



The TOTEM Experiment at the LHC : First Results

V. Avati (CERN)

On behalf of the TOTEM Collaboration

*LISHEP 2011
4-9 July, Rio de Janeiro*

The TOTEM Collaboration

INFN Sezione di Bari and Politecnico di Bari, Bari, Italy

MTA KFKI RMKI, Budapest, Hungary

Case Western Reserve University, Cleveland, Ohio, USA

CERN, Geneva, Switzerland

Estonian Academy of Sciences, Tallinn, Estonia

Università di Genova and Sezione INFN, Genova, Italy

Università di Siena and Sezione INFN-Pisa, Italy

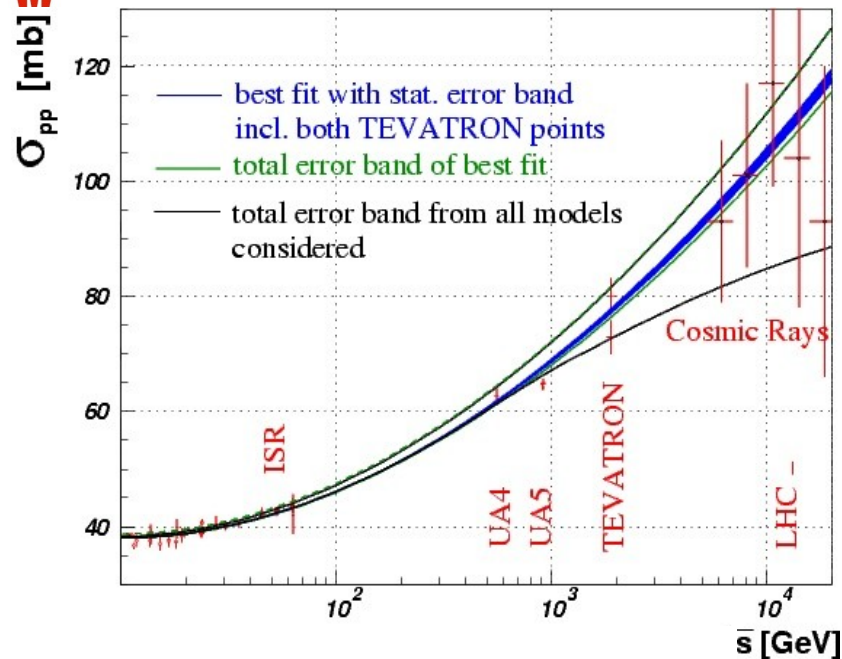
University of Helsinki and HIP, Helsinki, Finland

Academy of Sciences, Praha, Czech Republic

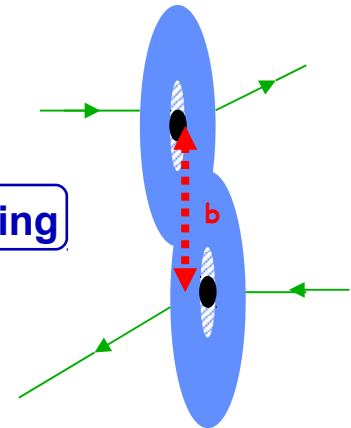
- **Detector Status**
- **First Results**
- **Outlook**

TOTEM Physics Overview

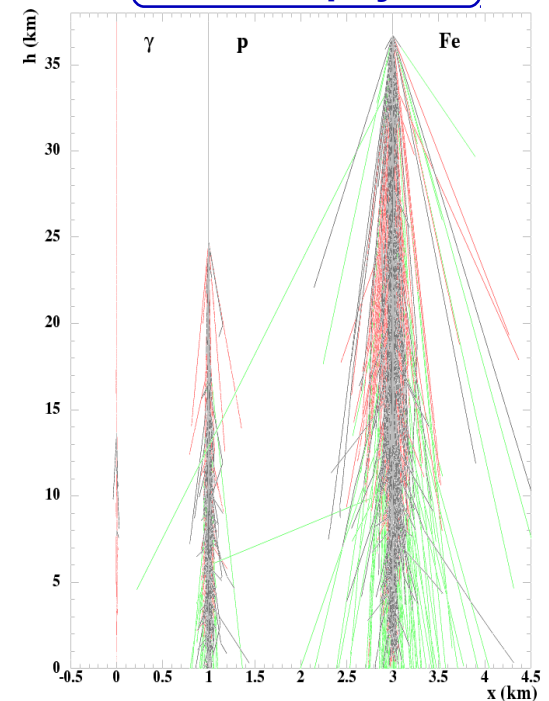
Total cross-section



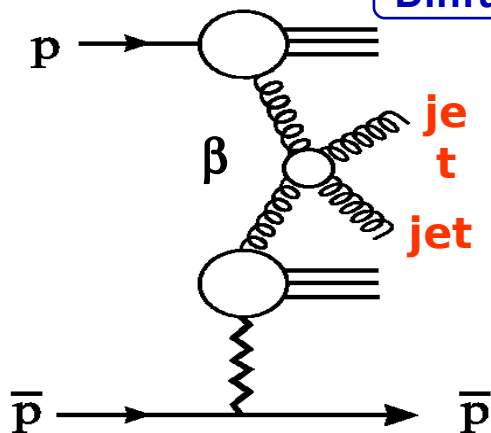
Elastic Scattering



Forward physics

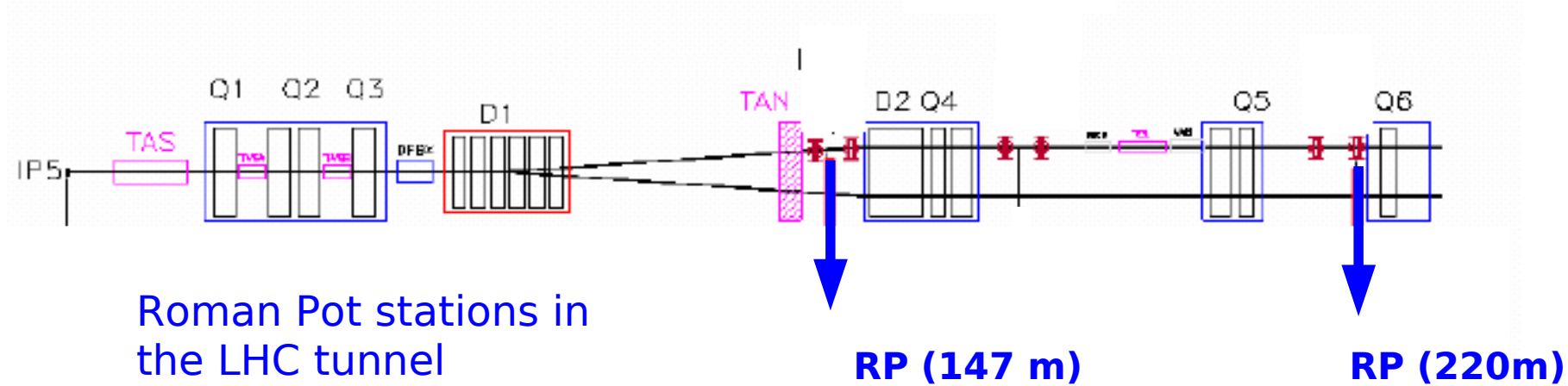
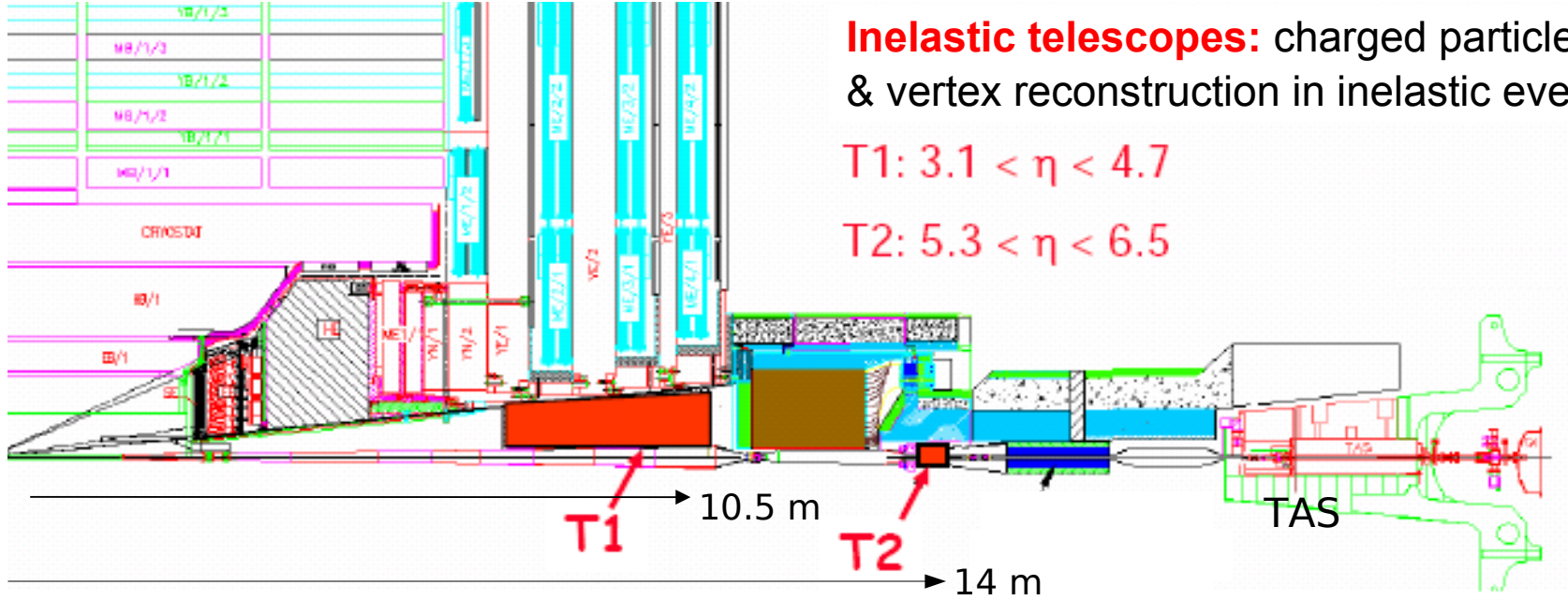


Diffraction: soft and hard



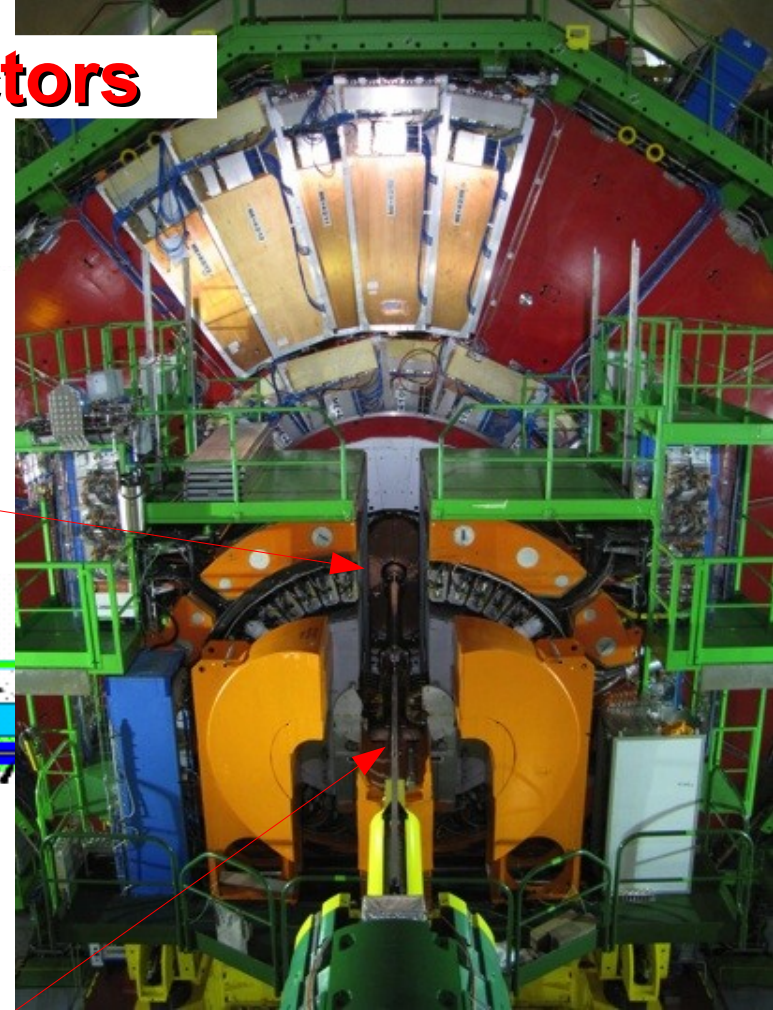
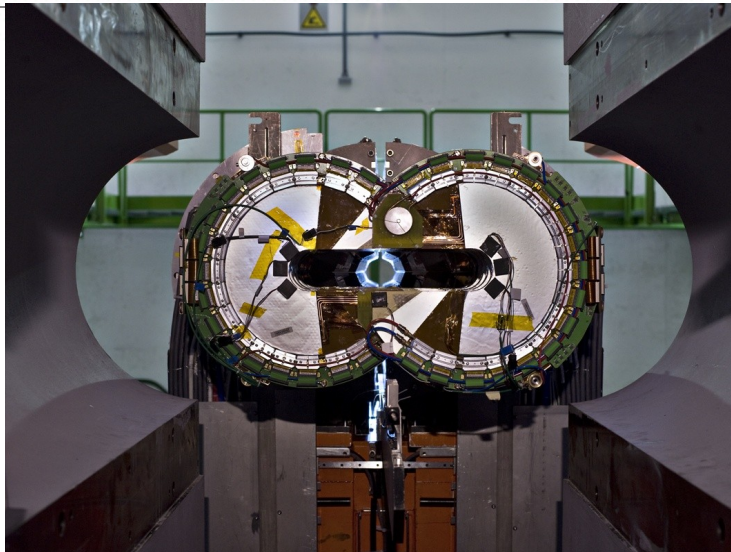


