THE TOTEM Experiment

V. Avati

on behalf of the

TOTEM Collaboration

http://www.cern.ch/totem/

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University of Helsinki and HIP,
Helsinki, Finland
Academy of Sciences,
Praha, Czech Republic
Penn State University
University Park, USA
Brunel University, Uxbridge, UK

TOTEM TDR is fully approved by the LHCC and the Research Board

TEV4LHC Workshop

CERN, 28 April 2005

TOTEM Physics

- Total p-p cross section at 14 TeV with a precision of 1% (Optical Theorem , Luminosity independent method)
- Elastic p-p scattering cross-section $d\sigma/dt$ in the range 10^{-3} GeV^2 < $-t$ < 10 GeV^2
- Particle and energy flow in the forward direction
- Measurement of leading particles
- Diffractive phenomena with high cross-sections
- Absolute luminosity measurement and calibration of CMS luminosity monitors

Different running scenarios (β^* = 1540, 170, 18, 0.5 m)

Total p-p Cross-Section

- Current models predict for 14 TeV: 90 – 130 mb
- Aim of TOTEM: ~ 1% accuracy
- **Luminosity independent method:**

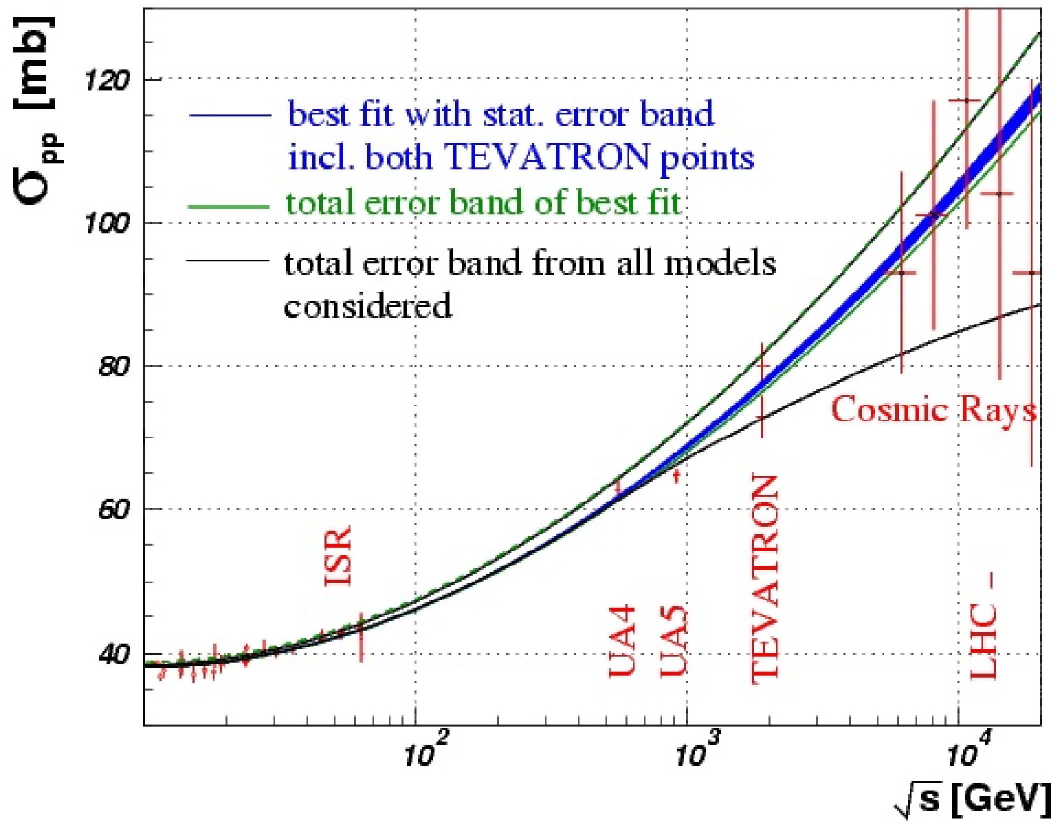
Optical Theorem $$\mathcal{L}\,\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \times \left.\frac{dN}{dt}\right|_{t=0}$$

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

$\Downarrow$

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

COMPETE Collaboration:



COMPETE Collaboration fits all available hadronic data and predicts at LHC:

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

[PRL 89 201801 (2002)]

Measurement of σ_{tot}

Luminosity-independent measurement of the total cross-section using the Optical Theorem:

$$\left.\begin{aligned} \mathcal{L}\sigma_{tot}^2 &= \frac{16\pi}{1+\rho^2} \times \left.\frac{dN_{el}}{dt}\right|_{t=0} \\ \mathcal{L}\sigma_{tot} &= N_{el} + N_{inel} \end{aligned}\right\} \Rightarrow \boxed{\sigma_{tot} = \frac{16\pi}{1+\rho^2} \times \frac{(dN_{el}/dt)|_{t=0}}{N_{el}+N_{inel}}}$$

- Measure the elastic and inelastic rate with a precision better than 1%
- Extrapolate the elastic cross-section to t = 0

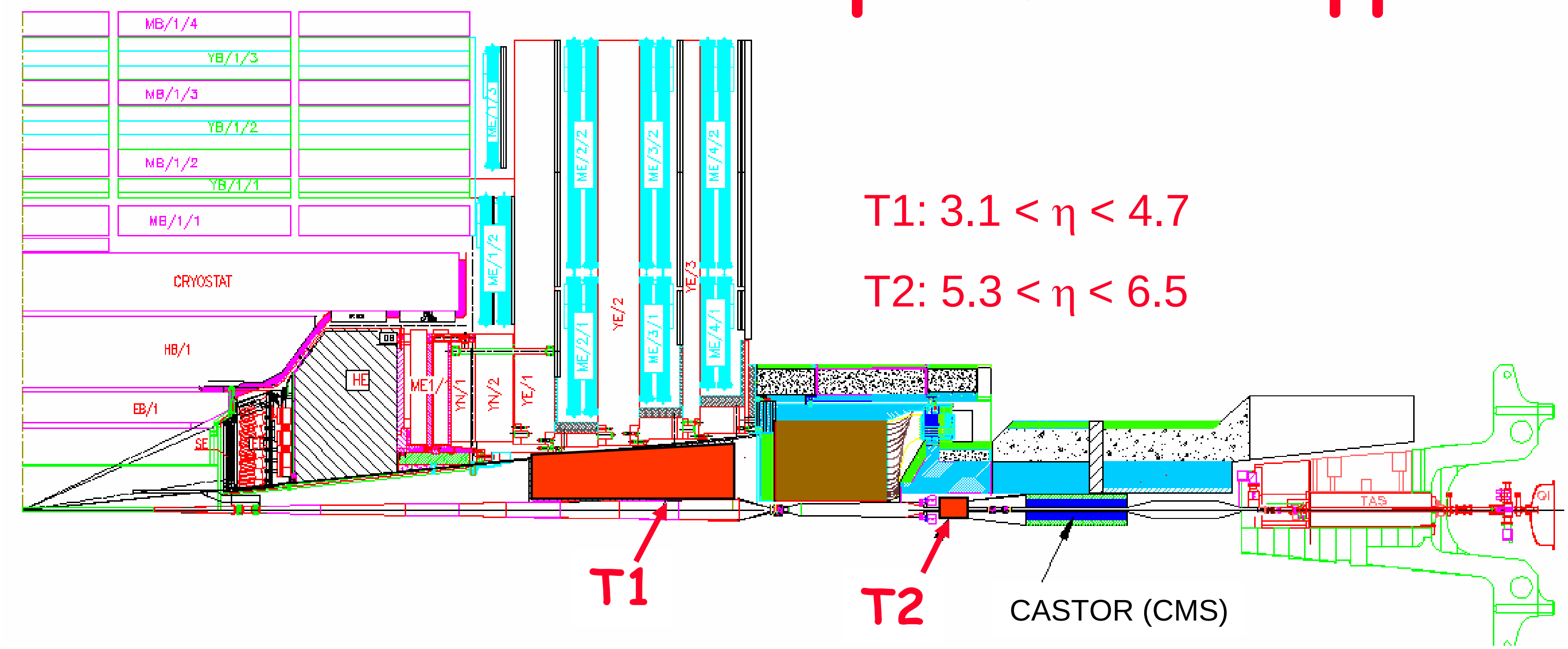
Or conversely:
Extract luminosity:

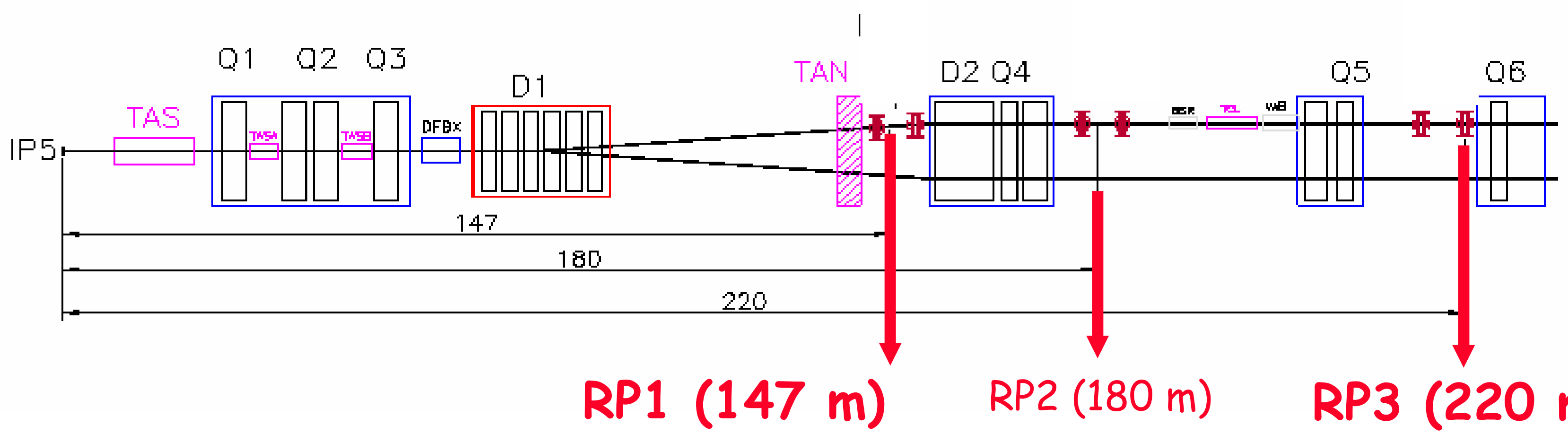
$$\mathcal{L} = \frac{1+\rho^2}{16\pi} \frac{(N_{el}+N_{inel})^2}{(dN_{el}/dt)|_{t=0}}$$

Experimental apparatus

T1: $3.1 < \eta < 4.7$

T2: $5.3 < \eta < 6.5$





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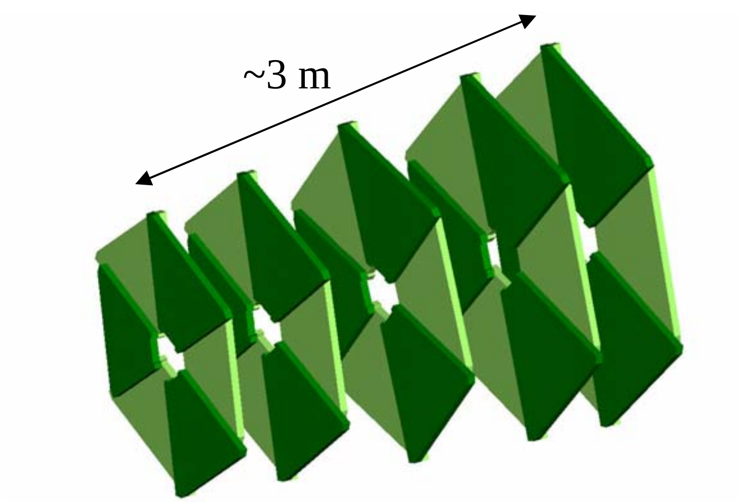
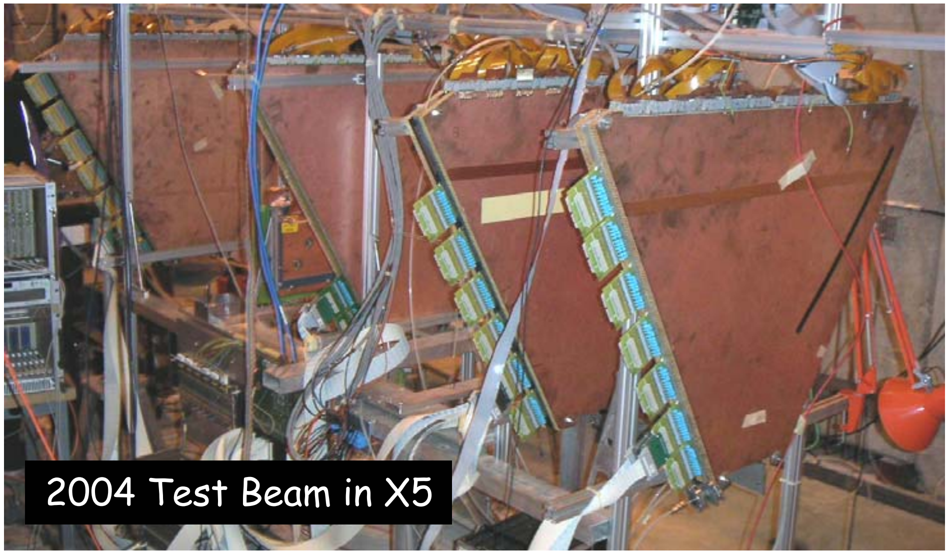
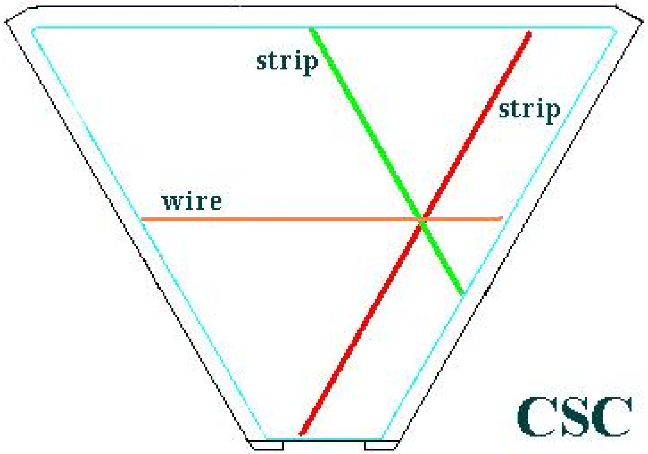
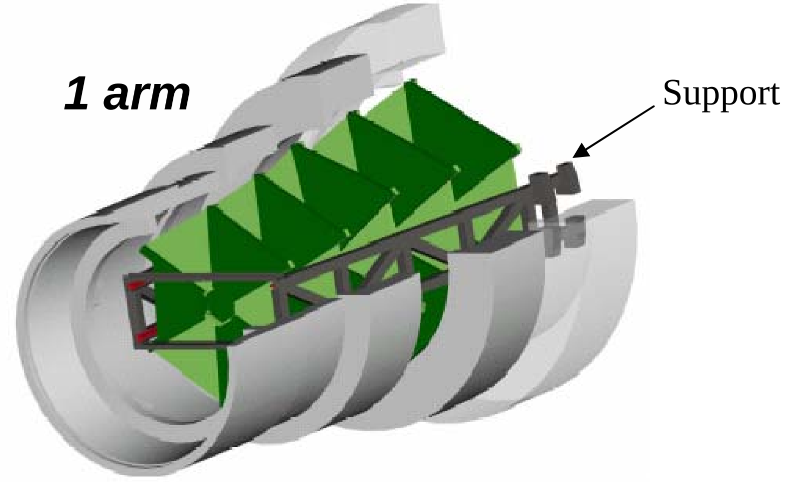
T1 Telescope

