Diffraction at TOTEM

EDS’09

S. Giani
on behalf of the
TOTEM Collaboration

TOTEM Physics programme

All scattered protons — Total pp cross section at 14TeV with a precision of 1-2%

Elastically scattered protons — Elastic pp scattering, 10^{-3} GeV^2 < –t < 10 GeV^2

Inelastically scattered protons:

- Soft Single & Central Diffraction (SD, DPE)
- 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
- Low–x dynamics
- $\gamma\gamma$ & γp physics

The last four items are marked: WITH CMS

Physics program for the LHC start

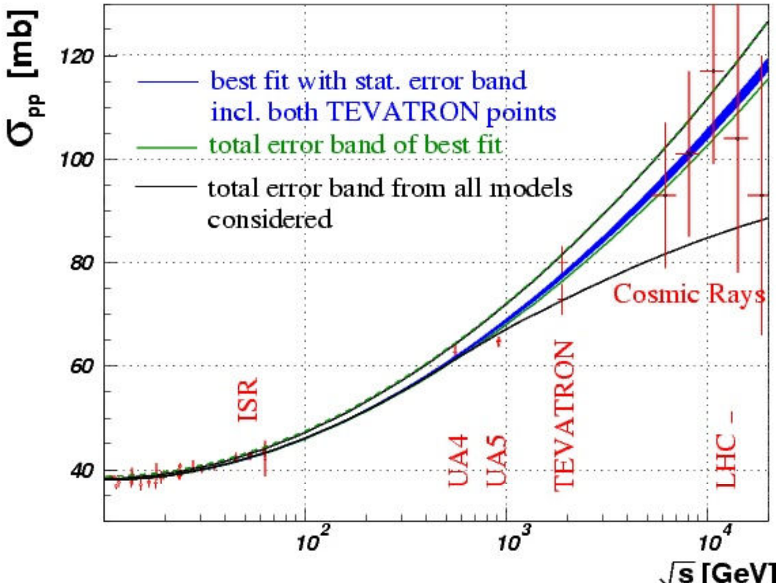
Diffraction at low/medium luminosity: SD, DPE

Total cross section with a precision of about 5% (special optics B*=90m)

