Getting into the Swing
of things in Heavy Ion Collisions

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Lund University

Hard Probes 2020-06-04

Outline

- Parton showers and Colour (re)connections
- The perturbative dipole swing
- Angantyr and the swing in heavy ion collisions
- Outlook

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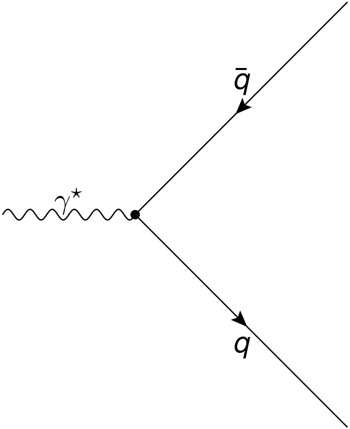
- WARNING: NO RESULTS YET

The importance of colour connections

- All hadrons are colour singlets.
- Any realistic hadronisation model must ensure this.
- Exact treatment of colour structures in LHC events is impossible(?)
- All partons shower approaches use the $N_C \to \infty$ approximation which gives a unique colour strucure.

Dipole showers



- Dipole splitting
- How are the dipoles connected?
- Pre-confinement: partons close in phase space are likely to be colour-connected.

- $N_C \to \infty$ gives a unique colour flow.
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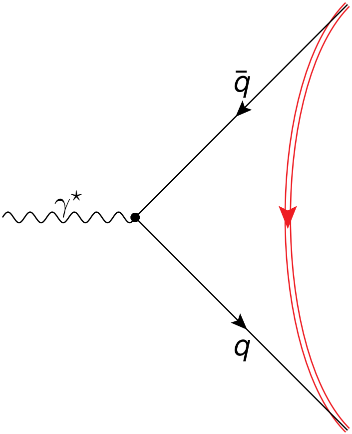

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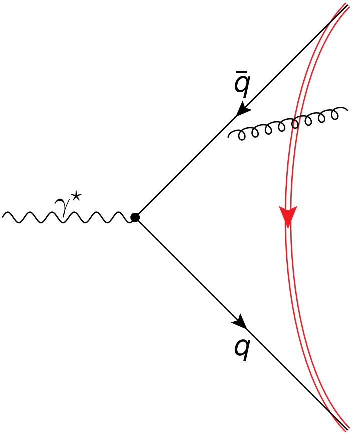

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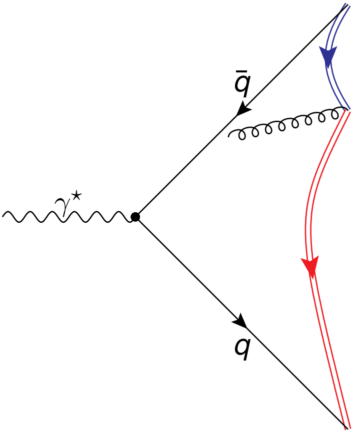

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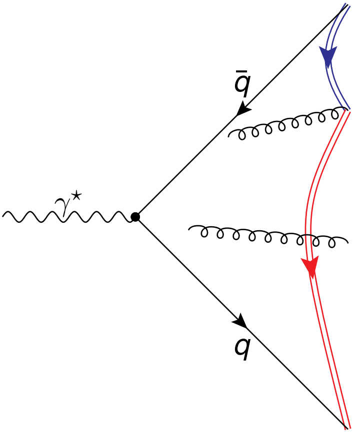

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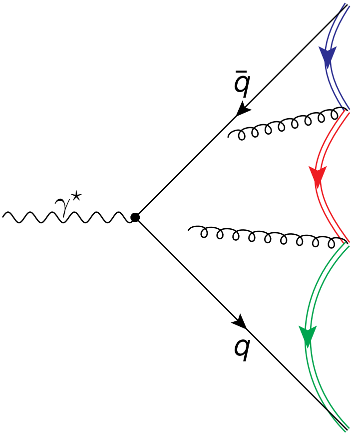

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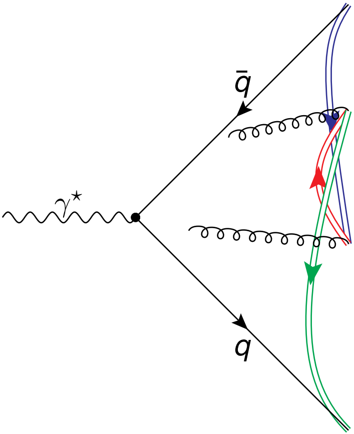

