Parton splitting scales of reclustered large-radius jets in high-energy nuclear collisions

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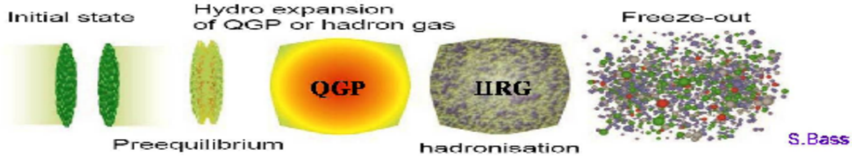
Collaborated with Shan-Liang Zhang, Ben-Wei Zhang

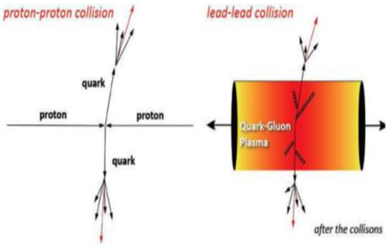
09/08/2022

Outline

- Motivation
- pp baseline
- LBT model
- Results
- Summaryg

Motivation





Jet

↓

Jet quenching

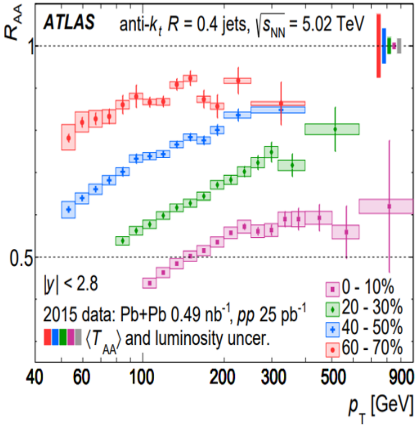
↓ Hard probe

The quark-gluon plasma

↓ observables

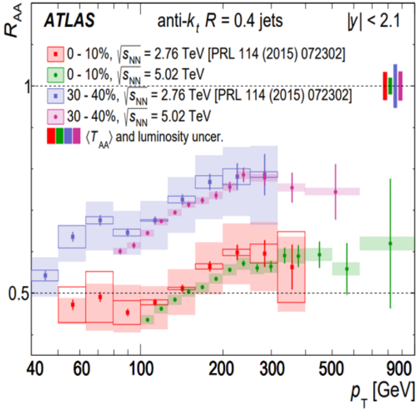
Nuclear modification, jet shapes, jet fragmentation function

Phys. Lett. B 790 (2019) 108



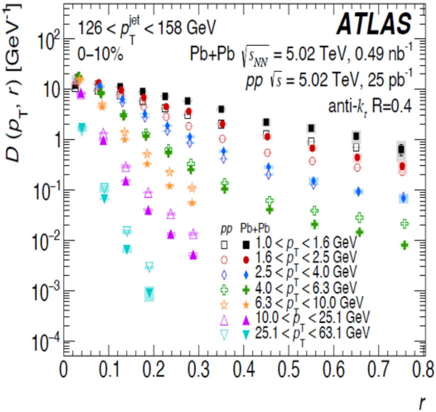
Phys. Lett. B 790 (2019) 108

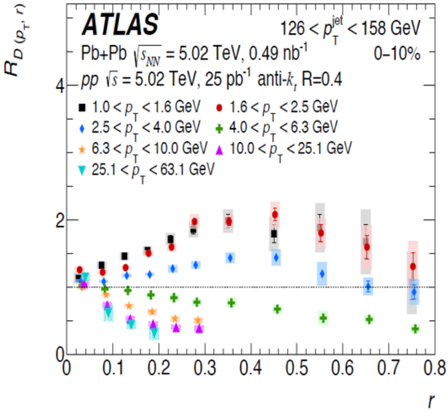
Phys. Rev. Lett. 114 (2015) 072302



$$R_{AA} = \frac{dN_{jet}^{AA}/dp_T dy}{\langle N_{coll} \rangle dN_{jet}^{pp}/dp_T dy}$$

