IFAE 2004 - Torino

TOTEM: fisica diffrattiva all'LHC

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

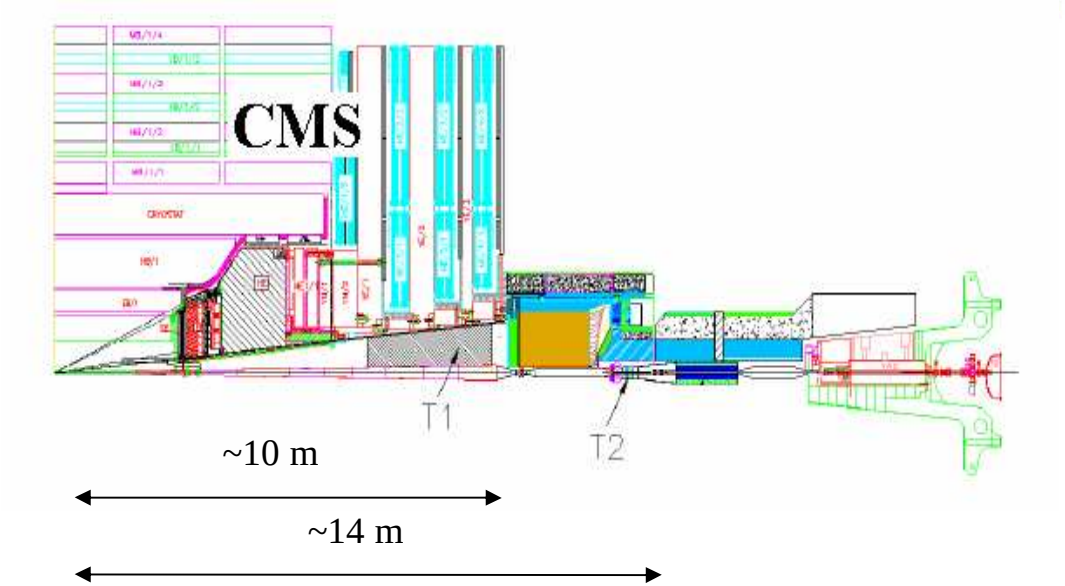
Collaborazione TOTEM:
INFN Bari, CERN, ILK Dresda, INFN Genova, HIP Helsinki, IP Praga, Brunel University

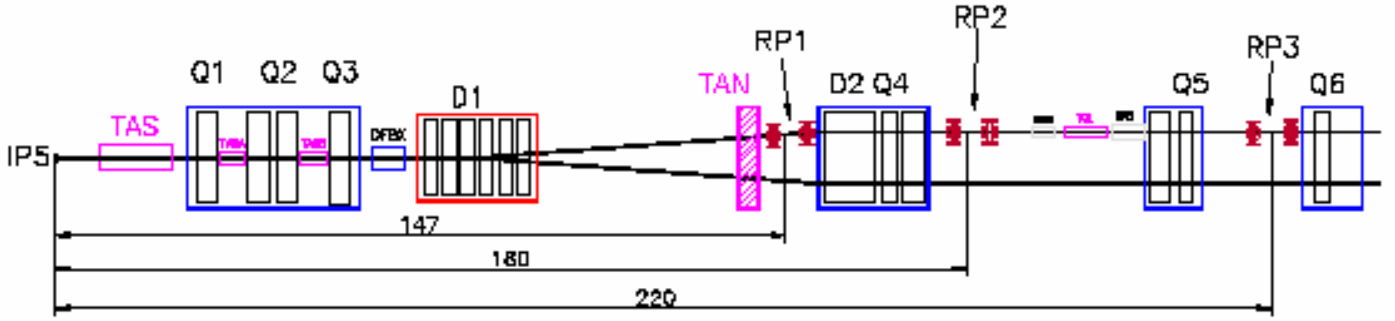
Obiettivi di TOTEM

- Misura della sezione d'urto totale p-p a 14 TeV con un'incertezza dell'1% e indipendentemente dalla luminosità
- Misura dello scattering elastico p-p nel range $10^{-3} < -t < 10$ GeV^2
- Studio di eventi diffrattivi, insieme con CMS.

Apparato sperimentale

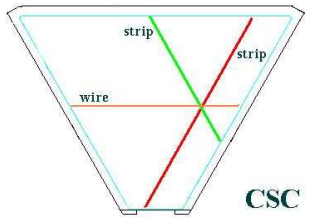
- Rivelatori inelastici
  - T1 – CSC Copertura ~3<|η|<~5
  - T2 – GEM Copertura ~5<|η|<~7
- Leading proton detectors
  - Rivelatori al Silicio dentro a Roman Pots (a 147,180,220 m dall'IP)





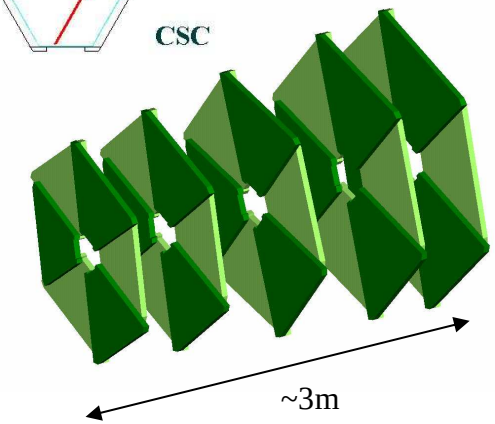
Rivelatori inelastici

I rivelatori inelastici di TOTEM sono tracciatori, disegnati per discriminare tra eventi beam-beam e di background (eg. beam-gas) per mezzo della riconstruzione del vertice primario.

