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

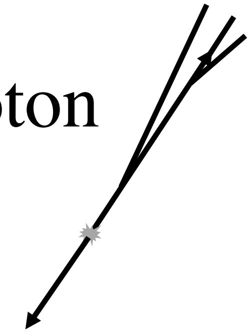
Jasmine Brewer

In collaboration with Jesse Thaler and Andrew Patrick Turner

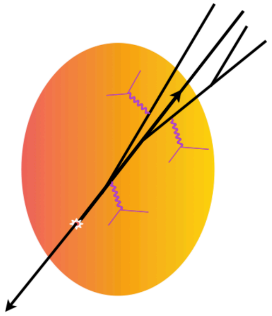
Based on arXiv:2008.08596

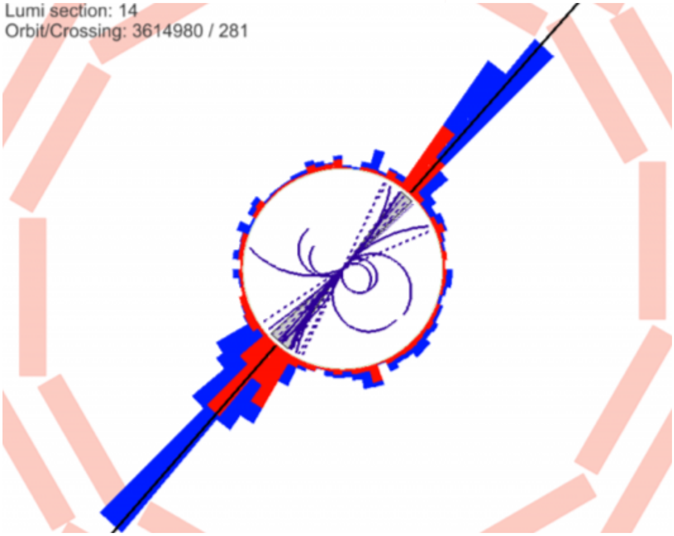
Modification of jets a probe of quark-gluon plasma

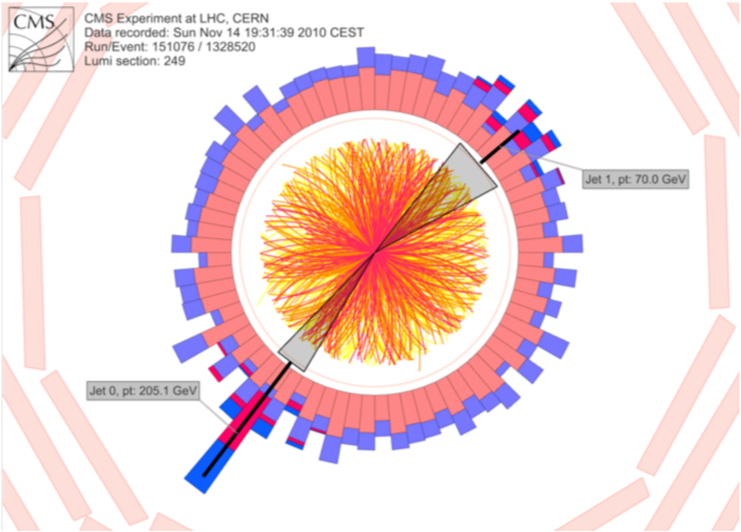
proton–proton



heavy-ion

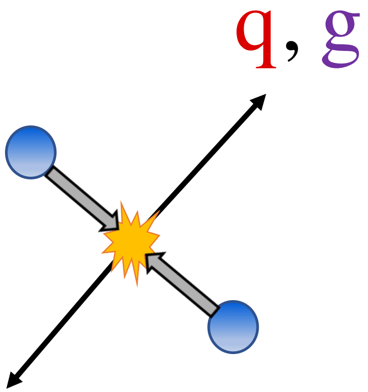






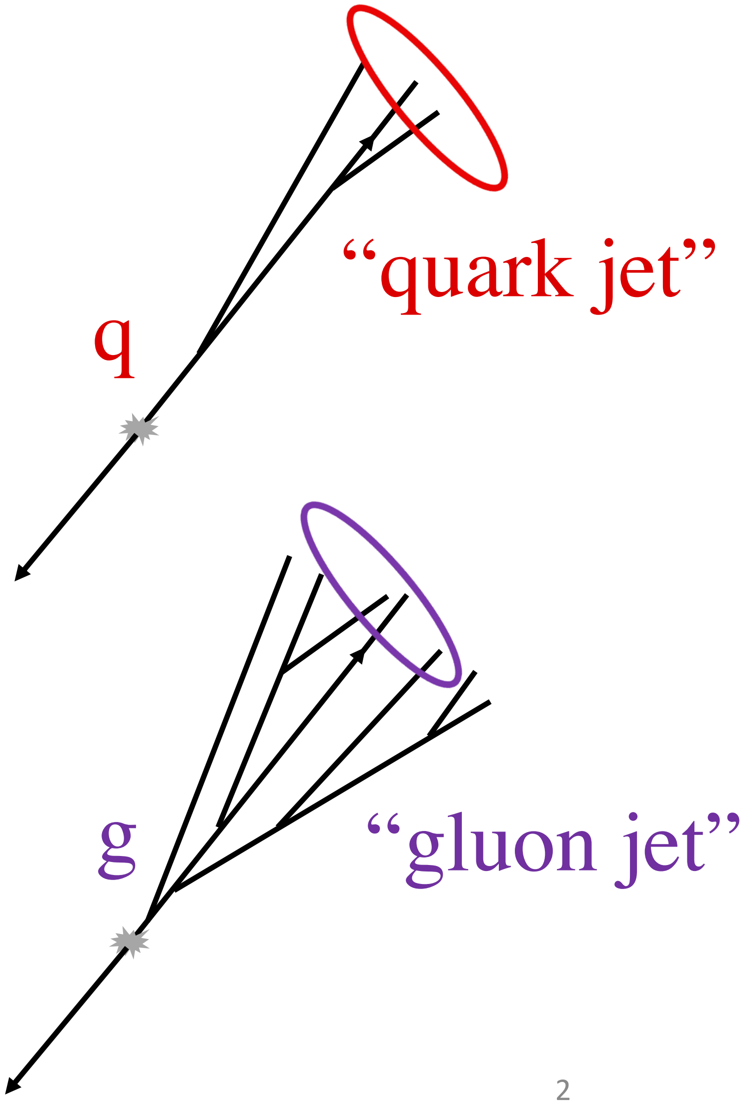
“baseline” jet properties

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



$C_q = 4/3$

$C_g = 3$

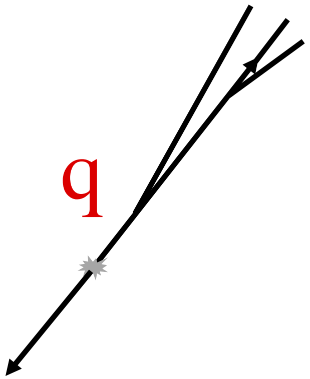


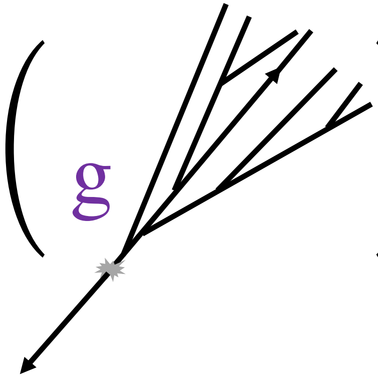
Differences in quark and gluon jet energy loss in quark-gluon plasma

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

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

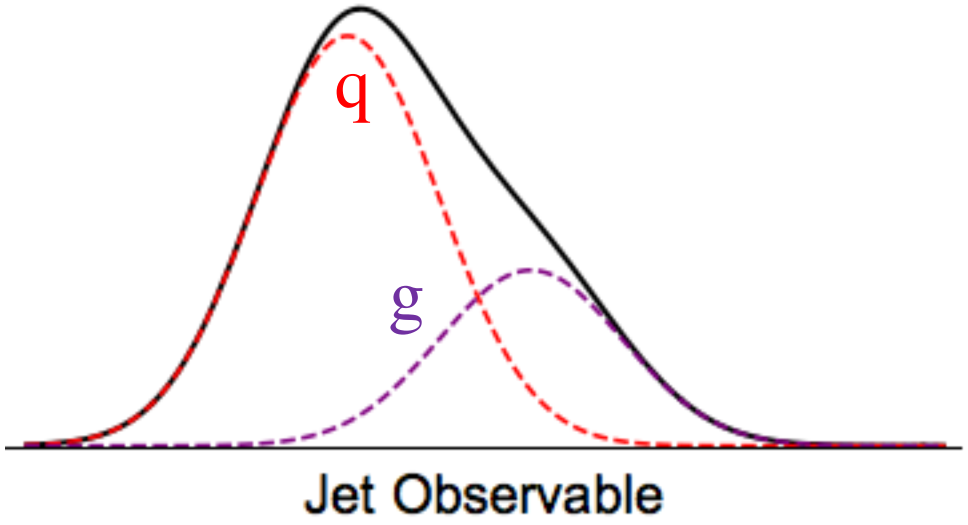
Quark and gluon jets are extended objects whose energy loss may depend on their structure

$$\frac{dE}{dx}\Bigg($$


$$\Bigg) = ???\ \frac{dE}{dx}\Bigg($$


$$\Bigg)$$

Separating quark and gluon jets is challenging because jet measurements are mixture of contributions from both



