Prospects for Diffractive and Forward Physics at the LHC

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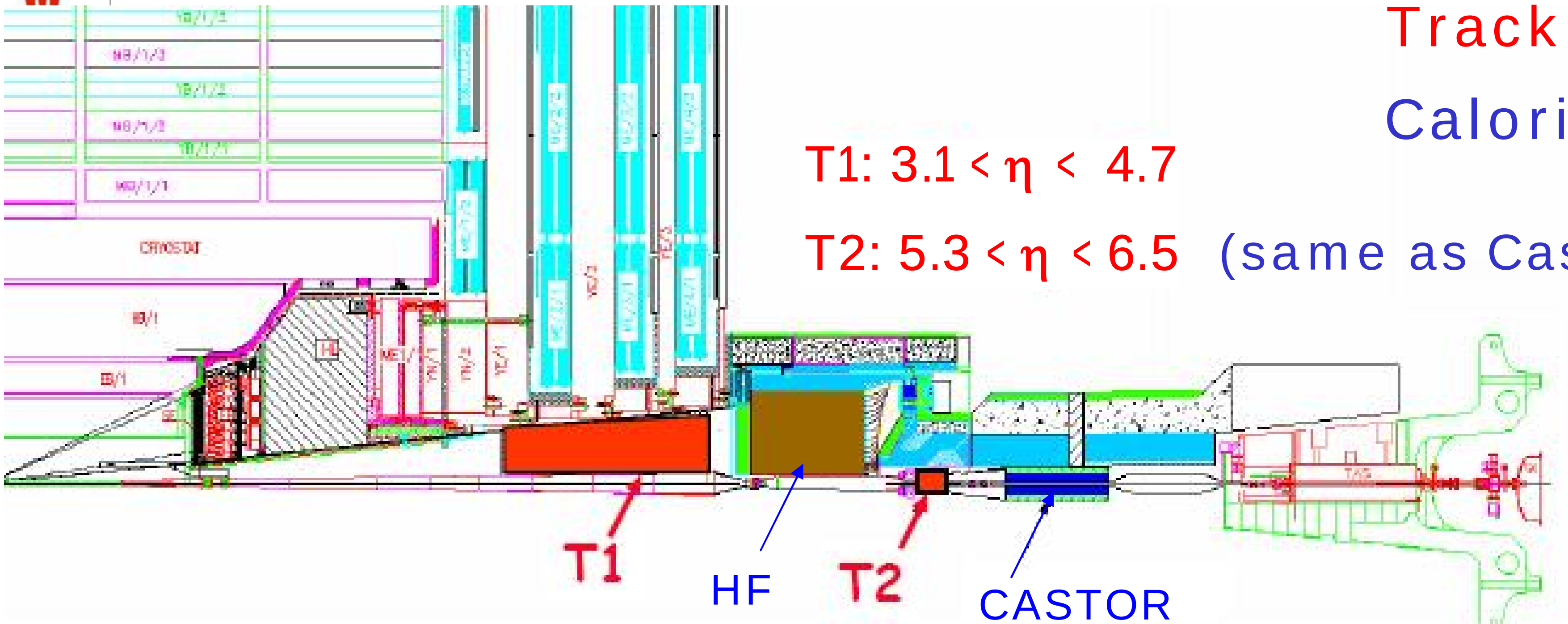
Experimental apparatus

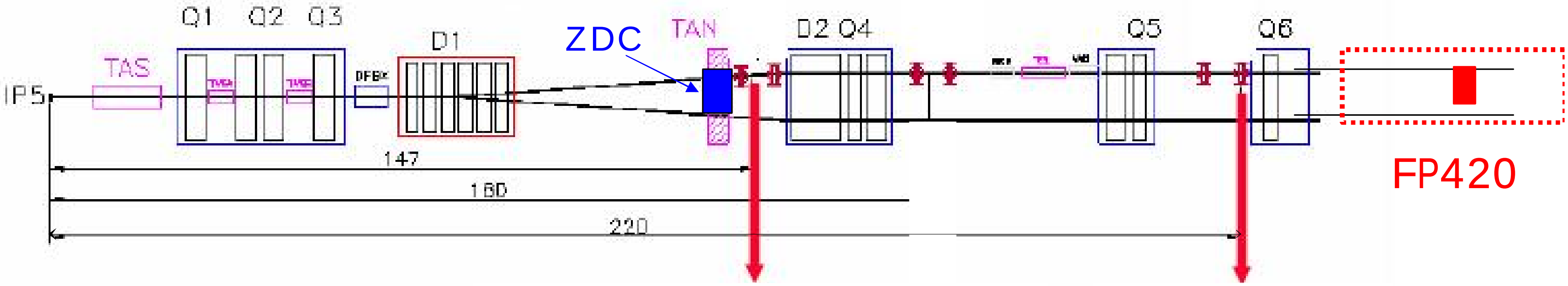
Tracking

Calorimetry

T1: 3.1 < η < 4.7

T2: 5.3 < η < 6.5 (same as Castor)





TOTEM physics program

Total cross section with a precision of 1%

Elastic pp scattering in wide t–range $[10^{-3},10]$ GeV^2

Soft single & central Diffraction

Low–x dynamics

Charged particle & energy flow in forward direction

Semi–hard + hard single & central diffraction:
production of jets, W, heavy flavours.....

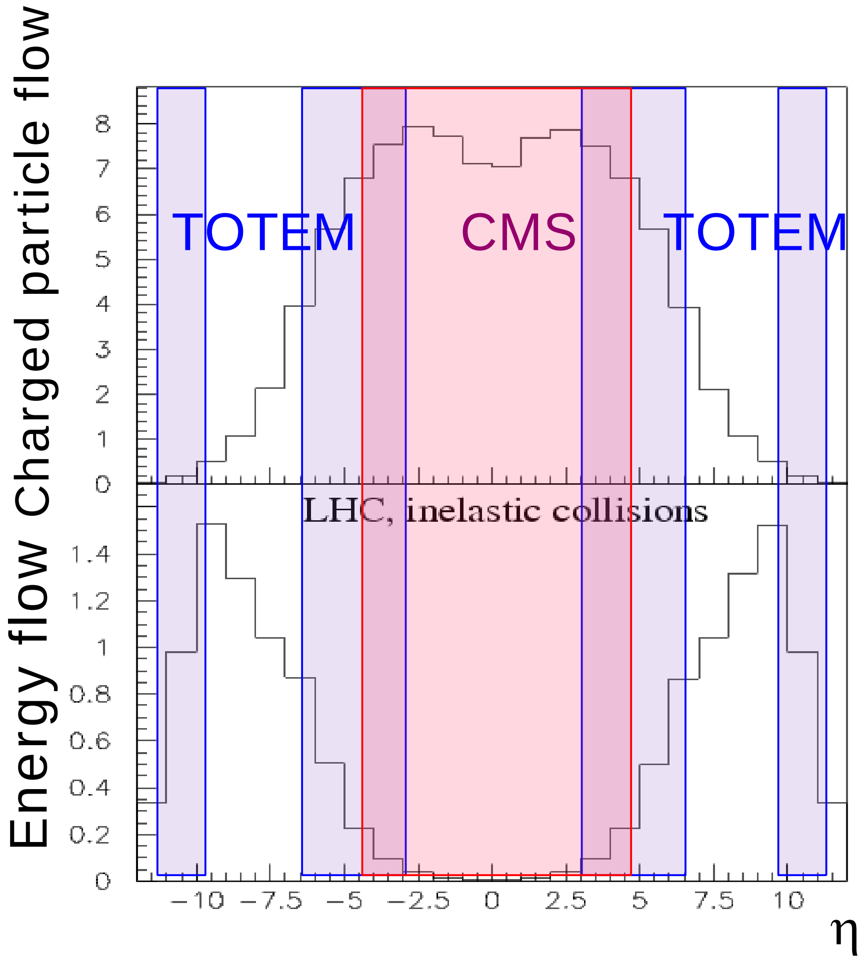
Exclusive particle production in central diffraction

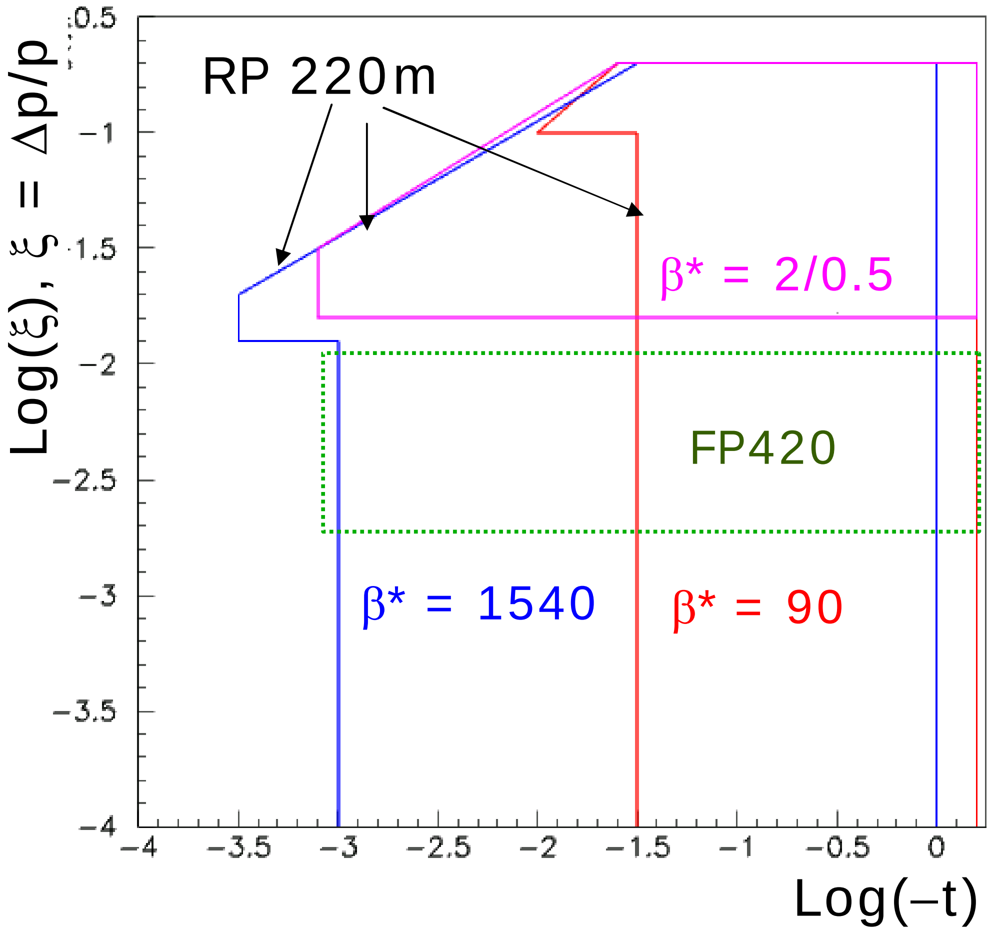
$\gamma\gamma$ & γp physics

WITH CMS

CMS/TOTEM common physics program

Combined coverage makes a wide range of physics studies possible – from diffraction & proton low-x dynamics to production of SM/MSSM Higgs

