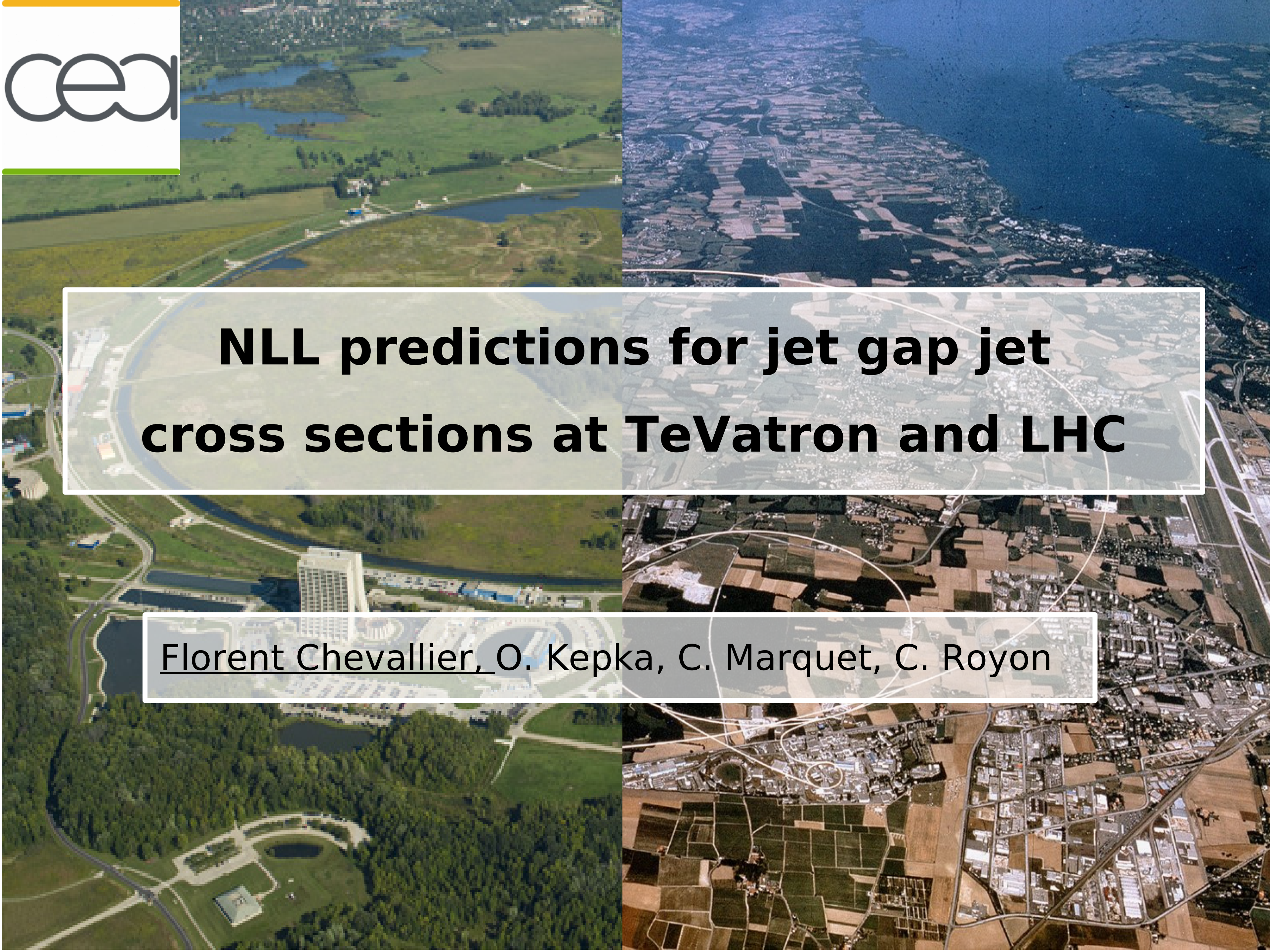

NLL predictions for jet gap jet cross sections at TeVatron and LHC

Florent Chevallier, O. Kepka, C. Marquet, C. Royon

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Introduction

- BFKL evolution
- Process of interest

Phenomenology of jet-gap-jet events

- Theoretical production cross-section
- Going to NLL-BFKL
- Implementation in Herwig Monte Carlo

