Jet probes of QCD matter

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Outline

- Introduction
- Jet observables in HIC

1) inclusive jet cross section

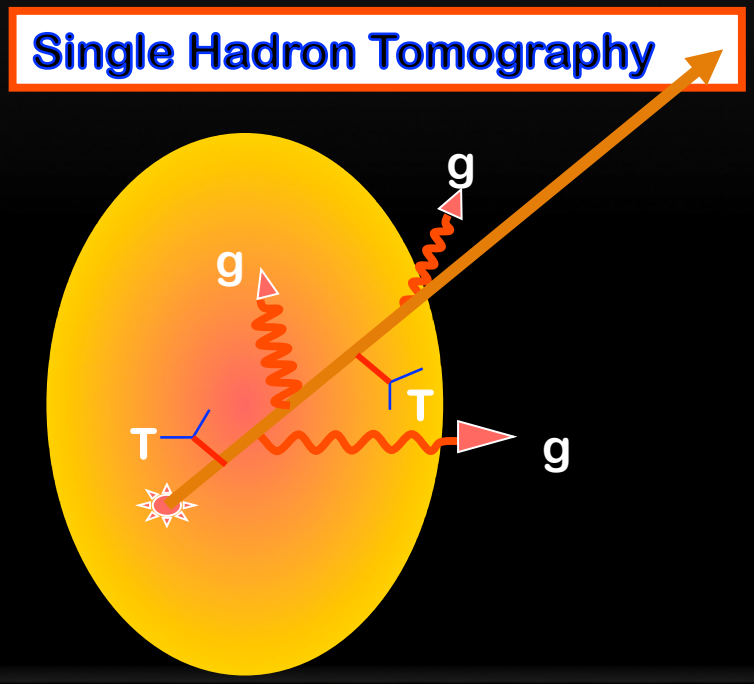
2) di-jet momentum imbalance

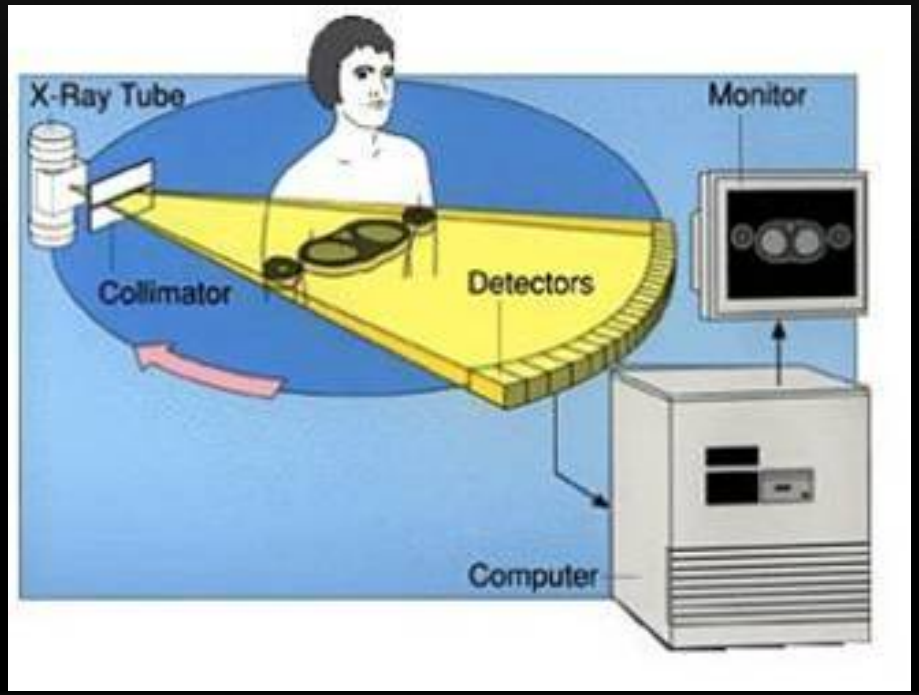
- Summary

Jet quenching: From hadrons to jets

Jet quenching as a hard probe

Jet quenching has been proposed as an excellent probe of the hot/dense matter created at HIC.

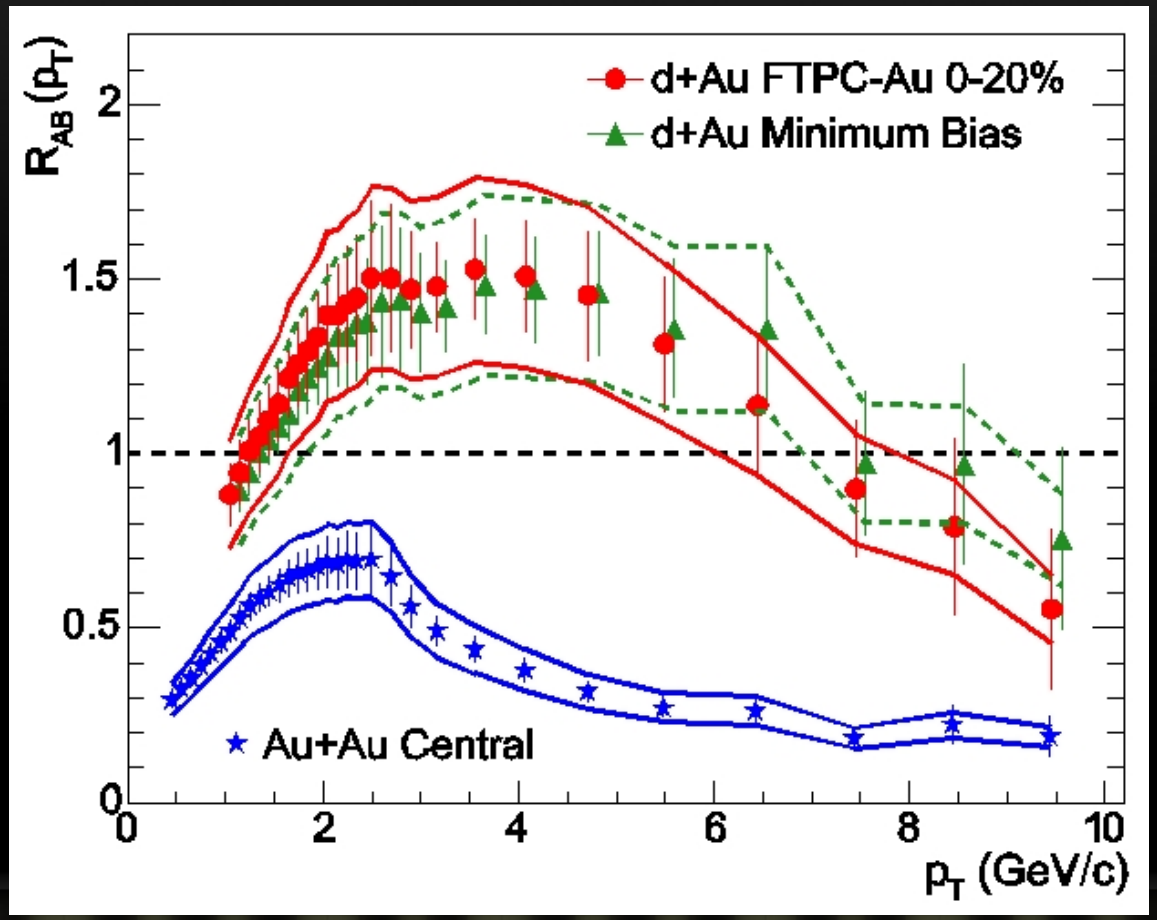




Xin-Nian Wang, M. Gyulassy, PRL68(1992)1480

Jet quenching at RHIC: leading hadrons

$$R_{AA} = \frac{\text{Yield}_{AuAu} / \langle N_{binary} \rangle_{AuAu}}{\text{Yield}_{pp}}$$

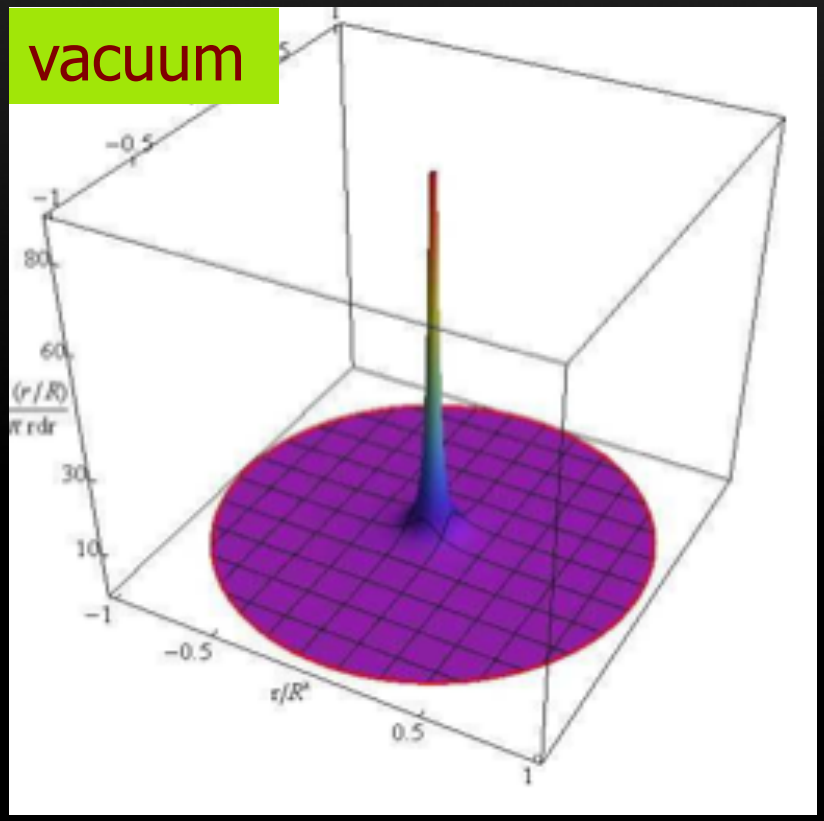


Gyulassy, Vitev, X.N.Wang, BWZ, 《QGP3》 p123-191 (2004); nucl-th/0302077.

