

First measurement of σ_{tot} and σ_{el} expectations for 2011/12



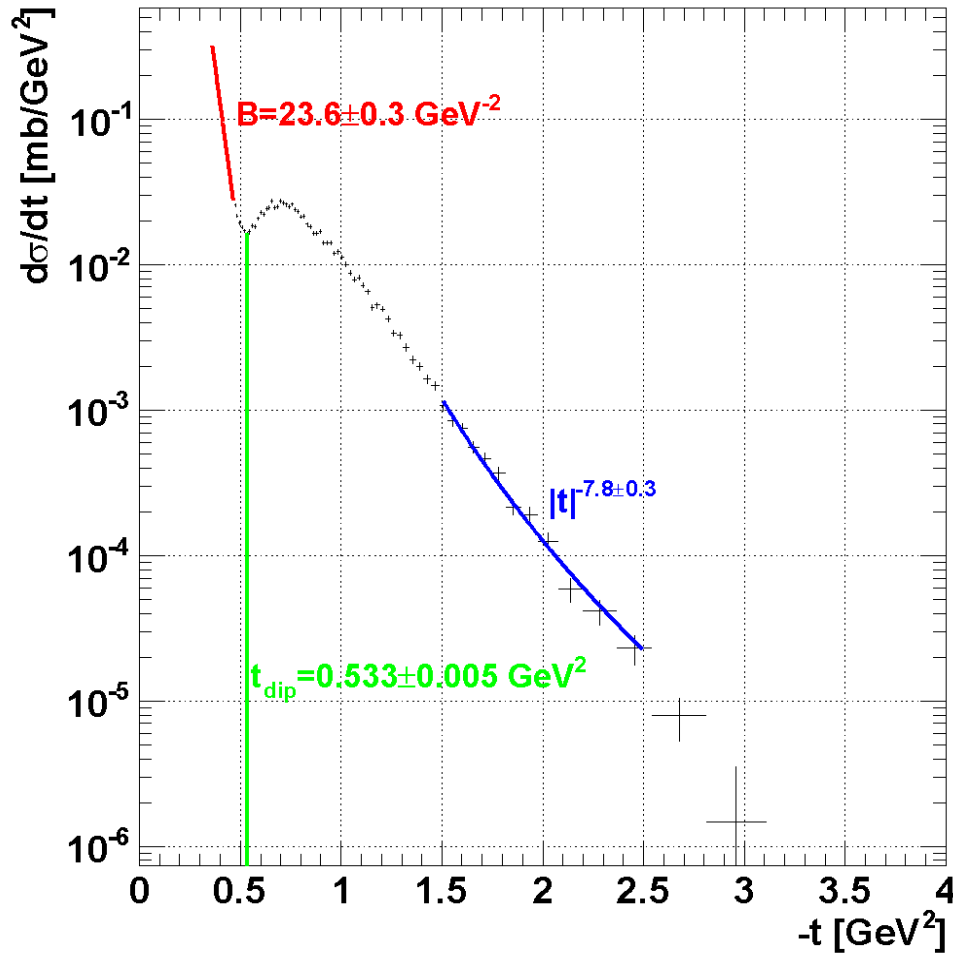
LHCC
21 Sept 2011

Karsten Eggert
on behalf of the TOTEM Collaboration

Elastic scattering differential cross-section



$\beta^* = 3.5$ m, Oct. 2010 (EPL 95 2011, 41001)



Extend the measurement to lower $|t|$ values

Total Cross-Section Measurement



Optical Theorem:

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

Use ρ from COMPETE fit:

$$\rho = 0.14^{+0.01}_{-0.08}$$

Normalisation with luminosity from CMS

Uncertainty $\pm 4\%$

$$\frac{d\sigma_{EL}}{dt} = \frac{1}{L} \cdot \frac{dN_{EL}}{dt}$$

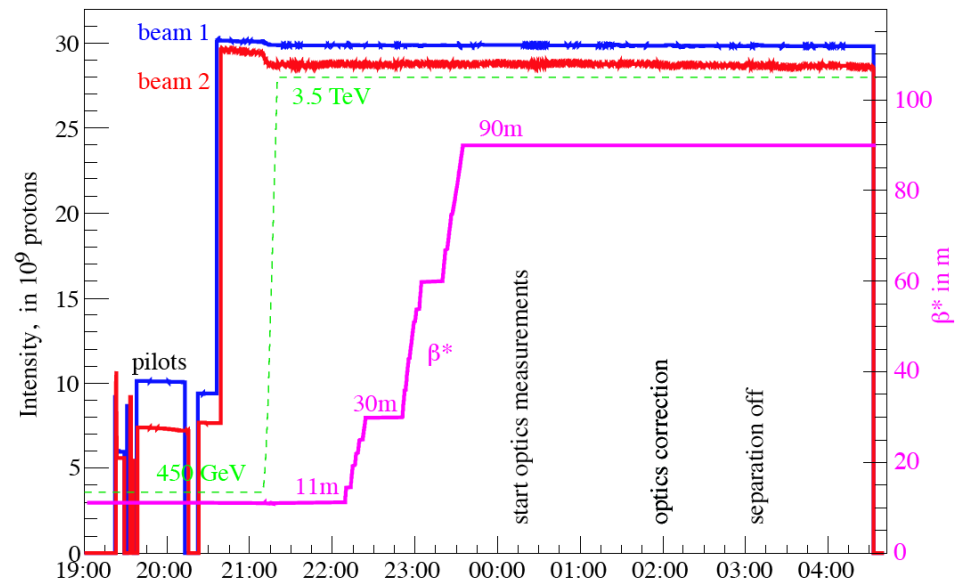
→ Measure $d\sigma_{el} / dt$ at lowest possible $|t|$

First run with the $\beta^* = 90$ m optics and RP insertion



Evolution with time : intensity, energy, β^*

scheduled : 28/06/2011, beam for 90m from 20:00 - 04:00 Fill 1902



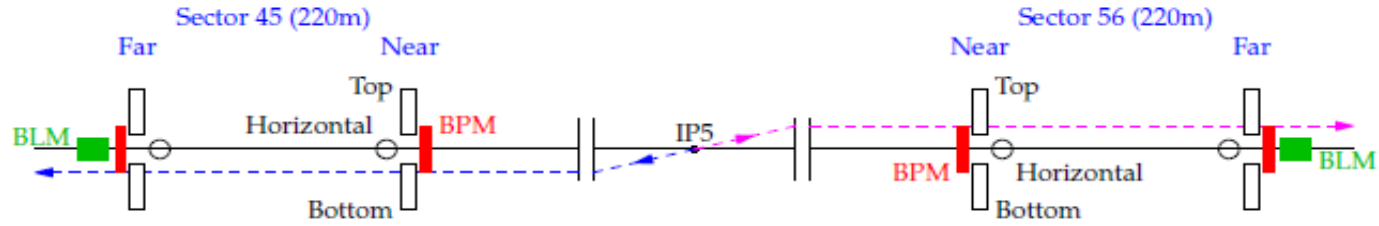
Fill 1902 Beam process SQUEEZE_HIGHBETA-90M_3.5TeV_IP1_IP5_LONG

