σ_T @ VLHC

NEED:

1. SOME IR QUADS OF HIGHER GRADIENT
2. QUADS BE TUNEABLE
3. WARM SECTIONS FOR DETECTORS
4. BEAM SCRAPING
5. STABLE BEAM POSITION

PRECISE MEASUREMENT OF THE TOTAL CROSS SECTION AND THE COULOMB SCATTERING AT THE LHC*

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Abstract

A precise measurement of the total cross section and the Coulomb scattering at LHC requires the observation of elastically scattered particles at extremely small angles (14 μrad, $-t \leq 0.01$ GeV^2 for the first case; 3 μrad, $-t \leq 0.0006$ GeV^2) for the second one). In this paper a very high-β insertion optics which fulfills both conditions is presented. A feasibility study, including the acceptance of the detectors, for an experiment to be installed in IR1 or IR5, is also presented.

optics	standard	new		
ϵ_z	5.03 10^{-10}			m rad
β^*_z	1100.0			m
measurement vertical				
	before $D2$		$Q4-Q5$	
		close $D2$	close $Q4$	
β_{y_d}	20.1	20.6	22.2	m
$\Delta\mu_{y_d}$	0.250	0.250	0.250	2π
$M_{y,12_d}$	148.6	150.5	156.3	m
$\lvert\theta_{y_{min}}\rvert$	14.3	14.1	13.6	μrad
$\lvert t_{y_{min}}\rvert$	0.010	0.010	0.009	GeV^2

Table 1: Performance of a total cross section experiment at the IP and at the detector place of Ring 1 for optics with β^*=1100, Version 6.0 at 7 TeV for nominal emittance and for different positions of the Roman Pots ($RP2$ and $RP3$ in middle part of figure 1). $|\theta_{y_{min}}| = \sqrt{2}y_d/M_{y,12_d}$ with $y_d = 1.5$ mm.

ϵ_z	5.03 10^{-10}	m rad
β^*_z	3500.0	m
α^*_z	0.0	
D^*_x	0.0	m
D'^*_x	0.0	
σ^*_z	1.33	mm
σ'^*_z	0.38	μrad
measurement vertical		
detector between $Q6-Q7$		
β_{y_d}	18.4	m
$\Delta\mu_{y_d}$	0.750	2π
$M_{y,11_d}$	0.0	
$M_{y,12_d}$	-253.4	m
y_d	-3.62	mm
$\lvert y_d/\sigma_{y_d}\rvert$	37.7	
$\lvert\theta_{y_{min}}\rvert$	8.4	μrad
$\lvert t_{y_{min}}\rvert$	0.003	GeV^2

Table 2: Performance of a precise total cross section measurement at the IP and at the detector place of Ring 1 for optics with β^*=3500, Version 6.0 at 7 TeV for nominal emittance and the Roman Pots between $Q6$ and $Q7$. $|\theta_{y_{min}}| = \sqrt{2}y_d/M_{y,12_d}$ with $y_d = 1.5$ mm.

ϵ_z	5.03 10^{-10}	1.258 10^{-10}	m rad
β^*_z	3500.0		m
α^*_z	0.0		
D^*_x	0.0		m
D'^*_x	0.0		
σ^*_z	1.33	0.66	mm
σ'^*_z	0.38	0.19	μrad
measurement horizontal			
detector between $Q6-Q7$			
β_{x_d}	177.4		m
$\Delta\mu_{x_d}$	0.250		2π
$M_{x,11_d}$	0.0		
$M_{x,12_d}$	787.9		m
x_d	2.5	2.5	mm
$\lvert x_d/\sigma_{x_d}\rvert$	8.4	16.8	
$\lvert\theta_{x_{min}}\rvert$	2.7	2.7	μrad
$\lvert t_{x_{min}}\rvert$	0.0004	0.0004	GeV^2

Table 3: Performance of a Coulomb measurement at the IP and at the detector place of Ring 1 for optics with β^*=3500, Version 6.0 at 7 TeV for different emittance values with the Roman Pots between $Q6$ and $Q7$. $|\theta_{x_{min}}| = \sqrt{2}x_d/M_{x,12_d}$ with $x_d = 1.5$ mm.

