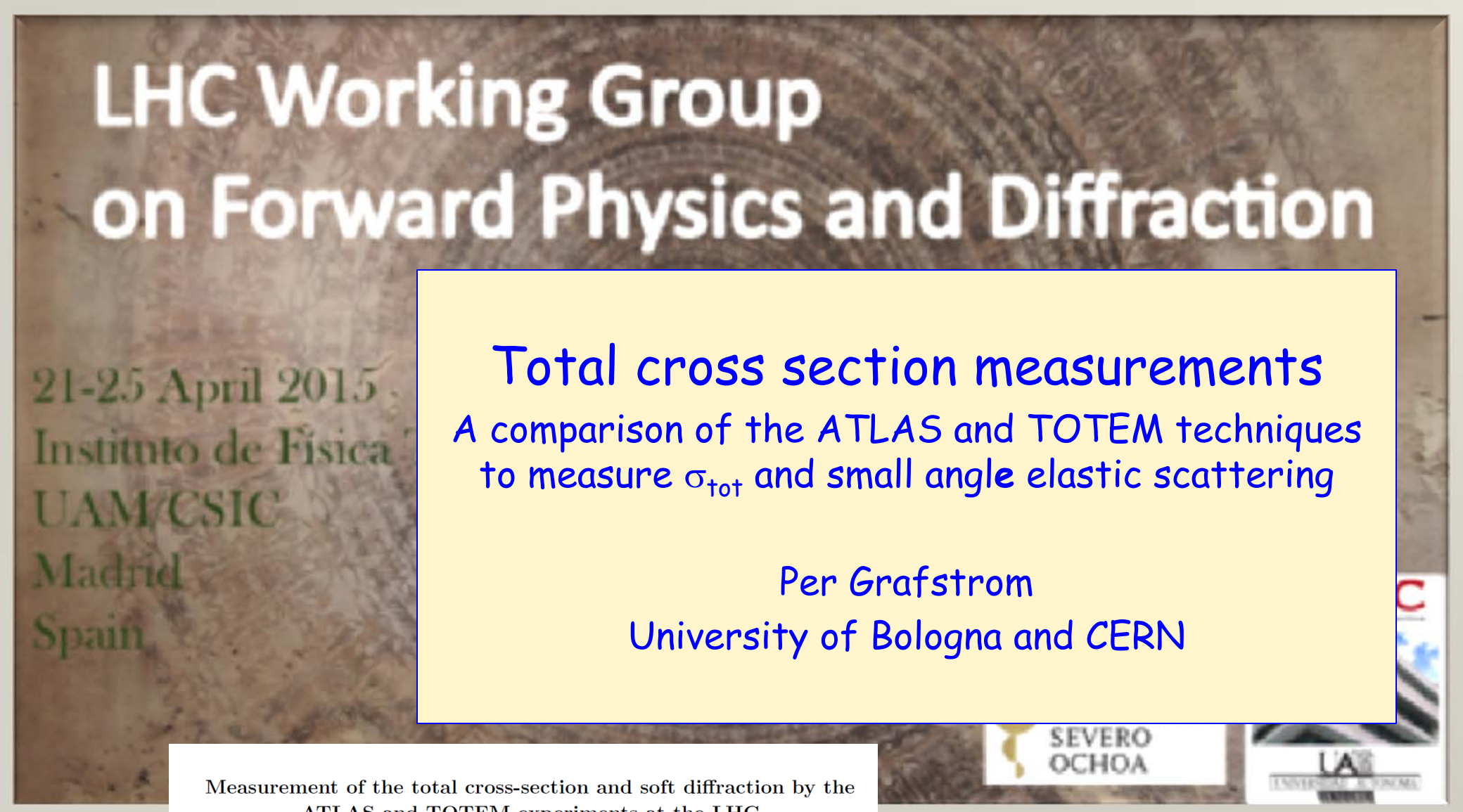

Total cross section measurements

A comparison of the ATLAS and TOTEM techniques to measure σ_{tot} and small angle elastic scattering

Per Grafstrom
University of Bologna and CERN

Measurement of the total cross-section and soft diffraction by the ATLAS and TOTEM experiments at the LHC

