pp Cross-section Measurements at ATLAS

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on behalf of the ATLAS collaboration

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September 2 2015

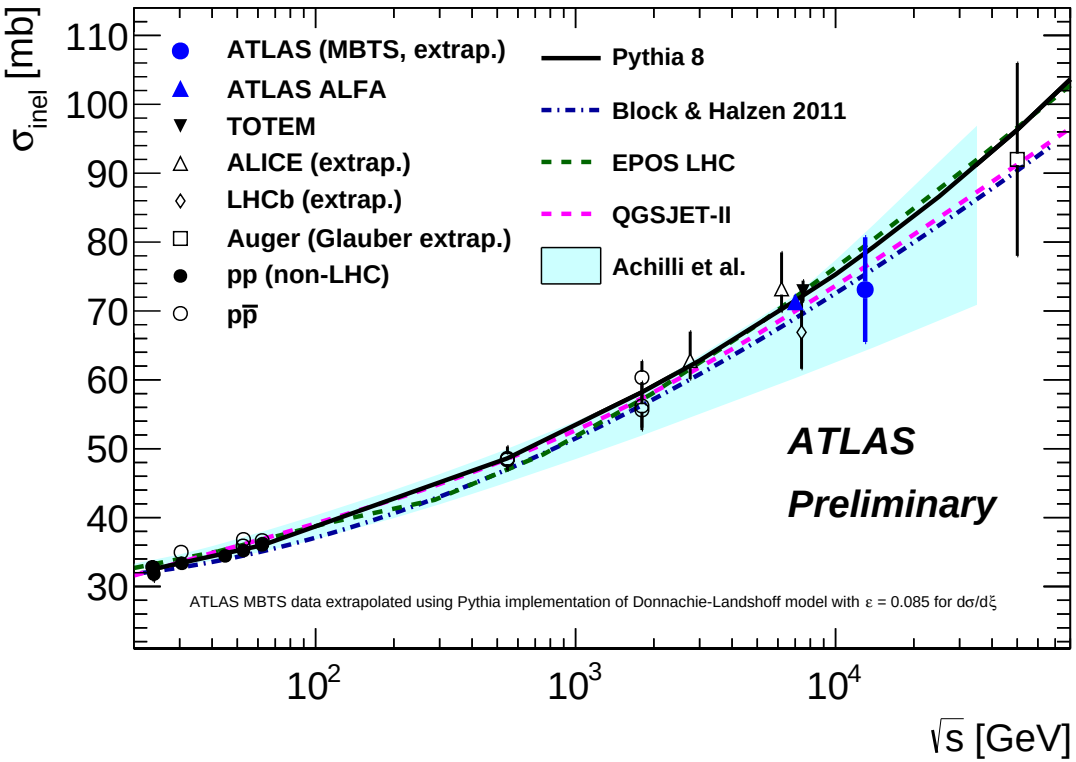
Outline

- Inelastic σ_{pp} Measurement with MBTS
- Elastic σ_{pp} Measurement with ALFA

Interest in Measuring *pp* Cross-sections

- **Predictions from QCD**
  - **Perturbation theory not applicable**: predictions provided by models.
  - **Optical theorem**: Relation between elastic-scattering amplitude to total cross-section.
- **Cosmic Ray Showers**
  - **Glauber-Gribov model**: $pp \leftrightarrow p - \text{Air}$
  - **Modeling of X_{max}**: ID initiating particle using shower depth.

ATLAS-CONF-2015-038



- **Determination of average number of simultaenous pp_{inel} interactions at LHC**

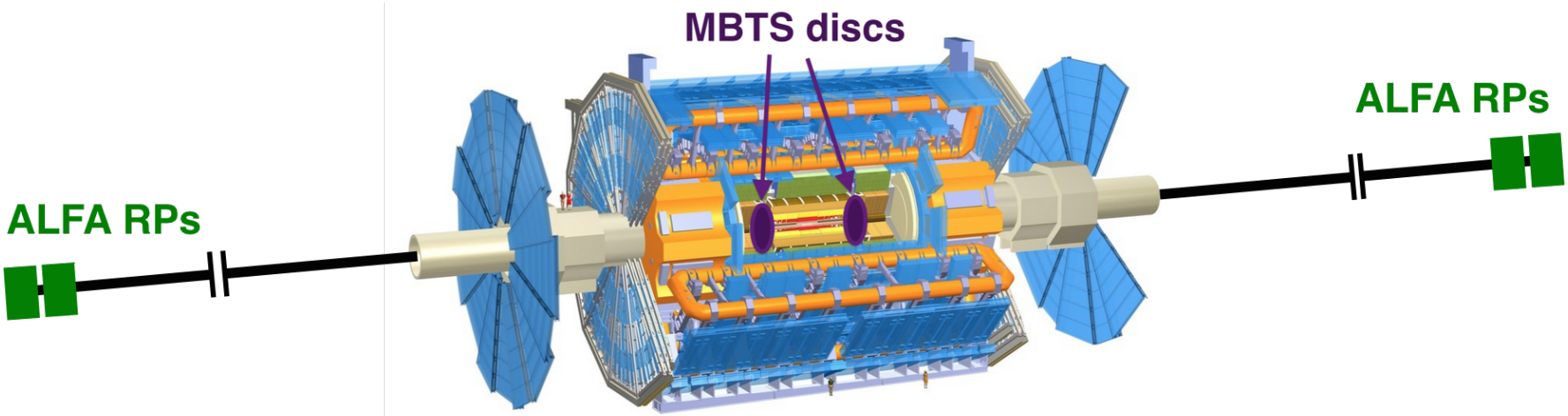
σ_{pp} Measurements at ATLAS

MBTS (inelastic)

- Measure $\sigma_{pp}^{\text{inel}}$ in fiducial region.
- Extrapolate to total $\sigma_{pp}^{\text{inel}}$ using model.
- Measurement at 7 TeV.
- → **new!** Preliminary measurement at 13 TeV.

ALFA (elastic)

- Measure elastic event rates in fiducial region.
- Correct for acceptance and resolution, obtain $\frac{d\sigma_{pp}^{\text{el}}}{dt}$.
- Fit to model (using optical theorem), obtain σ_{pp}^{tot}, σ_{pp}^{el} and $\sigma_{pp}^{\text{inel}}$.
- → Measurement at 7 TeV.
- Measurement at 8 TeV in the works, 13 TeV planned.

