Measurement of the Inelastic Proton-Proton Cross Section at $\sqrt{s}$ = 7 TeV with the ATLAS Detector

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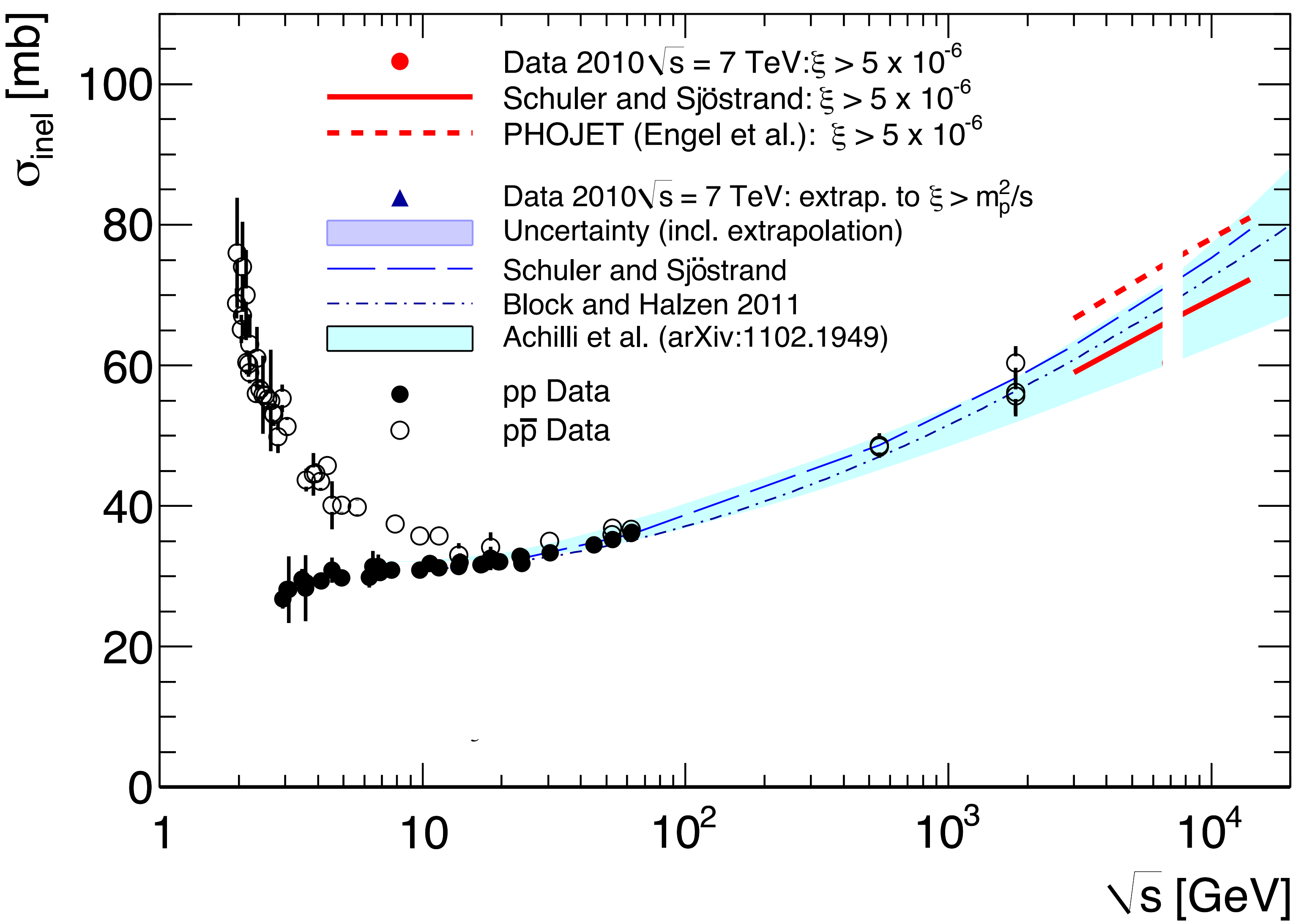
on behalf of the ATLAS Collaboration

Outline

- Motivation
- The ATLAS detector
- Cross section measurement
- Results

Motivation

- Proton-(anti)proton cross sections have been a fundamental quantity since the earliest days of particle physics
- Yet, they cannot be calculated from first principle
- Common models manage to describe existing data
- The extrapolation to high $\sqrt{s}$ uncertain
- Power laws: Donnachie & Landshoff
- Logarithmic: Block & Halzen
- Or using aspects of QCD: Achilli et al.



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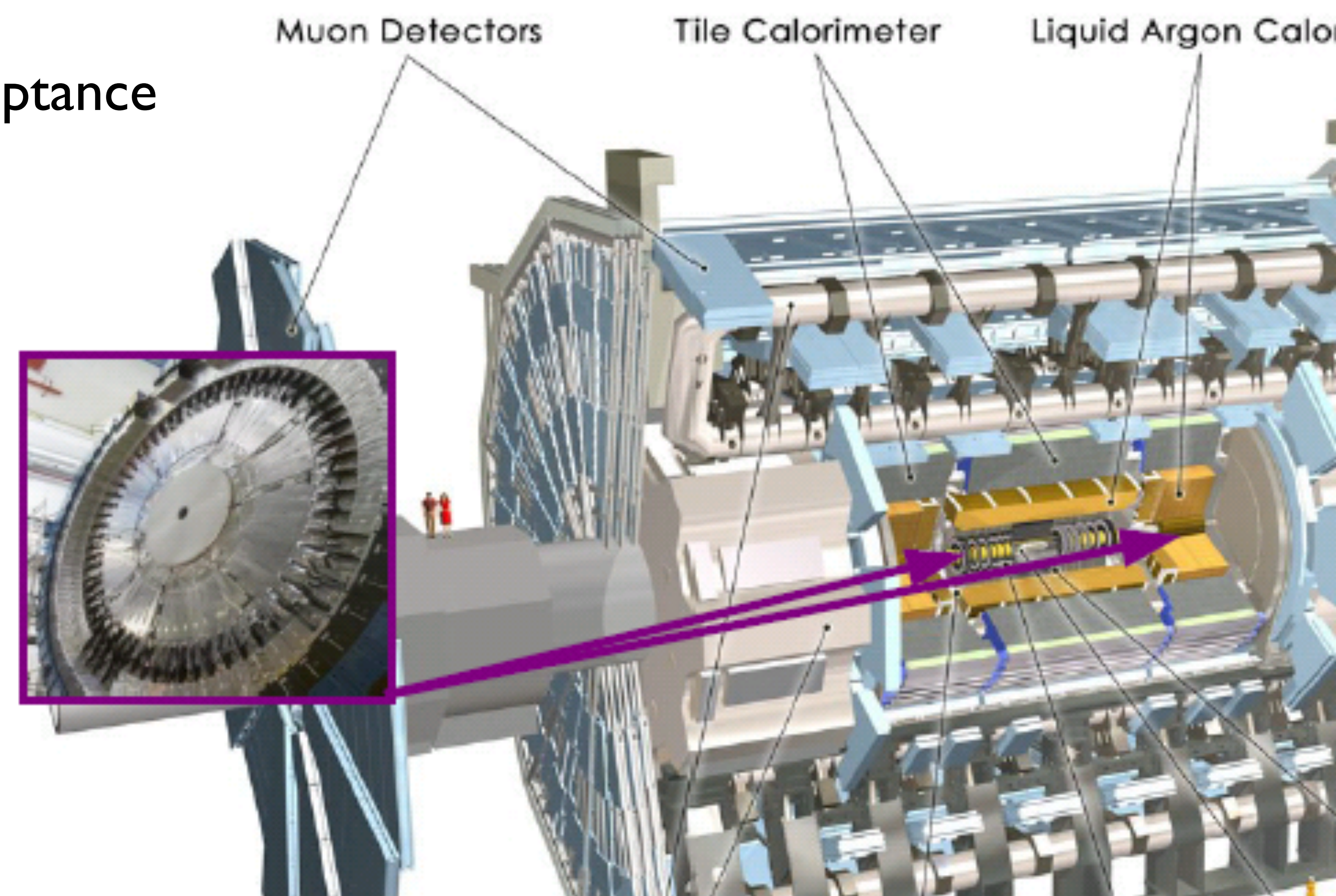
The ATLAS detector

