Recent Diffractive and Related Measurements with the ATLAS Detector

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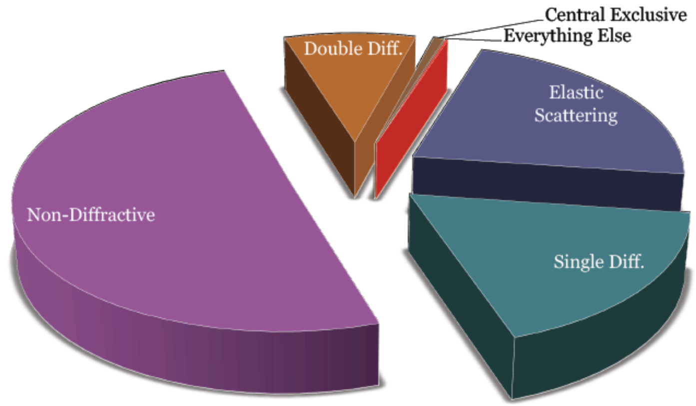
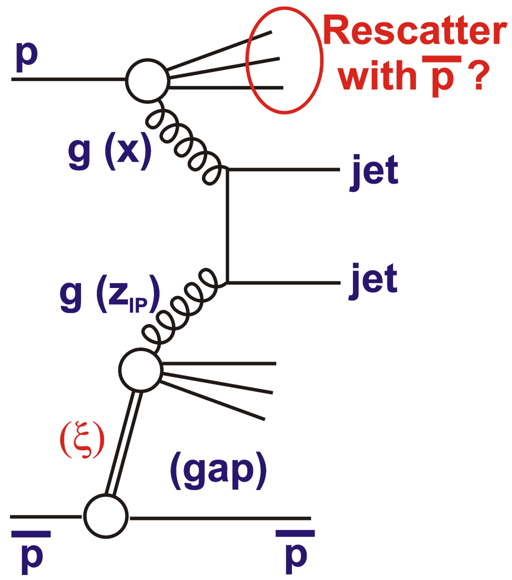


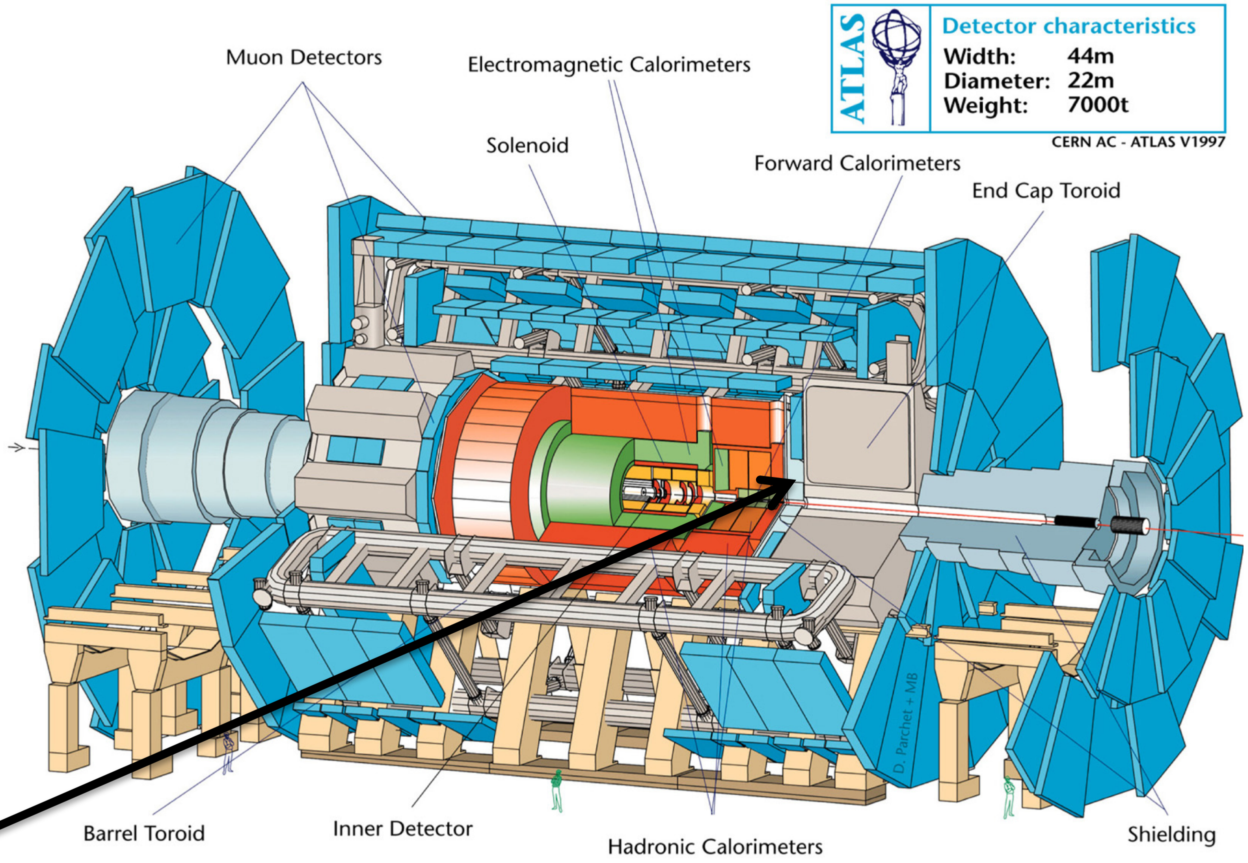


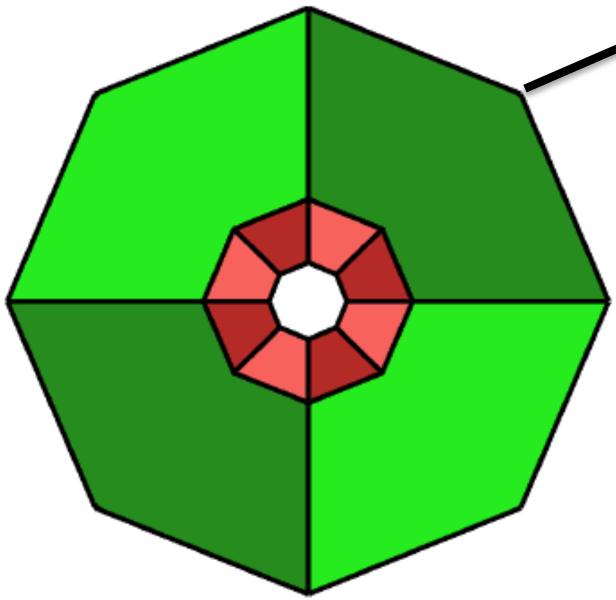
Low x Workshop, Gyongyos, Hungary
6-10 June 2016

→ Total Inelastic Cross Section at 13 TeV
→ Diffractive Dijet Cross Sections
→ Via a touch of elastic and soft diffractive measurements

ATLAS

Both measurements are based on minimum bias samples triggered using the MBTS scintillators



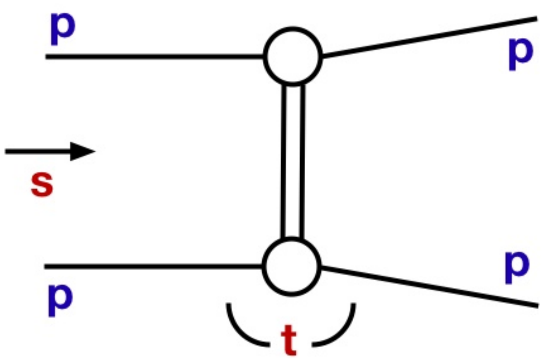


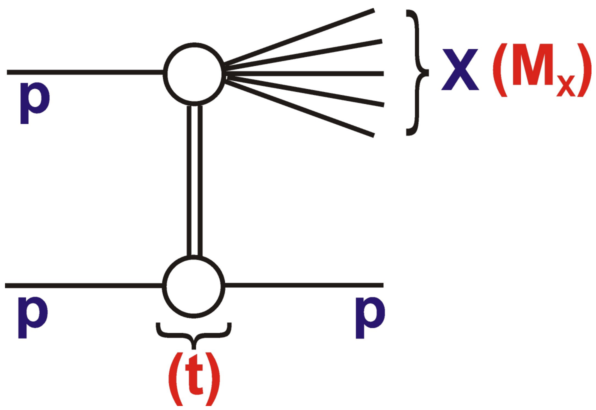
$z = \pm 3.6\text{m}, 2.1 < |\eta| < 3.8$

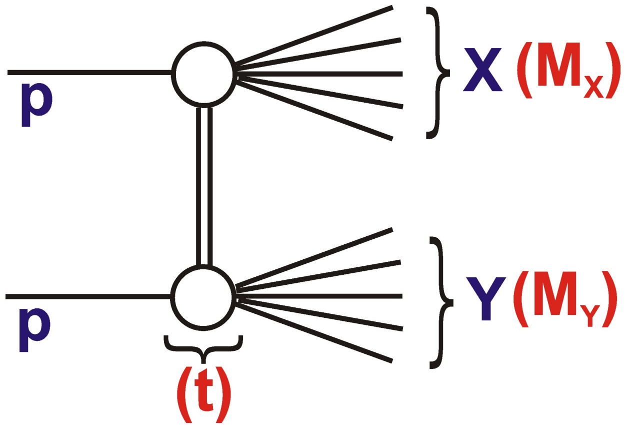
Run 1 version had 2 x 8-fold segmentation

Replaced for Run 2 – 8 fold segmentation nearest beam-pipe, 4-fold further out

Decomposing the pp Cross Section







Elastic

Single diffractive dissociation

Double diffractive dissociation

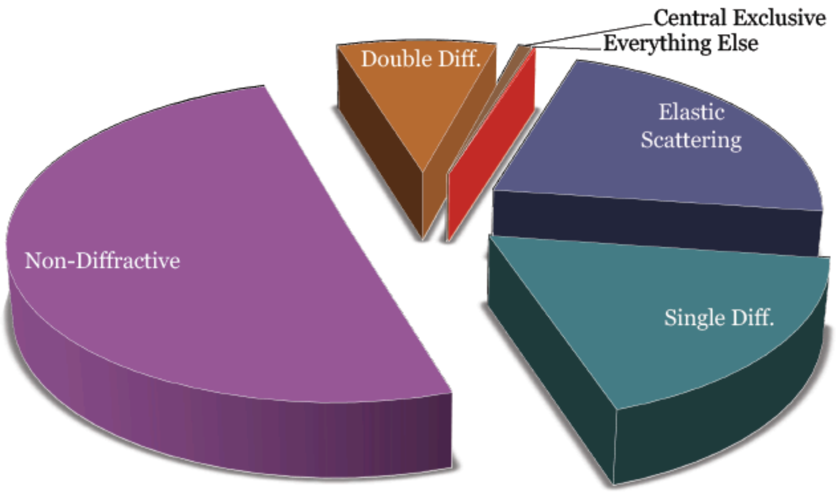
1 degree of freedom
→ scattering angle / t

Also M_X

$$\xi = \frac{M_X^2}{s} = 1 - \frac{E_p^{/}}{E_p}$$

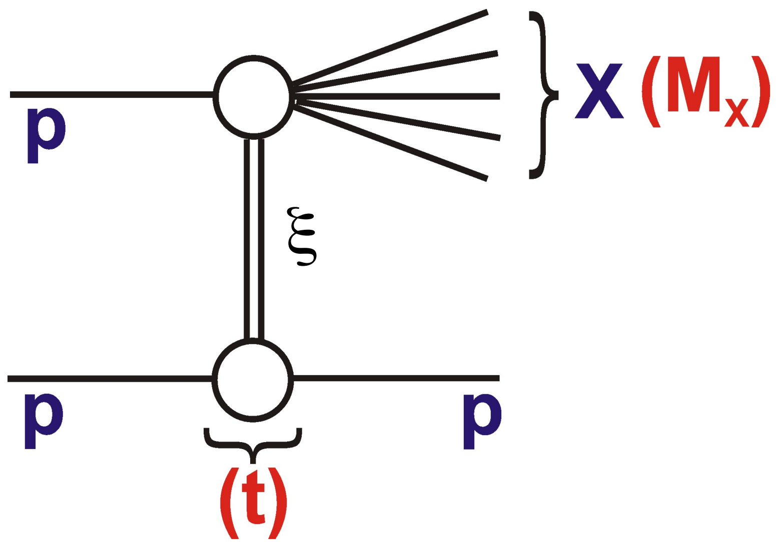
Also M_Y

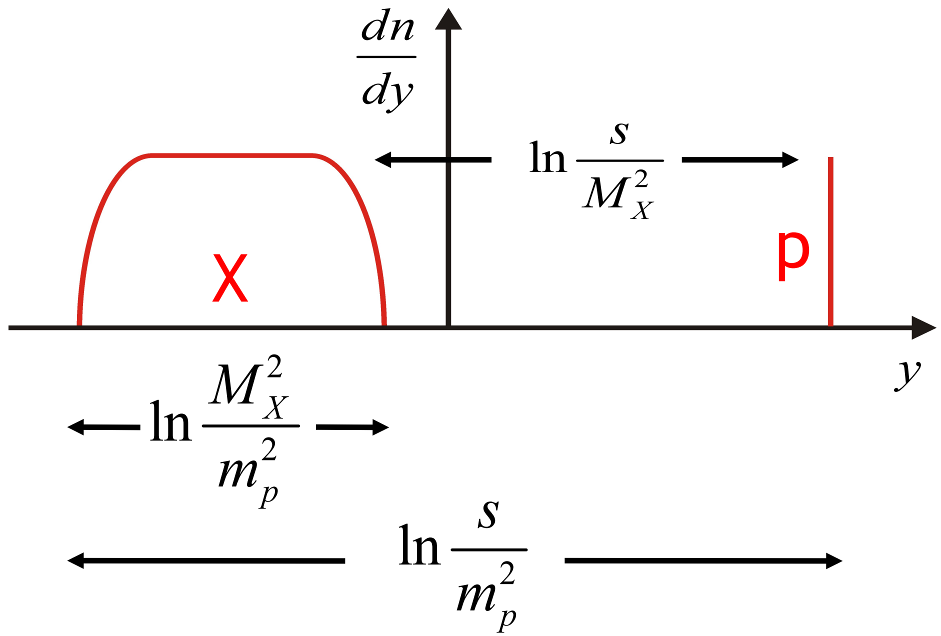
$$\xi_Y = \frac{M_Y^2}{s}$$



At LHC, M_X, M_Y can be as large as 1 TeV → plenty of phase space to produce jets and other hard probes

