Exclusive distributions in the Regge limit

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Exclusive distributions in the Regge limit

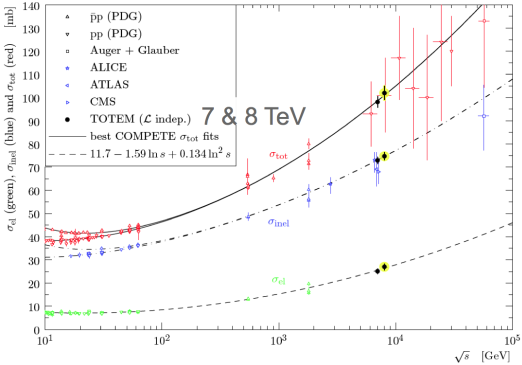
1. Basic Concepts
2. Phenomenology
3. Distributions generated by Monte Carlo integration

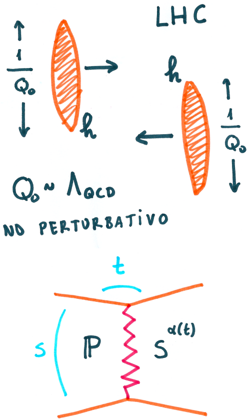
1. Basic Concepts

- At very high energies new degrees of freedom arise
- Present in QCD, SUSY and gravity
- They allow to calculate many processes to all orders in the coupling

1. Basic Concepts

Hadron-hadron total cross-section rises (also at LHC):





Consistent with Regge theory (soft Pomeron exchange):

$$\sigma_{tot} \sim s^{\alpha(0)-1} = s^{0.1} \quad \text{(Donnachie-Landshoff)}^{2013}$$

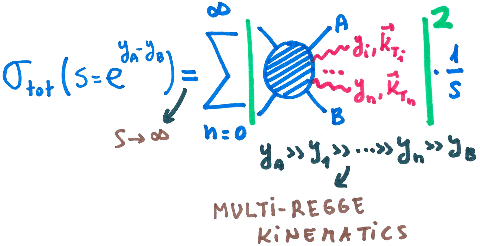
1. Basic Concepts

Regge theory preludes QCD.
Microscopic description of Pomeron in terms of quarks & gluons?

We need a large scale $Q > \Lambda_{\rm QCD}$ to use perturbation theory in $\alpha_s(Q) \ll 1$.

In the limit $s \gg t, Q^2$ we have $\alpha_s(Q) \log\left(\frac{s}{t}\right) \sim \mathcal{O}(1)$.
These dominate the amplitudes and must be resummed to all orders.

Kinematic origin:



where $y_A - y_B$ is the difference in rapidity of particles A and B.

1. Basic Concepts

When $s \to \infty$ we should resum $\alpha_s^n \log^n(s) \sim \alpha_s^n (y_A - y_B)^n$.

$$\sigma_{\rm tot}^{\rm LL} = \sum_{n=0}^{\infty} \mathcal{C}_n^{\rm LL}(\mathbf{k}_i)\, \alpha_s^n \int_{y_B}^{y_A} dy_1 \int_{y_B}^{y_1} dy_2 \ldots \int_{y_B}^{y_{n-1}} dy_n$$

$$= \sum_{n=0}^{\infty} \frac{\mathcal{C}_n^{\rm LL}(\mathbf{k}_i)}{n!} \underbrace{\alpha_s^n (y_A - y_B)^n}_{\rm LL}$$

