ATLAS jet veto measurement and jet gap jet events at the LHC

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Contents:

- ATLAS jet veto measurement
- Banfi Smye Marchesini equation
- Description of jet veto measurement
- Jet gap jet production

References:

- A QCD description of the ATLAS jet veto measurement Y. Hatta, C. Marquet, C. Royon, G. Soyez, T. Ueda, D. Werder, Phys.Rev. D87 (2013) 5, 054016

- Gaps between jets in double-Pomeron-exchange processes at the LHC C. Marquet, C. Royon, M. Trzebinski, R. Zlebcik, Phys.Rev. D87 (2013) 3, 034010

- Gaps between jets in hadronic collisions O. Kepka, C. Marquet, C. Royon, Phys.Rev. D83 (2011) 034036

ATLAS measurement
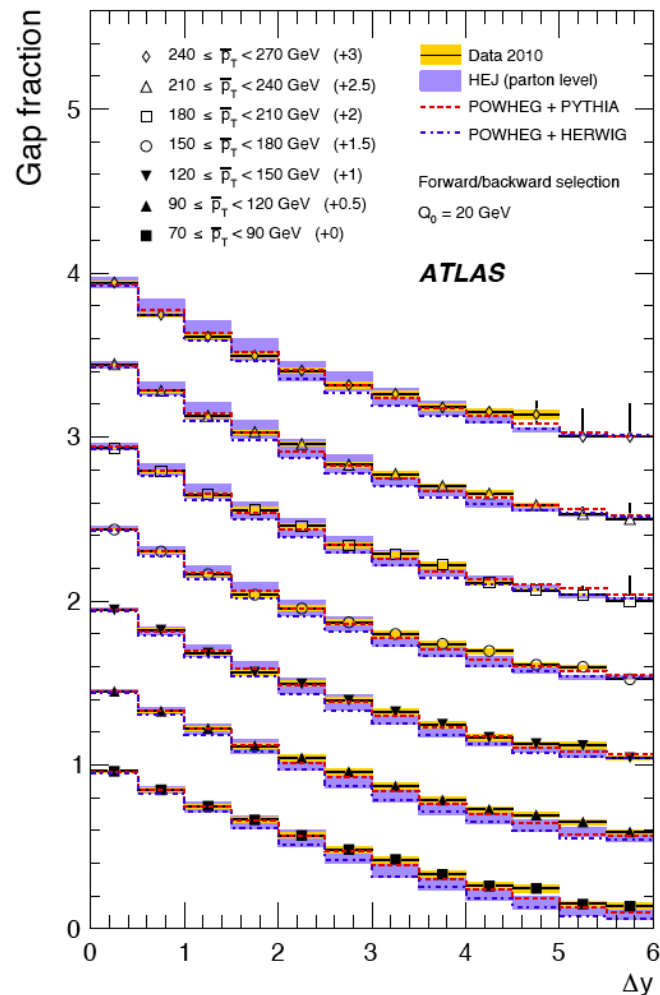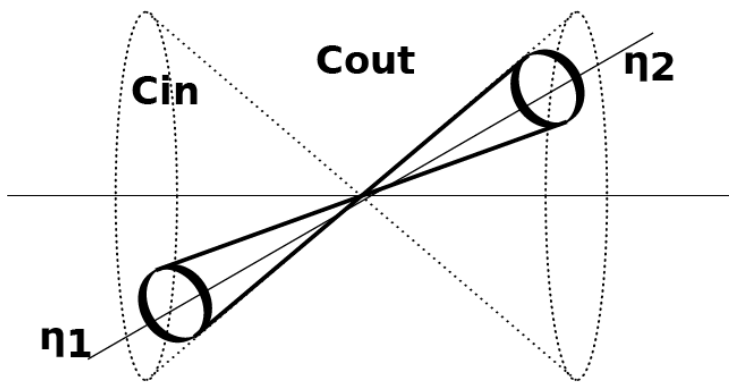
- Select events with two high p_T jets, well separated in rapidity by Δy

- Veto on additional jet activity (with $k_T > Q_0$, with $Q_0 \gg \Lambda_{QCD}$) between the two jets

