

Bayesian extraction of jet energy loss distributions in heavy-ion collisions

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Based on: Yayun He, Long-Gang Pang, Xin-Nian Wang, PRL 122, 252302 (2019)

第十一届晨光杯
August 16, 2021

Motivation

QCD: a non-abelian SU(3) gauge theory

asymptotic freedom:

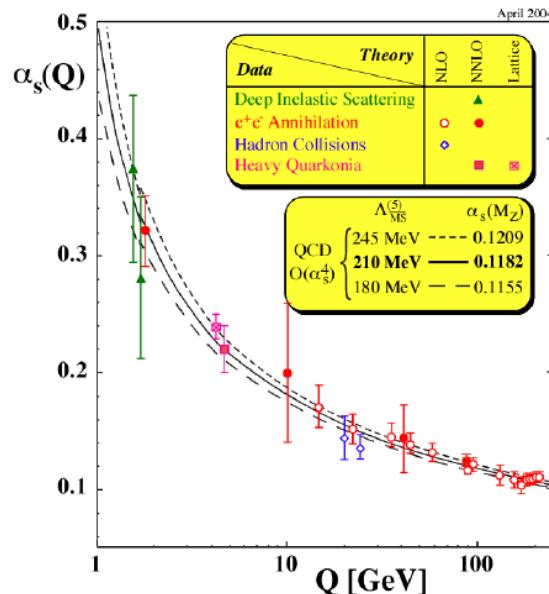


Fig: Running coupling constant in QCD.
C. A. G. Canal, Braz. J. Phys. 38, 3B (2008)

$$\alpha_s(\mu) \approx \frac{4\pi}{(11 - \frac{2}{3}n_f) \ln(\mu^2/\Lambda^2)}$$

color confinement:

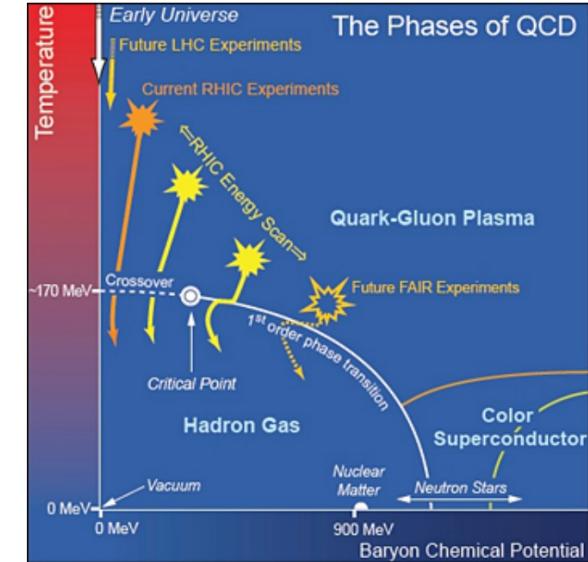


Fig: The QCD phase diagram.
C. Montag and A. Fedotov, arXiv:1410.4076

$$T_c \sim 170 \text{ MeV}$$

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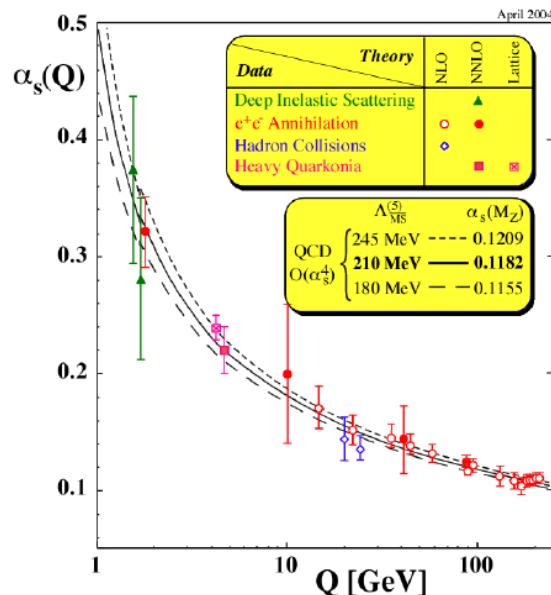


