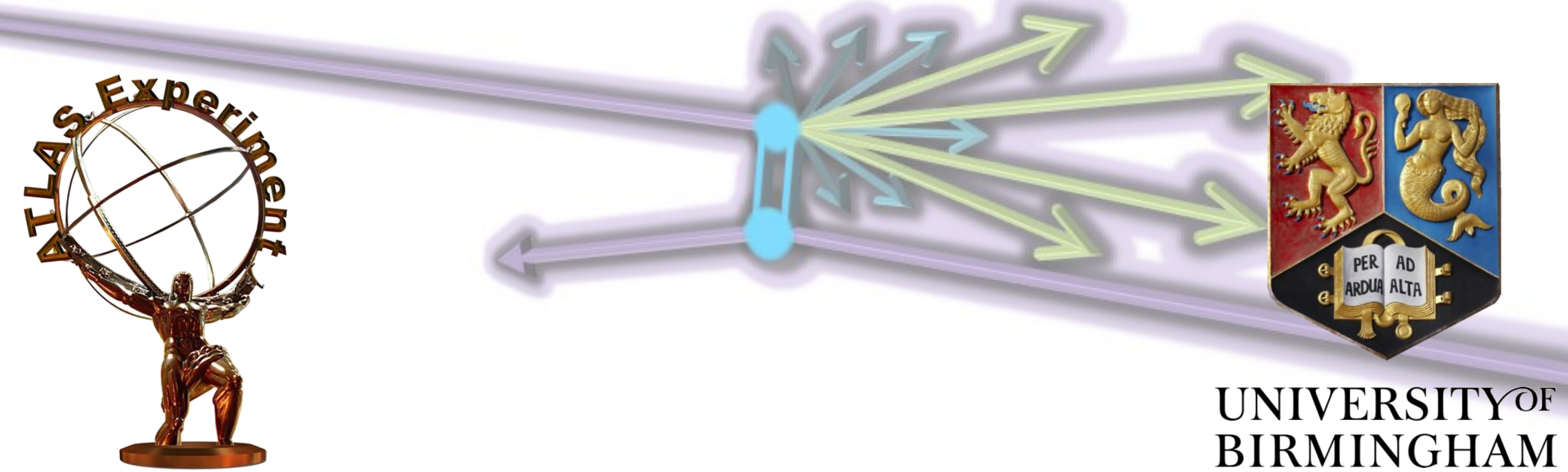
Eur. Phys. J. C (2012) 72:1926

Large rapidity gaps and soft diffraction at ATLAS

IoP HEPP & APP Annual Meeting

2th – 4th April 2012, Queen Mary

Tim Martin - University of Birmingham



Overview

Modeling Inelastic Diffraction

Diffractive Events in ATLAS

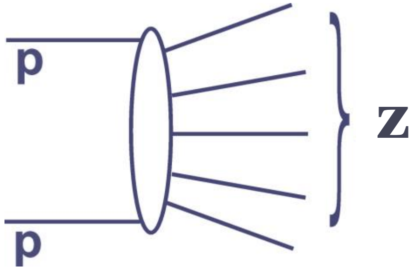
Large Rapidity Gaps

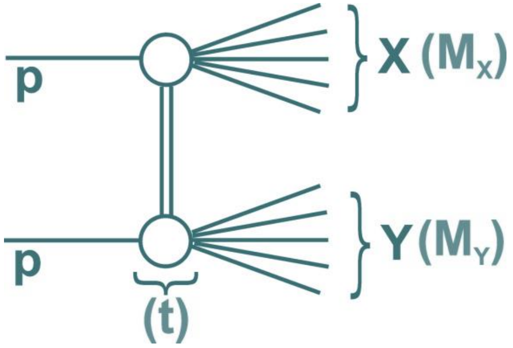
Interpreting the Data

Soft QCD – Inelastic Processes

Non Diffractive Events

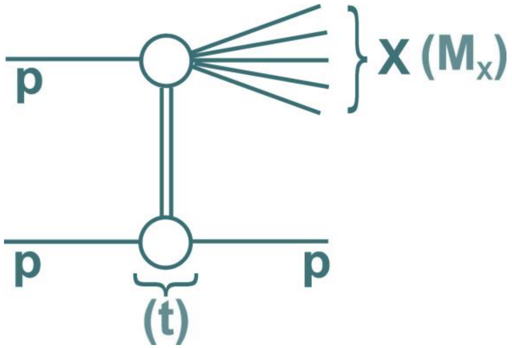
Coloured exchange.
High multiplicity final states peaking at central rapidity.
Soft P_T spectrum.
Largest cross section at LHC.



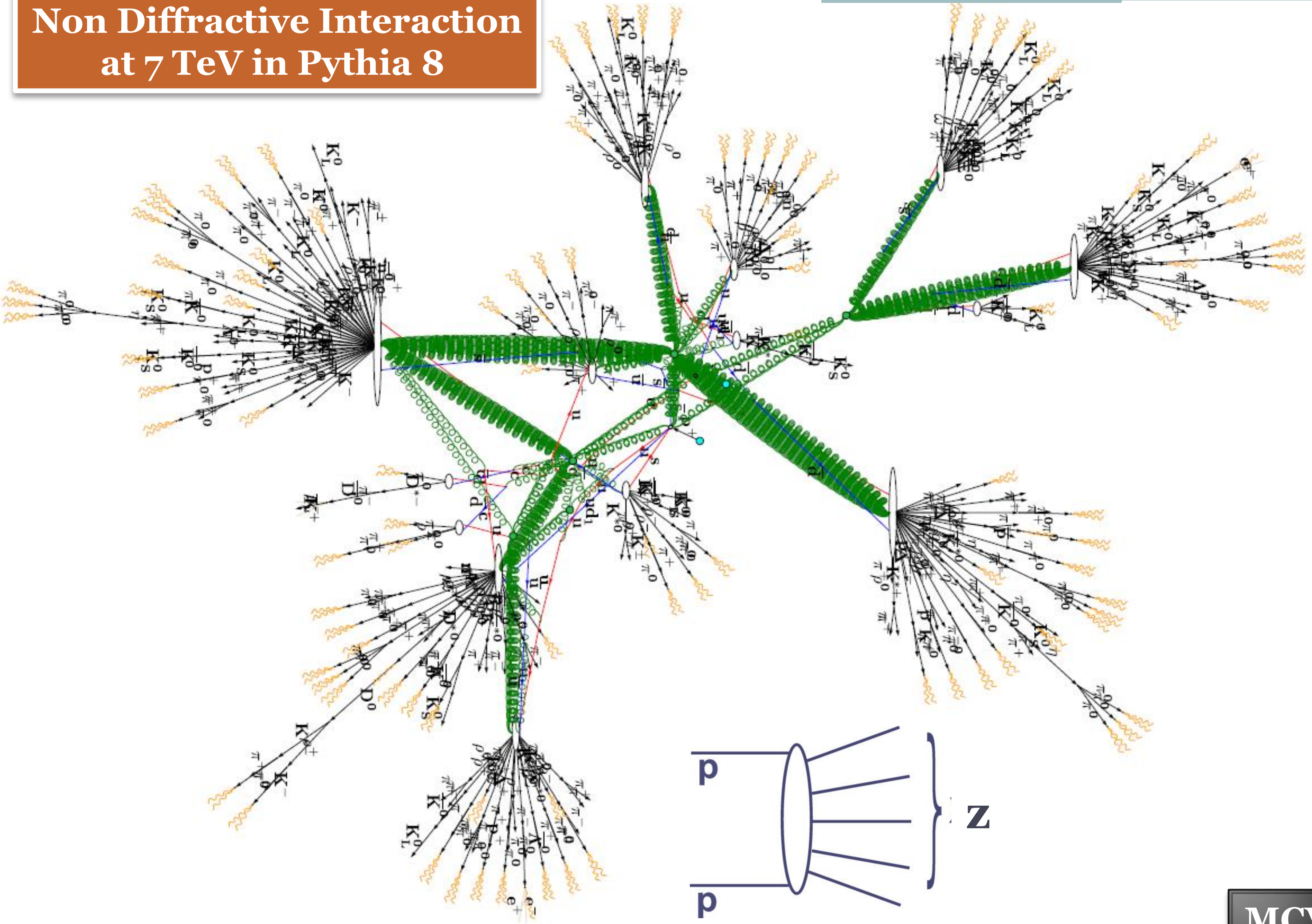


Diffractive Events

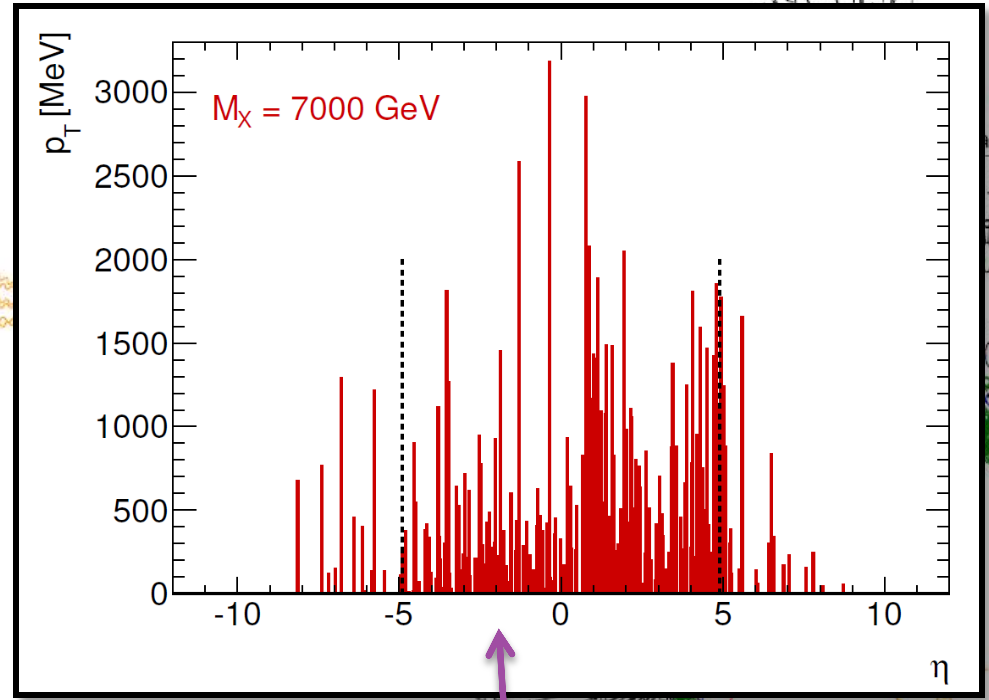
Colour singlet exchange.
Can be **Single** or **Double** proton **dissociation**.
Diffractive mass can be anything from **$p+\pi^o$** up large systems with **hundreds of GeV** invariant mass.
Soft P_T spectrum.
Large forward energy flow.
Less activity in the inner detector.