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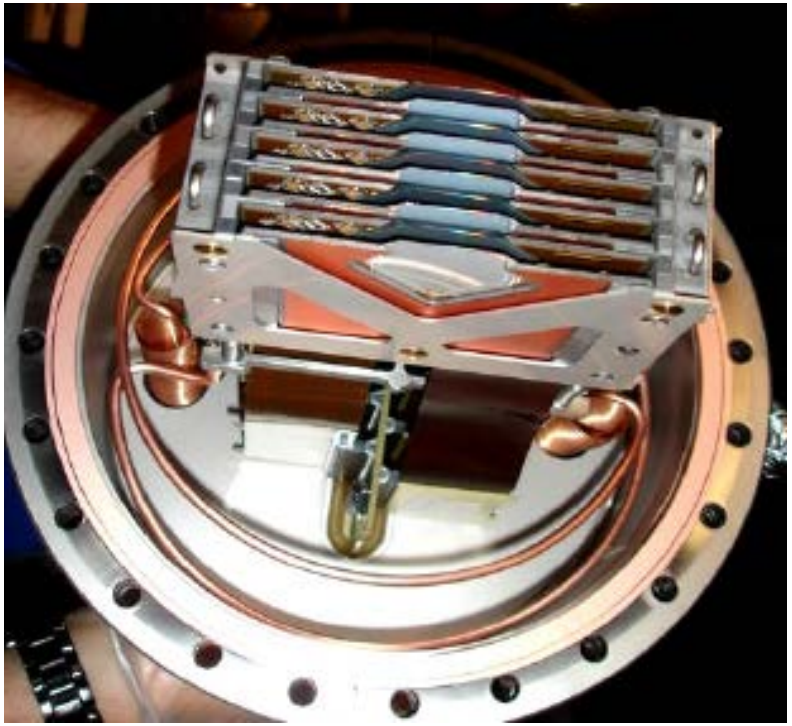
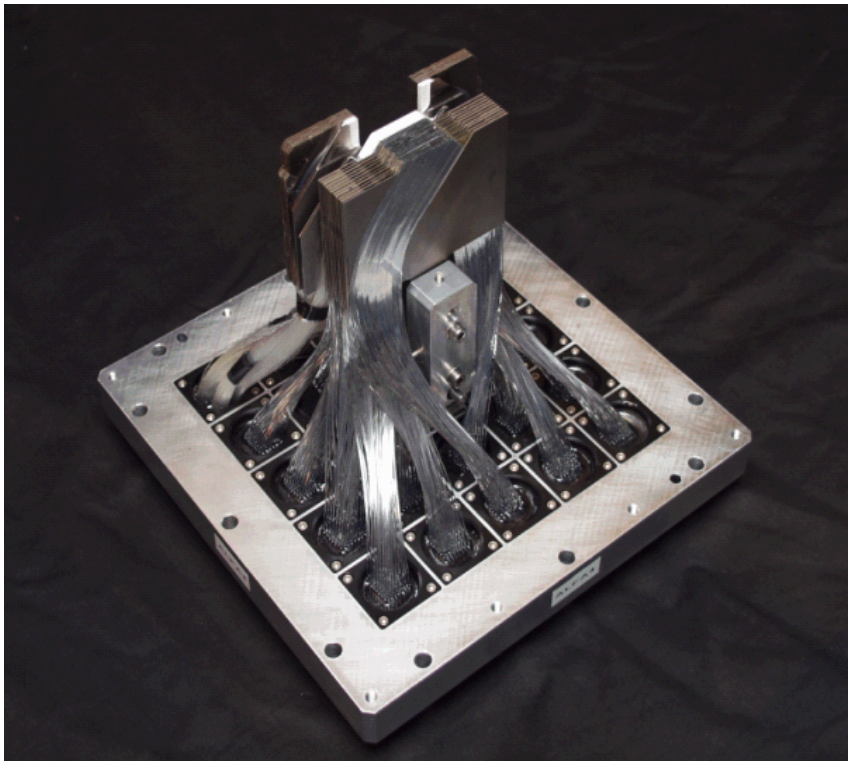
Detectors

TOTEM



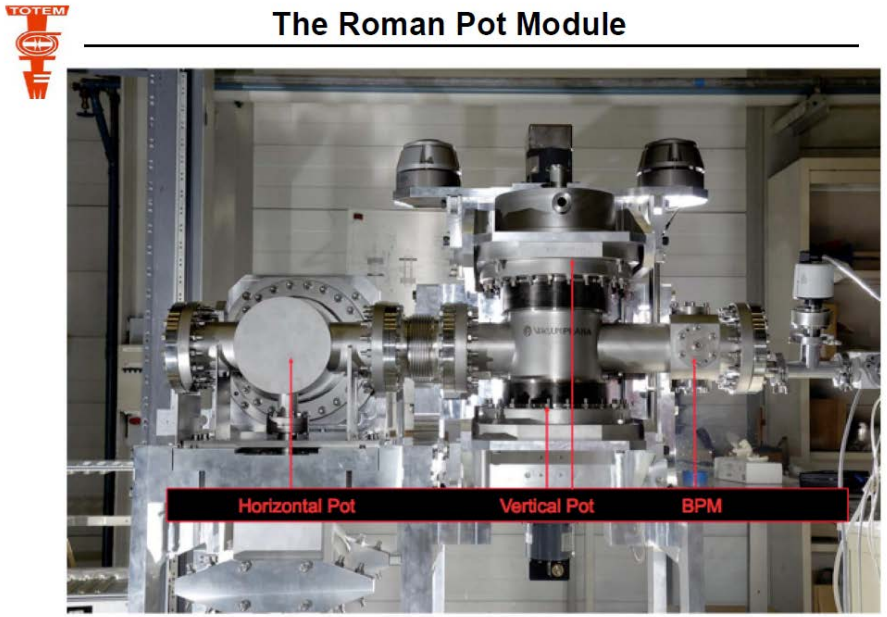
Planar silicon detectors
Stack of 10
Insensitive region < 60-70μm
Space resolution 11μm per stack

ATLAS/ALFA



Scintillating fibres
10 staggered planes
Insensitive region < 20-30μm
Space resolution 35 μm