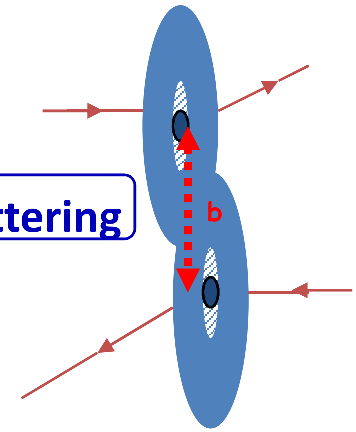
Multiplicity distributions

TOTEM Physics Overview

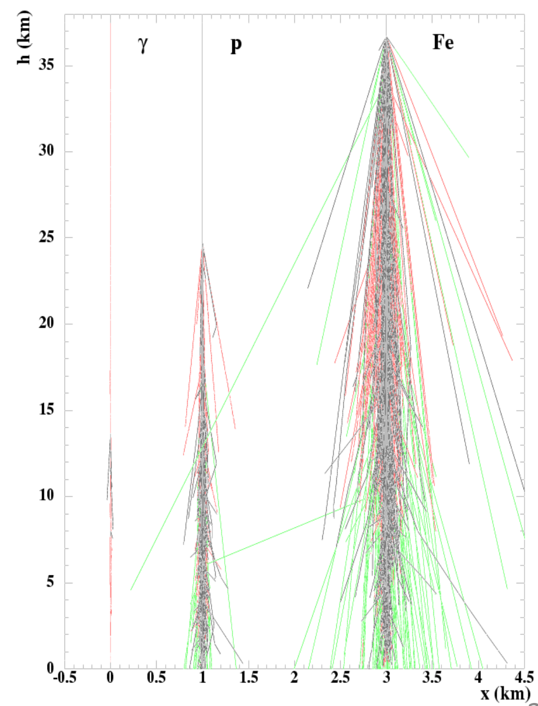
Total cross-section



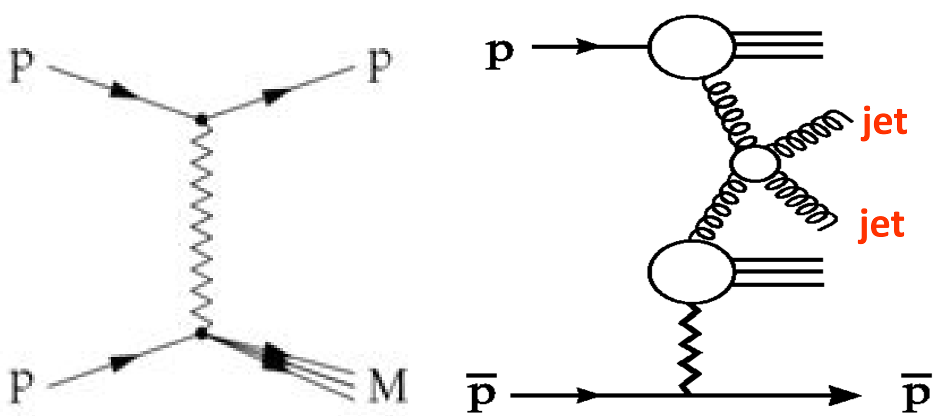
Elastic Scattering



Forward physics



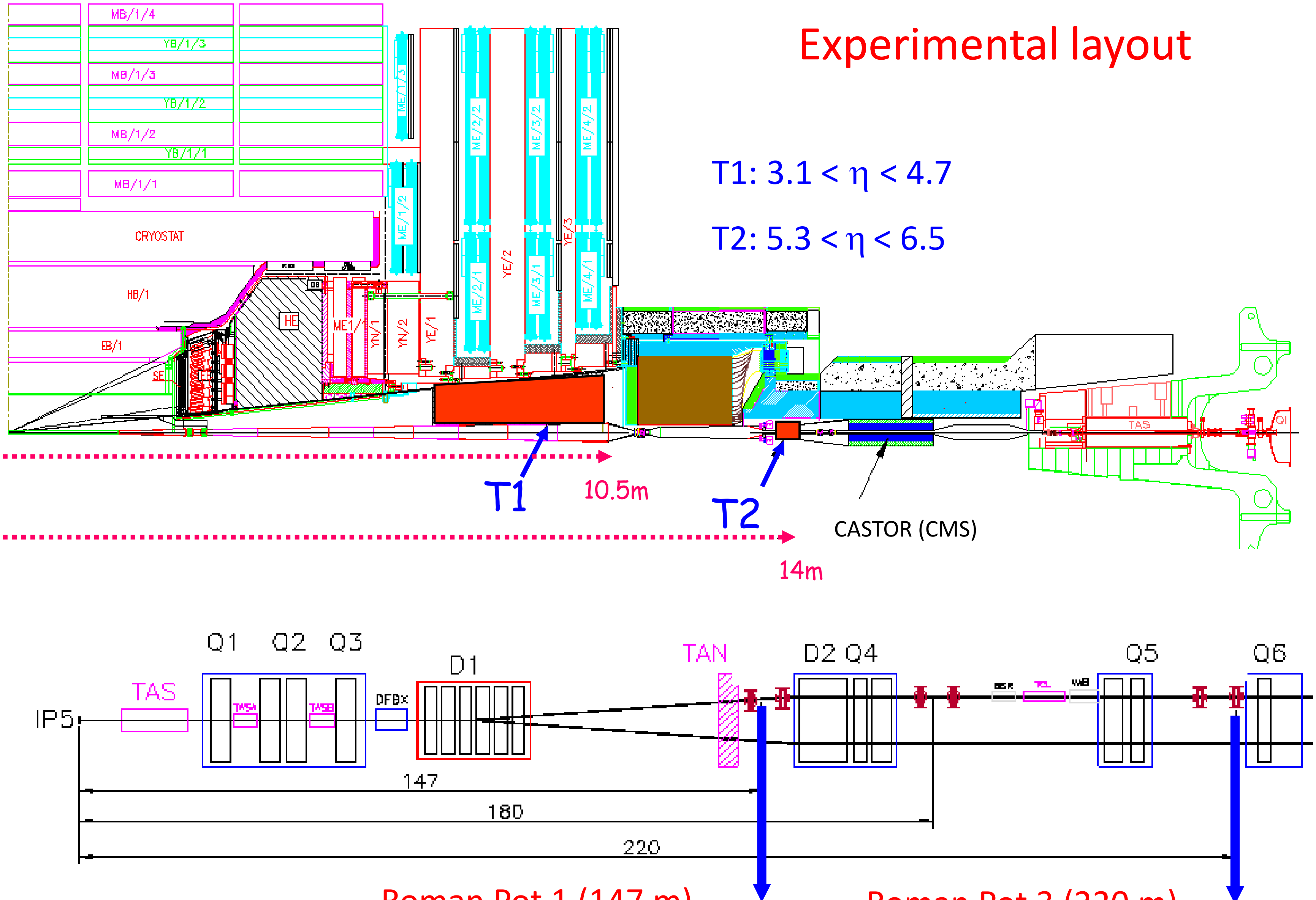
Diffraction: soft (and hard with CMS)



Experimental layout

T1: $3.1 < \eta < 4.7$

T2: $5.3 < \eta < 6.5$



Roman Pot 1 (147 m)

Roman Pot 3 (220 m)

pp Interactions

Non-diffractive

Colour exchange

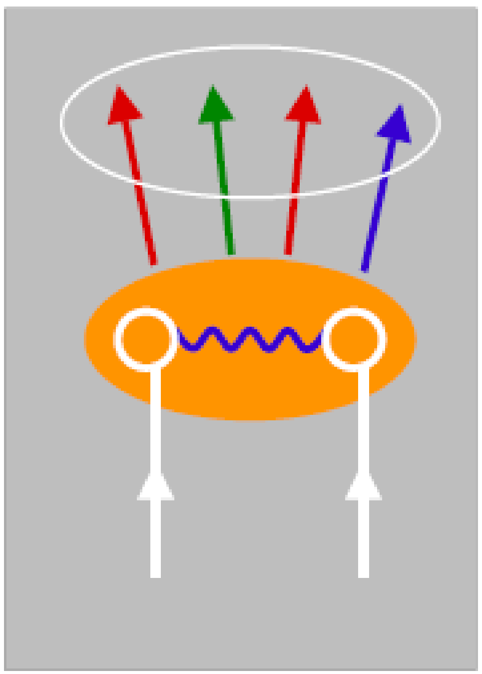
dN / d $\Delta\eta$ = exp (-$\Delta\eta$)

