Gaps between jets at Tevatron/LHC

Christophe Royon
IRFU-SPP, CEA Saclay

Diffraction 2012, September 10- 15 2012, Lanzarote, Spain

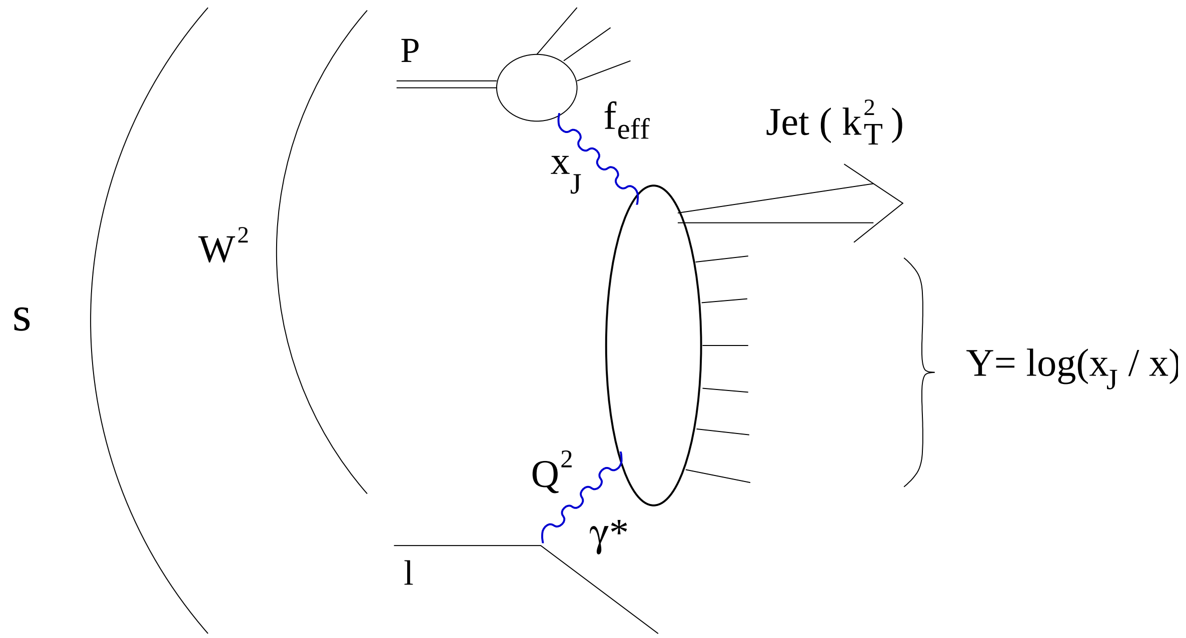
Contents:

- BFKL NLL cross sections
- Forward jets at HERA (short summary)
- Jet gap jet at Tevatron, LHC
- Jet gap jet in diffraction at the LHC

Work done in collaboration with D. Werder, O. Kepka, C. Marquet, R. Peschanski, M. Trzebinski, Y. Hatta, G. Soyez, T. Ueda

- Forward jets: Nucl. Phys. B 739 (2006) 131; Phys. Lett. B 655 (2007) 236; Eur. Phys. J. C55 (2008) 259;
- Mueller Navelet jets: Phys. Rev. D79 (2009) 034028;
- Jet Gap Jet: Phys. Rev. D79 (2009) 094019; Phys.Rev. D83 (2011) 034036
- Jet gap jet in diffraction, jet cross section with jet veto in preparation
- See talk by Cyrille at this workshop

Forward jet measurement at HERA

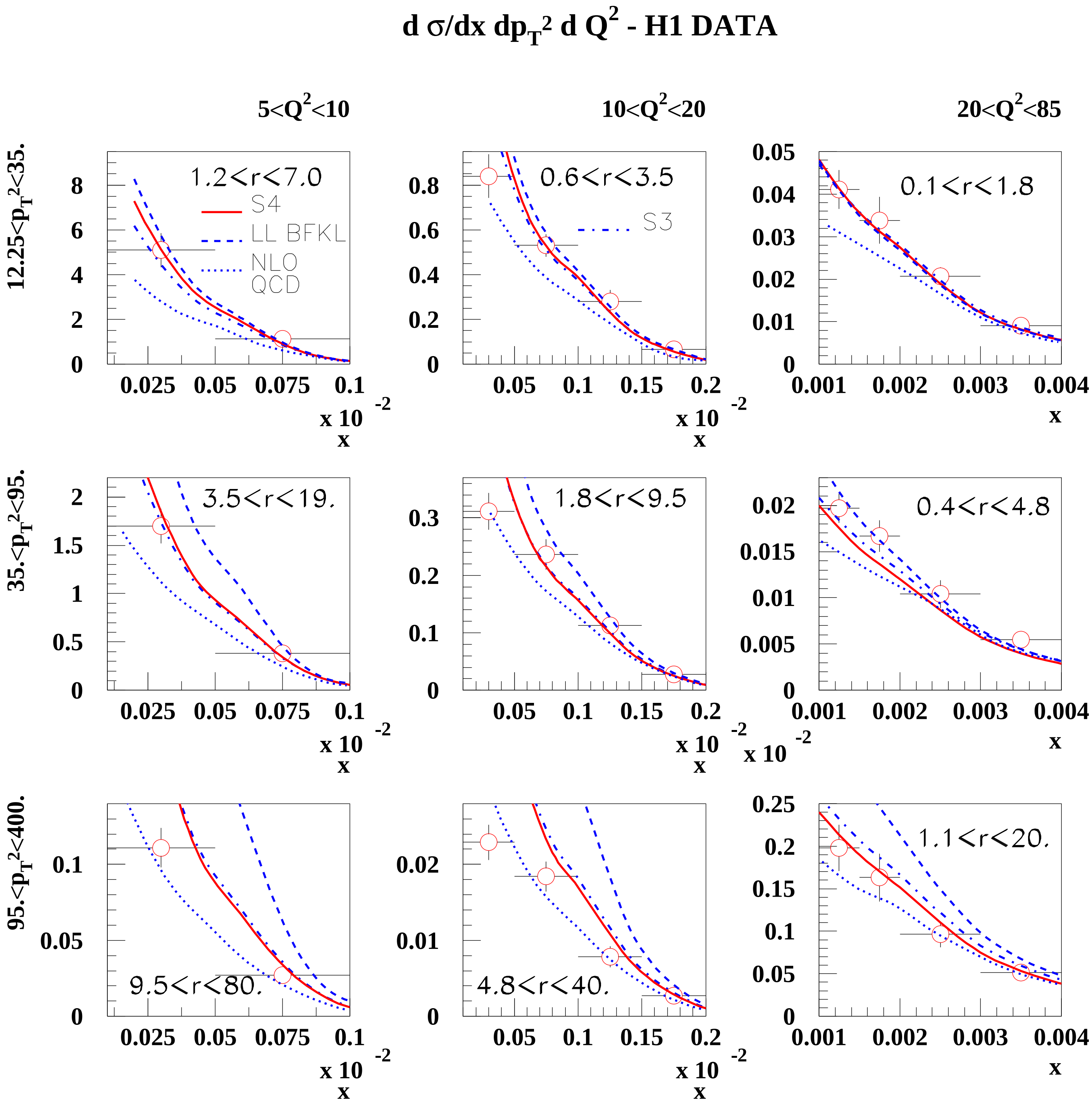


- Full BFKL NLL calculation used for the BFKL kernel, available in S3 and S4 resummation schemes to remove the spurious singularities (modulo the impact factors taken at LL)
- Equation:

$$\frac{d\sigma_{T,L}^{\gamma^* p \to JX}}{dx_J dk_T^2} = \frac{\alpha_s(k_T^2)\alpha_s(Q^2)}{k_T^2 Q^2} \; f_{eff}(x_J, k_T^2)$$
$$\int \frac{d\gamma}{2i\pi} \left(\frac{Q^2}{k_T^2}\right)^\gamma \phi_{T,L}^\gamma(\gamma) \; e^{\bar{\alpha}(k_T Q)\chi_{eff}[\gamma, \bar{\alpha}(k_T Q)]Y}$$