Un-squeeze from injection optics
 $\beta^* = 11\text{m}$ to 90m
[Helmut Burkhardt, Andre Verdier]

Very robust optics with high precision

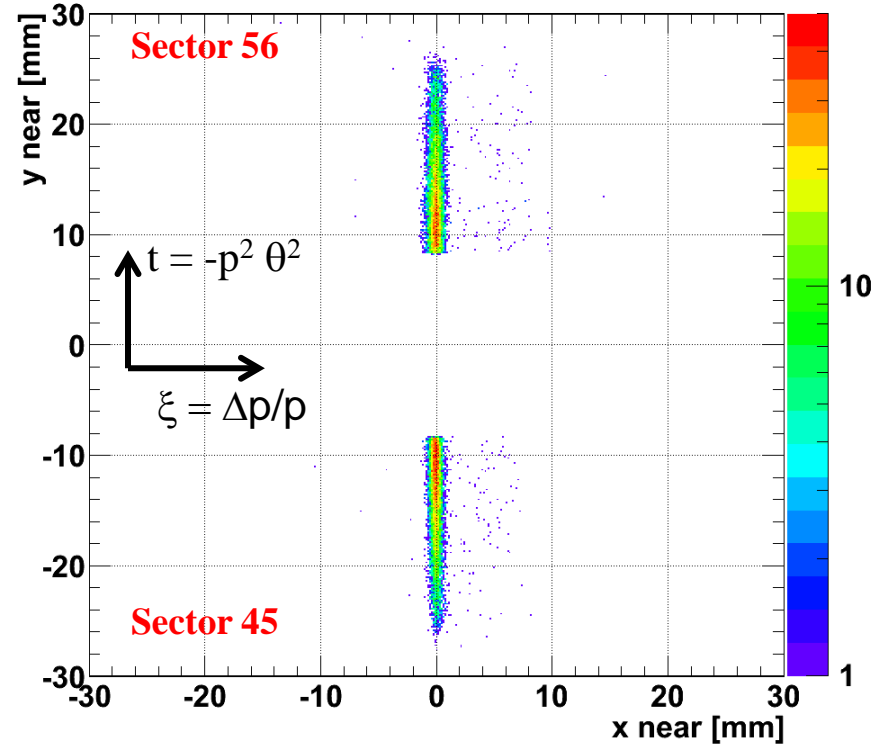
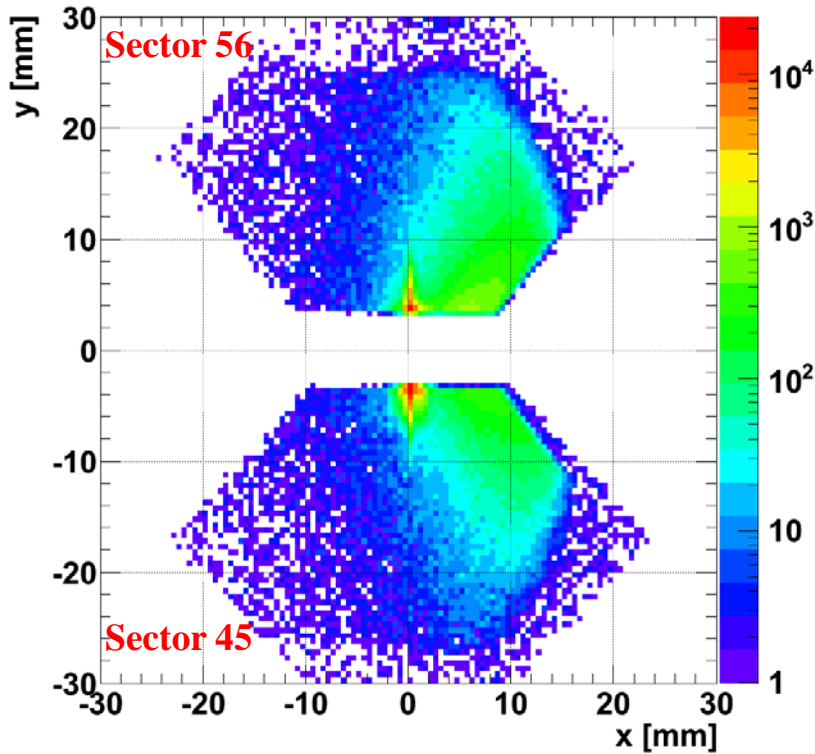
- Two bunches with 1 and 2×10^{10} protons / bunch
- Instantaneous luminosity: $8 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$
- Integrated luminosity: $1.7 \mu\text{b}^{-1}$
- **Estimated pile-up: $\sim 0.5 \%$**
- Vertical Roman Pots at 10σ from beam center
- Trigger rate : $\sim 50 \text{ Hz}$
- Recorded events in vertical Roman Pots: 66950

Proton tracks of a single diagonal (left-right coincidences)