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prediction

color confinement:

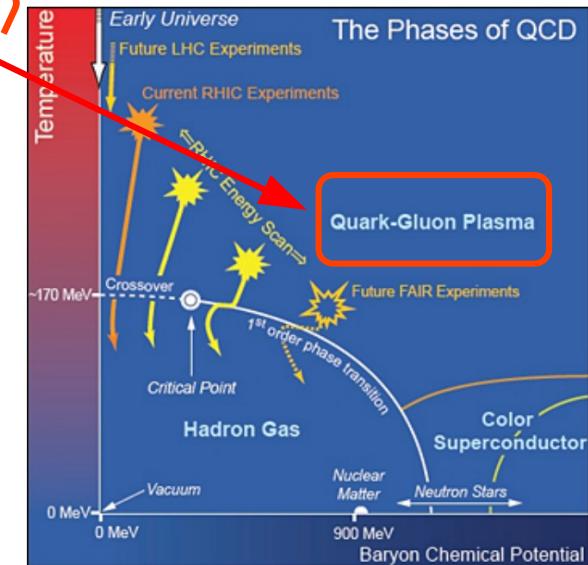


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Motivation

QGP: a hot and dense quark-gluon “soup”, created by “the little bang”, like an early universe

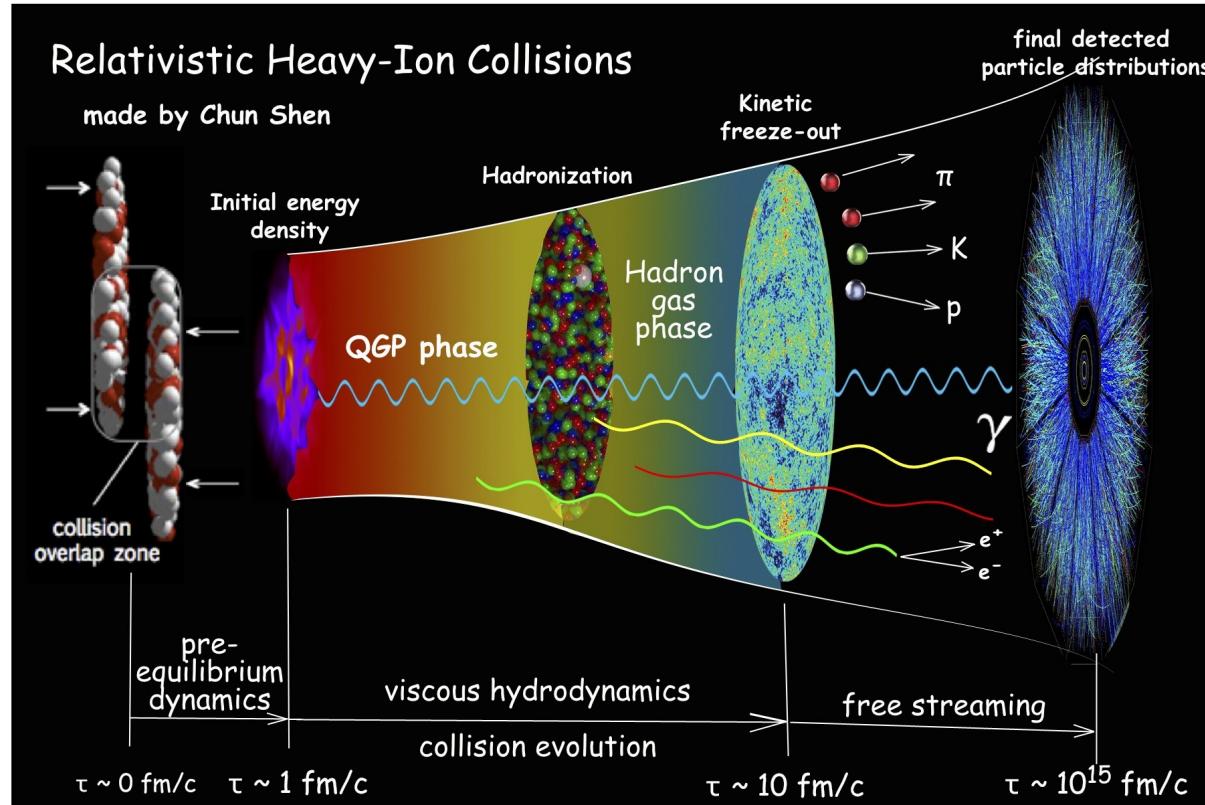


Fig: made by Chun Shen, <https://u.osu.edu/vishnu/category/visualization/>

Nucleus collision
+
Pre-equilibrium
+
Initial state
+
QGP evolution
+
Hadron rescattering
+
Detection

Motivation

What properties does the QGP have?

- ✓ The most **perfect** fluid $\eta/s \approx (1 - 2)/4\pi$
- ✓ The most **vortical** fluid $\omega/T \approx 0.001$