Phys.Rev.C 100 (2019) 6, 064901

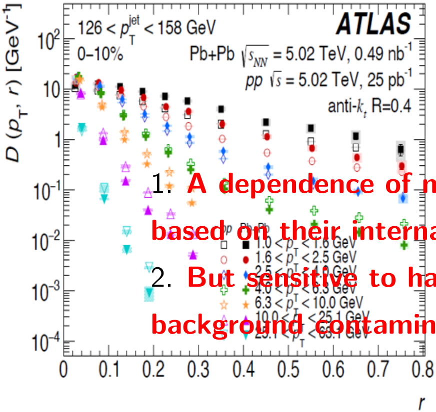


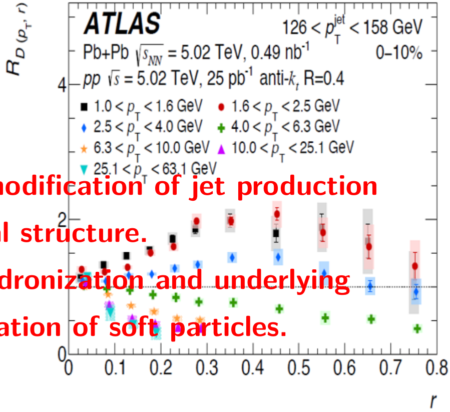


$$D(p_T, r) = \frac{1}{N_{jet}} \frac{1}{2\pi r dr} \frac{dn_{ch}(p_T, r)}{dp_T}$$

$$R_{D(p_T, r)} = \frac{D(p_T, r)_{Pb+Pb}}{D(p_T, r)_{pp}}$$

Phys.Rev.C 100 (2019) 6, 064901



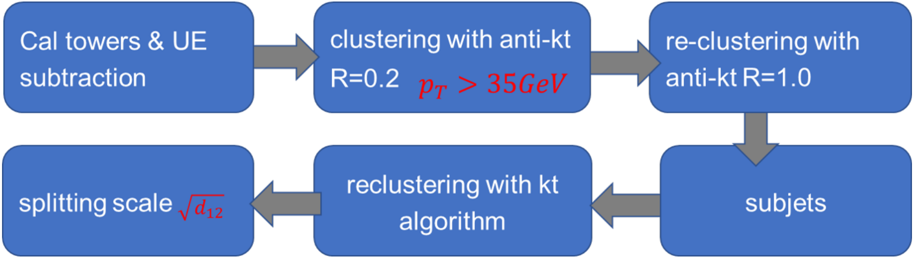


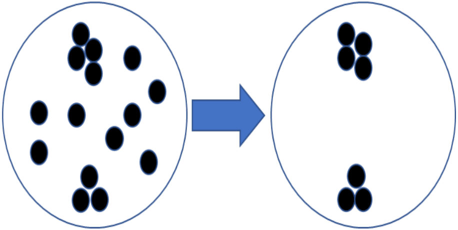
1. **A dependence of modification of jet production based on their internal structure.**
2. **But sensitive to hadronization and underlying background contamination of soft particles.**

$$D(p_T, r) = \frac{1}{N_{jet}} \frac{1}{2\pi r dr} \frac{dn_{ch}(p_T, r)}{dp_T}$$

$$R_{D(p_T,r)} = \frac{D(p_T, r)_{Pb+Pb}}{D(p_T, r)_{pp}}$$

Definition of large-radius jets



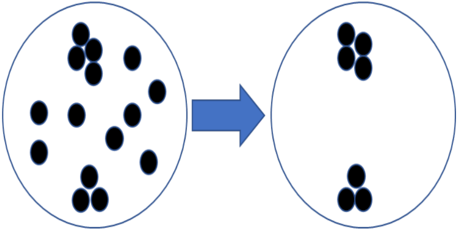


$$\sqrt{d_{12}} = \sqrt{min(p_{T,1}^2, p_{T,2}^2) * \Delta R_{12}^2}$$

$\sqrt{d_{12}} = 0$, single sub-jet (SSJ)

Definition of large-radius jets

Cal towers & UE subtraction → clustering with anti-kt R=0.2 $p_T > 35GeV$ → re-clustering with anti-kt R=1.0 → subjets → reclustering with kt algorithm → splitting scale $\sqrt{d_{12}}$

