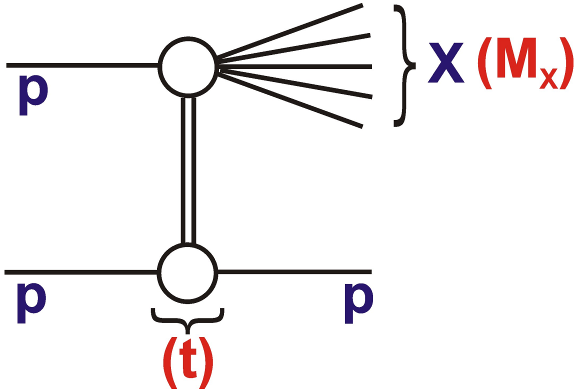
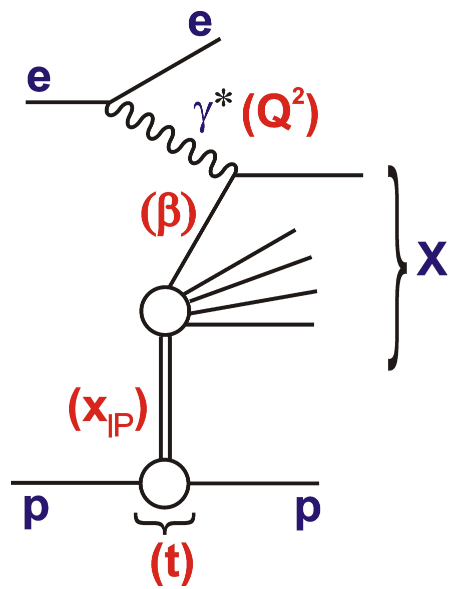
# Diffraction and Multi-Parton Interactions: an experimental perspective

Paul Newman (University of Birmingham)



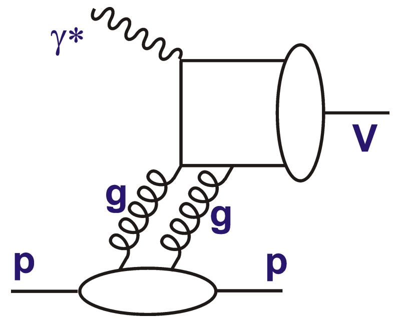

MPI@LHC, DESY
23 November 2011



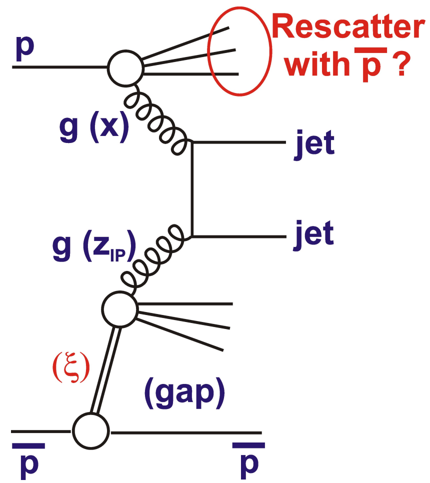

→ Diffraction and Multi-Parton Interactions
→ Soft diffraction at the LHC
→ Radiation patterns between jets at the LHC
→ Diffractive DIS at HERA → Diffractive Partons
→ Testing the Diffractive Partons at HERA
→ Breaking the Diffractive Partons: $\gamma$p, pbar-p & pp

# Diffraction & Multi-Parton Interactions

- Trivially, more than 1 parton in t channel

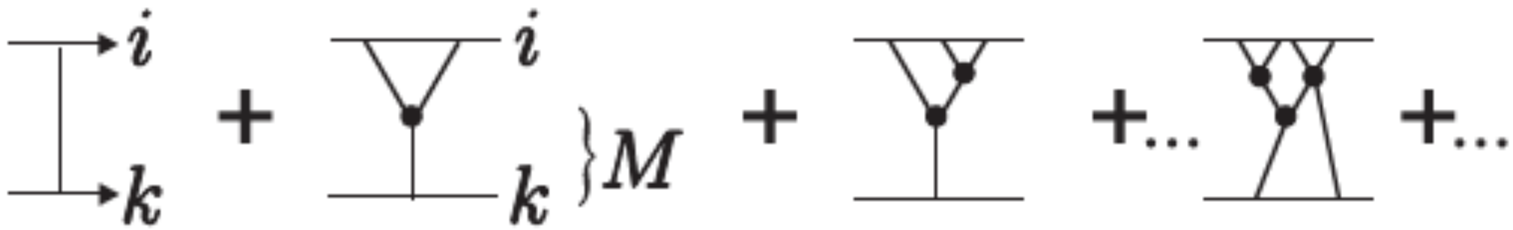



- Gap survival probabilities / absorption:
… multiple interactions with large impact parameters




- Absorptive effects due to multiple soft exchanges in minimum bias models

- Less obviously, small rapidity gaps as sensitive probe of hadronisation fluctuations and underlying event

$\Omega_{ik} =$ 

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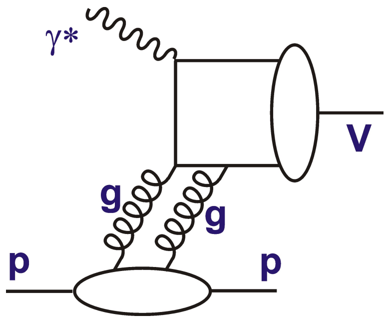
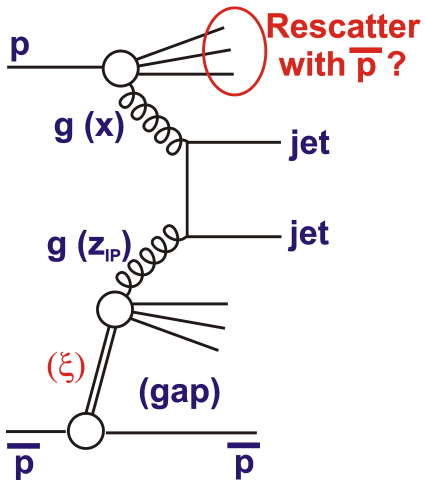


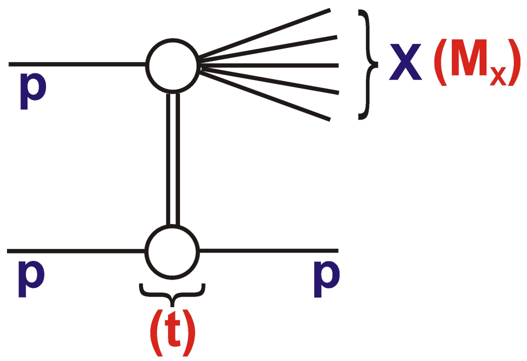

## Not covered here

- Elastic scattering in pp / ppbar (see Ken Osterberg)
- Exclusive vector mesons in ep and pp (see Marcella Capua)

# Soft Diffraction at the LHC: Processes and Kinematic Variables

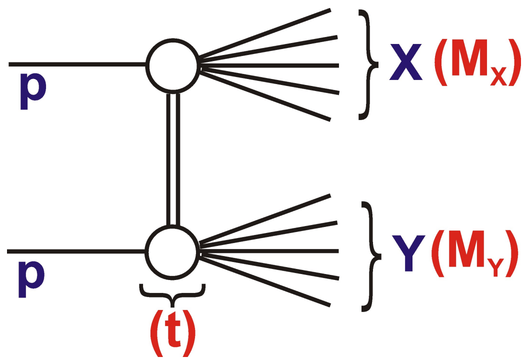
Single diffractive (SD), pp → Xp

$$\xi_X = M_X^2/s$$




Double diffractive (DD), pp → XY

$$\xi_Y = M_Y^2/s$$



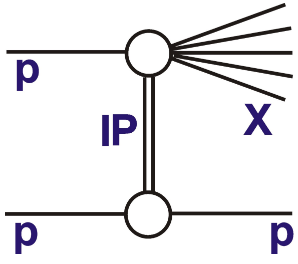

- At LHC energies, $M_X$, $M_Y$ can range from $m_p + m_\pi$ → ~1 TeV
- Large uncertainties in LHC cross sections, especially DD
- No proton tagged SD data (yet) …

… integrate over t

… select based on energy flow / rapidity gap topologies

# "Standard Model" of Soft Diffraction

Factorise SD into a pomeron (IP) flux and total p+IP cross section

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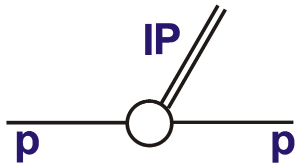
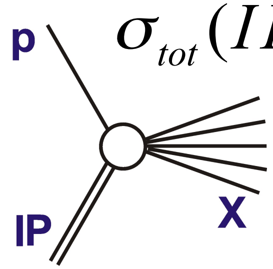



$f_{IP/p}\left(\xi_X, t\right)$

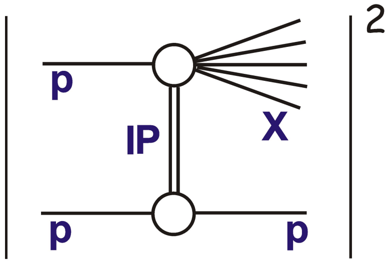
×

$\sigma_{tot}(IP + p \rightarrow X)$




Optical theorem relates $\sigma_{tot}$(IP+p) to elastic IP+p amplitude

Calculate SD cross sections from triple pomeron amplitudes

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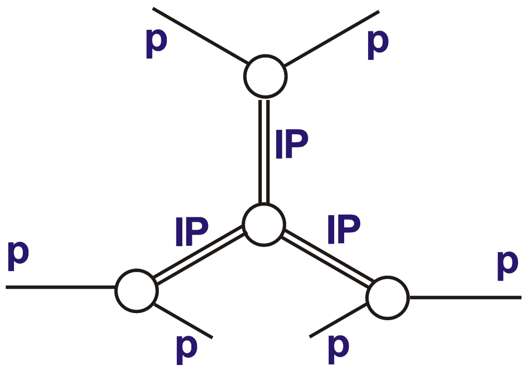



$$\frac{d\sigma}{d\xi\, dt} \propto \left(\frac{1}{\xi_X}\right)^{2\alpha(t)-\alpha(0)} e^{bt} \quad \text{(fixed s)}$$

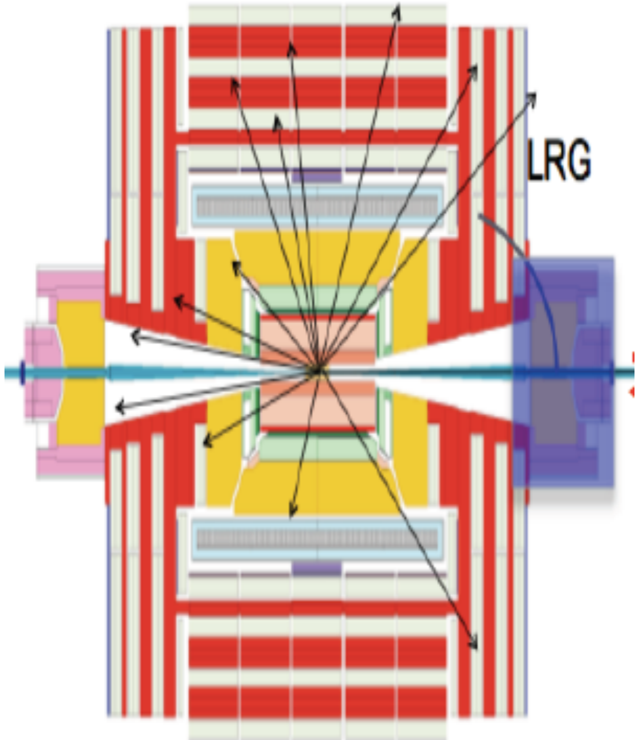
$$\left[\alpha(t) = \alpha(0) + \alpha' t\right]$$

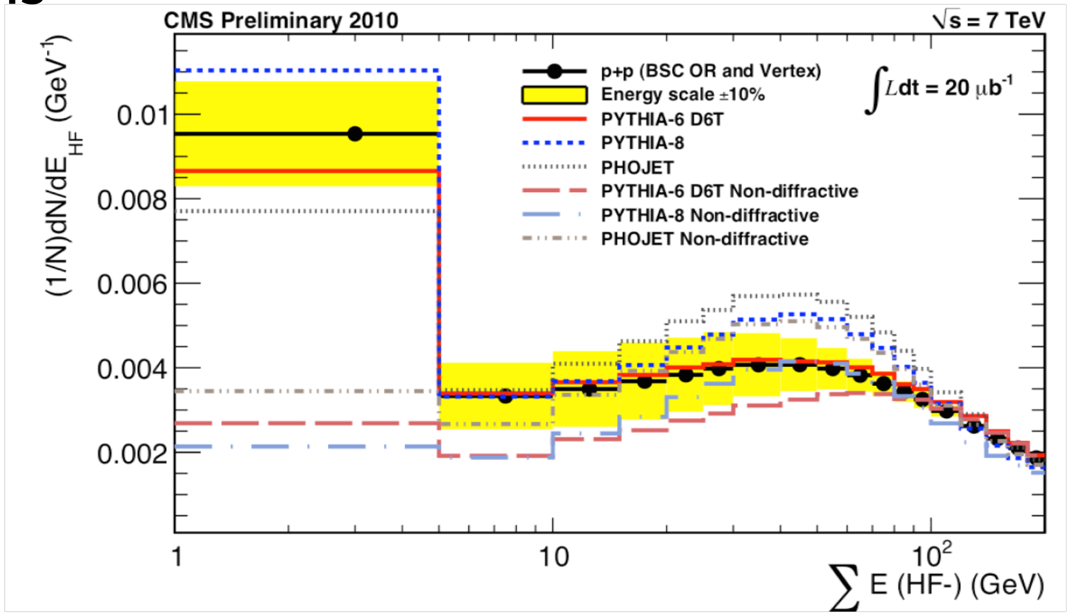
i.e approx: $\dfrac{d\sigma}{d\xi_X} \propto \dfrac{1}{\xi_X}$

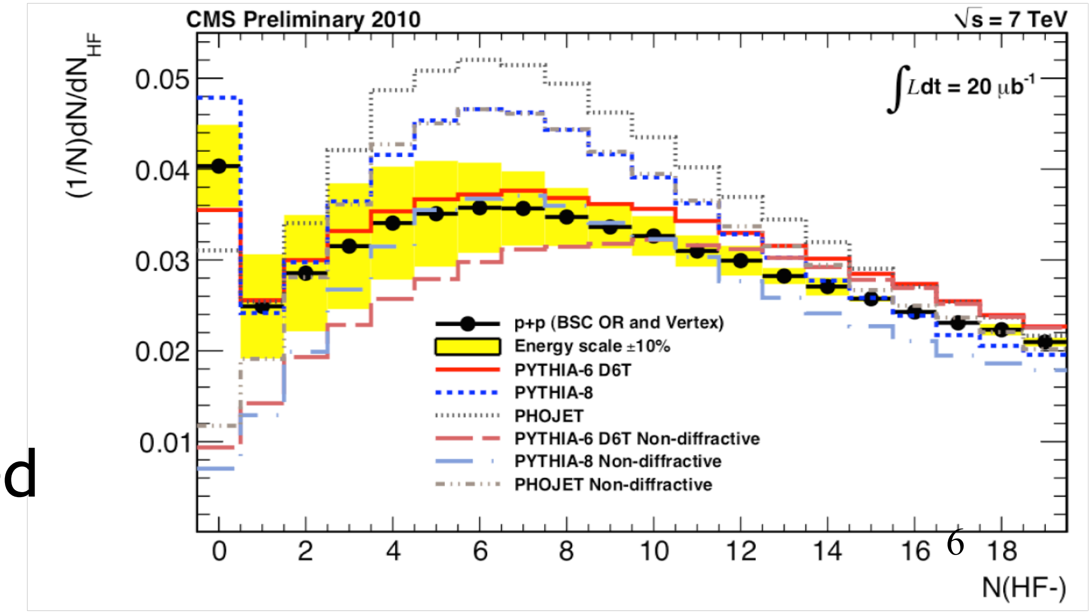
PHOJET, PYTHIA models based on this approach.
Real life $\alpha(0) \neq 1$ … LHC data sensitive to this
Deviations from triple-pom behaviour from multiple interactions?

