Separating quark and gluon jet distributions in heavy-ions

Jasmine Brewer

Based on:

JB, Jesse Thaler and Andrew P. Turner *to appear soon*

Thanks to the organizers for pushing on!

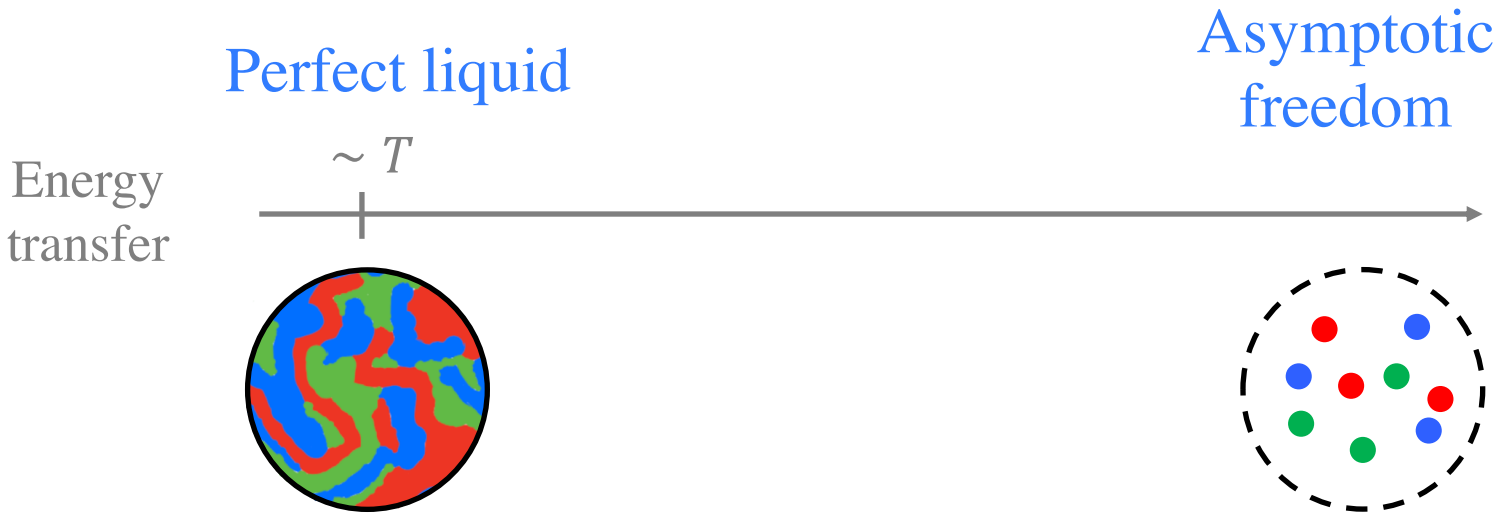
A time for global thinking, strength and unity…

Thanks to the organizers for pushing on!

