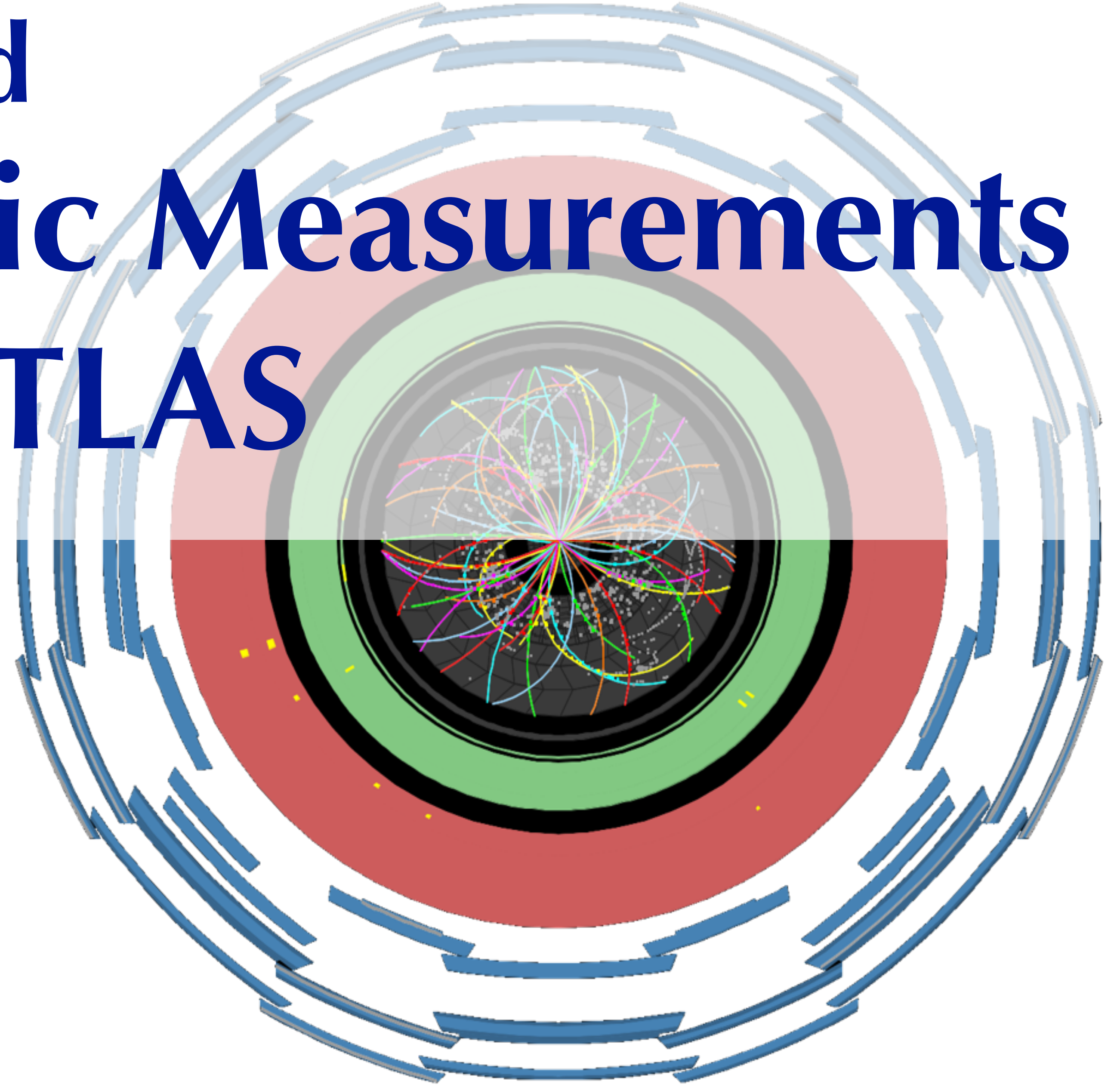
XIX International Workshop on Deep-Inelastic Scattering and Related Subjects

The Inelastic Cross-Section and Prospects for Elastic Measurements with ATLAS



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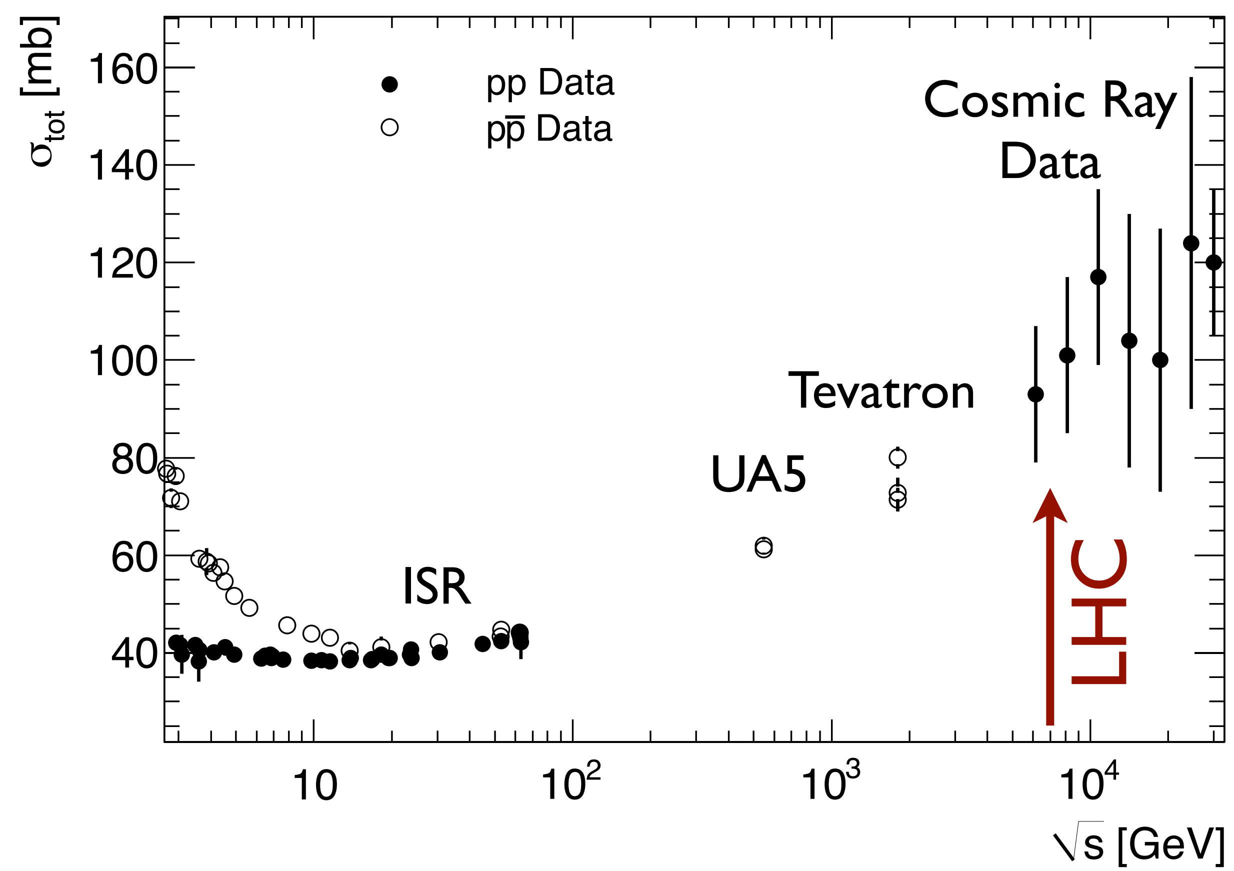
for the
ATLAS Collaboration

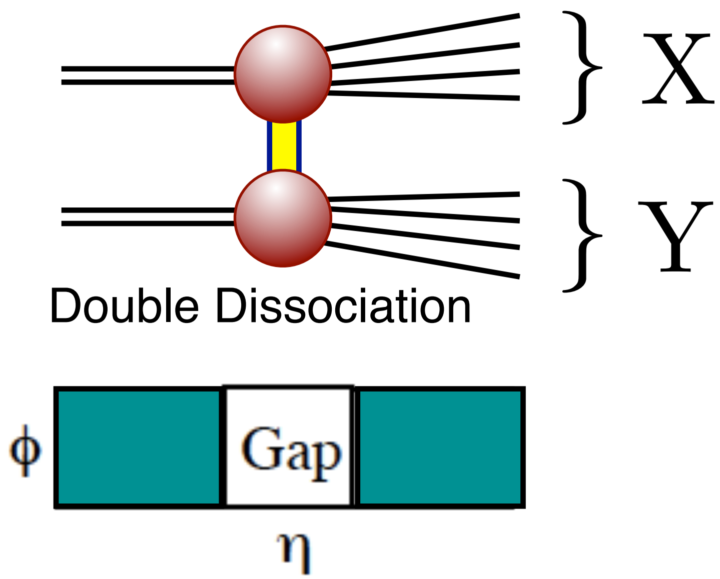
Proton Cross-Sections

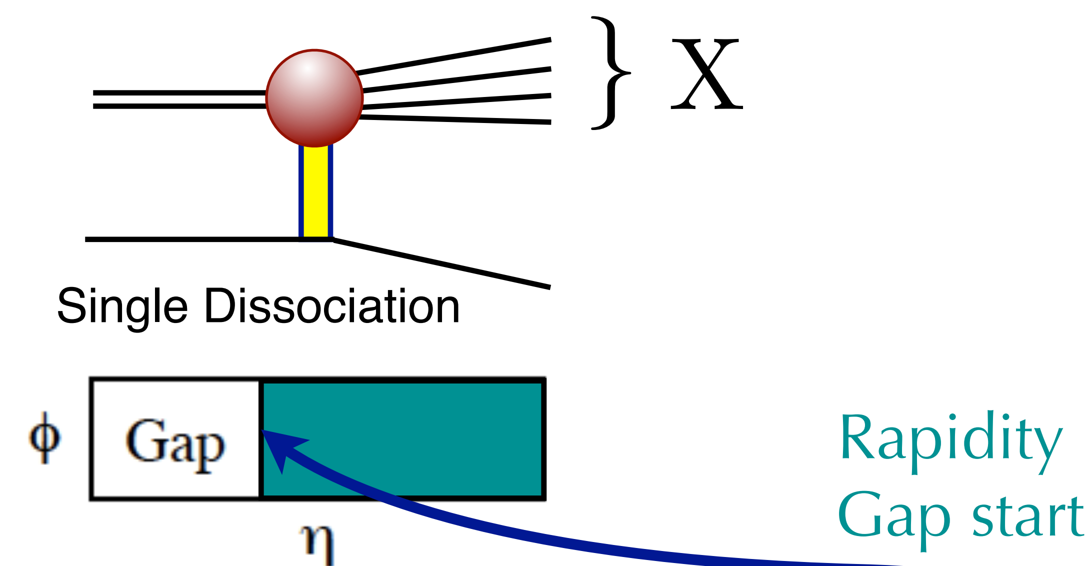
- Total proton-proton σ at 7 TeV:
  - 20% elastic, 80% inelastic
  - Diffractive contribution: σ_D/σ_{inel} ~0.2-0.3
- Total proton cross-section is typically measured 2 ways:
  - Forward elastic cross-section at colliders (Optical Theorem)
  - Cosmic ray air showers
- Specialized experiments/detectors LHC for these measurements:
  - Totem
  - **ALFA**



- **Well-defined**, direct measurements of σ_{inel} is an important complement to these measurements

Diffractive Dissociation



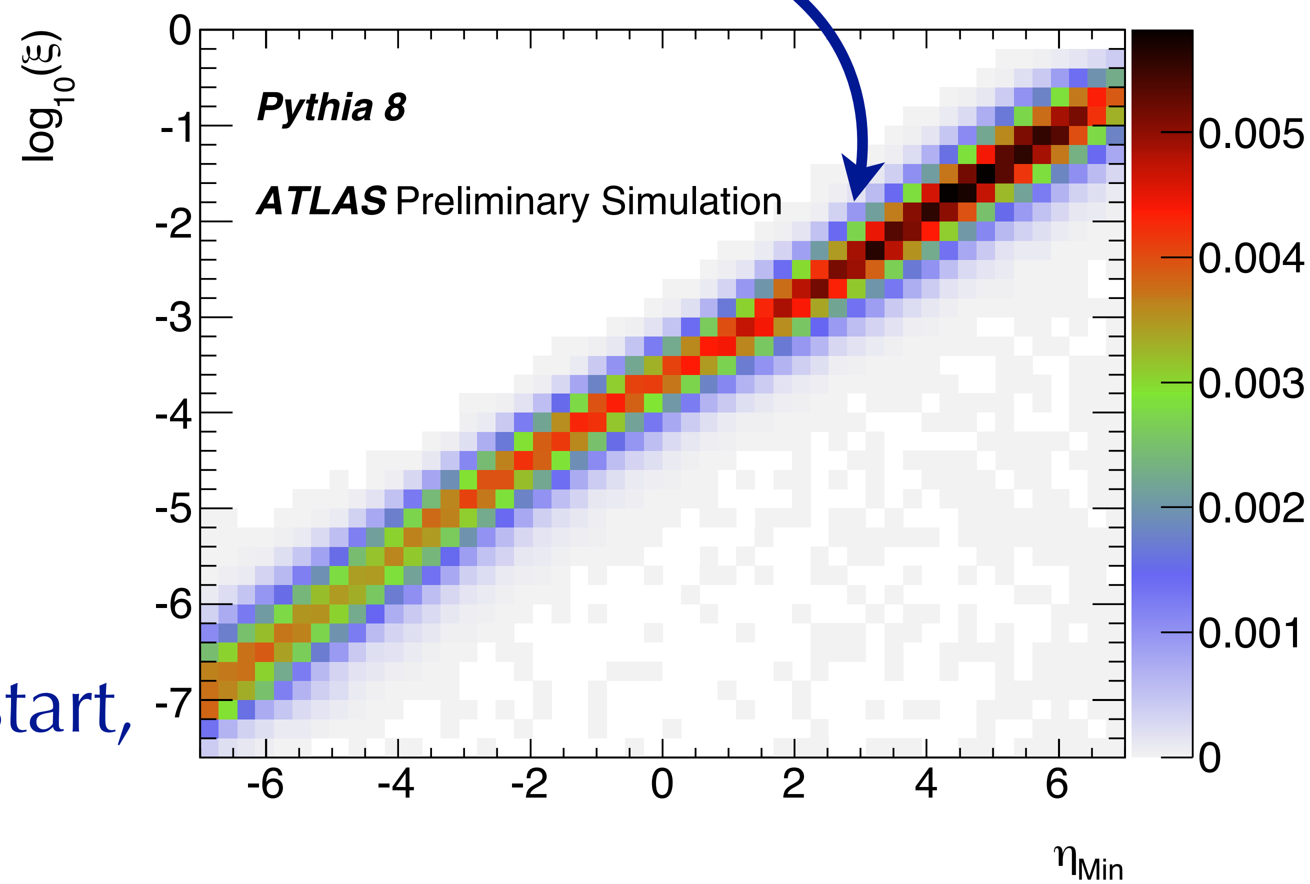


- Color singlet exchange leads to **rapidity gaps**
- Mass of dissociation product describes systems:

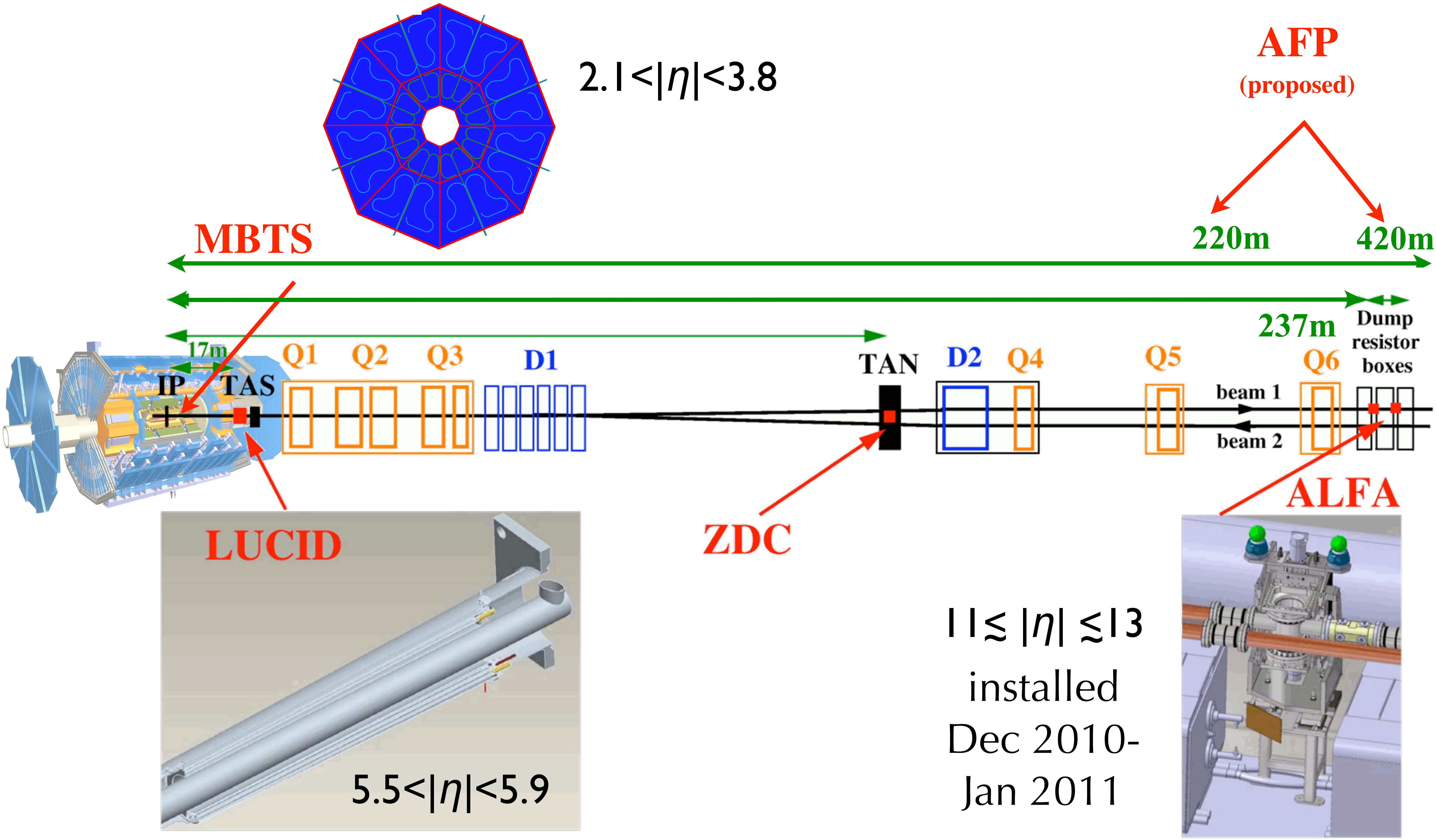
$$\xi = M_X^2/s$$

- ξ relates to (pseudo)rapidity gap start, therefore **detector acceptance**:

$$\eta_{\min} \propto \log \frac{M_X^2}{s}$$



ATLAS Forward Detectors



The Inelastic Cross-Section Measurement

At least two MBTS hits

Background and trigger efficiency measured in Data

$$\sigma(\xi > 5 \times 10^{-6}) = \frac{(N - N_{BG})}{\epsilon_{trig} \times \int L \mathrm{d}t} \times \frac{1 - f_{\xi < 5\times 10^{-6}}}{\epsilon_{sel}}$$

Limit measurement to detector acceptance
($M_X > 15.7$ GeV)

From Beam Scan Calibration

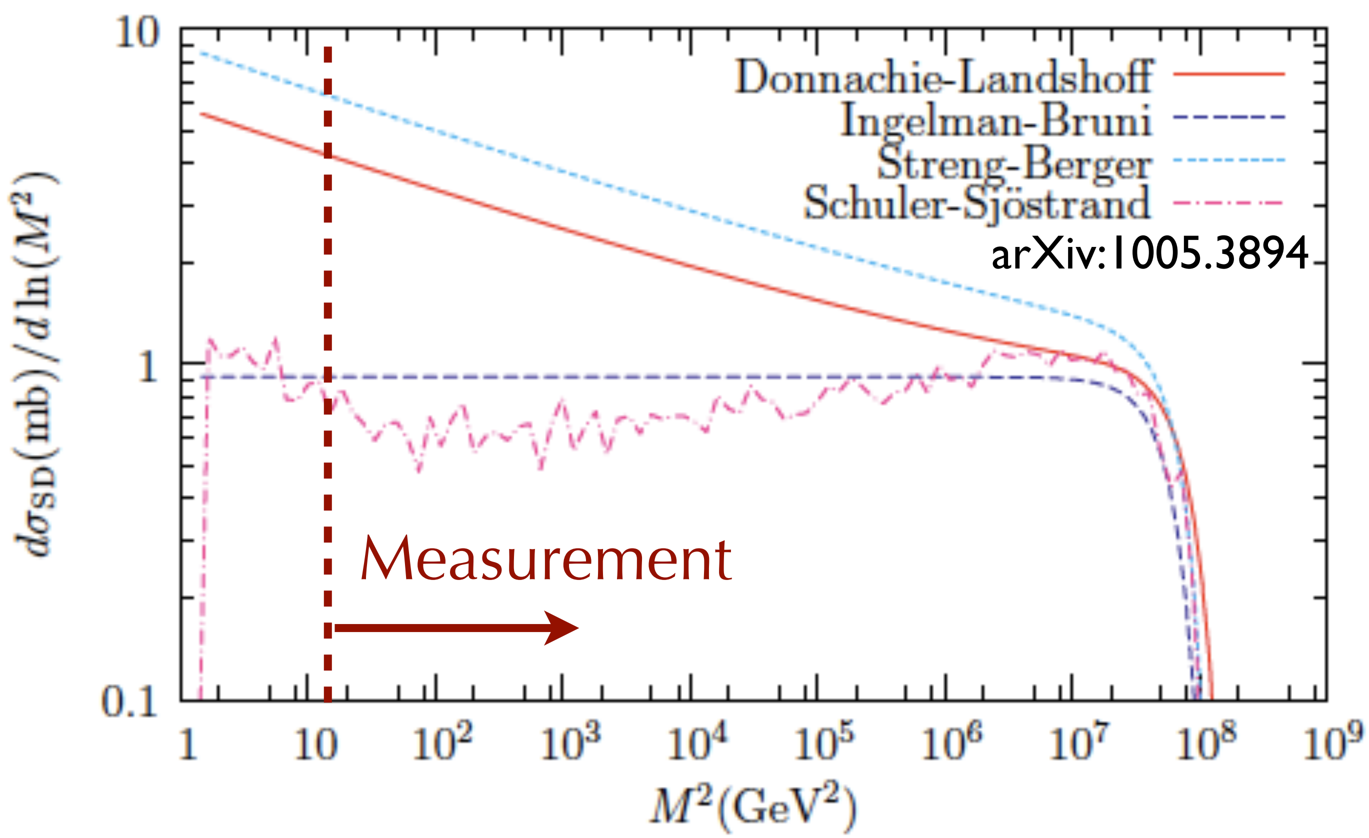
Correction factors taken from MC, detector response tuned on data

Dataset: 1.2M events
(2nd day of 7 TeV Stable LHC Beams)

ATLAS paper: **arXiv:1104.0326**

Diffractive Models

- ε_{sel} and $f_{\xi<5x10^{-6}}$ **depend on M_X distribution** near ξ cut
  - But we can't measure M_X!
  - Use a variety of models to assess dependence on M_X distribution



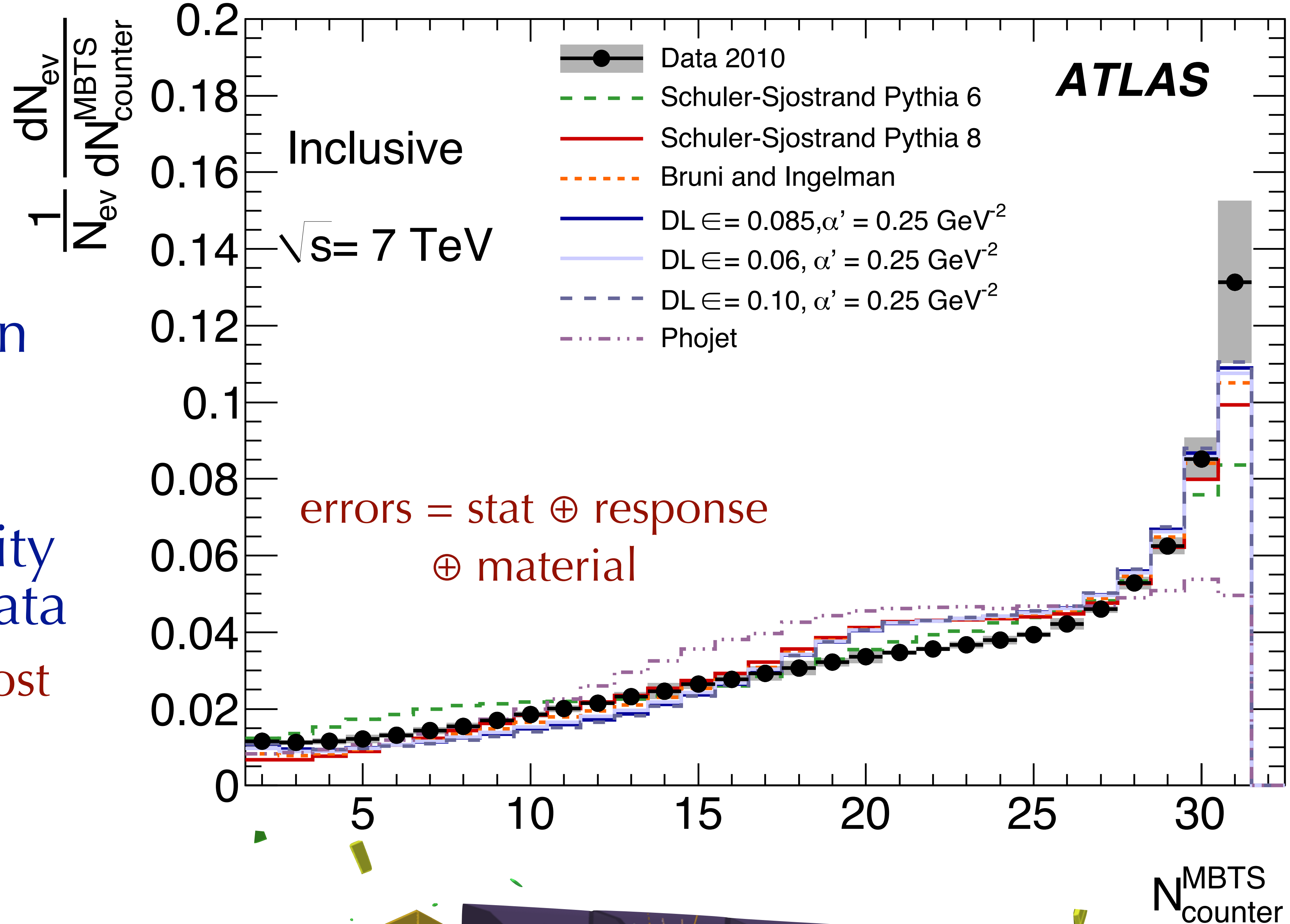
- Consider many models for the diffractive mass distribution
  - Generators: Pythia, Phojet
    - 2 different fragmentation schemes (Pythia 6 vs Pythia 8)
  - Flat
  - Multiple variations of power law
- Default model is **Donnachie and Landshoff** with $\varepsilon = 0.085$, $\alpha' = 0.25$ GeV^{-2} :

