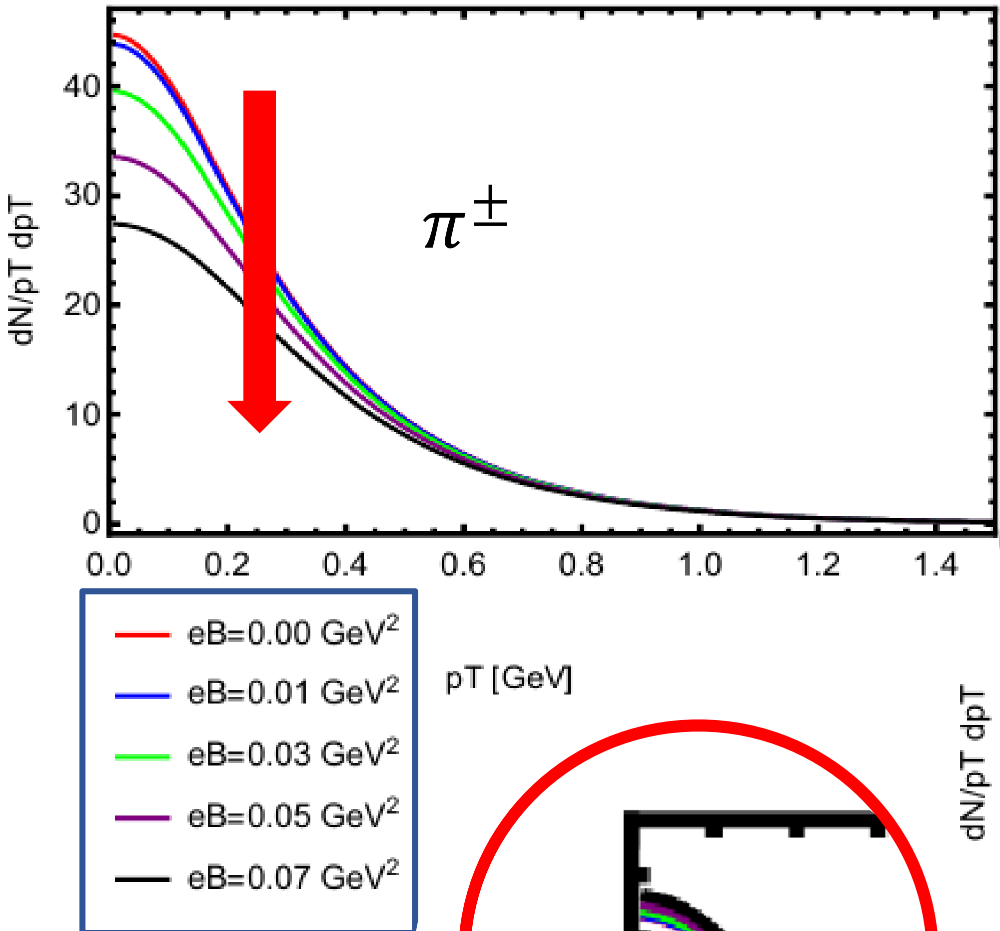
2、 "averaged freeze out time" τ_{ave};

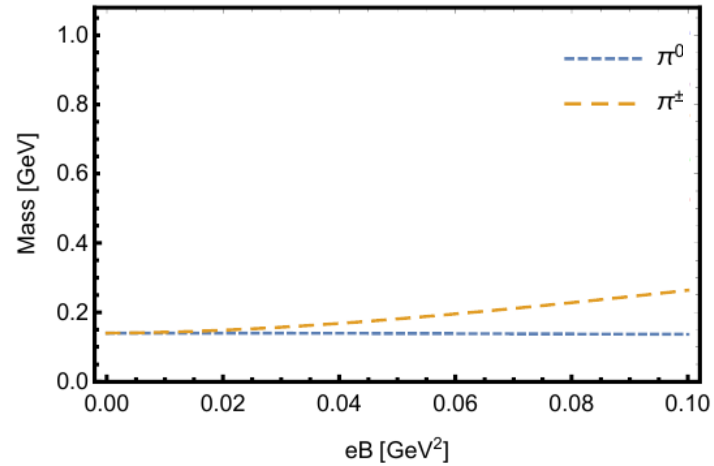
$$\tau_{ave} = \frac{\int (dN/d\tau)\tau d\tau}{\int (dN/d\tau) d\tau}$$

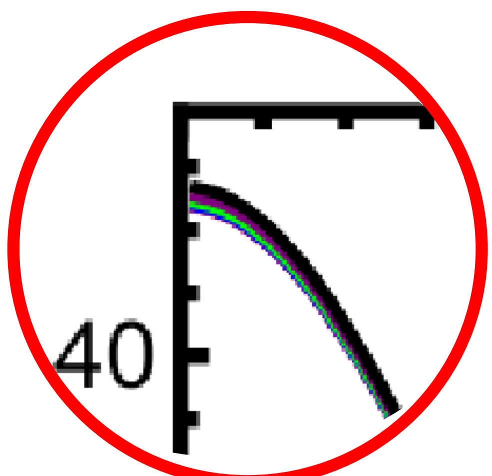
dN: number of hadrons freeze out at τ--->$\tau + d\tau$

