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Herwig 7

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At the
MC4EIC Workshop
Online | 18 November 2022

Herwig 7 Overview

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[Herwig collaboration – Eur.Phys.J. C76 (2016) 665]

Two shower modules: angular ordered and dipole-type.

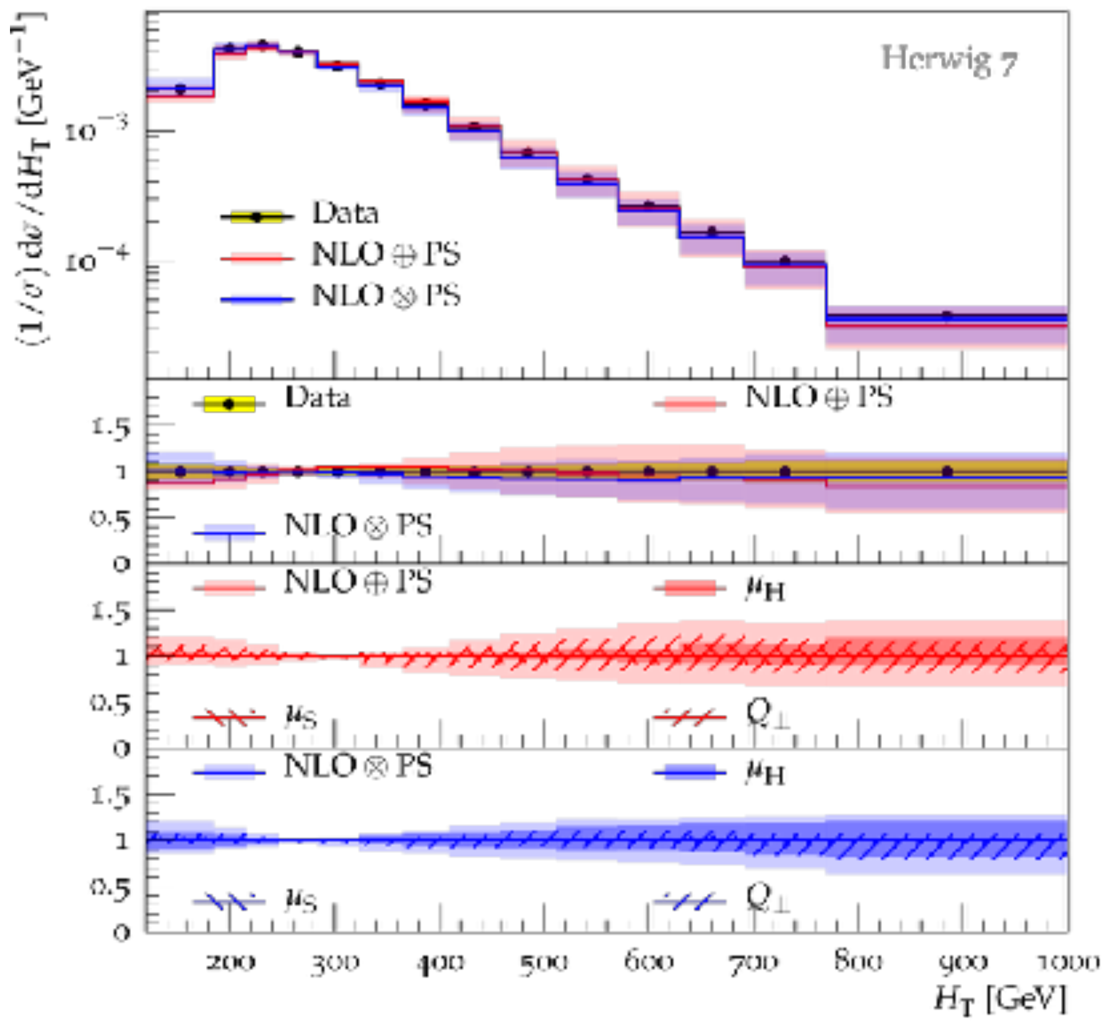
[Gieseke, Stephens, Webber – JHEP 0312 (2003) 045]
[Plätzer, Gieseke – JHEP 1101 (2011) 024]

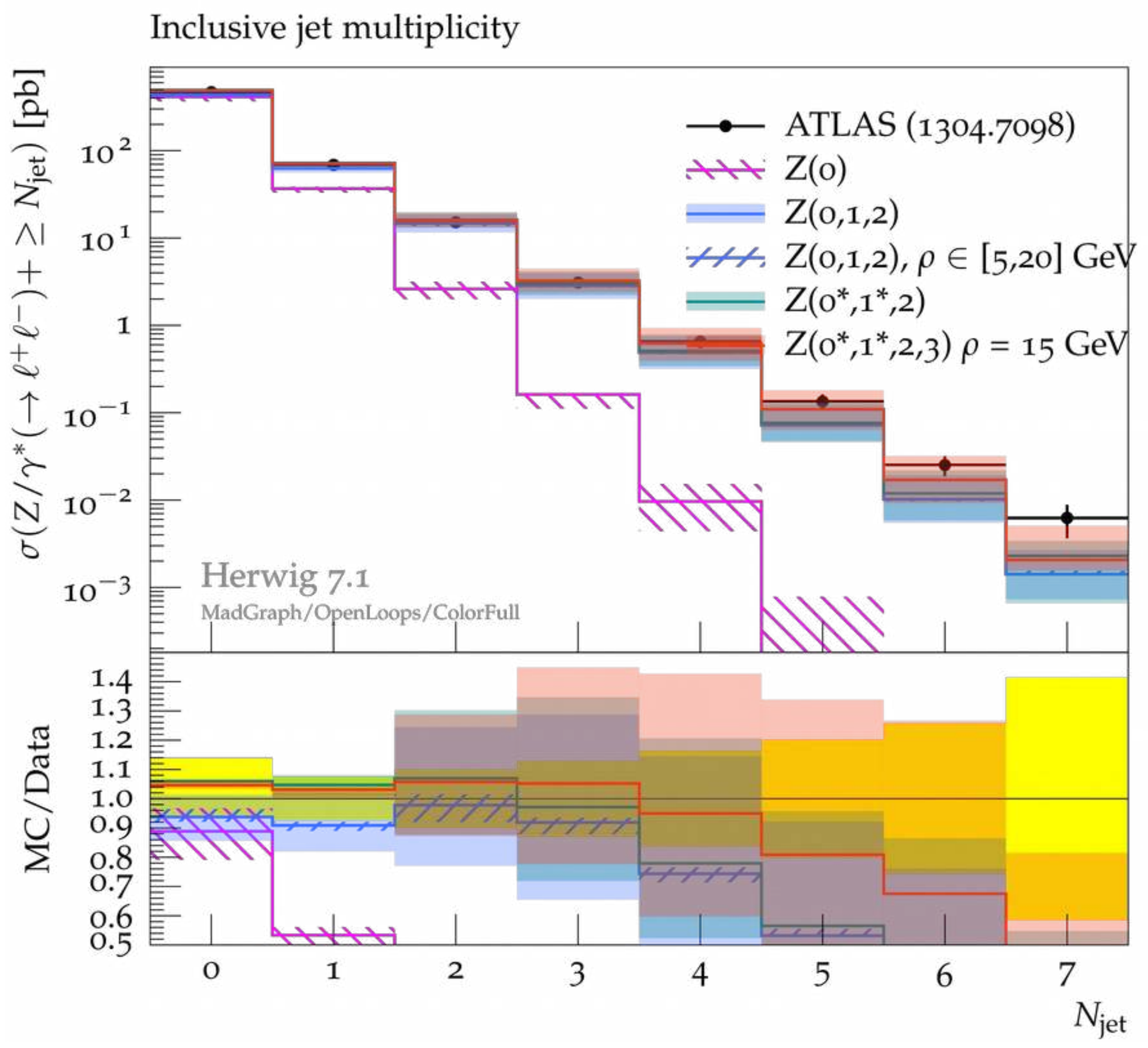
[Plätzer, Gieseke – EPJ C72 (2012) 2187]
[Plätzer — JHEP 1308 (2013) 114]
[Bellm, Gieseke, Plätzer — EPJ C78 (2018) 244]

Automated NLO matching and multi jet merging.

Automated BSM simulations using UFO model files.

[Gigg, Richardson — EPJ C51 (2007) 989]
[Richardson, Wilcock — EPJ C74 (2014) 2713]

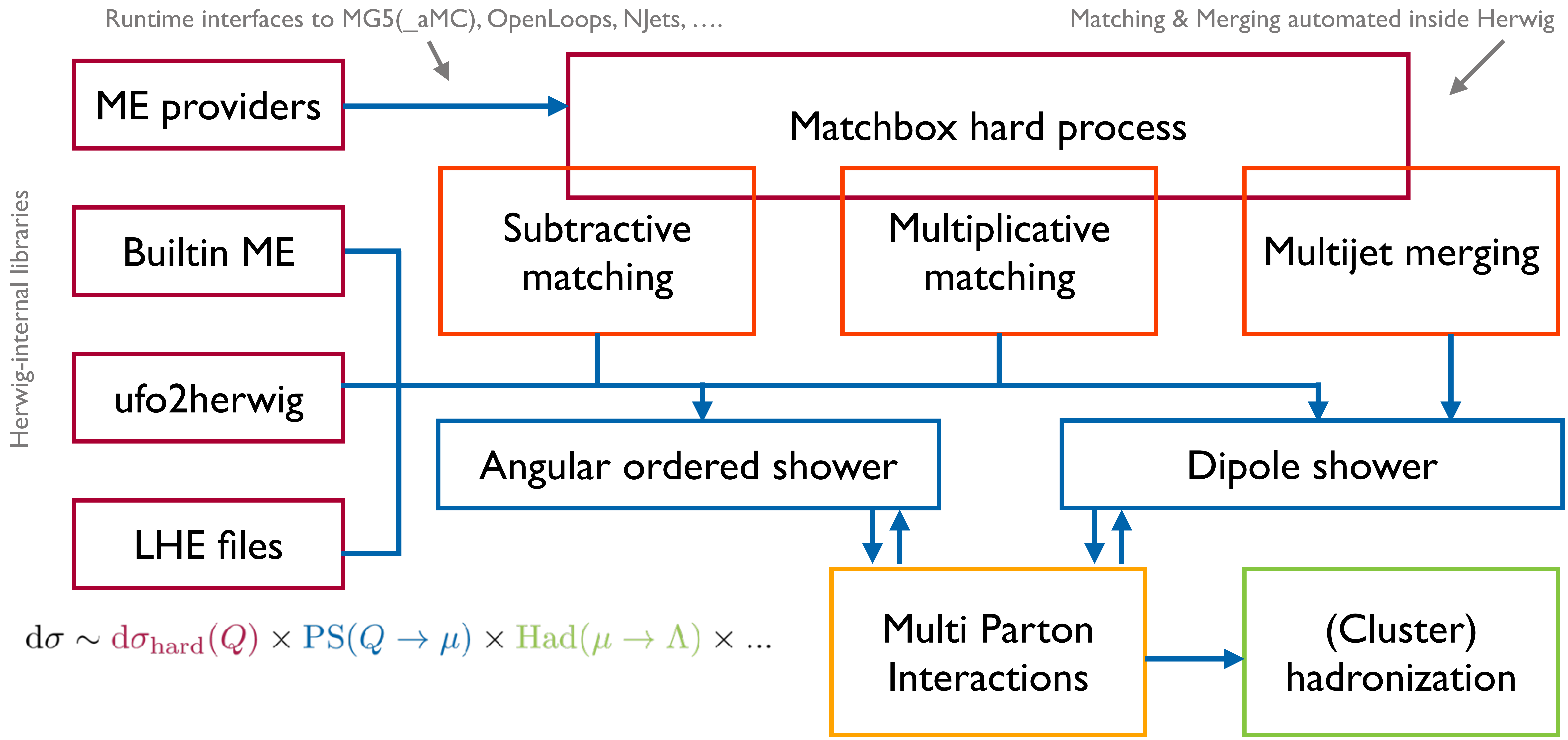




Cluster hadronization model

Eikonal MPI model

Under the Hood



$$d\sigma \sim d\sigma_{\rm hard}(Q) \times {\rm PS}(Q \to \mu) \times {\rm Had}(\mu \to \Lambda) \times \ldots$$

BSM Simulation

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- Most of the work over the last 10 years has focused on simulation of Standard Model processes.
- Still a number of BSM improvements:
  - Handling of colour sextets;
  - More BSM models;
  - full correlations (i.e. including in shower);
  - use τ decay currents for nearly degenerate BSM decays.
- Major improvement with the ability to use models in the UFO format
  - python ufo2herwig program converts UFO to C++ code implementing the model.
  - can then be used like an internal model with simulation of production, decay and QCD radiation from the BSM particles.
- Herwig 7.2, handling of general Lorentz structures for the vertices and more colour structures.
- Next minor release 7.2.3 will include supprt for python3 although many issues as most UFO models still in python2.

7.2.3 already out (old slides)

[Gigg, Richardson — EPJ C51 (2007) 989]
[Richardson, Wilcock — EPJ C74 (2014) 2713]

[Richardson for Tools 2020]

- Model with:
  - spin-$\frac{3}{2}$ particles;
  - complicated Dirac structures;
  - $\epsilon^{\alpha\beta\gamma\delta}$ in many vertices;
- Tough test for automatic parsing of the vertices.
- Excellent agreement with MC5-aMCNLO.

Process	σ/pb Hw 7	σ/pb Mad	Ratio	Fractional Difference	χ
$gu \to \tilde{u}_1 gld$	$(27.20200 \pm 0.0040) \times 10^{-1}$	$(27.21160 \pm 0.0079) \times 10^{-1}$	0.9996	-0.0002	-1.0852
$gu \to \tilde{u}_1 grv$	$(18.53800 \pm 0.0030) \times 10^{-1}$	$(18.53830 \pm 0.0044) \times 10^{-1}$	1.0000	-0.0000	-0.0564
$gu \to \tilde{u}_4 gld$	$(28.13400 \pm 0.0040) \times 10^{-1}$	$(28.13260 \pm 0.0085) \times 10^{-1}$	1.0000	0.0000	0.1495
$gu \to \tilde{u}_4 grv$	$(19.48900 \pm 0.0030) \times 10^{-1}$	$(19.49400 \pm 0.0048) \times 10^{-1}$	0.9997	-0.0001	-0.8891
$gs \to \tilde{d}_2 gld$	$(1.11250 \pm 0.0002) \times 10^{-1}$	$(1.11264 \pm 0.0003) \times 10^{-1}$	0.9999	-0.0001	-0.4102
$gs \to \tilde{d}_2 grv$	$(1.08280 \pm 0.0002) \times 10^{-1}$	$(1.08255 \pm 0.0003) \times 10^{-1}$	1.0002	0.0001	0.7631
$gs \to \tilde{d}_5 gld$	$(1.22070 \pm 0.0002) \times 10^{-1}$	$(1.22098 \pm 0.0003) \times 10^{-1}$	0.9998	-0.0001	-0.7607
$gs \to \tilde{d}_5 grv$	$(1.22890 \pm 0.0002) \times 10^{-1}$	$(1.22904 \pm 0.0003) \times 10^{-1}$	0.9999	-0.0001	-0.4333
$gc \to \tilde{u}_2 gld$	$(7.69000 \pm 0.0010) \times 10^{-2}$	$(7.68954 \pm 0.0020) \times 10^{-2}$	1.0001	0.0000	0.2080
$gc \to \tilde{u}_2 grv$	$(7.61300 \pm 0.0010) \times 10^{-2}$	$(7.61320 \pm 0.0017) \times 10^{-2}$	1.0000	-0.0000	-0.1001
$gc \to \tilde{u}_5 gld$	$(8.06500 \pm 0.0010) \times 10^{-2}$	$(8.06697 \pm 0.0021) \times 10^{-2}$	0.9998	-0.0001	-0.8579
$gc \to \tilde{u}_5 grv$	$(8.12600 \pm 0.0010) \times 10^{-2}$	$(8.12763 \pm 0.0018) \times 10^{-2}$	0.9998	-0.0001	-0.7919
$gb \to \tilde{d}_3 gld$	$(5.65120 \pm 0.0008) \times 10^{-2}$	$(5.64113 \pm 0.0014) \times 10^{-2}$	1.0018	0.0009	6.2993
$gb \to \tilde{d}_3 grv$	$(6.21400 \pm 0.0010) \times 10^{-2}$	$(6.20548 \pm 0.0013) \times 10^{-2}$	1.0014	0.0007	5.1251
$gb \to \tilde{d}_6 gld$	$(4.94500 \pm 0.0008) \times 10^{-2}$	$(4.95255 \pm 0.0012) \times 10^{-2}$	0.9985	-0.0008	-5.1105
$gb \to \tilde{d}_6 grv$	$(5.20610 \pm 0.0008) \times 10^{-2}$	$(5.21305 \pm 0.0012) \times 10^{-2}$	0.9987	-0.0007	-4.8722
$g\bar{d} \to \tilde{d}_1^* gld$	$(2.12470 \pm 0.0003) \times 10^{-1}$	$(2.12507 \pm 0.0005) \times 10^{-1}$	0.9998	-0.0001	-0.5958
$g\bar{d} \to \tilde{d}_1^* grv$	$(2.01050 \pm 0.0003) \times 10^{-1}$	$(2.01034 \pm 0.0005) \times 10^{-1}$	1.0001	0.0000	0.2877
$g\bar{d} \to \tilde{d}_4^* gld$	$(2.32600 \pm 0.0004) \times 10^{-1}$	$(2.32610 \pm 0.0006) \times 10^{-1}$	1.0000	-0.0000	-0.1367
$g\bar{d} \to \tilde{d}_4^* grv$	$(2.27300 \pm 0.0004) \times 10^{-1}$	$(2.27331 \pm 0.0005) \times 10^{-1}$	0.9999	-0.0001	-0.4704
$g\bar{u} \to \tilde{u}_1^* gld$	$(1.71460 \pm 0.0003) \times 10^{-1}$	$(1.71493 \pm 0.0004) \times 10^{-1}$	0.9998	-0.0001	-0.6189
$g\bar{u} \to \tilde{u}_1^* grv$	$(1.65060 \pm 0.0003) \times 10^{-1}$	$(1.65038 \pm 0.0004) \times 10^{-1}$	1.0001	0.0001	0.4498
$g\bar{u} \to \tilde{u}_4^* gld$	$(1.79670 \pm 0.0003) \times 10^{-1}$	$(1.79669 \pm 0.0004) \times 10^{-1}$	1.0000	0.0000	0.0188
$g\bar{u} \to \tilde{u}_4^* grv$	$(1.75910 \pm 0.0003) \times 10^{-1}$	$(1.75882 \pm 0.0004) \times 10^{-1}$	1.0002	0.0001	0.5742
$g\bar{s} \to \tilde{d}_2^* gld$	$(9.70200 \pm 0.0010) \times 10^{-2}$	$(9.70334 \pm 0.0024) \times 10^{-2}$	0.9999	-0.0001	-0.5159
$g\bar{s} \to \tilde{d}_2^* grv$	$(9.59600 \pm 0.0010) \times 10^{-2}$	$(9.59757 \pm 0.0022) \times 10^{-2}$	0.9998	-0.0001	-0.6553
$g\bar{s} \to \tilde{d}_5^* gld$	$(1.06630 \pm 0.0002) \times 10^{-1}$	$(1.06679 \pm 0.0003) \times 10^{-1}$	0.9995	-0.0002	-1.4664
$g\bar{s} \to \tilde{d}_5^* grv$	$(1.09190 \pm 0.0002) \times 10^{-1}$	$(1.09190 \pm 0.0002) \times 10^{-1}$	1.0000	-0.0000	-0.0032
$g\bar{c} \to \tilde{u}_2^* gld$	$(7.69000 \pm 0.0010) \times 10^{-2}$	$(7.68954 \pm 0.0020) \times 10^{-2}$	1.0001	0.0000	0.2080
$g\bar{c} \to \tilde{u}_2^* grv$	$(7.61300 \pm 0.0010) \times 10^{-2}$	$(7.61320 \pm 0.0017) \times 10^{-2}$	1.0000	-0.0000	-0.1001
$g\bar{c} \to \tilde{u}_5^* gld$	$(8.06500 \pm 0.0010) \times 10^{-2}$	$(8.06697 \pm 0.0021) \times 10^{-2}$	0.9998	-0.0001	-0.8579
$g\bar{c} \to \tilde{u}_5^* grv$	$(8.12600 \pm 0.0010) \times 10^{-2}$	$(8.12763 \pm 0.0018) \times 10^{-2}$	0.9998	-0.0001	-0.7919
$g\bar{b} \to \tilde{d}_3^* gld$	$(5.65120 \pm 0.0008) \times 10^{-2}$	$(5.64113 \pm 0.0014) \times 10^{-2}$	1.0018	0.0009	6.2993
$g\bar{b} \to \tilde{d}_3^* grv$	$(6.21400 \pm 0.0010) \times 10^{-2}$	$(6.20548 \pm 0.0013) \times 10^{-2}$	1.0014	0.0007	5.1251
$g\bar{b} \to \tilde{d}_6^* gld$	$(4.94500 \pm 0.0008) \times 10^{-2}$	$(4.95255 \pm 0.0012) \times 10^{-2}$	0.9985	-0.0008	-5.1105

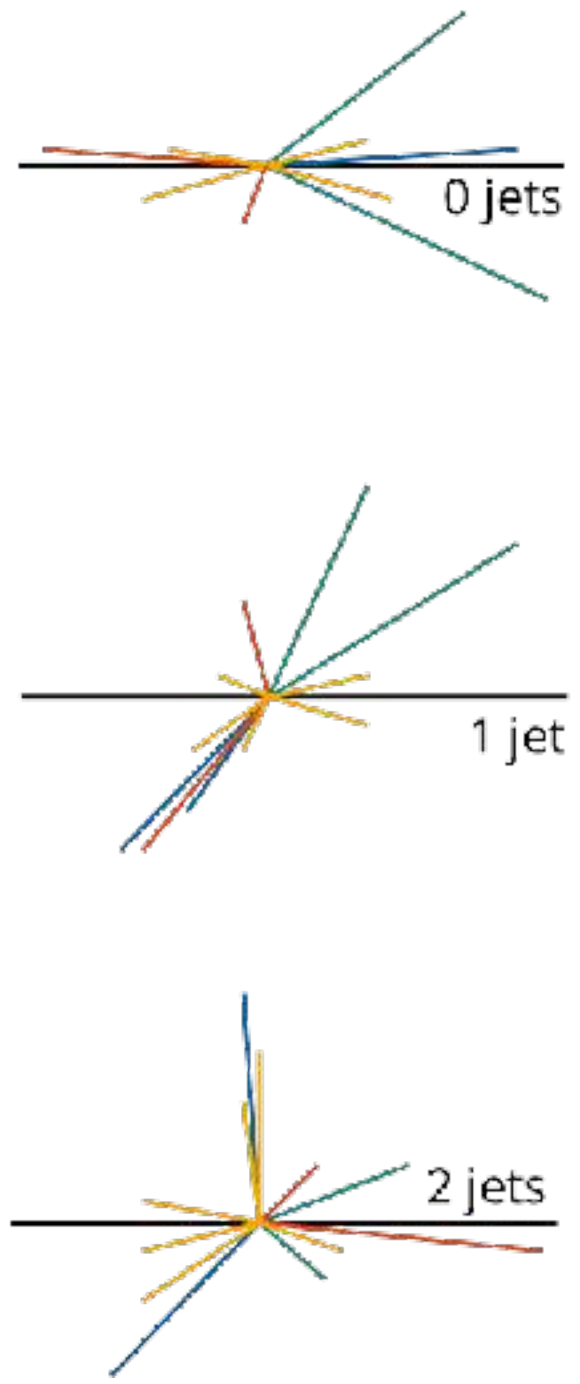
Matching & Merging

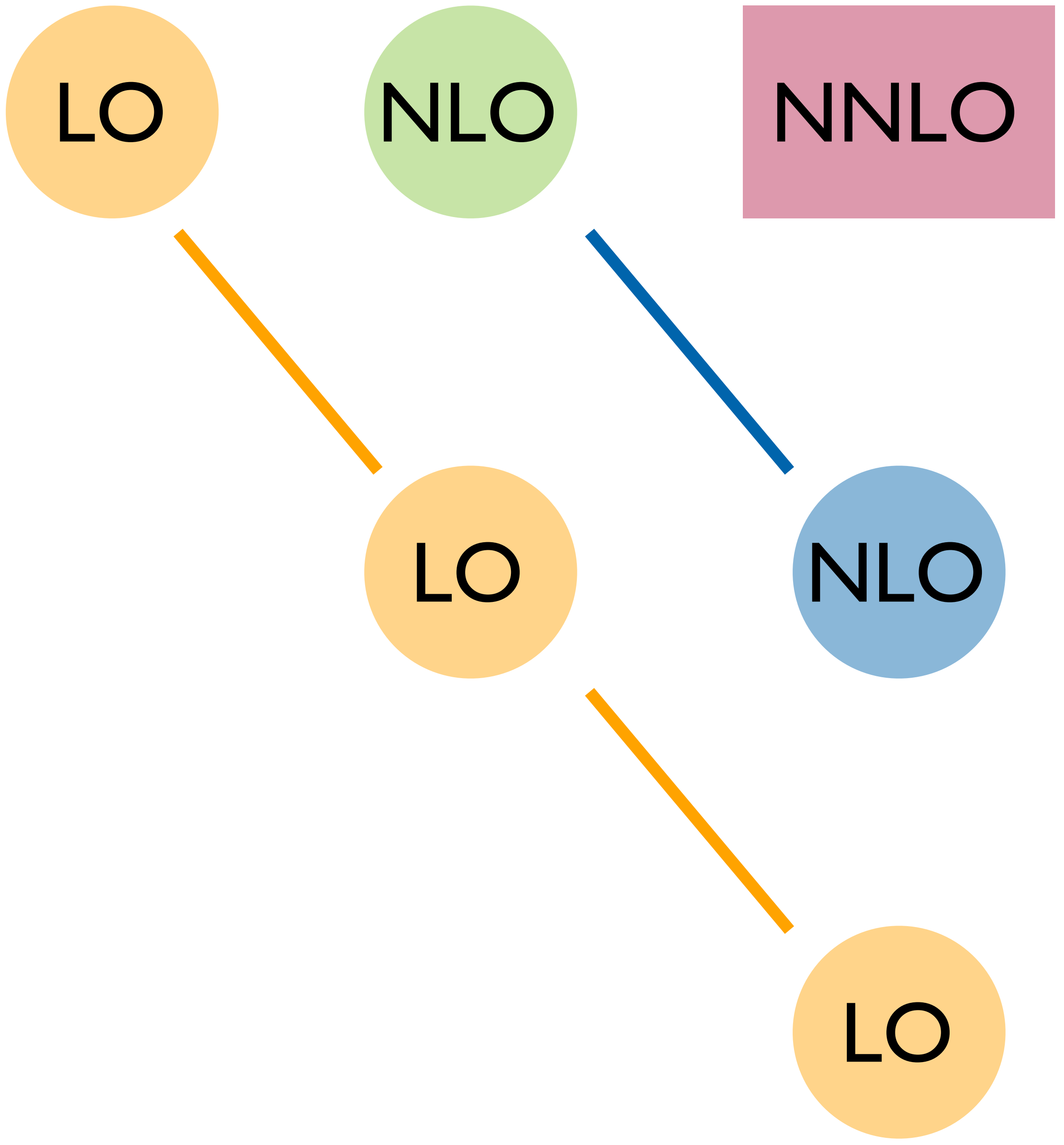
Matching & merging at NLO — works for general hard process.