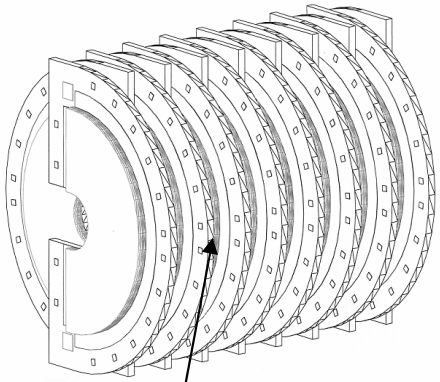


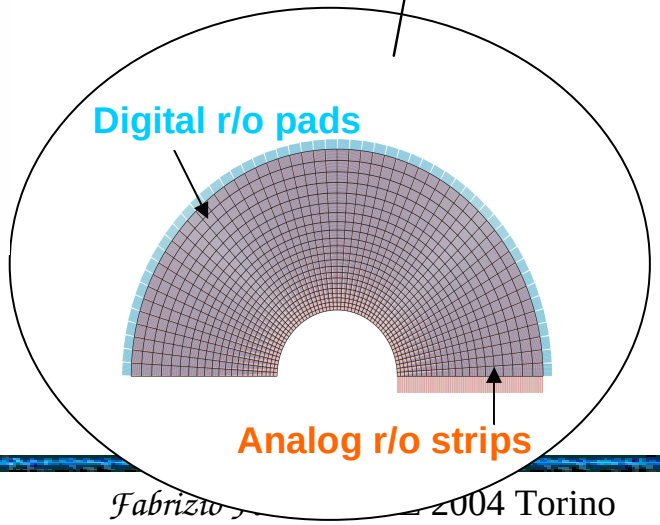
T1

CSC

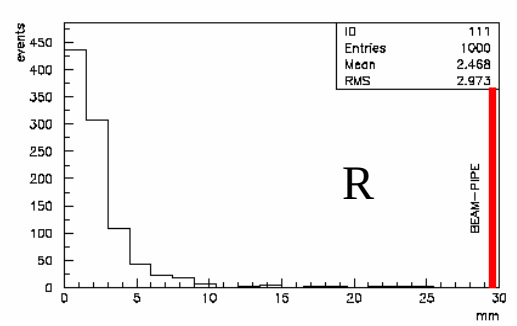


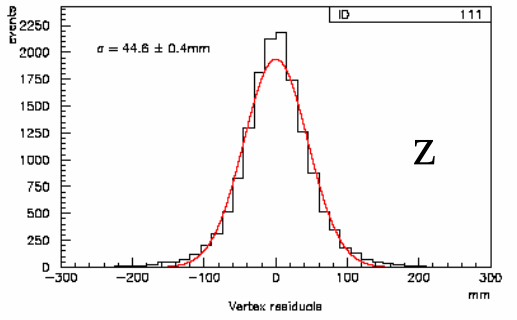
T2





Risoluzione del vertice

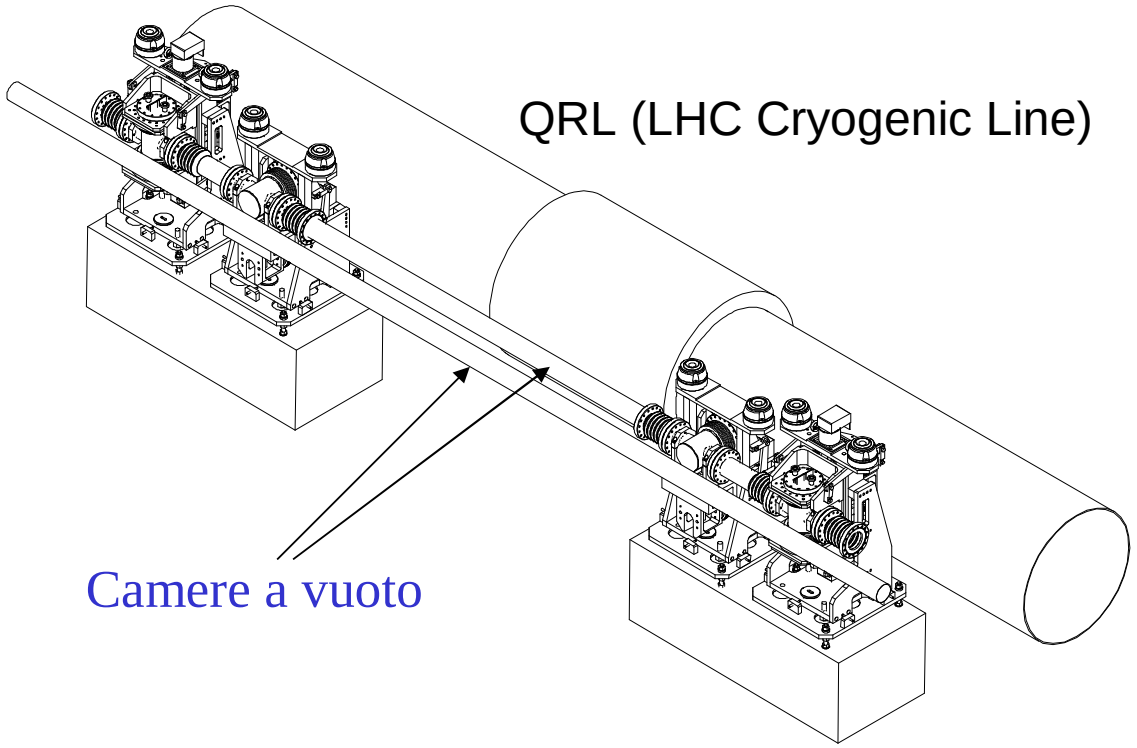




Roman pots

Prototipo 2004

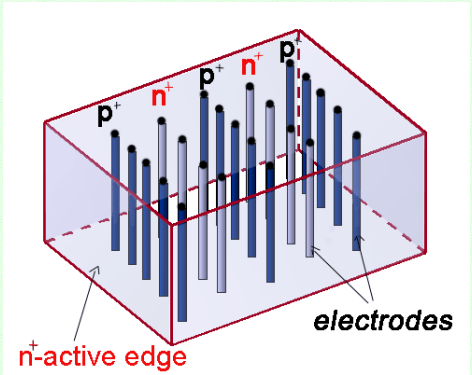
Le RP consentono ai leading proton detectors di avvicinarsi al fascio.



Leading proton detectors

I LPD devono essere efficienti a partire da 10σ(~1mm)+0.5mm e devono fornire una buona risoluzione (~20μm).

Si 3D

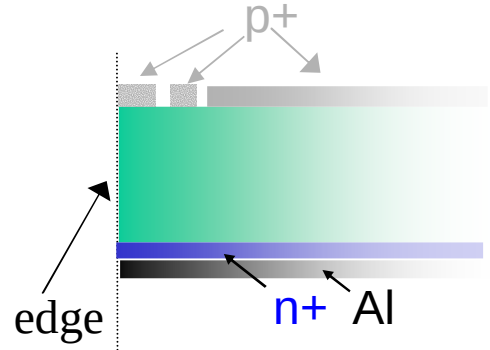


Elettrodi creati dentro il *bulk*.

Il bordo stesso è un elettrodo.

Regione morta < 10 μm

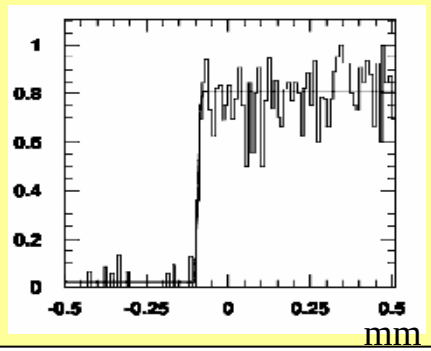
Si planari con *guard rings*

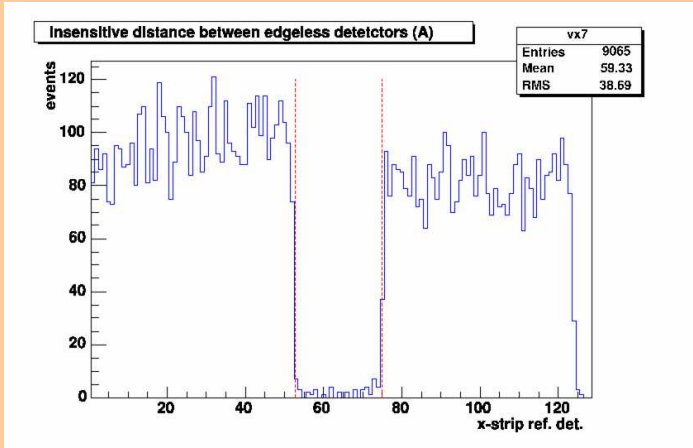


T~-20C

Guard rings ridotti ~70μm

Test SPS: transizione in ~6μm





Transizione in ~60μm

Ottica di LHC per TOTEM

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

TOTEM necessita di brevi run con un'ottica speciale ad alto-β* (1540m) e bassa ε

Angoli di scattering di pochi μrad

Alto-β per una misura precisa dell'angolo di scattering $\sigma(\theta^*) = \sqrt{\varepsilon} / \beta^* \sim 0.3\ \mu rad$

Di conseguenza: elevata dimensione del fascio $\sigma^* = \sqrt{\varepsilon}\,\beta^* \sim 0.4\ mm$

Numero di bunches ridotto (43 e 156) per evitare interazioni "a valle"

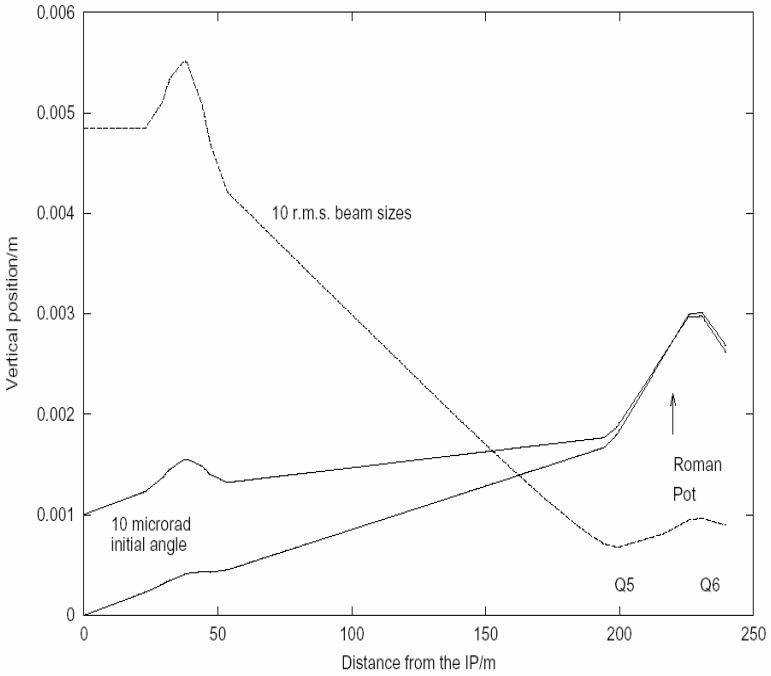
Parallel-to-point focusing (v=0) :

Le traiettorie di protoni diffusi allo stesso angolo ma provenienti da vertici differenti

