p_T dispersion of inclusive jets in high-energy nuclear collisions

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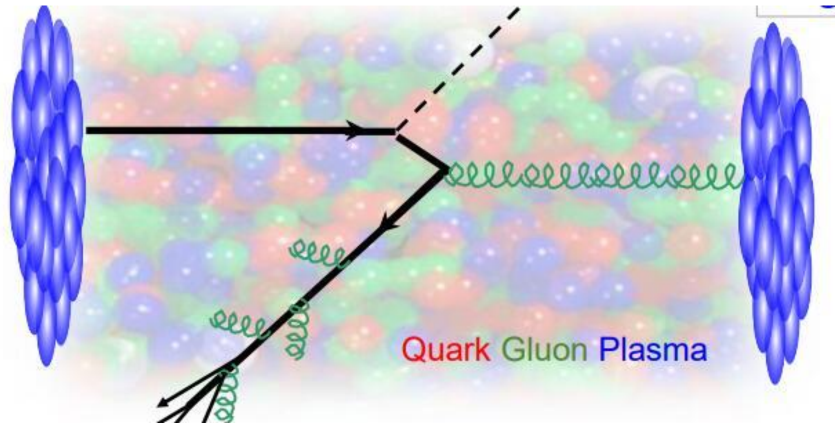
Shi-Yong Chen, Jan Yan, Wei Dai, Ben-Wei Zhang and En-Ke Wang arXiv:2204.01211

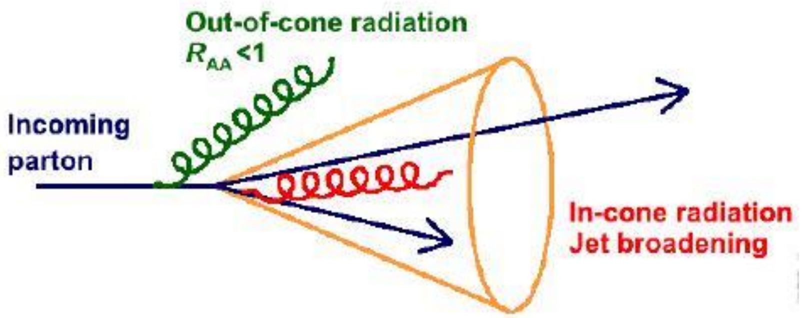
Outline

- Motivation
- Jet momentum dispersion ($p_T D$) in pp and AA collisions
- Results and disscussion
- Summary

Motivation

Heavy-ion collisions: Quark Gluon Plasma





- Jet quenching is one of the most powerfull hard probe to investigate QGP.
- High p_T hadron and full jet observables: productions and correlations.
- Jet substructures: jet shape, jet splitting functions, jet fragmentation functions, jet charge…

Xin-Nian Wang, M.Gyulassy, PRL68(1992)1480

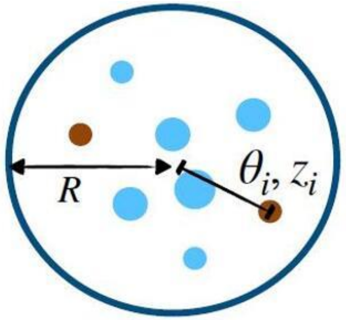
Motivation: jet angularity

Generalized jet angularities defined as,

$$\lambda_\alpha^\kappa = \sum_{i\epsilon jet} z_i^\kappa \theta_i^\alpha , \qquad \left(z_i \equiv \frac{p_{Ti}}{\sum_{i\epsilon jet} p_{Ti}} , \ \theta_i \equiv \frac{\Delta R_i}{R} \right)$$

(the transverse momentum of jet consititunent i)

(the angle of the ith constitunent relative to jet axis)