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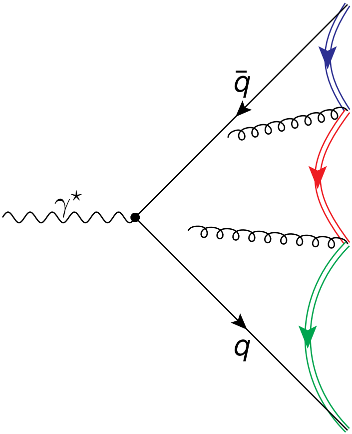

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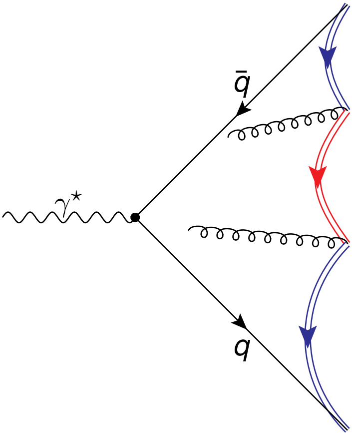

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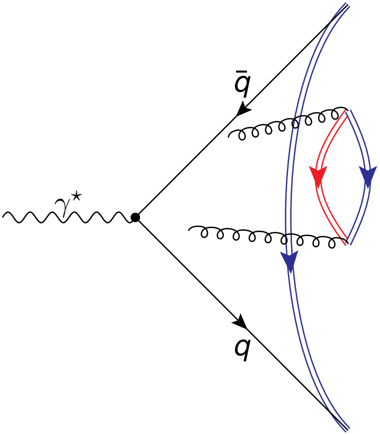

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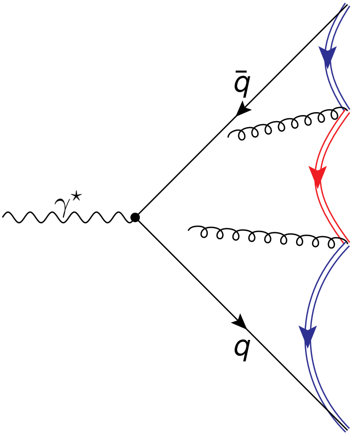

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Colour reconnections

Colour reconnections is a way to include effects of $N_C < \infty$. The guiding principles are:

- Probability to reconnect $\sim 1/N_C^2$
- Nature likes short strings
- There are no colour-singlet gluons.

[Sjöstrand, Khoze, Gustafson, Zerwas, Lönnblad, Edin, Ingelman, Rathsman, Gieseke, Kirchgaeßer, . . .]

Short strings?

We typically measure the string lengths in terms of the λ-measure

For a string consisting of n dipoles between a quark and an anti-quark connected with $n-1$ gluons:
$(q_0 - g_1 - g_2 - \cdots - g_{n-1} - \bar{q}_n)$

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$\lambda \propto$ number of produced hadrons

Perturbative effects

We expect effects of $N_C = 3 < \infty$ also on the perturbative level.

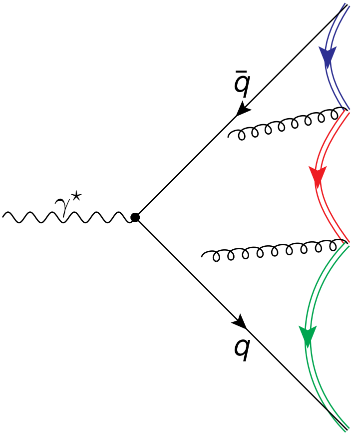
We want a full-colour parton shower, but this probably requires an amplitude-level parton shower scheme, which can become very messy.

Instead modify what we have: the dipole shower.

Amend it with dipole reconnections between each emission.

Let's put some swing into the the dipole shower!