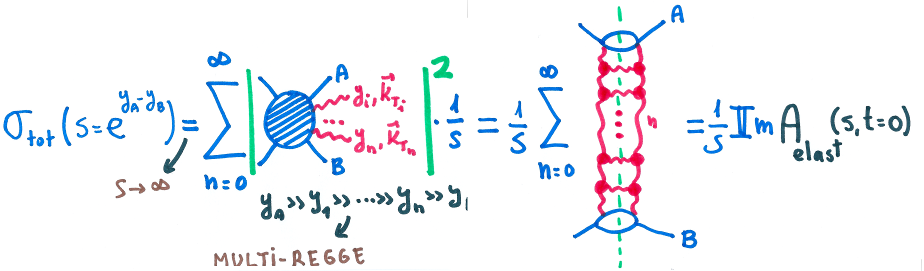
LL BFKL formalism allows us to calculate the coefficients $\mathcal{C}_n^{\rm LL}(\mathbf{k}_i)$.
NLL is more complicated, sensitive to the running & choice of energy scale:

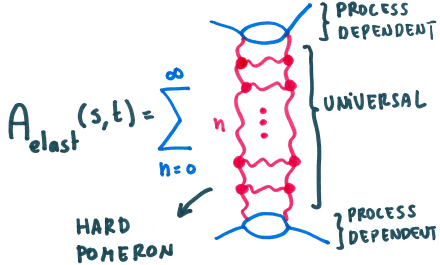
$$\sigma_{\rm tot} = \sum_{n=1}^{\infty} \frac{\mathcal{C}_n^{\rm LL}(\mathbf{k}_i)}{n!} \left(\alpha_s - \mathcal{A}\alpha_s^2\right)^n (y_A - y_B - \mathcal{B})^n$$

$$= \sigma_{\rm tot}^{\rm LL} - \sum_{n=1}^{\infty} \frac{\left(\mathcal{B}\,\mathcal{C}_n^{\rm LL}(\mathbf{k}_i) + (n-1)\,\mathcal{A}\,\mathcal{C}_{n-1}^{\rm LL}(\mathbf{k}_i)\right)}{(n-1)!} \underbrace{\alpha_s^n (y_A - y_B)^{n-1}}_{\rm NLL}$$

besides, quarks enter the game ...

Linked to elastic amplitudes due to optical theorem:





New degree of freedom $= g_R$
("Reggeized" gluon)

Pomeron= Bound state of 2 g_R

Hamiltonian interaction in 2 dims

Exclusive distributions in the Regge limit

2. Phenomenology

Associated phenomenology is very rich and present in different colliders: lepton-lepton (LEP, $\sigma_{\gamma^*\gamma^*}$), lepton-hadron (DIS at low x), hadron-hadron (Tevatron, LHC), heavy ions (RHIC, LHC)

Diagram with a cut: events with high multiplicity :

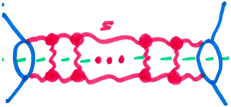
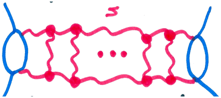


Diagram without a cut: diffractive events:

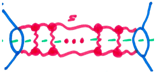


Two key elements in the calculations:

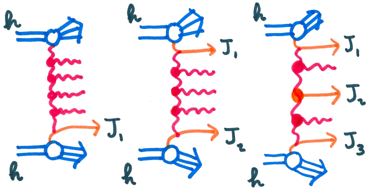
1. Coupling of gluon ladder to external states (Process dependent) High energy effective action at NLL.
2. Control of universal exchange (gluon ladder): Monte Carlo event generator at NLL.

2. Phenomenology

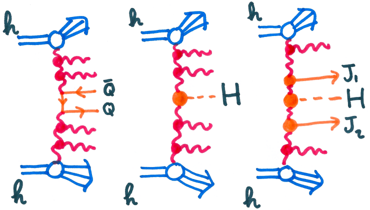
LHC phenomenology : examples with a cut

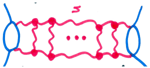


Production of Jets, W, Z y Drell-Yan in different topologies:

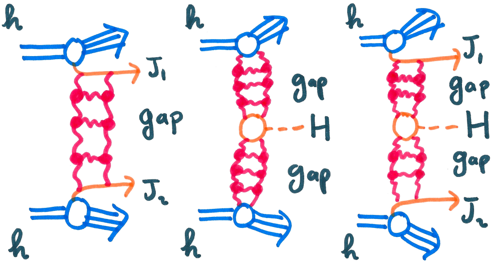


Production of quark pairs & Higgs in different topologies:



LHC phenomenology : examples without a cut 

Diffractive production in different topologies:



Gap = region in the detector without hadronic activity. Clear signal.