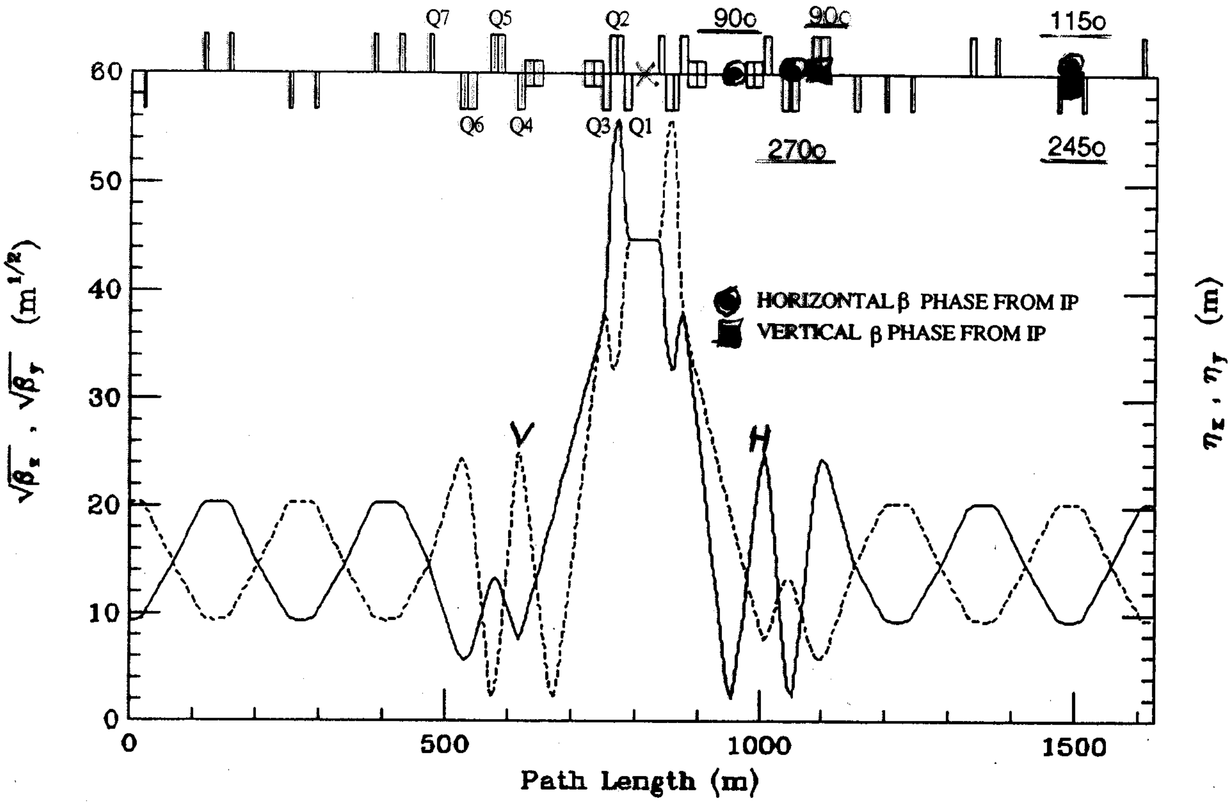
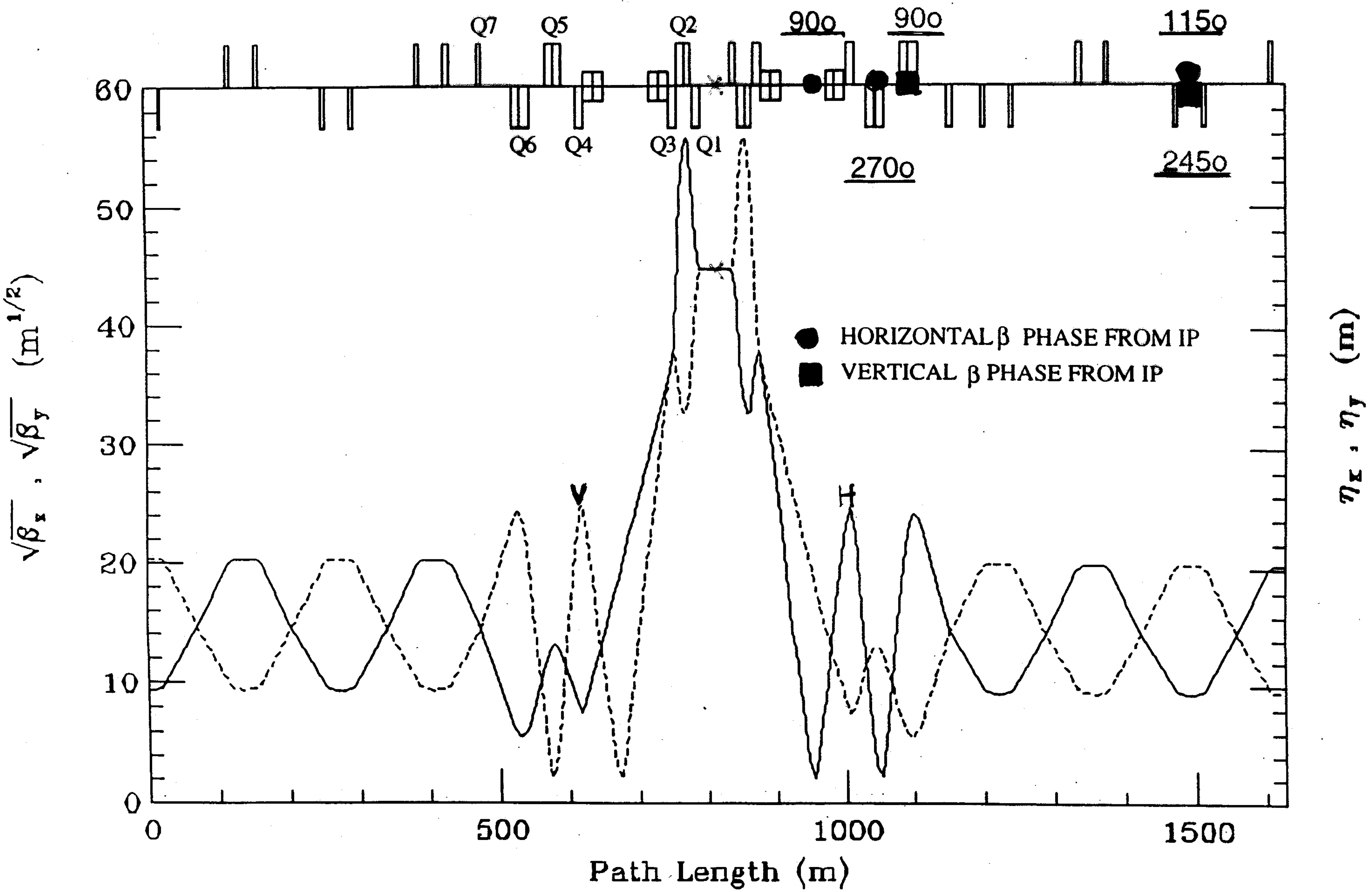


