HERA and the LHC workshop

TOTEM: Early diffractive physics at the LHC

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on behalf of the TOTEM collaboration

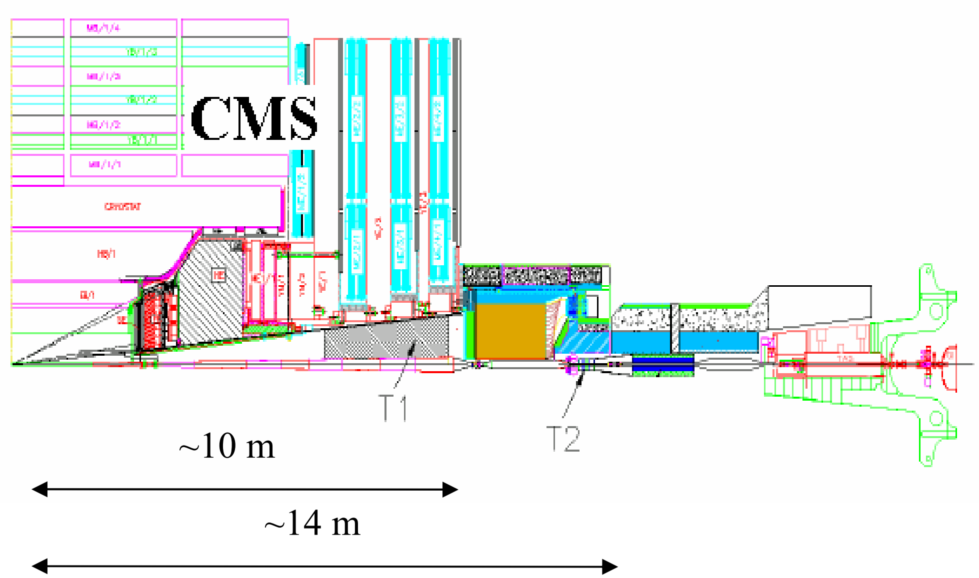
http://totem.web.cern.ch/Totem/

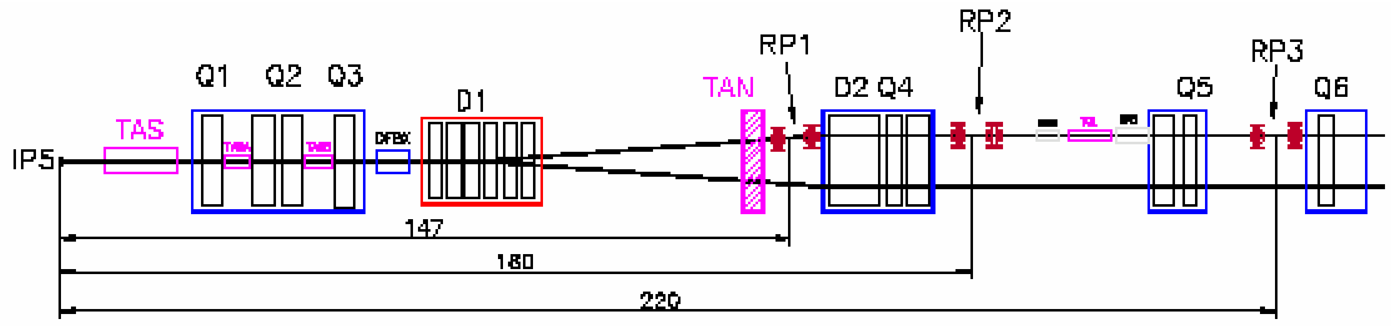
TOTEM goals

- Measurement of the p-p total cross section at 14 TeV with 1% uncertainty with the luminosity independent method
- Measurement of the p-p elastic scattering in the range $10^{-3} < -t < 10$ GeV^2
- Study of diffractive events, together with CMS.

Experimental apparatus

- Inelastic detectors
  - T1 – CSC Coverage ~3<|η|<~5
  - T2 – GEM Coverage ~5<|η|<~7
- Leading proton detectors
  - Silicon detectors inside Roman Pots (at 147,180,220 m from IP)

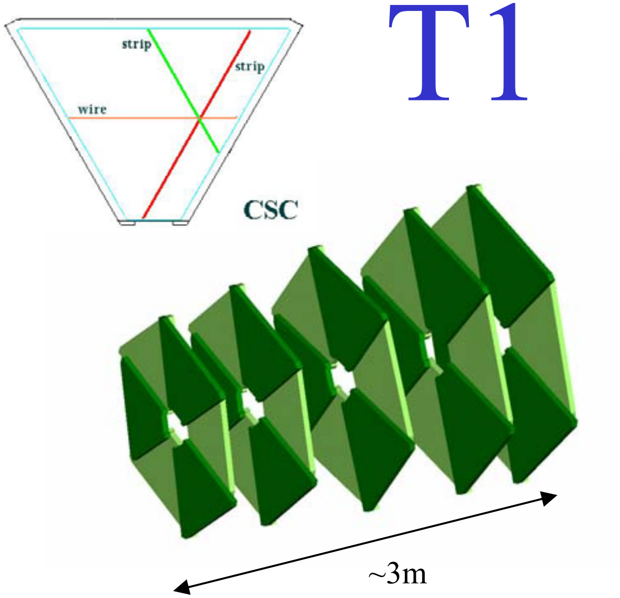




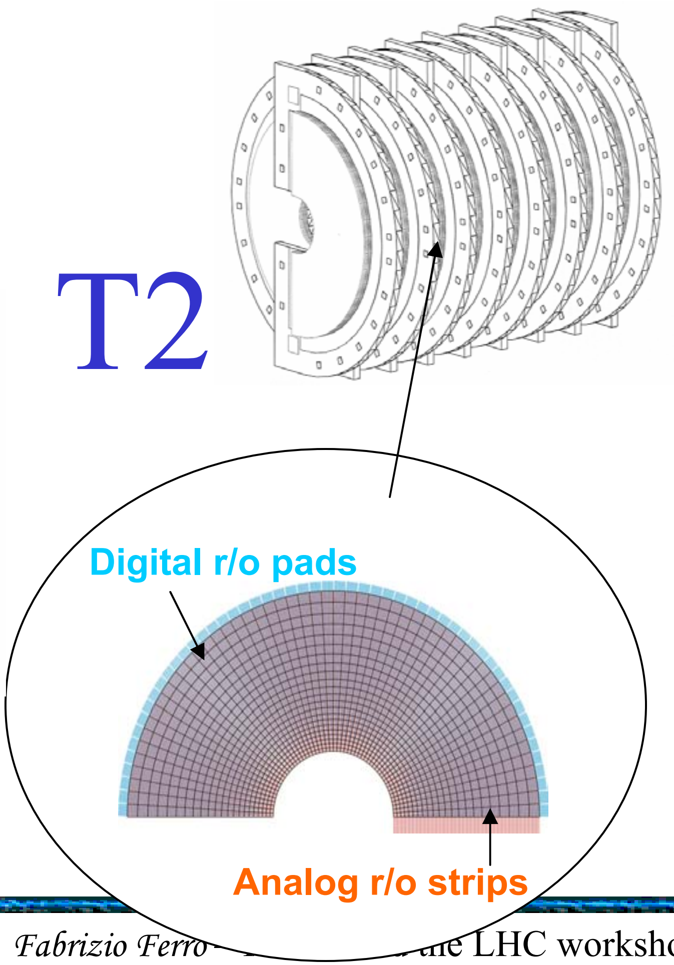
Inelastic detectors

TOTEM inelastic detectors are trackers which have been designed to discriminate between beam-beam and background (eg. beam-gas) events by means of the primary vertex reconstruction.