$\beta^* = 3.5 \text{ m}$

$\beta^* = 90 \text{ m}$



Integrated luminosity : 6.2 nbarn⁻¹

$$y = L_y \Theta_y + v_y y^*$$

$$x = L_x \Theta_x + \xi D + v_x x^*$$

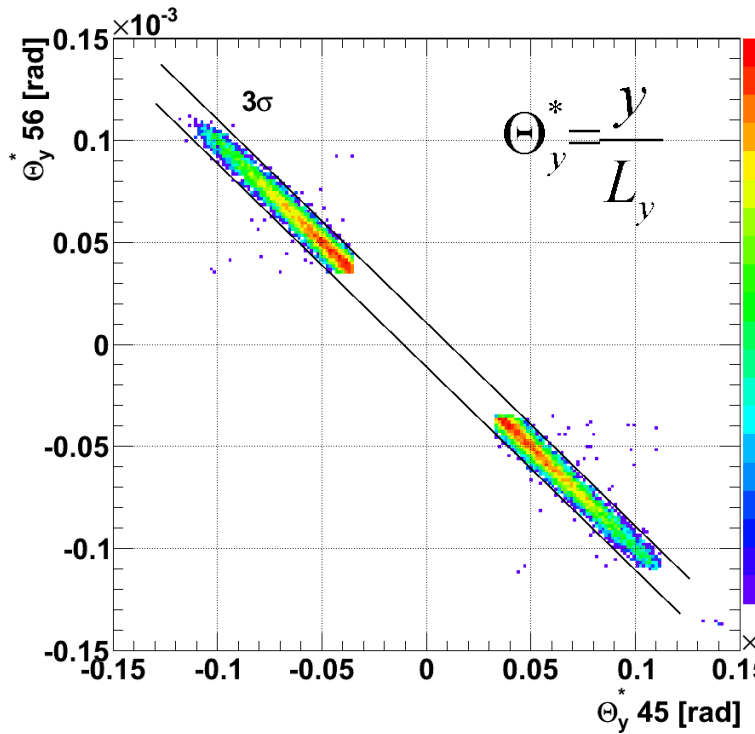
$$L_x \sim 0$$

Integrated luminosity : 1.65 μbarn⁻¹

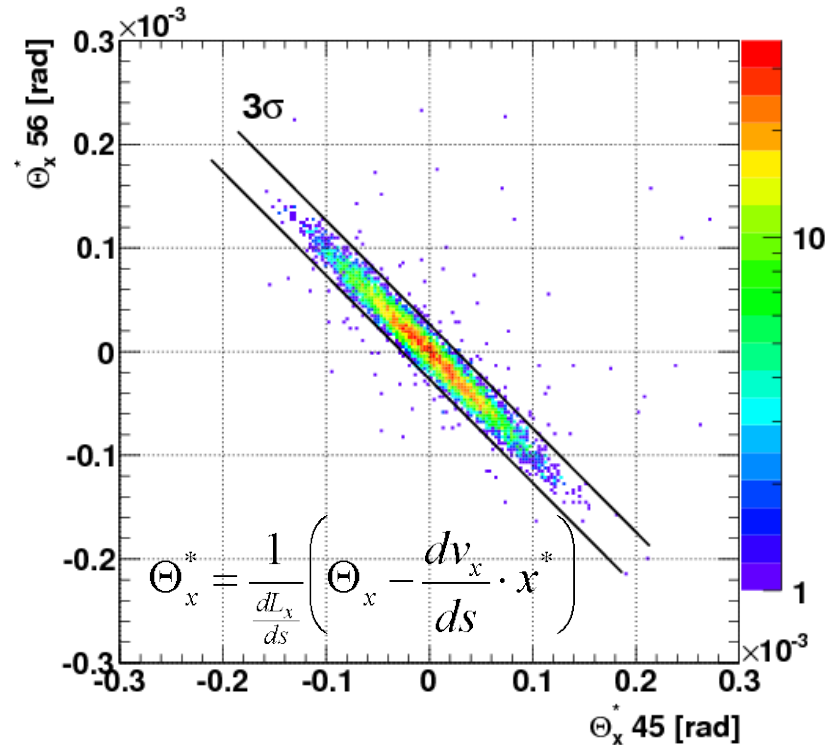
Incl. pile-up ~ 0.8 ev/bx₋

Incl. pile-up ~ 0.005 ev/bx

Angular Correlations between outgoing protons



$L_y \sim 260 \text{ m}$



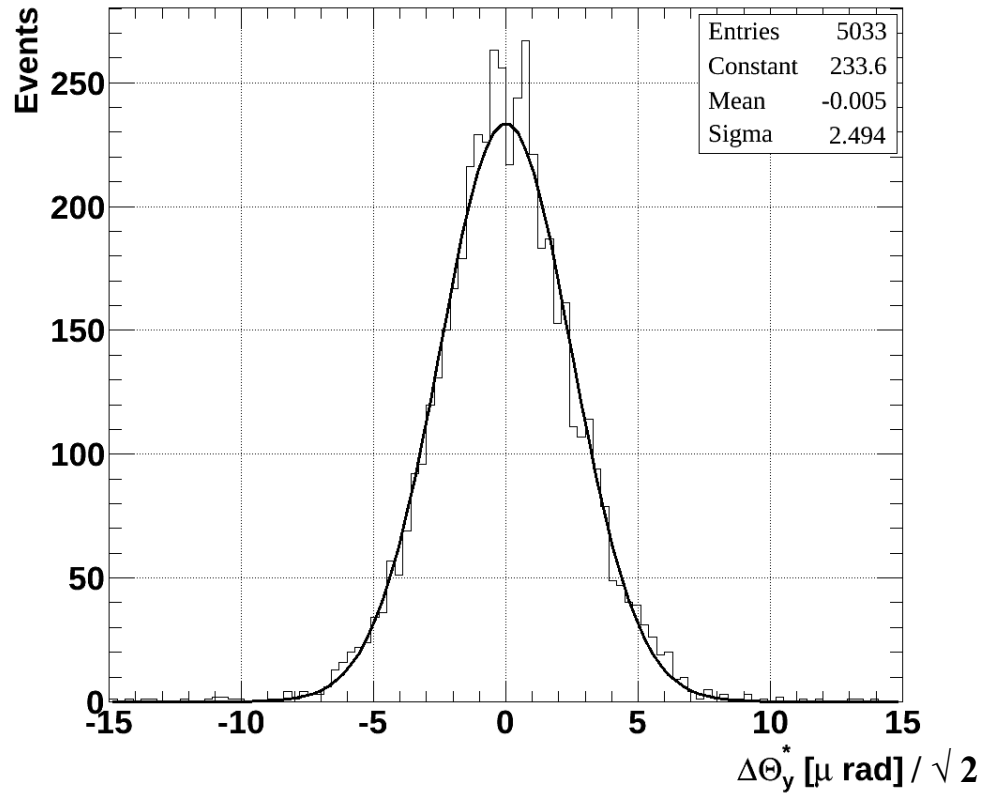
$L_x \sim 0 - 3 \text{ m}$

- Background negligible < 1%
- Width of correlation band in agreement with beam divergence ($\sim 2.4 \mu\text{rad}$)

