News on the Cluster Model

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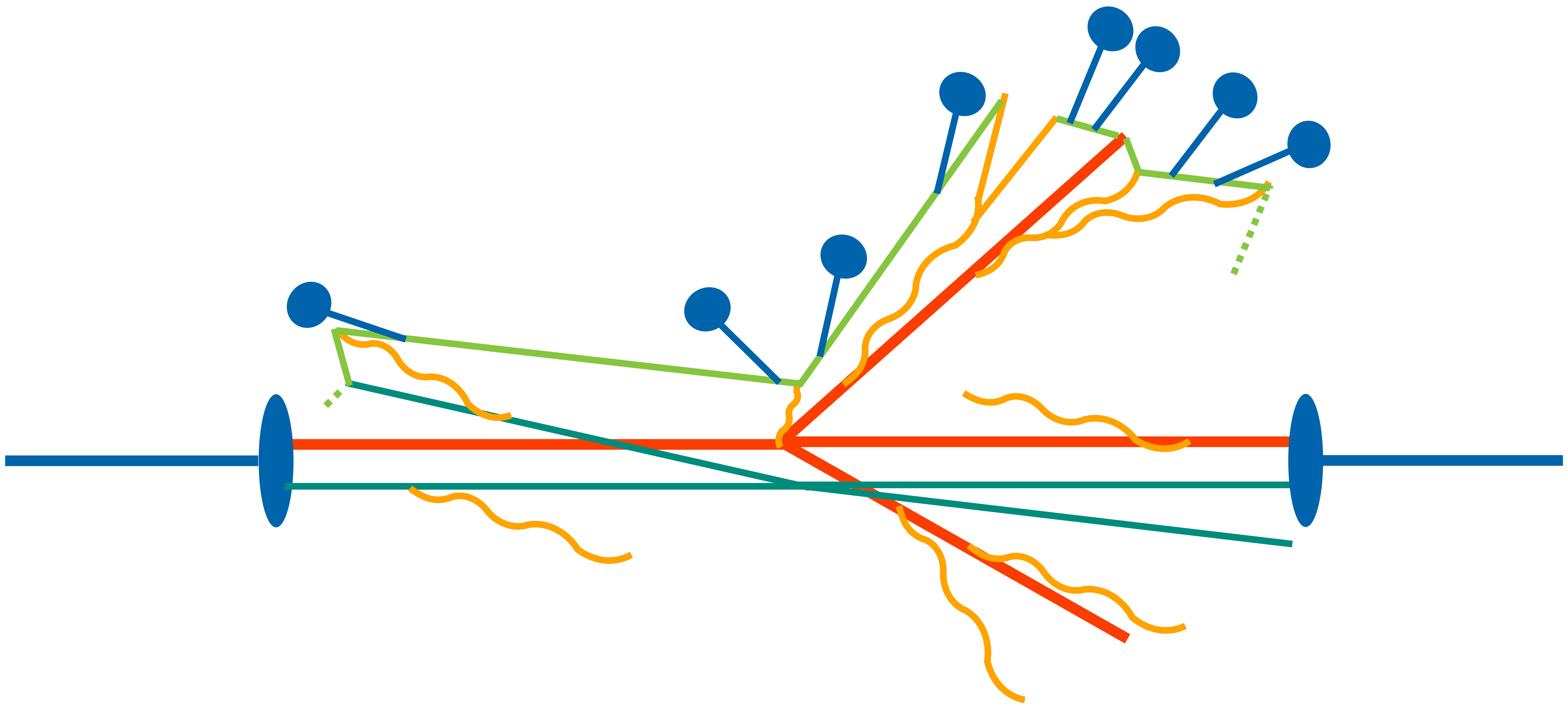
Particle Physics — University of Vienna

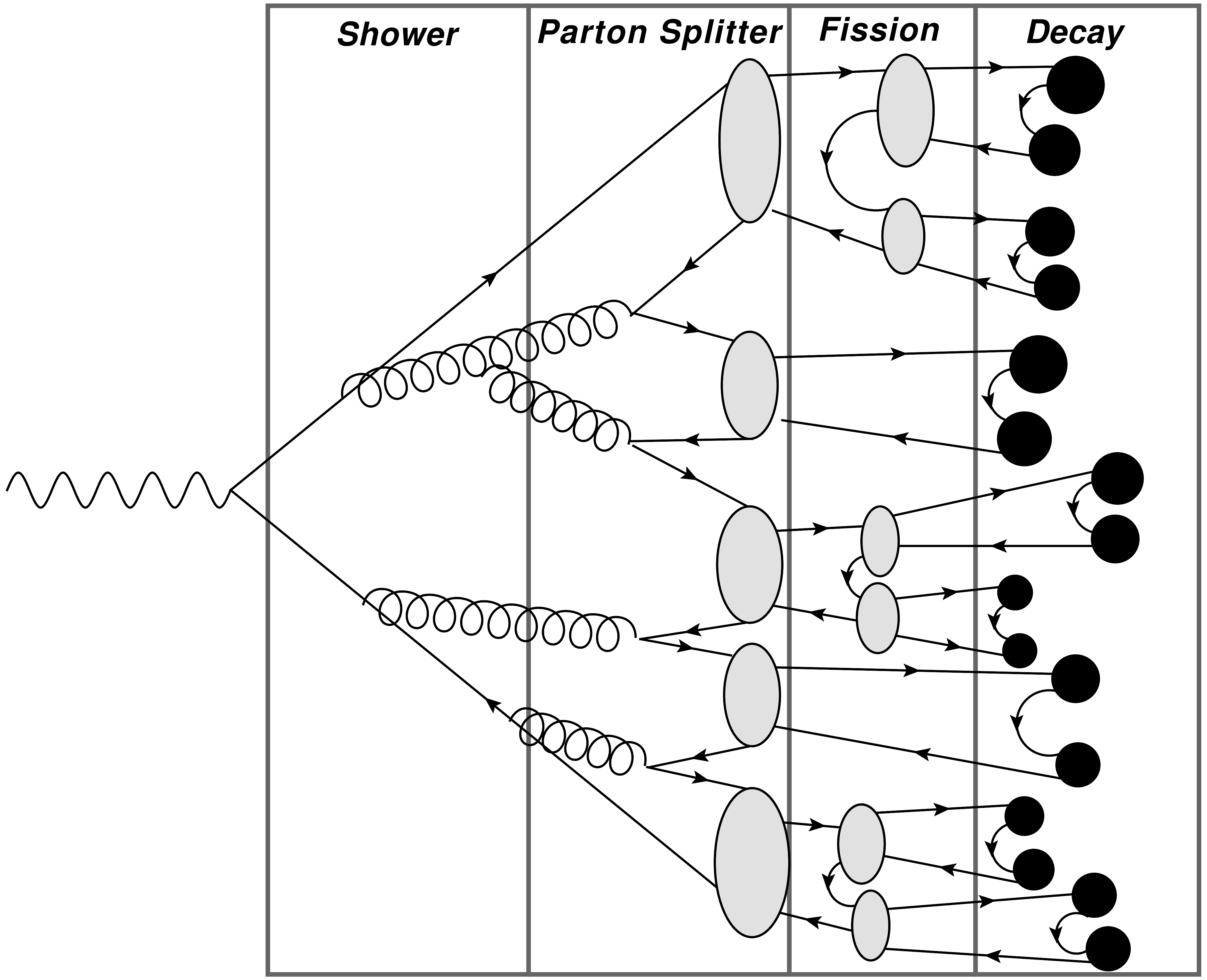
At the
MPI@LHC workshop
Madrid/Online | 17 November 2022

QCD & Event Generators

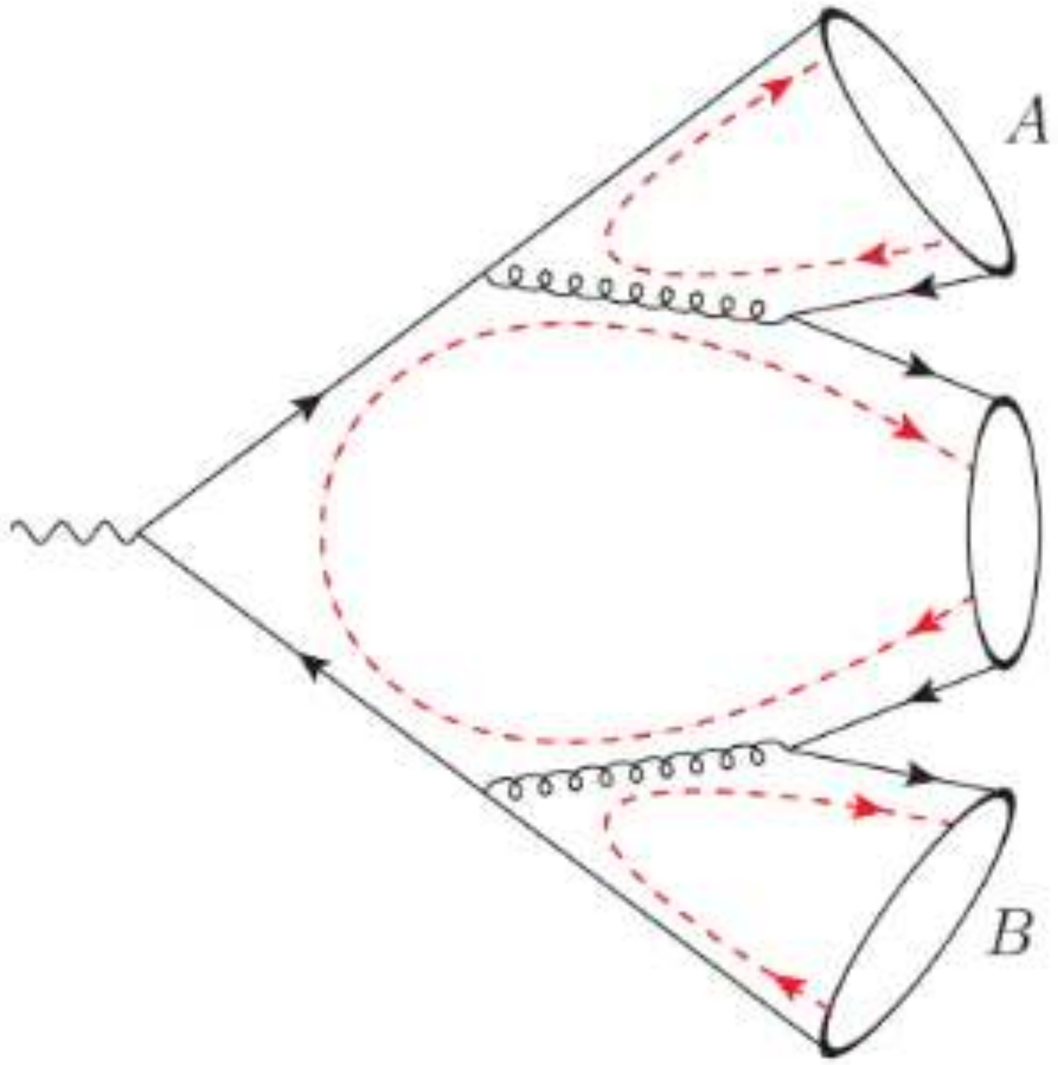


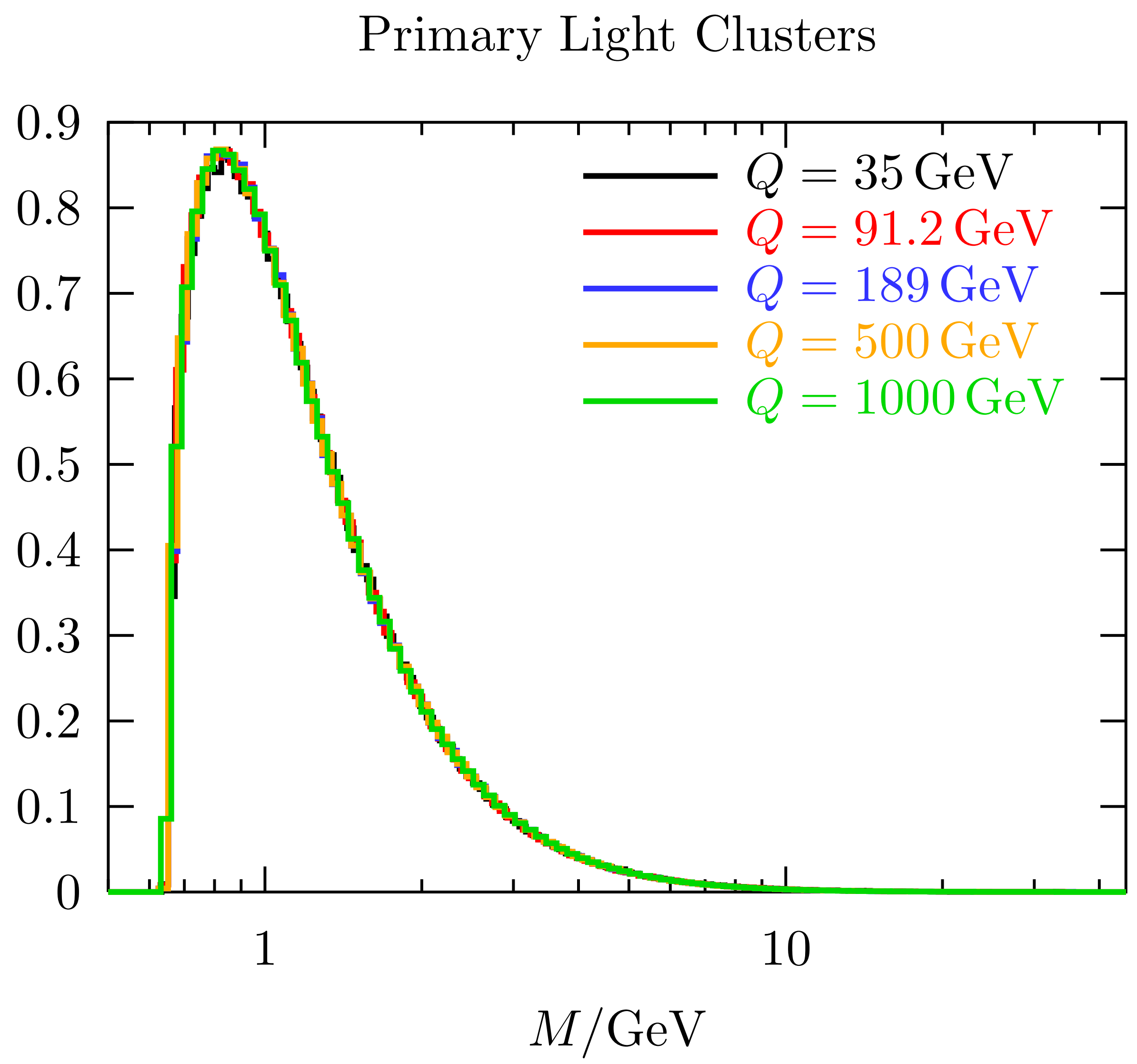
$$\mathrm{d}\sigma \sim \mathrm{L} \times \mathrm{d}\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$

The Herwig hadronization model



Coherent shower evolution triggers universal cluster spectrum: pre-confinement.





