BFKL at colliders

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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

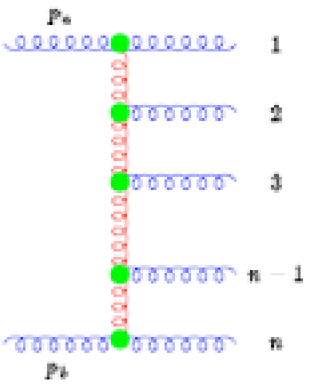
PHENOM. Process-dependent questions:

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

BFKL RESUMMATION

- in any scattering process with $s \gg |t|$ gluon exchange in the t channel dominates

- BFKL is a resummation of multiple gluon radiation out of the gluon exchanged in the t channel



- for $s \gg |t|$ BFKL resums the Leading Log (and Next-to-Leading Log) contributions, in $\log(s/t)$, of the radiative corrections to the gluon propagator in the t channel, to all orders in α_S

- the LL terms are obtained in the approximation of strong rapidity ordering $(y_1 \gg y_2 \gg \ldots \gg y_n)$ and no k_t ordering of the emitted gluons

- the NLL terms are universal

- the resummation yields a 2-dim integral equation for the evolution of the gluon propagator in the t channel

BFKL Phenomenology

- in principle, the BFKL resummation can be applied to any scattering process with $s \gg |t|$, where t is a typical (squared) transverse energy scale

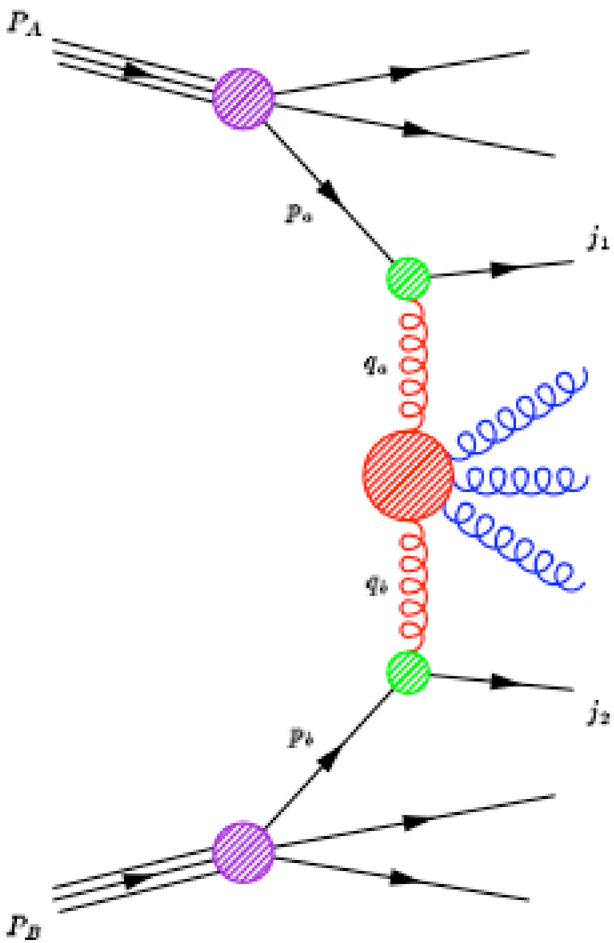
  - in $p\,p$ collisions $\left\{ \begin{array}{c} \text{dijet} \\ V,\ H + 2\ \text{jet} \\ \text{heavy diquark} \end{array} \right\}$ production at large rapidities

  - in DIS $\left\{ \begin{array}{c} F_2 \text{ scaling violations} \\ \text{forward jet production} \end{array} \right.$

  - in e^+e^-, $\gamma^*\gamma^* \to$ hadrons at large Y

- in HEL, the partonic cross section is $\hat{\sigma}(AB \to j_1 j_2) \sim \mathcal{I}(j_1)\mathcal{F}_{BFKL}\mathcal{I}(j_2)$
- the BFKL ladder $\mathcal{F}_{BFKL}$ is universal
- the impact factors $\mathcal{I}(j) \sim |C^{g;g}|^2$ are process dependent

