The 7th Asian Triangle Heavy-Ion Conference (ATHIC 2018)

Nuclear modification of full jets and jet structure in PbPb collisions at 2.76 TeV and 5.02 TeV

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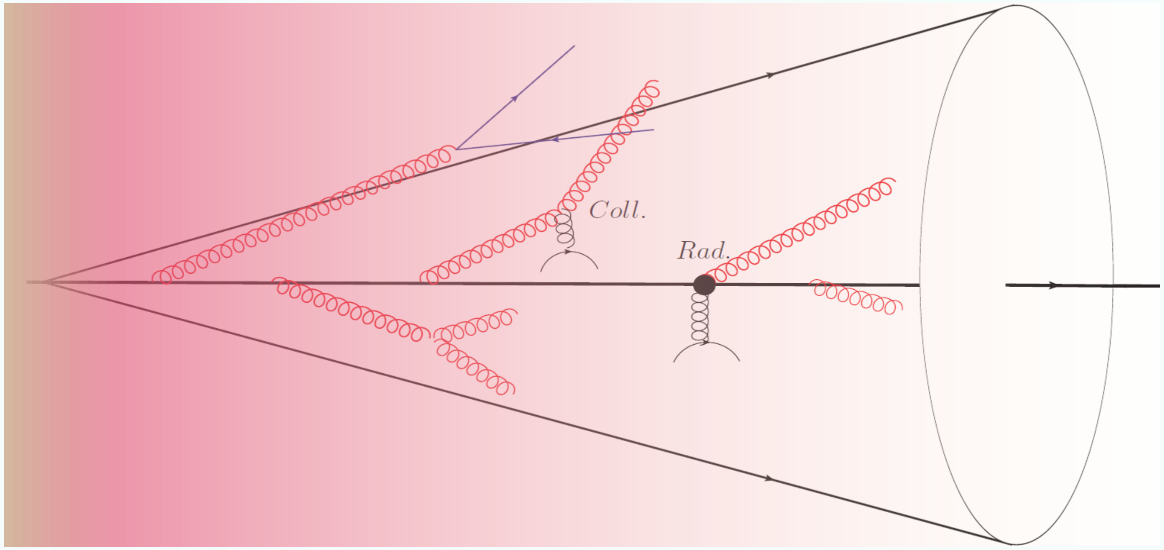
In collaboration with Guang-You Qin and Yasuki Tachibana

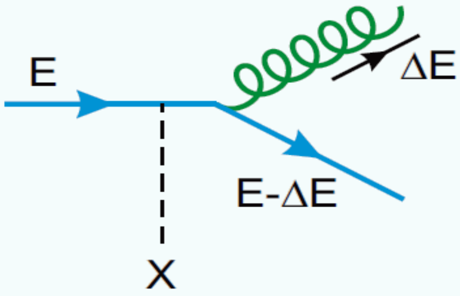
Based on PRC.94.024902, PRC.95.044909 and paper in preparation.

Outline

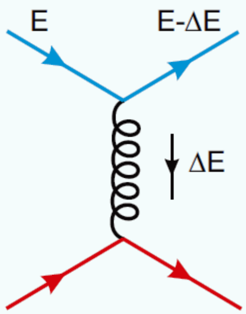
- Motivation and Framework
- Jet energy loss
- Jet shape modification
- Medium response
- Summary and Outlook

Full jet evolution in medium



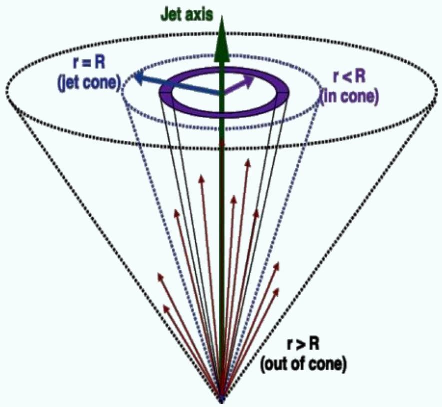


Inelastic scattering



Elastic scattering

- Radiative energy loss for full jet may be not so important as it for leading parton.
- Collisional energy loss may be more important for full jets than single hadrons.
- Jet structure and its modification provides more observables, can reveal more detailed information.



Framework: Boltzmann transport equation

$$f_j(\omega_j, k_{j\perp}^2, t) = \frac{dN_j(\omega_j, k_{j\perp}^2, t)}{d\omega_j dk_{j\perp}^2}$$

$$\begin{aligned}
\frac{d}{dt} f_j(\omega_j, k_{j\perp}^2, t) &= \hat{e}_j \frac{\partial}{\partial \omega_j} f_j(\omega_j, k_{j\perp}^2, t) \\
&+ \frac{1}{4}\hat{q}_j \nabla_{k_\perp}^2 f_j(\omega_j, k_{j\perp}^2, t) \\
&+ \sum_i \int d\omega_i dk_{i\perp}^2 \tilde{\Gamma}_{i\to j}(\omega_j, k_{j\perp}^2 | \omega_i, k_{i\perp}^2) f_i(\omega_i, k_{i\perp}^2, t) \\
&- \sum_i \int d\omega_i dk_{i\perp}^2 \tilde{\Gamma}_{j\to i}(\omega_i, k_{i\perp}^2 | \omega_j, k_{j\perp}^2) f_j(\omega_j, k_{j\perp}^2, t)
\end{aligned}$$

Collisional energy loss

K_T broadening

Radiation: gain, loss

$$\hat{e} = dE/dt \qquad \hat{q} = d(\Delta p_\perp)^2/dt \qquad \hat{q} = 4T\hat{e}$$

$$q \begin{cases} g \to q\bar{q},\ q \to qg \\ q \to qg,\ q \to gq \end{cases}$$

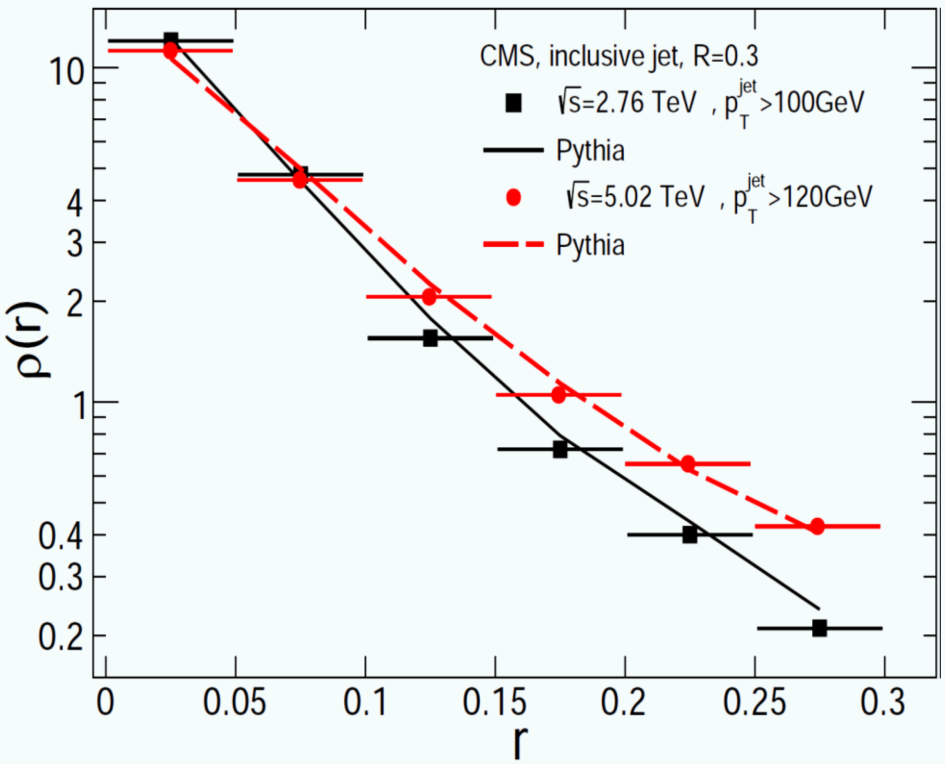
$$g \begin{cases} q \to gq,\ g \to gg \\ g \to gg,\ g \to q\bar{q} \end{cases}$$

$$\Gamma(\omega, k_\perp^2 | E, 0) = \frac{2\alpha_s}{\pi} \frac{xP(x)\hat{q}(t)}{\omega k_\perp^4} \sin^2 \frac{t - t_i}{2\tau_f}$$

$$t_i = \frac{2Ex_i(1-x_i)}{k_{i\perp}^2} \qquad \tau_f = \frac{2\omega_i x_{ij}(1-x_{ij})}{k_{ij\perp}^2}$$

Framework: input from Pythia and Hydro.

$$\rho(r) = \frac{1}{\delta r}\frac{1}{N_{\rm jet}}\sum_{\rm jets}\frac{\sum_{{\rm tracks}\in[r_a,r_b)} p_T^{\rm track}}{p_T^{\rm jet}}$$



Parameters in Pythia differ from 2.76A TeV to 5.02A TeV.

At same jet energy, jets at 2.76A TeV are steeper.

Hydrodynamic simulation from VISH2+1 or Yasuki Tachibana

$$\hat{q}(\tau,\vec{r}\,) = \hat{q}_0 \cdot \frac{T^3(\tau,\vec{r}\,)}{T_0^3(\tau_0,\vec{0})} \cdot \frac{p\cdot u(\tau,\vec{r}\,)}{p_0}$$

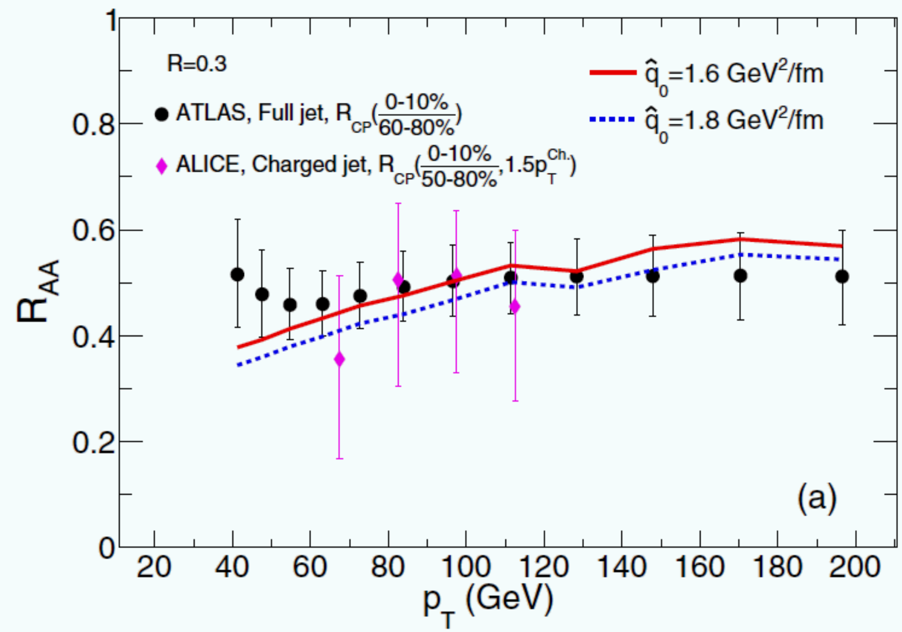
Jet R_{AA} and dijet/ γ-jets asymmetry @ 2.76A TeV