- Measure the "gap" fraction: dijet events with jet veto / total dijet events
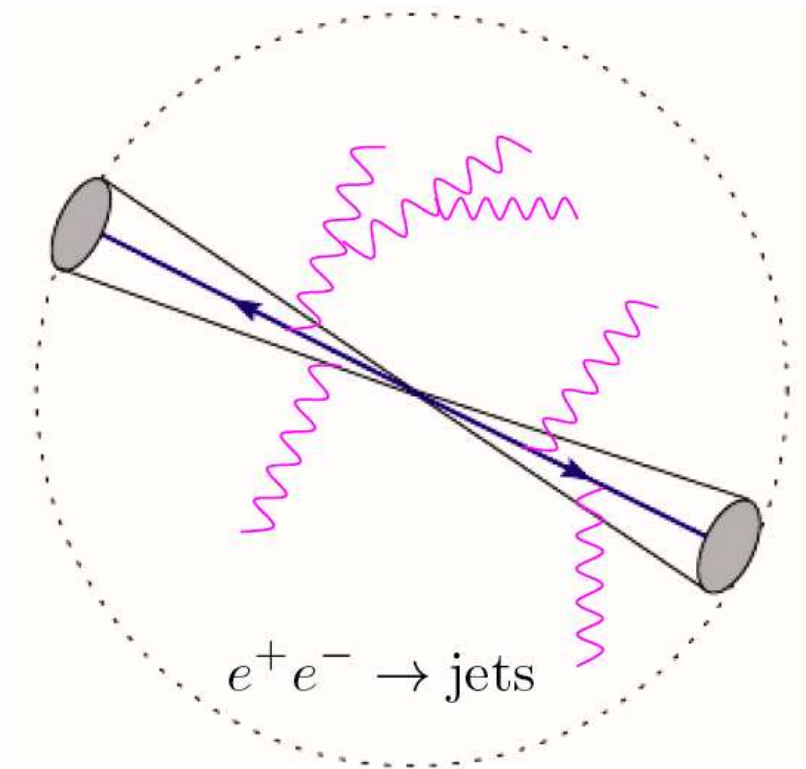
Comparison with QCD calculation
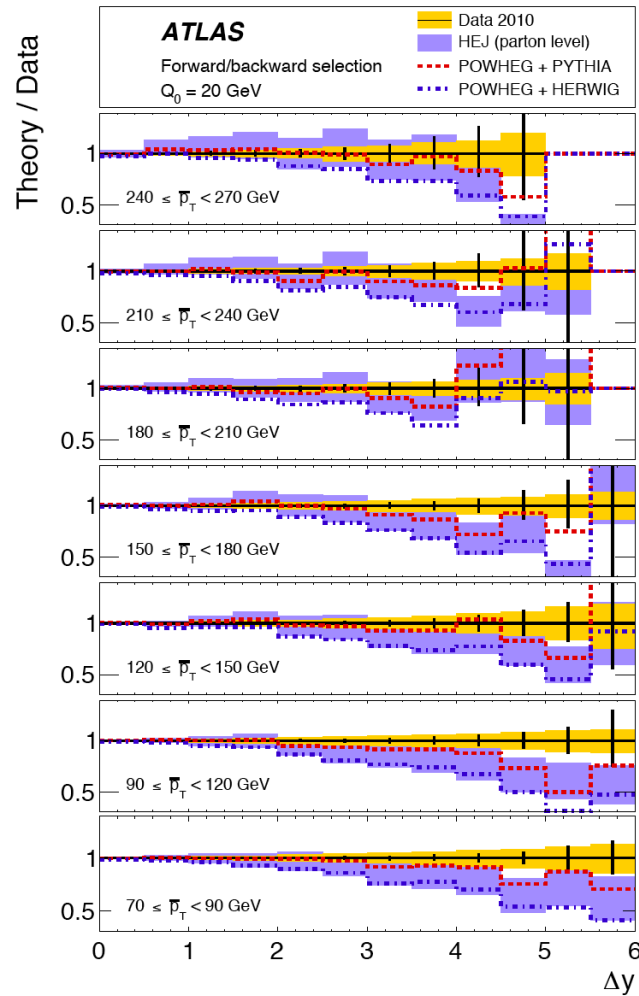
- The standard NLO and parton shower approach (POWHEG + pythia or herwig) fails to describe data

$$\frac{(d\sigma^{2\to2} + d\sigma^{2\to3})_{p_{T_3} < E_{out}}}{d\sigma^{2\to2} + d\sigma^{2\to3}}$$

- BFKL resummation (HEJ Monte Carlo) also fails to describe data
- Both approaches miss the resummation of soft gluons at large angles

Gluon emission at large angles

$e^+e^- \to \text{jets}$

- Resummation of soft gluon emissions at large angle not taken into account in parton showers

- Resummation of soft emissions performed in e^+e^- case: when $p_T \gg E_{out}$, one can resum the soft logarithms $(\alpha_S \log p_T/E_{out})^n$ while requiring that the energy flow into the region between the jets is less than E_{out}

