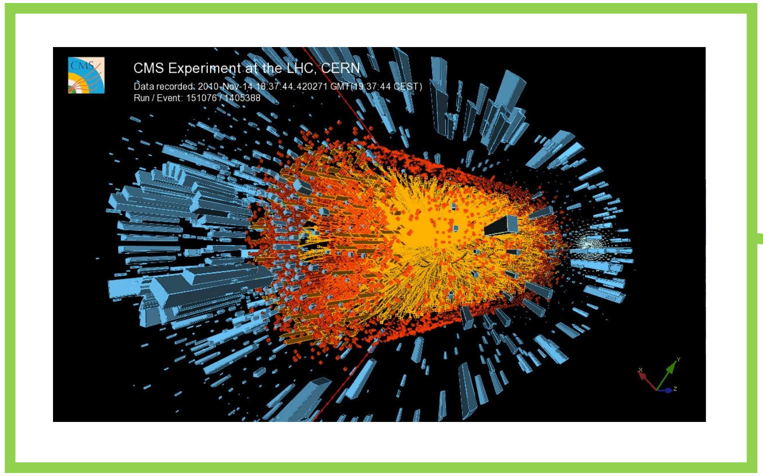
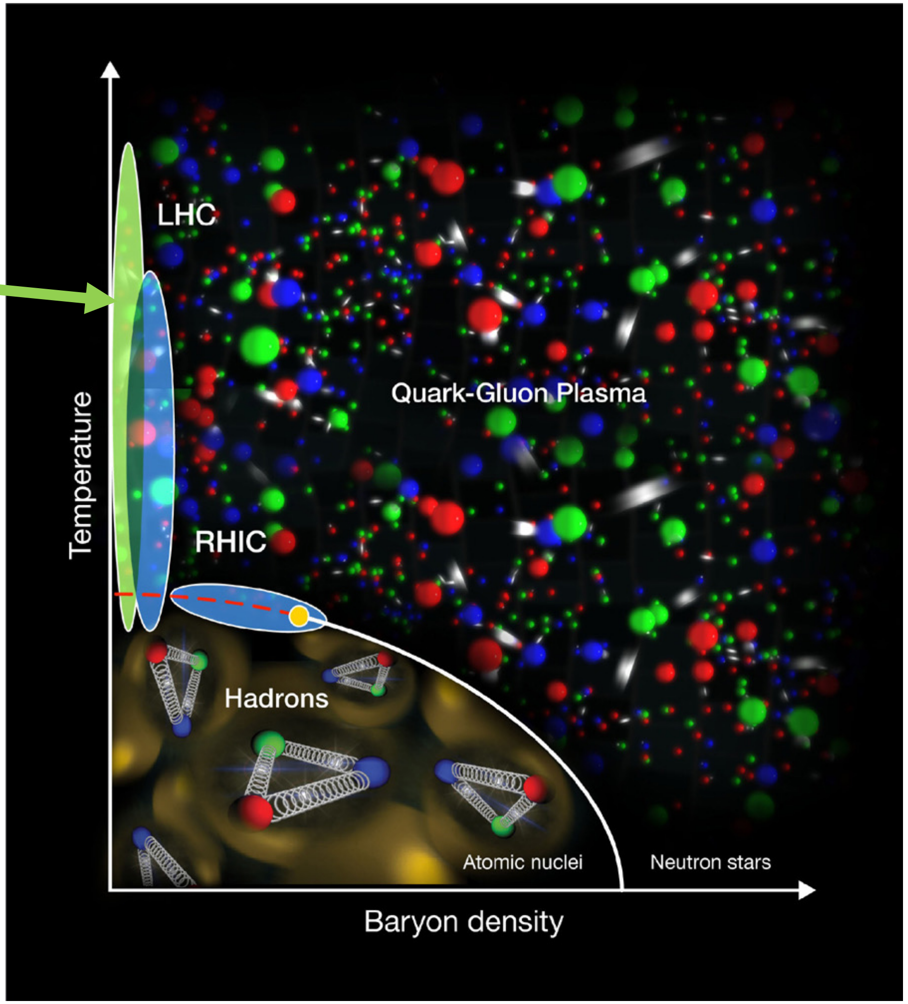
Quark and gluon jet modification in heavy-ion collisions

Jasmine Brewer

A new phase of matter, the quark–gluon plasma, is created in heavy-ion collisions





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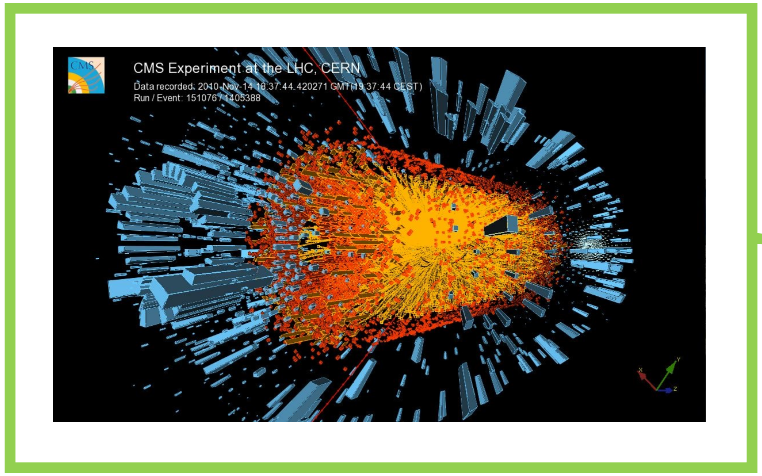
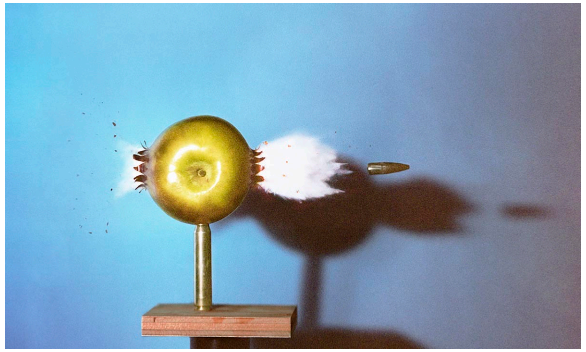
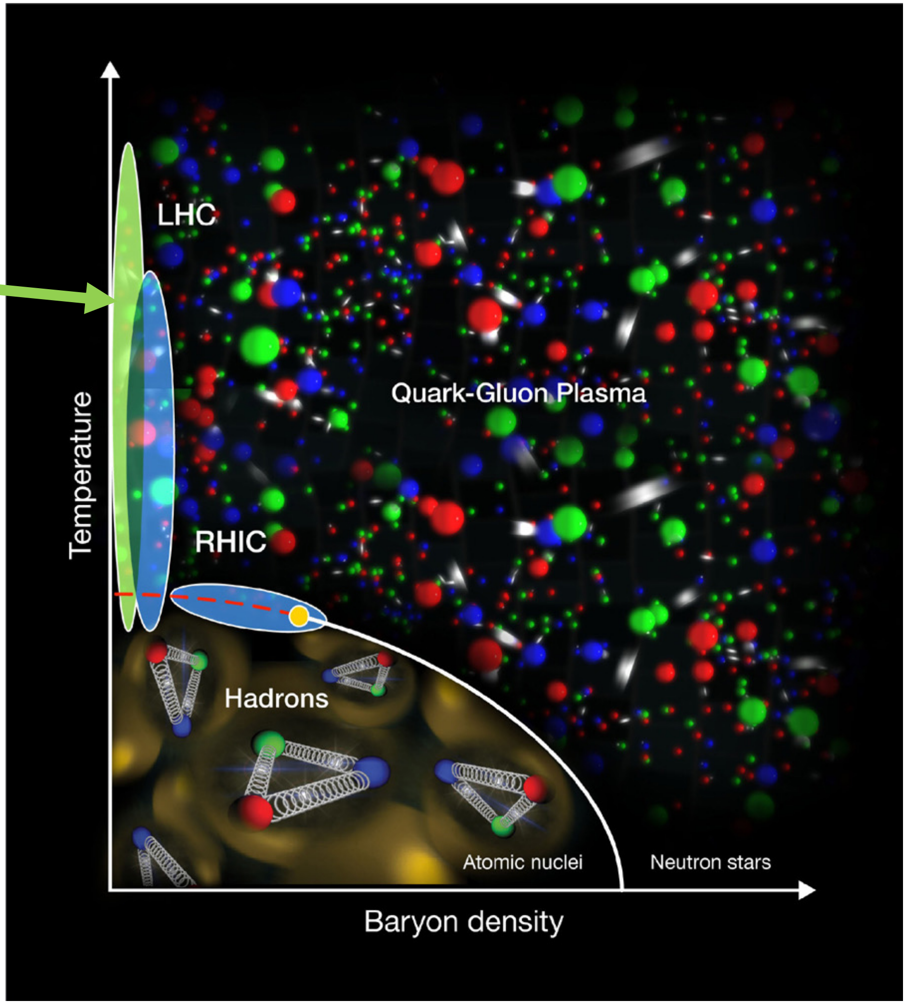
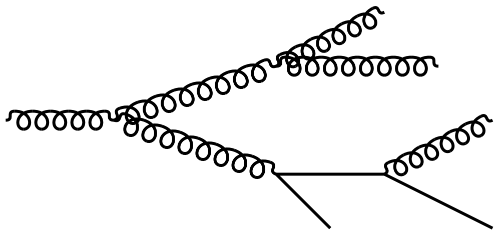