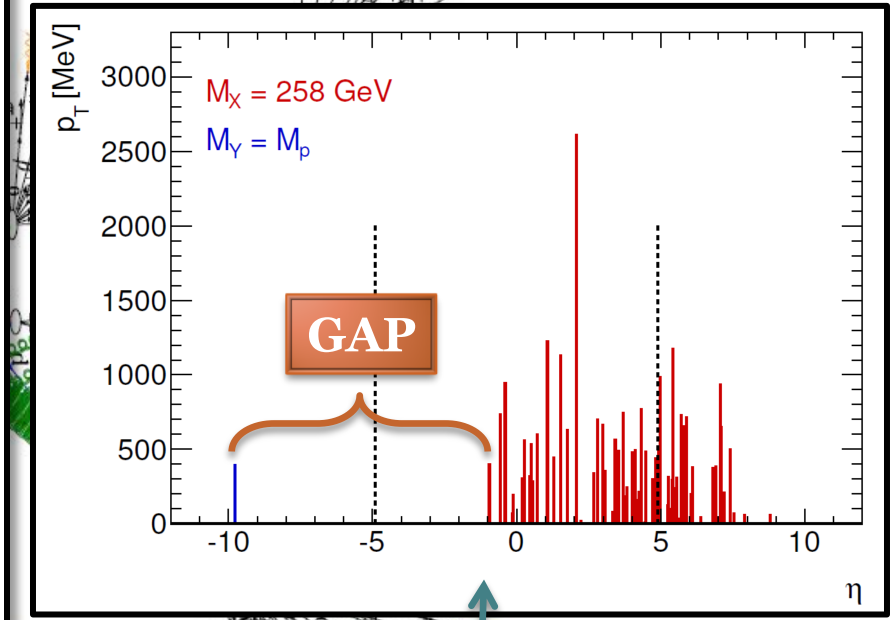


Non Diffractive Interaction at 7 TeV in Pythia 8



MCViz

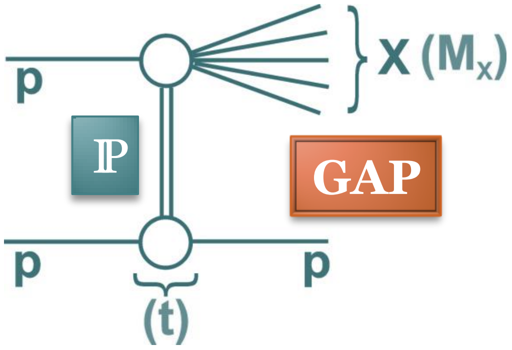


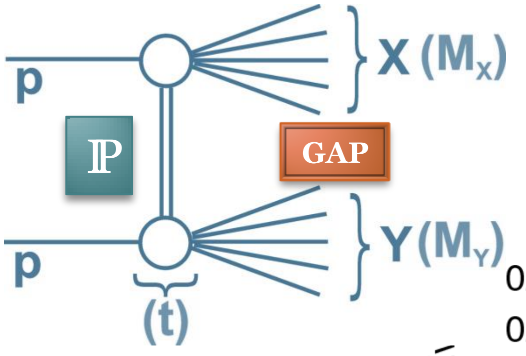


~75% of all inelastic interactions at the LHC are non-diffractive.

~25% of the time the inelastic interaction is *diffractive* which can result in a characteristic rapidity gap.

LHC Diffraction



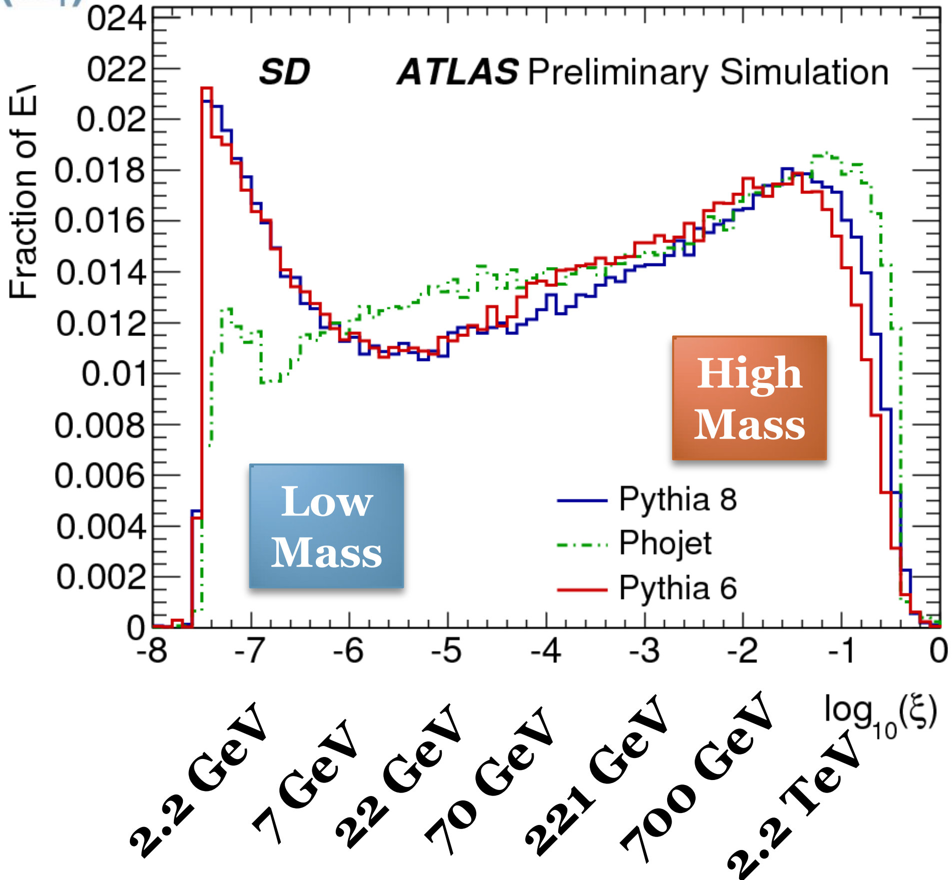


$$\xi_X = \frac{M_X^2}{s}$$

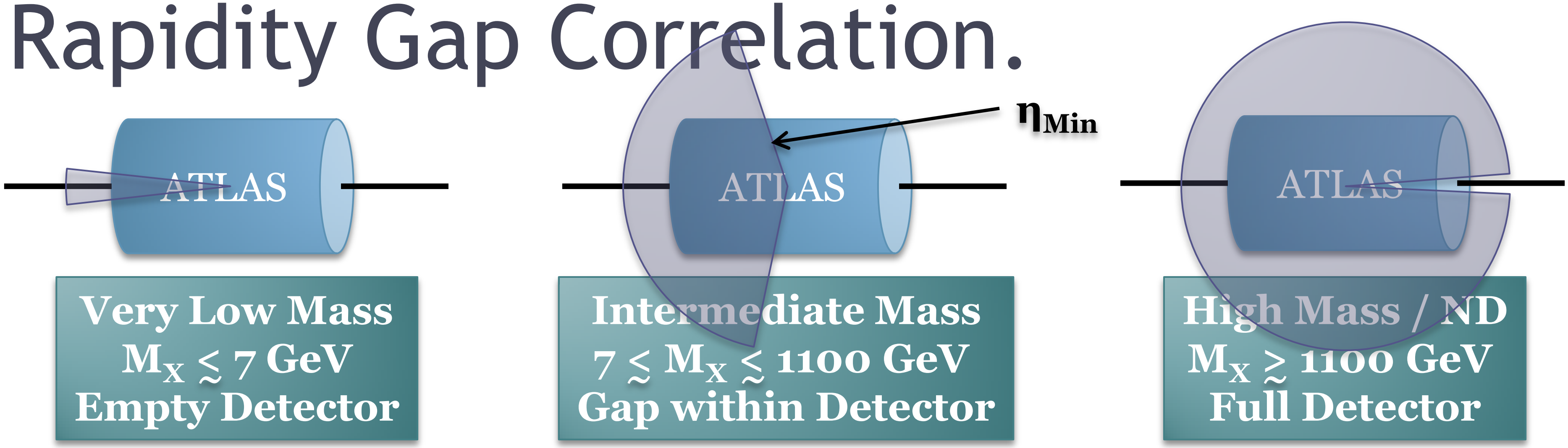
$$\boxed{\begin{array}{c} \mathbf{M_X > M_Y} \\ \textbf{(By Construction)} \end{array}}$$

$$f_D = \sigma_{Diffractive} / \sigma_{Inelastic}$$

- f_D = 25-30% of the **total inelastic cross section** ($\xi_X > 5\text{x}10^{-6}$) is measured to be **inelastic diffractive.**
- **Cross section approximately constant in log(ξ_X).**
- **Lack of colour flow** results in a **rapidity gap** between the **two dissociated systems** (Double Diff.) or the **dissociated system and the intact proton** (Single Diff.) **devoid of soft QCD radiation**.
- **The size of the rapidity gap** is related to the **invariant mass of the dissociated system(s)**.



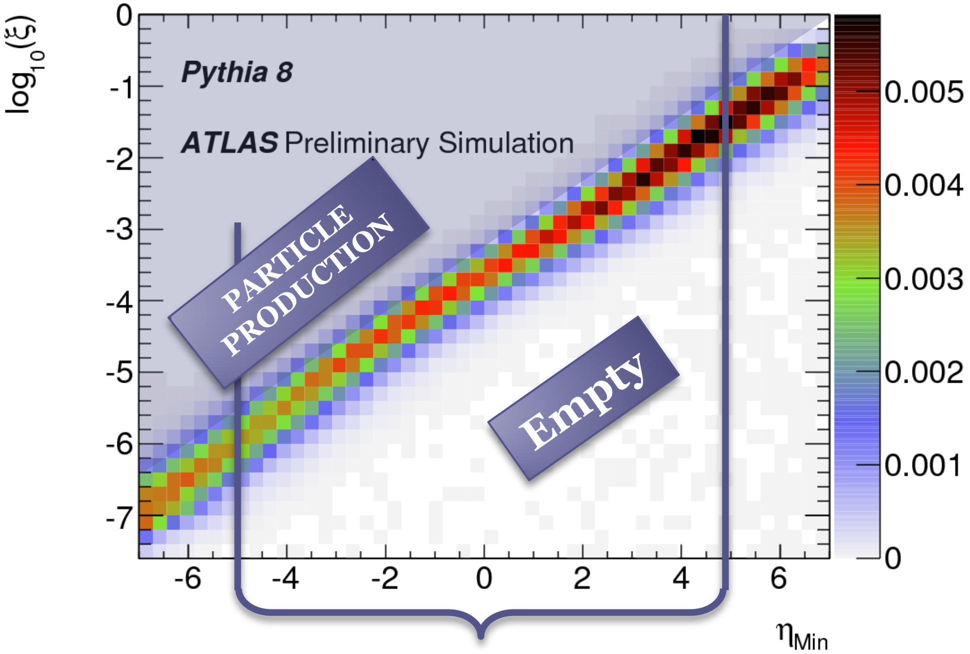
Rapidity Gap Correlation.



