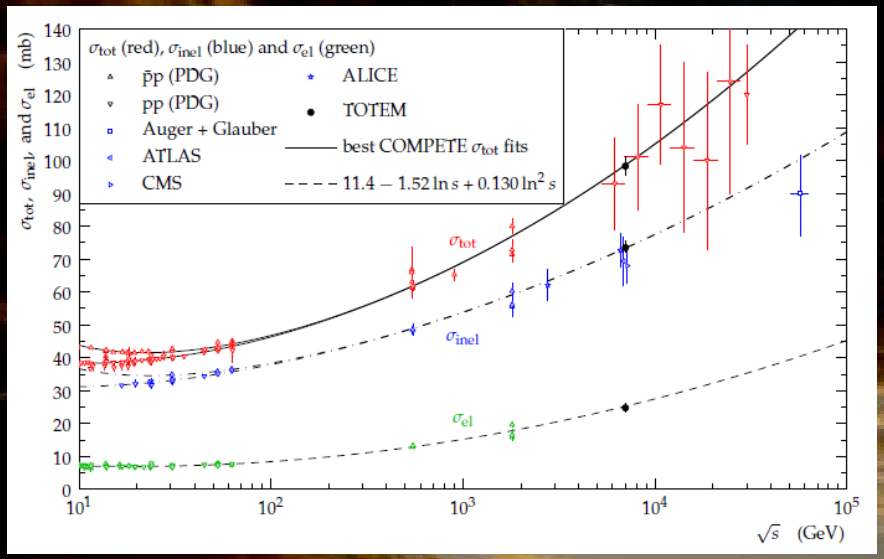
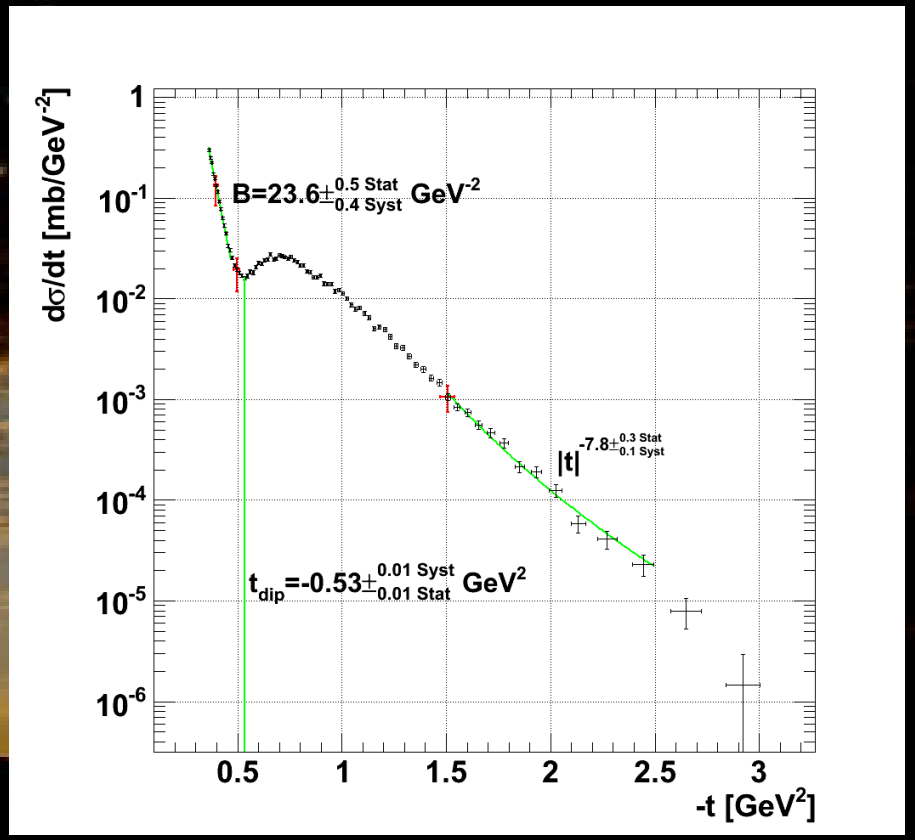
Proton-proton elastic scattering and total cross-section at 7 TeV by TOTEM at CERN LHC





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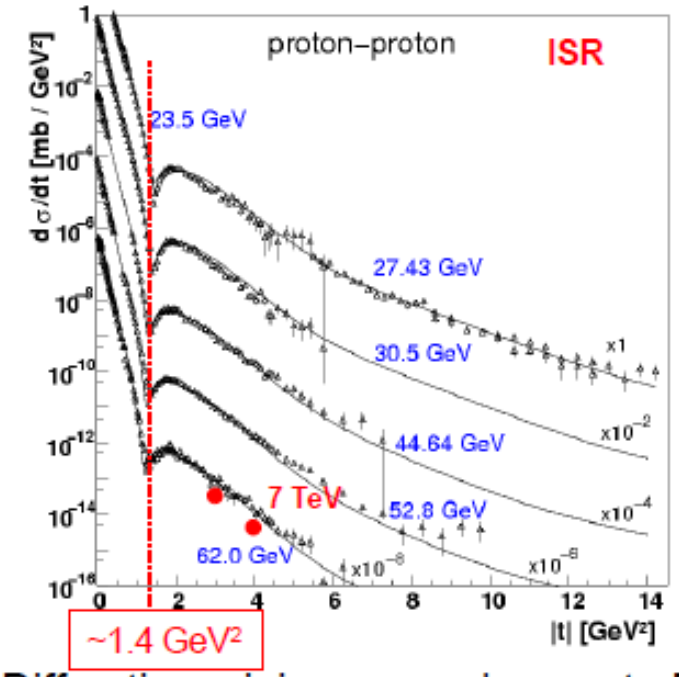
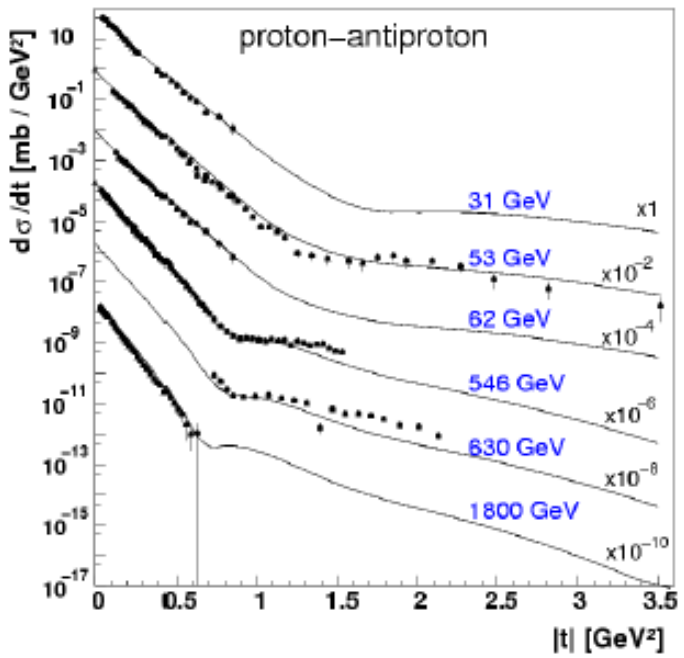
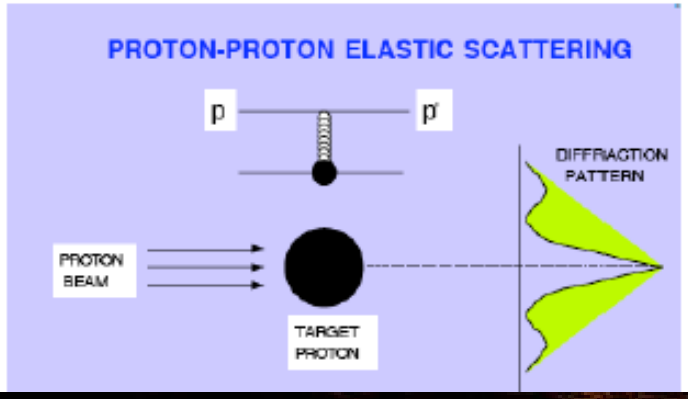
Elastic scattering from ISR toTevatron