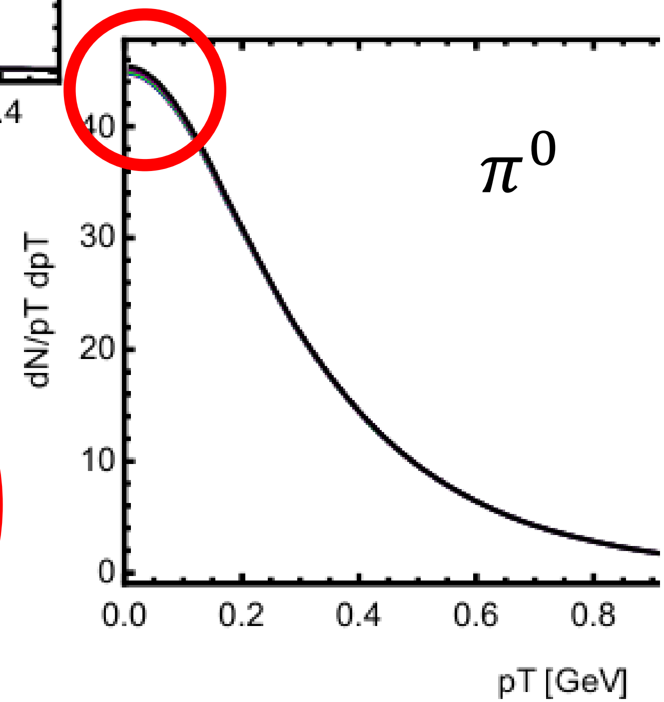
3、 no magnetic field at hadron resonance decay stage.