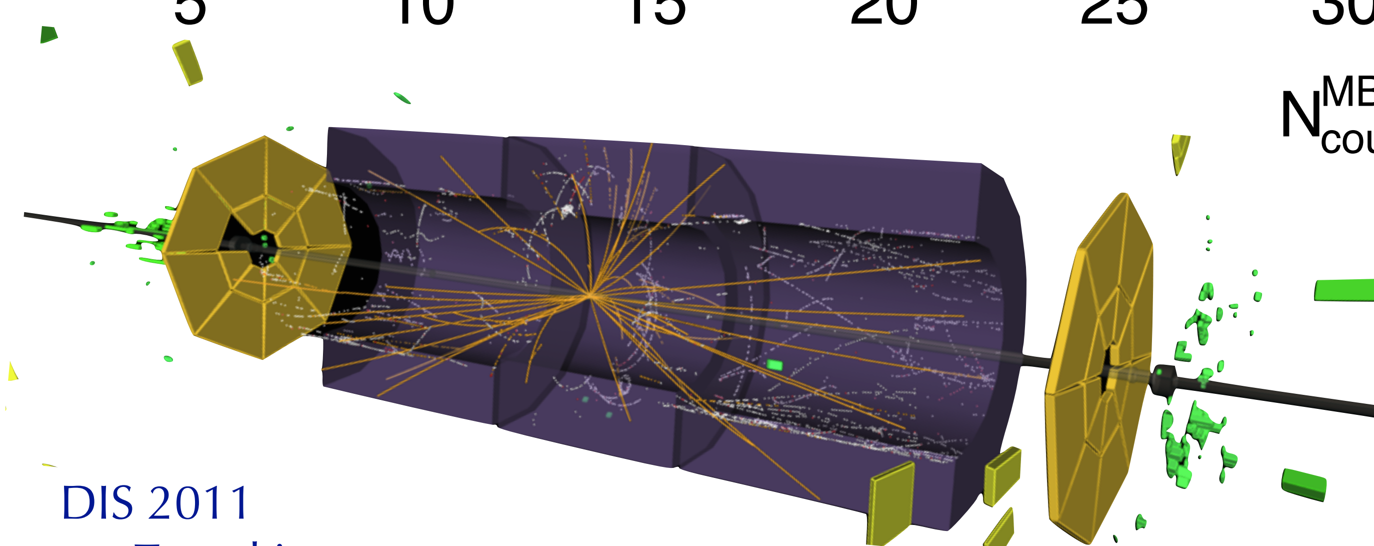
$$\frac{\mathrm{d}\sigma_{SD}}{\mathrm{d}M^2} \propto \left(\frac{s}{M}\right)^{2\alpha(t)-1}$$

$$\alpha(t) = \epsilon + \alpha'(t)$$

Inclusive Event Sample: N_{inc}

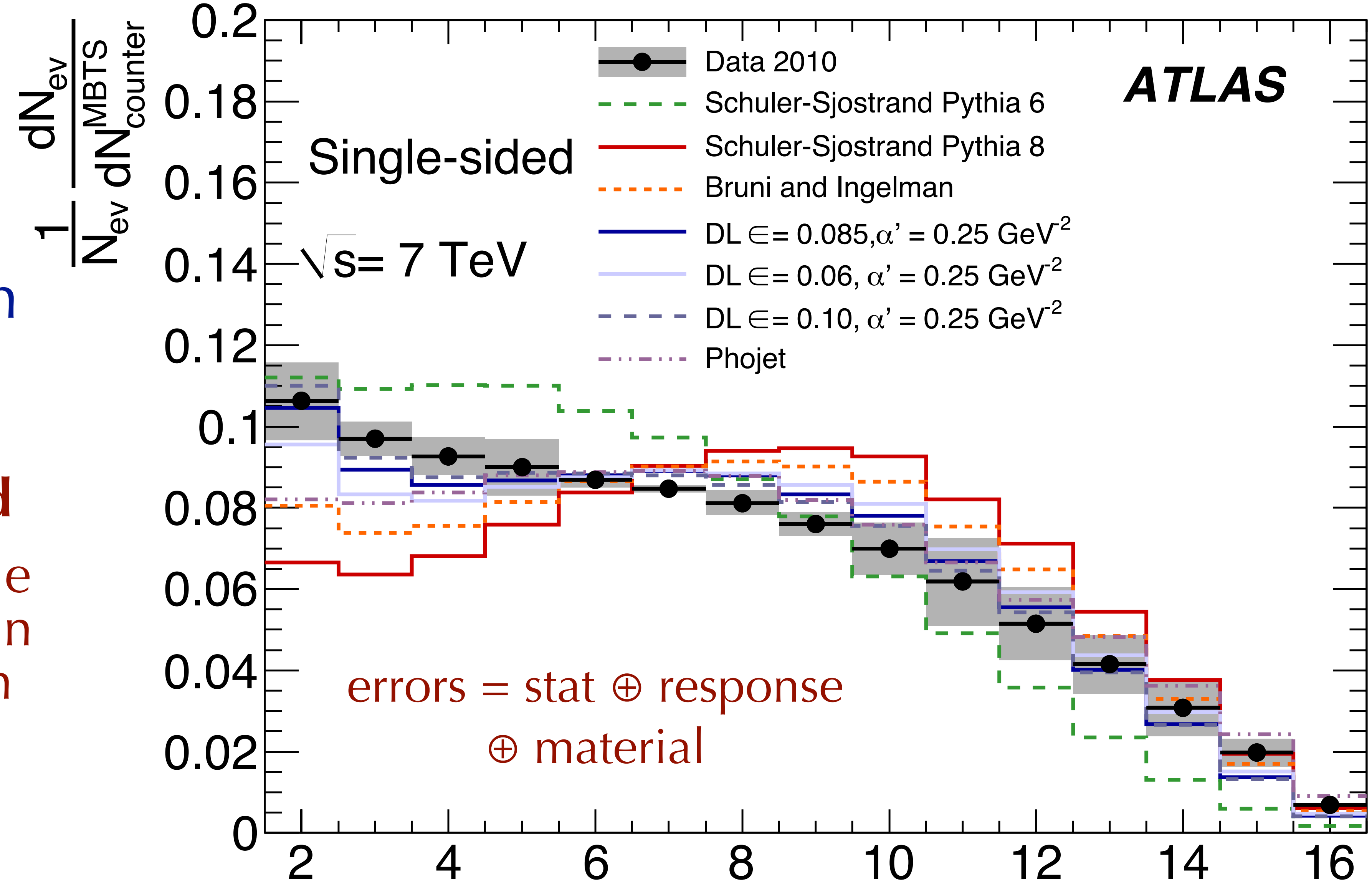
- Used for cross-section measurement
- For most of multiplicity range models span data
  - Low $N_{counter}$ region most important for measurement

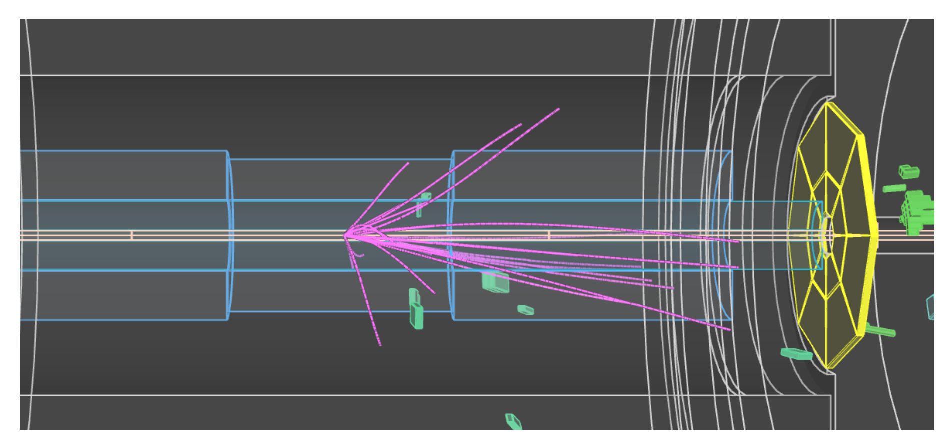




Single-Sided Event Sample: N_{SS}

- Sample of events with hits on one side of MBTS
  - **Diffraction-dominated**
  - Models give reasonable spread of uncertainty in diffractive contribution
- Used to **constrain** contribution of diffractive events to inclusive event sample

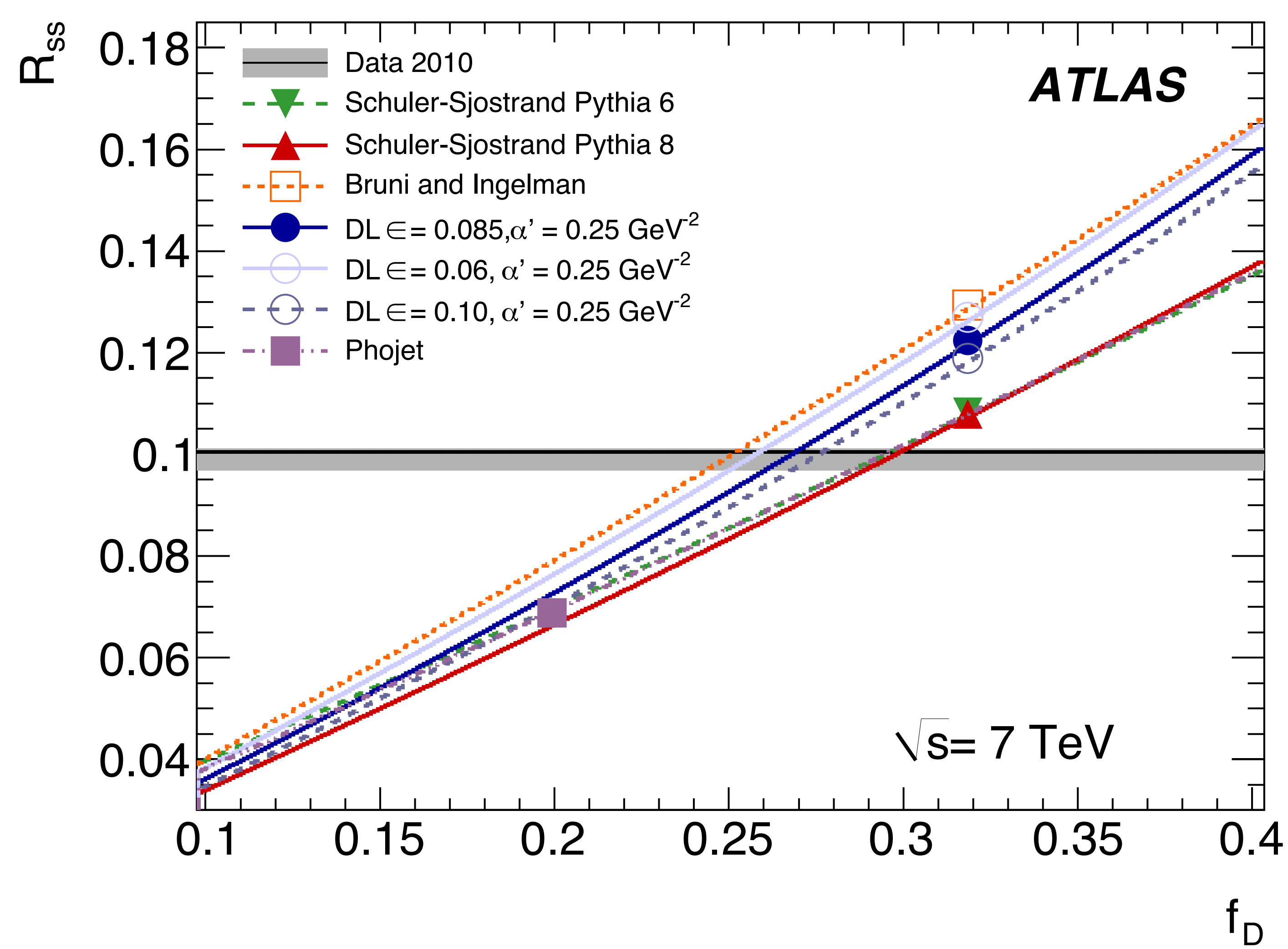




Relative Diffractive Contribution

$$R_{ss}(f_D) = \frac{N_{SS}}{N_{inc}} = \frac{A^D_{SS} f_D + A^{ND}_{SS}(1-f_D)}{A^D_{inc} f_D + A^{ND}_{inc}(1-f_D)}$$

- Fractional contribution of diffractive process (f_D) varies significantly between generators
  - Model dependent quantity
- Constrain f_D for **each model** by finding value which produces same ratio of single-sided to inclusive event sample (R_{ss}) as data
  - Default model yields **$f_D = 26.9^{+2.5}_{-1.0}$ %**