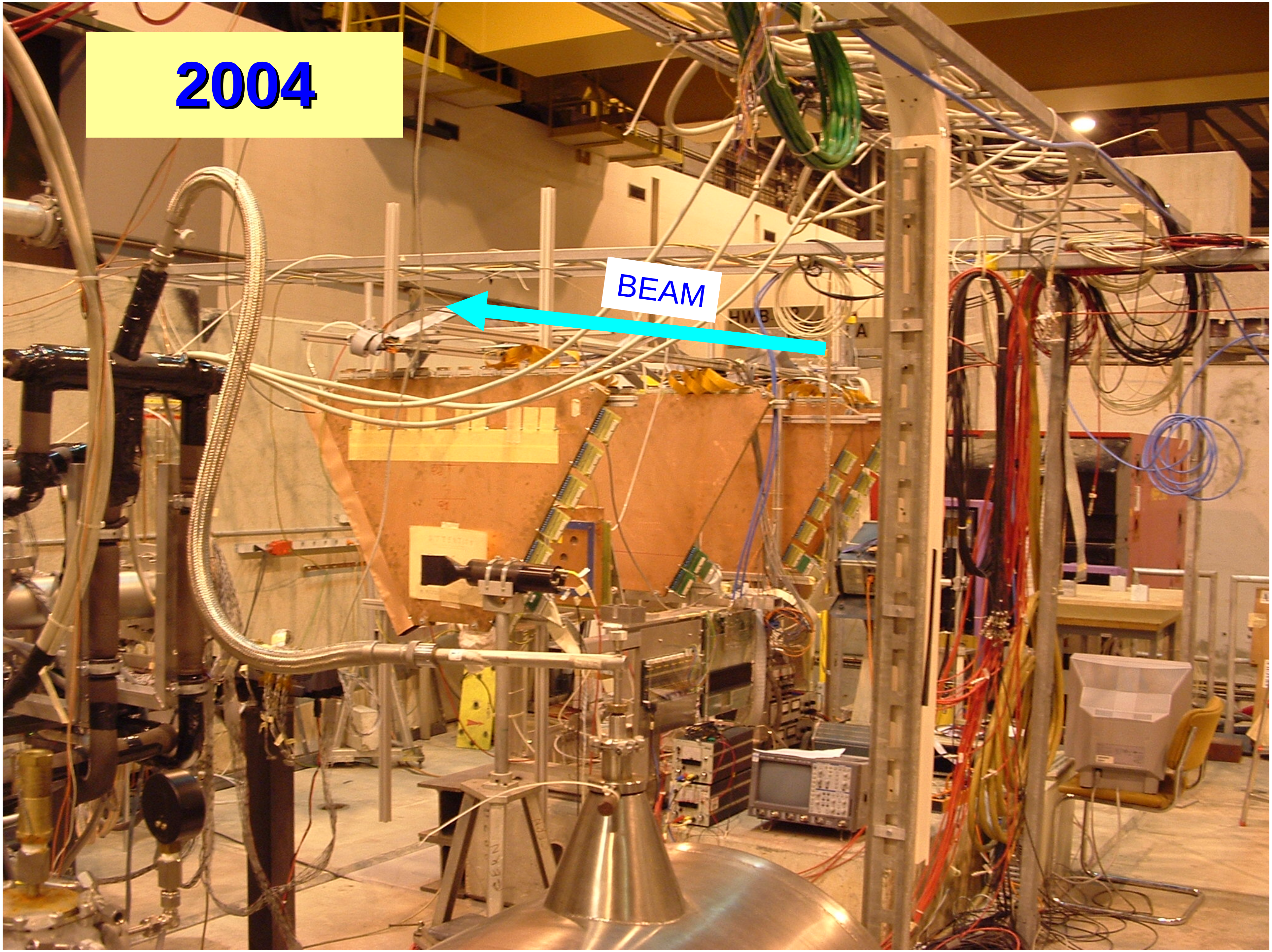




5 planes of Cathode Strip Chambers
Measurement of 3 coordinates per plane

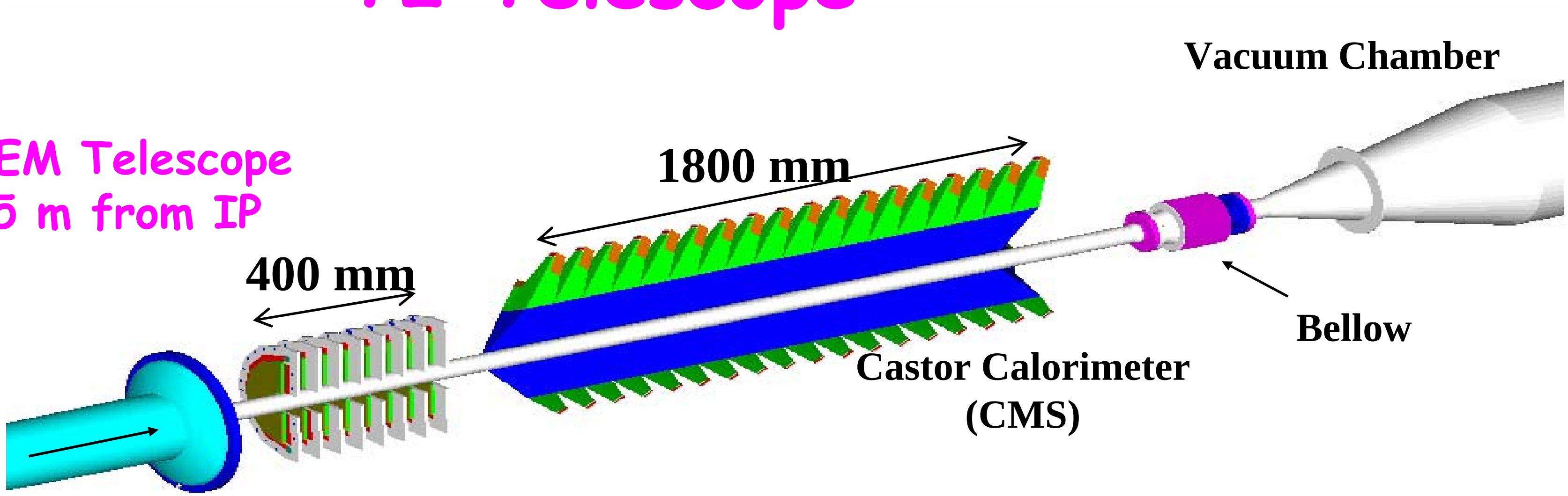


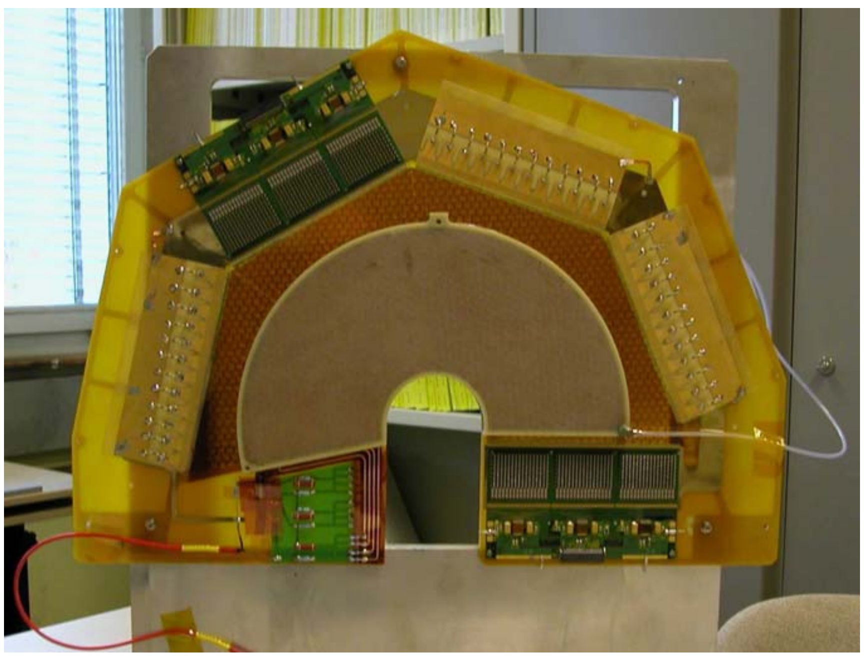



2004
BEAM

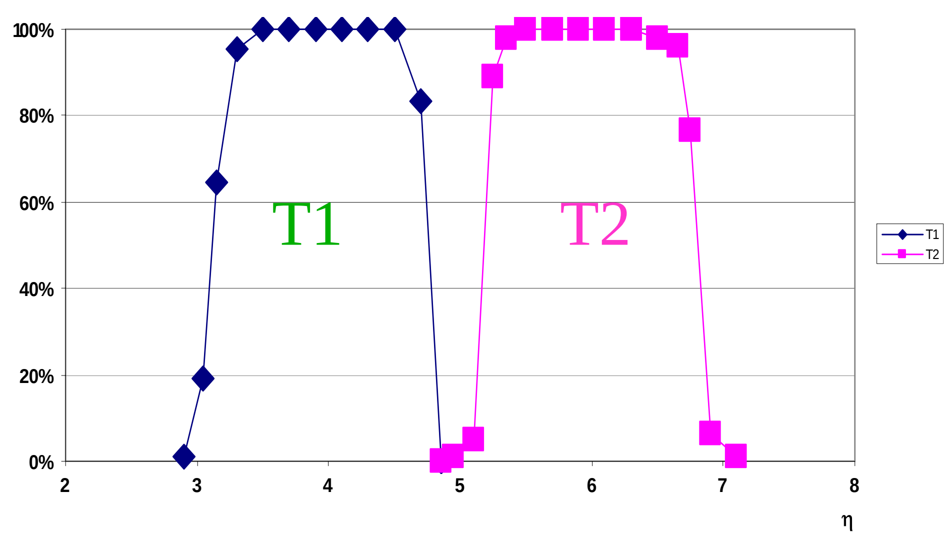
T2 Telescope

$5.3 < |\eta| < 6.8$





Geometric acceptance

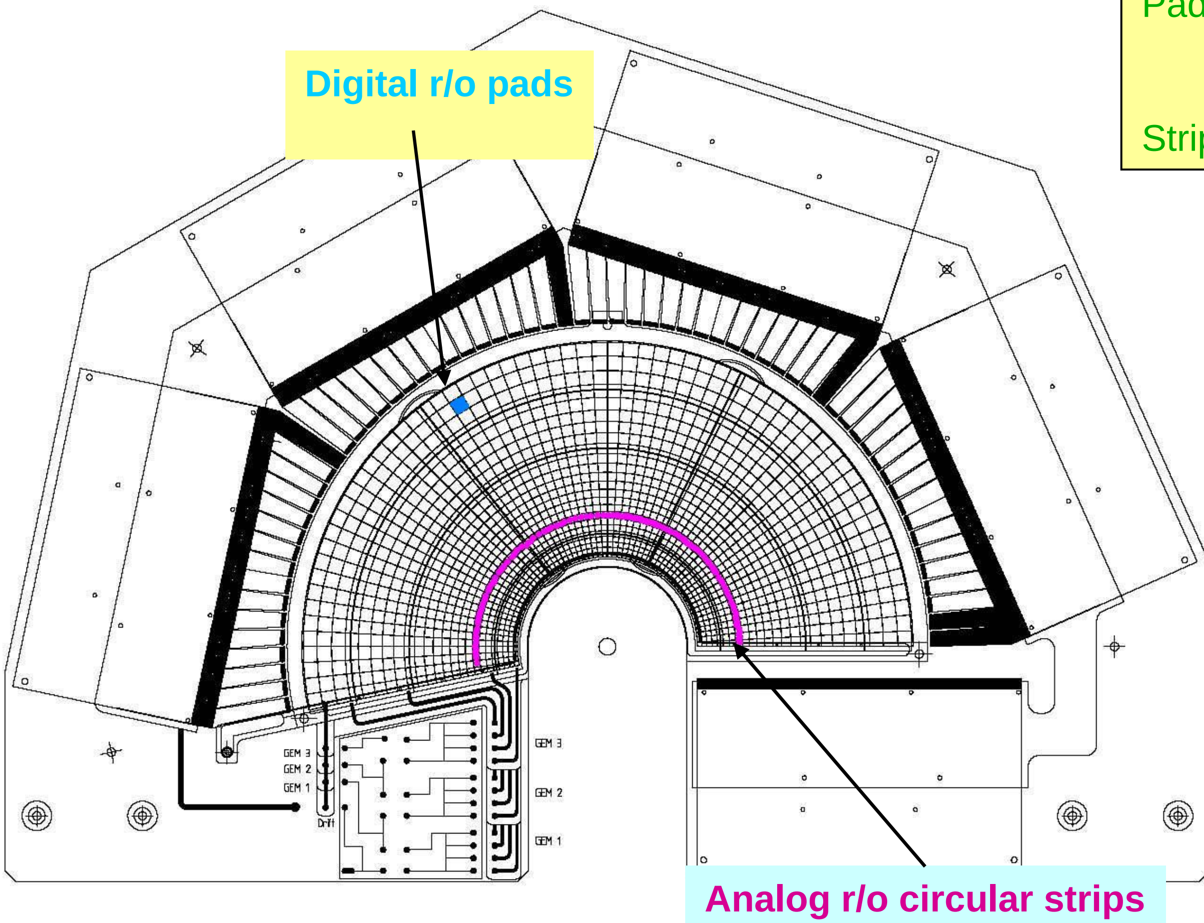


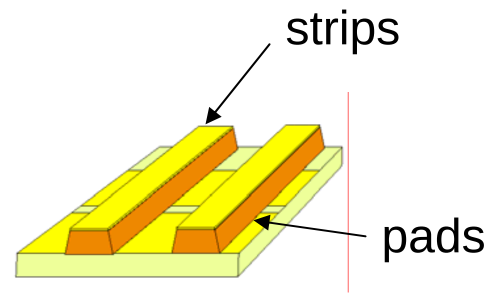
T2 telescope

10 triple-GEM planes, to cope with high particle fluxes

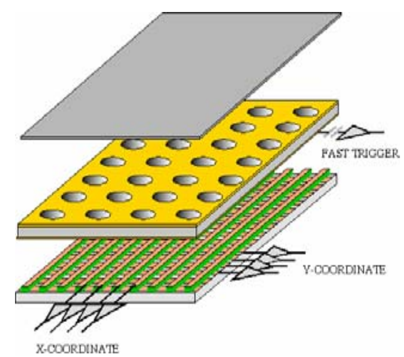
Pads: $65(\varphi) \times 24(\eta) = 1536$ pads
$\Delta\eta \times \Delta\varphi = 0.06 \times 0.018\pi$
$2\text{x}2\ \text{mm}^2 — 7\text{x}7\ \text{mm}^2$

Strips: 256 (width: 80 μm, pitch: 400 μm)





