Total Cross Section, Elastic Scattering and Diffraction Dissociation at the LHC

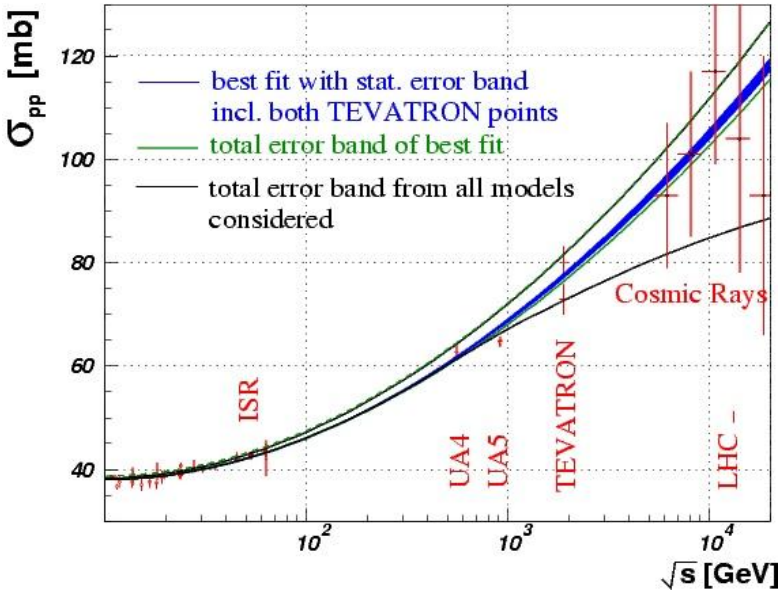
Marco Bozzo – INFN Genova and University of Genova (Italy)
on behalf of the TOTEM Collaboration

Overview:

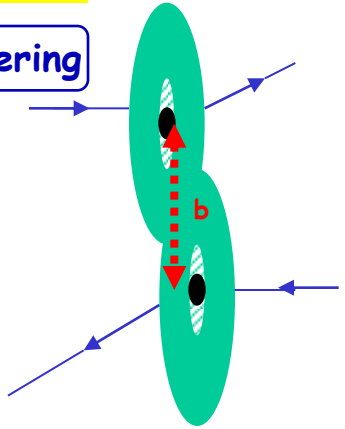
- The experiment and the detectors
- First observations with the inelastic telescopes
- Measurement of large-t pp elastic scattering (0.36-2.5 GeV^2)
- A look at diffractive and DPE events with TOTEM

TOTEM Physics Overview

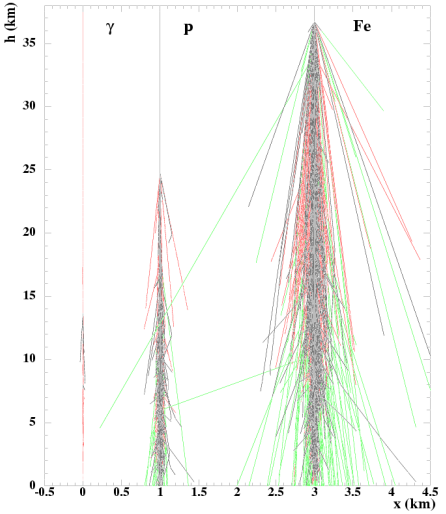
Total cross-section



Elastic Scattering



Forward physics



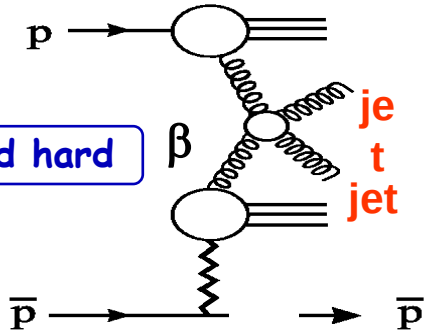
$$L\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \times \left.\frac{dN}{dt}\right|_{t=0}$$

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

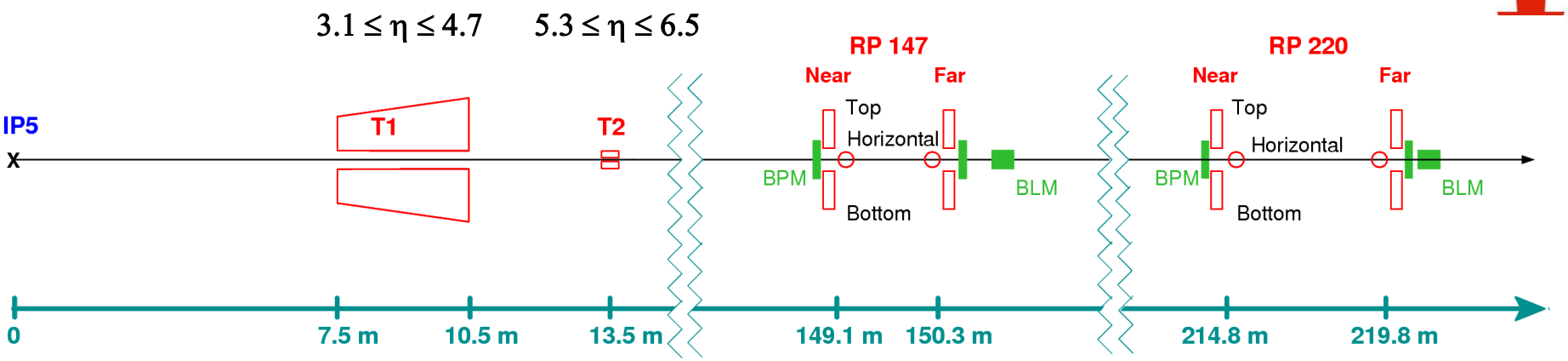
Optical Theorem

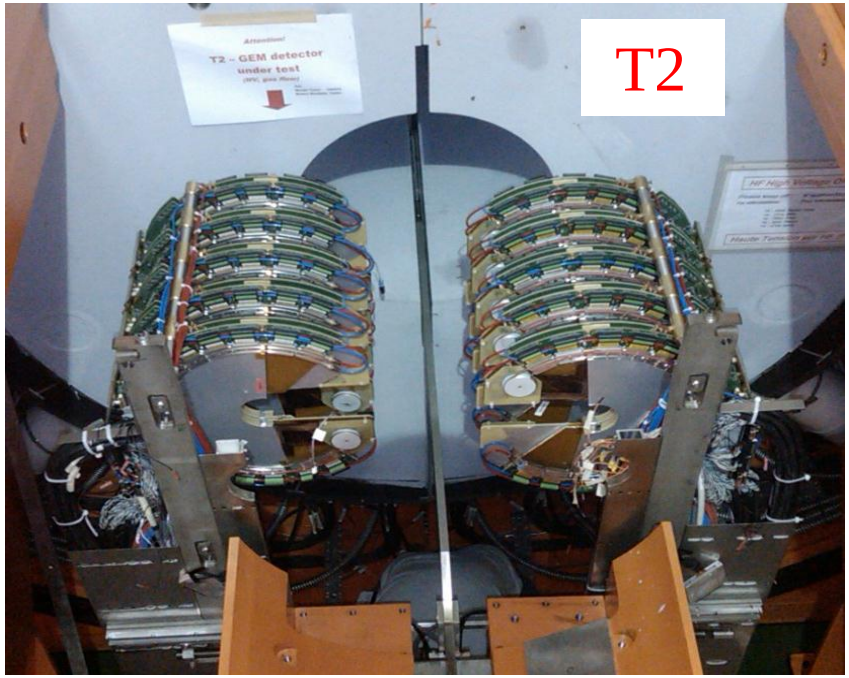
$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \times \frac{(dN/dt)|_{t=0}}{N_{el} + N_{inel}}$$

Diffraction: soft and hard



The TOTEM detector set-up





T1 and T2 in the forward region of CMS

T1 telescope

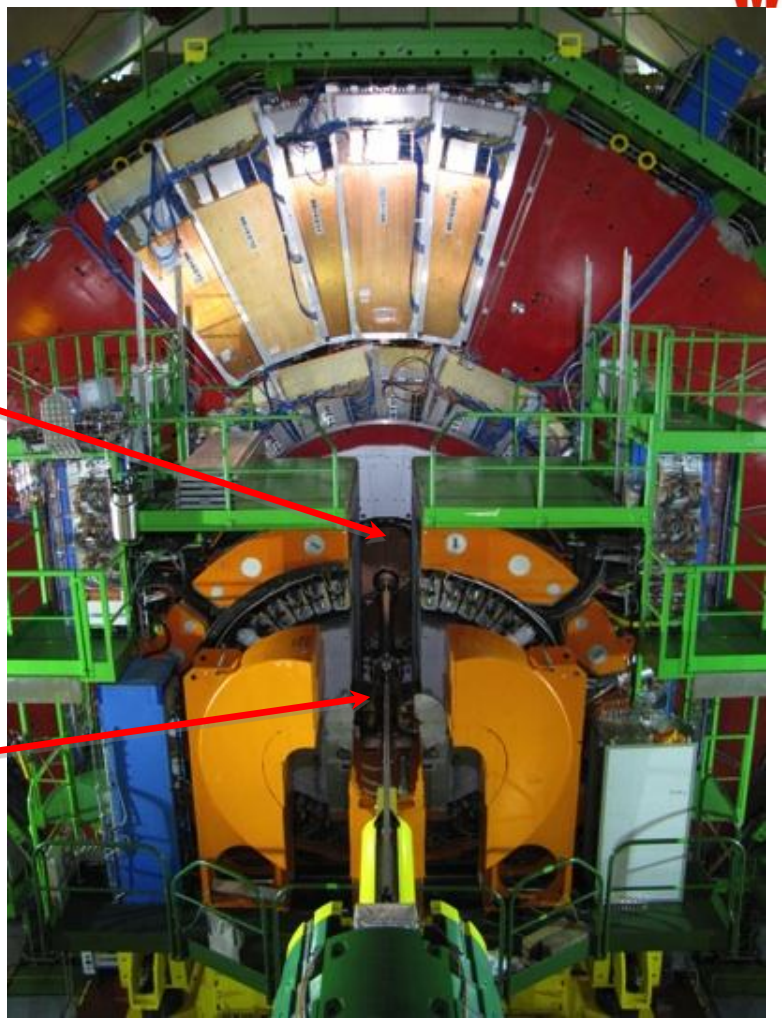
5 planes of CSC chambers

Wires and cathode strips

T2 telescope

10 planes of GEM chambers

Strips and pads



Preliminary dN/dη *results (T2)*

Low luminosity runs 2010

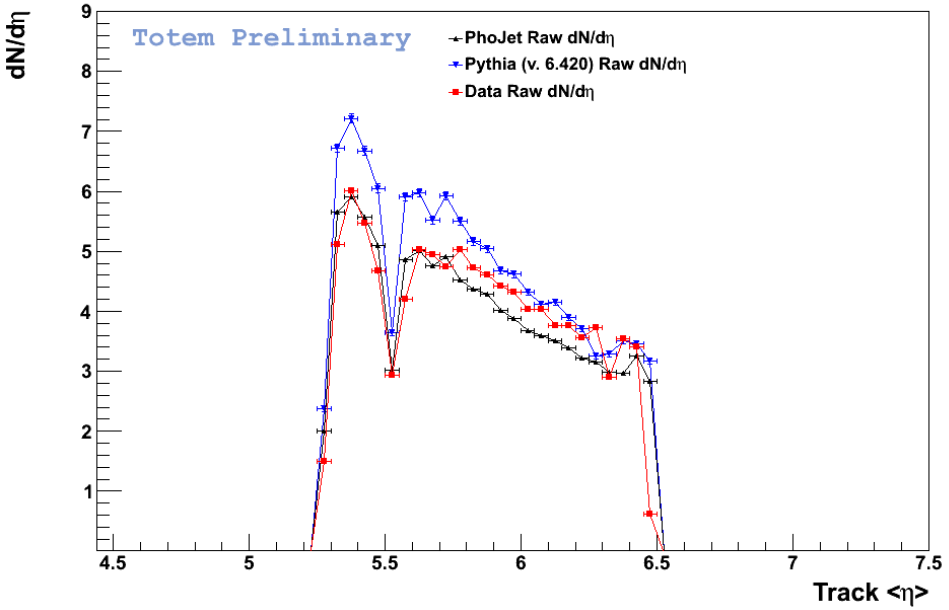
T2 'plus' and 'minus' sides superimposed