# CMS: Forward energy flow approach

Inclusive min-bias distributions of forward HCAL activity ($2.9 < |\eta| < 5.2$)

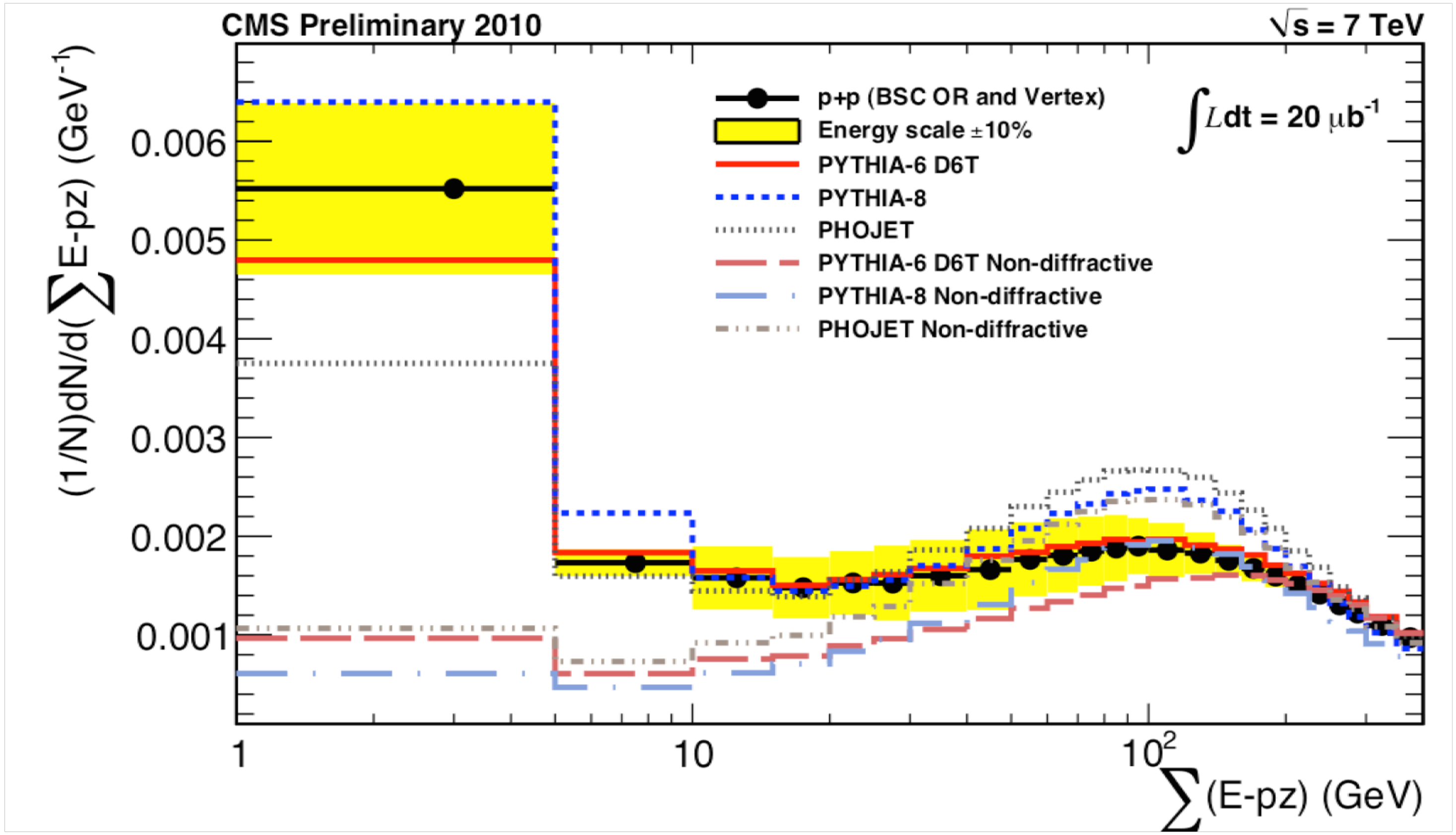



Excess of events with diffractive topology observed at all 3 LHC beam energies

# A Promising Variable to Reconstruct $\xi_X$




Potentially strong sensitivity to diffractive dynamics

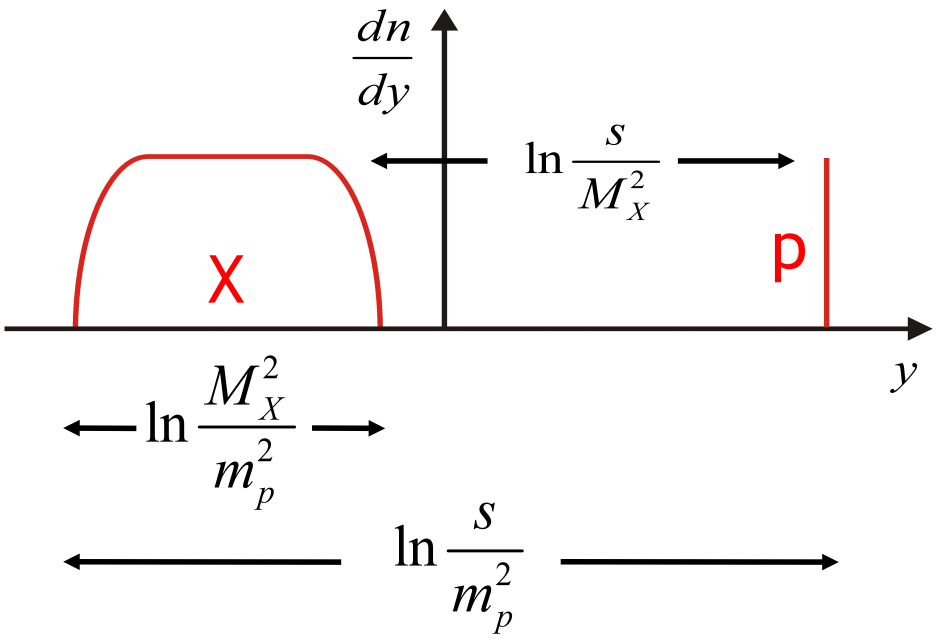
$$\sum_X E - p_z = 2E_p \cdot \xi_X$$

… and lost particles have $E\text{-}p_z \sim 0$



So far uncorrected for experimental effects

# Alternative Approach: Rapidity Gaps



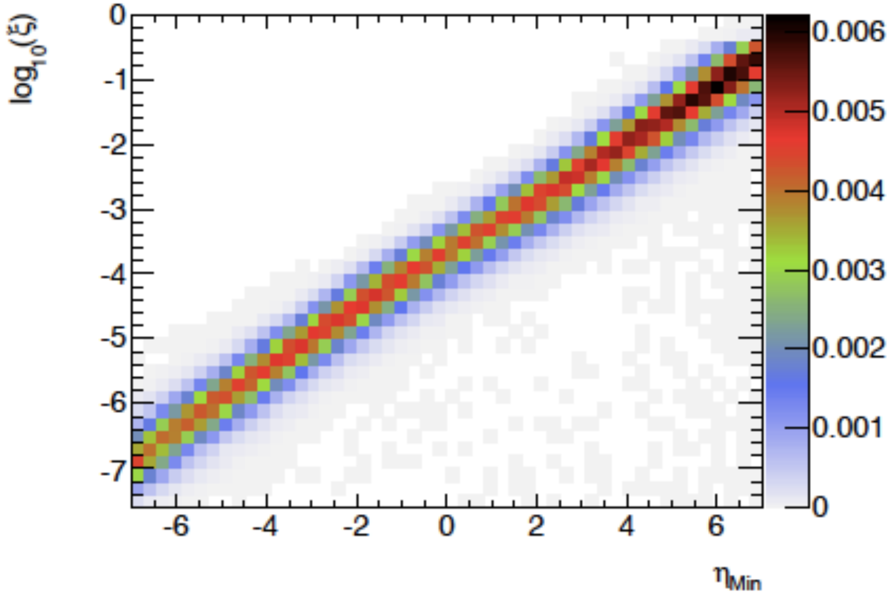

Up to event-by-event hadronisation fluctuations, ξ variables are predictable from empty rapidity regions

→Large rapidity gaps

$$\Delta\eta \approx -\ln\xi$$

and ~ flat gap distributions

$$\frac{d\,\sigma}{d\,\Delta\eta} \approx \text{const.}$$



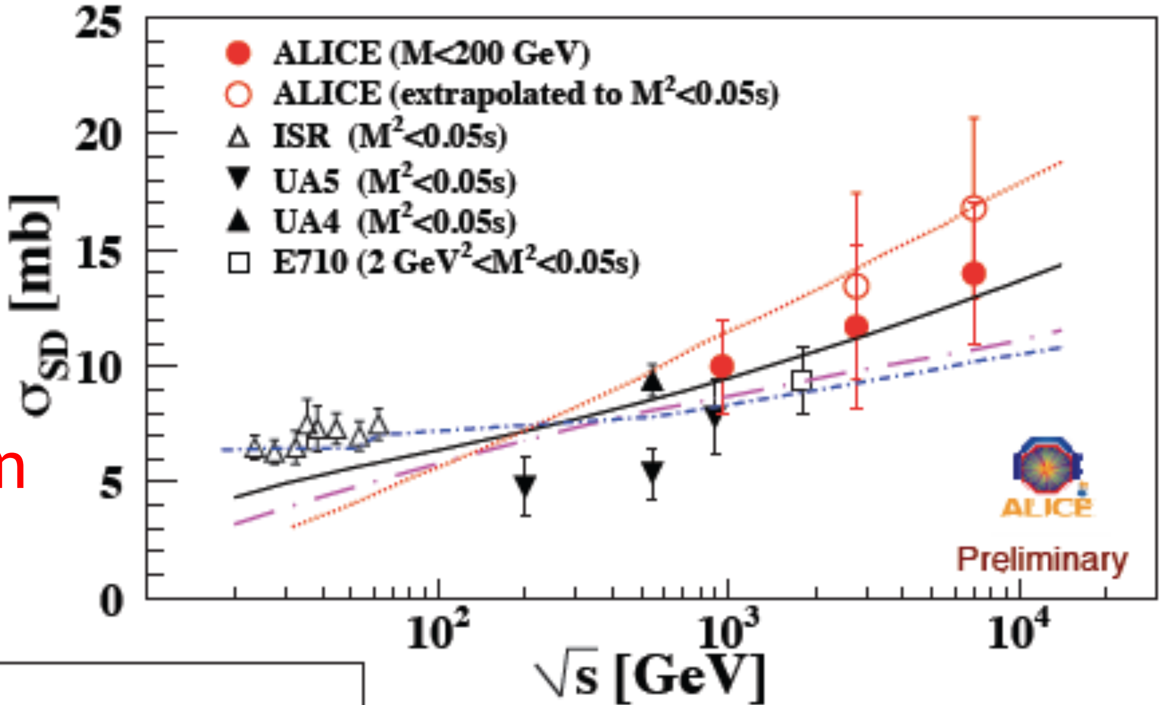

LHC coverage (|η| < 4.9) gives sensitivity with large gap to:

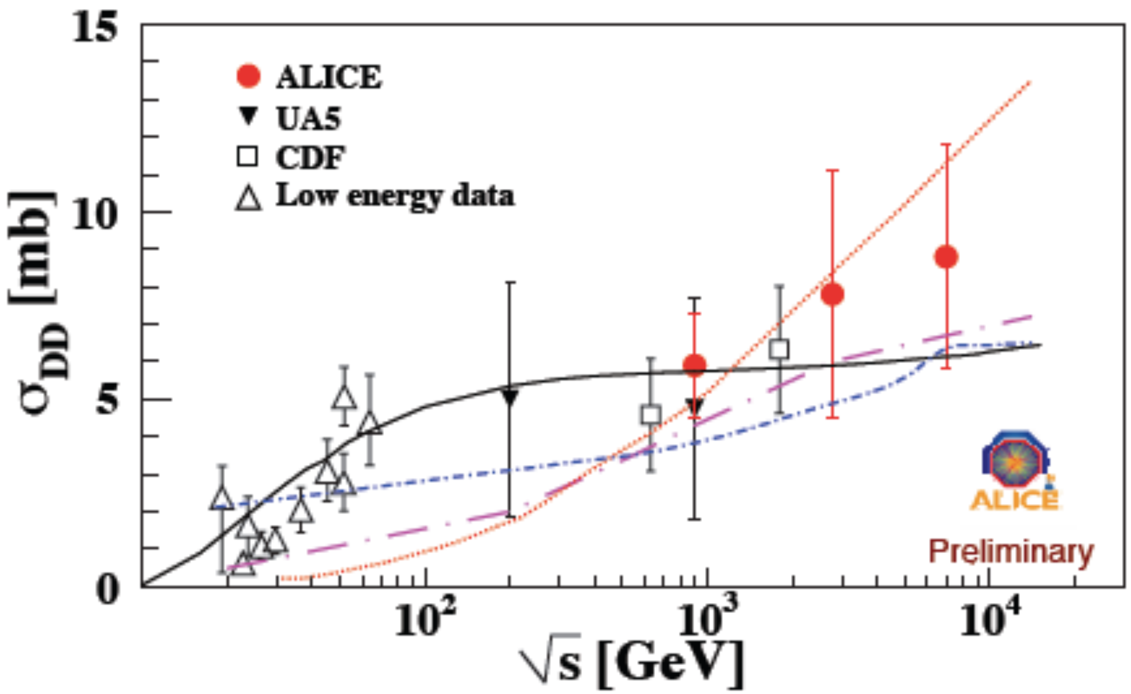
$10^{-6}$ <~ ξ <~ $10^{-2}$

(equivalently 7 <~ $M_X$ <~ 700 GeV)

# ALICE: Total SD and DD Cross Sections

ALICE: Unfold integrated SD and DD cross sections at all three CMS energies based on gap rates and topologies.
[implies some extrapolation Into lowest ξ regions]




σ(SD) with ξ < 0.05

σ(DD) with gap Δη > 3

Good agreement with SPS data and wide range of model predictions

# ATLAS: Differential gap x-sections

NEW!