The Dipole Swing



- Assign a colour index (1-9) to each dipole
- Dipoles connected with a gluon must have $c_i \neq c_j$
- Only dipoles with the same index may swing
- Let's Swing

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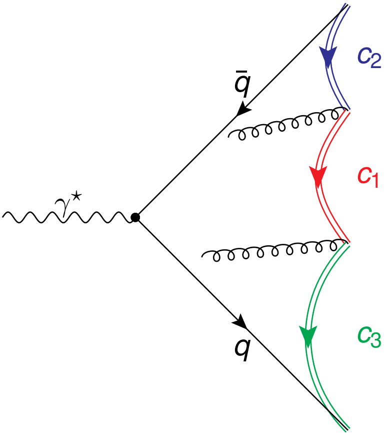

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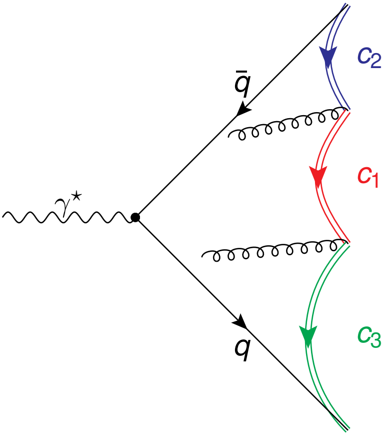

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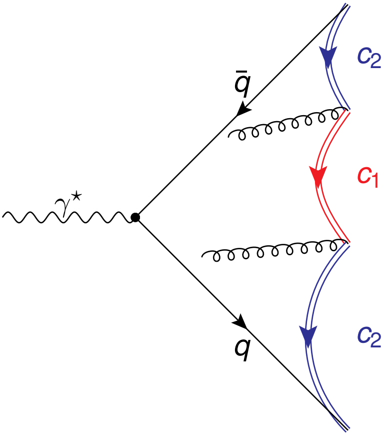

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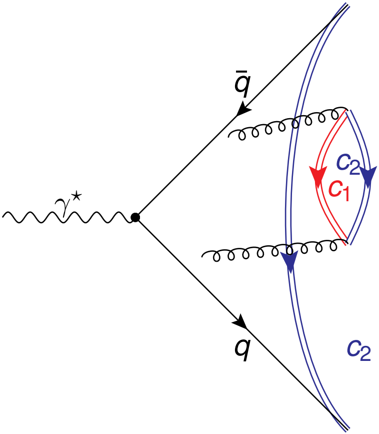

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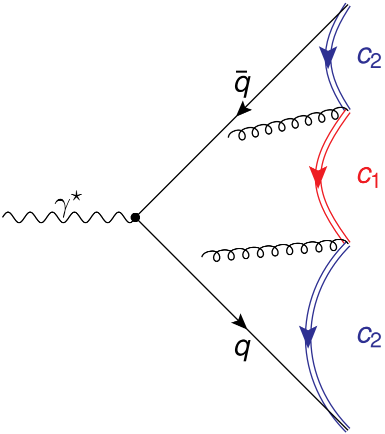

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- Let's Swing both ways

The dipole emissions are limited by the dipole mass (cf. angular ordering)

The dipole shower is ordered in transverse momentum, $k_\perp$

The distribution of the *next* emission is given by

$$\frac{d\mathcal{P}}{dk_\perp^2} = \frac{\alpha_S}{k_\perp^2}\sum_i \int dz\, P_i(z) \times \Delta(k_{\perp\max}^2, k_\perp^2)$$

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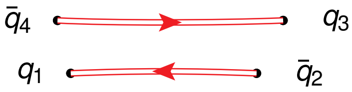
Add the probability that a dipole may swing

$$\frac{d\mathcal{P}_{\rm swing}}{dk_\perp^2} = \lambda \frac{m_{12}^2 m_{34}^2}{m_{14}^2 m_{32}^2} \times \Delta_{\rm swing}(k_{\perp\max}^2, k_\perp^2)$$

where λ is a strength parameter



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- For large λ the effect saturates
- The weighted average of the radiation from the two dipole pair configuration emulates quadrupole radiation.
- Prefers small mass dipoles giving less radiation
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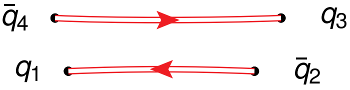

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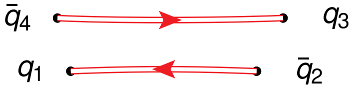

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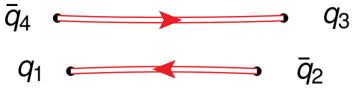