$\sqrt{s} = 7$ TeV

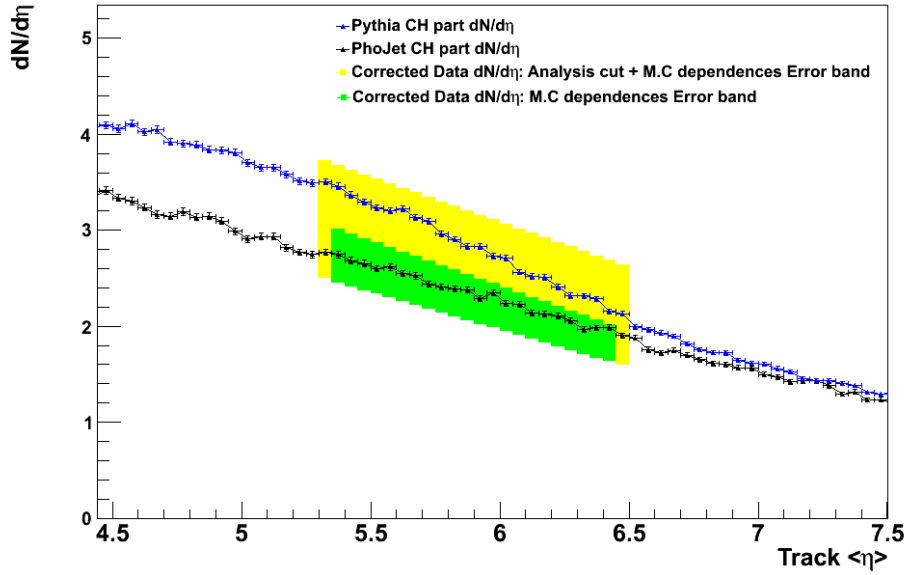
Raw data

Unfolded data

Reconstructed dN/dη (Not unfolded)



Corrected data and Phojet/Pythia comparison



Green band = data after vertex cuts

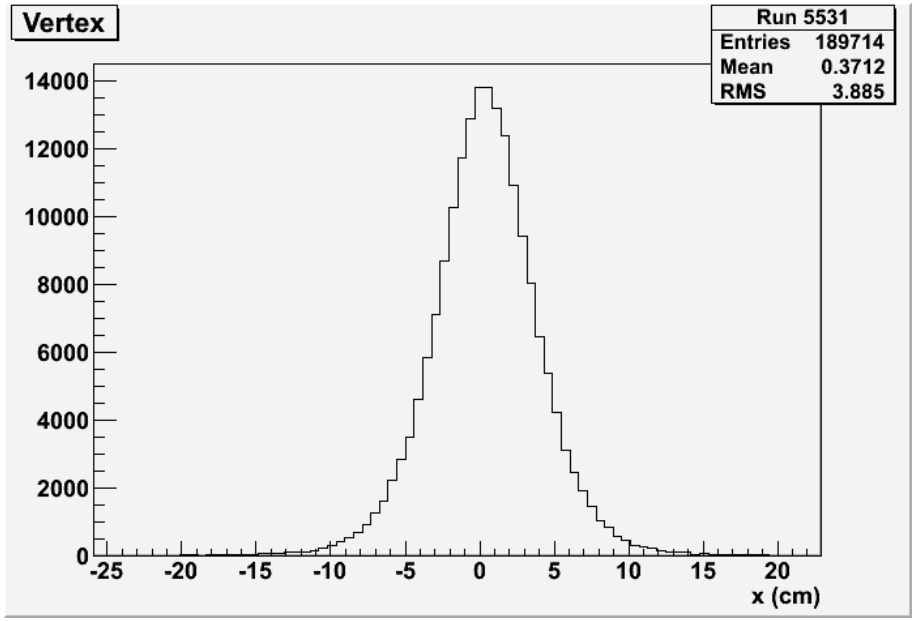
Data taken during scraping exercise

And with low intensity bunches of 10^{10} p (low pile-up)

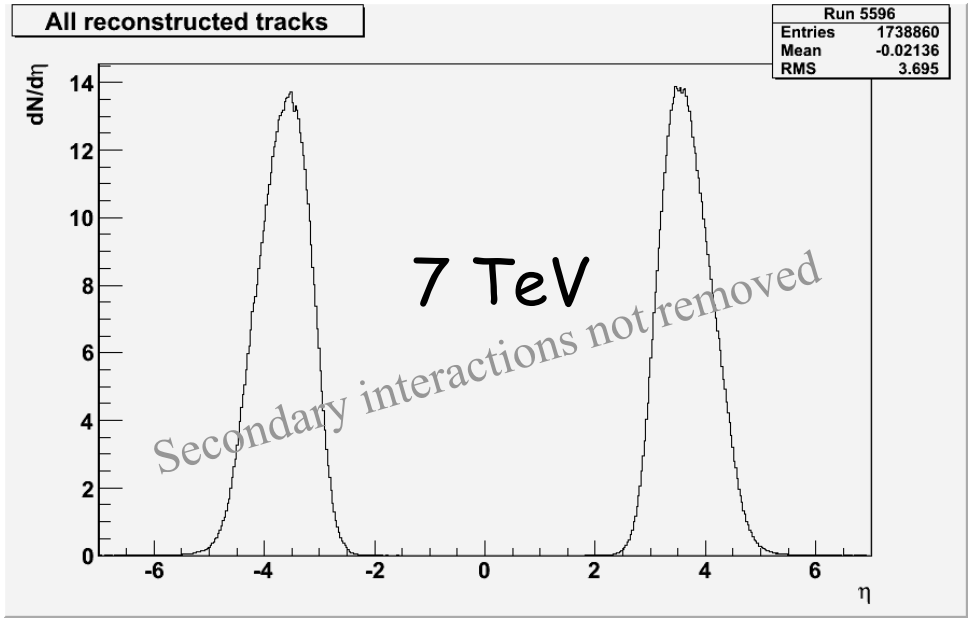
First data (T1)

- Telescope installed in 2010-11 shutdown
- So far short periods of data taking with low luminosity (L = 10^{28} – 10^{30} cm^{-2} s^{-1}) [March (2.76 TeV), May (7 TeV)]
- Detector working
- Data analysis in progress

Vertex reconstruction



η Distributions (uncorrected)

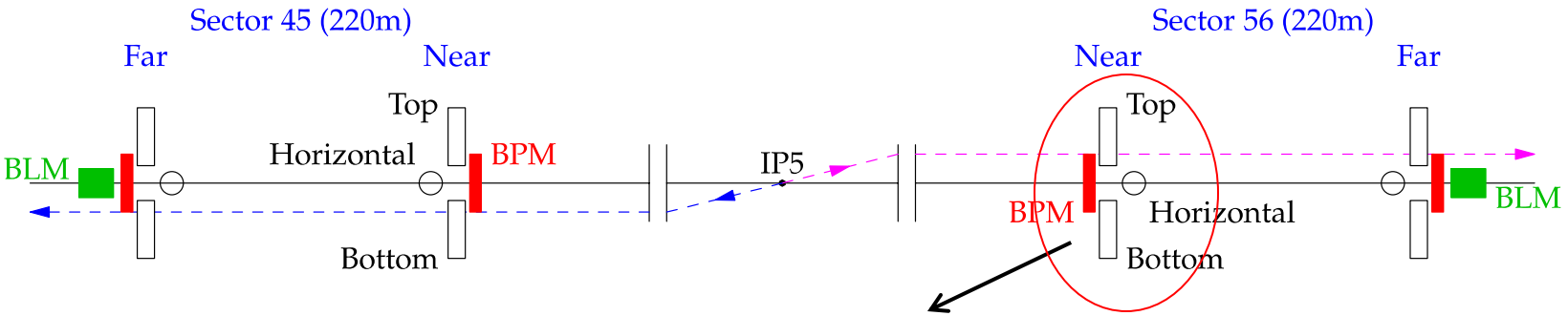


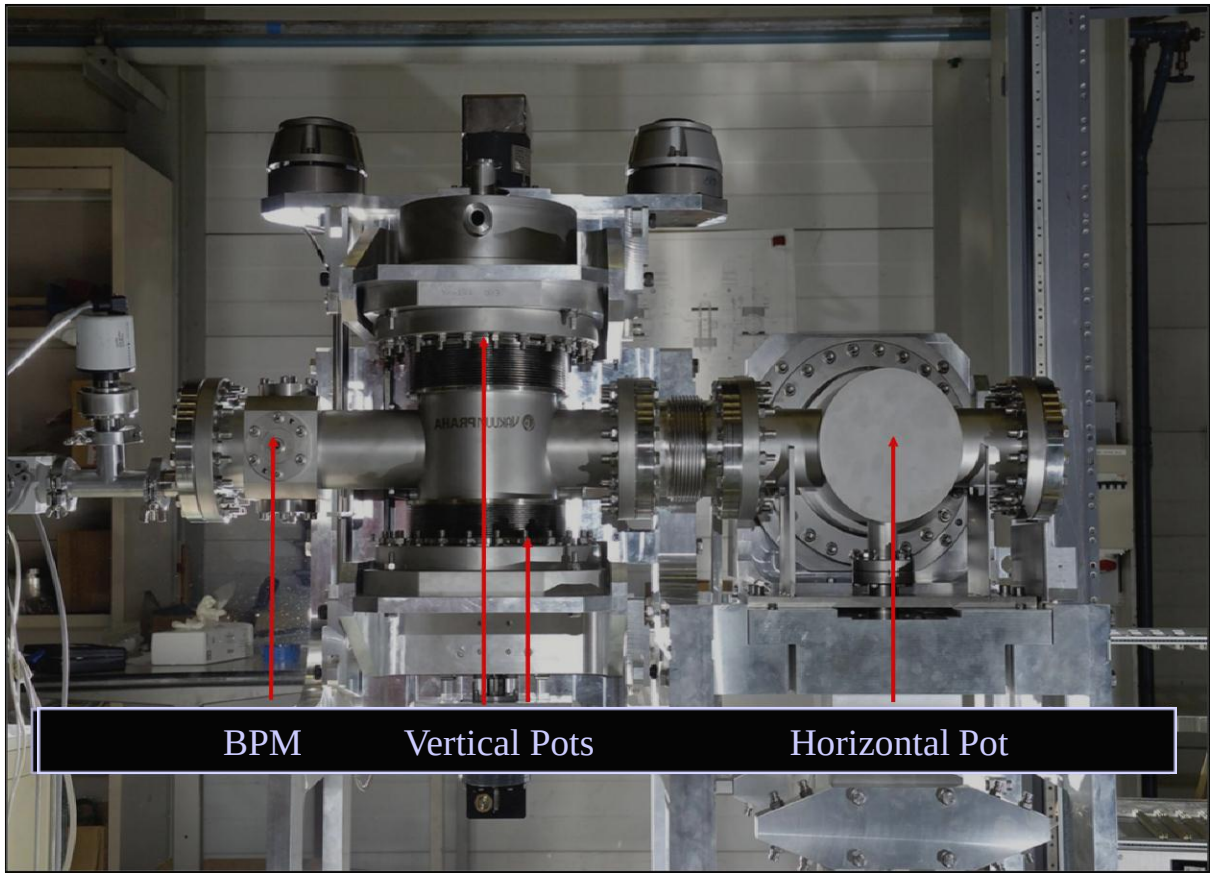
Vertex reconstruction is affected by the CMS magnetic field.

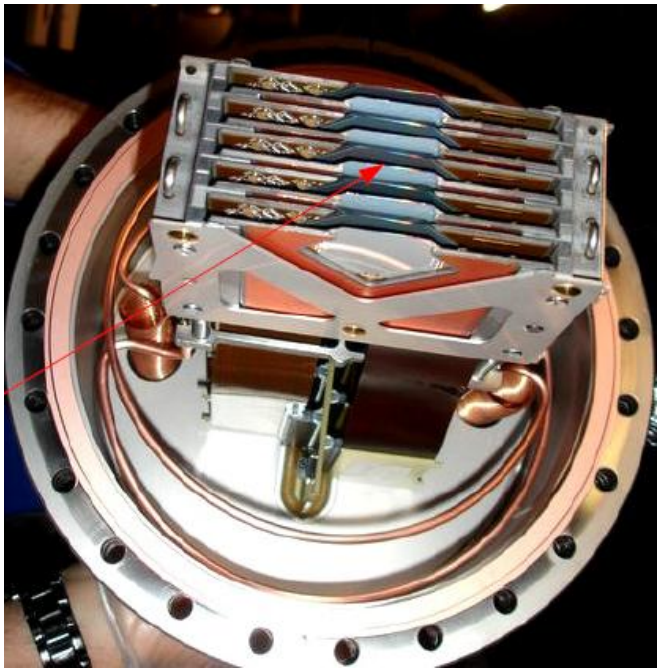
PP *ELASTIC SCATTERING*

t-range: 0.36 – 2.5 GeV^2

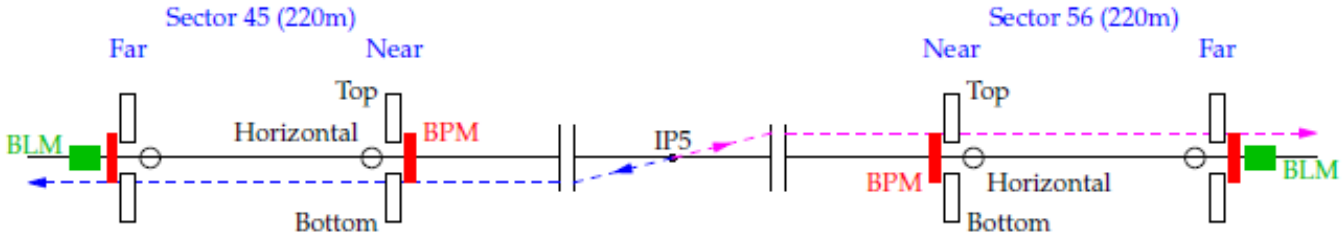
The Roman Pot Unit







2010 Runs



- 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 colinearity (3σ)
  - $\theta_{x,45}^* \leftrightarrow \theta_{x,56}^*$
  - $\theta_{y,45}^* \leftrightarrow \theta_{y,56}^*$