TOTEM Detectors



Roman Pot stations in the LHC tunnel

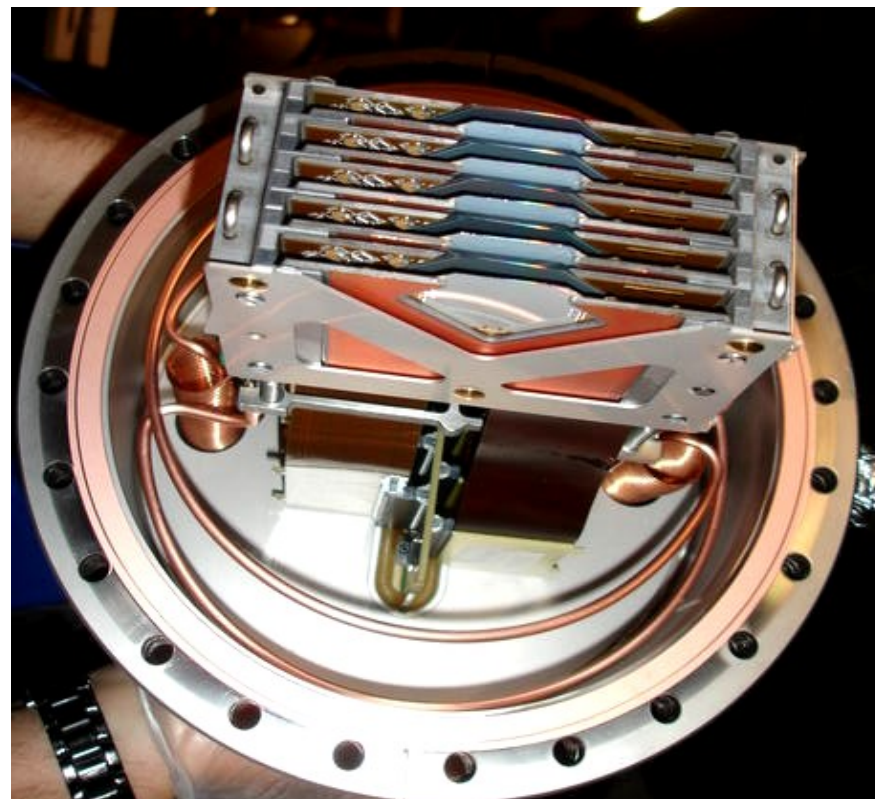
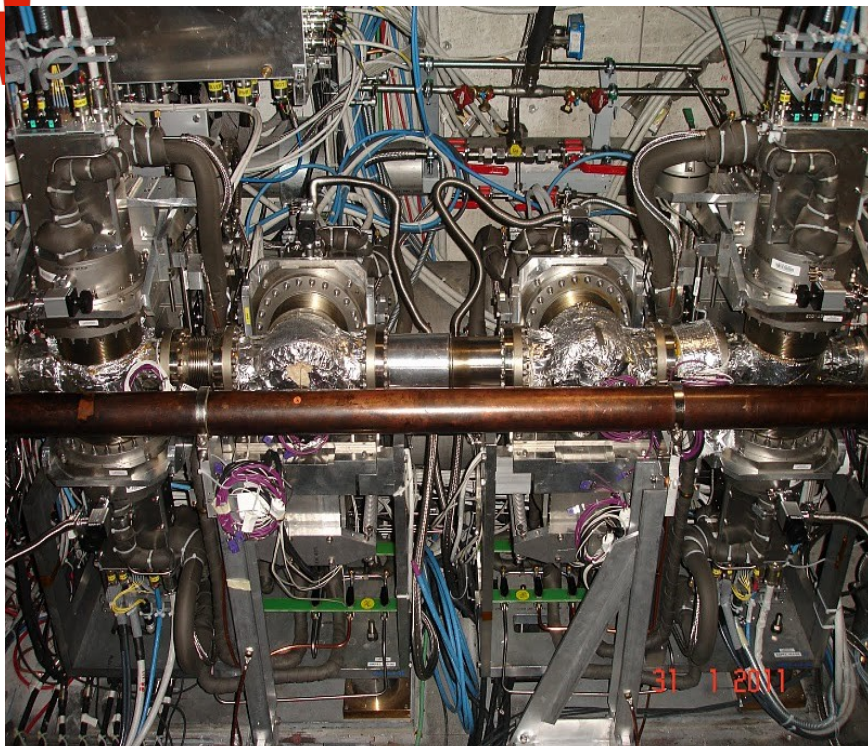
TOTEM Detectors



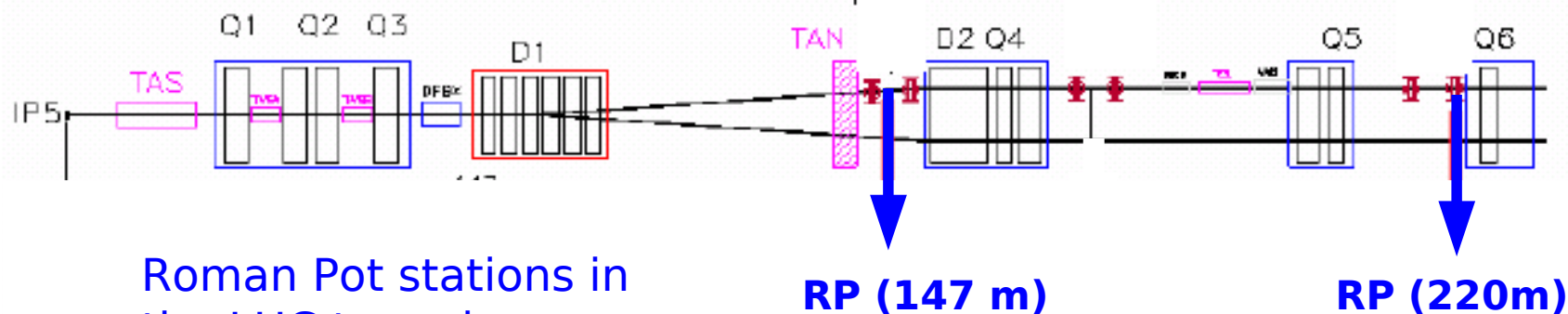
Inelastic telescopes: charged particle
& vertex reconstruction in inelastic events



TOTEM Detectors



Roman Pots: measure elastic & diffractive protons close to outgoing beam

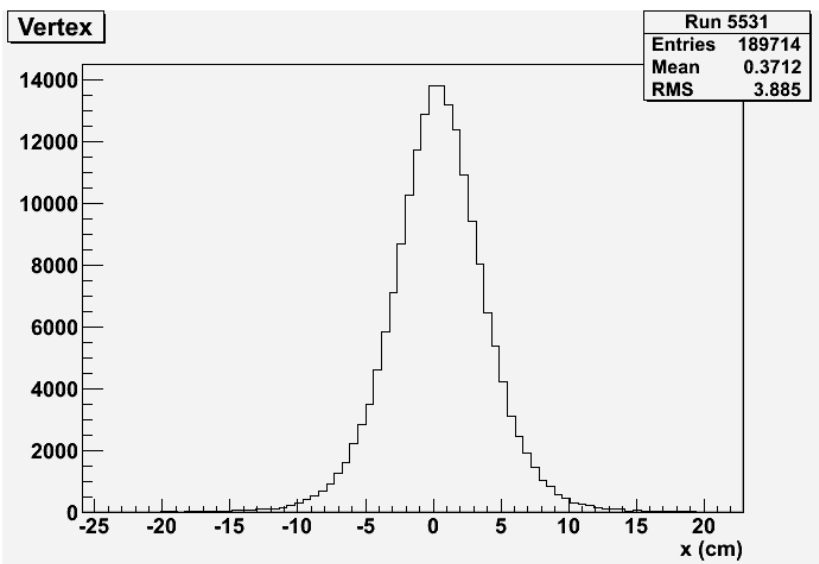




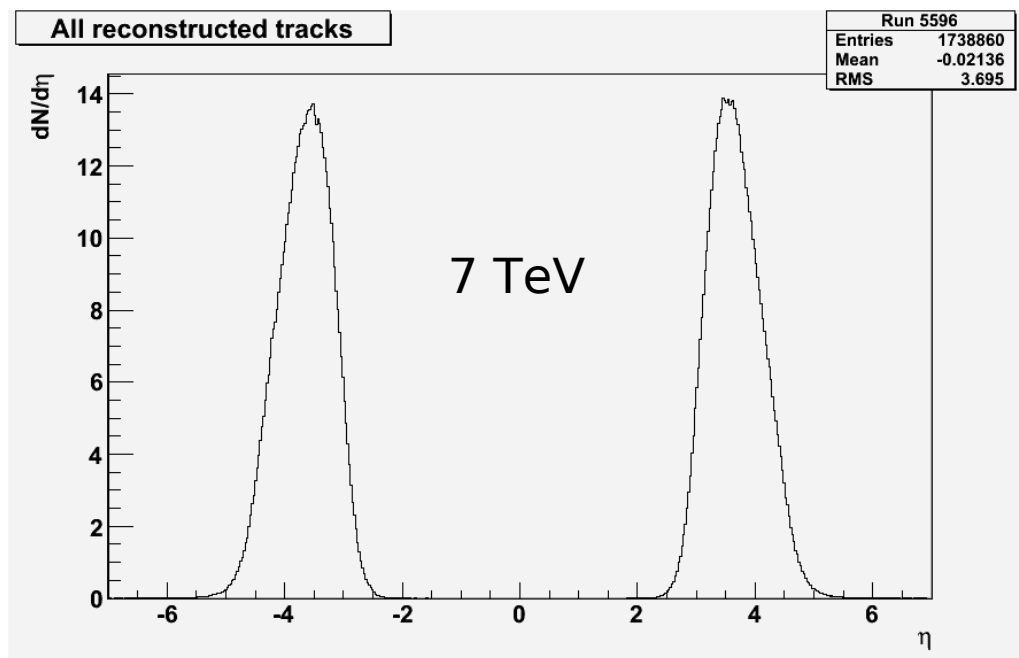
Preliminary $dN/d\eta$ results: T1

- 3 short periods of data taking with useful conditions for T1
($L = 10^{28} - 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$)
- Commissioning and Data analysis in progress
- T1 ready for physics

Vertex reconstruction



η Distributions (uncorrected)



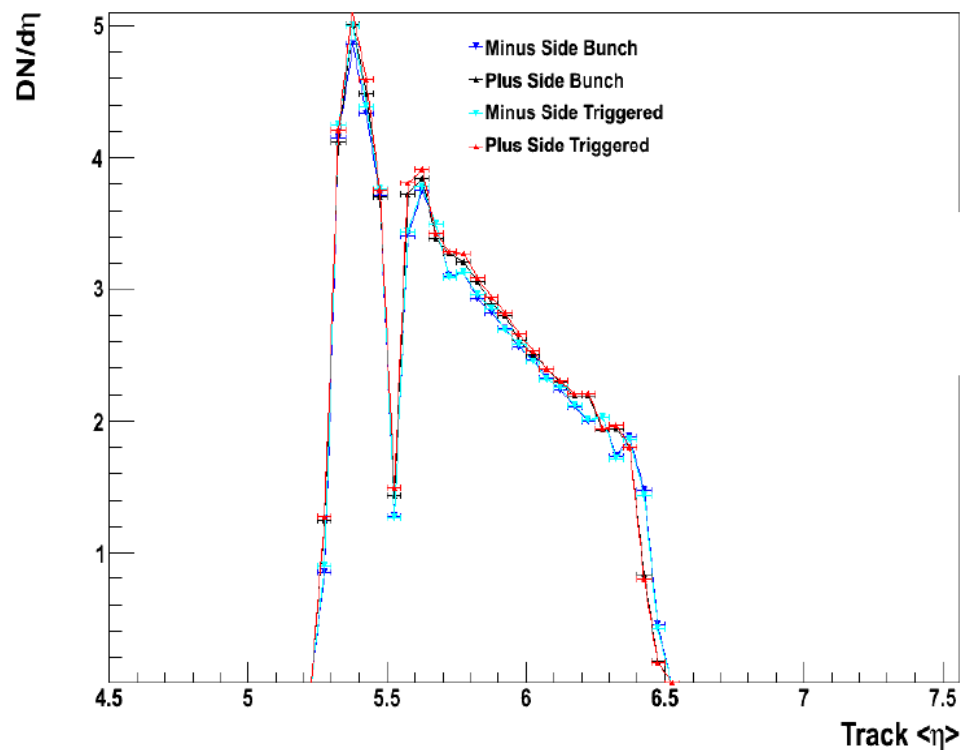
Vertex reconstruction is
effected by the CMS
magnetic field



