Jet modification within a Linear Boltzmann Transport model

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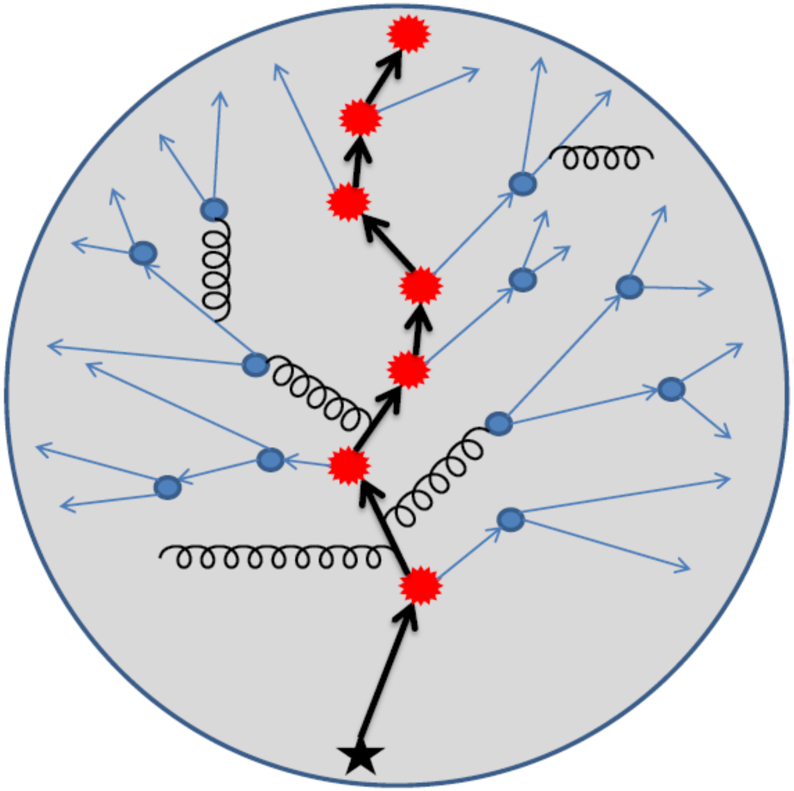
Outline

- A Linear Boltzmann Transport (LBT) model
- Jet modification in heavy ion collisions
- Summary and Outlook

A Linear Boltzmann Transport (LBT) Model

$$p_1 \cdot \partial f_1(x_1, p_1) = E_1\left(C_{elastic} + C_{inelastic}\right)$$



Jet induced medium excitation

("Negative" parton for the back reaction)

Linear Boltzmann jet Transport

- Elastic collision + Induced gluon radiation.
- Follow the propagation of recoiled parton.
- Include recoiled parton in jet reconstruction.

Linear Approximation

It works when the jet induced medium excitation $\delta f \ll f$.

A Linear Boltzmann Transport (LBT) Model

$$p_1 \bullet \partial f_1(x_1, p_1) = E_1 (C_{elastic} + C_{inelastic})$$

- **Scattering rate:** Jussi Auvinen, Kari J. Eskola, Thorsten Renk Phys.Rev. C82 024906

$$\Gamma_{ij\to kl} = \frac{1}{2E_1}\int \frac{d^3p_2}{(2\pi)^3 2E_2}\int \frac{d^3p_3}{(2\pi)^3 2E_3}\int \frac{d^3p_4}{(2\pi)^3 2E_4} \times f_j(p_2\cdot u, T)$$
$$\times |M|^2_{ij\to kl}(s,t,u)\times S_2(s,t,u)\times(2\pi)^4\delta^4(P_1+P_2-P_3-P_4)$$

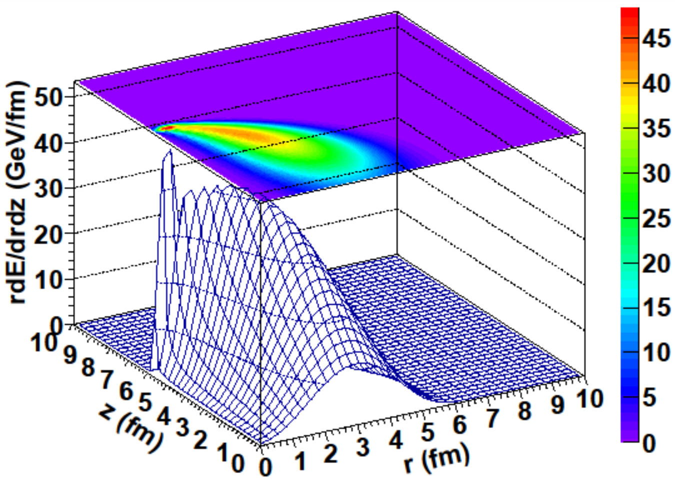
- **Radiated gluon distribution:** Guo and Wang (2000), Majumder (2012); Zhang, Wang and Wang (2004)

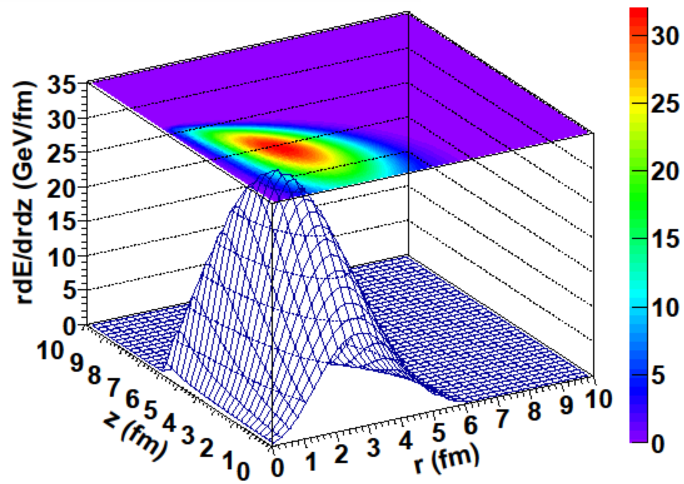
$$\frac{dN_g}{dx dk_\perp^2 dt} = \frac{2C_A\alpha_s P(x) k_\perp^4}{\pi(k_\perp^2 + x^2M^2)^4}\hat{q}\sin^2\frac{t-t_i}{2\tau_f} \qquad \tau_f = 2Ex(1-x)/(k_\perp^2 + x^2M^2)$$

- **Multiple gluon emissions:** $P(N_g, \langle N_g\rangle) = \dfrac{\langle N_g\rangle^{N_g} e^{-\langle N_g\rangle}}{N_g!}$

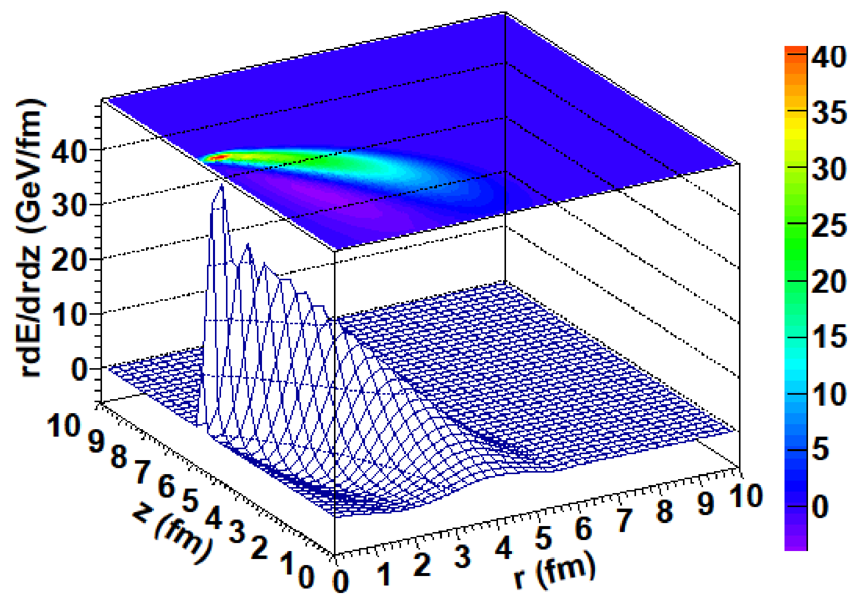
Jet induced medium excitation

- Mach Cone like wave and the diffusion wake.





Positive
(recoiled parton
& radiated gluon)



Negative
(back reaction)

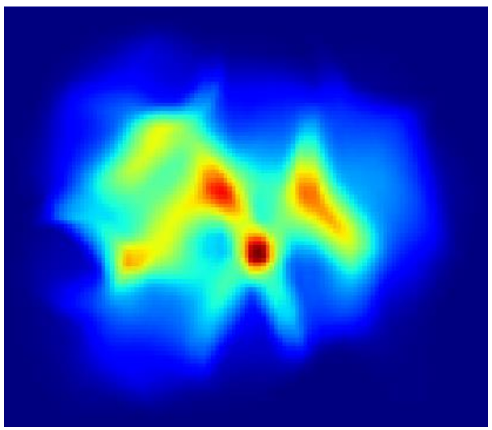
Initial jet parton: gluon
E = 100 GeV
T = 0.4 GeV $\alpha_s = 0.3$

Jets in a 3+1D hydro

Initial jet shower partons from a p+p collision (Pythia or Hijing)

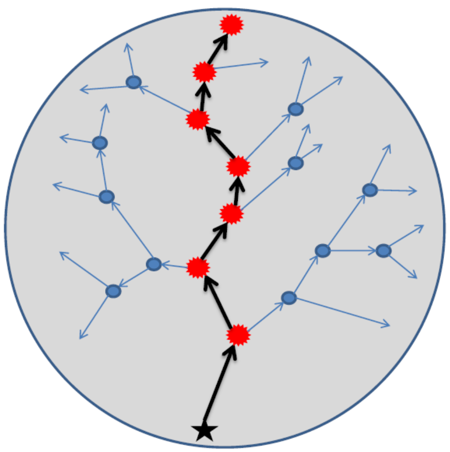
- Location of jets are decided according probability of binary collision.