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

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

Massimizzare L e minimizzre v



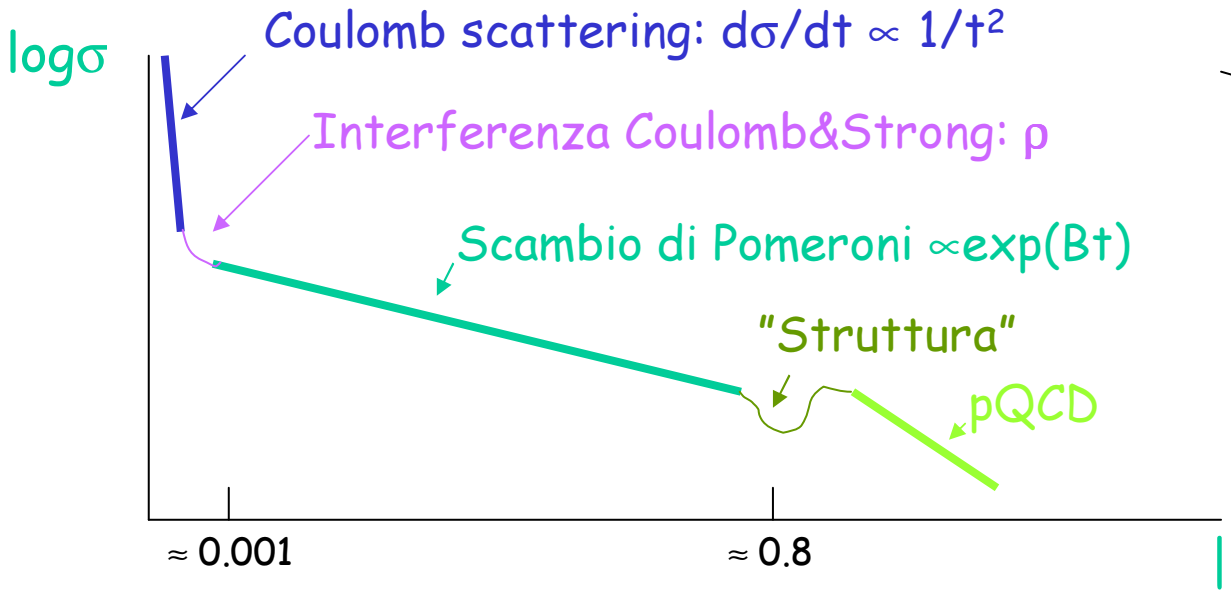
Misura di σ_{tot}

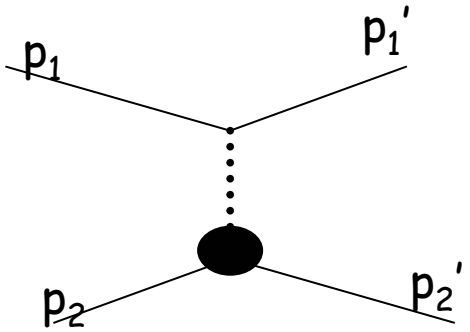
Misura della sezione d'urto totale indipendentemente dalla luminosità usando il Teorema Ottico.

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

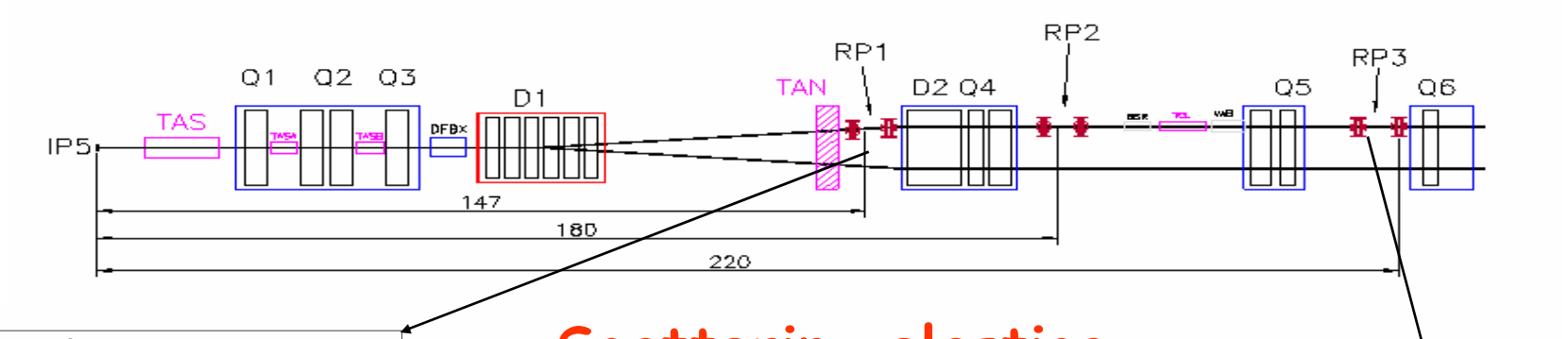
Misura dello scattering elastico e inelastico con una precisione inferiore all'1%.

Scattering elastico e diffrazione



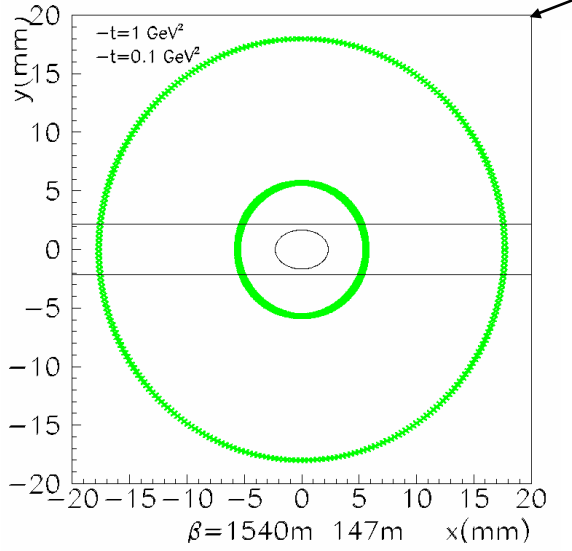


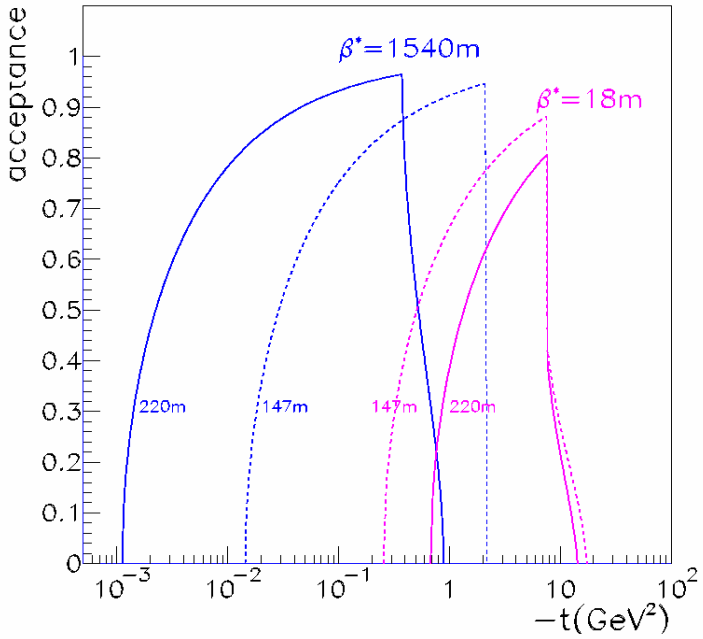
Regione	-t caratteristico(GeV/c)²	Tipo di run
Coulomb	$\leq 10^{-4}$	β* molto alto
Interferenza Coulomb -Strong	$\approx 10^{-3}$	alto β*
Pomeron - Diffrazione	$\geq 10^{-3}$	alto/basso β*
Struttura	≈ 0.8	basso/alto β*
Grande -t - Perturbative QCD	≥ 5	basso β*