Diffractive Channels:
& Rapidity Gap Kinematics





- ξ variable strongly correlated with empty rapidity regions

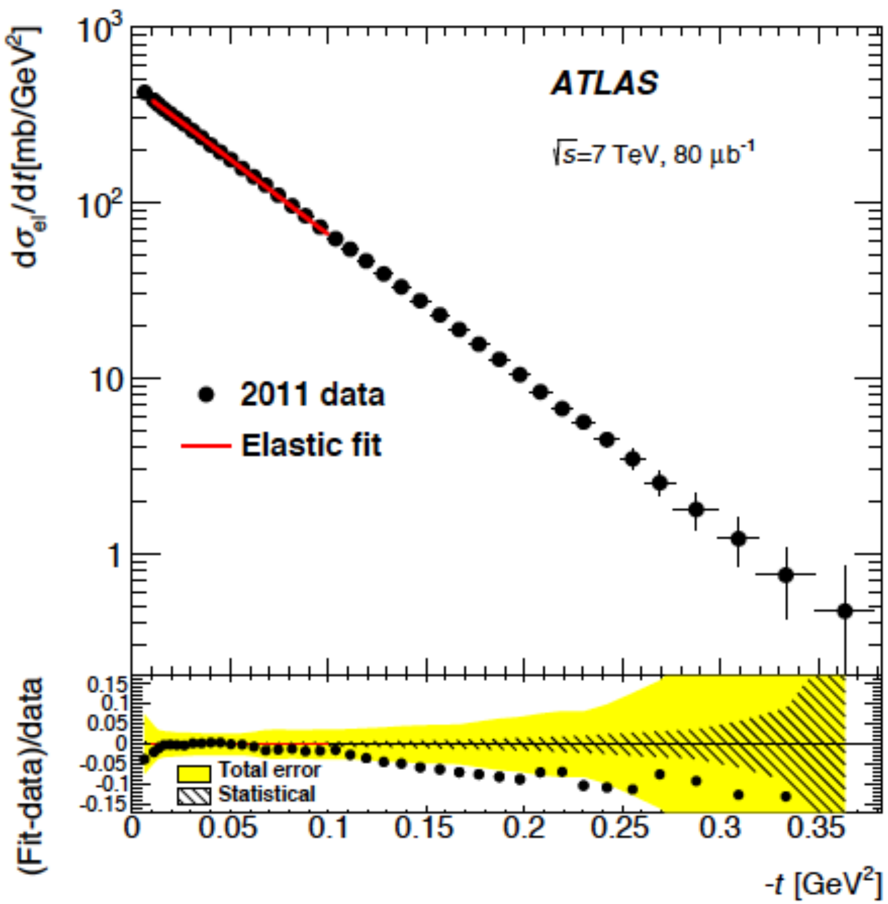
$$\Delta\eta \approx -\ln \xi$$

… exploited in both measurements to be shown

- Correlation limited by hadronisation fluctuations

Total and elastic cross sections

Meaasurements of the elastic cross section and its t-dependence (eg in ALFA) also determine the total cross section via the optical theorem



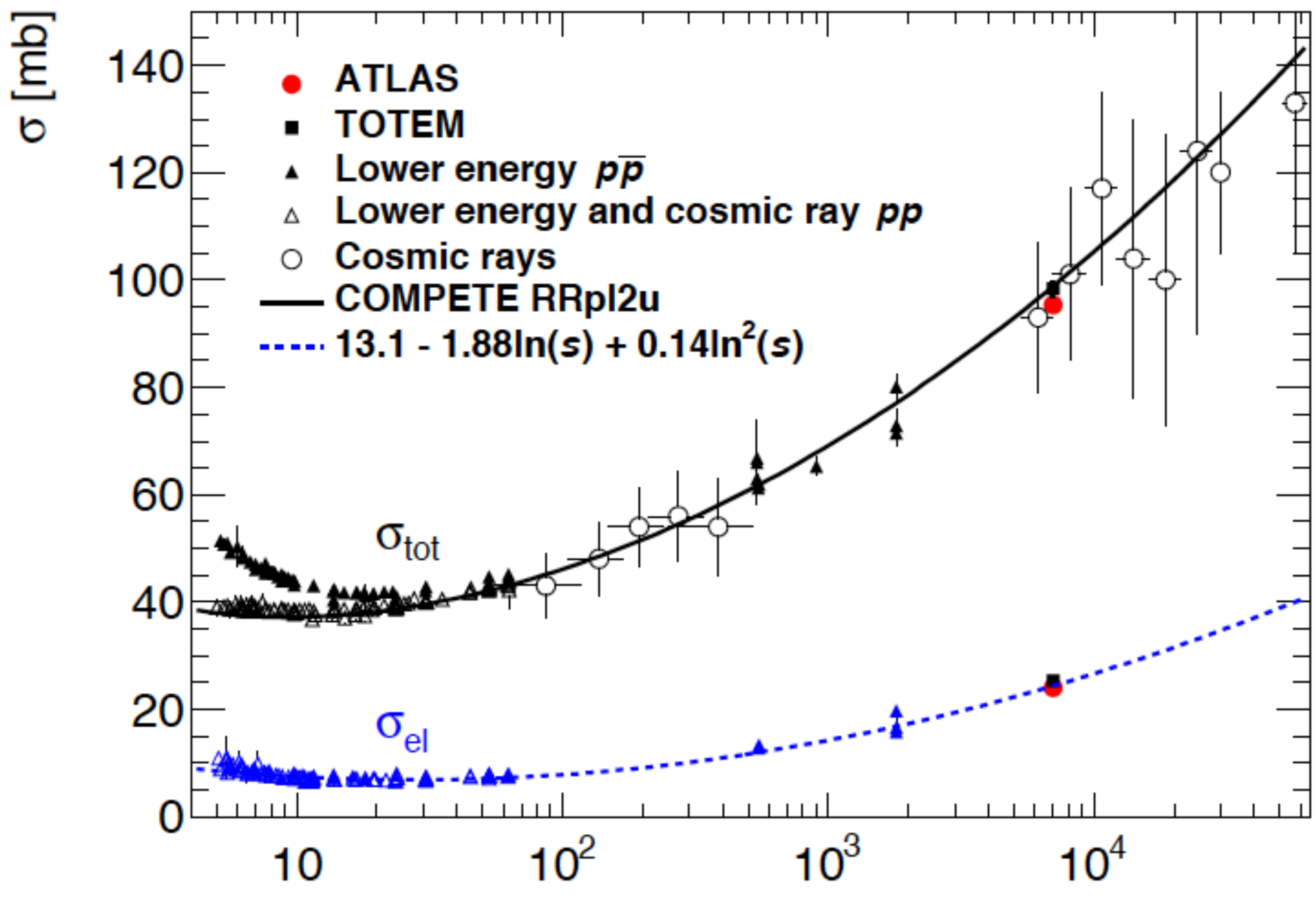
$$\sigma_{TOT}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}$$

[ρ~0.1 = phase of Coulomb-nuclear interference at t=0]

At fixed s: $$\frac{d\sigma}{dt} = \left.\frac{d\sigma}{dt}\right|_{t=0} e^{Bt}$$

B=19.73±0.24 GeV^{-2} (ALFA)

Total, Elastic and Inelastic Cross Sections



ATLAS: $\sigma_{tot} = 95.4 \pm 1.4$ mb

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Consistent with fits to previous data (with either a logarithmic or power law dependence).

[$\alpha_{IP}(0) \sim 1.08$]

- Knowledge of σ_{tot} and σ_{el} also in principle determines the total inelastic cross section σ_{inel}
- Direct σ_{inel} tests self-consistency (expt and theory).

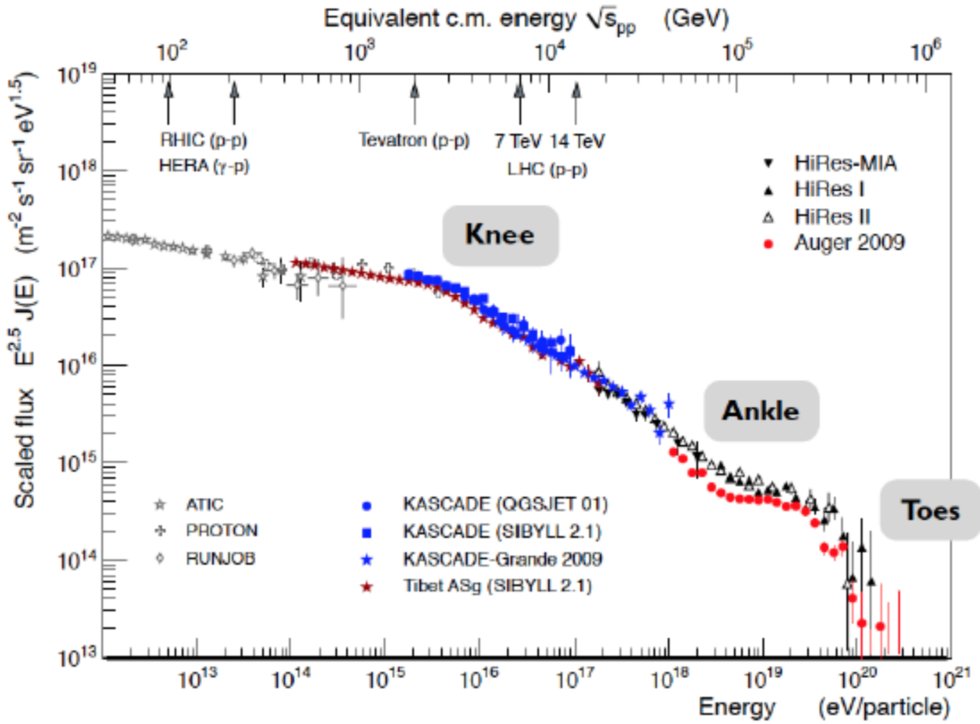
Total Inelastic Cross Section

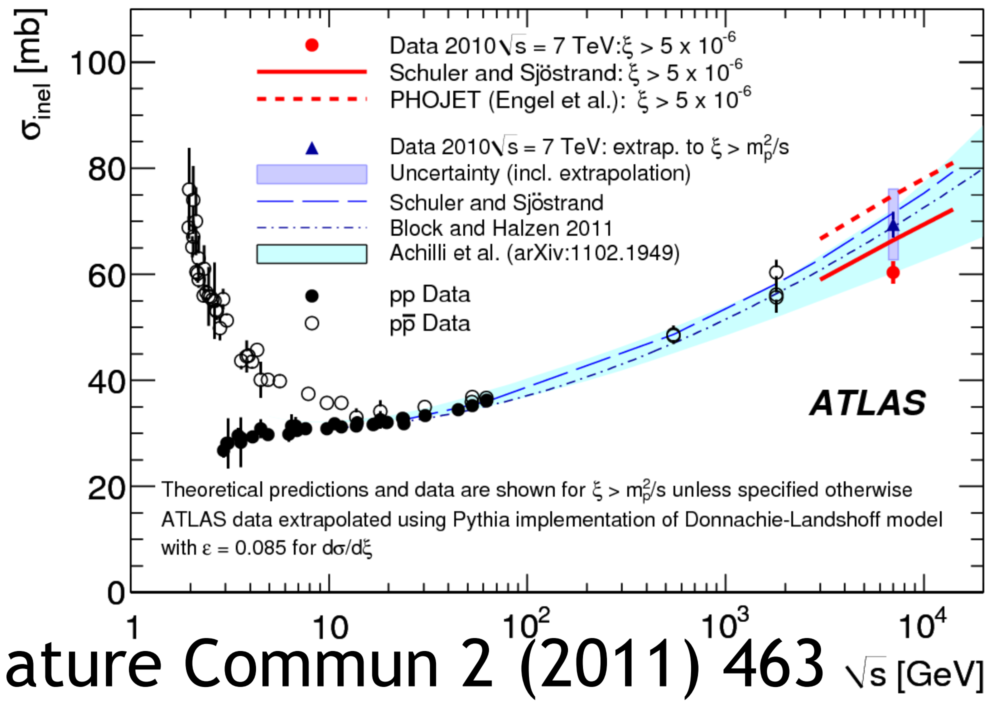
- Crucial quantity for understanding cosmic ray air showers

- Ingredient for modelling pile-up (and lumi) at LHC

- MBTS sees 90-95% of all inelastic events → counting experiment.