Only RPs @ 220 moved 'close' to the beams

- vertical RPs @ $7\sigma \sim 3$ mm from circulating beams
- low pile-up

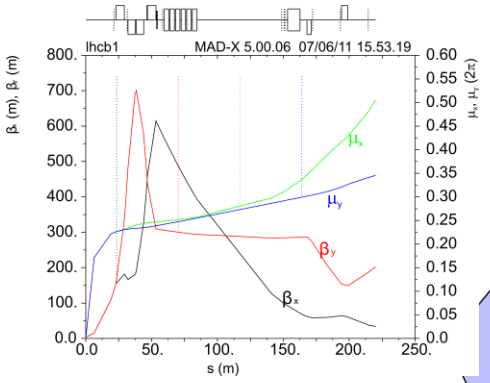
Integrated luminosity : 6.2 nbarn^{-1}

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

Diagonals analysed independently

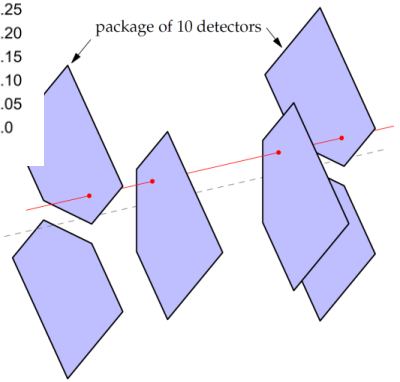
Proton reconstruction

- **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 beam optics understanding**

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



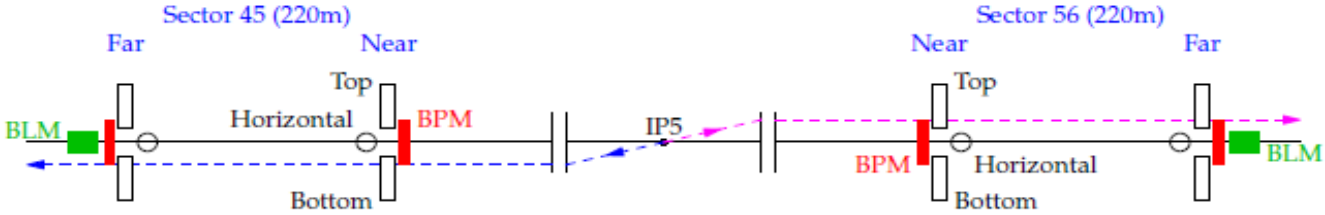
Track based alignment

→ **Fine geometric 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)

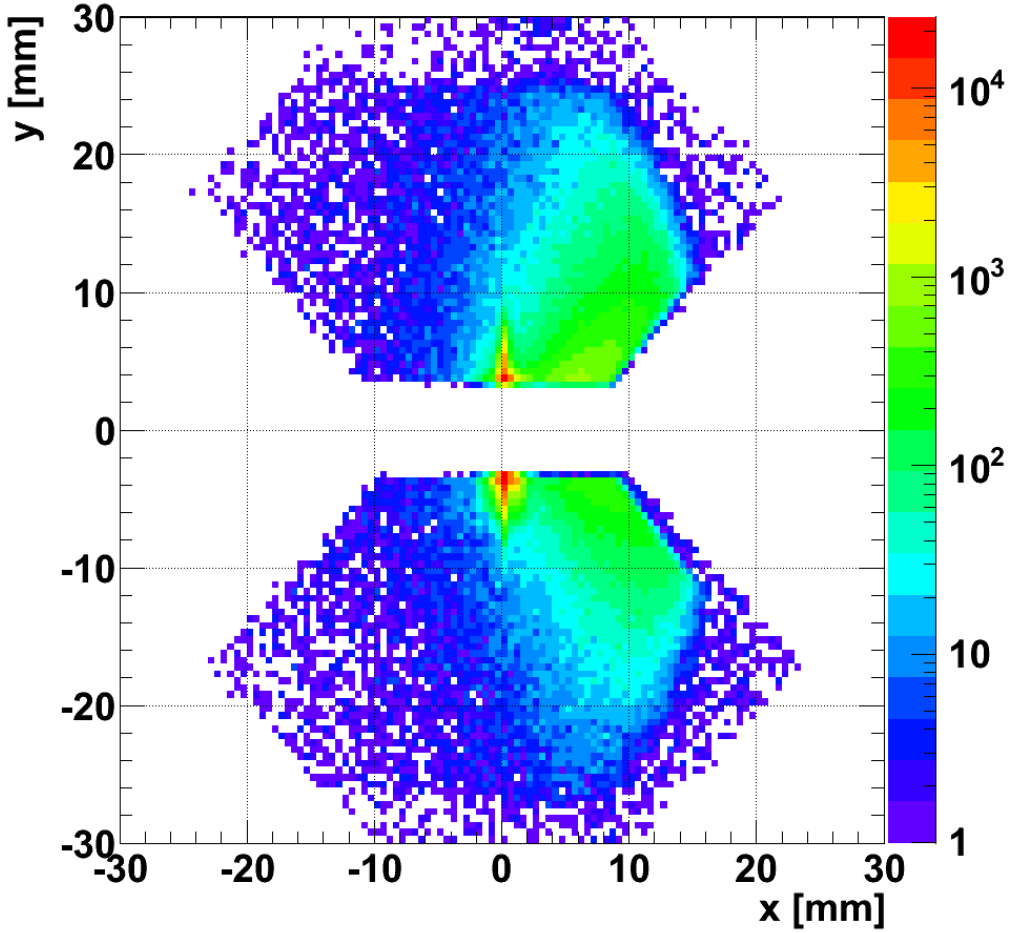
Proton tracks in one diagonal

(left-right coincidences)