- Crucial sub-detector for this measurement:
  Minimum bias trigger scintillators
- Scintillator modules mounted in frond of the end-cap calorimeters ($z = \pm 3.5$m), two wheels on each side
- Coverage: $2.09 < |\eta| < 3.84$
- Translates in to limited acceptance in terms of the mass of the dissociated system:
- $\xi = M_x^2/s > 5\times10^{-6}$
- ↪ will need extrapolation for the total cross section to $\xi_{min} = m_p^2/s = 2\times10^{-8}$



Cross section definition

- The master formula for the fiducial, inelastic cross section:

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

- Ingredients:
  - The total number of events: N
  - The number of background events: N_{BG}
  - The integrated luminosity: $\int L\,dt$
  - Trigger and event selection efficiencies: ε_{trig}
  - Acceptance ε_{sel} and pollution from events migrating into the fiducial region: $f(\xi < 5 \times 10^{-6})$
    - Corrections derived from Monte Carlo simulation

Event selection

- Trigger: require at least one hit in the MBTS counters:
  Very efficient w.r.t. to the offline selection: 99.98%
- Offline selection: require two counter's charge to be above 0.15 pC
  (Significantly above the noise of 0.02 pC)
- Collected two event samples
  - *Inclusive sample* - for the actual cross section measurement:
    - require in total two counters above threshold
    - ~1.2 million events
  - *Single-sided sample* - to be able to constrain the diffractive contribution:
    - two counters above threshold on one side
    - none on the opposing side
    - ~120k events

Background estimation

- Possible backgrounds arise from direct beam interactions with:
  - residual gas in the beam-pipe or the beam-pipe itself
  - material upstream from the detector

  - Exercise analysis using bunch crossings with only a single proton bunch
    ↪ all these events are background
  - Background estimates:
    - Inclusive selection: 0.1%
    - Single-sided: 0.3%

- Additional background from ‘afterglow‘:
  - Slowly decaying beam remnants
  - Can be estimated from timing distributions to be $< 0.4\%$

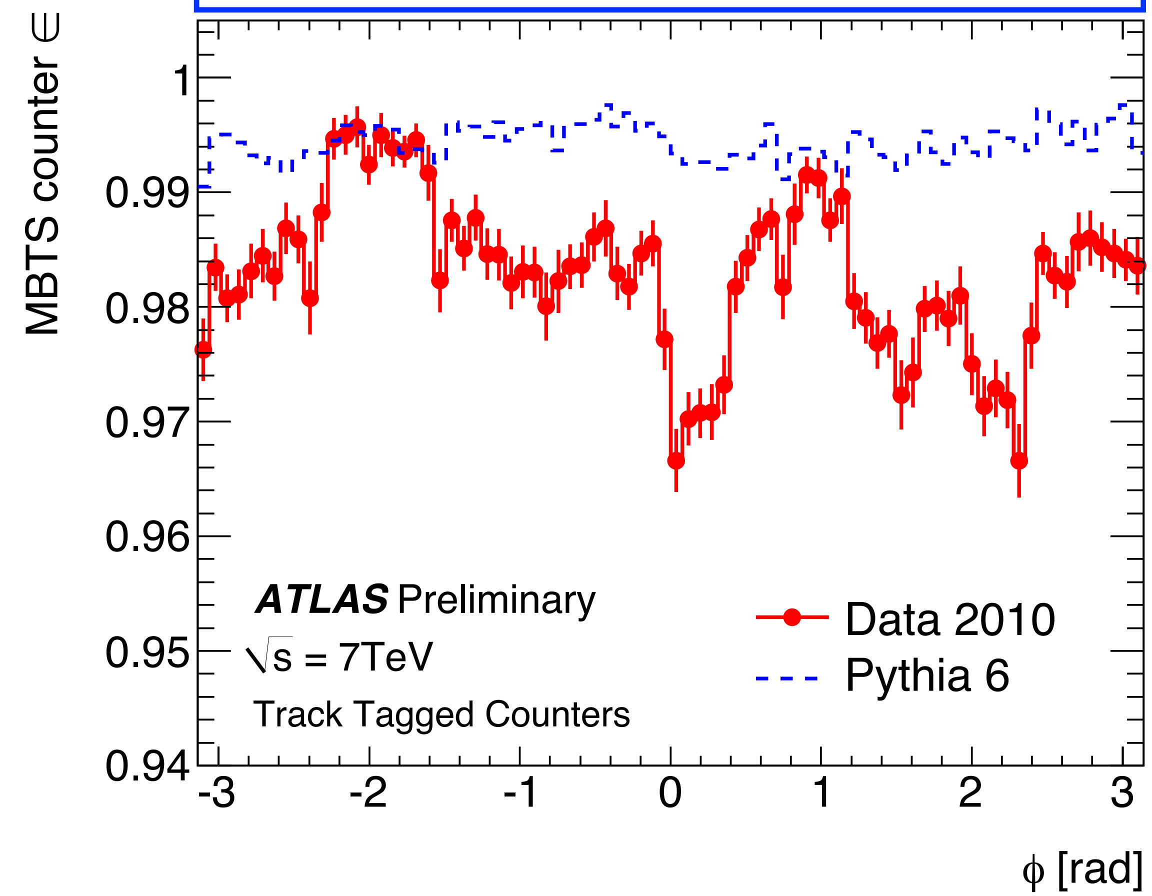
MBTS response

- MBTS hit multiplicities dependent on efficiencies of single scintillators and material budget