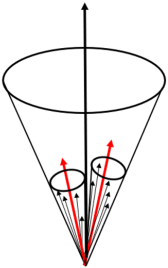


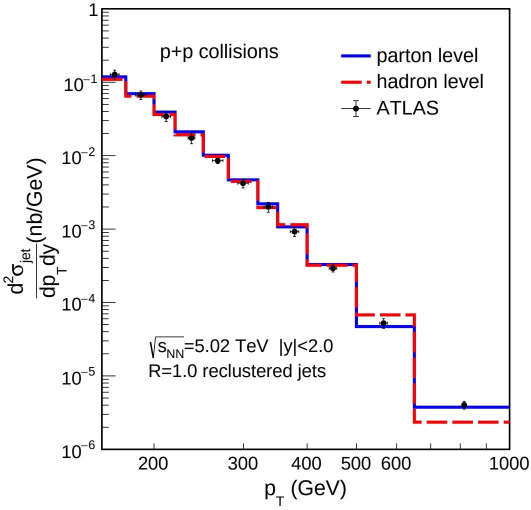
$$\sqrt{d_{12}} = \sqrt{min(p_{T,1}^2, p_{T,2}^2) * \Delta R_{12}^2}$$

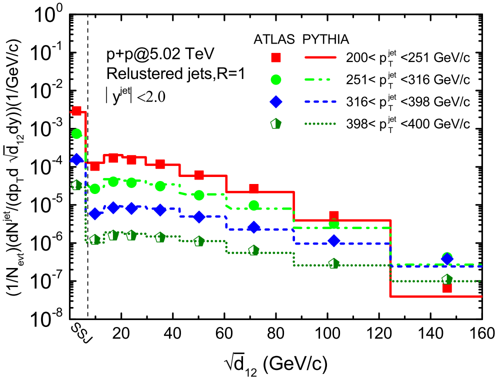
$\sqrt{d_{12}} = 0$, single sub-jet (SSJ)

remove soft radiation

Insensitive to hadronization.







Pythia8 calculations provide well agreement with experimental data.

LBT model

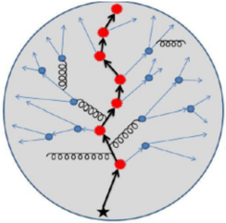
$$p_a \cdot \partial f_a = \frac{\gamma_b}{2} \int \sum_{bcd} \prod_{i=b,c,d} \frac{d^3 p_i}{2E_i(2\pi)^3} (f_c f_d - f_a f_b) |M_{ab\to cd}|^2$$

$$\times S(\hat{s}, \hat{t}, \hat{u})(2\pi)^4 \delta^4(p_a + p_b - p_c - p_d) + inelastic$$

He, Luo, Wang and Zhu, Phys. Rev. C 91 (2015) 054908

$$\frac{dN_g^a}{dz dk_\perp^2 dt} = \frac{6\alpha_s P_a(z) k_\perp^4}{\pi(k_\perp^2 + z^2 m^2)^4} \frac{p \cdot u}{p_0} \hat{q}_a(x) \sin^2 \frac{\tau - \tau_i}{2\tau_f}$$

Zhang, Wang, Wang, PRL 93 (2014) 072301



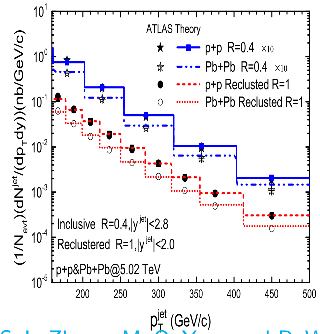
Medium Excitation

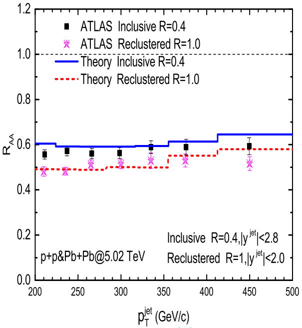
LBT model has been used successfully to describe light-favor, heavy-flavor hadron and jet suppression, Z/W/γ+jet correlations in heavy-ion collisions.

Luo, Cao, He and Wang, Phys. Lett. B 782 (2018), 707-716

Zhang, Luo, Wang and Zhang, Nucl. Phys. A 982 (2019), 599-602

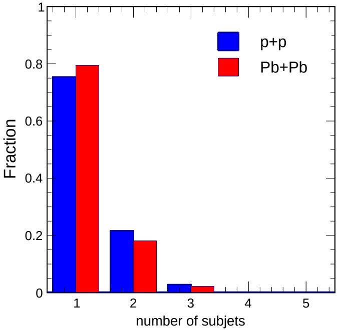
p_T spectra and the nuclear modification factor



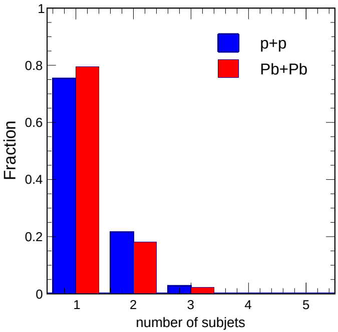


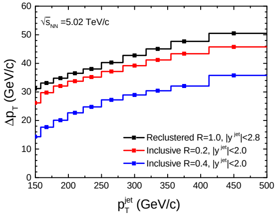
S. L. Zhang, M. Q. Yang and B. W. Zhang, Eur. Phys. J. C **82**, no.5, 414 (2022).

