Diffractive and exclusive production at HERA and LHC

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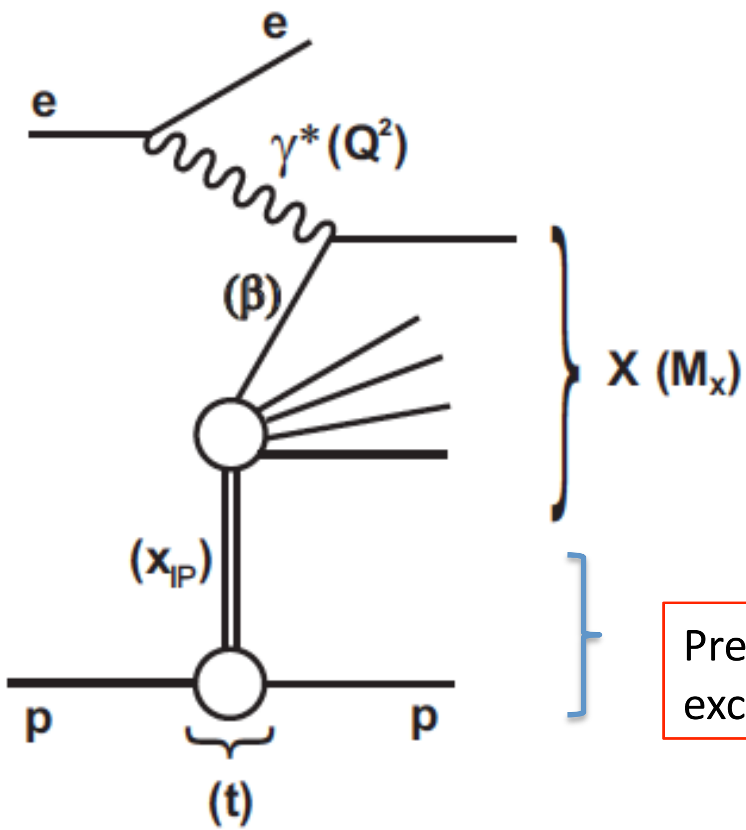
On behalf of HERA, CMS and ATLAS

- Combined HERA results with a leading proton
- Inelastic cross section at ATLAS and CMS
- Diffractive dijets and exclusive processes at CMS

(All results presented here based on recent published papers)

Introduction

Diffractive events observed and studied extensively at HERA in DIS. The exchanged photon probes the partonic structure of the colour-singlet object. It is part of the understanding of the proton structure at low $x_{Bjorken}$, through the so-called dPDFs, diffractive PDFs.



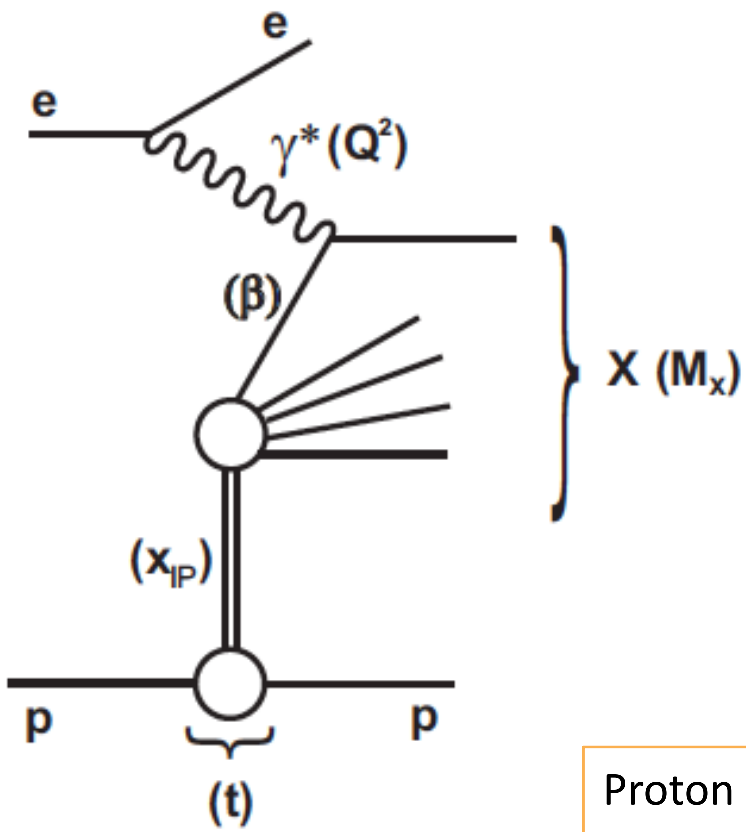
Diffractive events are selected at HERA via the requirement of a forward proton or a Large Rapidity Gap (LRG) or a small M_X above the exponentially suppressed tail .

Presence of a gap due to the exchange of a colourless object

Diffractive PDFs at HERA

Diffractive cross section:

$$\frac{d\sigma^{ep\rightarrow eXp}}{d\beta dQ^2 dx_{I\!P} dt} = \frac{4\pi\alpha^2}{\beta Q^4}\left[1 - y + \frac{y^2}{2}\right]\sigma_r^{D(4)}(\beta, Q^2, x_{I\!P}, t)$$

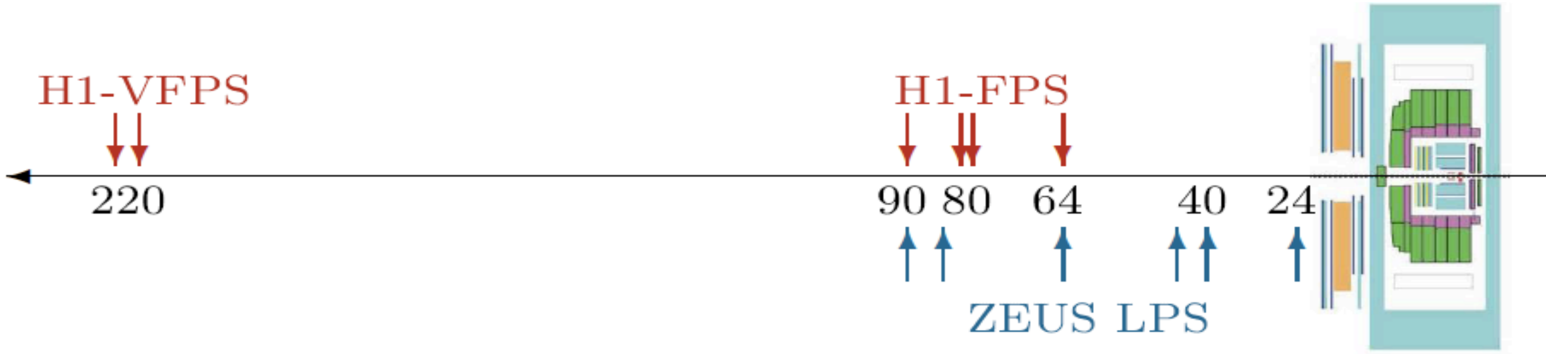


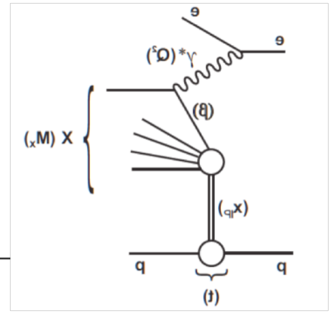
Q^2 - virtuality of the photon
β - analogous to $x_{Bjorken}$ for the parton in coulourless object
x_{IP} – fraction of proton momentum carried by the colourless object
t - 4-momentum transfer at the proton vertex

Proton can stay intact or dissociate into a low mass system, considered here as a background

Selection of diffraction

The events are selected here requiring a leading proton in the Proton Spectrometer stations close to the beam lines in H1 (FPS,VFPS) and ZEUS (LPS)





H1 FPS HERA I+HERA II and ZEUS LPS HERA I data used, mainly at √s=318 GeV, Q^2~2-700 GeV^2

Advantages: very clear signature, basically no proton dissociation background, can measure t

Disadvantages: very low acceptance (low statistics) and large systematics due to the calculation of the proton tagging efficiency.

Combination of FPS-LPS results

EPJC 72 (2012) 2175

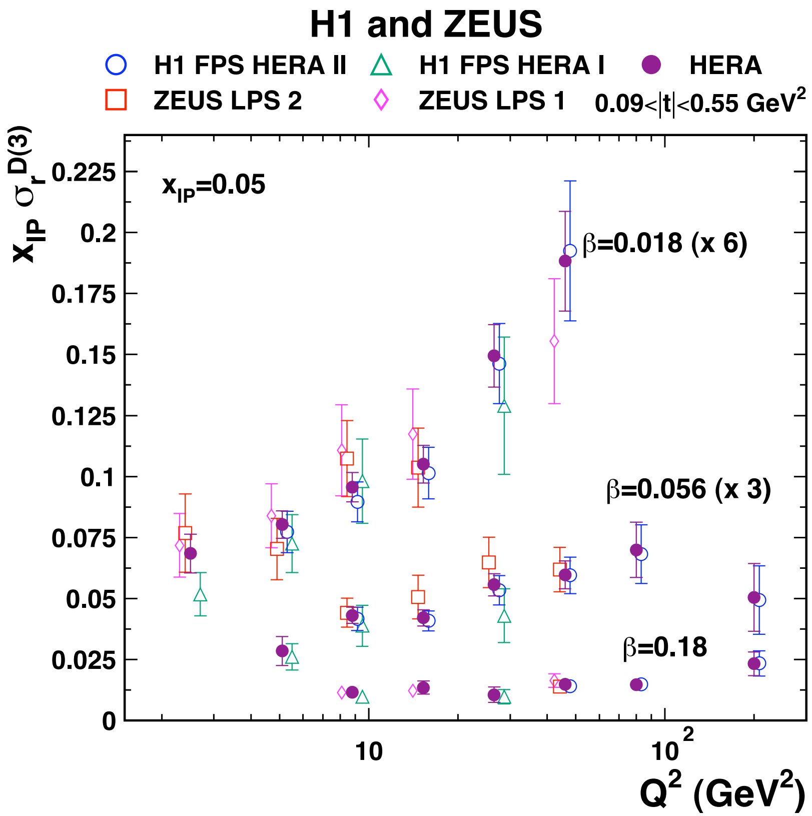
Recent paper on a combination of results from H1 and ZEUS, in a common t range
0.09 < |t| < 0.55 GeV^2.
Same method used for combining the structure functions results, the assumption is that H1 and ZEUS are measuring the same cross section in the same point (A. Glazov AIP Conf. Proc. 792 (2005) 237). Correlated systematic errors in each experiment get „calibrated“ from the other experiment.

