Jets and energy loss: chapter status

Marta Verweij (Vanderbilt)
for the jet group

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Contributors
Theory: Guilherme Milhano
Experiment: Peter Jacobs, Mateusz Ploskon, Leticia Cunqueiro, Anne Sickles, Martin Spousta, Yen-Jie Lee
Outline

- Introduction
- Precision Energy Loss
- Jet Deflection
- Jet Internal Structure
- Rare Events / Jets
- Heavy Quark Jets + Top Quarks
- Interplay with RHIC
- Summary

Will start writing soon
Introduction

What is jet quenching and what can it tell us?
- how can jet quenching be used to constrain the QGP properties?
- how do jet quenching measurements connect to flow/bulk observables?
- how can jet quenching help differentiating between fundamentally different pictures?

Review of what we learned so far

Potential of jet quenching measurements will be shown using projections of specific analyses
Precision energy loss

Main tool: $X+$ jet ($X=\gamma,Z,h$) measurements

Try to measure **ALL** the recoiling energy

- Photon + multijet: NLO + semi hard emissions
- Photon + hadrons (missing $p_T$, radial profiles)

\[
\gamma\text{-jet}
\]
\[
Z\text{-jet}
\]
Precision energy loss: low $p_T$

Main tool: $X+\text{jet (X}=\gamma,Z,h)\text{ measurements}$

Very low jet $p_T$ measurements: measure full energy loss distribution

- Potentially larger sensitivity to medium properties
- Connection to small systems where low $p_T$ measurements are easier
- Larger sensitivity to non-perturbative effects
  $\Rightarrow$ should measure nevertheless

ALICE: can go down to $p_T=10$ GeV

ATLAS/CMS: in pp can go down to $p_T=20$ GeV. Needs work in AA

Alternative: go to higher $p_T$ photon/Z so that you can measure the full energy loss distribution
A classic: inclusive jet $R_{AA}$

Projection from ATLAS for $200 < p_T < 1000$ GeV available

Very high precision over wide jet $p_T$ range

- Forward high-$p_T$:
  - interplay between flavor and spectral steepness, path length.

- Future runs allow to access higher $p_T$ where the rapidity dependence is stronger.

Missing: model comparisons.
Plan to have 1-2 models with various values of medium density.
R-dependence might be added.
A classic: inclusive jet $R_{AA}$

Projection from ATLAS for $200 < p_T < 1000$ GeV available
Very high precision over wide jet $p_T$ range

- Forward high-$p_T$: interplay between flavor and spectral steepness, path length.
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arXiv:1805.05635
A classic: hadron $R_{AA}$

Current data limited precision at very high momentum

With $10/\text{nb}$ negligible uncertainty up to $p_T=300$ GeV

→ Does $R_{AA}$ reach unity?

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**CMS Performance 2015 Data**

<table>
<thead>
<tr>
<th>$p_T$ (GeV)</th>
<th>$R_{AA}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;50$ GeV</td>
<td>$0.02 \text{ nb}^{-1}$</td>
</tr>
<tr>
<td>$&gt;50$ GeV</td>
<td>$0.4 \text{ nb}^{-1}$</td>
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</tbody>
</table>

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**CMS Projection**

<table>
<thead>
<tr>
<th>$p_T$ (GeV)</th>
<th>$R_{AA}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;50$ GeV</td>
<td>$0.2 \text{ nb}^{-1}$</td>
</tr>
<tr>
<td>$&gt;50$ GeV</td>
<td>$10 \text{ nb}^{-1}$</td>
</tr>
</tbody>
</table>

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Not final
A classic: hadron $v_2 + v_3$

Current data limited precision at very high momentum

High momentum $v_2$: sensitivity to path length dependent energy loss
With HL-LHC study path length dependence at highest momenta

CMS Projections

$\sqrt{s_{NN}} = 5.02$ TeV

$\int L = 10$ nb$^{-1}$

$\bullet v_2$(SP)

$\bigcirc v_3$(SP)
Jet Deflection

Angular distribution of recoil jet relative to trigger axis

- Trigger: hadron, jet, boson (γ, Z, W)
  - Boson cleanest since it isn’t affected by the medium
  - Hadron and jet much higher statistics + tool to probe geometry

Coherent scattering of recoil jet

- In competition with shower broadening
- Significant if early in-medium

No evidence for jet deflection within uncertainties

→ Rule out or not with run3+4 data

It is very unlikely the distributions are different
p-value > 0.4
But effect might be larger for lower momentum partons

Expecting projections from ALICE soon
Jet internal structure

1) Fragmentation functions + jet shapes

- high $p_T$: sensitive to parton shower modification
- low $p_T$: sensitive to medium response?

Still missing: projections to 10/nb
Jet internal structure
2) substructure with ‘new’ tools

Can we probe the evolution of the medium using jet substructure techniques?

Experimental tools: \( p_T \)-dependence, angular separation, mass
10 nb\(^{-1} \) will allow us to study the \( p_T \)-dependence of jet substructure modifications in detail.
Rare events / jets

Isolate events in which at least one jet was heavily modified or not modified at all

Tools: $A_j/x_j$ as done during run1. Studies were limited by statistics
New opportunities with more data.

With the selections one applies, systematically go to extreme

Jets with exotic substructure that are super rare in pp

→ Hard to predict what the unknown will bring

No projections expected.
To be decided if we add a short discussion to the YR

For anything that is rare: smaller ion favorable in order to accumulate more rare events
Heavy quark jets

Consistency of picture re extracted with light and heavy quark jets
-- cross talk with heavy flavor section --

Top quarks
   - not measured before
   - clean probe for b-quark energy loss
   - less dependent on assumptions of b-tagging

Smaller ion favorable in order to accumulate more top quark pairs

Connection with HE-LHC and FCC
Summary of section

Where do the biggest constraints come from?

Table to be produced:
- sensitivity of qhat to different observables within a certain model.
- Ideally ‘independent’ observables:
- least correlated experimental and theoretical uncertainties
Summary

Goal for HL-LHC: Measure the microscopic structure of the QGP

Large statistics of jets up to $p_T=1$ TeV for ATLAS+CMS
and $p_T=200$ GeV for ALICE

Precision energy loss and jet deflection measurement with X+jet

Dynamics of parton shower accessible through
- Jet correlations
- Jet shape observables
- Jet substructure with subjets

Probe different regimes of the radiation phase space to
1) Understand the mechanism responsible for jet quenching
2) Map out the properties of the QGP