Jet-gap-jet cross-sections at hadron colliders

- Corrections to LL-BFKL
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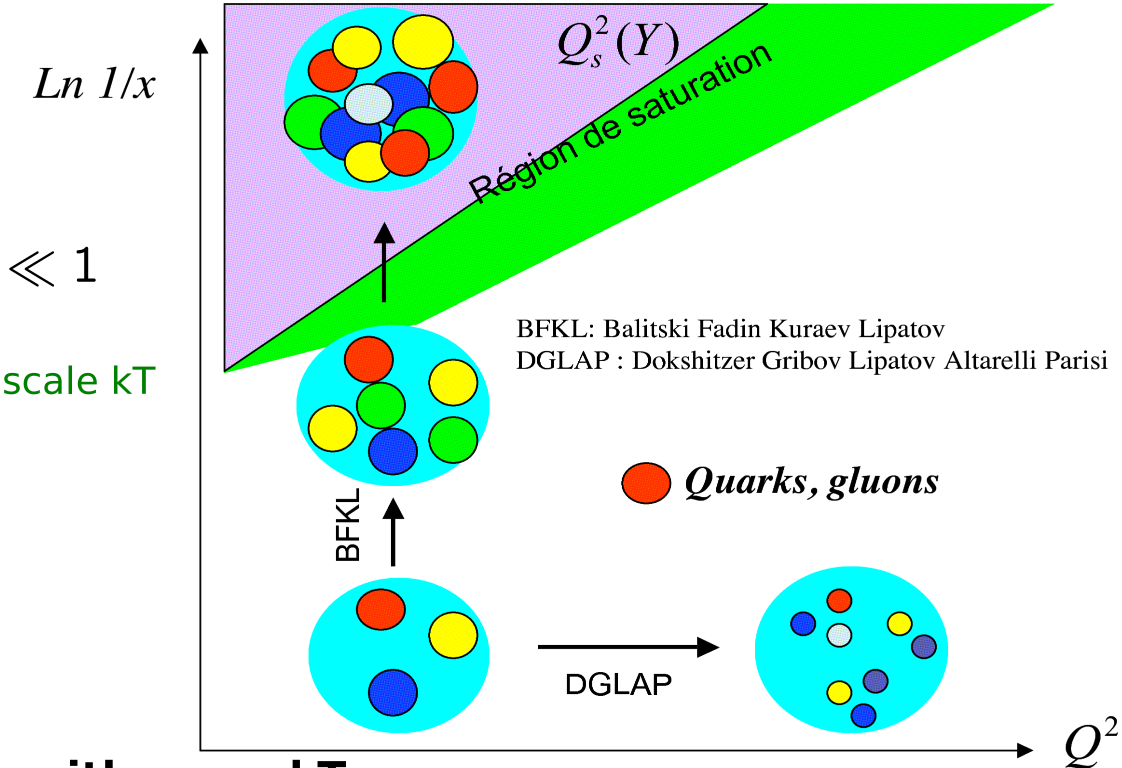
Introduction : BFKL evolution



Linear pQCD evolutions $\alpha_s \ll 1$

- DGLAP evolution
  Towards larger momentum scale kT
- BFKL evolution
  Towards smaller x

2 to 2 scattering processes with same kT

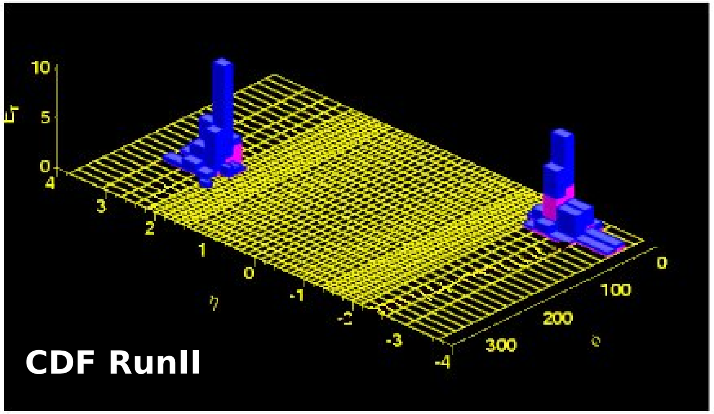
- DGLAP evolution
  No additional radiation is possible since jets have same kT
- BFKL evolution with Regge limit
  Large rapidity interval between final-state particles
  Resummation of the large higher-order leading logs

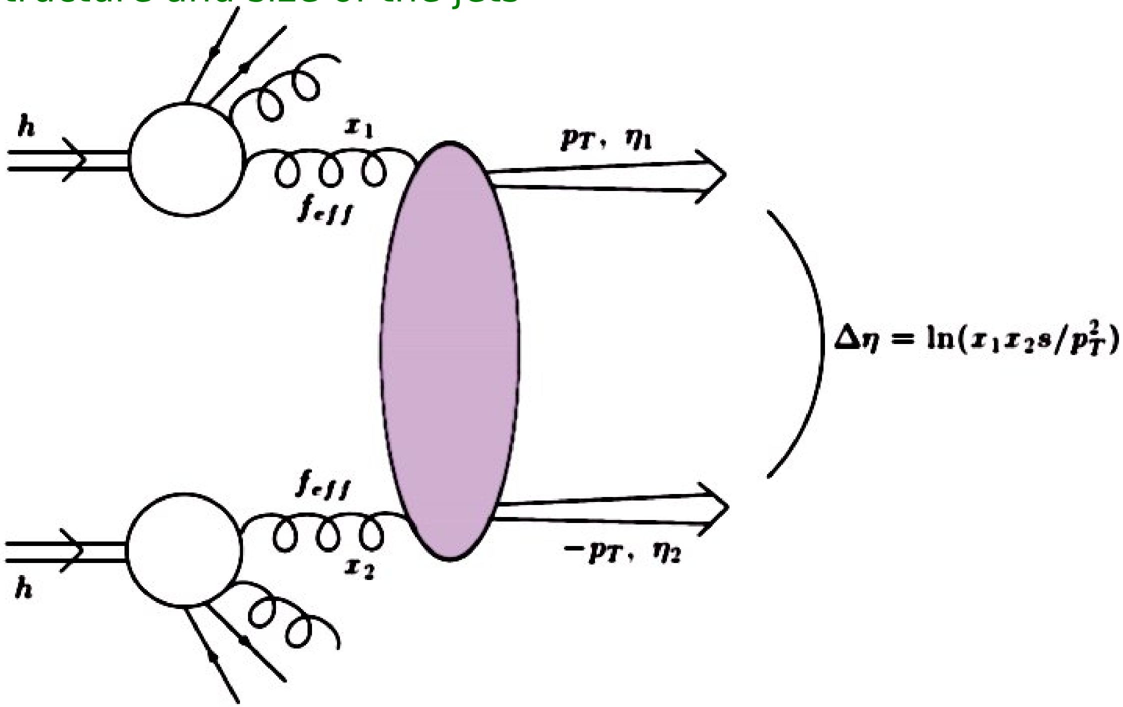
Signs of BFKL evolution in di-jets processes with same p_T and large $\Delta\eta$.