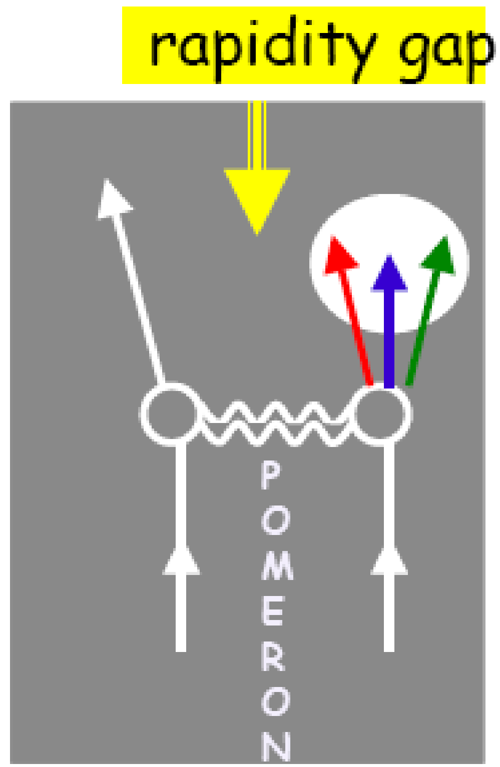
Diffractive

Colourless exchange with vacuum quantum numbers

dN / d $\Delta\eta$ = const

Incident hadrons acquire colour and break apart



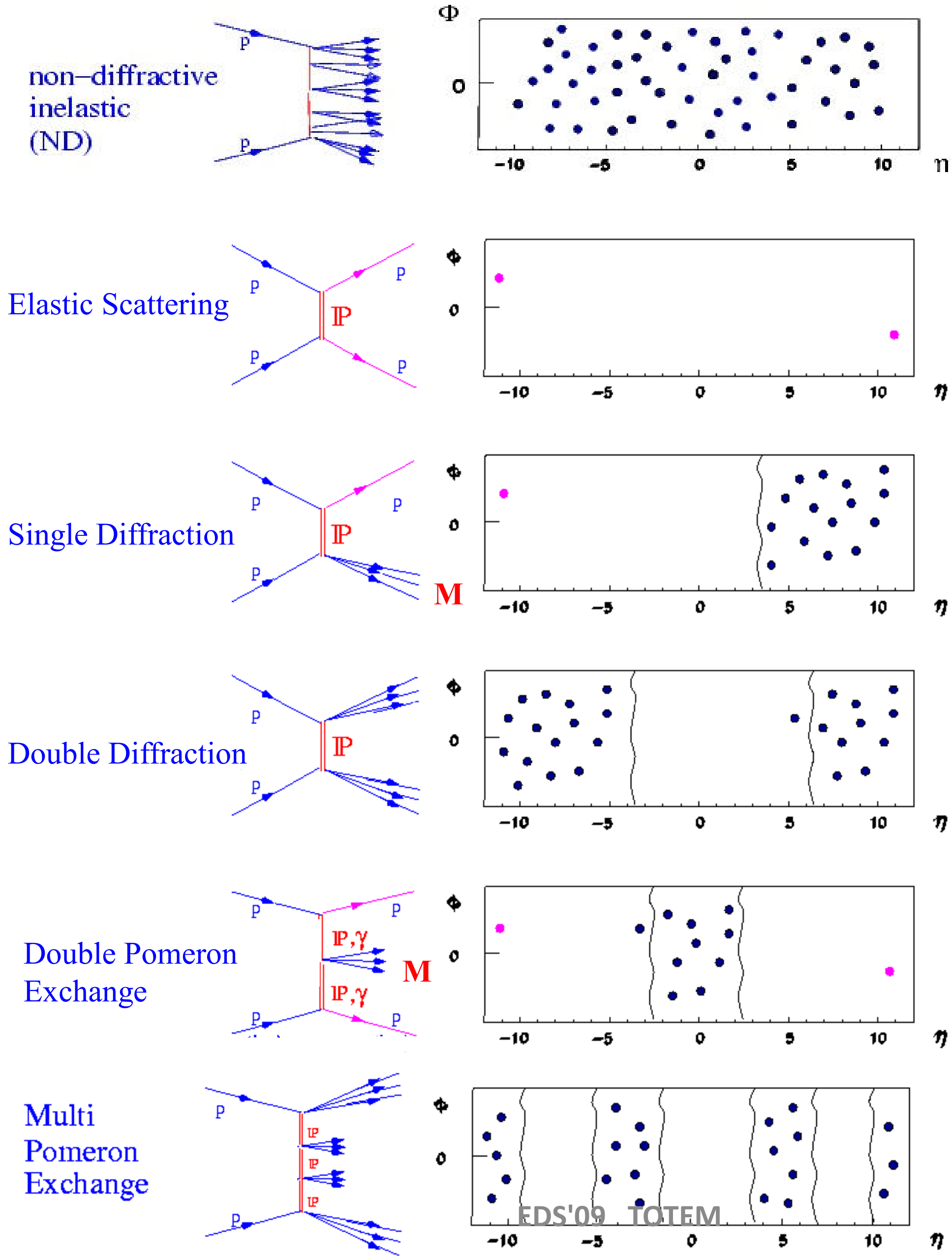


Incident hadrons retain their quantum numbers remaining colourless

GOAL: understand the QCD nature of the diffractive exchange

Inelastic and Diffractive Processes ($\eta = -\ln tg\ \theta/2$)

All the drawings show soft interactions.
In case of hard interactions there should be jets,
which fall in the same rapidity intervals.



~65 mb

~30 mb

~10 mb

~7 mb

~1 mb

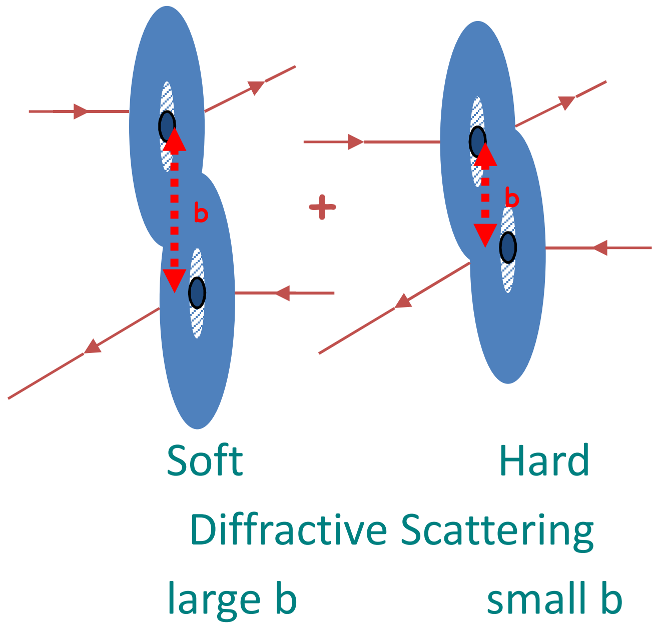
<< 1 mb

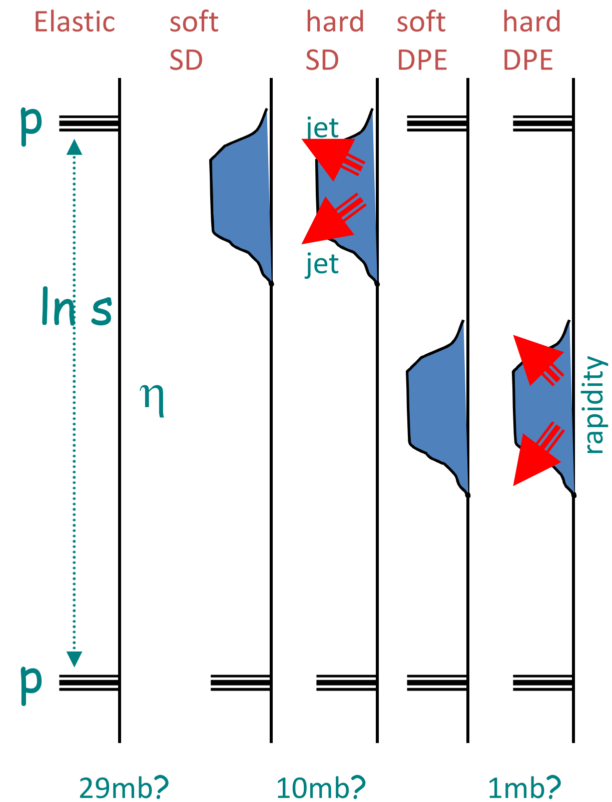
Diffractive scattering is a unique laboratory of confinement & QCD: A hard scale + hadrons which remain intact in the scattering process

Rapidity gap survival & ”underlying” event structures are intimately connected with a geometrical view of the scattering - eikonal approach!

Cross sections are <u>large</u>
Measure σ (M,ξ,t)

Lorentz contracted longitudinal view





Soft processes:
Coherent interactions
-impact parameter picture.

Hard processes:
Jet momenta correlated with the initial parton momenta.

