Heavy Quarks in Herwig 7

Simon Plätzer
Particle Physics — University of Vienna

at the
Heavy Flavour Hadronization Workshop
CERN | 3 March 2020

Herwig 7 Overview

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

Two shower modules: angular ordered and dipole-type, both including parton shower uncertainty estimates.

[Gieseke, Stephens, Webber – JHEP 0312 (2003) 045]
[Plätzer, Gieseke – JHEP 1101 (2011) 024]
[Bellm, Nail, Plätzer, Schichtel, Siodmok – EPJ C76 (2016) 665]

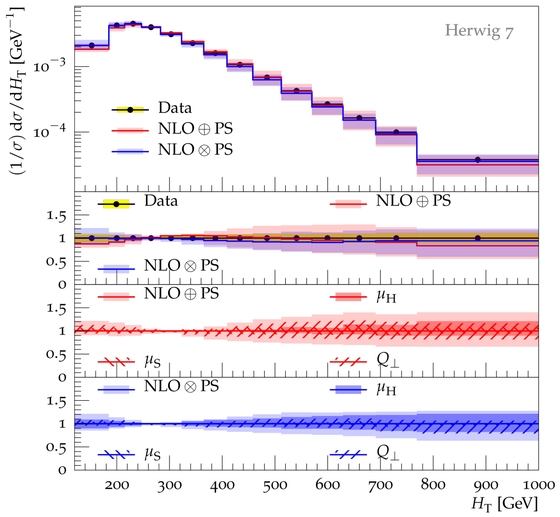
[Plätzer –- with Bellm, Wilcock, Rauch, Reuschle, 2011 – 2015]
[Plätzer, Gieseke – EPJ C72 (2012) 2187]
[Plätzer — JHEP 1308 (2013) 114]
[Bellm, Gieseke, Plätzer — EPJ C78 (2018) 244]

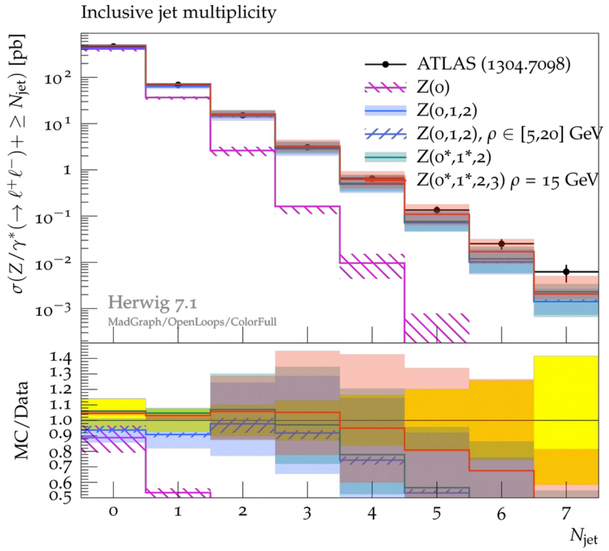
Automated NLO matching and multi jet merging.

Cluster hadronization model

Eikonal MPI model

Colour Reconnection





Shower Evolution of Heavy Quarks

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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]

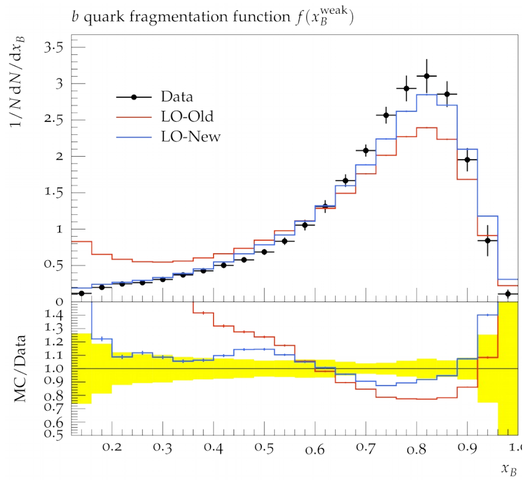
$$z\,(1-z)\,\tilde{q}^2 = -m_{\tilde{ij}}^2 + \frac{m_i^2}{z} + \frac{m_j^2}{1-z} - \frac{p_\perp^2}{z\,(1-z)}$$

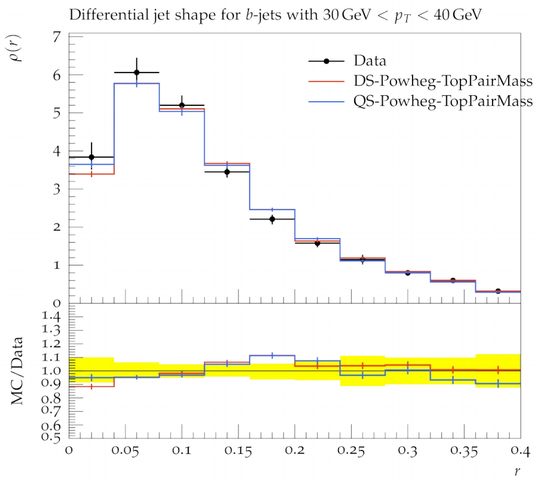
$$P_{q\to qg} = \frac{C_F}{1-z}\left[1 + z^2 - \frac{2m_q^2}{z\tilde{q}^2}\right]$$

