A smuggled Technical Note on Mueller Navelet jets from the Fellows' Garden

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TeV scale Physics

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GOAL to analyse the QCD dynamics in the $s \gg |t|$ limit: the high energy limit (HEL)

FACT in HEL the scattering processes are dominated by sub-processes with gluon exchange in the t channel

BFKL theory resums multiple gluon radiation out of the gluon exchanged in the t channel

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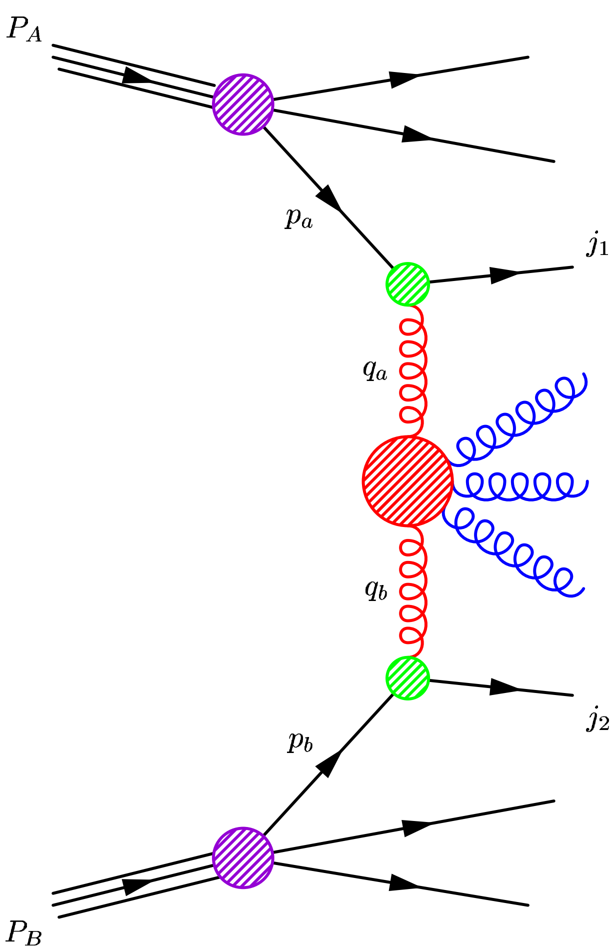
PHENOM. Process-dependent questions:

* does a fixed-order expansion in α_s suffice to describe the data ?
* can the data be described in terms of other, e.g. Sudakov, resummations ?
* in phase space, where do sub-processes with gluon exchange in the t channel dominate over the other sub-processes ?

DIJET PRODUCTION IN $p\,p$ COLLISIONS



KINEMATICS

$p_a = x_a P_A \quad p_b = x_b P_B$:

incoming parton momenta

S : hadron c.m. energy

$s = x_a x_b S$: parton c.m. energy

$E_{j_{1,2}\perp}$: jet transverse energy

$Q^2 = -t$: typical momentum transfer

Ô $Q^2 \sim E^2_{j\perp}$

$\Delta y = |y_{j_1} - y_{j_2}|$:

rapidity difference between the jets

k $\ln \frac{S}{Q^2} = \ln \frac{1}{x_a} + \ln \frac{s}{Q^2} + \ln \frac{1}{x_b}$

k $x_{a,b} = \mathcal{O}(1) \qquad \ln \frac{s}{Q^2} \simeq \Delta y \gg 1$

Ô physics of large rapidity intervals,

and not small-x physics

Dijet Production in HEL

the cross section for dijet production in HEL:

$$\frac{d\sigma}{d^2p_{j_1\perp}\,d^2p_{j_2\perp}\,dy_{j_1}\,dy_{j_2}} = x_a^0 f_{\rm eff}(x_a^0,\mu_F^2)\, x_b^0 f_{\rm eff}(x_b^0,\mu_F^2)\, \frac{d\hat\sigma_{gg}}{d^2p_{j_1\perp}\,d^2p_{j_2\perp}}$$

the parton momentum fractions in HEL:

$$x_a^0 = \frac{|p_{j_1\perp}|}{\sqrt{S}} e^{y_{j_1\perp}}\,, \qquad\qquad x_b^0 = \frac{|p_{j_2\perp}|}{\sqrt{S}} e^{-y_{j_2\perp}}$$

the effective p.d.f.