- 3+1D Ideal hydro



$\varepsilon \ T \ \boldsymbol{u}$

LBT Model



L-G. Pang, Q. Wang, X-N. Wang
Phys.Rev. C86 (2012) 024911

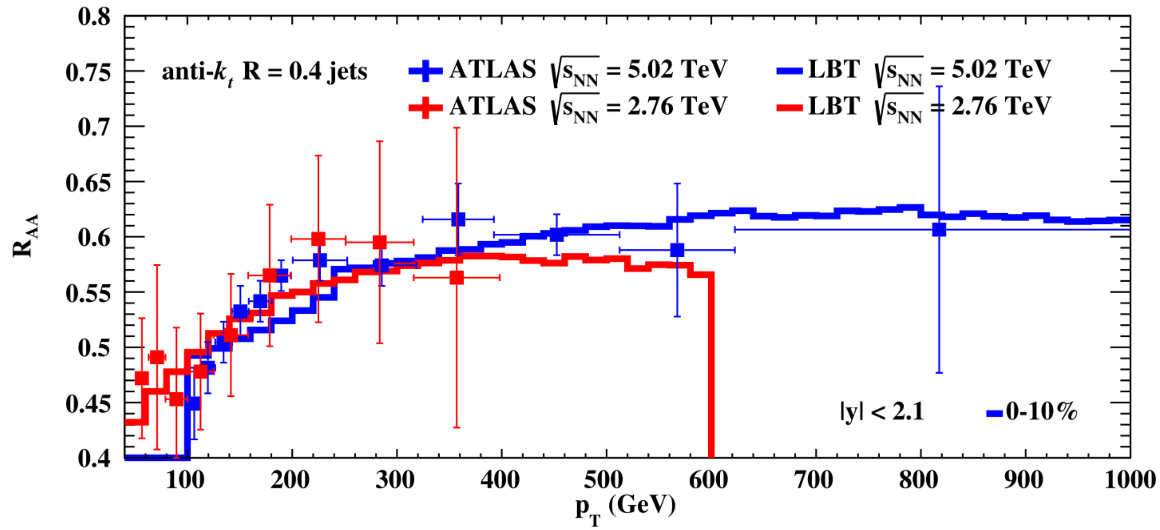
M. Cacciari, G. P. Salam and
G. Soyez Eur. Phys. J. C 72, 1896 (2012).

Jet reconstruction(Fastjet) on parton level

Jet energy loss

- Single jet R_{AA}

The only parameter effective strong coupling constant α_s is fixed. (fix the strength of jet-medium interaction)



- Fluctuation effect

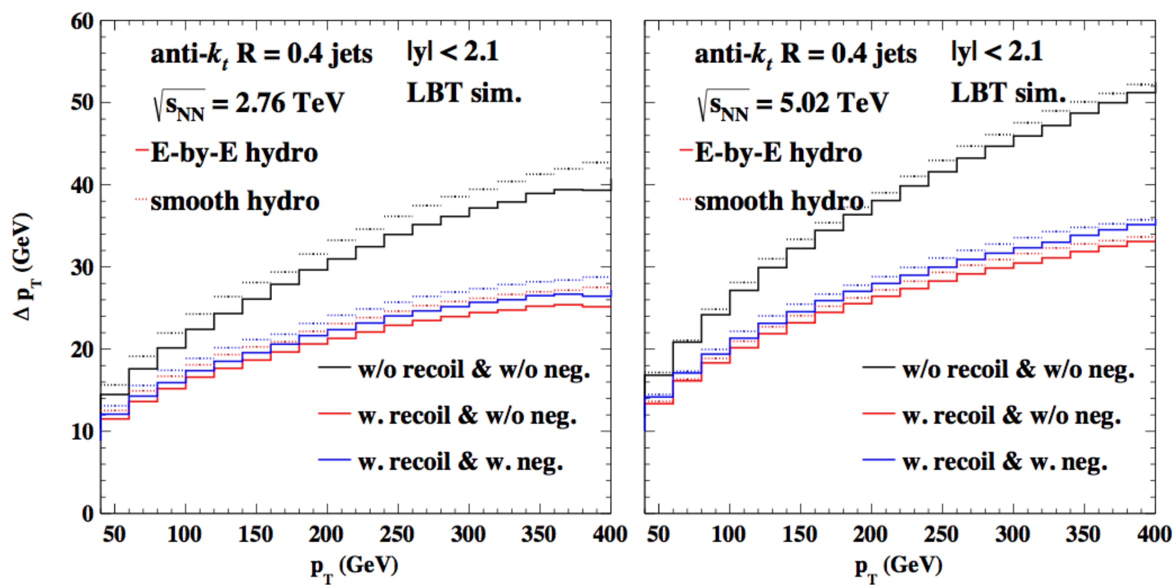
  (solid vs dotted)

- Recoiled effect

  (black vs blue)

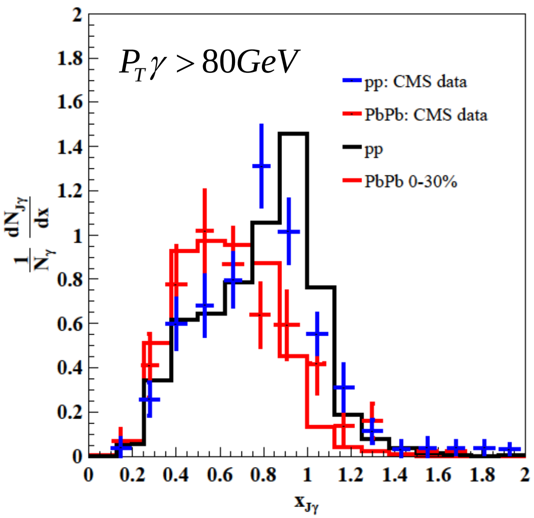
- Back reaction effect

  (red vs blue)

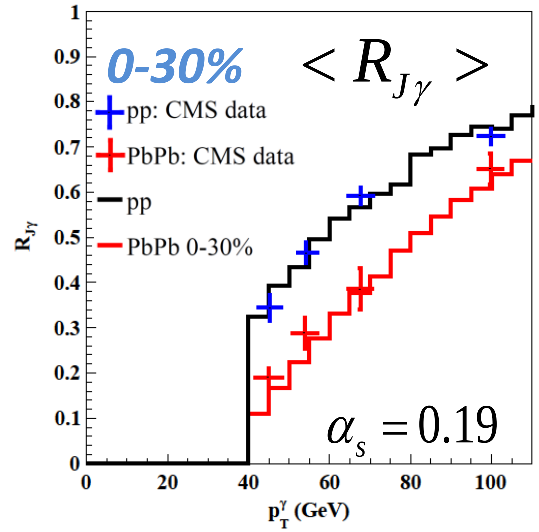


Gamma-Jet & Z-jet

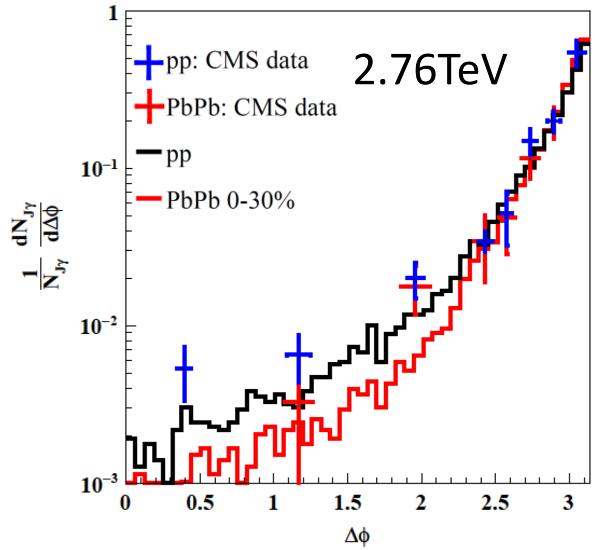
Gamma-jet



gamma-jet asymmetry

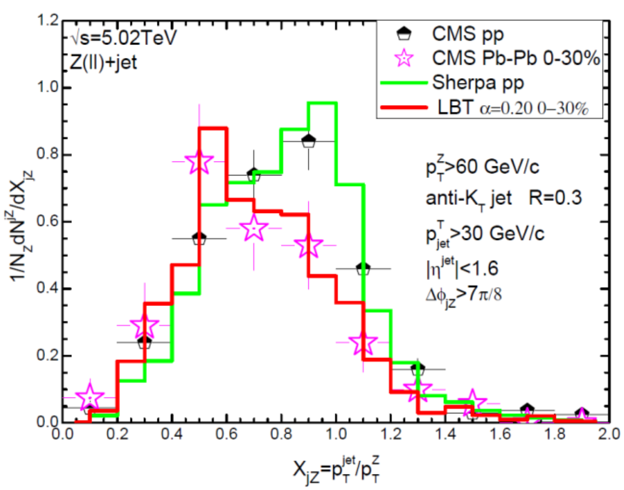


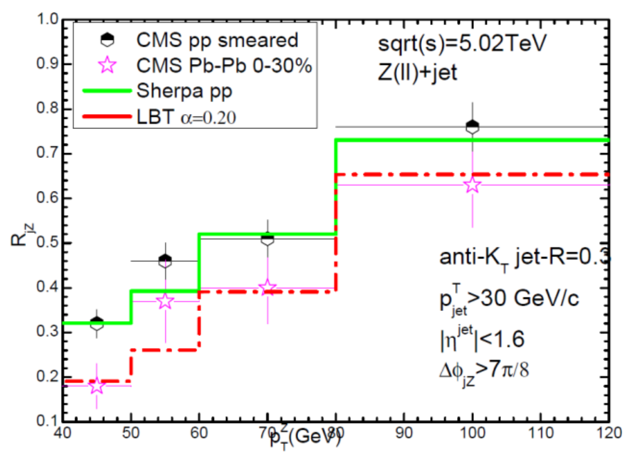
gamma-jet ratio

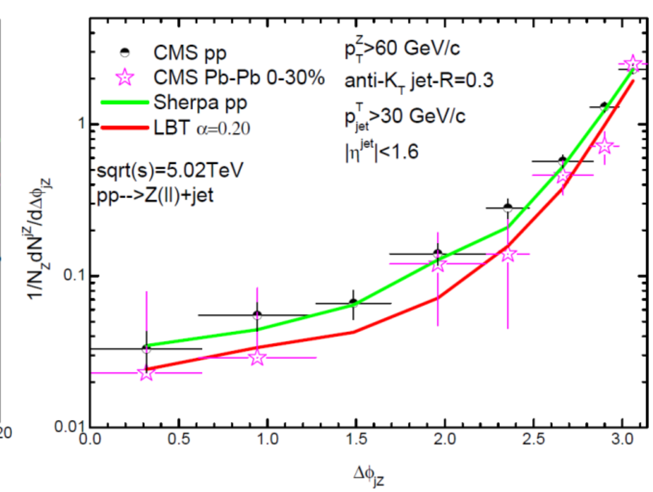


gamma-jet correlation

Z-jet *(improved pp baseline with Sherpa) in collaboration with Shan-Liang Zhang*