- Efficiencies measured data driven:
  - Using extrapolated tracks with p_T > 200 MeV
  - Calorimeter signals behind the MBTS detectors
  - Efficiency overestimated in the MC, by ~1%

- Impact of material estimated using MC with different amount of dead material, in combination with data

Efficiency using tracks



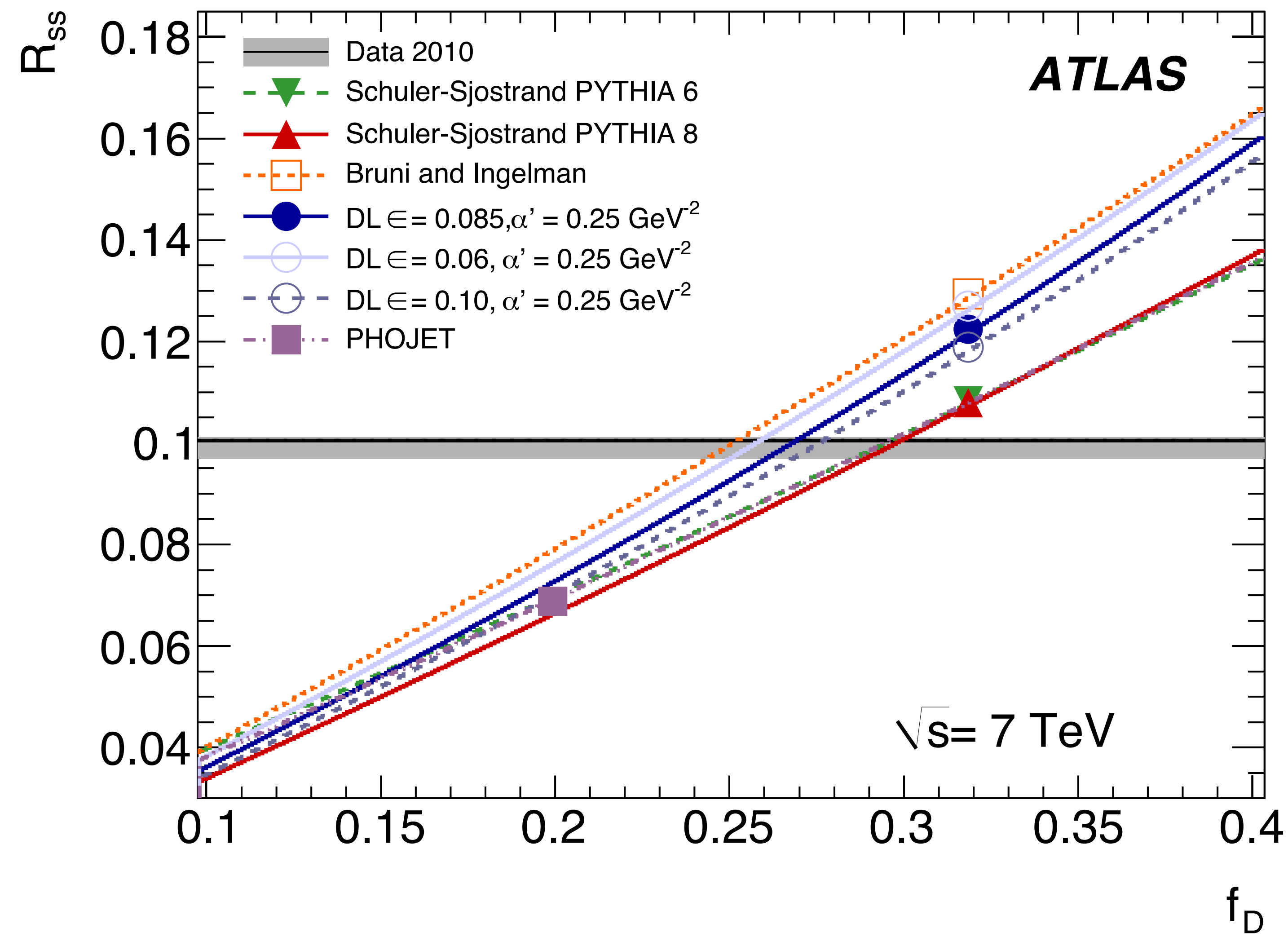
Relative diffractive contribution

- Measure $R_{ss} = N_{Single-Sided} / N_{Inclusive}$:
- Constrain the diffractive fraction f_D to match the measured R_{ss}

$$f_D = \frac{\sigma_{SD} + \sigma_{DD} + \sigma_{CD}}{\sigma_{inel}}$$

- Default f_D = 32.2% (20.2% for PHOJET)
- Fix f_D such that it reproduces the measured R_{ss}
- Systematic uncertainties:
  - Propagated from R_{ss}
  - Variation of the ratio SD / DD
- Result for the Donanchie & Landshoff model: $f_D = 26.9^{+2.5}_{-1.0}$ %

