Transverse Momentum Balance and Angular Correlation of $b\bar{b}$ Dijets in Pb+Pb collisions

Wei. Dai

In Collaboration with S. Wang, S.L Zhang, B.-W Zhang, Enke Wang

[arXiv:1806.06332]

23/06/2019

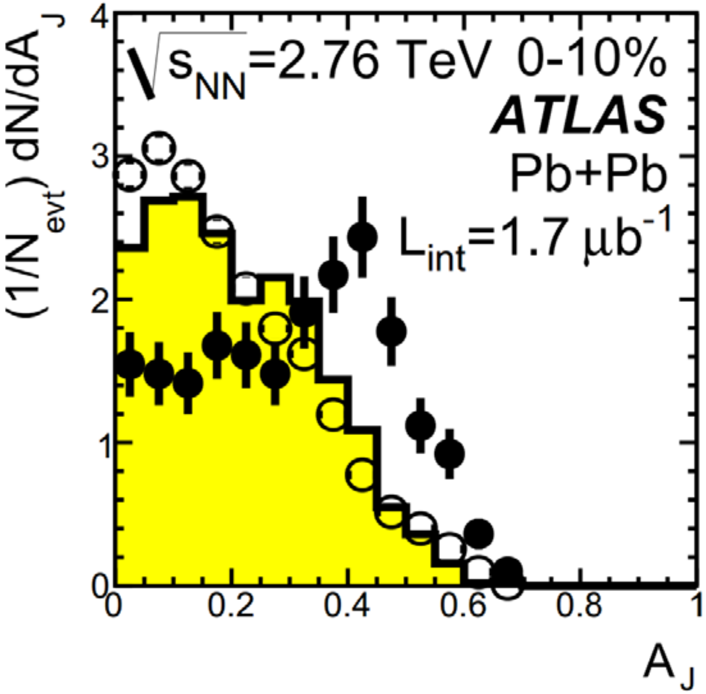
Physics Department,

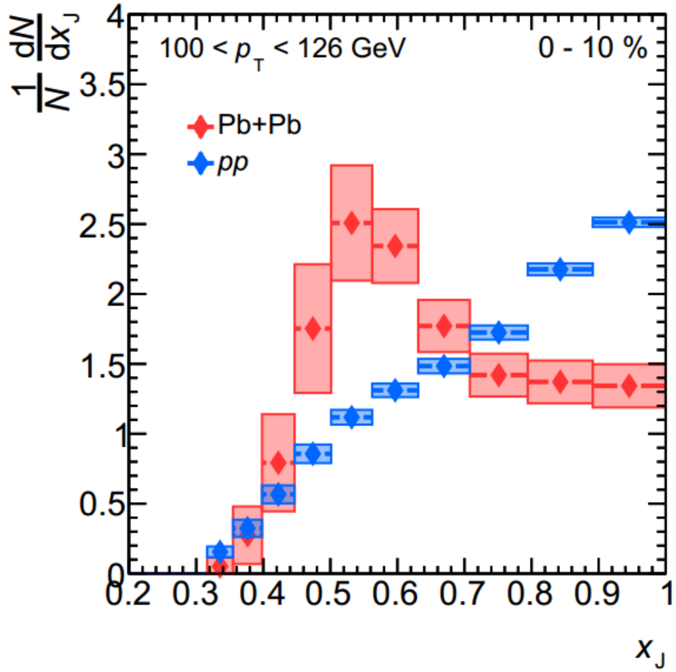
China University of Geosciences (Wuhan)

Outline

- Introduction
- p+p Baseline and Setup of Simulation
- Implementation of In-medium Evolution
- Results
  - ✓ Transverse momentum balance of $b\bar{b}$ dijet
  - ✓ Angular correlation of $b\bar{b}$ dijet
- Summary

Dijet Asymmetry





$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}, \Delta\phi > \frac{\pi}{2}$$

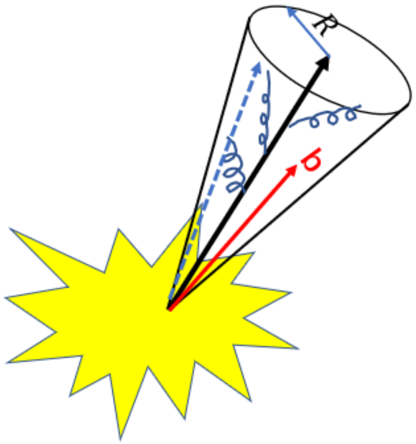
ATLAS Collaboration
Phys. Rev. Lett. 105 (2010) 252303

$$x_J = \frac{p_{T2}}{p_{T1}}, \Delta\phi > \frac{7\pi}{8}$$

ATLAS Collaboration
Phys. Lett. B774 (2017) 379

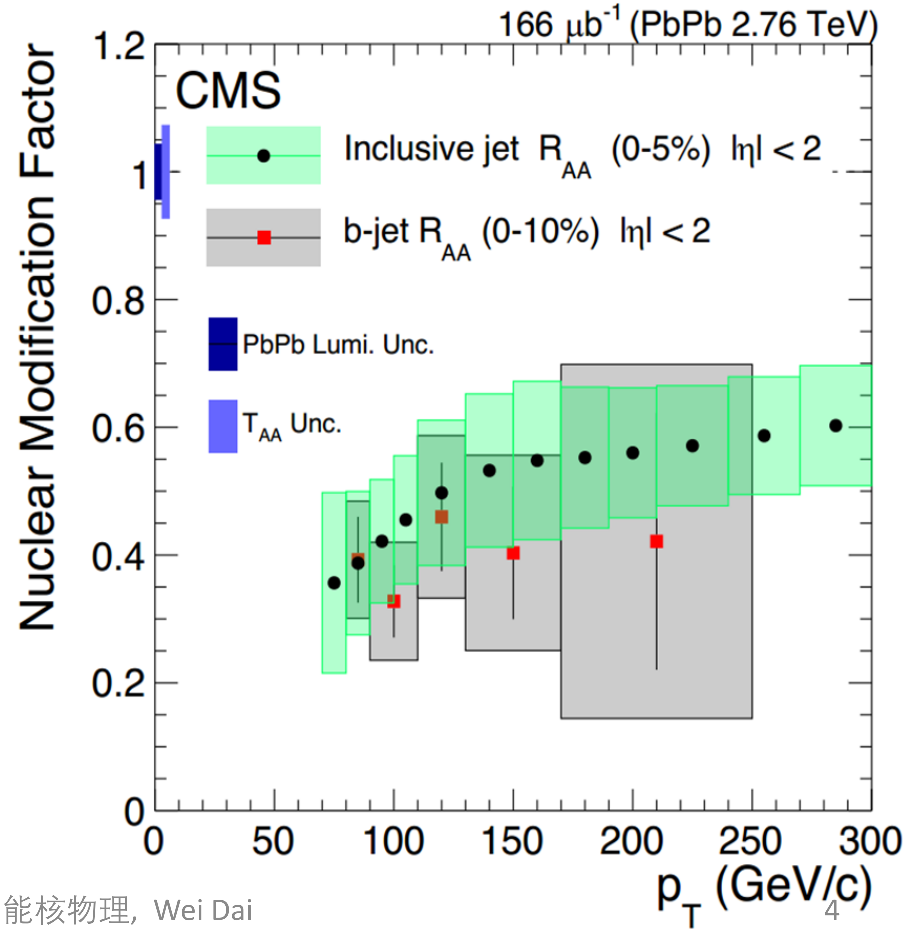
Initial paron flavor dependences determined in dijets ?

Inclusive b-jet R_{AA}



b jet---at least one b or $\bar{b}$ quark inside the jet cone with the jet radius parameter R.

