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Soft gluon resummation for gaps between jets

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In collaboration with Jeff Forshaw and James Keates

arXiv:0905.1350 [hep-ph]
(accepted by JHEP)

Outline

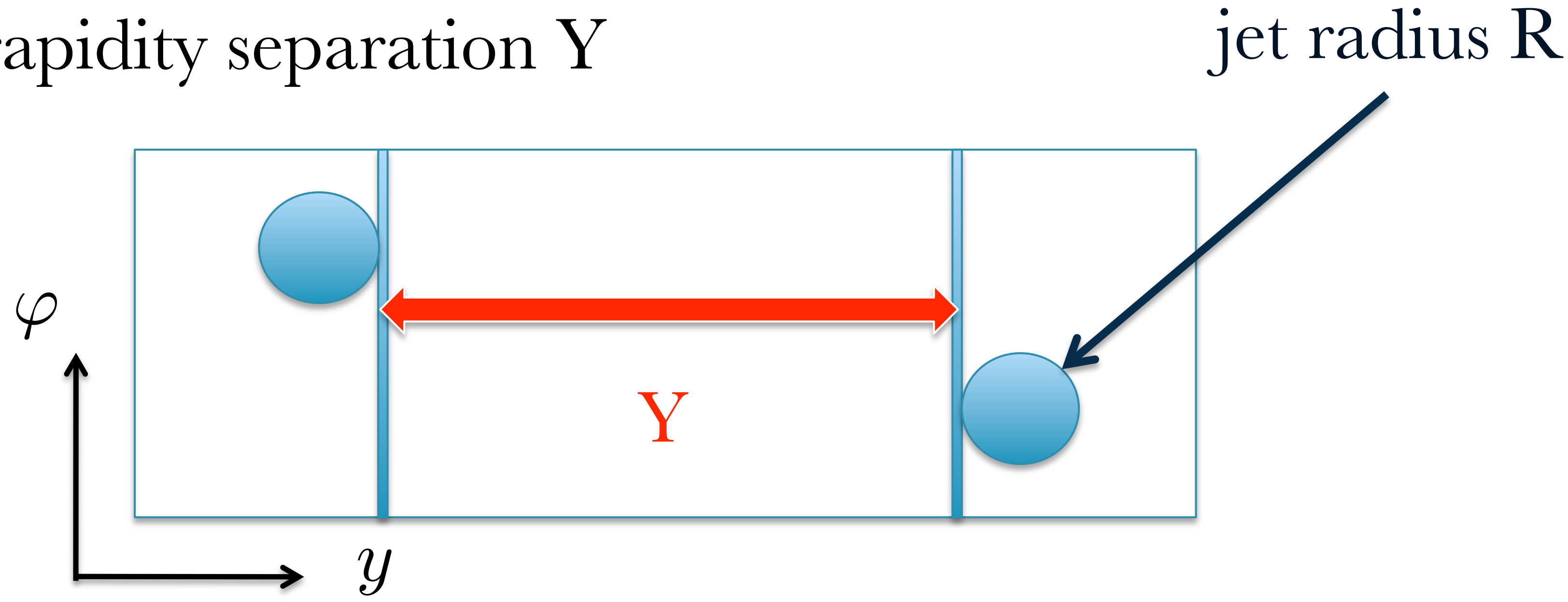
- Jet vetoing: Gaps between jets
  - Global and non-global logarithms
  - Discovery of super-leading logarithms
- Some LHC phenomenology
  - Global logarithms
  - Super-leading logarithms
- Conclusions and Outlook