Very Low Mass
$M_X \lesssim 7$ GeV
Empty Detector

Intermediate Mass
$7 \lesssim M_X \lesssim 1100$ GeV
Gap within Detector

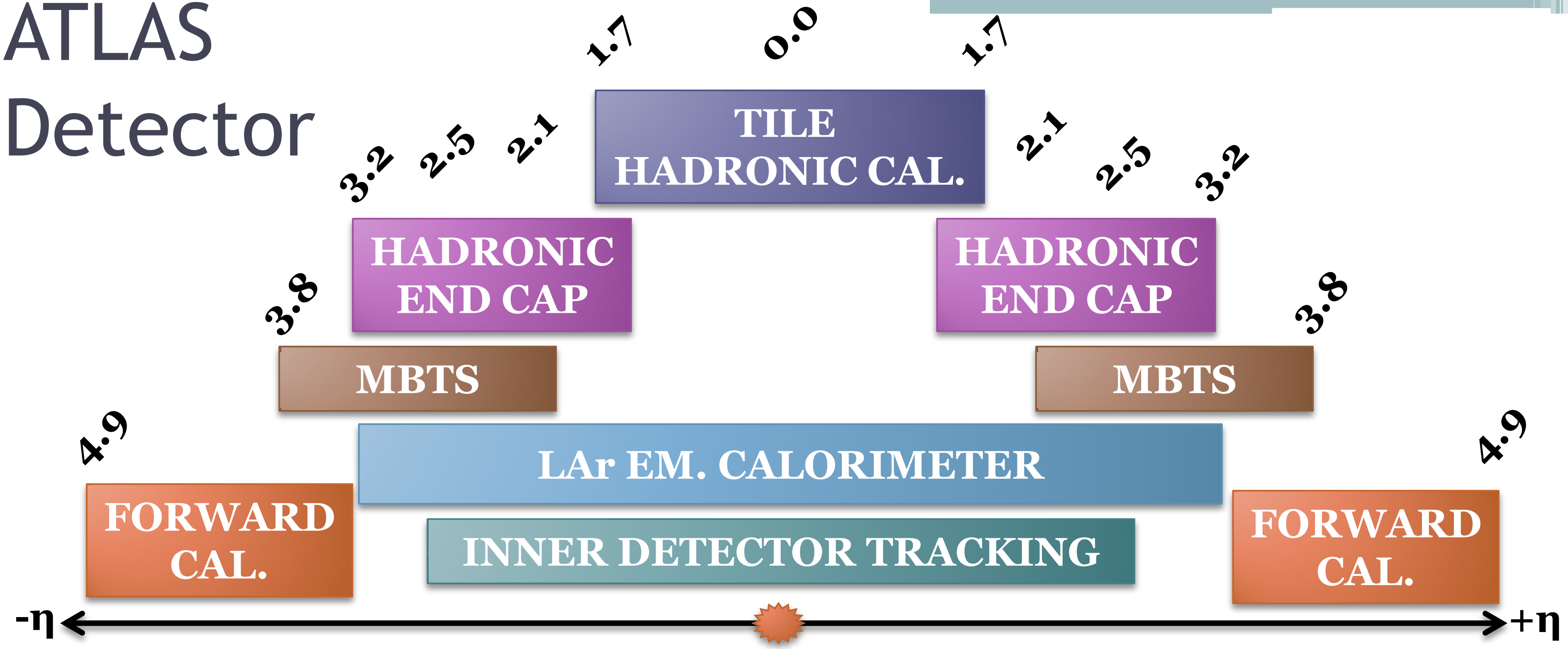
High Mass / ND
$M_X \gtrsim 1100$ GeV
Full Detector



ATLAS Fiducial Acceptance

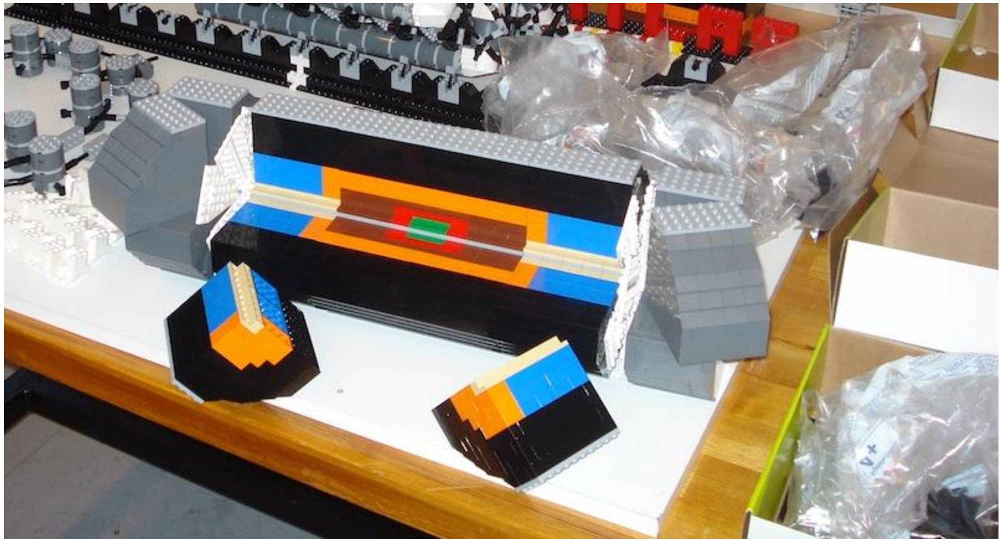
- **Rapidity interval** of **final state** **kinematically linked** to size of **diffractive mass**.
- **Linear relation** between **η of edge of diffractive system** and **$\ln(M_X)$**, smeared out slightly by **hadronisation effects**.

ATLAS Detector



We utilise the full tracking and calorimetric range of the detector.

We want to set our thresholds *as low as the detector will allow us.*



Data Set

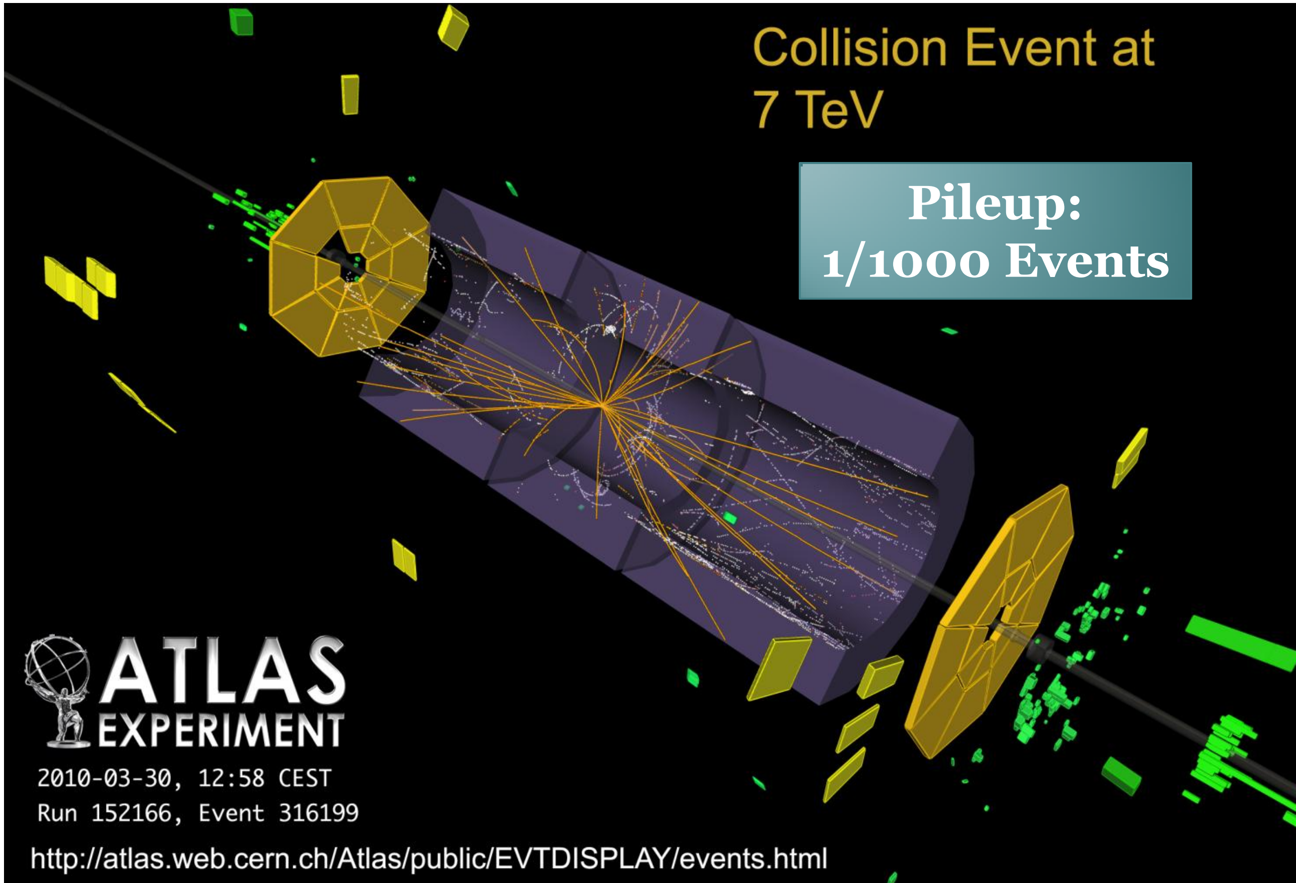
- Utilising the **first stable beam physics run at 7 TeV centre of mass**.
- Data taking started at **13:24** and finished at **16:38** on **30th March 2010**.
- In that time **ATLAS accumulated 422,776 minimum bias events**.
- This corresponds to **$7.1\ \mu b^{-1}$** at peak instantaneous luminosity **$1.1 \times 10^{27}\ cm^{-2}s^{-1}$**.