Kurt Jung,
talk on QM2017

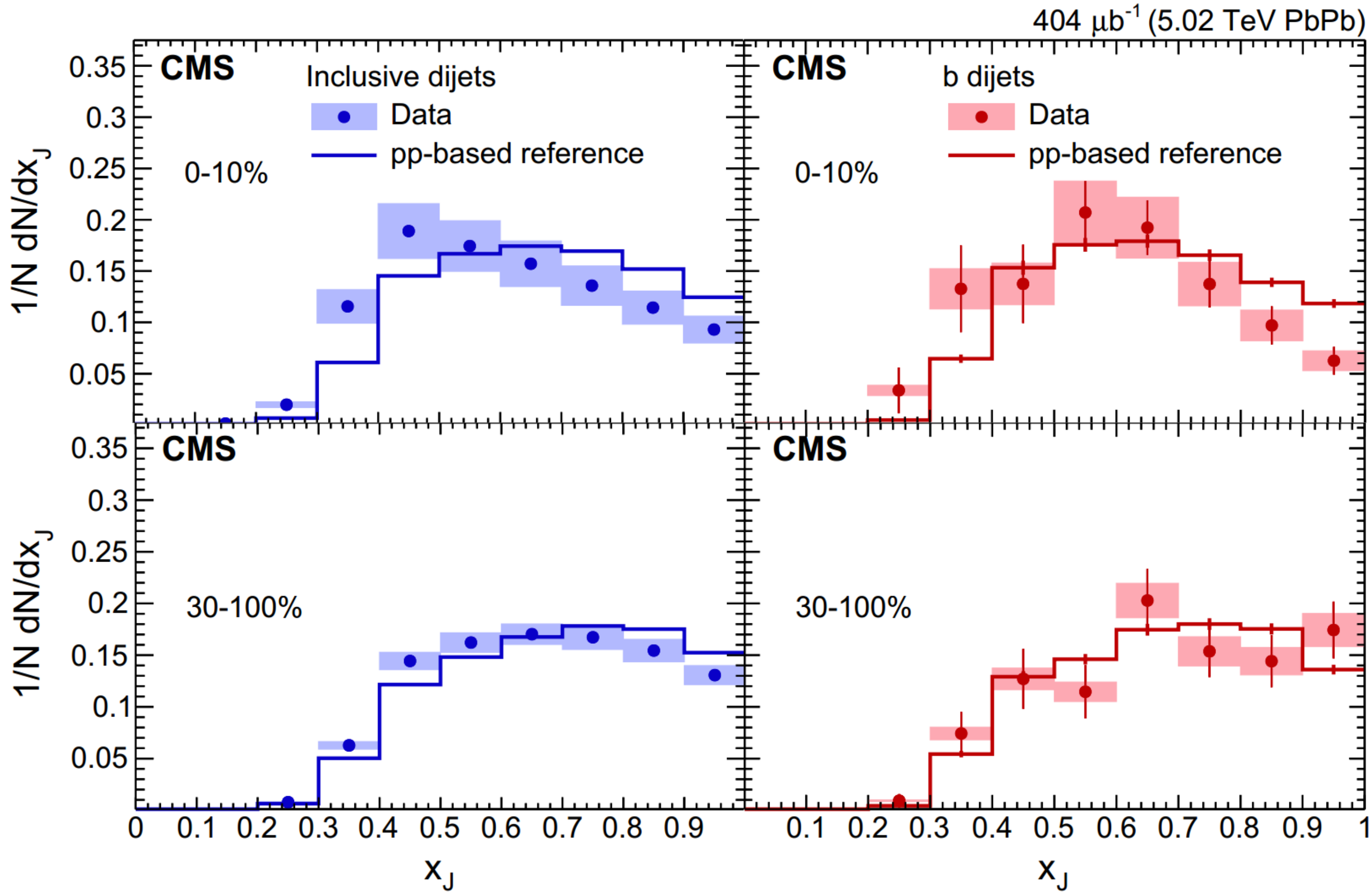


$$R_{AA}^{\text{b-jet}}(p_T;\,R) = \frac{\dfrac{d^2\sigma^{AA}(p_T;R)}{dy\,dp_T}}{\langle N_{\text{bin}}\rangle \dfrac{d^2\sigma^{pp}(p_T;R)}{dy\,dp_T}}$$