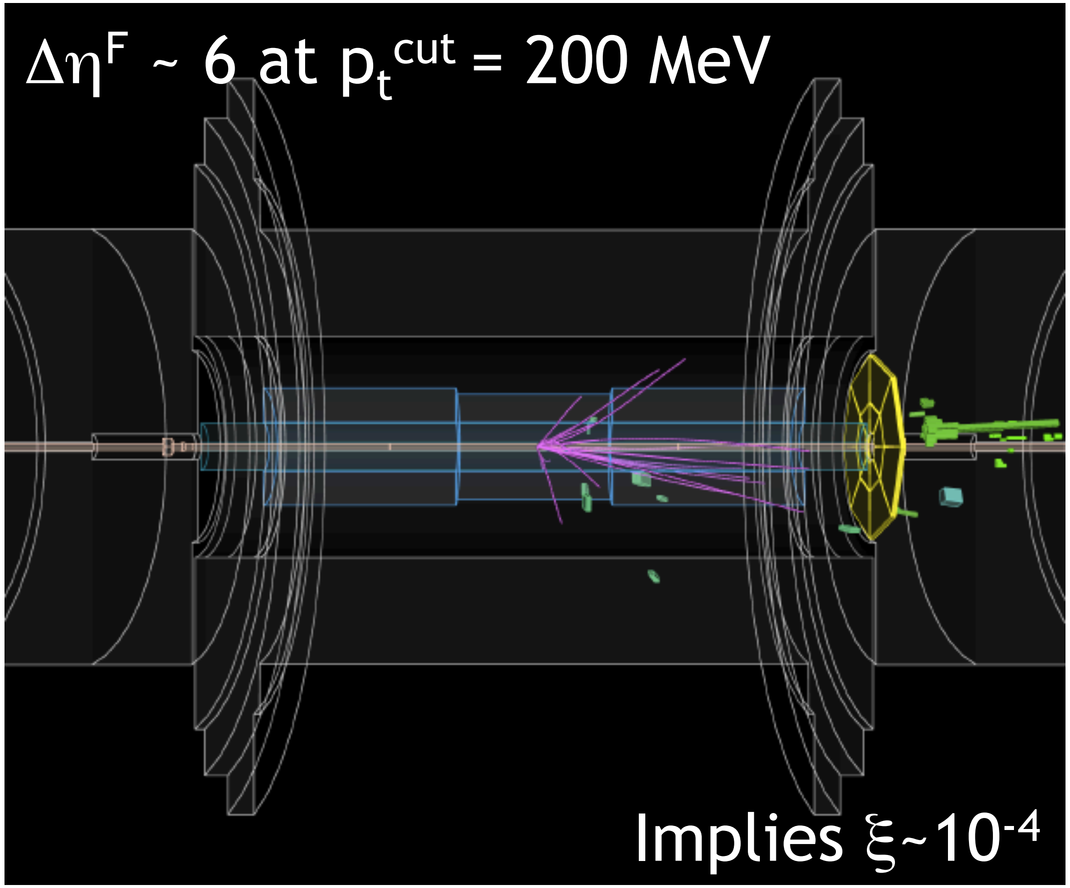
- Cross sections measured from first $\sqrt{s}$ = 7 TeV LHC run
- Differential in rapidity gap size $\Delta\eta^F$
- $\Delta\eta^F$ extends from $\eta = \pm 4.9$ to first particle with $p_t > p_t^{cut}$

[Larger of gaps at $\pm\eta$ taken]

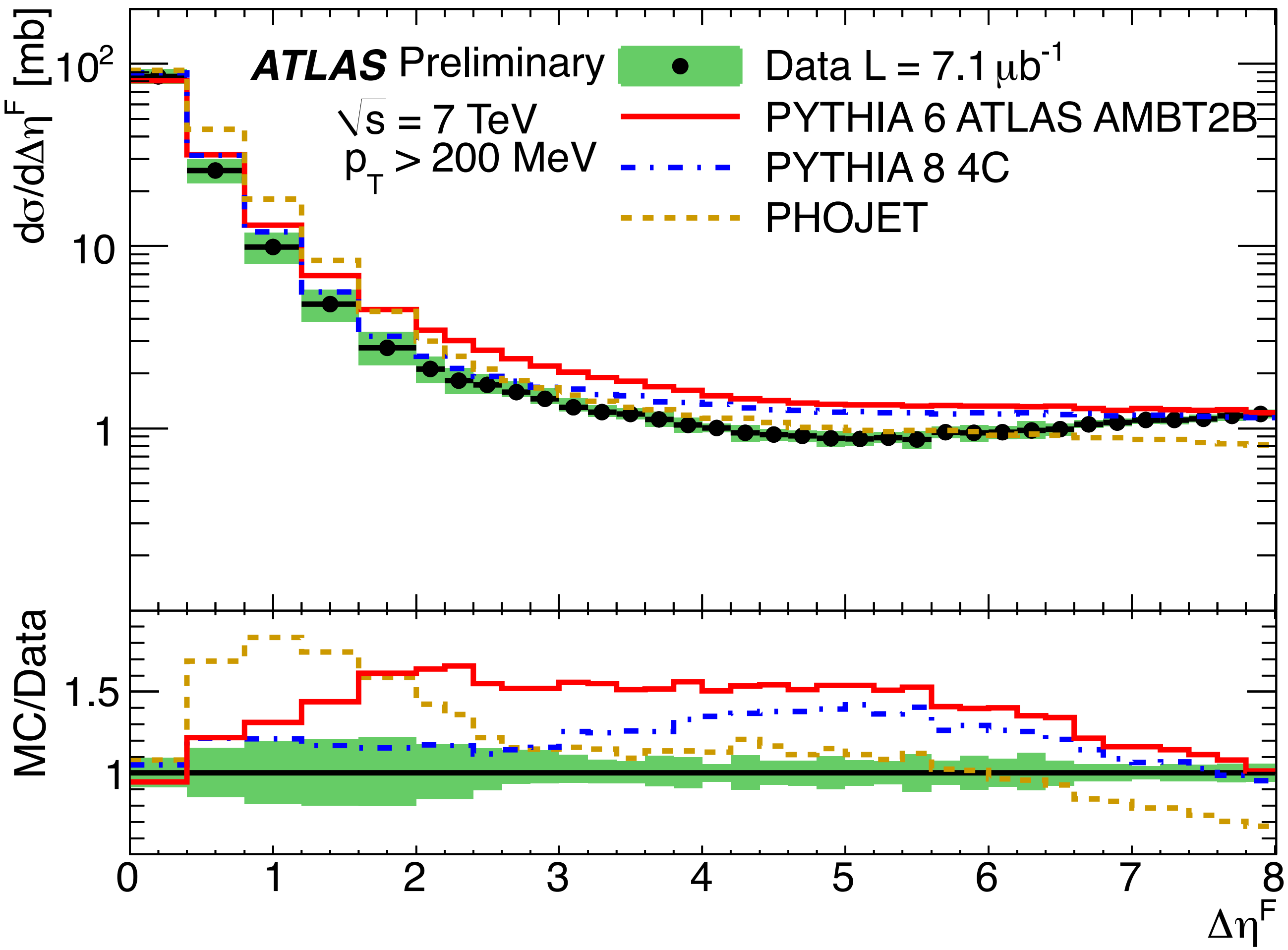
$200 \text{ MeV} < p_t^{cut} < 800 \text{ MeV}$

$0 < \Delta\eta^F < 8$

Corrected for experimental effects to level of stable hadron

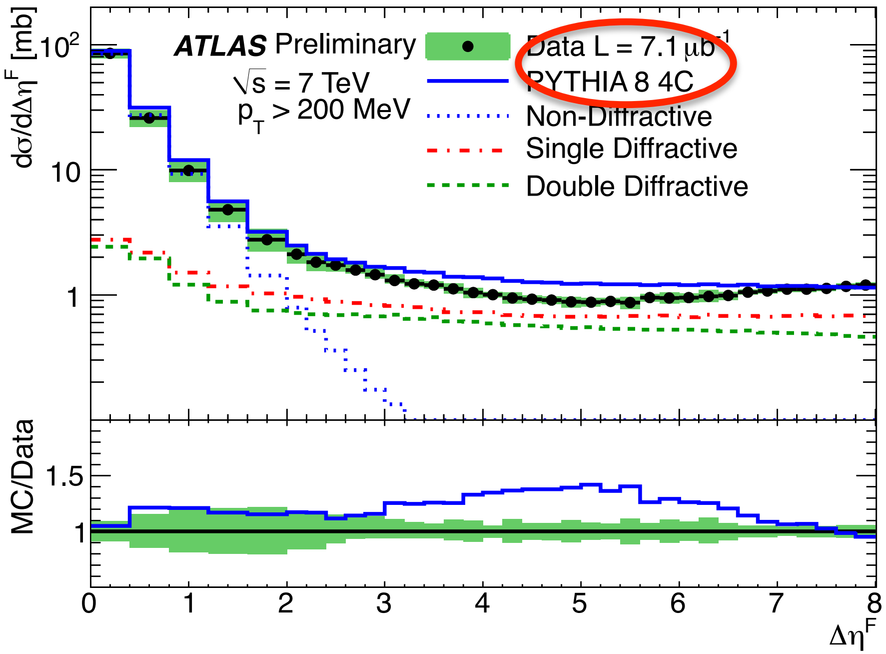


# ATLAS Differential Gap Cross Section

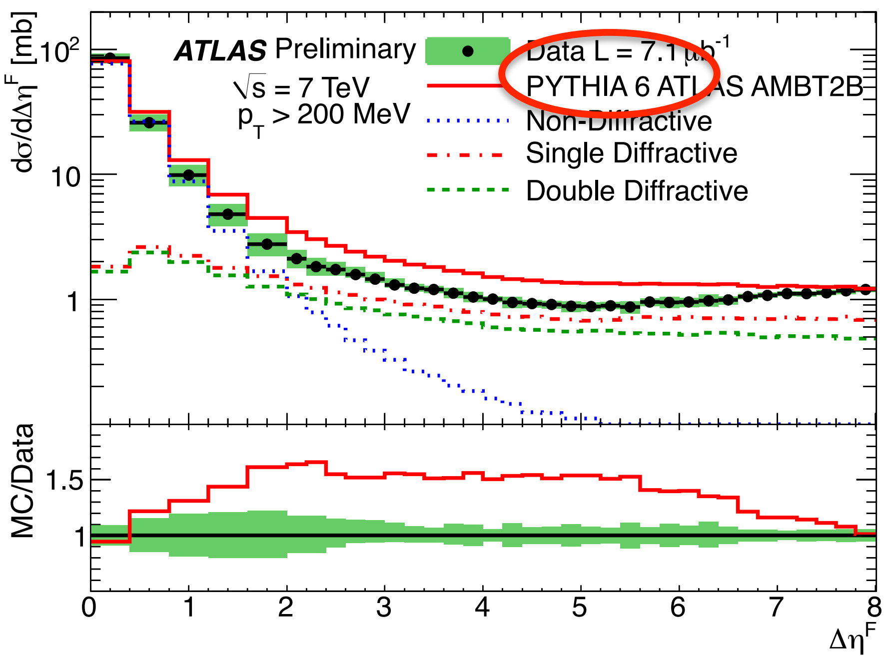


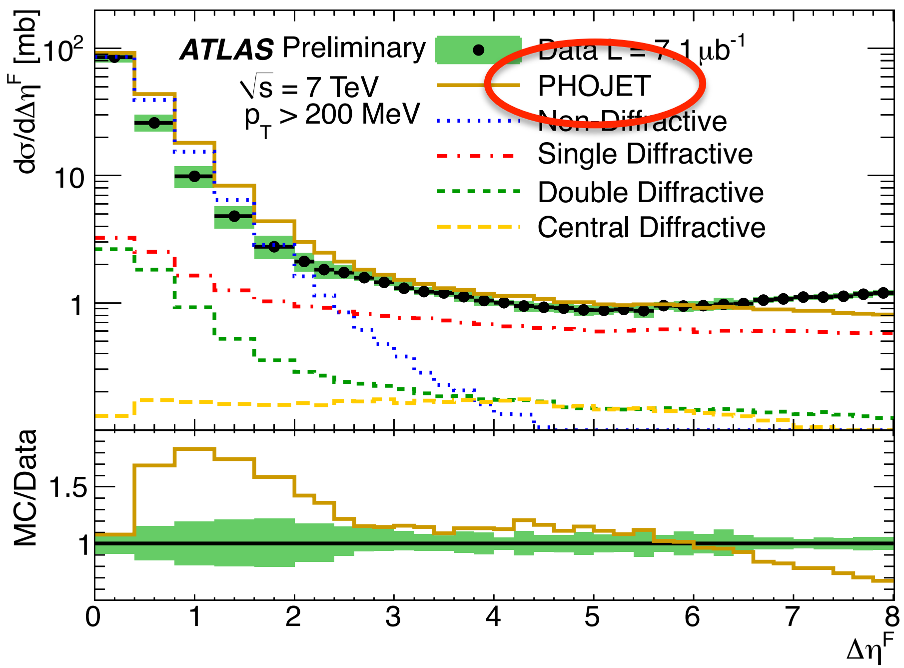

- Precision between ~8% (large gaps) and ~20% ($\Delta\eta^F$ ~ 1.5)
- Small gaps sensitive to hadronisation fluctuations / MPI
- Large gaps measure x-sec for SD [+ DD with $M_Y$ <~ 7 GeV]

# Small Gaps and Hadronisation

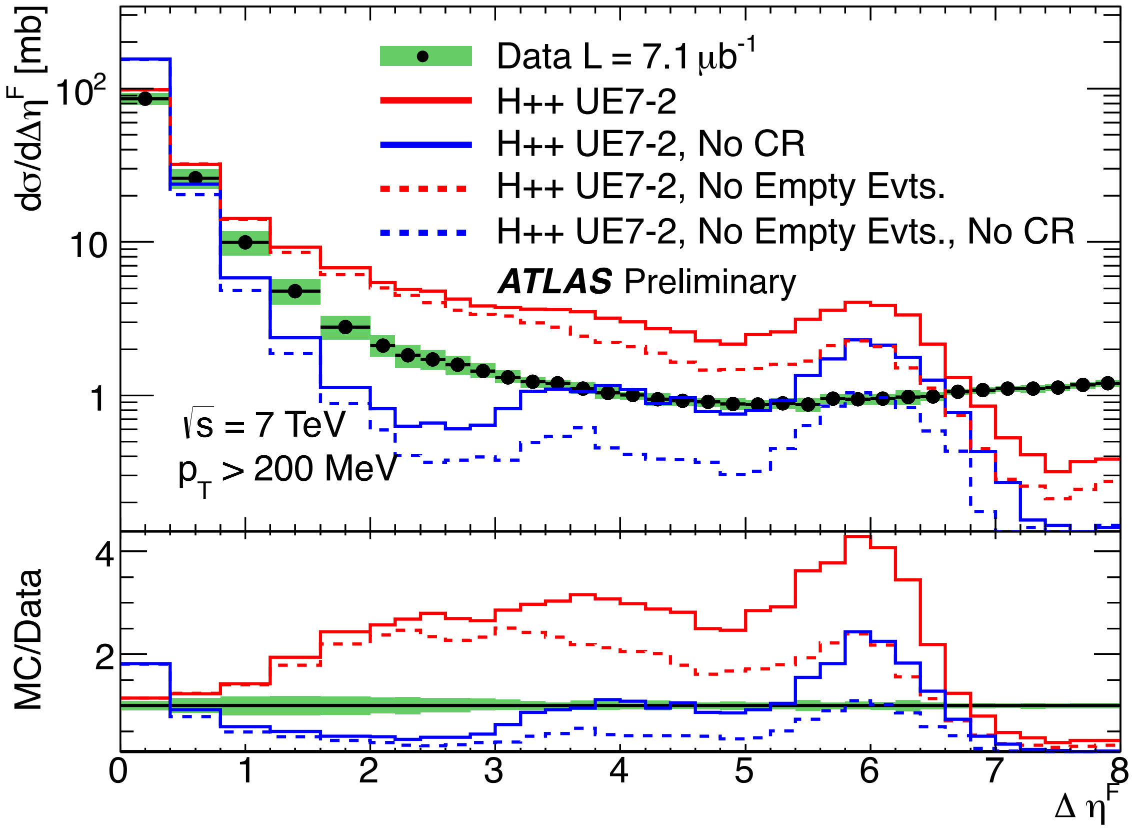



- Big variation between MCs in small non-zero gap production via ND → fluctuations / UE
- PYTHIA8 best at small gaps
- PHOJET > 50% high at $\Delta\eta^F \sim 1.5$



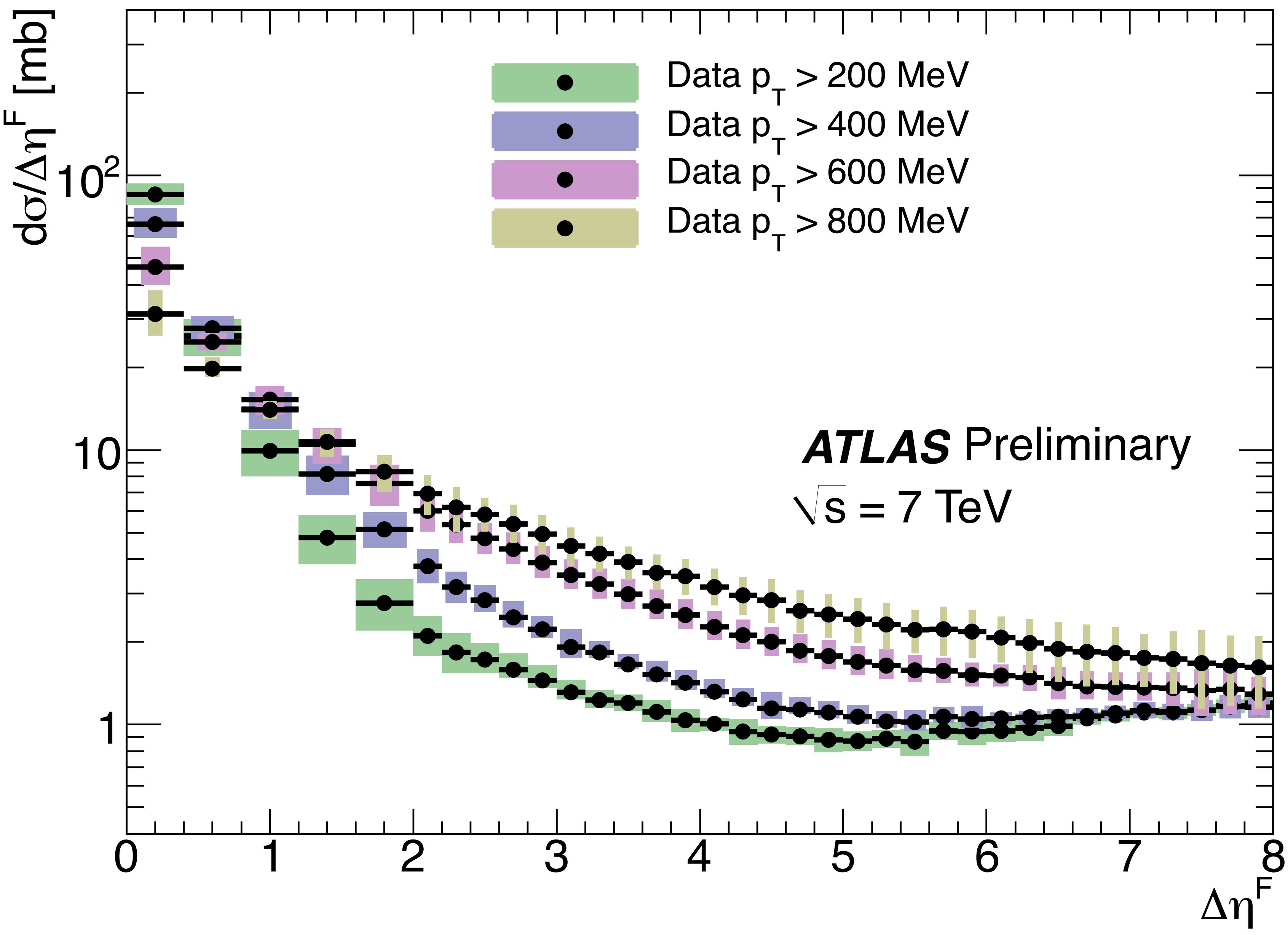
# Cluster Fragmentation: HERWIG++




- HERWIG++ with underlying event tune UE7-2 contains no explicit model of diffraction, but produces large gaps at higher than measured rate and a "bump" near $\Delta\eta^F = 6$