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

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

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

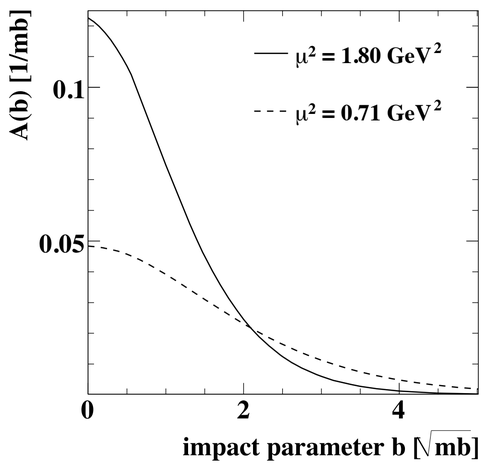




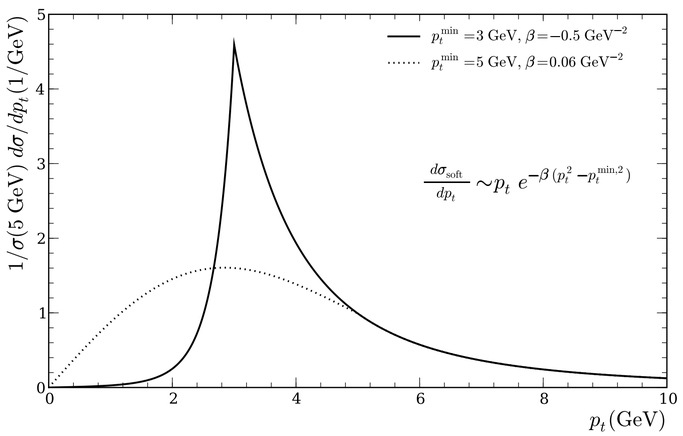
- Significantly improved b fragmentation from dipole shower
- Comparable description of heavy quark observables across both showers

Multi-parton Interactions

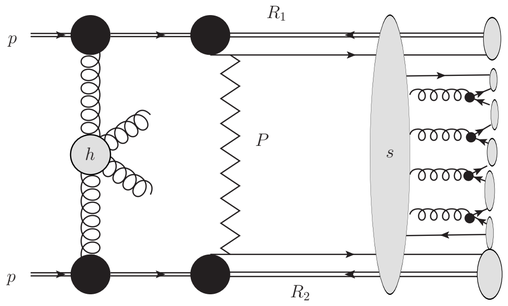
Key ingredients for MPI modelling in Herwig 7

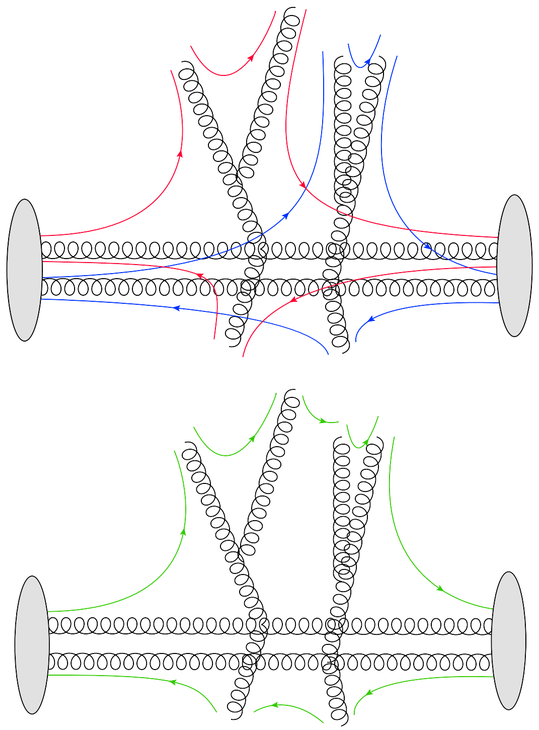


matter distribution



soft & hard scatters
+ diffraction





[Figure by Stefan Gieseke]