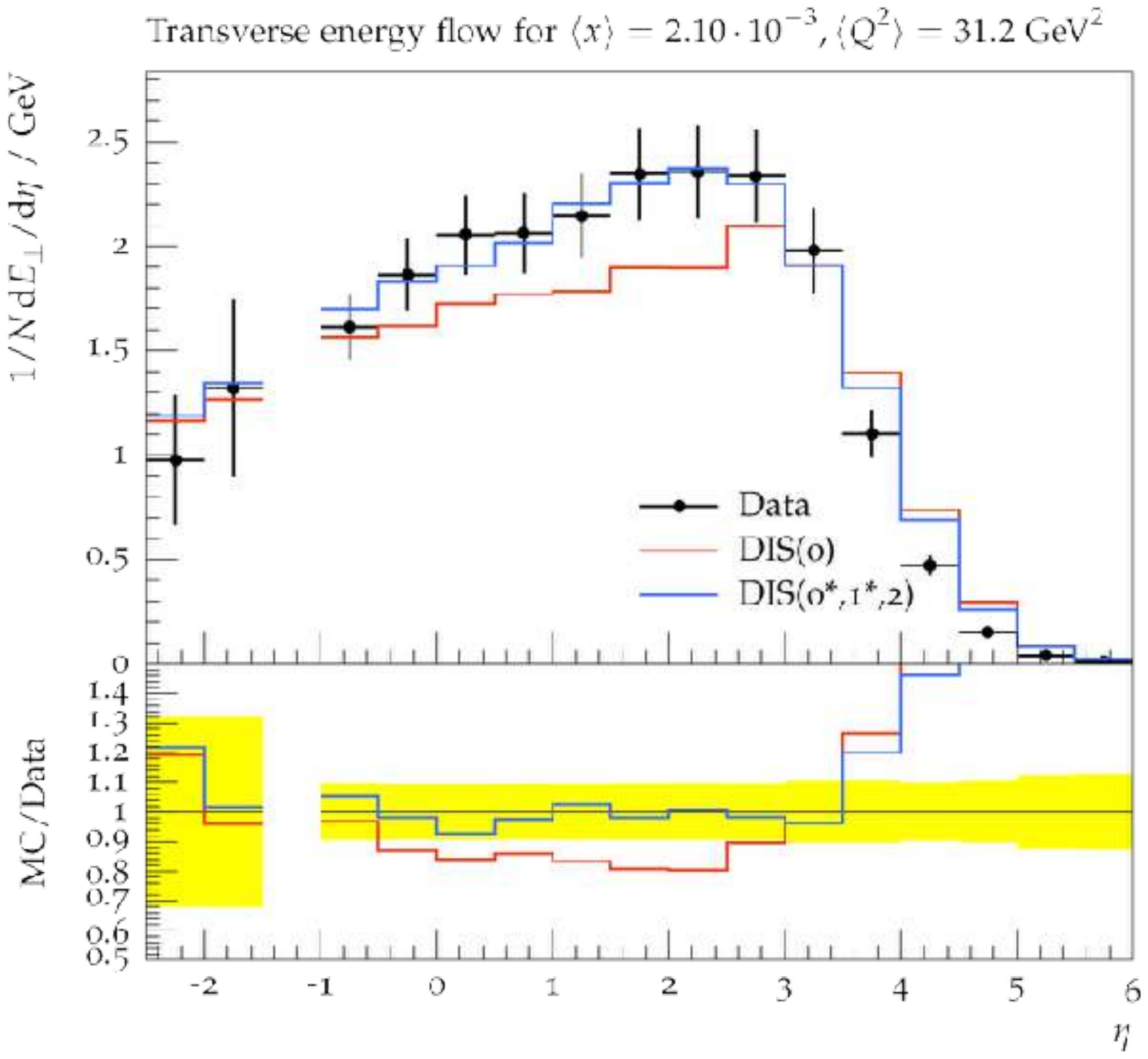
[Plätzer, Gieseke – EPJ C72 (2012) 2187]

NLO matching also applied to decay chains

[Richardson, Wilcock — EPJ C74 (2014) 2713]







Merging & matching
Unitarized merging

[Plätzer — JHEP 08 (2013) 114]
[Bellm, Gieseke, Plätzer — EPJ C78 (2018) 244]
see also [Lönnblad, Prestel — JHEP 02 (2013) 049]

DIS example — re-validating with new analyses

Parton showers

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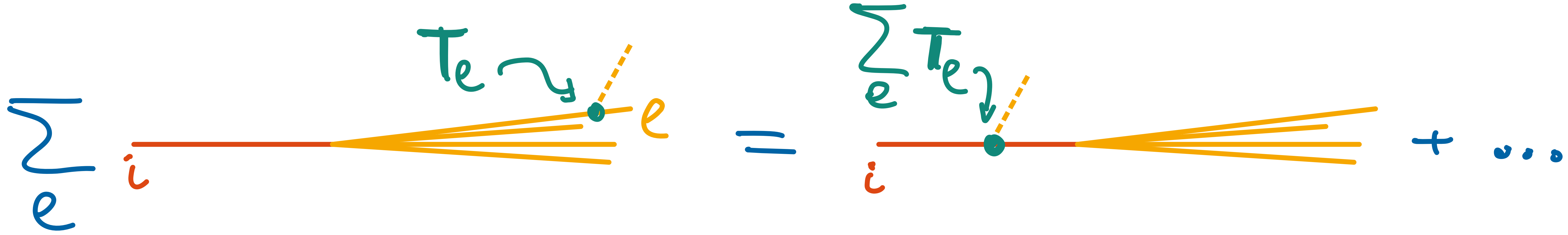
QCD coherence

If we could fix which emissions were soft and which collinear:

collinear

soft



Re-arranging amplitudes in soft-collinear limit.
Tremendous simplification of colour correlations, up to right colour factor for quark emissions

Coherent branching showers

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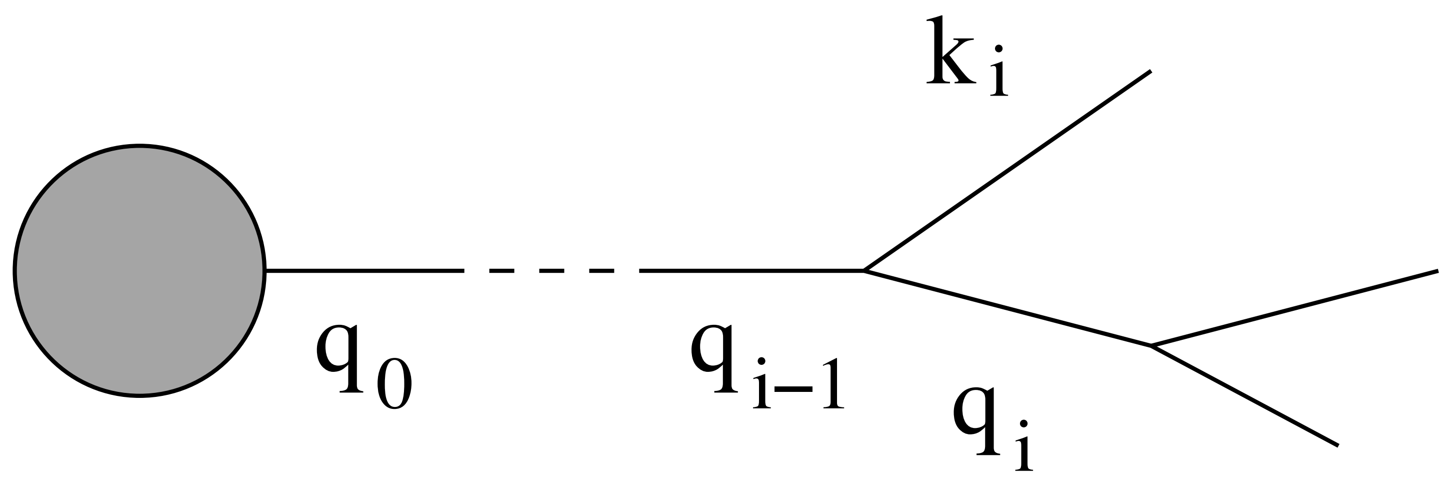
Iterations of 1 to 2 branchings collinear to a jet progenitor direction.

$$k_i^\mu = \alpha_i \; p^\mu + \beta_i \; \bar{n}^\mu + k_{i,\perp}^\mu$$

$$z_i = \frac{\alpha_i}{\alpha_{i-1}} \qquad k_{i-1}^2 = \frac{k_i^2}{z_i} + \frac{q_i^2}{1-z_i} + z_i(1-z_i)\tilde{q}_i^2$$

$$q_{i,\perp}^\mu = k_{i-1,\perp}^\mu - z_i k_{i,\perp}^\mu$$



[Catani, Trentadue, Turnock, Webber — Nucl.Phys.B 407 (1993) 3]
[Catani, Marchesini, Webber — Nucl.Phys.B 407 (1991) 654]

Order in collinearity, soft large-angle first:

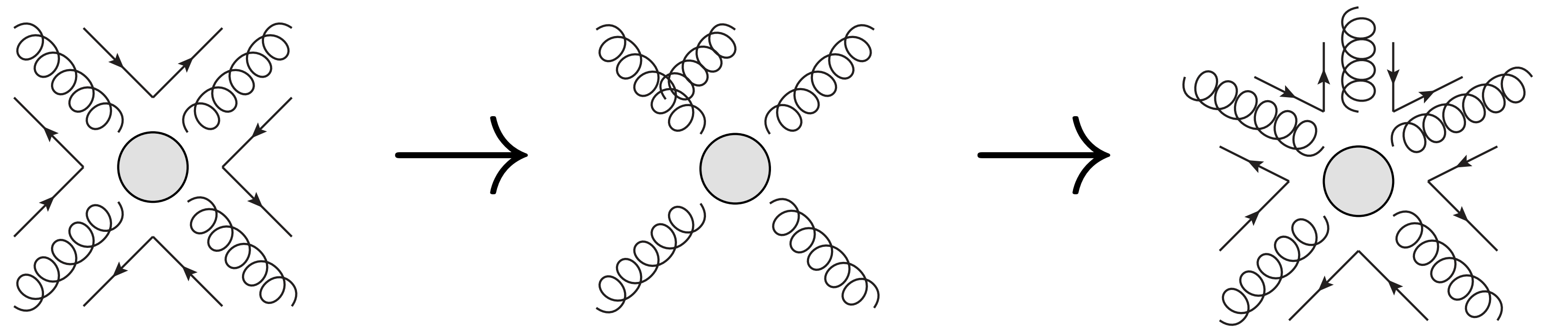
$$\tilde{q}_i^2 = \frac{p_{i,\perp}^2}{z_i^2(1-z_i)^2} \qquad \tilde{q}_{i+1}^2 < z_i^2 \; \tilde{q}_i^2$$

Sudakov factor and splitting function for each internal line and branching vertex:

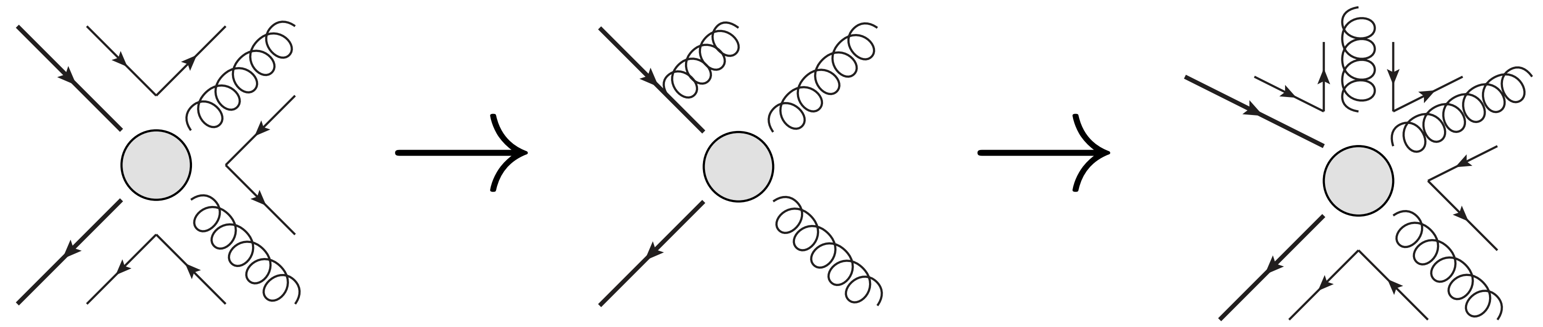
$$\mathrm{d}S = \frac{\alpha_s}{2\pi}\frac{\mathrm{d}\tilde{q}_i^2}{\tilde{q}_i^2}\mathrm{d}z P(z_i) \exp\left(-\int_{\tilde{q}_i^2}^{Q^2}\frac{\mathrm{d}q^2}{q^2}\int_{z_-(k^2)}^{z_+(k^2)}\mathrm{d}\xi \frac{\alpha_s}{2\pi}P(z)\right)$$

[Marchesini, Webber — Nucl.Phys.B 238 (1984) 29]
[Gieseke, Stephens, Webber — JHEP 0312 (2003) 045]

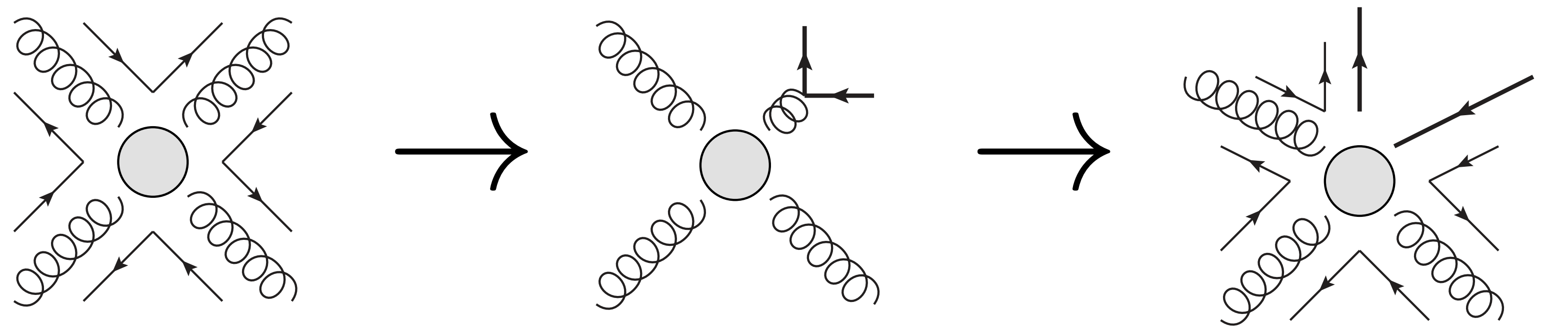
Dipole showers



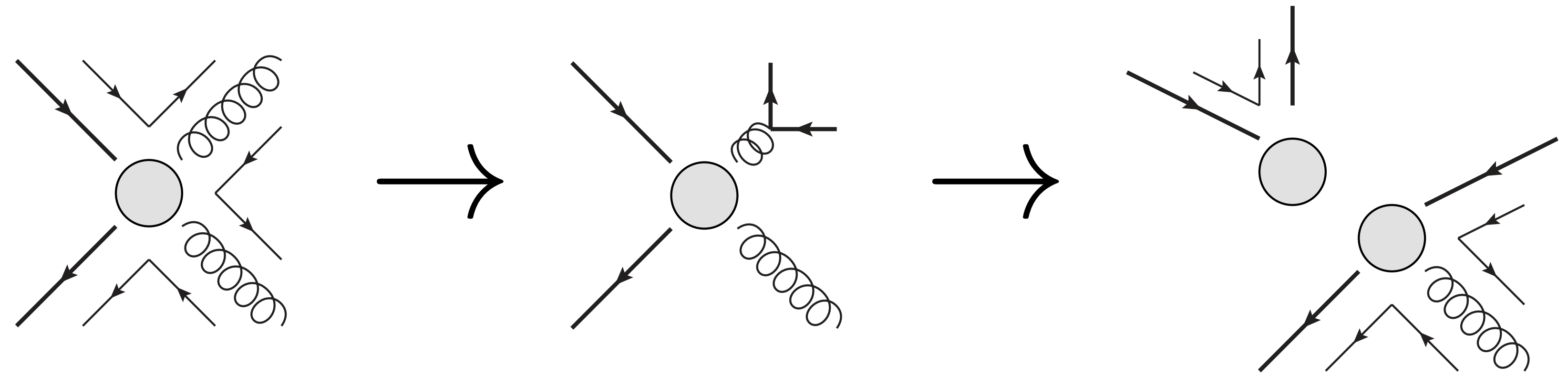
Gluon emission off a circular chain.
The chain stays circular.



Gluon emission off a non-circular chain.
The chain stays non-circular.

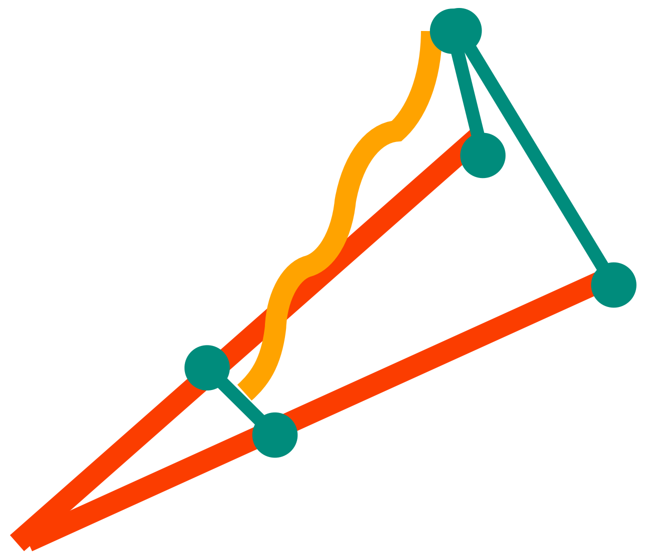


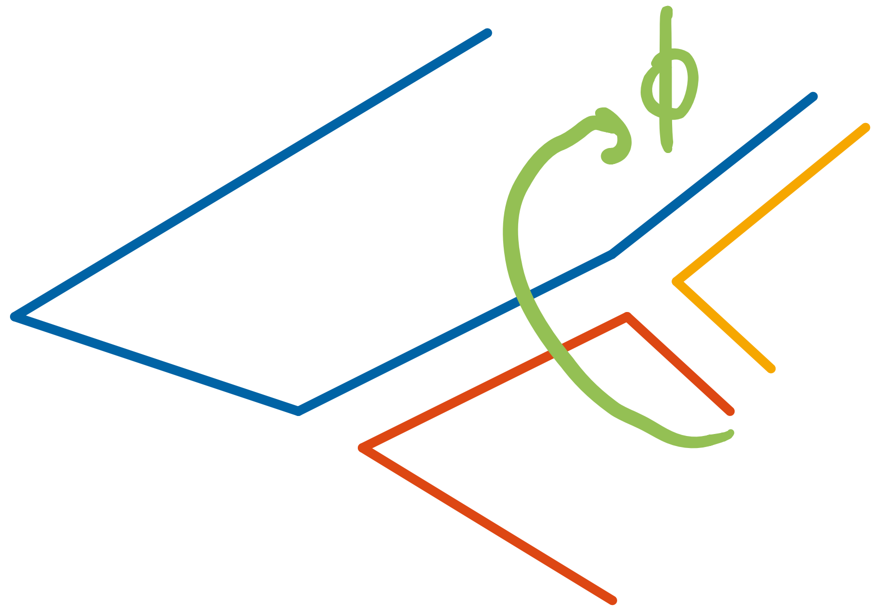
$g \to q\bar{q}$ splitting in a circular chain.
The chain becomes non-circular.



$g \to q\bar{q}$ splitting in a non-circular chain,
triggering breakup of the chain.

Account for change in radiation pattern from change in colour charges, azimuthal colour correlations built-in.





Can also implement momentum conservation locally, e.g.

$$q_i = zp_i + \frac{p_\perp^2}{zs_{ij}}p_j + k_\perp$$

$$q = (1-z)p_i + \frac{p_\perp^2}{(1-z)s_{ij}}p_j - k_\perp$$

$$q_j = \left(1 - \frac{p_\perp^2}{z(1-z)s_{ij}}\right)p_j ,$$

The Herwig showers

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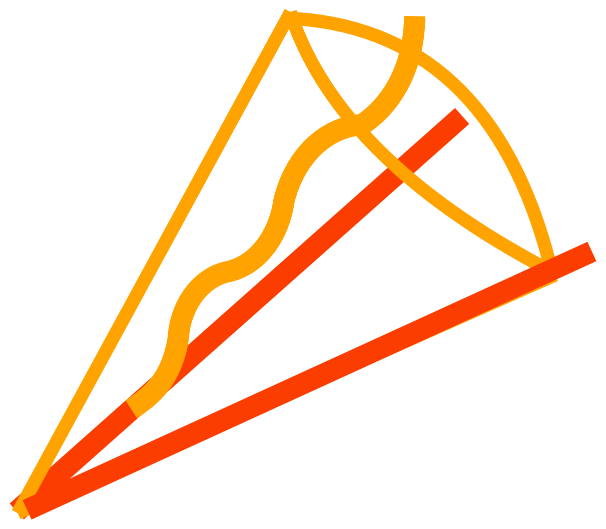
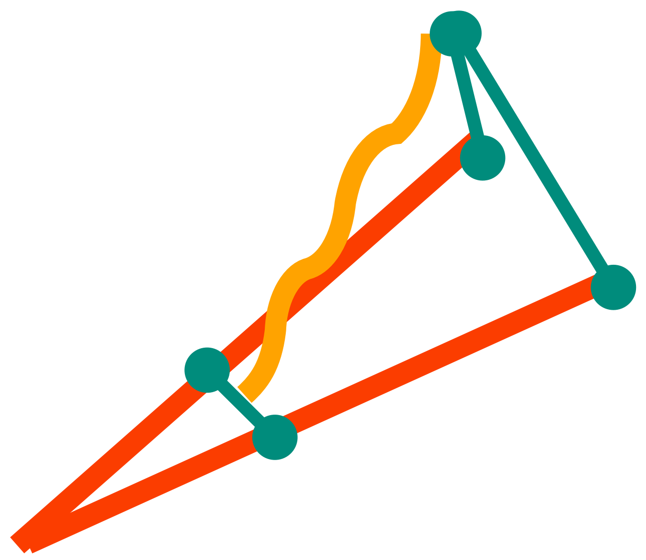
Two complementary approaches, mostly similar in physics capabilities.

Parton branchings order in angle.



Dipole branchings order in transverse momentum.



Full mass effects	✓	✓
Spin correlations	✓	✓
Colour ME corrections	✗	✓
Matching plugin	✓	✓
Multijet merging	✗	✓
QED radiation	✓	✗

(Initial) soft radiation pattern set by initial conditions from colour flows of the hard process.

Heavy quark evolution

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Quasi-collinear limit, ordering in angular variable

[Gieseke, Stephens, Webber – JHEP 0312 (2003) 045]
[Herwig++ Physics and Manual – EPJ C58 (2008) 639]

$$z\,(1-z)\,\tilde{q}^2 = -m_{\widetilde{ij}}^2 + \frac{m_i^2}{z} + \frac{m_j^2}{1-z} - \frac{p_\perp^2}{z\,(1-z)}$$

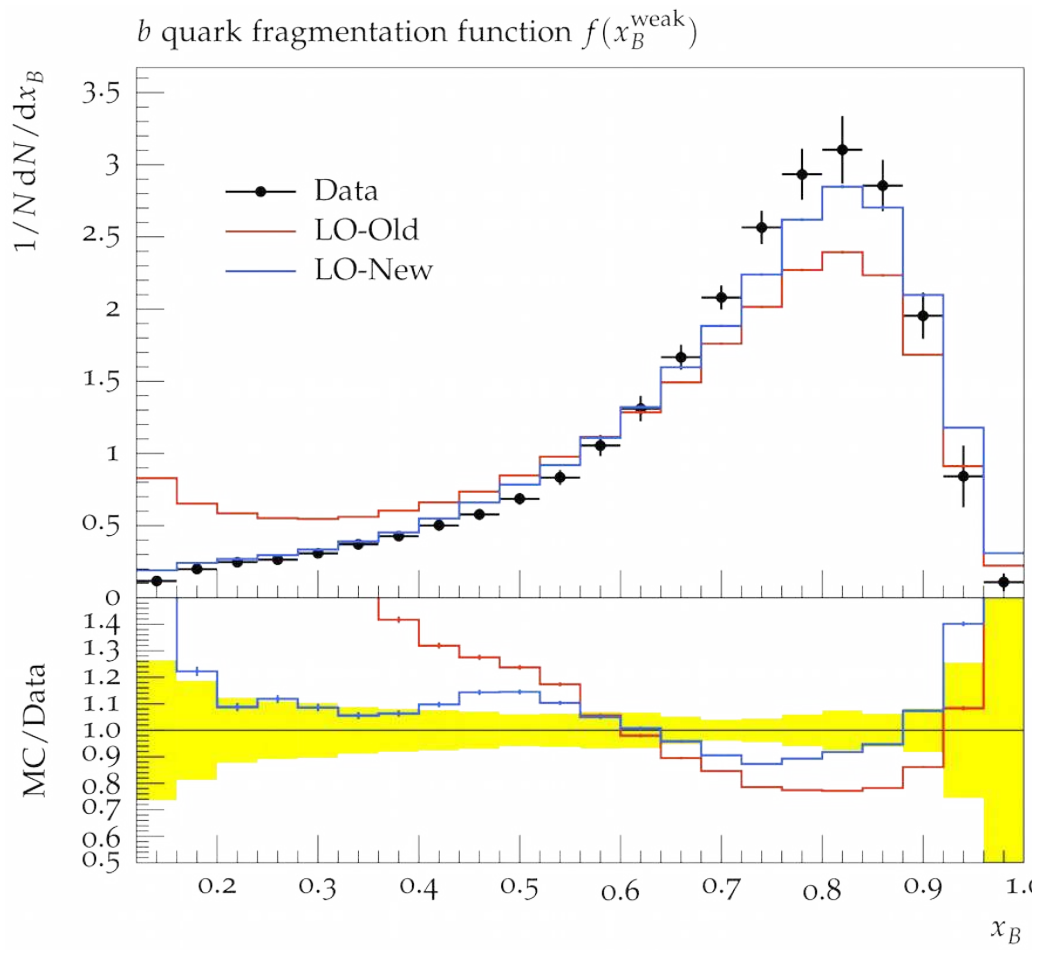
$$P_{q\to qg} = \frac{C_F}{1-z}\left[1 + z^2 - \frac{2m_q^2}{z\tilde{q}^2}\right]$$