Dijet Production in pp 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

➥ $Q^2 \sim E_{j\perp}^2$

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

rapidity difference between the jets

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

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

➥ physics of large rapidity intervals,

and not small-x physics

Hunting for BFKL

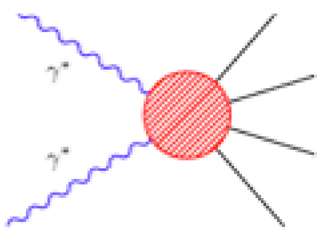
- take an observable whose kinematics are dominated by t-channel gluon exchange
- take the best fixed-order prediction, and compare it to the data
- if possible, make sure that other resummations are not relevant
- include BFKL radiation (possibly conserving energy & momentum through a MC implementation)
- estimate uncertainties
- compare to data

BFKL phenomenology

- dijet production in pp collisions
  Mueller Navelet 1987
  Schmidt VDD; Stirling 1993-95
  Orr Stirling 1997-98
  Andersen Frixione Schmidt Stirling VDD 2001
- forward jet in DIS
  Mueller 1991
  Bartels De Roeck Loewe 1992
  Bartels De Roeck Graudenz Wusthoff VDD 1996
  Aurenche, Basu, Fontannaz, Godbole 2004
- $\gamma^*\gamma^* \to \text{hadrons}$
  Bartels De Roeck Lotter 1996
  Brodsky Hautmann Soper 1997
  Cacciari Frixione Maltoni Trocsanyi VDD 2000-02
- $pp \to Wjj$
  Andersen Maltoni Stirling VDD 2001
- $pp \to Hjj \quad \text{(gluon fusion)}$
  Kilgore Oleari Schmidt Zeppenfeld VDD 2003
- $pp \to Q\bar{Q}Q\bar{Q}$
  Andersen Frixione Maltoni Stirling VDD 2004

$\gamma^*\gamma^* \to$ hadrons

The fixed order expansion in α_s



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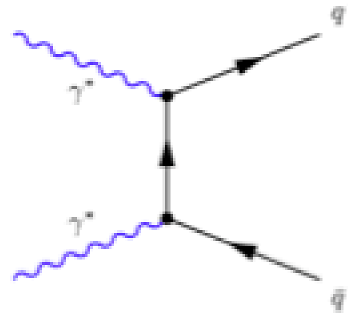
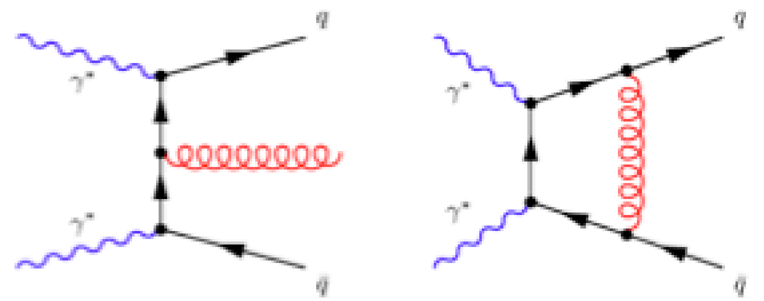
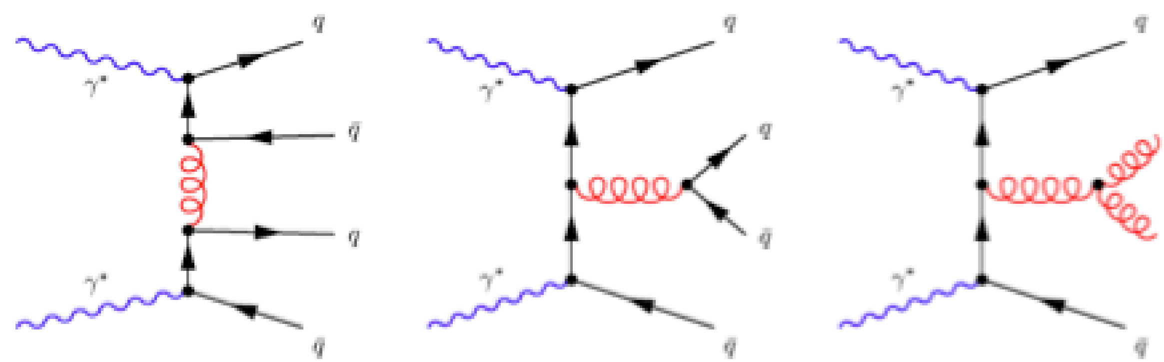


