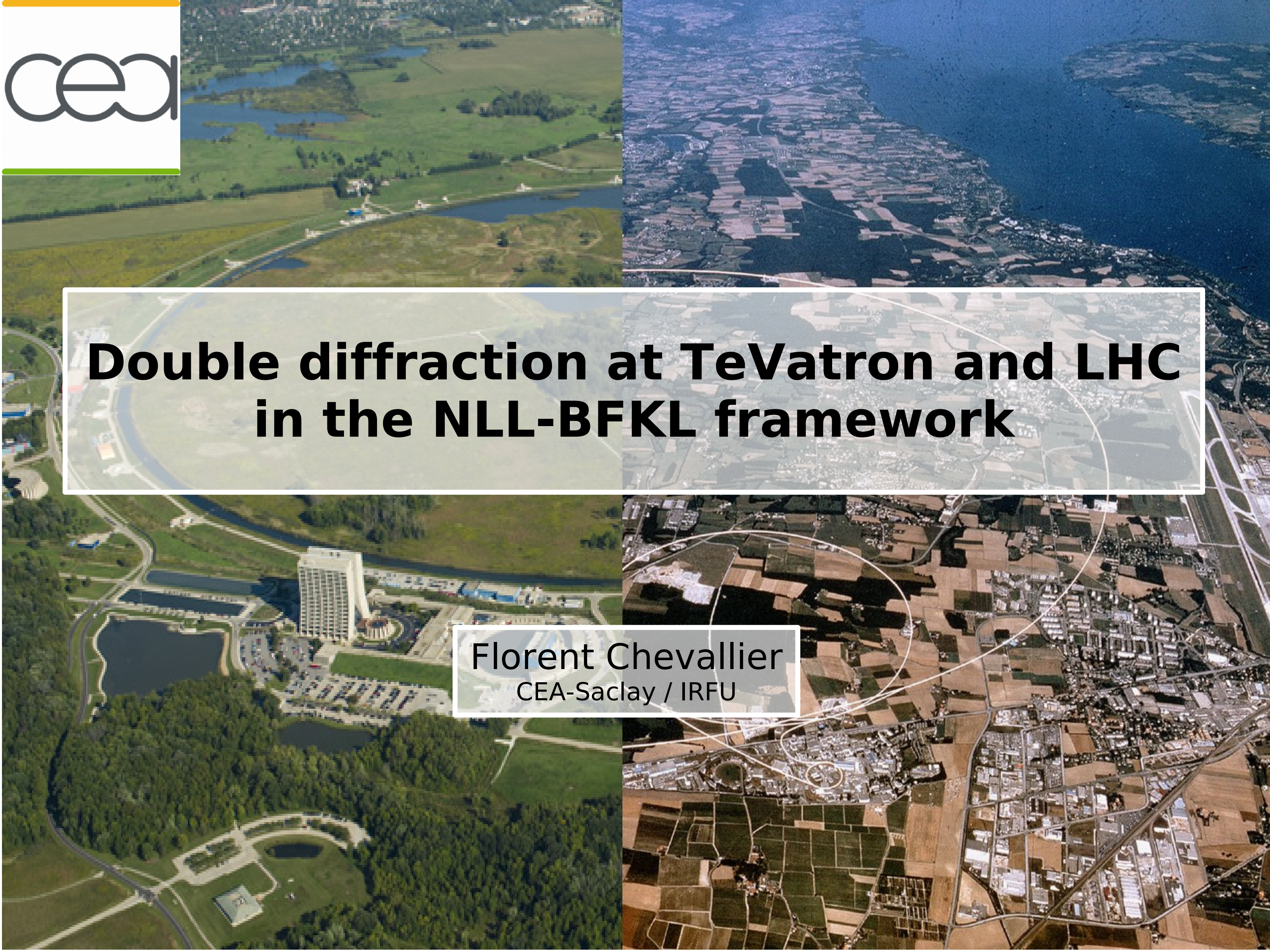

Double diffraction at TeVatron and LHC in the NLL-BFKL framework

Florent Chevallier
CEA-Saclay / IRFU

Content

Introduction

- BFKL evolution
- Process of interest
- Going to NLL-BFKL

Mueller-Navelet jets

C. Marquet, C. Royon, arXiv:0704.3409v2

- Correlations in azimuthal angle $d\sigma/d\Delta\Phi$
- Effects of systematic uncertainties

Gap between jets

F.C, O. Kepka, C. Marquet, C. Royon, arXiv:0903.4598v1

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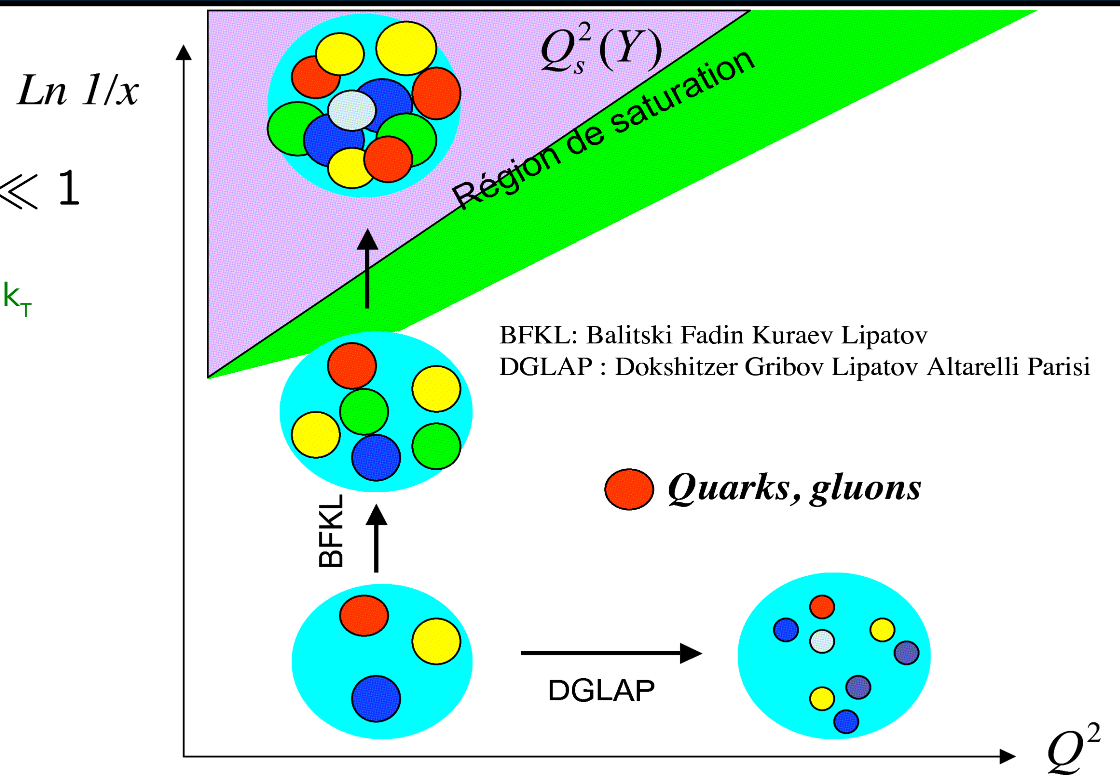
Introduction : BFKL evolution

