Atlas results on diffraction

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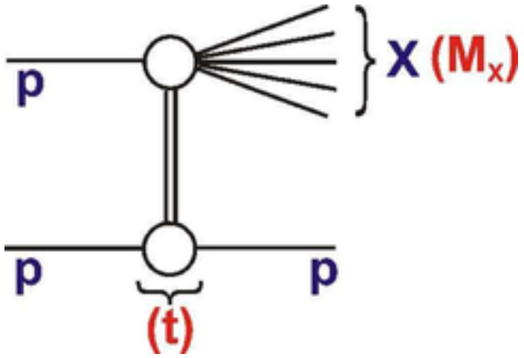
Rencontres du Viet Nam
14th Workshop on Elastic and Diffractive Scattering

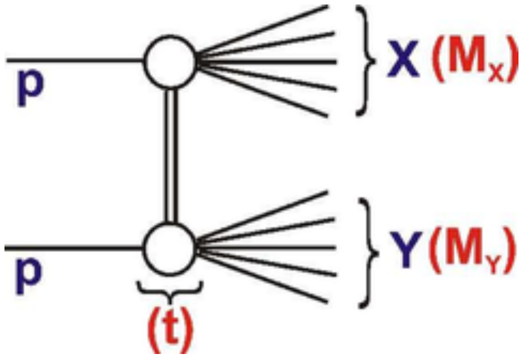
Qui Nhon, 16/12/2011

Introduction – diffraction

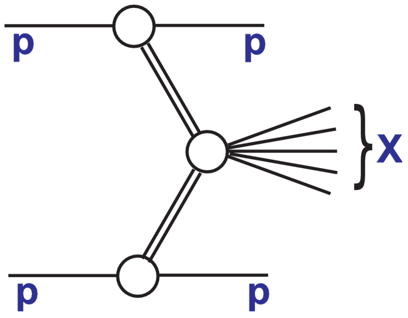
Substantial fraction (~30%) of total cross section of pp interactions is due to diffractive dissociation processes.



Single Diffraction (SD)



Double Diffraction (DD)



Central Diffraction (CD)
~1/10 of the SD

Kinematic variables:

- t, the 4-momentum exchanged at the proton vertex,
- the mass of diffractive system, M_X, M_Y, or $\xi \equiv M_X^2/s$

There is no unique definition of diffraction

Bjorken: events with large rapidity gap not exponentially suppressed

Theoretically:

1. Interactions where the beam particles emerge intact or dissociated into low-mass states
2. in a wider viewpoint, interactions mediated by t-channel exchange of object with the quantum numbers of the vacuum, color singlet exchange or Pomeron

Description based on phenomenological approach or on QCD

In general such processes lead to final state particles separated by large rapidity gaps; ie. in SD $\Delta\eta \sim -\ln \xi_X$, where $\xi \equiv M_X^2/s$

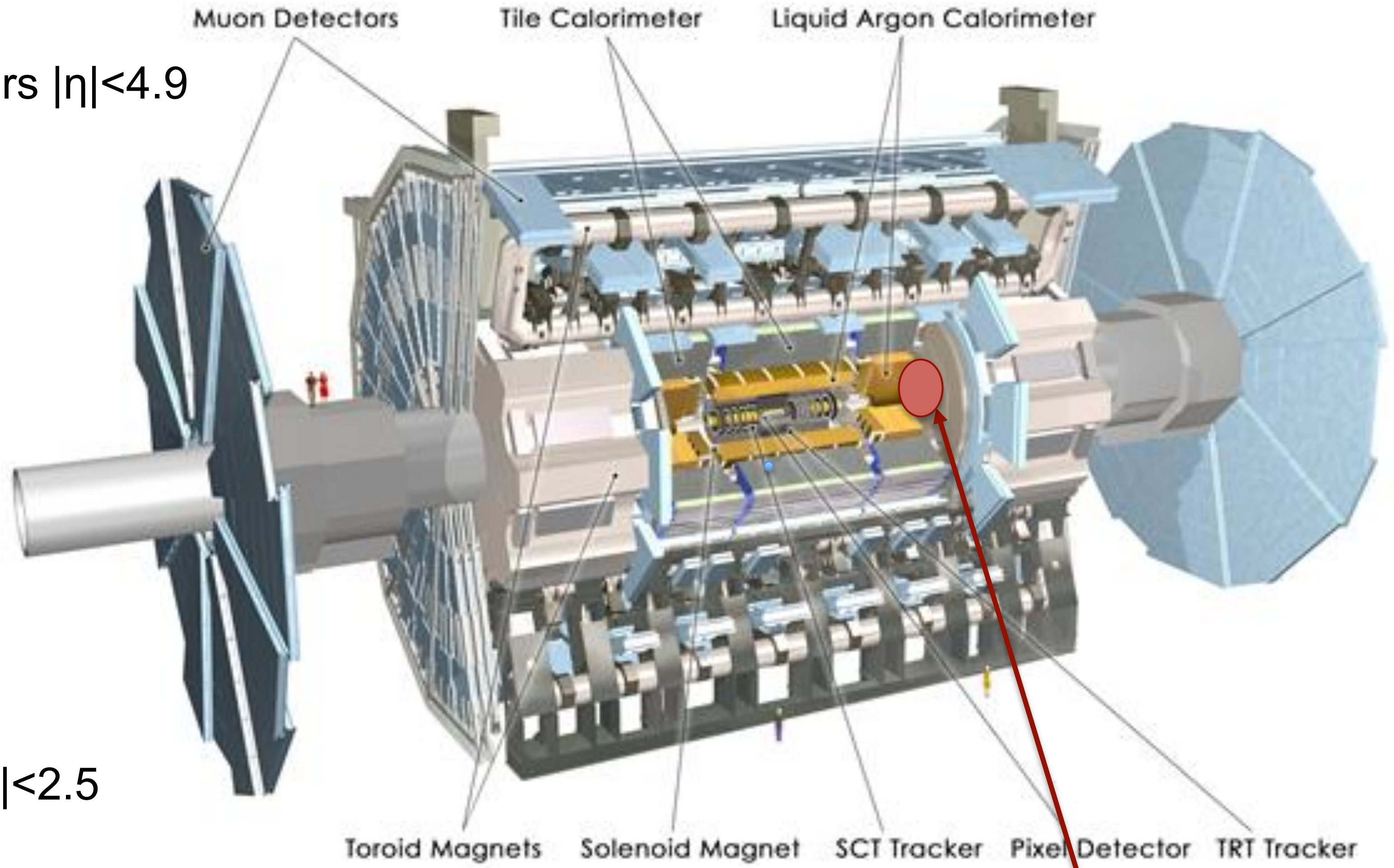
However only a fraction of large rapidity gap is due to diffractive events, gaps can arise from fluctuations in the hadronisation process

Experimentally: ATLAS central detector sensitive to high mass diffraction; low-mass diffractive dissociation not immediately observable

ATLAS: $|\eta| < 4.9 \Rightarrow \xi_X > 10^{-5}$; $M_X > 7$ GeV for $\sqrt{s}=7$TeV

Atlas detector

Calorimeters |η|<4.9

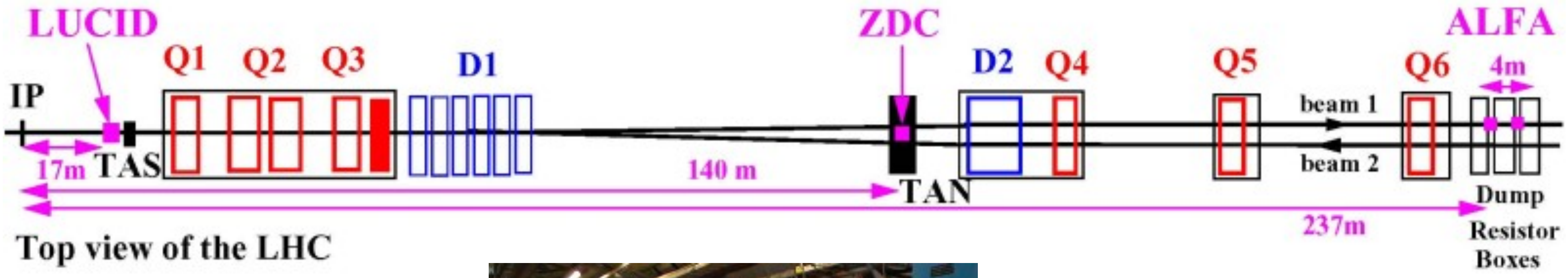


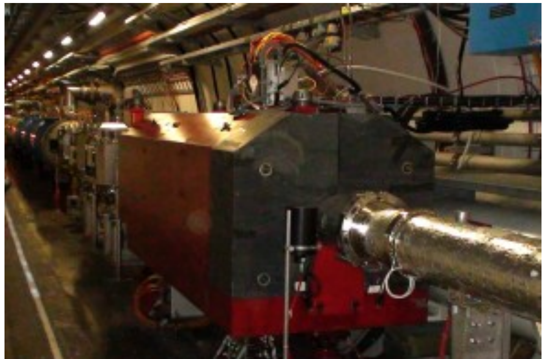
Trackers |η|<2.5

Forward detectors: luminosity monitor 5.6<|η|<6
Zero Degree Calorimeter |η|>8.3
ALFA roman pots 10.6<|η|<13.5

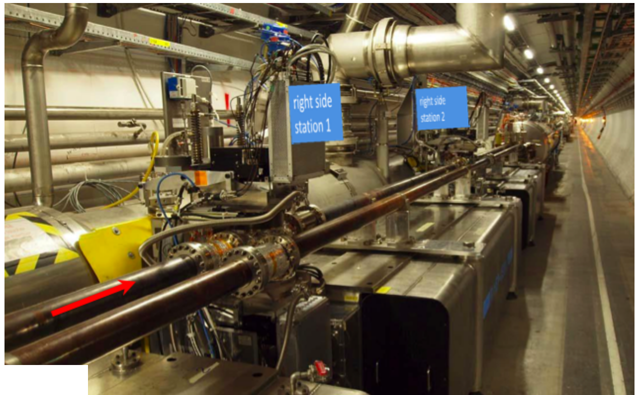
Minimum Bias
Trigger Scintillator
2.1< |η|<3.8

