The final state swing

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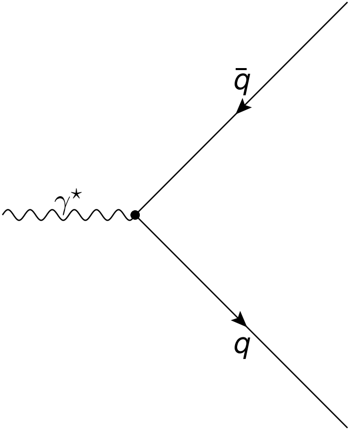
Outline

- Parton showers,“Pre-confinement” and the size of N_C
- Colour reconnections
- The dipole swing in the shower
- Outlook ($\mathrm{p}A$ & AA)

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.

Parton and dipole showers



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- Dipole splitting
- Pre-confinement: partons close in phase space are likely to be colour-connected.
  Nature likes short strings.
- $N_C \to \infty$ gives a unique colour flow.
- But $N_C = 3$.

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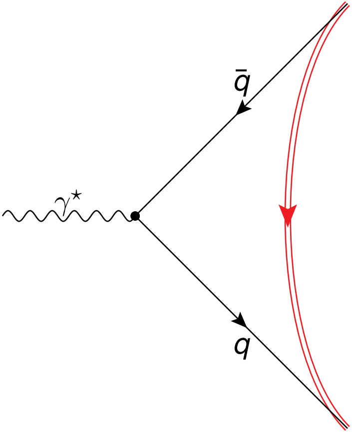

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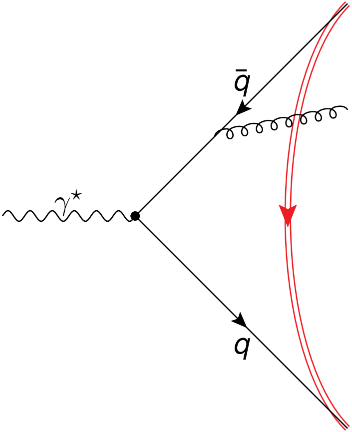

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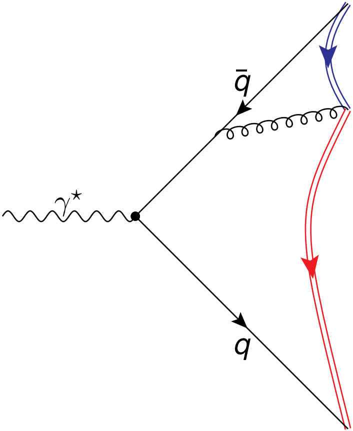

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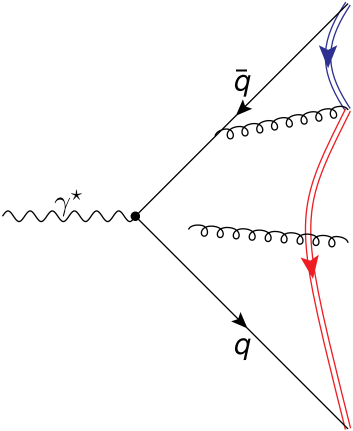

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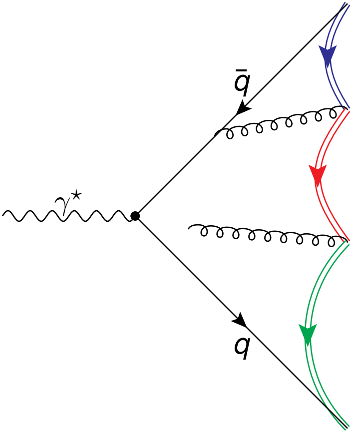

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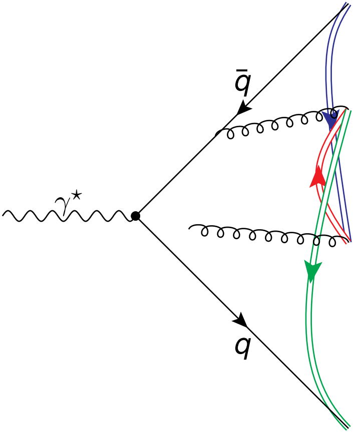