Jinrui Huang, Zhong-Bo Kang, Ivan Vitev
PLB 726(2013)251-256

CMS collaboration ,PRL 113(2014)132301

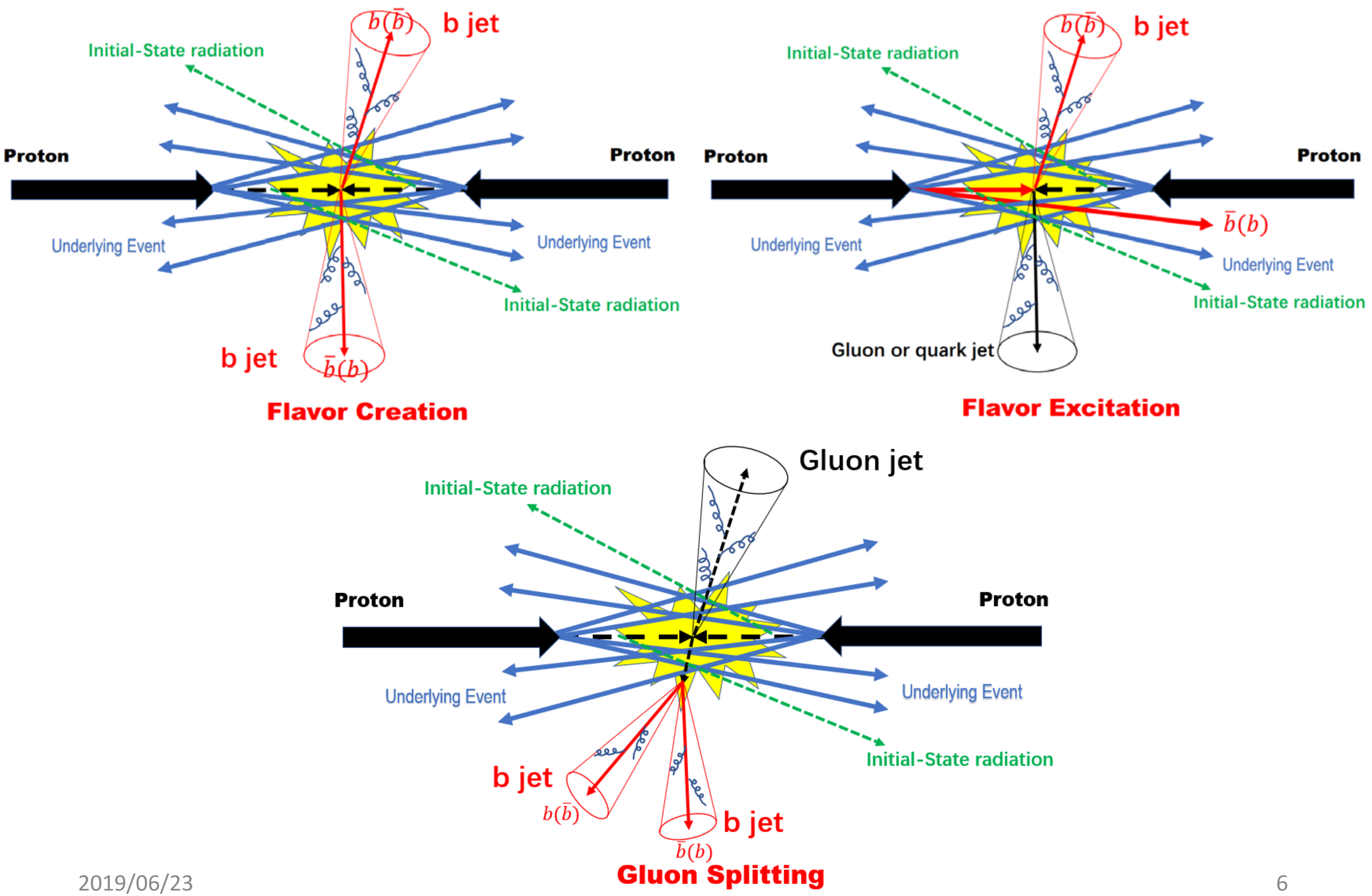
$b\bar{b}$ Dijets Asymmetry



CMS Collaboration JHEP 03(2018)181

$$x_J = \frac{p_{T2}}{p_{T1}}, \Delta\phi > \frac{2\pi}{3}$$

$b\bar{b}$-Dijets Production

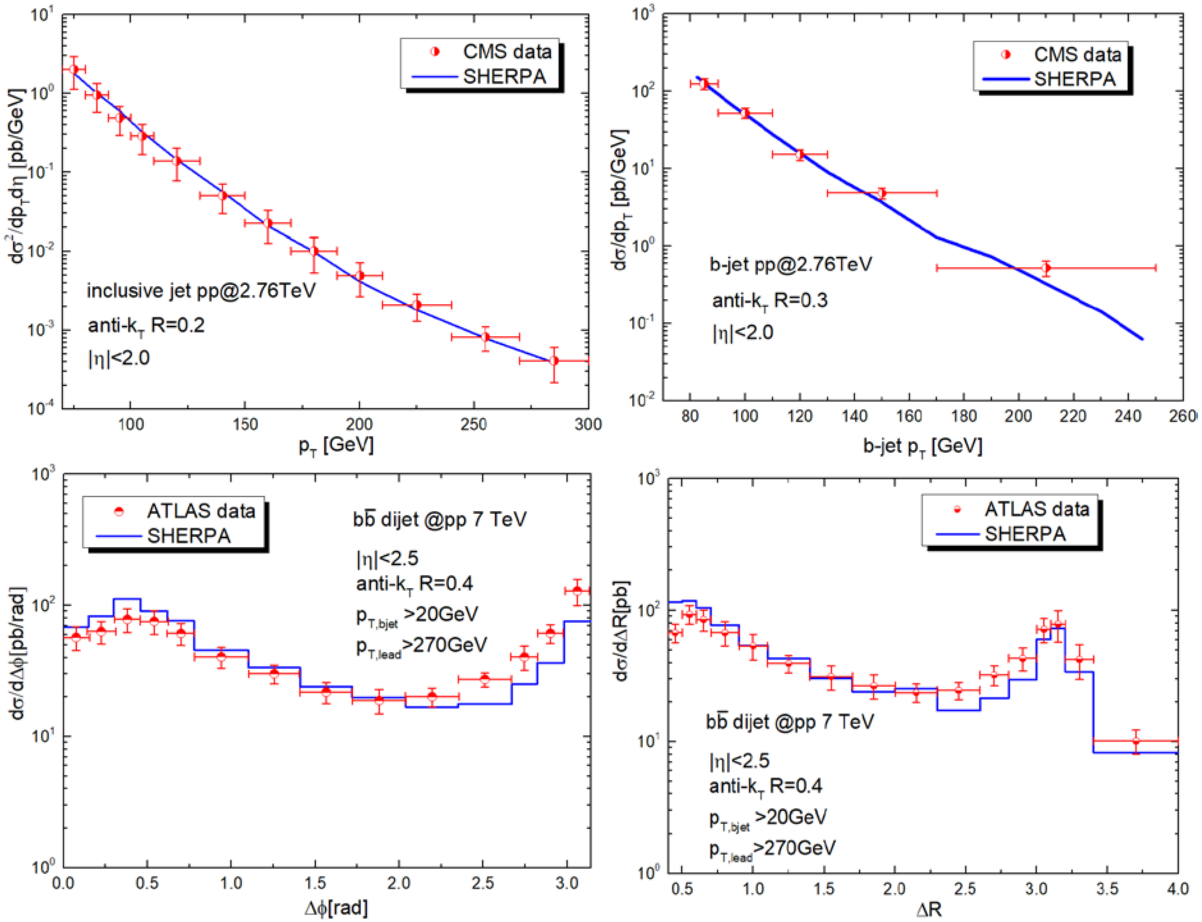


p+p SETUP

Monte Carlo event generator: **Sherpa**

- The tree-level matrix elements---**Amegic** and **Comix**.
- The one-loop virtual corrections ---**BlackHat**.
- Parton Shower---**Catani-Seymour subtraction method** .
- Matching of NLO+PS: **MC@NLO.**
- **NNPDF3.0** NLO-5FS PDF .
- **FASTJET** ---jet reconstruction at parton level.

p+p Baseline



Azimuthal angle difference between two b jets:

$$\Delta\phi = |\phi_{b1} - \phi_{b2}|$$

Angular distance:

$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$

A good pp baseline:
not only on jet production but also on angular distribution
[CMS ,PRC 96 015202(2017); CMS,PRL 113(2014)132301; ATLAS, Eur. Phys. J. C 76, no. 12, 670 (2016)]

In-Medium E-loss: Heavy Quark

- For heavy quark, the discrete Langevin transport equations are used to describe the propagating of heavy quarks in the QGP. [Eur. Phys. J. C 71, 1666 (2011); Physical Review C, 2009, 79(5): 054907.]:

$$\vec{x}(t+\Delta t) = \vec{x}(t) + \frac{\vec{p}(t)}{E}\Delta t$$

$$\vec{p}(t+\Delta t) = \vec{p}(t) - \Gamma(p)\vec{p}\Delta t + \vec{\xi}(t)\Delta t \quad -\vec{p}_g$$

Radiative E-loss

The Fluctuation-Dissipation Theorem:$\kappa = 2ET\Gamma = \frac{2T^2}{D_s}$. Based on the Lattice calculation[arXiv:1508.04543 [hep-lat]], D_s is fixed as $2\pi T D_s = 4$.

- For light partons, the collisional energy loss is described by Hard Thermal Loop calculation.[J.D. Bjorken, Fermilab preprint PUB-82/59-THY; Markus H.Thoma Physics Letters B 273 (1991)128-132; R.B.Neufeld PRD 83 (2011) 065012]

$$\frac{dE}{dz} = \frac{\alpha_s C_i m_D^2}{2} ln\frac{\sqrt{ET}}{m_D}$$

In-Medium E-loss: Radiative

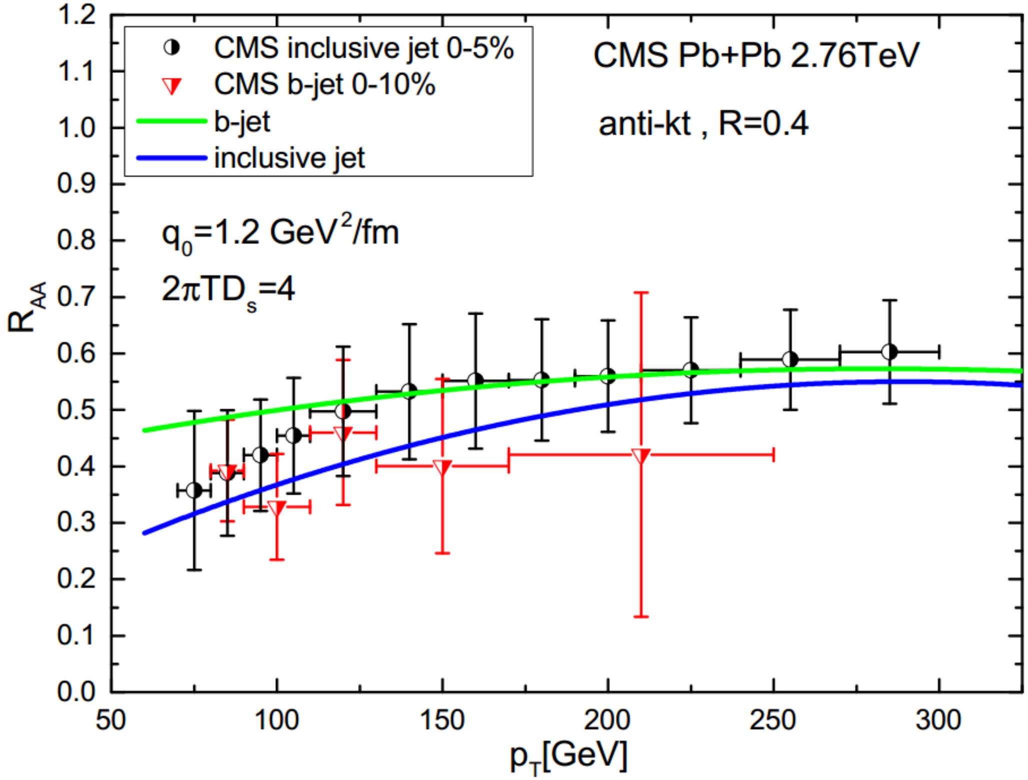
- The medium-induced radiative energy loss of final-state patons is described by the Higher-Twist scheme [X.-F. Guo and X.-N. Wang, Phys. Rev. Lett. 85, 3591(2000);B.-W. Zhang, E. Wang, and X.-N. Wang, Phys. Rev.Lett. 93, 072301 (2004);A. Majumder, Phys. Rev. D85, 014023 (2012).]