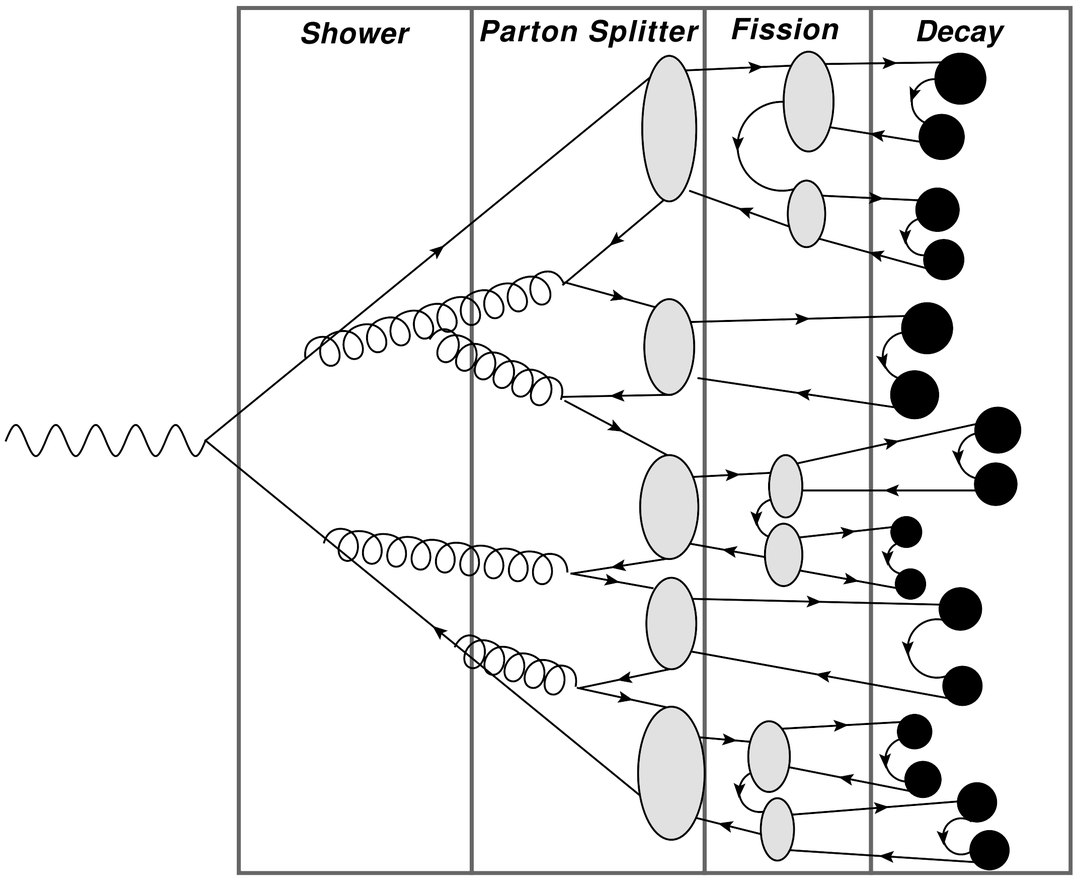
colour reconnection

[Gieseke, Loshaj, Kirchgasser — EPJ C77 (2017) 156]

[Bellm, Gieseke, Kirchgasser — arXiv:1911.13149]

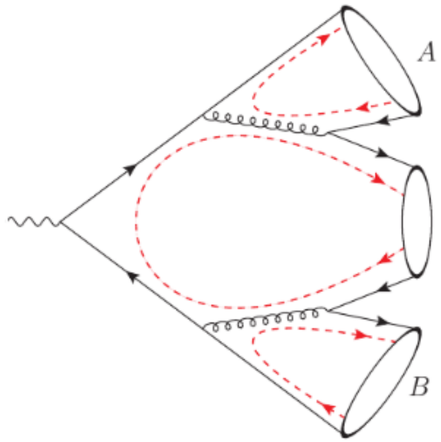
in total six parameters, hard MPI in principle allow for HQ

Cluster Hadronization



[Figure by Patrick Kirchgaesser]

Clusters formed by splitting gluons after shower evolution



Different weights for light flavours

Clusters fission if too heavy:

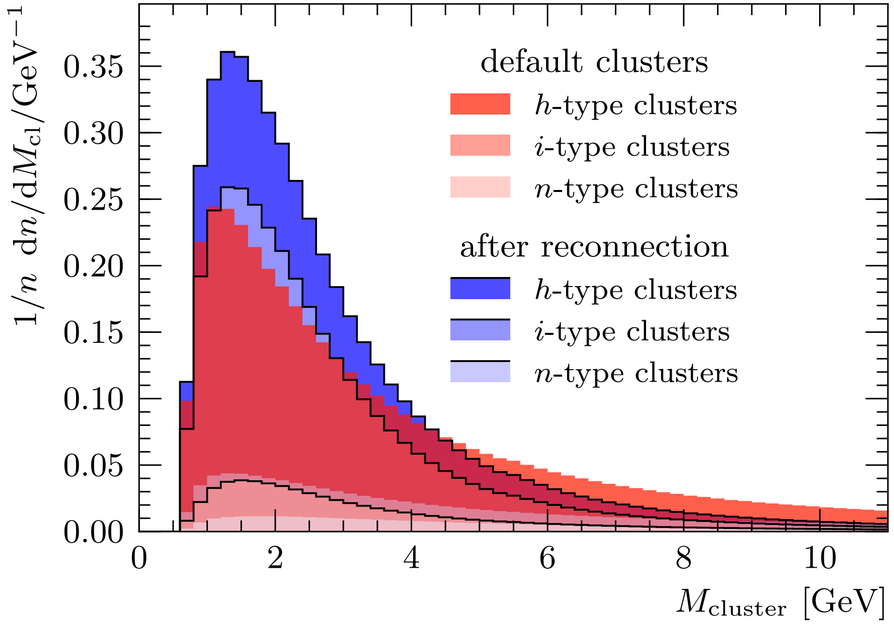
$$M^p \geq q^p + (m_1 + m_2)^p$$

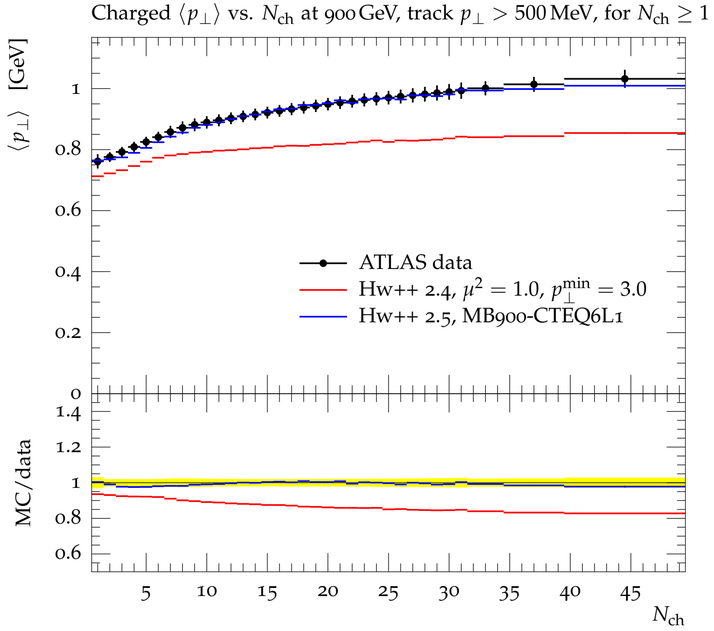
Fission parameters different for uds, c and b, but only uds produced