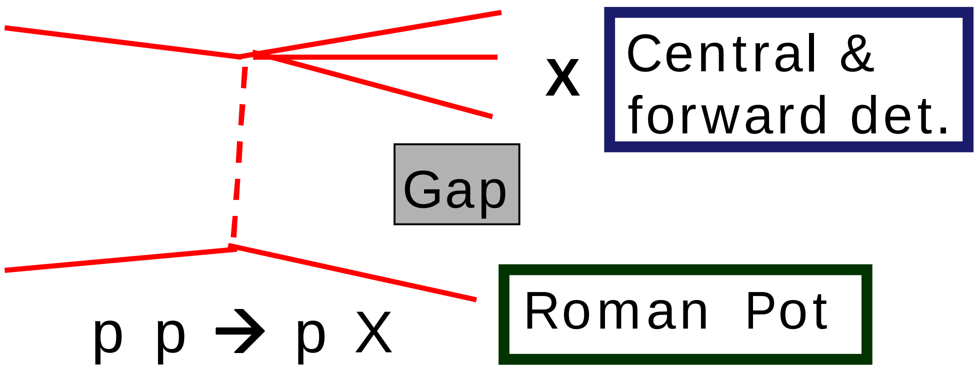




Wide coverage in pseudorapidity & proton detection

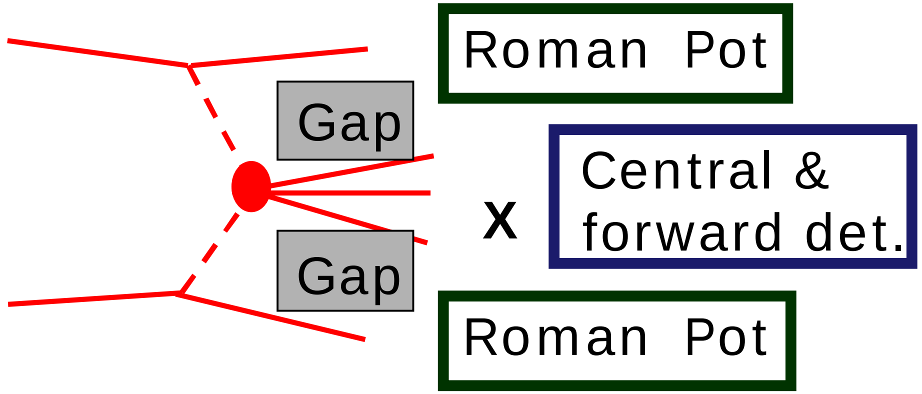
Physics motivation – diffraction

Single diffraction:



p p → p X

Central diffraction:



p p → p X p

X = anything : dominated by soft physics
Single diffractive (SD) & central diffractive (CD) inclusive cross sections + their s, t, M_X dependence. Fundamental measurements of non–perturbative QCD at LHC!!

X = jets, W, Z, Higgs: hard processes calculable in pQCD
Give info on proton structure (dPDFs & GPDs),
QCD at high parton densities, multi-parton interactions ...
New physics searches in exclusive central diffraction

Content of common document

Includes important experimental issues in measuring forward and diffractive physics but not an exhaustive physics study

- Detailed studies of acceptance & resolution of forward proton detectors
- Trigger
- Background
- Reconstruction of kinematical variables

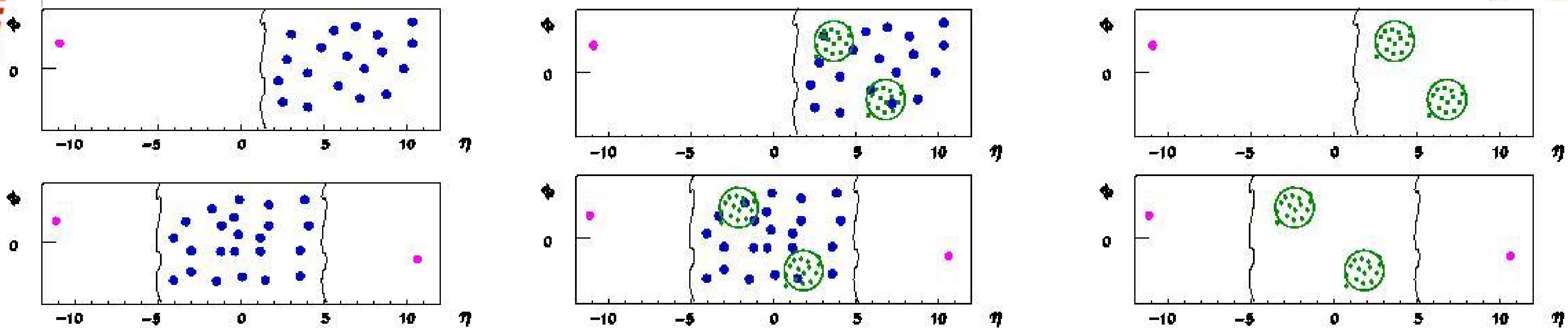
Several processes studied in detail

Ch 1: Introduction
Ch 2: Experimental Set-up
Ch 3: Measurement of Forward Protons
Ch 4: Machine induced background
Ch 5: Diffraction at low and medium luminosity

Ch 6: Triggering on Diffractive Processes at High Luminosity
Ch 7: Hard diffraction at High Luminosity
Ch 8: Photon-photon and photon-proton physics
Ch 9: Low-x QCD physics
Ch 10: Validation of Hadronic Shower Models used in cosmic ray physics

An important milestone for collaboration between the 2 experiments

Running scenario



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 →

σ	mb	µb	nb	
β* (m)	1540	90	2	0.5
L (cm^{-2} s^{-1})	10^{28}	10^{30}	10^{32}	10^{34}
	TOTEM runs		Standard runs	

Accessible physics depends on luminosity & β* (i.e. proton acceptance)

TOTEM runs

Short special runs at high β* with reduced # of bunches & no crossing angle at IP for measurement of protons scattered only a few μrad at IP

β* = 1540 m @ 220 m:

large effective length (“magnification of scattering angle”) + parallel–to–point focusing in both transverse planes, low–t detection ($t \sim 2 \cdot 10^{-3}$ GeV^2)

requires special injection optics ⇒ probably not available at LHC start

optimized for good extrapolation of differential elastic cross section to the optical point ⇒ for a precise total cross section measurement

β* = 90 m @ 220 m:

parallel–to–point focusing + large effective length in vertical plane, zero effective length in horizontal plane, t detection to $\sim 2 \cdot 10^{-2}$ GeV^2

achievable by un-squeezing standard LHC injection optics

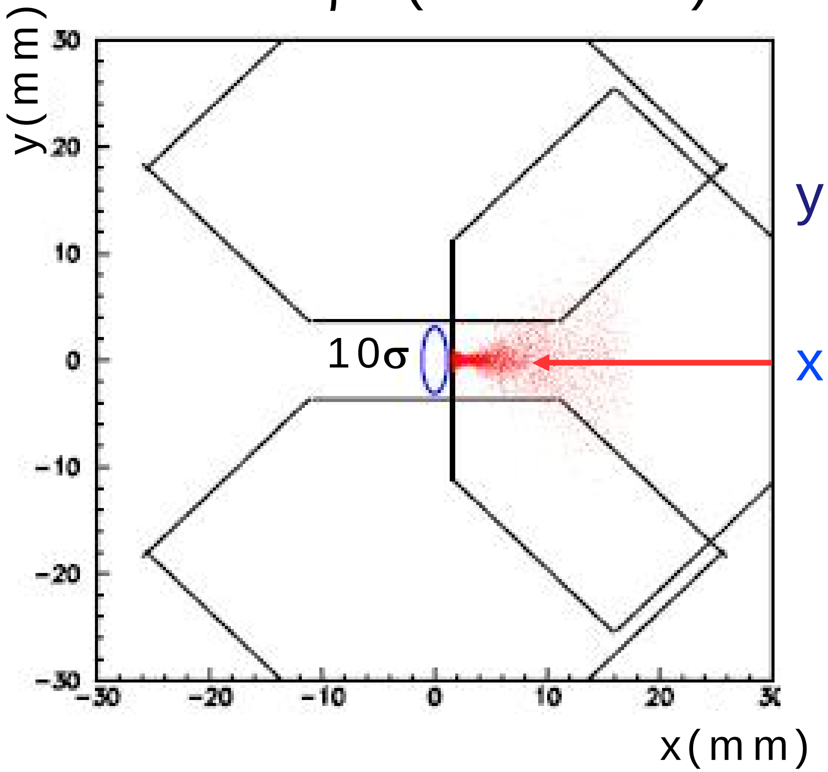
optimized for a good fractional momentum loss measurement for diffractive protons ⇒ for diffractive measurements

