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XVI International Workshop on Deep-Inelastic Scattering and Related Subjects

Conformal signatures in Mueller-Navelet and forward jets in DIS

1. QCD in Regge limit
2. Jet production at the LHC
3. Forward jets in DIS

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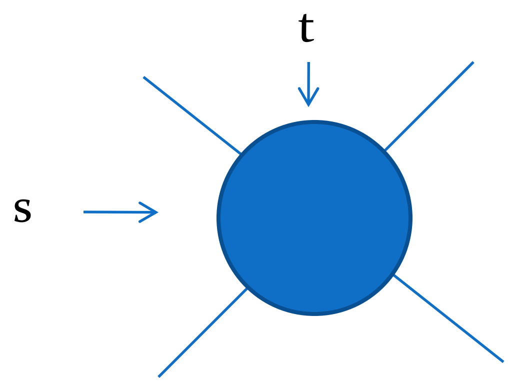
1. QCD in the Regge limit

High energy limit of scattering amplitudes in QCD:



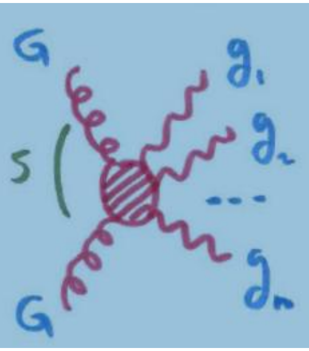
$$s \gg |t|,\ Q^2 \gg \Lambda^2_{QCD}$$

$$\alpha_s(Q^2) \ll 1$$

Large logarithms in s compensate the small coupling:

$$\text{BFKL} \sim \sum_{n=1}^{\infty} (\alpha_s \ln s)^n$$ resummation to all orders

In multi-Regge kinematics:



$y_1, \vec{k}_1$ $\quad$ $y_2, \vec{k}_2$ $\quad$ $y_n, \vec{k}_n$

$Y \sim \ln s$

$\vec{k}_i \sim \vec{k}_{i+1}$

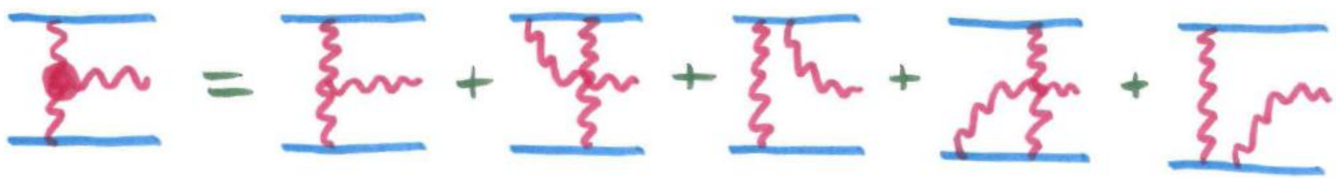
$y_i \ll y_{i+1}$

$$\bar{\alpha}_s^n \int_0^Y dy_1 \int_0^{y_1} dy_2 \cdots \int_0^{y_{n-1}} dy_n \sim \frac{(\alpha_s Y)^n}{n!}$$

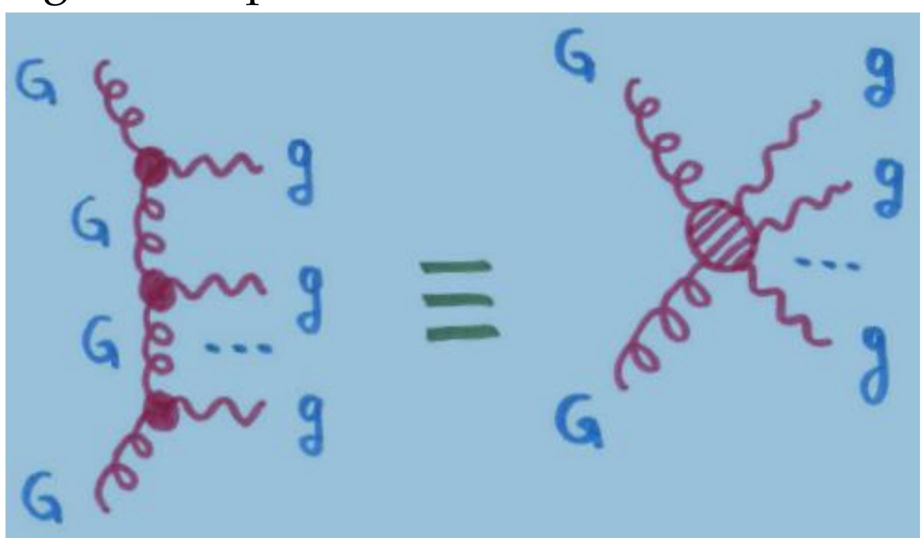
New effective degrees of freedom arise at high energies:

VIRTUAL contributions Reggeize t-channel gluons:

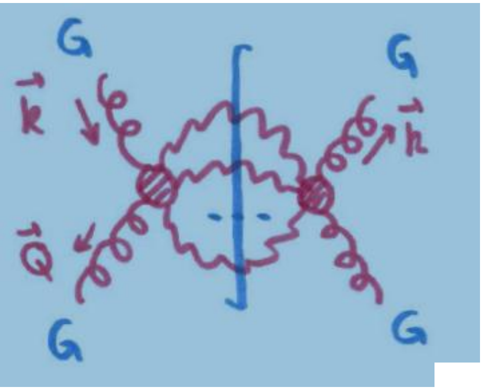
REAL emissions create a gauge-invariant effective vertex:



2 to 2+n soft gluon amplitudes are ladder-like :



Multi-jet cross sections :



$$f(\vec{k},\vec{Q},Y) \sim \sum_{n=-\infty}^{\infty} \int \frac{d\omega}{2\pi i} e^{\omega Y} \int \frac{d\gamma}{2\pi i} \left(\frac{\vec{k}^2}{\vec{Q}^2}\right)^{\gamma} \frac{e^{in\theta}}{\omega - \bar{\alpha}_s \chi_n(\gamma)}$$

2-d transverse momenta

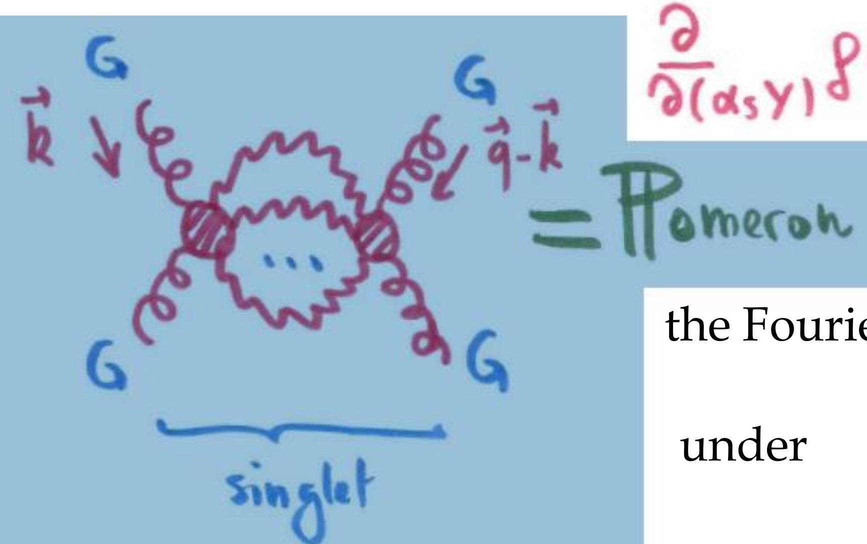
Azimuthal angle between emissions

$$\chi_n(\gamma) = 2\psi(1) - \psi\left(\gamma + \frac{|n|}{2}\right) - \psi\left(1-\gamma+\frac{|n|}{2}\right)$$

↳ conformal spins

n is a conformal spin in elastic scattering

Hard Pomeron = bound state of 2 Reggeized gluons.