We use fully simulated MC samples roughly three times larger

Pythia 8
Nominal MC

Pythia 6
Different modelling of the final state.

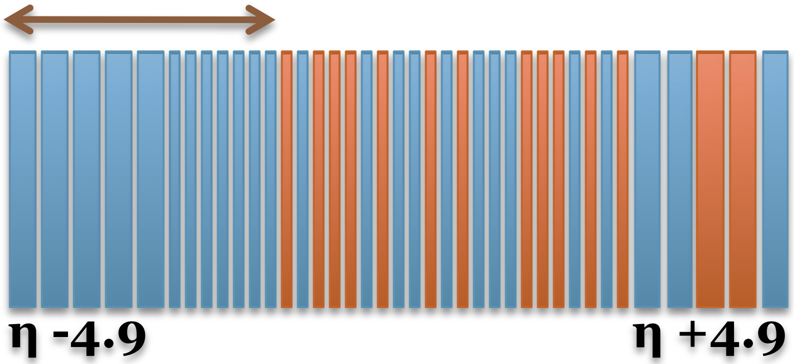
Phojet
Different dynamical diffraction model.



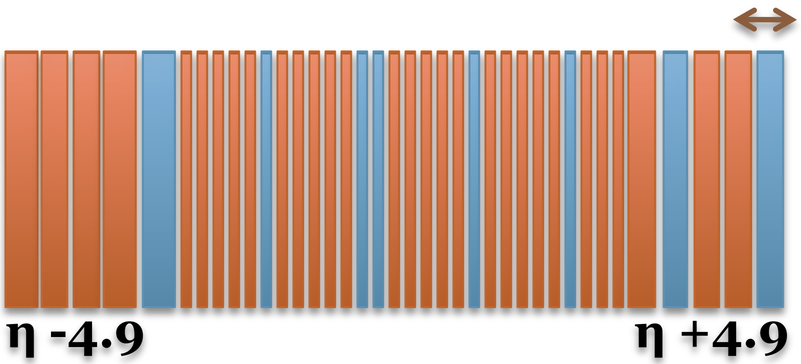
Pileup:
1/1000 Events

Gap Finding Algorithm

- The detector is binned in **η**.
- **Detector Level Bin** contains particle(s) if one or more **noise suppressed calorimeter clusters** above **E_T *cut*** **AND/OR** one or more **tracks** are reconstructed above **p_T *cut***. (**E_T=p_T**) .
- **Generator Level Bin** contains particle(s) if it contains one or more **stable** (cτ > 10 mm) **generator** particles **> p_T *cut***.
- **$\Delta\eta^F$ = Largest region of pseudo-rapidity from detector edge containing no particles with p_T > *cut***.
- For **each event**, we **calculate $\Delta\eta^F$ at p_T cut = 200, 400, 600 & 800 MeV.**
- **Main Physics result** is the at the lowest cut, **200 MeV**.

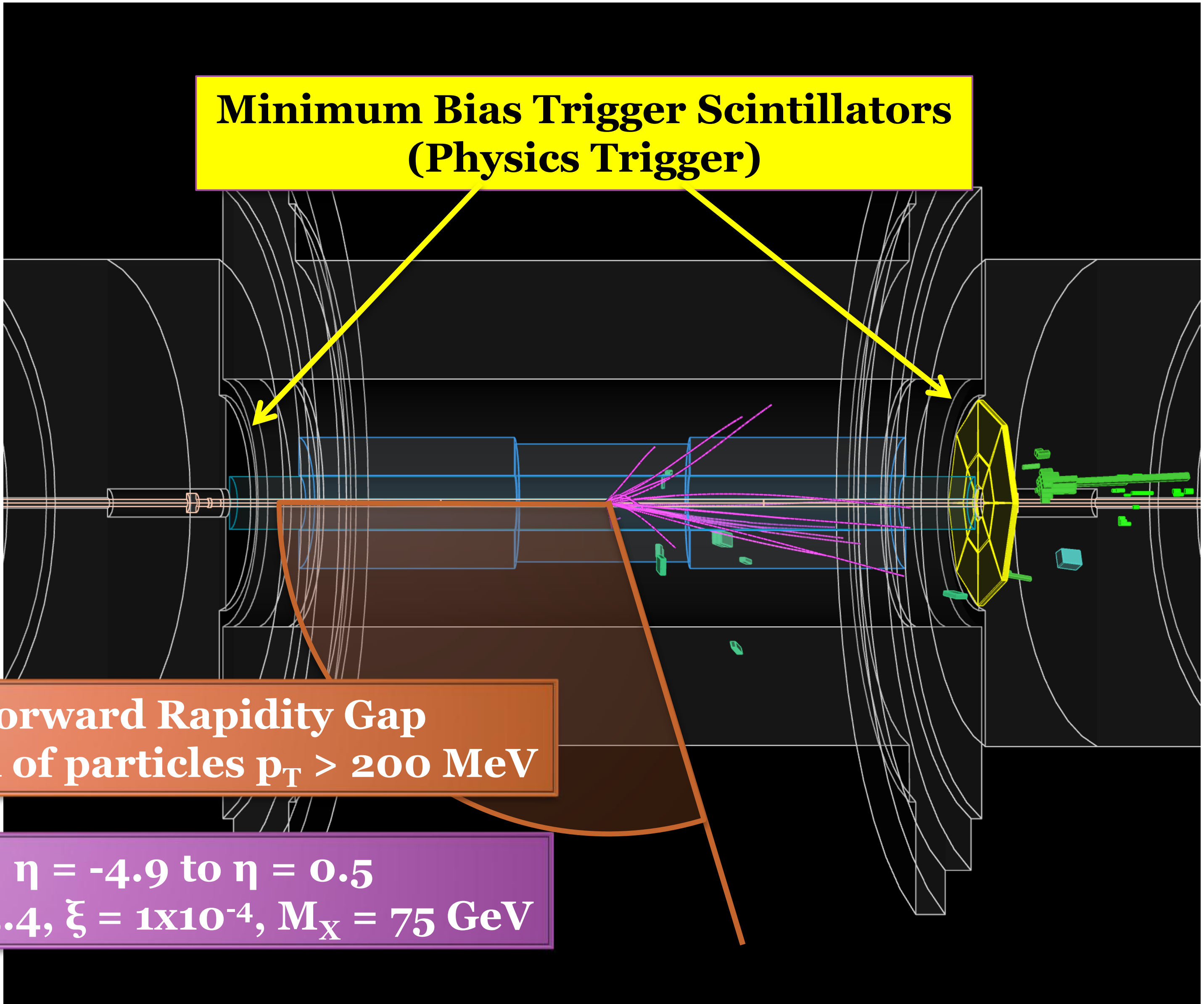


E.G Intermediate Diffractive Mass
$\Delta\eta^F$ = 3.4, ξ = 9x10^{-4}, M_X = 210 GeV



E.G Non Diffractive
$\Delta\eta^F$ = 0.4

Example of Inclusive Gap Algorithm



Minimum Bias Trigger Scintillators (Physics Trigger)

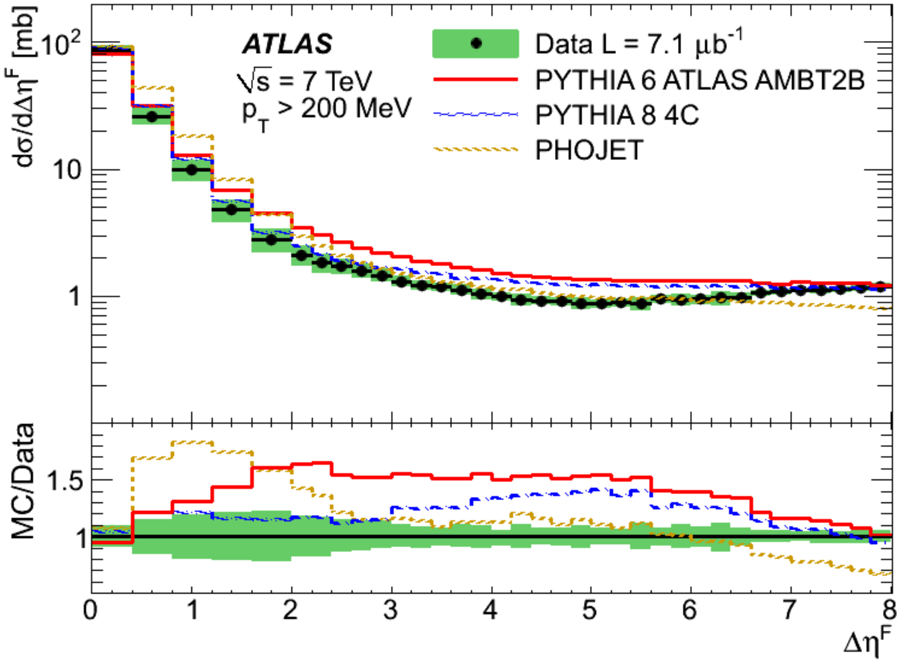
Forward Rapidity Gap
Devoid of particles $p_T > 200$ MeV

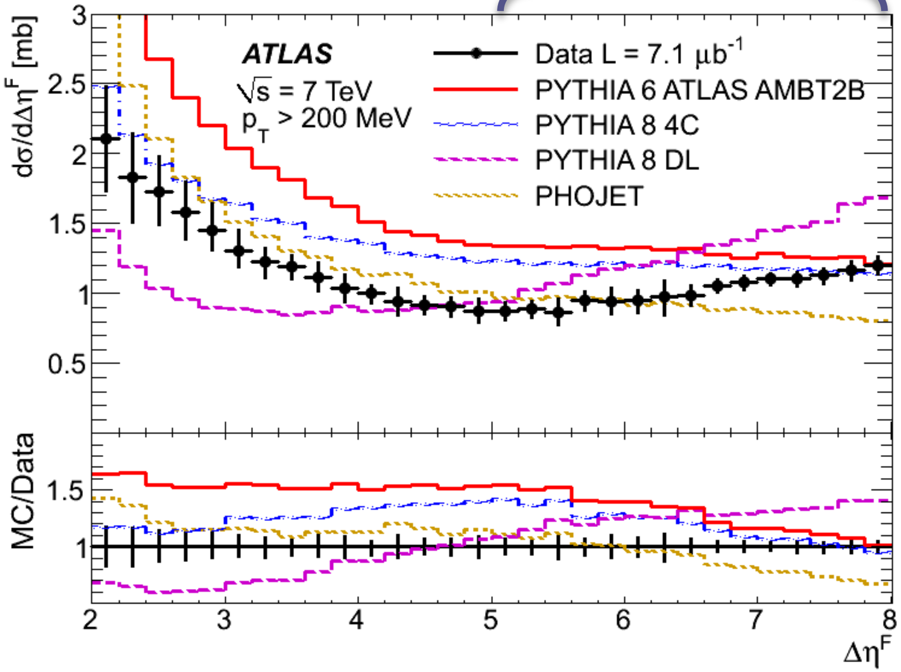
$\eta = -4.9$ to $\eta = 0.5$
$\Delta\eta^F = 5.4$, $\xi = 1\mathrm{x}10^{-4}$, $M_X = 75$ GeV