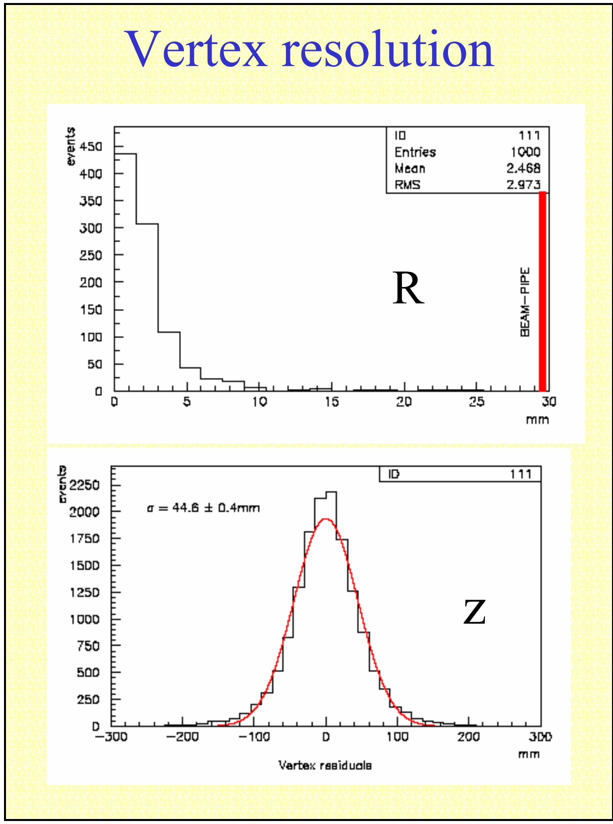
T1



T2



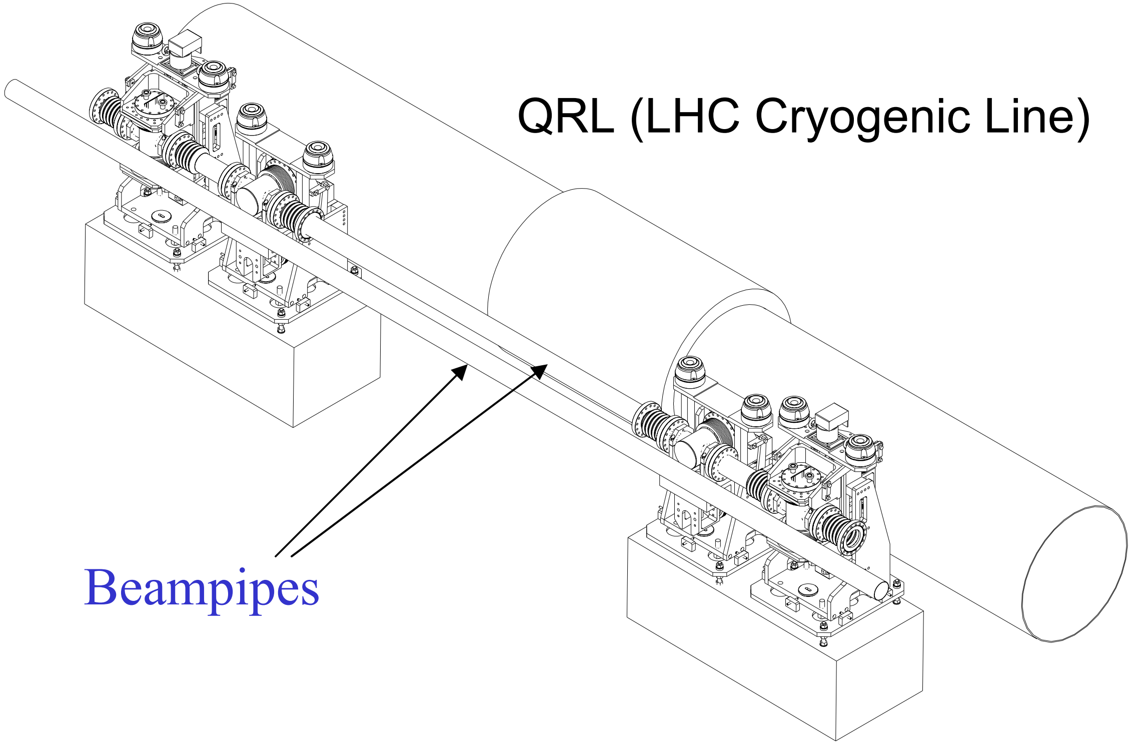
Vertex resolution



Roman pots

2004 prototype

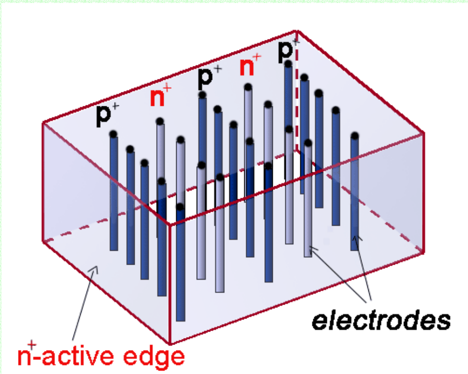
The RPs allow the leading proton detectors to move close to the circulating beam



Leading proton detectors

The LPD have to be efficient starting at 10σ(~1mm)+0.5mm and must provide good (~20μm) resolution, hence detectors with a small inefficient edge.

Si 3D

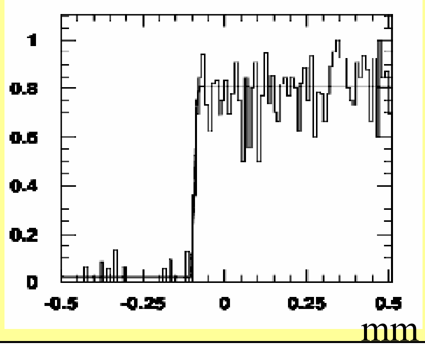


Electrodes created inside the *bulk*.

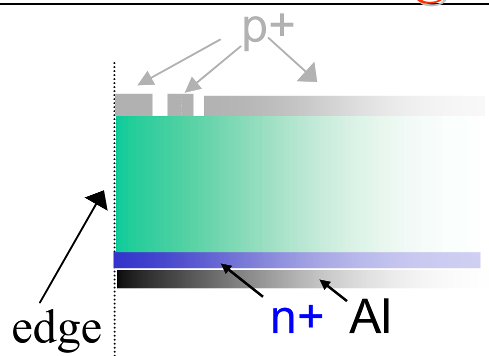
The edge is an electrode.

Dead edge < 10 μm

Test SPS: transition in ~6μm

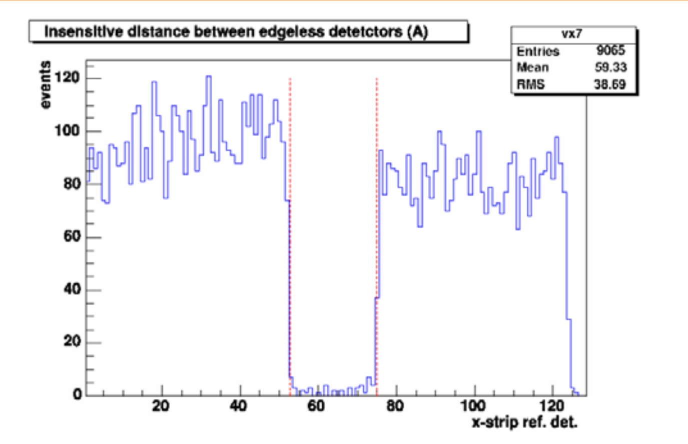


Planar Si with *guard rings*



T~-20C

Reduced guard rings ~70μm



Transition in ~60μm

TOTEM Optics Conditions

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

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

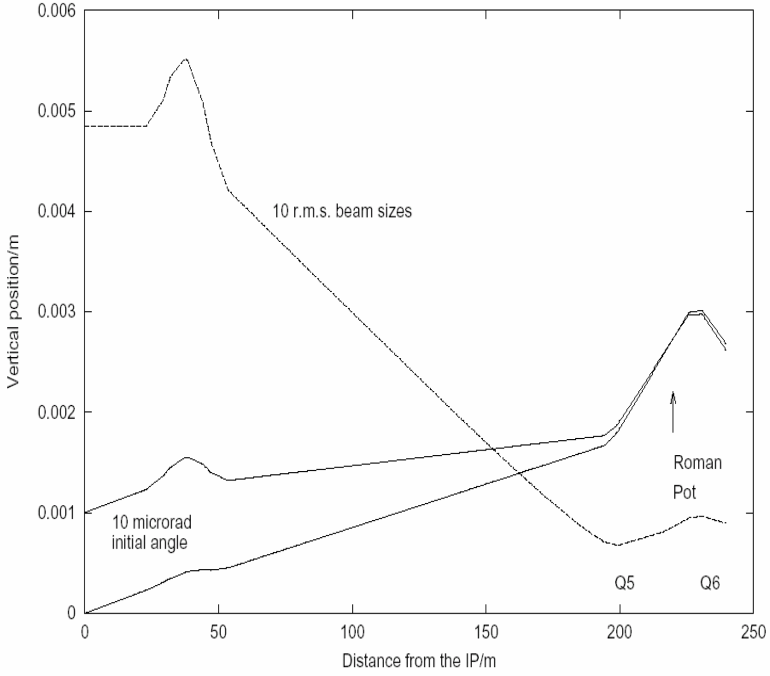
Parallel-to-point focusing (v=0) :

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



Measurement of σ_{tot}

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

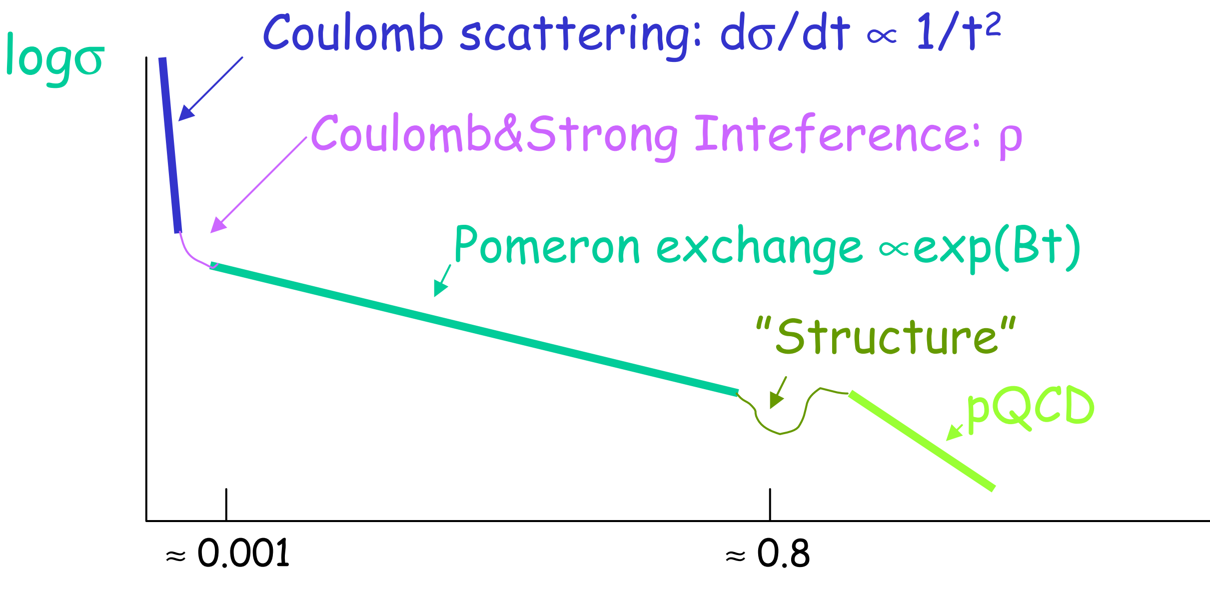
$$\mathrm{L}\sigma_{tot}^{2} = \frac{16\pi}{1+\rho^{2}} \times \left.\frac{dN}{dt}\right|_{t=0}$$