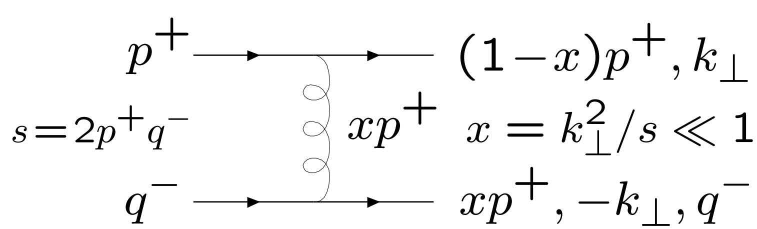


Linear pQCD evolutions $\alpha_s \ll 1$

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

2 to 2 scattering processes with same k_T

- DGLAP evolution
  No additional radiation is possible since jets have same k_T
- BFKL evolution wiin Regge limit $s \gg -t = k_\perp^2$
  Large rapidity interval between final-state particles
  Resummation of the large higher-order leading logs



$$\Delta\eta = \ln(s/k_T^2)$$

Signs of BFKL evolution in di-jets processes with same p_T and large Δη gap.

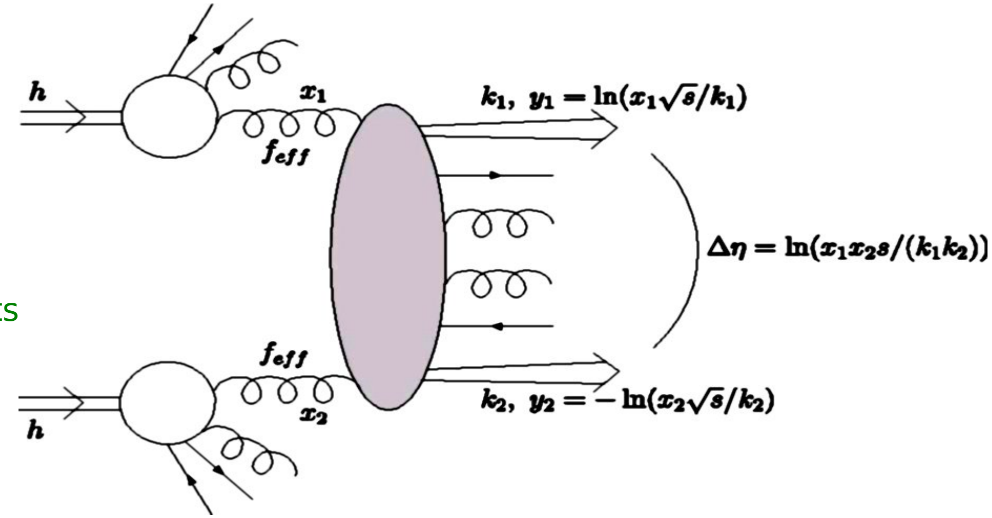
Processes of interest

Mueller-Navelet jets

- Two jets in forward regions
- Test of the BFKL approach

  Correlation in azimuthal angle between jets

Study $d\sigma/d\Delta\Phi$



Gaps between jets

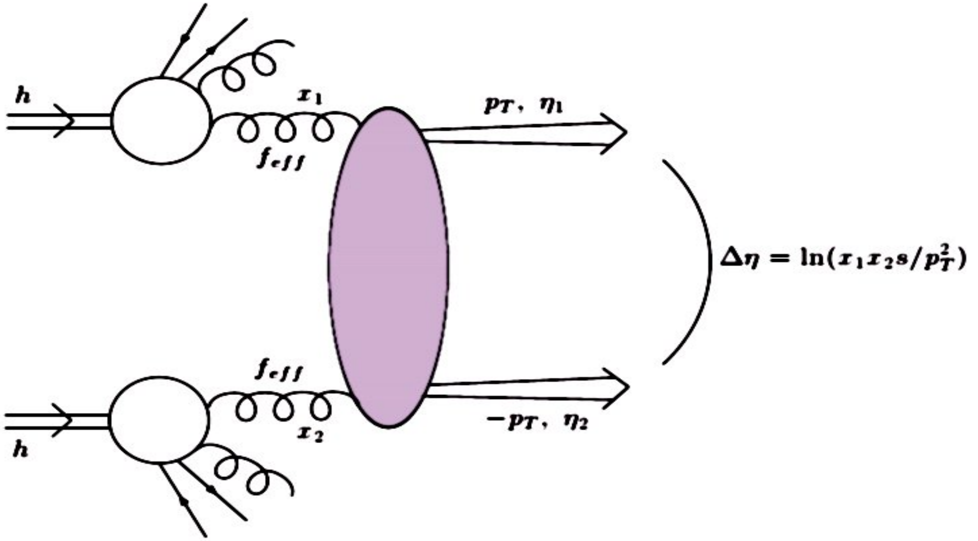
- No energy deposits between jets

  Observed at TeVatron and HERA

- Test of the BFKL approach

  Production cross-sections

Study $d^2\sigma / dp_T\, d\Delta\eta$



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 Mellin (γ) space

- 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 calculation available

- Resolution of implicit equation performed by numerical methods

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

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

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Correlations in azimuthal angle dσ/dΔΦ

Theoretical predictions

- DGLAP evolution
  Jets are back-to-back
  dσ/dΔΦ should peak towards π
  No dependence vs Δη
- BFKL evolution
  Smoother distribution via multi-gluon emission