$$\chi^2_{\exp}(\vec{m},\vec{b}) = \sum_i \frac{[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i]^2}{\delta^2_{i,stat}\mu^i(m^i - \sum_j \gamma^i_j m^i b_j) + (\delta_{i,uncor} m^i)^2} + \sum_j b_j^2$$

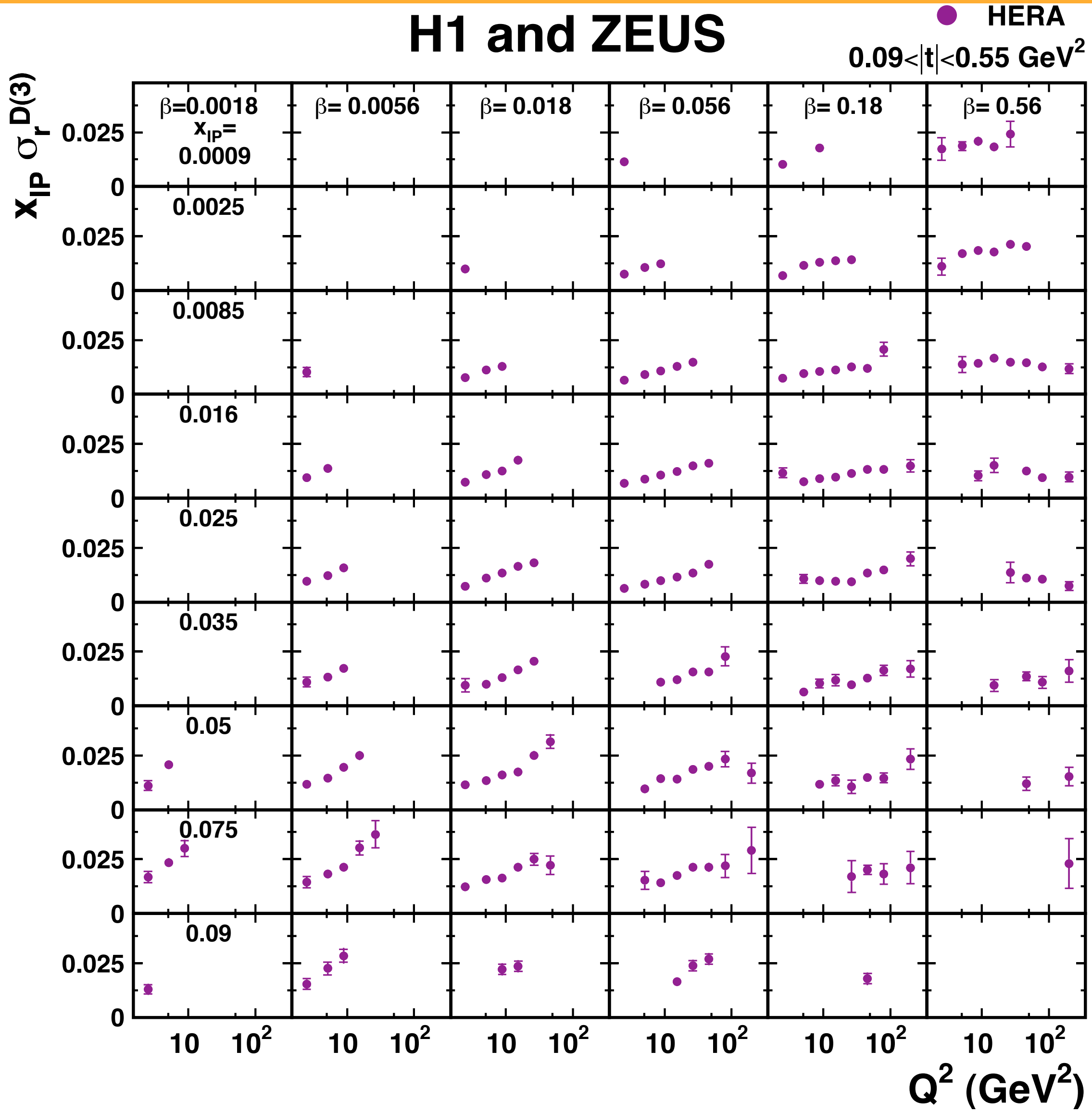
b = shift of correlated uncertainties

m = combined cross section values

Total of 352 data points combined in 191, with a χ^2/ndf= 133/161



HERA Results

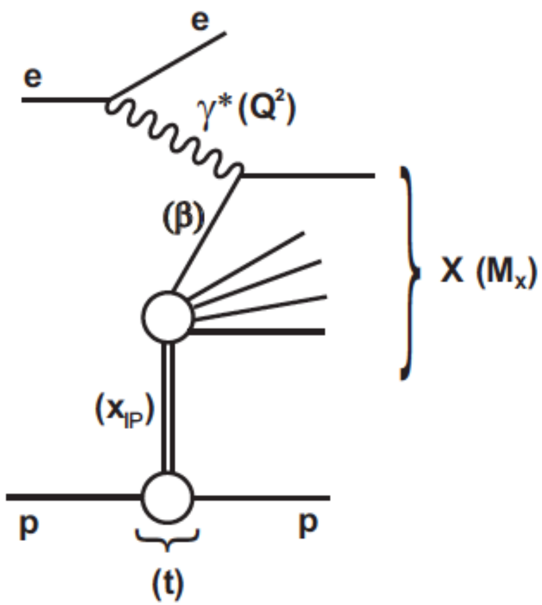


$\sigma_r^{D(3)} = \int \sigma_r^{D(4)}\, dt$
multiplied here by x_{IP} to put in evidence the Q^2 dependence

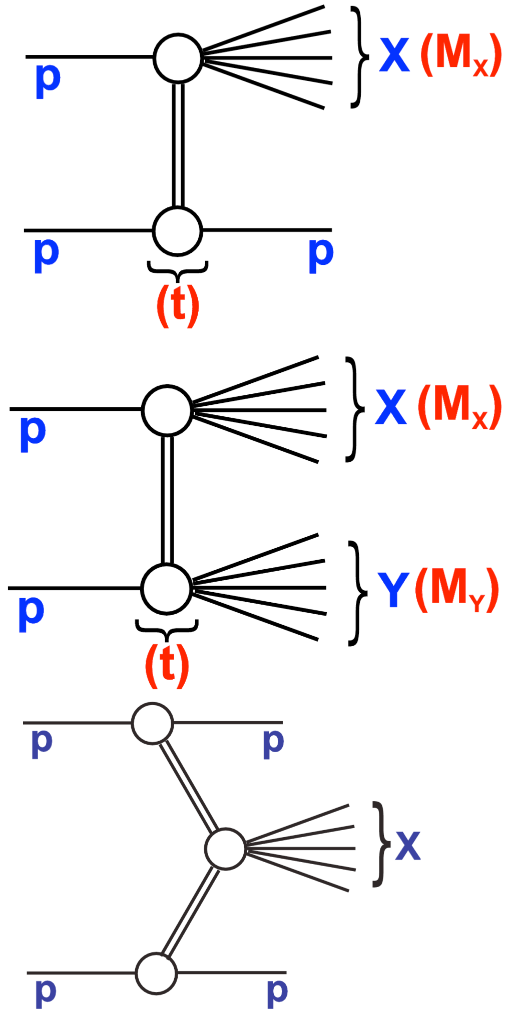
The strong scaling violation in diffraction are evident.
Precise measurement of the cross section of the absolute normalization at low $x_{IP.}$ (4%).
Uncertainty of 6% for most precise points and 14% on average.