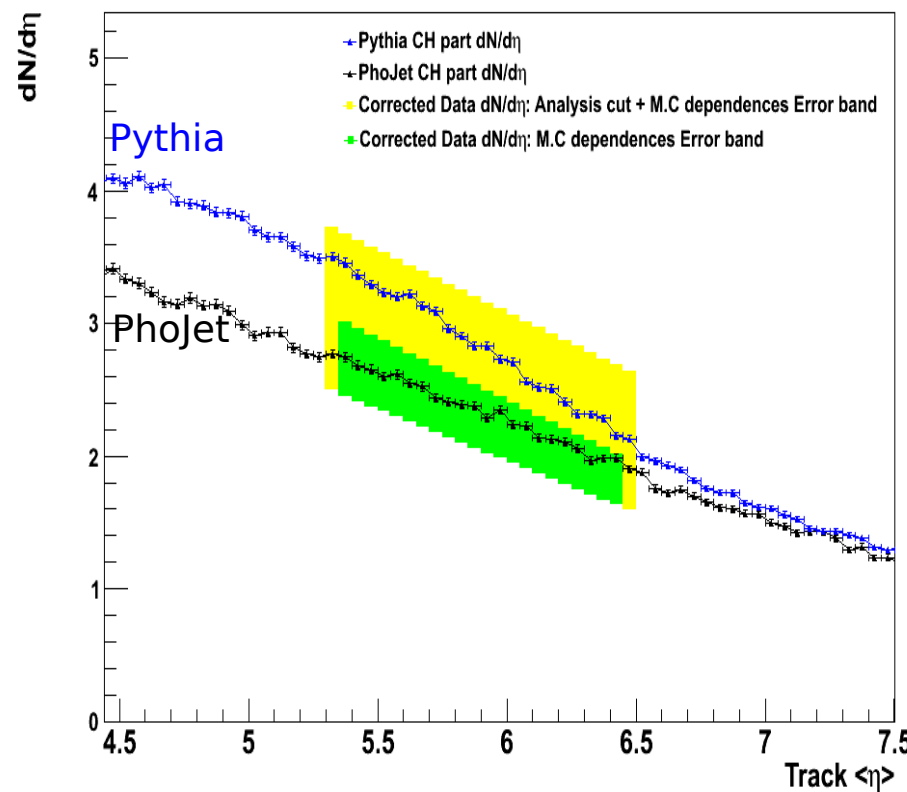
Preliminary $dN/d\eta$ results: T2

Data with low intensity bunches ($\sim 10^{10}$ p; low pile-up)

Data 2011 NOT Unfolded



Unfolded



‘Plus’ and ‘minus’ T2 sides superimposed

Very good agreement:
- left and right side
- bunch and active trigger

Low luminosity runs 2010



pp Elastic cross section t-range: 0.36 – 2.5 GeV²

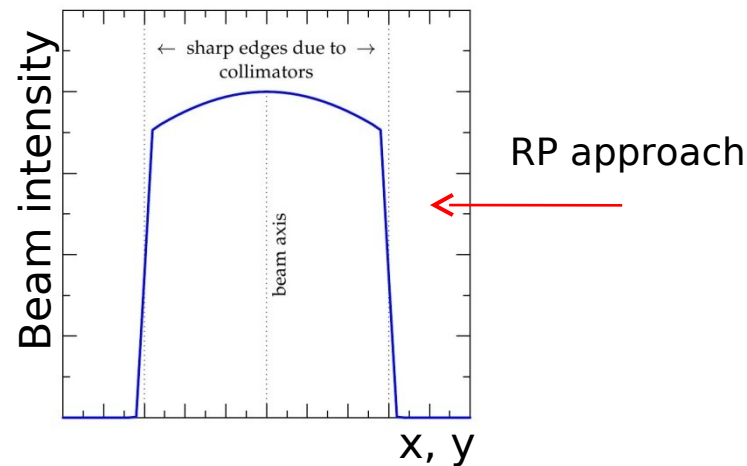
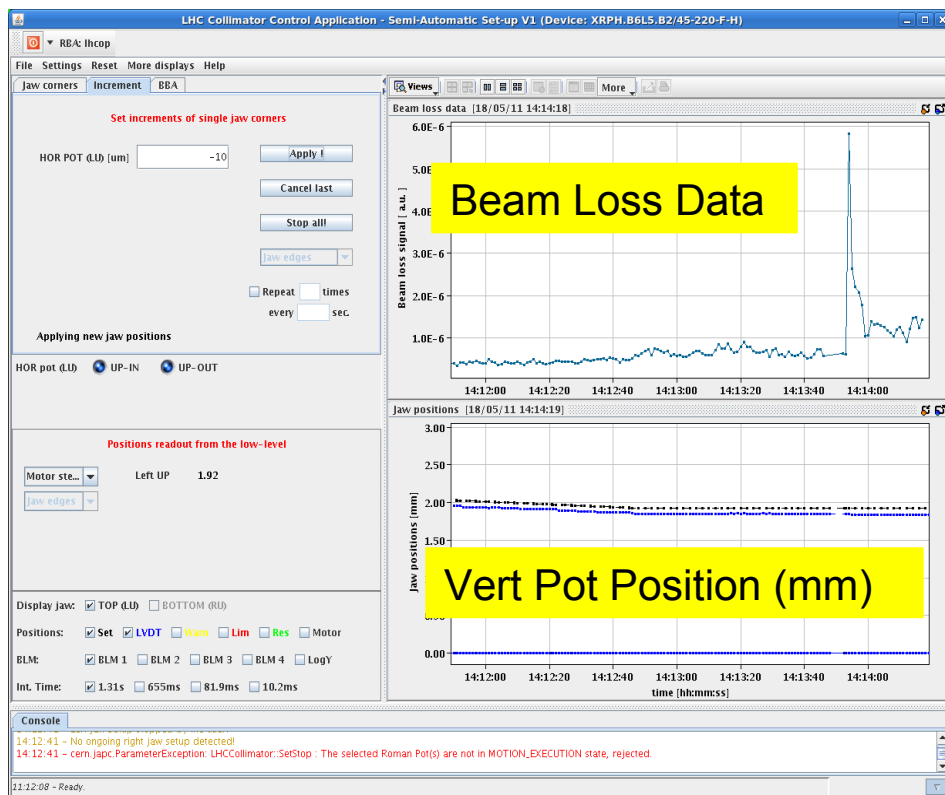
“Elastic pp Scattering at the LHC at $\sqrt{s} = 7$ TeV”
CERN-PH-EP-2011-101
To be published in EPL



Elastic pp scattering : data collection

- Data taking 2010 with different distances of the Roman pots to the beam center:
- 7σ runs (this analysis): during special runs dedicated to the RP alignment (5 bunches nominal intensity, $L \sim 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$)
 - 18σ runs: during normal LHC operation (total luminosity collected $\sim 5.8 \text{ pb}^{-1}$)

Alignment: RP220 approached the low intensity beam in $10 \mu\text{m}$ steps



$7\sigma \sim 3 \text{ mm (V)}; 1 \text{ mm (H)}$



Elastic pp scattering : Alignment

Very critical and fundamental for any physics reconstruction

Misalignments within detector assembly: metrology, tracks

Relative positions of the pot & beam:

Constraints between top and bottom pots ($\sim 10\mu\text{m}$)

Scraping: RP aligned vertically wrt beam center ($\sim 20\mu\text{m}$)

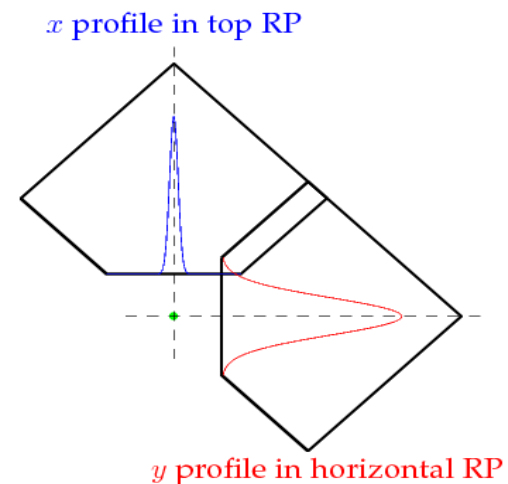
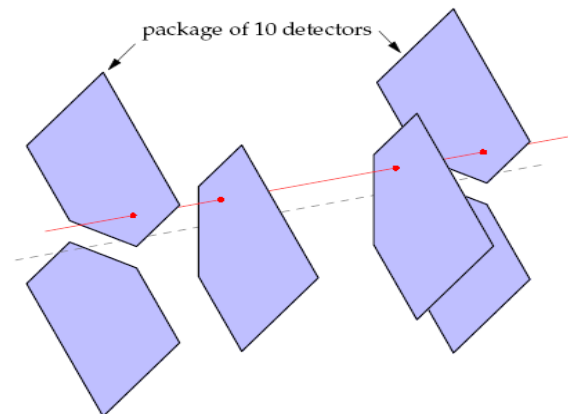
Alignment between pots with overlapping tracks ($\sim \text{few } \mu\text{m}$)

Physics process (“elastic”):

x vs y correlation : horizontal alignment wrt beam

far vs near correlation: vertical alignment between units

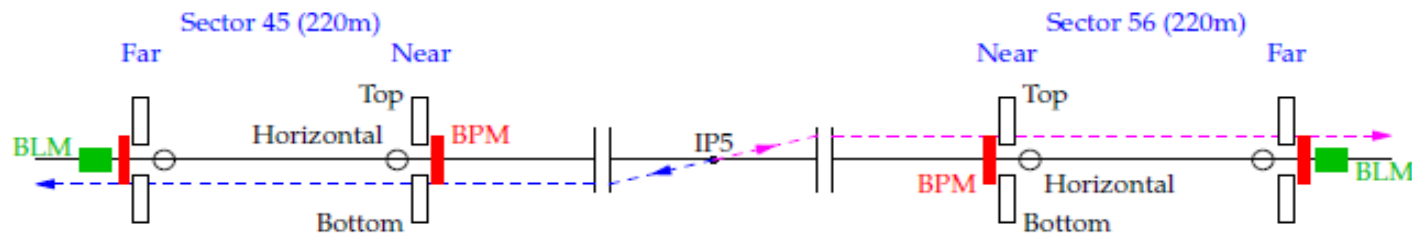
Θ^* constraint : vertical alignment wrt beam & left-right arm alignment



$$\delta x, \delta y \leq 10\mu\text{m} \quad \delta t/t \sim 0.3-0.6\%$$



Elastic pp scattering : proton reconstruction



$$\text{Measured in RP} \begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \Delta p/p \end{pmatrix}_{\text{RP}} = \begin{pmatrix} v_x & L_x & 0 & 0 & D_x \\ v'_x & L'_x & 0 & 0 & D'_x \\ 0 & 0 & v_y & L_y & 0 \\ 0 & 0 & v'_y & L'_y & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x^* \\ \Theta_x^* \\ y^* \\ \Theta_y^* \\ \Delta p/p \end{pmatrix}_{\text{IP5}} \text{Reconstructed}$$

$$\beta^*=3.5\text{m} \quad L_x \sim 0 ; L_y \sim 20\text{m} @ 220\text{m} \quad (L = \sqrt{\beta\beta^*} \sin \Delta\mu)$$