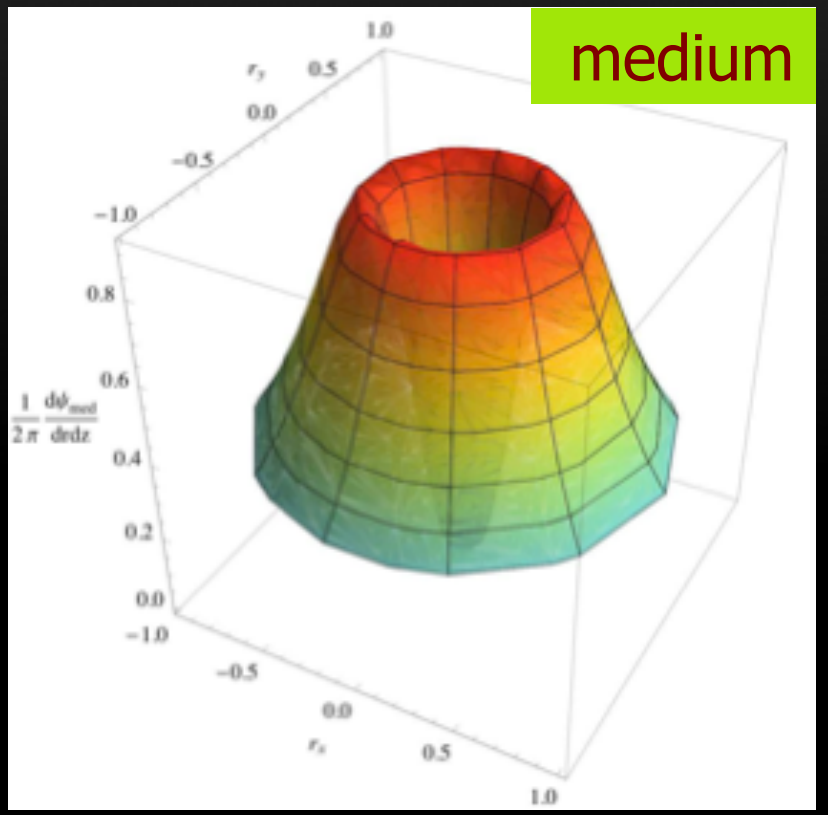
From leading hadrons to jets: Th

Jet shape

vacuum

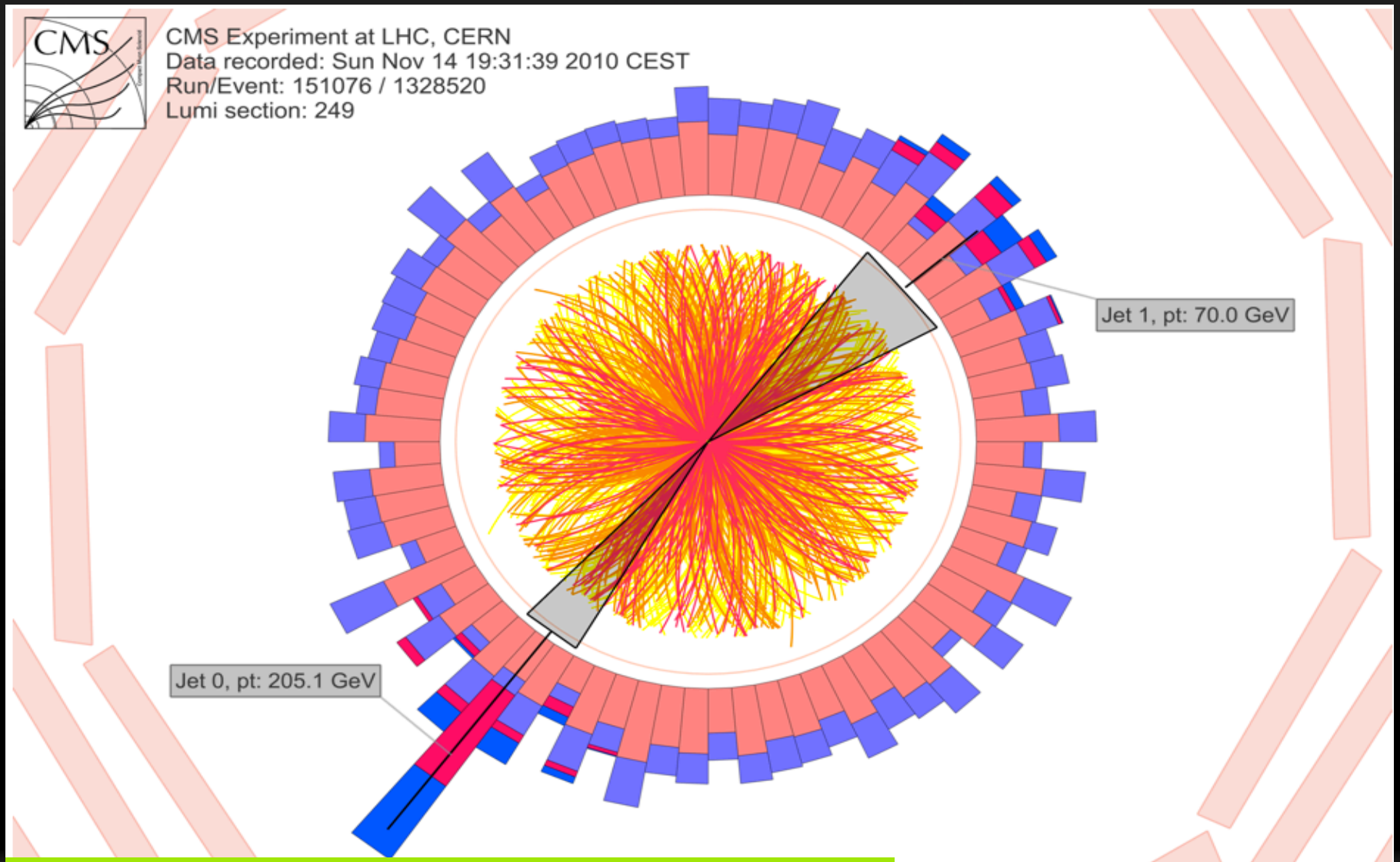


medium



I Vitev, S Wicks, BWZ, JHEP 0811,093 (2008)

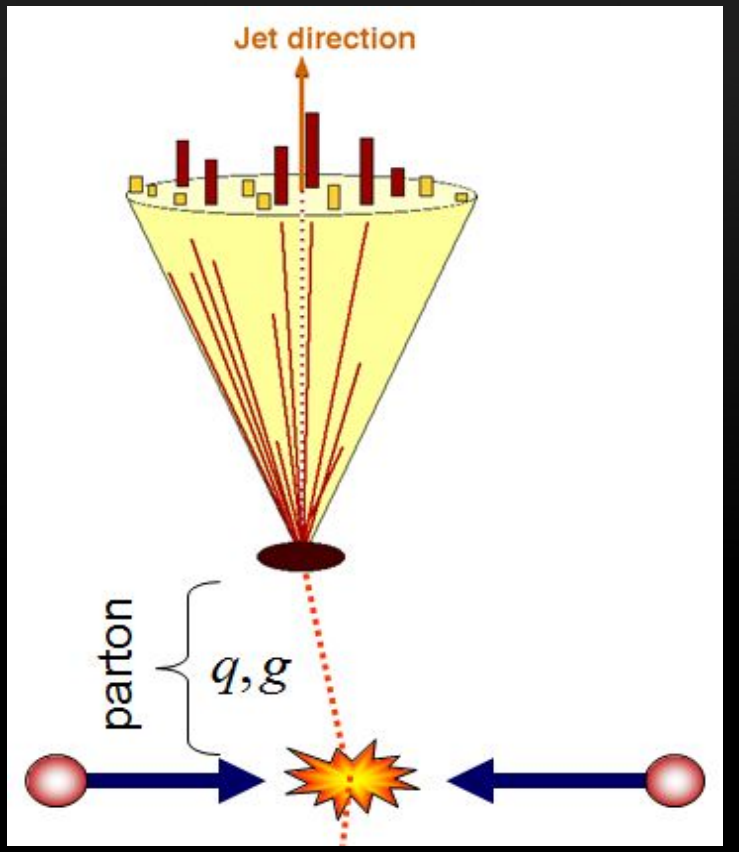
From leading hadrons to jets: Exp



A Dijet event by CMS on Nov. 14, 2010.

What is a jet?

- At LO pQCD, jet ≈parton.
- A jet is a spray of final-state particles roughly moving in the same direction and defined by jet finding algorithms.
- In pQCD local-parton-hadron duality (LPHD) is used
- Jet: more precise and powerful



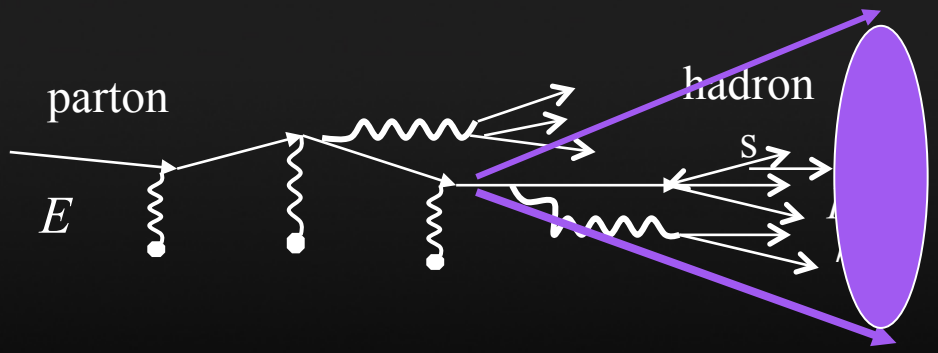
$$E_T = \sum_{i \in jet} E_{T,i}$$

$$y = \sum_{i \in jet} y_i E_{T,i} / E_T$$

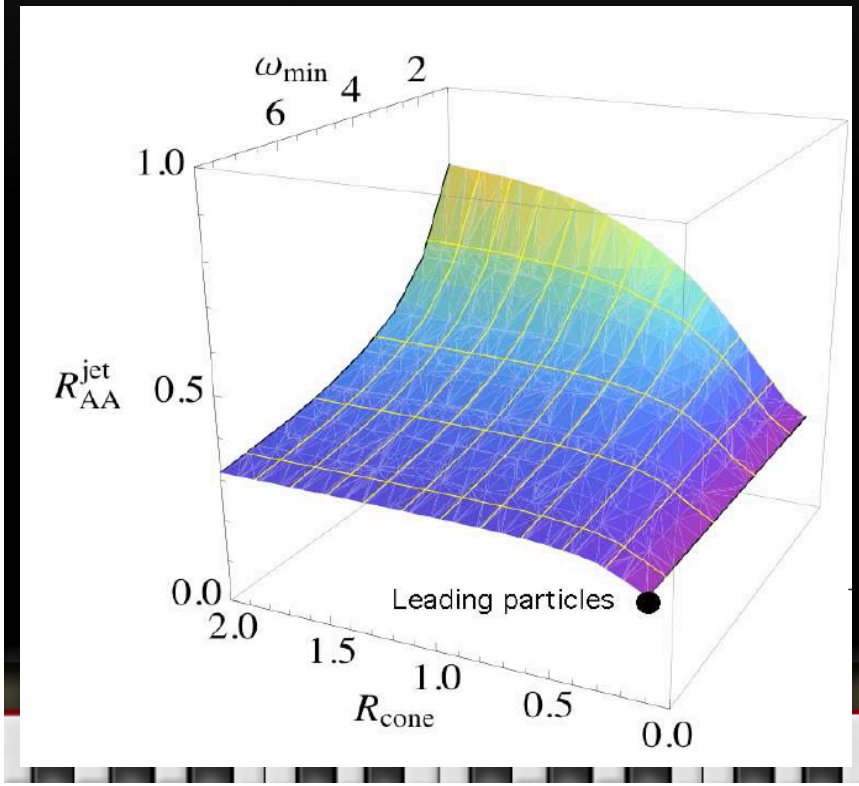
$$\phi = \sum_{i \in jet} \phi_i E_{T,i} / E_T$$

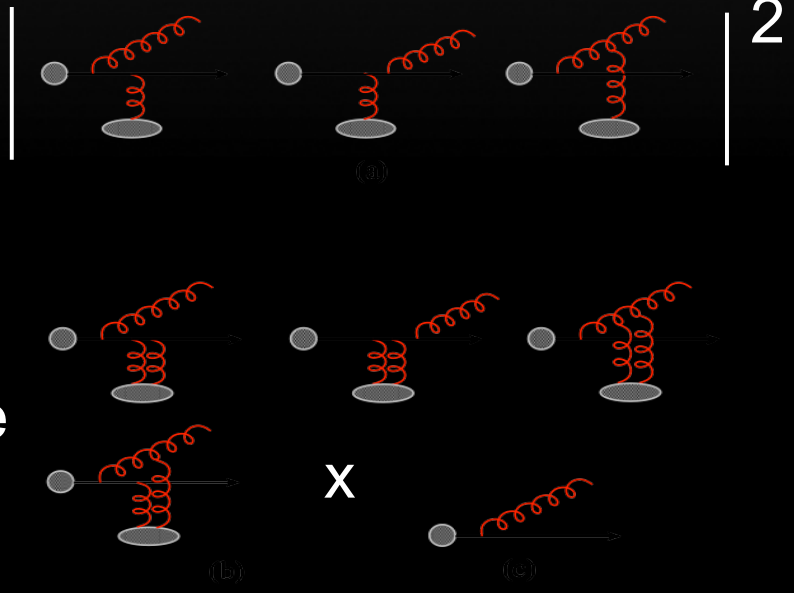
$$R_{ij} = \sqrt{(y_i - y_j)^2 + (\phi_i - \phi_j)^2}$$