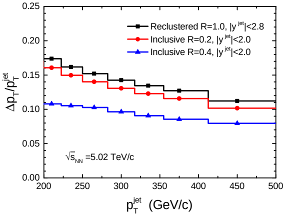
- An obvious suppression of the inclusive jets as well as the reclustered LR jets in Pb+Pb collisions relative to pp collisions can be seen.
- R_{AA} goes up slowly with increasing p_T^{jet}.
- R_{AA} of LR jets with R=1.0 is a bit smaller than that of inclusive jets with R=0.4.


p+p
Pb+Pb
Fraction
0
0.2
0.4
0.6
0.8
1
1
2
3
4
5
number of subjets

LR jets will lose more energy than both R=0.2 and R=0.4 inclusive jets.

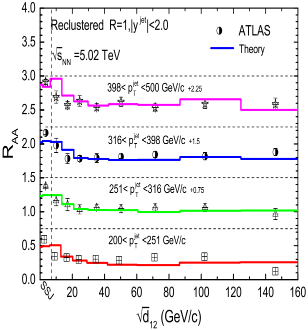






R_{AA} goes up slowly with increasing p_T^{jet}.

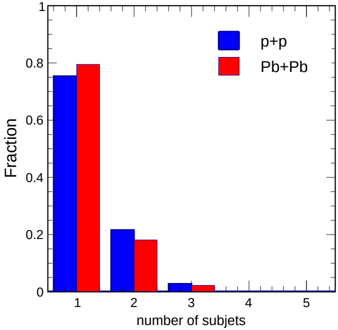
The splitting scale ($\sqrt{d_{12}}$)



S. L. Zhang, M. Q. Yang and B. W. Zhang, Eur. Phys. J. C **82**, no.5, 414 (2022).

- R_{AA} for LR jets with SSJ is significantly different compared to those with MSJ.
- R_{AA} sharply decreases with increasing $\sqrt{d_{12}}$ for smalle values of the splitting scale followed by flattening for larger $\sqrt{d_{12}}$.

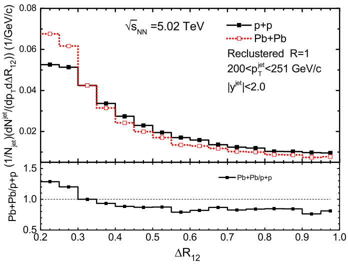
LR jets with a SSJ

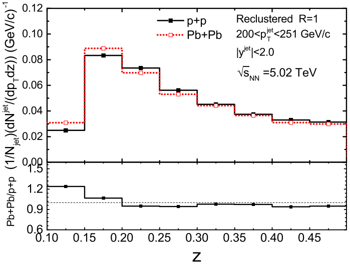


- Jets with SSJ are less suppressed than jets with MSJ.
- The change of jet substructure due to jet medium interactions may play an indispensable role.

LR jets with MSJ

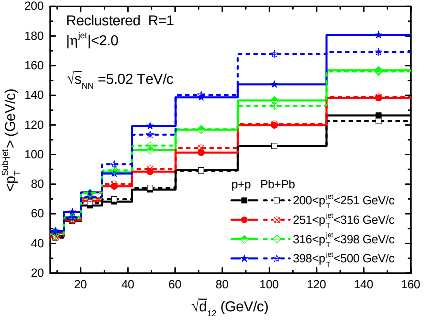
$$\sqrt{d_{12}} = \sqrt{min(p_{T,1}^2, p_{T,2}^2) * \Delta R_{12}^2} \qquad z = p_T^{min} / p_T^{Jet}$$

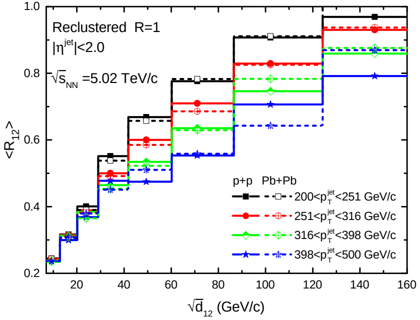




S. L. Zhang, M. Q. Yang and B. W. Zhang, Eur. Phys. J. C **82**, no.5, 414 (2022).

- At small ΔR_{12}, z region, enhancement, $R_{AA} > 1$.
- At large areas, suppression, $R_{AA} < 1$.