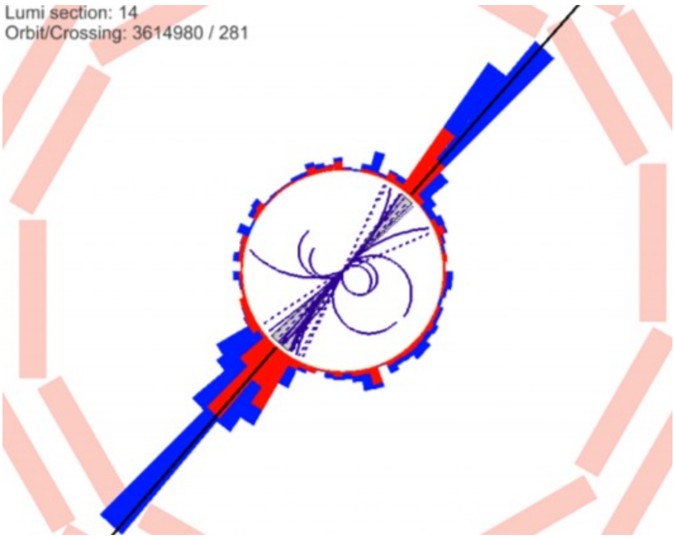




proton–proton

high energy scatterings





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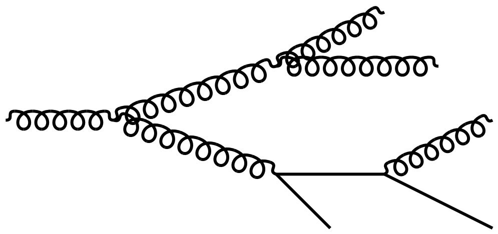
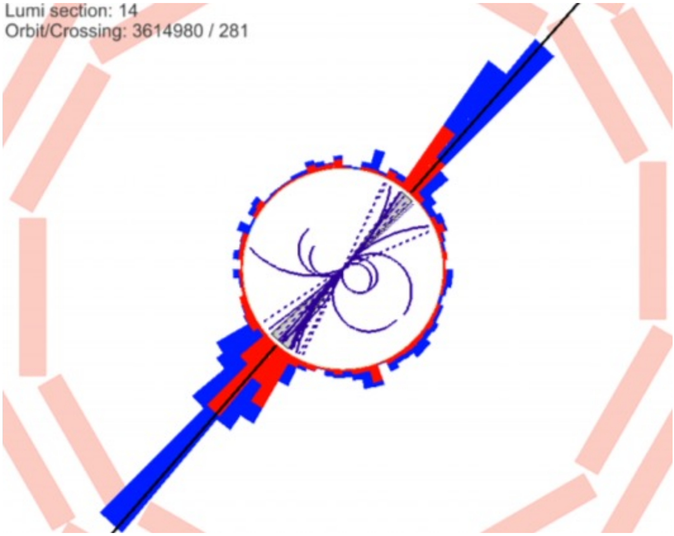
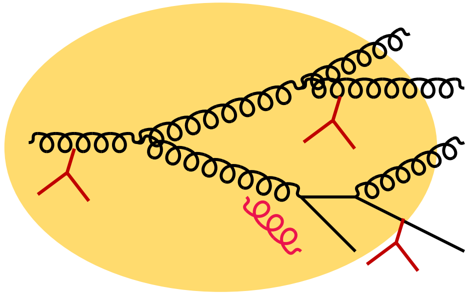




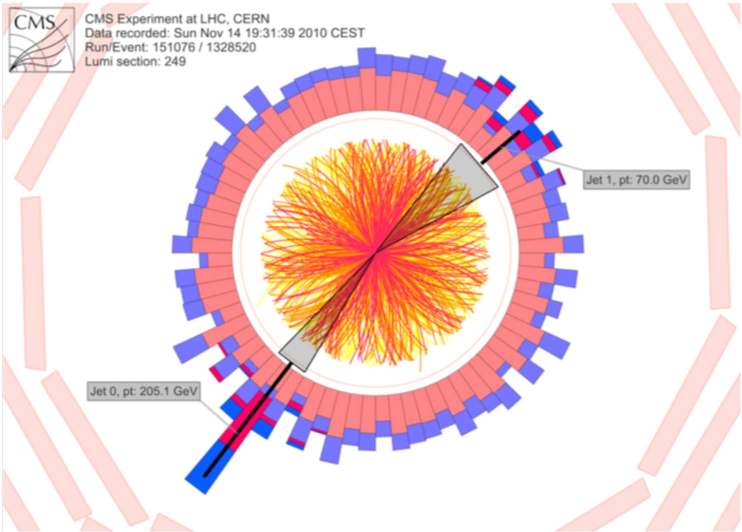
"baseline" jet properties

heavy-ion

energy loss to quark-gluon plasma

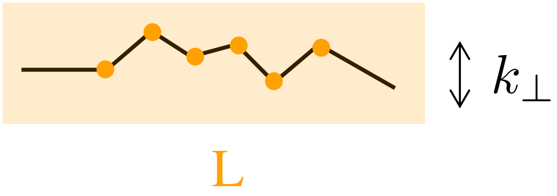


+ medium-induced emission



Energy loss of a parton in finite-temperature QCD

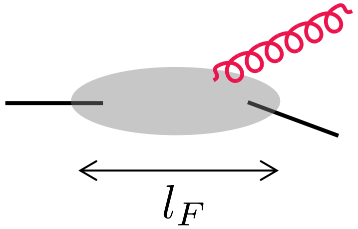
Parton undergoes transverse momentum diffusion



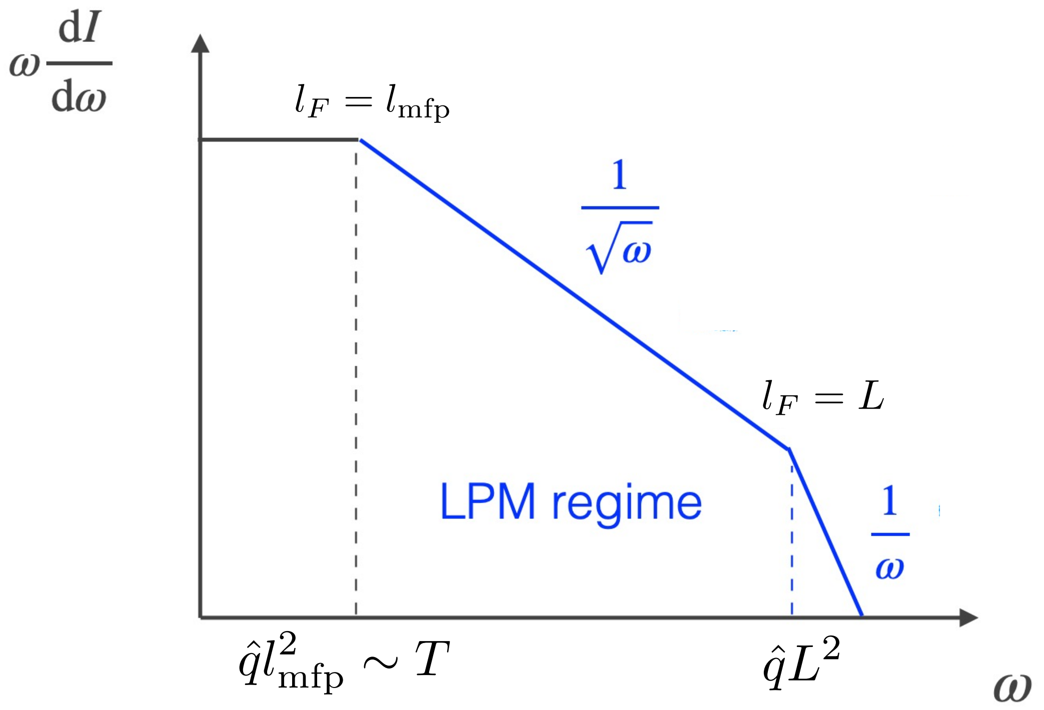
$$\hat{q} \equiv \frac{\mathrm{d}\langle k_\perp^2 \rangle}{\mathrm{d}t}$$

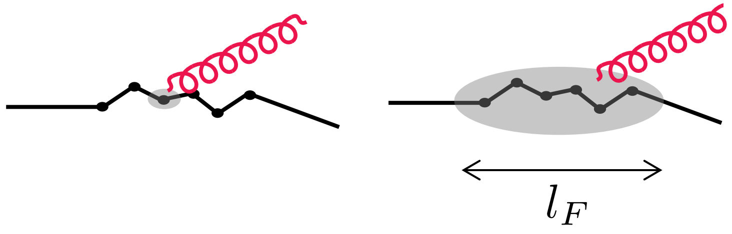
Kicks occasionally induce gluon radiation

Radiation can't be resolved instantaneously



$$l_F \propto \sqrt{\omega}$$



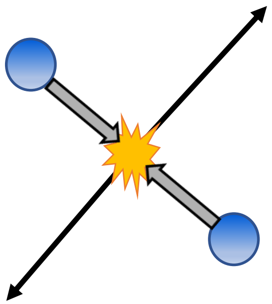


Baier, Dokshitzer, Mueller, Peigne, Schiff (1996), Zakharov (1996)
Arnold, Moore, Yaffe (2003)

Fig: adapted from Yacine Mehtar-Tani QM'19

At leading order, jets are initiated by a quark or gluon from the hard process

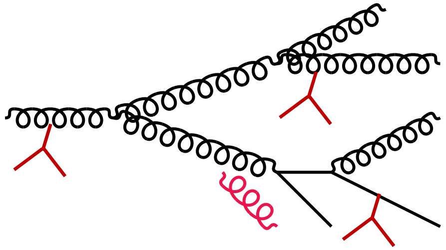
q, g

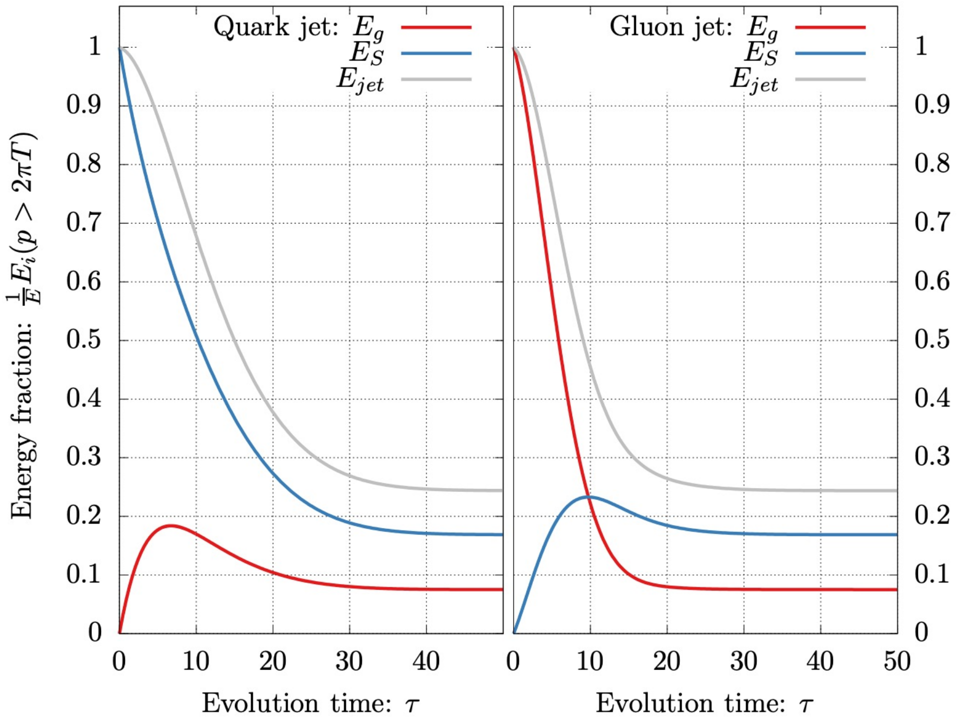


$C_q = 4/3$

$C_g = 3$

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



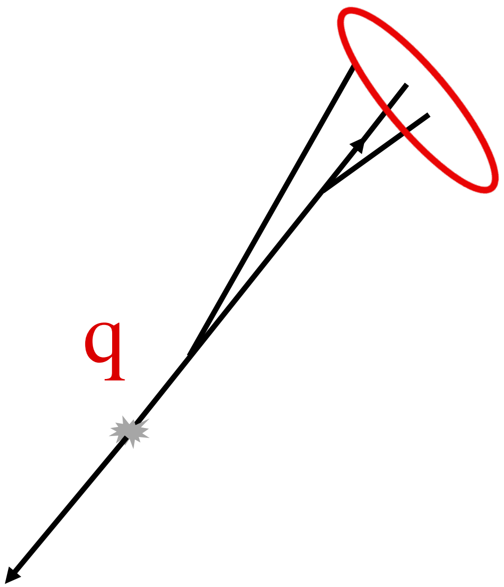


Schlichting, Soudi [2008.04928]

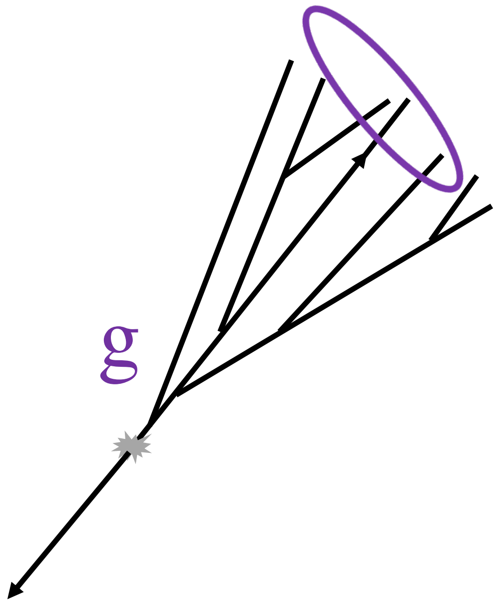
How are quark and gluon jets modified differently by the quark-gluon plasma?