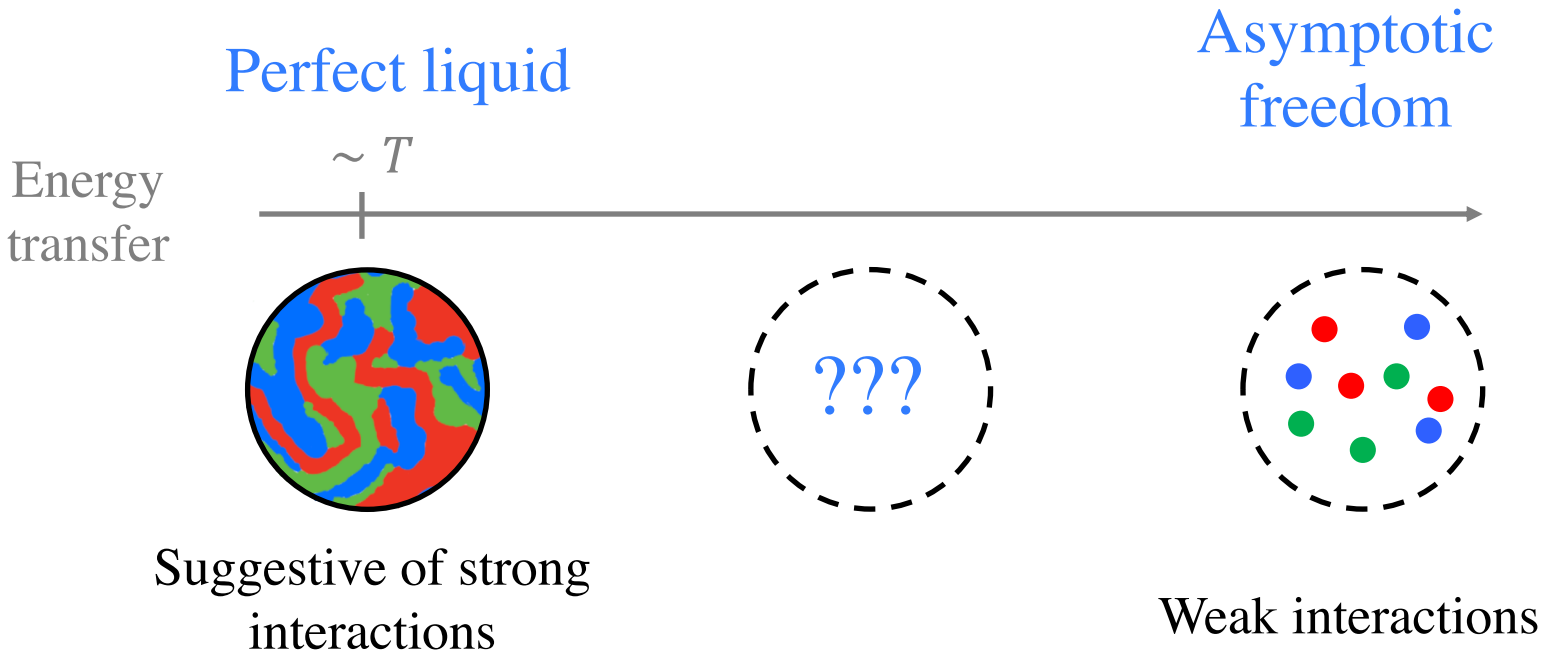
Except don't hold hands

A time for global thinking, strength and unity…

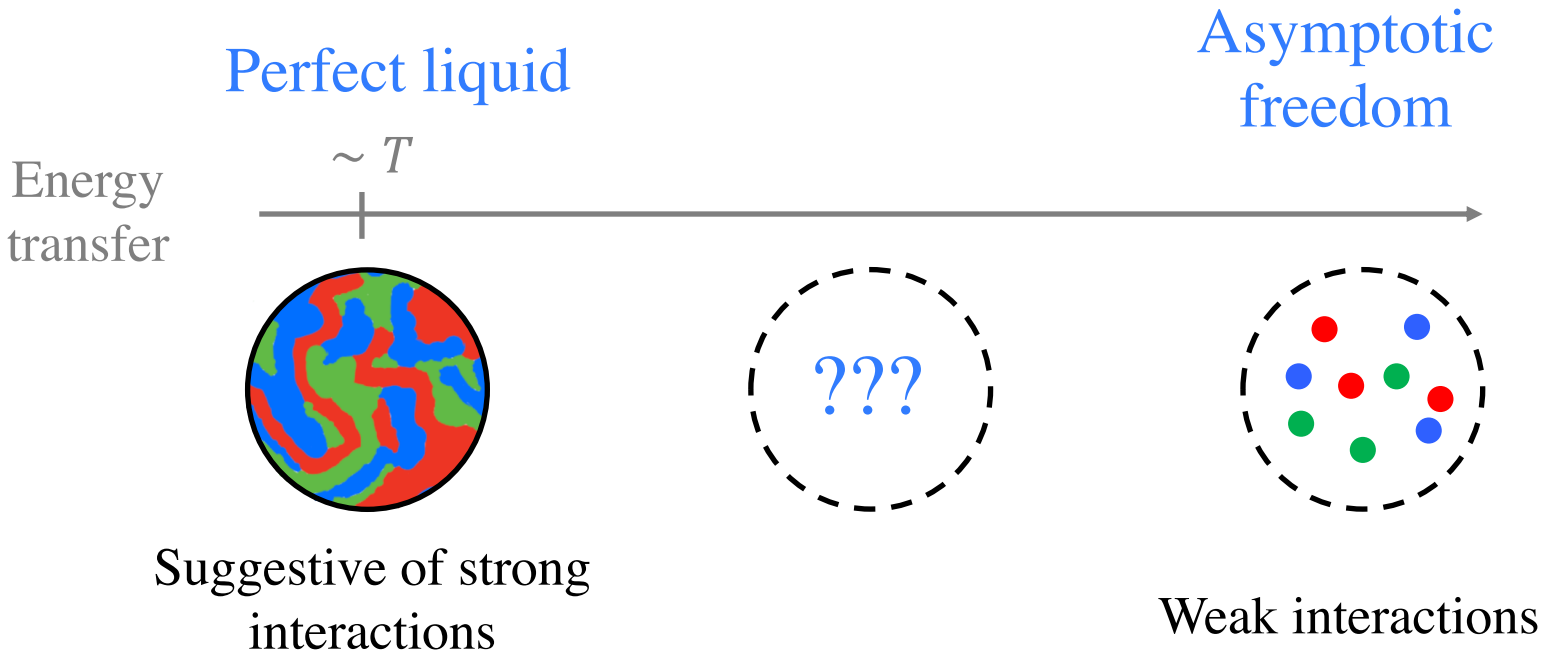
How do the degrees of freedom of the QGP depend on length scale?



How do the degrees of freedom of the QGP depend on length scale?



How do the degrees of freedom of the QGP depend on length scale?



Use jets as a multi-scale probe of QGP

Use quark and gluon jets as a (colored) probe of the (color) structure of the QGP

Strong interactions

Weak interactions

In pQCD picture energy loss difference given by ratio of color charges

How to study differences in quark and gluon jet modification?

How to study differences in quark and gluon jet modification?

1. Jet modification in samples with different q/g fraction

2. Template fitting (e.g. Hangal (CMS) QM 2019)
   - assume template for quark and gluon jet distributions and fit fractions

3. Machine learning (e.g. Chien, Elayavalli 1803.03589)
   - typically relies on some Monte Carlo labelling
   - difficult to parametrize model-dependence

How to study differences in quark and gluon jet modification?

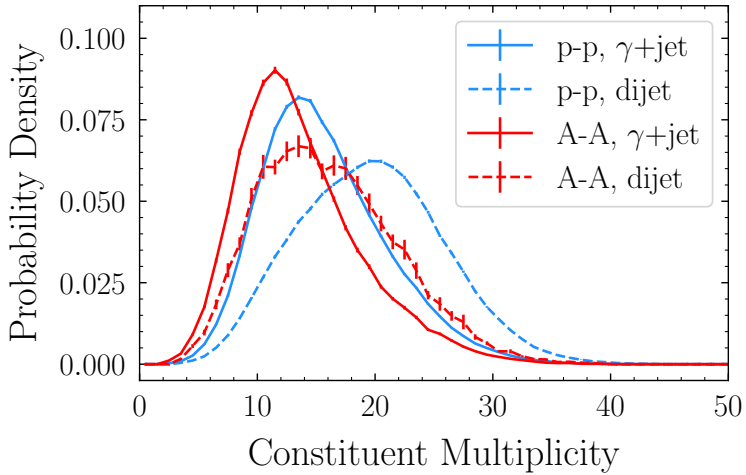
1. Jet modification in samples with different q/g fraction

2. Template fitting (e.g. Hangal (CMS) QM 2019)
   - assume template for quark and gluon jet distributions and fit fractions

3. Machine learning (e.g. Chien, Elayavalli 1803.03589)
   - typically relies on some Monte Carlo labelling
   - difficult to parametrize model-dependence