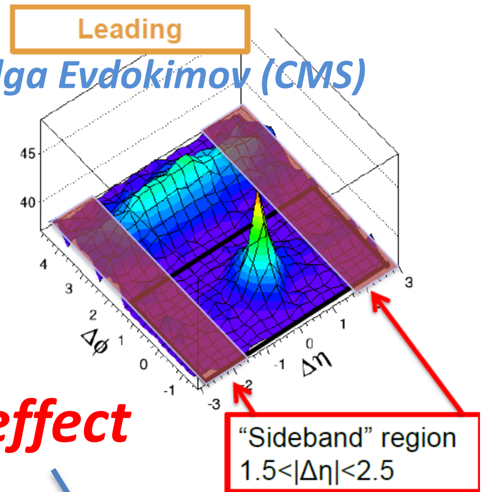


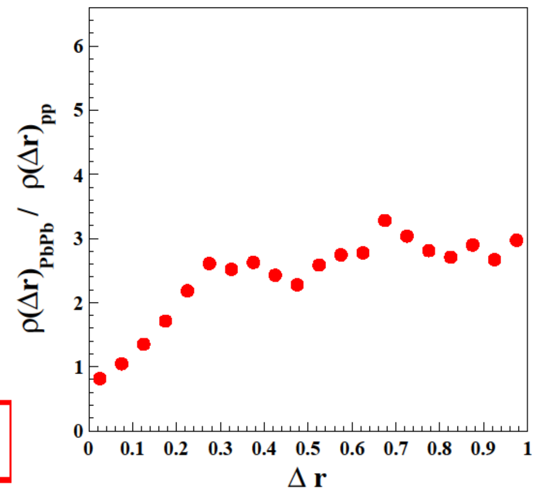




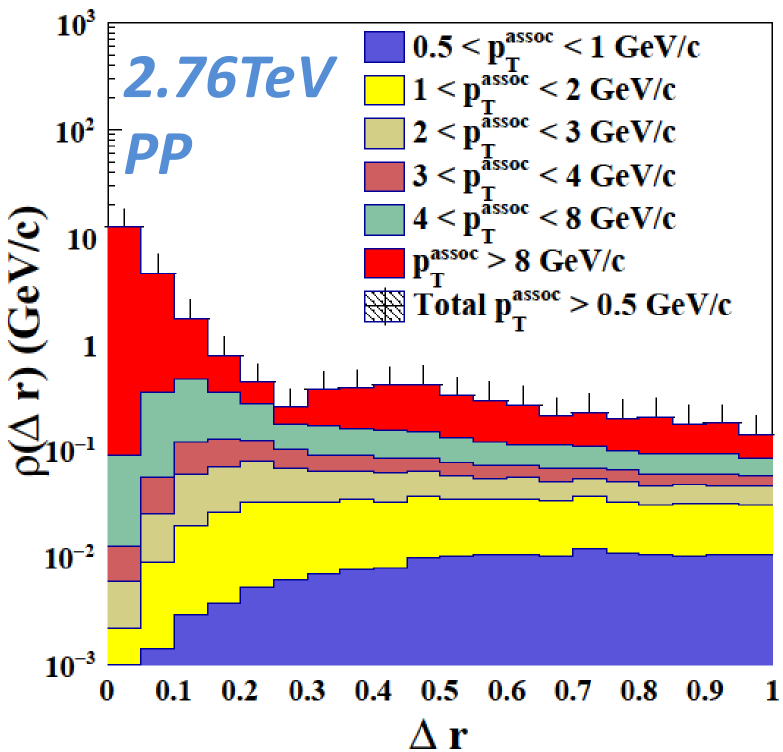
Jet shape of gamma-jets in heavy-ion collisions

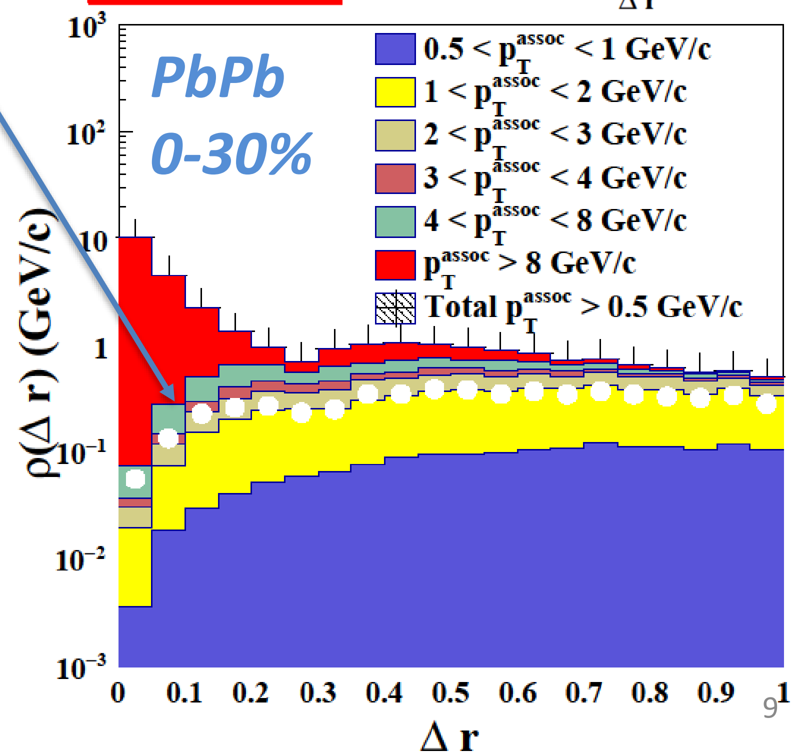
- Energy lost by the hard parton is transport out of the jet cone by the soft parton.