Roman Pots and their position

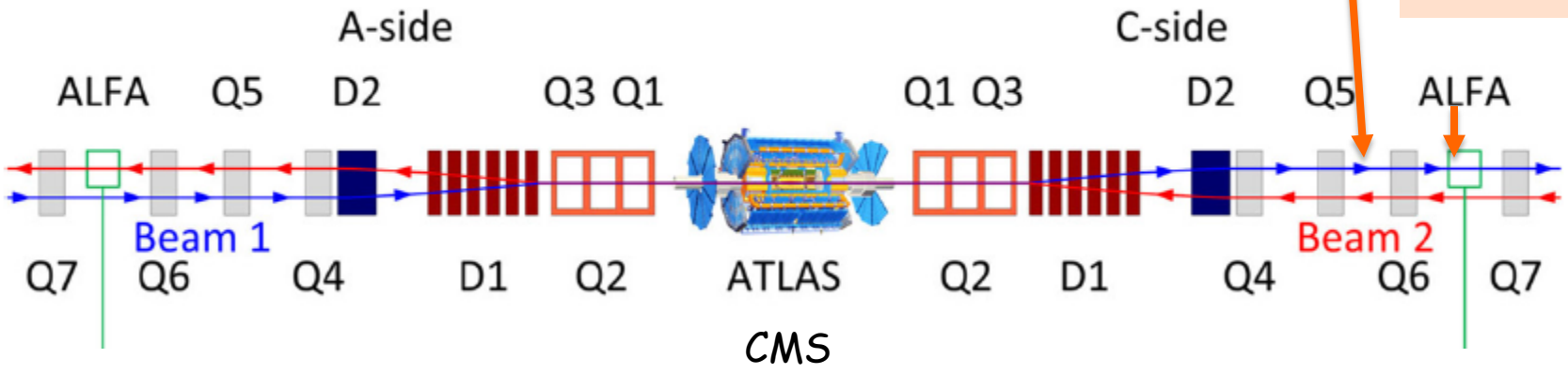


TOTEM

Two units separated by 5 m at 220m

ATLAS

Two units separated by 4 m at 240 m

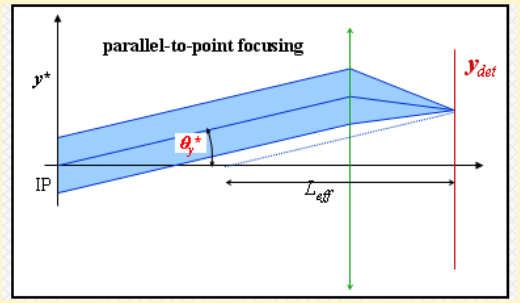


Similarities and differences ATLAS/TOTEM measurements

OPTICS

In general for small angle elastic scattering:

- Divergence smaller than angles to be measured $\Rightarrow \sqrt{\varepsilon}/\beta^*$ small
  $\Rightarrow$ large β^*; ATLAS/TOTEM used β^*=90m
- "parallell to point" in at least one plane
  ATLAS/TOTEM in vertical plane



- Large effective lever arm in at least one plane for good t-resolution.
  $\theta_y = y/L_y^{eff}$ ATLAS/TOTEM vertical plane

However

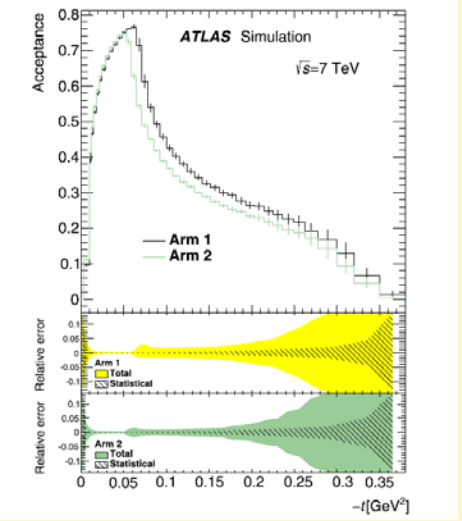
Difference in horizontal lever arm ($\theta_x = x/L_x^{eff}$)

TOTEM ~ 0 m for clean separation of diffractives
ATLAS ~ 10 m
$\Rightarrow$ Different methods for t-reconstruction

Similarities and differences ATLAS/TOTEM measurements

Conditions for data taking and triggering

- 1-2 bunches with 7x 10^{10} protons; some few low intensity bunches; one non- colliding bunch
- Luminosity typically 5 x 10^{27}-10^{28}/cm^{2}s
- Detectors roughly 5 mm from the beam
- Basically the same acceptance
- t - range 5x10^{-3} $\rightarrow$ 0.4 GeV^2
- Triggers based upon back-to-back topology with >99 % eff.



ATLAS trigger scintillators covering the detector

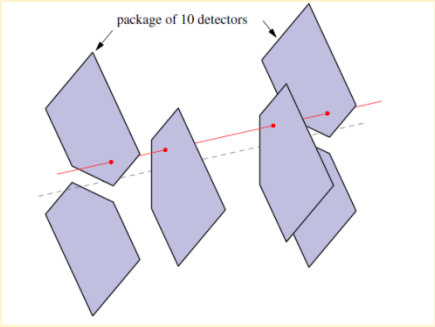
TOTEM OR's of 16 strips and loose track roads

Similarities and differences ATLAS/TOTEM measurements

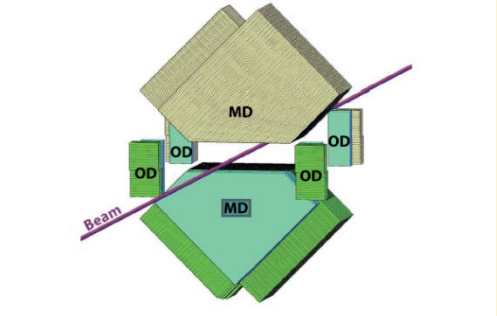
Alignment

1. Pots relative to the beam.
   Define beam with sharp edge. Move in in small step and detect beam interactions with pot-window using Beam Loss Monitor
2. Relative position of each detector using tracks

TOTEM



ATLAS



3. Global alignment on both sides using the symmetry of the kinematics of elastics

Precision:	Horizontal	Vertical
TOTEM	1-2 μm	30 μm
ATLAS	1-2 μm	80 μm

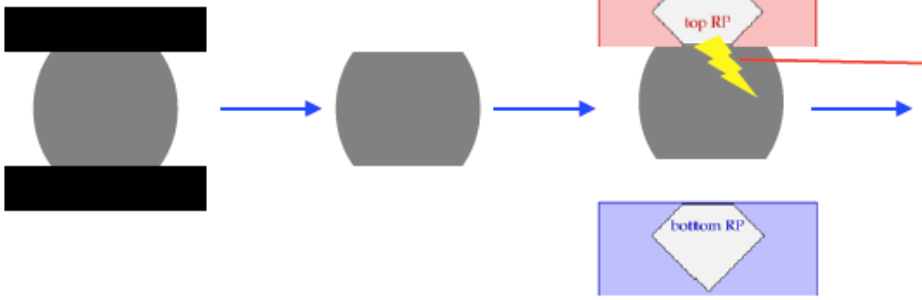
Beam-Based Roman Pot Alignment (Scraping)