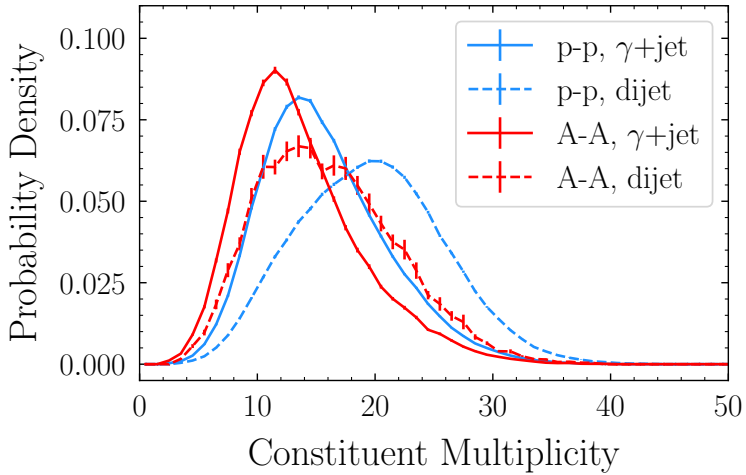
1. Jet modification in samples with different q/g fraction

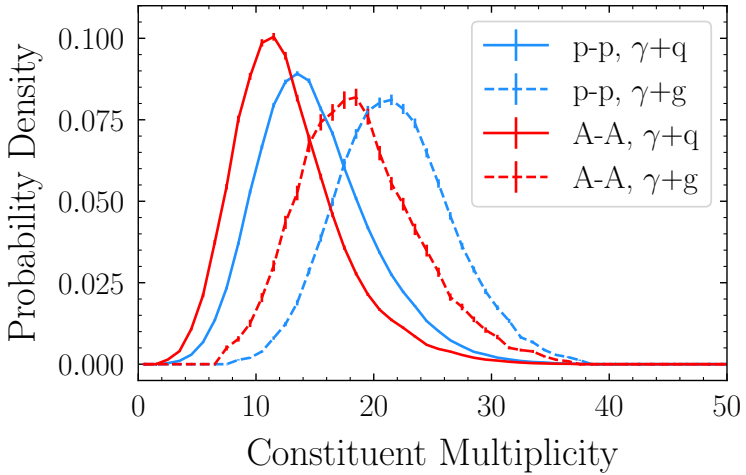
Convolutes modification of quark/gluon jets with modification of quark-gluon fractions of samples



1. Jet modification in samples with different q/g fraction

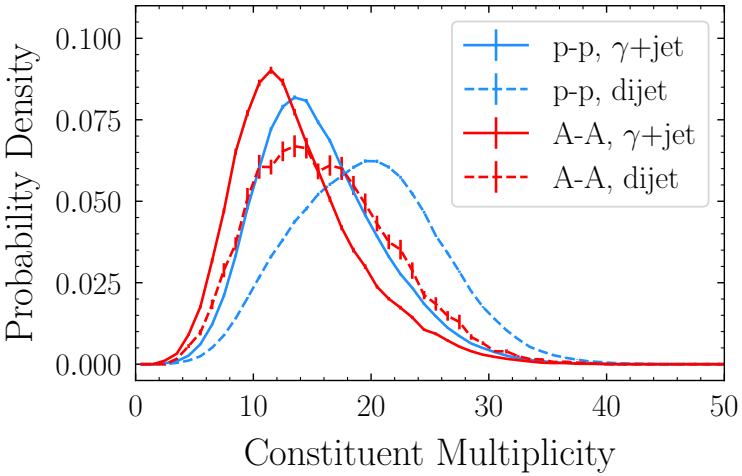
Convolutes modification of quark/gluon jets with modification of quark-gluon fractions of samples

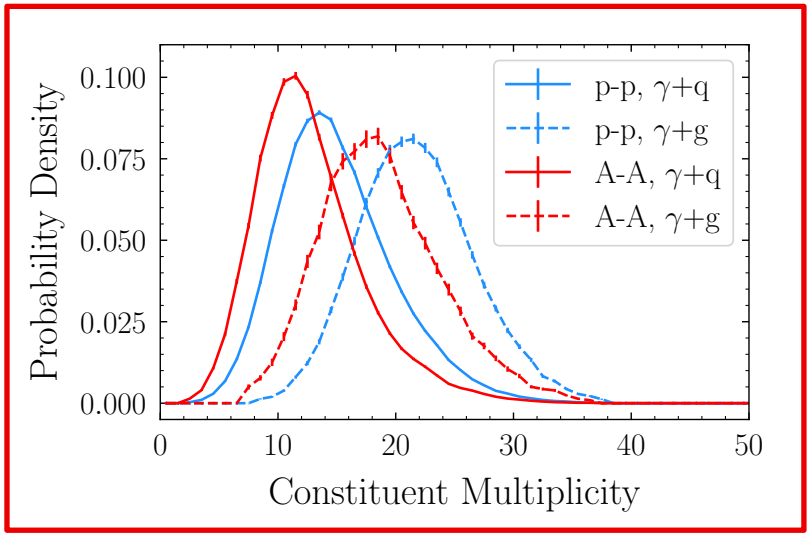




1. Jet modification in samples with different q/g fraction

Convolutes modification of quark/gluon jets with modification of quark-gluon fractions of samples

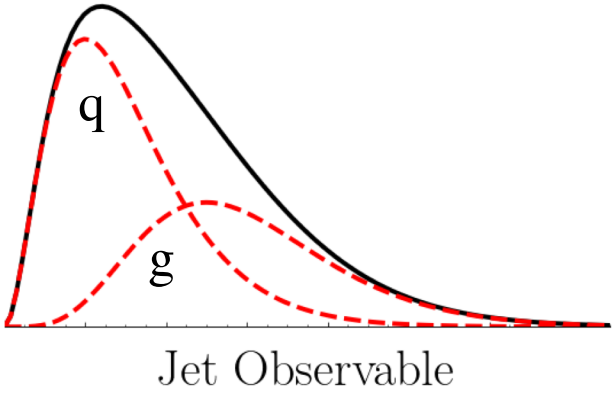




How to access fractions and distributions separately in experiment?