Repeat and refinement of 7 TeV procedure using short low pile-up run at 13 TeV taken in June 2015





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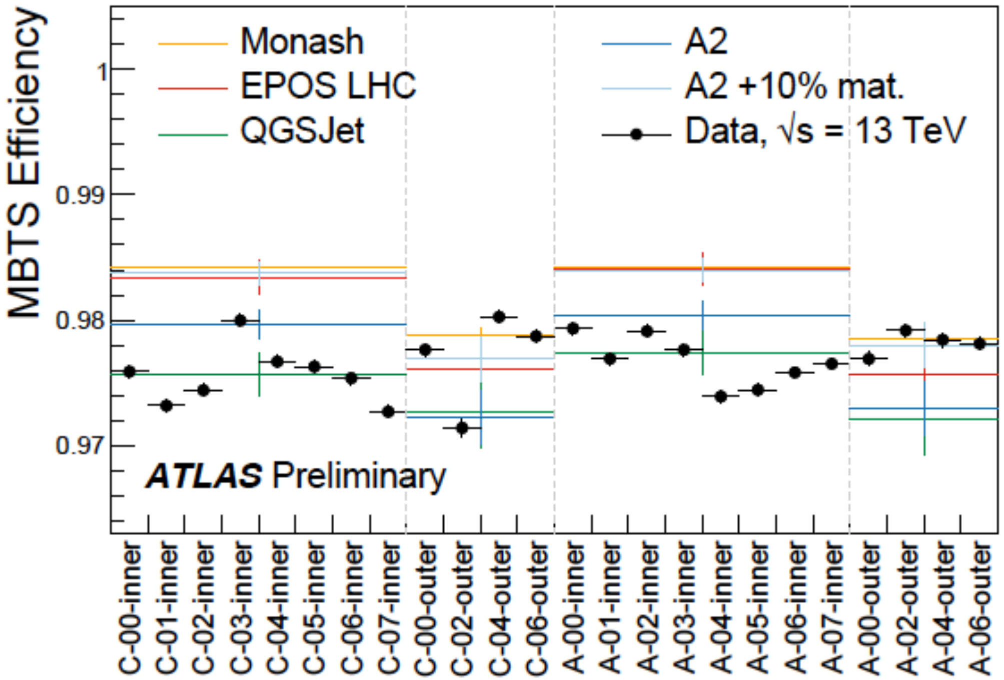
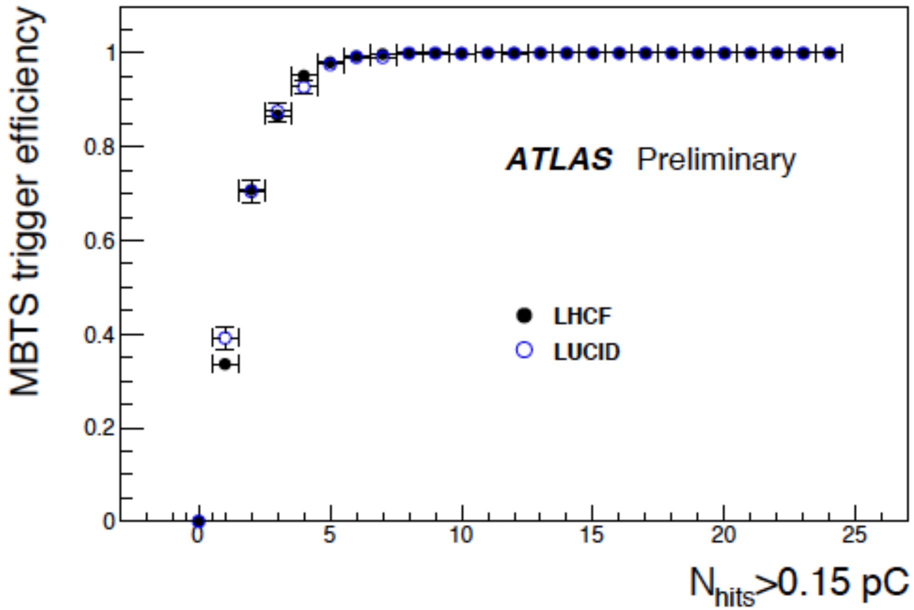
Controlling the MBTS Efficiency



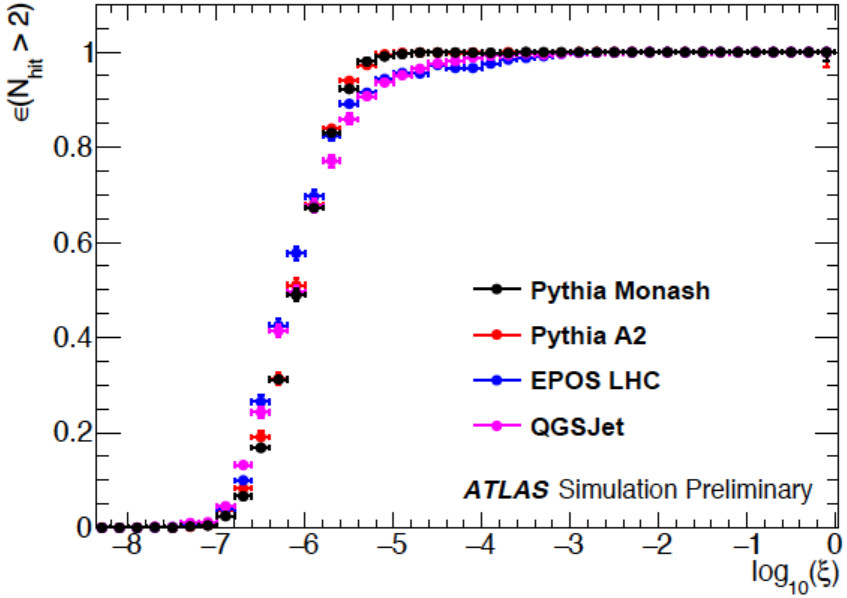
- Efficiencies for each counter measured relative to tracks in inner detector where posible and calorimeter clusters where not.
→MC efficiencies tuned accordingly

- Trigger efficiencies monitored relative to independent LUCID and LHCf triggers

- Efficiency / acceptance is a strong function of hit multiplicity



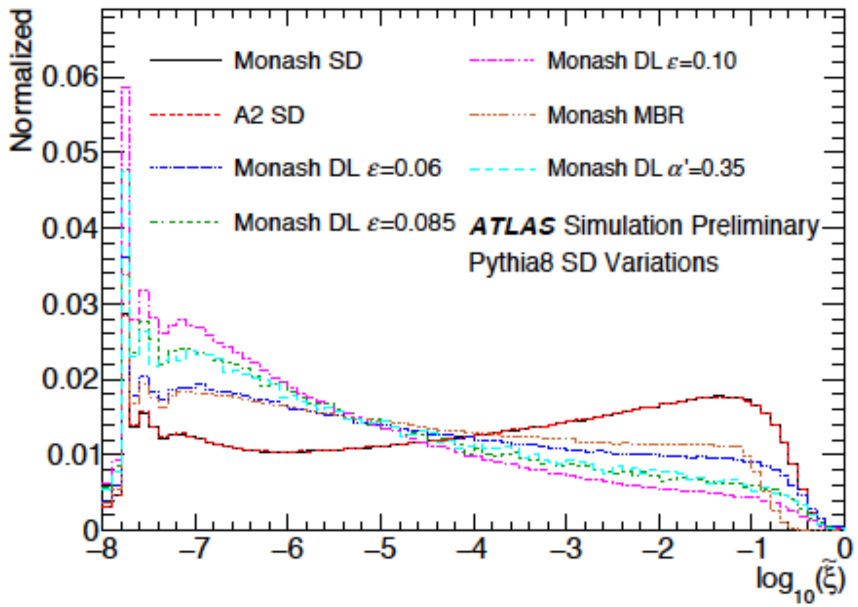
The bit we can't see: low mass diffraction

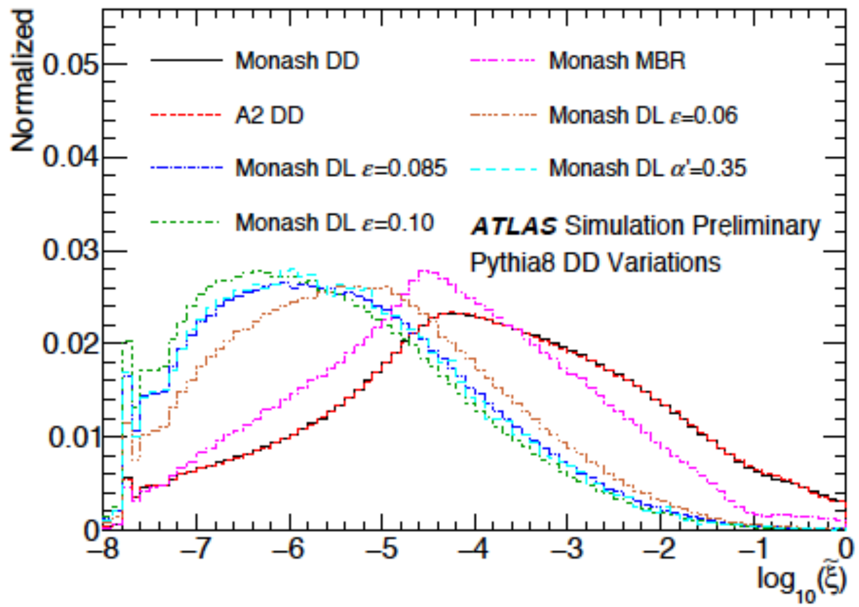


$$\Delta\eta \approx -\ln\xi$$

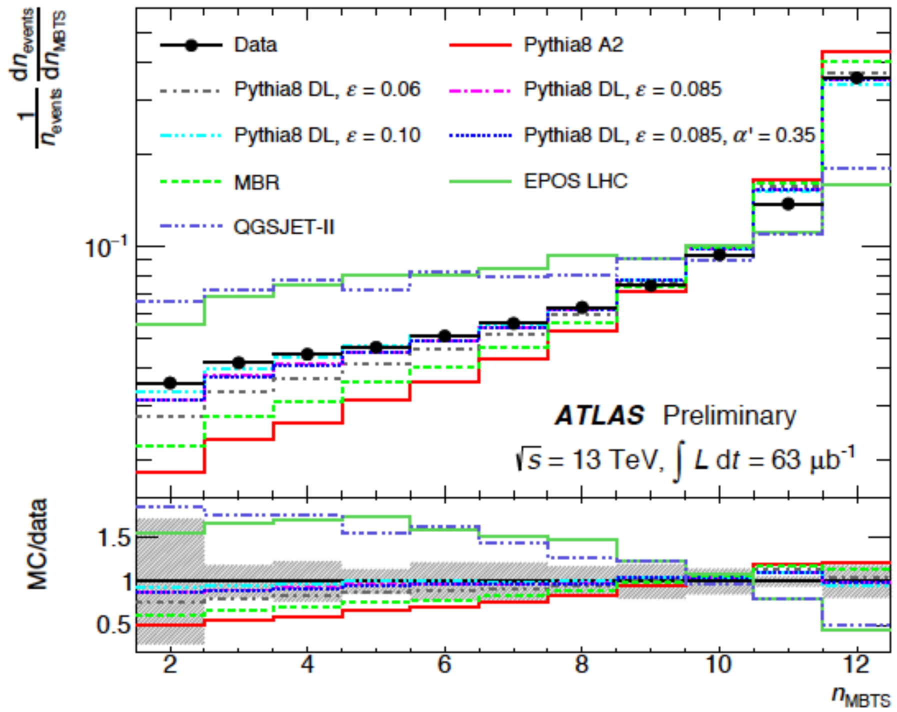
Acceptance limit of MBTS (|η|~4) corresponds to $\xi \sim 10^{-6}$

