LOW X MEETING:
LISBON, PORTUGAL
June 2006

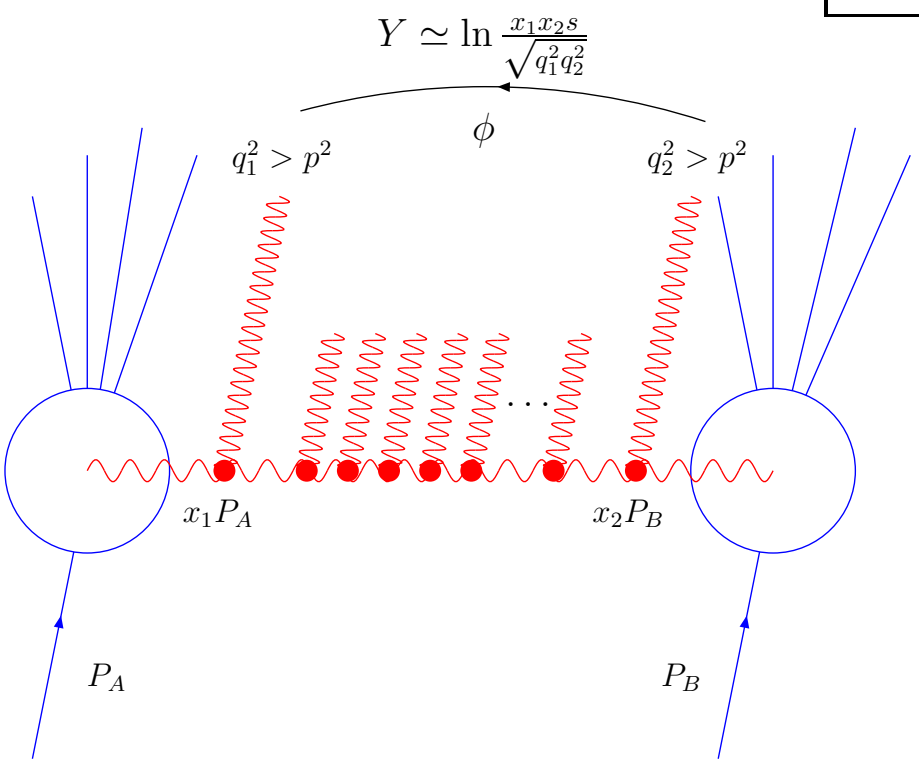
"BFKL phenomenology at the LHC"

1. A fresh look at Mueller–Navelet jets:
   NLO effects in azimuthal angle decorrelations
2. NLO jet production in $\mathbf{k}_T$ factorization
3. NLO effects in Pomeron exchange

Agustín Sabio Vera[a]

[a] CERN Research Fellow

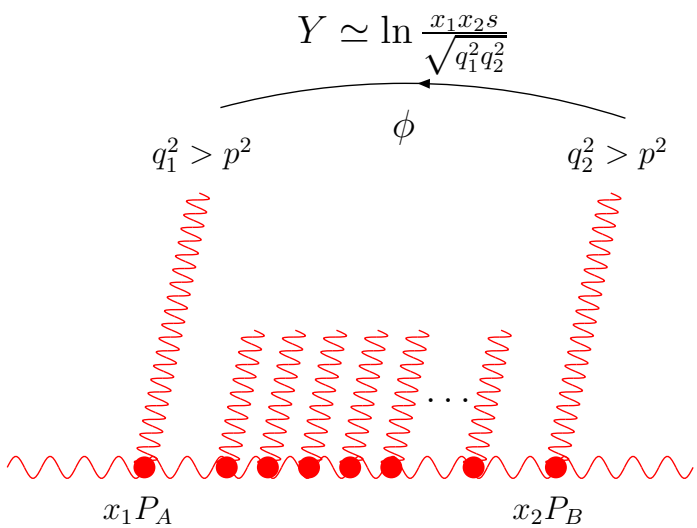
1. A fresh look at Mueller–Navelet jets:



[Mueller–Navelet, 1987]: INTERCEPT

[Del Duca–Schmidt, Stirling, 1994]: AZIMUTHAL ANGLE

1. A fresh look at Mueller–Navelet jets:

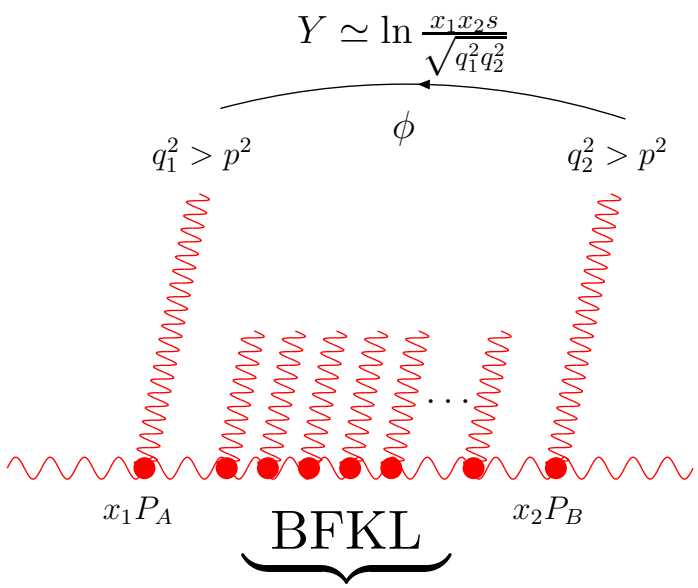


$$\longrightarrow \Phi_{\rm jet}^{\rm LO}\left(\vec{q}, p^2\right) = \theta\left(q^2 - p^2\right)$$

$$\hat{\sigma}\left(\alpha_s, \mathrm{Y}, p_{1,2}^2\right) \simeq \int d^2\vec{q}_1 \int d^2\vec{q}_2 \, \frac{\Phi_{\rm jet_1}^{\rm LO}\left(\vec{q}_1, p^2\right)}{q_1^2} \, \frac{\Phi_{\rm jet_2}^{\rm LO}\left(\vec{q}_2, p^2\right)}{q_2^2} \, \underbrace{f^{\rm NLO}\left(\vec{q}_1, \vec{q}_2, \mathrm{Y}\right)}_{\rm OPERATOR}$$

[Ivanov–Papa, 2006]

1. A fresh look at Mueller–Navelet jets:



$$\langle \vec{q} | \, \nu, n \rangle = \frac{1}{\pi\sqrt{2}} \left(q^2\right)^{i\nu - \frac{1}{2}} \, e^{in\theta}$$

$$f\left(\vec{q}_1, \vec{q}_2, \mathrm{Y}\right) = \int \frac{d\omega}{2\pi i} e^{\omega \mathrm{Y}} f_\omega \left(\vec{q}_1, \vec{q}_2\right)$$

$$\left(\omega - \bar{\alpha}_s \hat{K}_0 - \bar{\alpha}_s^2 \hat{K}_1 + \ldots\right) \hat{f}_\omega = \hat{1}$$

$$\hat{f}_\omega = \left(\omega - \bar{\alpha}_s \hat{K}_0\right)^{-1} + \bar{\alpha}_s^2 \left(\omega - \bar{\alpha}_s \hat{K}_0\right)^{-1} \hat{K}_1 \left(\omega - \bar{\alpha}_s \hat{K}_0\right)^{-1}$$

[Kotikov–Lipatov, 2000]

$$\hat{K}\,|\nu,n\rangle = \left\{\bar{\alpha}_s\,\chi_0 + \bar{\alpha}_s^2\,\chi_1 + \bar{\alpha}_s^2\,\frac{\beta_0}{4N_c}\chi_0\left(i\frac{\partial}{\partial\nu} + \log\mu^2\right)\right\}|\nu,n\rangle$$

$$\begin{aligned}
\chi_0\,(n,\nu) &= 2\psi\,(1) - \psi\left(\frac{1}{2} + i\nu + \frac{n}{2}\right) - \psi\left(\frac{1}{2} - i\nu + \frac{n}{2}\right) \\
\chi_1\,(n,\gamma) &= \mathcal{S}\chi_0\,(n,\gamma) + \frac{3}{2}\zeta\,(3) - \frac{\beta_0}{8N_c}\chi_0^2\,(n,\gamma) \\
&+\frac{1}{4}\left[\psi''\left(\gamma + \frac{n}{2}\right) + \psi''\left(1 - \gamma + \frac{n}{2}\right) - 2\,\phi\,(n,\gamma) - 2\,\phi\,(n,1-\gamma)\right] \\
&-\frac{\pi^2\cos\,(\pi\gamma)}{4\sin^2\,(\pi\gamma)\,(1-2\gamma)}\left\{\left[3 + \left(1 + \frac{n_f}{N_c^3}\right)\frac{2 + 3\gamma\,(1-\gamma)}{(3-2\gamma)\,(1+2\gamma)}\right]\delta_{n0}\right. \\
&\left.\qquad - \left(1 + \frac{n_f}{N_c^3}\right)\frac{\gamma\,(1-\gamma)}{2\,(3-2\gamma)\,(1+2\gamma)}\delta_{n2}\right\}
\end{aligned}$$