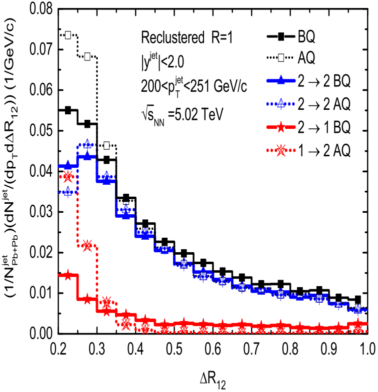


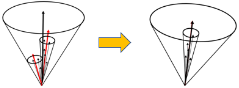


S. L. Zhang, M. Q. Yang and B. W. Zhang, Eur. Phys. J. C **82**, no.5, 414 (2022).

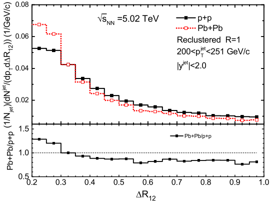
- $\left\langle p_T^{subjet} \right\rangle$ and $\langle \Delta R_{12} \rangle$are increasing with increasing $\sqrt{d_{12}}$.
- Almost no difference of $\left\langle p_T^{subjet} \right\rangle$ and $\langle \Delta R_{12} \rangle$ between p+p and Pb+Pb collisions with the same jet transverse momentum p_T^{Jet}.
- p_T^{Jet} is much larger for higher energy LR jets, while $\left\langle p_T^{subjet} \right\rangle$ is much smaller.

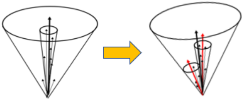
The splitting angle ΔR_{12}

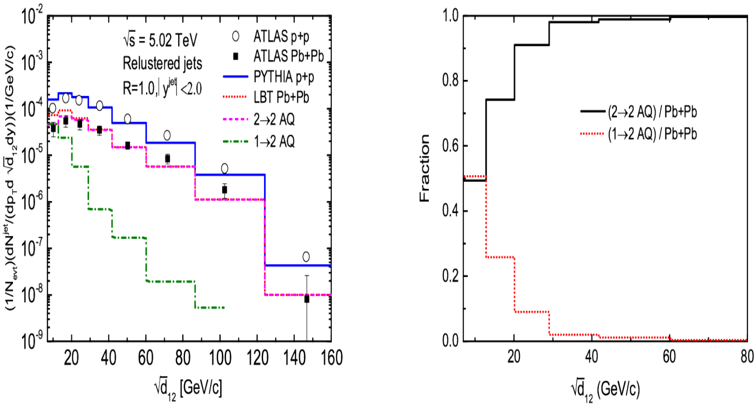




$$A \rightarrow B \begin{cases} A: N_{subjet} & before\ quenching(BQ) \\ B: N_{subjet} & after\ quenching(AQ) \end{cases}$$

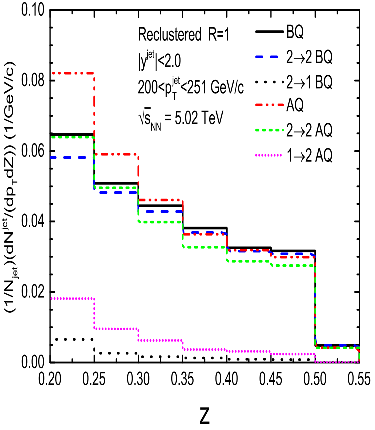




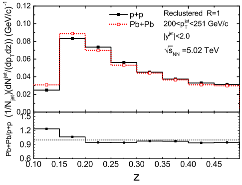


Medium modifications on jet substructure alter $\sqrt{d_{12}}$ distribution pattern.