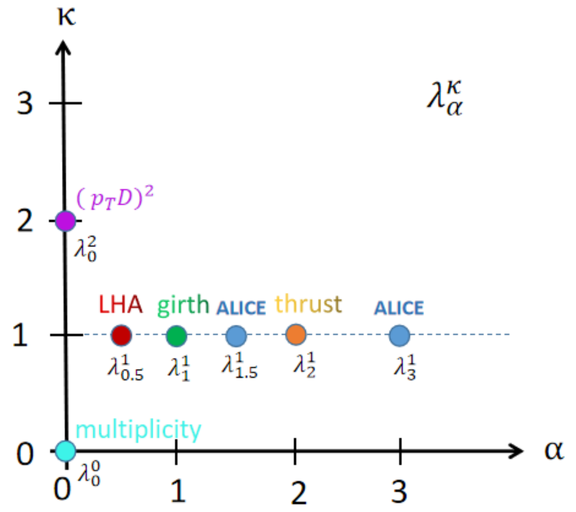


The exponents κ and α probe different aspects of the jet fragmentation,

(κ, α)

(1 , 1) ⇒ girth
(2 , 0) ⇒ $(p_T\mathrm{D})^2$
(0 , 0) ⇒ hadron multiplicity
(1 , 2) ⇒ jet-mass-squared divided by energy (thrust)
(1 , 0.5) ⇒ Les Houche Angularity(LHA)

- How $p_T D$ is modified by jet quenching?



[Larkoski, JDT, Waalewijn,1408.3122], [For a more complete catalog, see Gallicchio, Schwartz, 1106.3076, 1211.7038]
[based on Berger, Kucs, Sterman, hep-ph/0303051]; [Ellis, Vermilion, Walsh, Hornig, Lee, 1001.0014],
[see also Larkoski, Salam, JDT, 1305.0007; Larkoski, Neill, JDT.1401.2158]

p_T dispersion in pp collisions

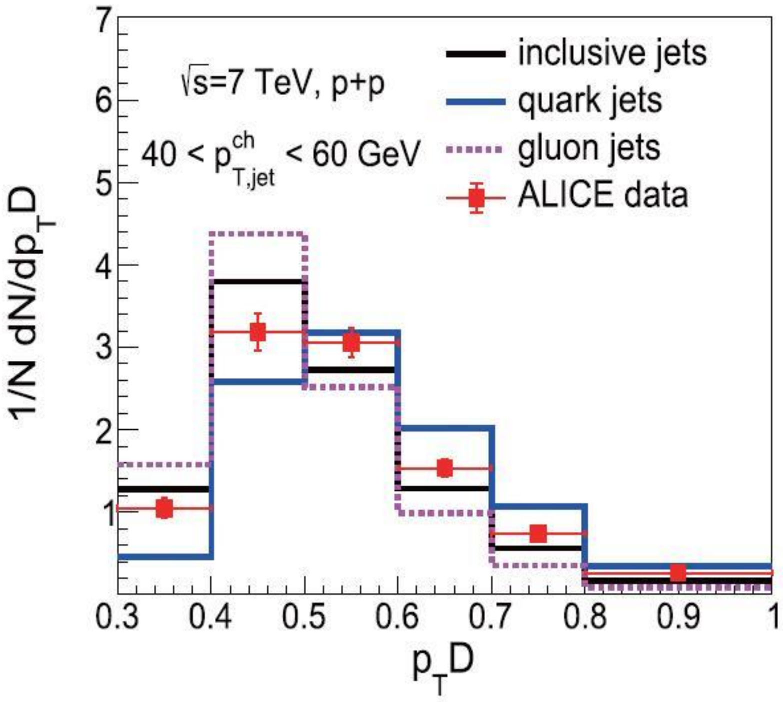
- The momentum dispersion $p_T D$ is defined as, $p_T D = \frac{\sqrt{\sum_{i\in jet} p_{T,i}^2}}{\sum_{i\in jet} p_{T,i}}$,
- Connect to how hard or soft of jet fragmentation.

e.g. in the extreme case of few constituents carrying a large fraction of the jet momentum, $p_T D$ will be close to 1, while in the case of jets with a large number of constituents and softer momentum, $p_T D$ would end up closer to 0.