$$\frac{dN_g}{dxdk_\perp^2 dt} = \frac{2\alpha_s C_A P(x)\hat{q}}{\pi k_\perp^4} \sin^2\left(\frac{t-t_i}{2\tau_f}\right)\left(\frac{k_\perp^2}{k_\perp^2 + x^2 M^2}\right)^4$$

Jet transport parameter $\hat{q}_0$ employed the results of recent study of re-extraction of 6 mesons R_{AA} at the RHIC and LHC. （iEBE-VISHNU Hydro）
[G.-Y. Ma, W. Dai, B.-W.Zhang and Enke Wang, EPJC 2019]

$$\hat{q}(\tau, r) = q_0 \frac{\rho^{QGP}(\tau, r)}{\rho^{QGP}(\tau_0, 0)} \frac{p^\mu u_\mu}{p^0}$$

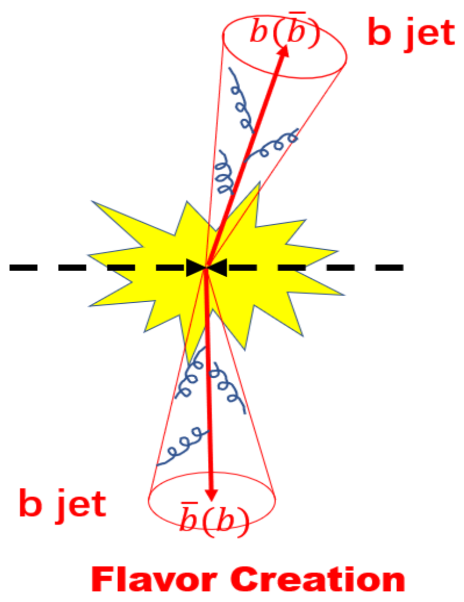
R_{AA} for Inclusive Jet and B-jet



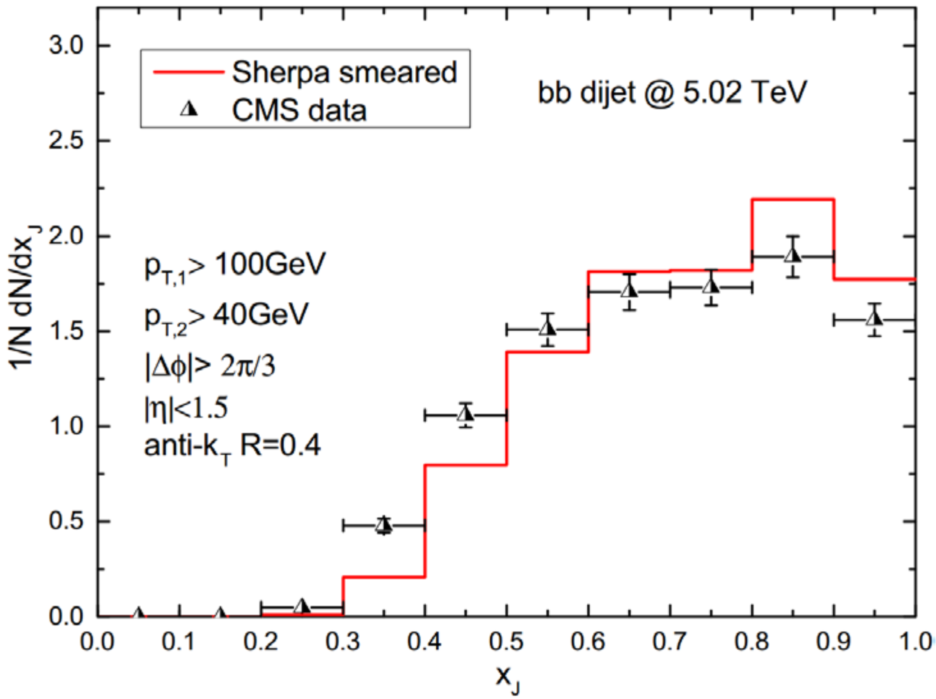
arXiv:1806.06332

- Our simulation can fairly describe the CMS data though b-jet R_{AA} slightly overestimates the data at low p_T region .
- The mass effect of the jet quenching trends to disappear.

Transverse Momentum Imbalance-x_J



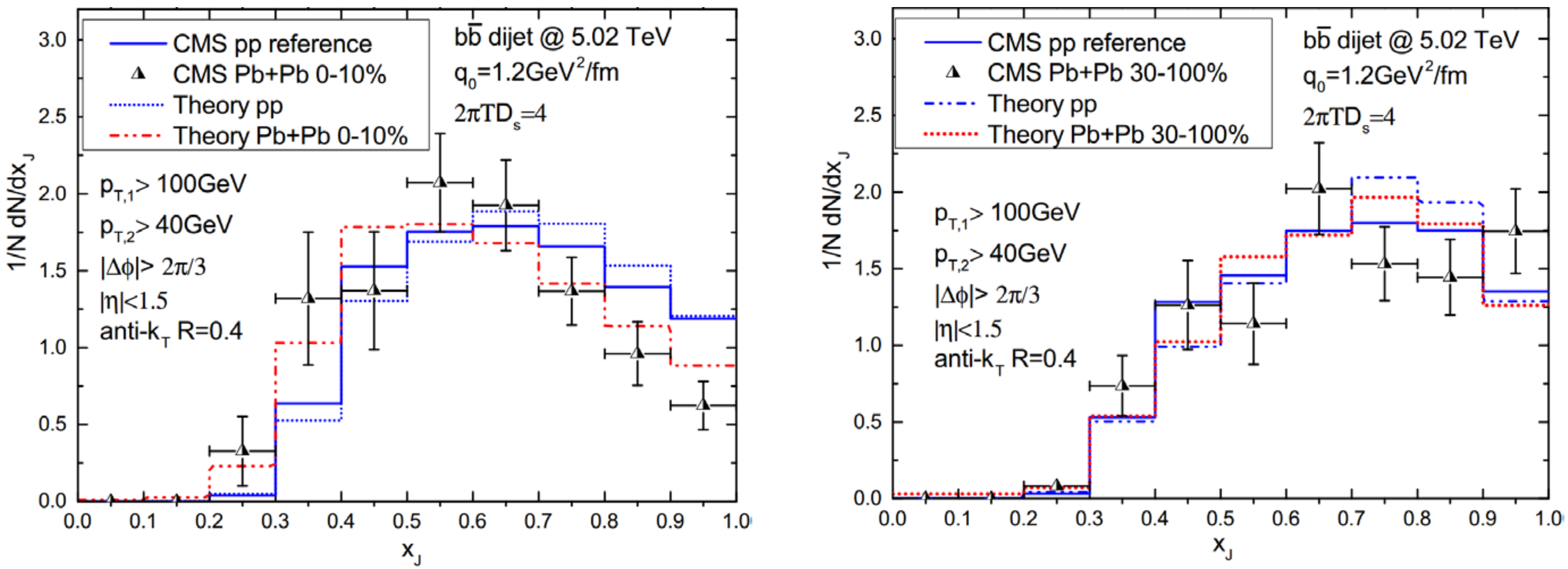
$$x_J = \frac{p_{T,2}}{p_{T,1}}$$



arXiv:1806.06332

- $|\eta|<1.5$, R = 0 .4
- Leading jet $p_T > 100\text{GeV}$
- Sub-leading jet $p_T > 40\text{GeV}$
- Leading and sub-leading jets must be b-tagged.
- $|\Phi_1 - \Phi_2| > \frac{2\pi}{3}$ suppresses the gluon splitting process, the two b jets are back-to-back.