Cross-section in the BFKL framework

- Relevant variables

$$y = \frac{y_1 + y_2}{2}, \quad Q = \sqrt{k_1 k_2}, \quad R = \frac{k_2}{k_1}, \quad \Delta\Phi = \pi - \phi_1 + \phi_2$$

- Normalized ΔΦ distribution

Sum over conformal spins

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

$$\sigma_p(\Delta\eta, R) = \int_{E_T}^{\infty} \frac{dQ}{Q^3} \alpha_s(Q^2/R) \alpha_s(Q^2 R) \left(\int_{y_<}^{y_>} dy\ x_1 f_{eff}(x_1, Q^2/R) x_2 f_{eff}(x_2, Q^2 R) \right)$$

$$\int_{1/2-\infty}^{1/2+\infty} \frac{d\gamma}{2i\pi} R^{-2\gamma}\ e^{\bar{\alpha}(Q^2)\chi_{eff}[p,\gamma,\bar{\alpha}(Q^2)]\Delta\eta}$$

⇒ parameter-free predictions

LL / NLL BFKL kernel

Results for (1/σ) dσ/dΔΦ

Results at TeVatron

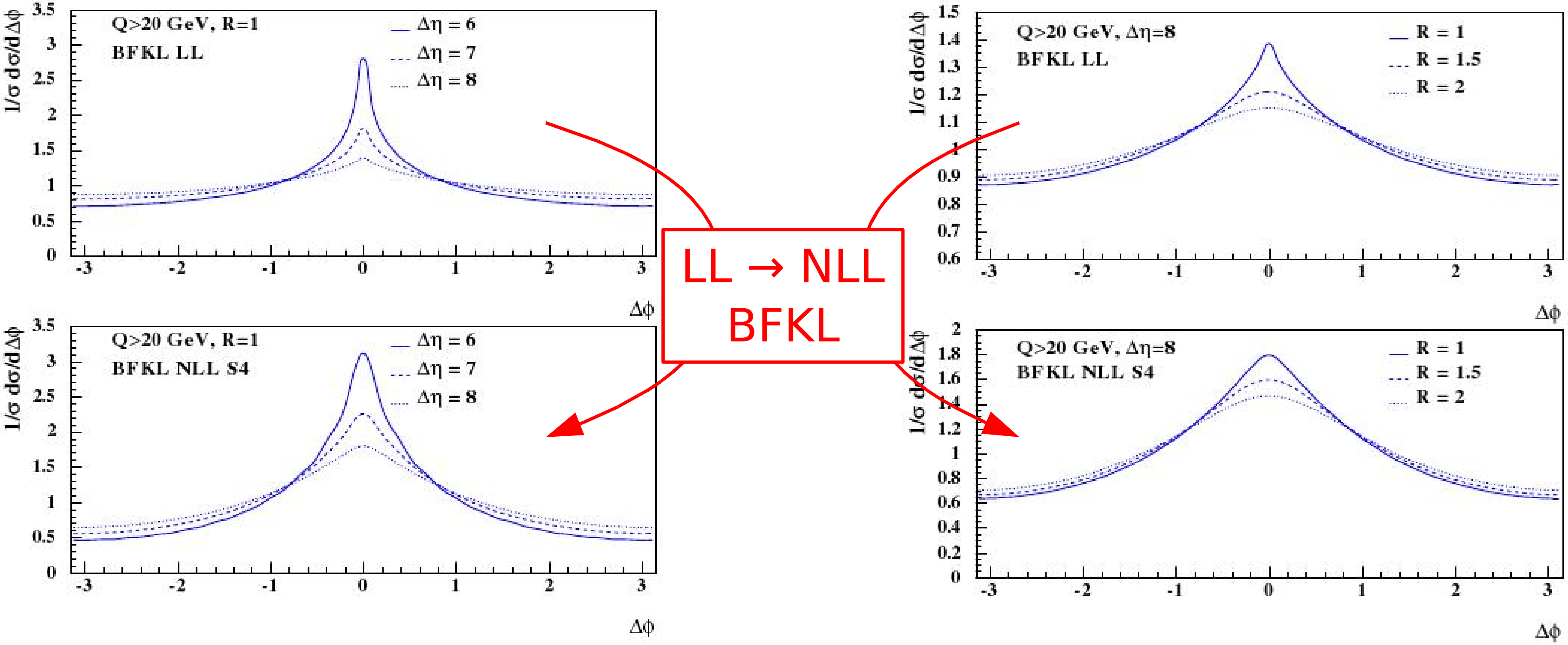
- Selection cuts

  E_T^{jet} > 20 GeV

  | $(y_1+y_2)/2$ |< 0.5 for a symmetric situation

Fixed R=1 and several Δη

Fixed Δη=8 and several R



Peak for back-to-back jets.

Flatten ΔΦ distribution with increasing rapidity interval Δη or jet E_T ratio.

Lower decorrelation with NLL-BFKL description.