In future: Combine LRG cross sections and extract dPDFs

Diffraction from HERA to LHC



$\sigma_{tot} = \sigma_{el} + \sigma_{inel} = \sigma_{el} + \sigma_{ND} + \sigma_{SD} + \sigma_{DD} + \sigma_{CD}$ at the LHC



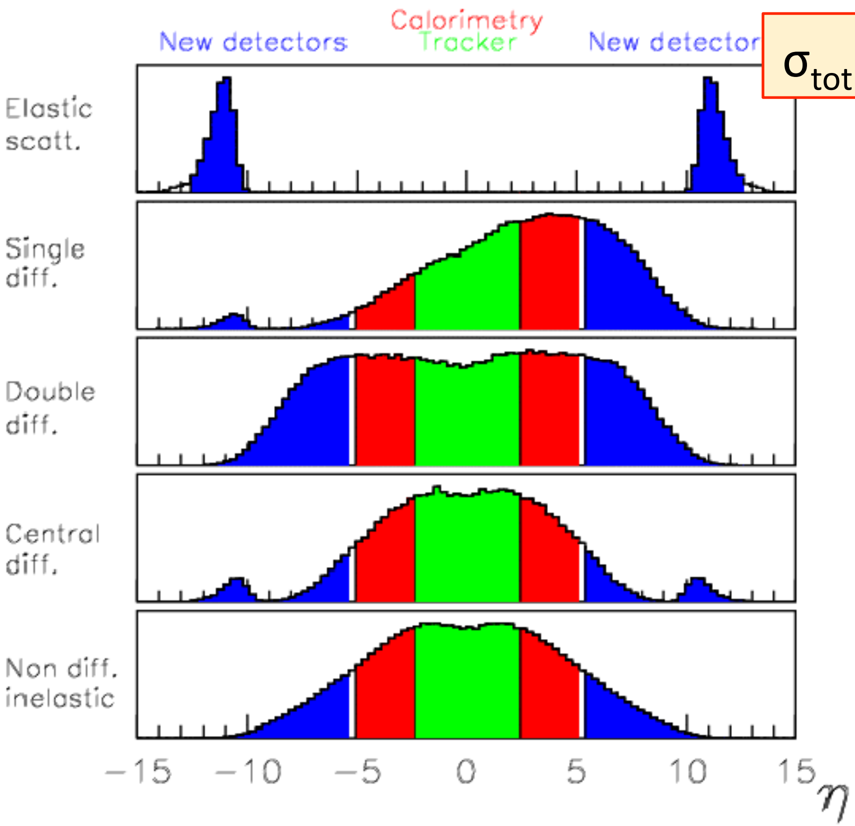
Single Diffraction

Double Diffraction

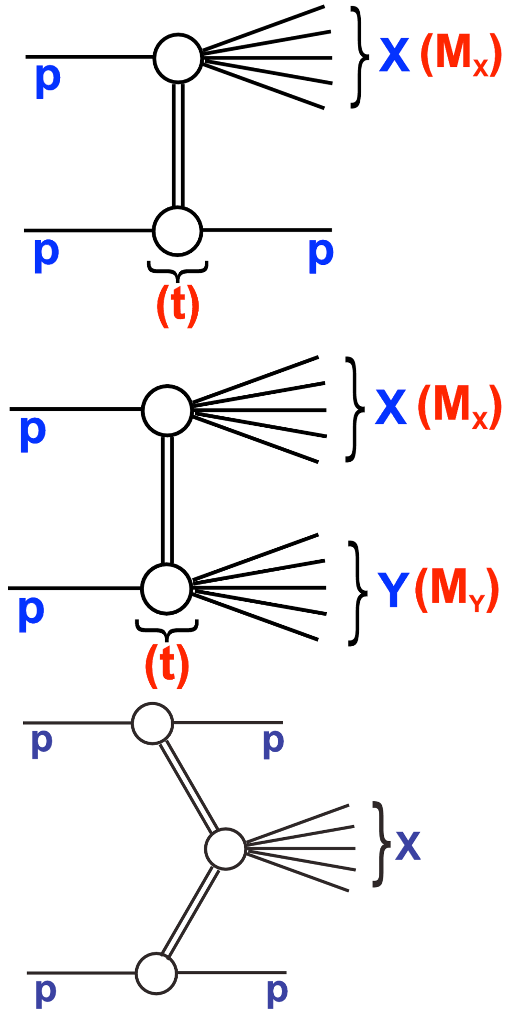
Central Diffraction

Diffraction from HERA to LHC

$\sigma_{tot} = \sigma_{el} + \sigma_{inel} = \sigma_{el} + \sigma_{ND} + \sigma_{SD} + \sigma_{DD} + \sigma_{CD}$ at the LHC



ATLAS and CMS calorimeter+tracking cover the region |η|~<5. Low pile-up data used for these measurements



Single Diffraction

Double Diffraction

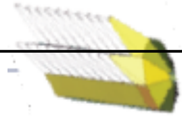
Central Diffraction

Diffraction at CMS

±140 m

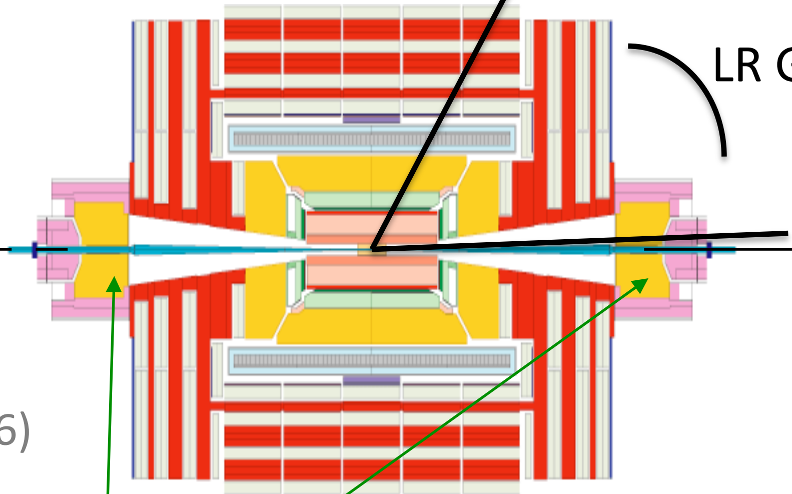
ZDC

(|η| > 8.1)

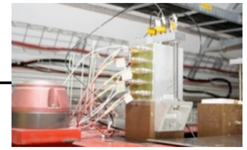


CASTOR

(5.3 < |η| < 6.6)



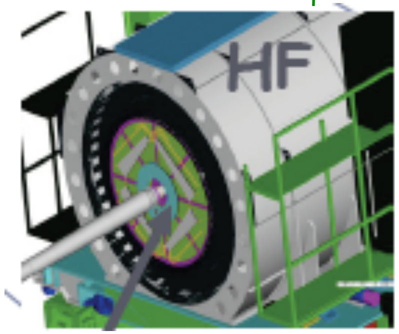
±175 m



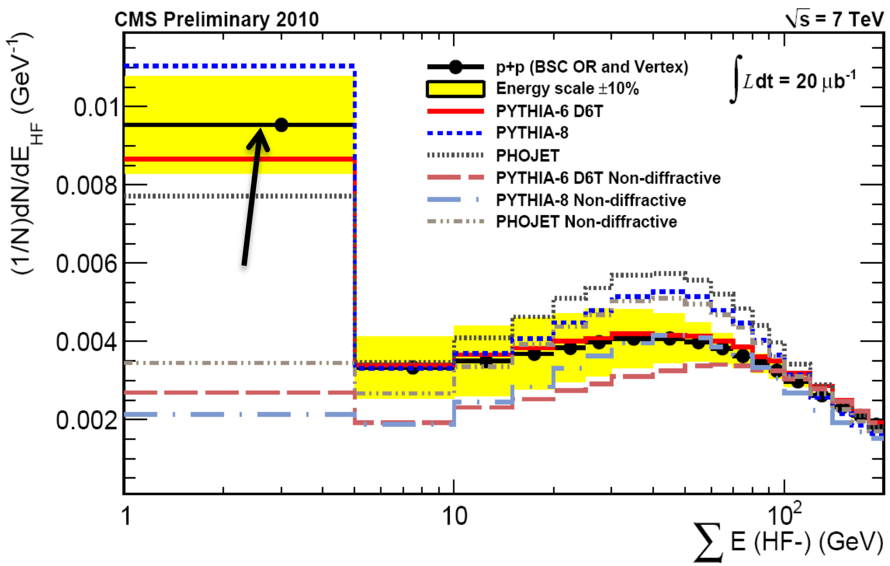
BPTX

Hadronic Forward (HF)

(2.9 < |η| < 5.2)