Jet vetoing:
Gaps between jets

The observable

Production of two jets with

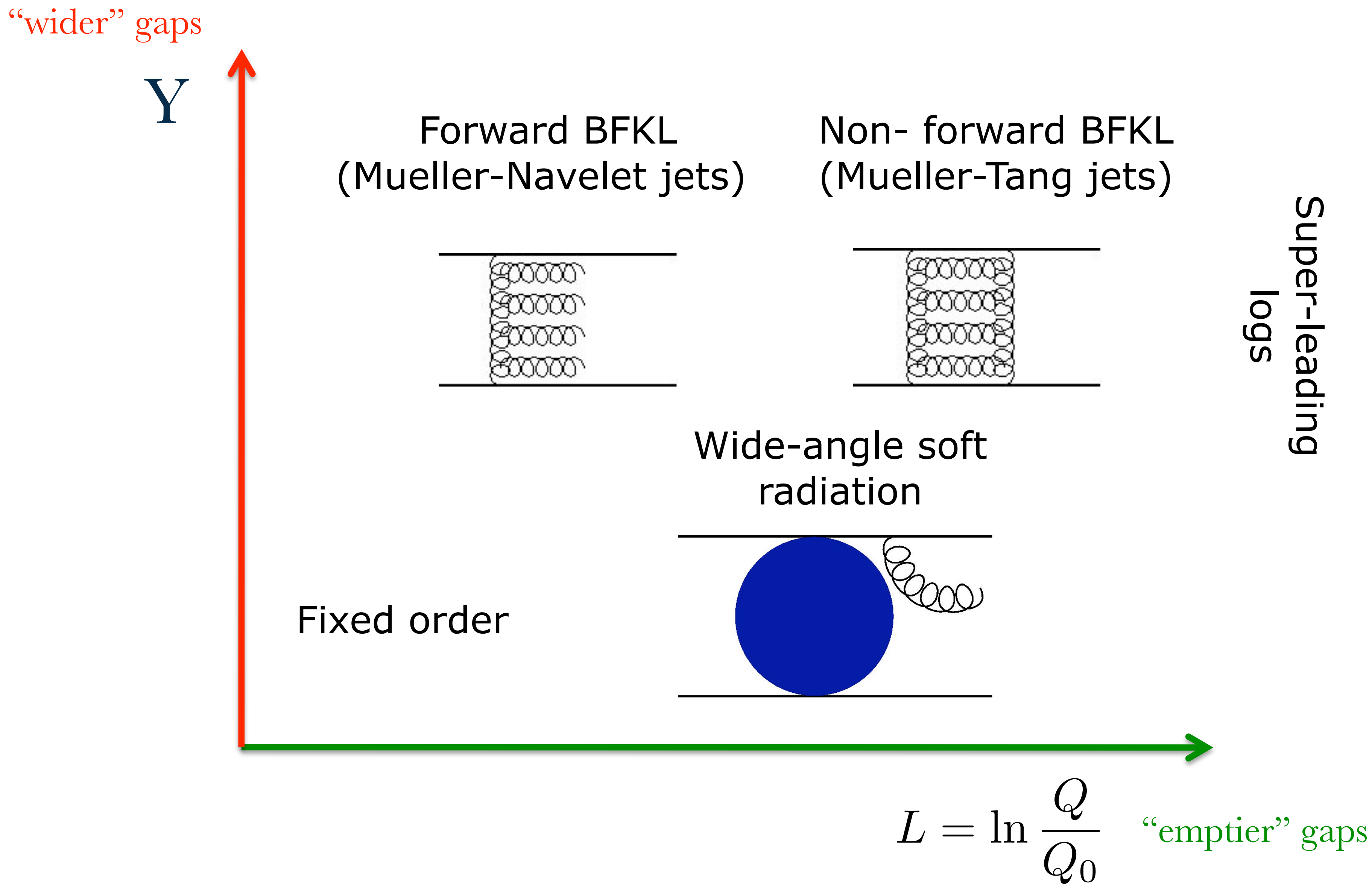
- transverse momentum Q
- rapidity separation Y



- Emission with $k_T > Q_0$ forbidden in the inter-jet region

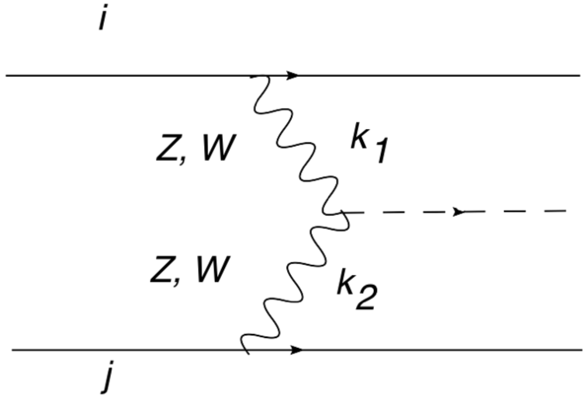
Q_0 can be rather large: the gap is a region of limited hadronic activity