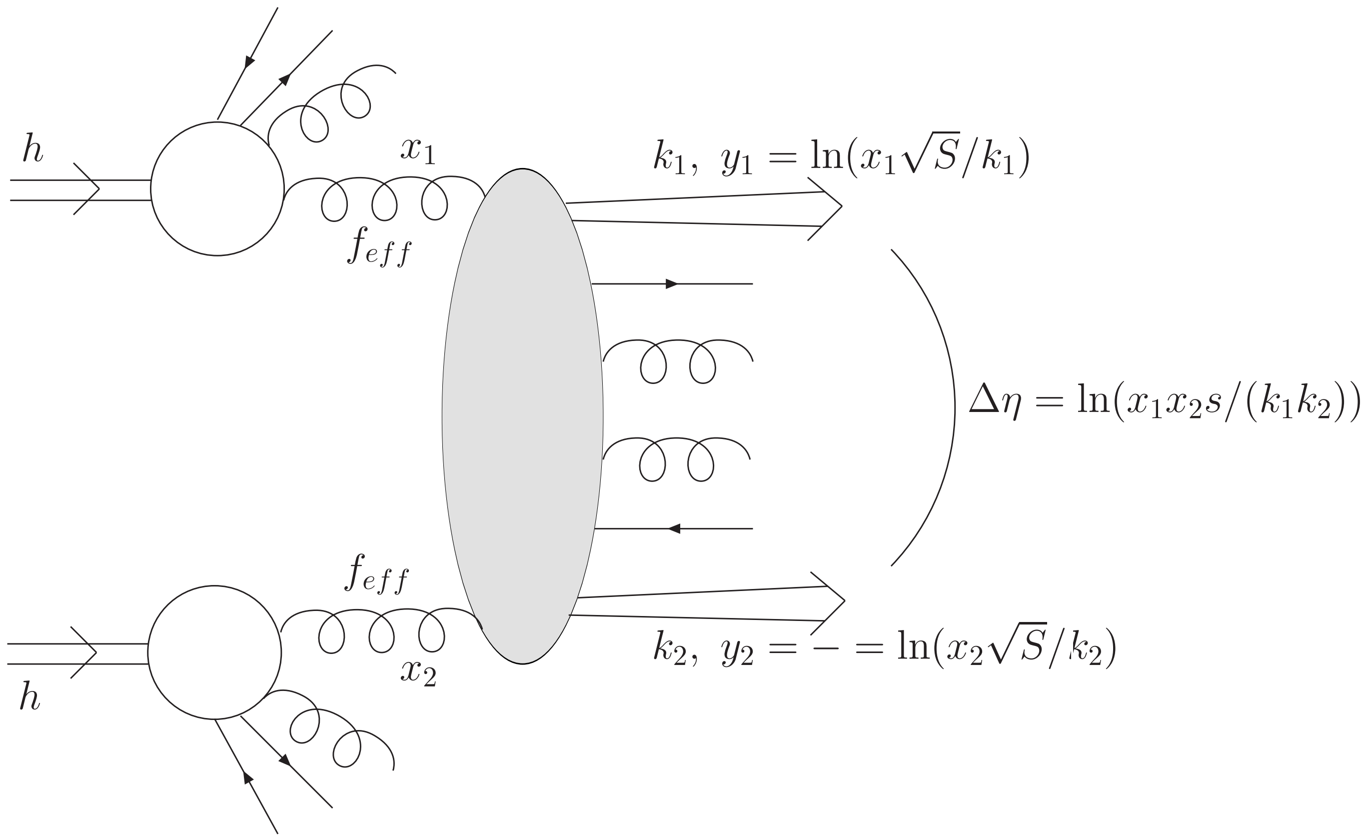
- Implicit equation: $\chi_{eff}(\gamma, \alpha) = \chi_{NLL}(\gamma, \alpha, \chi_{eff}(\gamma, \alpha))$ solved numerically

Comparison with H1 triple differential data



Mueller Navelet jets

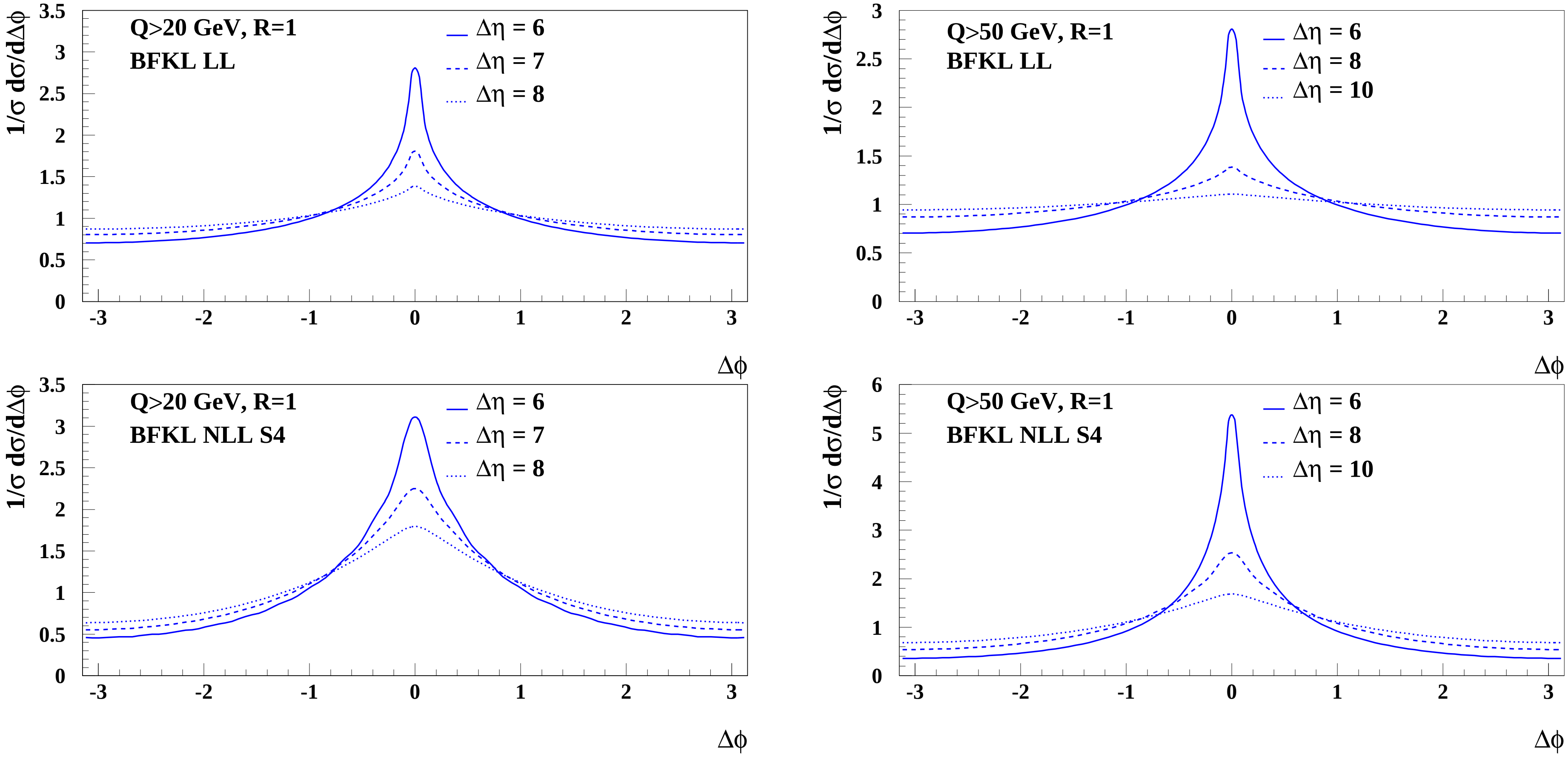
Same kind of processes at the Tevatron and the LHC



- Same kind of processes at the Tevatron and the LHC: Mueller Navelet jets
- Study the $\Delta\Phi$ between jets dependence of the cross section:

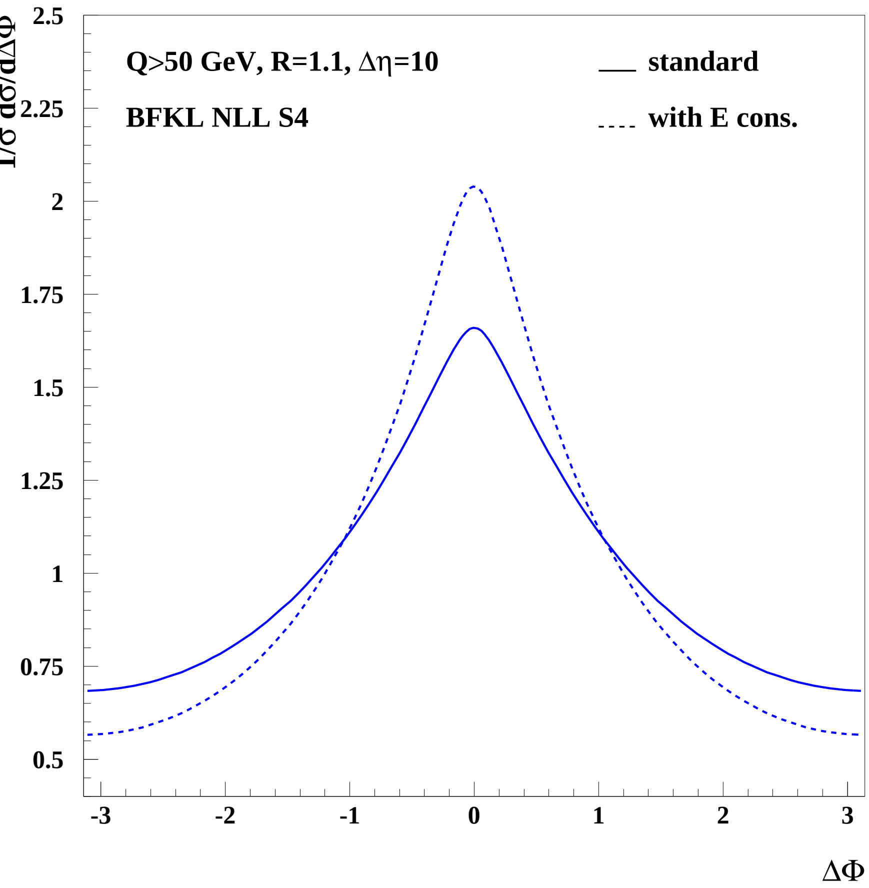
Mueller Navelet jets: $\Delta\Phi$ dependence