Forward proton measurement: principle

Diffractive protons : hit distribution @ RP220

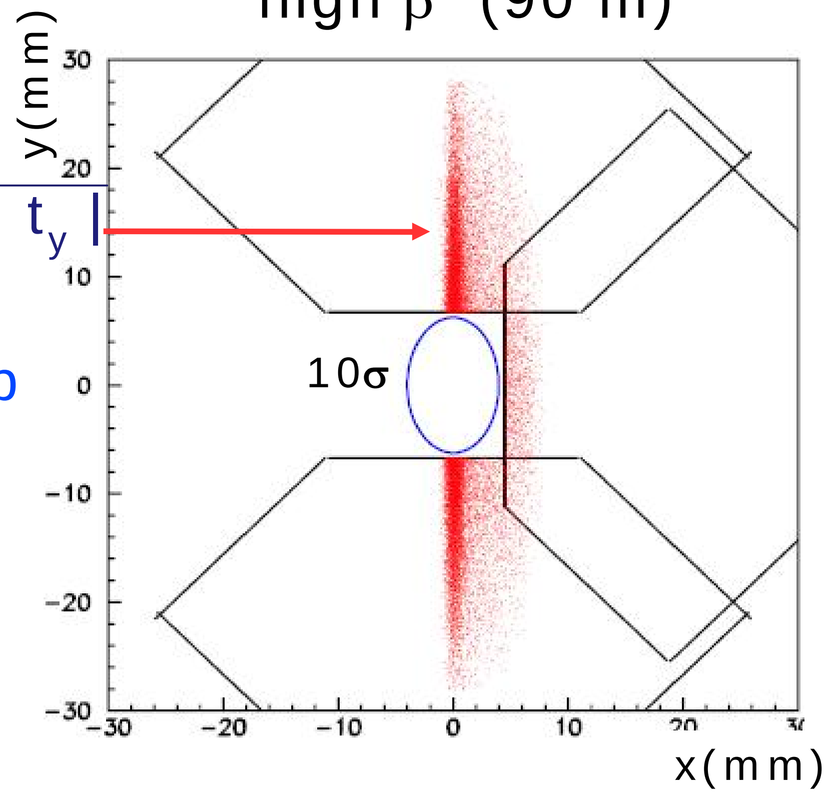
low β* (0.5 - 2 m)

high β* (90 m)



$y \sim \Theta_y^{scatt} \sim \sqrt{|t_y|}$

$x \sim \xi = \Delta p/p$

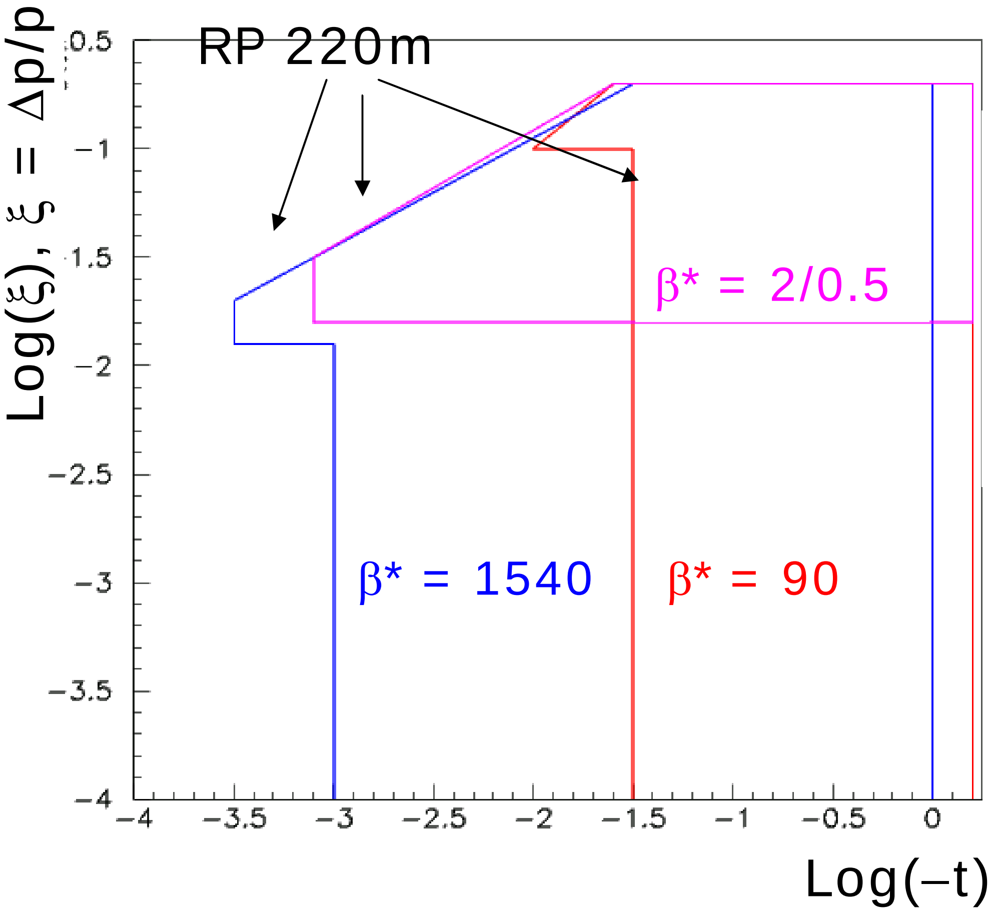


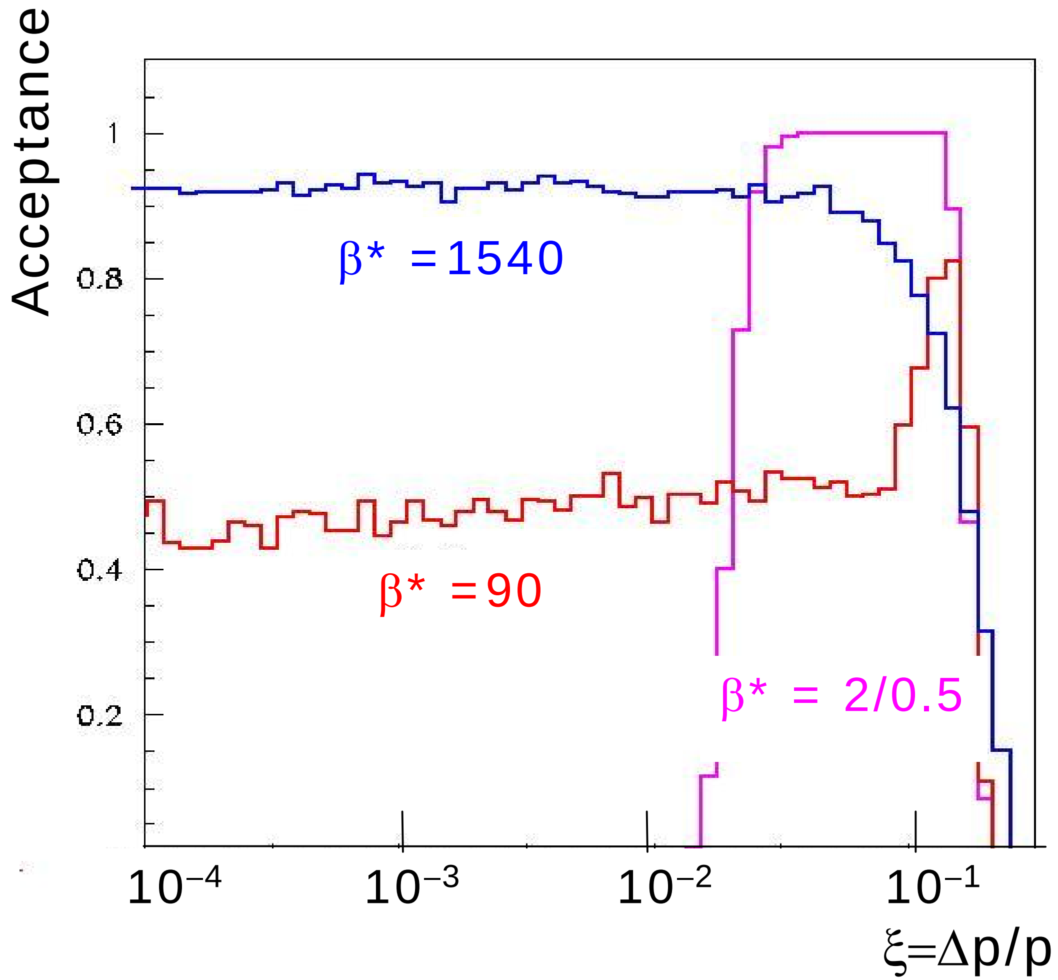
Detect the proton via:

its momentum loss (low **β***)

its transverse momentum (high **β***)

Forward proton measurement: acceptance (@220 m)





Forward proton measurement: momentum resolution (β* = 90 m)