[Herwig++ 1.0 release — Gieseke et al. JHEP 02 (2004) 005]

The Herwig hadronization model

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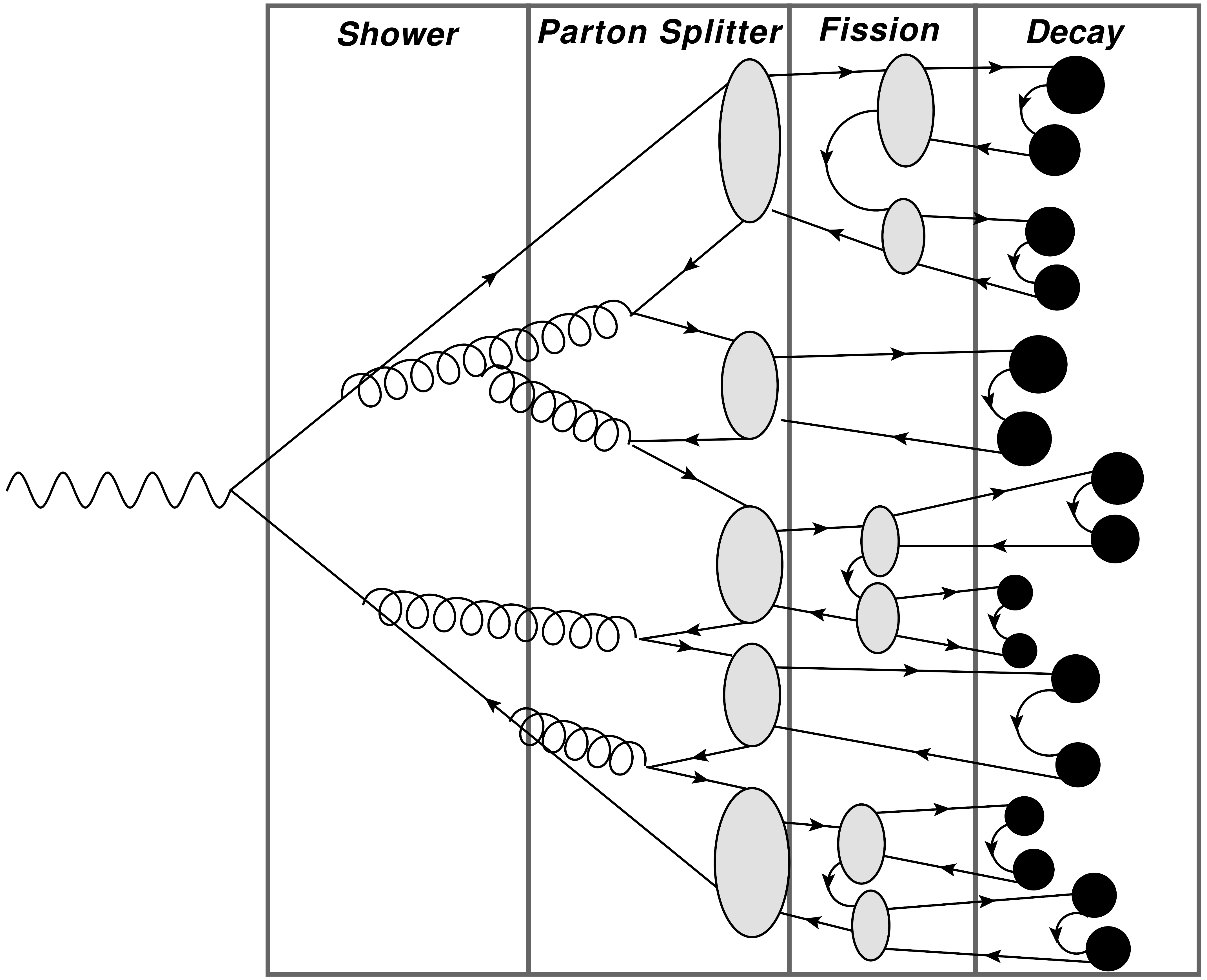


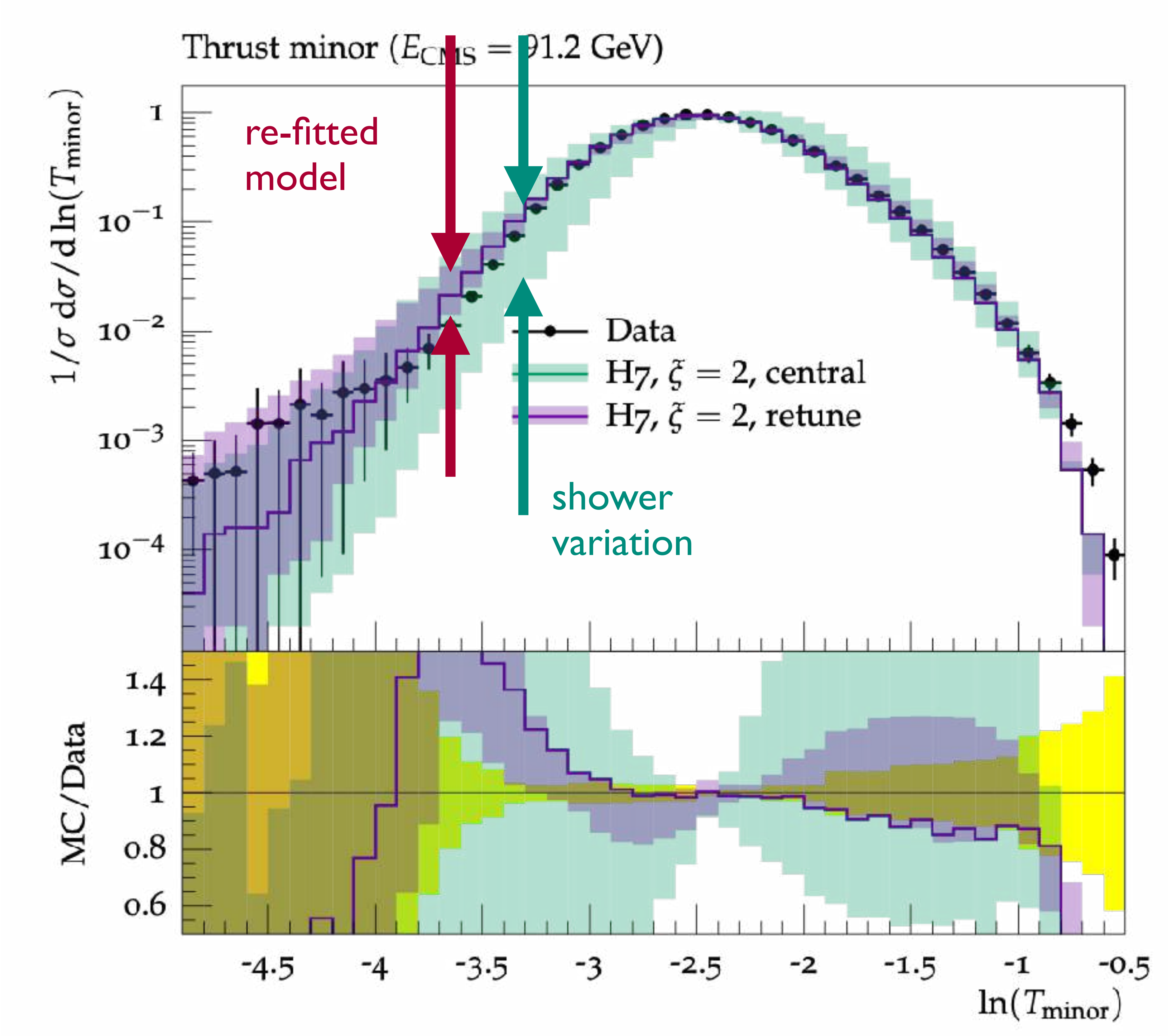
Clusters come as "mesonic" and "baryonic". The latter are only produced through beam remnants or colour reconnection.

Cluster fission happens above a mass threshold: ~ longitudinal decay into smaller mass clusters.

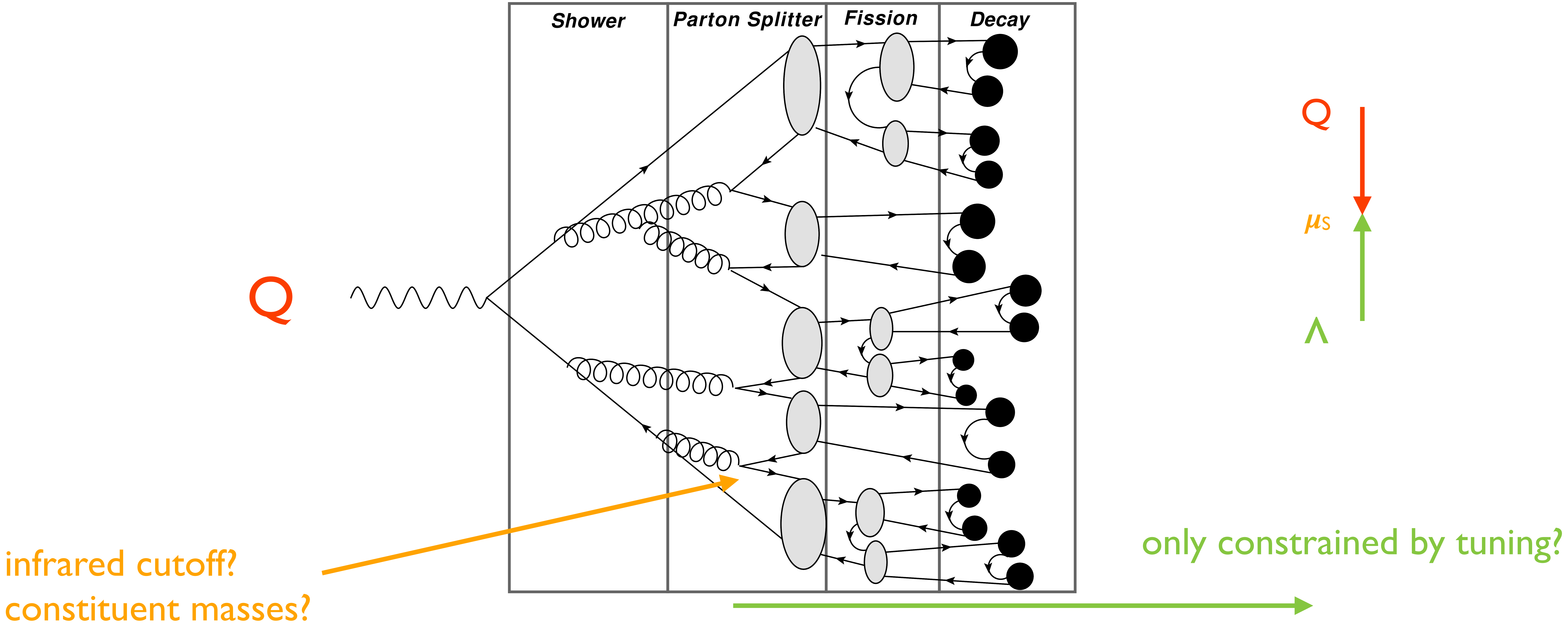
When light enough they decay into hadrons: driven by quark content, phase space, spin degeneracy.

Motivation

[Bellm, Lönnblad, Plätzer, Prestel, Samitz, Siodmok, Hoang — Les Houches 2017]

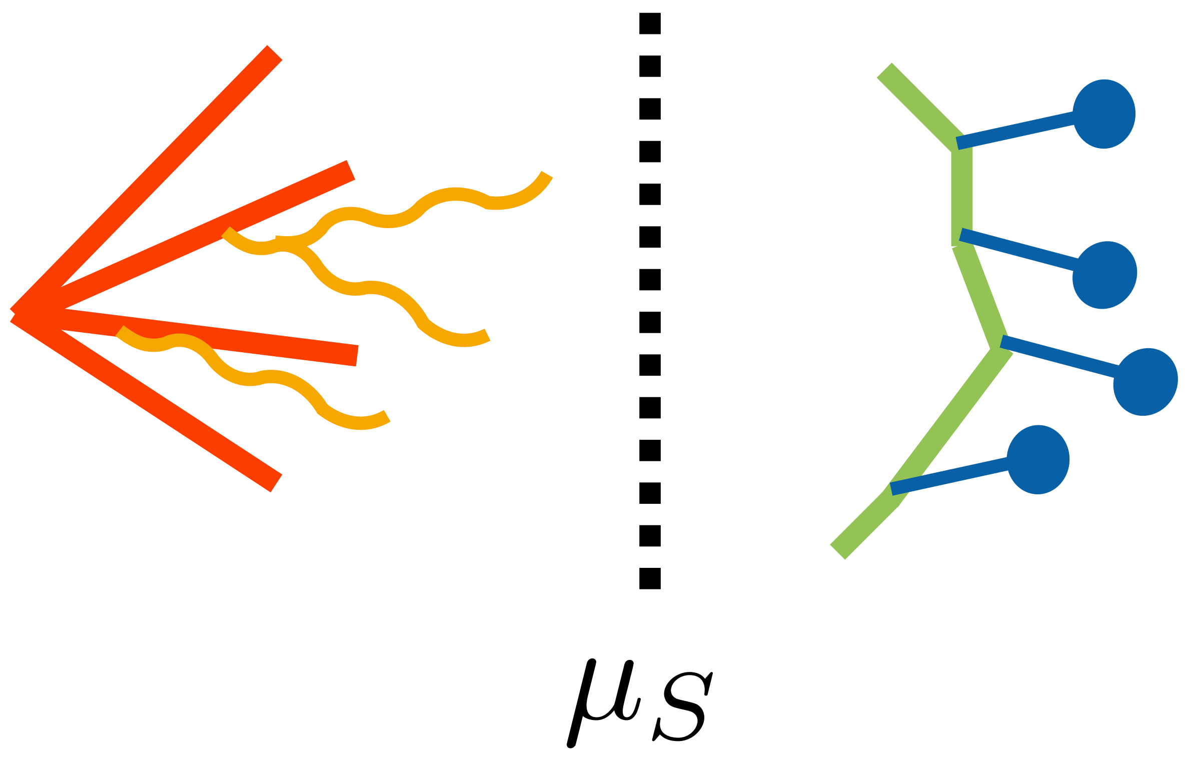


Motivation


Q
Shower
Parton Splitter
Fission
Decay
Q
μ_S
Λ
infrared cutoff?
constituent masses?
only constrained by tuning?