Banfi Marchesini Smye equation
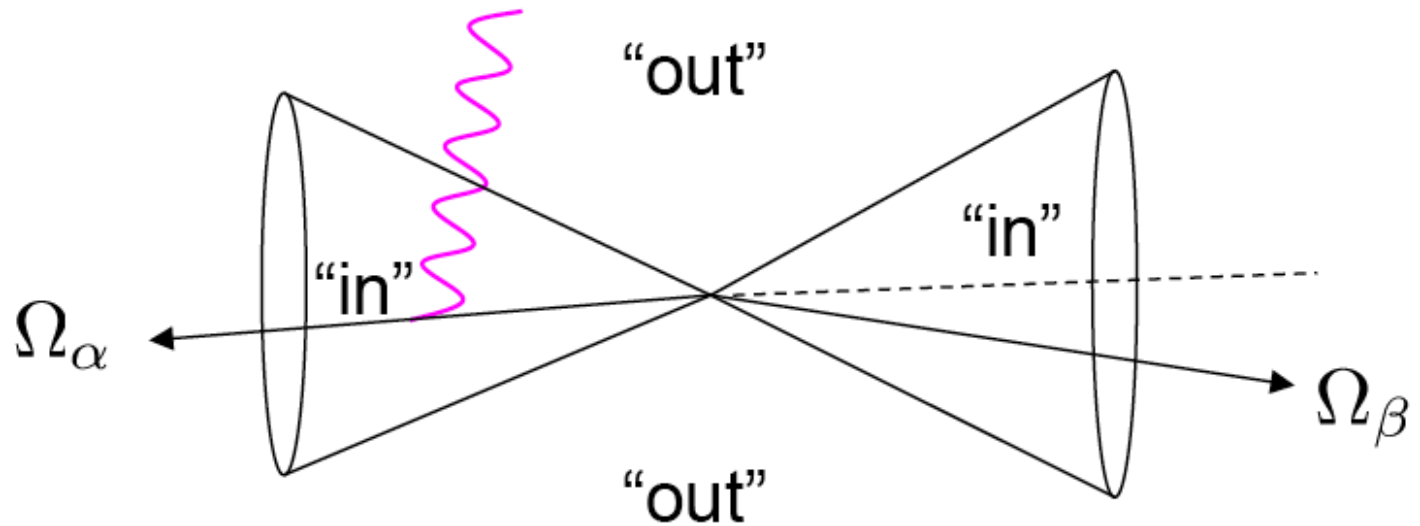
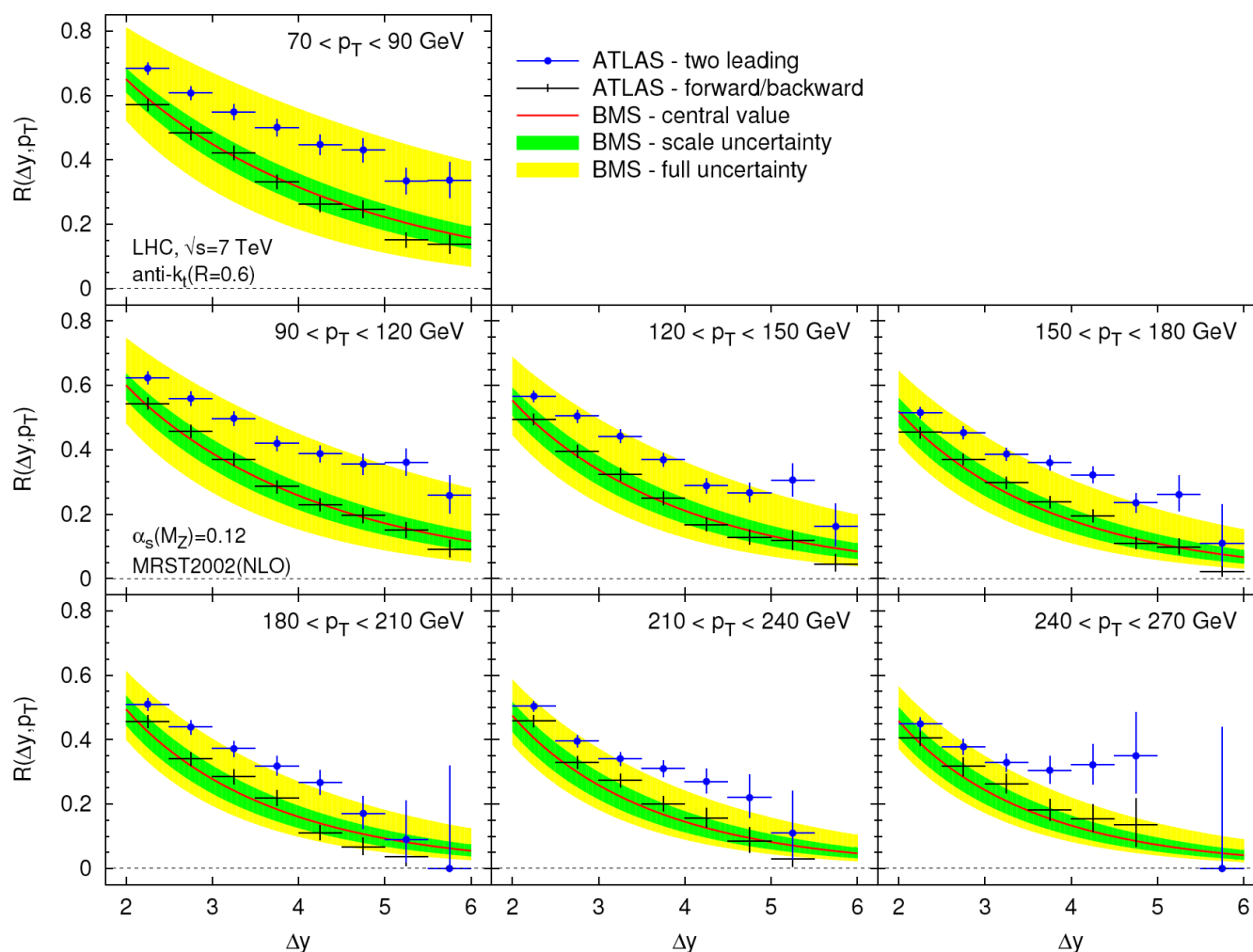- Compute the probability P_T that the total energy emitted outside the jet cone is less than E_{out}

$$\partial_\tau P_\tau(\Omega_\alpha, \Omega_\beta) = -\int_{C_{out}} \frac{d^2\Omega_\gamma}{4\pi} \frac{1 - \cos\theta_{\alpha\beta}}{(1 - \cos\theta_{\alpha\gamma})(1 - \cos\theta_{\gamma\beta})} P_\tau(\Omega_\alpha, \Omega_\beta)$$

$$+ \int_{C_{in}} \frac{d^2\Omega_\gamma}{4\pi} \frac{1 - \cos\theta_{\alpha\beta}}{(1 - \cos\theta_{\alpha\gamma})(1 - \cos\theta_{\gamma\beta})} \Big(P_\tau(\Omega_\alpha, \Omega_\gamma) P_\tau(\Omega_\gamma, \Omega_\beta) - P_\tau(\Omega_\alpha, \Omega_\beta) \Big)$$

Sudakov logs

non-global logs

differential probability for the soft gluon emission

- Numerical solutions are available (Hatta and Ueda, 2009)

Comparison with ATLAS data

- Good agreement between prediction and ATLAS data (black points when the most forward and backward jets are selected and E_{out}=20 GeV)

