The 16th Workshop on QCD Phase Transition and Relativistic Heavy-Ion Physics (QPT 2025)

Bayesian inference of the magnetic field and chemical potential on holographic jet quenching in heavy-ion collisions

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Outline

1、Introduction and motivation

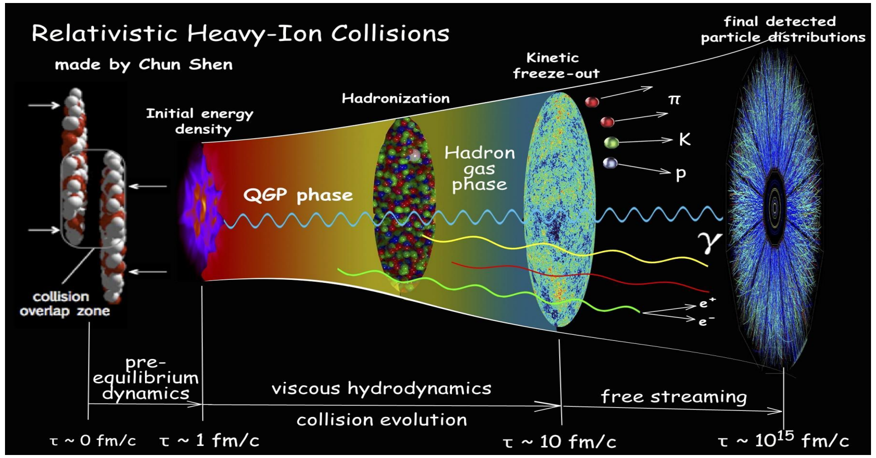
2、NLO pQCD parton model and Medium-modified FFs

3、Holographic Energy loss with magnetic field chemical potential

4、Bayesian extraction for the magnetic field and chemical potential

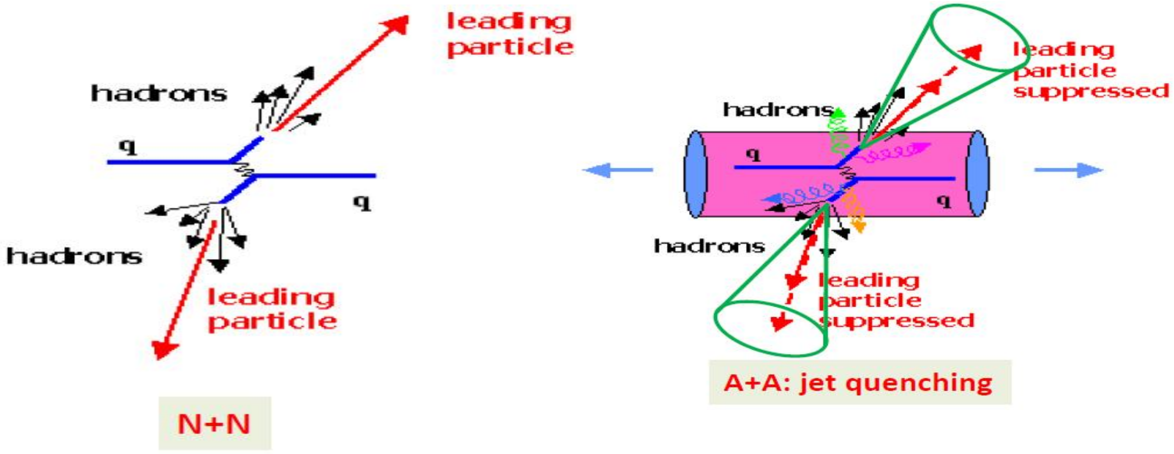
5、Summary

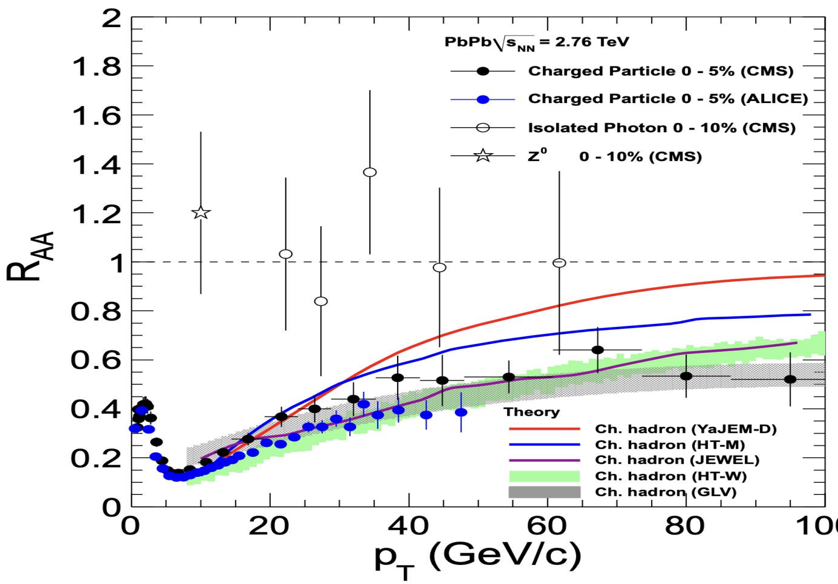
Introduction



Nuclear modification factor :

$$R_{AA} = \frac{dN^{AA}/d^2p_T dy}{N_{coll} dN^{pp}/d^2p_T dy}$$

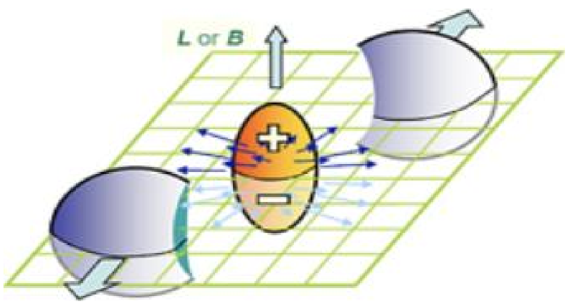


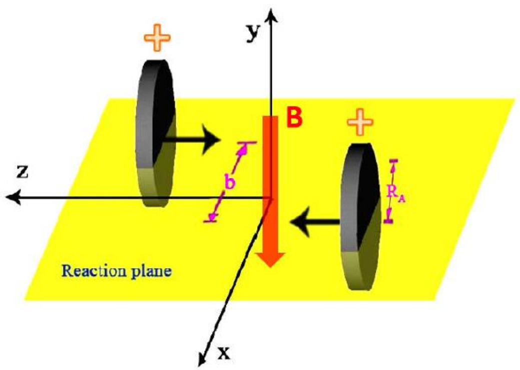


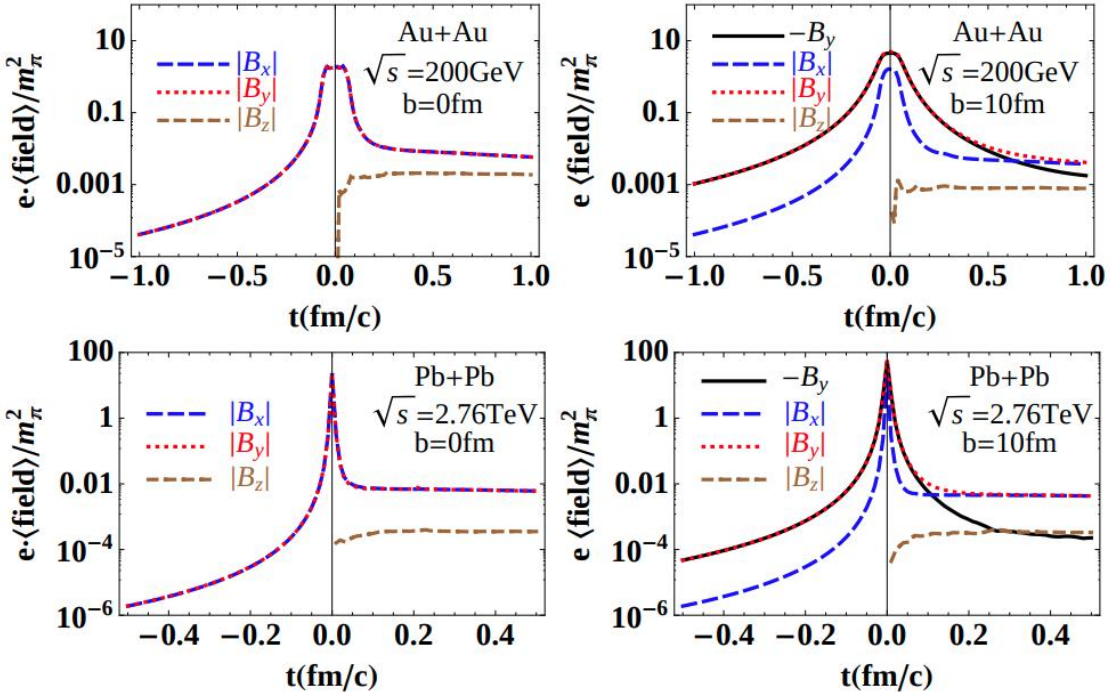
Jet quenching mainly originates from parton energy loss in hot QGP