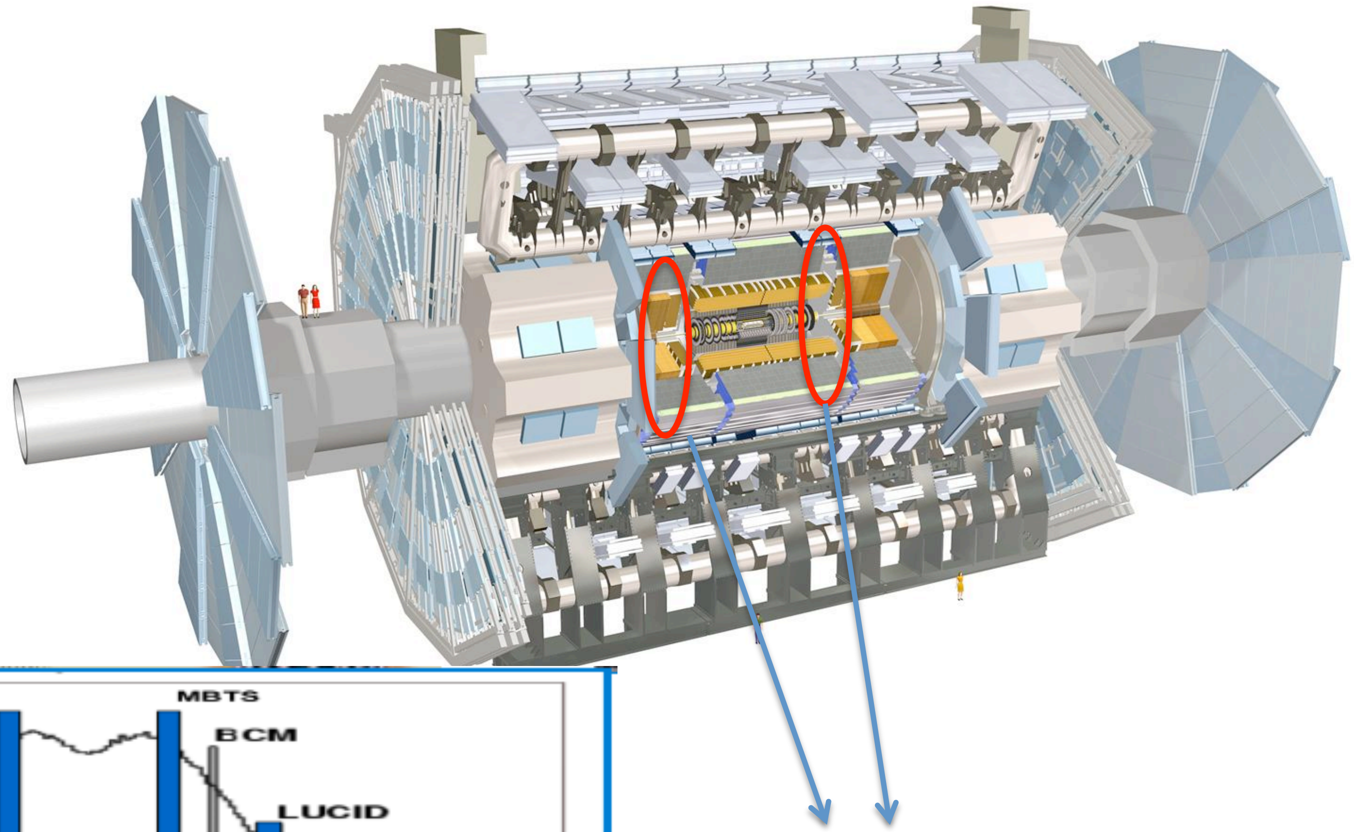
Observation of diffraction at CMS

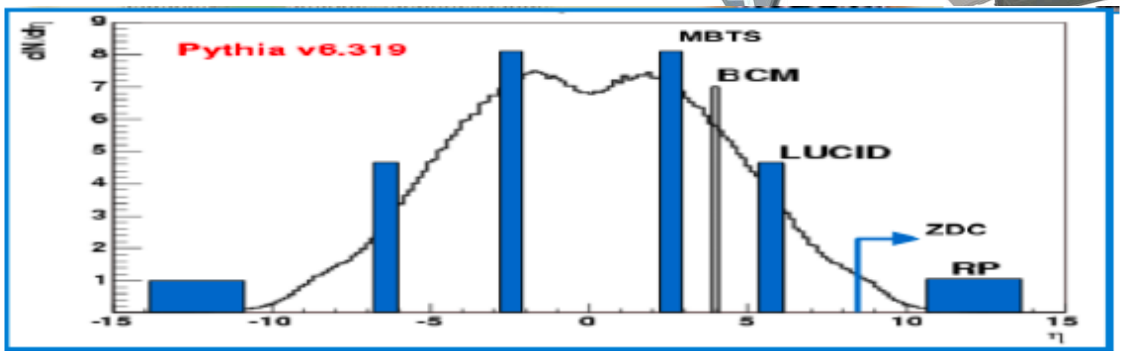


Diffraction at ATLAS

Trackers |η|< 2.5

Calorimeters |η|< 4.9





Minimum Bias Trigger
Scintillators 2.1< |η|< 3.8

Inelastic cross section at ATLAS

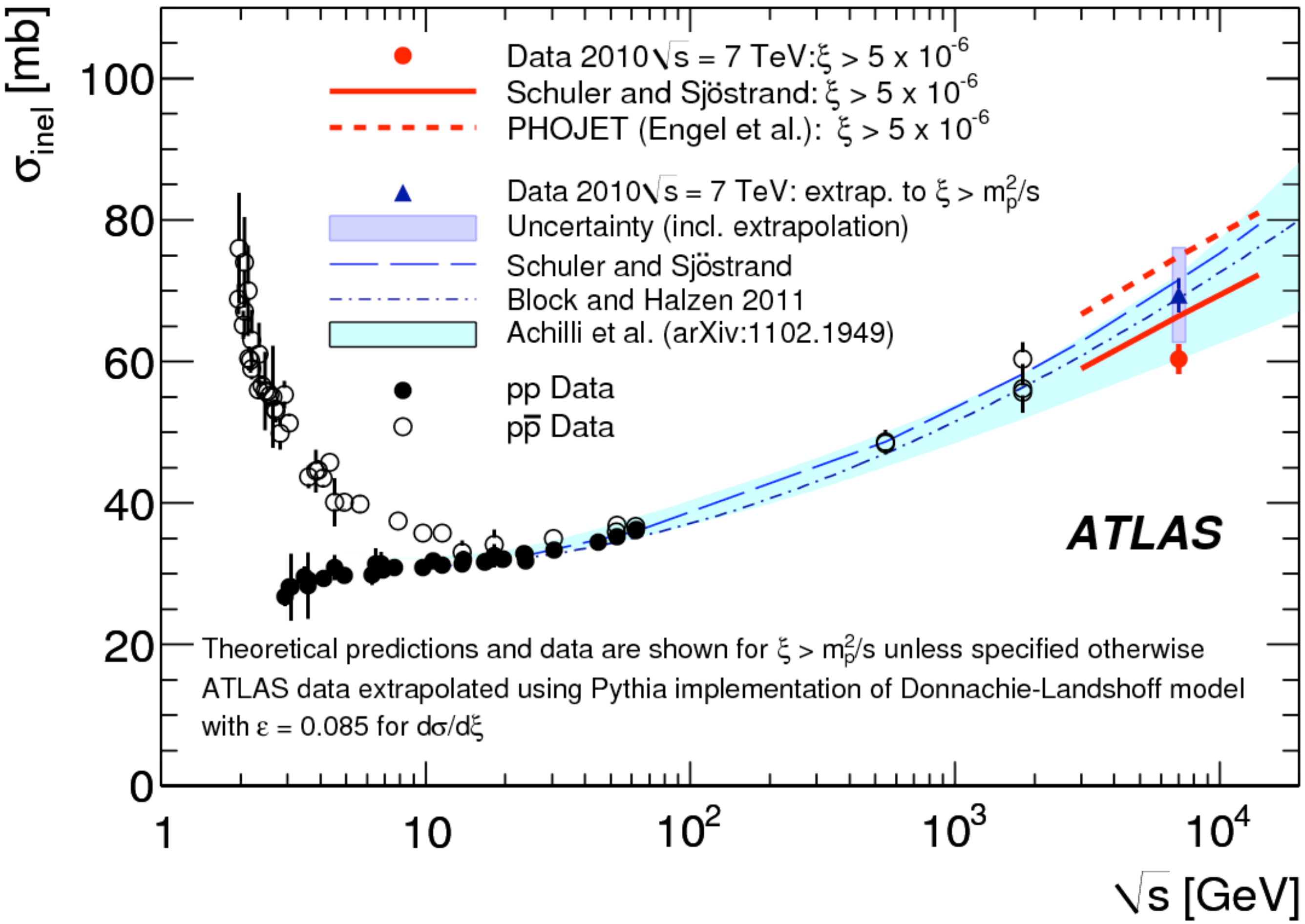
Nature Comm. 2 (2011) 463

- data from one fill in March 2010
- Activity in MBTS to select inelastic

$\xi=M_X^2/s$ fractional momentum of the p beam

Measurement at $M_X^2>15.6$ GeV, $\xi=M^2_X/s>5X10^{-6}$, then extrapolated to whole range

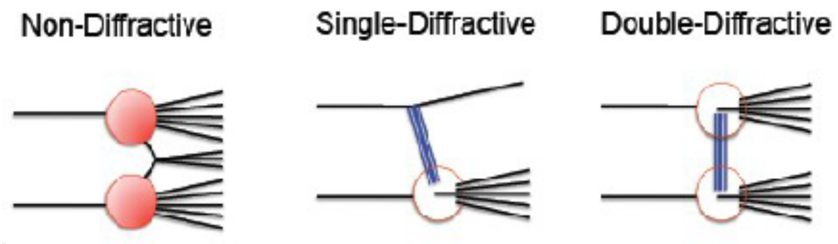
$\sigma_{inel} = s^{alpha(0)-1} = s^{\varepsilon}$ in DL model with alpha(0)=1.085, Pomeron intercept