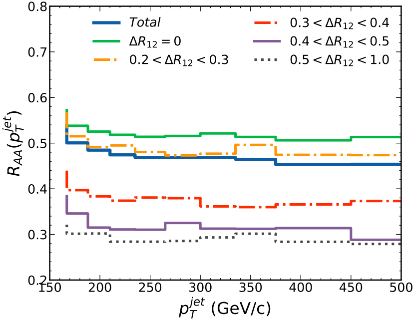
The splitting function $z = \frac{p_T^{min}}{p_T^{Jet}}$



- $2 \to 2$, enhanced in small region and suppressed in large region.
- The contributions from $1 \to 2$ is larger than that from $2 \to 1$.

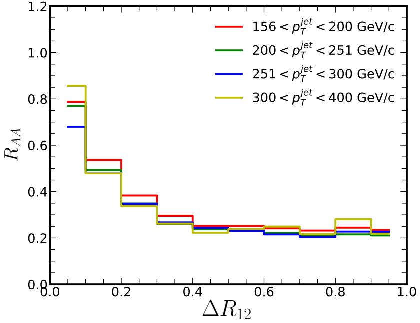


$R_{AA}(\Delta R_{12})$ for different ΔR_{12}



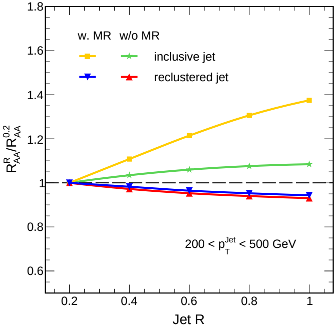
R_{AA} depends on ΔR_{12}, and jets having small ΔR_{12} values suppressed less than that with larger values.

$R_{AA}(p_T)$ for different p_T



R_{AA} does not significantly depend on p_T^{jet}.

R-dependence

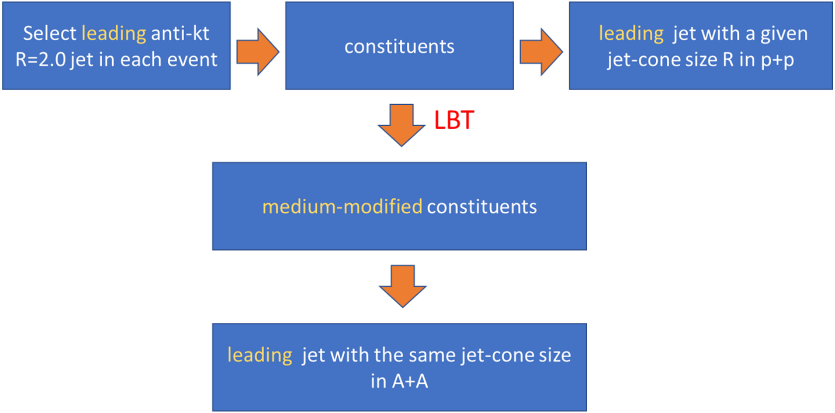


- $R_{AA}^{R}/R_{AA}^{0.2}$ significantly increases for inclusive jets but slightly decreases for LR jets with increasing jet R.
- The medium response has strong effect on inclusive jets while no significant effect is found for LR jets.

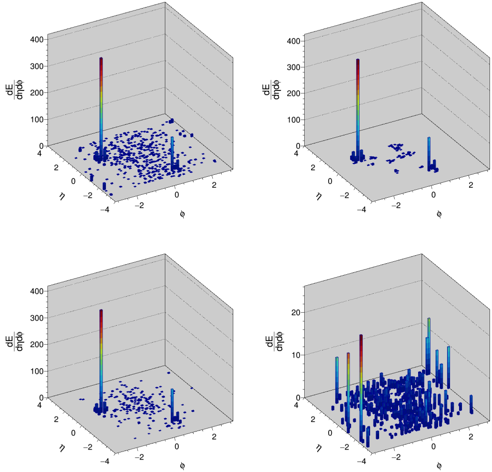
- on Pythia8 and LBT model, we have carried out the first detailed theoretical investigation of the medium modification on LR jets production and its the hardest parton splitting.
- The medium modifications on jet ΔR_{12} and z spectra are the combined result of both jet yields reduction and the changes of the jet substructures.
- The medium modification of ΔR_{12} and z lead to that of $\sqrt{d_{12}}$.
- jet suppression largely depends on θ_{SJ} and weakly depends on p_T.
- LR jets suppression indeed depends on its substructure.
- Inclusive jets with large R will lose less energy. Inclusive jets have obvious R-dependence and strong effect on medium response. however, LR jets with large R will lose more energy. no significant R-dependence and effect from medium response are found for LR jets.