LO



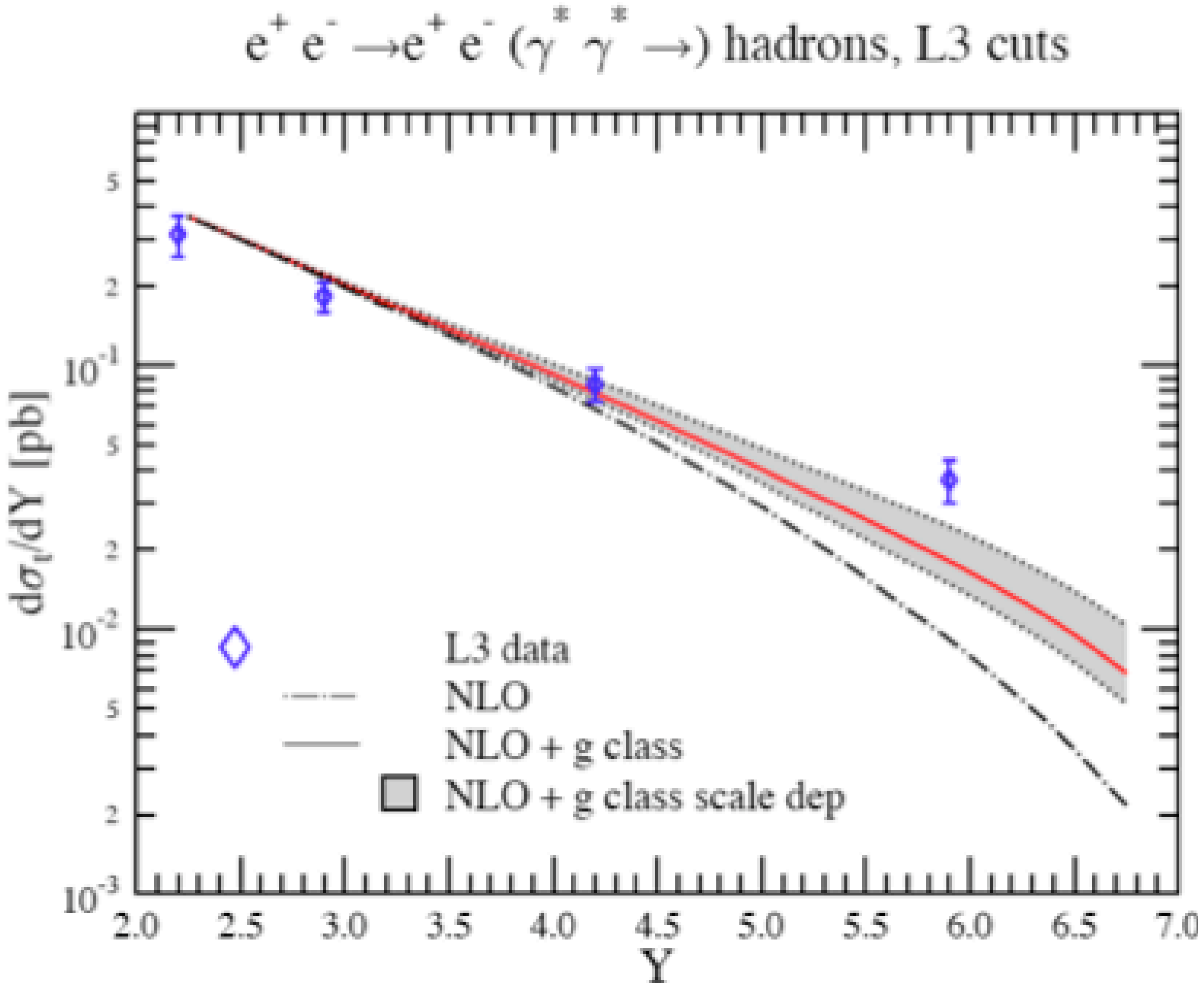
NLO



BFKL (Born)