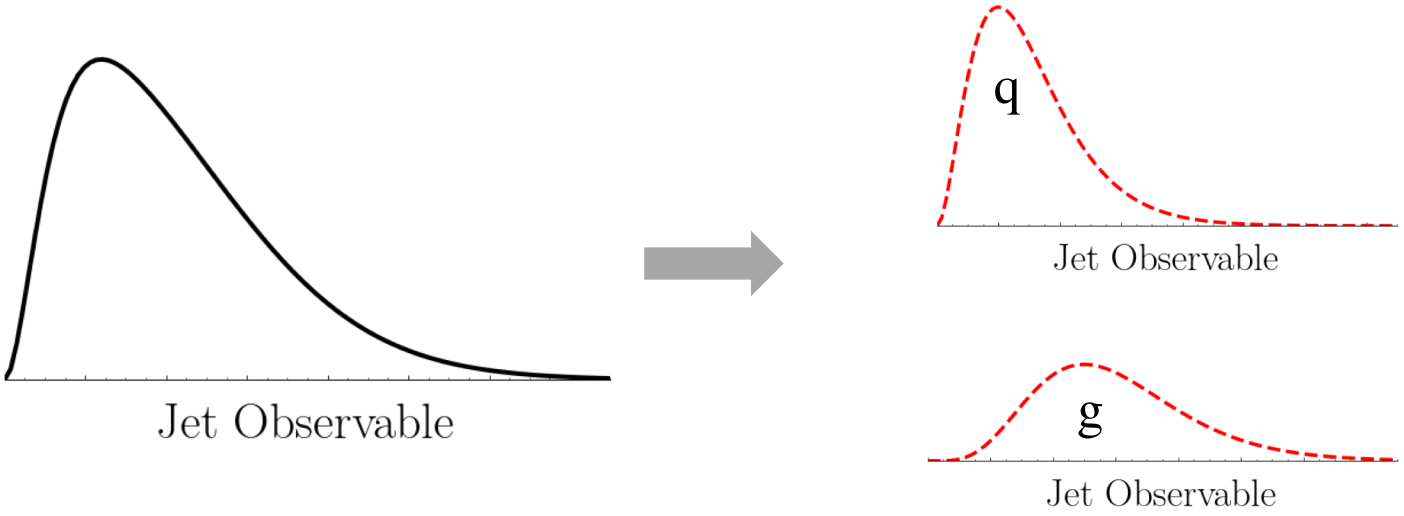
Template fitting without templates

Disentangling a mixture distribution



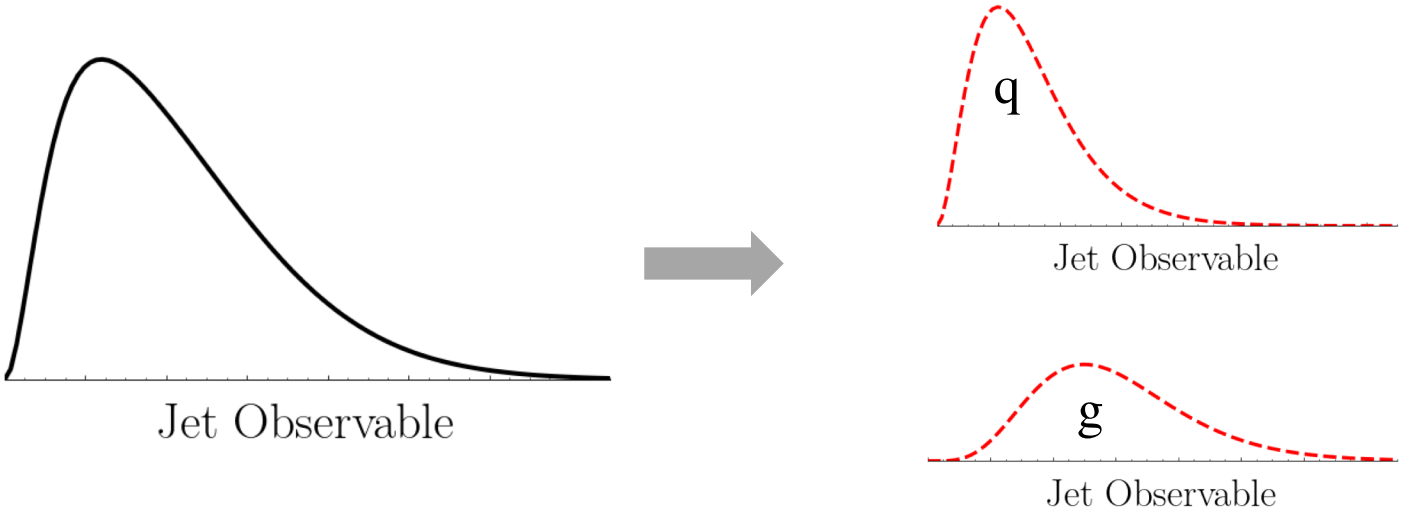
Disentangling a mixture distribution

Ideally…



Disentangling a mixture distribution

Ideally…



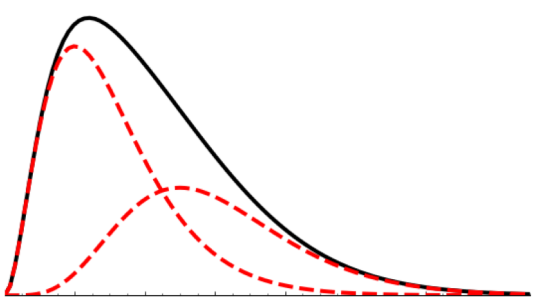
Turns out it is easy* to decompose two mixture distributions into two components

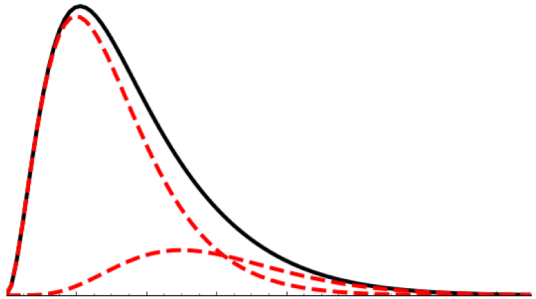
Done in p-p: Metodiev and Thaler PRL 120, 241602 (2018)