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

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parton cross section in terms of BFKL ladder f and impact factors:

$$\frac{d\hat\sigma_{gg}}{d^2p_{j_1\perp}\,d^2p_{j_2\perp}} = \left[\frac{C_A\alpha_s}{|p_{j_1\perp}|^2}\right] f(q_{a\perp},q_{b\perp},\Delta y) \left[\frac{C_A\alpha_s}{|p_{j_2\perp}|^2}\right]$$

asymptotically, the LL BFKL ladder is:

$$\lim_{\Delta y\gg 1} f(q_{a\perp},q_{b\perp},\Delta y) \sim \frac{e^{4C_A \ln 2\,\alpha_S \Delta y/\pi}}{\sqrt{7\zeta_3 C_A \alpha_S \Delta y/2}}$$

BFKL Monte Carlo

Drawbacks of the BFKL ladder

- the (N)LL BFKL resummation is performed at fixed α_S
  ⇒ any variation in the scale of α_S occurs in the (N)NLL terms

- energy and longitudinal momentum are not conserved:
  in dijet production, the exact x's are

$$x_a = \frac{e^{y_{j_1}}}{\sqrt{S}} \left(|p_{j_1\perp}| + |p_{j_2\perp}| e^{-\Delta y} + \sum_{i=1}^{n} p_{i\perp} e^{y_i - y_{j_1}} \right)$$

$$x_b = \frac{e^{-y_{j_2}}}{\sqrt{S}} \left(|p_{j_2\perp}| + |p_{j_1\perp}| e^{-\Delta y} + \sum_{i=1}^{n} p_{i\perp} e^{-y_i + y_{j_2}} \right)$$

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* a Monte Carlo solution of the BFKL equation can account for

Ô running of α_S

Ô energy and longitudinal momentum conservation

Schmidt 1996

Orr, Stirling 1997

DIJET PRODUCTION IN HEL

k in an event with two or more jets, tag the most forward and the most backward jets

$$\Delta y = |y_{j_1} - y_{j_2}| \simeq \ln \frac{x_a x_b S}{E_{j_1\perp} E_{j_2\perp}}$$

k minimise the jet transverse energy

k maximise $s = x_a x_b S$

¶ in a collider with ramping-up energy S, fix $= x_{a,b}$

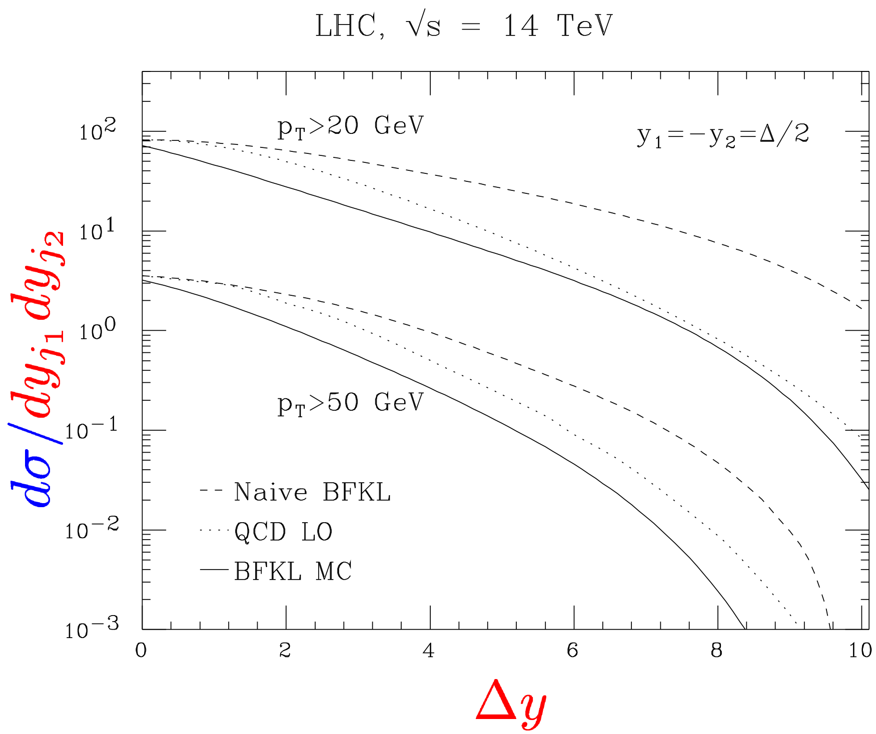
analyse $\frac{d\sigma}{dx_a dx_b}$ for different values of S Mueller, Navelet 1987