Berndt Muller, Jurgen Schukraft, Boleslaw Wyslouch, Ann. Rev. Nucl. Part. Sci. 62, 361 (2012)

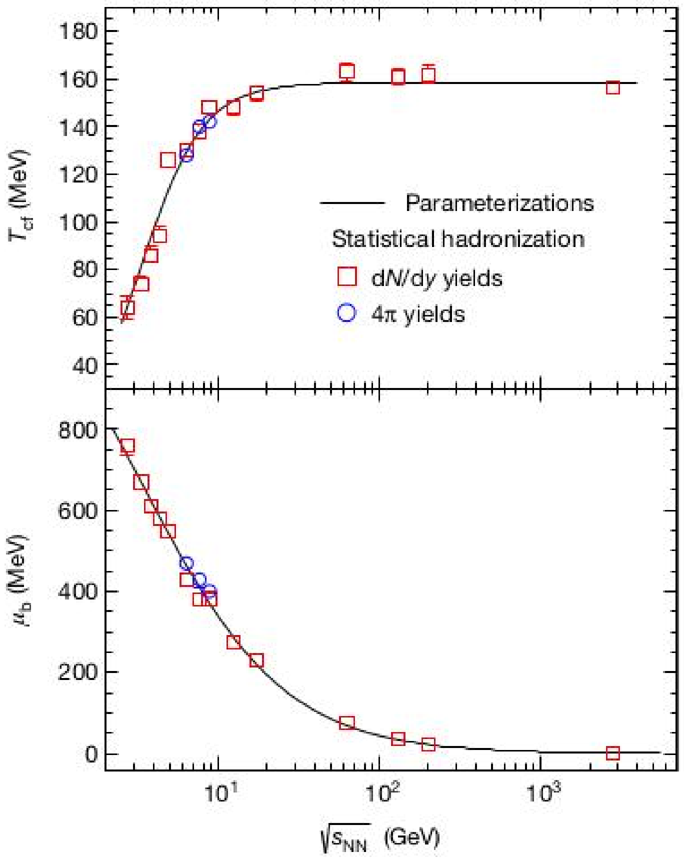
Motivation





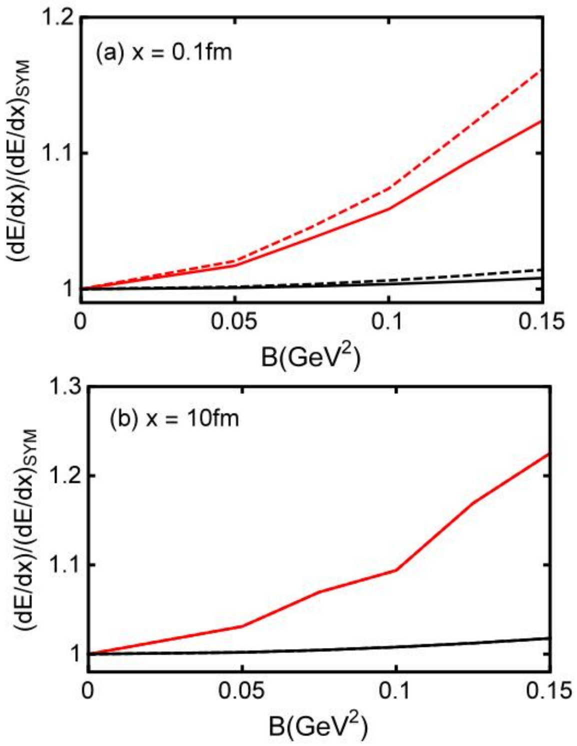


Wei-Tian Deng, Xu-Guang Huang. Phys.Rev.C 85 (2012) 044907.

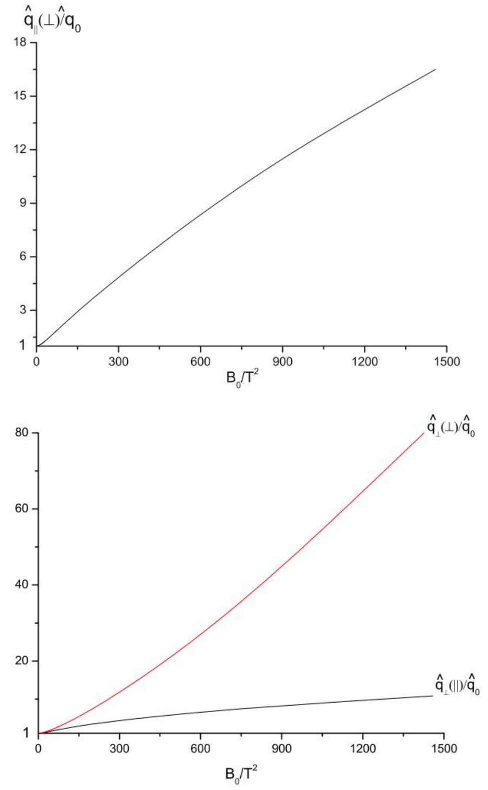


Anton Andronic, Peter Braun-Munzinger, Krzysztof Redlich, Johanna Stachel. Nature 561 (2018) 7723, 321-330.

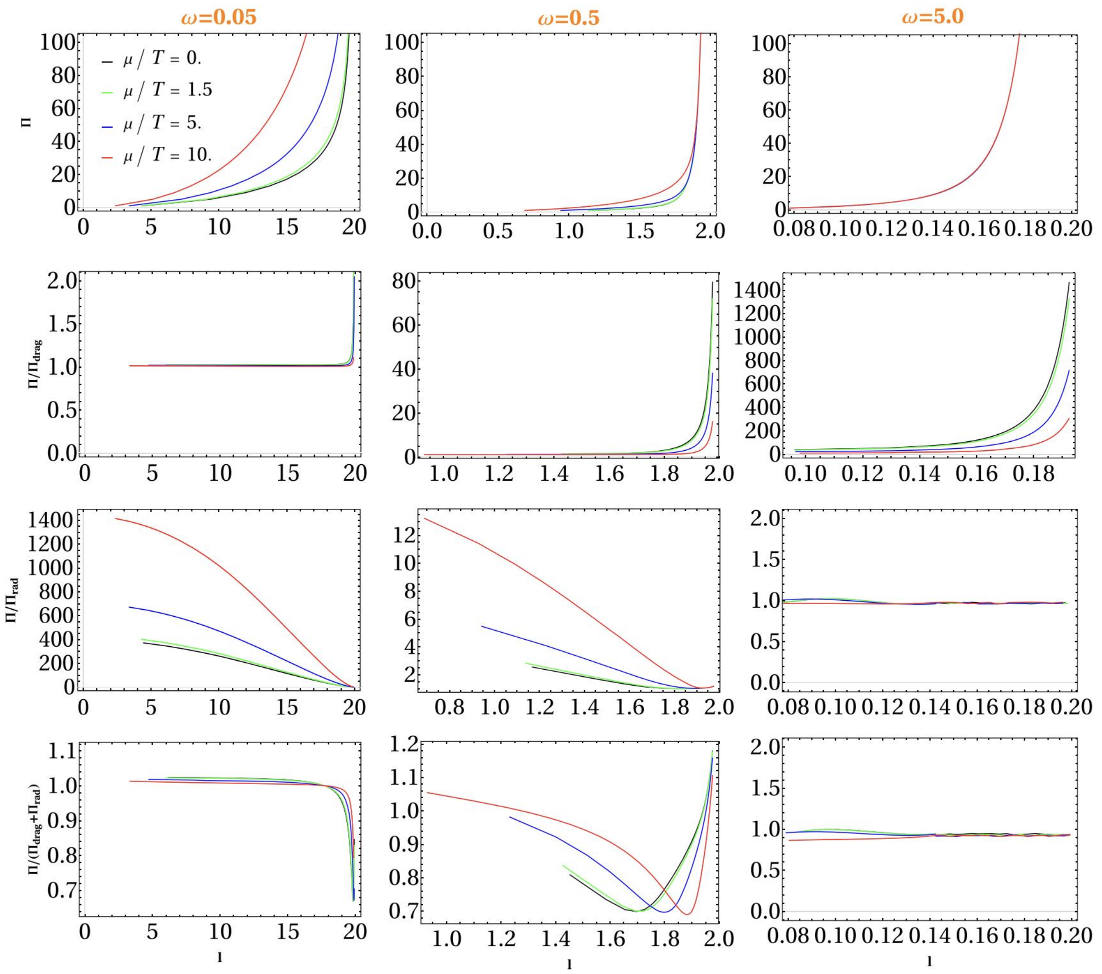
Motivation



Zhou-Run Zhu, Sheng-Qin Feng, Ya-Fei Shi, Yang Zhong, Phys.Rev.D 99 (2019) 12, 126001.