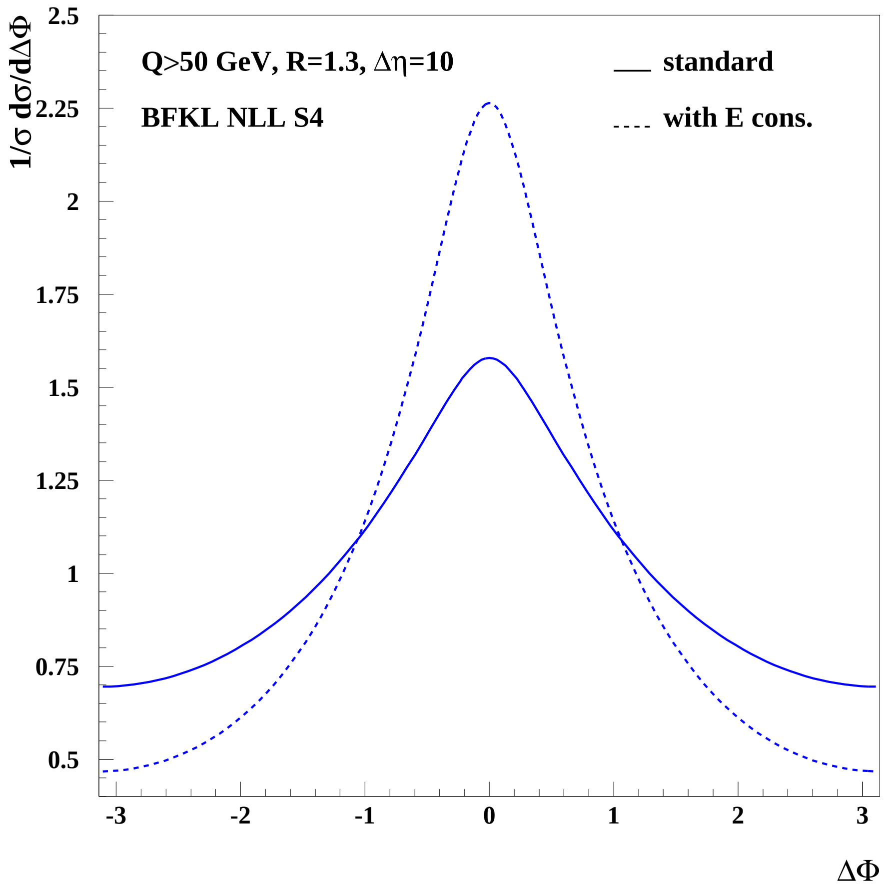
- $1/\sigma d\sigma/d\Delta\Phi$ spectrum for BFKL LL and BFKL NLL as a function of $\Delta\Phi$ for different values of $\Delta\eta$, scale dependence: $\sim$20%
- Measurement being done at CDF, CMS and ATLAS



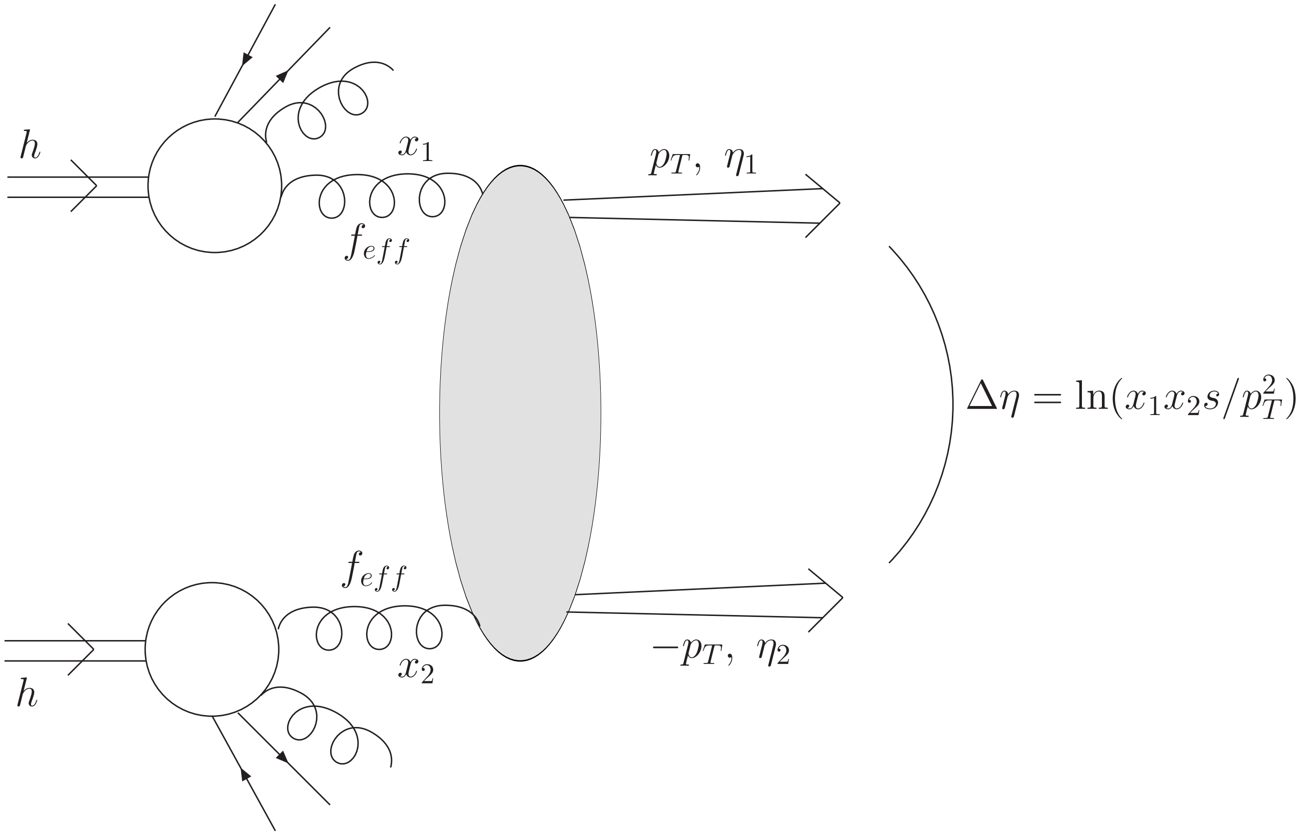
Mueller Navelet cross sections: energy conservation effect in BFKL

- Effect of energy conservation on BFKL dynamics
- Large effect if jet p_T ratios not close to 1: goes closer to DGLAP predictions, needs jet p_T ratio $<$ 1.1-1.15





Jet gap jet cross sections



- Test of BFKL evolution: jet gap jet events, large $\Delta\eta$, same p_T for both jets in BFKL calculation
- Principle: Implementation of BFKL NLL formalism in HERWIG Monte Carlo (Measurement sensitive to jet structure and size, gap size smaller than $\Delta\eta$ between jets)

BFKL formalism

- BFKL jet gap jet cross section: integration over ξ, p_T performed in Herwig event generation

$$\frac{d\sigma^{pp\to XJJY}}{dx_1 dx_2 dp_T^2} = \mathcal{S}\frac{f_{eff}(x_1,p_T^2)f_{eff}(x_2,p_T^2)}{16\pi}\left|A(\Delta\eta,p_T^2)\right|^2$$