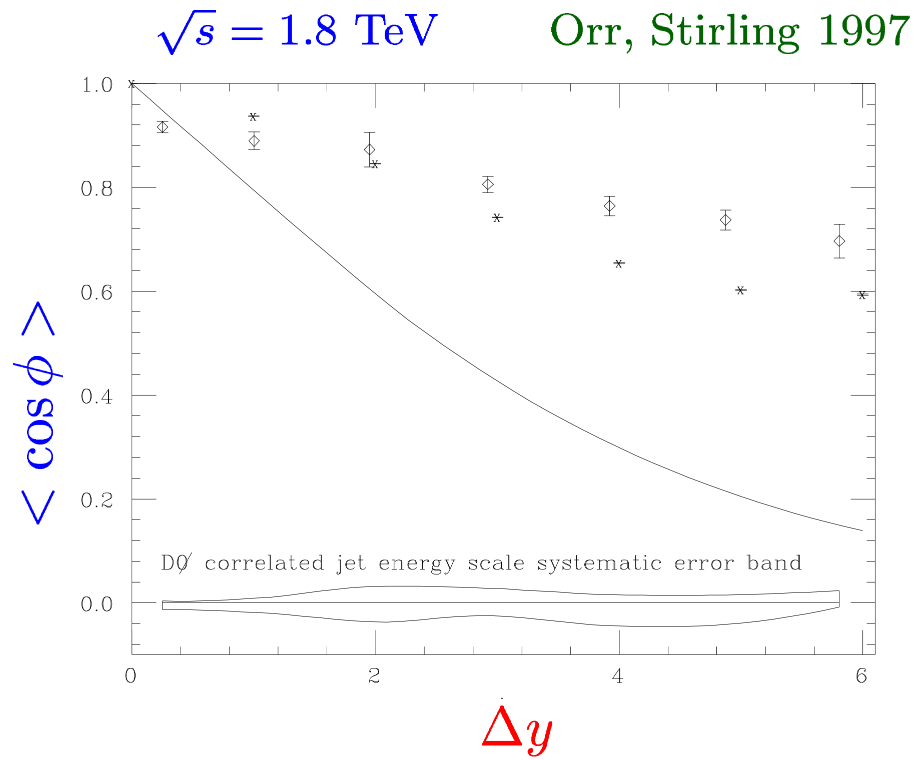
• in a fixed energy S collider, increase $= x_{a,b}$

analyse $\left\{ \begin{array}{ll} \frac{d\sigma}{d\Delta y} & \text{for different values of } \Delta y \\ \frac{d\sigma}{d\Delta y\, d\phi} & \phi: \text{ azimuthal angle between tagged jets} \end{array} \right.$

Schmidt, VDD; Stirling 1993-95

Dijet Production – Phenomenology





- in $\dfrac{d\sigma}{dy_{j_1}dy_{j_2}}$ the BFKL Monte Carlo yields a depletion rather than an enhancement, both for Tevatron & LHC, due to the falling parton luminosities

- $< \cos\phi >$ shows too much azimuthal decorrelation wrt Tevatron D0 data, while it is well described by a parton-shower Monte Carlo (HERWIG)

Caveat $< \cos\phi >$ is dominated by soft gluon (Sudakov) effects

Mueller-Navelet Jets

Mueller-Navelet proposal for colliders with ramping-up energy S:

- take the cross section for dijet production in HEL at fixed x's:

$$\frac{d\sigma}{dx_a^0 dx_b^0} = \int d^2p_{j_{1\perp}} d^2p_{j_{2\perp}} f_{\rm eff}(x_a^0, \mu_F^2)\, f_{\rm eff}(x_b^0, \mu_F^2)\, \frac{d\hat{\sigma}_{gg}}{d^2p_{j_{1\perp}} d^2p_{j_{2\perp}}}$$