(Momentum distribution)
Pion from chemical freeze out

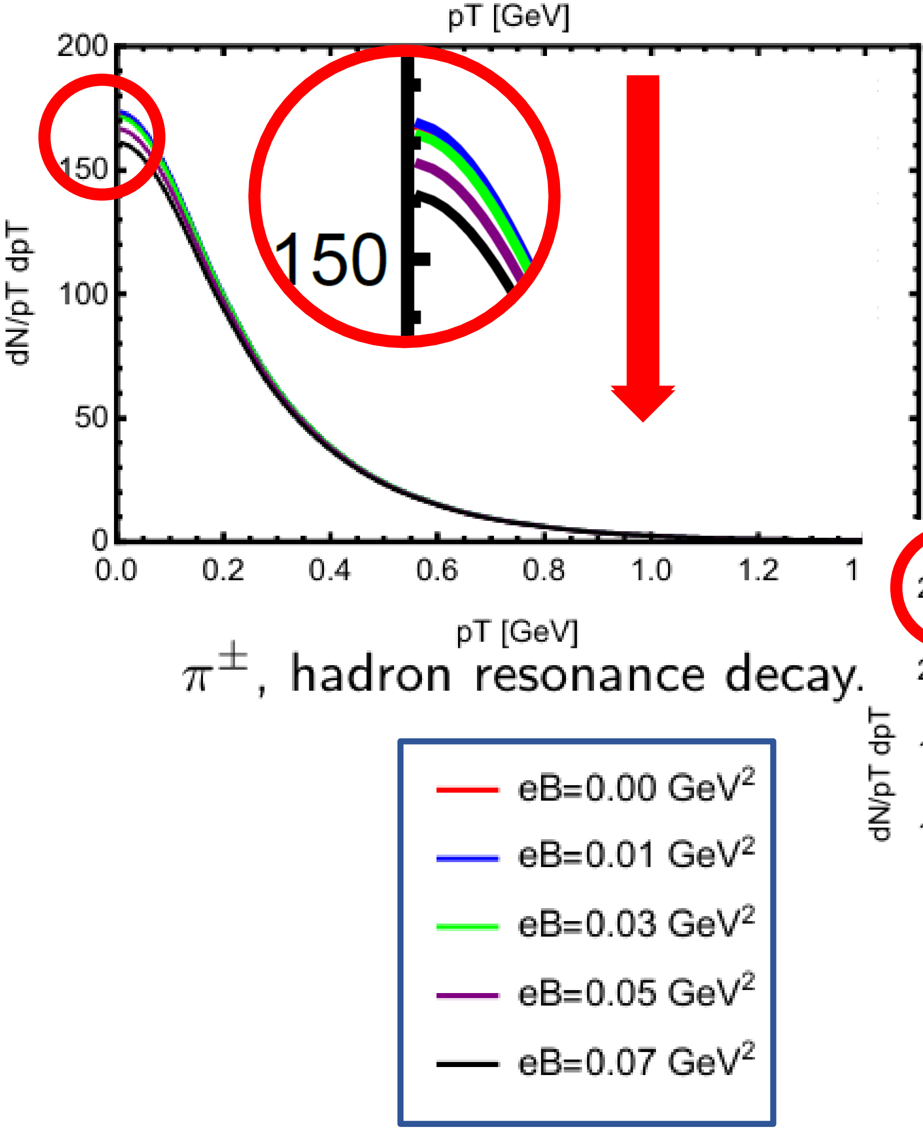




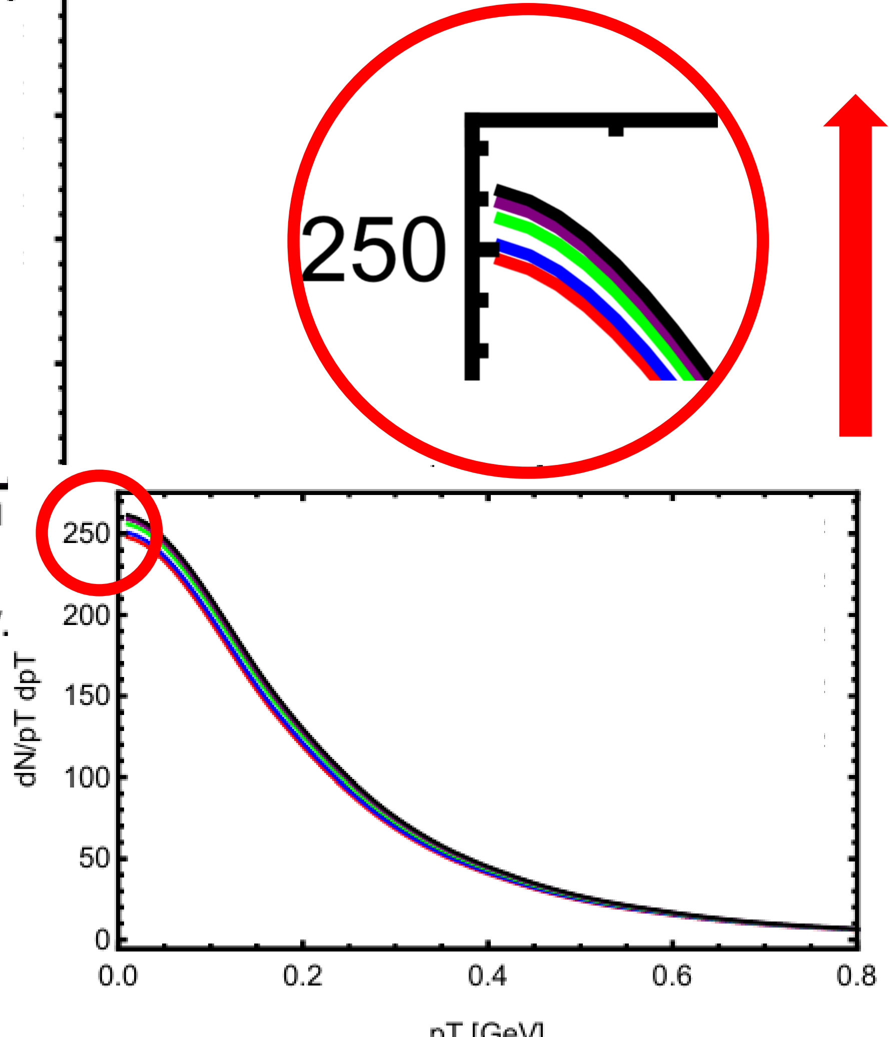




(Momentum distribution)
Pion after hadron resonance decay stage

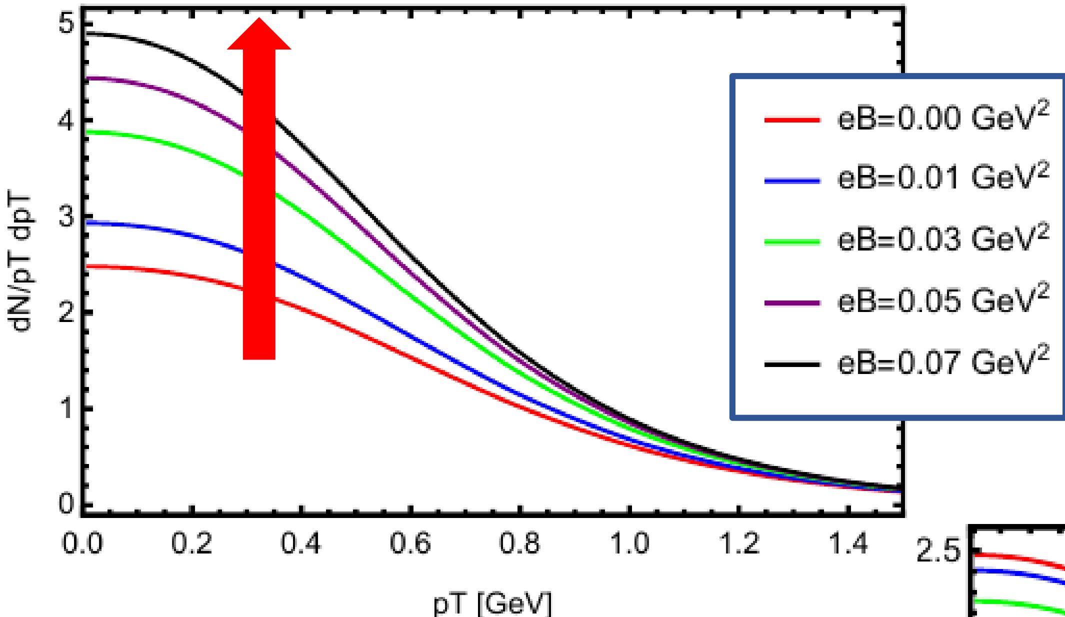


$\pi^{\pm}$, hadron resonance decay.