2. Phenomenology

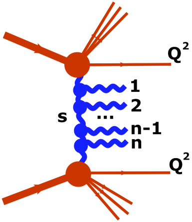
Observable proposed in [ASV][NPB746 2006] [ASV,Schwennsen][NPB 2007,PRD77 2008]

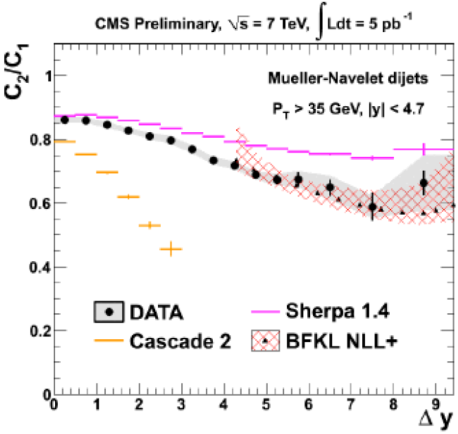
as perfect to isolate BFKL

$$\mathcal{R}_{2,1} = \frac{<\cos(2\theta)>}{<\cos(\theta)>}$$

Conformal observable:

[Angioni,Chachamis,Madrigal,ASV][PRL107 2011]



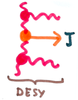


Confirmation of this idea in 2013 [Caporale,Murdaca,ASV,Salas][NPB 875 2013].

2. Phenomenology

NLL vertices already calculated :

Central Jet production [Bartels,ASV,Schwennsen][JHEP0611 2006]:

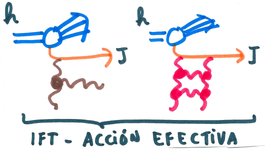


Forward Jet production [Hentschinski,ASV][PRD85 2012]
+ mini Jets

[Chachamis,Hentschinski,Madrigal,ASV] [NPB861 2012,PRD87,NPB876 2013]:

Forward Jet production
+ rapidity Gap

[Hentschinski, Madrigal, Murdaca, ASV] [1404.2937]:



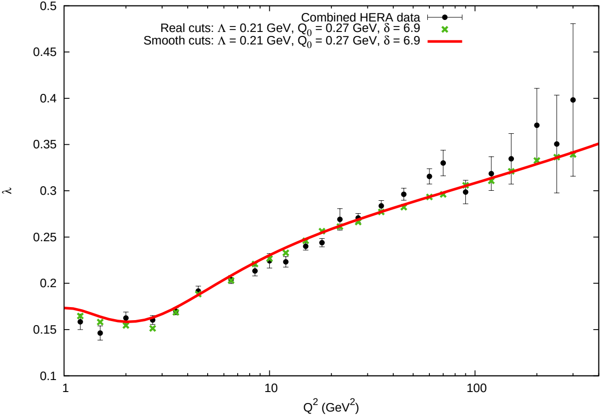
Working on numerical implementation in Monte Carlo generator...

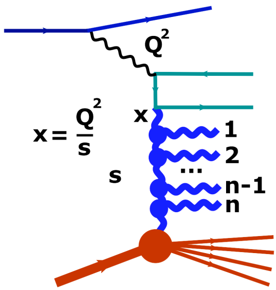
Together with a model for the coupling of Pomeron to the proton ...

2. Phenomenology

DIS data: $F_2(x, Q^2) \simeq x^{-\lambda}$

Hadron-Pomeron coupling based on NLL BFKL





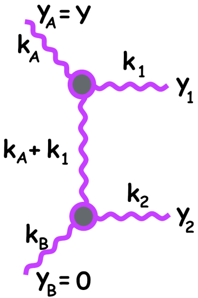
Transition from Hard to Soft Pomeron well described.