Evolving hadronization

$$0 = \frac{\mathrm{d}}{\mathrm{d}\mu_S}$$



Evolving hadronization

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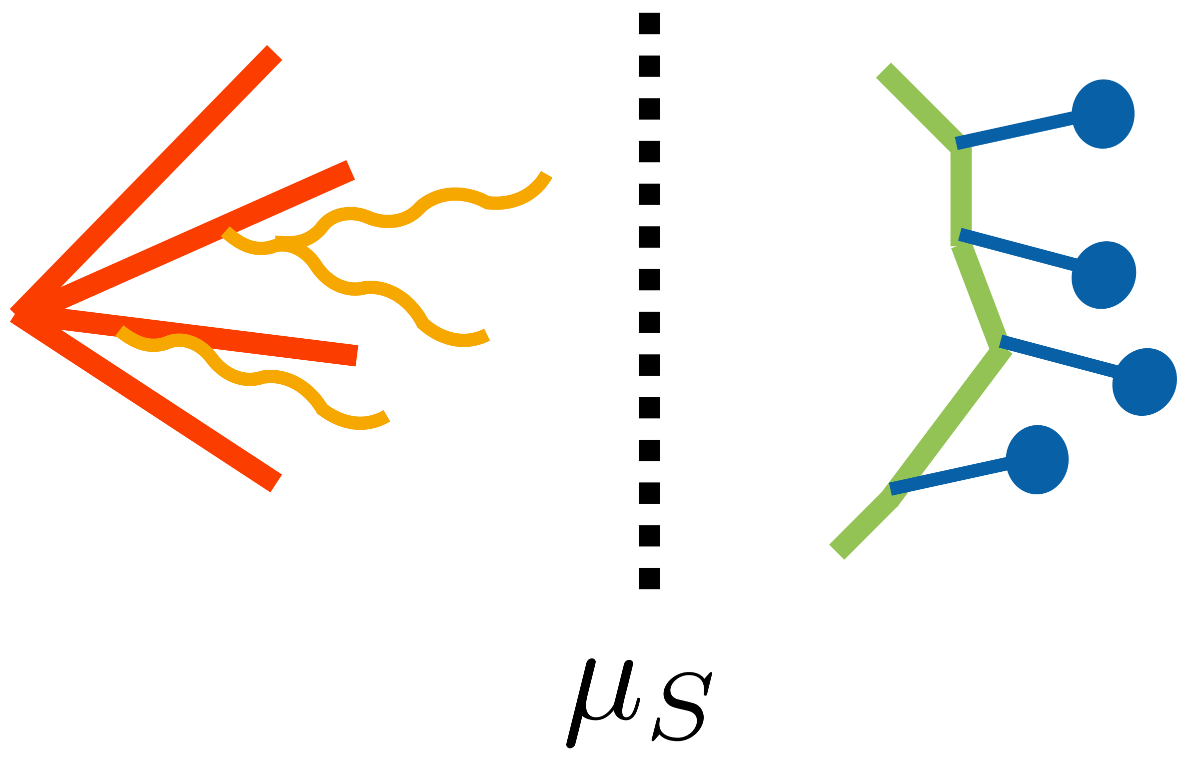


Hadronization corrections in (massive) thrust obey R evolution:

cutoff dependence of hadronization

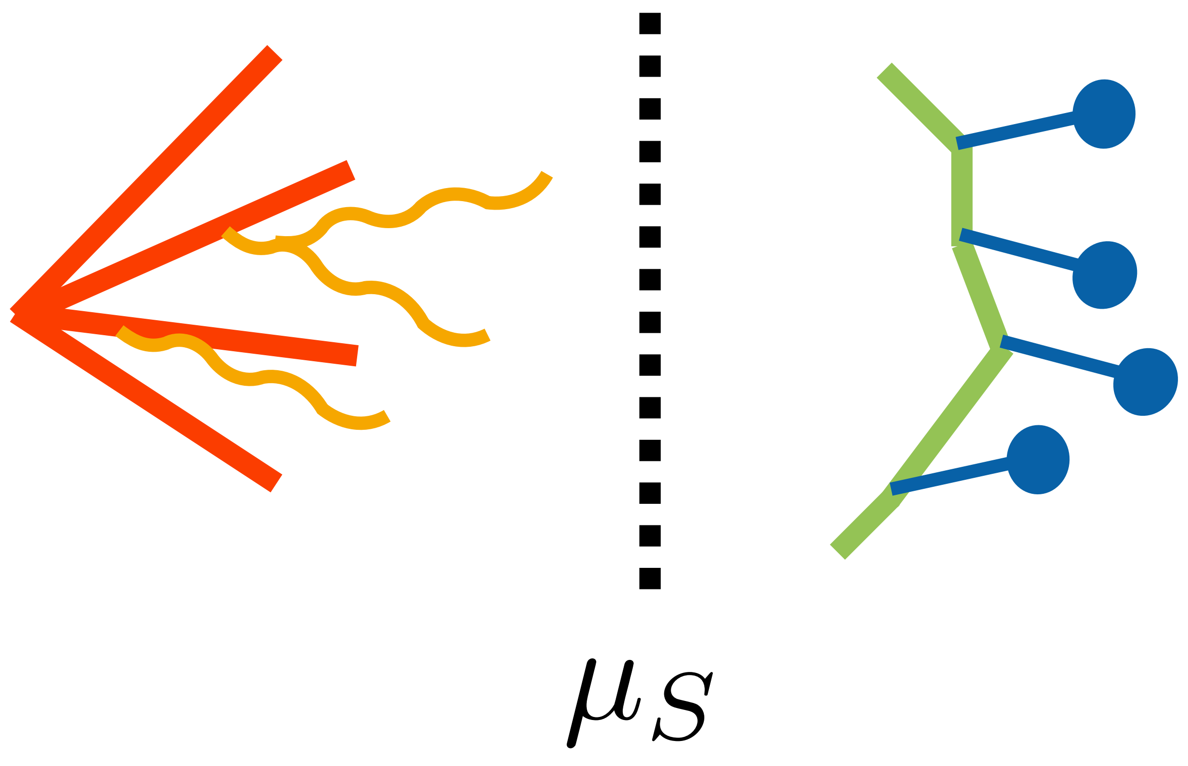
cutoff dependence of heavy quark

$$\tau_{\mathrm{peak}}(Q_0) = \tau_{\mathrm{peak}}(Q_0') - \frac{1}{Q}\left(16C_F - 8\pi C_F \frac{m}{Q}\right)\int_{Q_0'}^{Q_0} \mathrm{d}R \frac{\alpha_s(R)}{4\pi}$$

[Hoang, Plätzer, Samitz — JHEP 1810 (2018) 200]

Evolving hadronization

$$0 = \frac{\mathrm{d}}{\mathrm{d}\mu_S}$$



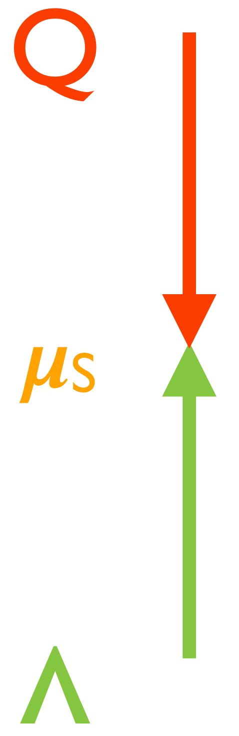
Colour evolution equations from projection onto hadrons

[Plätzer – arXiv:2204.06956]

$$\partial_S \mathbf{A}_n = \mathbf{\Gamma}_{n,S}\mathbf{A}_n + \mathbf{A}_n \mathbf{\Gamma}^\dagger_{n,S} - \sum_{s\geq 1} \alpha_S^s \mathbf{R}^{(s)}_{S,n}\mathbf{A}_{n-s}\mathbf{R}^{(s)\dagger}_{S,n}$$

$$\partial_S \mathbf{S}_n = -\tilde{\mathbf{\Gamma}}^\dagger_{S,n}\mathbf{S}_n - \mathbf{S}_n\tilde{\mathbf{\Gamma}}_{S,n} + \sum_{s\geq 1}\alpha_S^s \int \tilde{\mathbf{R}}^{(s)\dagger}_{S,n+s}\mathbf{S}_{n+s}\tilde{\mathbf{R}}^{(s)}_{S,n+s}\prod_{i=n+1}^{n+s}[\mathrm{d}p_i]\tilde{\delta}(p_i)$$

$$\partial_S \equiv \partial/\partial \log \mu_S$$



Evolving hadronization

[Plätzer — arXiv:2204.06956]

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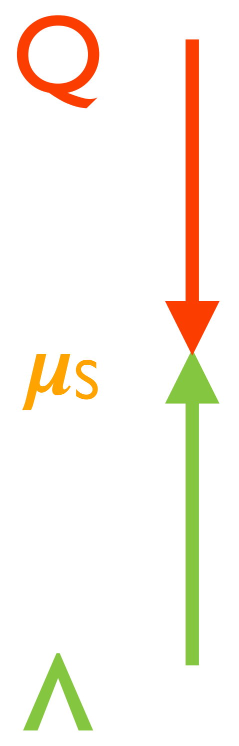

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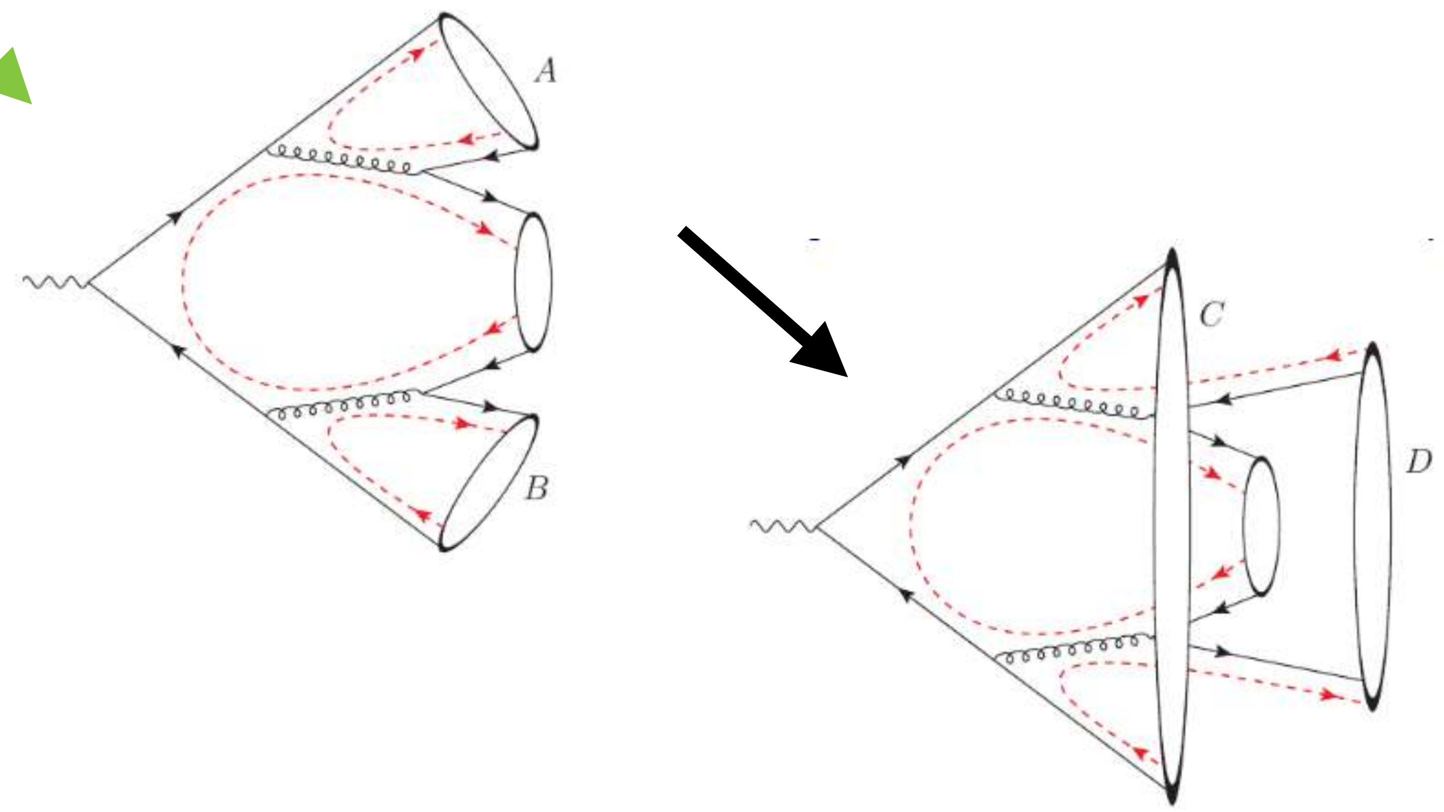