Plenty of QCD effects

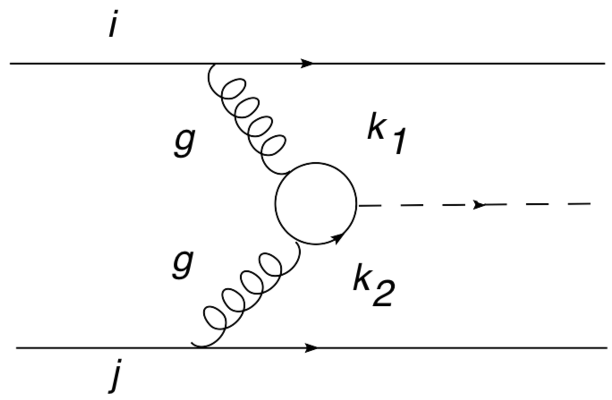


Higgs +2 jets

Weak boson fusion



Gluon fusion



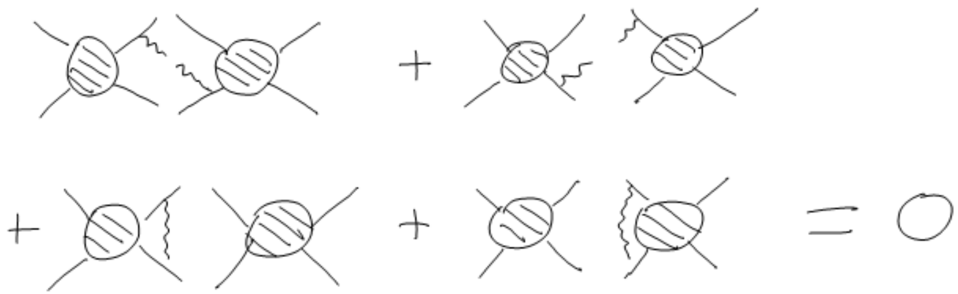
- Different QCD radiation in the inter-jet region
- To enhance the WBF channel, one can make a veto Q_0 on additional radiation between the tagged jets
- QCD radiation as in dijet production

Forshaw and Sjödahl
arXiv:0705.1504 [hep-ph]

- Important in order to extract the VVH coupling

Soft gluons in QCD

- What happens if we dress a hard scattering with soft gluons?
- Sufficiently inclusive observables are not affected: real and virtual cancel via Bloch-Nordsieck theorem



- Soft gluon corrections are important if the real radiation is constrained into a small region of phase-space
- In such cases BN fails and miscancellation between real and virtual induces large logarithms

$$-\alpha_s \int_0^{Q_0} \frac{dE}{E}\Big|_{\rm real} + \alpha_s \int_0^{Q} \frac{dE}{E}\Big|_{\rm virtual} = \alpha_s \int_{Q_0}^{Q} \frac{dE}{E}\Big|_{\rm virtual} = \alpha_s \ln \frac{Q}{Q_0}$$

Soft gluons in gaps between jets

- Naive application of BN:

  real and virtual contributions cancel everywhere except within the gap region for $k_T > Q_0$

  - One only needs to consider virtual corrections with

$$Q_0 < k_T < Q$$

- Leading logs (LL) are resummed by iterating the one-loop result:

$$\mathcal{M} = e^{-\alpha_s L \Gamma} \mathcal{M}_0$$

soft anomalous dimension

Born

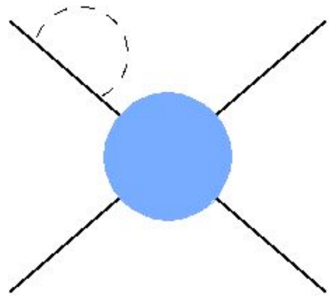
Oderda and Sterman
hep-ph/9806530

Colour evolution (I)

- The anomalous dimension can be written as

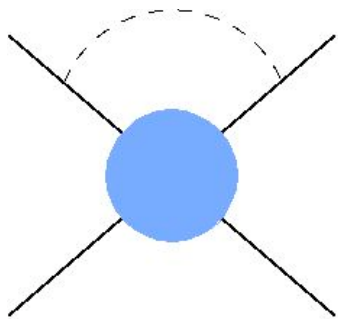
$$\Gamma = \frac{1}{2} Y T_t^2 + i\pi T_1 \cdot T_2 + \frac{1}{4}\rho(T_3^2 + T_4^2)$$

- T_i is the colour charge of parton i
- T_i^2 is a Casimir



- $T_t^2 = (T_1^2 + T_3^2 + 2T_1 \cdot T_3)$

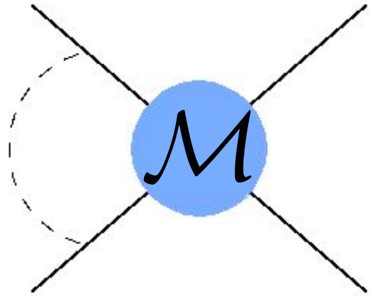
is the colour exchange in the t-channel



Coulomb gluons

- The $i\pi$ term is due to Coulomb (Glauber) gluon exchange

$$i\pi\, T_1 \cdot T_2\, \mathcal{M} =$$



- It doesn't play any role for processes with less than 4 coloured particles (e.g. DIS or DY)

$$T_1 + T_2 + T_3 = 0 \Rightarrow T_1 \cdot T_2 = \frac{1}{2}\left(T_3^2 - T_1^2 - T_2^2\right)$$