Jets in medium



Gyulassy-Levai-Vitev





Jets in HIC

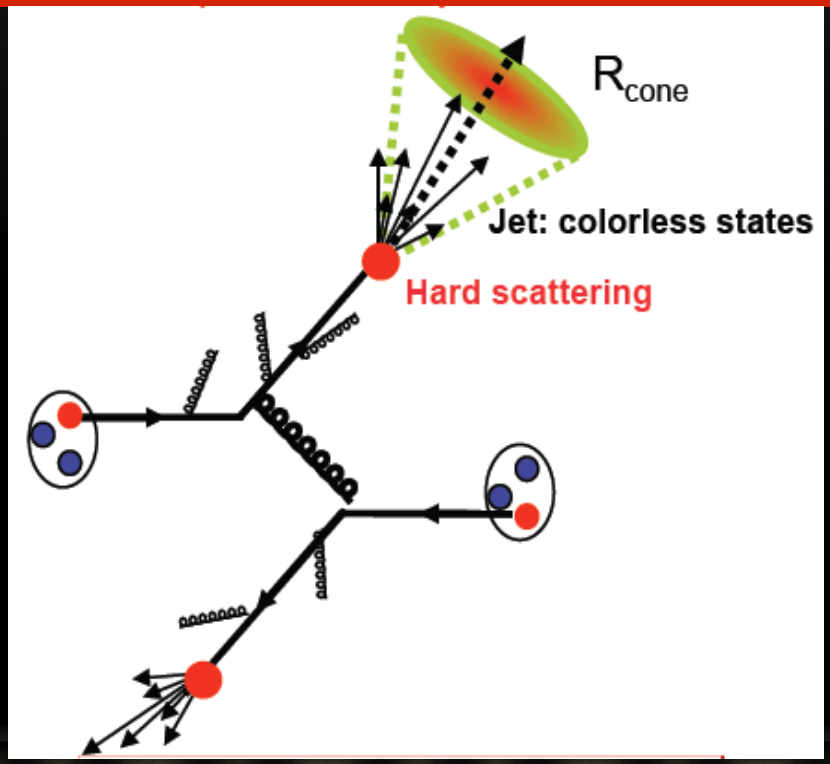
1) inclusive jet spectrum

2) dijet asymmetry

3) jet shapes

4) tagged jets production

Inclusive jet cross section in HIC at NLO



Jet cross section at NLO in p+p

- Jet cross sections at NLO in p+p :

$$\frac{d\sigma^{\text{jet}}}{dE_T dy} = \frac{1}{2!}\int d\{E_T, y, \phi\}_2 \frac{d\sigma[2 \to 2]}{d\{E_T, y, \phi\}_2} S_2(\{E_T, y, \phi\}_2) + \frac{1}{3!}\int d\{E_T, y, \phi\}_3 \frac{d\sigma[2 \to 3]}{d\{E_T, y, \phi\}_3} S_3(\{E_T, y, \phi\}_3)$$

- Function S_2 and S_3 contain jet find algorithm:

2 --→ 2

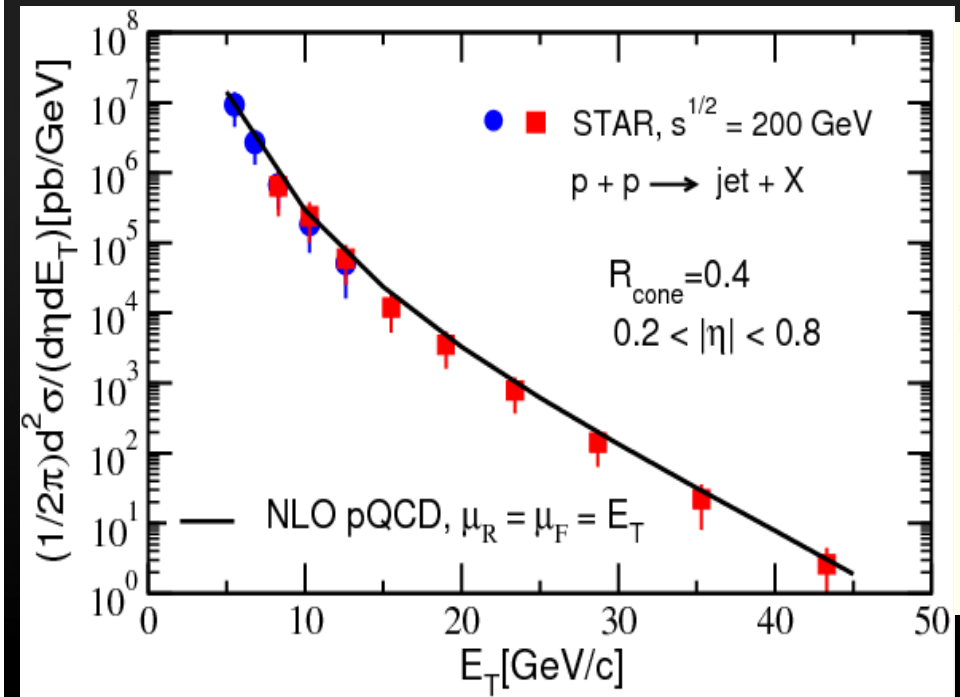
$$S_2 = \sum_{i=1}^{2} S(i) = \sum_{i=1}^{2} \delta(E_{T_i} - E_T)\delta(y_i - y)$$

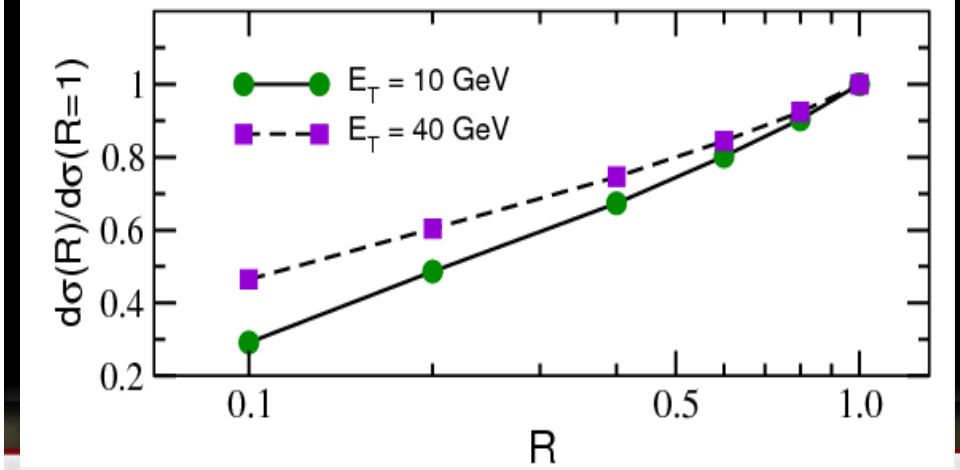
2 --→ 3

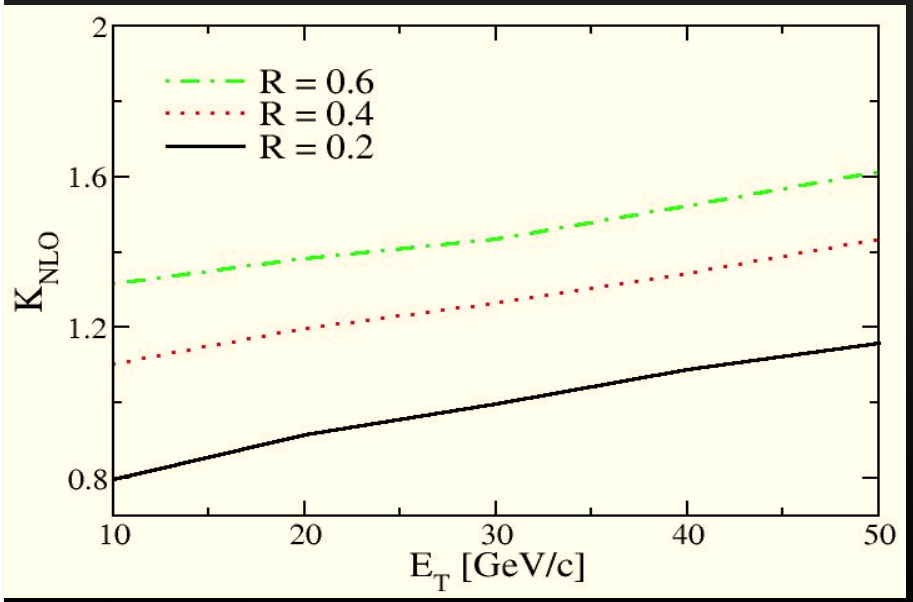
$$S_3 = \sum_i \delta(p_i - p_J)\delta(y_i - y_J) \prod_{j(j\neq i)} \theta\left(R_{ij} > \frac{p_i + p_j}{\max(p_i, p_j)} R\right) + \sum_{i,j(i<j)} \delta(p_i + p_j - p_J)\delta\left(\frac{p_i y_i + p_j y_j}{p_i + p_j} - y_J\right)\theta\left(R_{ij} < R_{\text{rc}}\right)$$

Ellis, Kunszt, Soper, PRL 64:2121(1990); PRL 69:1496(1992)