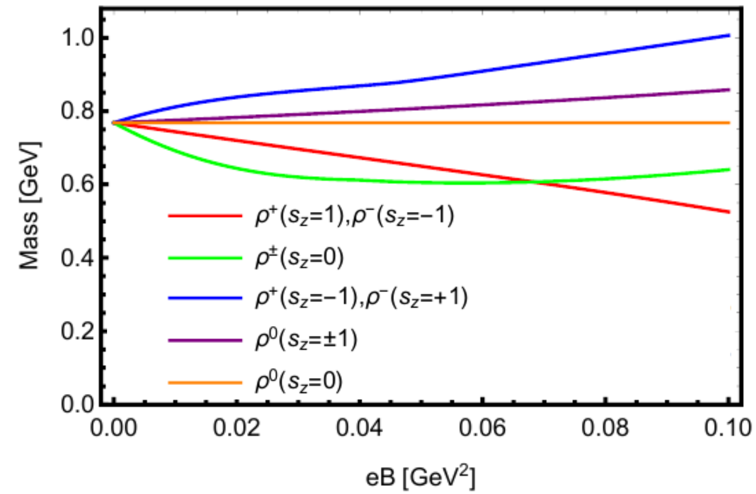


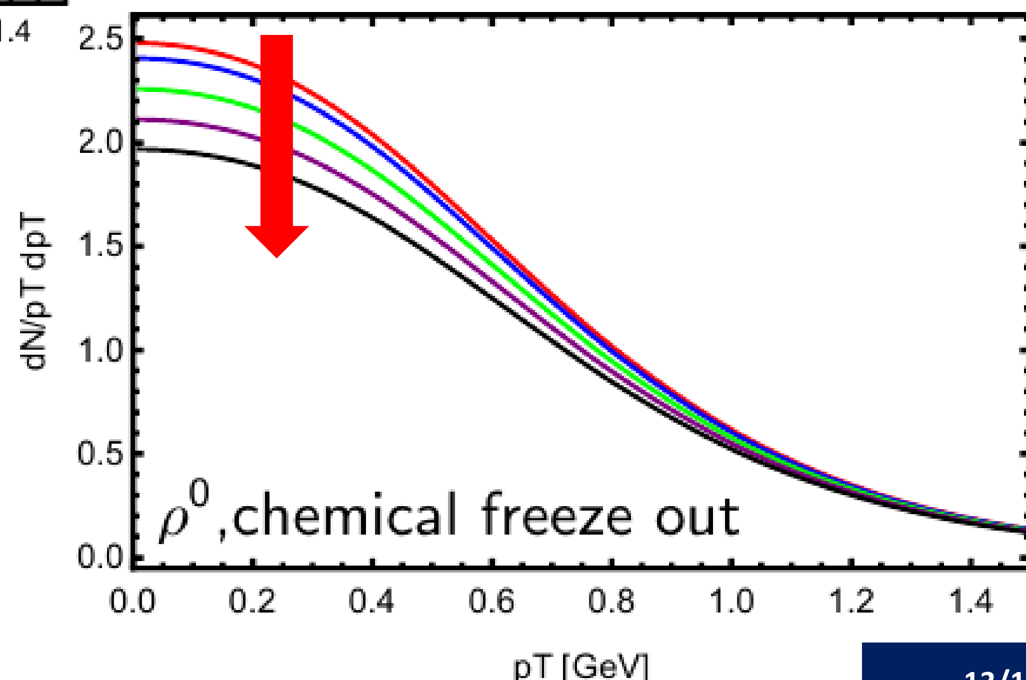
π^{0}, hadron resonance decay.