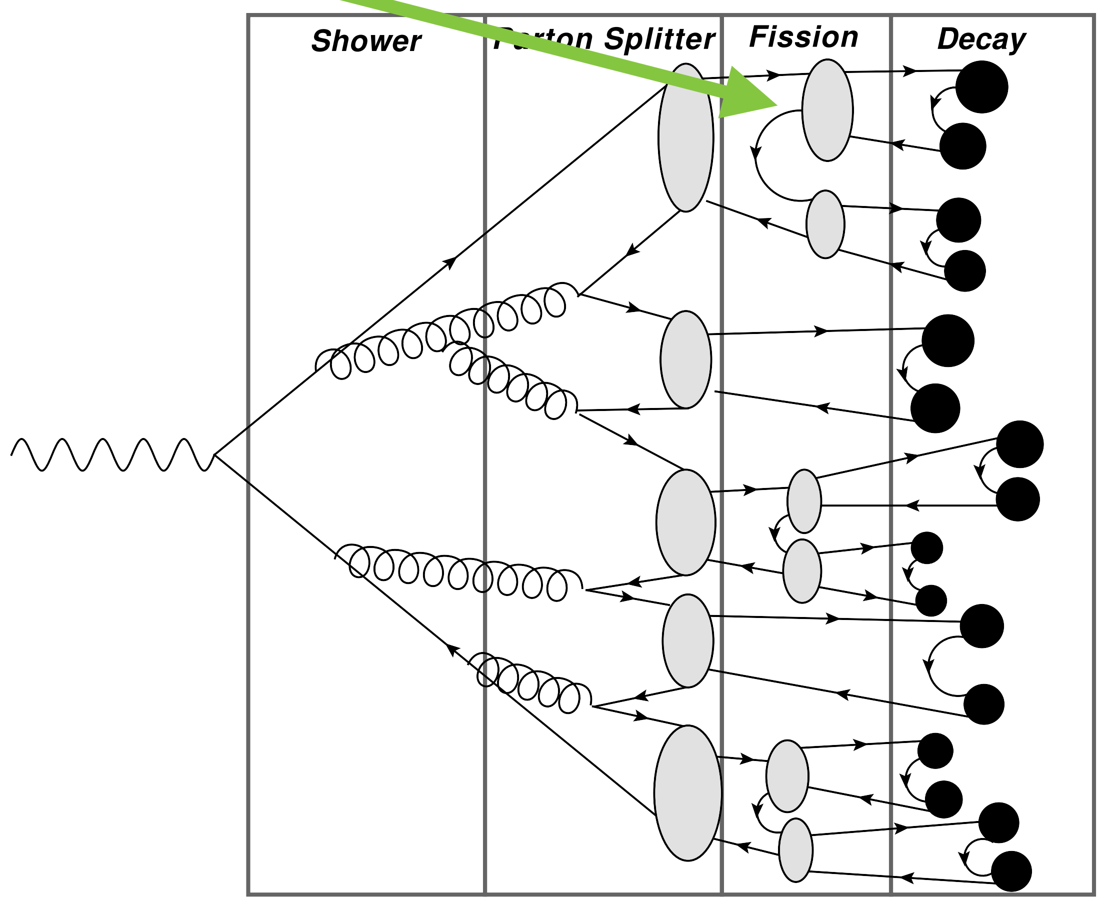

Reproduce key features of "high energy end" of cluster hadronization.

Evolving hadronization

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[Plätzer — arXiv:2204.06956]

$$\partial_S \mathbf{A}_n = \mathbf{\Gamma}_{n,S}\mathbf{A}_n + \mathbf{A}_n\mathbf{\Gamma}^\dagger_{n,S} - \sum_{s\geq 1}\alpha_S^s \mathbf{R}^{(s)}_{S,n}\mathbf{A}_{n-s}\mathbf{R}^{(s)\dagger}_{S,n}$$

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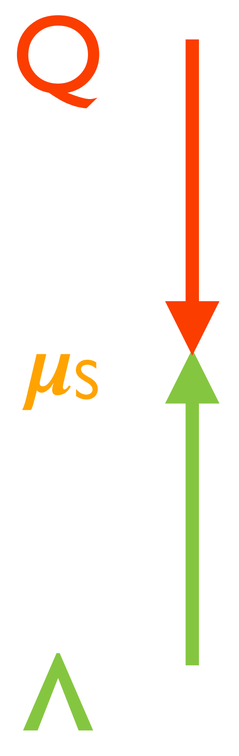

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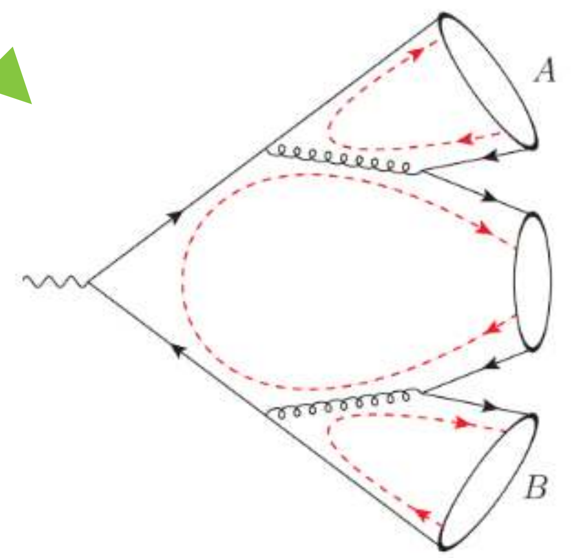
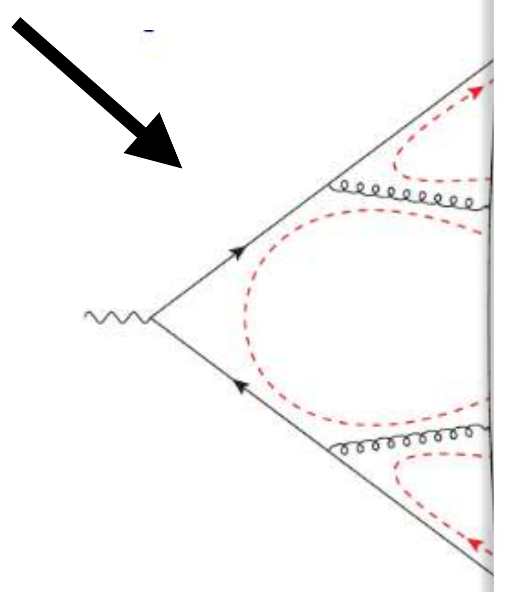
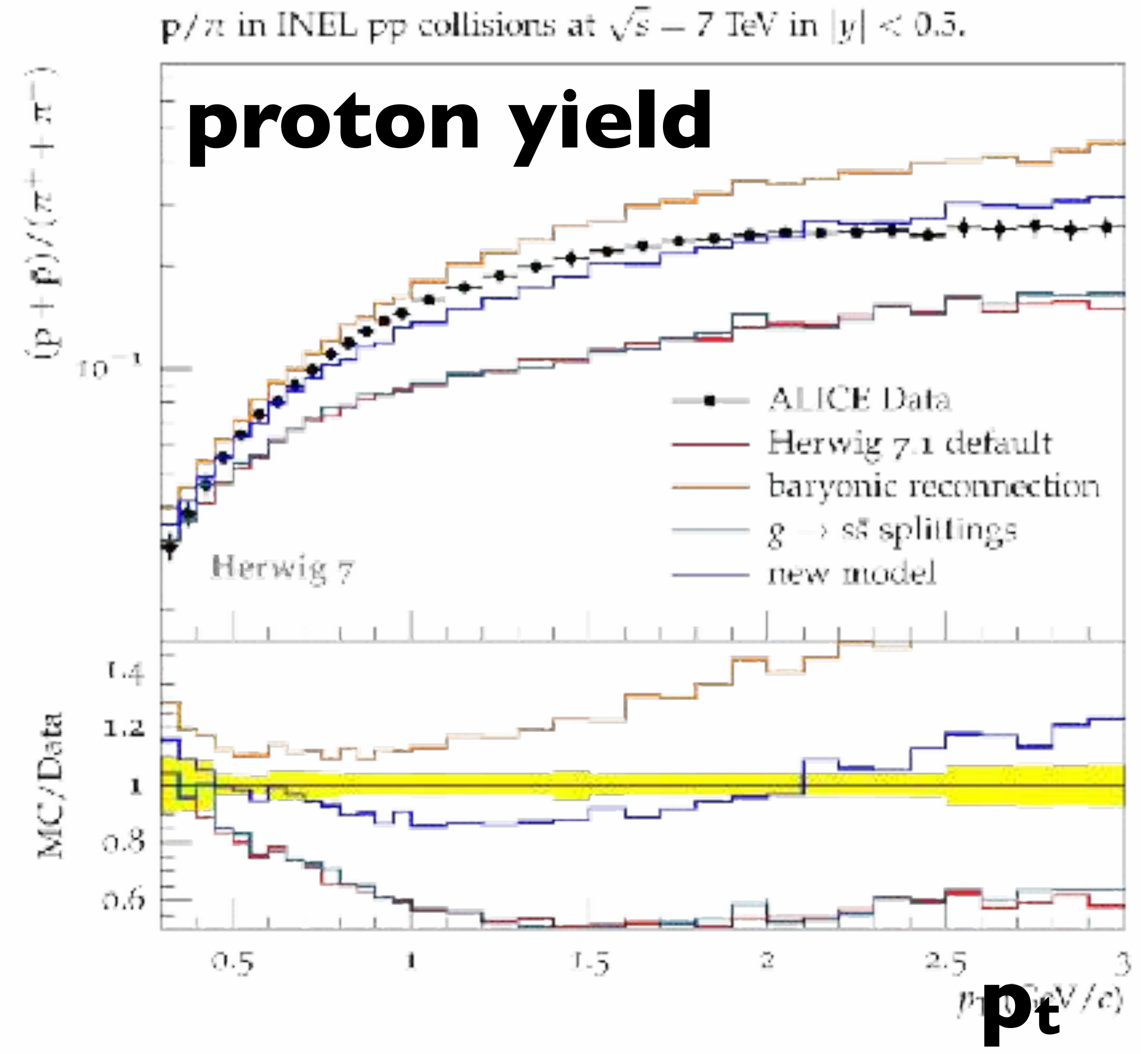


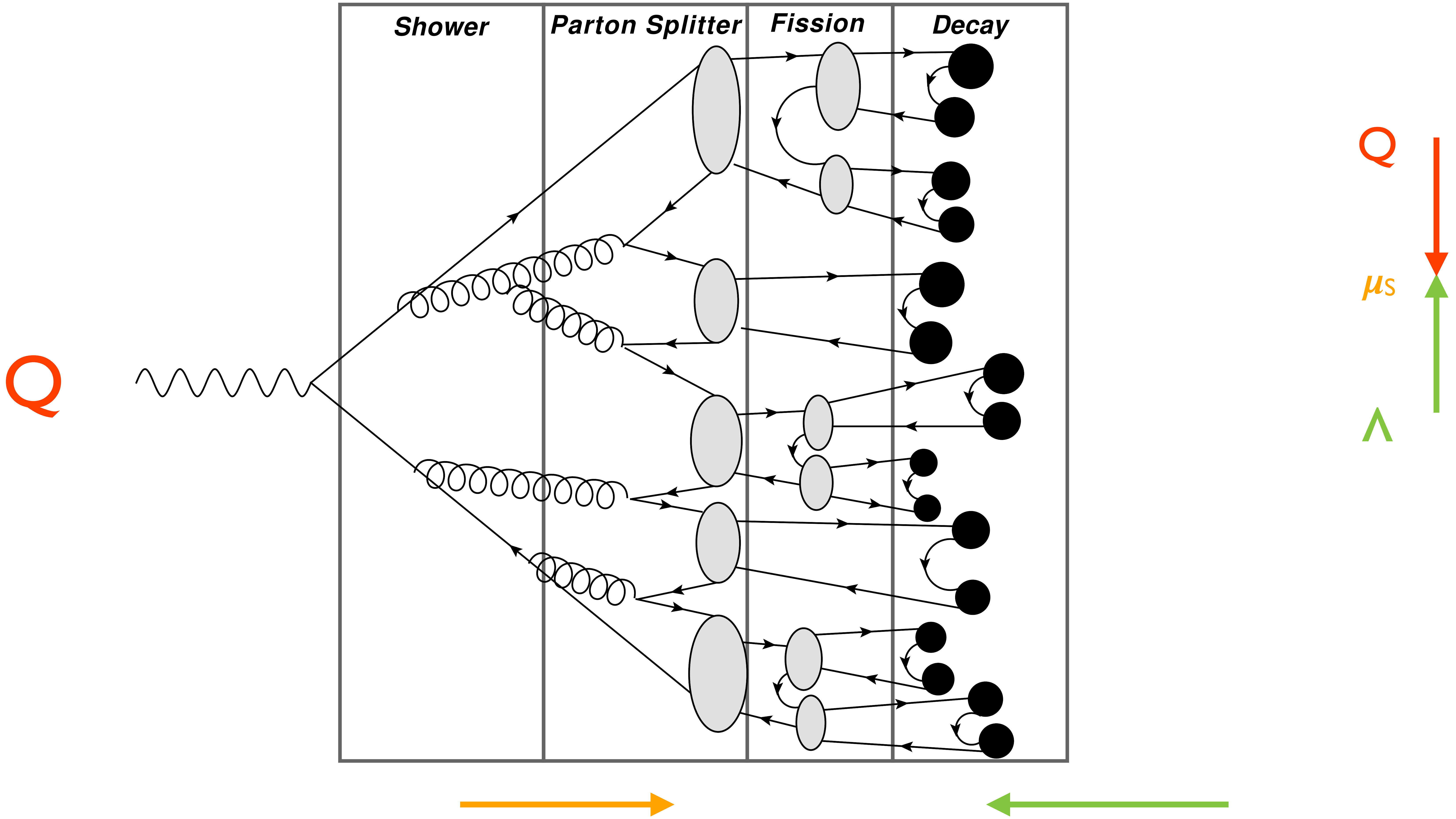




[Gieseke, Kirchgaesser, Plätzer – EPJ C 78 (2018) 99]

Reproduce key features of "high energy end" of cluster hadronization.