Process of interest

Gaps between jets

- No energy deposits between jets
  - Observed at TeVatron and HERA
  - Measurement sensitive to the structure and size of the jets
- Test of the BFKL approach
  - Production cross-sections





1) Compute $d^2\sigma / dp_T\, d\Delta\eta$ for large $\Delta\eta$, same pT for both jets

Process of interest

Gaps between jets

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  Observed at TeVatron and HERA

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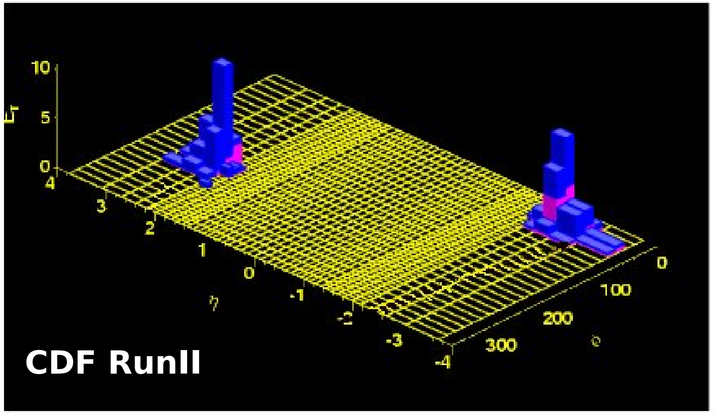

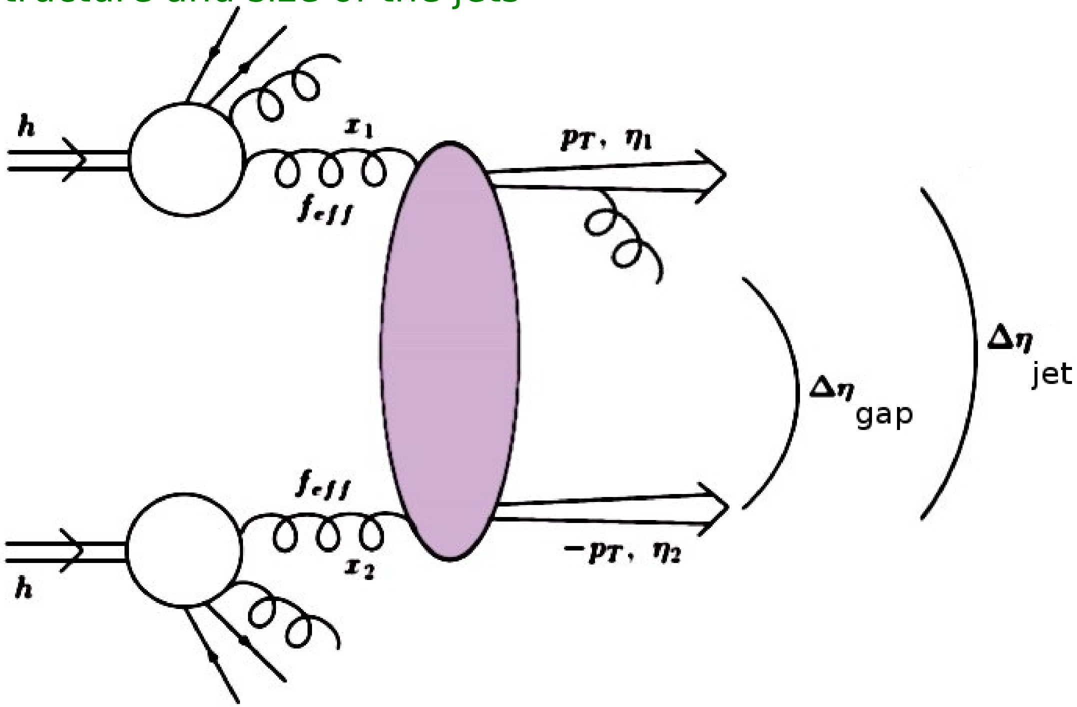

1) Compute $d^2\sigma / dp_T \, d\Delta\eta$ for large Δη, same pT for both jets

2) Implementation of BFKL NLL formalism in event generator (HERWIG)