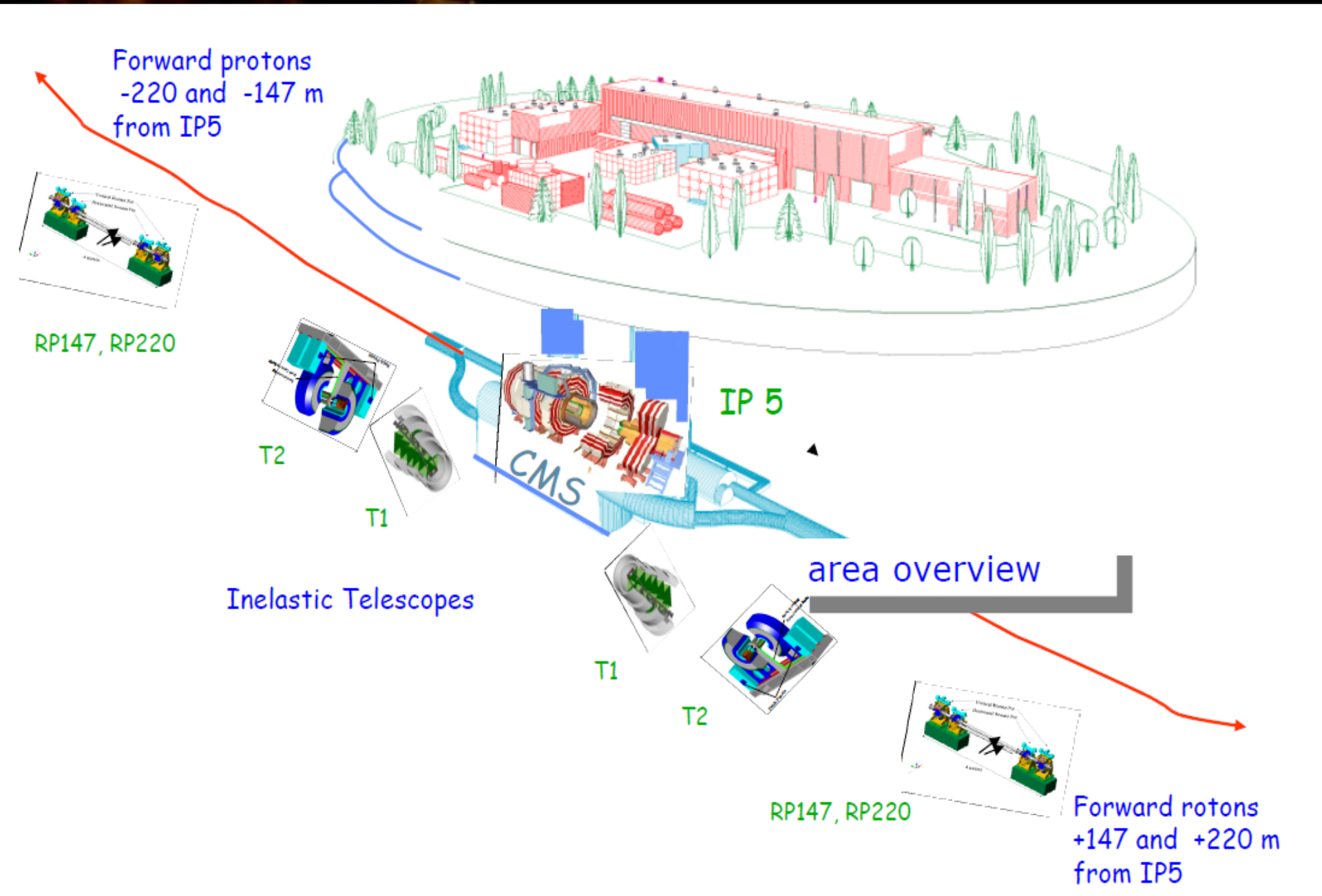


Diffractive minimum: analogous to Fraunhofer diffraction: $|t| \sim p^2 \theta^2$

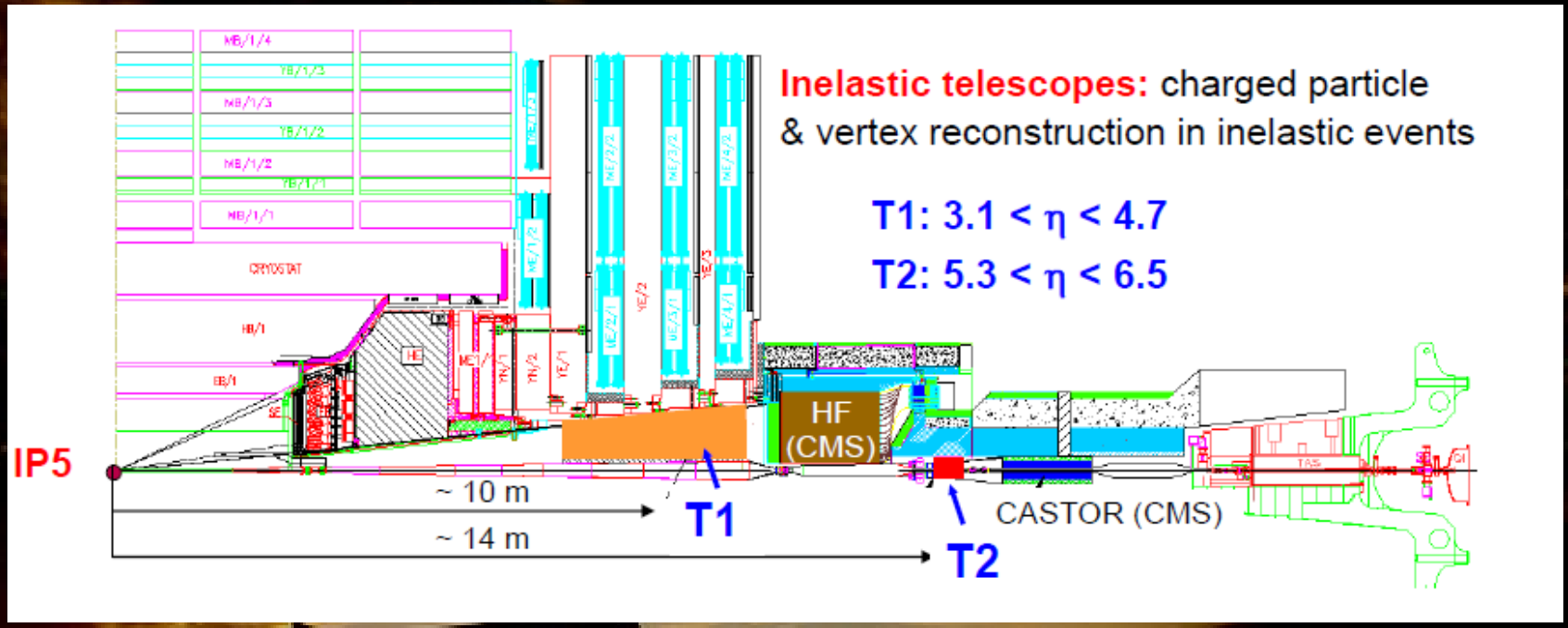


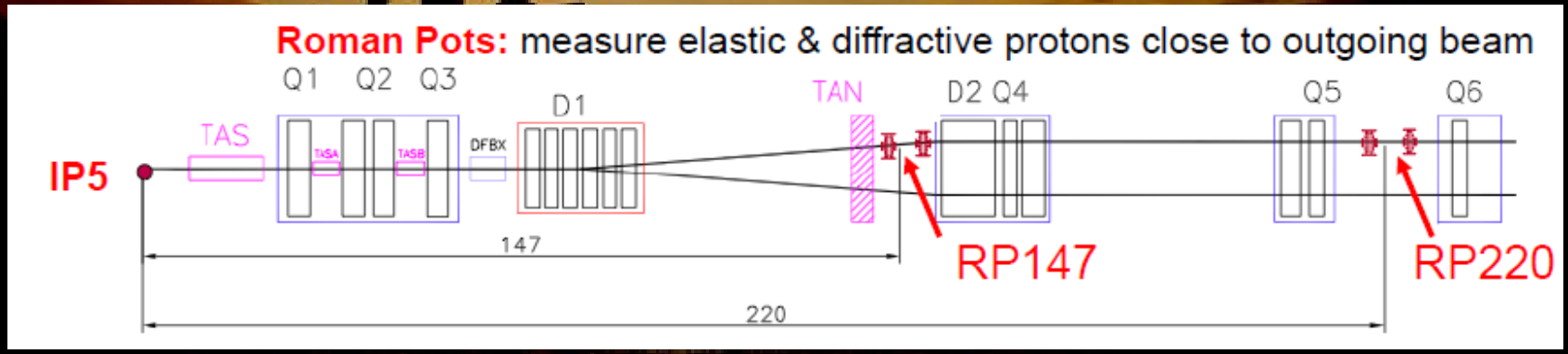
- exponential slope B at low |t| increases
- minimum moves to lower |t| with increasing s
  → interaction region grows (as also seen from σ_{tot})
- depth of minimum changes
  → shape of proton profile changes
- depth of minimum differs between pp, p^-p
  → different mix of processes