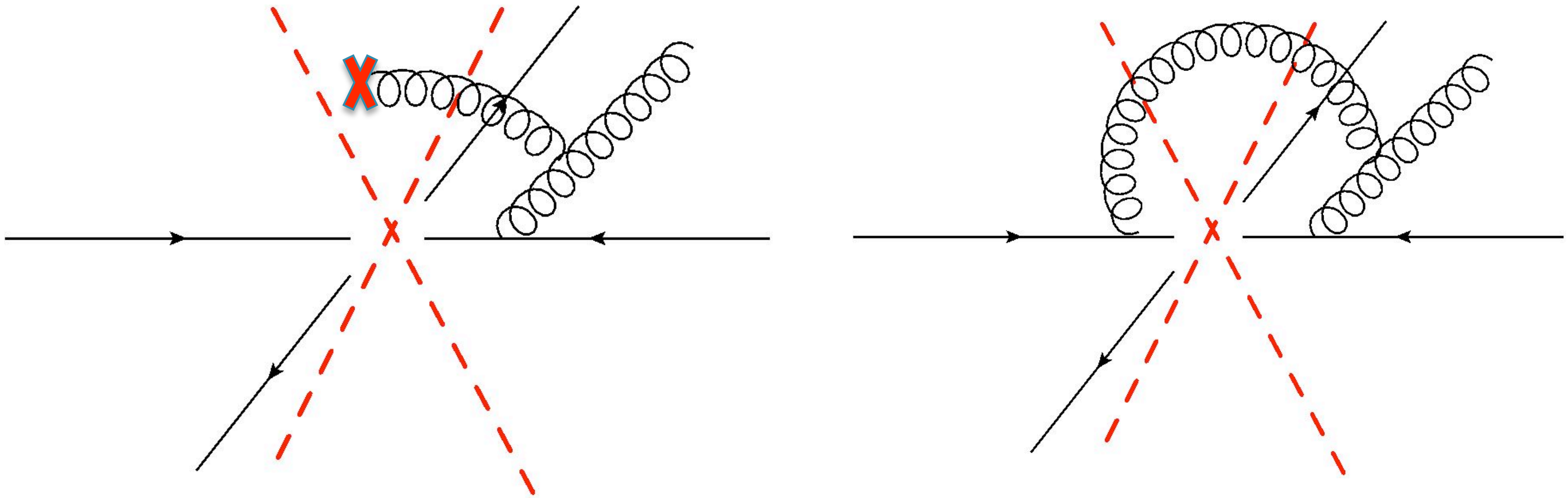
leading to an unimportant overall phase

- Coulomb gluon contributions are *not* implemented in parton showers

Non-global effects

Dasgupta and Salam
hep-ph/0104277

- However this approach completely ignores a whole tower of LL
- Virtual contributions are not the whole story because real emissions out of the gap are forbidden to remit back into the gap



Resummation of non-global logarithms

- The full LL result is obtained by dressing the $2 \rightarrow n$ (i.e. *n-2* out of gap gluons) scattering with virtual gluons (and not just $2 \rightarrow 2$)
- The colour structure soon become intractable
- Resummation can be done (so far) only in the large N_c limit

Dasgupta and Salam
hep-ph/0104277

Banfi, Marchesini and Smye
hep-ph/0206076

One gluon outside the gap

- As a first step we compute the tower of logs coming from only one out-of-gap gluon but keeping finite N_c:

$$\sigma^{(1)} = -\frac{2\alpha_s}{\pi} \int_{Q_0}^{Q} \frac{dk_T}{k_T} \int_{\text{out}} (\Omega_R + \Omega_V)$$

Real contribution:
- real emission vertex D^μ
- 5 - parton anomalous dimension Λ

Virtual contribution:
- virtual eikonal emission γ
- 4-parton anomalous dimension Γ

Sjödahl
arXiv:0807.0555 [hep-ph]

A big surprise

Conventional wisdom ("plus prescription" of DGLAP)
when the out-of-gap gluon becomes collinear with one of the external partons the real and virtual contributions should cancel

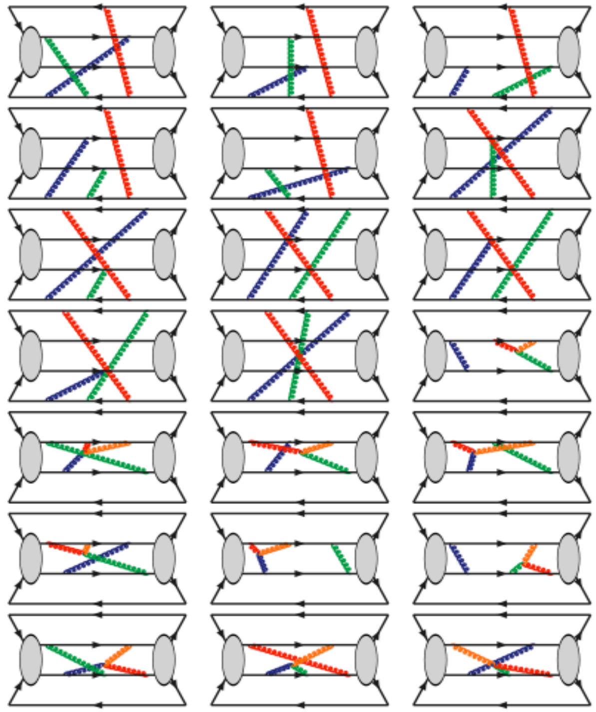
- It works when the out-of-gap gluon is collinear to one of the outgoing partons ✓
- But it fails for initial state collinear emission ✗
- Cancellation *does* occur for up to 3rd order relative to the Born, but fails at 4th order
- The problem is entirely due to the emission of Coulomb gluons
- As result we are left with super-leading logarithms (SLL):

$$\sigma^{(1)} \sim -\alpha_s^4 L^5 \pi^2 + \ldots$$

Forshaw Kyrieleis Seymour
hep-ph/0604094

Fixed order calculation

- Gluons are added in all possible ways to trace diagrams and colour factors calculated using COLOUR
- Diagrams are then cut in all ways consistent with strong ordering
- At fourth order there are 10,529 diagrams and 1,746,272 after cutting.
- SLL terms are confirmed at fourth order and computed for the first time at 5th order