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BFKL formalism for jet-gap-jet production

Cross-section in the BFKL framework

- Jet-gap-jet cross-section

Gap survival probability
S = 0.1 at Tevatron, 0.03 at LHC

$\propto |A(\Delta\eta, E_T^2)|^2$

$$\frac{d\sigma^{pp \to XJJY}}{dy.d\Delta\eta.dE_T^2} = S\, x_1 f_{eff}(x_1, E_T^2) \,.\, x_2 f_{eff}(x_2, E_T^2) \frac{d\sigma^{gg \to gg}}{dE_T^2}(y, \Delta\eta)$$

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

Sum over conformal spin

LL / NLL BFKL kernel

α_s = 0.17 at LL (constant), running using RGE at NLL

$\Rightarrow$ 1 free parameter : the normalization

Going to NLL-BFKL

- Large corrections w.r.t. LL and lead to unphysical results

  NLL BFKL kernels need resummation

  Truncation of the perturbative series → spurious singularities in BFKL-NLL kernel

- Use of Salam's regularisation schemes

  Singularities cancel when add some higher order corrections → meaningful NLL-BFKL results

  S3 and S4 schemes for forward jet production (modulo the impact factors taken at LL)

Full NLL-BFKL kernel available

- Resolution of implicit equation performed by numerical methods

$$\chi_{NLL} \xrightarrow{\text{regularization}} \chi_{NLL-S4} \xrightarrow{\text{implicit equation}} \chi_{eff}$$

$$\chi_{\mathrm{eff}} = \chi^{\mathrm{NLL-S4}}(\gamma, \alpha, \chi_{\mathrm{eff}})$$

Implementation in Herwig Monte Carlo

Full calculation of the hard cross-section

$$\frac{d\sigma^{gg\rightarrow gg}}{dE_T^2} \propto \left(\sum_p \int \frac{d\gamma}{2i\pi} \frac{p^2-(\gamma-1/2)^2 \,.\, \exp\{\bar{\alpha}\chi_{\mathrm{eff}}[2p,\gamma,\bar{\alpha}]\Delta\eta\}}{[(\gamma-1/2)^2-(p-1/2)^2][(\gamma-1/2)^2-(p+1/2)^2]} \right)^2$$

Simulation of $O(10^6)$ events takes too much time

Parametrization of the hard cross-section

- Replace the theoretical formula by a polynomial form

$$\frac{d\sigma^{gg\rightarrow gg}}{dE_T^2} = f(E_T,\Delta\eta)\,.\,\left(\hat{s}/E_T^2\right)^2 / \left(4\pi\alpha_s^4\right)$$

$$f(E_T,\Delta\eta) = A + C*E_T + E*\sqrt{E_T} + \left(B + D*E_T + F*\sqrt{E_T}\right)\left(\frac{3\pi\alpha_s\Delta\eta}{2}\right) + \ldots$$

- Fit to BFKL NLL cross section

  2200 points fitted between $10<E_T<120$ GeV, $0.1<\Delta\eta<10$

  Fit $\chi 2 \sim 0.1$ (difference per point < 1%)

Integration over Δη, E_T performed in Herwig event generation

⇒ **Meaningful predictions which takes into account jet structure and size**

Implementation in Herwig Monte Carlo

Full calculation of the hard cross-section

$$\frac{d\sigma^{gg\to gg}}{dE_T^2} \propto \left(\sum_p \int \frac{d\gamma}{2i\pi} \frac{p^2-(\gamma-1/2)^2 \;.\; \exp\{\bar{\alpha}\chi_{\mathrm{eff}}[2p,\gamma,\alpha]\Delta\eta\}}{[(\gamma-1/2)^2-(p-1/2)^2][(\gamma-1/2)^2-(p+1/2)^2]}\right)^2$$

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Resummation over conformal spins at LL