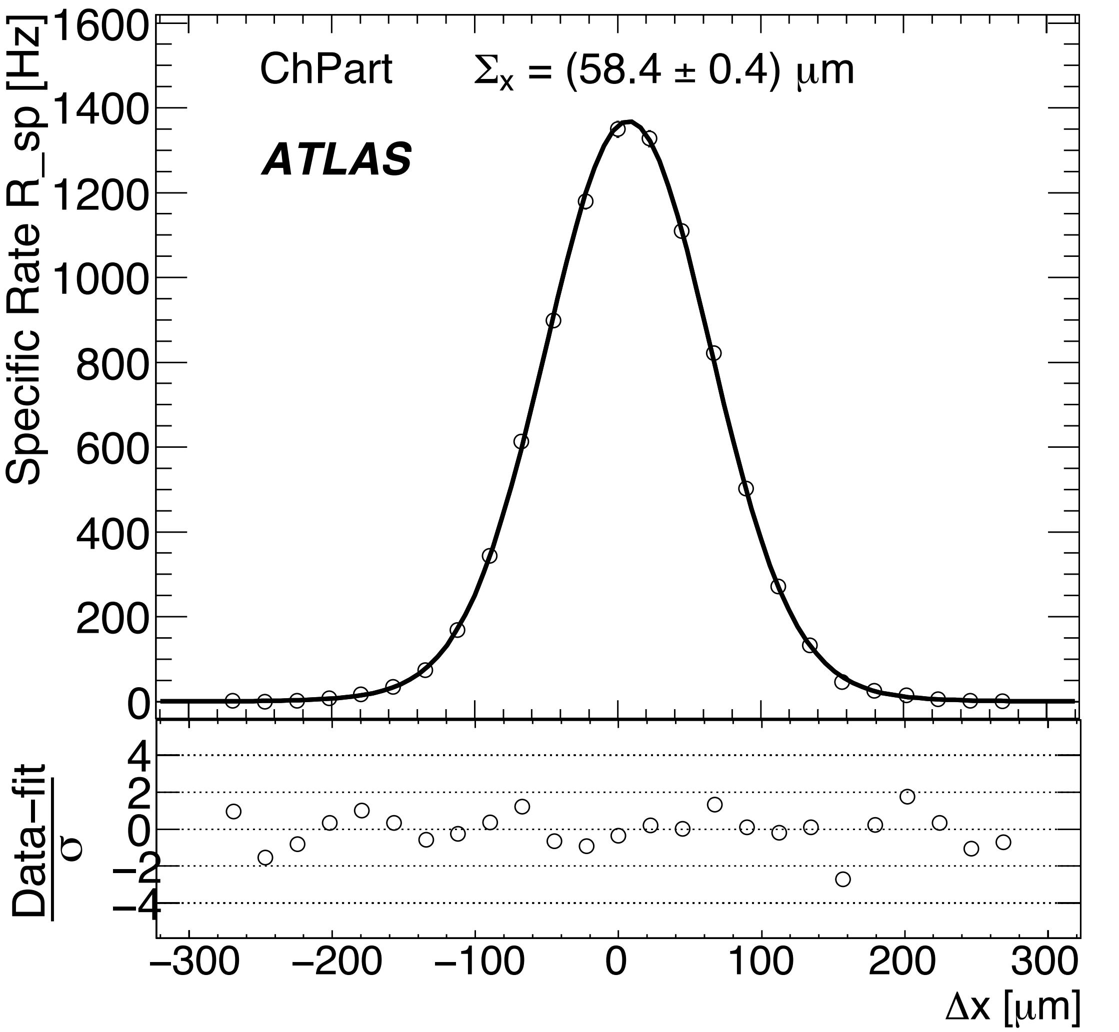
Summary of Systematic Uncertainties

- Trigger: Difference between measurement with 2 independent triggers
- MBTS Response: Vary thresholds over full range of data efficiencies
- Material: 40% uncertainty on material in $|\eta| > 2.5$.
- Relative Diffractive Contribution: Vary f_D within uncertainties
- Background: 100% uncertainty
- MC Multiplicity: Difference between Pythia 8 and Pythia 6
- ξ Distribution: largest difference between default and alternative models

Source	Uncertainty (%)
Trigger Efficiency	0.1
MBTS Response	0.1
Material	0.2
f_D	0.3
Beam Background	0.4
MC Multiplicity	0.4
ξ distribution	0.4
Luminosity	3.4
Total	3.5

Luminosity

- Luminosity calibration derived from beam separation (van der Meer) scans
- Default $\mathcal{L}$ comes from LUCID event counting
  - Several other methods
  - **Stability** of measurement over 2010 **better than 0.5%**
- Systematic uncertainty of 3.4%
  - Dominated by uncertainty on bunch charge (beam current) knowledge (3.1%)



arXiv:1101.2185v1
ATLAS-CONF-2011-011

Results

- Calculate cross-section using:
  - ε_{sel} = 98.8%,
  - ε_{trig} = 99.8%,
  - $f_{\xi<5x10^{-6}}$ = 1.0%
  - and $\mathcal{L}$ =20 μb^{-1}

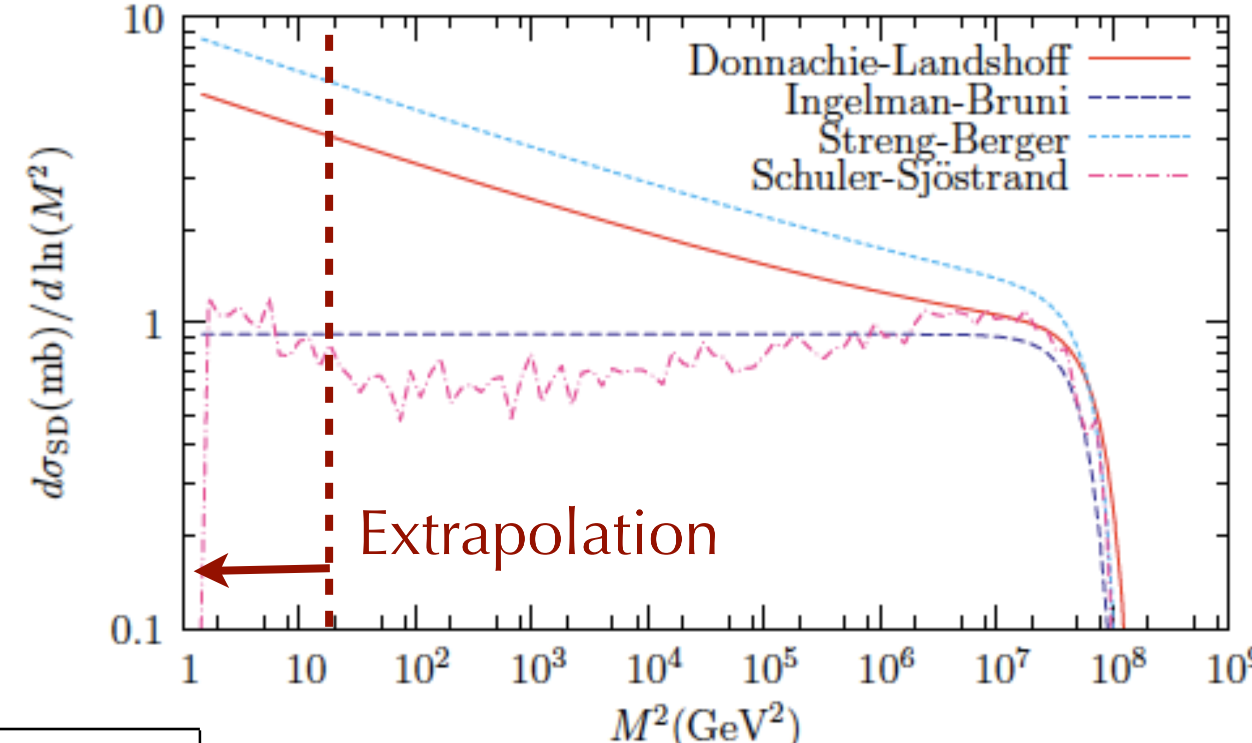
0.4% correction factor

$\sigma(\xi > 5 \times 10^{-6})$ [mb]	
ATLAS Data 2010	60.33 ± 2.10(exp.)
Schuler and Sjöstrand	66.4
PHOJET	74.2
Ryskin *et al.*	51.8 – 56.2

- Data are lower than MC generator predictions, higher than analytic calculation from Ryskin *et. al*.

Extrapolating to σ_{inel}

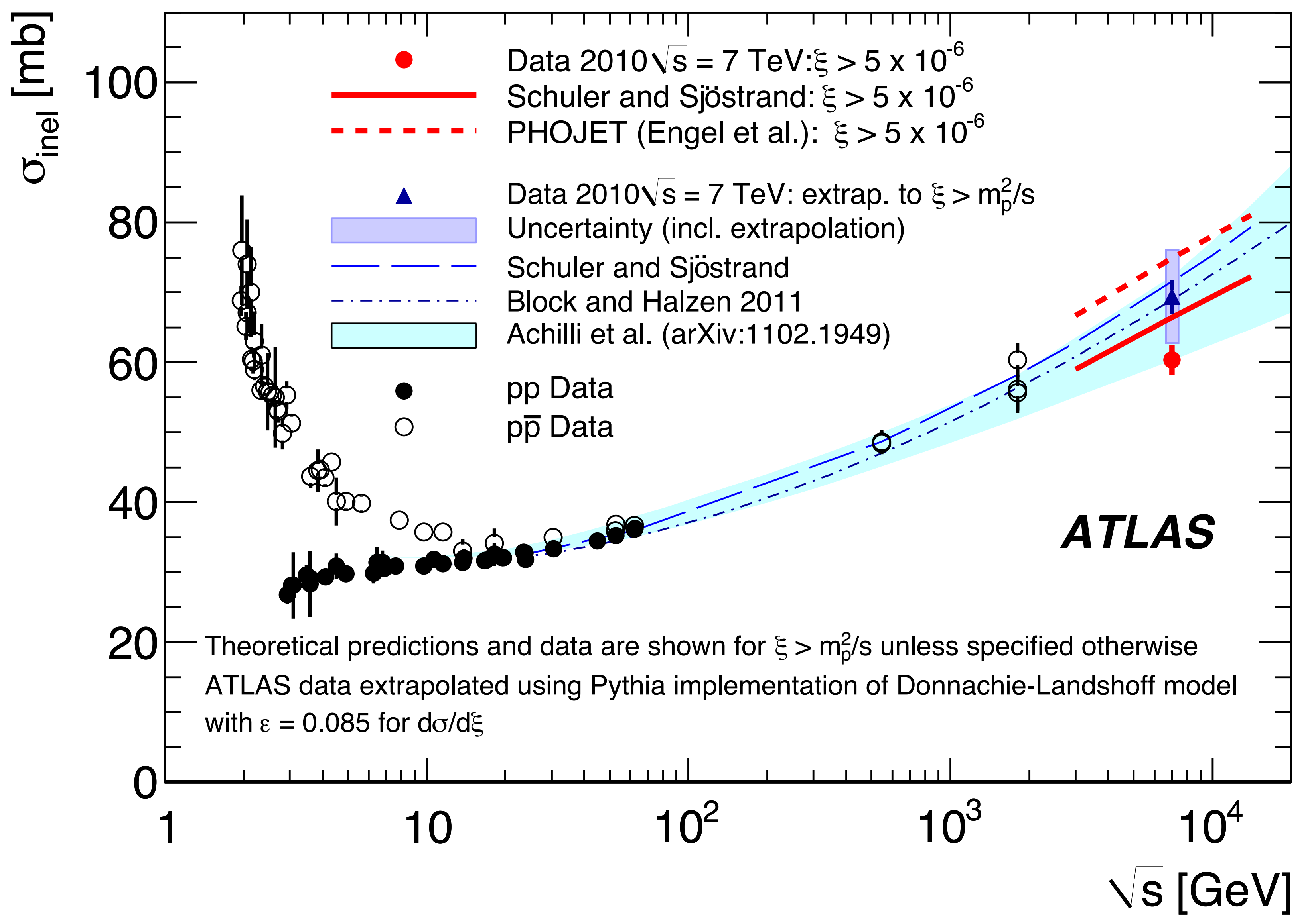
- To compare with previous measurements extrapolate using DL model (+15%)
  - Other models range from 5 to 25% extrapolations
  - Take +/- 10% as extrapolation uncertainty



$\sigma(\xi > m_p^2/s)$ [mb]	
ATLAS Data 2010	$69.4 \pm 2.4(\text{exp.}) \pm 6.9(\text{extr.})$
Schuler and Sjöstrand	71.5
PHOJET	77.3
Block and Halzen	69
Ryskin *et al.*	65.2 – 67.1
Gotsman *et al.*	68
Achilli *et al.*	60 – 75

- **Data agree** with most analytic calculations, lower than Phojet

Summary of the Present

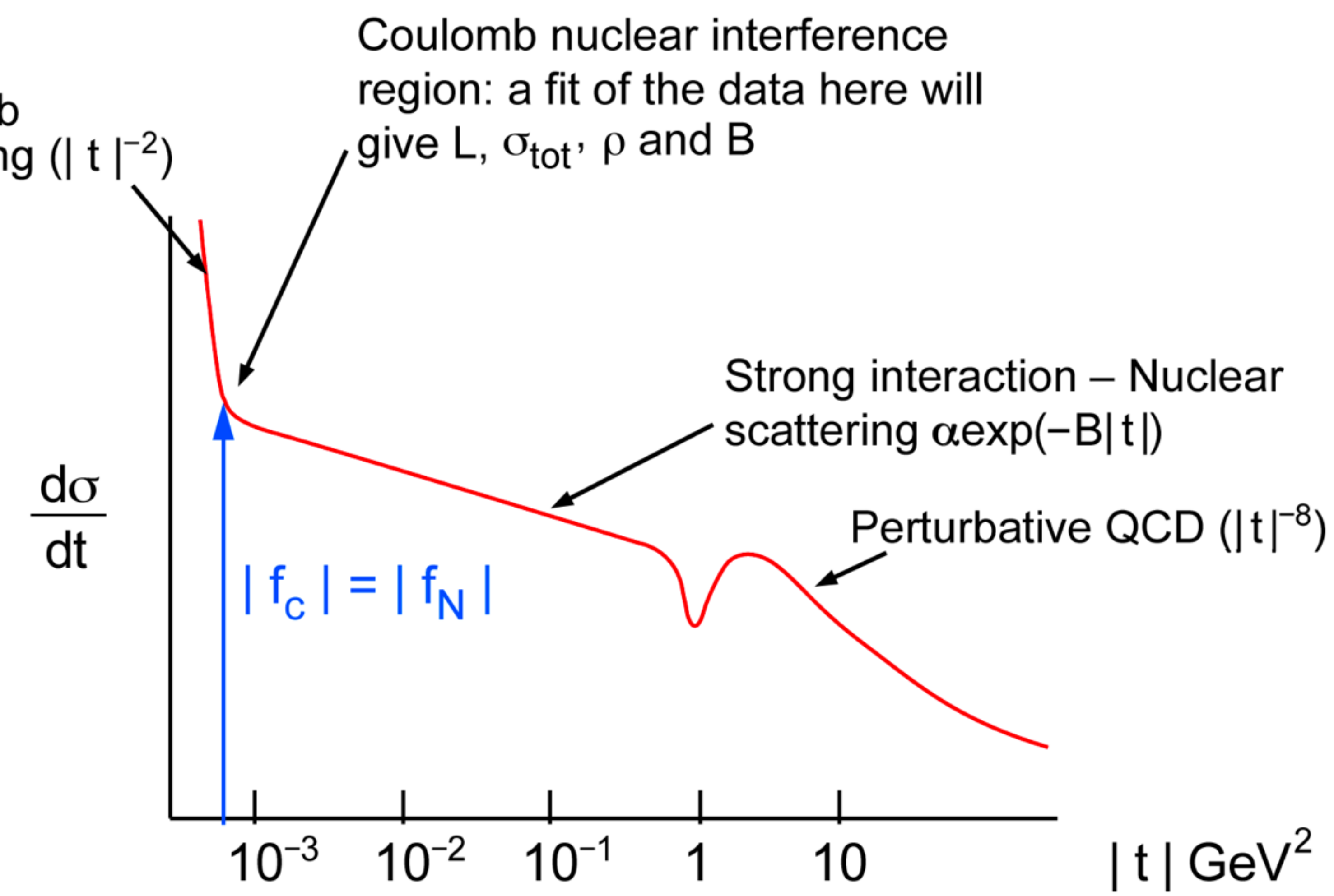


- Presented the first measurement of inelastic cross-section
  - Data are lower than MC predictions, extrapolated value agrees with most analytic models
- To be repeated at 2.76 TeV