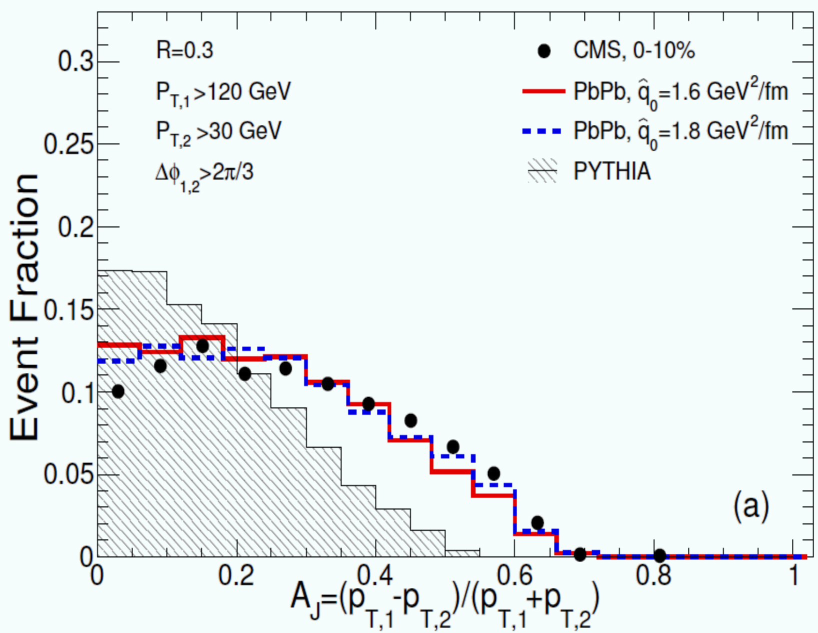
$$E_{jet}(R) = \sum_i \int_R \omega_i f_i(\omega_i, k_{i\perp}^2) d\omega_i dk_{i\perp}^2$$

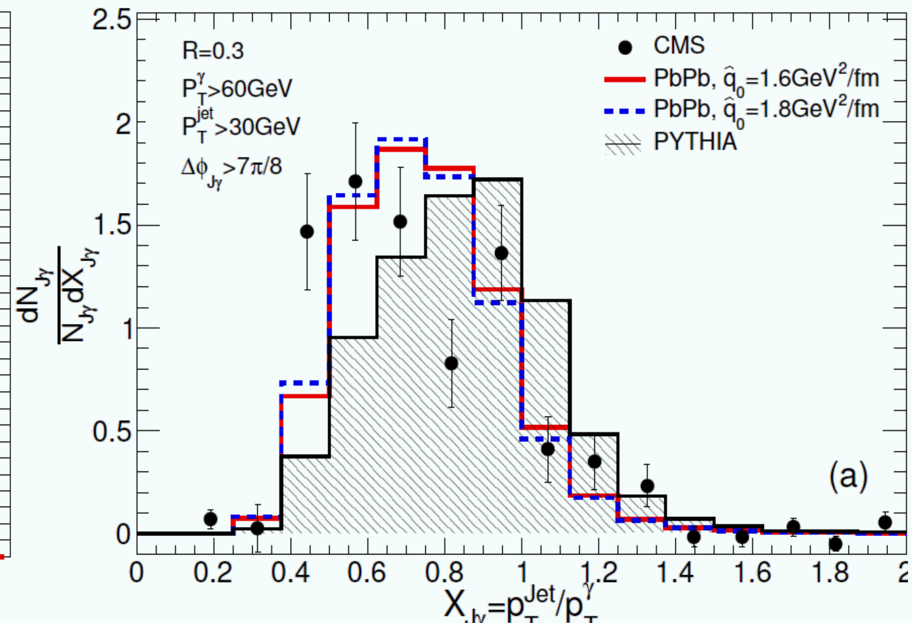
$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2N_{AA}/d\eta dp_T}{d^2N_{pp}/d\eta dp_T}$$

$$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$$

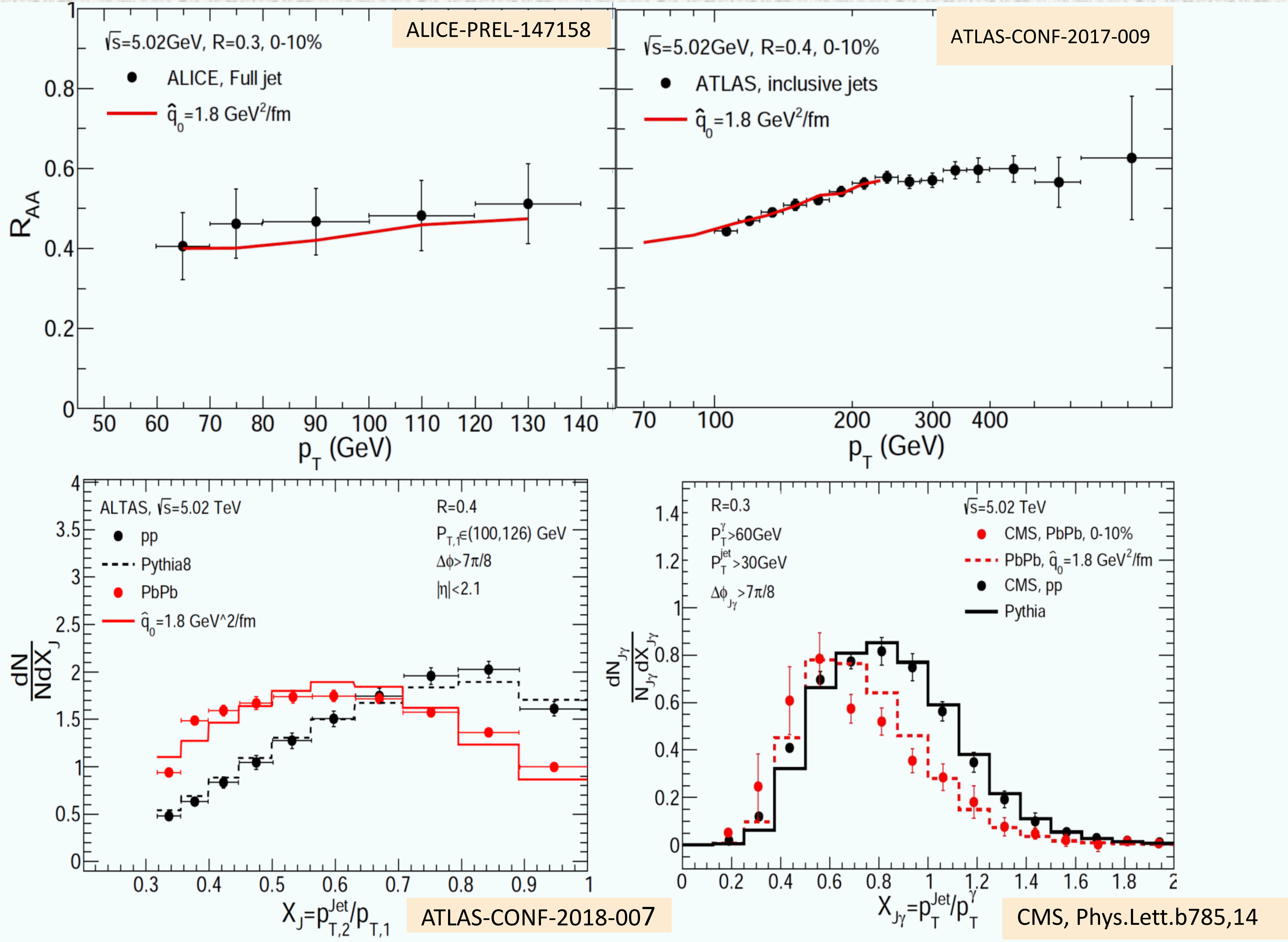
$$X_{J\gamma} = \frac{p_T^{Jet}}{p_T^{\gamma}}$$