Cross section at $\xi < 10^{-6}$ poorly constrained



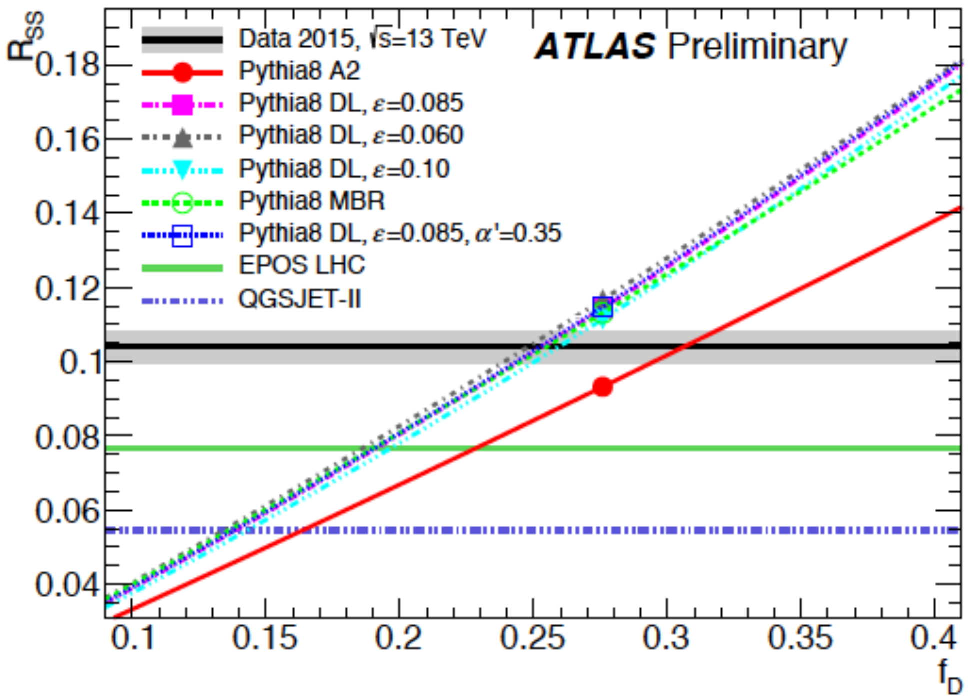


Benchmarking Diffractive MC models



Sample with only one side of the MBTS registering activity enriched in SD events → Number of MBTS counters firing distinguishes between MC models of diffraction

R_{SS} = Ratio of samples with one side of the MBTS firing to both sides used to tune fractions of events considered diffractive in each MC model



Baseline is PYTHIA8 with DL pomeron flux and $\alpha_{IP}(0) = 1.085$

Fiducial Cross Section Extraction

$$\sigma_{\rm inel}^{\rm fid}\left(\xi > 10^{-6}\right) = \frac{N - N_{\rm BG}}{\epsilon_{\rm trig} \times \mathcal{L}} \times \frac{1 - f_{\xi<10^{-6}}}{\epsilon_{\rm sel}}$$

N_{BG}: Small background from beam-gas, radiation & activation, determined using triggers in non-colliding bunches

$(1-f_{\xi<10\text{-}6})/\varepsilon_{sel}$ = acceptance and migration correction from MC

Luminosity from preliminary van der Meer scan → 9% error.

Factor	Value	Rel. unc.
Number of selected events (N)	4159074	–
Number of background events ($N_{\rm BG}$)	43512	±100 %
Luminosity [μb^{-1}] (L)	62.9	±9 %
Trigger efficiency ($\epsilon_{\rm trig}$)	99.7%	±0.1 %
MC Correction factor ($(1 - f_{\tilde{\xi}<10^{-6}})/\epsilon_{\rm sel}$)	0.993	±0.5 %

Cross Section in Fiducial Range

$$\sigma_{\text{inel}}^{\text{fid}}\left(\xi > 10^{-6}\right) = 65.2 \pm 0.8\ (\text{exp.})\ \pm 5.9\ (\text{lum.})\ \text{mb},$$

Source	Value
This measurement	65.2 ± 0.8 (exp.) ± 5.9 (lum.) mb
Pythia8 DL, $\epsilon = 0.06$	71.0 mb
Pythia8 DL, $\epsilon = 0.085$	69.1 mb
Pythia8 DL, $\epsilon = 0.1$	68.1 mb
Pythia8 A2	74.4 mb
EPOS LHC	71.2 mb
QGSJET-II	72.7 mb

Table 2: The measured inelastic cross section for $\xi > 10^{-6}$ and several theoretical predictions.

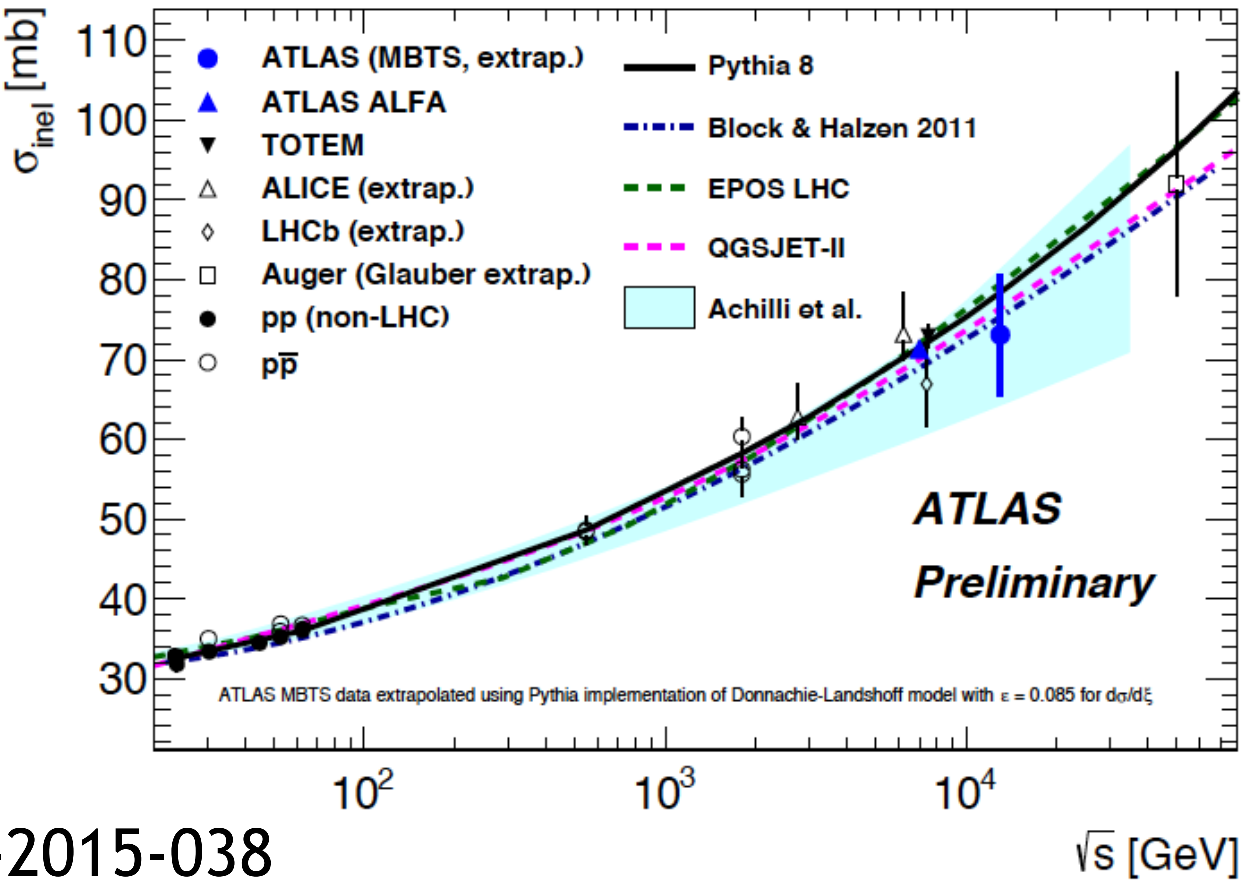
Lies lower than most MC models, but consistent within large luminosity uncertainty

Subsequent improvements in luminosity calibration
→ ~2% uncertainty in (pending) final result

Extrapolation to Full Inelastic Cross Sec

Extrapolation into region with $\xi < 10^{-6}$ done using MC models
Tuned using RSS from this measurement.
→ Significant model dependence uncertainty

$$\sigma_{inel} = 73.1 \pm 0.9\,(\text{exp.}) \pm 6.6\,(\text{lum.}) \pm 3.8\,(\text{extr.})\ \text{mb.}$$



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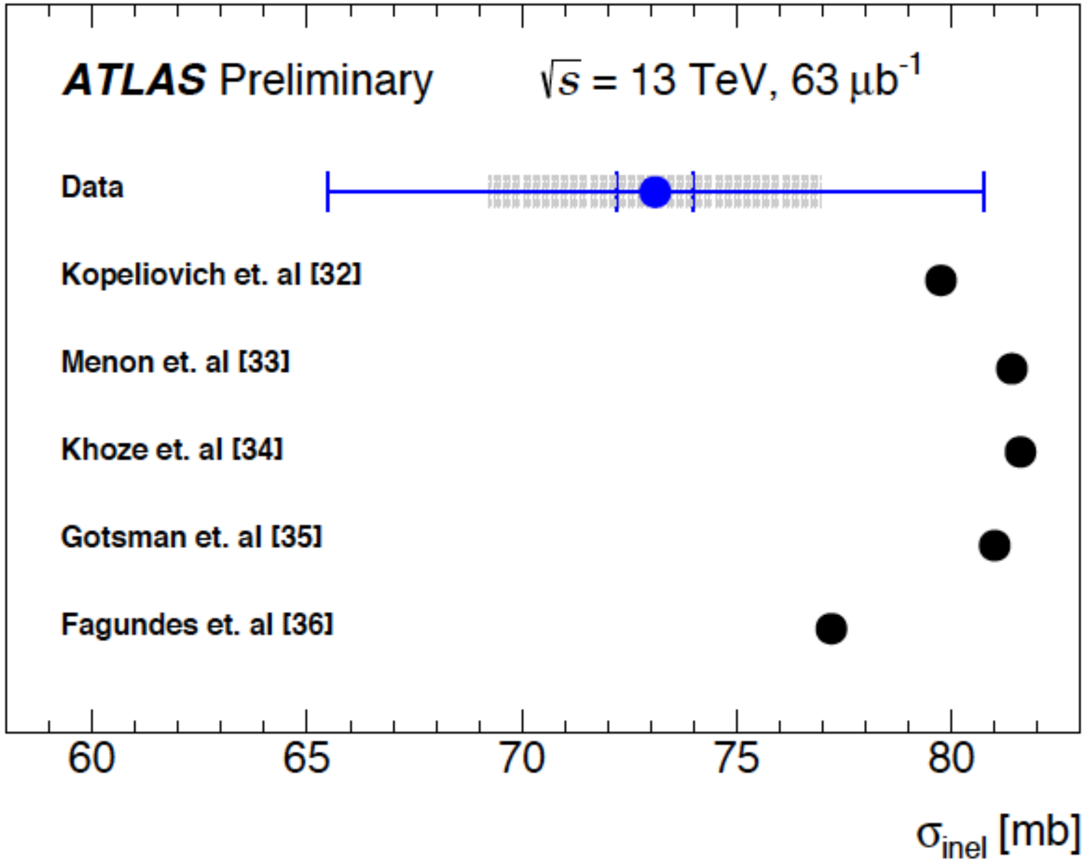
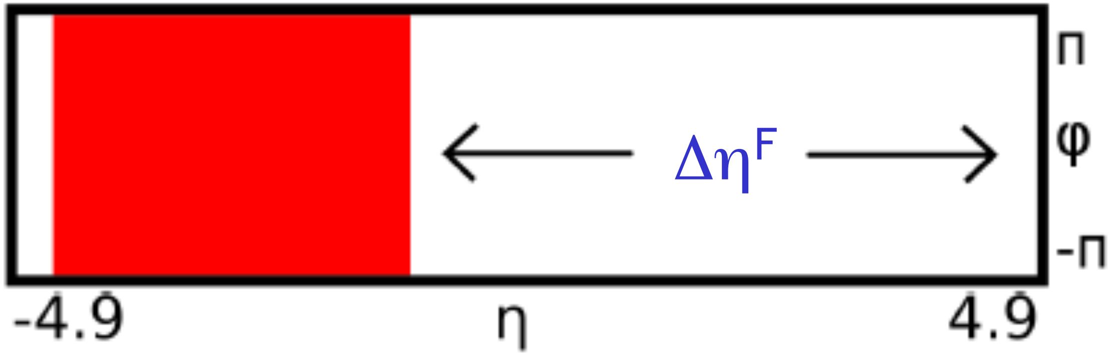
Total Inelastic Cross Section v Models

