Overall momentum balance and redistribution of the lost energy in asymmetric dijet events from a multi-phase transport model

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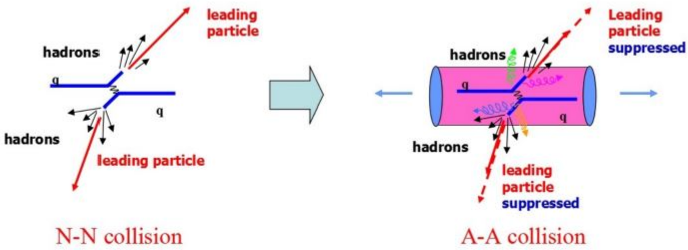
Outline

Introduction

Jet quenching

- Jets interact strongly with the medium, leading to a marked reduction of their energy. This energy reduction is called "jet quenching"
- Important evidence for the formation of QGP



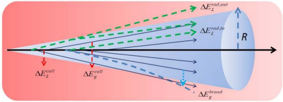
Suppression of large transverse momentum hadron production[1]

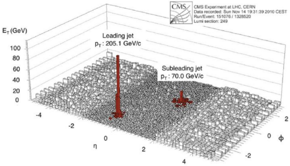
[1] Phys. Rev. Lett., 89:202301, Oct 2002

Introduction

Fully reconstructed jets modified by Jet quenching

- Include both leading and subleading fragments of the parton showers
- Expect to provide more detailed information than hadrons on interactions between jets and the medium.





- single inclusive full jet spectra[2],
- the transverse momentum asymmetry distributions and angular correlations for dijet and photon-jet events[3]
- the internal structures of the full jets[4] etc.

[2]ATLAS, PRL114 (2015) 072302
[3]CMS,PRC84 (2011) 024906
[4]CMS, Phys. Lett. B730 (2014) 243-263

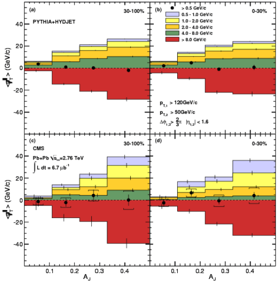
Motivation

It is of great interest to investigate the fate of the lost energy from the jets

- How it evolves with the dynamical medium and where it goes.

CMS studied such effect using $\langle \not{p}_T^{\parallel} \rangle$ observable:

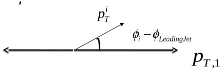
- Complementary information about the overall momentum balance in the dijet events can be obtained using the projection of missing P_T of reconstructed charged tracks onto the leading jet axis.



Phys. Rev.C84:024906, 2011

For each event, this projection was calculated as:

$$\not{p}_T^{\parallel} = \sum_i -p_T^i \cos(\phi_i - \phi_{LeadingJet})$$



$\not{p}_T^{\parallel}$ by all hadrons projected in a special direction: leading jet.

then average over events to obtain $\langle \not{p}_T^{\parallel} \rangle$.

Our work

We study $\langle \not{p}_T^{\parallel} \rangle$ observable using AMPT model

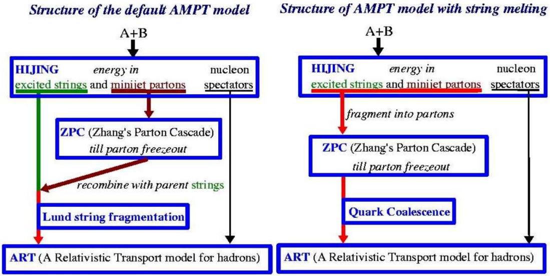
- Study the redistribution of lost energy from jets following the CMS

A recent study by Y. Tachibana and T.Hirano, Nucl.Phys. A932 (2014) 387-391

- 3+1D hydrodynamic model.
- Simplified energy deposition profile. (A single parton)

We simultaneously simulate jet propagation and medium evolution.

AMPT model



Structure of the default AMPT model (left) and the AMPT model with string melting (right)

- We use the AMPT with string melting mechanism
- Pb+Pb collisions at 2.76 ATeV
- Three sets of parton interaction cross sections ($\sigma = 0, 1.5, 3.0 mb$) are used
- Fastjet package[5] is used to reconstruct the full jets with the anti-k_t algorithm

[5]FastJet User Manual.Eur. Phys. J., C72:1896, 2012

Jet reconstruction

Sequential recombination jet algorithms:

- k_t algorithm, Cambridge/Aachen algorithm, anti-k_t algorithm

All these algorithms can generalise as:

$$d_{ij} = min(p_{ti}^{2p}, p_{tj}^{2p}) \frac{\Delta R_{ij}^2}{R^2} \qquad \Delta R_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2, \tag{1}$$

$$d_{iB} = p_{ti}^{2p} \tag{2}$$

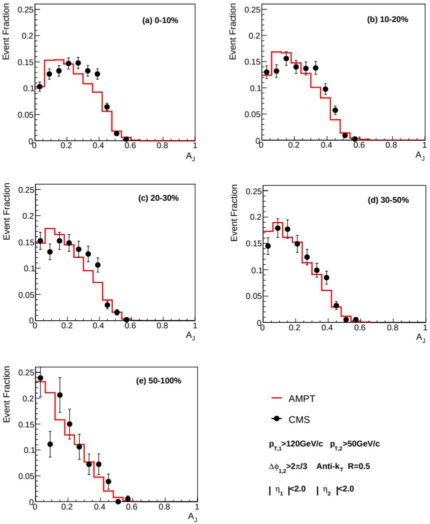
where p is a parameter that is 1 for the k_t algorithm, and 0 for C/A, -1 for anti-k_t.

They are formulated as follows:

- 1. Work out all the d_{ij} and d_{iB} ;
- 2. Find the minimum of the d_{ij} and d_{iB};
- 3. If it is a d_{ij} , recombine i and j into a single new particle and return to step 1;
- 4. Otherwise, if it is a d_{iB}, declare i to be a [final-state] jet, and remove it from the list of particles. Return to step 1;
- 5. Stop when no particles remain.

We use anti-k_t algorithm based on FASTJET package.

Transverse momentum asymmetry in dijet events



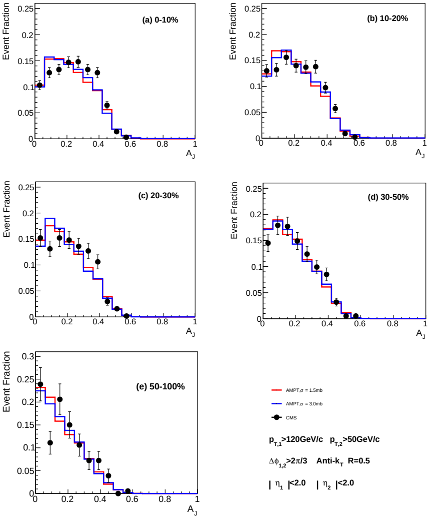
The asymmetry variable:

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

From the most peripheral PbPb (pp) to the most central PbPb collisions, A_J distribution shifts to the right side (larger A_J values).

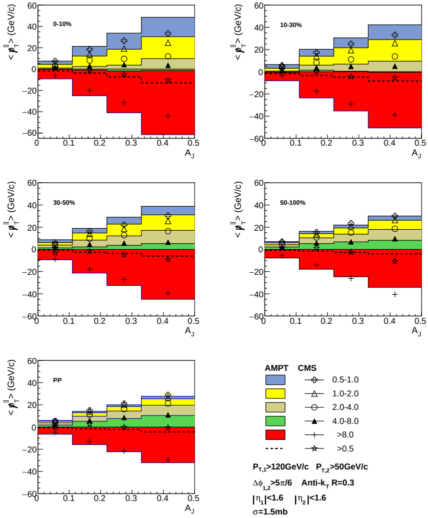
- Away-side sub-leading jets: longer passage, more energy loss
  Asymmetry is generated by JQ !

Transverse momentum asymmetry in dijet events



- Red line stands for $\sigma = 1.5$mb and Blue line for $\sigma = 3.0$mb in AMPT model
- There is no remarkable dependence on σ
- Interactions between jets and medium are strong enough for $\sigma = 1.5$mb
- Increasing the value of σ in this condition change little on A_J distribution

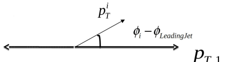
Overall transverse momentum balance in dijets events



$\langle p_T^{\parallel} \rangle$ by all hadrons projected in a special direction: leading jet. Event average.

Projected transverse momentum:

$$p_T^{\parallel} = \sum_i -p_T^i \cos(\phi_i - \phi_{LeadingJet})$$



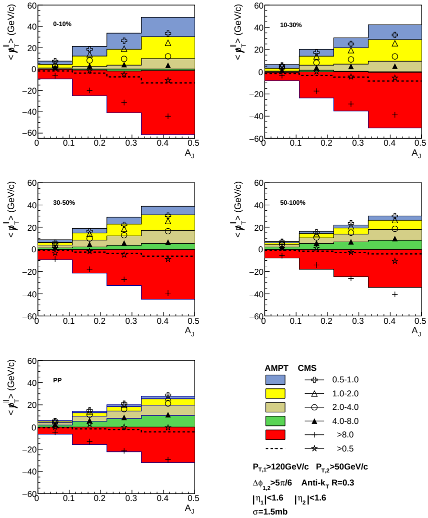
"−" value: leading jet direction

Qualitatively describe data for:

- different A_J bin.
- different P_T bin.
- different centrality bin.