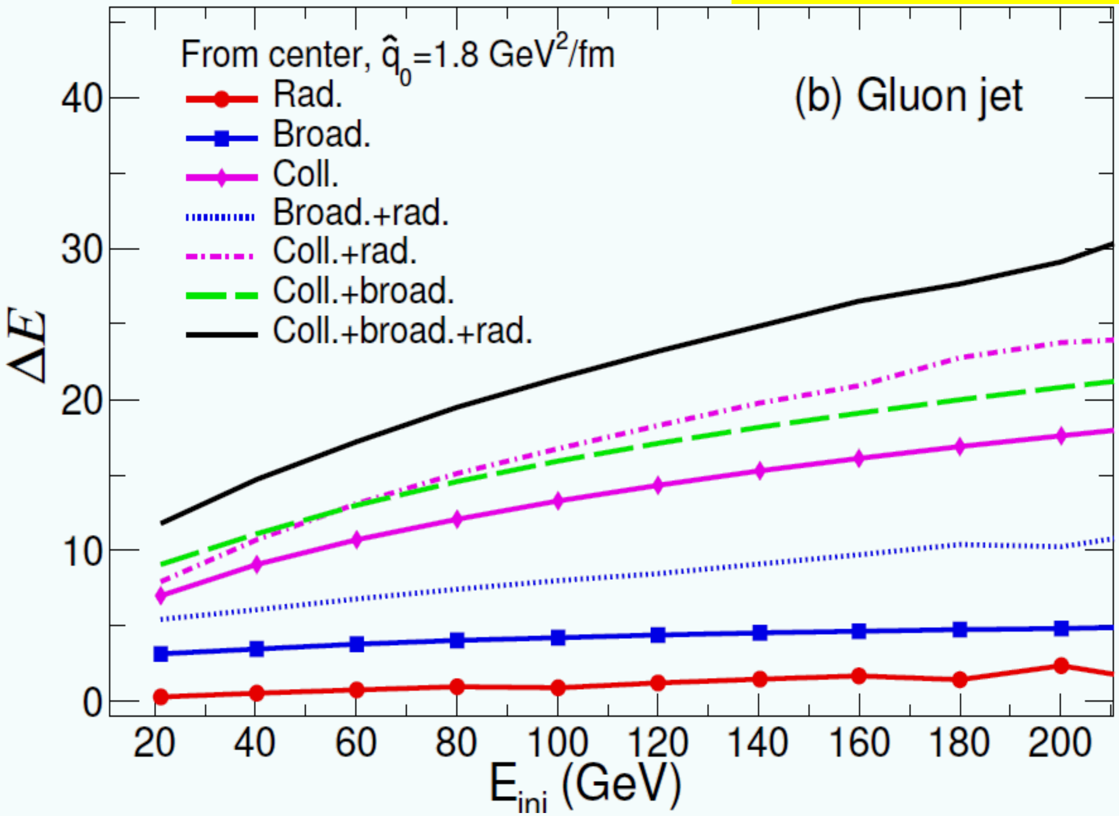


Jets energy loss observables @ 5.02A TeV



Jet Energy Loss from different mechanisms

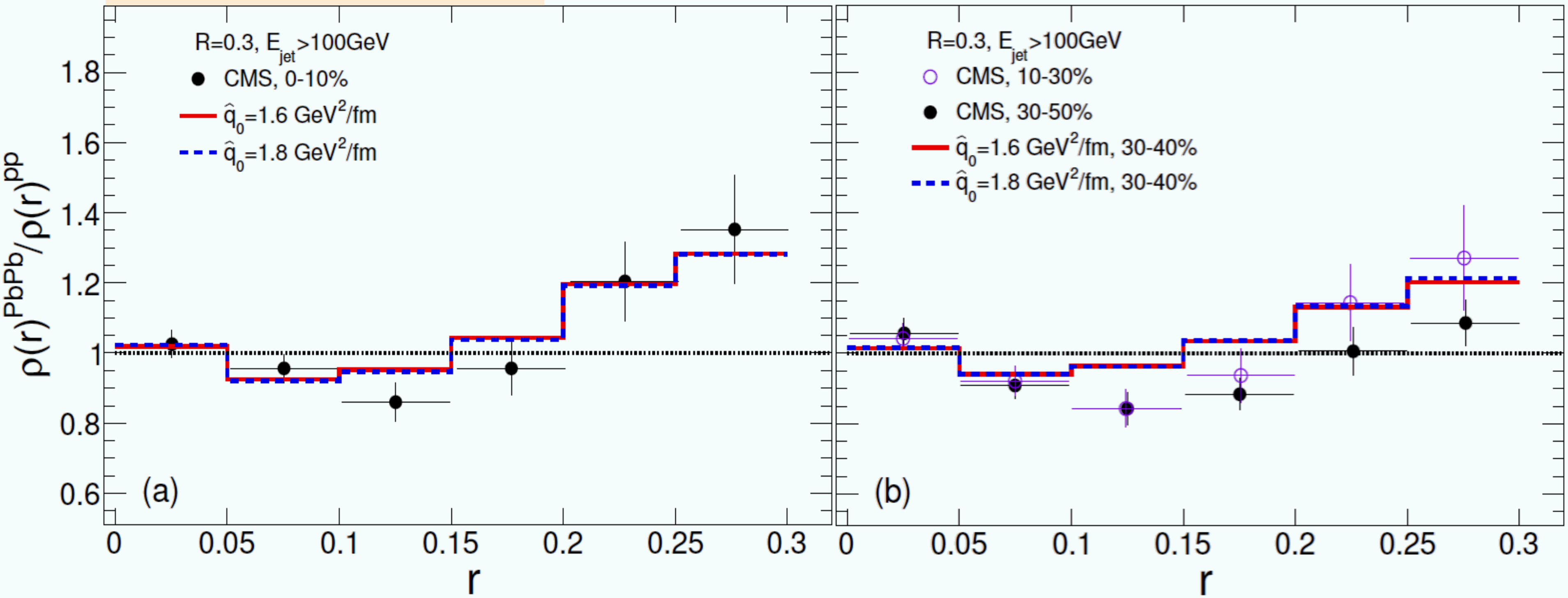
@ 2.76A TeV



Collisional energy loss contributes the most,
medium induced radiation contributes least,
but can enhance other mechanism.

Nuclear modification of Jet shape @ 2.76A TeV

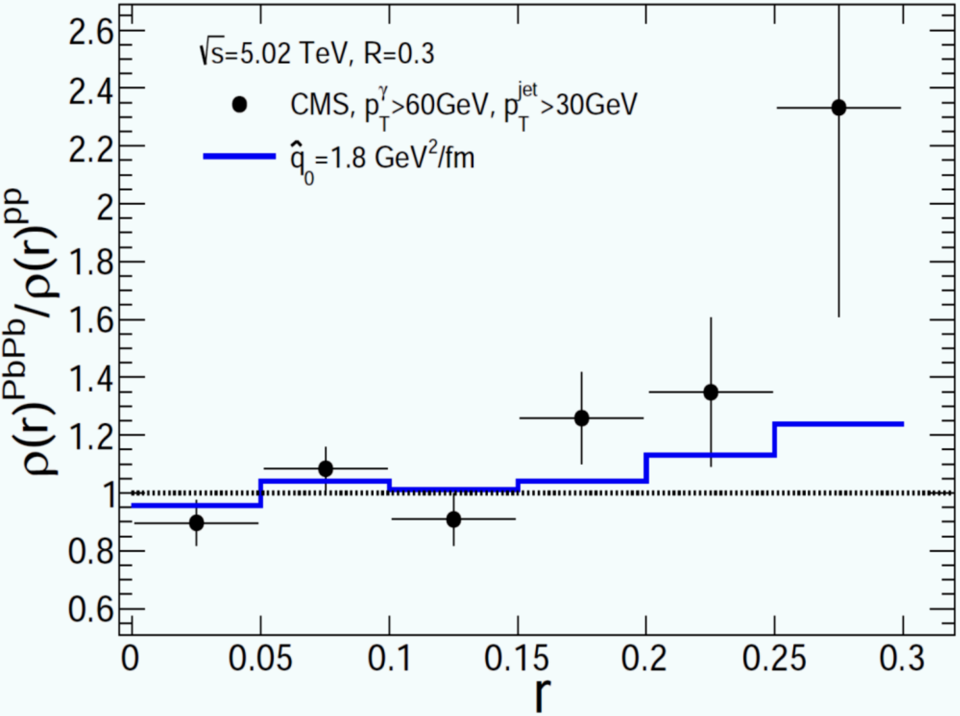
CMS, Phys.Let.B730(2014),243



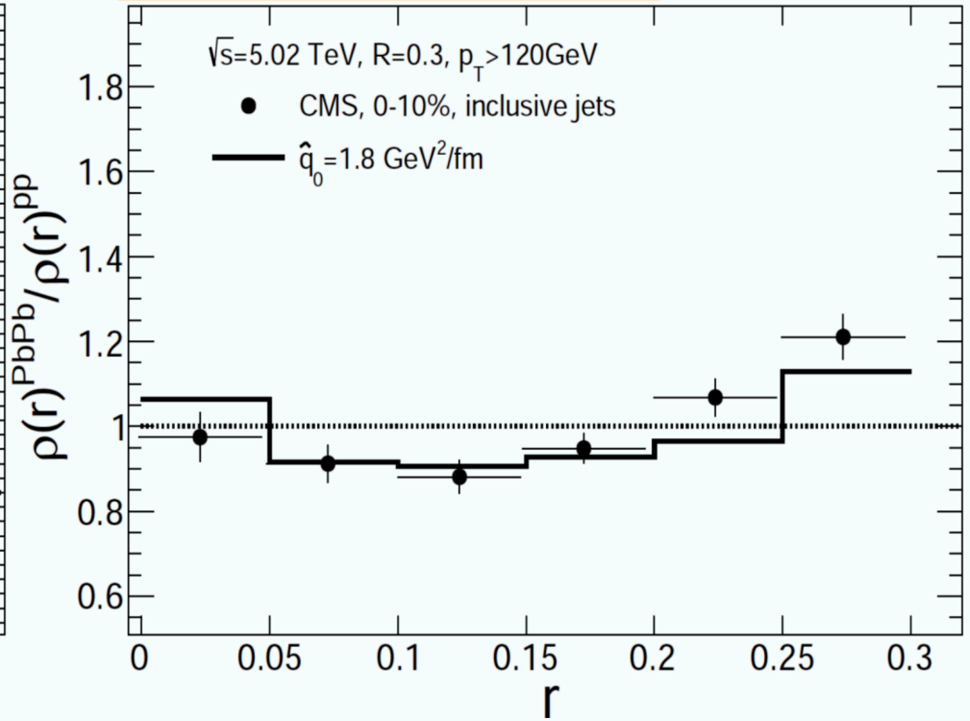
Jet shape is modified little at small r, suppressed at middle r and enhanced at large r.