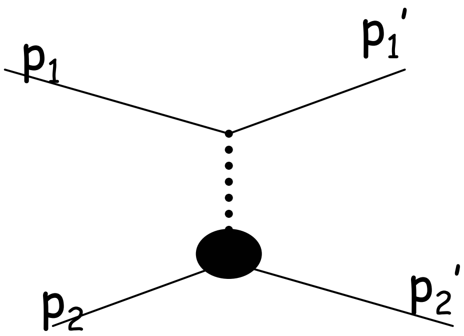
$$\mathrm{L}\sigma_{tot} = N_{elastic} + N_{inelastic}$$

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

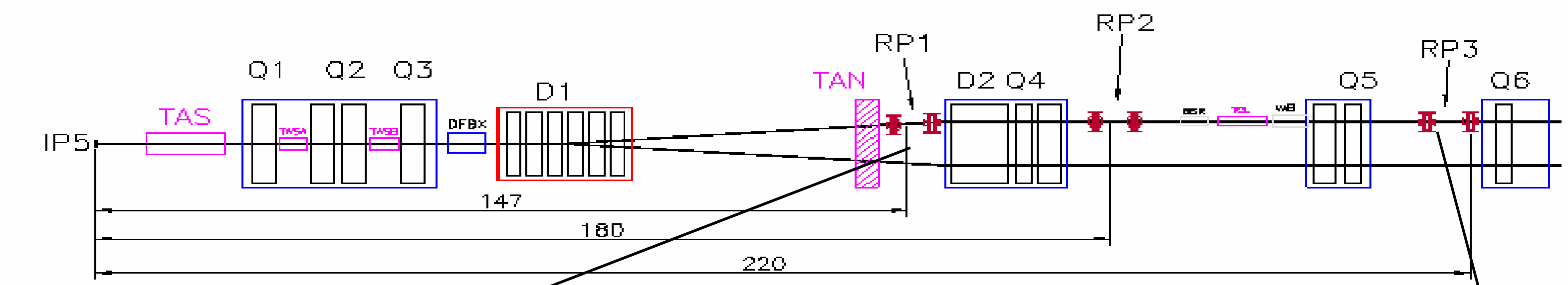
Measurement of the elastic and inelastic rate with a precision better than 1%.

Elastic Scattering and Diffraction



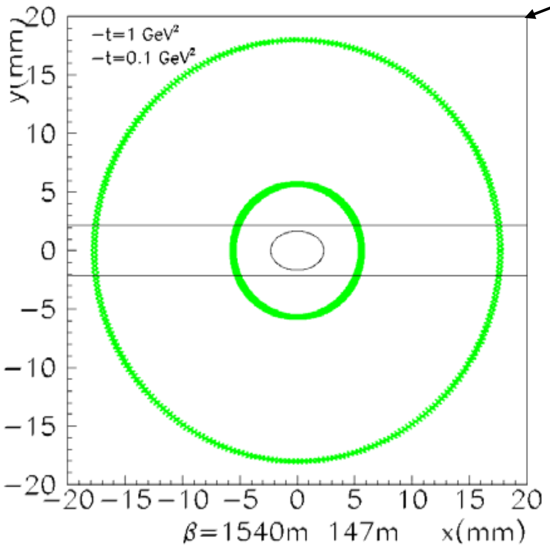


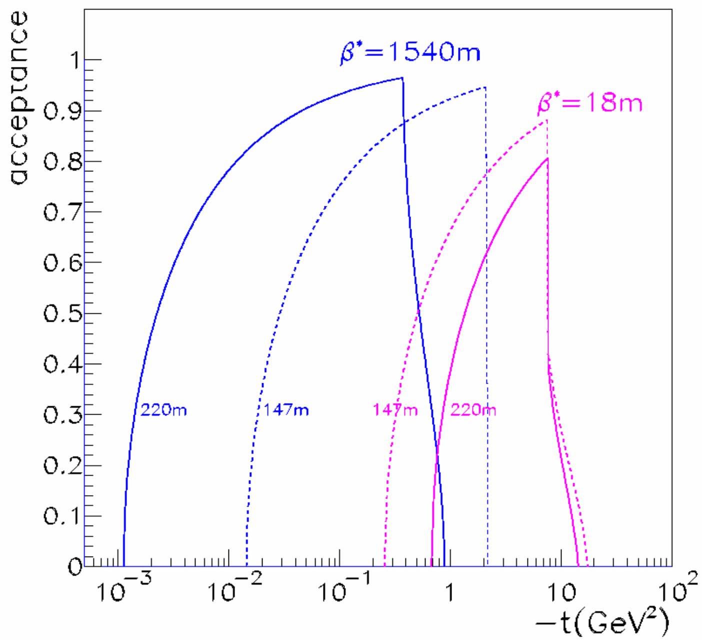
Region	Characteristic $-t$ $(GeV/c)^2$	Run type[1]
Coulomb region	$\leq 10^{-4}$	very high β^*
Coulomb –Strong Interference	$\approx 10^{-3}$	high β^*
Pomeron – Diffraction	$\geq 10^{-3}$	high/low β^*
Structure – Peaks & Bumps	≈ 0.8	low/high β^*
Large $-t$ – Perturbative QCD	≥ 5	low β^*