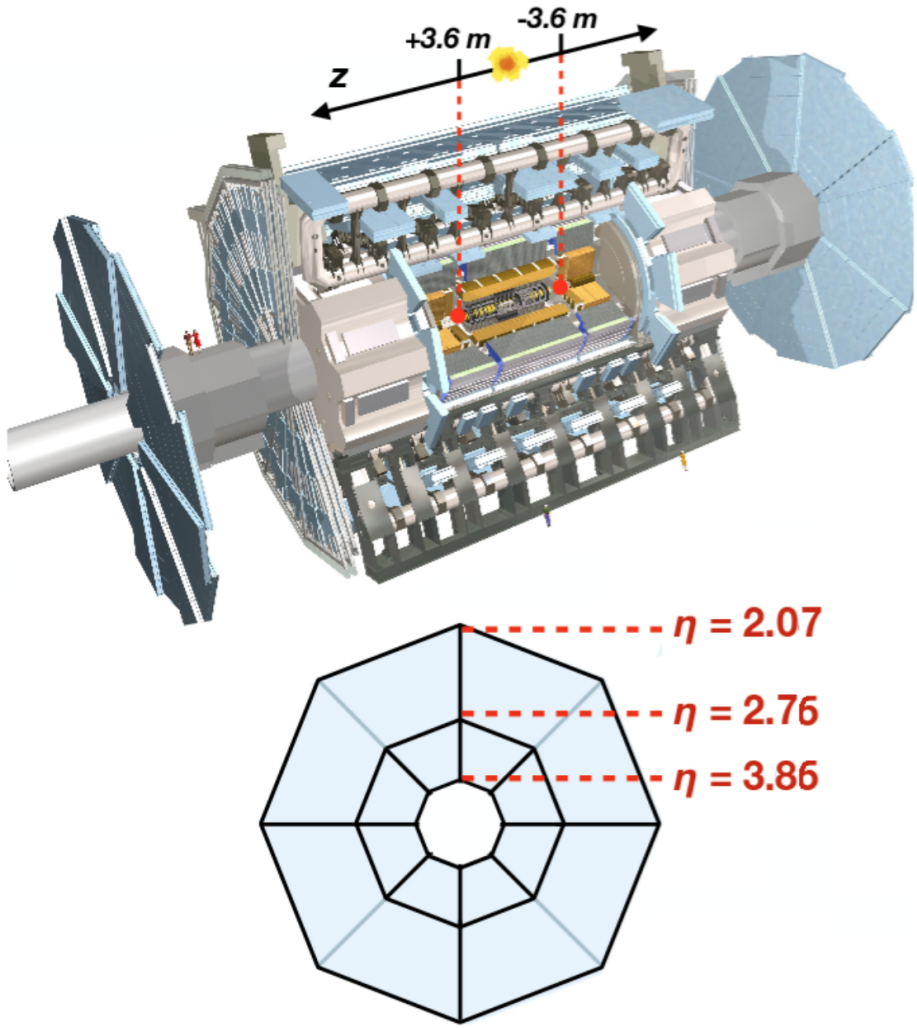


MBTS 13TeV Measurement

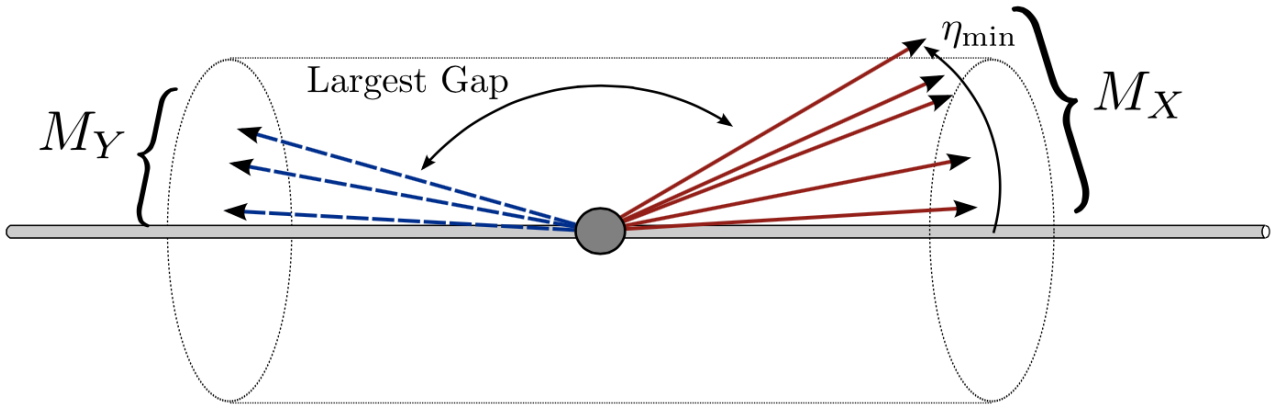
ATLAS-CONF-2015-038

MBTS: Detector and Acceptance

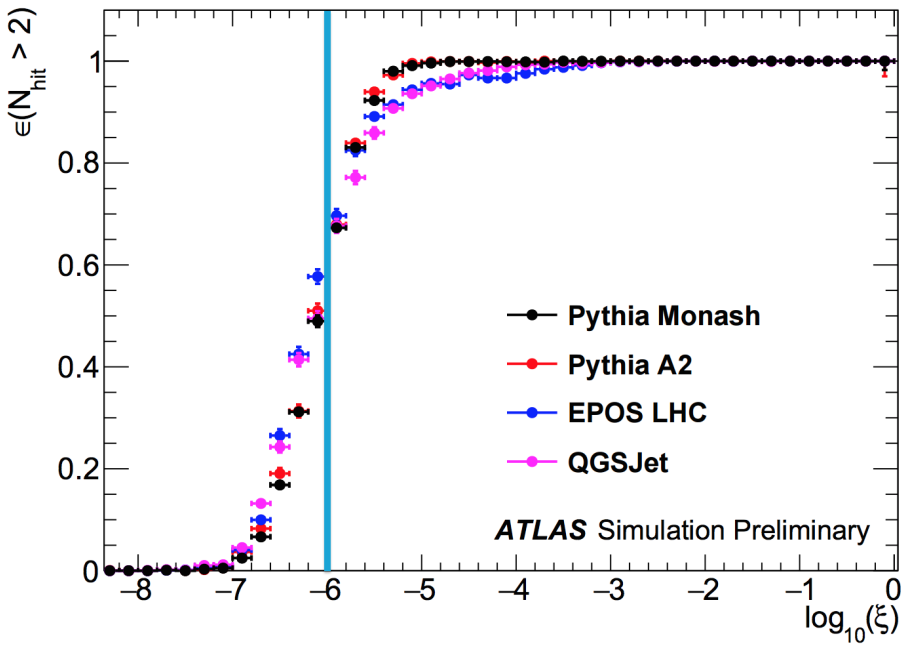
- Polystyrene scintillator discs placed on both sides of the interaction point.
- Each disk has 12 counters (8 inner, 4 outer).
- Acceptance $2.07 < |\eta| < 3.86$.
- Completely replaced between 7 TeV and 13 TeV measurements.
- $\sim$99% efficient to charged particles.
- ATLAS calorimeter and inner detector also used.
- **LUCID**: forward luminosity detector, used for special triggering.
- **LHCf**: study π^0 multiplicity to understand cosmic ray showers, used for special triggering.



MBTS: Acceptance and $\tilde{\xi}$ Definition

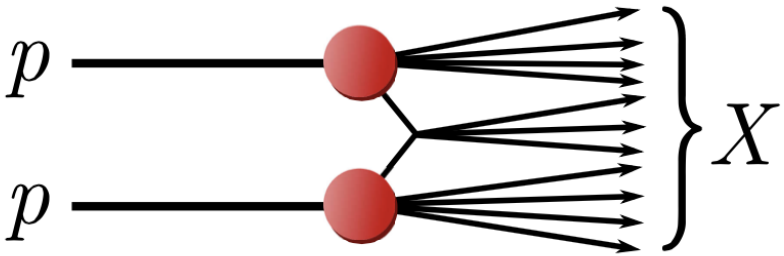


- M_X, M_Y: invariant masses of the dissociated protons.
- M_X: the largest of the two.
- $\tilde{\xi} = M_X^2/s$: is closely correlated with the largest η of a dissociated system.
- $|\eta| < 3.86 \rightarrow \tilde{\xi} > 1 \times 10^6$ ($M_X > 13$ GeV).

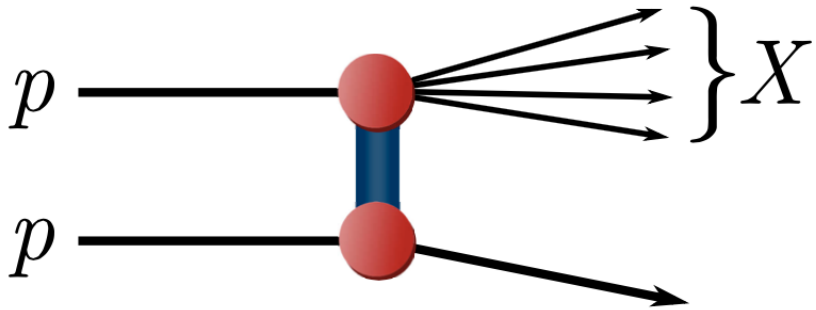


MBTS: Inelastic Interactions MC Modeling

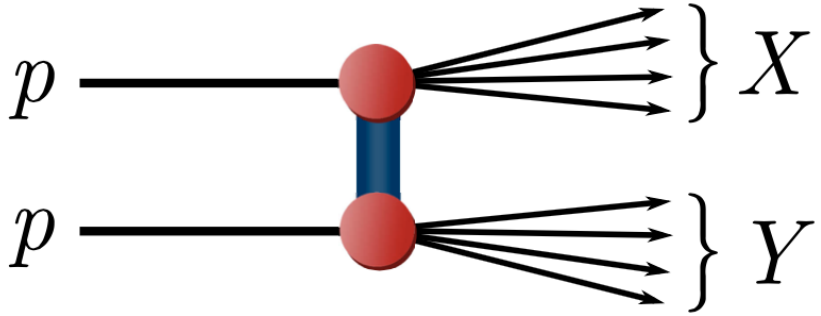
Types of inelastic proton dissociations in MC generators used



Non-Diffractive (ND)
(color-exchange)



Single-Dissociation (SD)