Jet shape modification in γ-jets and inclusive jets @ 5.02A TeV

CMS, PAS HIN-18-006

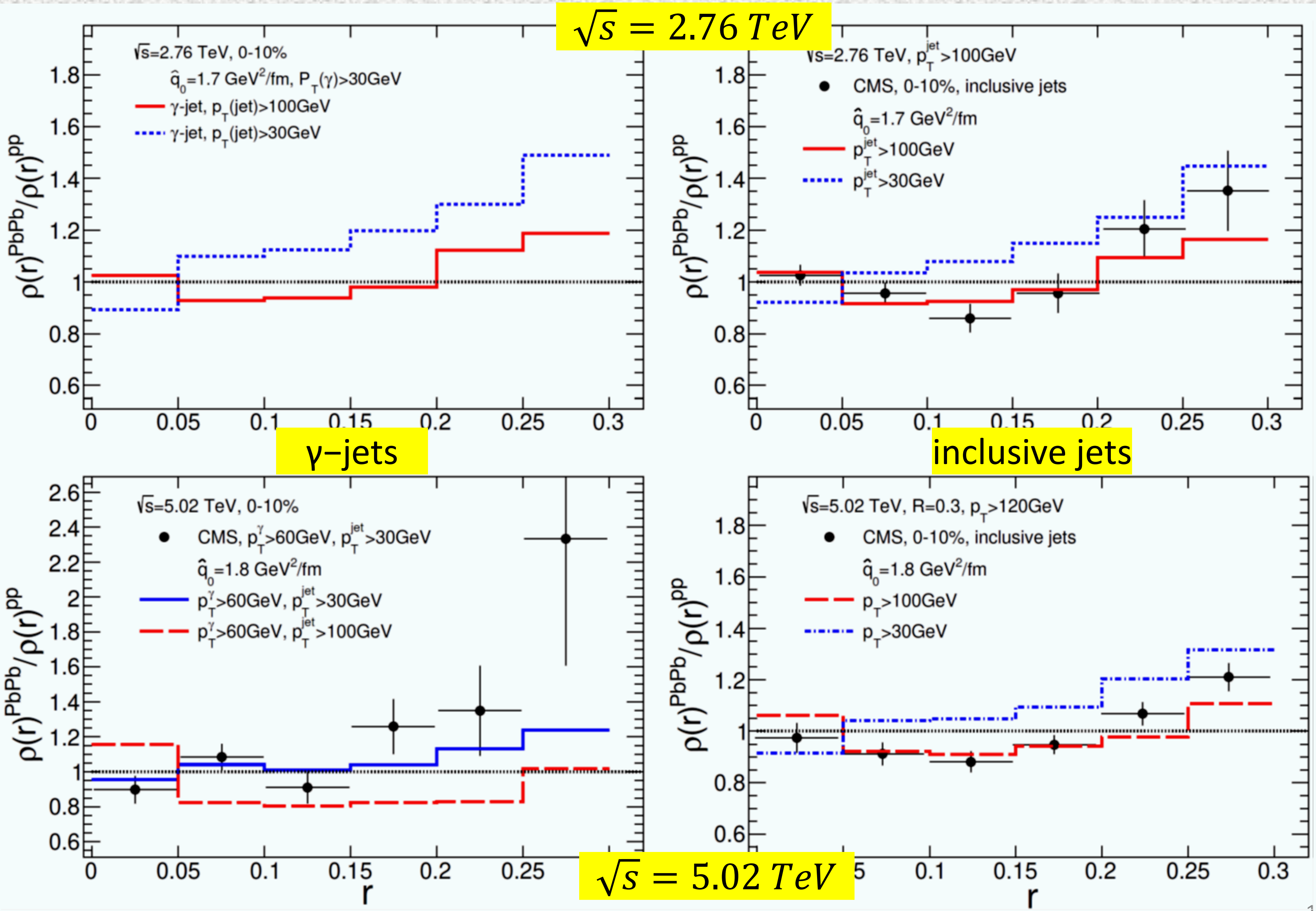


CMS, JHEP.1805(2018),006



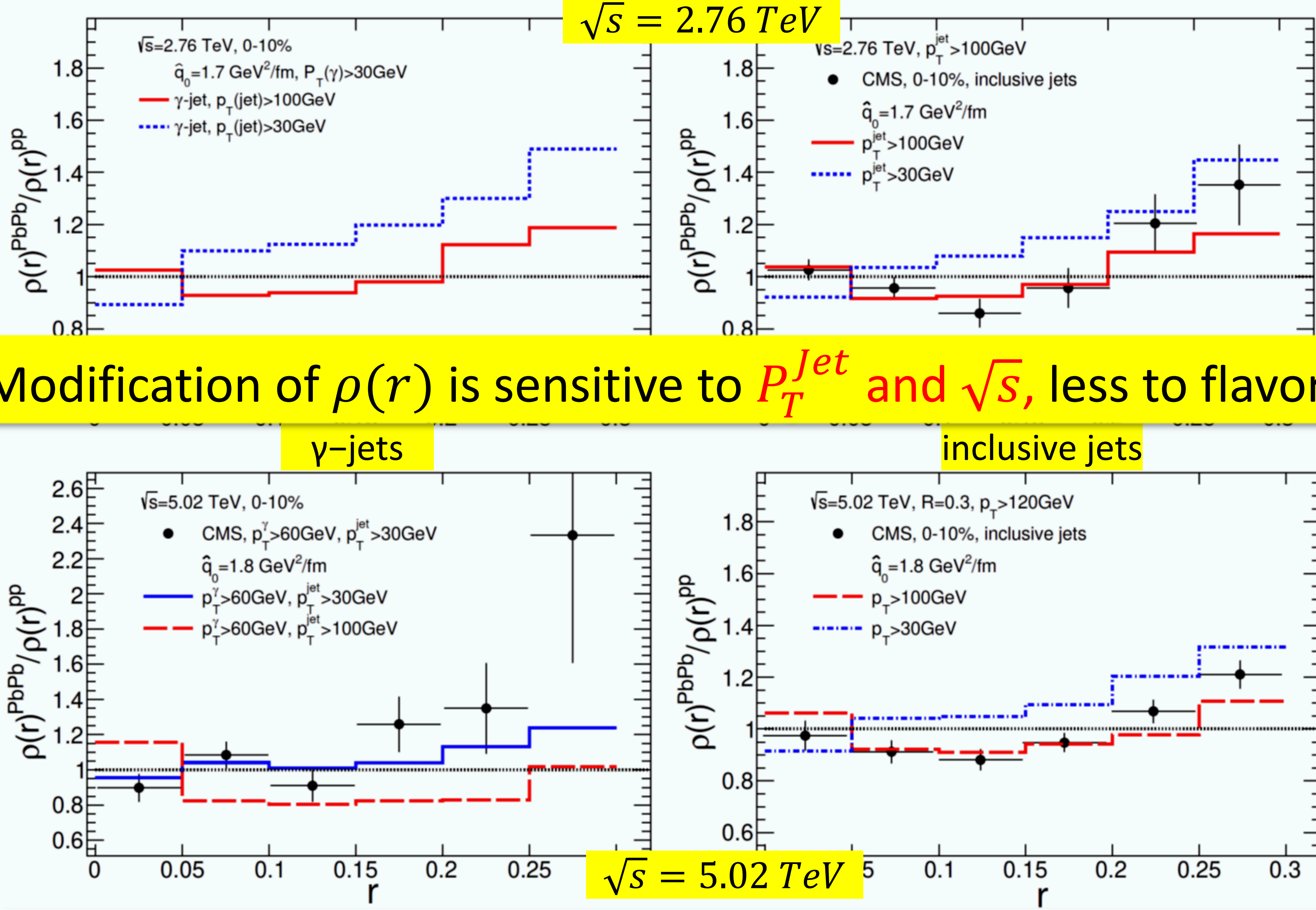
Describe the jet shape modification
for γ-jets and inclusive jets, in two p_T ranges .

P_T^{Jet} , $\sqrt{s}$ and flavor dependence



P_T^{Jet}, $\sqrt{s}$ and flavor dependence

$\sqrt{s} = 2.76\ TeV$

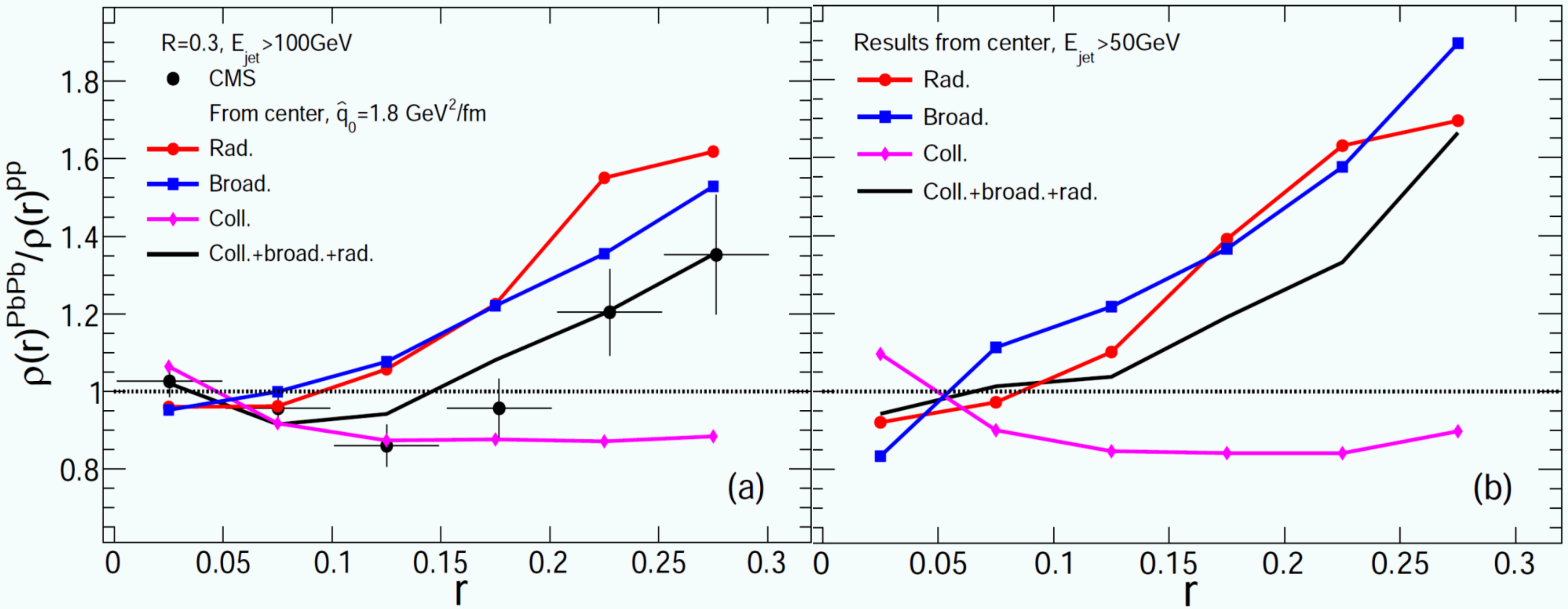


Modification of $\rho(r)$ is sensitive to P_T^{Jet} and $\sqrt{s}$, less to flavor.

$\sqrt{s} = 5.02\ TeV$

Effects of different mechanisms on **Jet shape**

@ 2.76A TeV



Rad. and Broad. transport energy from center to periphery,

Coll. leads inner core losing less fraction of energy than outer part.

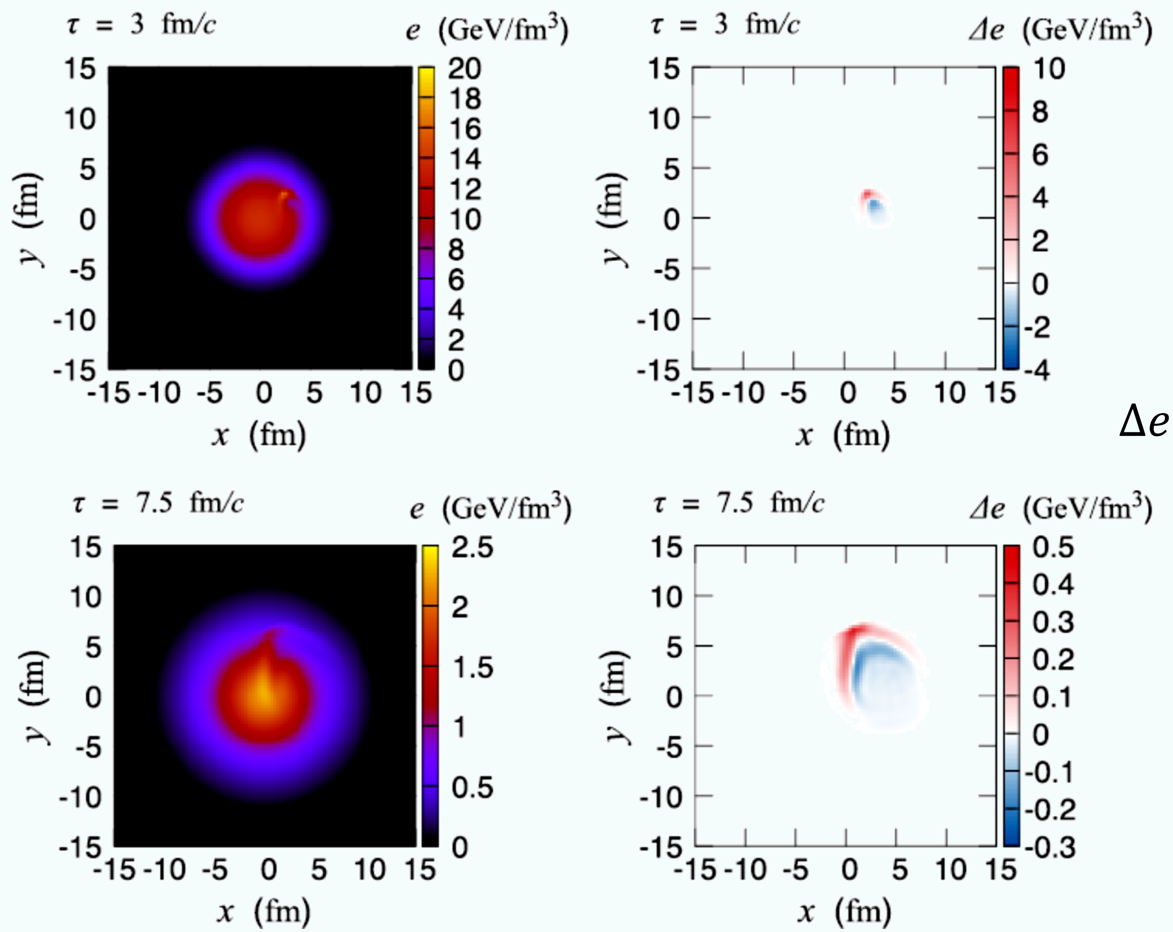
For lower energy jet, its inner core is changed more.

