# TOTEM Physics Programme for the LHC Start


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Brunel University / CERN

on behalf of the

**TOTEM Collaboration**
http://totem.web.cern.ch/Totem/

## HERA - LHC Workshop

14 March 2007

TOTEM

# Physics programme

Total cross section at 14TeV with a precision of 1%

Elastic pp scattering, $10^{-3}$ GeV$^2$ < –t < 10 GeV$^2$

Soft Single & Central Diffraction

Low–x dynamics

Leading particle & energy flow in forward direction

Semi–hard + hard Single & Central Diffraction: production of jets, W, heavy flavours.....

Exclusive particle production in Central Diffraction

$\gamma\gamma$ & $\gamma$p physics

WITH CMS

See talks by K. Oesterberg & M. Grothe

# Physics program for the LHC start

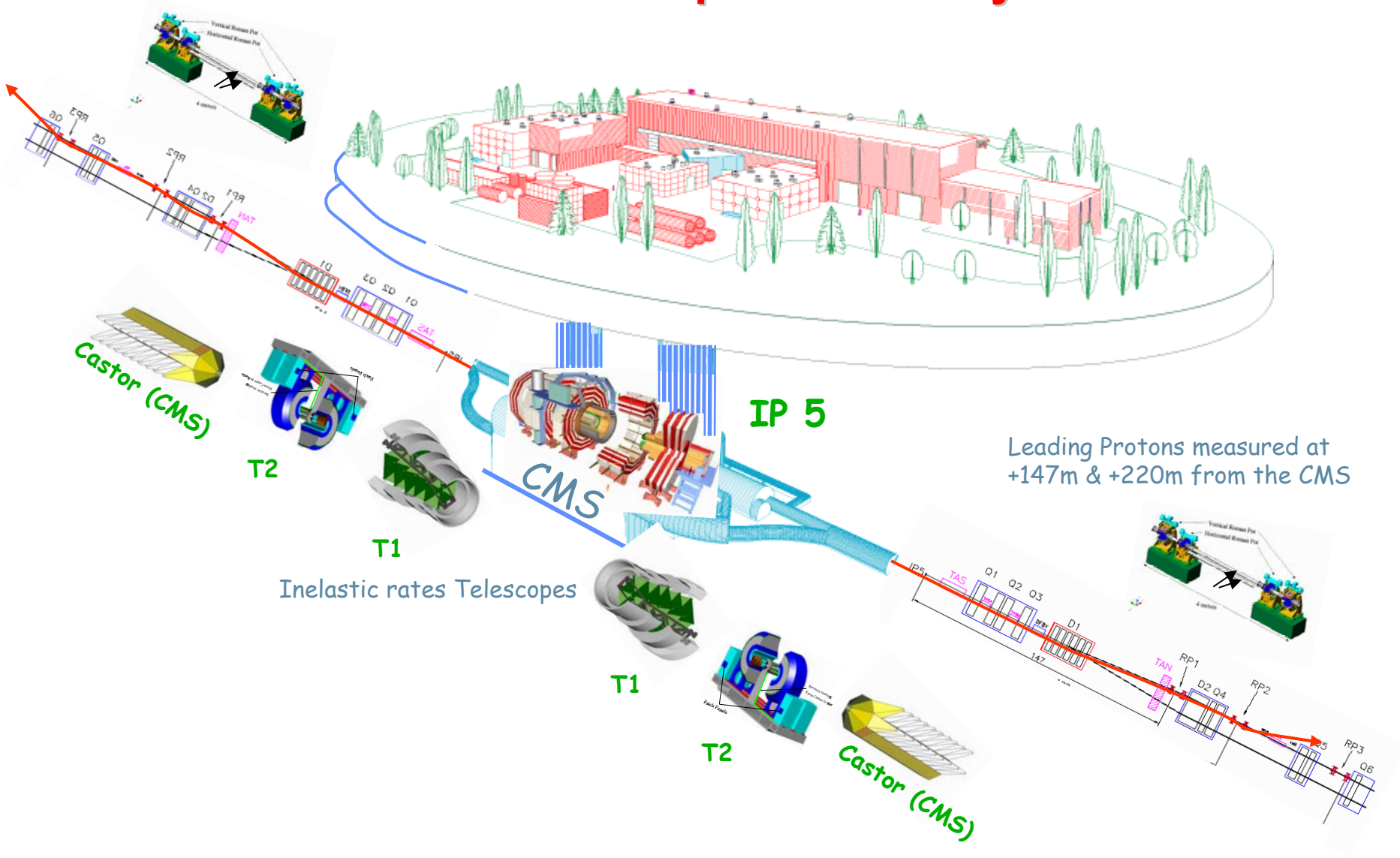
Total cross section with a precision of about 5%

Multiplicity distributions

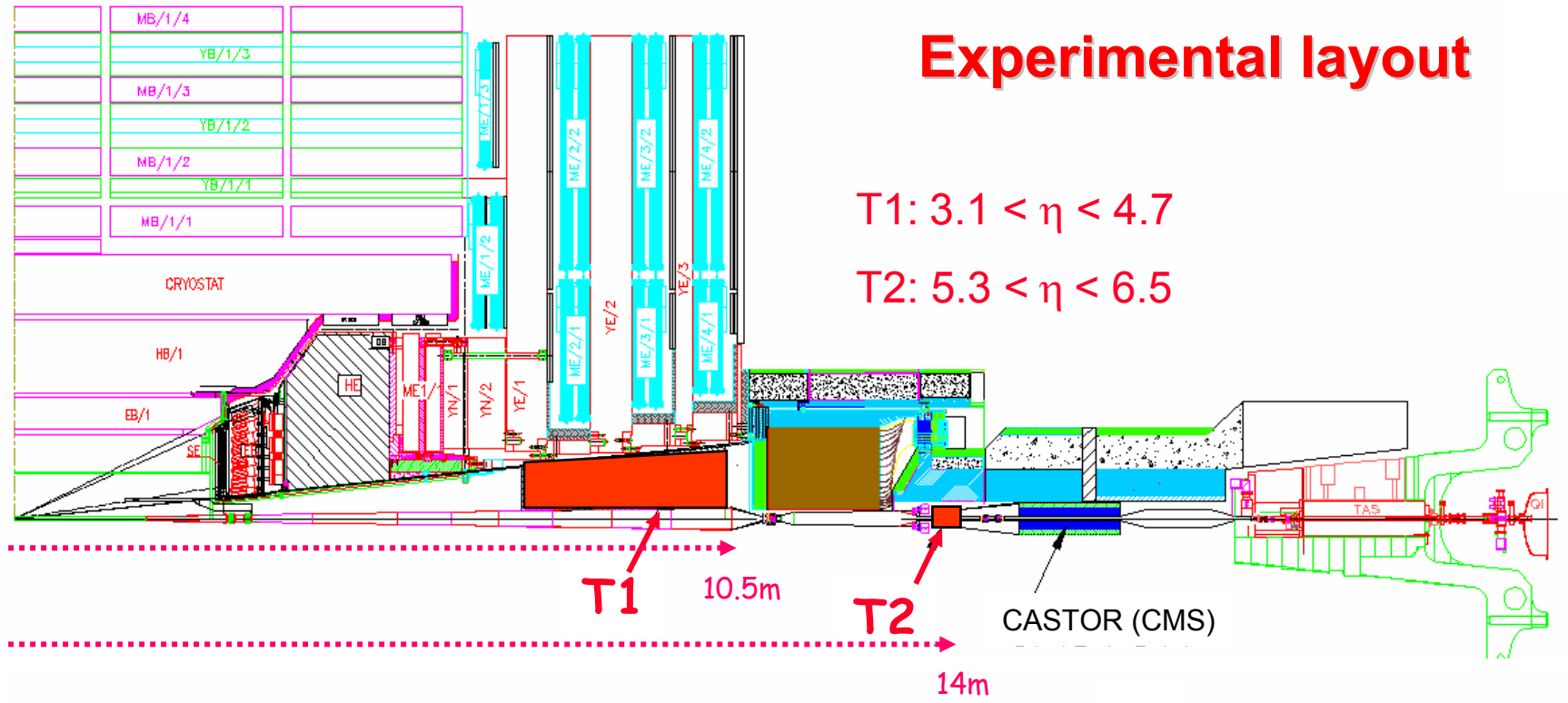
Diffraction at low/medium luminosity: SD, DPE