For the Future: ALFA

- Principle: use **elastic scattering** in Coulomb interference region to measure for σ_{tot} and $\mathcal{L}$

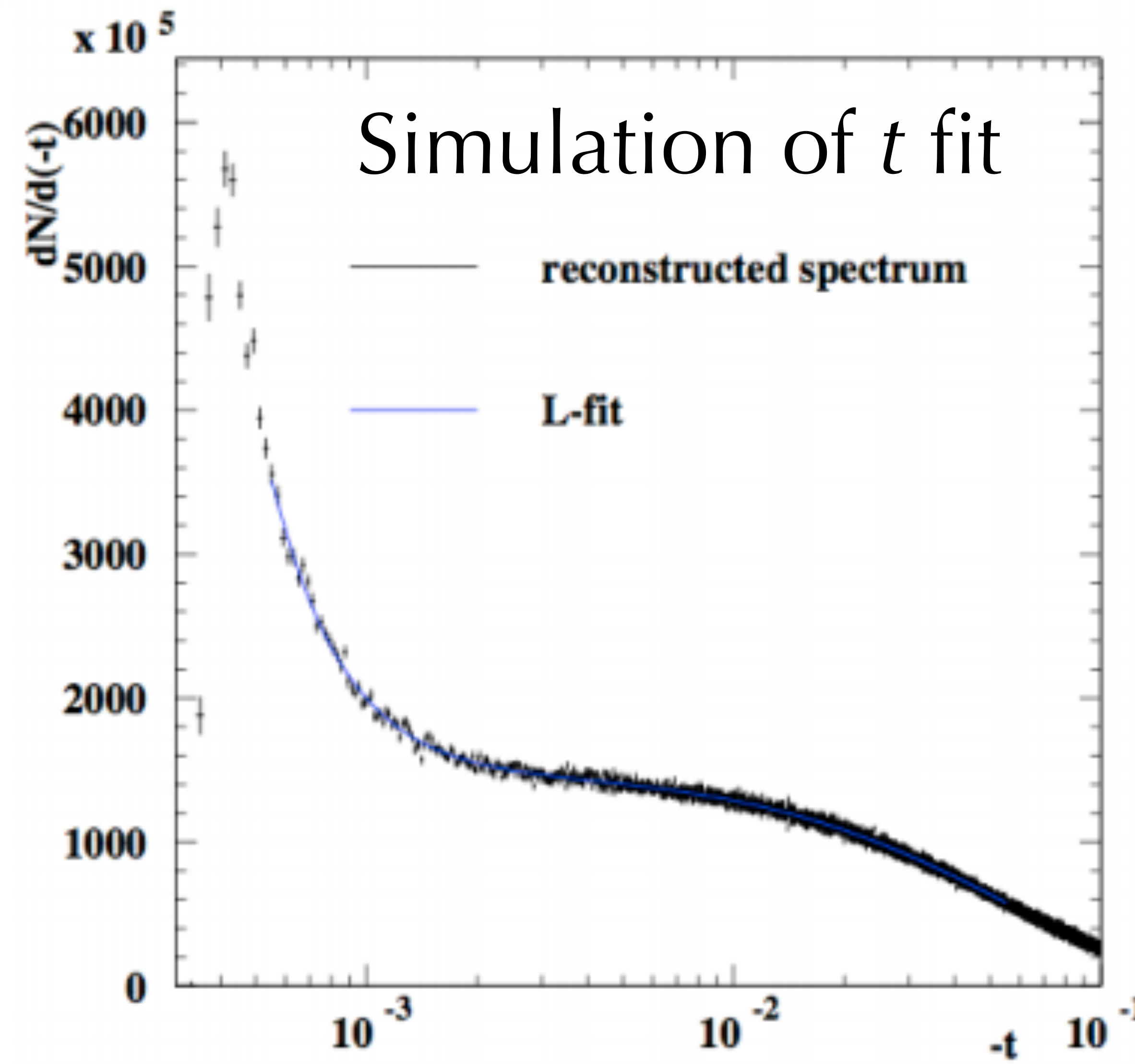
- Use measured $\mathcal{L}$ value to calibrate luminosity detectors to 2-3%
  - **Complementary** to beam-separation scans with uncorrelated systematic uncertainties

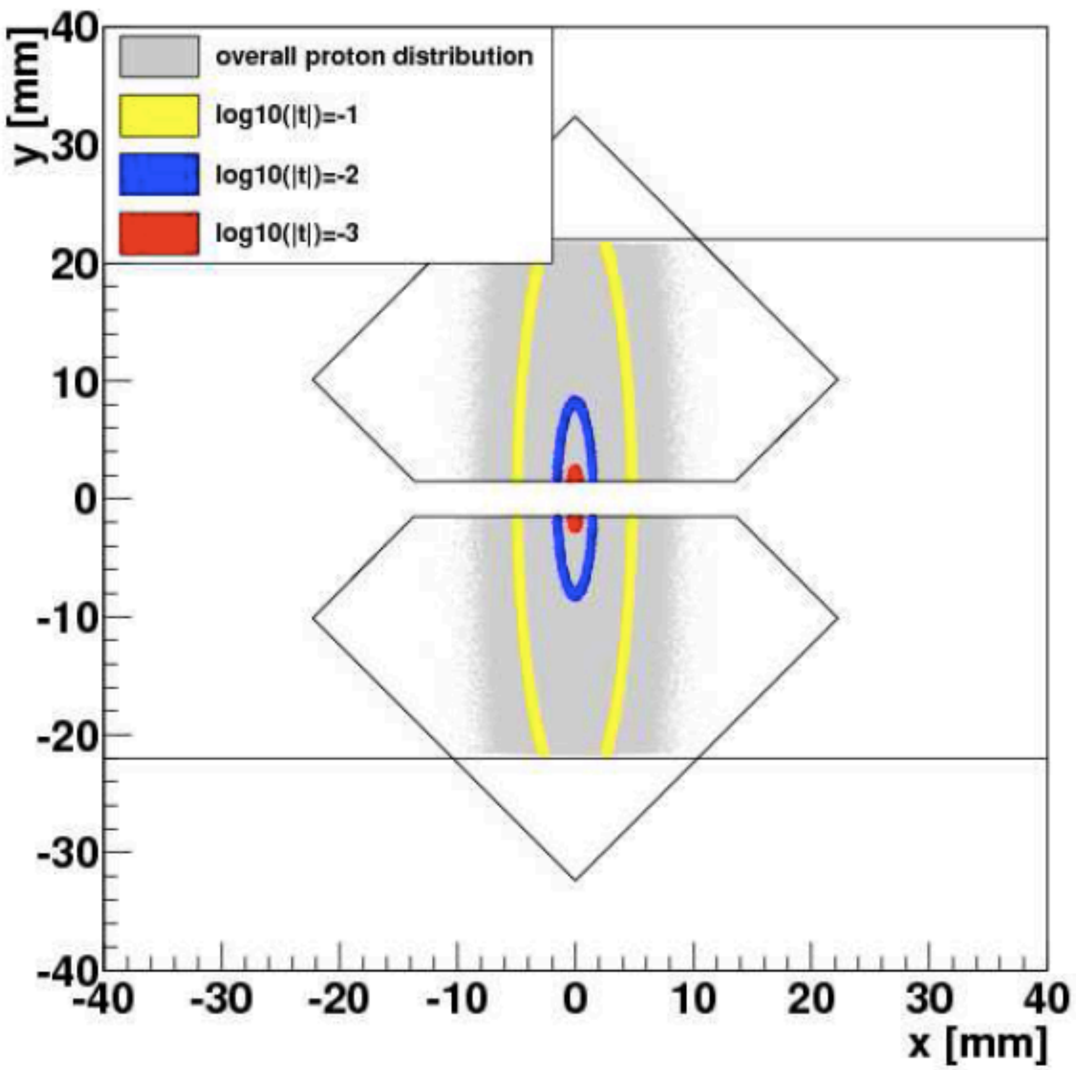


- Technically challenging:
  - need to measure at 3.5 μrad (10σ) from LHC beam:
  - Will require special LHC runs at high β^* and low $\mathcal{L}_{inst}$: 90m (2011), 2km (2013+)

ALFA Future Measurements

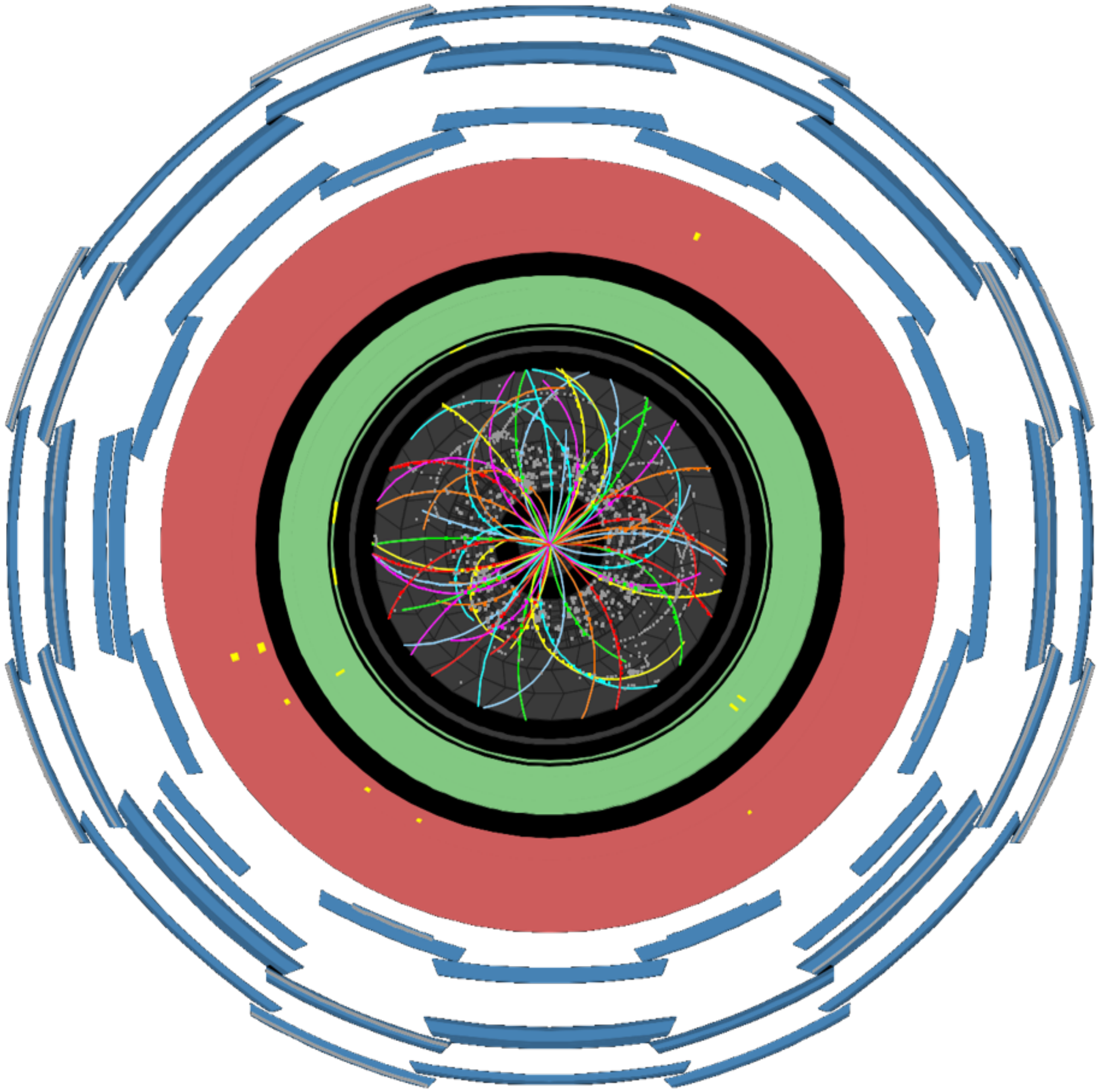
- Scintillating fiber tracker in roman pots
  - Alternating I-D planes
  - *t* measured by position on the detector





- First plots from installed detector expected soon!
  - **Stay tuned for results in 2011**