Fig.2 Betatron phase advance from the IP (modulo 2π).

Quad #	Lmagnetic (m)	Gradients (T/m) ß* = 2000 m [ßmax = 3.12 km]		ß* = 6 m [ßmax = 575 m]		ß* = 0.30 m [ßmax = 11.27 km]		MAX.
1	10.90	-127.9	127.9	-301.5	301.5	-298.2	298.2	300
2a & 2b	9.22	160.2	-160.2	304.3	-304.3	294.5	-294.5	300
3	10.90	-179.7	179.7	-301.5	301.5	-298.2	298.2	300
4	12.19	-262.5	262.5	-51.11	51.11	62.40	-62.40	70
5a & 5b	12.19	96.20	-96.20	69.44	-69.44	-65.51	65.51	70
6a & 6b	12.19	-96.01	96.01	-62.00	62.00	-65.51	65.51	70
7	7.62	49.55	-49.55	0.802	-0.802	66.69	-66.69	70

Table 1. IR gradient variations across the whole low-ß* (30 cm) to high-ß* (2 km) spectrum.

In the transition from injection optics to high-beta* at no point does beta in the arc quads exceed 1000m (and is just 625 m at beta* = 2000 m). Aperture shouldn't pose any problems then. At 20 TeV/c, with a normalized emittance of 1.5 mm-mr, and beta=1000m, the one sigma beam width is just 0.265 mm -- compared to the physical magnet aperture of 22 mm. One nice feature of this design (from an accelerator standpoint) is that the insertion is completely localized. At no stage of the unsqueeze (de-squeeze? anti-squeeze?) does any information about the IR optics leak out & need to be corrected elsewhere in the machine. (I hadn't thought this would be possible, so I'm very pleased).



Q7
Q5
Q2
90o
90o
115o
Q6
Q4
Q3
Q1
270o
245o
V
H
HORIZONTAL β PHASE FROM IP
VERTICAL β PHASE FROM IP
$\sqrt{\beta_x}$, $\sqrt{\beta_y}$ ($m^{1/2}$)
η_x , η_y (m)
0
10
20
30
40
50
60
0
500
1000
1500
Path Length (m)

Transport Notation:

$$\begin{vmatrix} x \\ x' \end{vmatrix} = \begin{vmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{vmatrix} \begin{vmatrix} x_0 \\ x_0' \end{vmatrix}$$

$$x = M_{11} x_0 + M_{12} x_0'$$

Want: $M_{11} \to 0$, $M_{12} \to L_{eff}$ large

Accelerator Notation:

$$x = \sqrt{\beta/\beta^*}\,(\cos\psi + \alpha^* \sin\psi)\cdot x_0 + \sqrt{\beta\beta^*}\,\sin\psi \cdot x_0'$$

Want: $\sqrt{\beta/\beta^*} \to$ small, $\cos\psi \to 0$, $\alpha^* \to 0$, $\sqrt{\beta\beta^*} \to$ large, $\sin\psi \to 1$