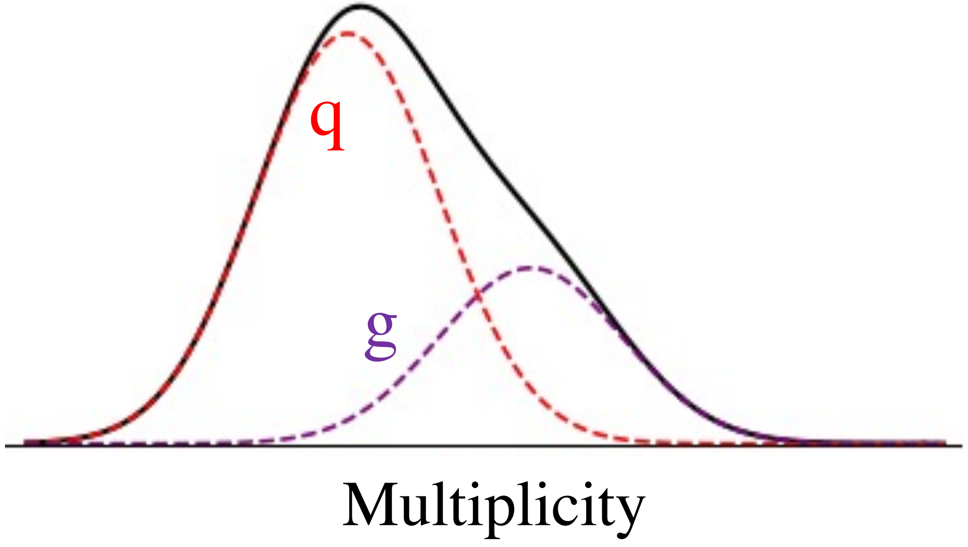
Quark and gluon jets look different in terms of (sub)structure

“quark jet”



“gluon jet”



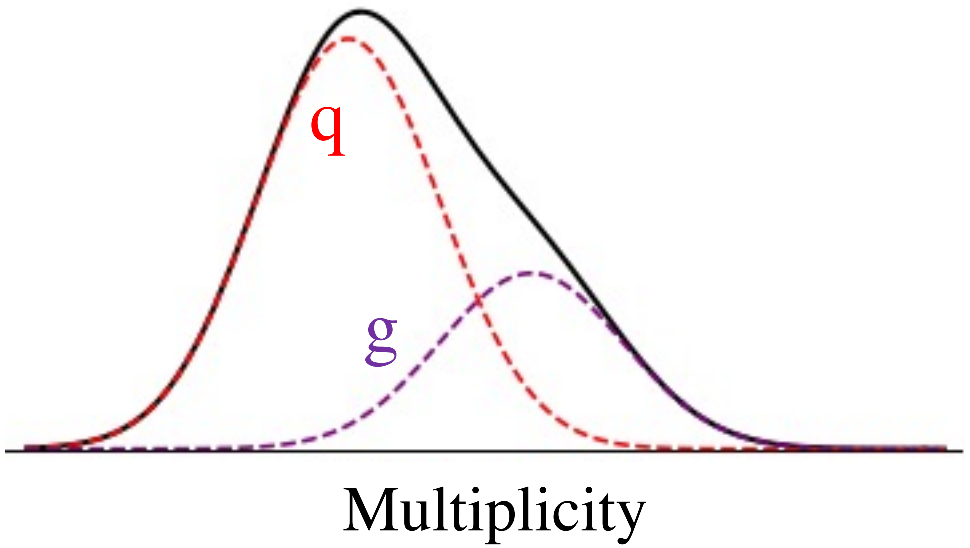


Can we use it?

Quark and gluon jets look different in terms of (sub)structure

Outline

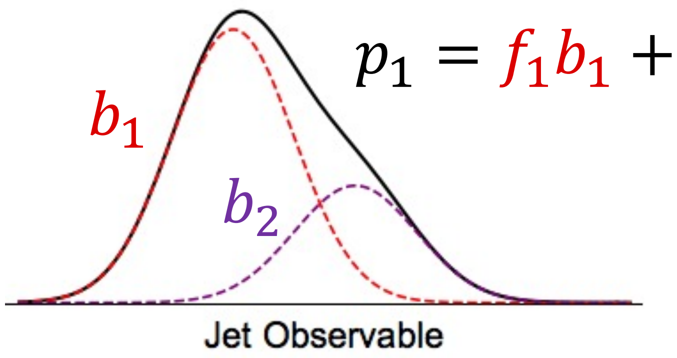
- A data-driven method for q/g separation (in cartoons)
- Monte Carlo studies in pp and AA



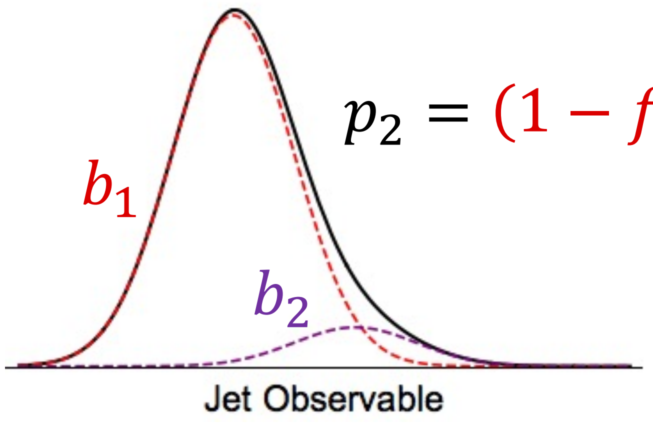
In collaboration with Jesse Thaler and Andrew Patrick Turner

Based on arXiv:2008.08596

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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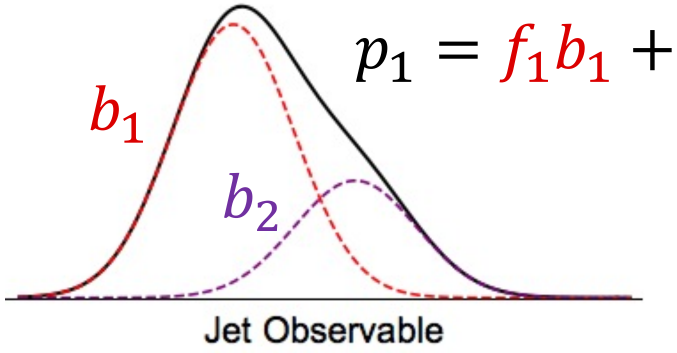

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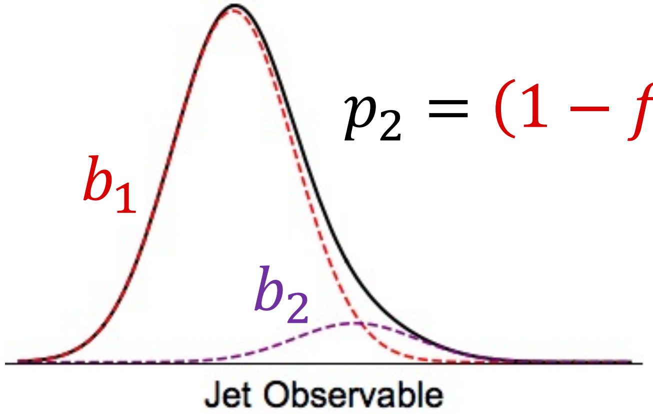

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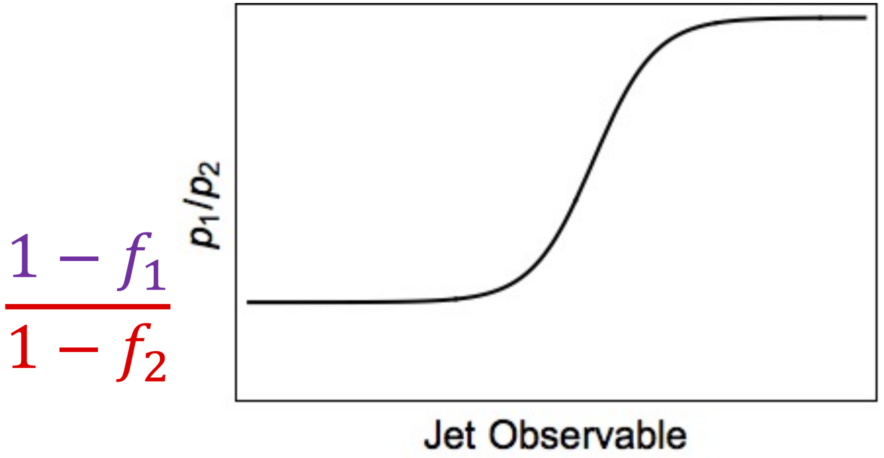

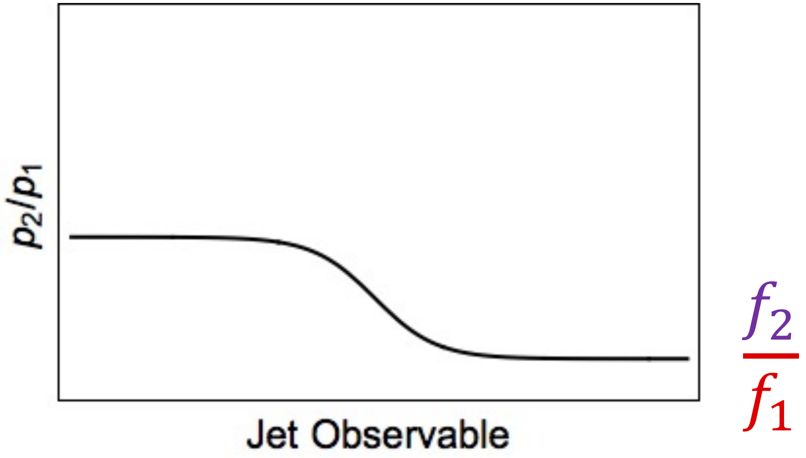

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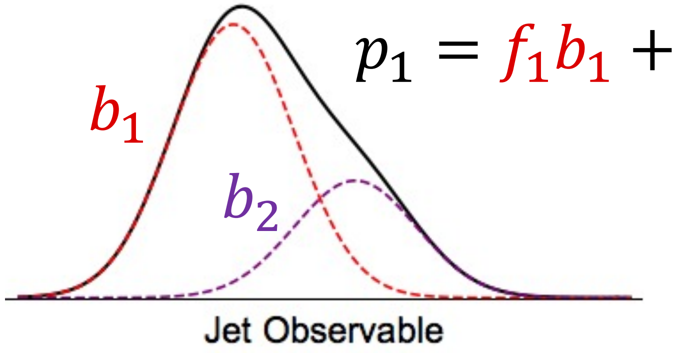