- use approximate x's: $x_a^{MN} = \frac{E_\perp}{\sqrt{S}} e^{y_{j_{1\perp}}}$ $\qquad x_b^{MN} = \frac{E_\perp}{\sqrt{S}} e^{-y_{j_{2\perp}}}$
  - the x's are in a one-to-one correspondence with the rapidities
  - Δy is fixed at its max: $\Delta y = \ln \frac{x_a^{MN} x_b^{MN} S}{E_\perp^2}$
- integrate out transverse energies above a threshold $E_\perp$: $|p_{j_{1,2\perp}}| \geq E_\perp$
  - the Mueller-Navelet gluon-gluon cross section is

$$\hat{\sigma}_{gg} = \frac{9\pi\alpha_S^2}{2E_\perp^2} \frac{e^{4C_A \ln 2\alpha_S \Delta y/\pi}}{\sqrt{7\zeta_3 C_A \alpha_S \Delta y/2}}$$

- compute the cross section at different c.m. energies S

Mueller-Navelet Jets – D0 Analysis

D0 implementation of Mueller-Navelet: D0 Collaboration 1999

* exact LO x's: $\begin{cases} x_1 = \dfrac{2|p_{j_1\perp}|}{\sqrt{S}} e^{\bar{y}} \cosh \dfrac{\Delta y}{2} \\ x_2 = \dfrac{2|p_{j_2\perp}|}{\sqrt{S}} e^{-\bar{y}} \cosh \dfrac{\Delta y}{2} \end{cases}$ $\quad \bar{y} = \dfrac{y_{j_1\perp} + y_{j_2\perp}}{2}$

* acceptance cuts:

$$\begin{cases} |p_{j_{1,2\perp}}| \geq 20 \text{ GeV} \qquad Q^2 = |p_{j_1\perp} p_{j_2\perp}| \leq Q^2_{MAX} = 1000 \text{ GeV}^2 \\ |y_{j_{1,2\perp}}| \leq 3 \qquad \Delta y \geq 2 \end{cases}$$

* measure the cross section at $\sqrt{S_A} = 1800$ GeV and $\sqrt{S_B} = 630$ GeV in 6 (x_1, x_2) bins, with $0.06 \leq x_1, x_2 \leq 0.22$

* using the Mueller-Navelet cross section, compute the ratio $R = \dfrac{\sigma(S_A)}{\sigma(S_B)}$

⇒ get the BFKL intercept

$$\alpha_{BFKL} = 1.65 \pm 0.07$$

Our Mueller-Navelet/D0 Analysis

* D0 uses an upper bound on Q^2, such that $E_\perp^2 / Q^2_{MAX} = 0.4$

* in HEL $\begin{cases} x_1 \to x_a^0 \neq x_a^{MN} \\ x_2 \to x_b^0 \neq x_b^{MN} \end{cases}$

  $x_{a,b}^{MN}$ are not good approximations to $x_{1,2}$

* the rapidity interval can be written as

  $$\Delta y = Y + \ln \frac{E_\perp^2}{p_{j_{1\perp}} p_{j_{2\perp}}} \quad \text{with} \quad Y = \ln \frac{x_a^0 x_b^0 S}{E_\perp^2}$$

  $\Delta y \geq 2$ Ô $Q^2_{MAX} = E_\perp^2 e^{(Y-2)}$

  Ô an effective maximum momentum transfer

  $$Q^2_{MAX} = \min(1000\,\mathrm{GeV}^2,\ E_\perp^2 e^{(Y-2)})$$

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we analysed Mueller-Navelet/D0 with

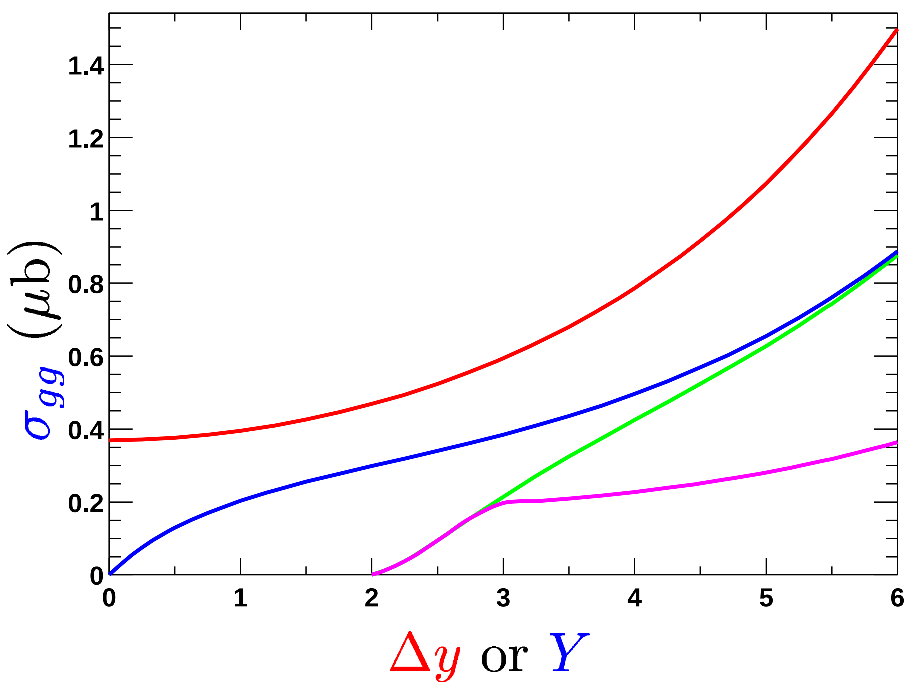
k analytic BFKL — Andersen, Frixione, Schmidt, Stirling, VDD 2001