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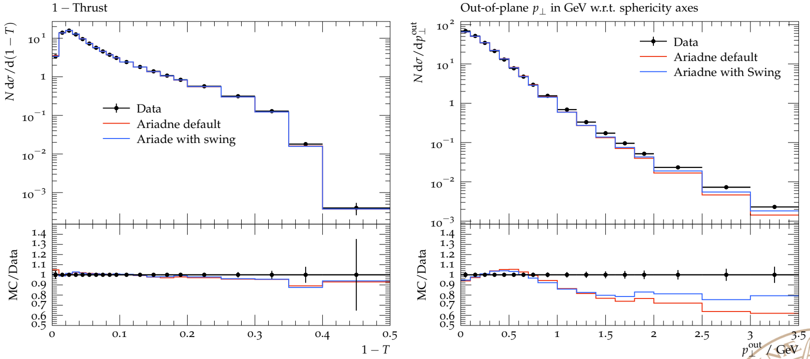
Small effects in e^+e^- (after retuning)



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- Collective effect are generated through *string interactions* (Rope model, shoving model and *Swing*)

Swing in Angantyr

Basic assumption 1: There is no *medium*, only quarks and gluons with varying $p_\perp$.

Basic assumption 2: The interesting DoF are not the partons themselves but the colour field (*dipoles*) between them.

Basic requirement 1: The momentum-space picture of dipole swings needs to be amended with a space-time picture.

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(c.f. *parallel frame* in S. Charkraborty's talk)

Preliminary Results

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- No Jets → hadron correlations
- No AA → pp@7TeV
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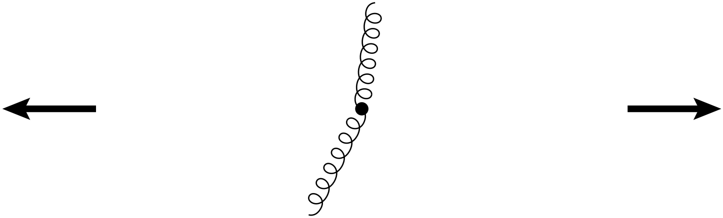
Pythia MPI and Colour (Re-)connections



[PRD**36**(1987)2019]

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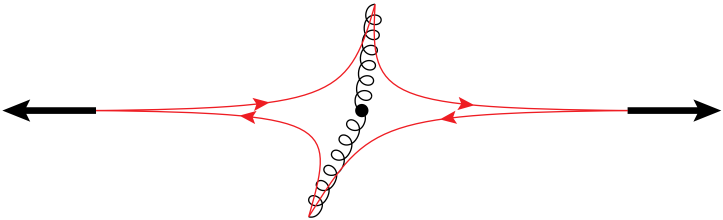

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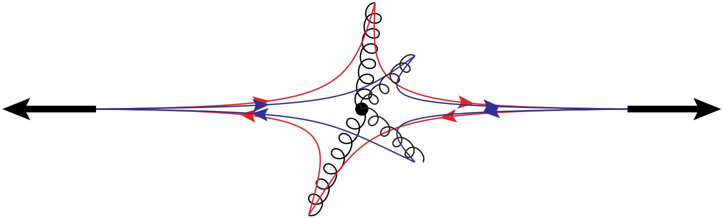

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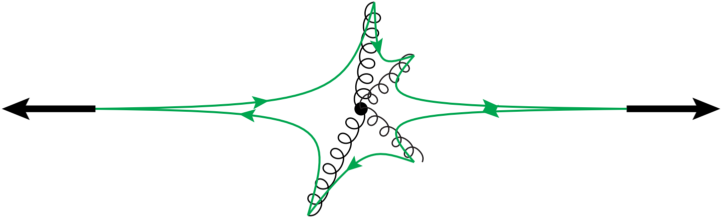

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If all of them can stretch all the way back to the proton remnants soft multiplicity increases too much

To be able to describe observables such as $\langle p_\perp \rangle(n_{\mathrm{ch}})$ we need (a lot of) colour (re-)connections.