$$\frac{\partial}{\partial(\alpha_s Y)} f(\vec{k},\vec{q},Y) = \int d\vec{k}' \, K(\vec{k},\vec{k}',\vec{q}) \, f(\vec{k}',\vec{q},Y)$$

When momenta are complexified

$q = q_x + i\, q_y \qquad q^* = q_x - i\, q_y$

the Fourier transform of $K(\vec{k},\vec{k}',\vec{q})$ is invariant

under $z_i \to z_i' = \dfrac{a z_i + b}{c z_i + d}$ [Lipatov]

2. Jet production at the LHC

In collaboration with

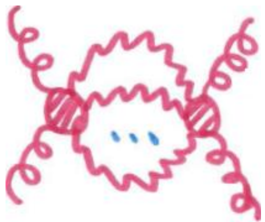
Jochen Bartels (DESY)

Florian Schwennsen (Paris)

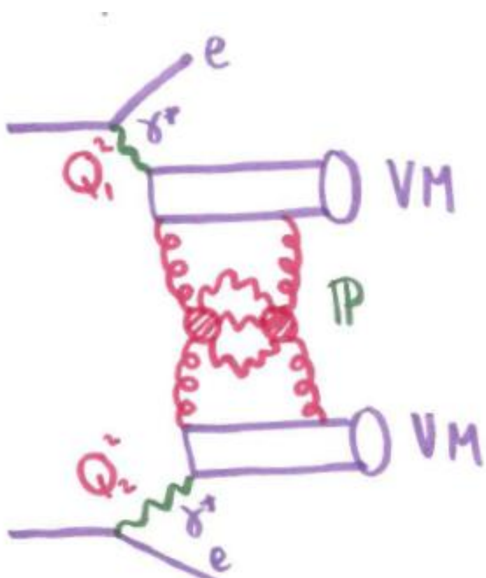
References:

SV, NPB 722 (2005), NPB 746 (2006)
Bartels, SV, Schwennsen, JHEP 0611:051 (2006)
SV, Schwennsen, NPB 776 (2007)

Phenomenology of multi-Regge kinematics:

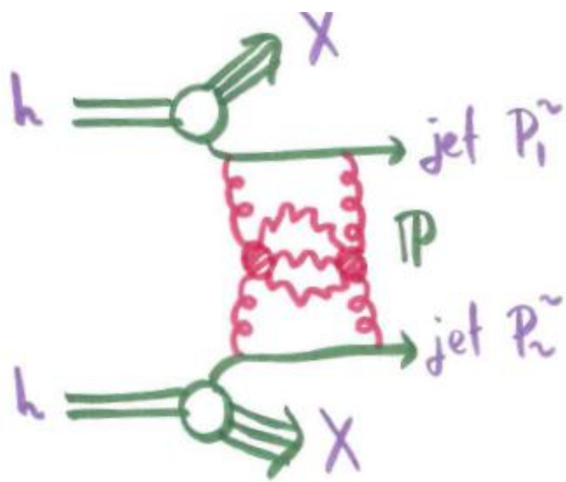
Uncut diagram  describes DIFFRACTIVE events with rapidity gaps