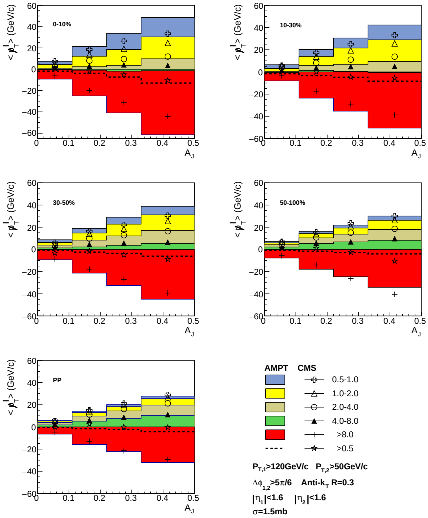
The "−" part is balanced by the "+" part due to momentum conservation.

Imbalance is enlarged by Jet quenching



- "−" contribution from $p_T > 8.0$ GeV/c.
- The "−" contribution increases from peripheral to central PbPb.
- The subleading jets tend to hadronize into less hard fragments due to stronger jet-medium interaction and energy loss.

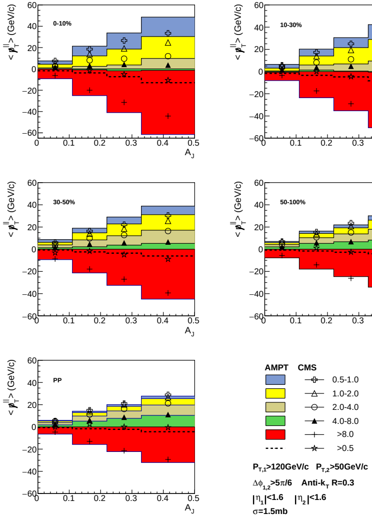
Lost energy is carried by soft hadrons

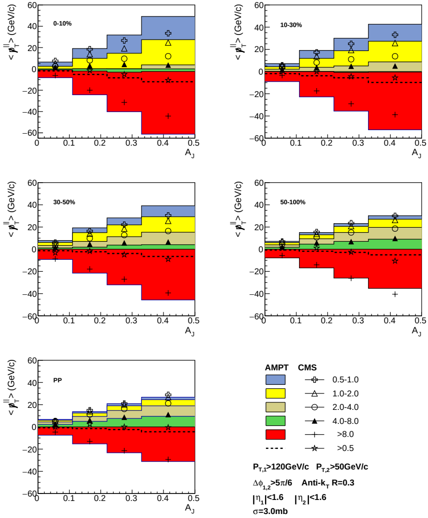


- "+" contribution from $p_T = 0.5\text{-}2.0$ GeV/c.
- The "+" contribution increases from peripheral to central PbPb.
- Soft "+" domination in the most central PbPb collisions.
- A large portion of the lost energy from the jets is carried by the final state soft hadrons
- Only elastic processes in AMPT, the transportation of the lost energy from hard jets into the soft hadrons are mainly caused by elastic scatterings

Compare with the results for $\sigma = 3.0$mb (right)

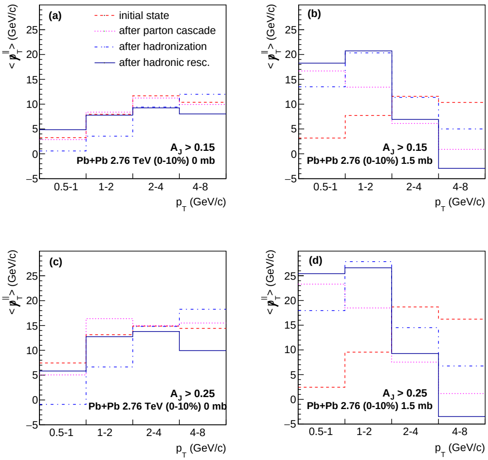
- Looked similar, maybe $\sigma = 1.5$mb already produces strong enough interaction like A_J





How and when energy loss happens ?