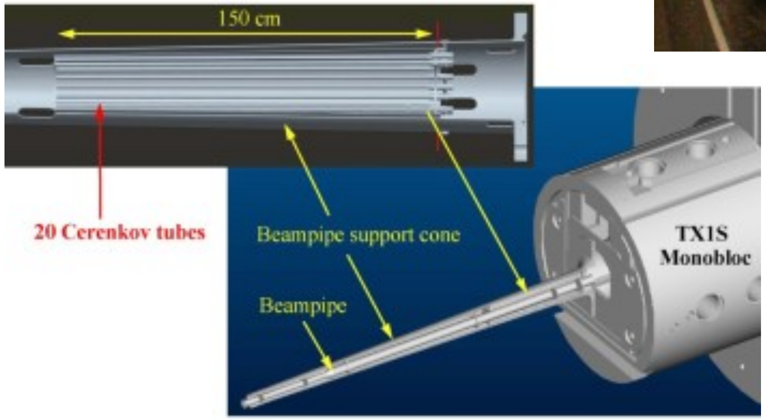
ATLAS forward detectors



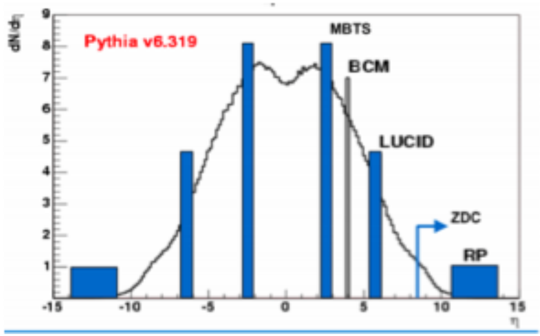


Zero Degree Calorimeter
|η|>8.3





LUCID Cherenkov tubes 5.6<|η|<6



ALFA roman pots
10.6<|η|<13.5

Measurement of the inelastic pp cross-section at $\sqrt{s}=7$ Tev with the ATLAS Detector

Nature Comm. 2 (2011), April 2011

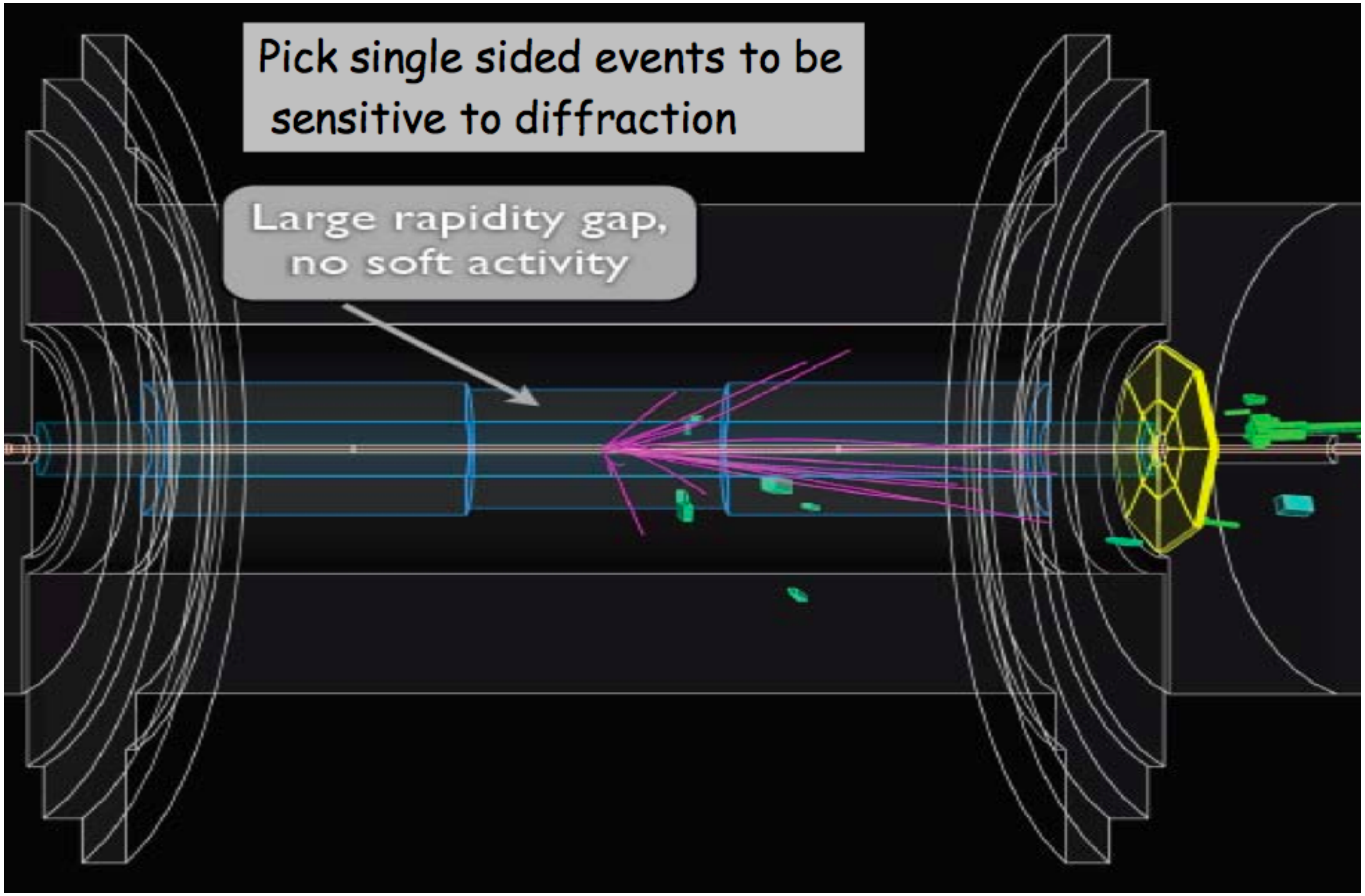
20 μb^{-1}, single fill in March 2010,

trigger by minimum bias trigger scintillator detectors,

with acceptance for $\xi \sim 10^{-6}$, $M_X>15.7$ GeV.

Analysis extrapolated also at $M_X>Mp$

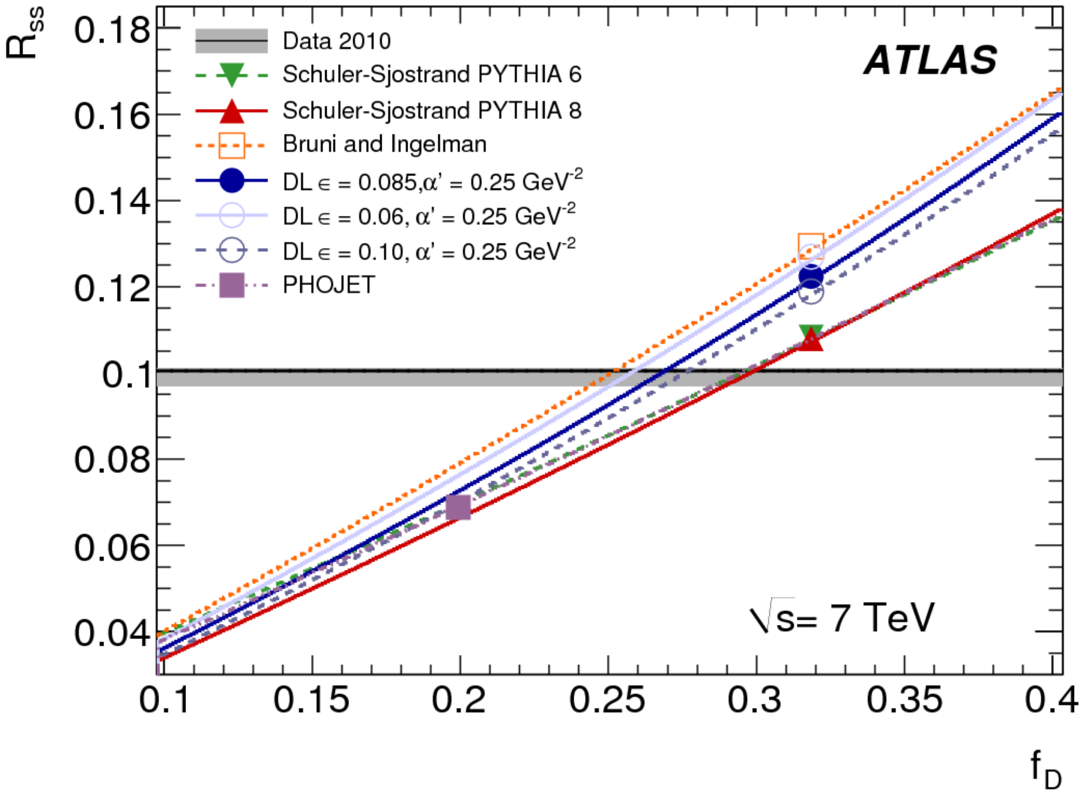
Fraction of diffractive events constrained by the ratio of single sided to inclusive events


Pick single sided events to be sensitive to diffraction

Large rapidity gap, no soft activity

minimum bias
trigger scintillator
$2.1< |\eta|<3.8$
$\xi \sim 10^{-6}$,
$M_X>15.7$ GeV

Fraction of diffractive events in inclusive cross section



The ratio of the single-sided to inclusive event sample R_{ss} as a function of the fractional contribution of diffractive events to the inelastic cross-section f_D.