TOTEM

# Experimental layout

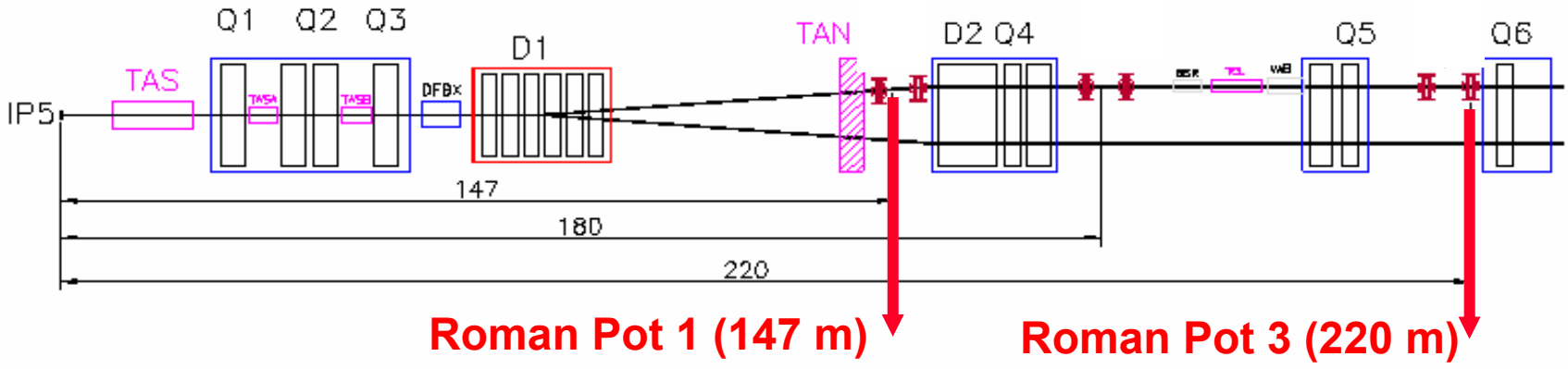


# Experimental layout

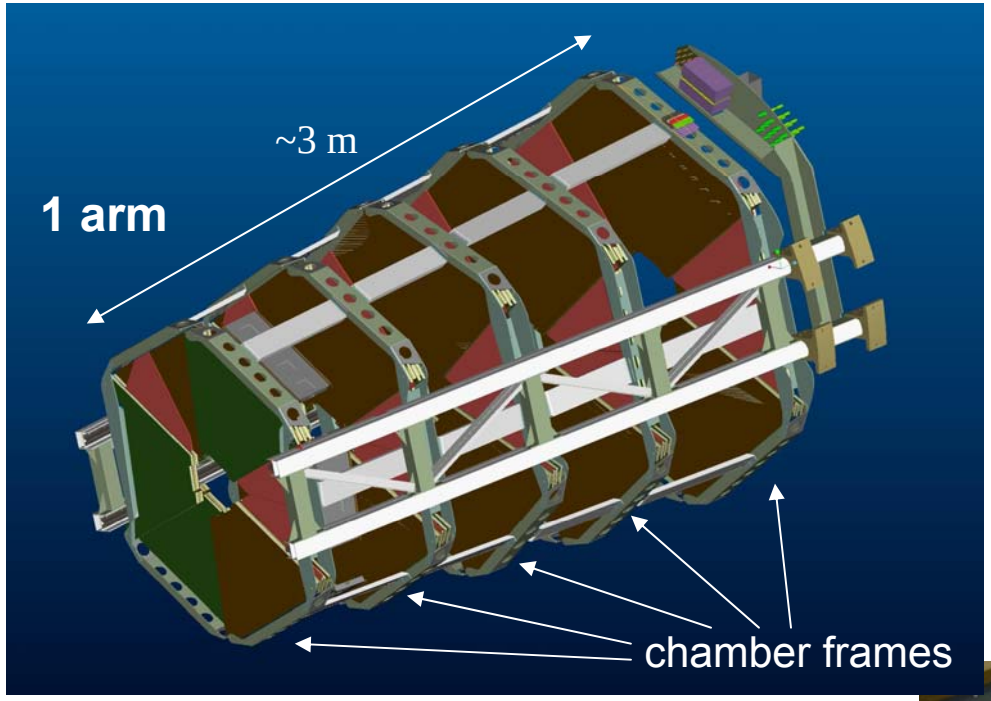



T1: 3.1 < η < 4.7

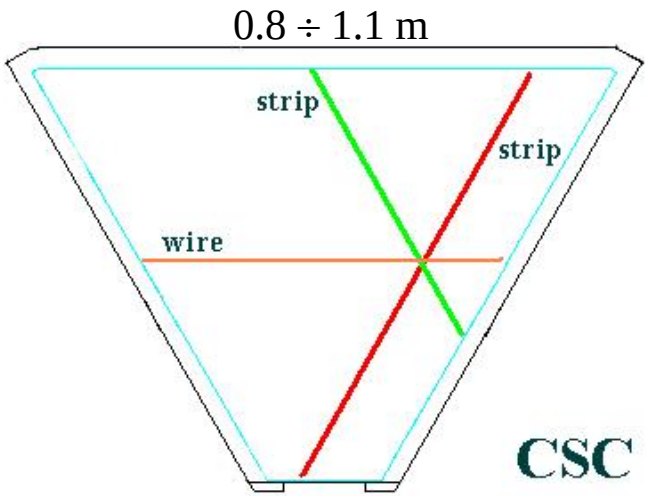
T2: 5.3 < η < 6.5

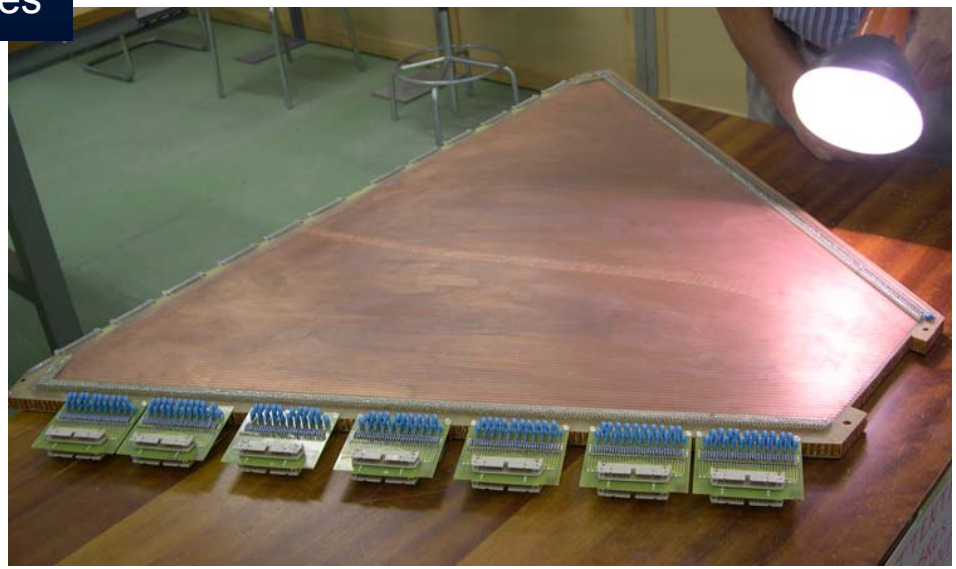


# T1 Telescope

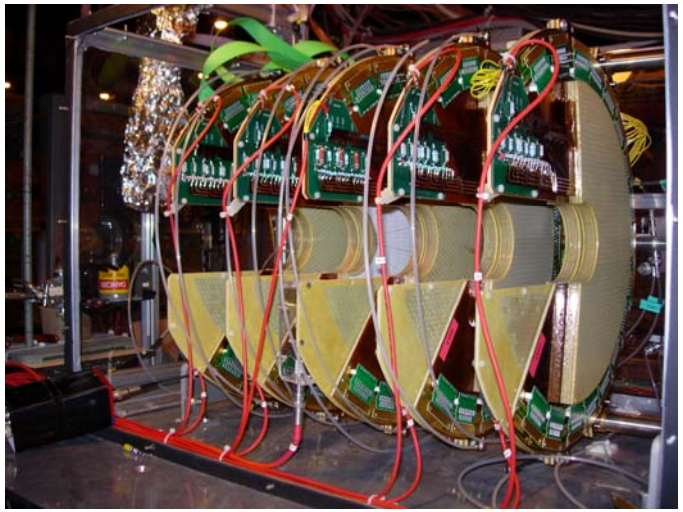



- Cathode Strip Chambers (CSC)
- 3.1 < |η| < 4.7
- 5 planes with measurement of three coordinates per plane.
- 3 degrees rotation and overlap between adjacent planes
- Primary vertex reconstruction (beam-gas interaction removal)
- Trigger with anode wires
- Connected to new VFAT chips

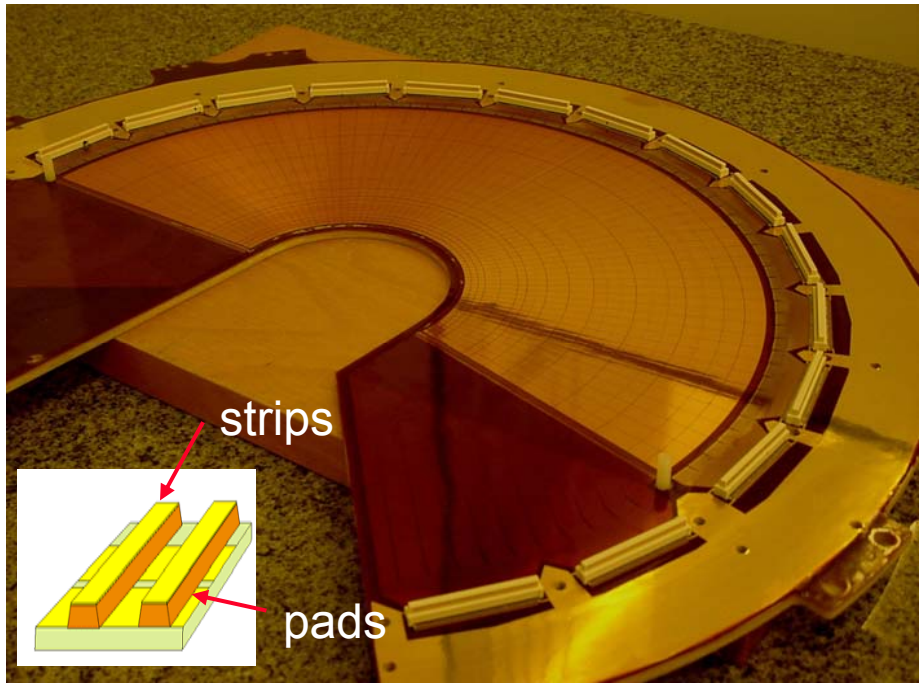


# T2 Telescope



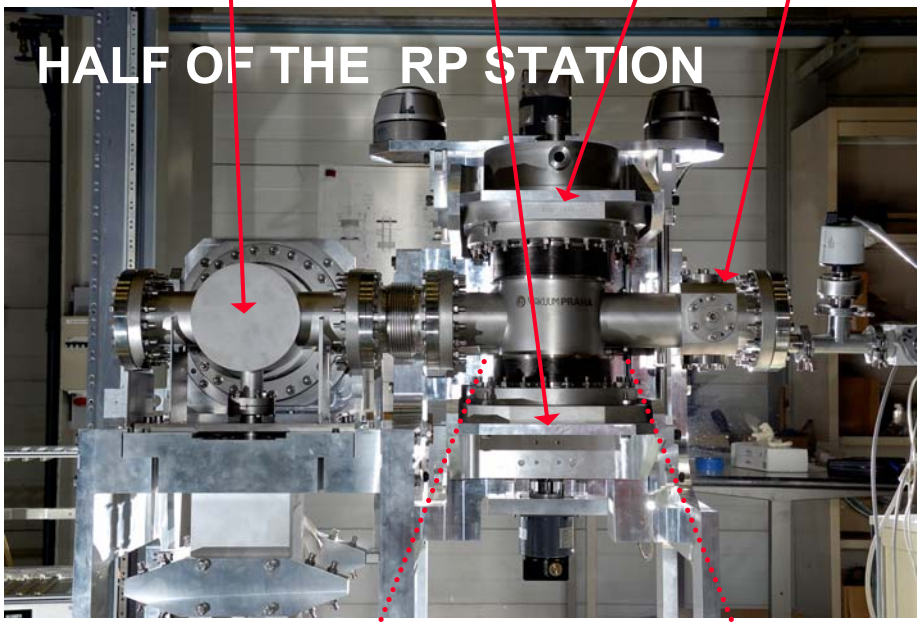

- Gas Electron Multiplier (GEM)
- $5.3 < |\eta| < 6.5$
- 10 half-planes @ 13.5 m from IP5
- Half-plane:
  - 512 strips (width 80 μm, pitch of 400 μm)
  - 65*24=1560 pads (2x2 $mm^2$ -> 7x7 $mm^2$)
- Primary vertex reconstruction (beam-gas interaction removal)
- Trigger using (super) pads
- Detectors tested in a testbeam with new VFAT chips
- First beam profiles, cluster distributions and detector characteristics