NNLO (4-partons)

$\gamma^*\gamma^* \rightarrow$ hadrons



NLO is not enough to describe the data

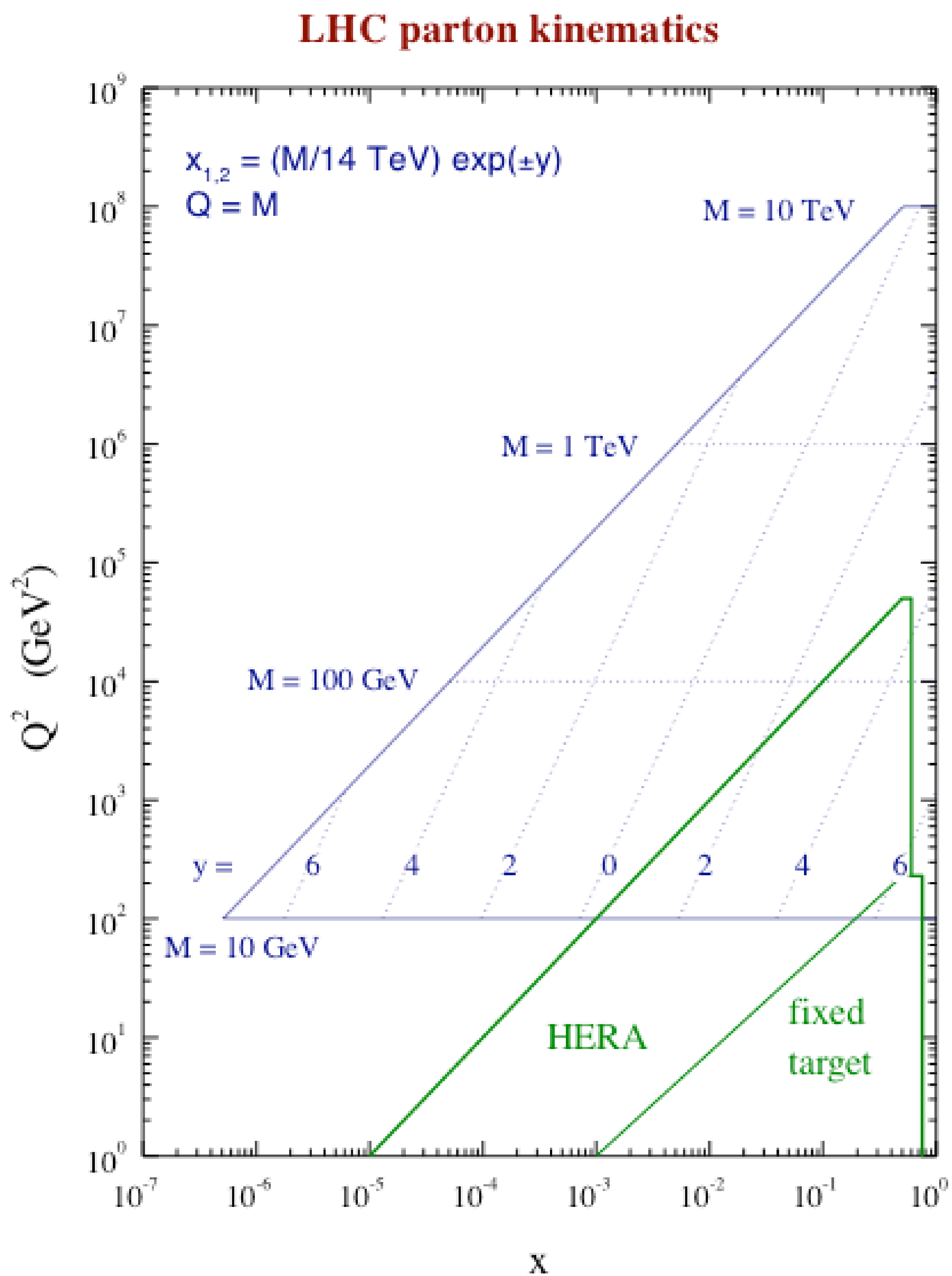
Adding some NNLO (finite) terms, which correspond to the BFKL LO term, softens the discrepancy.

