Dynamically groomed jet radius in heavy-ion collisions

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Based on: arXiv:2103.06566 vacuum baseline
arXiv:2111.14768 resolving the medium phase space

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QCD@LHC (Orsay 28 Nov.- 2 Dec. 2022)
Jets in pp and in AA

[O. Saarimäki’s (2018)]

Adam Takacs

QCD@LHC
Grooming splittings in jets

The Lund plane: phase space of emissions [Dreyer, Salam, Soyez]
1. Find a jet
2. Recluster with C/A (widest angle first)
3. Follow the hardest branch ($z_i > \frac{1}{2}$)

Soft Drop grooming [Larkovsky, Marzani, Soyez, Thaler]:
4. Stop if $z_i > z_{cut}\theta_i^\beta$ (with the widest angle)
   • Free parameters $z_{cut}$ and $\beta$.

Dynamically grooming [Mehtar-Tani, Soto-Ontoso, Tywoniuk]:
4. Find the hardest $\max_i (z_i\theta_i^\alpha)$
   • No cuts, autogenerated jet-by-jet
Grooming splittings in jets

The Lund plane: phase space of emissions [Dreyer, Salam, Soyez]

1. Find a jet
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Soft Drop grooming [Larkovski, Marzani, Soyez, Thaler]:

4. Stop if \(z_i > z_{cut} \beta \) (with the widest angle)
   - Free parameters \(z_{cut}\) and \(\beta\).

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4. Find the hardest \(\max_i (z_i \beta_i)\)
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Dynamically grooming [Mehtar-Tani, Soto-Ontoso, Tywoniuk]:

4. Find the hardest $\max(z_i \theta_i^a)$
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   • No cuts, autogenerated jet-by-jet
     • $W/Z$, $t$ tagging, [Mehtar-Tani, Soto-Ontoso, Tywoniuk]
     • color coherence [Caucal, Soto-Ontoso, Takacs],
     • time drop [Apolinaro, Cordeiro, Zapp],
     • dead-cone [Cunqueiro, Napoletano, Soto-Ontoso]
     • Moliere scatterings [in prep., Raymond’s talk]
Proton-Proton Baseline

arXiv:2103.06566
Analytic properties

Probability of \((z, \vartheta)\) is the hardest \((\kappa^{(a)} = z\vartheta^a)\):

\[
\frac{d^2 \mathcal{P}_i(z, \vartheta|a)}{d\vartheta dz} = p_i(z, \vartheta) \Delta_i(\kappa^{(a)})
\]

Measuring \(\vartheta_g\):

\[
\left. \frac{1}{\sigma} \frac{d\sigma}{d\vartheta_g} \right|_a = \int_0^1 dz \mathcal{P}_i(z, \vartheta_g|a)
\]

Prediction at LO+\(N^2\)DL:

- Splitting function and running coupling at 2-loop
- Non-global contributions (boundary logs)
- Matching to NLO MadGraph5
Analytic properties

Probability of \((z, \vartheta)\) is the hardest \((k^{(a)} = z\vartheta^a)\):

\[
\frac{d^2 P_i(z, \vartheta | a)}{d\vartheta dz} = p_i(z, \vartheta) \Delta_i(k^{(a)})
\]

Measuring \(\vartheta_g\):

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Measuring \(\vartheta_g\):

\[
\left. \frac{1}{\sigma} \frac{d\sigma}{d\vartheta_g} \right|_a = \int_0^1 dz \, p_i(z, \vartheta_g|a)
\]

Prediction at LO+N^2DL [Silvia’s talk]:
- Splitting function and running coupling at 2-loop
- Non-global contributions (boundary logs)
- Matching to NLO MadGraph5
Results - Comparison to ALICE data

The angle of the hardest $k_t$ emission inside the jet

![Graph showing comparison to ALICE data](ALICE 2204.10246)

60 < $p_T^{ch}$ < 80 GeV
$|\eta| < 0.5$, anti-$k_\perp (R = 0.4)$
Emission Phase Space in Heavy-Ion Collisions

arXiv:2111.14768
Medium-Induced Emissions

Vacuum emission:

\[ p_{i}^{\text{vac}}(z,\vartheta) = 2\alpha_s(k_t)C_i \frac{1}{\vartheta^2} \]

Medium-induced emission and broadening: [BDMPS-Z, Fabio’s talk]

\[ p_{i}^{\text{med}}(z,\vartheta) = \alpha_{s,med} C_i \frac{1}{z^{3/2}} B(z,\vartheta) \]

\[ \omega \ll \omega_c \]
\[ k_\perp \ll Q_s \]

Both splitting can be tagged!

Energy goes out of the jet cone \(\rightarrow\) energy-loss of jets
Medium-Induced Emissions

Vacuum emission:

\[ p_{i \text{vac}}(z, \vartheta) = 2\alpha_s(k_t)C_i \frac{1}{\vartheta z} \]

Medium-induced emission and broadening: [BDMPS-Z, Fabio’s talk]

\[ p_{i \text{med}}(z, \vartheta) = \alpha_{s,\text{med}}C_i \frac{1}{z^{3/2}}B(z, \vartheta) \]

Both splitting can be tagged!

Energy goes out of the jet cone → energy-loss of jets
Energy-loss and resolution in medium

In-medium Lund plane:

- $t_f < t_{med}$: resolved emissions

- Jets with wide substructure angle loose more energy!

[Caical, Iancu, Soyez, Mehtar-Tani, Casalderrey-Solana, Tywoniuk]

\[
\ln k_t, \quad \ln 1/\vartheta \quad \text{resolved emission} \quad \text{unresolved emission}
\]

\[
\ln k_t \quad t_f < t_{med} < L \quad \vartheta_c \quad \ln 1/\vartheta
\]
Energy-loss and resolution in medium

In-medium Lund plane:

- $t_f < t_{med}$: resolved emissions

- Jets with wide substructure angle loose more energy!
Our simple analytic model

- Jets with wide subjet loose more energy
- Huge jump around $\vartheta_c$!
- Which $a$ is the best?
- Is $\vartheta_c$ measurable?
Our simple analytic model

- Jets with wide subjet lose more energy
- Huge jump around $\theta_c$!
- Which $a$ is the best?
- Is $\theta_c$ measurable?
Is $\psi_c$ really measurable?

- HI Event generator study:
  - JetMed [Caucal, Iancu, Soyez]
  - Jewel [Zapp, Krauss, Wiedemann]
  - Hybrid [Casalderrey-Solana, Milhano, Pablos, Rajagopal]

Different energy-loss models

- Non-perturbative physics:
  - Embedded hydro/kinetic background
  - Fluctuating geometry
  - Medium response
  - Hadronization
Medium response

angle of the hardest emission $a = 0.7$

- Not sensitive to med. resp. $→$ grooming ✓
- Enhancement remains
Summary

• Understanding the resolution in quark-gluon plasma [also Carlota’s talk with EEC]

• pp baseline:
  ▪ Dynamical tagging at LO+N²DL
  ▪ Good agreement with ALICE data

• Heavy-Ion collisions:
  ▪ analytical understanding of enhancement around $\vartheta_c$
  ▪ MCs to test $\vartheta_c$ and the phase space: JetMed, Jewel, Hybrid
  ▪ Best parameter: $0.5 < a < 1$ and $R \sim 0.2$ to resolve the difference btw MCs
Thank you for the attention!