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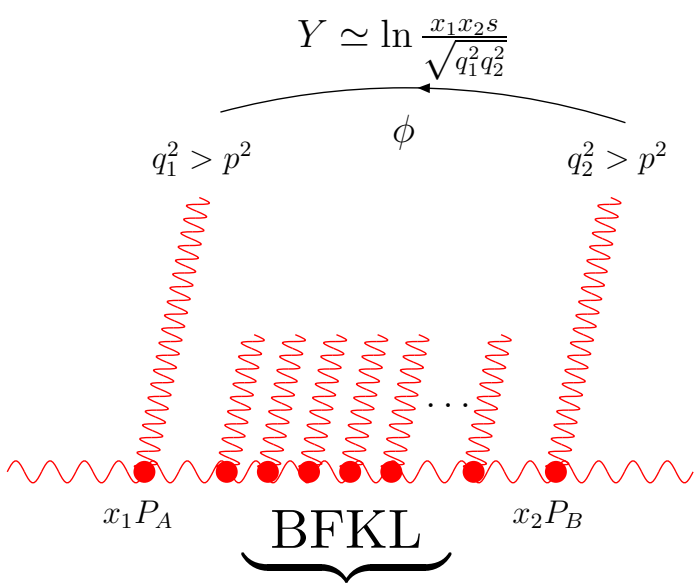


$$\hat{\sigma}\left(\alpha_s, \mathrm{Y}, p^2\right) = \frac{\pi^3 \bar{\alpha}_s^2}{2p^2} \mathcal{C}_0\left(\mathrm{Y}\right)$$

$$\frac{\hat{\sigma}(\mathrm{Y})}{\hat{\sigma}(0)} = \frac{\mathcal{C}_0(\mathrm{Y})}{\mathcal{C}_0(0)}$$

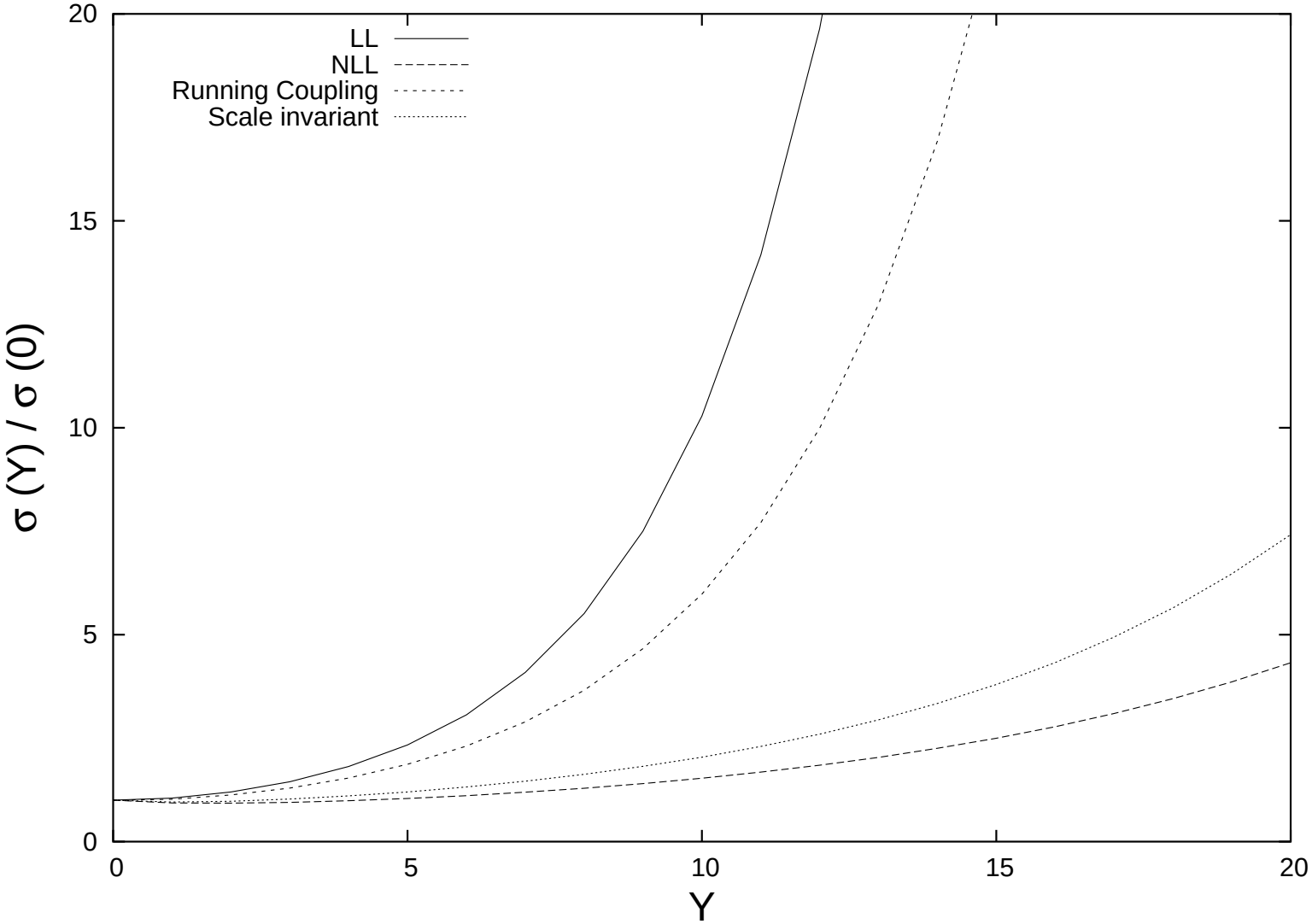
$$\langle \cos\left(m\phi\right) \rangle = \frac{\mathcal{C}_m(\mathrm{Y})}{\mathcal{C}_0(\mathrm{Y})}$$