Considering the strong scale dependence there is no evidence for the need of resummation.

Very similar to the DIS situation!

Cacciari Frixione Maltoni Trocsanyi VDD 2000-02

J. Stirling

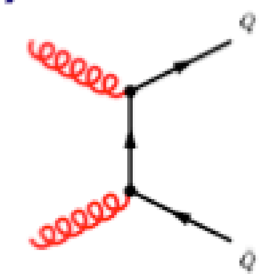


LHC parton kinematics
x1,2 = (M/14 TeV) exp(±y)
Q = M
M = 10 TeV
M = 1 TeV
M = 100 GeV
M = 10 GeV
y = 6 4 2 0 2 4 6
HERA
fixed target
Q² (GeV²)
x

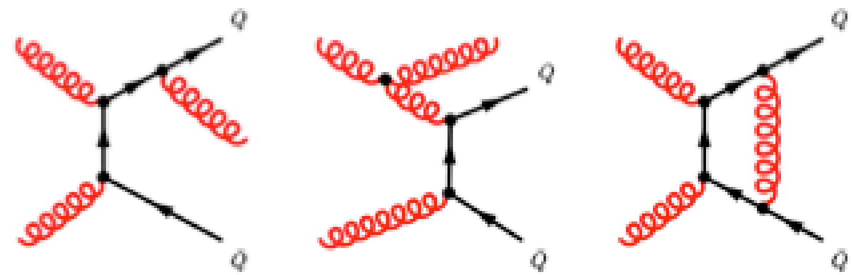
The perturbative expansion for two b's at large rapidity

$$\frac{d\sigma_{Q\bar{Q}}}{d\Delta y} \sim \alpha_S^2 \sum_{j=0}^{\infty} a_{0j}\alpha_S^j$$