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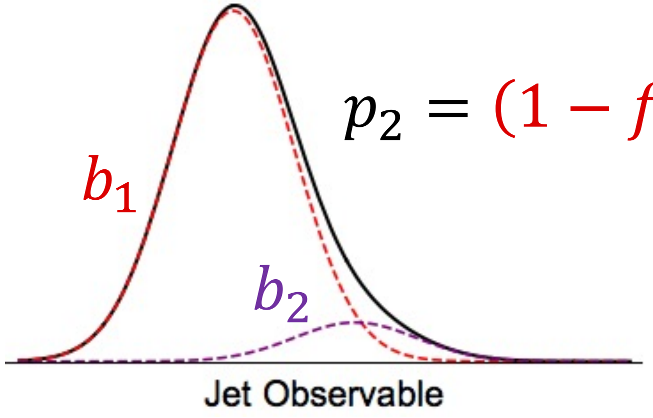
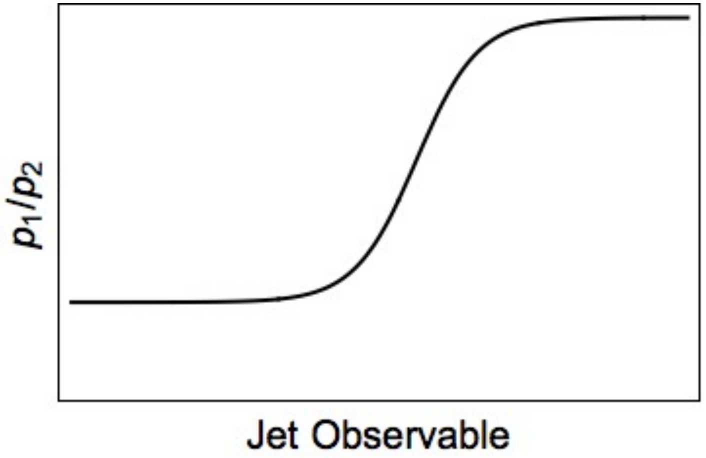
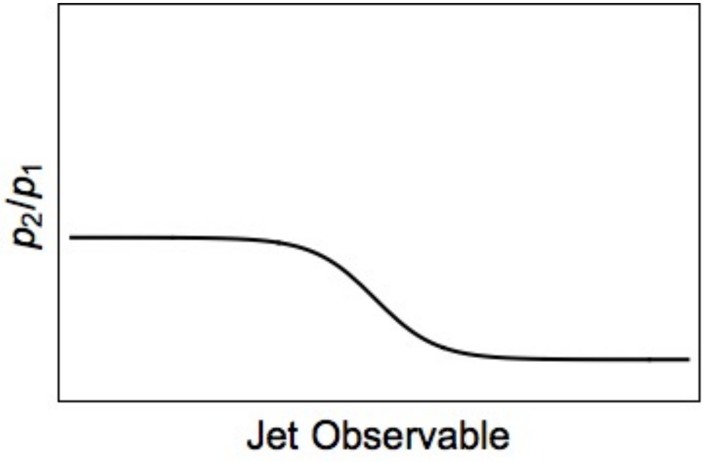


$$p_2 = (1 - f_2) b_1 + f_2 b_2$$

$$\frac{1 - f_1}{1 - f_2}$$





$$\frac{f_2}{f_1}$$

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

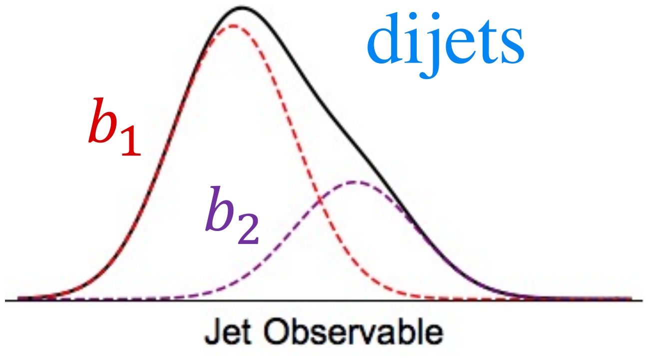
p–p: Metodiev and Thaler [1802.00008] Komiske, Metodiev, Thaler [1809.01140]

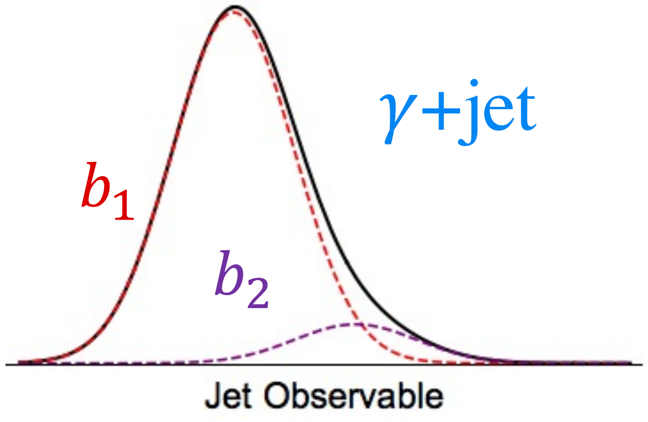
Disentangling mixture distributions into "quark" and "gluon"

example

Requires…

Sample independence:





Disentangling mixture distributions into “quark” and “gluon”

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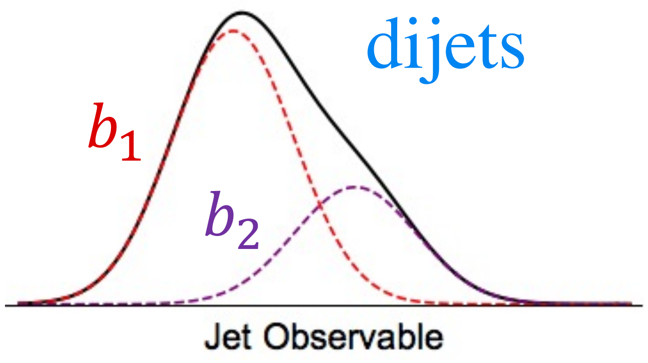
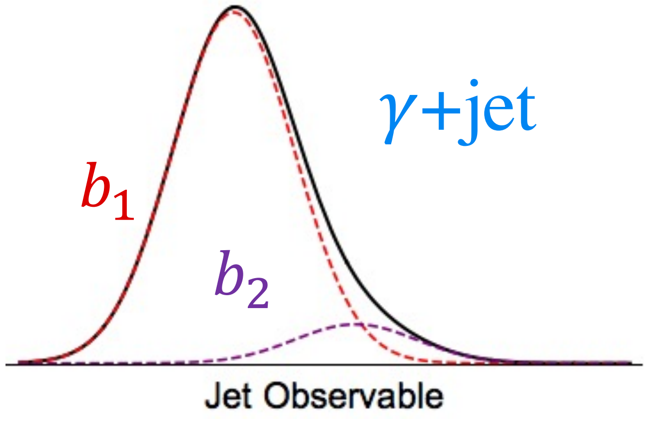




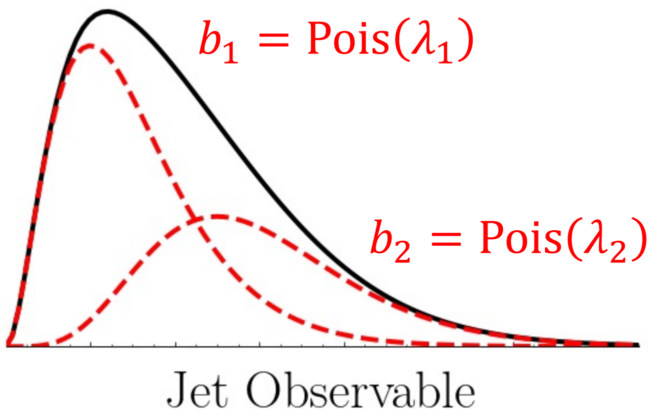
Mutual Irreducibility: samples are pure quark and pure gluon in some limits

Above: base distributions are completely separated at $\pm\infty$

Quantified by $\lim_{\mathcal{O}\to\infty} \frac{b_1(\mathcal{O})}{b_2(\mathcal{O})} = 0 \qquad \lim_{\mathcal{O}\to-\infty} \frac{b_2(\mathcal{O})}{b_1(\mathcal{O})} = 0$

Mutual irreducibility of counting observables

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



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

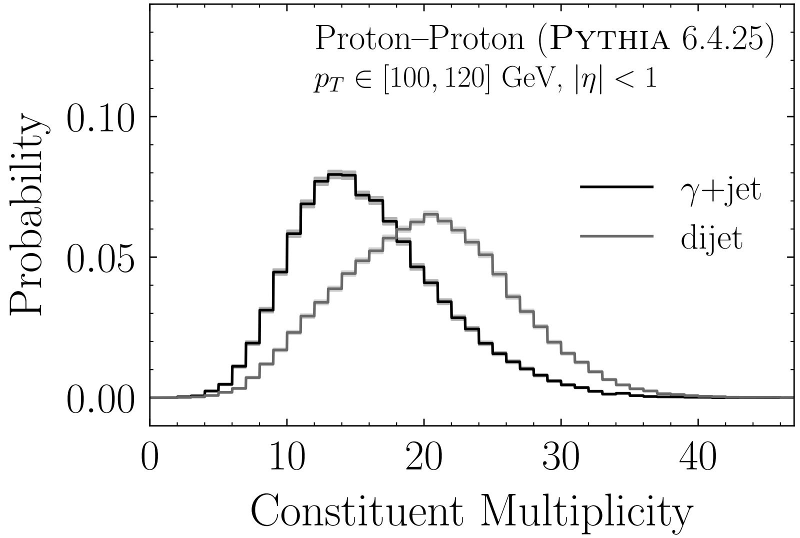
$$\lim_{\mathcal{O}\to 0} \frac{b_2(\mathcal{O})}{b_1(\mathcal{O})} = \exp(\lambda_1 - \lambda_2)$$