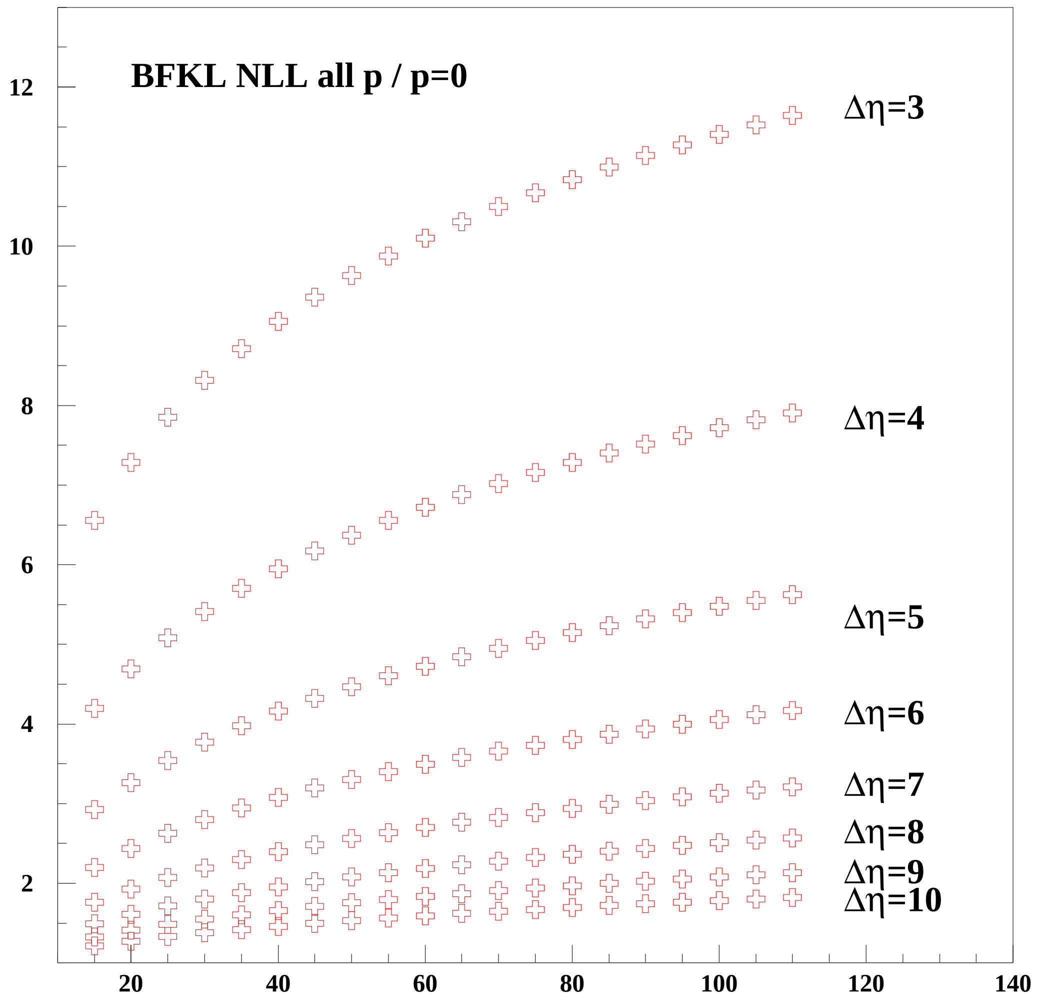
where S is the survival probability (0.1 at Tevatron, 0.03 at LHC)

$$A(\Delta\eta,p_T^2) = \frac{16N_c\pi\alpha_s^2}{C_F p_T^2}\sum_{p=-\infty}^{\infty}\int\frac{d\gamma}{2i\pi}\frac{[p^2-(\gamma-1/2)^2]}{[(\gamma-1/2)^2-(p-1/2)^2]}\frac{\exp\left\{\frac{\alpha_S N_C}{\pi}\chi_{eff}\Delta\eta\right\}}{[(\gamma-1/2)^2-(p+1/2)^2]}$$

- α_S: 0.17 at LL (constant), running using RGE at NLL
- BFKL effective kernel χ_{eff}: determined numerically, solving the implicit equation: $\chi_{eff}=\chi_{NLL}(\gamma,\bar{\alpha}\ \chi_{eff})$
- S4 resummation scheme used to remove spurious singularities in BFKL NLL kernel
- Implementation in Herwig Monte Carlo: needed to take into account jet size and at parton level the gap size is equal to $\Delta\eta$ between jets
- Herwig MC: Parametrised distribution of $d\sigma/dp_T^2$ fitted to BFKL NLL cross section (2200 points fitted between $10 < p_T < 120$ GeV, $0.1 < \Delta\eta < 10$ with a $\chi^2 \sim 0.1$)

BFKL formalism: resummation over conformal spins

- Study of the ratio $\frac{d\sigma/dp_T(all\ \ p)}{d\sigma/dp_T(p=0)}$
- Resummation over p needed: modifies the p_T and $\Delta\eta$ dependences...:

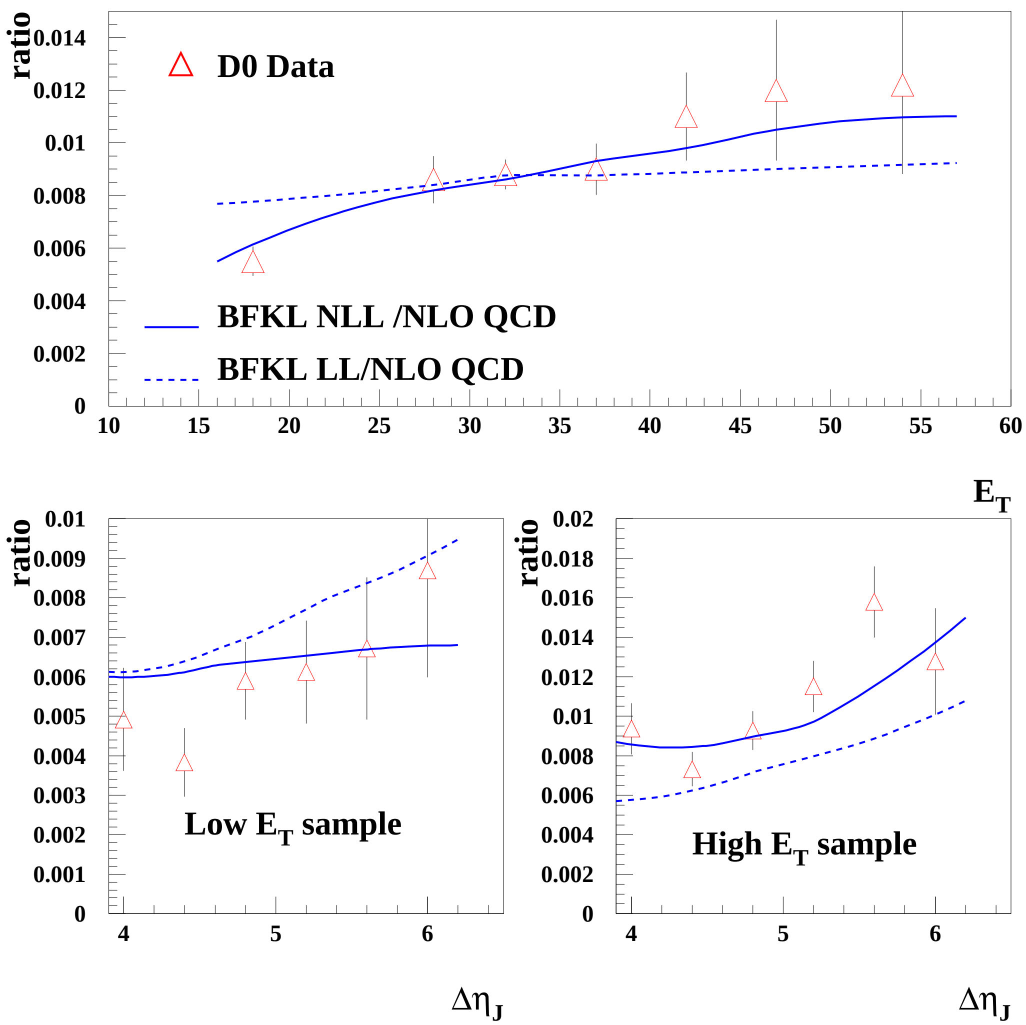


Comparison with D0 data

- D0 measurement: Jet gap jet cross section ratios as a function of second highest E_T jet, or $\Delta\eta$ for the low and high E_T samples, the gap between jets being between -1 and 1 in rapidity
- Comparison with BFKL formalism:

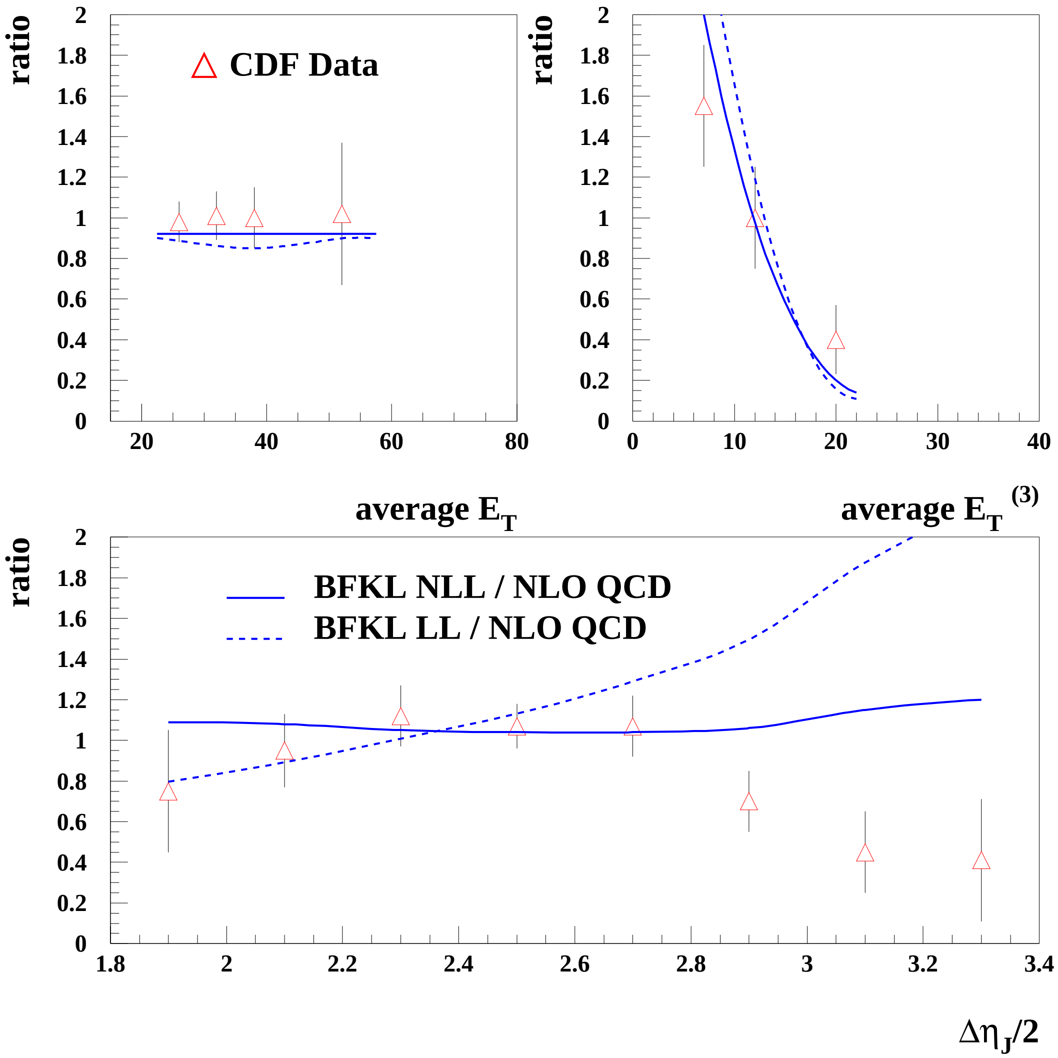
$$Ratio = \frac{BFKL\ NLL\ Herwig}{Dijet\ Herwig} \times \frac{LO\ QCD\ NLOJet++}{NLO\ QCD\ NLOJet++}$$

- Reasonable description using BFKL NLL formalism



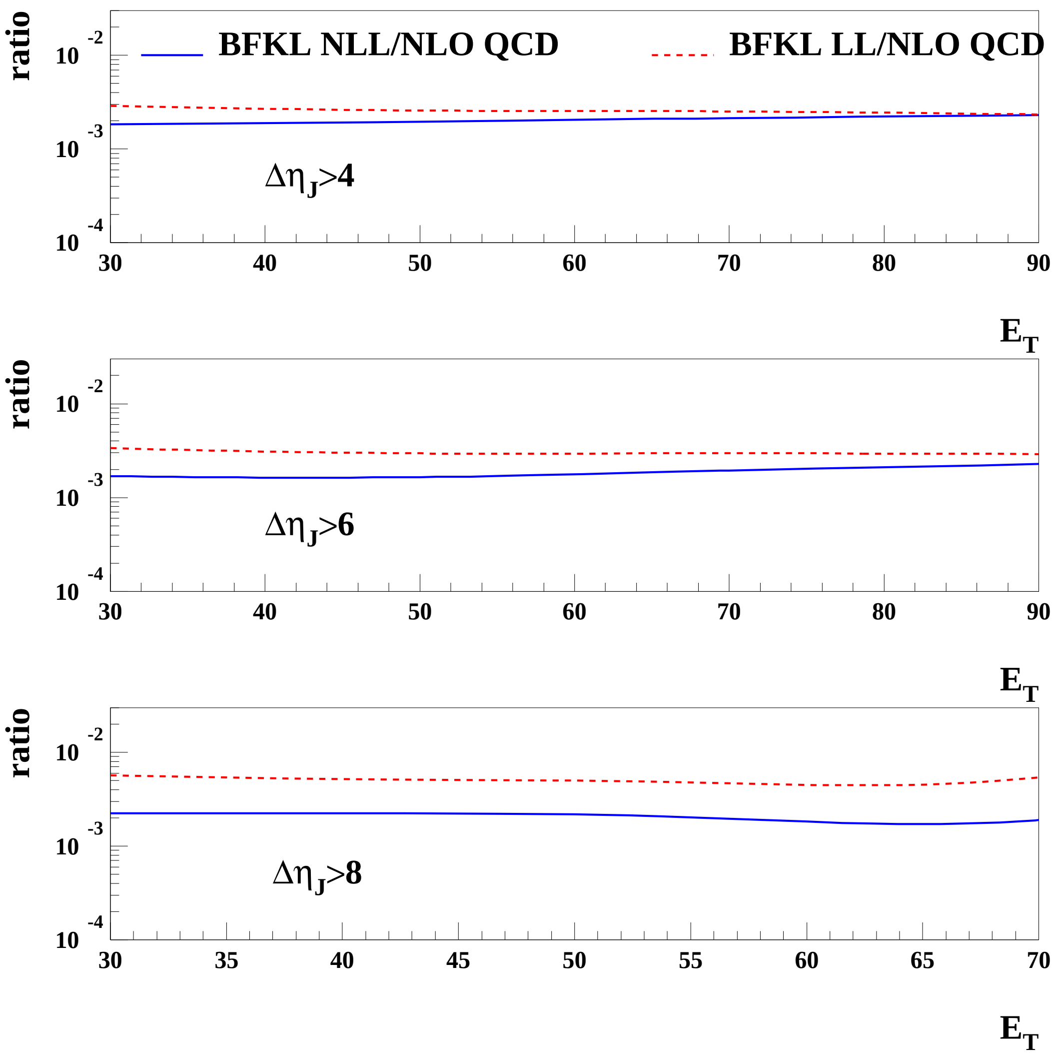
Comparison with CDF data

- Measurement of jet gap jet cross section ratio as a function of average E_T of the two leading jets, and the rapidity interval between the two leading jets divided by 2, the gap between jets being between -1 and 1 in rapidity; decrease at high $\Delta\eta$ cannot be reproduced
- BFKL NLL calculation leads to a better description than LL