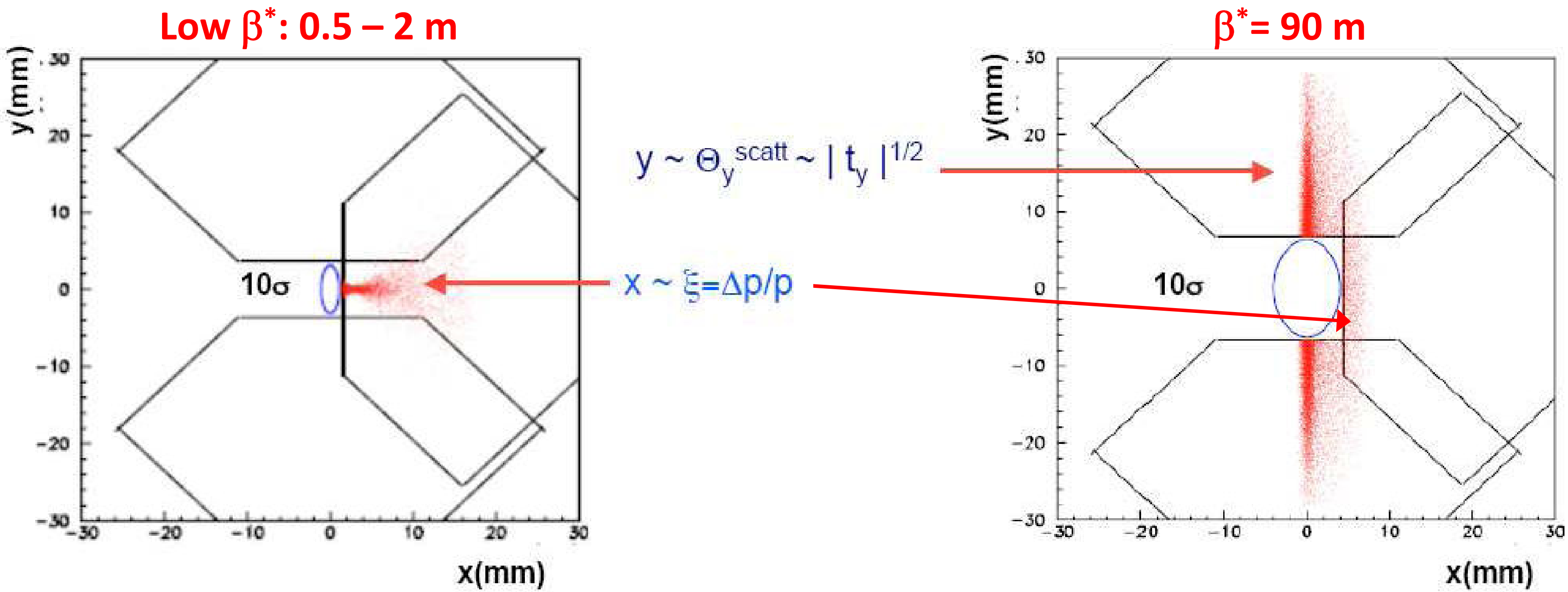
Totem sees SDE M_X > 5 GeV

Diffractive forward protons @ RPs

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

Dispersion shifts diffractive protons in the horizontal direction

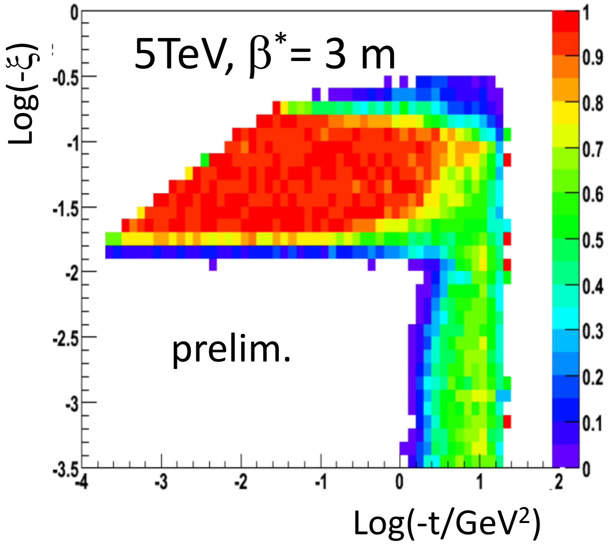
Diffractive protons : hit distribution @ RP220

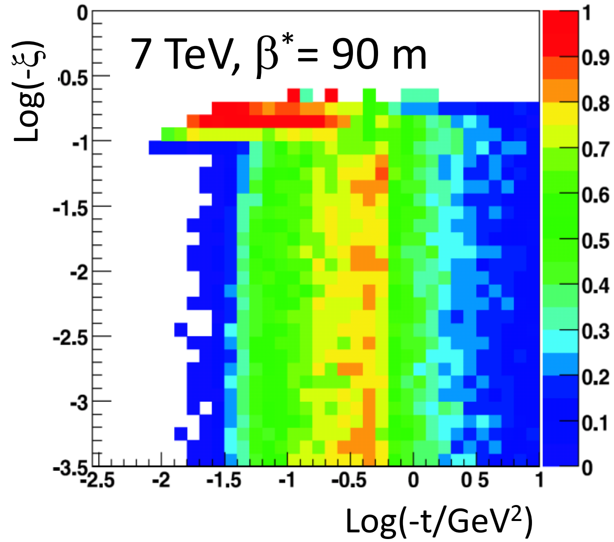


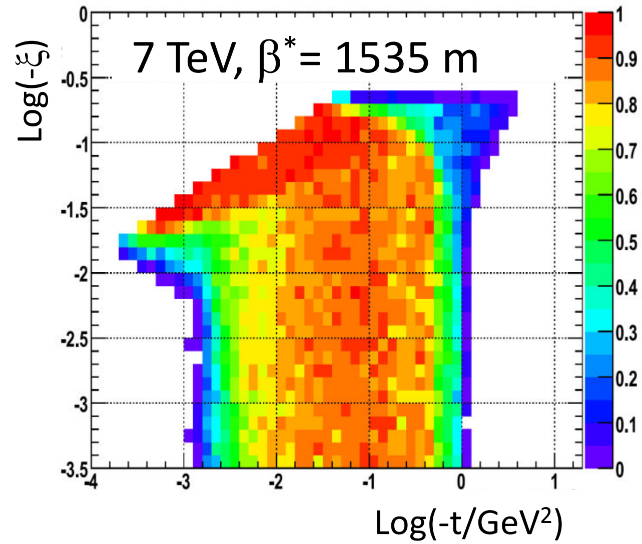
- For low-β^* optics L_x, L_y are low
- v_x, v_y are not critical because of small IP beam size