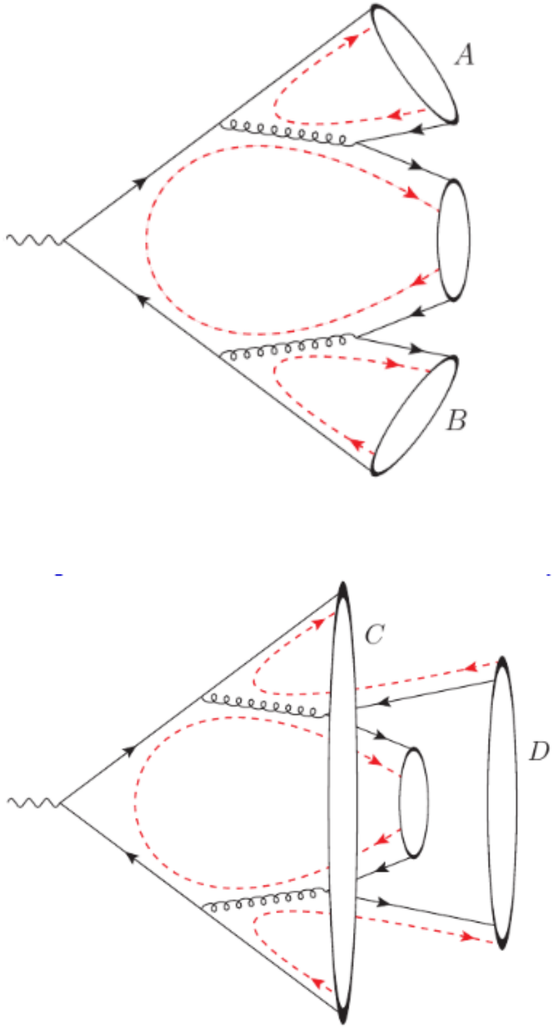
Lighter clusters decay into hadrons

Colour Reconnection

Preconfinement assumption violated in hadronic environments: colour reconnection crucial.







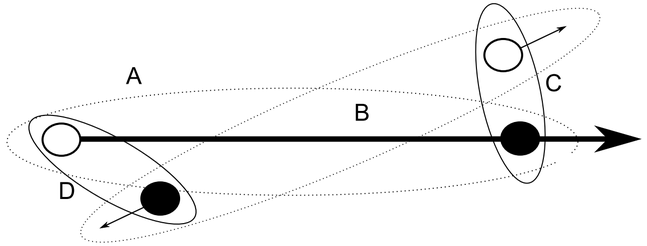
[Gieseke, Röhr, Siodmok — EPJ C72 (2012) 2225]

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

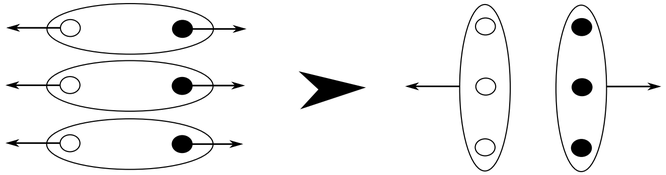
No flavour dependence!

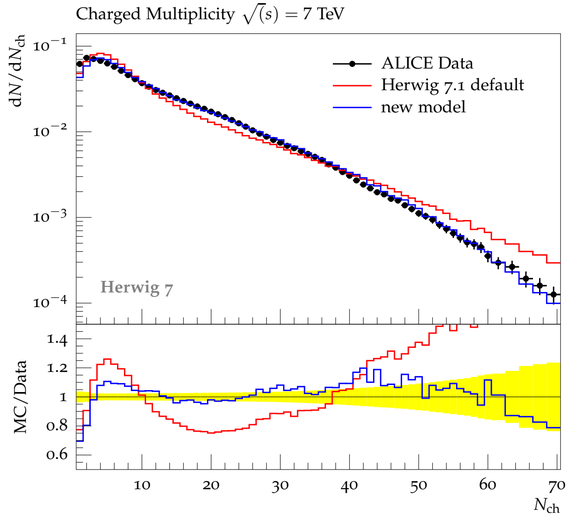
Geometric & Baryonic Reconnection

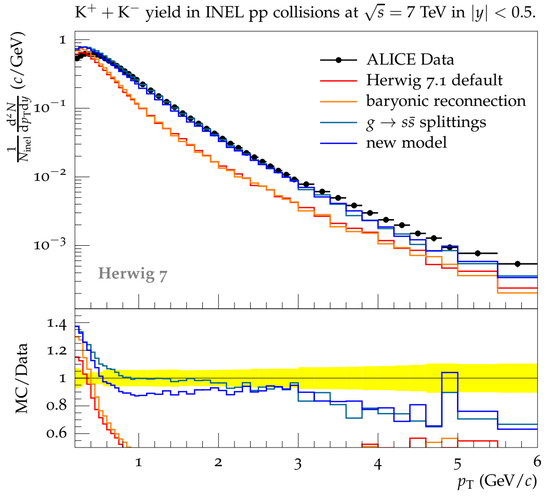
New model uses geometric measure instead of 'string length' and introduces baryonic degrees of freedom