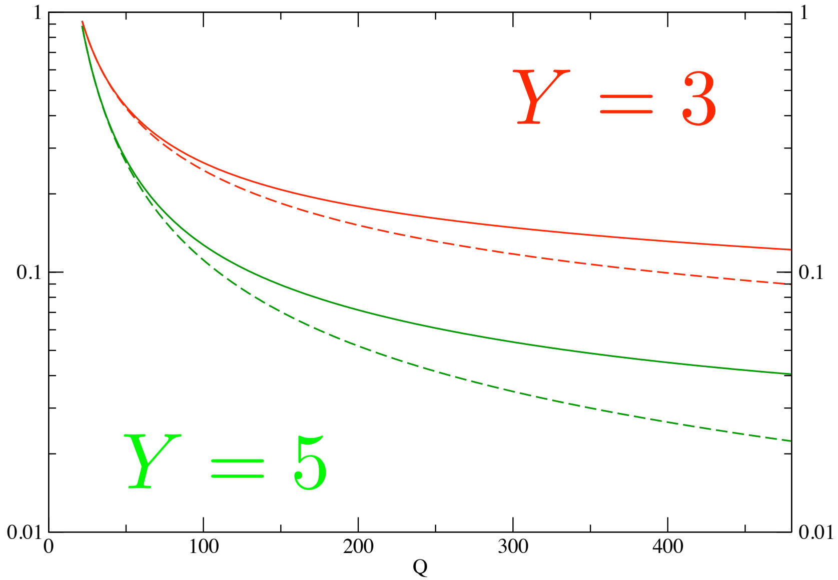
Keates and Seymour
arXiv:0902.0477 [hep-ph]

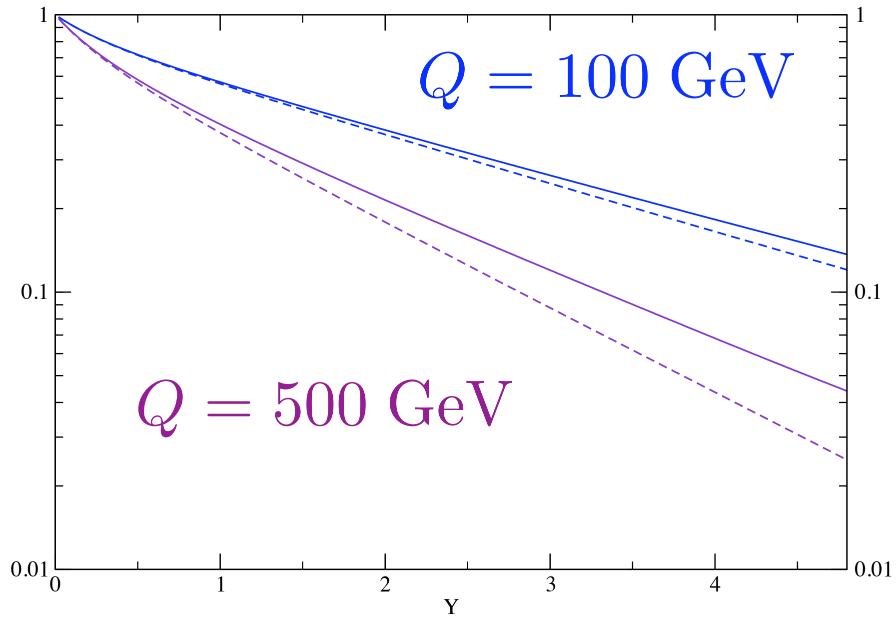
Some LHC phenomenology

Global logs and Coulomb gluons (no gluon outside the gap)