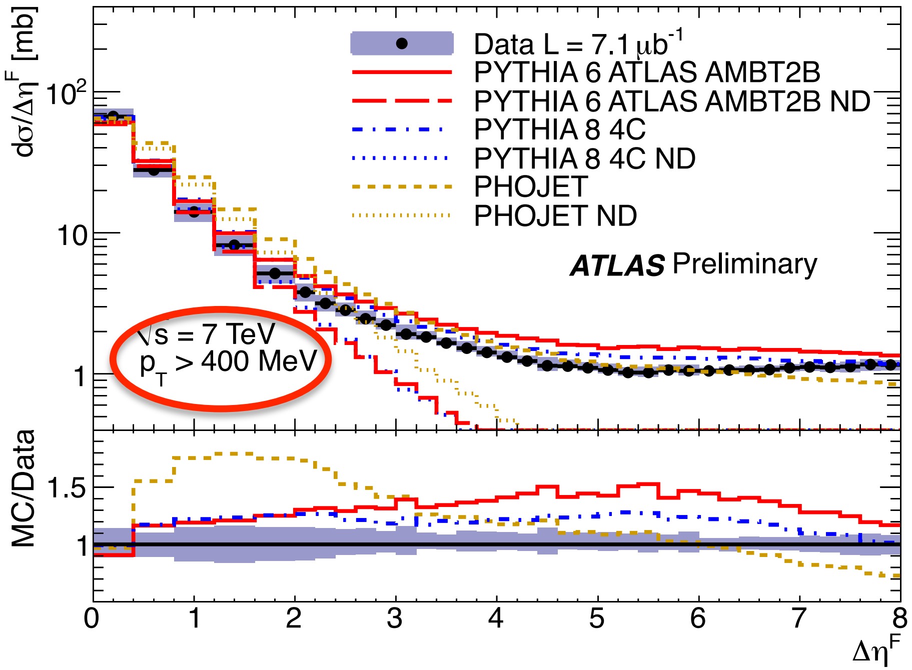
- Effect not killed by removing colour reconnection or events with zero soft or semi-hard scatters in eikonal model

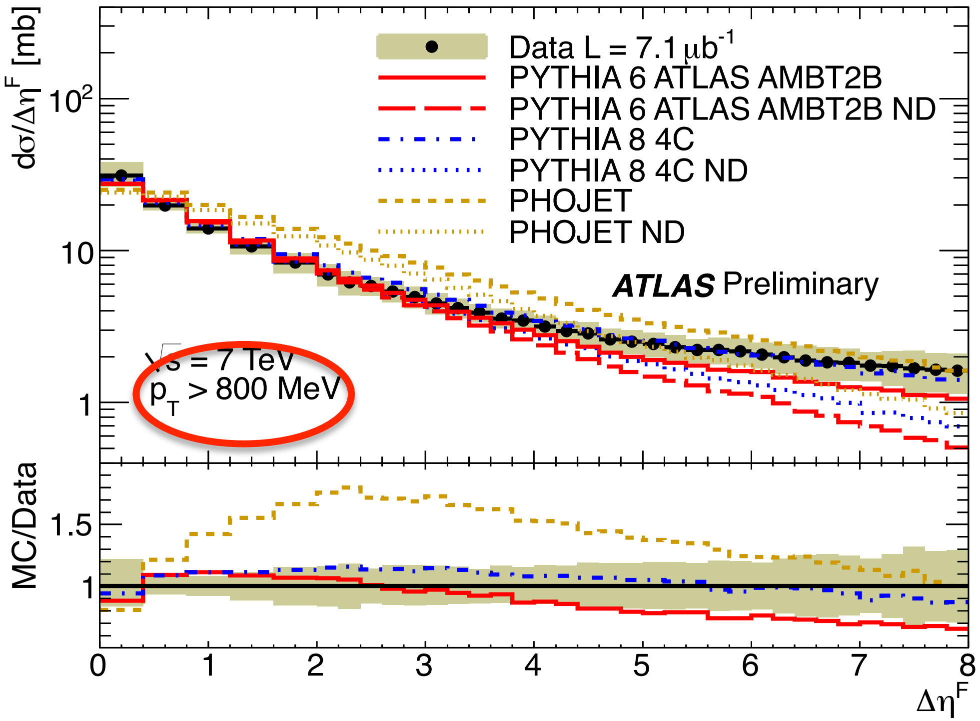
# Increasing the pt cut defining gaps



# Increasing the pt cut defining gaps

As $p_t^{cut}$ increases, data shift to larger $\Delta\eta^F$ in a manner sensitive to hadronisation fluctuations and underlying event

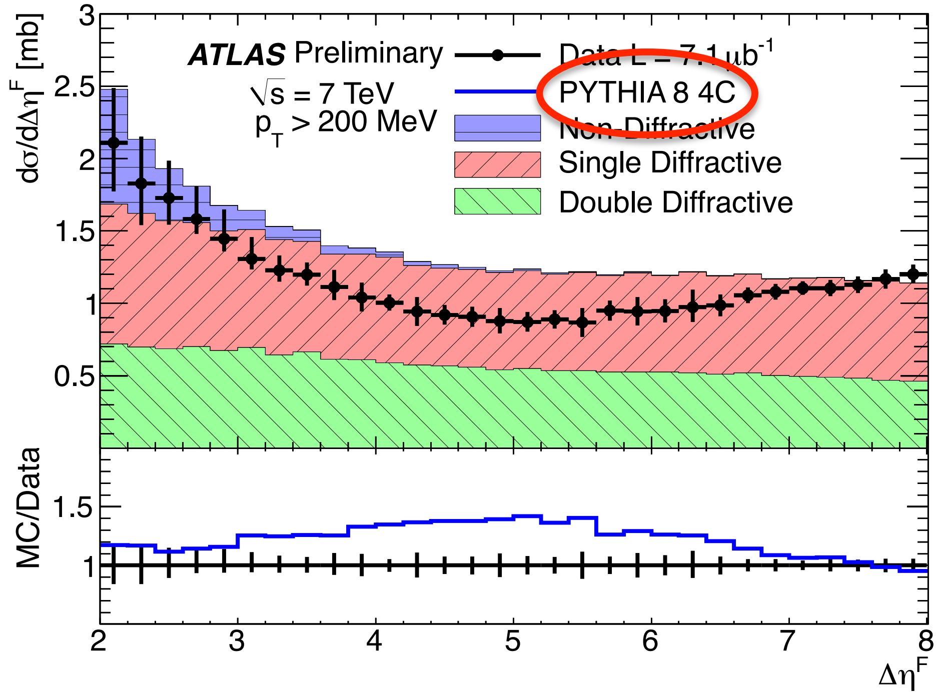



- Switching to $p_t^{cut}$ = 400 MeV doesn't change qualitative picture

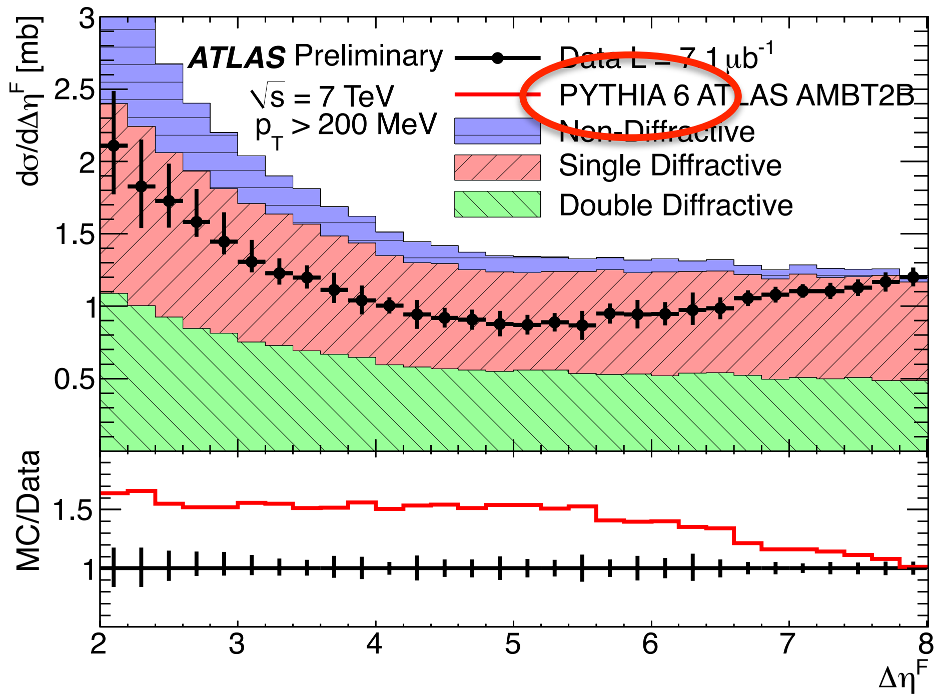
- Diffractive / non-diffractive processes barely distinguished at $p_t^{cut}$ = 800 MeV

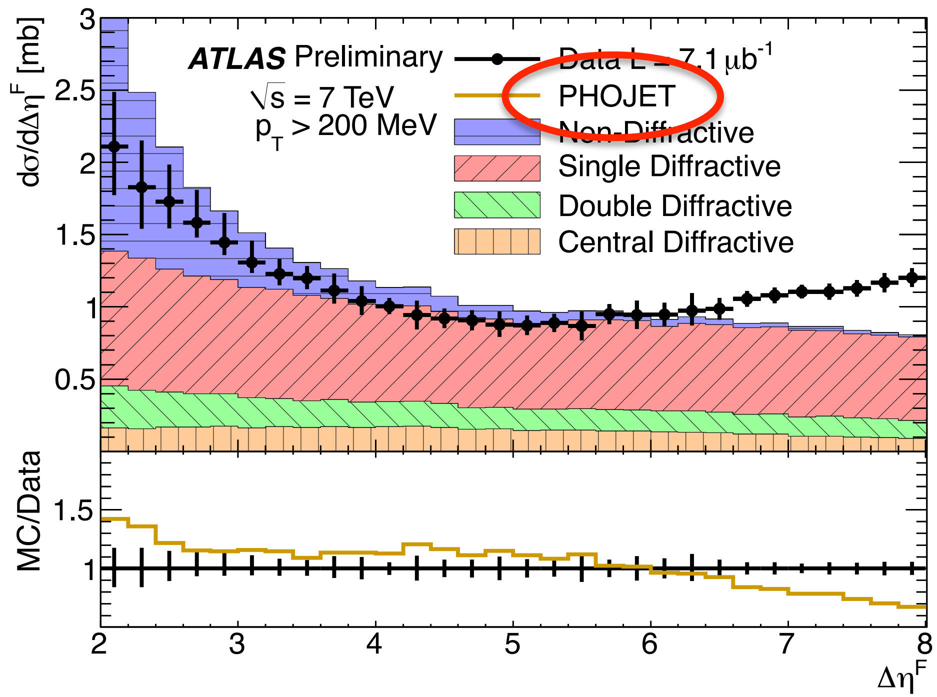
# Large Gaps and Diffractive Dynamics




-Diffractive plateau with ~ 1 mb per unit of gap size for $\Delta\eta^F > 3$ broadly described by models

- PYTHIA high (DD much larger than in PHOJET)
- PHOJET low at high $\Delta\eta^F$



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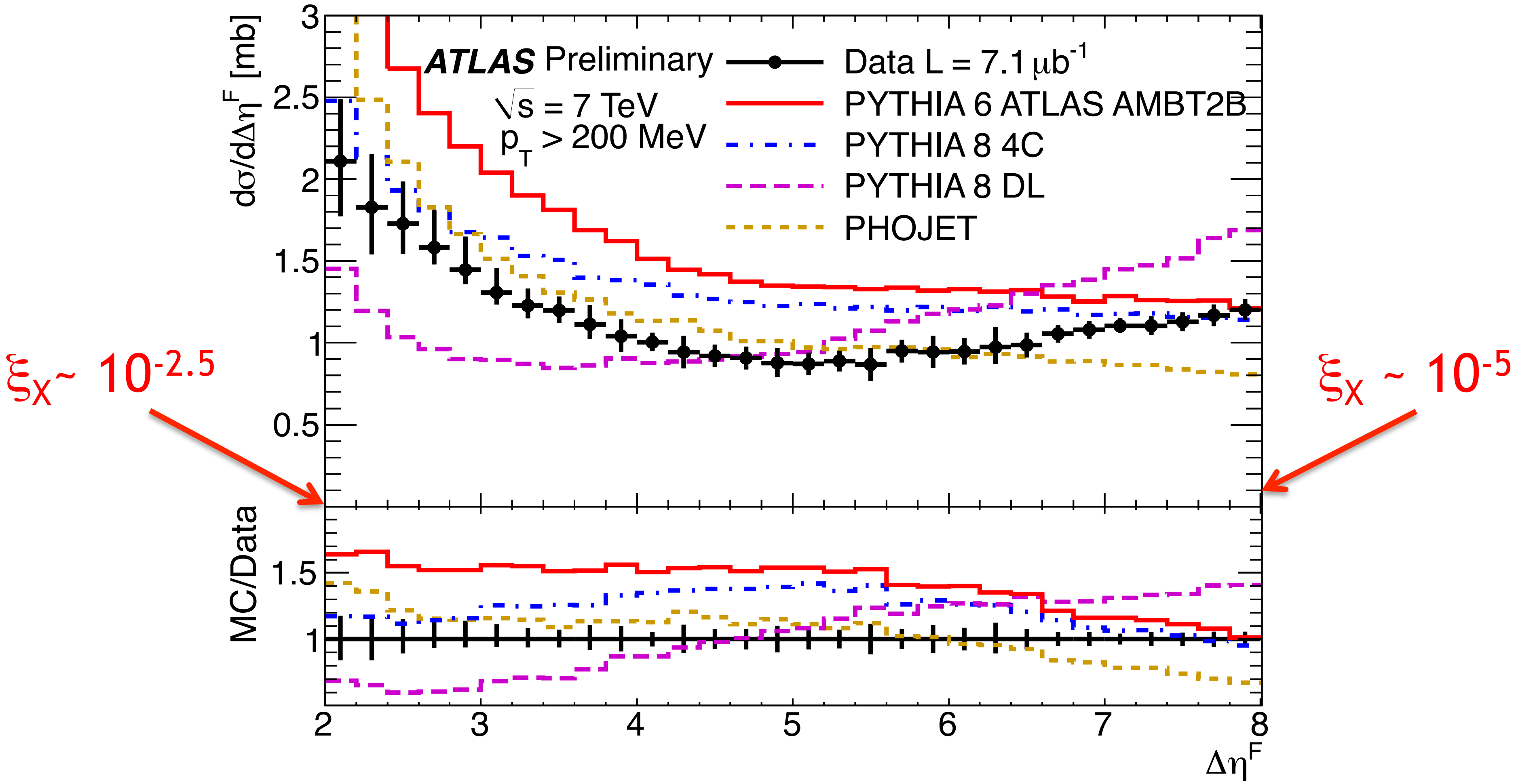