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

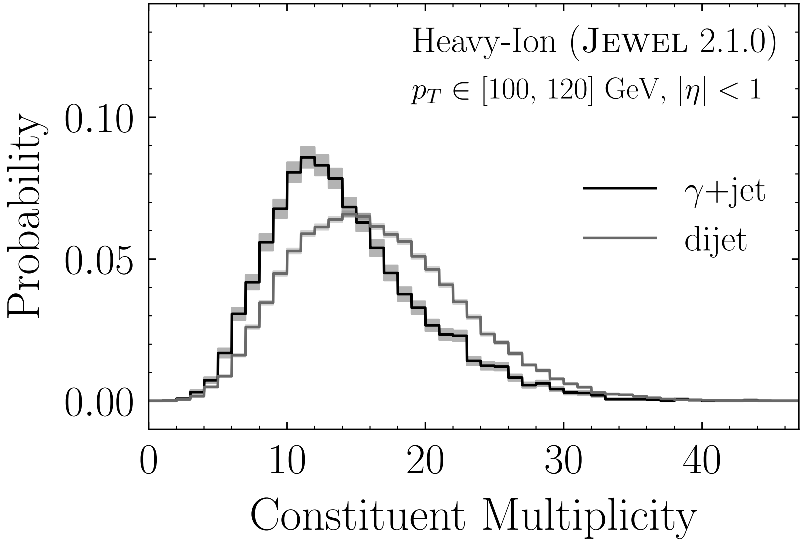
Frye et al [1704.06266]

How are quark- and gluon-initiated jets modified by the quark–gluon plasma?

proton–proton



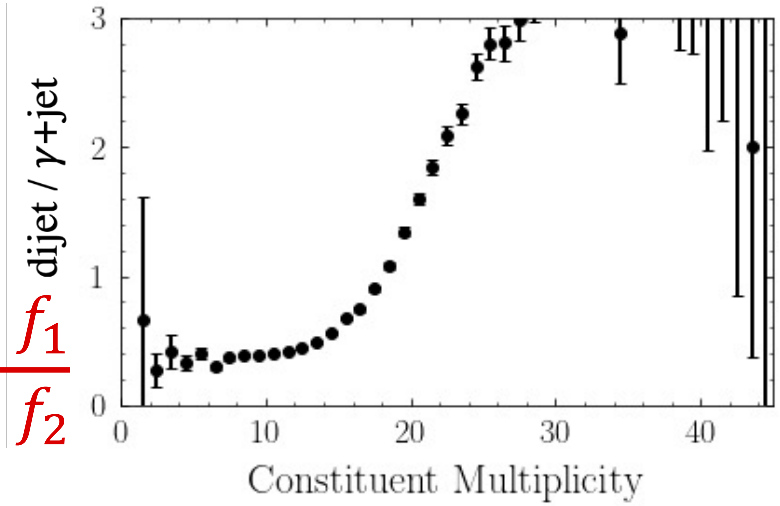
heavy-ion

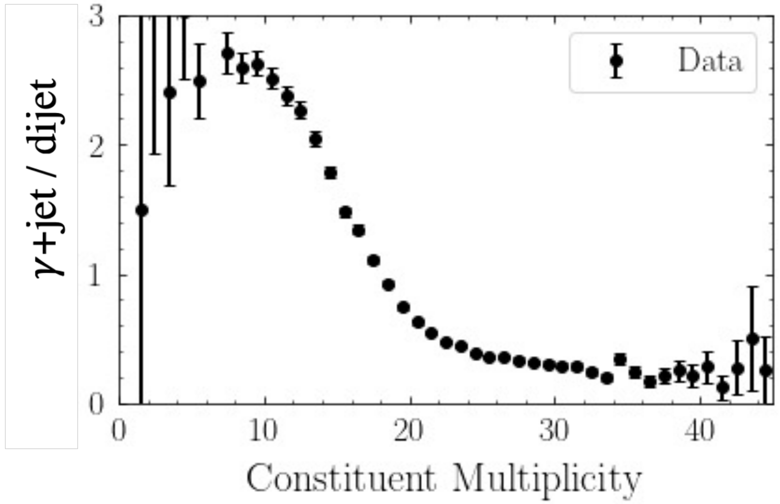


Fractions are sensitive to tails of the distribution where statistics are low

proton–proton

$$\frac{1-f_1}{1-f_2}$$





$$\frac{f_2}{f_1}$$

Fractions are sensitive to tails of the distribution where statistics are low

proton–proton

$$\frac{1-f_1}{1-f_2}$$

$$\frac{f_2}{f_1}$$

heavy-ion

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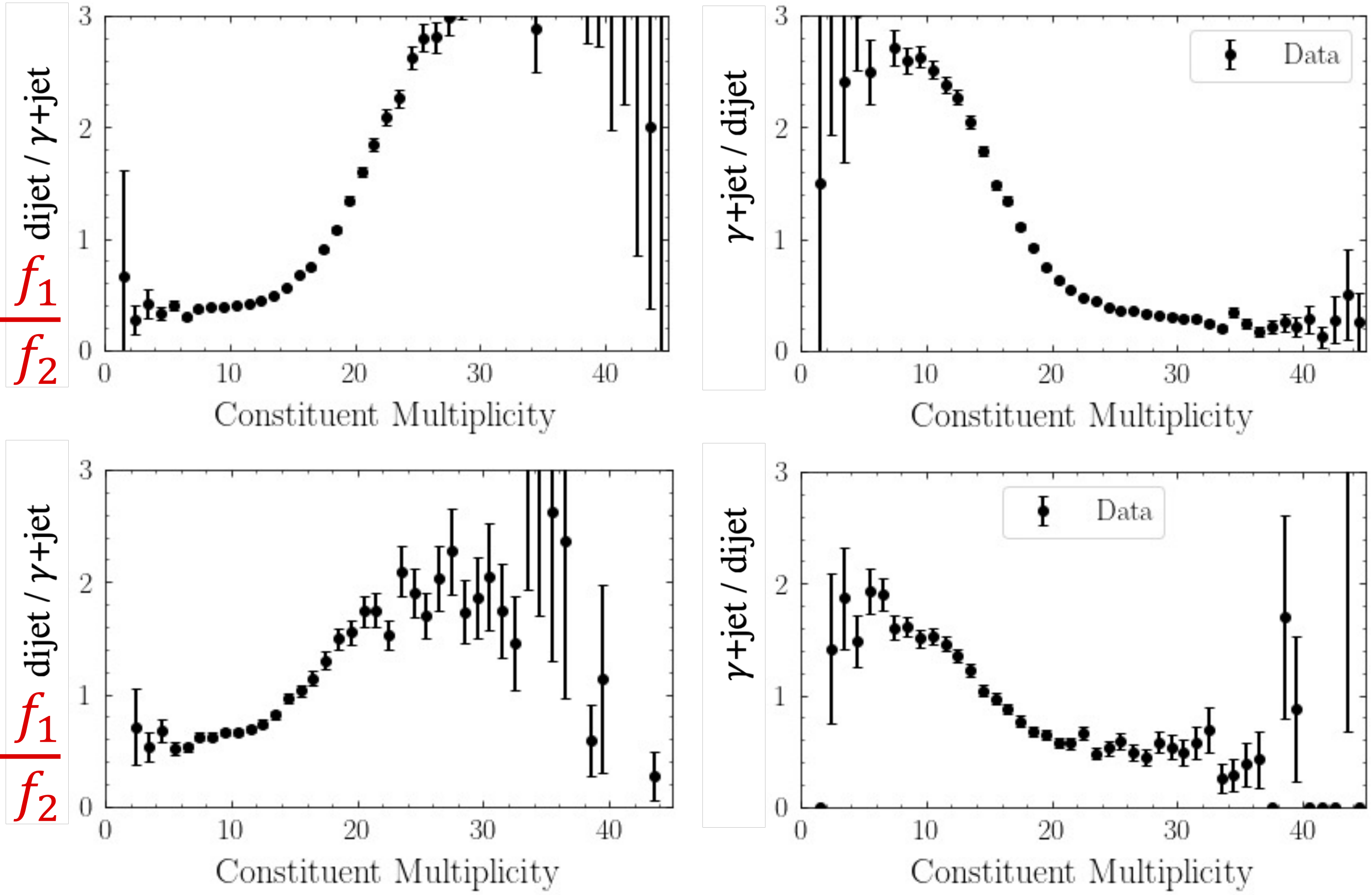

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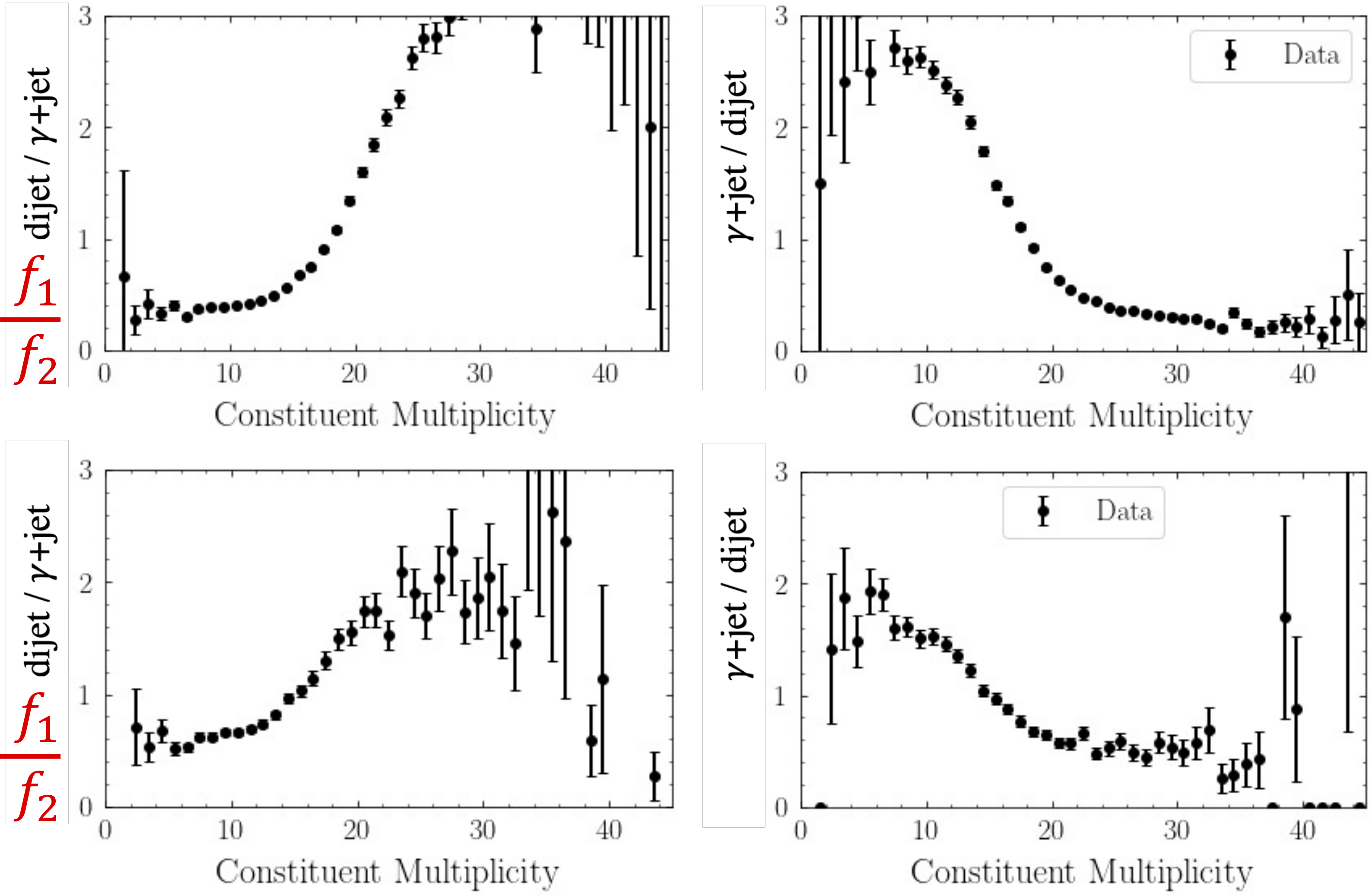