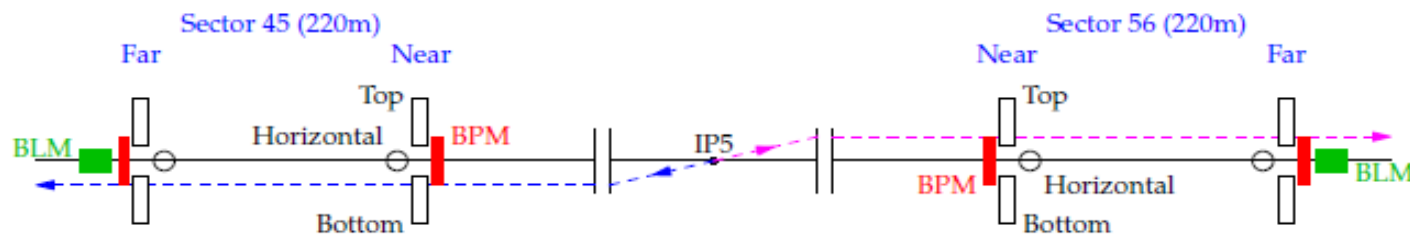
Both angle projections can be reconstructed:

$$\Theta_x = L'_x \Theta_x^* \quad y = L_y \Theta_y^*$$

precise values of $L'_x = dL_x/ds$ and L_y @ RP locations needed

Need excellent optics understanding

Elastic pp scattering : optics



$$\text{Measured in RP} \begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \Delta p/p \end{pmatrix}_{\text{RP}} = \begin{pmatrix} v_x & L_x & 0 & 0 & D_x \\ v'_x & L'_x & 0 & 0 & D'_x \\ 0 & 0 & v_y & L_y & 0 \\ 0 & 0 & v'_y & L'_y & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x^* \\ \Theta_x^* \\ y^* \\ \Theta_y^* \\ \Delta p/p \end{pmatrix}_{\text{IP5}} \text{Reconstructed}$$

Strategy:

- Magnet currents measurements → MADX optics model
- Selection of elastic protons
- Determination of the optics parameters constraints with proton tracks
 - $\Theta_{\text{left}}^* = \Theta_{\text{right}}^*$ (proton pair collinearity)
 - Proton position ↔ angle correlations
 - $L_x=0$ determination, coupling corrections
- Matching of the optics (transport matrix) → $\delta L'_x/L'_x \sim 1\%$
 $\delta L_y/L_y \sim 1.5\%$

[cfr. H. Niewiadomski - "Roman Pots for beam diagnostic" - Optics Measurements, Corrections and Modelling for High-Performance Storage Rings workshop (OMCM) CERN, 20-23.06.2011]

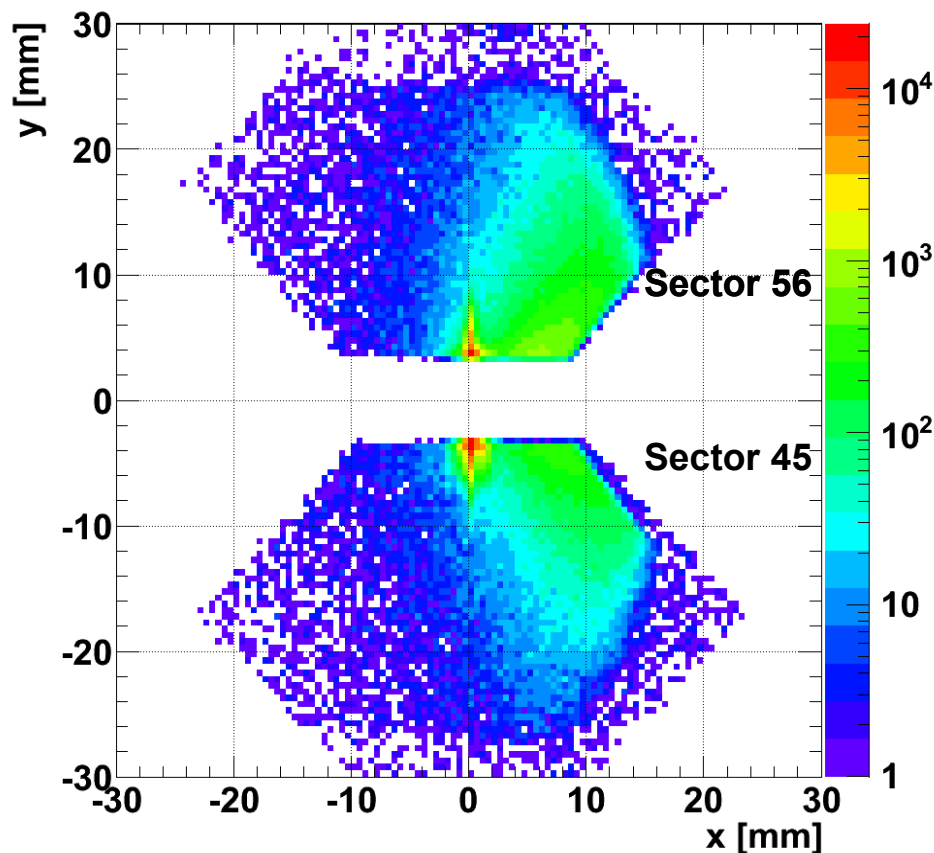
Elastic pp scattering : cuts and data reduction

Integrated luminosity : 6.2 nb⁻¹

Topology:

- near and far units
- diagonals

Total triggers	5.28M	↑ showers ↓
Reconstructed tracks & elastic topology	293k	



Two diagonals analysed independently

$$\begin{array}{c} \uparrow t = -p^2 \theta^2 \\ \xi = \Delta p/p \end{array}$$

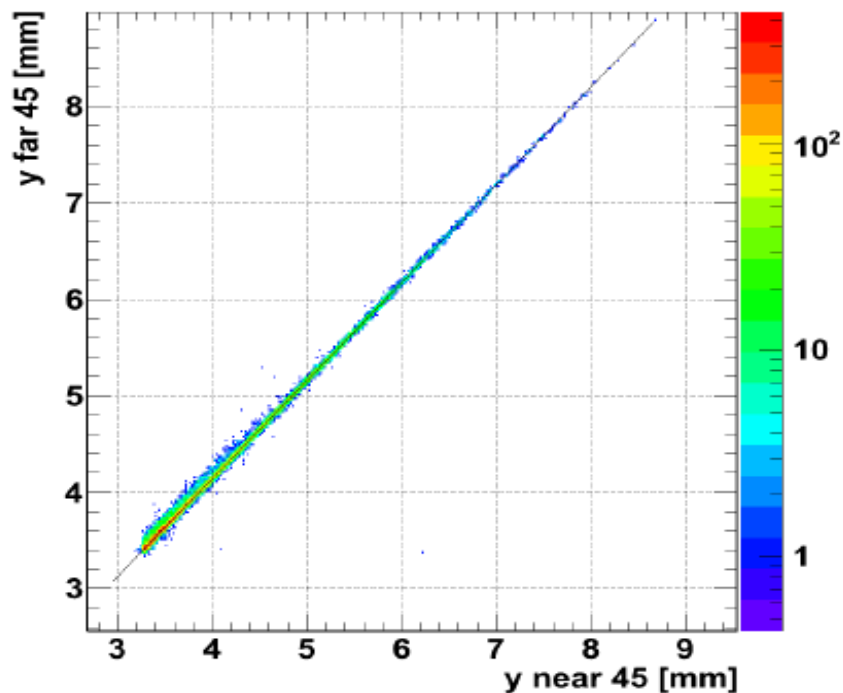
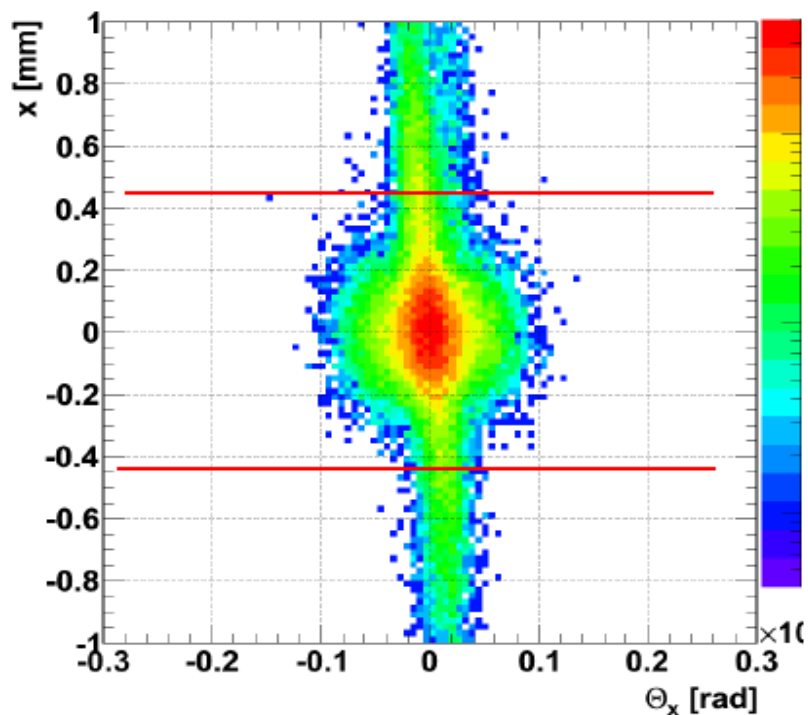
Elastic pp scattering : cuts and data reduction

Low $|\xi|$ selection (3σ):

- $|\mathbf{x}_{\text{RP}}| < 3\sigma_x @ L_x=0$
- $y_{\text{RP_NEAR}} \leftrightarrow y_{\text{RP_FAR}}$

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

↑ showers
↓



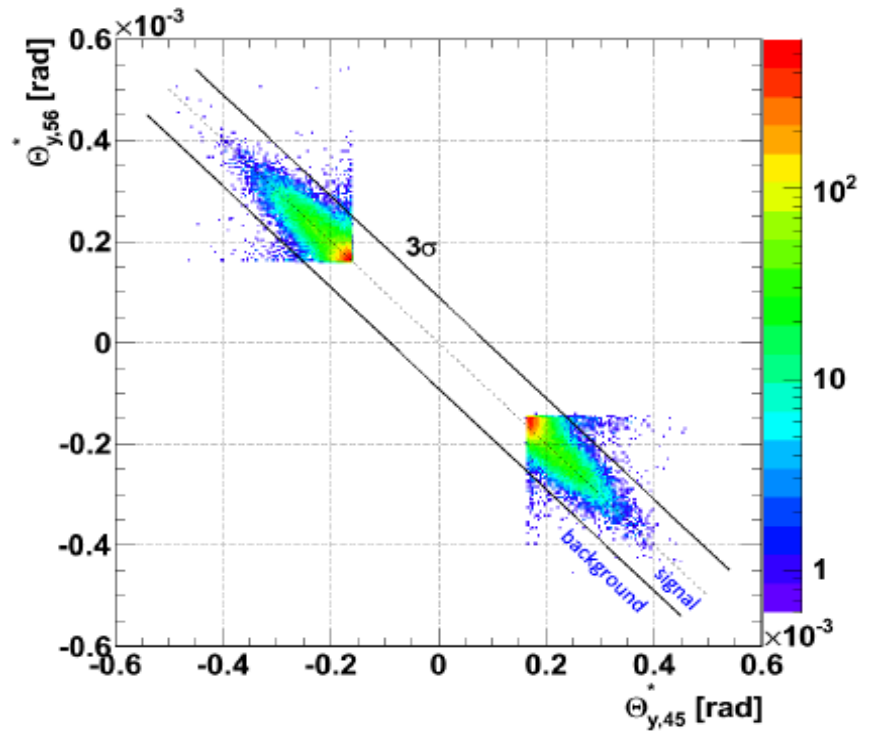
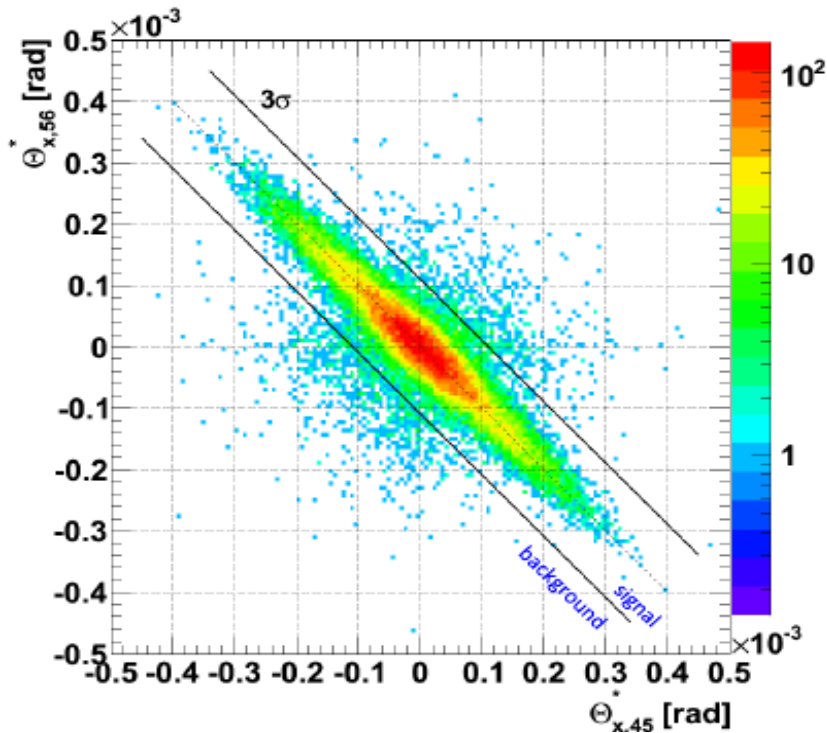
Elastic pp scattering : cuts and data reduction