Recoiled effect

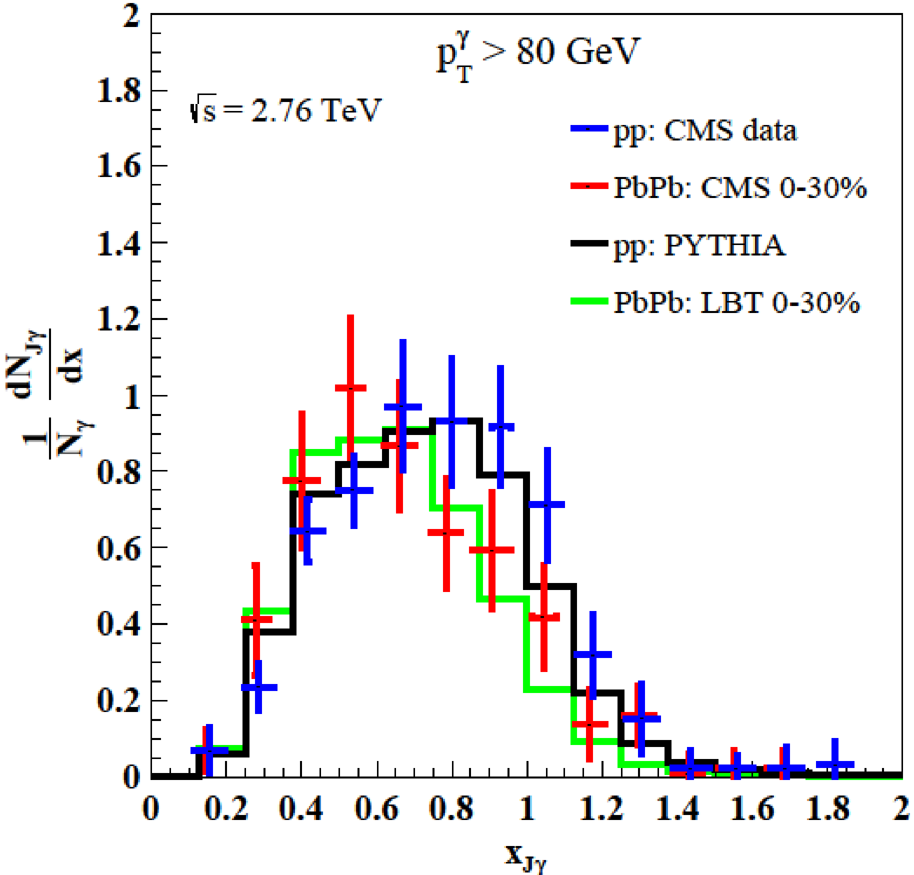




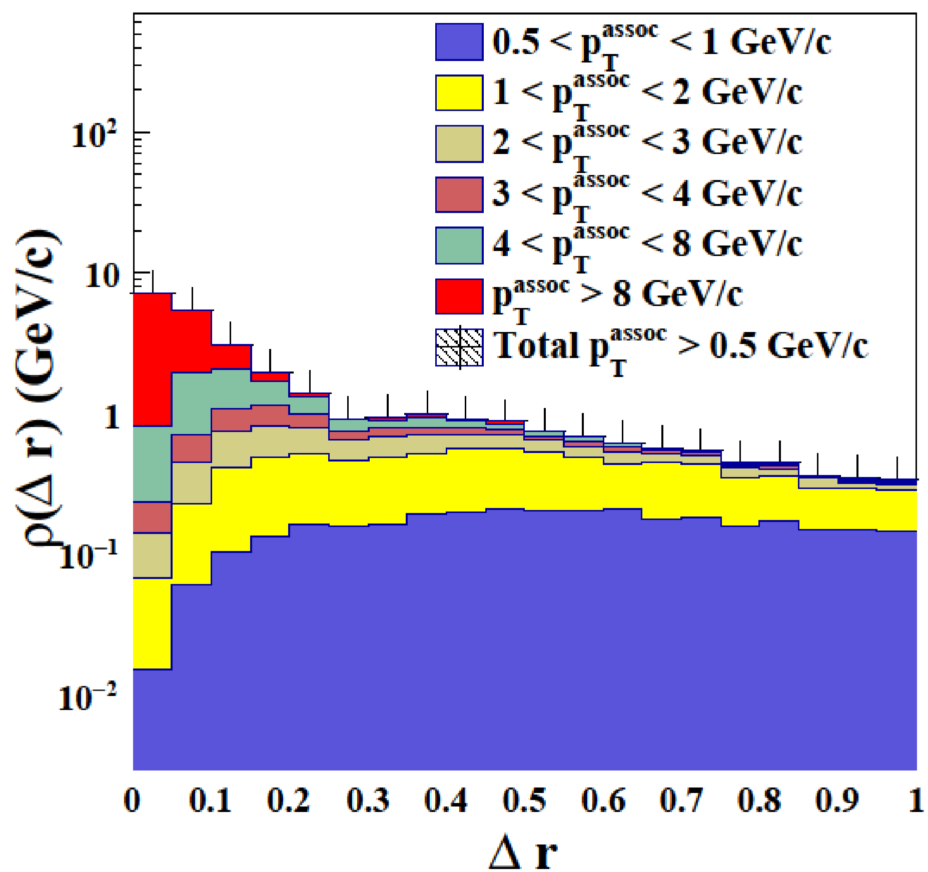
Jet reconstruction with recombination model

Han, Fries and Ko, Phys. Rev. C93 (2016) 045207

Gamma-jet asymmetry



Jet shape



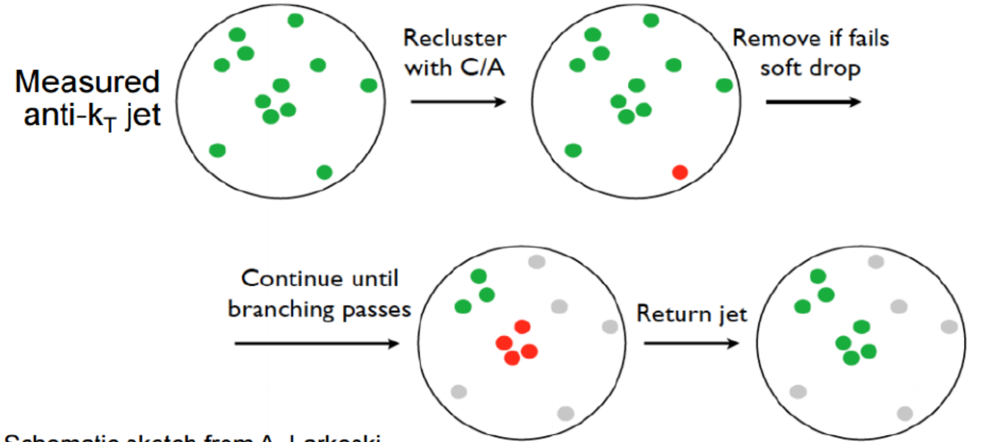
preliminary

Jet substructure

Jet grooming

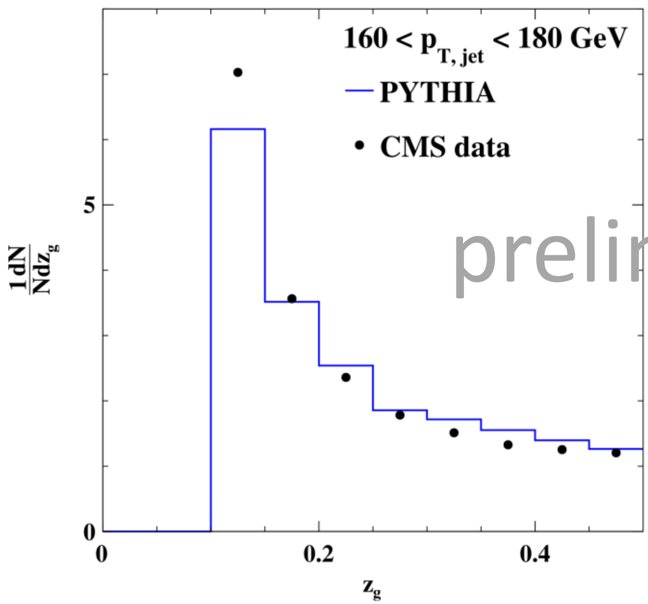
$$z_g \equiv \frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut} \left(\frac{\Delta R}{R_0}\right)^{\beta}$$

$$\frac{M_g}{p_T^{jet}} = \frac{\sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}}{p_T^{jet}}$$



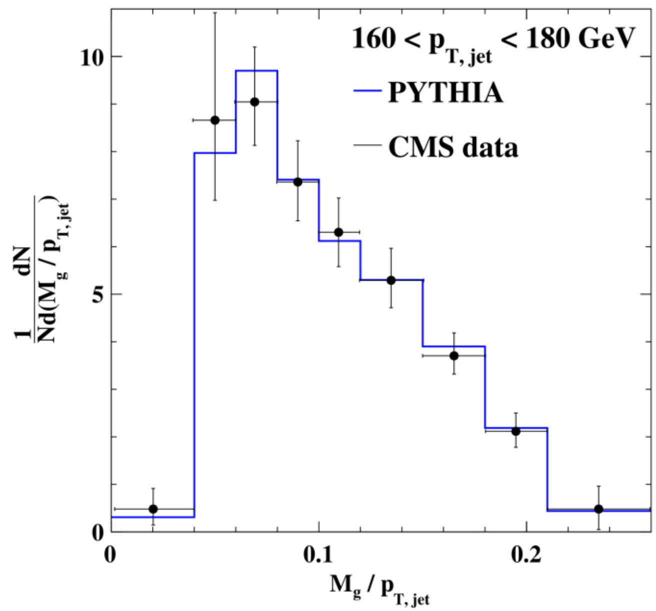
Schematic sketch from A. Larkoski
LPC Workshop JetMET Jan. 2014

Groomed Jet splitting function (pp)



preliminary

Groomed jet mass (pp)

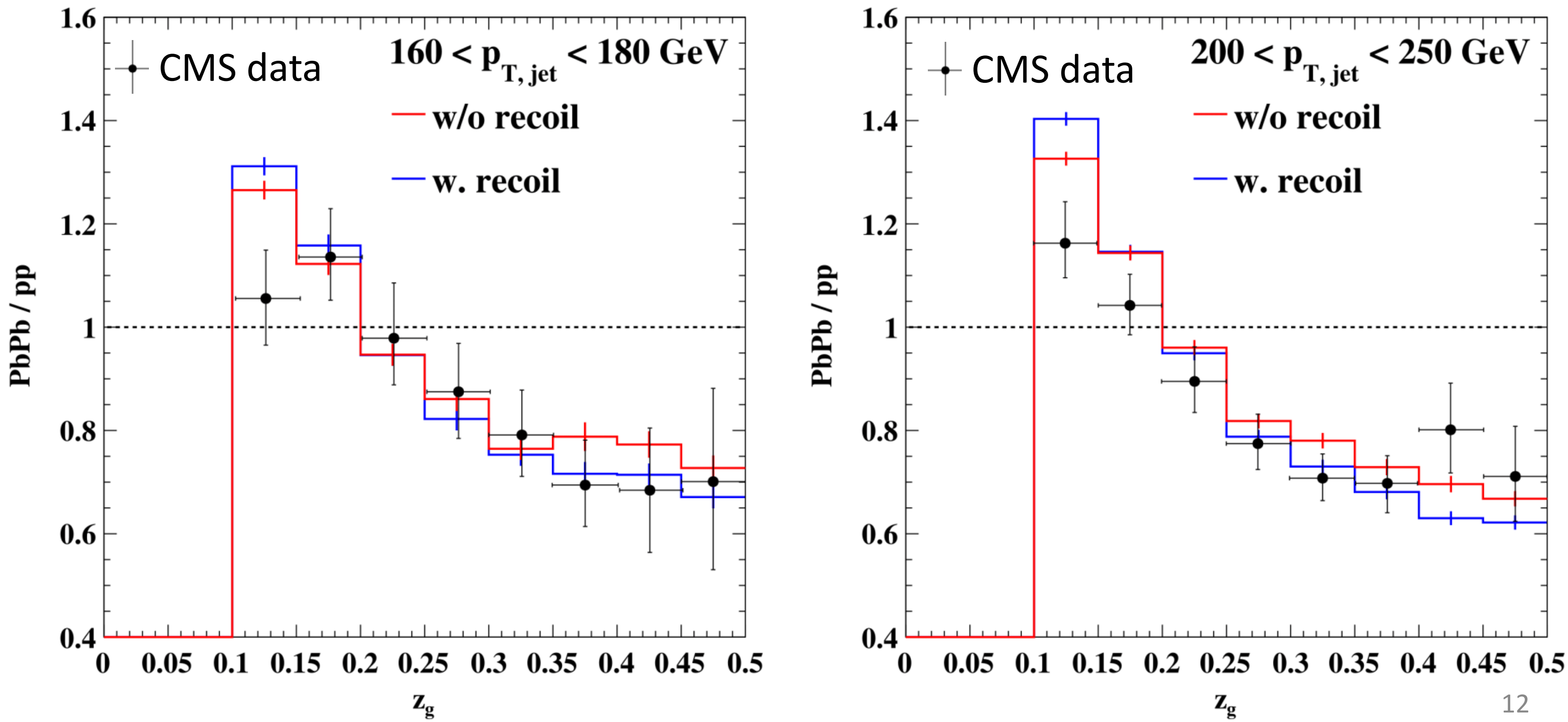


Groomed jet splitting function

- The inclusion of the recoil (medium response) will lead to stronger modification of the groomed jet splitting function.