heavy-ion

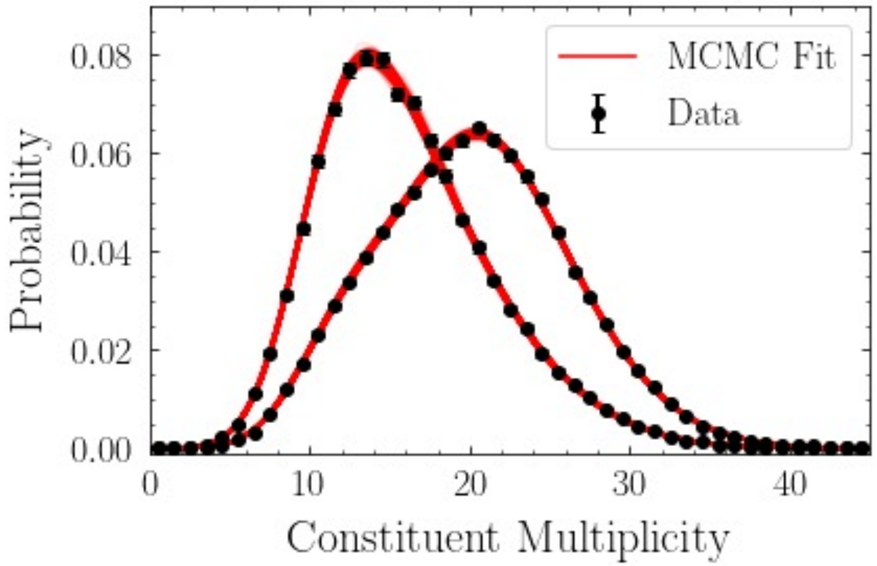
$$\frac{1-f_1}{1-f_2}$$

$$\frac{f_2}{f_1}$$

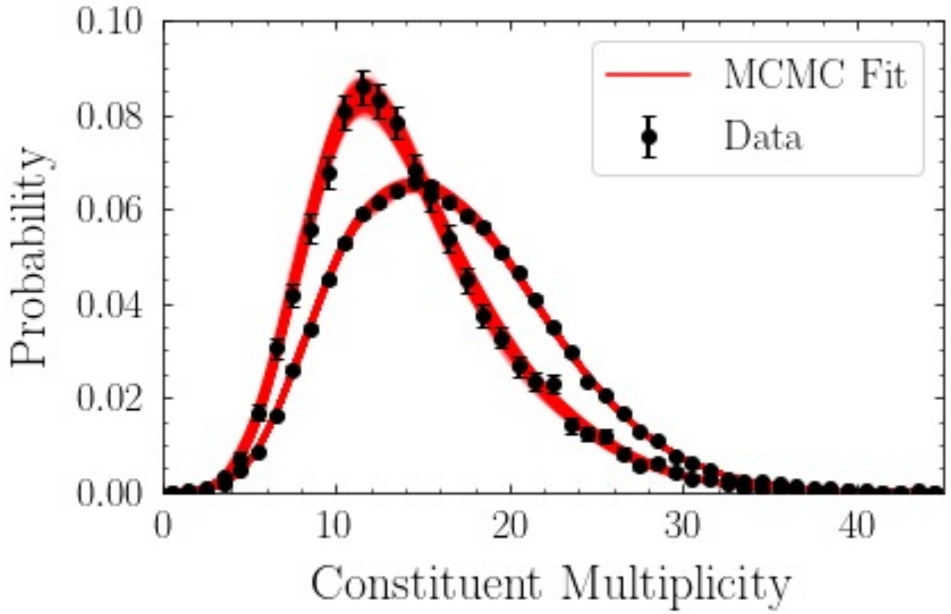
How to robustly extract fractions with statistical uncertainties?

A solution: use fitting to constrain the tails using the interior of the distribution

proton–proton



heavy-ion



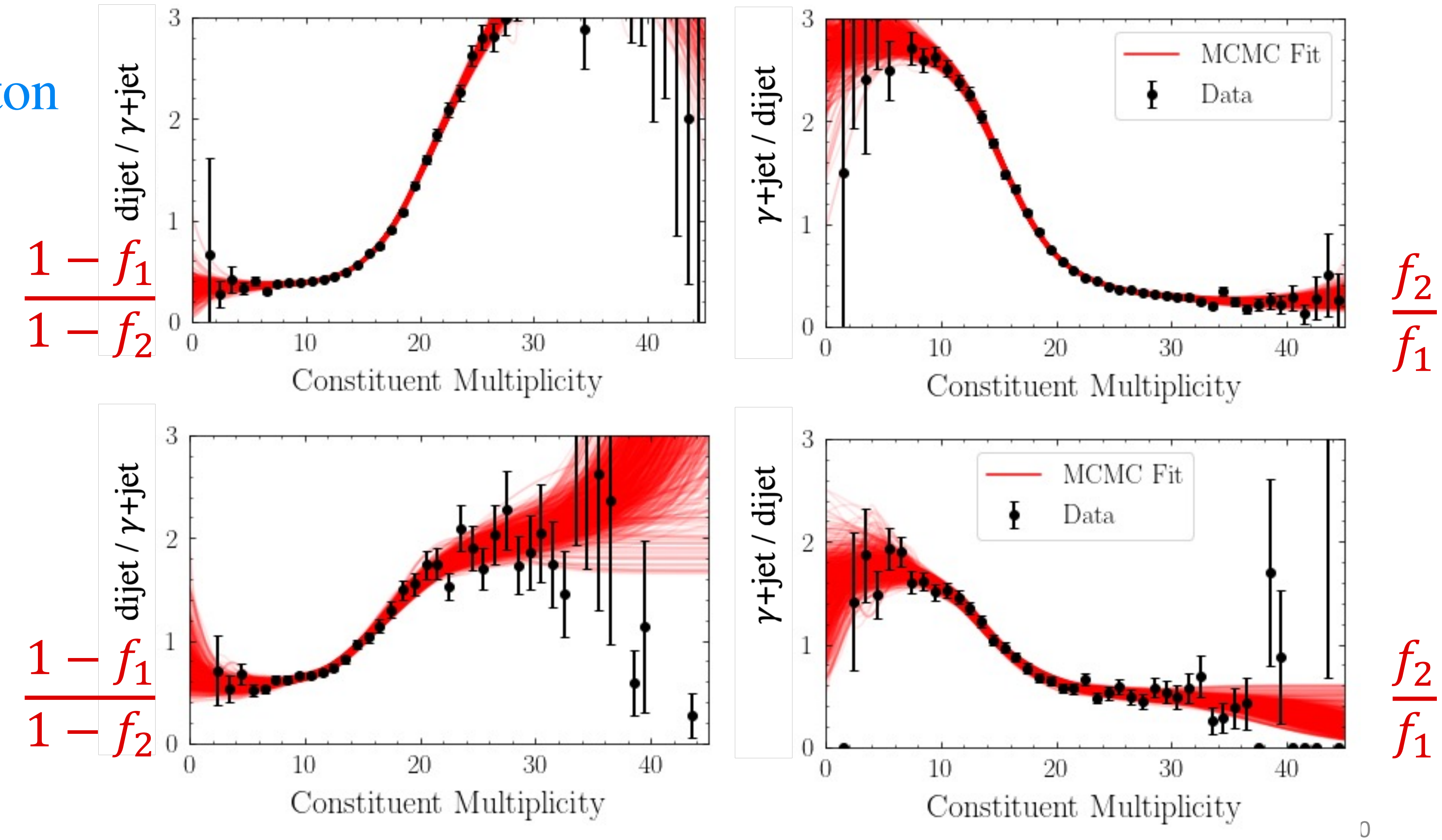
Each distribution is a distinct sum of 4 skew-normal distributions (18 fit parameters)

Fit using MCMC with Poisson likelihood function

A solution: use fitting to constrain the tails using the interior of the distribution