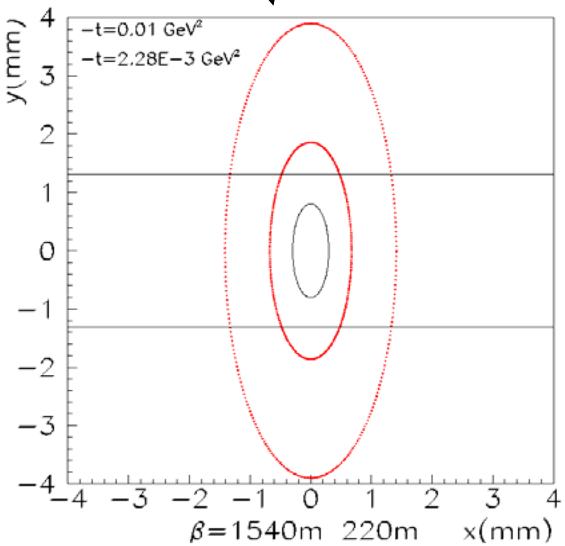


Elastic Scattering

β* = 1540 m

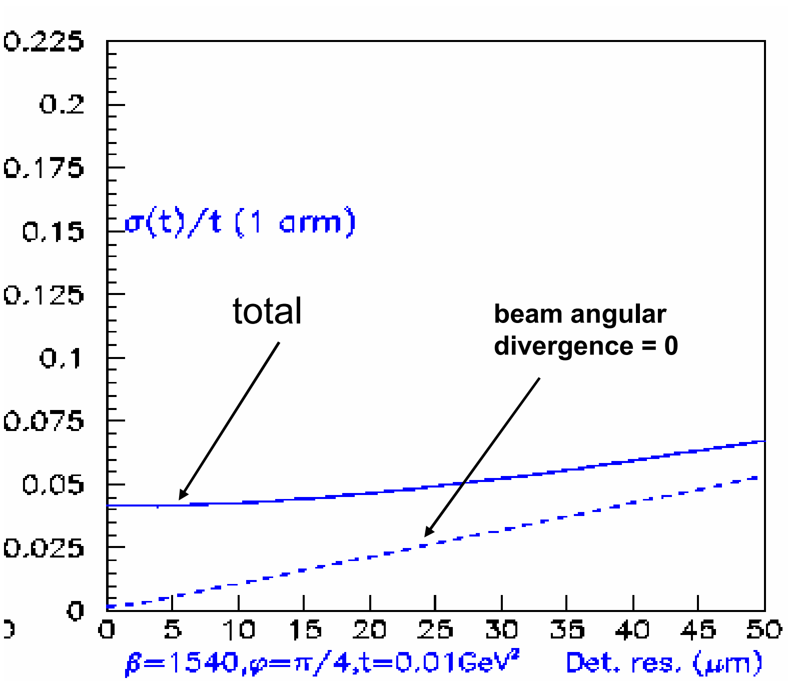




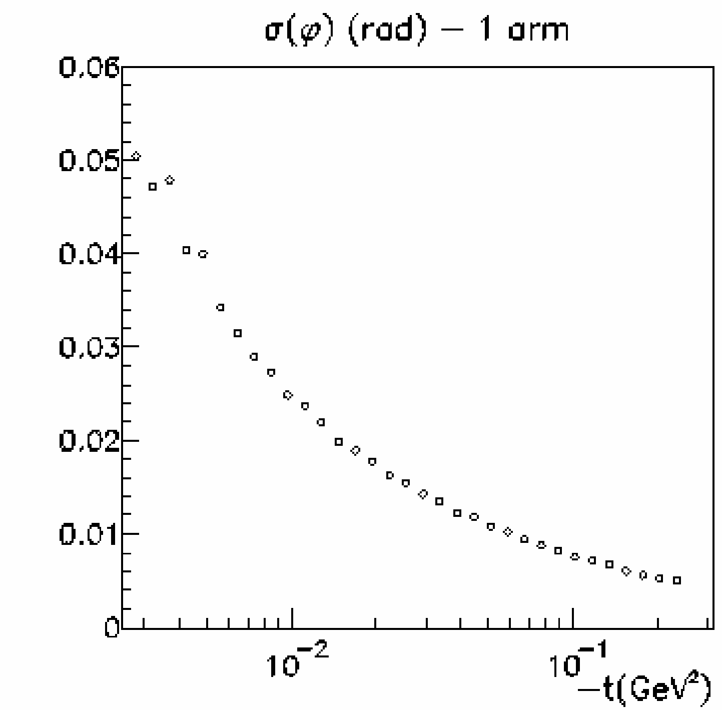


t and φ resolution

σ(t)/t vs detector resolution

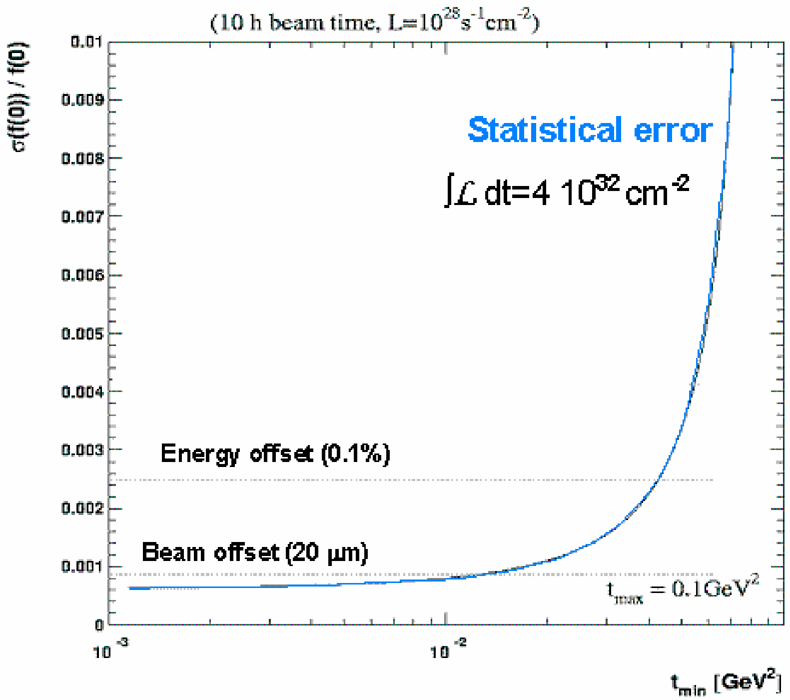


φ resolution vs t



Extrapolation to t=0

The measurement of σ_{tot} needs $(dN/dt)_{t=0}$ which can be estimated with a statistical uncertainty of ~0.1% (considering 10^7 reconstructed events after 10h run at $L=10^{28}$).



	Uncertainty	Fit error
Beam divergence	10%	0.05%
Energy offset	0.05%	0.1%
Beam/ detector offset	20µm	0.06/0.08 %
Crossing angle	0.2µrad	0.08/0.1%
Theoretical uncertainty (model dependent)		~ 0.5%

Inelastic cross section

Event selection:

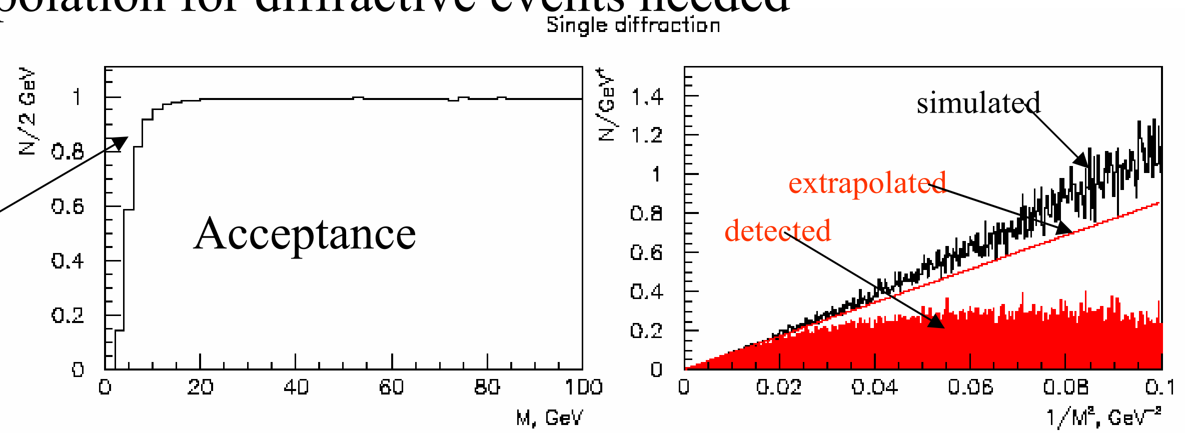
- trigger from T1 or T2 (*double arm o single arm*)
- Vertex reconstruction (to eliminate beam-gas bkg.)

Lost events

Losses	Double arm		Single arm	
Process	%	mb	%	mb
Minimum bias	0.5	0.3	< 0.1	< 0.06
Double Diffractive	39.5	2.8	4.6	0.3
Single Diffractive	-	-	17.9	2.5

Extrapolation for diffractive events needed

Loss at low masses



Total cross section

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

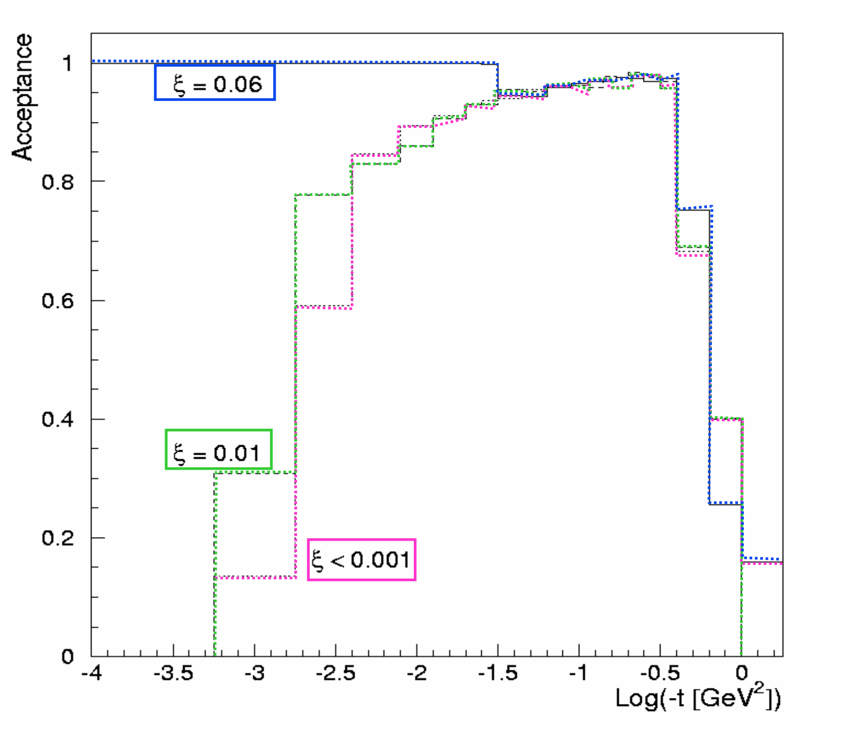
Losses (mb)