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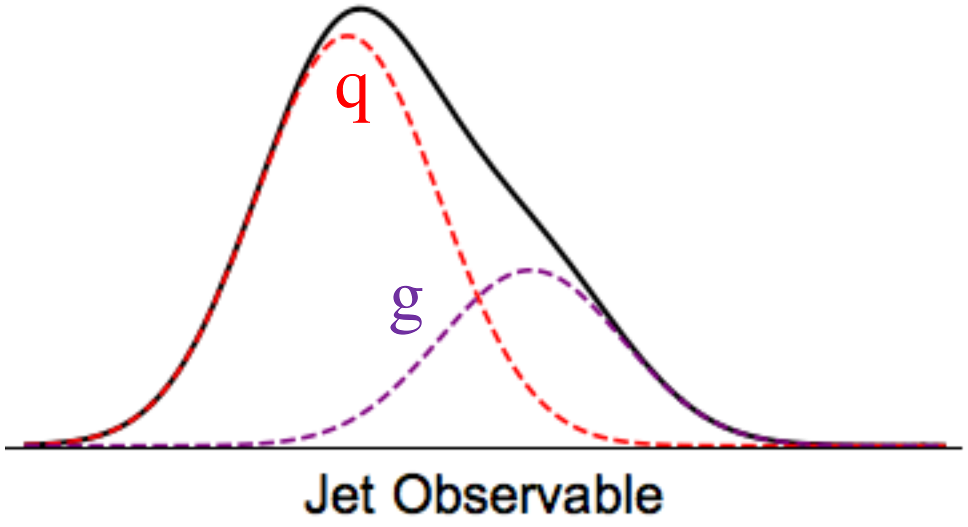
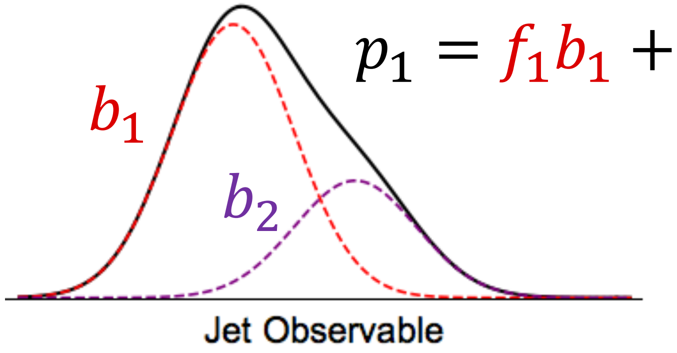


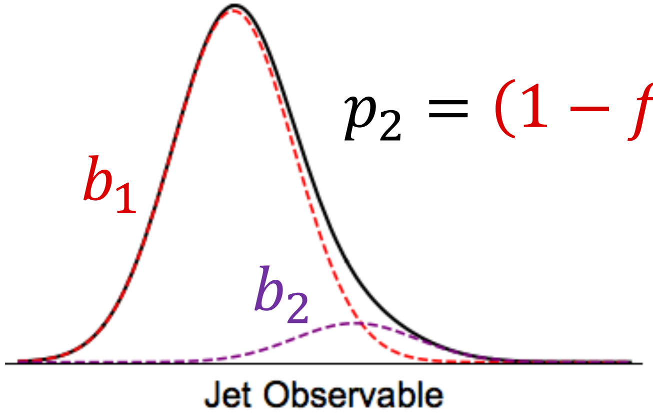
Outline

- 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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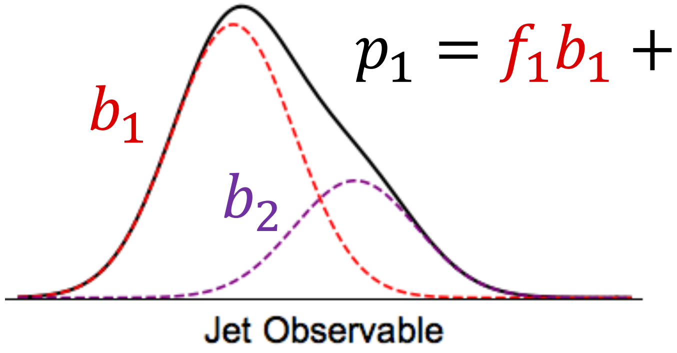

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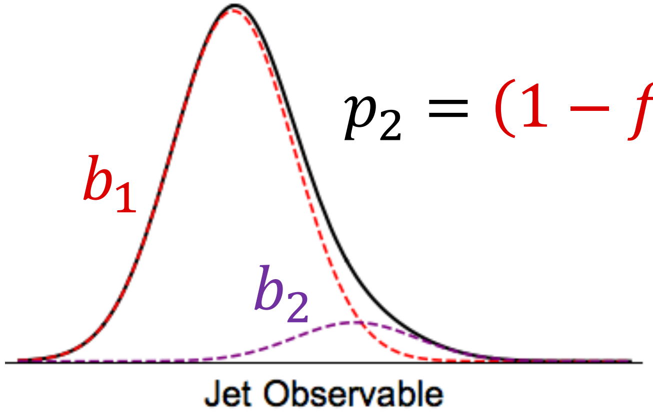
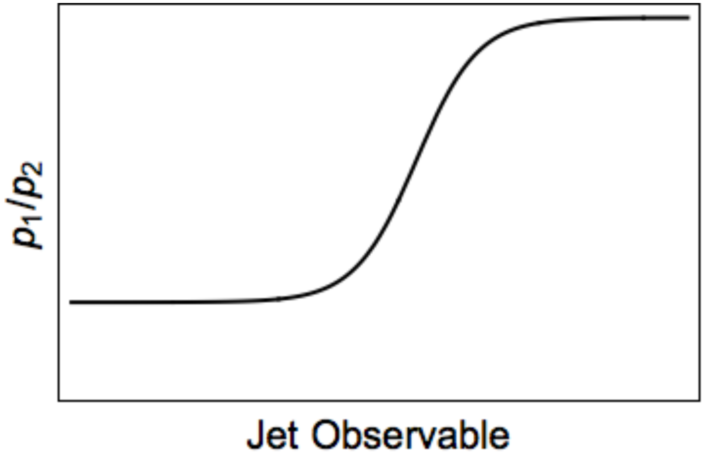
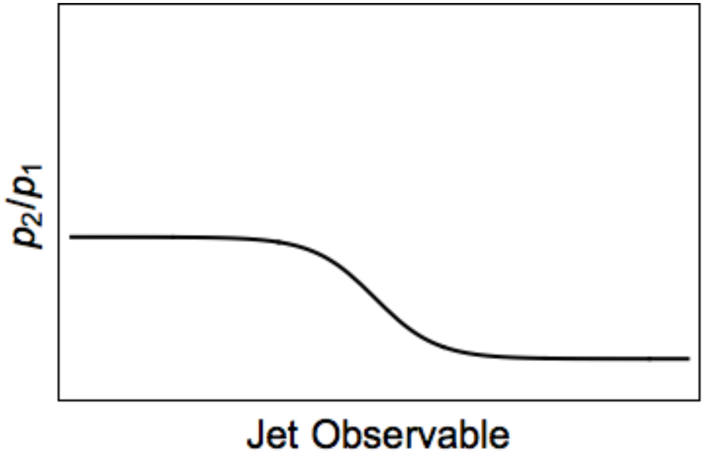


$$p_2 = (1 - f_2) b_1 + f_2 b_2$$

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





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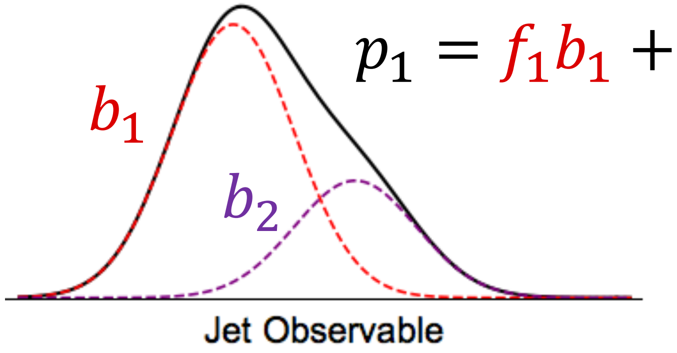