β^* large $\qquad \psi = (2n+1)\frac{\pi}{2}$

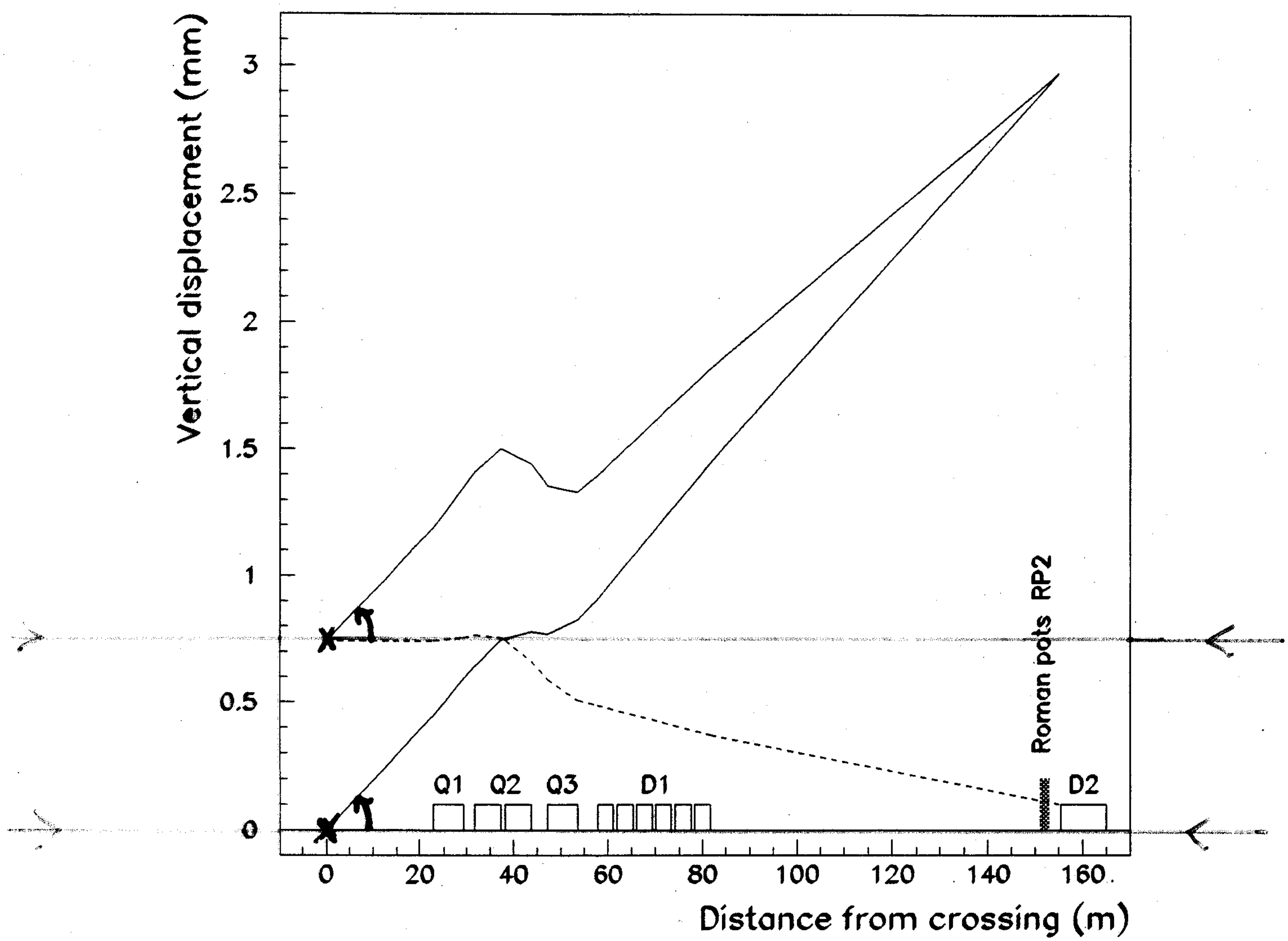


Figure 9: Trajectories of protons scattered in the vertical plane at the same angle of 20 μrad, corresponding to -t=2×10^{-2} GeV^2, with two different vertical positions of the collision point, y*=0 and y*=σ* (full lines). The r.m.s. value of the beam size is shown as a dashed line.