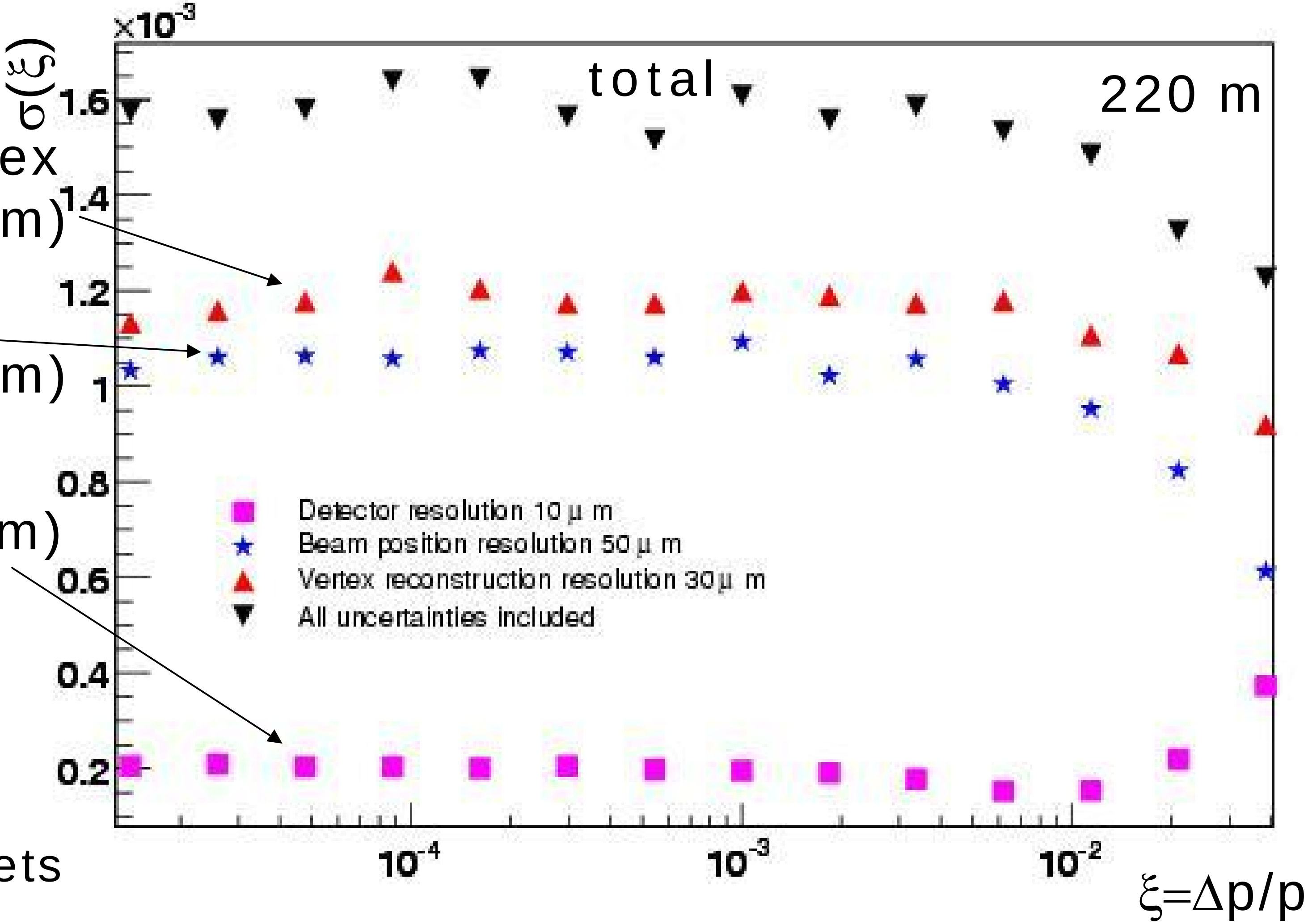
Individual contribution to the resolutio

Transverse vertex resolution (30 μm)

Beam position resolution (50 μm)

Detector resolution (10 μm)

Final state dependent; 30 μm for light quark & gluon jets



Forward proton measurement: momentum resolution (β^* = 2/0.5 m)

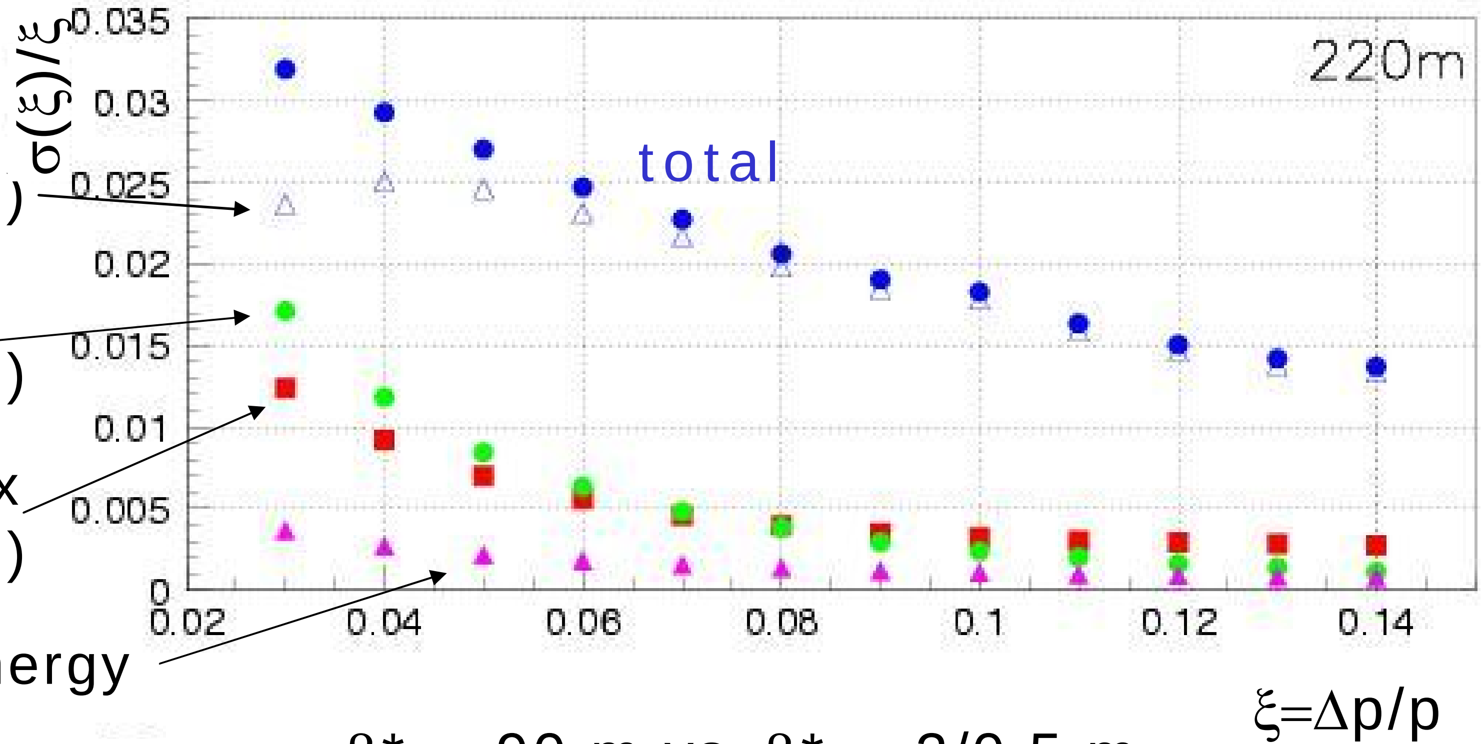
Individual contribution to the resolution:

Detector resolution (10 μm)

Beam position resolution (50 μm)

Transverse vertex resolution (10 μm)

Relative beam energy spread ($1.1 \cdot 10^{-4}$)

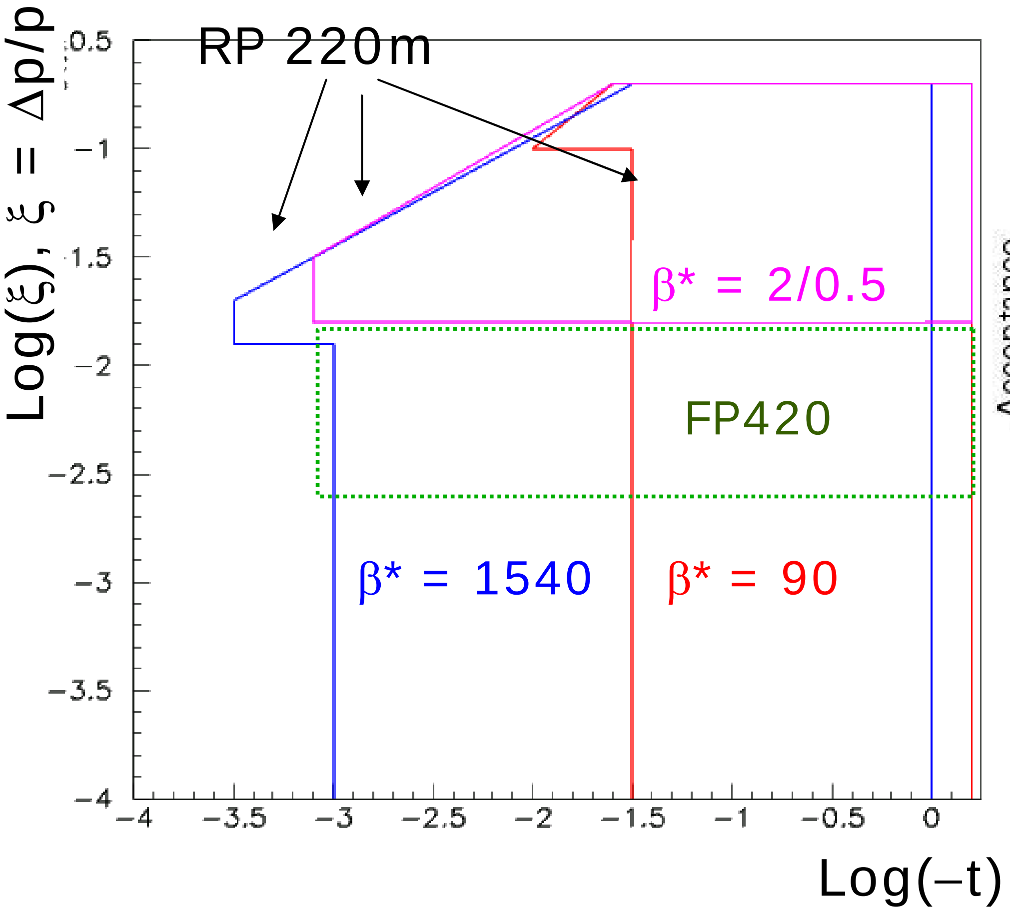


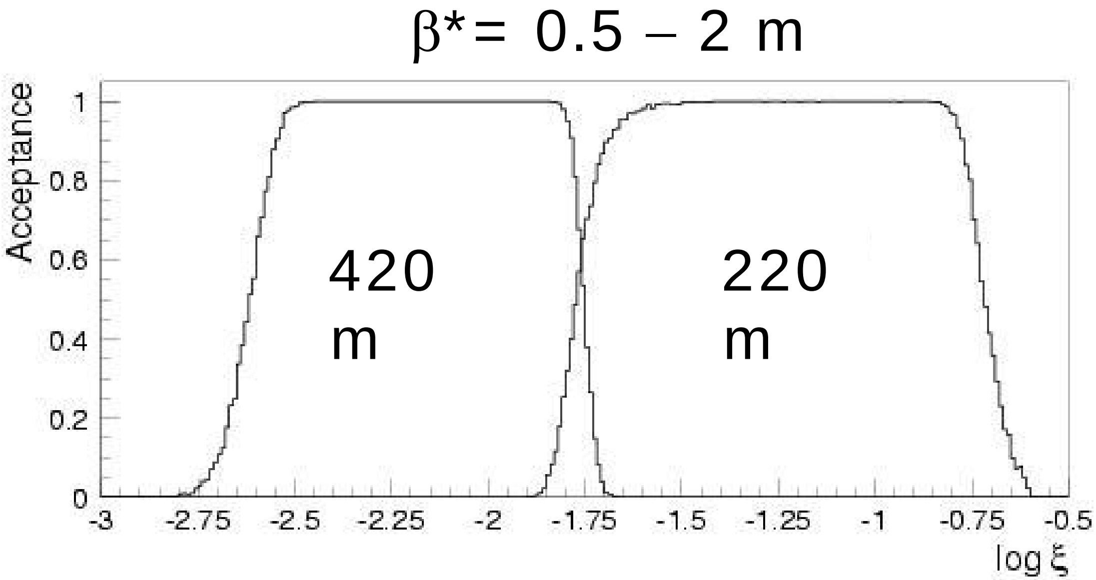
Very little final state dependence since transverse IP size is small.