Angular difference between the two outgoing protons



$$[\Theta_y^* (\text{proton1}) - \Theta_y^* (\text{proton2})] / \sqrt{2}$$



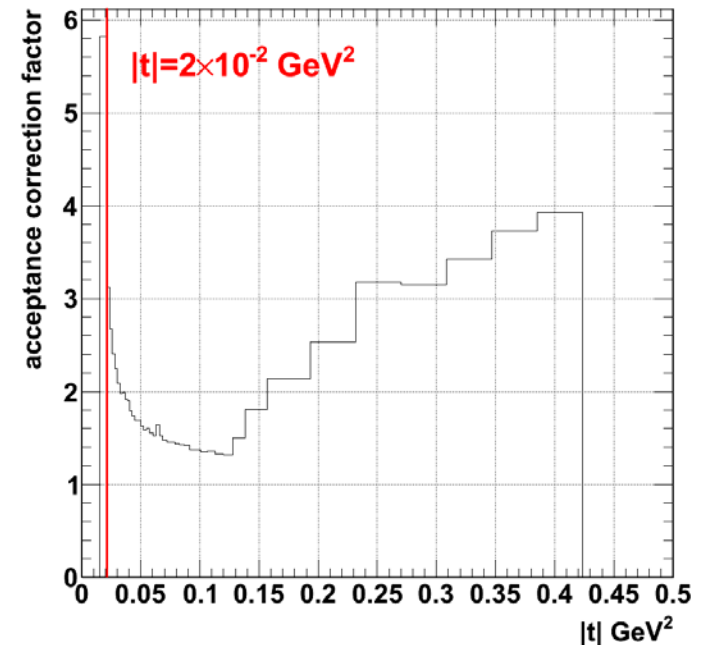
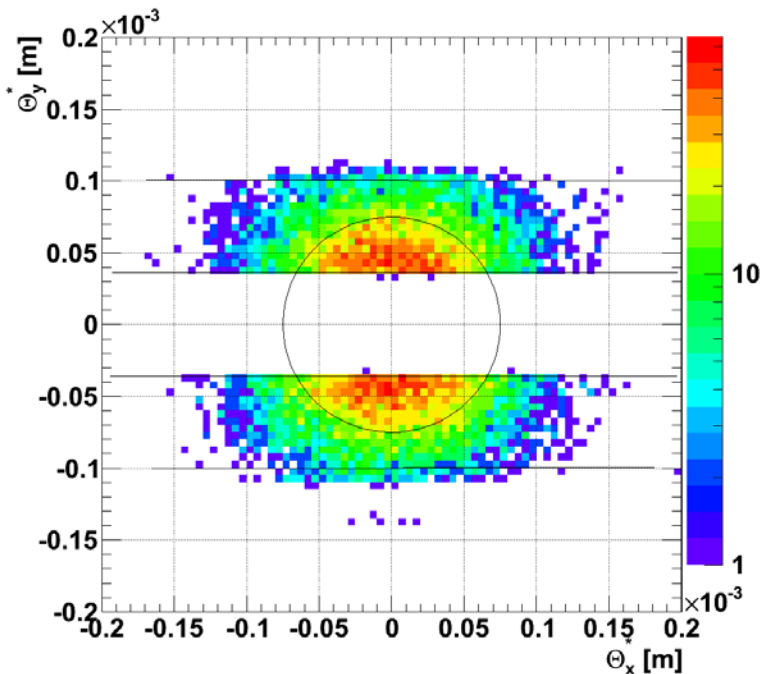
beam divergence σ_{Θ^*}

$$\sigma_{\Theta^*} = \sqrt{\frac{\varepsilon_n}{\gamma\beta^*}} = 2.4 \mu\text{rad}$$