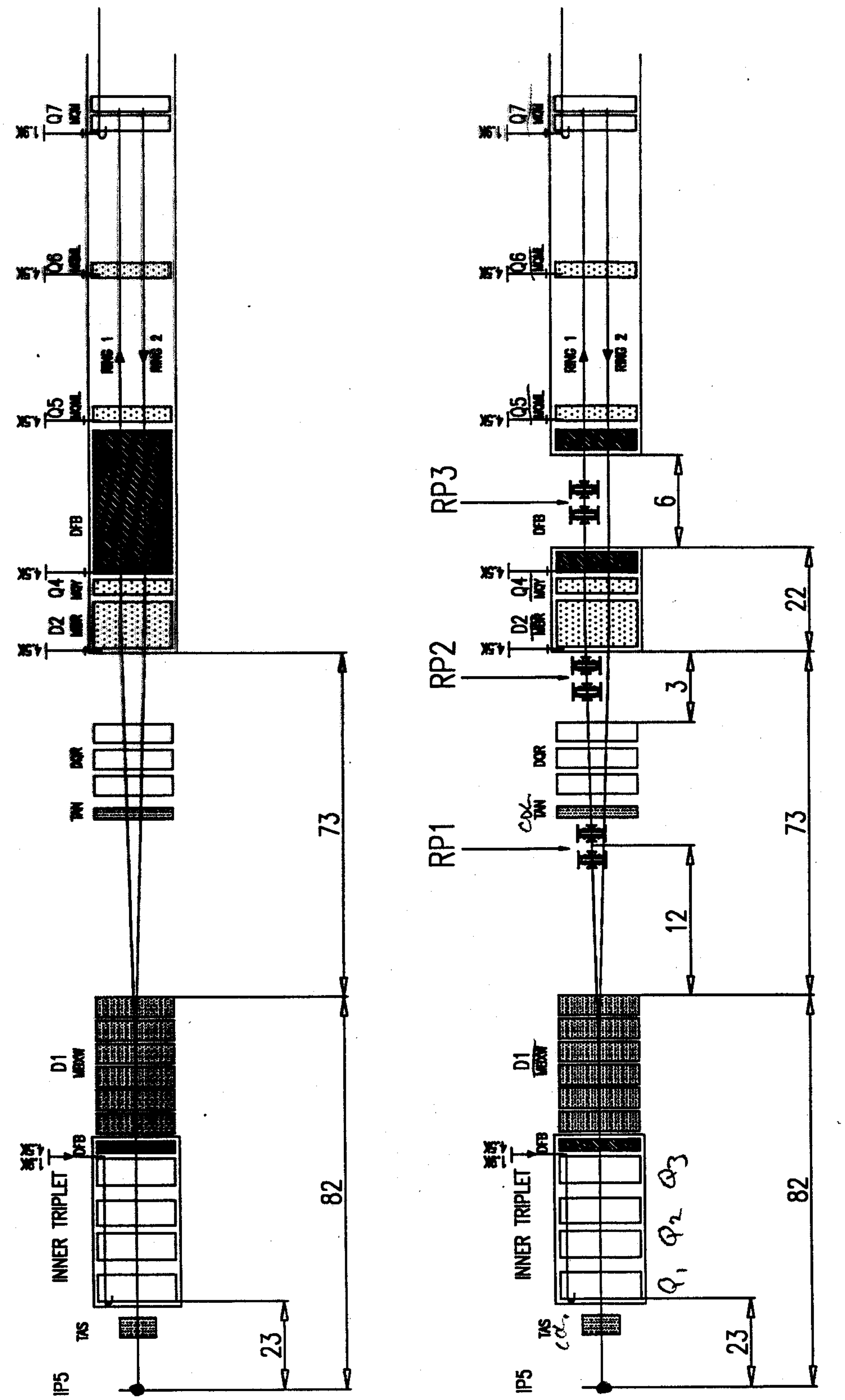


Figure 6: The insertion I5. The upper part reproduces the standard insertion while the lower part shows the location of the three Roman pot stations RP1, RP2 and RP3. The layout is symmetric with respect to the interaction point.

We use the luminosity independent method to obtain σ_T,

Using the optical theorem, the total cross section can be expressed in terms of the forward differential number of nuclear elastic events

$$\sigma_T^2 = \frac{1}{L} \; \frac{16\pi(\hbar c)^2}{1+\rho^2} \; \frac{dN_{el}}{dt}\Big|_{t=0} \tag{1}$$

where L is the integrated luminosity. Another expression for the total cross section is

$$\sigma_T = \frac{1}{L} \; (N_{el} + N_{inel}), \tag{2}$$

where N_{el} and N_{inel} are the total elastic and total inelastic number of events respectively. By combining eqs. (1) and (2), we obtain

