TOTEM Physics

- σ tot
- elastic scattering
- diffraction (together with CMS)

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on behalf of the
TOTEM Collaboration
http://totem.web.cern.ch/Totem/

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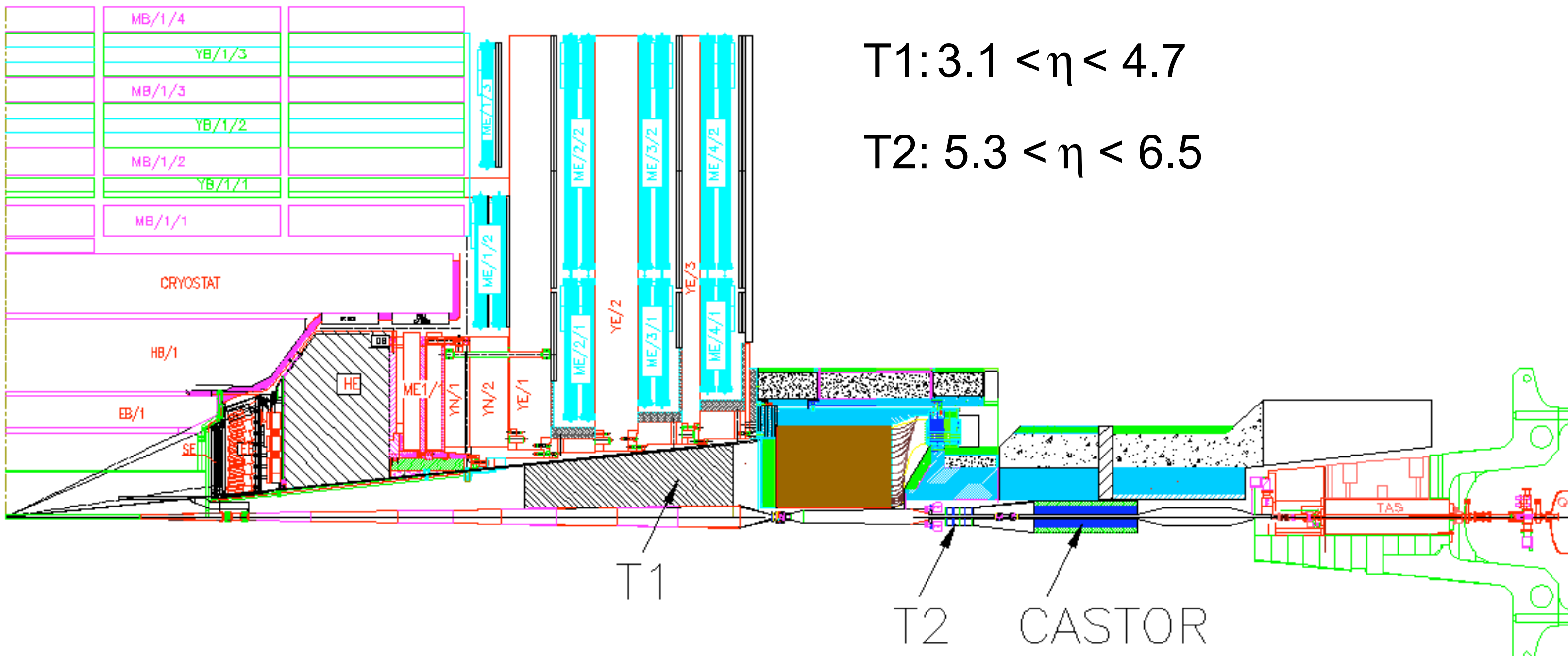
Penn State University
University Park, USA
Brunel University, Uxbridge, UK

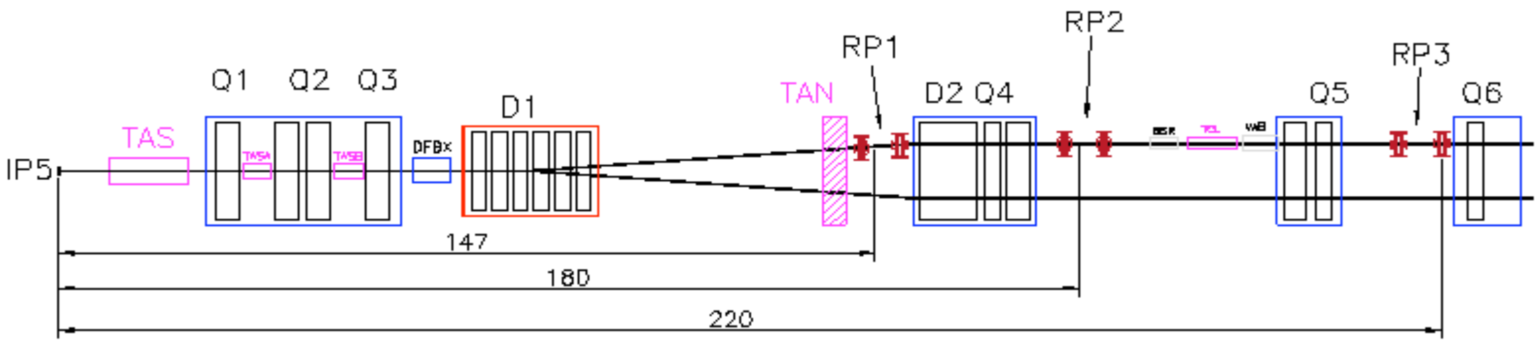
TOTEM TDR is fully approved by the LHCC and the Research Board

DIS 2005, Madison,Wisconsin,U.S.A.



T1: 3.1 < η < 4.7

T2: 5.3 < η < 6.5



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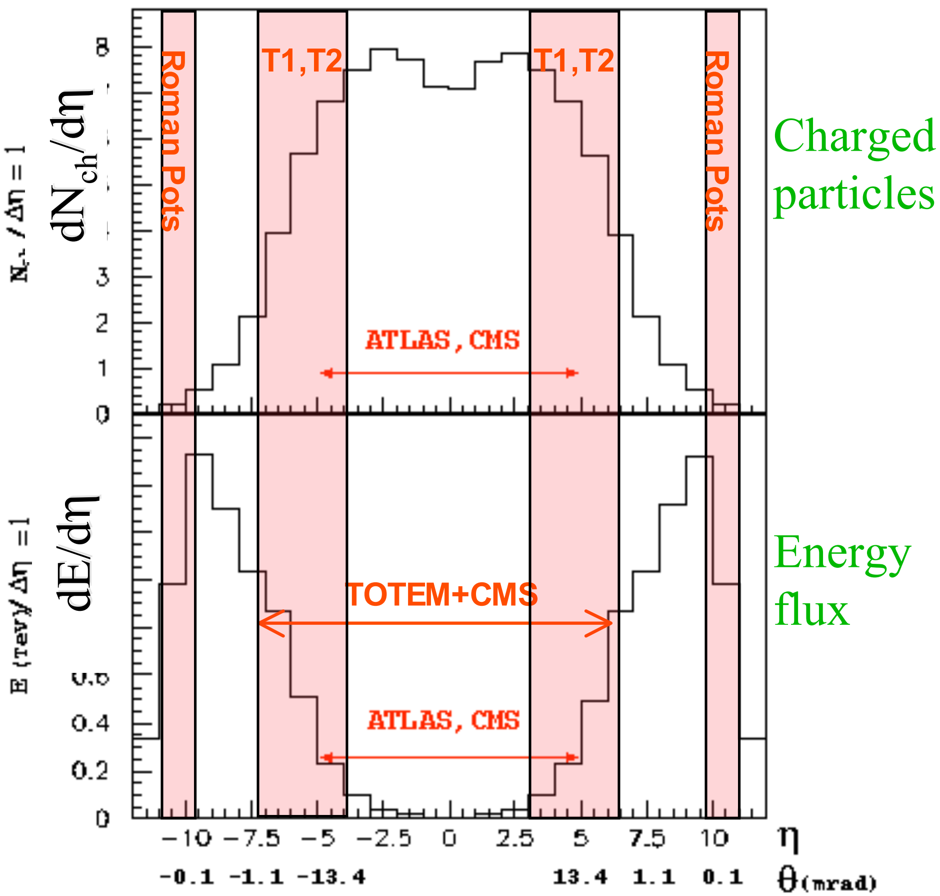
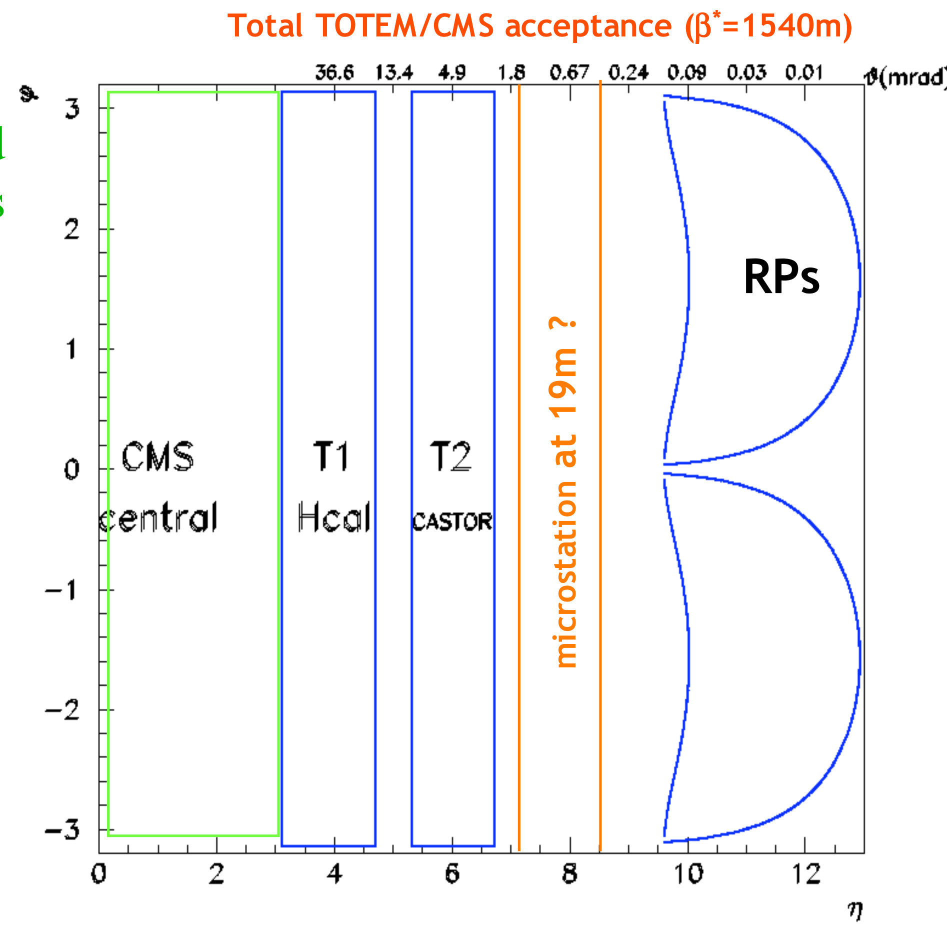
CMS + TOTEM: Acceptance

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 β* = 1540 m





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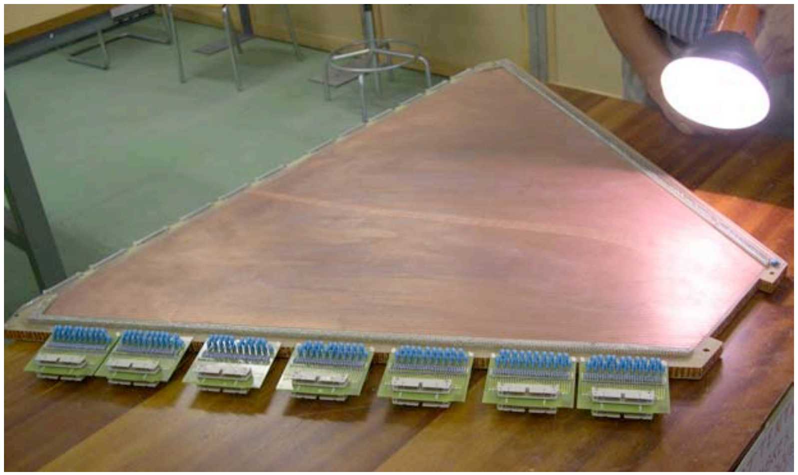
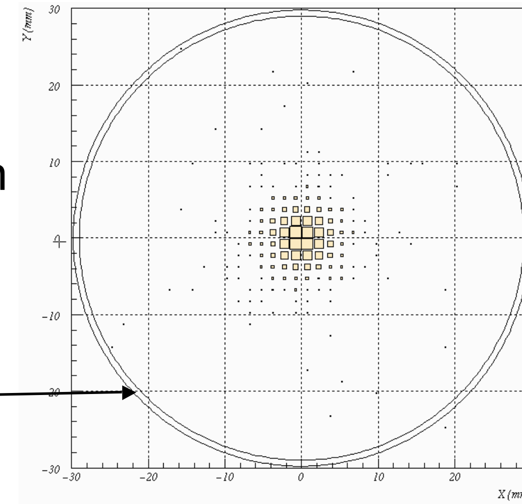
T1 telescope

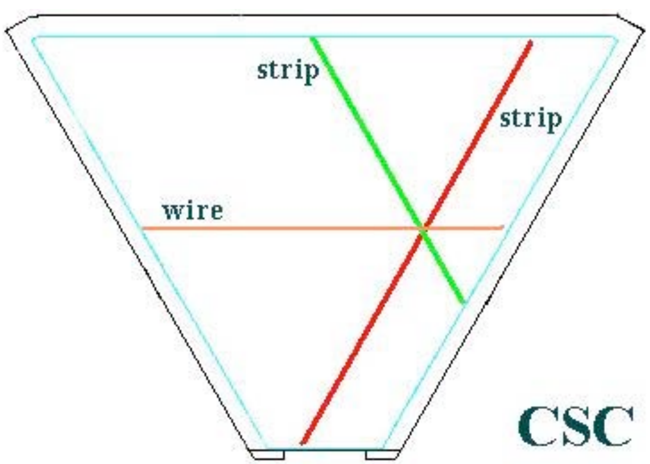
5 planes with measurement of three coordinates per plane



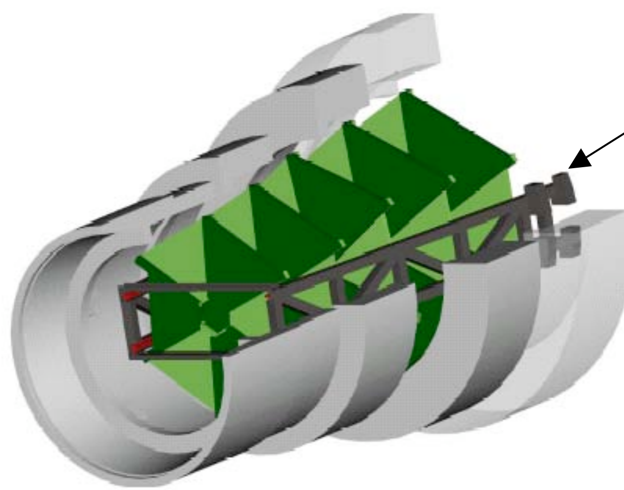
Vertex extrapolation
σ_x = 0.4 mm
σ_y = 0.6 mm