Cornering models



constrain by cutoff response

constrain by tuning

Matching the cluster model to the shower

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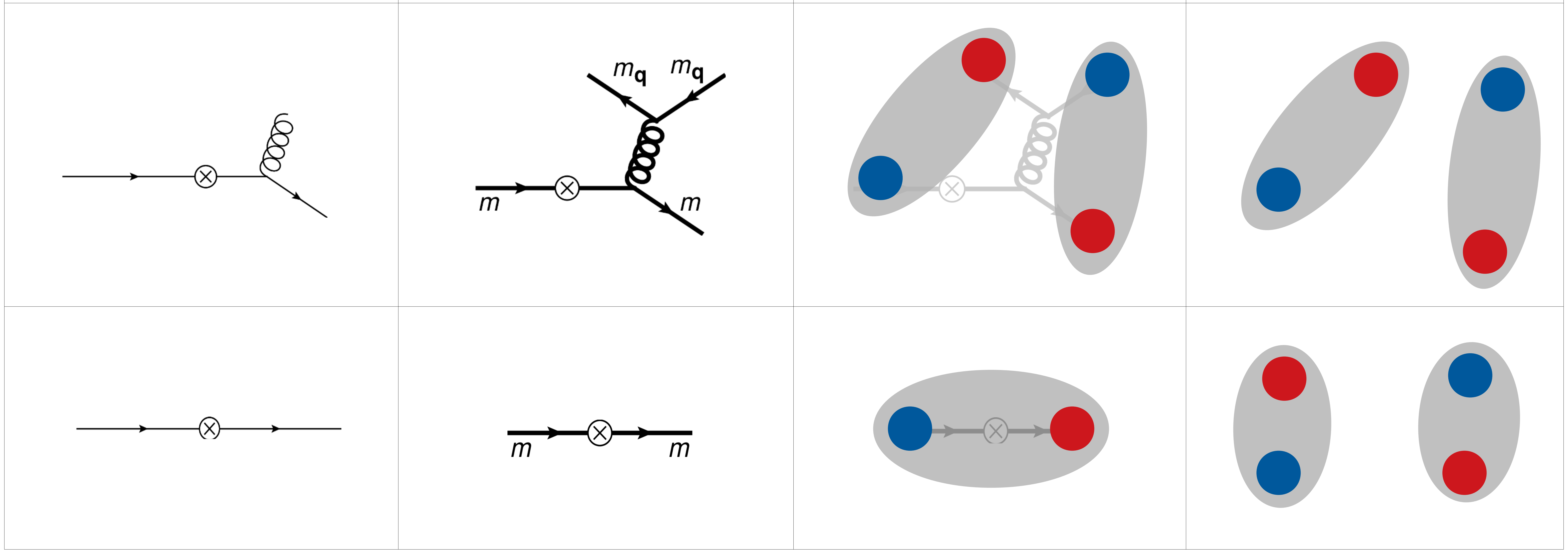
Soft limit of shower needs to reproduce UV limit of hadronization

parton shower	forced splitting and constituent masses	cluster formation	cluster fission

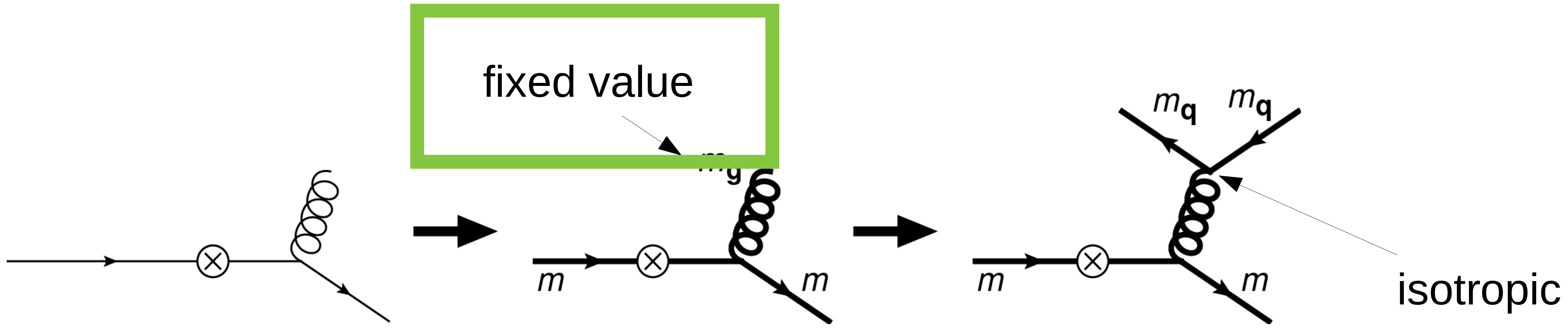


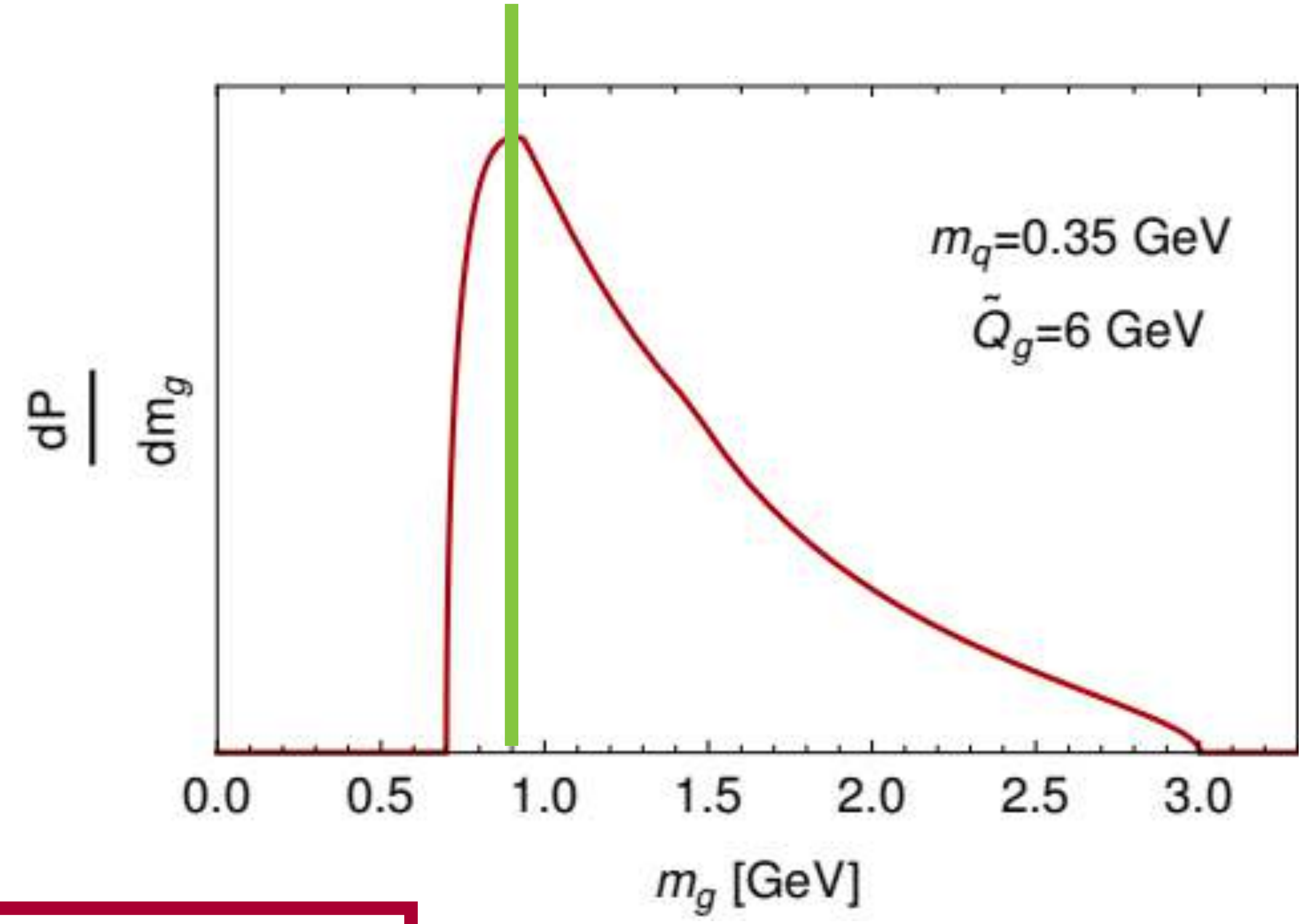
figures by Daniel Samitz

[Hoang, Plätzer, Samitz — in progress]

Gluon splitting

Default choice versus mass distribution from infrared continued splitting function



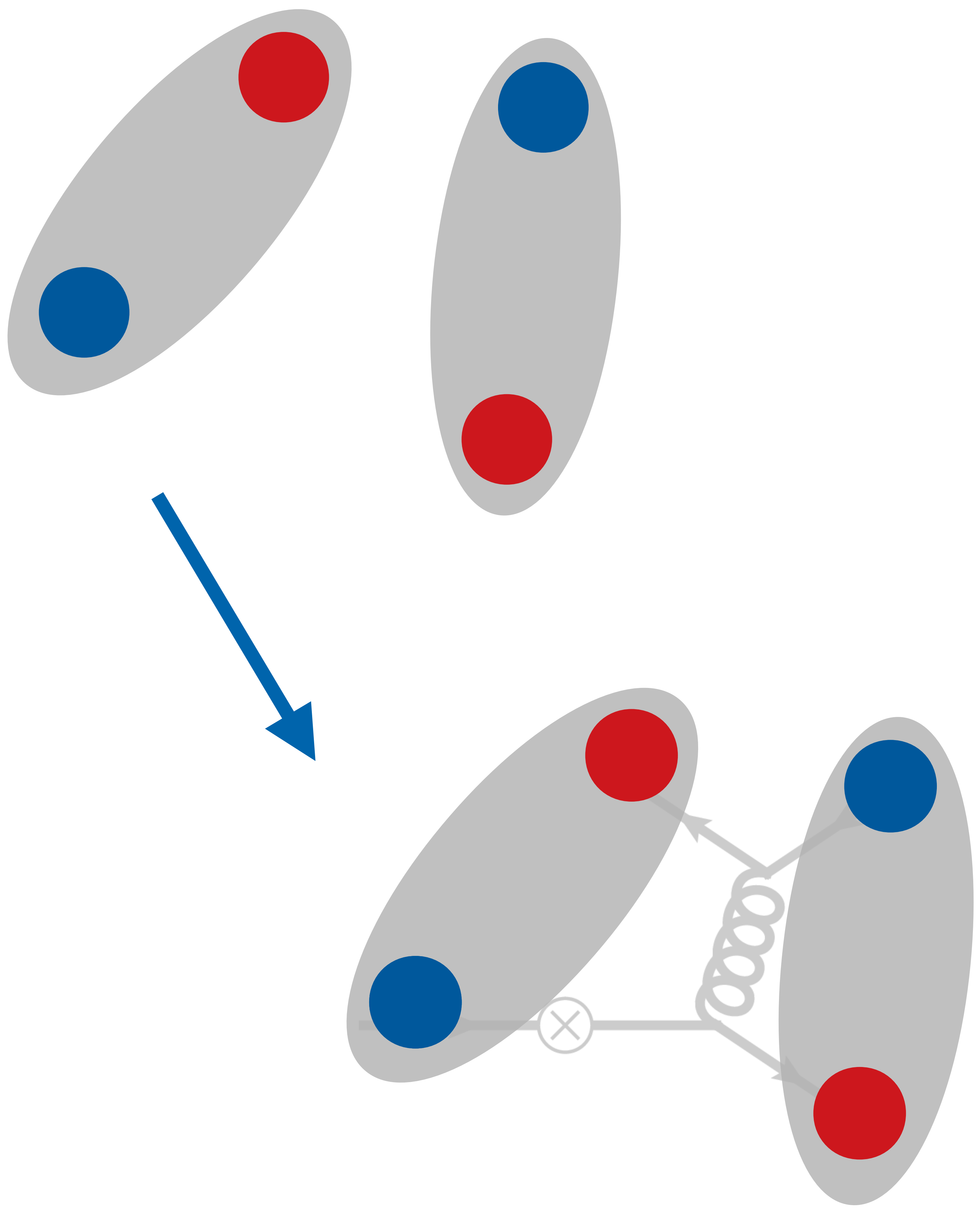


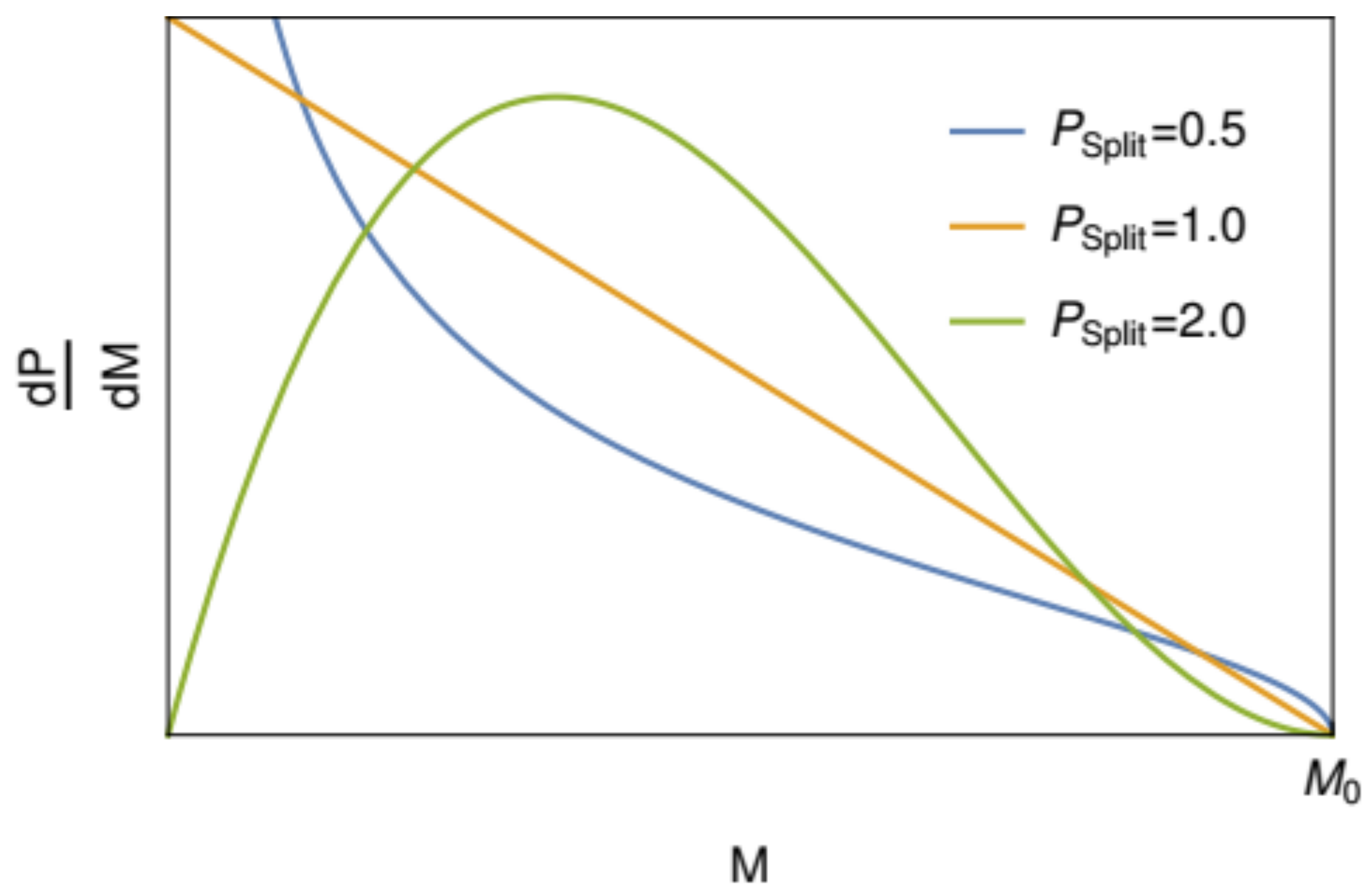
$$\mathrm{d}P(g \to q\bar{q}) \sim \frac{\mathrm{d}q^2}{q^2}\alpha_s(q^2)\left(1 - 2z(1-z) + \frac{2m_q^2}{q^2}\right)\Theta\left(q^2 z(1-z) - m_q^2\right)$$