# Roman Pots

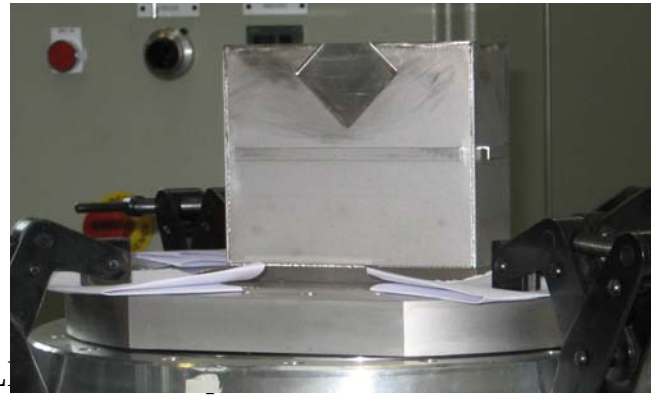
TOTEM

- Measurement of very small proton scattering angles (few μrad)
- Vertical and horizontal pots mounted as close as possible to the beam
- BPM fixed to the structure gives precise position of the beam



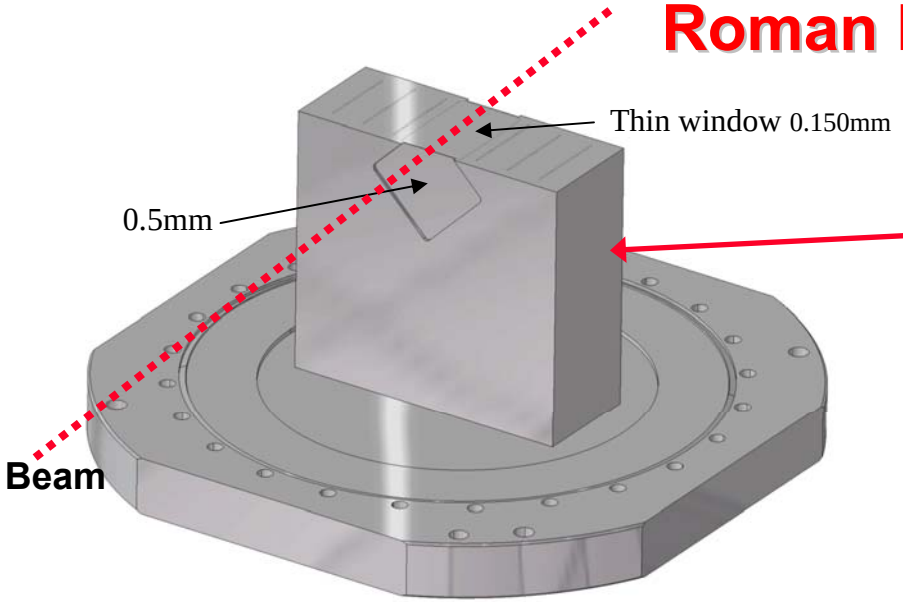

Assembly of 8 RP units

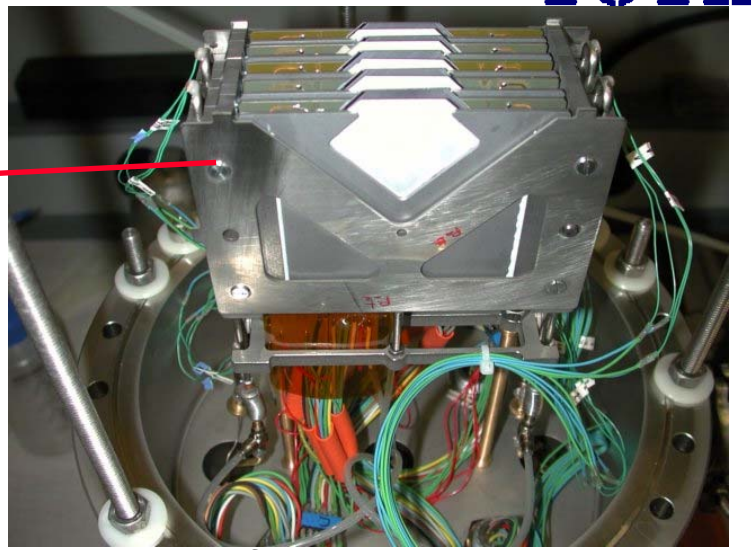
Roman Pot



# Roman Pot detectors

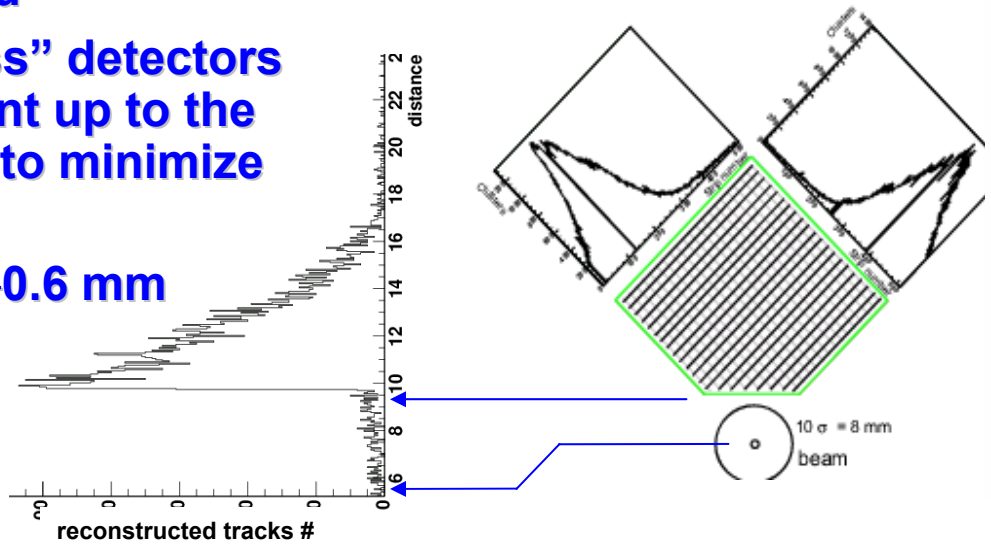
TOTEM

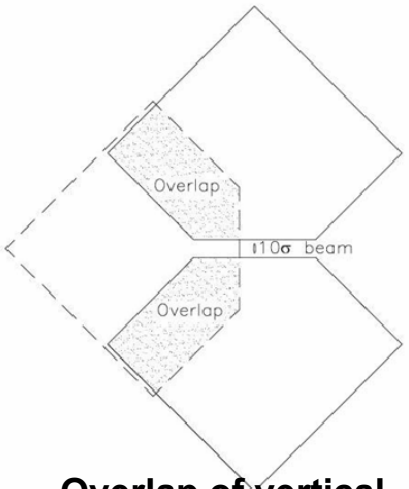


10 planes of edgeless detectors

- Leading proton detection at distances down to 10×σ(beam) + d
- Need "edgeless" detectors that are efficient up to the physical edge to minimize "d"
- σ(beam) ≈ 0.1–0.6 mm (optics dep.)



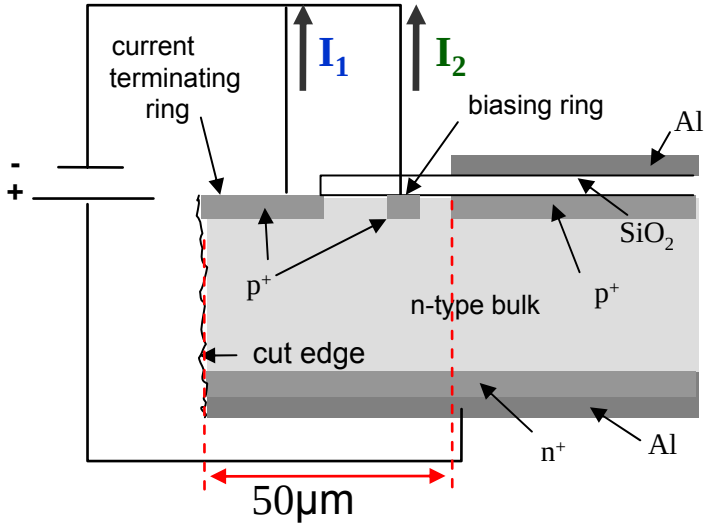



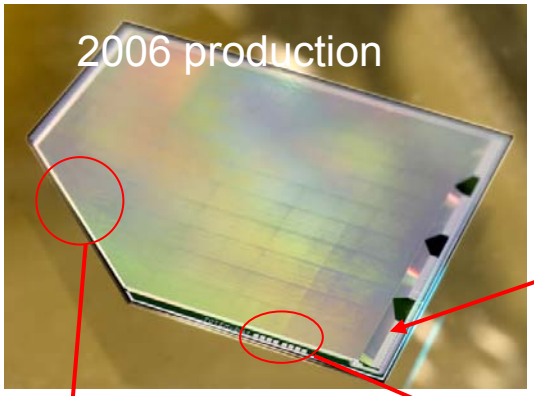

Overlap of vertical and horizontal dets.