a_{00}

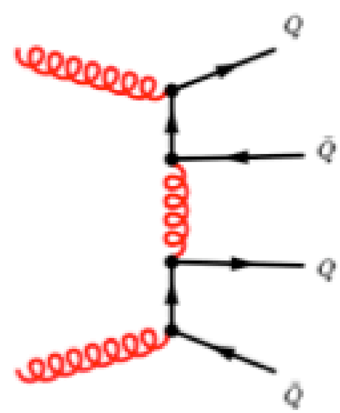


a_{01}

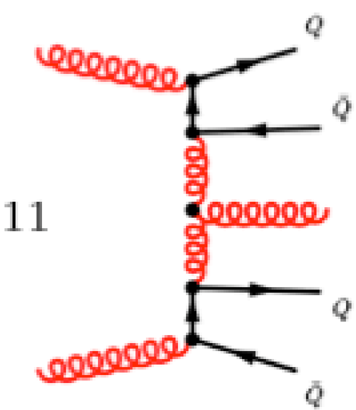


$$+\alpha_S^4 \sum_{j=0}^{\infty} a_{1j}(\alpha_S L)^j$$

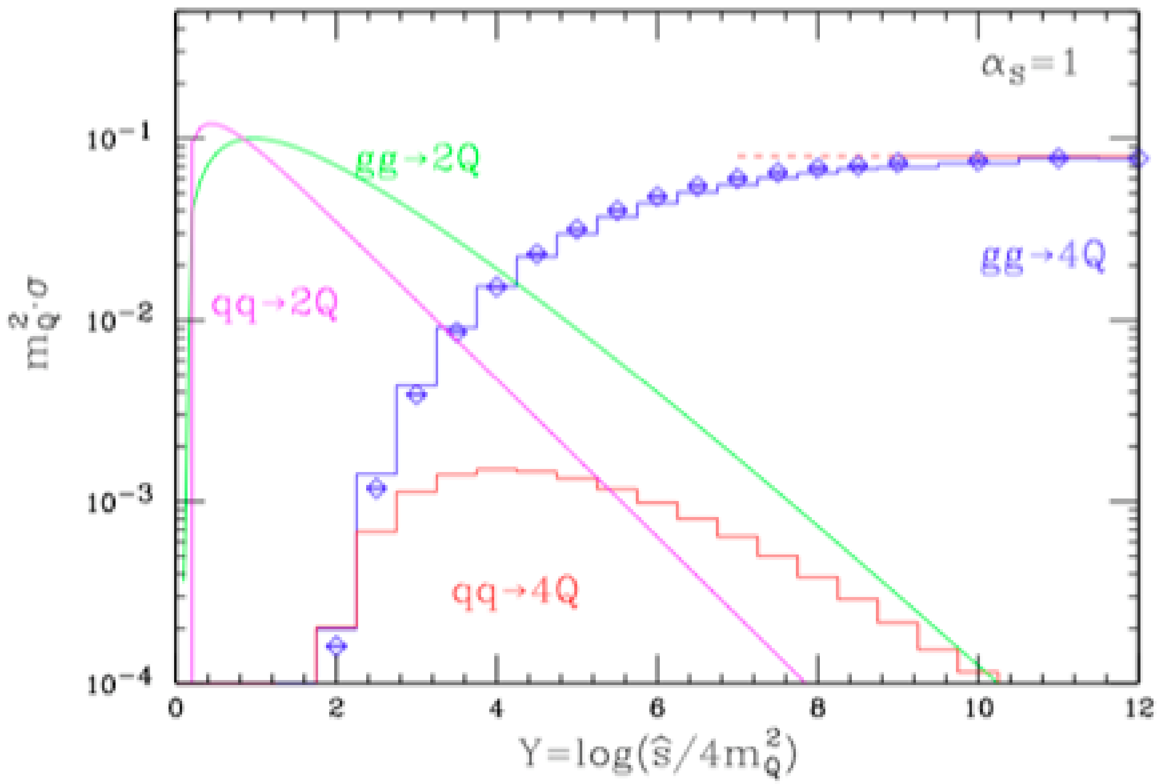
a_{10}



a_{11}



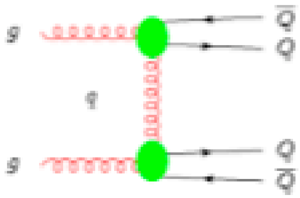
How well the HE limit works?