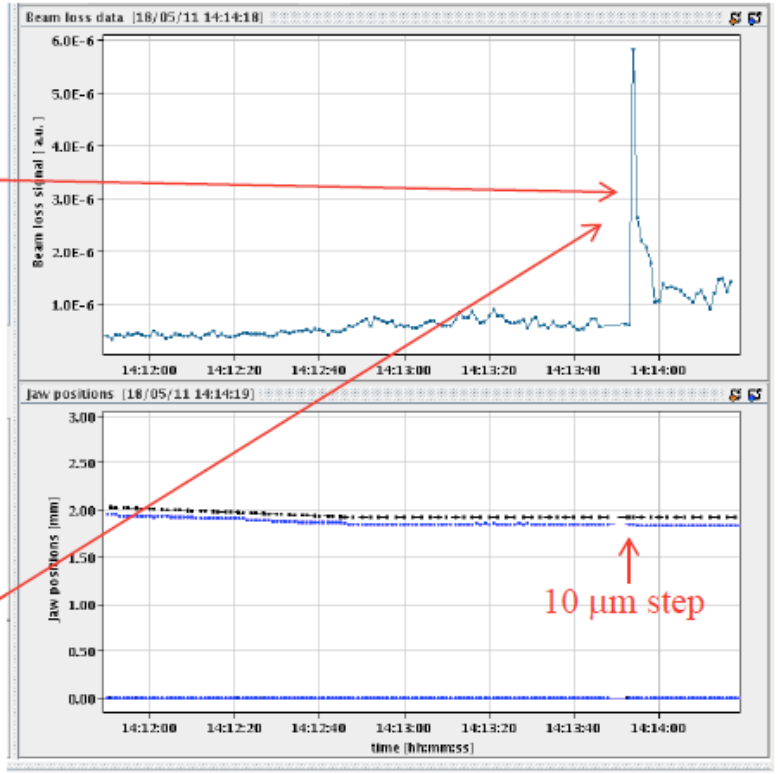
Standard Procedure for LHC Collimators

A primary collimator cuts a sharp edge into the beam, symmetrical to the centre

The top RP approaches the beam until it touches the edge

The last 10 µm step produces a spike in a **Beam Loss Monitor** downstream of the RP





Slide from Mario Deile

Similarities and differences ATLAS/TOTEM measurements

t - reconstruction

Here we have a clear difference ATLAS/TOTEM …a bit tricky to explain…

- Several possibilities to reconstruct t from the measurement at the Roman Pot
- The problem is simplified by the back-to-back topology and identical vertex position for left and right protons.
- Using those simplifications the scattering angle at the IP can be calculated ***either*** from a measurement of the ***position or*** the ***angle*** at the Roman Pot.
- Which method is best depends on factors like resolution and sensitivities to the optics

VERTICAL PLANE

The resolution in the vertical plane is determined by the beam divergence and thus the difference in spatial resolution between TOTEM and ATLAS does not matter

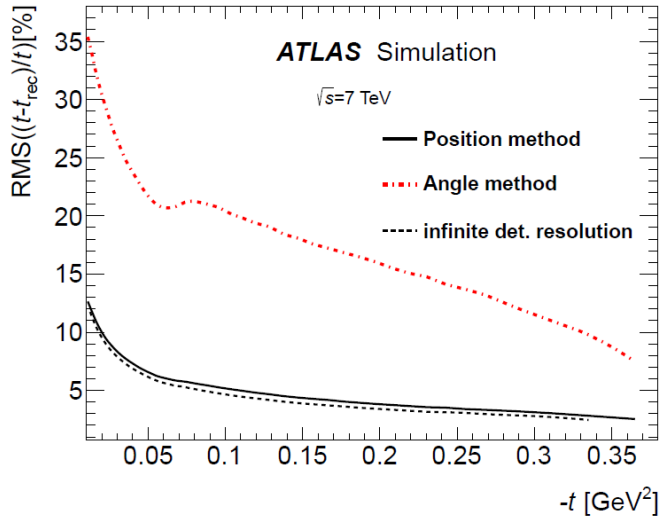
- the calculation of θ_y at the IP is straight forward due to the "parallell to point" optics and the large lever arm.
- Best resolution and smallest sensitivity to optics is obtained by transforming the ***position measurement*** at ***the RP*** to ***an angle at the IP***.
- TOTEM/ATLAS identical

HORIZONTAL PLANE TOTEM

- The effective lever arm small (~ 0 m)
- Thus TOTEM calculates θ_x at the IP using ***the horizontal angle at the RP***
- The θ_x resolution at the IP depends strongly on the angular resolution at the RP
- TOTEM has relative good angular resolution (5-10 μrad) at the RP.