- L_x=0, L_y is large
- beam σ = 212 μm → v_x, v_y important (deterioration of rec. resolution)

TOTEM diffractive protons' acceptance in RPs







low β^*

low β^* : 0.5 – 2 m, $L \approx 10^{33}$ cm^{-2}s^{-1}
early running: E = 5TeV, β^* = 3 m

elastic acceptance
2 GeV^2 < -t < 10 GeV^2

resolution
$\sigma(\Theta)$ = 16 – 30 μrad
$\sigma(\xi) = 1 - 6 \cdot 10^{-3}$

$-\xi$ > 2 % seen

(hard) diffraction, high |t| elastic scattering

β^* = 90 m

$L \approx 10^{30}$ cm^{-2}s^{-1}

elastic acceptance
$3 \cdot 10^{-2}$ GeV^2 < $-t_y$ < 10 GeV^2

resolution
$\sigma(\Theta)$ = 1.7 μrad
$\sigma(\xi) = 6 - 15 \cdot 10^{-3}$

all ξ seen, universal optics

diffraction, mid |t| elastic scattering, total cross-section

β^* = 1535 m

$L \approx 10^{28} - 10^{29}$ cm^{-2}s^{-1}

elastic acceptance
$2 \cdot 10^{-3}$ GeV^2 < $-t_y$ < 0.5 GeV^2

resolution
$\sigma(\Theta)$ = 0.3 μrad
$\sigma(\xi) = 2 - 10 \cdot 10^{-3}$

all ξ seen

total cross-section, low |t| elastic scattering

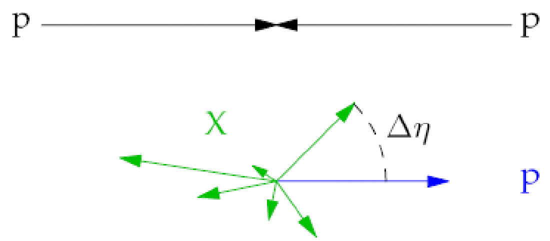
Early measurements with RPs (+ T1 & T2)

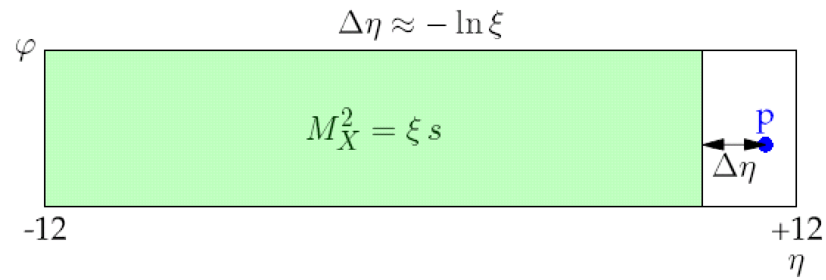
p = 5 TeV, $\beta^* = 3$m
Acceptance: $0.02 < -\xi < 0.18$, $\xi = \Delta p/p$
Resolution: $\sigma(\xi) \sim 1 - 6 \cdot 10^{-3}$, $\sigma(\Theta^*) \sim 15$ µrad

$$\left(\frac{d\sigma}{d\Delta\eta}\right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \Rightarrow \frac{d\sigma}{d\xi} \sim \frac{1}{\xi}$$

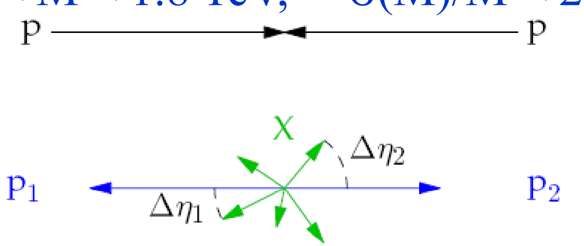
- Measure ξ
- Compare with rap. gap $\Delta\eta = -\ln\xi$
- Cross-section $\sigma(\xi, t)$

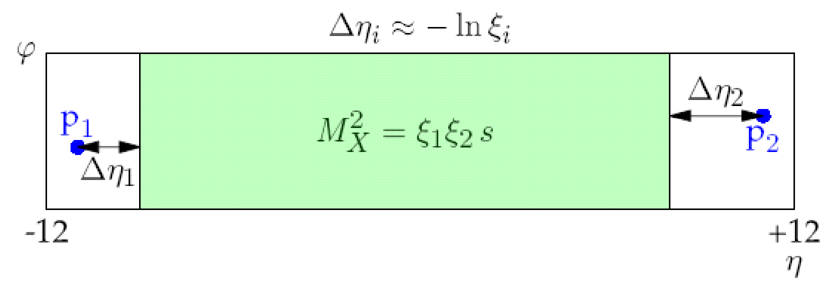
- Single Diffraction (SD), horizontal RPs:
  $d\sigma^{SD}/dM$ at high masses,
  $1.4 < M < 4.2$ TeV, $\sigma(M)/M = 2 - 4$ %





- Double Pomeron Exchange (DPE), horizontal RPs:
  $d\,\sigma^{DPE}/dM$ at high masses,
  $0.2 < M < 1.8$ TeV, $\sigma(M)/M < 2 - 4$ %