$$f^{(0)} = \sigma^{(0)}/\sigma^{\text{born}}$$

$\sqrt{S}$ = 14 TeV
Q_0 = 20 GeV
R = 0.4
η_{cut} = 4.5

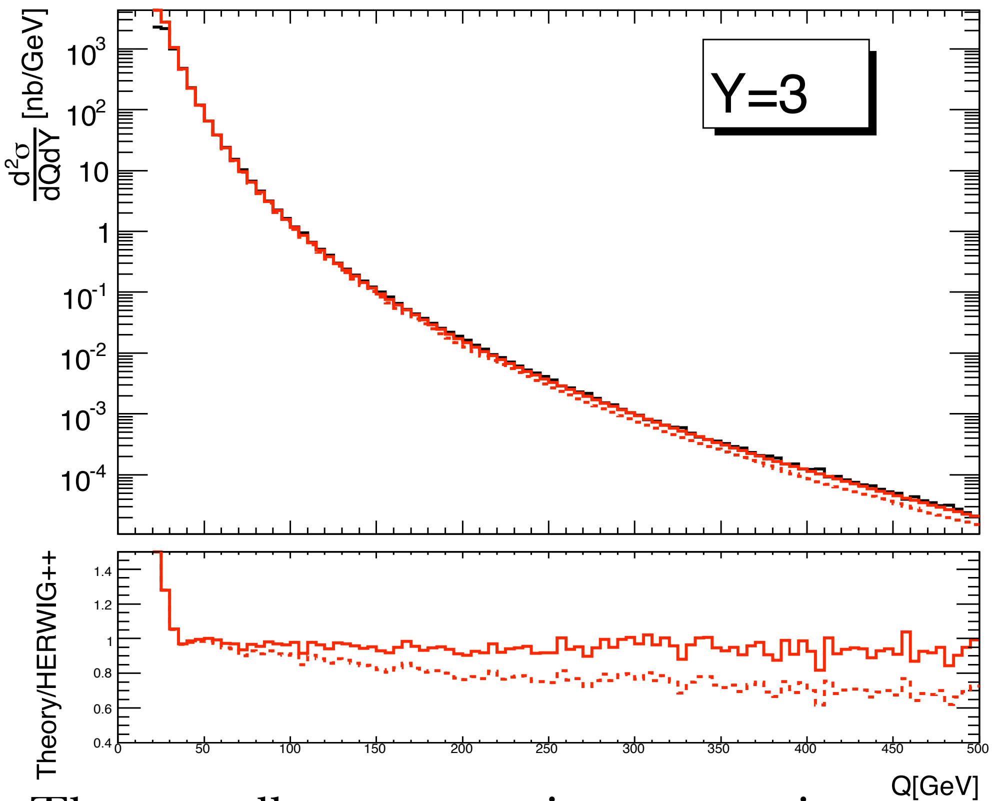




- solid lines: full resummation
- dashed lines: ignoring $i\,\pi$'s

Large Coulomb gluon contributions !

Comparison to HERWIG++ (gap cross-section)

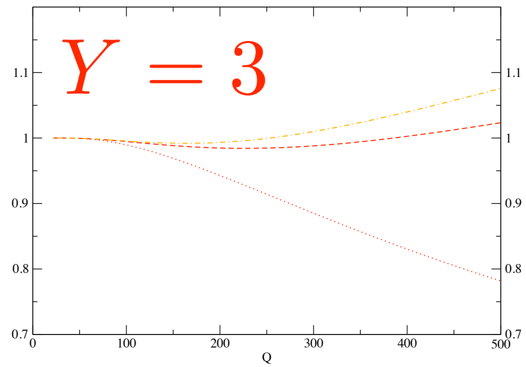


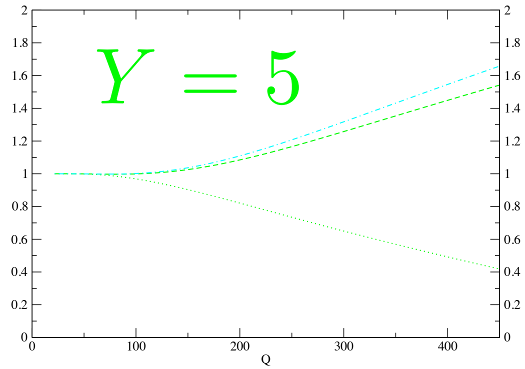
- We compare our results to HERWIG++
- LO scattering + parton shower (no hadronisation)
- Q is the mean p_T of the leading jets
- Jet algorithm SIScone

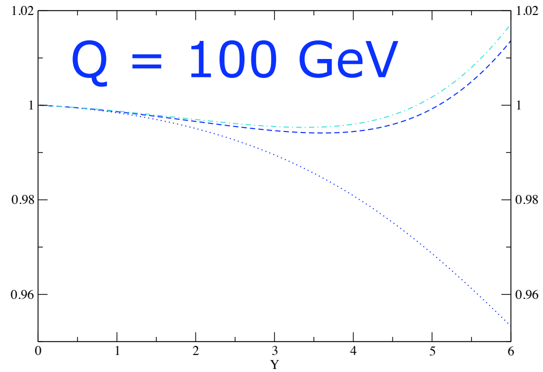
- The overall agreement is encouraging
- One should compare the histogram to the dotted curve (no Coulomb gluons)
- Energy-momentum conservation plays a role: we need matching to NLO
- Other differences: large N_c limit and non-global effects