HORIZONTAL PLANE ATLAS

- The effective lever arm ~10 m
- ATLAS has less good angular resolution at the RP
- ATLAS has chosen as default method to determine the angle at the IP from the ***position measurement at the RP*** because of the better resolution in the position measurement.
- Drawback- higher sensitivity to Optics



To overcome this difficulty and better understand the sensitivity to the optics , ATLAS has constrained the optics using the elastics and checked results by using four different methods to reconstruct *t*

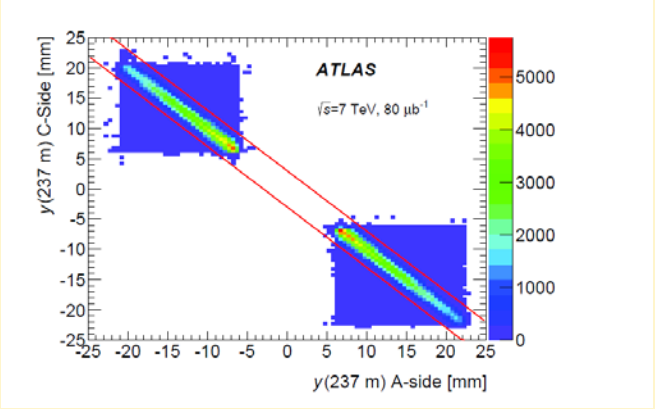
Similarities and differences ATLAS/TOTEM measurements
Event selection and background

Event selection – straight forward

- Back-to-back topology

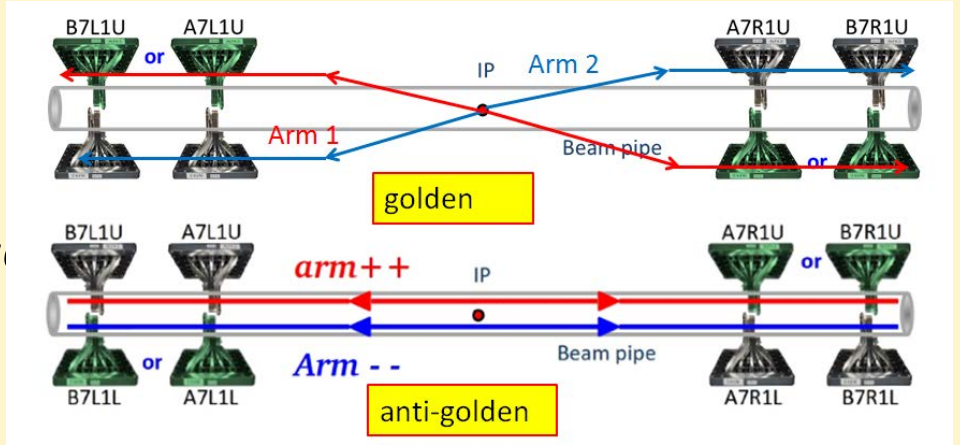
⇒ left-right correlation

- Position-angle correlation on each side independently
- TOTEM also uses horizontal vertex position (L and R)

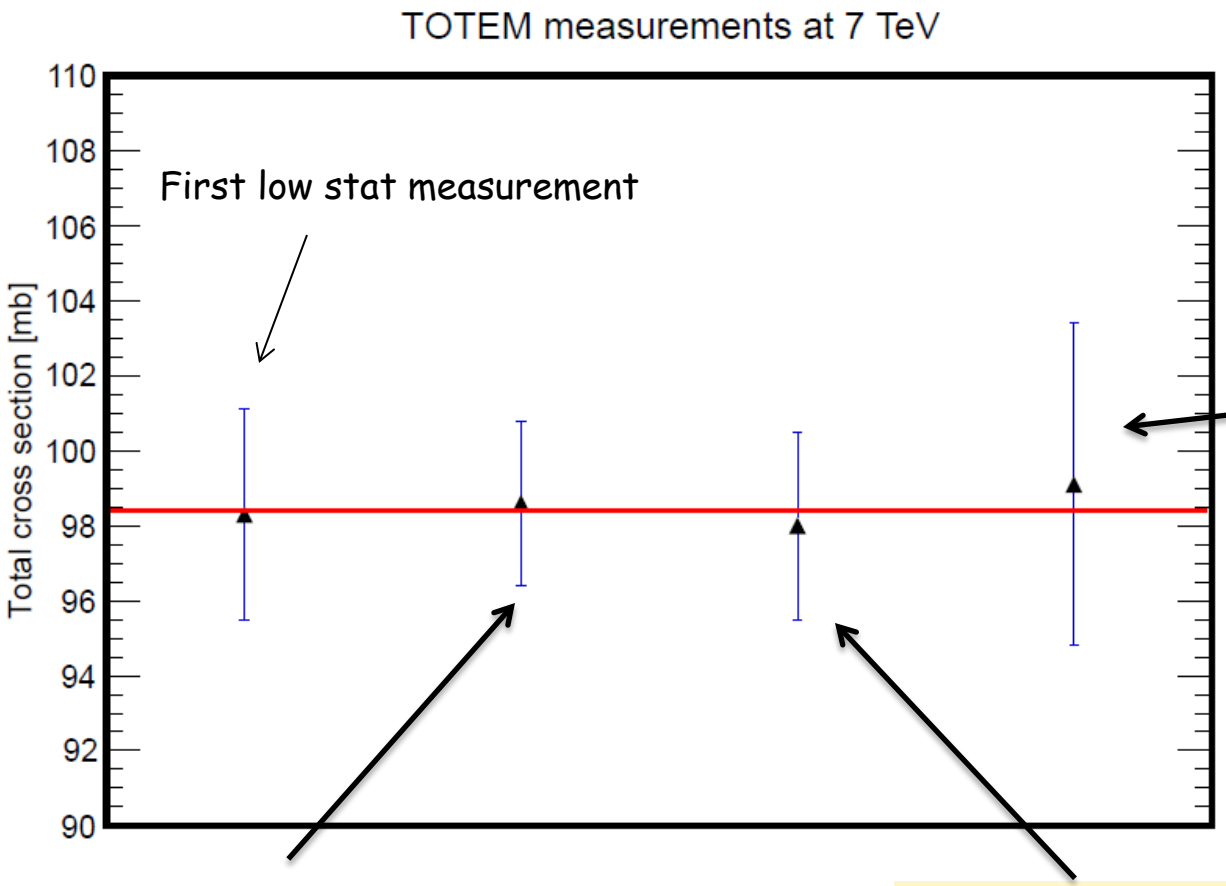


Background – low

- TOTEM uses vertex dist. in X obtains 0.8 % ± 0.4 %
- ATLAS uses topology left upper(lower)-right upper(low obtains 0.4 % ± 0.2 %