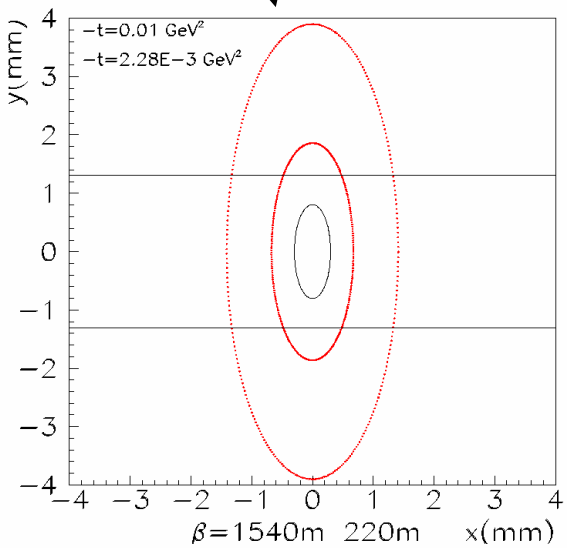


Scattering elastico

β* = 1540 m

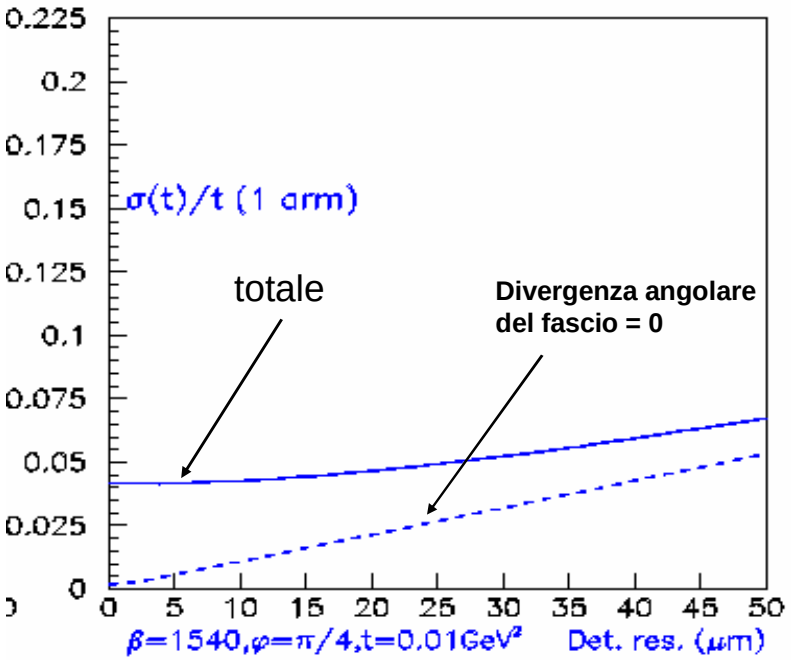




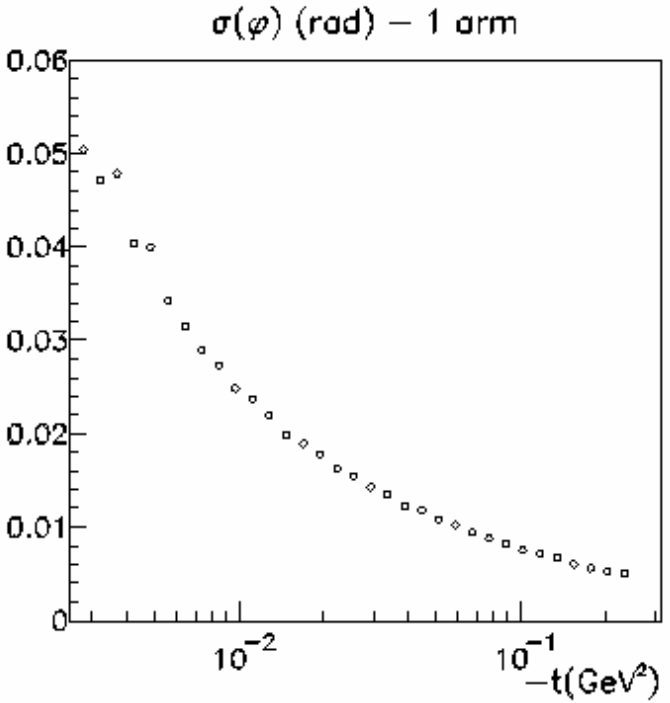


Risoluzione su t e ϕ

$\sigma(t)/t$ vs risoluzione del rivelatore

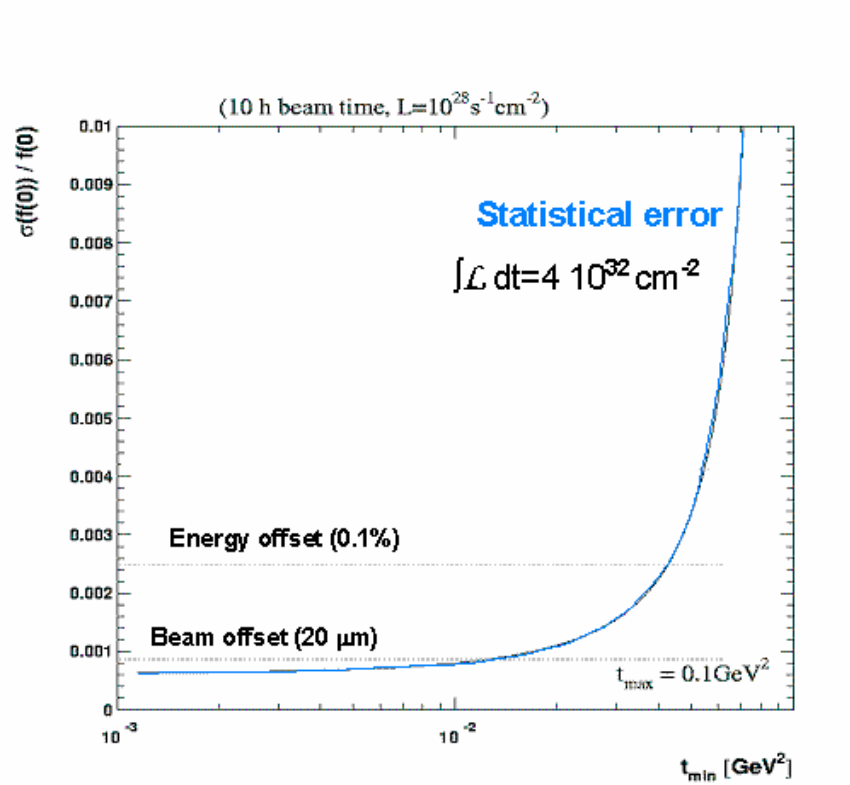


risoluzione su ϕ vs t



Estrapolazione a t=0

La misura di σ_{tot} necessita di $(dN/dt)_{t=0}$ che si può stimare con un errore statistico dello ~0.1% (considerando 10^7 eventi ricostruiti dopo 10h di run a $L=10^{28}$).



	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%

Sezione d'urto inelastica

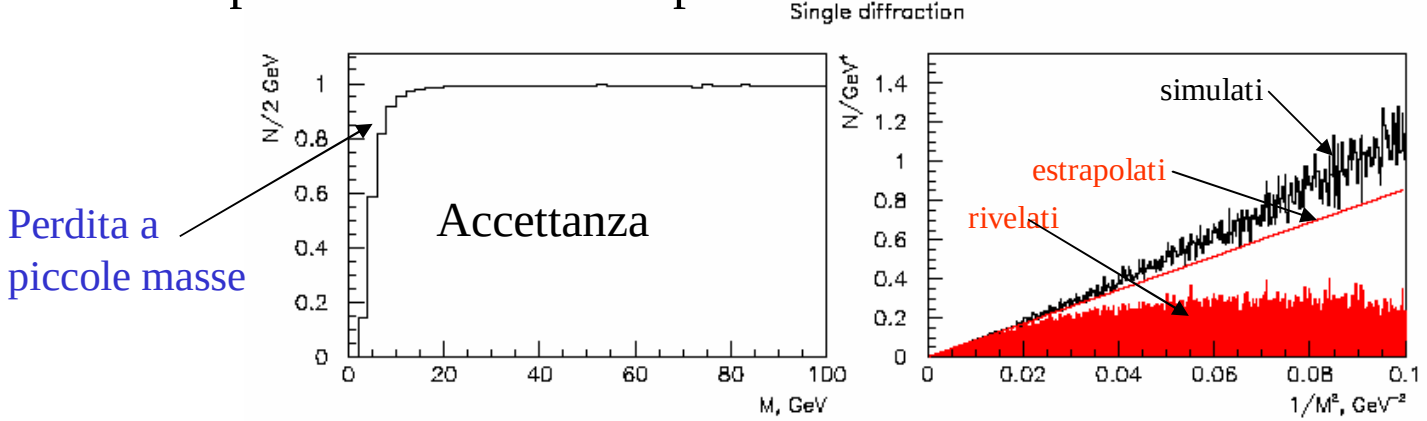
Selezione:

- trigger da T1 o T2 (*double arm o single arm*)
- Ricostruzione del vertice (per eliminare il fondo beam-gas)

Eventi persi

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

Estrapolatione necessaria per eventi diffrattivi



Sezione d'urto totale

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

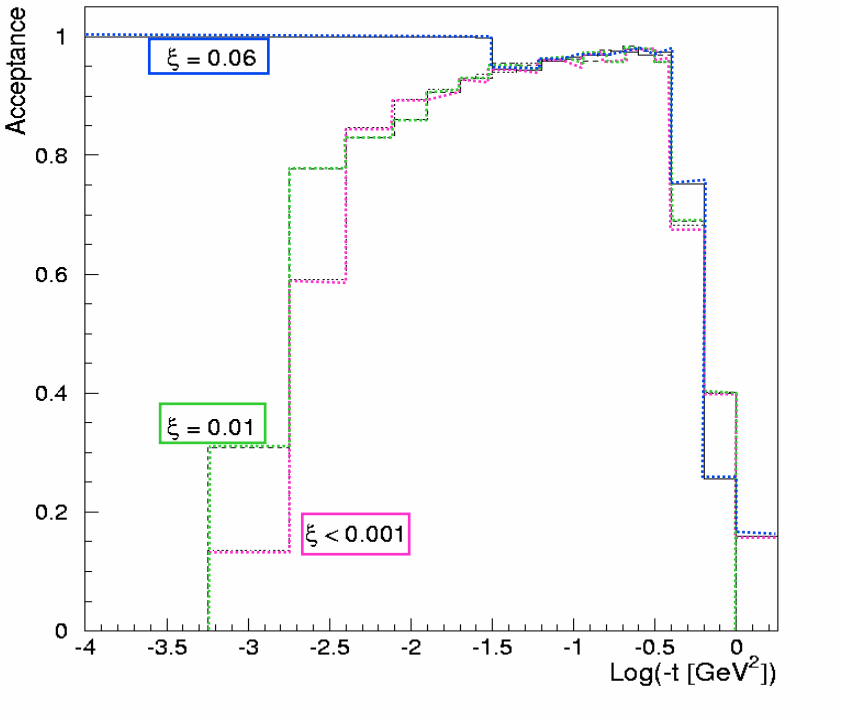
Perdite (mb)