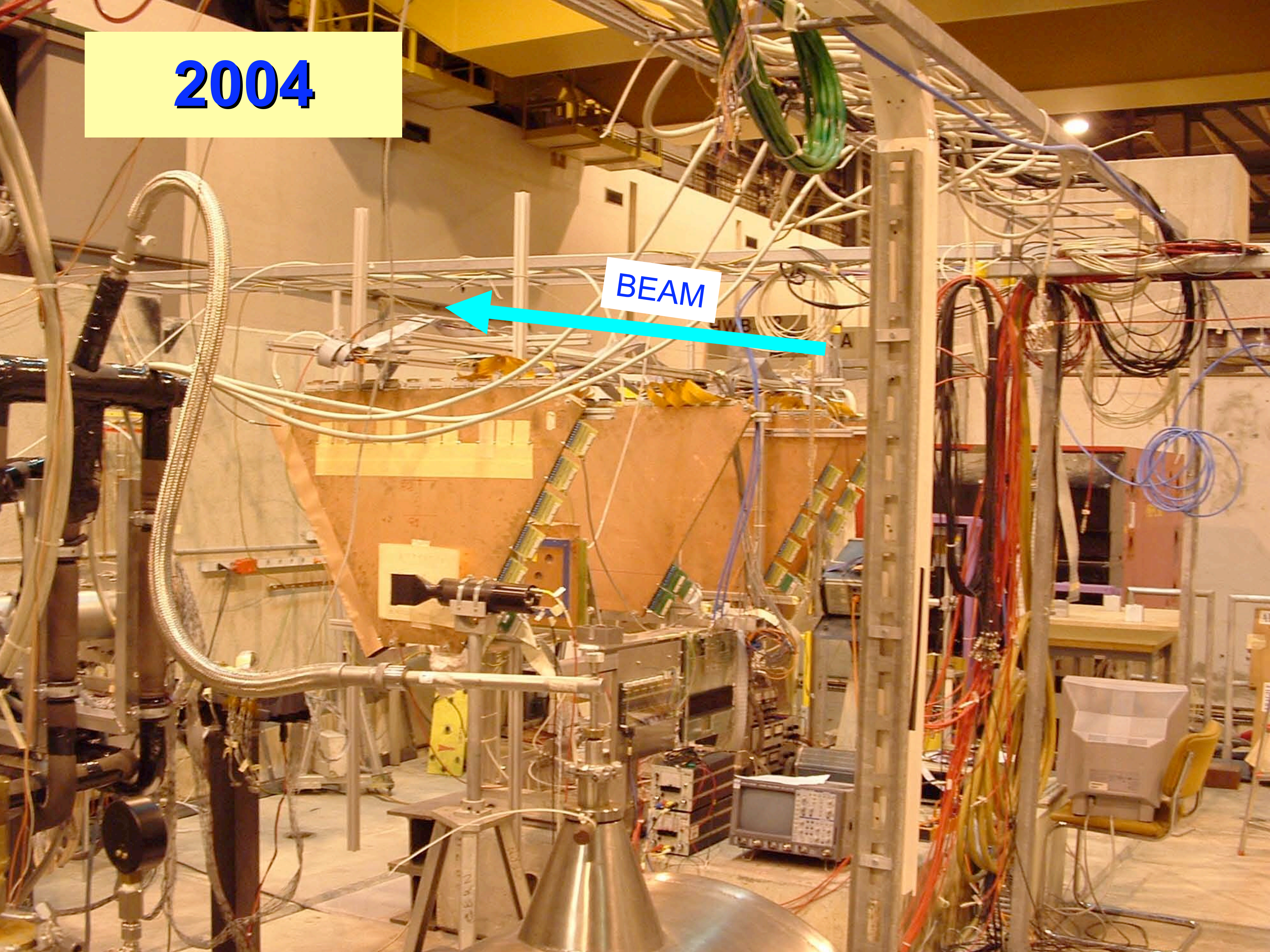
Beam tube





1 arm

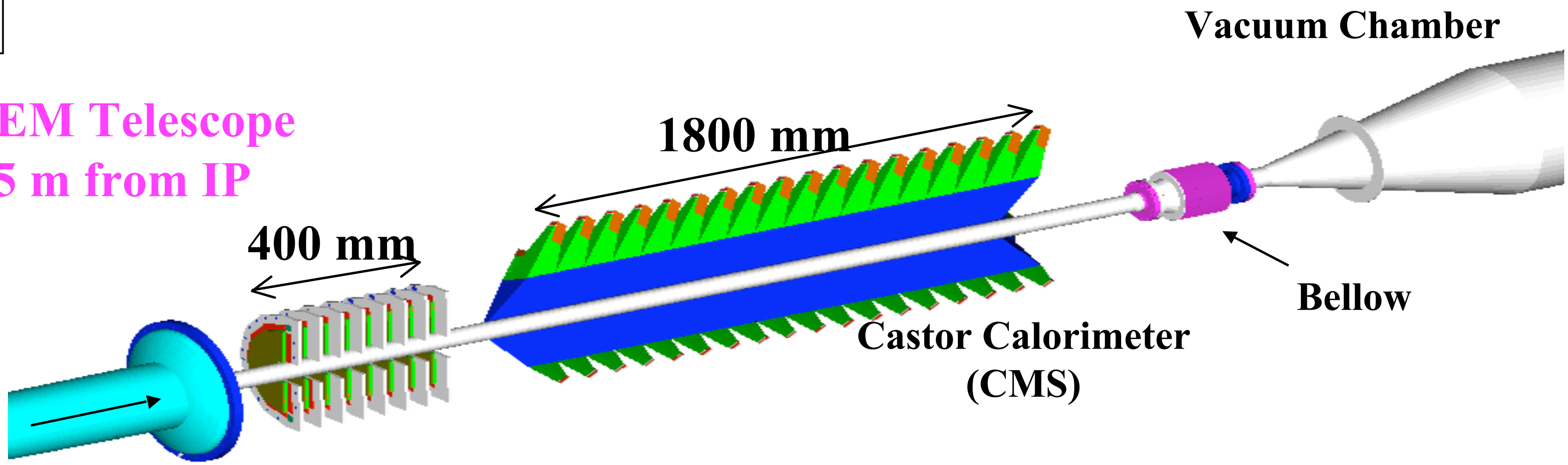


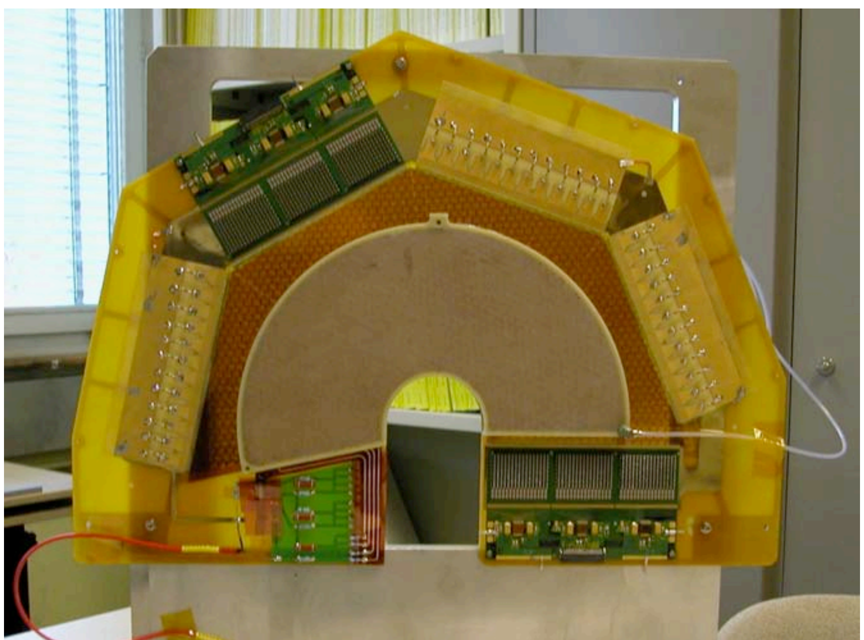

2004
BEAM

T2 Telescope

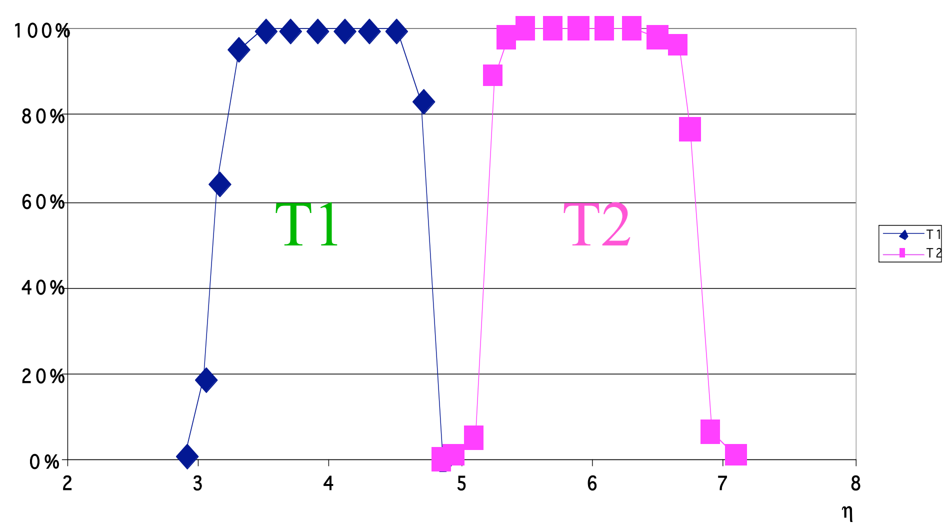
5.3< |η| < 6.8

T2 GEM Telescope
13.5 m from IP





Geometric acceptance



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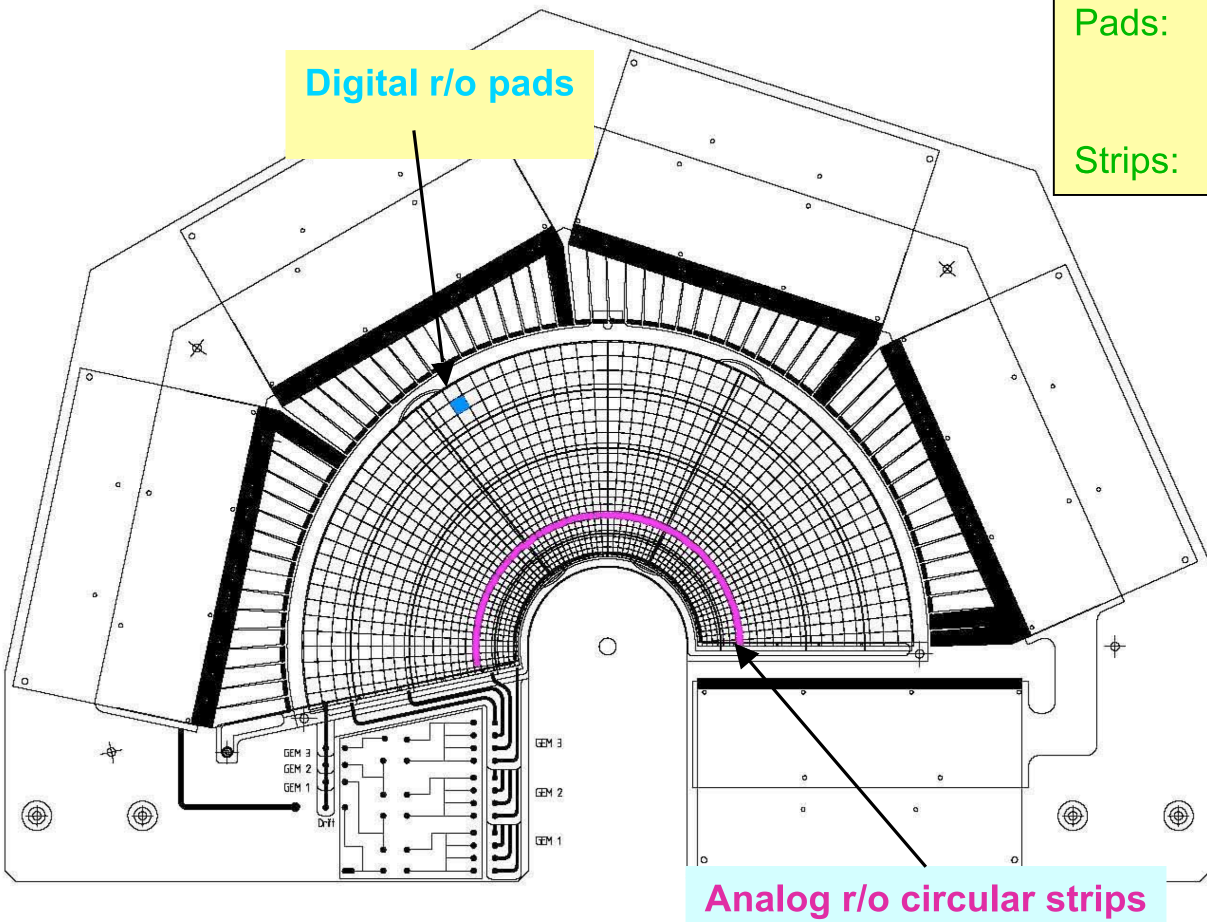
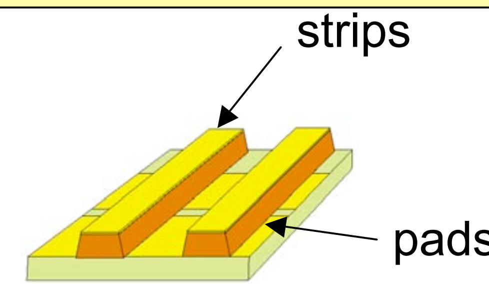
T2: telescope

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

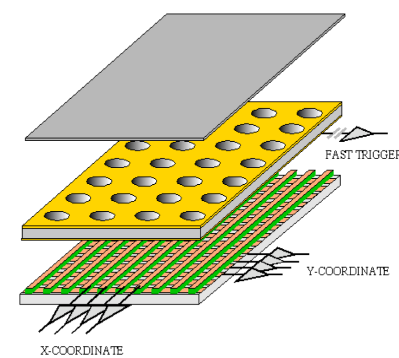
$5.3<|\eta|<6.8$

	$54(\varphi) \times 22(\eta) = 1536$ pads
Pads:	$\Delta\eta \times \Delta\varphi = 0.06 \times 0.018\pi$
	~2x2 mm² — ~7x7 mm²
Strips:	256 (width: 80 μm, pitch: 400 μm)





Technology used in COMPASS



Resolution: σ_R~115μm ; σ_ϕ~ 16mrad

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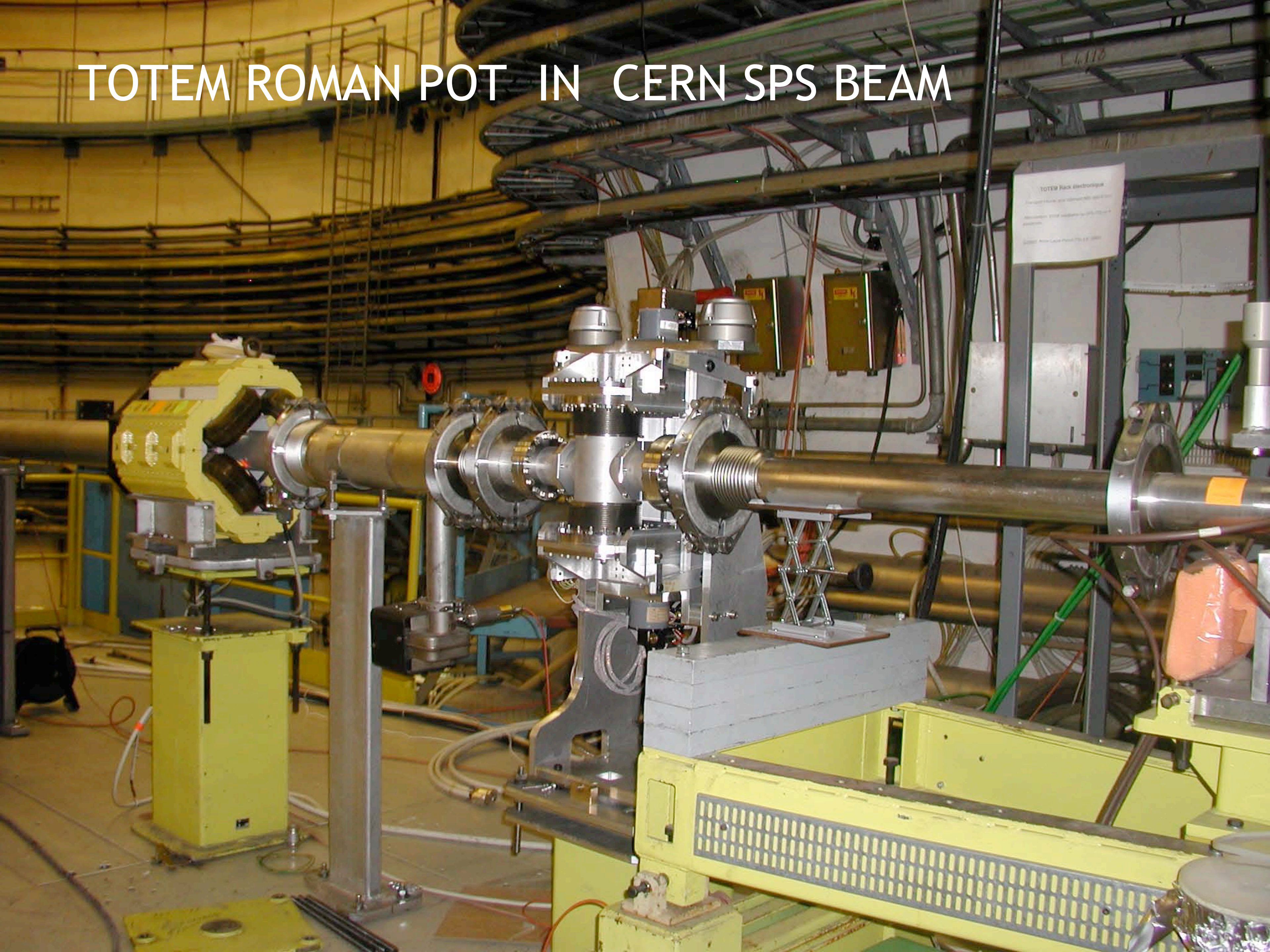
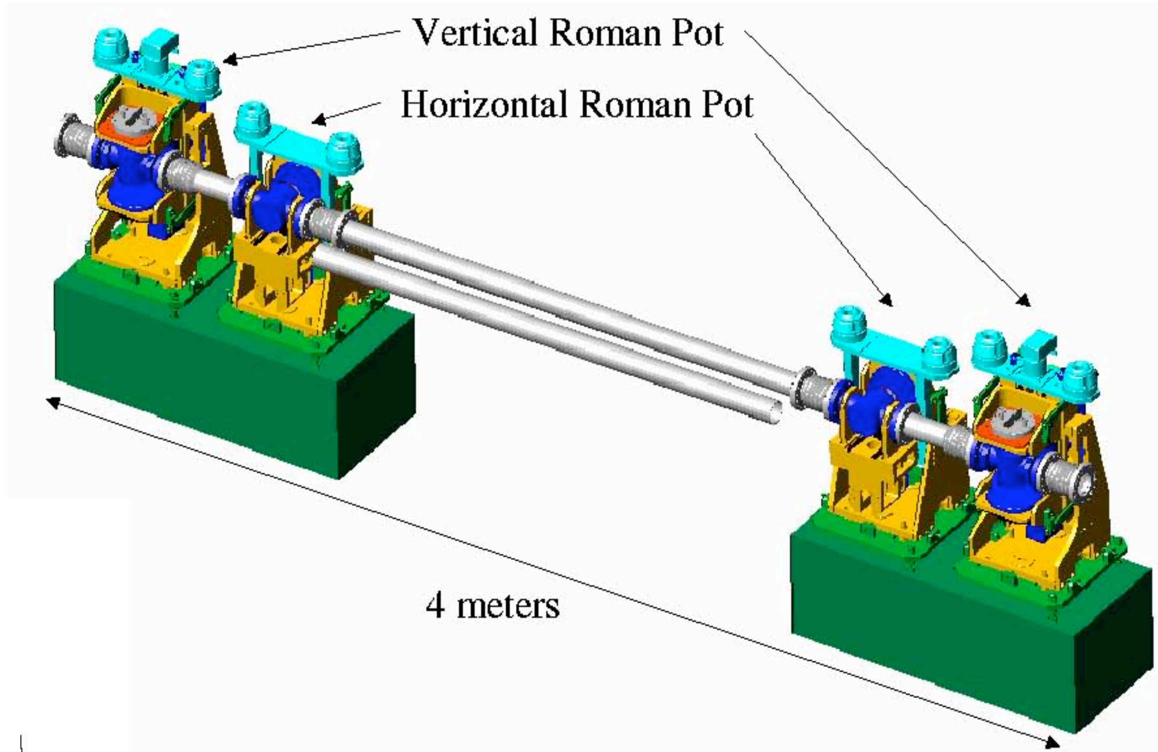
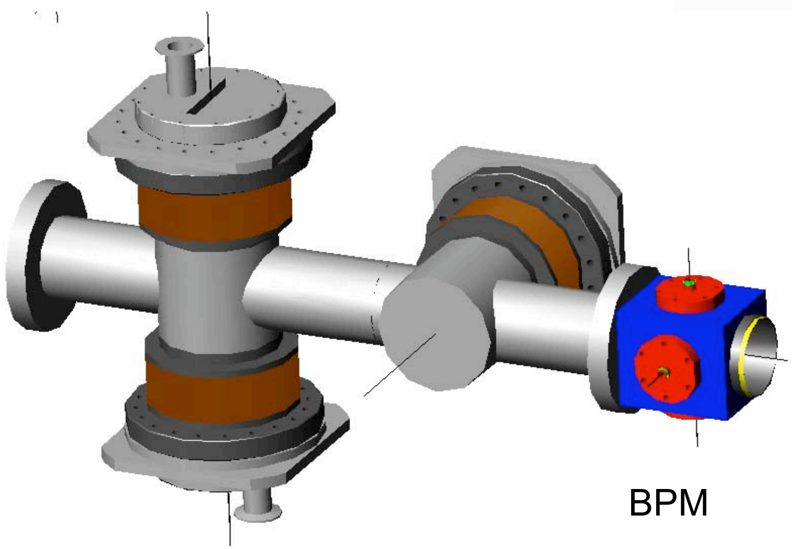
The Roman Pot and its installation on Aug. 18th