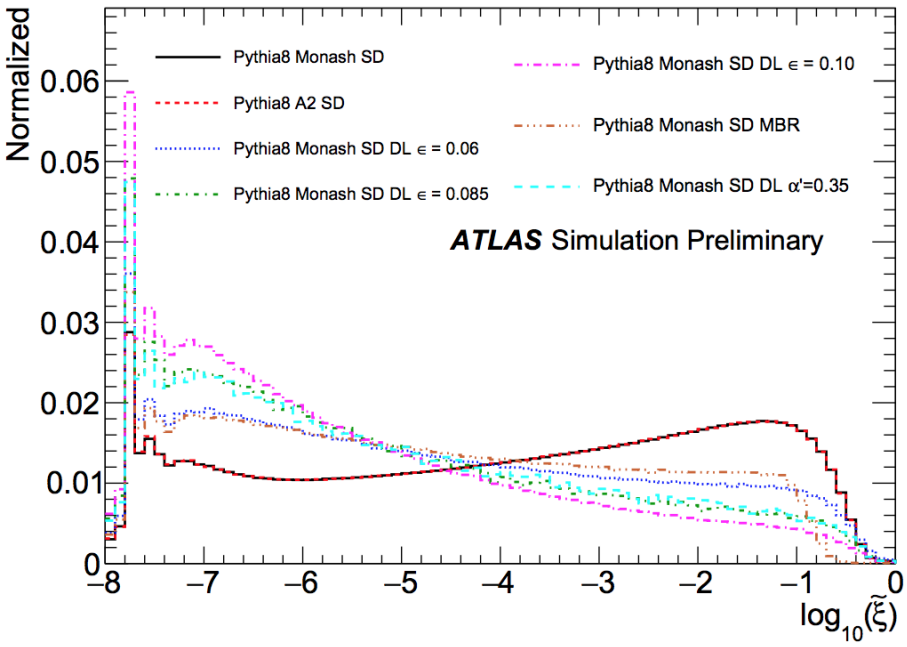


Double-Dissociation (DD)

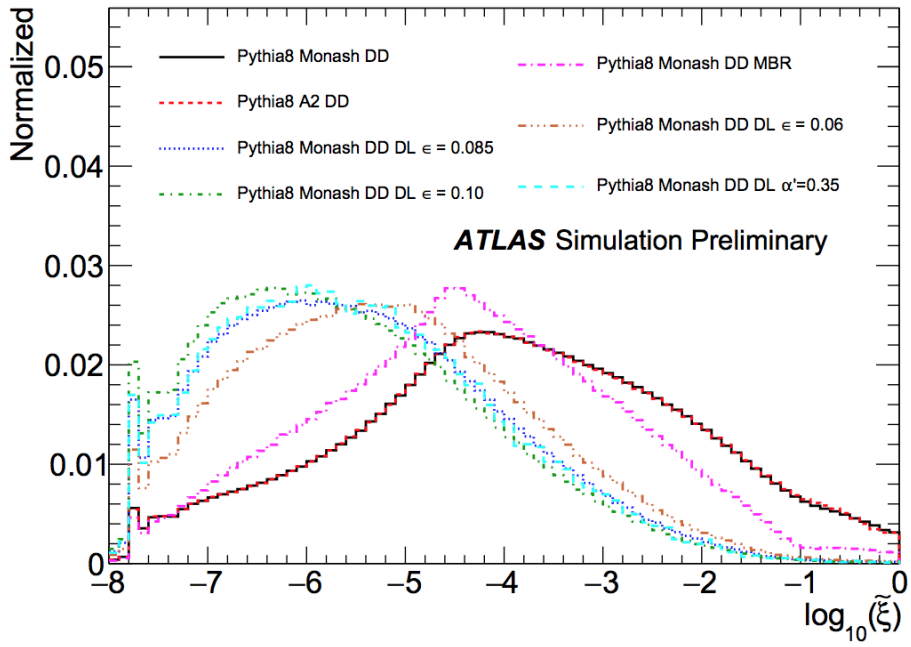
- Non-diffractive is dominant (70 $\sim$ 80%).
- Details of diffractive events drive theoretical uncertainties.
- Measurement sensitive to the proportions of these processes.

MBTS: Inelastic Interactions MC Modeling

Single-Dissociation



Double-Dissociation



- The various MC models considered agree fairly well on the sum of the ND, SD, and DD contributions.
- However, they disagree strongly on how these contributions are distributed.

MBTS: Data

- Using $\int \mathcal{L} = 63 \mu b^{-1}$ of data with ~ 0.003 peak interactions per bunch-crossing.
- Pileup is negligible, no need to correct for overlapping interactions.
- Recorded events have at least 1 hit in the MBTS.
- No full-fledged van der Meer scans available at the time: $\Delta\mathcal{L} \simeq 9\%$.
- The luminosity uncertainty completely dominates the uncertainty on this measurement.

MBTS: Measurement Strategy

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

N = Number of events with $n_{\mathrm{mbts}} \geq 2$

N_{BG} = Background estimated with unpaired bunches

ϵ_{trig} = trigger efficiency, measured in data wrt offline selection.

$\mathcal{L}$ = integrated luminosity, calibrated with vdM scan data.

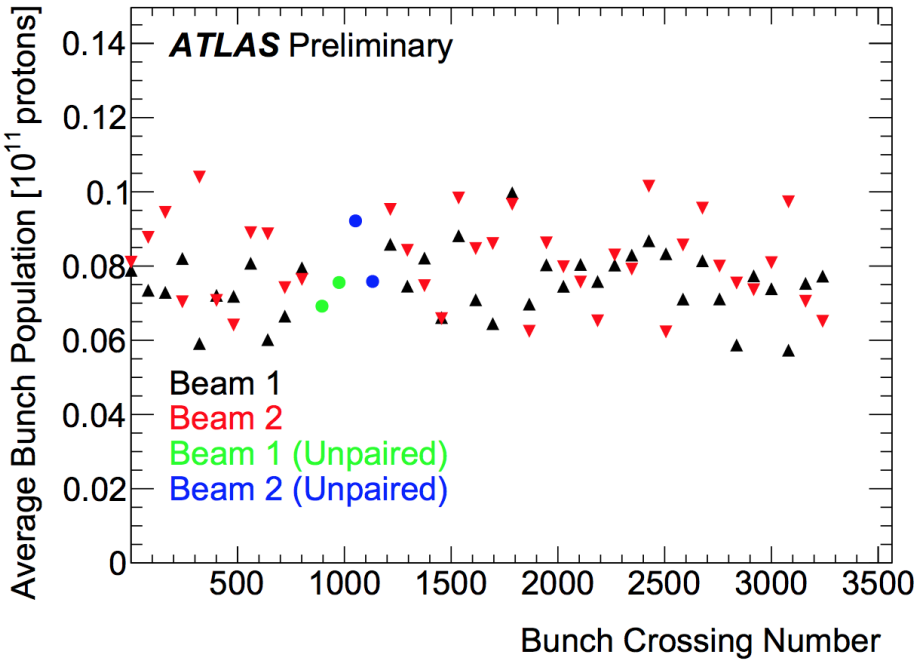
ϵ_{sel} = offline selection efficiency for events with $\tilde{\xi} > 10^{-6}$, from MC.

$f_{\tilde{\xi}<10^{-6}}$ = Migration from outside fiducial region, from MC.

Fiducial region definition gives: $C_{MC} \equiv \frac{1-f_{\tilde{\xi}<10^{-6}}}{\epsilon_{\mathrm{sel}}} \approx 1$

MBTS: Background and Trigger Efficiency

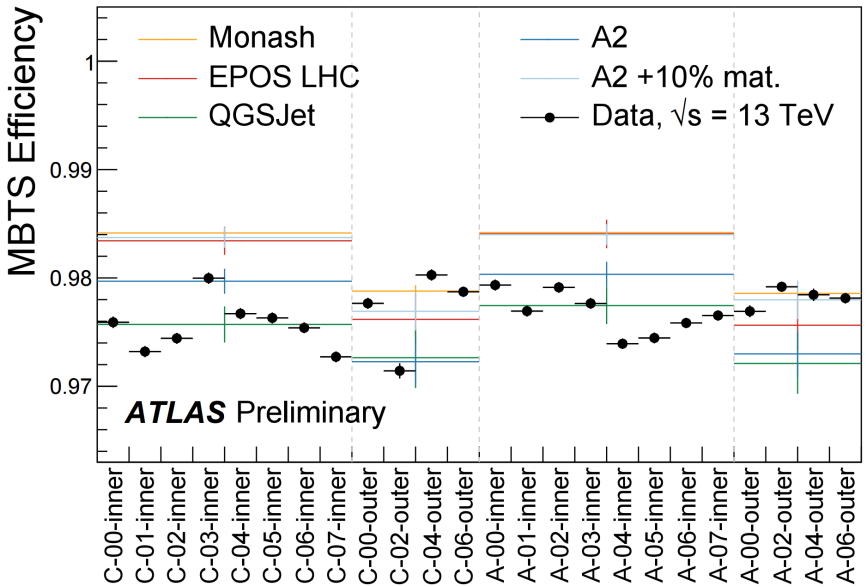
- **Background Estimation**
  - Trigger on bunches passing through ATLAS without colliding (unpaired).
  - Compatible with mostly beam-gas interactions.
  - $\sim$ 1% of the inclusive sample.
  - Estimate 100% uncertainty interchanging possible background sources.