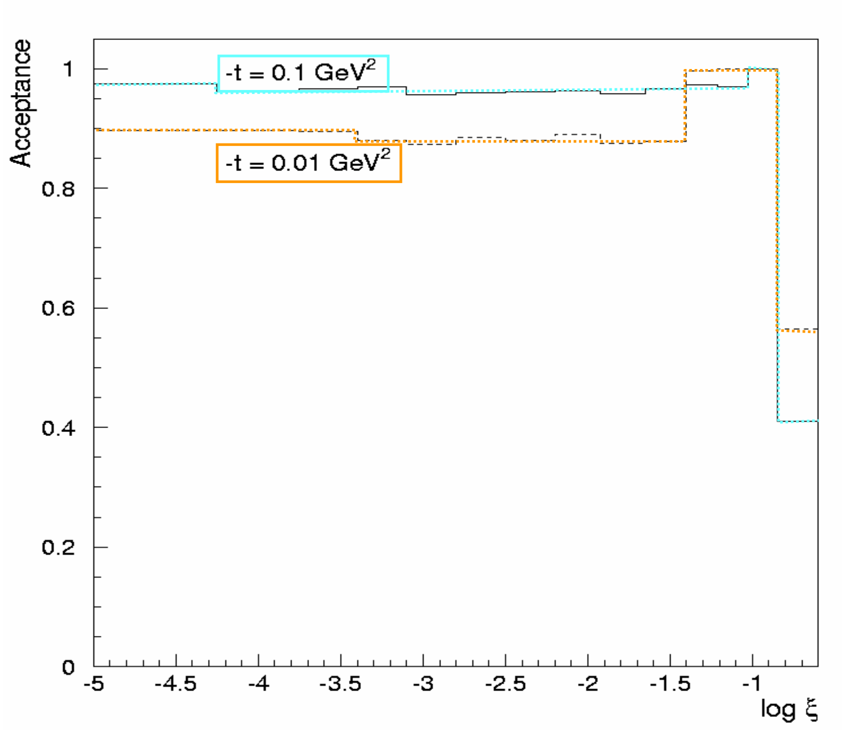
	σ(mb)	Double arm	Single arm	Uncertainty after extrapolation
Minimum bias	58	0.3	0.06	0.06
2 x single diffractive	14	-	2.5	0.6
Double diffractive	7	2.8	0.3	0.1
Double Pomeron	1	-	-	0.02
Elastic Scattering	30	-	-	0.1

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

1%

Diffraction at high β^*





>90% of all diffractive protons are seen in the Roman Pots

proton momentum can be measured with a resolution of few 10^{-3}

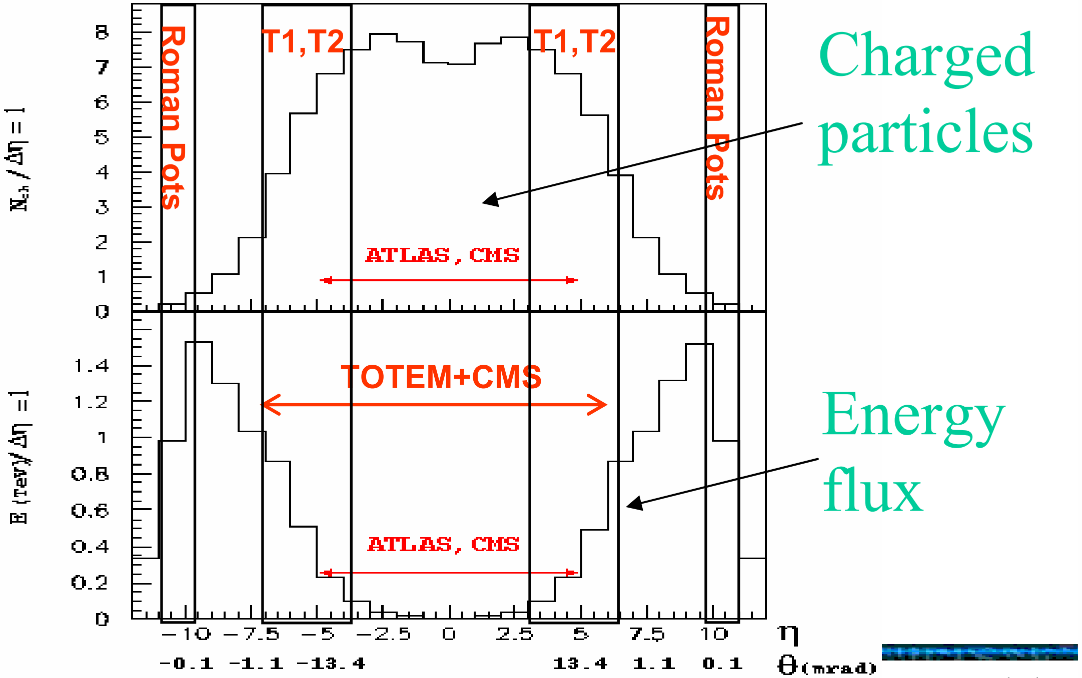
CMS/TOTEM

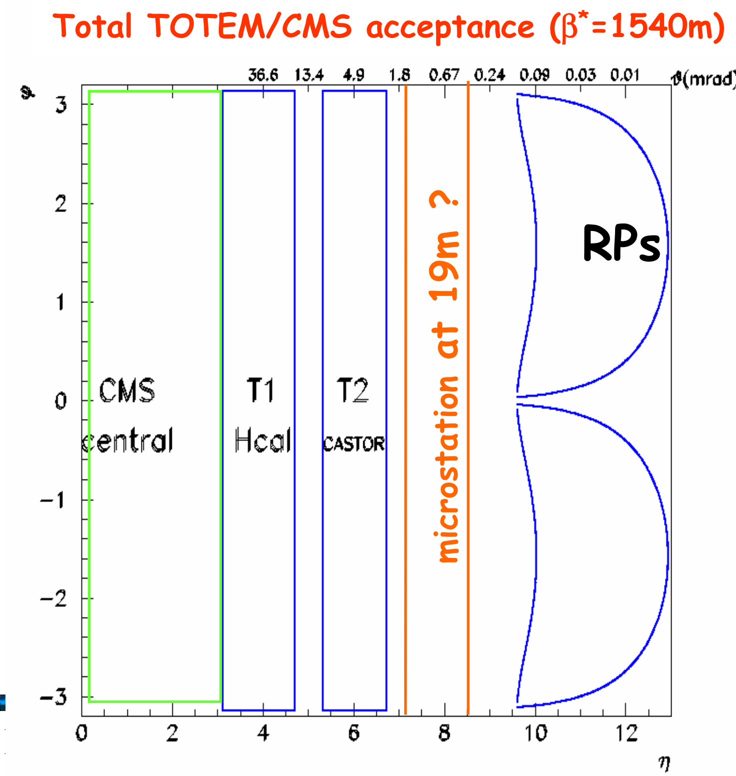
CMS/TOTEM is the largest acceptance detector ever built at a hadron collider

For the first time at a collider **large acceptance detector which measures the forward energy flow**

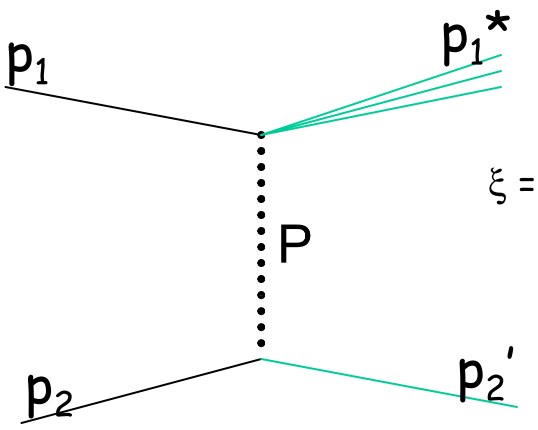
1 day run at large beta (1540m) and $L=10^{29} cm^{-2}s^{-1}$:
100 million minimum bias events, including all diffractive processes