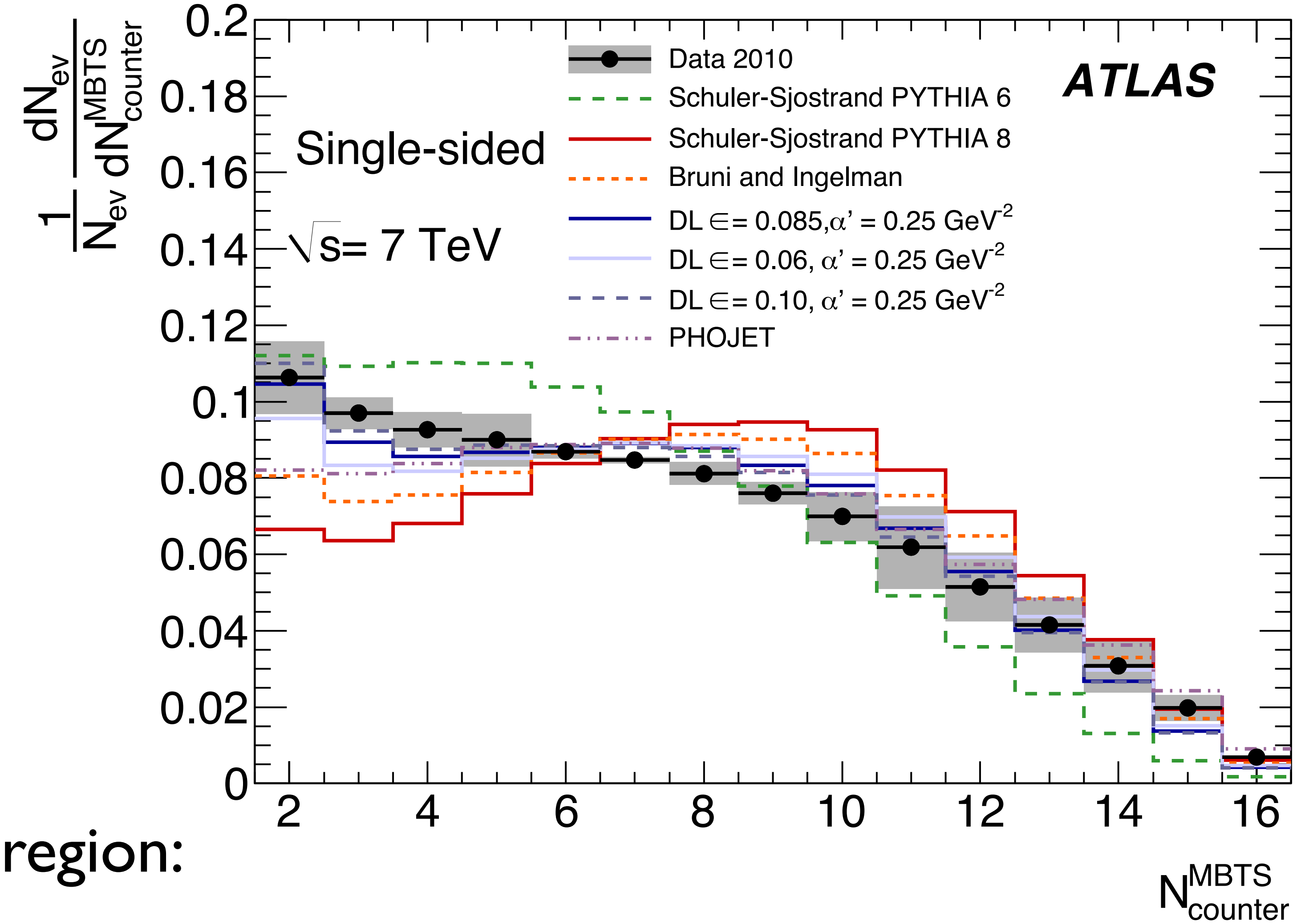
$$R_{ss} = [10.02 \pm 0.03(\text{stat.})^{+0.1}_{-0.4}(\text{sys.})]\%$$



Efficiency determination

- ε_{sel}: Fraction of events with $\xi > 5 \times 10^{-6}$ that pass the selection
- Choose single-sided sample as benchmark for the MC
- Data best described by Donnachie&Landshoff model, with $\varepsilon = 0.085$, $\alpha' = 0.25\ \mathrm{GeV}^{-2}$

  ↪ Taken as the default model for the efficiency estimate



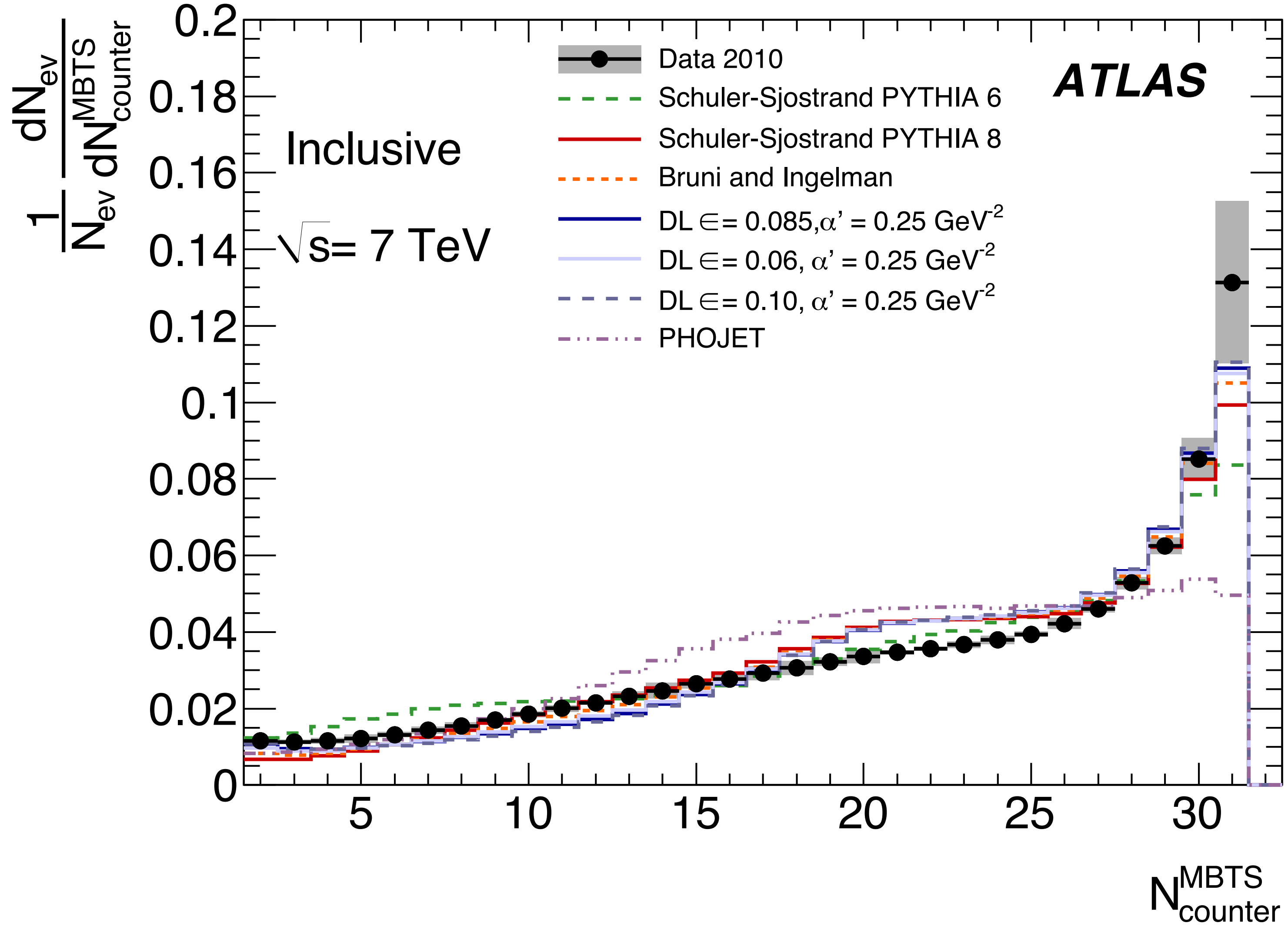
- Resulting efficiency: ε_{sel} = 98.77 %
- Very low migration into the fiducial region: $f(\xi < 5 \times 10^{-6})$ = 0.96 %
- Spread among other models considered: < 0.5%

Efficiency determination (2)

- Hit multiplicities in the inclusive sample:

- At low multiplicities, data is within the various predictions

- Systematic uncertainties due to:
  - Fragmentation: difference between Pythia6 vs. Pythia8: 0.4%
  - ξ dependence: max. deviation of default Donnachie&Landshoff, from all other DL models: 0.4%



Fiducial cross section

$$\sigma(\xi > 5 \cdot 10^{-6}) = 60.3 \pm 0.05\,(\text{stat.}) \pm 0.5\,(\text{sys.}) \pm 2.1\,(\text{lumi})\,\text{mb}$$

- Luminosity is the dominant sys. uncertainty
  - Measured using dedicated van der Meer scans: 20.25 μb^{-1}
  - Limited by bunch current measurement
- Very efficient and well understood trigger
- Detector response in general well modeled (~2%), differences corrected for in the MC
- Conservative estimate of beam backgrounds

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

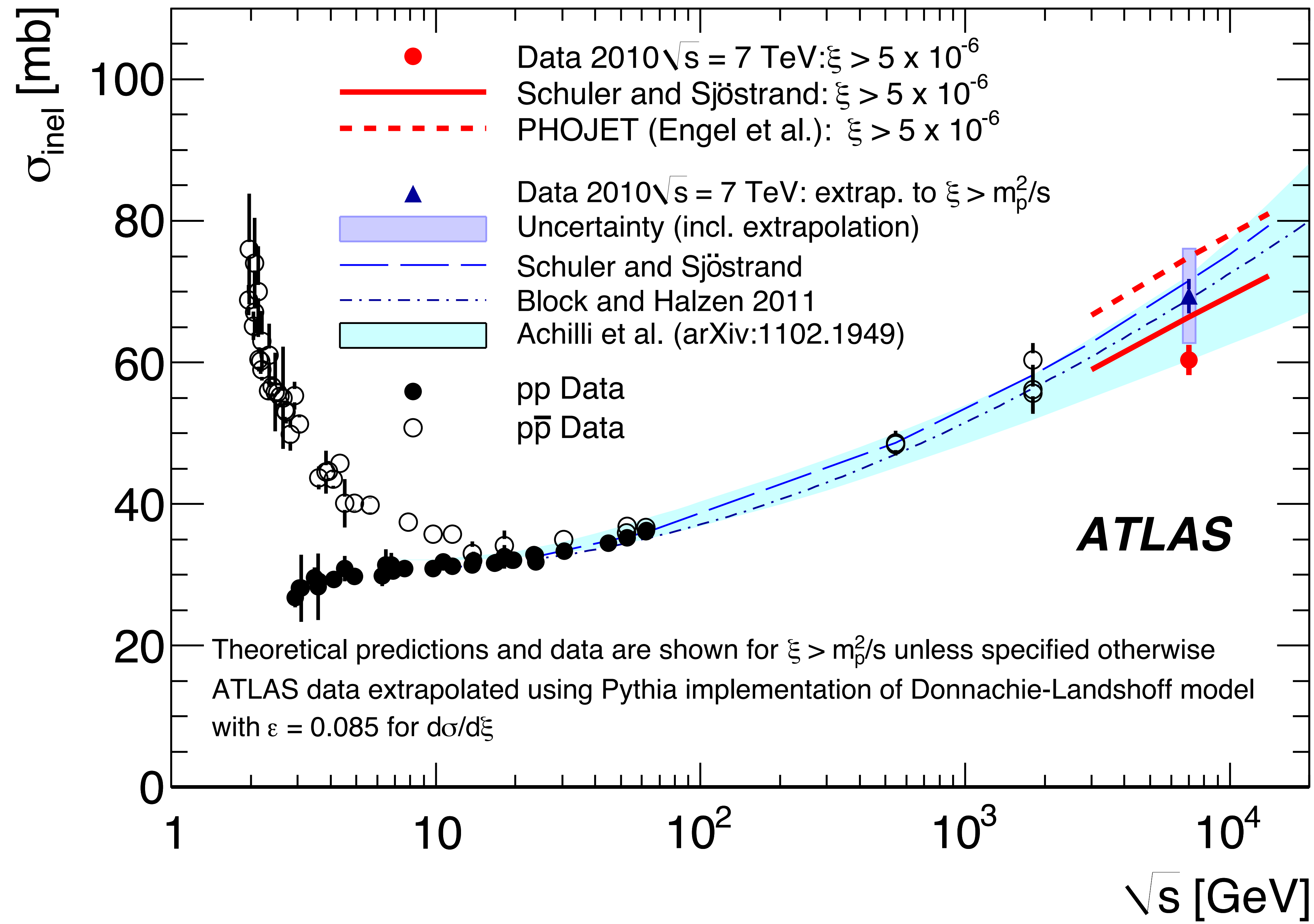
Extrapolation to total cross section

- Extrapolation crucial to enable meaningful comparisons to theo. predictions (and other measurements)
- Evaluate fraction of events in the selected fiducial region
- Depends on the ξ evolution of the cross section
- Result for the default DL model:
  - 87.3% of the total cross section within the kinematic region
- Significant difference among the models:
  - Minimum: 79%, from recent calculations by Ryskin, Martin & Khoze
  - Maximum: 96%, by PHOJET
  - Take 10% systematic uncertainty

Model	ξ-dependency
Schuler & Sjöstrand	~ flat
PHOJET	decreasing
Bruni & Ingelman	flat
DL, Berger & Streng	$\frac{d\sigma_{SD}}{d\xi} = \frac{1}{\xi^{1+\epsilon}}$

Results

$$\sigma(\xi > 5 \cdot 10^{-6}) = 60.3 \pm 0.05\,(\text{stat.}) \pm 0.5\,(\text{sys.}) \pm 2.1\,(\text{lumi})\,\text{mb}$$
$$\sigma_{inel} = 69.1 \pm 2.4\,(\text{exp.}) \pm 6.9\,(\text{extr.})\,\text{mb}$$



Summary

- ATLAS has performed a very precise, first measurement of the fiducial inelastic proton-proton cross section
- Uncertainty dominated by the absolute luminosity calibration
- Results are significantly below predictions by PHOJET and Schuler&Sjöstrand

- The extrapolation to the total cross section suffers from uncertainties on the ξ dependency
- Consistent with predictions from power law (Pythia) and logarithmic (Block&Halzen) dependencies on center-of-mass energy