$$\frac{d\hat{\sigma}\left(\alpha_s, \mathrm{Y}, p^2\right)}{d\phi} = \frac{\pi^3 \bar{\alpha}_s^2}{2p^2} \frac{1}{2\pi} \sum_{n=-\infty}^{\infty} e^{in\phi} \mathcal{C}_n\left(\mathrm{Y}\right)$$

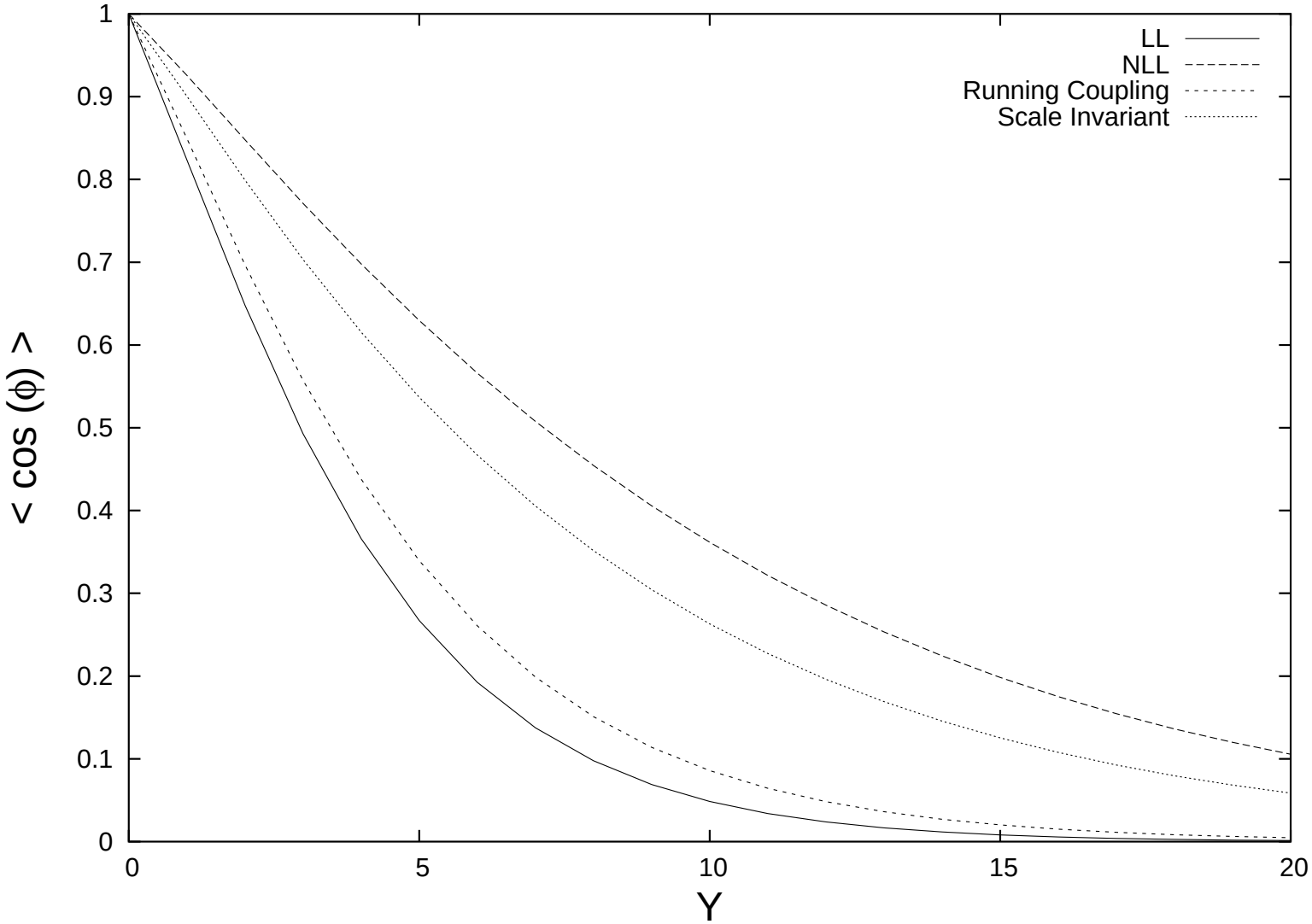
[SV(NPB746, 2006)]