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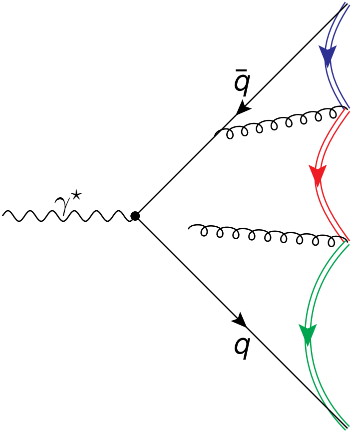

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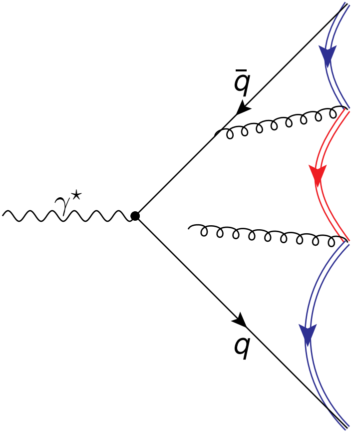

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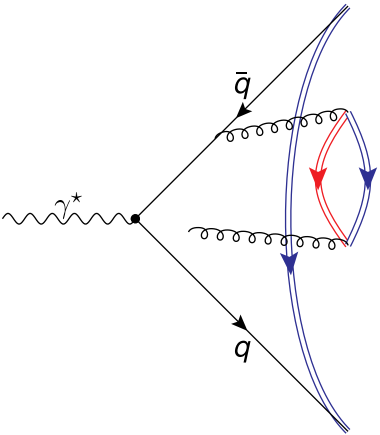

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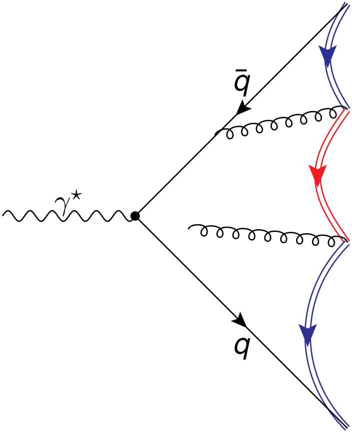

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Colour reconnections

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:
$(q_0 - g_1 - g_2 - \cdots - g_{n-1} - \bar{q}_n)$

$$\lambda = \sum_{i=0}^{n-1} \log\left(1 + \frac{m^2_{i,i+1}}{m_0^2}\right)$$

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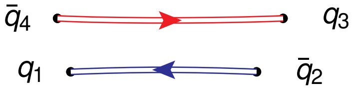
Simple reconnections



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- with probability $1/N_C^2$
- only if $m_{14}m_{23} < m_{12}m_{34}$

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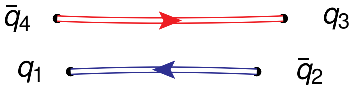

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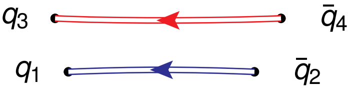

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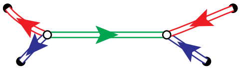

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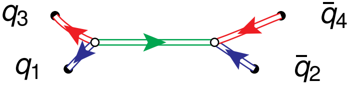

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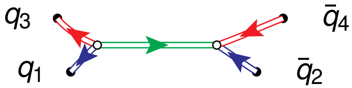

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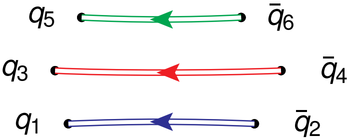

Reconnect?