TOTEM ROMAN POT IN CERN SPS BEAM



Roman Pot station with two units 4 m apart





BPM

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

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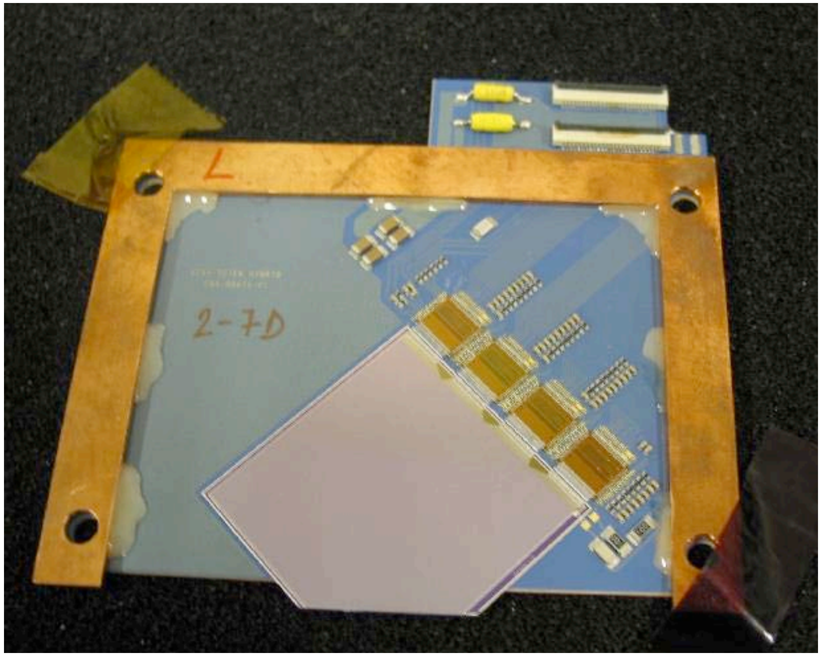
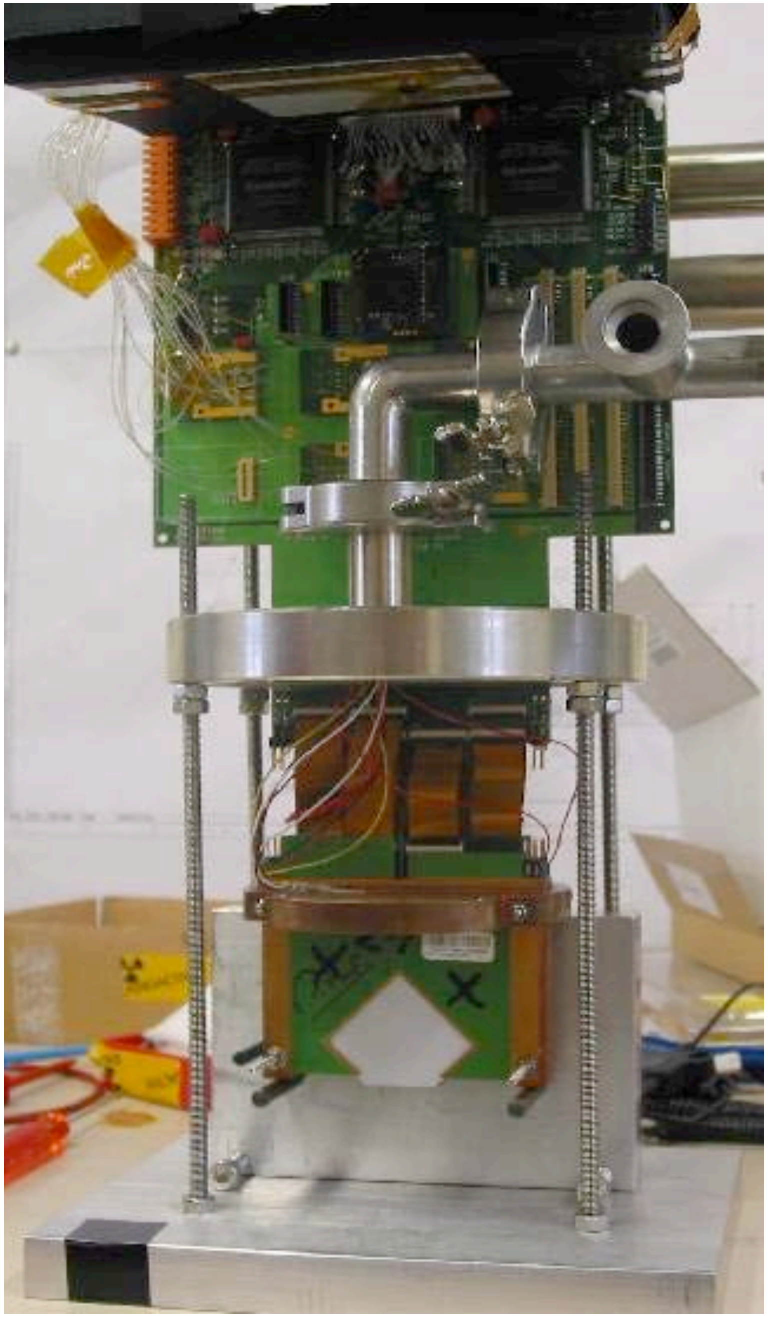
Si detectors and read-out inside the Roman Pots





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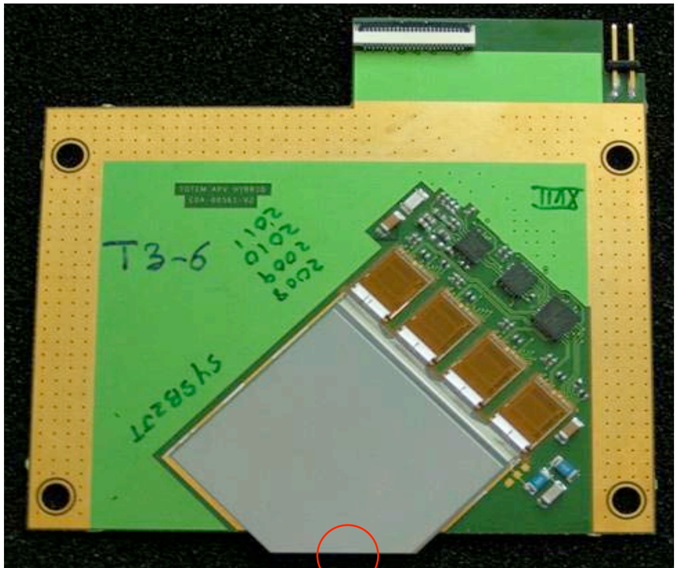
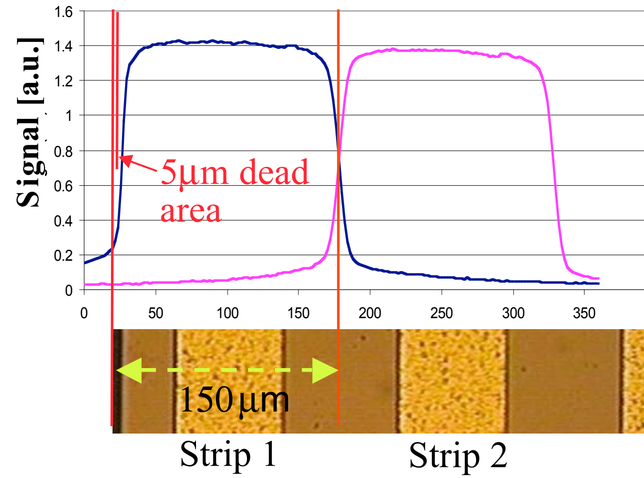
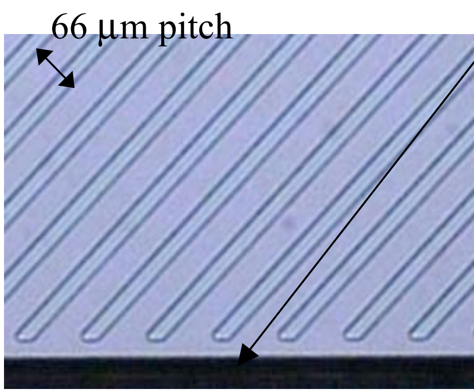
Edgeless Silicon Detectors for the RPs



Active edges: X-ray measurement

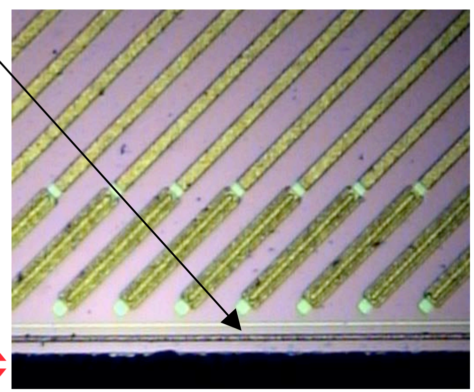




active edges (“planar/3D”)

10 µm dead area

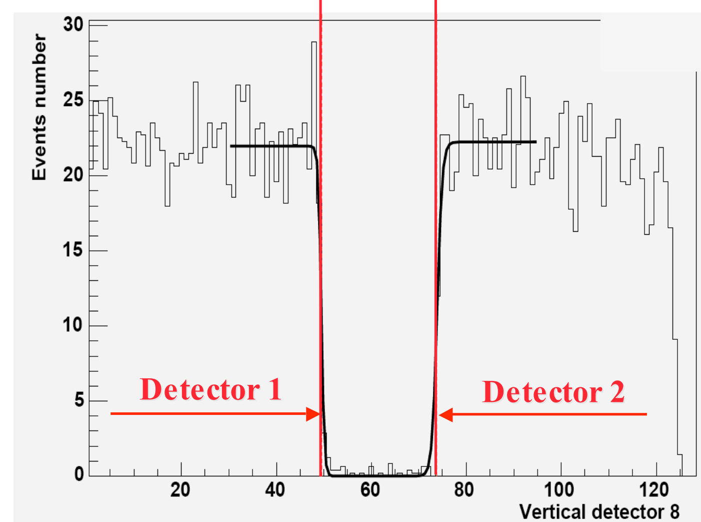
50 µm dead area



planar technology CTS (Curr. Termin. Struct.)

Planar technology: Testbeam

40 µm dead area



TOTEM Physics

Total cross-section with a precision of 1%

Elastic pp scattering in the range $10^{-3} < t = (p\,\theta)^2 < 10\ \mathrm{GeV}^2$

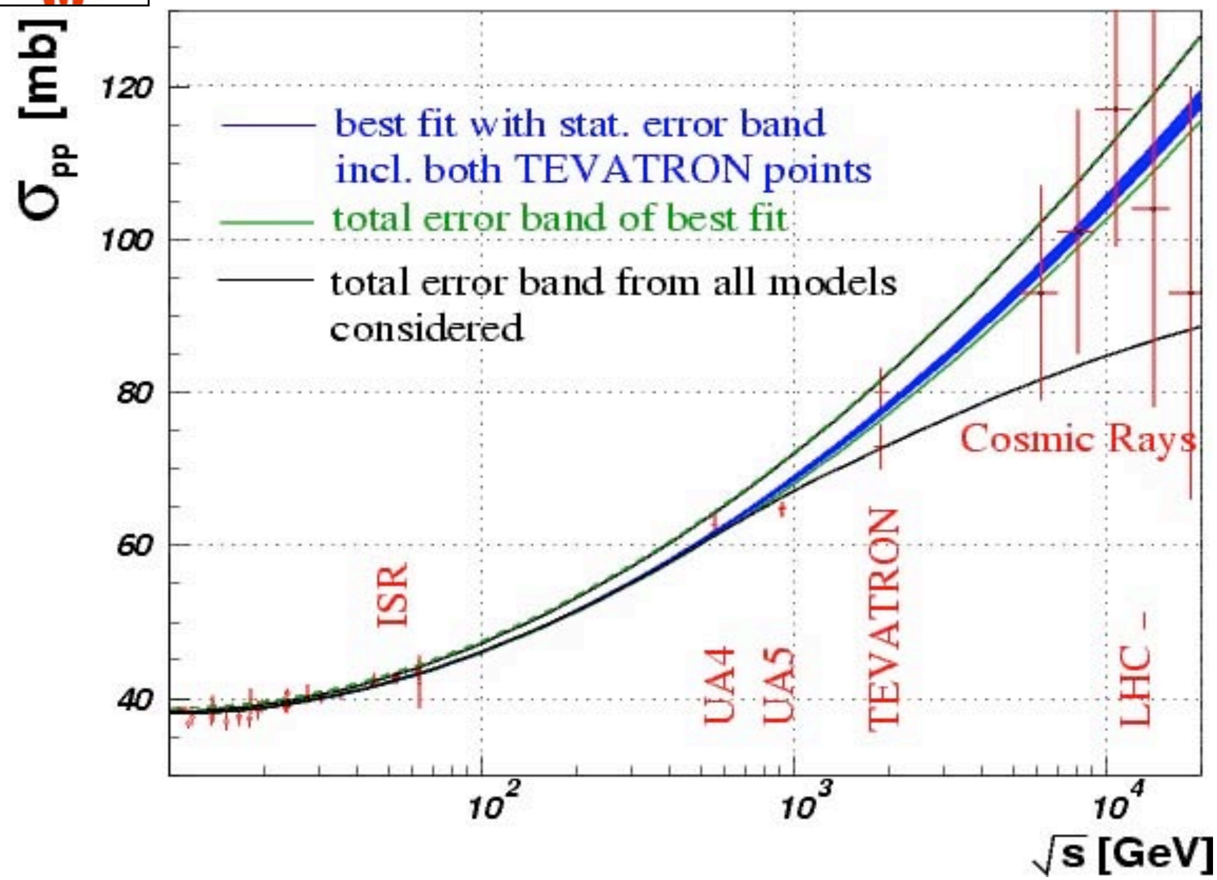
Particle and energy flow in the forward direction

Measurement of leading particles

Diffractive phenomena with high cross-sections

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

Total p-p Cross-Section



- Current models predictions: 90-130 mb
- Aim of TOTEM: **~1%** accuracy

COMPETE Collaboration fits all available hadronic data and predicts:

LHC:

$$\sigma_{tot} = 111.5 \pm 1.2 \begin{matrix} +4.1 \\ -2.1 \end{matrix} \text{ mb}$$

[PRL 89 201801 (2002)]

Measurement of σ_{tot}

Measurement of the total cross section with the luminosity independent method using the Optical Theorem.

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

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

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

Measurement of the elastic and inelastic rate with a precision better than 1%.