Very preliminary

$$z_g = \frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}}$$

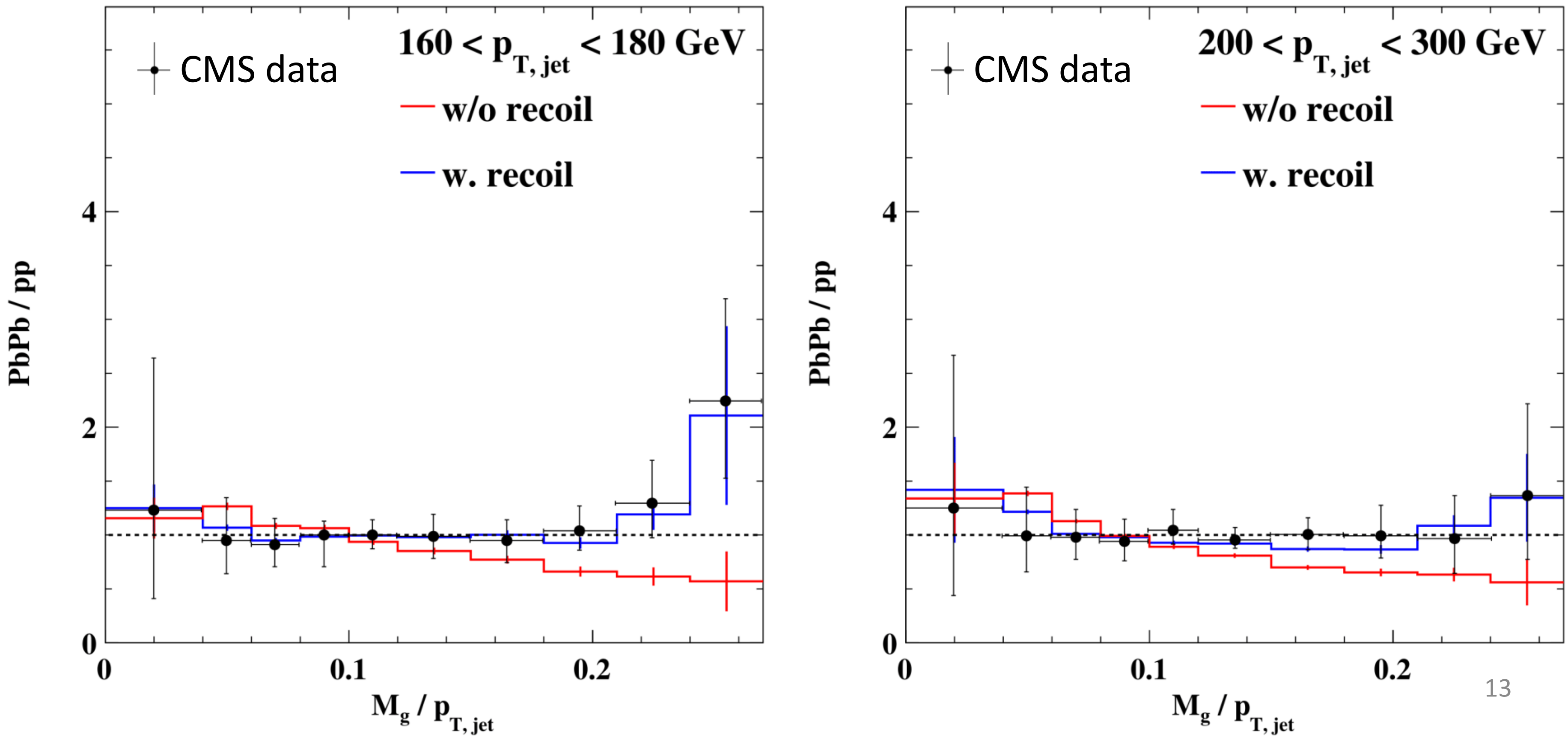


Groomed jet mass

- Jets become narrower in the medium without the medium recoil.
- The inclusion of recoiled partons will increase the groomed jet mass.

Very preliminary

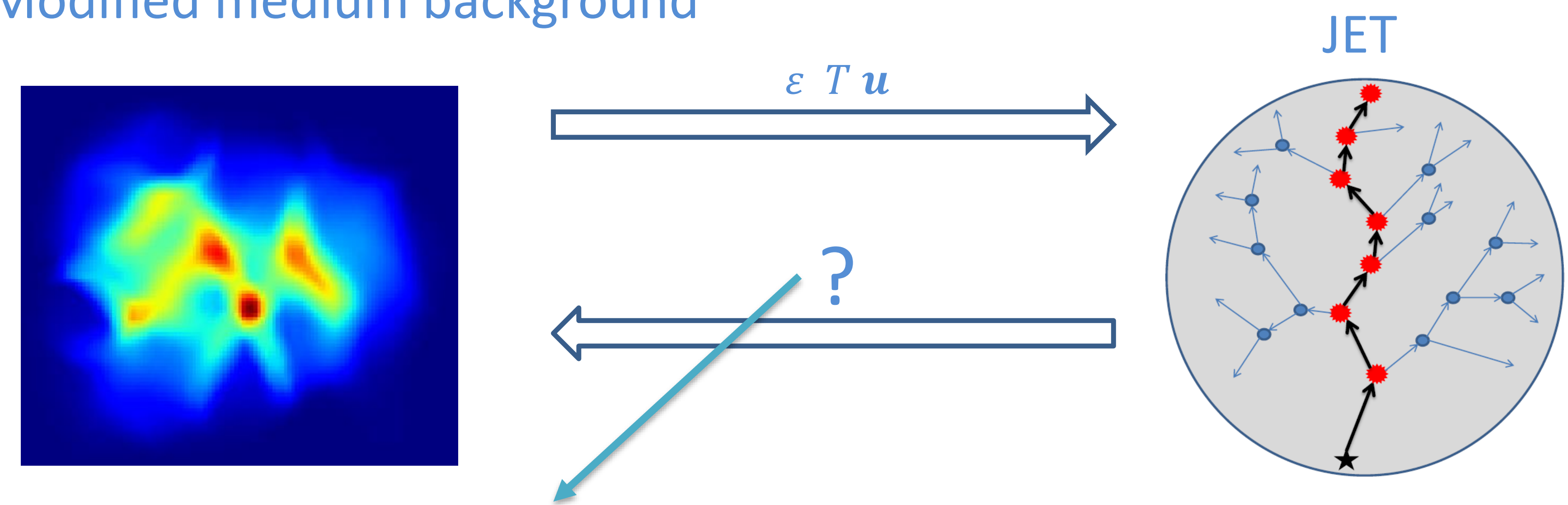
$$\frac{M_g}{p_T^{jet}} = \frac{\sqrt{(E_1+E_2)^2-(\vec{p}_1+\vec{p}_2)^2}}{p_T^{jet}}$$



Beyond LBT model (modified medium background)

- Linear approximation : jet induced medium excitation δf<<f .
- Jet-Medium interaction : Where is the modification of the thermal background ?

Modified medium background



Energy and momentum deposited from the jets as source terms into hydro

CoLBT-hydro

(A coupled LBT Hydro (3+1D) Model)

Summary

- We present a computation of jets modification in QGP within the Linear Boltzmann Transport (**LBT**) model in which both the elastic and inelastic processes are included.
- Recoil effect is found to be important in both jet energy loss and jet structure study.

Outlook

- *Jet in hadron level. (Hardon jet, Heavy flavor jet)*
  (with the recombination model developed by Texas A&M group)
- *Ideal hydro to viscous hydro. (CL-visc model)*
- *Further development of the LBT model: Coherent energy loss, Detailed balance and Heavy quarkonium propagation.*

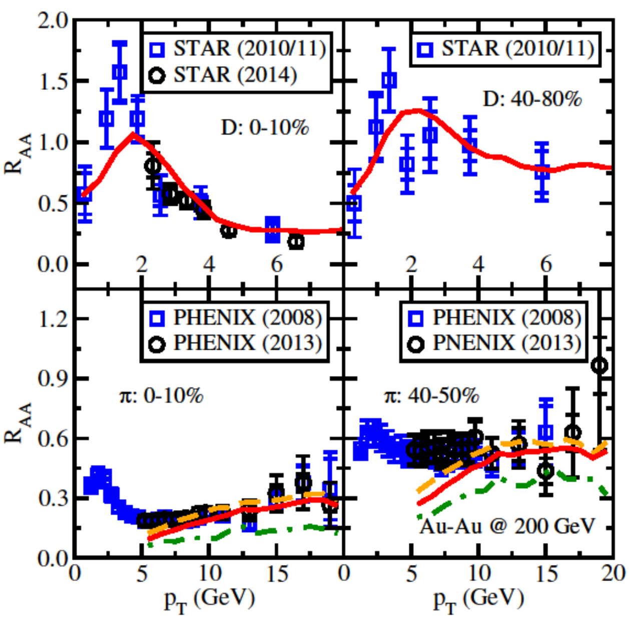
Thanks

Hadron R_{AA} in heavy ion collision

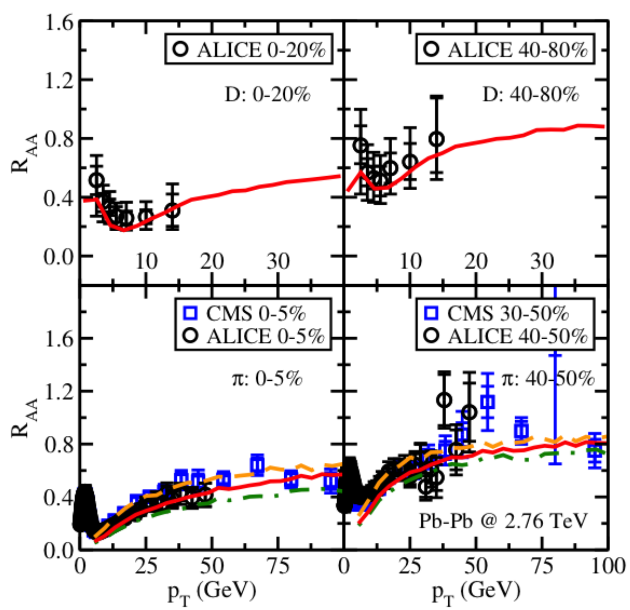
- Simultaneous description of single hadron(light and heavy) R_{AA} from RHIC to LHC.