<u>β^* = 90 m vs. β^* = 2/0.5 m</u>

Better $\sigma(\xi)/\xi$ for β^* = 2/0.5 m & larger luminosity but limited ξ acceptance (ξ > 0.02)

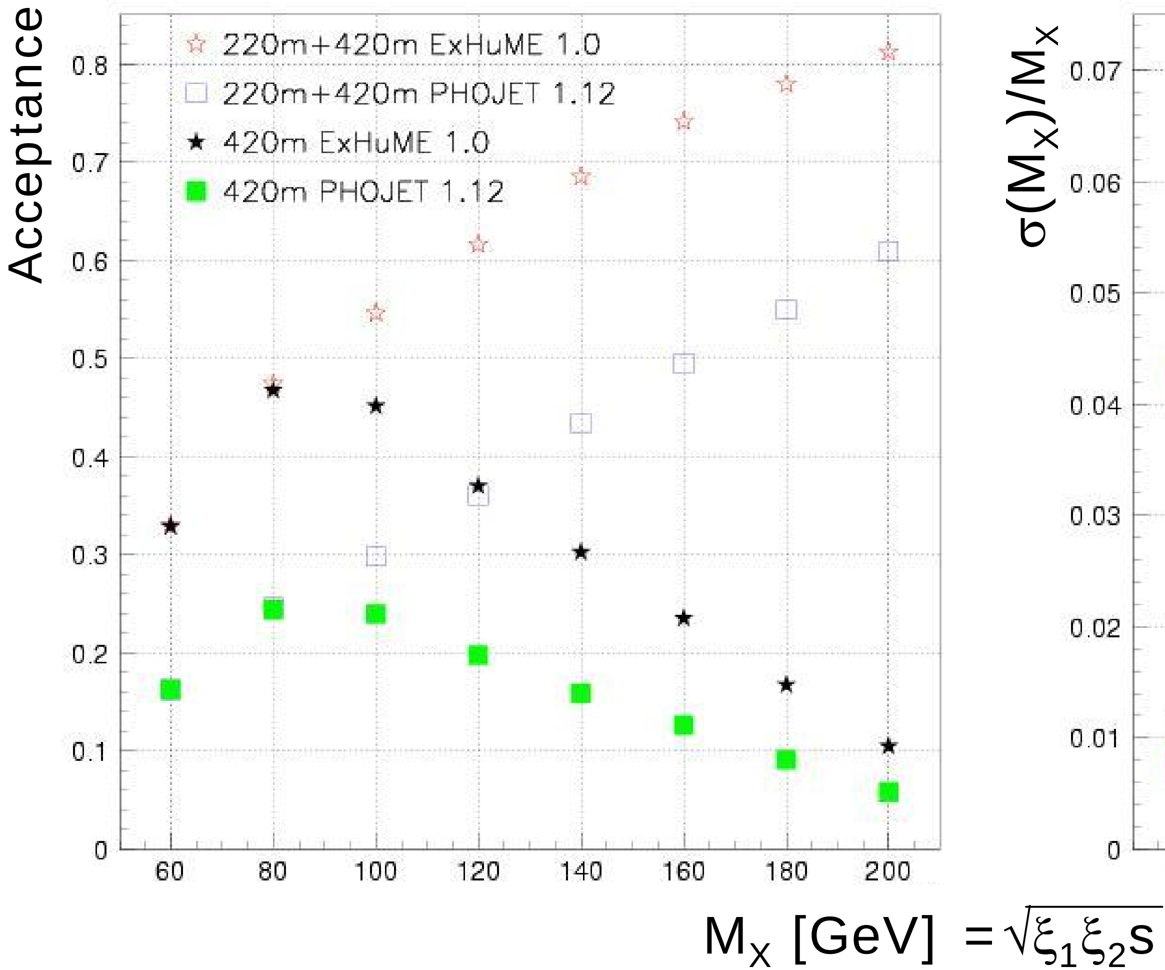
Forward proton measurement: acceptance (@220 m & 420 m)

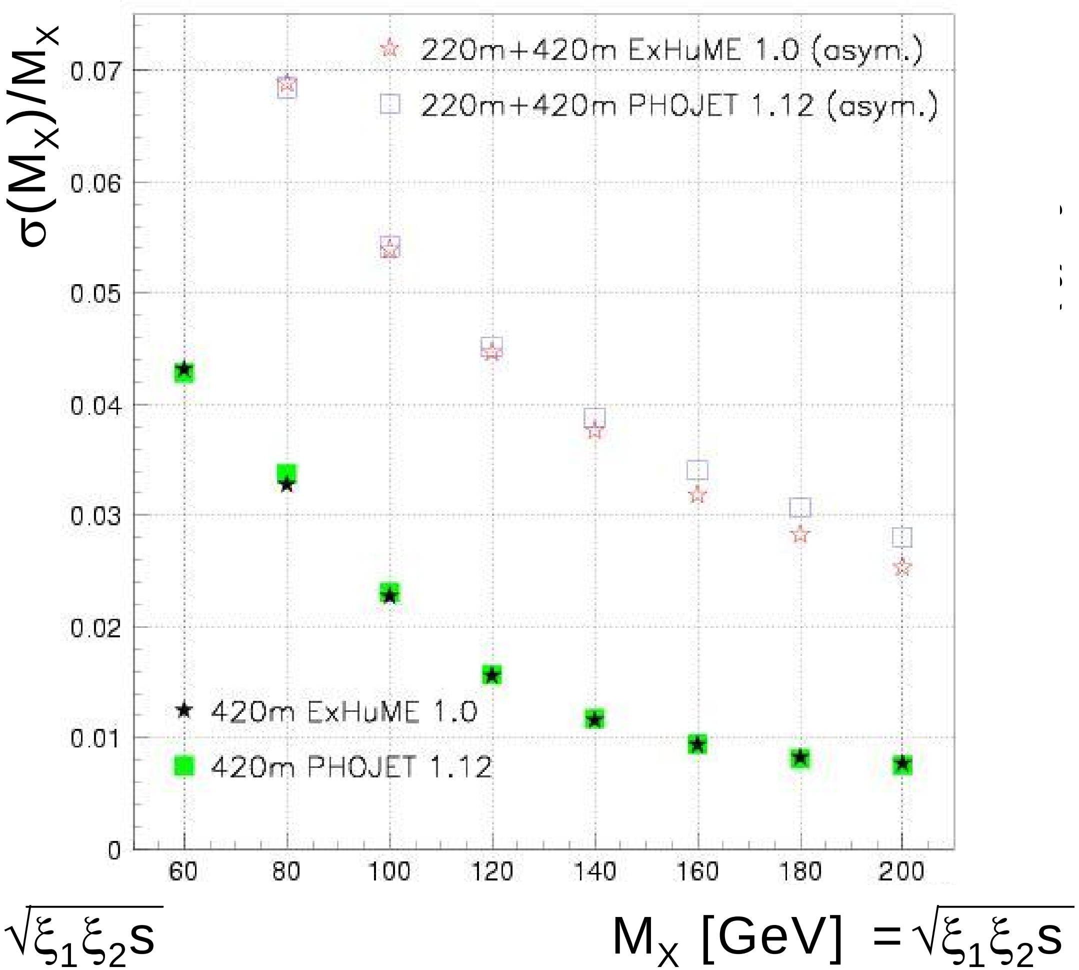




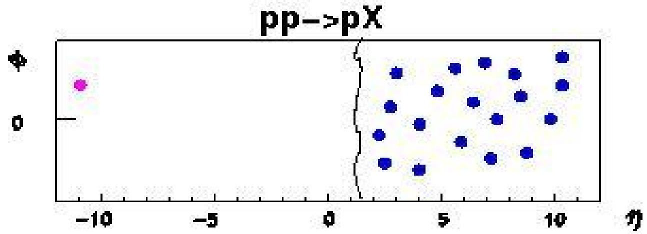
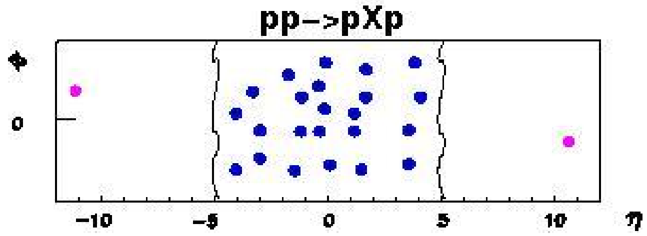
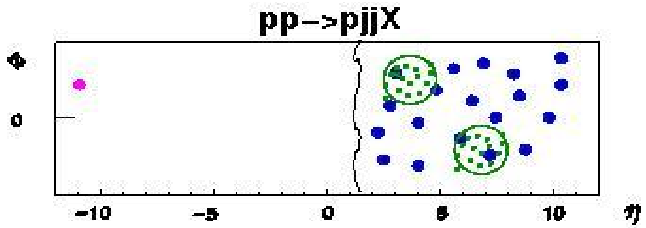
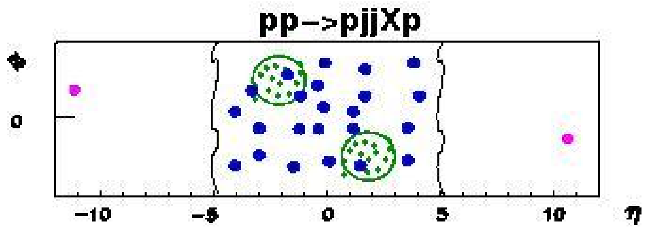
Proton detectors at 420 m would enlarge acceptance range down to ξ = 0.002 at high luminosity (= low β*).

