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A New Framework for Estimating Multijet Final States

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Overview

How can we reliably calculate final states with n hard jets?

- Existing methods for estimating final state jet radiation.
- New method - start with FKL factorisation and build in extra features of perturbation theory.
- Application to Higgs boson production via GGF.
- Outlook and further developments.

Calculating Final State Jets

Exact

- Use standard perturbation theory at LO, NLO...
- Best thing to do, but very difficult.
- Limited to small numbers of final state partons.

Approximate

- Combine tree level matrix elements (e.g. from MADGRAPH) with parton showers.
- Get more realistic final states.
- However, only soft / collinear enhanced radiation included (low p_t).

→ Can we instead estimate hard radiation in the final state?

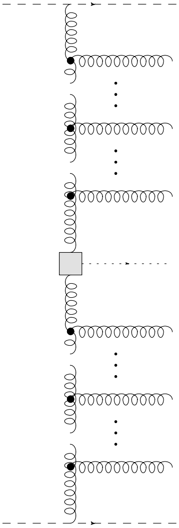
FKL Factorisation - Overview

- In a particular kinematic limit (MRK), particular Feynman diagrams dominate the matrix element (Fadin, Kuraev & Lipatov).
- These correspond to the process:

$$\alpha + \beta \to \alpha + \beta + ng,$$

  where α, $\beta \in \{q, \bar{q}, g\}$.
- The sum of such diagrams gives a factorised expression for the matrix element in terms of:
  1. Impact factors for the incoming jets and additional particles (e.g. Higgs, W bosons).
  2. Modified emission vertices for the outgoing gluons.
  3. Propagators for the (virtual) exchanged gluons.
  4. Leading virtual corrections.
- Let's look at this for Higgs production...

New Approximate Technique



- Start with FKL factorisation:

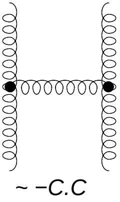
$$i\mathcal{M}^{ab\to abj_1\ldots j_n}_{\mu_1\ldots\mu_n} = 2s(g_s)^{n+2}$$
$$\times \left(\prod_{i=1}^{n_1+1} \frac{1}{t_i}\exp[\hat{\alpha}(t_i)(y_{i-1}-y_i)]\right)$$
$$\times \left(\prod_{i=1}^{n_1} C_{\mu_i}(q_{i-1},q_i)\right) C_H(q_{n_1+1},q_{n_1+2})$$
$$\times \left(\prod_{i=n_1+2}^{n+1} \frac{1}{t_i}\exp[\hat{\alpha}(t_i)(y_{i-1}-y_i)]\right)$$
$$\times \left(\prod_{i=n_1+2}^{n} C_{\mu_i}(q_{i-1},q_i)\right)$$

FKL factorisation

- Formally applies only in a certain high energy limit (MRK).
- Jets strongly ordered in rapidity, but not in transverse momentum (so “hard”).
- Problems:
  1. Outside this limit, the approximation is not very good.
  2. MRK not sufficiently relevant to the Tevatron or LHC.
- Solution: improve the description using known physics constraints.

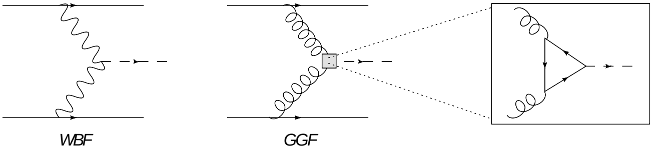
Improved Description

1. Impose 4-momentum conservation at emission vertices.
2. Use full dependence on virtual momenta instead of transverse components.
3. Impose $-C.C > 0$ for squared Lipatov emission vertex.



- Corresponds to keeping poles of full scattering amplitude in the same place...
- Also $-C.C > 0$ is related to *kinematic constraint* - a certain type of angular ordering.
- Validate approach by considering a particular process...

Higgs Production at the LHC

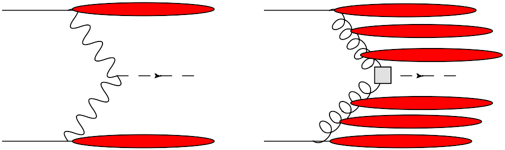


- Two main production modes - both can be used as a discovery channel.
- WBF - measure coupling of h to vector bosons. Is it the SM Higgs?
- GGF - measure nature of fermion coupling. CP even or odd?
- Can use cuts to separate processes.

$\Rightarrow$ Need a detailed understanding of both production modes.

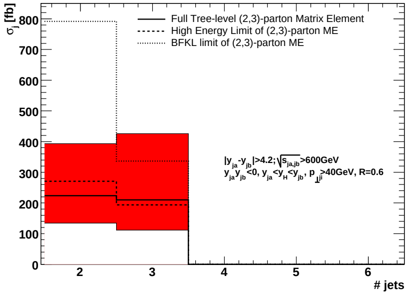
WBF & GGF - Differences

- No exchange of colour in WBF - QCD radiation limited mainly to incoming partons.
- Colour octet exchange in GGF - get lots of QCD radiation in central rapidity region.



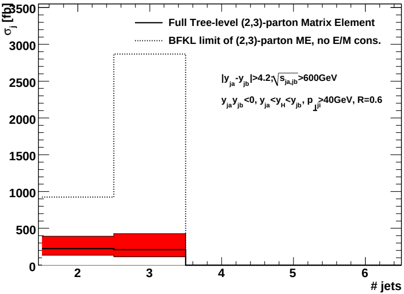
- Understanding of jet pattern in GGF crucial for:
  1. Measurement of coupling of h to fermions.
  2. Efficient background reduction of GGF w.r.t WBF.

Matrix Elements from New Technique



- Can compare our approximation expanded in α_S with known tree level results from MADGRAPH.
- FKL framework with minimal modification (4-momentum conservation only) does not work well.
- Approximation is well within scale variation!

Effect of Energy Conservation



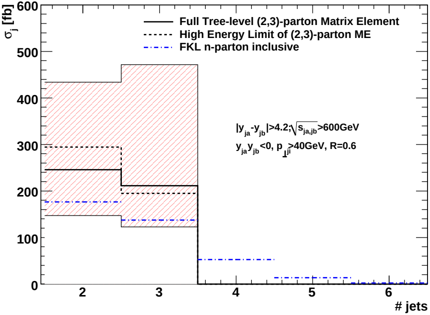
- Instructive to compare with traditional BFKL approach...

- Clearly not a good approximation for the LHC.

Implementation

- We produced a Monte Carlo implementation of our technique.
- Low order tree level matrix elements are included using a suitable matching procedure, which avoids double counting with the approximate matrix elements.
- Matching corrections important in the shape of some distributions.
- Having validated approximation where possible, will now consider higher order results...

Matched higher order results



- Significant number of events with > 3 hard jets.

- Also many softer partons which don't show up in this plot...

Conclusions

- Have devised a new technique for approximating matrix elements with multiple final state hard partons.
- Useful for estimating final state jet topology, rather than the jet substructure which is better estimated by a parton shower.
- Uses FKL factorisation as a starting point, but is different to the BFKL framework.
- Modifications include known analytic behaviour from the perturbation expansion.
- Have demonstrated validity of the approximation using Higgs production via GGF at the LHC.

Outlook

- More detailed phenomenology of Higgs boson production underway.
- Technique is readily generalised to other processes (e.g. $W +$ jets or pure jets, for which data exists).
- Technique can be interfaced with parton shower for a more complete description.
- Underlying FKL approximation can be extended.
- Work is in progress...