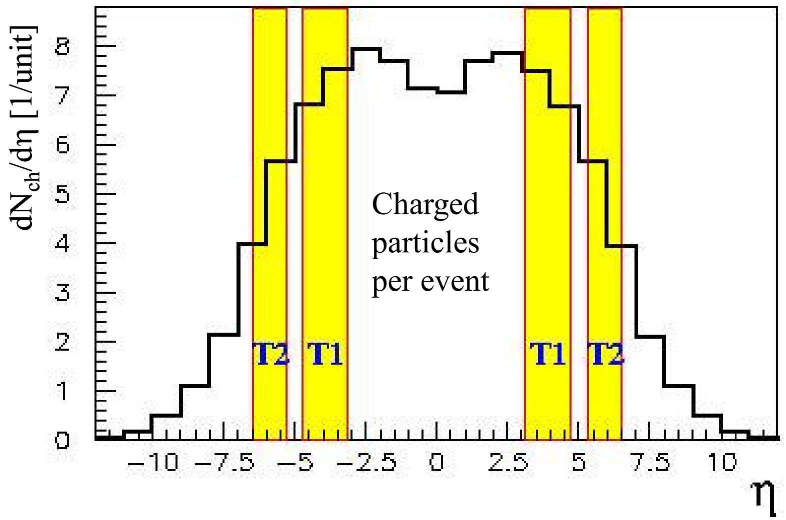




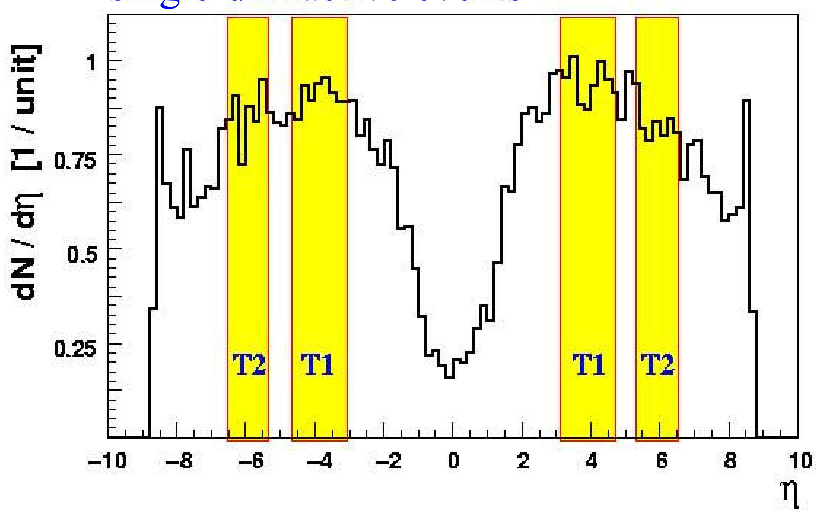
- Elastic Scattering, vertical RPs:
  $d\,\sigma^{ES}/dt$ for $2 < |t| < 10$ GeV^2, $\sigma(t)/t \sim 0.2/\sqrt{|t|}$

Early measurements T1 & T2

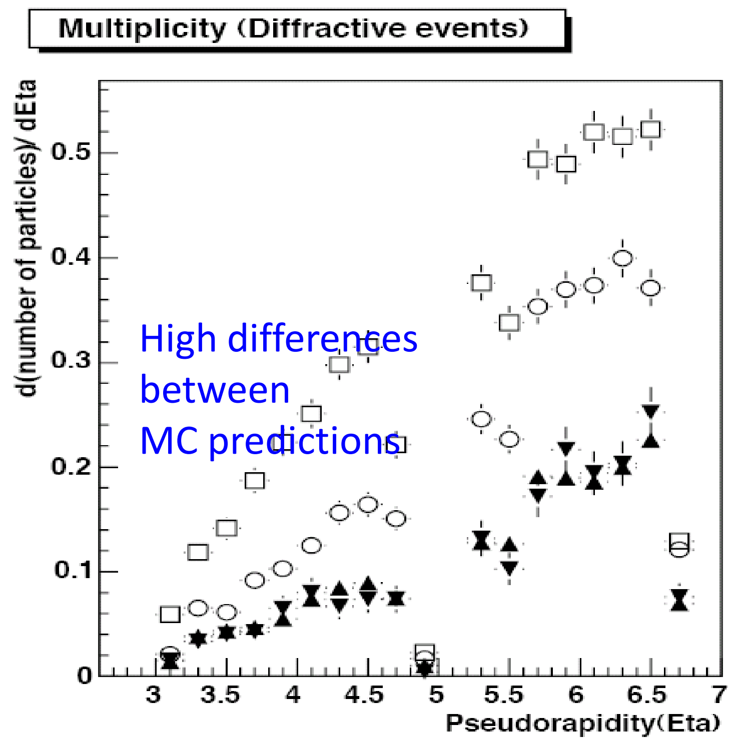
non-diffractive minimum bias events



single-diffractive events

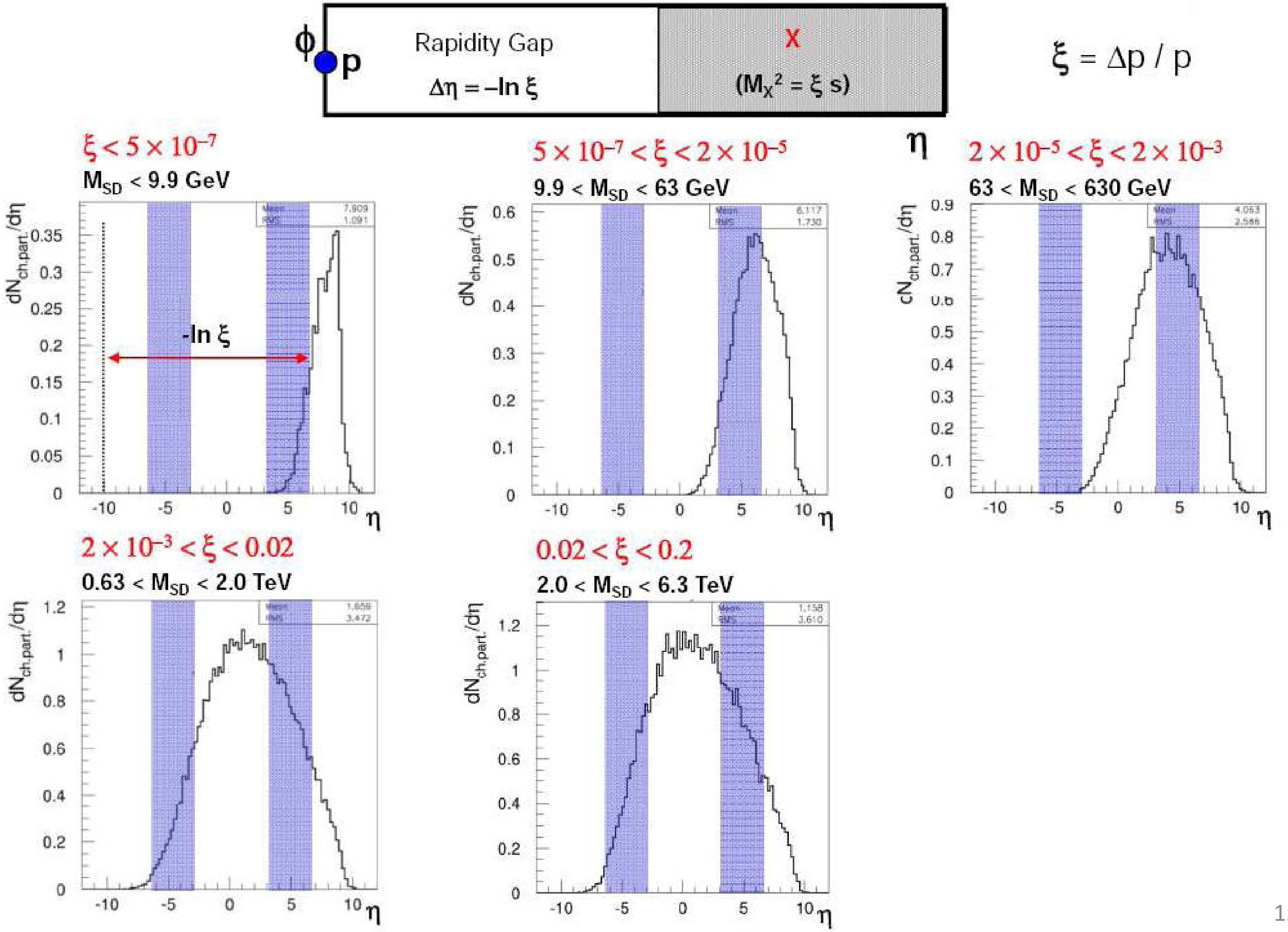


- Charged multiplicity studies (essential for minimum bias and cosmic ray MC generators tuning / validation)