TOTEM: area overview

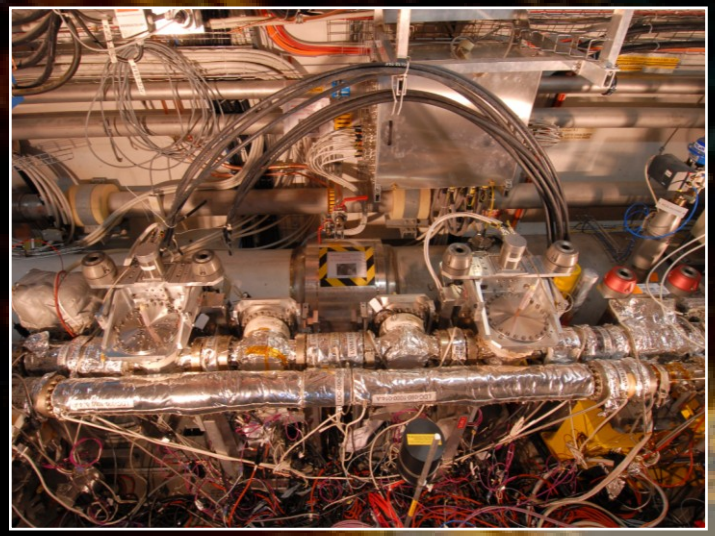


Experimental setup at IP5





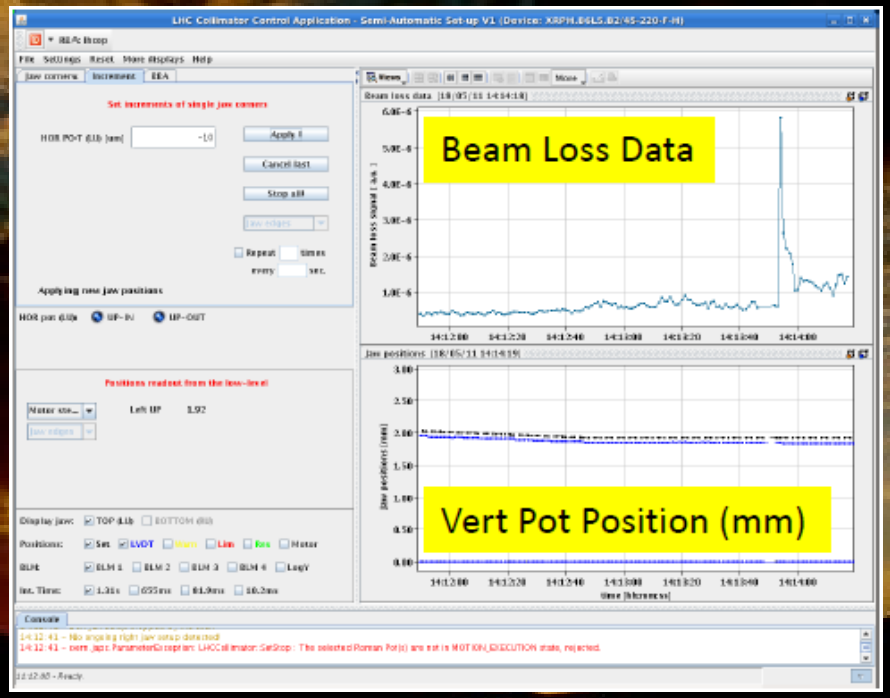
TOTEM: completely installed and running

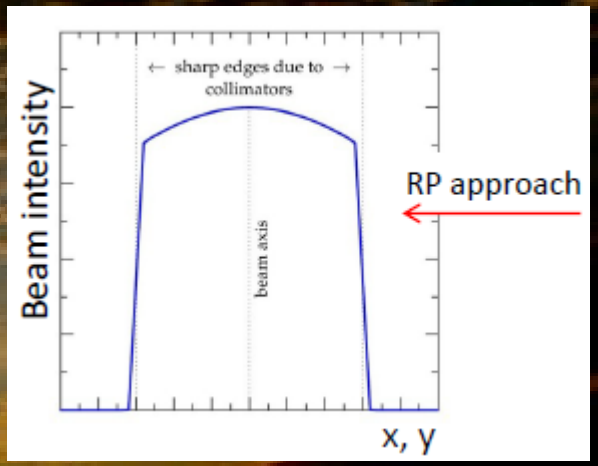


All Roman Pots at 147 and 220m installed (24 pots)
T1 detectors are installed on both sides
T2 detectors are installed on both sides
Trigger system based on all detectors is running
DAQ is running with an event rate capability of 1 kHz
Special runs with dedicated β^* and bunch structures

Beam based alignment of RPs @ 220 m

Scraping exercise:
RP220 approached the low intensity beam in 10 μm steps
RP220 for routine insertions in 2011

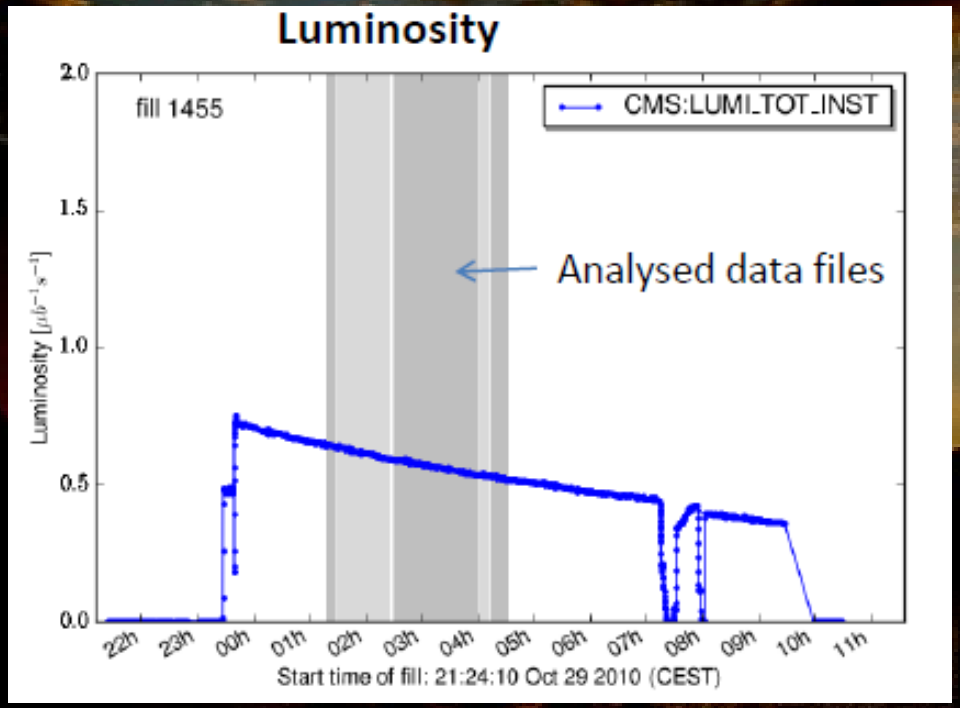




Data taking, RP220s close to beams
- vertical RPs @ 5σ = 2.2 mm
- horizontal RPs @ 7σ = 1 mm
- low pile-up

Elastic p+p scattering @ 7 TeV

Several runs were taken during 2010
different distances of the Roman pots to the beam center
7 σ runs were analyzed
18 σ runs with a total luminosity of ~5.8 pb^{-1} will come



RP dist.	Integrated luminosity
25 σ	1.5 nb^{-1}
20 σ	185 nb^{-1}
18 σ	5800 nb^{-1}
7 σ	9.5 nb^{-1}

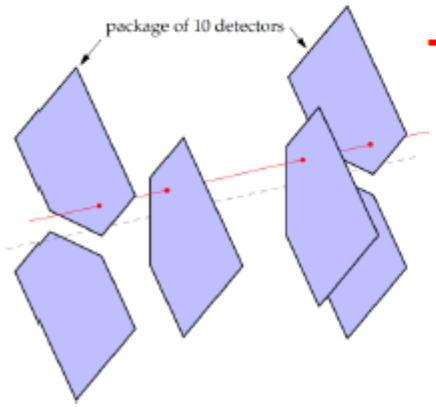
important for large t

Track based alignment and reconstruction

- **Both angle projections reconstructed: Θ_x^* and Θ_y^***
  - Θ_x^* from Θ_x @ RP220 (through dL_x/ds) $\quad \Theta_x = dL_x/ds\ \Theta_x^*$
  - Θ_y^* from y @ RP220 (through L_y) $\quad y = L_y\ \Theta_y^*$