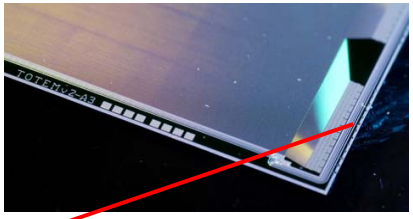
# Si Edgeless Detectors for RP

TOTEM

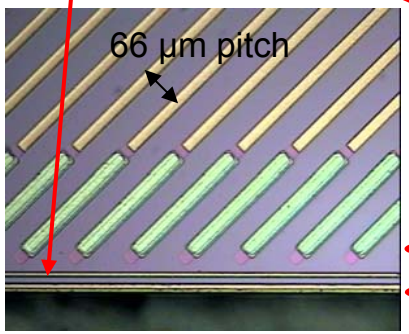
**Planar technology with CTS (Current Terminating Structure)**



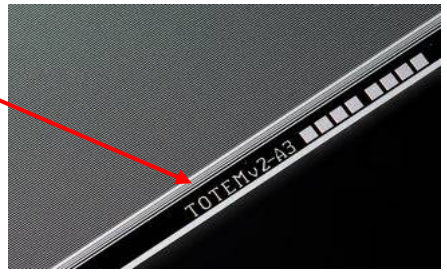



**Pitch adapter on detector**



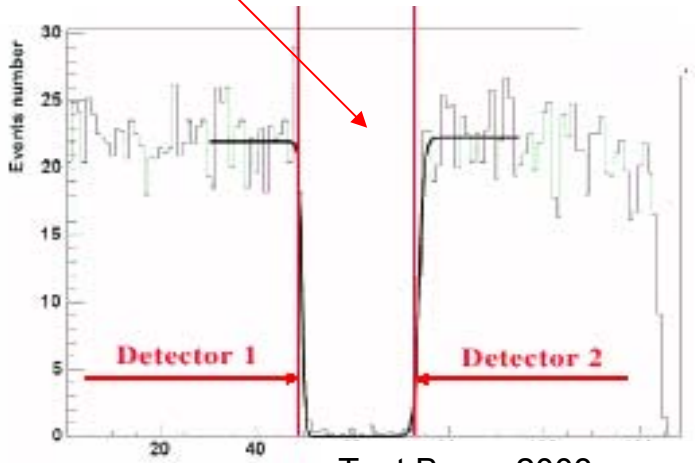

50 μm dead area




**Detector's ID**

- **AC coupled microstrips made in planar technology with novel guard-ring design and biasing scheme**
- **In production, all expected by June 2007**
- **First measurement of leakage current at CERN:**

  **60 nA at 200 V (excellent)**
- **Strong improvements on the cut at the sensitive edge**

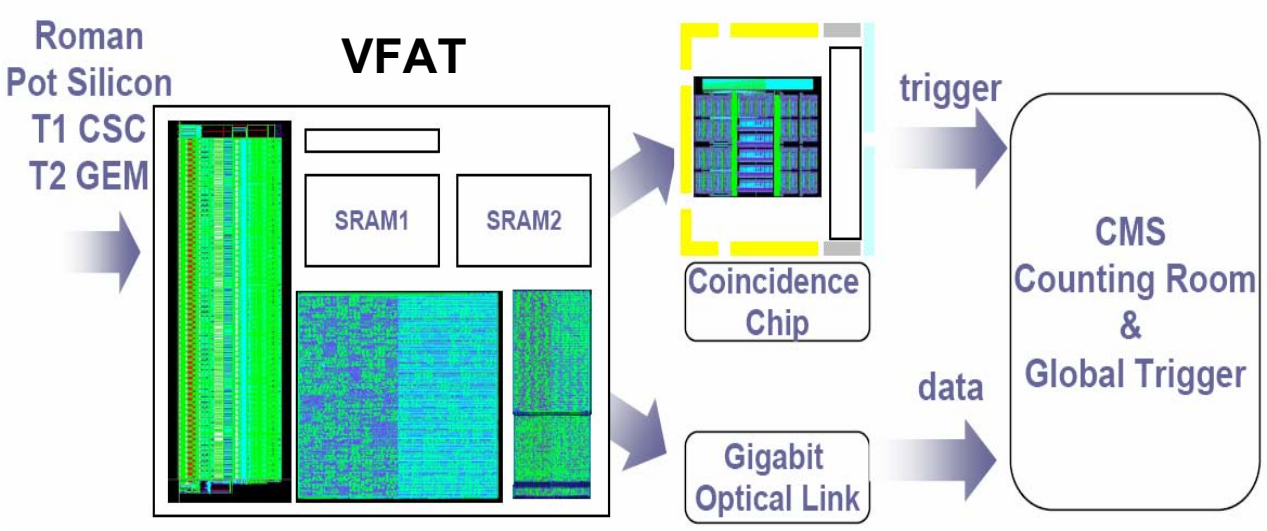



Test Beam 2003

# VFAT-2 chip

- Trigger and tracking ASIC
- Digital output
- Designed for TOTEM, used by all detectors
- 128 channels, thresholds adjustable per channel
- I2C controlled
- Radiation Hardness and Single Event Upset protection

- Successfully tested together with T1 & T2 detectors in a test beam
  - Noise scans, delay scans, functionality testing
- On-going tests with RP detectors



# Total cross section

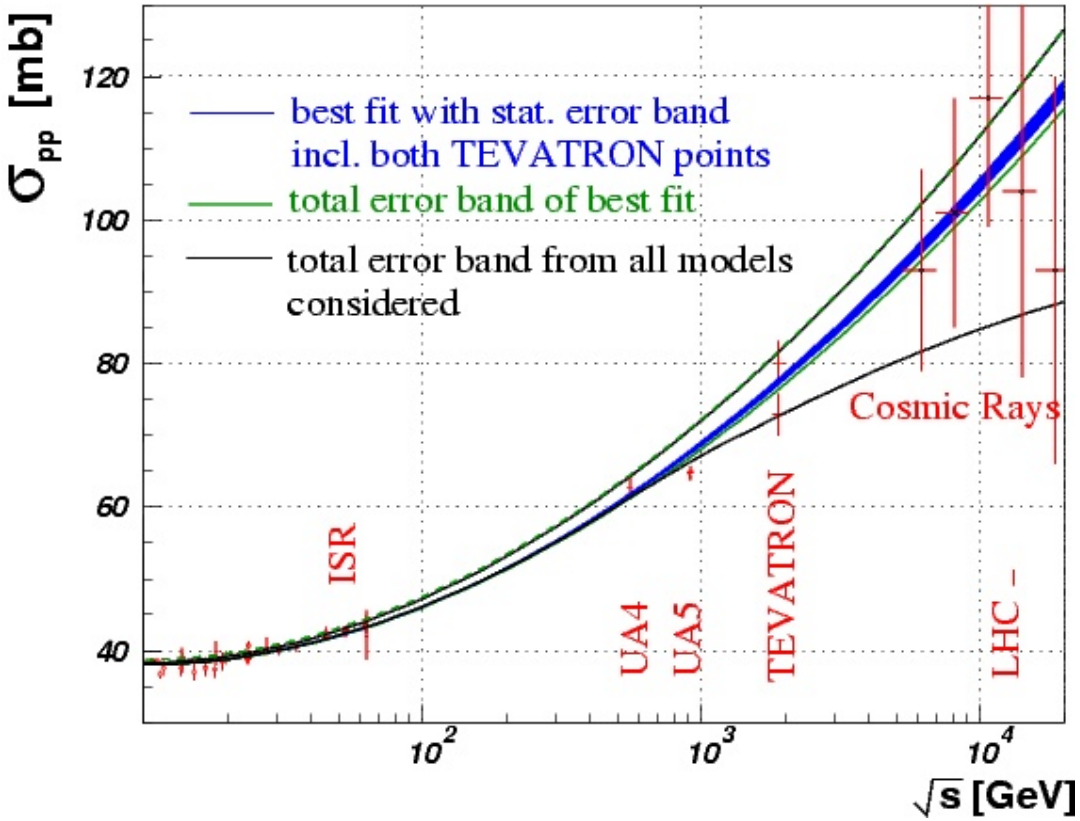
TOTEM

Disagreement E811–CDF: 2.6 σ

Best combined fit by COMPETE:

$$\sigma_{tot} = 111.5 \pm 1.2 \,^{+4.1}_{-2.1} \text{ mb}$$

Models vary within (at least) $^{+10}_{-20}$ %




## Luminosity independent method:

Optical Theorem

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

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

⇩

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

- Elastic rate $N_{el}$
- Extrapolation to the optical point $t$=0

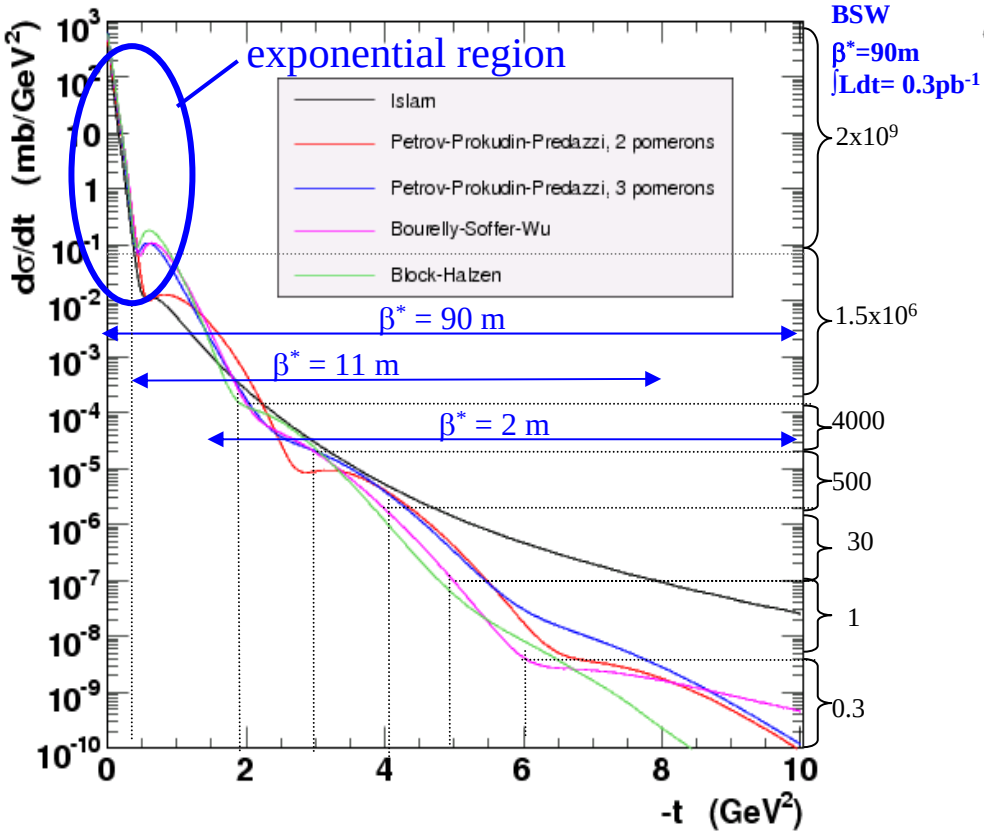
} Depend on optics

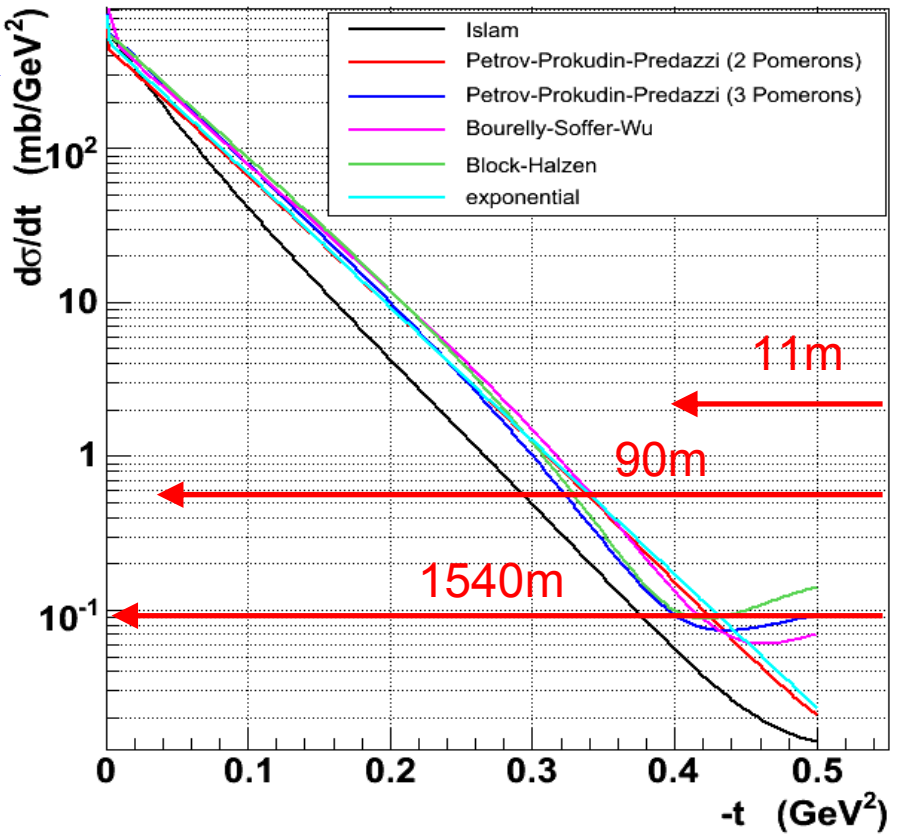
- Inelastic rate $N_{inel}$
- ρ - COMPETE extrapolation

$$\rho = 0.1361 \pm 0.0015 \,^{+0.0058}_{-0.0025}$$

# Elastic scattering

TOTEM




Necessary: optics with acceptance at low |t|:
β***=1540m** (difficult to have at the beginning – requires special injection optics);
acceptance at very low |t|: $|t| > 2 \cdot 10^{-3}$ GeV$^2$

Proposal submitted to LHCC:
β***=90m** (easier: un-squeezing of existing injection optics, $|t| > 3 \cdot 10^{-2}$ GeV$^2$)

# Proposal: Optics with $\beta^* = 90$ m

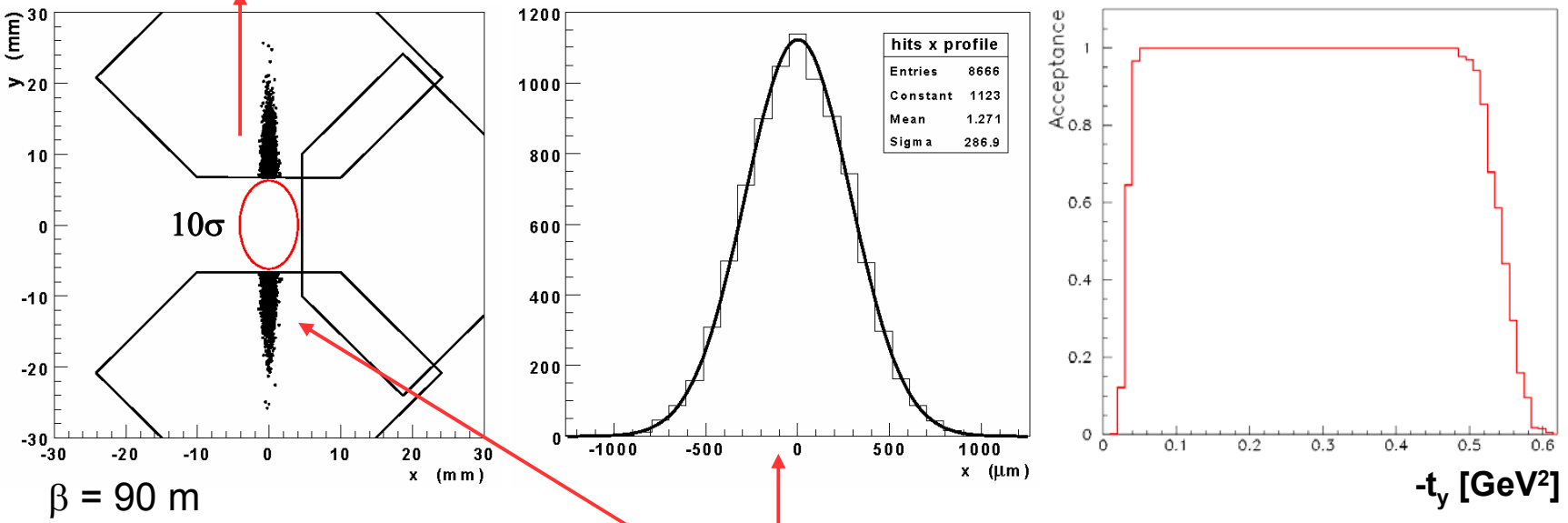
- |t|-acceptance down to 0.03 GeV$^2$ , covering well the exponential region of d$\sigma$/dt;
- Typical luminosity L ~ $10^{28}$ – $10^{29}$ cm$^{-2}$ s$^{-1}$
- **parallel–to–point focusing** only in **vertical** plane @ 220 m
- **no emmission-angle dependence** in **horizontal** displacement
- Thick beam usefull for commissioning of RP detectors

elastic

$$\begin{cases} y(220) = L_y \cdot \Theta_y^* \\ x(220) = v_x(s) \cdot x^* \end{cases}$$

