Jet Modification as a function of energy lost and jet mass depletion

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Quark Matter 2014, Darmstadt, May 21, 2014
Outline

1) MC generation and base mode
2) Review of MATTER and role of virtuality
3) Mass, virtuality scale
4) virtuality vs. distance
5) From virtuality to reconstructed mass
6) conclusions.... requests!
Motivation

We now have intra-jet data obtained by comparing medium modified and vacuum jets at the same energy.

But is Energy the only way to classify a jet?

Jet Mass: a boost invariant property of a jet.

To study this, need a MC generator.
Varieties of MC generators

Bottom-up MC generators:

JEWEL, YaJEM

Top-Down generators:

MARTINI, MATTER, Q-PYTHIA

Hybrid generators,

PYQUEN
Details of HT-MC code MATTER
Modular All Twist Transverse Elastic scattering and Radiation

\[ q \sim Q(\lambda^2, 1, \lambda) \]
\[ k \sim Q(\lambda^2, \lambda^2, \lambda) \]
\[ k \sim Q(\lambda^2, \lambda^2, \lambda) \]
\[ p \sim Q(1, \lambda^2, \lambda) \]
Details of HT-MC code MATTER
Modular All Twist Transverse Elastic scattering and Radiation

All of this evolution is hiding within $\hat{q}$

Light quark modification is sensitive to the high $Q^2$, low-$x$ part of the in-medium gluon distribution.
Bottom up vs. Top down: How good is your base formalism?

Tested in a 2+1D viscous hydro simulation
Tested in parameter free extensions to away side

And extrapolated to LHC energies!
Main problem: Introducing distance into a DGLAP shower
No space-time in the usual Monte-Carlo showers

\[ \bar{z} = \frac{z + z'}{2} \]

\[ \delta z = z - z' \]

what is the role of \( z \) and \( z' \)?

\[ \int_0^\infty d^4 \bar{z} \exp \left[ i (\delta q) \bar{z} \right] \]

\[ \int d^4 \delta z \exp \left[ i \delta z (l + l_q - q) \right] \]

\( \delta q \) is the uncertainty in \( q \),
How much uncertainty can there be?

To be sensible: $\delta q \ll q$

we assume a Gaussian distribution around $q^+$

And try different functional forms of the width

We set the form by insisting $\langle \tau \rangle = 2q^-/(Q^2)$

to obtain the $z^-$ distribution only need to assume a $\delta q^+$ distribution

$$
\rho(\delta q^+) = e^{-\frac{(\delta q^+)^2}{2[2(q^+)^2/\pi]}}
\sqrt{2\pi}[2(q^+)^2/\pi]
$$

A normalized Gaussian with a variance $2q^+/#\pi$

FT gives the following distribution in distance
Constructing the Sudakov form factor

\[ S_{\zeta_i}^{-}(Q_0^2, Q^2) = \exp \left[ - \int_{2Q_0^2}^{Q^2} \frac{d\mu^2}{\mu^2} \frac{\alpha_s(\mu^2)}{2\pi} \right] \]

\[ \times \int_{Q_0/Q}^{1-Q_0/Q} dy P_{qg}(y) \left\{ 1 + \int_{\zeta_i^-}^{\zeta_i^- + \tau} d\zeta K_{p^-, \mu^2}(y, \zeta) \right\} \]

\[ K_{p^-, \mu^2}(y, \zeta) = \frac{2\hat{q}}{\mu^2} \left[ 2 - 2 \cos \left\{ \frac{\mu^2(\zeta - \zeta_i)}{2p^- y(1 - y)} \right\} \right] \]

Valid as long as, \[ \frac{\hat{q} \tau}{\mu^2} \lesssim 1 \]
Mass, Virtuality and Scale

\[ \int_{Q_0^2}^{Q^2} d\mu^2 \]

\(Q^2\) is the scale,
\(\mu\) is the mass of jet = virtuality of first parton
virtuality drops as more shower partons produced

Reconstructed mass:

\[ M = \sqrt{p^2 - p_T^2 - p_z^2} \]

\[ \vec{p}_T = \sum_{i=1}^{n} \vec{p}_{T_i}, \quad p_T = |\vec{p}_T|, \quad p_{T_i} = |\vec{p}_{T_i}| \]
\[ p_z = \sum_{i=1}^{n} p_{T_i} \sinh \eta_i, \quad p = \sum_{i=1}^{n} p_{T_i} \cosh \eta_i. \]
What happens to the leading parton in vacuum/medium?

Virtuality or mass drops much more quickly than energy.

Note: once partons drop to 1 GeV, no further splitting occurs.
What happens to the leading parton in vacuum/medium?

How about the distributions?
Distribution of virtuality from initial hard scattering

Jagged distribution due to fewer events

M<1GeV clubbed with 0 GeV point

For E = 75 GeV

scale = max. virtuality = 75 GeV

E = 75 GeV

Probability (un-normalized)

0 20 40 60 80

M (GeV)

0 0.05 0.1 0.15 0.2

Vacuum

$\hat{q} = 1 \text{ GeV}^2/\text{fm}, L = 2 \text{ fm}$
Distribution of virtuality from initial hard scattering

Jagged distribution due to fewer events

$M < 1 \text{GeV}$ clubbed with $0 \text{ GeV}$ point

For $E = 75 \text{ GeV}$

scale = max. virtuality = $75 \text{ GeV}$

vs. Virt distribution of recon. Jet with $q=1 \text{GeV}^2/\text{fm}$ and $L = 2 \text{fm}$
Distribution of virtuality from initial hard scattering

Jagged distribution due to fewer events

\( M < 1 \text{GeV} \) clubbed with 0 GeV point

For \( E = 75 \text{ GeV} \)

scale = max. virtuality = 75 GeV

vs. Virt distribution of recon. Jet with \( q = 1 \text{GeV}^2/\text{fm} \) and \( L = 2 \text{fm} \)

mass distribution of leading parton From MATTER with no initial state (100K events)
The large difference is also present for PYTHIA jets

Due to presence of hard scattering and initial state the mass distribution in PYTHIA has a peak

Here we use reconstructed mass, which compares well with actual mass

Mass distribution of reconstructed jet in PYTHIA vs in-medium reconstructed jet

Reconstructed mass is very closely related to actual mass in PYTHIA
Reconstructed mass as a place holder for jet mass

The jet fragmentation function for a given mass range is very sensitive to that mass range

sensitivity very similar to the scale dependence of fragmentation function

Mono-energetic Pythia8 Jet (all particles) $|\eta|<0.3$
Leading Anti-$K_T$, $R=0.7$ and $p_T^{\text{jet}}=70-80$ GeV/c

![Graph showing the jet fragmentation function for different mass ranges.](image)
We are dividing two very different objects
Conclusions and request to experiment

While jets lose some energy in heavy-ion collisions

They lose a lot of mass in the course of radiation

If many of the soft partons are deflected in the medium, we are left with a mass-depleted jet

The mass of the depleted jet has a narrow distribution

This should be a noticeable effect if mass or some approximation to mass could be measured.
Please see poster by Michael Kordell

An explanation of the PHENIX $R_{dAu}$