Contributions from non-zero conformal spins

- Not perfomed before
- Study of the ratio

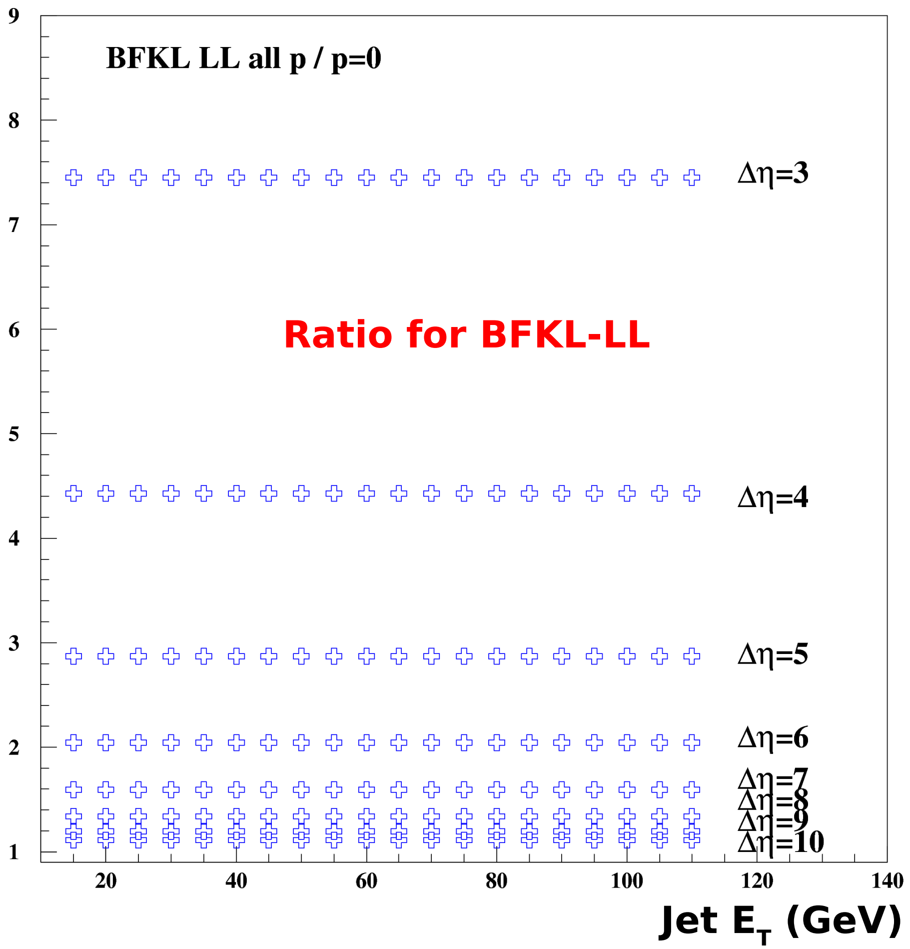
$$\frac{d\sigma/dE_T(\text{all}\,p)}{d\sigma/dE_T(p=0)}$$

- Large contribution

  x 4.5 for Δη=4

  x 1.5 for Δη=8

  Larger contribution at low Δη



Contributions from non-zero conformal spins

- Not perfomed before
- Study of the ratio

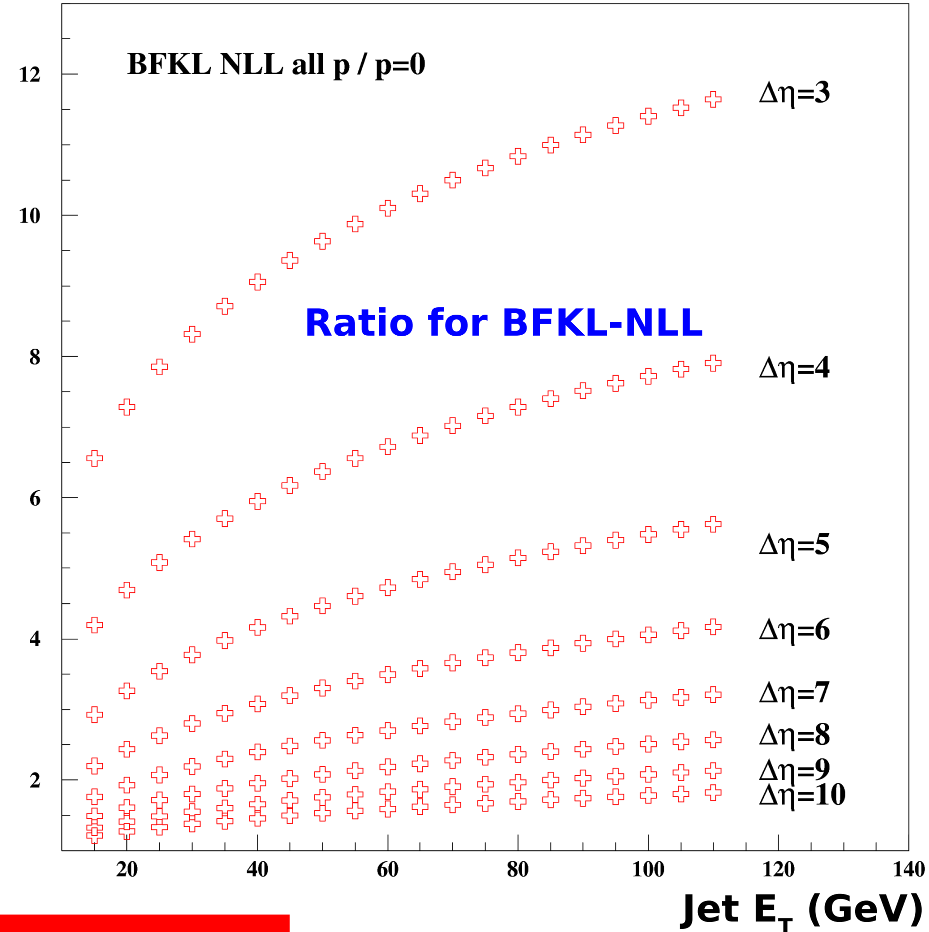
$$\frac{d\sigma/dE_T(\text{all}\,p)}{d\sigma/dE_T(p=0)}$$