MC models based on Regge phenomenology, cross section expressed as 3 IP exchange amplitude

$d\sigma/d\xi \sim 1/\xi^{1+\varepsilon}$, $\varepsilon = \alpha_{IP} - 1$

R_{SS} =10.0±0.4% ➔ f_D~25-30% depending on the models

See talk by Marcello Bindi: "*Measurement of the Inelastic proton-proton Cross Section at √s = 7 TeV* "

Rapidity gap cross-section in pp interactions at $\sqrt{s}=7$ TeV

ATLAS-CONF-2011-059 (April 2011)

Updated plots are presented

7.1 pb^{-1}, taken in March 2010, 2 bunches per beam

Idea is to select events with a large rapidity gap and to compare with models based on Regge phenomenology

Forward rapidity gap cross section

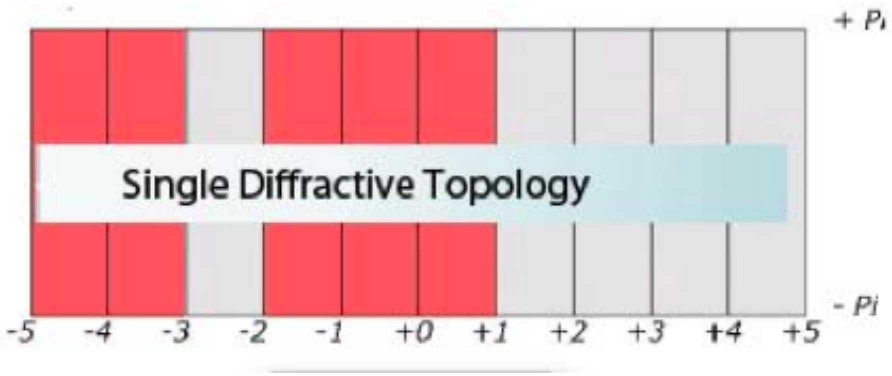
Sample is a sum of ND, SD and DD

Rapidity gap definition at detector level

- Detector divided into η-rings of size 0.1 between -4.9<η<4.9
- Ring is empty if there is

- No track with p_T>200 MeV (for |η|<2.5)

- No calorimeter cell with E above noise level



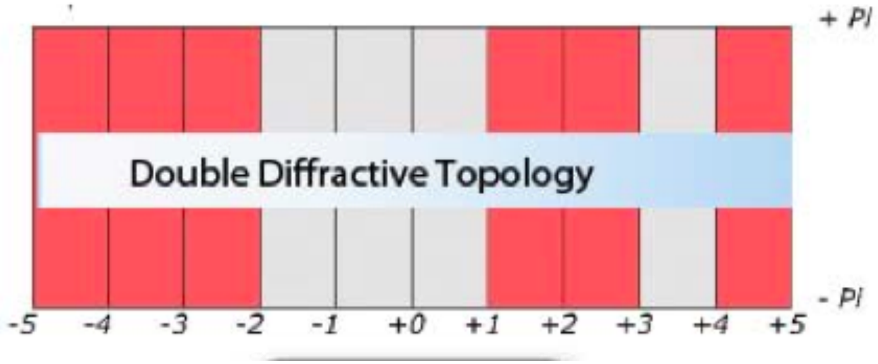
$\Delta\eta_F$=4

Data corrected back to hadron level

Hadron level gap definition

Phase space divided in the same η-rings

Ring empty if there is no stable particle with p_T>200 MeV for |η|<4.9

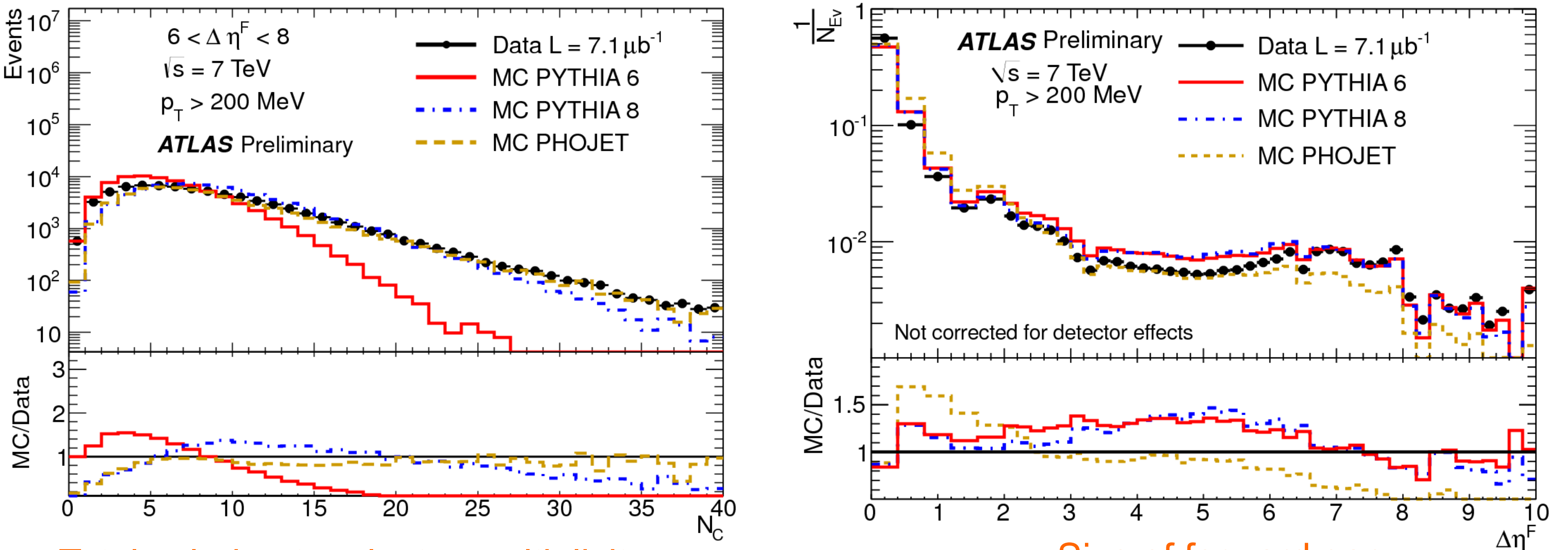


$\Delta\eta_F$=0

Forward gap $\Delta\eta_F$: largest consecutive set of empty rings starting from the edge of the acceptance (η = + - 4.9)

Cross section measured as a function of the <u>largest forward rapidity gap</u>

Forward rapidity gaps – data vs MC, control plots



Total calorimeter cluster multiplicity

Size of forward gap

Fraction of SD and DD in MC adjusted according CDF data

Pythia 8 and Phojet contain a hard scattering for IP-p interactions

No MC models gives a perfect description over the full $\Delta\eta^F$, but description is reasonable

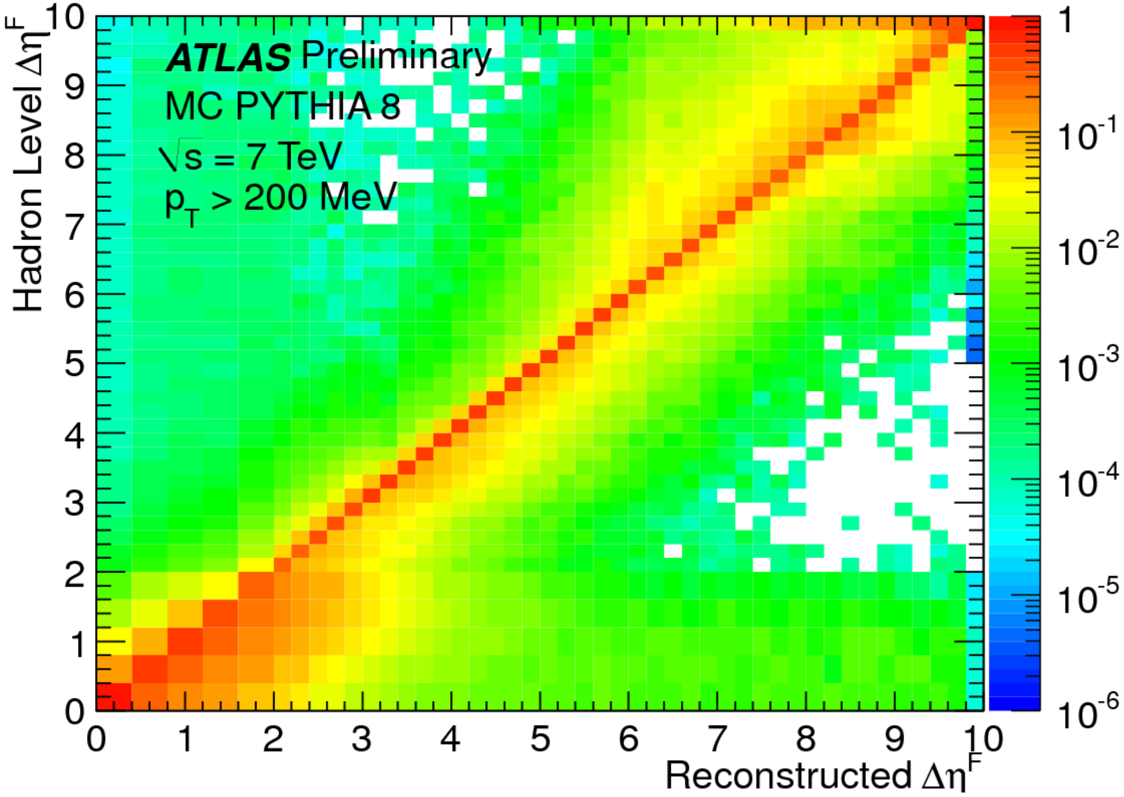
Forward rapidity gap cross section – MC corrections

Pythia 8 used to correct the data back to hadron level (stable final state particles)