Sector 56

Sector 45



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

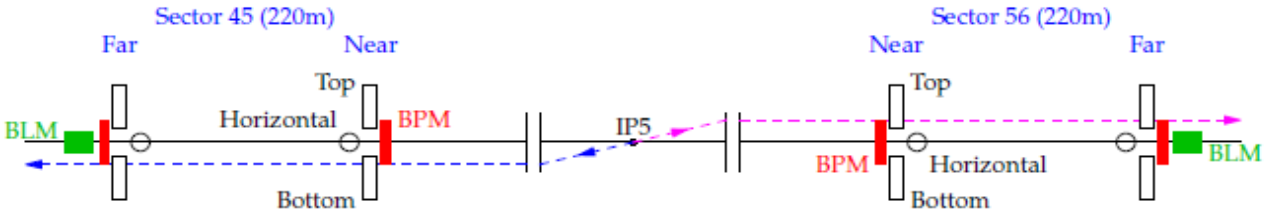
$\xi = \Delta p/p$

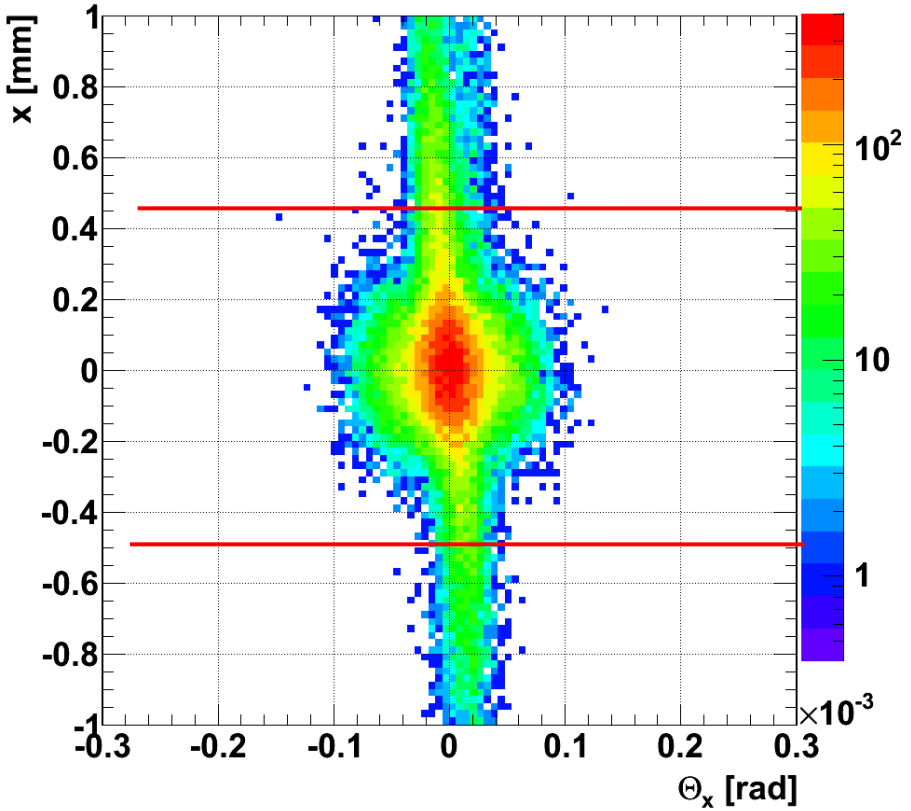
$y = L_y \Theta_y$

$x = L_x \Theta_x + \xi D$

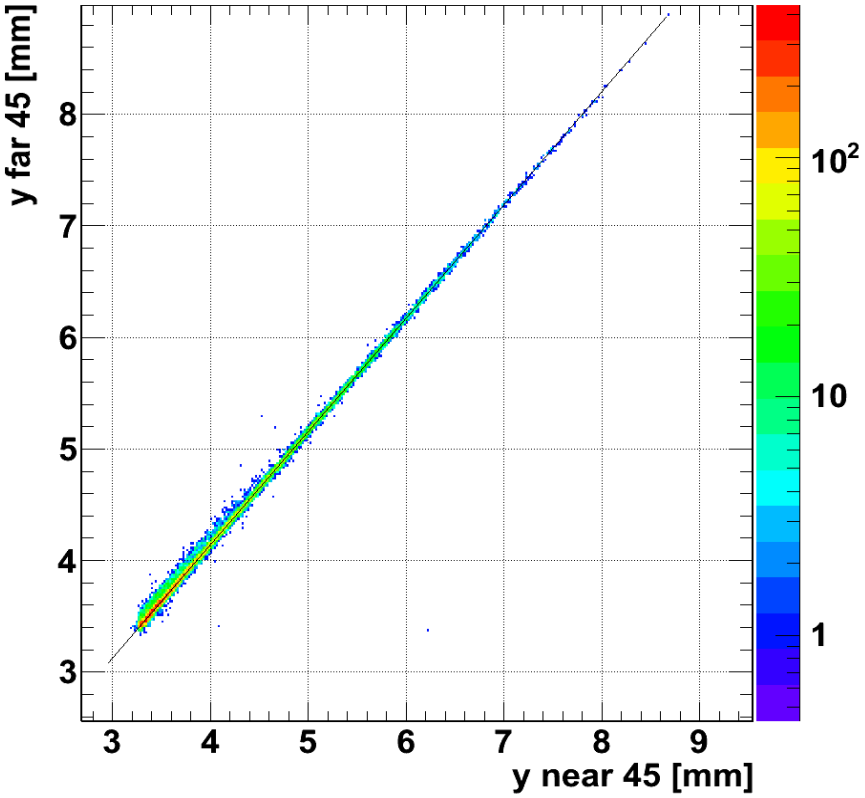
$L_x \sim 0$

Low $\xi = \Delta p/p$ cuts





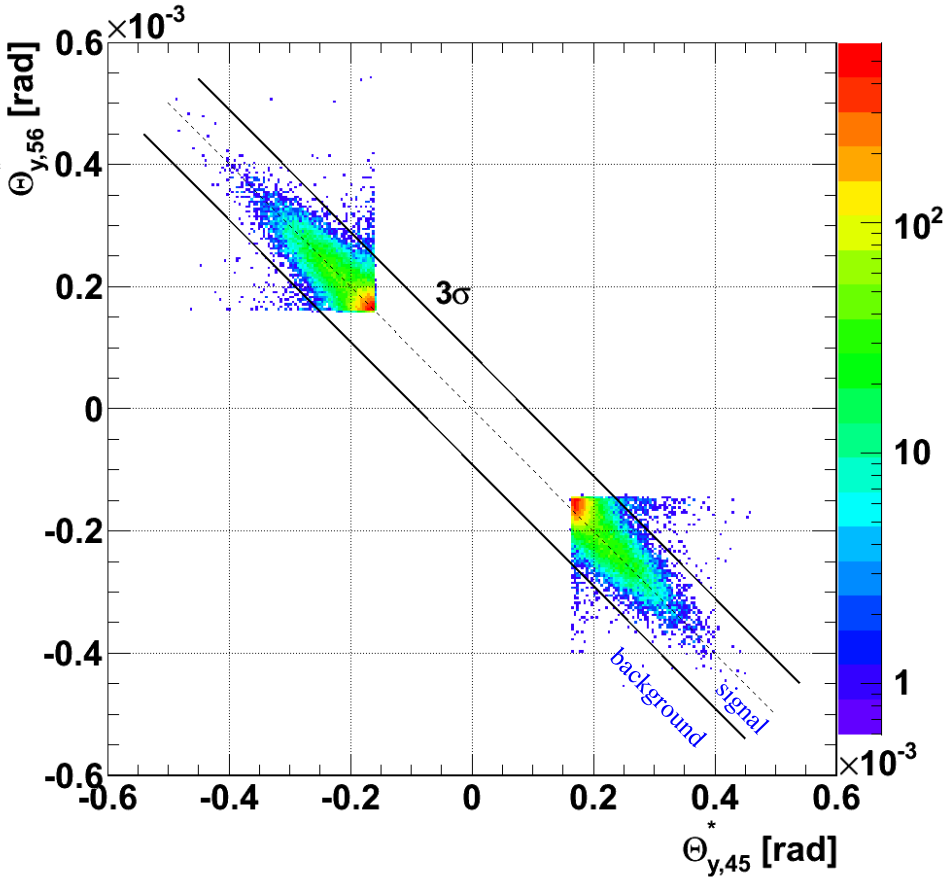
$|x| < 3\sigma_x$ @ $L_x = 0$

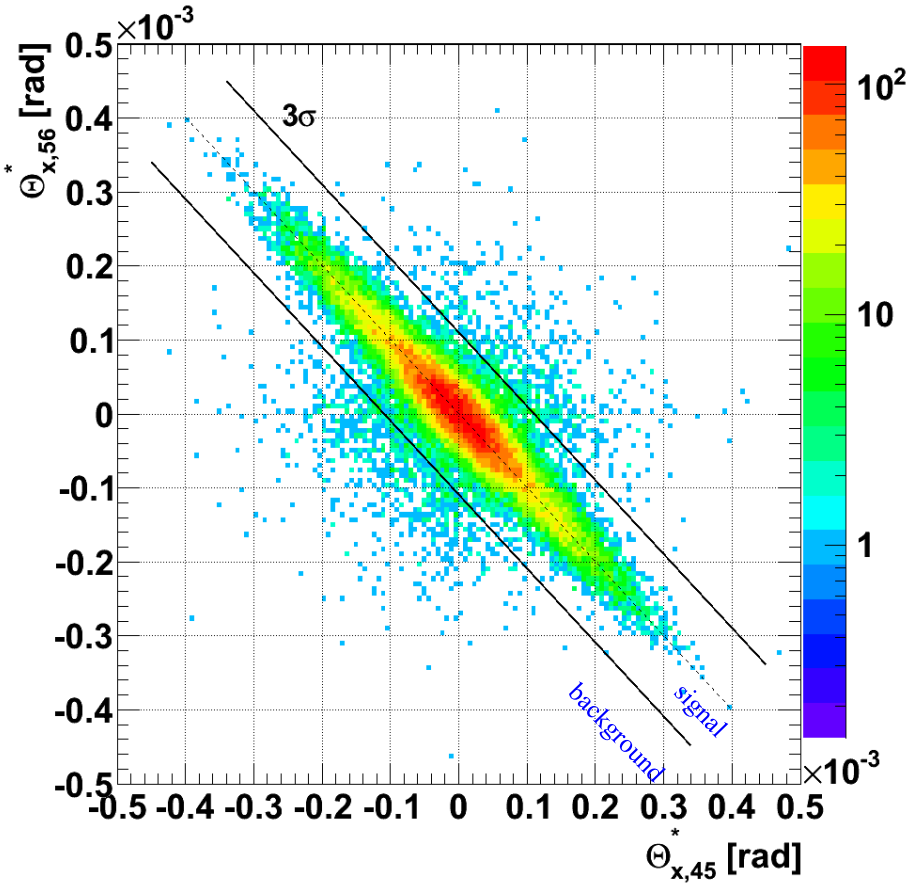


$y_{RP\ near,45} \leftrightarrow y_{RP\ far,45}$

(dLy/ds≈0)

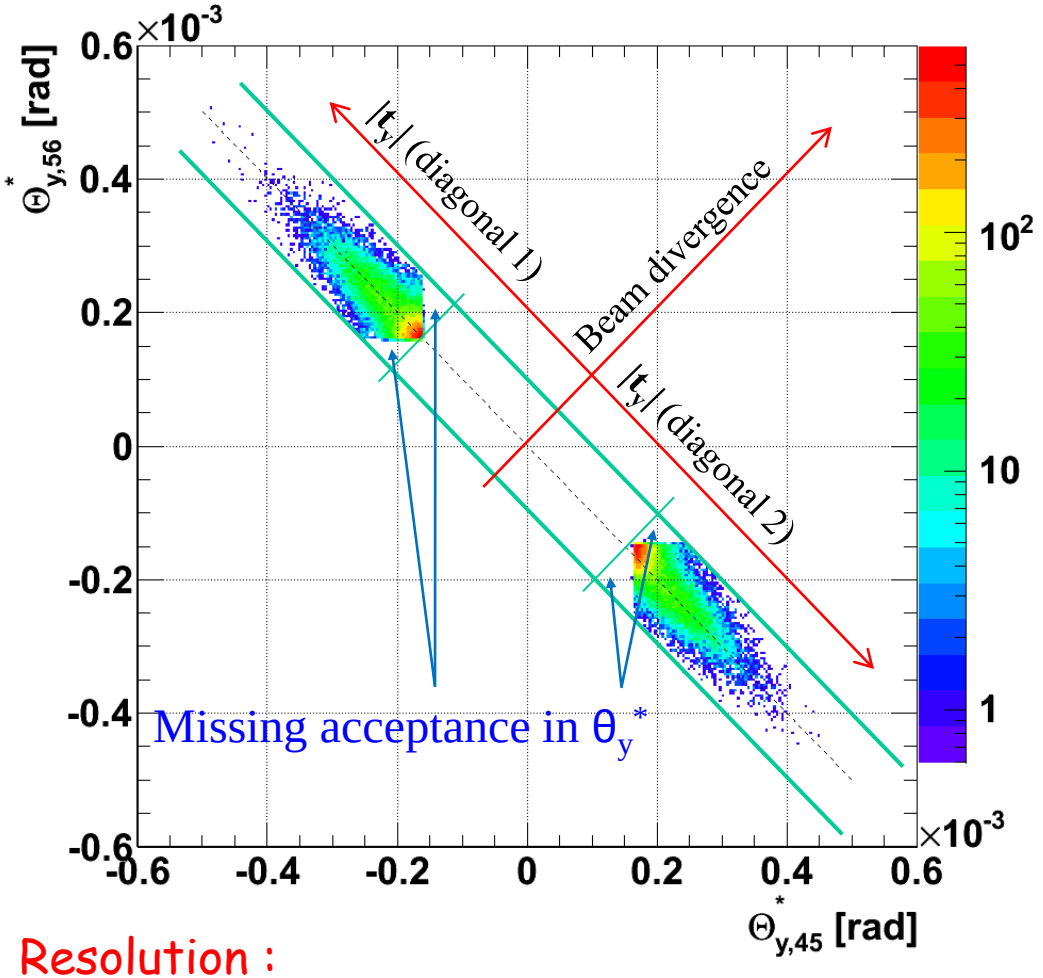
Elastic colinearity cuts

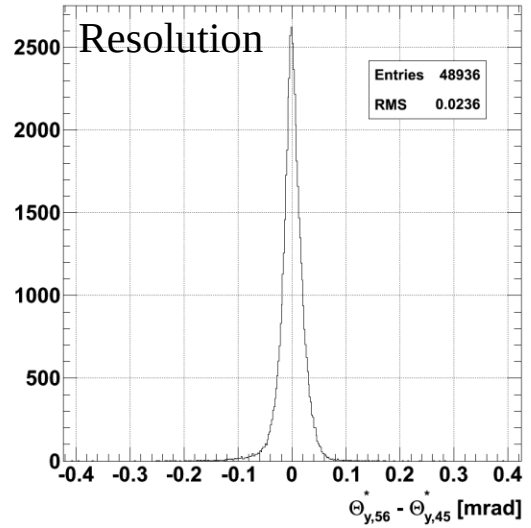


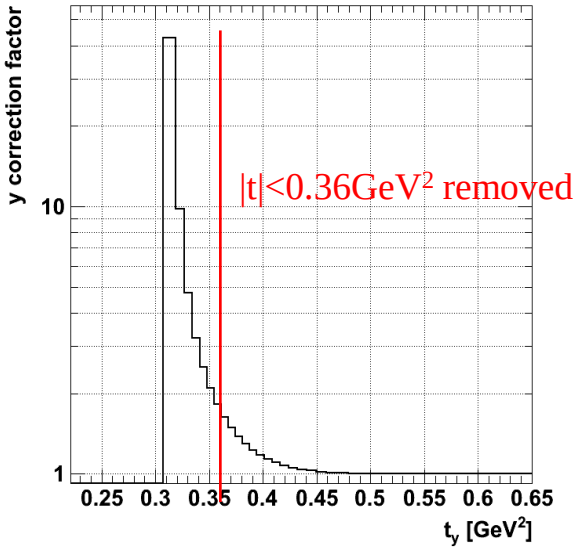


Data outside the 3σ cuts used for background estimation

t_y-acceptance corrections



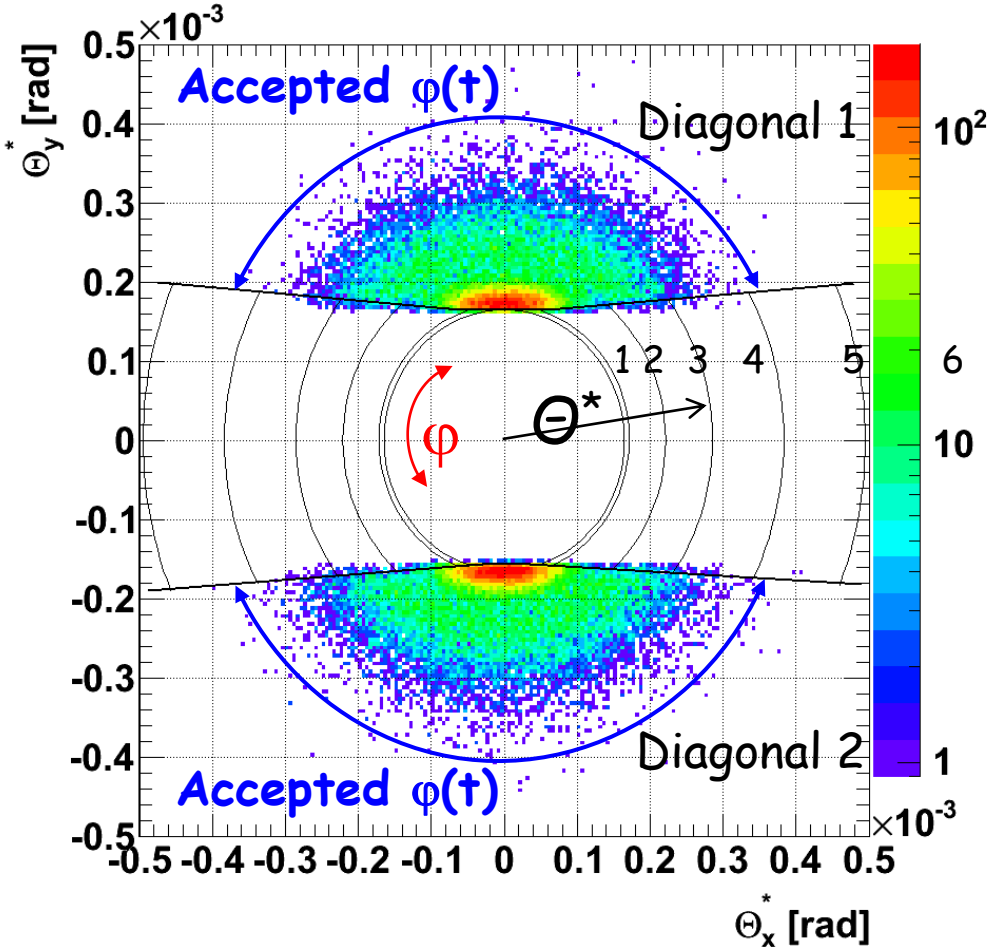




Resolution :

compatible with beam divergence of 17 μrad

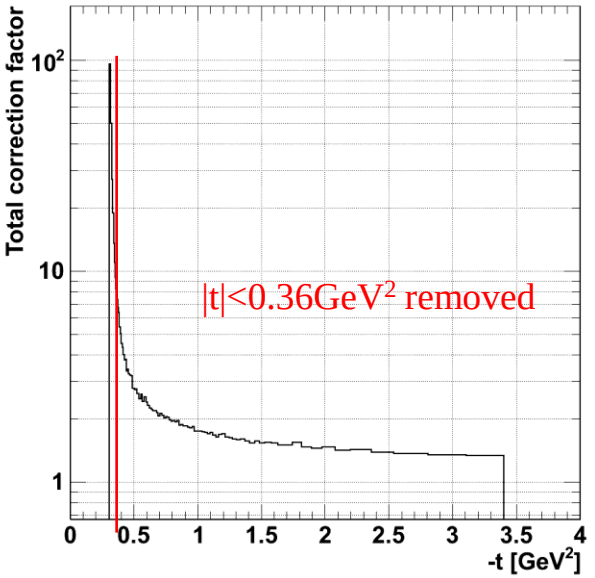
φ-acceptance correction



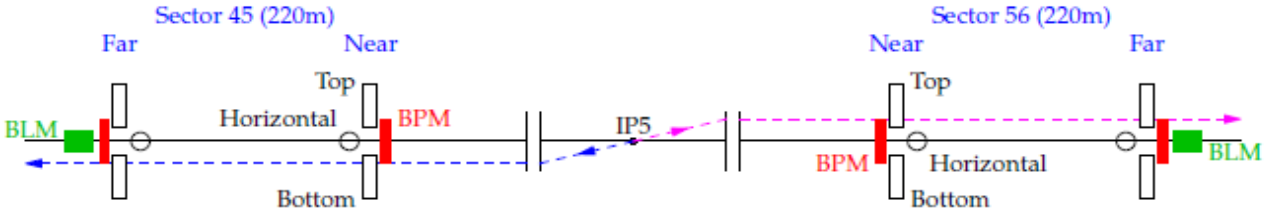
Critical at low t-acceptance limit

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**
2	**0.36**	1.71E-04	76.4	**4.7**
3	**0.60**	2.21E-04	162.5	**2.2**
4	**1.00**	2.86E-04	209.8	**1.7**
5	**1.80**	3.83E-04	246.3	**1.5**
6	**3.00**	4.95E-04	269.0	**1.3**