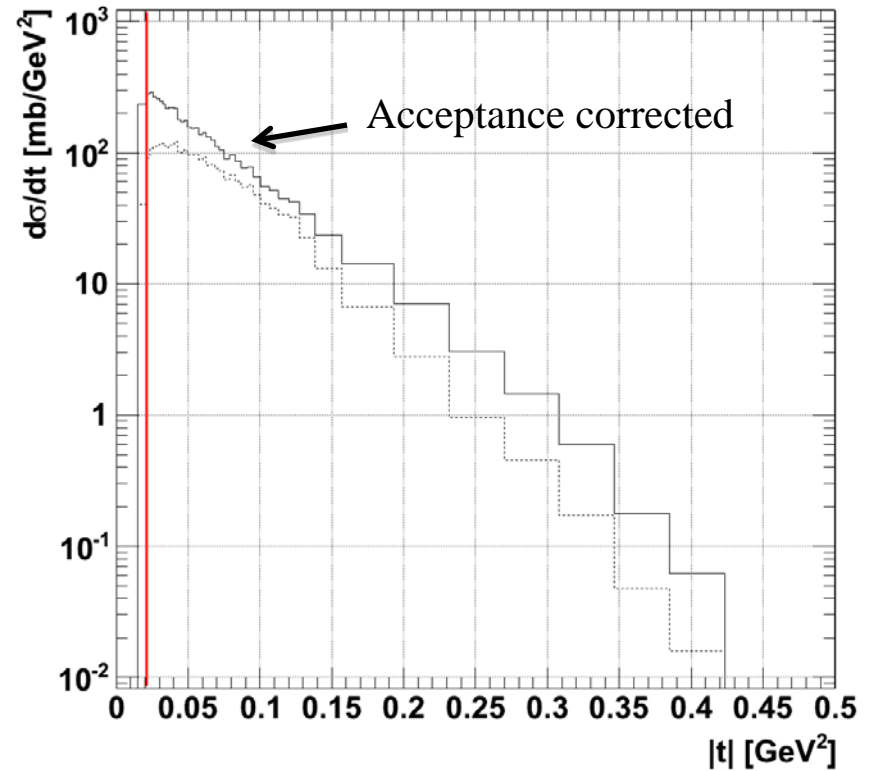
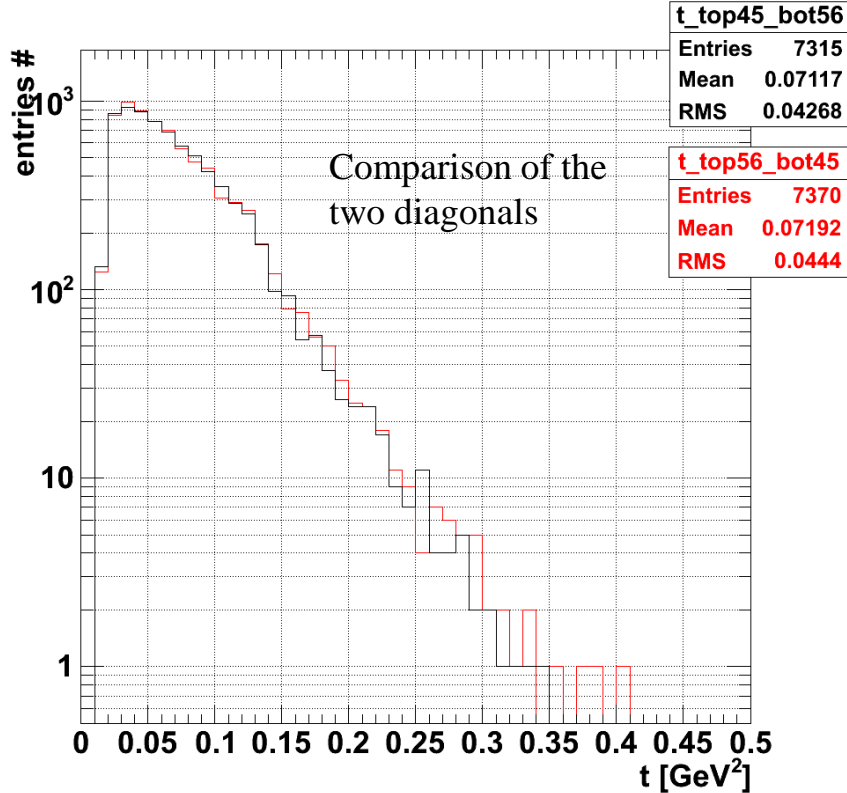
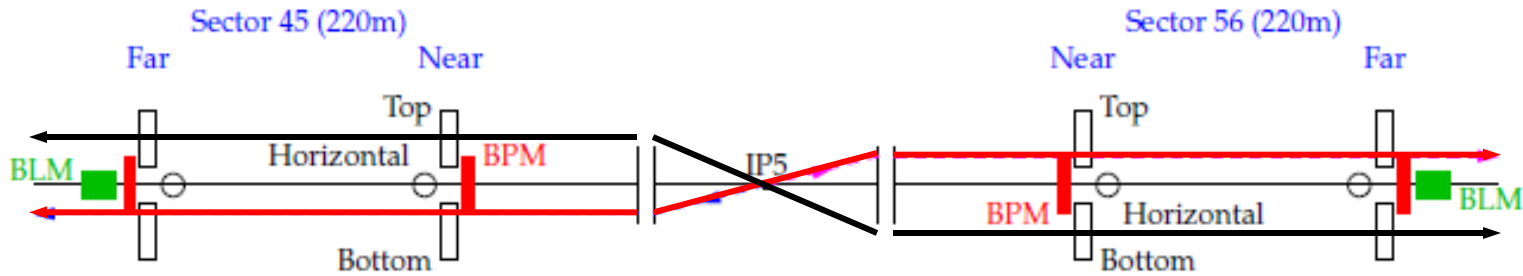
Optics, t-scale and acceptance



- Perturbations: optics very robust ($L_y \sim s_{RP}$), better than:
 - $\delta\Theta_x^*/\Theta_x^* = 1.3\%^{syst}$
 - $\delta\Theta_y^*/\Theta_y^* = 0.4\%^{syst}$
- Non-linearities in $\Theta_x^*(y)$ reconstruction due to dL_x / ds fixed: (checked via L_x)
- t systematics: $\delta t / t = 0.8\%$ (low t) up to 2.6% (large $|t|$)
- Acceptance correction factor < 3 at low $|t|$, based on ϕ symmetry



Raw t-Distributions



Efficiency Correction and Resolution Unfolding



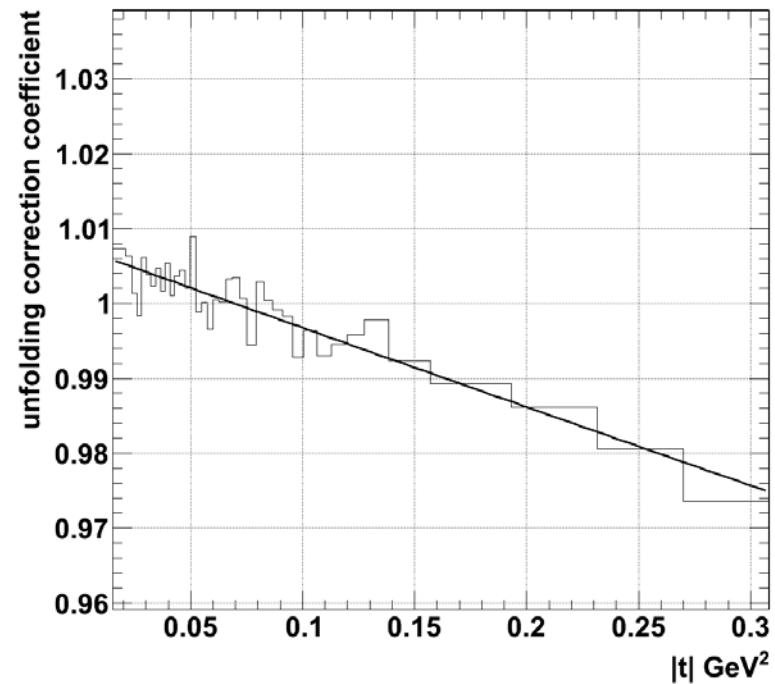
Trigger efficiency $\sim 99.9\%$

Reconstruction efficiency $\sim 91\%$

$$\sigma(\Theta_x^*) = \sqrt{1.7^2 (\text{from beam div.}) + 4^2 (\text{det. res.})} = 4.4 \mu\text{rad}$$