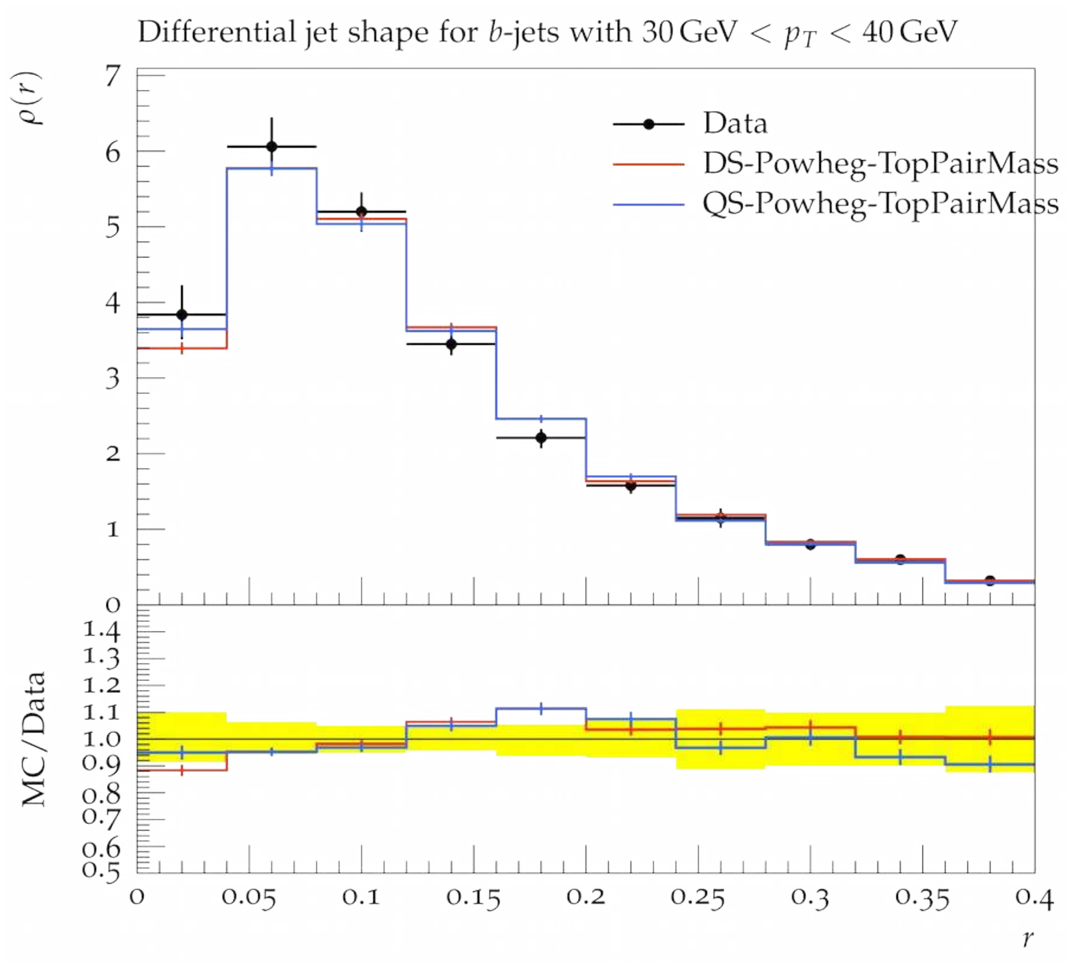
$$q_i = z\, q_{ij} + \frac{w_\perp s_{ijk} + m_i^2 - z^2 m_{ij}^2}{2 q_{ij}\cdot n_k\, z} n_k + \sqrt{w_\perp} n_\perp\,,$$

$$q_j = (1-z)\, q_{ij} + \frac{w_\perp s_{ijk} + m_j^2 - (1-z)^2 m_{ij}^2}{2 q_{ij}\cdot n_k\,(1-z)} n_k - \sqrt{w_\perp} n_\perp$$

Dipole shower from quasi-collinear limit, ordered in transverse momentum

[Plätzer, Gieseke – JHEP 01 (2011) 024 & EPJ C72 (2012) 2187]
[Cormier, Plätzer, Reuschle, Richardson, Webster — EPJ C79 (2019) 915]





- Significantly improved b fragmentation from dipole shower
- Comparable description of heavy quark observables across both showers

Parton shower extras

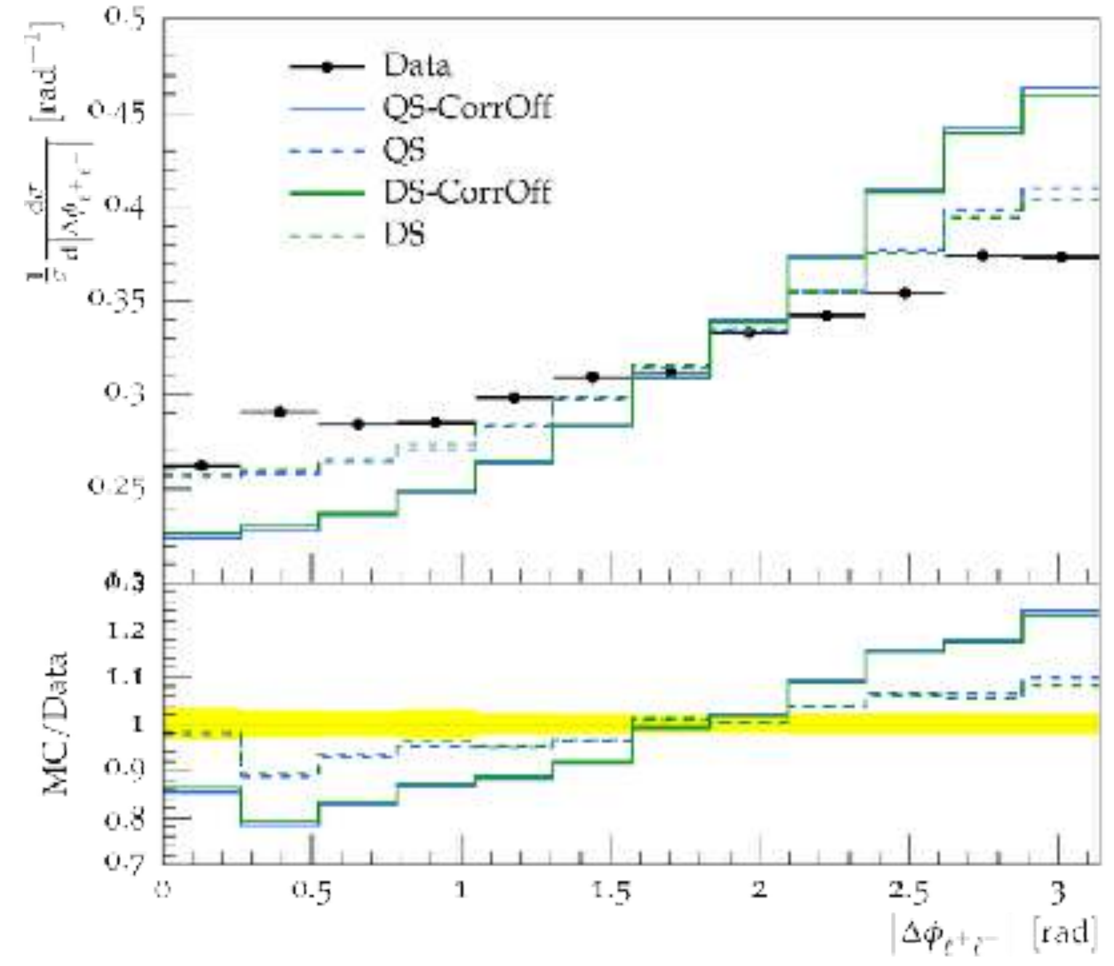
Several improvements on existing shower algorithms

- Spin correlations in both shower modules

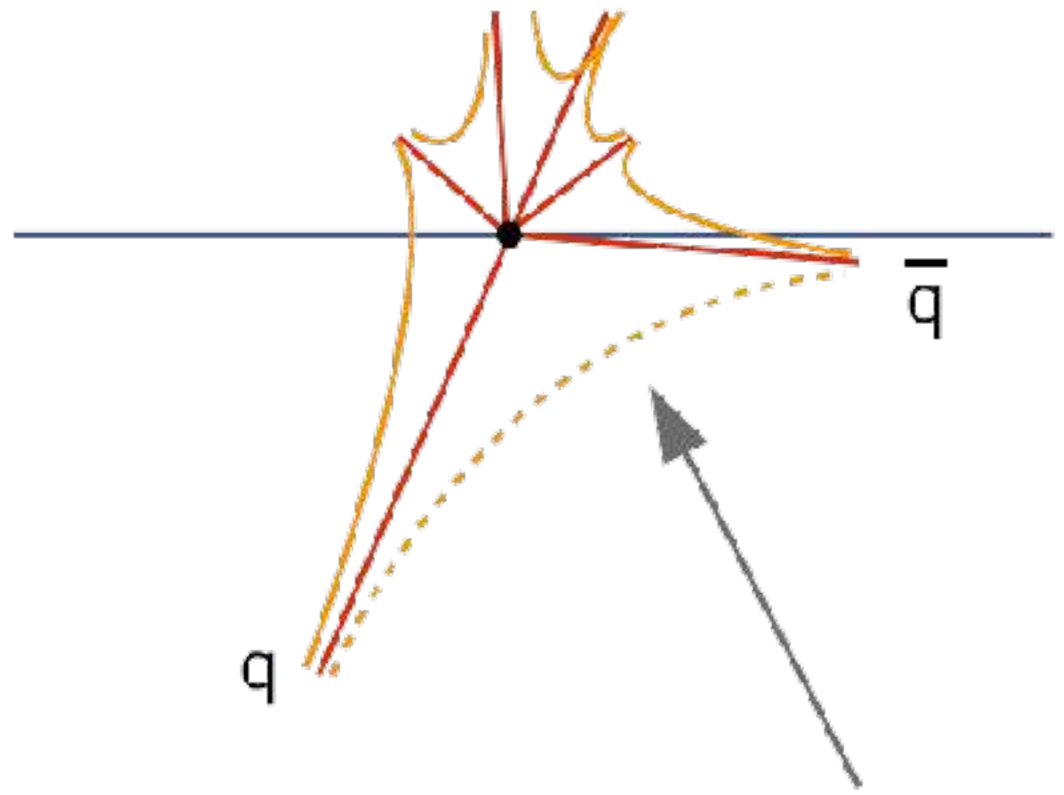
[Webster, Richardson - Eur.Phys.J.C 80 (2020) 2]

- QED radiation in angular ordered shower
- Shower reweighting algorithms encode some variations on-the-fly

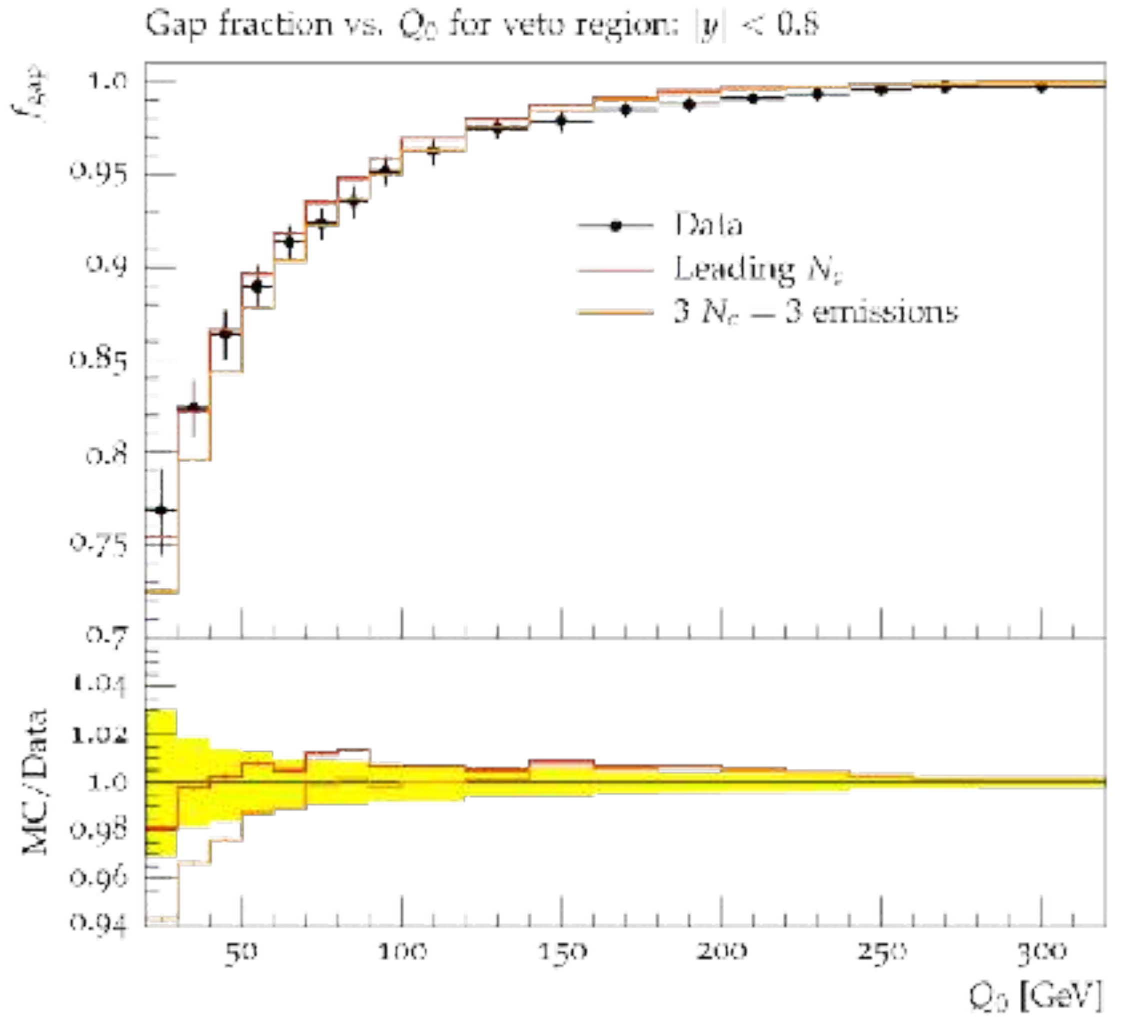
[Bellm, Plätzer, Richardson, Siodmok, Webster – PRD 94 (2016) 3]



Colour matrix element corrections available in the dipole shower evolution: Restore subleading colour corrections in dipole showers.

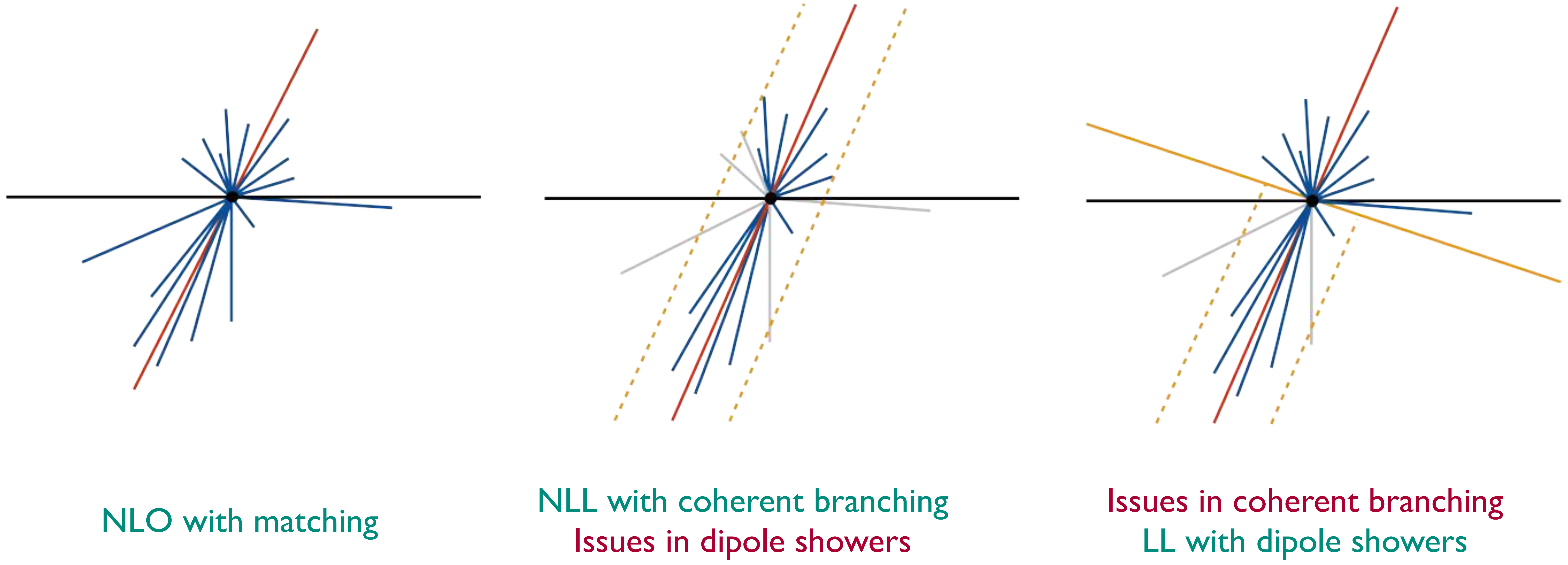


Some subleading-N corrections can be restored.



[Plätzer, Sjödahl – JHEP 1207 (2012) 042]
[Plätzer, Sjödahl, Thoren – JHEP 11 (2018) 009]

Accuracy of Parton Showers



Understand and decide on accuracy of (existing) parton shower algorithms, take as a starting point for incremental improvements.

[Dasgupta, Dreyer, Hamilton, Monni, Salam et al. — JHEP 09 (2018) 033, …]
[Hoang, Plätzer, Samitz — JHEP 1810 (2018) 200]
[Bewick, Ferrario, Richardson, Seymour — JHEP 04 (2020) 019]

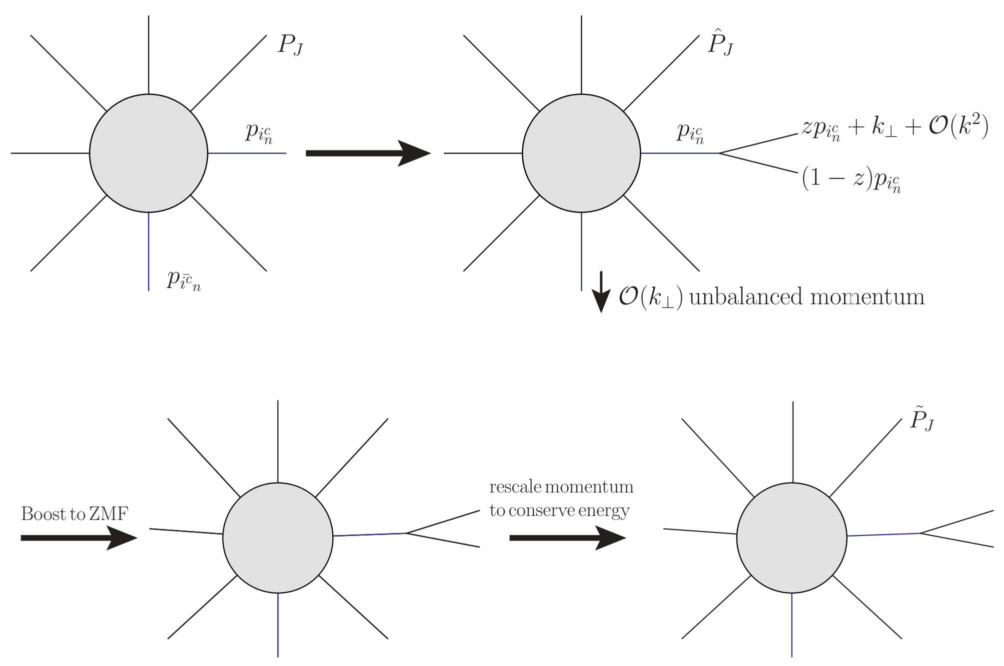
$$H(\alpha_s) \times \exp\left(L g_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \ldots\right)$$

LL NLL NNLL

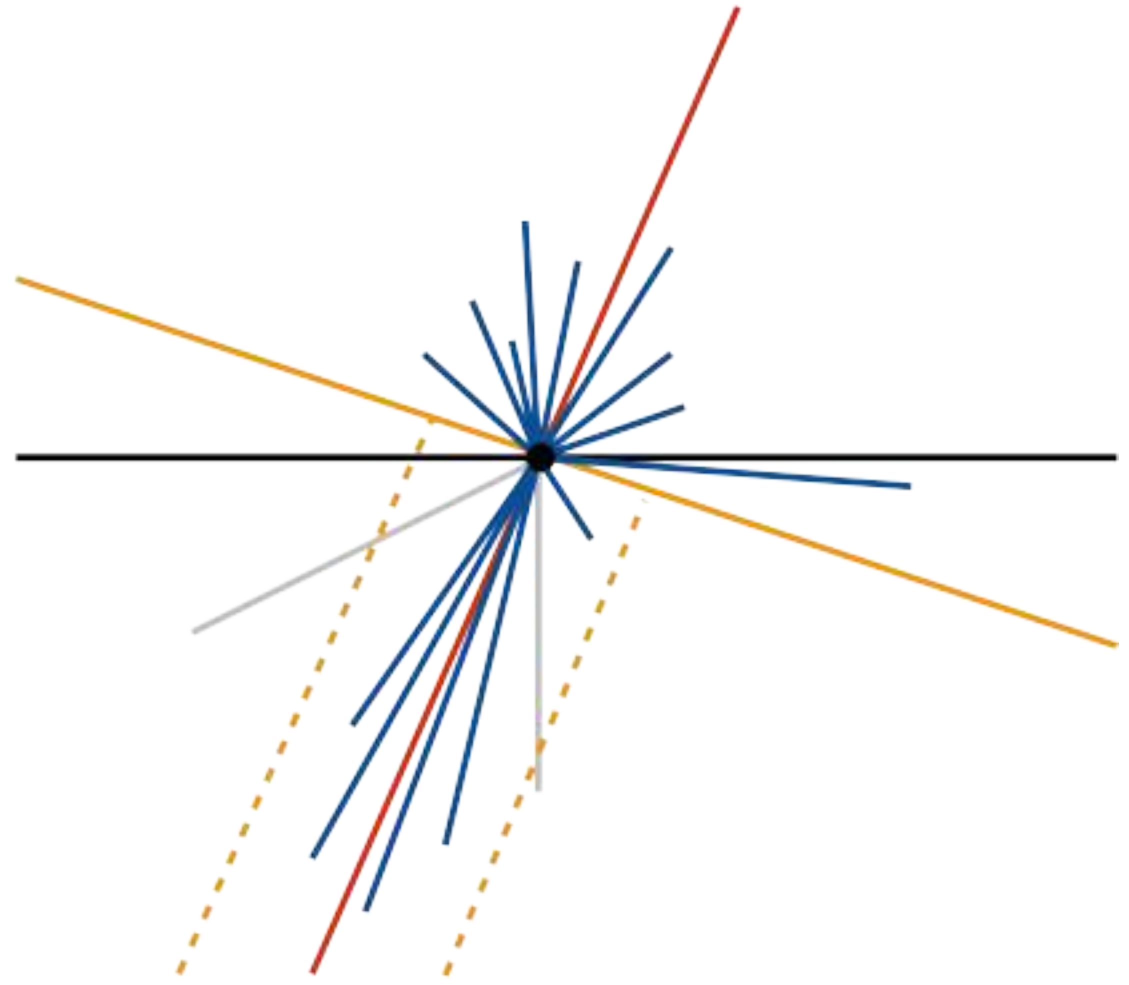
Accuracy of Parton Showers

$$\frac{p_{i_n}\cdot p_{j_n}}{p_{i_n}\cdot q_n\; p_{j_n}\cdot q_n} \longrightarrow$$

$$\frac{p_{i_n}\cdot p_{j_n}}{p_{i_n}\cdot q_n\; p_{j_n}\cdot q_n} - \frac{T\cdot p_{j_n}}{T\cdot q_n}\frac{1}{p_{j_n}\cdot q_n} + \frac{T\cdot p_{i_n}}{T\cdot q_n}\frac{1}{p_{i_n}\cdot q_n}$$



[Dasgupta, Dreyer, Hamilton, Monni, Salam —PRL 125 (2020) 5]
[Forshaw, Holguin, Plätzer – JHEP 09 (2020) 014]



Dipole showers reproducing coherent branching:
NLL & NLC global, LL & LC non-global

Understand and decide on accuracy of (existing) parton shower algorithms, take as a starting point for incremental improvements.