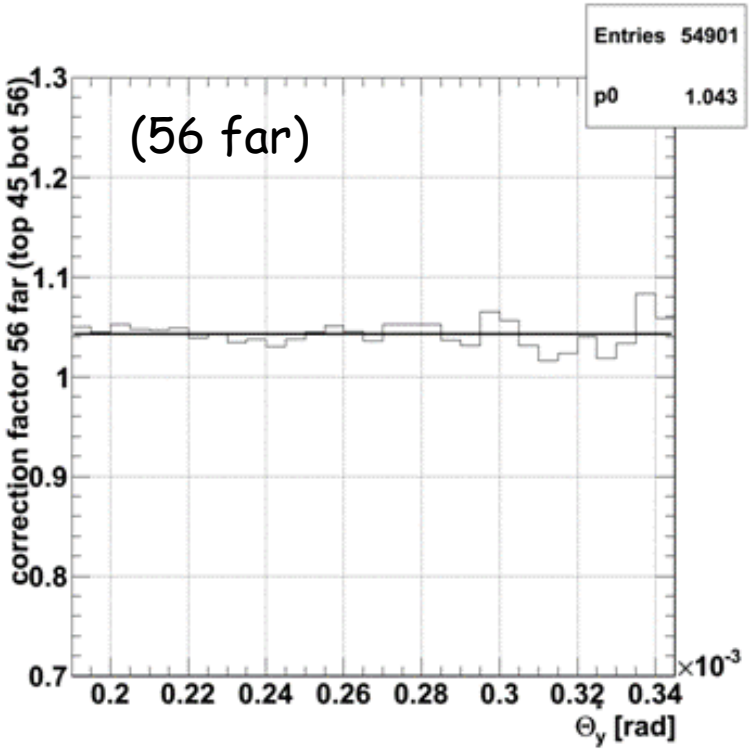
Efficiency determination



Method '3 out of 4':

- full elastic analysis with
  3 T (track segments) instead of 4
- 3 pots out of 4
  used to determine efficiency of missing pot
- 4 pot-diagonal efficiency
  computed via consequent combinations

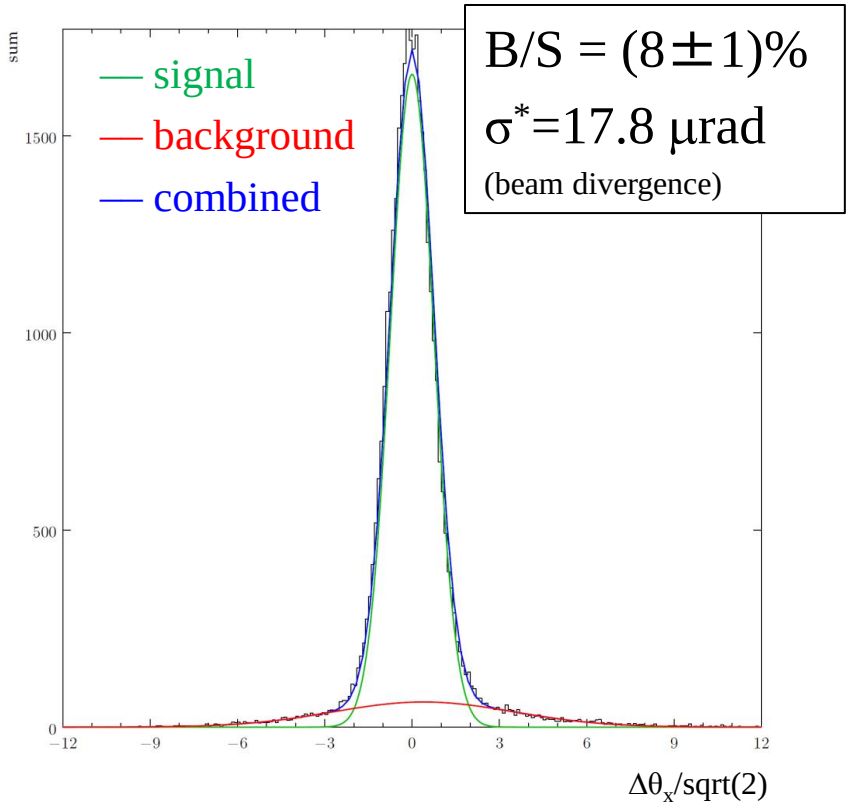
Studied Correlated pots inefficiencies
for 2T/4
Determine inefficiency in detection of pp



- **Efficiency correction t-independent = 1.18 - 1.19**

>>> breakdown of triggers :
~90% on background (showers) ; ~5% cut by RP acceptance ; ~5% pp pairs

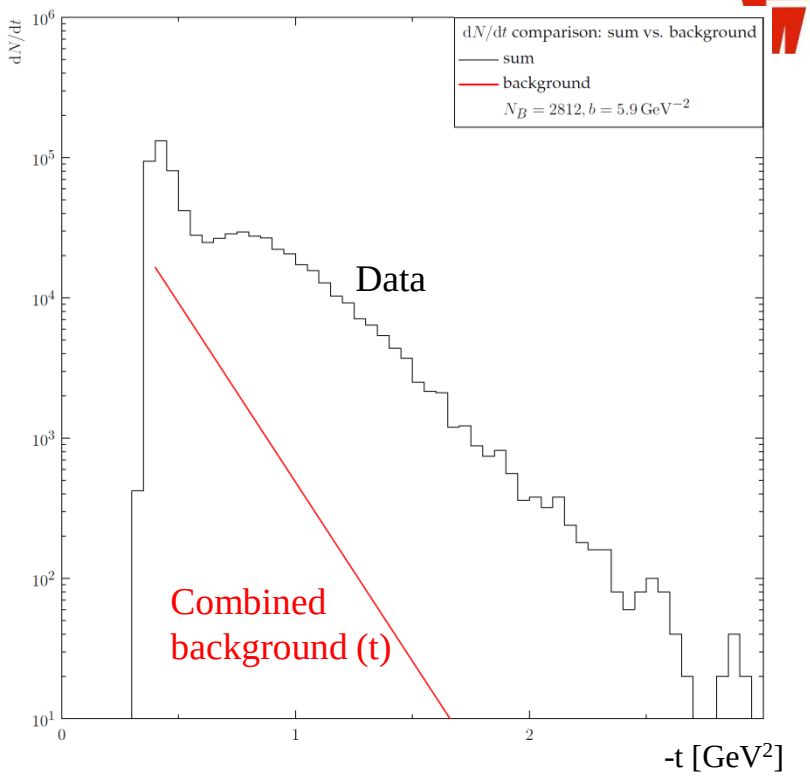
Background and resolution determination



B/S = (8±1)%

σ^*=17.8 μrad

(beam divergence)



Signal to background normalisation

(also as a function of $\Delta\theta_y$)

$\sigma^* \rightarrow$ **t-reconstruction resolution:**

$$\frac{\sigma(t)}{t} = \frac{\sqrt{2}p\sigma^*}{\sqrt{t}}: \begin{array}{l} 0.4\,\mathrm{GeV}^2 : 14\% \\ 1\,\mathrm{GeV}^2 : 8.8\% \\ 3\,\mathrm{GeV}^2 : 5.1\% \end{array}$$

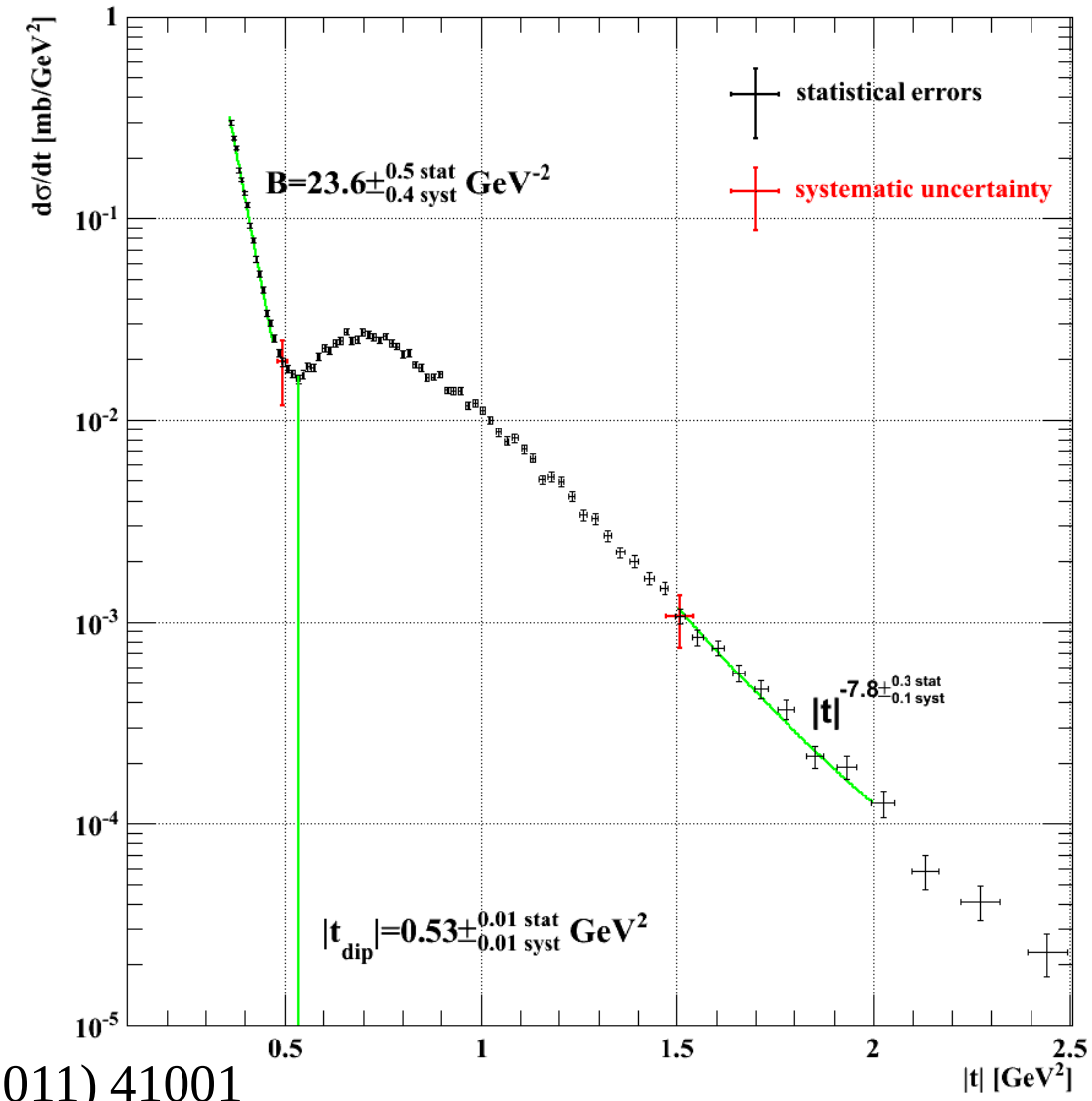
Signal vs. background (t)