[Hentschinski,ASV,Salas][PRL110, PRD87 2013]

Exclusive distributions in the Regge limit

Monte Carlo

Effective Feynman rules:
Simplest case, minijet production at LL.



Gluon Regge trajectory:

$$\omega\left(\vec{q}\right) = -\frac{\alpha_s N_c}{\pi} \log \frac{q^2}{\lambda^2}$$

Modified propagators in the t-channel:

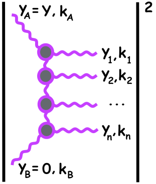
$$\left(\frac{s_i}{s_0}\right)^{\omega(t_i)} = e^{\omega(t_i)(y_i - y_{i+1})}$$

$$\left(\frac{\alpha_s N_c}{\pi}\right)^2 \int d^2\vec{k}_1 \frac{\theta\left(k_1^2 - \lambda^2\right)}{\pi k_1^2} \int d^2\vec{k}_2 \frac{\theta\left(k_2^2 - \lambda^2\right)}{\pi k_2^2} \delta^{(2)}\left(\vec{k}_A + \vec{k}_1 + \vec{k}_2 - \vec{k}_B\right)$$

$$\times \int_0^Y dy_1 \int_0^{y_1} dy_2 e^{\omega\left(\vec{k}_A\right)(Y - y_1)} e^{\omega\left(\vec{k}_A + \vec{k}_1\right)(y_1 - y_2)} e^{\omega\left(\vec{k}_A + \vec{k}_1 + \vec{k}_2\right) y_2}$$

$$\sigma(Q_1, Q_2, Y) = \int d^2\vec{k}_A d^2\vec{k}_B \underbrace{\phi_A(Q_1, \vec{k}_A)\,\phi_B(Q_2, \vec{k}_B)}_{\text{PROCESS−DEPENDENT}} \underbrace{f(\vec{k}_A, \vec{k}_B, Y)}_{\text{UNIVERSAL}}$$

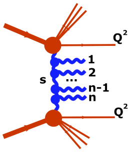
$$f\left(\vec{k}_A, \vec{k}_B, Y\right) = \sum_n \left| \cdots \right|^2$$

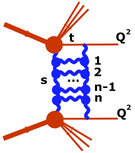


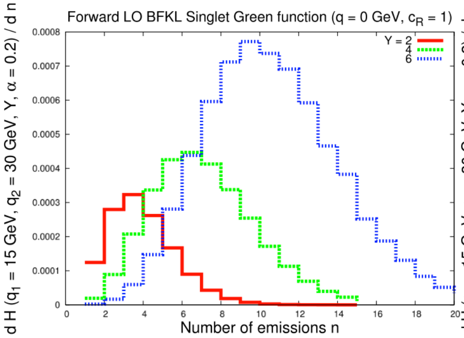
$$= e^{\omega(\vec{k}_A)Y}\left\{\delta^{(2)}\left(\vec{k}_A - \vec{k}_B\right) + \sum_{n=1}^{\infty}\prod_{i=1}^{n}\frac{\alpha_s N_c}{\pi}\int d^2\vec{k}_i \frac{\theta\left(k_i^2 - \lambda^2\right)}{\pi k_i^2}\right.$$

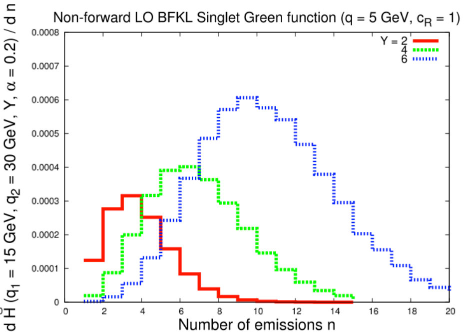
$$\left.\times \int_0^{y_{i-1}} dy_i e^{\left(\omega\left(\vec{k}_A + \sum_{l=1}^{i}\vec{k}_l\right) - \omega\left(\vec{k}_A + \sum_{l=1}^{i-1}\vec{k}_l\right)\right)y_i}\delta^{(2)}\left(\vec{k}_A + \sum_{l=1}^{n}\vec{k}_l - \vec{k}_B\right)\right\}$$

Number of emissions?