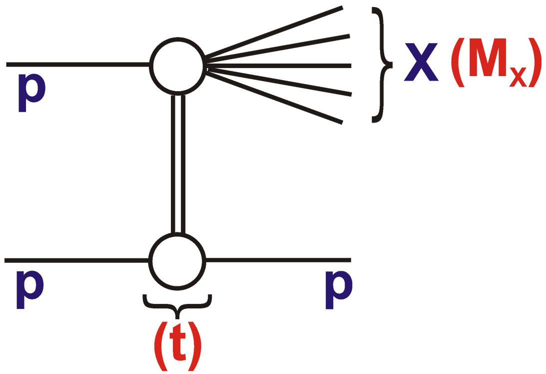


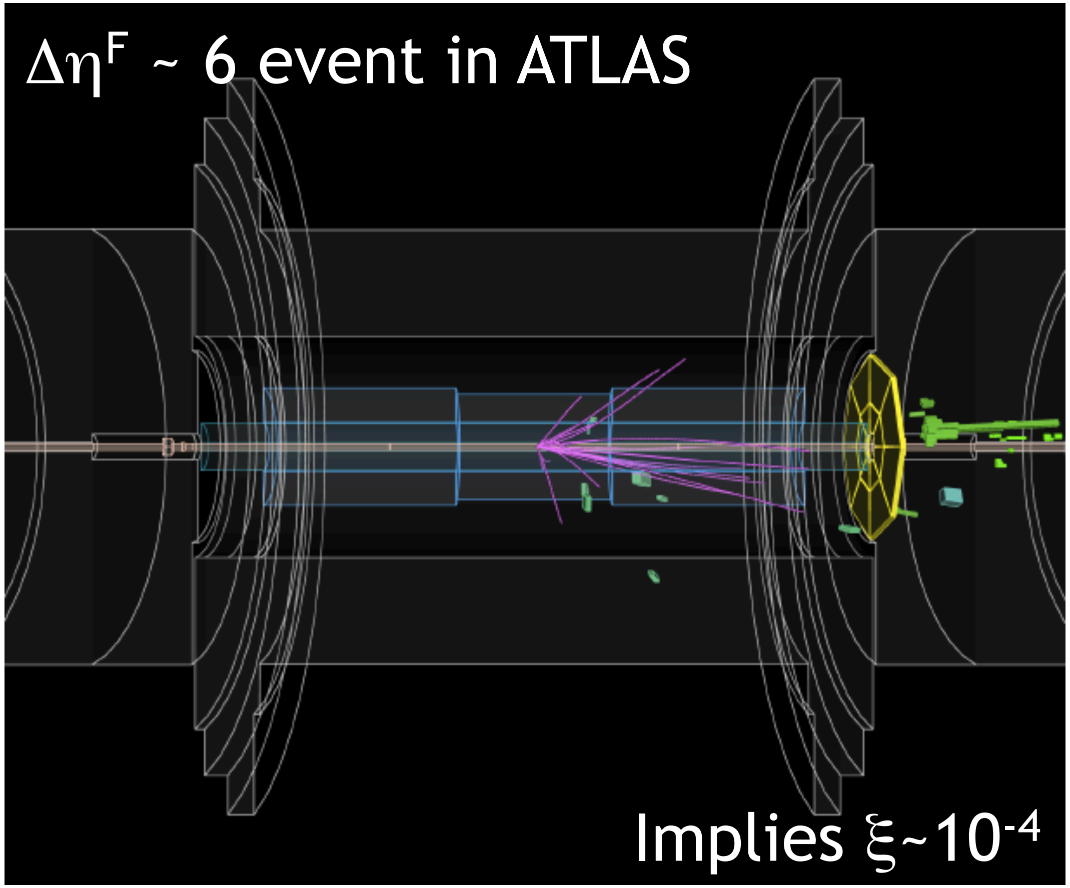
Within current uncertainties, result is consistent with indicative selection of models based on Regge phenomenology, eikonal models and other approaches to non-perturbative strong interactions

Rapidity gap cross-sections

Method developed in ATLAS to measure hadron Level Cross section as a Function of $\Delta\eta^F$: forward or backward rapidity gap extending to limit of instrumented range:
i.e. including $\eta = \pm 4.9$

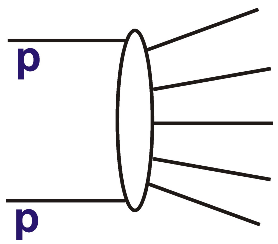


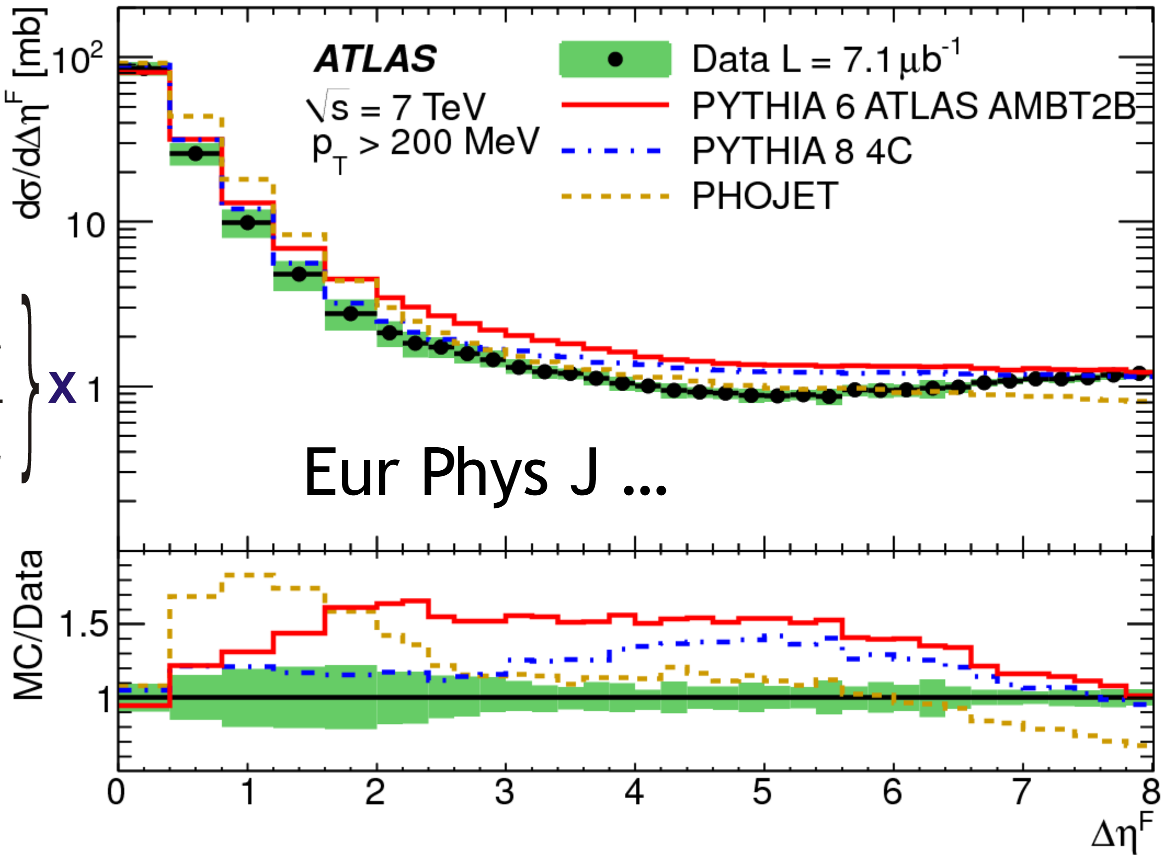


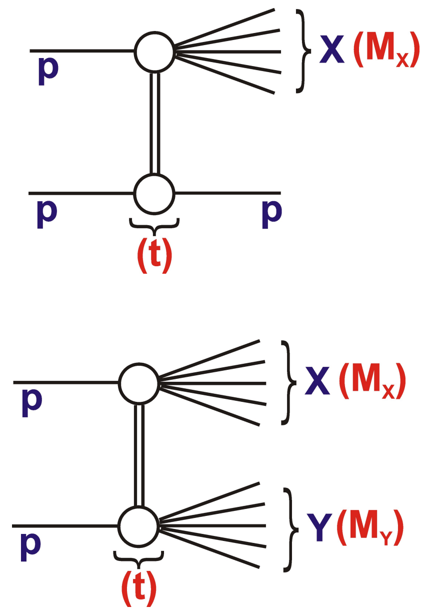


… no statement on η >~4.9
… Large $\Delta\eta^F$ sensitive to
SD + low M_Y DD

Inclusive Differential Gap Cross Section



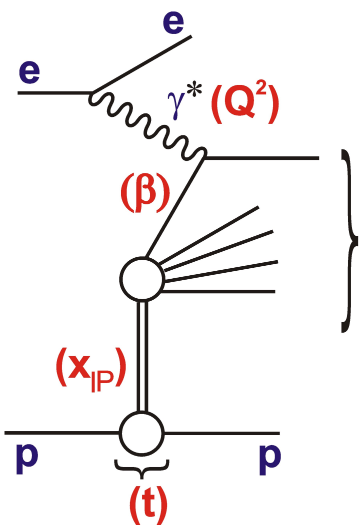




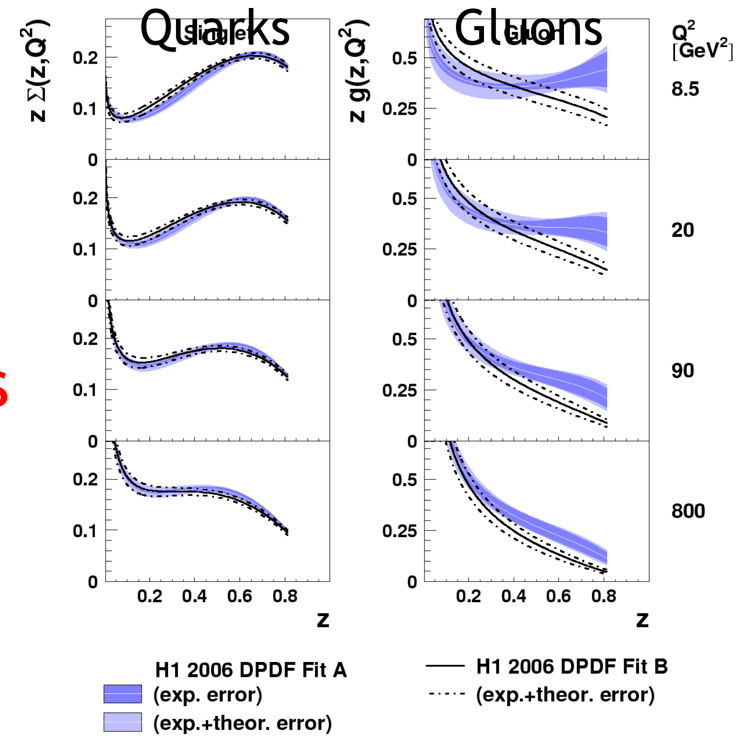
- Large $\Delta\eta^F$: Diffractive plateau with ~1mb per unit gap size, consistent with soft pomeron ($\alpha_{IP}(0) = 1.058 \pm 0.036$)
- Small $\Delta\eta^F$: sensitive to hadronisation fluctuations / MPI in ND

Can the same method be applied to hard diffractive processes?...

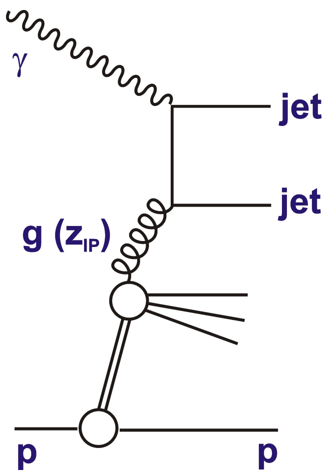
Hard Diffraction and Diffractive PDFs

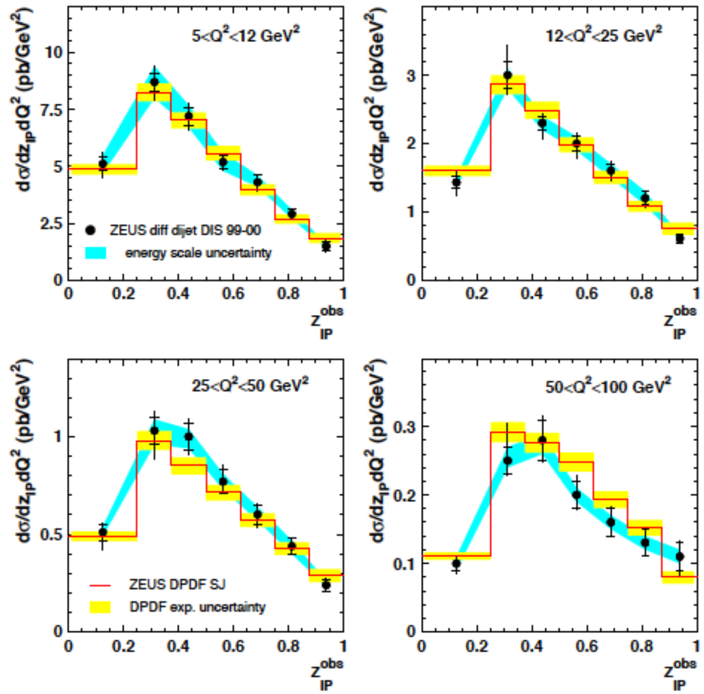


Diffractive DIS at HERA → Diffractive parton densities dominated by gluon, which extends to large momentum fractions



… NLO predictions based On HERA DPDFs give impressive description of all HERA 'hard' diffractive data, eg jet production …