(Momentum distribution)
Rho from chemical freeze out



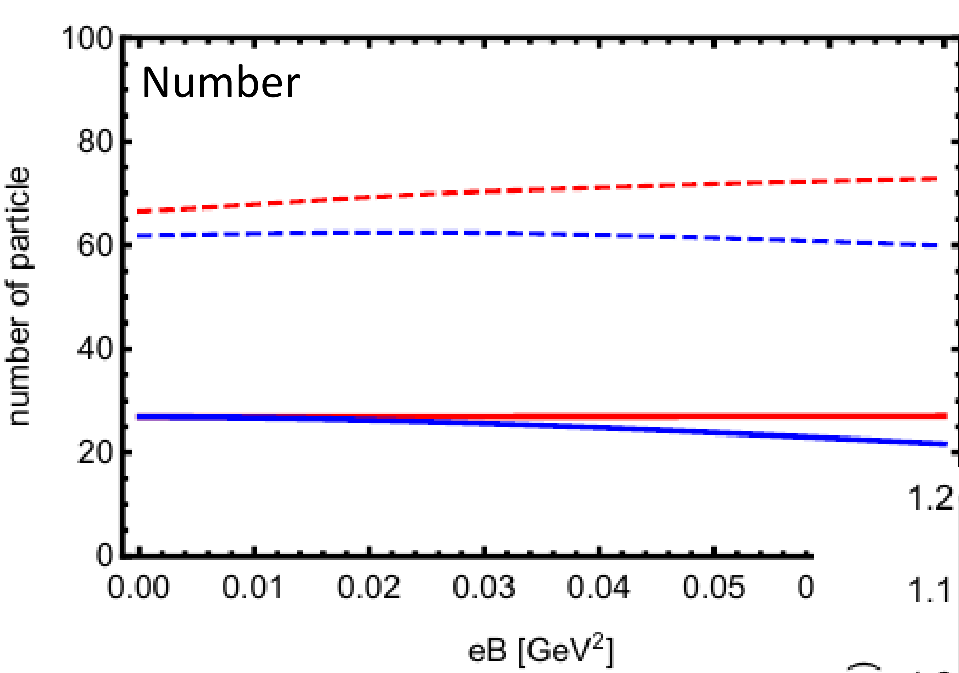
$\rho^{\pm}$,chemical freeze out

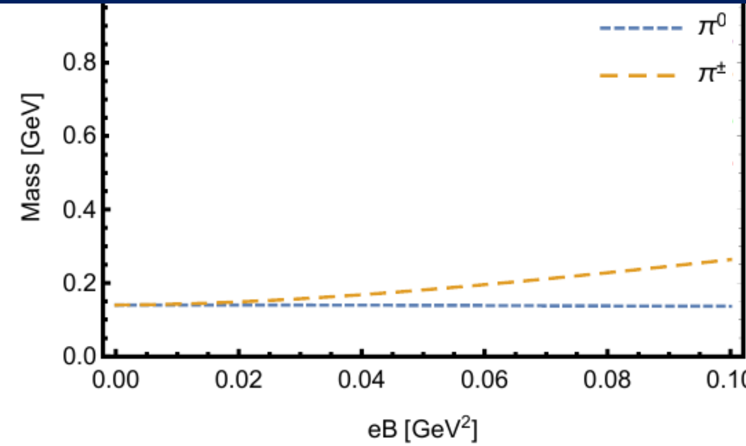


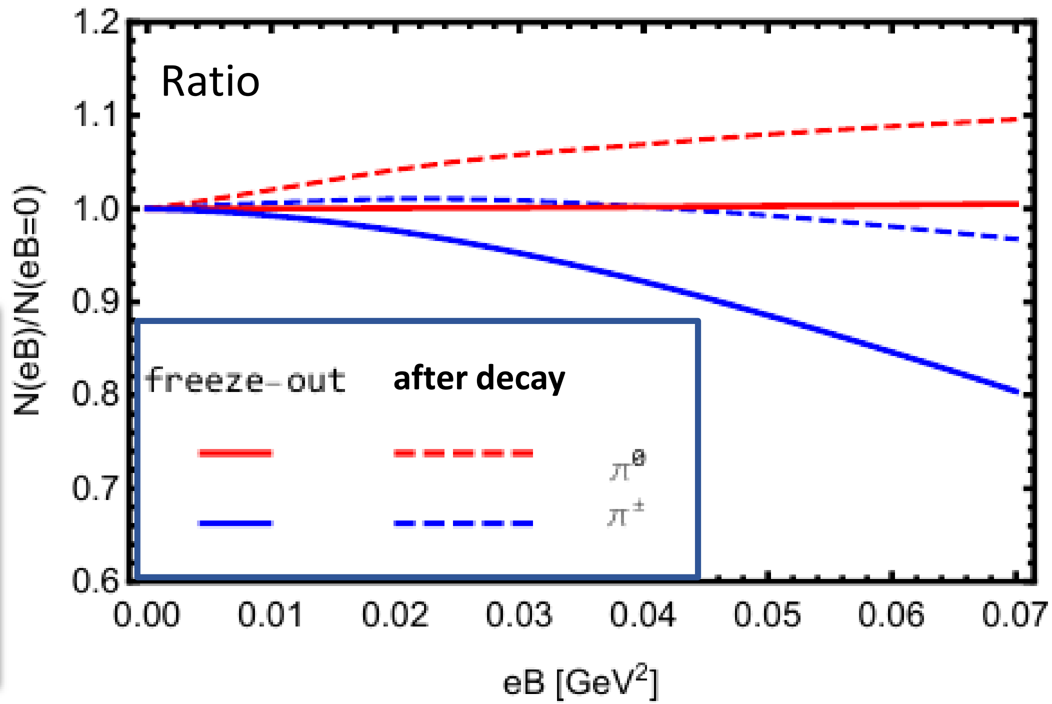


$$\rho^{\pm} \to \pi^{\pm} + \pi^{0}, \rho^{0} \to \pi^{+} + \pi^{-}$$

Production number of pion (0.15GeV<pt<2GeV)

