Data-driven quark and gluon jet modification in heavy-ion collisions

Jasmine Brewer

In collaboration with Jesse Thaler and Andrew Patrick Turner

Based on arXiv:2008.08596
Modification of jets a probe of quark-gluon plasma

proton–proton

heavy-ion

“baseline” jet properties
At leading order, jets are initiated by a quark or gluon from the hard process.

\[ C_q = \frac{4}{3} \]

\[ C_g = 3 \]
Differences in quark and gluon jet energy loss in quark-gluon plasma

Quarks and gluons interact with the plasma proportional to their color factor

\[
\frac{dE}{dx}(q) = \frac{C_q}{C_g} \frac{dE}{dx}(g)
\]

Quark and gluon jets are extended objects whose energy loss may depend on their structure

\[
\frac{dE}{dx}(q) = ??? \frac{dE}{dx}(g)
\]
Separating quark and gluon jets is challenging because jet measurements are mixture of contributions from both
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Outline

• A data-driven method for q/g separation (in cartoons)

• Monte Carlo studies in pp and AA
Disentangling mixture distributions into “quark” and “gluon”

\[ p_1 = f_1 b_1 + (1 - f_1) b_2 \]

\[ p_2 = (1 - f_2) b_1 + f_2 b_2 \]

p–p: Metodiev and Thaler [1802.00008] Komiske, Metodiev, Thaler [1809.01140]
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\[ \frac{f_2}{f_1} \]

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Solve for base distributions \( b_1, b_2 \) in terms of mixture distributions and fractions

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Disentangling mixture distributions into “quark” and “gluon”

Requires…

Sample independence:

![Example diagram showing dijets and γ+jet distributions with overlapping regions labeled b₁ and b₂.](image-url)
Disentangling mixture distributions into “quark” and “gluon”

Requires...

Sample independence:

Mutual Irreducibility: samples are pure quark and pure gluon in some limits

Above: base distributions are completely separated at ±∞

Quantified by

\[
\lim_{O \to -\infty} \frac{b_1(O)}{b_2(O)} = 0 \quad \lim_{O \to +\infty} \frac{b_2(O)}{b_1(O)} = 0
\]
Mutual irreducibility of counting observables

Poisson distributions are mutually irreducible for large $\Delta \lambda$

\[
\lim_{\mathcal{O} \to \infty} \frac{b_1(\mathcal{O})}{b_2(\mathcal{O})} = 0
\]

\[
\lim_{\mathcal{O} \to 0} \frac{b_2(\mathcal{O})}{b_1(\mathcal{O})} = \exp(\lambda_1 - \lambda_2)
\]

Quark and gluon constituent multiplicity distributions are mutually irreducible in the high-energy limit

Frye et al [1704.06266]
How are quark- and gluon-initiated jets modified by the quark–gluon plasma?

proton–proton

Heavy-Ion (JEWEL 2.1.0)
\[ p_T \in [100, 120] \text{ GeV}, |\eta| < 1 \]

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**proton–proton**

\[
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**heavy-ion**

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**proton–proton**

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How to robustly extract fractions with statistical uncertainties?
A solution: use fitting to constrain the tails using the interior of the distribution

proton–proton

Each distribution is a distinct sum of 4 skew-normal distributions (18 fit parameters)

Fit using MCMC with Poisson likelihood function

heavy-ion
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proton–proton

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heavy-ion

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Extracting quark/gluon contributions to constituent multiplicity

proton–proton

Proton–Proton (PYTHIA 6.4.25)
\( p_T \in [100, 120] \text{ GeV}, |\eta| < 1 \)

- \( \gamma + \text{jet} \)
- \( \text{dijet} \)

Constituent Multiplicity

Proton–Proton (PYTHIA 6.4.25)
\( p_T \in [100, 120] \text{ GeV}, |\eta| < 1 \)

- “q” Topic
- “g” Topic
- \( \gamma + \text{q} \)
- \( \gamma + \text{g} \)

Constituent Multiplicity

Proton–Proton
PYTHIA 6.4.25

- \( \gamma + \text{jet} \)
- \( \text{dijet} \)

Jet \( p_T \) (GeV)
Extracting quark/gluon contributions to constituent multiplicity

**heavy-ion**
Data-driven quark and gluon jet modification from dijet and $\gamma$+jet

proton–proton

heavy-ion
Data-driven quark and gluon jet modification from dijet and $\gamma + \text{jet}$

**proton–proton**

![Proton-Proton (PYTHIA 6.4.25) plot](image1)

**heavy-ion**

![Heavy-Ion (JEWEL 2.1.0) plot](image2)
Outlook

Toward measuring quark- and gluon-like jet modification and energy loss

• This type of method has been used in p—p by ATLAS [1906.09254]

• Method of posterior estimation substantially improves robustness of the method to statistical uncertainties
  How to deal with systematic uncertainties?

• What observables are robust to background subtraction? charged particle multiplicity? constituent multiplicity of soft-dropped jets?
  Work in progress with Kylie Ying, Yi Chen, Yen-Jie Lee (MIT)

Applications to other category problems in heavy-ions?
What do differences between topic and MC fractions mean?

![Graph showing Gluon-like Fraction vs Jet $p_T$ for Proton-Proton and Heavy-Ion interactions.](image)

**Proton-Proton**
- **PYTHIA 6.4.25**
  - Topic
  - MC
  - γ+jet
  - dijet

**Heavy-Ion**
- **JEWEL 2.1.0**
  - Topic
  - MC
  - γ+jet
  - dijet

Jasmine Brewer (CERN)
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  Slight decrease in extracted gluon fraction for jets with an initiating parton within the jet radius
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• Deviations from quark/ gluon mutual irreducibility in constituent multiplicity

• “Quark-initiated” jets become more gluon-like