Next-to-Leading Logarithmic Contributions to Scattering at High Energy

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September 22, 2022





Introduction

Outline of talk:

- 1. Amplitudes in the High Energy Limit
- 2. From Amplitudes to All-Order Corrections
- 3. Impact of NLL corrections Predictions and Comparison to Data

High Energy Jets:

- Factorisation of matrix elements using currents retains analytic properties such as crossing symmetries
- systematic power expansion of QCD amplitudes
- all-order leading and sub-leading logarithmic corrections
- matching, results...

Regge theory describes scattering from a **central potential** in terms of the projections on Legendre polynomial and states of **definite orbital angular momentum**

The analysis of **scattering amplitudes** in terms of Regge Theory: Regge (1959)

$$\mathcal{M} = \sum_i \Gamma_i(t) \ (s)^{j_i}$$

At **large energies** *s*, the contribution from particle of **highest spin** *j* **dominates**

 $\mathcal{M}
ightarrow \Gamma(t) (s)^j$

Regge limit: $s \gg -t$ or $s \gg p_t^2$



Multi-Regge limit:

Large s of course leads to the possibility of multiparticle production



This framework obtains good descriptions of hadronic processes. Based primarily on analyticity of scattering matrix.

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*s*₁₂

S23

n



 t_1

ťэ



Scaling of QCD Amplitudes

The scaling extends to all QCD processes involving also Higgs bosons, W, Z and photon production.



The **scaling** for different kinematic evaluations of the same amplitude is exactly as predicted by Regge theory applied to the **planar graph** connecting the rapidity-ordered configuration.

Perurbative Corrections in the High Energy Limit

Since the perturbative corrections have $|M|^2/s^2 \rightarrow \text{constant}$ for large $\Delta y \sim \log(s/p_t^2)$, it will contribute a correction $\alpha_s \log(s/p_t^2)$.

The other orderings of momenta (and other processes) contribute sub-leading corrections which can be included at next-to-leading order (see later).

Also virtual corrections for gg
ightarrow gg at one loop have logarithmic piece:

$$\begin{split} m_{4:1}(-,-,+,+) &= m_4(-,-,+,+) \ c_{\Gamma} \\ &\times \left\{ \left(-\frac{\mu^2}{s_{14}} \right)^{\epsilon} \left[N_c \left(-\frac{4}{\epsilon^2} - \frac{11}{3\epsilon} + \frac{2}{\epsilon} \ln \frac{s_{12}}{s_{14}} - \frac{64}{9} - \frac{1}{3} + \pi^2 \right) \right. \\ &+ N_f \left(\frac{2}{3\epsilon} + \frac{10}{9} \right) \right] - \frac{\beta_0}{\epsilon} \right\} \end{split}$$

Logarithmic structure predicted to all orders (BFKL, Regge, VDD,...). Control perturbative corrections of $\alpha_s^n \log^n(s/p_t^2)$ (leading logarithm).

Logarithmic Classificiation of Processes



Cross sections vs logarithmic ordering



pp
ightarrow W3j pp
ightarrow W4j The cross sections really do follow the logarithmic ordering. Have LL, want NLL

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Logartihmic split for other observables



The logarithmic ordering is less good for p_t -based observables – expect NLL to be as important as LL, and therefore corrections necessary.

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NLL Contributions at High Energies

NLL Corrections to W+Jets

Will calculate NLL processes and their LL corrections (work ongoing to obtain full NLL corrections to dijet processes), e.g. three-jet et al., A. Maier, E. Byrne, J.M. Smillie, JRA, arXiv:2012.10310



with **no kinematic assumption** on s_{12} , or no kinematic assumption on s_{13} . Technically, the calculation controls **not just the logarithmic structure**, but (new to HE and resummation considerations) also maintains **crossing symmetry of amplitudes**, explicit dependence on all momenta, energy & momentum conservation, ... Crossing symmetry maintained by applying much fewer approximations than in standard HE studies.

NLL Corrections to W+Jets



From four jets and above there there NLL contributions from central $q\bar{q}$ -production and central $q\bar{q}'W$ -production.

Logarithmic corrections calculated by effective vertices (a la Lipatov) and virtual corrections through *t*-channel (Lipatov ansatz). Fixed-order matching if remaining configurations.

Impact of NLL corrections



Impact of NLL corrections



Much less fixed order matching, much bigger resummation component. Final result of the inclusive distribution changes little (20%).

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NLL Contributions at High Energies

Comparison to Data



Inclusive jet rates for $pp \rightarrow WJJ$ @8TeV

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Comparison to Data



The NLL corrections and improvement in matching are sufficient to ensure the predictions agree well with data even in the most difficult regions of phase space.

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NLL Contributions at High Energies

Unsurprisingly, the inclusion of sub-leading logarithms leads to

- small changes in the leading regions of phase space
- a better description in sub-leading regions of phase space

Hall-marks of a well-behaved perturbative expansion.

The work to include full NLL accuracy in the resummation of High Energy Jets is ongoing.