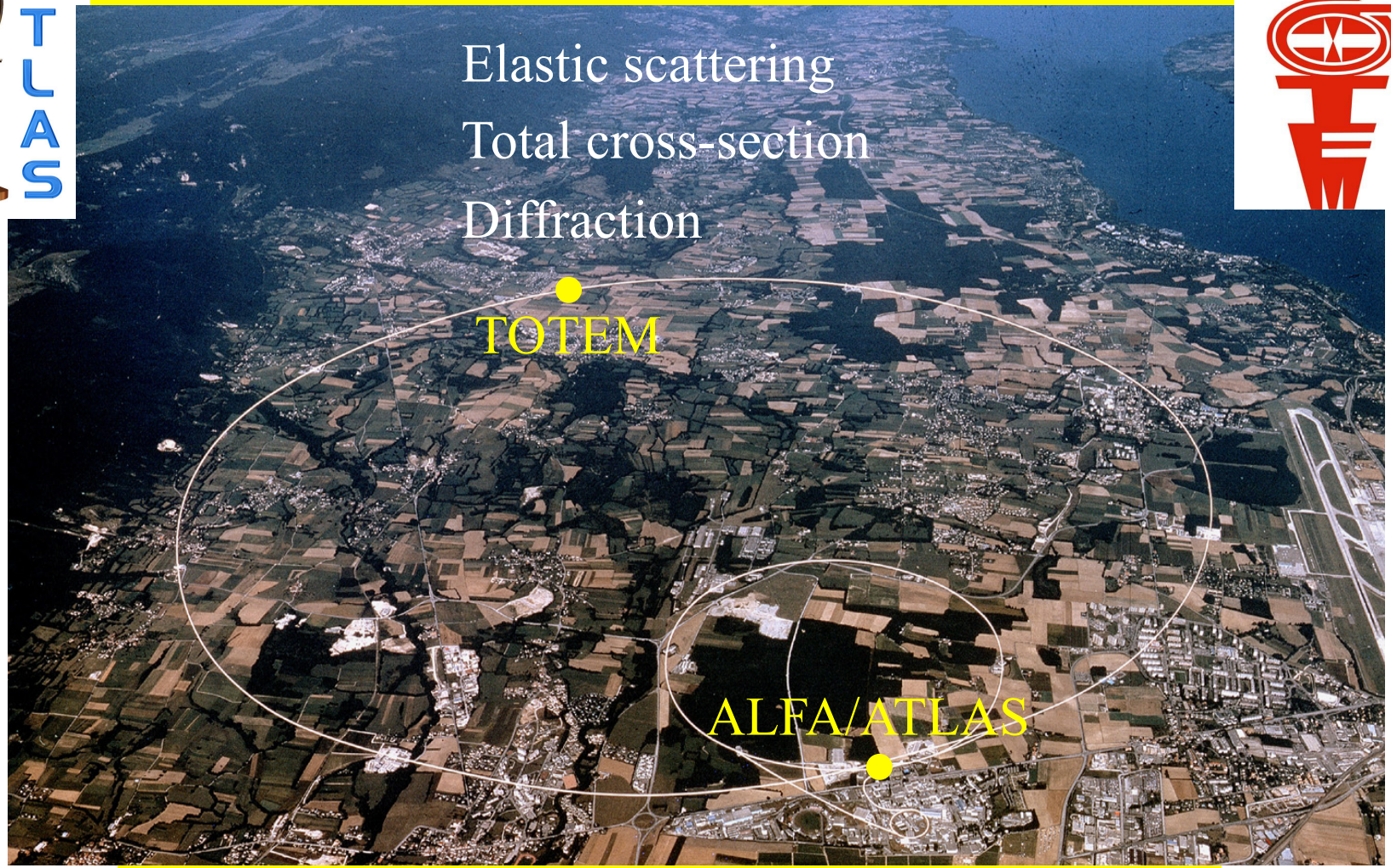
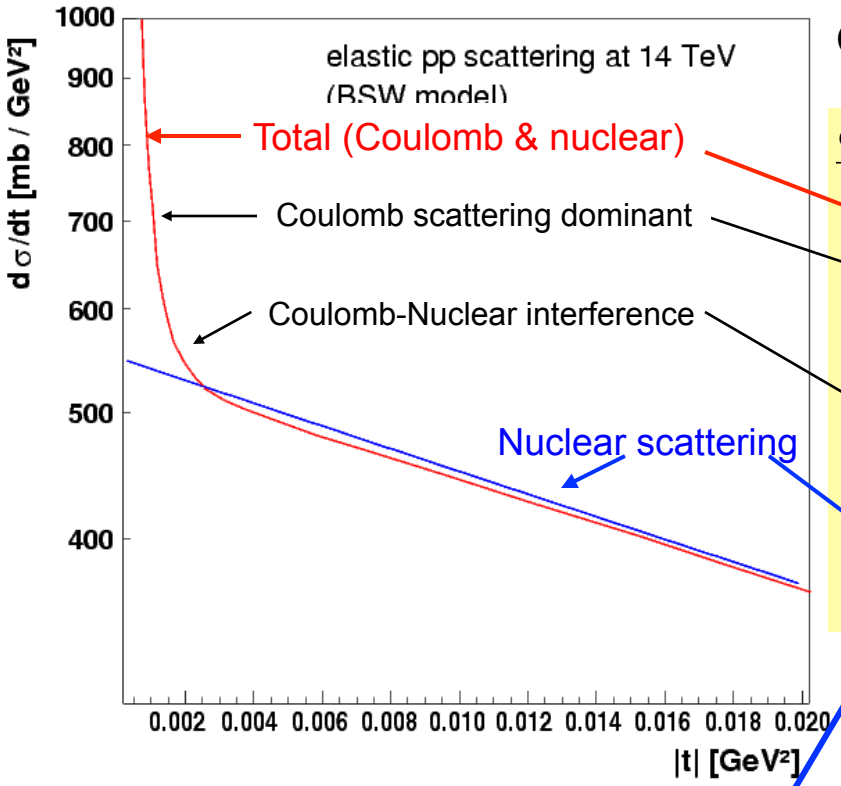
ALFA/ATLAS and TOTEM at the LHC



Karsten Eggert
on behalf of the ATLAS and TOTEM Collaborations

Hadron Collider Physics Symposium 2011 (14 – 18 Nov.) Paris, France

Total Cross-Section and Elastic Scattering at low |t|



Optical Theorem: $\sigma_{tot} = \frac{4\pi}{s}\Im\left(T_{elastic,nuclear}(t=0)\right)$

$$\frac{d\sigma}{dt} = \frac{4\pi\alpha^2 (hc)^2 G^4(t)}{|t|^2} + \frac{\alpha(\rho - \alpha\phi)\sigma_{tot} G^2(t)}{|t|} e^{-B|t|/2} + \frac{\sigma_{tot}^2 (1+\rho^2)}{16\pi (hc)^2} e^{-B|t|}$$

ALFA Approach:
Measure dσ/dt down into Coulomb region and use el.-mag. cross-section for normalisation

α = fine structure constant
ϕ = relative Coulomb-nuclear phase
G(t) = nucleon el.-mag. form factor = $(1 + |t| / 0.71)^{-2}$
ρ = $\Re / \Im\ [T_{elastic,nuclear}(t = 0)]$

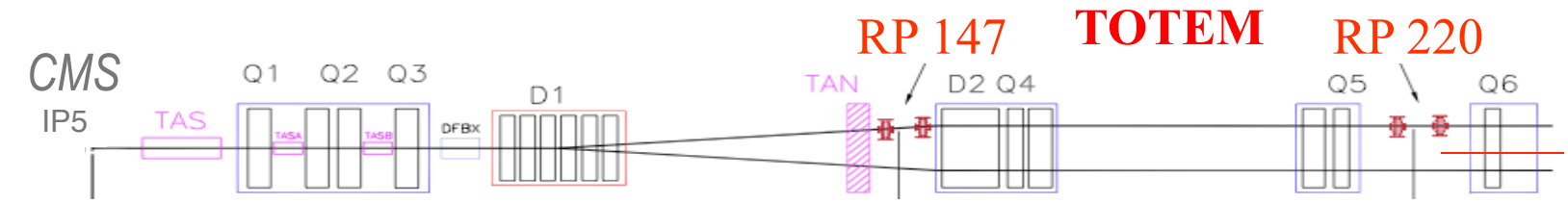
TOTEM Approach:
Measure the exponential slope B in the t-range 0.002 - 0.2 GeV^2 , extrapolate dσ/dt to t=0, measure total inelastic and elastic rates **(all TOTEM detectors provide L1 triggers)**:

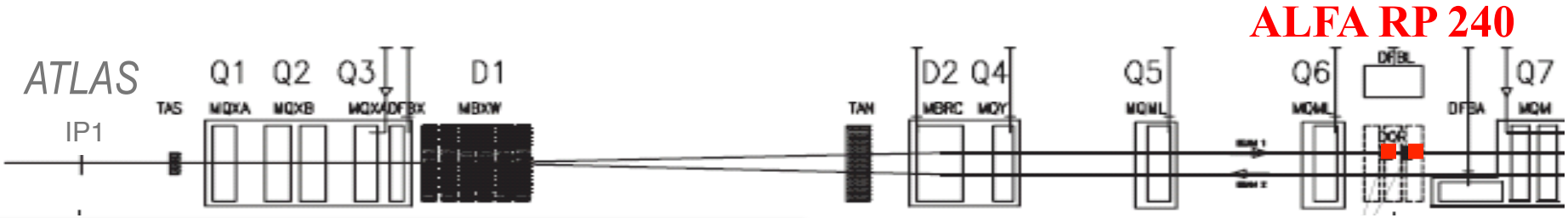
$$L\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \times \left.\frac{dN_{elastic,nuclear}}{dt}\right|_{t=0}$$

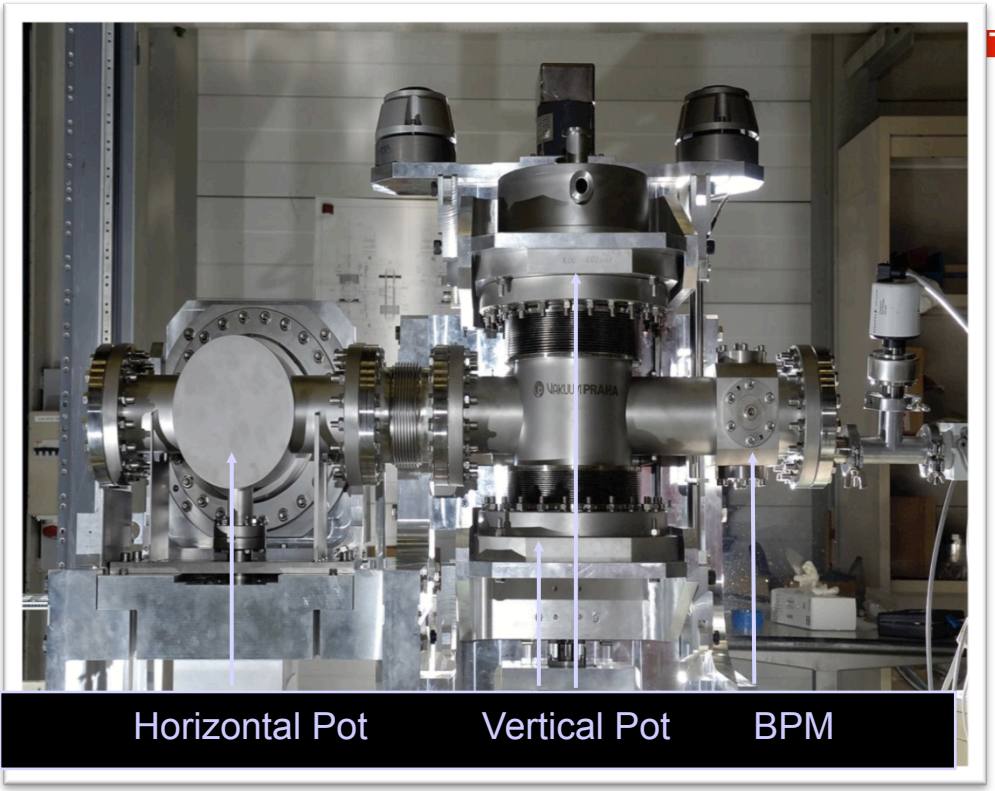
$$L\sigma_{tot} = N_{elastic,nuclear} + N_{inelastic}$$

$$\Rightarrow \quad \sigma_{tot} = \frac{16\pi}{1+\rho^2} \times \frac{\left.(dN_{elastic,nuclear}/dt)\right|_{t=0}}{N_{elastic,nuclear} + N_{inelastic}}$$