- Plot as a function of Δy between jets in different jet p_T bins

- Green band: renormalisation and factorisation scale uncertainties (between $2p_T$ and $p_T/2$); yellow band: uncertainties related to sub-leading logs
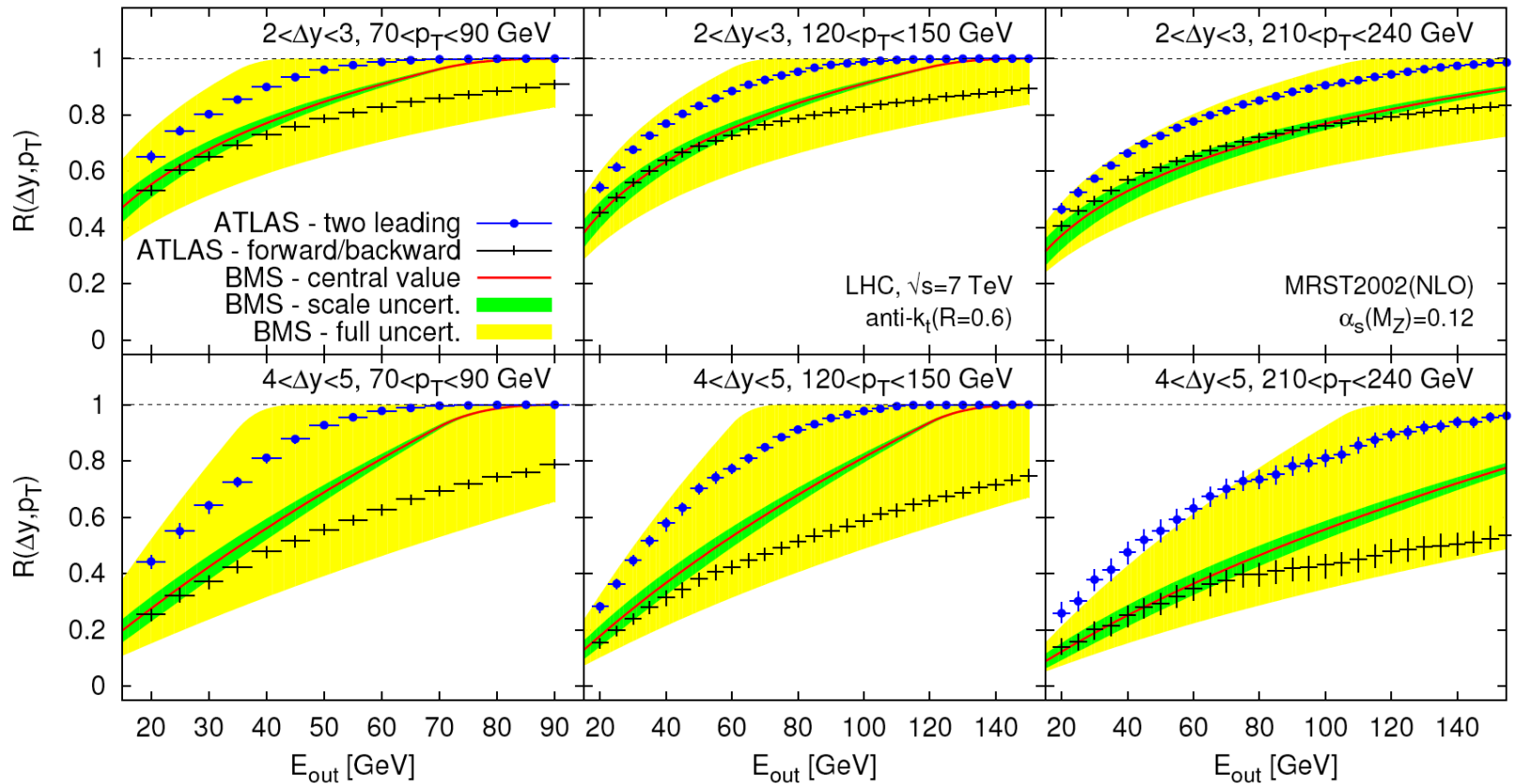
Comparison with ATLAS data
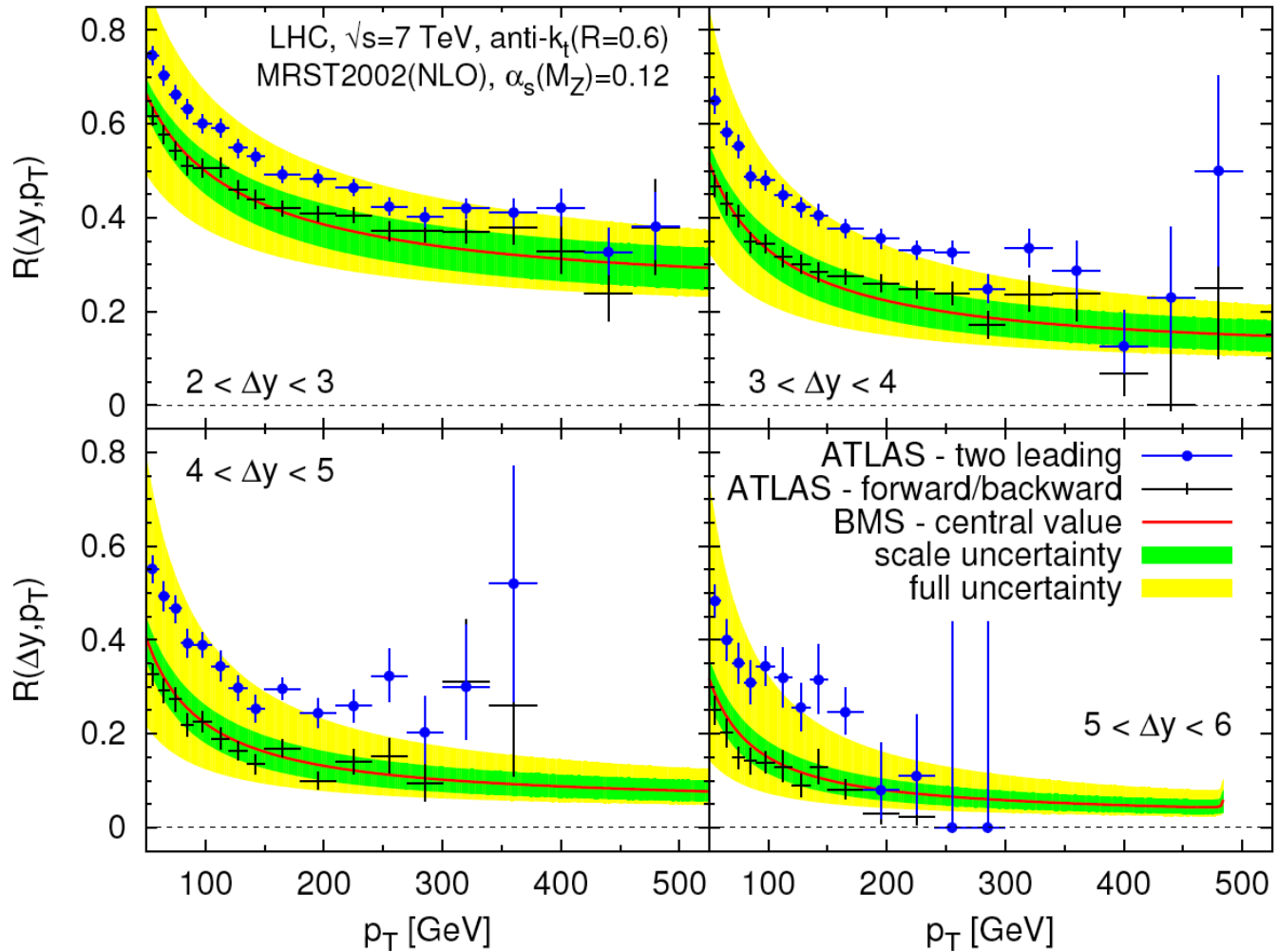
- Good agreement between prediction and ATLAS data (black points when the most forward and backward jets are selected and E_{out}=20 GeV)