k BFKL Monte Carlo

k general-purpose NLO partonic Monte Carlo

Our Mueller-Navelet/D0 Analysis

analytic BFKL



red: Mueller-Navelet (at fixed $x_{a,b}^{MN}$)

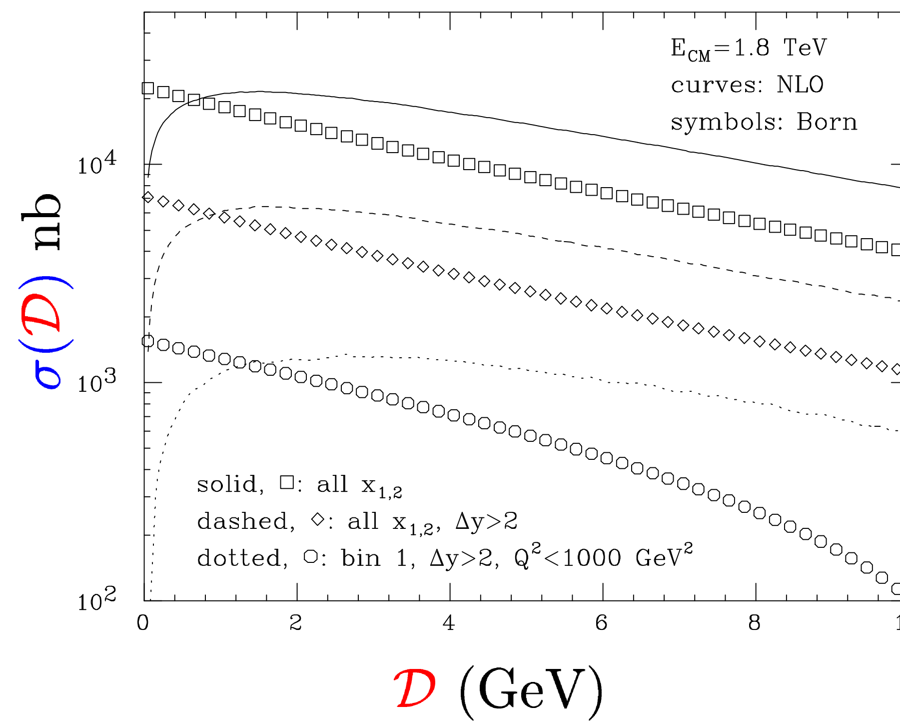
blue: at fixed $x_{a,b}^{0}$

green: at fixed $x_{a,b}^{0}$ with $\Delta y \geq 2$

magenta: green + $p_{j_1\perp} p_{j_2\perp} \leq 1000\,\mathrm{GeV}^2$

k in σ_{gg} all curves have asymptotically the same shape Ô sub-leading terms are important

NLO partonic Monte Carlo



$\mathcal{D} = |\min(p_{j_1\perp}) - \min(p_{j_2\perp})|$

symbols: LO

curves: NLO

Caveat

soft gluon effects at $\mathcal{D} = 0$

CONCLUSIONS

* **AZIMUTHAL DECORRELATION** No evidence of BFKL radiation has been found. Data are described well by parton shower generators (HERWIG)

* **MUELLER-NAVELET JETS** Sub-leading effects forbid the extraction of the BFKL intercept

* **CAVEAT** Both analyses above are contaminated by soft gluon (Sudakov) effects