- In pp collisions: POWHEG+PYTHIA

- Well consistent with ALICE data, provide soild pp baseline.

- $p_T D$ distribution for gluon jets located in smaller $p_T D$ region.



ALICE Collaboration, JHEP 1810,139(2018) [arXiv:1807.06854[nucl-ex]]
S.Y. Chen, J.Yan, Wei Dai, Ben-Wei Zhang and En-Ke Wang. arXiv: 2204.01211.

p_T dispersion in pp collisions

Standard deviation $\delta = \frac{\sqrt{\sum(p_{Ti} - \langle p_{Ti}\rangle)^2}}{n\langle p_{Ti}\rangle}$

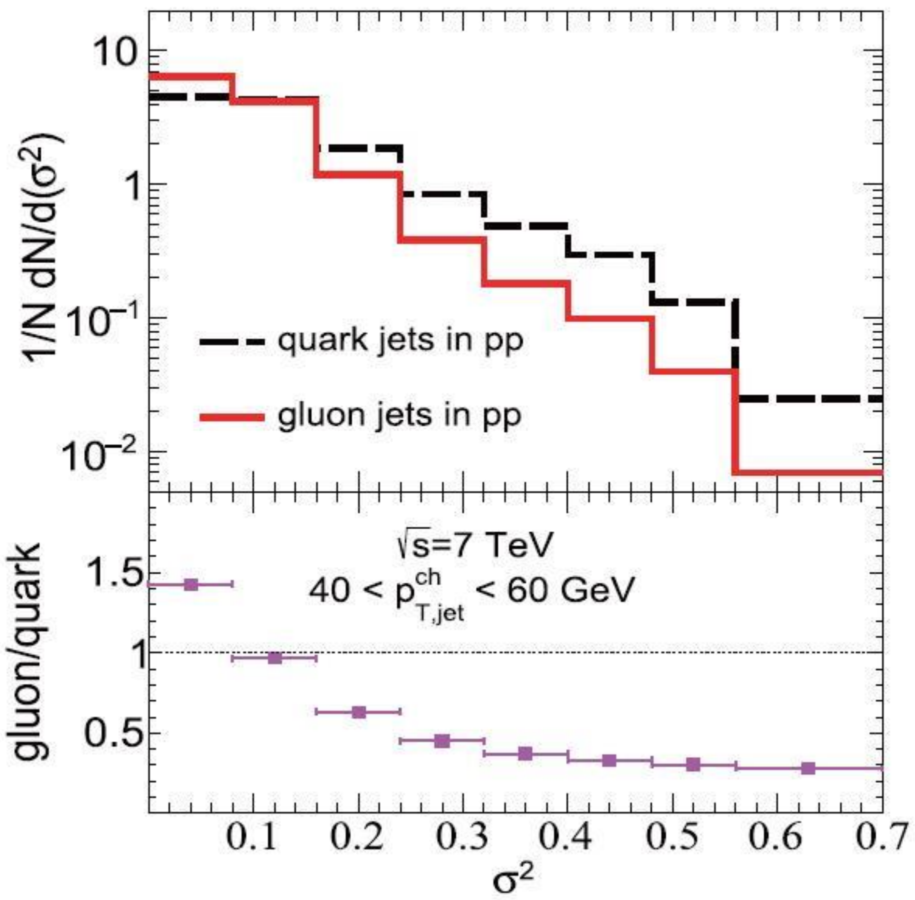
- Analytical connected with $(p_T D)^2$ and 1/n.

$$\delta^2 = \frac{\sum(p_{Ti} - \langle p_{Ti}\rangle)^2}{n^2\langle p_{Ti}\rangle^2}$$

$$= \frac{\sum(p_{Ti}^2 - 2p_{Ti}\langle p_{Ti}\rangle + \langle p_{Ti}\rangle^2)}{n^2\langle p_{Ti}\rangle^2}$$

$$= (p_T D)^2 - \frac{1}{n}$$

- Higher δ means more p_{Ti} are generally far from the mean value $\langle p_{Ti}\rangle$, lower δ indicates that more p_{Ti} are clustered close to $\langle p_{Ti}\rangle$.
- At the same p_T, δ of gluon jets are smaller than quark jets because of containing more fragment constituents.



