Geometric Scaling in Mueller-Navelet Jets

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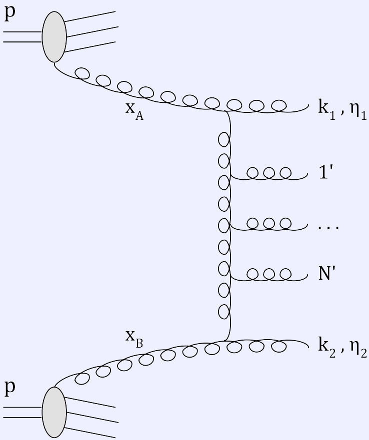
Outline

- Mueller-Navelet Jets
  - Definition
  - BFKL resummation
  - Properties: K-factor, decorrelations
- γ^*-p Deep Inelastic Scattering
  - Geometric scaling at small Bjorken-x
  - Theoretical explanation (BFKL and saturation)
- Geometric Scaling in Mueller-Navelet Jets

Mueller-Navelet Jets

- Inclusive production of two jets separated by large rapidity interval in p-p or p-$\bar{p}$ collisions



$$Y = \eta_1 - \eta_2 \\ = \ln \frac{x_A x_B s}{k_1 k_2} \gg 1$$

Cross Section

- Cross section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}x_{\mathrm{A}}\mathrm{d}x_{\mathrm{B}}\mathrm{d}^2\boldsymbol{k}_1\mathrm{d}^2\boldsymbol{k}_2} = f_{\mathrm{eff}}(x_{\mathrm{A}},\mu^2)f_{\mathrm{eff}}(x_{\mathrm{B}},\mu^2)\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}^2\boldsymbol{k}_1\mathrm{d}^2\boldsymbol{k}_2}$$

- Choose $x_{\mathrm{A}}, x_{\mathrm{B}}$ to be "large". Say $\sim \mathcal{O}(0.1)$
  Parton distributions are known
- Large logarithms of $Y = \ln \hat{s}/k^2$ in partonic cross section
- Rapidity strong ordering gives dominant contribution
  $\eta_1 \gg \eta_{1'} \gg \ldots$ and $-\eta_2 \gg -\eta_{N'} \gg \ldots$

Resummation

- Born level (no minijet)
  Back to back jets : $\boldsymbol{k}_1 = -\boldsymbol{k}_2$
  In terms of Y : $\hat{\sigma} \sim \mathcal{O}(1)$
- One minijet $\rightsquigarrow$ Decorrelation : $\boldsymbol{k}_1 \neq -\boldsymbol{k}_2$
  In terms of Y : $\hat{\sigma} \sim \mathcal{O}(Y)$
- Two minijets $\rightsquigarrow$ More decorrelation
  In terms of Y : $\hat{\sigma} \sim \mathcal{O}(Y^2)$
- Integrate over minijet phase space and sum

BFKL

- Resumed cross section

$$\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}^2\boldsymbol{k}_1\mathrm{d}^2\boldsymbol{k}_2} \sim \frac{\alpha_s^2}{k_1^2 k_2^2}\, f(Y, \boldsymbol{k}_1, \boldsymbol{k}_2)$$

- f satisfies BFKL equation

$$\frac{\partial f(\boldsymbol{k}_1, \boldsymbol{k}_2, Y)}{\partial Y} = \int \mathrm{d}^2\boldsymbol{\ell}\, \mathcal{M}(\boldsymbol{k}_1, \boldsymbol{k}_2, \boldsymbol{\ell}) f(\boldsymbol{k}_1, \boldsymbol{\ell}, Y) - \text{virtual}$$

  Linear evolution equation in Y

  Local in Y, nonlocal kernel in transverse momenta

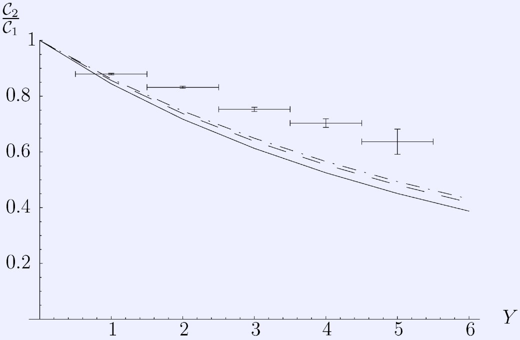
- At large Y

$$f \sim \frac{1}{k_1 k_2} \exp(\omega_{\mathbb{P}} Y)$$

Properties

Properties-signatures of MN jets (hence BFKL)

- Exponential in Y K-factor (Mueller, Navelet)
- Momentum decorrelation (Del Duca, Schmidt)
- Angular decorrelations (Sabio Vera, Schwennsen)