[Hoang, Plätzer, Samitz — in progress]

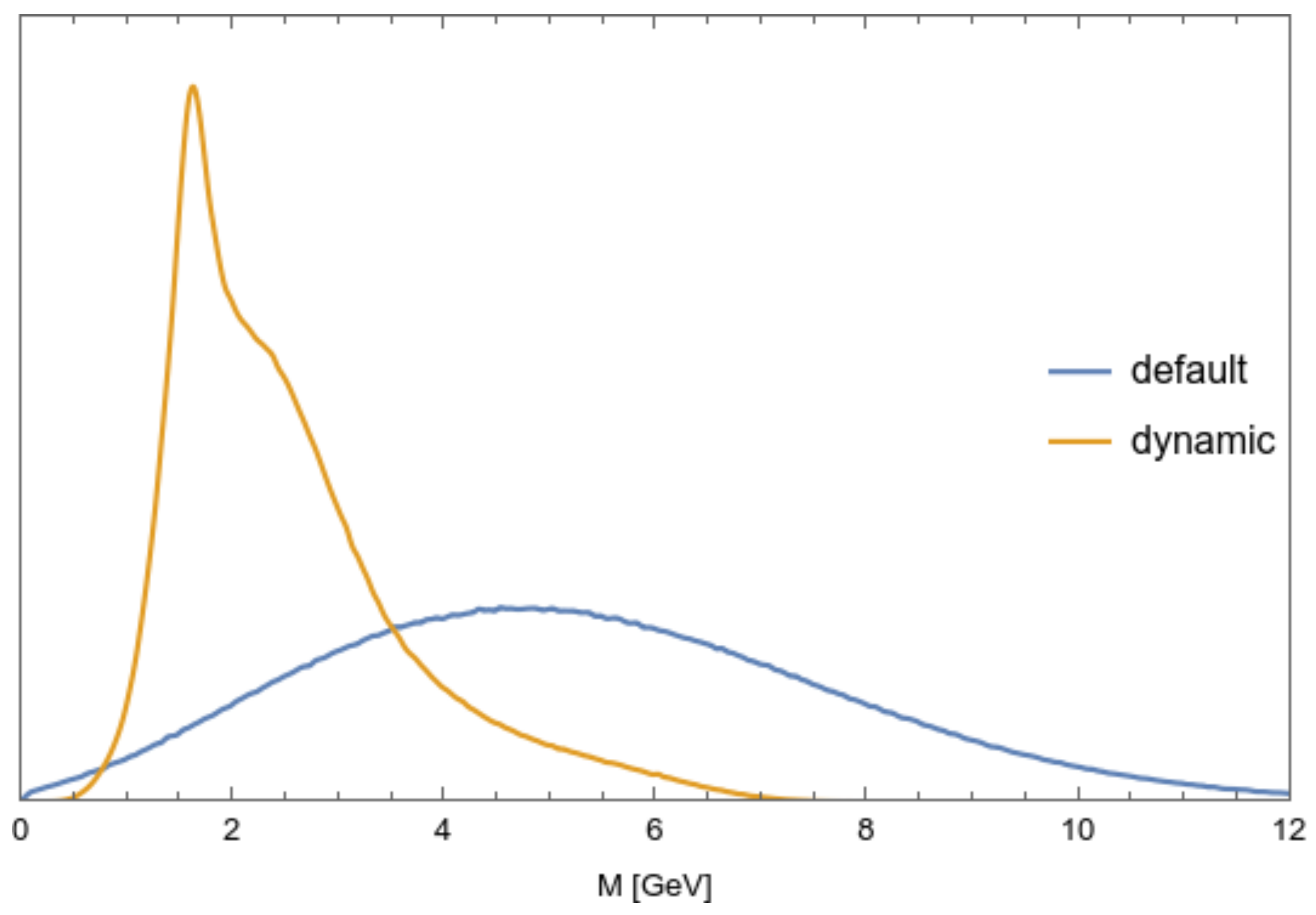
Cluster fission

Embed infrared continued parton branchings to also obtain cluster mass spectra





tuned by P_{split}
typically very steep



tuned by infrared shower scale

[Hoang, Plätzer, Samitz — in progress]

Tuning and hadronization corrections

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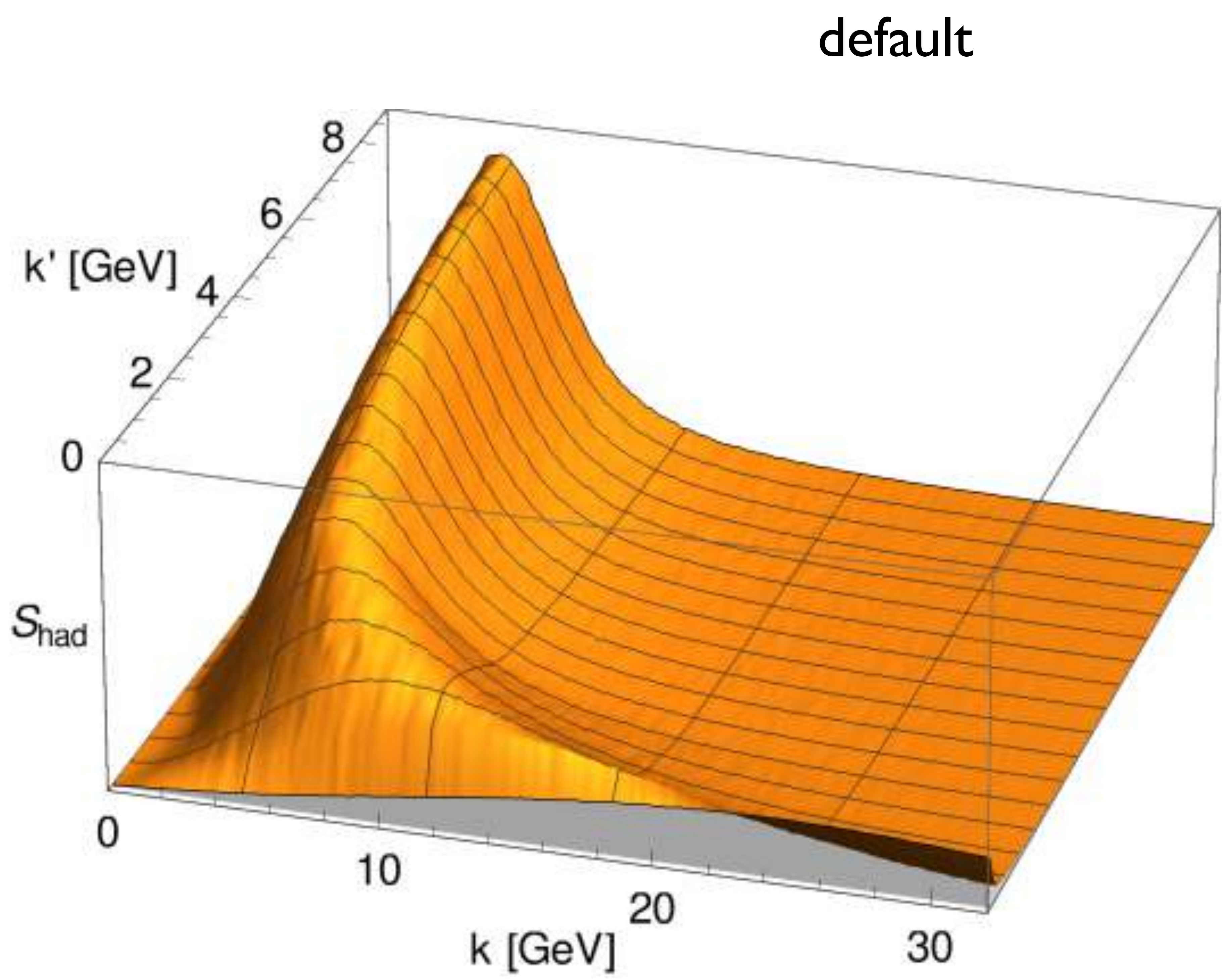
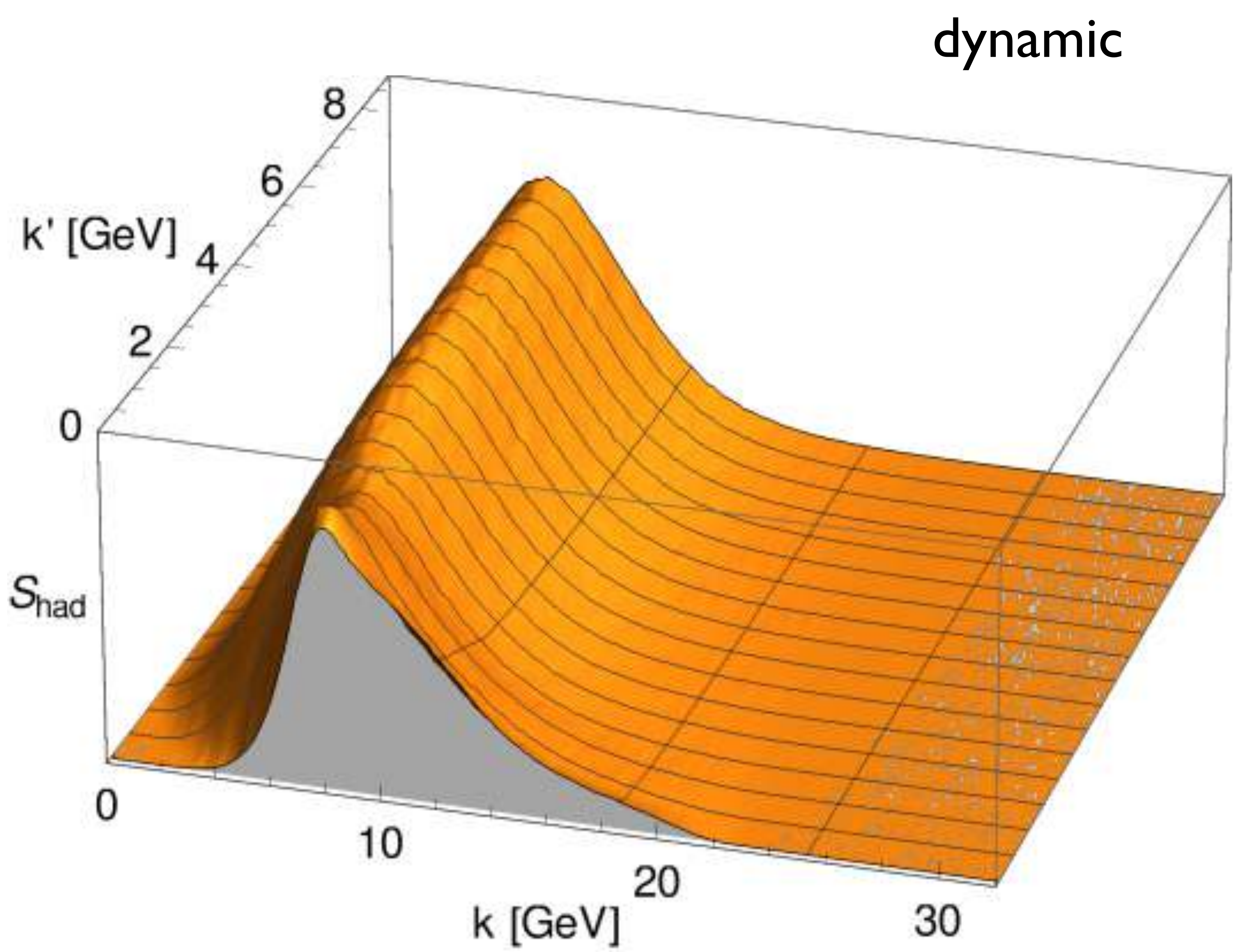
Significantly different shapes of hadronization corrections