→ **Excellent optics understanding**

- Magnet currents measured
- Measurements of optics parameters with elastic scatt.
  - $\Theta_{left}^* = \Theta_{right}^*$ (proton pair collinearity)
  - Proton position ↔ angle correlations
  - L_x=0 determination, coupling corrections

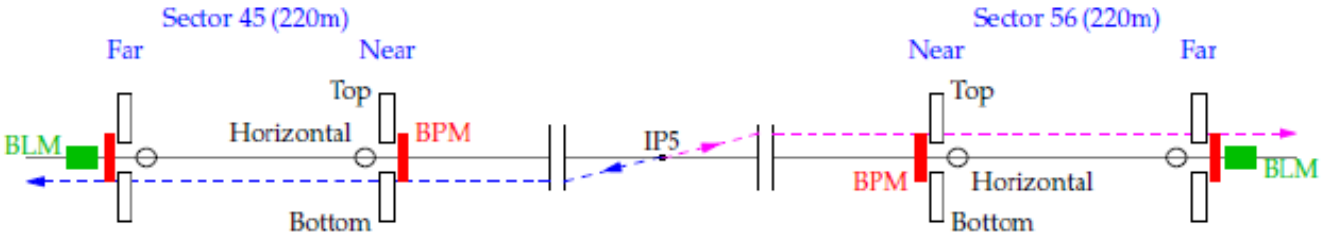


Track based alignment

→ **Fine alignment**

- Alignment between pots with overlapping tracks (~1μm)
- Alignment with respect to the beam – scraping exercise (~20μm)
- Mechanical constraints between top and bottom pots (~10μm)

Cuts and data reduction



Topology

- near and far units
- diagonals

Low $|\xi|$ selection (3σ)

- $|x_{RP,45}| < 3\sigma_x$ @ $L_{x,45}=0$
- $|x_{RP,56}| < 3\sigma_x$ @ $L_{x,56}=0$
- corr. $y_{RP216,45} \leftrightarrow y_{RP220,45}$
- corr. $y_{RP216,56} \leftrightarrow y_{RP220,56}$

Elastic collinearity (3σ)

- $\theta_{x,45}^* \leftrightarrow \theta_{x,56}^*$
- $\theta_{y,45}^* \leftrightarrow \theta_{y,56}^*$

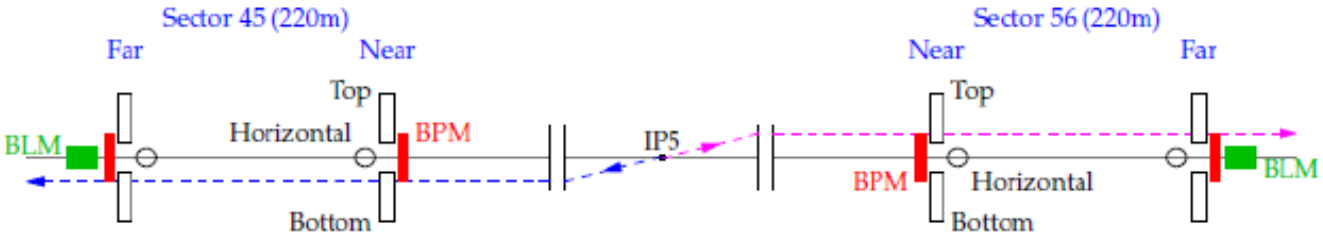
Intergrated luminosity : 6.2 nbarn^{-1}

Total triggers	5.28M
Reconstructed tracks & elastic topology	293k
Low $\|\xi\|$ selection	70.2k
Collinearity cuts	66.0k

showers

Diagonals analysed independently

Proton tracks at a single diagonal (left-right)



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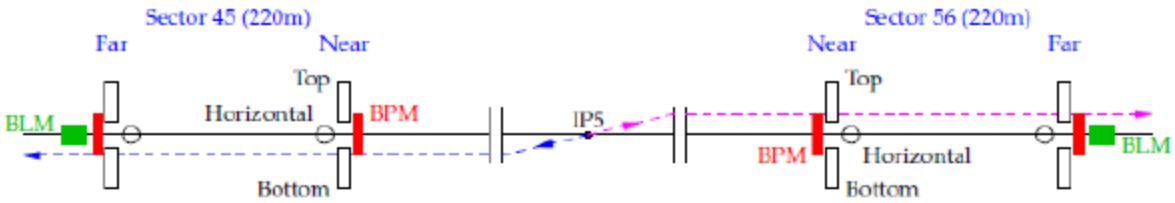
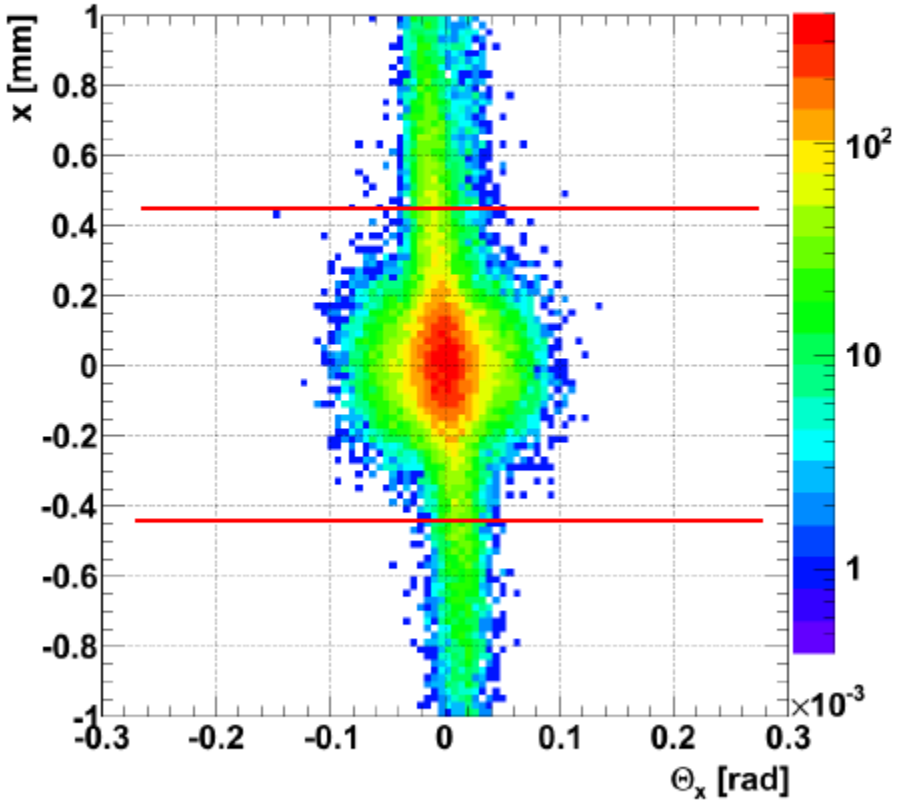
showers