Corrected $\Delta\eta^F$ Distribution

- **MC normalised to Default ND, DD and SD Cross section up to $\Delta\eta^F = 8$.**
- **Integrated cross section** in diffractive plateau:
  - **$5 < \Delta\eta^F < 8$** (*Approx:* $-5.1 < \log_{10}(\xi_X) < -3.1$) = **3.05 ± 0.23 mb**
  - **~4% of σ_{Inelas} (From TOTEM)**

Primary Sources of Uncertainty:
Unfolding with Py6 [Final State] & Pho [Dynamics]
Energy scale systematic from π->γγ & Test Beam





Eur. Phys. J. C (2010) 69: 85–93
DOI 10.1140/epjc/s10052-010-1392-5

THE EUROPEAN
PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Diffraction and correlations at the LHC: definitions and observables

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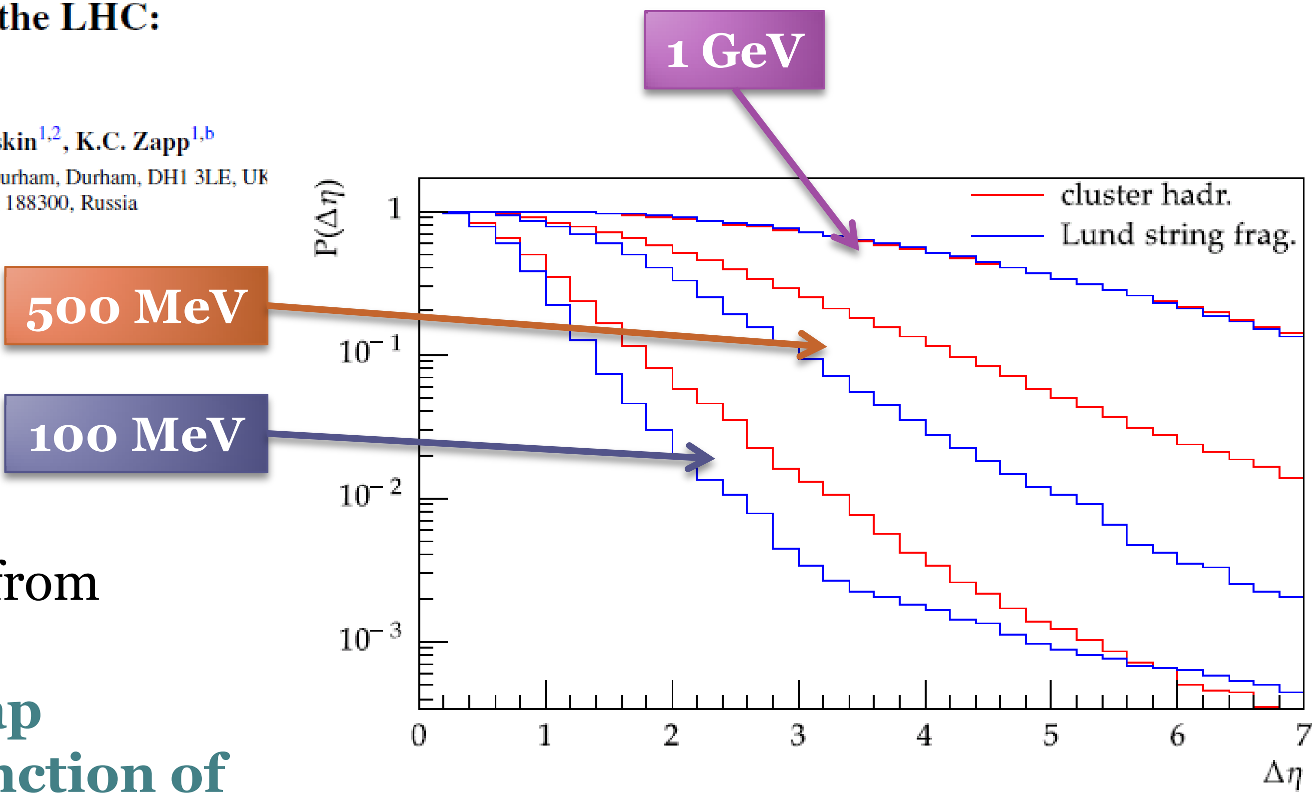


1 GeV

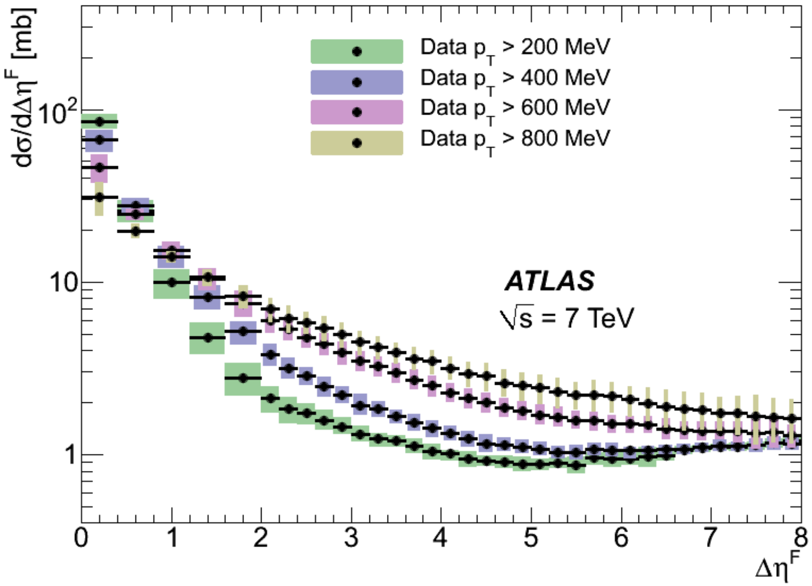
500 MeV

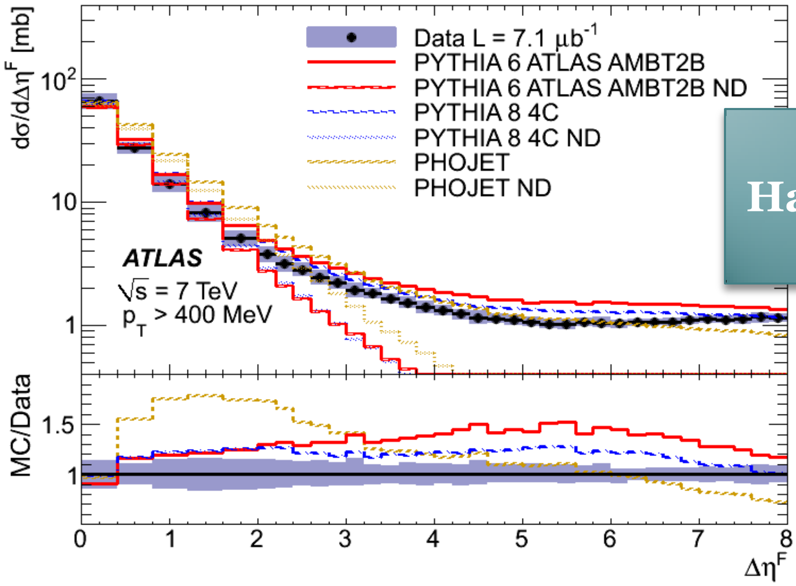
100 MeV

Fig. 4 Probability for finding a rapidity gap (definition 'all') larger than $\Delta\eta$ in an inclusive QCD event for different threshold $p_\perp$. From top to bottom the thresholds are $p_{\perp,\text{cut}} = 1.0, 0.5, 0.1$ GeV. Note that the lines for cluster and string hadronisation lie on top of each other for $p_{\perp,\text{cut}} = 1.0$ GeV. No trigger condition was required, $\sqrt{s} = 7$ TeV

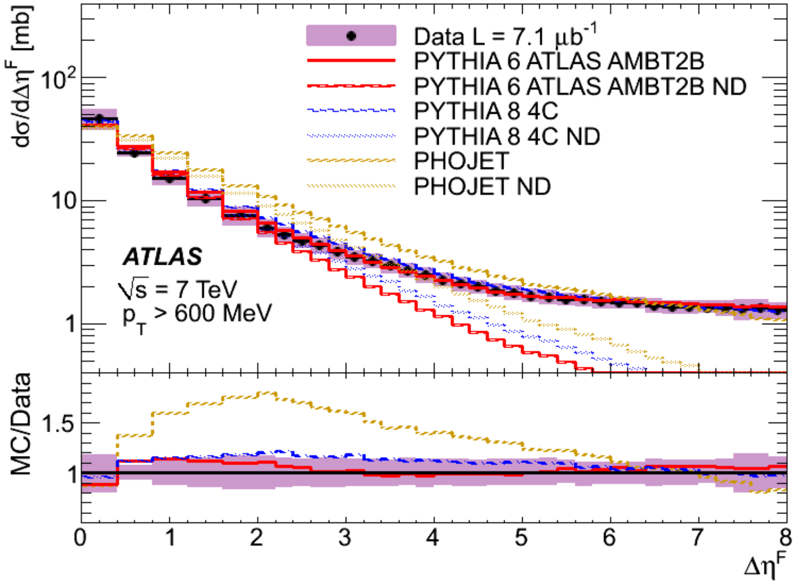
- Motivated by work from **Durham**, we **also investigate the gap spectrum as a function of the p_T cut placed on particles.**