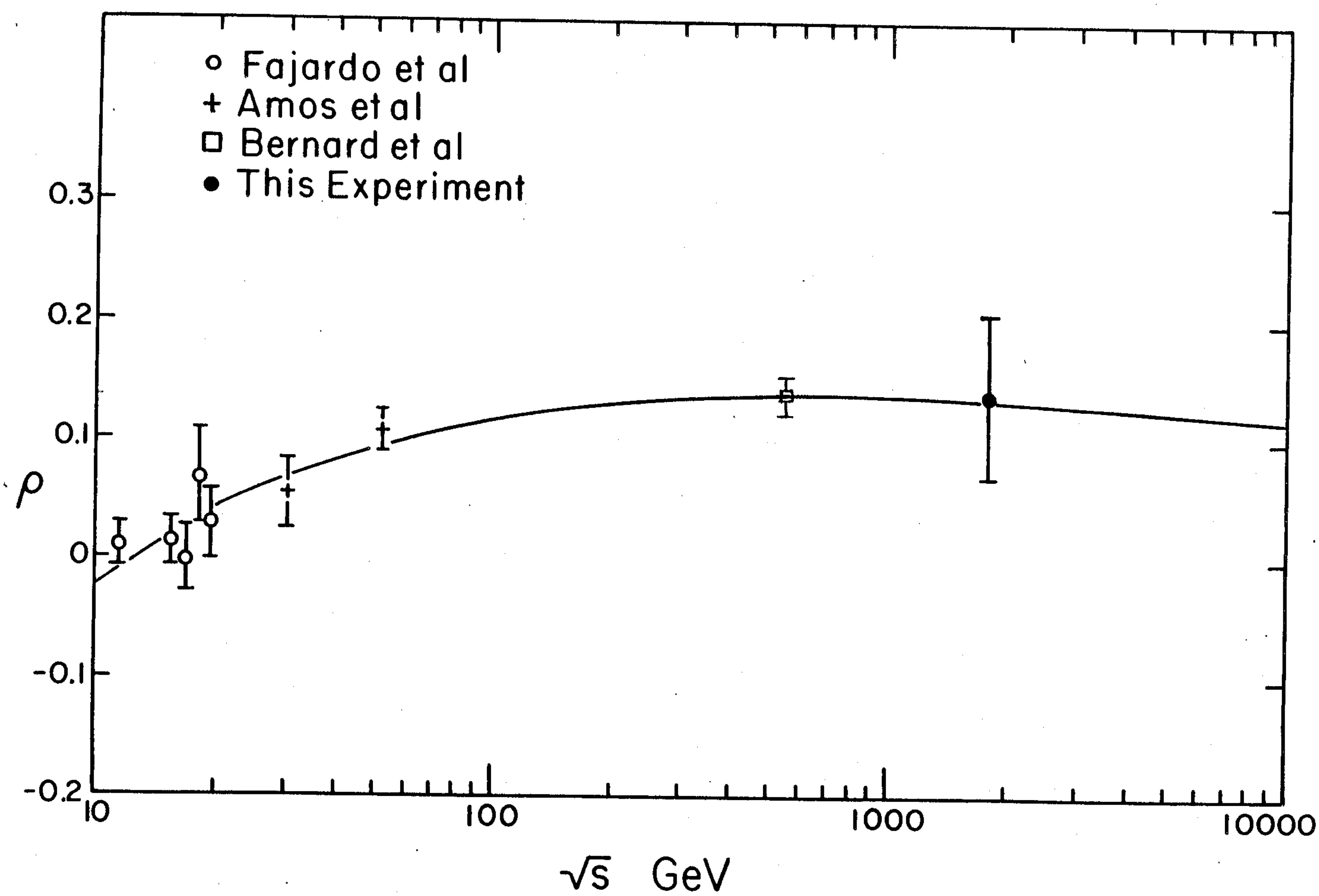
$$\sigma_T = \frac{16\pi(\hbar c)^2}{1+\rho^2} \; \frac{dN_{el}}{dt}\Big|_{t=0} \; \frac{1}{N_{el} + N_{inel}} \tag{3}$$

In equation (3), σ_T is determined independently of luminosity, which often has a large uncertainty. We measure N_{el} and N_{inel} simultaneously; the measured nuclear elastic distribution

$$\frac{dN_{el}}{dt} = \frac{dN_{el}}{dt}\Big|_{t=0} \; \exp(-B|t|)$$

is used to extrapolate elastic data to $t = 0$.

N_{el} is obtained by integrating the fit to elastic data from $t = 0$ to $t = -\infty$,



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This Experiment
0.3
0.2
0.1
0
-0.1
-0.2
ρ
10
100
1000
10000
√s GeV

Figure 4

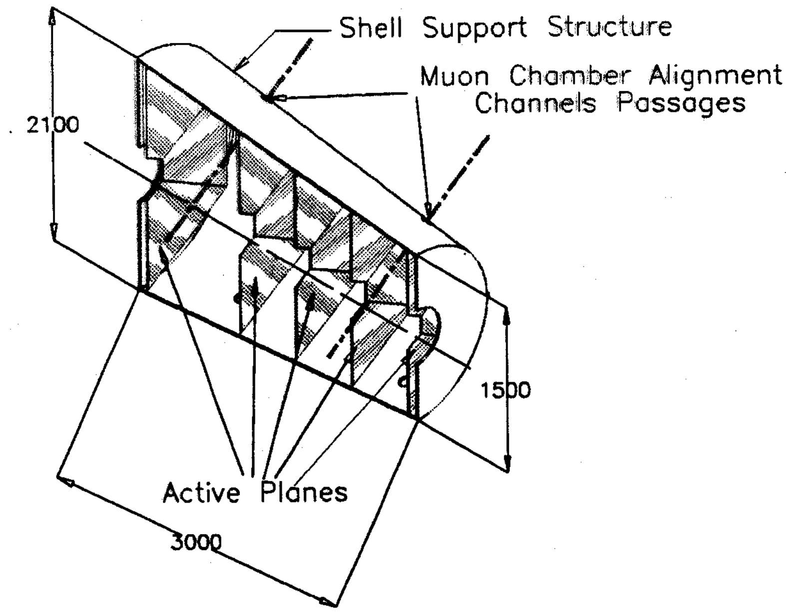


Figure 19: Sketch of the telescope T1.