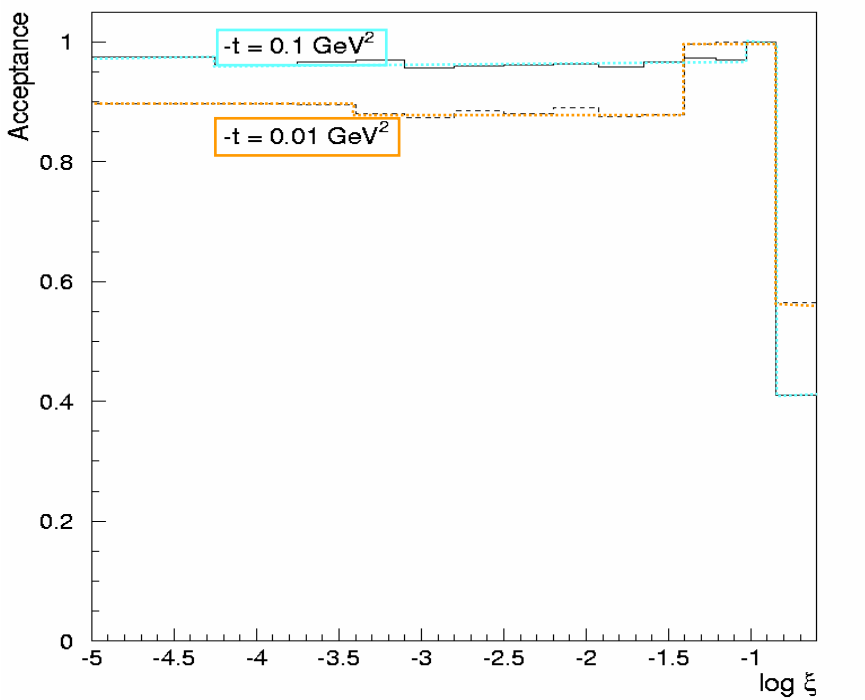
	σ(mb)	Double arm	Single arm	Incertezza dopo l'estrapolazione
Minimum bias	58	0.3	0.06	0.06
2 x singolo diffractivo	14	-	2.5	0.6
Doppio diffractivo	7	2.8	0.3	0.1
Doppio Pomerone	1	-	-	0.02
Elastico	30	-	-	0.1

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

1%

Diffrazione ad alto β*





>90% dei protoni diffrattivi sono visti nelle the Roman Pots

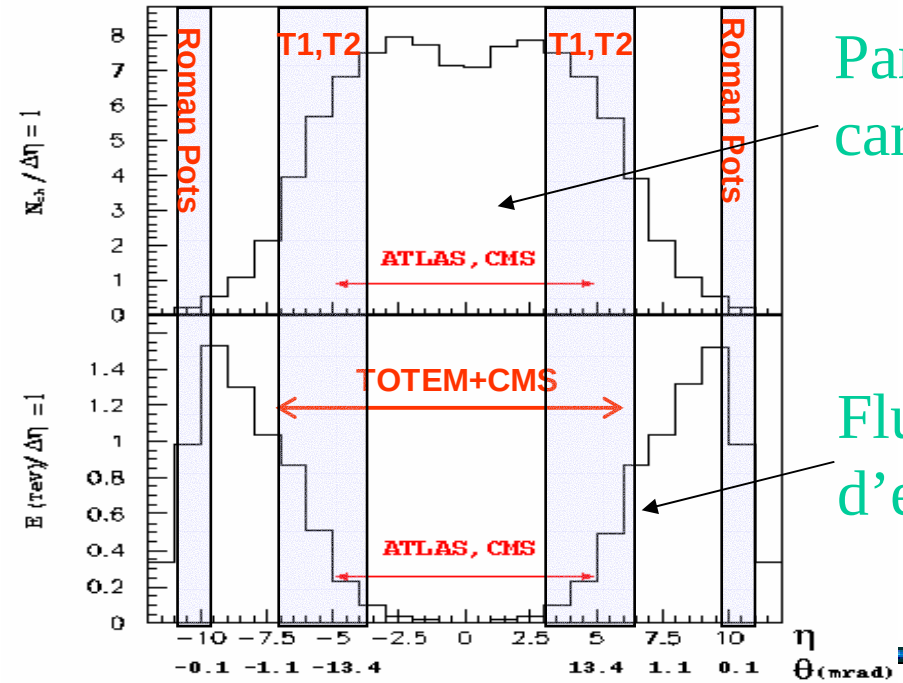
Il momento del protone può essere misurato con una risoluzione di qualche per mille

CMS/TOTEM

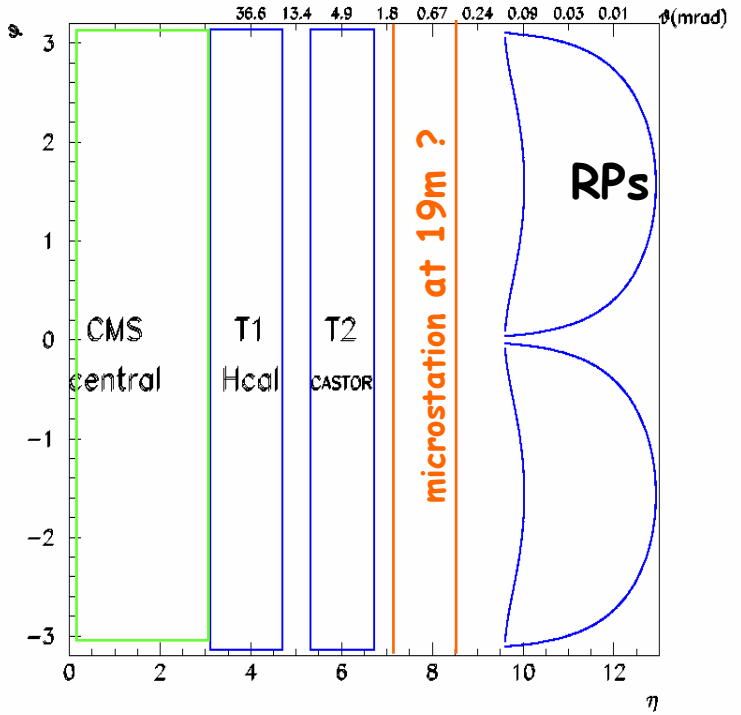
CMS/TOTEM è il rivelatore con la più grande accettanza mai costruito ad collider adronico

1 giorno di run a alto beta (1540m) e $L=10^{29}cm^{-2}s^{-1}$:
100 milioni di eventi minimum bias, includendo tutti i processi diffrattivi

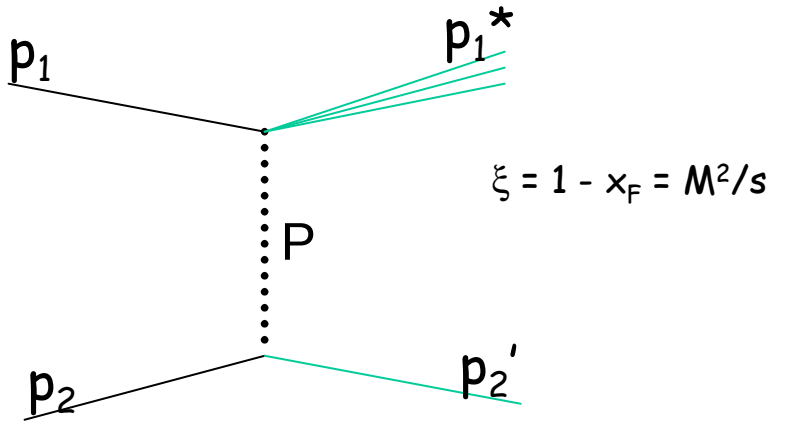
>90% di tutti i protoni diffrattivi vengono rivelati



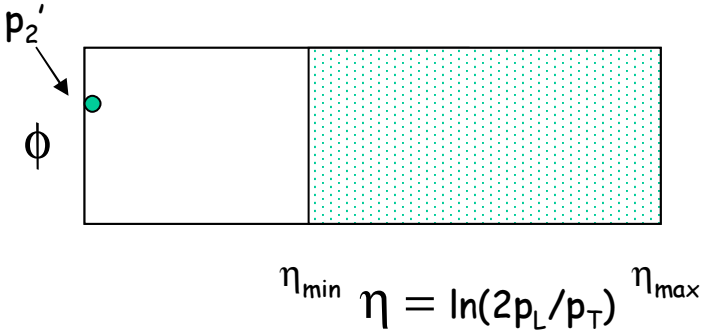
Accettanza complessiva TOTEM/CMS (β^*=1540m)