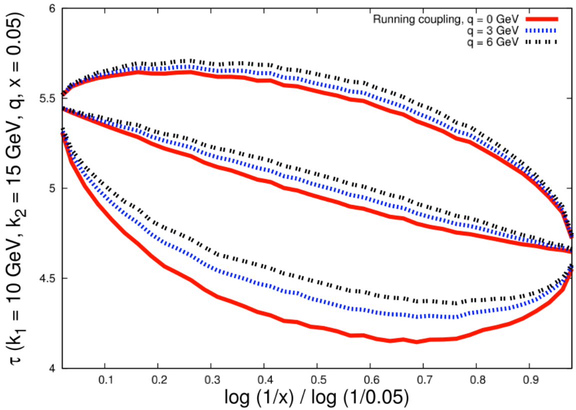


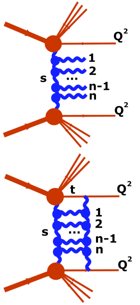


[Chachamis,ASV] [PLB709 2012]

3. Distributions generated by Monte Carlo integration

Gluon $|p_T|$ in a given rapidity bin?

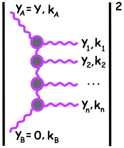


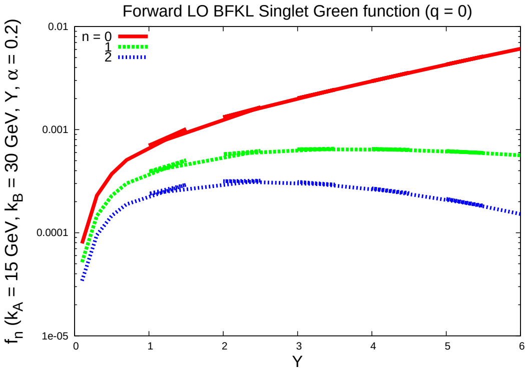


[Chachamis, ASV][PLB717 2012] [...+Salas][PRD87 2013][...+Murdaca, Caporale, Madrigal][PLB724 2013]

Growth with energy?

$$f\left(\vec{k}_A, \vec{k}_B, Y\right) = \sum_n \left| \right|^2$$





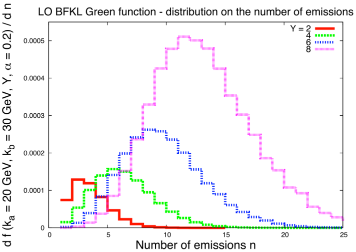
Different growth for different components in the azimuthal angle:

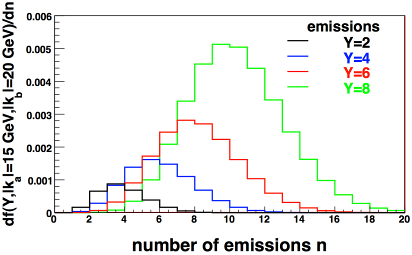
$$f_n\left(|\vec{k}_A|, |\vec{k}_B|, Y\right) = \int_0^{2\pi} \frac{d\theta}{2\pi} f\left(\vec{k}_A, \vec{k}_B, Y\right) \cos(n\theta)$$

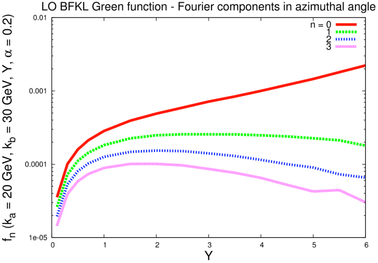
VERY IMPORTANT: this happens only in BFKL dynamics