Zi-qiang Zhang, Ke Ma, Eur.Phys.J.C 78 (2018) 7, 532.

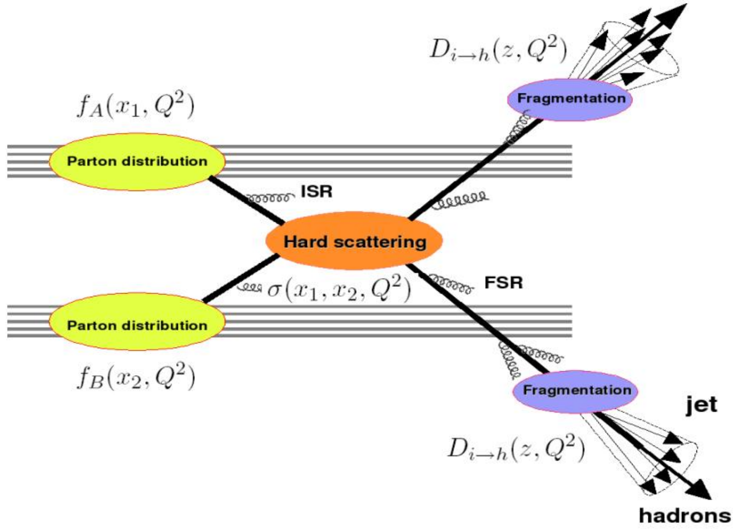


Defu Hou, Mahdi Atashi, Kazem Bitaghsir Fadafan, Zi-qiang Zhang, Phys.Lett.B 817 (2021) 136279.

It is found that the jet quenching parameter and Instantaneous energy loss is generally enhanced in the presence of a magnetic (constant) field.

The inclusion of chemical potential (constant) tends to increase the energy loss.

NLO pQCD parton model



In pp collisions:

Single inclusive hadron:

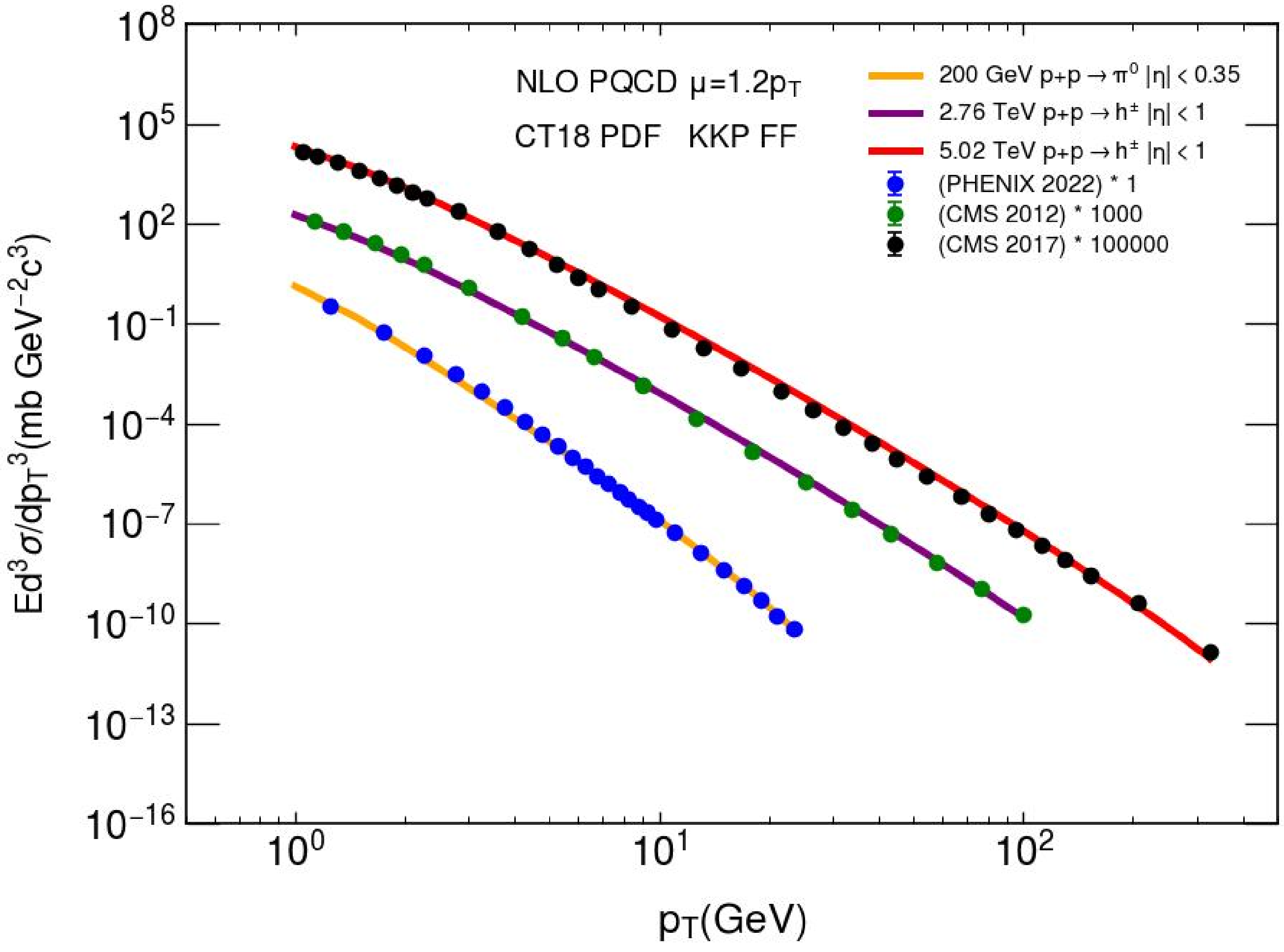
$$\frac{d\sigma^h_{pp}}{dy_h d^2p_T} = \sum_{abcd} \int dx_a dx_b f_{a/p}(x_a,\mu^2) f_{b/p}(x_b,\mu^2) \frac{1}{\pi} \frac{d\sigma_{ab\to cd}}{d\hat{t}} \frac{D^h_c(z_c,\mu^2)}{z_c} + \mathcal{O}(\alpha_s^3)$$

J.F. Owens. Rev.Mod.Phys. 59 (1987) 465

$f_{a/p}(x_a,\mu^2)$: CT18 PDF   CT18, Phys.Rev.D 103 (2021) 1, 014013

$D^h_c(z_c,\mu^2)$: KKP FF   KKP, Nucl.Phys.b582,514(2000)

pp baseline



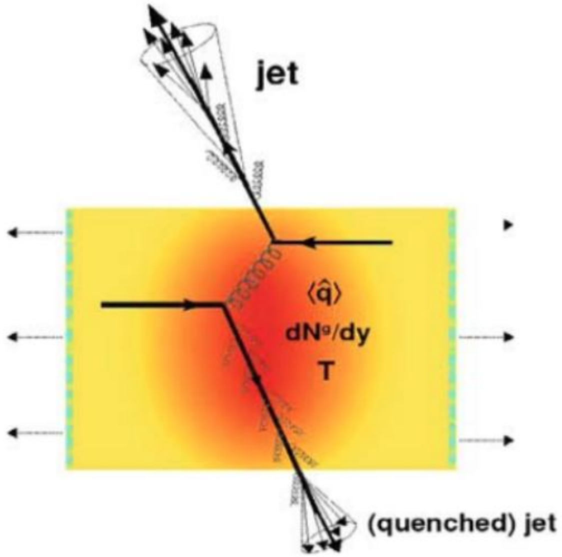
Experiment Data from:

PHENIX Collaboration, Phys.Rev.C 105 (2022) 064902.

CMS Collaboration, Eur. Phys. J. C (2012) 72:1945.

CMS Collaboration, JHEP 04 (2017) 039.