Results for (1/σ) dσ/dΔΦ

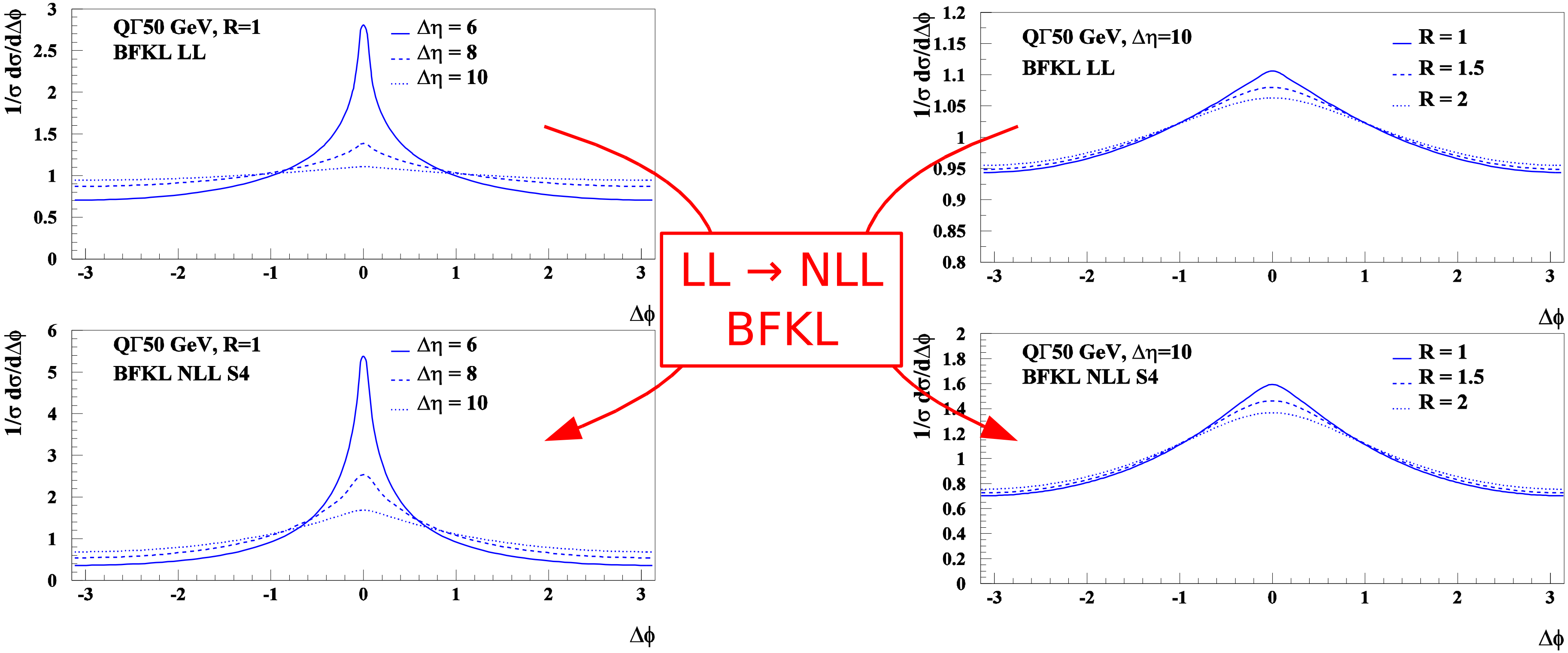
Results at LHC

- Selection cuts

  $E_T{}^{jet} > 50$ GeV

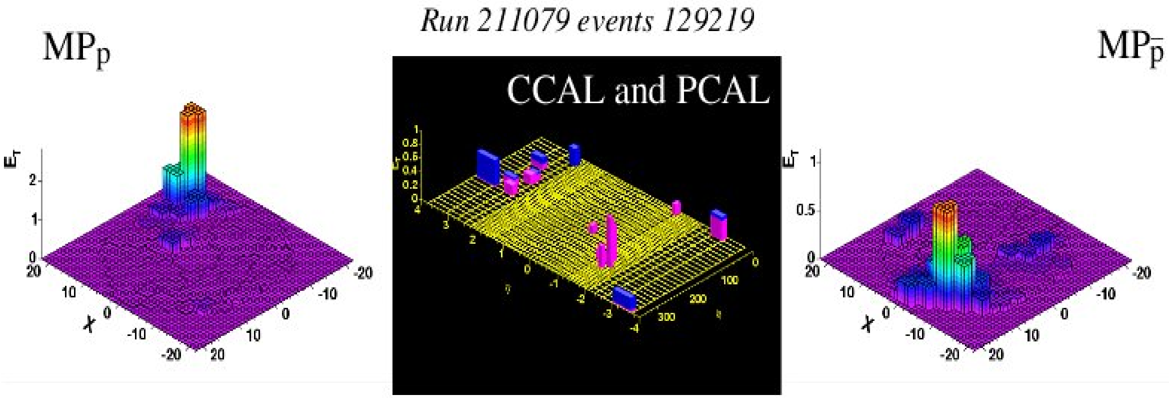
  $| (y_1+y_2)/2 | < 0.5$ for a symmetric situation