Running Scenarios

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	0.3×10^{11}	1.15×10^{11}	$(0.6 - 1.15) \times 10^{11}$	1.15×10^{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 [$cm^{-2} s^{-1}$]	1.6×10^{28}	3.6×10^{32}	2.4×10^{29}	$\sim 0.5\ 10^{32}$

TOTEM Optics Conditions

$L_{TOTEM} \sim 10^{28}\ cm^{-2}\ s^{-1}$

TOTEM needs special/independent short runs at high-β* (1540m) and low ε

Scattering angles of a few μrad

High-β optics for precise measurement of the scattering angle $\sigma(\theta^*) = \sqrt{\varepsilon / \beta^*} \sim 0.3\ \mu rad$

As a consequence large beam size $\sigma^* = \sqrt{\varepsilon \beta^*} \sim 0.4\ mm$

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

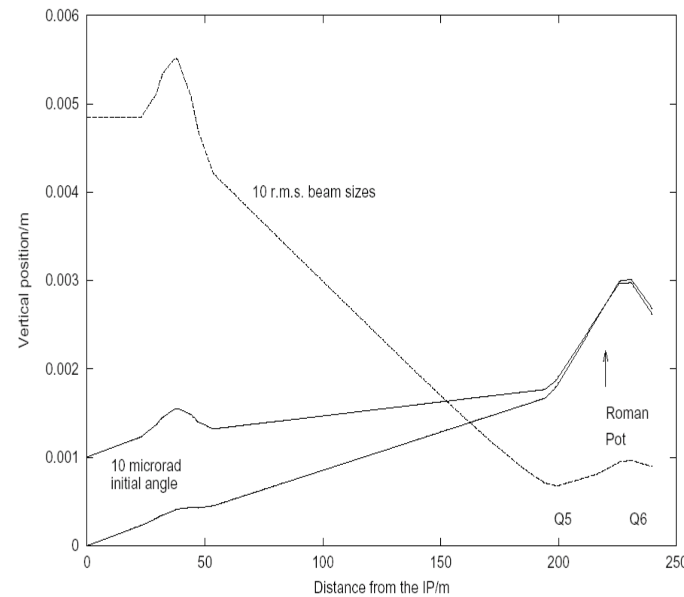
Parallel-to-point focusing (v=0) :

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

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

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

Maximize L and minimize v



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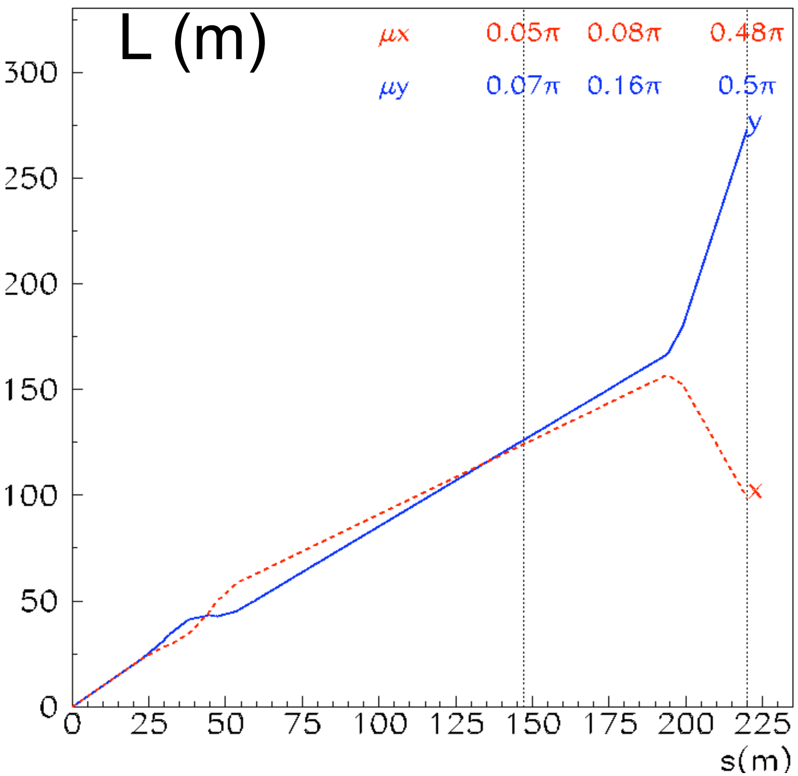
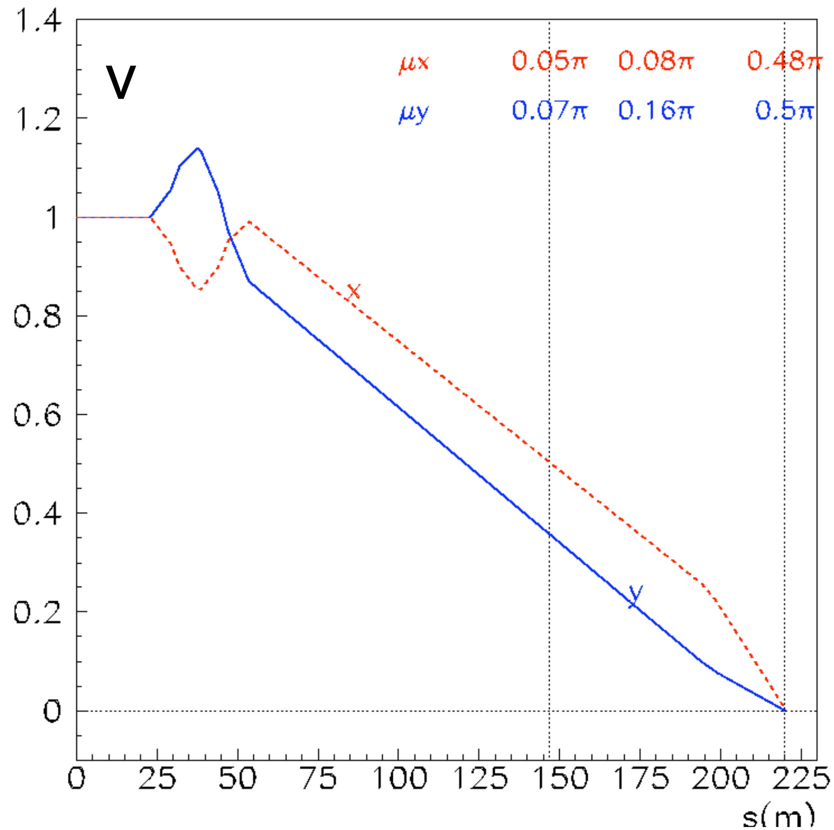
High β optics (1540 m): lattice functions

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

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



Parallel to point focusing in both projections



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

$$x = L_x \theta_x^* + v_x x^* + D\xi$$

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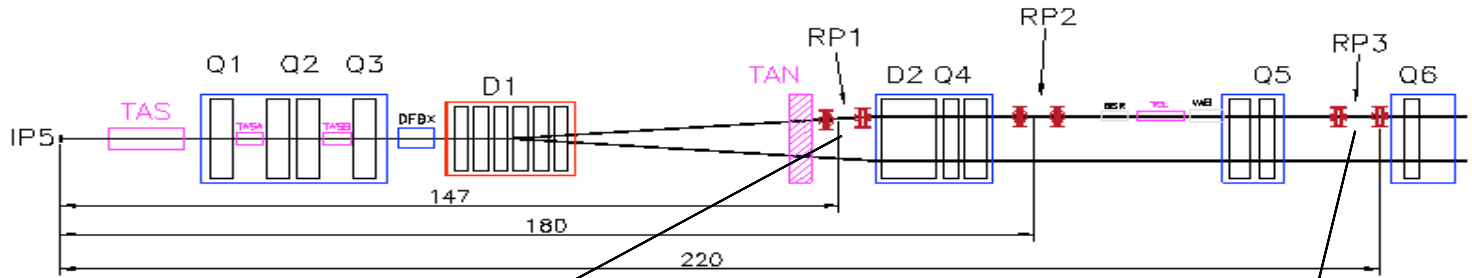
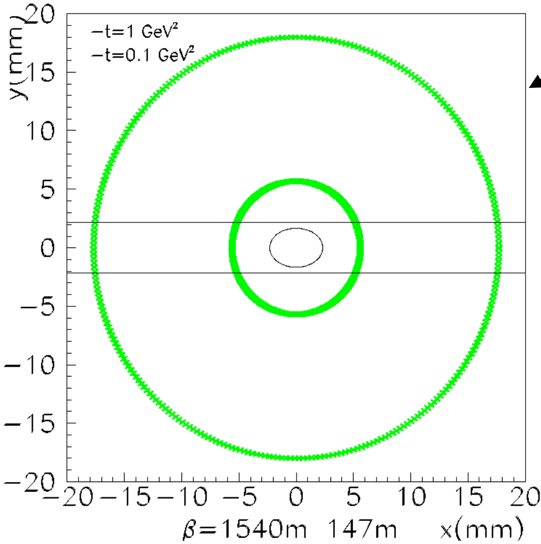
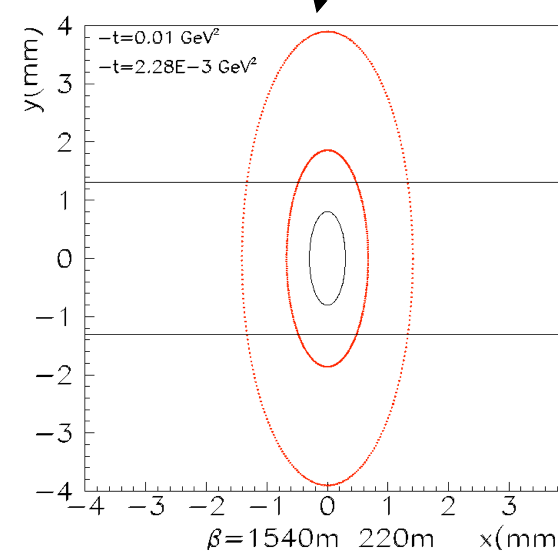


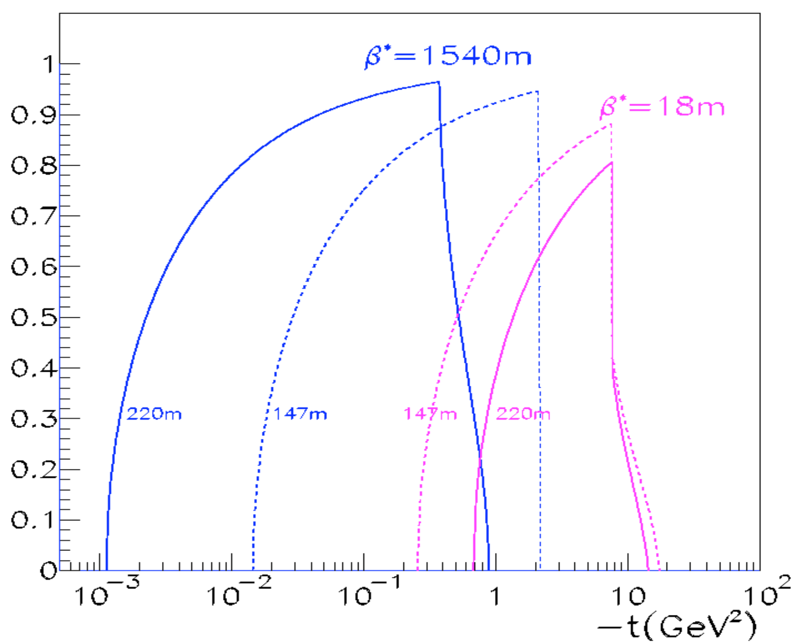


Elastic Scattering

β* = 1540 m



acceptance



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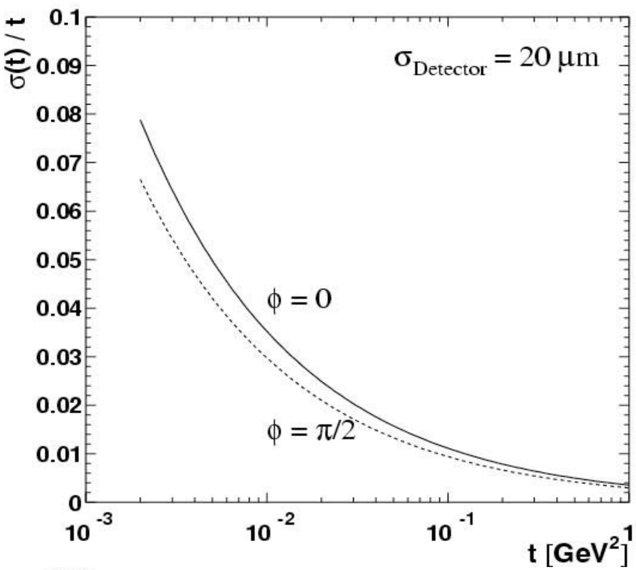
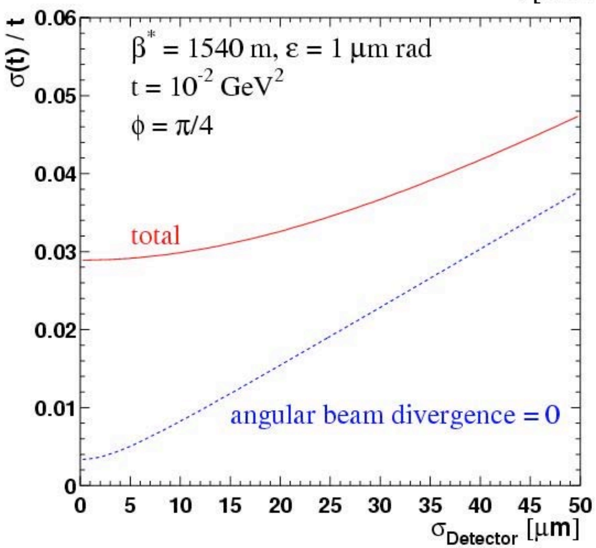
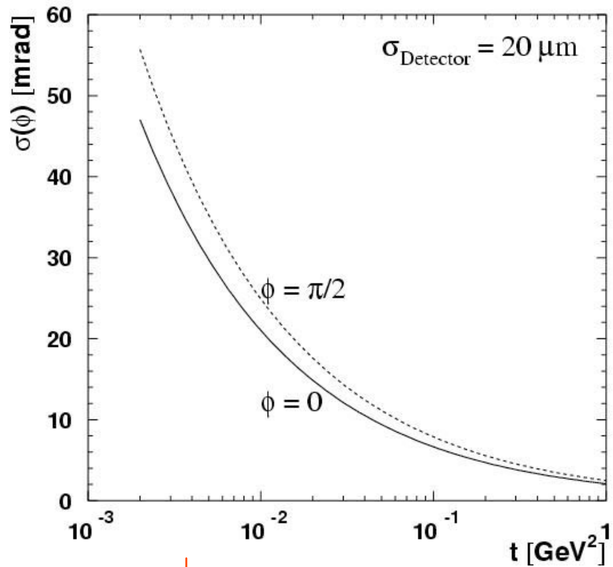
Elastic Scattering: Resolution

t-resolution (2-arm measurement)





φ-resolution (1-arm measurement)

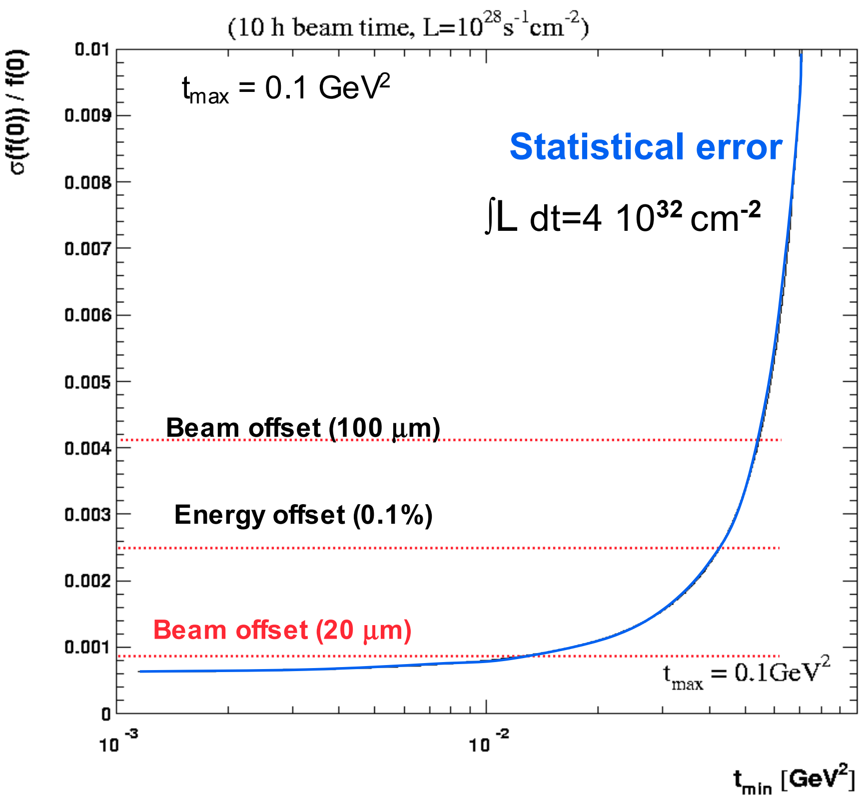


↓

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

φ correlation in DPE

Elastic Cross section (t=0)



