Novel tools and jet observables for jet physics in heavy-ion collisions

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Workshop at CERN

- bring together theorists and experimentalists

- connect theoretical ideas with clearly defined observables & exploring technical challenges

- focal point of discussions: grooming techniques for jet substructure observables

OC: Matteo Cacciari, Leticia Cunqueiro, Yen-Jie Lee, Yacine Mehtar-Tani, Guilherme Milhano, Matthew Nguyen, Dennis Perepelitsa, Konrad Tywoniuk, Marta Verweij, Urs Wiedemann, Korinna Zapp
Questions we asked ourselves

• Can we devise a strategy that reduces sensitivity to background while preserving theoretical control of perturbative jet structure?

• Can we isolate specific physics effects using jet substructure? (regimes of dominant contribution)
Conclusion from discussions

+ many figures from simulations on the group chat
Novel tools and observables for jet physics in heavy–ion collisions


Documented in a report after the workshop: arXiv:1808.03689
Parton splittings

Generic 1 → 2 splitting in QCD

\[ p_{T,1} = (1-z_{\text{split}})p_T \]
\[ p_{T,2} = z_{\text{split}} p_T \]

Two relevant scales:
- Opening angle between the two branches: \( \theta \)
- Momentum balance between the two branches: \( z_{\text{split}} \)

Splitting probability in vacuum:

\[ dP_{\text{vac}} = 2 \frac{\alpha_s C_R}{\pi} \, d \log z \theta \, d \log \frac{1}{\theta} \]
The Lund diagram

Just a plane to depict parton splittings

$k_{\perp}/E \sim z\theta$

Triangle uniformly filled for unquenched parton shower

F. Dreyer, G. Salam, G. Soyez arXiv:1807.04758
Lund and grooming

Grooming selects on momentum fraction and angle of branches in angular ordered tree

\[ z > z_{\text{cut}} \theta^\beta \]

First branching in angular ordered tree

\[ Z_{\text{cut}} = 0.1 \text{ and } \beta = 0 \]

\[ (z_c, \beta) = (0.1, 0) \]
Lund and grooming

Grooming selects on momentum fraction and angle of branches in angular ordered tree

Varying the grooming condition allows to select different regions of radiation phase space
Grooming settings and $z_g$

Comparison of jet quenching MCs (JEWEL,QPYTHIA) with vacuum model (PYTHIA)

$Z_{cut} = 0.1$ and $\beta = 0$

$Z_{cut} = 0.5$ and $\beta = 1.5$

$Z_{cut} = 0.1$ and $\beta = -1$

Not all grooming settings equally sensitive to different physics assumptions
Grooming settings and $\Delta R_{12}$

Comparison of jet quenching MCs (JEWEL,QPYTHIA) with vacuum model (PYTHIA)

$Z_{\text{cut}} = 0.1$ and $\beta = 0$

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$Z_{\text{cut}} = 0.1$ and $\beta = -1$

Not all grooming settings equally sensitive to different physics assumptions
In or outside the medium

A splitting can either occur inside or outside the medium → depends on the formation time of the splitting

\[
\begin{align*}
t_f & \sim \frac{1}{z p_T \theta^2} \\
\Rightarrow \quad \log z \theta &= \log \frac{1}{\theta} + \log \frac{1}{p_T L}
\end{align*}
\]
Coherent or incoherent splitting

\[ \log z\theta = \frac{1}{3} \log \frac{1}{\theta} + \log \frac{\hat{q}^{1/3}}{p_T}, \]

Formation time: \( t_f \sim \frac{1}{z p_T \theta^2} \)

Decoherence time: \( t_d \sim \frac{1}{(\hat{q} \theta^2)^{1/3}} \)

Splitting not resolved by medium
Phase space in medium

3 regions for a splitting happening in medium
1) vacuum splitting inside medium
2) medium-induced splitting → not uniform in Lund plane
3) unresolved splitting

\[
\begin{align*}
A_{t_f < t_d < L} &= \frac{1}{2} \ln \frac{R^2}{\theta_c^2} \left( \ln \frac{p_T}{\omega_c} + \frac{1}{3} \ln \frac{R^2}{\theta_c^2} \right) \\
A_{t_d < t_f < L} &= \frac{1}{12} \ln^2 \frac{R^2}{\theta_c^2} \\
A_{t_f < L < t_d} &= \frac{1}{4} \ln^2 \frac{p_T}{\omega_c} \\
&= A_{t_f < L} = \frac{1}{4} \ln^2 \frac{p_T R^2 L}{\omega_c}
\end{align*}
\]
Lund plane in MC

Measure Lund diagram in data or Monte Carlo event generator:
Use **iterative declustering technique** to unwind the angular ordered tree retrieving information about all parton splittings
→ probe of QCD branching history

More radiation for larger $k_T$ due to running coupling

+ some distortion from underlying event uncorrelated to jet
Medium effects visible in difference distribution (quenched – vacuum)
Correcting for detector inefficiencies not trivial
Well-defined selections

Example: photon-jet

Select population of jets using groomed angle
- Narrow jets (small angle)
- Wide jets (large angle)

Could help pinning down details of jet quenching mechanism
- Role of coherence
- Energy loss dependence on number of partons in shower
+ eventually medium properties
Summary

Effort to establish strategy to get the most out of jet substructure observables
- requires theory & experiment collaboration

At this conference already results based (partially) on these findings from both theory and experiment communities

Thanks to all workshop participants

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