MC migration matrix,

~ diagonal for this p_T cut

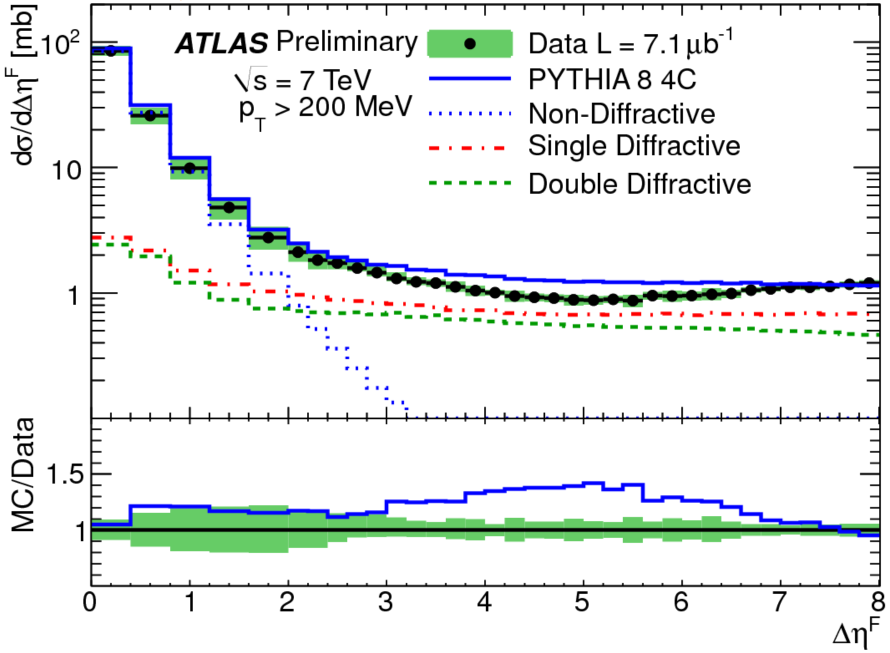
Largest migration in the region dominated by ND events



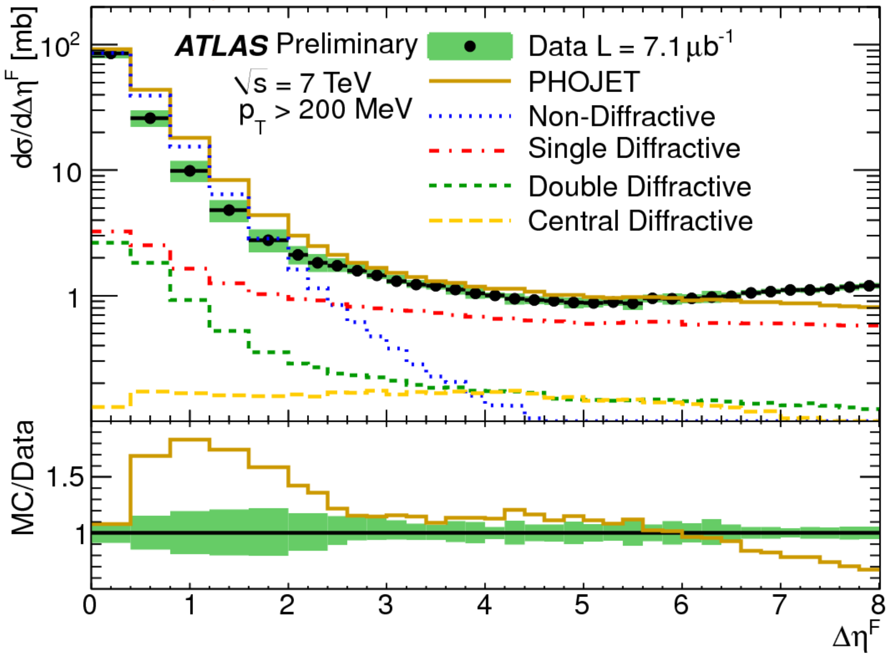
Largest systematic uncertainties from unfolding and calorimeter energy scale, typically is approximately 20%

Cross section vs forward rapidity gaps compared to MC with default settings

Pythia



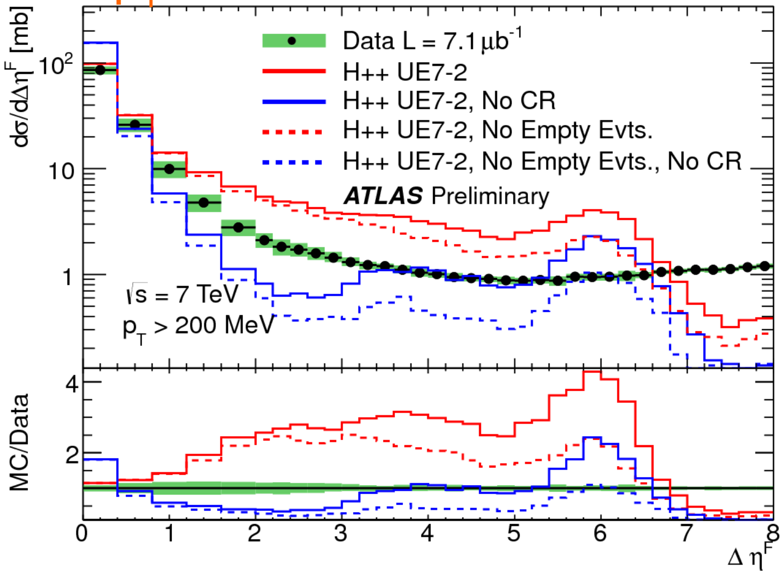
Phojet



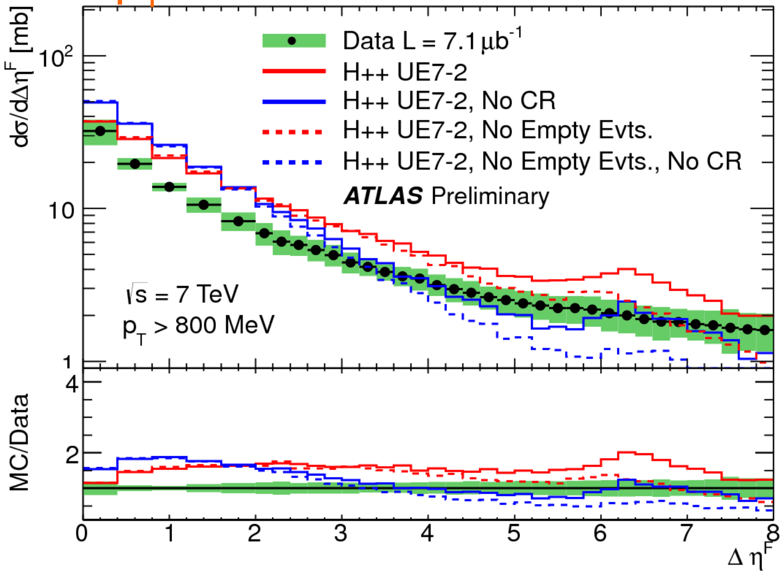
At small $\Delta\eta^F$, gaps dominated by the hadronisation fluctuations of ND events, differences in MC show that there are large uncertainties in the probability of obtaining large hadronisation fluctuations

Uncertainty in the hadronisation fluctuations investigated for different models and p_T cut

p_T>200 MeV



p_T>800 MeV



Herwig++ minimum bias does not contains an explicit diffractive components, but produces a sizeable fraction of events with large gaps

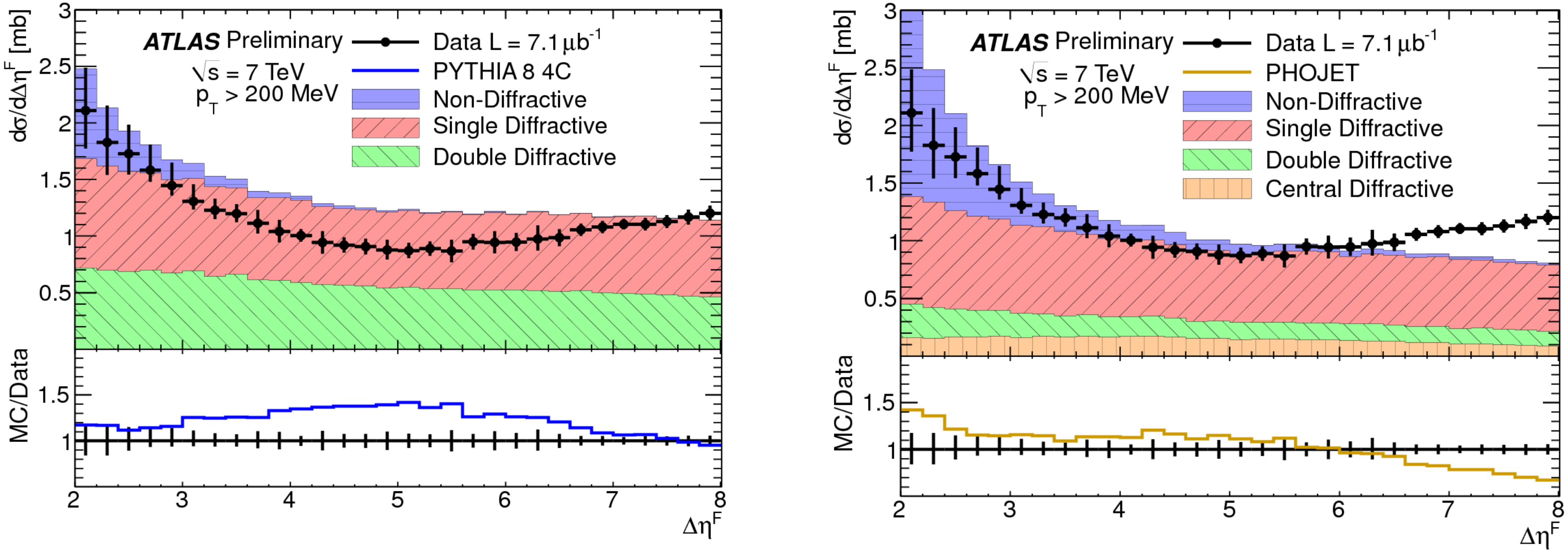
H++ with different models of Underlying Events, turning off the colour reconnection (no CR), excluding soft events (no Empty)