The TOTEM results at 7 TeV



P-independent (not using the optical theorem)

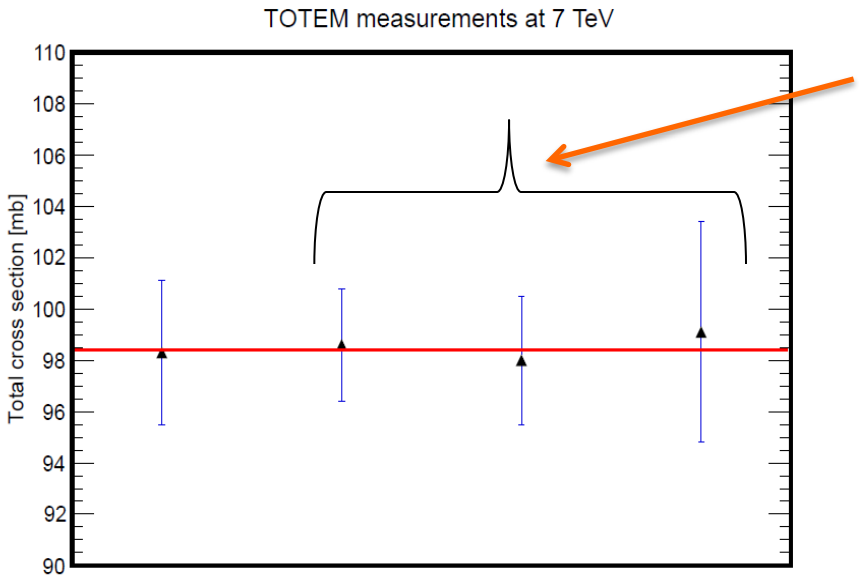
$\sigma_{tot}=\sigma_{el}+\sigma_{inel}= (N_{EL}+N_{INEL})/L$

Luminosity dependent

Luminosity independent

$$\sigma_{\rm tot}^2 = \frac{16\pi}{1+\rho^2}\frac{1}{L}\left(\frac{dN_{\rm el}}{dt}\right)_{t=0}.$$

$$\sigma_{\rm tot} = \frac{16\pi}{1+\rho^2}\frac{(dN_{\rm el}/dt)_{t=0}}{N_{\rm tot}}.$$



The three measurements are obviously correlated

Three independent ingredients are measured

1) Luminosity,

2) The inelastic rate,

3) Differential elastic rate

Each method use at least 2 out of 3 of the ingredients

⇒ Correlations are unavoidable

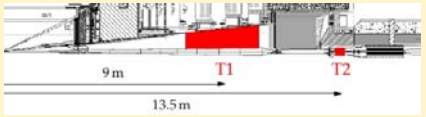
However

- The fact that the three values are very close indicates that the measurements are basically correct
- A significant mistake in one of the three ingredients
  ⇒ two out of the three could agree but not the third
- In order to generate three values of the cross section so close to each other and still being significantly incorrect would require a conspiracy in the miss measurement of all three ingredients

The ATLAS result

ATLAS η-coverage : $-5 < \eta < 5$

(TOTEM covers with T2 : $5.3 < |\eta| < 6.5$
moreover with T1 tracking in : $3.1 < |\eta| < 4.7$)



⇒ Difficult to determine the inelastic rate precisely for ATLAS

⇒ Luminosity-independent and ρ-independent methods give large errors

The ATLAS result with the luminosity-dependent method:

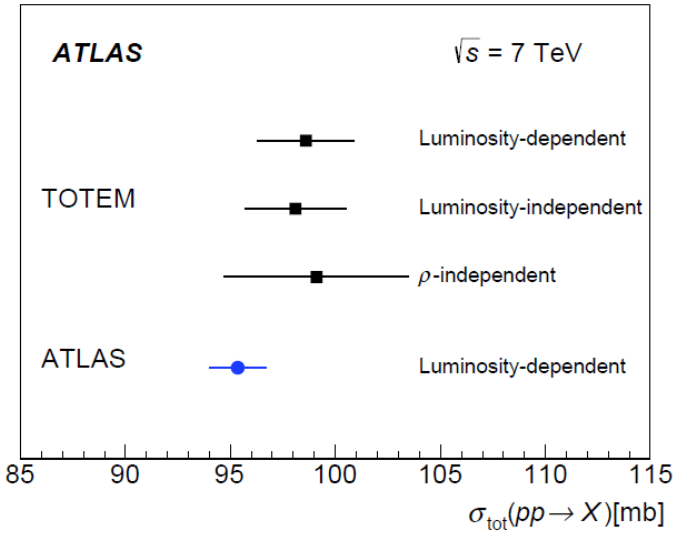
$$\sigma_{\text{tot}} = 95.35 \pm 1.36 \text{ mb}$$

Comparison of the ATLAS/TOTEM results

Luminosity-dependent: ATLAS/TOTEM
1.3 σ difference- basically OK

$\sigma^{TOTEM}_{tot}/\sigma^{ATLAS}_{tot} = 1.03$

$\sigma^{TOTEM}_{el}/\sigma^{ATLAS}_{el} = 1.06$



SPECULATION on possible explanation for the small discrepancy:

σ_{tot} varies as √ with luminosity….. while σ_{el} varies linearly with luminosity ⇒ correction of relative luminosity of the two experiments of 6% would bring both ratios to 1.