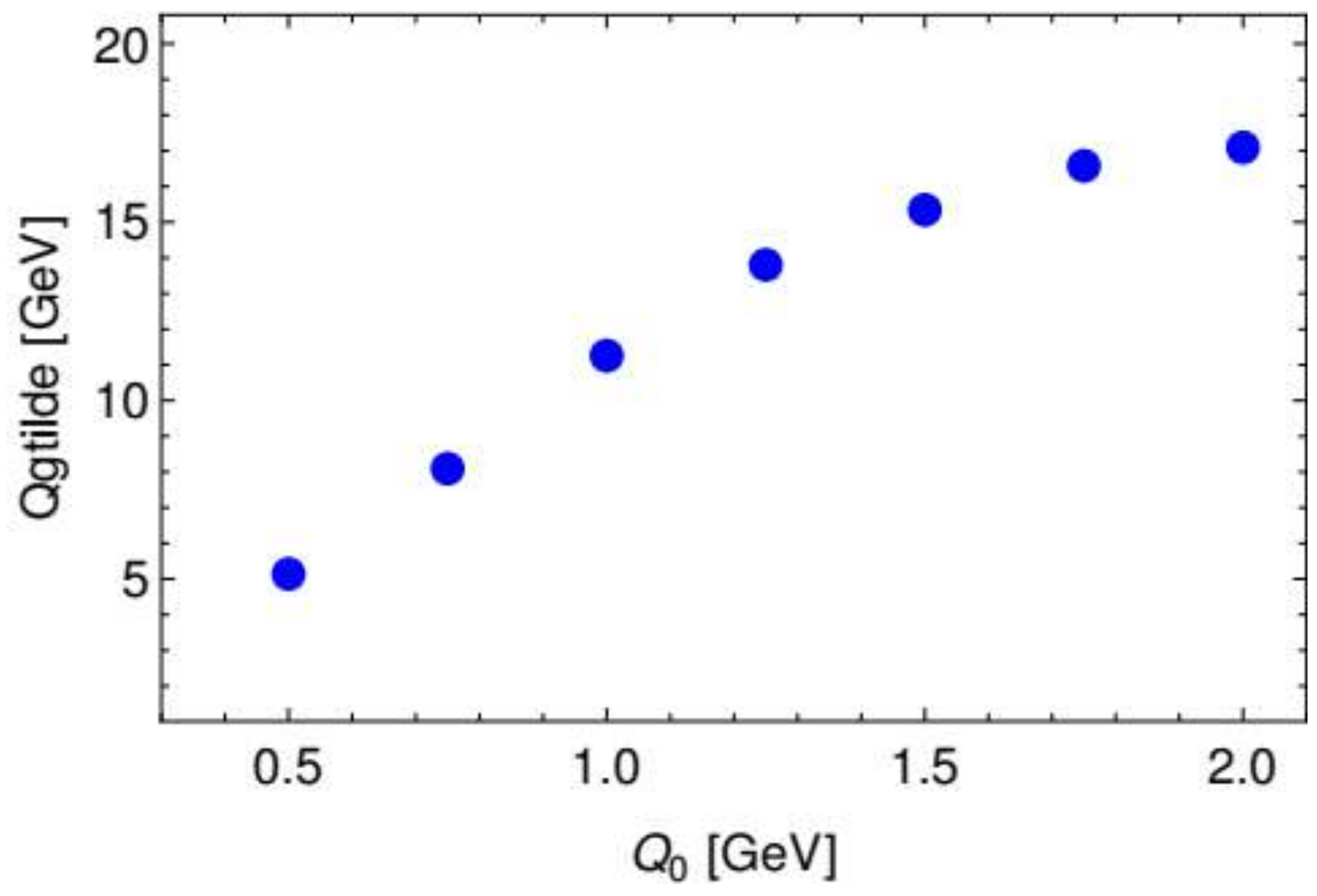


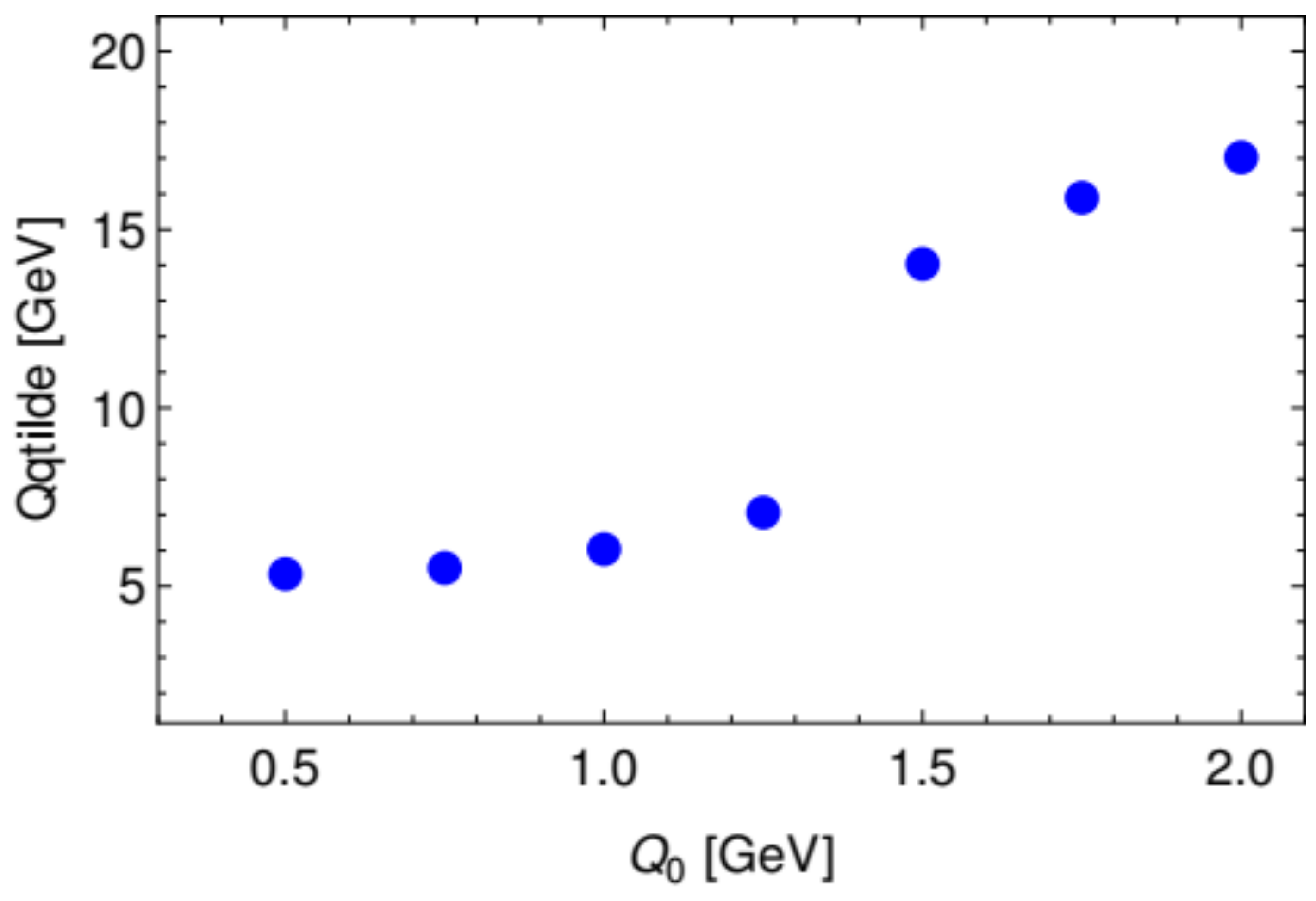


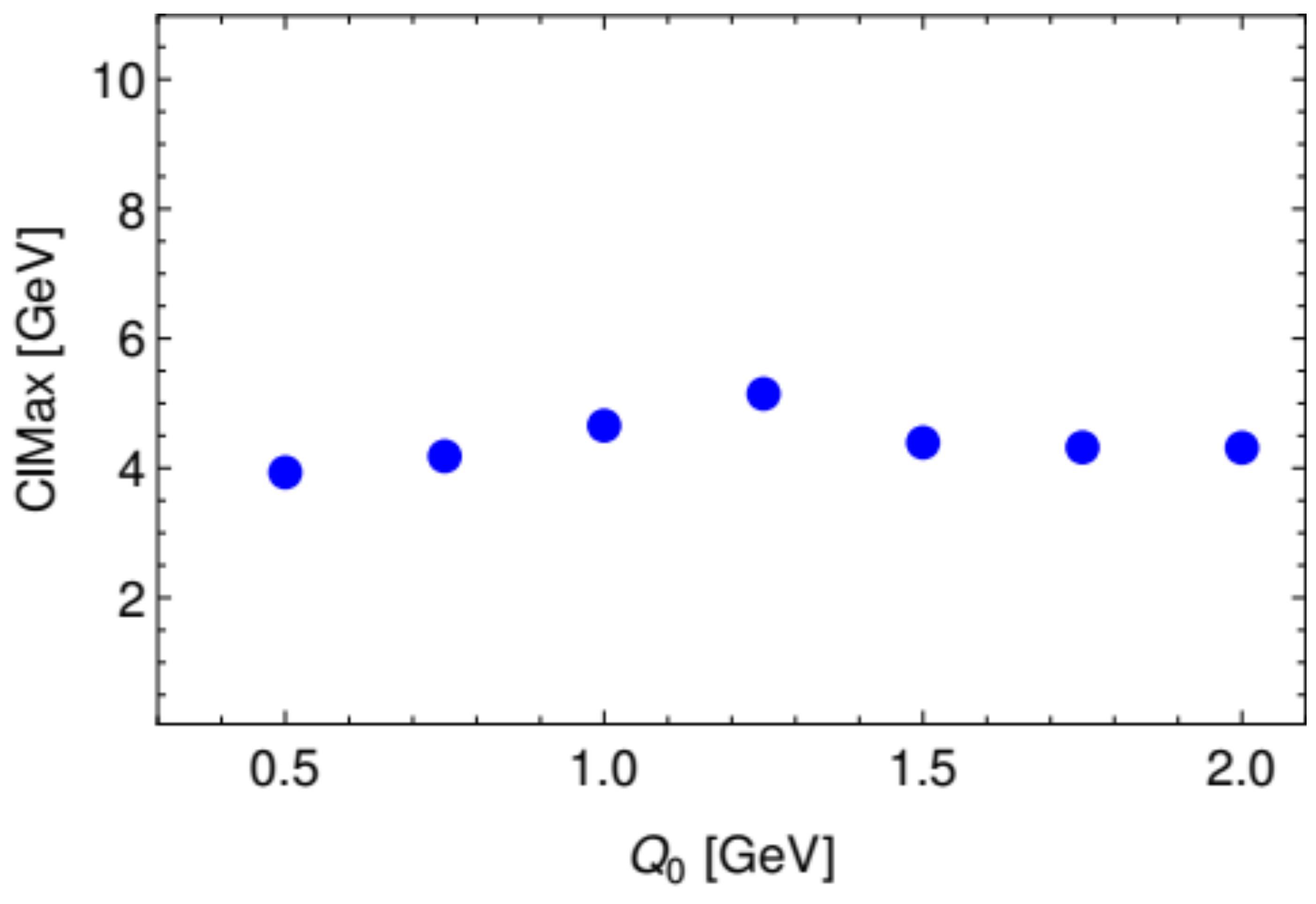
C parameter parton versus hadron level

[Hoang, Plätzer, Samitz — in progress]

Cutoff response





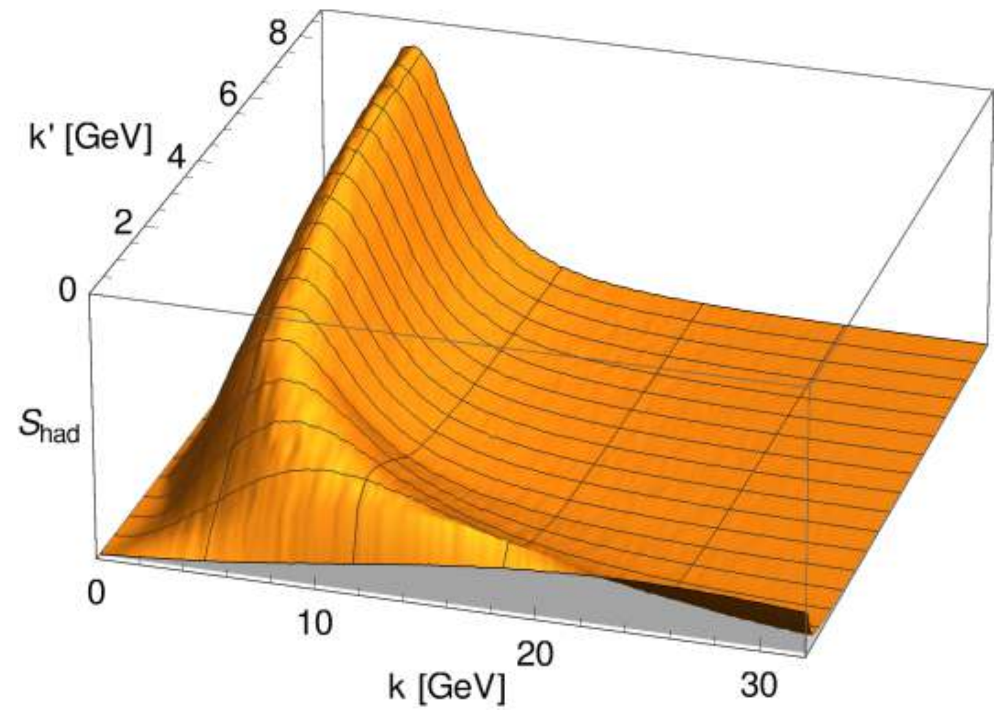


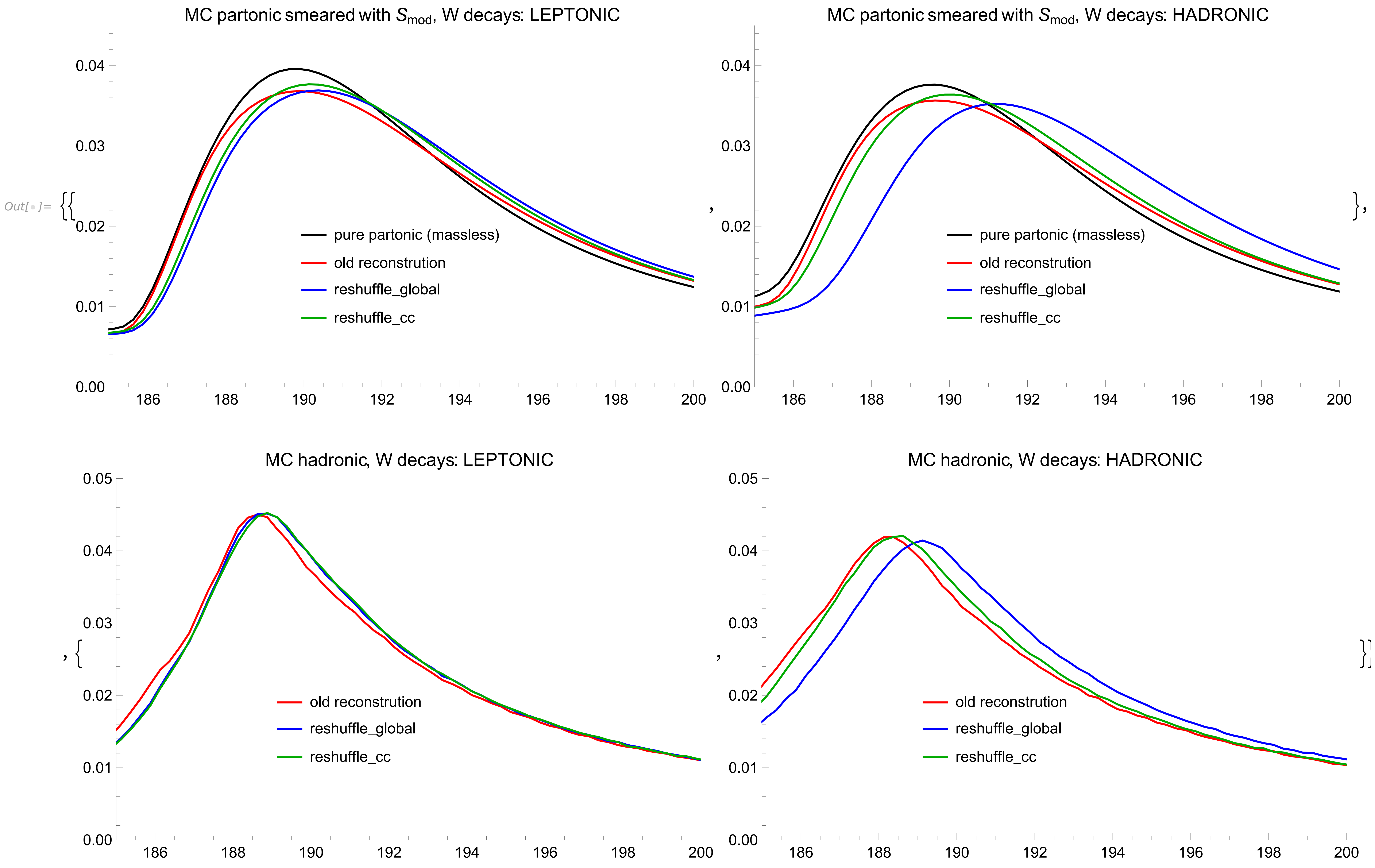
Gluon splitting and cluster fission drivers pick up cutoff dependence.