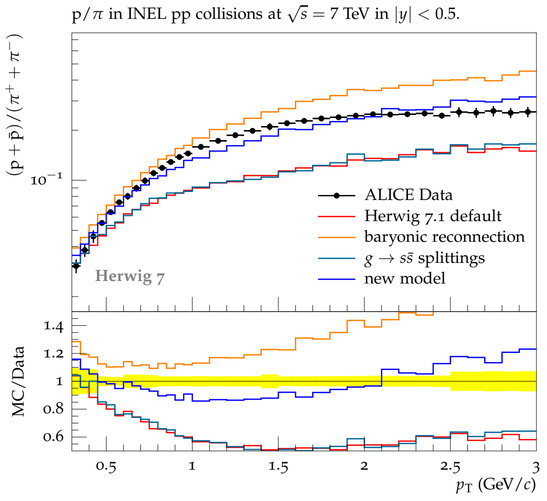


$$R_{q,qq} + R_{\bar{q},\bar{q}\bar{q}} < R_{q,\bar{q}} + R_{qq,\bar{q}\bar{q}}$$









Combination with globally enhanced strange production.

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

Kinematic Strange Production & Spacetime Information

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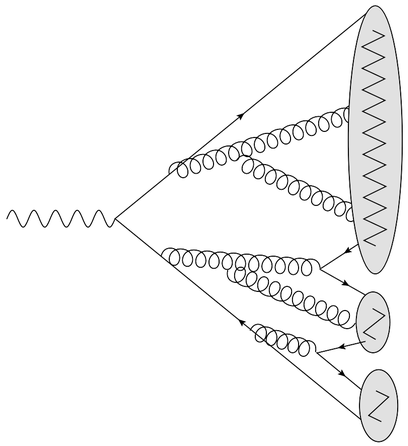
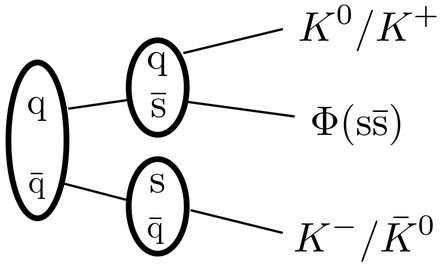
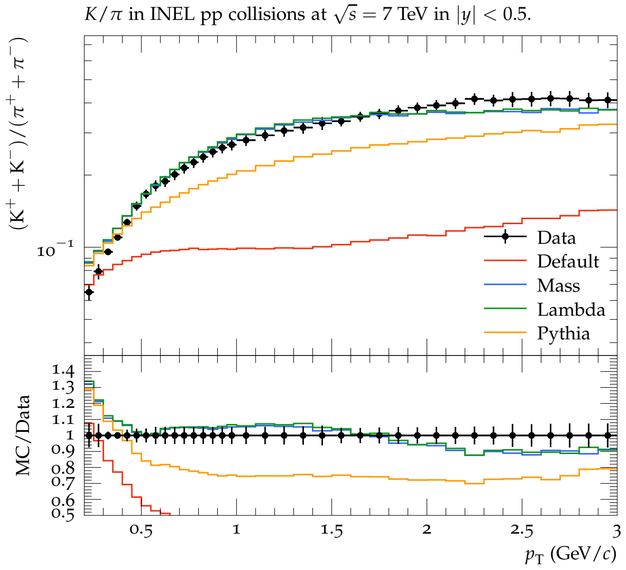
Strange production in gluon splitting and fission dependent on environment.

[Duncan, Kirchgaesser – EPJ C79 (2019) 61]

$$w_s(m)^2 = \exp\left(\frac{-m_0^2}{m^2}\right)$$

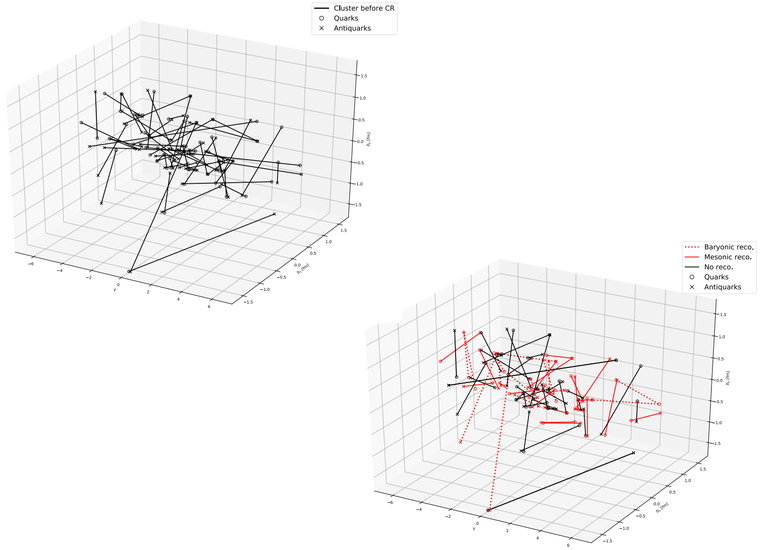






Open questions remain in correlations

Spacetime information in colour reconnection possibly relevant in dense environments