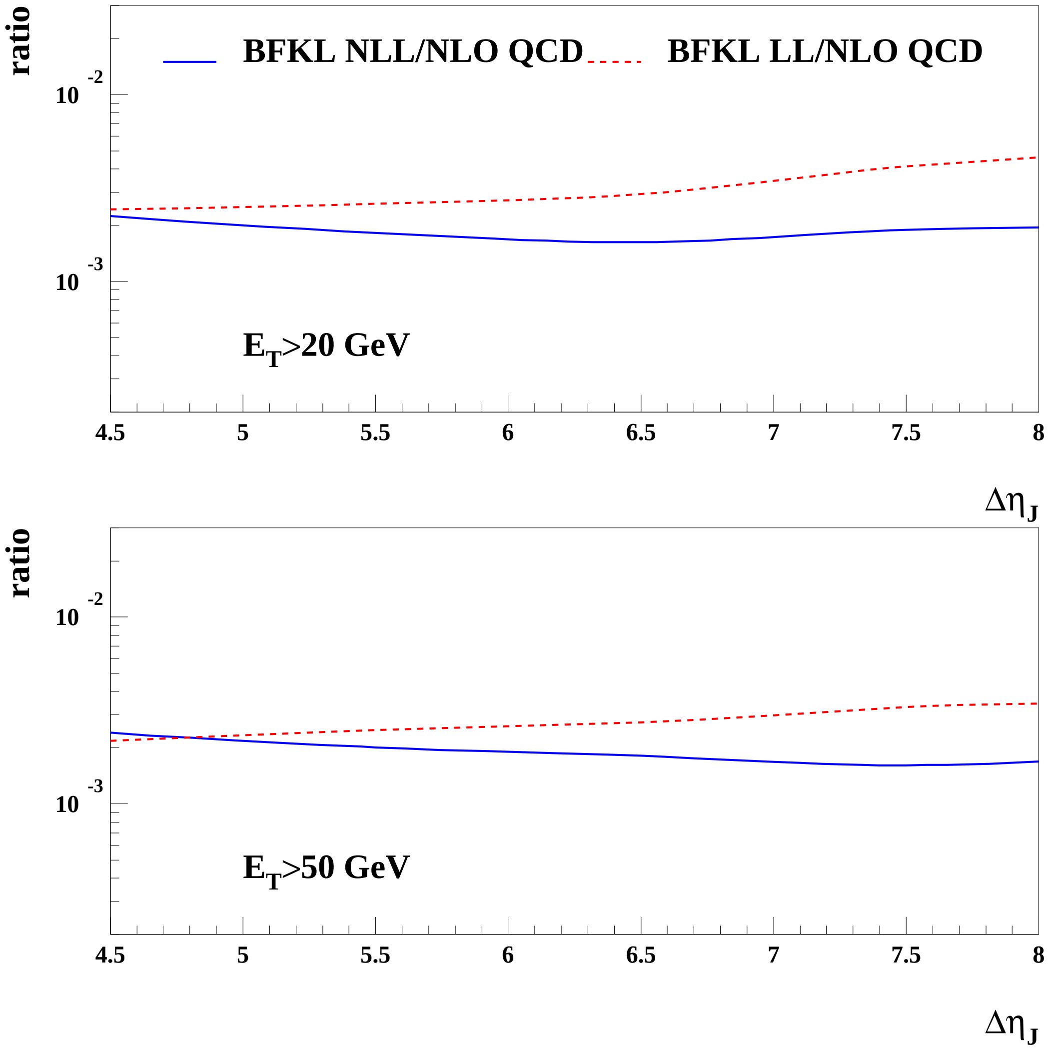
Predictions for the LHC

- Weak E_T dependence
- Large differences in normalisation between BFKL LL and NLL predictions



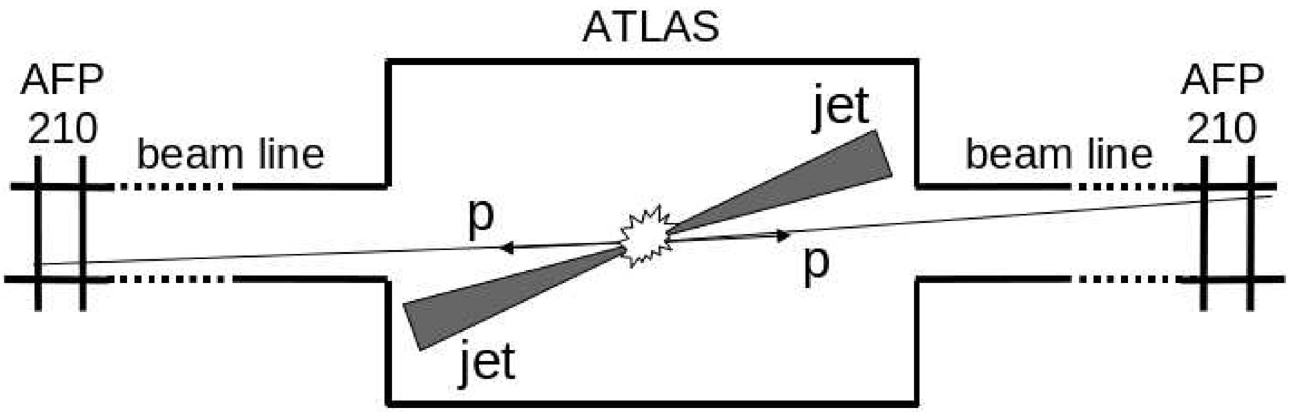
Predictions for the LHC

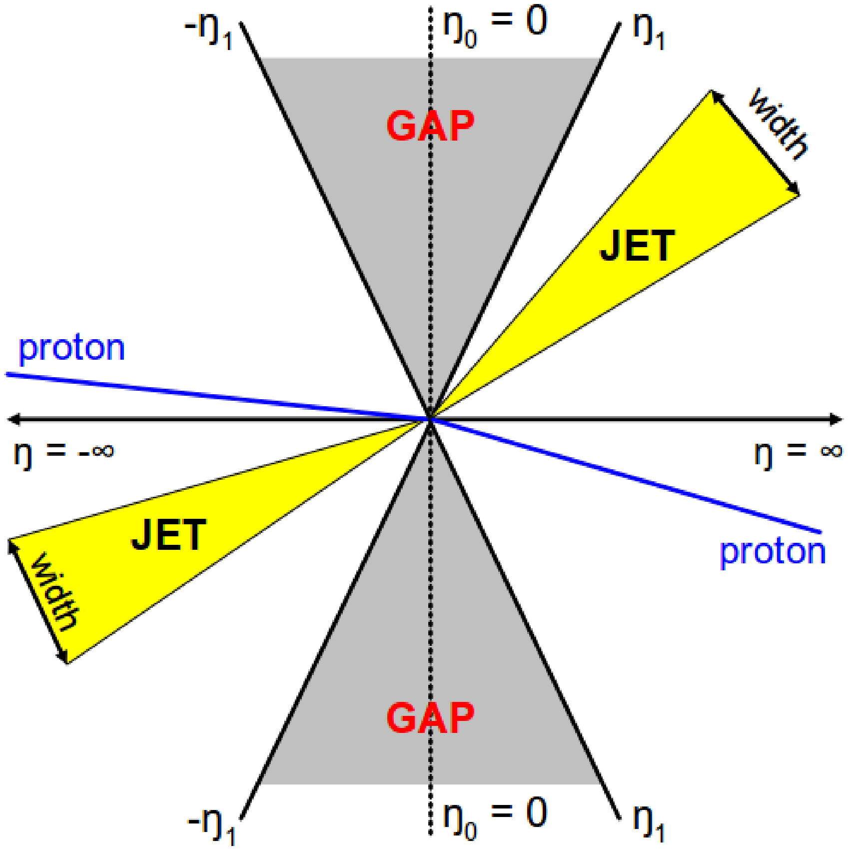
- Weak $\Delta\eta$ dependence
- Large differences in normalisation between BFKL LL and NLL predictions



Jet gap jets in diffraction

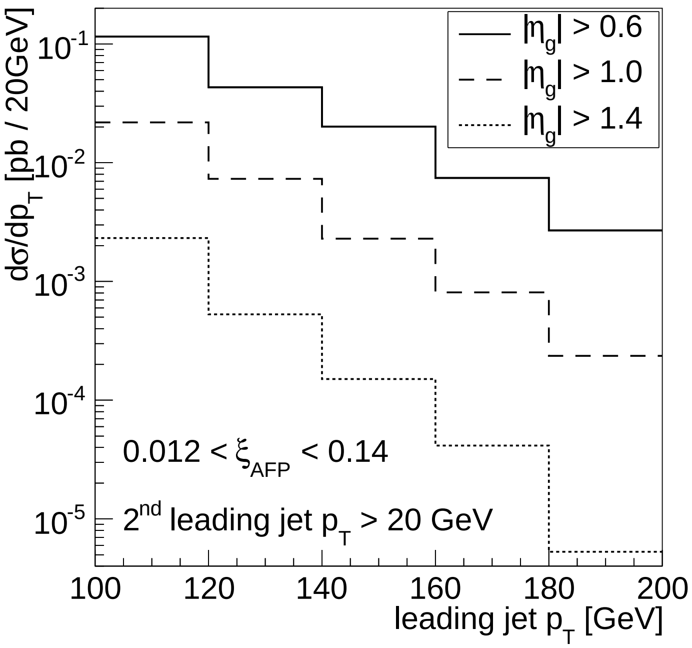
- Measure gap between jets for diffractive events
- Use AFP to measure intact protons