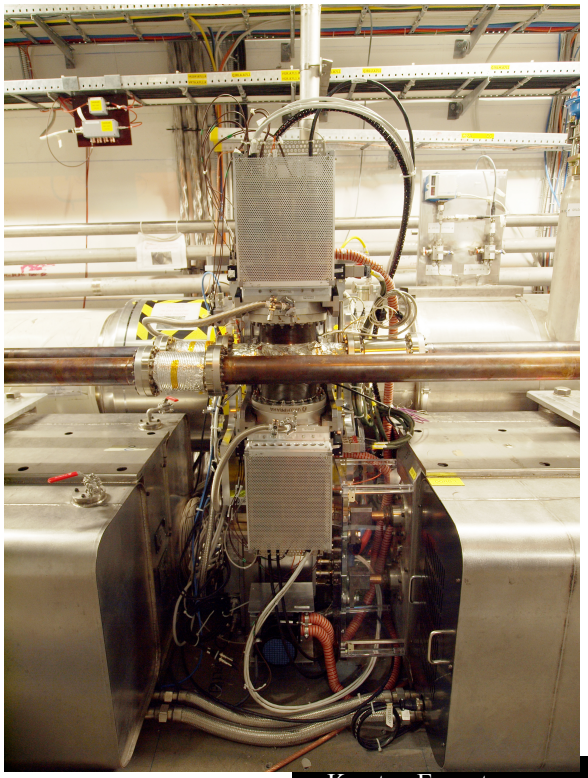
Beam Lines with Roman Pots



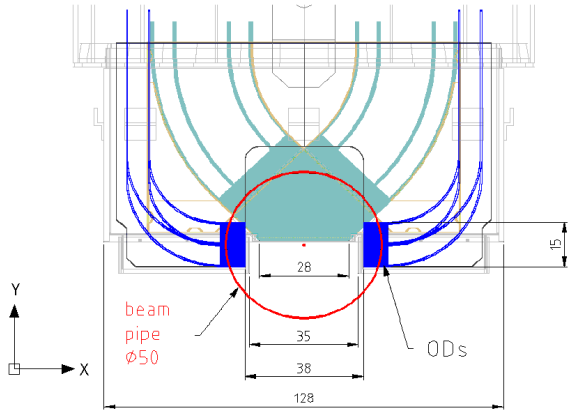




TOTEM



The ALFA Scintillating Fiber Detector

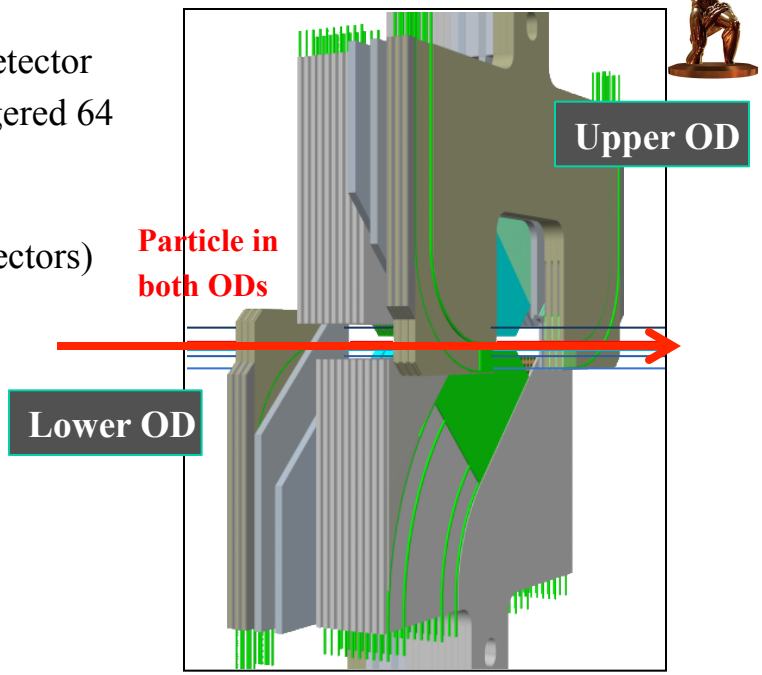


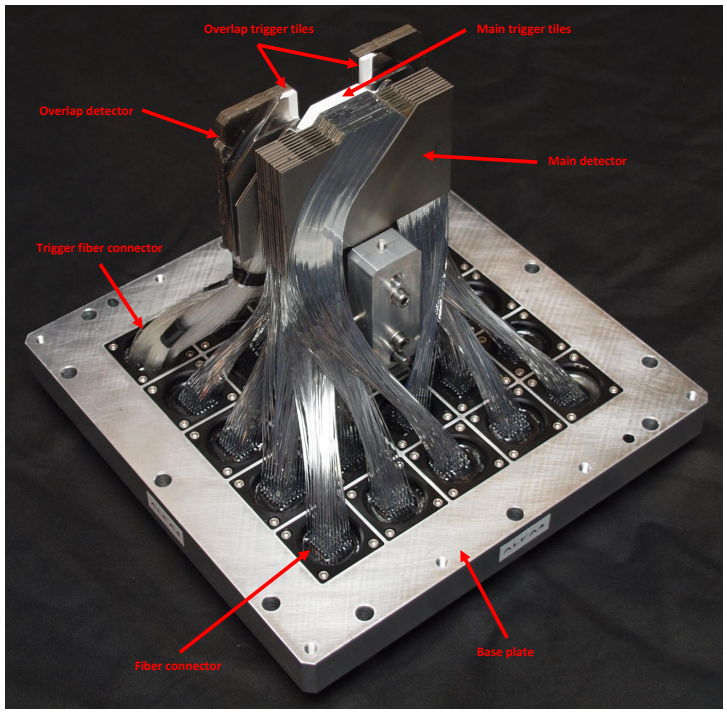
Principle of multi-layer fiber detector

2 x 10 planes (u and v) of staggered 64 fibers (0.5 mm)

Overlap detectors for position calibration (upper-to-lower detectors)

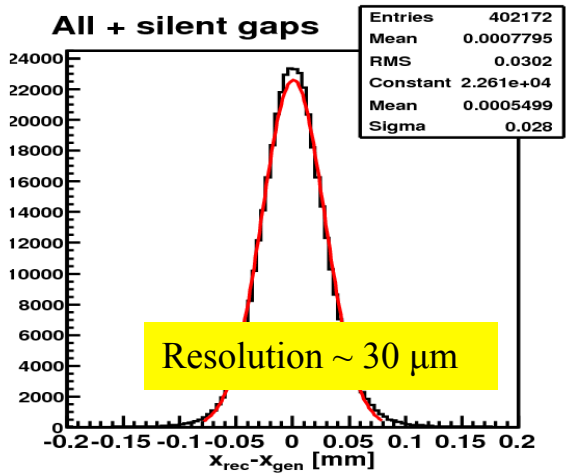
Trigger scintillators



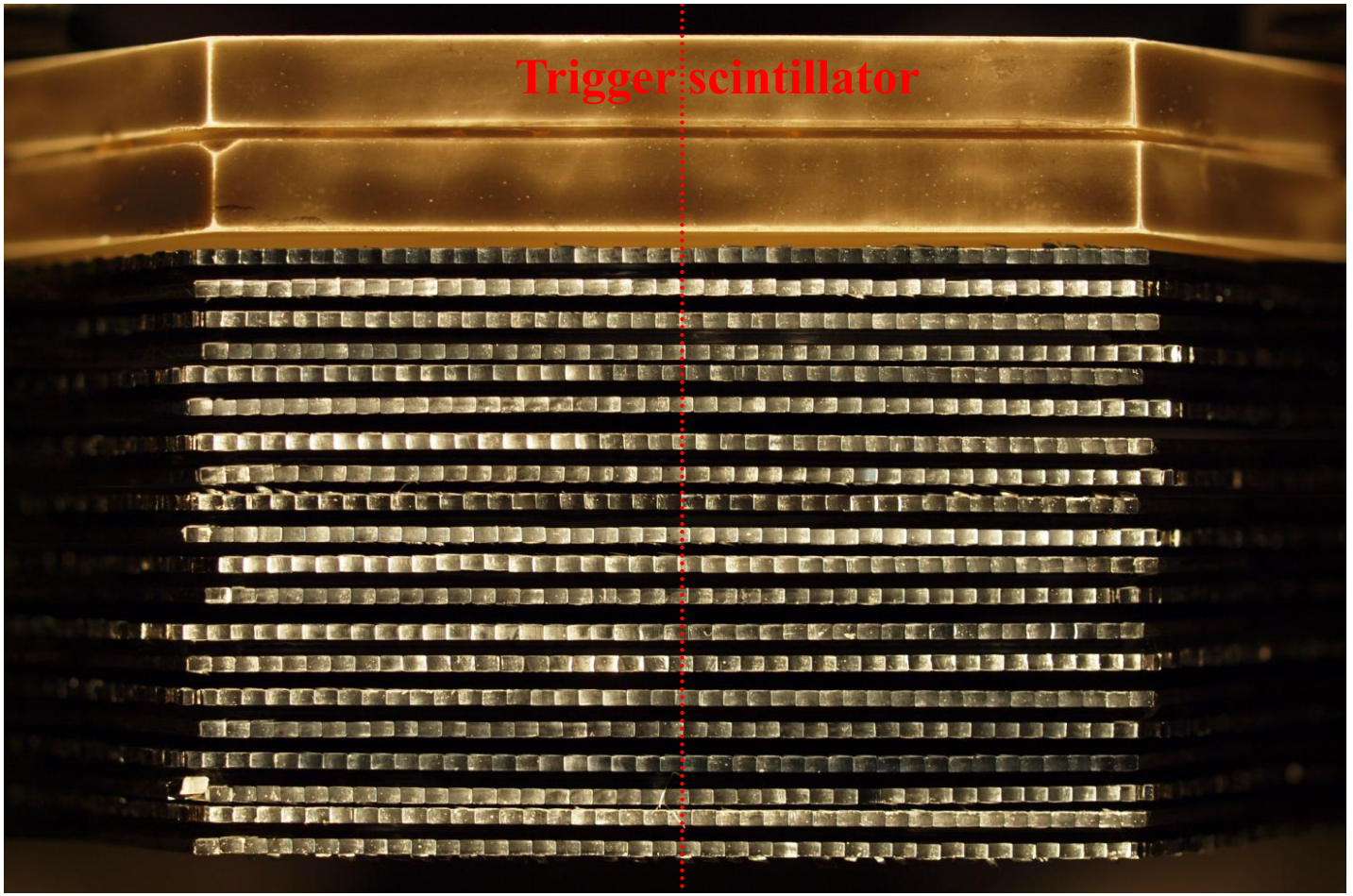


2 stations
with a lever arm of 4 m

Measurement of
position and angle
in both projections



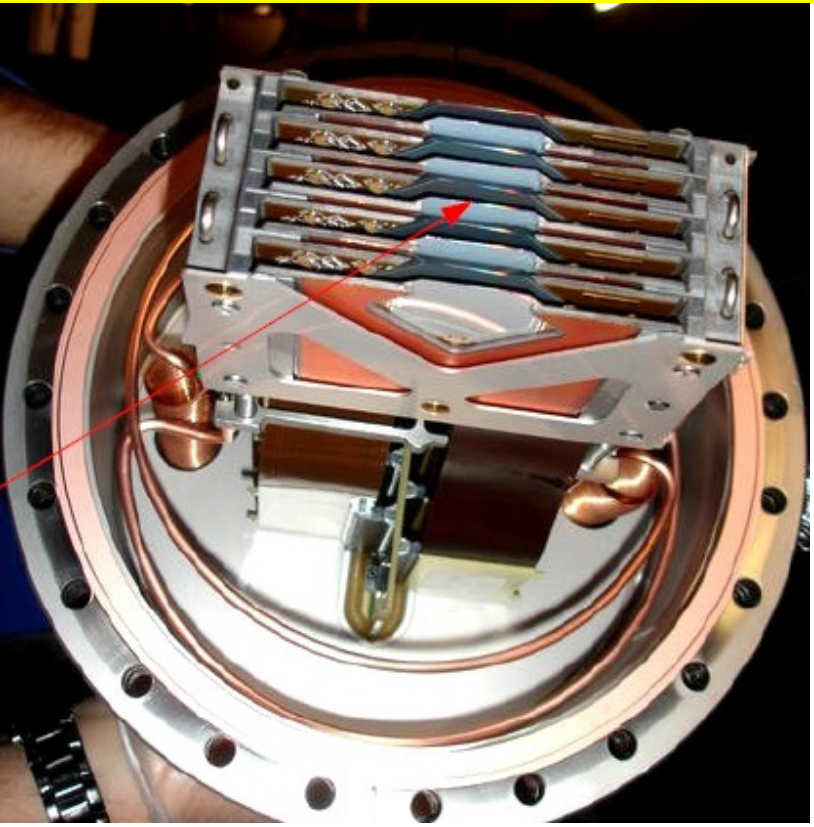
Top-View of the ALFA scintillating fiber detector