Default PHOJET and PYTHIA models have $\alpha_{IP}(0) = 1$

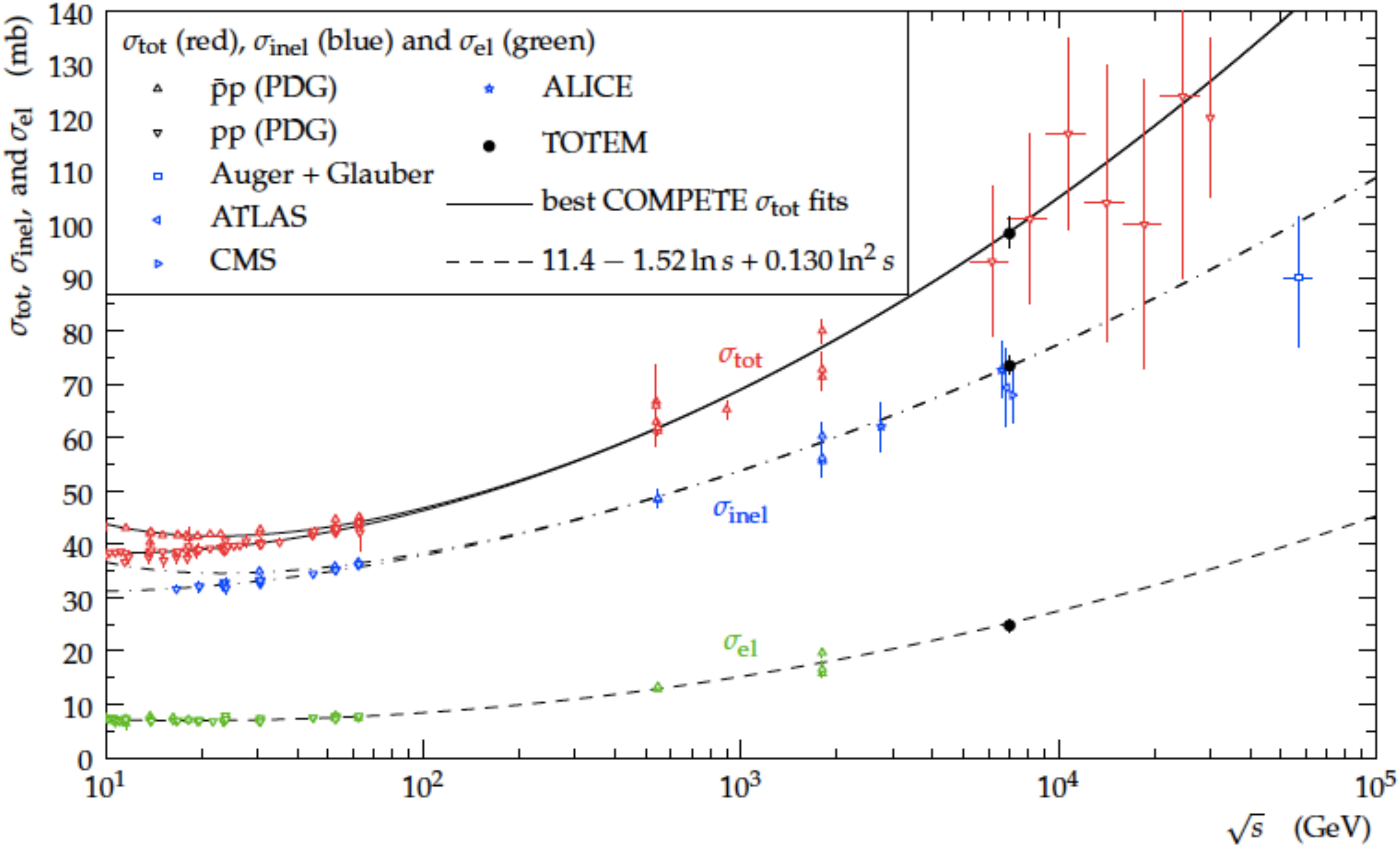
Donnachie-Landshoff flux has $\alpha_{IP}(0) = 1.085$

Data exhibit slope in between these models at large $\Delta\eta^F$

Full interpretation pending …

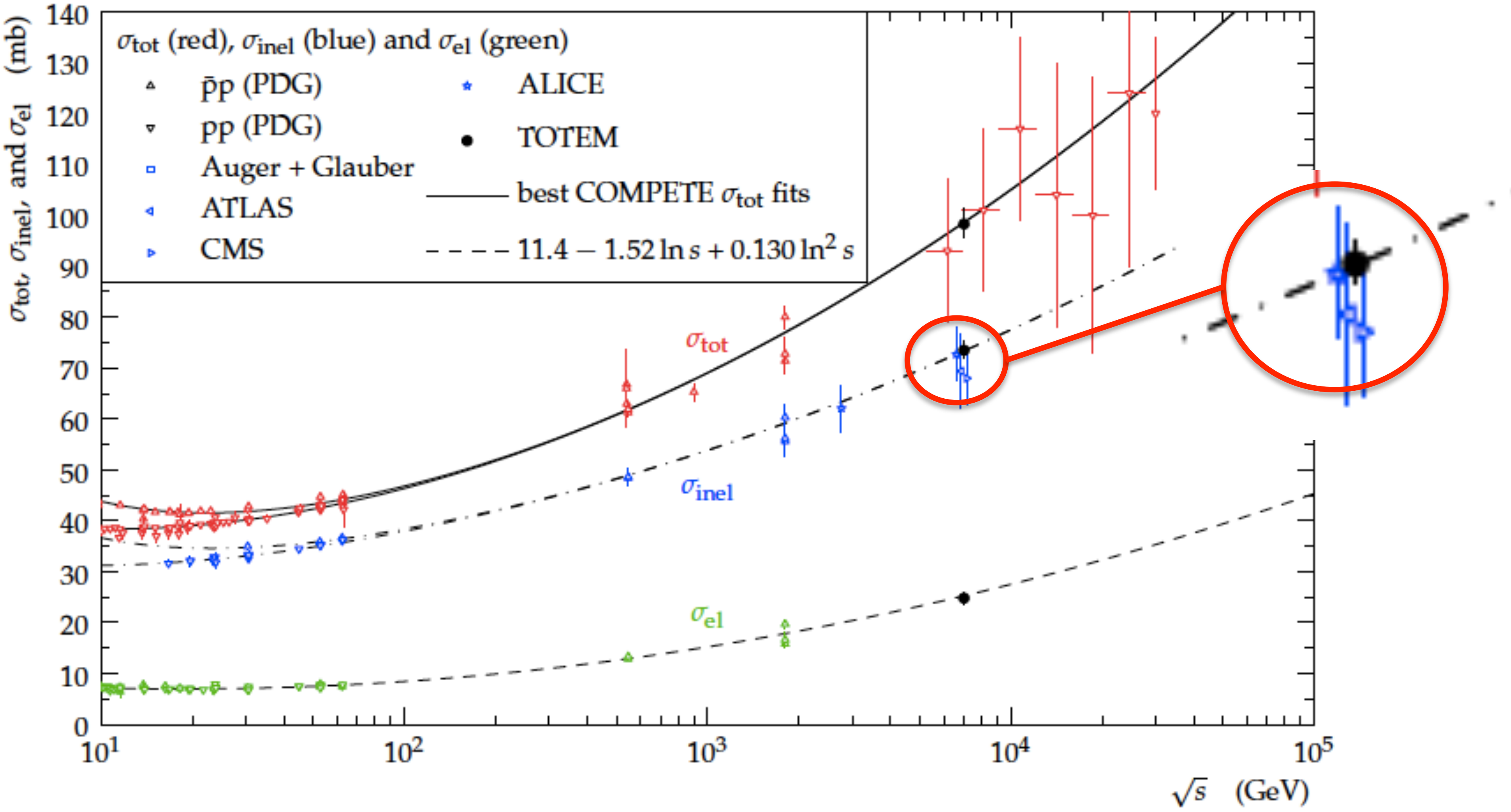
# Total Inelastic pp Cross Section

- Full current picture on total cross section (from TOTEM)

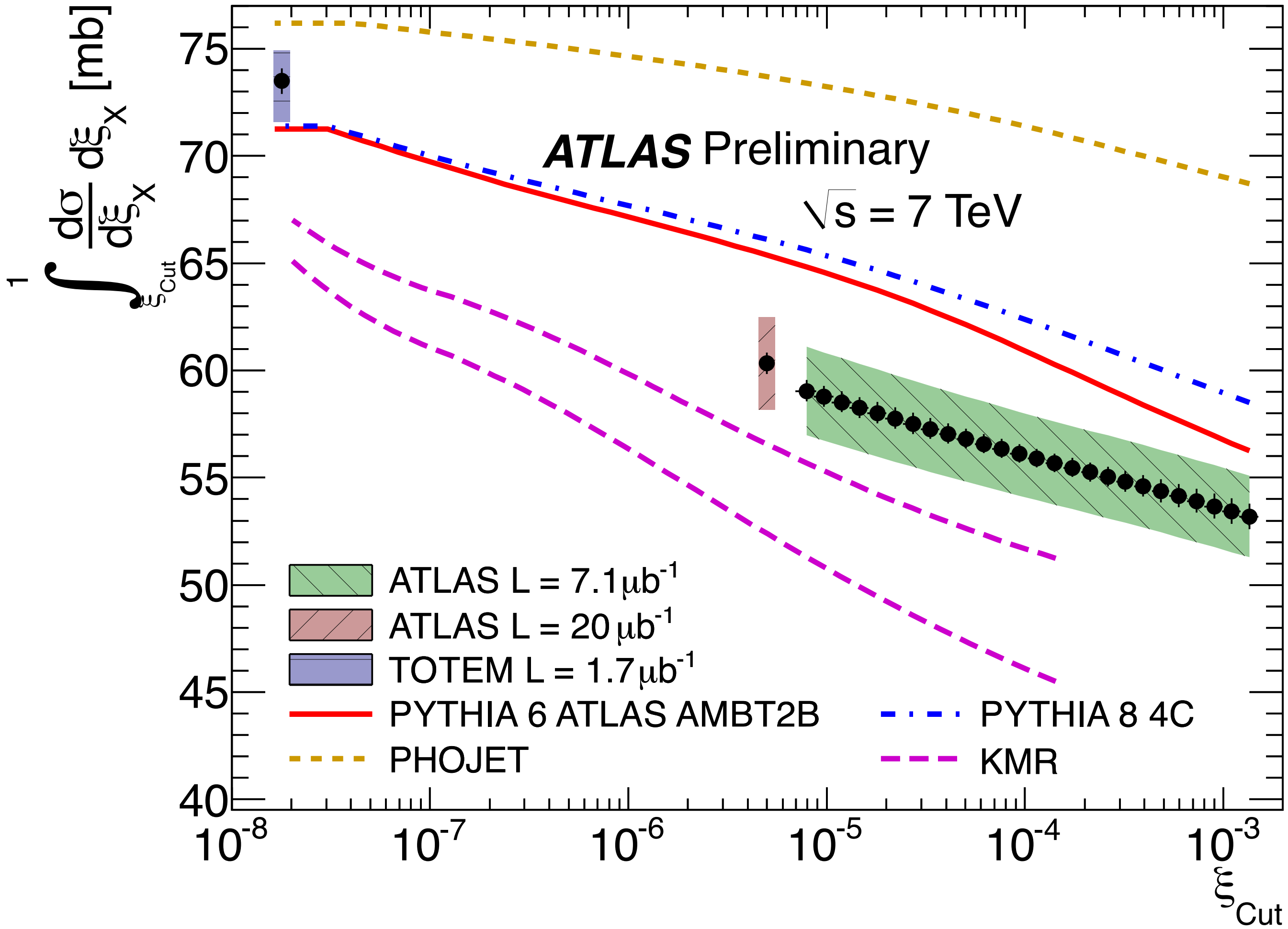


# Total Inelastic pp Cross Section

- Full current picture on total cross section (from TOTEM)
- ATLAS and CMS central values lower than TOTEM after extrap'n into region of very low ξ (extrapolation error is dominant)



# Uncertainties in Low ξ Extrapolations

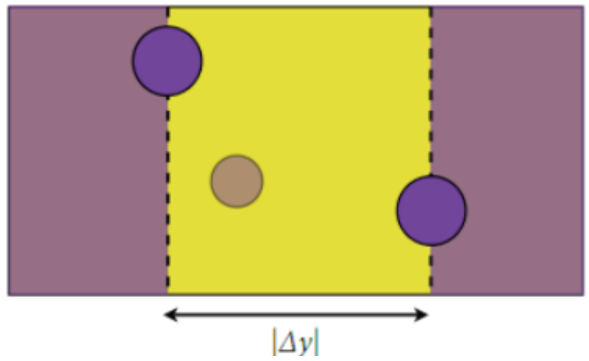


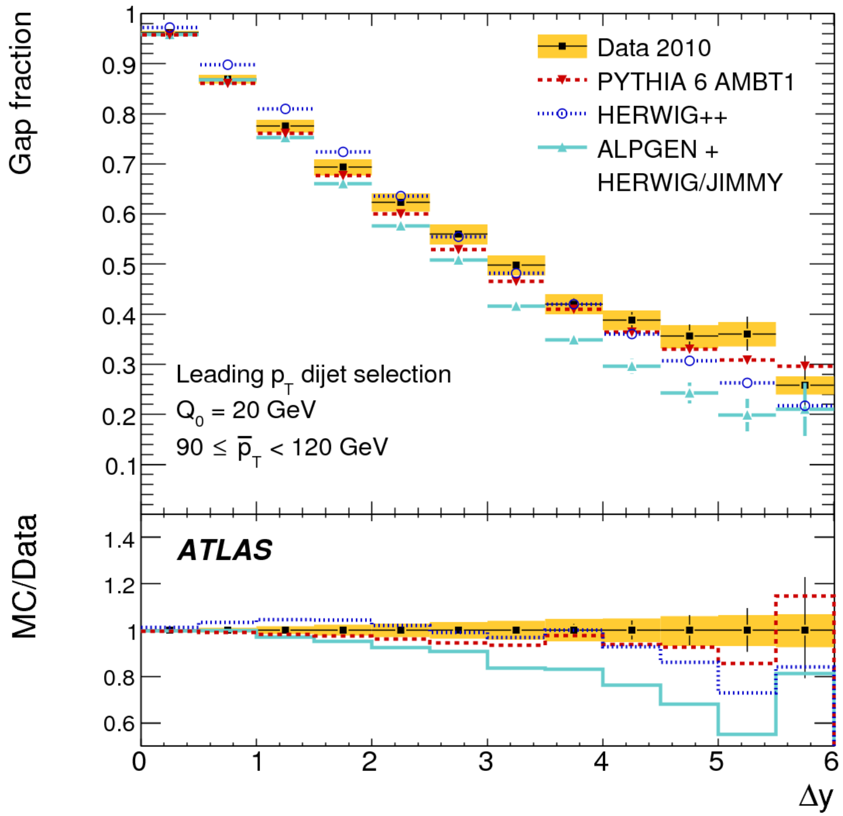

- Integrating gap cross section up to some max $\Delta\eta^F$ (equivalently min $\xi_X$) and comparing with TOTEM indicates that small $\xi_X$ region underestimated in PHOJET and PYTHIA:
- 14 mb with $\xi < 10^{-5}$, compared to 6 (3) mb in PYTHIA (PHOJET)