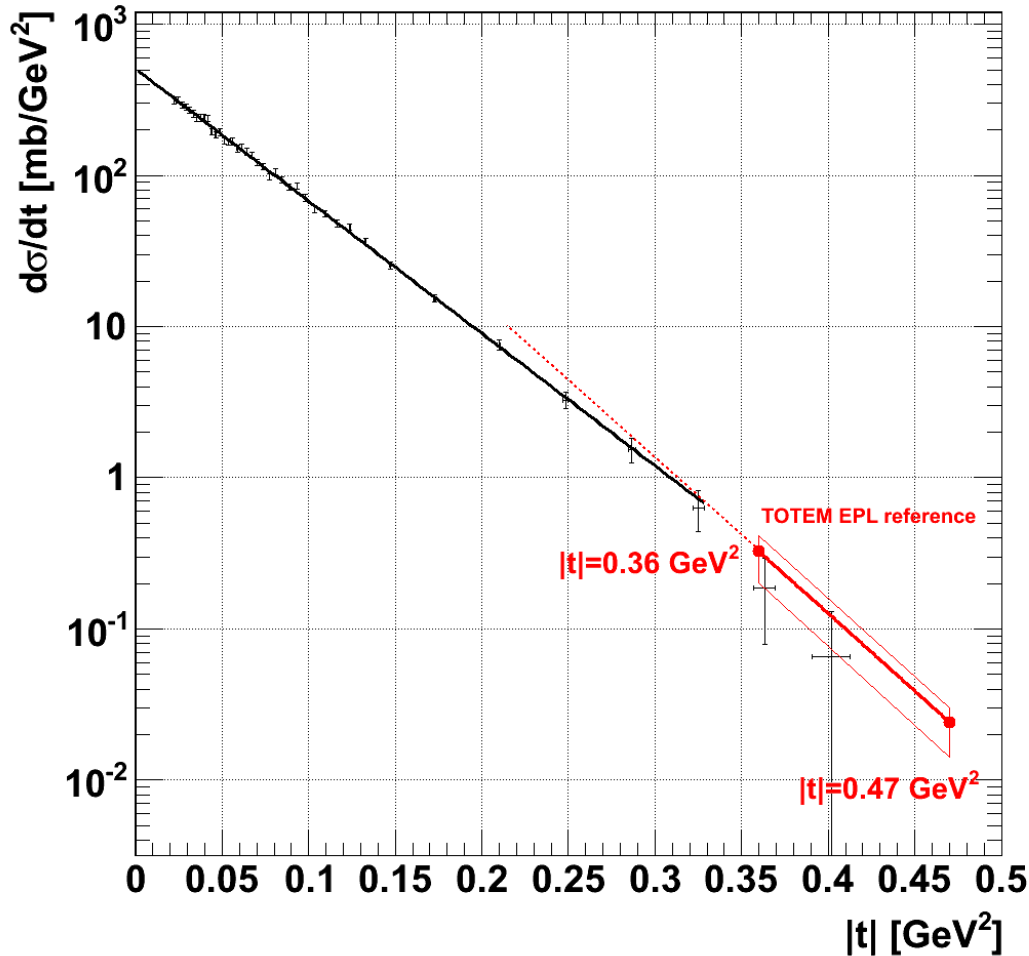
$$\sigma(\Theta_y^*) = 1.7 \mu\text{rad} (\text{from beam div.})$$

Unfolding correction



Effect on slope: $\Delta B = 0.11 \text{ GeV}^{-2}$

Final Differential Cross-Section



Extrapolation to $t = 0$:

$$\left. \frac{d\sigma}{dt} \right|_{t=0} = 5.037 \times 10^2 \text{ mb} / \text{GeV}^2$$

Exponential slope

$$B \Big|_{t=0} = 20.1 \text{ GeV}^{-2}$$

Good agreement with the measurement
at $|t| > 0.36 \text{ GeV}^2$
[EPL 95 (2011) 41001]

Total elastic cross-section:

$$\sigma_{\text{EL}} = 8.3 \text{ mb}^{(\text{extrapol.})} + 16.5 \text{ mb}^{(\text{measured})} = 24.8 \text{ mb}$$



- t : $\pm [0.6 \div 1.8]\%_{\text{syst optics}} \pm <1\%_{\text{align.}} \pm [3.4 \div 11.9]\%_{\text{stat}}$ (before unfolding)
- $d\sigma/dt$: $\pm 4\%_{\text{syst lumin}} \pm 1\%_{\text{syst (acc.+eff.+backg.+tag)}} \pm 0.7\%_{\text{syst unfold.}}$
- B : $\pm 1\%_{\text{stat}} \pm 1\%_{\text{syst from } t} \pm 0.7\%_{\text{syst from unfolding}}$
- $d\sigma/dt(t=0)$: $\pm 0.3\%_{\text{stat}} \pm 0.3\%_{\text{syst (optics)}} \pm 4\%_{\text{syst lumin}} \pm 1\%_{\text{syst (acc.+eff.+backg.+tag)}}$
- $\int d\sigma/dt dt$: $\pm 4\%_{\text{syst lumin}} \pm 1\%_{\text{syst (acc.+eff.+backg.+tag)}} \pm 0.8\%_{\text{stat extrap.}}$

- σ_{TOT} : $(+0.8\% ; -0.2\%)_{\text{syst } \rho} \pm 0.2\%_{\text{stat}} \pm 2.7\%_{\text{syst}}$
= $(+2.8\% ; -2.7\%)_{\text{syst}} \pm 0.2\%_{\text{stat}}$
- σ_{EL} : $\pm 5\%_{\text{syst}} \pm 0.8\%_{\text{stat}}$
- σ_{INEL} : $(+2.4\% ; -1.8\%)_{\text{syst}} \pm 0.8\%_{\text{stat}}$



Elastic exponential slope:

$$B|_{t=0} = (20.1 \pm 0.2^{(stat)} \pm 0.3^{(syst)}) \text{ GeV}^{-2}$$

Elastic diff. cross-section at optical point: $\left. \frac{d\sigma_{el}}{dt} \right|_{t=0} = (503.7 \pm 1.5^{(stat)} \pm 26.7^{(syst)}) \text{ mb} / \text{ GeV}^2$

↓ Optical Theorem, $\rho = 0.14^{+0.01}_{-0.08}$

$$\sigma_T = \left(98.3 \pm 0.2^{(stat)} \pm 2.7^{(syst)} \begin{bmatrix} +0.8 \\ -0.2 \end{bmatrix}^{(syst \text{ from } \rho)} \right) \text{ mb}$$