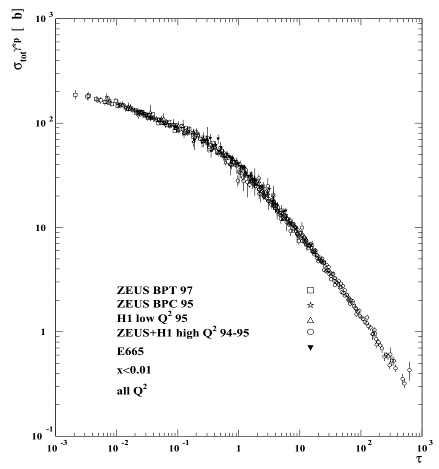


$$\mathcal{C}_n = \langle \cos n\phi \rangle$$

$$\phi = \sphericalangle(\boldsymbol{k_1}, \boldsymbol{k}_2)$$

DIS - Scaling

- Cross section $\sigma(x, Q^2, \Lambda)$ in γ^*-p DIS. Data for $x < 10^{-2}$ (Golec-Biernat, Kwieciński, Staśto)



Geometric scaling

$$\sigma \sim \frac{1}{\Lambda^2} f(Q^2/Q_s^2)$$

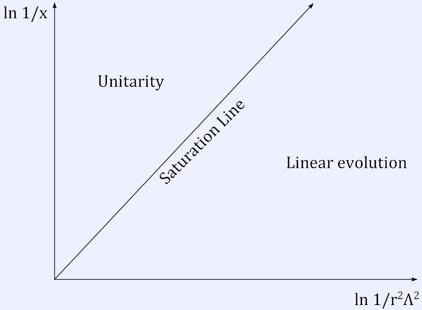
Saturation momentum

$$Q_s^2 \sim \Lambda^2 x^{-\lambda}$$

Saturation - Unitarity

- Frame : $\gamma^*(Q) \longrightarrow q\bar{q}(\boldsymbol{r}) \longrightarrow$ interaction with proton
- At small-x saturated proton wavefunction
- Dipole - proton cross section unitarizes

  Satisfies BFKL + nonlinear equation (Balitsky, Kovchegov)



Scaling

Scaling above Q_s (Iancu, Itakura, McLerran / Mueller, DNT)

- Eigenfunctions are pure powers

  A single one selected asymptotically

$$\sigma_{\mathrm{dp}} \sim \exp[\chi(\gamma_s)\ln(1/x)](r^2\Lambda^2)^{1-\gamma_s} \sim (r^2 \underbrace{\Lambda^2 x^{-\lambda}}_{Q_s^2})^{1-\gamma_s}$$

- Approximate scaling with running coupling

  NLO computation of $\lambda \simeq 0.3$ (DNT) in agreement with fits
- Scaling in Q^2 after convoluting with γ^* wavefunction
- Dynamically generated scale sets the scale for observables

MN Jets and Unitarity

- Inclusive dijet cross section should respect unitarity limits (exchange of many ladders)
- Not a total cross section but difficult to imagine otherwise
- More established for single forward jet (...)

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\eta \mathrm{d}^2\boldsymbol{k}} \sim \frac{1}{k^2}\, xG_{\mathrm{A}}(x,k^2) \int \mathrm{d}^2\boldsymbol{r}\ \exp[-\mathrm{i}\boldsymbol{k}\cdot\boldsymbol{r}] \nabla^2_{\boldsymbol{r}} \sigma_{\mathrm{gg-B}}(\boldsymbol{r})$$

  $\sigma_{\mathrm{gg-B}}(\boldsymbol{r})$ unitarizes too

  Not virtual gluonic dipole. From amplitude $\times$ amplitude*

- Conjecture expression involving $\sigma_{\mathrm{gg-gg}}(\boldsymbol{r}_1, \boldsymbol{r}_2)$ (Marquet)

  Not necessary for our purposes

MN Jets and Scaling

- Integrate jet transverse momenta above Q_1, Q_2

$$\frac{\mathrm{d}\sigma}{\mathrm{d}x_\mathrm{A}\mathrm{d}x_\mathrm{B}} = F_\mathrm{eff}\,\frac{\alpha_s^2}{Q_2^2}\int\frac{\mathrm{d}\gamma}{2\pi\mathrm{i}}\,\exp[\bar{\alpha}_s\chi(\gamma)Y]\left(\frac{Q_2^2}{Q_1^2}\right)^{1-\gamma}$$

- Saddle point and vanishing exponent $(Q_2 \ll Q_1) \rightsquigarrow$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}x_\mathrm{A}\mathrm{d}x_\mathrm{B}} \sim F_\mathrm{eff}\,\frac{1}{Q_2^2}\left(\frac{Q_2^2\,\mathrm{e}^{\lambda(Y-Y_0)}}{Q_1^2}\right)^{1-\gamma_s} \qquad \text{with} \quad \gamma_s = 0.372$$

Geometric scaling. Similar to DIS : $\Lambda \to Q_2$

MN Jets

- Q_2 will be large

  $(+)$ <u>Large initial</u> saturation scale

  $(-)$ Cross section $\sim 1/Q_2^2$

- Cannot vary total energy energy s
  - Keep kinematics of the softer (2) jet fixed
  - Vary kinematics of harder (1) jet so that

  $x_{\mathrm{A}} = Q_1 \mathrm{e}^{\eta_1}/\sqrt{s} =$ fixed

Conclusion

- Inclusive cross section for production of two jets very separated in rapidity should exhibit geometric scaling
- Particular case of strong momentum decorrelation

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