H++ fails to describe the ND decrease vs the gap size

Cross section vs forward rapidity gaps for $\Delta\eta^F > 2$

Pythia

Phojet

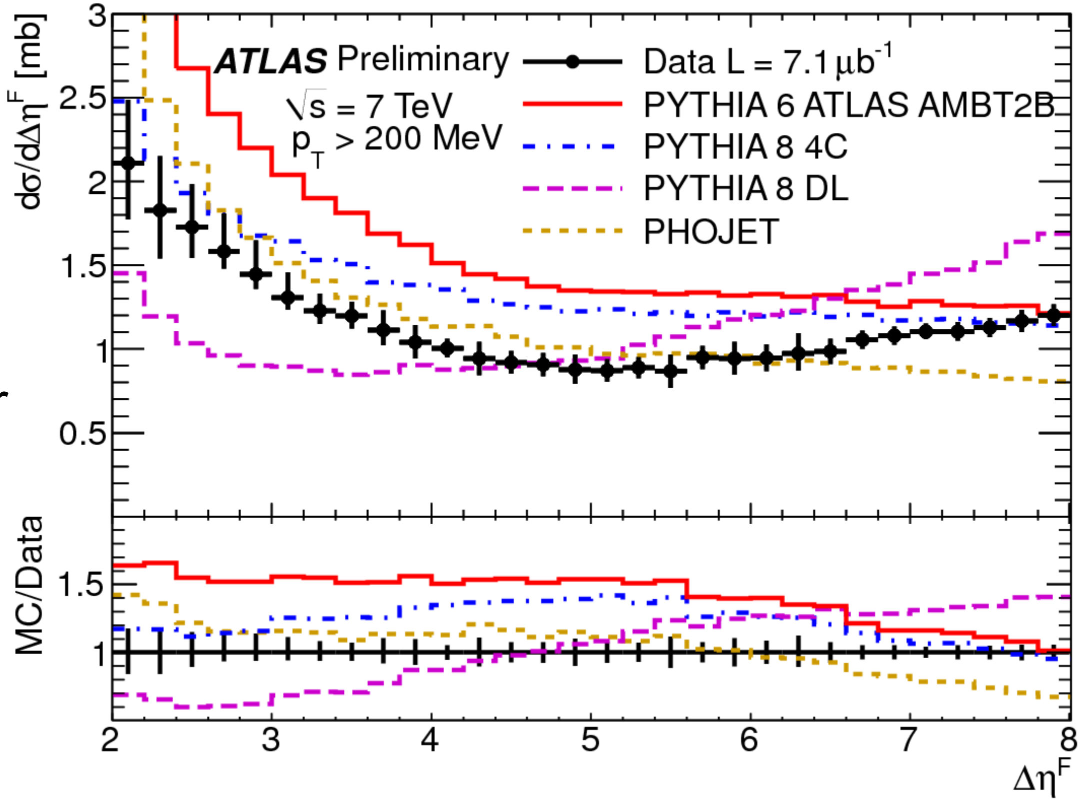


PYTHIA 8 overshoots the data, probably due to an overestimation of DD (ie. Pythia compared to Tevatron data for DD)

PHOJET has a CD contribution and a much smalled DD contribution with respect to Pythia. It overestimate of the total inelastic cross section

Cross section vs forward rapidity gaps for $\Delta\eta^F > 2$ and diffractive dynamics

ND events decrease with $\Delta\eta^F$ and are supposed to be negligible for $\Delta\eta^F > 3$



Increase at large $\Delta\eta^F$ due to $\alpha_{IP}(0) > 1$

DL $\alpha_{IP}(0)=1.085$

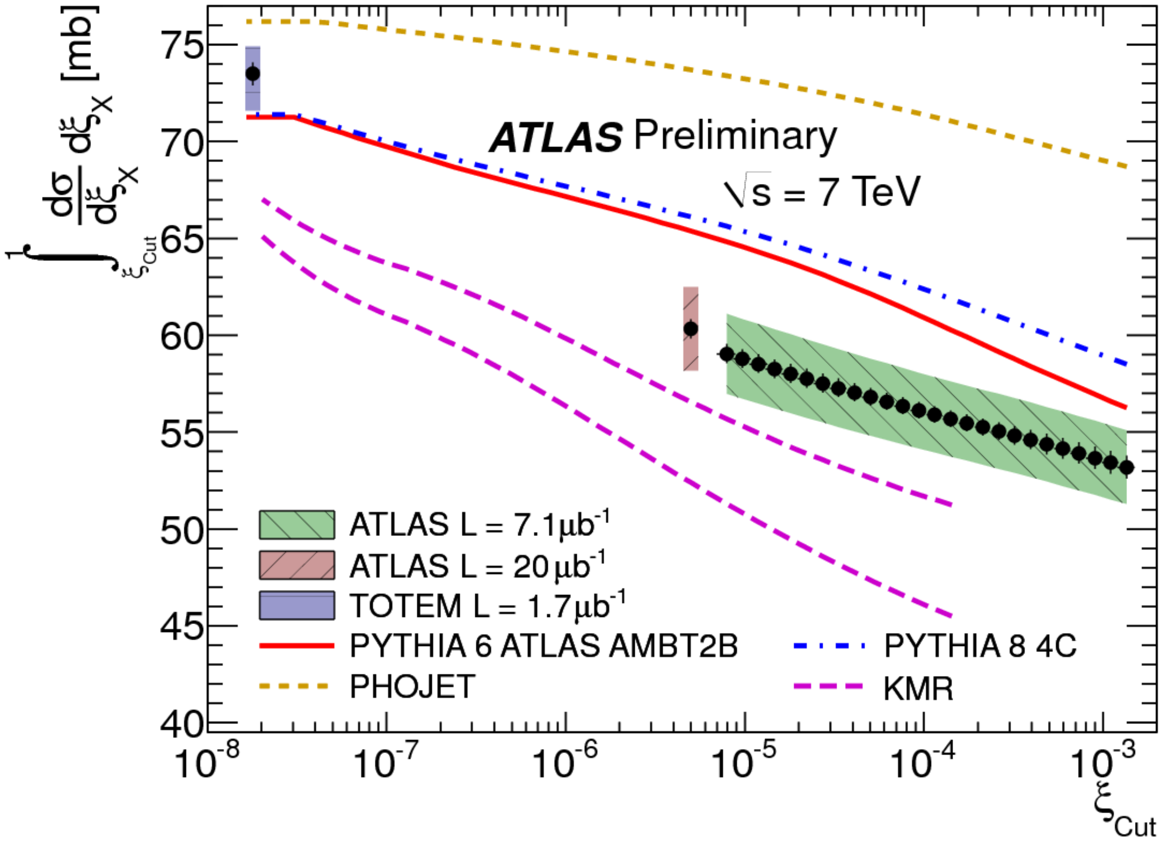
At large $\Delta\eta^F$ a plateau, flatness indicates a Pomeron intercept close to 1

No MC reproduces the rise of cross section at large $\Delta\eta^F$

Cross-section of ~1mb per unit rapidity predicted ie. by KMR, arXiv:1102.2844

Inelastic cross section integrated for $\xi>\xi_{cut}$ as a function of ξ_{cut}

These data contains a large fraction of inelastic pp cross section, they can be compared to previous measurements for inclusive cross sections



ATLAS and TOTEM data compared to predictions

Khoze Martin Ryskyn model reproduce the enhancement at low ξ, assuming a IPIPIR term and not just the IPIPIP term

Dijet production with a central jet veto in pp collisions at $\sqrt{s}=7$ TeV

JHEP 09 (2011) 053

37 pb^{-1}, full 2010 dataset

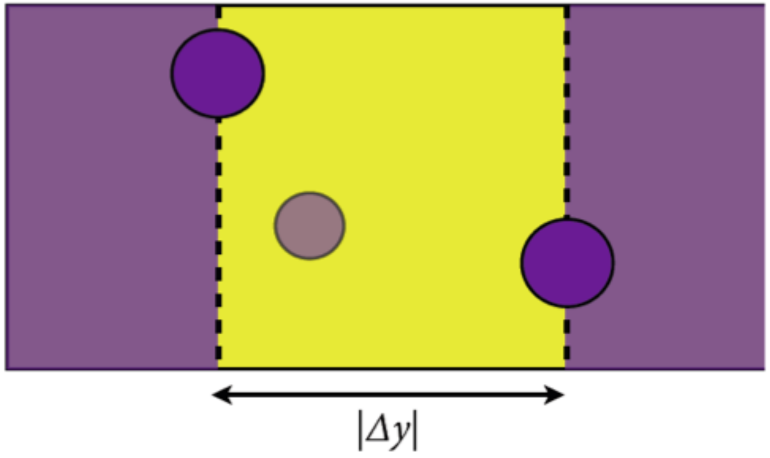
Idea is to compare events with dijet and a central jet veto against models based on NLO QCD to investigate

QCD dynamics

Dijet production with a central jet veto

Jet reconstruction

Jets are identified using the anti-kt algorithm, with p_T>20 GeV and |y|<4.4 (good region for energy scale)



Dijet system (boundary jets) defined in 2 ways:

1) the most forward and most backward jets
2) the two highest p_T jets

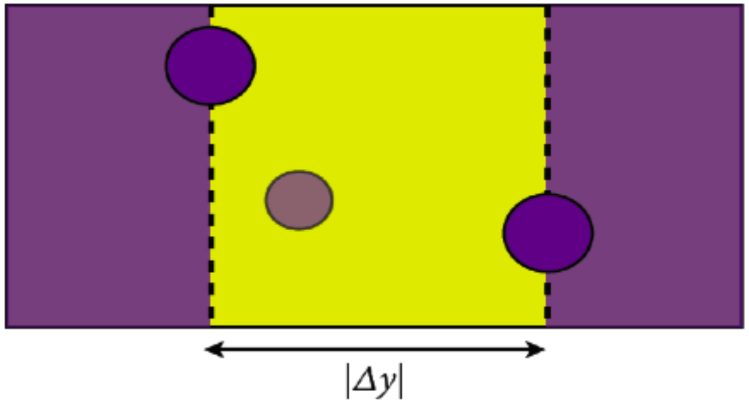
Dijets required to have average $\underline{p_T} > 50$ GeV

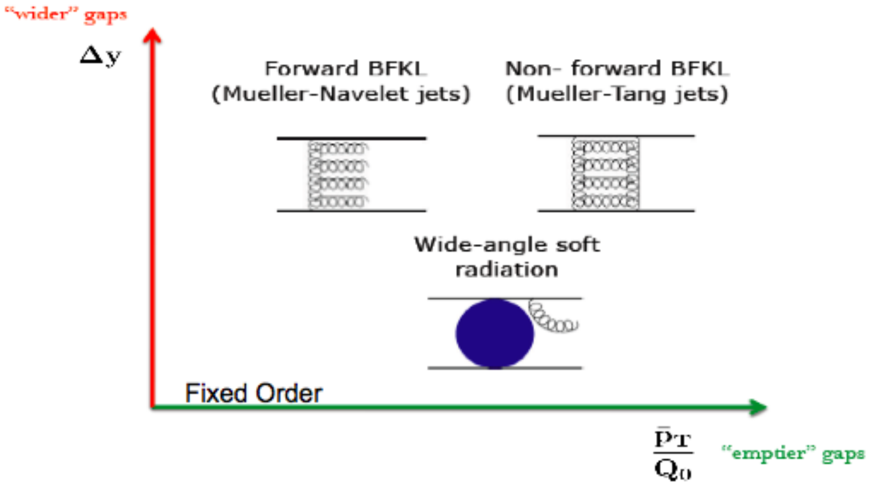
Main observables: fraction of gap events

Gap events are the subset of events that do not contain an additional jet with p_T above the veto scale Q_0 in the rapidity interval between the boundary jets

Data corrected back to hadron level = final state particles

Dijet production with a central jet veto – check QCD dynamics





Select dijet events and check for events that do not contain an additional jet above a veto scale (Q_0) in the rapidity region bounded by the dijet system.