[Dasgupta, Dreyer, Hamilton, Monni, Salam et al. — JHEP 09 (2018) 033, …]
[Hoang, Plätzer, Samitz — JHEP 1810 (2018) 200]
[Bewick, Ferrario, Richardson, Seymour — JHEP 04 (2020) 019]

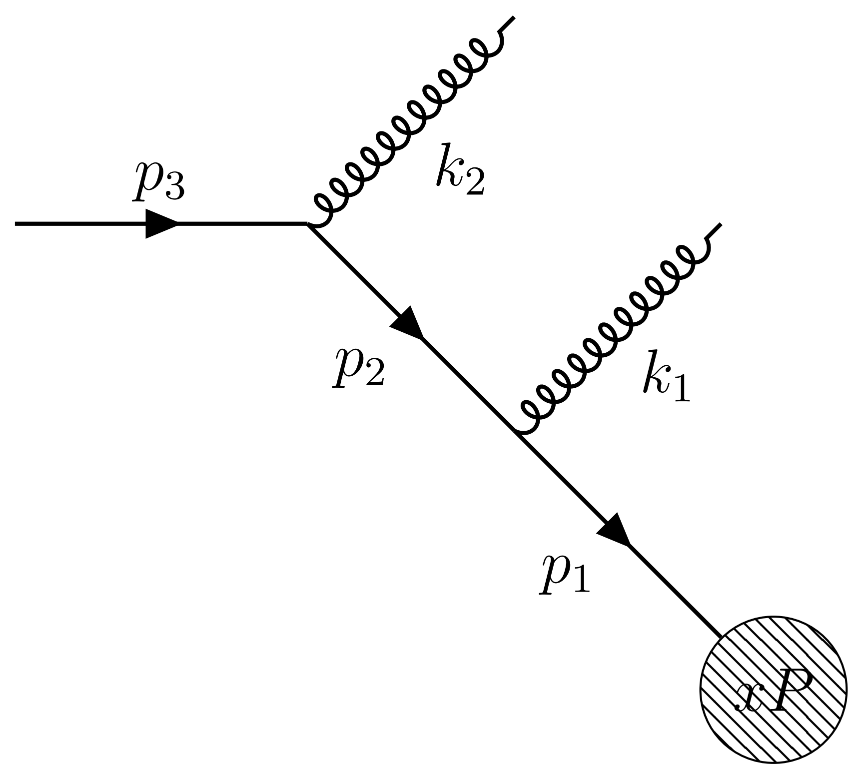
$$H(\alpha_s) \times \exp\left(L g_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \ldots\right)$$

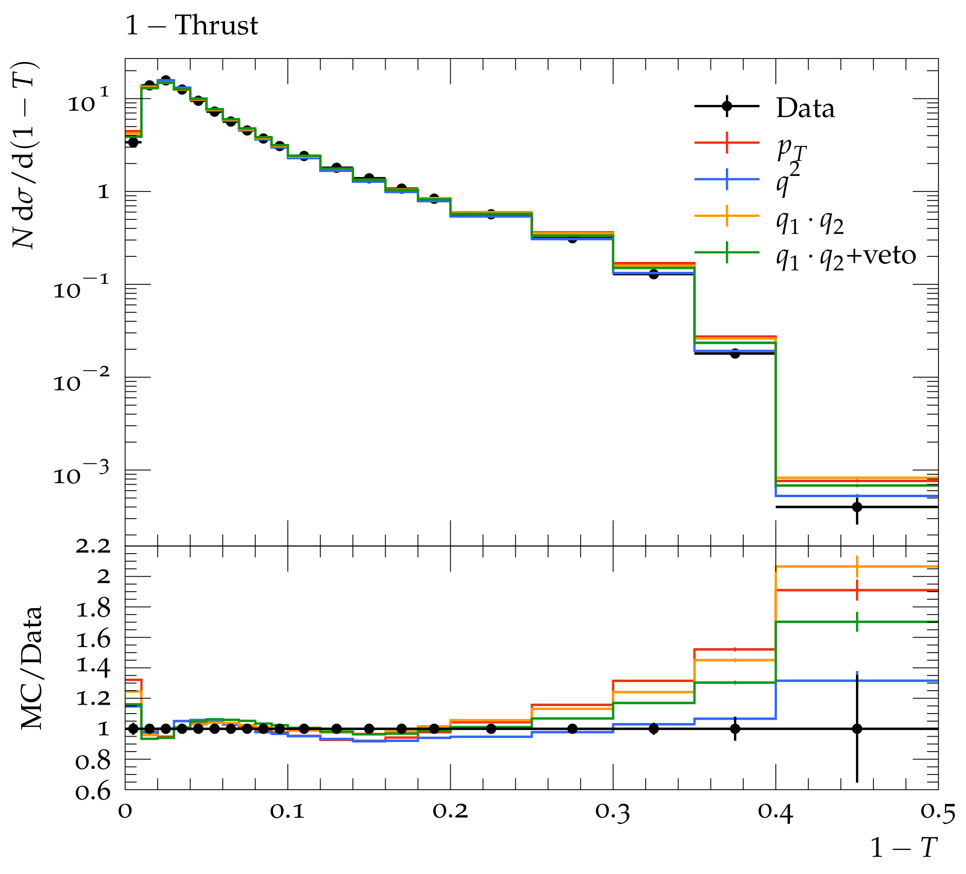
LL NLL NNLL

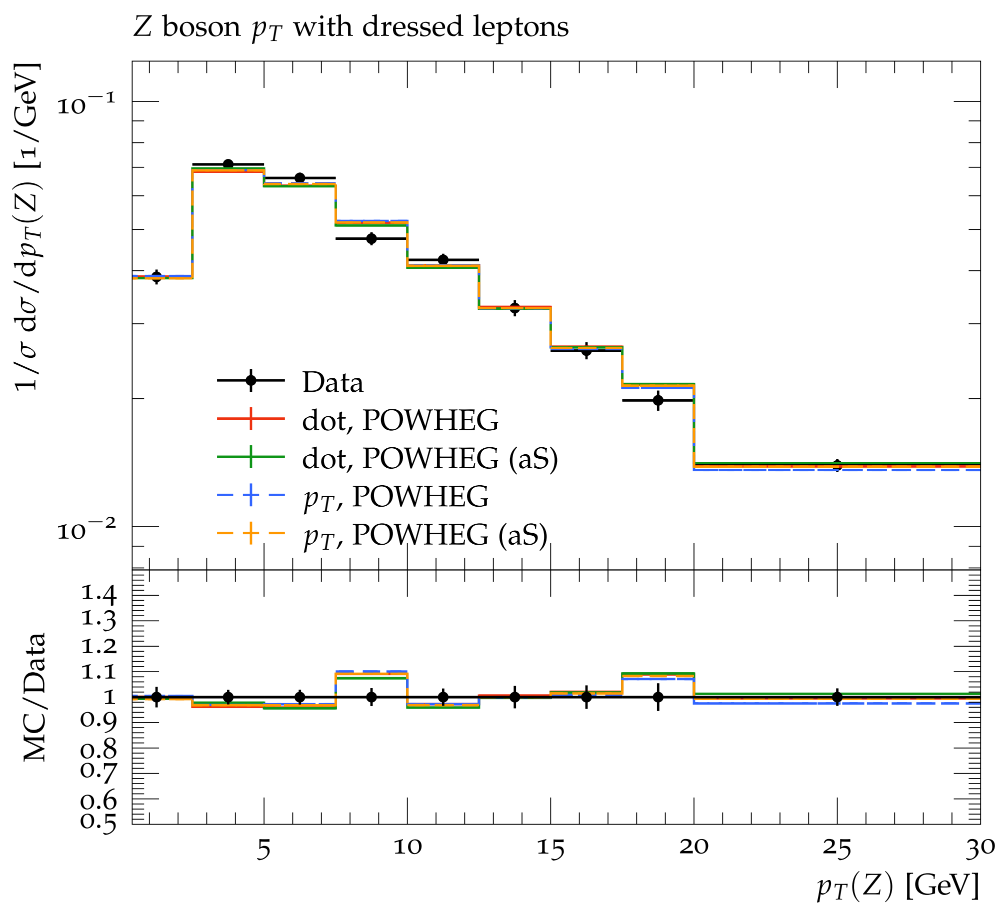
(Dipole) shower improvements

Not only present in dipole showers, can even screw up angular ordered ones:

[Bewick, Ferrario, Richardson, Seymour —JHEP 04 (2020) 019 & 01 (2022) 026]

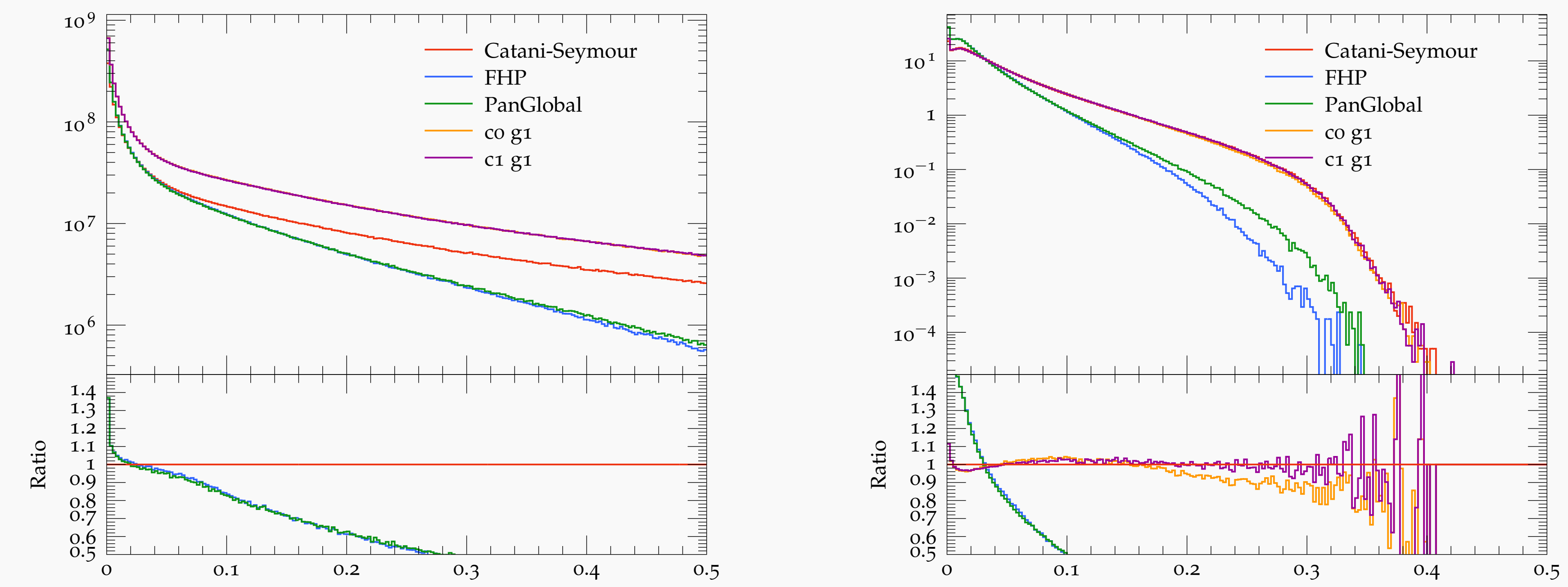






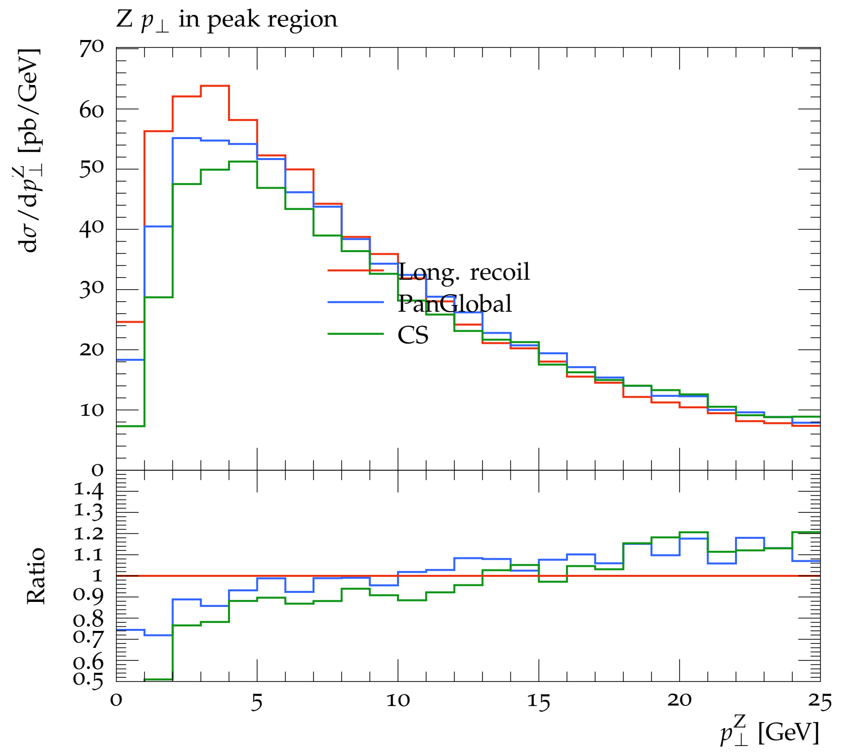
Need to allow building up high-mass events to not constrain shower evolution.

Herwig dipole shower is on track:



(e) C Parameter (f) Heavy Jet Mass

Investigating a large class of accurate kinematic mappings and issues in the initial state.



[Duncan, Holguin, Plätzer — ongoing]

Showering beyond QCD

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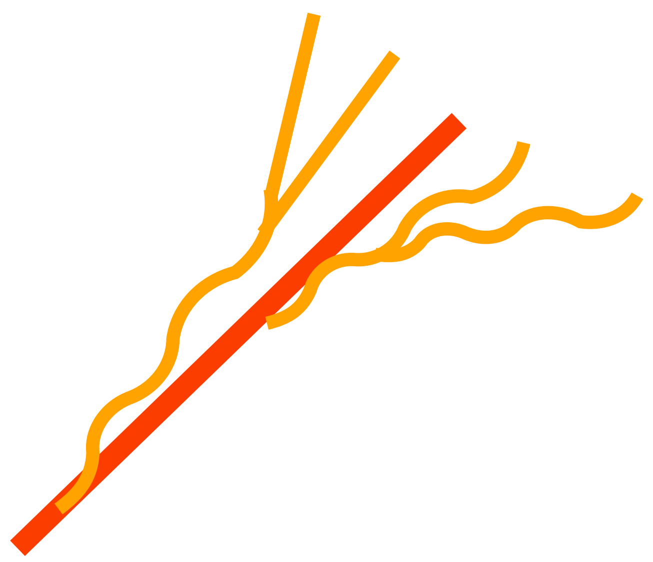
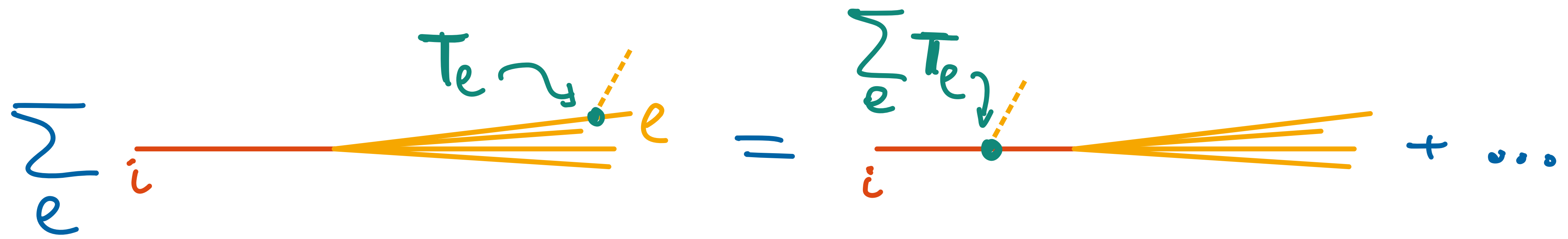
We have started to extend showers from QCD to other interactions:

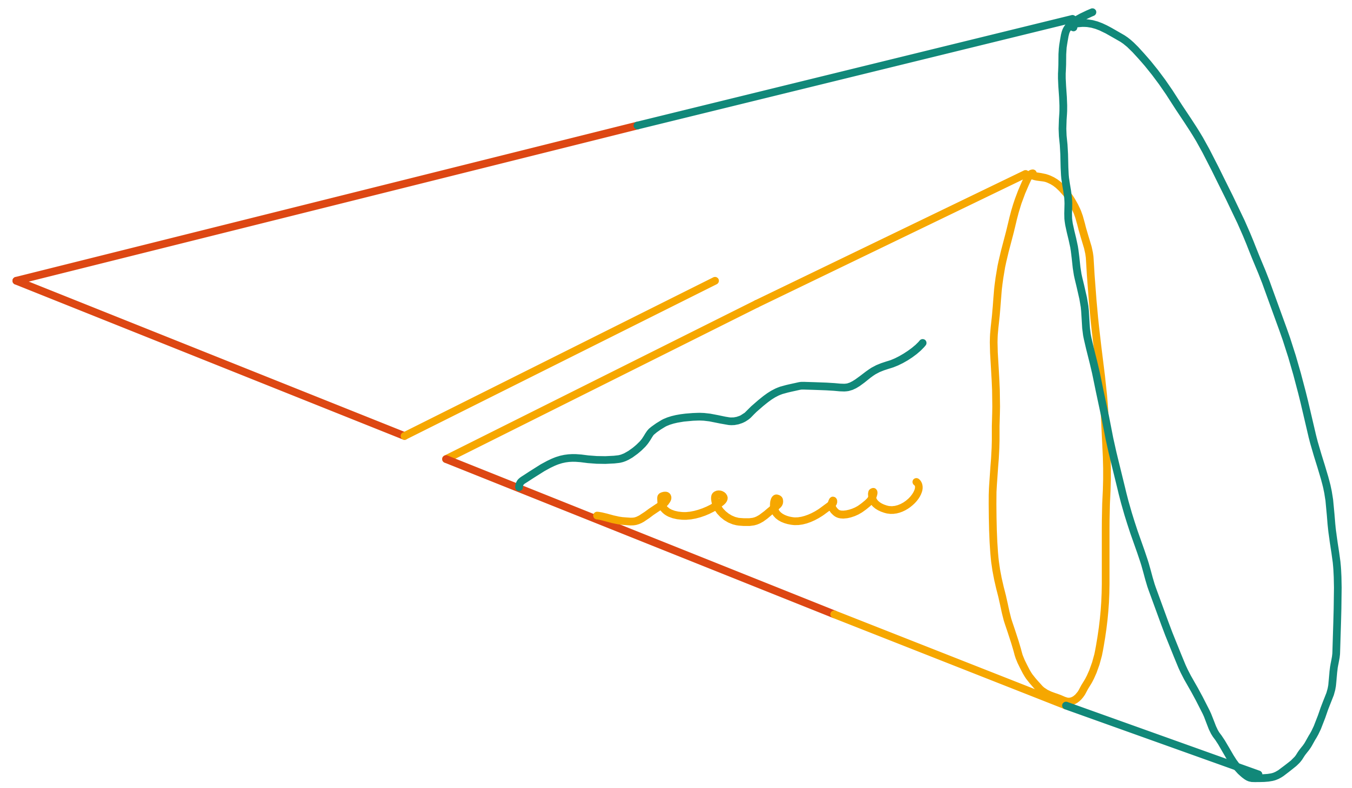


- Angular ordered shower in quasi-collinear limit rather straightforward.
- Relation to large-angle soft pattern and initial conditions still need investigation

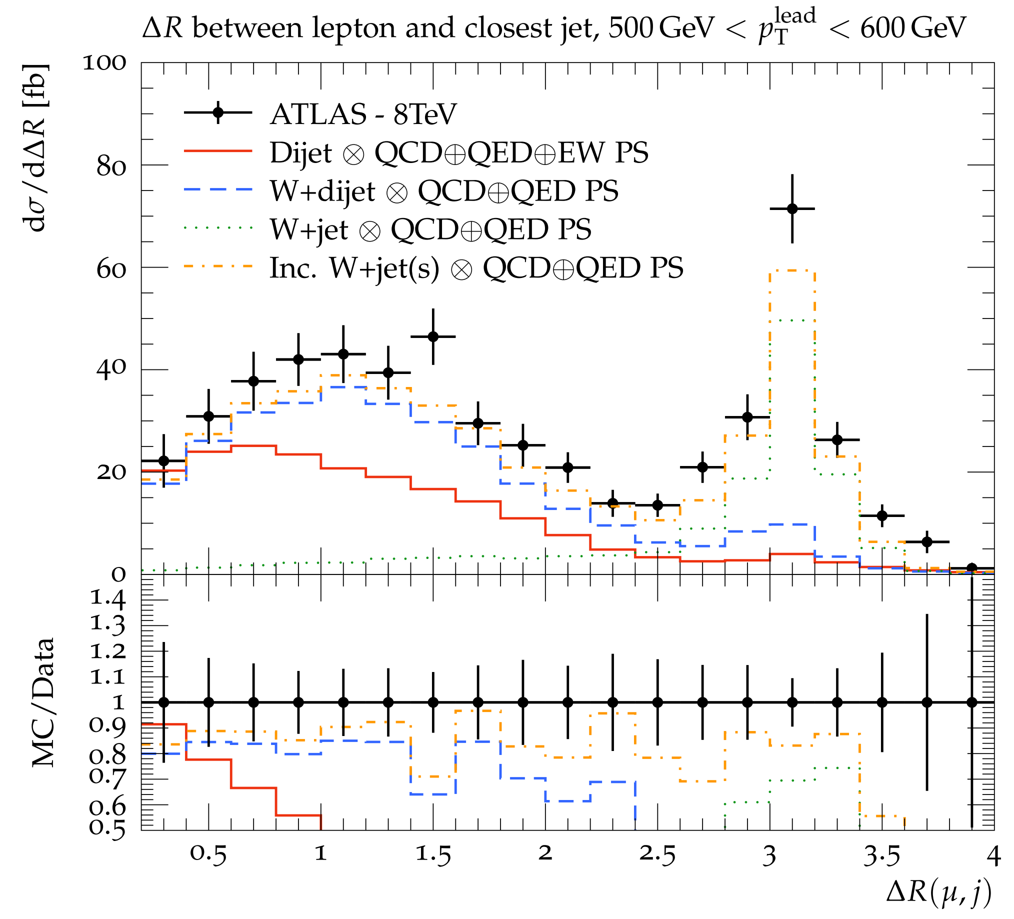
Work ongoing, e.g. [Plätzer, Sjödahl — arXiv:2204.03258]



Different charges require different angular ordering cones:
one evolution variable per interaction.



In place for QED, soon for
electroweak and possibly beyond.

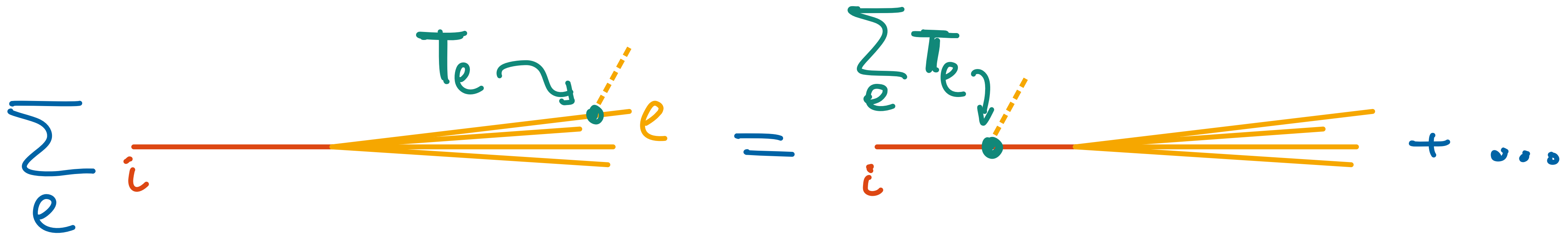


[Masouminia, Richardson — arXiv:2108.10817]

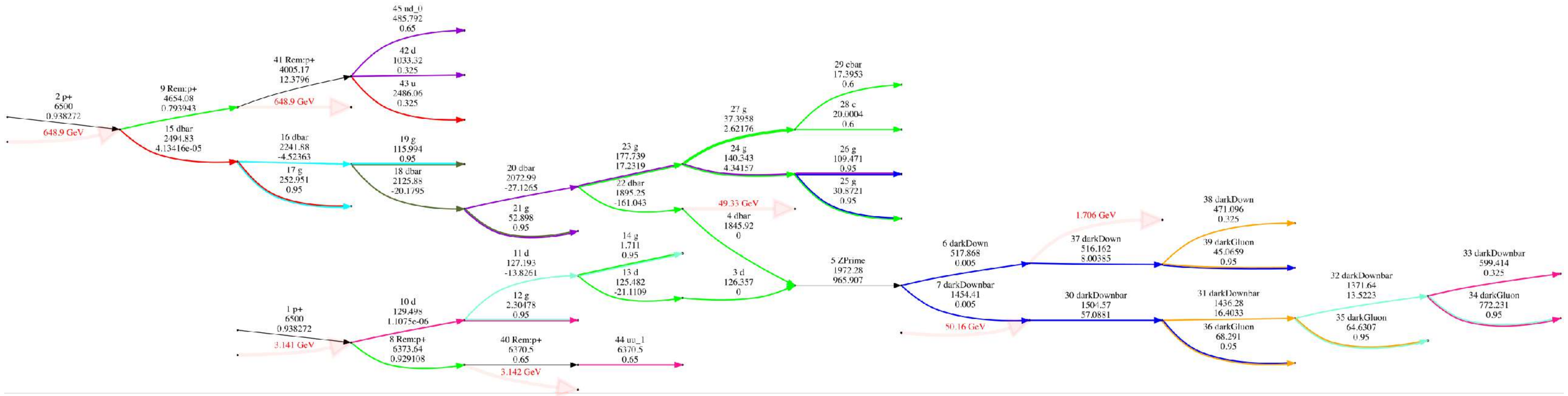
Hidden valley angular ordered showers

First application now to a copy of QCD in the angular ordered shower for a dark sector.

[Masouminia, Papaefstathiou, Plätzer, Siodmok — in progress]



Again applicable in quasi-collinear limit, group structure only in Casimirs. Much more investigations needed.



Hidden valley angular ordered showers

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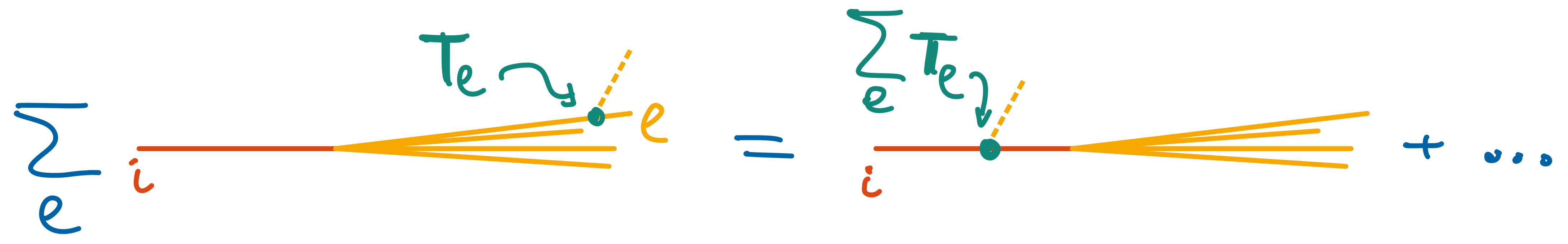
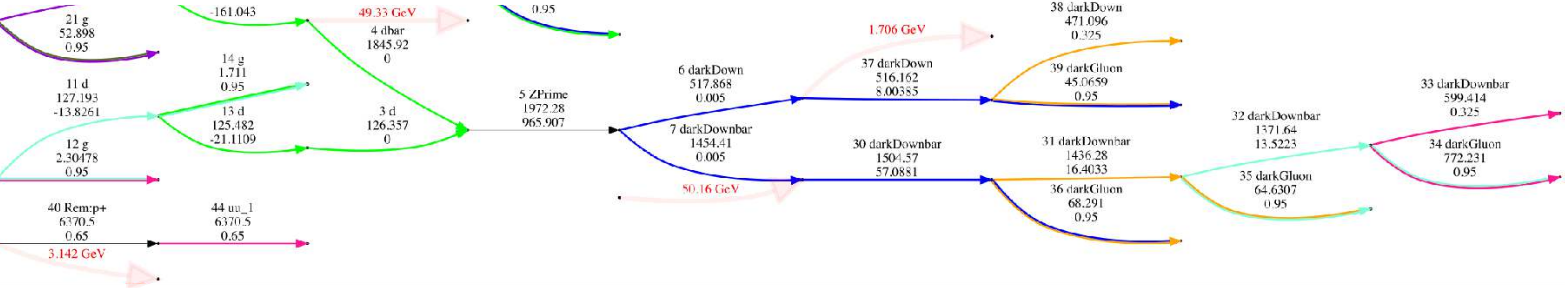


Again applicable in quasi-collinear limit, group structure only in Casimirs. Much more investigations needed.