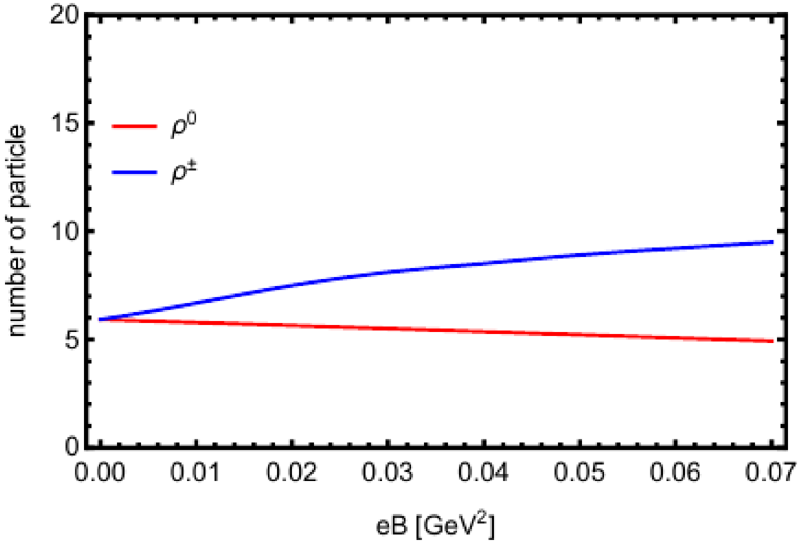


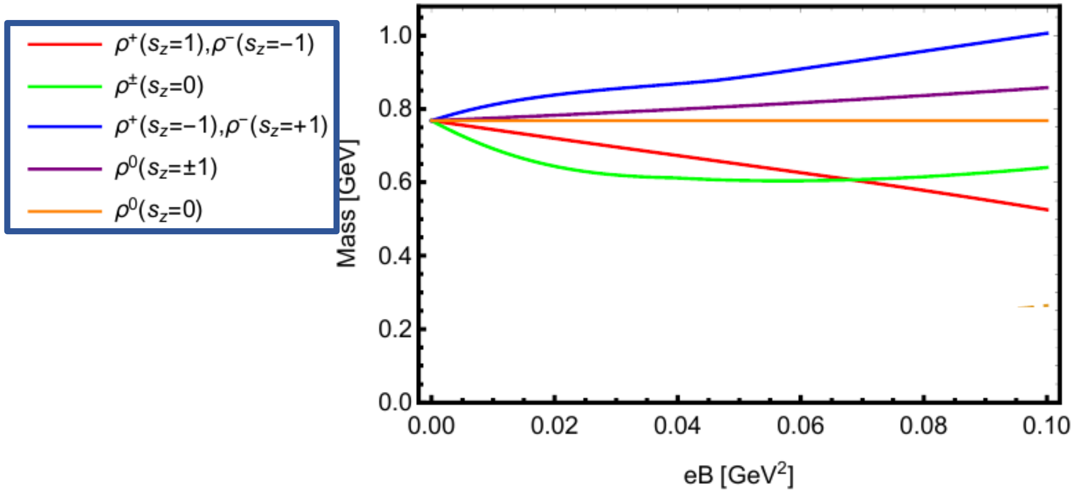




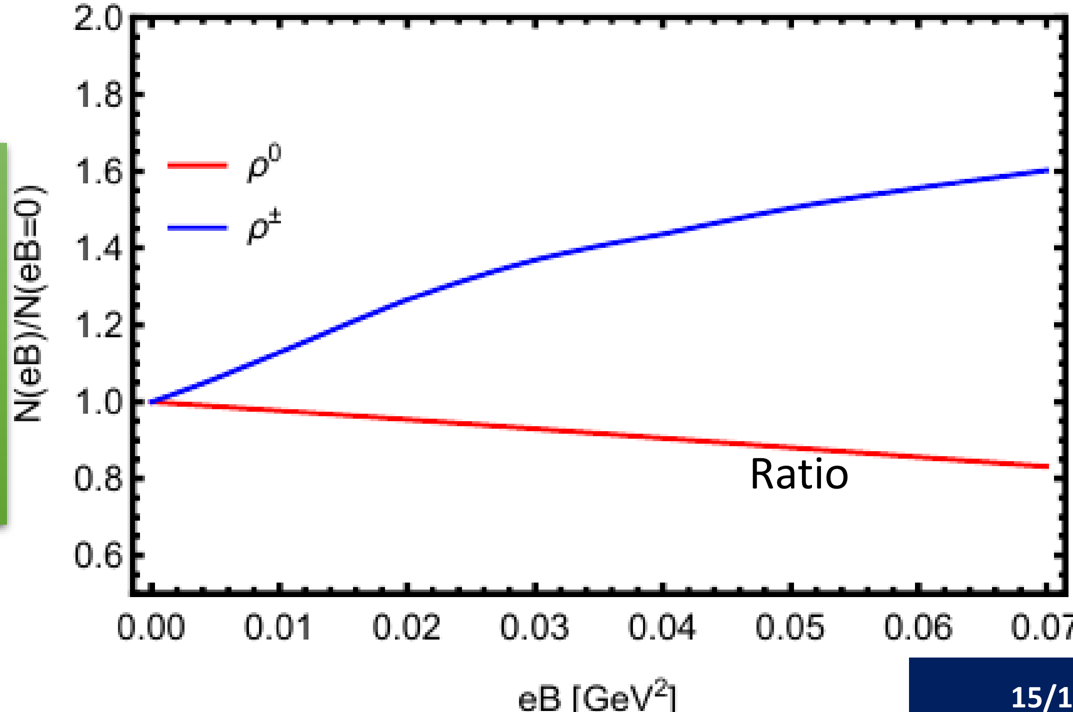
Magnetic field influences significantly the production number of charged pion