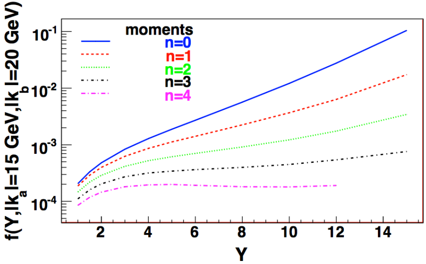
BFKL

CCFM









All CCFM projections grow, not in BFKL. [Chachamis,Deak,ASV,Stephens][NPB849 2011]

3. Distributions generated by Monte Carlo integration

Need to extend the formalism to include collinear regions [Salam] [ASV][NPB722 2005]

$$f = e^{\omega(\vec{k}_A)Y}\left\{\delta^{(2)}\left(\vec{k}_A-\vec{k}_B\right)+\sum_{n=1}^{\infty}\prod_{i=1}^{n}\frac{\alpha_s N_c}{\pi}\int d^2\vec{k}_i\frac{\theta\left(k_i^2-\lambda^2\right)}{\pi k_i^2}\right.$$
$$\left.\times\int_0^{y_{i-1}}dy_i e^{\left(\omega\left(\vec{k}_A+\sum_{l=1}^{i}\vec{k}_l\right)-\omega\left(\vec{k}_A+\sum_{l=1}^{i-1}\vec{k}_l\right)\right)y_i}\delta^{(2)}\left(\vec{k}_A+\sum_{l=1}^{n}\vec{k}_l-\vec{k}_B\right)\right\}$$

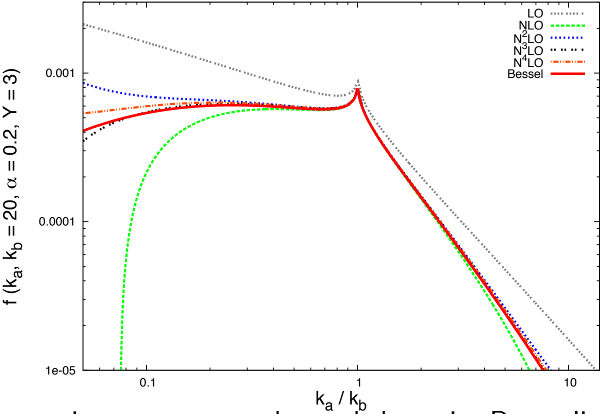
Key at NLL: $\theta\left(k_i^2-\lambda^2\right)\to\theta\left(k_i^2-\lambda^2\right)\underbrace{-\frac{\bar{\alpha}_s}{4}\ln^2\left(\frac{\vec{k}_A^2}{\left(\vec{k}_A+\vec{k}_i\right)^2}\right)}_{\text{NLL}}$

Origin: We must resum collinear emissions to have convergent observables in a more general kinematics (less constrained impact factors):

$$\theta\left(k_i^2-\lambda^2\right)\to\theta\left(k_i^2-\lambda^2\right)+\sum_{n=1}^{\infty}\frac{(-\bar{\alpha}_s)^n}{2^n n!(n+1)!}\ln^{2n}\left(\frac{\vec{k}_A^2}{\left(\vec{k}_A+\vec{k}_i\right)^2}\right)$$

3. Distributions generated by Monte Carlo integration

$$\sigma(Q_1, Q_2, Y) = \int d^2\mathbf{k}_a d^2\mathbf{k}_b \, \phi_A(Q_1, \mathbf{k}_a) \, \phi_B(Q_2, \mathbf{k}_b) \, f(\mathbf{k}_a, \mathbf{k}_b, Y)$$



This is very important to go beyond the strict Regge limit.
To remain in strict BFKL domain we need

"delta-like" impact factors $\phi_{A,B}$ & $Q_1 \simeq Q_2$.

Exclusive distributions in the Regge limit

- Rich phenomenology, all ingredients are ready. New observables?
- Workshops Series in Madrid on MRK (October 2012, February 2014)