Hadronization & Colour Reconnection

Eikonal MPI Model

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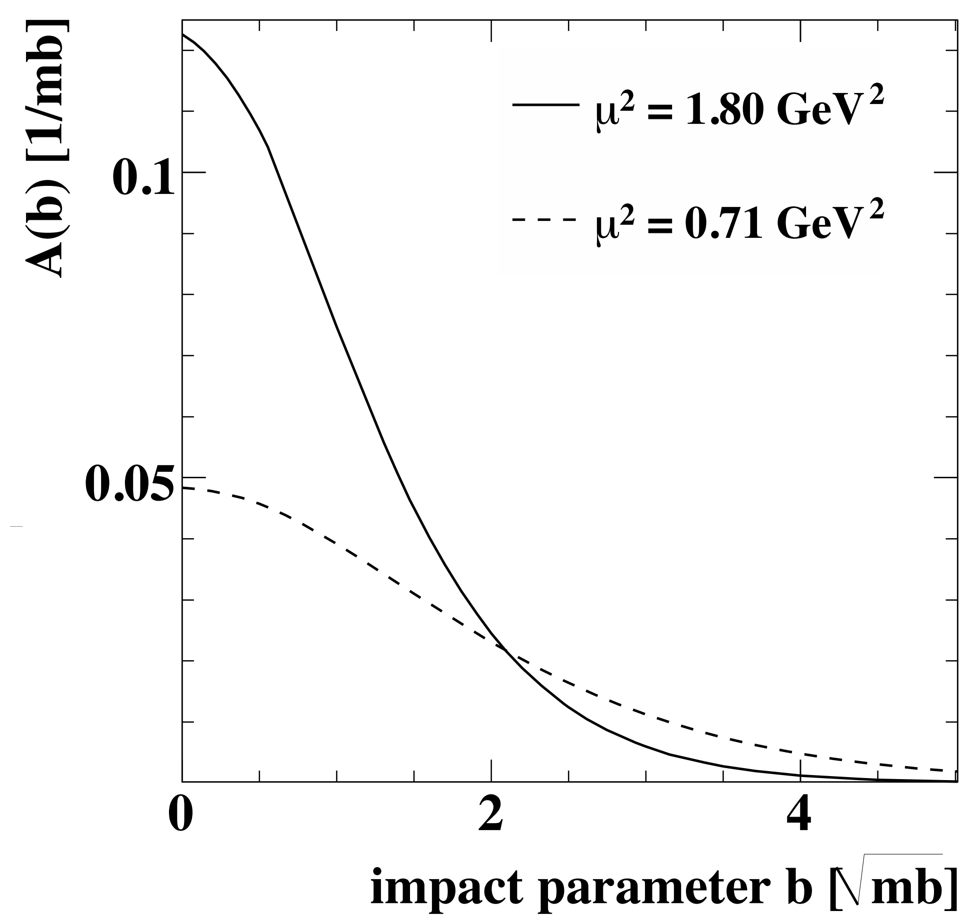
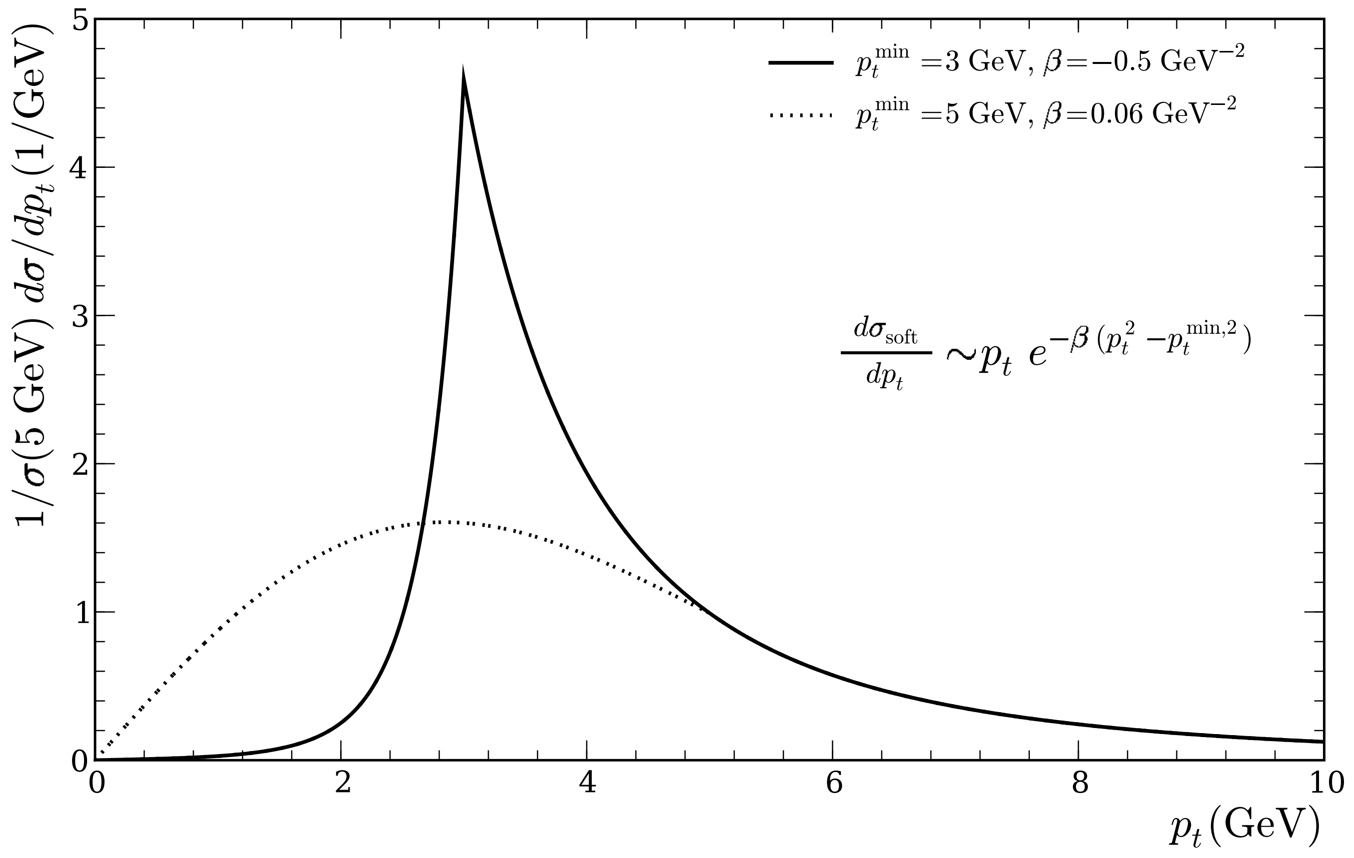
Key ingredients for MPI modelling in Herwig 7

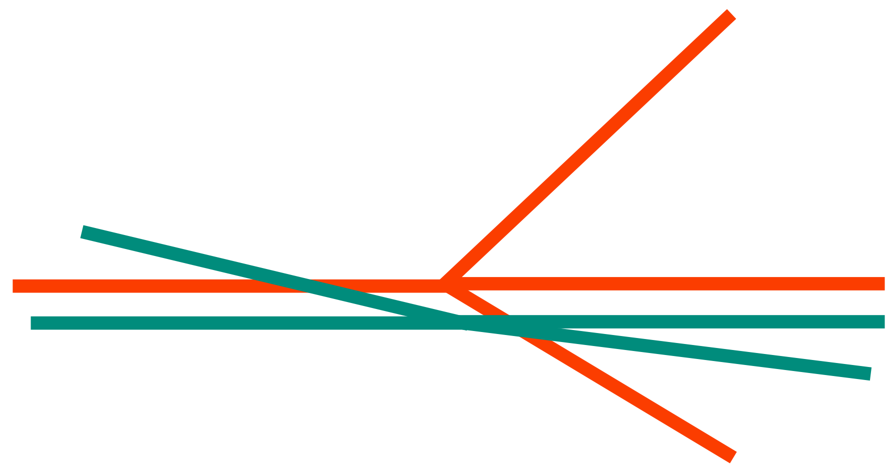


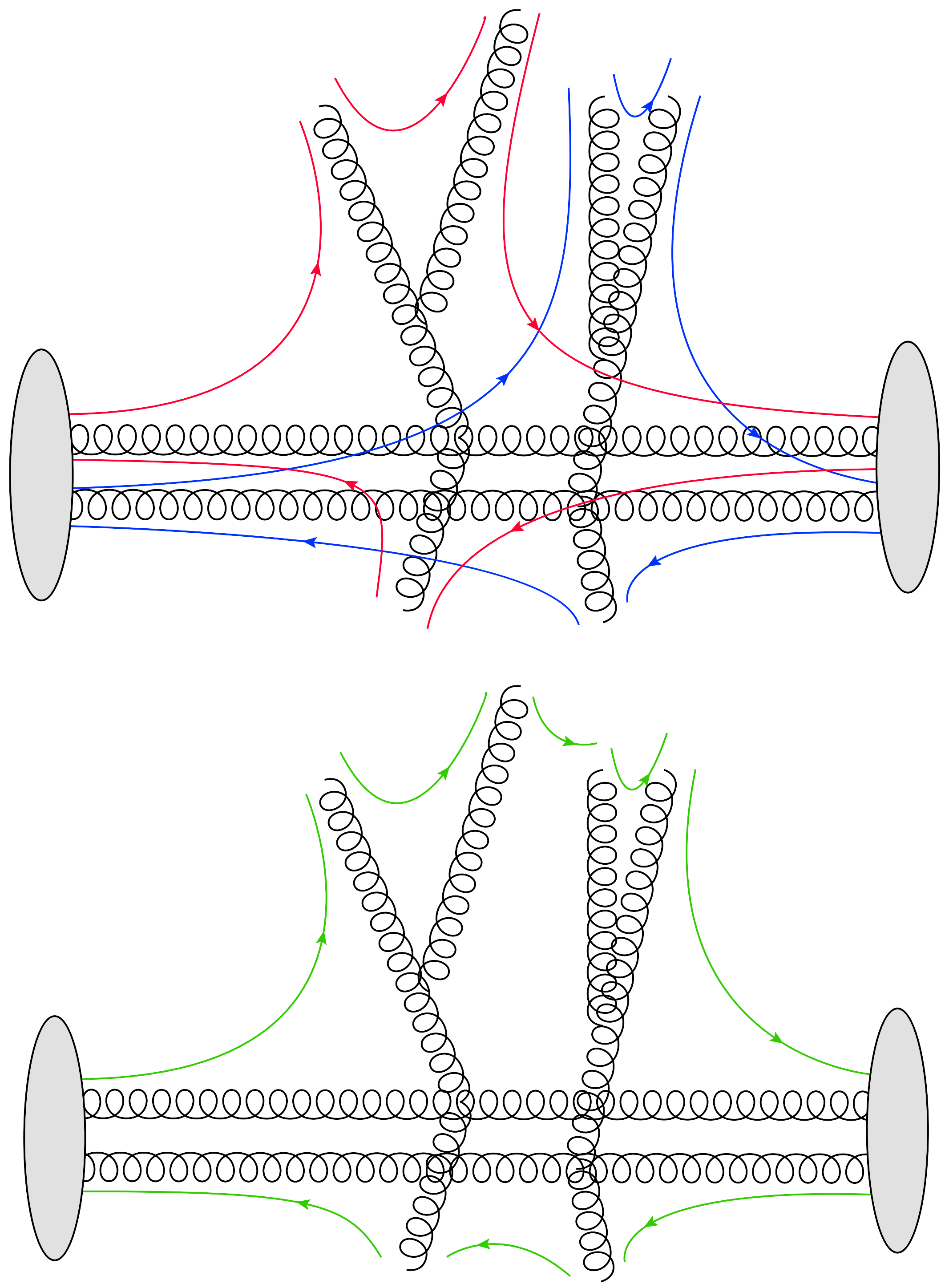
matter distribution



soft & hard scatters

$$p_\perp^{\min}(s) = p_{\perp,0}^{\min}\left(\frac{b+\sqrt{s}}{E_0}\right)^c$$





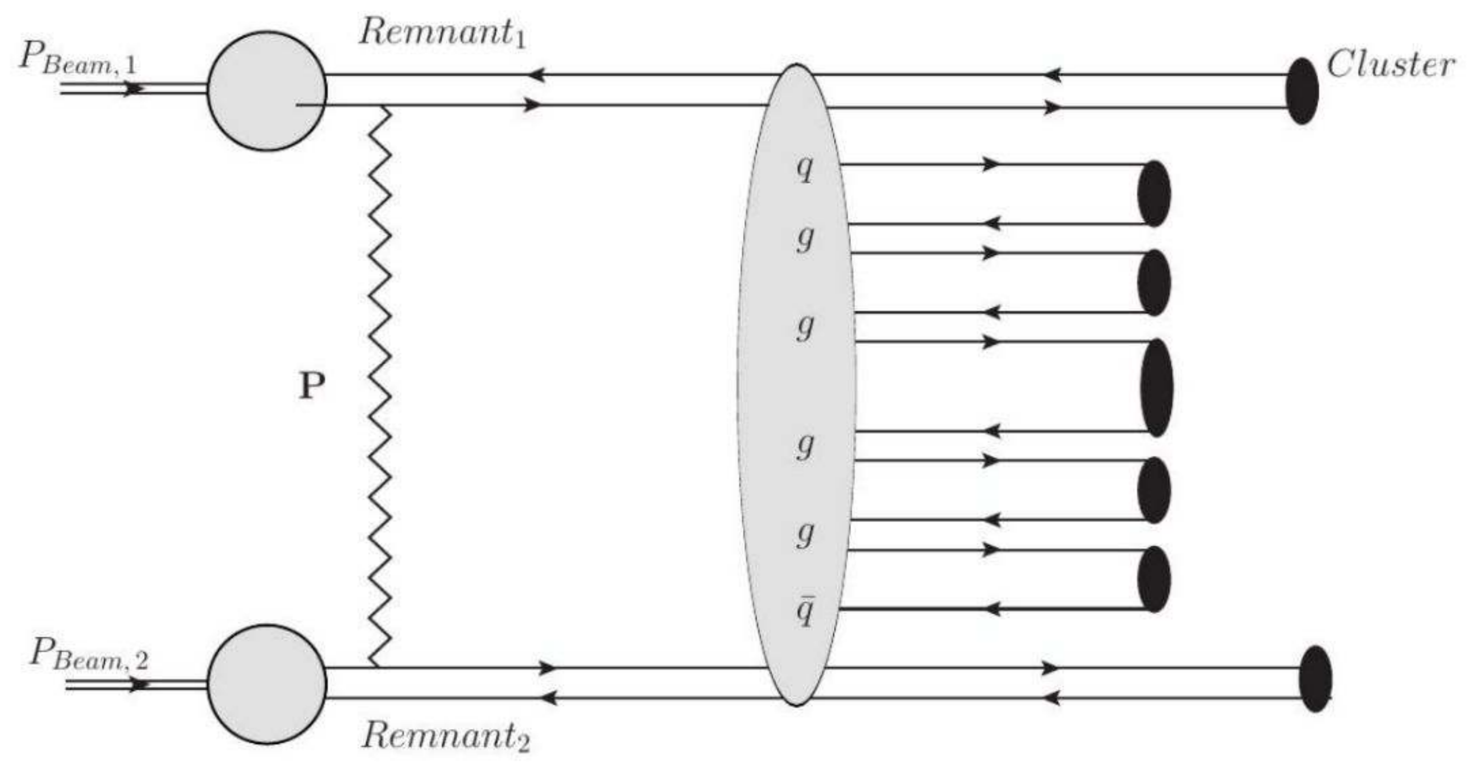
colour reconnection

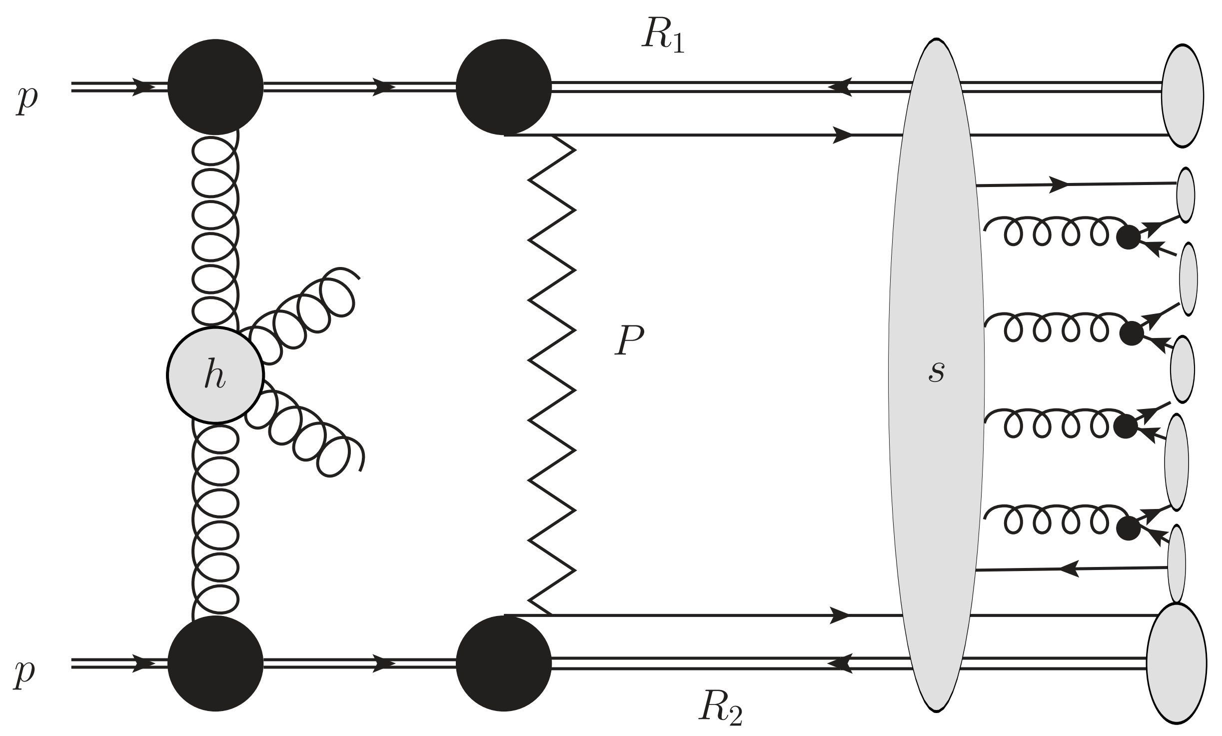
[Figure by Stefan Gieseke]

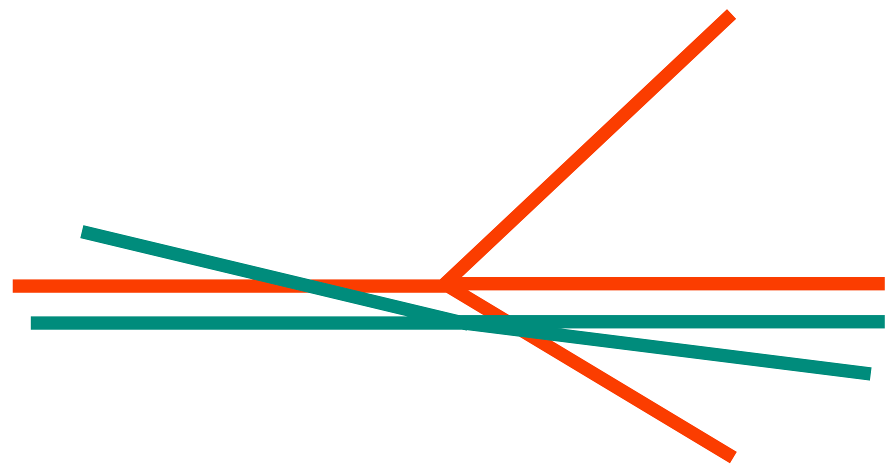
[Gieseke, Loshaj, Kirchgasser — EPJ C77 (2017) 156]
[Bellm, Gieseke, Kirchgasser — EPJC 80 (2020) 469]
[Gieseke, Kirchgaesser, Plätzer – EPJ C 78 (2018) 99]

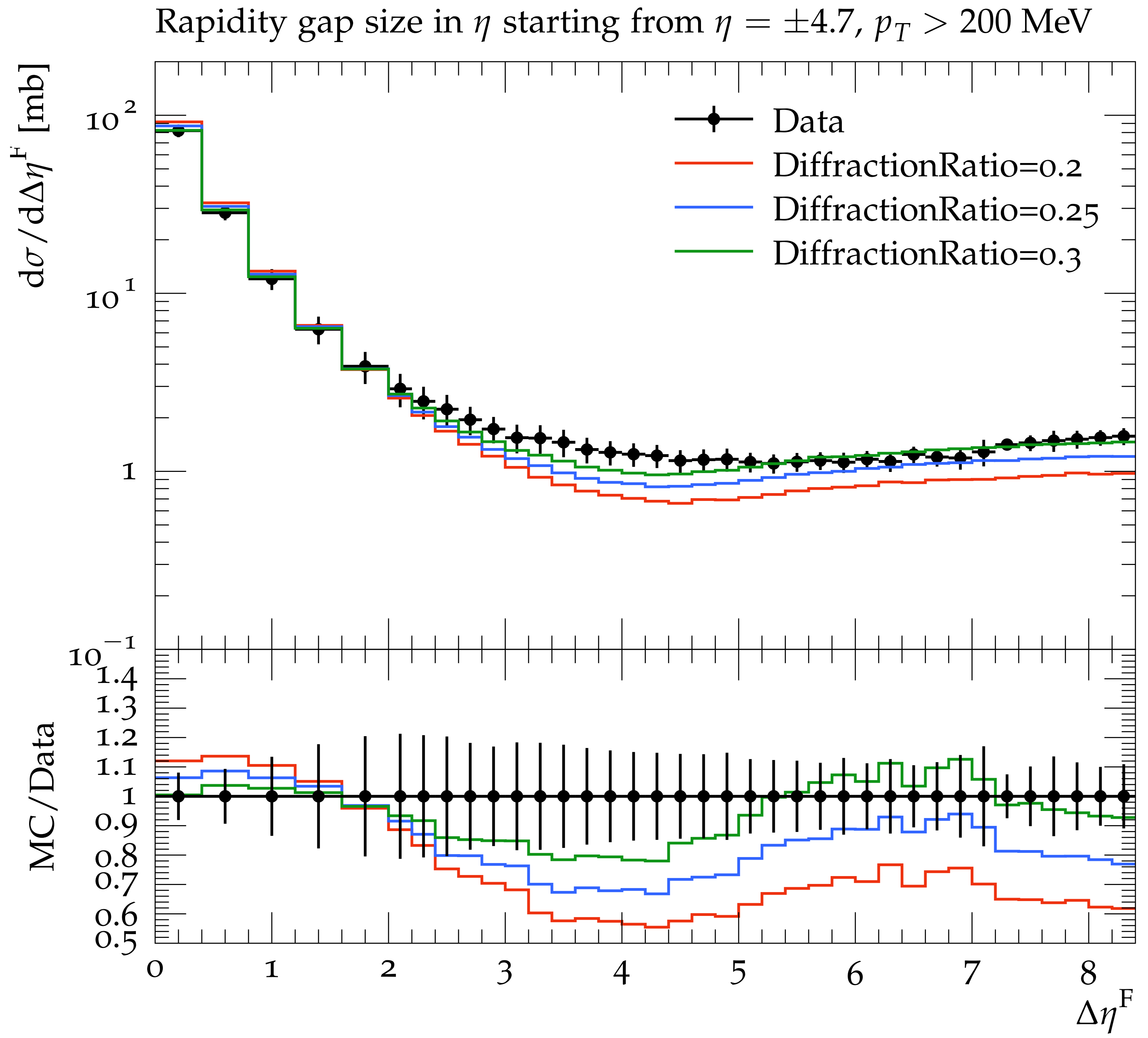
Soft MPI

Additional soft ladders and diffractive topologies





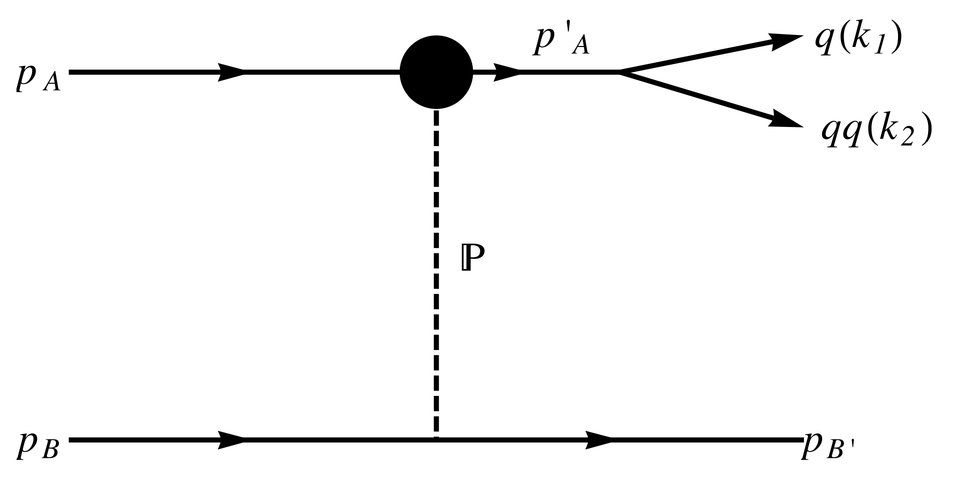


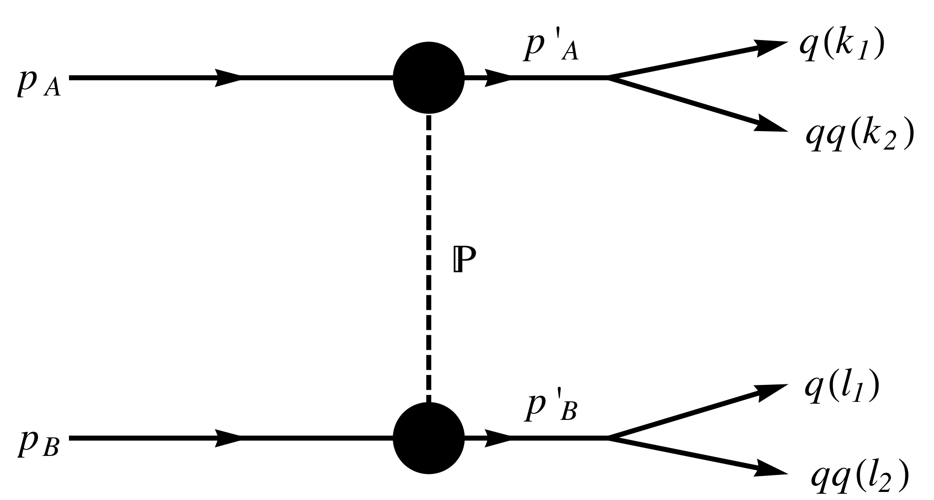


Single and double diffraction only included through tuning:
lack of energy extrapolation.

$$\sigma_{\mathrm{inel}}(s) \equiv \sigma_{\mathrm{inel}}^{\mathrm{non-diff}}(s) = \sigma_{\mathrm{tot}}(s) - \sigma_{\mathrm{el}}(s) - \sigma_{\mathrm{diff}}(s)$$