Forward proton measurement: CD mass acceptance & resolution (β^* = 0.5–2 m @ 220& 420 m)



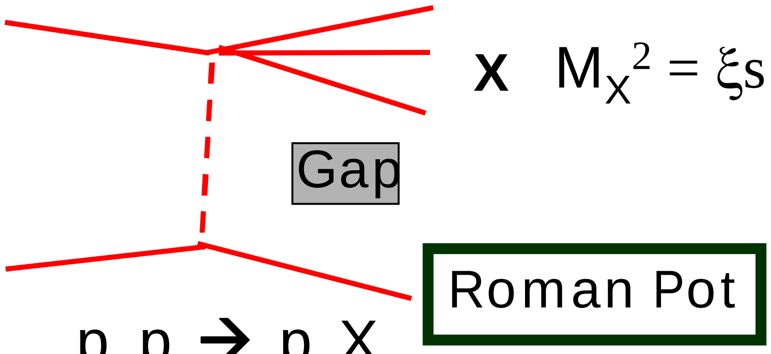


Triggering on soft & semi-hard diffraction

		σ	Estimated Rates (Hz) [acceptance corrected] $L = 10^{30}\,cm^{-2}s^{-1}$, $\beta^* = 90$ m	$L = 10^{32}\,cm^{-2}s^{-1}$, $\beta^* = 2$ m
	1p T1/T2	14 mb	6000	$1.4 \cdot 10^5$
	2p T1/T2	1 mb	200	$3.5 \cdot 10^3$
	1p T1/T2 jet(s)	1μb ($p_T^{jet} > 20$ GeV)	0.2	
		30nb ($p_T^{jet} > 50$ GeV)	0.01	0.5
	2p T1/T2 jet(s)	60nb ($p_T^{jet} > 20$ GeV)	$7 \cdot 10^{-3}$	
		1.5 nb ($p_T^{jet} > 50$ GeV)		0.03

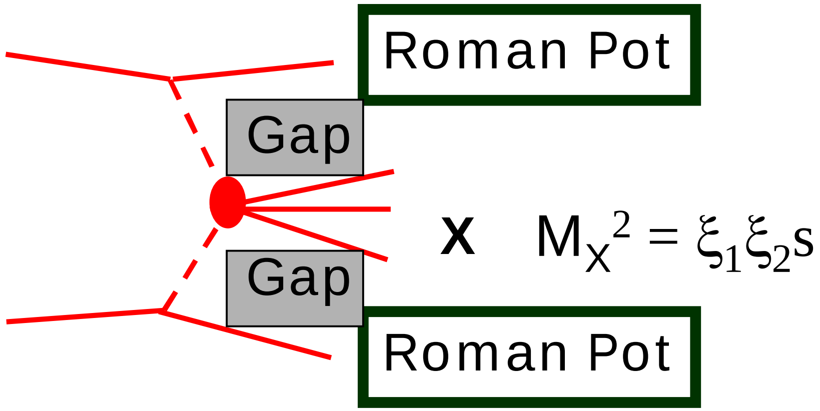
Diffraction at low luminosity ($< 10^{32}$ cm^{-2} s^{-1}): soft diffraction

Single diffraction:



p p → p X

Central diffraction:



p p → p X p

Inclusive cross sections & their *t*, M_X dependence

Event topology

Measure ξ and central mass via:

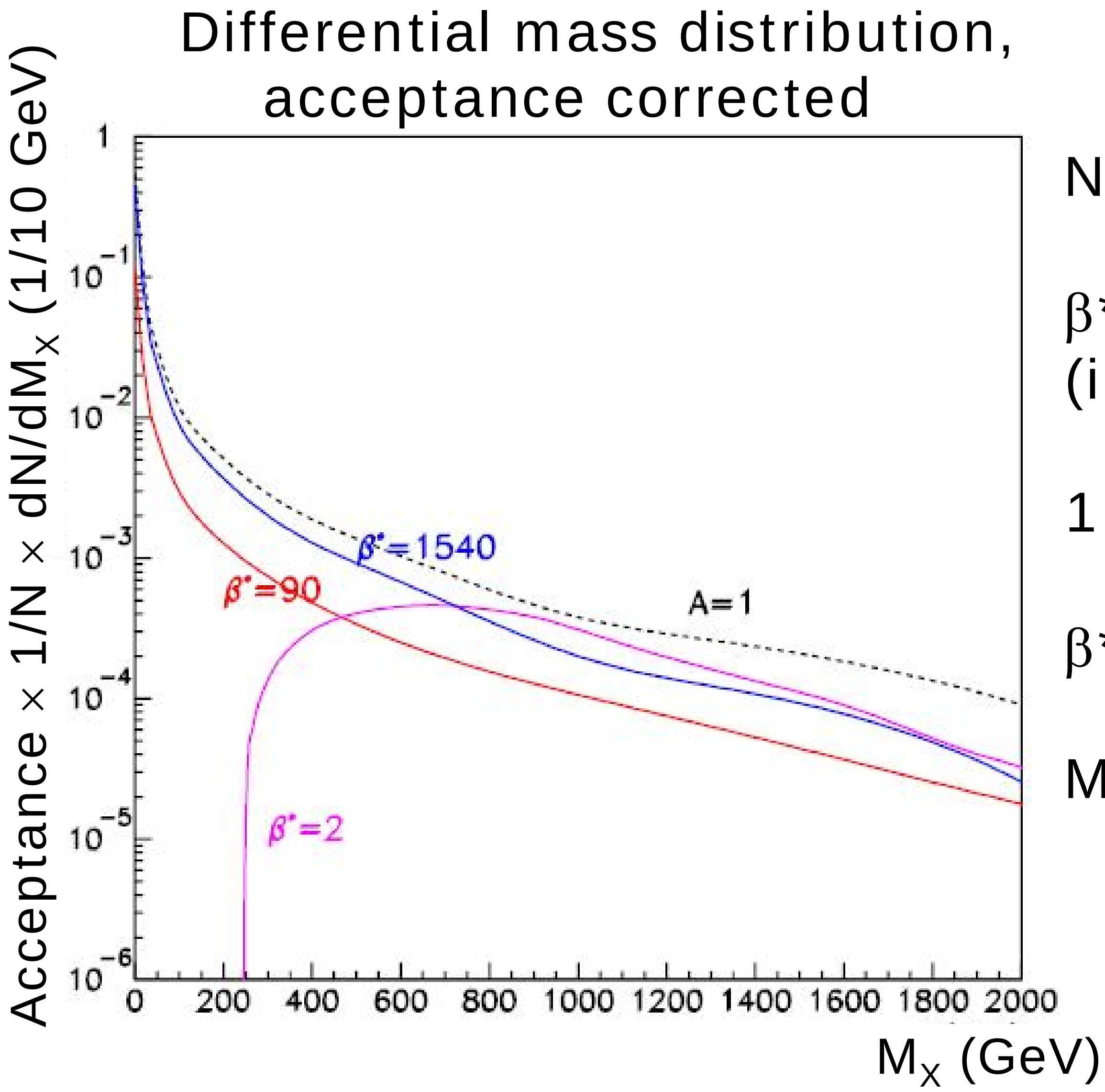
- proton(s)
- rapidity gap relation $\Delta\eta = -\ln\xi$
- calorimeters

$$\xi^{\pm} = \Sigma_i E_T^i e^{\pm\eta_i} / \sqrt{s}$$

Wide t & ξ acceptance range with TOTEM optics

Soft diffraction important contribution to pile-up at high luminosity

Diffraction at low luminosity: soft central diffraction



Number of events collected:

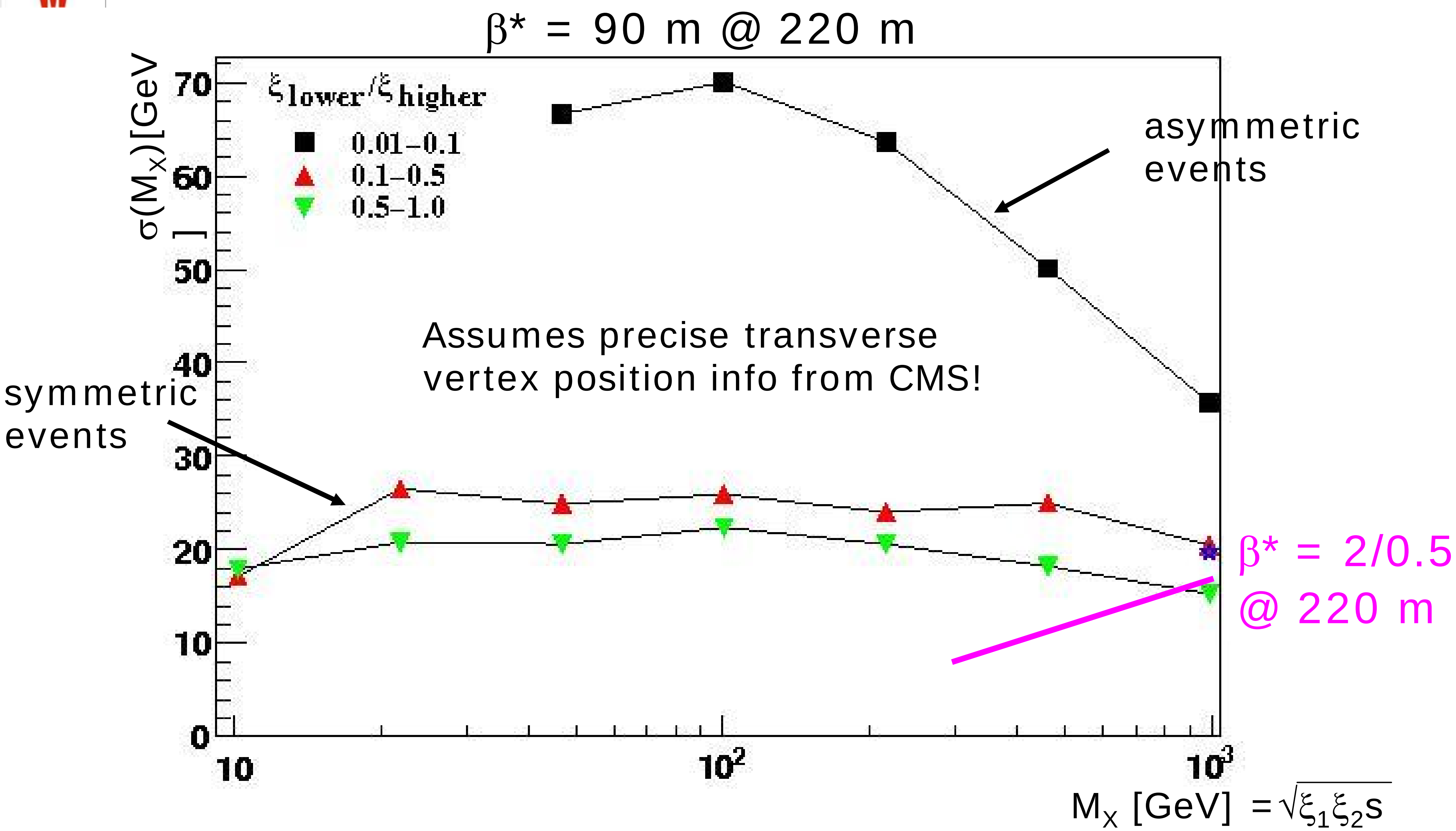
$\beta^* = 90$ m $\int L dt = 0.3$ (pb^{-1})
(in a few days running):