## Elastically scattered protons

$y \sim \Theta_y^{scatt} \sim \sqrt{|t_y|}$




$\beta = 90$ m

$x = v_x \cdot x^*$

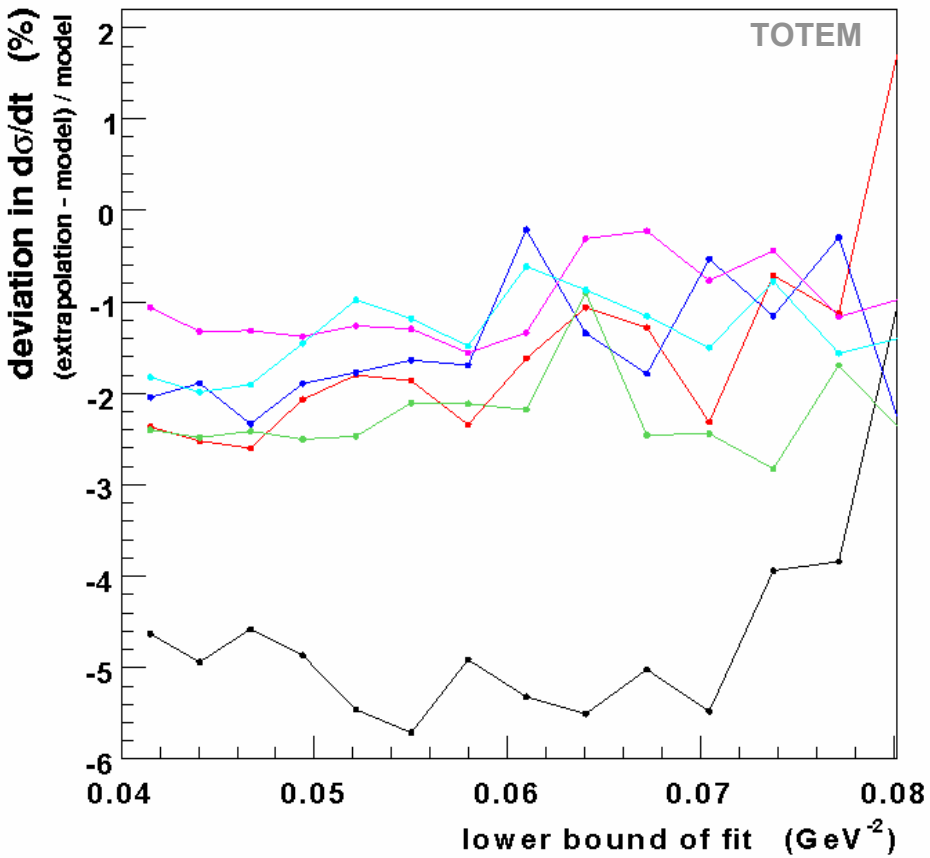
Usefull for BPMs calibration

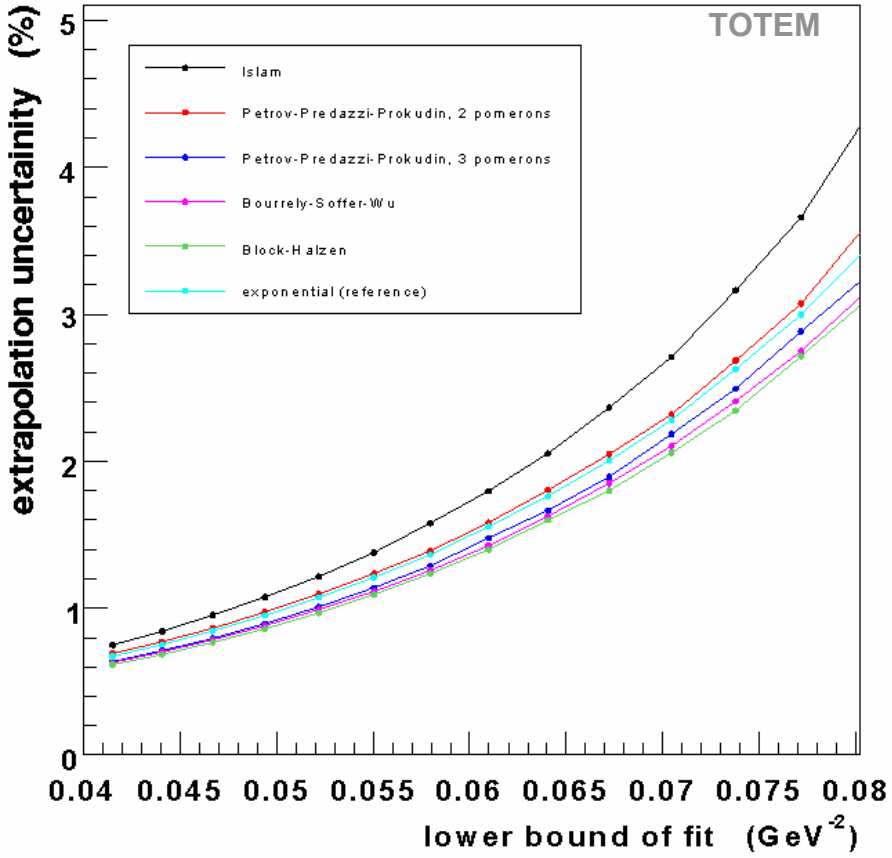
# Extrapolation of the elastic cross-section to t = 0, β*=90 m

Fitting function: $\frac{d\sigma}{dt} = Ae^{B(t)t}$ with $B(t) = a + bt + ct^2$,

$\int Ldt = 2\ nb^{-1}$ (5h, $L=10^{29}\ cm^{-2}s^{-1}$)

## Errors of extrapolation for different models (MC)




**Exponential slope fit up to 0.25 GeV²**

## Errors of $d\sigma/dt$ $t \to 0$ extrapolation, $\beta^*=90$m

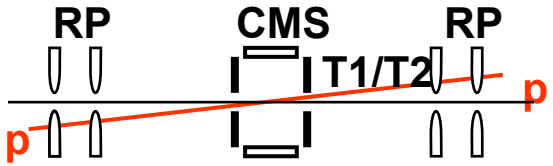
- Smearing effects due to beam divergence: -2% shift
- Statistical errors
- Uncertainty of effective length $L_{eff}$: 3% extrapolation offset
- RP position systematics less critical ($\sigma_{220\ y}$ = 0.625 mm, $\Delta t/t \propto \Delta y/\ \sigma_y$)
- Model dependent deviations: ±1% (except Islam)

**Total uncertainty < 4% @** $\beta^*=90$m

(~0.5% @ $\beta^*$ = 1540 m)

## Elastic event rate $N_{el}$

- ≤ 2%, high correlation with error of $d\sigma/dt$

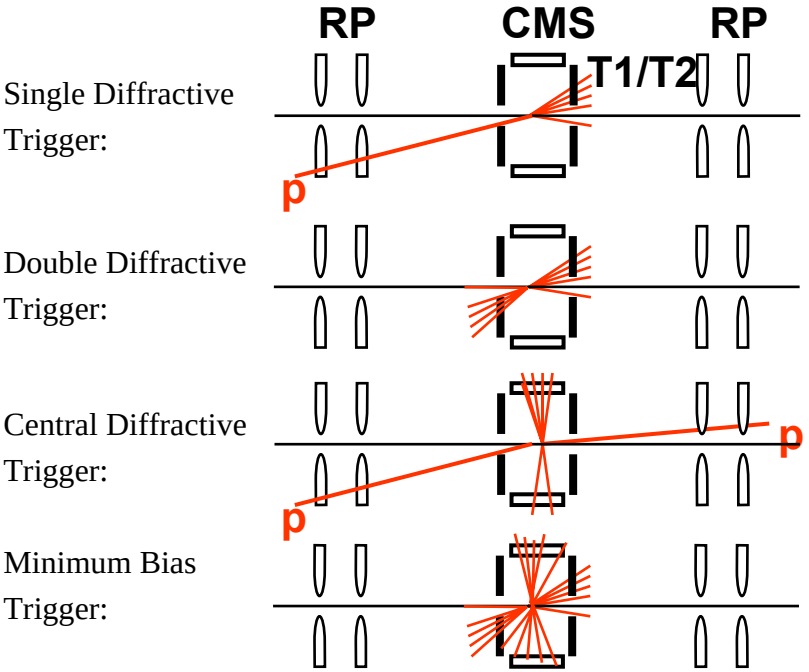


# Inelastic event rate $N_{inel}$

**T1&T2 + RP provide fully inclusive trigger:**

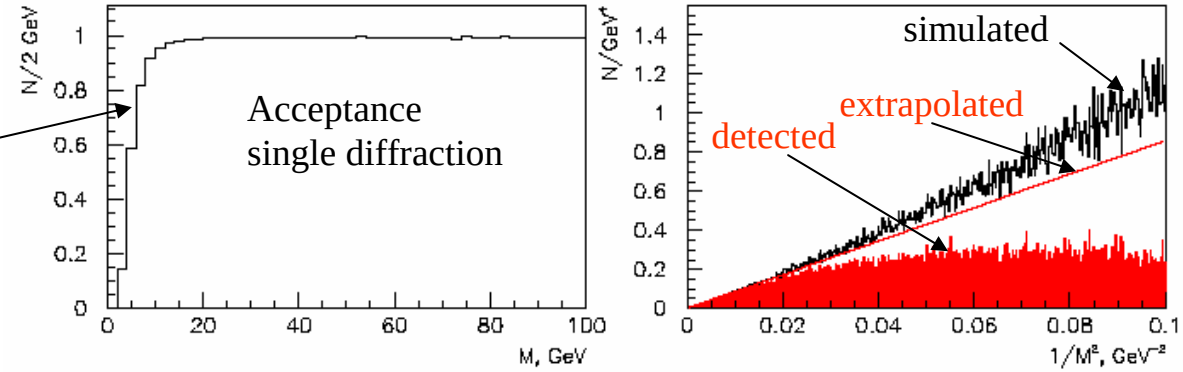
**reconstruct primary vertex to discriminate against beam-gas interactions**

**TOTEM Trigger efficiency:**
**SD: 82 %,**
**NSD > 99 % !**




Extrapolation of SD cross-section to large $1/M^2$ using $d\sigma/dM^2 \sim 1/M^2$ .

Loss at low masses



Losses for TOTEM inelastic trigger

| | σ [mb] | T1/T2 double arm trigger loss [mb] | T1/T2 single arm trigger loss [mb] | Systematic error after extrapolation [mb] |
|---|---|---|---|---|
| Minimum bias | 58 | 0.3 | 0.06 | 0.06 |
| Single diffractive | 14 | – | 3 | 0.6 |
| Double diffractive | 7 | 2.8 | 0.3 | 0.1 |
| Double Pomeron | 1 | 0.2 | | 0.02 |

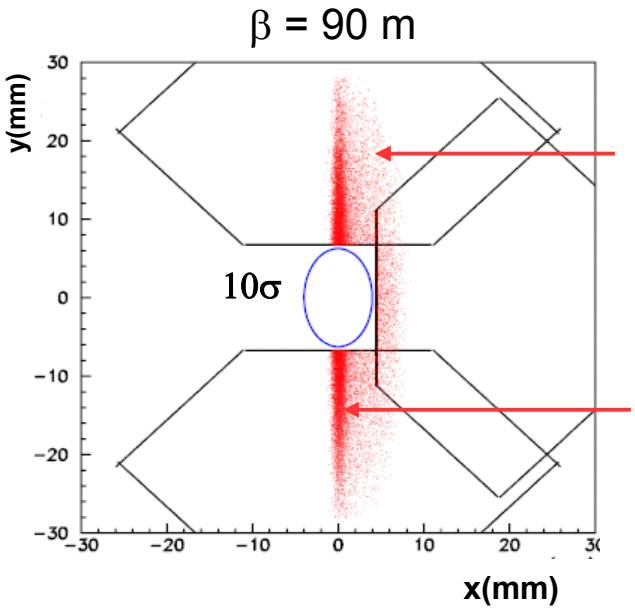
**Inelastic event rate uncertainty ~ 1%**

**Error of $\sigma_{tot}$**

$$\begin{cases} \sim 1\ \% \quad @\ \beta^* = 1540\ \text{m} \\ \mathbf{\sim 5\ \%\ \ @\ \beta^* = 90\ m} \end{cases}$$