Technology used in COMPASS



Resolution: σ_R~115μm ; σ_ϕ~ 16mrad

Telescopes performances: provide full inclusive trigger

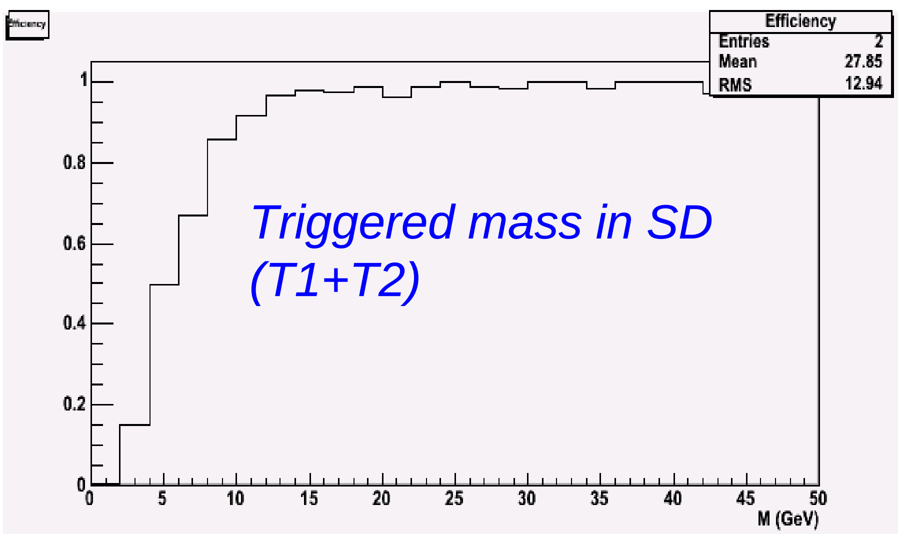
T1

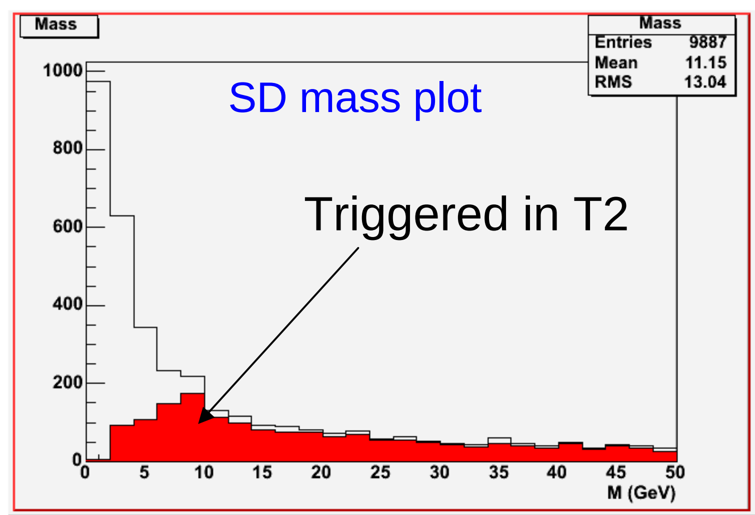
- LVL1 trigger done with anode wires: pattern optimized to trigger on primary tracks
- Pointing power at LVL1
- Non Single Diffractive (Minimum bias+double diffr):
  Trigger efficiency: 1arm >98% - 2arms >88%
- Single diffractive:
  Trigger efficiency: 1arm >70%

T2

- LVL1 trigger done using sectors (5x3 pads)
- NSD:
  Trigger efficiency: 1arm >94%
- Single diffractive:
  Trigger efficiency: 1arm >80

T1+T2 Trigger efficiency ⟹ NSD: 1arm > 99% - 2arms > 91% SD: 1 arm> 81%





Telescopes performances: vertex reconstruction

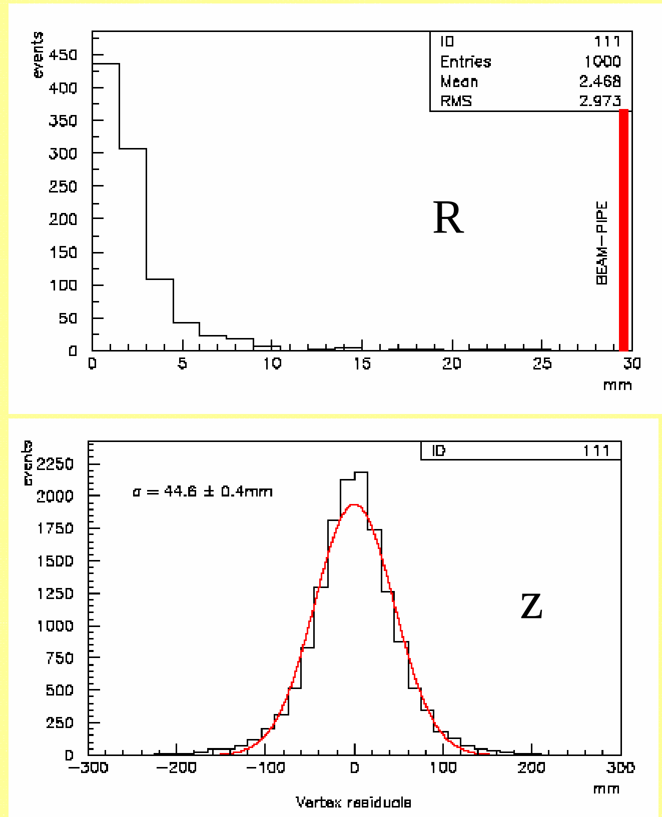
T1 resolution : σx = 0.36 mm
σy = 0.62 mm

T2 resolution: $\sigma_R \sim 115 \mu m$
$\sigma_\phi \sim$ 16mrad

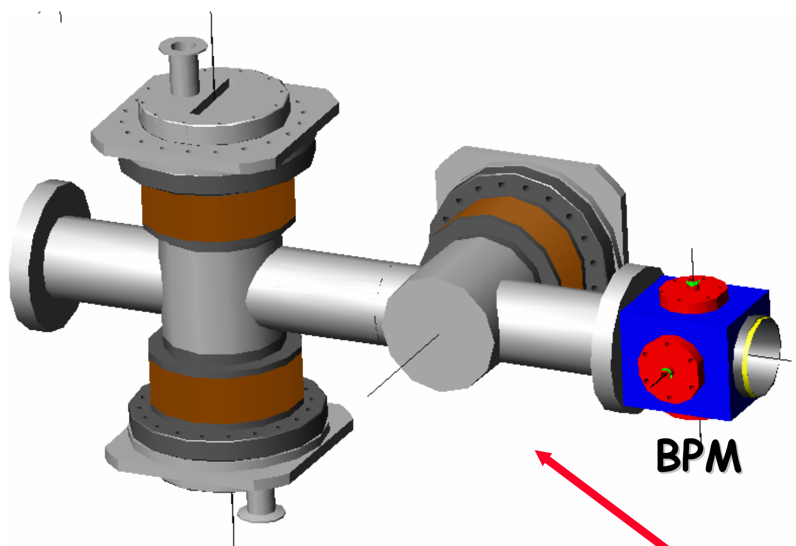
Reconstructed vertex well inside the beampipe ($\sigma \sim$3mm) and within $\pm$5 cm along the beam axis

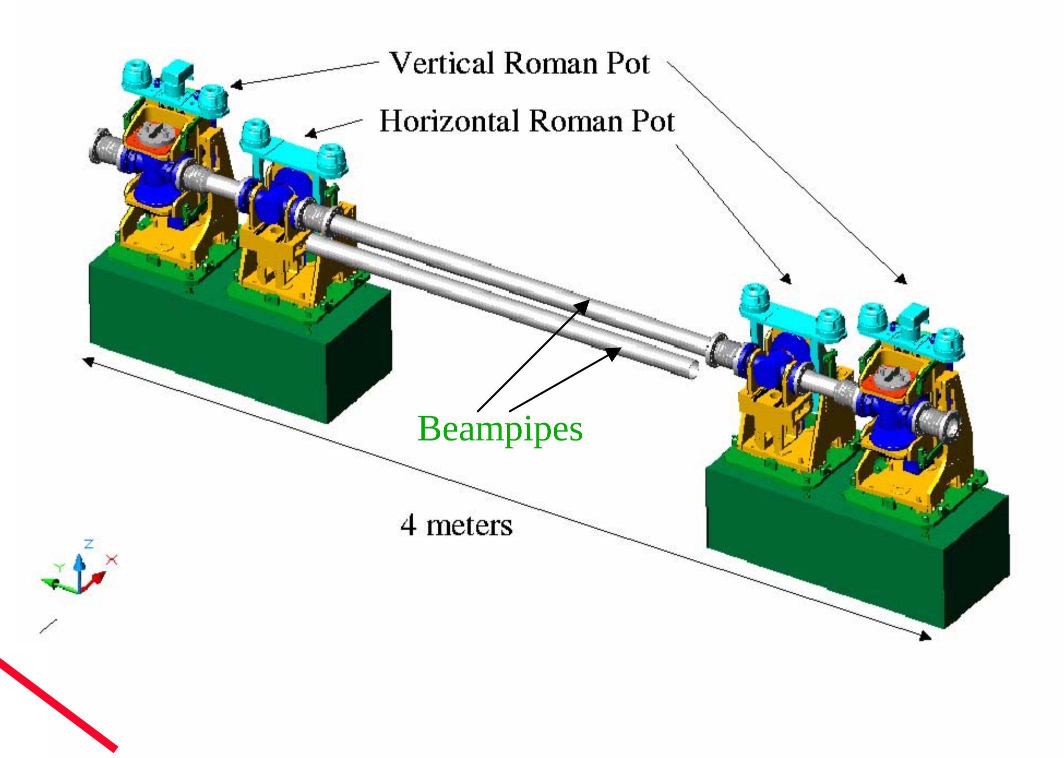
The primary vertex resolution is sufficient to discriminate beam-beam from beam-gas events

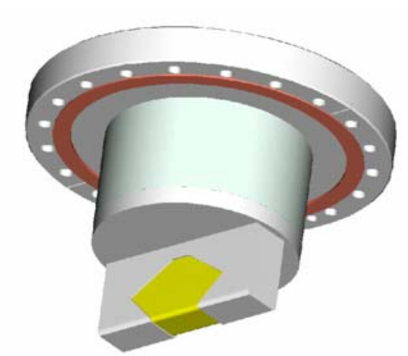
Primary vertex resolution

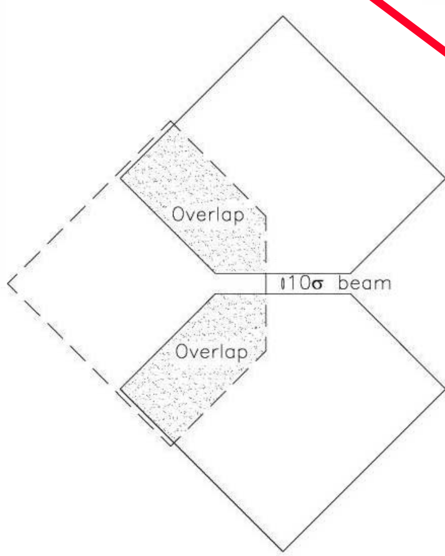


Roman Pot station with two units 4 m apart





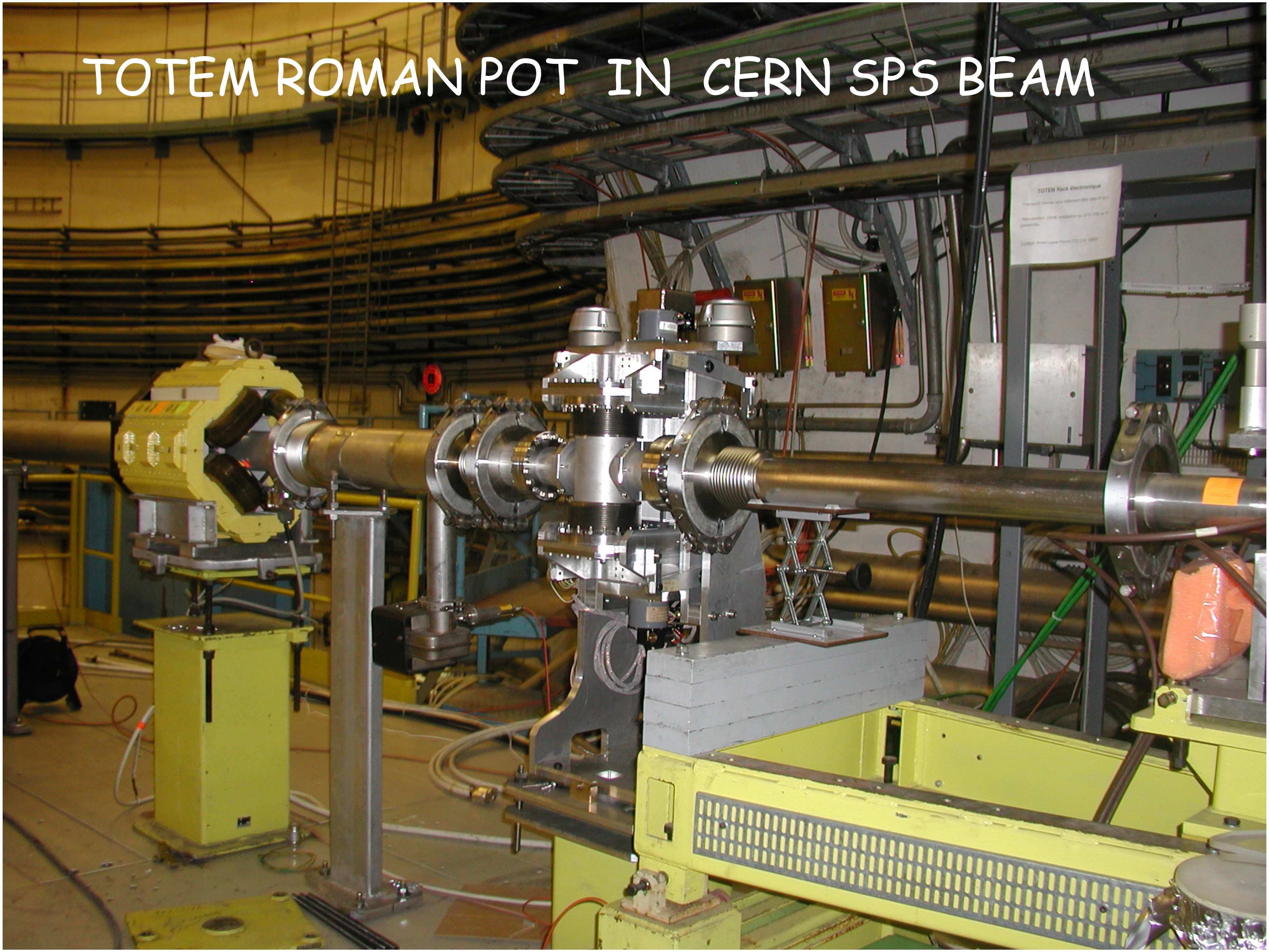




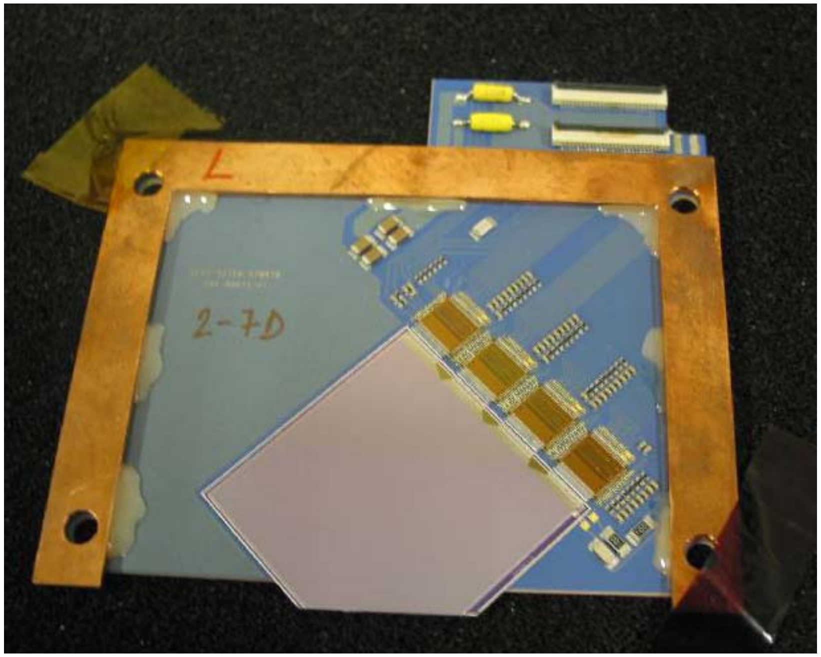
Roman Pot unit

-Vertical and horizontal pots mounted as close as possible
-BPM fixed to the structure gives precise position of the beam
-Final prototype at the end of 2005