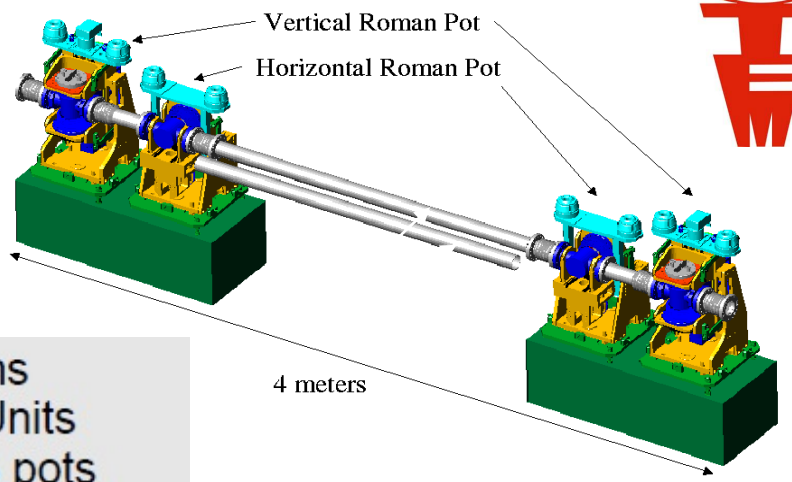


20 fiber planes in u & v

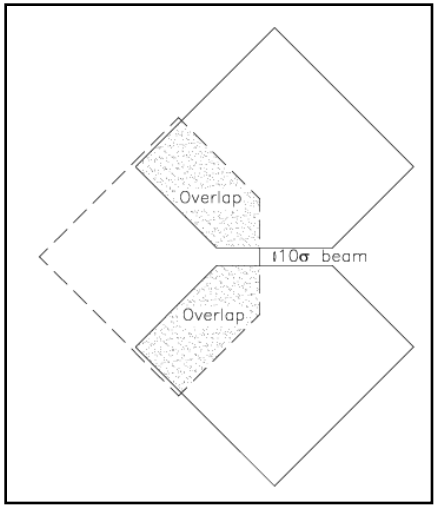
2 trigger scintillators

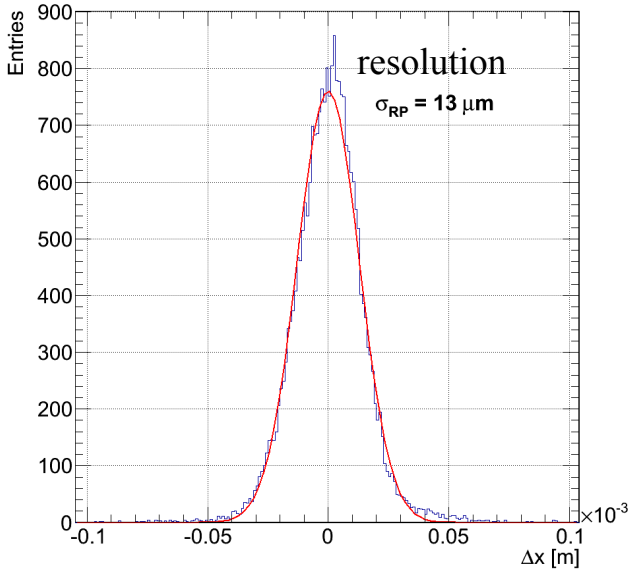
The TOTEM Silicon Detectors





4 Stations
→ 2 Units
→ 3 pots
1 BPM
(Beam Position Monitor)





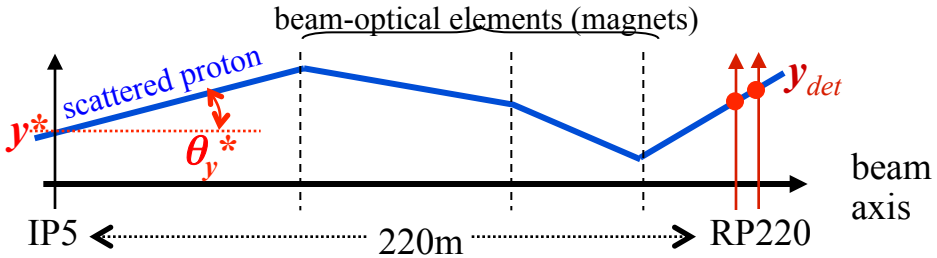
Edgeless Silicon Detectors (< 50 μm)
10 planes (u & v) with 60 μm strip
Horizontal Detector:
Track alignment
Diffraction

Beam Optics

(x^*, y^*): vertex position

(θ_x^*, θ_y^*): emission angle: $t \approx -p^2 (\theta_x^{*2} + \theta_y^{*2})$

$\xi = \Delta p/p$: momentum loss (diffraction)



$$y_{det} = L_y \theta_y^* + v_y y^*$$

$\beta^* = 90$ m: $L_y = 270$ m, $v_y \approx 0$

→ Reconstruct via track positions

$$x_{det} = L_x \theta_x^* + v_x x^* + D\xi$$

Elastic: $\xi = 0$

$\beta^* = 90$ m: $L_x \approx 0$, $v_x \approx 3$

→ Use derivative (reconstruct via local track angles):

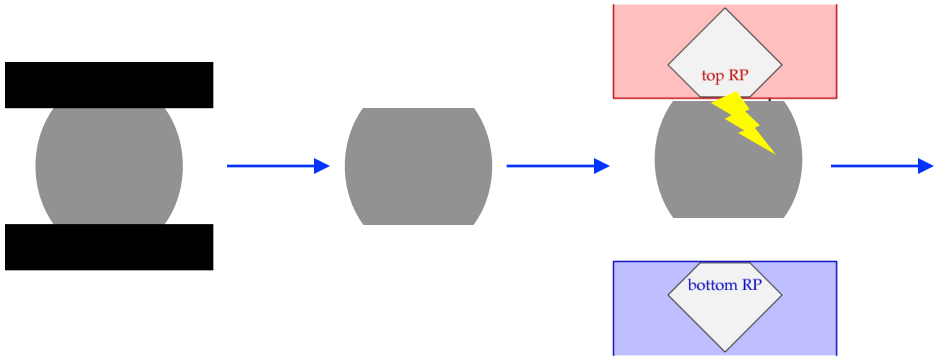
$$\frac{dx_{det}}{ds} = \frac{dL_x}{ds}\theta_x^* + \frac{dv_x}{ds}x^*$$

	Beam width @ vertex $\sigma^*_{x,y} = \sqrt{\varepsilon\beta^*}$	Angular beam divergence $\sigma^*_\Theta = \sqrt{\frac{\varepsilon}{\beta^*}}$	Min. reachable $\lvert t\rvert$ $\lvert t_{min}\rvert = n_\sigma^2 \frac{p^2\varepsilon}{\beta^*}$
Standard optics $\beta^* \sim 1$–3 m	$\sigma_{x,y}^*$ small	$\sigma(\theta_{x,y}^*)$ large	$\lvert t_{min}\rvert \sim 0.3$–$1$ GeV^2
Special optics $\beta^* = 90$ m	$\sigma_{x,y}^*$ large	$\sigma(\theta_{x,y}^*)$ small	$\lvert t_{min}\rvert \sim 10^{-2}$ GeV^2

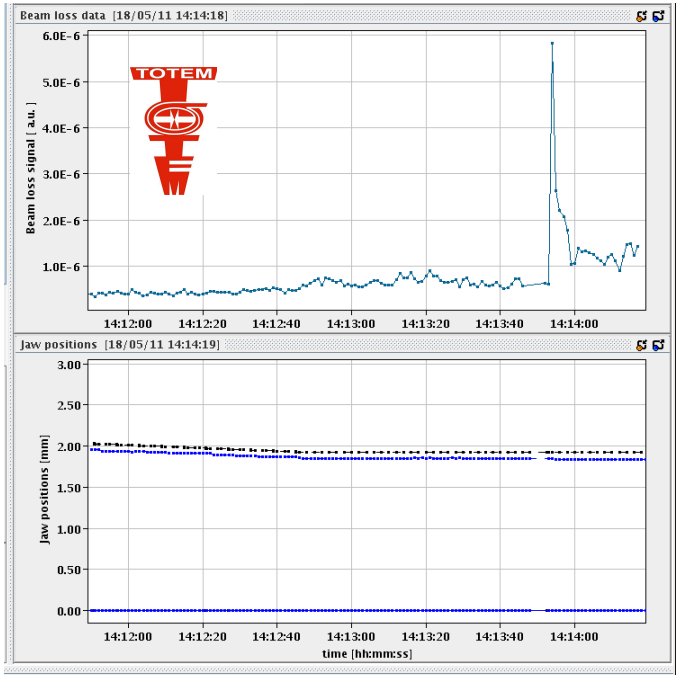
Beam-Based Roman Pot Alignment (Scraping)

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

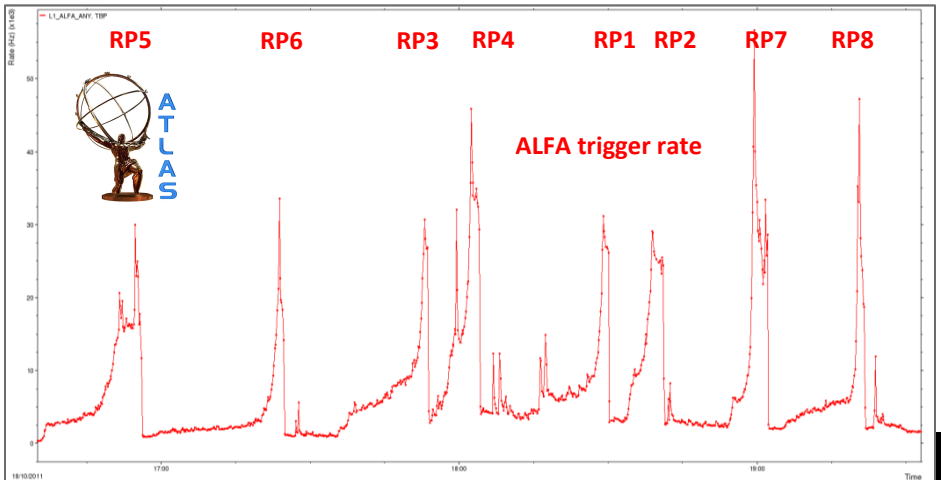


When both top and bottom pots are touching the beam edge:

- they are at the same number of sigmas from the beam centre as the collimator
- the beam centre is exactly in the middle between top and bottom pot

→ **Alignment of the RPs relative to the beam**

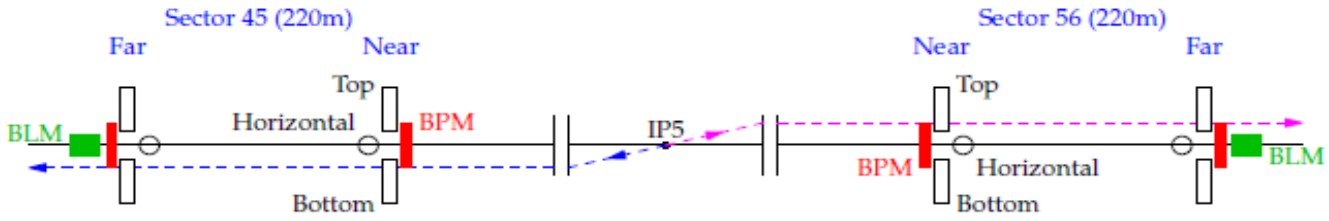
The RP – beam contacts are also registered as spikes in the trigger rate



Elastic Scattering: Proton Tracks (left-right coincidences) (data taking from 2010 with β* = 3.5 m)

Data from 2010

25 σ	1.5 nb^{-1}
20 σ	185 nb^{-1}
18 σ	3867 nb^{-1} in progress
7 σ	9.5 nb^{-1} analysed