|t|=0.4GeV²: B/S = (11±2)%

|t|=0.5GeV²: B/S = (19±3)%

|t|=1.5GeV²: B/S = (0.8±0.3)%

Differential pp cross-section

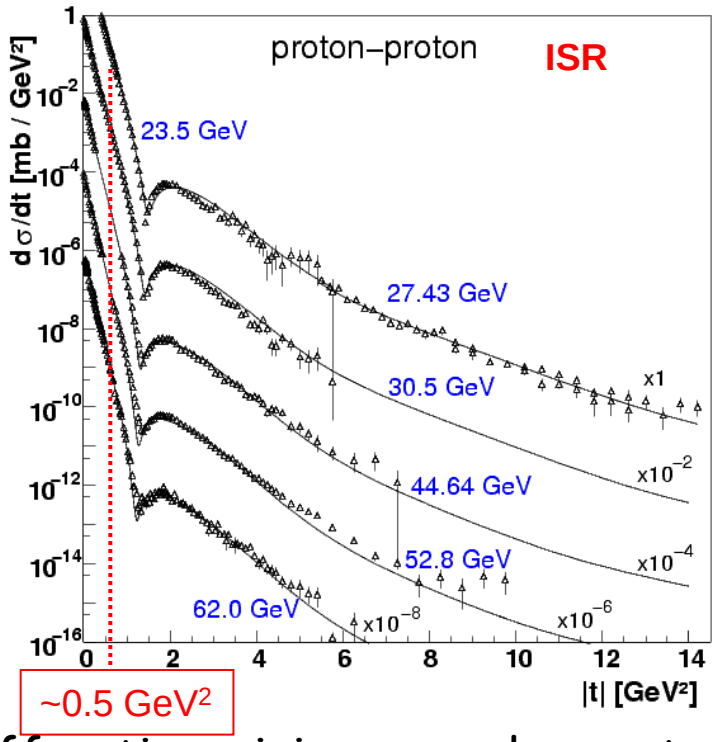


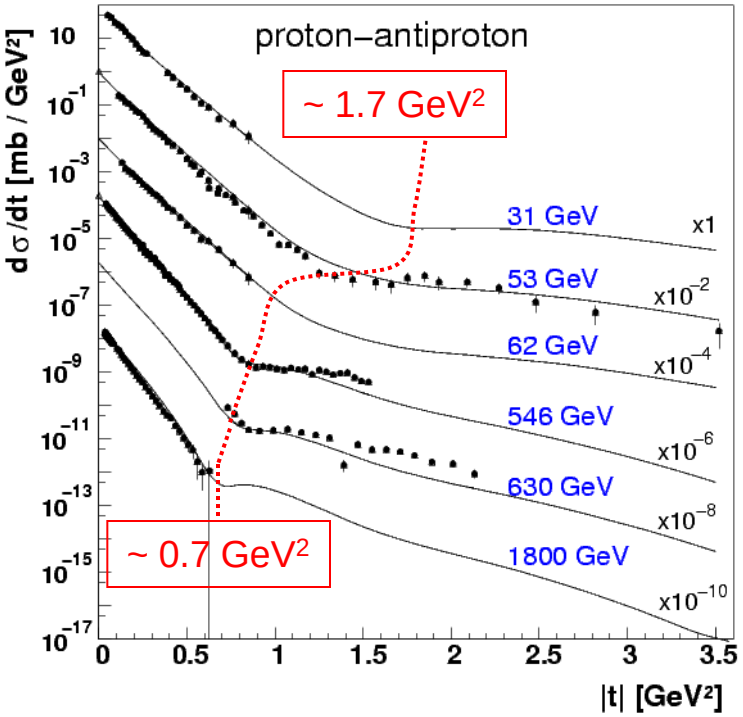
EPL, 95 (2011) 41001

Statistical and Systematic uncertainties for the *t* and dσ/d*t* results

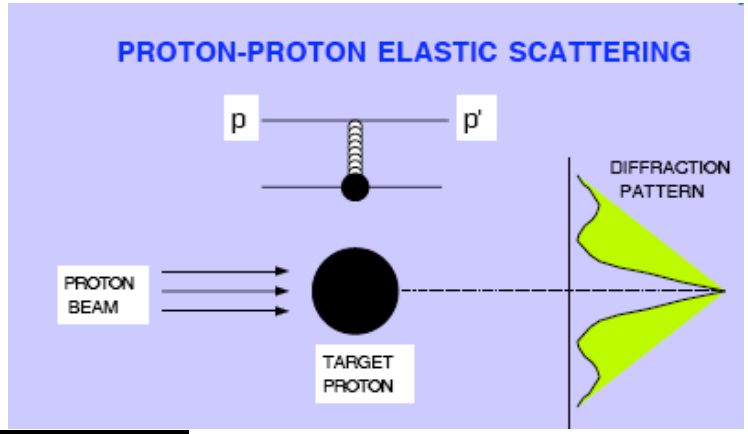
	$\frac{\delta t}{t}$ on single t meas.	$\delta t = \delta\,{}^{\text{stat}}_{t}(t) \oplus \delta^{\text{syst}}_{t}(t)$	$\delta(\mathrm{d}\sigma/\mathrm{dt}) = \delta\,{}^{\text{stat}}_{\mathrm{d}\delta/\mathrm{dt}}(t) \oplus \delta^{\text{syst}}_{\mathrm{d}\sigma/\mathrm{dt}}(t)$
$\lvert t\rvert = 0.4\,\mathrm{GeV}^2$	13 % (from beam div.)	$\frac{\delta t}{t} = \pm 0.5\%^{\text{stat}} \pm 2.6\%^{\text{syst}}$	$\frac{\delta(\mathrm{d}\sigma/\mathrm{dt})}{\mathrm{d}\sigma/\mathrm{dt}} = \pm 2.6\%^{\text{stat}}\ {}^{+25}_{-37}\ \%^{\text{syst}}$
$\lvert t\rvert = 0.5\,\mathrm{GeV}^2$	12 % (from beam div.)	$\frac{\delta t}{t} = \pm 0.7\%^{\text{stat}} \pm 2.5\%^{\text{syst}}$	$\frac{\delta(\mathrm{d}\sigma/\mathrm{dt})}{\mathrm{d}\sigma/\mathrm{dt}} = \pm 4.4\%^{\text{stat}}\ {}^{+28}_{-39}\ \%^{\text{syst}}$
$\lvert t\rvert = 1.5\,\mathrm{GeV}^2$	7 % (from beam div.)	$\frac{\delta t}{t} = \pm 0.8\%^{\text{stat}} \pm 2.3\%^{\text{syst}}$	$\frac{\delta(\mathrm{d}\sigma/\mathrm{dt})}{\mathrm{d}\sigma/\mathrm{dt}} = \pm 8.2\%^{\text{stat}}\ {}^{+27}_{-30}\ \%^{\text{syst}}$

pp *Elastic Scattering* - *ISR to Tevatron*



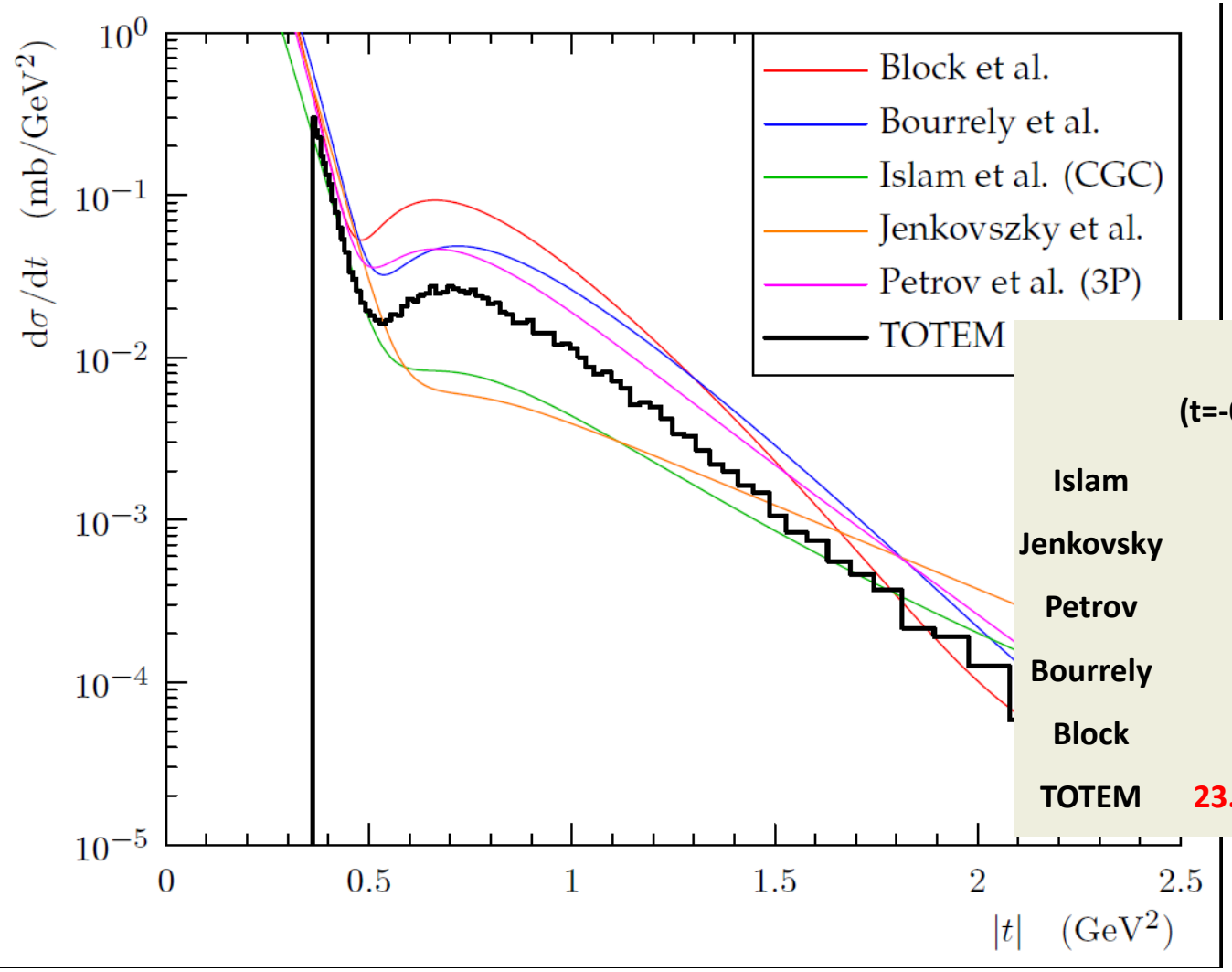


Diffractive minimum: analogous to Fraunhofer diffraction: $|t| \sim p^2 q^2$



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

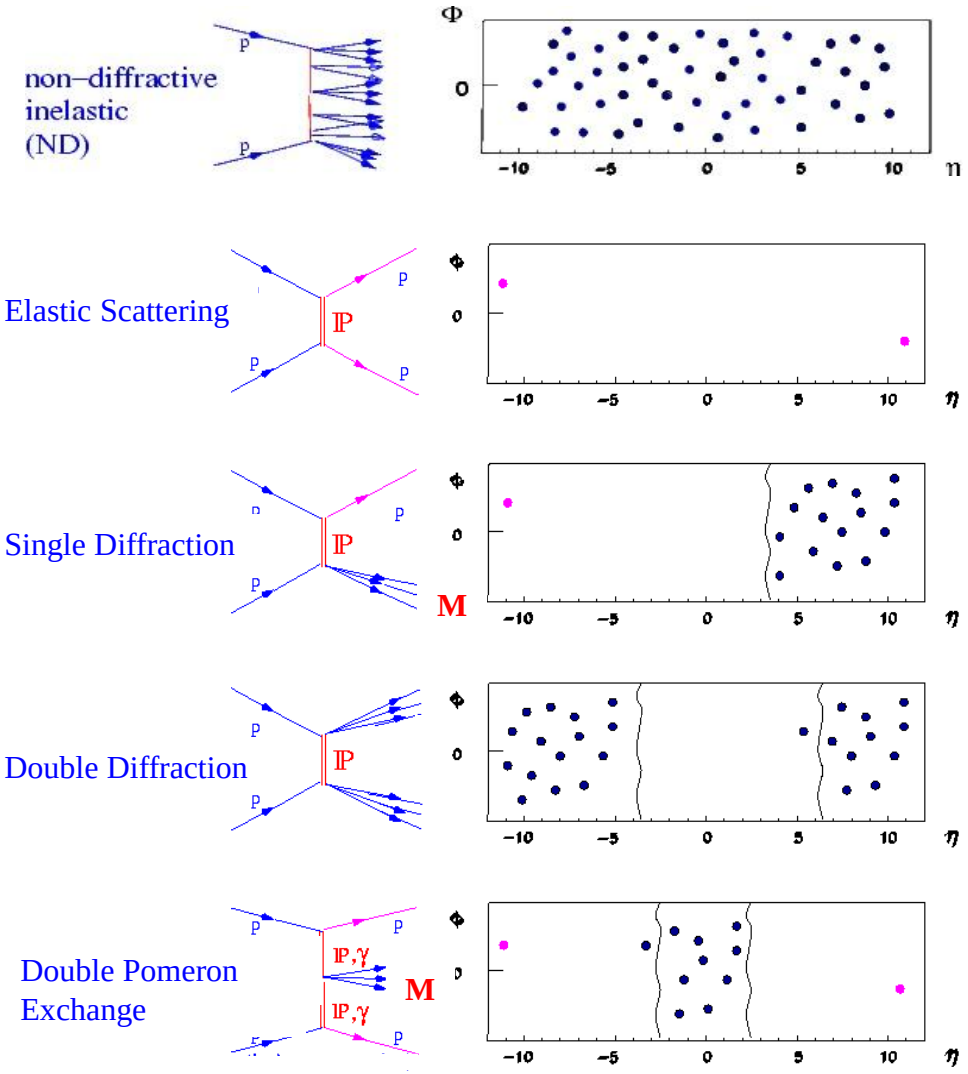
Comparison with models



	B (t=-0.4 GeV²)	t_{DIP}	t^{-x} [1.5–2 GeV²]
Islam	20.2	0.60	5.0
Jenkovsky	20.1	0.72	4.2
Petrov	23.3	0.51	7.0
Bourrely	22.0	0.54	8.4
Block	25.3	0.48	10.4
TOTEM	23.6 ± 0.3	0.53 ± 0.01	7.8 ± 0.3