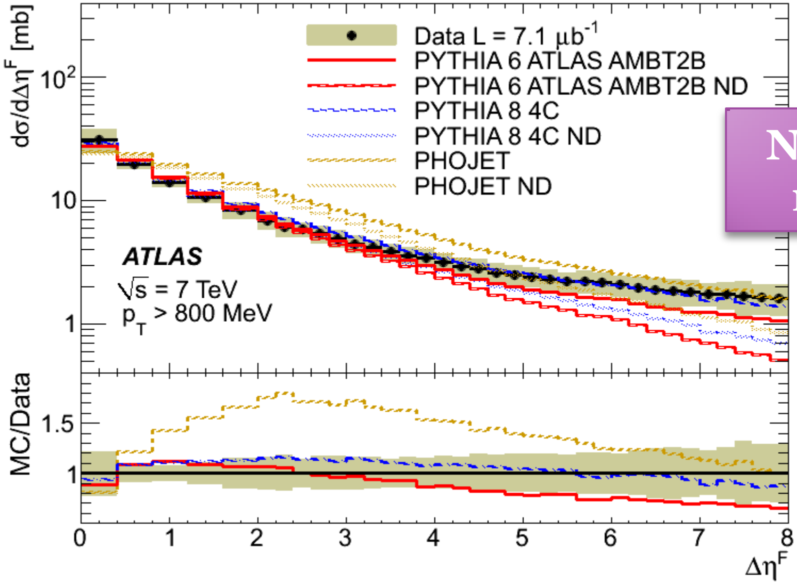
$\Delta\eta^F$ at Different p_T Cut





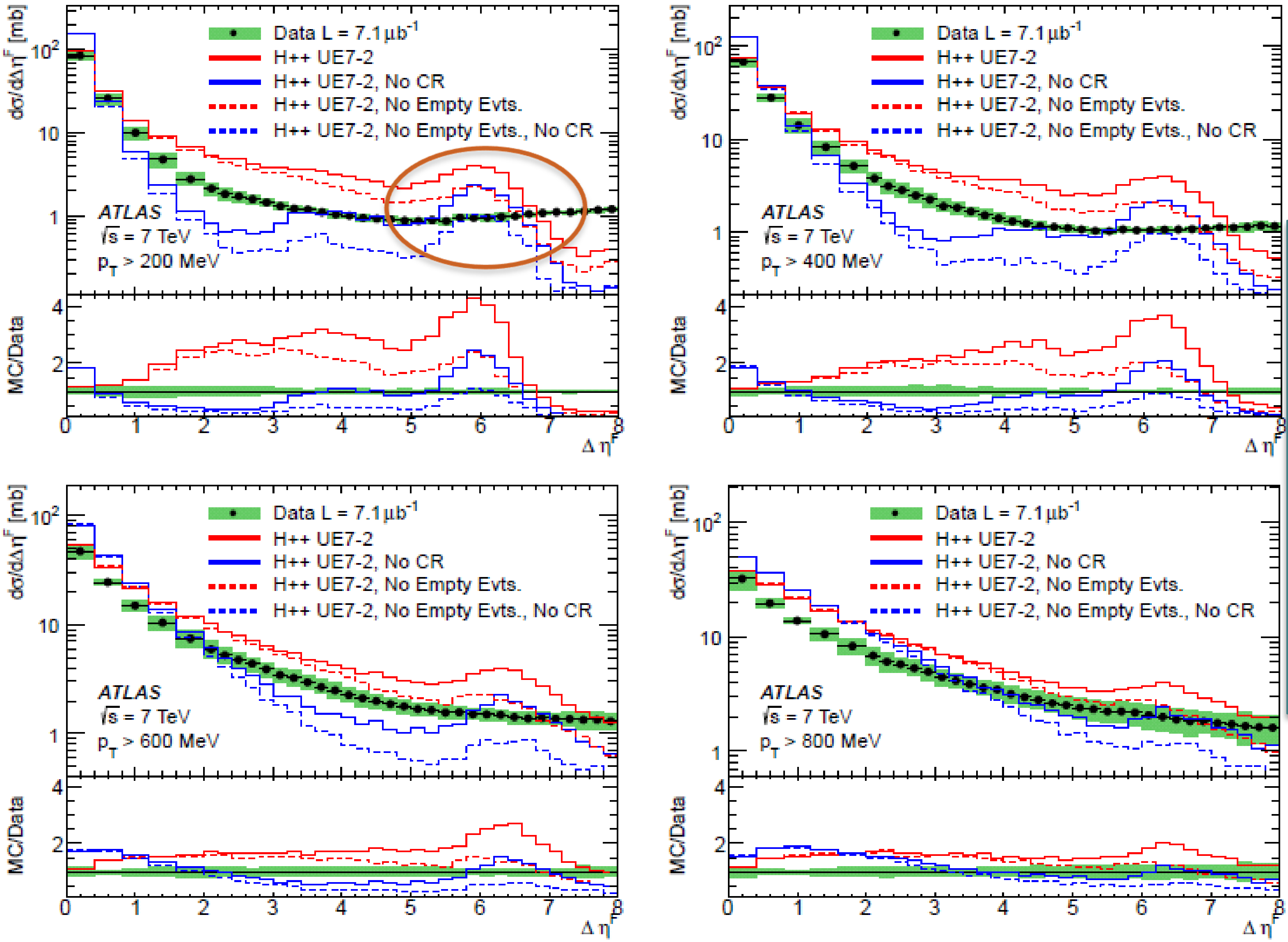
Constrain Hadronisation Models





Never before measured.

H++ at Different p_T Cut

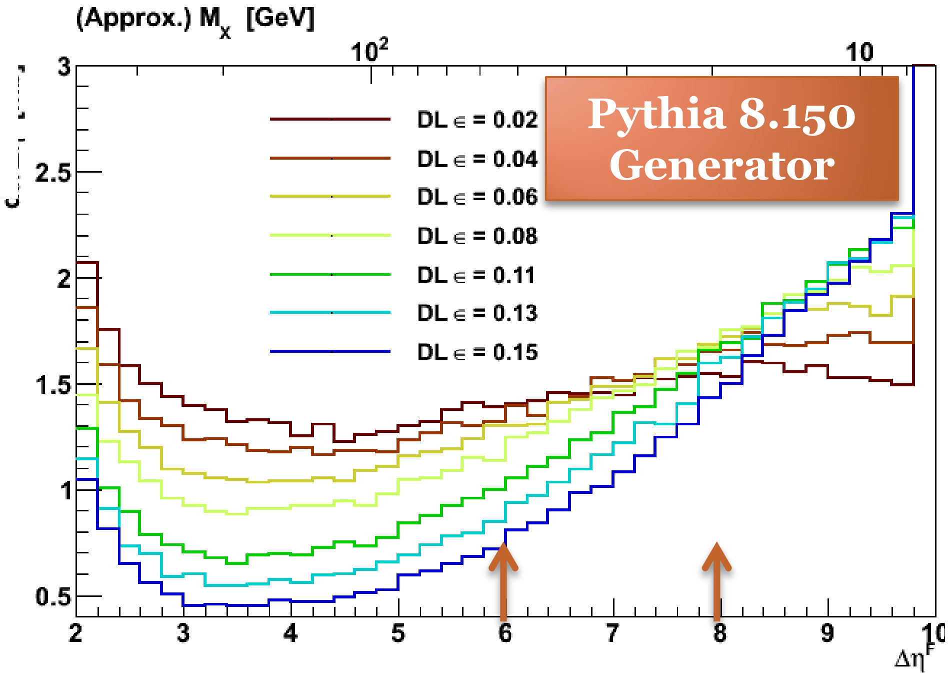


Explicitly Only Non Diffractive! But large gaps produced? Challenge for H++ authors!

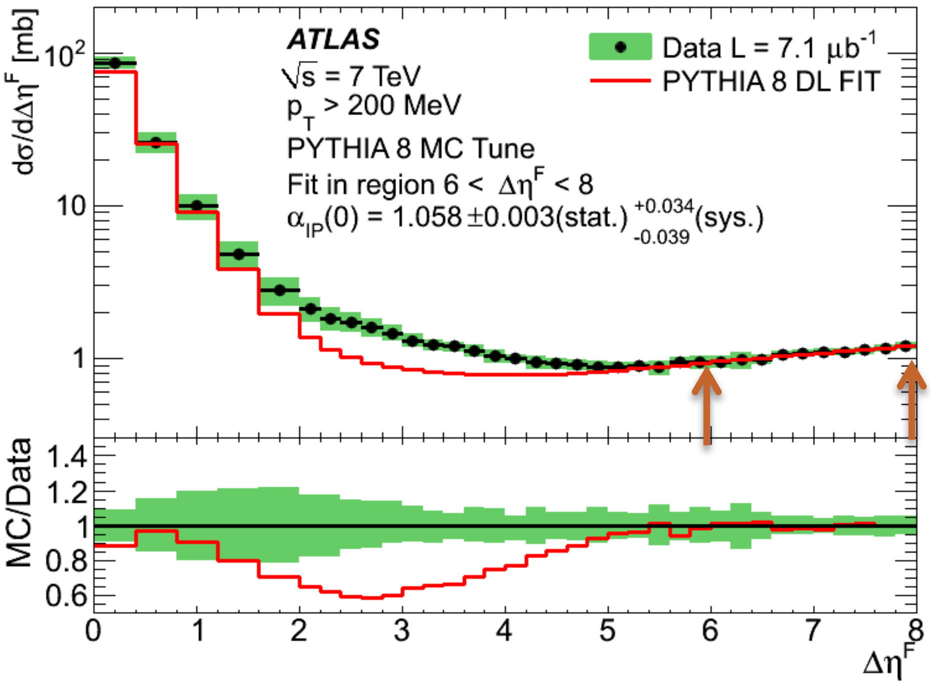
Best Fit to Data

55 > M_X (GeV) > 20

- We **fit to our data in the region 6 < $\Delta\eta^F$ < 8** to tune **the Pomeron intercept Pythia 8** using the **Donnachie and Landshoff** (and Berger-Streng) **Pomeron** flux. **Insensitive to the non-diffractive** modelling.
- Each **correlated systematic is fitted separately** and the resultant uncertainty is **symmetrised.**
- Default : **$\alpha_{IP}(0) = 1.085$**
- Tuned: **$\alpha_{IP}(0) = 1.058 \pm 0.003\ (\text{stat.})\ ^{+0.034}_{-0.039}\ (\text{sys.})$**