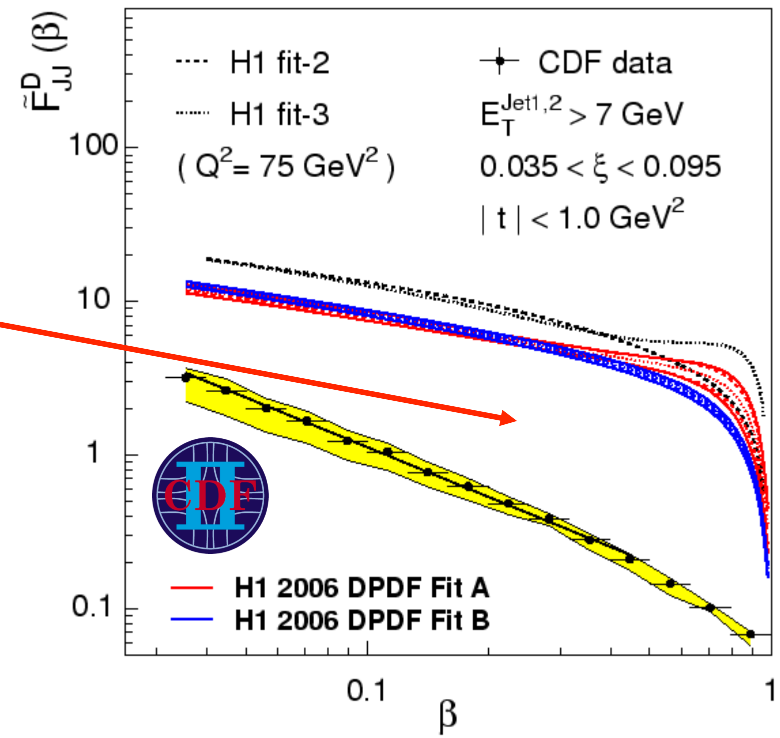




→ DPDFs used in many models in pp(bar)

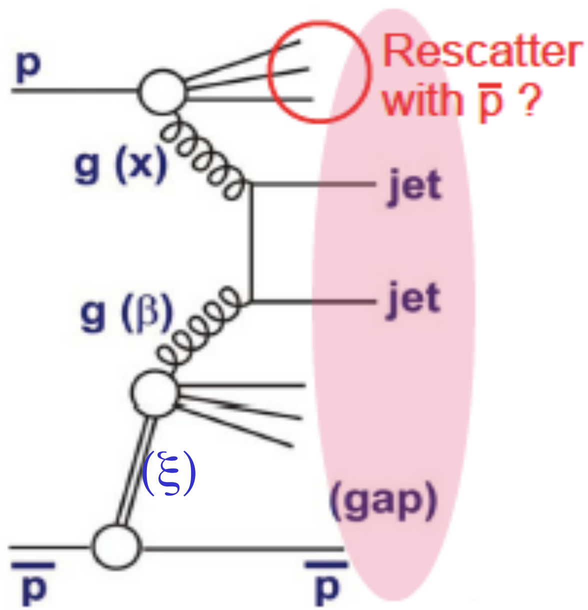
... but in pp(bar)

Spectacular failure in comparison of Tevatron proton-tagged diffractive dijets with HERA DPDFs



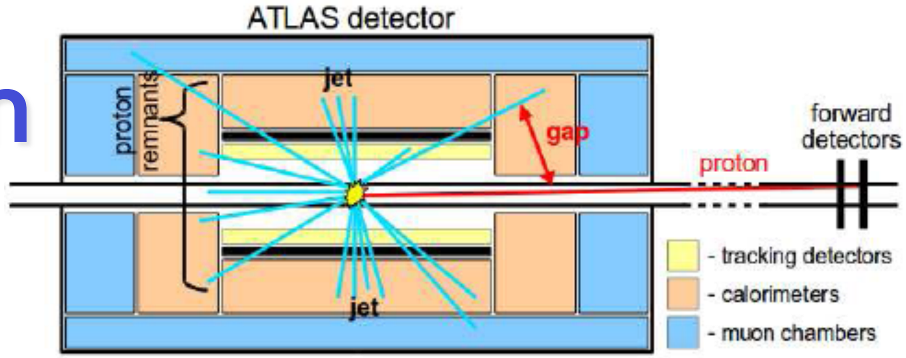
CMS data suggest similar effect

... `rapidity gap survival probability' ~ 0.1 due to rescattering (absorptive corrections / related to MPI ...) breaks factorisation



LHC hard diffraction sensitive to both DPDFs and gap survival probability → First results from ATLAS:
... dijets with large rapidity gaps ...

Kinematics & Selection



Low pile-up data sample from 2010 with $\sqrt{s}$ = 7 TeV and integrated luminosity of 6.8 nb^{-1}.

Triggered using either MBTS or calorimeter jet triggers

Jets with anti-k_T algorithm, p_T > 20 GeV, $|\eta|$ < 4.4, R=0.4, 0.6

Gaps characterised using $\Delta\eta^F$, based on tracks ($|\eta|$ < 2.5) and calo cells ($|\eta|$ < 4.8) that are >5σ out of noise distribution.

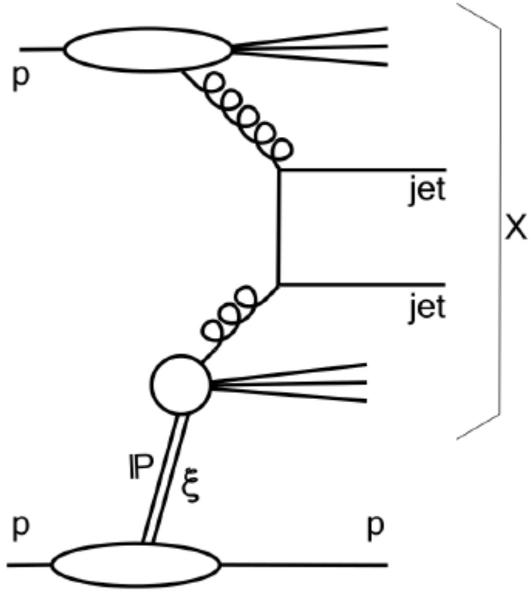
Corrected cross sections correspond to gaps with no neutral particle with p > 200 MeV and no charged particle with p > 500 MeV or p_T > 200 MeV.

Uncertainty dominated by jet energy scale

Models

- POMWIG: Dedicated hard diffraction model with standard factorisable pomeron approach: Cross section ingredients are Proton PDFs, pomeron Flux and DPDfs

- PYTHIA8: Inclusive model with hard and soft ND, DD and SD contributions; smoothly interfaced.



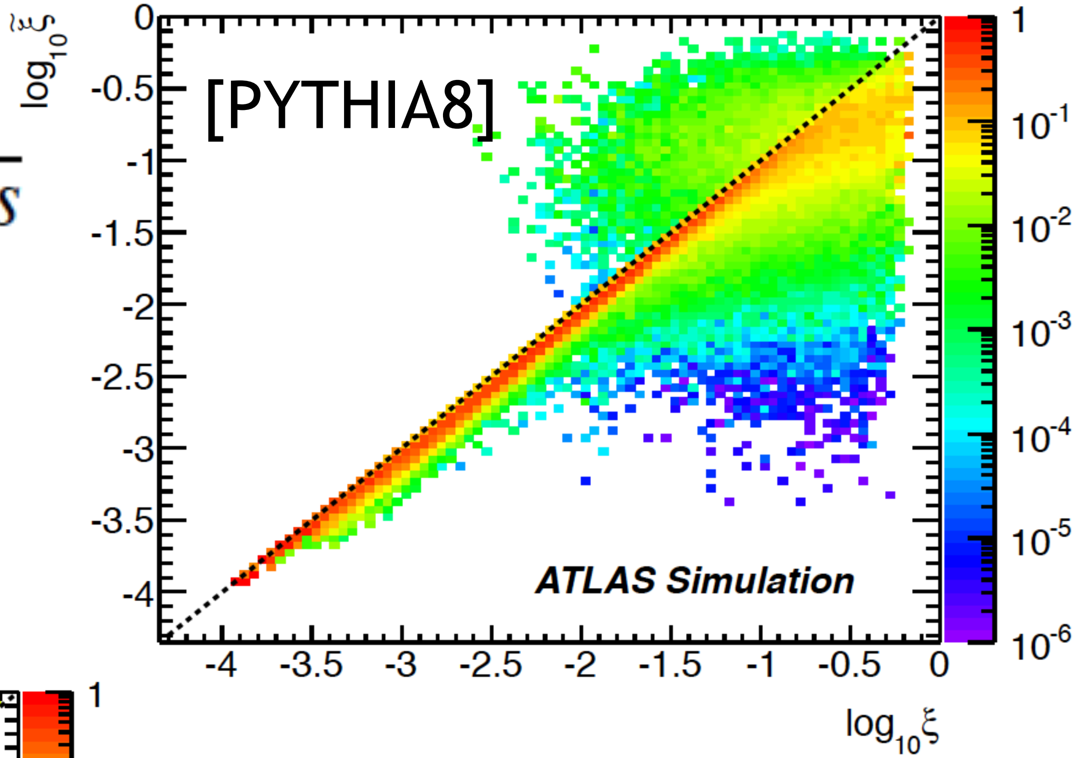
- Both models use HERA DPDFs (H12006-FitB)

