Realistic modelling of jets in heavy-ion collisions

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Jets and dijets

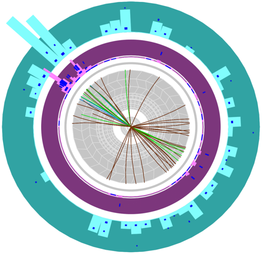
- Jets in a thermal medium
- The importance of full Monte Carlo
- MUSIC+MARTINI+fastjet
- Dijet observables at RHIC and the LHC

Jets in general

Hard processes can be factorized to perturbative and non-perturbative functions:

$$d\sigma_h = \sum_{i,j} \int dx_1 dx_2 f_i^1(x_2, Q^2) f_j^2(x_2, Q^2) d\sigma_{ij\to ab} D_{a\to h}(z, Q^2) :$$

The physics of hadronization non-perturbative, dominated by *collinear* and *soft* processes, resulting in a *narrow* cone of hadrons (jet). $\vec{p}_{Ti} + \vec{p}_{Tj} \approx 0$, therefore in a dijet $\vec{P}_{T1} = -\vec{P}_{T2}$ in elementary collisions.



From ATLAS (2010).

Reconstructing jets

A definition insensitive to non-perturbative physics is needed.

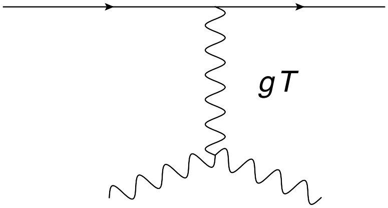
The anti-k_T algorithm (Cacciari et al. 2008): The metric between hadrons 1 and 2 is

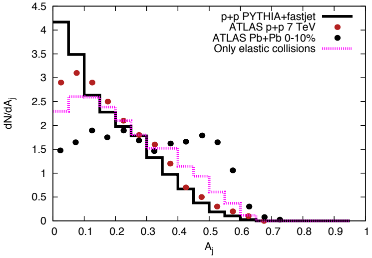
$$d_{12} = \underbrace{\min\left(\frac{1}{k_{1T}^2}, \frac{1}{k_{2T}^2}\right)}_{\text{infrared safe}} \times \underbrace{\frac{(y_1 - y_2)^2 + (\phi_1 - \phi_2)^2}{R^2}}_{\text{collinearly safe}} .$$

A list of distances between all hadrons is constructed and *ordered*. The momenta of the hadrons are summed and the list shortened until all distances exceed some R.

Thermal processes modifying jets

HTL effective theory inspires the consideration of these processes:
First, collisions with HTL quasiparticles:

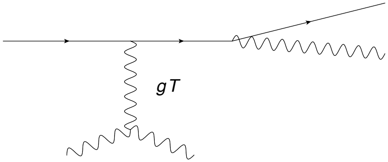


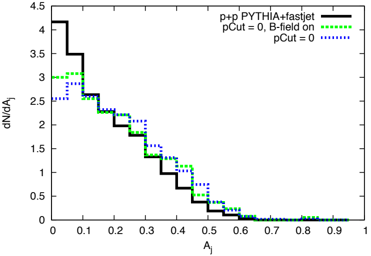


Effect on dijets: leads to *some* asymmetry.

Thermal processes modifying jets

HTL effective theory inspires the consideration of these processes:
Next, collinearly enhanced radiative splittings:

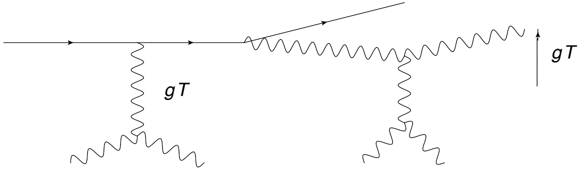




In HTL effective theory, radiative splittings are collinearly enhanced (contribute at leading order), but also affected by coherence effects (LPM effect) (Arnold, Moore, and Yaffe 2002).
Effect on dijets: leads to almost no asymmetry! Anti-k_T algorithms find split partons efficiently.

Thermal processes modifying jets

HTL effective theory inspires the consideration of these processes:
Finally, transverse momentum broadening of slowed and split partons:



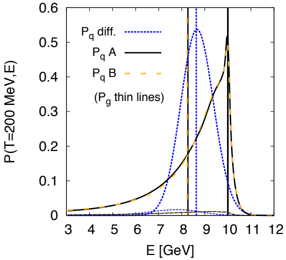
Effect on dijets: deflects partons by $\delta\theta \sim gT/p_T$, can be large for $p_T \sim gT$.

Full Monte Carlo for solving rate equations

The evolution of partons in-medium is determined by an *integral* equation:

$$\frac{dP(E)}{dt} = \int d\omega \left[P(E+\omega)\frac{d\Gamma(E+\omega, E)}{d\omega} - P(E)\frac{d\Gamma(E, E+\omega)}{d\omega} \right]$$

Diffusive approximations turn this into a differential equation but miss some of the physics! Specifically, the evolution of a jet to small z is underestimated:



Schenke and Qin (2009).

