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BFKL effects at High Energies

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Outline:

- High-energy Llimit of QCD: BFKL
- BFKL: LO and NLO
- BFKL: $\gamma^\star\gamma^\star$ collisions
- BFKL: jet production
- Summary

Motivation

ALL (!) particles behave like hadrons

at high-energy limit: $s \to \infty$

Motivation

QCD:

All-order resummation at $s \to \infty$ (BFKL):

$\Rightarrow$ rising gluon-gluon cross section

$\Rightarrow$ rising hadronic cross section

Electro-Weak:

Emission of (virtual) quarks and gluons

via (virtual) photon and weak bosons

$\Rightarrow$ rising cross sections due to gluons

The strong energy dependence (BFKL)

eventually overcomes the suppression

by coupling constants (α_{EW}, α_S)

$\Downarrow$

ALL (!) particles behave like hadrons

at high-energy limit: $s \to \infty$

$Q^2 \to \infty$, $x = \frac{Q^2}{s}$ **- fixed**

Bjorken-limit

GLAPD-evolution

$\sigma(s, Q^2) \quad \Rightarrow$

$s \to \infty \quad \Rightarrow$

Q^2 **- fixed,** $x = \frac{Q^2}{s} \to 0$

Regge-limit

(LO) BFKL-evolution

High-energy $\gamma\gamma$ in QED

Gribov, Lipatov, Frolov & Gorshkov (67-71)

Cheng & Wu (67-70)

$$\sigma \sim \alpha^2 \left(\frac{\log s}{s} \right) \qquad \sigma \sim \alpha^4 s^0 \qquad \sigma \sim \alpha^4 s^\omega$$

$$\omega = \frac{11}{32} \pi \alpha^2 \simeq 6 \cdot 10^{-5}$$

High-energy $\gamma\gamma$ in QCD

Lipatov, Fadin & Kuraev (75-77)

Balitsky & Lipatov (78)

$$\sigma \sim \alpha^2 \alpha_S^2 s^0 \qquad \sigma \sim \alpha^2 \alpha_S^2 s^\omega$$

BFKL: $\omega_{LO} = \frac{12 \log 2}{\pi} \alpha_S \simeq 0.5 \quad \omega_{NLO} \simeq 0.13 \div 0.18$

LO and NLO BFKL

$$\sigma(s,Q^2) \quad \sim \quad \left(\frac{s}{s_0}\right)^{\omega(Q^2)}$$

$$\omega = \alpha_{I\!P} - 1 \leftarrow \text{NOT A FREE PARAMETER!}$$

The only parameter in (N)LO BFKL: $s_0 \sim Q^2$

[due to neglected (sub-)subleading subserieses] :

- **at** $s \to \infty$ **cross sections do not depend on** s_0
- **at finite** $s \Rightarrow$ s_0**-dependence**

LO BFKL: $\omega = 0.55$ at $\alpha_S = 0.2$

Fadin, Kuraev & Lipatov (75-77)

NLO BFKL: ...

Fadin & Lipatov (98); Ciafaloni& Camici (98)

NLO BFKL in BLM: $\omega = 0.13$–0.18

Brodsky,Fadin,VK,Lipatov&Pivovarov (99)

V.K., Lipatov & Pivovarov (99)

Brodsky,Fadin,V.K.,Lipatov&Pivovarov (01)

$k_\perp$-factorization scheme

Catani,Ciafaloni & Hautmann (90-91)

Collins & K.Ellis (91)

Levin, Ryskin, Shabelsky & Shuvaev (91)

Mueller-Navelet-factorization scheme

Mueller & Navelet (87)

BFKL-factorization scheme

V.K. & G.Pivovarov (96)

V.K. & Pivovarov (98)

V.K. & Pivovarov (96)

Available BFKL MC Generators

Custom-written BFKL MC generators:

- **C.Schmidt: Mueller-Navelet factorization, only parton level**
- **L.Orr & J.Stirling: Mueller-Navelet factorization, only parton level**

Pythia-based BFKL MC generators:

- **H.Jung & G.Salam (Cascade): $k_\perp$-factorization, only heavy quark production**
- **L.Lonnblad (Ariadne-LDC): only electron-proton scattering**
- **D.Gulevich & V.Kim: BFKL-improved Pythia 6.2, BFKL-evolution for parton shower**

BFKL MC Generator Based on Pythia

Modified Pythia 6.2 with unified GLAPD-BFKL evolution kernel:

• Backward GLAPD-evolution algorithm of Pythia based on Sudakov formfactor

$$\Downarrow$$

• extended to unified GLAPD-BFKL evolution (including angle ordering & energy-momentum constrains)

Summary

BFKL dynamics might be very important at LHC in:

⋆ $pp-$ ($AA-$ **and** $\gamma\gamma$**-) collisions**

⋆ **inclusive jet and multijet production**

⋆ **jets associated with Higgs, SUSY, etc.**

⋆ **heavy-quark production**

⋆ **rapidity gap (hard diffraction) physics**

- **Study of BFKL-effects at LHC will provide a very unique opportunity to test high-energy asymptotics of QCD**

- **Incorporation of BFKL into MC generators should help to discover new phenomena**