- Plot as a function of jet p_T in different Δy bins

Comparison with ATLAS data

- Plot as a function of the energy between the two jets in different jet p_T and Δy bins

- Description not so good when $E_{out} \sim p_T$ as expected

- No need of BFKL resummation: other observables

Jet gap jet cross sections
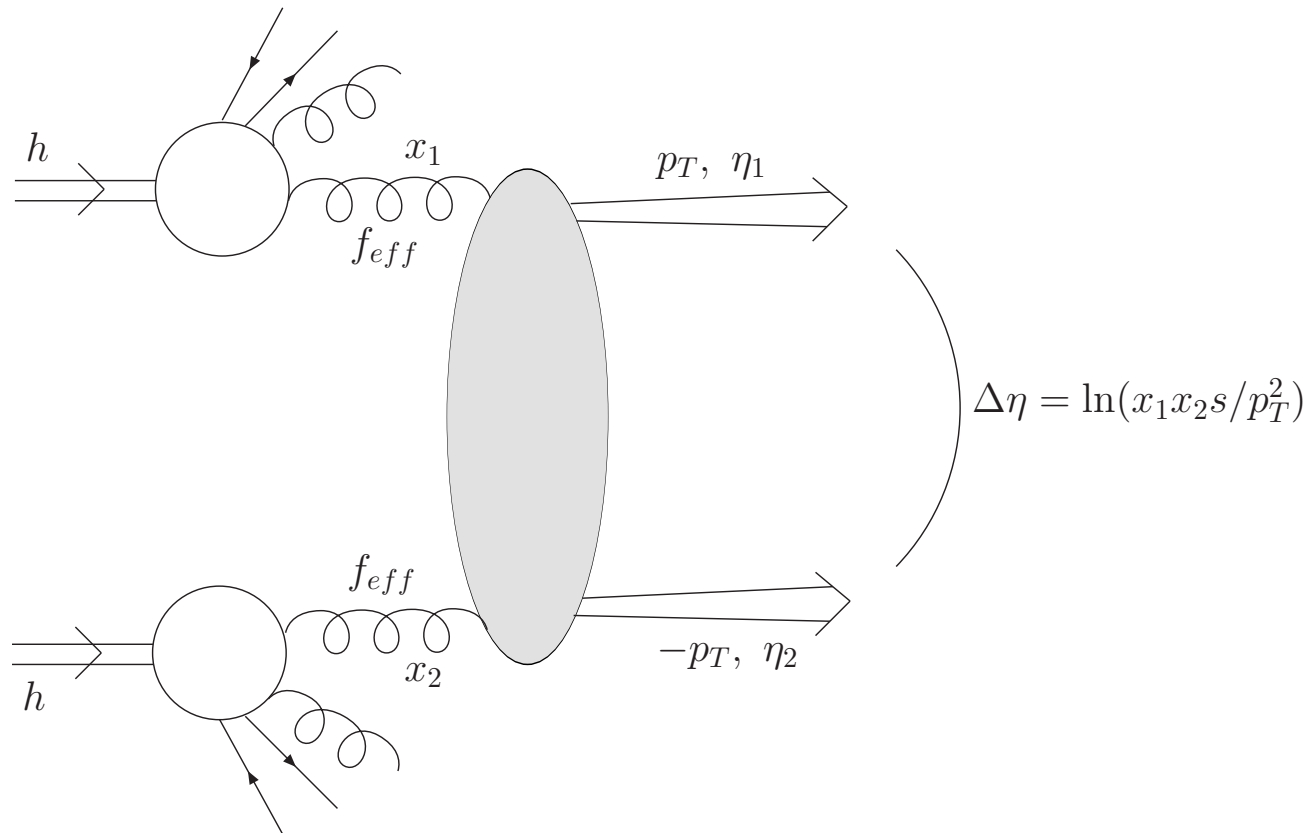
- Test of BFKL evolution: jet gap jet events, large $\Delta\eta$, same p_T for both jets in BFKL calculation

- 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)

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

$$\frac{\exp\left\{ \frac{\alpha_S N_C}{\pi} \chi_{eff} \Delta\eta \right\}}{[(\gamma - 1/2)^2 - (p + 1/2)^2]}$$

- 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 $\chi^2 \sim 0.1$)