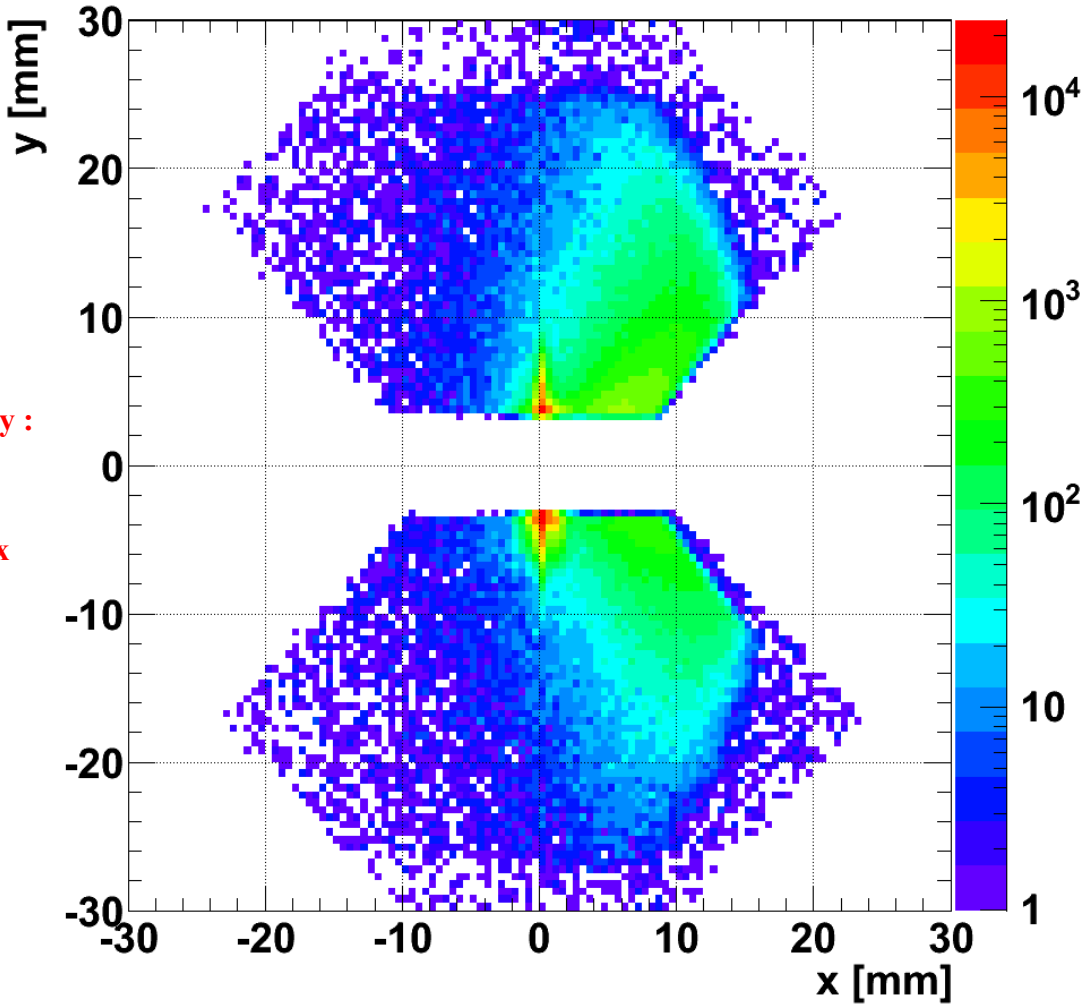
Sector 56

Integrated luminosity : 6.2 $nbarn^{-1}$

β* = 3.5 m

inel. pile-up 0.8 ev/bx

Sector 45



$t = -p^2 \theta^2$

$\xi = \Delta p/p$

$y = L_y \Theta_y$

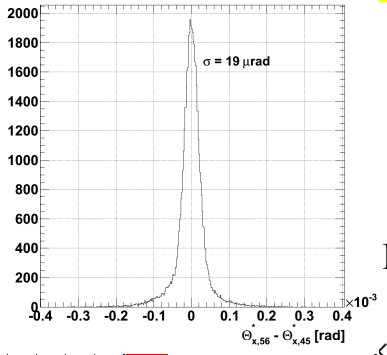
$x = L_x \Theta_x + \xi D$

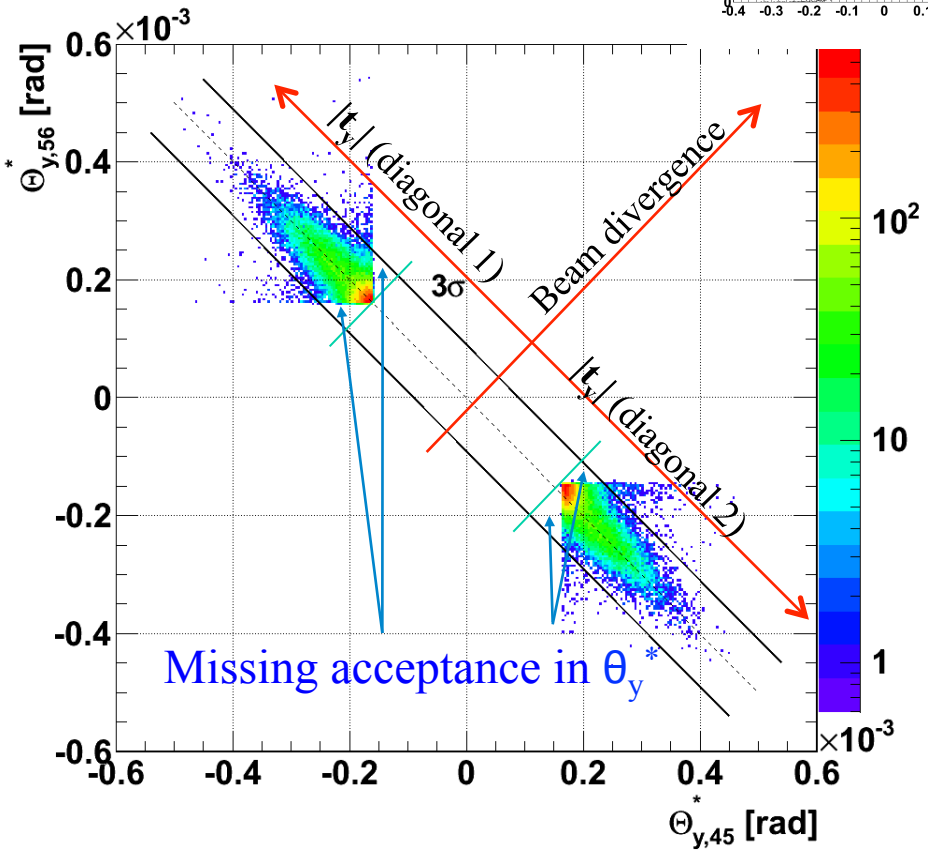
$L_x \sim 0$

Elastic Scattering: Collinearity

Collinearity in θ_y^*

Scattering angle on one side versus the opposite side

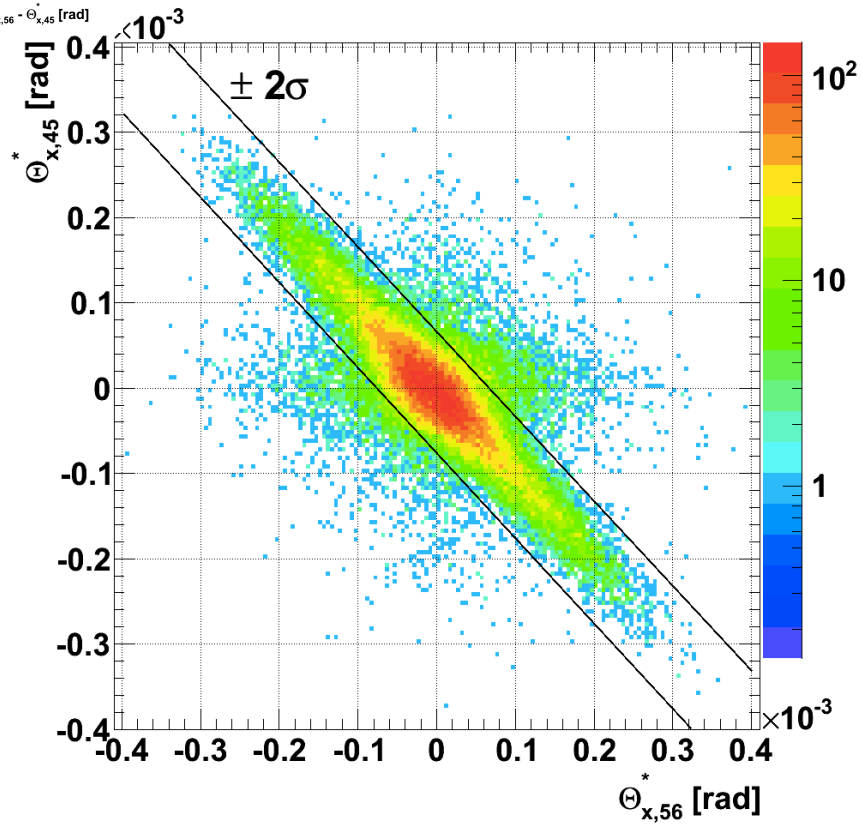




Width in agreement with beam divergence of 17 μrad

Collinearity in θ_x^*

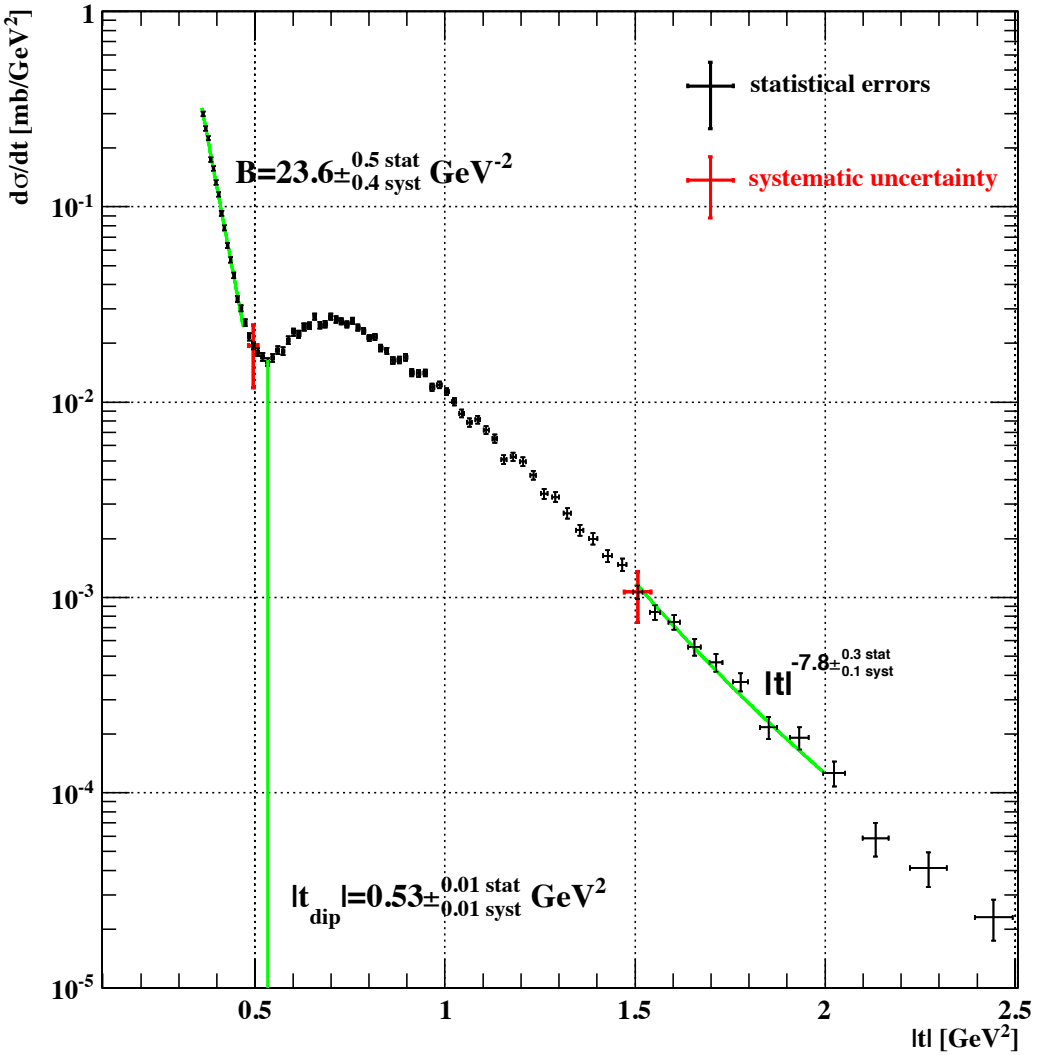
Low ξ, i.e. |x| < 0.4 mm and 2σ cut in $\Delta\theta_y^*$



Θ_x is measured with 5m lever arm spectrometer

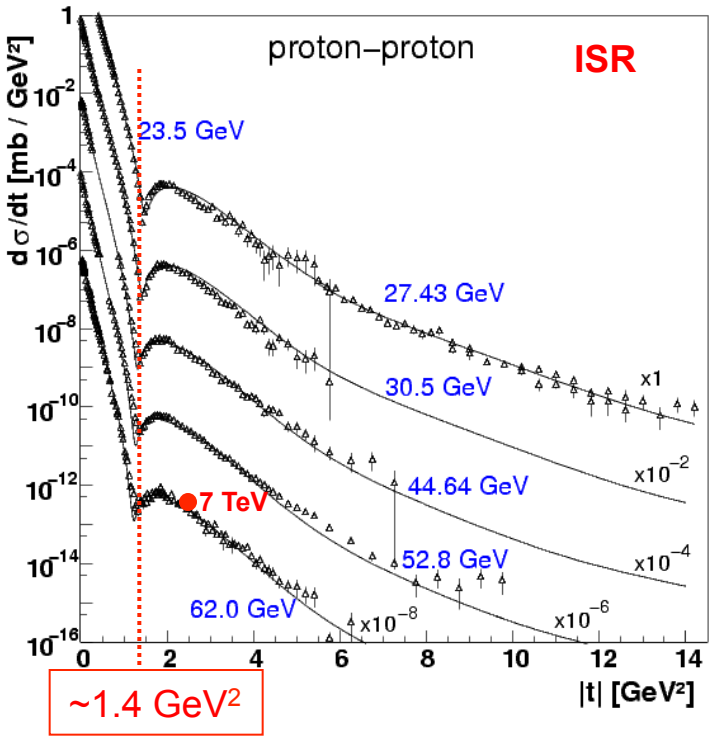
Elastic scattering: differential cross-section

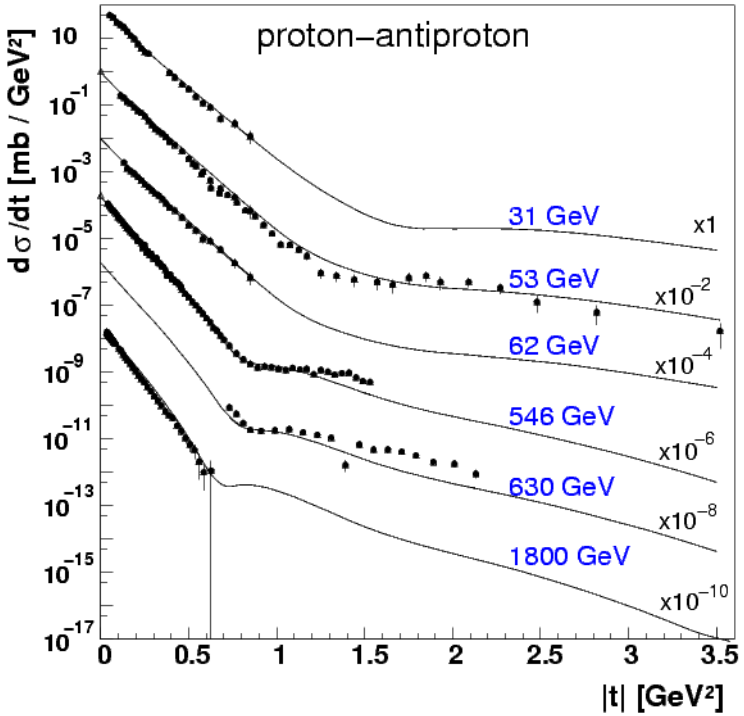
Final result after acceptance corrections and t - smearing