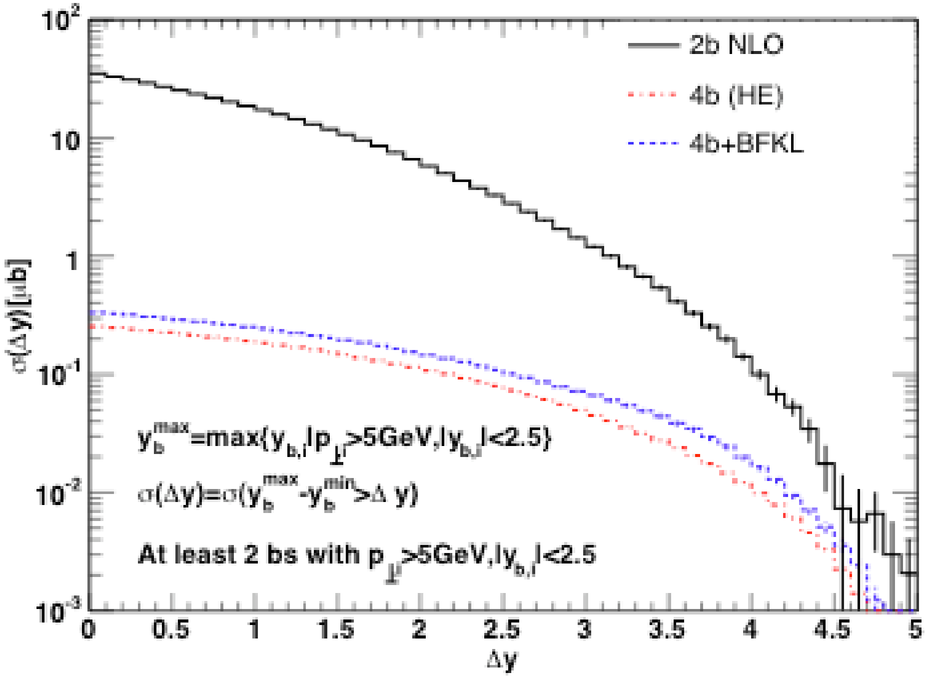


The asymptotic result can be obtained exactly (Ross and Ellis 1990):

$$\sigma_{gg} = \frac{\alpha_S^4}{\pi m_Q^2} \frac{1}{N_c^2 - 1} \left[\frac{23 N_c^2}{81} - \frac{277}{486} + \left(\frac{175\zeta(3)}{576} - \frac{19}{288} \right) \frac{1}{N_c^2} \right] \simeq \frac{\alpha_S^4}{\pi m_Q^2} 0.803$$

Results for 4b





The 4b cross section never dominates over the 2b in the allowed kinematical range.

Modest increase due to the BFKL radiation.

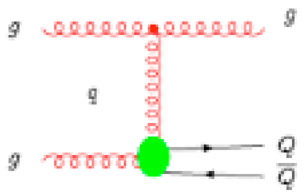
In order to suppress the 2b contribution one could:

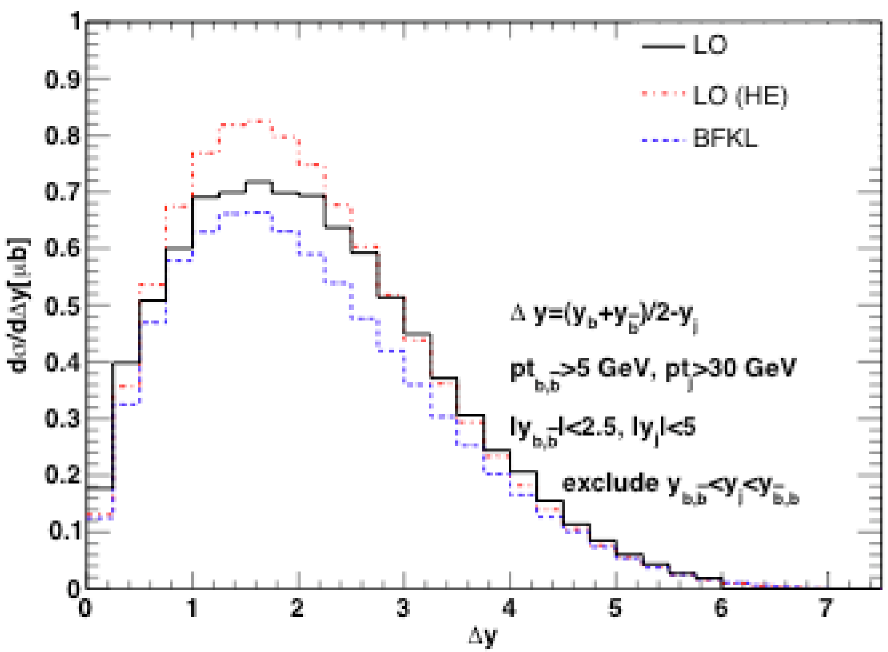
1. ask for at least 3b in the final state

2. identify the charge of the b and ask for same two same charge b's at large rapidity

Andersen Frixione Maltoni Stirling VDD 2004

Results for 2b+jet





The 2b+jet signature is similar to the MN jet setting, but with a QQ pair on one side.

It's part of the bb cross section @ NLO, but features a gluon in the t-channel.

The addition of BFKL radiation slightly reduces the cross section.

Possibility of studying azimuthal angular decorrelation without soft logs?

Conclusions

- hunting for BFKL has gone on for many years
- no clear evidence of the need of resumming BFKL logs yet
- in heavy-quark production, there is no dominance of t-channel gluon exchange for the kinematic set-up currently envisaged for LHC experiments