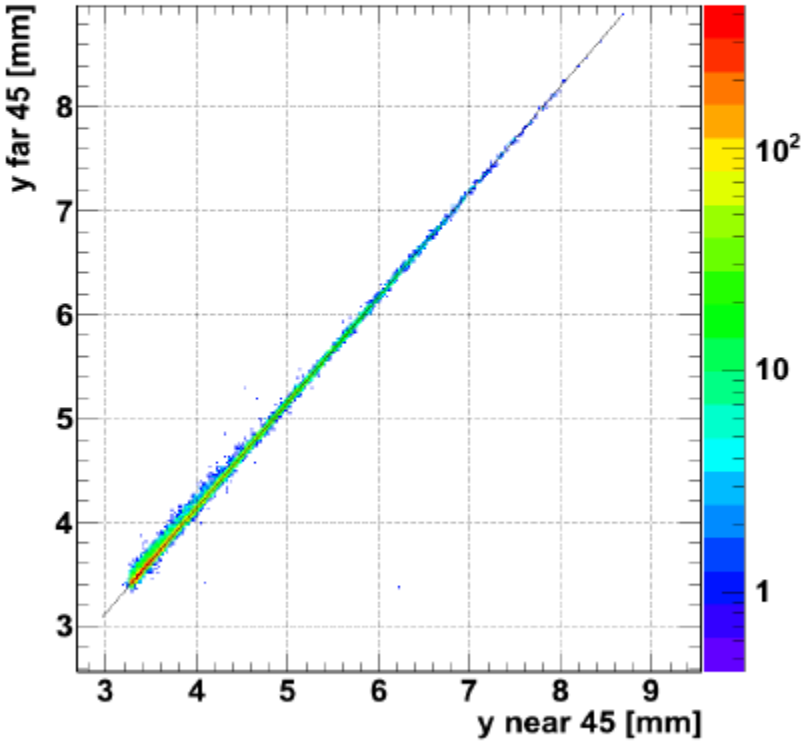
Diagonals analysed independently

Cuts on momentum transfer





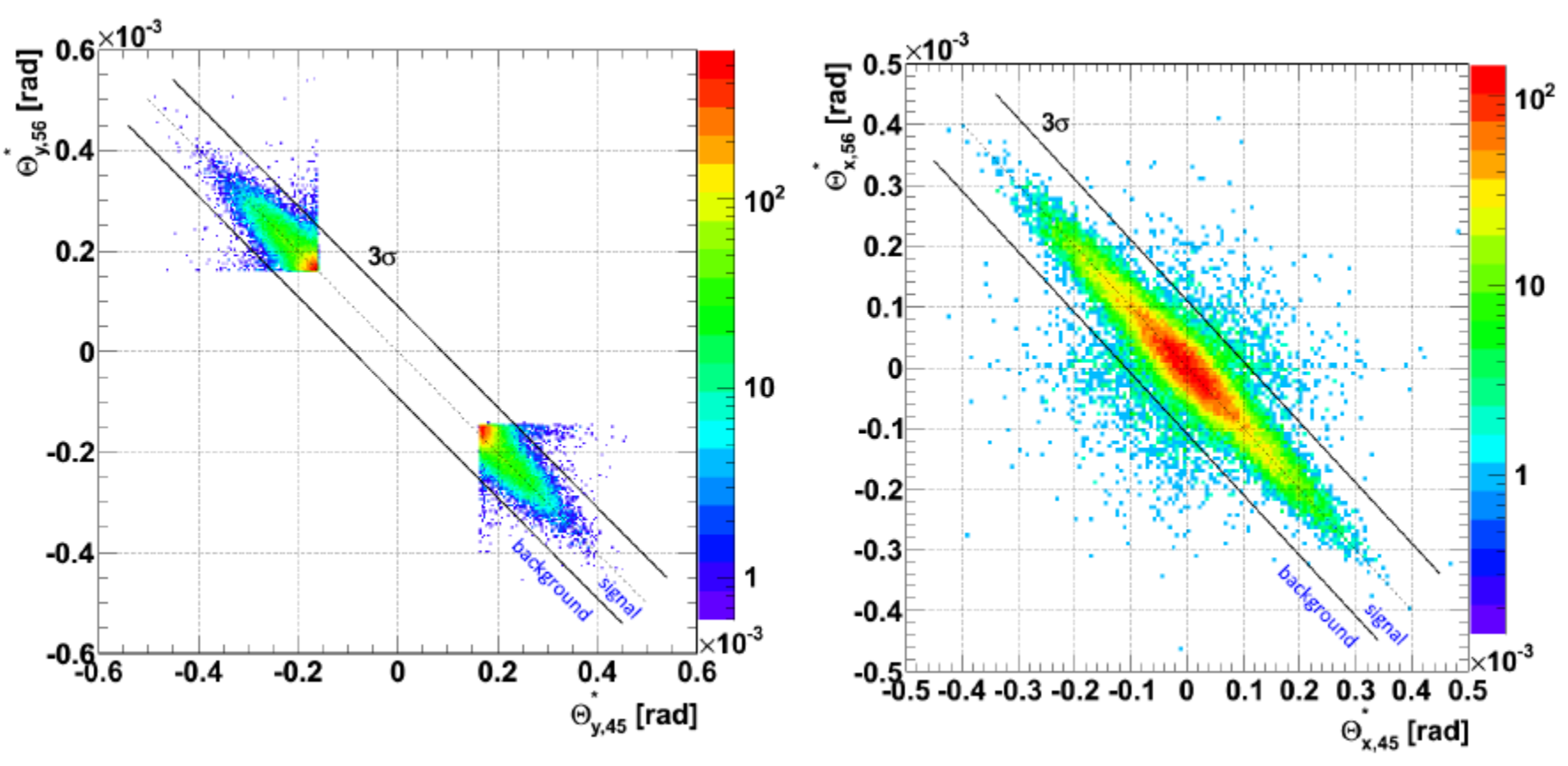
$|x| < 3\sigma_x$ @ $L_x = 0$



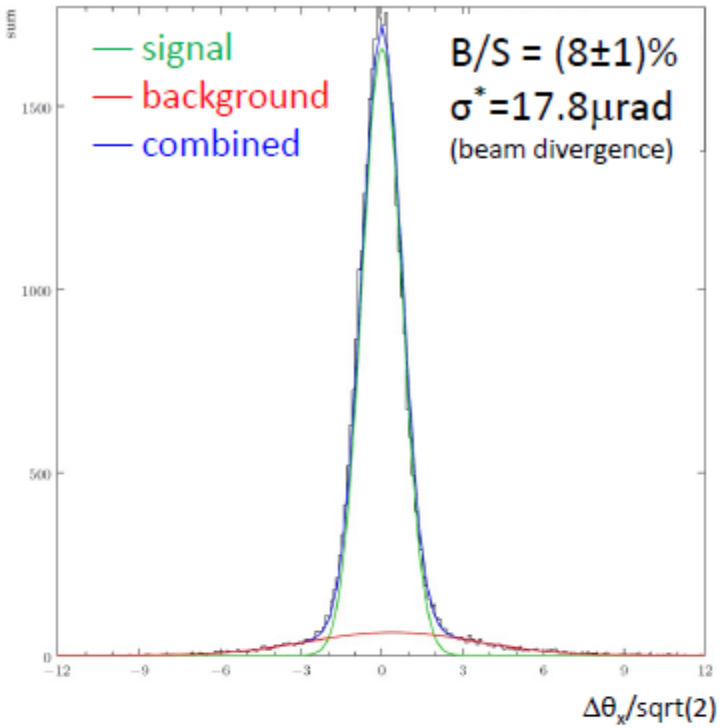
$y_{RP\ near,45} \leftrightarrow y_{RP\ far,45}$

(dLy/ds≈0)

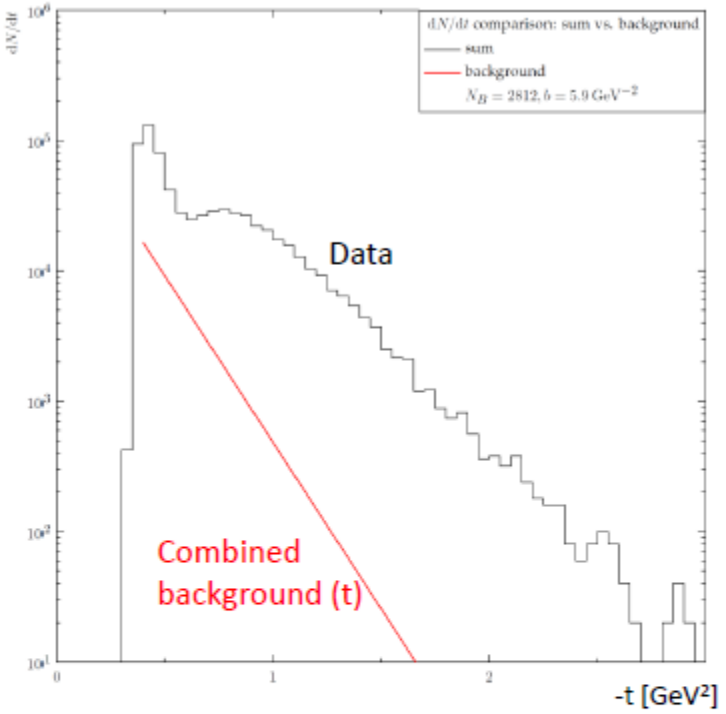
Elastic collinearity cuts



Background and t-resolution determination



Signal to background normalisation
(also as a function of $\Delta\theta_y$)



Signal vs. background (t)