Fixed R=1 and several Δη — **Fixed Δη=10 and several R**



Decorrelation with NLL-BFKL description more pronounced at LHC

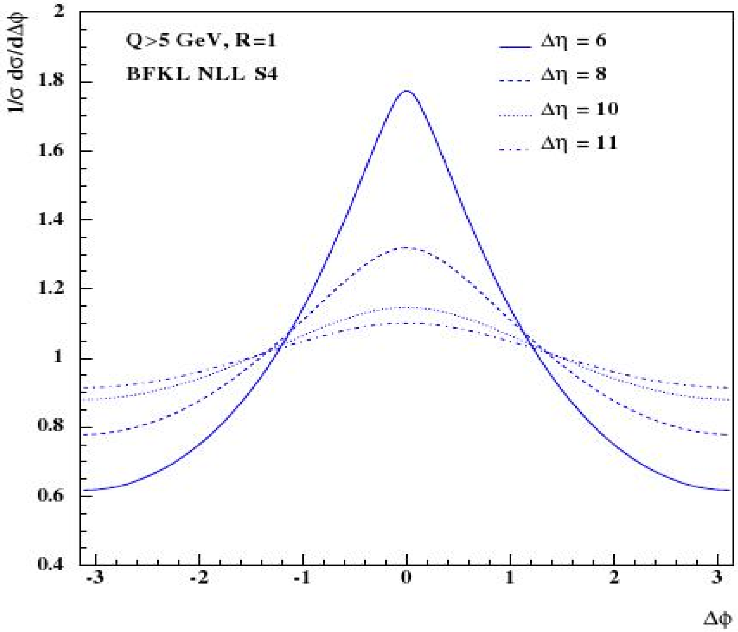
Mueller-Navelet jets at CDF

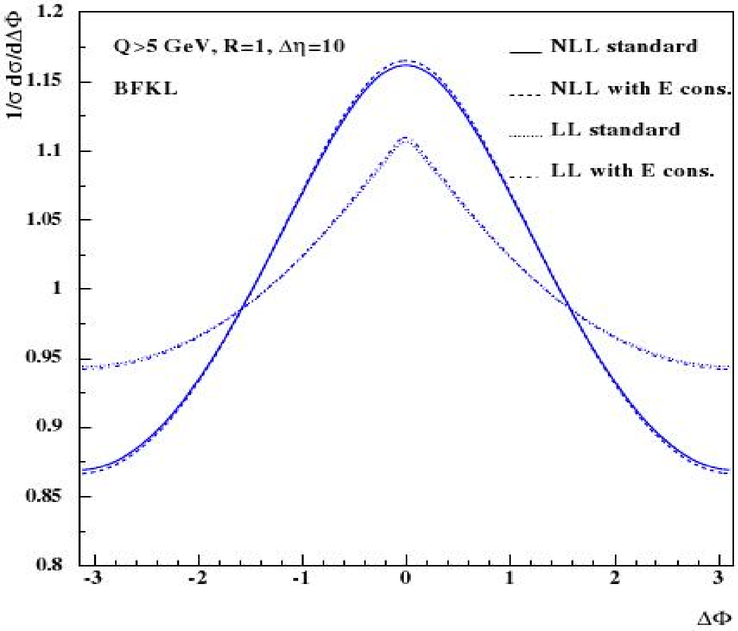


Forward jet detection

- Installation of mini-plug calorimeters
  $\eta^{\ jet} \sim$ 4-5
  $E_T^{\ jets} > 5$ GeV
- See Christina Mesropian's talk (CDF)

Expectations with BFKL framework



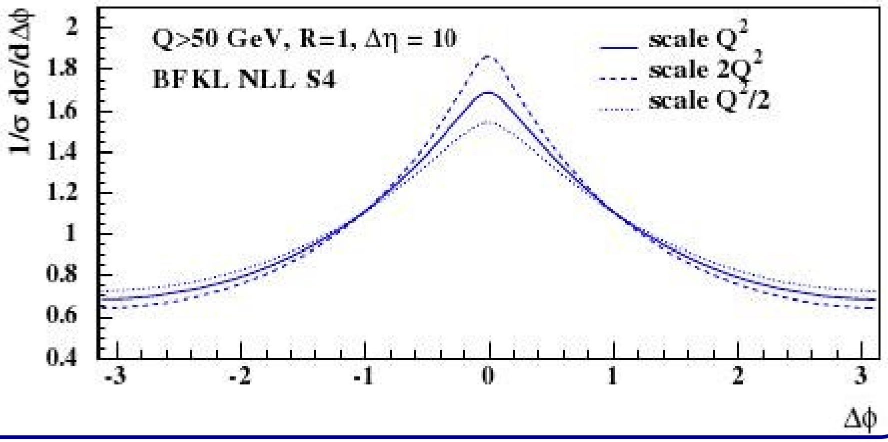


ΔΦ decorrelation between jets can be seen at CDF using the miniplugs.
Saturation effects could play an important role at these transverse momenta.

Systematic uncertainties

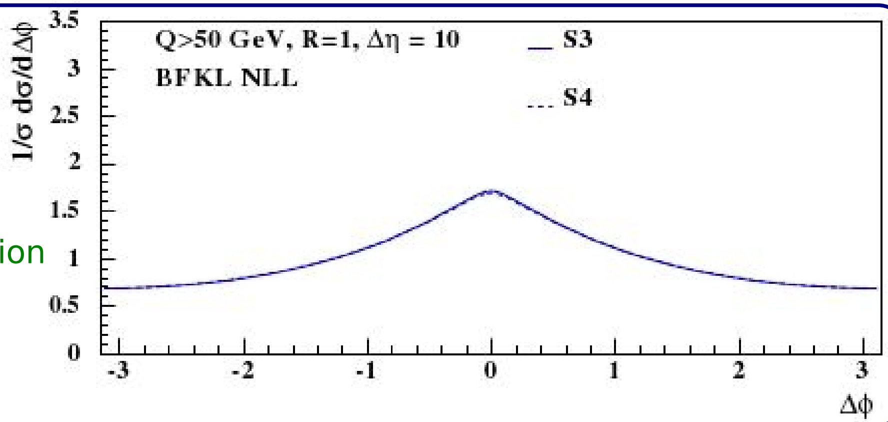
Renormalization scale dependence

- Method
  - Variation ½ $Q^2 \rightarrow 2\ Q^2$
  - Appropriate substitution in $\bar{\alpha}(Q^2)$
  - Modify the effective BFKL kernel
  - Modify energy scale
- Results
  - Small effects 5 - 20%



Scheme dependence

- Method
  - Compare S3 & S4 schemes
- Results
  - No visible difference in the normalized ΔΦ distribution



PDF and impact factor uncertainties

- PDF uncertainties cancel in this ratio $(1/\sigma)\ d\sigma/d\Delta\Phi$: negligible effect
- The effect of NLO impact factor is suppressed in this ratio

Small systematic uncertainties.
ΔΦ between forward jets is an interesting observable

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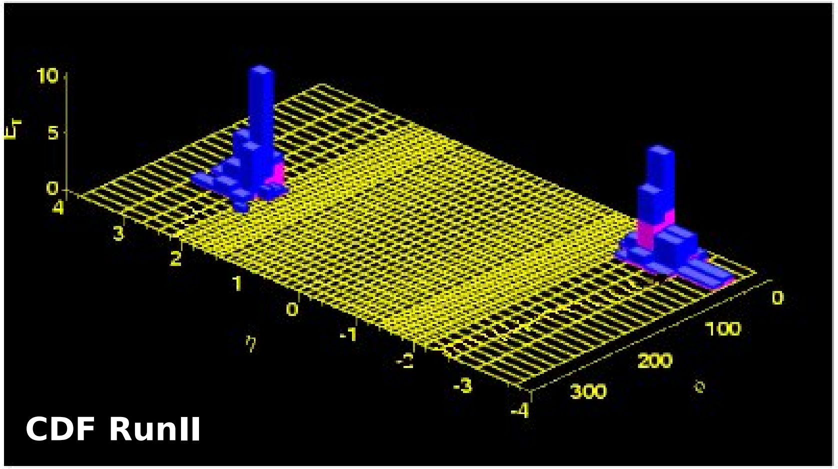
Central rapidity gaps between forward jets



Different models proposed

- QCD di-jets production
  Soft QCD radiations → no gaps
- Color-singlet exchange
  Gap between jets
  One color-singlet candidate is the BFKL pomeron