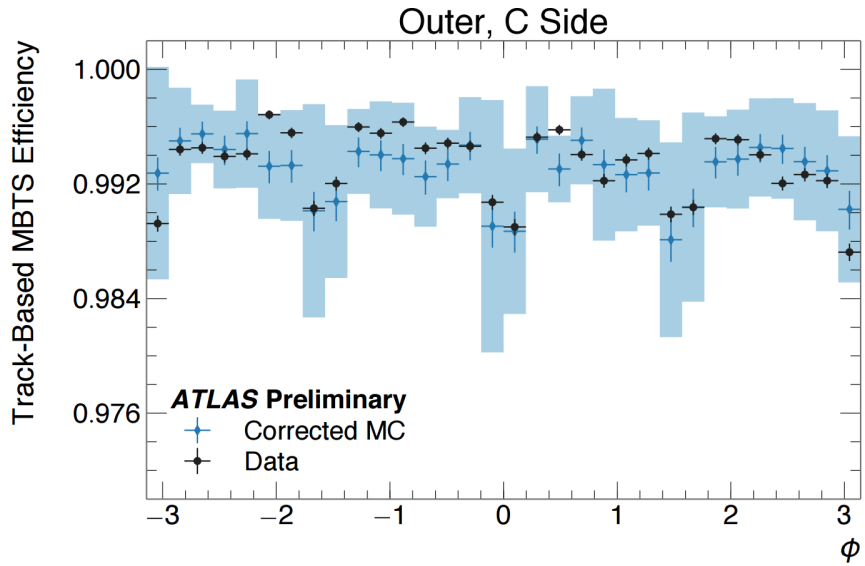


- **Trigger Efficiency**
  - Estimated w.r.t. triggers from LUCID and LHCf, two highly efficient forward detectors.
  - LUCID measures luminosity at ATLAS.
  - Efficiency of 99.7% in the inclusive sample.
  - Statistical uncertainty of 0.1%.

MBTS: Efficiency to Charged Particles, Material

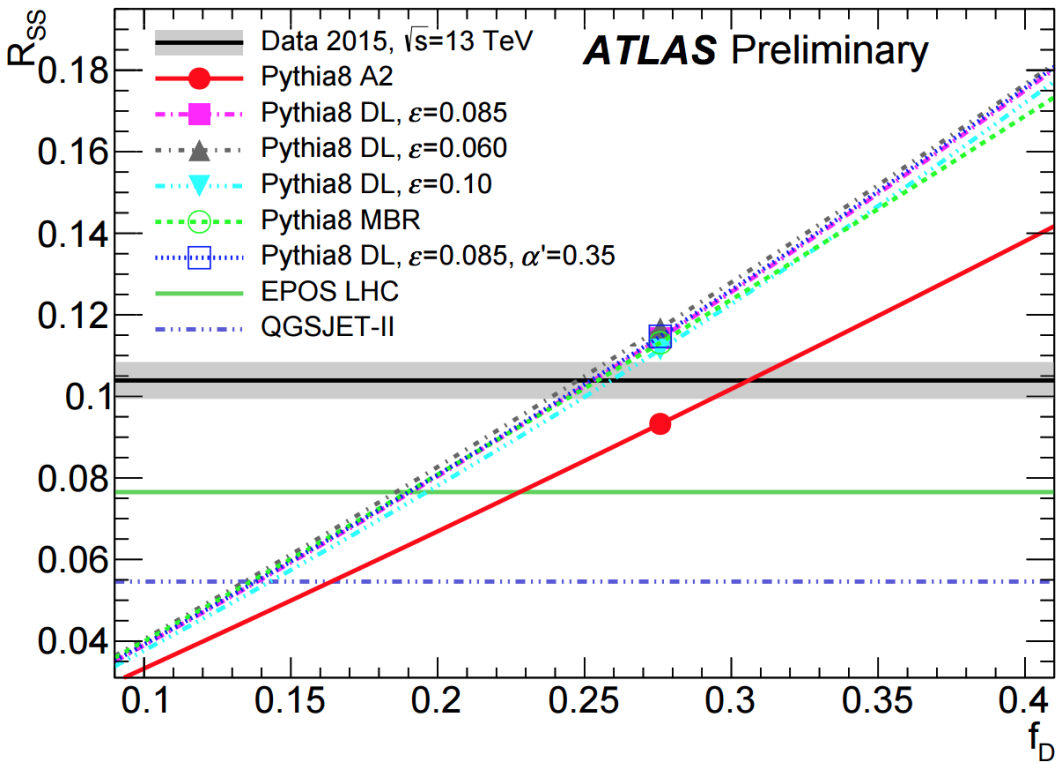
- **MBTS Efficiency**
  - Track-based: tracks reconstructed in $|\eta| < 2.5$, covers outer modules.
  - Calo-based: energy deposits reconstructed in full MBTS acceptance, but detect neutrals.
  - Neutrals can convert and yield a signal in the MBTS: test material model in front of MBTS.
  - The MC simulation is corrected to the efficiency measured in data.
  - Effect of variations in efficiency and material negligible.





MBTS: Constraining the Fraction of Diffractive Events

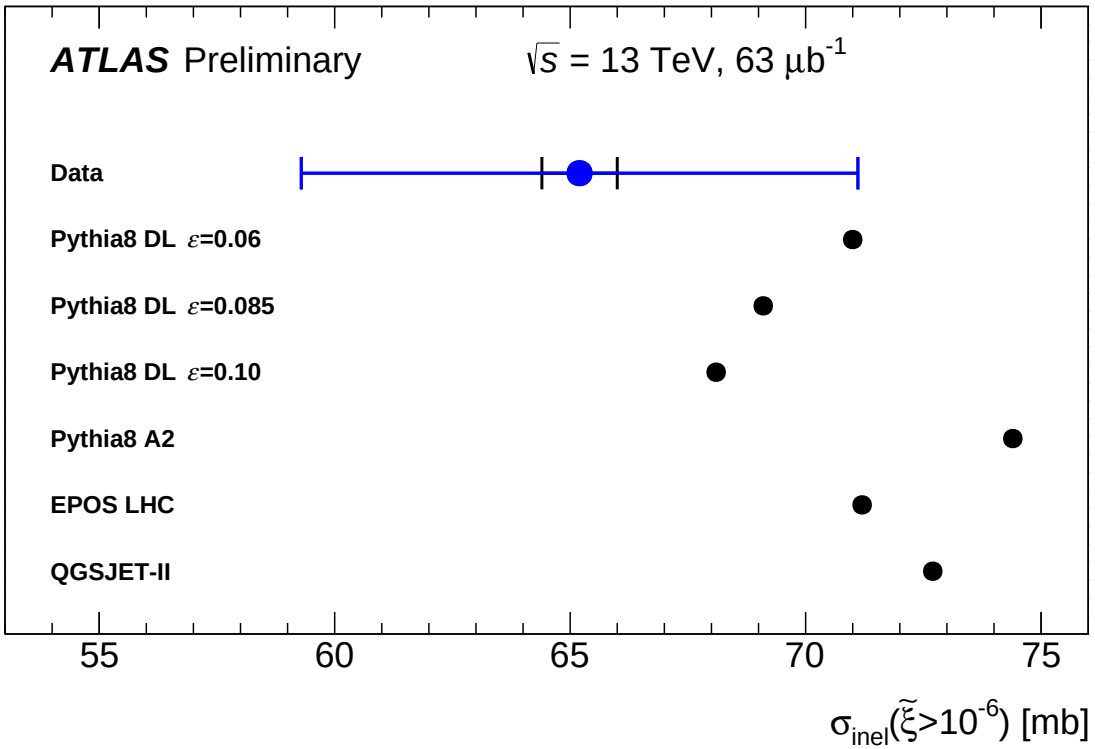
- **Constraining f_D**
  - The ratio of single-sided events to inclusive events R_{SS} can be measured to constrain $f_D = \frac{\sigma_{SD}+\sigma_{DD}}{\sigma_{pp}^{\text{inel}}}$
  - R_{SS} is measured to be $10.4 \pm 0.5\%$.
  - f_D is adjusted in each model to match the measurement in data (except EPOS LHC & QGSJet).