Jet quenching model

1. POWHEG+PYTHIA generate showered partonic event
2. parton initial position generated by Glauber model (r_0, T)
3. the parton suffer radiative energy loss during t_1,t_2 by probability:

$$\left\langle N_g(t,\Delta t)\right\rangle = \Delta t\int dxd^2k_\perp \frac{dN}{dxd^2k_\perp} \qquad P_{rad}(\mathrm{t},\Delta t) = 1-e^{-\left\langle N_g\right\rangle}$$

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

QGP transport coefficient: $\hat{\mathrm{q}}(\tau,\mathrm{r}) = \mathrm{q}_0\frac{\rho^{QGP}(\tau,r)}{\rho^{QGP}(\tau_{0,}0)}\frac{p^\mu u_\mu}{p^0}$

the spectrum is given by Higher-Twist, P(x) is splitting function

$$P_{\mathrm{q}\to qg} = \frac{(1-x)(2-2x+x^2)}{x}$$

$$P_{g\to gg} = \frac{2(1-x+x^2)^3}{x(1-x)}$$

4. the number of radiated gluon is given by Poisson distribution

$$P(\mathrm{n}) = \frac{\left\langle N_g\right\rangle^n}{n!}e^{-\left\langle N_g\right\rangle}$$

5. the collisional energy loss: Hard Thermal Loop calculation

$$\frac{\mathrm{d}E}{dz} = \frac{\alpha_s C_i m_D^2}{2}\ln\frac{\sqrt{ET}}{m_D}$$

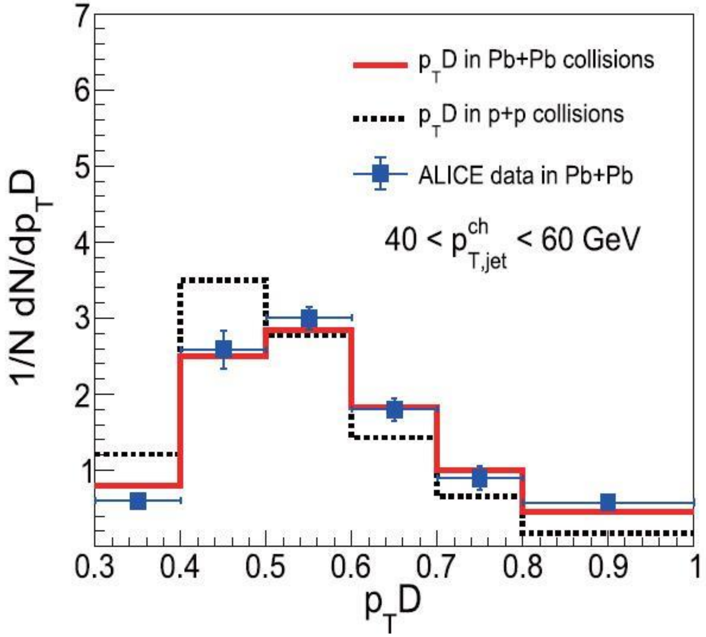
6. the temperature is read from 2+1 D viscos hydro