NLO pQCD parton model and Medium-modified FFs



In AA collisions:

Single inclusive hadron:

$$\frac{dN^h_{AB}}{dyd^2p_T} = \sum_{abcd} \int dx_a dx_b d^2 r t_A(\vec{r}) t_B(\vec{r}+\vec{b}) f_{a/A}(x_a,\mu^2,\vec{r}) f_{b/B}(x_b,\mu^2,\vec{r}+\vec{b}) \times \frac{1}{\pi}\frac{d\sigma_{ab\to cd}}{d\hat{t}} \frac{D^h_c(z_c,\mu^2,\triangle E_c)}{z_c} + \mathcal{O}(\alpha_s^3).$$

Hanzhong Zhang, J.F. Owens, Enke Wang, Xin-Nian Wang, Phys.Rev.Lett.98,212301(2007)

$$f_{a/A}(x_a,\mu^2,\vec{r}) = S_{a/A}(x_a,\mu^2,\vec{r})\left[\frac{Z}{A} f_{a/p}(x_a,\mu^2) + \left(1-\frac{Z}{A}\right) f_{a/n}(x_a,\mu^2)\right]$$

$$S_{a/A}(x_a,\mu^2,\vec{r}) = 1 + \left[S_{a/A}(x_a,\mu^2) - 1\right] \frac{A t_A(\vec{r})}{\int d^2 r [t_A(\vec{r})]}$$

EPPS21 nPDF: Eur.Phys.J.C 82 (2022) 5, 413

$$D_{h/c}(z_c,\mu^2,\Delta E_c) = \frac{z'_c}{z_c} D_{h/c}(z'_c,\mu^2) = \frac{1}{1-\epsilon} D_{h/c}(\frac{z_c}{1-\epsilon},\mu^2),\ z_c = \frac{p_T}{P_{Tc}},\ z'_c = \frac{P_T}{P_{Tc}-\Delta E_c},\ \epsilon = \frac{\Delta E_c}{P_{Tc}}$$

Carlos A.Salgado,Urs Achim Wiedemann,Phys.Rev.D 68 (2003) 014008

Formalisms to jet quenching

1、Fast parton **weakly** coupled to a **weakly** coupled medium **AMY**

2、Fast parton **weakly** coupled to an **arbitrary** medium **Higher Twist、BDMPS-Z-ASW、GLV**

3、Fast parton **strongly** coupled to a **strongly** coupled medium **AdS/CFT**

Holographic Energy loss

The Einstein-Maxwell action :

$$I = \frac{1}{2\kappa^2}\int d^5x\sqrt{-g}(\mathcal{R} + \frac{12}{L^2} - \frac{L^2}{g_F^2}F_{\mu\nu}F^{\mu\nu})$$

The metric:

$$ds^2 = \frac{1}{z^2}\left(-f(z)dt^2 + d\vec{x}^2 + \frac{dz^2}{f(z)}\right)$$

$$f(z) = 1 - (1+Q^2)\left(\frac{z}{z_h}\right)^4 + Q^2\left(\frac{z}{z_h}\right)^6$$

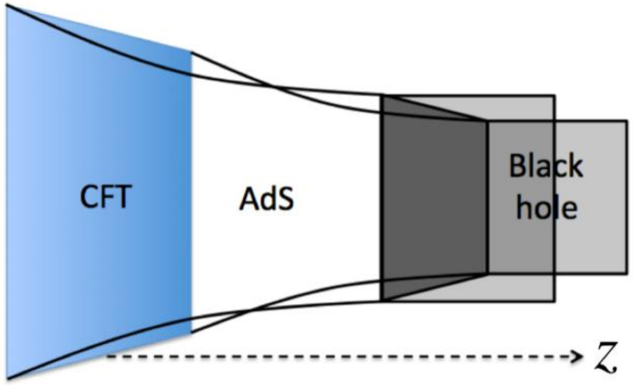
$$T(z_h,\mu_B,B) = \frac{1}{\pi z_h}(1 - \frac{Q^2}{2})$$

$$Q^2 = \mu_B^2 z_h^2 + B^2 z_h^4$$

$$\frac{dE}{dx} = -\frac{\sqrt{\lambda}}{2\pi}\frac{\sqrt{f(z_\star)}}{z^2}$$

$$\frac{dx}{dz} = \frac{1}{\sqrt{f(z_*) - f(z)}} = \frac{1}{\sqrt{1-f(z)}},\quad z_\star = 0 \to \sqrt{f(z_\star)} = 1$$

$$x = \int_z^{z_h}\frac{dz}{\sqrt{\frac{z^3}{z_h^3}(1+\mu_B^2 z_h^2 + B^2 z_h^4) - \frac{z^4}{z_h^4}(\mu_B^2 z_h^2 + B^2 z_h^4)}}$$



Diego M. Rodrigues, Danning Li, Eduardo Folco Capossoli, Henrique Boschi-Filho, Phys.Rev.D 103 (2021) 6, 066022.

Andrew Chamblin, Roberto Emparan, Clifford V. Johnson, Robert C. Myers, Phys.Rev.D 60 (1999) 064018.

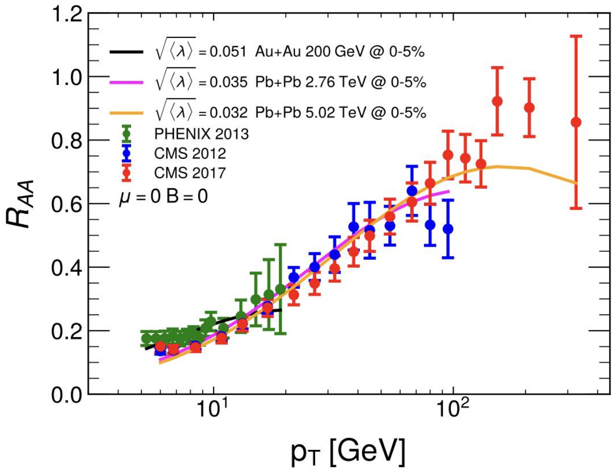
Andrej Ficnar, Steven S. Gubser, Miklos Gyulassy, Phys.Lett.B 738 (2014) 464-471.

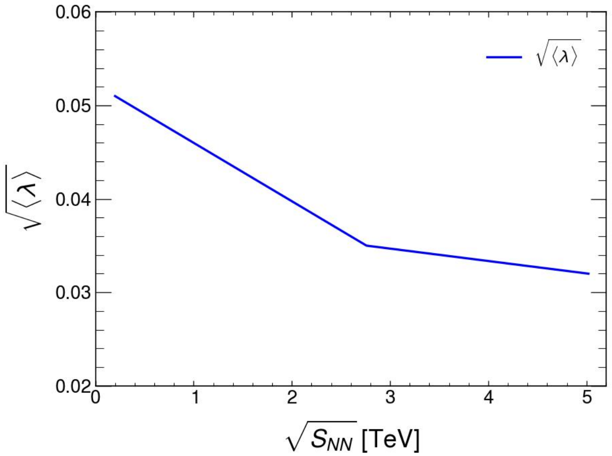
The connection between $\sqrt{\lambda}$ and $\frac{\hat{q}}{T^3}$

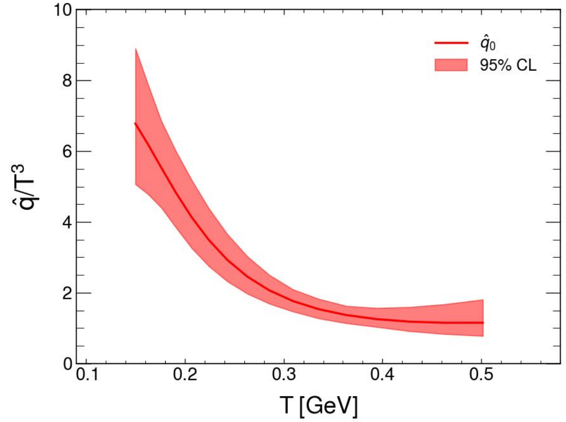
$$\hat{q}_{\mathrm{SYM}} = \frac{\pi^2}{a}\sqrt{\lambda}T^3 = \frac{\pi^{3/2}\Gamma(\frac{3}{4})}{\Gamma(\frac{5}{4})}\sqrt{\lambda}T^3$$
$$\approx 26.69\sqrt{\alpha_{\mathrm{SYM}}N_c}T^3$$