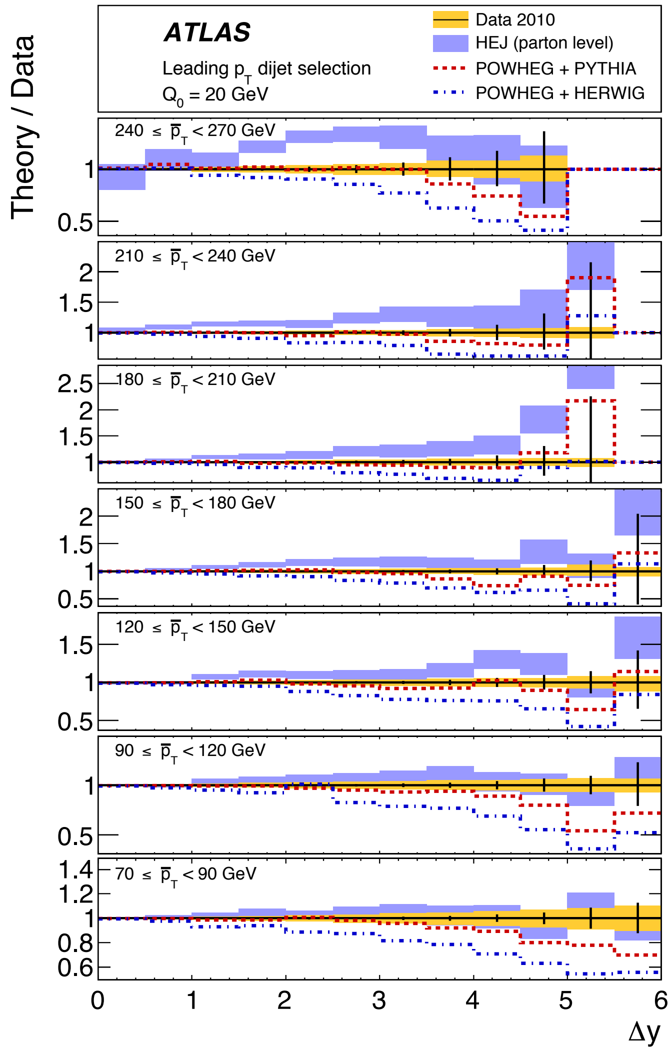
# Dijets with Vetoes

Similar approach to harder physics: gaps between jets-type topology, but with typically $E_T$ < 20 GeV in intermediate region

(JHEP 09 (2011) 053)



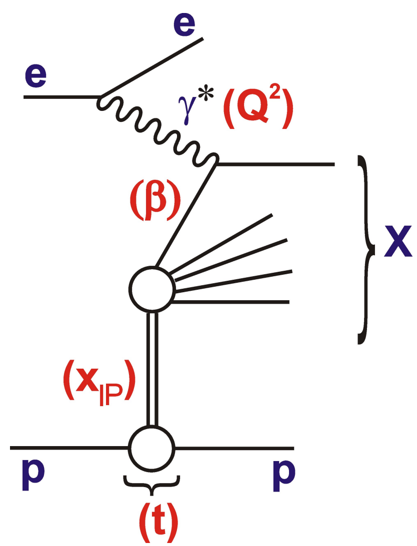



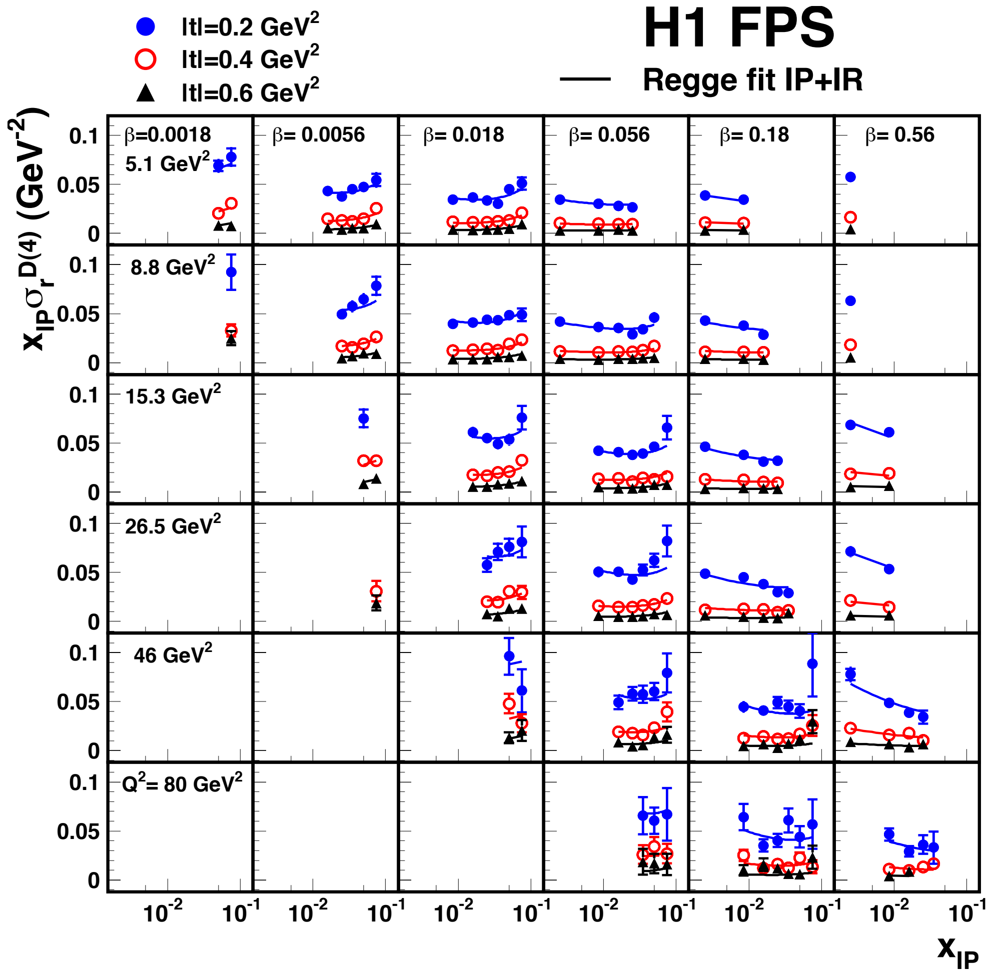



# Hard Diffraction at HERA

Inclusive data as ‘reduced’x-sec …

$$\boxed{\sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t)} = F_2^{D(4)} - \frac{y^2}{Y_+} F_L^{D(4)} \sim F_2^{D(4)}$$




Most recent developments from tagging intact protons

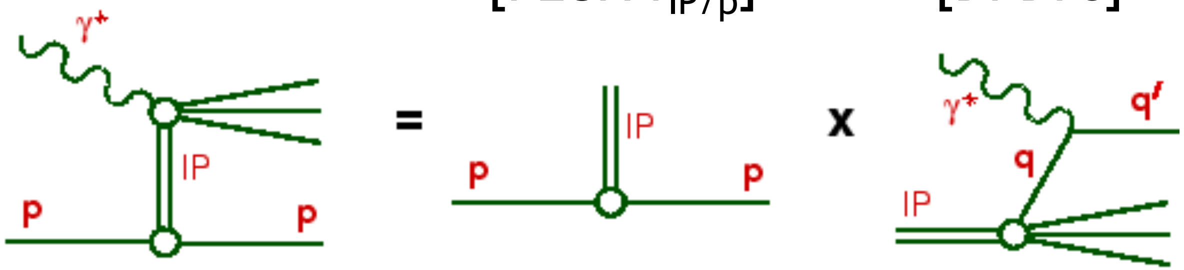
Final H1 HERA-II FPS data
→ Roman pots at 60-80m
(156 pb$^{-1}$ = 20 x HERA-I)

4D structure function, 3 t bins

Final VFPS data still to come…

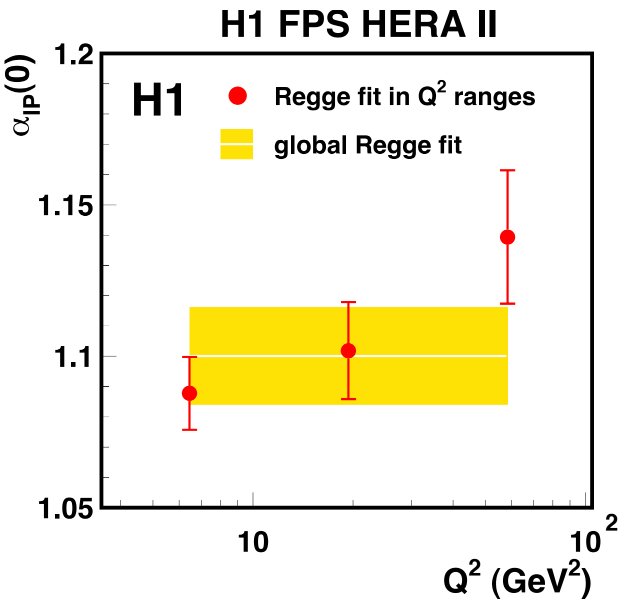
# Factorisation and Pomeron Trajectory

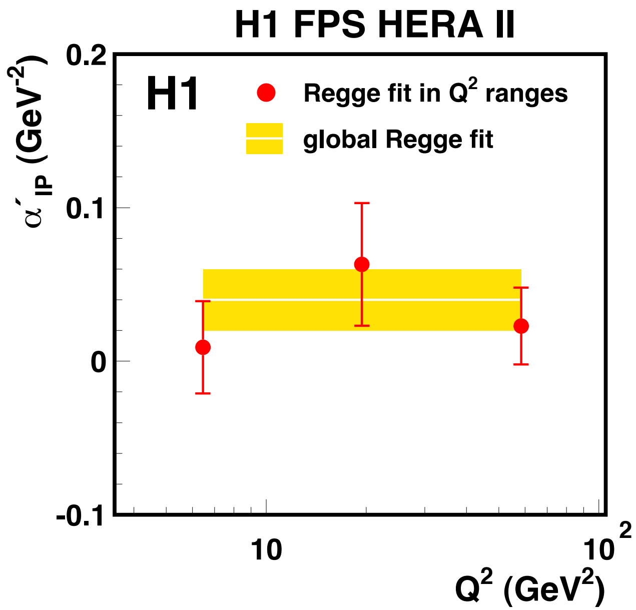
[FLUX $f_{IP/p}$] [DPDFs]

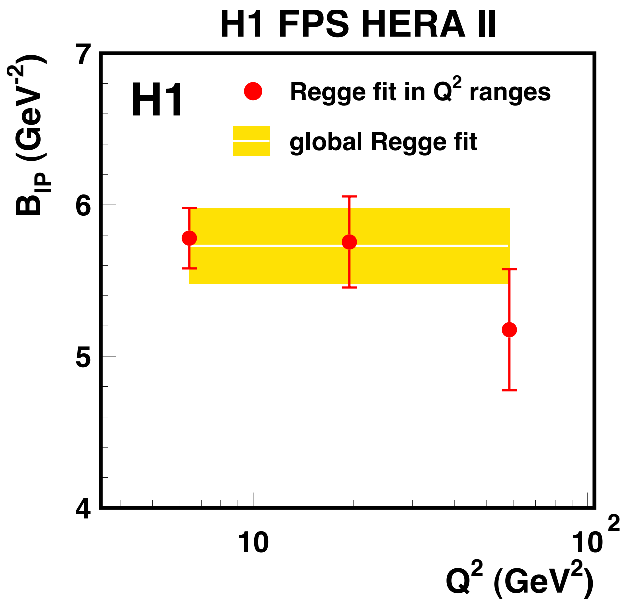



$$f_{IP/p}(x_{IP},t) = \frac{e^{B_{IP}t}}{x_{IP}^{2\alpha_{IP}(t)-1}}$$

$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP}t$$




No evidence for $Q^2$ or $\beta$ dependence of $\alpha_{IP}(t)$ or t slope

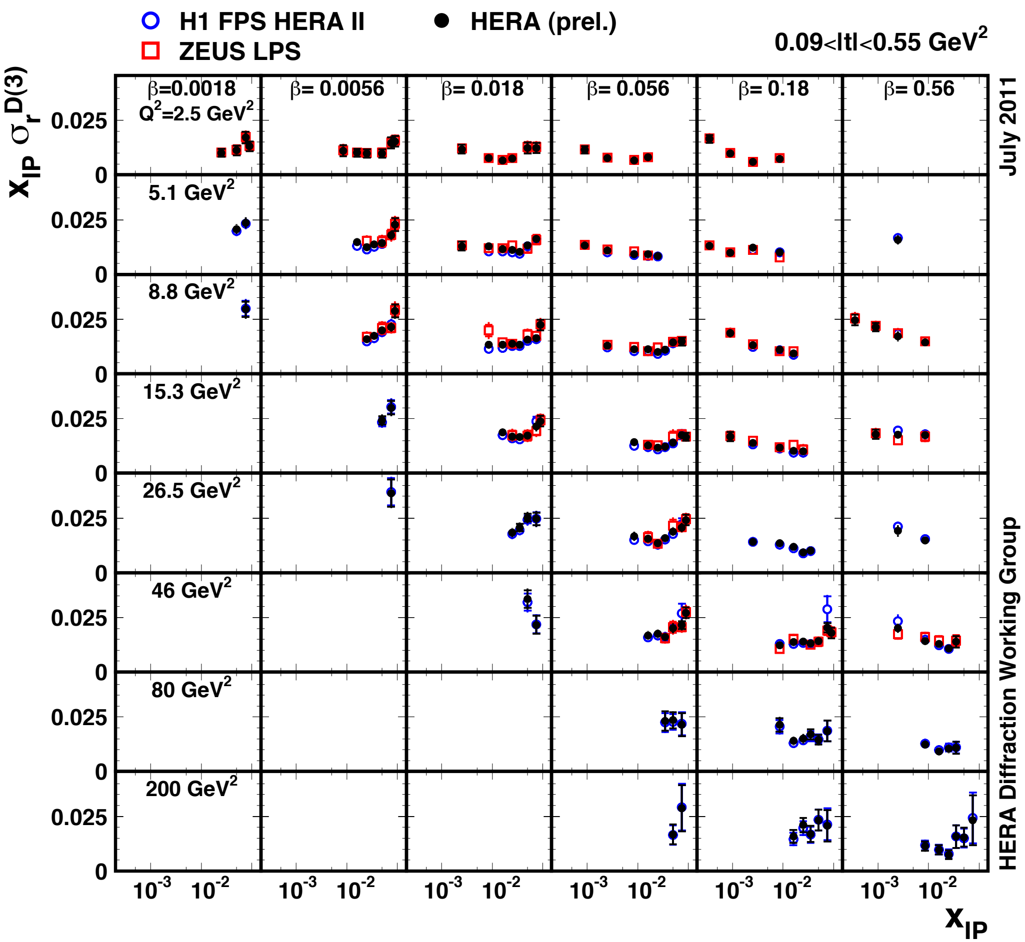
$\alpha_{IP}(0)$ consistent with soft IP → Dominantly soft exchange

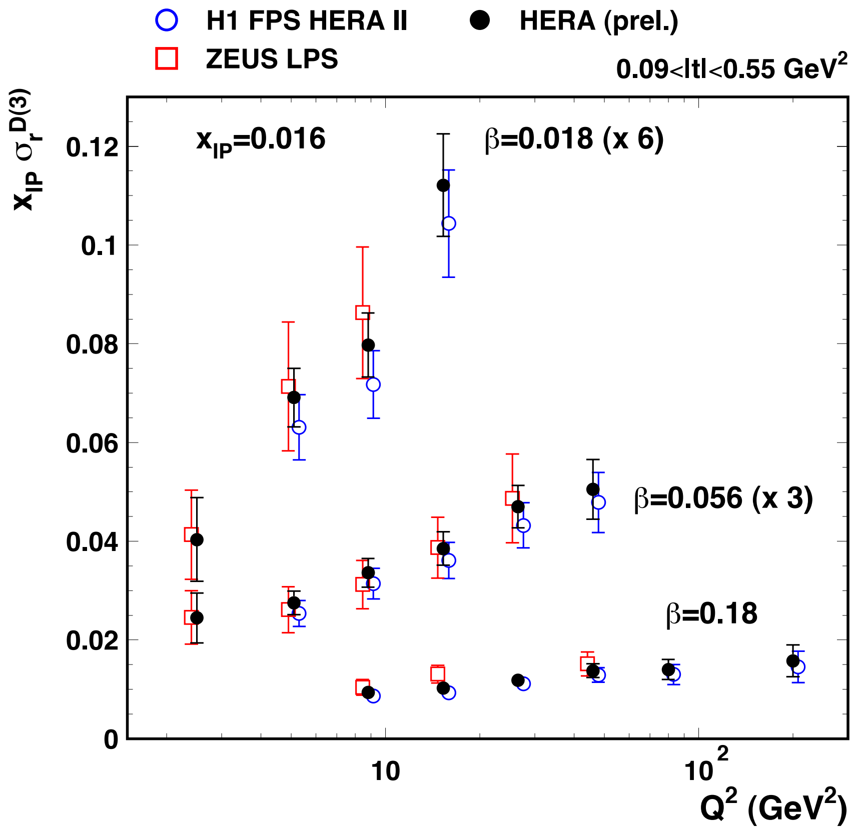
$\alpha_{IP}$' smaller than soft IP → Absorptive effects?...