MBTS: Result in Fiducial Region

- The smaller error bar indicates the uncertainty without $\mathcal{L}$ uncertainty.
- $\mathcal{L}$ uncertainty will go from 9% to $< 3\%$ with proper calibration (based on Run I experience).
- The measurement is smaller, but compatible with Pythia 8 Donnachie-Landshoff models.

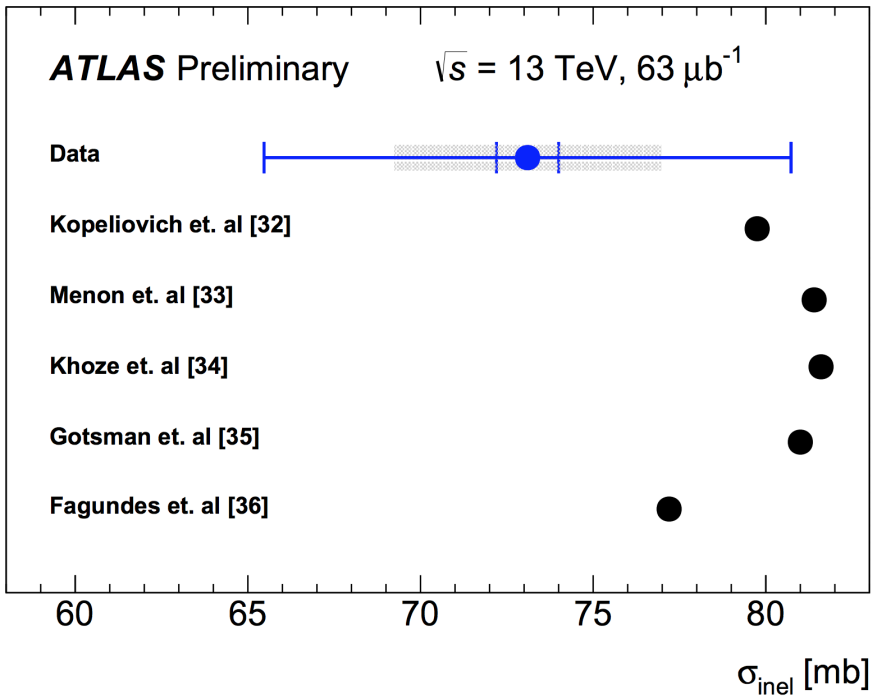
Factor	Value	Rel. unc.
Number of selected events (N)	4159074	–
Number of background events (N_{BG})	43512	±100 %
Luminosity [$\mu\mathrm{b}^{-1}$] (L)	62.9	±9 %
Trigger efficiency (ϵ_{trig})	99.7%	±0.1 %
MC Correction factor ($(1 - f_{\tilde{\xi}<10^{-6}})/\epsilon_{\mathrm{sel}}$)	0.993	±0.5 %



MBTS: Extrapolation to Total $\sigma_{pp}^{\text{text inel}}$

- Extrapolation factor obtained from MC (Pythia 8 D-L $\epsilon = 0.085$, as in the 7 TeV measurement).
- The uncertainty is taken as the envelope of the extrapolation factors from the different models.
- Compatible with different theoretical models.
- Luminosity and extrapolation from fiducial region dominate the uncertainty.
- Recent vdM scan luminosity calibration will be used to reduce the former.

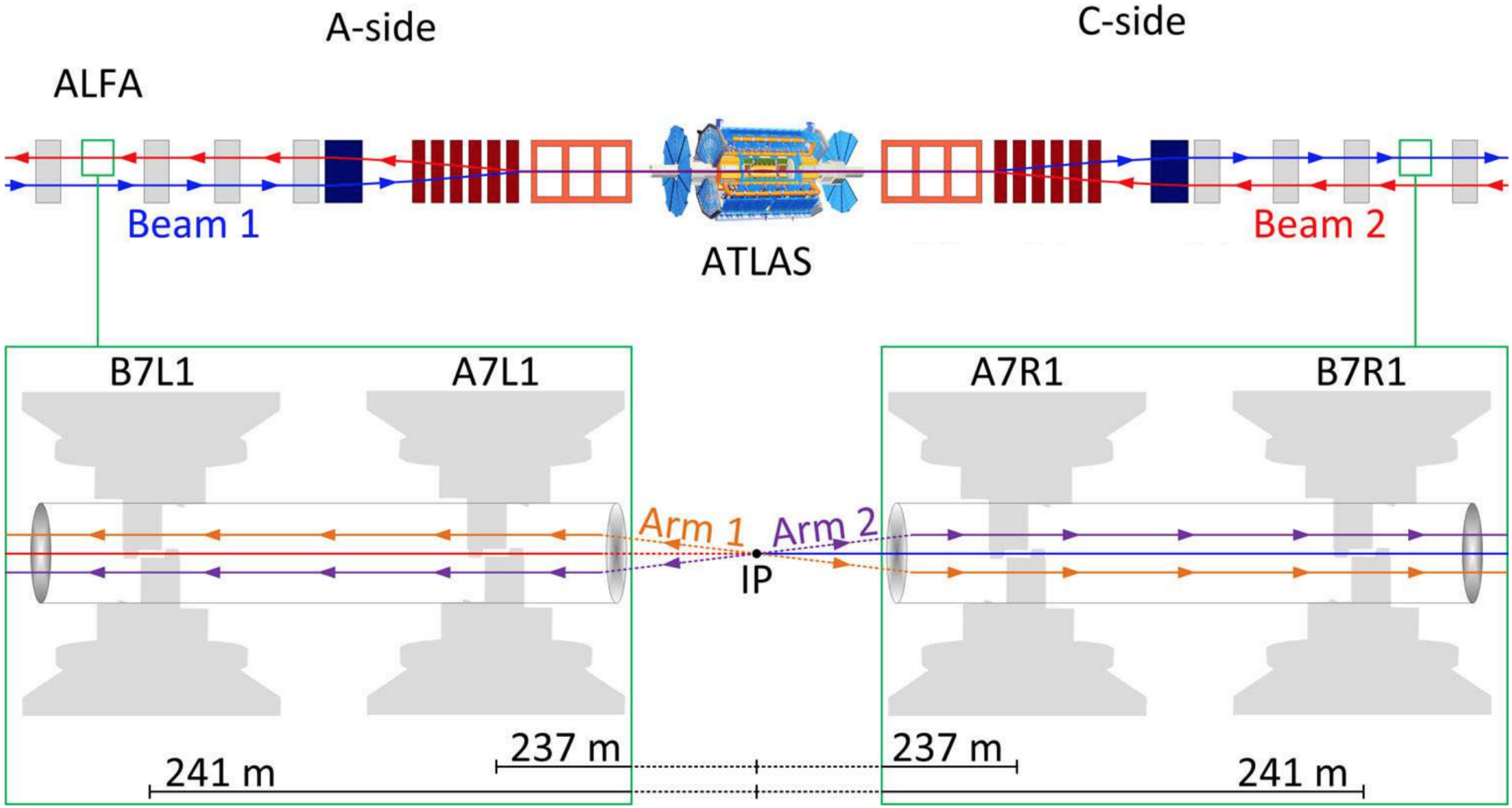
Source	Value
This measurement	73.1 ± 0.9 (exp.) ± 6.6 (lum.) ± 3.8 (extr.) mb
Pythia8	78.4 mb
Kopeliovich et al. [33]	79.8 mb
Menon et al. [34]	81.4 ± 2.0 mb
Khoze et al. [35]	81.6 mb
Gotsman [36]	81.0 mb
Fagundes [37]	77.2 mb