>90% of all diffractive protons are detected

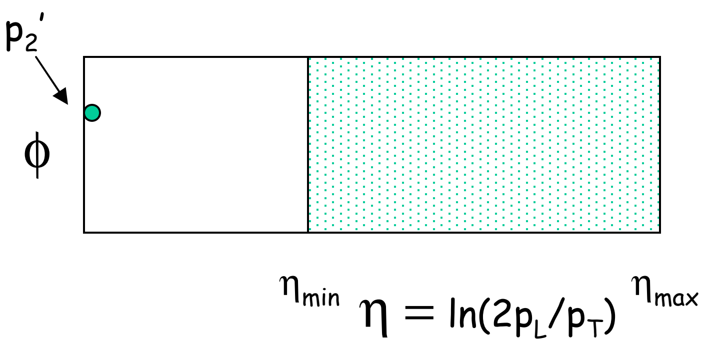


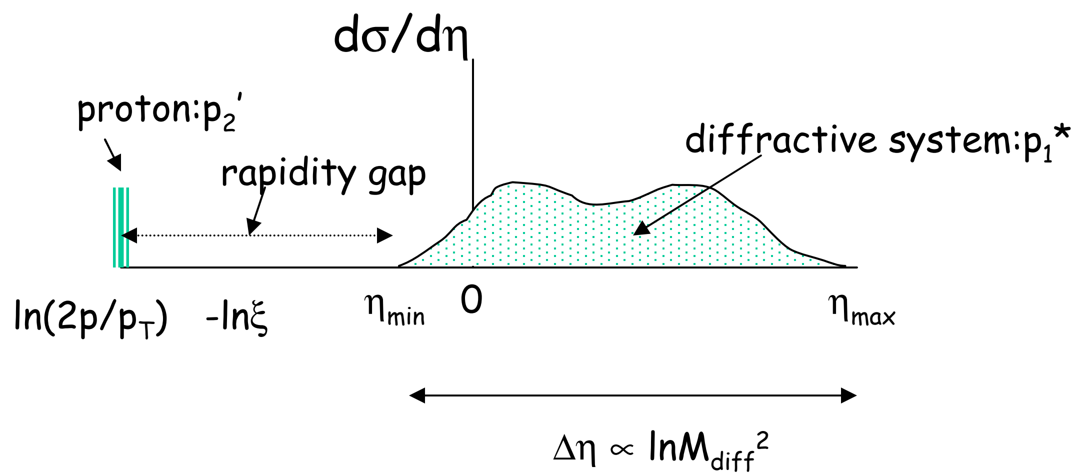


Single Diffractive Excitation

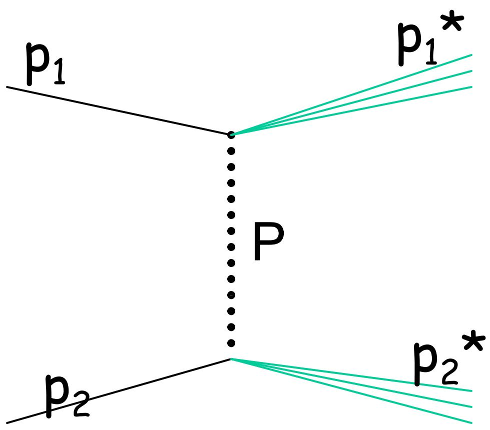


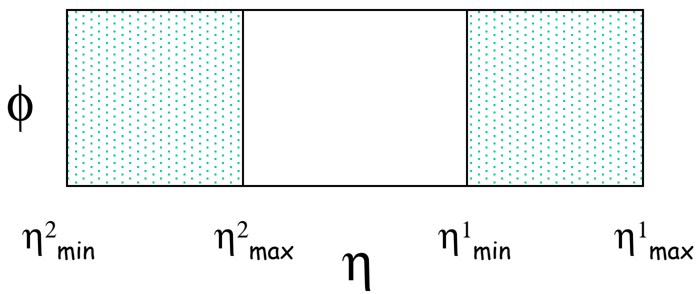
$\xi = 1 - x_F = M^2/s$

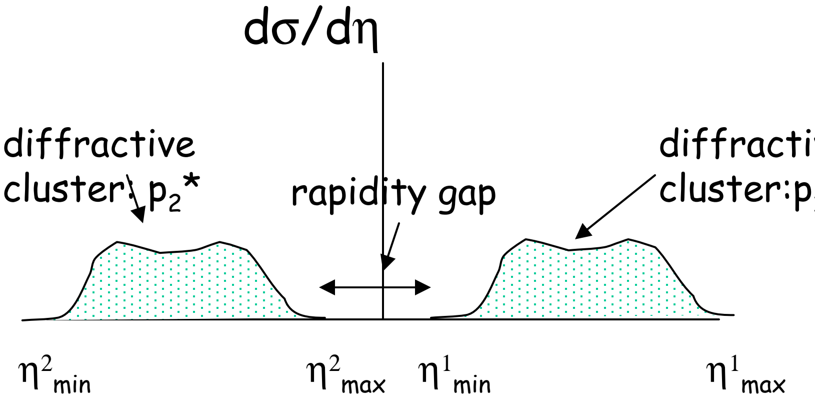




Double Diffractive Excitation

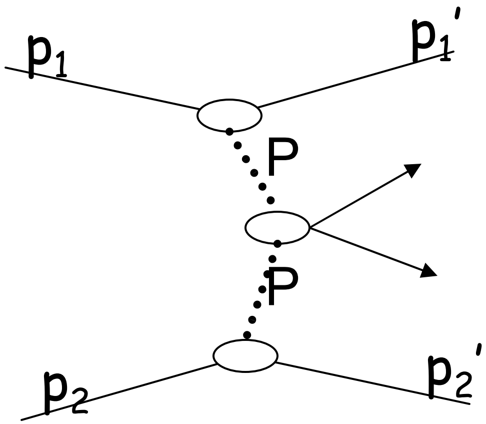






Double Pomeron Exchange

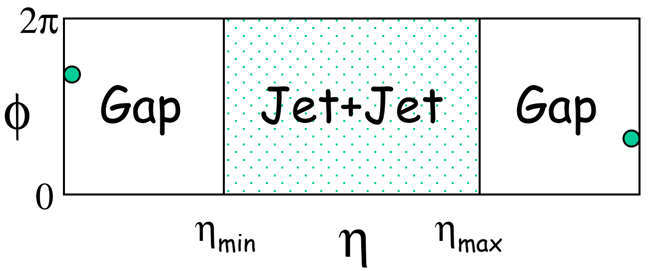
The Pomeron has the internal quantum numbers of vacuum.

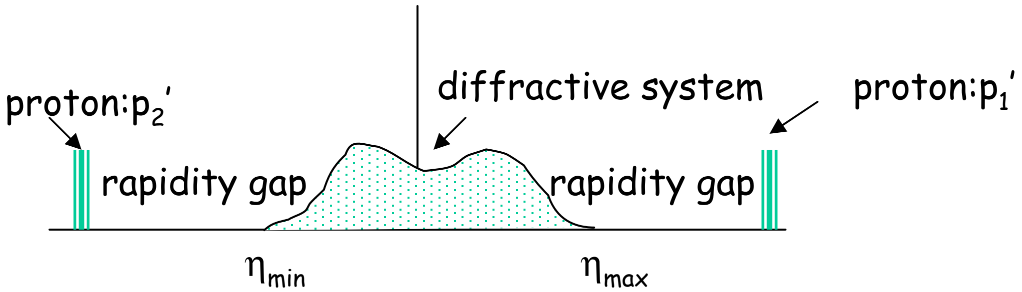


PP: C = +, I=0,...