Additional Slides



References

M. M. Block and F. Halzen, arXiv:1102.3163.

M. Ryskin, A. Martin, V. Khoze, arXiv:1102.2844, submitted to Eur. Phys. J. C.; private communication.

A. Achilli *et al.*, CERN-PH-TH/2011-018, arXiv:1102.1949, submitted to JHEP.

R. Engel, Z. Phys. C **66** (1995) 203-214; R. Engel, J. Ranft, Phys. Rev. D **54** (1996) 4244-4262.

G. Schuler and T. Sjöstrand, Phys. Rev. D **49** (1994) 2257-2267.

P. Bruni and G. Ingelman, Phys. Lett. B311 (1993) 317.

A. Donnachie and P. V. Landshoff, Nucl. Phys. B244 (1984) 322.

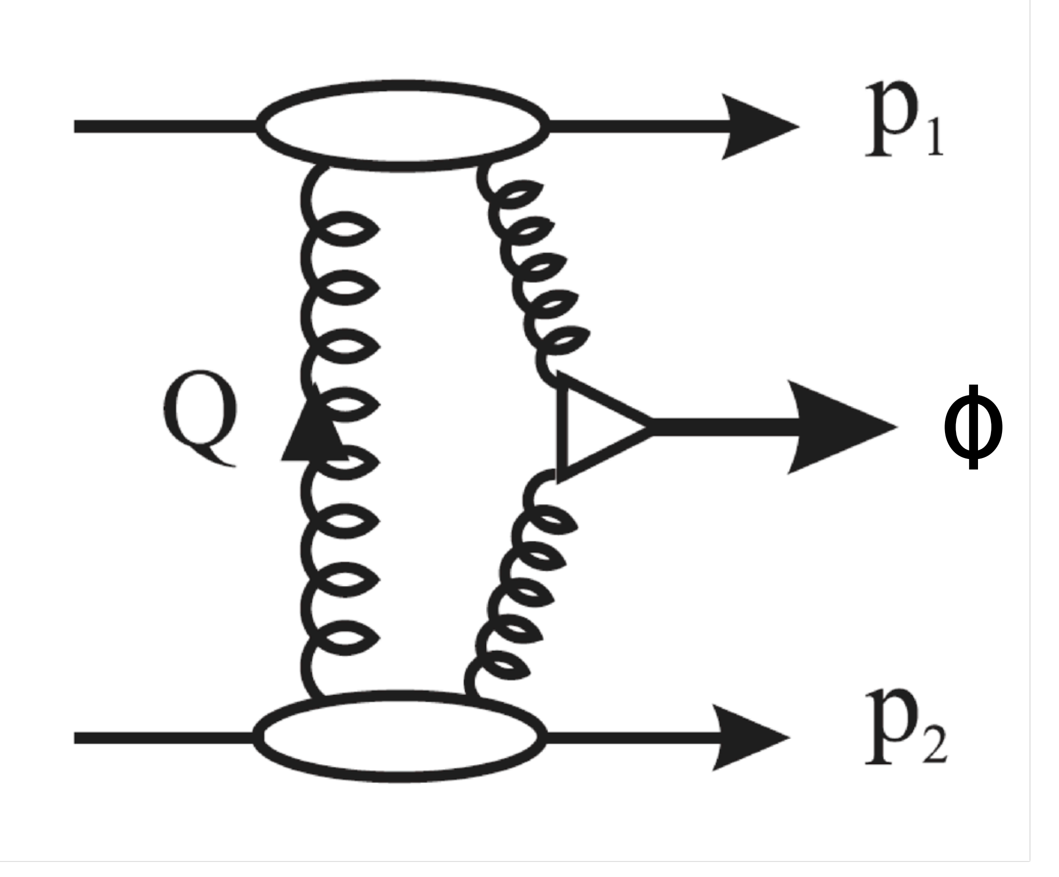
E. L. Berger et al., Nucl. Phys. B286 (1987) 704.

K. Streng, CERN-TH.4949 (1988)

E. Gotsman, E. Levin, U. Maor, J. S. Miller, Eur. Phys. J. C**57** (2008) 689-709; E. Gotsman, E. Levin, U. Maor, arXiv:1010.5323.

Central-Exclusive Measurements

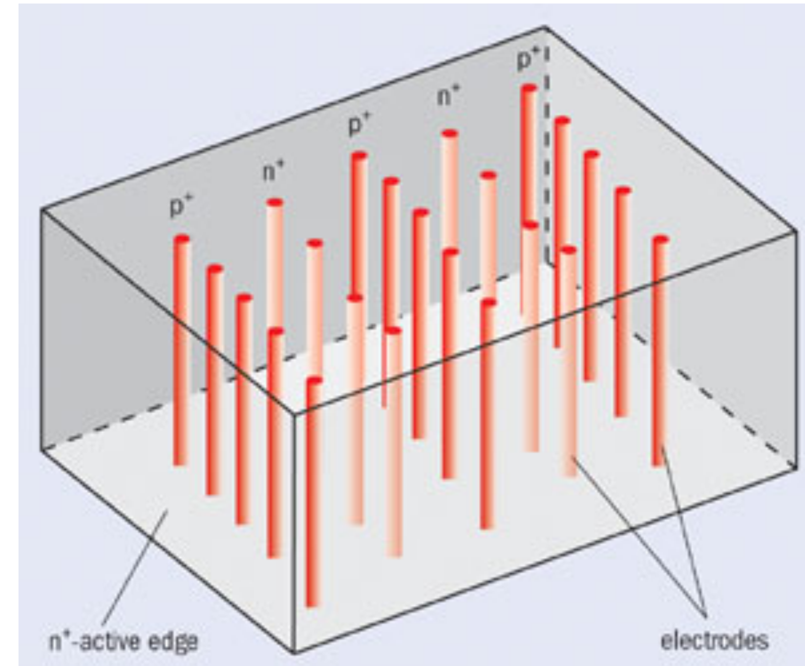
- 2 ways to do central-exclusive measurements:
  - Best: forward proton tagging
    - But AFP not approved/installed yet
  - Runner up: rejection of activity in any of the forward detectors
    - Not efficient with pile-up
    - Don't have full η coverage

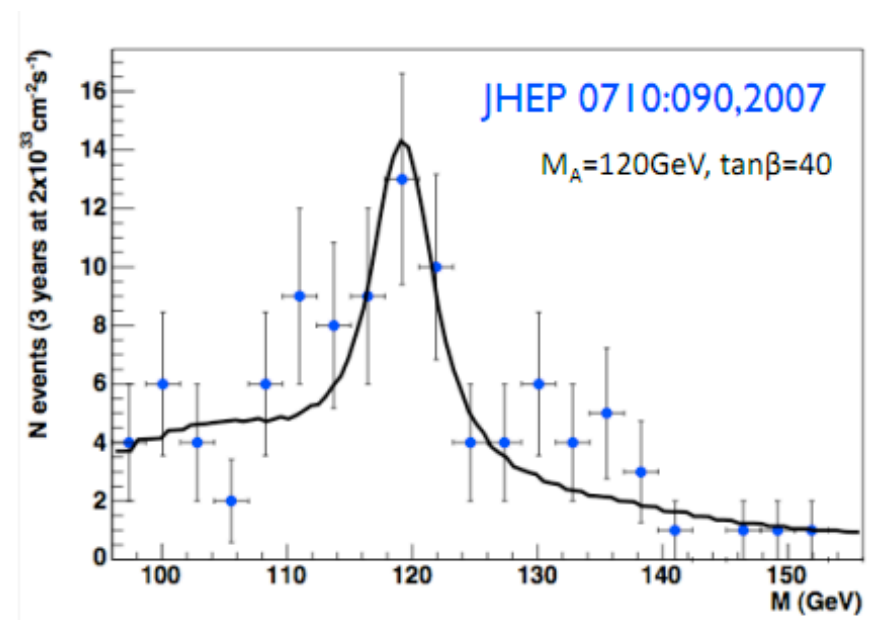


- Pre-AFP measurements requiring forward detector vetos
  - Central jet production to test Double Pomeron Exchange (DPE)
  - Photon induced dilepton pair production, photo-production of resonances

ATLAS Forward Protons (AFP)

- 3D silicon trackers to measure proton momentum loss → mass of ϕ
  - Located at 220m & 420m from IP
  - $M_\phi^2 = s\,(p_{1z}^f/p_{1z}^i)\,(p_{2z}^f/p_{2z}^i)$
- Time of Flight detectors to determine primary vertex position
  - Reduce backgrounds, improve resolution
- With 30 fb^{-1} can measure Higgs, Wϒ couplings, exotic Higgs-less models



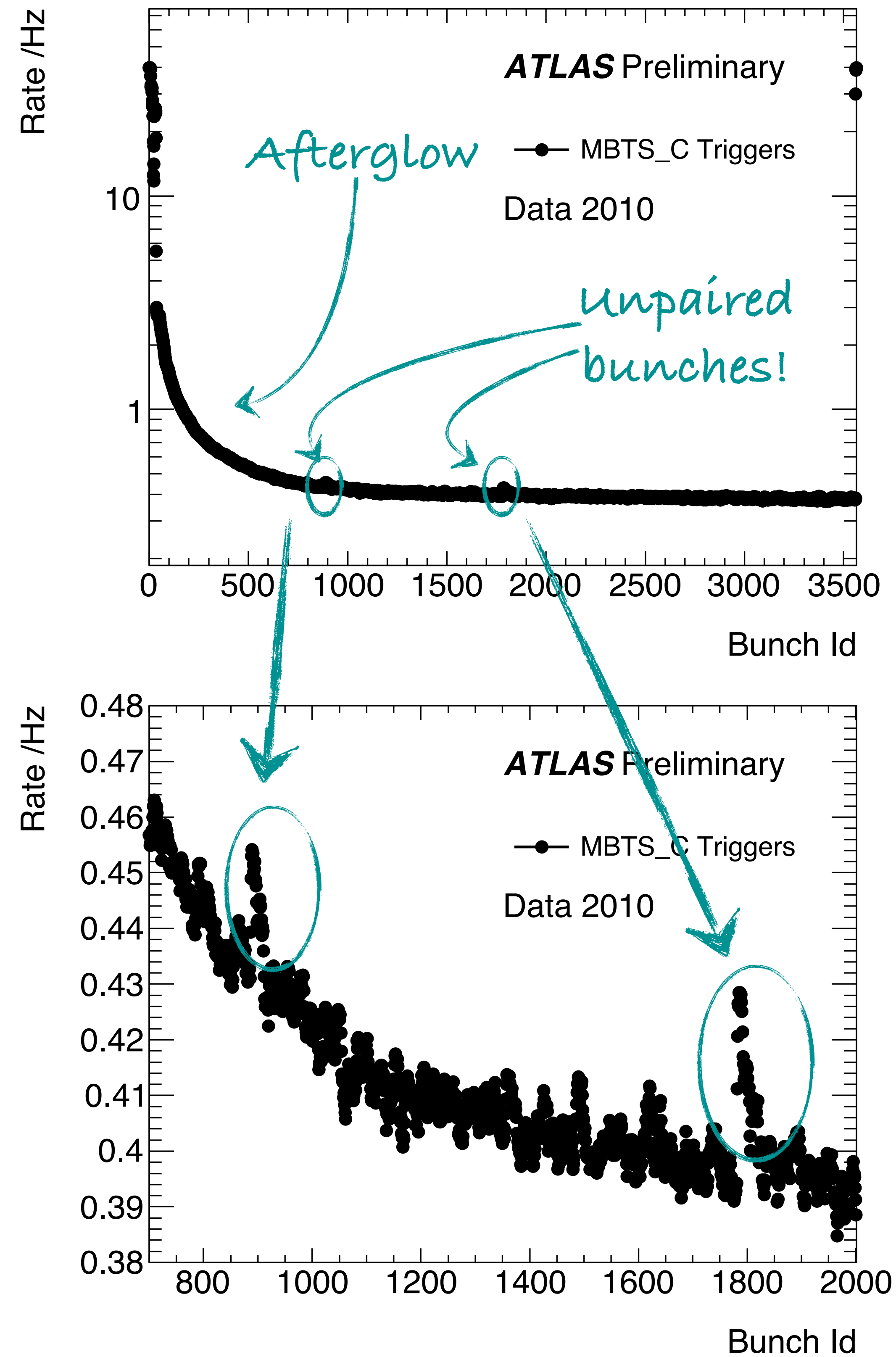


60fb^{-1}, collected at 2x10^{33}cm^{-2}s^{-1}

1) Protons tagged at 420m from IP.
2) TOF resolution: 10ps
3) Trigger rate equivalent to AFP study
4) Significance = 3.5σ

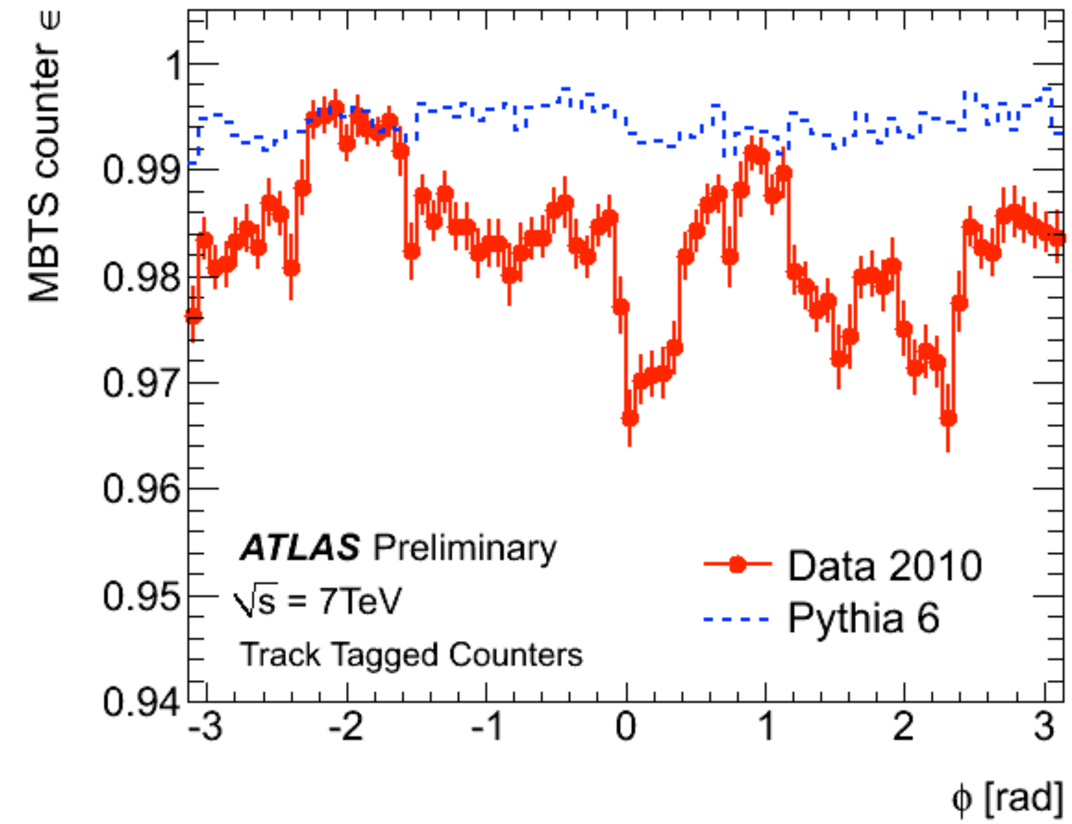
Backgrounds (N_{bkgd}) & Trigger (ε_{trig})