Medium response

$$\partial_\mu T^{\mu\nu}_{\rm QGP} = 0 \Rightarrow \partial_\mu T^{\mu\nu}_{\rm QGP}(x) = J^\nu(x)$$

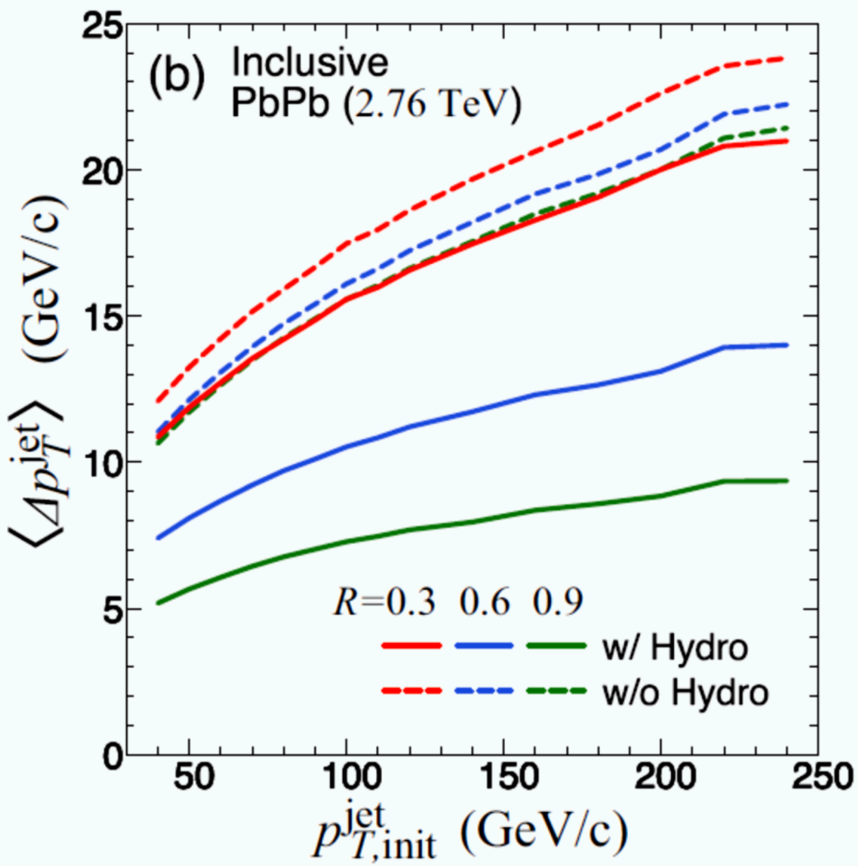
Yasuki Tachibana, Ning-Bo Chang and Guang-You Qin, PRC.95.044909

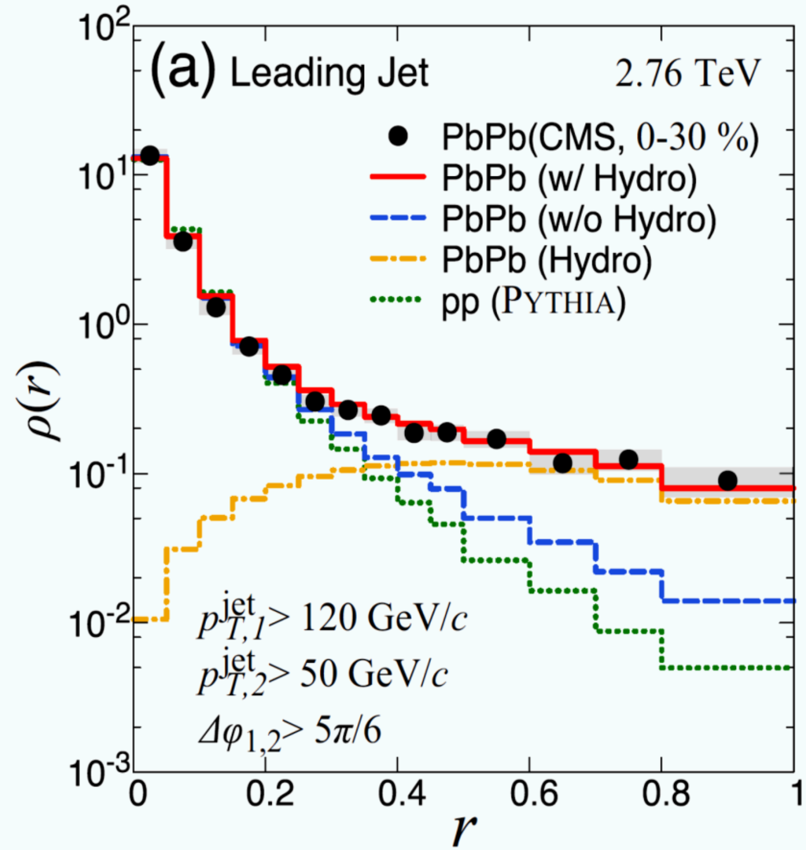
$$J^\nu(x) = -\sum_j \int d^3k_j k_j^\nu \frac{df_j(\boldsymbol{k}_j,t)}{dt}\bigg|_{\rm col.} \delta^{(3)}\left(\boldsymbol{x} - \boldsymbol{x}_0^{\rm jet} - \frac{\boldsymbol{k}_j}{\omega_j}t\right)$$



$$\Delta e = e|_{w/jet} - e|_{w/ojet}$$

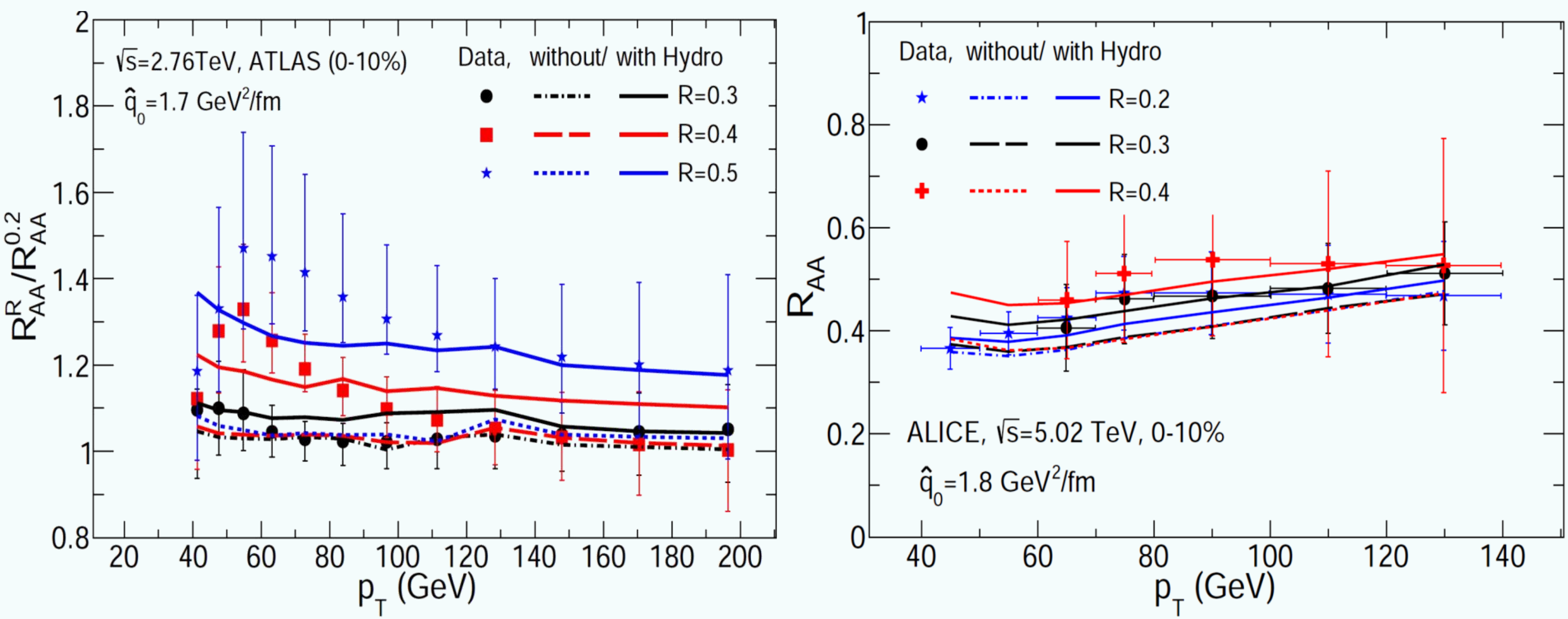
Effect of medium response





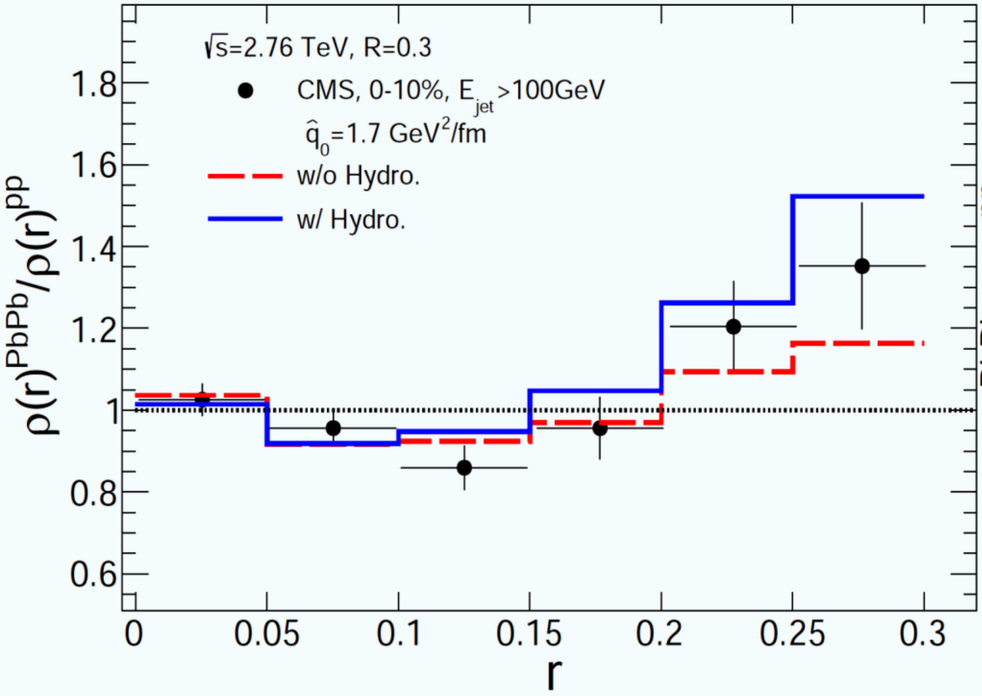
Lost energy is transported to medium at large r,
Medium response dominates jet shape at large r.