Disentangling a mixture distribution

Requires…

Sample independence:



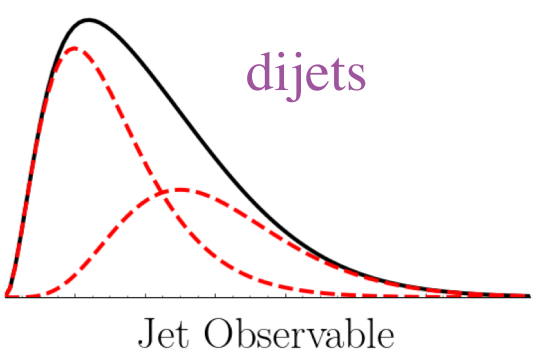


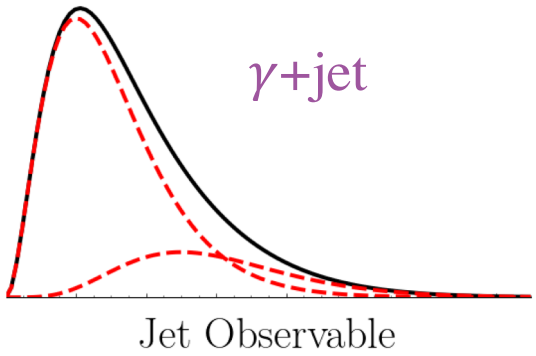
Disentangling a mixture distribution

Requires…

Sample independence:

EX.



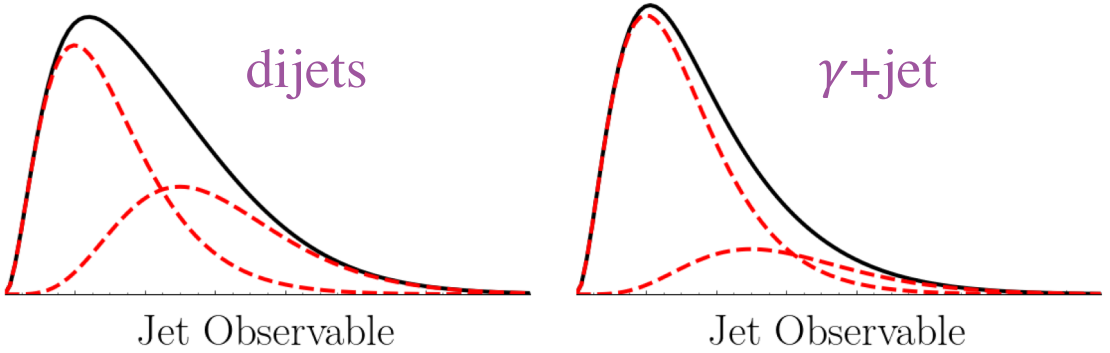


Disentangling a mixture distribution

Requires…

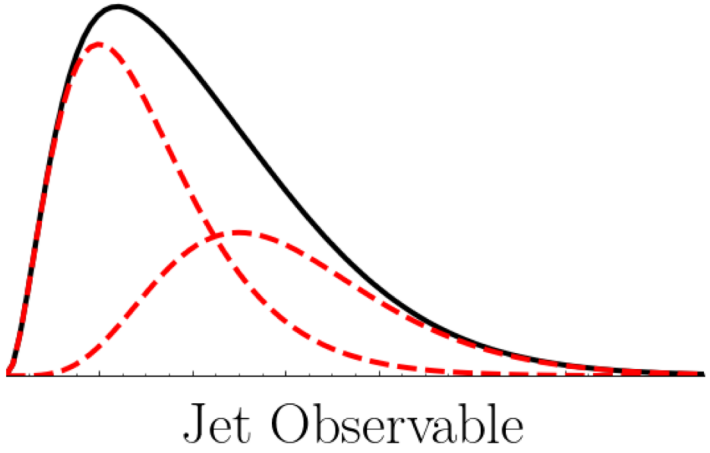
Sample independence:

EX.

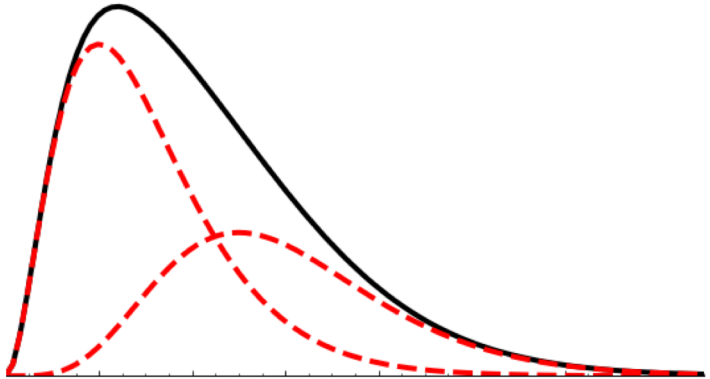


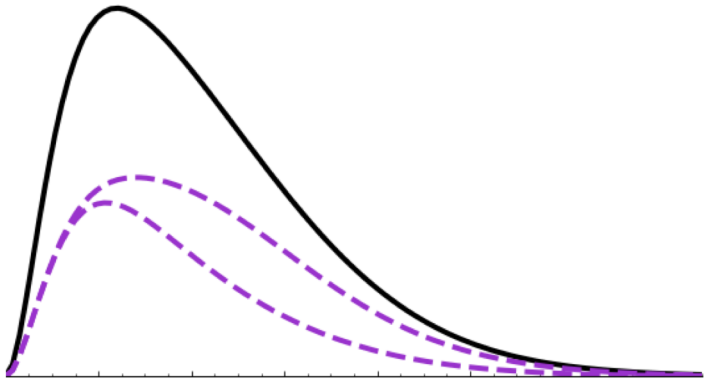
Mutual Irreducibility: samples are pure quark and pure gluon in some limits