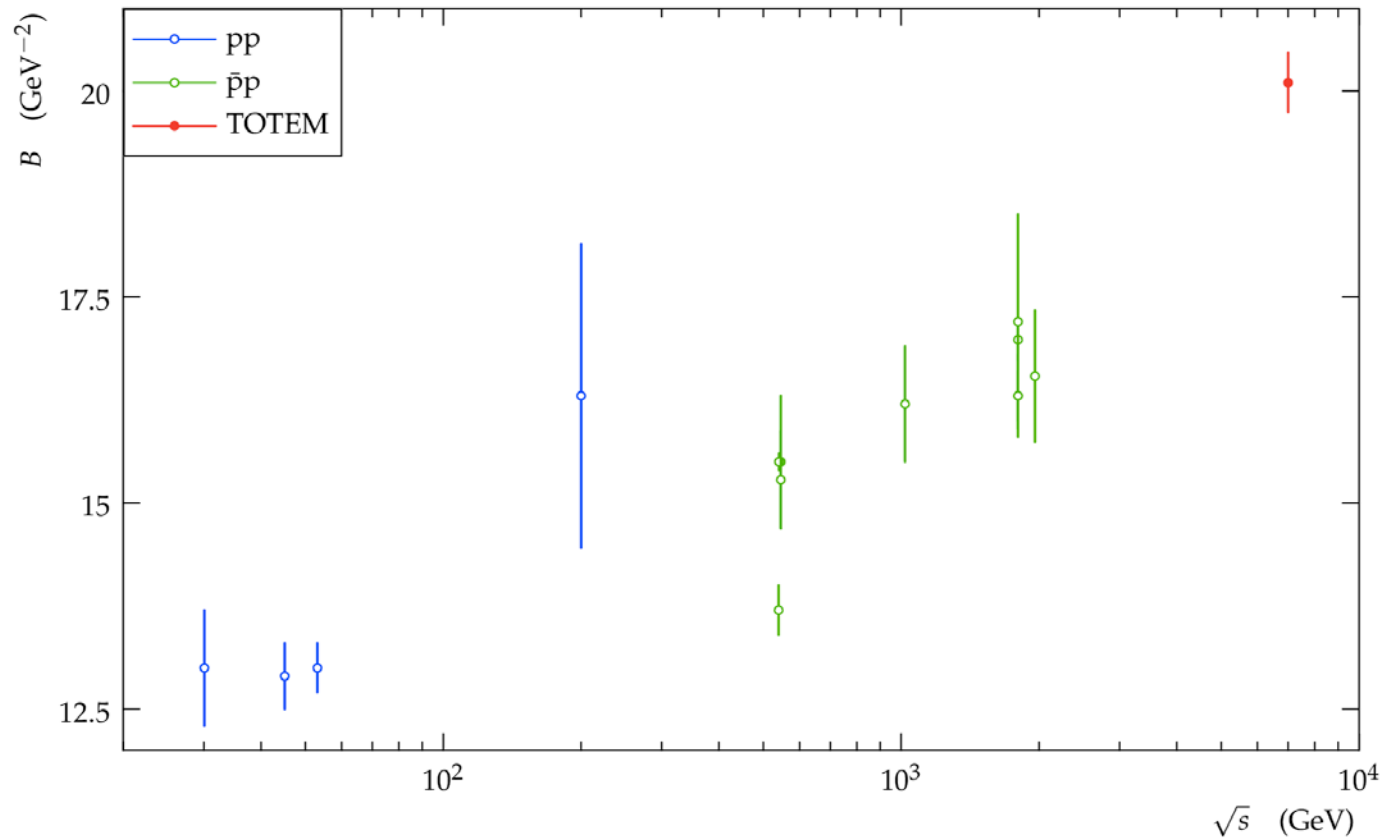
$$\sigma_{el} = 8.3 \text{ mb}^{(extrapol.)} + 16.5 \text{ mb}^{(measured)} = (24.8 \pm 0.2^{(stat)} \pm 2.8^{(syst)}) \text{ mb}$$

$$\sigma_{inel} = \sigma_{tot} - \sigma_{el} = (73.5 \pm 0.6^{(stat)} \begin{bmatrix} +1.8 \\ -1.3 \end{bmatrix}^{(syst)}) \text{ mb}$$

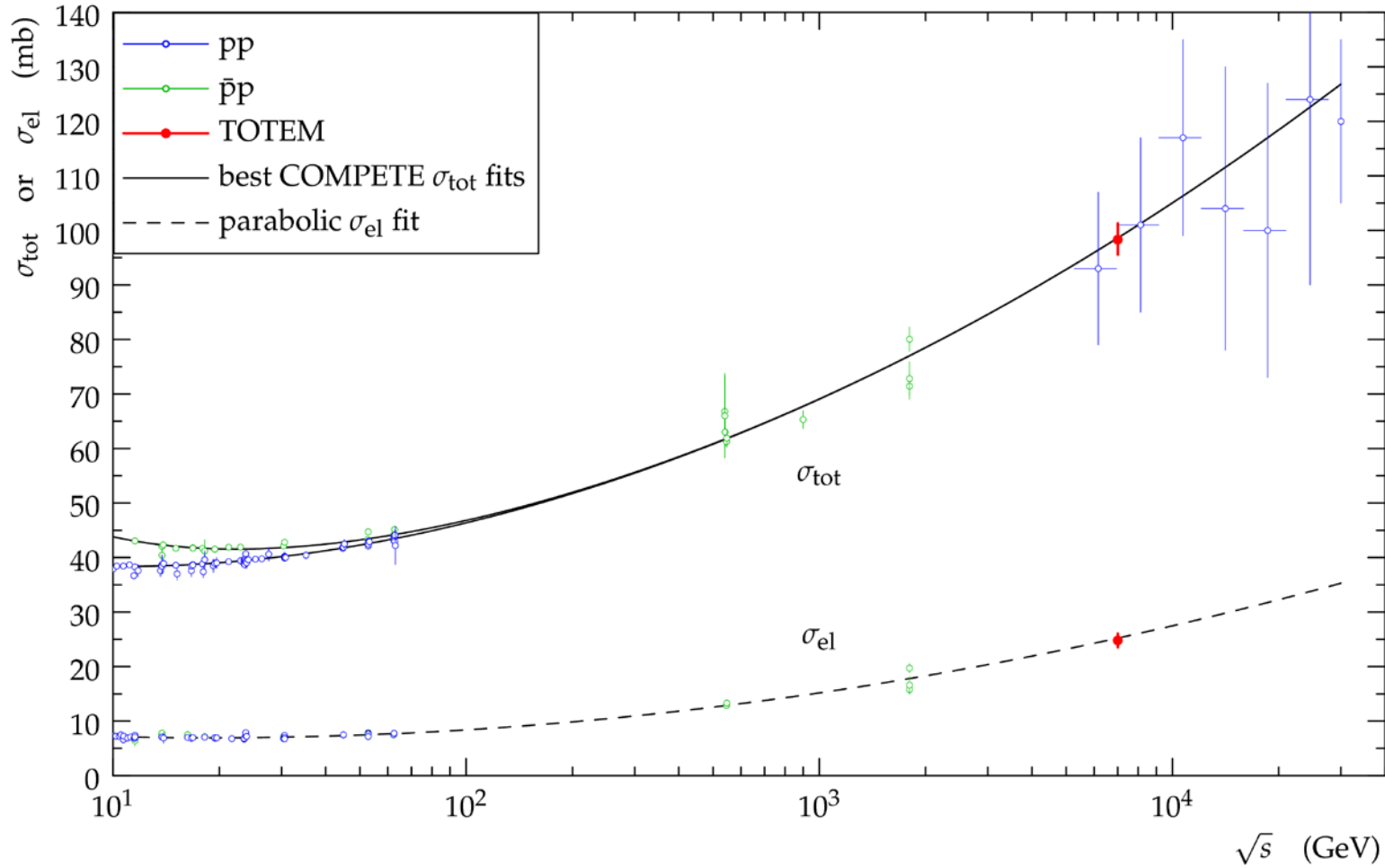
$$\sigma_{inel} \text{ (CMS)} = (68.0 \pm 2.0^{(syst)} \pm 2.4^{(lumi)} \pm 4.0^{(extrap)}) \text{ mb}$$