- ✓ The most **opaque** medium $\hat{q}/T^3 \approx 4 - 8$

P. Romatschke and U. Romatschke, Phys. Rev. Lett. 99, 172301 (2007)

L. Adamczyk et al. [STAR Collaboration], Nature 548, 62 (2017)

K. M. Burke et al. [JET Collaboration], Phys. Rev. C 90, no. 1, 014909 (2014).

How to probe the QGP?

Soft probes: hydrodynamics, ...

Hard probes: large transverse momentum,
such as **jets**, hadrons and heavy flavors

Jet quenching: jet energy loss and transverse
momentum broadening due to **jet-medium**
interaction

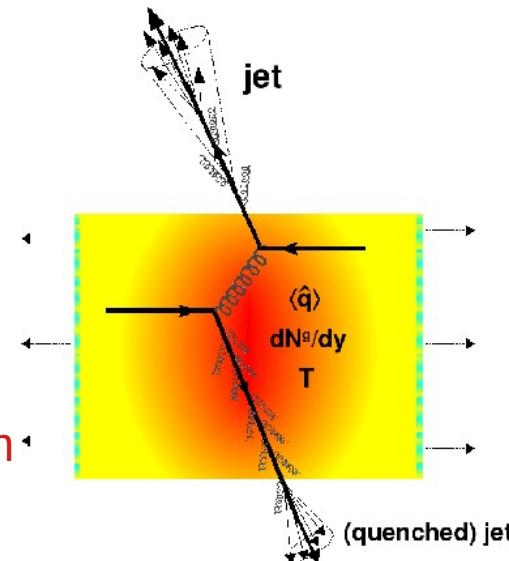


Fig: An illustration of jet quenching.
D. d'Enterria & B. Betz, (2009). 10.1007/978-3-642-02286-9_9.
W. Chen et al, Phys. Lett. B 777 (2018) 86-90