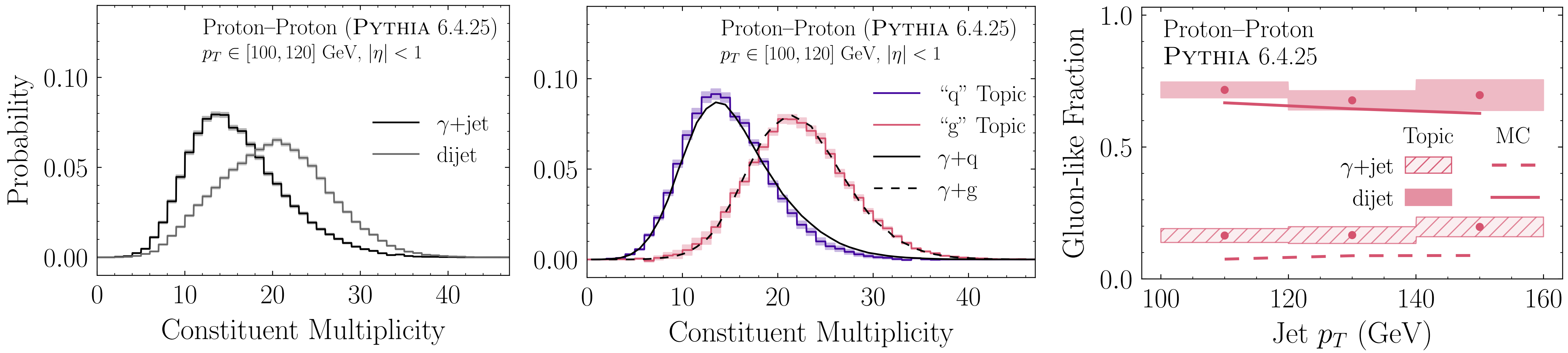
proton–proton

heavy-ion



Extracting quark/gluon contributions to constituent multiplicity

proton–proton



Extracting quark/gluon contributions to constituent multiplicity

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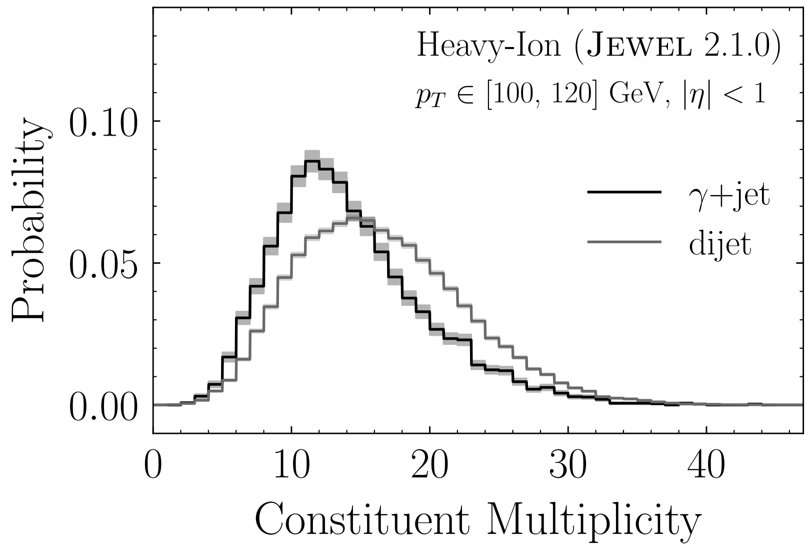
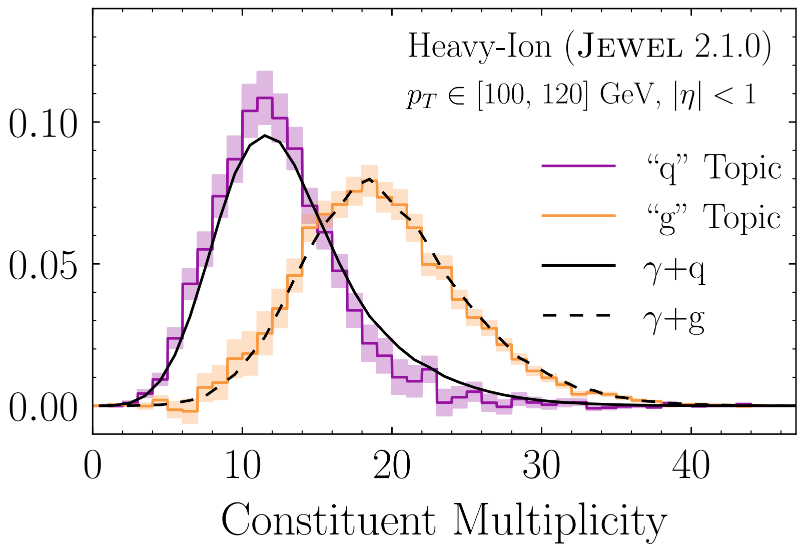
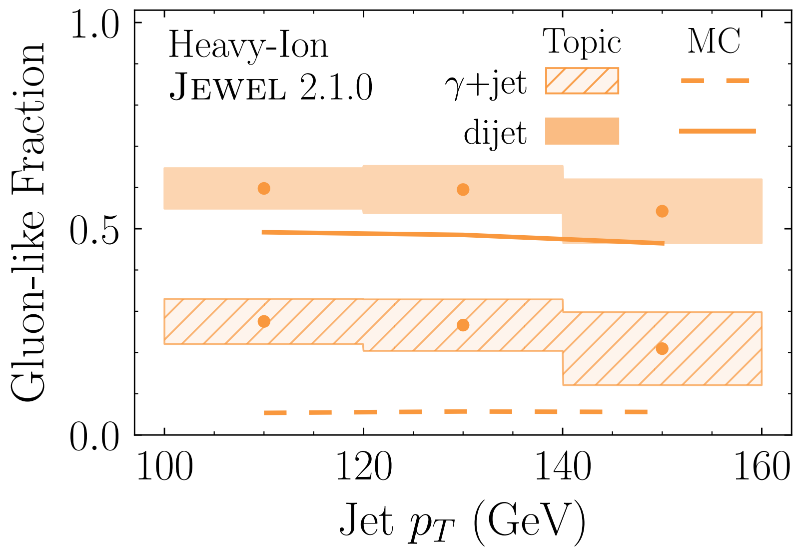
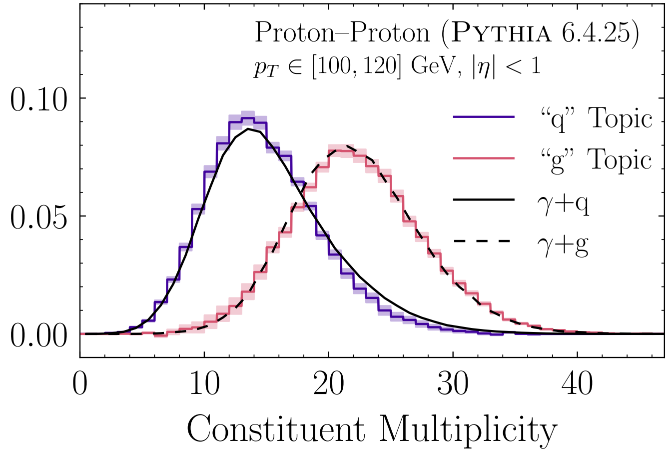






Data-driven quark and gluon jet modification from dijet and γ+jet

proton–proton



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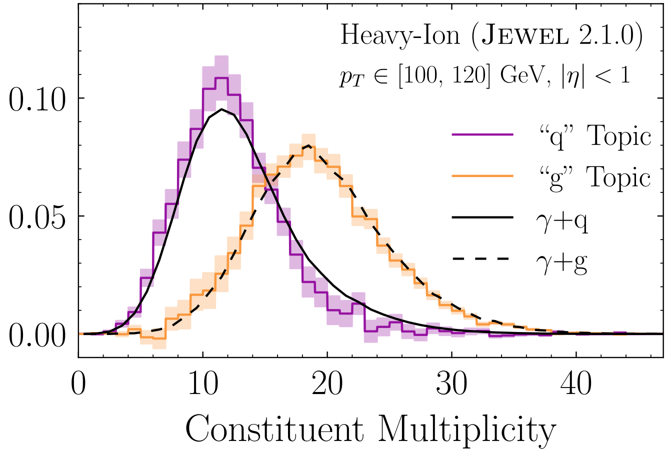
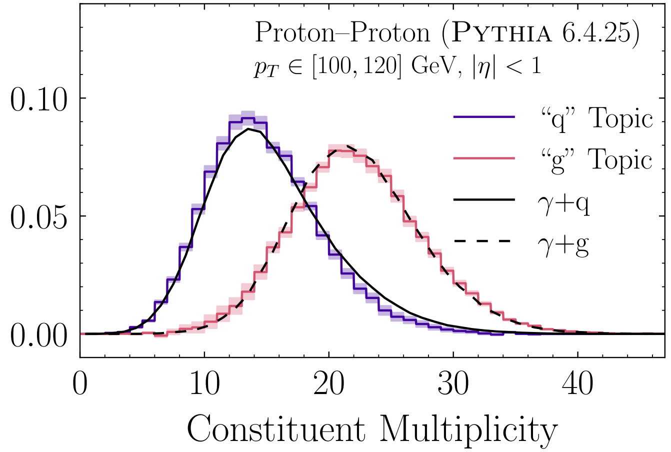
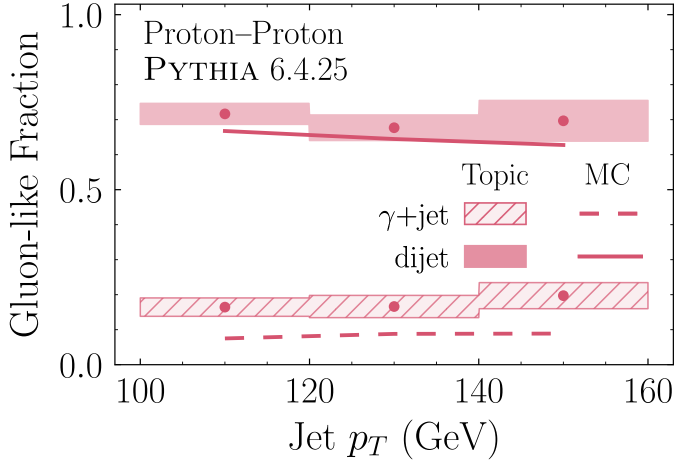


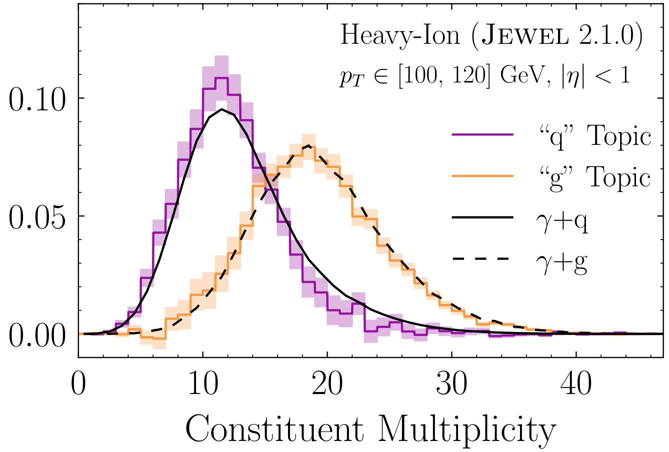
Data-driven quark and gluon jet modification from dijet and γ+jet

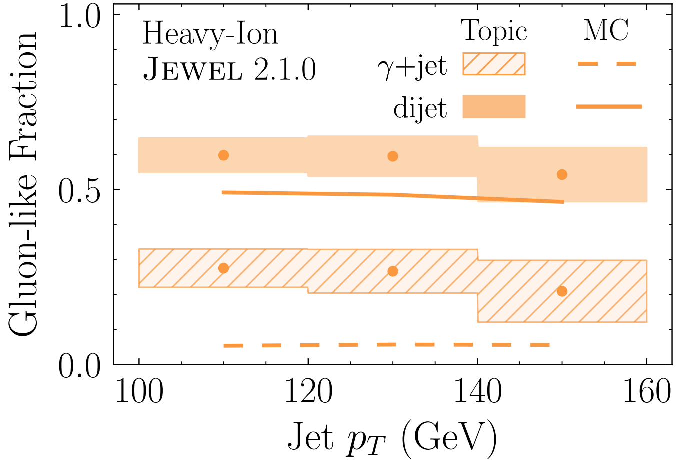
proton–proton





heavy-ion





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?