Jets in p+p at RHIC



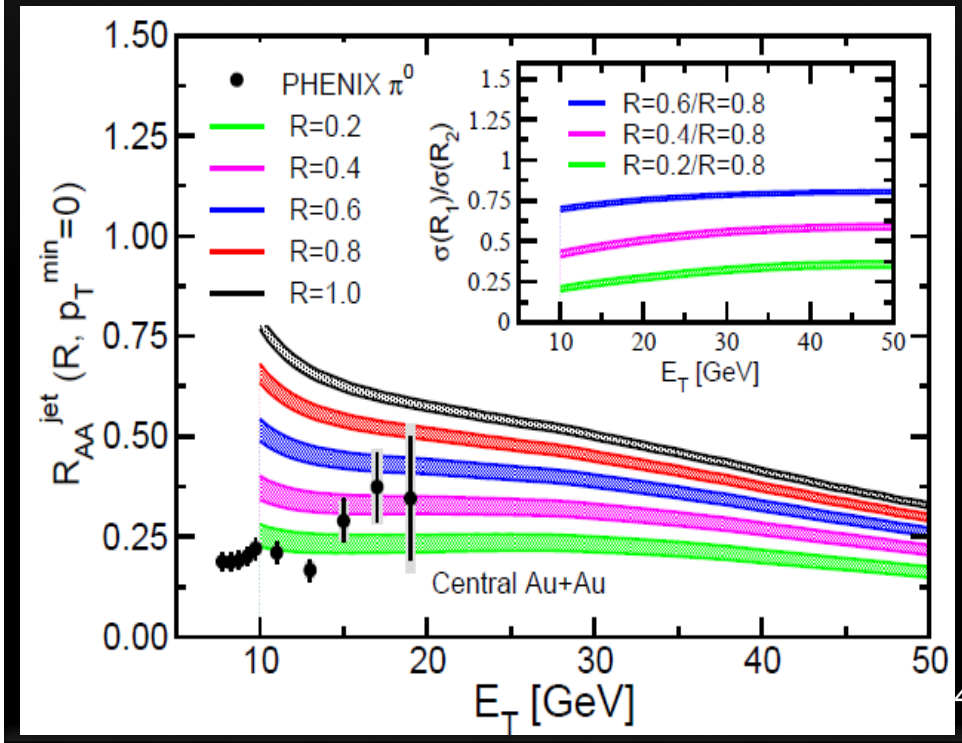


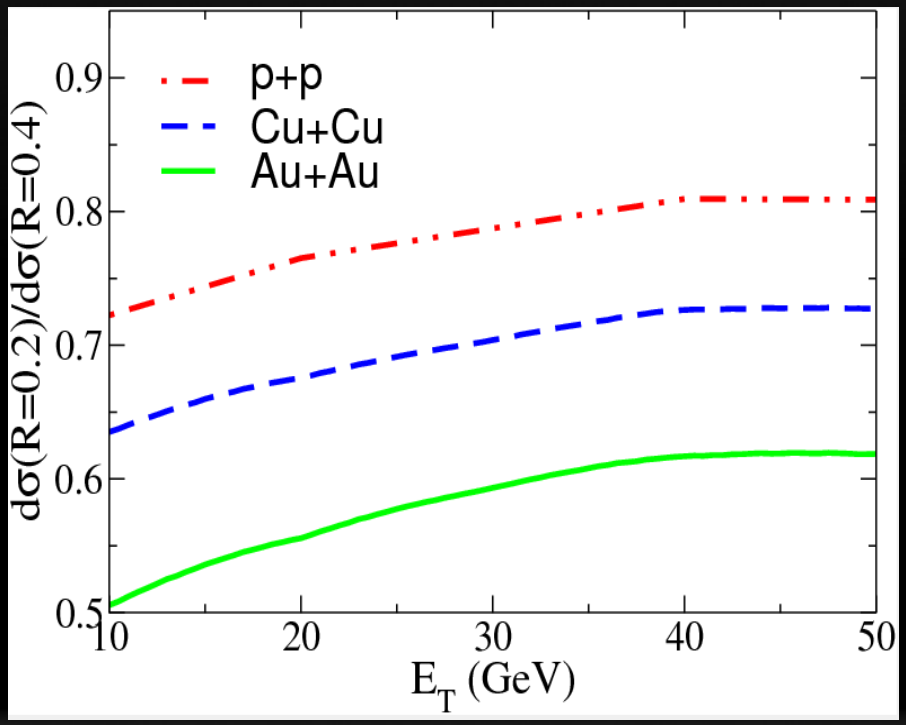


- Very good agreement between data and theory is achieved;
- K_{NLO}=NLO/LO can be smaller than 1 at small cone radius.

Inclusive jets in A+A at RHIC

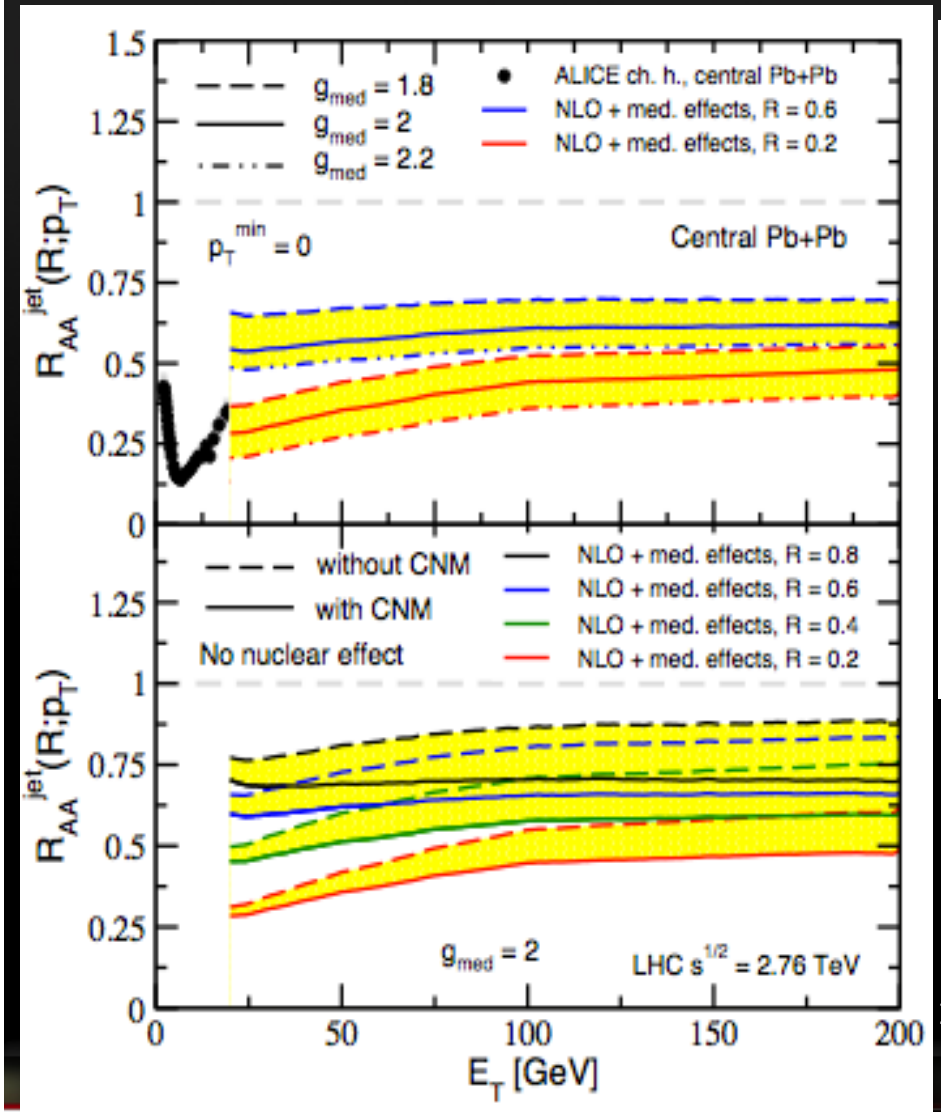
- R_{AA} for inclusive jets evolves continuously with cone size R,
- Ratios of jet cross sections at different R in p+p, Cu+Cu and Au+Au have a similar trend but with different magnitudes.

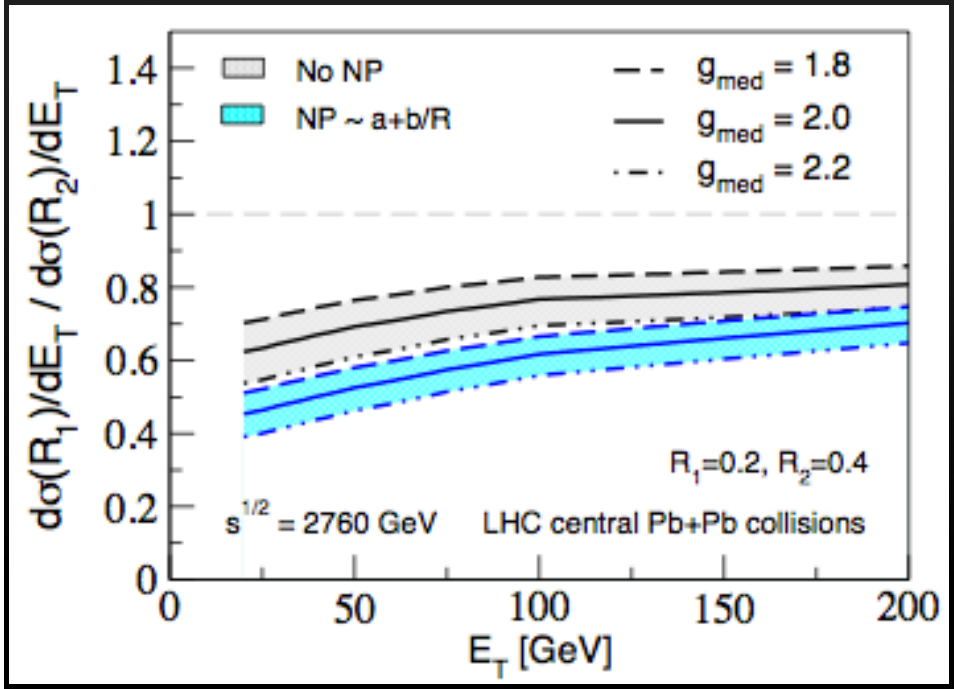




I Vitev, BWZ, PRL 104,132001 (2010).

Inclusive jets in Pb+Pb at LHC



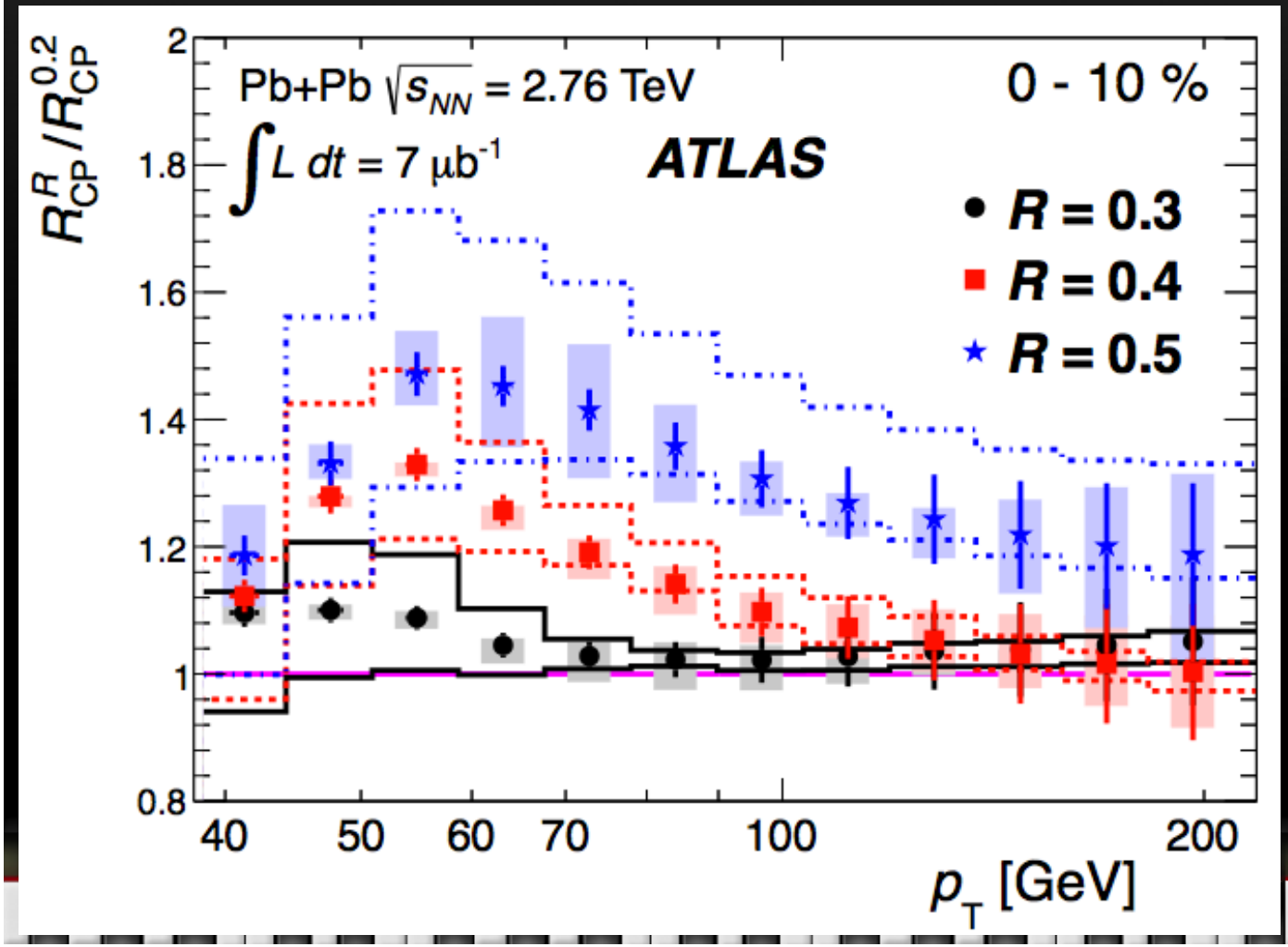


Y He, Vitev, BWZ, PLB (2012)

arXiv: 1105.2566

Inclusive jet in Pb+Pb: Exp.