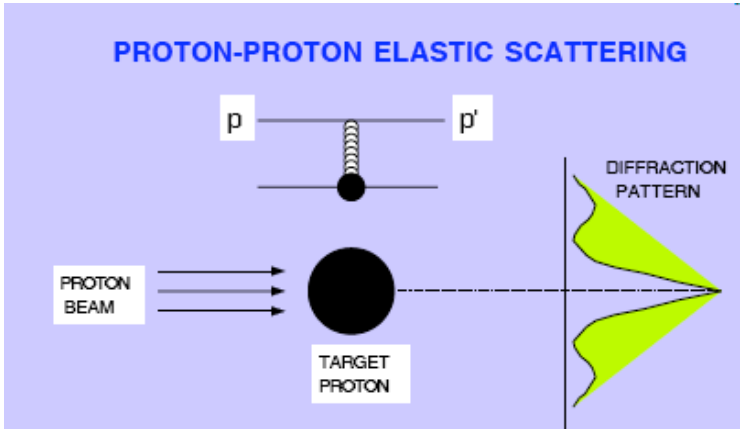
momentum transfer squared

Elastic scattering – from ISR to Tevatron



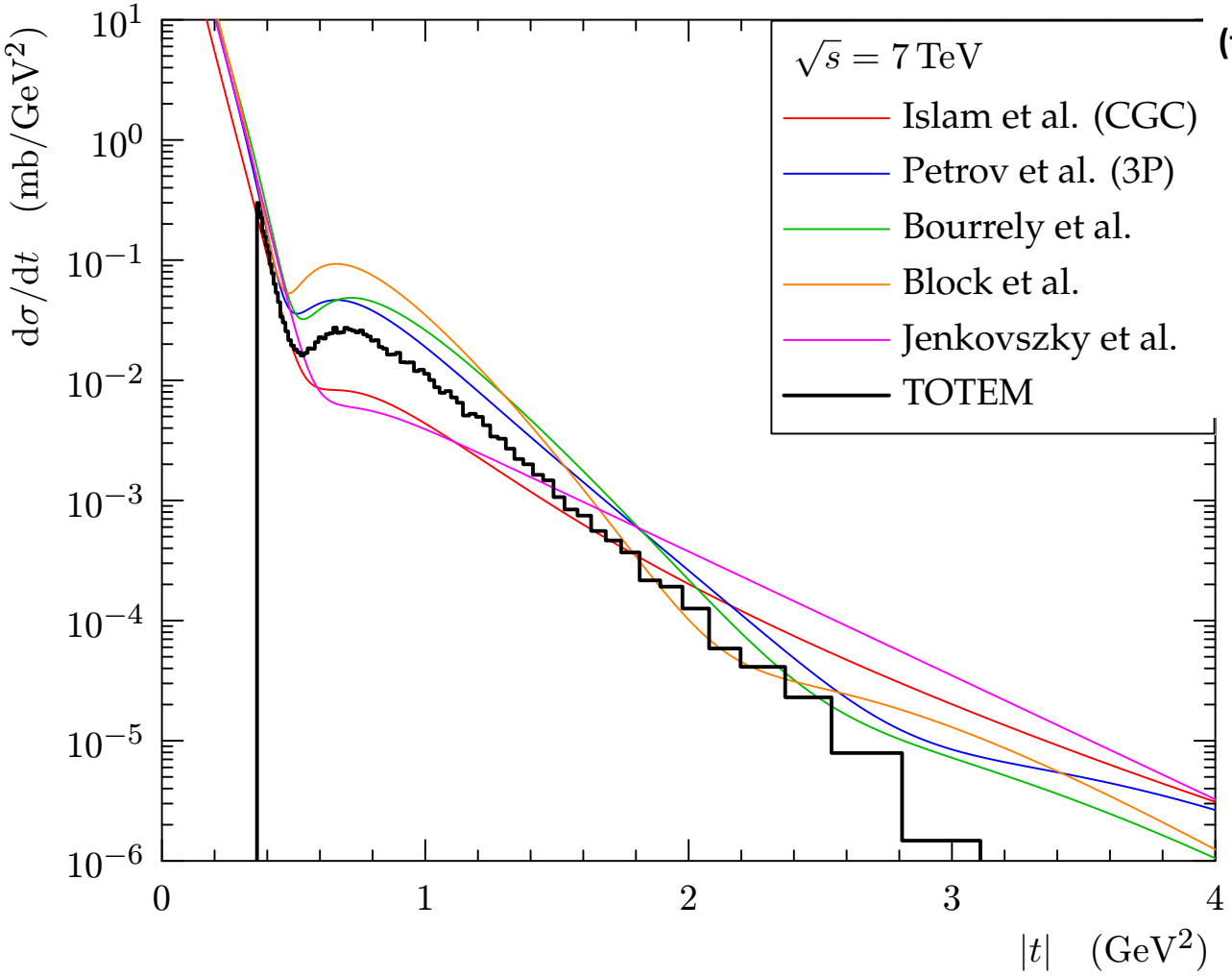


Diffractive minimum: analogous to Fraunhofer diffraction: $|t| \sim p^2 \theta^2$



- 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

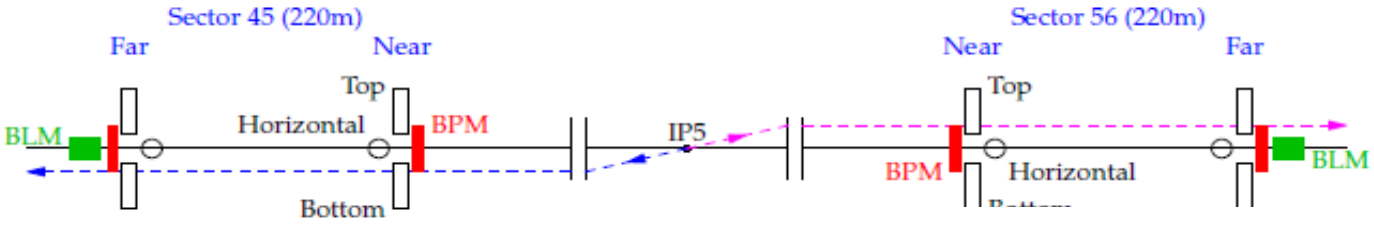
Comparison to some models



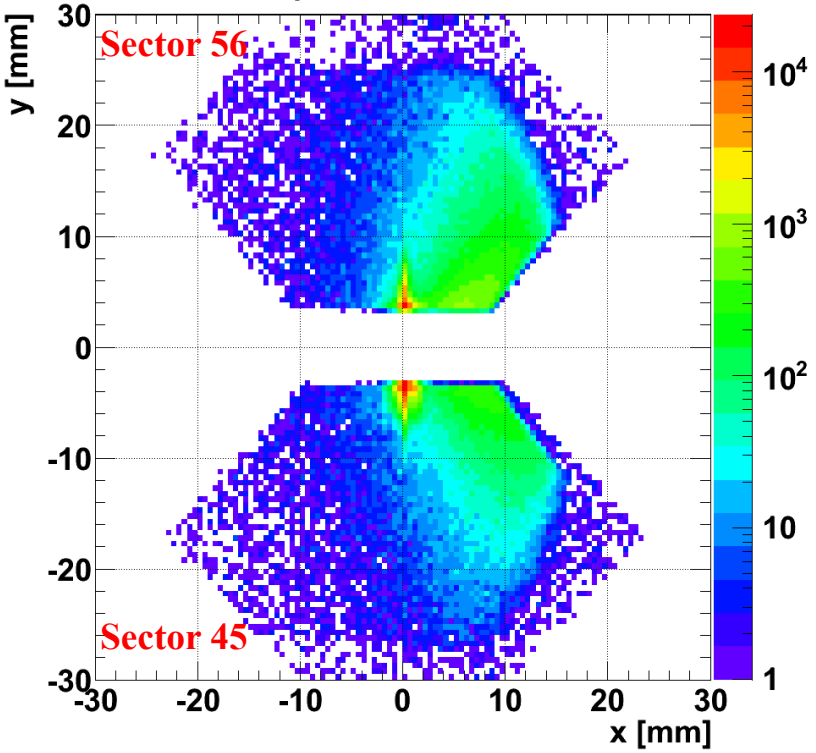
B (t=-0.4 GeV²)	t_{DIP}	t^{-n} [1.5–2.5 GeV²]
20.2	0.60	5.0
23.3	**0.51**	**7.0**
22.0	**0.54**	**8.4**
25.3	0.48	10.4
20.1	0.72	4.2
23.6 ± 0.5	**0.53 ± 0.01**	**7.8 ± 0.3**

Better statistics at large t needed (in progress)

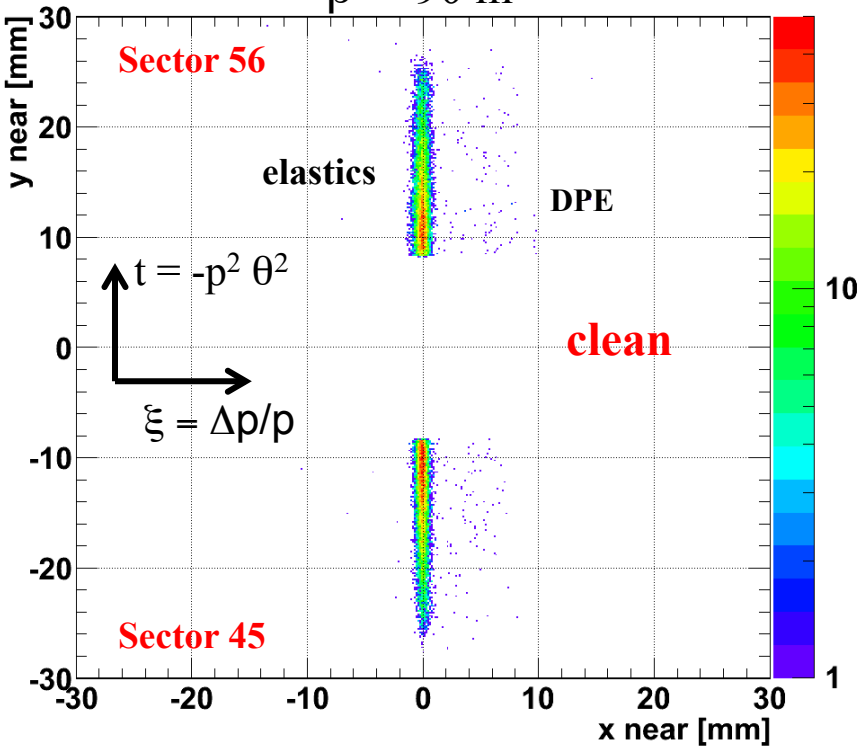
2. measurement with β* = 90 m to reach lower |t| values (data taking June 2011)



β*=3.5 m



β*= 90 m



Integrated luminosity : 6.2 nbarn^{-1}

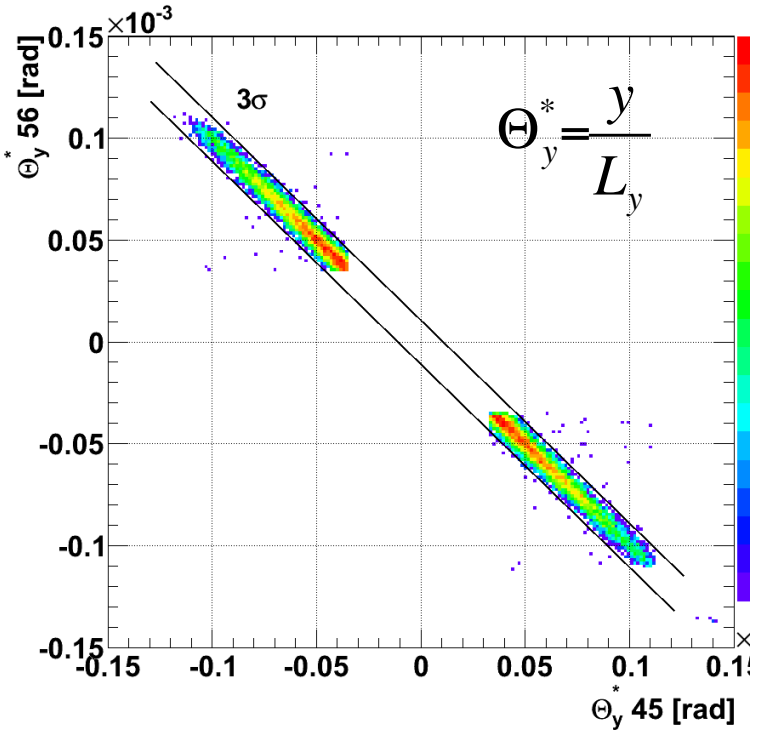
Inel. pile-up ~ 0.8 ev/bx_

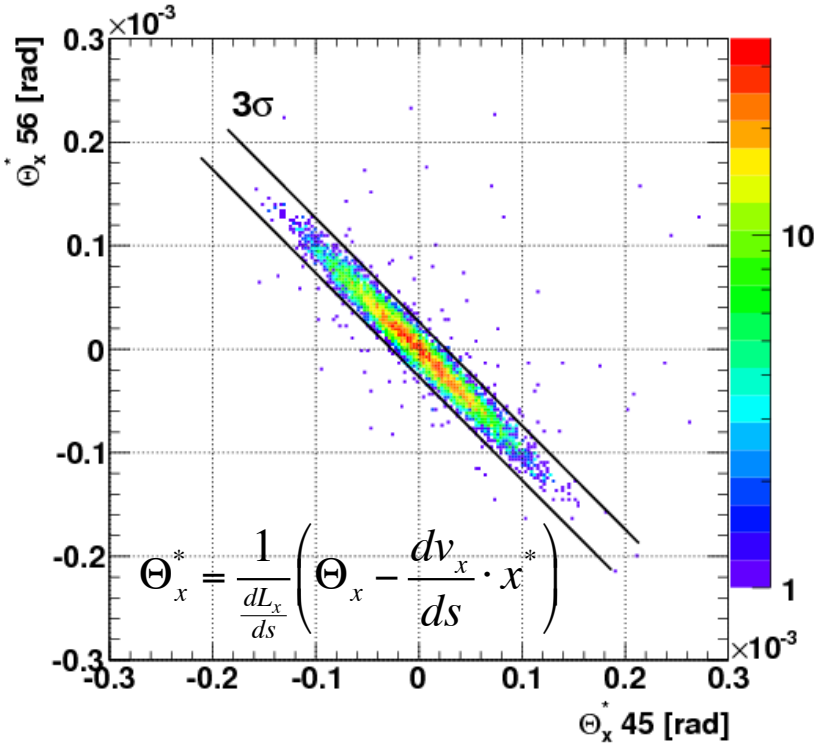
$$y = L_y \Theta_y + v_y y^*$$
$$x = L_x \Theta_x + \xi D + v_x x^*$$
$$L_x \sim 0$$