- Neither model includes rapidity gap destruction effects

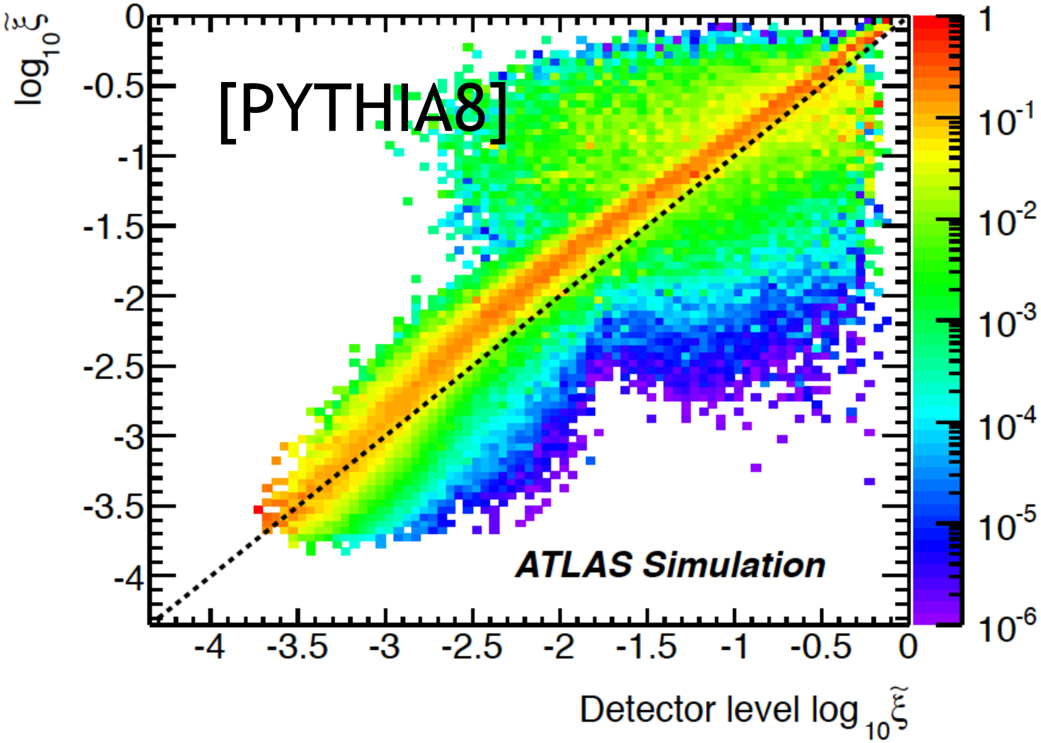
- Alternative ND model from POWHEG-NLO

Constraining ξ

$$\tilde{\xi} \simeq M_X^2/s = \sum p_T e^{\pm\eta}/\sqrt{s}$$



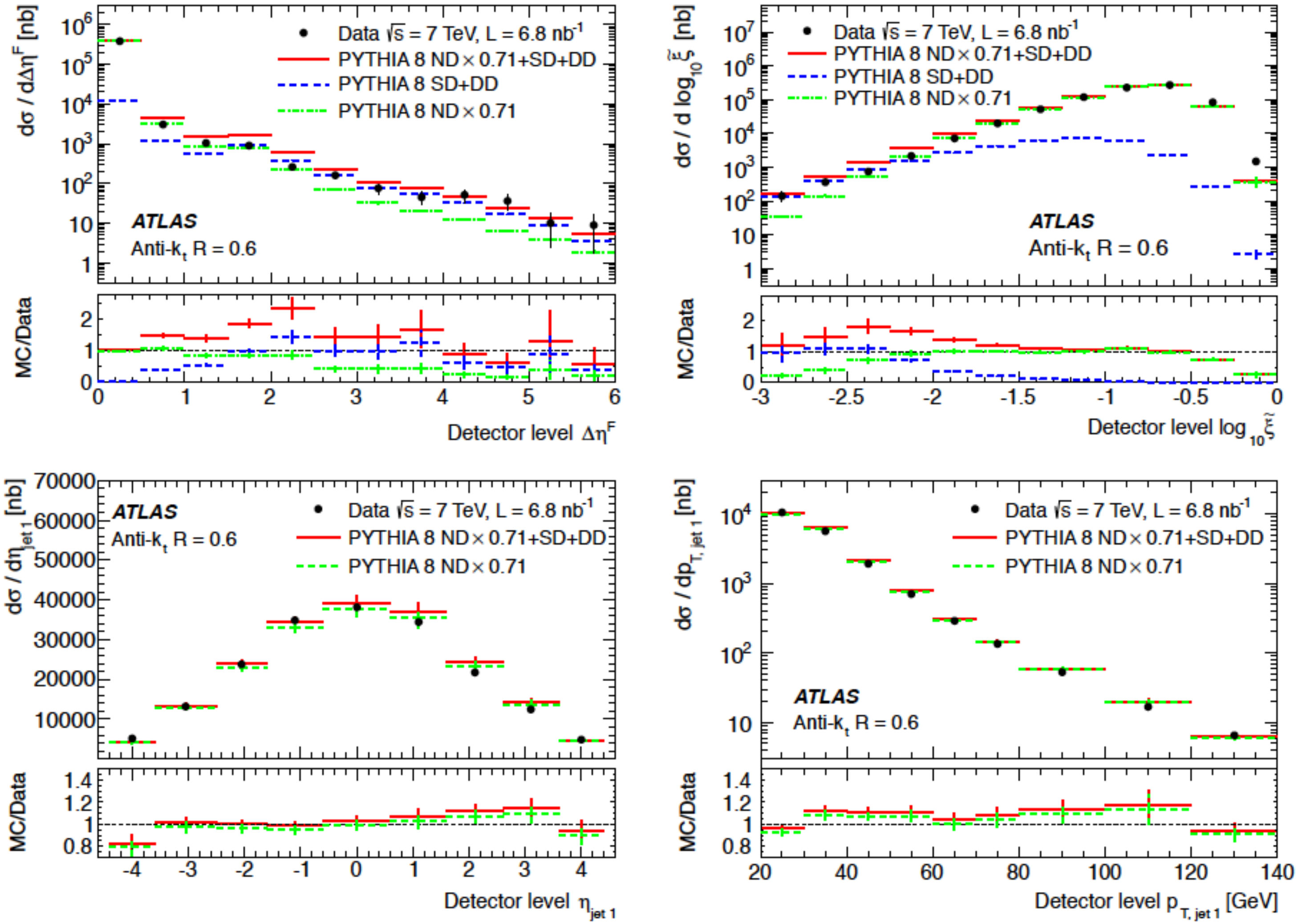
Approximation to ξ which is relatively insensitive to losses of parts of X system into the beam-pipe



tilde{xi} close to true xi at particle level up to ~10^{-2}

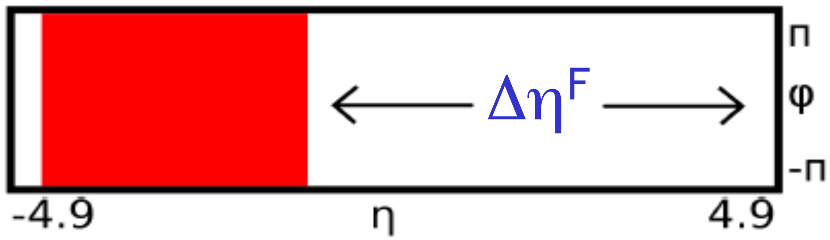
Experimental resolution on log(tilde{xi}) is approximately 10%.

Control Distributions

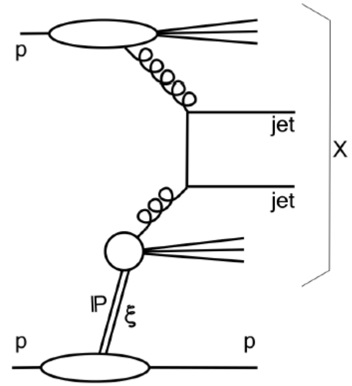


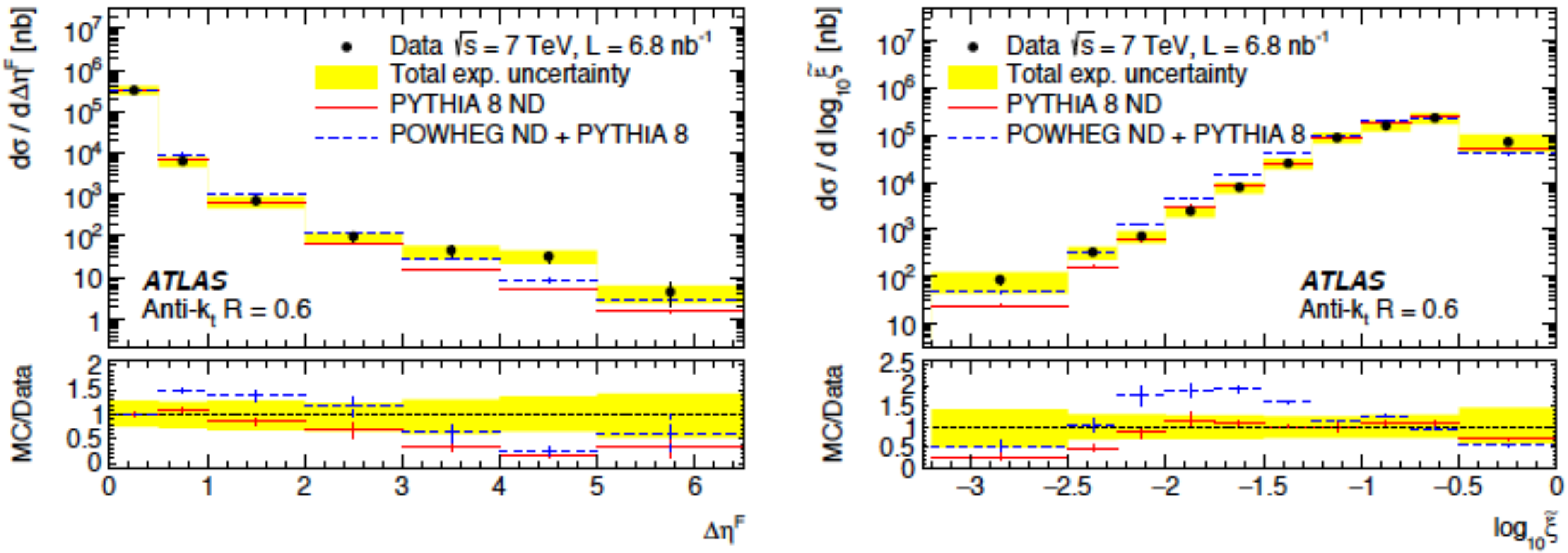
PYTHIA8 MC: ND scaled x 0.71 to match first bin of $\Delta\eta^F$, added to SD and DD ‘out of the box’ → Satisfactory descriptions of all relevant distributions; used for unfolding.

Dijets with Gaps Compared with Non-Diffractive Models



- Kinematic suppression of large gaps → no clear diffractive plateau (unlike minimum bias case)
- ND models matched to data atsmall gap sizes give contributions compatible with data up to largest $\Delta\eta_F$ and smallest ξ … no clear diff signal …



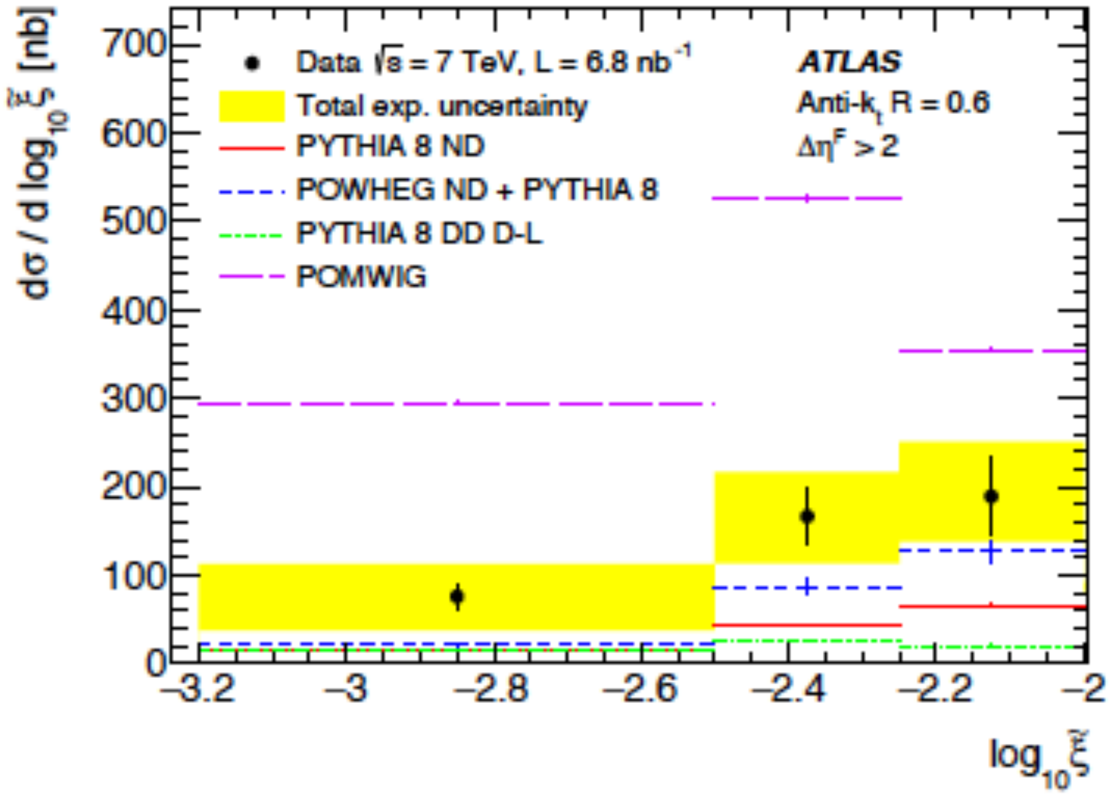


Evidence for Diffractive Contribution

Focusing on small ξ, whist simultaneously requiring large gap size ($\Delta\eta_F$ > 2) gives best sensitivity to diffractive component

→ Models with no SD jets below data by factor >~3

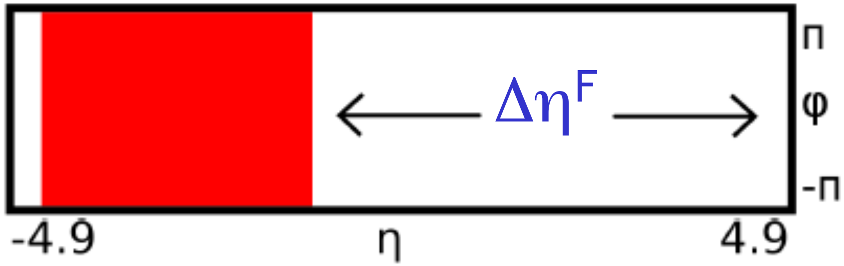
→ Comparison of smallest ξ with DPDF-based model (POMWIG) leads to rapidity gap survival probability estimate …



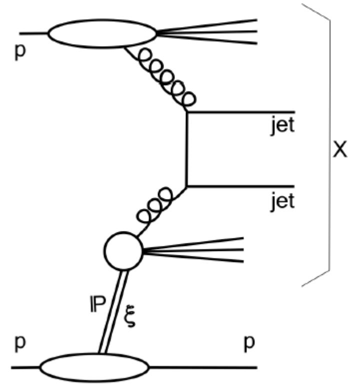
- In context of POMWIG, using anti-kT with R=0.6:

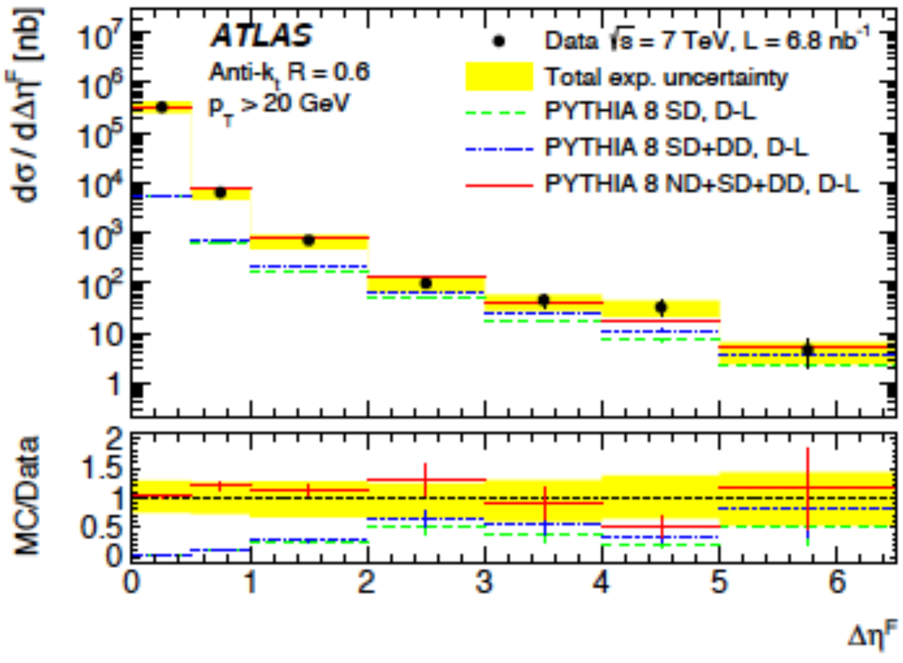
$$S^2 = 0.16 \pm 0.04\ (\text{stat.}) \pm 0.08\ (\text{exp. syst.})\ ,$$