Adjusting the TOTEM luminosity up one sigma of the luminosity uncertainty (4%) and the ATLAS luminosity down one sigma (2.3%) would do it!

Observe that after such an adjustment the σ_{tot} from the luminosity-independent measurement would be completely compatible with the other measurements.

Comparison of the uncertainties in the ATLAS/TOTEM results

TOTEM Luminosity-dependent	$\sigma_{\rm tot} = 98.6 \pm 2.2\,{\rm mb}.$	Luminosity error 4 % completely dominant
TOTEM Luminosity-independent	$\sigma_{\rm tot} = 98.0 \pm 2.5\,{\rm mb}.$	Uncertainties from inelastic and elastic rate close to equal
TOTEM P-independent	$\sigma_{\rm tot} = 99.1 \pm 4.3\,{\rm mb}.$	Luminosity error completely dominant
ATLAS Luminosity-dependent	$\sigma_{\rm tot} = 95.35 \pm 1.36\ {\rm mb}.$	Luminosity error 2.3 % dominant

Further comparison of the uncertainties in the ATLAS/TOTEM results

The ATLAS result splits up in three components

$$\sigma_{\rm tot} = 95.35 \pm 1.36 \text{ mb},$$

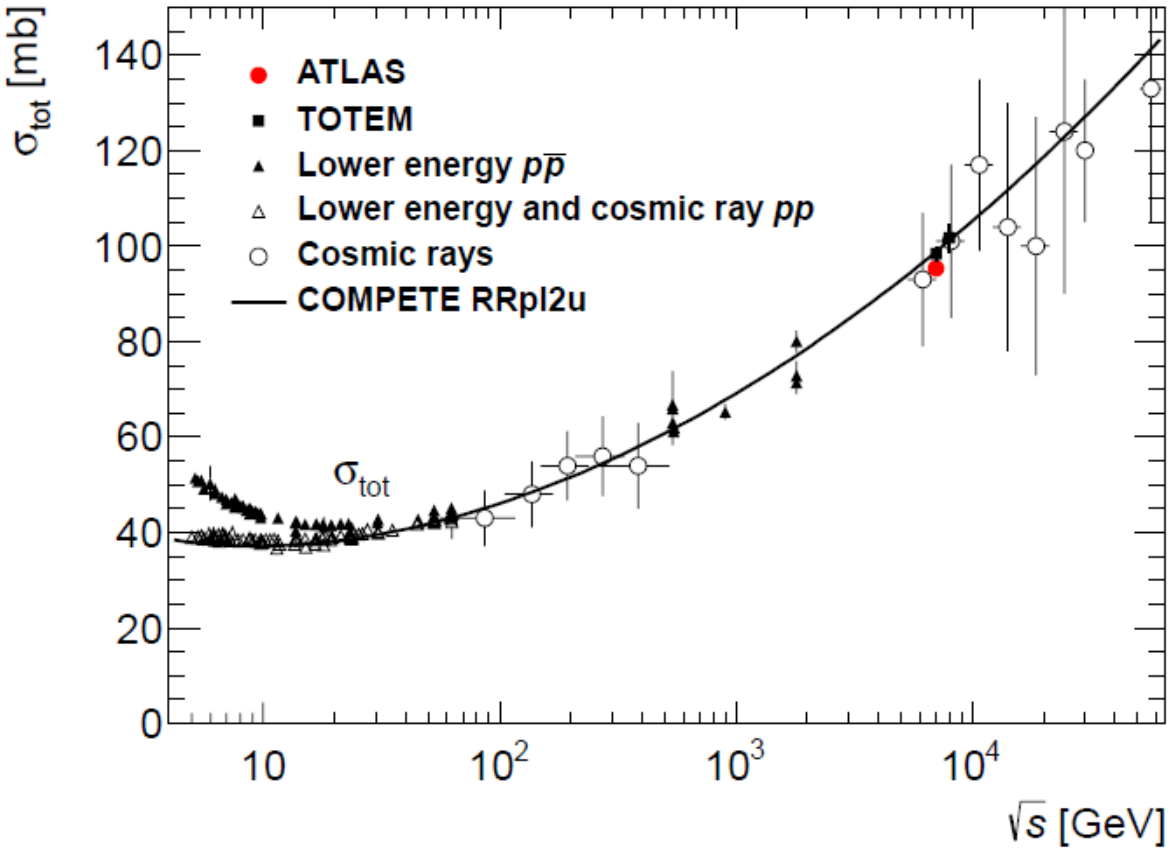
$$\sigma_{\rm tot} = 95.35 \pm 0.38\,(\text{stat.}) \pm 1.25\,(\text{syst.}) \pm 0.37\,(\text{extr.})\,\text{mb}.$$

Unfolding of the data introduce statistical correlation between the different t-bins and the resulting covariance matrix is calculated and included in the fit for σ_{tot} .
TOTEM does not quote a statistical error.

Dominated by luminosity followed by beam energy (0.4 mb)
TOTEM does not quote error from the beam energy.

From dependence of fit range.
TOTEM does not see such dependence.