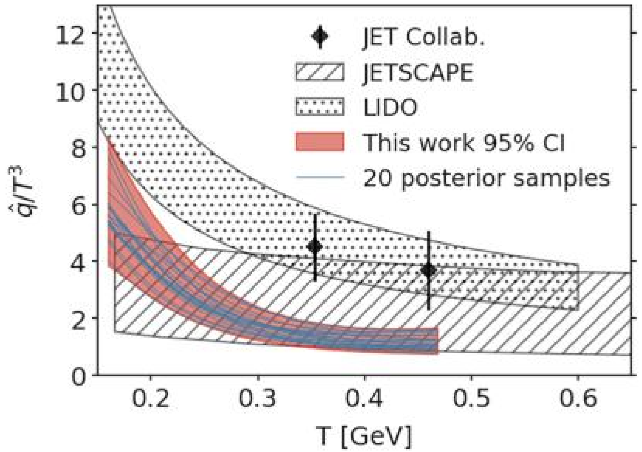
$$\frac{\hat{q}_{SYM}}{T^3} \sim \sqrt{\lambda}$$

Hong Liu, Krishna Rajagopal, Urs Achim Wiedemann, Phys. Rev. Lett. 97, 182301



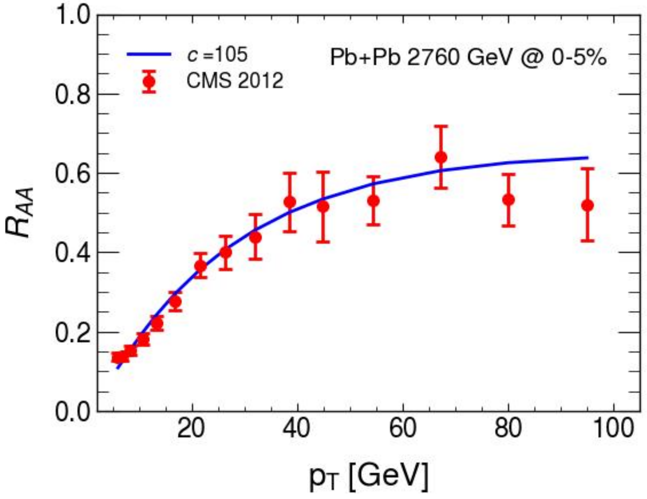




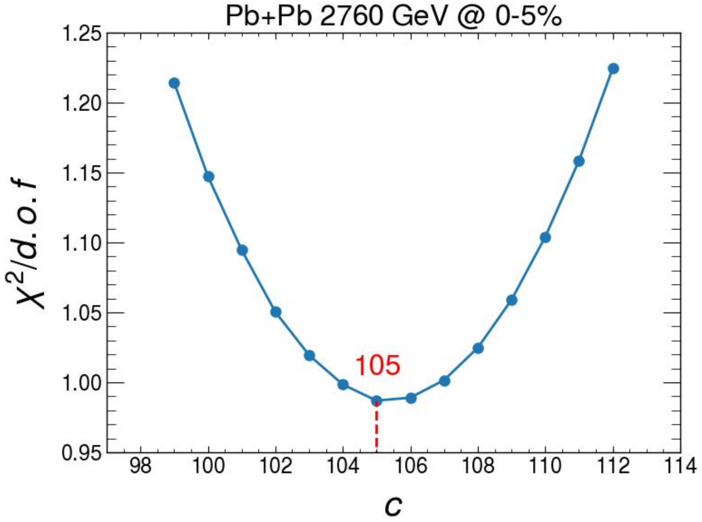


Man Xie, Weiyao Ke, Hanzhong Zhang, Xin-Nian Wang, Phys. Rev. C 108, L011901

$$\sqrt{\lambda} = \frac{\hat{q}}{T^3}/c$$