Backup

$\sigma(\xi > m_p^2/s)$ [mb]	
ATLAS Data 2010	$69.4 \pm 2.4(\text{exp.}) \pm 6.9(\text{extr.})$
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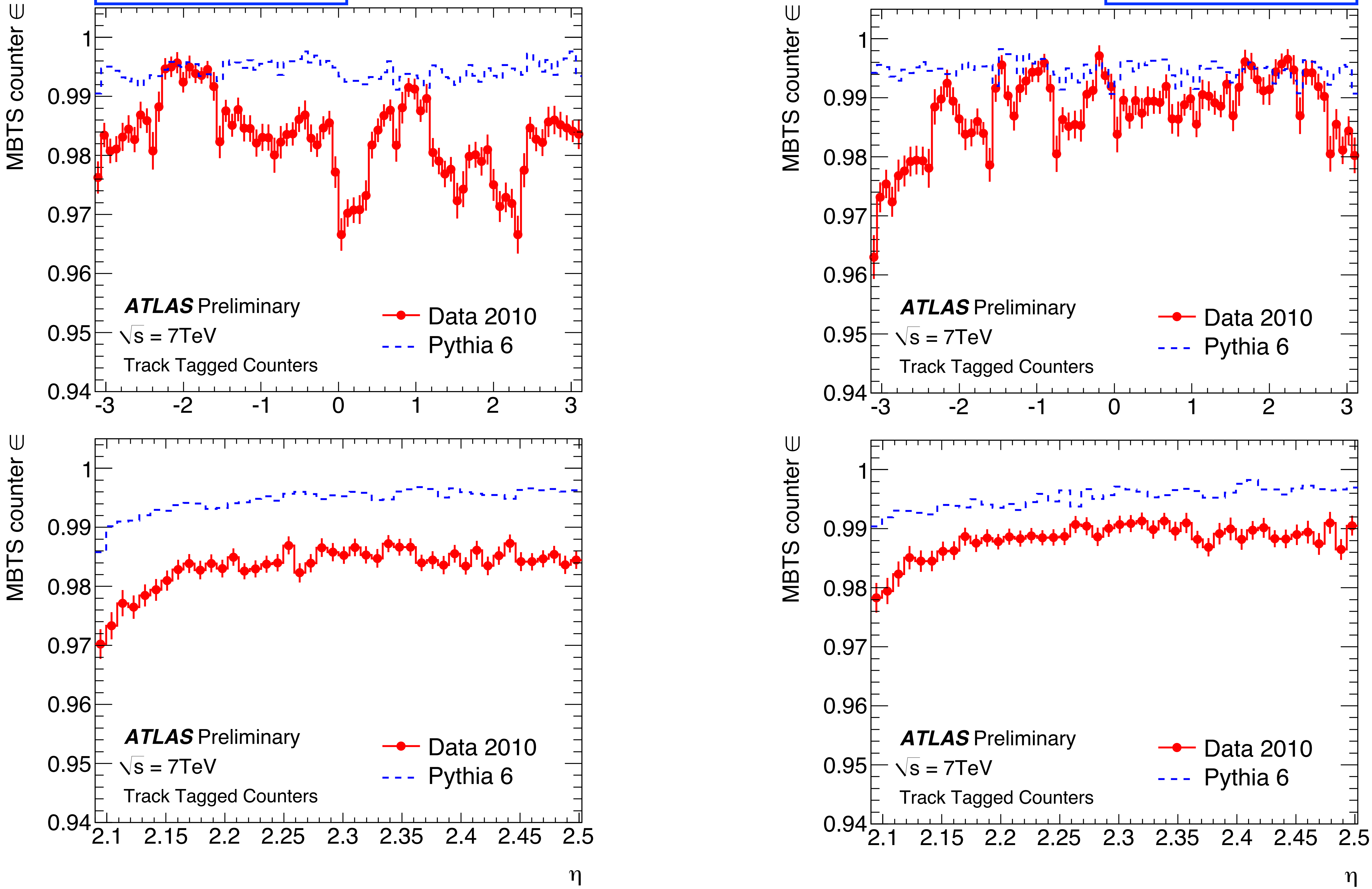
MBTS efficiencies

A - side

C - side



Background estimation

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  - Exercise analysis using bunch crossings with only a single proton bunch
    ↪ all these events are background
  - Background estimates:
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- Additional background from 'afterglow':
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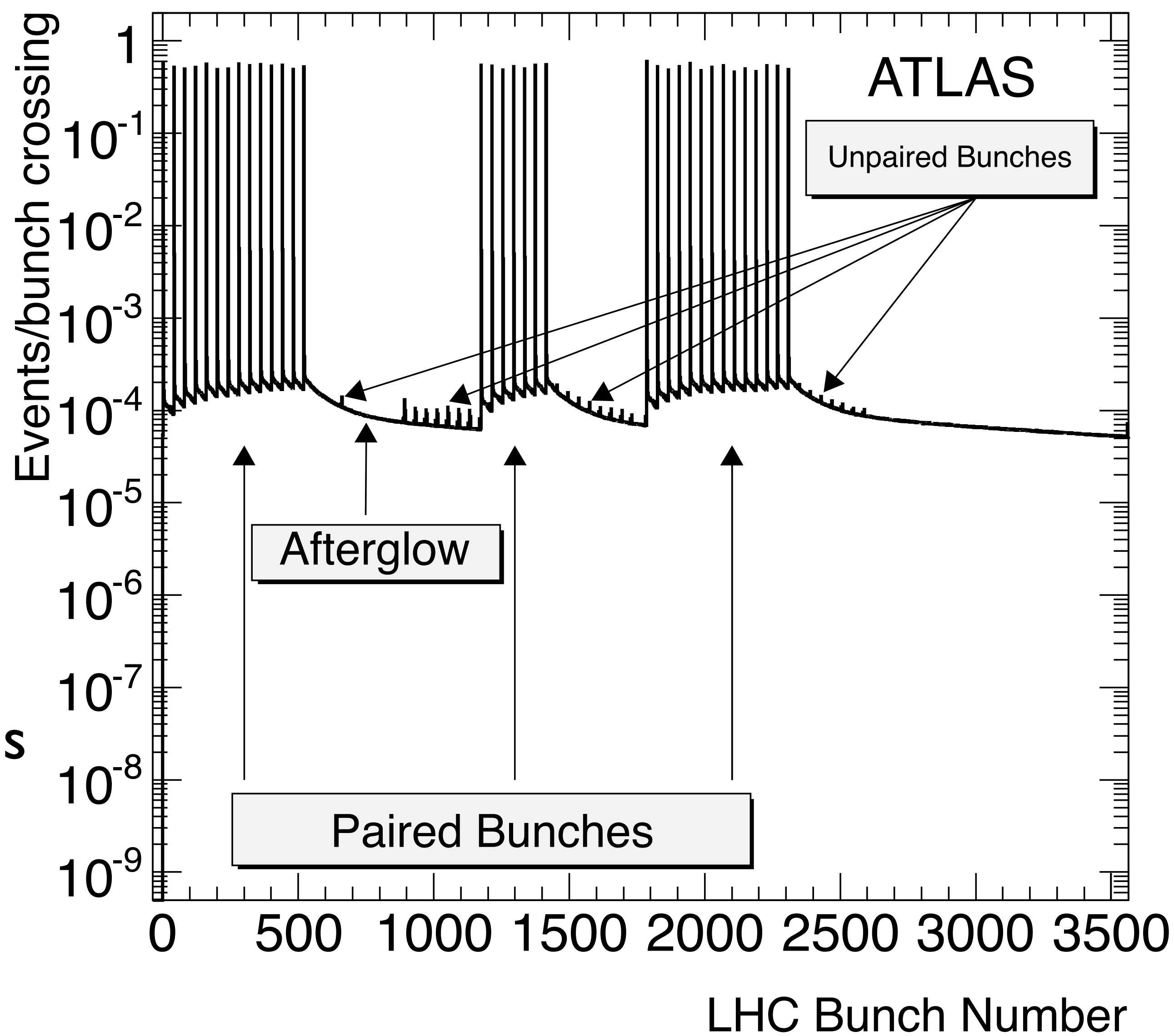
  - Can be estimated from timing distributions to be < 0.4%
- Only 1 paired & unpaired crossing in the data analyzed