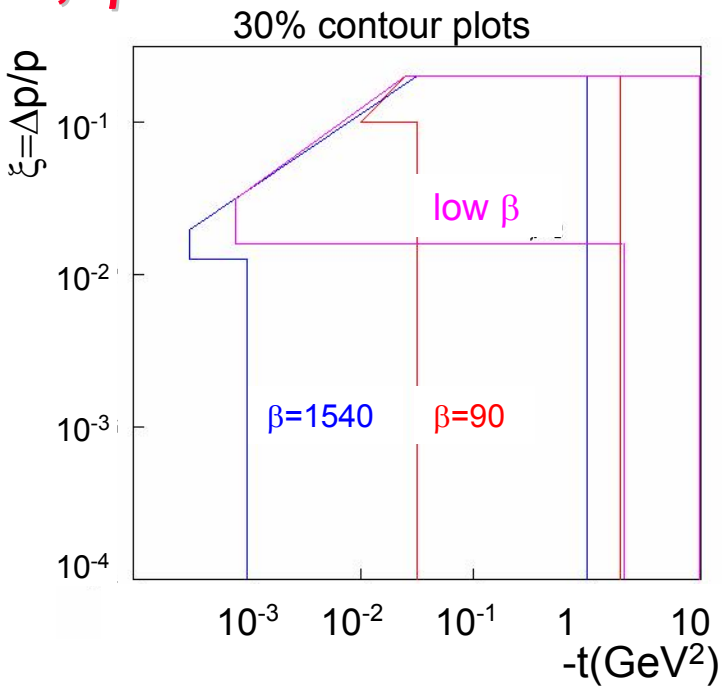
# Diffractive forward protons, β*=90 m

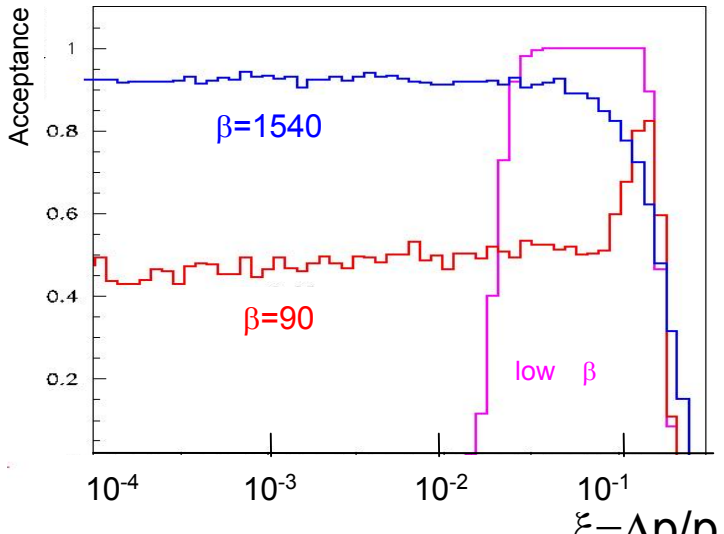
- **Excellent horizontal beam position calibration at 220 m**
- **Good acceptance for ξ**




$$y \sim \Theta_y^{scatt} \sim \sqrt{|t_y|}$$

$$x = v_x \cdot x^* + D(s) \cdot \xi$$

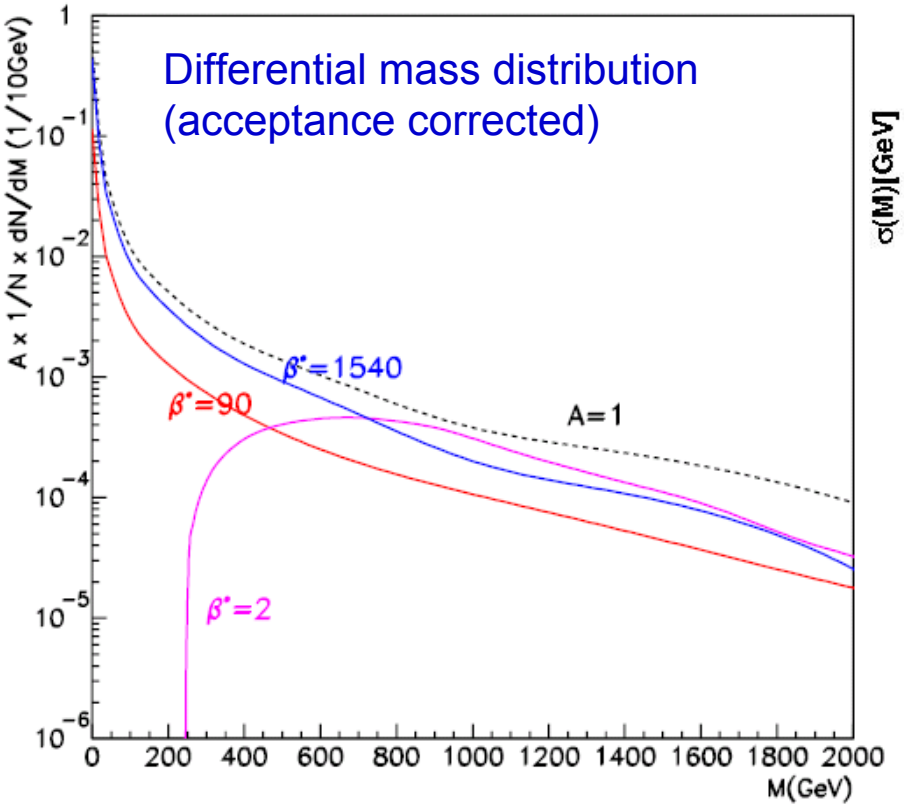


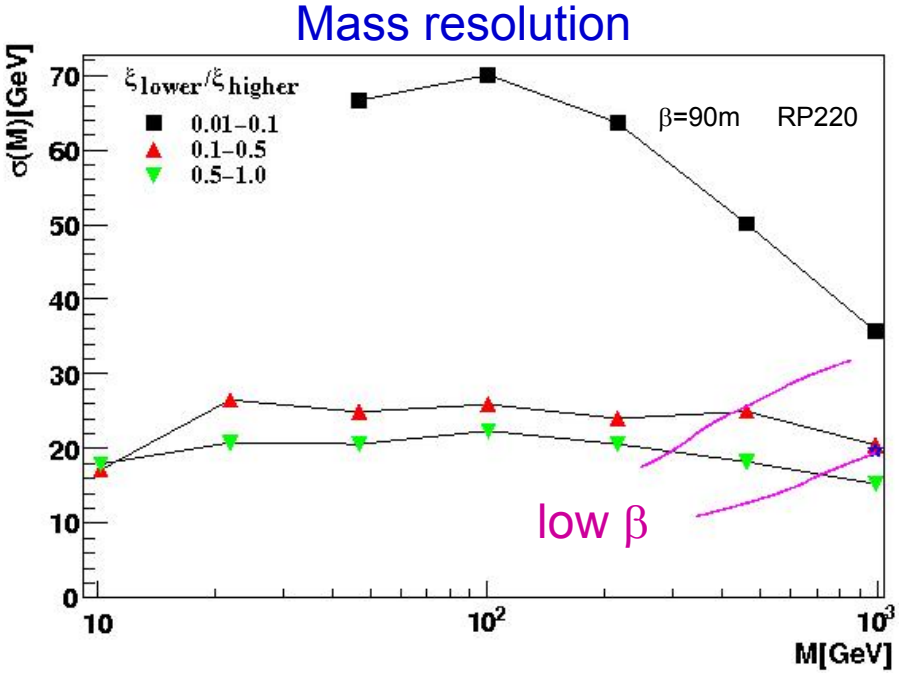



# Differential mass distribution in DPE

- **Study of mass distributions via the 2 protons**
  - **Trigger with 2p+T1/T2: rate ~200Hz @ β*=90m, L=$10^{30}$cm$^{-2}$s$^{-1}$** — **low/medium luminosity**
  - **(TOTEM limit ~2kHz)**
- **ξ measured directly (TOTEM) or**
  - **With rapidity gap Δη=-ln ξ**
  - **With calorimeters** $\xi = \sum_i E_T^i e^{\mp\eta_i} / \sqrt{s}$

} (TOTEM+CMS)




Best resolution for symmetric events

TOTEM

# Summary

- TOTEM will be ready for first LHC runs in 2008 and can profit from early LHC beams
- TOTEM needs $\beta^*$=1540m optics to measure Total Cross Section with 1% precision
- During first running (2008) an intermediate $\beta^*$=90m optics can be achieved by un-squeezing the existing injection optics (proposal to LHCC)
- In a few days TOTEM can measure $\sigma_{tot}$ with 5% precision
- TOTEM can start studying soft diffraction with DPE + SD events in a wide mass range

# Transverse proton displacement

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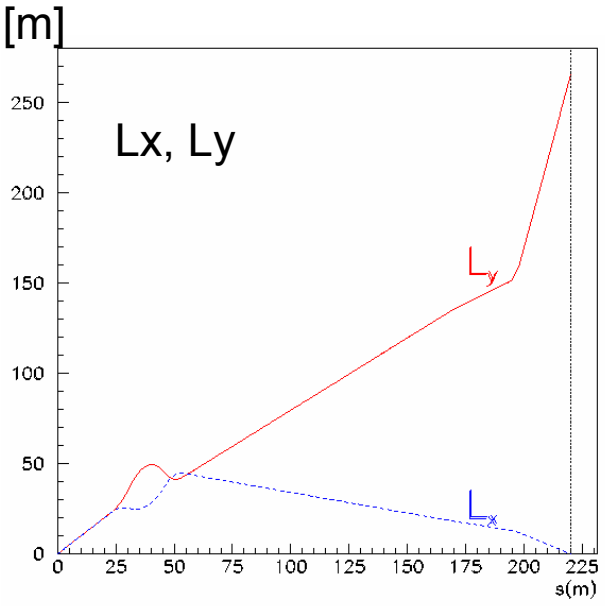
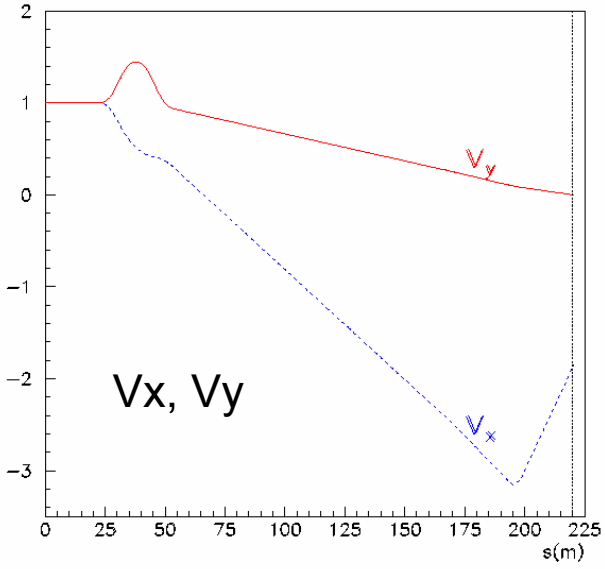
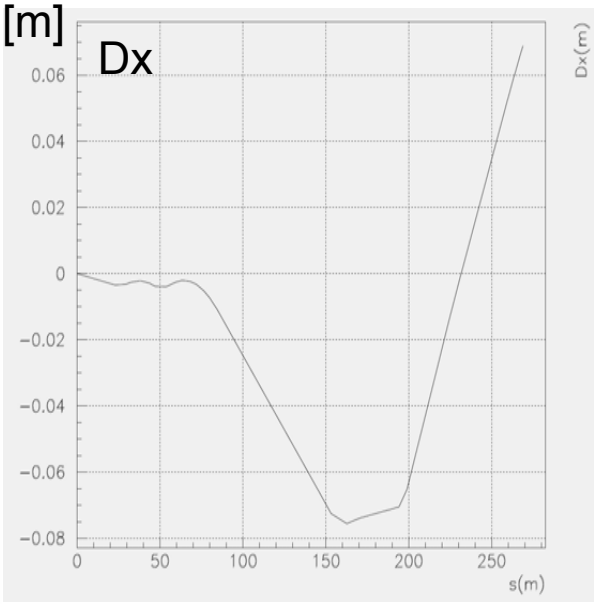
**Beta* = 90 m**