arXiv:1703.00822 (accepted by PLB)
Shanshan Cao, Tan Luo, Guang-You Qin, Xin-Nian Wang

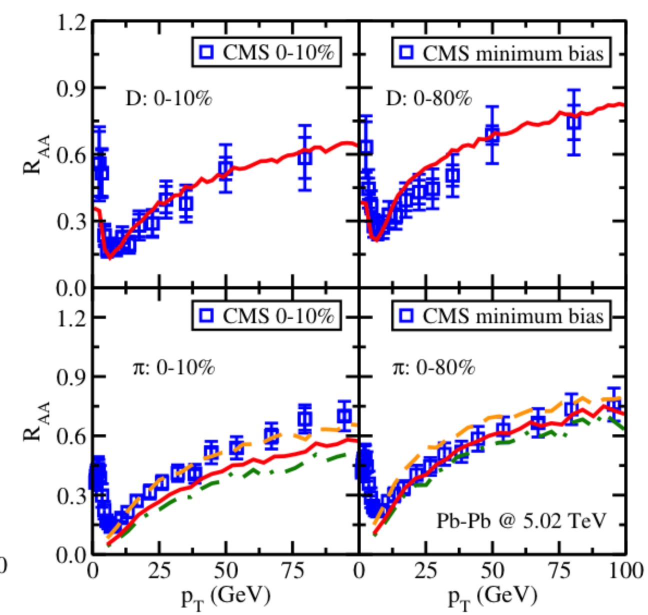
AuAu@200GeV



PbPb@2760GeV



PbPb@5020GeV

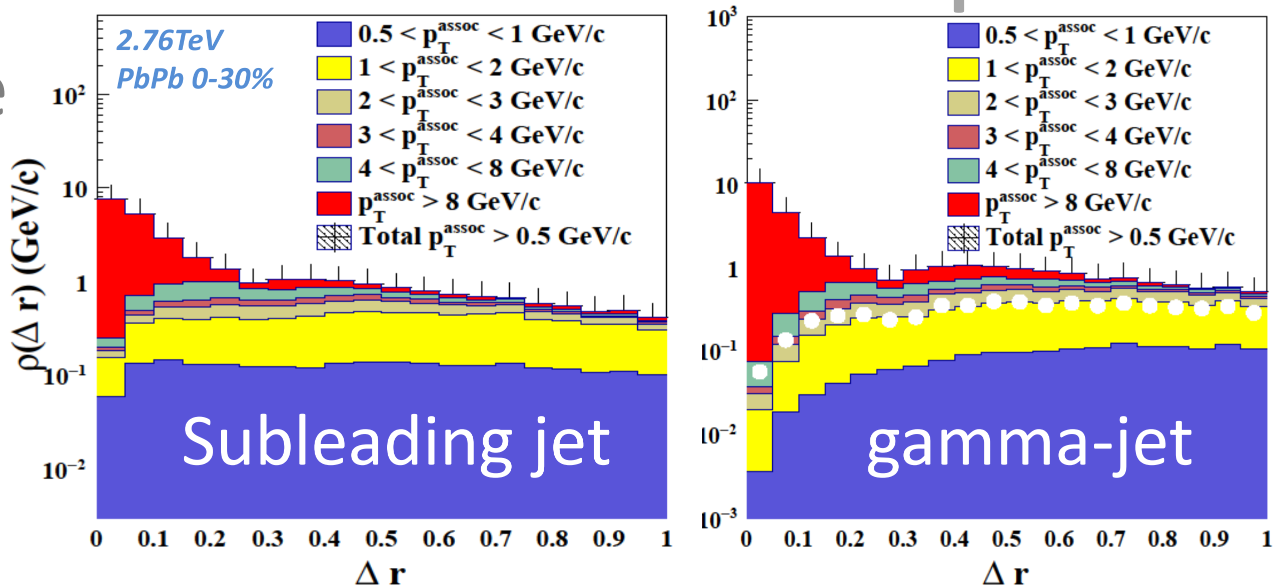


Multiple jets interference

- Gamma-jet .vs. Dijet

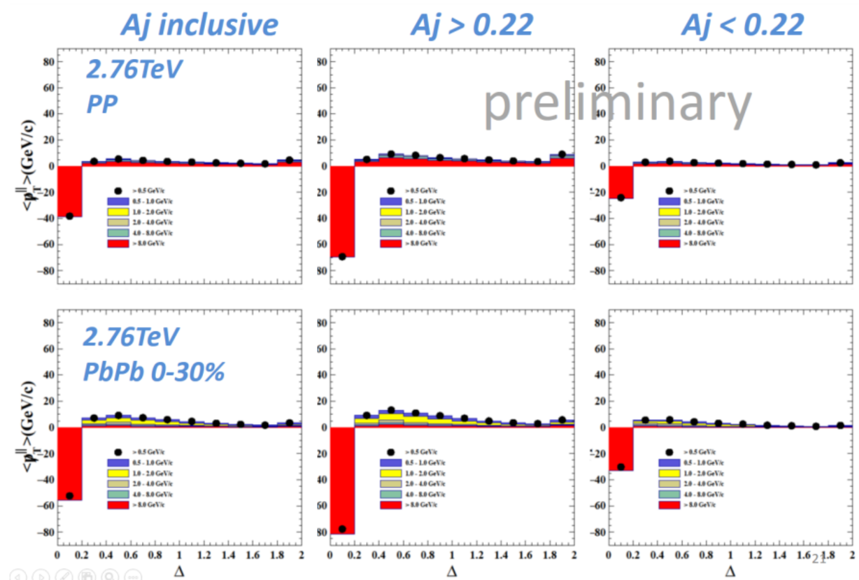
preliminary

Jet shape



pT distribution away from jet axis

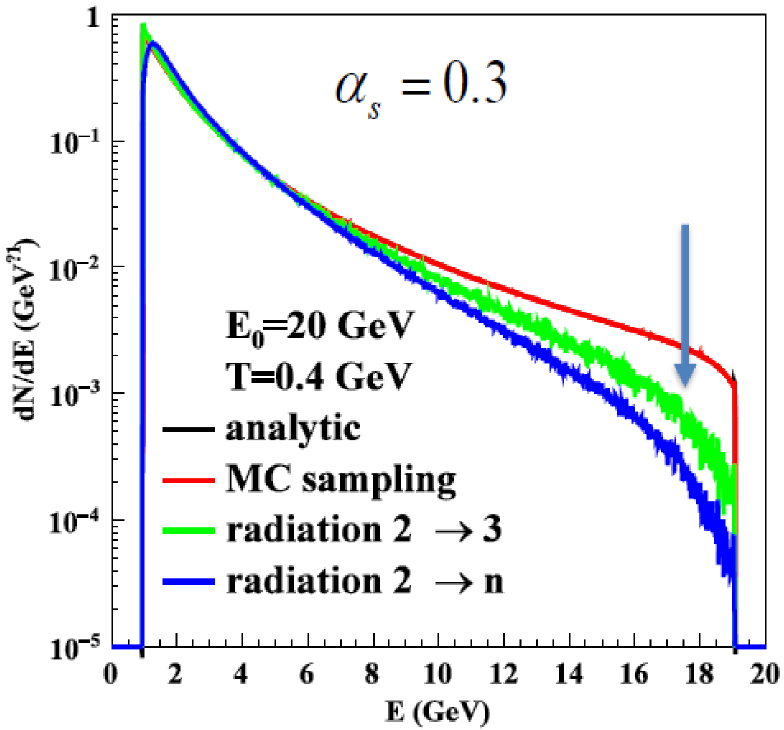
pT imbalance of dijet in heavy-ion collisions