Idea is select kinematic region where the phase space allows higher order

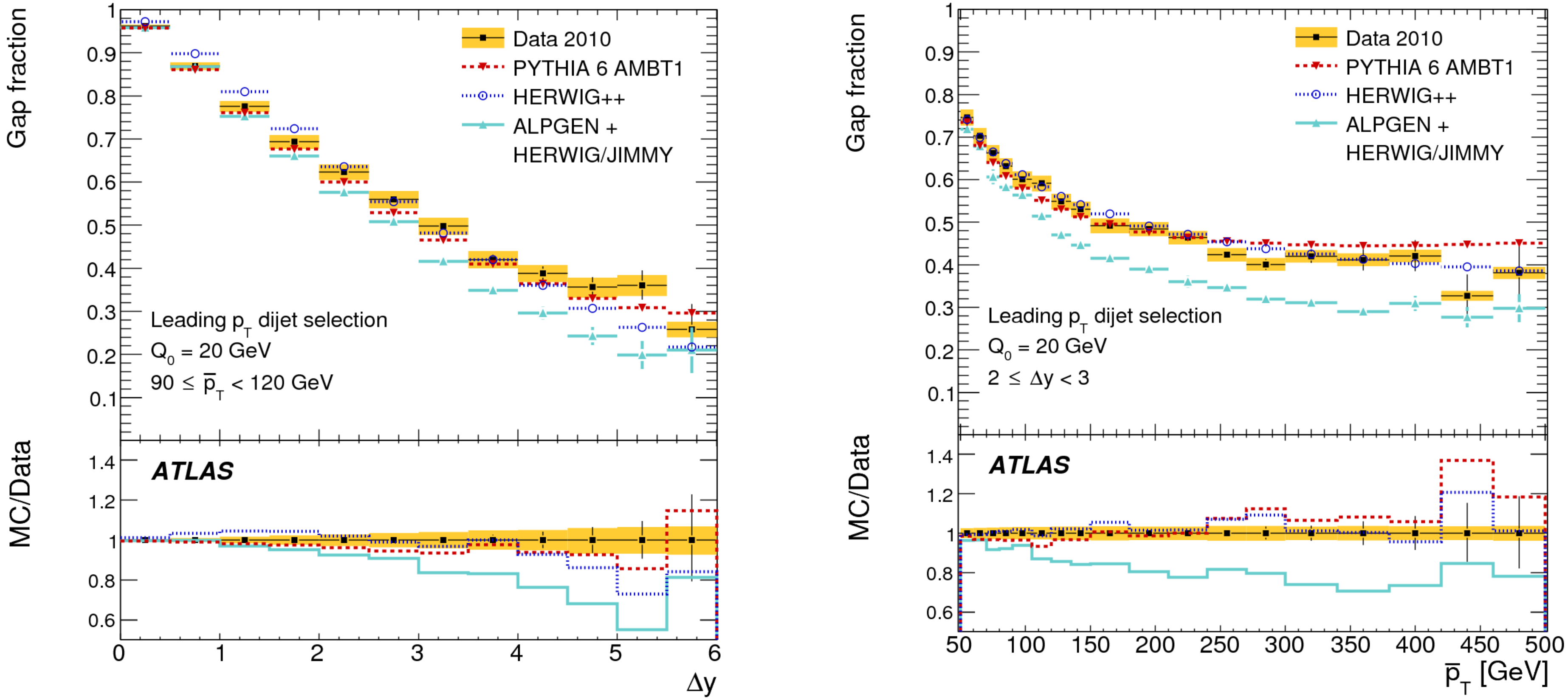
Expect that fixed order calculations will do well when there is no hierarchy of scales.

All order resummation necessary when:

- the boundary jet rapidity separation (Δy) is large => sensitive to BFKL dynamics
- or the average transverse momentum of the boundary jets is much larger than Q_0

=> wide angle soft gluon radiation

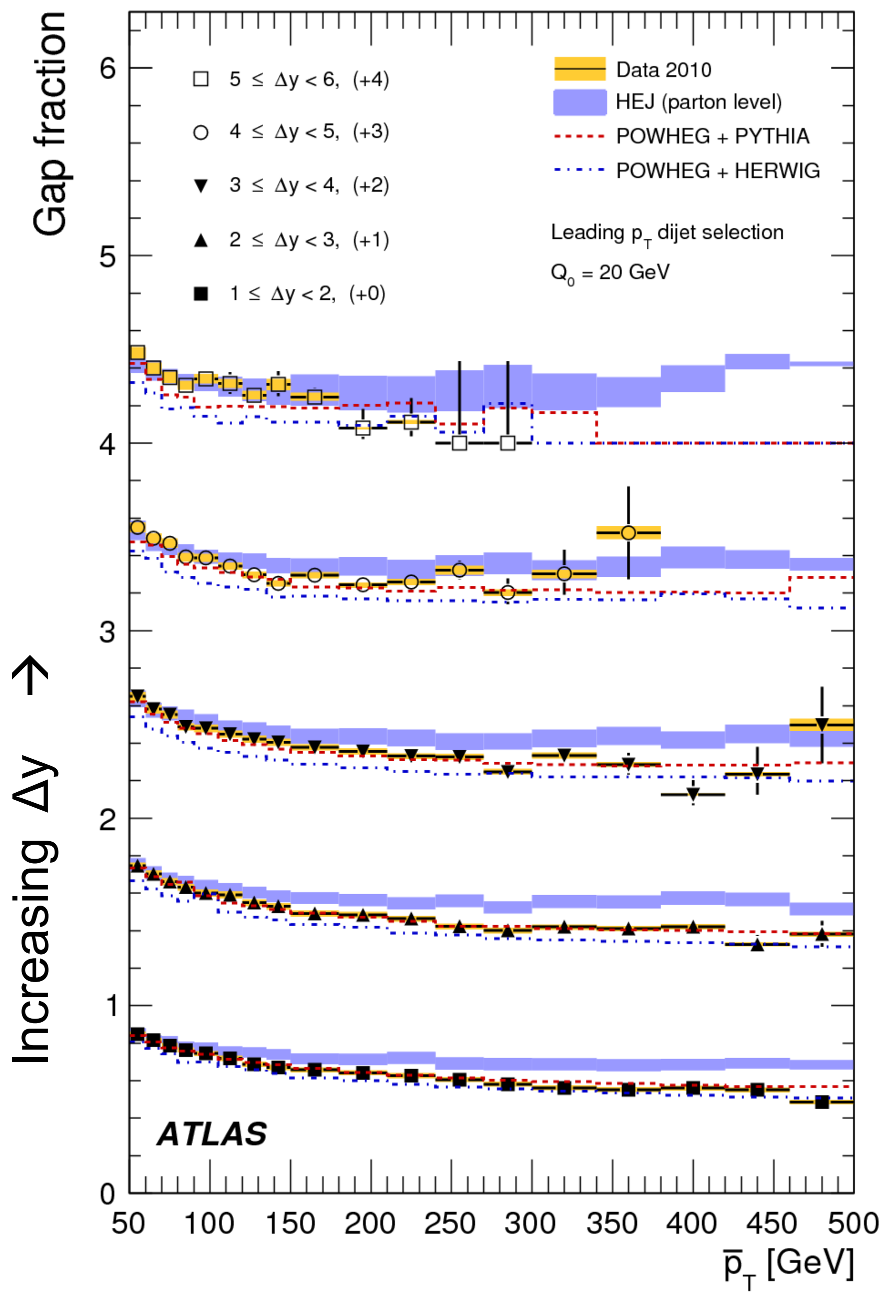
Dijet production - fraction of events without an additional jet of energy >Q_0(20 GeV)



Sizeable gap fraction also for large rapidity interval between the two leading jets

Data compared to LO MC: spread between MC indicative of need of higher order corrections