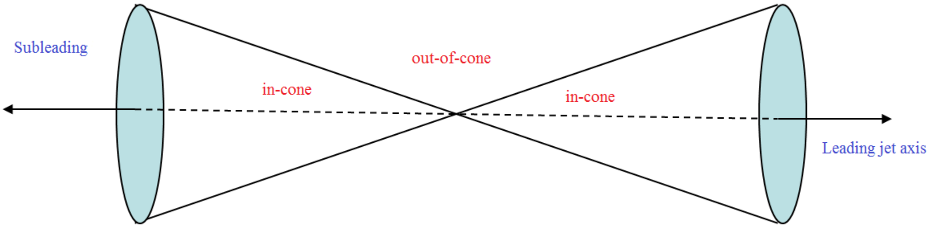
Check "+" contributions by $p_T < 8.0$ GeV/c for 4 different evolution stages in AMPT



- Figure for pp is very similar to PbPb ($\sigma = 0$ mb)
- In PbPb, $\sigma = 1.5$mb, contributions to $\langle \not{p}_T^{\parallel} \rangle$ changes dramatically after ZPC
- Dijet asymmetry is mainly due to jet-medium interactions and jet energy loss in the partonic phase
- Decrease (low p_T) and increase (others) after hadronization due to recombination
- The lost energy from the jets is carried by the partons which are fragmented into final state soft hadrons

To check where lost energy goes

In the $\phi - \eta$ space, define almost back-to-back di-cone with jet axis

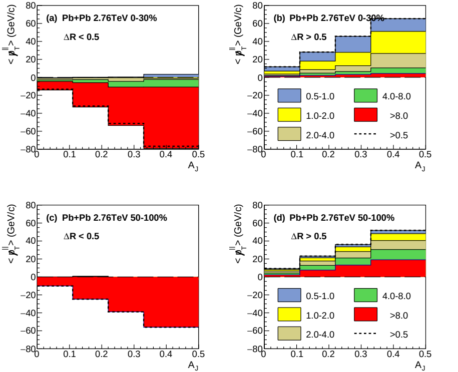


The cone size: $\Delta R = \sqrt{(\phi - \phi_J)^2 + (\eta - \eta_J)^2}$

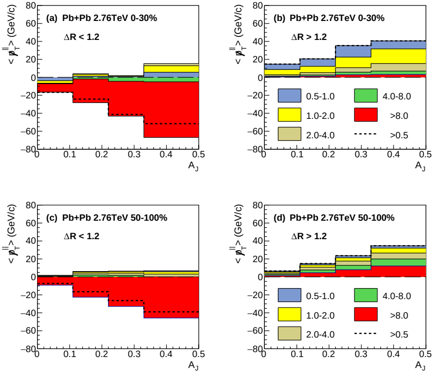
For infinitely large ΔR, one includes all charged hadrons in the cones.

Large angle scattering for Jet quenching

$\Delta R = 0.5$



$\Delta R = 1.2$

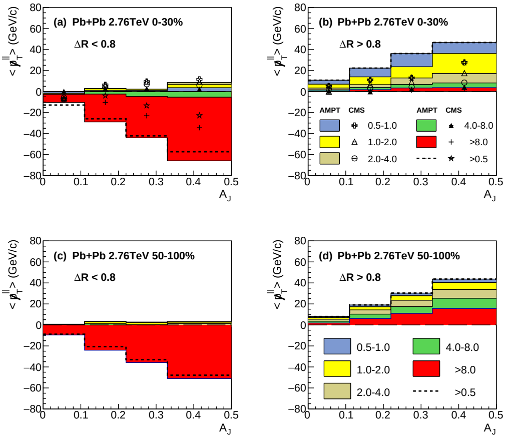


in-cone out-of-cone in-cone out-of-cone

- In-cone by large P_T hadrons from hard fragments of leading and subleading jets
- Out-of-cone by soft hadrons in central PbPb even if large cone size is chosen

Lost energy carried by soft hadrons is redistributed at large angles away from dijet axis by elastic collisions.

Compare with CMS data



- For the case $\Delta R = 0.8$, compared to CMS data
- Overestimation of CMS data
- The reason might be: neglection of radiative energy loss

Summary

- A detailed analysis is performed for $\langle \not{p}_T^{\parallel} \rangle$ within AMPT model, to study the overall P_T balance and the redistribution of the lost energy from hard jets for asymmetric dijet events.
- We find that $\langle \not{p}_T^{\parallel} \rangle$ in the leading jet direction is mainly contributed by hard hadrons, while $\langle \not{p}_T^{\parallel} \rangle$ in the opposite direction in central collisions is dominated by soft hadrons, which obeys momentum conservation.
- A large amount of the lost energy from hard jets due to elastic collisions in the partonic stage in AMPT model is transported into the soft partons at large angles.
- Future studies including also inelastic processes should be helpful in understanding the overestimation of in-cone and out-of-cone imbalances, and shed light on different roles played by radiative and collisional processes in the redistribution of the lost energy from hard jets.

Thank you !