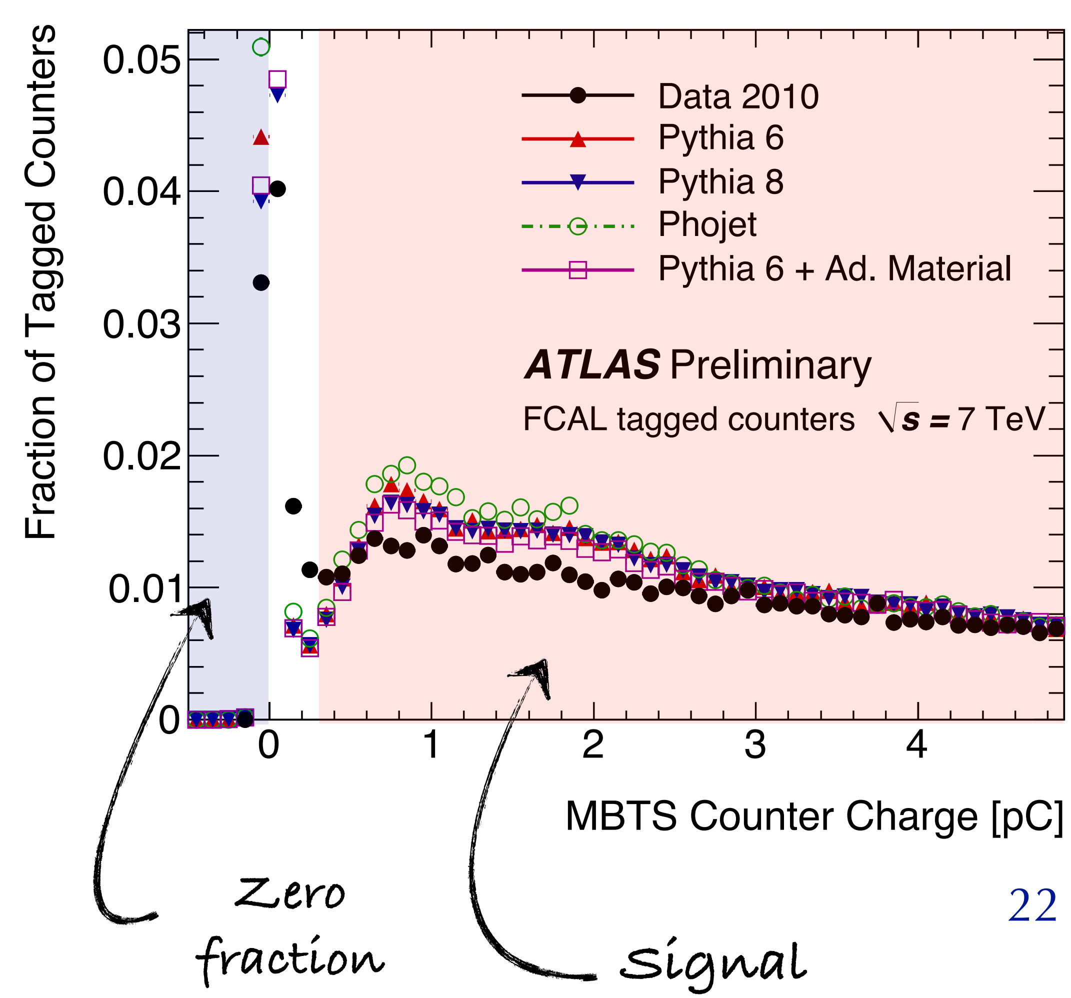
- Beam gas and beam halo:
  - Measure with unpaired bunches : 0.13% of total event sample
- "Afterglow": cavern radiation produced after a collision
  - Out-of-time afterglow measured by unpaired bunches
  - In-time afterglow measured from fractions of late hits in MBTS (0.4%)
- Take 100% uncertainty on backgrounds: 0.42%
- Trigger is single MBTS trigger hit:
  - Measured with respect to offline selection to be 99.98% with an uncertainty of 0.09%



Detector Simulation

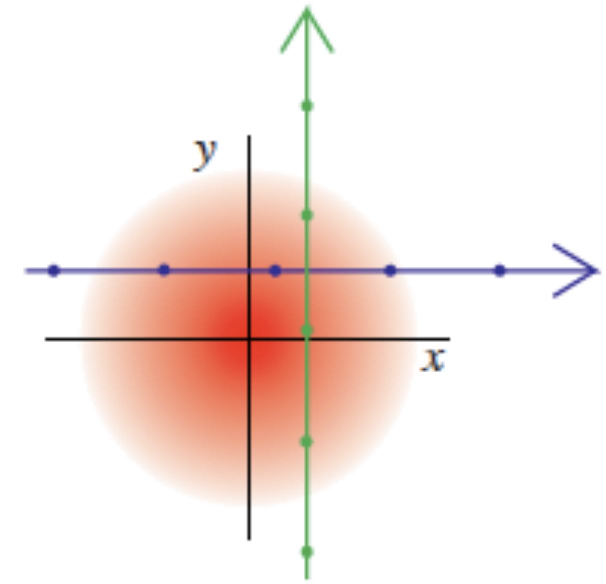
- Detector simulation of MBTS single counter response
  - Compare data and MC efficiency by using tracks or calorimeter cells to tag MBTS counters
  - Adjust MC thresholds to match data efficiency
  - Systematic uncertainty on σ: 0.1%
- Detector simulation of material between interaction point and MBTS
  - Extra material causes more conversion of neutrals, increasing probability of an MBTS hit
  - Plot fraction of hits tagged by calorimeter which are not seen by MBTS
  - Observe a difference of data with Pythia 6 that is twice the difference of Pythia 6 with nominal geometry and with 20% extra material.
  - Use 40% uncertainty on material->0.2% uncertainty on σ

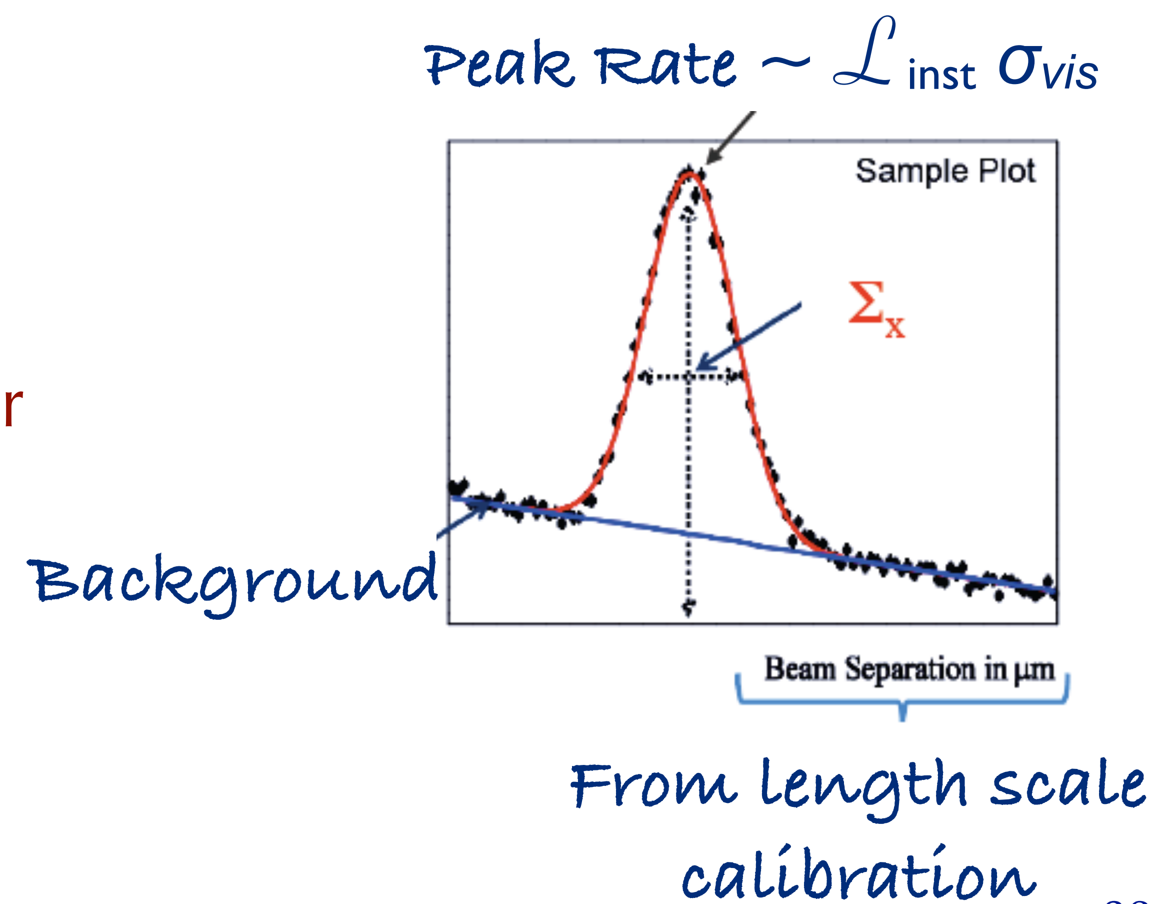




Beam Separation Scans

- Proposed in 1968 by Simon van der Meer as a means of measuring beam sizes at the ISR.
- Principle:
  - Measure the beam widths by scanning interaction rate as a function of beam separation
  - Can simultaneously measure σ_{vis}
  - Then use σ_{vis} as calibration constant for future luminosity determination



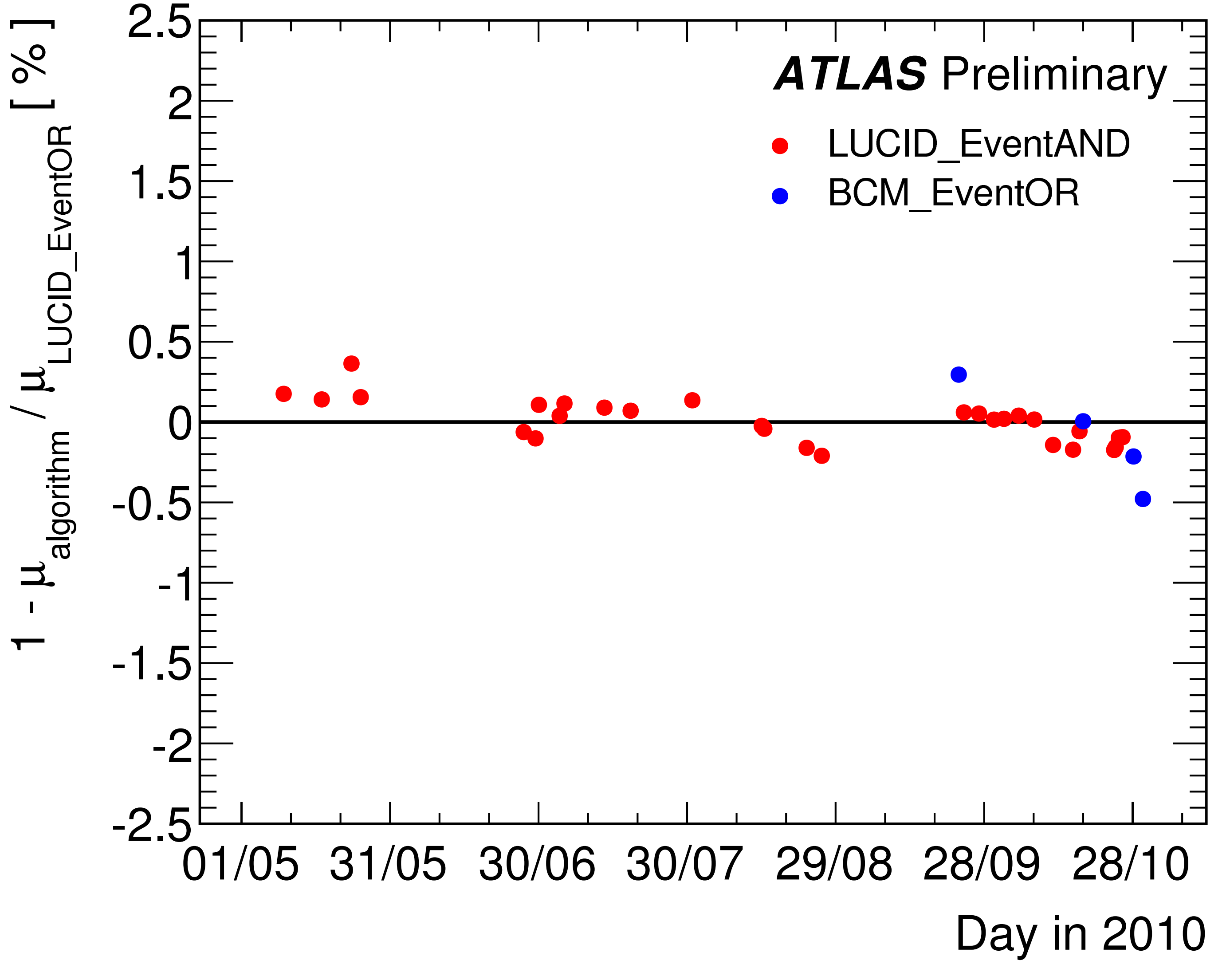


$$\frac{\mathrm{d}N}{\mathrm{d}t} = \frac{n_b f_r I_1 I_2}{2\pi \Sigma_x \Sigma_y} \sigma_{vis}$$