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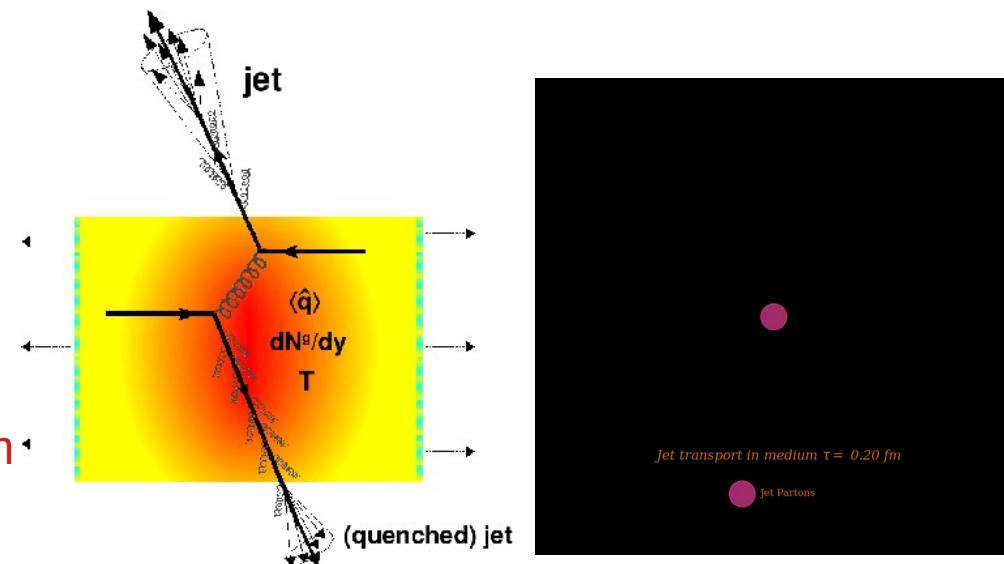
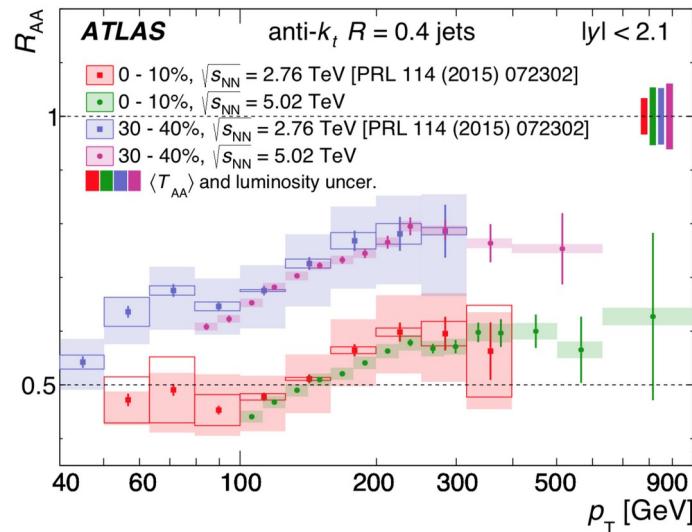


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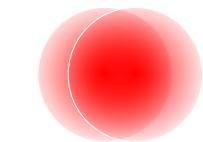
Motivation

Jet quenching observables:

- ✓ Inclusive jet nuclear modification factors $R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d\sigma_{AA}^{jet}}{d\sigma_{pp}^{jet}}$



0-10%



30-40%

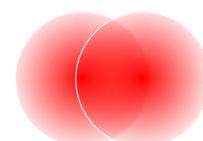


Fig: Inclusive jet nuclear modification factor.
ATLAS, Phys. Rev. Lett. 114 (2015),072302 arXiv:1411.2357,
ATLAS, Phys. Lett. B 790 (2019) 108, arXiv:1805.05635