Roman Pot : installation in the SPS on Aug. 18th 2004

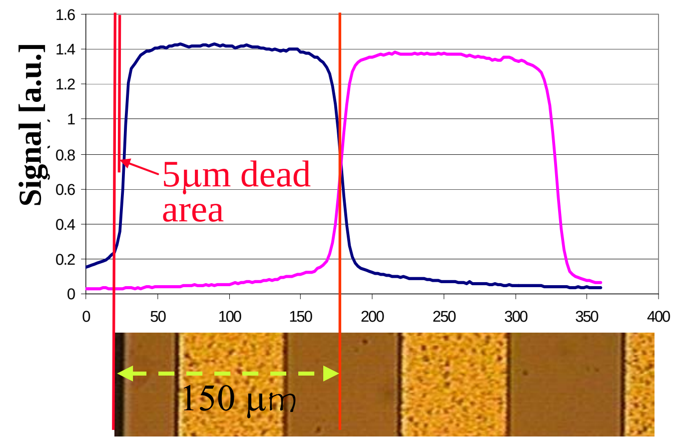

TOTEM ROMAN POT IN CERN SPS BEAM

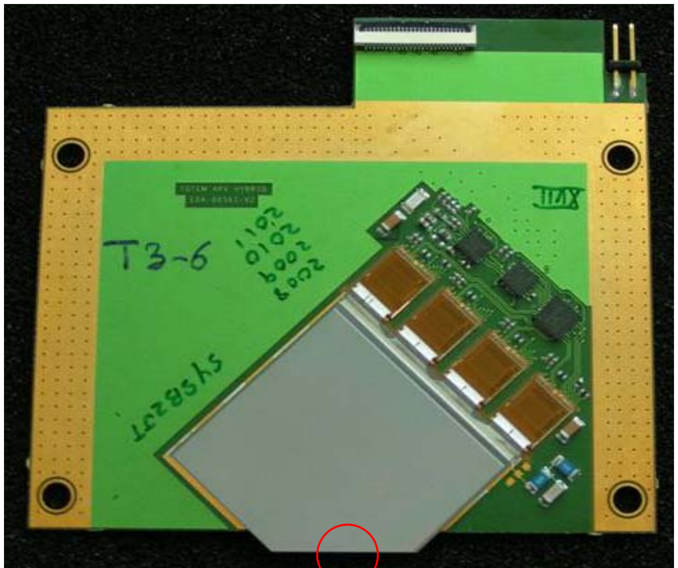
Si detectors and read-out inside the Roman Pots (Test Beam 2004)



Edgeless Silicon Detectors for the RPs

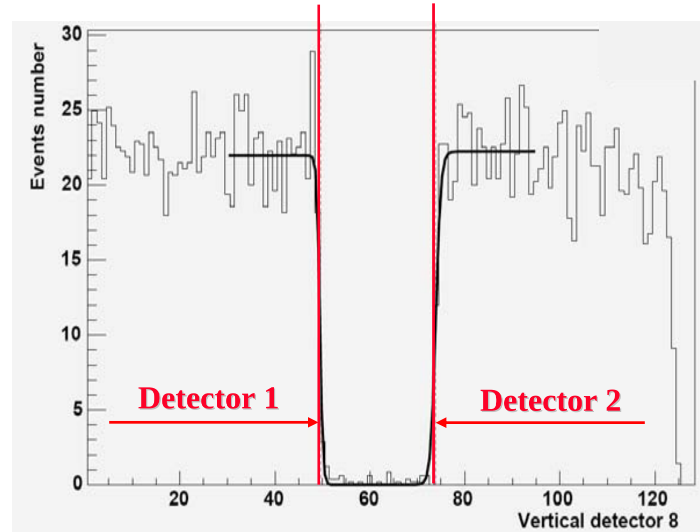
Active edges: X-ray measurement



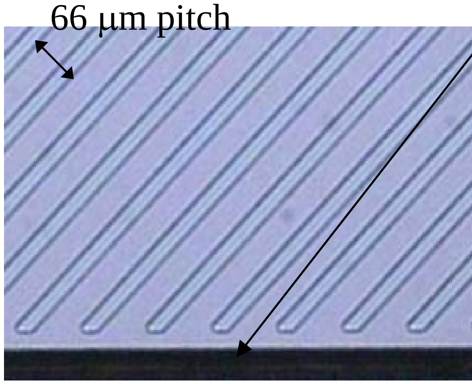


Planar technology:

Testbeam: 40 µm dead area

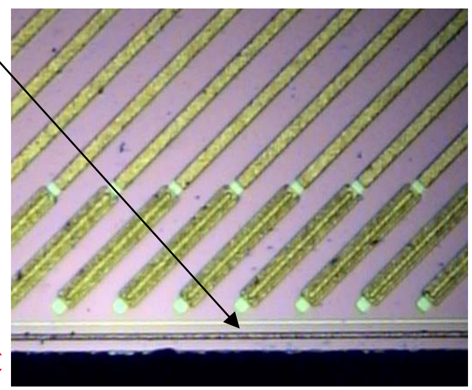


66 µm pitch



10 µm dead area

50 µm dead area

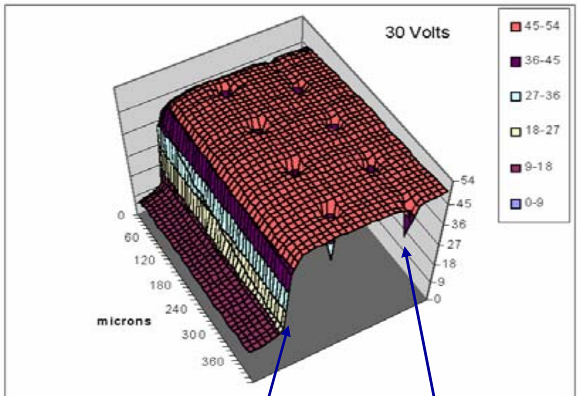


active edges ("planar/3D")

planar technology CTS (Curr. Termin. Struct.)

3D-Si Detector: Edge Sensitivity (Test Beam 2003)

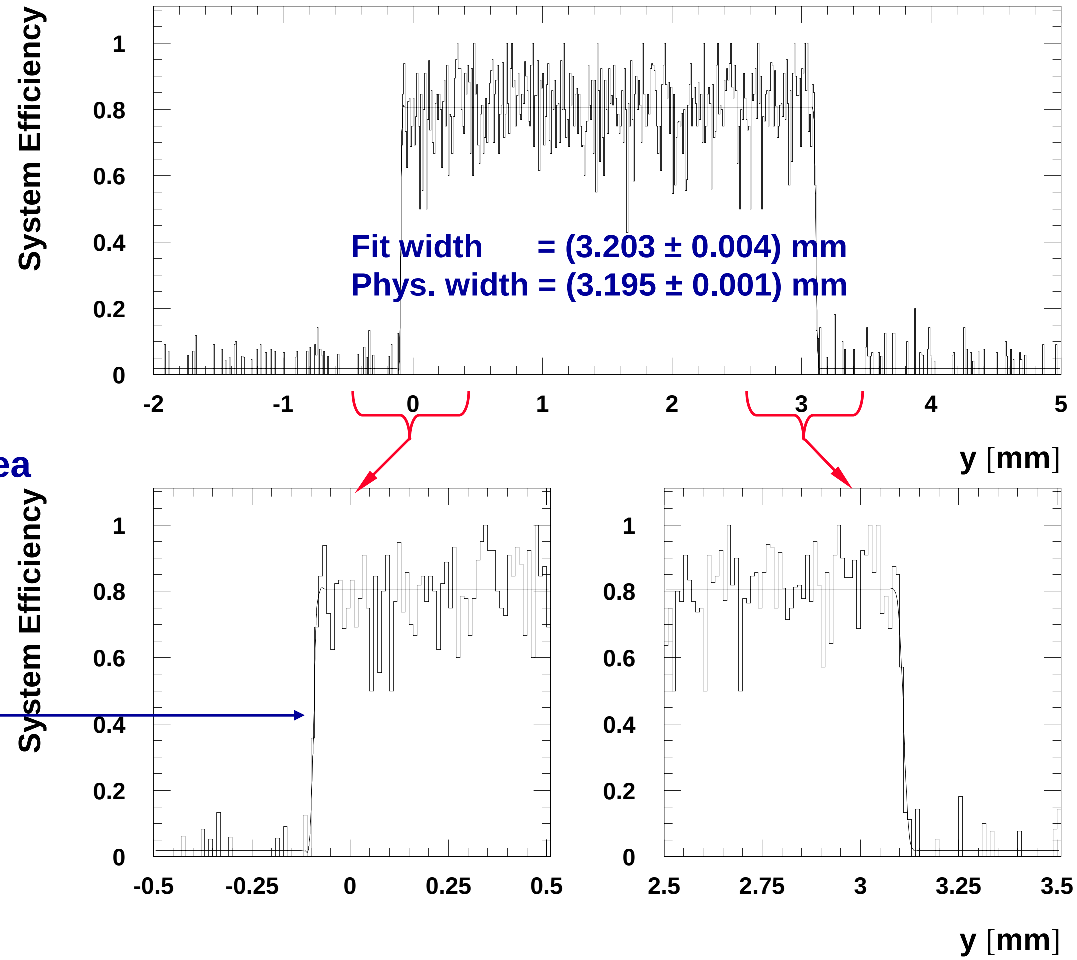
With 6 μm 13 keV X-rays



Electrodes
~ 1.8% of total area

10 – 90 % signal
transition = (6 ± 2) μm

With high energy particle tracks



Running Scenario

Scenario Physics:	**1** low |t| elastic, σ_{tot}, min. bias, soft diffraction	**2** large |t| elastic	**3** diffraction	**4** hard diffraction **(under study)**
β^* [m]	1540	18	1540	170
N of bunches	43	2808	156	2808
N of part. per bunch	0.3 x 10^{11}	1.15 x 10^{11}	(0.6 - 1.15) x 10^{11}	1.15 x 10^{11}
Half crossing angle [μrad]	0	160	0	150
Transv. norm. emitt. [μm rad]	1	3.75	1 - 3.75	3.75
RMS beam size at IP [μm]	454	95	454 - 880	270
RMS beam diverg. [μrad]	0.29	5.28	0.29 - 0.57	1.7
Peak luminosity [cm^{-2} s^{-1}]	1.6 x 10^{28}	3.6 x 10^{32}	2.4 x 10^{29}	~ 0.5 10^{32}

TOTEM Optics Conditions

$\mathcal{L}_{TOTEM} \sim 10^{28}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

TOTEM needs special/independent short runs at high-β^* (1540m) and low ε for precise measurement of the scattering angle down to few μrad

$\sigma(\theta^*) = \sqrt{\varepsilon / \beta^*} \sim 0.3\ \mu\mathrm{rad}$

Consequence: large beam size at IP

$\sigma^* = \sqrt{\varepsilon \beta^*} \sim 0.4\ \mathrm{mm}$

$$y = L_y\, \theta_y^* + v_y\, y^* \qquad L = (\beta\beta^*)^{1/2} \sin \mu(s)$$

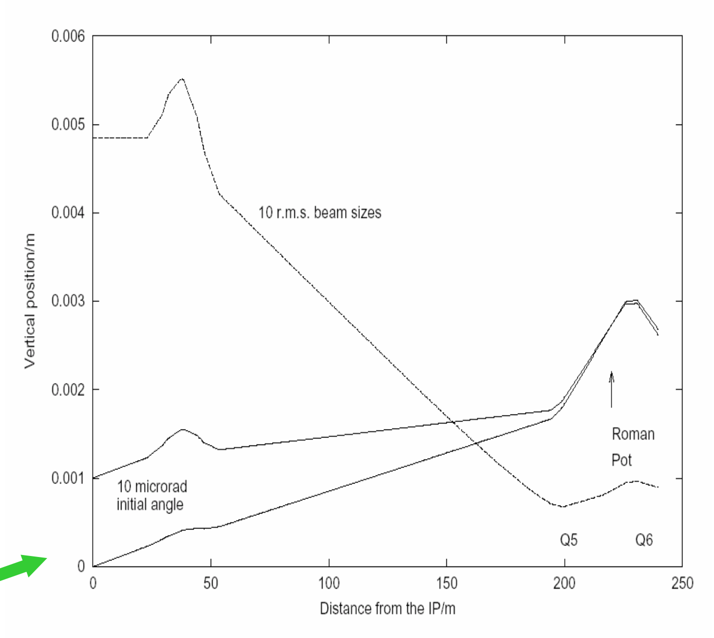
$$x = L_x\, \theta_x^* + v_x\, x^* + \xi D_x \qquad v = (\beta/\beta^*)^{1/2} \cos \mu(s)$$

At the detector: Maximize L and minimize v

- parallel to point focussing (v=0) → unique position-angle relation

- Maximize L_{eff} → sizeable distance to the beam center(~1mm)

Reduced number of bunches (43 and 156) to avoid interactions further downstream

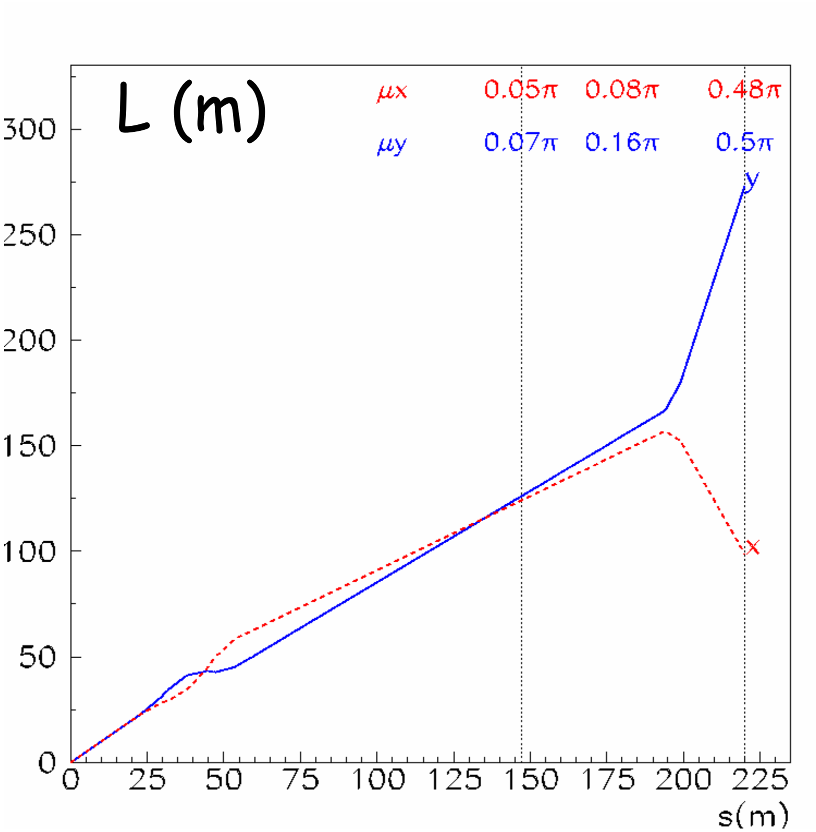


Trajectories of protons scattered at the same angle but at different vertex locations