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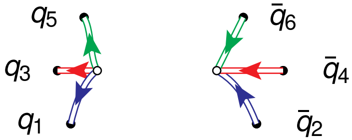

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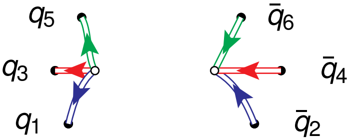

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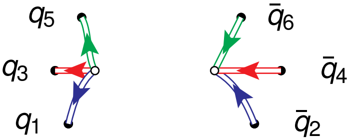

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Perturbative effects

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

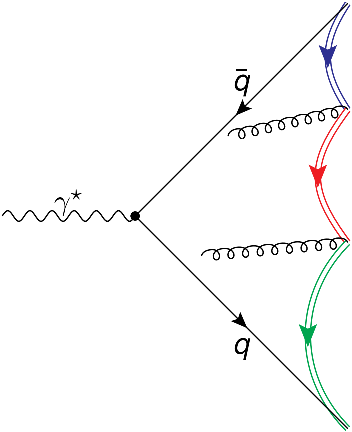
We want a full-colour parton shower, but this probably requires an amplitude-level parton shower scheme, which can become very messy.

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 $c_i \neq c_j$
- New colour index between the emitted gluon and the emitter
- Only dipoles with the same index may swing
- Let's Swing

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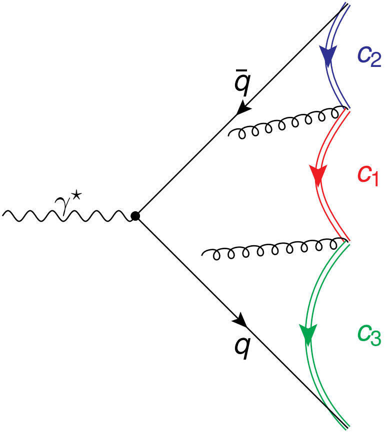

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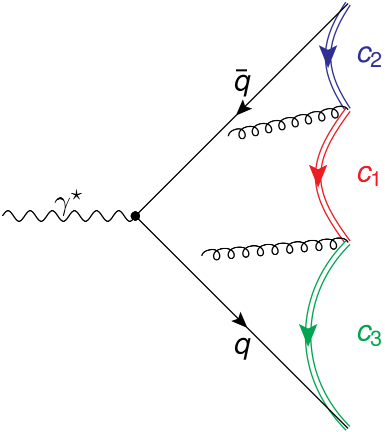

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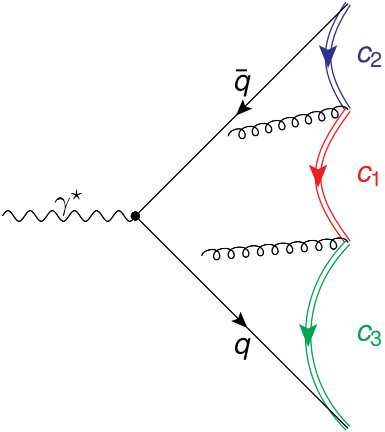

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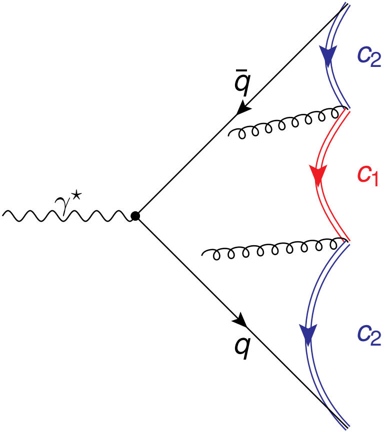

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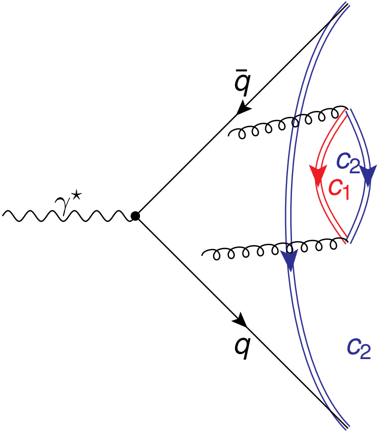