$$\mathcal{C}_n\left(\mathrm{Y}\right) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{d\nu}{\frac{1}{4}+\nu^2} \exp\left\{ \bar{\alpha}_s\left(p^2\right) \mathrm{Y} \left(\chi_0 + \bar{\alpha}_s \left(\chi_1 - \frac{\beta_0}{8N_c} \frac{\chi_0}{\left(\frac{1}{4}+\nu^2\right)} \right) \right) \right\}$$

1. A fresh look at Mueller–Navelet jets:

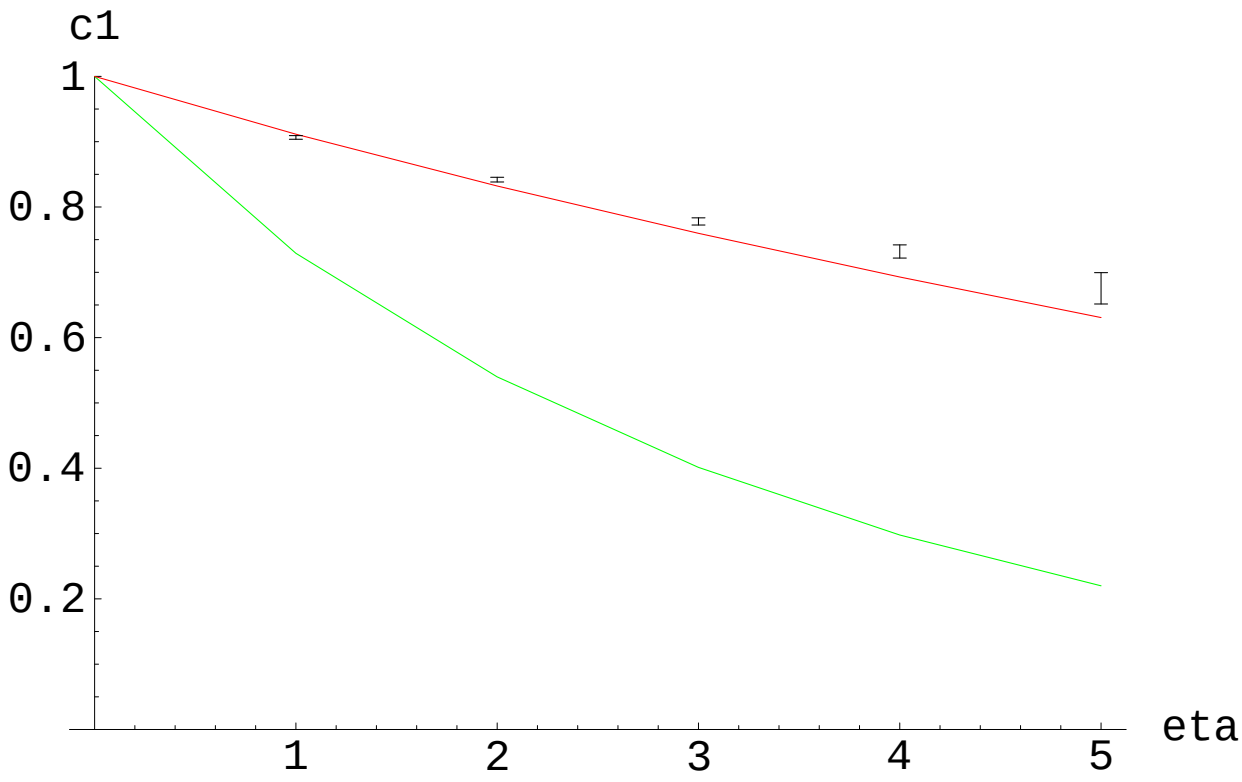


1. A fresh look at Mueller–Navelet jets:



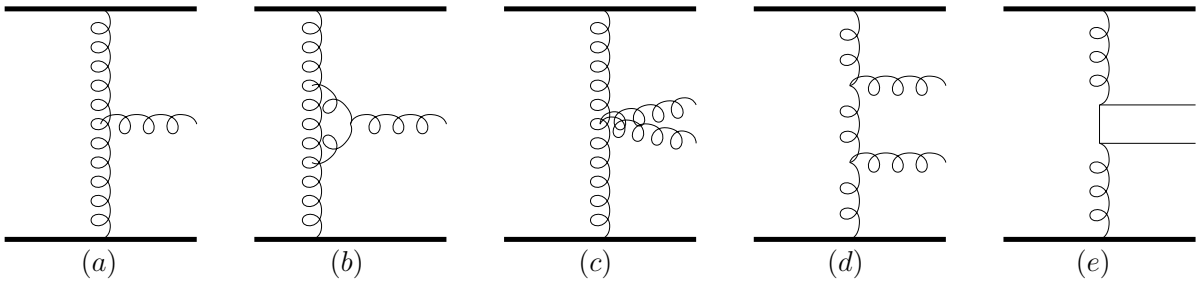
[SV–Florian Schwennsen, 2006]