$1 < M_X < 2000$ GeV N ~ 10^7

$\beta^* = 2$ m $\int L dt = 100$(pb^{-1}):

$M_X > 300$ GeV N ~ 10^8

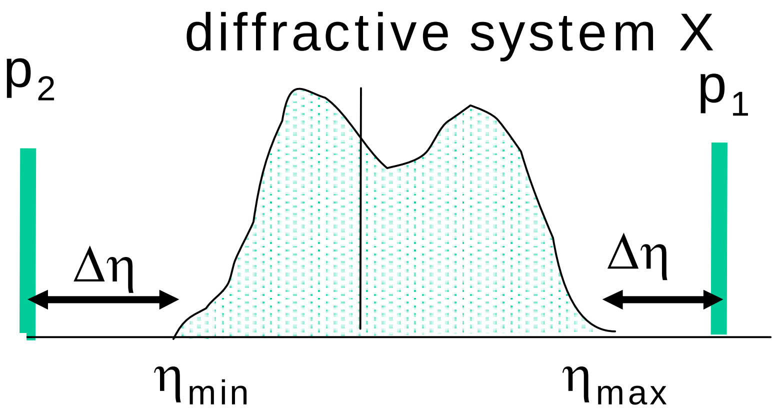
Diffraction at low luminosity: central mass resolution in CD



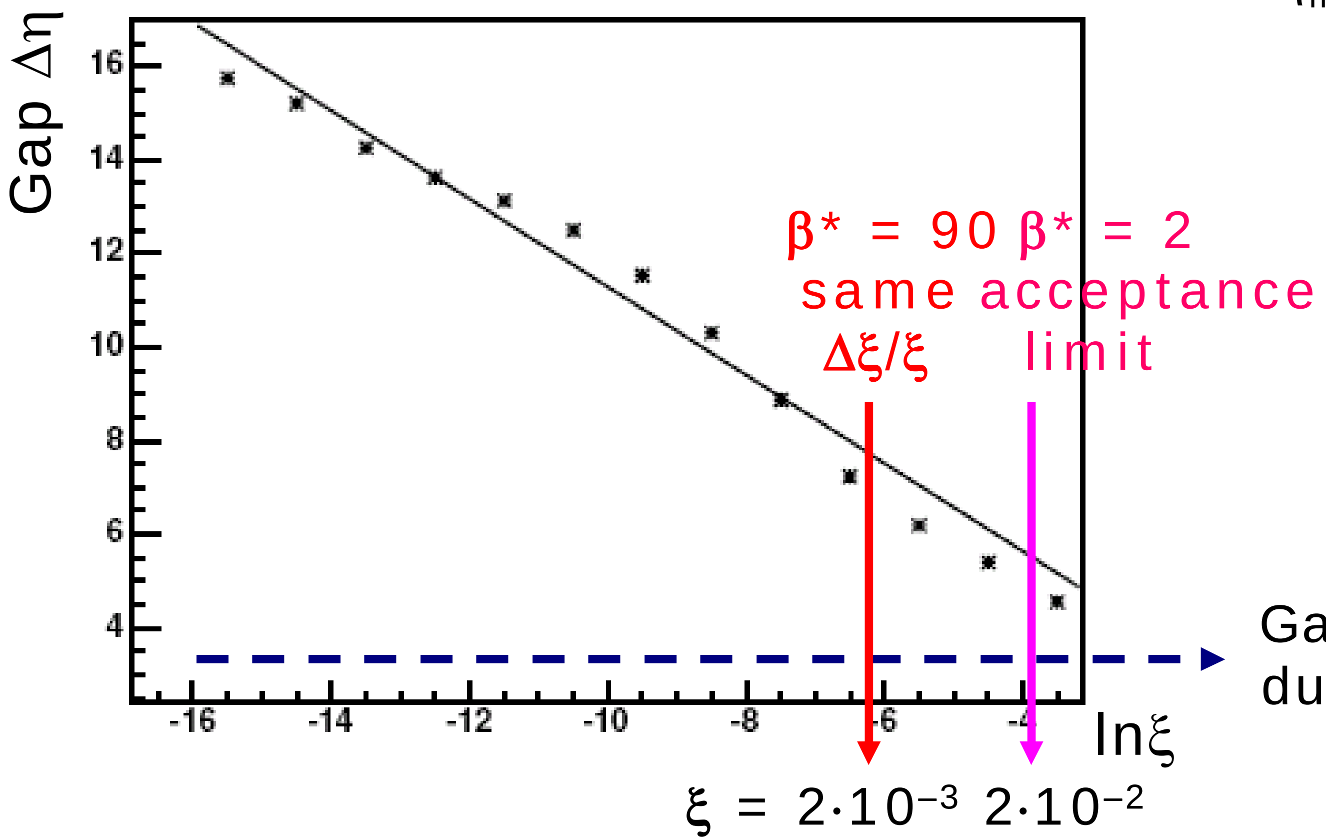
Diffraction at low luminosity: rapidity gaps