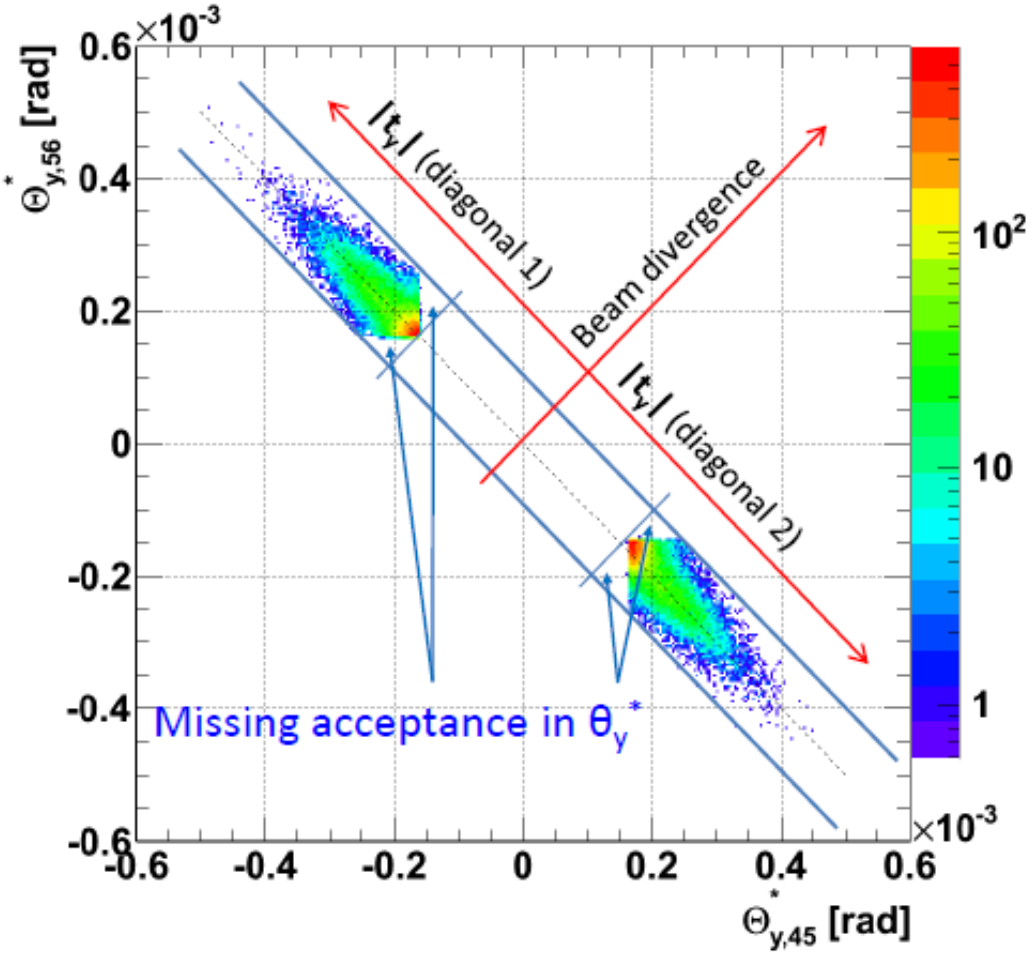
σ^* → t-reconstruction resolution:

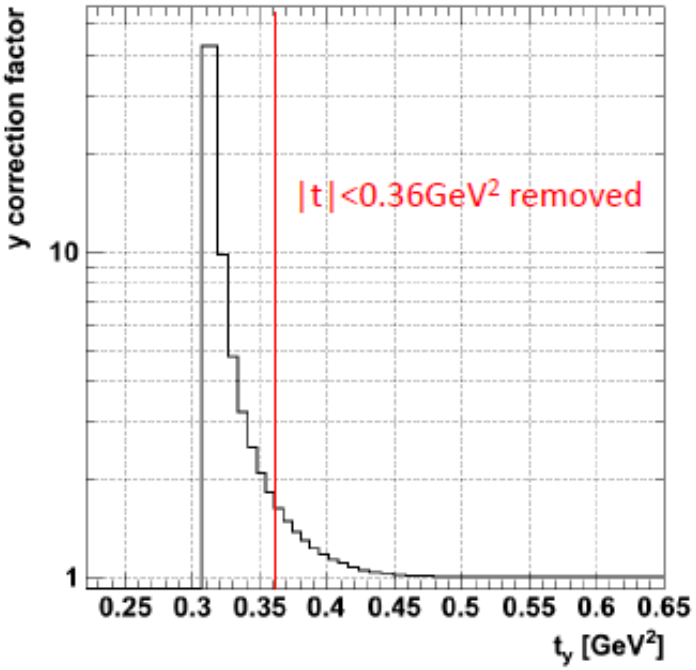
$$\frac{\sigma(t)}{t} = \frac{\sqrt{2}\,p\,\sigma^*}{\sqrt{t}}:$$

0.4 GeV^2 : 14 %
1 GeV^2 : 8.8 %
3 GeV^2 : 5.1 %

|t|=0.4GeV^2: B/S = (11±2)%
|t|=0.5GeV^2: B/S = (19±3)%
|t|=1.5GeV^2: B/S = (0.8±0.3)%

t_y acceptance correction





Correction error (t_y):