Mutual irreducibility: decomposing a mixture is ambiguous

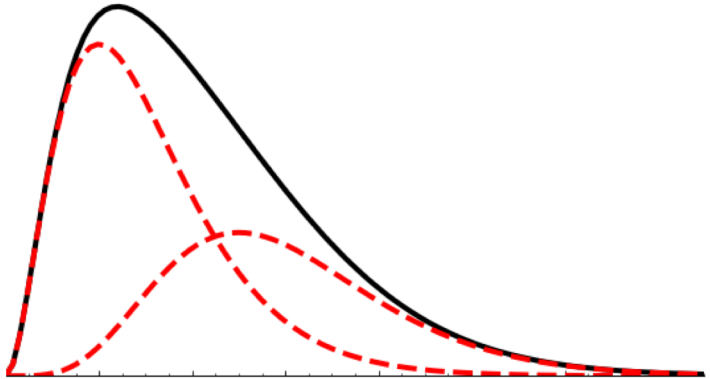


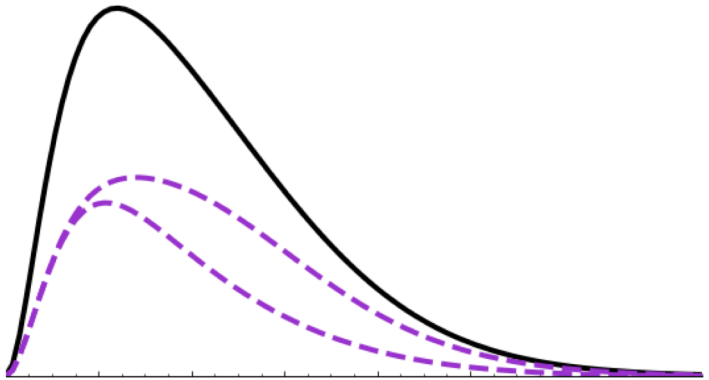
Mutual irreducibility: decomposing a mixture is ambiguous





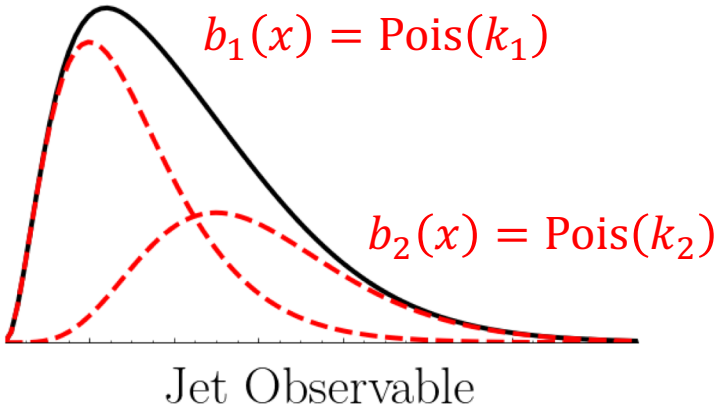
Mutual irreducibility: decomposing a mixture is ambiguous





To resolve ambiguity, extract base distributions that are mutually irreducible

Mutual irreducibility: regime of complete purity

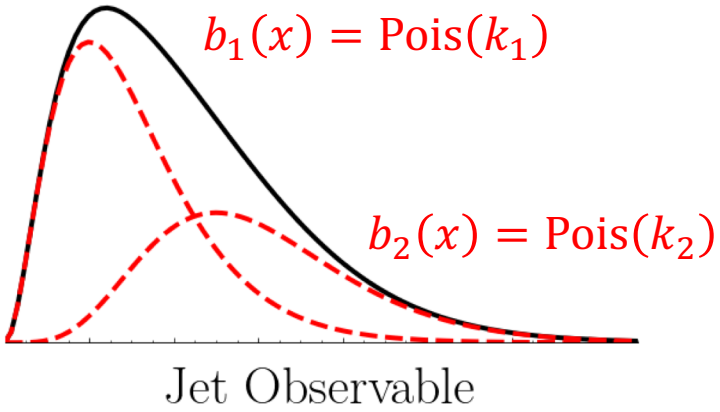


$b_1(x), b_2(x)$ completely separated from one another at $0, \infty$

Quantified by $\lim_{x\to\infty} \frac{b_1(x)}{b_2(x)} = 0$

$$\lim_{x\to 0} \frac{b_2(x)}{b_1(x)} = 0$$

Mutual irreducibility: regime of complete purity



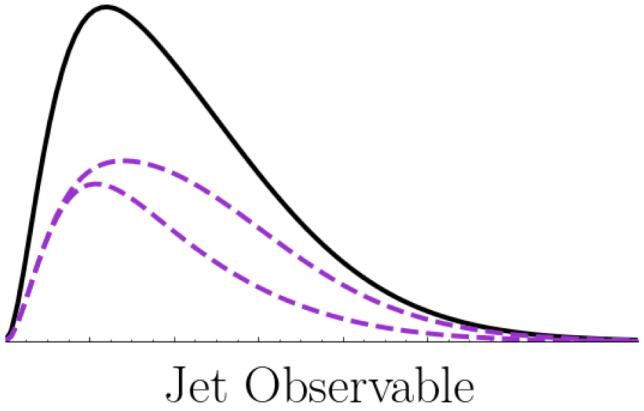
$b_1(x), b_2(x)$ completely separated from one another at $0, \infty$

Quantified by $\lim_{x\to\infty} \frac{b_1(x)}{b_2(x)} = 0$

$$\lim_{x\to 0} \frac{b_2(x)}{b_1(x)} = 0$$

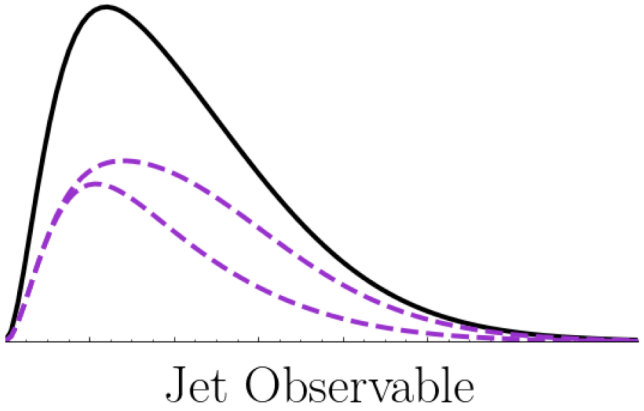
Two distinct mixtures of $b_1(x), b_2(x)$ can be separated into fractions at $0, \infty$