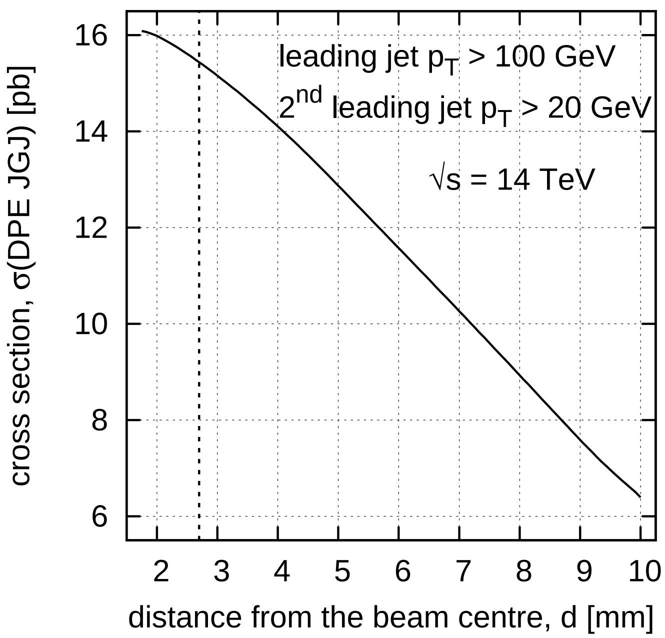




Jet gap jets cross sections in diffraction

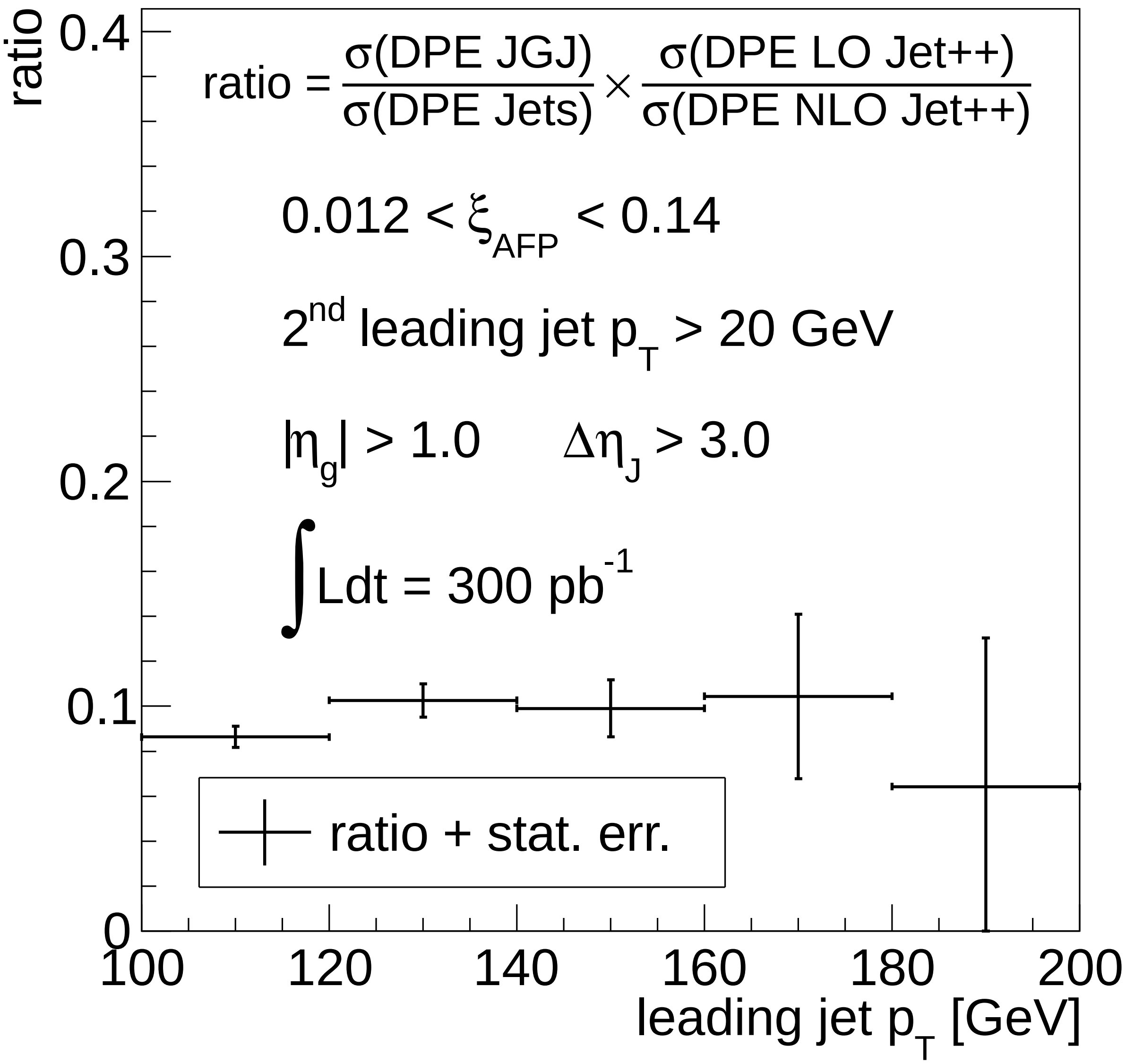
- Normalisation fixed from fits to D0 data: remove survival probability factor since disappear in the ratio (diffractive tagged protons in numerator and denominator)
- Protons tagged in ATLAS Forward physics detector (AFP) at 210 m
- Cross sections for different gap size



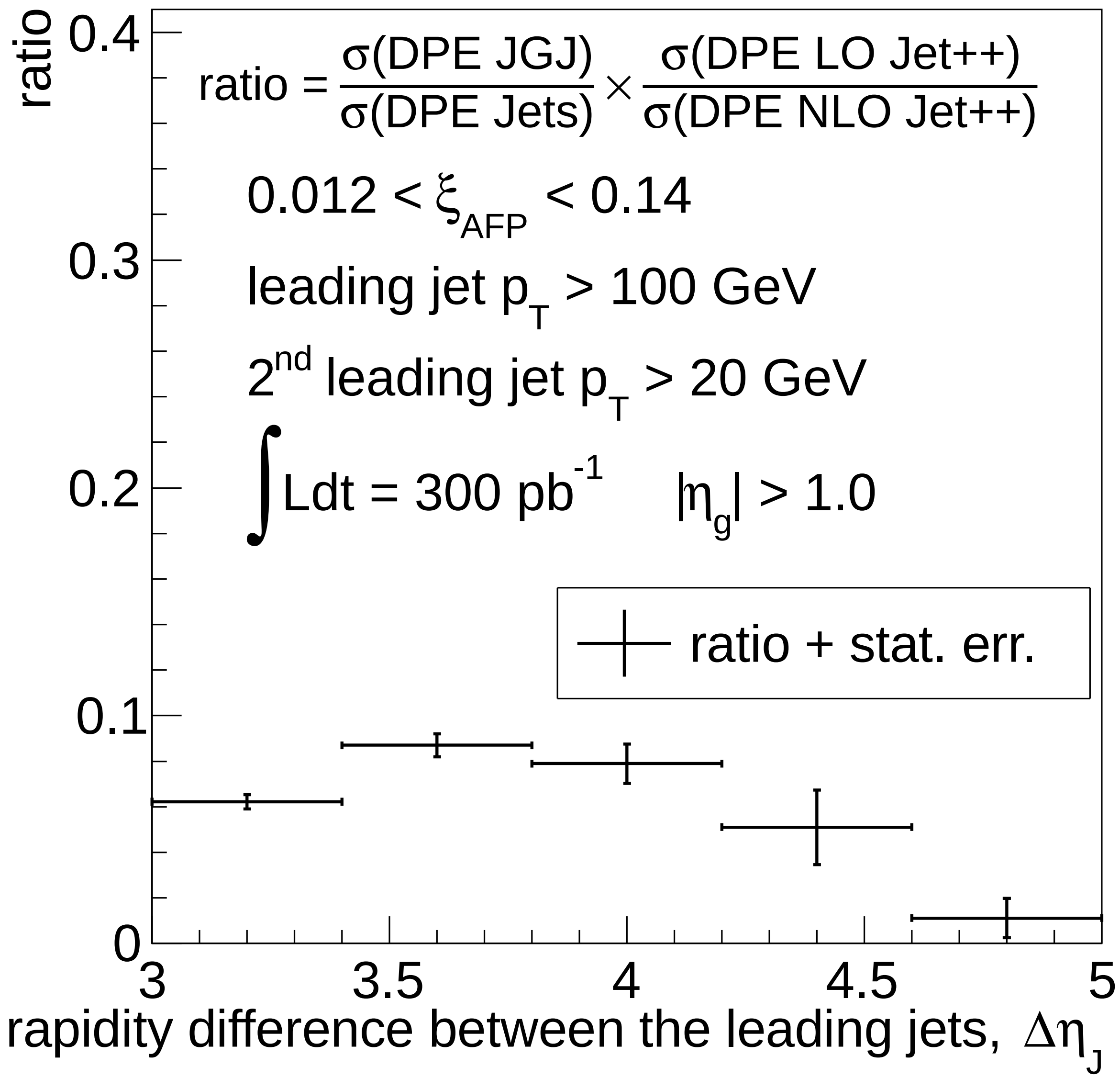


Jet gap jets cross section in diffraction

- Determination of the jet gap jet cross section ratio for diffractive events
- Advantage: ratio close to 10% (no survival probability), very clean events since jets not "polluted" by remnants)