0.31 GeV^2 : 30%

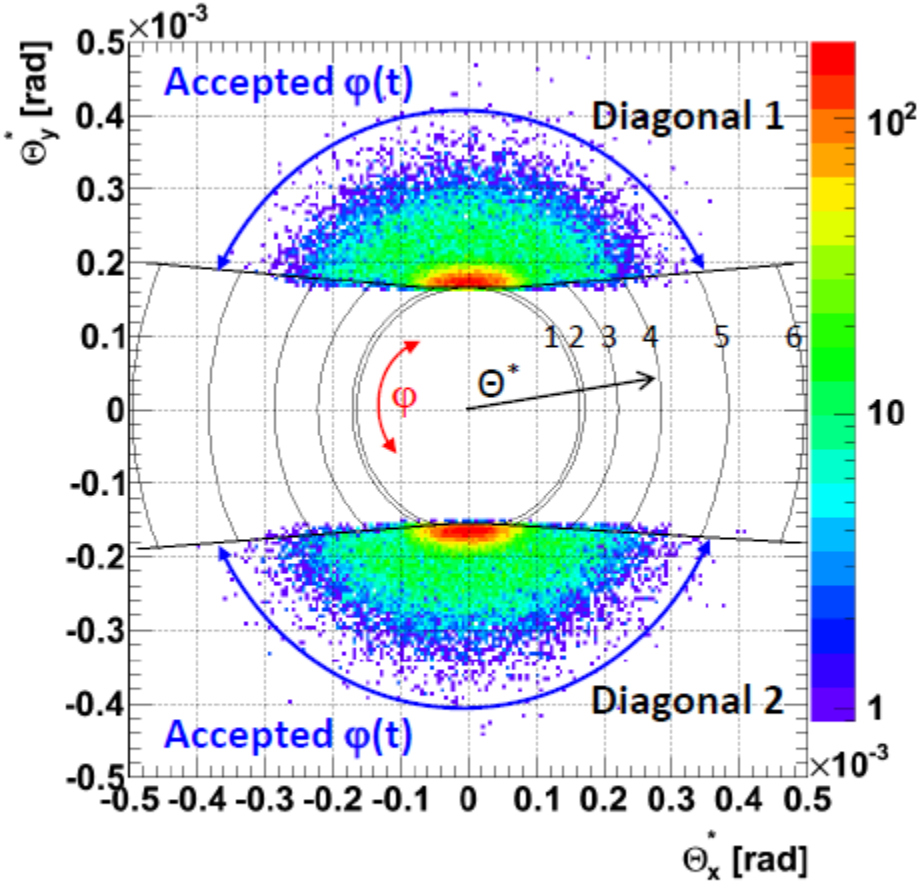
0.33 GeV^2 : 11%

0.35 GeV^2 : 2%

0.4 GeV^2 : 0.8%

0.5 GeV^2 : 0.1%

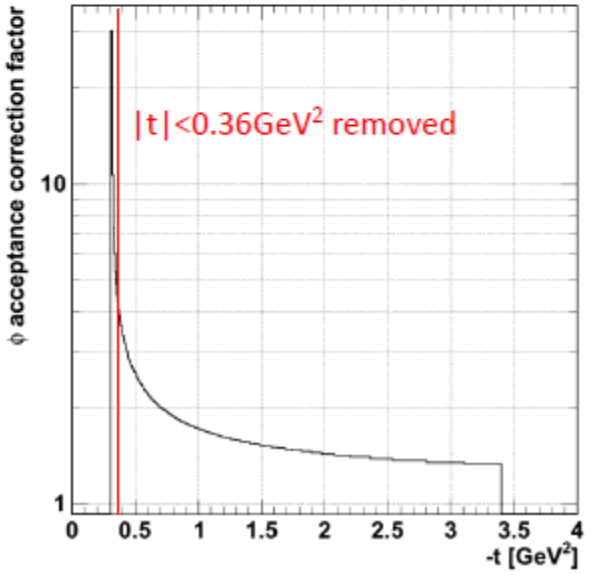
ϕ acceptance correction



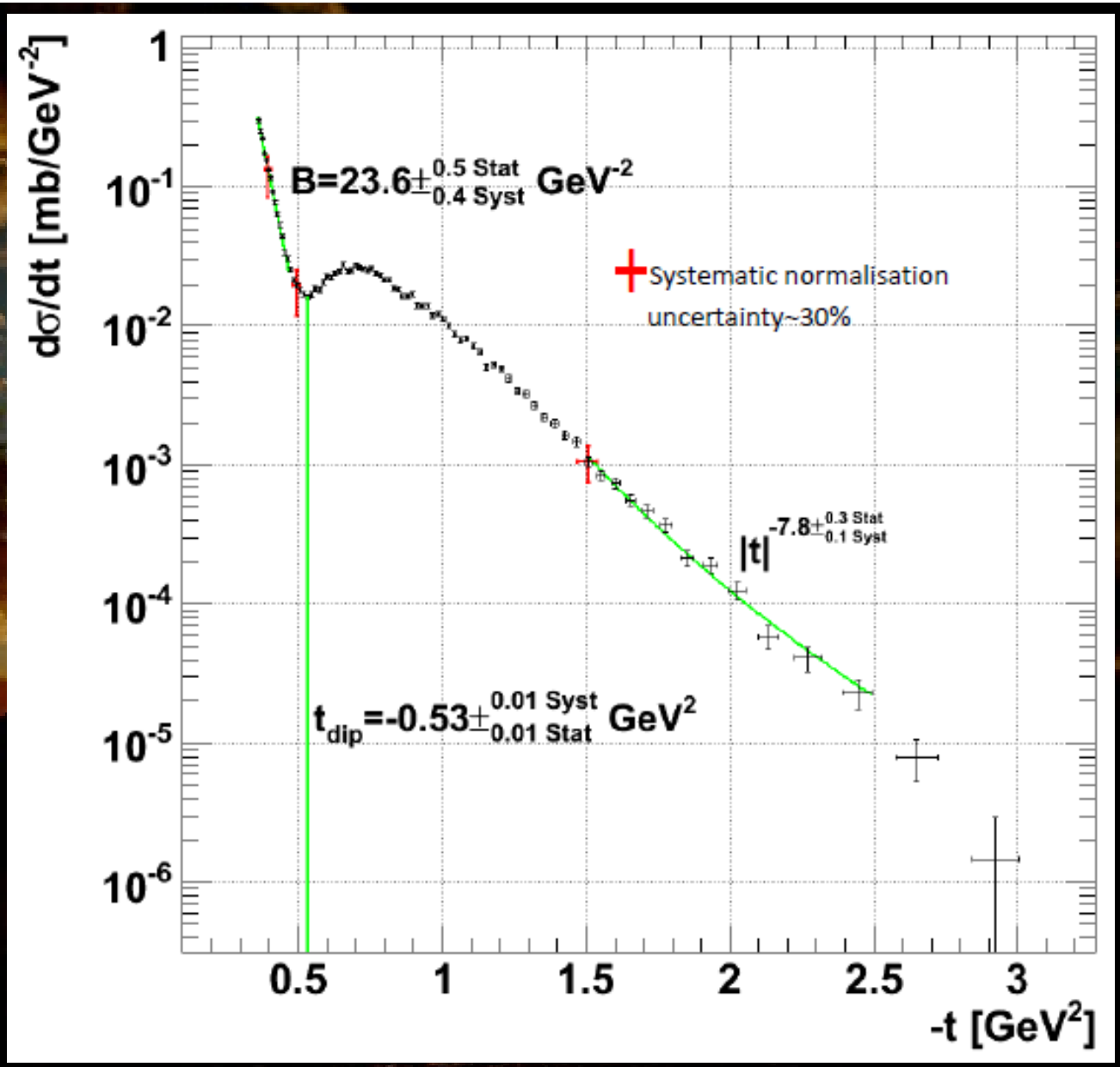
Critical at low t-acceptance limit

Total φ-acceptance correction

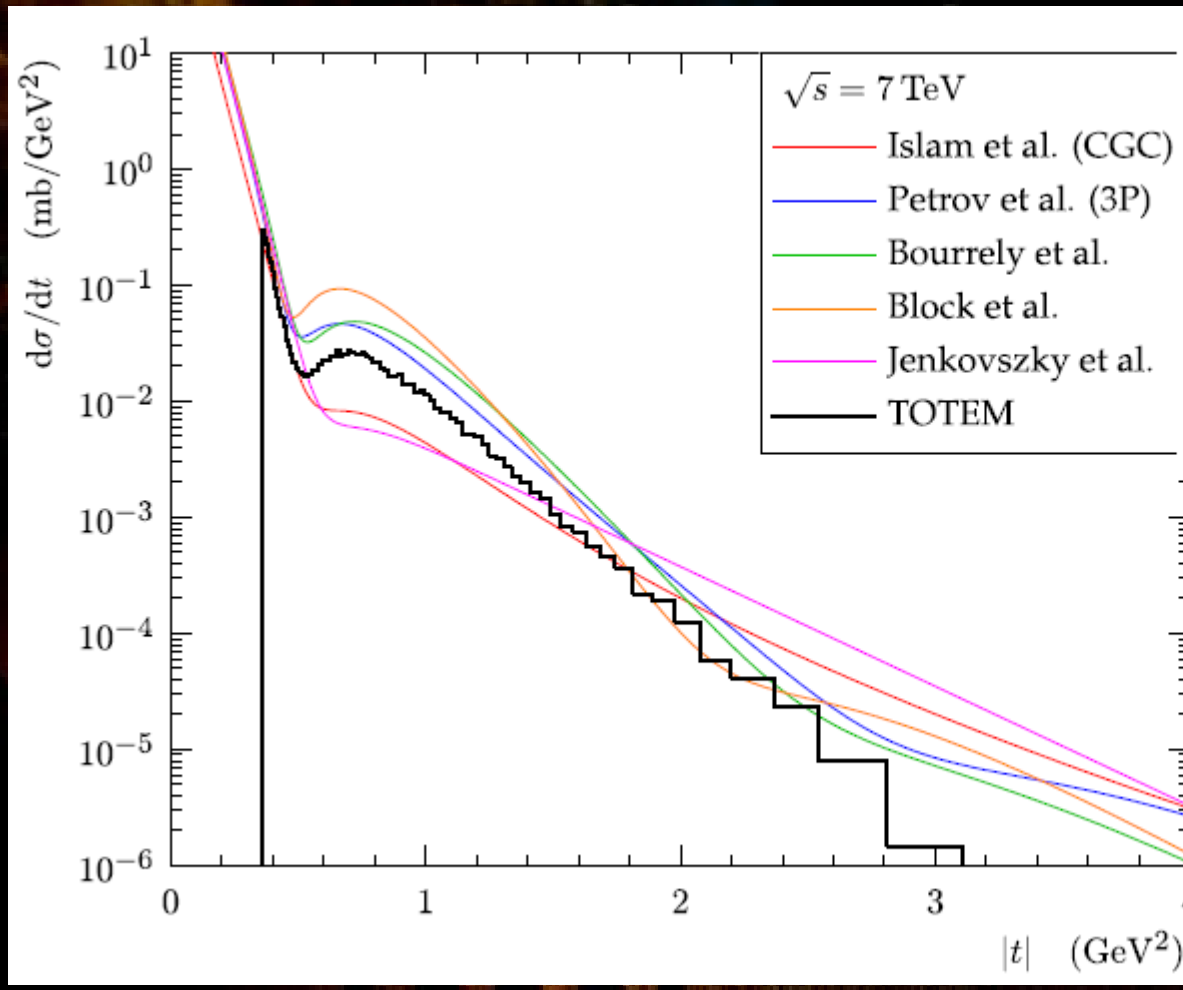
No.	t [GeV²]	Θ* [rad]	Accepted φ (2 diag.) [°]	φ accept. correct. factor
1	**0.33**	1.65E-04	38.6	**9.3±4.7%**
2	**0.36**	1.71E-04	76.4	**4.7±1.8%**
3	**0.60**	2.21E-04	162.5	**2.2±0.3%**
4	**1.00**	2.86E-04	209.8	**1.7±0.1%**
5	**1.80**	3.83E-04	246.3	**1.5**
6	**3.00**	4.95E-04	269.0	**1.3**