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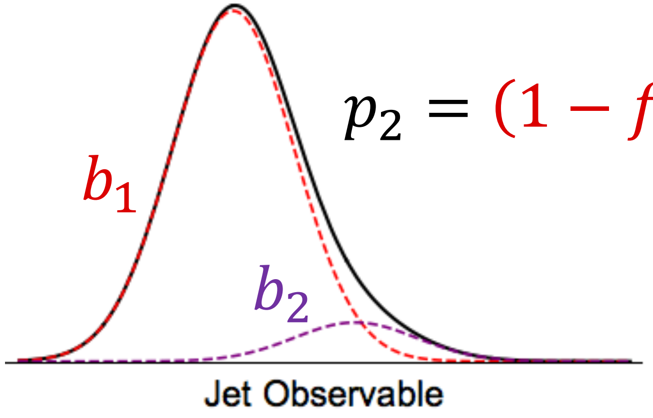

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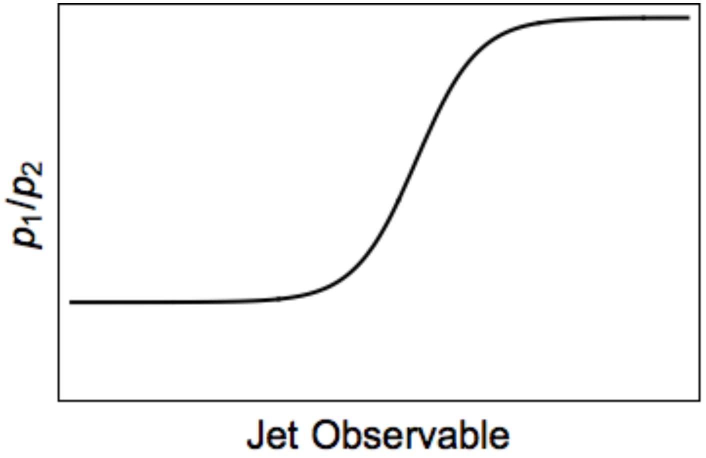
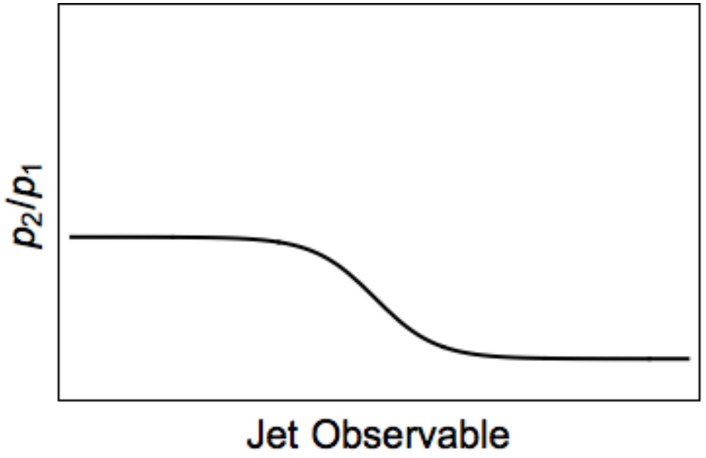




$$\frac{f_2}{f_1}$$

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

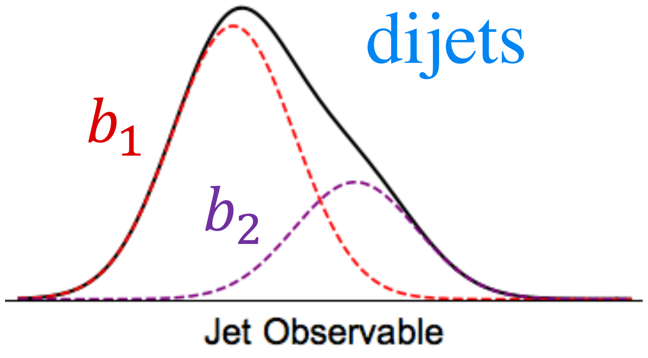
p–p: Metodiev and Thaler [1802.00008] Komiske, Metodiev, Thaler [1809.01140]

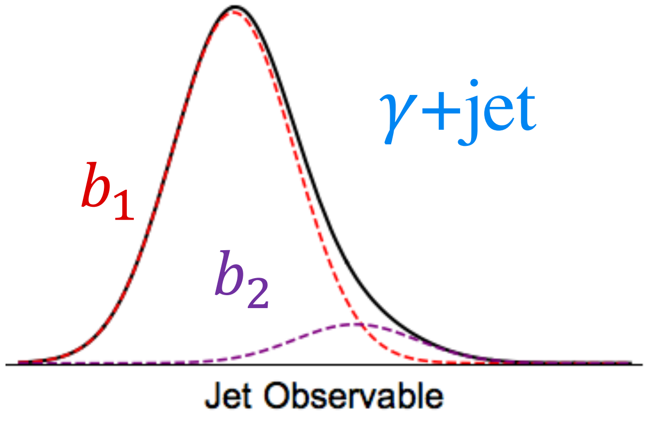
Disentangling mixture distributions into “quark” and “gluon”

Requires…

Sample independence:

example





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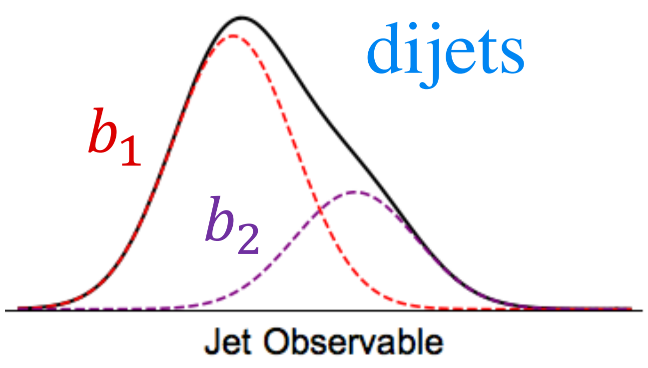
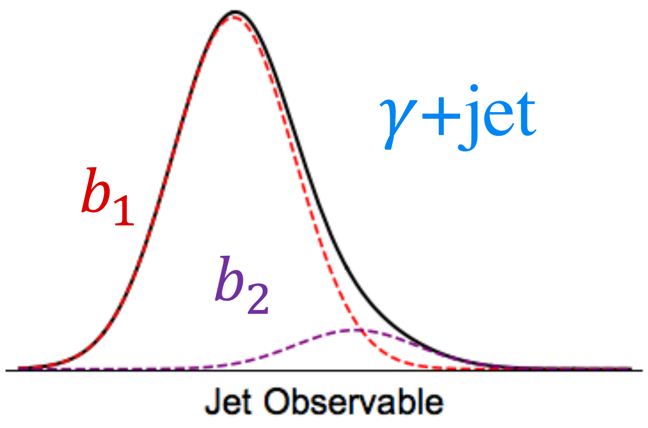




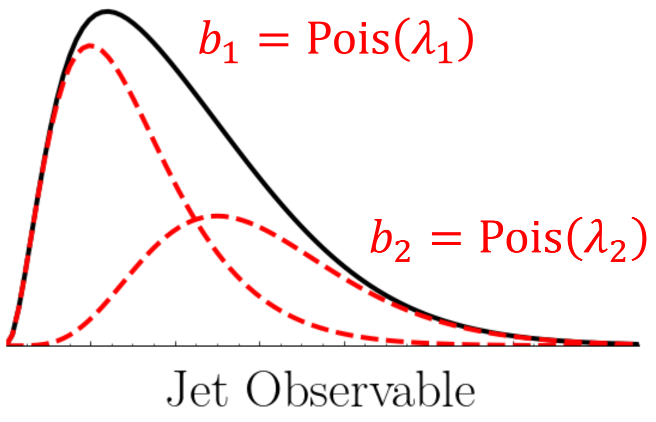
Mutual Irreducibility: samples are pure quark and pure gluon in some limits

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

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

Mutual irreducibility of counting observables

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



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

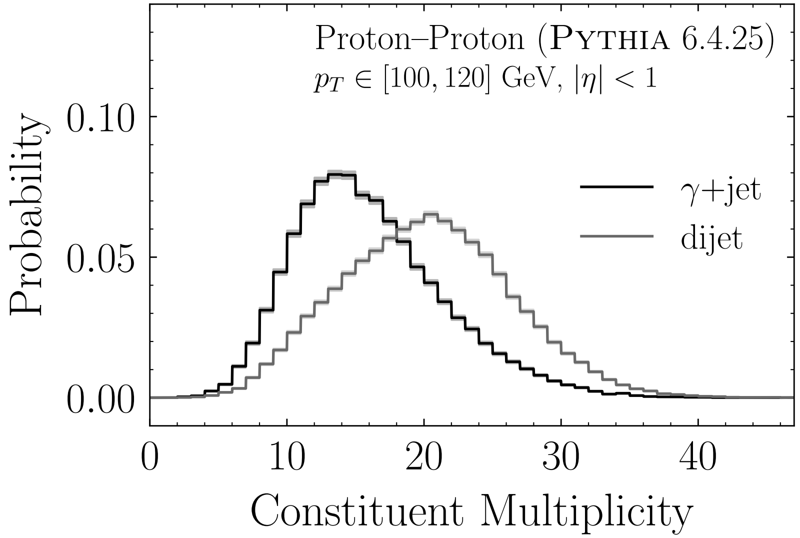
$$\lim_{\mathcal{O}\to 0} \frac{b_2(\mathcal{O})}{b_1(\mathcal{O})} = \exp(\lambda_1 - \lambda_2)$$