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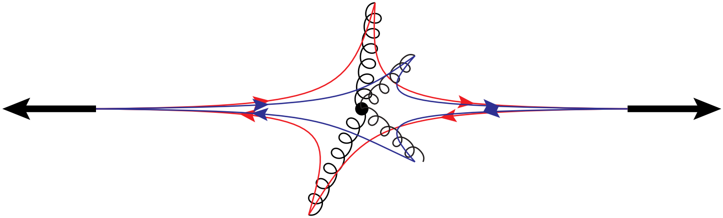

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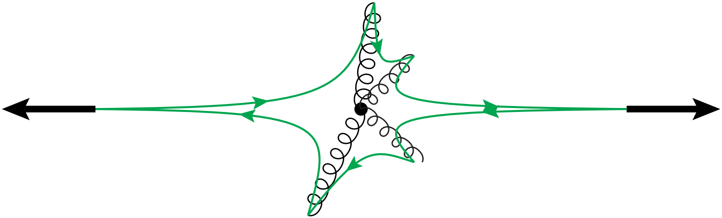

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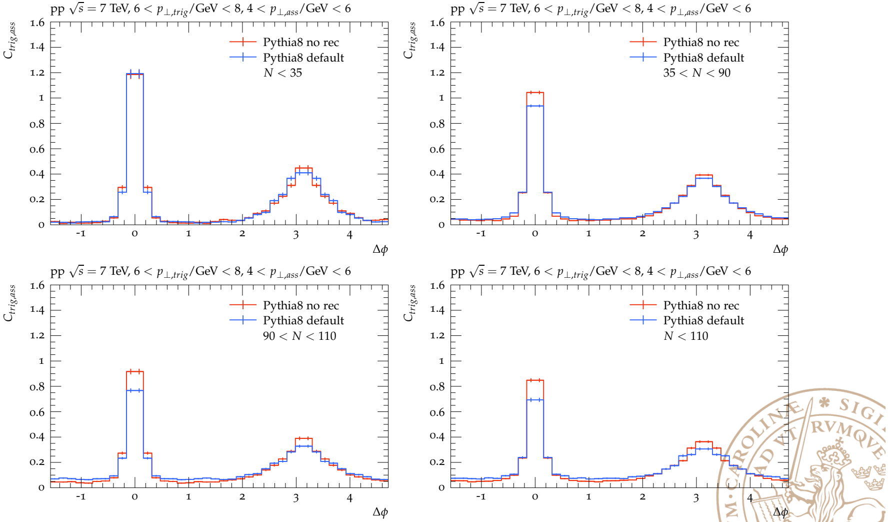
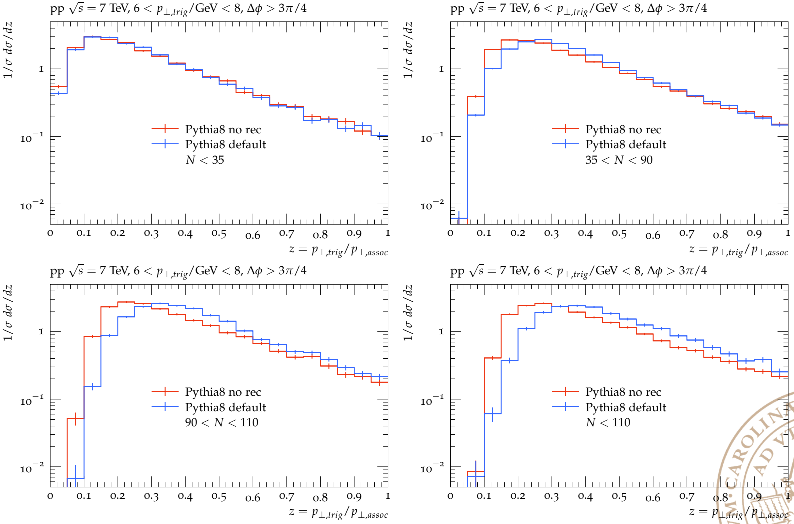
Charged hadron correlations



Hadron $p_\perp$ ratios



Outlook

- Colour reconnections will affect jets
- Swing will affect the perturbative evolution of jets
- With a proper space-time picture we can investigate quenching-like effect in pp, $\mathrm{p}A$ and AA with Angantyr.

Thanks!

Vetenskapsrådet

MCnet
Marie Curie Actions Human resources and mobility

erc
European Research Council
Established by the European Commission

Knut and Alice Wallenberg Foundation

CLASH

Colour Reconnections

- Sjöstrand et al., Phys.Rev. D36 (1987) 2019
- Gustafson et al., Z.Phys. C64 (1994) 659-664
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