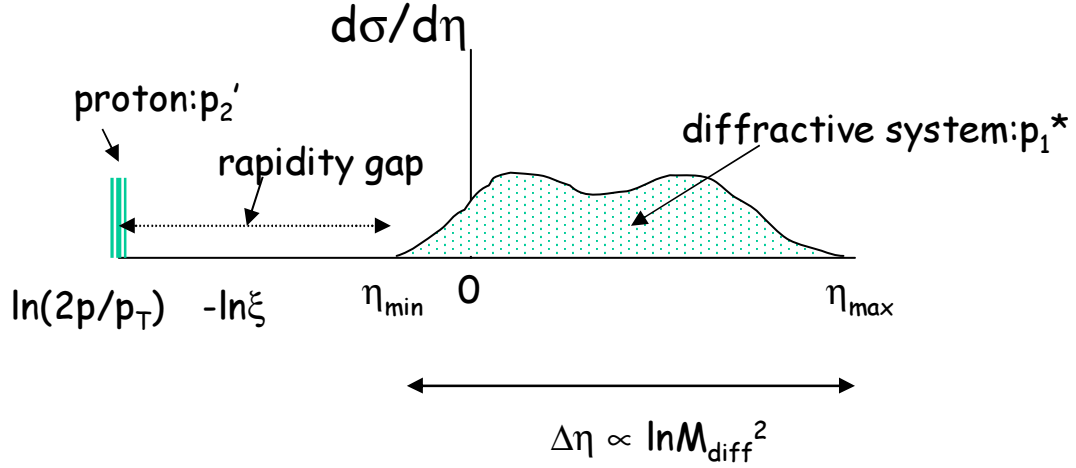
Processi singolo diffrattivi



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

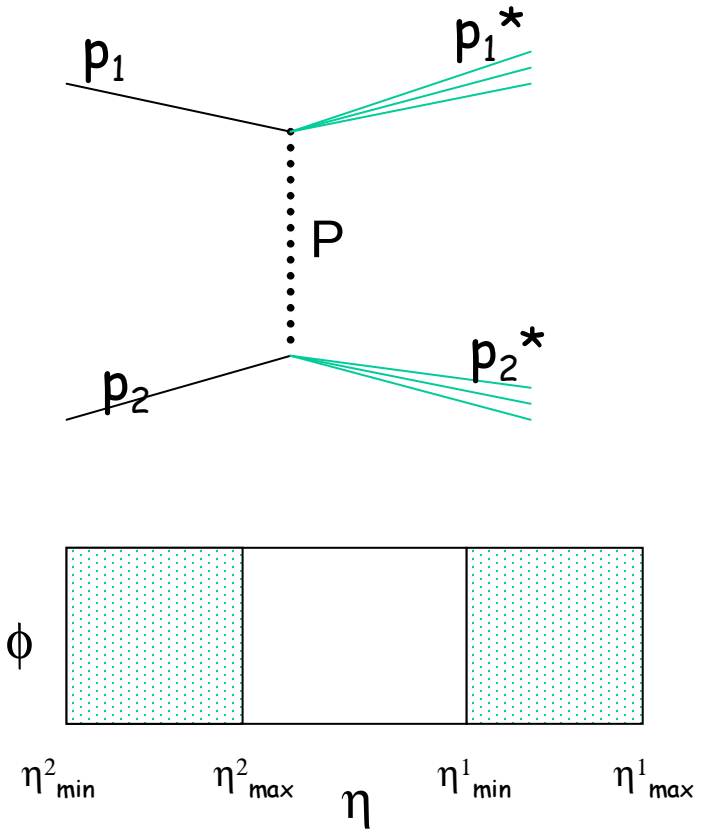


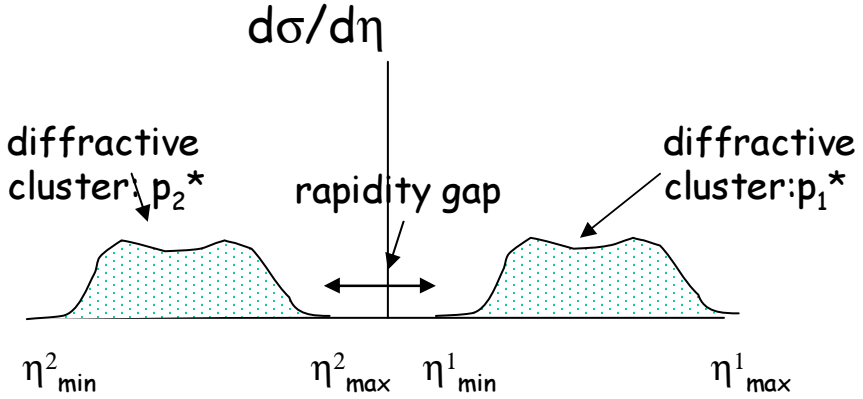
η_{min} $\eta = \ln(2p_L/p_T)$ η_{max}



$\Delta\eta \propto \ln M_{diff}^2$

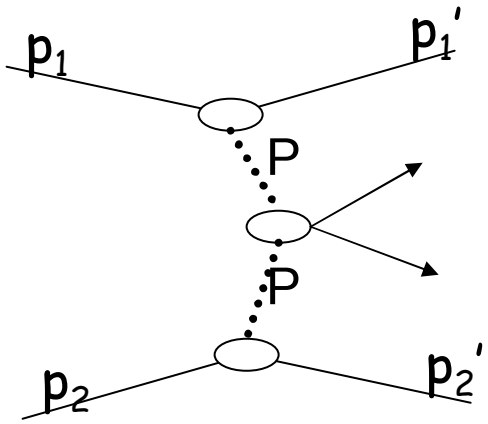
Processi doppio diffrattivi





Scambio di doppio Pomerone

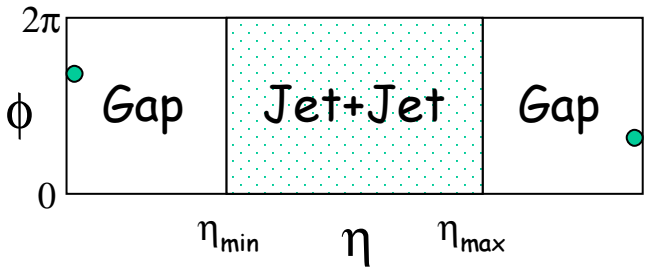
Il Pomerone ha i numeri quantici del vuoto.

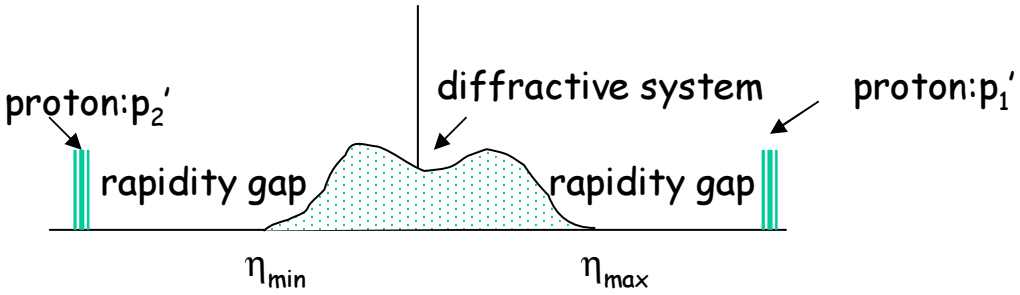


PP: $C = +$, $I=0$,...

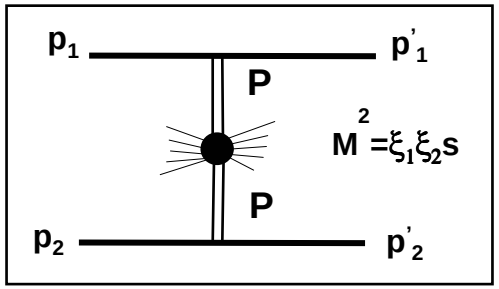
P: $J^P = 0^+, 2^+, 4^+,...$

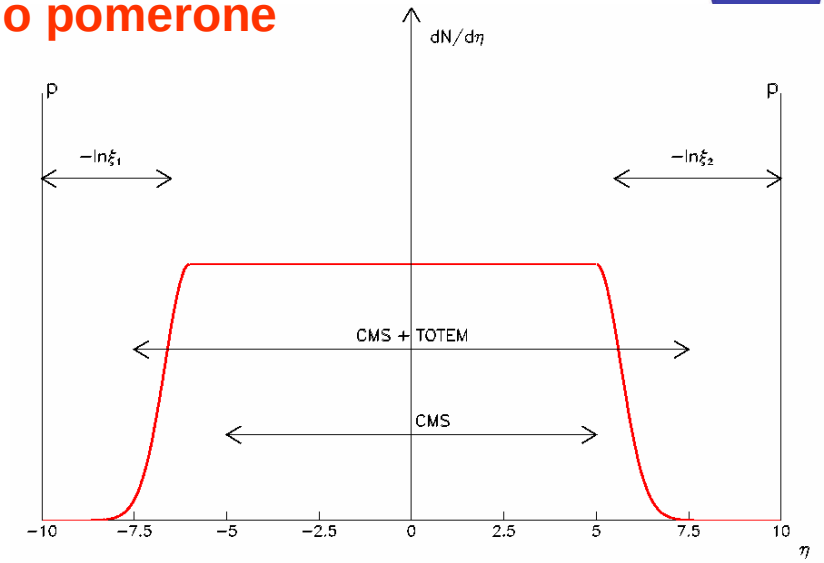
$\Rightarrow$ PP: $J^{PC} = 0^{++}$

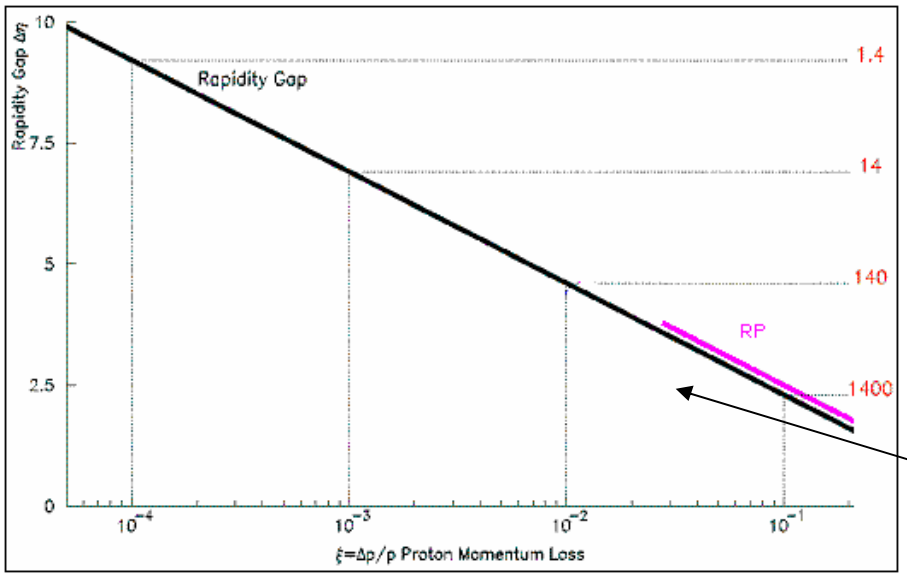




Scambio di doppio pomerone







ξ=Δp/p

M (GeV)