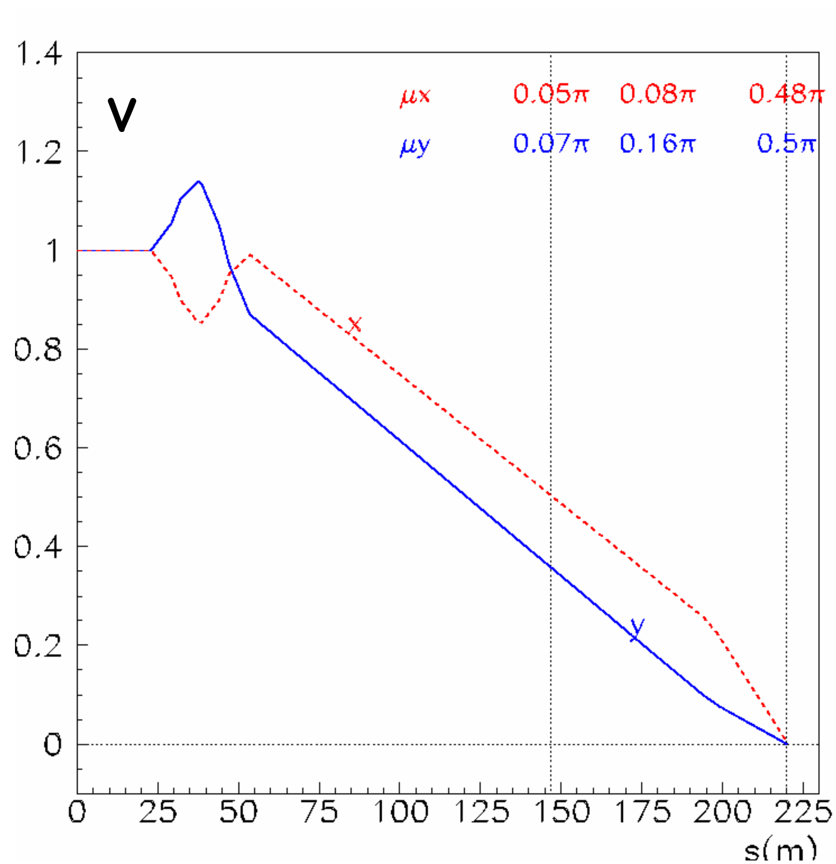
High β optics (1540 m): lattice functions

$$v = (\beta/\beta^*)^{1/2} \cos \mu(s)$$

$$L = (\beta\beta^*)^{1/2} \sin \mu(s)$$

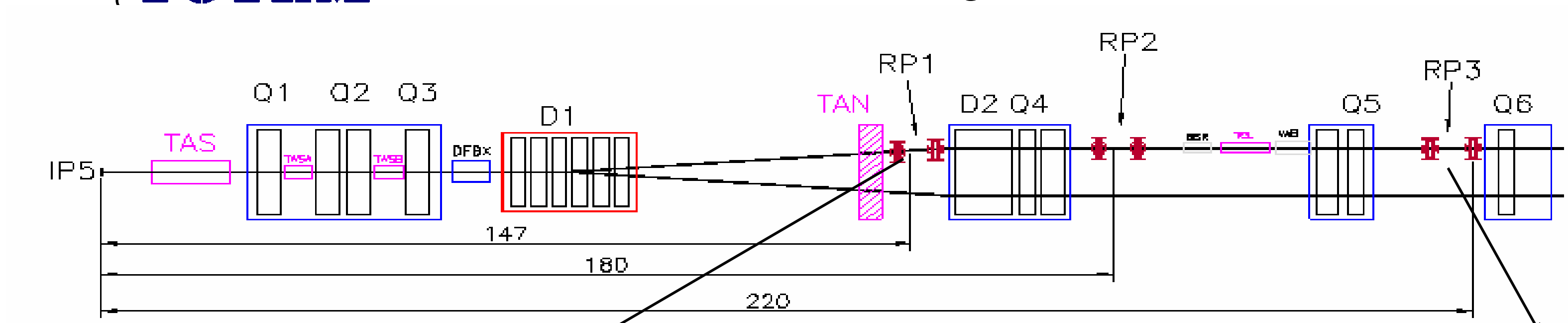


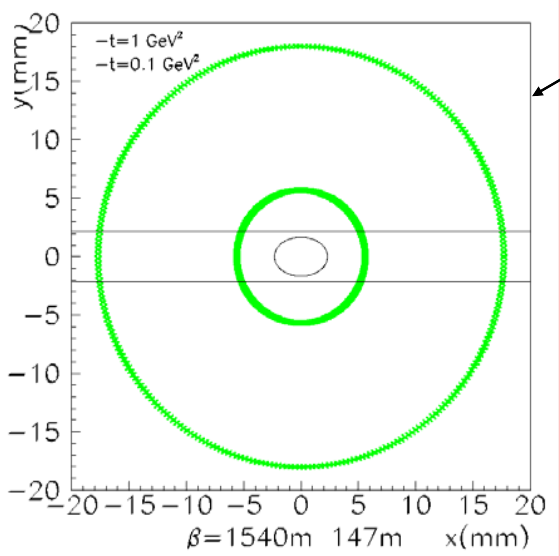
Parallel to point focusing in both projections



$$y = L_y\, \theta_y^* + v_y\, y^*$$

$$x = L_x\, \theta_x^* + v_x\, x^* + \xi\, D_x$$

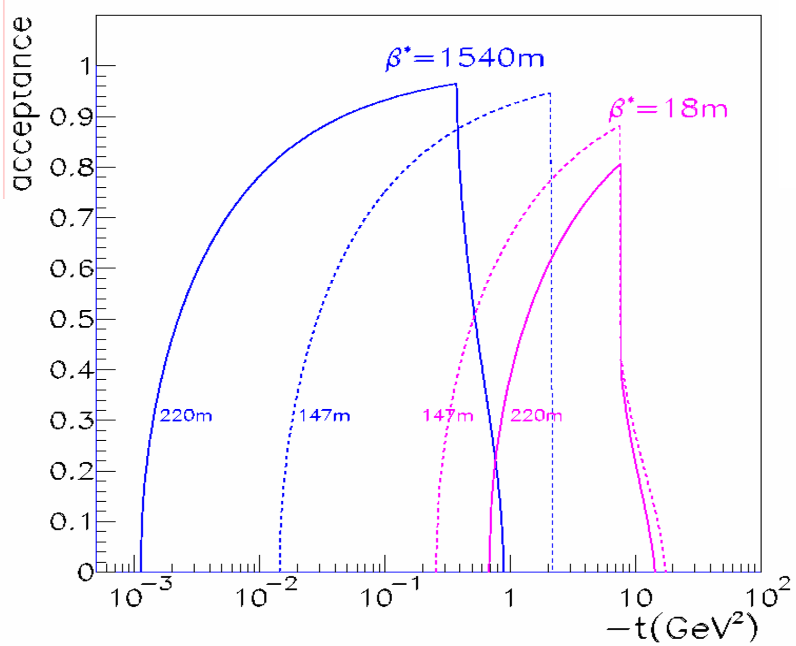


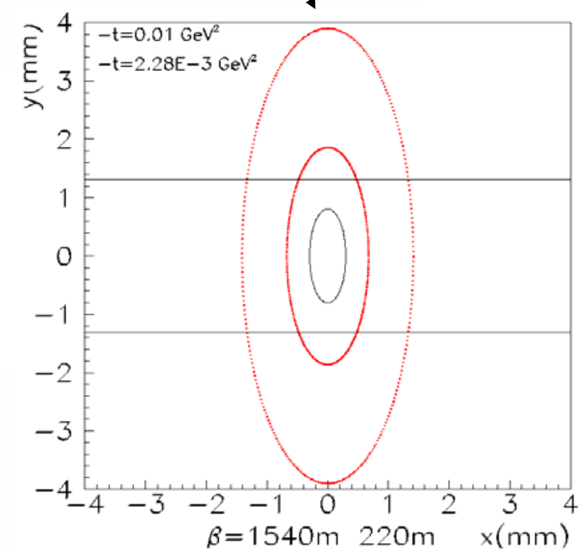


Elastic Scattering

β* = 1540 m

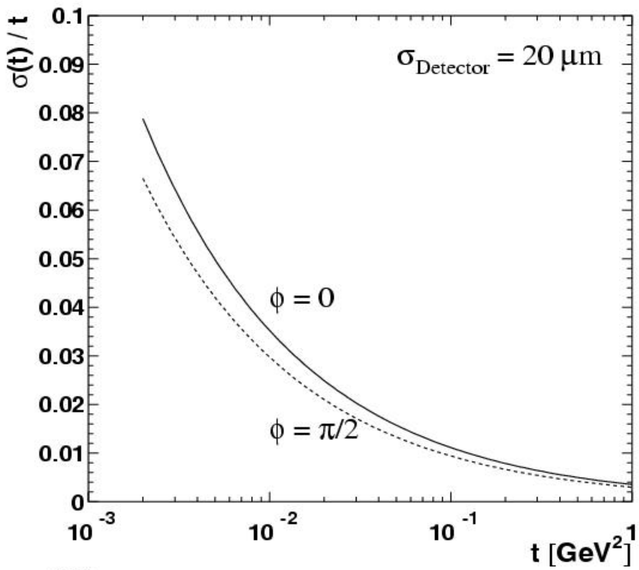
acceptance

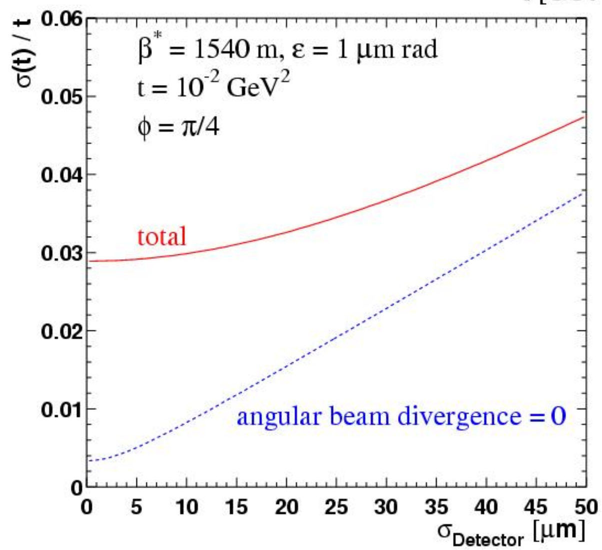




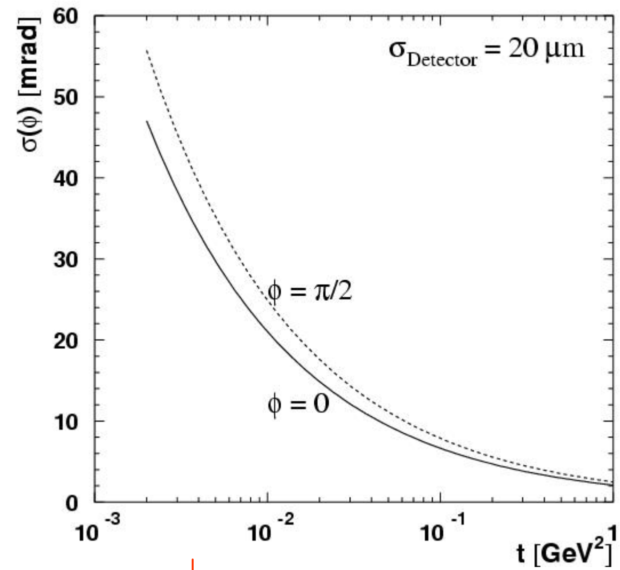
Elastic Scattering: Resolution

t-resolution (2-arm measurement)



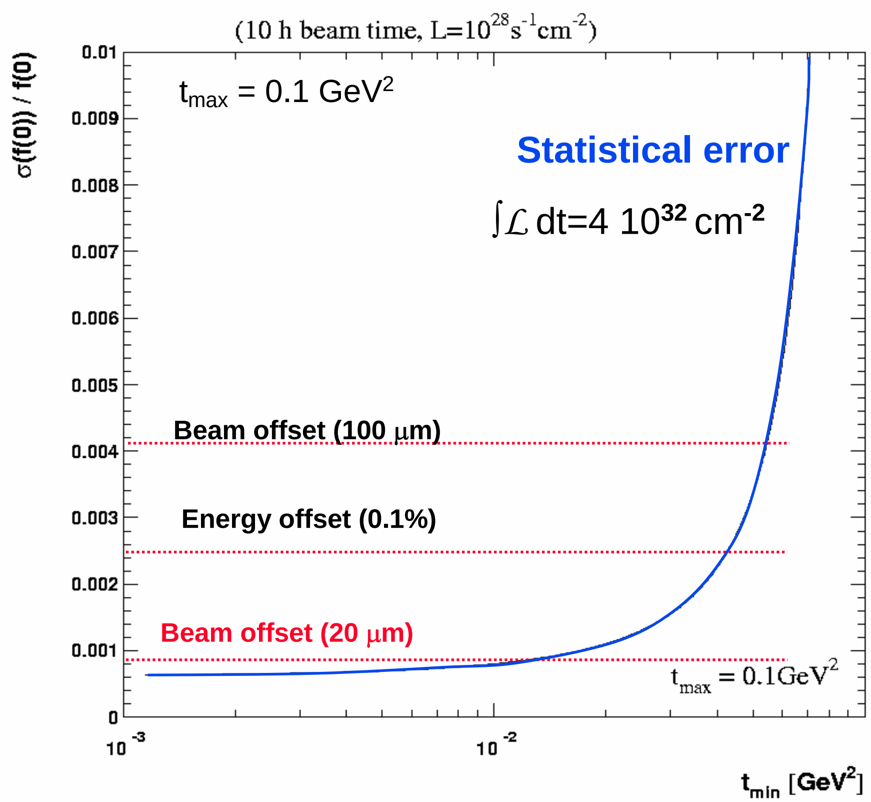


φ-resolution (1-arm measurement)



Test collinearity of particles in the 2 arms
⇒ Background reduction.

Elastic Cross section (t=0)



		Extrapolation Uncertainty
Beam divergence	10%	-0.05%
Energy offset	0.1%	-0.25%
	0.05%	-0.1%
Beam/ detector offset	100μm	-0.32/-0.41 %
	20μm	-0.06/-0.08 %
Crossing angle	0.2μrad	-0.08/-0.1%
Theoretical uncertainty (model dependent)		~ 0.5%

Accuracy of σ_{tot}

1%

($\sigma_{inel.}$~80mb, $\sigma_{el.}$~30mb)

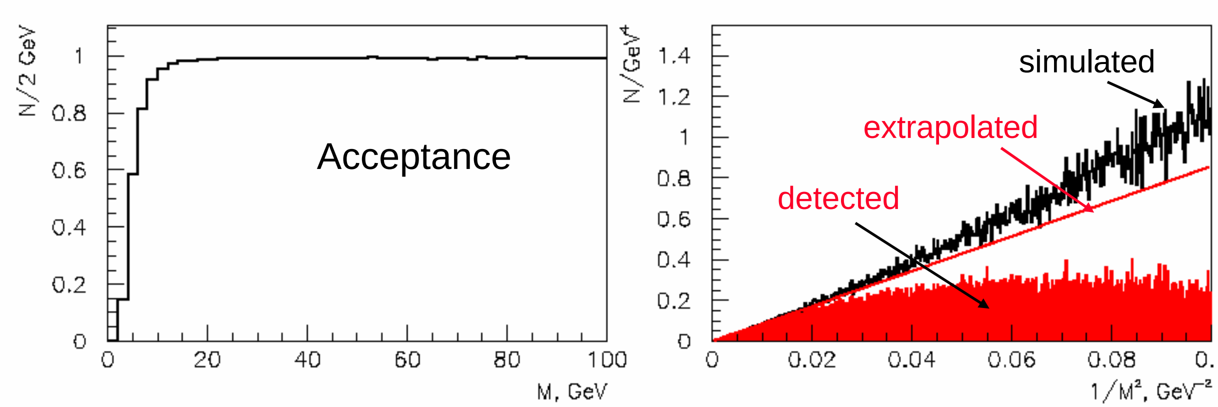
Trigger Losses (mb)

	σ(mb)	Double arm	Single arm	After Extrapolation
Minimum bias	58	0.3	0.06	0.06
Single diffractive	14	-	2.5	0.6
Double diffractive	7	2.8	0.3	0.1
Double Pomeron	1	-	-	0.02
Elastic Scattering	30	-	-	0.1

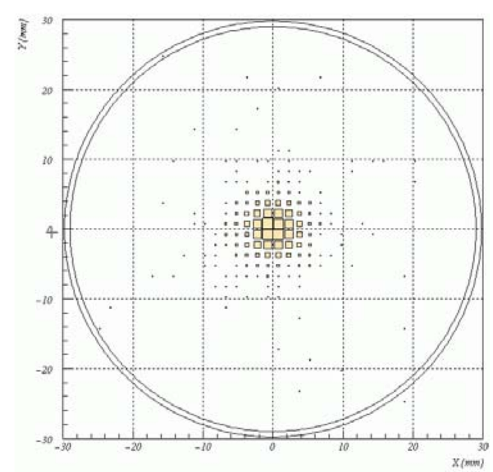
$$\frac{\Delta\sigma_{tot}}{\sigma_{tot}} \approx \sqrt{0.008^2 + 0.005^2} \approx 0.01$$