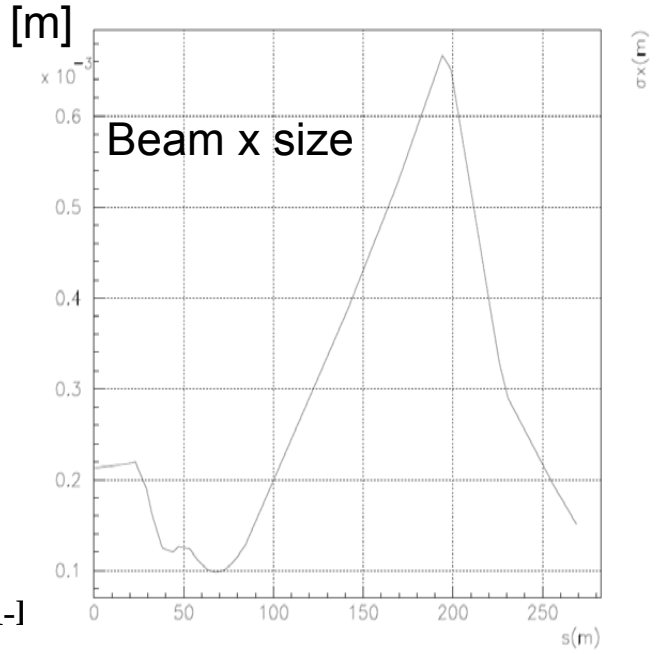



$$y(s) = v_y(s) \cdot y^* + L_y(s) \cdot \Theta_y^*$$
$$x(s) = v_x(s) \cdot x^* + L_x(s) \cdot \Theta_x^* + \xi \cdot D(s)$$

$$\xi = \Delta p / p$$



# Elastic scattering, t-acceptance

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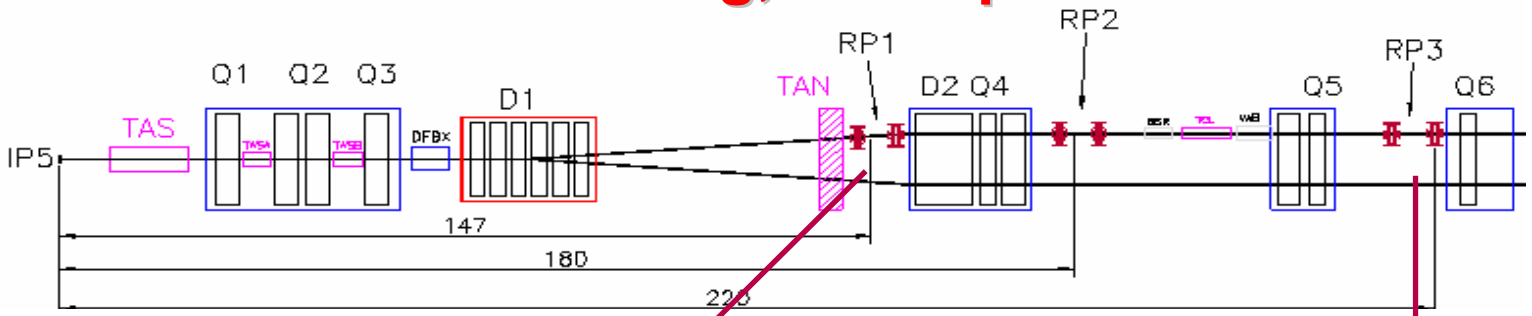
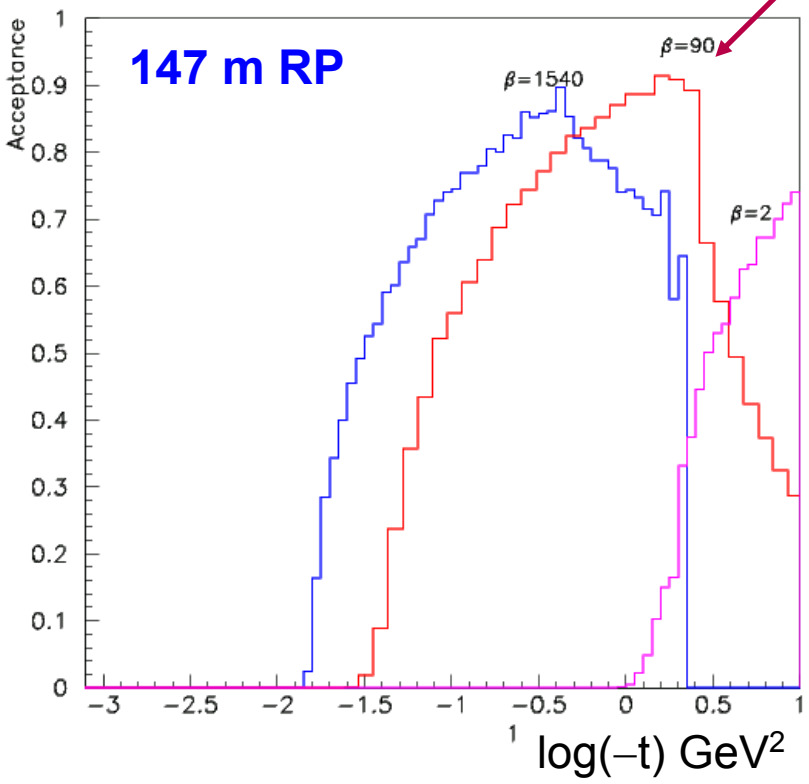
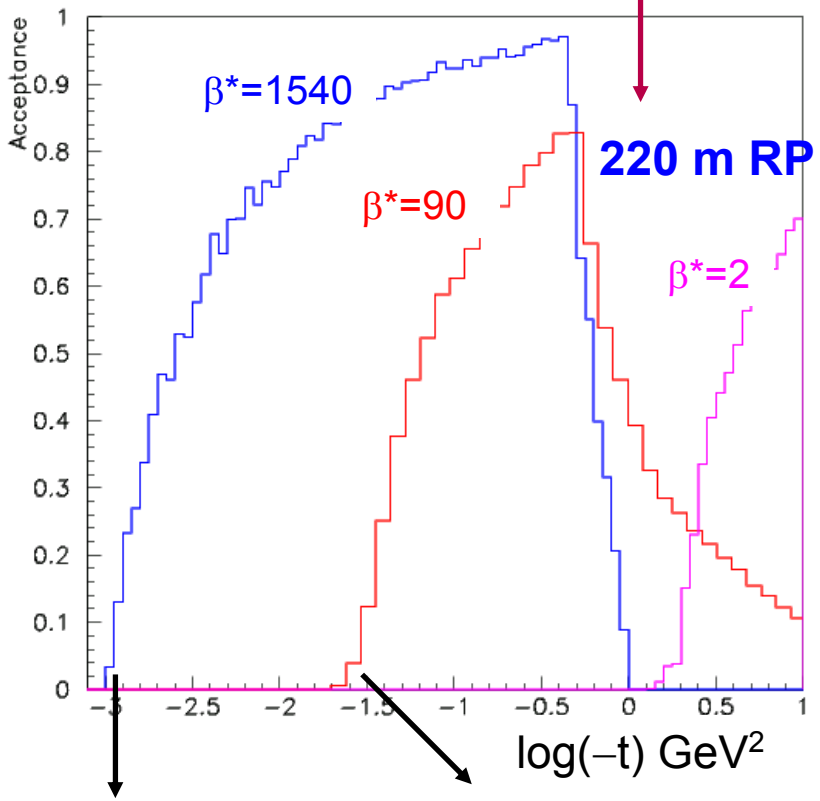


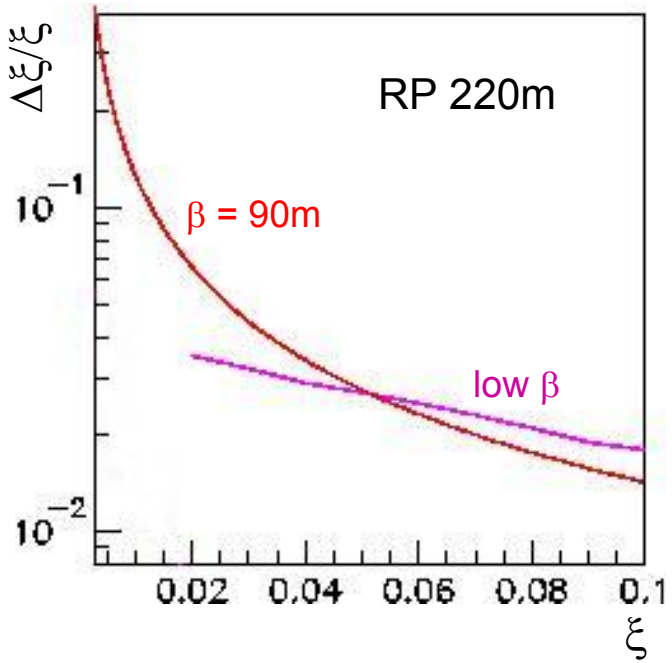




detector distance to beam: 1.3 mm (β* = 1540) & 6 mm (β* = 90 m)

TOTEM

# Double Pomeron Exchange (DPE) at low/medium luminosity

ξ resolution form direct measurement




Gap vs ln (ξ)  T1+T2+Calorimeters