   if $\mathrm{T_i} < \mathrm{T_C}$, escape QGP

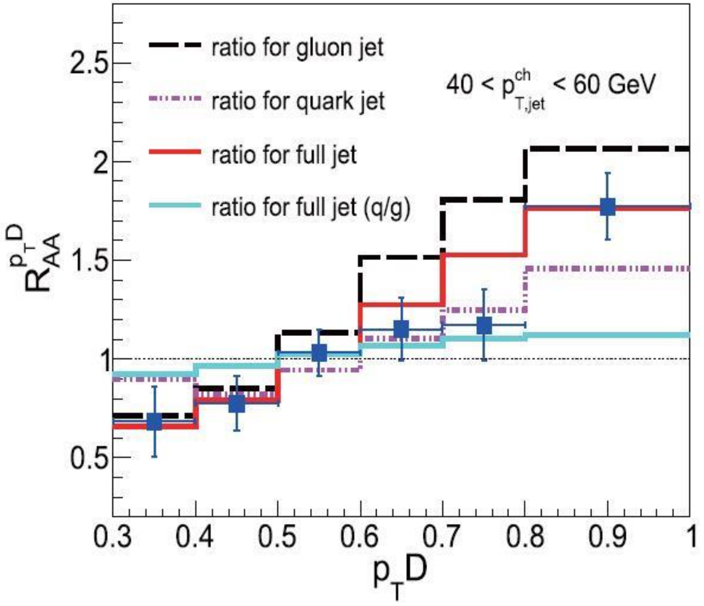
7. Perform hadronization with pythia

Xiao-feng Guo , Xin-Nian Wang Phys. Rev. Lett. 85 (2000) 3591-3594
Ben-Wei Zhang , Xin-Nian Wang Phys. Rev. Lett. 93 (2004) 072301
A. Majumder, Phys.Rev. D85(2012)014023
W.T. Deng and X.N Wang, Phys.Rev.C 81(2010)024902

p_T dispersion in PbPb collisions



$$R_{AA}^{p_T D} = \frac{1}{N_{AA}} \frac{dN_{AA}}{dp_T D} \Big/ \frac{1}{N_{pp}} \frac{dN_{pp}}{dp_T D} \,.$$



- In Pb+Pb collisions: well consistent with ALICE data. Distribution of $p_T D$ shifted to higher value.

- $R_{AA}^{p_T D} < 1$ in lower $p_T D$ region and $R_{AA}^{p_T D} > 1$ in higher $p_T D$ region. $R_{AA}^{p_T D}$ for gluon jets is much stronger than quark jets.

- What causes this?
  - Parton energy loss
  - q/g fraction alteration

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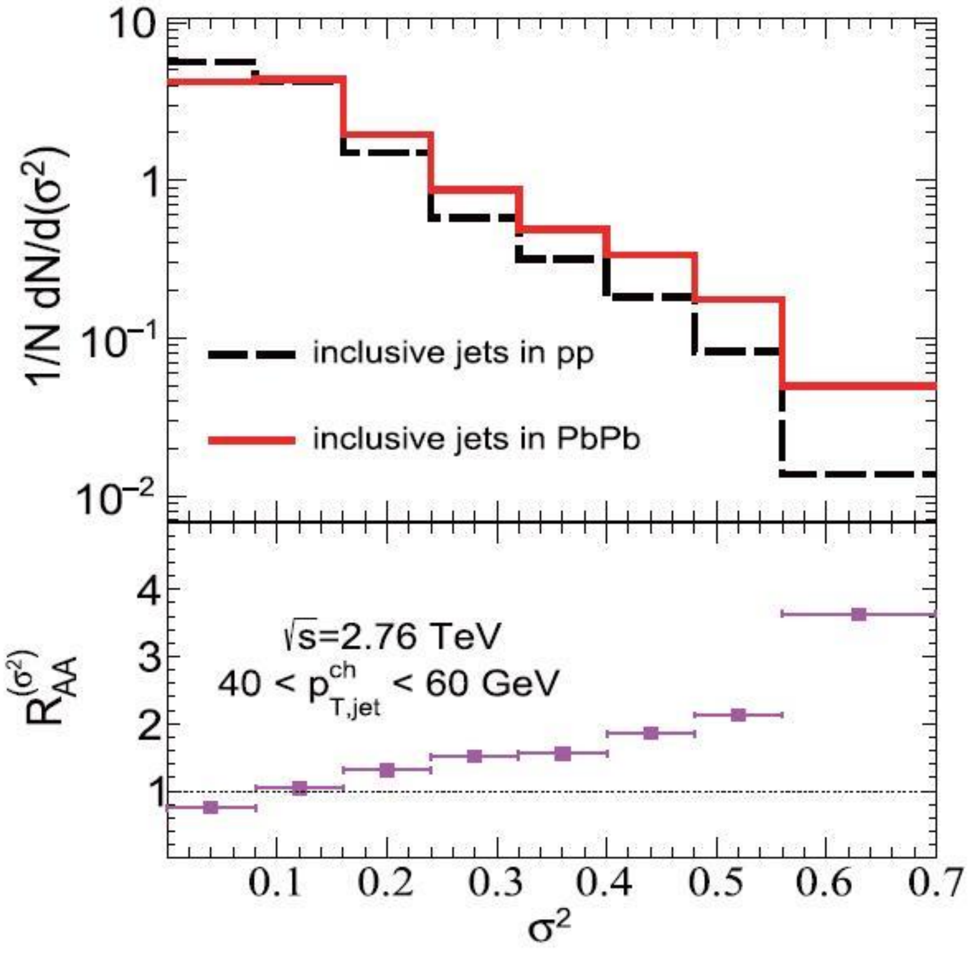
p_T dispersion in PbPb collisions