Dijet production with a central jet veto, data vs theory



Dijet defined as the 2 leading-p_T jets

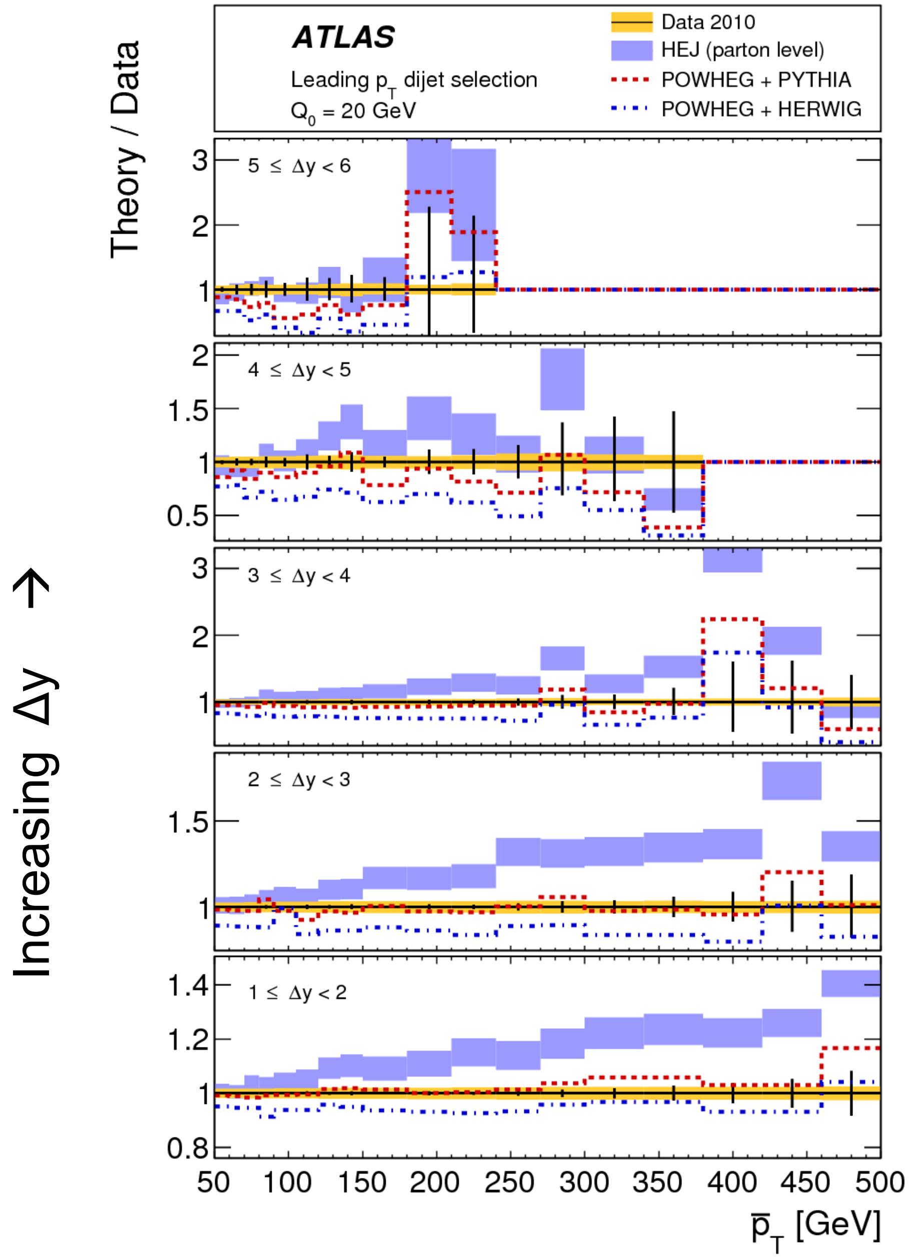
Gap fraction as a function of p_T =>
test the wide angle soft radiation

Powheg-box provides a full NLO dijet calculation, interfaced to Pythia and Herwig for parton emission

HEJ (High Energy Jets) is a parton level generator, provides all order description for wide-angle emissions (of similar p_T).
Expected to mimic BFKL for large Δy

HEJ describes data well as Δy increases, but not as p_T/Q_0 increases=> HEJ missing higher order QCD effects, provided by a traditional parton shower approach

Dijet production with a central jet veto, data vs theory



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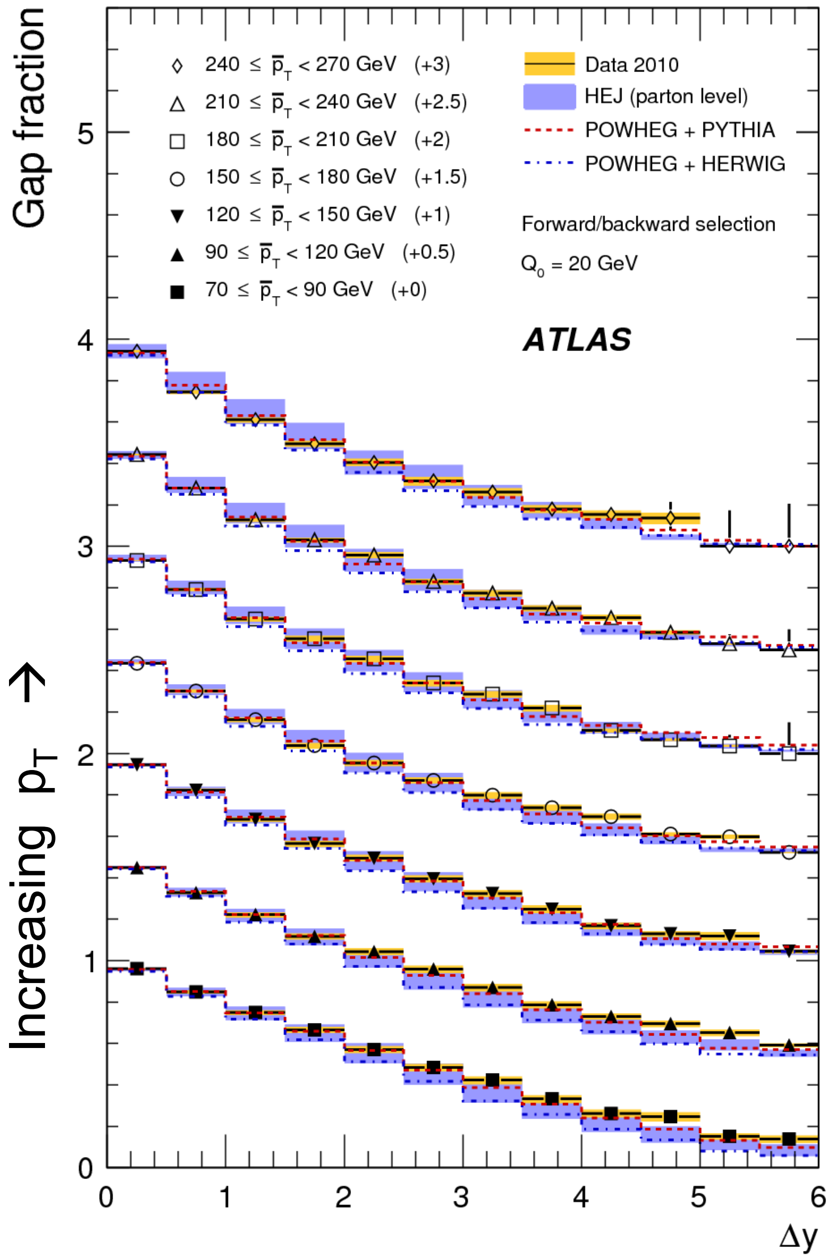
Dijet production with a central jet veto – gap fraction



Dijet defined by the most forward and most backward jet in the event

Gap fraction as a function of Δy=> test BFKL dynamics

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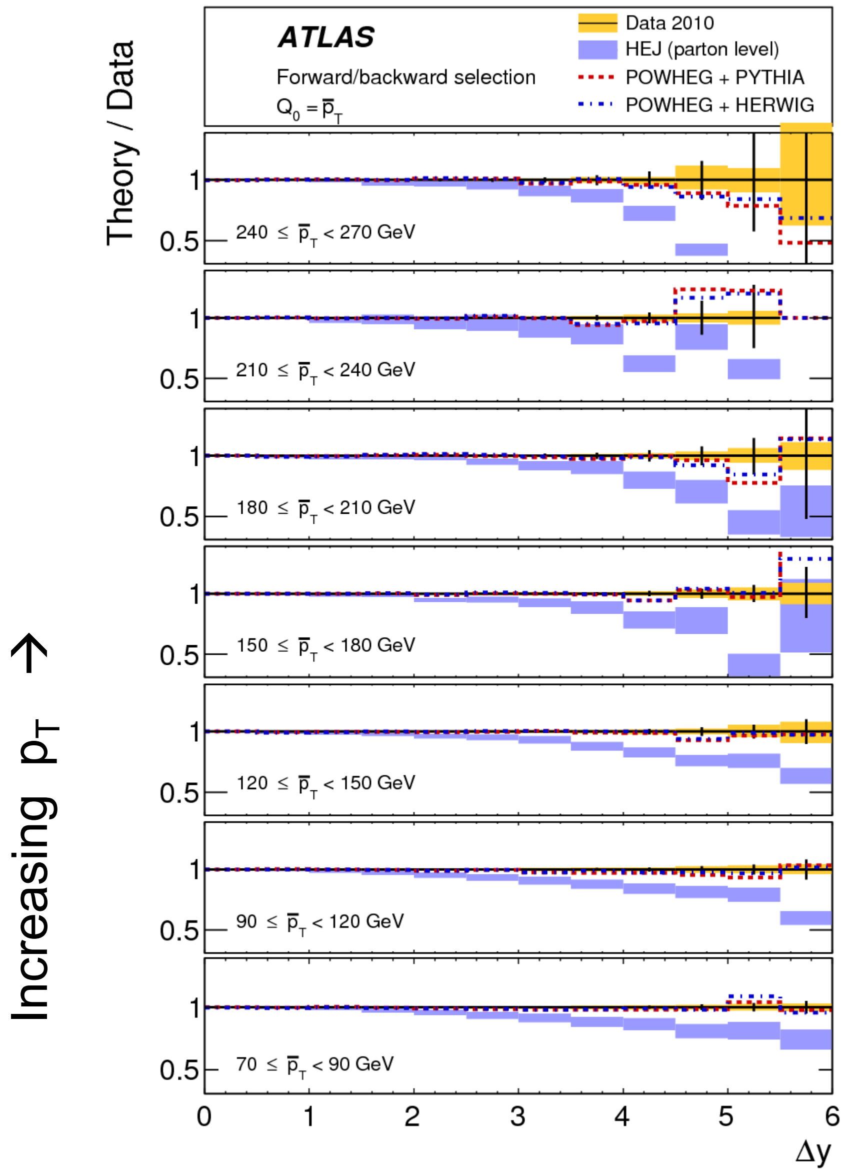
Dijet production with a central jet veto – gap fraction



Dijet defined by the most forward and most backward jet in the event.
Gap fraction as a function of Δy=>
Test BFKL dynamics

Increasing veto scale Q_0

Powheg-box is a full NLO dijet calculation, interfaced to Pythia and Herwig for parton emission

- POWHEG improving al larger veto scale

HEJ (High Energy Jets) is a parton level generator, provides all order description for wide-angle emissions (of similar p_T).