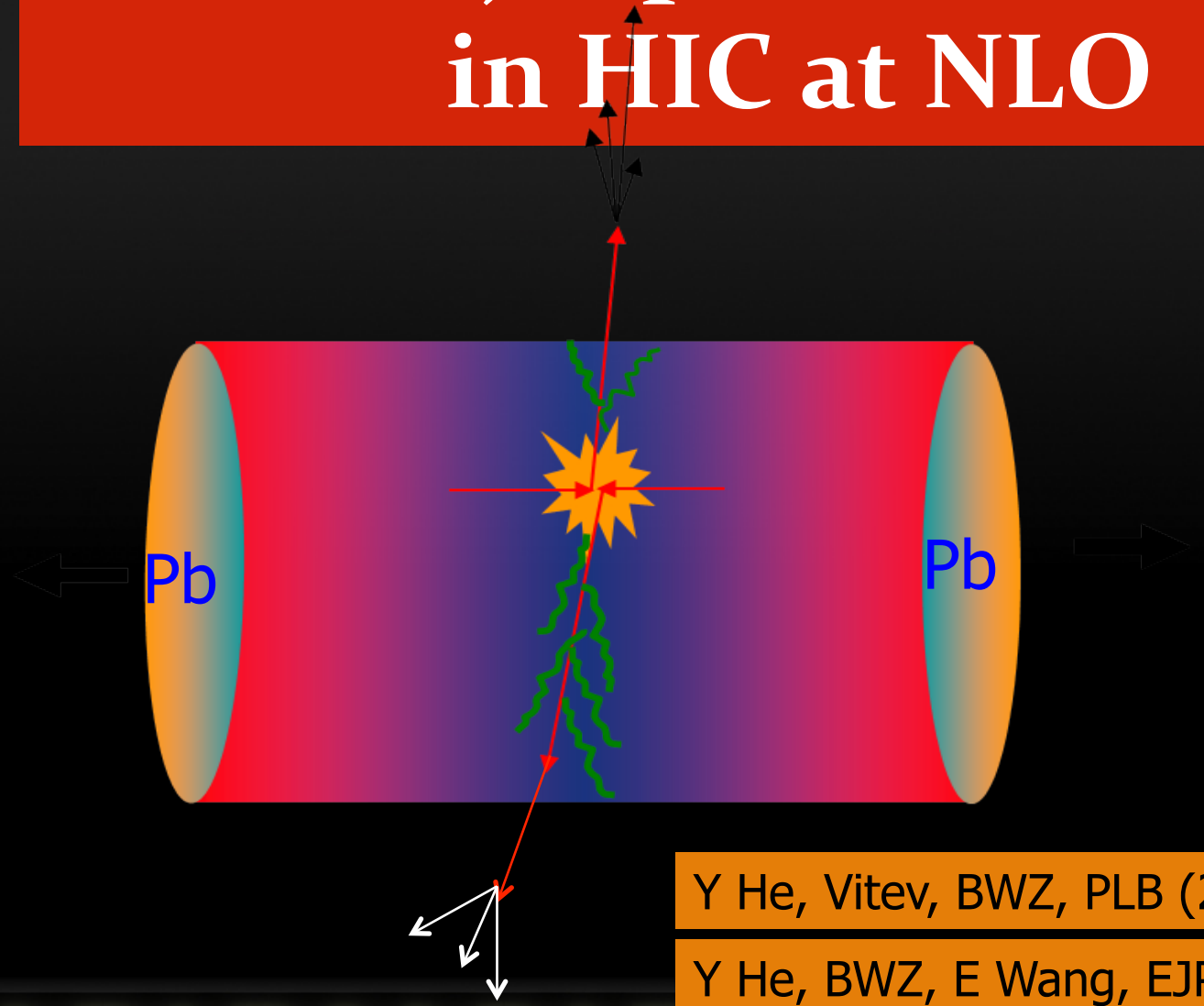
- The jet radius dependence of Raa on inclusive jets has been confirmed by ATLAS measurements most recently.



ATLAS,

arXiv: 1208.1967

Dijet production in HIC at NLO



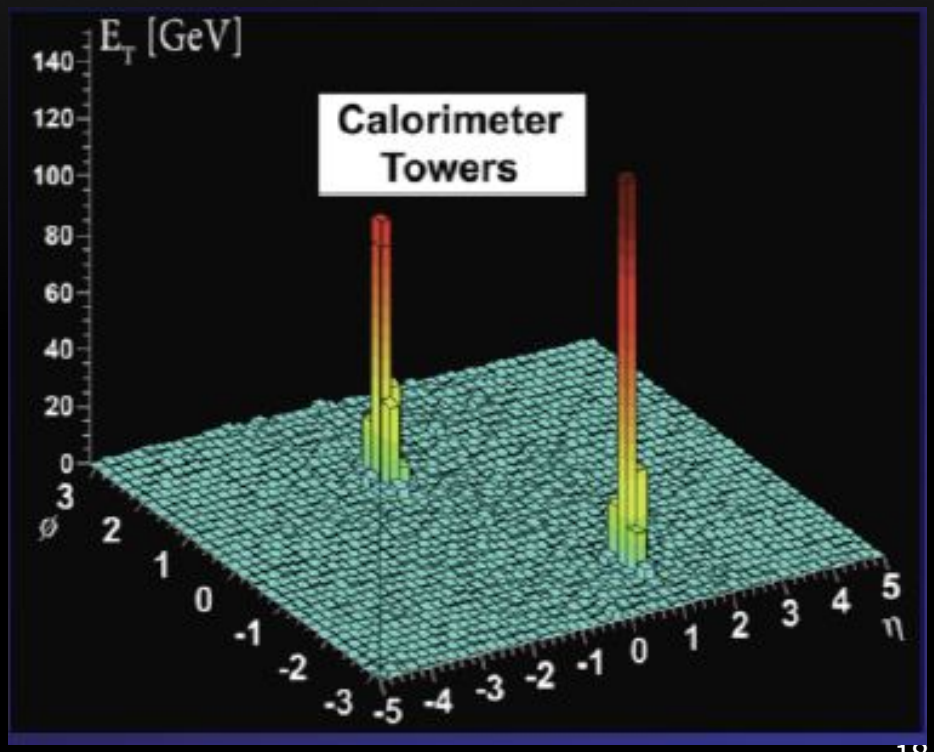
Y He, Vitev, BWZ, PLB (2012)

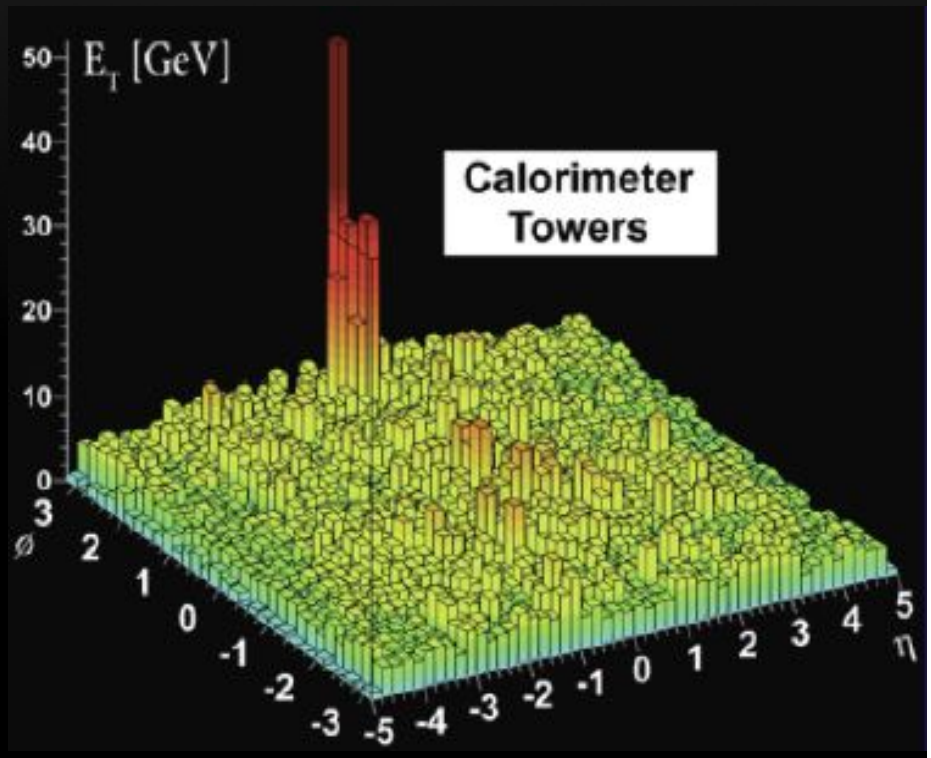
Y He, BWZ, E Wang, EJPC (2012)

Y He, Neufeld, Vitev, BWZ, in preparation

Measuring Dijets in Pb+Pb

- Jet quenching at LHC has been observed for the first time in dijet productions at Pb+Pb by ATLAS and CMS。