$$(p_T D)^2 = \delta^2 + \frac{1}{n}$$

- smaller <n>   larger 1/n. ($\overline{n_{pp}} = 6.74$, $\overline{n_{PbPb}}$=6.52)
- σ^2 shift to larger value region , means more p_T of jet constituents stay further away from the mean value.

$$\sigma^2\uparrow \qquad 1/n\uparrow \quad \longrightarrow \quad (p_T D)^2\uparrow$$



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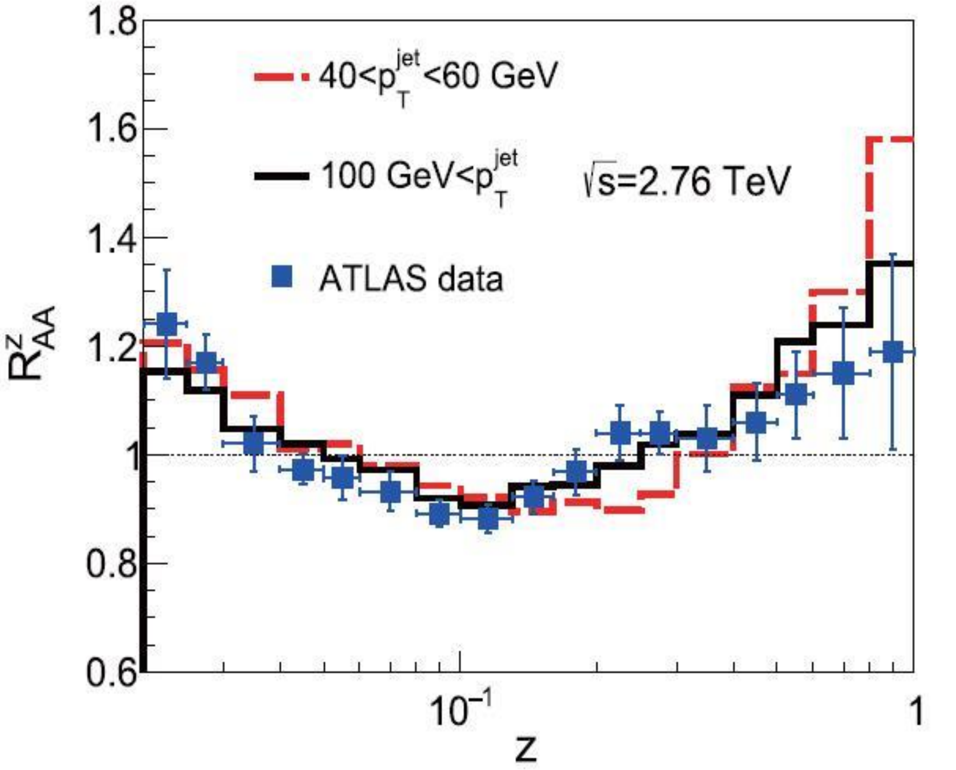
p_T dispersion in PbPb collisions