Inelastic error   t=0 extrapol. error

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



Vertex extrapolation



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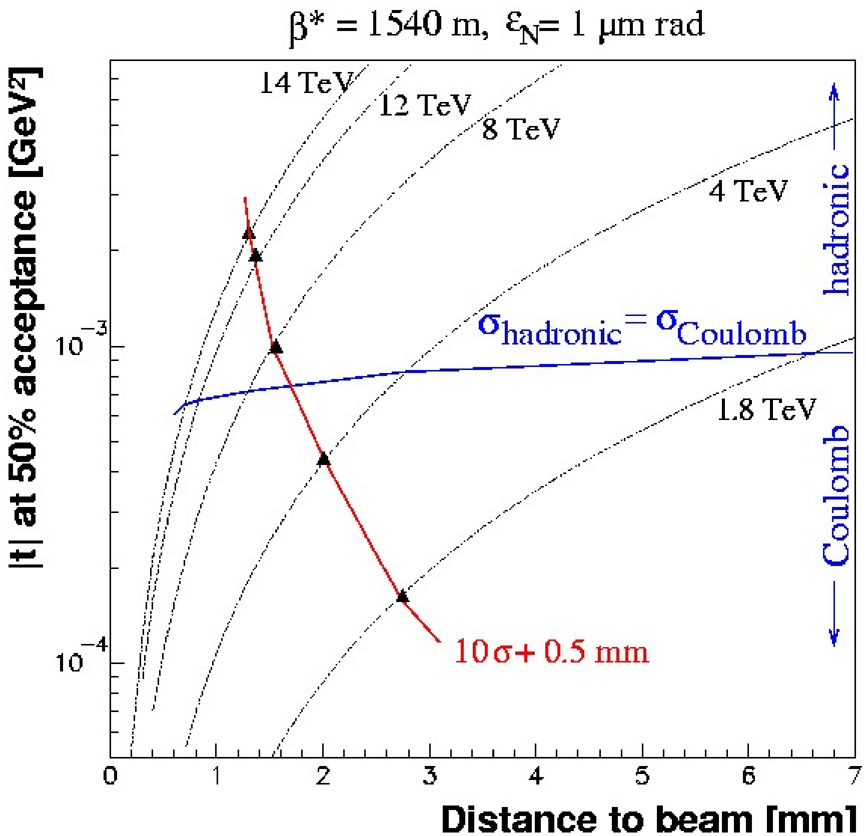
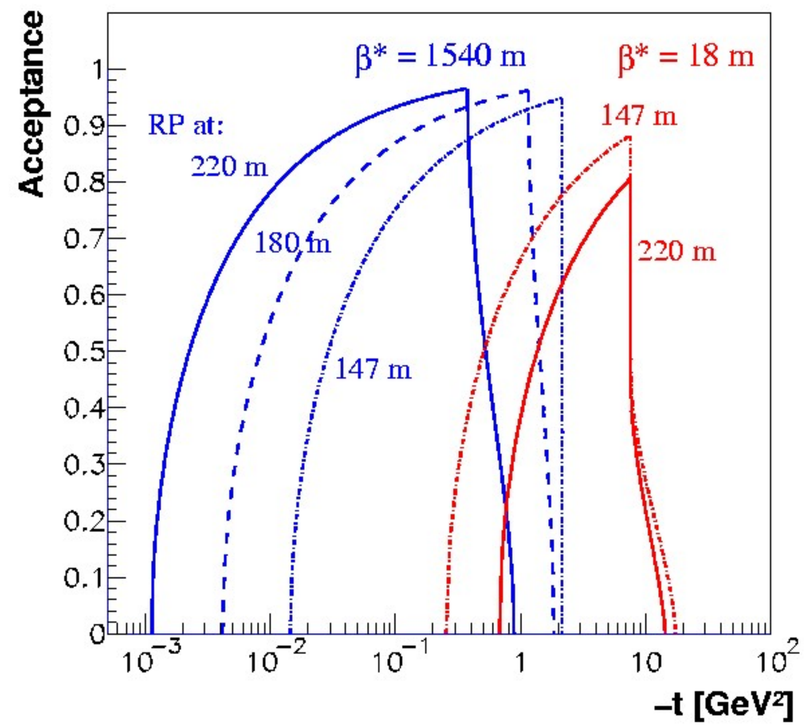
Elastic Scattering: -t acceptance



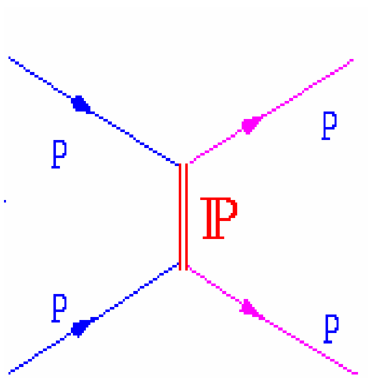


Run at lower energy $\sqrt{s}$ < 14 TeV (or move the detectors closer than 10 σ + 0.5 mm) :

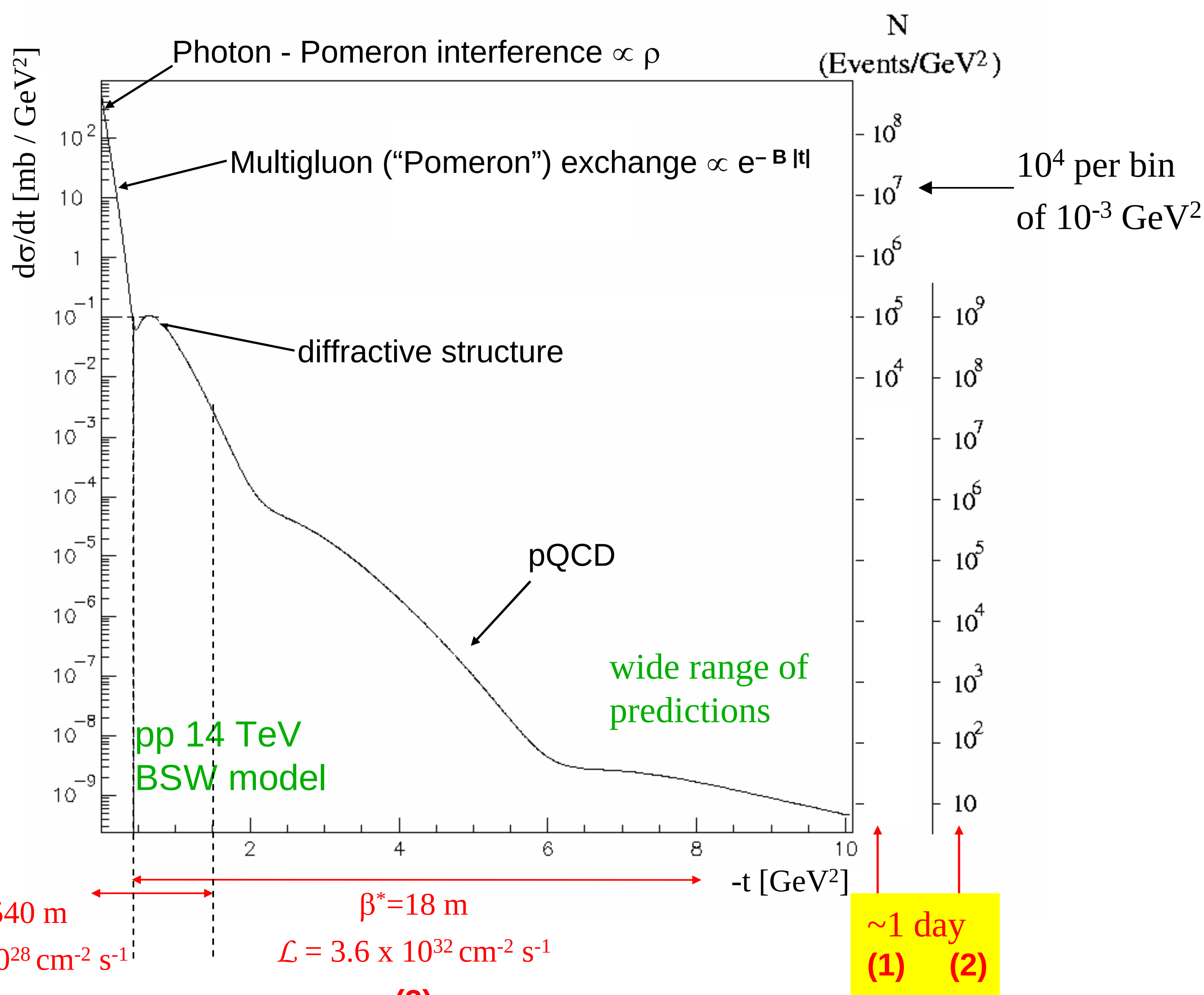
$|t| = 2\times10^{-4} \div 2\times10^{-3}$ GeV^2 ⟹ **Coulomb region, Interference, ρ measurement, B slope**

Large |t| $|t| = 1 \div 10$ GeV^2 β^* =18,170 m

Elastic Scattering Cross-Section



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



(1) **(2)**

Running Scenarios

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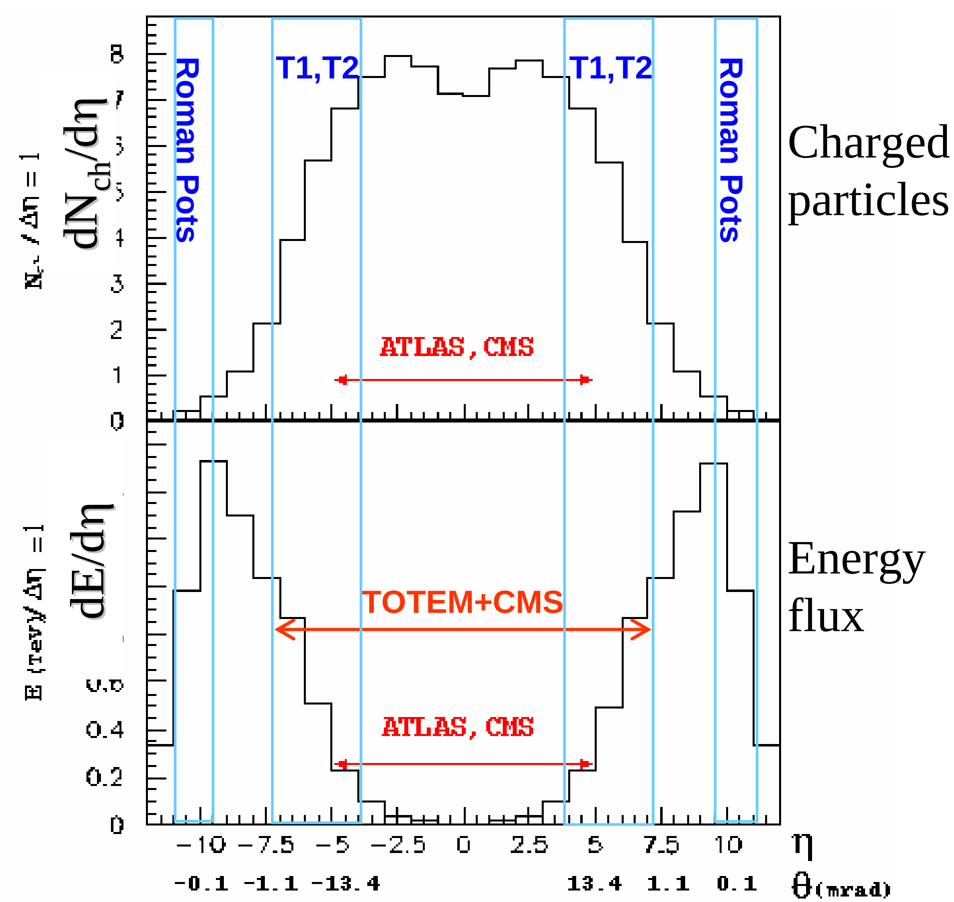
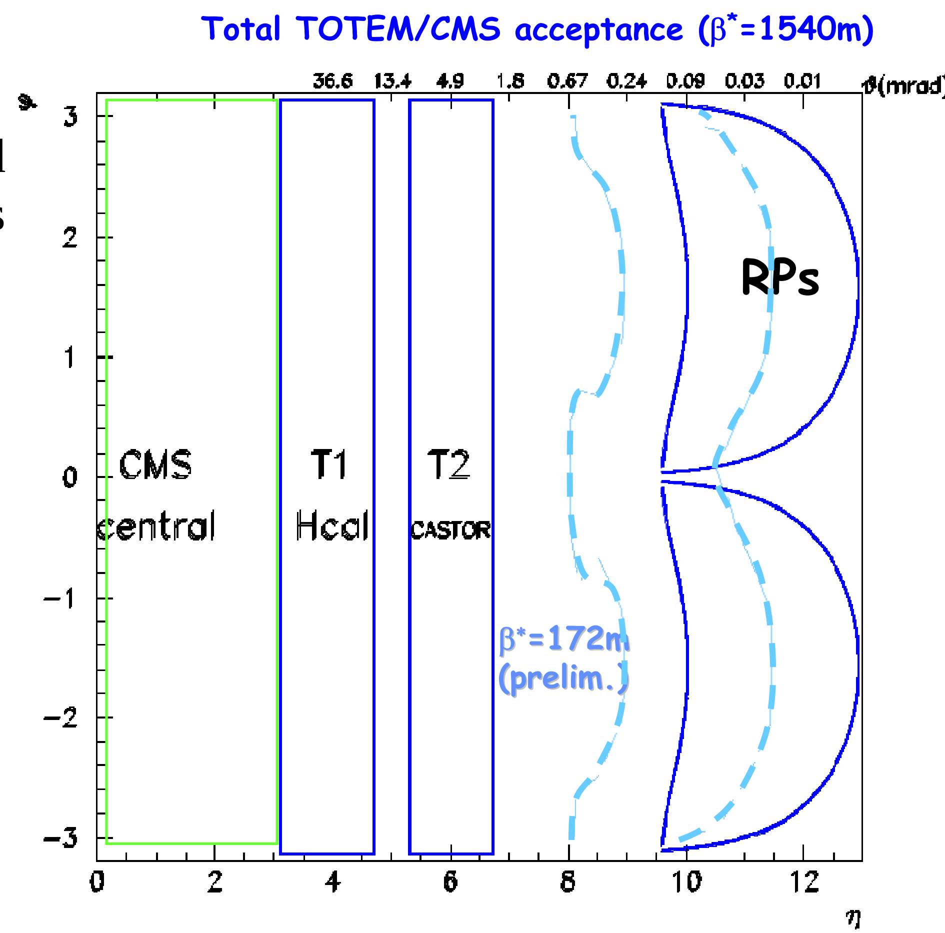
Peak luminosity [$cm^{-2} s^{-1}$]	1.6×10^{28}	3.6×10^{32}	2.4×10^{29}	$\sim 0.5\ 10^{32}$

CMS + TOTEM: Acceptance

CMS+TOTEM: largest acceptance detector ever built at a hadron collider

> 90 % of all diffractive protons are detected
10 million min. bias events, including all diffractive processes, in a 1 day run with $\beta^* = 1540$ m