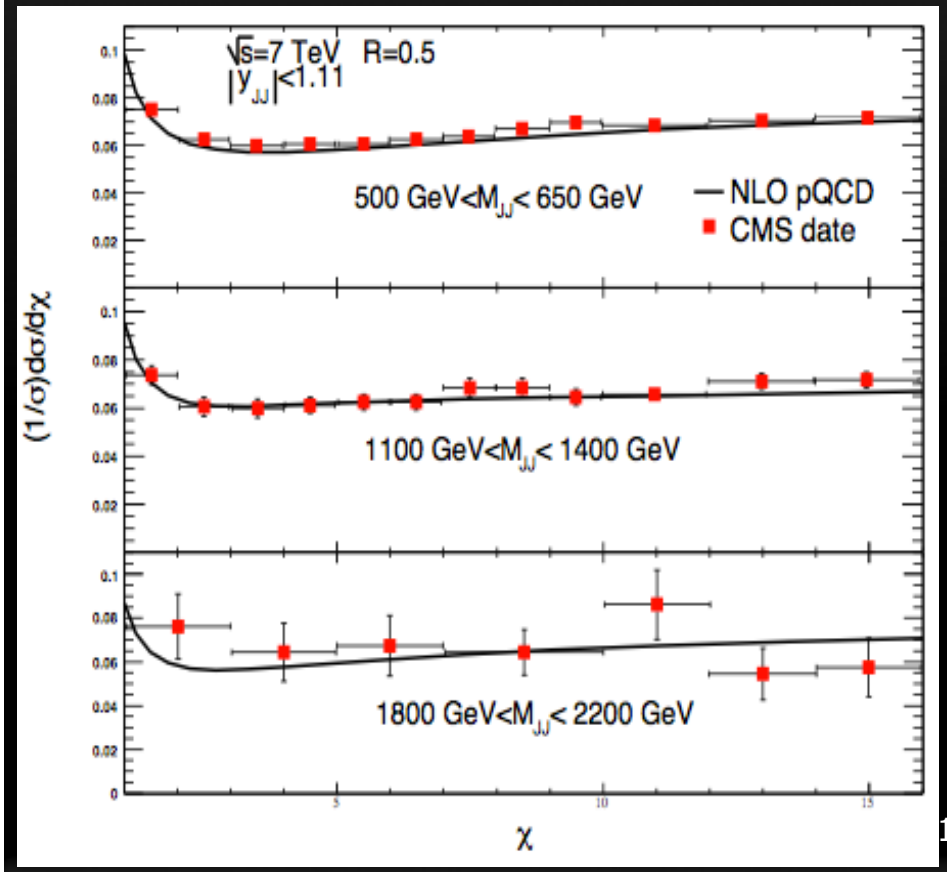


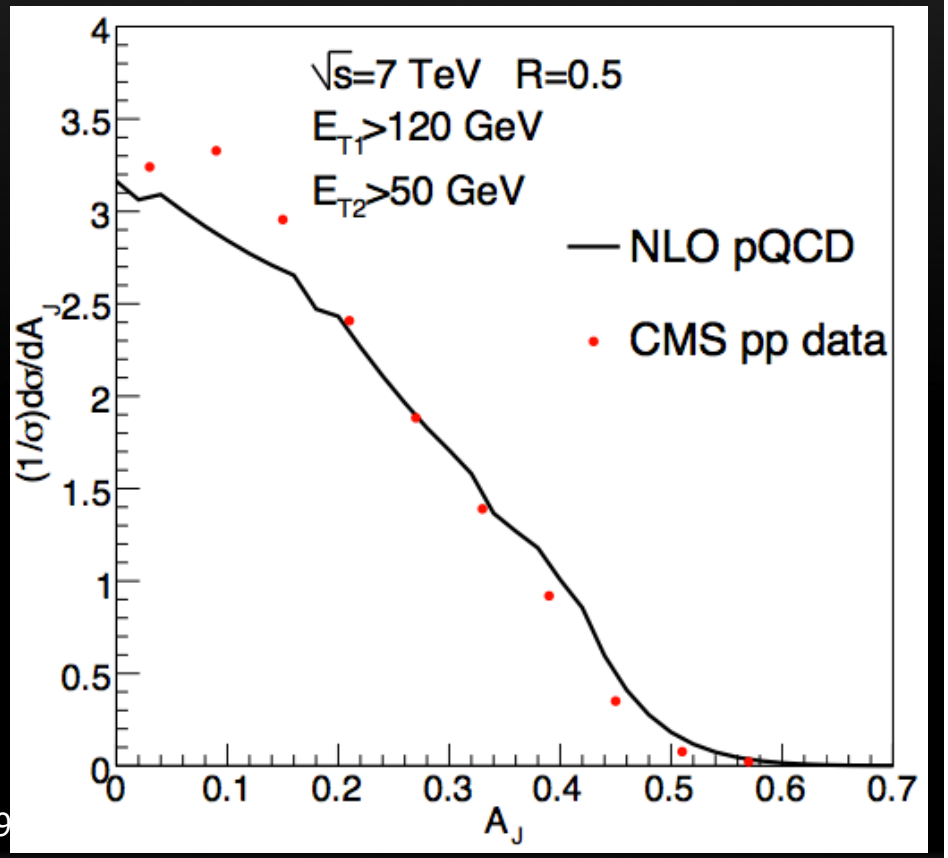
ATLAS, arXiv:1011.6182, PRL (2011); CMS, arXiv: 1102.1957, PRC(2012)

Dijet in p+p at NLO

$$\chi = \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

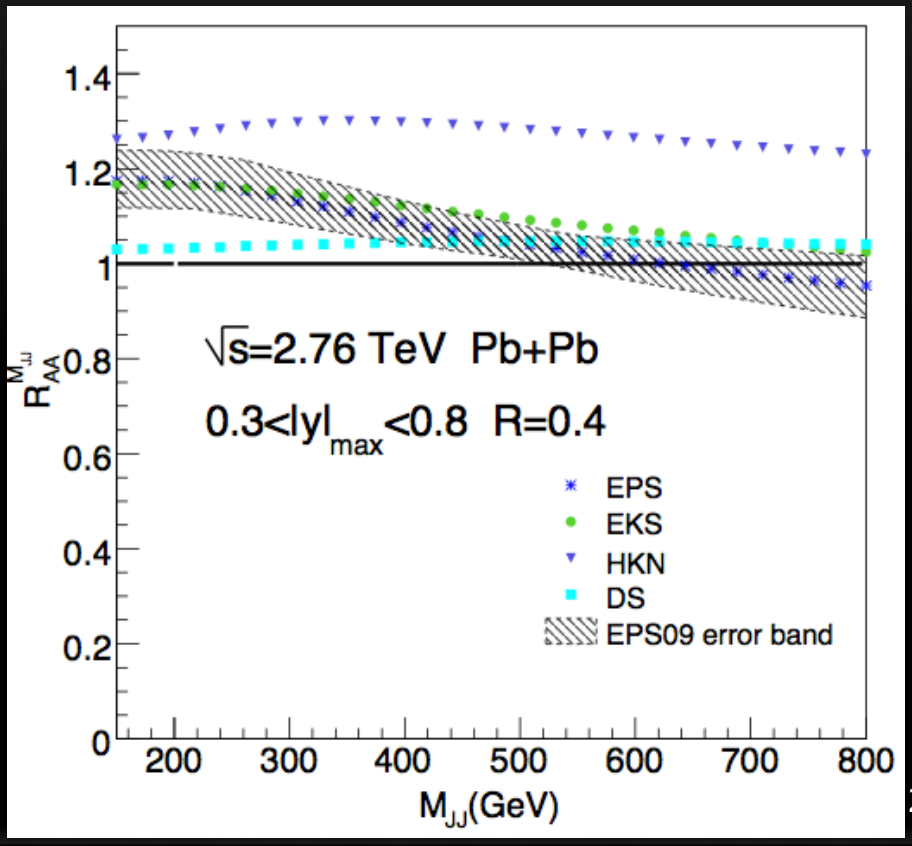


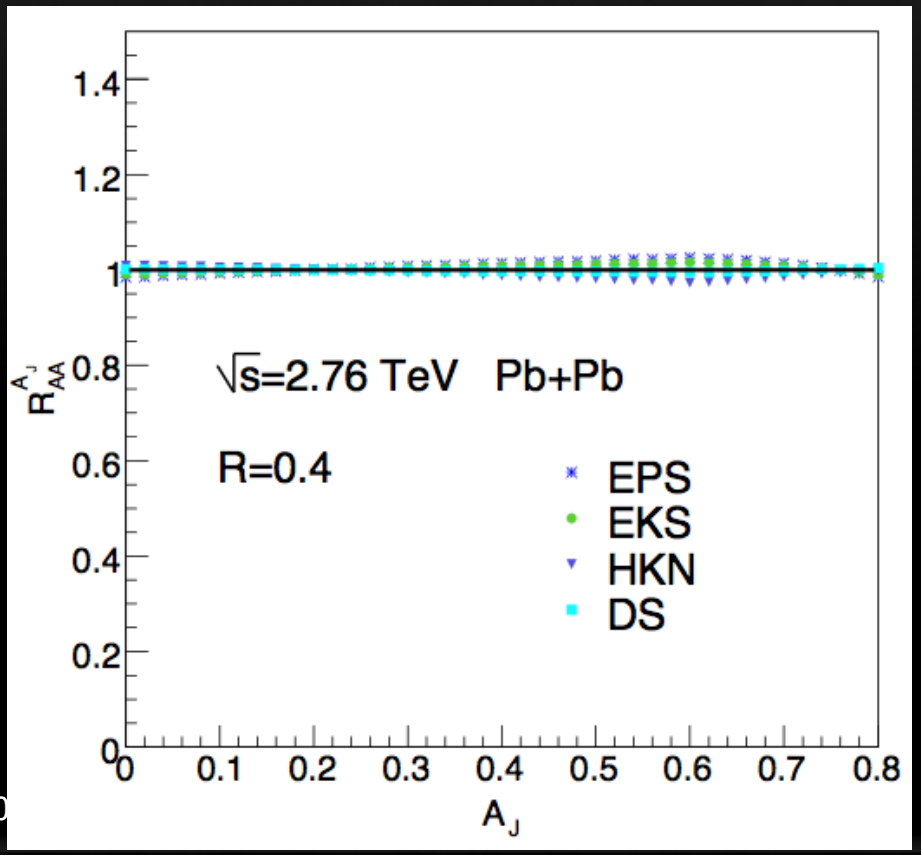


Dijet in HIC: CNM

$$M_{jj}^2 = 2p_T^2[1 + cosh(y_1 - y_2)]$$

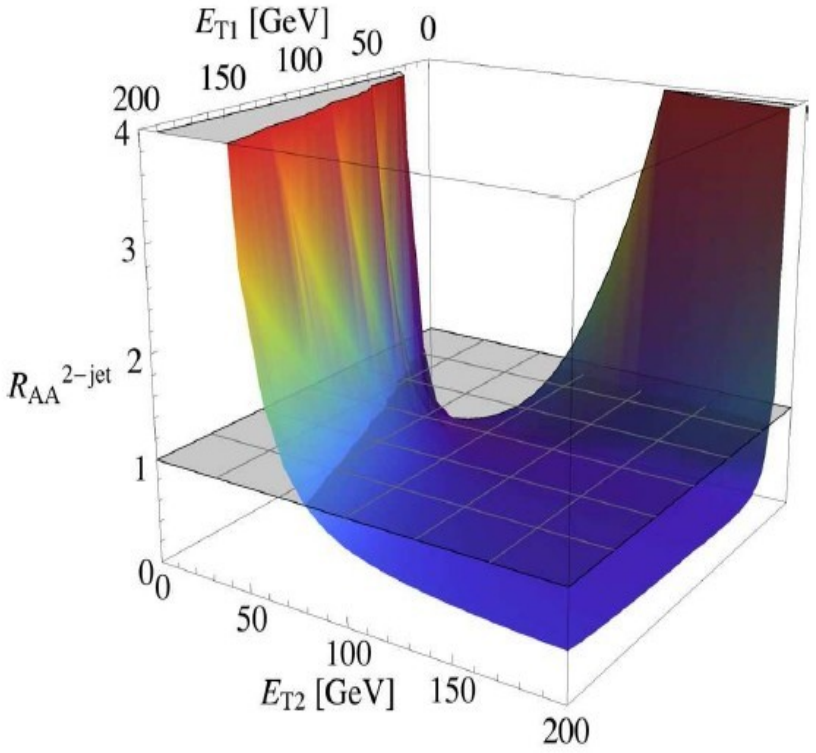
$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