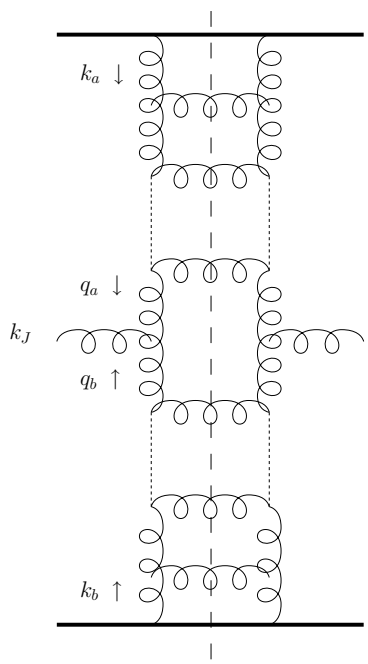
PRELIMINARY: Old Tevatron data

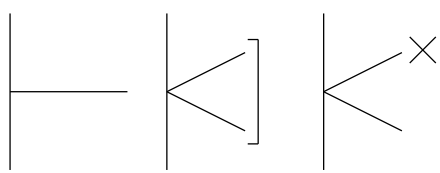


2. NLO jet production in $\mathbf{k}_T$ factorization:

[Bartels–SV–Florian Schwennsen, 2006]

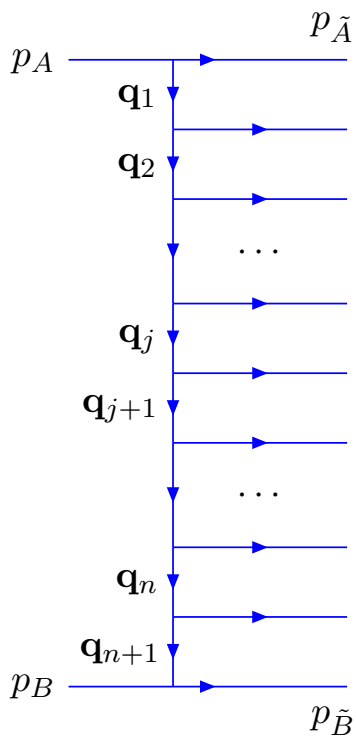






2. NLO jet production in $\mathbf{k}_T$ factorization:

MRK: $\quad p_{\tilde{A}}^2 \sim p_{\tilde{B}}^2 \sim \mathbf{k}_i^2 \sim \mathbf{k}_j^2 \gg \Lambda_{\rm QCD}^2, \;\; y_{\tilde{A}} = y_0 \gg y_1 \gg \cdots \gg y_n \gg y_{n+1} = y_{\tilde{B}}$



$$\mathbf{k}_0^2 = s_{R;0}$$

$$\mathbf{k}_1^2 = s_{R;1} \qquad \left(\frac{s_{0,1}}{s_{R;0,1}=\sqrt{\mathbf{k}_0^2\mathbf{k}_1^2}}\right)^{\omega} = e^{\omega(y_0-y_1)}$$

$$\mathbf{k}_2^2 = s_{R;2} \qquad \left(\frac{s_{1,2}}{s_{R;1,2}=\sqrt{\mathbf{k}_1^2\mathbf{k}_2^2}}\right)^{\omega} = e^{\omega(y_1-y_2)}$$

$$\cdots$$

$$\mathbf{k}_{j-1}^2 = s_{R;j-1} \qquad \left(\frac{s_{j-1,j}}{s_{R;j-1,j}=\sqrt{\mathbf{k}_{j-1}^2\mathbf{k}_j^2}}\right)^{\omega} = e^{\omega(y_{j-1}-y_j)}$$

$$\mathbf{k}_j^2 = s_{R;j} \qquad \left(\frac{s_{j,j+1}}{s_{R;j,j+1}=\sqrt{\mathbf{k}_j^2\mathbf{k}_{j+1}^2}}\right)^{\omega} = e^{\omega(y_j-y_{j-1})}$$

$$\mathbf{k}_{j+1}^2 = s_{R;j+1}$$

$$\cdots$$

$$\mathbf{k}_{n-1}^2 = s_{R;n-1} \qquad \left(\frac{s_{n-1,n}}{s_{R;n-1,n}=\sqrt{\mathbf{k}_{n-1}^2\mathbf{k}_n^2}}\right)^{\omega} = e^{\omega(y_{n-1}-y_n)}$$