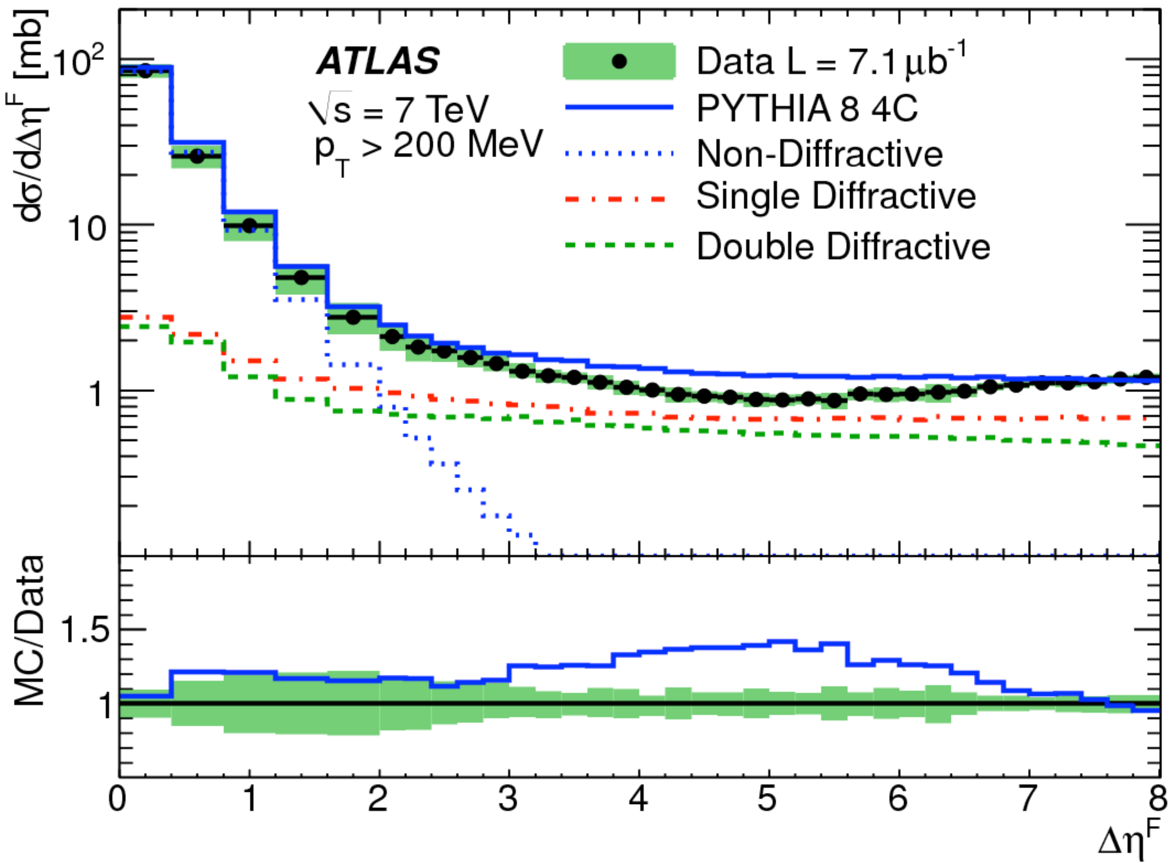


Rapidity Gap cross section at ATLAS

Eur. Phys. J. C72 (2012) 1926

Take largest of the two forward rapidity gaps $\Delta\eta^F$, between the first track with p_T > 200 MeV in $|\eta|<2.5$ or the first CAL activity above noise , and the detector edge $|\eta|=4.9$



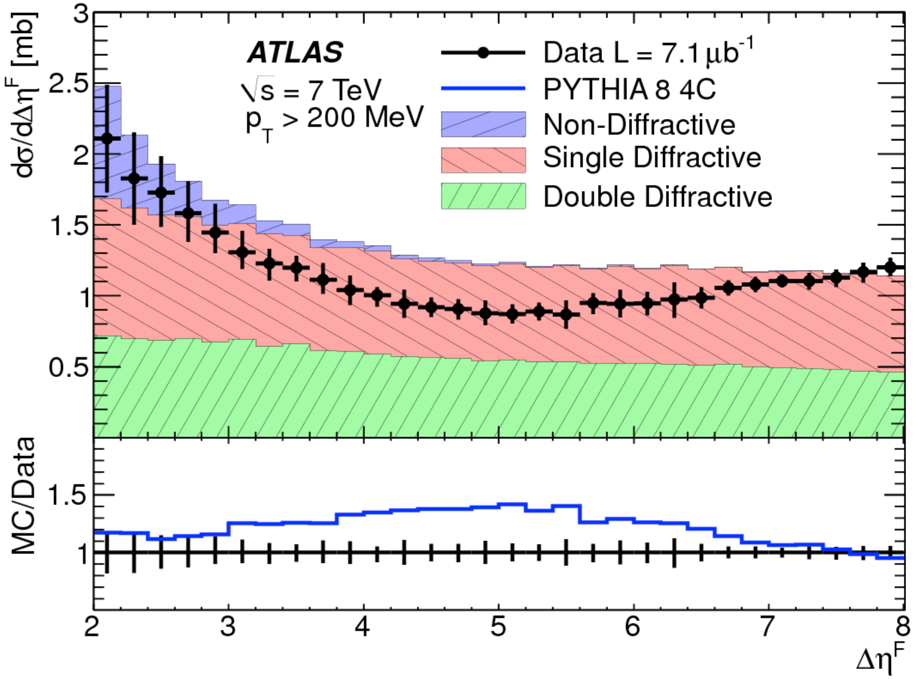


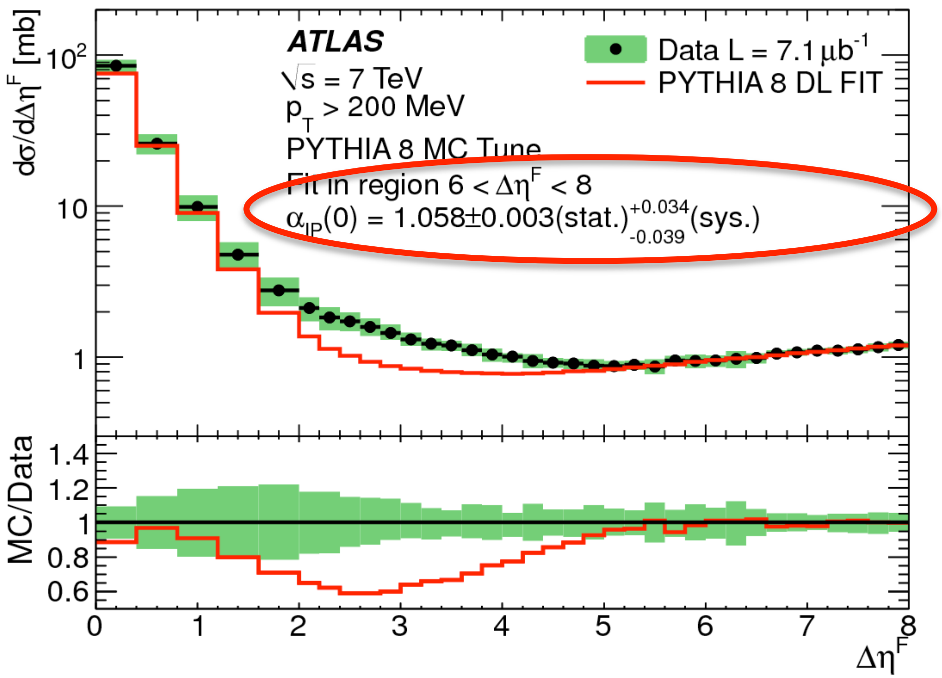
Measure cross section: Data show an exponential decrease at low $\Delta\eta$ (non-diffractive) and a plateau at large $\Delta\eta$ - characteristic of diffraction

Rapidity Gap cross section at ATLAS

Integrate over $5 < \Delta\eta^F < 8$ and measure the cross section = 3.05 ± 0.23 mb
~ 1mb per unit of gap size
(PYTHIA8 3.58 mb, PYTHIA6 3.89 mb, PHOJET 2.71 mb)

Consider data at $6 < \Delta\eta < 8$, which is sensitive to the Pomeron intercept. In agreement with the DL model (alpha(0)=1.085 in DL)

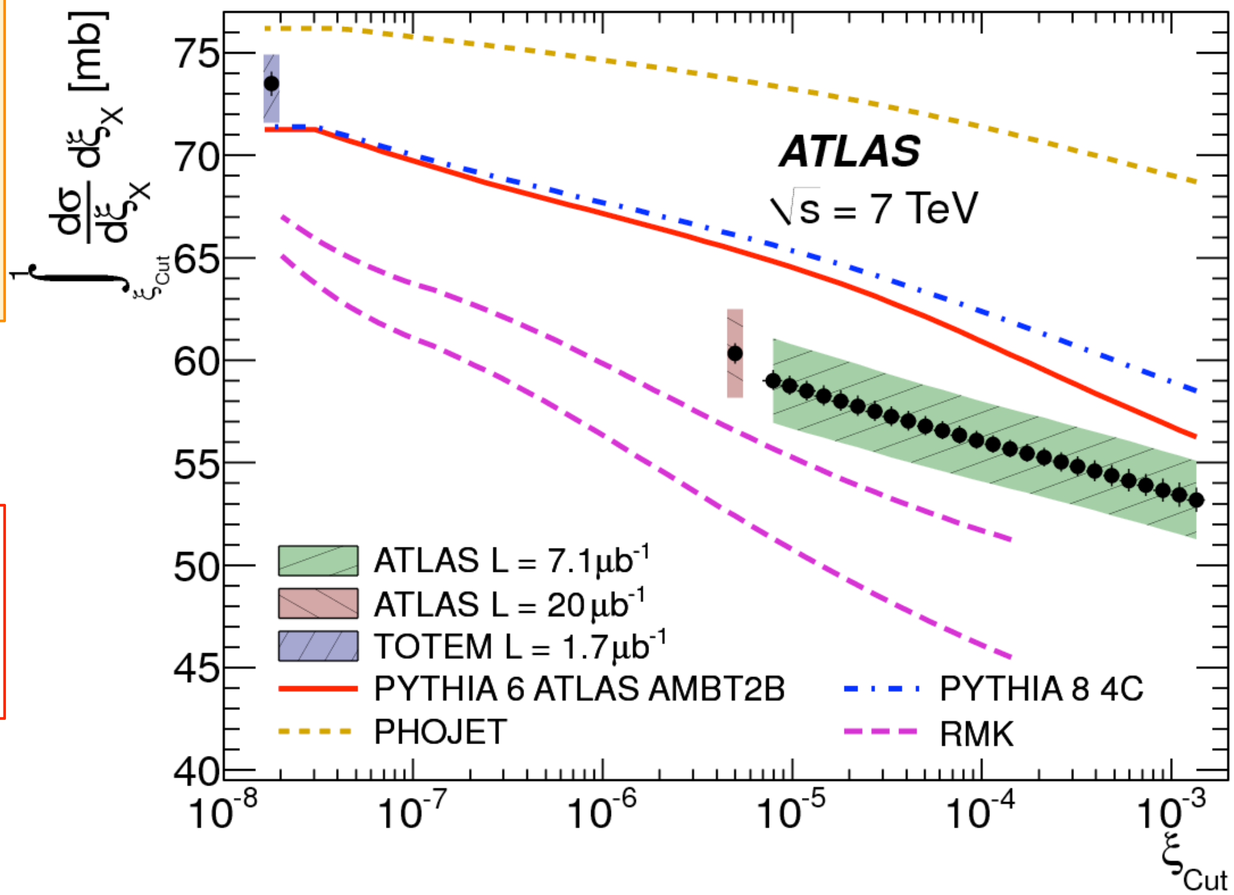




Rapidity Gap cross section at ATLAS

$\Delta\eta$ strongly correlated with ξ, $\Delta\eta \sim -\ln\xi$
With $\xi \approx 10^{-5}$-10^{-3}