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
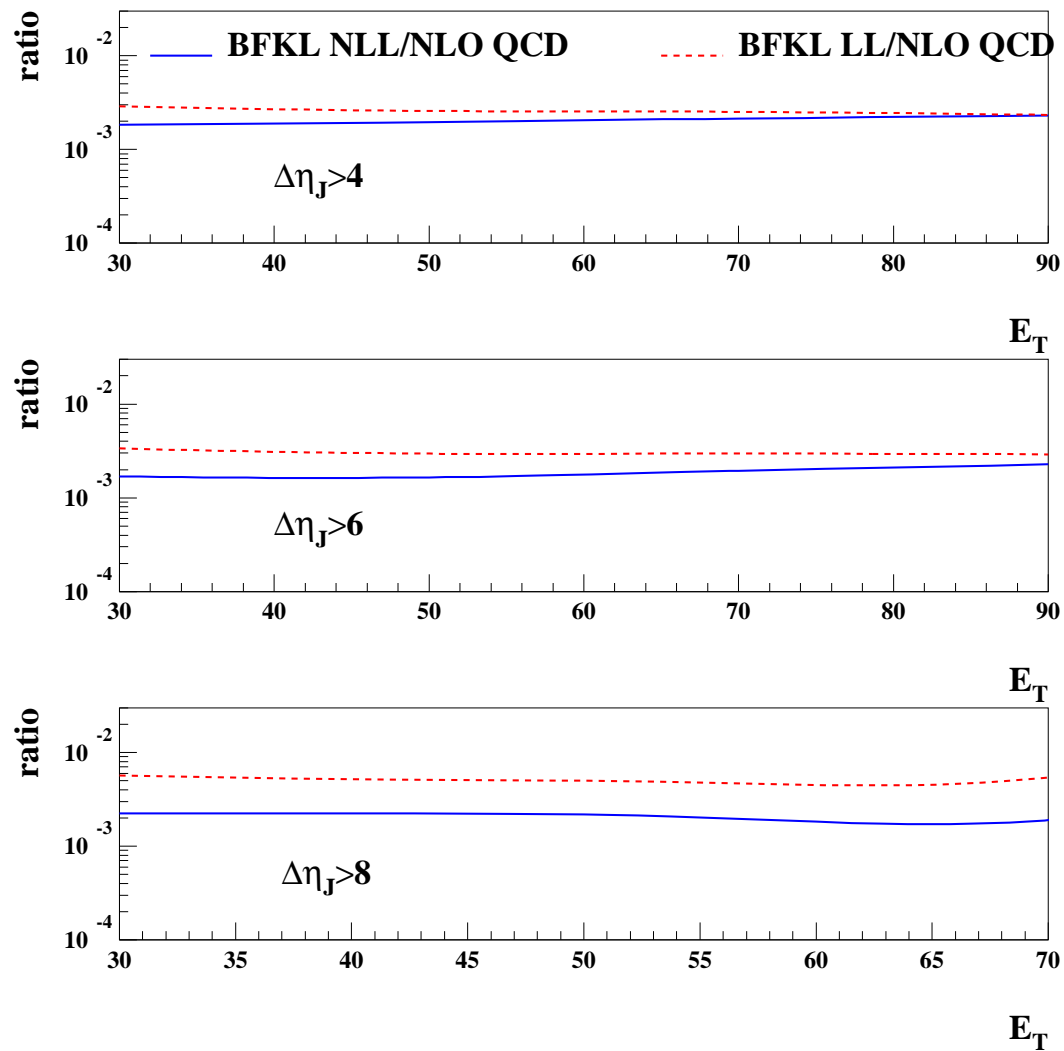
- Comparison with BFKL formalism:

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

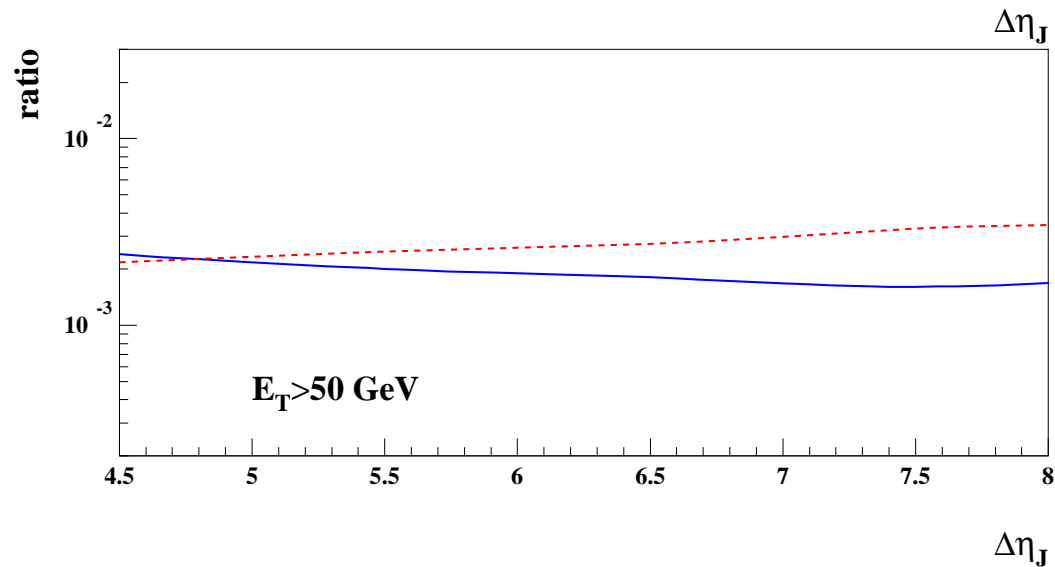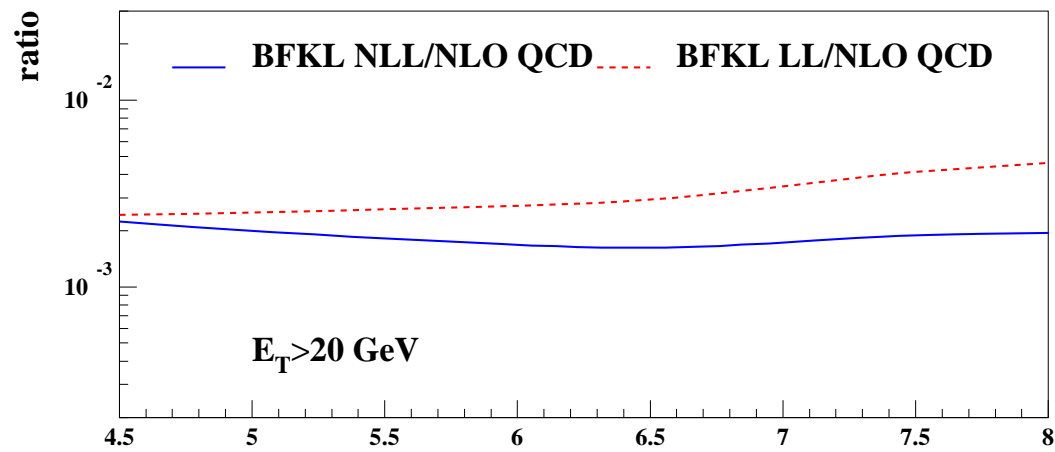- Reasonable description using BFKL NLL formalism
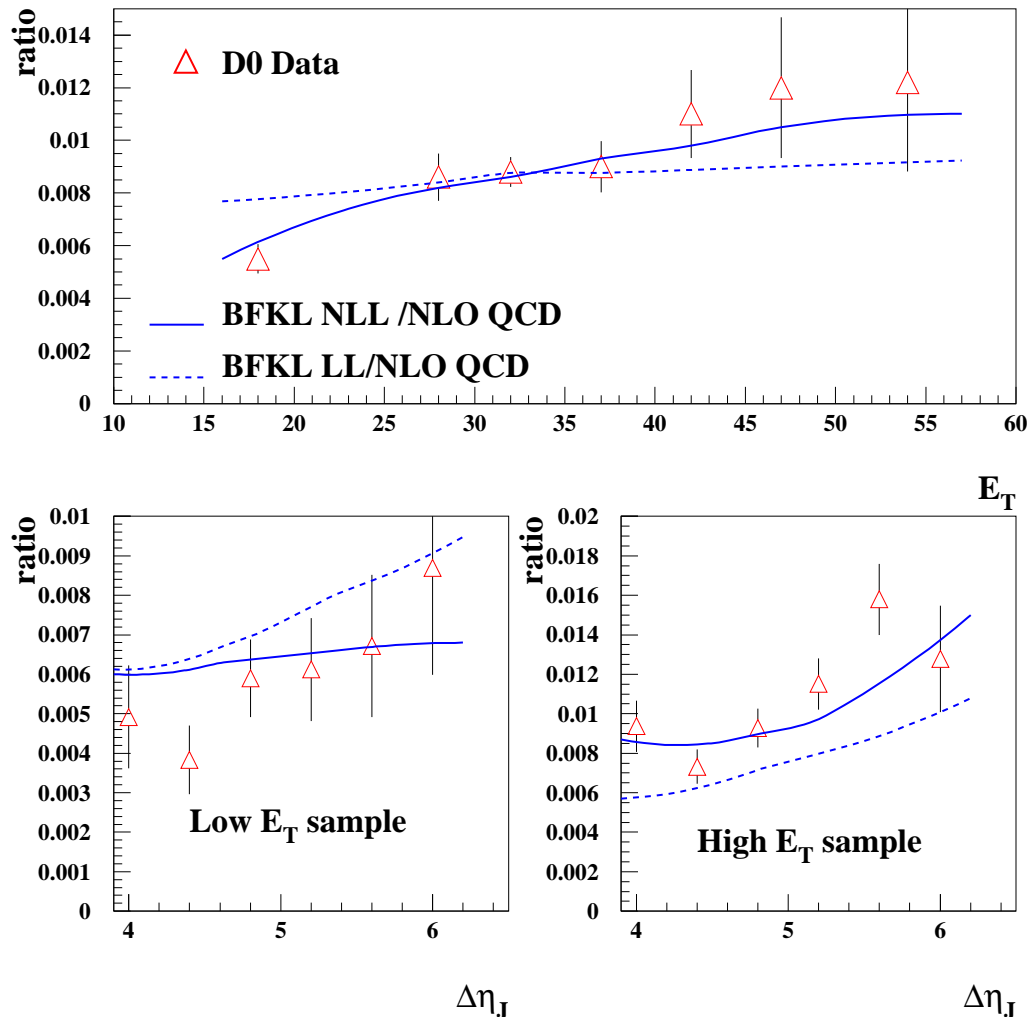
Predictions for the LHC