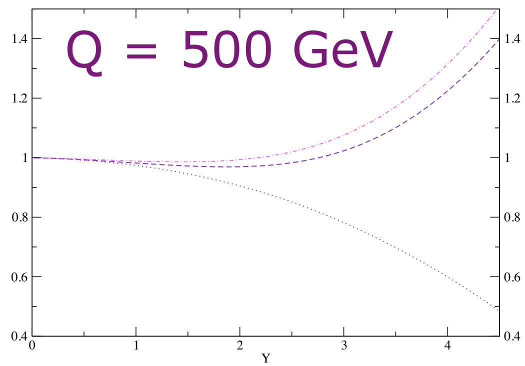
Phenomenology of SLL (I)

$$(\sigma^{(0)} + \sigma^{(1)} + \sigma^{(2)})/\sigma^{(0)}$$







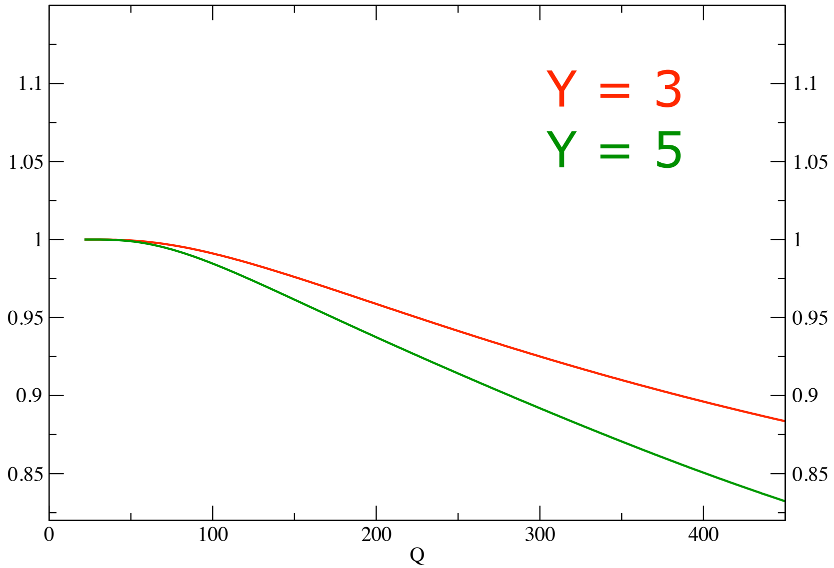


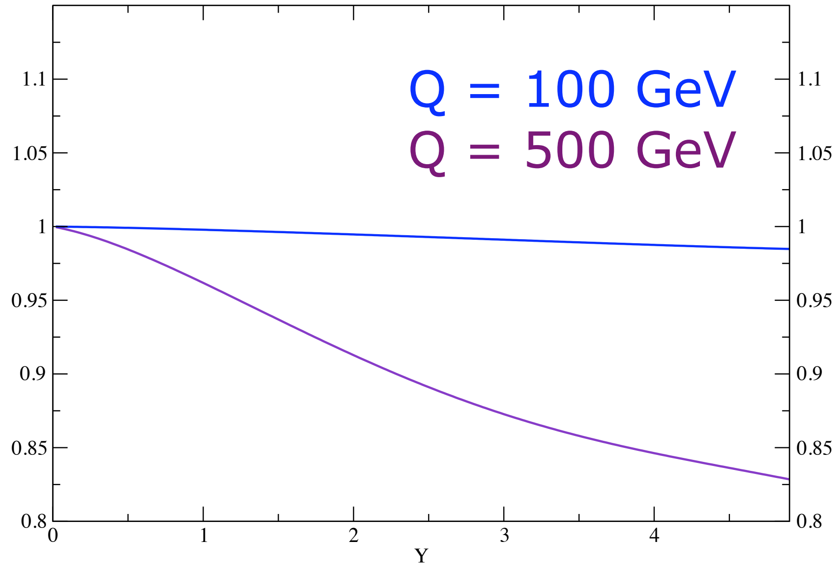
- dotted, one gluon, α_s^4
- dashed: one gluon, up to α_s^5
- dash-dotted: one+two gluons, up to α_s^5

instability:
need of resummation

Phenomenology of SLL (II)

Resummed results (one out-of-gap gluon)





- Y = 3, ~ 5 %
- Y = 5, ~10 -15%

- Q = 100 GeV, ~ 2 %
- Q = 500, ~10 -15%

- SLL could have an effect as big as 10-15 % in quite extreme dijet configurations
- There are no SLL effect on Higgs+ jj, unless Q_0 < 10 GeV

Conclusions

- There is plenty of interesting QCD physics in gaps between jets
- Soft logs may be relevant for extracting the Higgs coupling to the weak bosons
- Coulomb gluons play an important role
- Dijet cross-section could be sensitive to SLL at large Y and L (e.g. 300 GeV and $Y = 5$, ~15%)