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

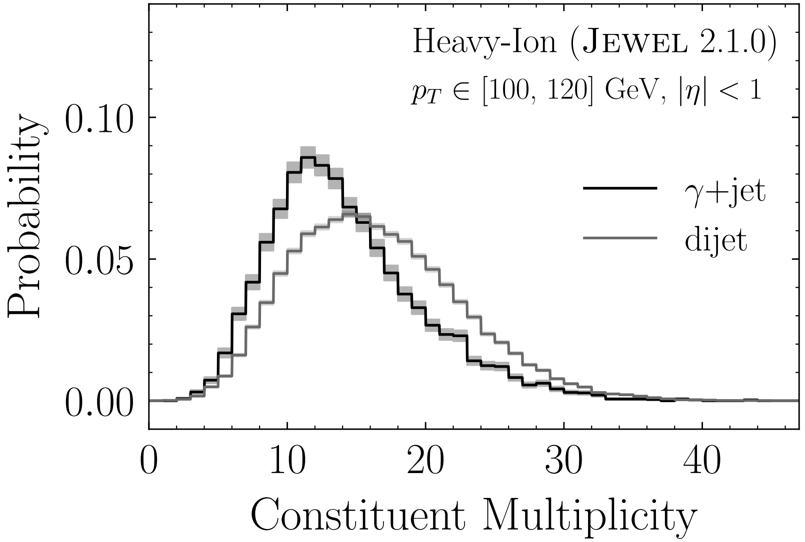
Frye et al [1704.06266]

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

proton–proton



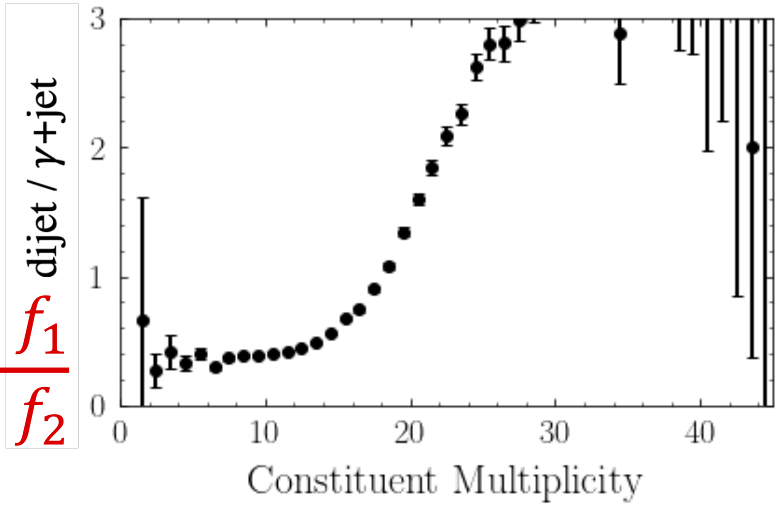
heavy-ion

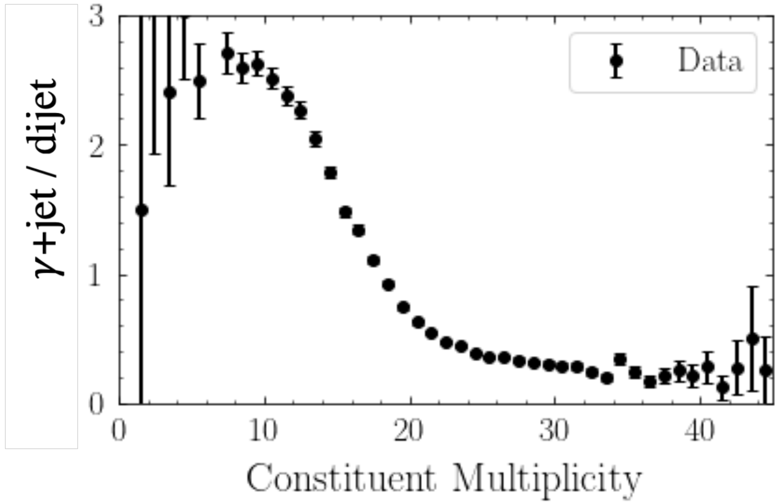


Fractions are sensitive to tails of the distribution where statistics are low

proton–proton

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





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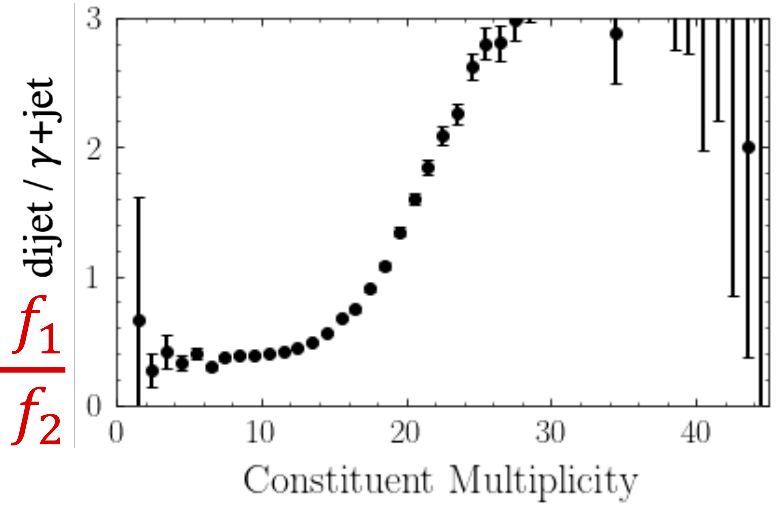

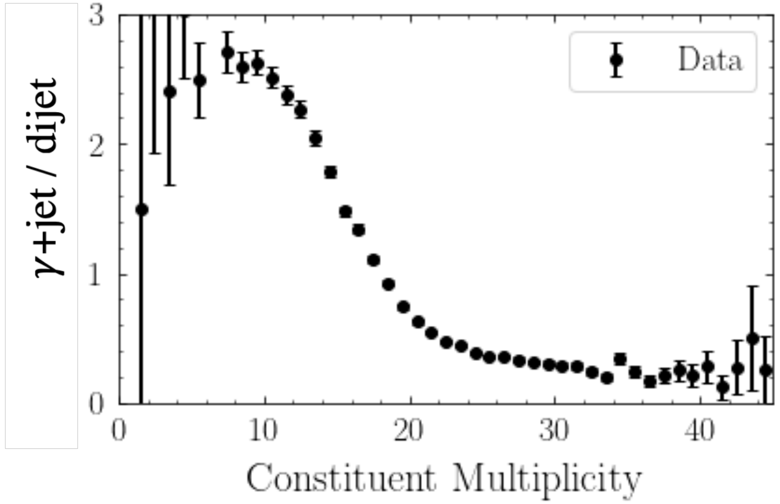

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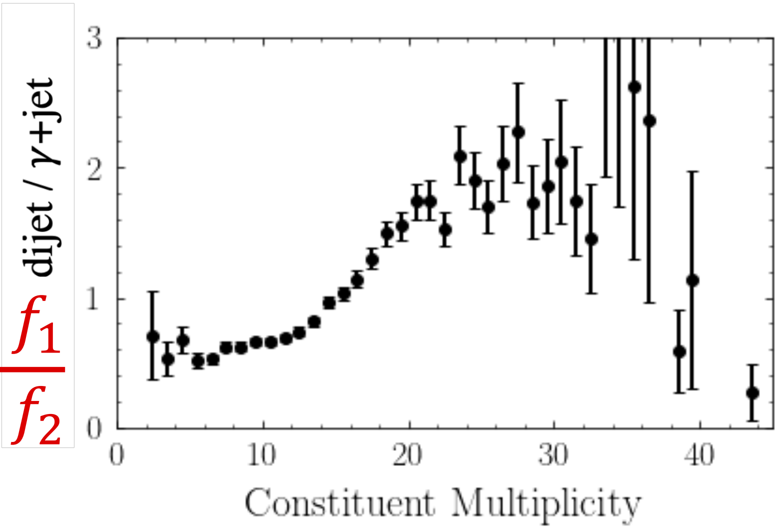