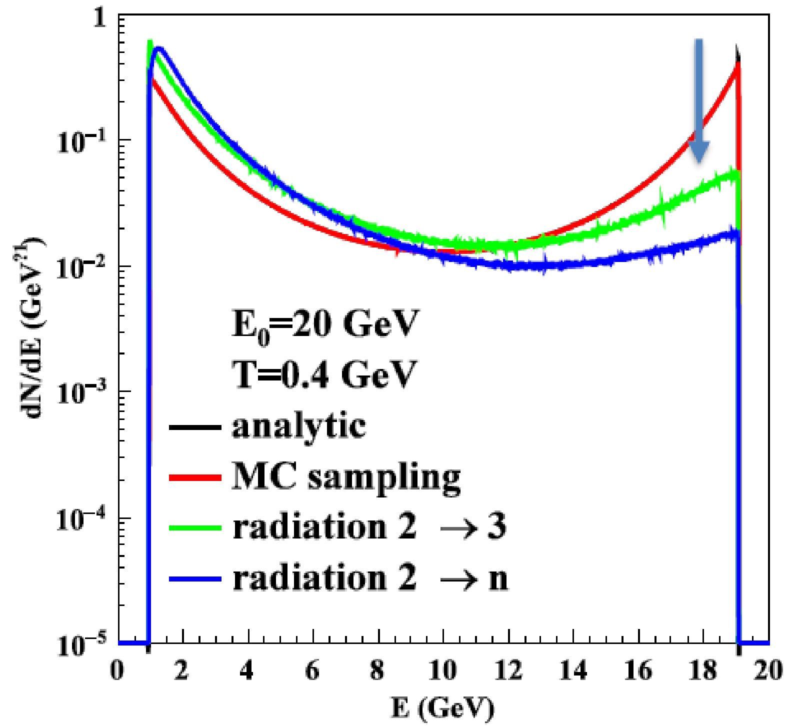


Jet-hadron correlation

Energy distribution of the radiated gluon

Global energy-momentum conservation in 2->3 and 2->n processes

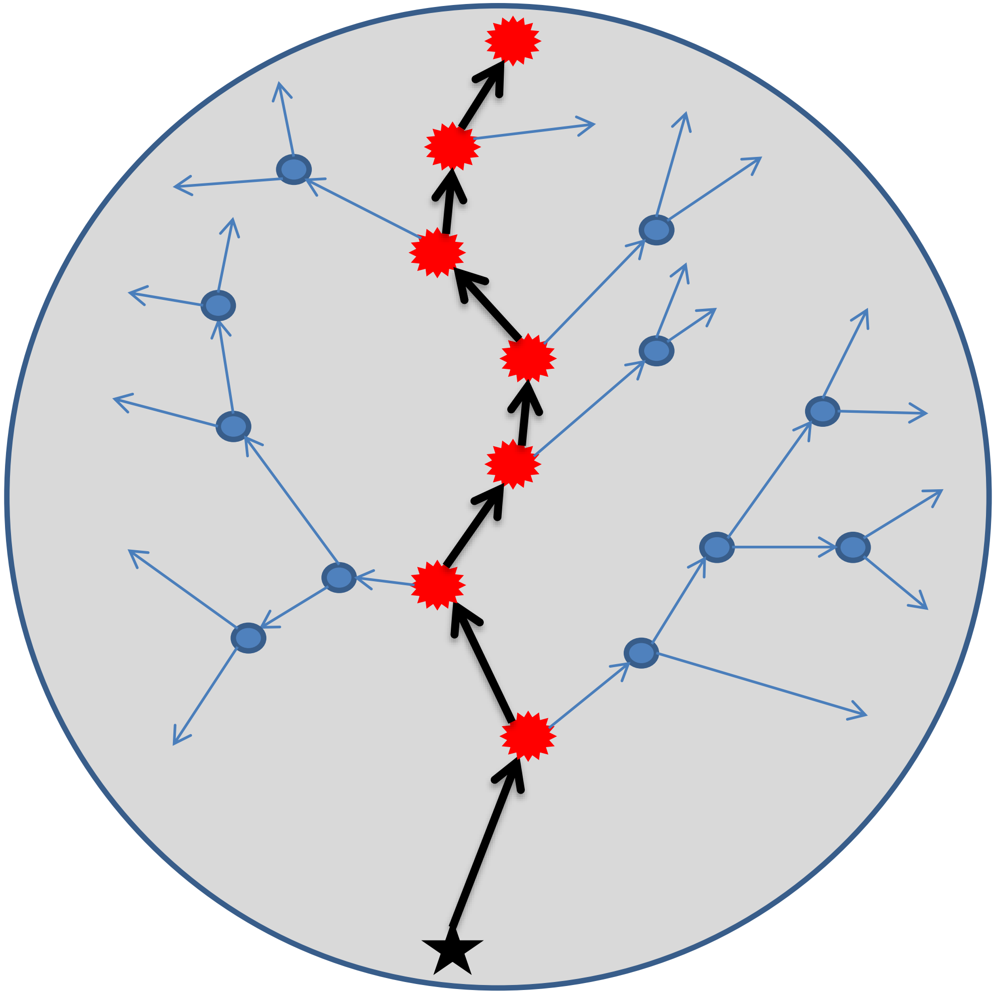


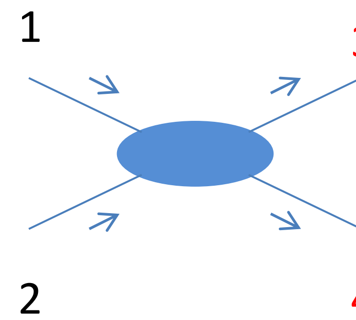


$$P_{q\to qg}(x) = \frac{(1-x)(1+(1-x)^2)}{x}$$

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

Jet induced medium excitation: recoiled parton





Leading parton-----thermal parton scattering

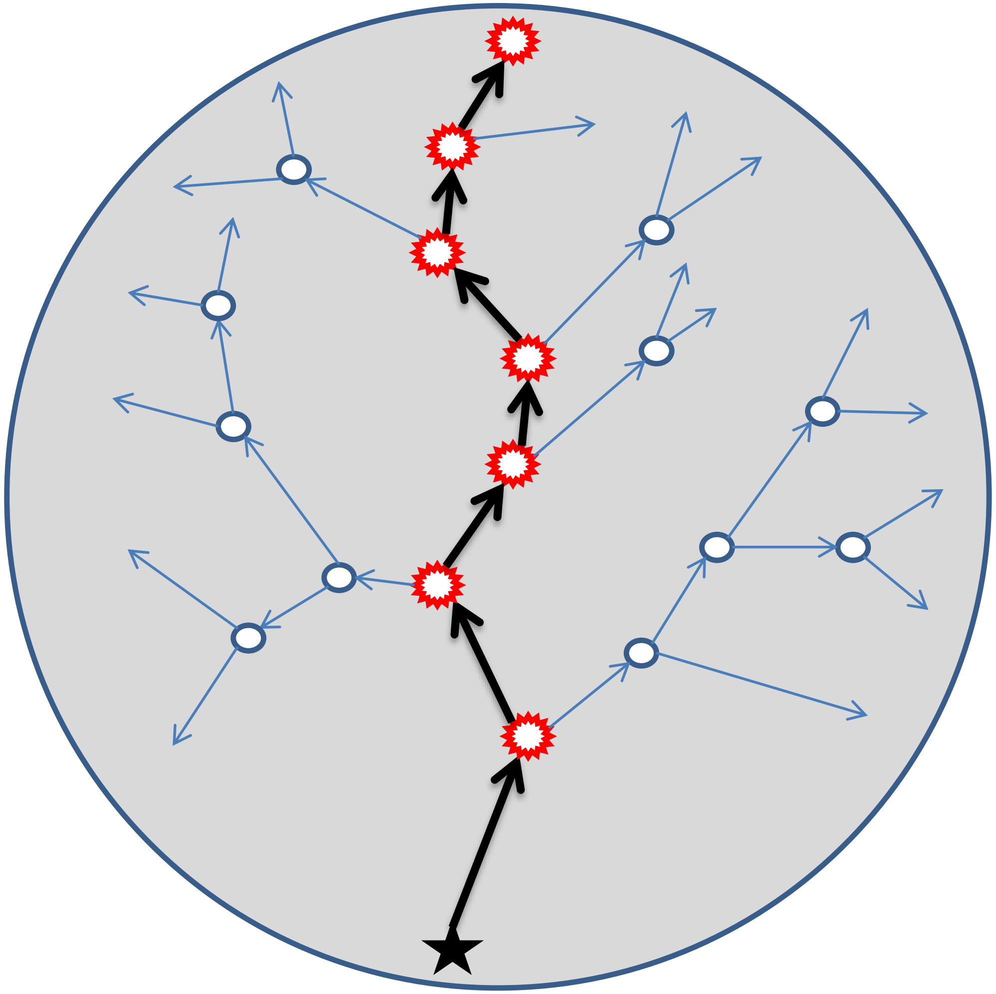
recoiled parton-----thermal parton scattering

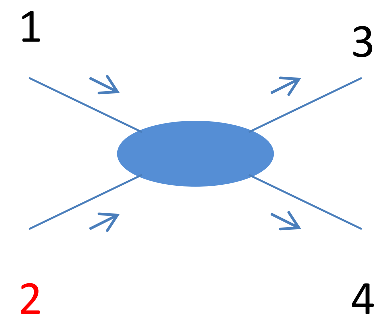
Linearized Boltzmann jet transport

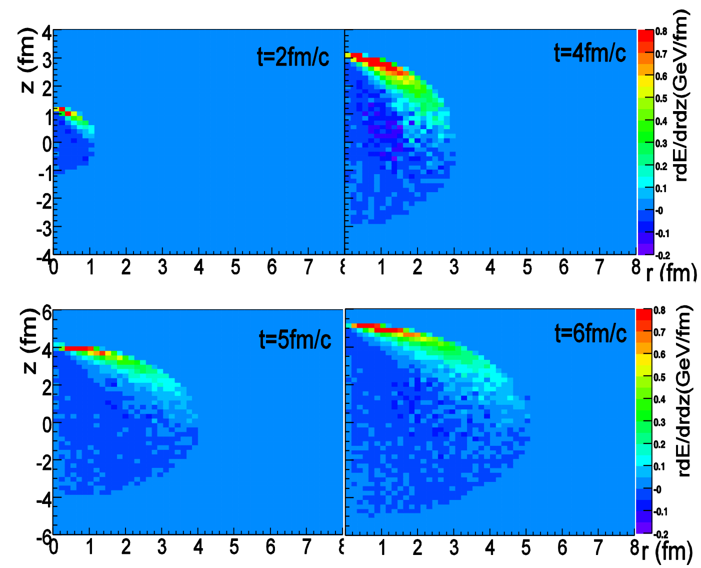
neglect scatterings between recoiled medium partons.

It’s a good approximation when the jet induced medium excitation δf<<f.