Elastic collinearity (3σ):

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

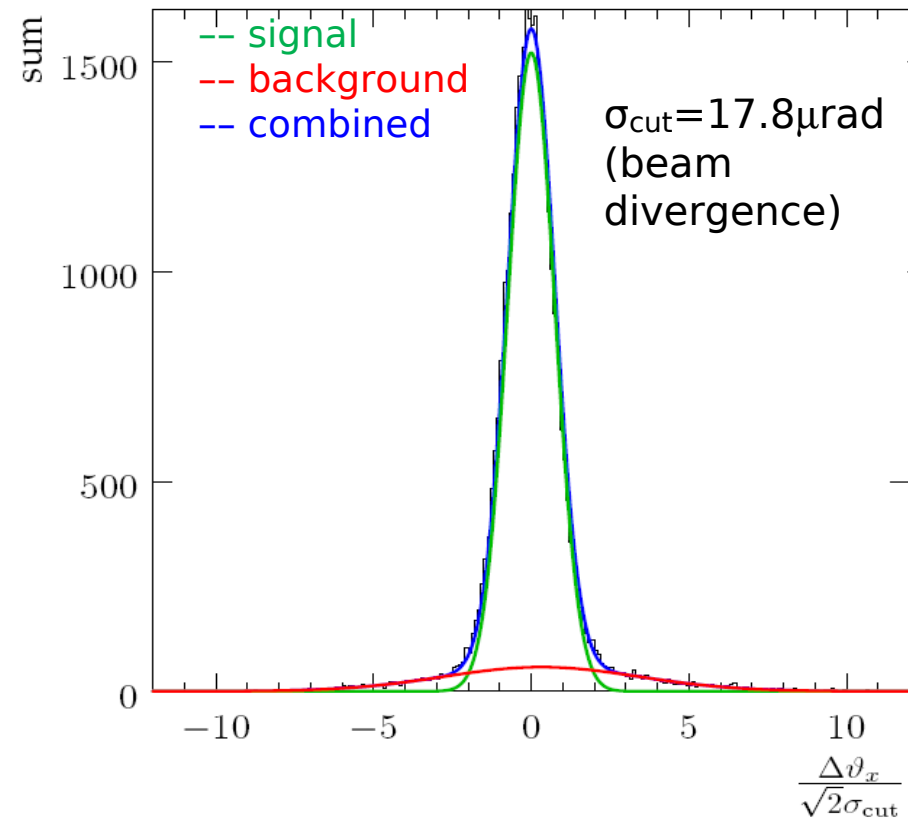
Total triggers	5.28M
Reconstructed tracks & elastic topology	293k
Low $ \xi $ selection	70.2k
Collinearity cuts	66.0k

↑ showers

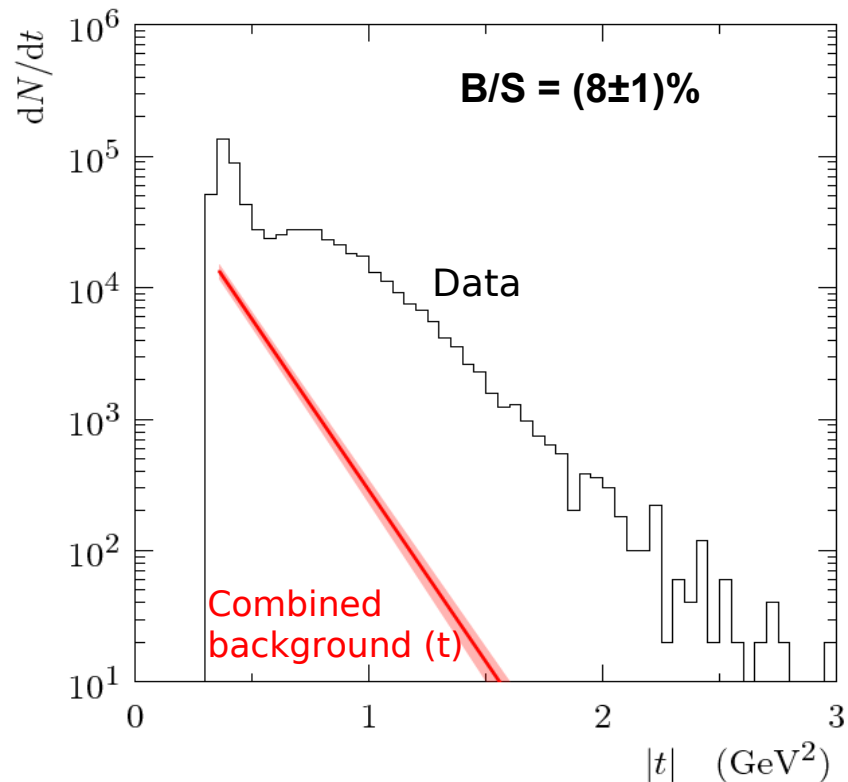




Elastic pp scattering : background



Signal to background normalisation

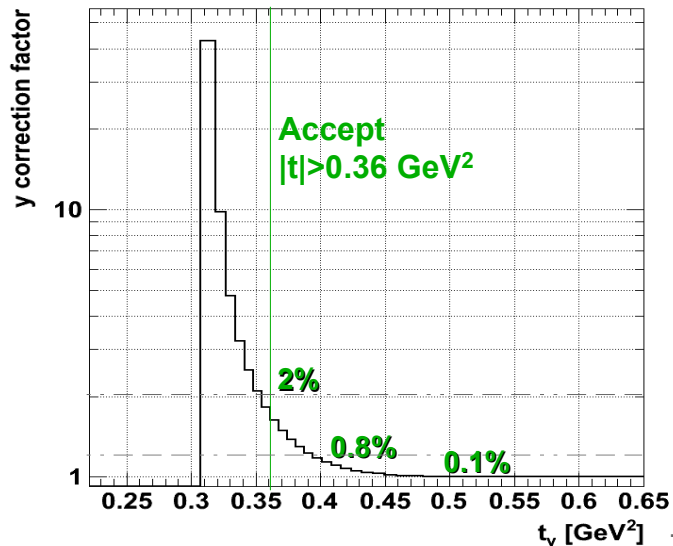
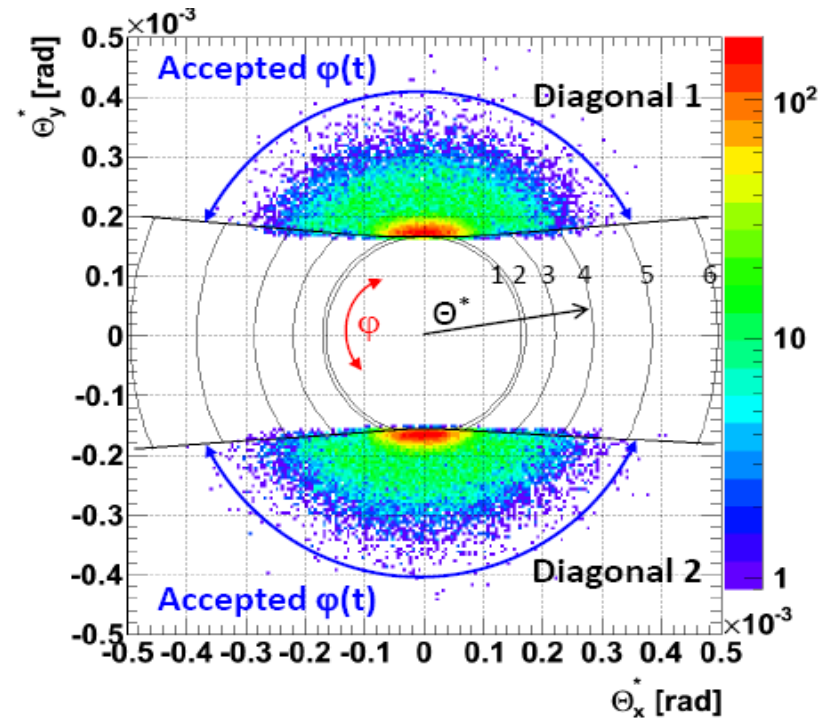
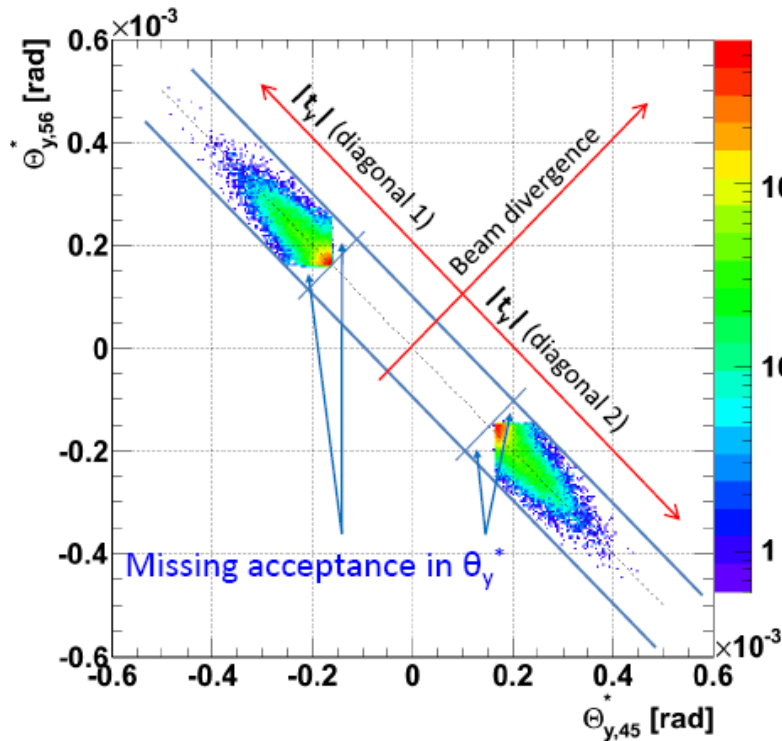


Signal vs. background (t)

$|t|=0.4\text{GeV}^2$: $B/S = (11 \pm 2)\%$
 $|t|=0.5\text{GeV}^2$: $B/S = (19 \pm 3)\%$
 $|t|=1.5\text{GeV}^2$: $B/S = (0.8 \pm 0.3)\%$



Elastic pp scattering: acceptance corrections



	t [GeV 2]	θ^* [mrad]	Accepted ϕ (2 diag.) [°]	ϕ correction
1	0.33	165	38.6	9.3±4.7%
2	0.36	171	76.4	4.7±1.8%
3	0.60	221	162.5	2.2±0.3%
4	1.00	286	209.8	1.7±0.1%
5	1.80	383	246.3	1.5 %
6	3.00	495	269.0	1.3 %



Elastic pp scattering: corrections & systematics

Resolution unfolding:

*Smearing only due to beam divergence ;
detector resolution negligible*

t-reconstruction resolution: $\delta t/t = \sqrt{2} p \sigma_{\text{beam}} / \sqrt{t} \sim 0.1 \sqrt{t}$

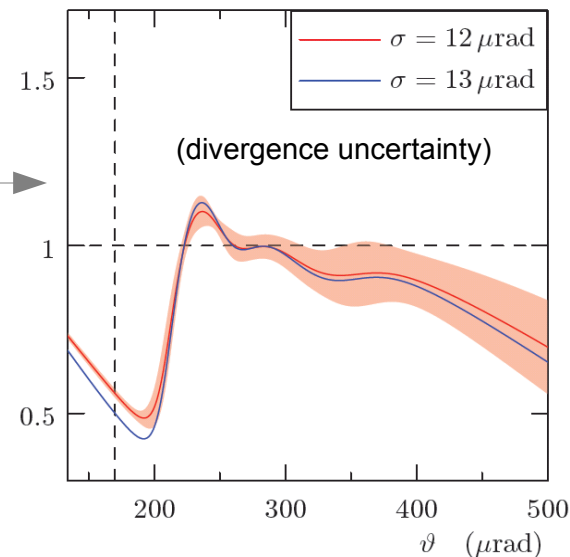
Luminosity : 4%

[CMS-PAS-EWK-10-004; CMS-DP-2011-002 C]