# First H1-ZEUS Combined Diffractive Data

Proton tagged data in region of mutual acceptance:

H1/ZEUS norm: = 0.91 ± 0.01 (stat) ± 0.03 (syst) ± 0.08 (norm)

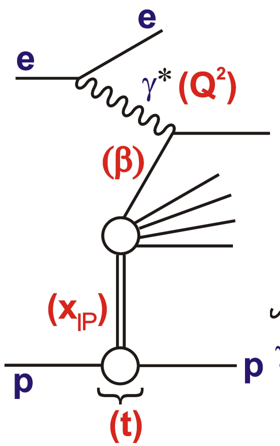


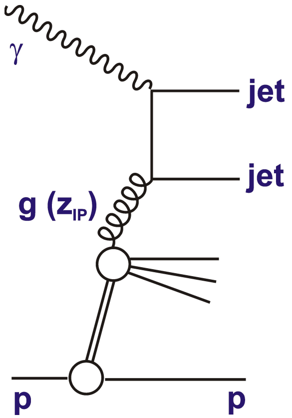



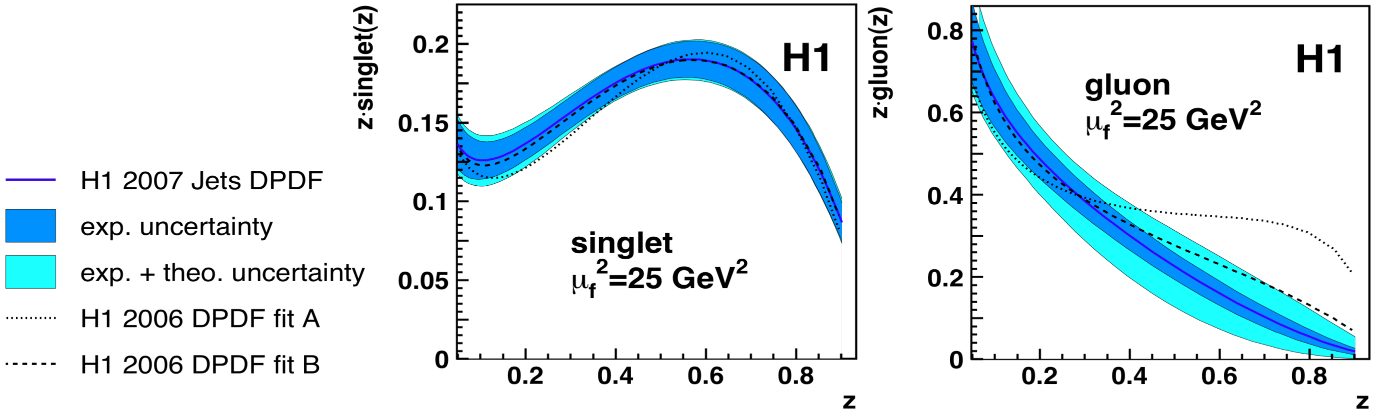

Improvements beyond the statistical → cross-calibration of systematics

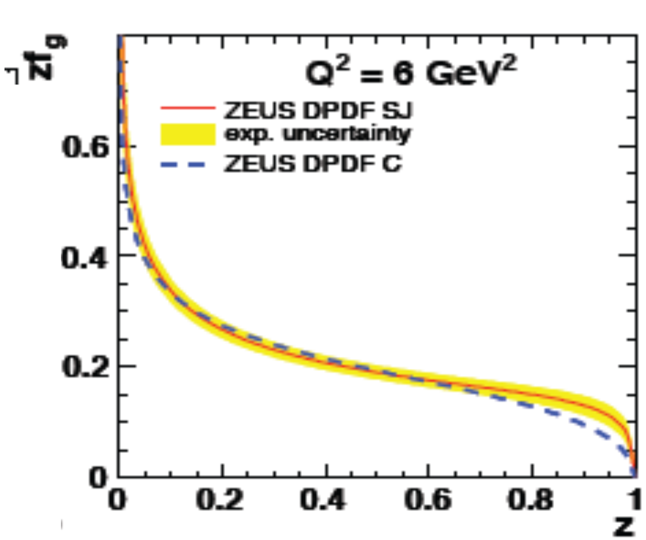
More to follow …

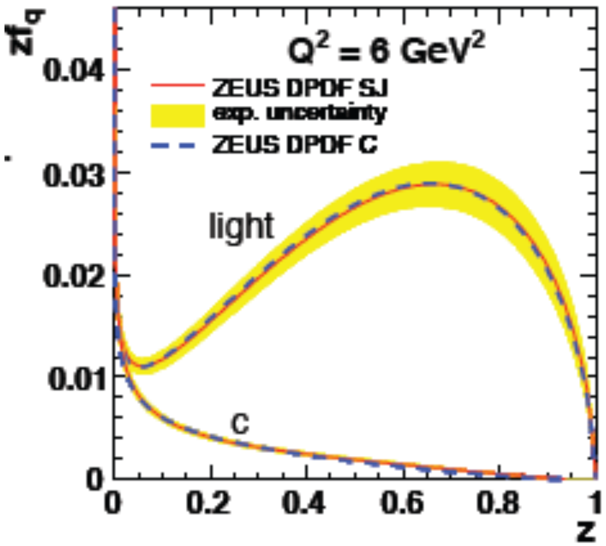
# Hard Processes: Diffractive PDFs



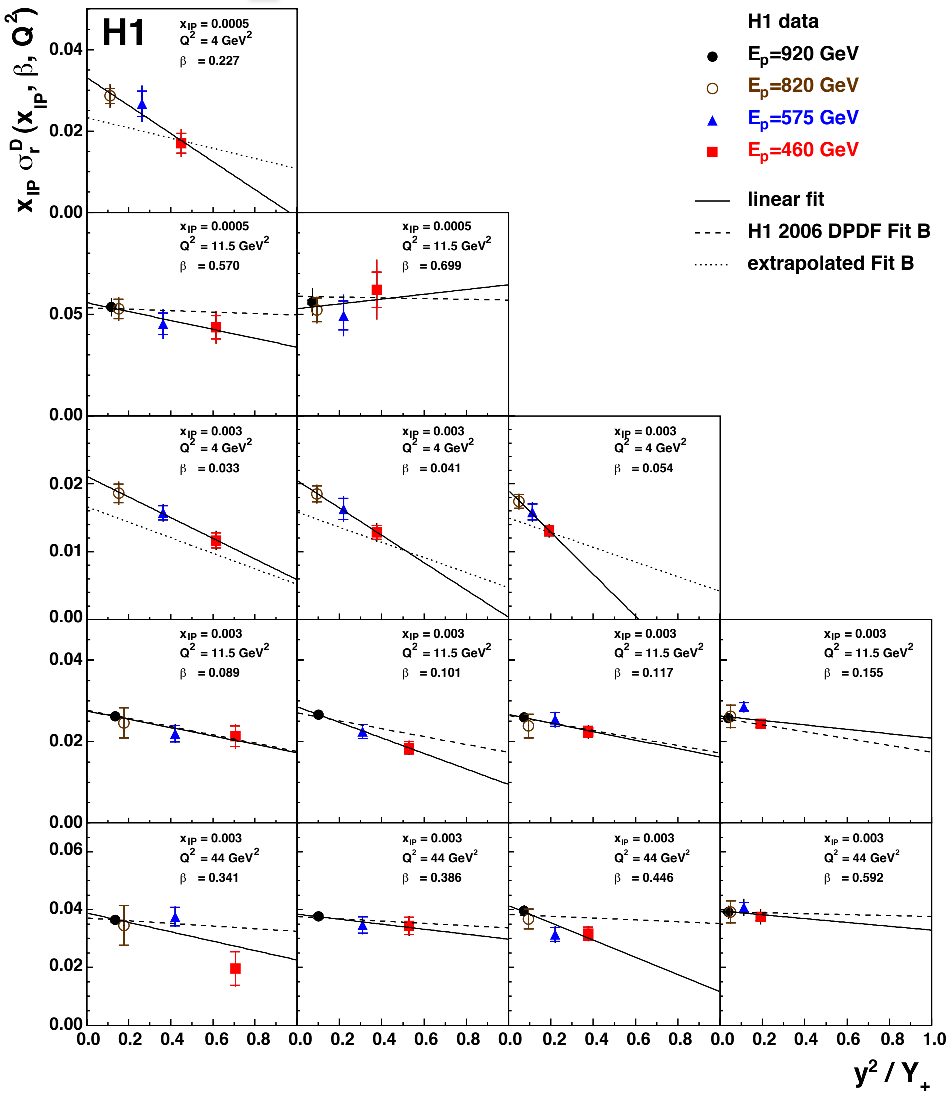




Lead to impressive descriptions of all hard diffractive DIS data

DPDFs dominated by a gluon density which extends to large z

# Testing the DPDFs: First $F_L^D$ Measurement




$$\sigma_r^{D(3)}\left(\beta, Q^2, x_{IP}, \sqrt{s}\right) = F_2^{D(3)} - \frac{y^2}{Y_+} F_L^{D(3)}$$

Investigate role of longitudinally polarised photons in bulk of diffractive DIS

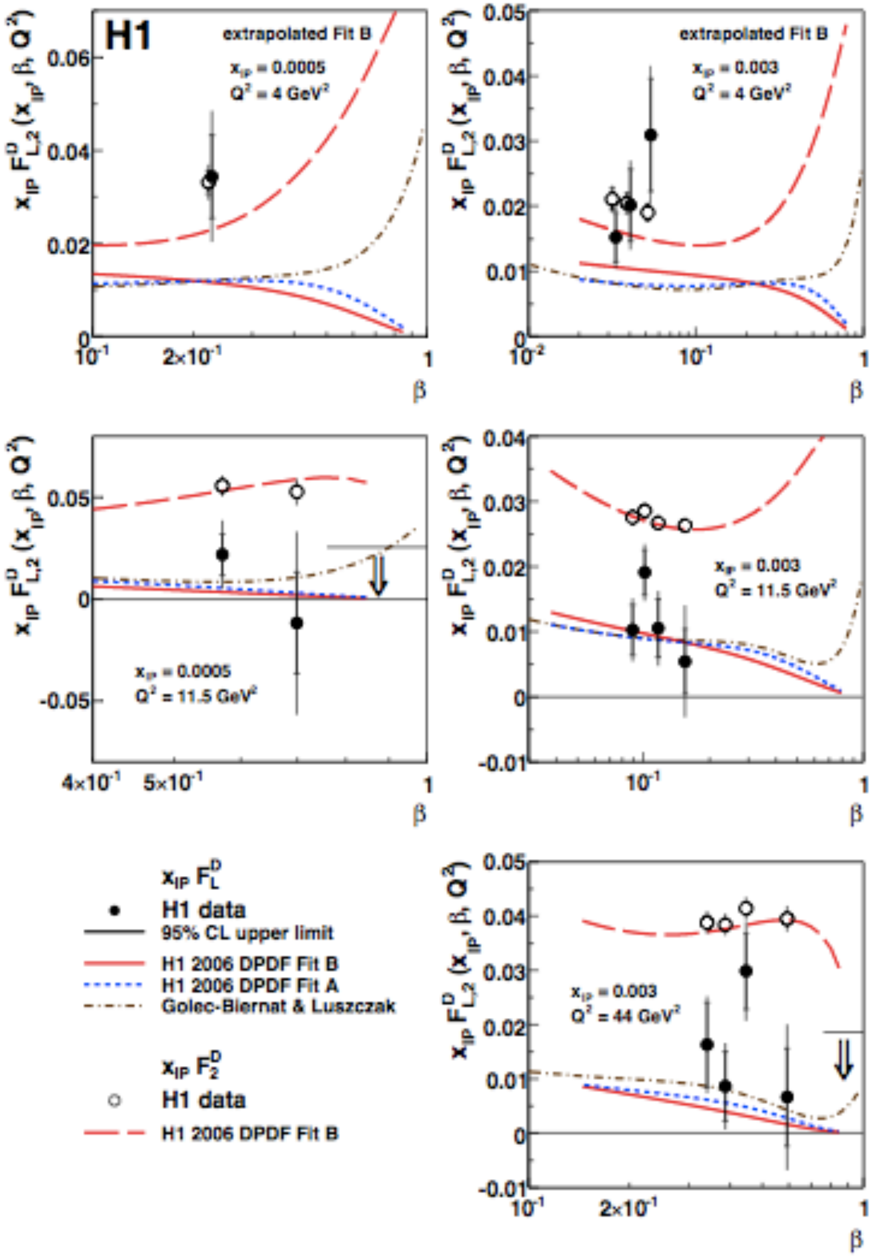
Novel test of diffractive gluon density

… $F_L^D$ sensitivity @ highest y ($E_e \to$ 3.4 GeV)
… vary $E_p$ $\to$ change y at fixed $\beta$, $x_{IP}$, $Q^2$

Large Rapidity Gap data

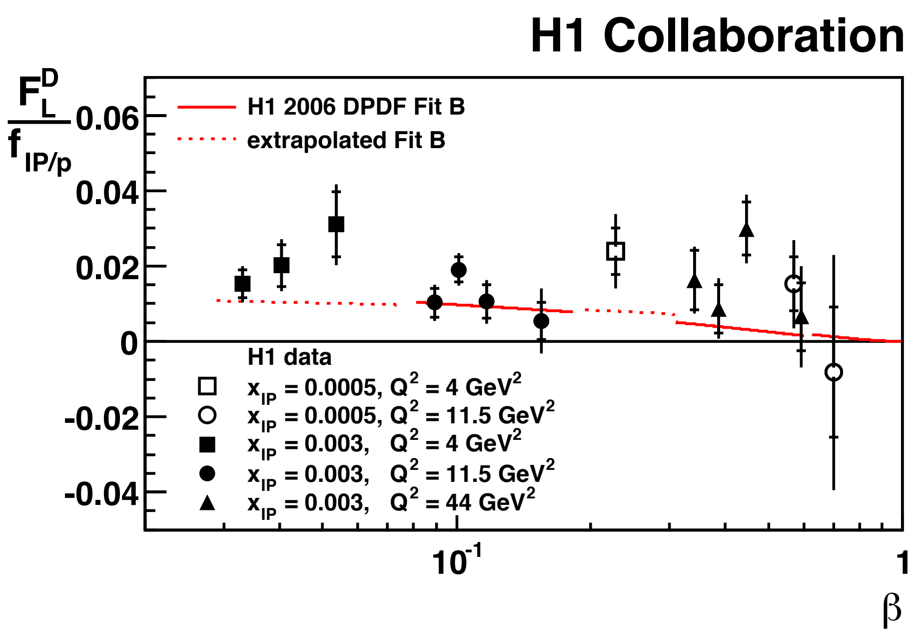
… 11pb$^{-1}$ @ 575 GeV, 6pb$^{-1}$ @ 460 GeV, in addition to 820 GeV, 920 GeV data

# $F_L^D$ Measurement



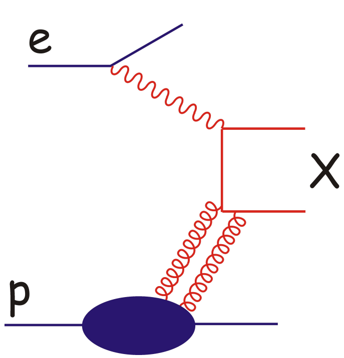

- $F_L^D$ shown to be several σ from zero over wide β range

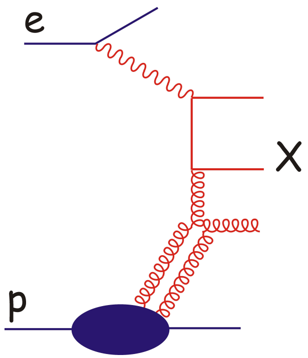
- Compatible with all predictions based on NLO DGLAP fits to $\sigma_r^D$, including model with large higher twist $F_L^D$ component as $\beta \rightarrow 1$



# Forward Jets in Diff DIS

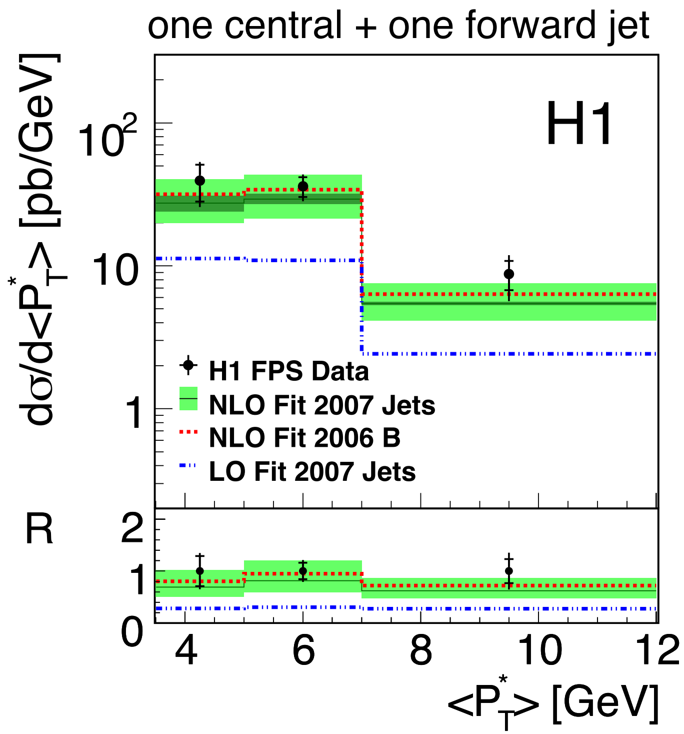
New analysis with FPS proton tag …
extends $x_{IP}$ and $\eta_{jet}$ ranges … search for ‘hard’ pQCD-calculable contributions … exclusive 2/3 jets with DGLAP $p_t$ ordering broken?