- Large contribution

  x 4 – 8 for Δη=4

  x 1.5 – 2 for Δη=8

  Larger contribution at high E_T and low Δη

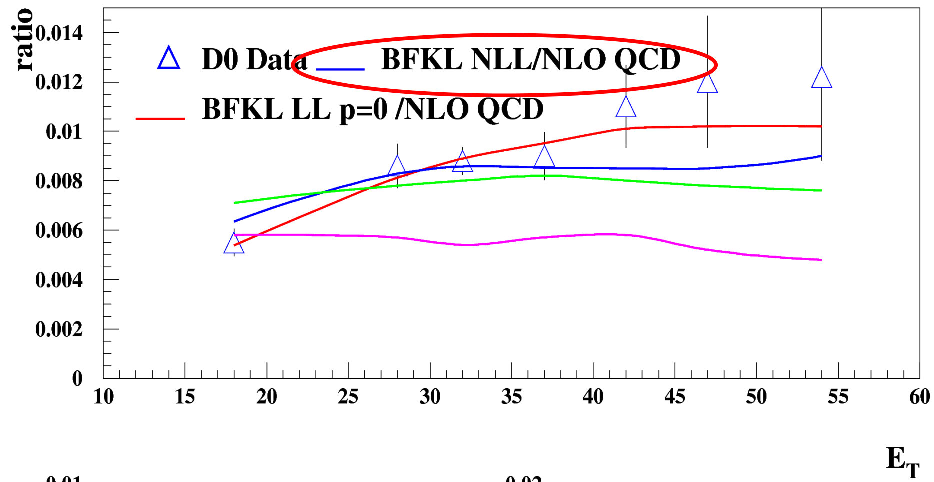


p≠0 contributions are needed both at LL and NLL

Comparisons with DØ data

DØ measurements

- Fraction of di-jets events with gap
  - Ratio of jet gap jet / Inclusive di-jet cross sections
- Data selection
  - Central gap between jets Δη>2 with no significant energy
  - 2 high E_T jets in opposite forward regions



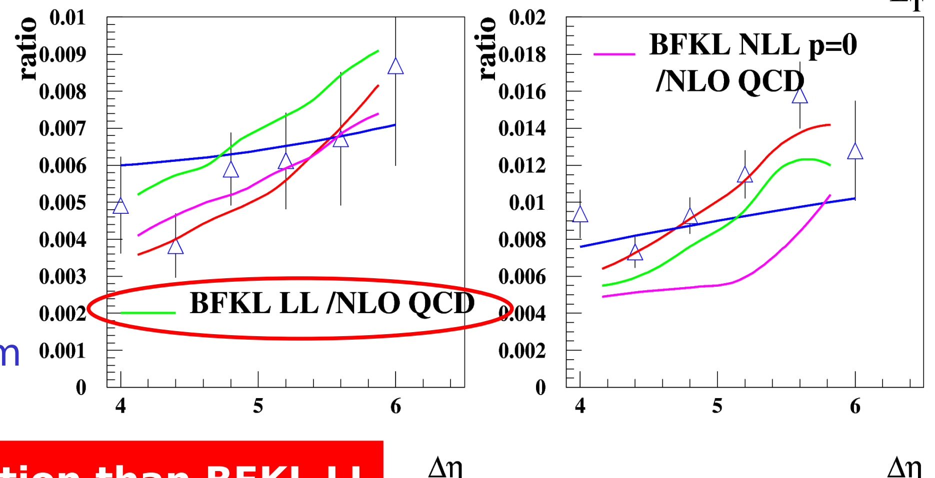
Predictions

- Normalization is a free parameter
  - Is adjusted to describe the data
  - → Compare the shape of distributions

$$\text{Prediction} \propto \frac{\left.\left|\dfrac{\sigma^{\mathrm{NLL}}(\text{jet-gap-jet})}{\sigma^{\mathrm{LO}}(\text{di-jet})}\right|\right._{\text{Herwig}}}{\left.\left|\dfrac{\sigma^{\mathrm{NLO}}(\text{di-jet})}{\sigma^{\mathrm{LO}}(\text{di-jet})}\right|\right._{\text{NLOJet++}}}$$

Comparisons with BFKL formalism

- Good agreement with LL p=0 BFKL
  - but p≠0 contributions are important
- Better description with BFKL NLL formalism