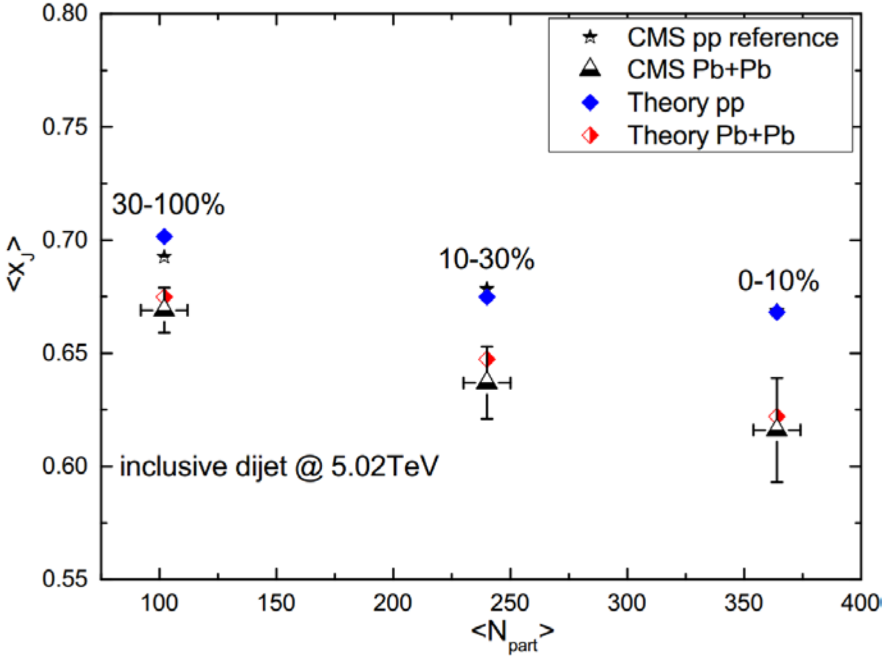
x_J for $b\bar{b}$ dijets

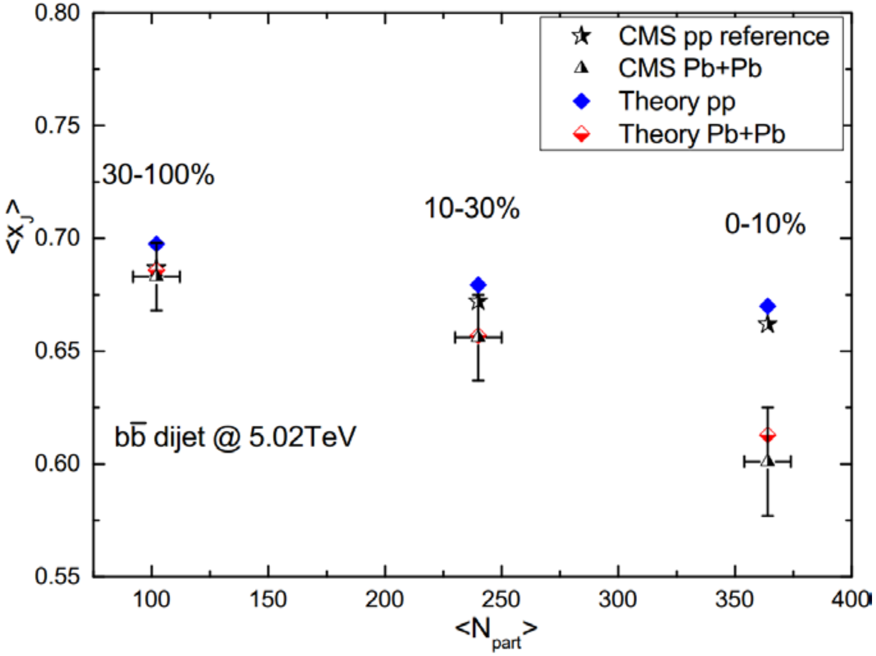


arXiv:1806.06332

- A visible shift of x_J towards smaller in the central Pb+Pb collision, relative to pp reference .
- Much smaller shift is observed in the peripheral Pb+Pb collision, indicating smaller energy loss.

x_J for $b\bar{b}$ dijets

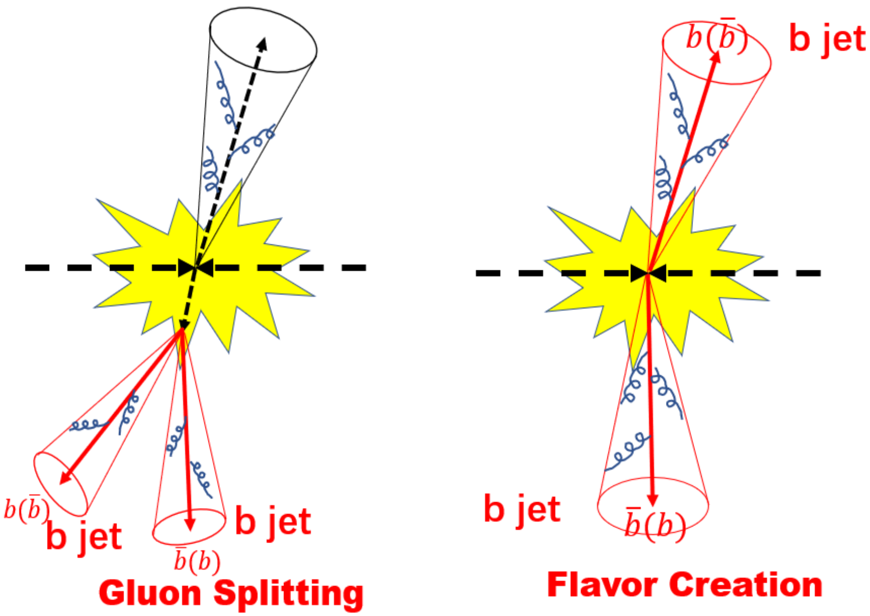


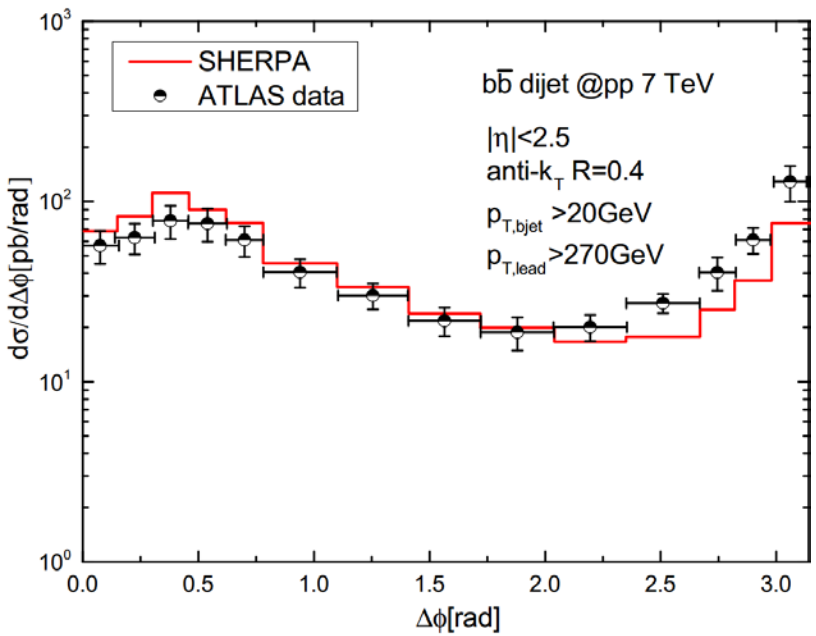


arXiv:1806.06332

- Imbalance of $b\bar{b}$ dijet increasing due to jet quenching is visible in central Pb+Pb collision.
- A smaller energy loss of $b\bar{b}$ dijets than inclusive dijet in peripheral Pb+Pb collision.