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

More theoretical understanding

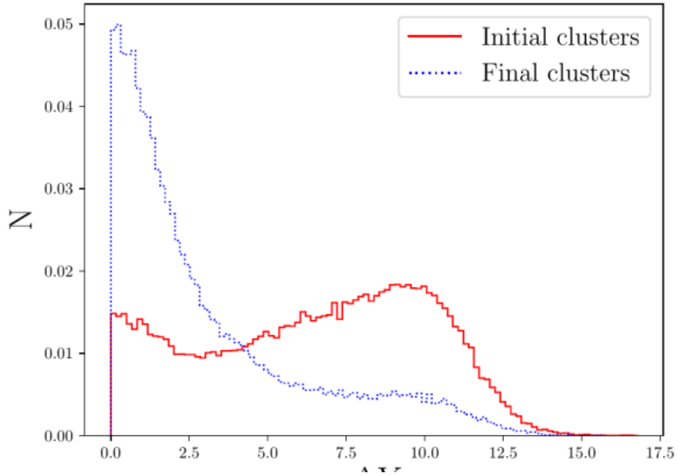
Approach colour reconnection from amplitude evolution algorithms: perturbative component?

[Angeles, De Angelis, Forshaw, Plätzer, Seymour – JHEP 05 (2018) 044]
[Forshaw, Holguin, Plätzer – JHEP 1908 (2019) 145]

$$\mathcal{A}_{\tau\to\sigma} = \langle\sigma|\mathbf{U}\left(\{p\},\mu^2,\{M_{ij}^2\}\right)|\tau\rangle$$

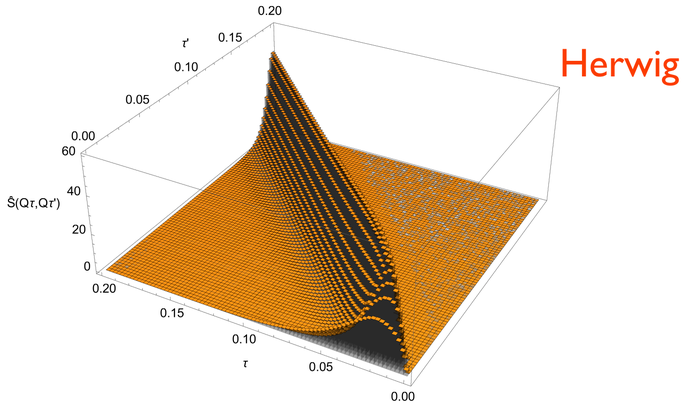
$$P_{\tau\to\sigma} = \frac{|\mathcal{A}_{\tau\to\sigma}|^2}{\sum_\rho |\mathcal{A}_{\tau\to\rho}|^2}$$

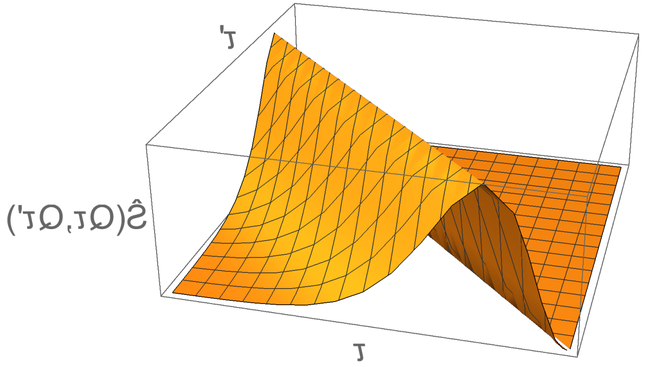
Strong support for geometric models from perturbative evolution.



[Gieseke, Kirchgaesser, Plätzer, Siodmok – JHEP 11 (2018) 149]

Confronting hadronization models with analytic power correction models





[Hoang, Plätzer, Samitz — in progress]

More theoretical understanding

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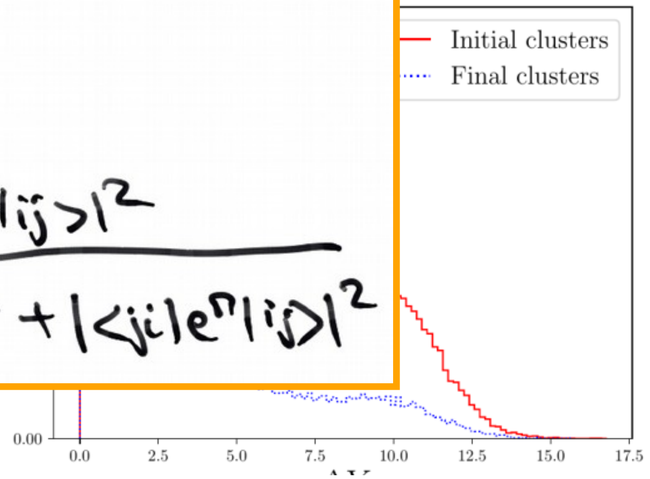
[Ar … 05 (2018) 044]
… 08 (2019) 145]

$$|M_0\rangle \sim |ij\rangle \equiv \begin{matrix} j \\ j \end{matrix}$$

$$e^{\Gamma}|M_0\rangle \sim a|ij\rangle + b|ji\rangle$$

$$P_{\tau\to\sigma}$$

$$P\left(\begin{matrix} j \\ j \end{matrix} \to \begin{matrix} j \\ j \end{matrix}\right) = \frac{|\langle ji|e^{\Gamma}|ij\rangle|^2}{|\langle ij|e^{\Gamma}|ij\rangle|^2 + |\langle ji|e^{\Gamma}|ij\rangle|^2}$$



Strong su…
geometri…
from per…
evolution.