- Rapidity gap studies (topologies of diffractive events)

Pseudorapidity Distributions for SD



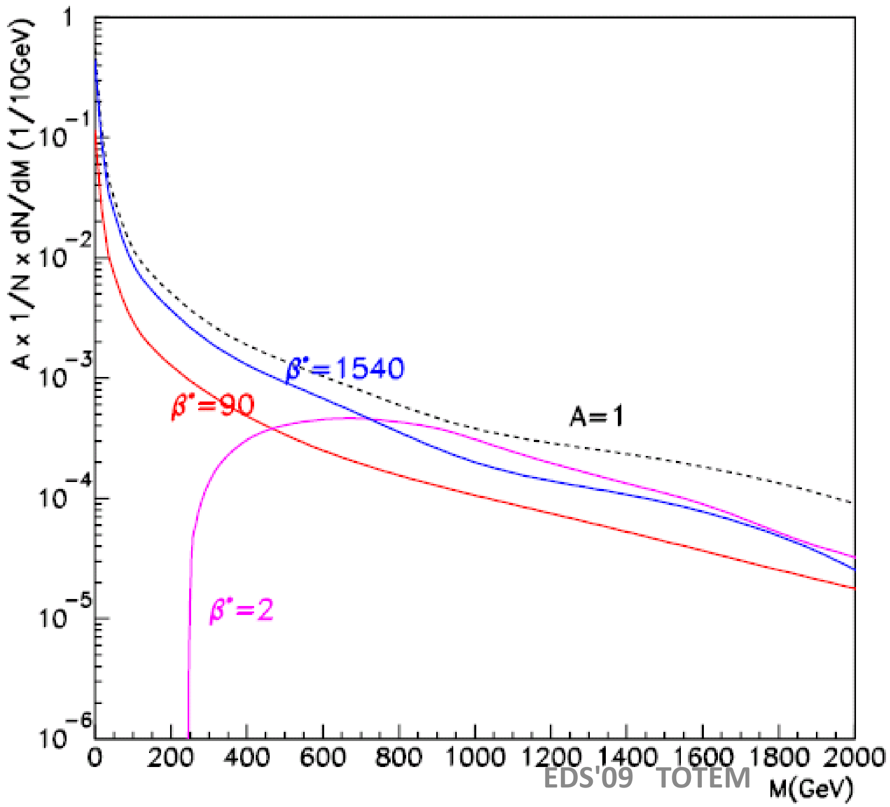
Differential mass distribution in DPE

- Study of mass distributions via the 2 protons
  - Trigger with 2p+T1/T2: rate ~200Hz @ β^*=90m, L=$10^{30}cm^{-2}s^{-1}$
  - TOTEM trigger rate limit ~2kHz

low/medium luminosity

- ξ measured directly (TOTEM) or
  - With rapidity gap $\Delta\eta = -\ln \xi$
  - With calorimeters $\xi = \sum_i E_T^i e^{\mp\eta_i} / \sqrt{s}$

(TOTEM+CMS)