Lepton-lepton



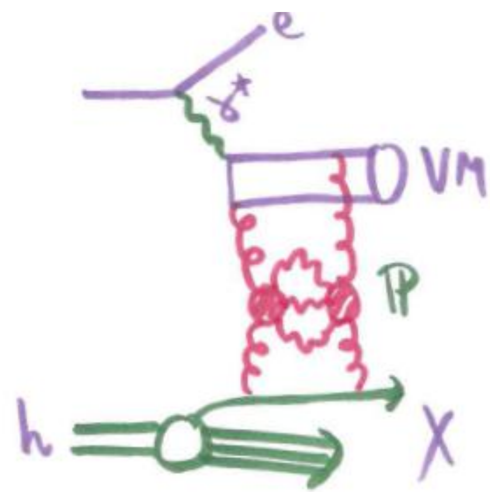
Production of light vector mesons

Hadron-hadron



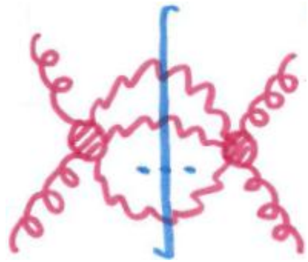
Mueller-Tang jets

Lepton-hadron



Vector meson production in DIS

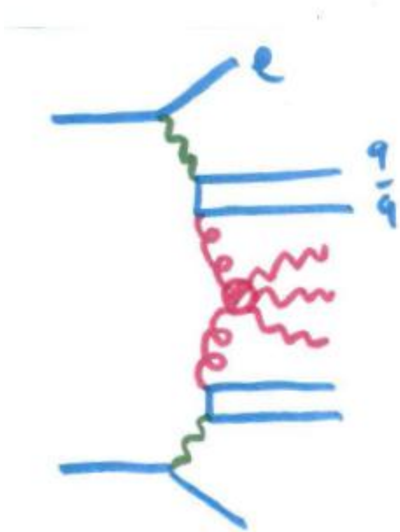
Cut diagram



describes high multiplicity events

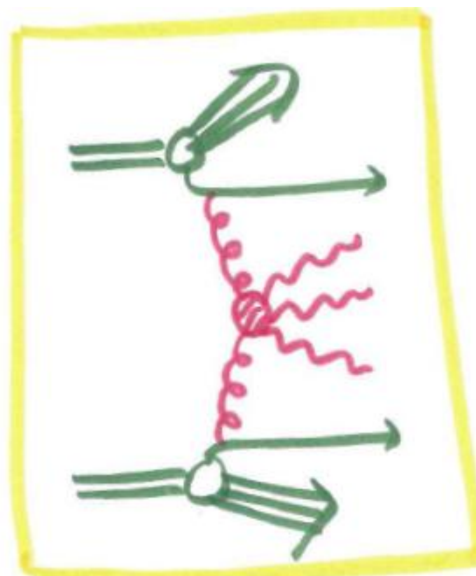
Multi-jet events with 2 large and similar hard scales:

Lepton-lepton



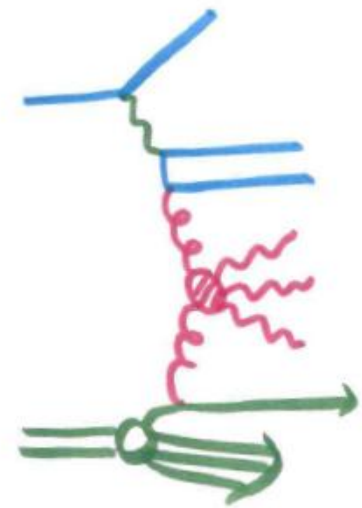
Total cross section for two virtual photons

Hadron-hadron



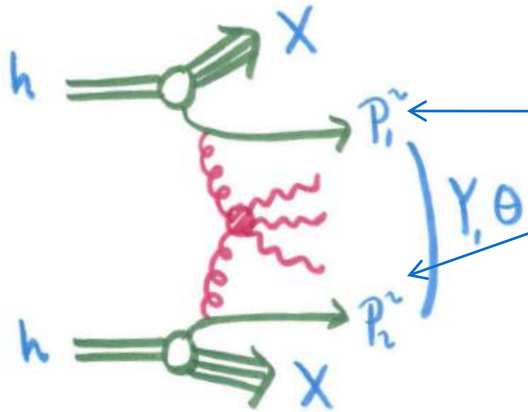
Mueller-Navelet jets

Lepton-hadron



Forward jets in DIS

BFKL conformal structure can be identified in the azimuthal angle decorrelation of Mueller-Navelet jets



Tag most forward / backward jets with large and similar transverse momenta

Relative azimuthal angle / rapidity

Large center of mass energy

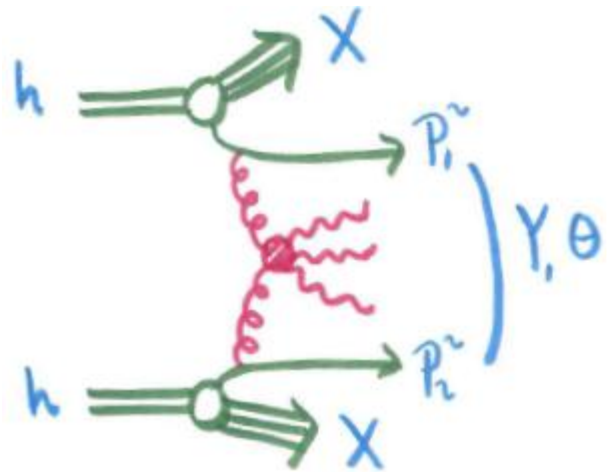
Project out the conformal components of the kernel with the observable:

$\langle \cos m\theta \rangle$

↳ Direct information about conformal spins

[Del Duca-Schmidt]

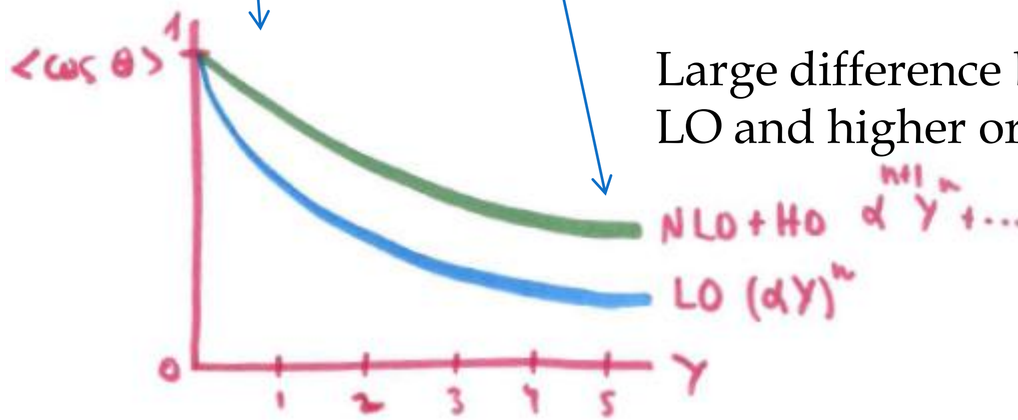
[Stirling]



At small Y MN jets are back-to-back

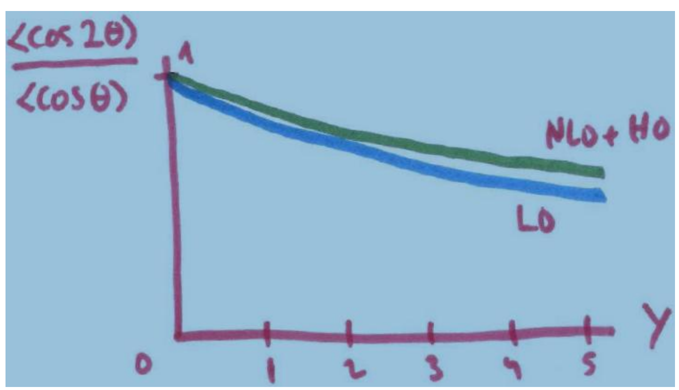
At large Y more gluon emissions decorrelate the MN jets

Large difference between LO and higher order



The ´perfect´ BFKL observable should remove the dependence on the zero conformal spin. This is the one most affected by collinear configurations not in original BFKL.

$$\frac{\langle \cos m\theta \rangle}{\langle \cos n\theta \rangle}$$



Small difference between LO and higher order calculations

Pythia and Herwig++ predict more correlation than BFKL

At the LHC we will go up to Y=12 and this observable will be measured

3. Forward jets in DIS

In collaboration with

Florian Schwennsen (Paris)

References:

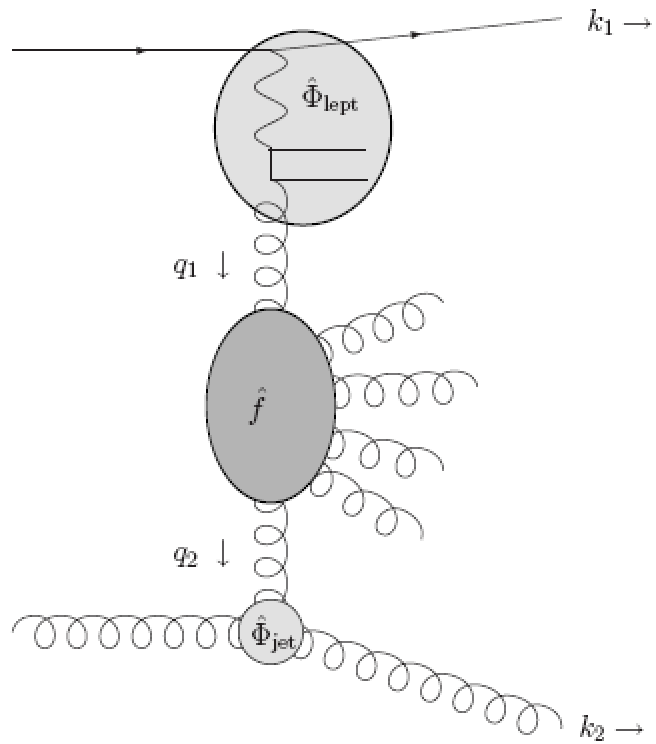
SV, Schwennsen, PRD 77 (2008)

$$\sigma(s) = \int dx_{\mathrm{FJ}}\; f_{\mathrm{eff}}(x_{\mathrm{FJ}}, \mu_F^2)\hat{\sigma}(\hat{s})$$

$$f_{\mathrm{eff}}(x, \mu_F^2) = G(x, \mu_F^2) + \frac{4}{9}\sum_f \left[Q_f(x, \mu_F^2) + \bar{Q}_f(x, \mu_F^2)\right]$$

$$Q^2 = -q_\gamma^2$$

$$x_{\mathrm{Bj}} = \frac{Q^2}{2Pq_\gamma}$$



$$\mathbf{k}_1^2 = (1-y)Q^2$$

$$y = \frac{Pq_\gamma}{P(q_\gamma + k_1)}$$

$$Y = \ln x_{\mathrm{FJ}}/x_{\mathrm{Bj}}$$

$$\hat{\sigma}(\hat{s}) = \frac{\pi^2\bar{\alpha}_s^2}{2}\int d^2\mathbf{k}_1 \int d^2\mathbf{k}_2 \int \frac{d\omega}{2\pi i} e^{\omega Y}\,\langle \mathbf{k}_1|\hat{\Phi}_{\mathrm{leptonic}}\hat{f}_\omega\hat{\Phi}_{\mathrm{jet}}|\mathbf{k}_2\rangle$$

$$\langle \mathbf{q}_1 | \nu, n \rangle = \frac{1}{\pi\sqrt{2}} \left(\mathbf{q}_1^2\right)^{i\nu - \frac{1}{2}} e^{in\theta_1} \qquad \hat{\mathcal{K}}_0 | \nu, n \rangle = \bar{\alpha}_s \chi_0 \left(|n|, \frac{1}{2} + i\nu \right) | \nu, n \rangle$$

$$\chi_0(n,\gamma) = 2\psi(1) - \psi\left(\gamma + \frac{n}{2}\right) - \psi\left(1 - \gamma + \frac{n}{2}\right)$$

$$\hat{\sigma}(\hat{s}) = \frac{\pi^2 \bar{\alpha}_s^2}{2} \sum_{n,n'=-\infty}^{\infty} \int d\alpha_1 \int dy \int d^2\mathbf{k}_2 \int \frac{d\omega}{2\pi i} \int d^2\mathbf{q}_1 \int d^2\mathbf{q}_2 \int d\nu \int d\nu'$$

$$\times \langle y, \alpha_1 | \hat{\Phi}_{\text{leptonic}} | \mathbf{q}_1 \rangle \langle \mathbf{q}_1 | \nu, n \rangle \langle n, \nu | \hat{f}_\omega | \nu', n' \rangle \langle n', \nu' | \mathbf{q}_2 \rangle \langle \mathbf{q}_2 | \hat{\Phi}_{\text{jet}} | \mathbf{k}_2 \rangle e^{\omega Y}$$