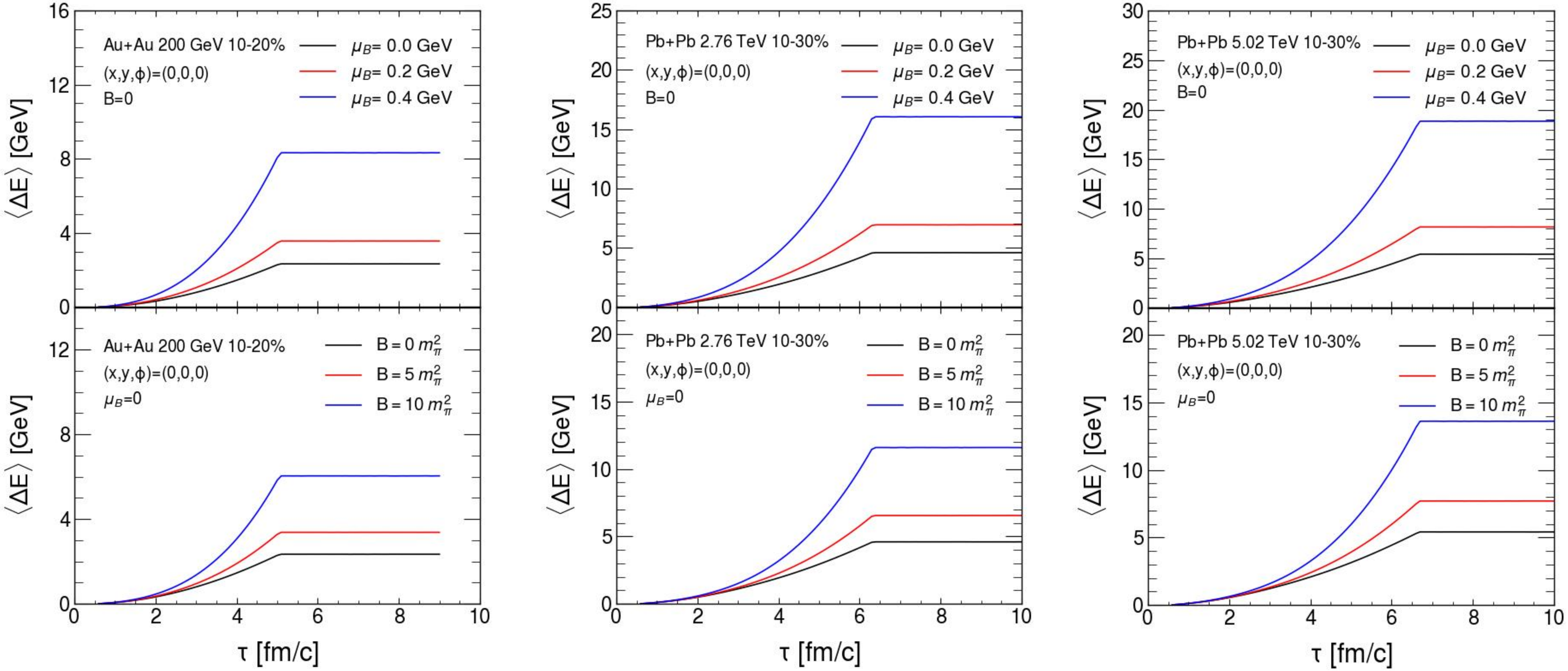


c=105



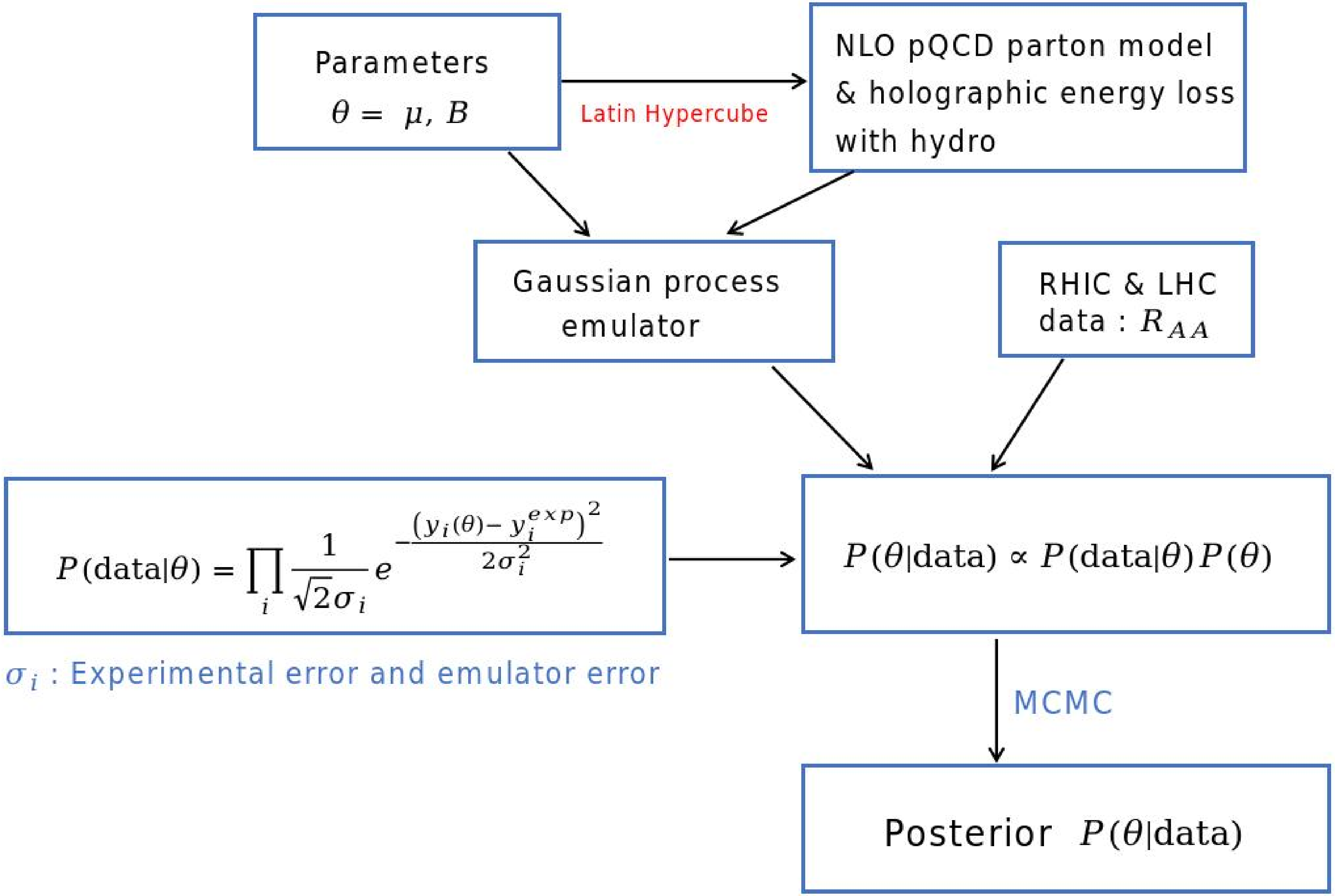
μ = 0, B = 0

The effect of magnetic field and chemical potential on energy loss

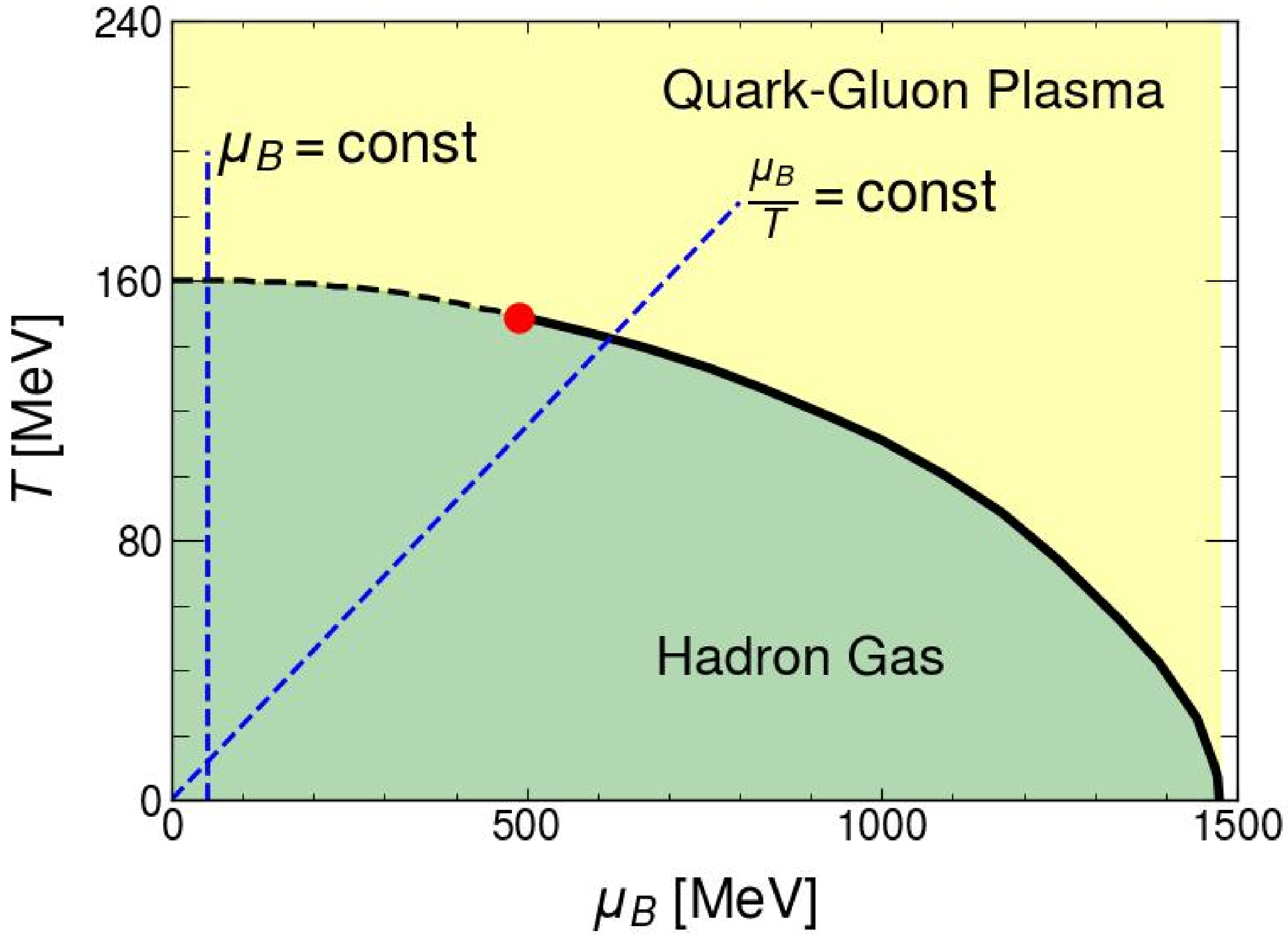


Both magnetic field and chemical potential can increase energy loss.

Bayesian analysis



Paramtrizing the time-evolution of B and μ_B



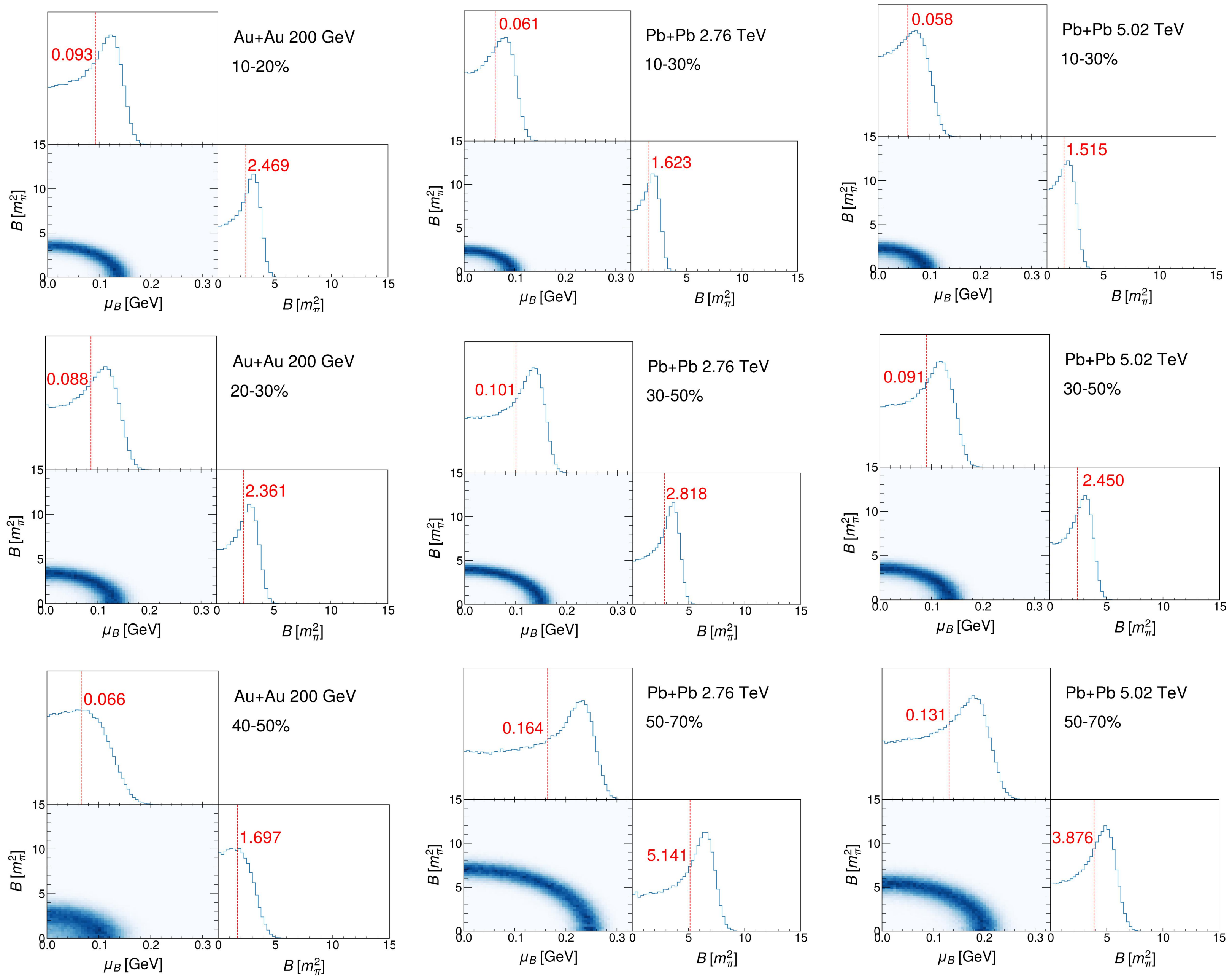
Scenario I :