BFKL NLL leads to a better description than BFKL LL

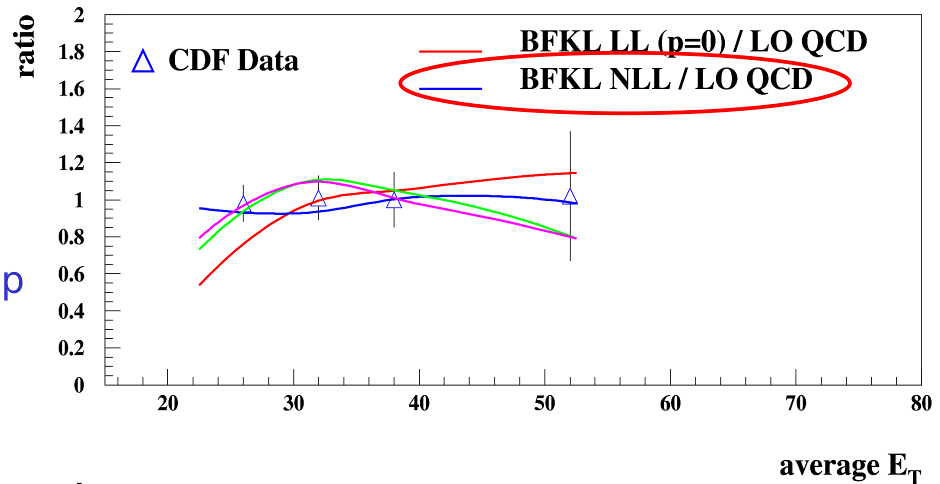
Comparisons with CDF data

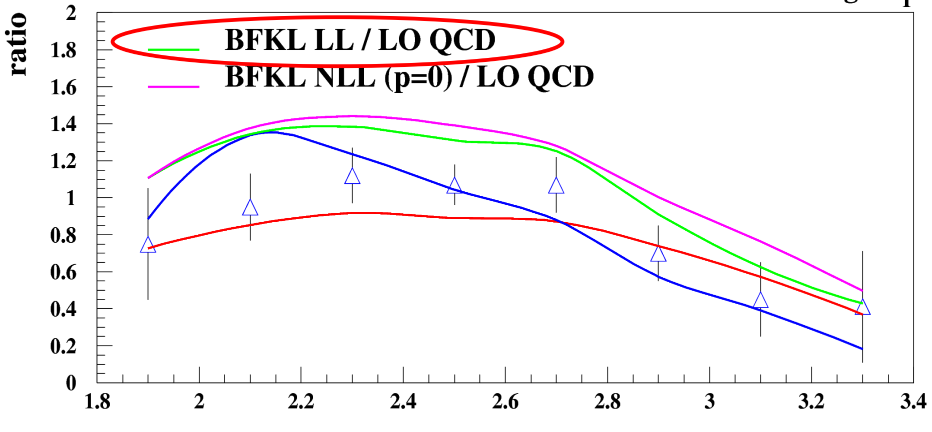
CDF measurements

- Same measurement as for DØ analysis
- Different selection cuts

Comparisons with BFKL formalism

- Better description using BFKL NLL with all p





BFKL NLL leads to a better description than BFKL LL

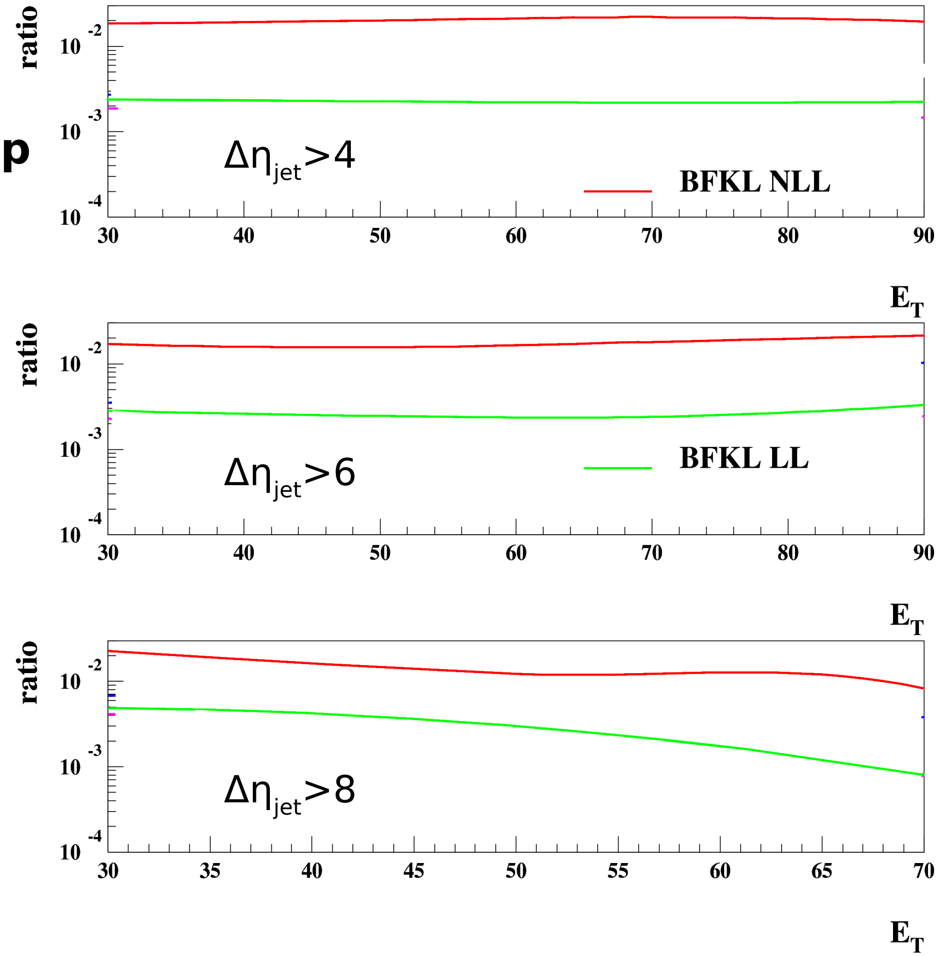
Predictions for LHC

Predictions

- Use the same BFKL NLL formalism in Herwig at LHC energies
- Gap survival probability for LHC
- Rapidity gap $-1 < \Delta\eta_{gap} < 1$

Fraction of di-jets events with gap

- Versus jet E_T
- Versus jet $\Delta\eta$



Weak E_T dependence

Large differences in normalisation between BFKL LL and NLL predictions

Predictions for LHC

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Fraction of di-jets events with gap