	Uncertainty	Fit error
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}

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

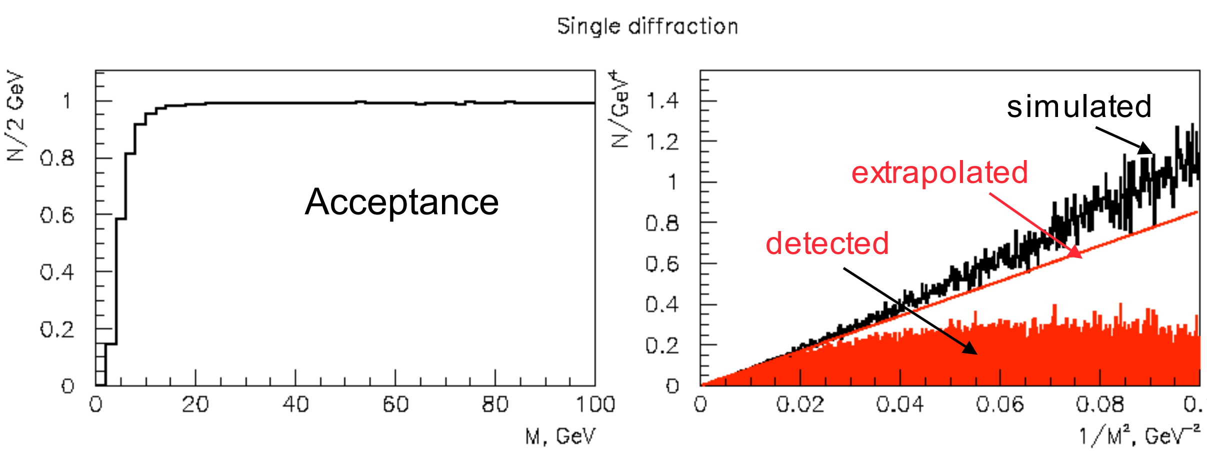
1%

Trigger Losses (mb)

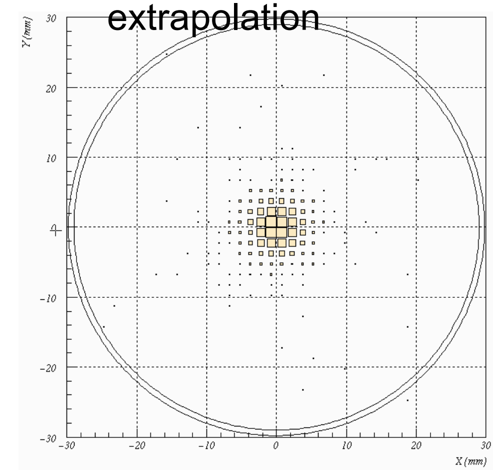
	σ(mb)	Double arm	Single arm	After Extrapolation
Minimum bias	58	0.3	0.06	0.06
Single diffractive	14	-	2.5	0.6
Double diffractive	7	2.8	0.3	0.1
Double Pomeron	1	-	-	0.02
Elastic Scattering	30	-	-	0.1

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

Inelastic error t=0 extrapol. error



Vertex extrapolation



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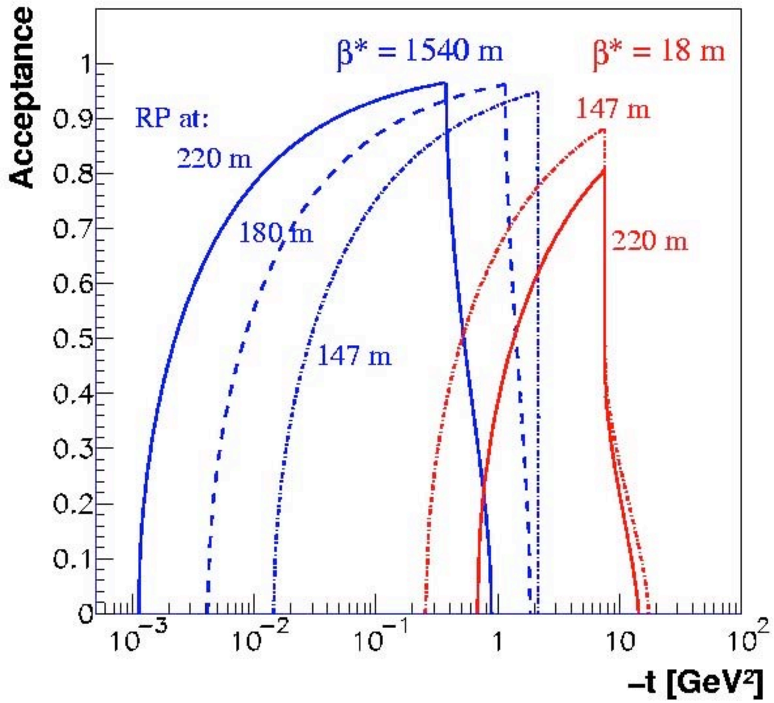
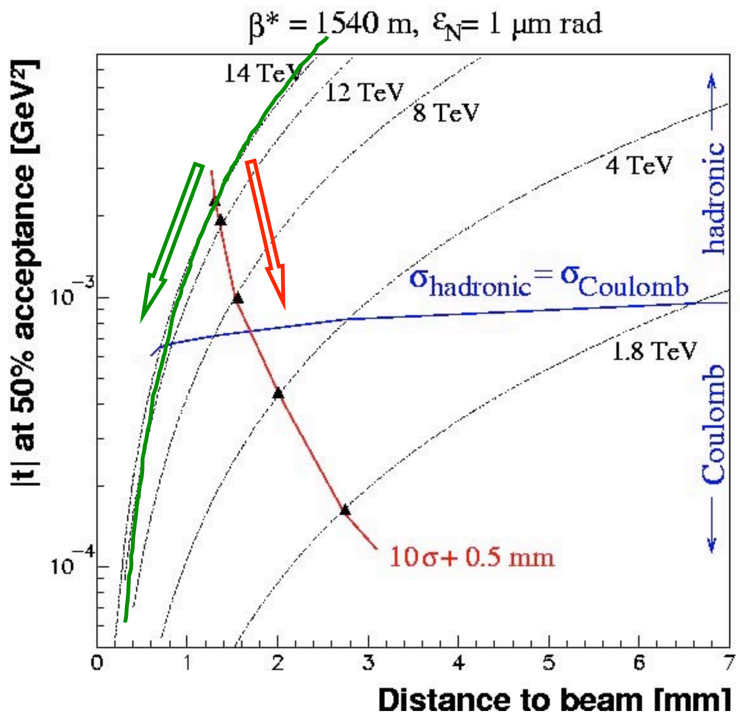
Possibilities of ρ measurement

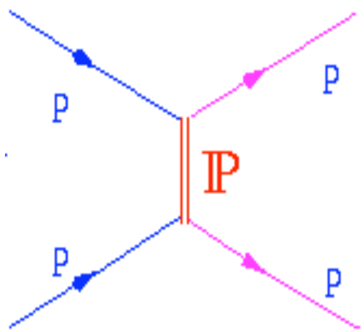




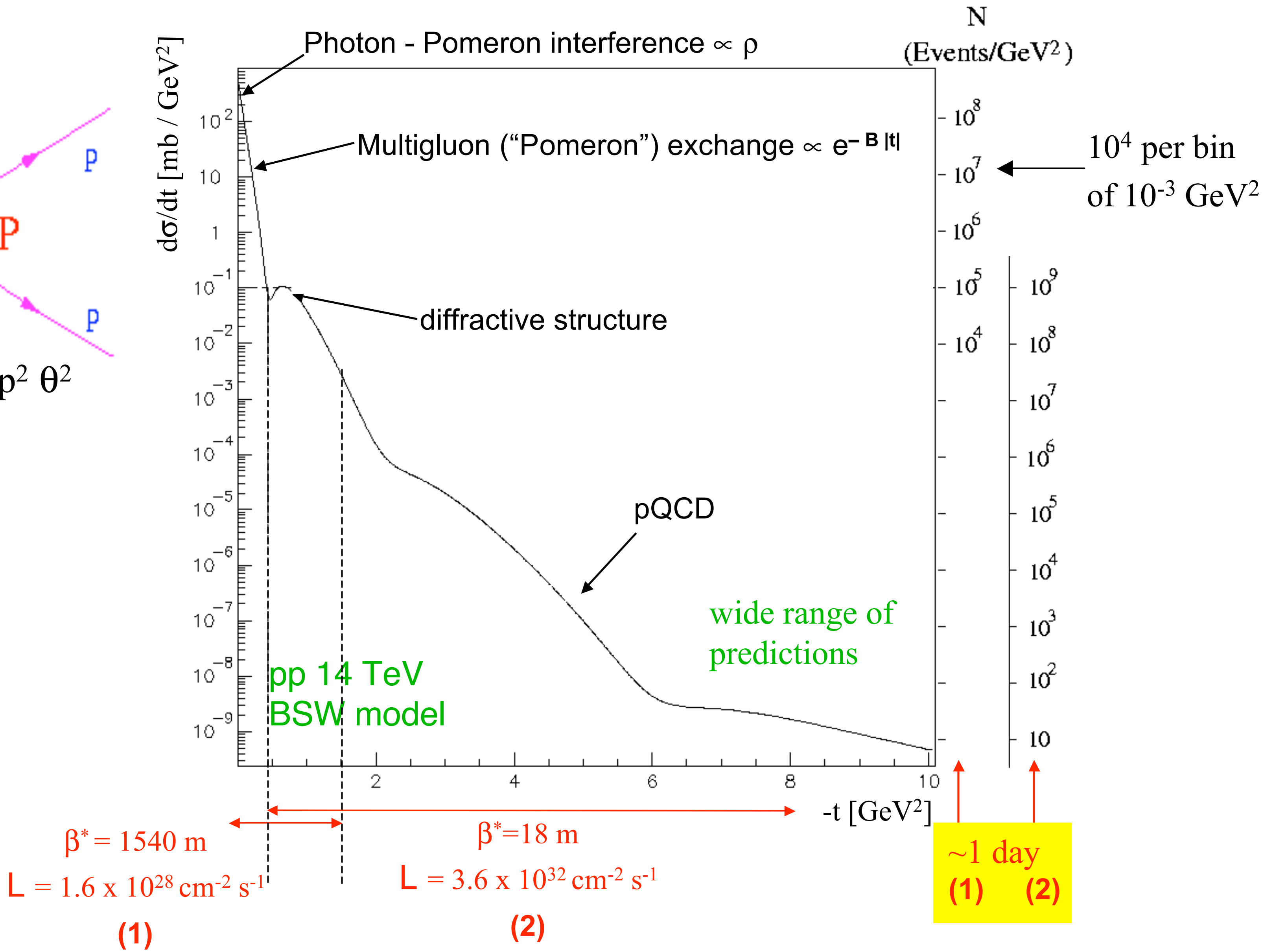
Try to reach the Coulomb region and measure interference:

- move the detectors closer to the beam than 10 σ + 0.5 mm
- run at lower energy $\sqrt{s} < 14$ TeV

Elastic Scattering Cross-Section



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



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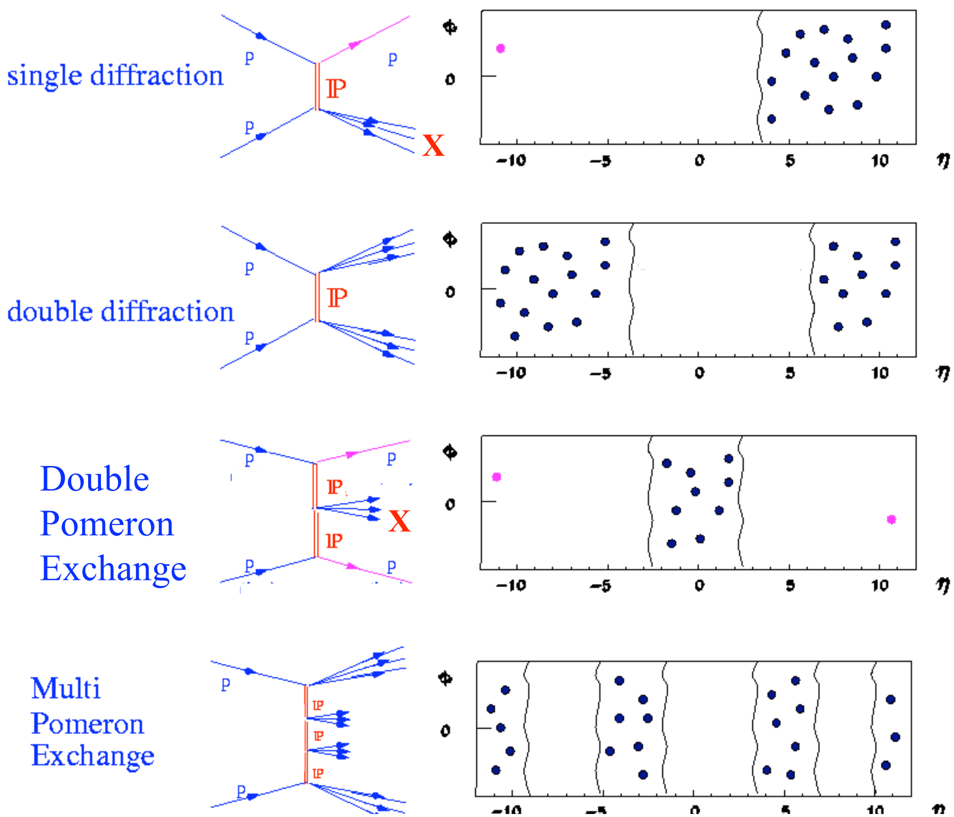
CMS/TOTEM Physics

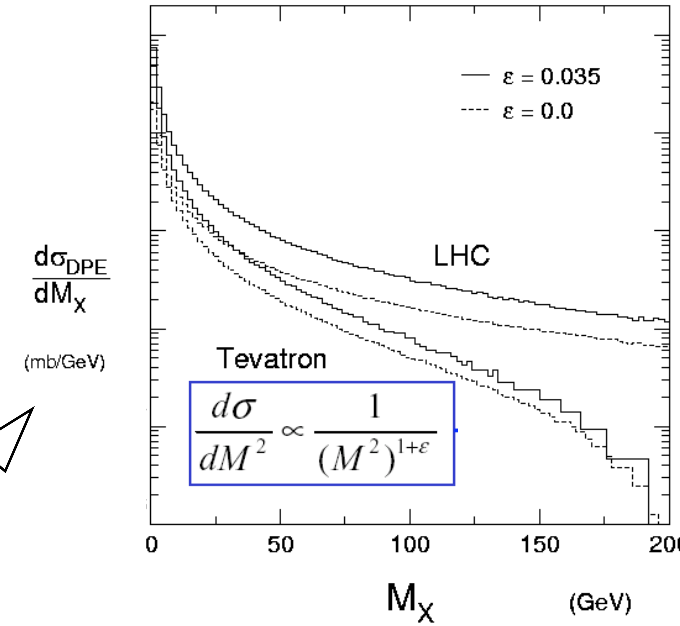
CMS / TOTEM detector ideal for study of diffractive and forward physics

- 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.



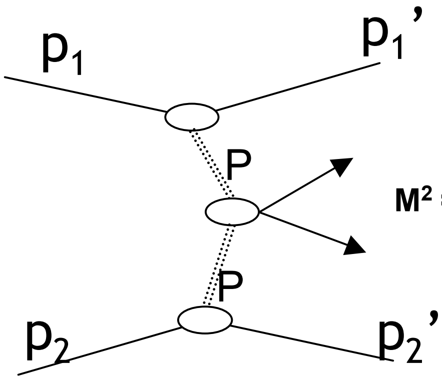


-Triggered by leading proton and seen in CMS

-Central production of states X:

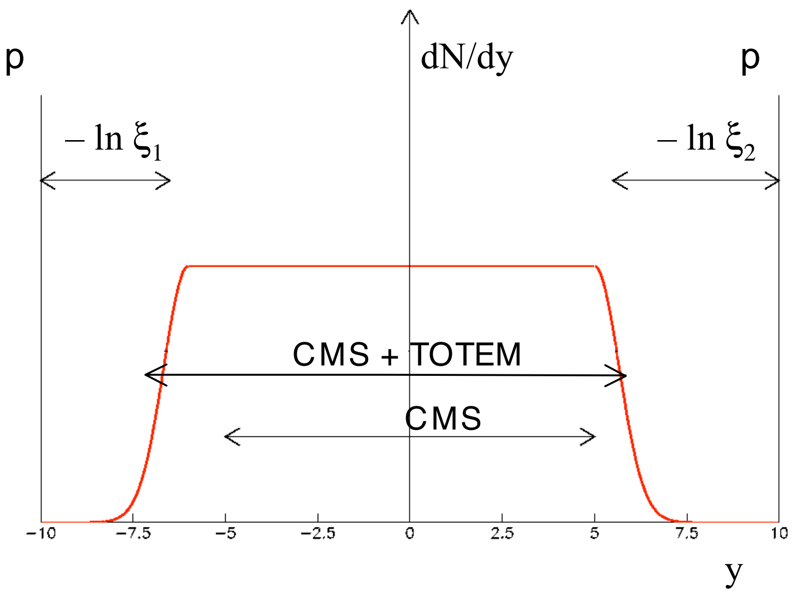
X = χ_c, χ_b, Higgs, dijets,
SUSY particles, ...