[Gieseke, Kirchgaesser, Plätzer, Siodmok – JHEP 11 (2018) 149]

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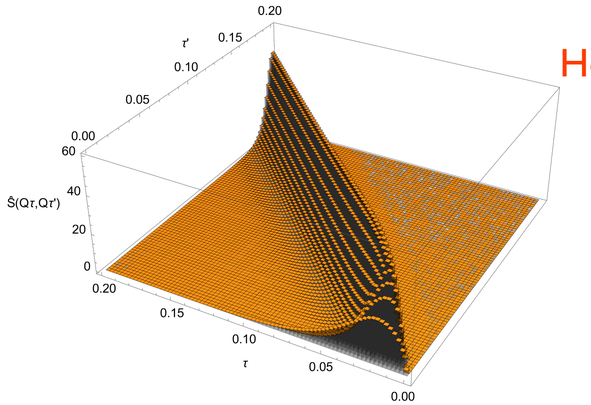

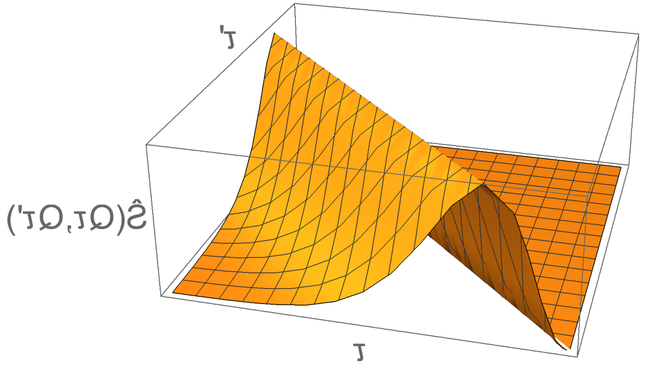

analytic

[Hoang, Plätzer, Samitz — in progress]

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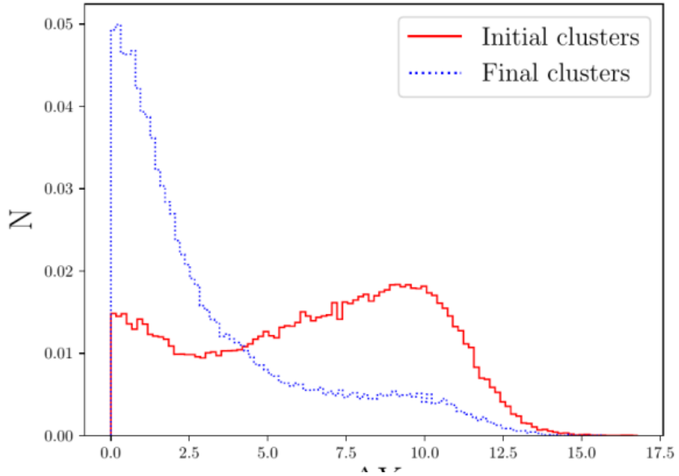

[Gieseke, Kirchgaesser, Plätzer, Siodmok – JHEP 11 (2018) 149]

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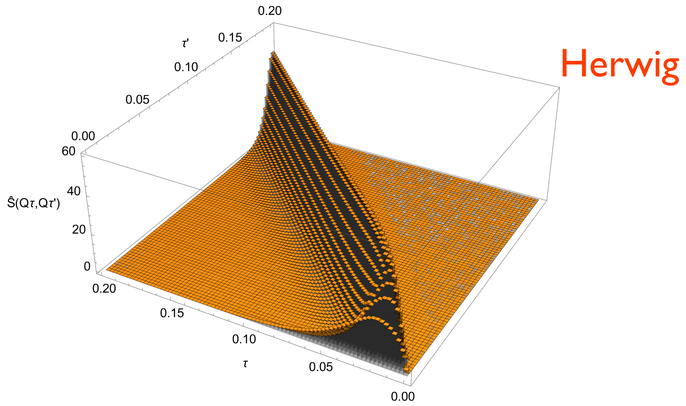
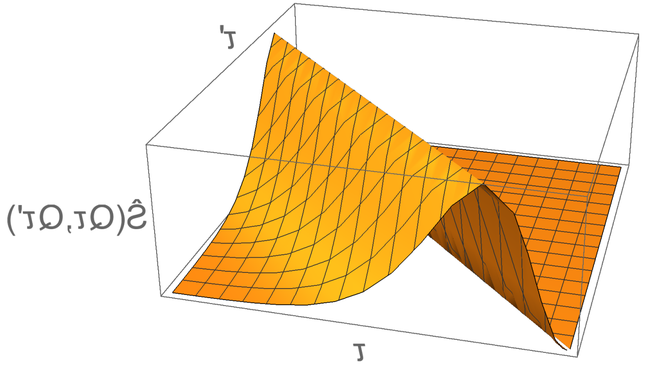