Cross-section in the BFKL framework

- Relevant variables

$$y = \frac{y_1 + y_2}{2} \quad ; \quad \Delta\eta = | y_1 - y_2 |$$

- Jet-gap-jet cross-section

Gap survival probability

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

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

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

Sum over conformal spin

LL / NLL BFKL kernel

$\Rightarrow$ 1 free parameter : the normalization

Effect of higher-order BFKL corrections

Contributions from non-zero conformal spins

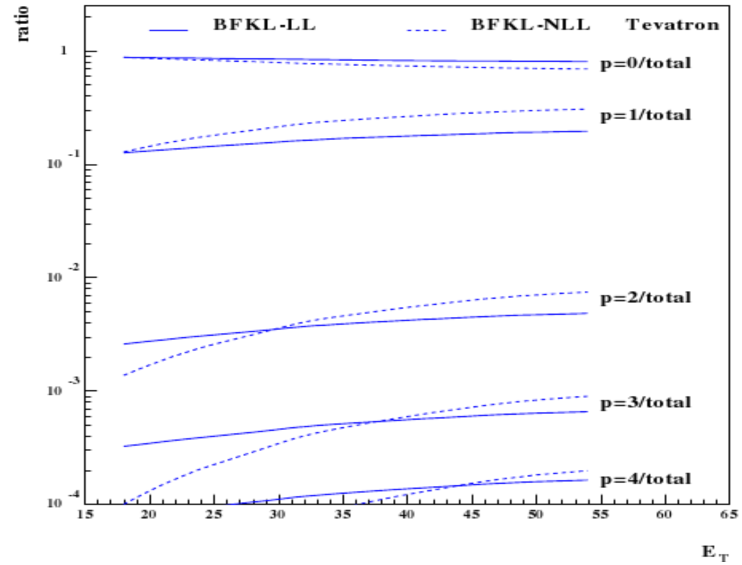
- Not perfomed before
- Large contribution

  +20% for p=1

  + 1% for p=2

  Larger contribution at high E_T and at low $\Delta\eta$

  Larger contribution at NLL-BFKL



LL / NLL-BFKL comparison

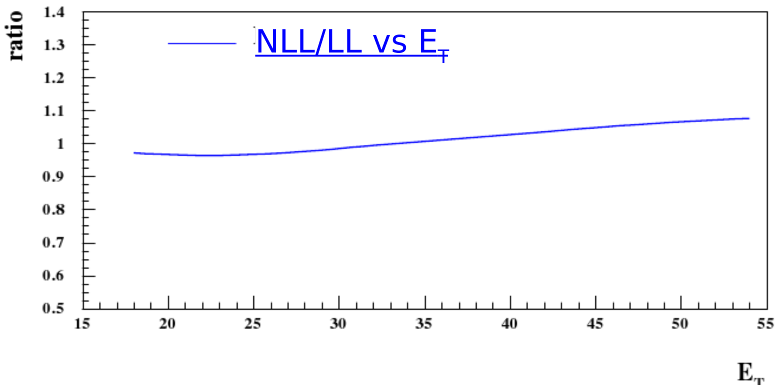
- Normalization is a free parameter

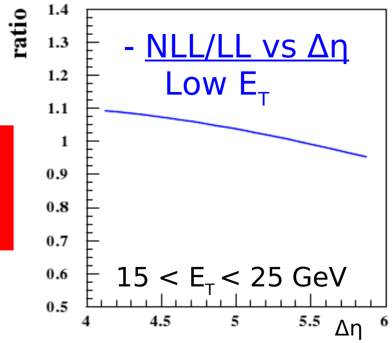
  Will be adjusted to describe the data

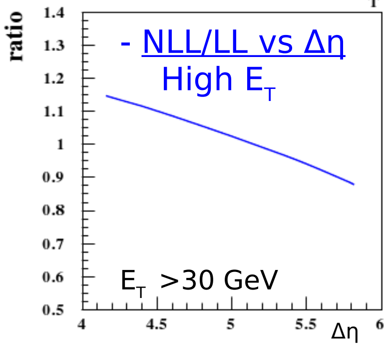
  → Compare the shape of distributions
- Small differences in shape

  NLL effect more important at high E_T → +10%

  Dependence vs $\Delta\eta$







Large higher-order corrections

p≠0 contributions are as large as LL → NLL

Comparisons with DØ data

DØ data selection

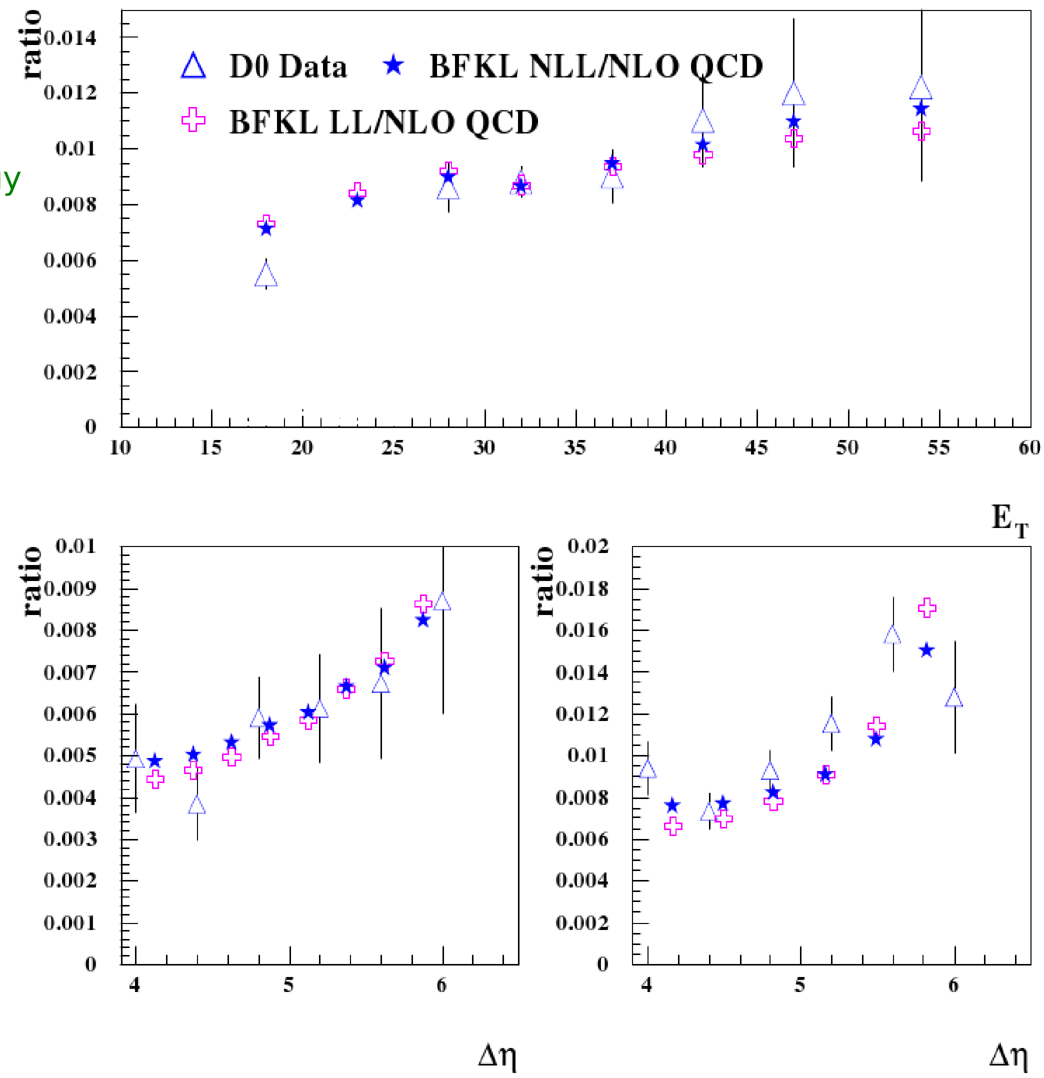
- Inclusive di-jet sample
  - 2 high E_T jets in opposite forward regions
  - Central gap $\Delta\eta>2$ with no significant energy
- Fraction of di-jets events with gap