$$\text{ZEUS :} \qquad \frac{1}{2} < \frac{\mathbf{k}_2^2}{Q^2} < 2$$

$$\text{H1 :} \qquad \frac{1}{2} < \frac{\mathbf{k}_2^2}{Q^2} < 5$$

$$\frac{1}{2} \int d\mathbf{k}_2^2 \int d^2\mathbf{q}_2 \, \langle n', \nu' | \mathbf{q}_2 \rangle \langle \mathbf{q}_2 | \hat{\Phi}_{\text{jet}} | \mathbf{k}_2 \rangle$$

$$=: c_2(\nu') \frac{e^{-in'\alpha_2}}{2\pi} = \frac{1}{\sqrt{2}} \frac{1}{\frac{1}{2} + i\nu'} \left(\frac{Q^2}{2}\right)^{-i\nu' - \frac{1}{2}} \left[1 - \left(\frac{1}{4}\right)^{i\nu' - \frac{1}{2}}\right] \frac{e^{-in'\alpha_2}}{2\pi}$$

In the case of the H1 condition the 1/4 should be replaced for a 1/10

$$\int d^2\mathbf{q}_1 \langle y,\alpha_1|\hat{\Phi}_{\rm leptonic}|\mathbf{q}_1\rangle\langle\mathbf{q}_1|\nu,n\rangle$$

$$= \int dQ^2 \left[2A_1^{(0)}\left(\nu,y,Q^2\right) + A_1^{(2)}\left(\nu,y,Q^2\right)\left(\delta_{n,-2}e^{-2i\alpha_1} + \delta_{n,2}e^{2i\alpha_1}\right)\right]$$

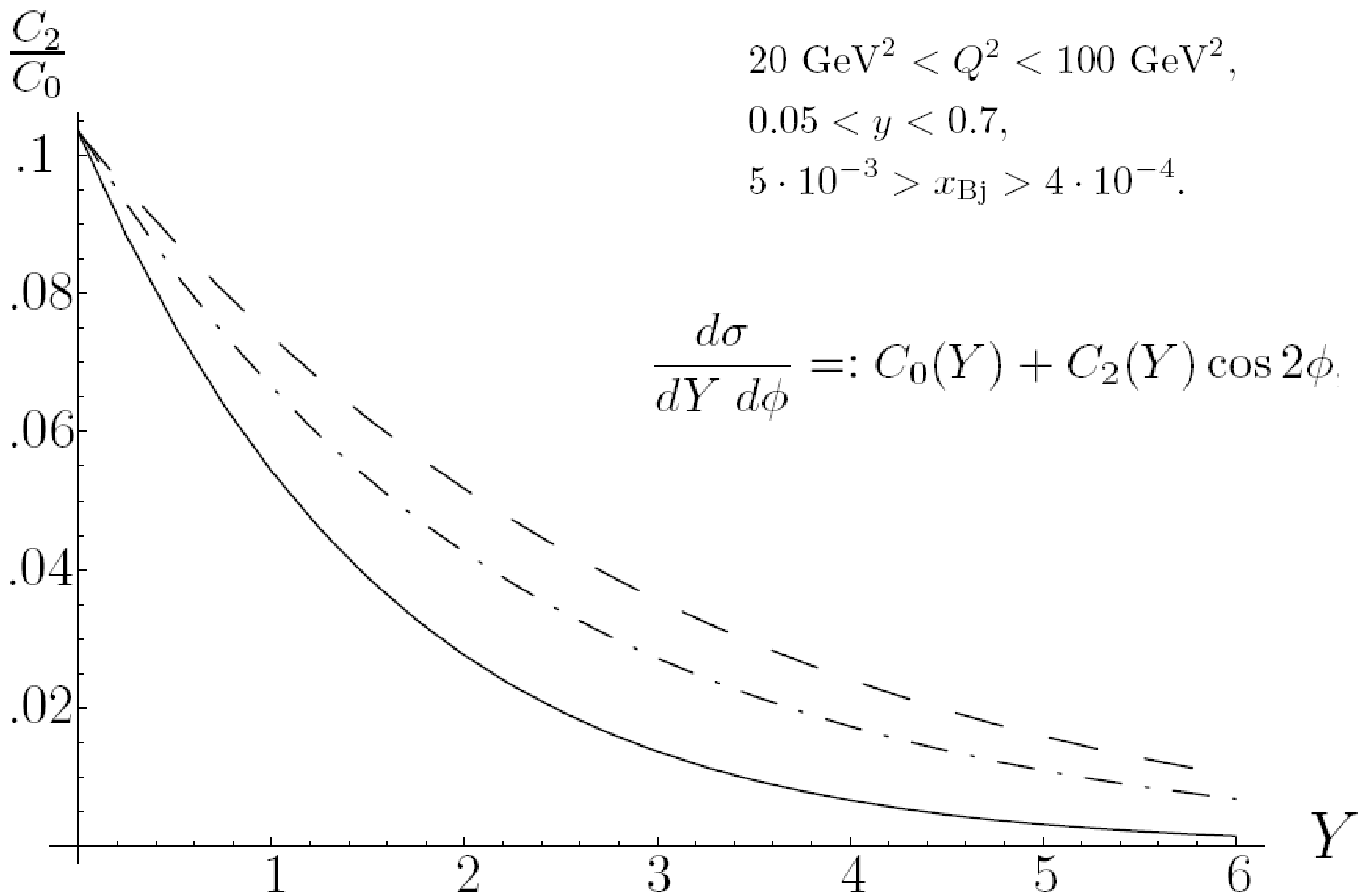
$$\langle n,\nu|\hat{f}|\nu',n'\rangle = \int \frac{d\omega}{2\pi i}\langle n,\nu|\hat{f}_\omega|\nu',n'\rangle e^{\omega Y} = e^{\chi\left(|n|,\frac{1}{2}+i\nu,\bar{\alpha}_s\right)Y}\ \delta(\nu-\nu')\delta_{nn'}$$