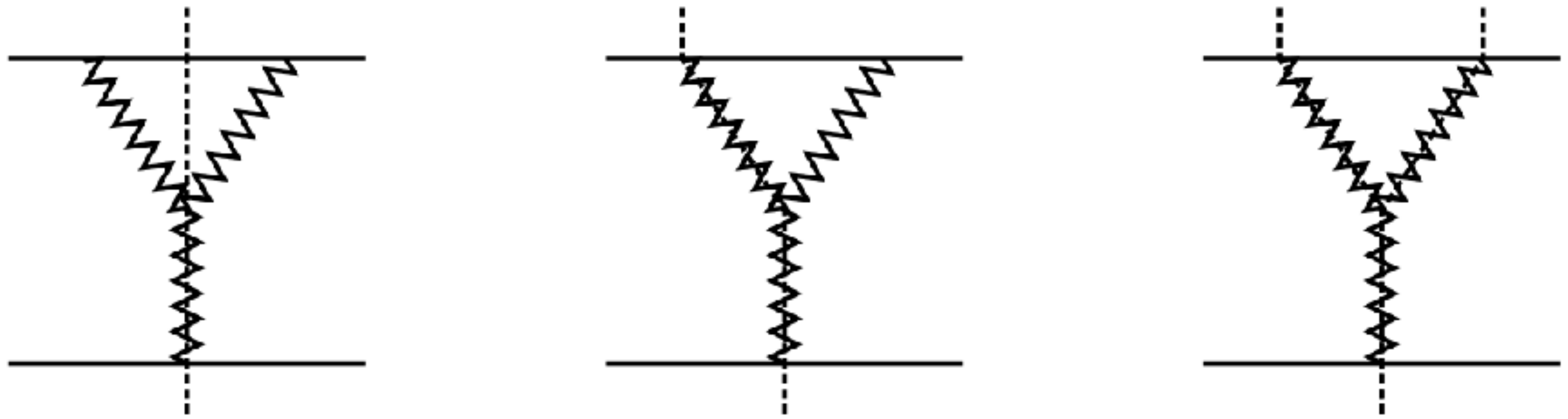
$$\sigma_{\mathrm{diff}}(s) = R_{\mathrm{diff}}\sigma_{\mathrm{tot}}(s)$$





[Bellm, Gieseke, Kirchgasser — EPJC 80 (2020) 469]
[Gieseke, Loshaj, Kirchgasser — EPJ C77 (2017) 156]

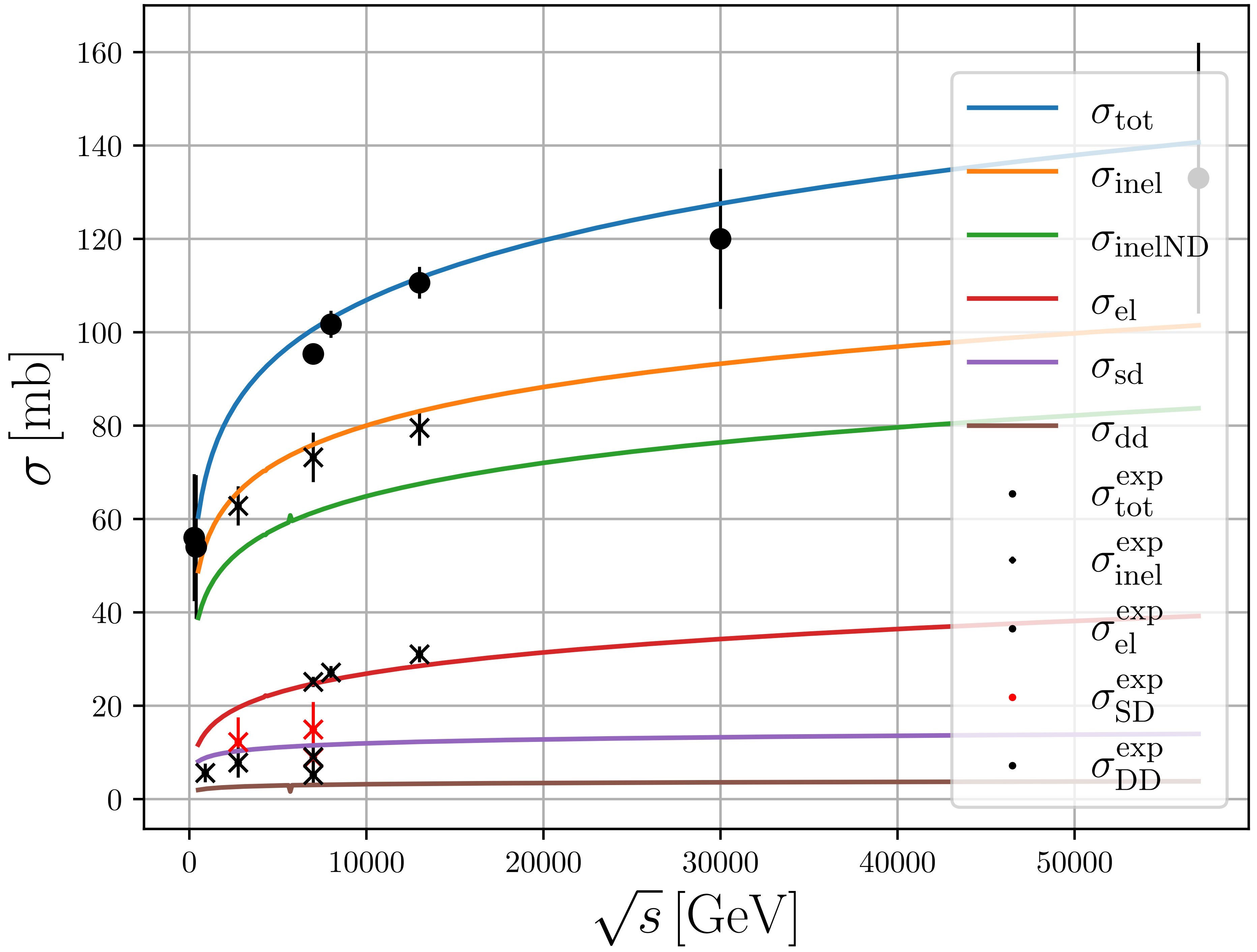
Diffraction



High-mass diffraction

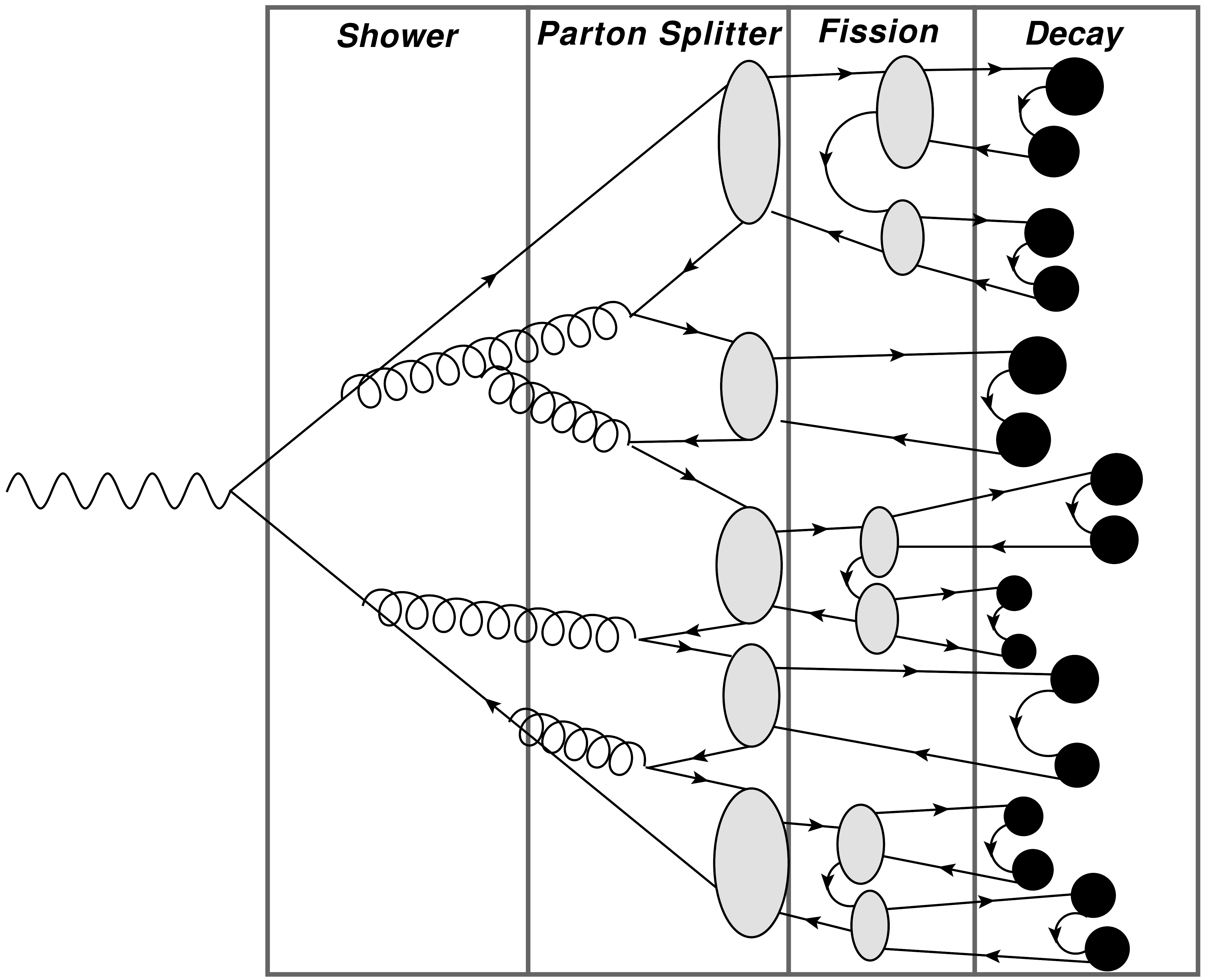
Multiperipheral particle production

- So far best description of cross sections for g3p=0
- Cross sections as predictions of the model (no DL parametrisation)
- Good extrapolation of energy dependence

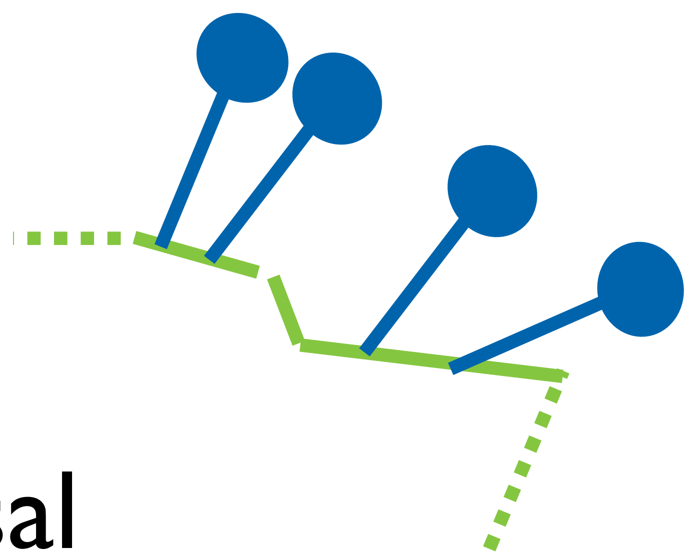


[Seymour, Kirchgaesser, Gieseke — in progress]

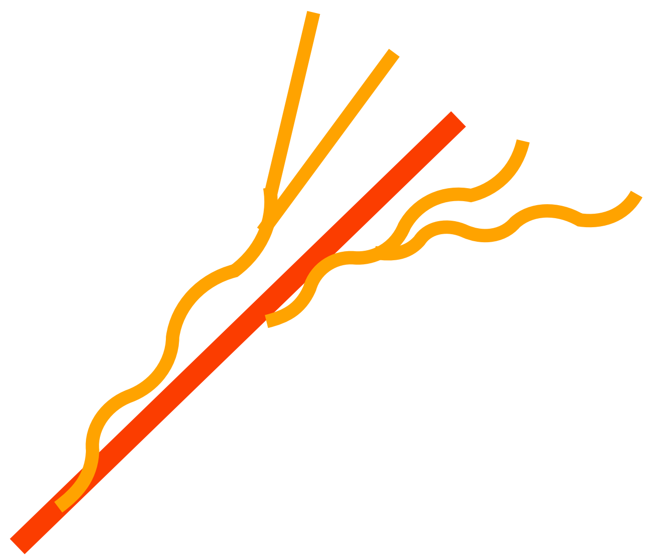
Cluster Hadronization

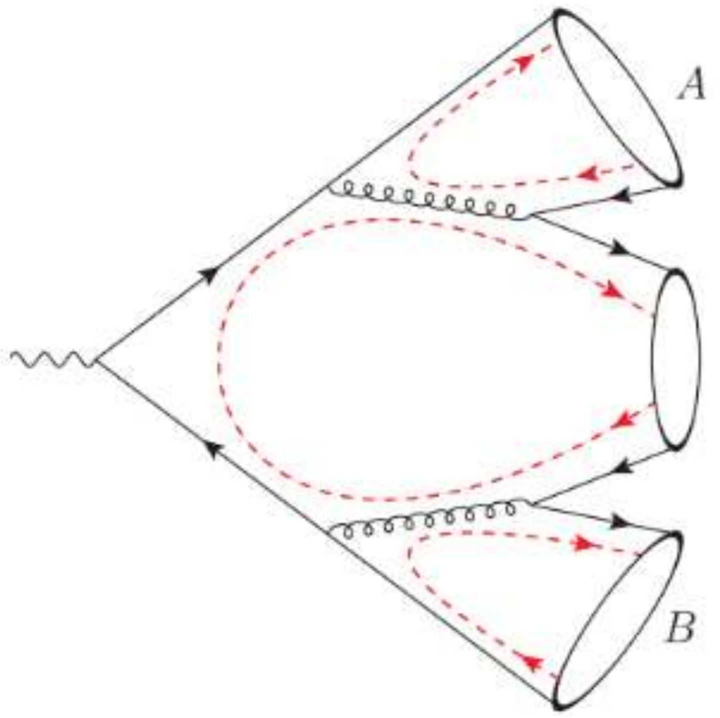


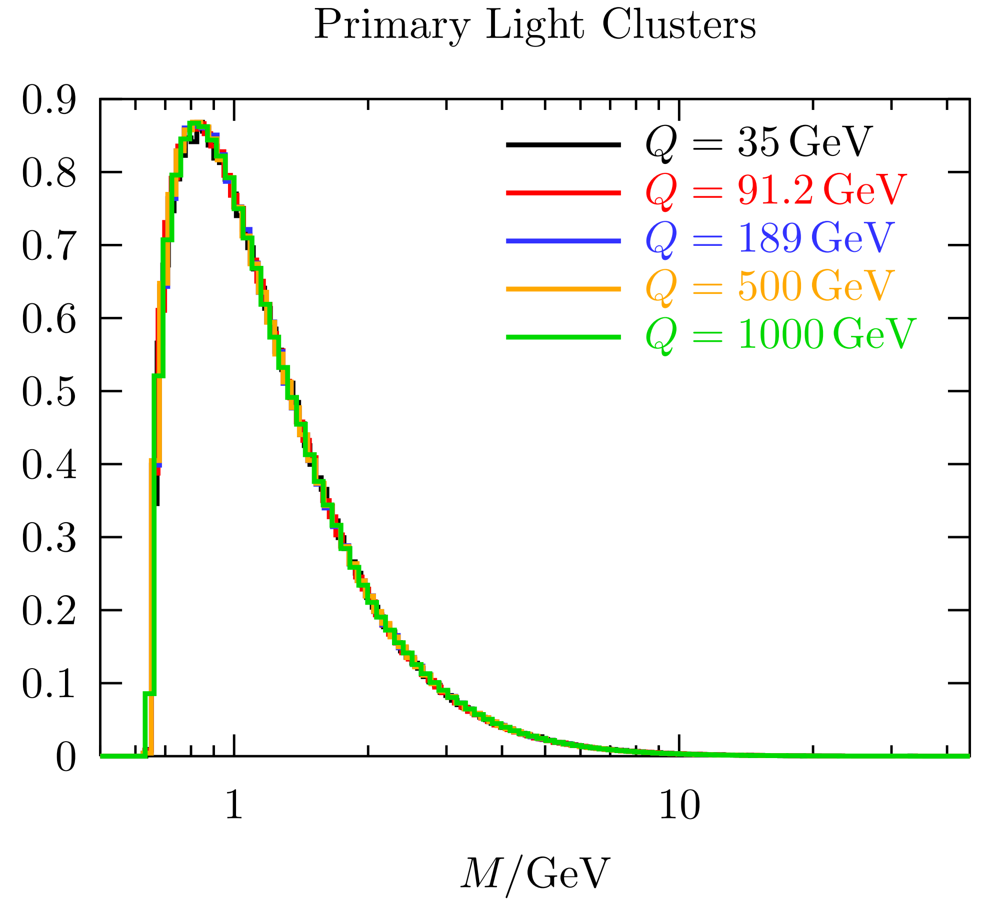
[Figure by Patrick Kirchgaesser]



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

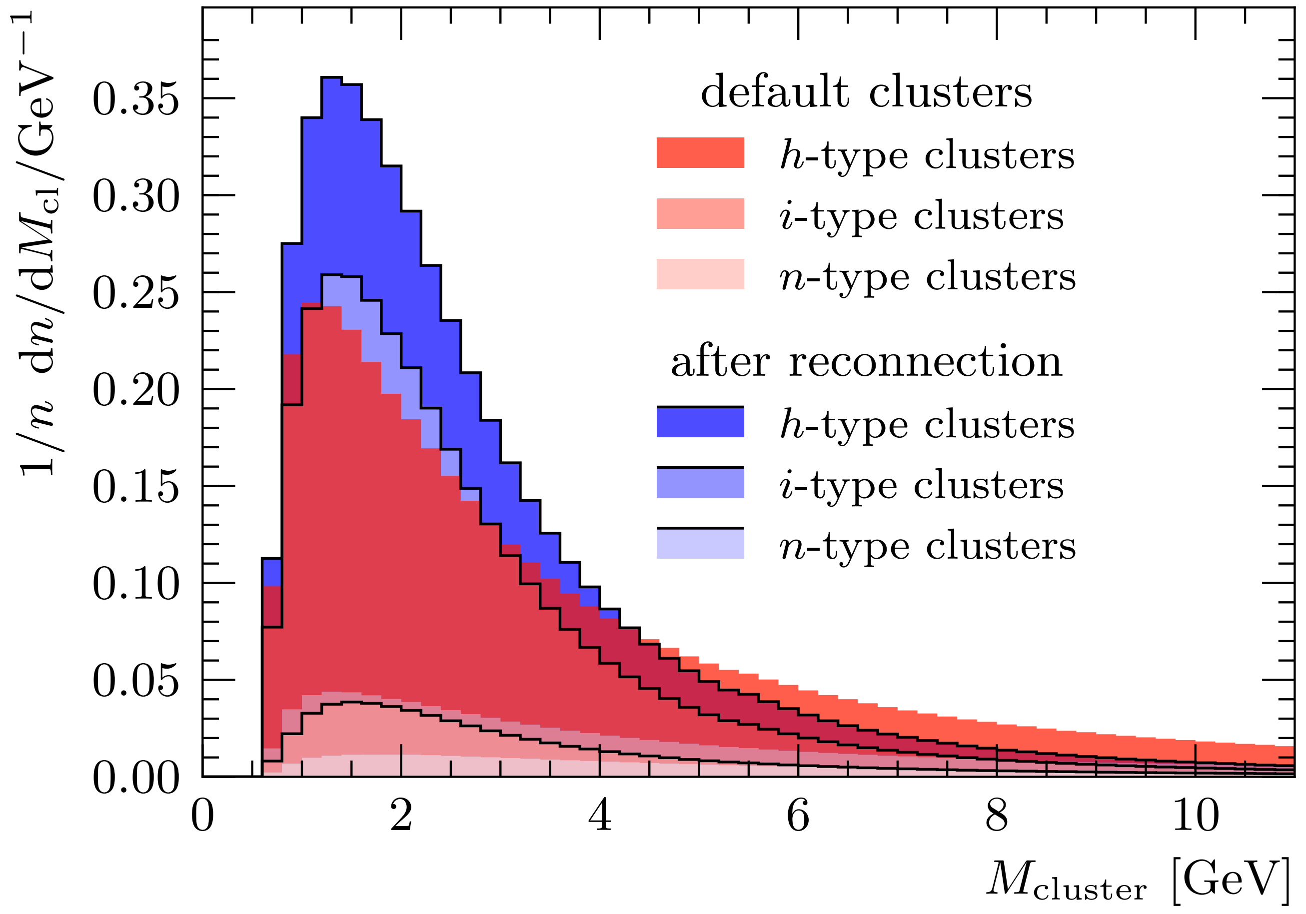






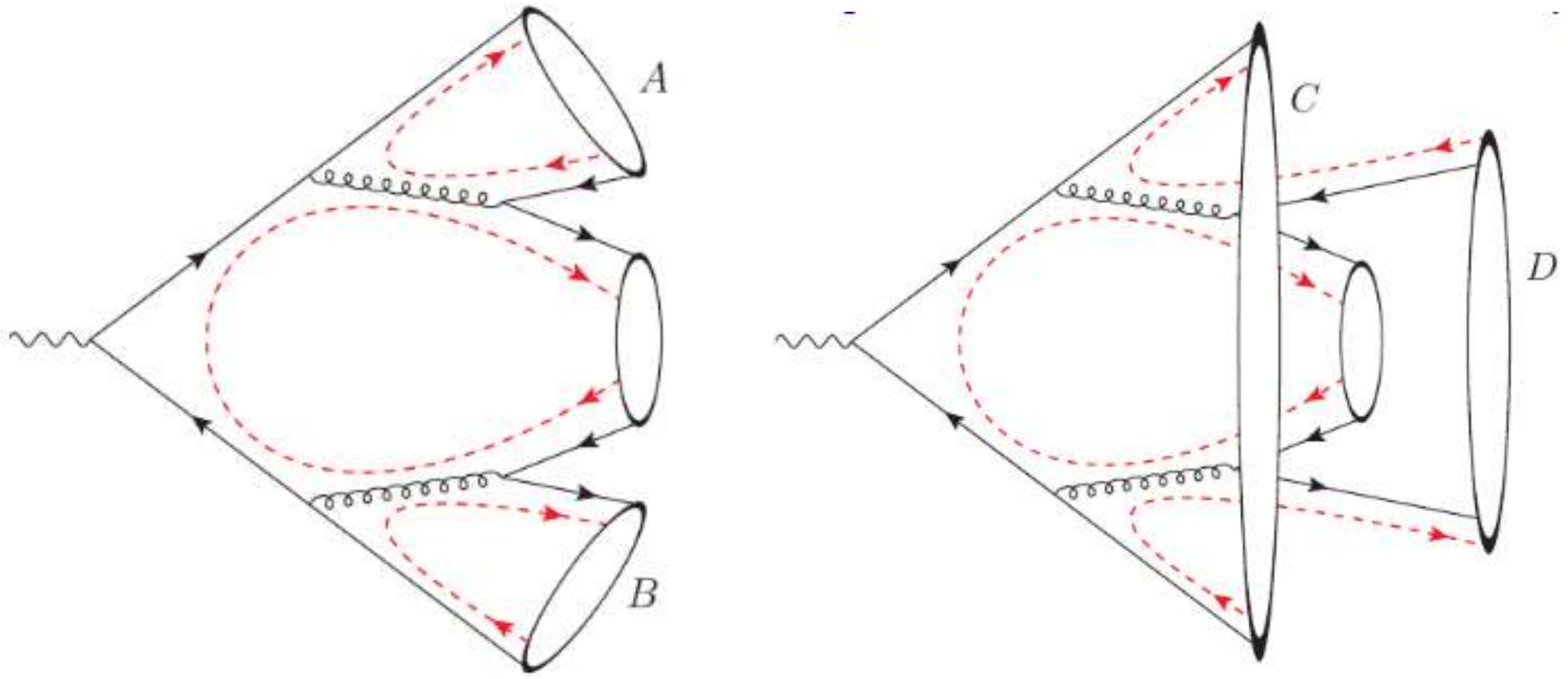
[Herwig++ 1.0 release — Gieseke et al. JHEP 02 (2004) 005]

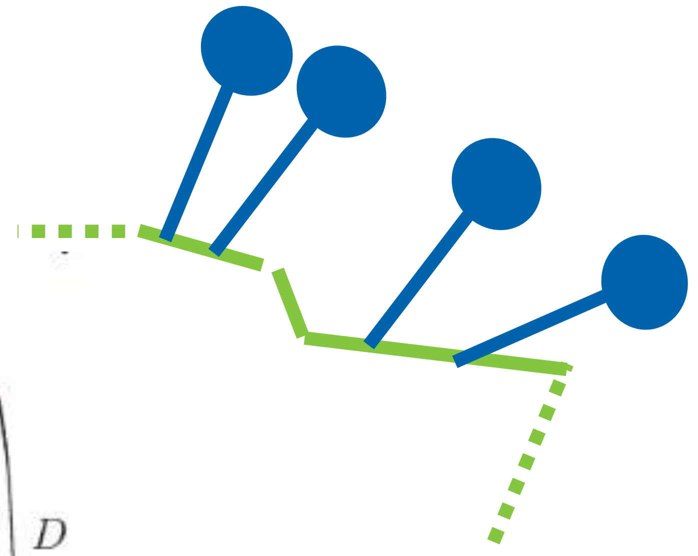
Colour Reconnection



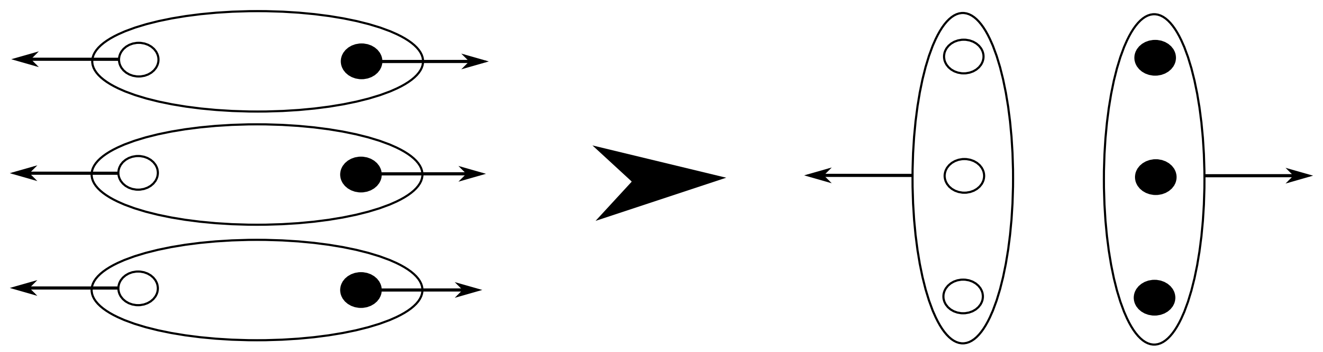
[Gieseke, Röhr, Siodmok — EPJ C72 (2012) 2225]

Plain colour reconnection uses fixed reconnection probability and lambda measure.