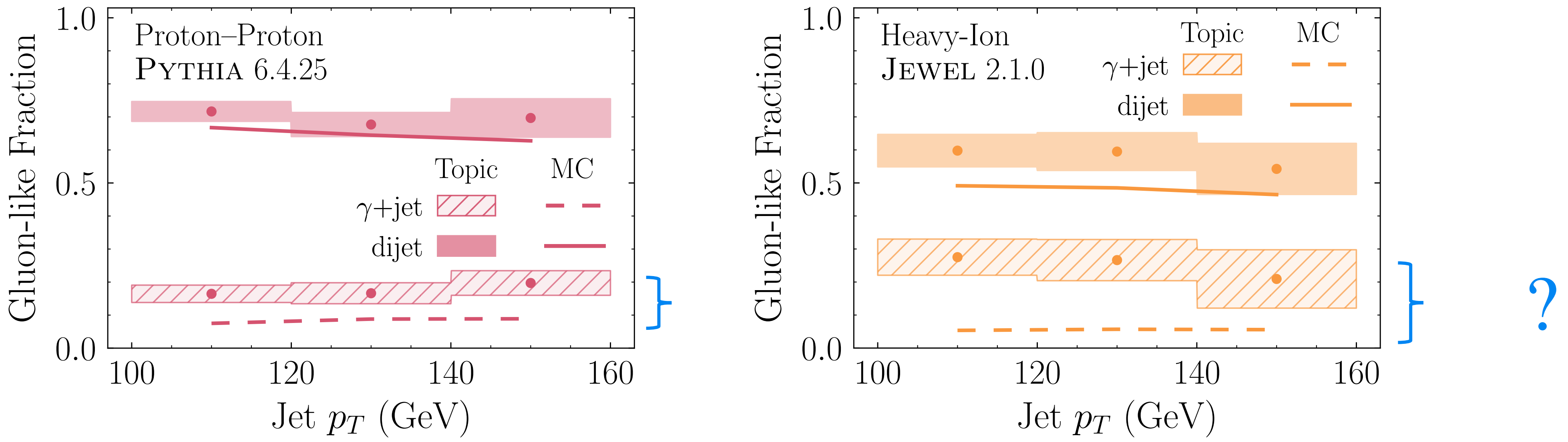
- What observables are robust to background subtraction?
  charged particle multiplicity? constituent multiplicity of soft-dropped jets?

Work in progress with Kylie Ying, Yi Chen, Yen-Jie Lee (MIT)

Applications to other category problems in heavy-ions?

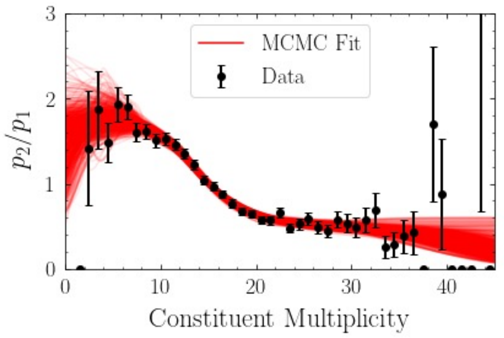
Backup

What do differences between topic and MC fractions mean?



What do differences between topic and MC fractions mean?

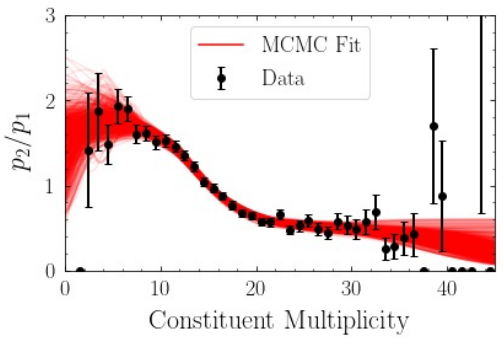
- Limited statistics effects on topic fractions

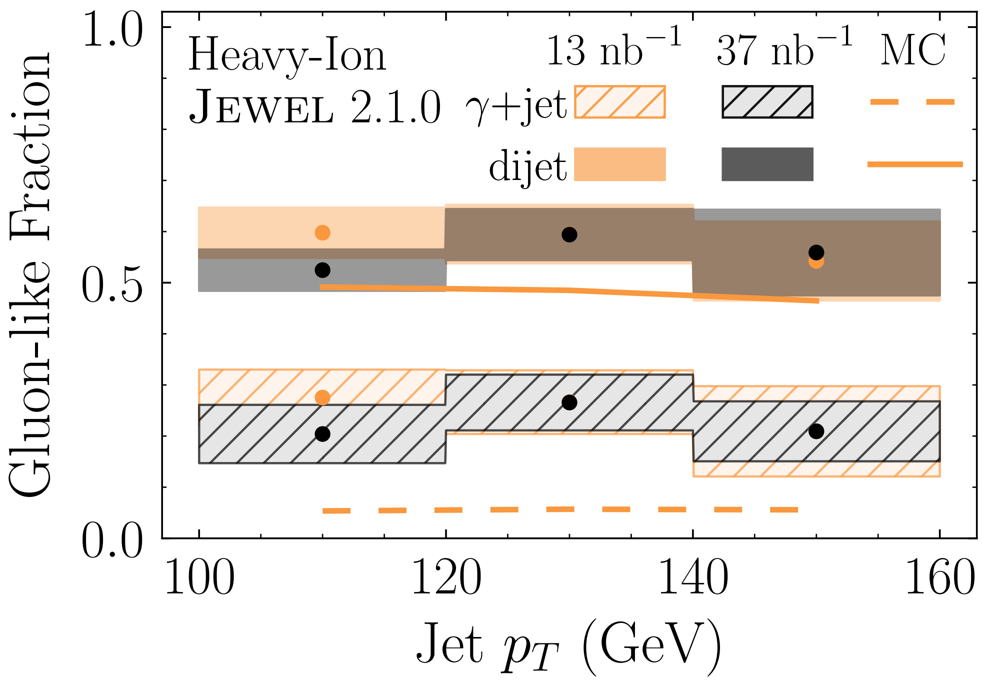


What do differences between topic and MC fractions mean?

- Limited statistics effects on topic fractions

Insignificant change in fractions due to factor 2.8 increase in statistics





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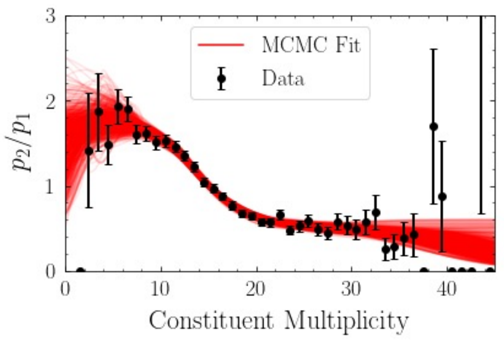
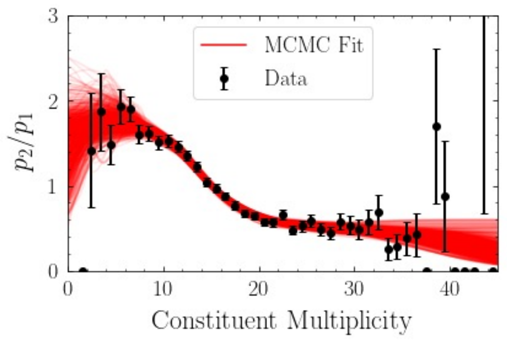


- Limited statistics effects on topic fractions

  Insignificant change in fractions due to factor 2.8 increase in statistics

- Ambiguity in MC quark and gluon labelling

What do differences between topic and MC fractions mean?

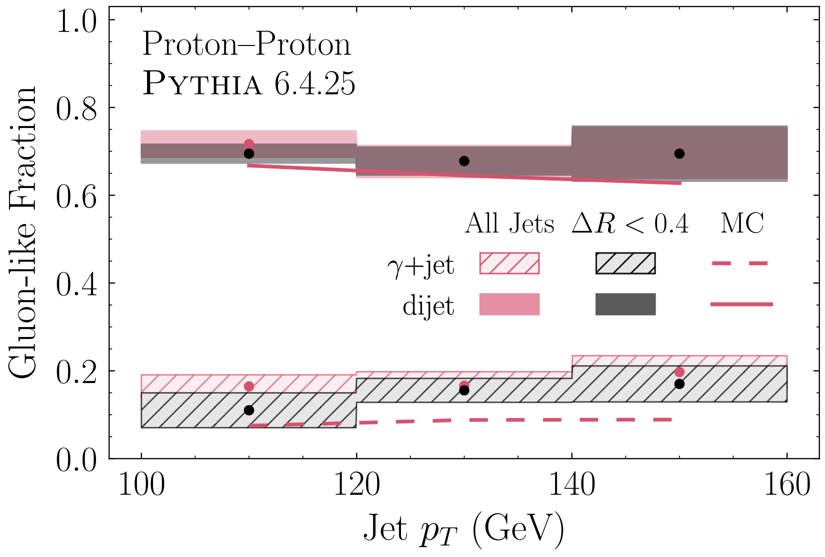


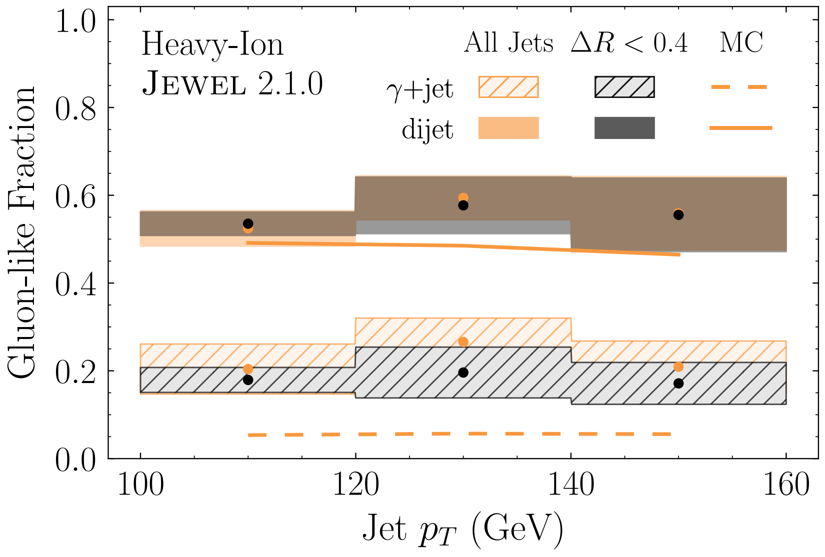
- Limited statistics effects on topic fractions

Insignificant change in fractions due to factor 2.8 increase in statistics

- Ambiguity in MC quark and gluon labelling

Slight decrease in extracted gluon fraction for jets with an initiating parton within the jet radius





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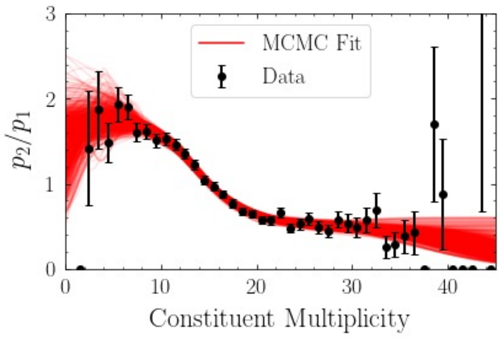

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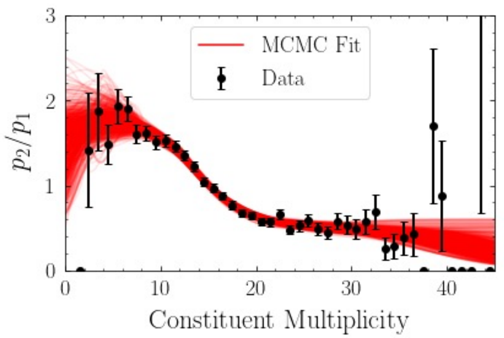

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- “Quark-initiated” jets become more gluon-like