Super-leading Logarithms in QCD and Gaps-between-Jets at ATLAS

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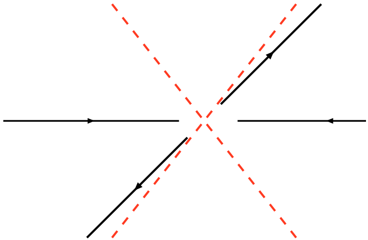
Real and Virtual Emission

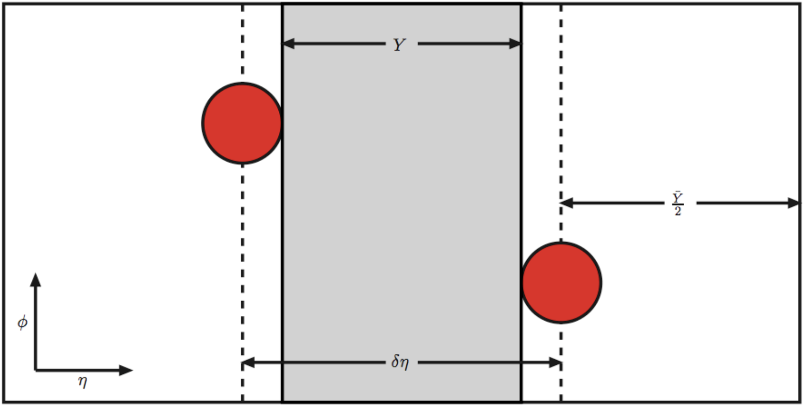
- Emission of a gluon off a quark has singularities in the soft and colinear limits.
- These singularities cancel between real and virtual emissions.
- In the soft (Eikonal) limit, the entire correction cancels.
- Observables which restrict these emissions contain large logarithms.
- The logarithms are resummed (exponentiated) to provide an all orders solution.

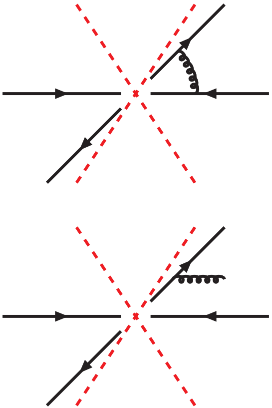
Gaps between Jets

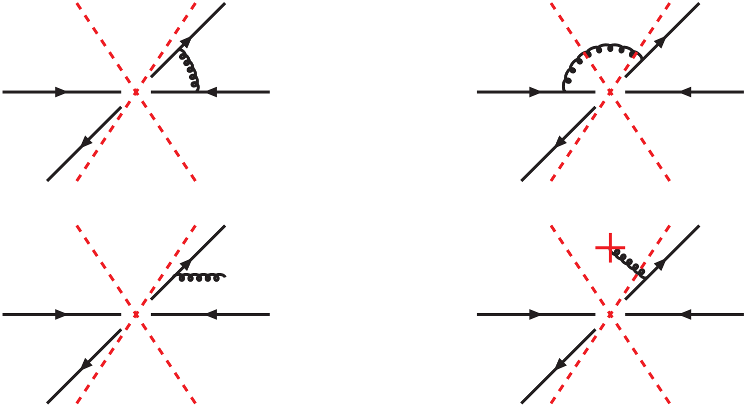
- One example of a process restricting emission is when a rapidity gap (of size Y) is required in di-jet events.
- Real emissions above a certain energy (Q_0) are not allowed between the two jets.
- This removes the cancelation between real and virtual parts, within the gap.



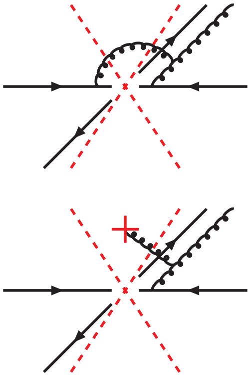
Gaps between Jets







Non-global Effects



- The work of Dasgupta and Salam [hep-ph/0203009] showed that it is also necessary, at higher orders to take into account out of gap gluons which re-emit.
- This provides a new source of logarithmic corrections, known as non-global as they appear only in non-global observables.

Super-leading Logarithms

- Non-global logarithms can be resummed only in the limit of large N_C.
- Forshaw, Kyrieleis and Seymour [hep-ph/0604094] investigated what happened in the exact N_C limit, for the case of one gluon outside the gap in qq scattering.
- They found the unexpected result that a previously unknown term should appear in the perturbation series.
- They called this formally more important term, appearing at order α_s^4, a super-leading logarithm.