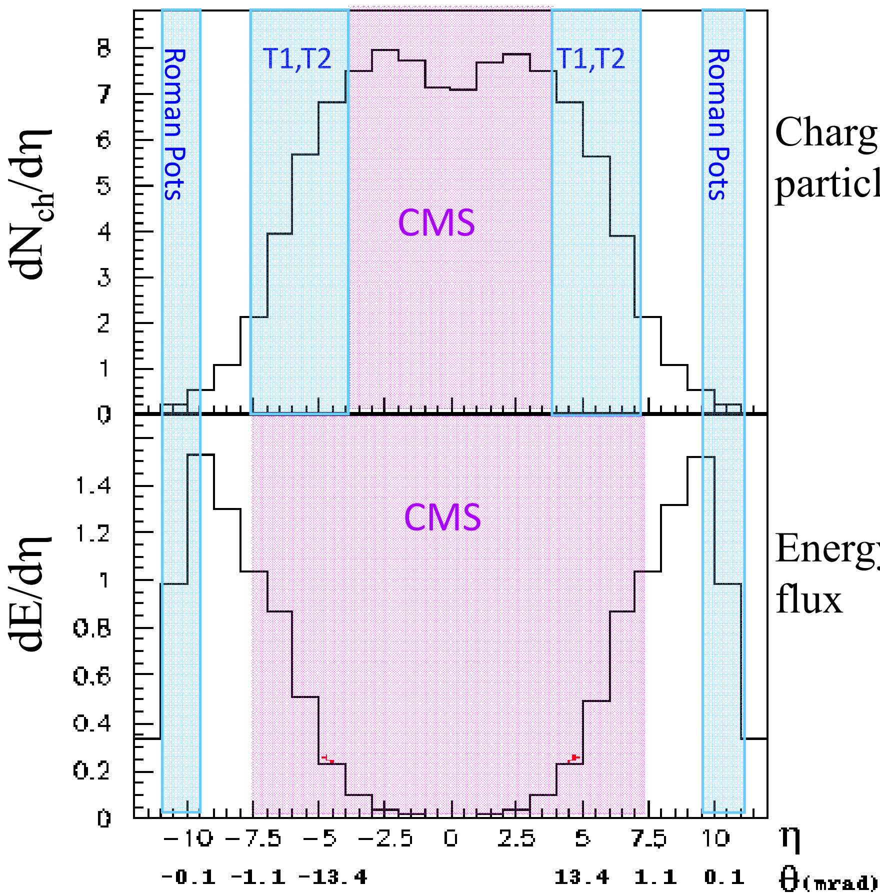


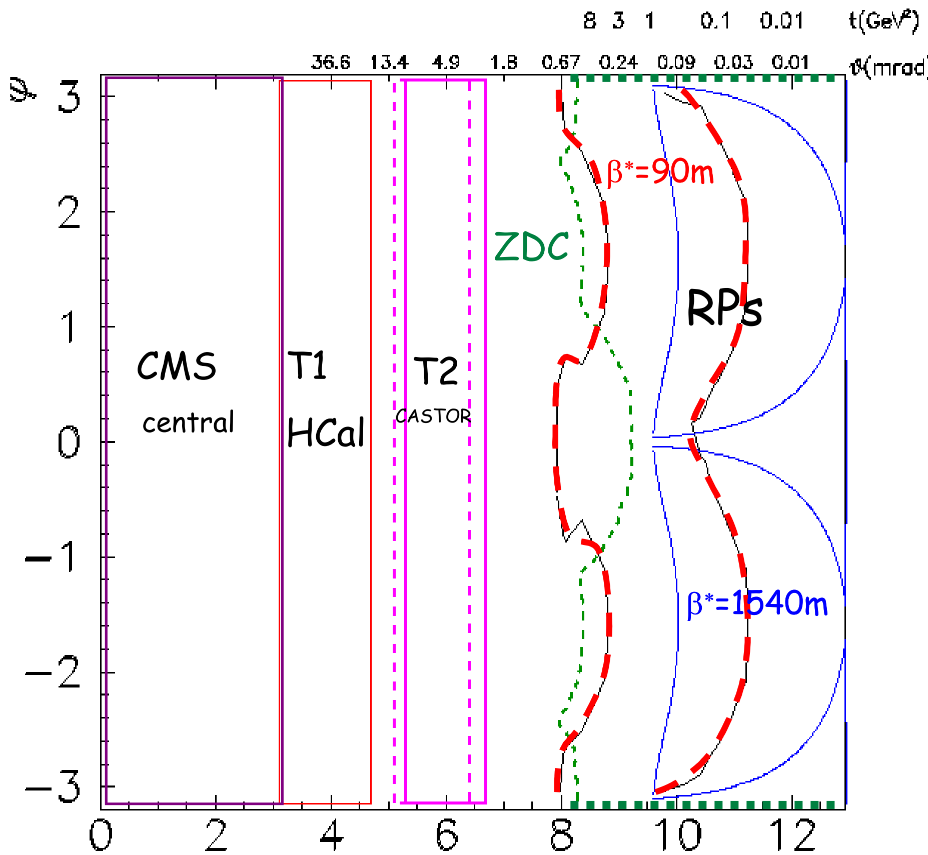
Differential mass distribution (acceptance corrected)

CMS + TOTEM: Acceptance

largest acceptance detector ever built at a hadron collider

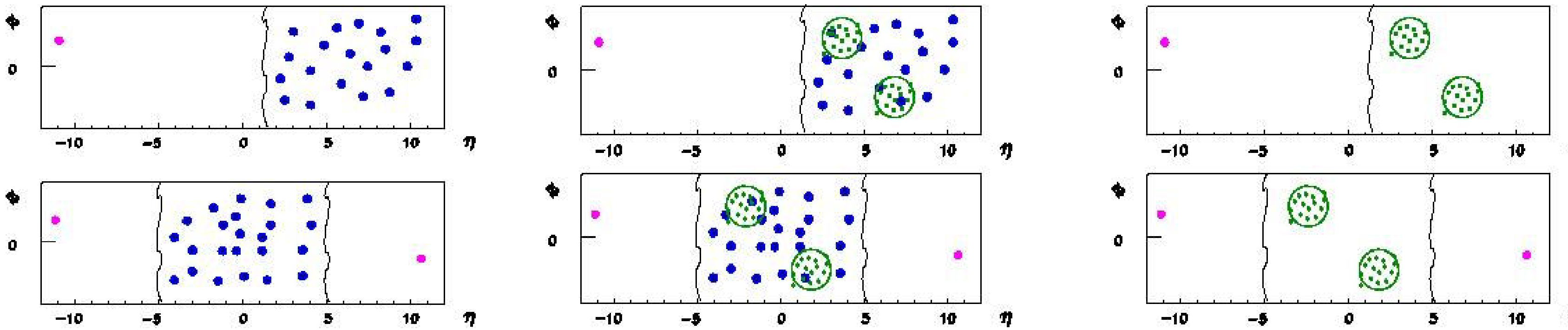
90% (65%) of all diffractive protons are detected for β^* = 1540 (90) m





η = - ln tg θ/2

CMS + TOTEM running scenarios



pp->pX pp->pXp	pp->pjjX pp->pjjXp	pp->pjj (bosons, heavy pp->pjjp quarks,Higgs...)
soft diffraction	(semi)-hard diffraction	hard diffraction

Cross section ⟵ ⟶ Luminosity

β (m)	1540	90	2	0.5	
L (cm^{-2} s^{-1})	10^{29}	10^{30}	10^{32}		10^{34}
	TOTEM LHC runs			Standard LHC runs	

Running Scenarios Summary

Scenario Physics:	1 low |t| elastic, σ_{tot} (@ ~1%), MB, soft diffr.	2 low/large |t| elastic, σ_{tot} (@ ~5%), MB, soft/semi-h. diffr.	3 large |t| elastic, hard diffraction
β^* [m]	1540	90	2 ÷ 0.5
N of bunches	43 ÷ 156	156	936 ÷ 2808
Bunch spacing [ns]	2025 ÷ 525	525	25
N of part. per bunch	(0.6 ÷ 1.15) x 10^{11}	1.15 x 10^{11}	1.15 x 10^{11}
Half crossing angle [μrad]	0	0	92
Transv. norm. emitt. ε_n [μm rad]	1	3.75	3.75
RMS beam size at IP [μm]	450	213	32
RMS beam diverg. at IP [μrad]	0.3	2.3	16
Peak Luminosity [cm^{-2} s^{-1}]	10^{28} ÷ 2 x 10^{29}	3 x 10^{30}	10^{33}

← Cross section   Luminosity →

β^* (m)	1540	90	2	0.5
L (cm^{-2} s^{-1})	10^{29}	10^{30}	10^{32}	10^{33}
	TOTEM runs		Standard runs	

beam ang. spread at IP: $\sigma_{\theta*} = \sqrt{(\varepsilon / \beta^*)}$

beam size at IP: $\sigma^* = \sqrt{(\varepsilon \beta^*)}$

- Optimal β^* = 1540m optics requires special injection optics: probably NOT available at the beginning of LHC
- Early β^* = 90m optics achievable using the standard LHC injection optics

→ Accessible physics depends on luminosity & β^*