Integrated luminosity : 1.65 μbarn^{-1}

Inel. pile-up ~ 0.005 ev/bx

Angular Correlations between outgoing protons





$L_y \sim 260$ m

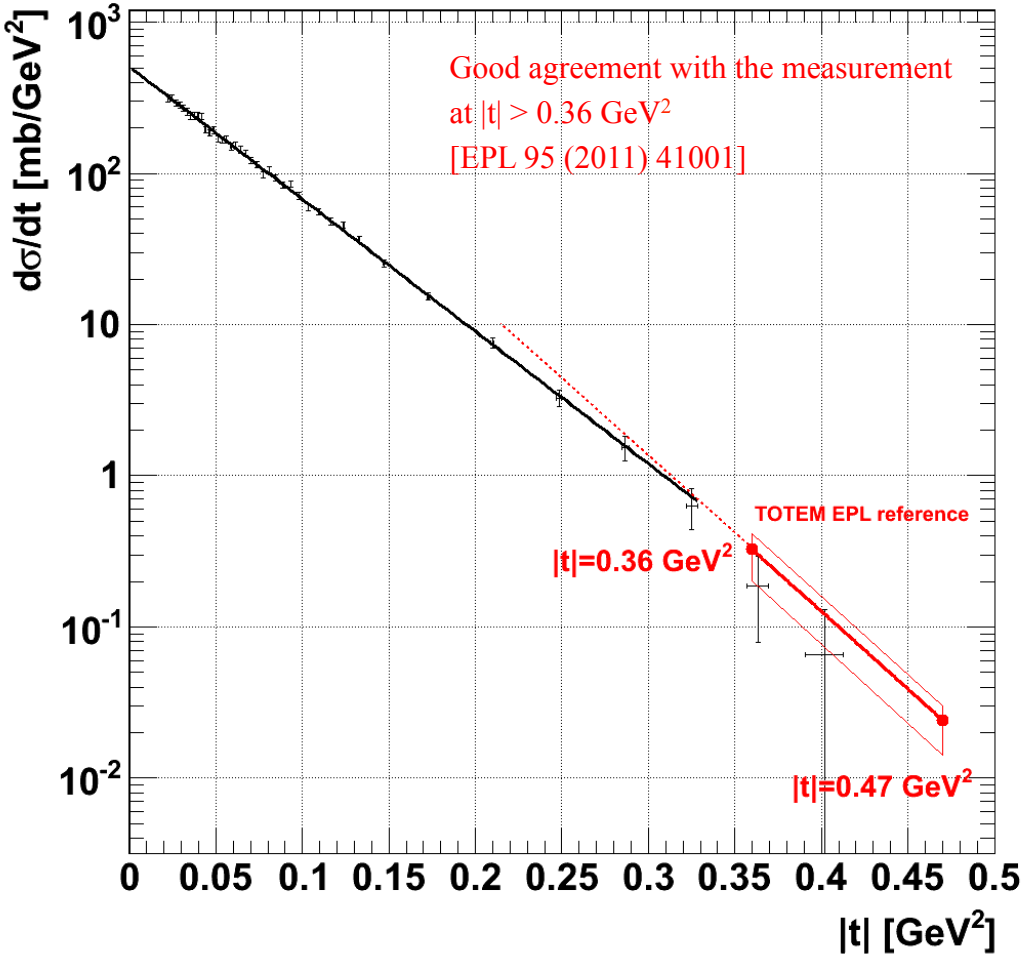
$L_x \sim 0$ - 3 m

Background negligible $< 1\%$

Width of correlation band in agreement with beam divergence (~ 2.4 μrad)

Final Differential Cross-Section for $t > 2 \times 10^{-2}$ GeV^2

(Data taking: June 2011 for 20 min.)



Extrapolation to t = 0:

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

Exponential slope

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

Extract total cross-section

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

$\rho = 0.14^{+0.01}_{-0.08}$ from Compete Coll.

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

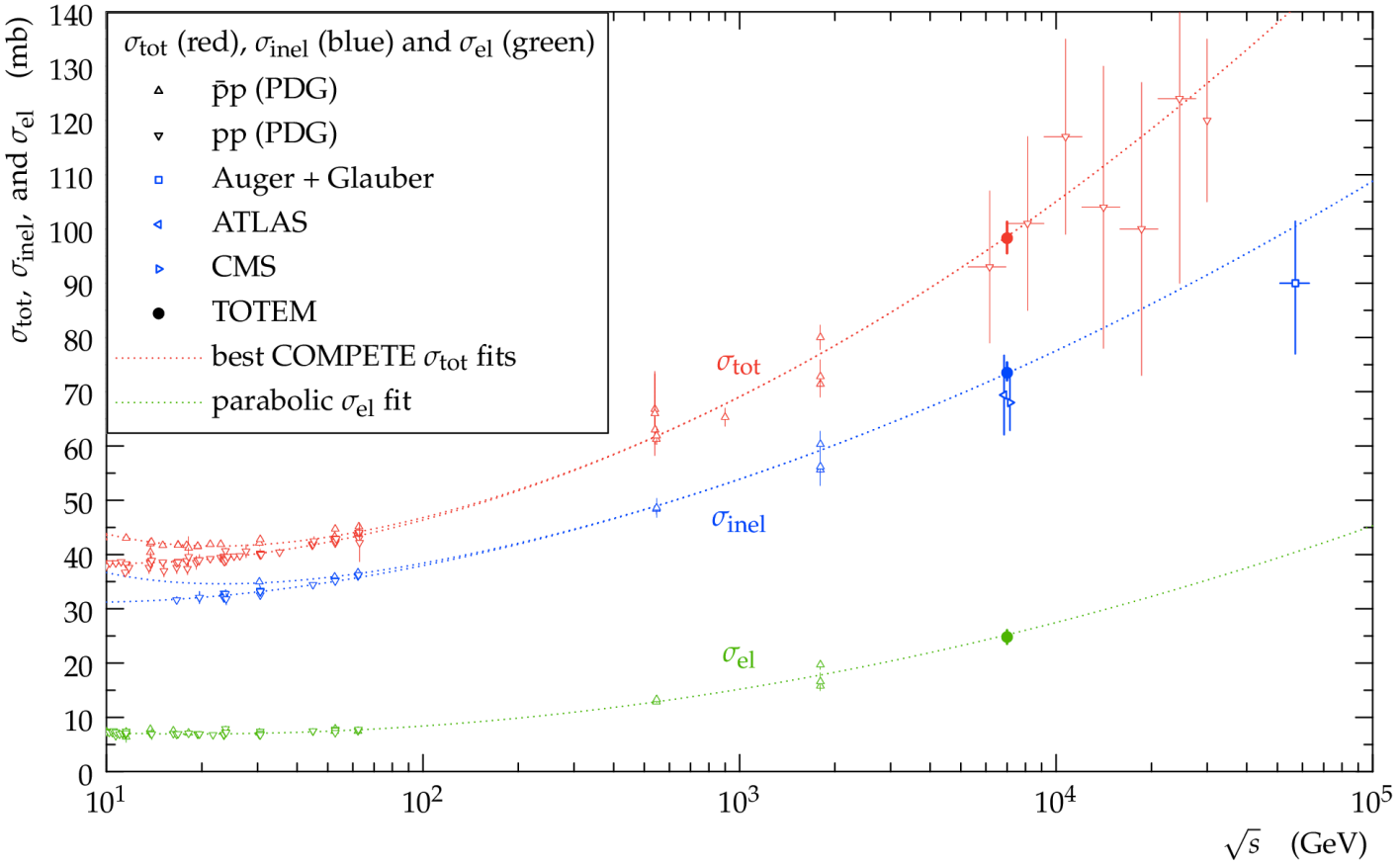
Normalisation with luminosity from CMS

Uncertainty ± 4%

Total elastic cross-section:

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

Measurement of total, inelastic and elastic cross-sections comparison with previous results



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

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

3. Data taking Oct. 2011 with β* = 90 m

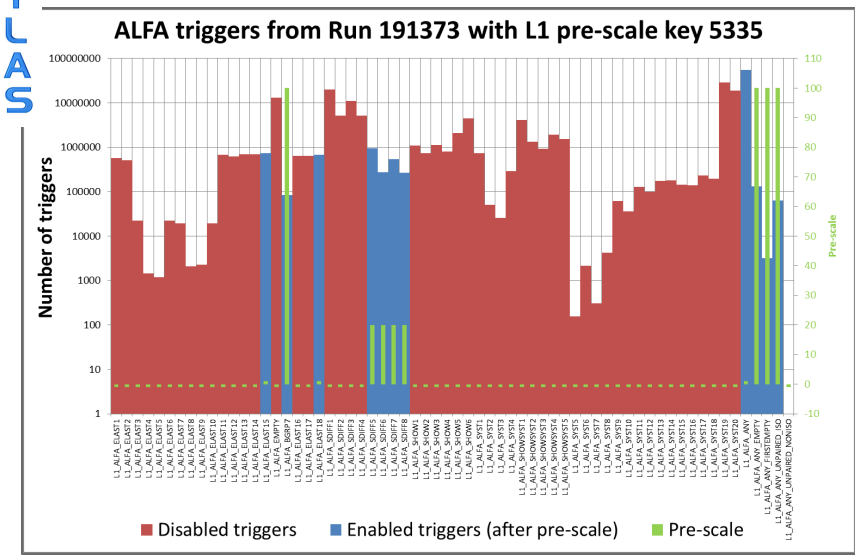
MD = main detector, OD = Overlap Detector

Date	Run	Triggers	Position	Trigger & Purpose
Oct 18	191291-191305	17 million	Various, 7mm	Scraping
Oct 18	191312-191313	0.5 million	7mm	OD only for distance
Oct 18	191321	2 million	5.5 sigma	MD&OD standalone
Oct 18	191322	10 million	8.0 sigma	MD&OD standalone
Oct 18	191323	0.5 million	8.0 sigma	OD only for distance
Oct 20	191366	10 million	6.5 sigma	MD&OD standalone
Oct 20	191367	1.2 million	6.5 sigma	OD only for distance
Oct 20	191373	55 million 8 million	6.5 sigma	ALFA PEB stream Full ATLAS stream
Oct 20	191377-191383	4 million	6.5 sigma	OD only for distance
Oct 20	191386-191388	10 million	6.2 sigma	MD&OD standalone

Total amount of triggers ~ 100 million

1.4 x 10 ^{6} elastic triggers

2 x 10 ^{6} diffractive triggers



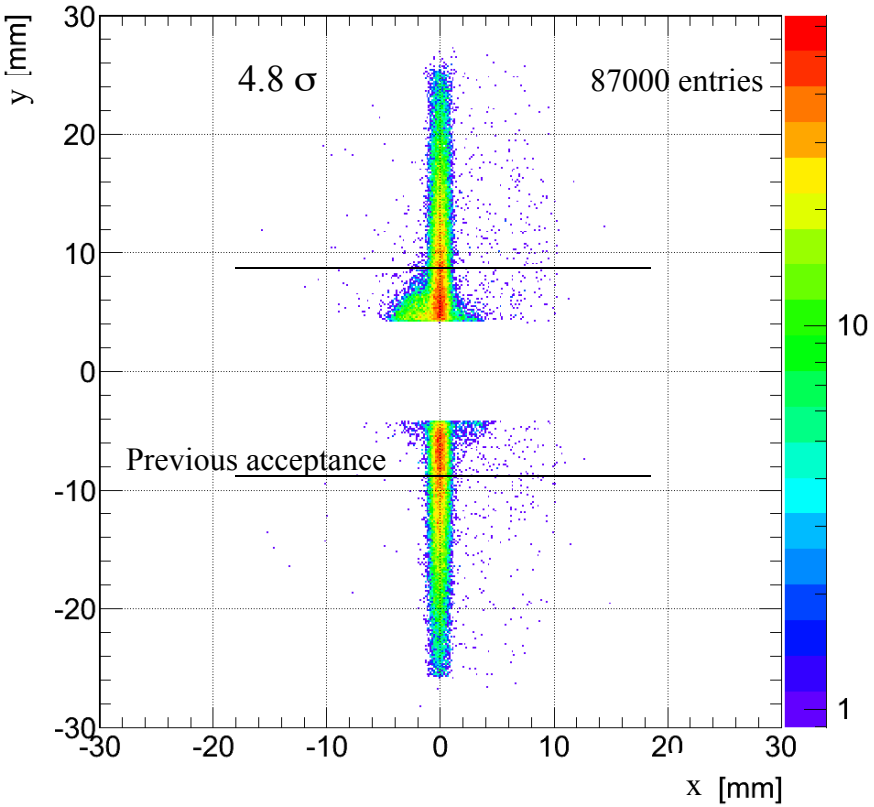
Trigger menu

RP position (V) [sigma]	trigger schema	trigger on bunch	Run time [min]	Events	Integ. Lumi [ub^{-1}]
6.5	RP_all_OR + T2 + BX	1950,2000,2050 2100, 2200, 2300	64.9	2.4E+6	1.6
6.5	RP_V_and + T2 + BX	all	13.4	5.8E+5	5.2
6.5	RP_all_and + T2 + BX	all	217.5	9.3E+6	77
5.5	RP_all_and + T2 + BX	all	50.7	1.9E+6	16
4.8	RP_all_and + T2 + BX	all	16.4	6.2E+5	4.9
		sum	363	1.5E+7	104