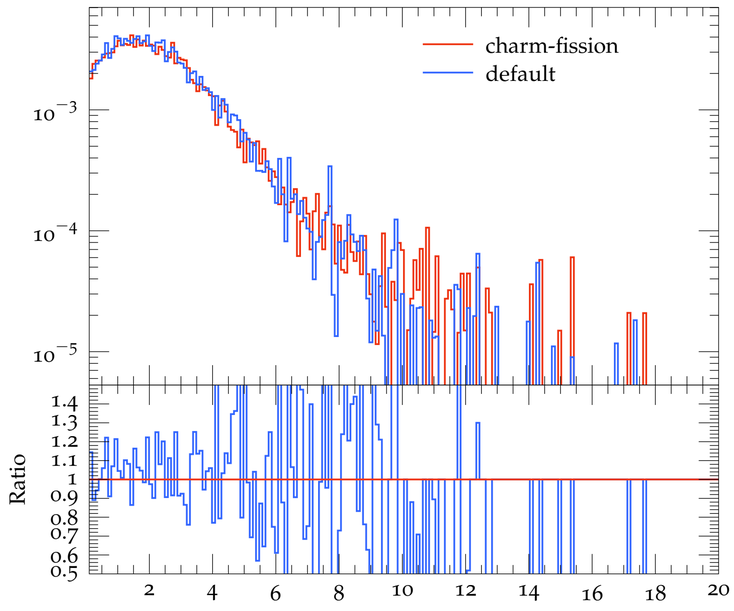


[Hoang, Plätzer, Samitz — in progress]

Outlook

- Some first tries in heavy flavour formation within gluon splitting, but needs kinematic feedback to only happen at relevant scales. [Kirchgaesser, Plätzer — in progress]
- Further investigations into gluon splitting and cluster fission driven by comparison to analytic power corrections, including flavour dependence [Hoang, Plätzer, Samitz — in progress]
- Study mass effects in theoretical investigations of colour reconnection such as colour evolution.

D yield



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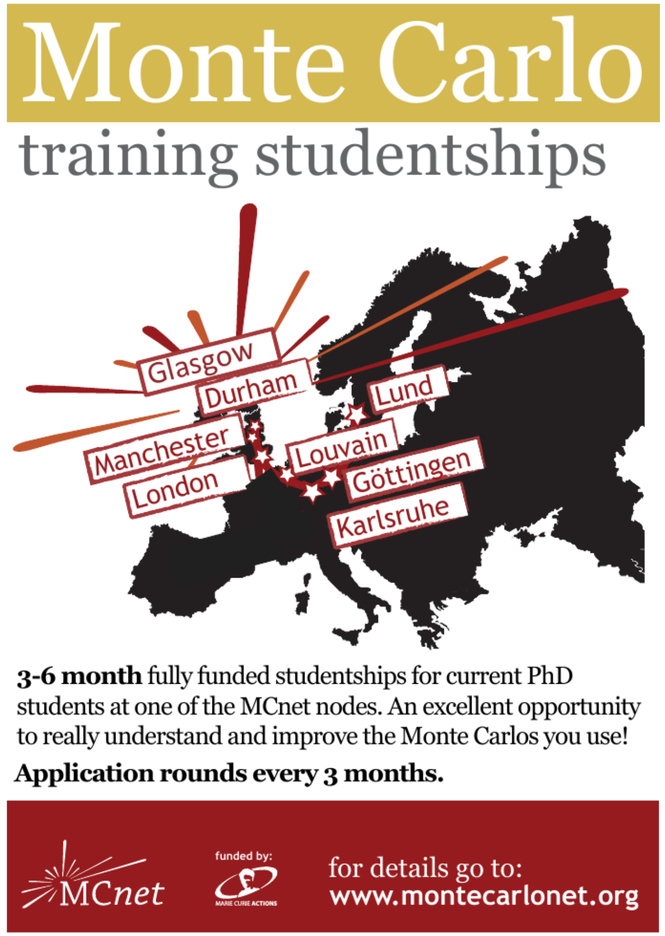
Thank you!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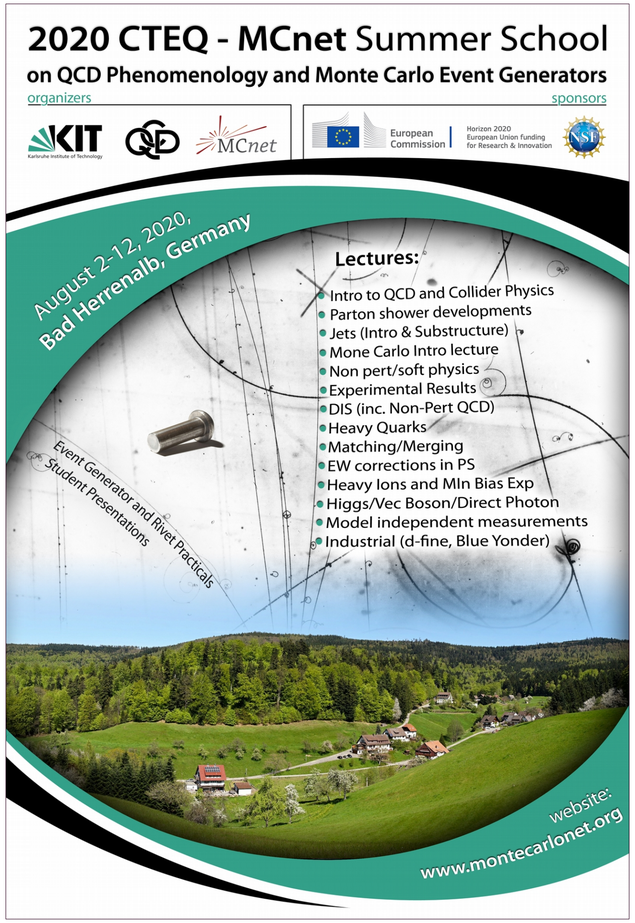
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