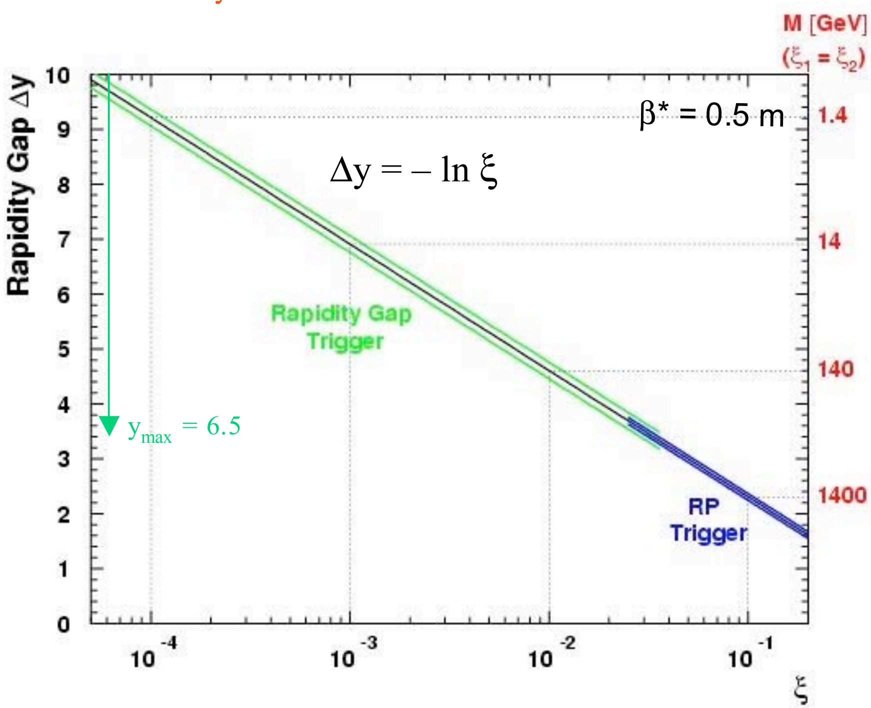
Detection Prospects for Double Pomeron Events



$M^2 = \xi_1 \xi_2 s$

$\beta^* = 1540$ m:	$\sigma_\xi \sim 0.5\%$	$L \leq 2.4 \times 10^{29}$ cm^{-2} s^{-1}
$\beta^* = 172$ m:	$\sigma_\xi \sim 0.4$ ‰	$L \sim 0.5\ 10^{32}$ cm^{-2} s^{-1}
$\beta^* = 0.5$ m:	$\sigma_\xi \sim 0.2$-0.6 ‰	$L \sim 10^{33}$ cm^{-2} s^{-1}





Trigger via Roman Pots $\xi > 2.5 \times 10^{-2}$

Trigger via rapidity gap $\xi < 2.5 \times 10^{-2}$

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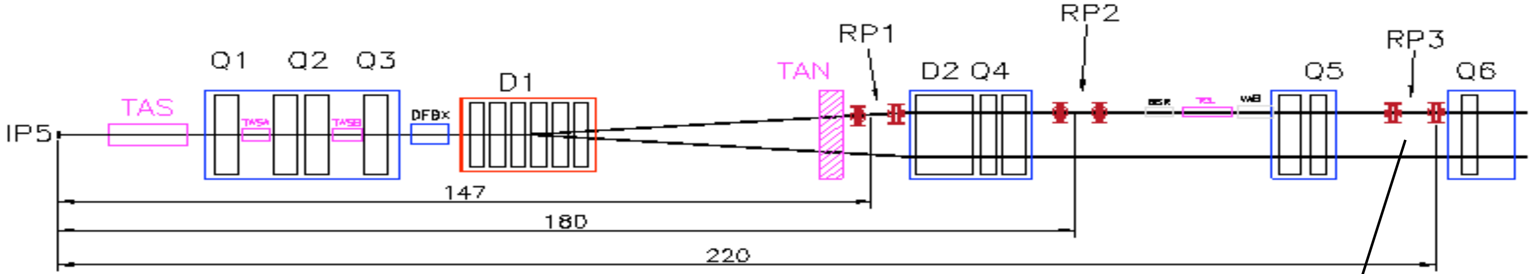
Peak luminosity [$cm^{-2}\ s^{-1}$]	1.6×10^{28}	3.6×10^{32}	2.4×10^{29}	$\sim 0.5\ 10^{32}$

Diffractive protons at β*=1540 m

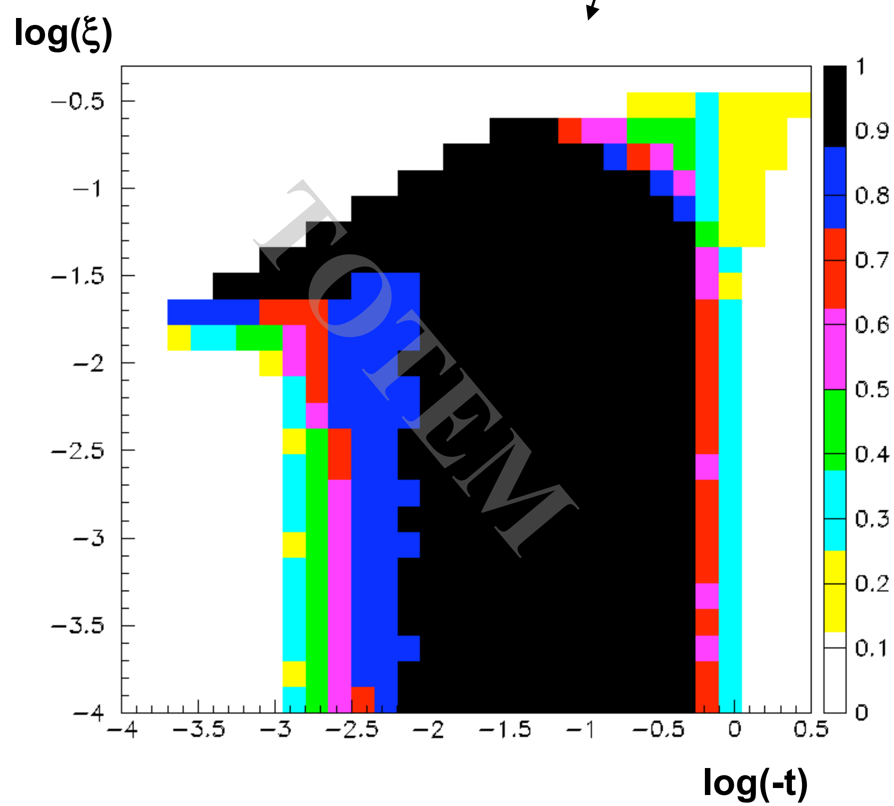


Diffractive protons are observed in a large ξ-t range
> 90% are detected

$-t > 2.5\ 10^{-3}\ GeV^2$

$10^{-8} < \xi < 0.1$

ξ resolution ~ few ‰



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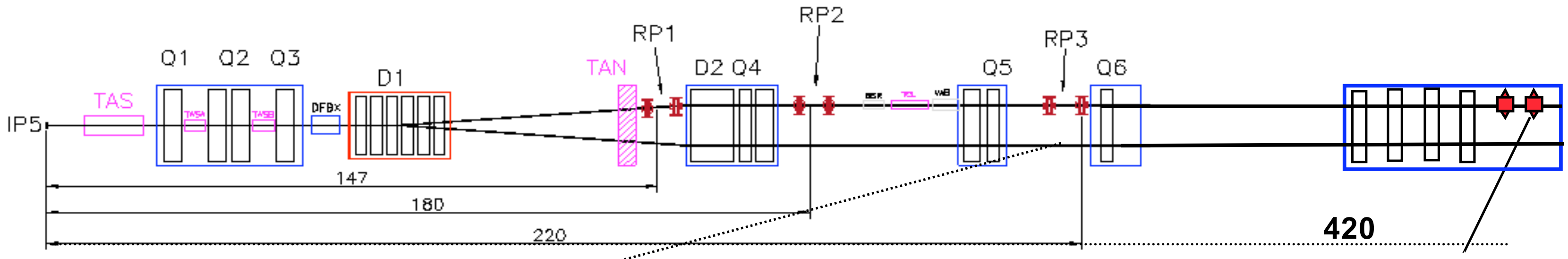
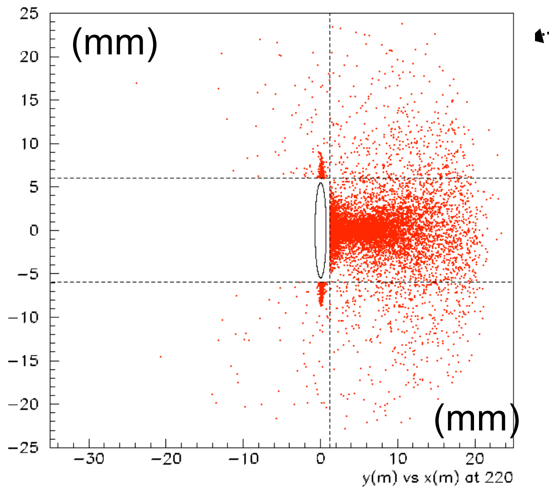
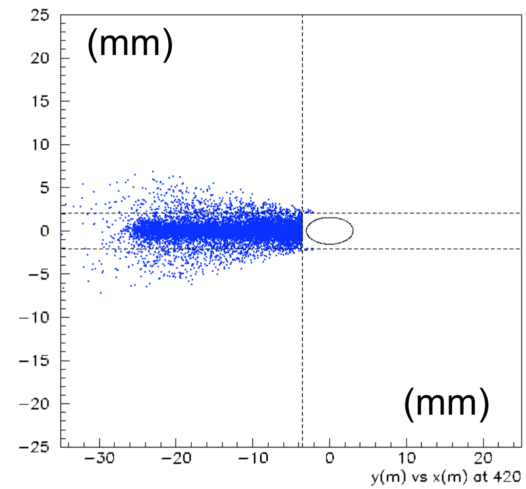
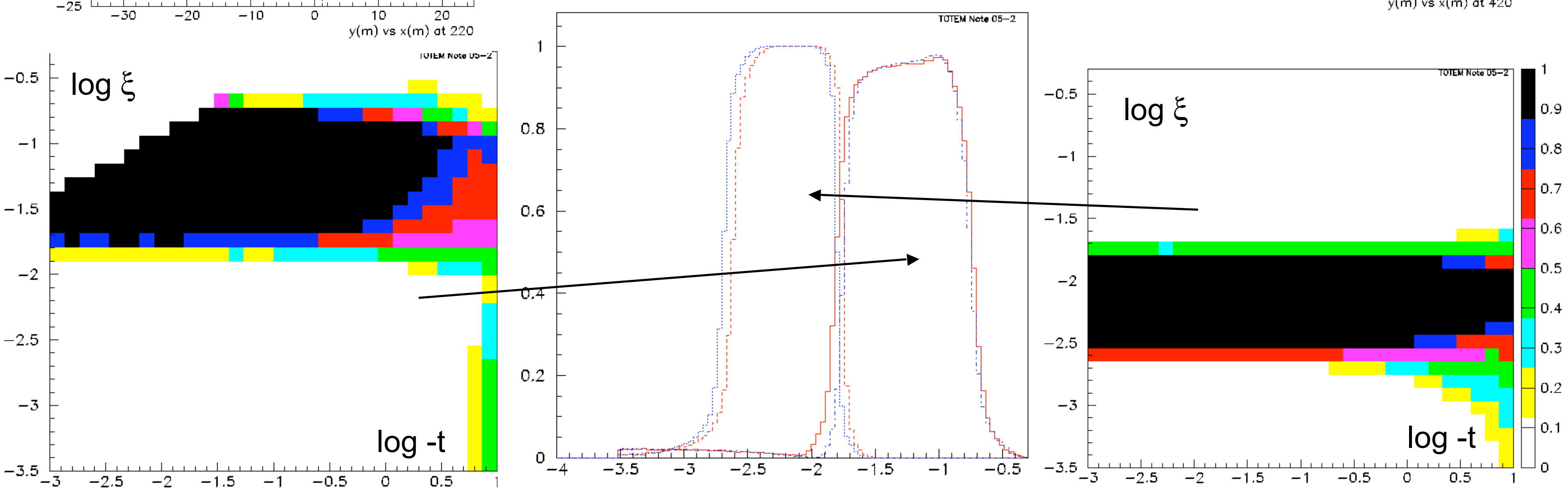


Diffractive proton detection at $\beta^* = 0.5$ m







New optics β^*=172 m

To optimize diffractive proton detection at $L=10^{32}$ in the "warm" region at 220m

- L_y large (~270 m)

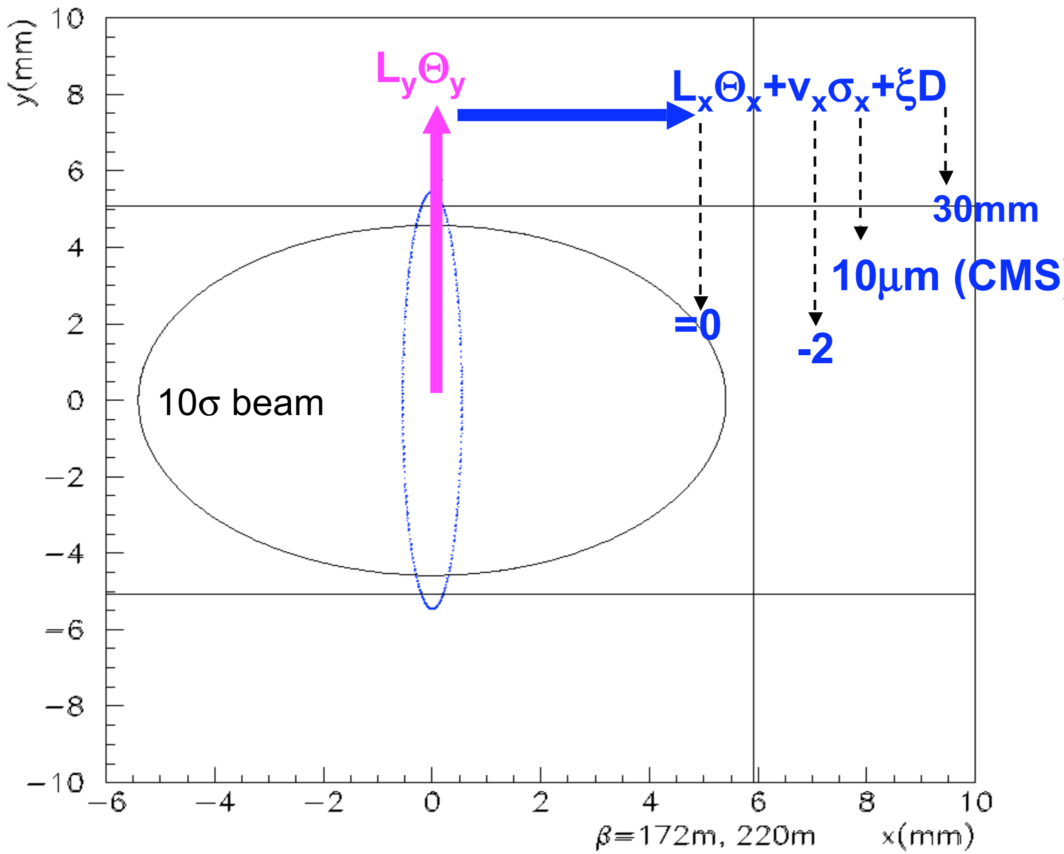
  ⇨ $t_{min} = 2 \times 10^{-2}$ GeV^2

- $L_x \sim 0$ ⇨ θ independent

- Vertex measured by CMS

⇩

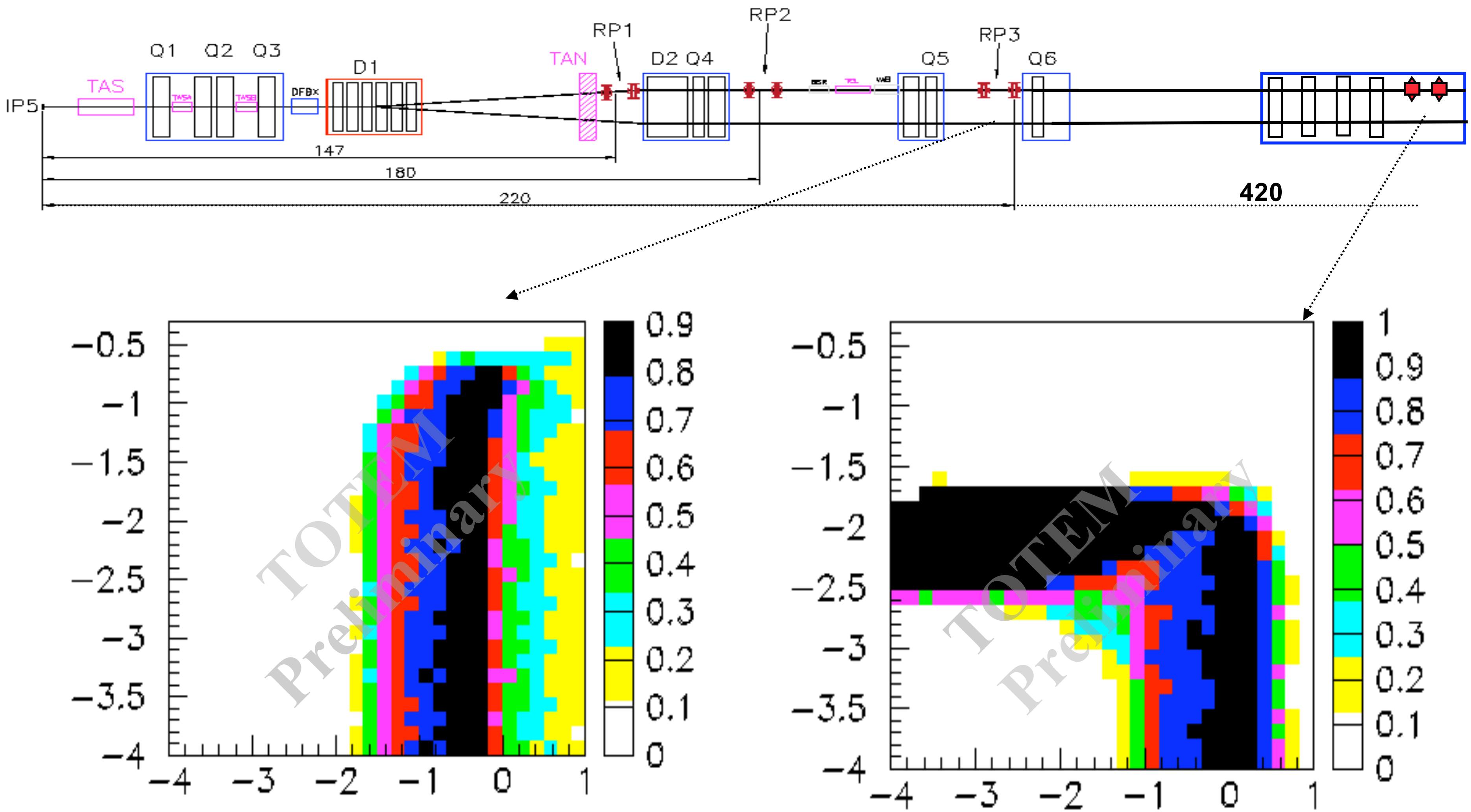
~ 65% of all diffractive protons are seen