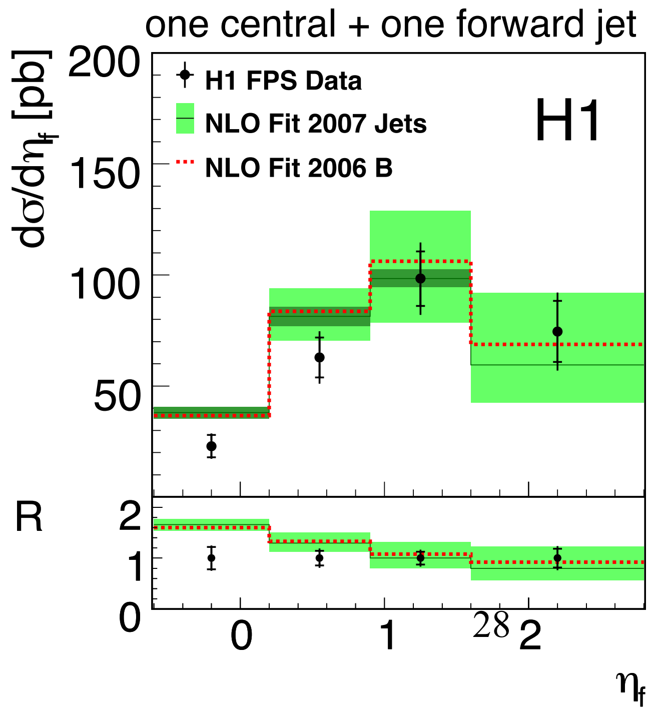



$p_t$ > 3.5 GeV, $m_{jj}$ > 12 GeV
Forward jet: 1 < $\eta_{fwd}$ < 2.8
Central jet -1 < $\eta_{cen}$ < $\eta_{fwd}$

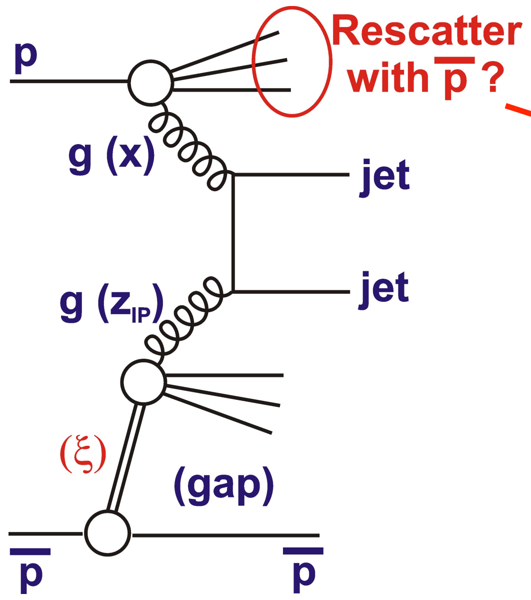
… No evidence for configurations beyond those predicted from NLO DGLAP & DPDFs

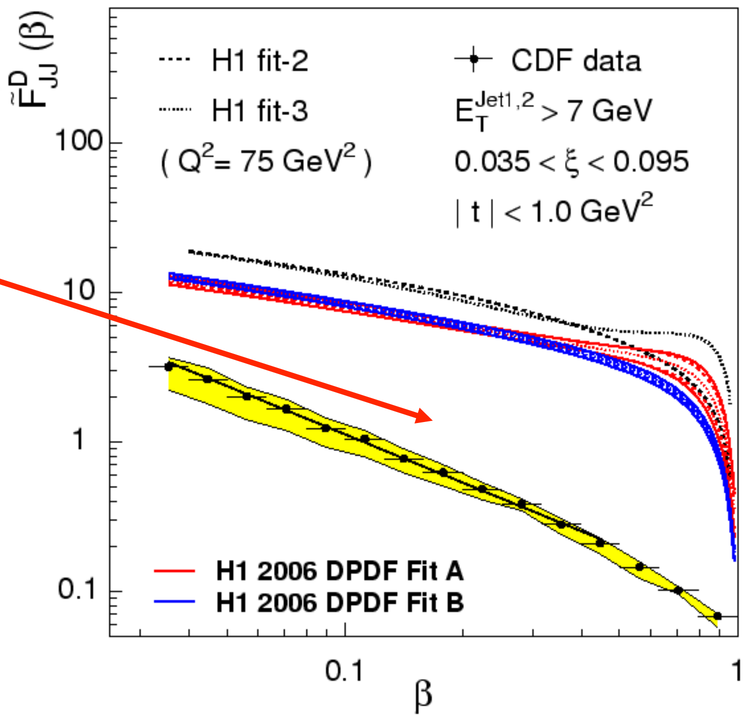


# Predicting Tevatron Data

Tevatron effective DPDFs from dijets show strong factor$^n$ breaking compared with HERA DPDFs … \`gap survival' factor $S^2$ ~ 0.1




… usually explained by multiple interactions / absorption

• Rapidity gap survival probabilities should in principle be calculable using multiple (~~parton~~?) interaction models

• However (in contrast to most MPI models) impact parameters are usually large (governed by t) → Challenging!

Currently described by soft phenomenology (Durham, Tel Aviv)

# Hard Diffraction: Tevatron

Most recent paper from CDF: Phys Rev D82 (2010) 112004:
Using Roman pot proton taggers …
Diffraction with $0.03 < \xi < 0.1$, $|t| < 1$ GeV$^2$ accounts for

- $1.00 \pm 0.05$ (stat.) $\pm 0.10$ (syst.) % of W production
- $0.88 \pm 0.21$ (stat.) $\pm 0.08$ (syst.) % of Z production

at the Tevatron (suggests small gap survival probability)

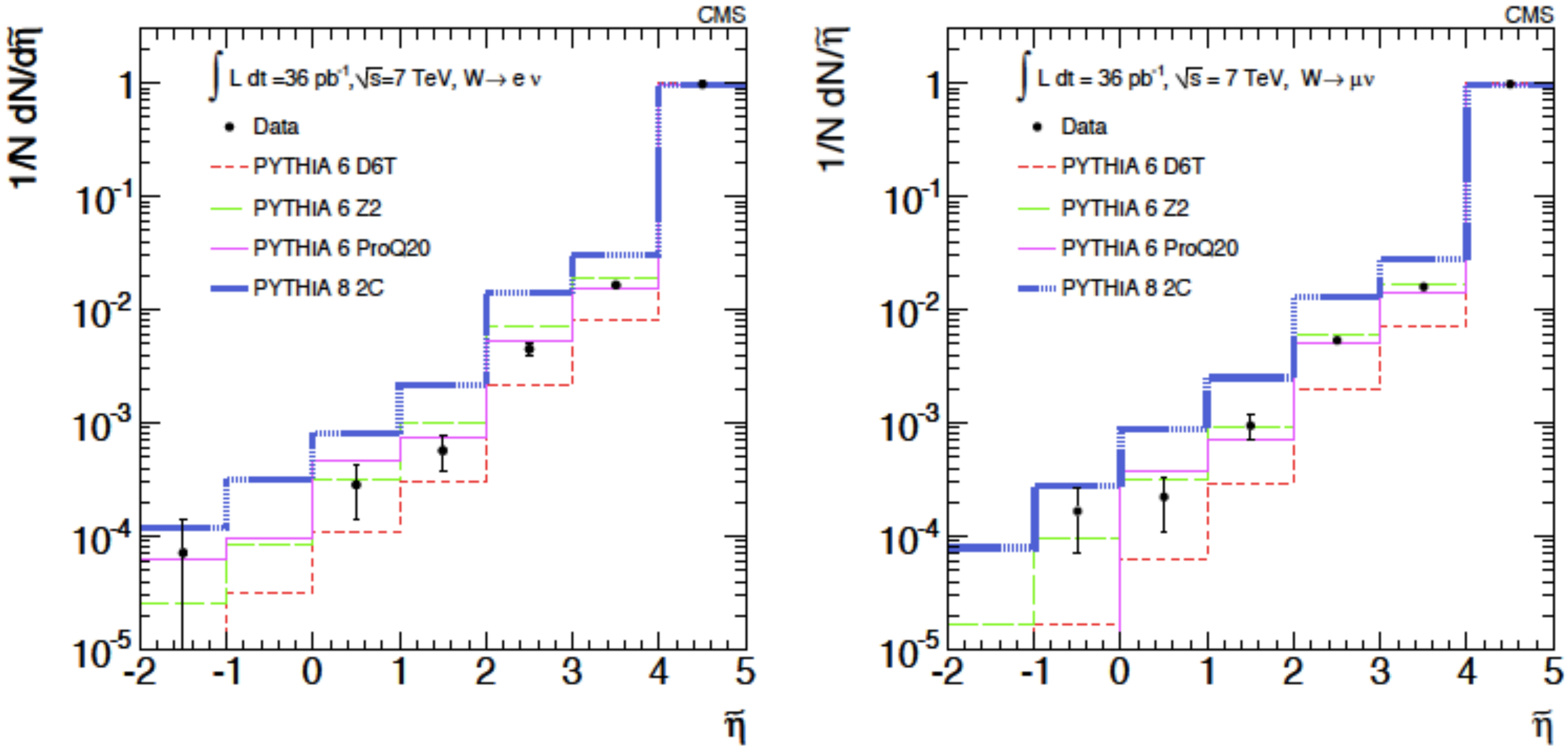
Comparable with lots of other diffractive processes measured using large rapidity gap approach …

| Hard component | Fraction ( R ) % |
|---|---|
| Dijet | $0.75 \pm 0.10$ |
| W | $1.15 \pm 0.55$ |
| b | $0.62 \pm 0.25$ |
| $J/\psi$ | 1.45 V 0.25 |

Universal suppression relative to factorised predictions?

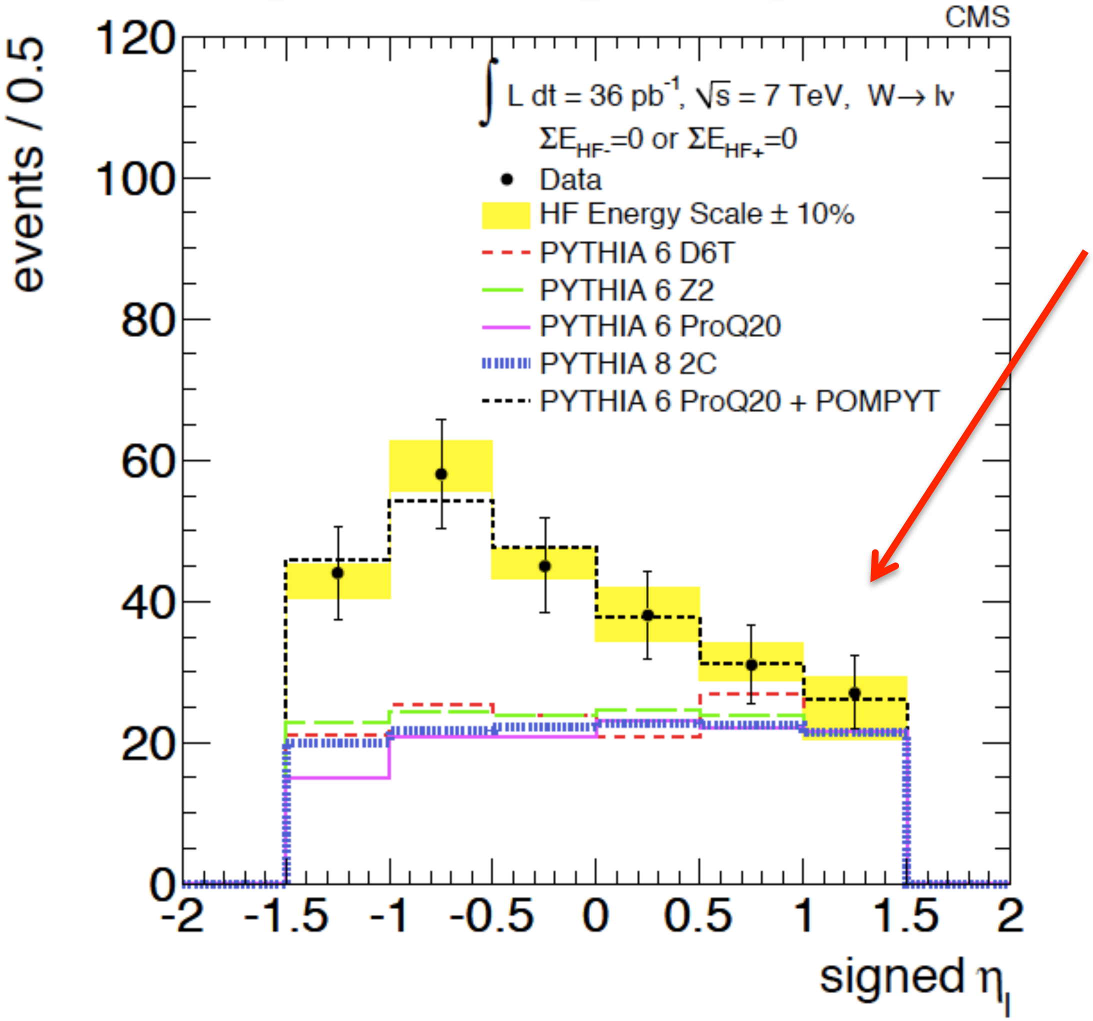
# W and Z events with gaps at CMS

After pile-up corrections, ~1% of W and Z events exhibit no activity above noise thresholds over range 3 < ±η < 4.9 … interpretation not yet clear …




$\tilde{\eta}$ (= 4.9 – Δη) end-point of gap - starting at acceptance limit

# Exploiting Gap-Lepton η Correlation




Lepton pseudorapidity with + sign if lepton in same hemisphere as gap, else – sign.

Fit to combination of PYTHIA and POMPYT hard diffraction model suggests significant (~50%) diffractive contribution

Extraction of (limits on?) gap survival probabilities at the LHC from diffractive W/Z and jet production eagerly awaited … survival may be small (~3% according to phenomenology)

# Summary

## Soft diffractive processes at the LHC

- Precision data emerging
- Small non-zero gaps sensitive to had$^n$ / MPI
- Large gaps sensitive to diffractive dynamics
- Detailed tests of soft MC models $\rightarrow$ tunes
- Compare v TOTEM $\rightarrow$ insight on low mass diffraction

## Diffractive Deep Inelastic Scattering

- First H1-ZEUS combinations
- Novel diffractive factorisation tests – DPDFs work
- No big gap survival effects

## Hard Diffraction at the Tevatron and the LHC

- Big gap destruction effects (~90%) at Tevatron
- First results with W/Z at the LHC … survival probability?..