$\xi_1 = \xi_2$

Collaborazione CMS/TOTEM per la fisica diffrattiva

β* = 1540 m σ_ξ = 0.5%

β* = 200-400 m σ_ξ = qualche ‰

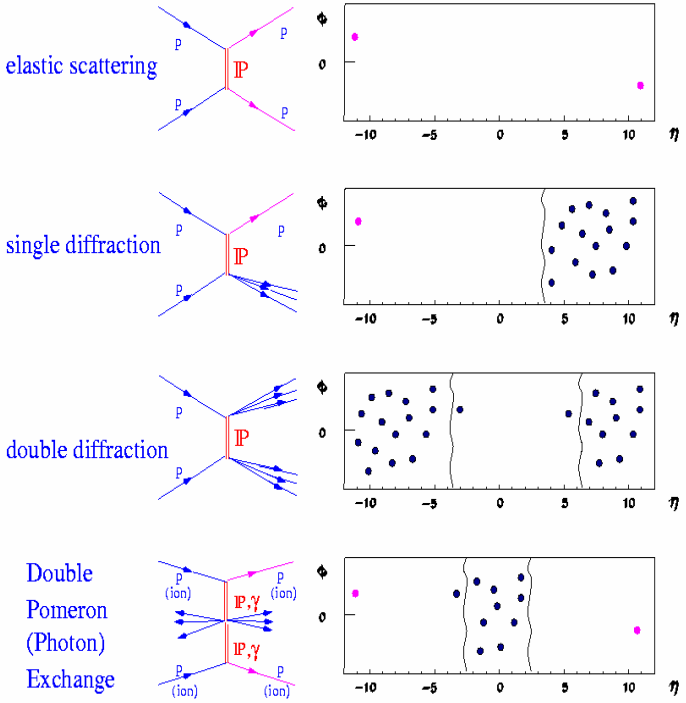
β* = 0.5 m σ_ξ = qualche ‰

Trigger tramite Roman pots $\xi > 2.5\ 10^{-2}$

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

Level-1 Trigger

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



Elastic Trigger:

Segnale: 500 Hz
Background: 20 Hz

Single diffractive Trigger:

Segnale: 200 Hz
Background: 0.1 Hz

Double Diffractive Trigger:

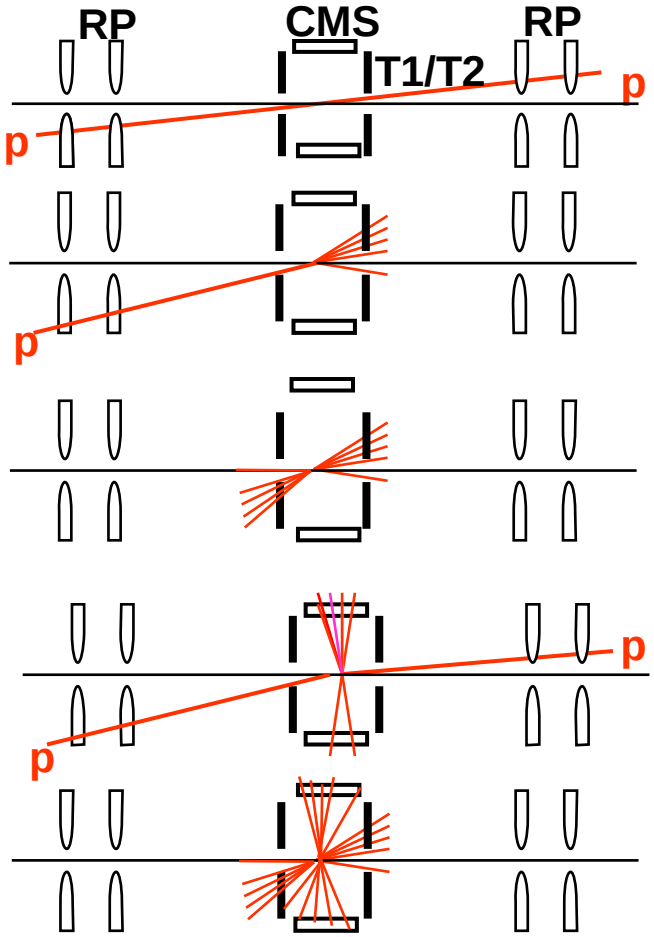
Segnale: 100 Hz

Central Diffractive Trigger:

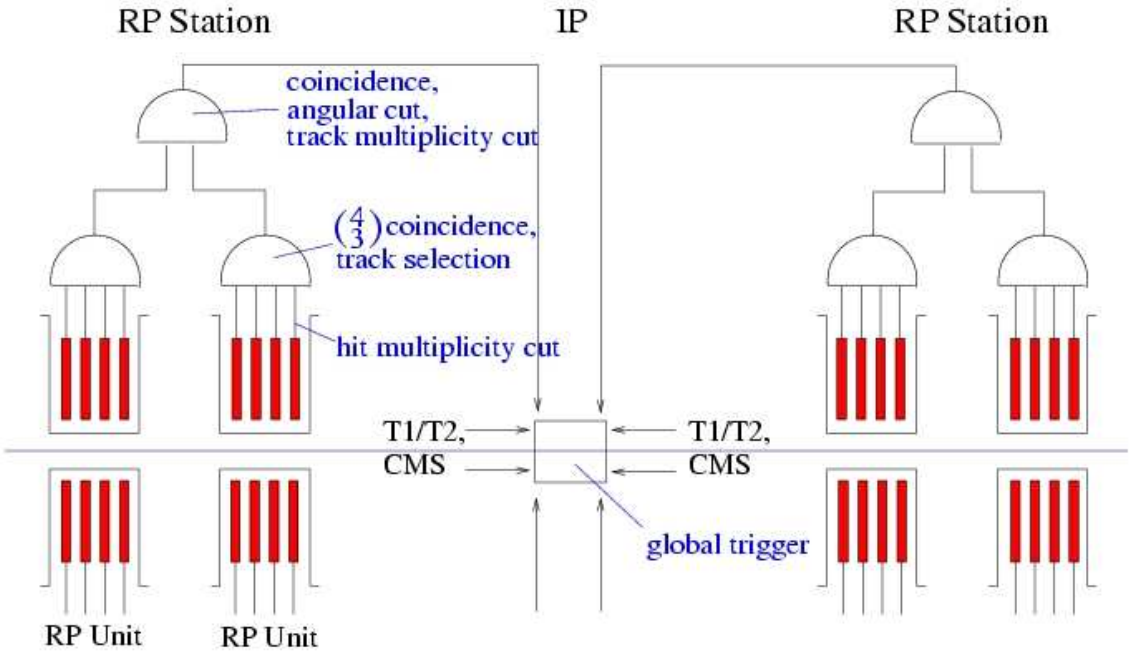
Segnale: 10 Hz
Background: 2 Hz

Minimum Bias Trigger:

Segnale: 1 kHz



Eliminazione fondi



- Beam Halo (dominante): riducibile con la coincidenza a 2-bracci
- Shower particles da interazioni beam-beam, beam-gas, beam-machine: Riducibile tramite:
  - Coincidenze mutiple
  - Tagli angolari
  - Tagli sulla molteplictà di hit e tracce

- Per facilitare l'acquisizione comune, DAQ e Trigger saranno implementati in maniera CMS-compatibile
  - La compatibilità hardware e software apre la possibilità per TOTEM di unirsi al DAQ di CMS durante i run comuni.
  - I front-ends si conformeranno al CMS Trigger Control System nel caso in cui TOTEM voglia contribuire al Trigger di CMS.
- Possibili schemi di trigger
  - Il GT di CMS riceve il trigger di TOTEM e manda un L1A sia ai front-ends di TOTEM sia a quelli di CMS.