$$\mathbf{k}_n^2 = s_{R;n} \qquad \left(\frac{s_{n,n+1}}{s_{R;n,n+1}=\sqrt{\mathbf{k}_n^2\mathbf{k}_{n+1}^2}}\right)^{\omega} = e^{\omega(y_n-y_{n+1})}$$

$$\mathbf{k}_{n+1}^2 = s_{R;n+1}$$

2. NLO jet production in $\mathbf{k}_T$ factorization:

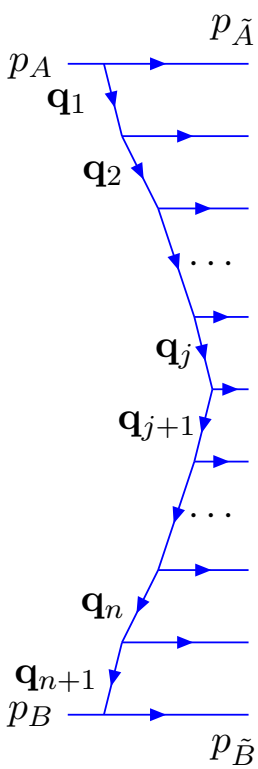
k_t–**ordered MRK:**

$$\Lambda^2_{\rm QCD} \sim p^2_{\tilde{A}} \ll \mathbf{k}_1^2 \ll \ldots \ll \mathbf{k}_{j-1}^2 \ll \mathbf{k}_j^2 \ (\textbf{Jet})\ \mathbf{k}_j^2 \gg \mathbf{k}_{j+1}^2 \cdots \gg \mathbf{k}_n^2 \gg p^2_{\tilde{B}} \sim \Lambda^2_{\rm QCD}$$

$$y_{\tilde{A}} = y_0 \gg y_1 \gg \ldots \gg y_{j-1} \gg y_j \gg y_{j+1} \cdots \gg y_n \gg y_{n+1} = y_{\tilde{B}}$$

To impact factor

To kernel



$$\mathbf{k}_0^2 = s_{R;0}$$

$$\mathbf{k}_1^2 = s_{R;1}$$

$$\mathbf{k}_2^2 = s_{R;2}$$

$$\ldots$$

$$\mathbf{k}_{j-1}^2 = s_{R;j-1}$$

$$\mathbf{k}_j^2 = s_{R;j}$$

$$\mathbf{k}_{j+1}^2 = s_{R;j+1}$$

$$\ldots$$

$$\mathbf{k}_{n-1}^2 = s_{R;n-1}$$

$$\mathbf{k}_n^2 = s_{R;n}$$

$$\mathbf{k}_{n+1}^2 = s_{R;n+1}$$

$$\left(\frac{s_{0,1}}{s_{R;0,1}=\mathbf{k}_1^2}\right)^{\omega} = e^{\omega(y_0-y_1)} \left(\frac{\mathbf{k}_0^2}{\mathbf{q}_1^2}\right)^{\frac{\omega}{2}}_{\rm up} \left(\frac{\mathbf{q}_1^2}{\mathbf{k}_1^2}\right)^{\frac{\omega}{2}}_{\rm down}$$

$$\left(\frac{s_{1,2}}{s_{R;1,2}=\mathbf{k}_2^2}\right)^{\omega} = e^{\omega(y_1-y_2)} \left(\frac{\mathbf{k}_1^2}{\mathbf{q}_2^2}\right)^{\frac{\omega}{2}}_{\rm up} \left(\frac{\mathbf{q}_2^2}{\mathbf{k}_2^2}\right)^{\frac{\omega}{2}}_{\rm down}$$

$$\left(\frac{\mathbf{q}_1^2}{\mathbf{q}_2}\right)^{\frac{\omega}{2}}$$

To emission vertex

$$\left(\frac{s_{j-1,j}}{s_{R;j-1,j}=\mathbf{k}_j^2}\right)^{\omega} = e^{\omega(y_{j-1}-y_j)} \left(\frac{\mathbf{k}_{j-1}^2}{\mathbf{q}_j^2}\right)^{\frac{\omega}{2}}_{\rm up} \left(\frac{\mathbf{q}_j^2}{\mathbf{k}_j^2}\right)^{\frac{\omega}{2}}_{\rm down}$$

$$\left(\frac{s_{j,j+1}}{s_{R;j,j+1}=\mathbf{k}_j^2}\right)^{\omega'} = e^{\omega'(y_j-y_{j-1})} \left(\frac{\mathbf{k}_{j+1}^2}{\mathbf{q}_{j+1}^2}\right)^{\frac{\omega'}{2}}_{\rm down} \left(\frac{\mathbf{q}_{j+1}^2}{\mathbf{k}_j^2}\right)^{\frac{\omega'}{2}}_{\rm up}$$

$$\left(\frac{\mathbf{q}_j^2}{\mathbf{k}_j^2}\right)^{\frac{\omega}{2}} \left(\frac{\mathbf{q}_{j+1}^2}{\mathbf{k}_j^2}\right)^{\frac{\omega'}{2}}$$