Mutual irreducibility: regime of complete purity



Mixtures of $b_1(x), b_2(x)$ are *not* completely separated at $0, \infty$

Mutual irreducibility: regime of complete purity



Mixtures of $b_1(x), b_2(x)$ are *not* completely separated at $0, \infty$

Requirement of mutual irreducibility restricts space of jet observables that can be used to extract quark/gluon fractions

Quark/gluon mutual irreducibility at high energies in QCD

- Counting observables (constituent multiplicities, n_{SD}) are Poissonian in high-energy limit

Mutually irreducible

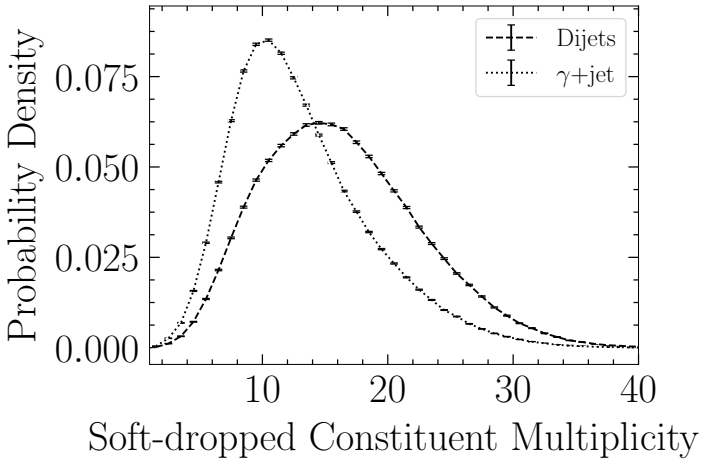
- Observables with Casimir scaling in high-energy limit (mass, angularities)

Not mutually irreducible

Frye, Larkoski, Thaler and Zhou. JHEP 09 (2017) 083

Extracting quark/gluon contributions to constituent multiplicity

p-p

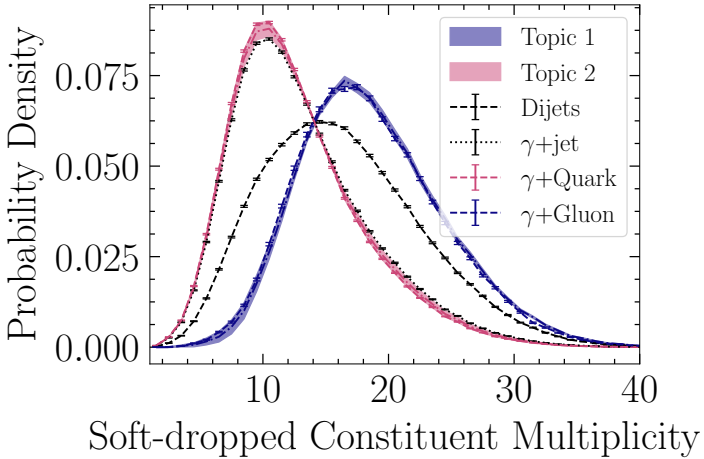


$$\kappa_{ij} = \inf_x \frac{p_i(x)}{p_j(x)} \quad \text{gives fractions} \quad \kappa_{21} = \frac{f_2}{f_1} \;, \quad \kappa_{12} = \frac{1-f_1}{1-f_2}$$

$$b_1(x) = \frac{p_1(x) - \kappa_{12} p_2(x)}{1-\kappa_{12}} \qquad b_2(x) = \frac{p_2(x) - \kappa_{21} p_1(x)}{1-\kappa_{21}}$$

Extracting quark/gluon contributions to constituent multiplicity

p-p

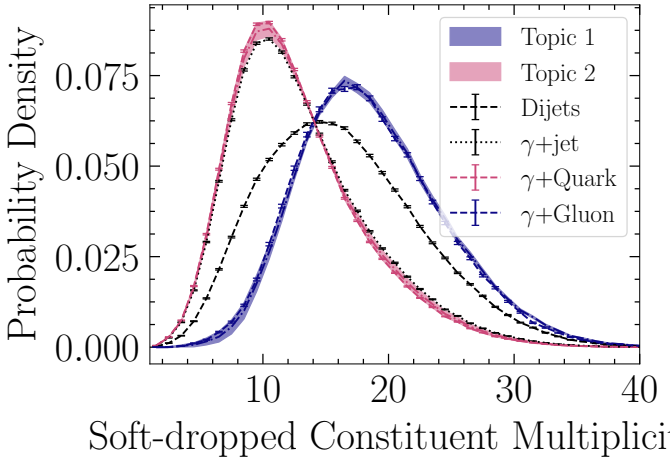


$$\kappa_{ij} = \inf_x \frac{p_i(x)}{p_j(x)} \quad \text{gives fractions} \quad \kappa_{21} = \frac{f_2}{f_1} \;, \quad \kappa_{12} = \frac{1-f_1}{1-f_2}$$

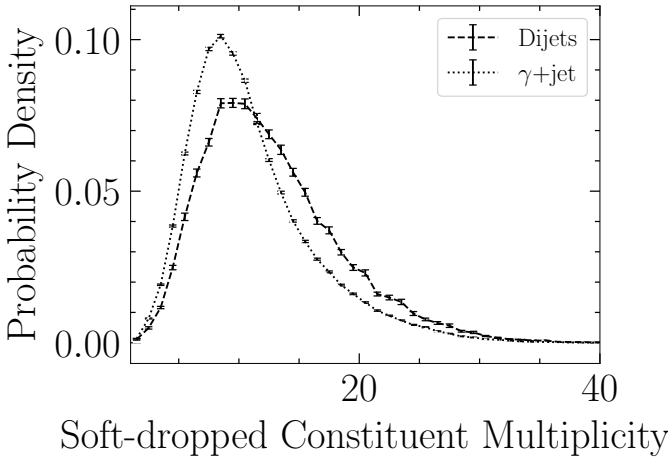
$$b_1(x) = \frac{p_1(x) - \kappa_{12} p_2(x)}{1-\kappa_{12}} \qquad b_2(x) = \frac{p_2(x) - \kappa_{21} p_1(x)}{1-\kappa_{21}}$$