ξ determination with a precision of few 10 $^{-4}$

K.Eggert/CERN

Diffractive protons at β^*=172 m



Log(ξ) vs Log(-t)

Log(ξ) vs Log(-t)

K.Eggert/CERN

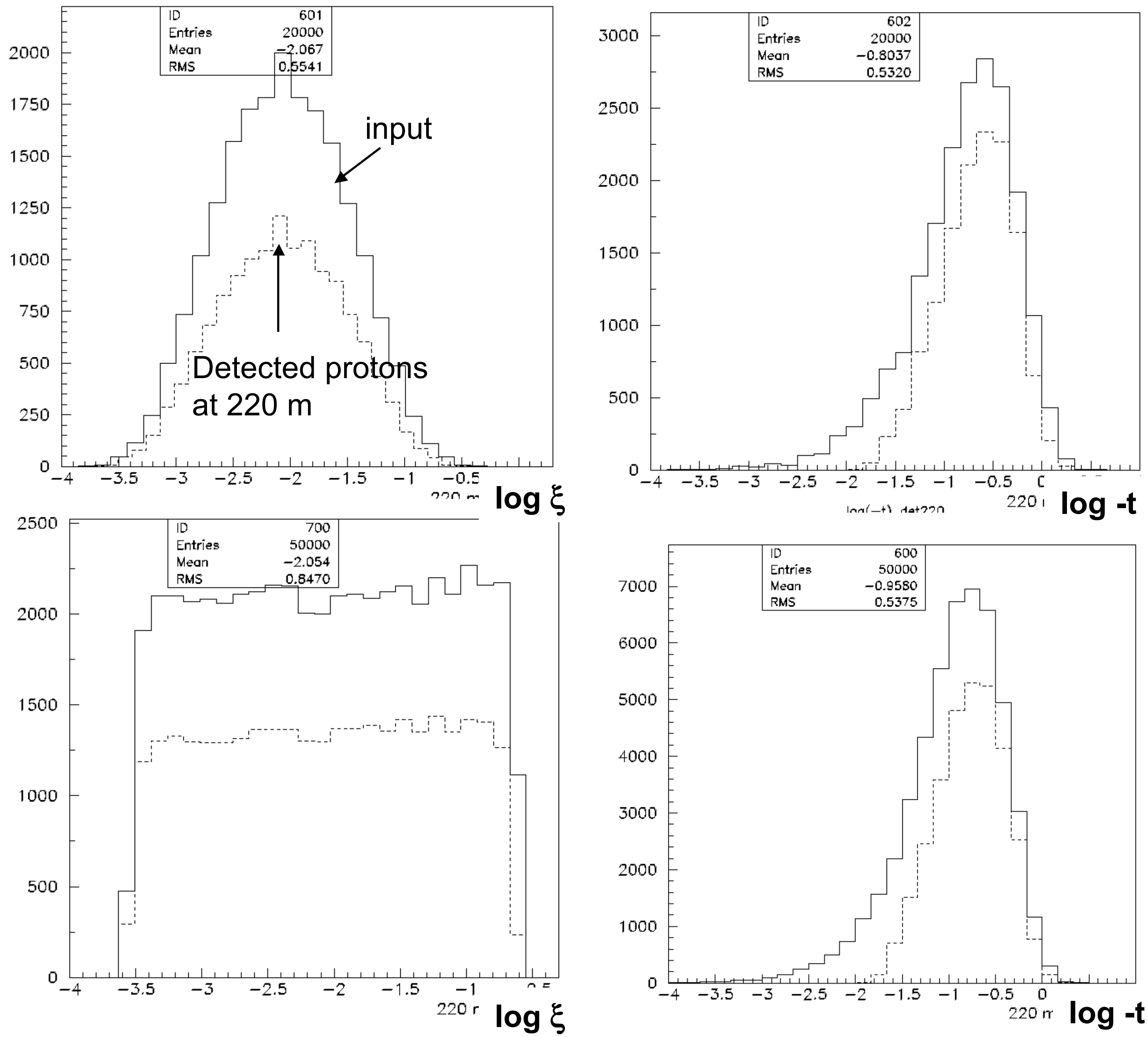
ξ and t distributions for 120 GeV Higgs

ExHume

Proton acceptance 68%

Phojet

Proton acceptance 63%



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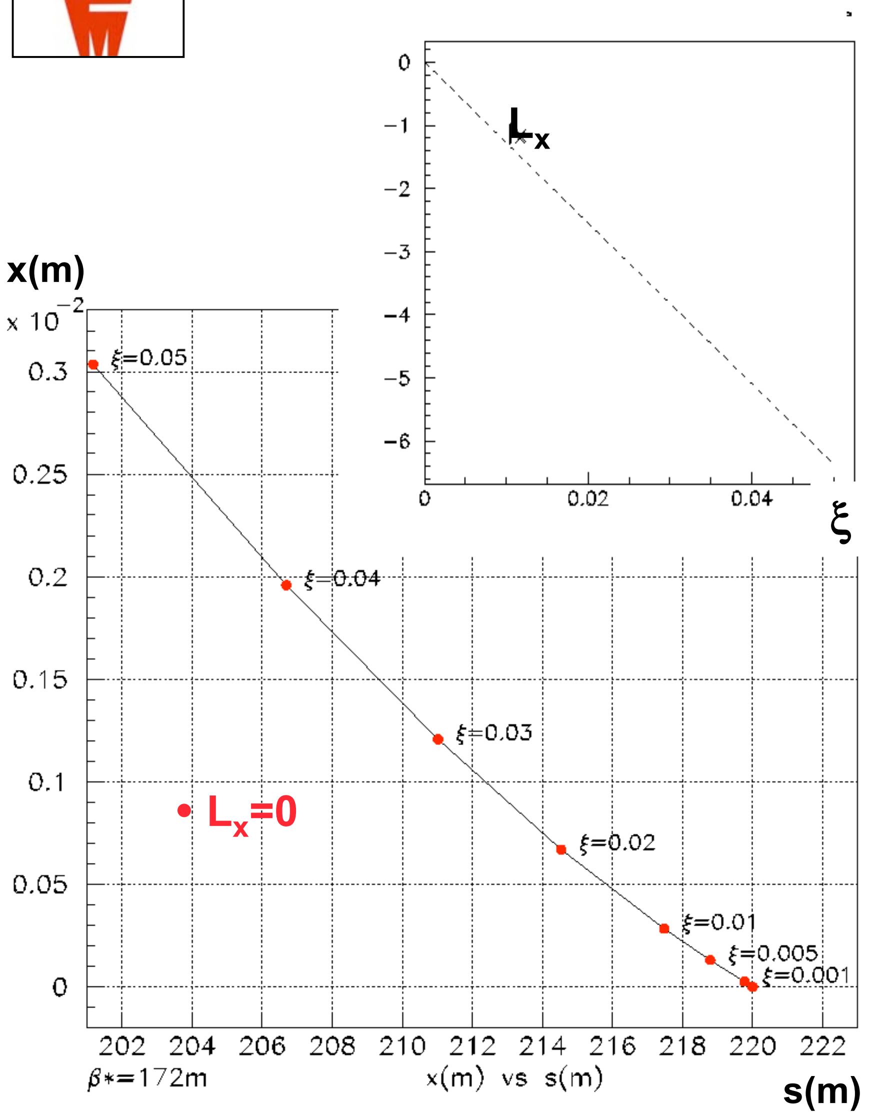
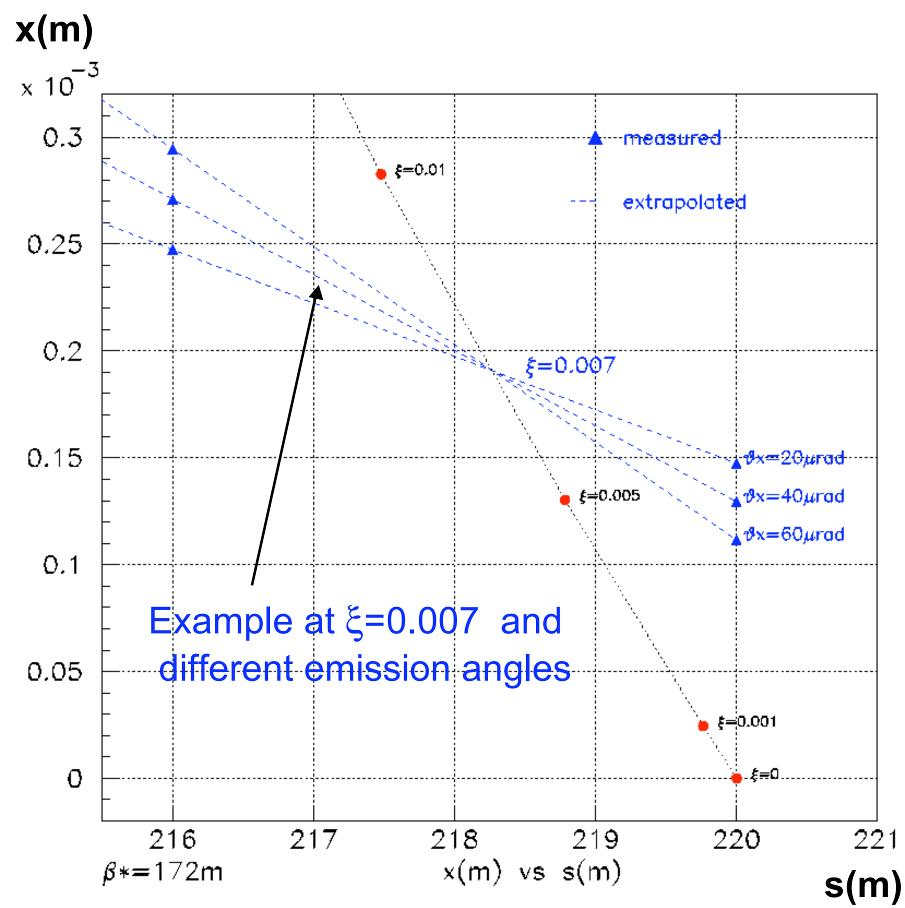
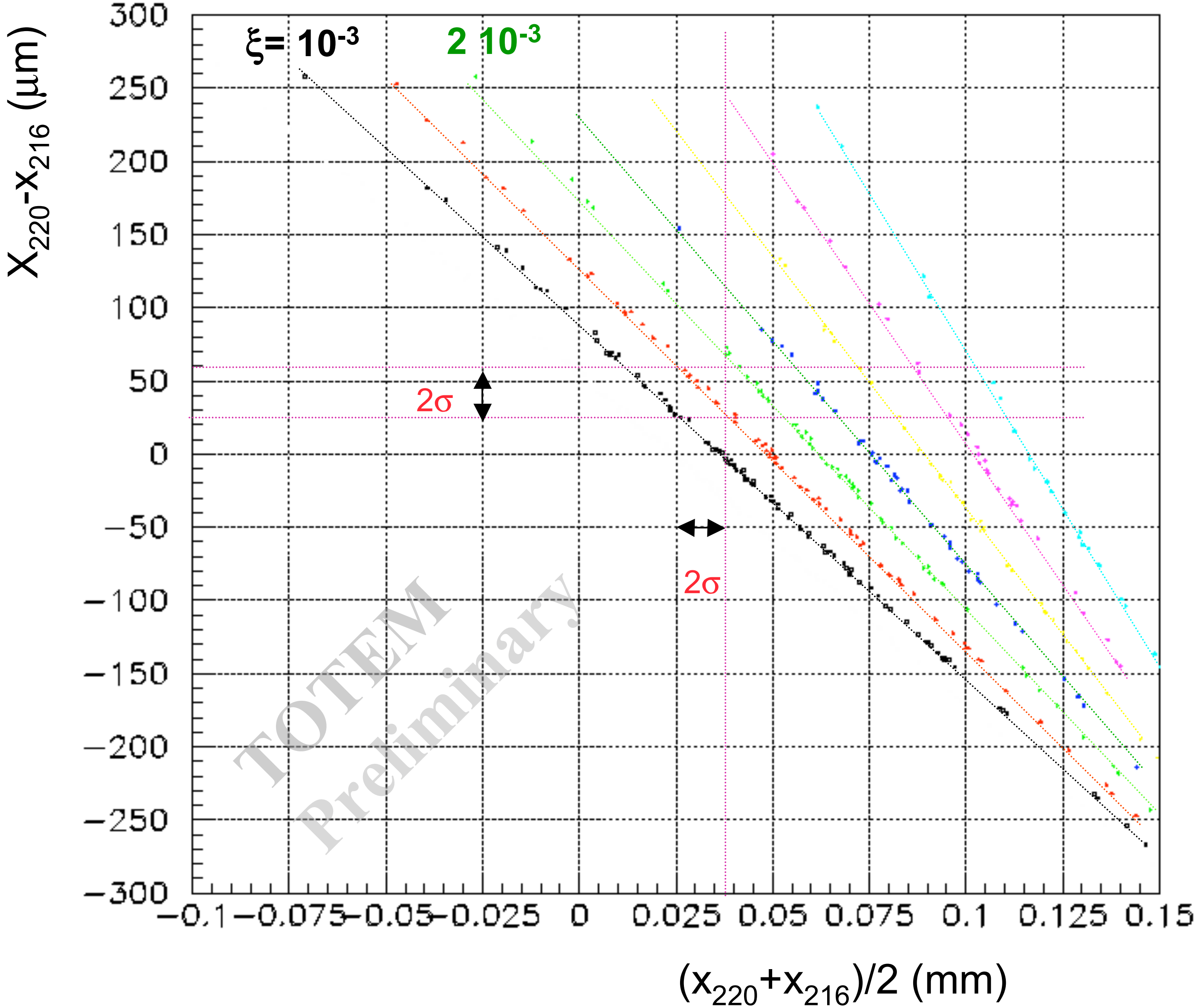
Particle elongation (x) for L_x=0 and different ξ-values





β^*=172 m: ξ resolution ~ 4 10^{-4} (preliminary)



Conclusion on new optics (β^*=172 m) - preliminary

- Luminosity of 0.5 x 10^{32} cm^{-2} s^{-1}
- About 65% of diffractive protons are seen in the RP at 220 m
- ξ resolution of 4 10^{-4}
- θ resolution of few μrad

Future:

- more detailed studies on resolution
- further optimization towards higher luminosities