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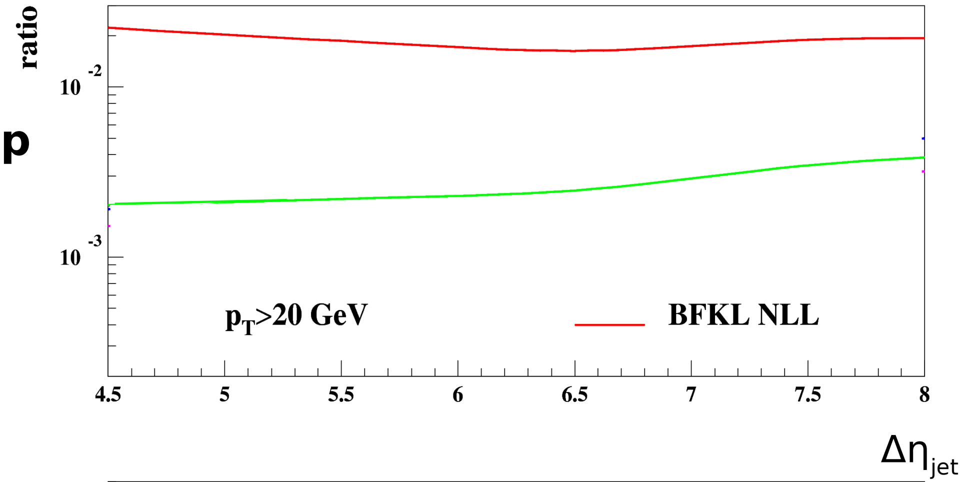
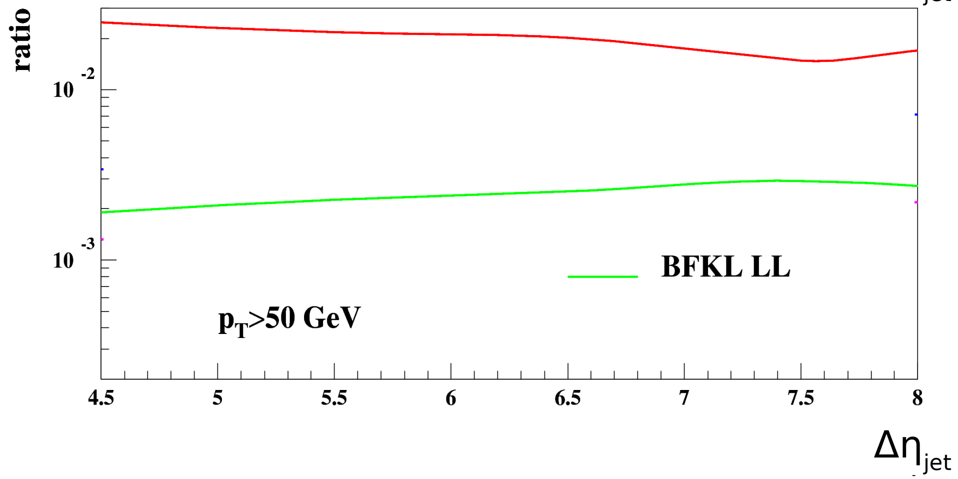
- Versus jet Δη





Weak Δη dependence

Large differences in normalisation between BFKL LL and NLL predictions

Conclusion

First study of processes with the BFKL kernel at next-leading accuracy

Predictions obtained with the full analytic expression of the NLL-BFKL kernel

Non-zero conformal spins have large contributions

BFKL NLL kernel fully implemented in HERWIG

Fundamental to compare with data (takes into account jet structure and jet size)

→ Provides meaningful predictions

Comparison with TeVatron data and prediction for LHC

Good agreement data/predictions

Better agreement with NLL calculation than with full LL

For LHC : large differences in normalisation/shape between LL and NLL

→ Effects of higher order terms in the di-jet cross-section have to be checked