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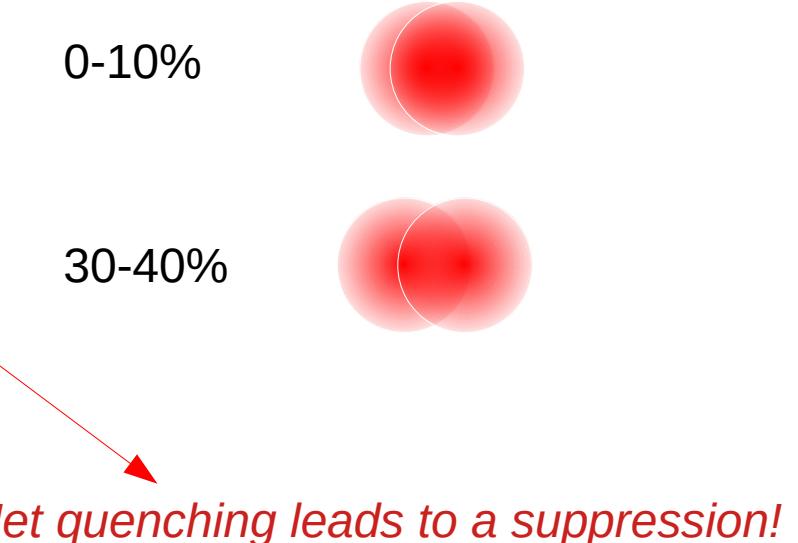
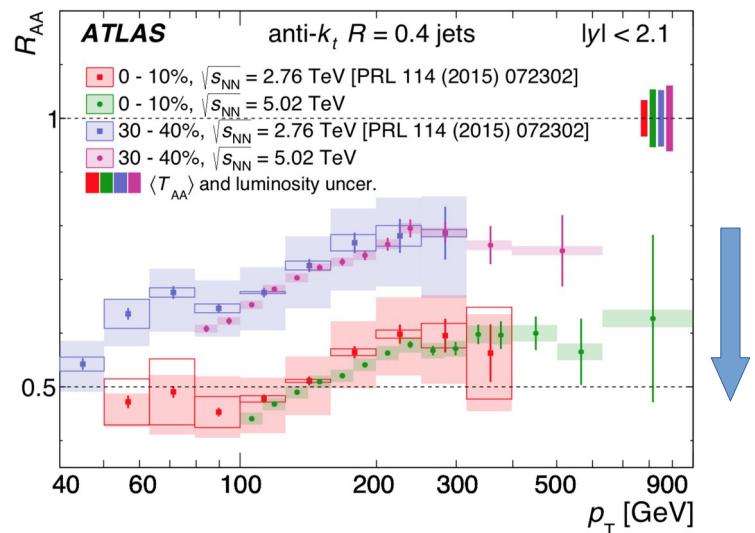


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Jet quenching observables:

- ✓ Inclusive jet nuclear modification factors
- ✓ Gamma-triggered jet transverse momentum imbalance $x_{J\gamma} = p_T^{\text{jet}} / p_T^\gamma$
- ✓ Many more ...

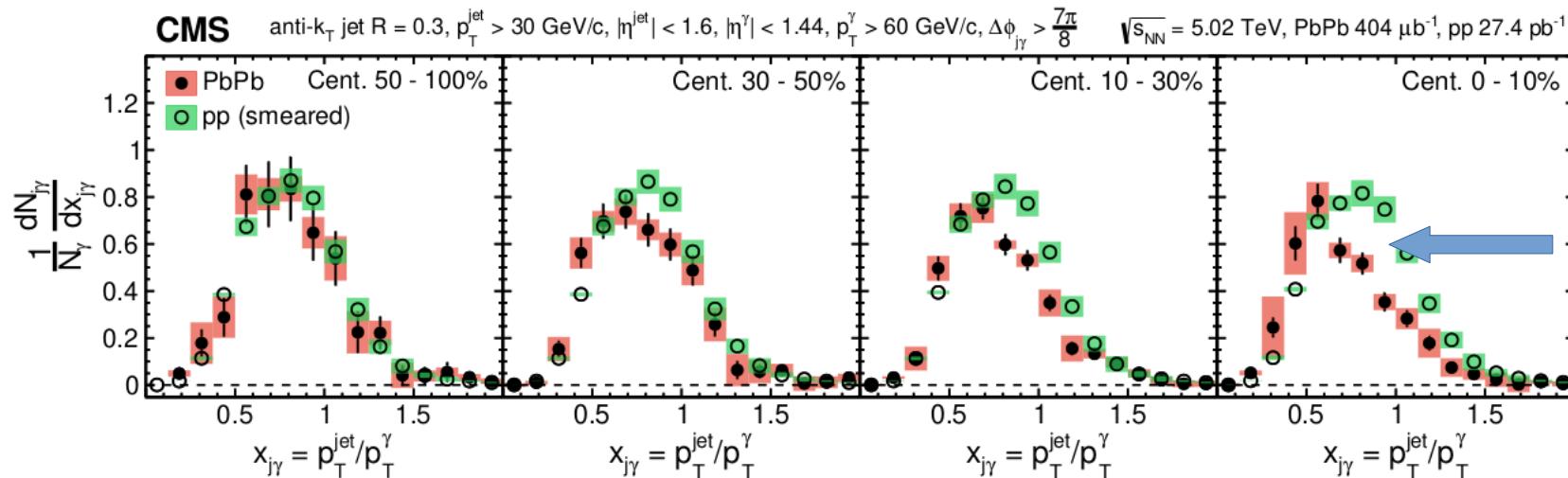


Fig: Gamma-triggered jet transverse momentum imbalance.
CMS, CMS-16-002

Jet quenching leads to a suppression!