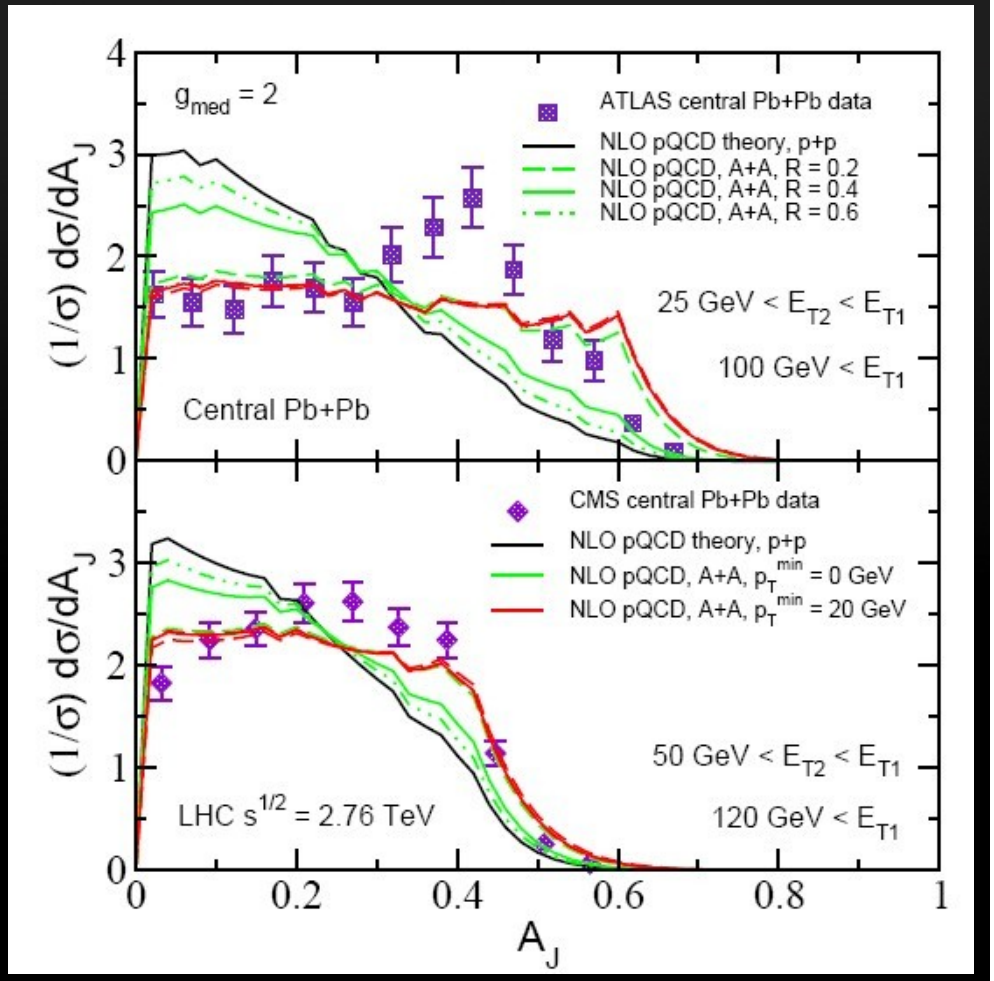




Y He, BWZ, E Wang, EPJC (2012)

Dijet in Pb+Pb at LHC



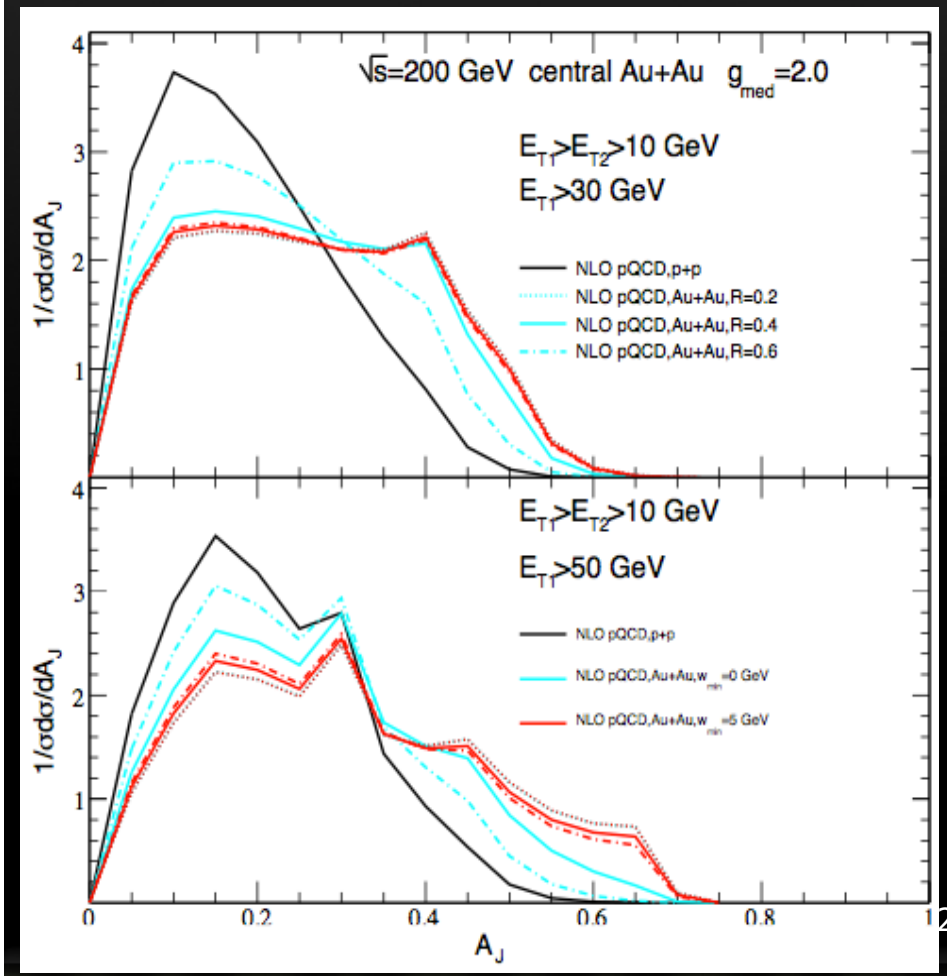


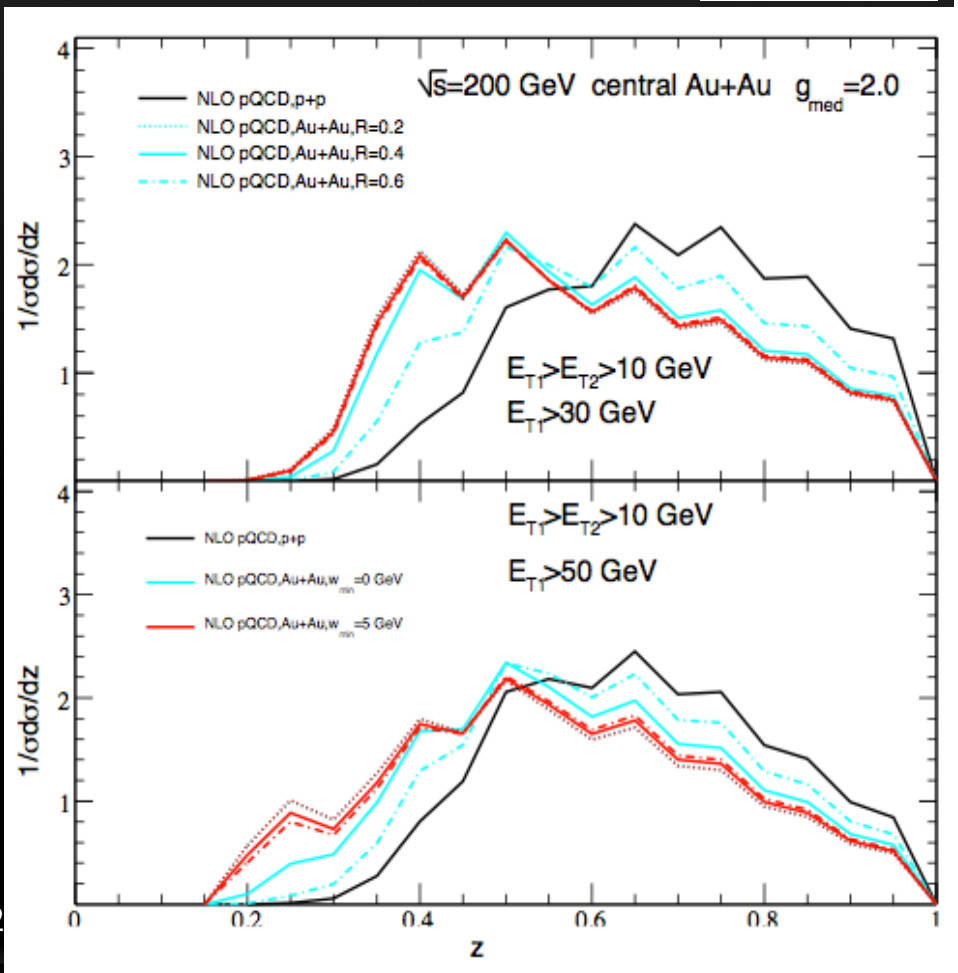
Y He, Vitev, BWZ, PLB (2012)

Dijet in Au+Au at RHIC

Y He, Neufeld, Vitev, BWZ, in preparation

$$z = \frac{E_{T2}}{E_{T1}}$$





He, Neufeld, Vitev, Wang, BWZ, arXiv: 1207.6558

Recap

leading hadrons

Recap

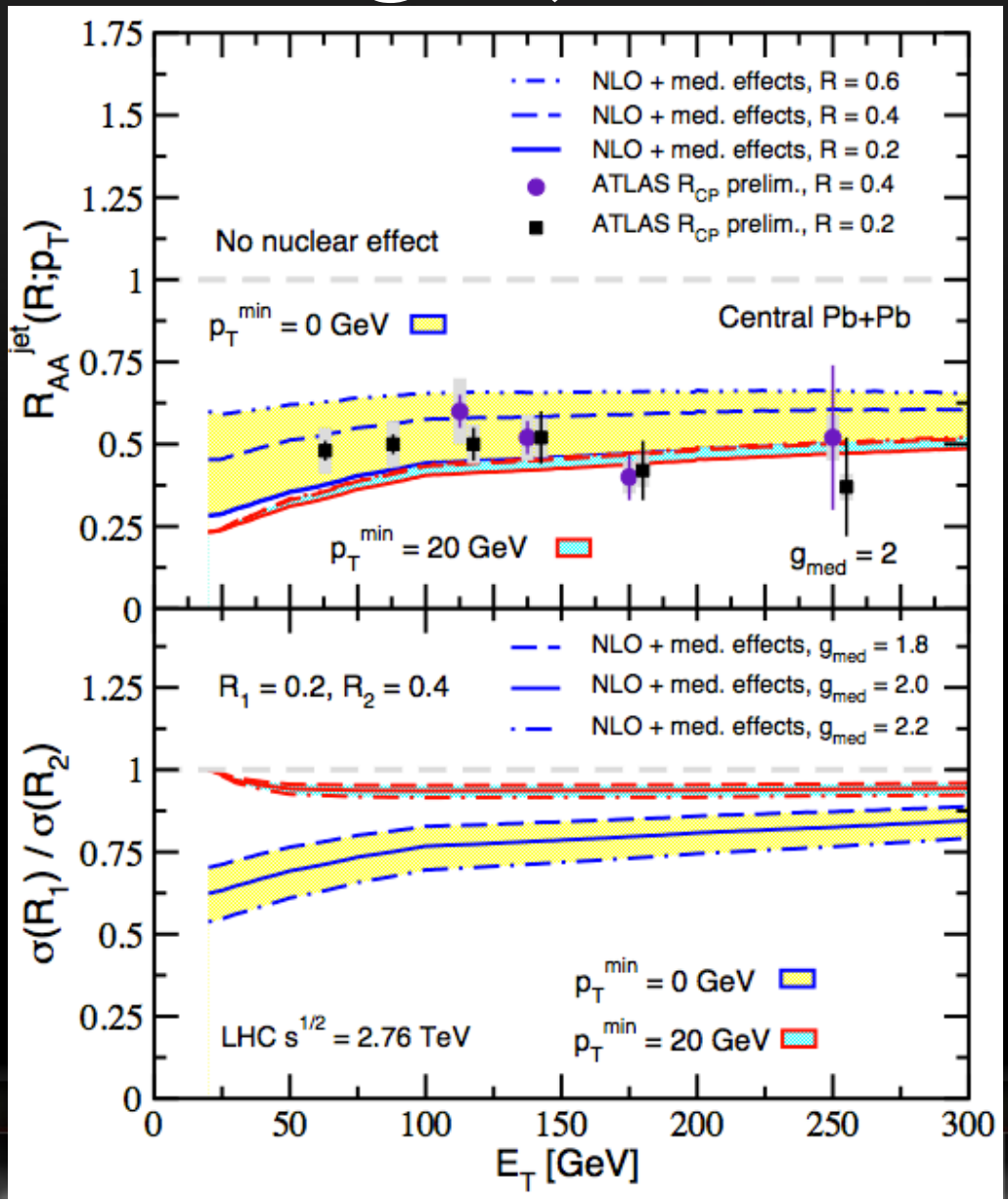
leading hadrons

jets

非常感谢！

Thank you!