μ_B = const , B= const

Scenario II :

μ_B/T = const , B/T^2 = const

Posterior distributions of the μ_B and B $\longrightarrow$ Scenario Ⅰ



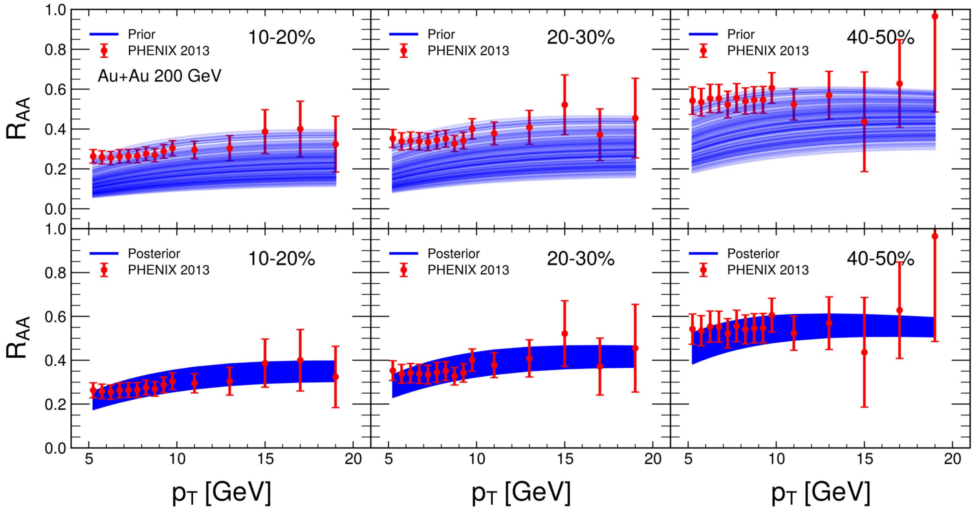
Over 300 sets of θ for prior calculation, Posterior distributions of the μ_B and B (diagonal panels: the red dashed line indicates the position of the median), together with their correlations (off-diagonal panels).

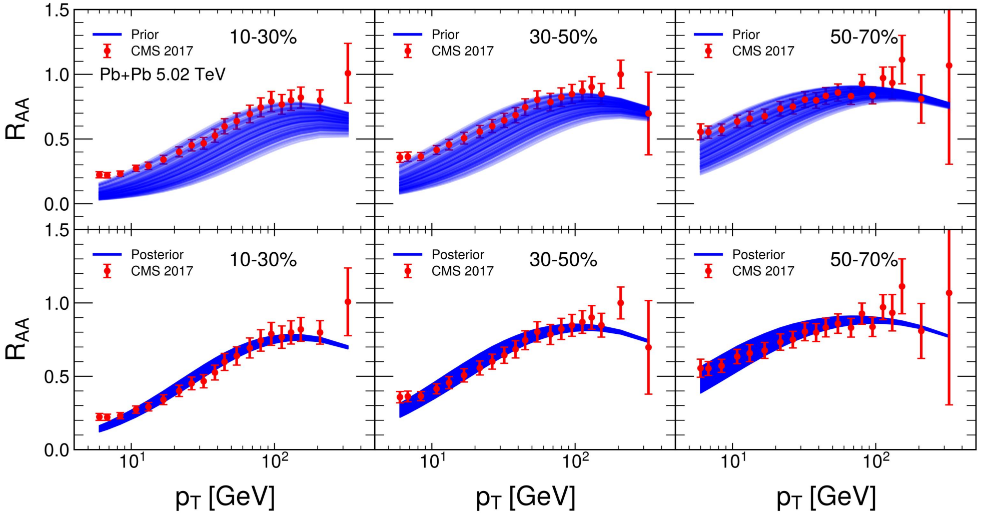
As the centrality increase (the more eccentric the collision), both the μ_B and B increase. With the increase in collision energy, both the μ_B and B decrease.