Production number of rho (0.15GeV<pt<2GeV)

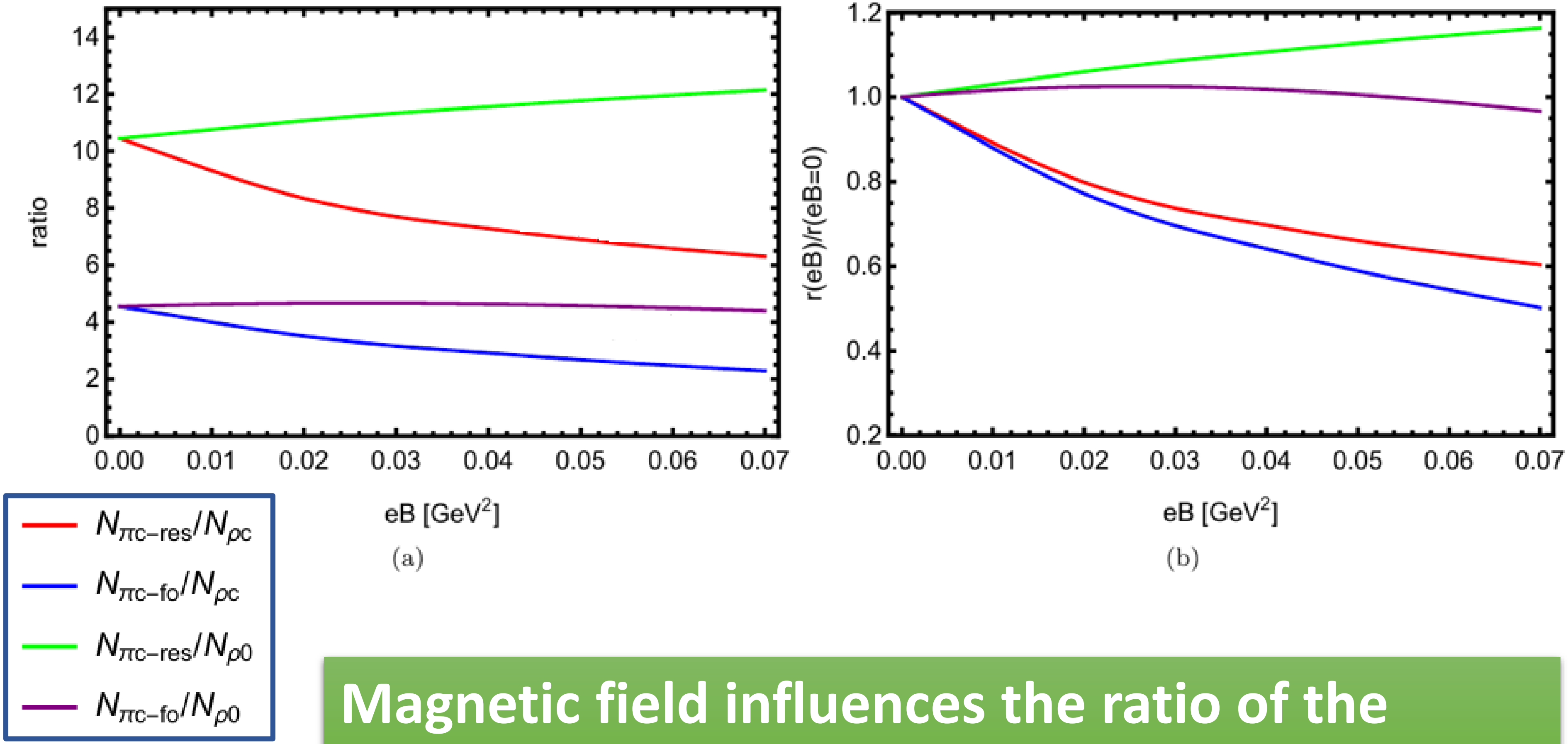




Magnetic field influences significantly the production number of charged rho



Ratio of pion number over rho number



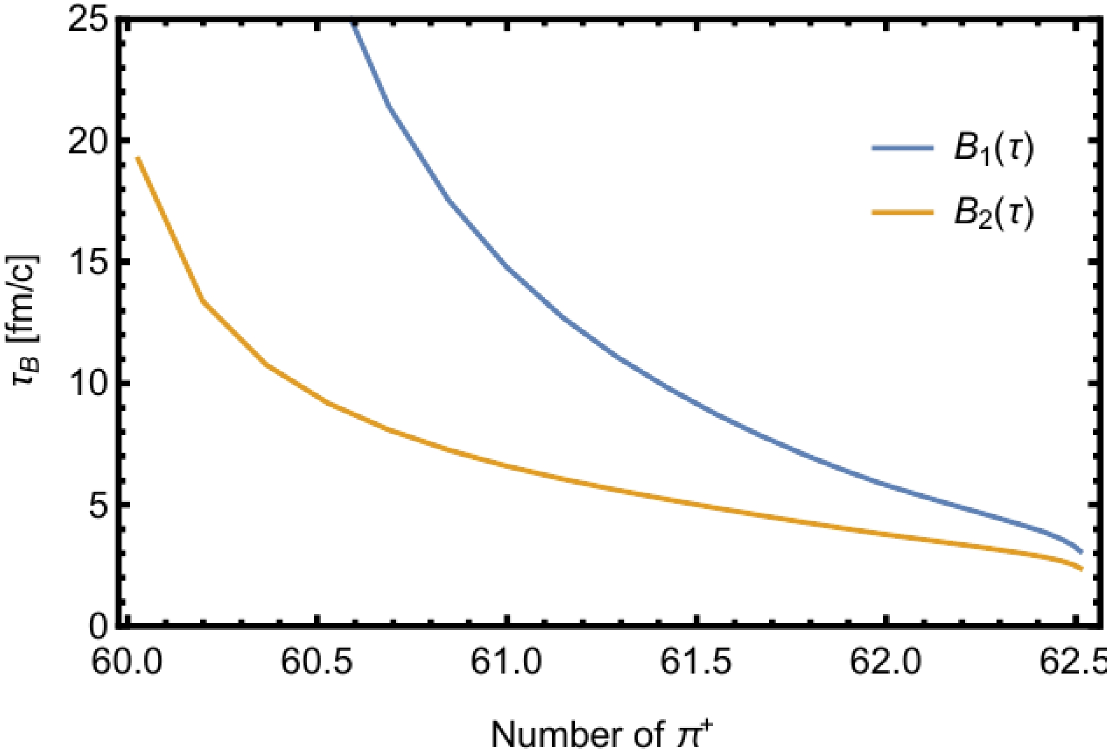
Magnetic field influences the ratio of the number of charged pion over the number of charged rho significantly.

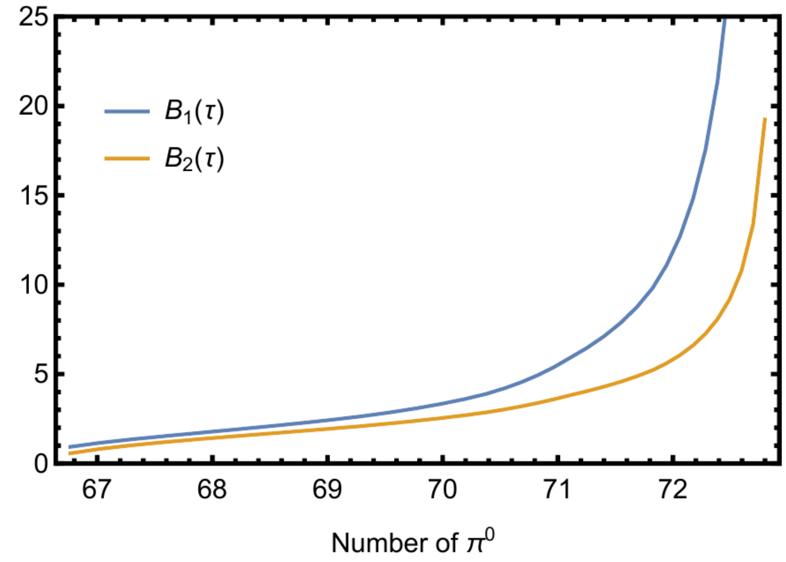
Assumed evolution function

[Yin Jiang, Shuzhe Shi, Yi Yin, Jinfeng Liao] 1611.04586
[Shuzhe Shi, Yin Jiang, Elias Lilleskov, Jinfeng Liao] 1711.02496

$$B_1(\tau) = B_0 e^{-\frac{\tau}{\tau_{1,B}}}, \quad B_2(\tau) = \frac{B_0}{1+(\tau/\tau_{2,B})^2}, \quad eB_0 = 0.07\mathrm{GeV}^2$$

$$\tau_{ave} = \frac{\int (dN/d\tau)\tau d\tau}{\int (dN/d\tau) d\tau} \approx 3.29\mathrm{fm/c}$$





tau_B can be determined by the production number of pion;
tau_B is sensitive to the production number of pion

Summary

- Magnetic field influences the production number of rho and pion, significantly for charged rho and charged pion;
- Magnetic field influences the ratio of the production number of pion over the production number of rho, significantly for charged pion over charged rho;
- tau_B can be determined by the production number of pion;
- tau_B is sensitive to the production number of pion

FUTURE:

- **realistic freeze out;**
- **magnetic field evolution;**
- **temperature dependence**

THANKS