- Expected to mimic BFKL for large Δy
- Predictions low as Δy increases

Dijet production with a central jet veto – gap fraction

Data compared to POWHEG predictions

- NLO-plus-parton shower (for soft and collinear resummation)
- POWHEG describes data well as p_T/Q_0 increases, but not as Δy increases,
- => higher order QCD effects are relevant as Δy increases

HEJ (High Energy Jets) predictions

- All order predictions for wide-angle emissions (of similar p_T)
- HEJ describes data well as Δy increases, but not as p_T/Q_0 increases
- => HEJ miss higher order QCD effects, i.e provided by a traditional parton shower approach

None of the predictions reproduce well this phase space region

=> data can be used to constrain QCD models.

summary

Soft -QCD

1) Inelastic cross-section measured for $\xi > 5.10^6$,and extrapolated to $\xi > m_p^2/s$

- Large modelling uncertainty in extrapolation, due to low-mass diffraction
- Rapidity gap studies gives a diffractive fraction $f_D = 30\%$

2) Cross-section measured as a function of the forward rapidity gap, for $\Delta\eta_F$ up to 7 (measured from calorimeter edge)

- Data compared with models based on 3 IP exchange, allowing to validate MC
- Data sensitive to diffractive dynamics
- Diffractive cross section $d\sigma/\Delta\eta_F \sim 1.0 \pm 0.2$ mb per unit of $\Delta\eta_F$ for $\Delta\eta_F > 3.5$

Perturbative-QCD

3) Dijet events with a central jet veto selected and compared to resummed/NLO QCD models

- All theory predictions breakdown, either at large Δy or at large p_T/Q_0

Backup slides

summary

Soft -QCD

1) Inelastic cross-section measured for $\xi>5.10^6$,and extrapolated to $\xi>m_p^2/s$

- Large modelling uncertainty in extrapolation, due to low-mass diffraction
- Rapidity gap studies gives a diffractive fraction f_D= 30.2 ± 0.3 (stat) ±3.8 (syst) %

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- Data compared with models based on 3 IP exchange, allowing to validate MC
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- Diffractive cross section $d\sigma/\Delta\eta_F \sim$ 1.0 ±0.2 mb per unit of $\Delta\eta_F$ for $\Delta\eta_F > 3.5$

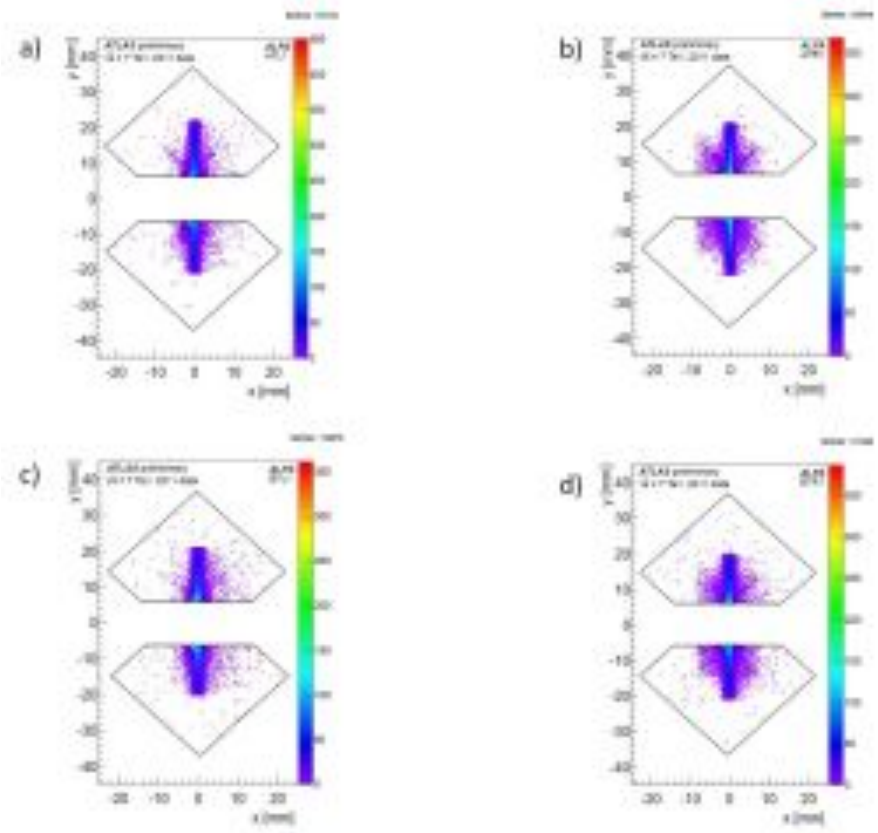
Perturbative-QCD

3) Dijet events with a central jet veto selected and compared to resummed/NLO QCD models

- All theory predictions breakdown, either at large Δy or at large p_T/Q_0

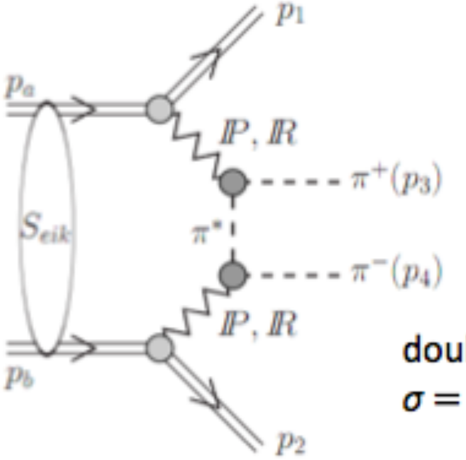
ALFA - Absolute Luminosity For ATLAS

- Designed to detect protons t ~3.7 10^{-4} GeV^2
- primary goal is to measure absolute luminosity and to reach the level of a precision 2-3%
- Single diffractive measurements are possible for $\xi < 0.01$
- and non-diffractive proton measurements for $0.01 < \xi < 0.1$

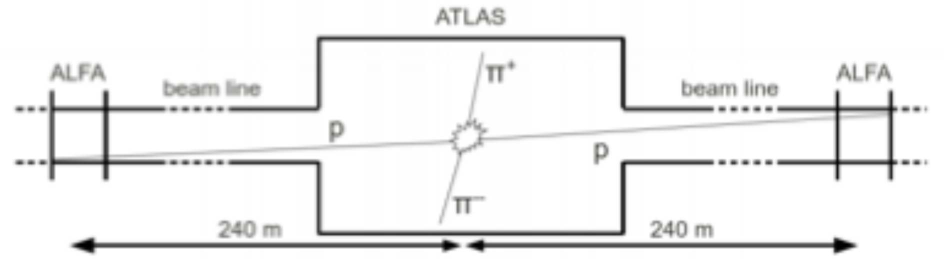


Dedicated high β*= 90m run (october 2011)
Track patterns of candidates of elastic scattering for a recent run in the LHC beam coordinate system with a preliminary alignment.

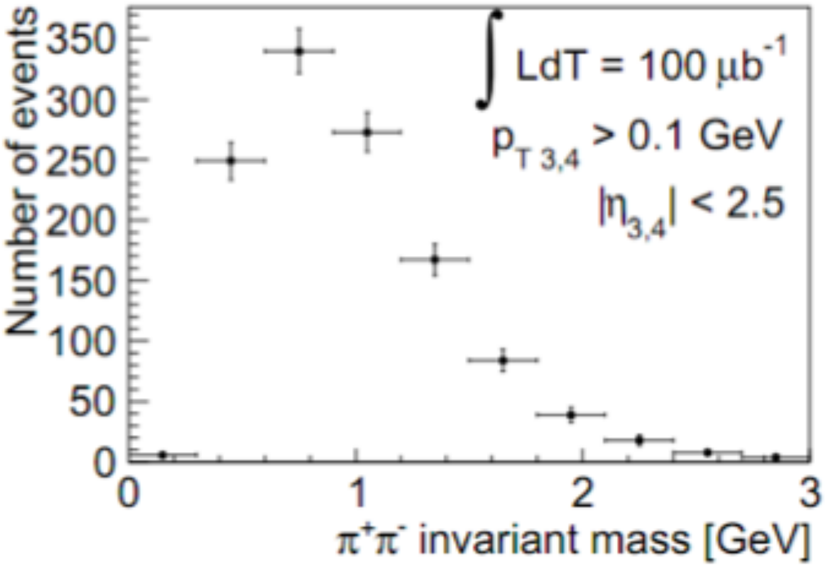
exclusive processes



double diffraction
$\sigma = 200\ \mu b$ for $\sqrt{s} = 7$ TeV



3 (4) ↔ $\pi^{+(-)}$



- measurement of *pp* → *pp* $\pi^+\pi^-$ possible, expect ~ 2000 events for $L = 10^{27}\ cm^{-2}s^{-1}$, 30 hours
- it requires ALFA elastic AND trigger + low-p_T tracking
- so far only measurements were performed at $\sqrt{s}$ = 62 & 63 GeV by ABCDHW Collaboration, ISR
- observed asymmetry in $\pi^+\pi^-$ may be a signal of odderon interaction

- other processes such as K^+K^- or p^+p^- can be studied
- with enough statistics, other exclusive processes involving $f_2(1270)$, glueballs, charmonia

Exclusive *pp* → *pp* $\pi^+\pi^-$ reaction: from the treshold to LHC
P. Lebiedowicz, A. Szczurek, Phys. Rev. **D81** (2010) 0360

R. Staszewski, P. Lebiedowicz, M. Trzebinski, J. Chwastowski and A. Szczurek, archiv:1104.3568

Luminosity in 2011

- Integrated luminosity
- Peak luminosity