ALFA 7TeV Measurement

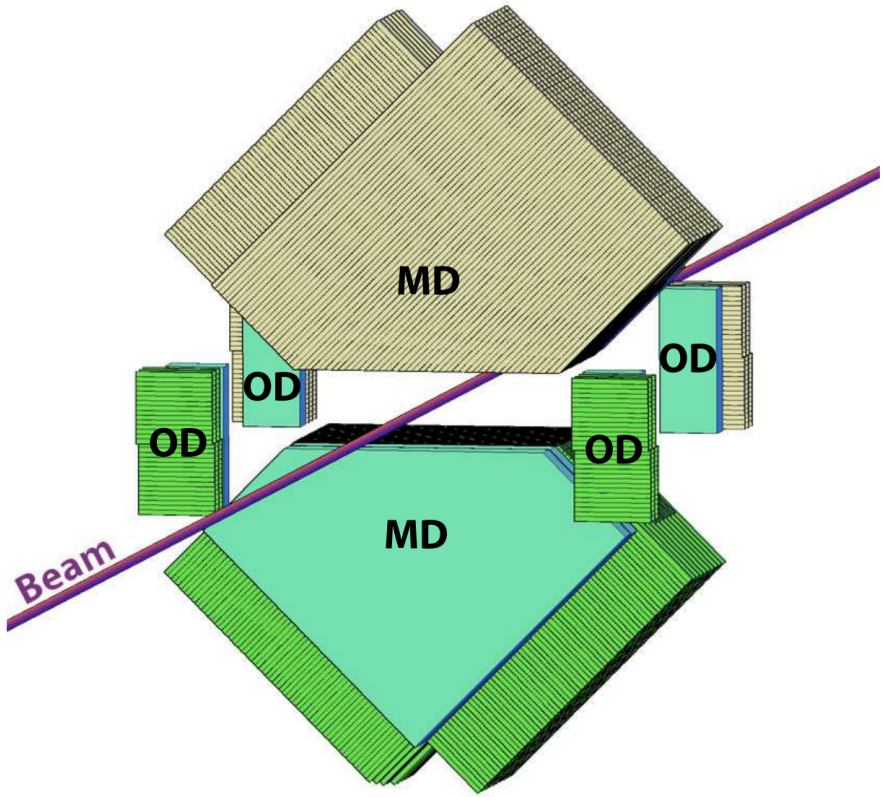
CERN-PH-EP-2014-177

ALFA: Detector



ALFA: Detector

- Small-angle proton scattering: $|\eta| > 8.5$, scattering angles down to 10 μrad.
- Main Detectors (MDs): arrays of scintillating fibers in criss-cross pattern at 45°.
- Overlap Detectors (ODs): allow for precise position calibration of MDs.
- ALFA mechanically moved in closer to the beam.
- One trigger plate in front or behind each MD.

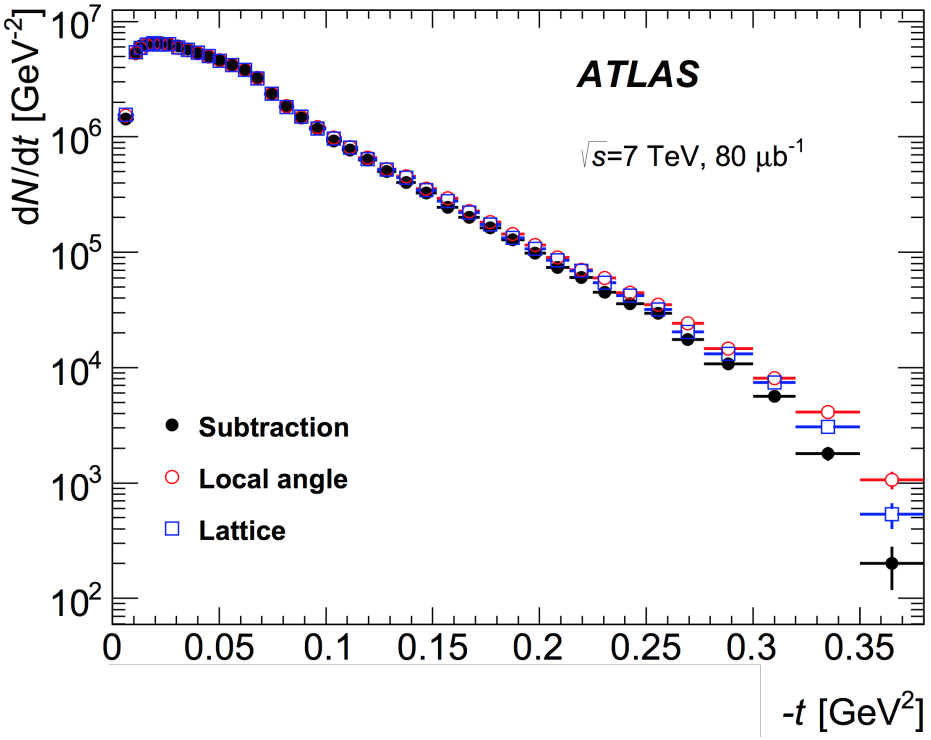


ALFA: Measurement Strategy

- **1)** Measure $\frac{d\sigma_{pp}^{\text{el}}}{dt}$, where $t = -(p\theta^*)^2$
  - p: scattered proton momentum $\simeq$ beam momentum
  - θ^*: scattering angle
- Made easier with parallel-to-point focusing:
  - $\beta^* = 90$ m, phase advance of 90° at ALFA position
  - particles emitted at the same angle at IP = same position in y at ALFA
- **2)** Calculate acceptance vs. t in simulation, used to unfold total $\frac{d\sigma_{pp}^{\text{el}}}{dt}$
- **3)** Fit $\frac{d\sigma_{pp}^{\text{el}}}{dt}$ while floating σ_{pp}^{tot} and B (nuclear slope parameter)
- **4)** Obtain σ_{pp}^{el} and $\sigma_{pp}^{\text{inel}}$ from fit result.

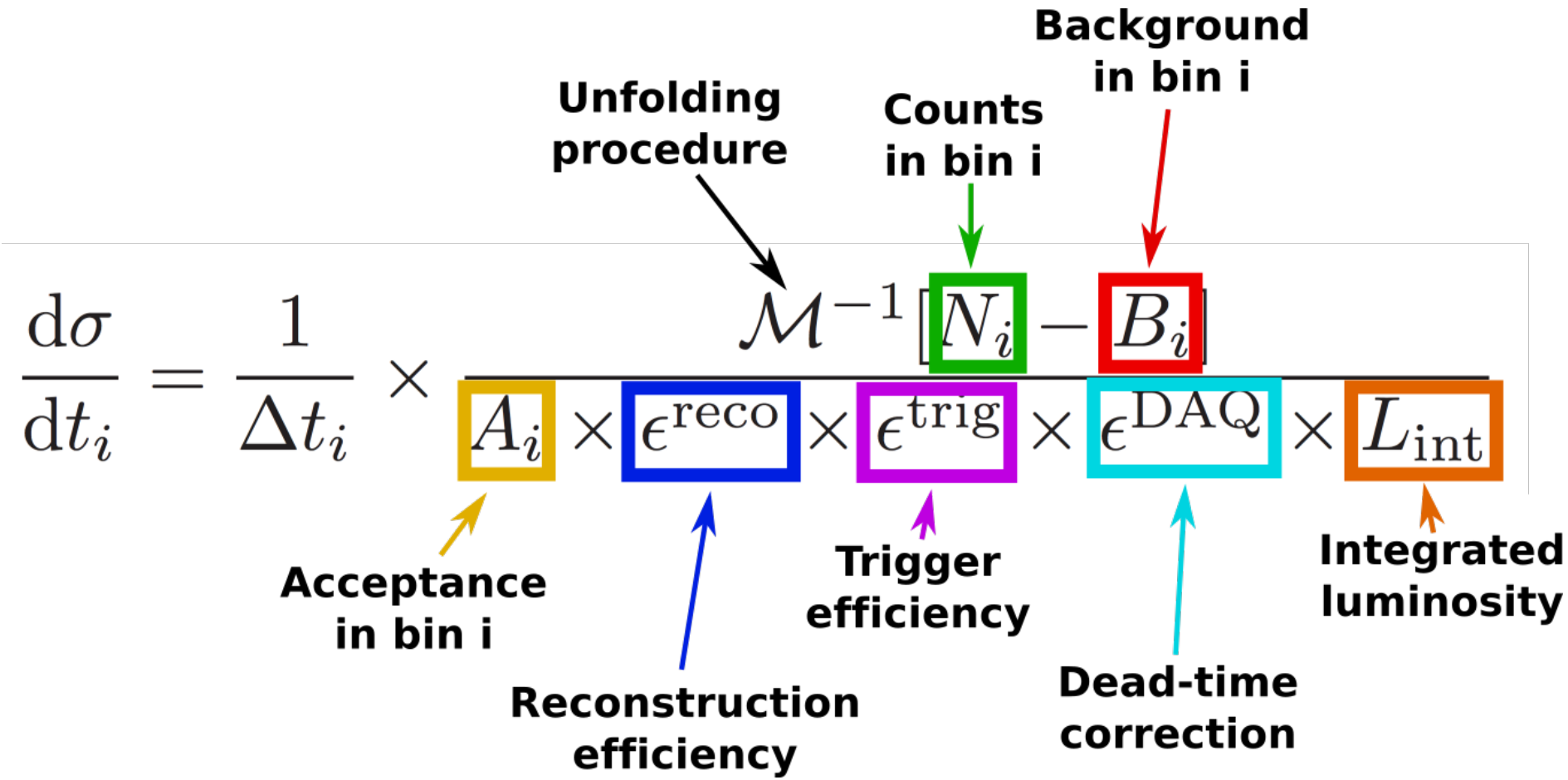
ALFA: Measurement

- 4 different methods to measure counting rates.
- **Subtraction** method is the **nominal**.
- $\beta^* = 90$m beam optics crucial for t precision.
- Various cuts:
  - Trigger selection
  - Data quality
  - Geometrical acceptance (region of full efficiency)
  - Select back-to-back events (hits in the same arm)
  - Event topology and background rejection

