Next-to-Leading Log Contributions to Jet Production with High Energy Jets

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James D Cockburn
J.D.Cockburn@ed.ac.uk

Higgs Centre for Theoretical Physics, University of Edinburgh

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Outline

- High Energy Jets (HEJ) - An overview
- Leading and Next-to-Leading Log
- Results
- Conclusion

HEJ - Overview

- In the limit of infinite rapidity separation between all final state particles of fixed transverse momenta (MRK limit), QCD amplitudes are dominated by t-channel gluon exchanges. Moreover, they adopt a simple form. For example;

$$|M^{MRK}_{qQ\to q\ldots Q}|^2 = \frac{4s^2}{N_C^2-1}\frac{g^2 C_F}{|p_{1\perp}|^2}\left(\prod_{i=2}^{n-1}\frac{4g^2 C_A}{|p_{i\perp}|^2}\right)\frac{g^2 C_F}{|p_{n\perp}|^2}$$

- This equation has a very limited applicability
- Question - How few approximations can we make and still create this simple structure?

HEJ - Overview

Why would it be useful to have such a structure?

- Fast evaluation of the matrix element per point in phase space
- Allows for an efficient all-order sum! (See later)

HEJ - Overview

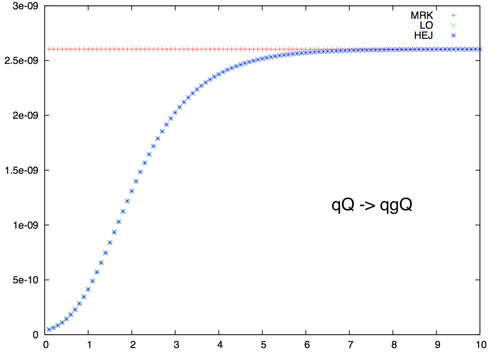
- Use method of *currents* and *effective vertices*;

$$|M^{HEJ}_{qQ\to q\ldots Q}|^2 = \frac{||S_{qQ\to qQ}||^2}{4(N_C^2-1)} \frac{g^2 C_F}{t_1} \left(\prod_{i=1}^{n-2} \frac{-g^2 C_A}{t_i t_{i+1}} V^\mu V_\mu \right) \frac{g^2 C_F}{t_{n-1}}$$

- Produced by considering high energy behaviour, but in such a way as to minimise the amount of approximation in the end. For example, $S_{qQ\to qQ}$ is exact
- Important check - by applying the MRK limit to this expression, we arrive back at the MRK equation

HEJ - Overview

- The approximation agress well with the LO result and reduces to the MRK equation in the right limit



HEJ - Overview

- Amplitude behaviour dictated by t-channel poles
- Can employ the *Lipatov Ansatz* for the virtual corrections to the process;

$$\frac{1}{t_i} \to \frac{1}{t_i} \exp\left[\hat{\alpha}(q_i)(y_{i-1} - y_i)\right]$$

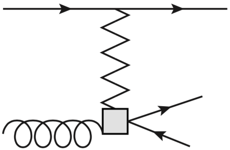
$$\hat{\alpha}(q_i) = \alpha_s C_A \frac{\Gamma(1-\varepsilon)}{(4\pi)^{2+\varepsilon}} \frac{2}{\varepsilon} \left(\frac{q_\perp^2}{\mu^2}\right)^{\varepsilon}$$

- This ansatz is accurate to *Leading Logarithmic* (LL) accuracy
- When combined with real corrections, the IR singularities from the real emissions are cancelled to all orders, and finite regularised matrix elements can be evaluated in 4D

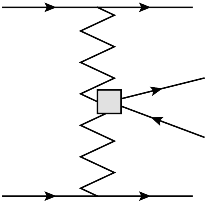
HEJ - Overview

- A key part of the HEJ amplitude is the effective vertex that captures the emission of extra gluons. Without them, the explicit factorisation of the t-channel poles cannot be done
- We can extend this idea to study other partonic processes in the same manner - for example, processes where we emit $q\bar{q}$ pairs
- Such considerations are formally sub-leading in the jet process - *Next-to-Leading Log* (NLL). They also have the added advantage that they will produce LL predictions for some partonic subprocesses that we didn't have before

- Diagrammatically, we want to search for a way to describe;



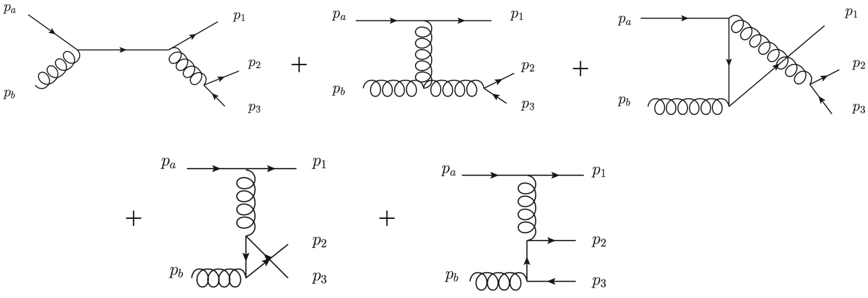
$$M_{qg\to qQQ} \sim \frac{\langle 1|\mu|a\rangle\, V^{\mu\nu}\varepsilon_\nu(p_b)}{t_1}$$



$$M_{qQ\to qq'\bar{q}'Q} \sim \frac{\langle 1|\mu|a\rangle\, V^{\mu\nu}\,\langle 4|\nu|b\rangle}{t_1 t_3}$$