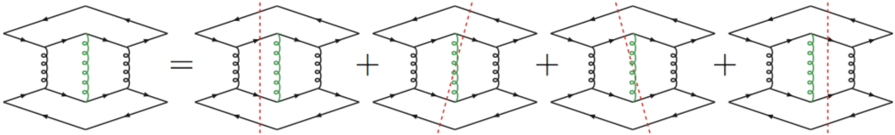
$$\sigma_4 \propto \sigma_0 \alpha_s^4 ln^4\left(\frac{Q}{Q_0}\right) \quad (1) \qquad \sigma_{SLL} \propto -\sigma_0 \alpha_s^4 ln^5\left(\frac{Q}{Q_0}\right) \quad (2)$$

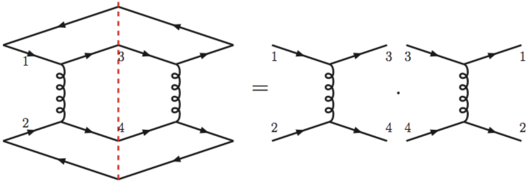
Fixed Order Approach

- To perform these calculations approximations must be made
- Non-global logarithms: large N_C limit, resummed
- Super-leading logarithms: Exact N_C, resummed for one gluon outside the gap
- Fixed order: Exact N_C, any number of out of gap gluons, fixed order in α_s
- JK and M. H. Seymour [arXiv:0902.0477]

Diagrammatic Method

- Keep track of calculation using diagrams
- Uncut diagrams represent sum of cut diagrams
- Cut diagrams represent squared matrix elements
- We assume soft gluons and strong k_t ordering
- By producing all uncut, cut and ordered diagrams, we can produce whole calculation
- Computerised due to large number of diagrams



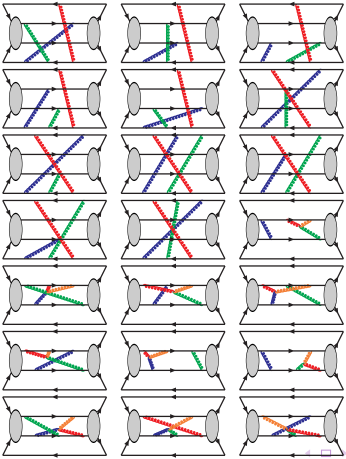


$|\mathcal{M}|^2$ $\qquad$ $\mathcal{M}$ $\qquad$ $\mathcal{M}^*$

How the Program Works.

- First, from an input hard process, form an uncut diagram.
- Add required number of gluons in all possible ways (6, 55, 681, 10529, 193741. . .).
- Calculate colour factors for all diagrams at this stage, by interface to COLOUR program.
- Cut diagrams in all possible ways consistent with strong ordering, to produce normal Feynman diagrams. (127 million at fifth order!).
- Sum over all cut diagrams, collecting together integrals to be done
- Nested k_t and y integrals retrieved from a look-up table

Diagrams produced by Program



Results

$$\sigma_{0,qq,\alpha_s^4} = \sigma_0 \left(\frac{2\alpha_s}{\pi}\right)^4 \ln^4\left(\frac{Q}{Q_0}\right)\left[Y^4 \frac{N^4}{24} - \pi^2 Y^2 \frac{5(N^2-1)}{96}\right], \quad (3)$$

$$\sigma_{1,qq,\alpha_s^4} = -\sigma_0 \left(\frac{2\alpha_s}{\pi}\right)^4 \ln^5\left(\frac{Q}{Q_0}\right)\pi^2 Y \frac{3N^2-4}{240}, \quad (4)$$

$$\sigma_{0,qq,\alpha_s^5} = -\sigma_0 \left(\frac{2\alpha_s}{\pi}\right)^5 \ln^5\left(\frac{Q}{Q_0}\right) \left[Y^5 \frac{N^5}{120} - \pi^2 Y^3 \frac{17(N^3-N)}{960} + \pi^4 Y \frac{(N^2-1)}{240N}\right], \quad (5)$$

$$\sigma_{1,qq,\alpha_s^5} = \sigma_0 \left(\frac{2\alpha_s}{\pi}\right)^5 \ln^6\left(\frac{Q}{Q_0}\right)\pi^2 Y^2 \frac{8N^3-11N}{960}, \quad (6)$$

$$\sigma_{2,qq,\alpha_s^5} = \sigma_0 \left(\frac{2\alpha_s}{\pi}\right)^5 \ln^7\left(\frac{Q}{Q_0}\right)\pi^2 Y \frac{27N^3-44N}{20160}. \quad (7)$$

Interpretation

- The presence of these logarithms points to a break down in QCD colour coherence (Seymour, arXiv:0710.2733v1 [hep-ph]).
- Colour coherence is the basis for angular ordering in parton shower event generators.
- Colour coherence states that soft and wide-angle gluon emission, when summed over particles in a jet, acts as if emitted from the jet as a whole.
- It is known that it breaks down for imaginary parts of incoming partons, and sums involving hadron remnants are needed.
- For exclusive observables such as the gaps cross section factorising out these hadron remnants is possible and the cancelation fails.

Future Work

- Phenomenology of super-leading logarithms - work in progress with Jeff Forshaw and Simone Marzani (see his talk)
- Look to measure gaps-between-jets cross section at ATLAS - work in progress, first look we should have plenty of statistics for gap events
- More work on theory implications (colour coherence/plus prescription)
- and more...