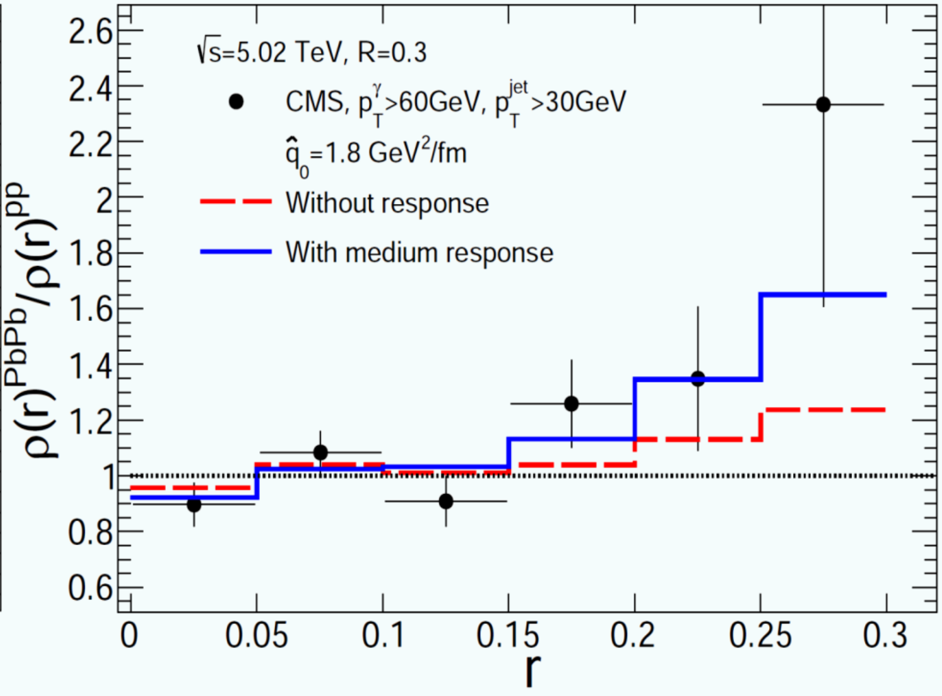
Effect of medium response



Rise R_{AA} value, important to cone size dependence of jet R_{AA} .

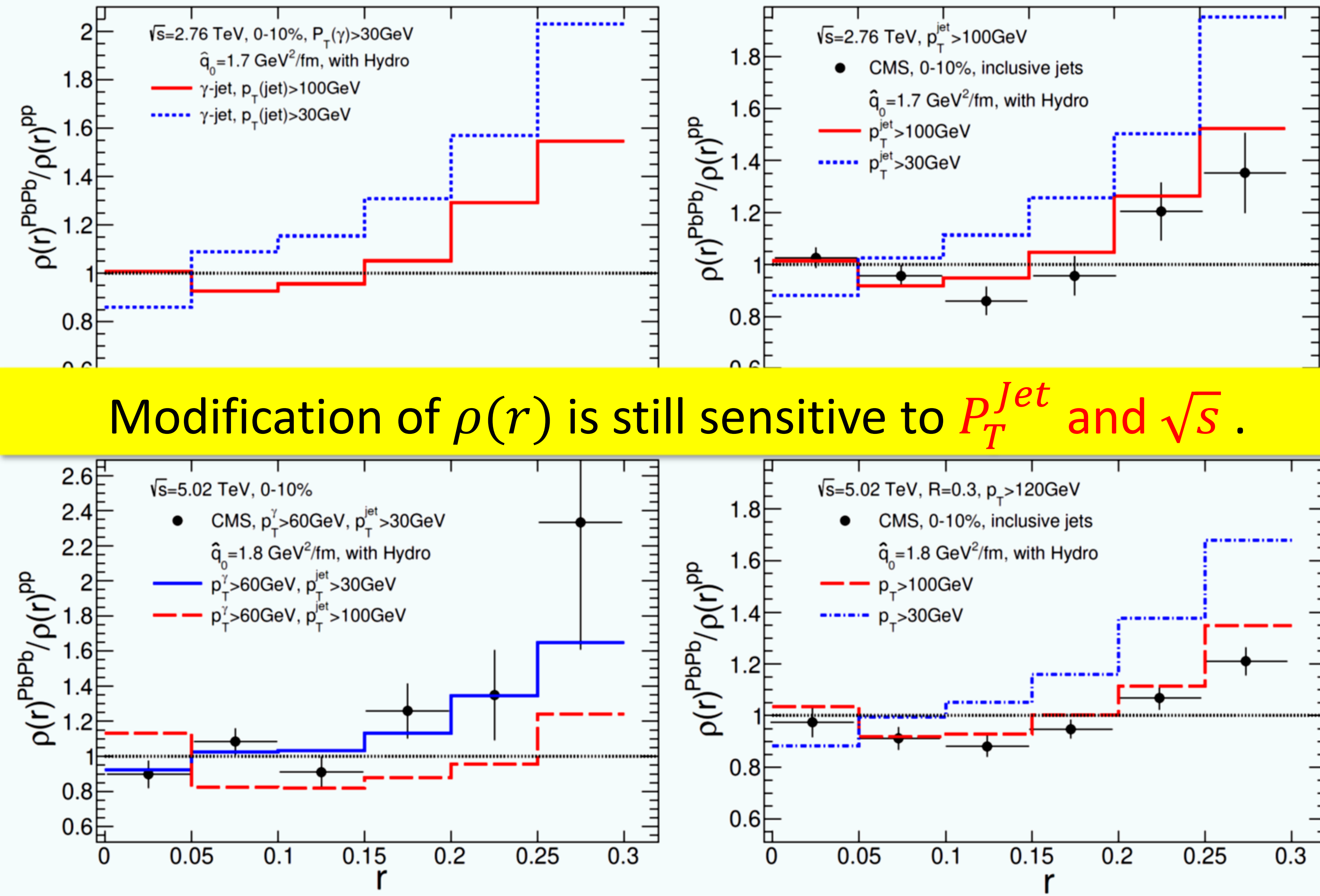
Effect of medium response





Medium response rise the jet shape function at large r.

Effect of medium response



Modification of $\rho(r)$ is still sensitive to P_T^{Jet} and $\sqrt{s}$.

Summary

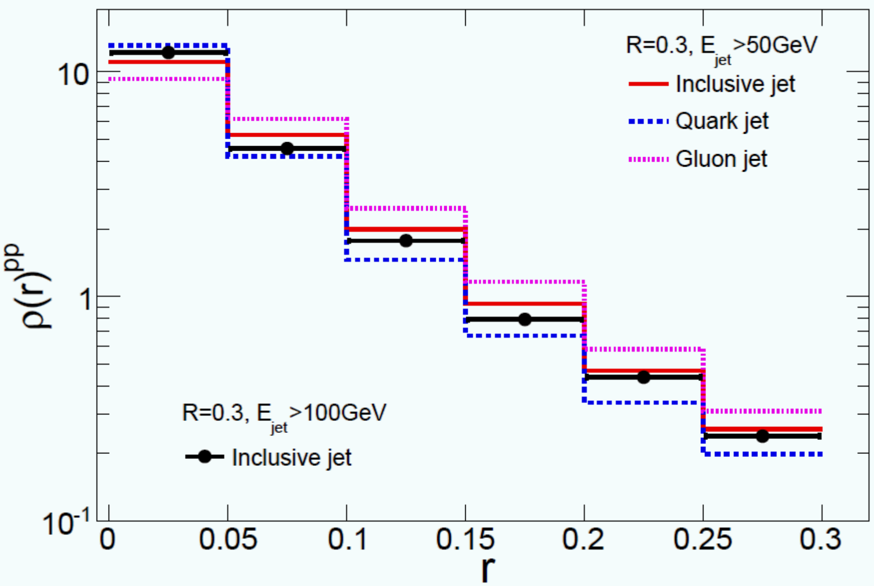
- Coupled differential transport equations are constructed to study the evolution of the partonic jet shower in the QGP medium, can describe the nuclear modification of the full jet energy and jet structure at both 2.76A TeV and 5.02A TeV.
- Collisional energy loss contributes most to full jet energy loss, and must be combined with other mechanisms to explain the modification of jet shape function.
- Modification of jet shape is sensitive to jet energy and collision energy, and not much to jet flavor. Need more measurements.
- Medium response feeds back some energy, and is important to jet shape at large r and cone size dependence of jet R_{AA}.

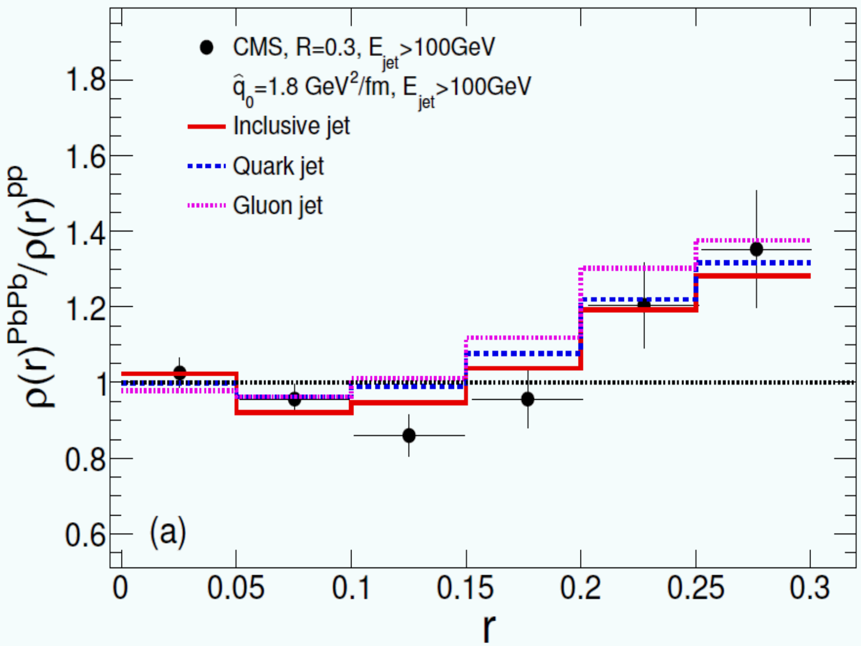
Outlook: R_{AA} at very high p_T, Energy dependent transport coefficients, hadronization, jet FF…

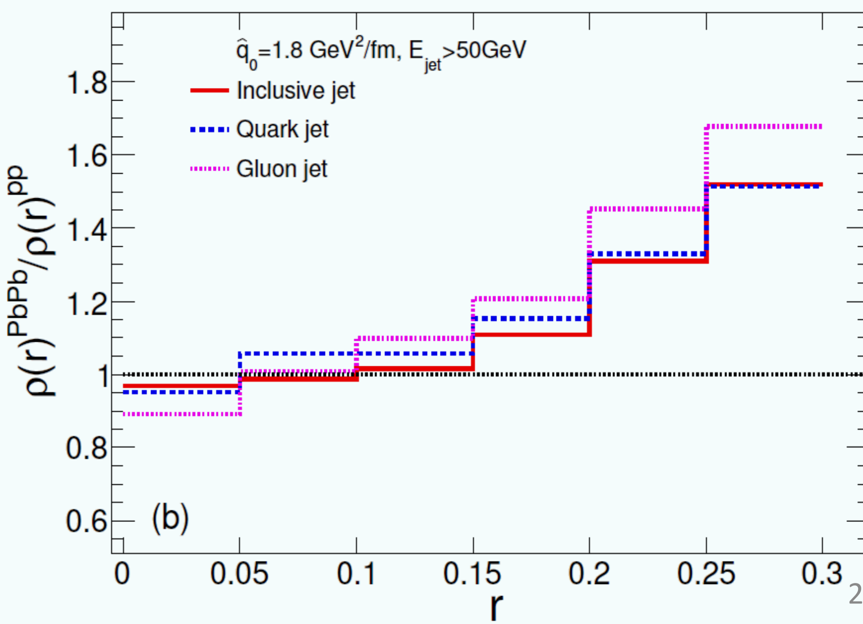
Thanks for your attention!