- Factorised, general, gauge invariant

NLL



p_a
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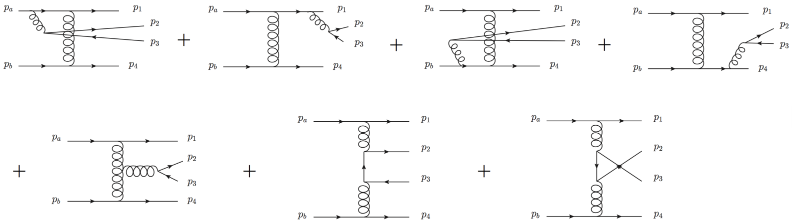
NLL



NLL

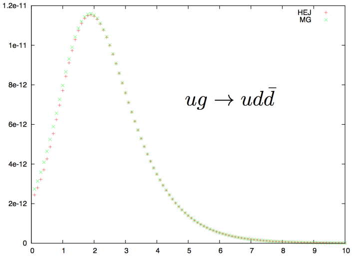
- After making some sensible approximations and combining the graphs, we get;

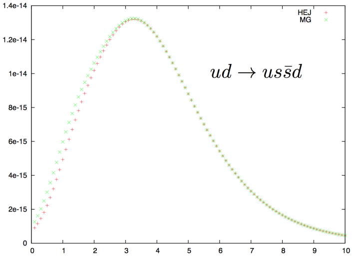
$$V^{\mu\nu}_{extremal} = \frac{C_1}{s_{nb}}\left(\bar{u}_{n-1}\gamma^{\mu}(\not{p}_n - \not{p}_b)\gamma^{\nu}u_n\right) - \frac{C_2}{s_{n-1,b}}\left(\bar{u}_{n-1}\gamma^{\nu}(\not{p}_{n-1} - \not{p}_b)\gamma^{\mu}u_n\right) + i\frac{C_t}{s_{n,n-1}}V^{\mu\nu\rho}_{3g}\langle n-1|\rho|n\rangle$$

$$V^{\mu\nu}_{central} = \frac{C_1}{s_{q\bar{q}}}\left(\eta^{\mu\nu}V^{\sigma}_{eik,sym} + V^{\mu\nu\sigma}_{3g}\right)\langle p_q|\sigma|p_{\bar{q}}\rangle + \frac{iC_2}{(q_{in}-p_q)^2}V^{\mu\nu}_{qprop} - \frac{iC_3}{(q_{in}-p_{\bar{q}})^2}V^{\mu\nu}_{crossed}$$

NLL

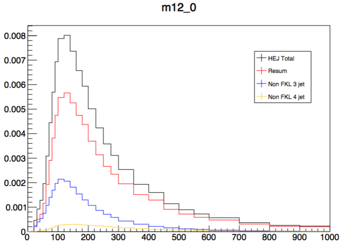
- These derived vertices show good agreement with the full, LO calculation

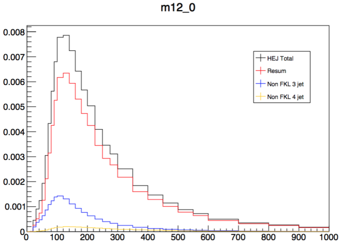




NLL

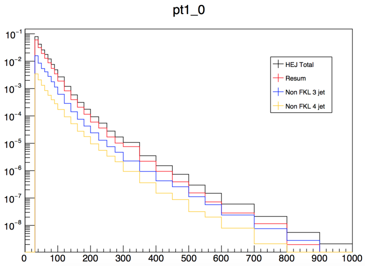
- HEJ currently uses a fixed-order matching to include contributions not captured by the equation we derived (non-FKL configurations). By considering these types of processes, we are able to reduce our dependence on this

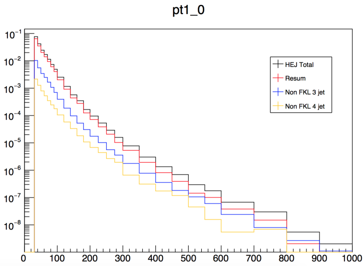




NLL

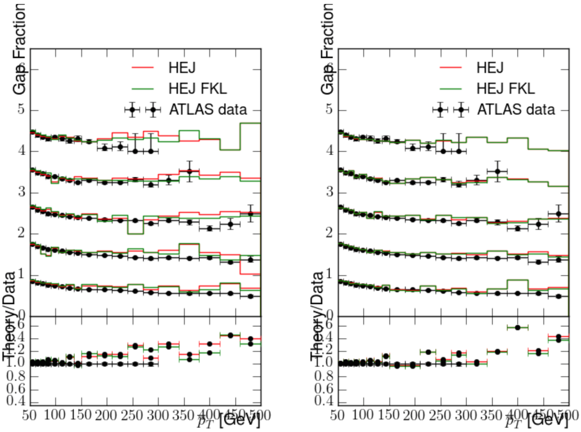
- One advantage of this is that the resum part of HEJ can now do a better job in regions where these non-FKL contributions become important





NLL

- Another advantage is that it improves our description of observables that are sensitive to the resummation procedure, such as the ‘gap fraction’



NLL

This is not the only contribution to consider at NLL, so we do not have full NLL accuracy yet. Also need;

- Loop corrections to one gluon emission
- Two gluon emission without assumption of large rapidity gap
- "Unordered" emissions (done)

Conclusions

- **Part of the NLL contribution** to jet processes has been calculated. These contributions will become part of standard HEJ
- HEJ is now able to **produce LL predictions for certain partonic subprocesses** that it could not before
- The derivation of these new effective vertices is such that they can be **applied to other processes in HEJ**, away from pure jets