Jet induced medium excitation: particle hole

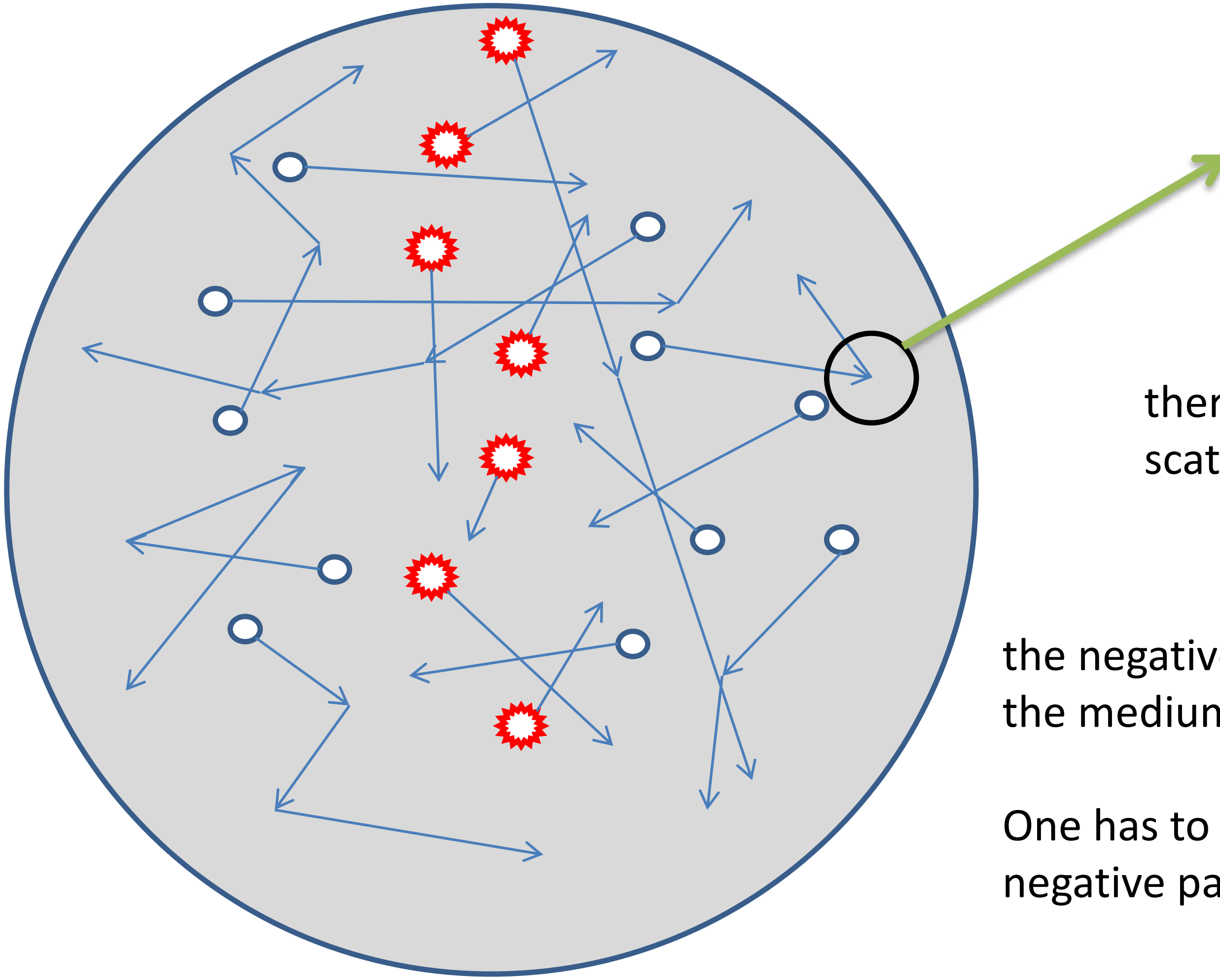


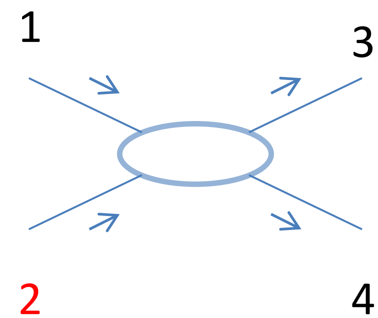




One has to subtract the 4-momentum of negative particle when combine it to jet

Jet induced medium excitation: back reaction



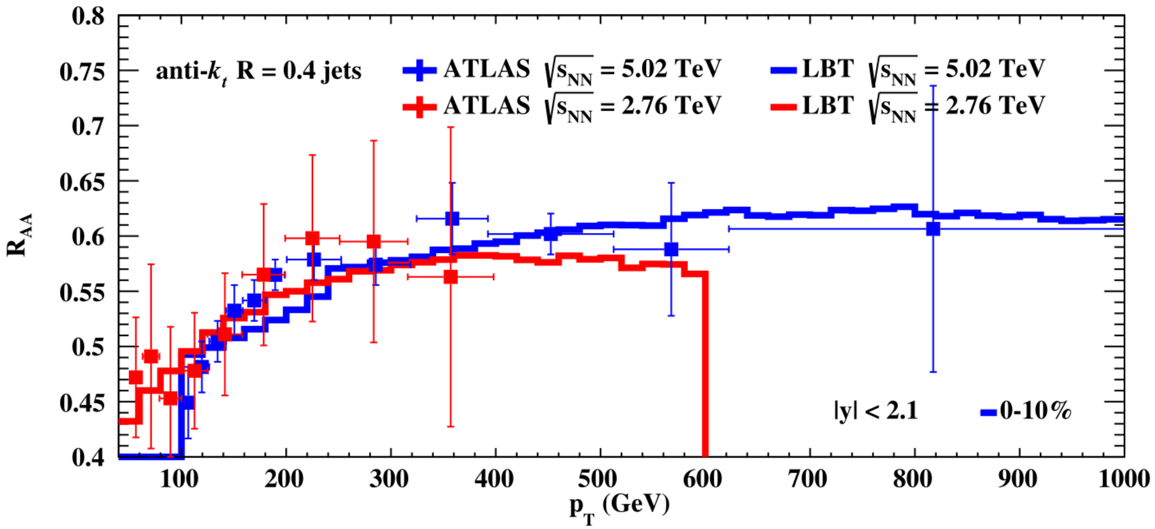


thermal parton-----thermal parton scattering

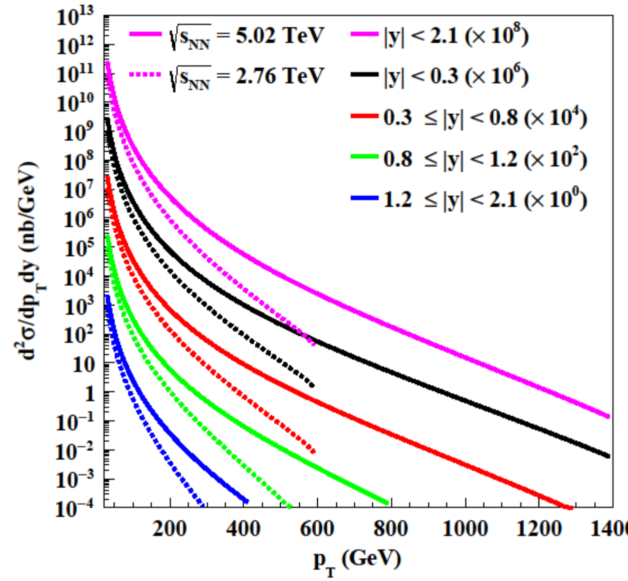
the negative particle is also traveling in the medium

One has to subtract the 4-momentum of negative particle when combine it to jet

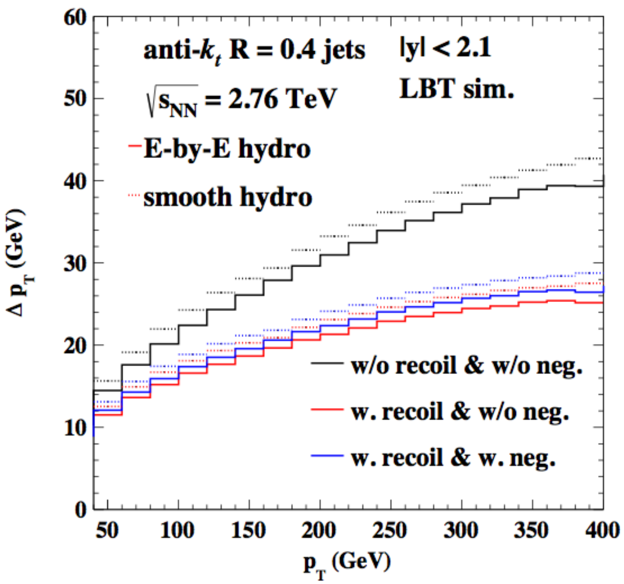
Jet R_{AA}



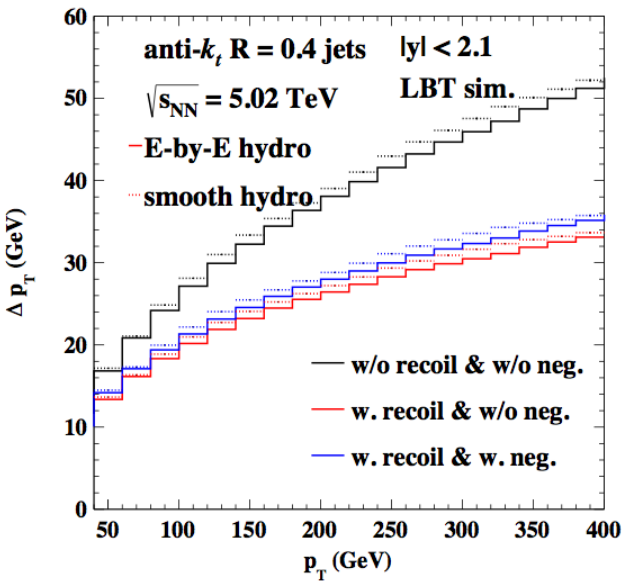
anti-k_t R = 0.4 jets
ATLAS $\sqrt{s_{NN}}$ = 5.02 TeV
ATLAS $\sqrt{s_{NN}}$ = 2.76 TeV
LBT $\sqrt{s_{NN}}$ = 5.02 TeV
LBT $\sqrt{s_{NN}}$ = 2.76 TeV
|y| < 2.1
0-10%
R_{AA}
p_T (GeV)



$\sqrt{s_{NN}}$ = 5.02 TeV
$\sqrt{s_{NN}}$ = 2.76 TeV
|y| < 2.1 (× 10^8)
|y| < 0.3 (× 10^6)
0.3 ≤ |y| < 0.8 (× 10^4)
0.8 ≤ |y| < 1.2 (× 10^2)
1.2 ≤ |y| < 2.1 (× 10^0)
$d^2\sigma/dp_T dy$ (nb/GeV)
p_T (GeV)



anti-k_t R = 0.4 jets
|y| < 2.1
$\sqrt{s_{NN}}$ = 2.76 TeV
LBT sim.
E-by-E hydro
smooth hydro
w/o recoil & w/o neg.
w. recoil & w/o neg.
w. recoil & w. neg.
Δp_T (GeV)
p_T (GeV)



anti-k_t R = 0.4 jets
|y| < 2.1
$\sqrt{s_{NN}}$ = 5.02 TeV
LBT sim.
E-by-E hydro
smooth hydro
w/o recoil & w/o neg.
w. recoil & w/o neg.
w. recoil & w. neg.
Δp_T (GeV)
p_T (GeV)

Jet induced medium excitation (Angular distribution)

t = 2 fm   t = 4 fm   t = 6 fm