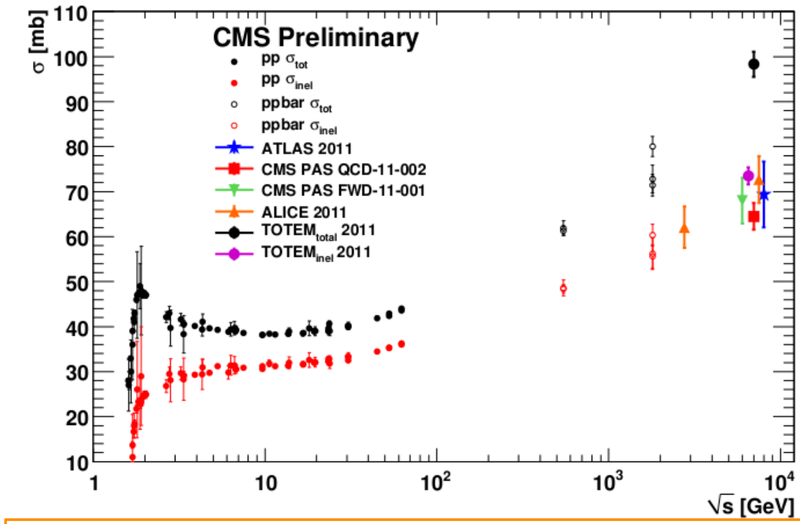
Integrate the cross section from a certain ξ cut . In agreement with previous ATLAS result. Contribution from $\xi<10^{-5}$ is 20% of the total inelastic cross section

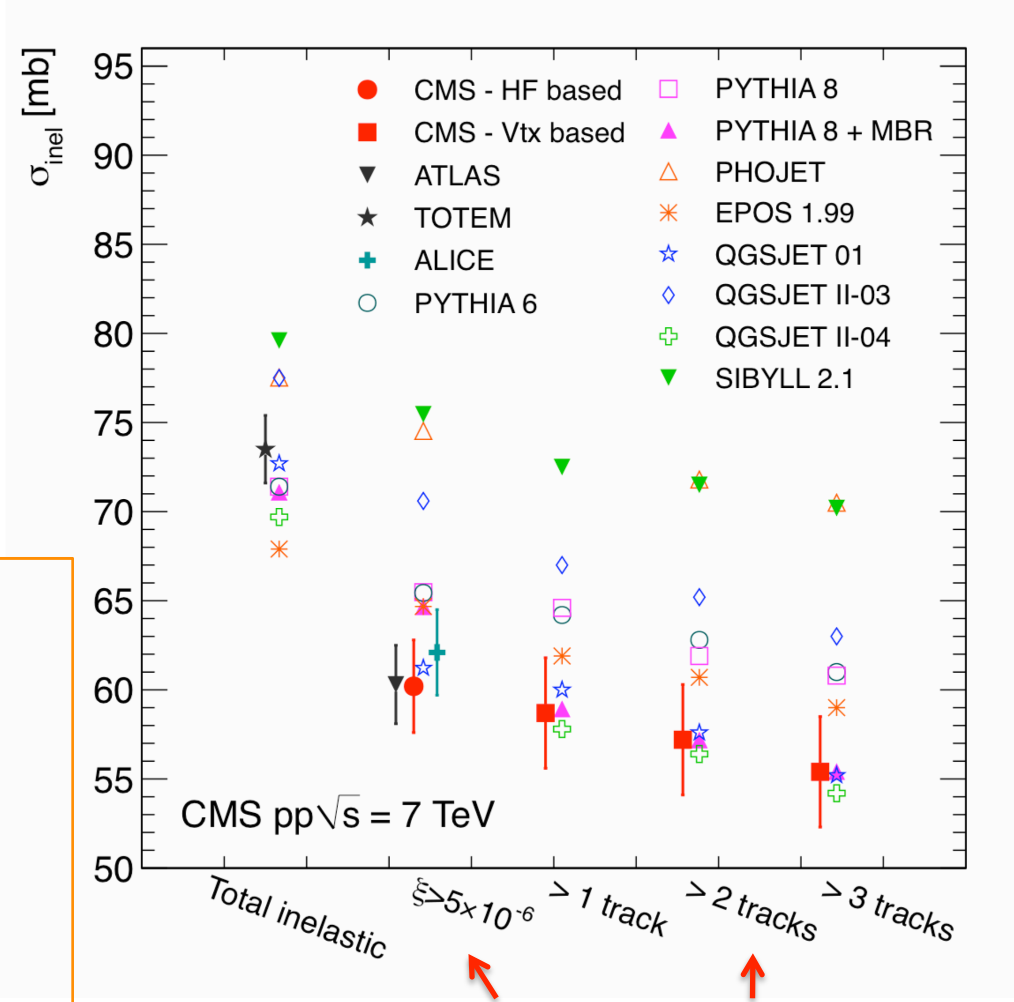


No model describe all the features of this cross section

Inelastic cross section at CMS

arXiv:1210.6718



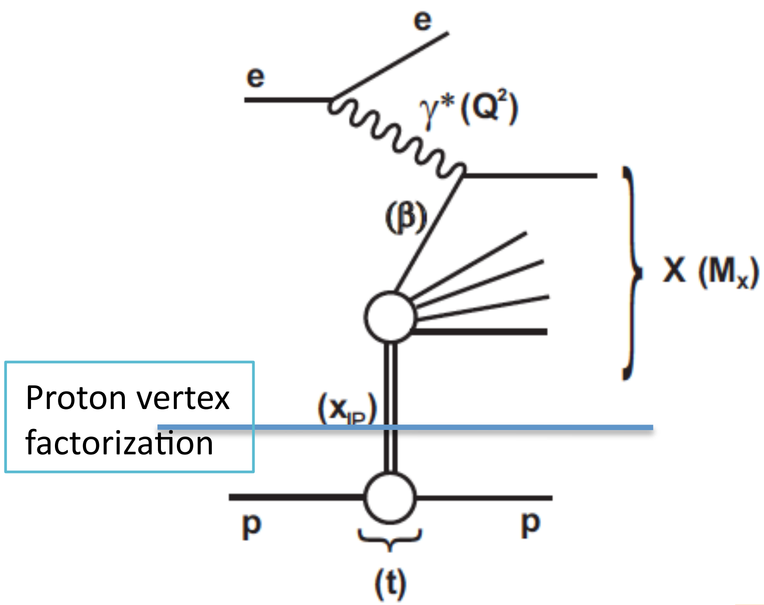


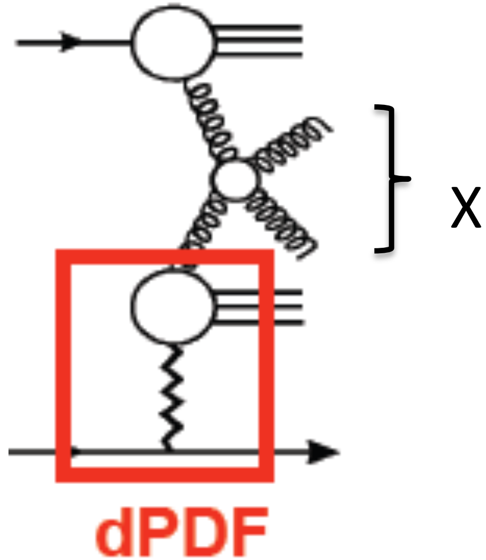
(HF) (Tracker)

Two methods used:

- Count number of events with E_{HF}>5 GeV in either of the two HF calorimeters, $\xi > 5 \times 10^{-6}$
- Count number of inelastic interactions, which follow a Poisson distribution with mean $\lambda = L_{inst} \times \sigma_{inel}$
- MC models QGSJET 01, QGSJET II-04 describe the CMS data best, PYTHIA8+MBR agrees with tracking measurements