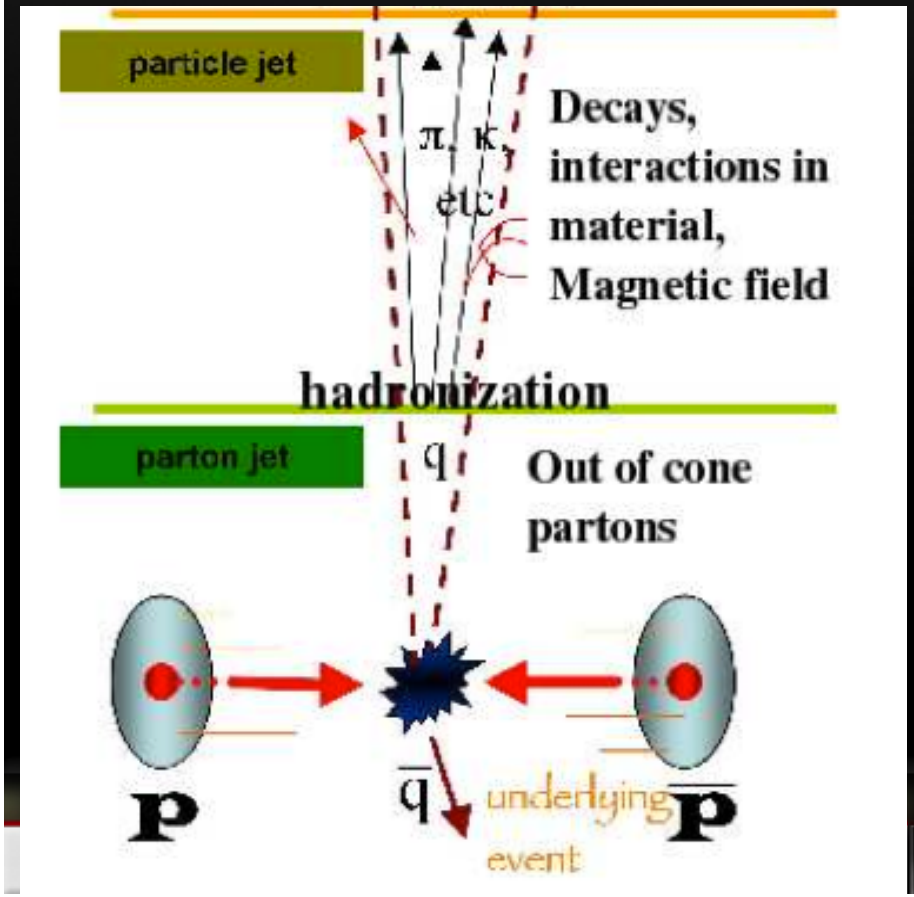
Single jets in Pb+Pb at LHC

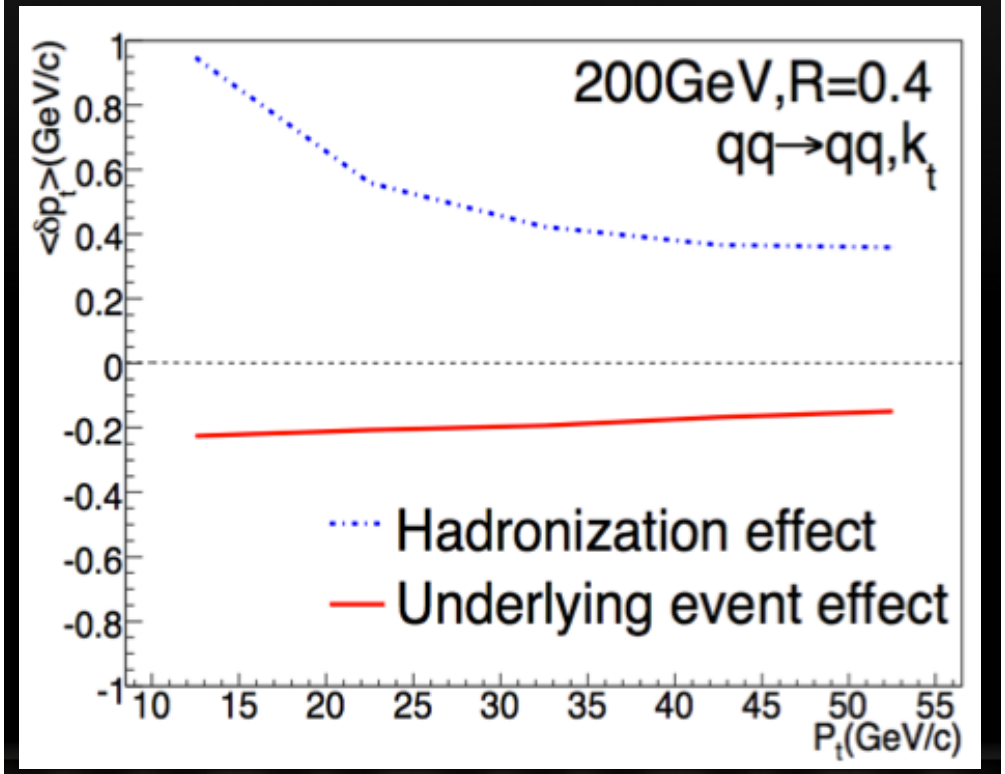


Y He, Vitev, BWZ, PLB (2012)

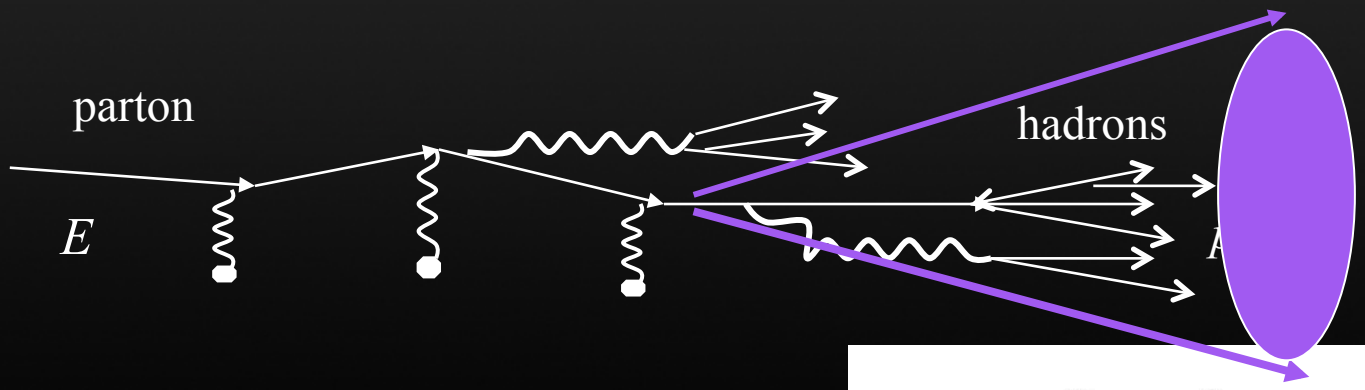
Non-perturbative effects

- Non-perturbative effects: hadronization & underlying event.
- Two effects will go in opposite direction: partial cancellation between “splash-out” effect and “splash-in” effect.

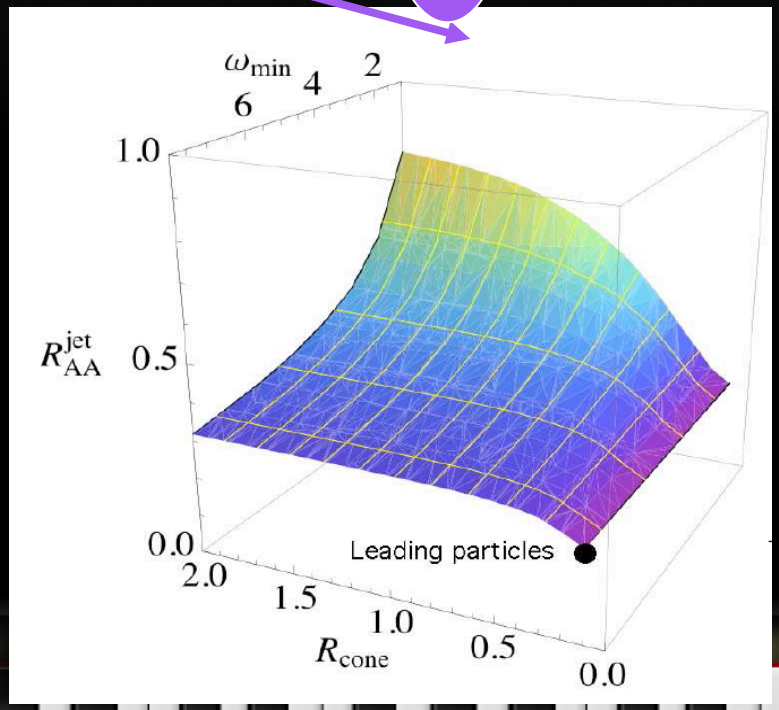




How a "jet" quenches in HIC?



- Radiated gluon can fall inside the jet area.
- Two leverage variables: jet size R & minimum momentum cut pT_{min} .



Jet finding algorithms

- Cone algorithm
- Midpoint cone algorithm
- k_T algorithm

$$k_{T,i}^2 = p_{T,i}^2 \qquad k_{T,(i,j)}^2 = \min(p_{T,i}^2, p_{T,j}^2)\frac{R_{i,j}^2}{D^2}$$

$$\text{if } k_{T,(i,j)}^2 < k_{T,i}^2, \text{ merge}$$

- Anti-k_T algorithm
- Seedless algorithm

Parton merge parameter

NLO

$$R_{\mathrm{rc}} = \min\left(R_{sep}R, \frac{E_{T_i} + E_{T_j}}{\max(E_{T_i}, E_{T_j})}R\right)$$

- Midpoint cone $R_{sep} = 2$
- Cone $1 < R_{sep} < 2$
- K_T $D = R,\ R_{sep} = 1$