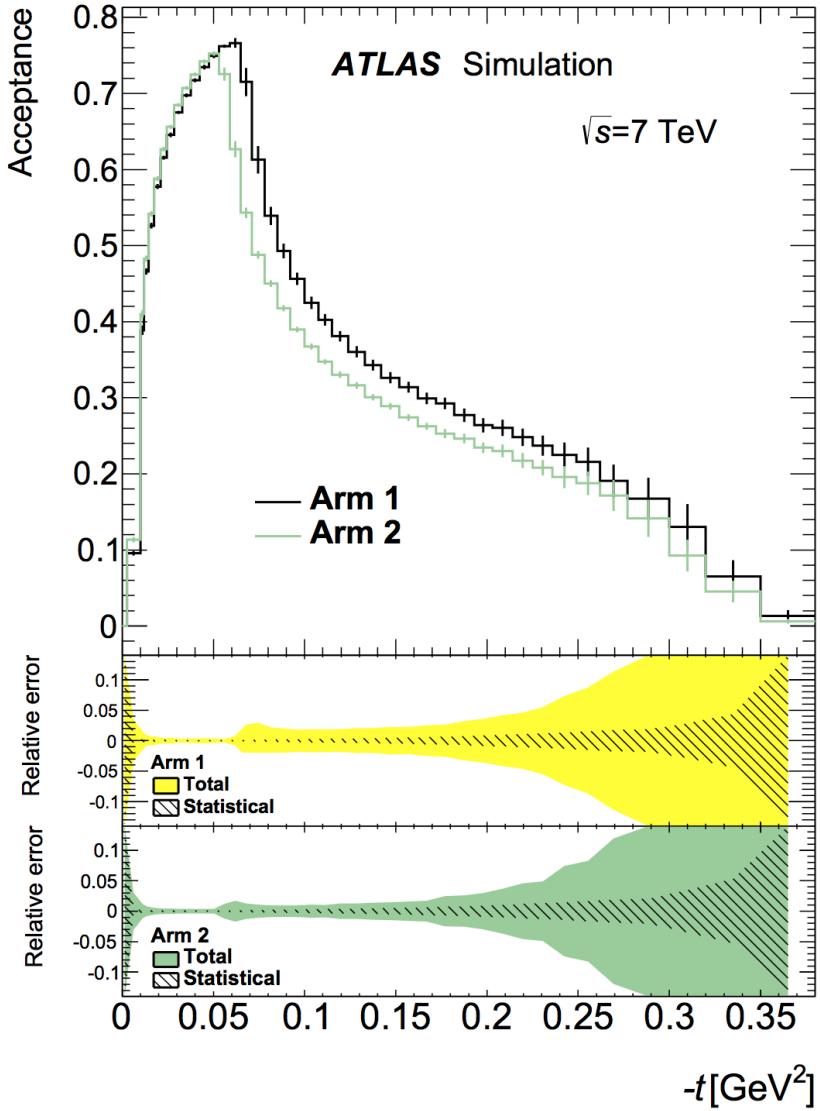


Raw pp elastic event counting rates in arm 1 for 3 different measurement methods.

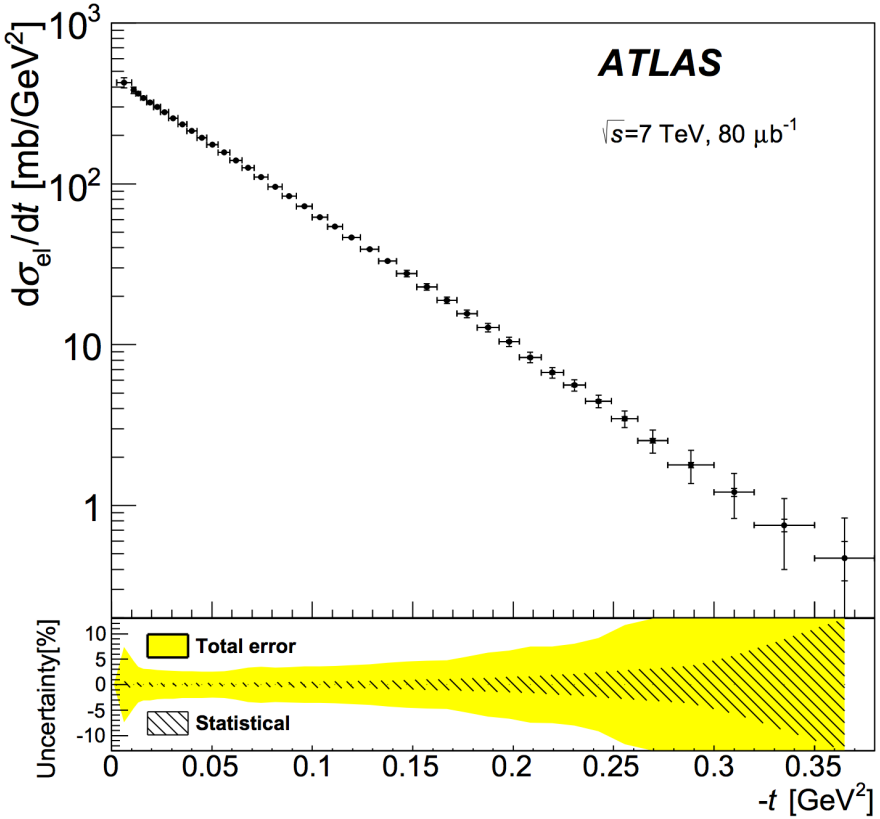
ALFA: Measurement



ALFA: Acceptance & Unfolding

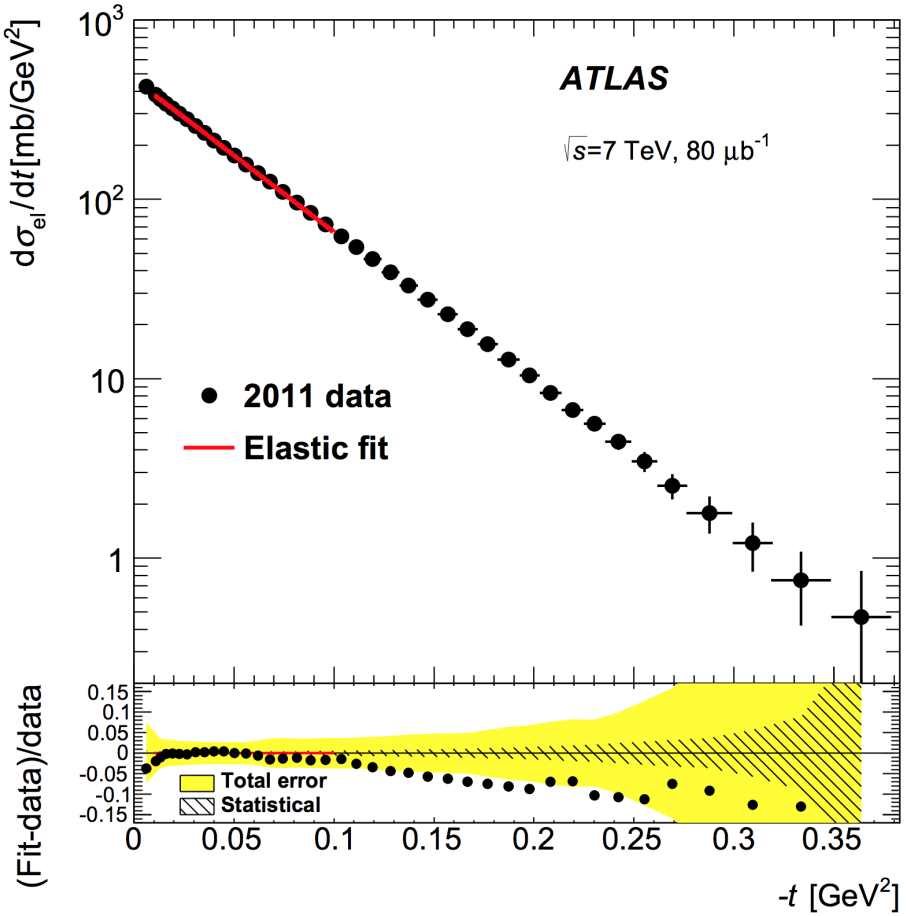


- Simulation used to calculate acceptance unfolding matrix for each arm.
- An unfolding procedure "undoes" bin migration due to resolution effects.