Prediction

- BFKL jet-gap-jet cross-section
  - LL or NLL kernel
  - Gap survival probability S=0.1
  - Hadronization not taken into account
- Inclusive di-jet cross-section
  - QCD predictions with NLOJet++
  - Hadronization not taken into account

Comparisons

- Overall normalization fit to data
  - k=0.84 with LL-BFKL prescription
  - k=1.00 with NLL-BFKL prescription
- Shape
  - E_T , $\Delta\eta$ dependence are well described



Correct agreement between NLL-BFKL prediction and DØ data
Need checks with NNLO QCD

Predictions for LHC

Selection cuts

- Inclusive di-jet sample

  2 high E_T jets in opposite forward regions + trigger condition

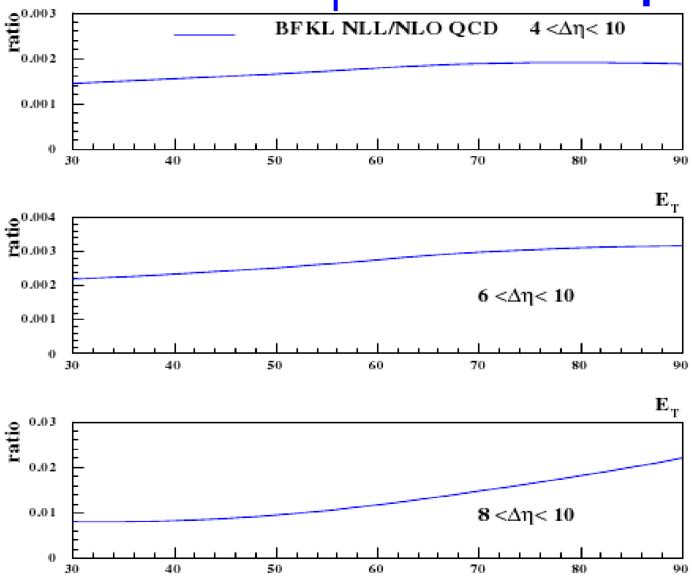
  Central gap with no significant energy

  → Need low-luminosity runs

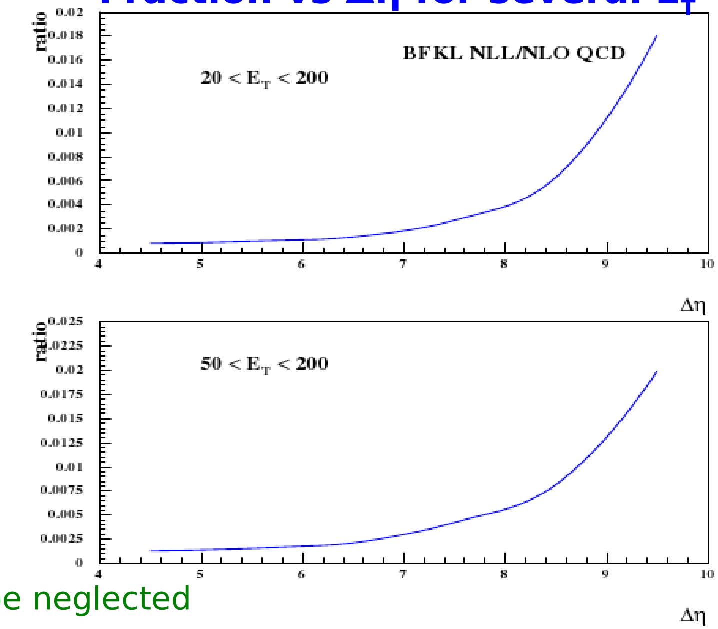
Fraction of gap events

- σ(jet-gap-jet) / σ(inclusive di-jets)

Fraction vs E_T for several Δη



Fraction vs Δη for several E_T



Contributions from p≠0 conformal spins cannot be neglected

Percentage of jet-gap-jet events increases with Δη and jet E_T

⇒ **High jet-gap-jet cross-section at LHC → need $O(100\ pb^{-1})$**
Challenging because it needs a good calibration of forward jets

Systematic uncertainties

Renormalization scale dependence

- Method

  Variation ½ $Q^2 \rightarrow 2\ Q^2$

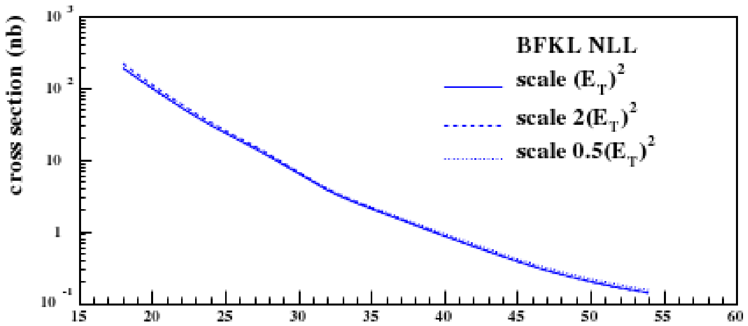
  Appropriate substitution in $\bar{\alpha}(Q^2)$