$$\chi\left(n,\frac{1}{2}+i\nu,\bar{\alpha}_s\right) = \bar{\alpha}_s\chi_0\left(n,\frac{1}{2}+i\nu\right) + \bar{\alpha}_s^2\left(\chi_1\left(n,\frac{1}{2}+i\nu\right) - \frac{\beta_0}{8N_c}\chi_0\left(n,\frac{1}{2}+i\nu\right)h_{\rm rc}^{(n)}\left(\nu,y,Q^2\right)\right)$$

$$\frac{d\hat{\sigma}}{d\phi\ dy\ dQ^2} = \frac{\pi^2\bar{\alpha}_s^2}{2}\left[B^{(0)}\left(y,Q^2,Y\right) + B^{(2)}\left(y,Q^2,Y\right)\cos 2\phi\right]$$

$$B_{\rm LO}^{(n)}\left(y,Q^2,Y\right) = \int d\nu\ A^{(n)}\left(\nu,y,Q^2\right)\ c_2(\nu)e^{Y\bar{\alpha}_s\chi_0(|n|,\nu)}$$

$$B_{\rm NLO}^{(n)}\left(y,Q^2,Y\right) = \int d\nu\ A^{(n)}\left(\nu,y,Q^2\right)\ c_2(\nu) \times e^{\bar{\alpha}_s(Q^2){\rm Y}\left(\chi_0(|n|,\nu)+\bar{\alpha}_s(Q^2)\left(\chi_1(|n|,\nu)-\frac{\beta_0}{8N_c}\chi_0(n,\frac{1}{2}+i\nu)h_{\rm rc}^{(n)}(\nu,y,Q^2)\right)\right)}$$



$\frac{C_2}{C_0}$
.1
.08
.06
.04
.02
1
2
3
4
5
6
Y
$20\ \mathrm{GeV}^2 < Q^2 < 100\ \mathrm{GeV}^2$,
$0.05 < y < 0.7$,
$5 \cdot 10^{-3} > x_{\mathrm{Bj}} > 4 \cdot 10^{-4}$.
$\frac{d\sigma}{dY\, d\phi} =: C_0(Y) + C_2(Y) \cos 2\phi$