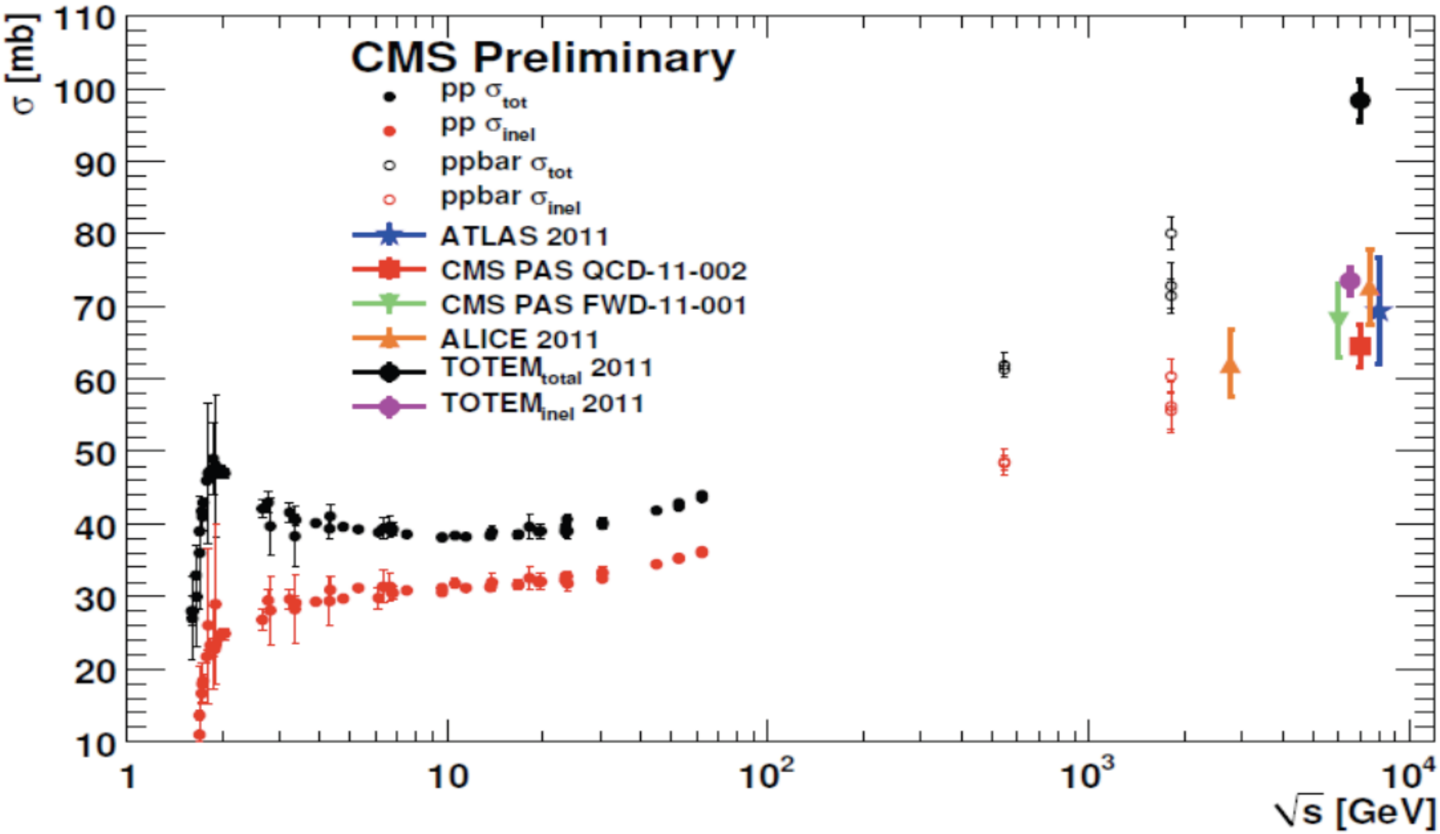


Pythia 8.150 Generator



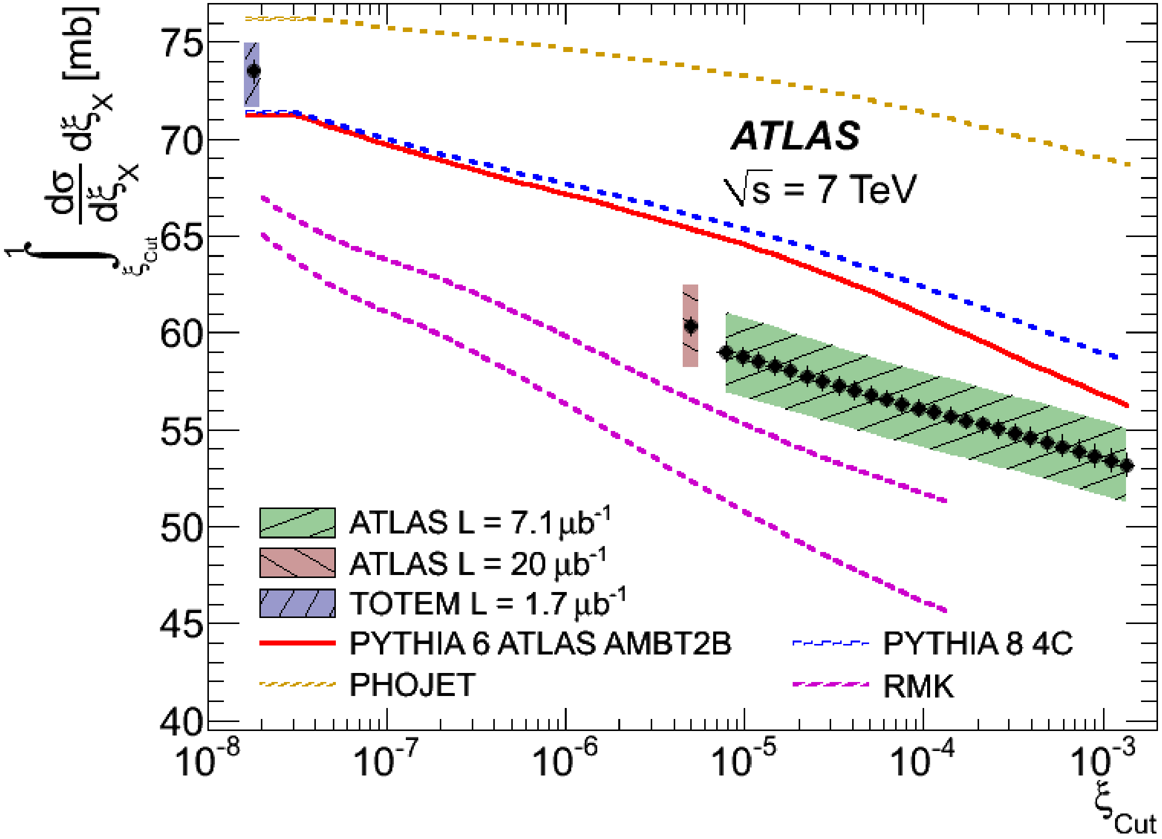
Statement on $\sigma_{\text{Inelastic}}$

- Both **ATLAS** and **CMS** measure **smaller values** for the **total inelastic cross section** than **TOTEM** (which utilises the **optical theorem** on $\boldsymbol{\sigma}_{\textbf{Elastic}}$).
- Uncertainty is **dominated by extrapolation to low ξ** which is outside of the **detector acceptance**.



Integration of $\sigma_{\text{Inelastic}}$

- We measure the **total inelastic cross section which produces particles in the main ATALS detector**. Can **integrate** up to a cut point.
- We apply all **correlated systematics symmetrically**.
- Additional **correction** from **$\Delta\eta^F$** to **ξ** derived from **MC**, at most **1.3±0.6%**
- **Luminosity error** dominates.
- Comparison with published **ATALS** paper good to **0.8%**, this is the measured **run-to-run lumi** error.
- Also included, **TOTEM**.
- And **Durham RMK** prediction.



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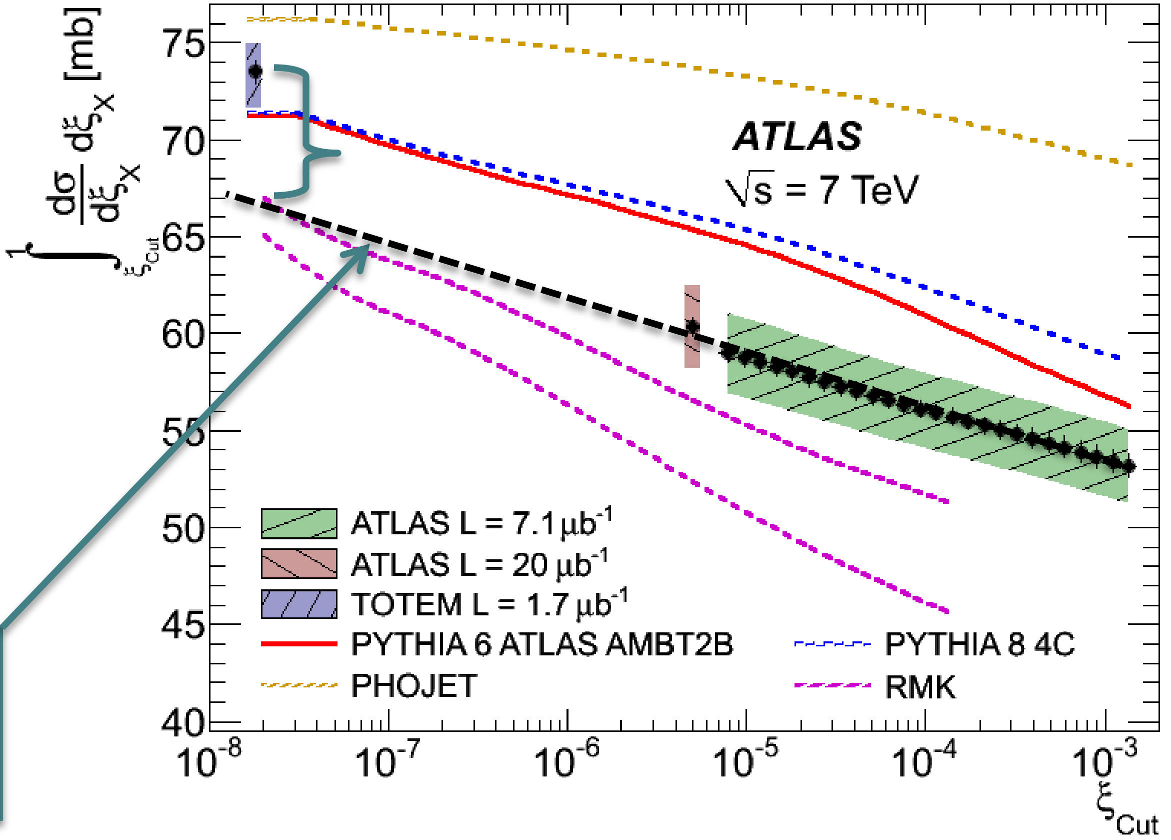


Tension of ~7 mb of low mass diffractive cross section.