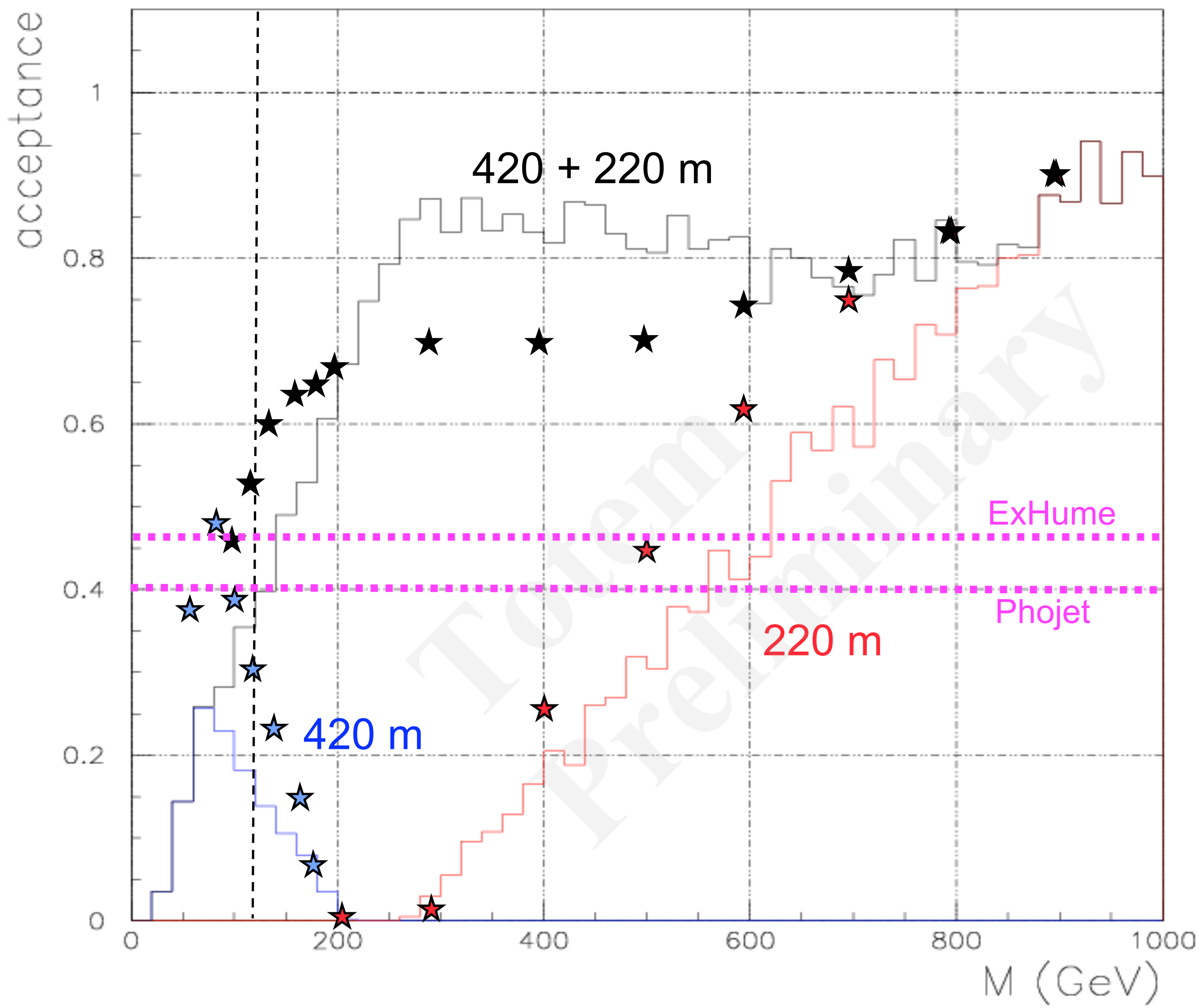
Mass Acceptance in DPE (preliminary)

β=0.5 m

Phojet

ExHume

β=172 m



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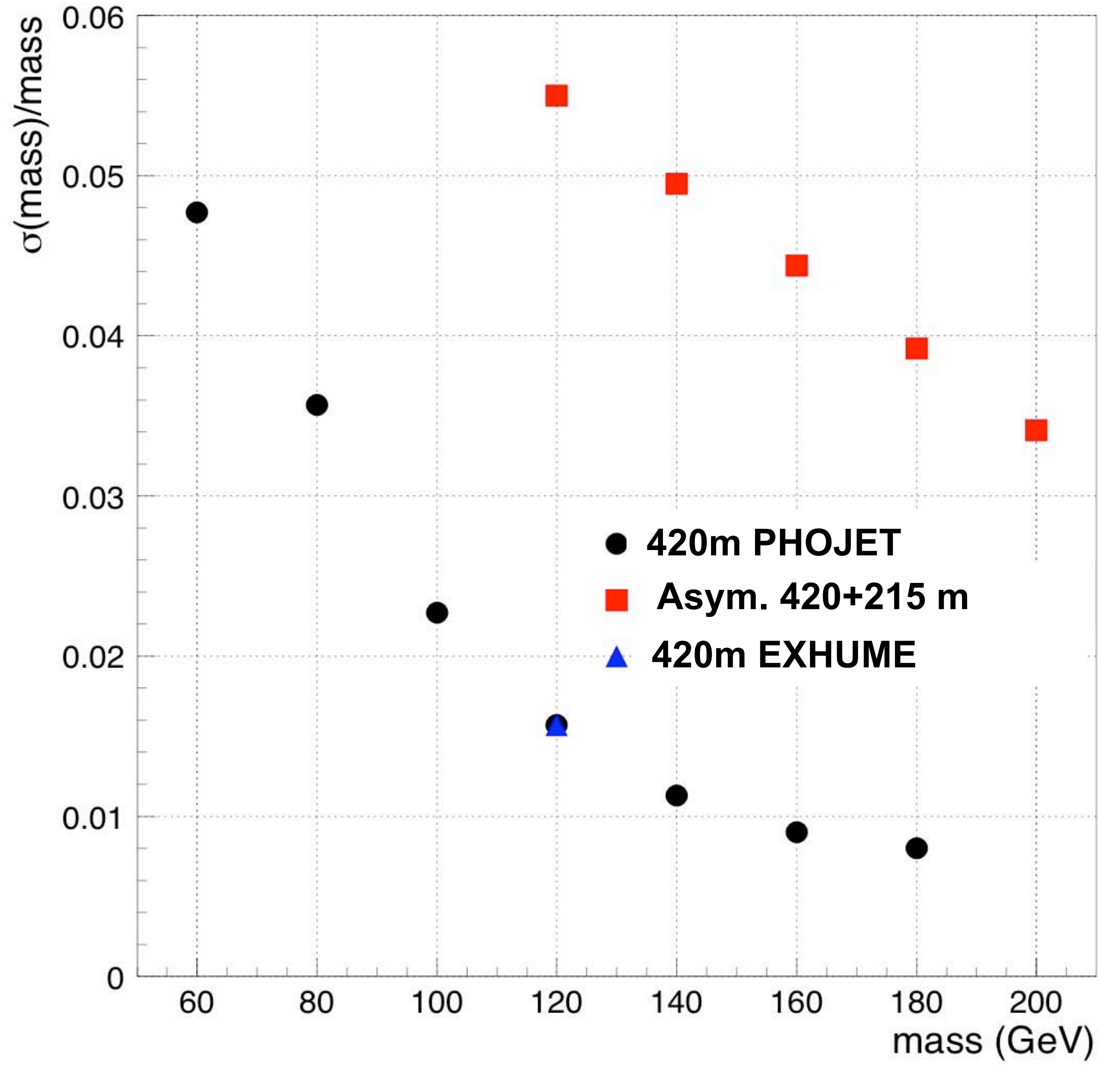
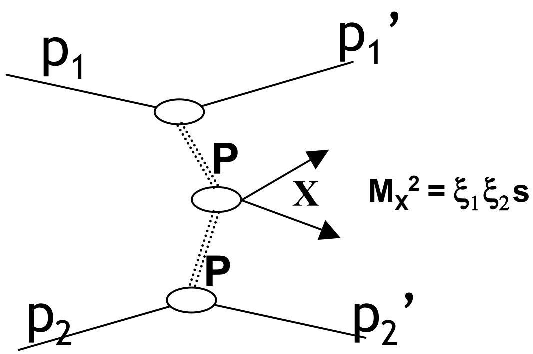
Mass resolution at 420 m and 420+220m

Note:
beam position accuracy
10 μm



DPE cross-sections



β^*=1540 m $\int_{1} L\, dt = 40\ \mathrm{nb}^{-}$

β^*=172 m $\int_{3days}^{3days} \mathbf{L}\, dt = 10\ \mathrm{pb}^{-1}$

- χ_{c0} 3μb x BR(10^{-3}) ~ 3 nb
- χ_{b0} 4nb x BR(10^{-3}) ~ 4 pb

- pp → pXp ~ 0.1 - 1 mb
- pp → p j_1 j_2 p

  pt_{jet} >10 GeV inclusive ~ 1 μb

  exclusive ~ 7 nb

jet-jet background to the Higgs:

- pp → p j_1 j_2 p

  M(j_1 j_2) = 120 GeV

  exclusive ~ 18 pb / ΔM= 10 GeV

(Eur. Phys. J.C25,391)

Conclusions

Measure total cross-section σ_{tot} with a precision of 1 %
L = ~10^{28} cm^{-2} s^{-1} with β^{*} = 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 β^{*} = 1540 m optics at L = 2×10^{29} cm^{-2} s^{-1} :
semi-hard diffraction (p_T > 10 GeV)

With β^{*} = 170 m optics (under study) at L ~ 0.5 10^{32} cm^{-2} s^{-1}:
hard diffraction and DPE

Study of rare events (Higgs, Supersymmetry,…) with β^{*} = 0.5 m
using eventually detectors in the cold region (420m)

TOTEM and CMS will write a common physics LOI in 2005

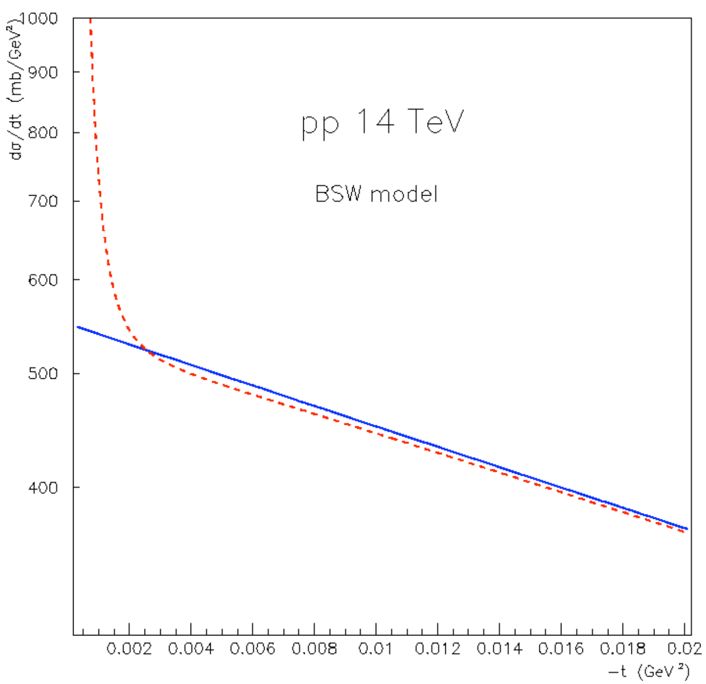
Extrapolation uncertainty due to Coulomb interference

Extrapolation to t=0 model dependent

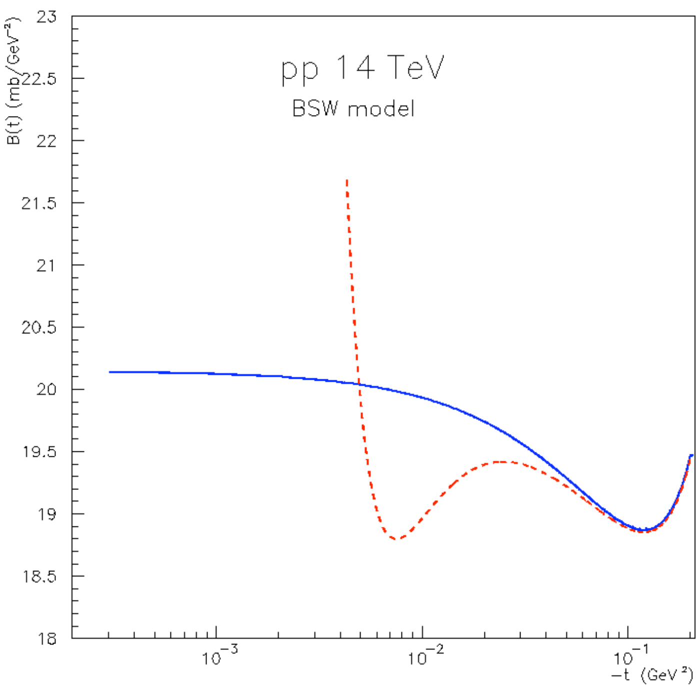
Error < 0.5 %

$d\sigma/dt \sim \exp(-Bt)$

Coulomb interference



Change of the slope B



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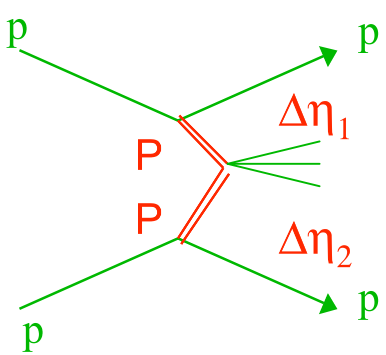
Diffraction

Example:

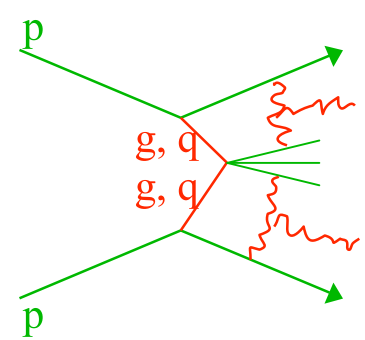


Exchange of colour singlets ("Pomerons")

→ rapidity gaps $\Delta\eta$

Most cases: leading proton(s) with momentum loss $\Delta p / p \equiv \xi$

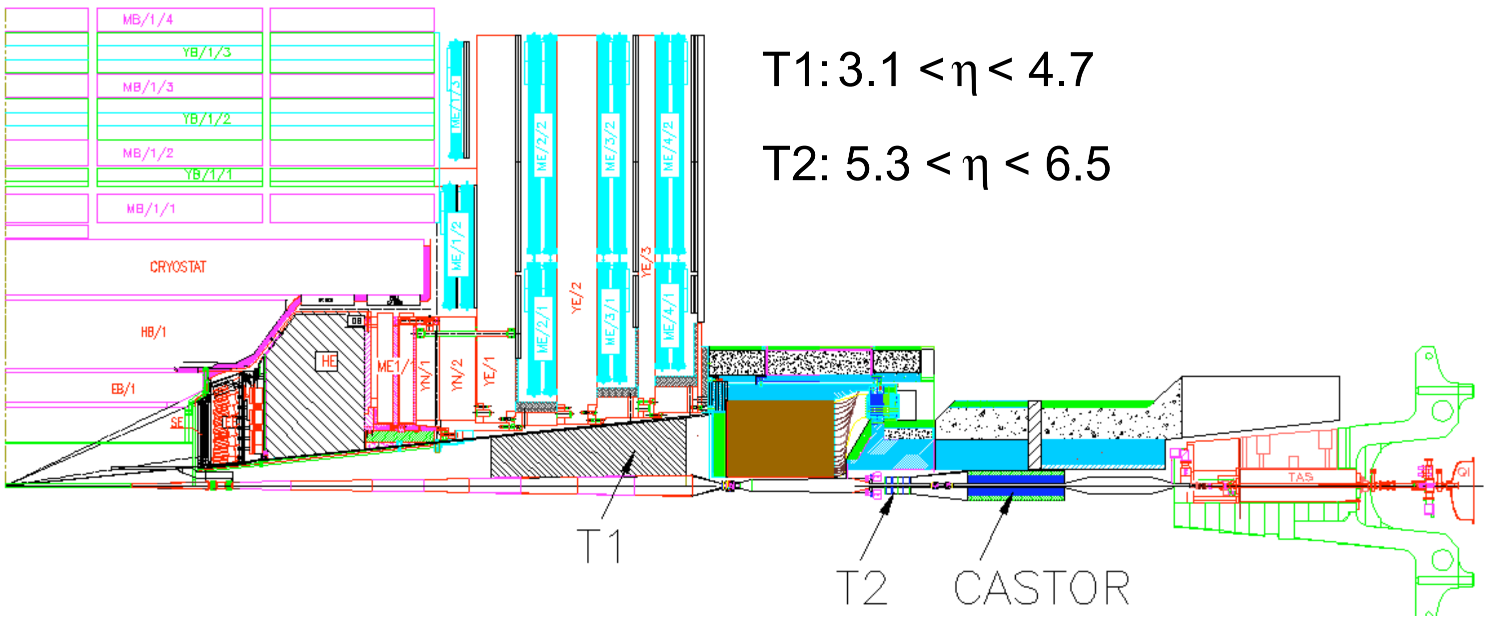
Unlike minimum bias events:



Exchange of colour triplets or octets:
Gaps filled by colour exchange in hadronisation

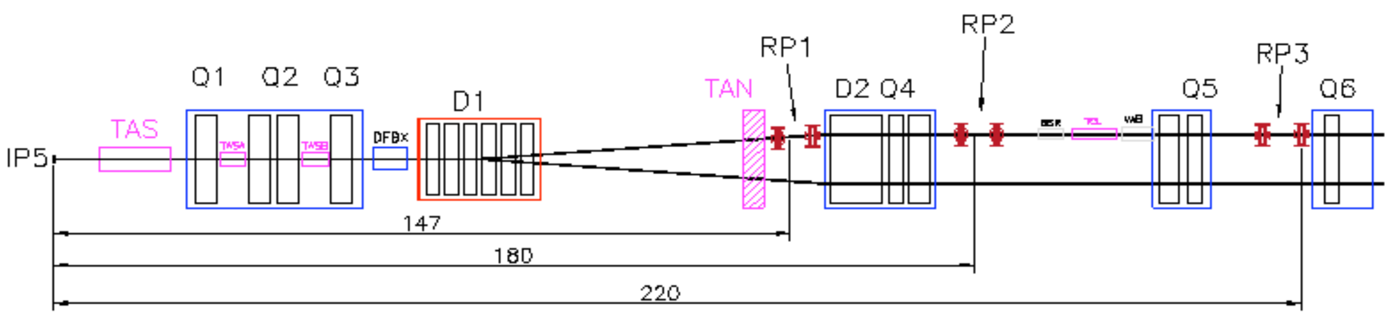
→ Exponential suppression of rapidity gaps:

$P(\Delta\eta) = e^{-\rho\,\Delta\eta}$, $\rho = dn/d\eta$



T1: 3.1 < η < 4.7

T2: 5.3 < η < 6.5



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

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

Optical Theorem ⇒

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

K.Eggert/CERN

Determination of the emission angle via the measurement at RP-147 m

θ precision ~ few μrad