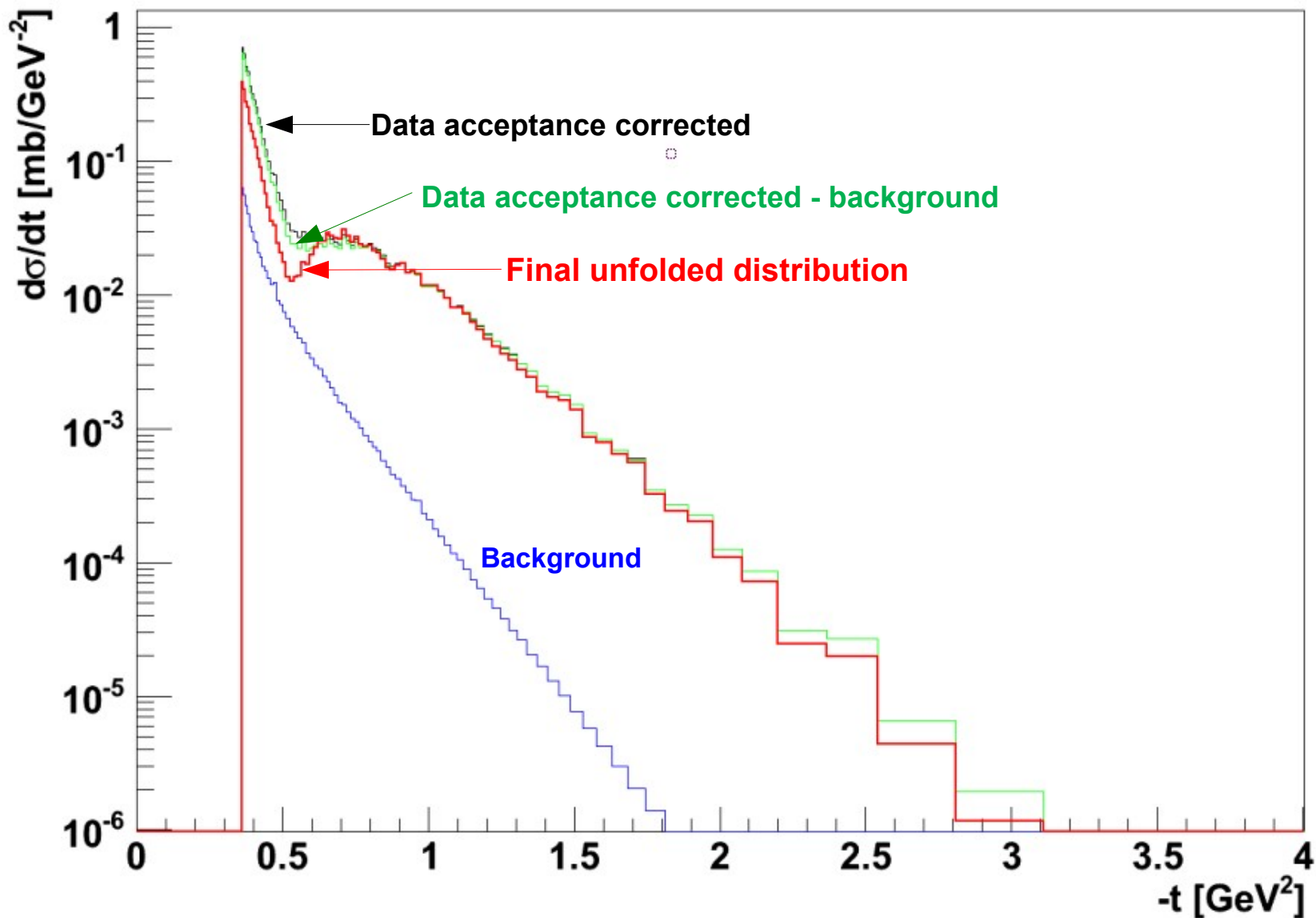
Event reconstruction Inefficiency : $(29 \pm 10)\%$

*Multiple tracks due to showers;
average inefficiency /pot : 3 – 7 % &
tracks induced correlations;
Pile-up < 0.5%*

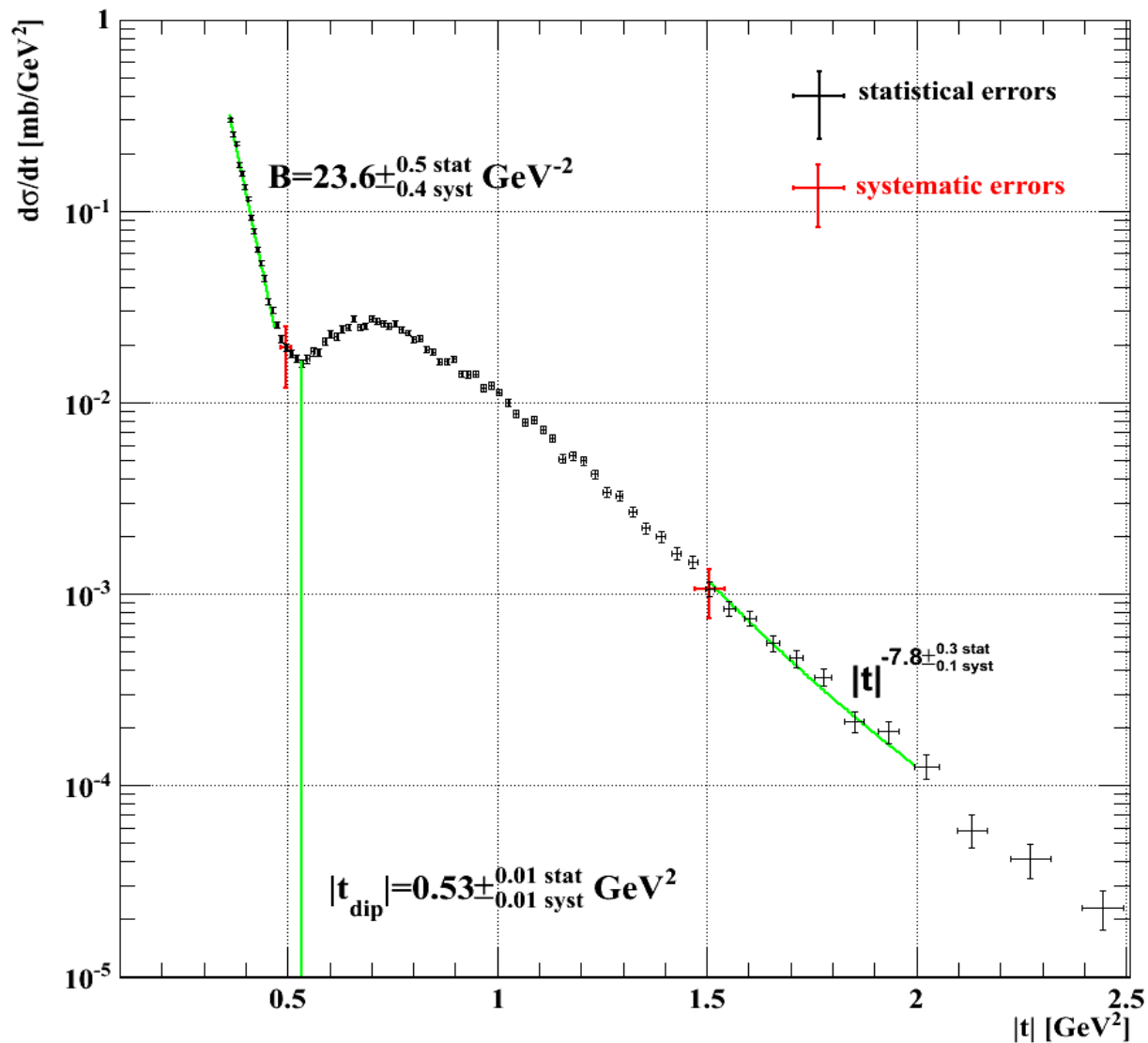
correction = unsmeared / fit



Elastic pp scattering: all corrections

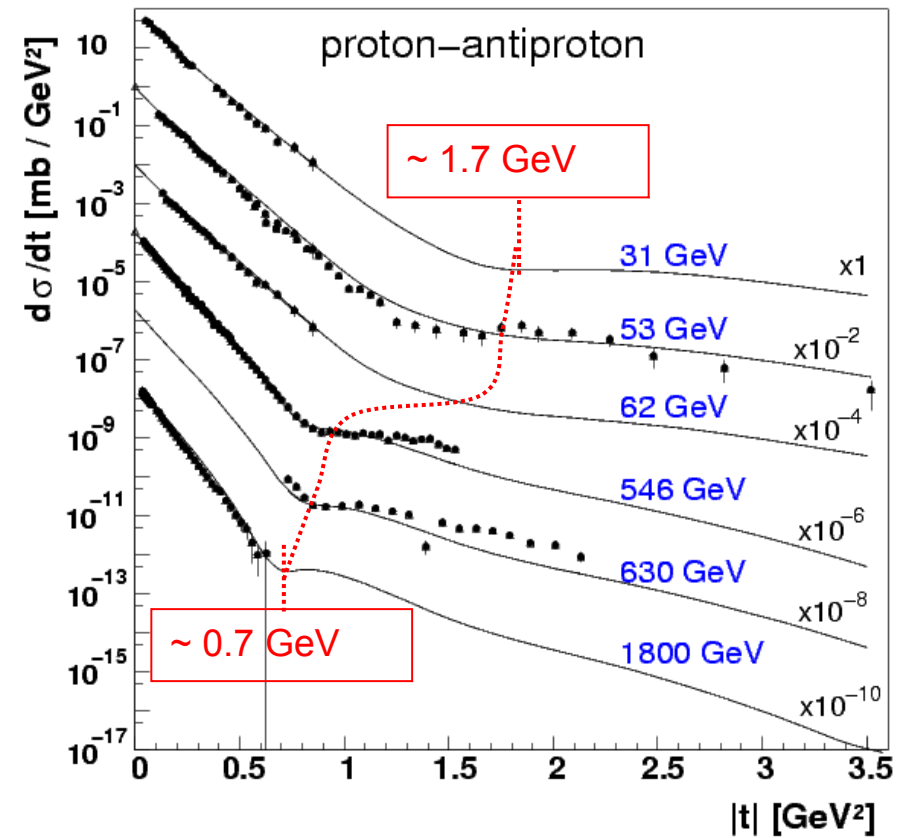
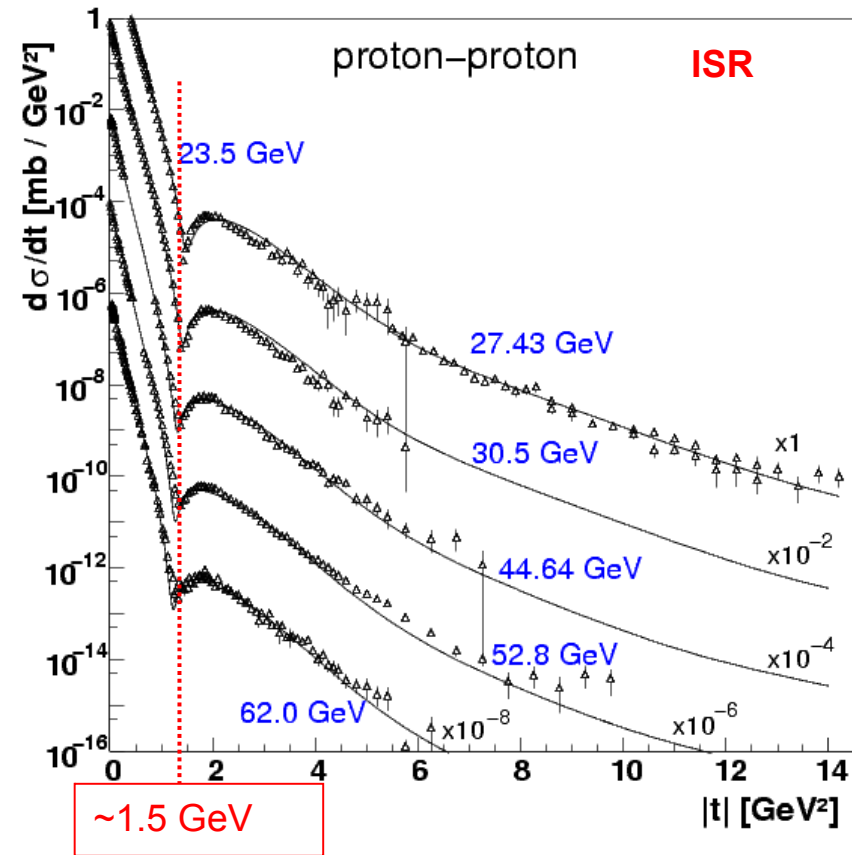