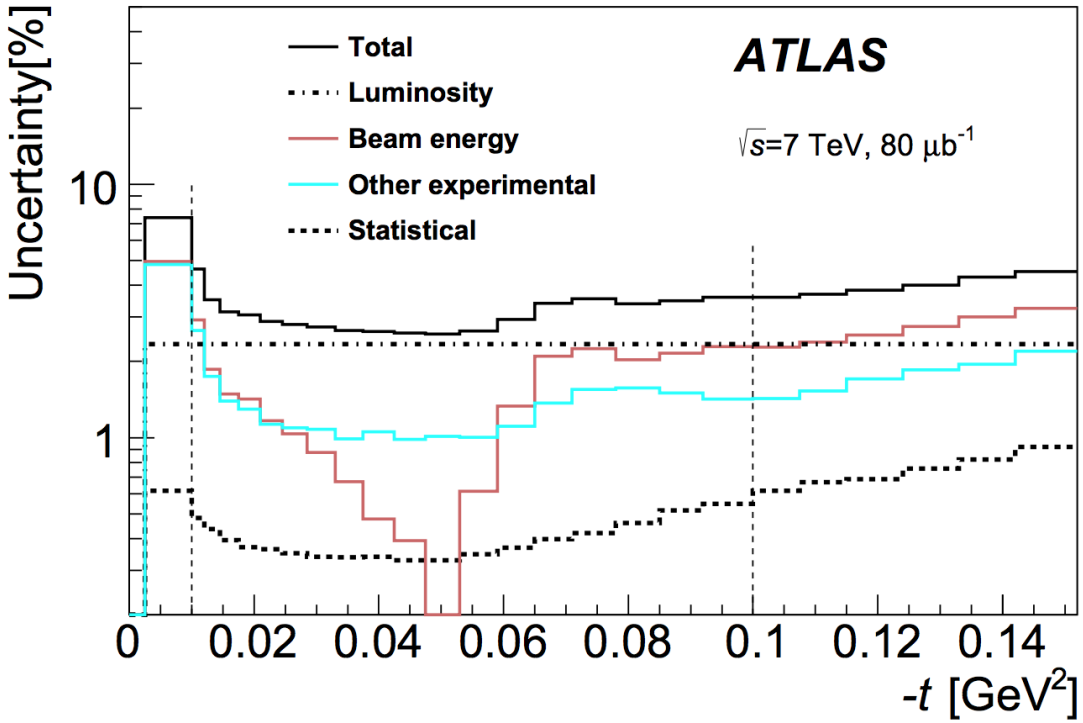
ALFA: Fit to Theory

- Fit theoretical prediction containing:
  - Coulomb term,
  - Coulomb-Nuclear interference term,
  - Dominant nuclear term.
- Fit within range where deviations from exponential behavior are small.
- Fit for σ_{pp}^{tot} and B.



ALFA: Uncertainties

- The fit to theory counts 24 nuisance parameters:
  - Luminosity,
  - Beam energy,
  - Beam optics,
  - Reconstruction efficiency,
  - Acceptance & unfolding corrections,
  - ...
- The dominant uncertainty is on the integrated luminosity at 2.3%.



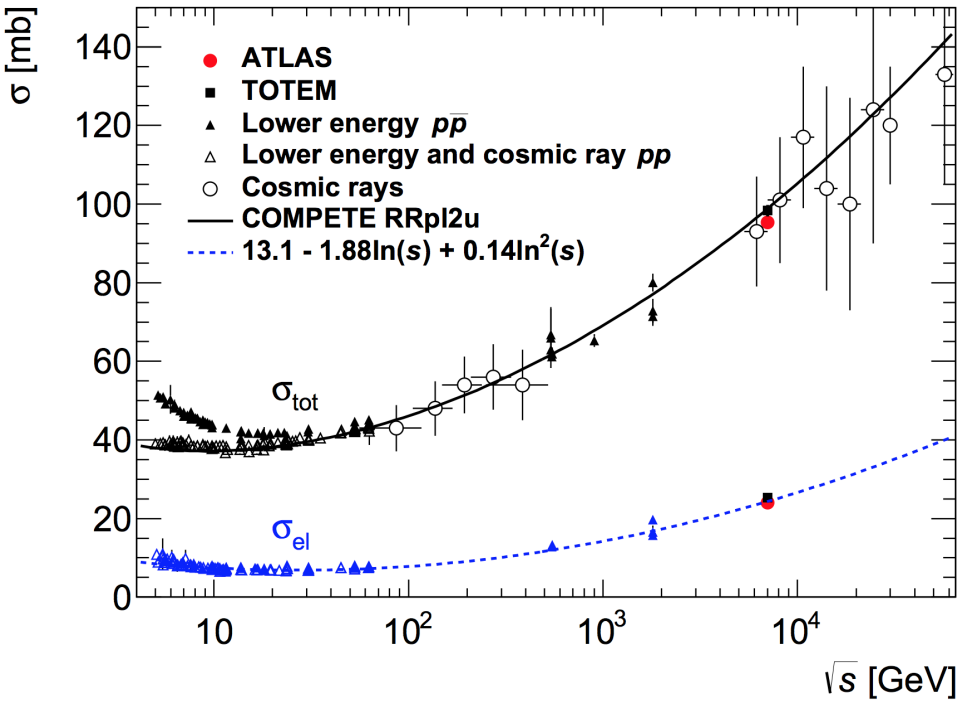
ALFA: Results

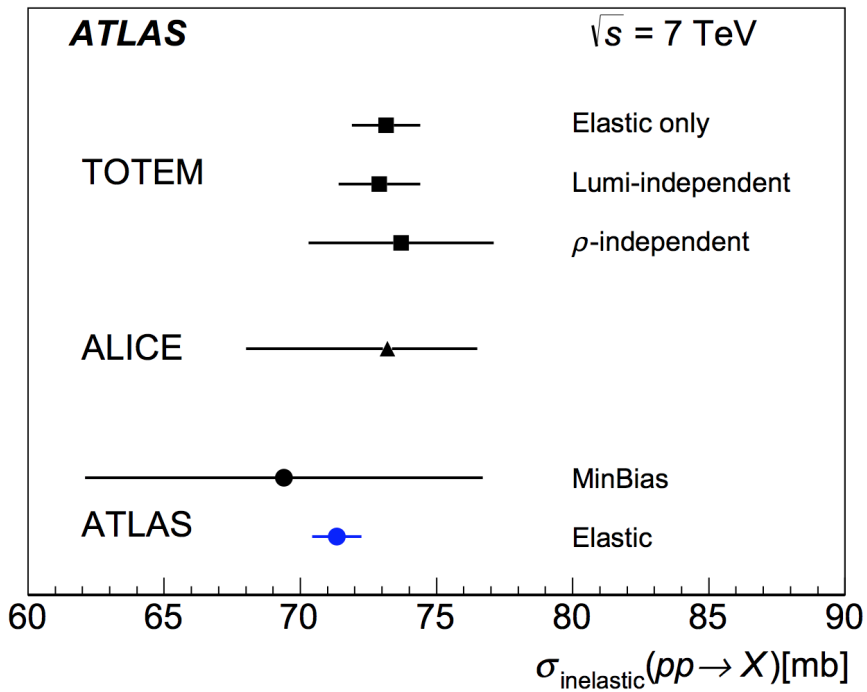
$$B = 19.73 \pm 0.24 \text{ GeV}^{-2}$$

$$\sigma_{pp}^{\text{tot}} = 95.35 \pm 1.20 \text{ mb}$$

$$\sigma_{pp}^{\text{el}} = 24.00 \pm 0.19 \text{ (stat.)} \pm 0.57 \text{ (syst.)} \text{ mb}$$

$$\sigma_{pp}^{\text{inel}} = 71.34 \pm 0.36 \text{ (stat.)} \pm 0.83 \text{ (syst.)} \text{ mb}$$





Summary & Outlook

- MBTS has first pp_{inel} cross-section measurement at 13 TeV.
- The measurement will be repeated with new data collected last week, with luminosity fully calibrated with recent vdM scan.

- ALFA has the most precise pp_{el} cross-section measurement at 7 TeV.
- ALFA is finishing their 8 TeV analysis.
- Data-taking is planned this Fall for a 13 TeV measurement.

Backup