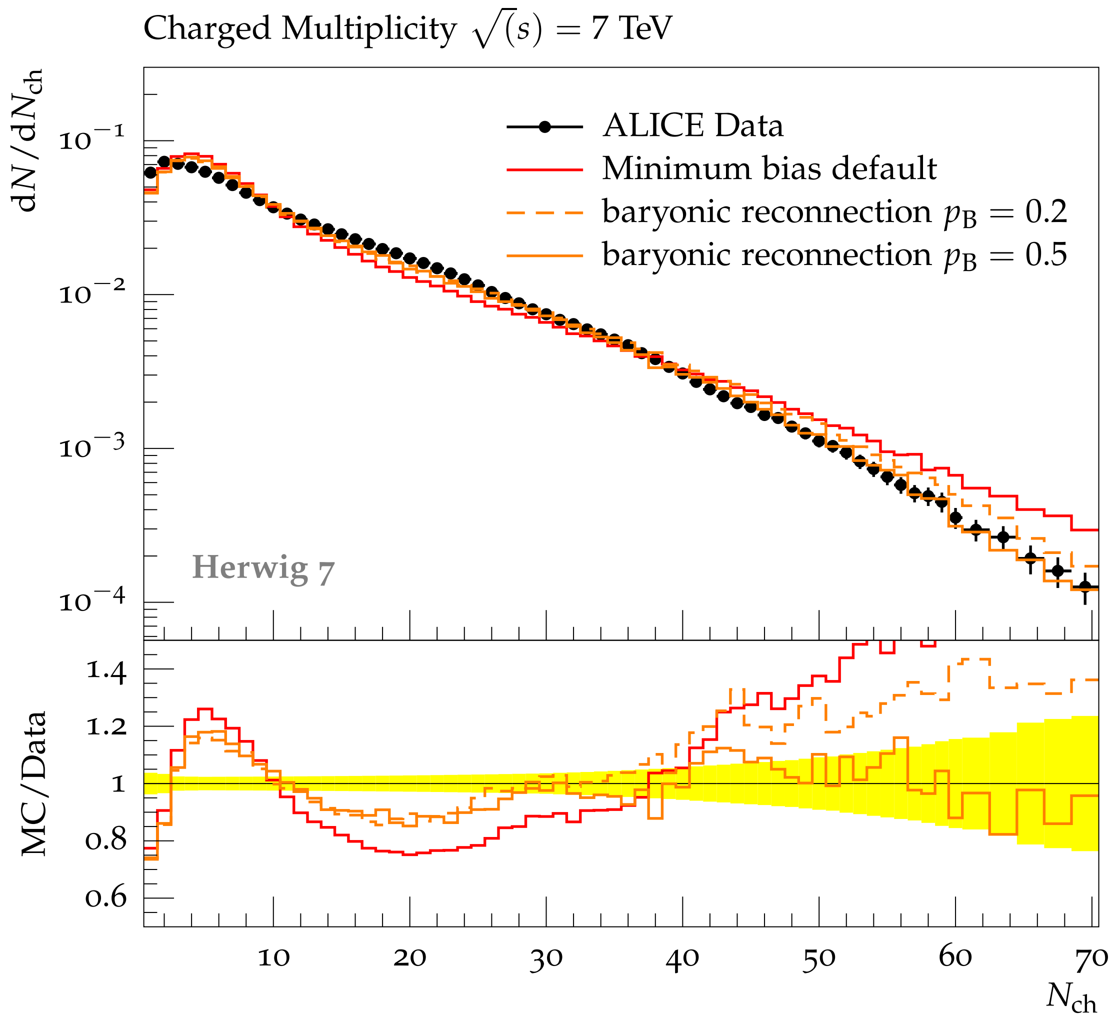


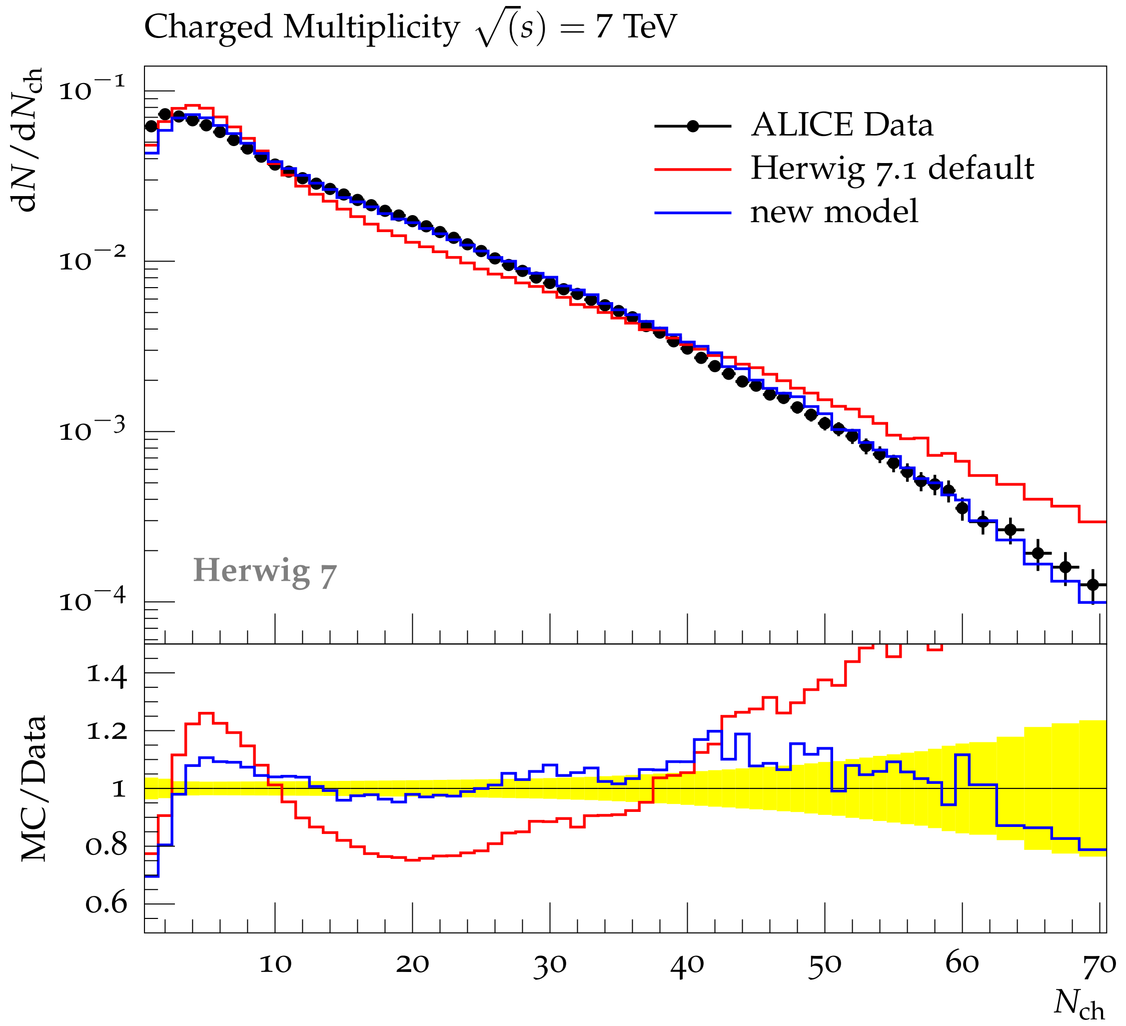
Generalize to geometric measure and baryonic systems



$$R_{q,qq} + R_{\bar{q},\bar{q}\bar{q}} < R_{q,\bar{q}} + R_{qq,\bar{q}\bar{q}}$$

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





Hadronization

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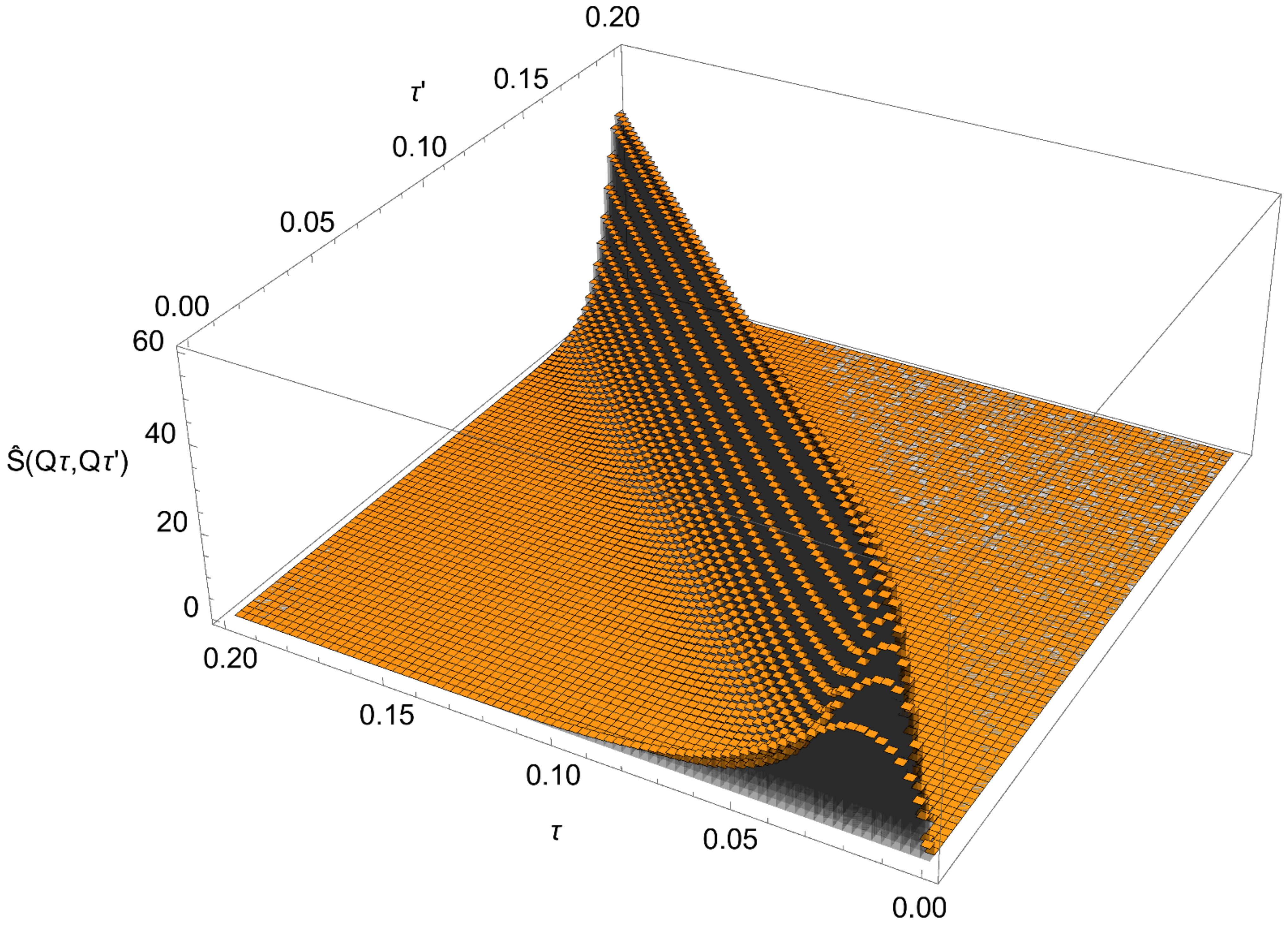
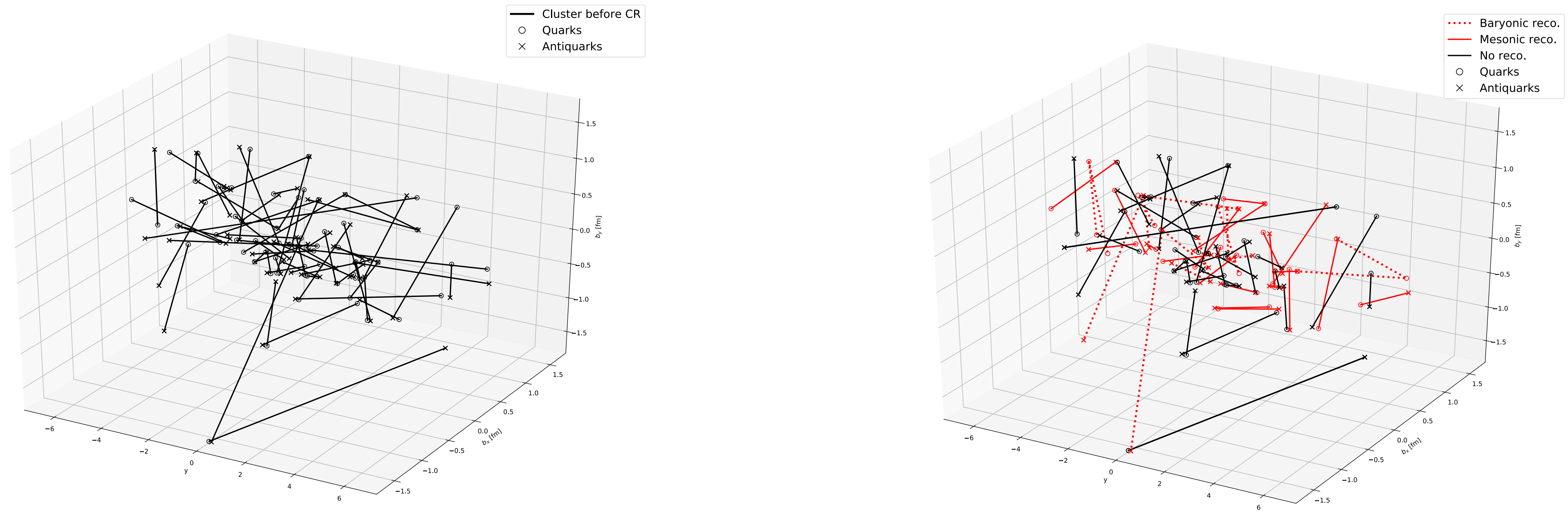
Extracting hadronization corrections event-by-event



[Hoang, Plätzer, Samitz — in progress]

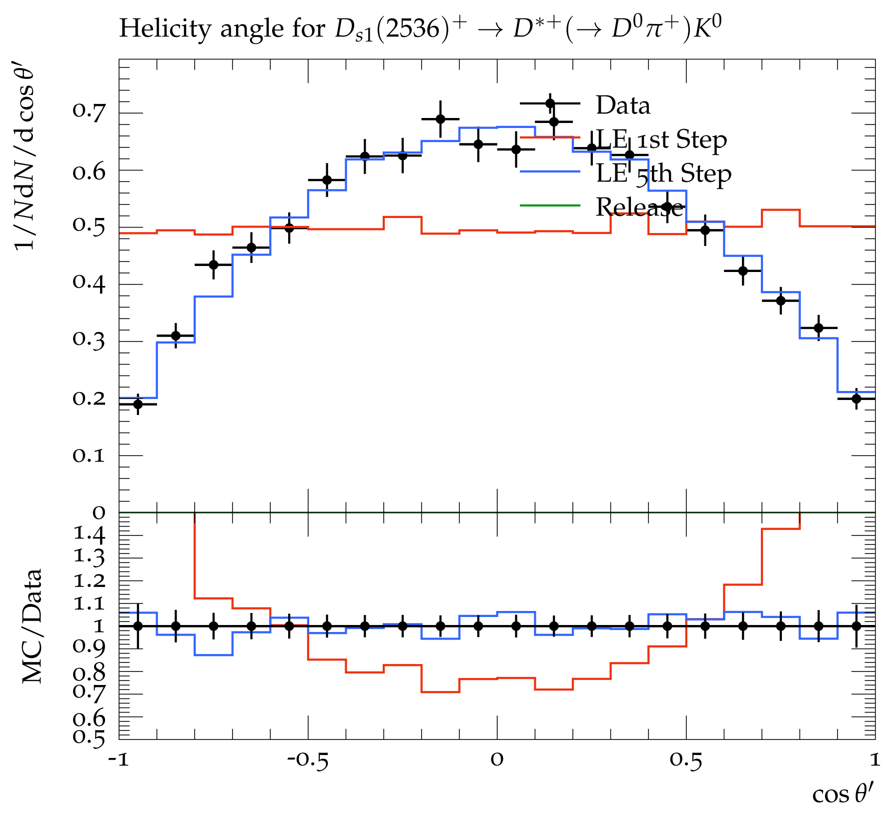
Spacetime information in colour reconnection possibly relevant in dense environments



[Bellm, Duncan, Gieseke, Myska, Siodmok – EPJ C79 (2019) 1003]

Interfacing to string model in progress.

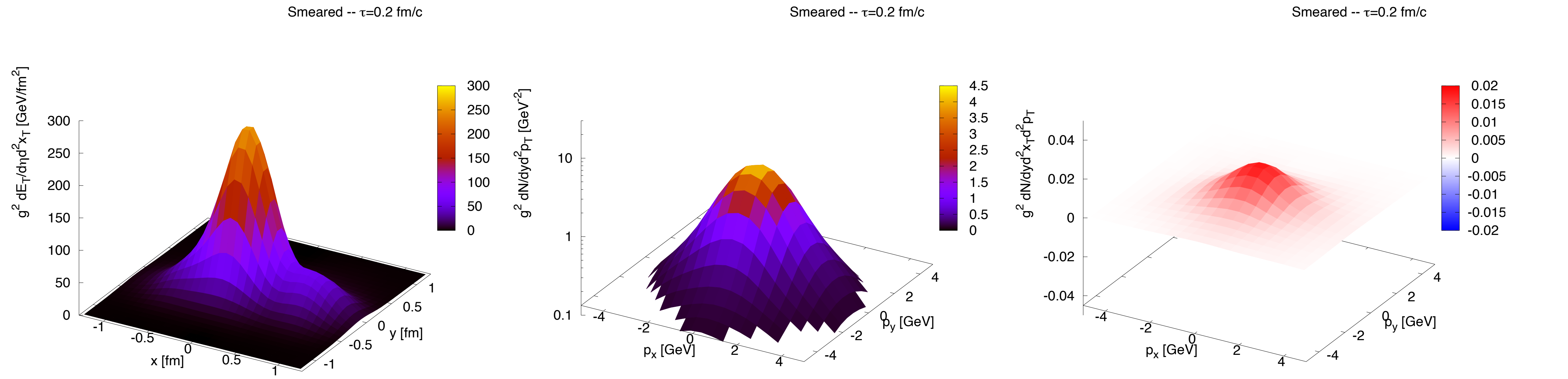
[Siodmok — in progress]



Low energy hadronization.

[Masouminia — in progress]

Ions

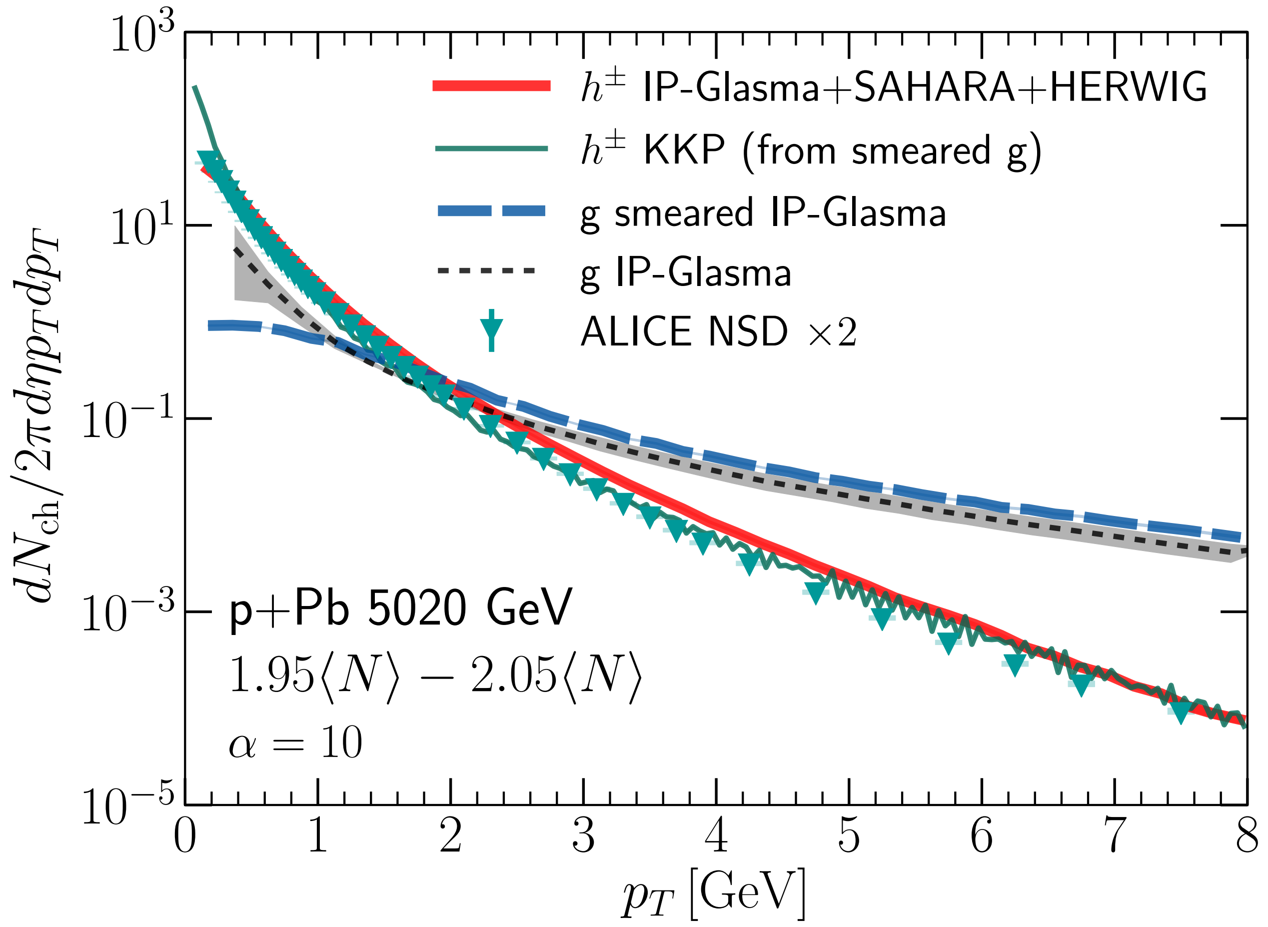


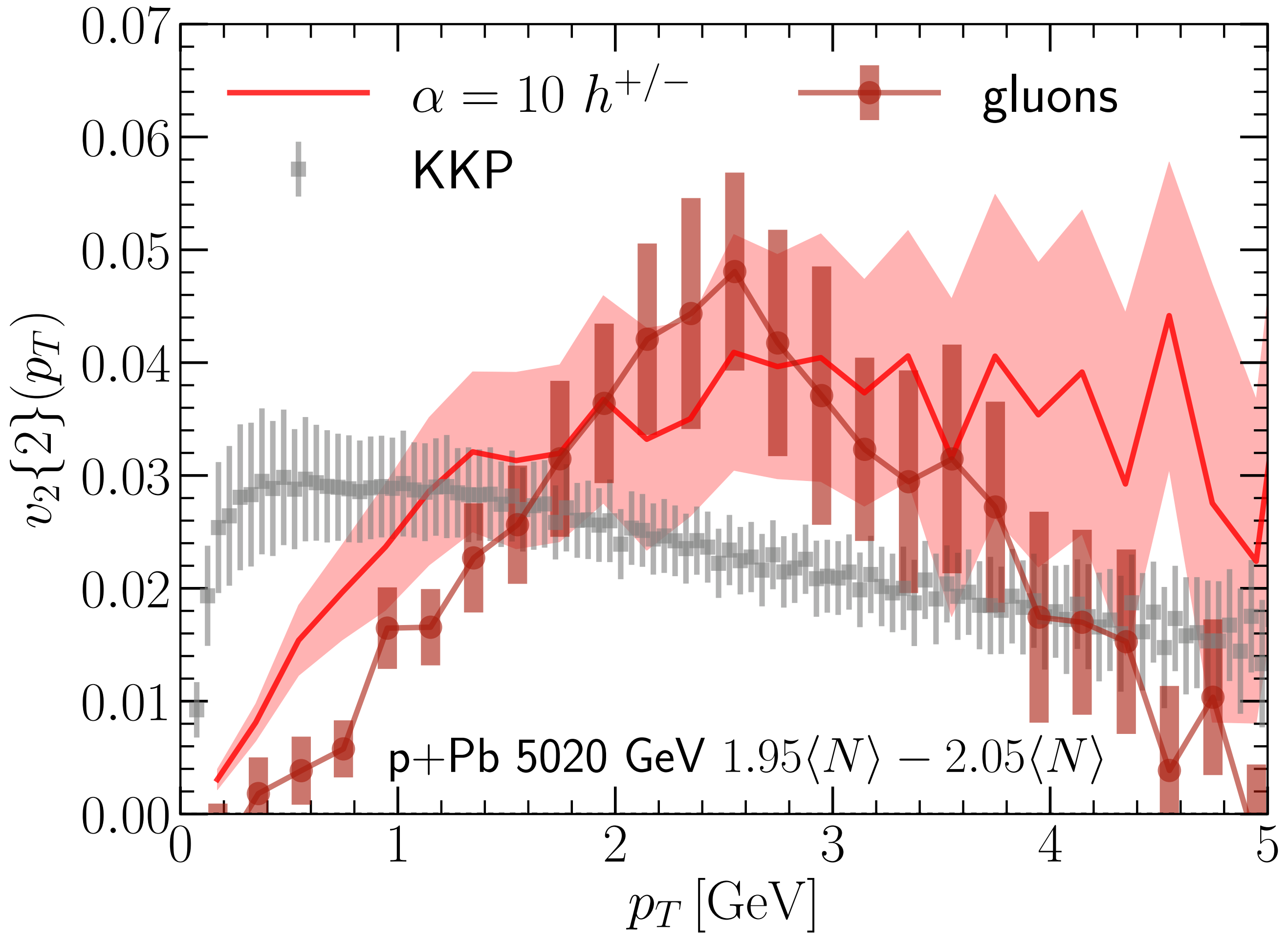
Clustering and hadronization of gluon ensembles from IP-Glasma simulations.