  Modify the effective BFKL kernel

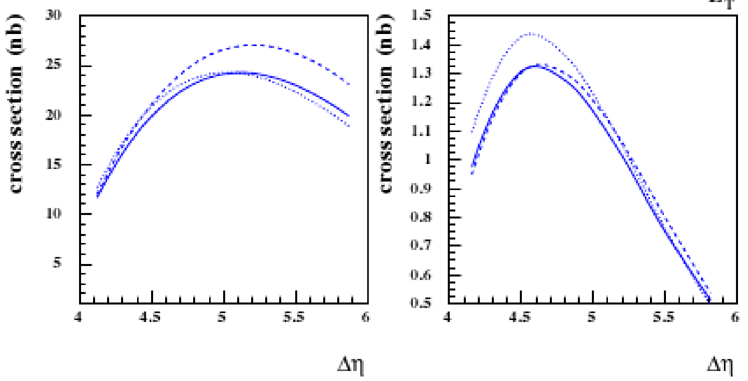
  Modify energy scale

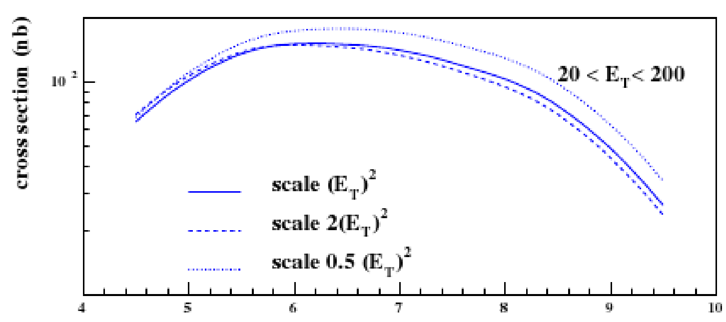
- Results

  Small effects 10 - 15%

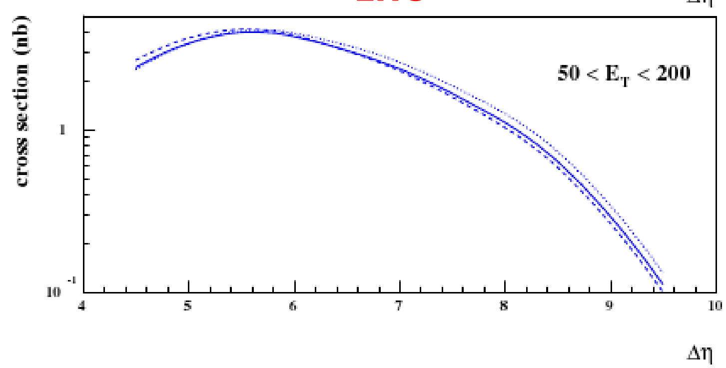


TeVatron





LHC



Jet-gap-jet cross-section is a robust test of the BFKL regime

Conclusion

First study of processes in the BFKL framework at next-leading accuracy

- Interesting processes : Mueller-Navelet jets and jet-gap-jet events
- Predictions obtained with the full analytic expression of the NLL-BFKL kernel
- LL → NLL corrections ~ 10%
- Non-zero conformal spins have large contributions
- Systematic uncertainties ~ 10 %

Comparison with TeVatron data

- NLL-BFKL predictions for jet-gap-jet cross-section is in good agreement with DØ data
- Analyses with CDF data about Mueller-Navelet jets and jet-gap-jet are ongoing

Predictions for LHC

- High jet-gap-jet cross-section at LHC
- Good calibration of forward jets is needed
- $\Delta\Phi$ measurements do not require a precise JES (Mueller-Navelet jets)
- idem for $\Delta\eta$ for jet-gap-jet

Conclusions

- the correlation in azimuthal angle between two jets gets weaker as their separation in rapidity increases
- we obtained parameter free predictions in the BFKL framework at next-leading accuracy, valid for large enough rapidity intervals
- there is some data from the D0 collaboration at the Tevatron, but for rapidity intervals $\Delta\eta$ smaller than 5
- our predictions underestimate the correlation while pQCD@NLO predictions overestimate it prospects for future measurements:
- at the Tevatron : the CDF miniplugs cannot measure pT well but are suited for azimuthal angle measurements
- at the LHC : feasibility study in collaboration with Christophe Royon (D0/Atlas) and Ramiro Debbe (Star/Atlas)

Therefore a measurement of the cross-section $d\sigma^{hh\to JXJ}/d\Delta\eta dR d\Delta\Phi$ at the Tevatron (Run 2) or the LHC would allow for a detailed study of the QCD dynamics of Mueller-Navelet jets. In particular, measurements with values of $\Delta\eta$ reaching 8 or 10 will be of great interest, as these could allow to distinguish between BFKL and DGLAP resummation effects and would provide important tests for the relevance of the BFKL formalism.

Effect of non-zero conformal spin

Different models proposed

- QCD di-jets production

  No gap because of soft QCD radiations
- Color-singlet exchange

  Gap between jets

  One color-singlet candidate is the BFKL pomeron

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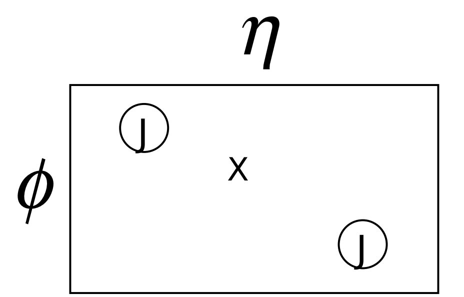
Sum over conformal spin

LL / NLL BFKL kernel

⇒ 1 free parameter : the normalization



ideas : study the BFKL evolution with :
azimuthal correlations of Mueller-Navelet jets

Kepka, Marquet, Peschanski and Royon (2007)
Balitsky, Fadin, Kuraev and Lipatov (2007)