Luminosity Uncertainties

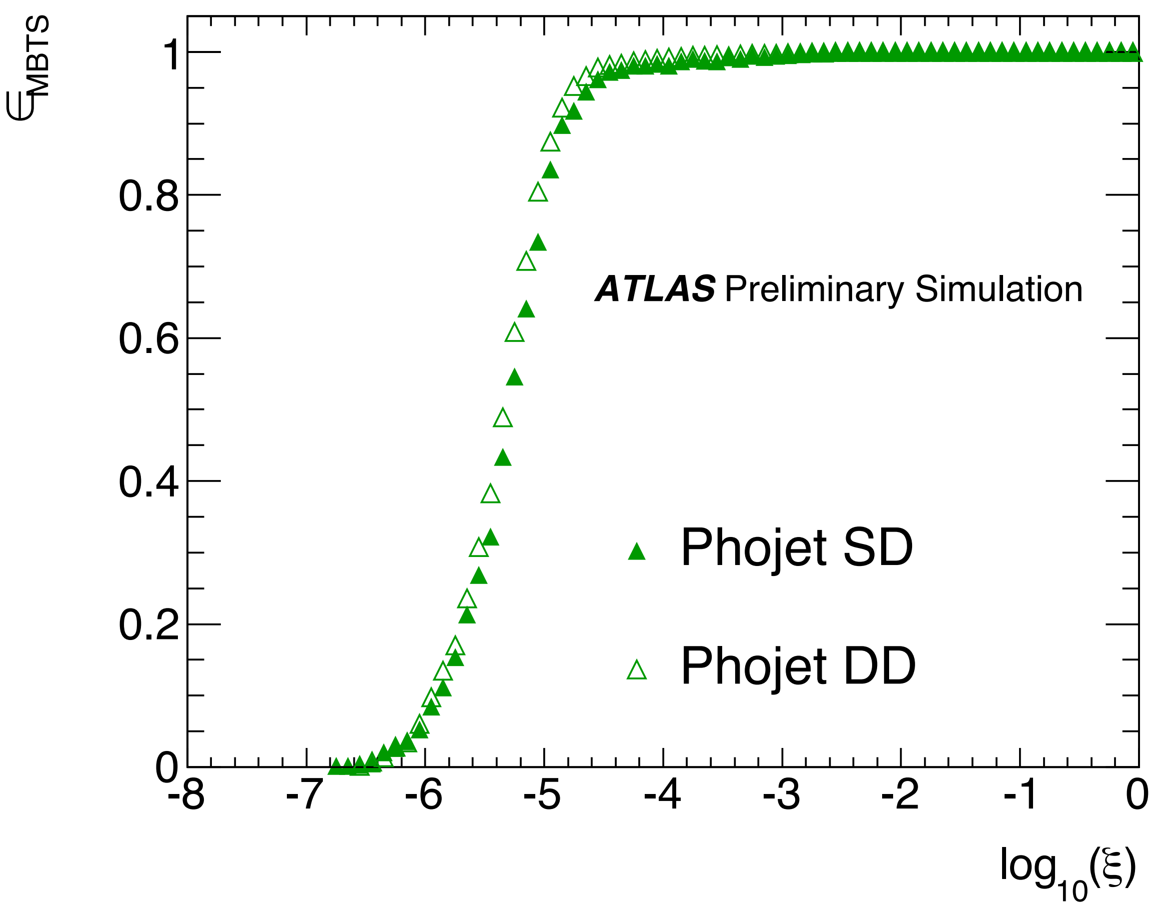
Scan Number Fill Number	I 1059	II–III 1089	IV–V 1386	
Bunch charge product	5.6%	4.4%	3.1%	Partially correlated
Beam centering	2%	2%	0.04%	Uncorrelated
Emittance growth and other non-reproducibility	3%	3%	0.5%	Uncorrelated
Beam-position jitter	–	–	0.3%	Uncorrelated
Length scale calibration	2%	2%	0.3%	Partially Correlated
Absolute ID length scale	0.3%	0.3%	0.3%	Correlated
Fit model	1%	1%	0.2%	Partially Correlated
Transverse correlations	3%	2%	0.9%	Partially Correlated
μ dependence	2%	2%	0.5%	Correlated
Total	7.8%	6.8%	3.4%	

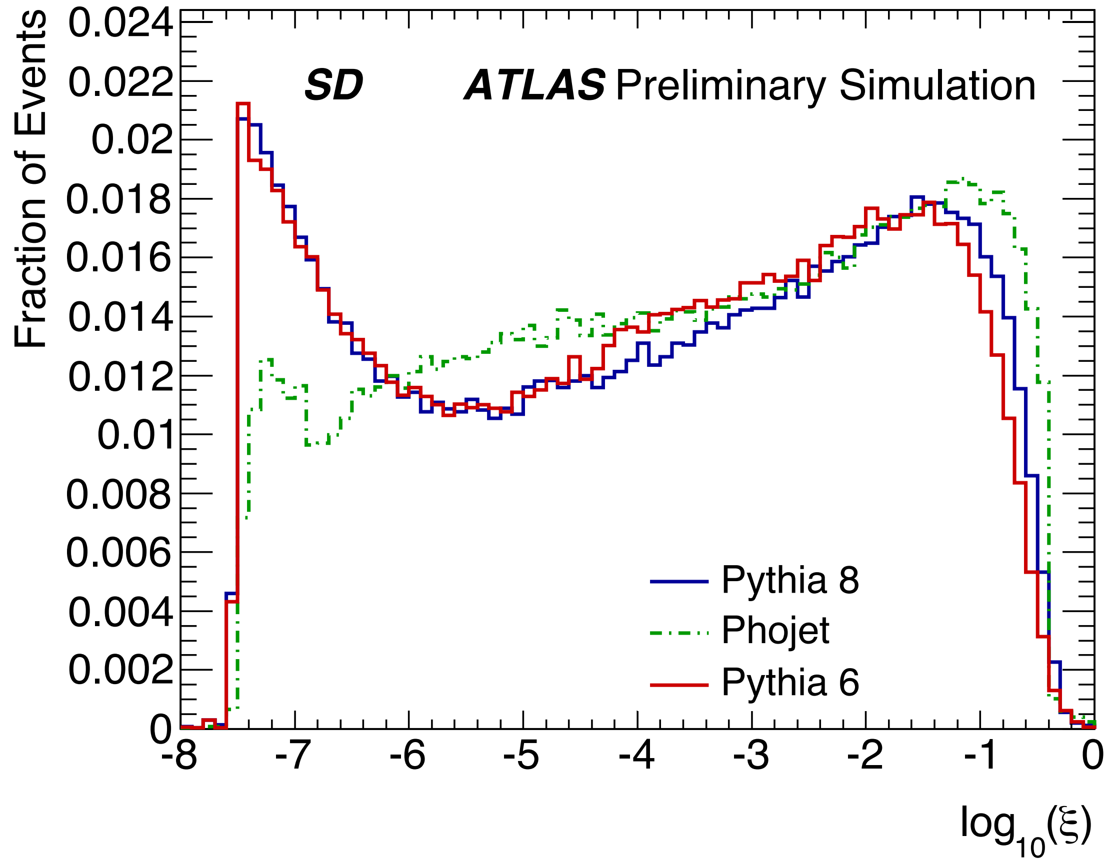
Luminosity Stability over 2010 Run

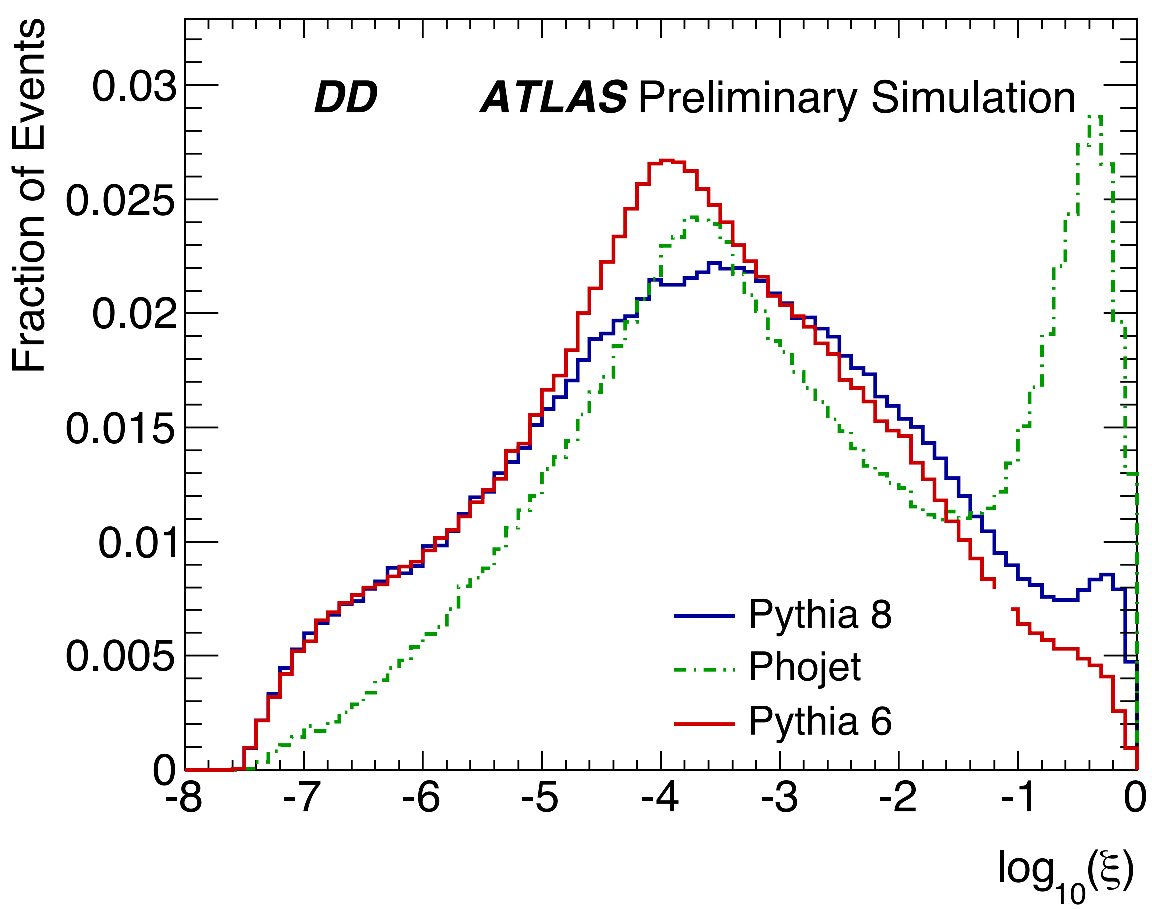


- Variations of 0.5% or less between different luminosity determinations over full 2010 run.

Efficiency vs. ξ





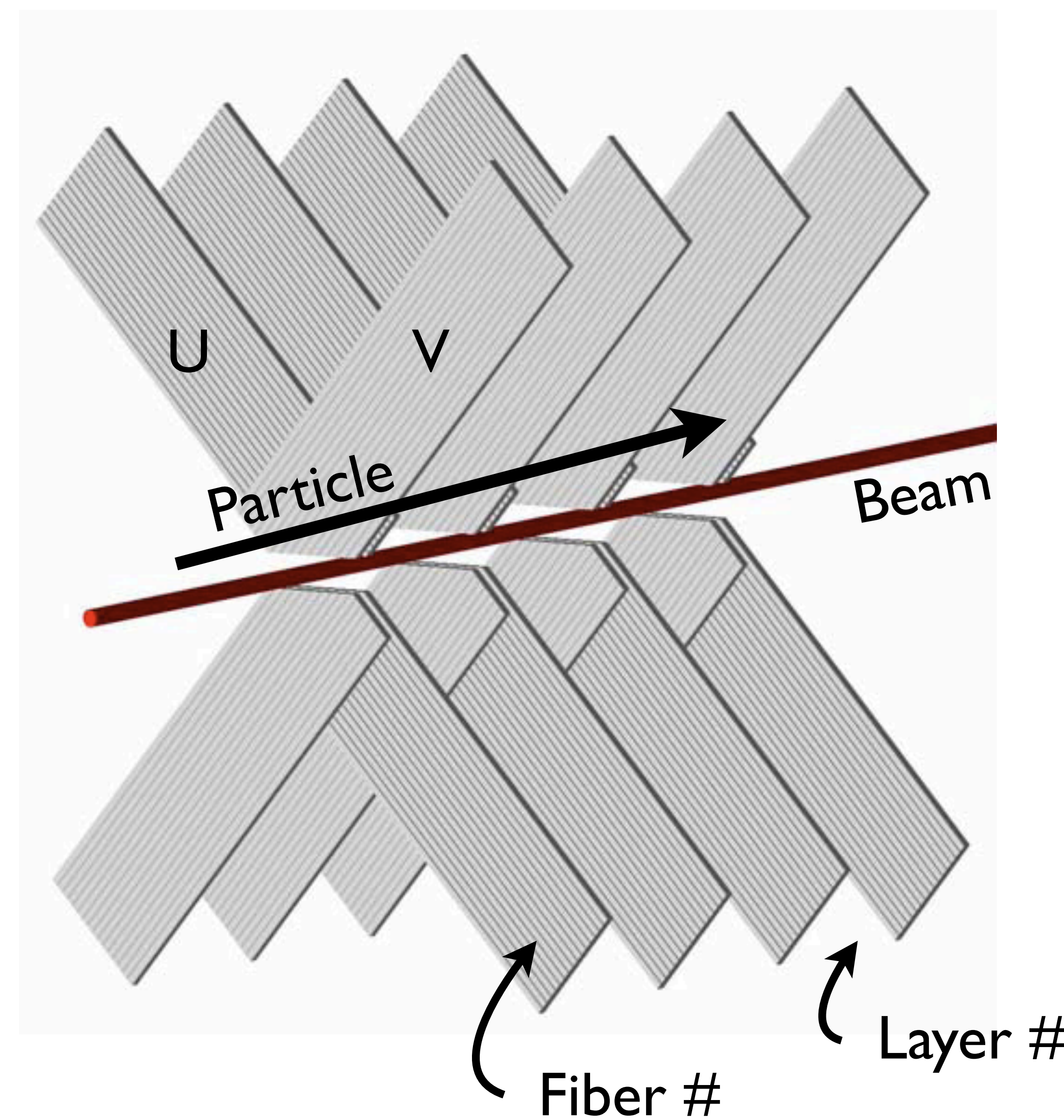


ALFA Extras

Fit function for dN/dt:

$$\frac{dN}{dt} = L\left(\frac{4\pi\alpha^2}{|t|^2} - \frac{\alpha\rho\sigma_{tot}e^{\frac{-b|t|}{2}}}{|t|} + \frac{\sigma^2_{tot}(1+\rho^2)e^{-b|t|}}{16\pi}\right)$$

Sketch of tracking detector:



MC cross-section models

Process	cross section (mb)	
	PYTHIA	PHOJET
non-diffractive	48.5	61.6
single diffractive dissociation	13.7	10.7
double diffractive dissociation	9.3	3.9
central diffractive dissociation	-	1.1
inelastic	71.5	77.3
	fractional contribution (%)	
f_D	32.2	20.2
f_{SD}	59.6	68.6