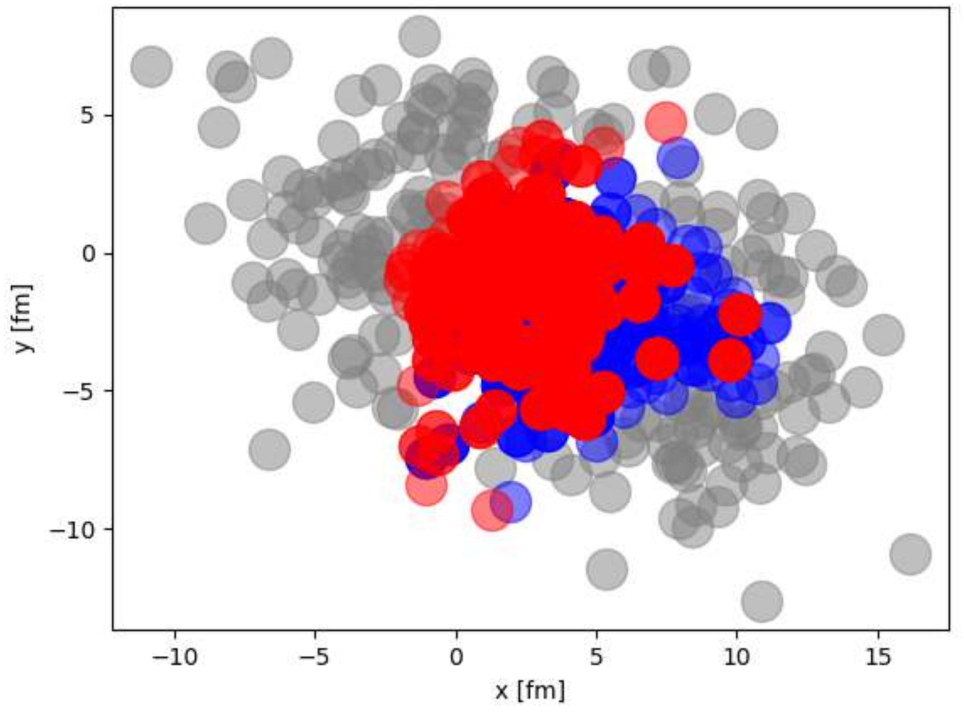
Transverse Husimi distribution

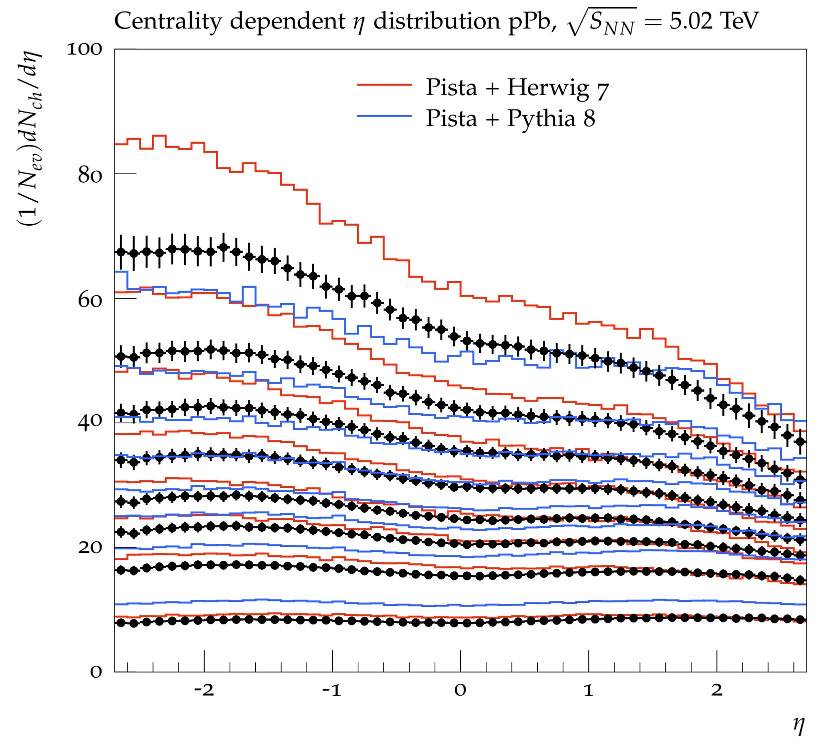
Transverse energy density

Glauber model "pre-burner": PISTA







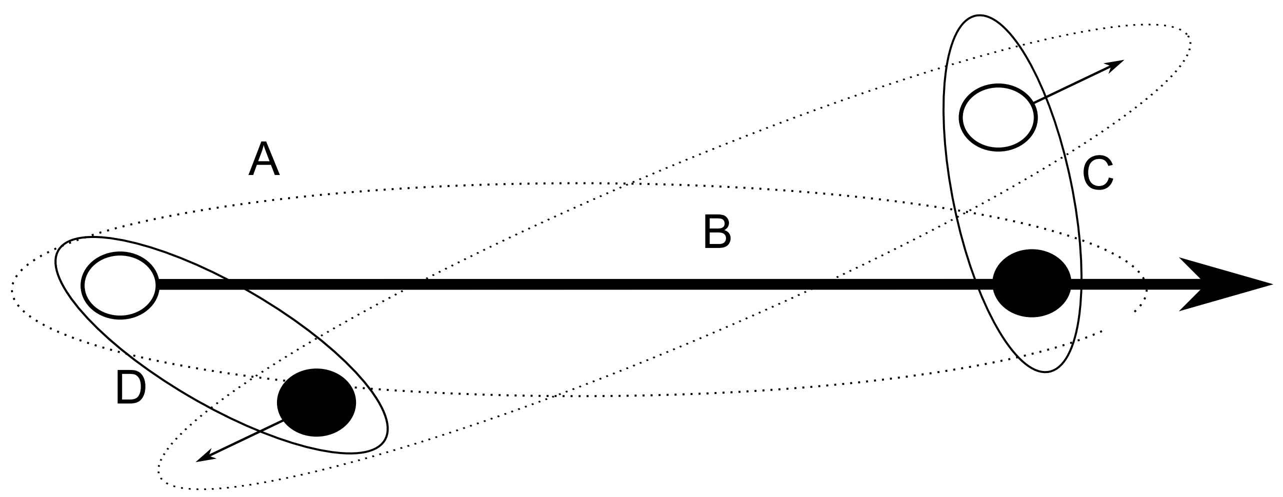


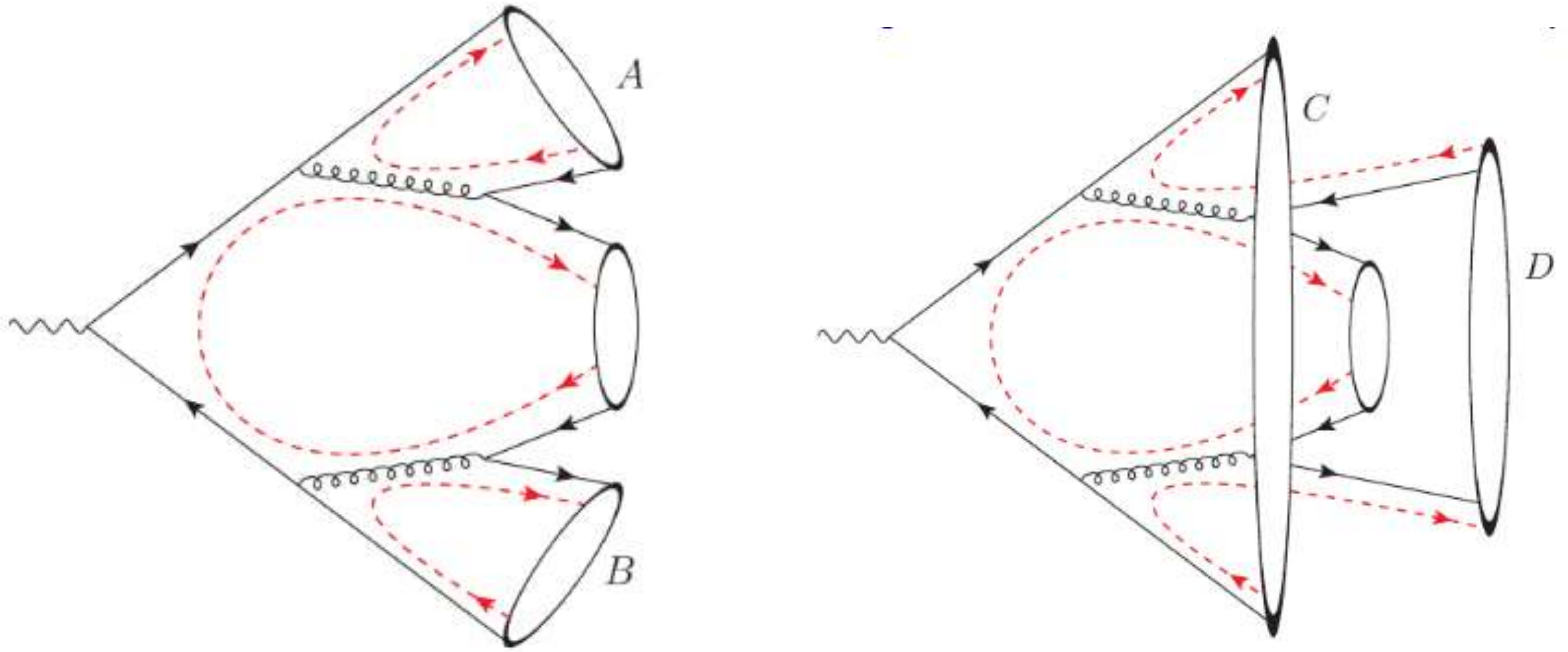
[Greif, Greiner, Plätzer, Schenke, Schlichting - Phys. Rev. D. 103 (2021) 5]

[Bellm, Bierlich — arXiv:1807.01291]

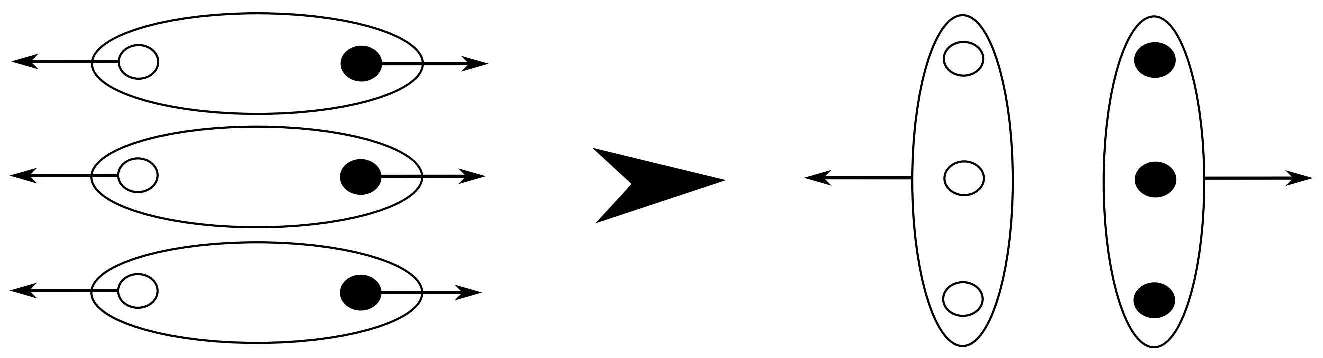
Geometric & Baryonic Reconnection

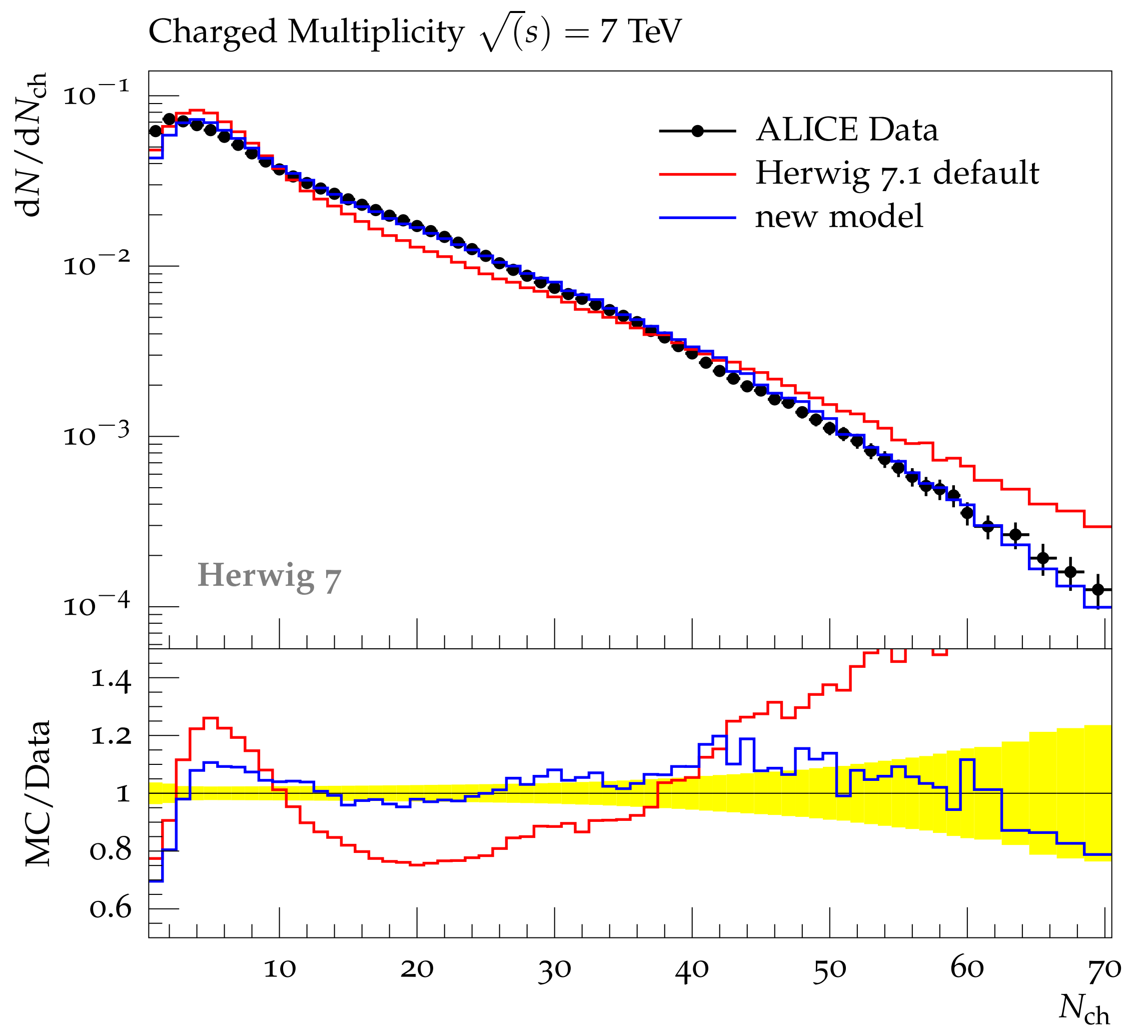
Large number of activities in improving cluster hadronization and colour reconnection.

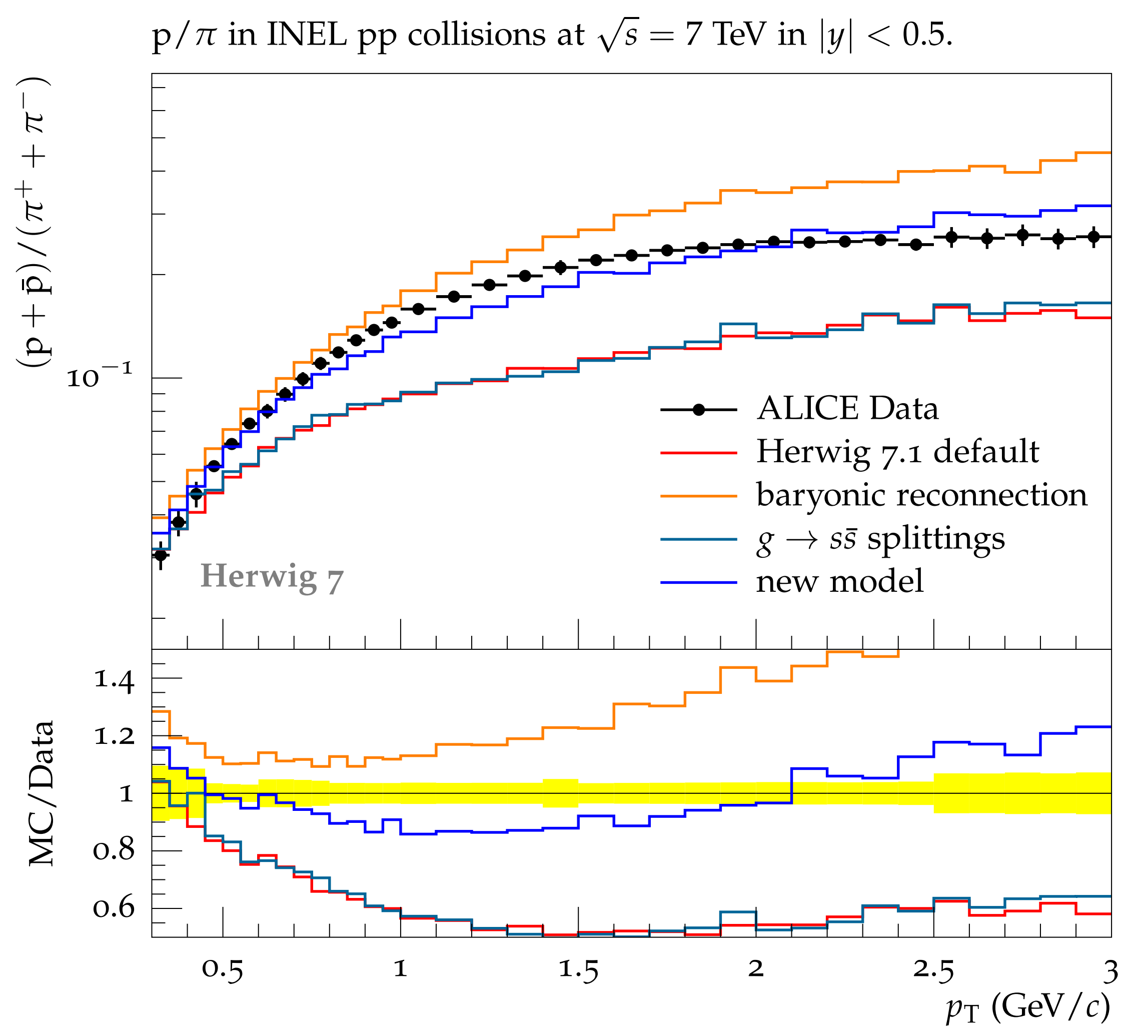




$$R_{q,qq} + R_{\bar{q},\bar{q}\bar{q}} < R_{q,\bar{q}} + R_{qq,\bar{q}\bar{q}}$$







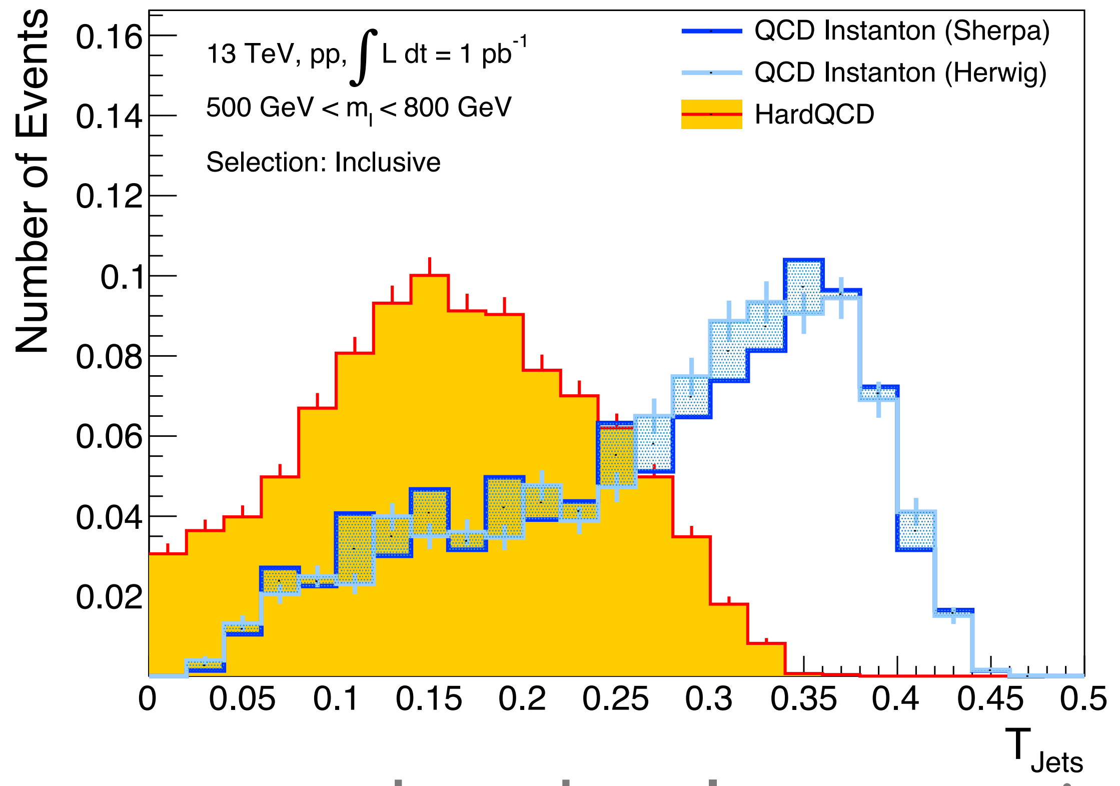
[Gieseke, Kirchgaesser, Plätzer – EPJ C 78 (2018) 99]

Flexibility for other phenomena

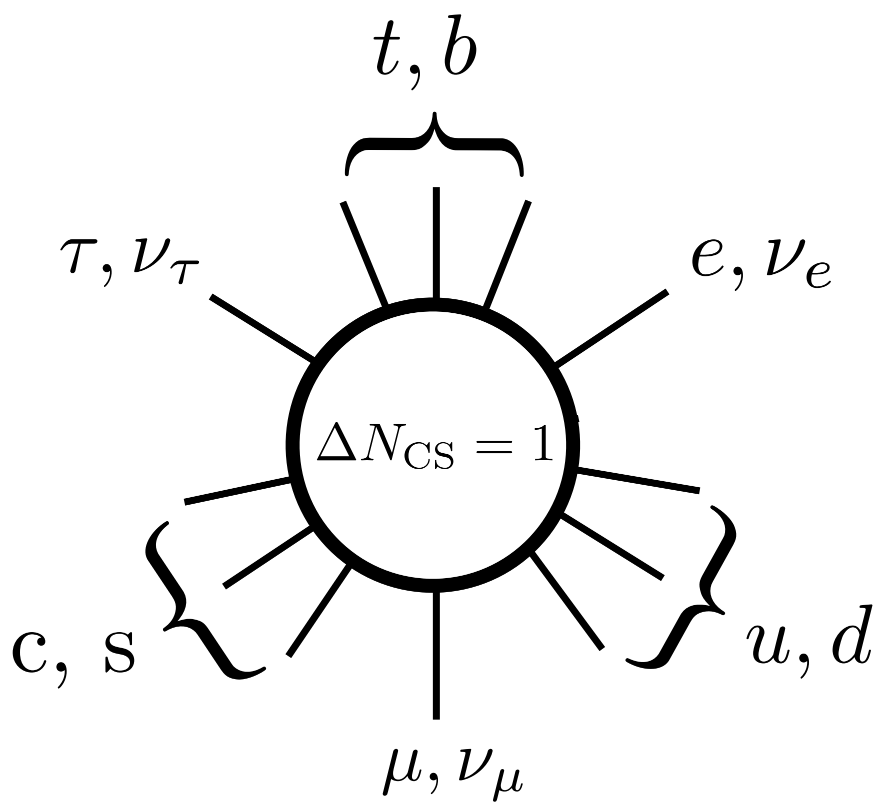
Framework for "blob" type processes and non-trivial vacua.
Electroweak sphalerons

[Papaefstathiou, Plätzer, Sakurai — JHEP 1912 (2019) 017]

QCD instantons



[Amoroso — based on Instanton simulation in Herwig 7]

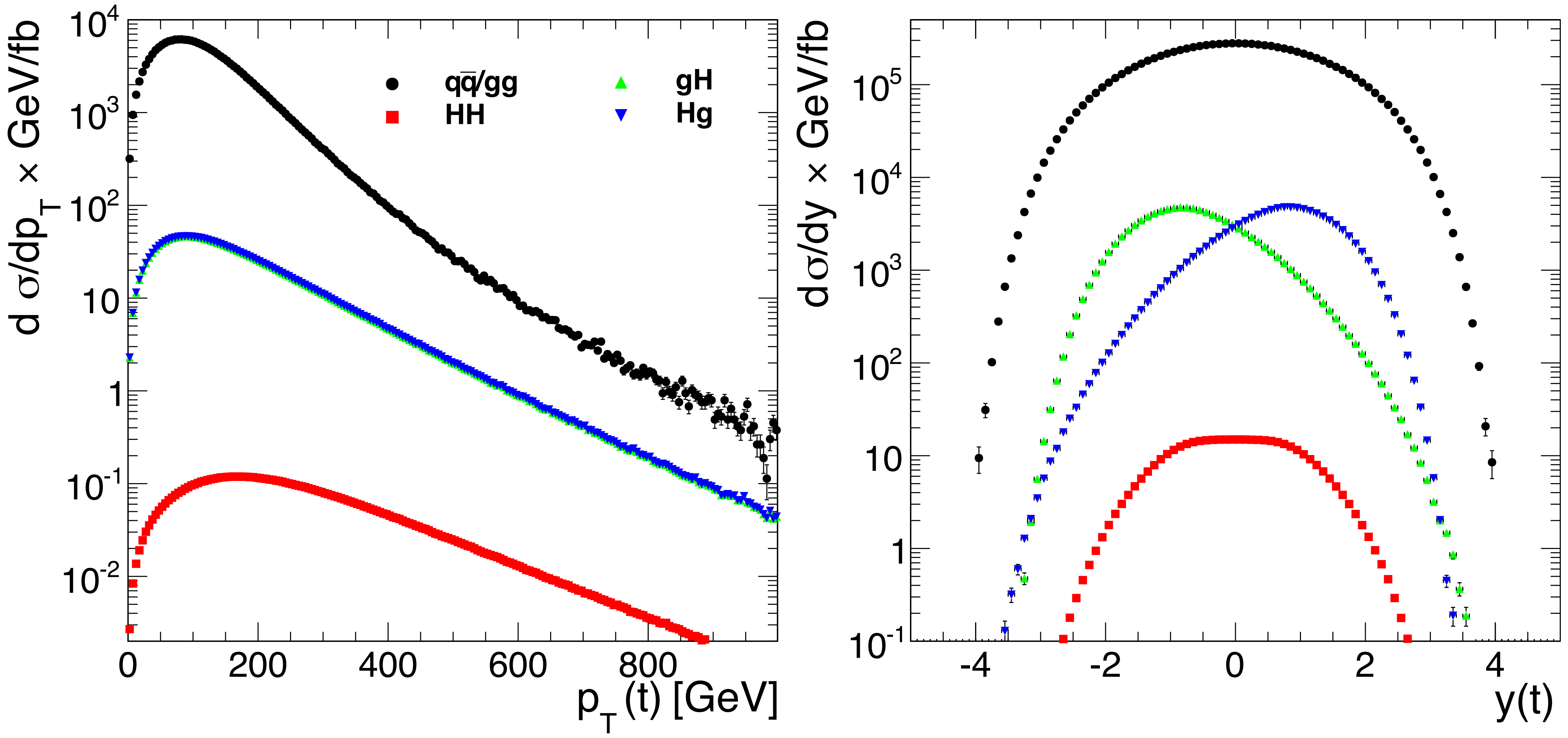


[Papaefstathiou, Plätzer — unpublished]
[Cormier, Jin, Kirchgaesser, Papaefstathiou, Plätzer — in progress]

Electroweak substructure:
Relevant for FCC ee physics.

[Maas — Prog.Part.Nucl.Phys. 106 (2019) 132]

$$\langle p(x)p(y)X(z_1,\ldots)\rangle = v^2 \langle (qqq)(y)(qqq)(x)X(z_1,\ldots)\rangle$$
$$+v \langle (qqq)(x)H(x)(qqq)(y)X(z_1,\ldots) + x \leftrightarrow y\rangle$$
$$+ \langle (qqq)(x)H(x)(qqq)(y)H(y)X(z_1,\ldots)\rangle$$



[Fernbach, Lechner, Maas, Plätzer, Schöfbeck — PRD 101 (2020) 11]

Summary

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Herwig 7 has a large range of opportunities for physics at the EIC.

Precision is addressed from the hard process to parton showers and new developments in hadronization (also see Herwig talks at MPI@LHC earlier this week).

Some structural changes are still needed to fully use the MPI model, but this will be in progress soon.

Thank you!

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