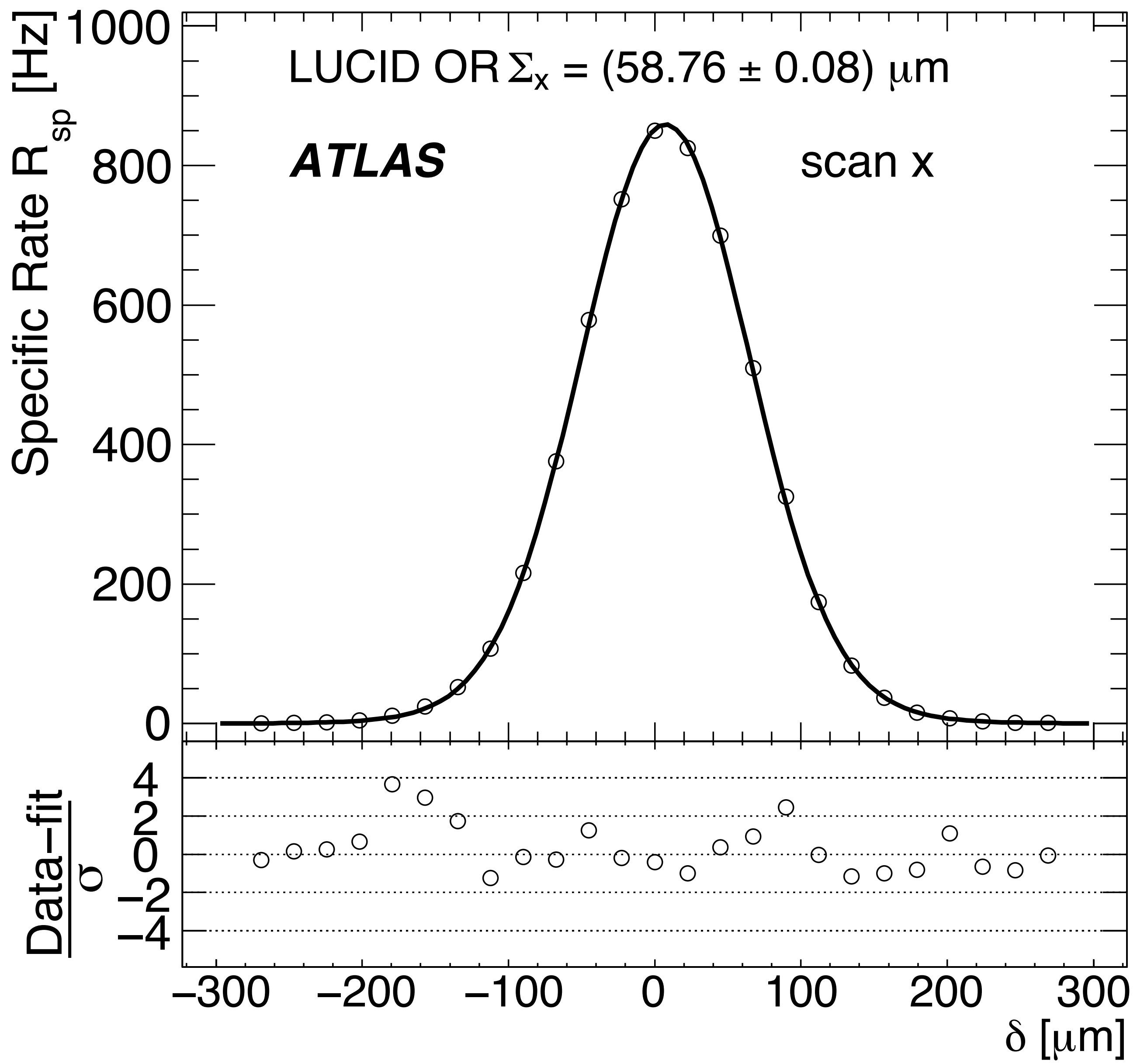


Luminosity Measurement

- Done using the van der Meer method
- Measure a detector specific, visible cross section σ_{vis}
- σ_{vis} serves as a calibration constant, to calculate the luminosity:

$$\mathcal{L} = \frac{\mu_{vis} n_b f_r}{\sigma_{vis}} = \frac{n_b f_r n_1 n_2}{2\pi \Sigma_x \Sigma_y}$$

- Σ_x, Σ_y: transverse beam profiles
- Measurable in beam-separation scans
- Dominant uncertainty: determination of beam currents
- Initially, 11% uncertainty on the beam currents
- Increasingly precise measurements result in a 3.4% systematic uncertainty