Elastic pp scattering: cross-section

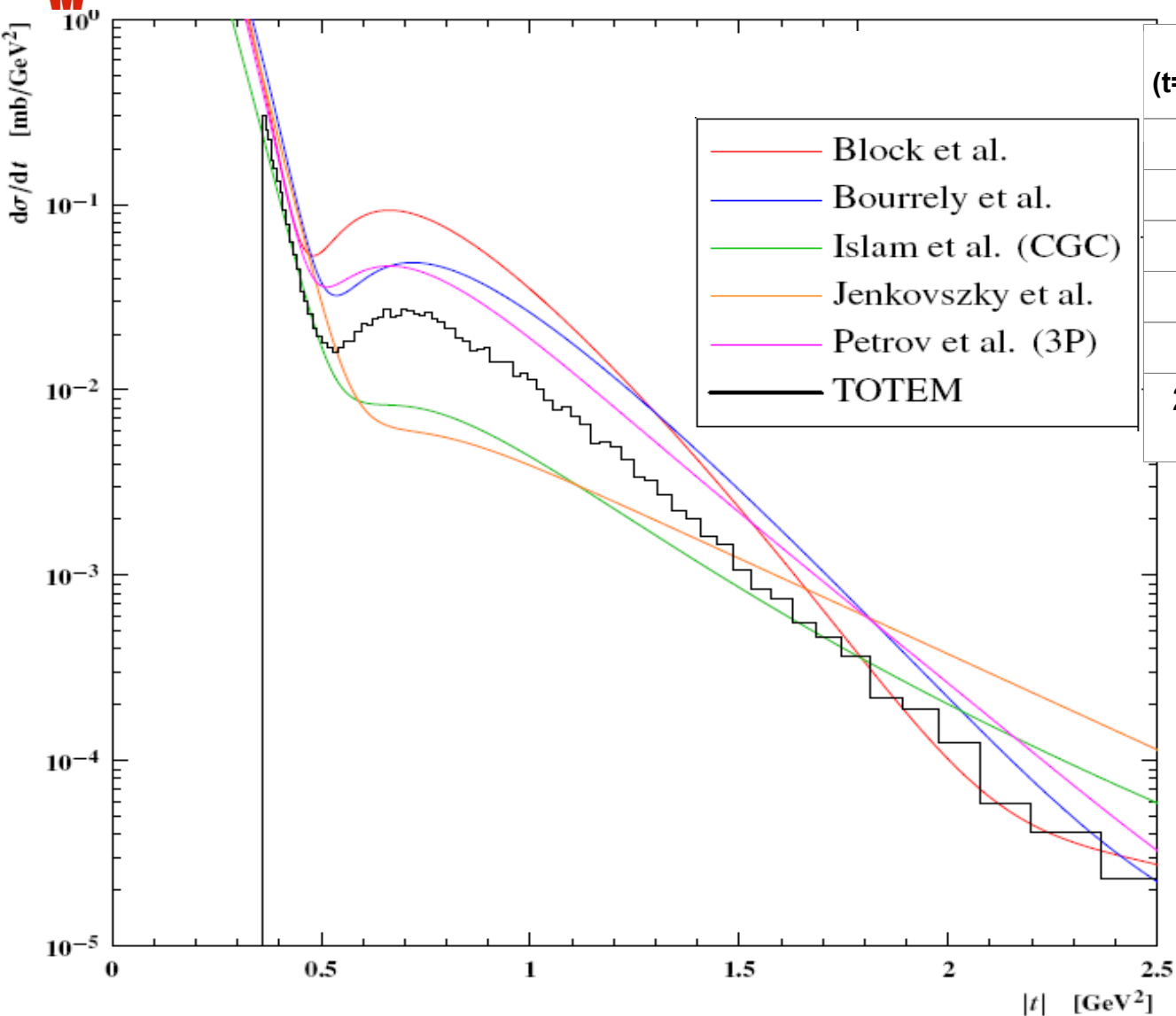




Elastic pp Scattering – from ISR to Tevatron



Elastic pp scattering: comparison to some models



B ($t=-0.4 \text{ GeV}^2$)	t_{DIP}	t^{-n} [1.5–2 GeV^2]
24.4	0.48	10.4
21.7	0.54	8.4
19.9	0.65	5.0
20.1	0.72	4.2
22.7	0.52	7.0
23.6 ± 0.5 $\pm 0.4^{\text{syst}}$	0.53 ± 0.01 $\pm 0.01^{\text{syst}}$	7.8 ± 0.3 $\pm 0.1^{\text{syst}}$



Outlook

Next analysis:

- 18σ 2010 data ($\sim 5 \text{ pb}^{-1}$)
- Double Pomeron Exchange, RP +T1 and T2
(2011 data - *low intensity runs*)
- T1, T2 Pseudorapidity distributions (including RP information)
- Multiplicity distributions and correlations
- Visible inelastic cross section

Data taking 2011

RP 220 m fully “validated” (14σ V, 17σ H in normal runs):
large- t elastic scattering, $\beta^*=1.5 \text{ m}$

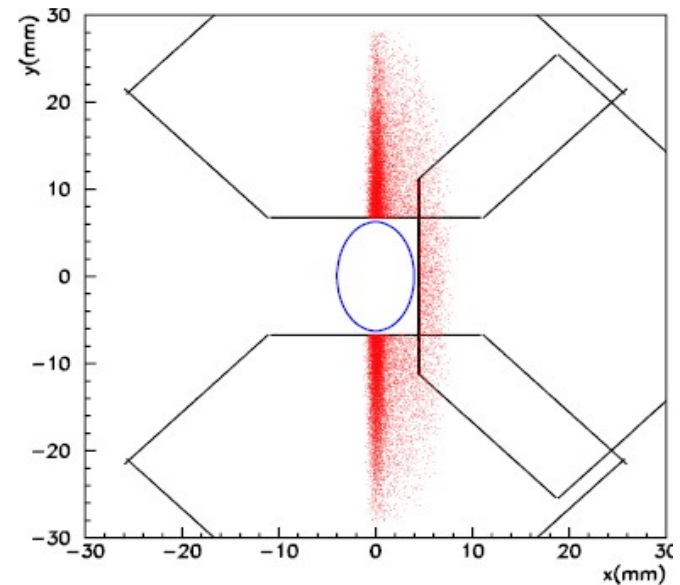
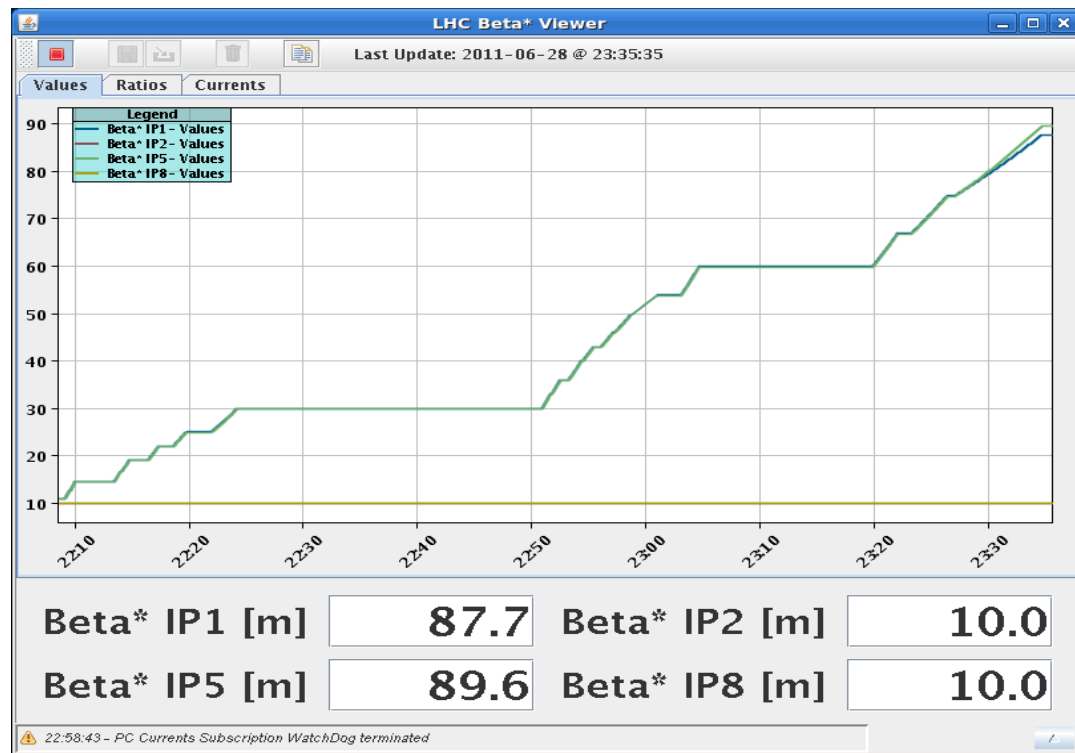
RP 147 m beam based alignment with data taking foreseen in August

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



$\beta^* = 90$ m optics

- 1st MD (done): successful for separated beams
- 2nd MD (28. June): successful ; established collisions & data taking for optics diagnostics
- Physics starting in late summer
 - Low-t (10^{-2} GeV²) elastic scattering
 - Total cross-section (extrapolation to t=0 possible)





Tracks in RPs : $\beta^*=90\text{m}$

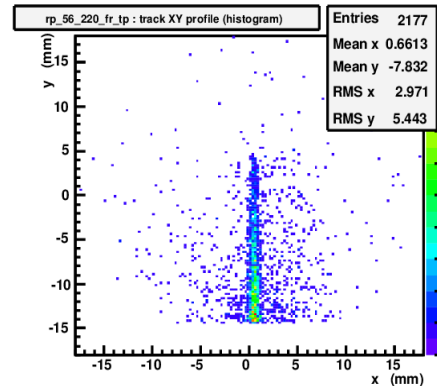
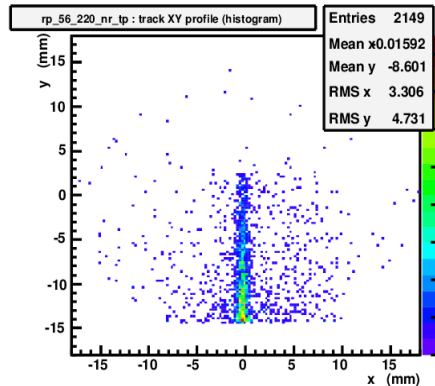
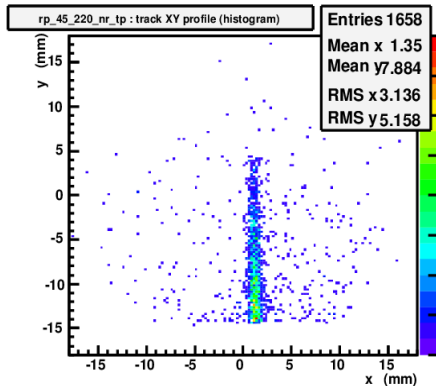
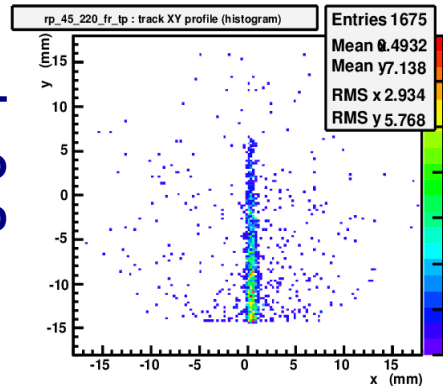
45far

45near

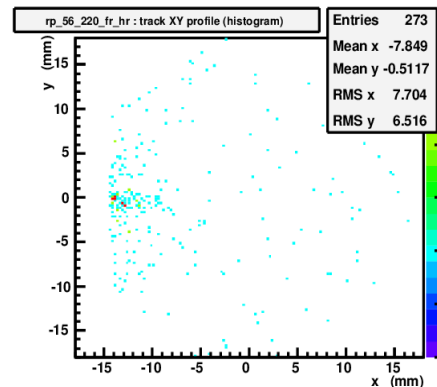
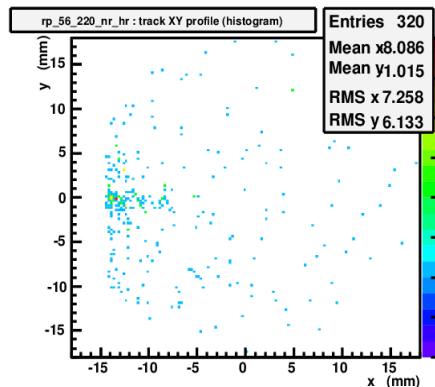
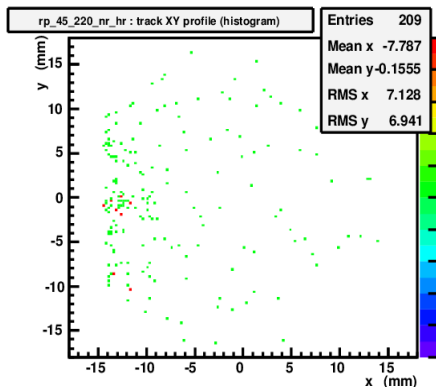
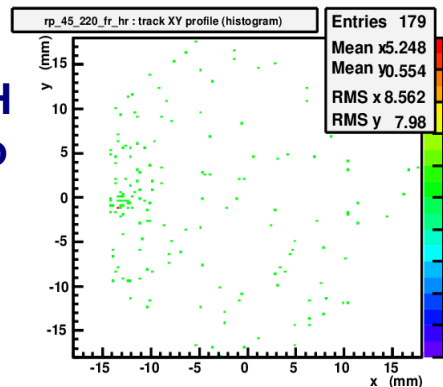
56near