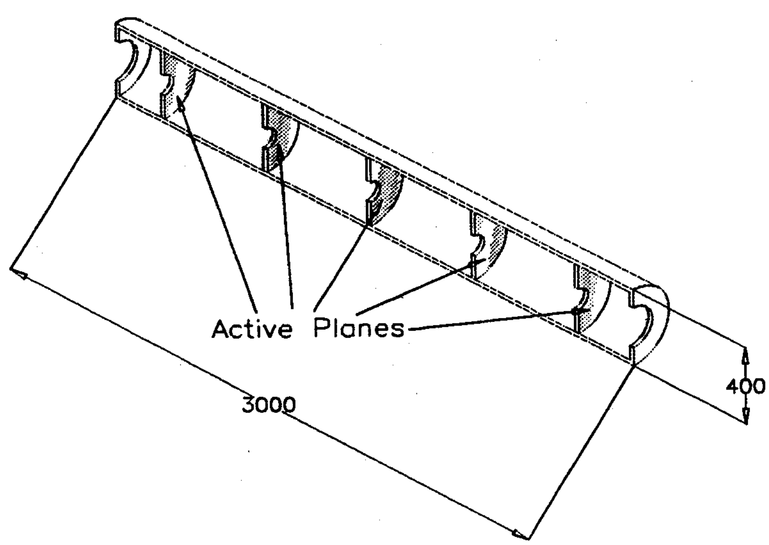


Figure 20: Sketch of the telescope T2.