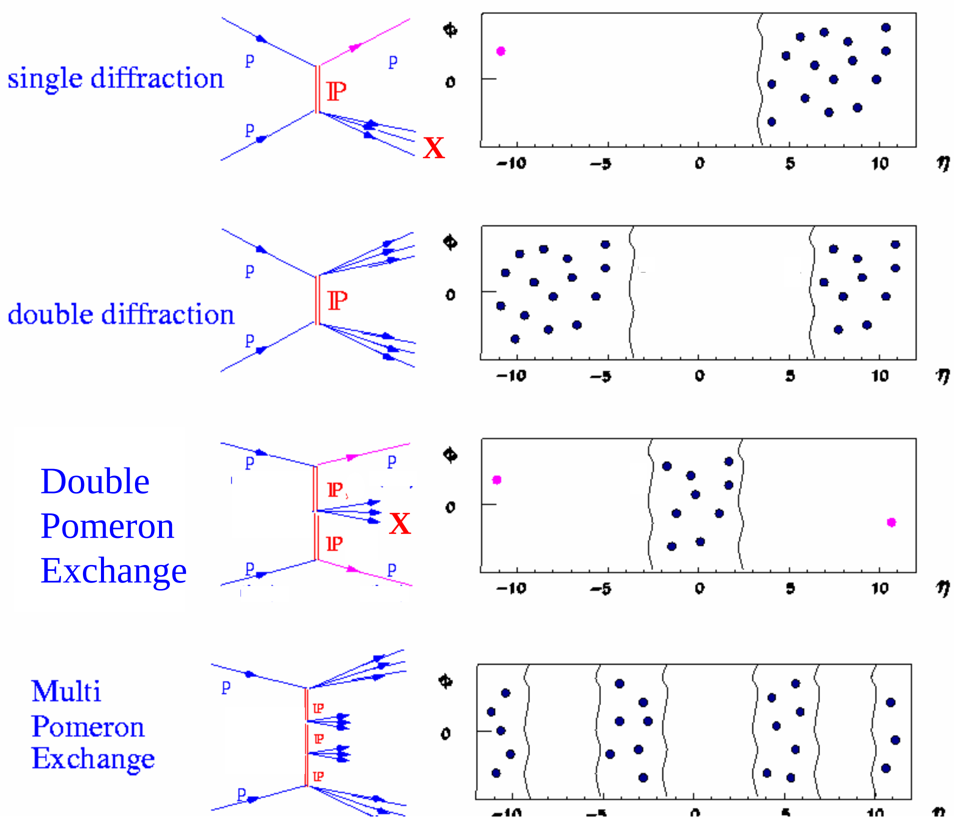
CMS/TOTEM Physics

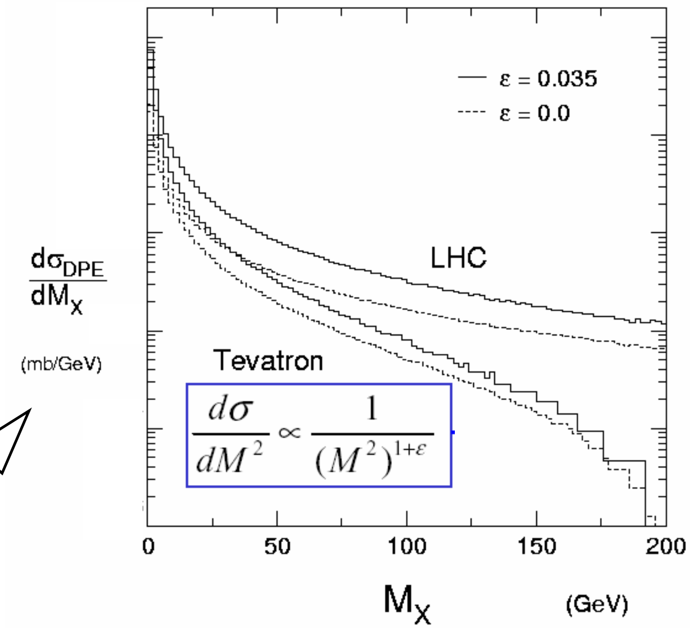
CMS / TOTEM detector ideal for study of diffractive and forward physics

- Soft and hard diffraction in Single and Double Pomeron Exchange production of jets, W, J/ψ, heavy flavours, hard photons
- Excellent proton measurement: gap survival
- Double Pomeron exchange as a gluon factory
  - Production of low mass systems (SUSY, χ ,D-Y,jet-jet, ...)
  - Glue balls, …
  - Higgs production ???
- Structure functions (parton saturation) with and without detected protons
- Forward physics: DCC, particle and energy flow
- $\gamma\gamma$ physics

TOTEM+CMS Physics: Diffractive Events

Measure > 90% of leading protons with RPs and diffractive system 'X' with T1, T2 and CMS.



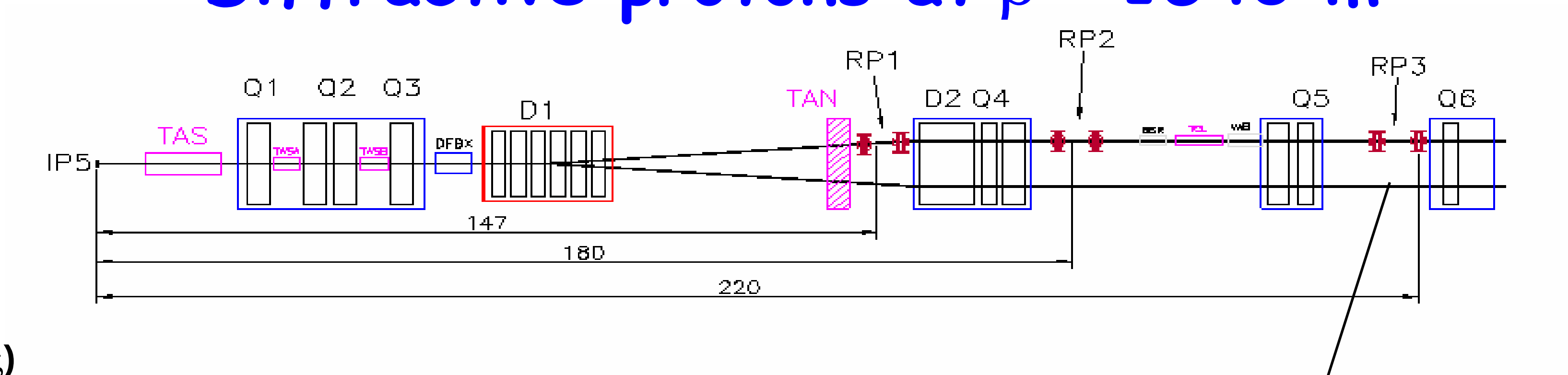


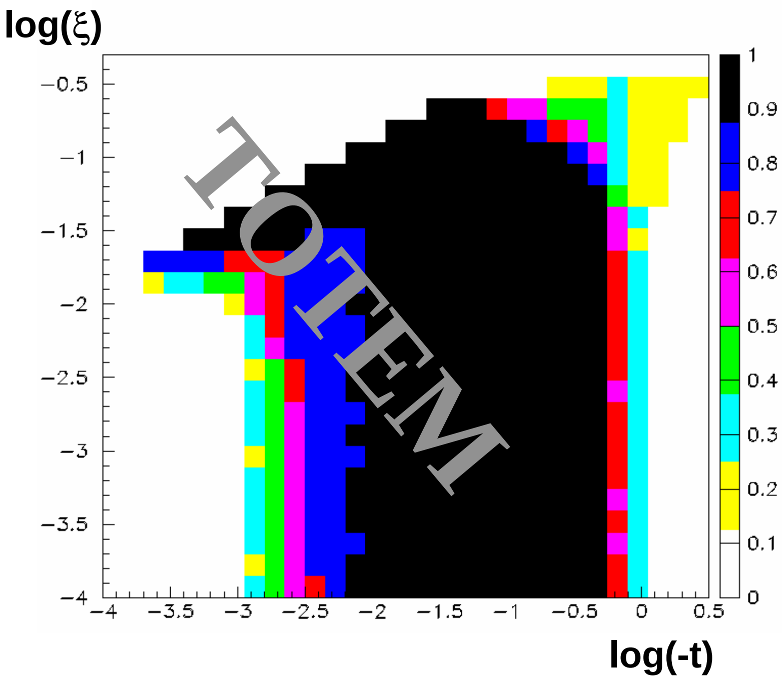
-Triggered by leading proton and seen in CMS

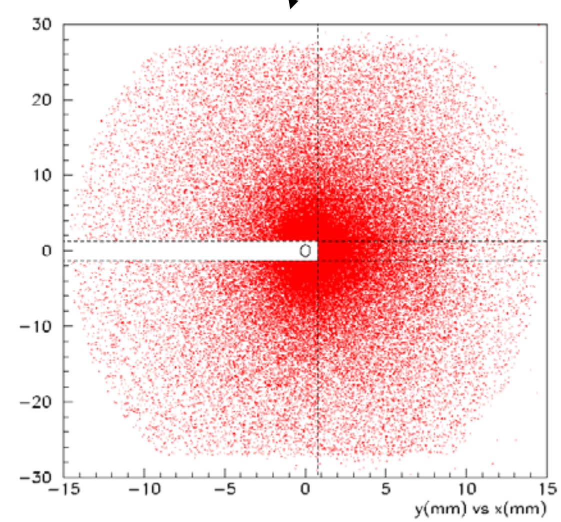
-Central production of states X:

X = χ_c, χ_b, Higgs, dijets,
SUSY particles, ...

Diffractive protons at β^*=1540 m





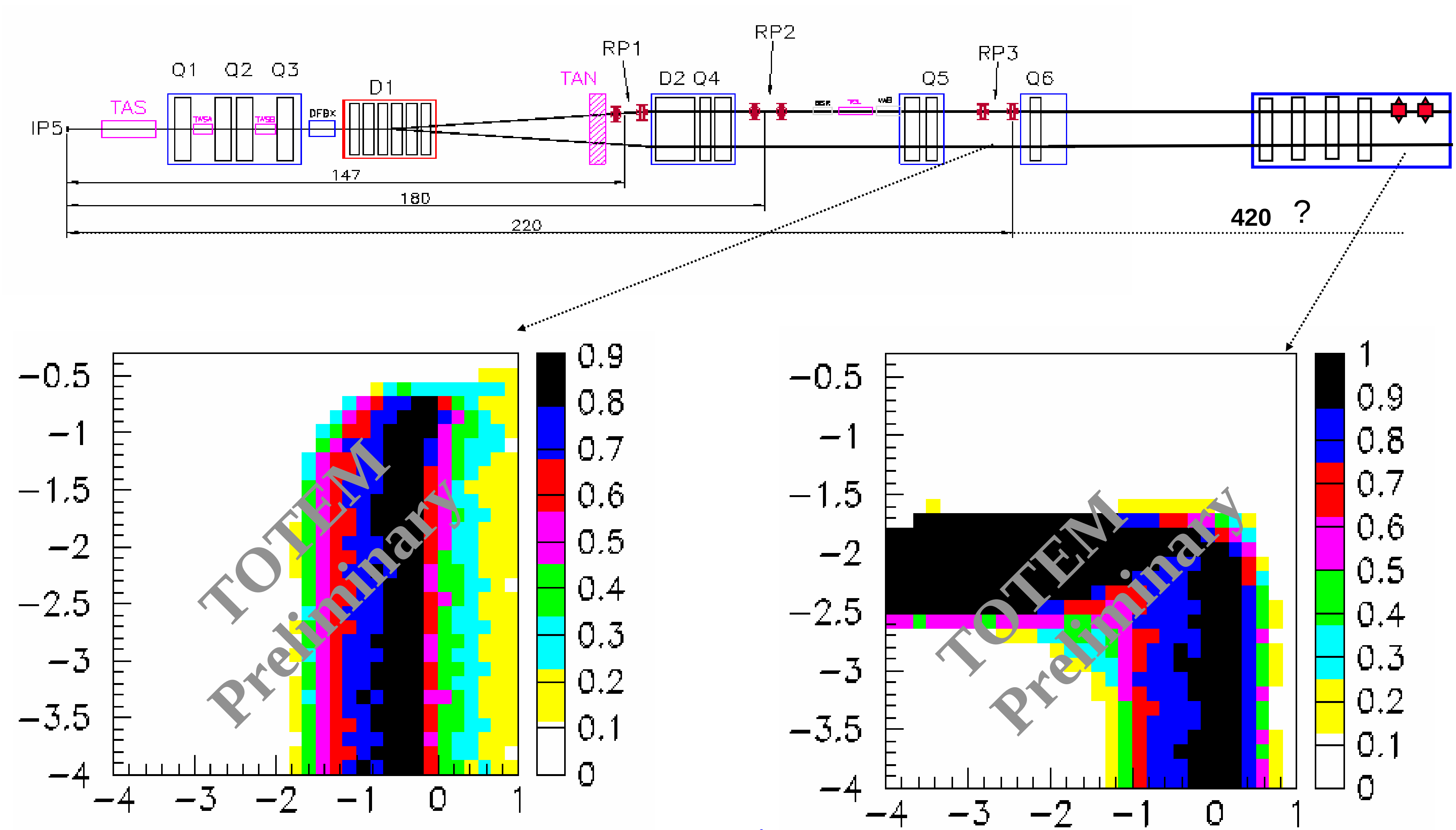


Diffractive protons are observed in a large ξ-t range> 90% are detected

$-t > 2.5\ 10^{-3}$ GeV^2 $10^{-8} < \xi < 0.1$

ξ resolution ~ few ‰

Diffractive protons at β^*=172 m (under study)



log(ξ) vs log(-t)

ξ resolution ~ 4 10^{-4}
(preliminary)

log(ξ) vs log(-t)

V.Avati/TOTEM

TOTEM+CMS Runs

Standalone running:

forseen only for elastic scattering and total cross-section

Common running:

DAQ and Trigger must be CMS-compatible
(hardware and software)

TOTEM can act as a CMS subdetector

TOTEM can trigger CMS:
Trigger from the Roman Pots must arrive at CMS within
the CMS trigger latency:
OK for the Pot at 220 m

Pots farther than 220 m from IP (none foreseen yet) cannot trigger!

Summary: physics

- Measure total cross-section σ_{tot} with a precision of 1 %
  $\mathcal{L} \sim 10^{28}$ cm^{-2} s^{-1} with $\beta^* = 1540$ m
- Measure elastic scattering in the range $10^{-3} < -t < 8$ GeV^2
- With the same data study of soft diffraction and forward physics:
  ~ 10^7 single diffractive events,~ 10^6 double Pomeron events
- With $\beta^* = 1540$ m optics at $\mathcal{L} = 2 \times 10^{29}$ cm^{-2} s^{-1} :
  semi-hard diffraction (p_T > 10 GeV)
- With $\beta^* = 170$ m optics (under study) at $\mathcal{L} \sim 0.5\ 10^{32}$ cm^{-2} s^{-1}:
  hard diffraction and DPE
- Study of rare events (Higgs, Supersymmetry,….) with $\beta^* = 0.5$ m
  using eventually detectors in the cold region (420m)
- TOTEM and CMS will write a common physics LOI in 2005

Summary: detectors

RP test in the SPS has been successful : TOTEM has gained experience in installing and operationg the system in the tunnel.

Final RP prototype ready at the end of 2005.

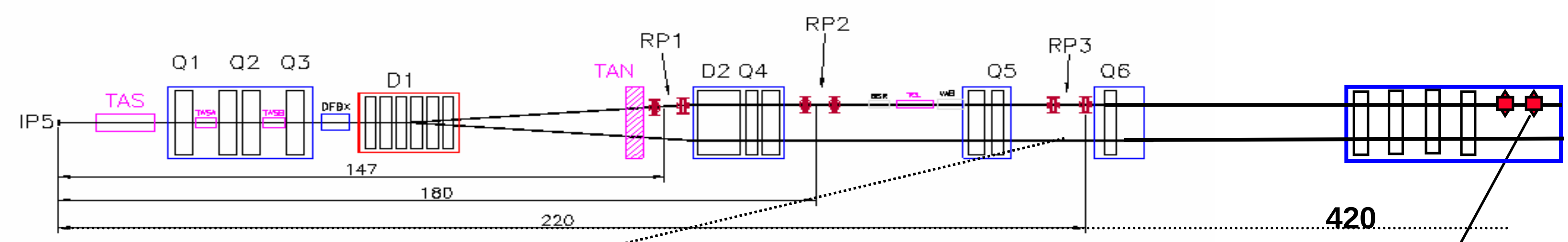
Installation in the LHC tunnel mid2006

Forward proton detectors: both technologies (Edgeless Planar & Planar 3D) are chosen. Full production & test in 2006.

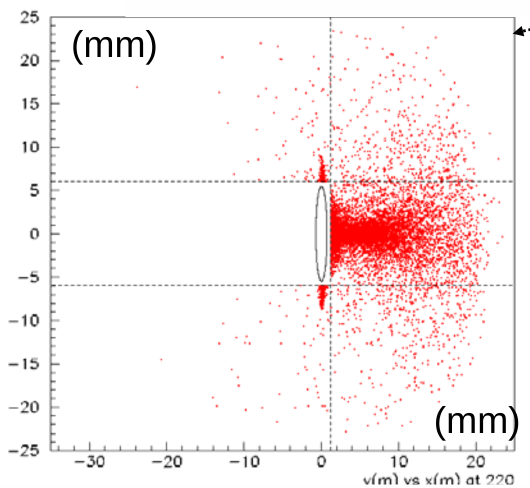
T1 telescope: ready for production. Integration test in CMS during Sept. 2005.