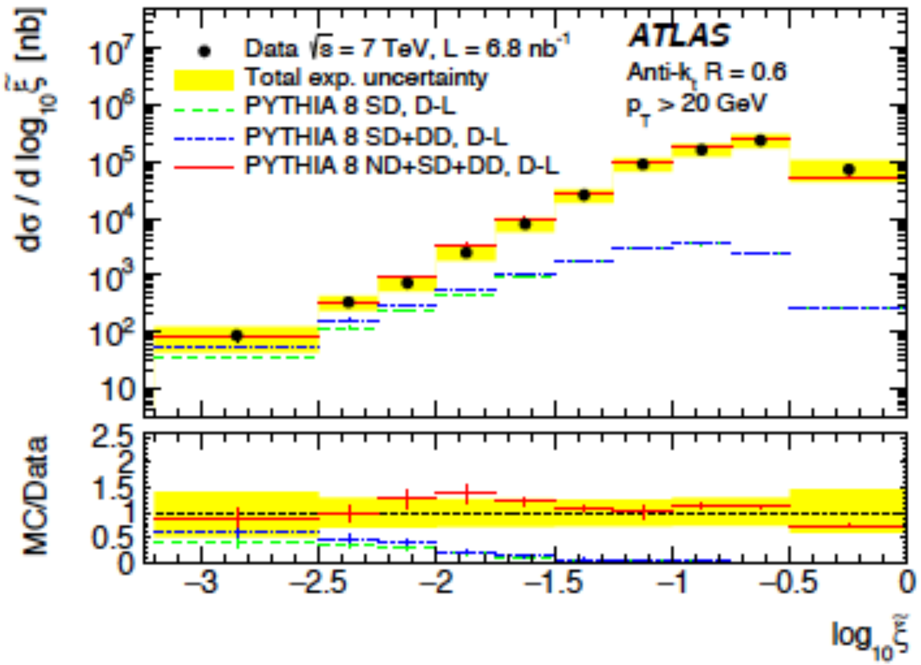
Comparison with Full PYTHIA8



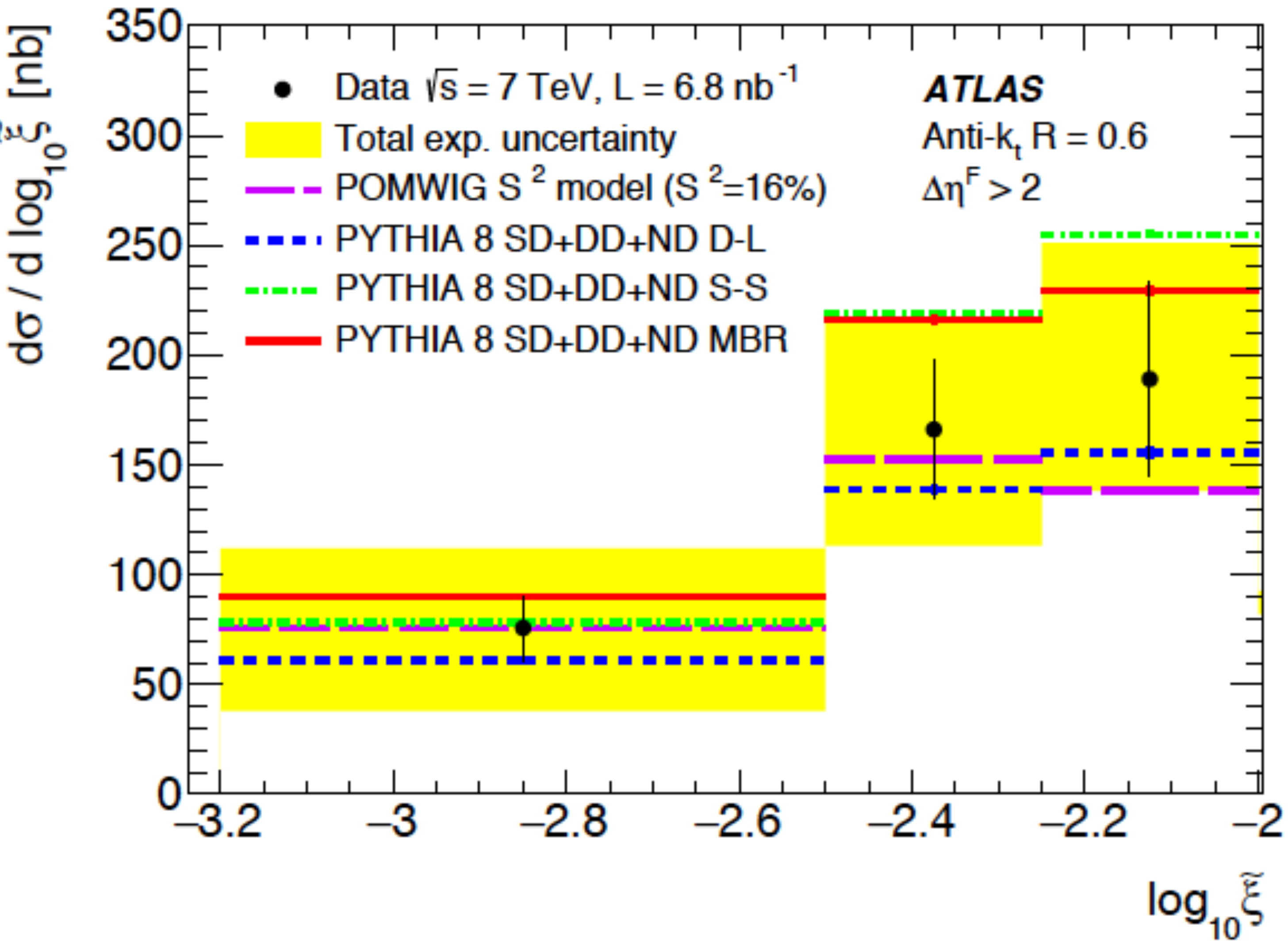
'Off-the shelf' PYTHIA8 ND + SD + DD does a good job at all $\Delta\eta_F$ and ξ, with no need for a gap survival factor (though also compatible with a wide range of S^2 values).







Diffractive Models Focusing on $\Delta\eta^F > 2$



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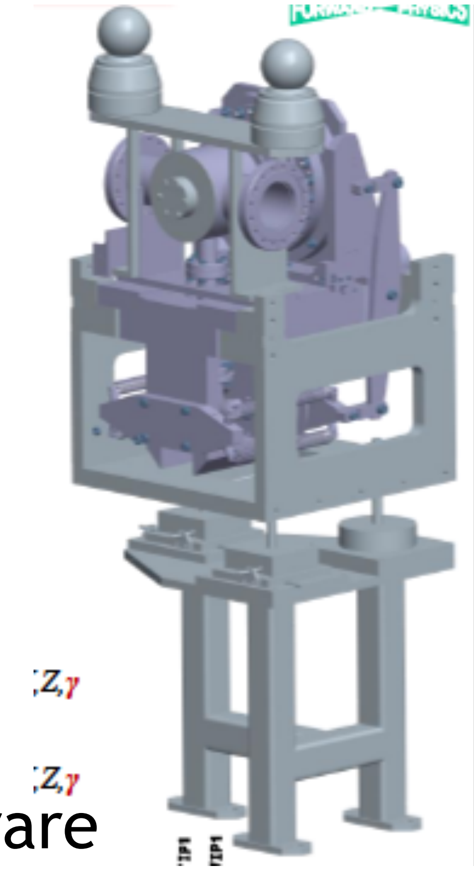
Future ATLAS Diffraction

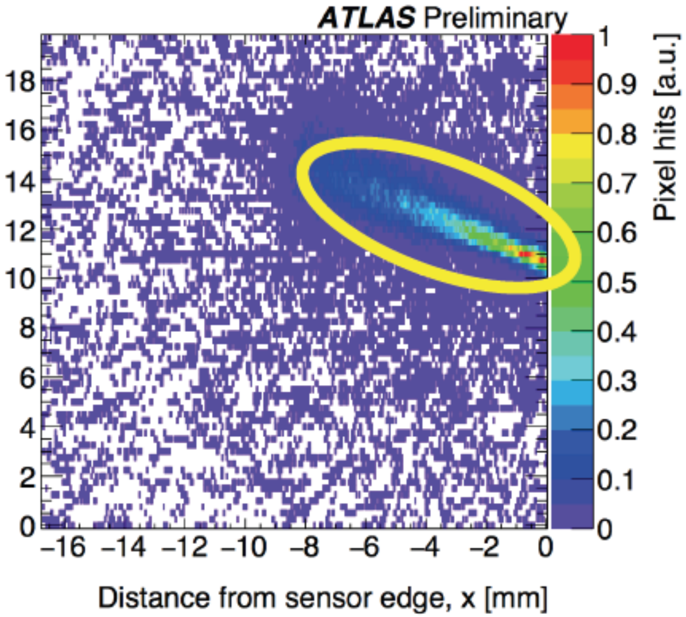
- Further progress will require proton tagging to unfold ND and DD from SD

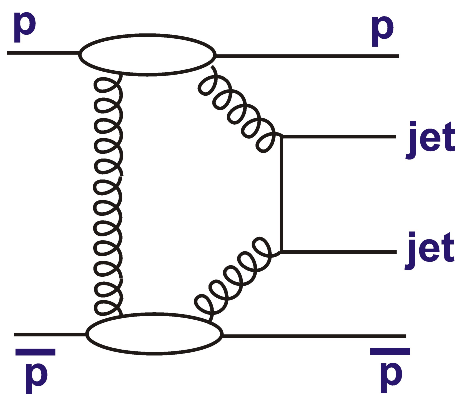
- Short term: ongoing ALFA analysis

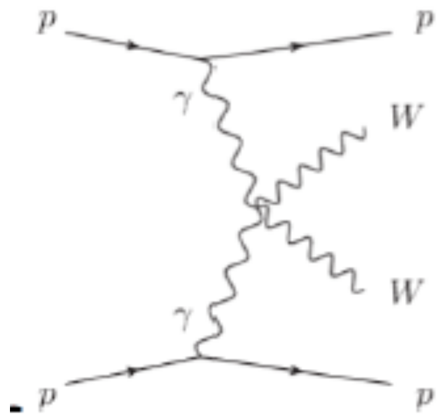
- Medium term = AFP, first arm commissioning underway → SD physics in 2016/17

- Longer term: AFP with two arms & high lumi → rare exclusive (or exotic) processes …

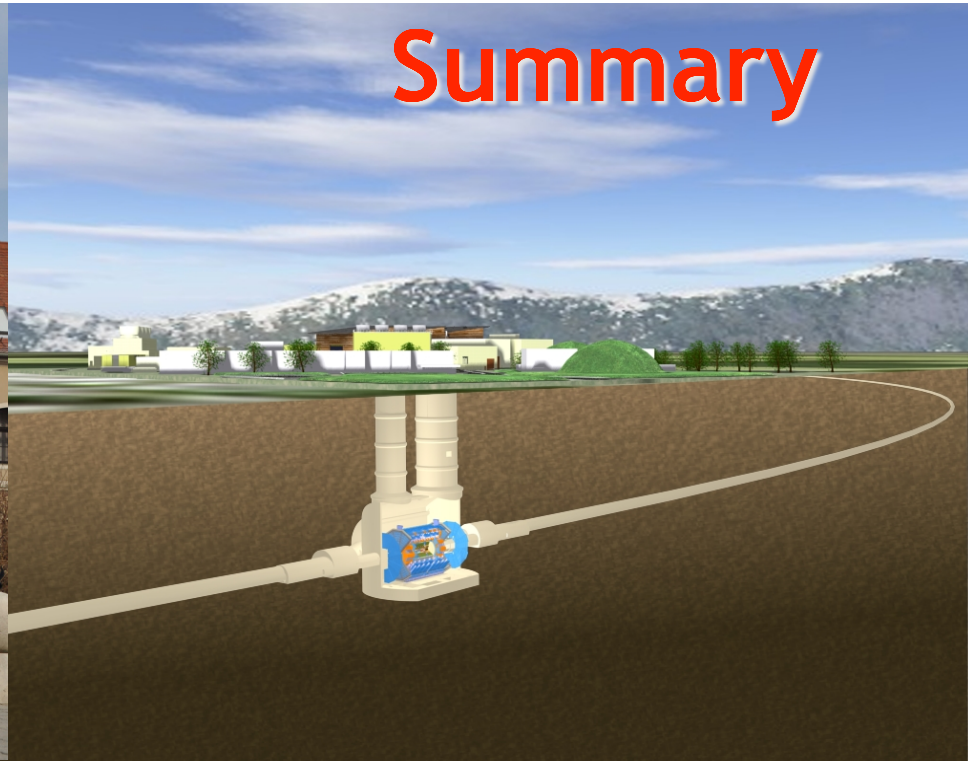








Summary



Direct Inelastic Cross Section Measurement at $\sqrt{s}$ = 13 TeV

- Agrees with all reasonable models at current level of precision
- Significant improvement (9% → 2%) imminent

Dijet Cross Sections Differential in Gap Size at $\sqrt{s}$ = 7 TeV

- Evidence for diffractive contribution
- Understanding heavily limited by poorly known non-diffractive contribution
- Future prospects with proton spectrometers (ALFA, AFP)