- Momentum fraction z： fragmentation function, related with $p_{T,i}$ only.

- R^{z}_{AA}>1 when 0.02<z,<0.05 and 0.3<z<1;
  R^{z}_{AA}>1 when 0.05<z<0.3.

means more constituents of $p_{\mathrm{T,i}}$ stay further away from the mean value.



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p_T dispersion in PbPb collisions

Soft-drop:

- First reclustered using the Cambridge-Aachen(C/A) algorithm.
- Then declustered in the reverse order by dropping the softer branch until two hard branches are found to satisfy the following condition,

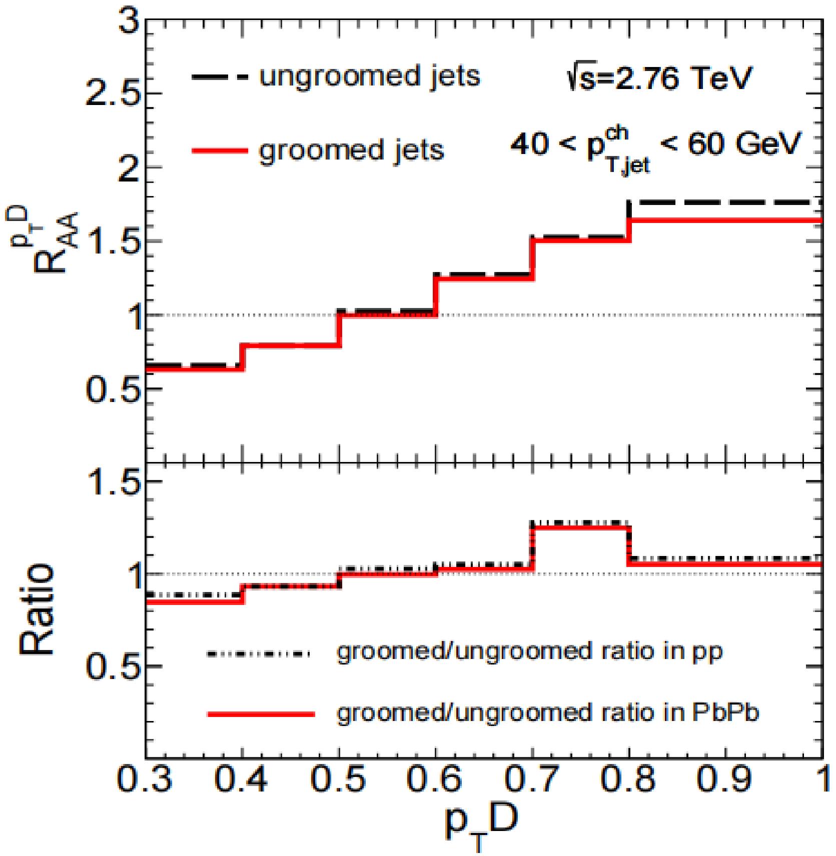
$$\frac{min(p_T1, p_T2)}{p_T1 + p_T2} \equiv z_g > z_{cut}(\frac{\Delta R}{R})^{\beta}$$

z_{cut}=0.1, β=0

Groomed vs ungroomed:

- medium modification reduced.

How does the grooming procedure modify $p_T D$ distrbution?