Measure ξ via rapidity gap: $\Delta\eta = -\ln\xi$

Achieved resolution: $\sigma(\xi)/\xi \sim 80\ \%$



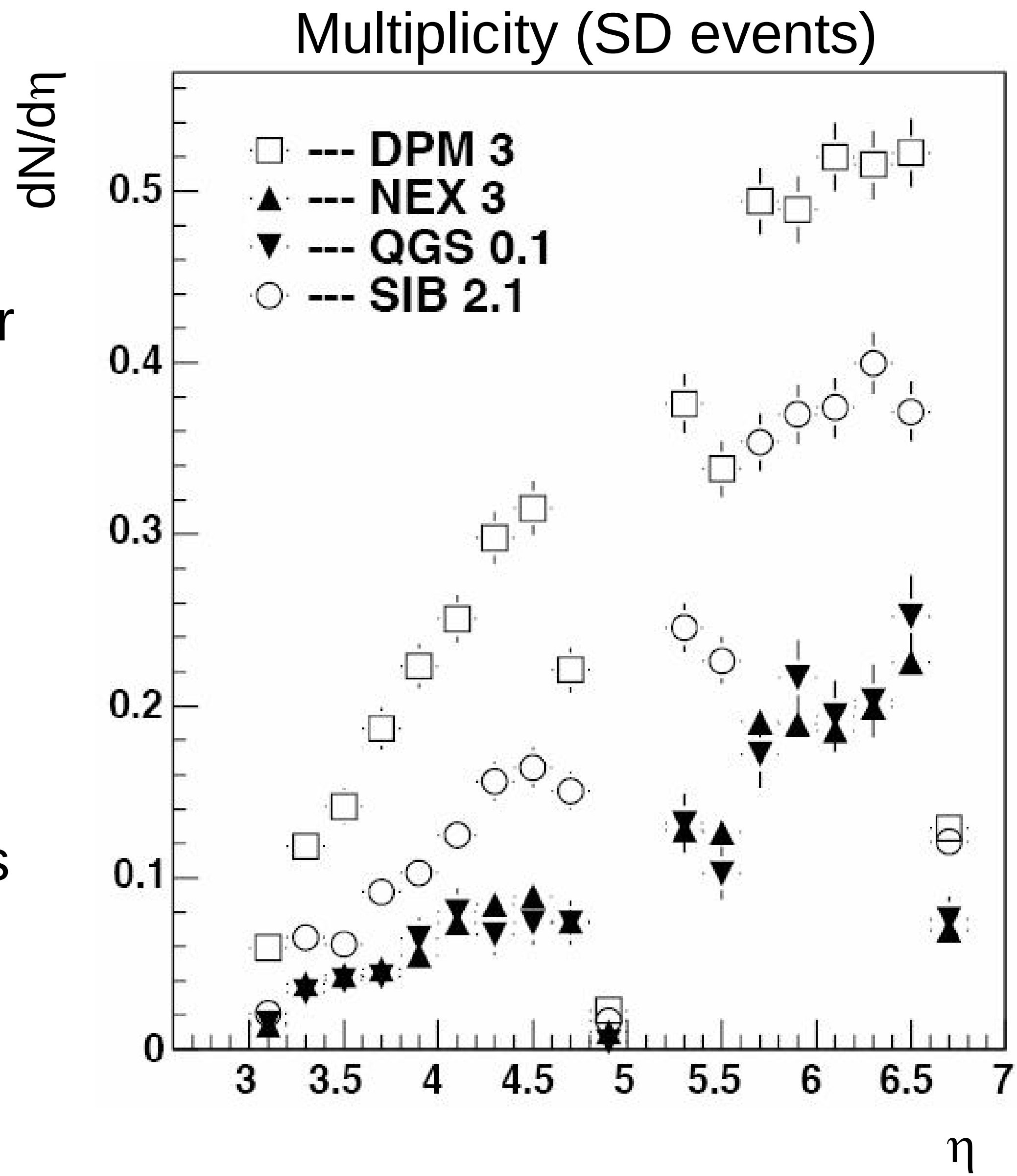
Gap vs ln (ξ) T1+T2+Calorimeters



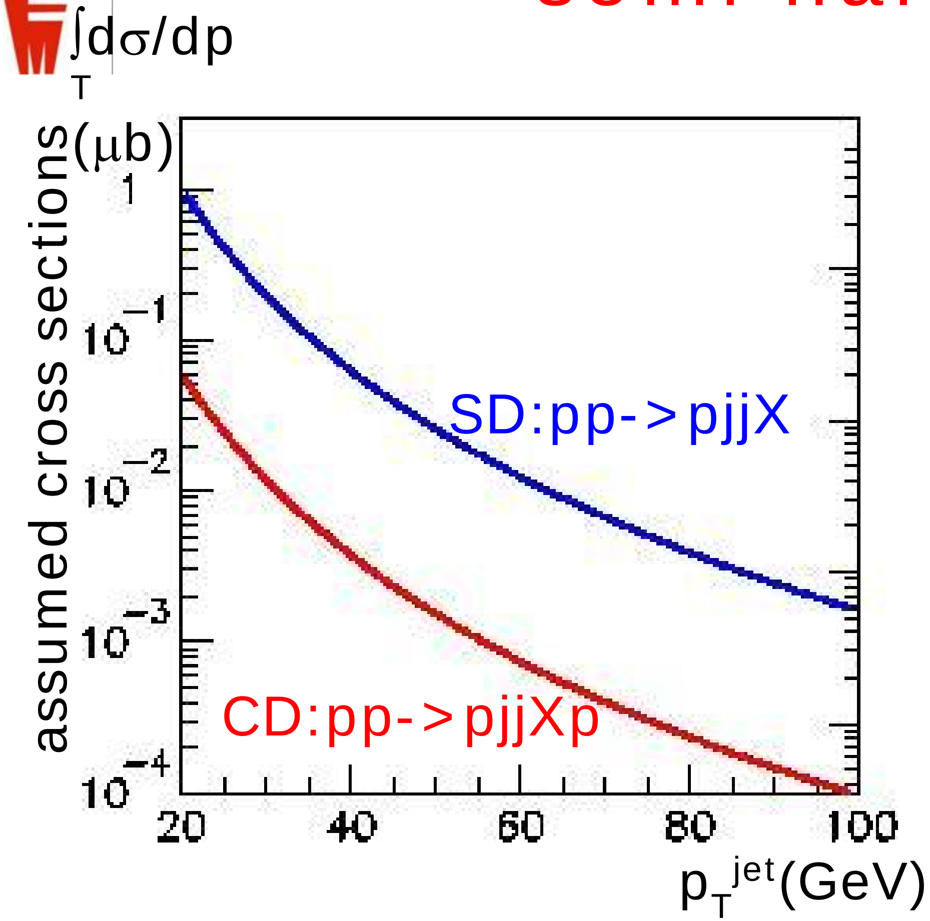
Gap measurement limit due to acceptance of T2

Forward particle multiplicity: connection to cosmic ray modelling

- Models used in hadronic simulation programs differ by more than a factor 2.
- Necessary measurement of forward particle and energy flow.
- SD events trigger: p+T1/T2 (opposite side)
- Study in details SD events



Diffraction at low luminosity: semi-hard diffraction



In case of jet activity ξ can also be determined from calorimeter info:

$$\xi^{\pm} = \Sigma_i E_T^i e^{\pm\eta_i} / \sqrt{s}$$

$$\sigma(\xi)/\xi \sim 40\ \%$$

Measure cross sections & their t, M_X, p_T^{jet} dependence

Event topology: exclusive vs inclusive jet production

N event collected [acceptance included]

$\beta^* = 90$ m $\int Ldt = 0.3\ (pb^{-1})$

SD:	$p_T > 20$ GeV	6×10^4
CD:	"	2000

$\beta^* = 2$ m $\int Ldt = 100\ (pb^{-1})$

SD:	$p_T > 50$ GeV	5×10^5
CD:	"	3×10^4

Summary

The common CMS/TOTEM physics document shows that

Short runs at β^* = 90 m will give excellent opportunities for a wide range of diffractive measurements with a large ξ & t acceptance

Complemented by large M & p_T^{jet} measurements at standard LHC runs

Rare diffractive processes need high luminosity & detectors at 420 m

TOTEM&CMS measure together at low & medium luminosity:

Inclusive diffractive processes from low masses up to a few TeV

Diffractive event topologies using rapidity gaps & calorimetry and correlated with leading proton measurements

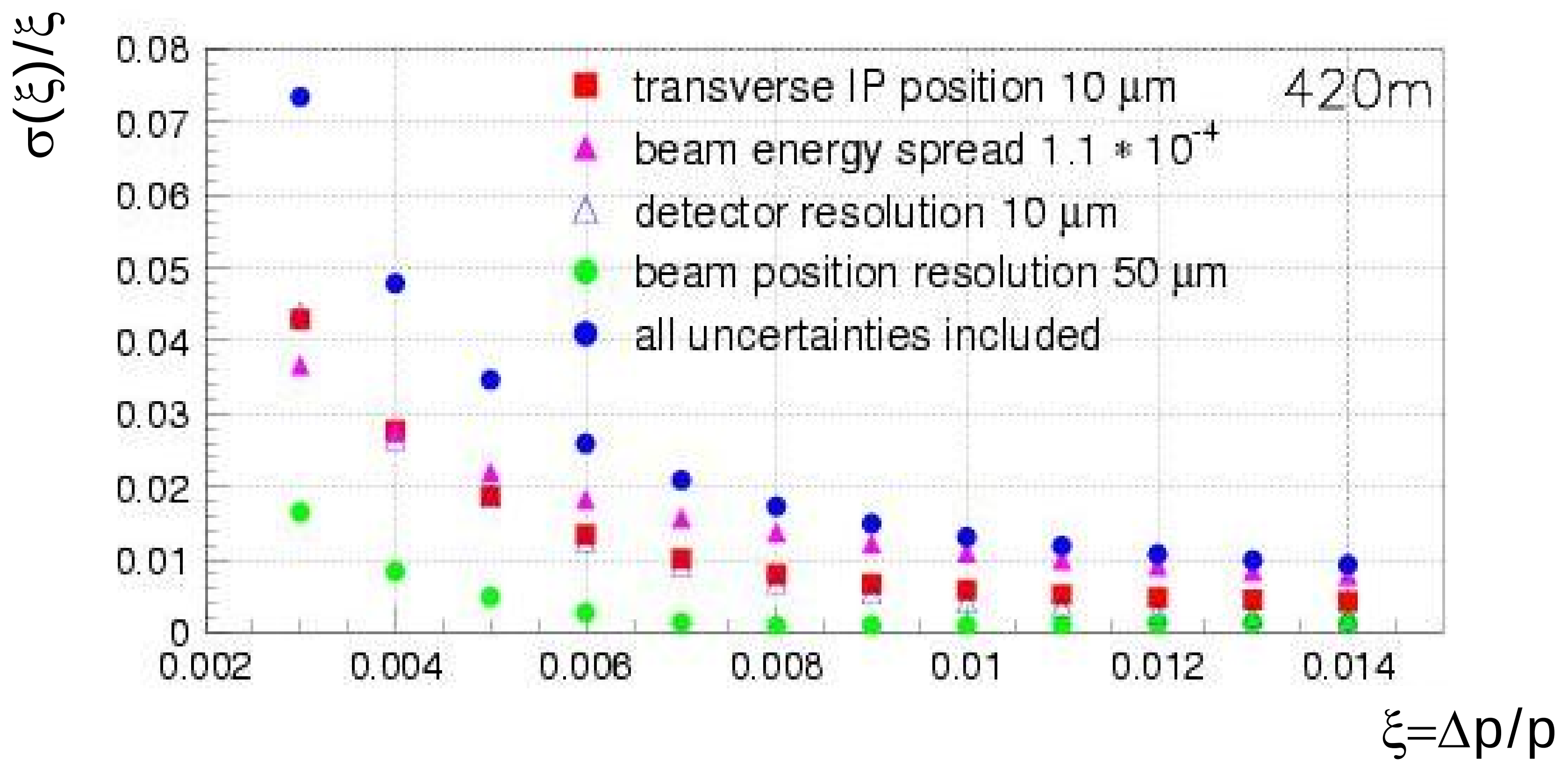
Forward particle multiplicity as input for cosmic ray modelling

Inclusive diffractive p_T^{jet} cross section from ~ 20 GeV onwards by combining measurements from runs at different β^*'s

Assumption on trigger rates

		L1(kHz)	HLT/tape (Hz)
	CMS	100	100
	TOTEM	~2	~2000
Common runs	CMS/TOTEM	~2	100
Common runs	CMS/TOTEM	1	1

Forward proton measurement: momentum resolution ($\beta^* = 0.5–2$ m @ 420 m)



CD: $\sigma(M_X) \sim 1.5 – 2.5$ GeV for $60 < M_X < 200$ GeV

Running scenarios

Physics:	low |t| elastic, σ_{tot} , min bias	large |t| elastic	Soft diffraction	Soft & semi-hard diffraction
β*[m]	1540 (90)	18, 2, 0.5	1540	90
N of bunches	43	2808	156	156
N of part. per bunch ($\times 10^{11}$)	0.3	1.15	(0.6 - 1.15)	1.15
Half crossing angle [μrad]	0	160	0	0
Transv. norm. emitt. [μm rad]	1 (3.75)	3.75	1 - 3.75	3.75
RMS beam size at IP [μm]	454 (200)	95	454 - 880	200
RMS beam diverg. [μrad]	0.29 (2.3)	5.28	0.29 - 0.57	2.3
Peak luminosity [$cm^{-2} s^{-1}$]	$1.6 (7.3) \times 10^{28}$	3.6×10^{32}	2.4×10^{29}	2×10^{30}