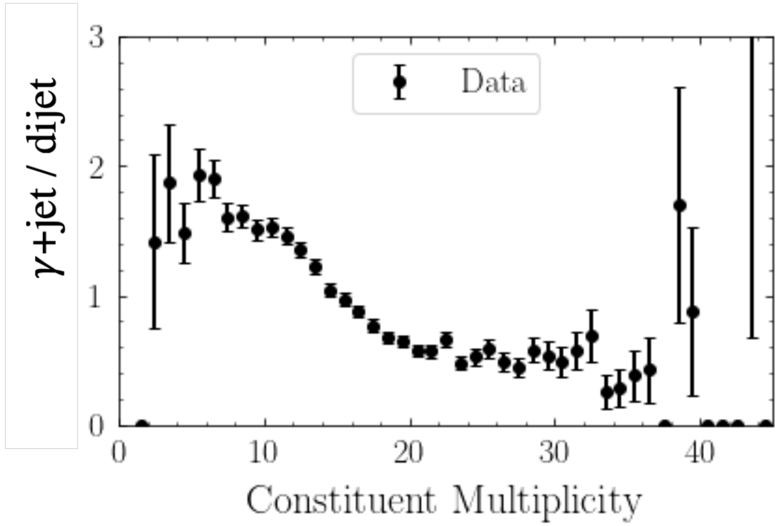

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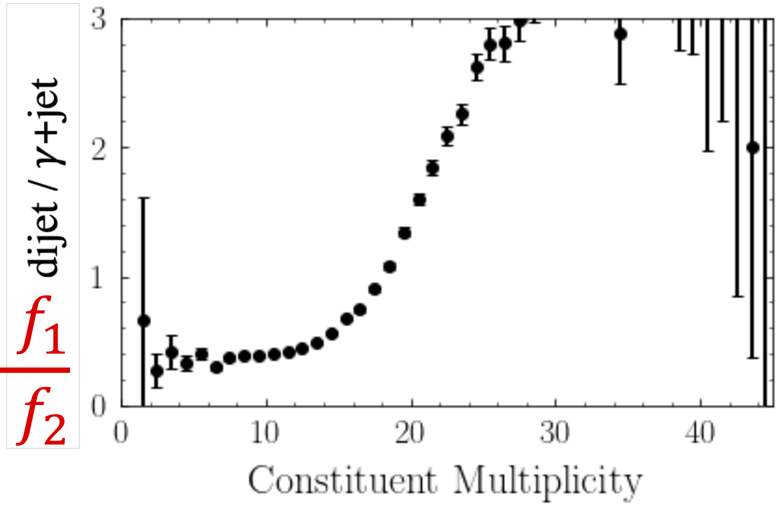

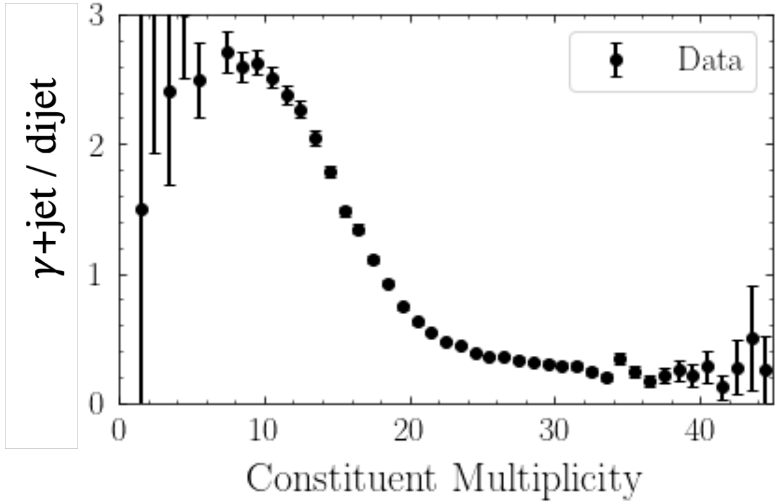

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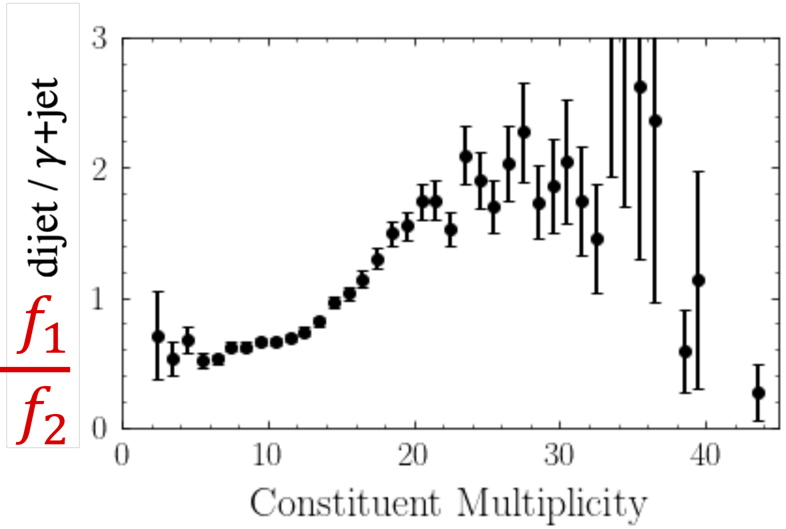
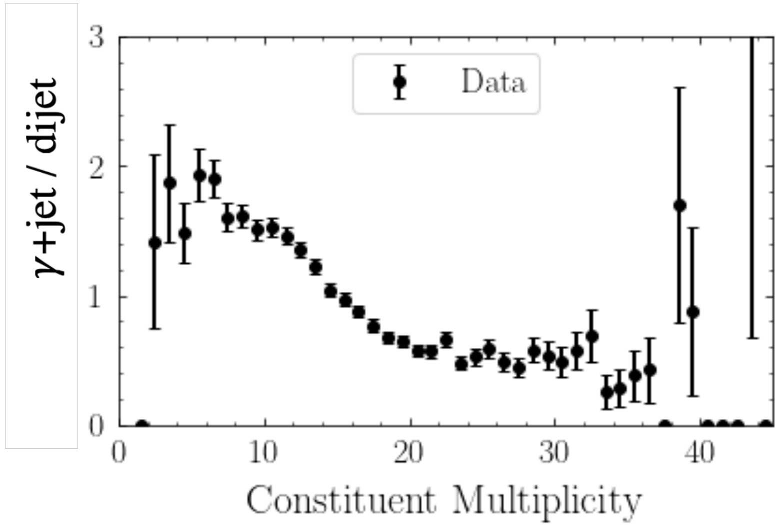


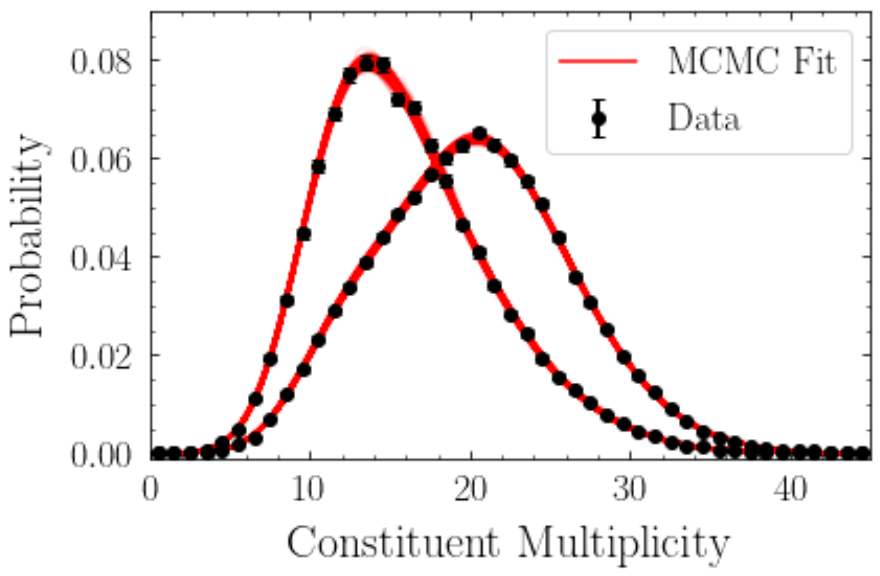


$$\frac{f_2}{f_1}$$

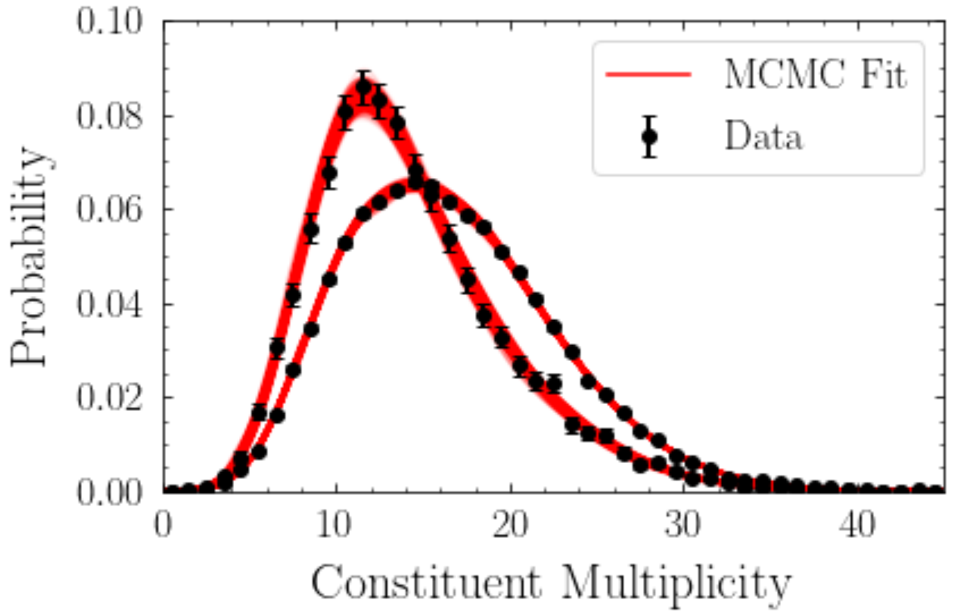
How to robustly extract fractions with statistical uncertainties?