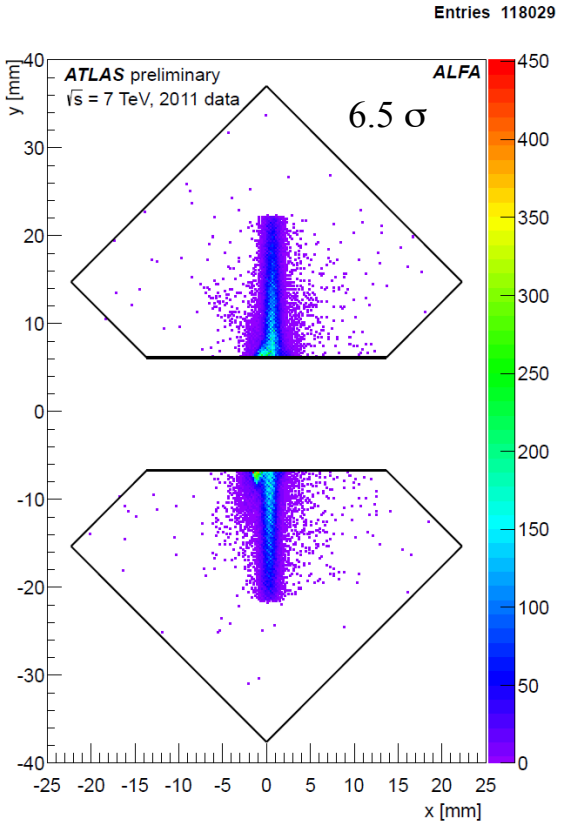
Run at β* = 90 m with closest approach

Diagonal double arm coincidence selects elastic candidates

Map of track intercepts in the Roman Pot Detectors



$x = L_x \Theta_x$



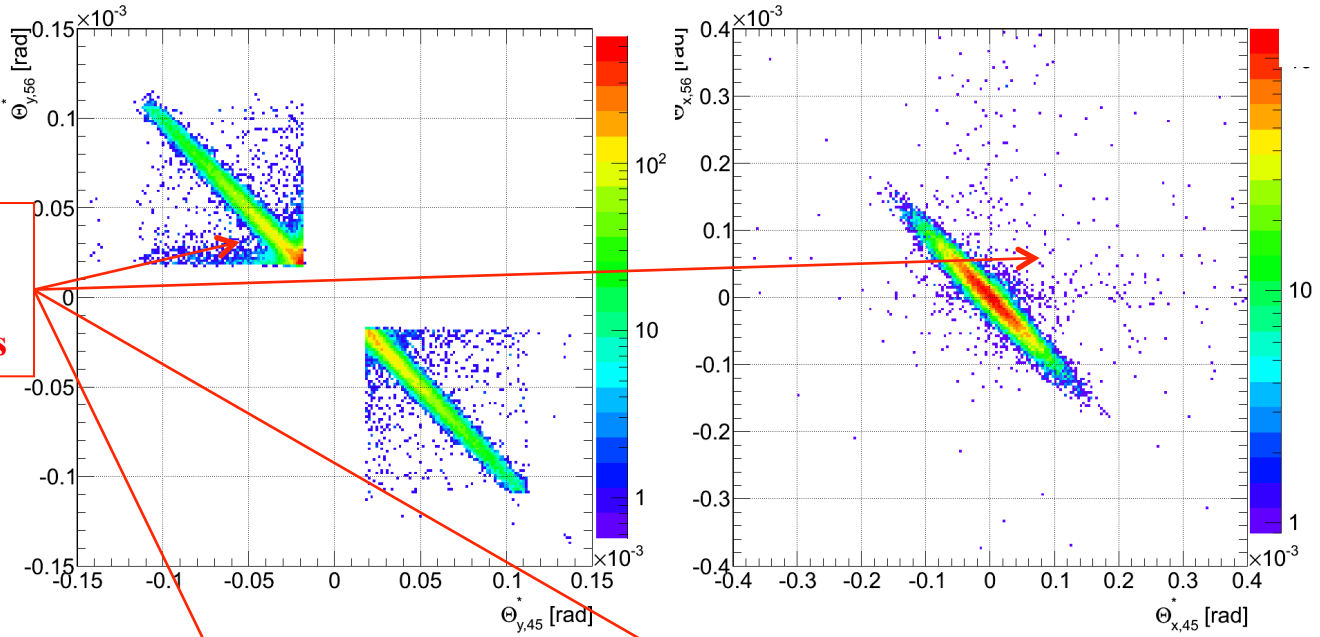
Clean elastic candidates due to low pile-up (< 5%)

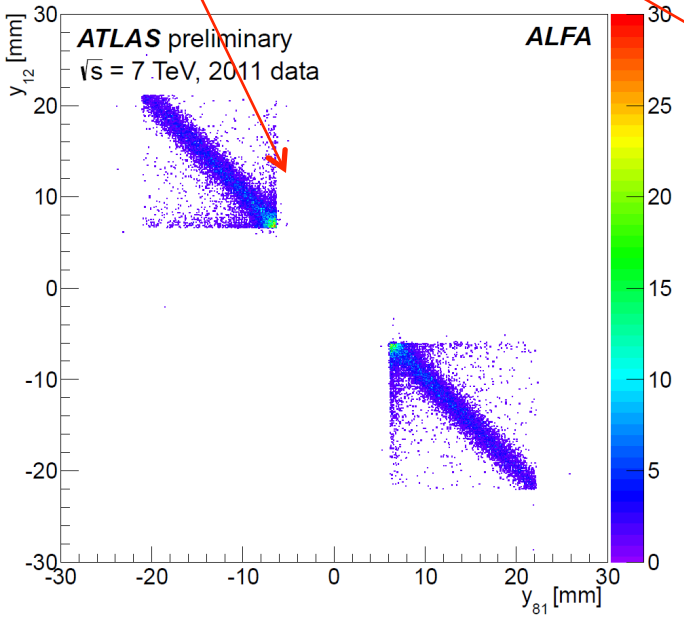
$L_x = 0 – 3$ m

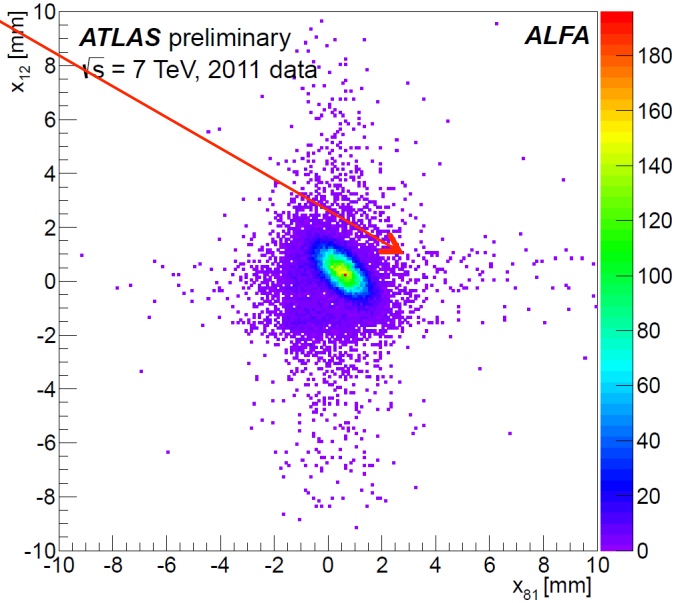
$L_x = 10 – 13$ m

Collinearity plots

Background from
Double Pomeron exchange
and accidental coincidences

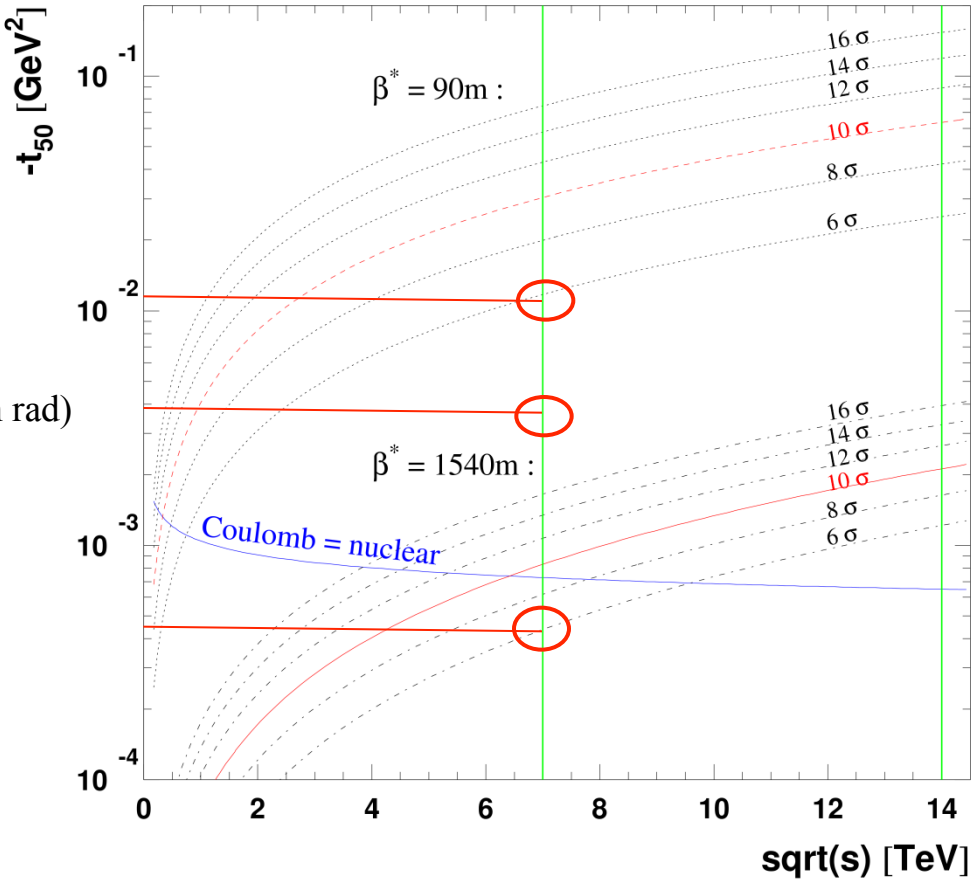






Outlook: Measurement of ρ in the Coulomb-nuclear Interference Region?

Aim: get also the last ingredient to σ_{tot} from measurement rather than theory.



(ε_N = 1. μm rad)

(ε_N = 3.75 μm rad)

(ε_N = 1 μm rad)

→might be possible at sqrt(s)=7 TeV with RPs at 6 σ

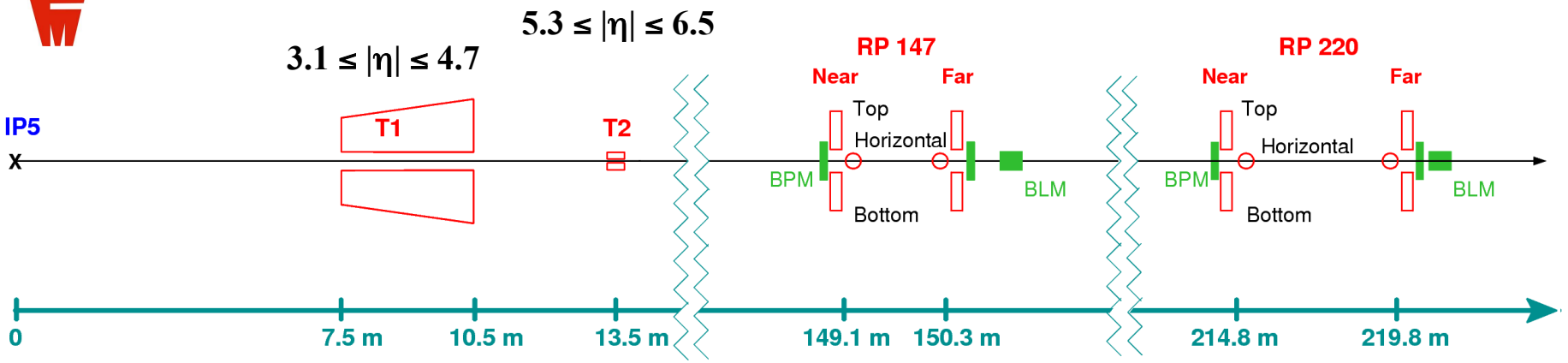
→incentive to develop very-high-β* optics before reaching 14 TeV !

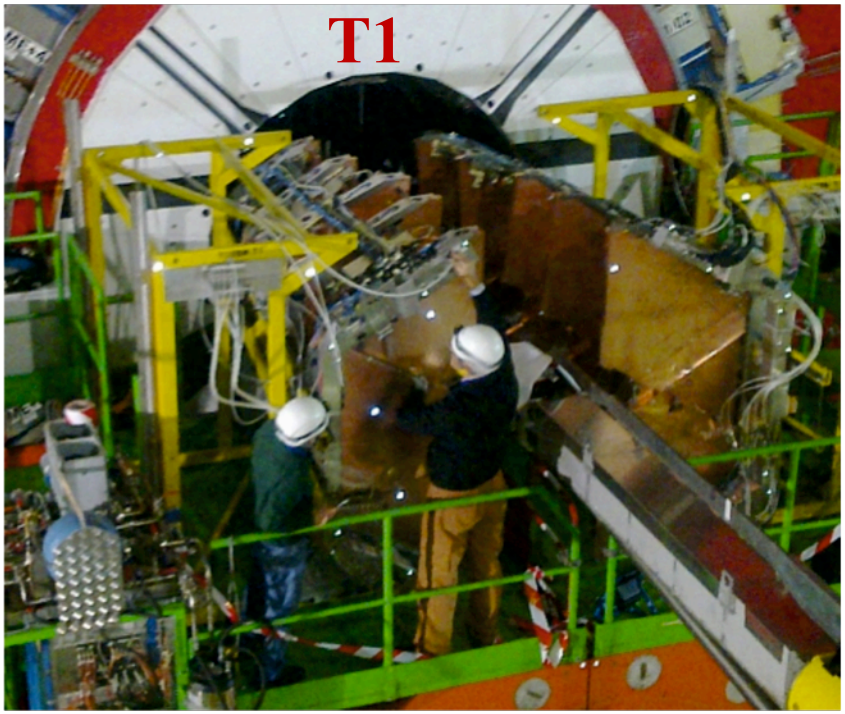
e.g. try to use the same optics principle as for 90m and unsqueeze further.