Single Hadron R_{AA} Piror vs Posterior $\longrightarrow$ Scenario I

Prior

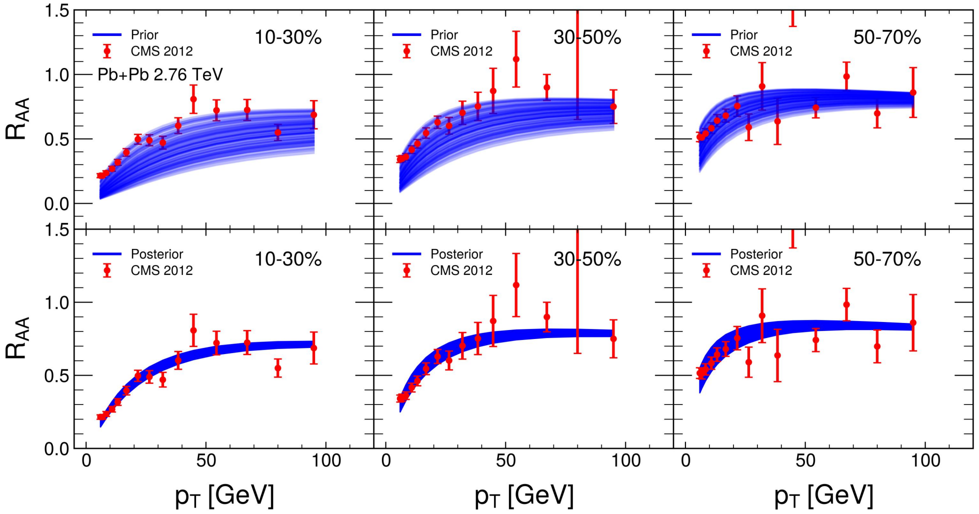
Posterior





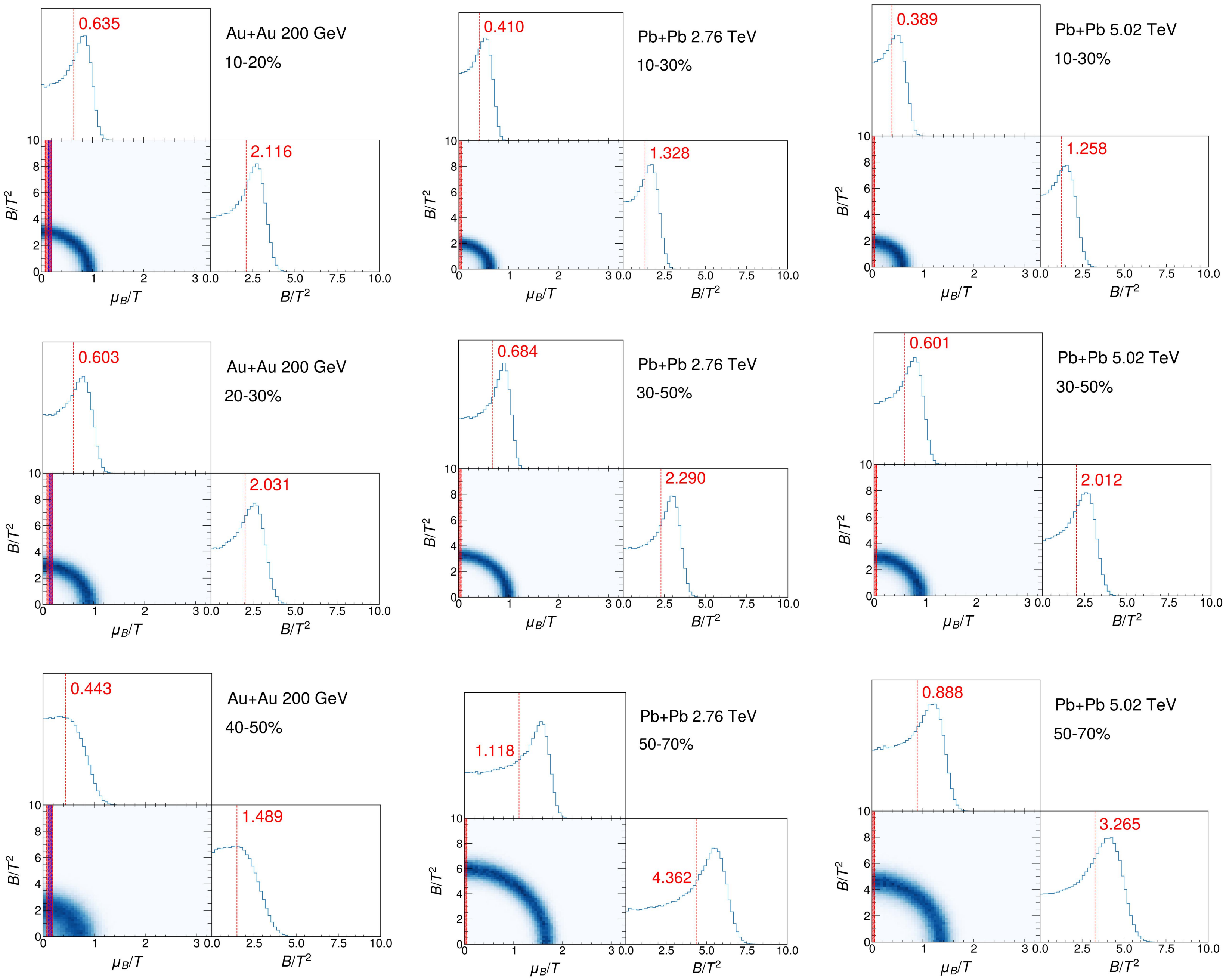
Prior

Posterior



One observes that after the Bayesian analysis, our model is able to provide a reasonable description of the hadron observables (R_{AA}) in heavy-ion collisions.

Posterior distributions of the μ_B/T and B/T^2 ⟶ Scenario II



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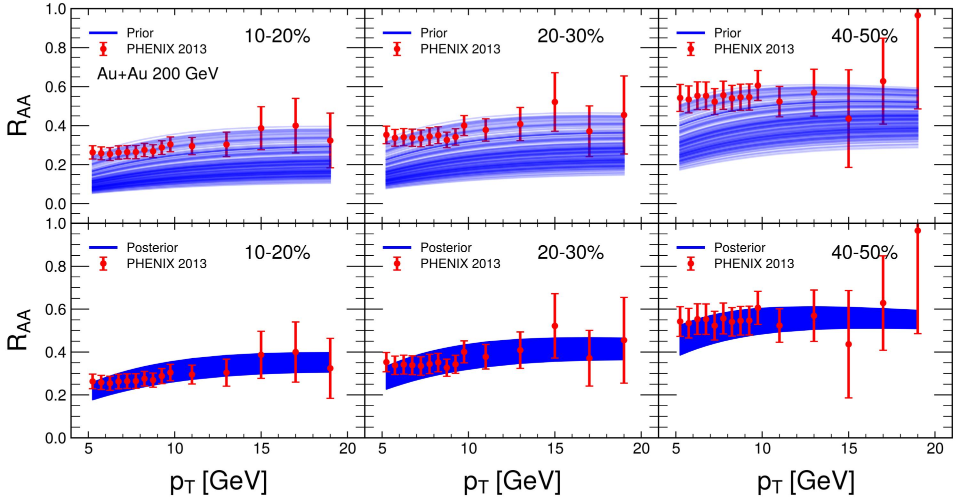
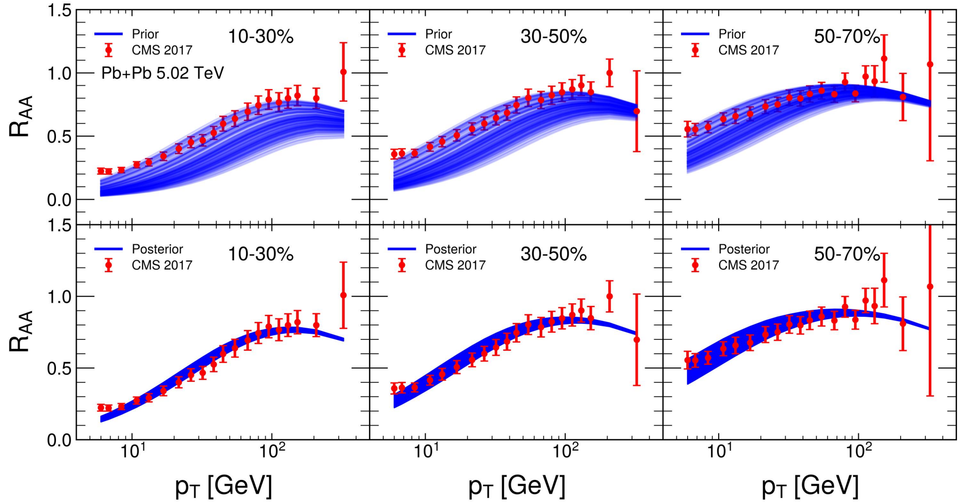
L. Adamczyk et al. (STAR), Phys. Rev. C 96, 044904 (2017).
A. Lysenko, M. I. Gorenstein, R. Poberezhniuk, and V. Vovchenko, Phys. Rev. C 111, 054903 (2025).

Single Hadron R_{AA} Piror vs Posterior → Scenario II

Prior

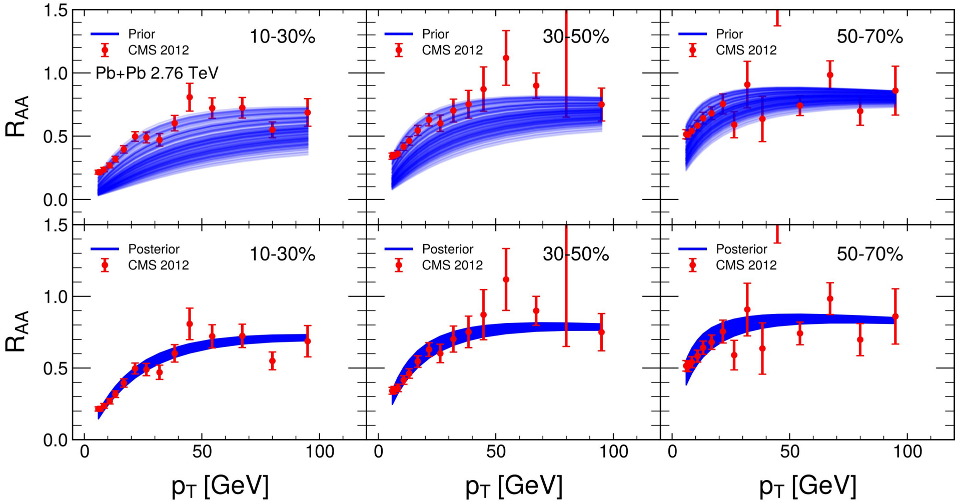
Posterior





Prior

Posterior



One observes that after the Bayesian analysis, our model is able to provide a reasonable description of the hadron observables (R_{AA}) in heavy-ion collisions.

Summary

1、Effects of Magnetic Field and Chemical Potential on Jet Energy Loss: The presence of the magnetic field and chemical potential significantly enhances the jet energy loss effect.

2、Impact of Collision Centrality: As the collisions tend to become more eccentric, the strengths of the magnetic field and chemical potential increase significantly.

3、Impact of Collision Energy: With increasing collision energy, both the magnetic field and chemical potential exhibit a decreasing trend.

4、Magnetic Field and Chemical Potential affects the energy loss in a highly correlated manner: Extracting the energy loss rate alone cannot provide a unique sensitivy to only one of the two effects.

Thank you