- Weak E_T dependence

- Large differences in normalisation between BFKL LL and NLL predictions

Predictions for the LHC

- Weak $\Delta\eta$ dependence

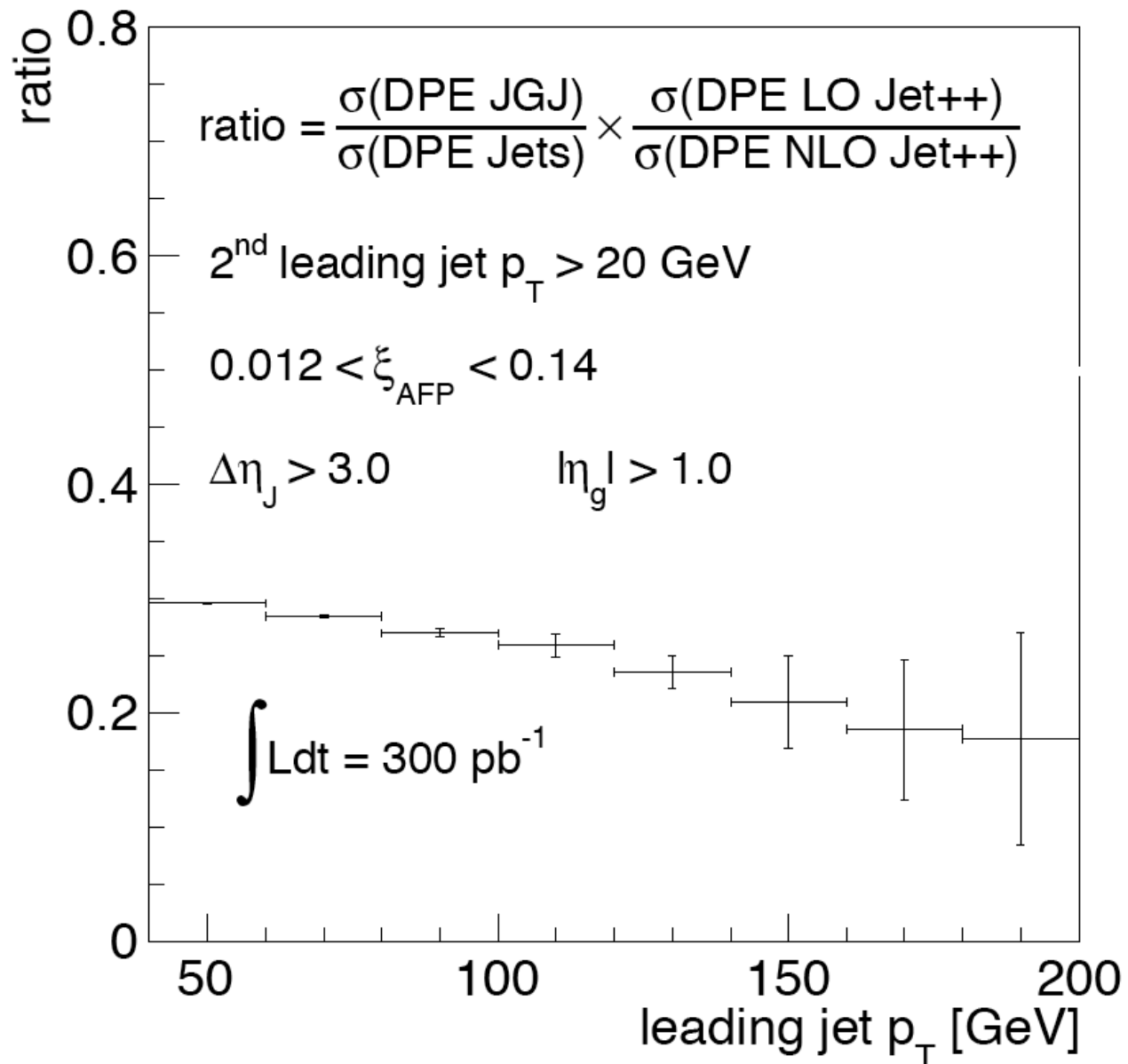- Large differences in normalisation between BFKL LL and NLL predictions