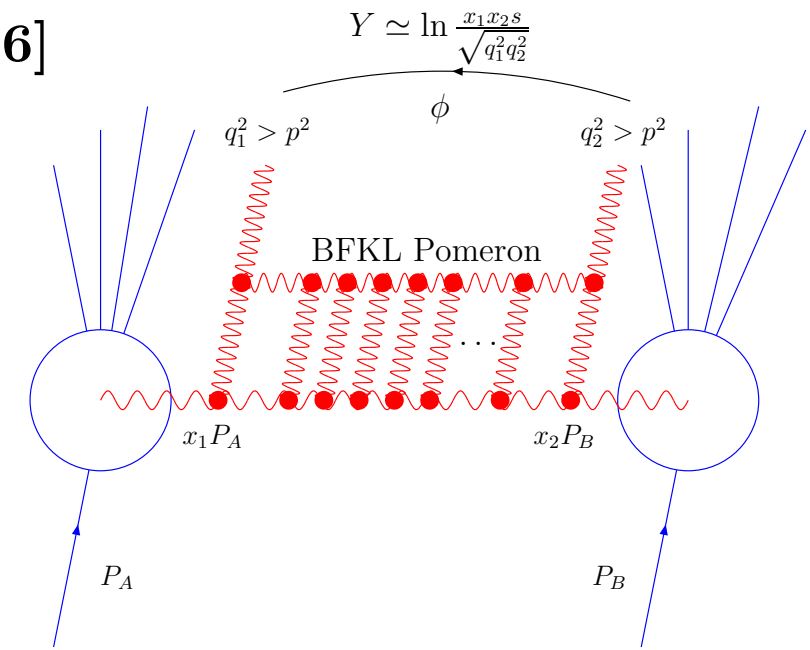
$$\left(\frac{s_{n-1,n}}{s_{R;n-1,n}=\mathbf{k}_{n-1}^2}\right)^{\omega'} = e^{\omega'(y_{n-1}-y_n)} \left(\frac{\mathbf{k}_n^2}{\mathbf{q}_n^2}\right)^{\frac{\omega'}{2}}_{\rm down} \left(\frac{\mathbf{q}_n^2}{\mathbf{k}_{n-1}^2}\right)^{\frac{\omega'}{2}}_{\rm up}$$

$$\left(\frac{s_{n,n+1}}{s_{R;n,n+1}=\mathbf{k}_n^2}\right)^{\omega'} = e^{\omega'(y_n-y_{n+1})} \left(\frac{\mathbf{k}_{n+1}^2}{\mathbf{q}_{n+1}^2}\right)^{\frac{\omega'}{2}}_{\rm down} \left(\frac{\mathbf{q}_{n+1}^2}{\mathbf{k}_n^2}\right)^{\frac{\omega'}{2}}_{\rm up}$$

3. NLO effects in Pomeron exchange:

[Fadin–SV–Philip Stephens, 2006]

[Fadin–Fiore, 2005]



$$\omega_\lambda\left(\mathbf{k}_a, \mathbf{q}\right) = -\frac{1}{2}\left\{\bar{\alpha}_s + \frac{\bar{\alpha}_s^2}{4}\left[\mathcal{S} - \frac{\beta_0}{2N_c}\ln\frac{\mathbf{k}_a^2\lambda^2}{\mu^4}\right]\right\}\ln\frac{\mathbf{k}_a^2}{\lambda^2} + 3\zeta(3)\bar{\alpha}_s^2 + \left\{\mathbf{k}_a \to \mathbf{k}_a - \mathbf{q}\right\}$$

$$\xi\left(\mathbf{k}_a, \mathbf{k}, \mathbf{q}\right) = \frac{\bar{\alpha}_s}{2}\left(1 + \frac{\left(\mathbf{k}_a - \mathbf{q}\right)^2\left(\mathbf{k}_a + \mathbf{k}\right)^2 - \mathbf{q}^2\mathbf{k}^2}{\mathbf{k}_a^2\left(\mathbf{k}_a - \mathbf{q} + \mathbf{k}\right)^2}\right)\left\{1 + \frac{\bar{\alpha}_s}{4}\left(\mathcal{S} - \frac{\beta_0}{N_c}\ln\frac{\mathbf{k}^2}{\mu^2}\right)\right\}$$

Good understanding of NLL BFKL corrections
Test **EXCLUSIVE** processes at HERA and Tevatron
to make reliable predictions for LHC: **JET PHYSICS**