Thank you

backup


Select leading anti-kt R=2.0 jet in each event
constituents
leading jet with a given jet-cone size R in p+p
LBT
medium-modified constituents
leading jet with the same jet-cone size in A+A

First step



Definition of a new seed jet:

$E_T^{max} > 3GeV$、 $\frac{E_T^{max}}{\langle E_T \rangle} > 4$

Event plane angle:

$\psi_2 = \frac{1}{2}\tan^{-1}\left(\frac{\sum_k w_k E_{Tk}\sin(2\phi_k)}{\sum_k w_k E_{Tk}\cos(2\phi_k)}\right)$

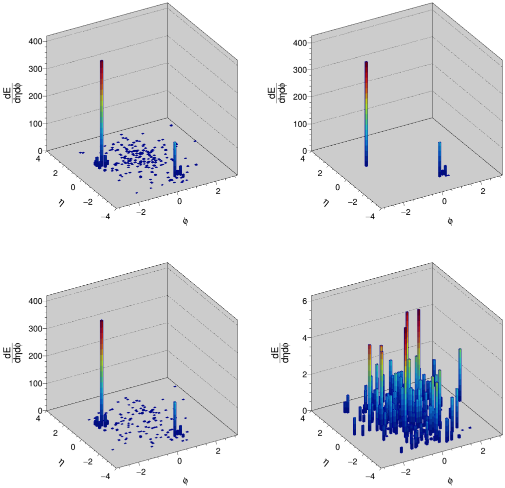
Elliptic flow:

$v_{2i} = \frac{\sum_{j\in i} E_{Tj}\cos(2(\phi_j - \psi_2))}{\sum_{j\in i} E_{Tj}}$

Transverse energies:

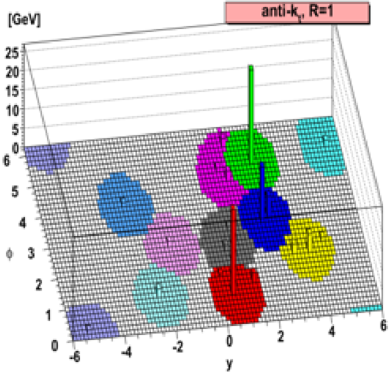
$E_T^{sub} = E_{Tj} - A_j \rho_i(\eta_j)(1 + 2v_2\cos(2(\phi_j - \psi_2)))$

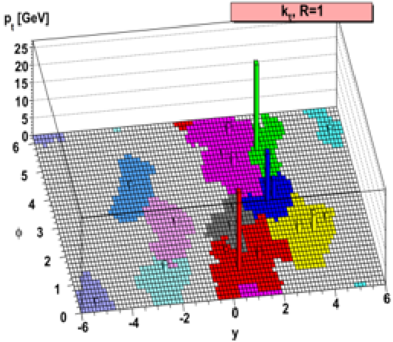
Second step



Definition of a new seed jet: $E_T > 25 GeV$, Update$\rho_i(\eta_j)$ and v_2

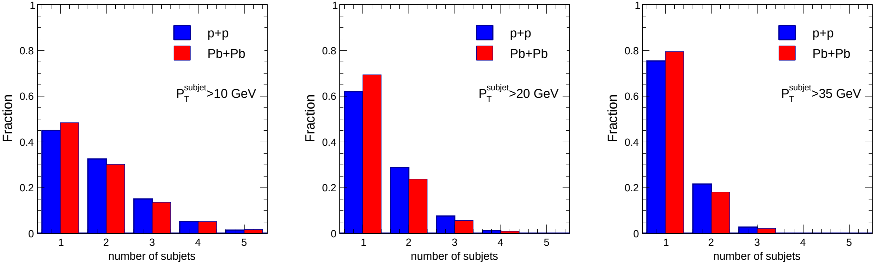
Algorithms





$anti-k_T$ algorithm $\quad d_{ij} = min(p_{Ti}^{-2}, p_{Tj}^{-2})\Delta R_{ij}/R_2$

k_T algorithm $\quad d_{ij} = min(p_{Ti}^{2}, p_{Tj}^{2})\Delta R_{ij}/R_2$



The fractions of large-radius jets with different structures indeed depend on the threshold of p_T^{subjet}.