Full simulation of of a jet in medium

MARTINI (Schenke et al. 2009) solves for the inclusive

$$d\sigma_{AA\to h} = \sum_{i,j} \int d\mathbf{b}\, dx_1\, dx_2\, f^i_{A_1}(x_1, Q^2) f^j_{A_2}(x_2, Q^2) d\sigma_{ij\to kl} \\ \times P(k, l|m, n; u^\mu, T) D_m D_n$$

using event generation and Monte Carlo:

- Shadowing and anti-shadowing of pdf's, averaging over isospin
- PYTHIA8 for multiple final states via parton showering
- Monte Carlo for solving the elastic and inelastic rate equations, informed by the 3+1-dimensional hydrodynamical evolution calculated by MUSIC (Schenke et al. 2009)
- Hadronization via the Lund string model, *including* color flow in splittings
- Jet reconstruction via FASTJET, an anti-k_T algorithm

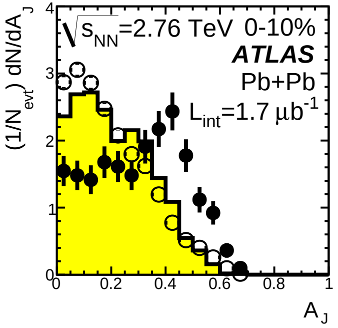
Dijets at the LHC

$A_j \equiv \frac{E_{T>} - E_{T<}}{E_{T>} + E_{T<}}$, dN/dA_j for dijets (like v_2 for bulk hadrons) a signal nearly absent in *pp*.

Also like v_2, no need for *pp* reference.

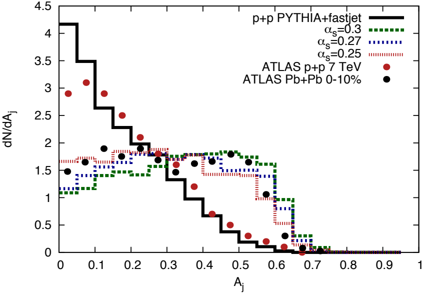
Possible sources of asymmetry:

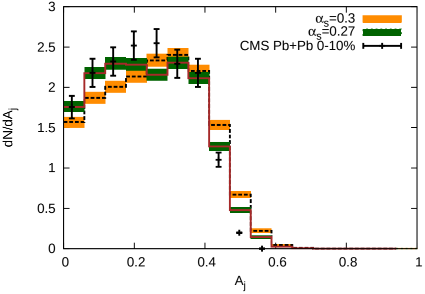
- The beginning: in-medium parton evolution (Majumder and Shen 2011).
- The middle: thermal rates (CY, Schenke et al. 2011), $\hat{q}$ (Qin and Müller 2010, Casalderrey et al. 2011).
- The end: colour flow (Beraudo et al. 2011), a fluctuating background (Cacciari et al. 2011).



From ATLAS (2010).

Dijets with MARTINI: applying all perturbative processes

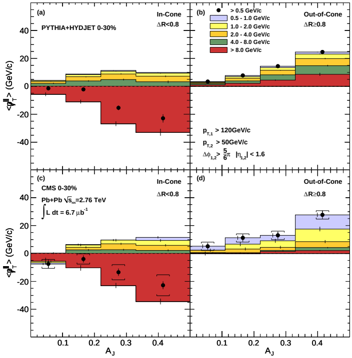




Physics conclusion: dN/dA_j can be explained with in-medium jet evolution to small z's, and collisions moving small-z partons out of the jet cone.

Dijets with MARTINI: applying all perturbative processes

Consistent with dijet momenta inside and outside the jet cones:



From CMS (2011).

dN/dA_j at RHIC

At sPHENIX, full azimuthal coverage, pseudorapidity covered for $|\eta| < 2$.

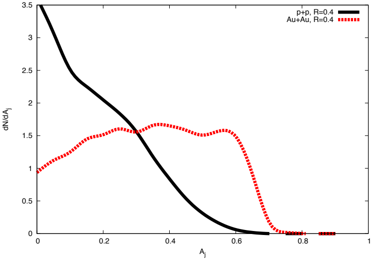
$\sqrt{s} = 200\mathrm{GeV}\ A$, $b = 4\ \mathrm{fm}$.

$R = 0.4$

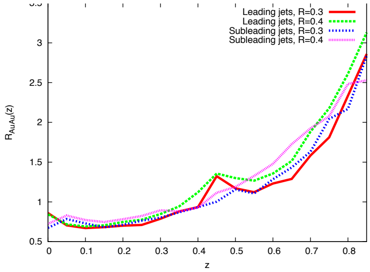
$p_T^{\mathrm{leading}} > 25\ \mathrm{GeV}/c$,

$p_T^{\mathrm{subleading}} > 5\ \mathrm{GeV}/c$.

$|\eta_{\mathrm{leading}}| < 1$.



AA fragmentation functions



- For PHENIX dijets in the same ranges as the asymmetry calculation above.
- Subleading jets a way to find jets strongly modified by the medium.
- Actually, after evolution, $R(z)$ large near $z = 1$ because small x partons are kicked out of the cone.
- Recoil from the medium needs to be included (in progress).

Conclusions

- Medium-induced soft radiation can be kicked out of the jet cone, causing dijet asymmetry.
- In-medium evolution modifies AA fragmentation functions.
- Recoil needs to be taken into account.

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