Azimuthal Angle Correlation



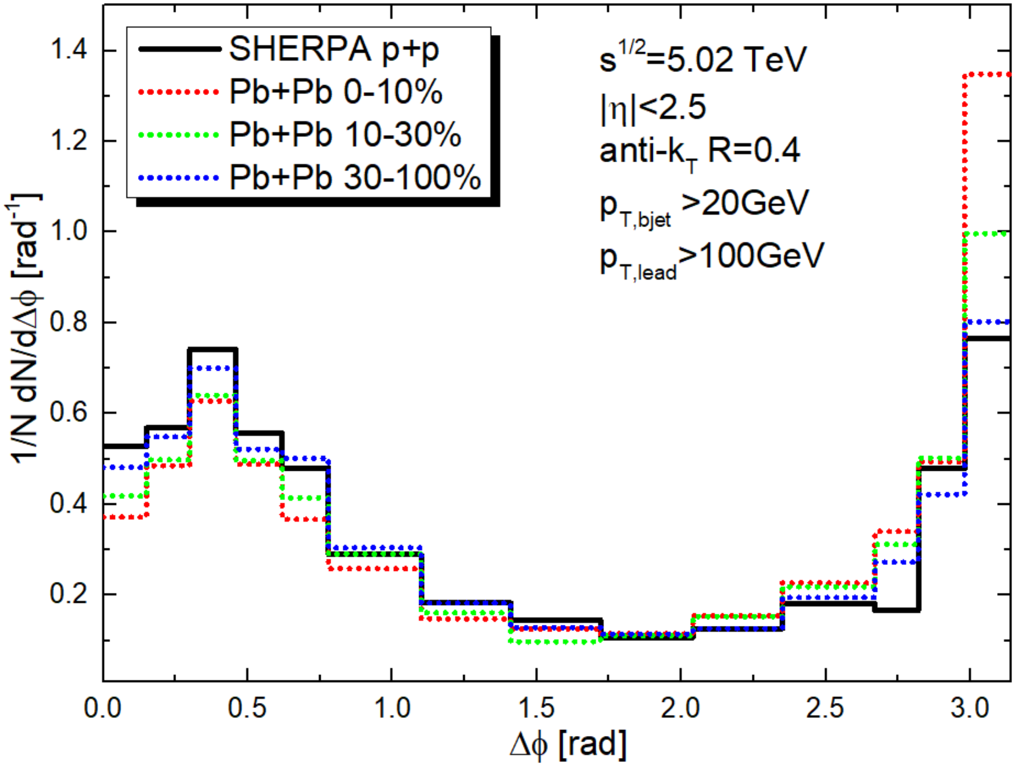


$$\Delta\phi = |\phi_{b1} - \phi_{b2}|$$

arXiv:1806.06332

- $0 < \Delta\phi < \pi$, $|\eta| < 2.5$, R = 0 .4
- Leading jet $p_T > 270GeV$
- $p_{T,bjet} > 20GeV$
- Leading and sub-leading jets are not required to be b-tagged.
- 2 b jets separated by ΔR > 0.4

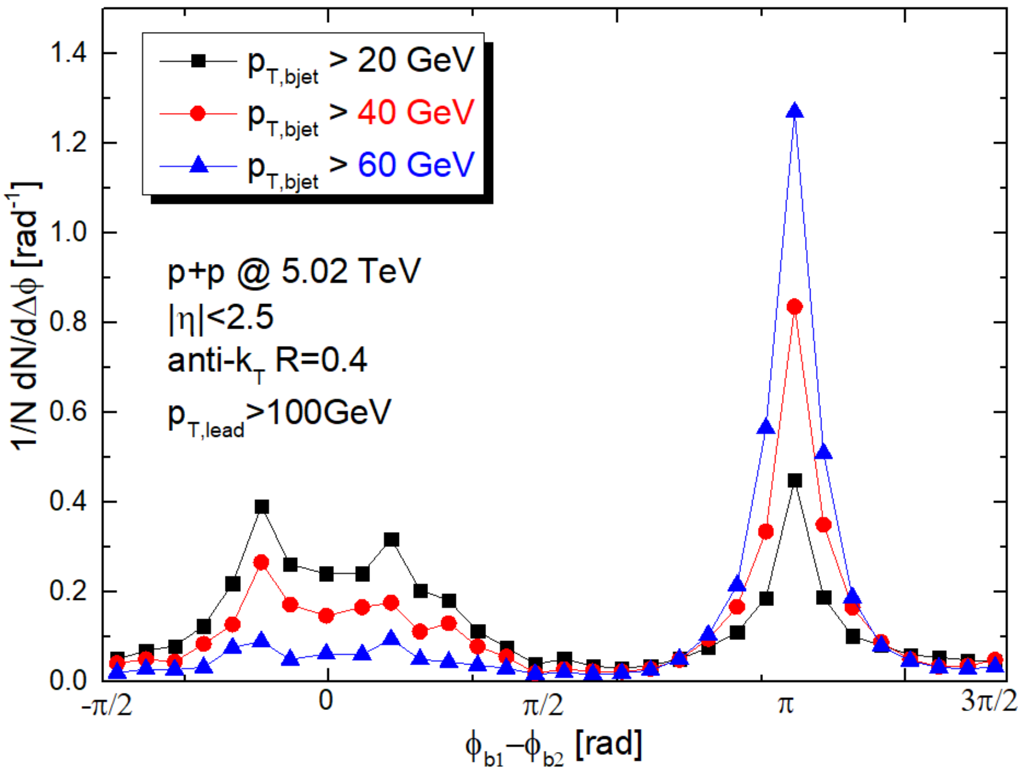
Azimuthal Angle Distribution---$\frac{1}{N}\frac{dN}{d\Delta\phi}$



arXiv:1806.06332

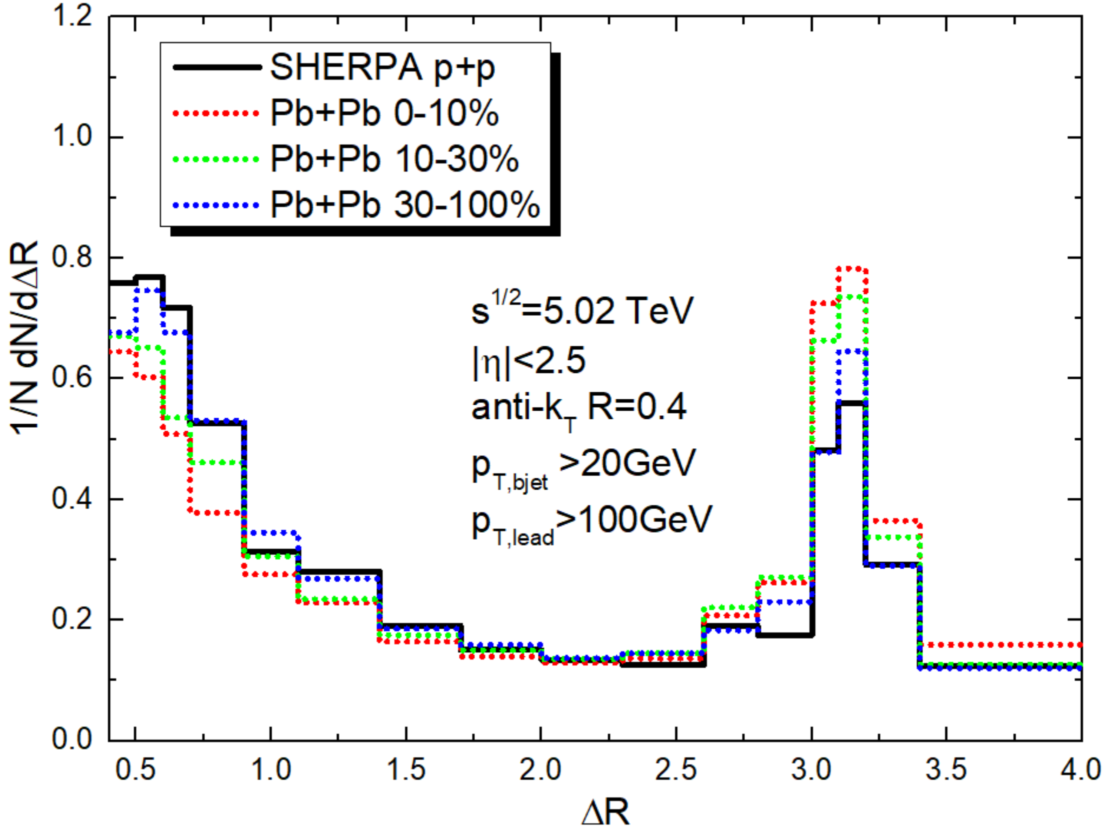
- The energy loss effect would suppress and broaden the near side (small $\Delta\phi$) peak, and also enhance and sharp the away side (near $\Delta\phi = \pi$) peak in the normalized $\Delta\phi$ distribution.
- In the small angle region, it suffers stronger suppression relative to the large angle region.

Azimuthal Angle Correlation



- The structure of azimuthal angle distribution between the two b jets was sensitive to the minimum p_T cut of b jet.
- GSP more likely produces two b jets with relatively lower p_T compared with FCR.

Angular Distance Distribution--- $\frac{1}{N}\frac{dN}{d\Delta R}$



$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$

- Suppression on small ΔR and enhancement on large ΔR with centrality dependence.

Summary and Outlook

- SHERPA for pp baseline, light and heavy quark in-medium evolution in one framework have been implemented to study the $b\bar{b}$ dijets production in Pb+Pb collisions.

- x_J

x_J shift to smaller value consistent with CMS data, and a similar trend as that in dijet has been observed.