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

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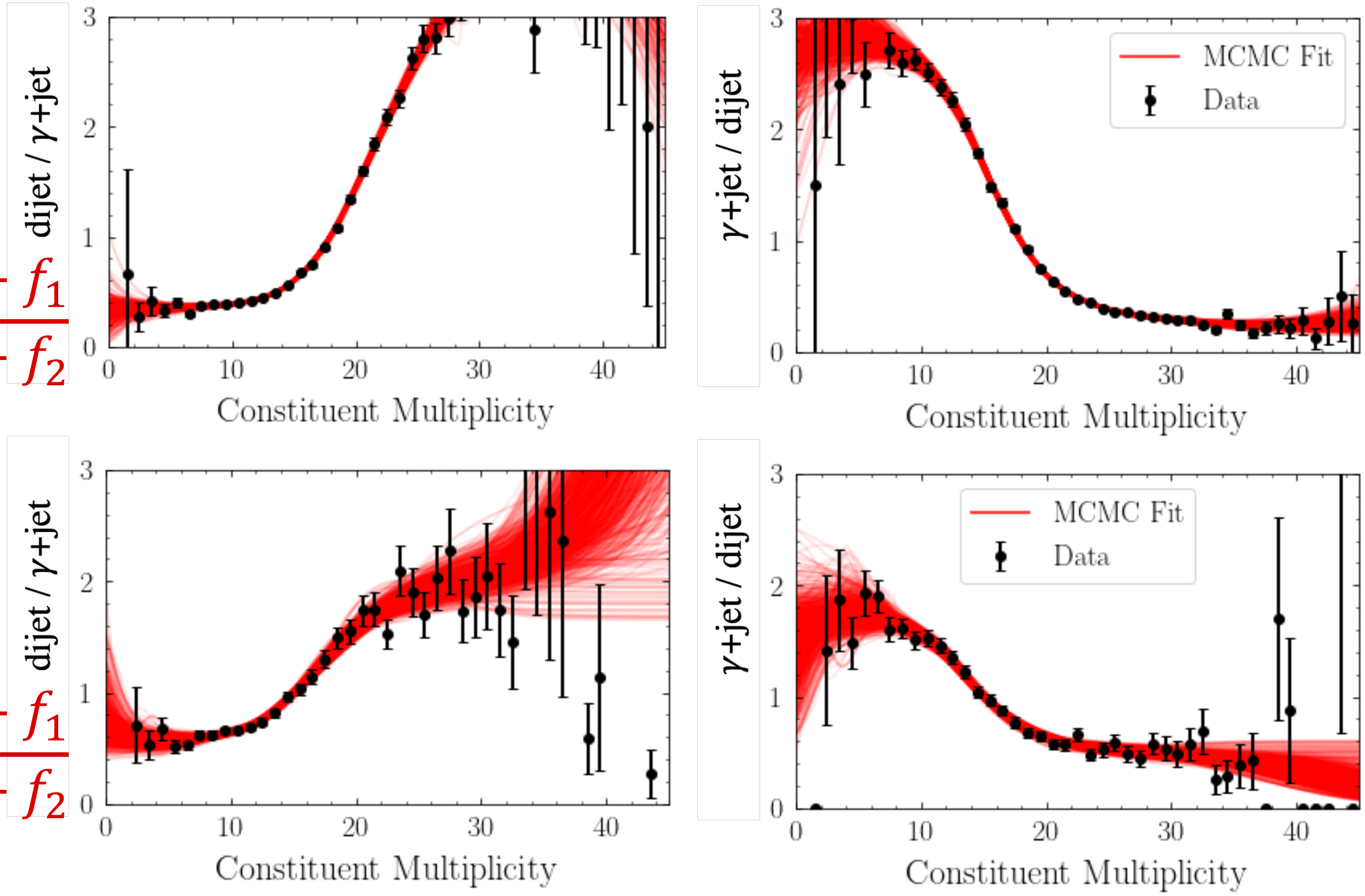
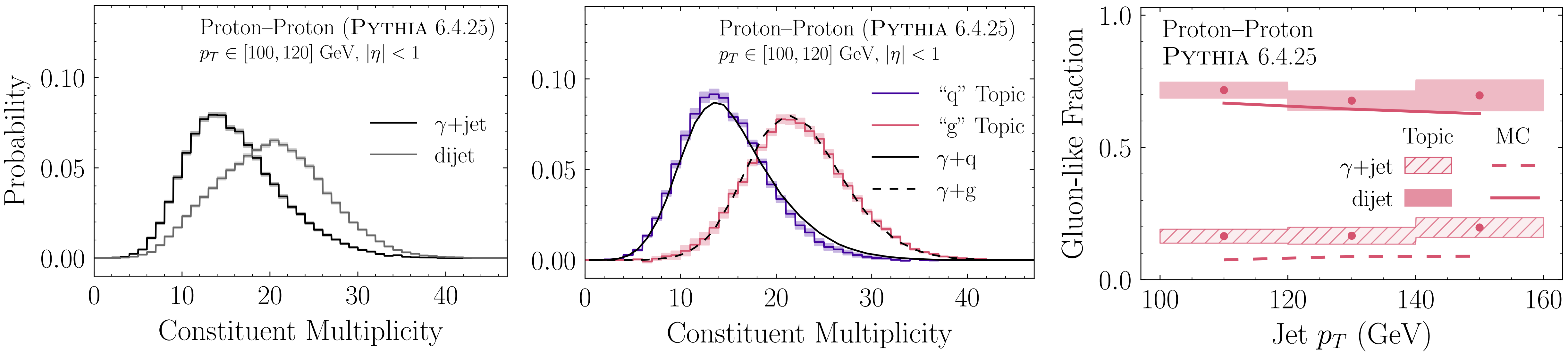


Extracting quark/gluon contributions to constituent multiplicity

proton–proton



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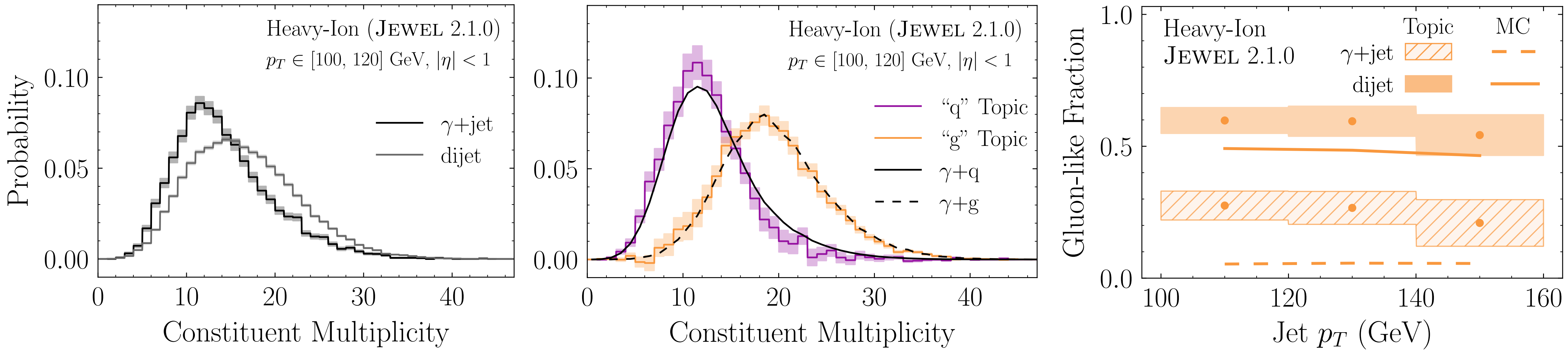
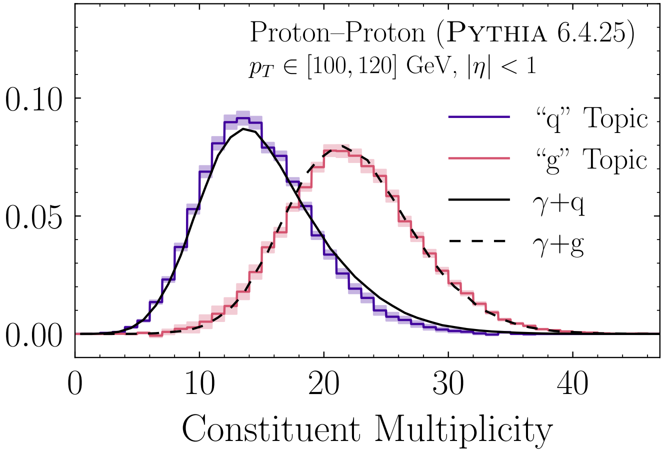