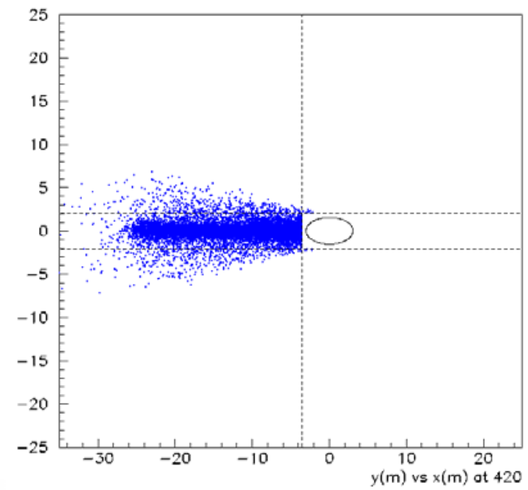
T2 telescope: production of a pre-series of 5 final detectors in 2005, full production in 2006

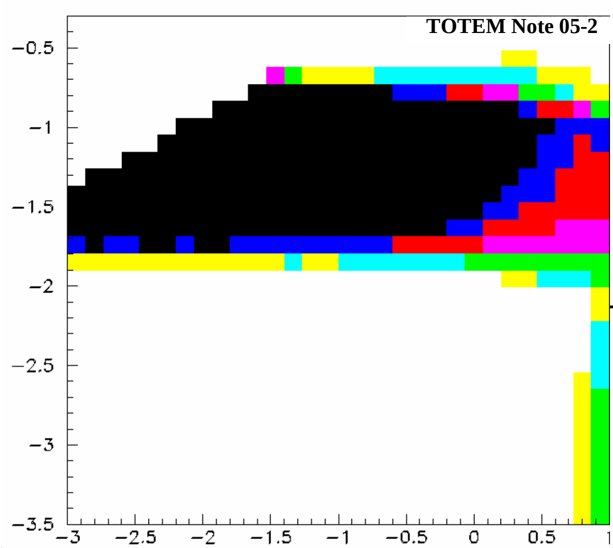
TOTEM

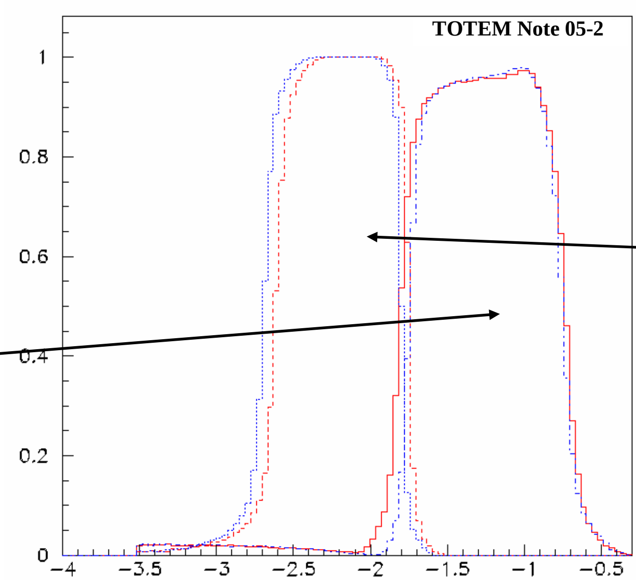


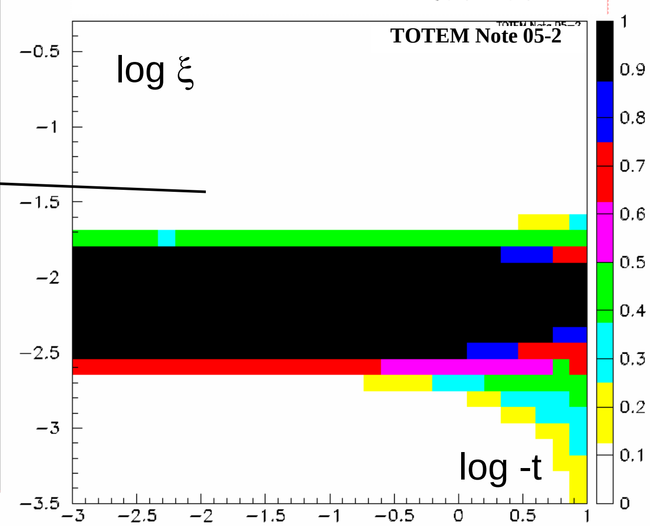
Diffractive proton detection at $\beta^* = 0.5$ m









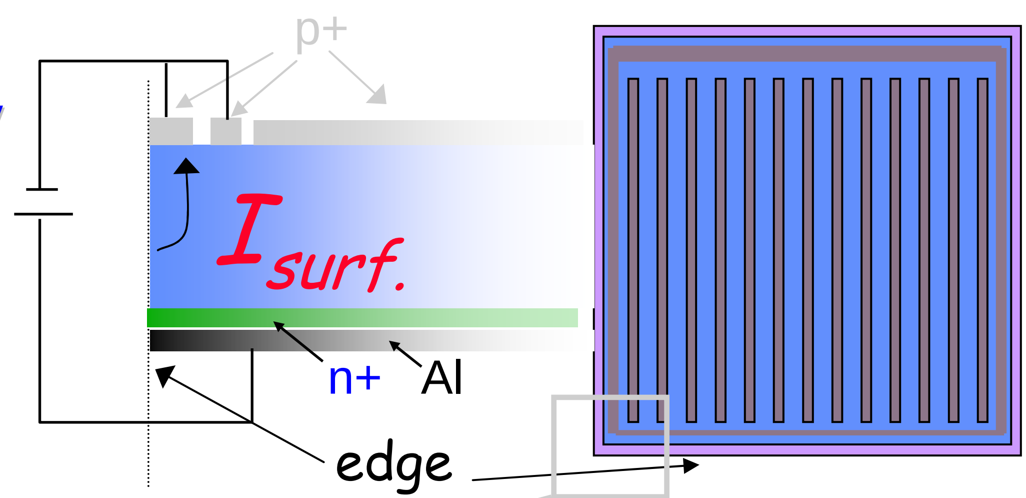


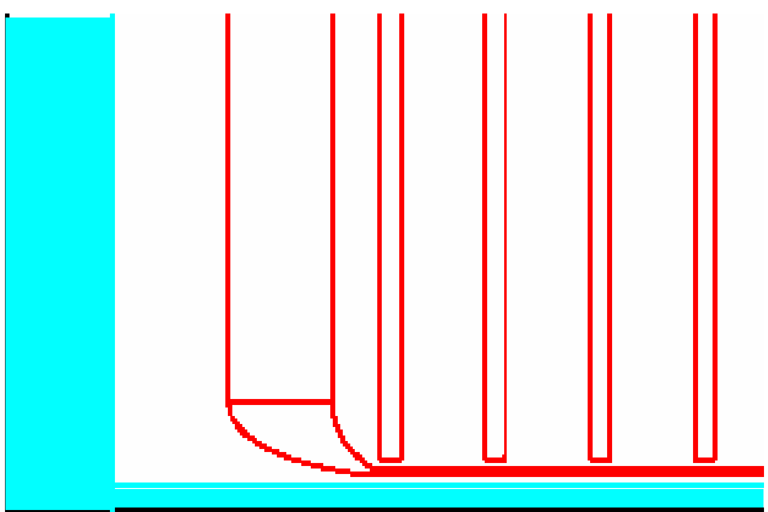
Current Terminating Structure on Microstrip detectors

(in collaboration with IOFFE PTI St. Petersburg/RIMST Moscow)

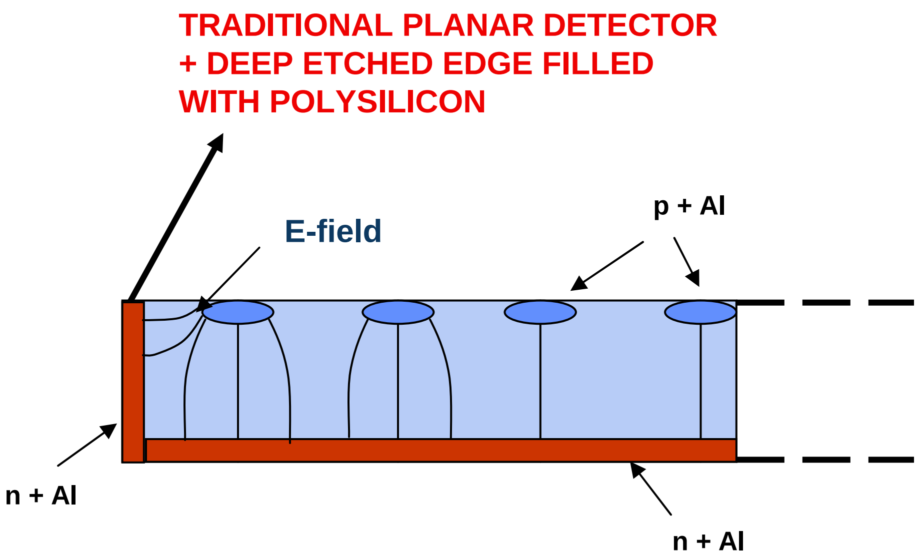
Objective:

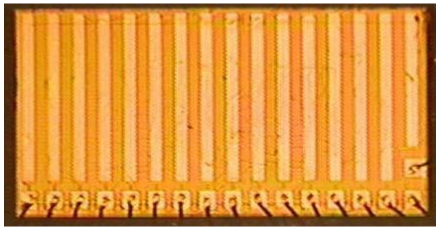
- **Use Standard Planar Technology**
- **Working Temperature >-20°C**
- **Reduction of the guard-ring structure to less than 100μm**





Planar with 3D edges

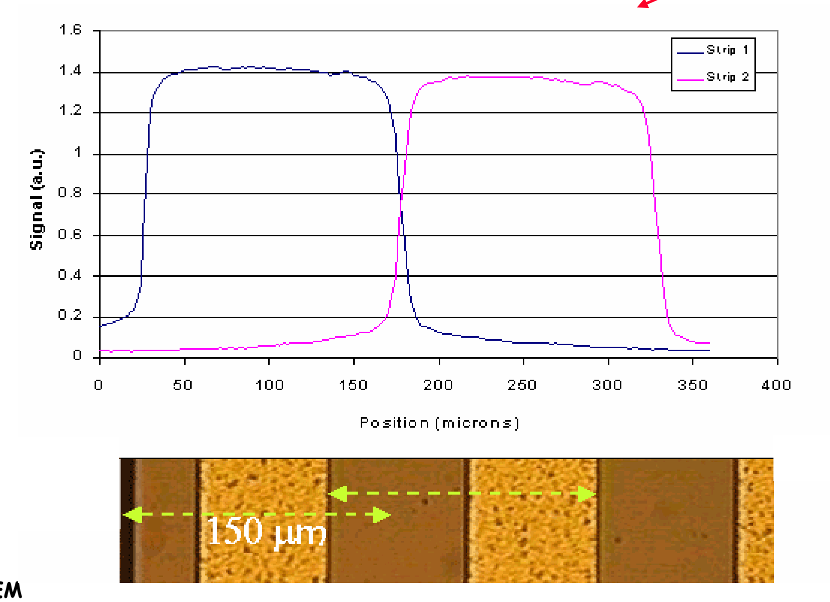


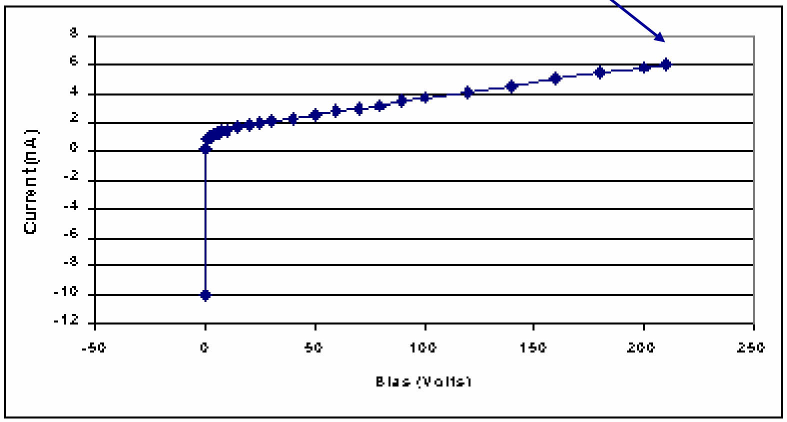


13keV 6 mm X-ray beam

Insensitive edge = 5 ± 2 μm

Leakage current = 6 nA at 200V

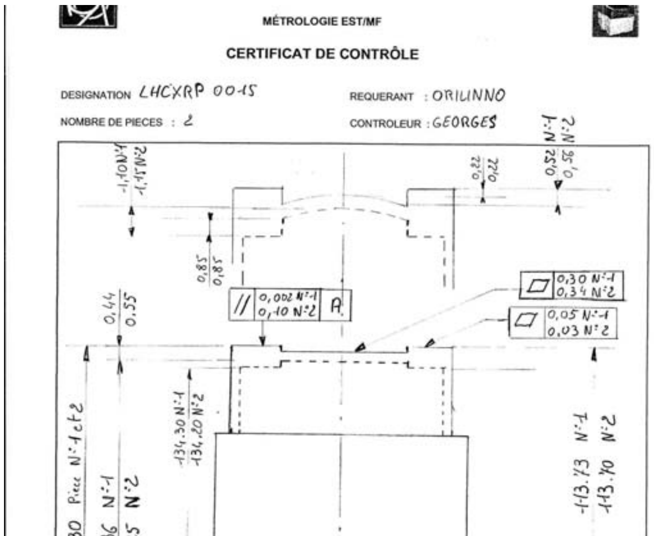


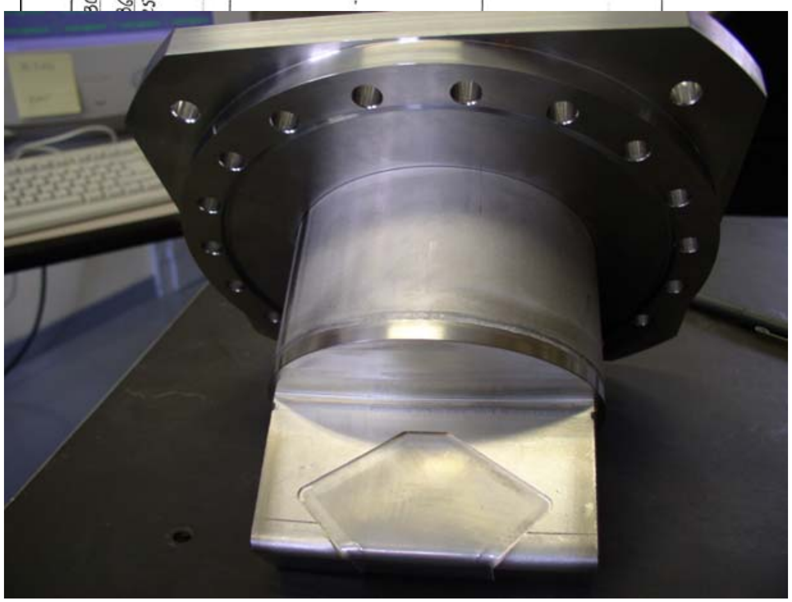


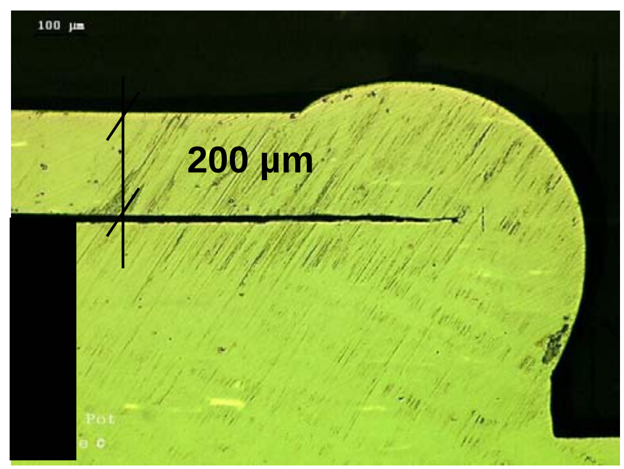
Mechanics: Thin window

R&D included in the TS/MME workpackage

- The shape and size of the window is defined
- Welding technology of the thin window is the main issue
- Brazing (used for the SPS) can be improved
- TIG welding gives better results, (i.e. planarity of 100microns)
- Laser and Electron-beam welding are considered for a new prototype in 2005







TIG weld cross section