Scenari

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}**

Esempi con differenti scenari

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

Acquisizione dati per diffrazione soffice : 20 mb ⟶ 4 kHz ⟶ $4 \cdot 10^{8}$ eventi / 1 giorno

Doppio Pomerone : 1 mb $2 \cdot 10^{7}$ eventi / 1 giorno

Studio preciso di fenomeni diffrattivi soffici

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

Alcuni run con $4\ 10^{5}$ s ⟶ $4\ 10^{36}$ cm $^{-2}$ ⟶ 4000 evts / nb

Scambio di Doppio Pomerone

Masse elevate dell'ordine del TeV

χ_c ⟶ $10^{6\text{-}7}$ eventi

χ_b ⟶ $10^{3\text{-}4}$ eventi

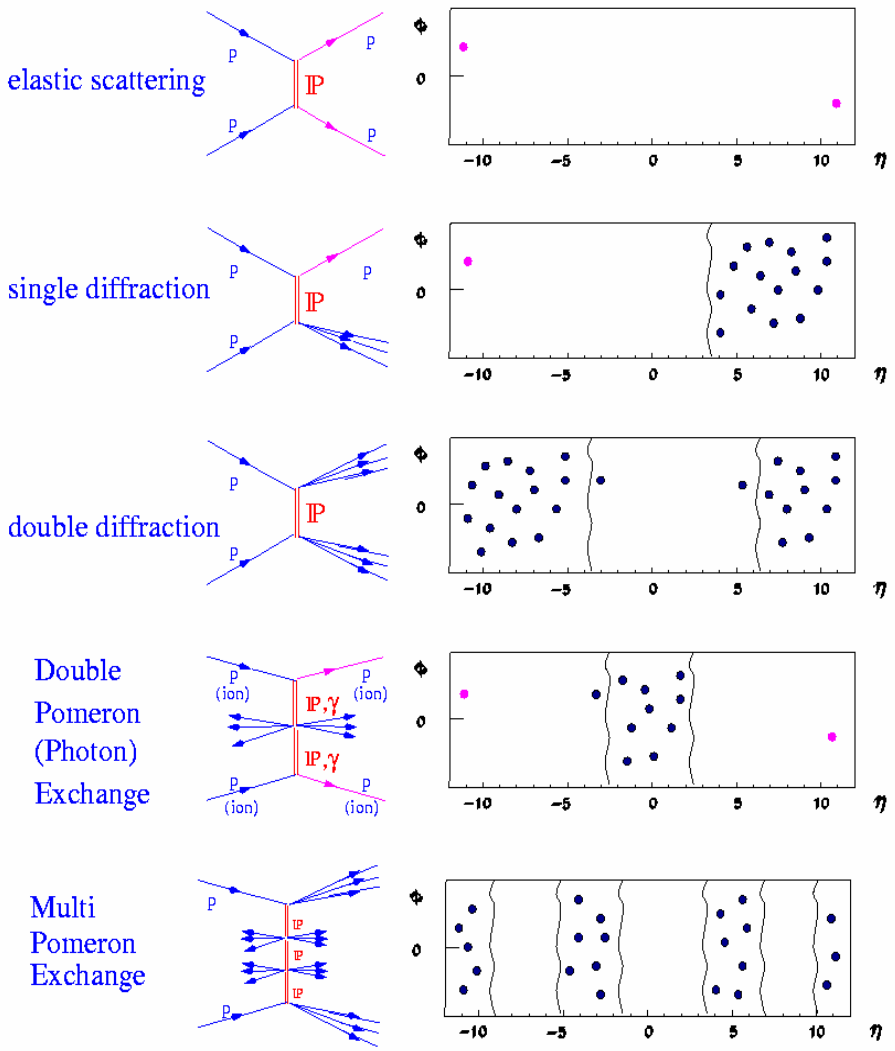
Getti ad alto pt ⟶ dijet coplanari con due protoni sopravvissuti e nient'altro

Diffrazione singola con getti ad alto pt e leptoni

Studio di rapidity gaps con l'identificazione dei protoni

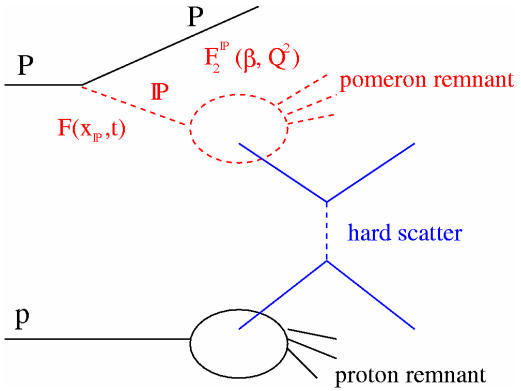
- **TOTEM TDR** presentato all'LHCC a gennaio LHCC 2004-002/TOTEM TDR 1
- Un TDR sul programma di fisica comune CMS/TOTEM verrà presentato in seguito.

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 $F(\beta,Q^2)$

β down to ~ 10^{-3} & Q^2 ~10^4 GeV^2

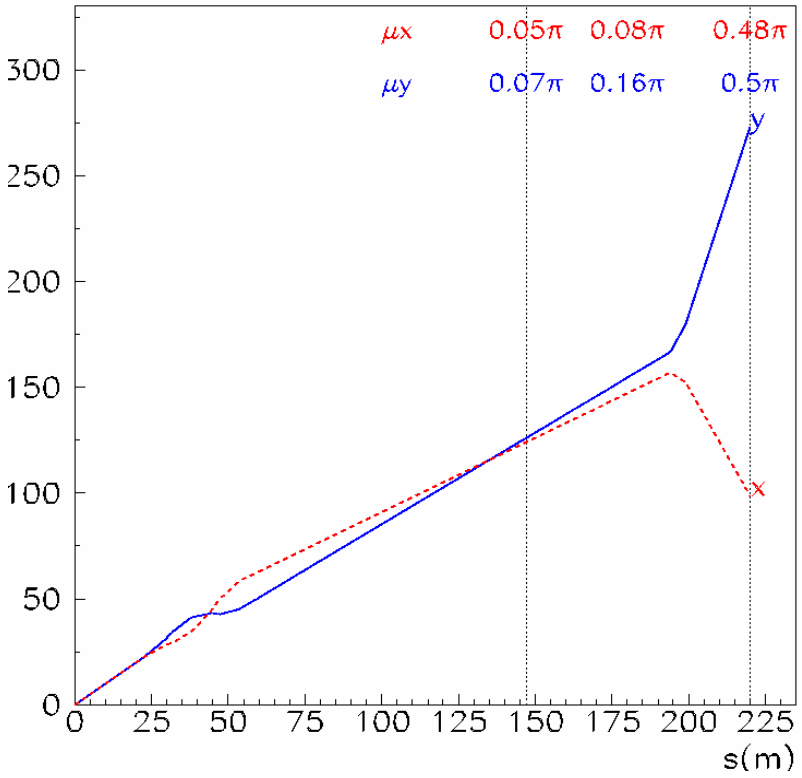
Diffraction dynamics?

Exclusive final states ?

Rapidity gap physics - multigaps!

High β optics: lattice functions

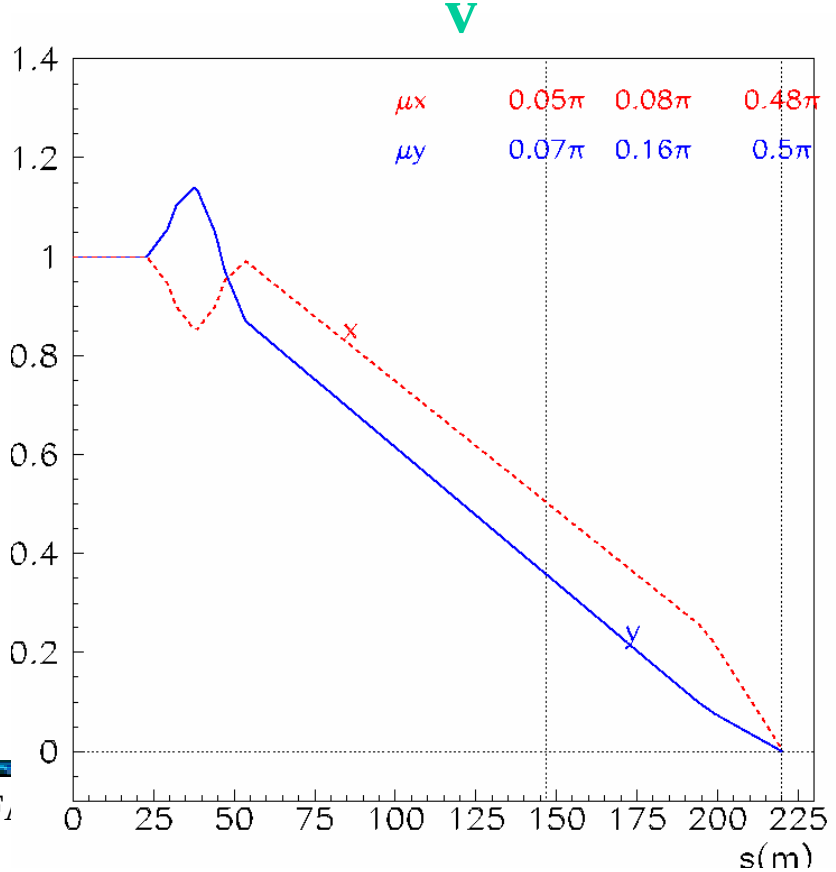
L



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

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

V



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

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