Data-driven quark and gluon jet modification from dijet and γ+jet

proton–proton



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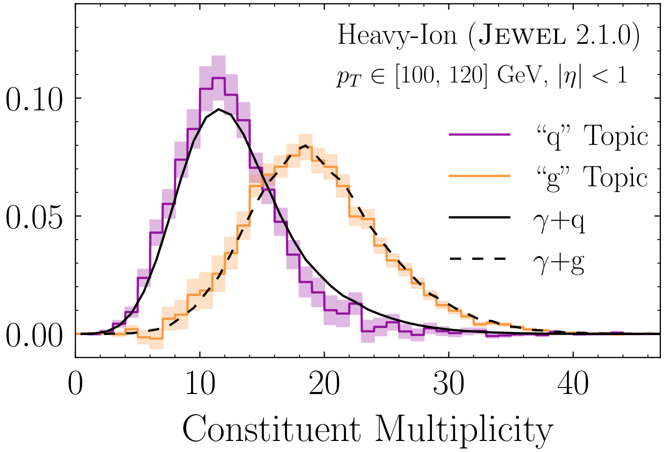

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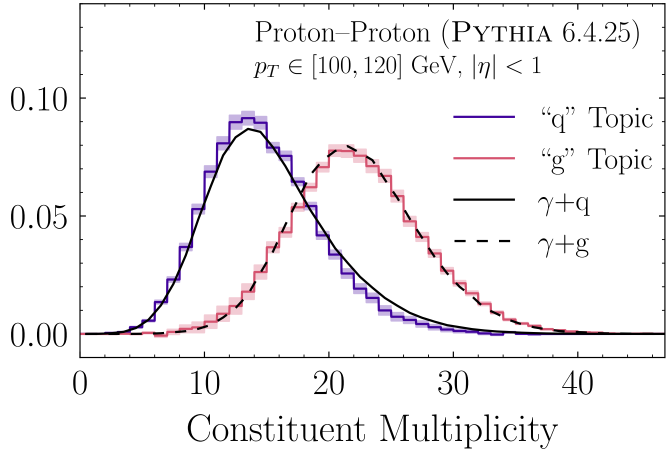

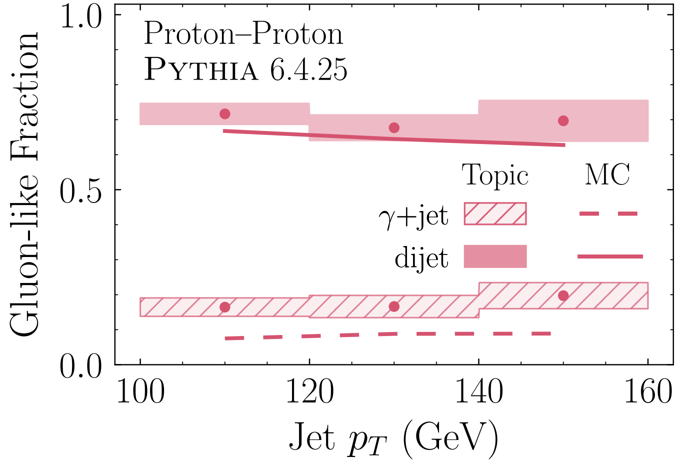

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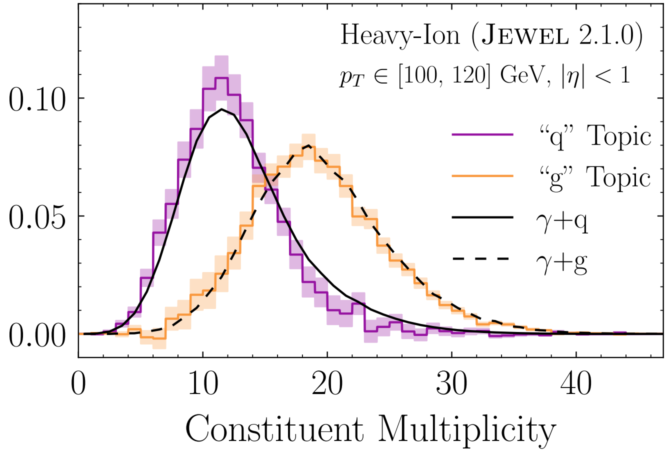
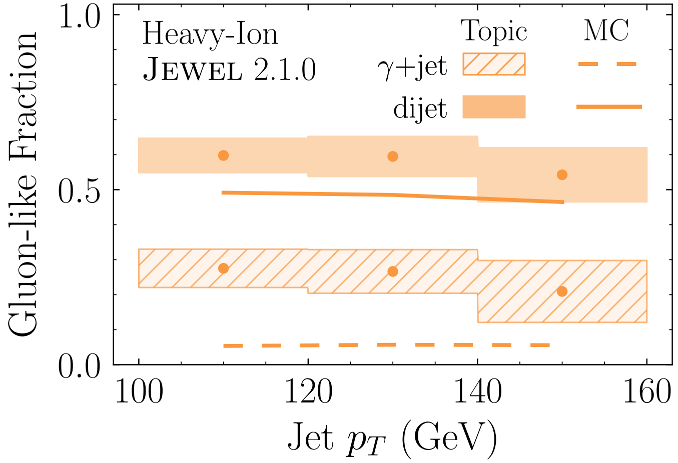




Outlook

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]

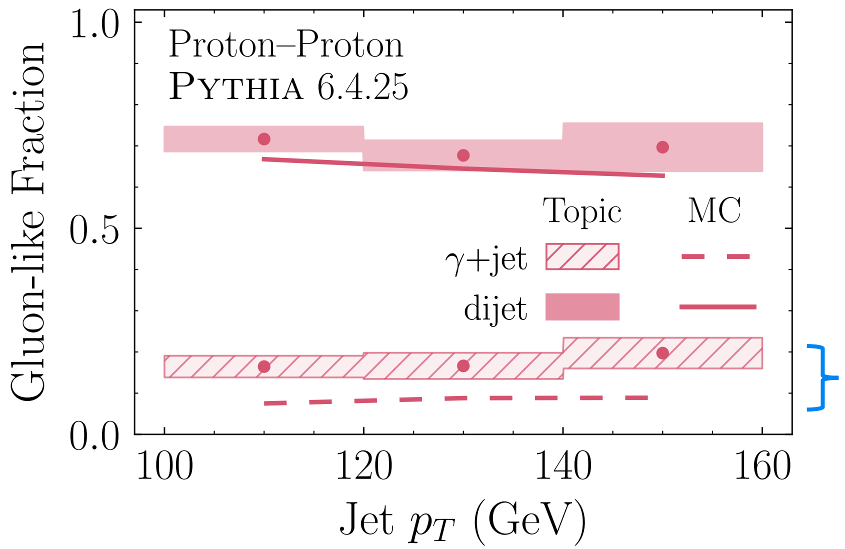
- Method of posterior estimation substantially improves robustness of the method to statistical uncertainties
  How to deal with systematic uncertainties?

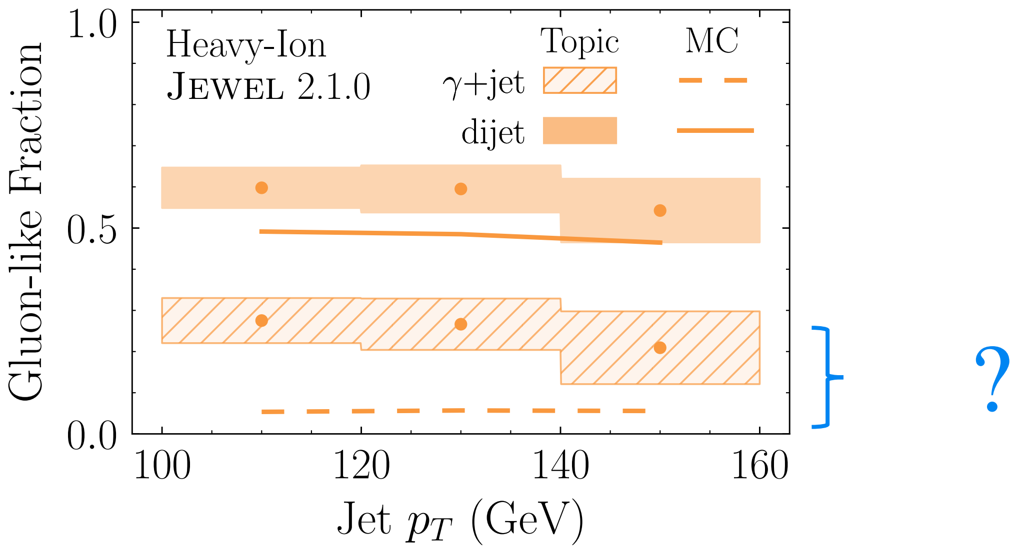
- What observables are robust to background subtraction?
  charged particle multiplicity? constituent multiplicity of soft-dropped jets?

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

Applications to other category problems in heavy-ions?