DIFFRACTIVE EVENTS

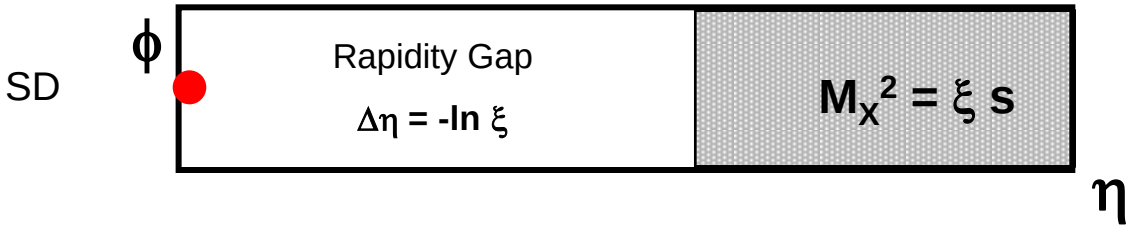
Dominant Event Classes in p-p Collisions

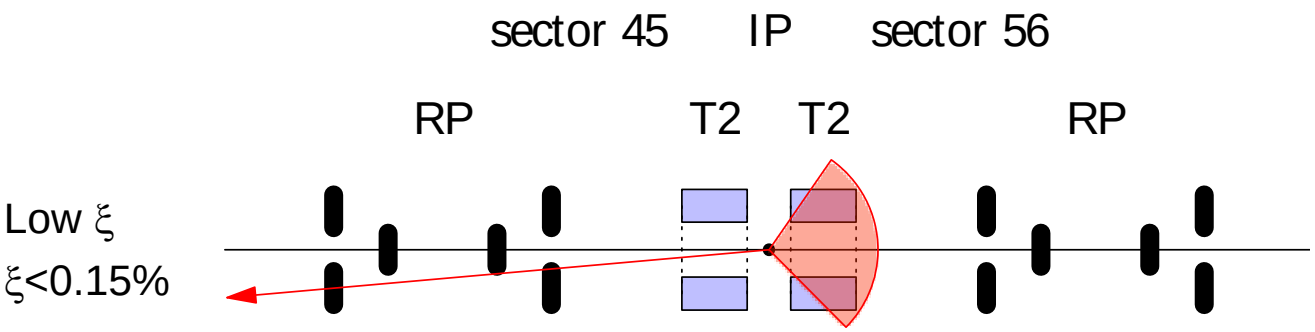


$\eta = -\ln \tan \theta/2$

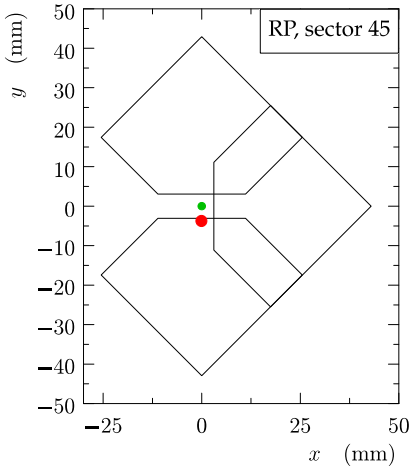
Single diffraction low ξ

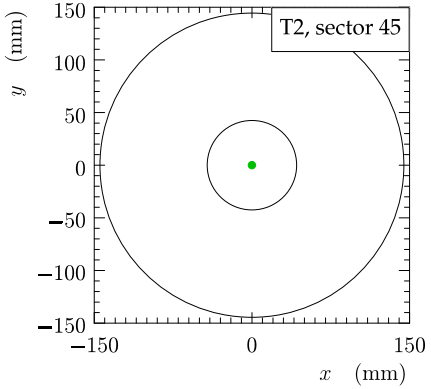
Correlation between leading proton and forward detector T2

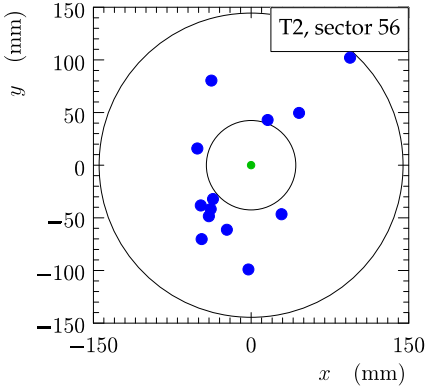


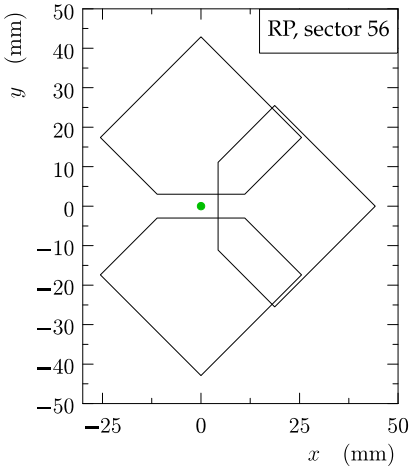


run: 37280003, event: 3000



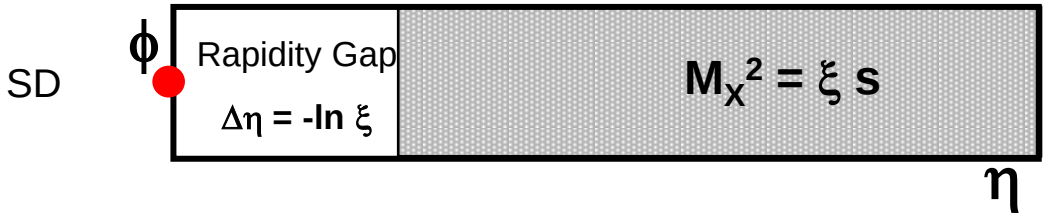


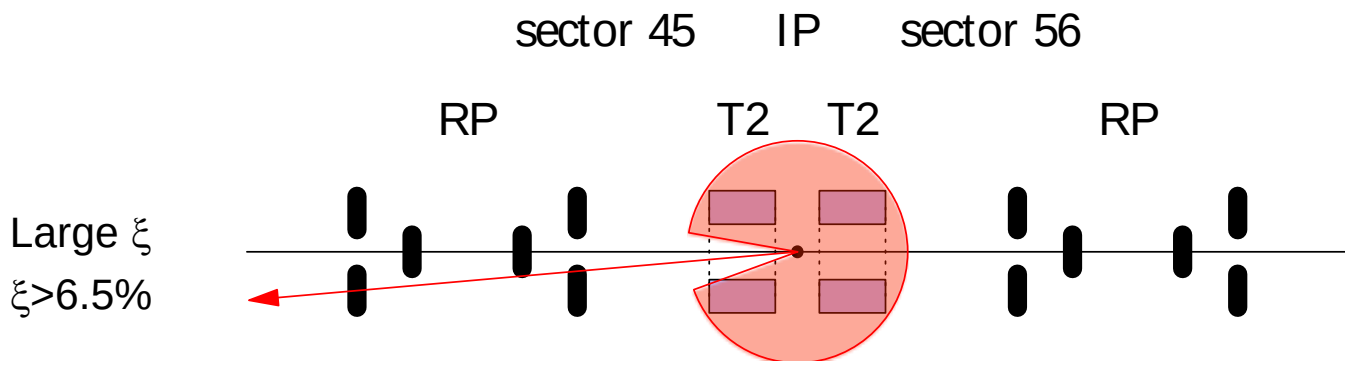




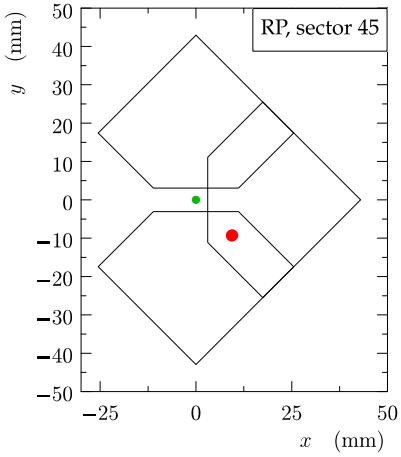
Single diffraction large ξ

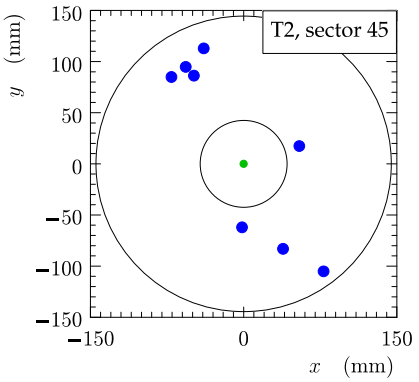
correlation between leading proton and forward detector T2

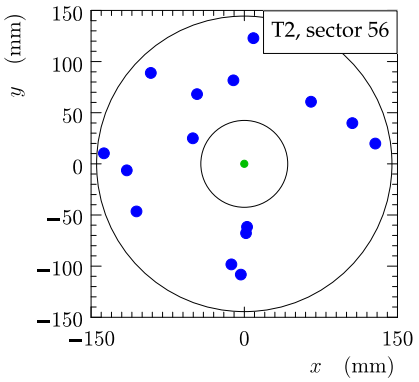


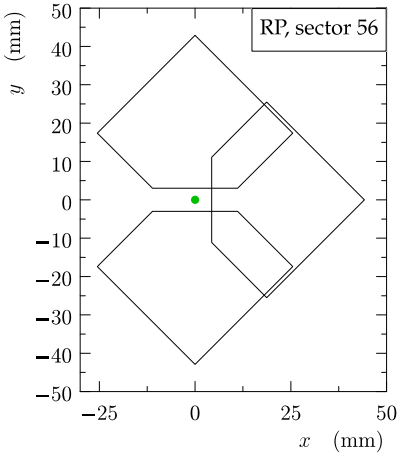


run: 37280006, event: 9522

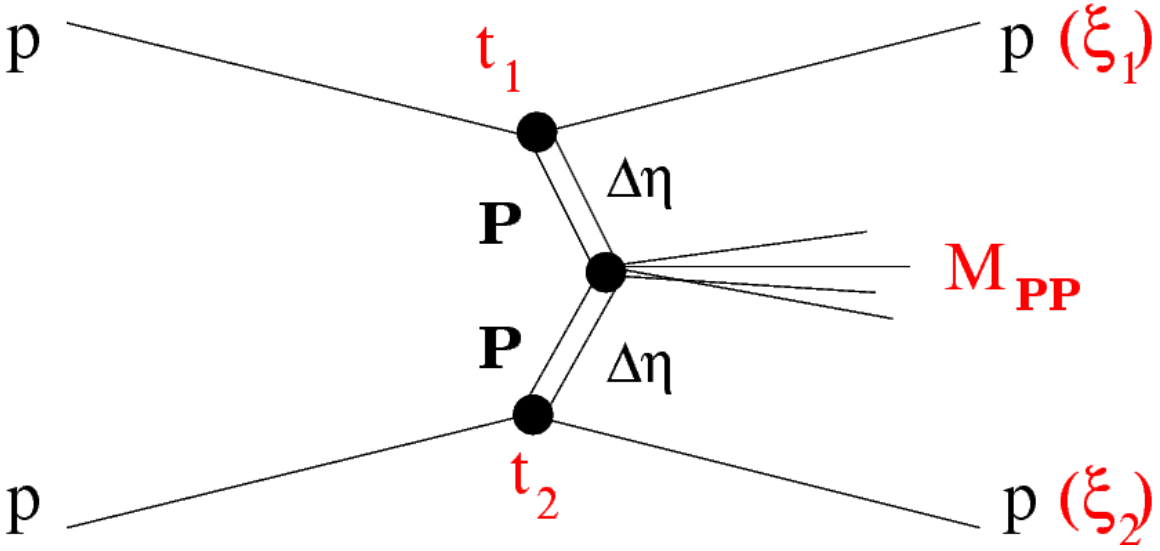


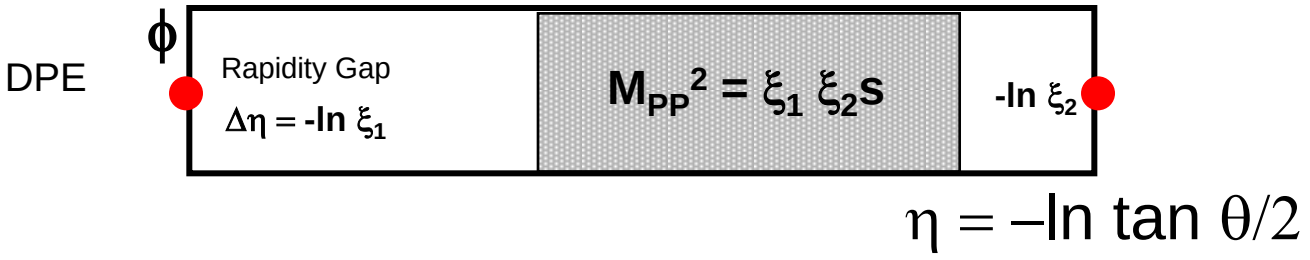






Double Pomeron Exchange (DPE)