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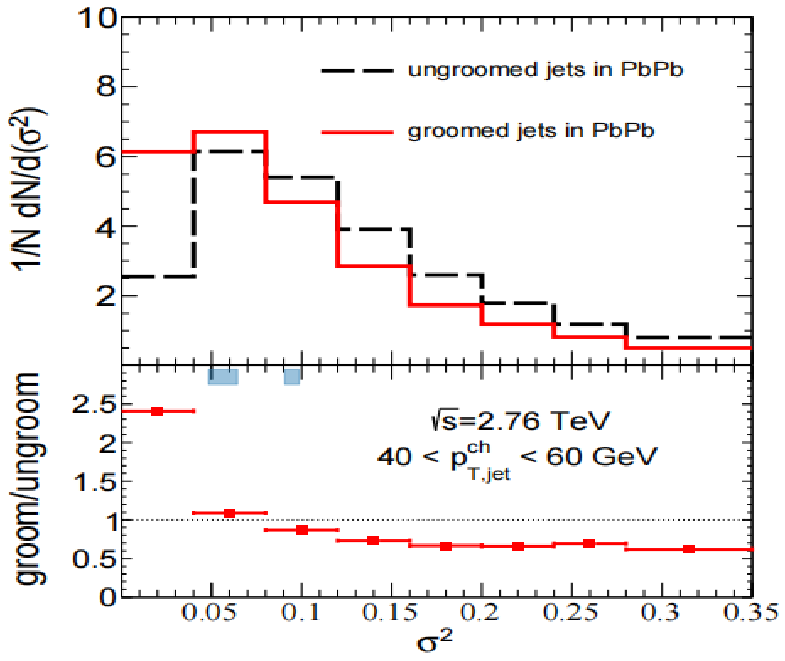
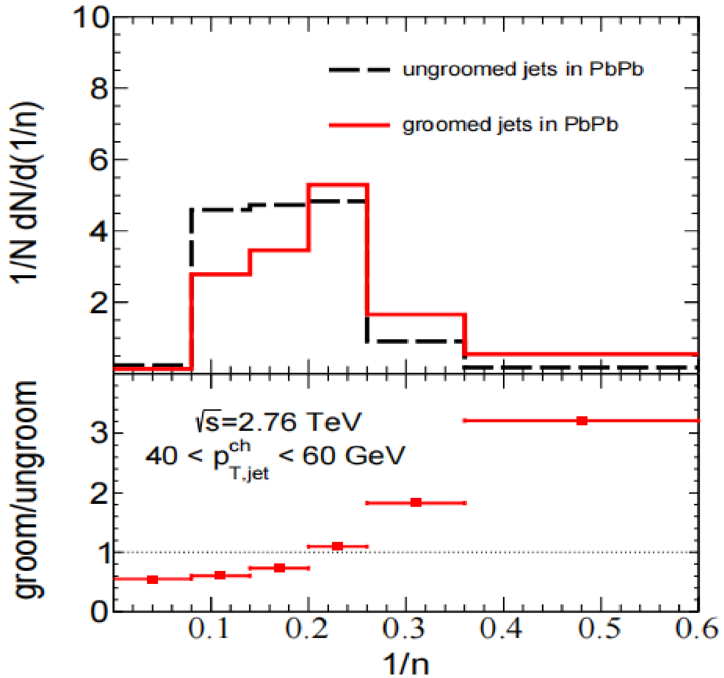
p_T dispersion in PbPb collisions





$$(p_T D)^2 = \delta^2 + \frac{1}{n}$$

- Grooming process will enhance the value of 1/n and meanwhile lead to lower δ.
- The correction of 1/n are more pronounced.

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Summary

- $p_T D$ distribution shifted to higher $p_T D$ value after jet quenching.
- Medium modification of $p_T D$ is caused by both parton redistribution (borth δ^2 and 1/n enhanced) and alteration of overall quark/gluon fraction.
- The trend of groomed $R_{AA}^{p_T D}$ is consistent with ungroomed, grooming procedure would weaken $p_T D$ nuclear modification.

Thank you for your attention !