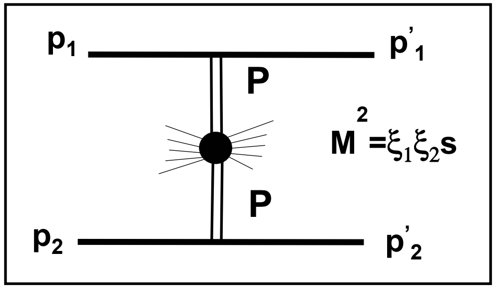
P: $J^P = 0^+, 2^+, 4^+,...$

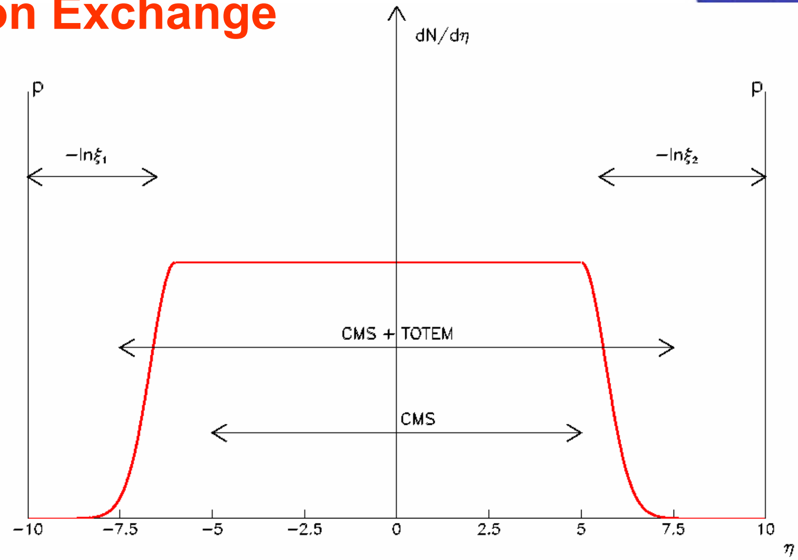
$\Rightarrow$ PP: $J^{PC} = 0^{++}$

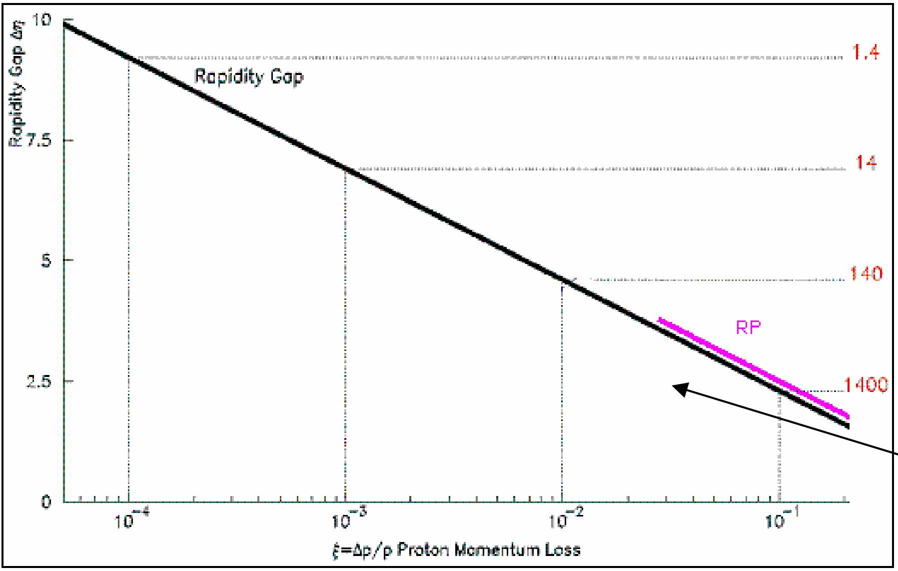




Double Pomeron Exchange







$\xi=\Delta p/p$ proton momentum loss

CMS/TOTEM collaboration for diffractive physics

β^* = 1540 m σ_ξ = 0.5%

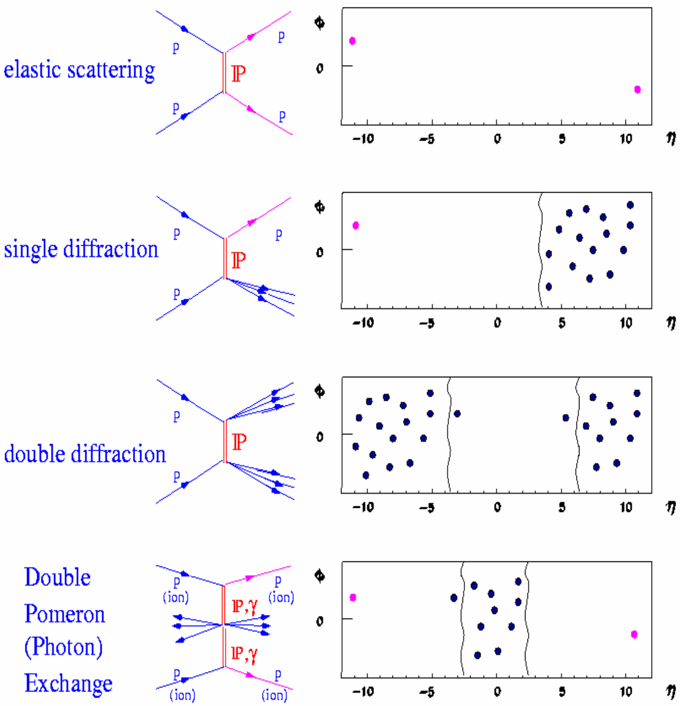
β^* = 200-400 m σ_ξ = few ‰

β^* = 0.5 m σ_ξ = few ‰

Trigger via Roman pots	$\xi > 2.5\ 10^{-2}$
Trigger via rapidity gap	$\xi < 2.5\ 10^{-2}$

Level-1 Trigger

$L=10^{28} cm^{-2} s^{-1}$



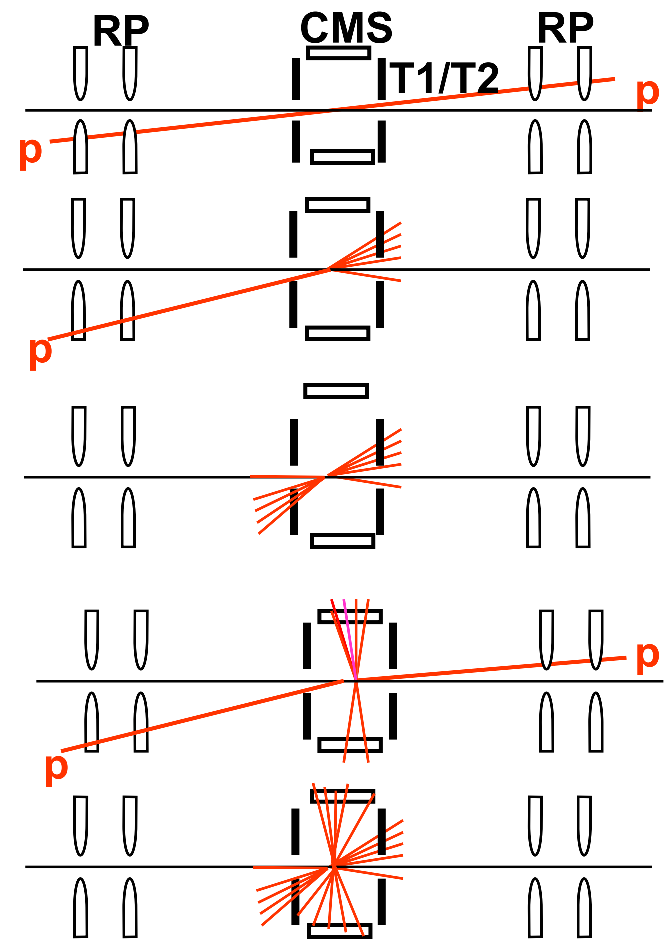
Elastic Trigger:
Signal: 500 Hz
Background: 20 Hz

Single Diffractive Trigger:
Signal: 200 Hz
Background: 0.1 Hz

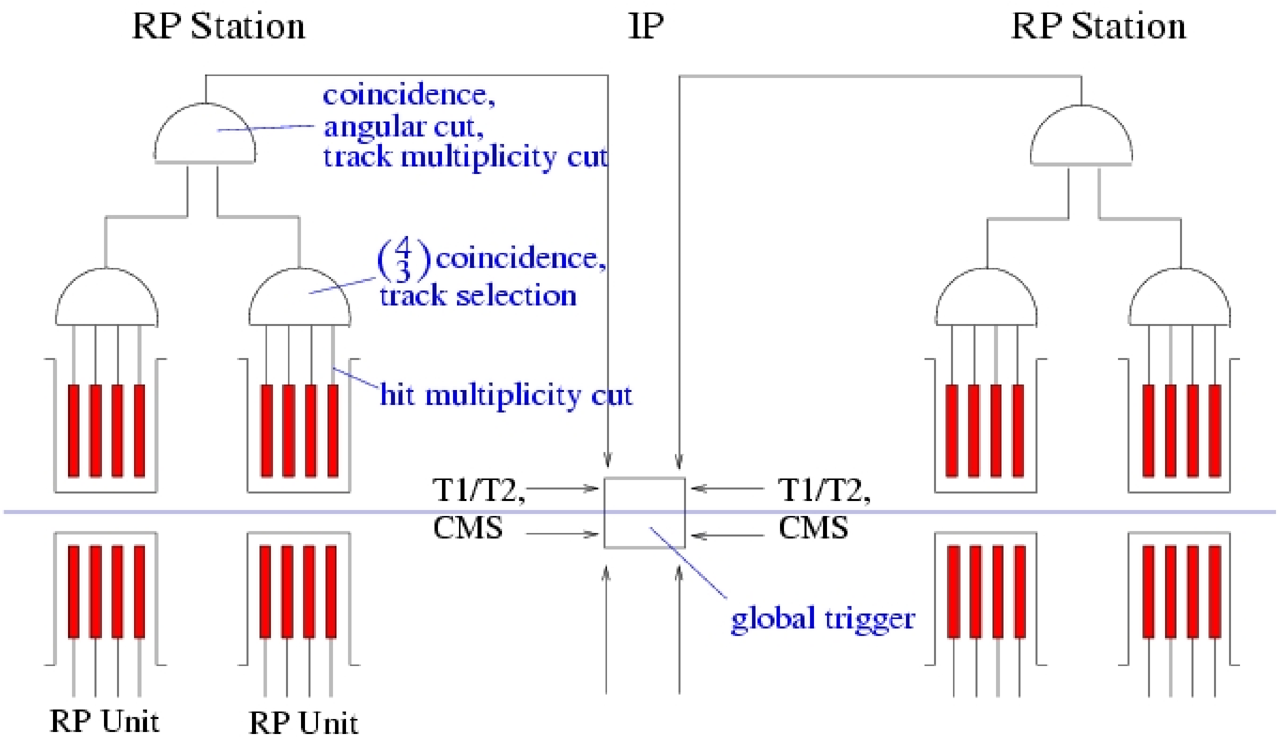
Double Diffractive Trigger:
Signal: 100 Hz

Central Diffractive Trigger:
Signal: 10 Hz
Background: 2 Hz

Minimum Bias Trigger:
Signal: 1 kHz



The Trigger Logic



Background Suppression

- Beam Halo (dominant): Reduction only by 2-arm coincidence
- Shower particles from beam-beam, beam-gas, beam-machine interactions: Reduction by:
  - Multiple coincidences
  - Angular cuts
  - Hit and track multiplicity cuts

- To make common running easier, DAQ and Trigger will be implemented in CMS-compatible fashion
  - Hardware and software compatibility opens the possibility for TOTEM to join the CMS DAQ when making common runs.
  - Front-ends will comply with CMS Trigger Control System if TOTEM wants to join the CMS Trigger.
- Possible triggering schemes
  - The CMS GT receives the TOTEM trigger decision and sends L1A both to TOTEM and CMS front-ends.