Jet energy and flavor dependence

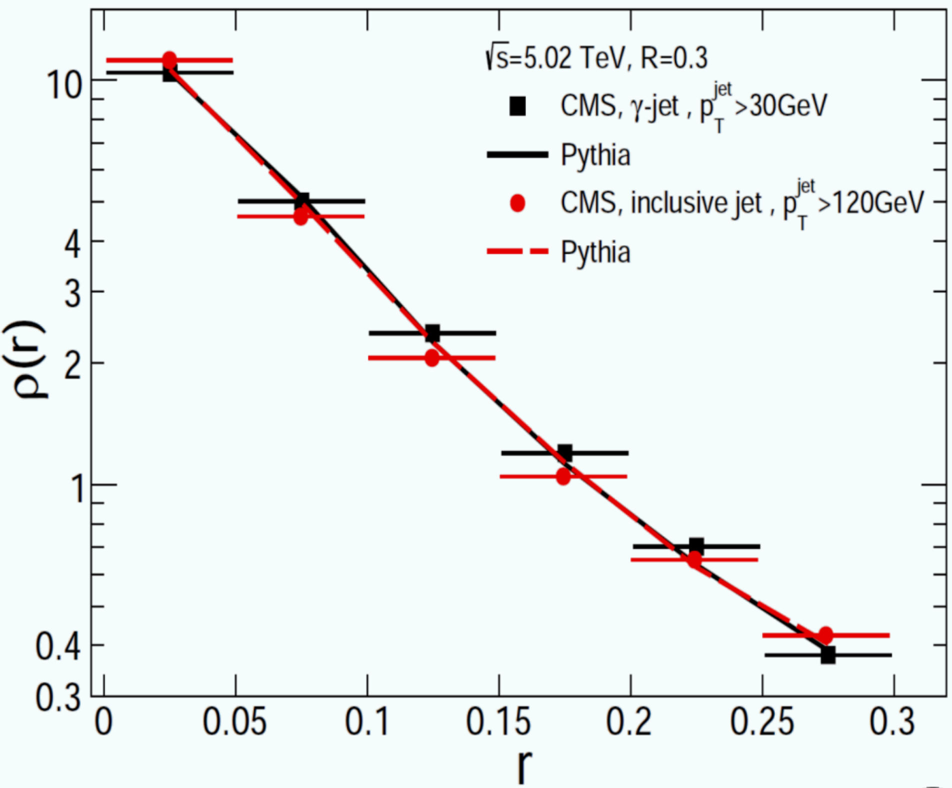
Lower energy jet is broader, gluon jet is broader.



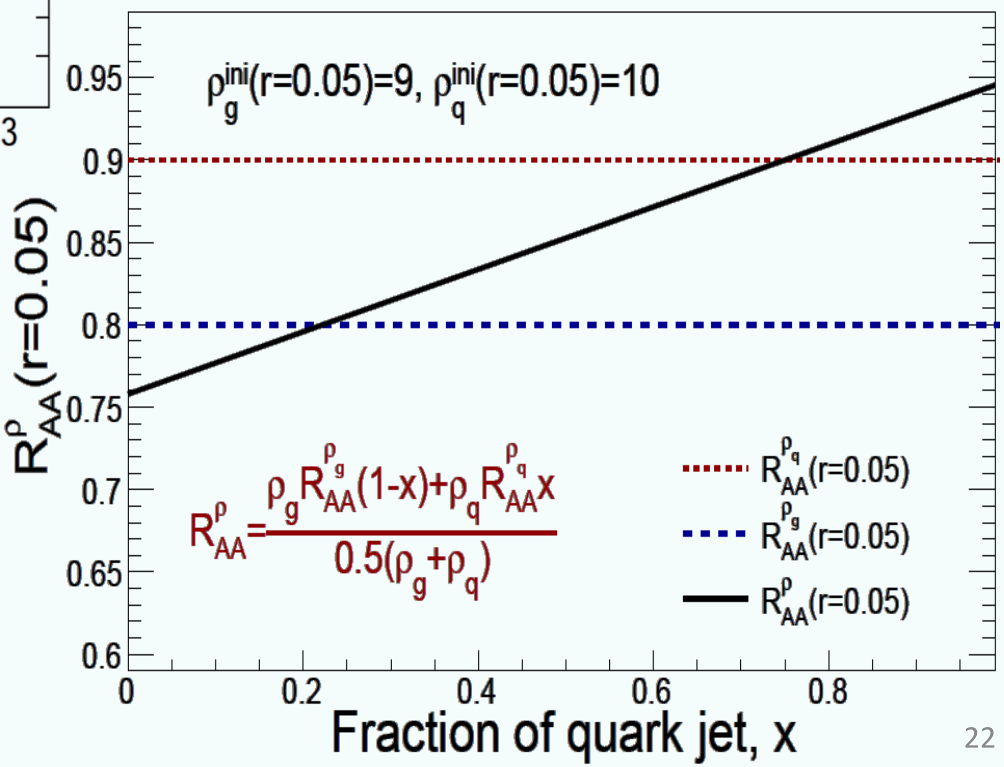




Modification of jet shape function is sensitive to jet energy, less to flavor.



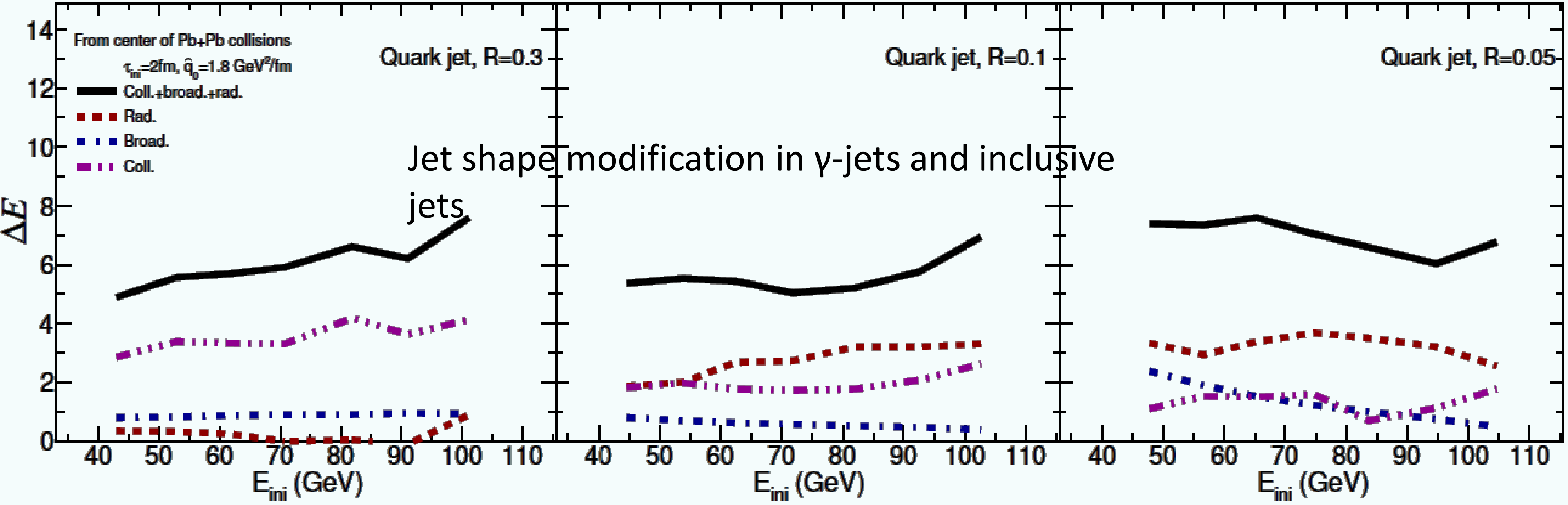
√s=5.02 TeV, R=0.3
CMS, γ-jet , p_T^{jet}>30GeV
Pythia
CMS, inclusive jet , p_T^{jet}>120GeV
Pythia
ρ(r)
r



$\rho_g^{ini}(r=0.05)=9,\ \rho_q^{ini}(r=0.05)=10$
$R_{AA}^{\rho}=\frac{\rho_g R_{AA}^{\rho_g}(1-x)+\rho_q R_{AA}^{\rho_q}x}{0.5(\rho_g+\rho_q)}$
$R_{AA}^{\rho_q}(r=0.05)$
$R_{AA}^{\rho_g}(r=0.05)$
$R_{AA}^{\rho}(r=0.05)$
Fraction of quark jet, x