Jet gap jet events in diffraction

- Study BFKL dynamics using jet gap jet events

- Jet gap jet events in DPE processes: clean process, allows to go to larger $\Delta\eta$ between jets

- See: Gaps between jets in double-Pomeron-exchange processes at the LHC, C. Marquet, C. Royon, M. Trzebinski, R. Zlebcik, ArXiv:1212:2059, accepted by Phys. Rev. D
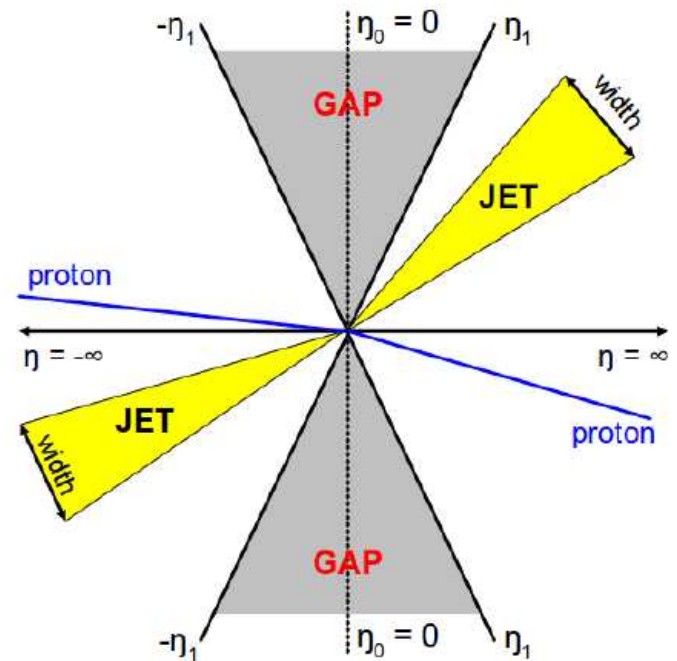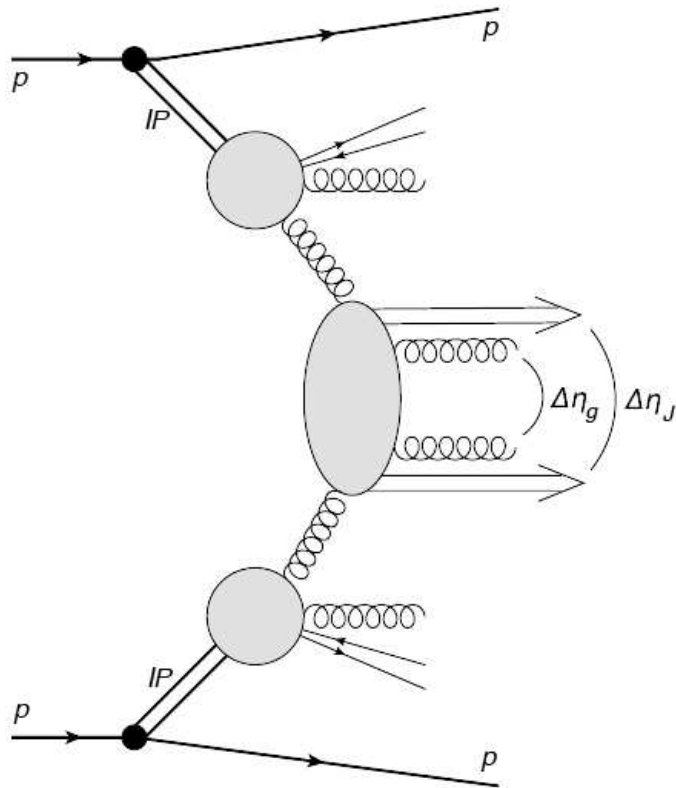
Jet gap jet events in diffraction

- Measure the ratio of the jet gap jet to the dijet cross sections: sensitivity to BFKL dynamics

- As an example, study as a function of leading jet p_T

Inside the plot:

$$\text{ratio} = \frac{\sigma(\text{DPE JGJ})}{\sigma(\text{DPE Jets})} \times \frac{\sigma(\text{DPE LO Jet++})}{\sigma(\text{DPE NLO Jet++})}$$

2nd leading jet $p_T > 20$ GeV

$0.012 < \xi_{AFP} < 0.14$

$\Delta\eta_J > 3.0$ $|\eta_g| > 1.0$

$\int L dt = 300 \text{ pb}^{-1}$

y-axis: ratio

x-axis: leading jet p_T [GeV]

Conclusion

- ATLAS measurement of jet veto cross section: good description of data using resummation of gluon emission at large angles (traditional QCD or BFKL formalism fail to describe data)

- Full implementation of BFKL NLL kernel for many jet proceeses at HERA, Tevatron and LHC

- Jet gap jets events to look for BFKL resummation effects:
  - 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
  - Jet gap jet events in diffraction