Comparison of the ATLAS/TOTEM results with others



The slope parameter B

Use pure exponential $e^{-B|t|}$ to describe differential elastic cross section for small t- values

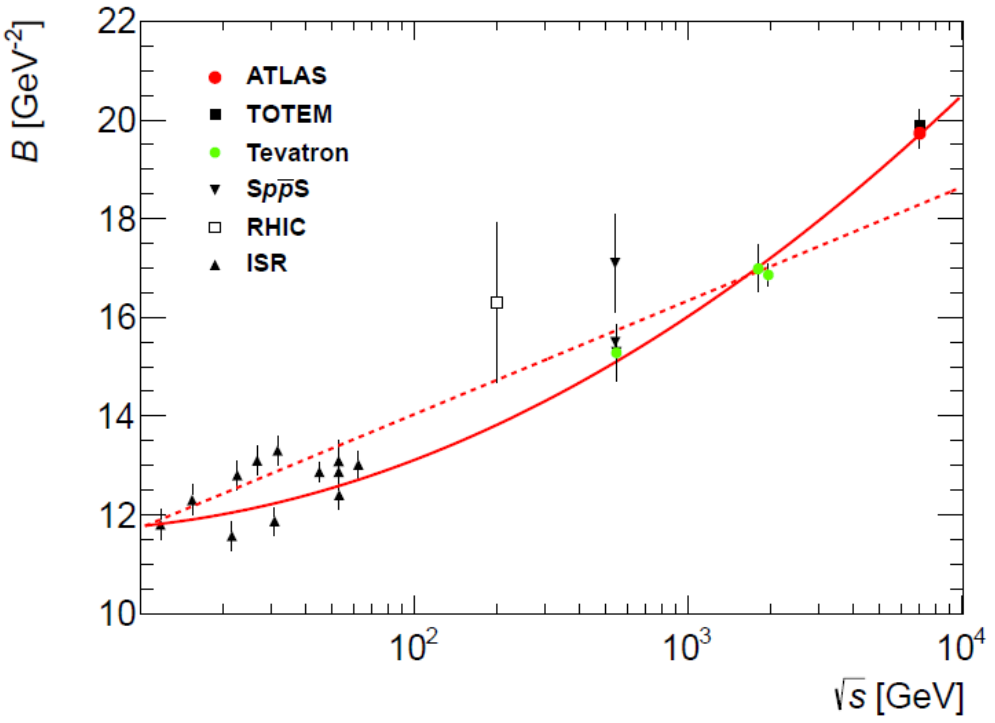
ATLAS with fit up $-t = 0.1$ GeV^2 obtains $B=19.73 \pm 0.14(\text{stat}) \pm 0.26(\text{syst})$ GeV^{-2}

TOTEM with fit up $-t = 0.2$ GeV^2 obtains $B=19.9 \pm 0.3$ (syst) GeV^{-2}

$$B = B_0 + 2\alpha_p'^{\text{eff}} \ln(s/s_0)$$

Dotted line:
Donnachie-Landshoff
$\alpha'^{\text{eff}}_p = 0.25$ GeV^{-2}

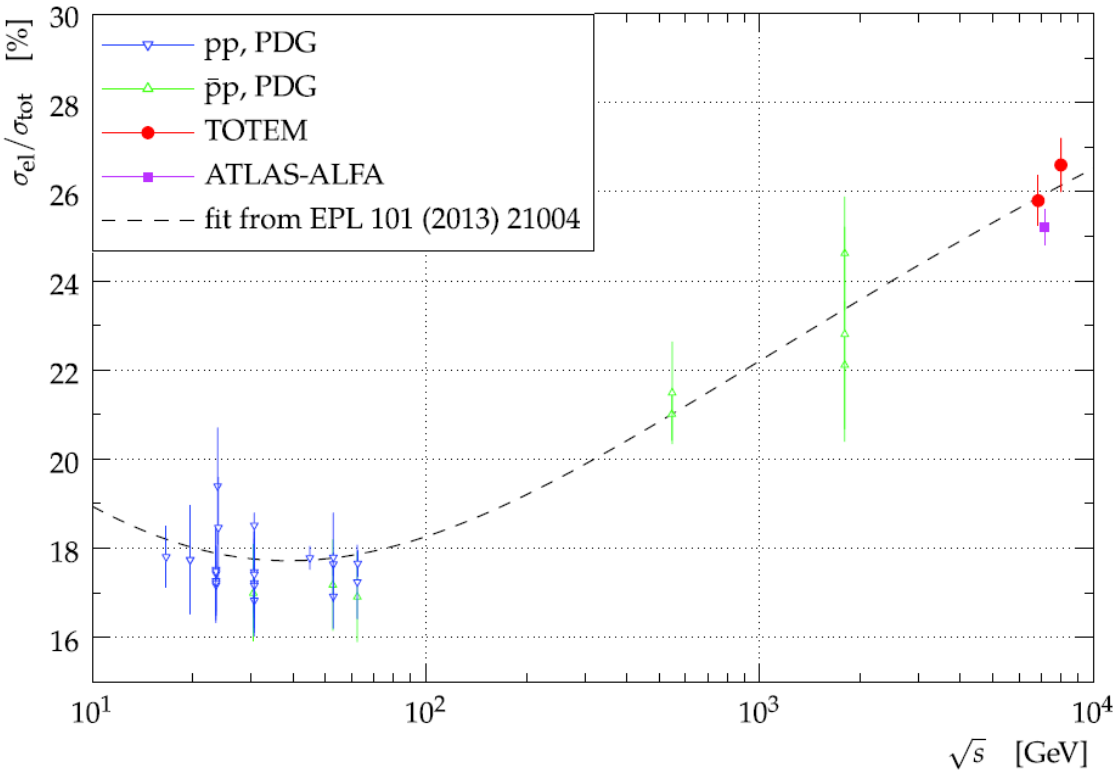
Full line:
Quadratic form from
Schegelsky and Ryskin



The ratio σ_{el}/σ_{tot}

Measure of the opacity of the proton

The ratio σ_{el}/σ_{tot} would be $\frac{1}{2}$ for the proton being opaque black disc



Prospects and Future Plans

- Finish analysis of 8 TeV data (ATLAS)
- Measure σ_{tot} at 13 TeV
- Reach the Coulomb interference region to measure ρ (and the luminosity in yet a different way)

BACK-UP

Similarities and differences ATLAS/TOTEM measurements
Unfolding

Not evident that I will treat this…may be skip

7.2. *Other results on soft diffraction*