Extracting quark/gluon contributions to constituent multiplicity

p-p



A-A

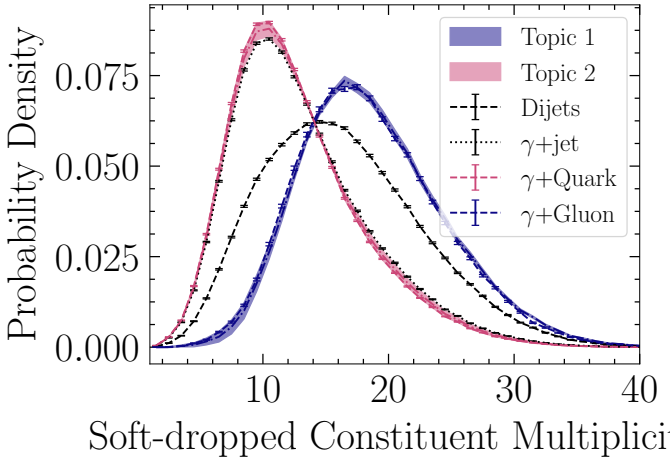


$$\kappa_{ij} = \inf_x \frac{p_i(x)}{p_j(x)} \quad \text{gives fractions} \quad \kappa_{21} = \frac{f_2}{f_1} \;, \quad \kappa_{12} = \frac{1-f_1}{1-f_2}$$

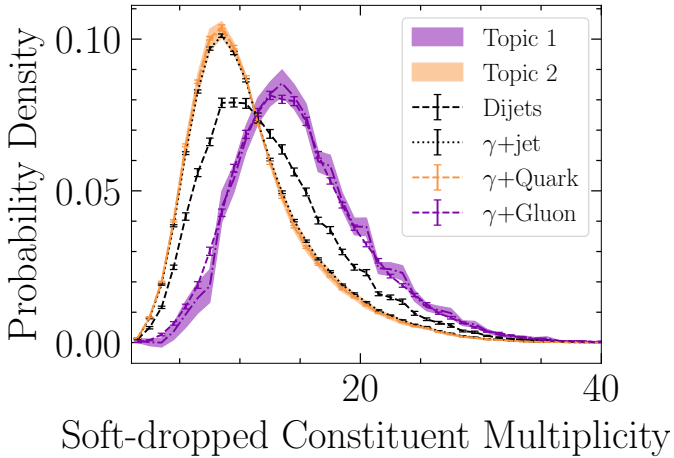
$$b_1(x) = \frac{p_1(x) - \kappa_{12} p_2(x)}{1-\kappa_{12}} \qquad b_2(x) = \frac{p_2(x) - \kappa_{21} p_1(x)}{1-\kappa_{21}}$$

Extracting quark/gluon contributions to constituent multiplicity

p-p



A-A

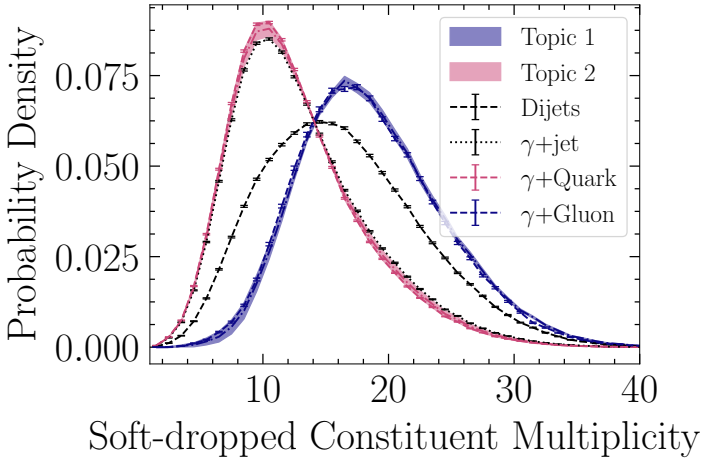


$$\kappa_{ij} = \inf_x \frac{p_i(x)}{p_j(x)} \quad \text{gives fractions} \quad \kappa_{21} = \frac{f_2}{f_1} \;, \quad \kappa_{12} = \frac{1-f_1}{1-f_2}$$

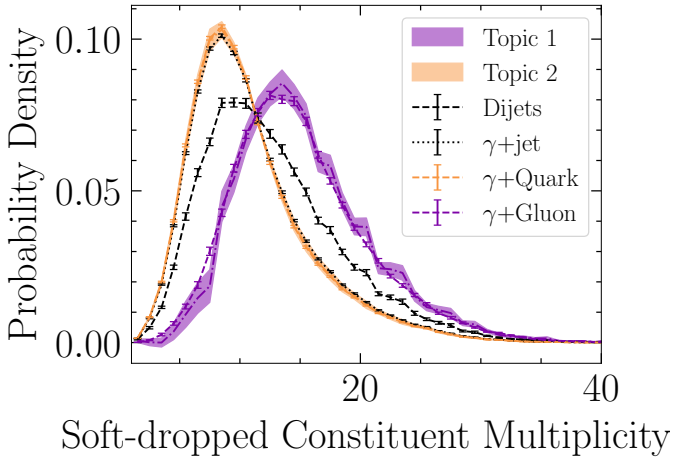
$$b_1(x) = \frac{p_1(x) - \kappa_{12} p_2(x)}{1-\kappa_{12}} \qquad b_2(x) = \frac{p_2(x) - \kappa_{21} p_1(x)}{1-\kappa_{21}}$$

Extracting quark/gluon contributions to constituent multiplicity

p-p



A-A



Primary difficulty: extraction sensitive to tails of the distribution

Going forward

- Quark and gluon fractions as a function of p_T allow for separate measurements of quark and gluon spectra, R_{AA}, Q_{AA}

- Separate distribution-level modification of quark and gluon jets from modification of their relative fractions (e.g. in dijet, photon+jet)