Conclusion

- **Rapidity gaps** in **ATLAS minimum bias data** are a **sensitive probe** to the **dynamics of diffractive proton dissociation at low |t|.**

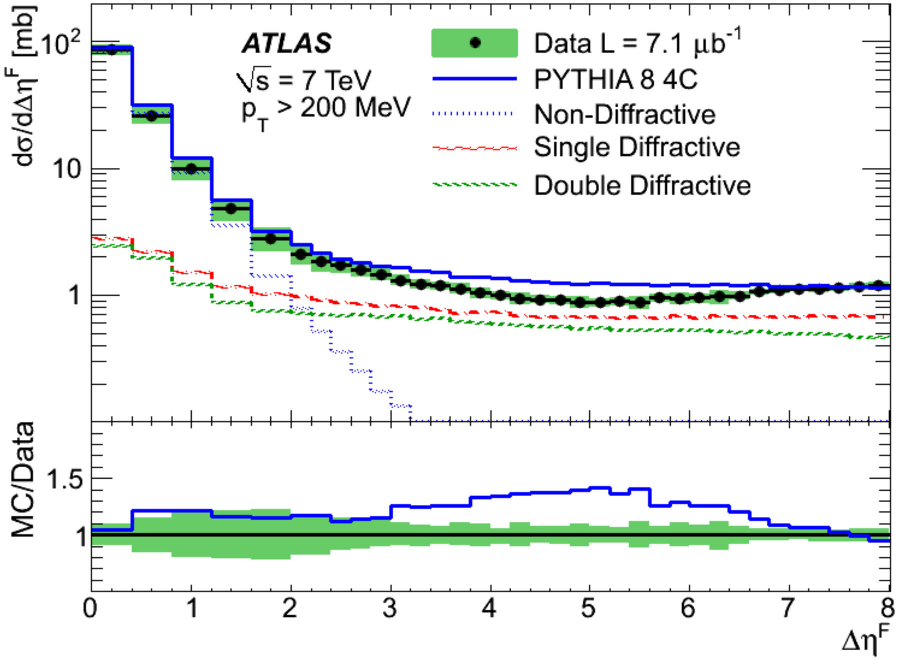
- **The data can be used to investigate and tune the current triple-Pomeron based MC models**.

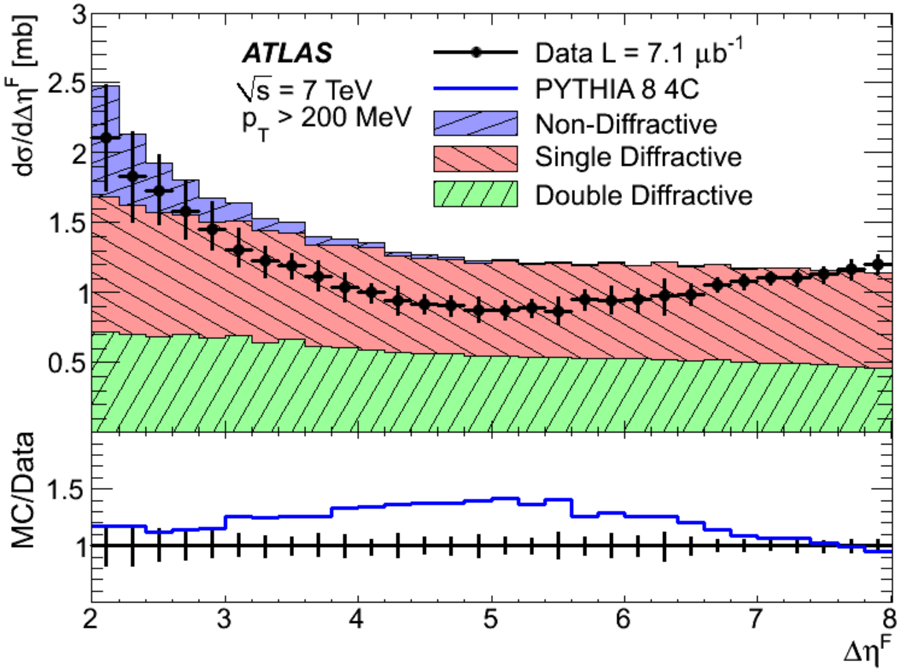
- **Data corrected to a range of p_T cuts allow for the tuning of particle production by hadronisation models**.

- **Integration of the gap spectrum** allows for the **inelastic cross section to be measured down to an arbitrary cut off in ξ**. This allows **direct comparisons with other experiments** which have different geometric acceptance and highlights the **difference between the inelastic cross section measured in ATLAS with the total inelastic cross section as measured by TOTEM**.

$\Delta\eta^F$ Vs. Pythia 8

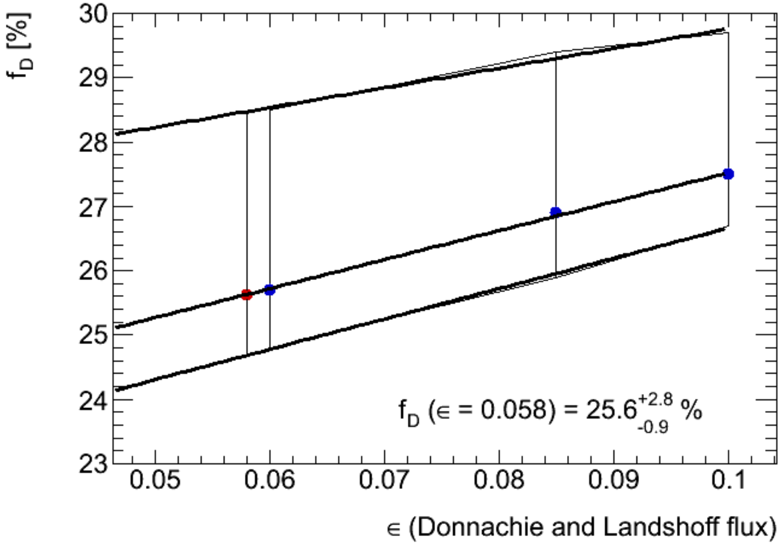
- **Pythia 8** split into **sub-components**.
- **Non-Diffractive contribution dominant** up to gap **size of 2, negligible for gaps larger than 3**.
- **Shape OK**, **overestimation of cross section in diffractive plateau**.
- Overestimation is **smaller than Pythi6** due to **author tune 4C** on **ATLAS data.**
- **Large Double Diffraction contribution**.

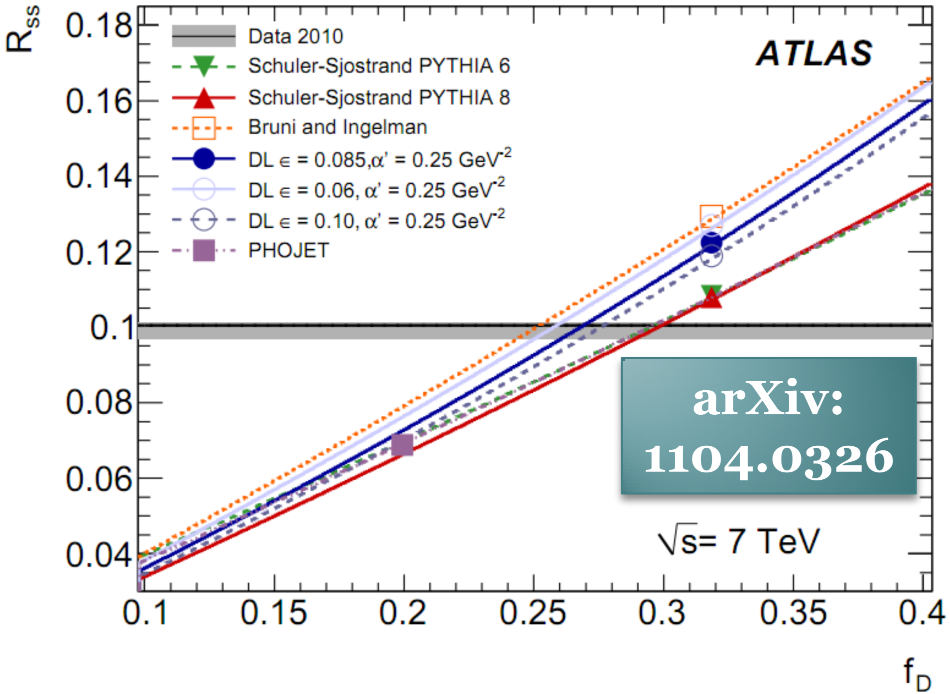




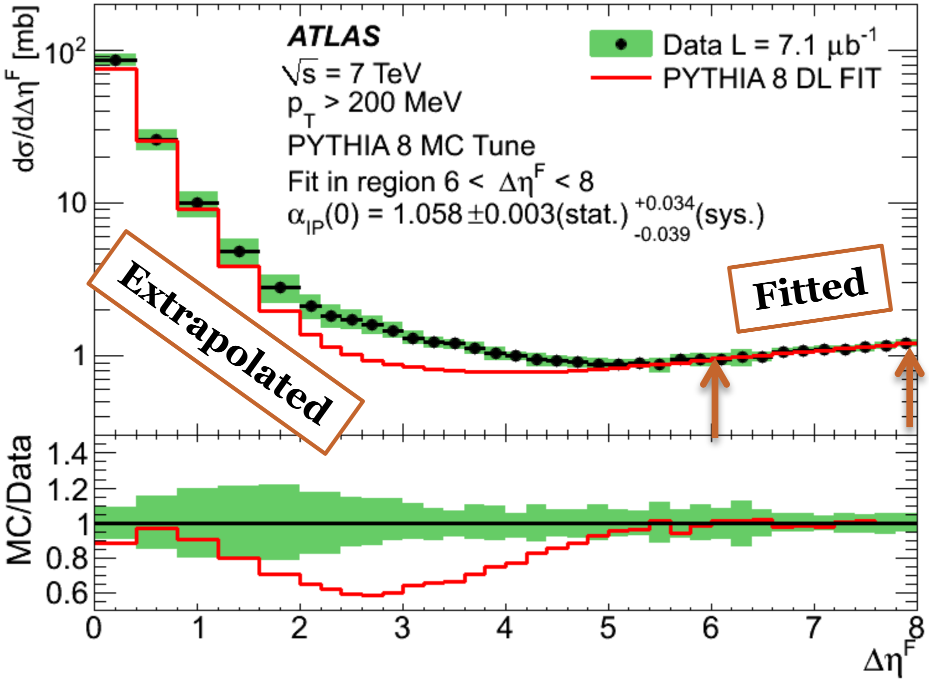
Best Fit to Data

- **R_{SS}** = Fraction of **exclusive single-sided** events measured in the **MBTS**.
- We take **α_{IP}** and the **normalisation** from the **fit region**.
- We take **f_D** from the inelastic cross section paper and we can then have Pythia **predict** the whole spectrum.





arXiv: 1104.0326



Extrapolated

Fitted