How to extract jet quenching information from experimental data?

Bayesian extraction of jet energy loss distributions

$$\frac{d\sigma_{AA}^{\text{jet}}}{dp_T dy}(p_T, R) \approx N_{\text{bin}}(b) \int d\Delta p_T \frac{d\sigma_{pp}^{\text{jet}}}{dp_T dy}(p_T + \Delta p_T, R) W_{AA}(\Delta p_T, p_T + \Delta p_T, R)$$

MC transport models:

$$\left. \begin{array}{l} \sigma_{pp}^{\text{jet}}(p_T) \\ W_{AA}(p_T, \Delta p_T) \end{array} \right\} \implies \sigma_{AA}^{\text{jet}}(p_T)$$

Bayesian analysis:

$$\left. \begin{array}{l} \sigma_{pp}^{\text{jet}}(p_T) \\ \sigma_{AA}^{\text{jet}}(p_T) \end{array} \right\} \implies W_{AA}(p_T, \Delta p_T)$$

Data-driven & model-independent

Parameterize:

$$x = \frac{\Delta p_T}{\langle \Delta p_T \rangle}$$

$$P(X|Y) = \frac{P(Y|X)P(X)}{P(Y)}, Y : \text{data}, X : W_{AA}$$

$$\langle \Delta p_T \rangle(p_T) = \beta p_T^\gamma \log(p_T)$$

$$W_{AA}(x) = \frac{\alpha^\alpha x^{\alpha-1} e^{-\alpha x}}{\Gamma(\alpha)}$$

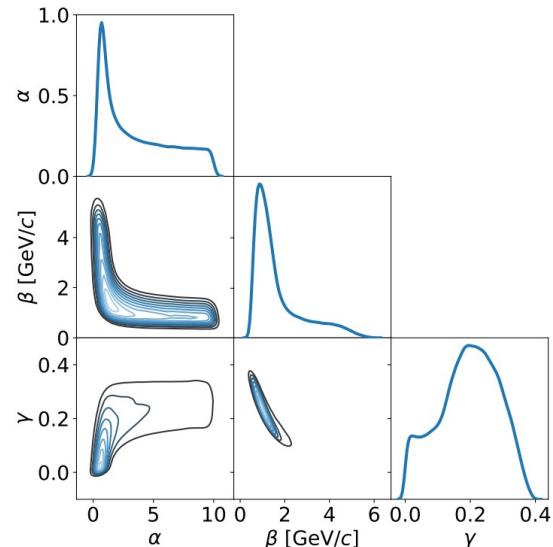
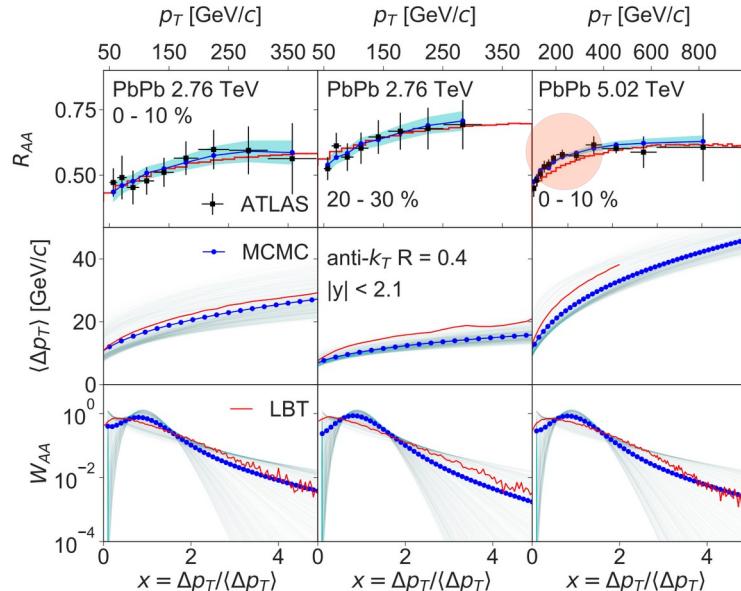