Running Scenarios

Scenario (goal)	1 low |t| elastic, σ_{tot} , min. bias	2 diffr. phys., large p_T phen.		3 intermediate |t|, hard diffract.	4 large |t| elastic
β^* [m]	1540	1540		200 - 400	18
N of bunches	43	156		936	2808
Half crossing angle [μrad]	0	0		100 - 200	160
Transv. norm. emitt. [μm rad]	1	1	3.75	3.75	3.75
N of part. per bunch	0.3×10^{11}	0.6×10^{11}	1.15×10^{11}	1.15×10^{11}	1.15×10^{11}
RMS beam size at IP [μm]	454	454	880	317 - 448	95
RMS beam diverg. [μrad]	0.29	0.29	0.57	1.6 - 1.1	5.28
Peak luminos. [$cm^{-2} s^{-1}$]	1.6×10^{28}	2.4×10^{29}		$(1 - 0.5) \times 10^{31}$	3.6×10^{32}

Running scenario examples

Luminosity $2 \cdot 10^{29}$ cm $^{-2}$ s $^{-1}$

Data taking for soft diffraction : 20 mb → 4 kHz → $4 \cdot 10^{8}$ events / 1 eff. Day

Double Pomeron : 1 mb $2 \cdot 10^{7}$ events / 1 eff. Day

Precise study of soft diffraction phenomena

Luminosity 10^{31} cm $^{-2}$ s $^{-1}$

Few day runs with 4 10^{5} s → 4 10^{36} cm $^{-2}$ → 4000 evts / nb

Double Pomeron exchange

High masses order of TeV

χ_c → 10^{6-7} events before decay

χ_b → 10^{3-4} events before decay

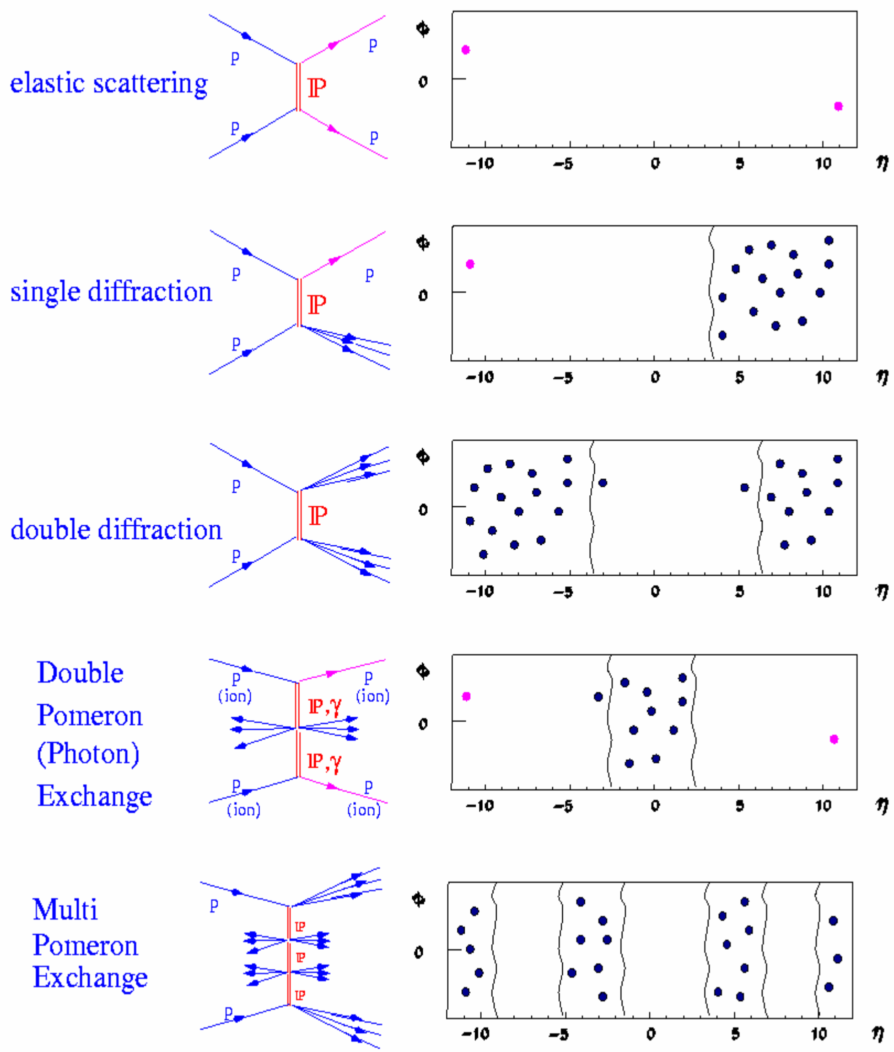
Large pt di jets → coplanar dijet with two accompanying protons and nothing else

Single diffraction with high pt jets and leptons

Study of rapidity gaps with identified protons

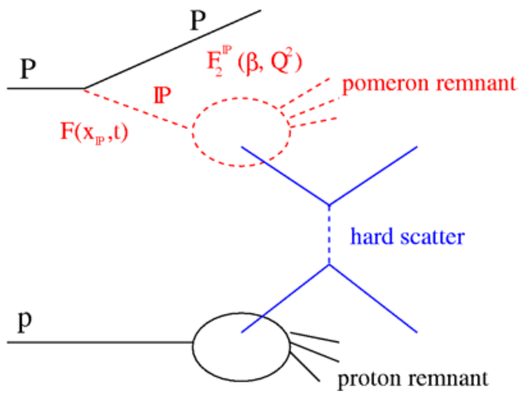
- **TOTEM TDR** submitted to the LHCC in January LHCC 2004-002/TOTEM TDR 1
- A TDR on the common CMS/TOTEM physics program will be submitted later.

Diffraction at LHC:



PP scattering at highest energy

Soft & Hard Diffraction



$\xi < 0.1 \Rightarrow$ O(1) TeV "gluon beams"

E.g. Structure of the Pomeron F(β,Q²)

β down to ~ 10^{-3} & Q^2 ~10^4 GeV²

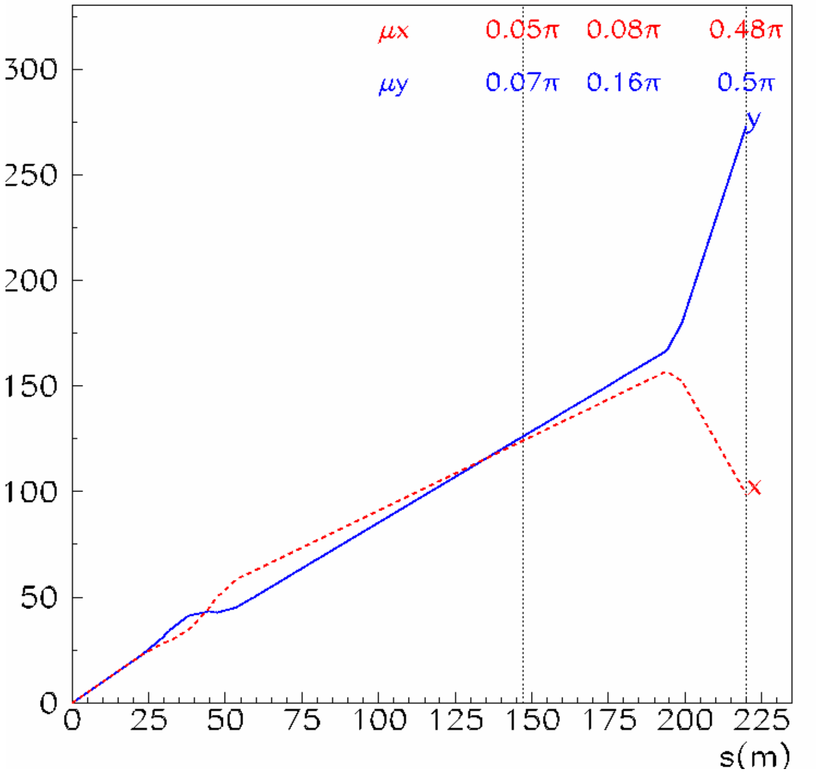
Diffraction dynamics?

Exclusive final states ?

Rapidity gap physics - multigaps!

High β optics: lattice functions

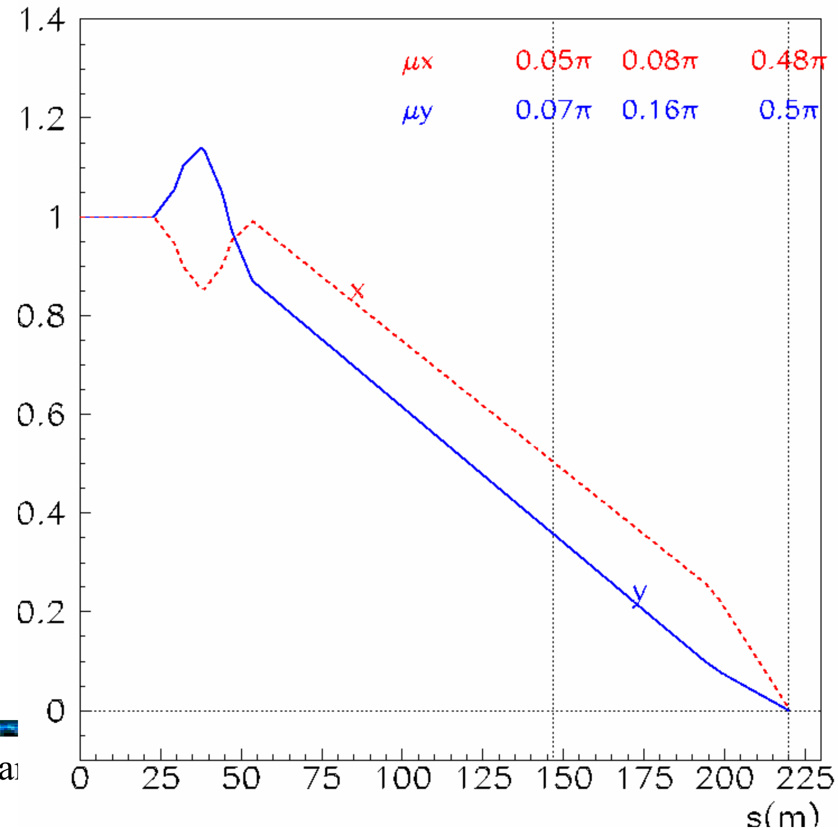
L



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

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

V



$$y = L_y \theta^*_y + v_y y^*$$

$$x = L_x \theta^*_x + v_x x^* + D\xi$$