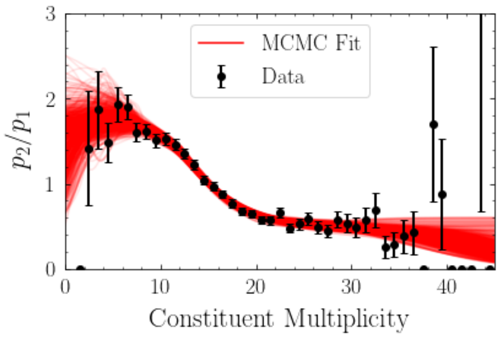
What do differences between topic and MC fractions mean?





What do differences between topic and MC fractions mean?

- Limited statistics effects on topic fractions



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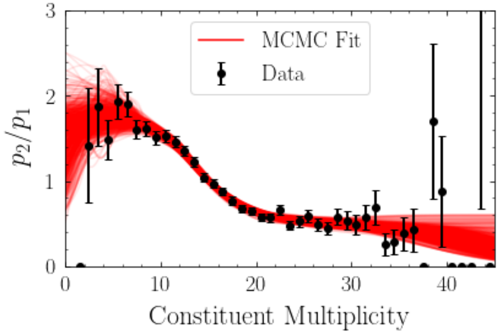
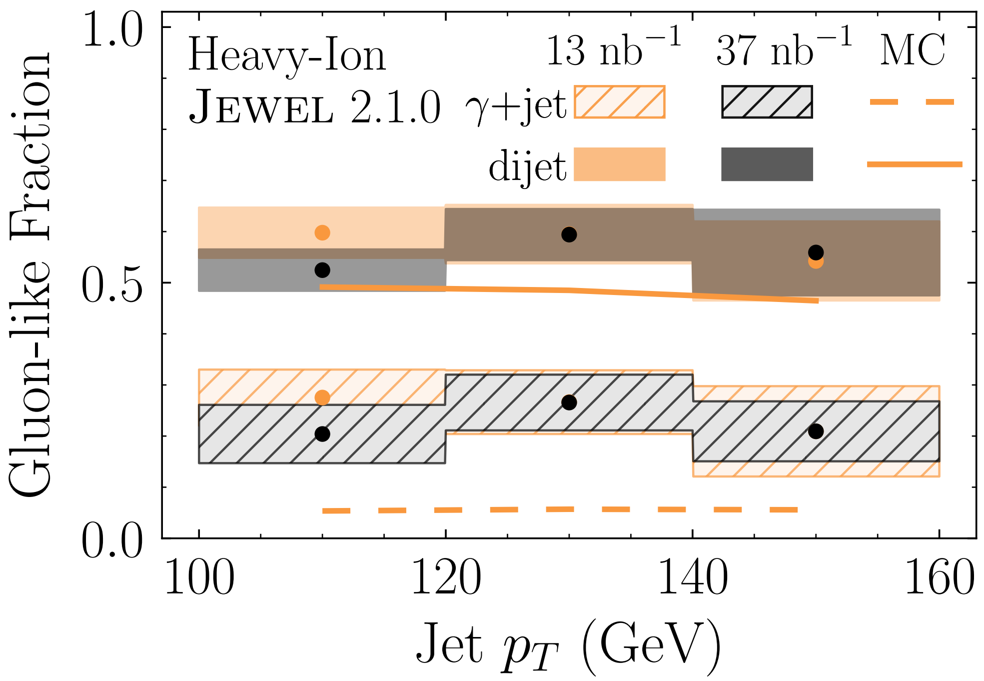


- Limited statistics effects on topic fractions

Insignificant change in fractions due to factor 2.8 increase in statistics



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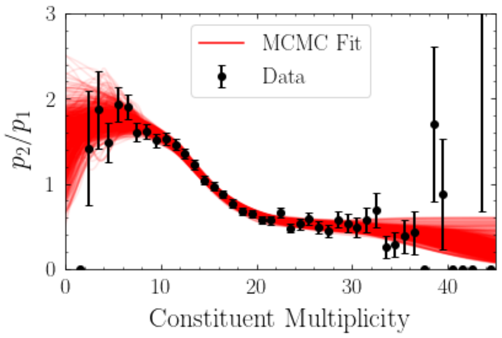

- Ambiguity in MC quark and gluon labelling

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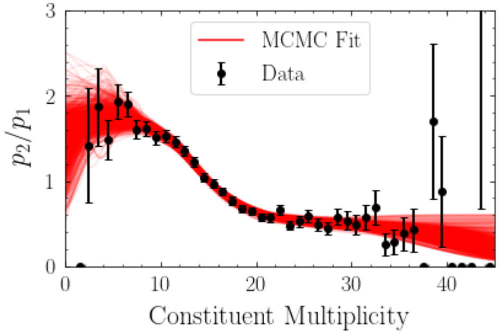

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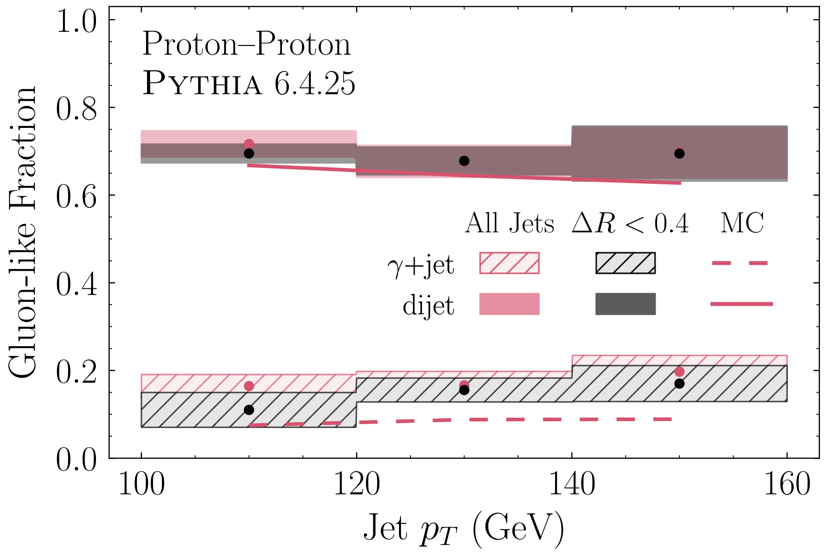
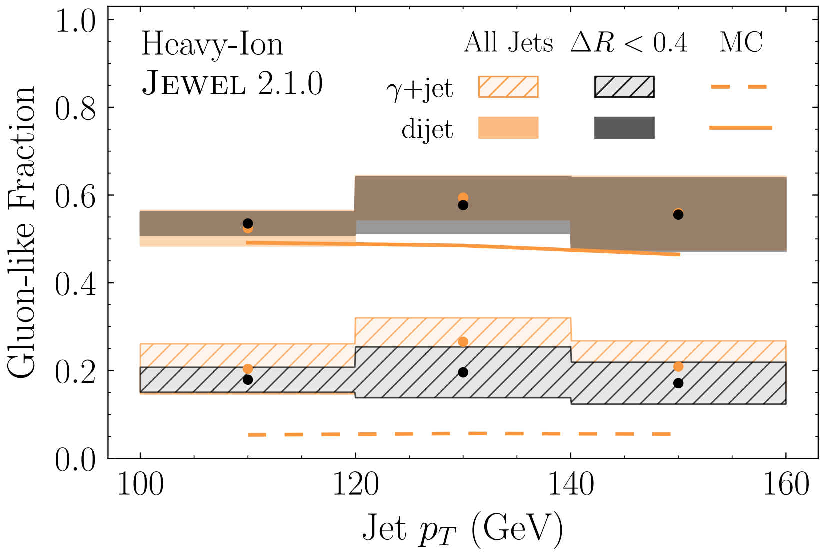
Slight decrease in extracted gluon fraction for jets with an initiating parton within the jet radius





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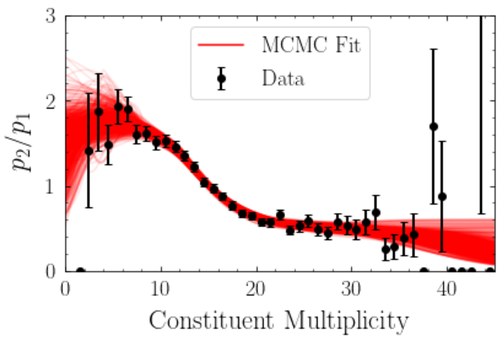

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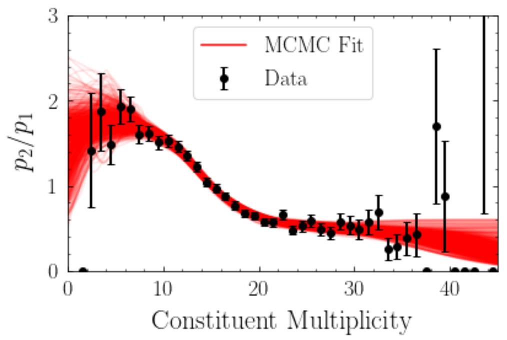

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- "Quark-initiated" jets become more gluon-like