Outlook

- Matching the resummation to fixed order
- Understanding the origin of super-leading logs
  - k_t ordering ?
  - interaction with the remnants ?

on-going projects in Manchester
(SM, Dasgupta, Forshaw,
Seymour, Wang)

- There is an interesting link between non-global logs and BK equation

Banfi, Marchesini and Smye
hep-ph/0206076
Avsar, Hatta and Matsuo
arXiv:0903.4285 [hep-ph]

BACKUP SLIDES

An interesting link to small-x

- The non-linear evolution equation which resums non-global logs resembles the BFKL/BK equations (in the dipole picture)

$$\frac{d^2\Omega_c}{4\pi} \frac{1-\cos\theta_{ab}}{(1-\cos\theta_{ac})(1-\cos\theta_{cb})} \to \frac{d^2\mathbf{x}_c}{2\pi} \frac{\mathbf{x}_{ab}^2}{\mathbf{x}_{ac}^2\mathbf{x}_{cb}^2}$$

- The two kernels can be mapped via a stereographic projection

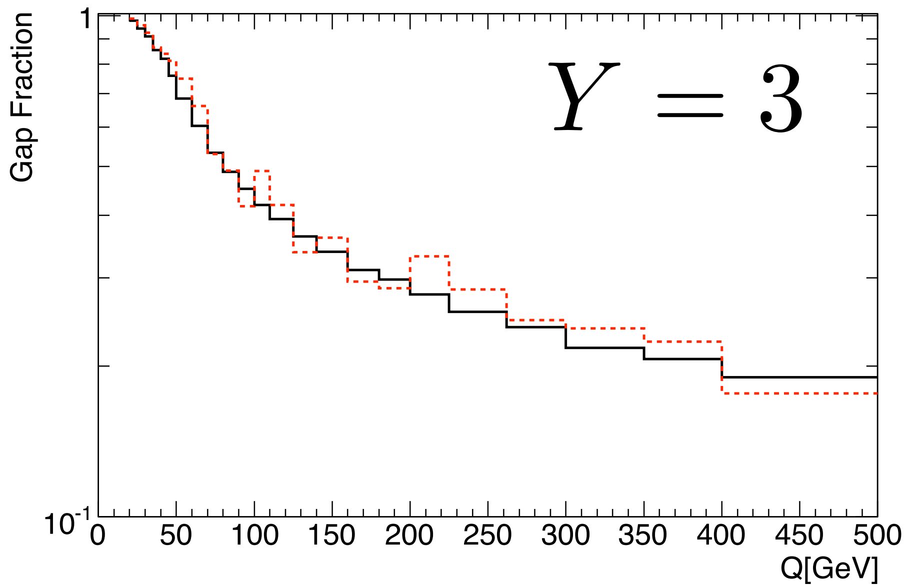
$$\Omega = (\theta, \phi) \to \mathbf{x} = (x^1, x^2)$$

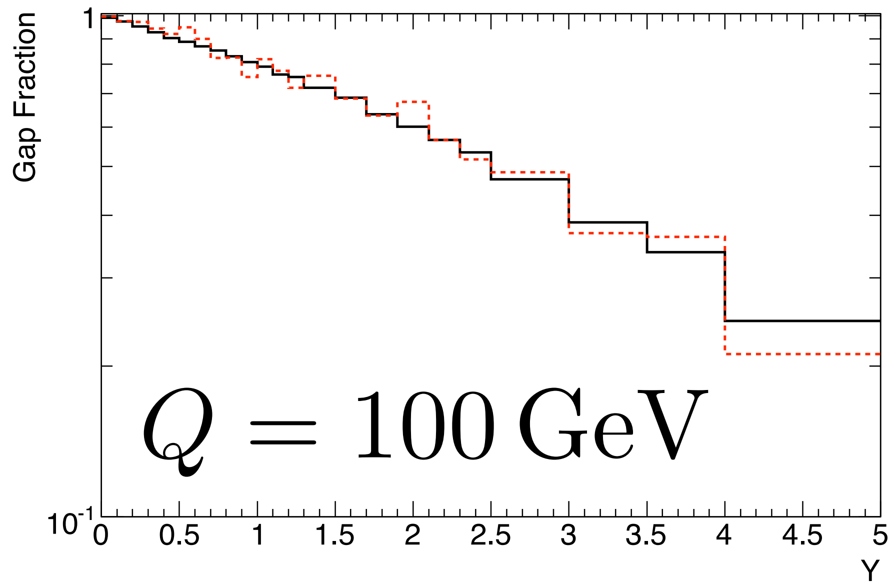
Avsar, Hatta and Matsuo
arXiv:0903.4285 [hep-ph]

- Is there a fundamental connection between non-global (soft) evolution and small-x ?

Hadronisation effects

- Hadronisation is “gentle”
- It does not spoil the gap fraction





- black line: after parton shower
- red line: after hadronisation