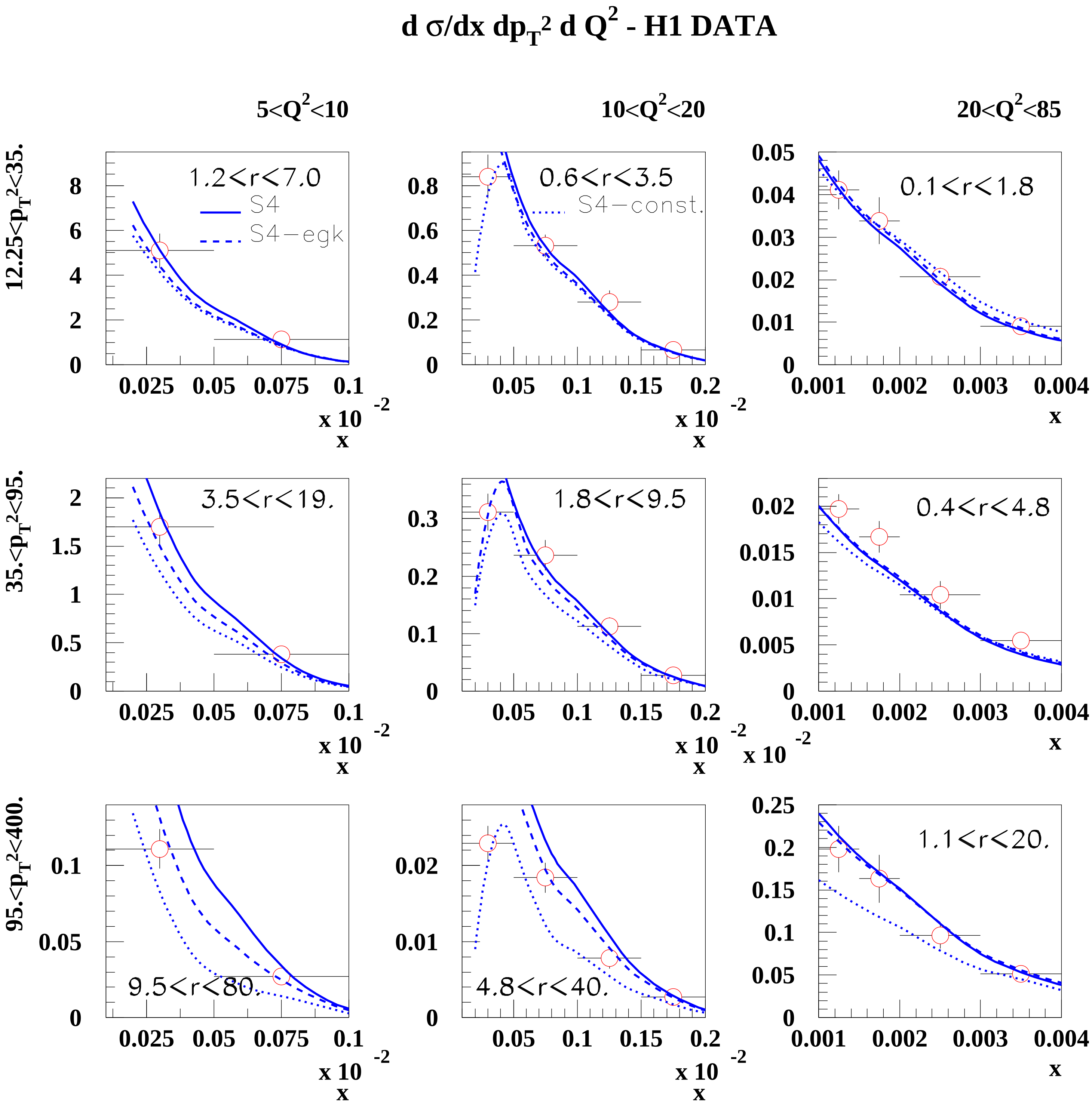
Jet gap jets cross section in diffraction



Conclusion

- Full implementation of BFKL NLL kernel for many jet proceeses at HERA, Tevatron and LHC
- Forward jets at HERA: DGLAP NLO fails to describe HERA data, good description of data using BFKL NLL formalism
- Mueller Navelet jets: Larger decorrelation expected for BFKL formalism, unfortunately suffers a lot of corrections intriduced when ones imposes the conservation of energy in the BFKL formalism (see Phys. Rev. D79 (2009) 034028)
- Jet gap jets:
  - NLL BFKL cross section implemented in HERWIG
  - Fair description of D0 and CDF data, decrease at higher rapidity of jet gap jet ratio to dijet data not expected by theory
  - Interesting measurement being performed at LHC
- Jet gap jet in diffraction: clean process allowing to go to larger $\Delta\eta$ between jets (not polluted by remnants)
- Jet cross section with jet veto: see talk by Cyrille

Comparison with H1 triple differential data



BFKL NLL and resummation schemes

- NLO BFKL: Corrections were found to be large with respect to LO, and lead to unphysical results
- NLO BFKL kernels need resummation: to remove additional spurious singularities in γ and $(1-\gamma)$
- NLO BFKL kernel: (γ and ω associated to $\log Q^2$ and rapidity after Mellin transform)

$$\chi_{NLO}(\gamma, \omega) = \chi^{(0)}(\gamma, \omega) + \alpha(\chi_1(\gamma) - \chi_1^{(0)}(\gamma))$$

- $\chi_1(\gamma)$: calculated, NLO BFKL eigenvalues (Lipatov, Fadin, Camici, Ciafaloni)
- $\chi^{(0)}$ and $\chi_1(0)$: ambiguity of resummation at higher order than NLO, different ways to remove these singularities, not imposed by BFKL equation, Salam, Ciafaloni, Colferai; use resummation schemes S3 and S4 from Salam et al.
- Transformation of the energy scale: $\gamma \to \gamma - \omega/2$ (Salam) needed for F_2 but not for forward jet cross sections (the problem is symmetric contrary to F_2)
- BFKL NLL full calculation available (no saddle point approximation): resolution of implicit equation performed by numerical methods

Mueller Navelet jets: $\Delta\Phi$ dependence

- Study the $\Delta\Phi$ dependence of the relative cross section
- Relevant variables:

$$\begin{aligned} \Delta\eta &= y_1 - y_2 \\ y &= (y_1 + y_2)/2 \\ Q &= \sqrt{k_1 k_2} \\ R &= k_2/k_1 \end{aligned}$$

- Azimuthal correlation of dijets:

$$2\pi \frac{d\sigma}{d\Delta\eta dR d\Delta\Phi} \Bigg/ \frac{d\sigma}{d\Delta\eta dR} = 1 + \frac{2}{\sigma_0(\Delta\eta, R)} \sum_{p=1}^{\infty} \sigma_p(\Delta\eta, R) \cos(p\Delta\Phi)$$

where

$$\sigma_p = \int_{E_T}^{\infty} \frac{dQ}{Q^3} \alpha_s(Q^2/R) \alpha_s(Q^2 R) \left(\int_{y_<}^{y_>} dy x_1 f_{eff}(x_1, Q^2/R) x_2 f_{eff}(x_2, Q^2 R) \right) \int_{1/2-\infty}^{1/2+\infty} \frac{d\gamma}{2i\pi} R^{-2\gamma}\ e^{\bar{\alpha}(Q^2)\chi_{eff}(p)\Delta\eta}$$

Effect of energy conservation on BFKL equation

- BFKL cross section lacks energy-momentum conservation since these effects are higher order corrections
- Following Del Duca-Schmidt, we substitute $\Delta\eta$ by an effective rapidity interval y_{eff}

$$y_{eff} = \Delta\eta \left(\int d\phi \cos(p\phi) \frac{d\sigma^{O(\alpha_s^3)}}{d\Delta\eta dy dQ dR d\Delta\Phi} \right)^{-1} \int d\phi \cos(p\phi) \frac{d\sigma^{LL-BFKL}}{d\Delta\eta dy dQ dR d\Delta\Phi}$$

  where $d\sigma^{O(\alpha_s^3)}$ is the exact $2 \to 3$ contribution to the $hh \to JXJ$ cross-section at order α_s^3, and $d\sigma^{LL-BFKL}$ is the LL-BFKL result
- To compute $d\sigma^{O(\alpha_s^3)}$, we use the standard jet cone size $R_{cut} = 0.5$ when integrating over the third particle's momentum