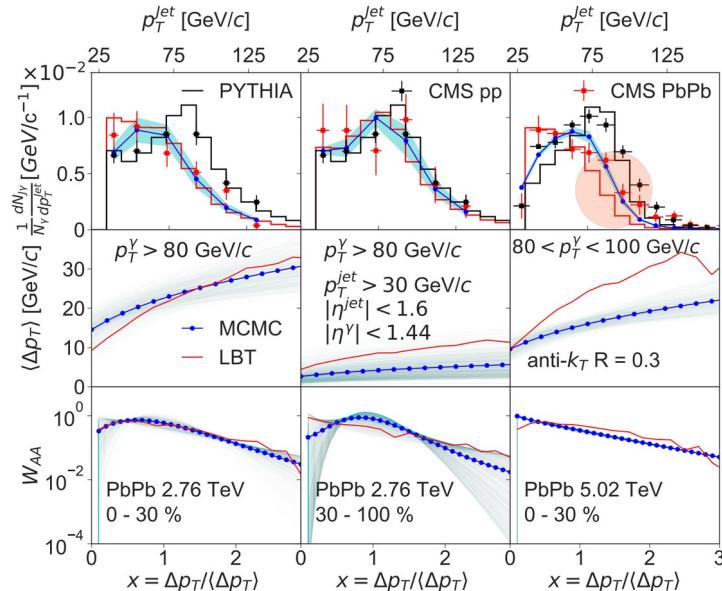
Fig: correlations of extracted parameters with 8 millions Monte Carlo Markov Chain (MCMC) samplings

Bayesian extraction of jet energy loss distributions

single inclusive jet in Pb+Pb			
	(0-10%)2.76 TeV	(20-30%)2.76 TeV	(0-10%)5.02 TeV
α	3.87 ± 2.93 (1.45 ± 0.01)	4.47 ± 2.83 (1.33 ± 0.02)	4.41 ± 2.86 (1.58 ± 0.02)
β	1.40 ± 1.12 (1.39 ± 0.06)	1.12 ± 0.47 (1.08 ± 0.07)	1.06 ± 0.97 (1.56 ± 0.06)
γ	0.21 ± 0.09 (0.21 ± 0.01)	0.15 ± 0.07 (0.20 ± 0.01)	0.26 ± 0.06 (0.23 ± 0.01)



γ -triggered jet in Pb+Pb			
	(0-30%)2.76 TeV	(30-100%)2.76 TeV	(0-30%)5.02 TeV
α	2.13 ± 1.28 (1.95 ± 0.12)	3.75 ± 2.81 (1.04 ± 0.06)	0.90 ± 0.09 (1.84 ± 0.13)
β	2.68 ± 1.40 (0.72 ± 0.06)	0.55 ± 0.44 (0.53 ± 0.04)	1.50 ± 0.85 (0.50 ± 0.04)
γ	0.16 ± 0.14 (0.44 ± 0.02)	0.13 ± 0.18 (0.30 ± 0.02)	0.21 ± 0.12 (0.56 ± 0.02)



Summary

- ✓ Jet energy loss distributions and averaged jet energy loss can be extracted from experimental data with the state-of-art Bayesian analysis.
- ✓ Averaged jet energy loss is slightly stronger than a logarithm form
- ✓ On average only a few number of out-of-cone jet-medium scatterings take place when a jet traverses the medium.
- ✓ Such a method can be used to constrain transport models of jet quenching.

Outlook

- How to extract jet quenching information, such as the path length dependence of jet quenching, with **multiple jet quenching observables** from the experimental data?

Thanks for your attention!