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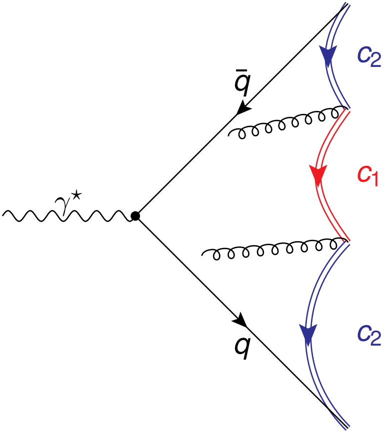

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- Let's Swing both ways

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

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

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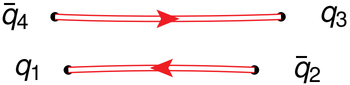
Add the probability that a dipole may swing

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

where λ is a strength parameter



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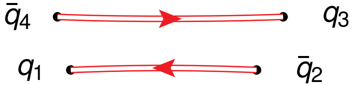

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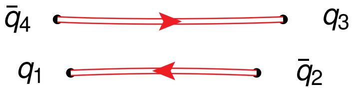

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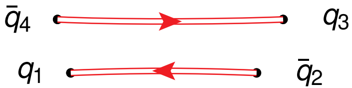

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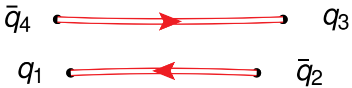

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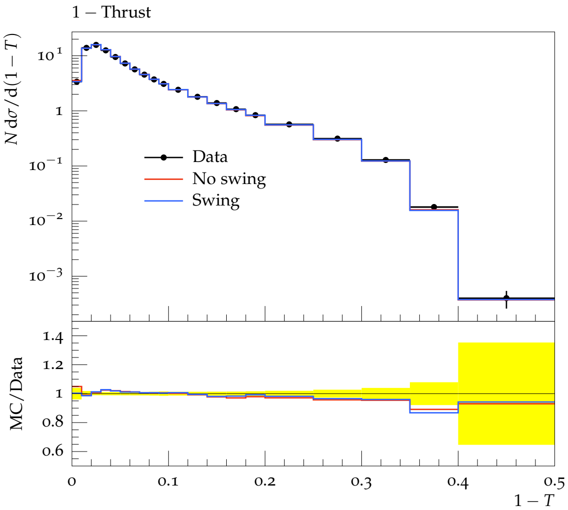

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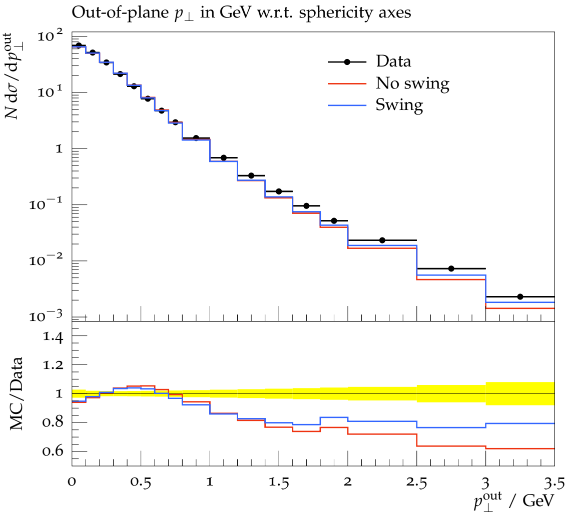

Outlook

- Implemented in Ariadne (DIPSY)
- Will be implemented in Pythia8 (Angantyr)
- Need to include a space-time picture in $\mathrm{p}A$ & AA
- Will affect flow and jet shapes

Thanks!

Vetenskapsrådet

MCnet
Marie Curie Actions Human resources and mobility

erc
European Research Council
Established by the European Commission

Knut and Alice Wallenberg Foundation

Colour Reconnections

- Sjöstrand et al., Phys.Rev. D36 (1987) 2019
- Gustafson et al., Z.Phys. C64 (1994) 659-664
- Sjöstrand et al., Phys.Rev.Lett. 72 (1994) 28-31
- Edin et al., Phys.Lett. B366 (1996) 371-378
- Lönnblad, Z.Phys. C70 (1996) 107-114
- Gieseke et al., JHEP 1811 (2018) 149