Hard diffraction at the LHC





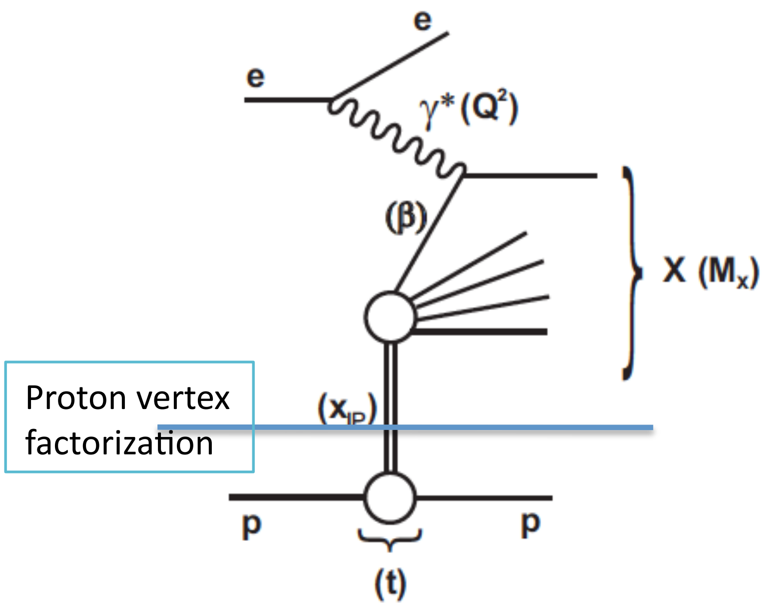
$$\frac{d\sigma}{d\xi dt} = \sum \int dx_1 dx_2 d\hat{t} \, f(\xi,t) f_{\mathbb{P}}(x_1,\mu) f_p(x_2,\mu) \frac{d\hat{\sigma}(\hat{s},\hat{t})}{d\hat{t}}$$

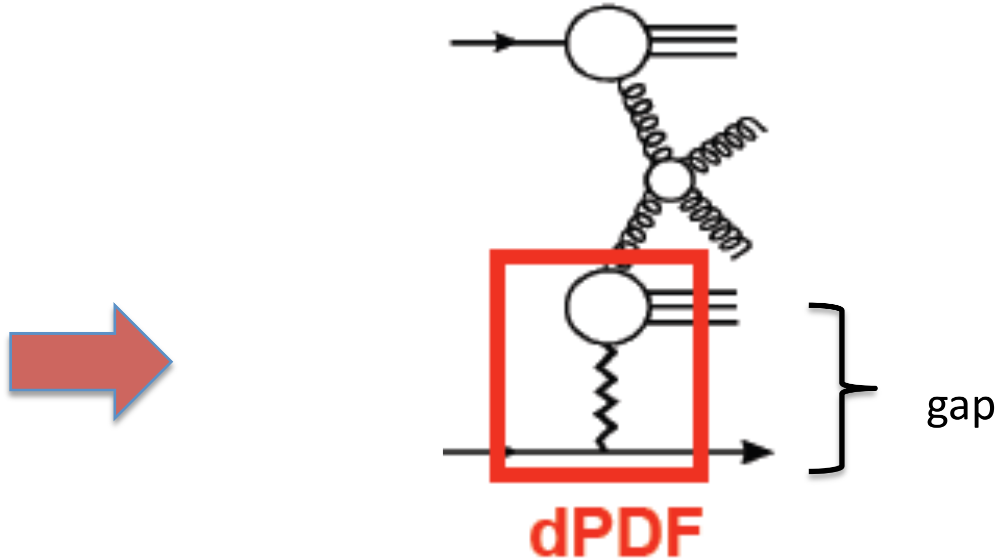
dPDF

Regge+QCD factorization in Diffractive DIS: can factorize the cross section in a flux and a PDF. Can apply the dPDF at other processes, i.e. at the LHC

$\xi = M_X^2/s$ fractional momentum of the p beam

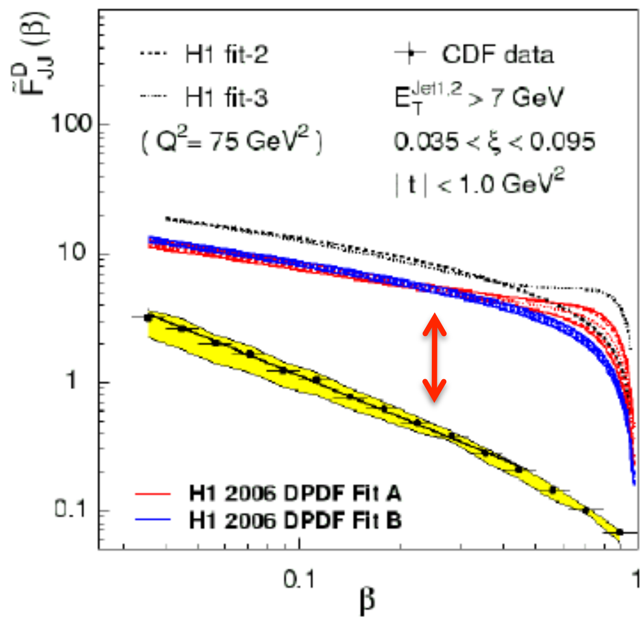
Hard diffraction at the LHC





But factorization breaking observed at Tevatron, due to soft interactions of spectator partons, that can „fill" the gap and suppress the cross section:

gap survival probability, can test this at the LHC



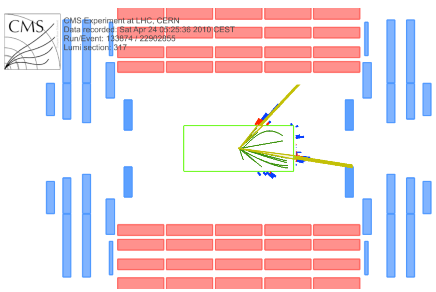
Observation of diffractive dijets at CMS

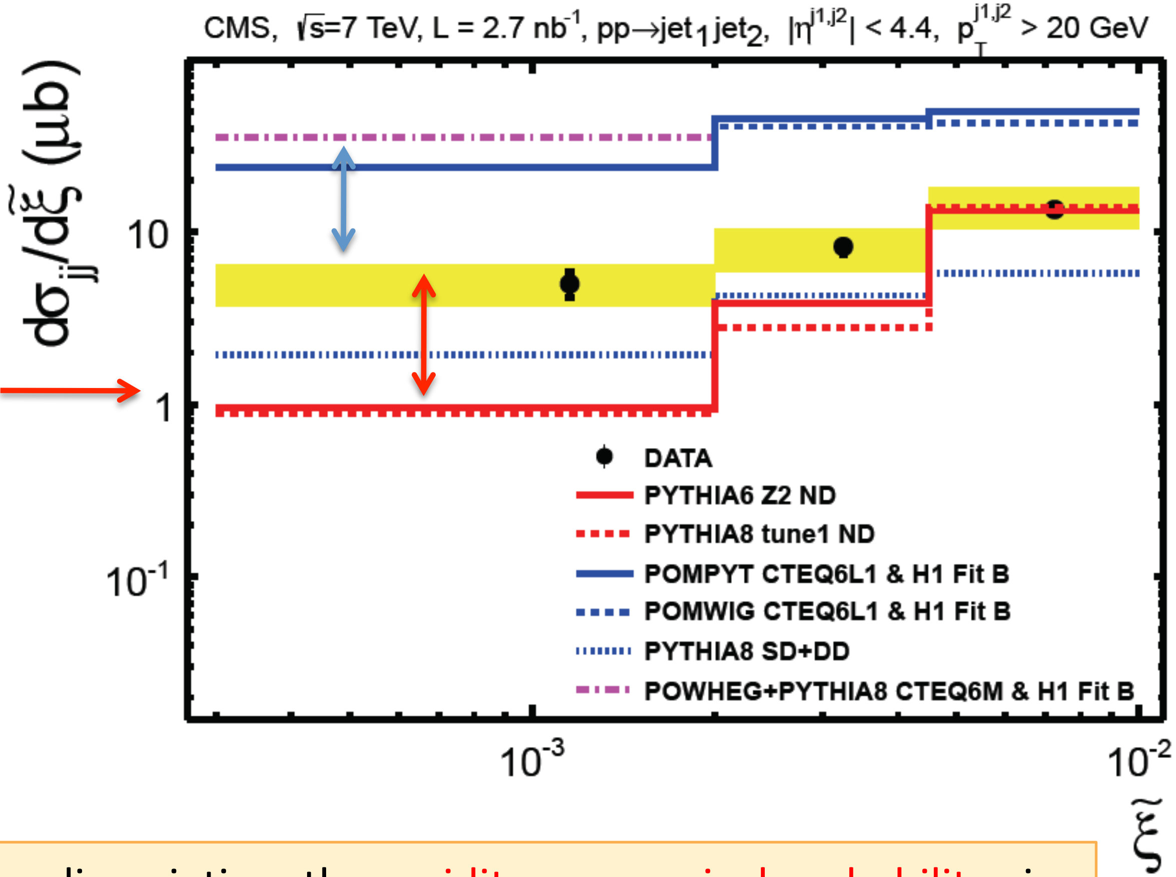
arXiv:1209.1805

Inclusive dijet cross section as function of ξ

Gap suppression, factor ~5

Evidence for hard diffraction at low ξ





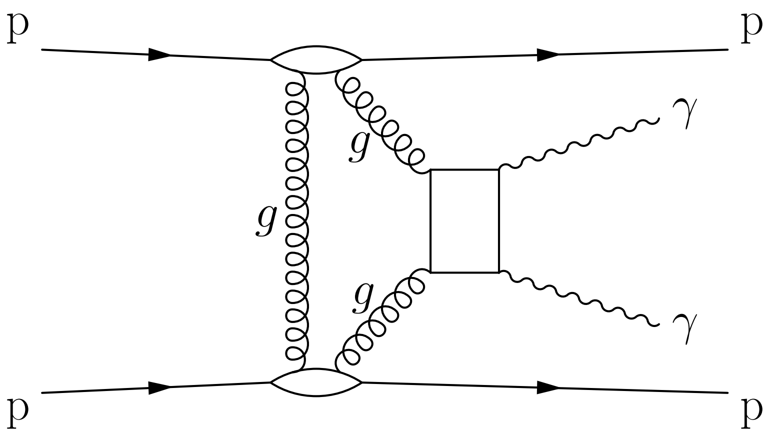
After correcting for proton dissociation, the rapidity gap survival probability is:

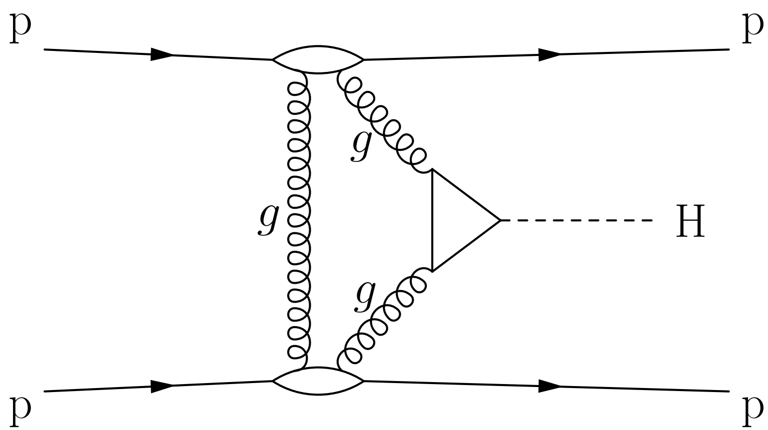
$S^2 = 0.12 \pm 0.05$ (LO) – comparing the data to the LO POMPYT MC

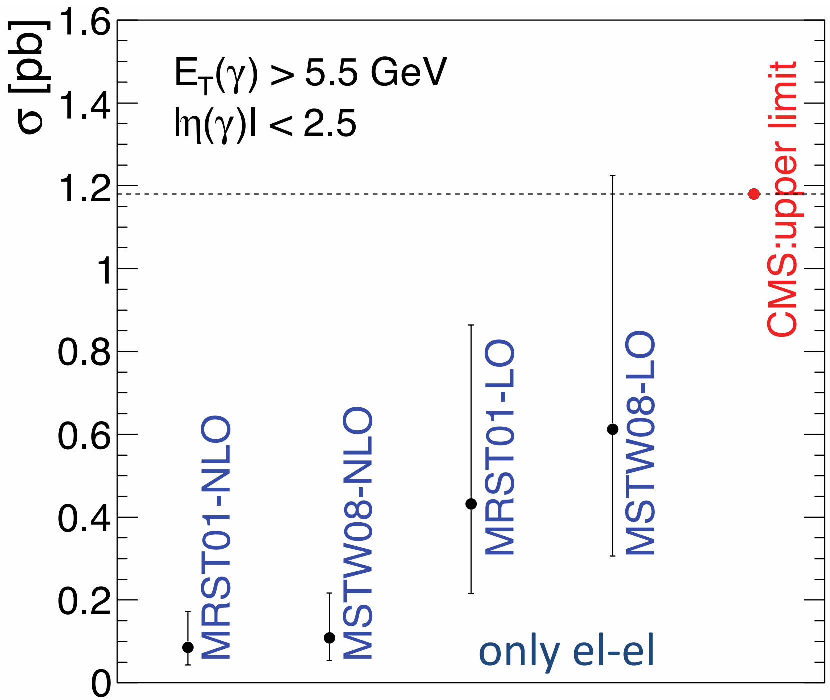
$S^2 = 0.08 \pm 0.04$ (NLO) – comparing the data to the POWHEG NLO calculation

Central production at CMS – Exclusive γγ

arXiv:1209.1666







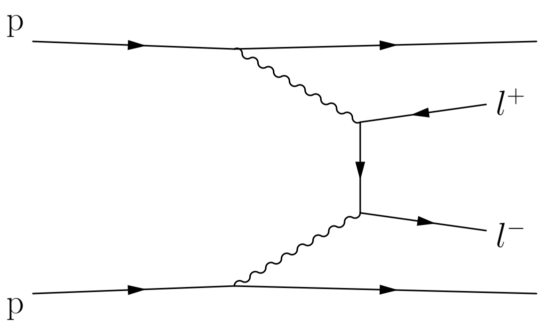
Process depends strongly on the gluon density at low x~ $g(x)^4$, it is closely related to exclusive Higgs production

Two central photons with p_T>5.5 GeV and nothing else in the detector (no tracks, no additional energy deposits in $|\eta|<5.2$).

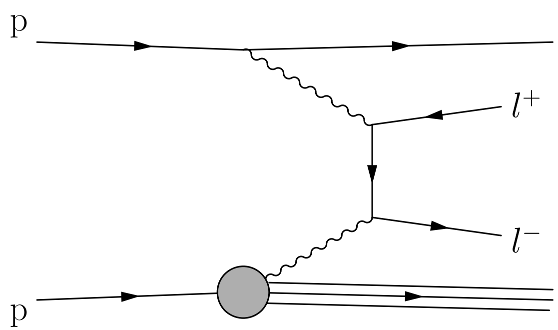
No event observed, σ(pp->γγ)<1.8 pb at 95% CL, for $E_T(\gamma)>5.5$ GeV, $|\eta(\gamma)|<2.5$

Central production at CMS – Exclusive e^+e^-

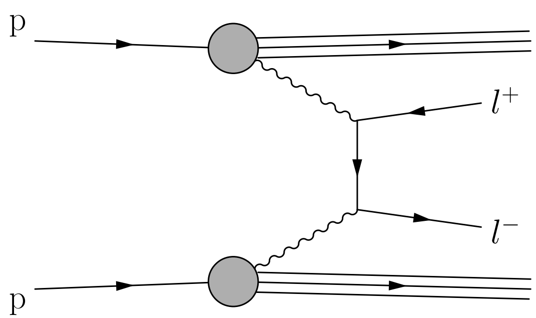
arXiv:1209.1666



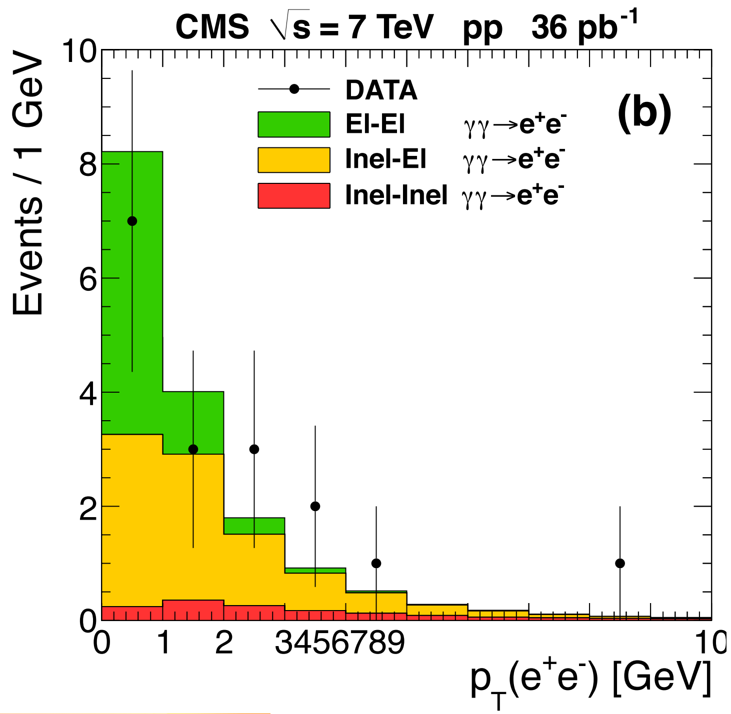
El-El



El-Inel



Inel-Inel



Number of events observed	17
Expected from QED (LPAIR)	16.3 ± 1.3
background	0.85 ± 0.28

No correction for rapidity gap survival probability needed

Data in good agreement with theory

Summary

• Diffraction has opened a new field of studies at HERA, is part of the understanding of the proton structure at low $x_{Bjorken}$ and the transition from soft to hard QCD
Precise measurement from combined H1+ZEUS measurement with the forward spectrometers

• Diffraction has been observed and measured at the LHC
Inelastic cross section and soft diffraction component measured at $\sqrt{s}$=7 TeV
Hard diffraction observed in dijet, suppression of the cross section as expected from QCD factorization breaking in hadron-hadron collisions

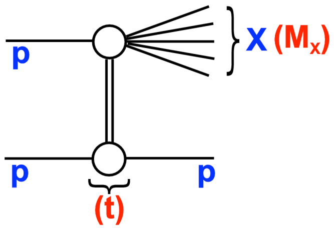
• Central exclusive production of dilepton and diphoton measured and in agreement with theory

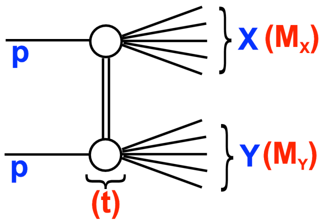
• New components in the forward part of CMS and ATLAS will give further interesting results

Inelastic cross section at Atlas

- data from one fill in March 2010
- Activity in MBTS to select SS, DS

Nature Comm. 2 (2011) 1926





Measure
$R_{SS}=N_{ss}/(N_{ss}+N_{DS})$
SS single sided
DS double sided

Extract from it
$f_D=\sigma_{diff}/\sigma_{inel}\sim$ 25-30%