Significantly reduced sensitivity
to other cluster parameters.

[Hoang, Plätzer, Samitz — in progress]

The issue of constituent masses





Constituent masses in kinematic reconstruction.

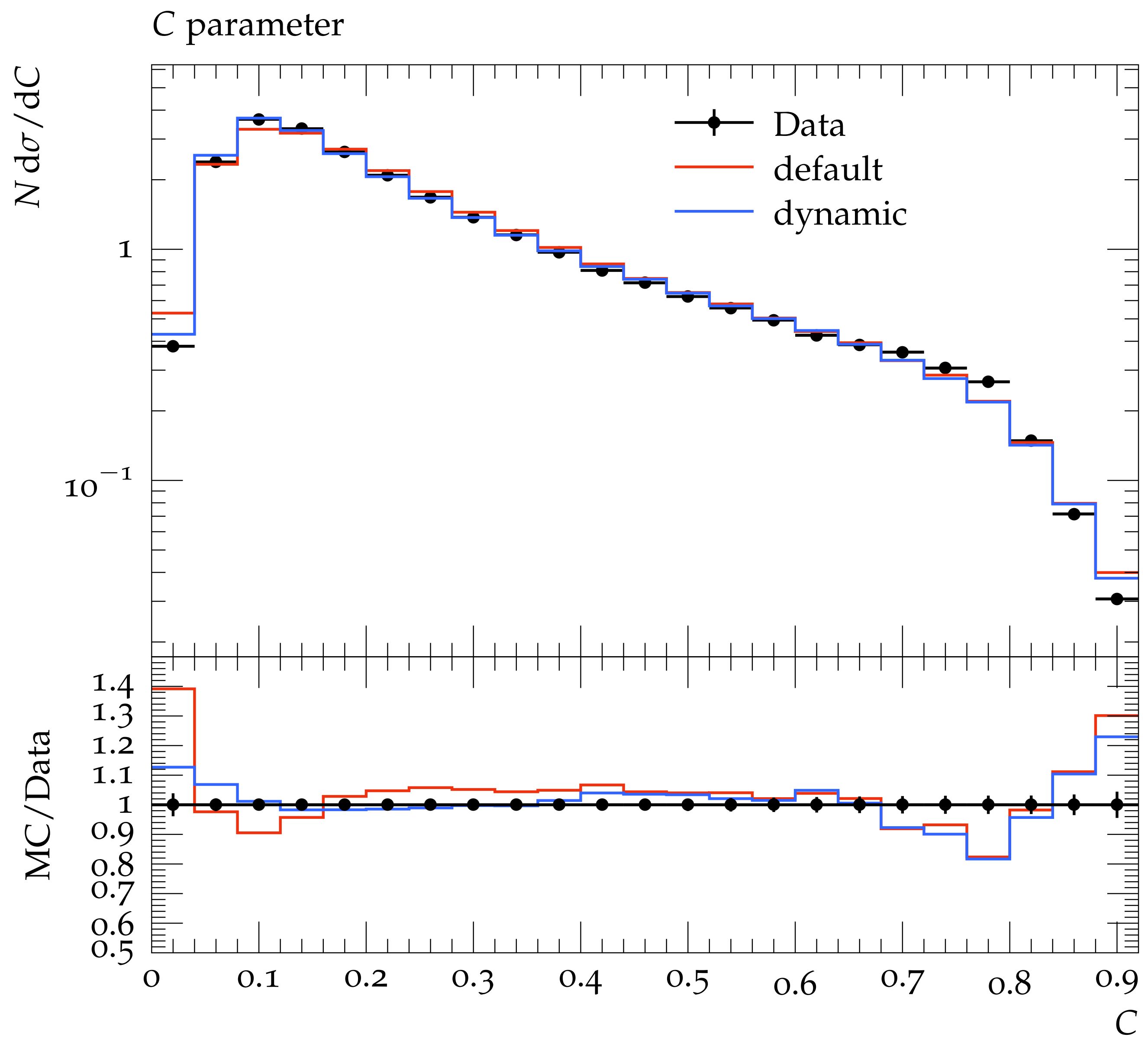
Reshuffle globally at beginning of hadronization.

Reshuffle colour singlets at beginning of hadronization.

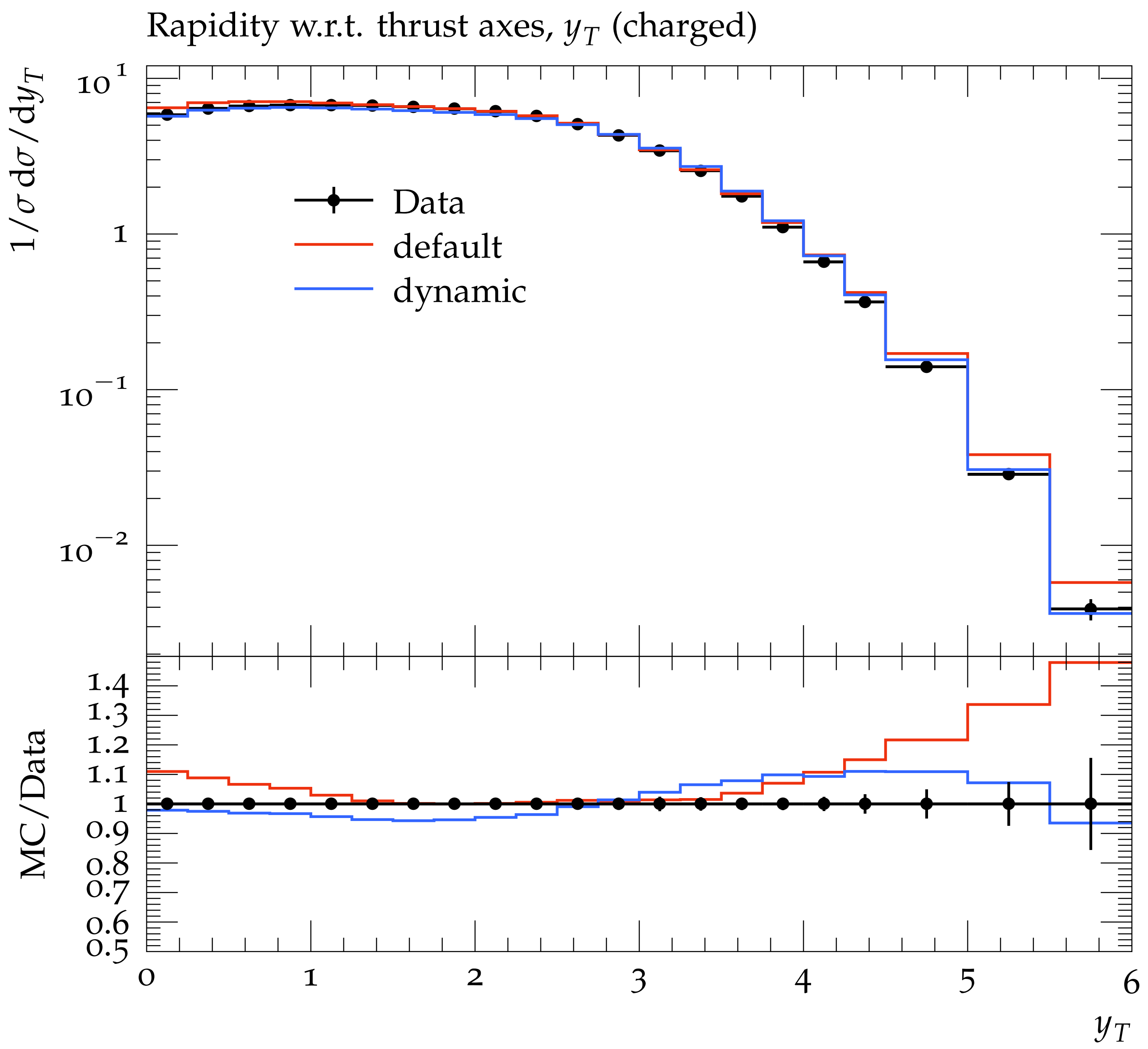
[Hoang, Plätzer, Samitz — in progress]

First new results

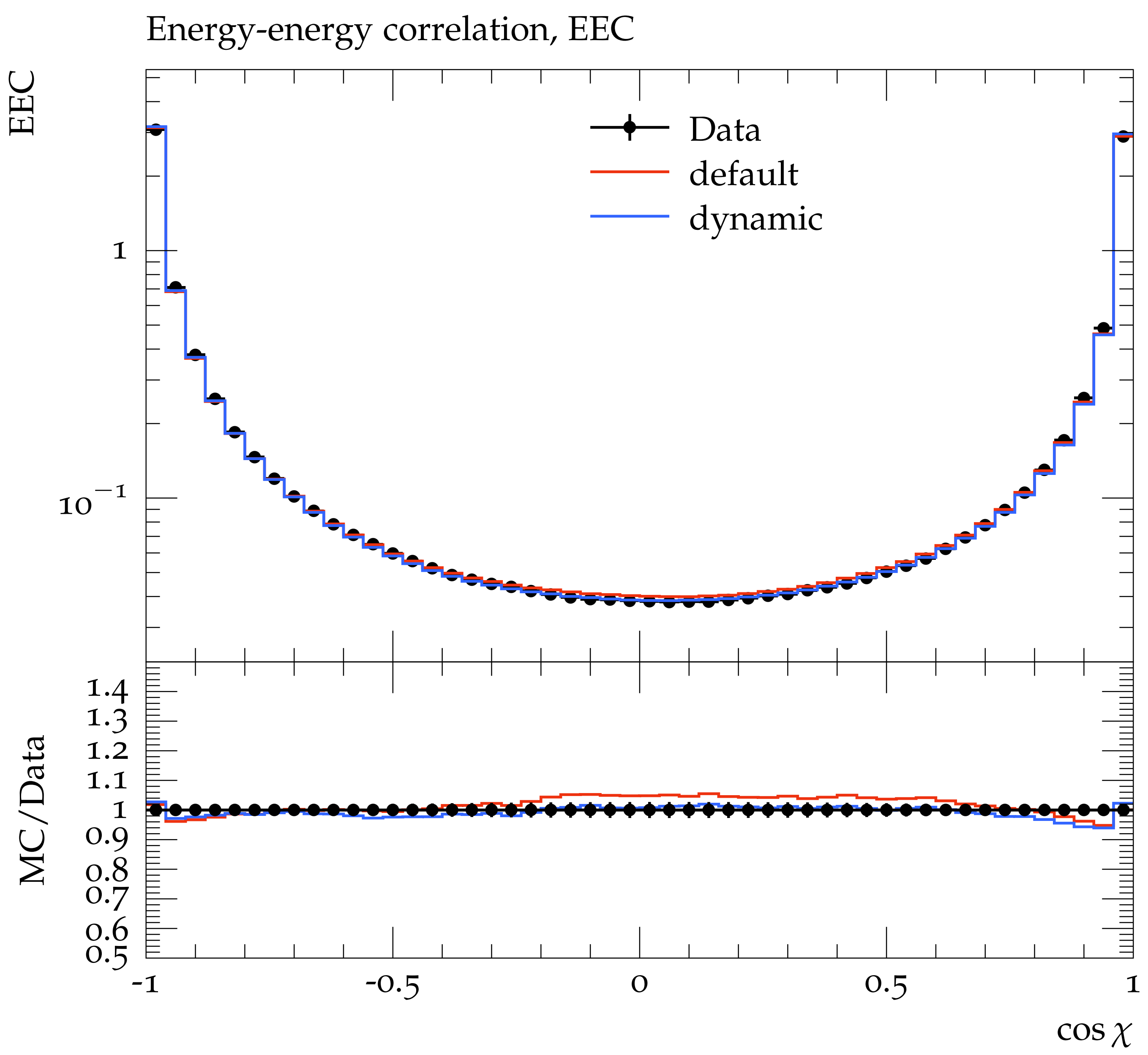
Tuning campaign underway …



C parameter



rapidity wrt thrust



EEC

Summary

We must understand how hadronization models respond to shower variations — they do not live in isolation, and we shouldn't be tuning the shower cutoff.

- Obvious in hadronization corrections from factorized cross sections in SCET: Soft functions do obey R evolution.
- Obvious also from analysing evolution equations in colour space, which contain (dipole) showers as limiting algorithms.

Both paradigms can and should be used to *construct models* at their "ultraviolet" end.

We are currently pursuing this for the Herwig cluster model — alongside many other developments like infrared continuations of the strong coupling and related.

Dark cluster hadronization

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Current hadronization module is too deeply rooted in SM QCD, and otherwise lacks flexibility.

Balance pressure of excavation walls …

Dig deep and rebuild — in light of models beyond SU(N), and deeper insight on the latter.

Construction site of Vienna's new U5 subway line (kurier.at)
Not just a new line, bridging a gap … U1,2,3,4 and 6 do exist …

Thank you!

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Herwig 7.3 coming soon …