Summary and Outlook

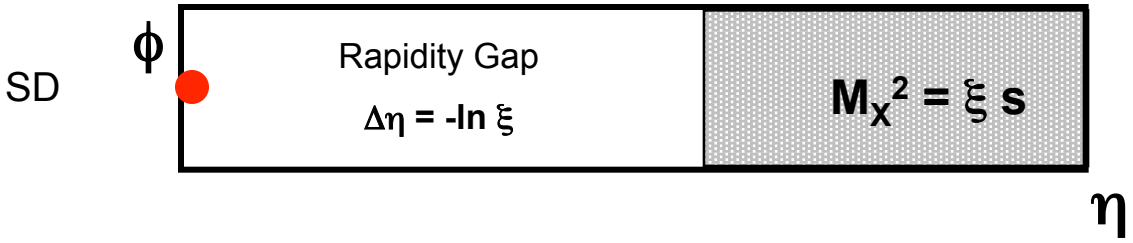
- **Totem results**
  - Measurements of the elastic scattering cross-section in the range $2\ 10^{-2} < |t| < 2.5$ GeV^2
  - Measurements of the elastic, inelastic and total cross-sections
  - Extend the |t| range to $5\ 10^{-3} < |t| < 4.$ GeV^2
- **Successful data taking in Oct. 2011 of both experiments with the dedicated optics $\beta^* = 90$ m**
  - Few 10^6 elastic scattering events in each experiment
  - Repeat the above measurements with both experiments and larger statistics
- **In 2012: Repeat data taking with $\beta^* = 90$ m and more sophisticated triggers**
  - TOTEM will take data together with CMS and exchange triggers
- **Develop and run a new optics with $\beta^* \sim 1$ km to study the Coulomb interference region**
- **Both experiments have started an extensive programm on diffractive physics**
  - Single diffraction
  - Double Pomeron Exchange

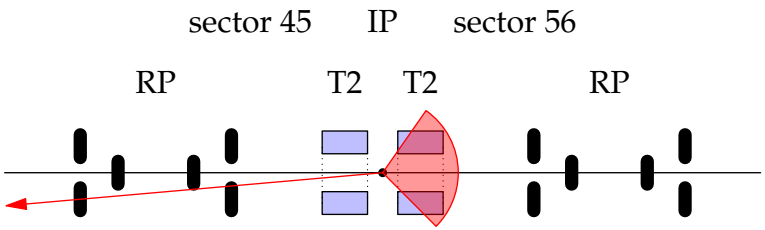
The Forward trackers (with trigger capability) in TOTEM



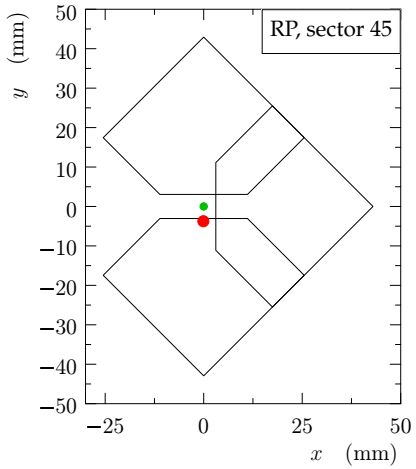


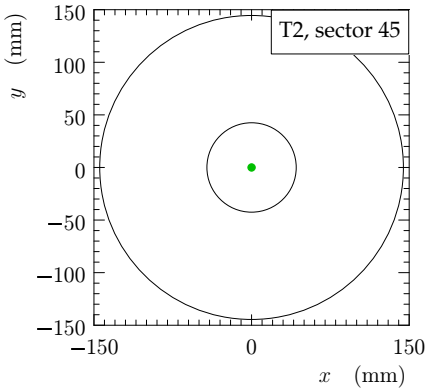
Single diffraction low ξ
Correlation between leading proton and forward detector T2

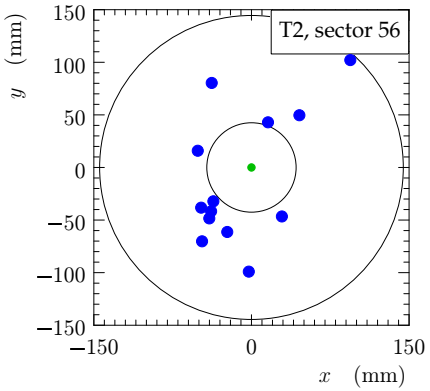


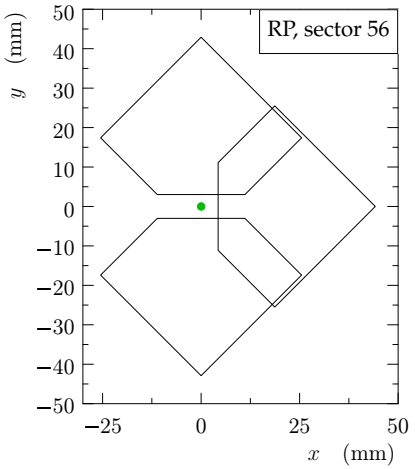


run: 37280003, event: 3000

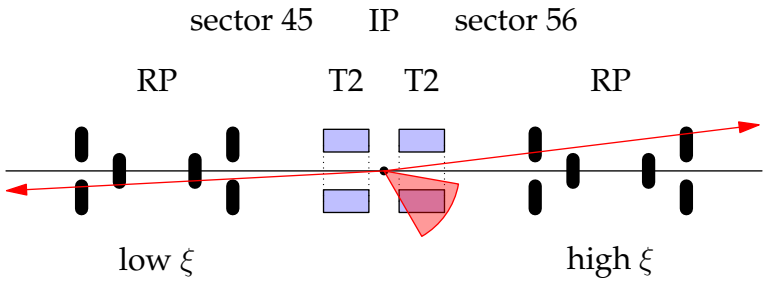








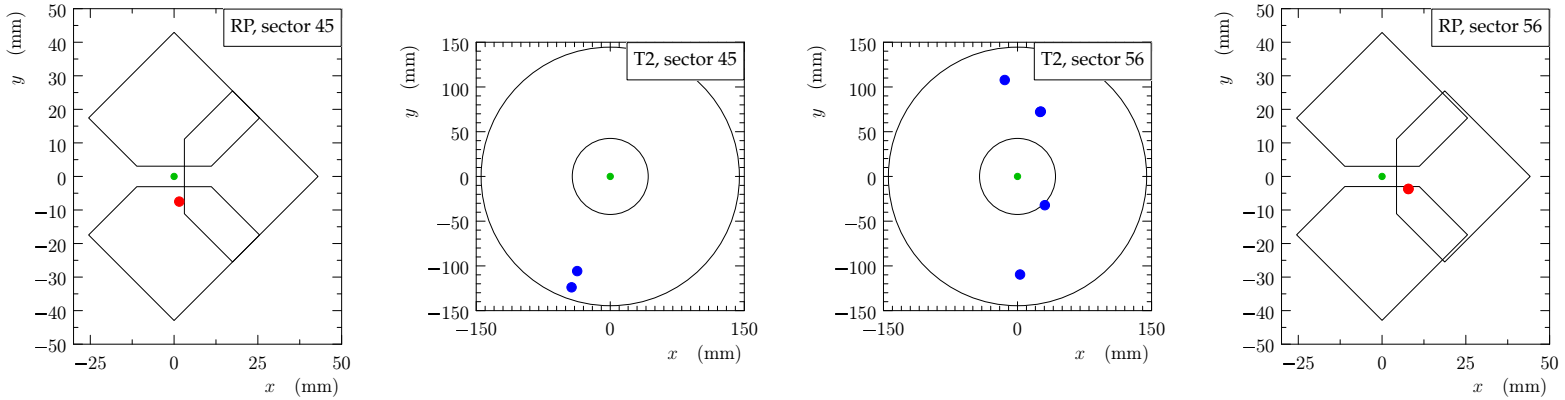
Double Pomeron Exchange



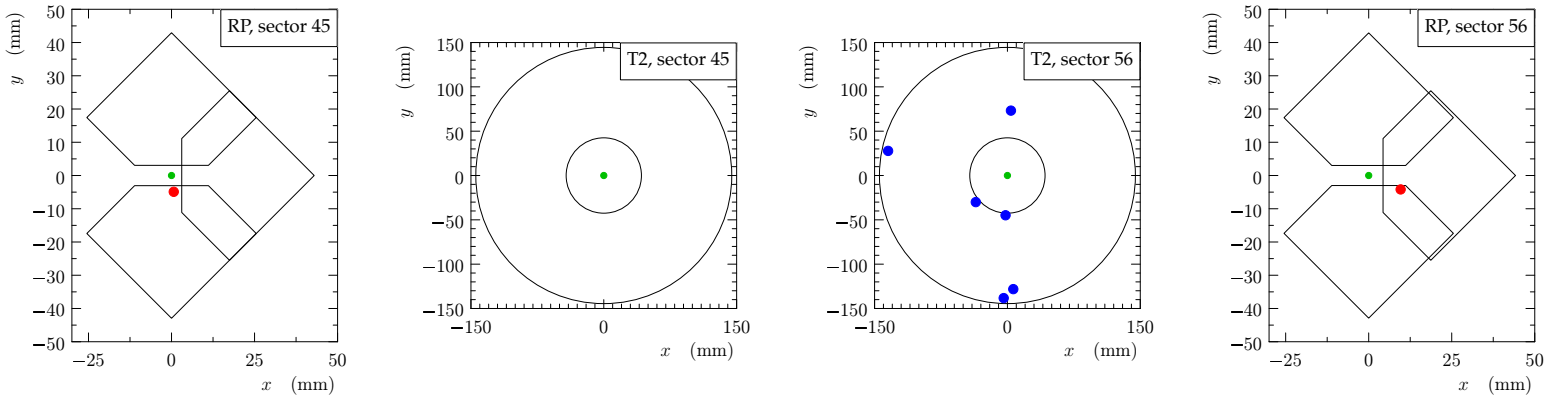
Much better acceptance with CMS

with ALFA and ATLAS

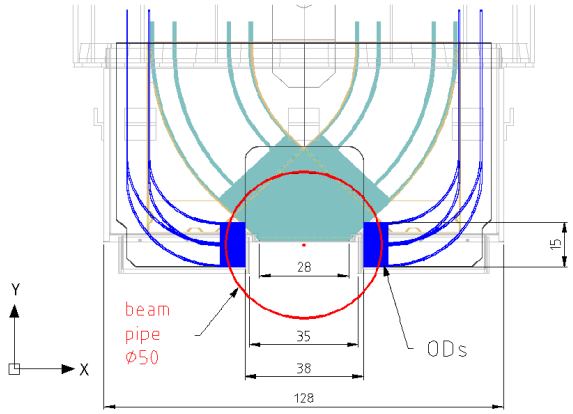
run: 37250009, event: 14125



run: 37220007, event: 9904



The ALFA Scintillating Fiber Detector

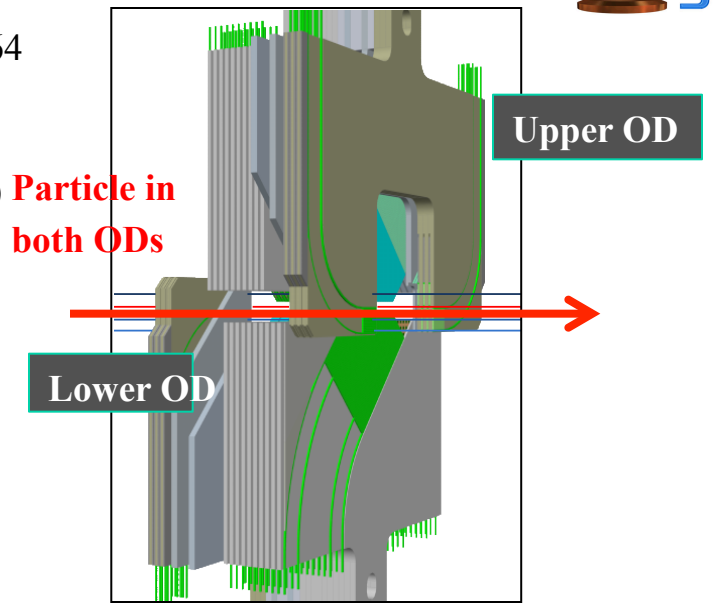


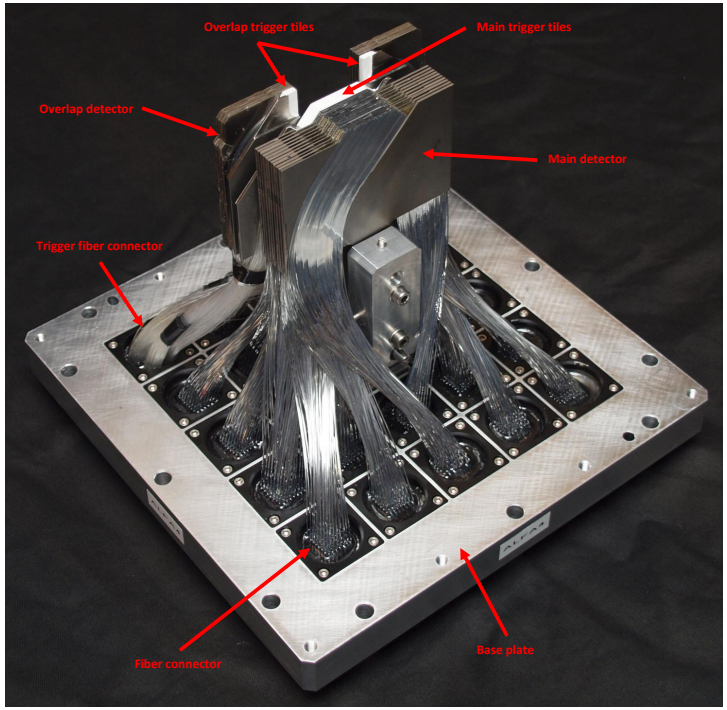
Principle of multi-layer fiber detector

2 x 10 planes (u and v) of staggered 64 fibers (0.5 mm)

Overlap detectors for position calibration (upper-to-lower detectors)

Trigger scintillators





2 stations

with a lever arm of 4 m

Measurement of position and angle in both projections