56far

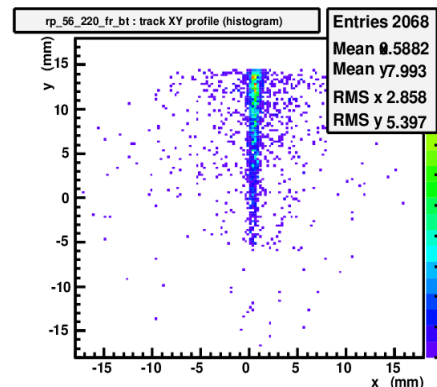
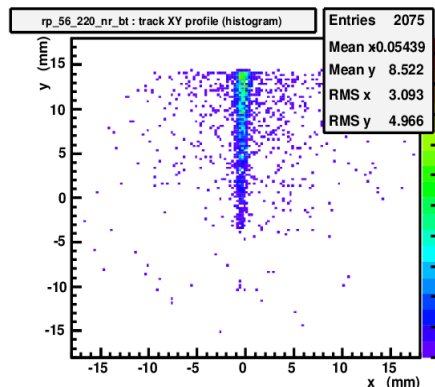
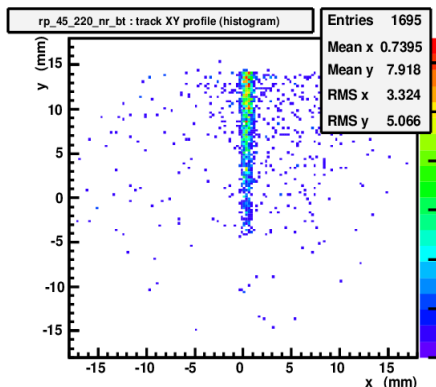
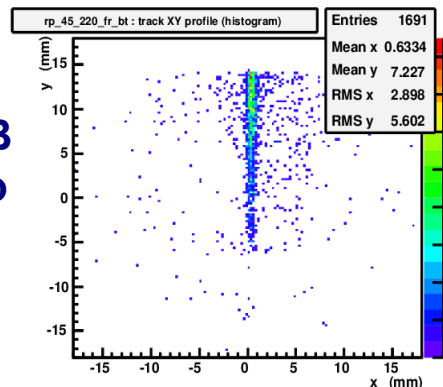
Top



Hor



Bot

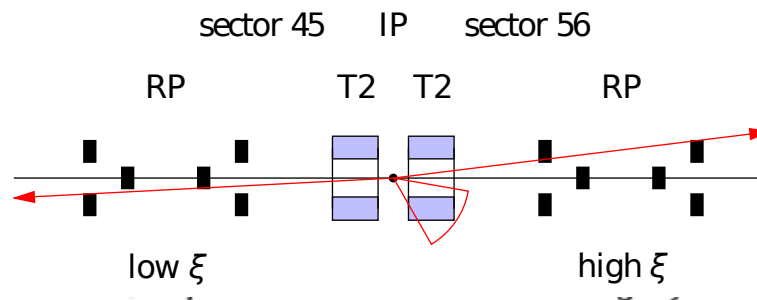




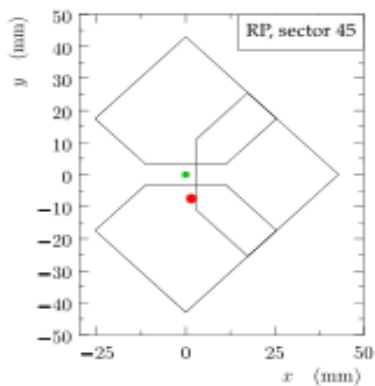
Backup



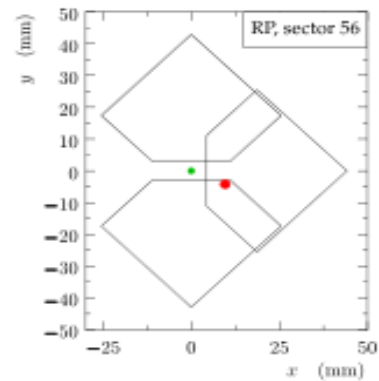
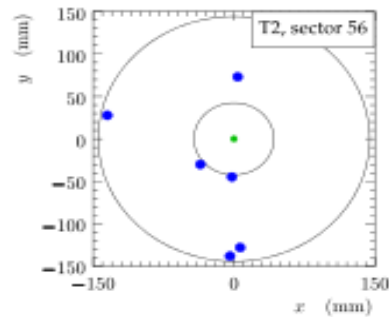
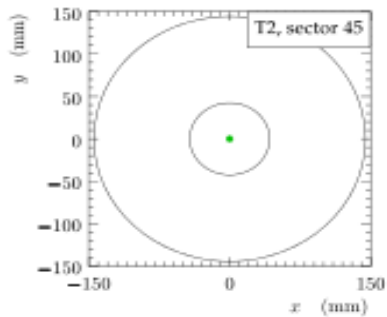
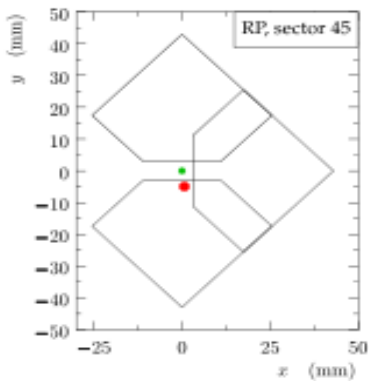
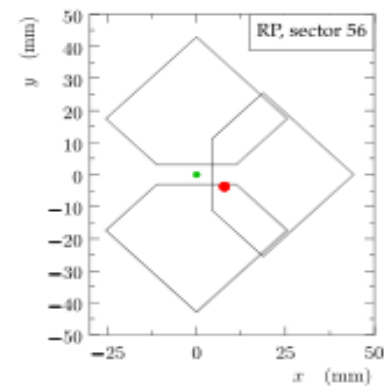
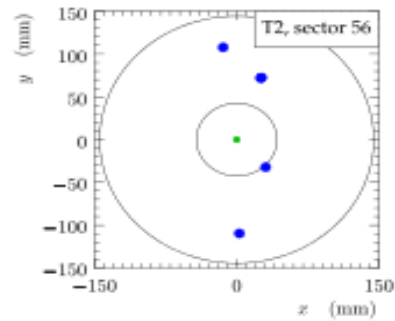
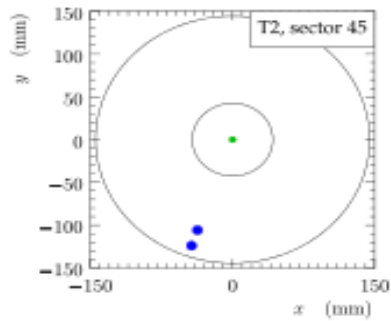
Double Pomeron Exchange



run: 37250009, event: 14125

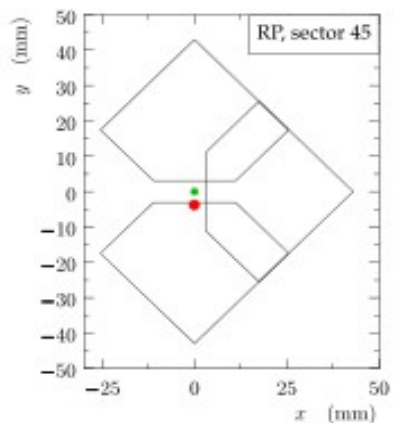
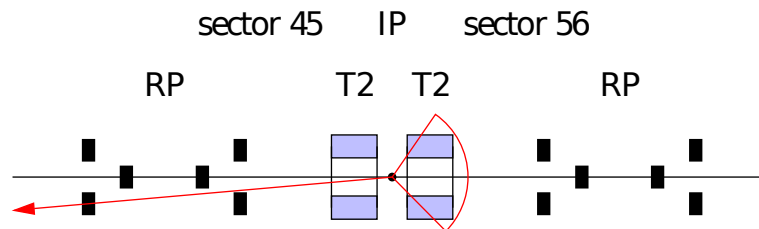


run: 37220007, event: 9904

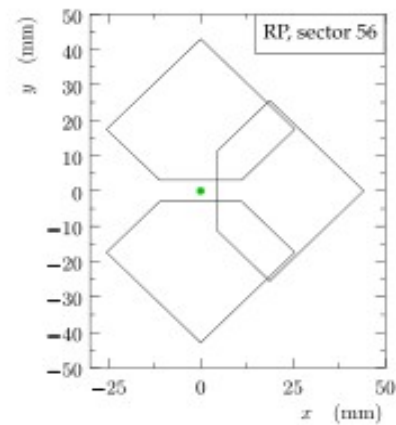
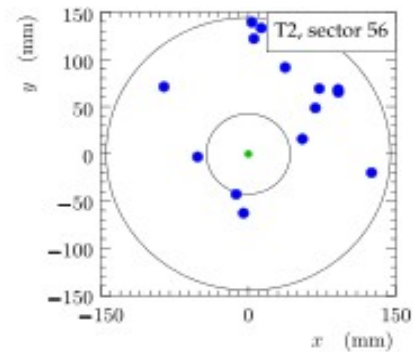
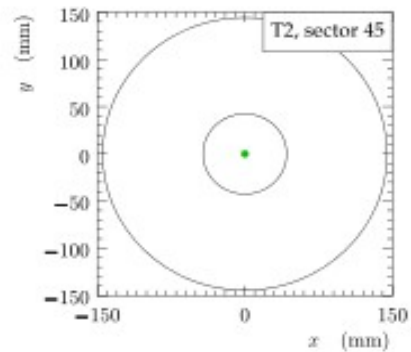
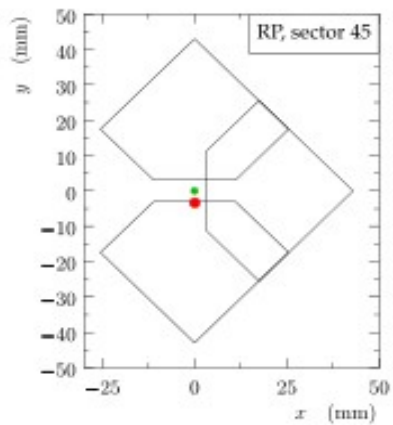
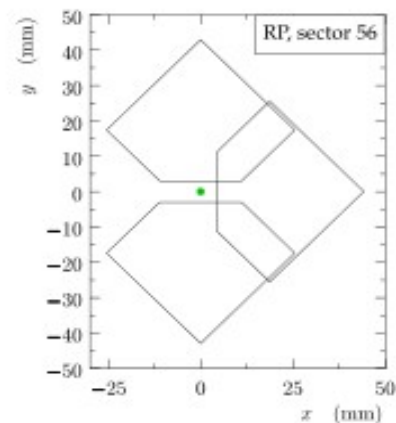
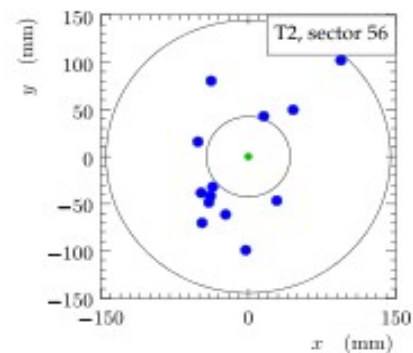
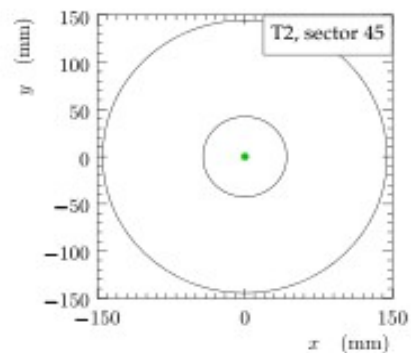




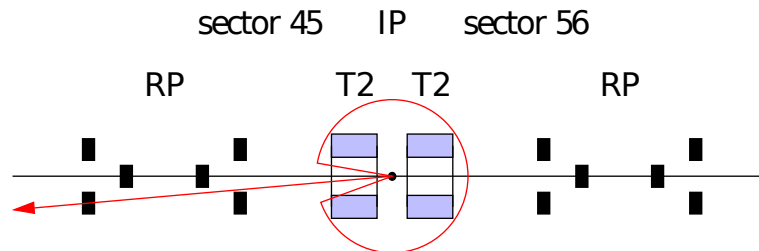
Single diffraction low ξ



run: 37280004, event: 22784



Single diffraction large ξ



run: 37280006, event: 9522