Jet cone size dependence

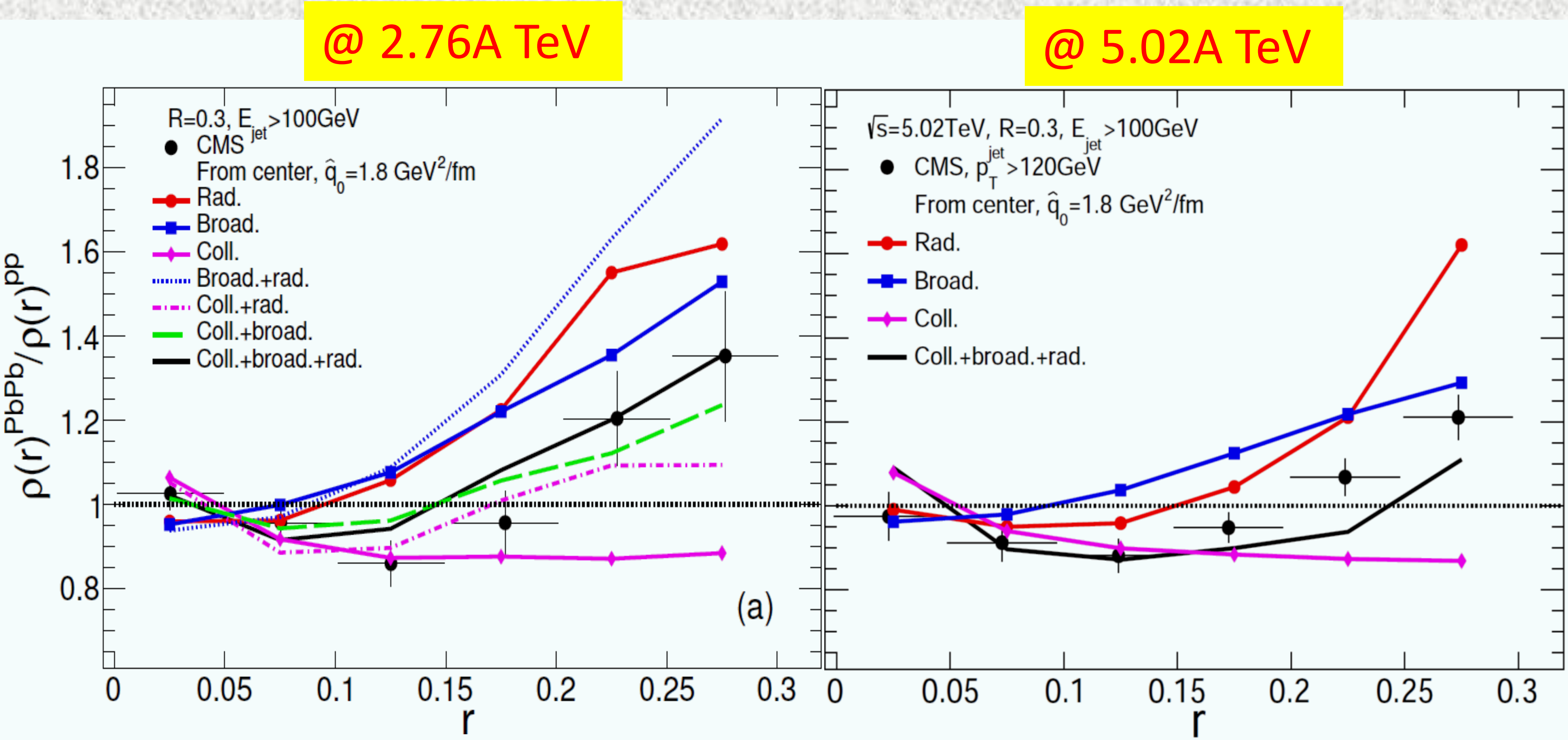
$$E_{\text{jet}}(R) = \sum_i \int_R \omega_i f_i(\omega_i, k_{i\perp}^2) d\omega_i dk_{i\perp}^2$$



Jet shape modification in γ-jets and inclusive jets

When jet cone size decreases, radiative energy loss increases, collisional energy loss decreases.

Effects of different mechanisms on **Jet shape**



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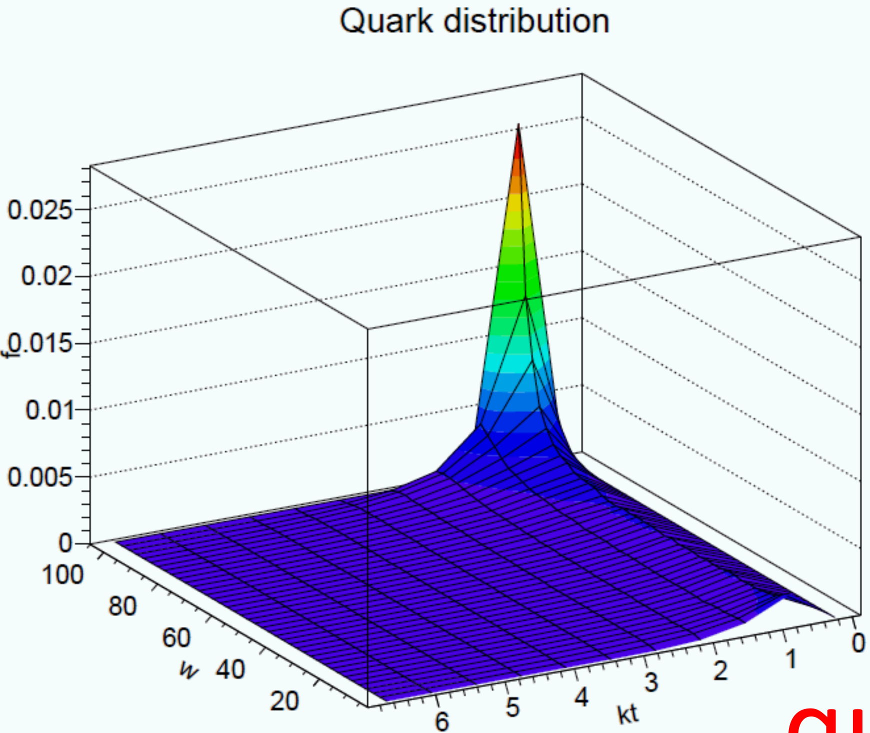
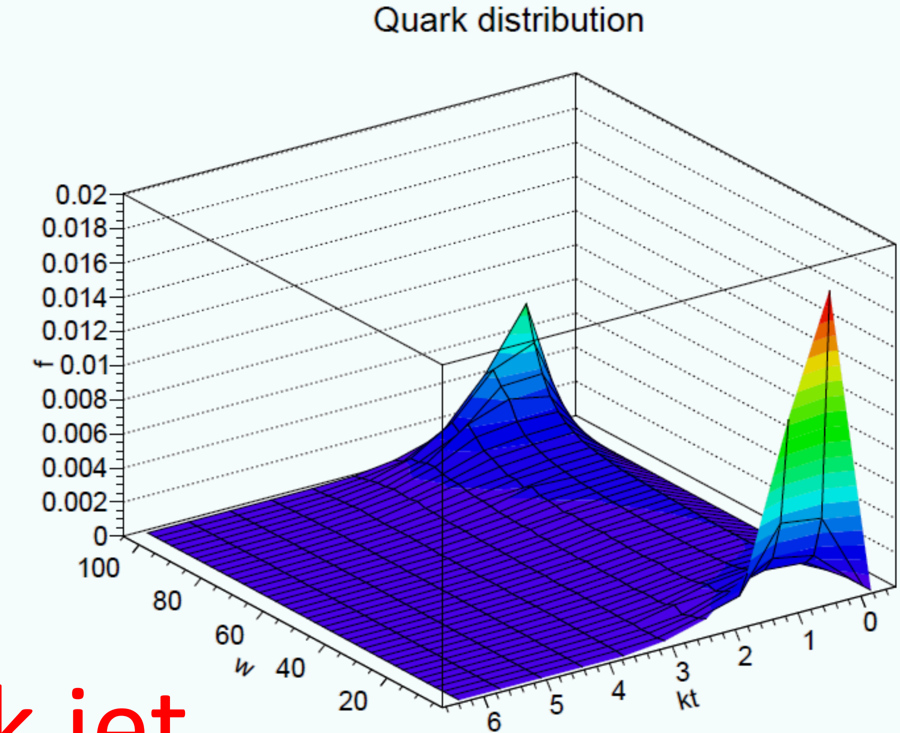

Quark distribution
f
0
0.005
0.01
0.015
0.02
0.025
w
100
80
60
40
20
kt
6
5
4
3
2
1
0


Quark distribution
f
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0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
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0.02
w
100
80
60
40
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kt
6
5
4
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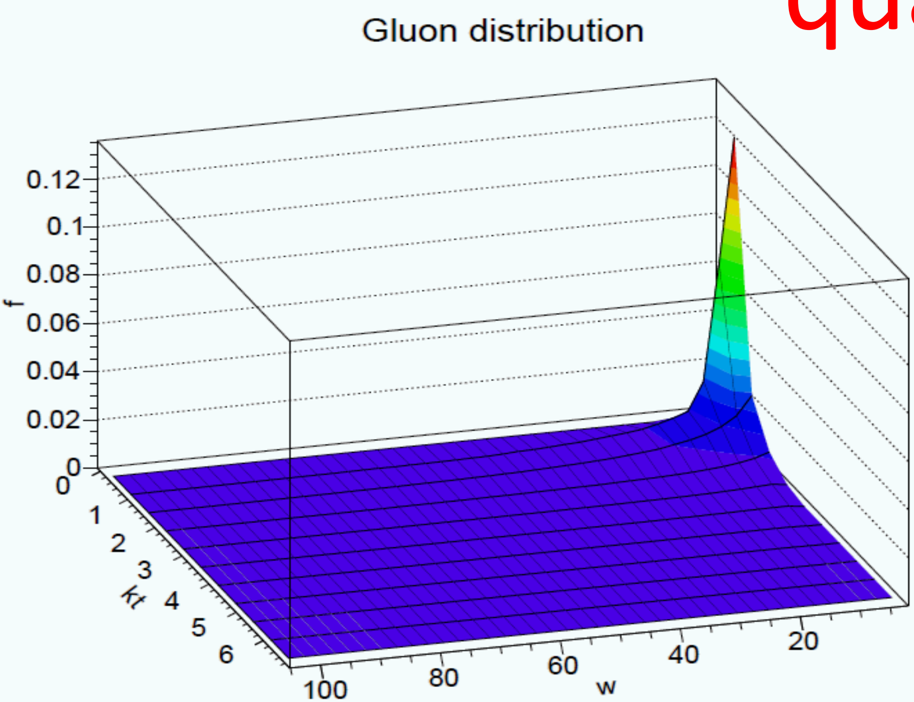
2
1
0

quark jet


Gluon distribution
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0.02
0.04
0.06
0.08
0.1
0.12
kt
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3
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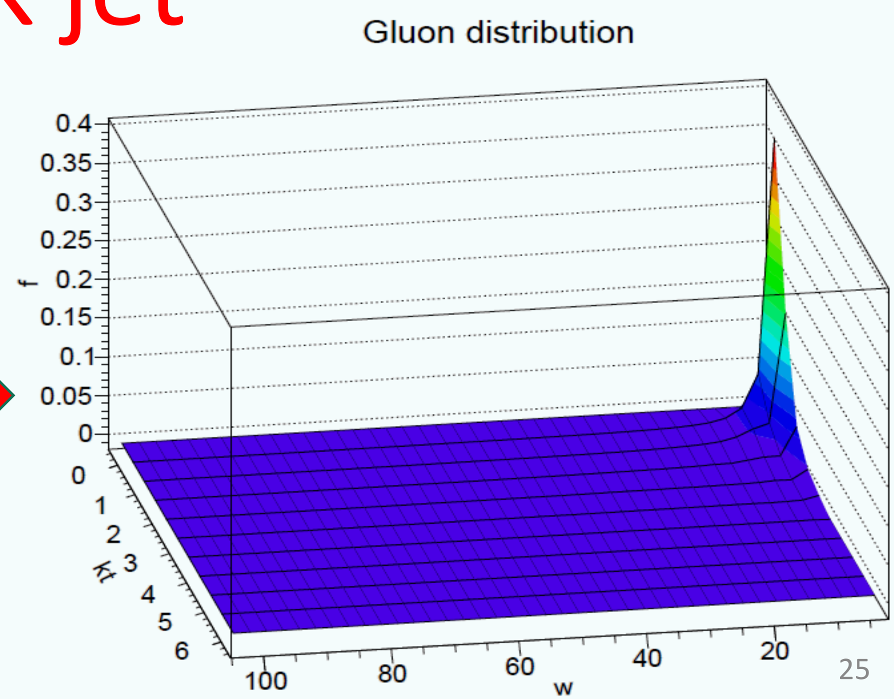
100
80
60
40
20


Gluon distribution
f
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
kt
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1
2
3
4
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6
w
100
80
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40
20