Elastic scattering cross-section



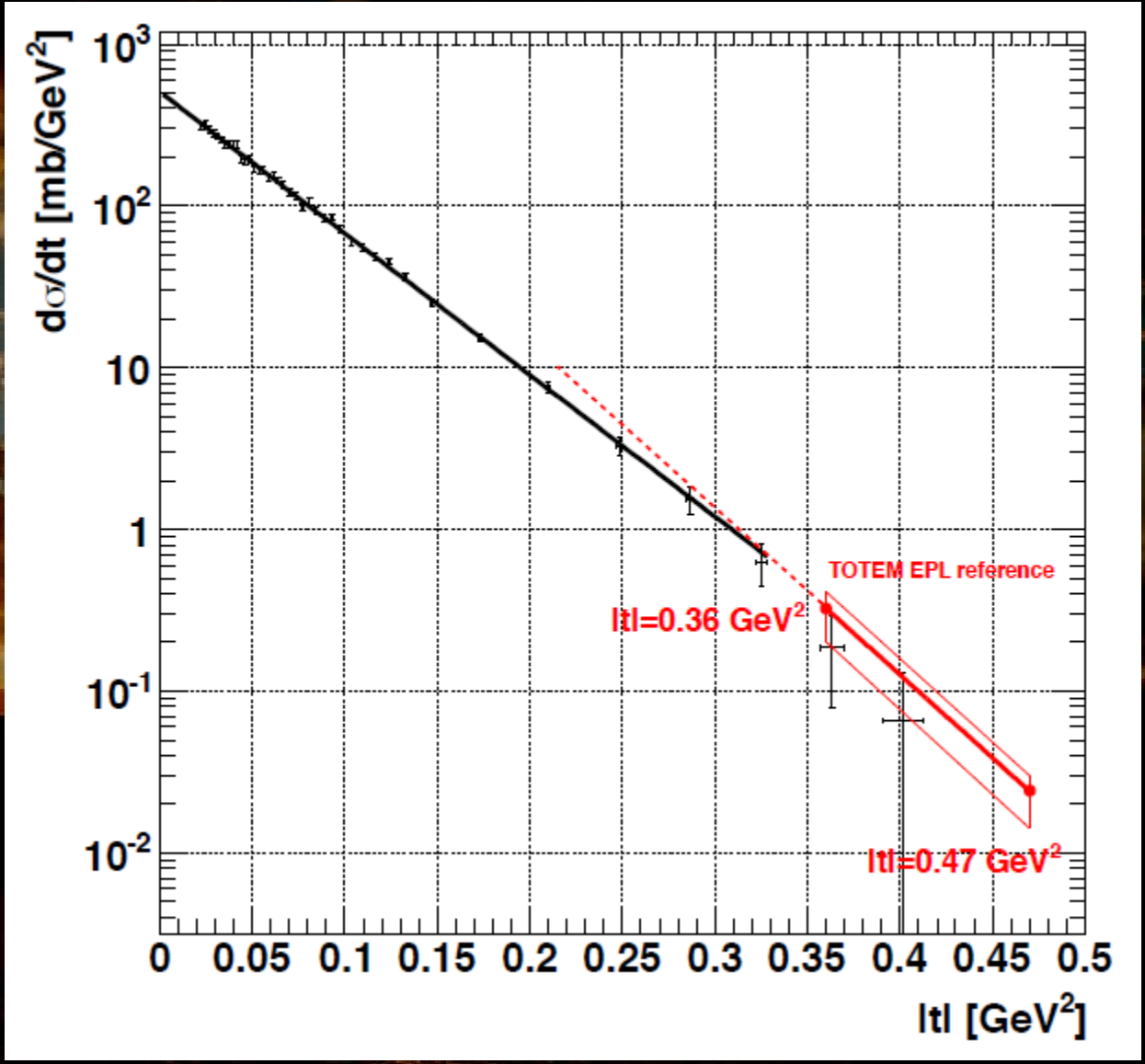
Comparison with models – selective result!



	B (t=-0.4 GeV^2)	t_{DIP}	t^{-n} [1.5–2.5 GeV^2]
Islam et al. (CGC)	20.2	0.60	5.0
Petrov et al. (3P)	**23.3**	**0.51**	**7.0**
Bourrely et al.	**22.0**	**0.54**	**8.4**
Block et al.	25.3	0.48	10.4
Jenkovszky et al.	20.1	0.72	4.2
TOTEM	23.6 ± 0.5	0.53 ± 0.01	7.8 ± 0.3

G. Antchev et al, TOTEM Collaboration, Eur. Phys. Lett. 95 (2011) 41001

New result at low t just released



New result at low t published

Elastic exponential slope: $B|_{t=0} = (20.1 \pm 0.2^{(stat)} \pm 0.3^{(syst)})\ \mathrm{GeV}^{-2}$

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

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

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

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

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

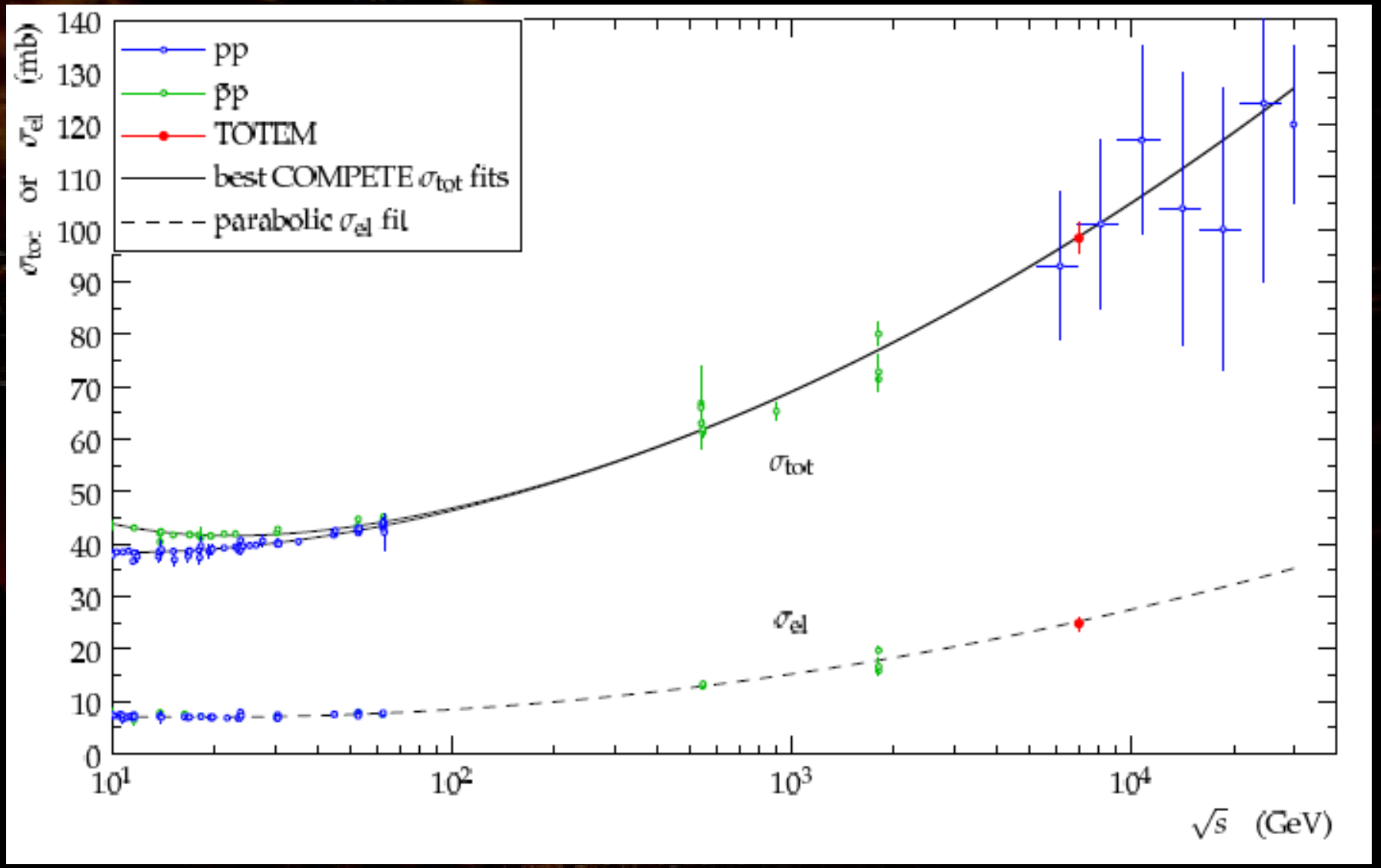
σ_{inel} (CMS) $= (68.0 \pm 2.0^{(syst)} \pm 2.4^{(lumi)} \pm 4.0^{(extrap)})$ mb

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

Σ_{inel} (ALICE) $= (72.7 \pm 1.1^{(mod)} \pm 5.1^{(lumi)})$ mb

CERN-PH-EP-2011-158; EPL 96 (2011) 21002

Total cross section at LHC determined first time



G. Antchev et al, TOTEM Collaboration, EPL 96 (2011) 21002

TOTEM Collaboration at CERN LHC

The TOTEM Collaboration

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7 countries,
15 institutions,
~ 80 persons.