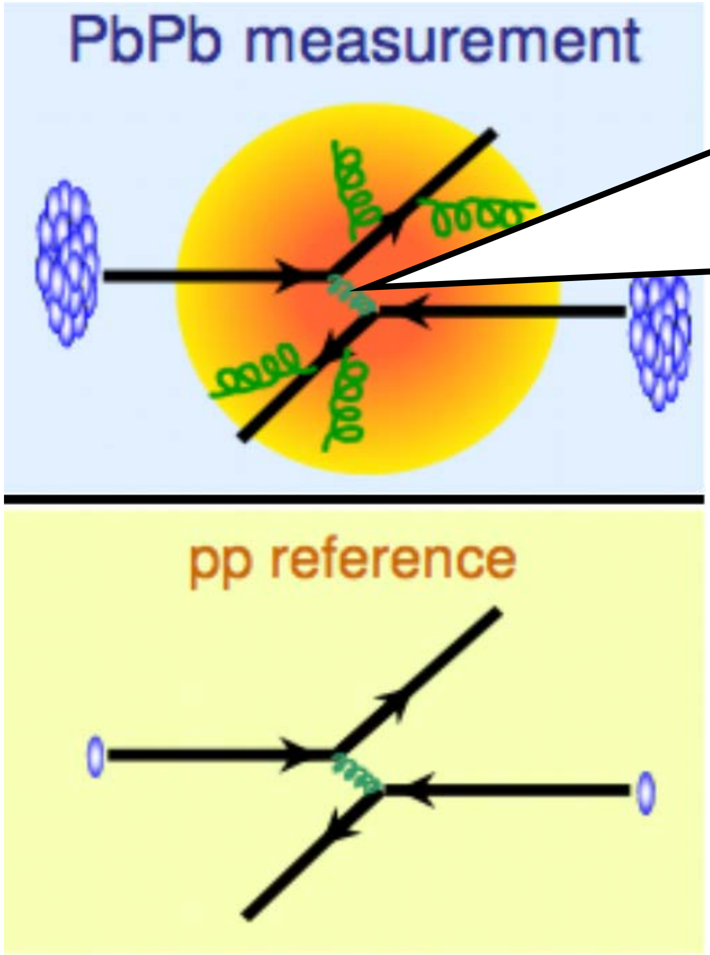
- $\Delta\phi$ *and* ΔR

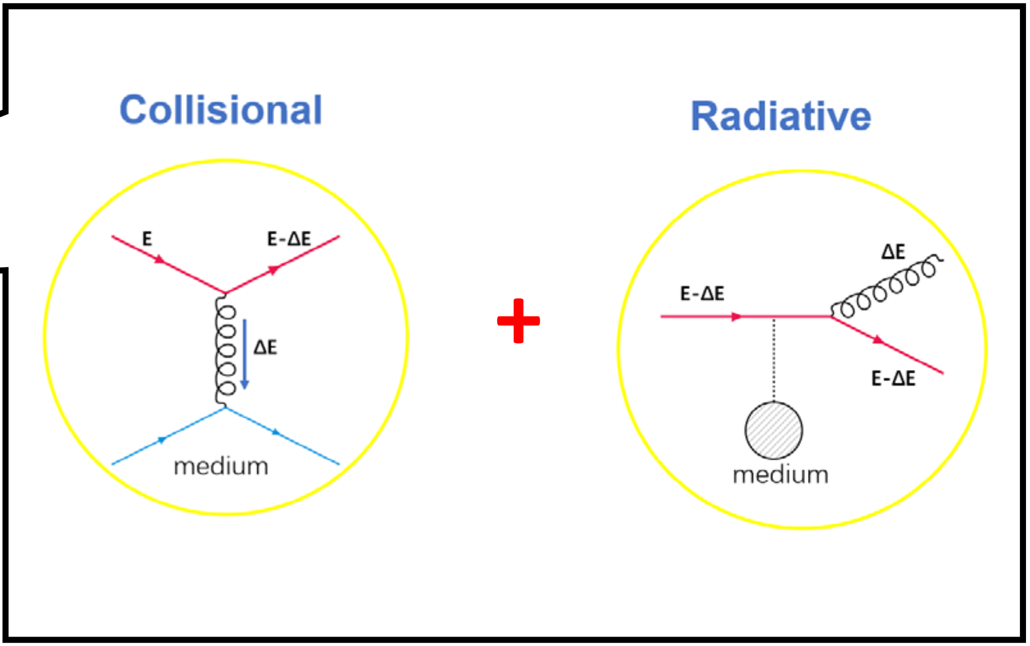
Suppression on the near side and the enhancement on the away side in the normalized distribution are predicted.

- More exclusive channel has been investigated

z+$b\bar{b}$ production， soon to be submitted.

In-Medium Energy Loss





Backup-1 Gluon Sampling Method

- The average number of radiative gluon during a time step[Phys.Rev. C94 (2016) no.1, 014909]:

$$\langle N_g(t,\Delta t)\rangle = \Delta t \int dxdk_\perp^2 \frac{dN_g}{dxdk_\perp^2 dt}$$

- Assuming that the number of radiative gluon n obeys the Possion distribution $P(n) = \frac{\langle N_g\rangle^n}{n!} e^{-\langle N_g\rangle}$, the total probability for radiation during a time step Δt:

$$P_{rad}(t,\Delta t) = 1 - e^{-\langle N_g\rangle}$$

- Then it's available to sample the energy xE and transverse momentum $k_\perp$ of the radiative gluons during every time step for arbitrary state (E, T, t) .
- The interval $t - t_i$ would be reset when a radiation occurred .

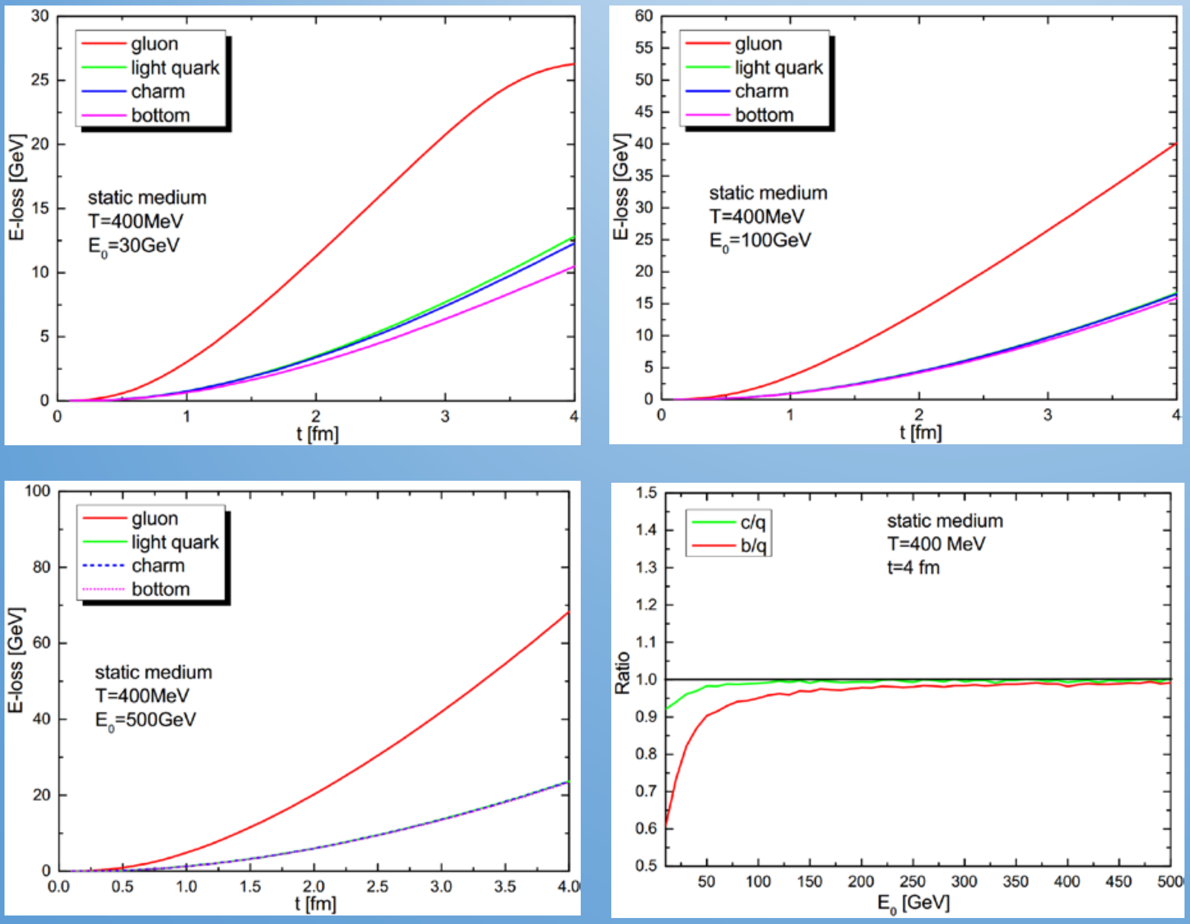
Backup-2 Smearing parameter

The jet p_T resolution is parametrized according the following form[arXiv:1607.03663]:

$$\sigma(p_T)/p_T = \sqrt{C^2 + \frac{S^2}{p_T} + \frac{N^2}{{p_T}^2}}$$

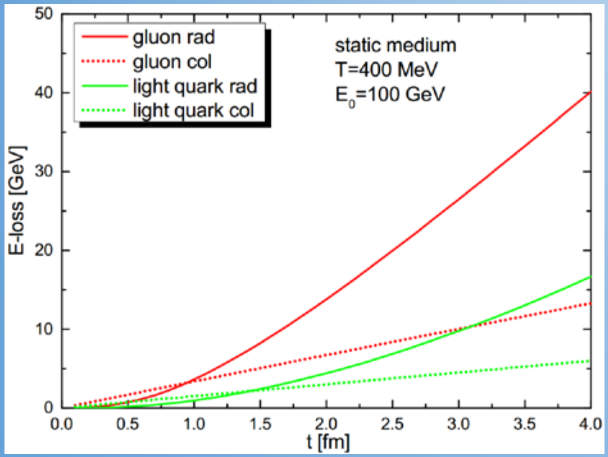
- In pp collisions, the constant C and stochastic S terms are 0.06 and 0.8 GeV^{-1}
- In Pb+Pb collisions the S term is slightly larger value of 1.0 GeV^{-1}, due to the underlying event.
- The noise parameter (N) depends on collision centrality, according to $N = 14.82 - centrality(\%)/5.40(GeV^2)$ subtraction.

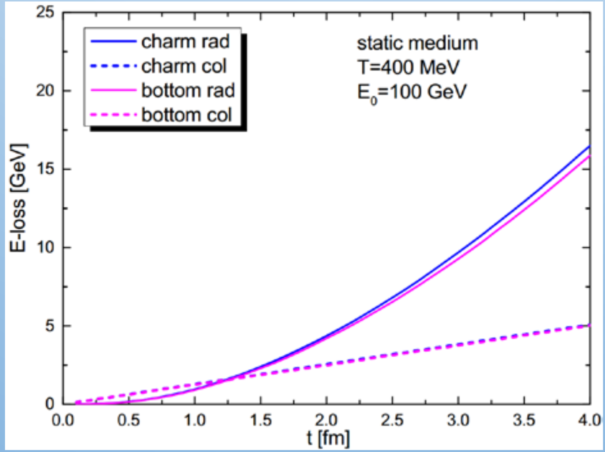
Radiative E-loss: gluon & light quark & heavy quark

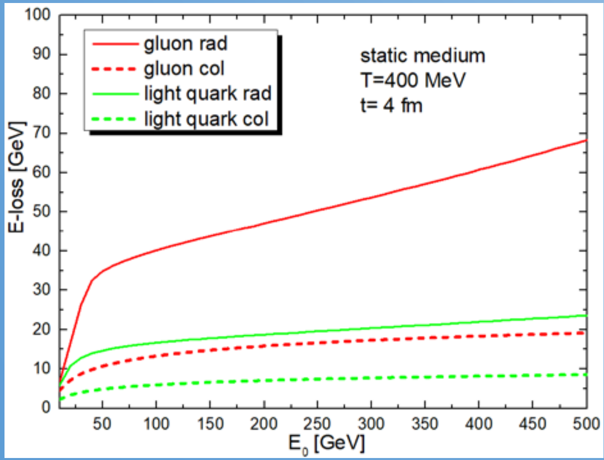


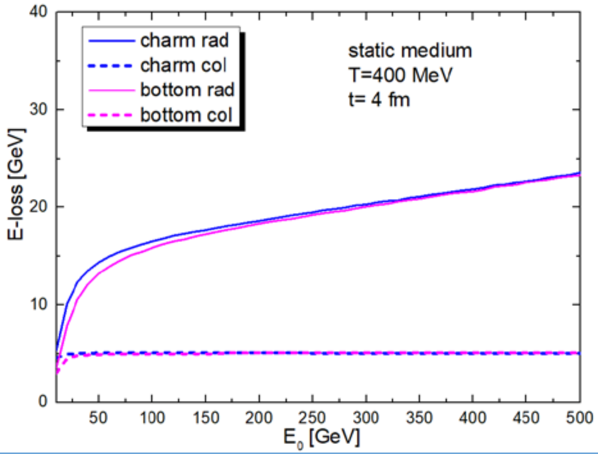
- The radiative energy loss of gluon is much larger than quarks.
- $\Delta E_g > \Delta E_q > \Delta E_c > \Delta E_b$.
- Mass effect of heavy quarks trends to disappear as energy increasing.

Radiative Vs. Collisional E-loss



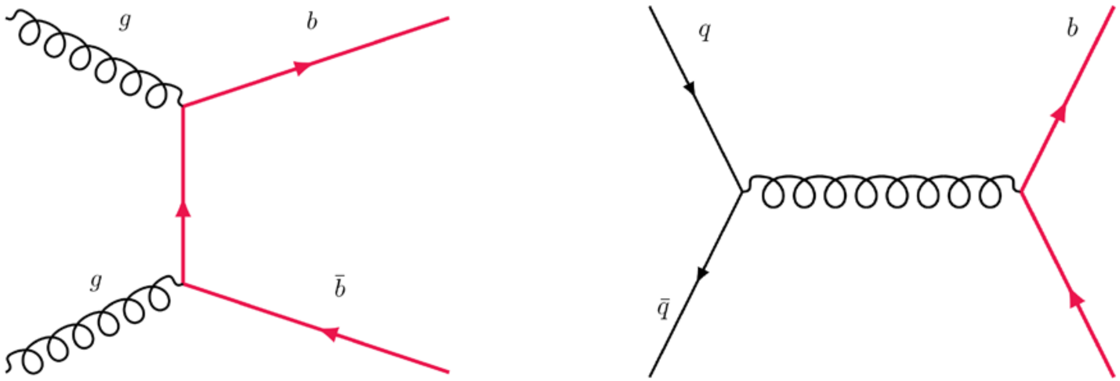




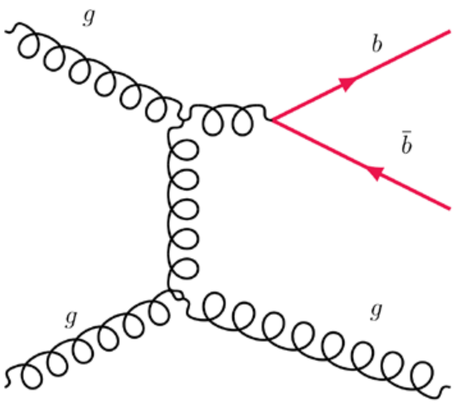


- In-medium energy loss is dominated by gluon radiation both for light and heavy flavor.
- Collisional E-loss shown no initial energy dependence.

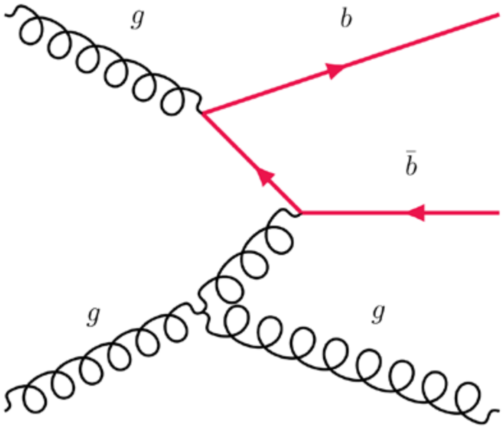
Bottom Production



Flavor Creation (FCR)



Gluon Splitting(GSP)



Flavor Excitation(FEX)