$$\sigma_{inel} \text{ (ATLAS)} = (69.4 \pm 2.4^{(exp)} \pm 6.9^{(extrap)}) \text{ mb}$$

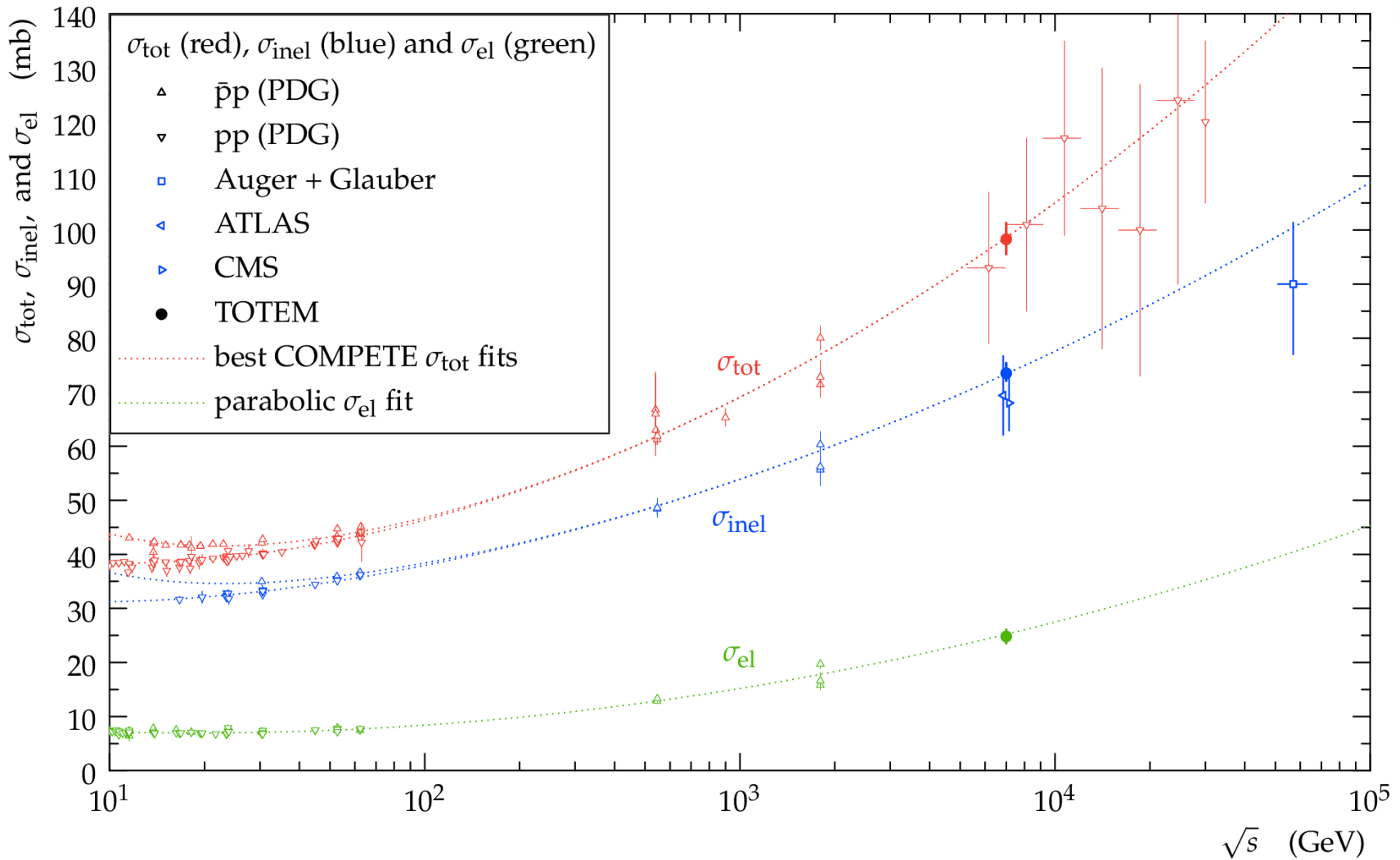
Energy dependence of the exponential slope B



Energy dependence of the elastic and total cross-sections



Energy dependence of inelastic cross-sections



Running Strategy for 2011/12



RP alignment was performed at $\beta^* = 1.5$ m

by approaching the RP detectors to the sharp beam edges produced by the LHC collimators

→ Qualification for running at $\beta^* = 1$ m, obtained via loss maps

$\beta^* = 90$ m

29. June : machine test run and first RP insertion to 10σ using alignment at $\beta^* = 1.5$ m

30 min of data taking → **first measurement of σ_{tot}**

August : alignment of all vertical RPs, beam lost before hor. Alignment

No data taking

Plan for end of September:

5 hours data taking at 5σ (vertical RP) → luminosity independent measurement

Horizontal alignment

October: at least one more run with 147 m alignment → diffraction

2012:

Toward larger $\beta^* \sim 1$ km

Acknowledgements



Thanks to:

The LHC crew

for giving us such a beautiful machine

for supporting continuously our TOTEM requests

The physics coordinator Massi Ferro-Luzzi

for his help in critical situations and not forgetting us

The Optics group

for the development of the magic 90m optics

The CMS collaboration

For the friendly collaboration and the luminosity measurement

All our friends, funding agencies and the CERN management