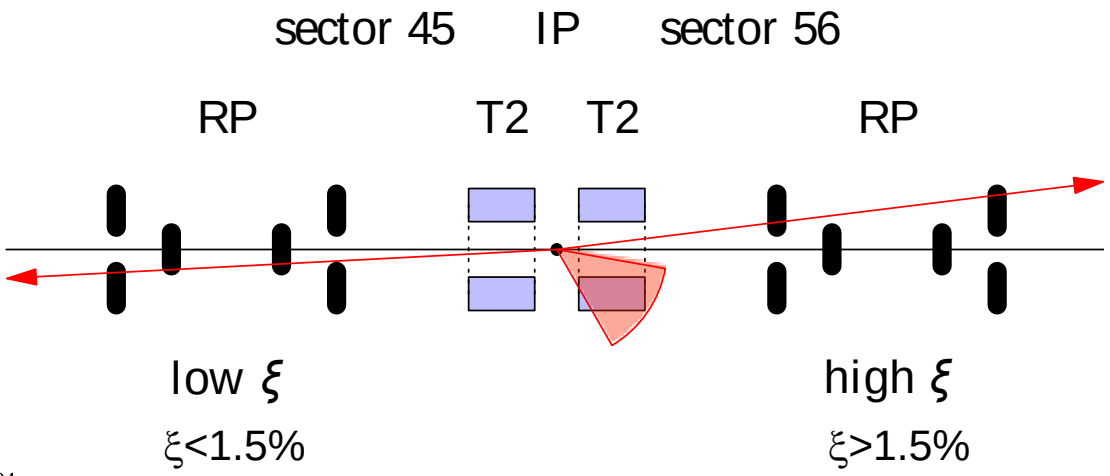


$$\eta = -\ln \tan \theta/2$$

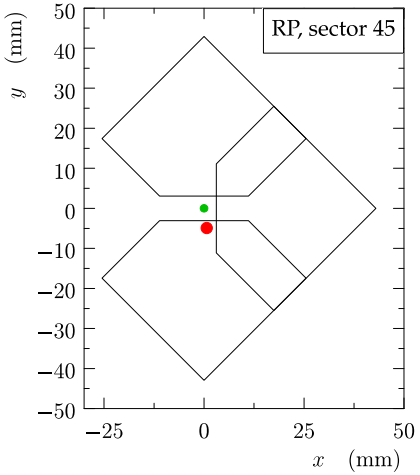
USE the LHC as a Pomeron-Pomeron (Gluon - Gluon) Collider

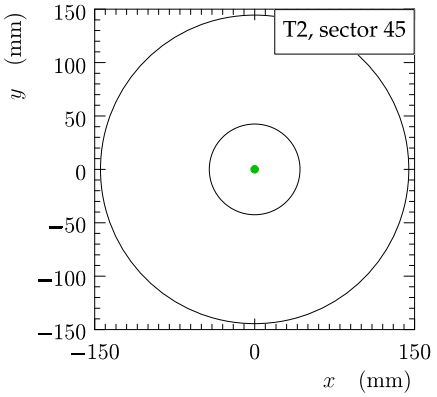
Double Pomeron Exchange

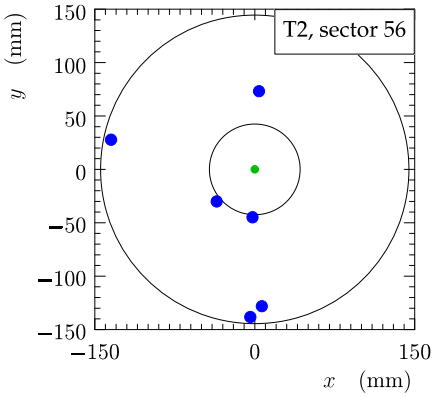
correlation between leading proton and forward detector T2

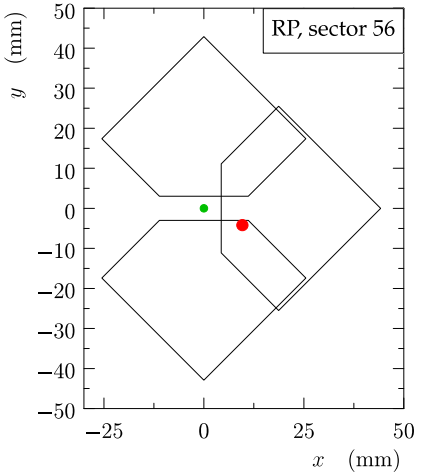


run: 37220007, event: 9904

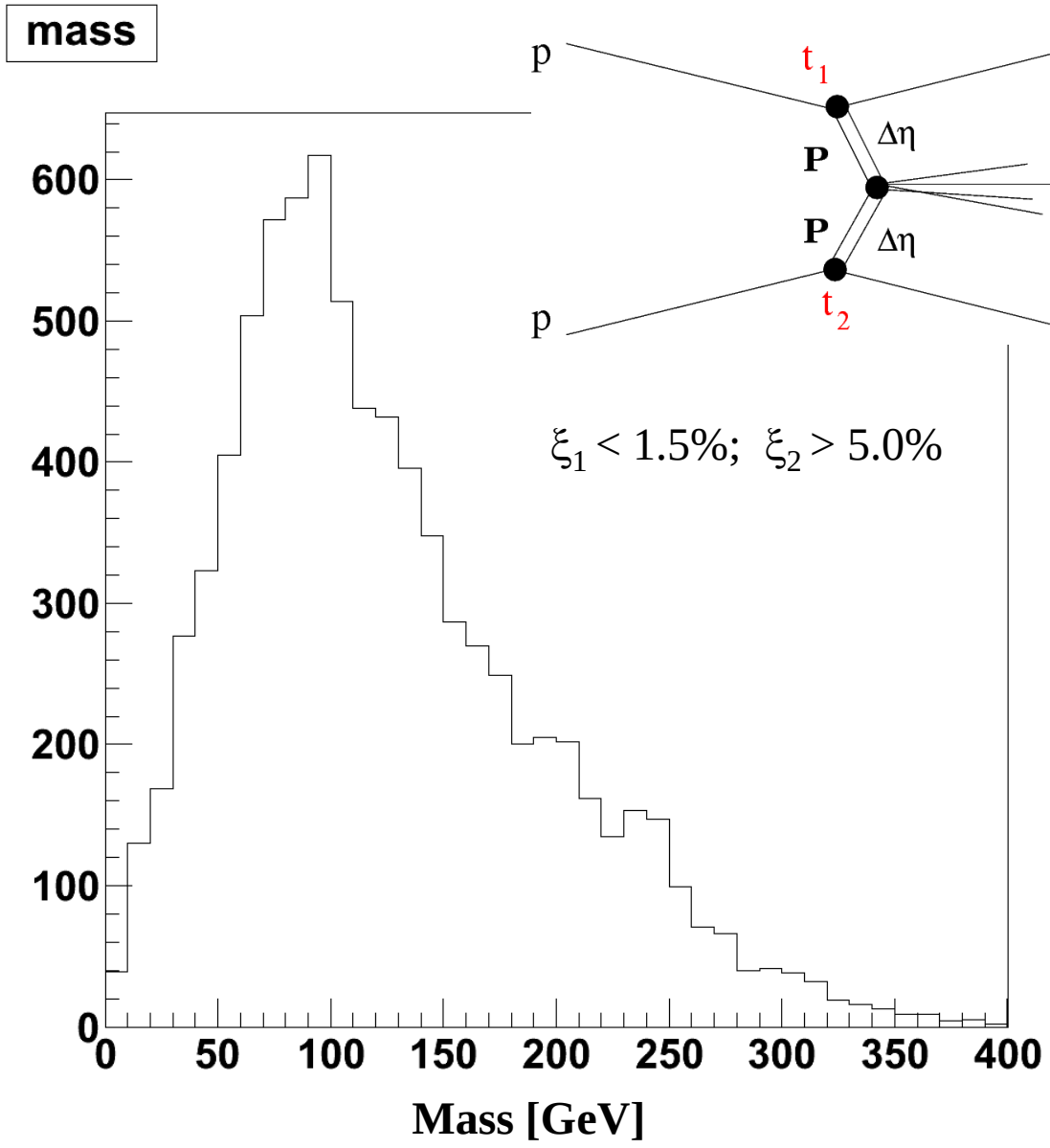








First attempt at DPE Mass Reconstruction



Summary

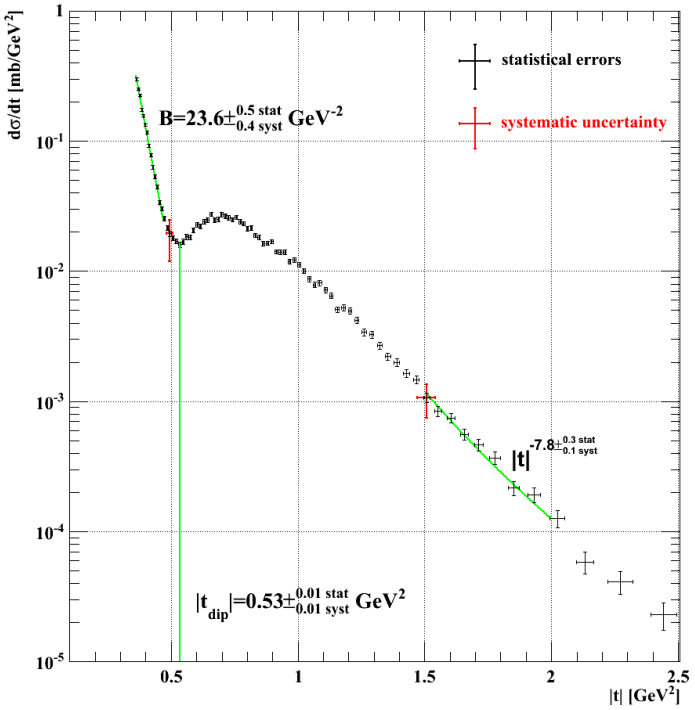
The TOTEM detector is fully installed and has started to produce Physics results

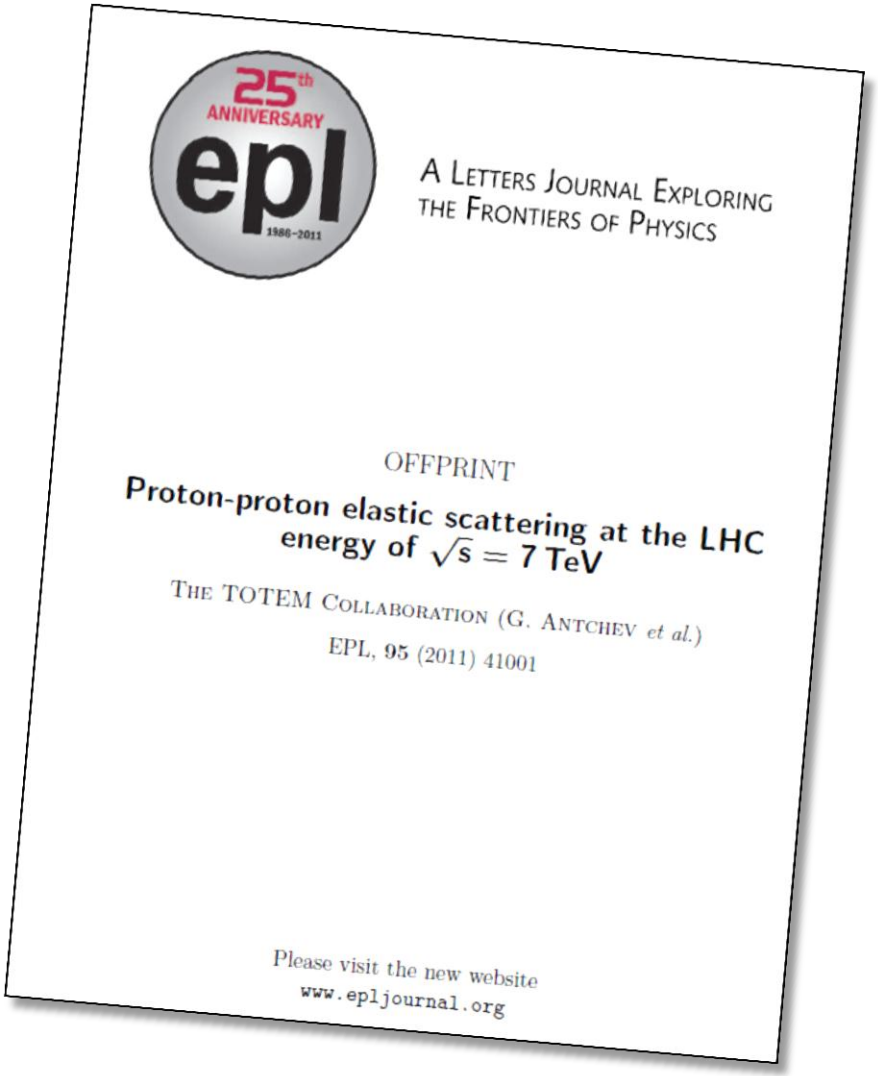
- Measurement of elastic scattering for t between .36 and 2.5 GeV2
  - the dip in proton proton has been clearly observed, data have been published
- Measurement of total cross section
  - T2 telescope: preliminary distribution $dN/d\eta$
  - T1 telescope: ready to do physics
- The potentiality of the combined system of RP and inelastic telescopes to observe and measure Single diffractive and Double Pomeron Exchange events has been demonstrated.

Thank you for your attention

Our data are now published in

EPL, 95 (2011) 41001




25th ANNIVERSARY epl 1986–2011

A Letters Journal Exploring the Frontiers of Physics

OFFPRINT

Proton-proton elastic scattering at the LHC energy of $\sqrt{s} = 7$ TeV

The TOTEM Collaboration (G. Antchev *et al.*)

EPL, 95 (2011) 41001

Please visit the new website
www.epljournal.org