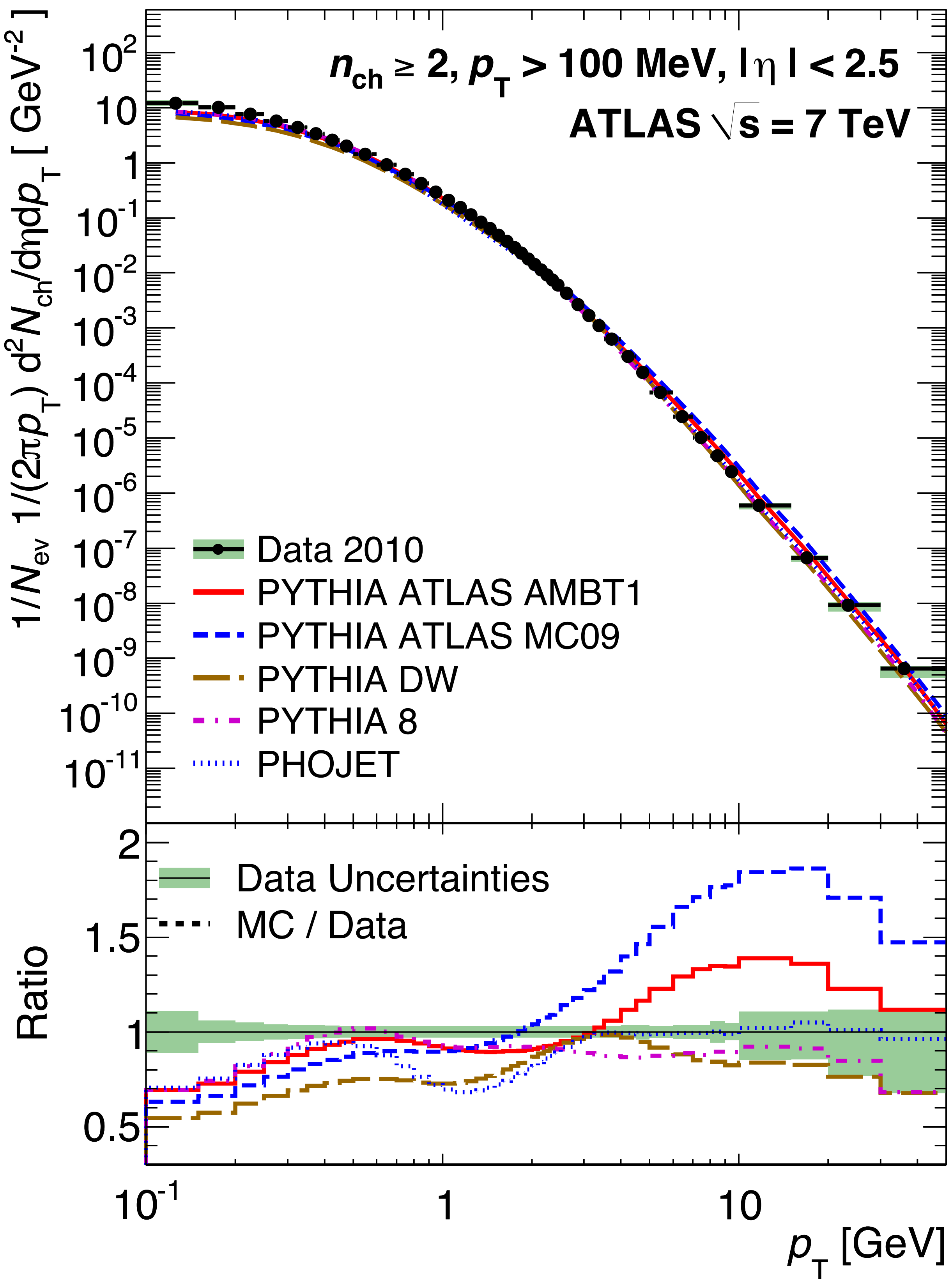


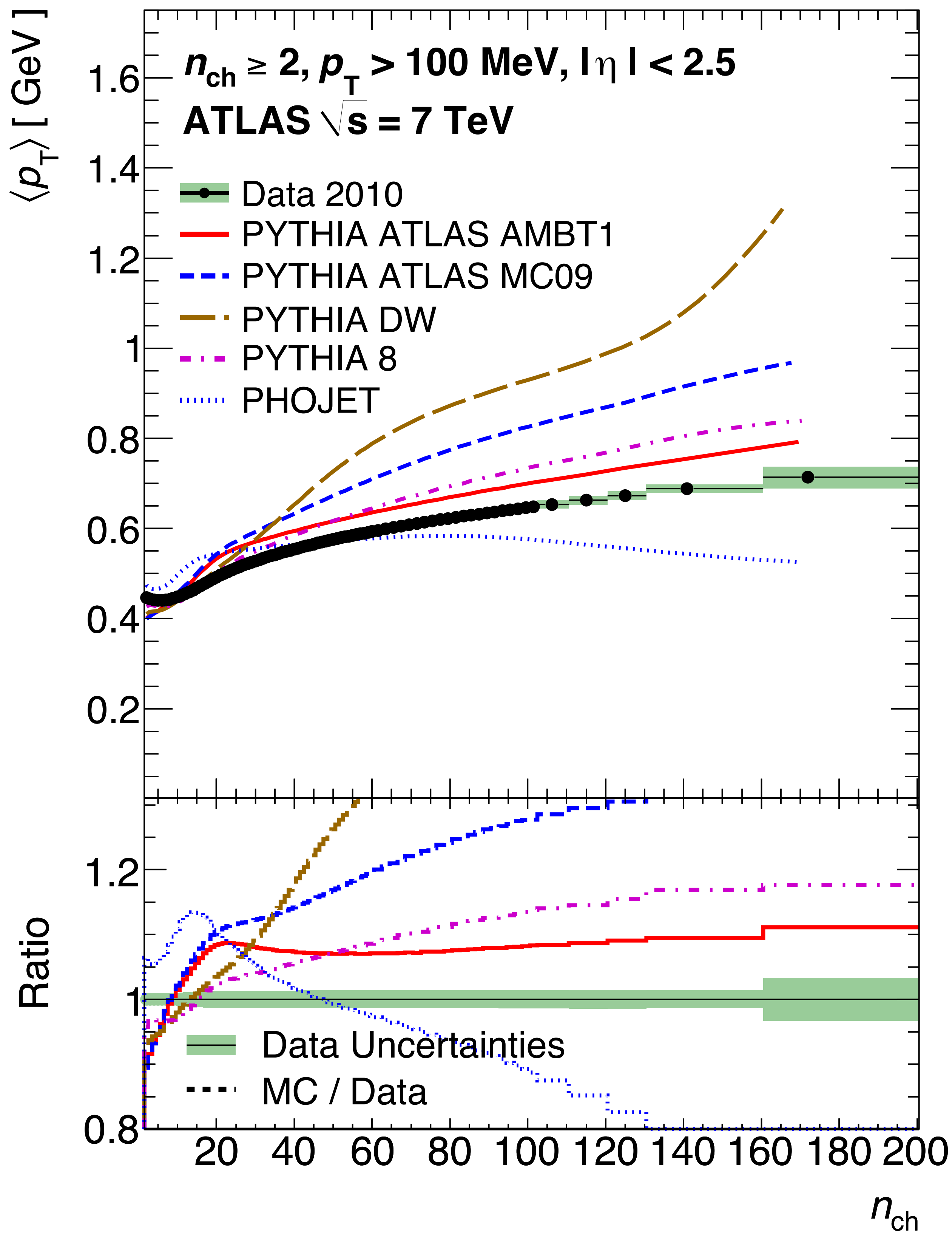
Trigger efficiency

- ε_{trig}: Determined using random triggered events

- Efficiency measured to be: $99.98^{+0.02}_{-0.12}\,\%$
- Systematic uncertainty estimated using another independent trigger
- Difference w.r.t. to random trigger approach taken as uncertainty, amounting to 0.1%

Other 'soft' QCD at ATLAS





The underlying event