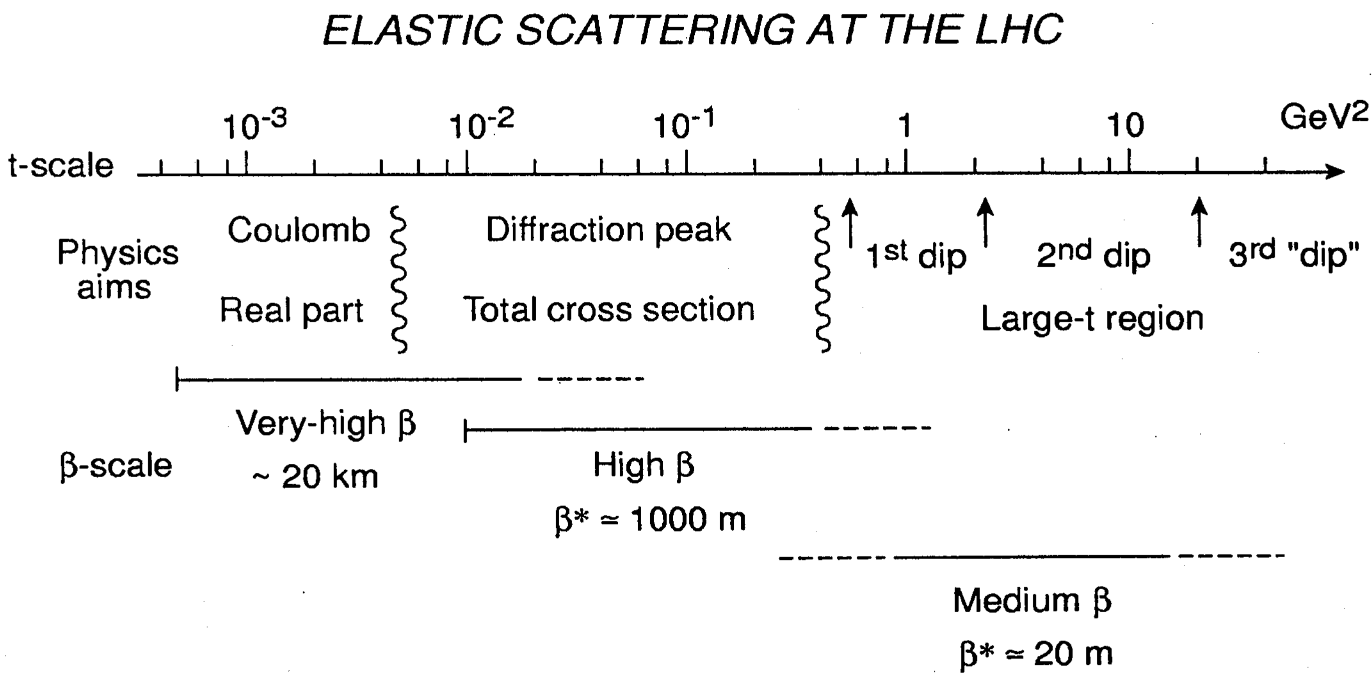
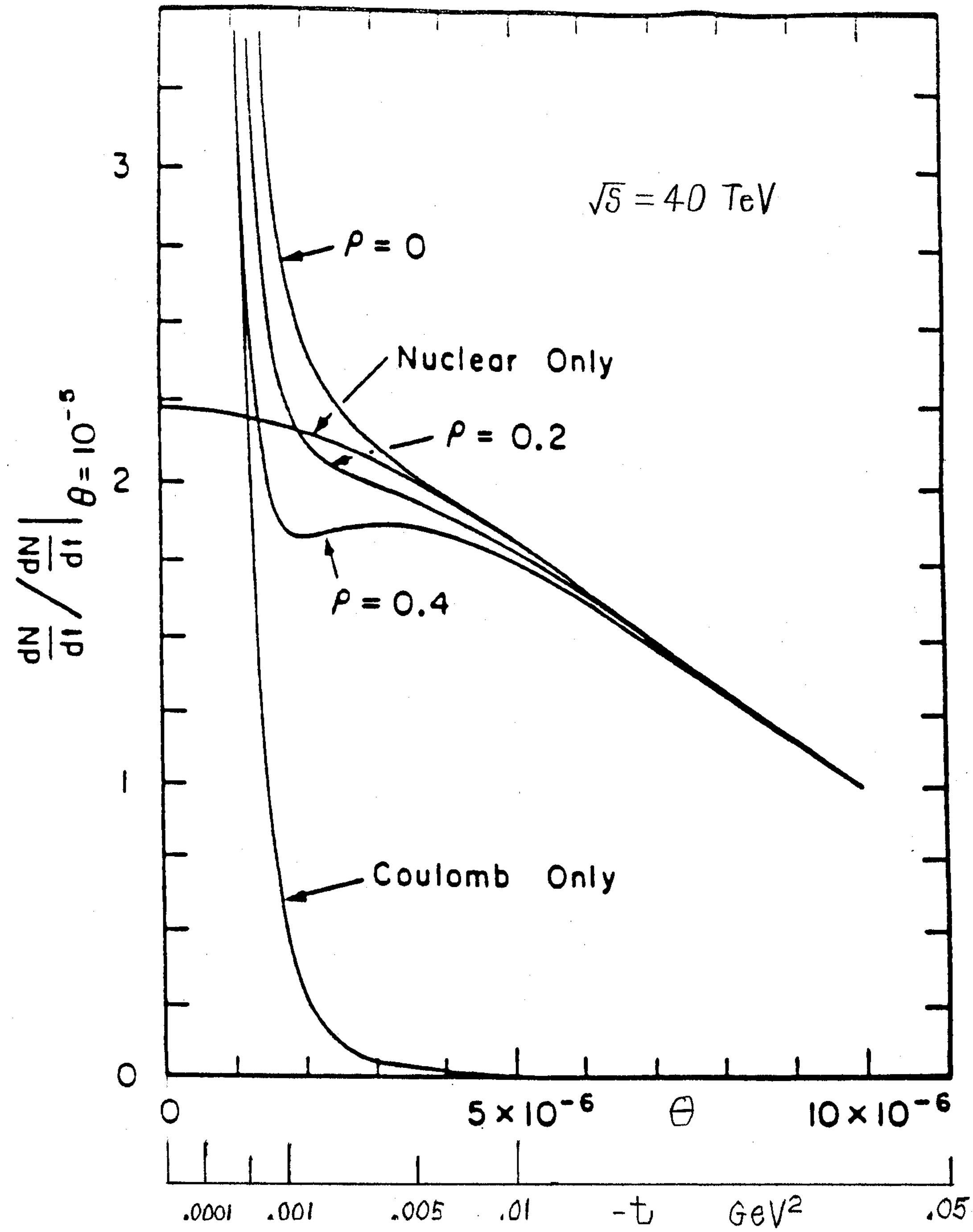


Figure 14: The proposed scheme for a complete study of elastic scattering at the LHC. The values of β^* were estimated assuming the nominal LHC emittance.



$\sqrt{S} = 40$ TeV
$\rho = 0$
Nuclear Only
$\rho = 0.2$
$\rho = 0.4$
Coulomb Only
$\frac{dN}{dt} \Big/ \frac{dN}{dt}\Big|_{\theta=10^{-5}}$
3
2
1
0
0
5×10^{-6}
θ
10×10^{-6}
.0001
.001
.005
.01
$-t$
GeV^2
.05

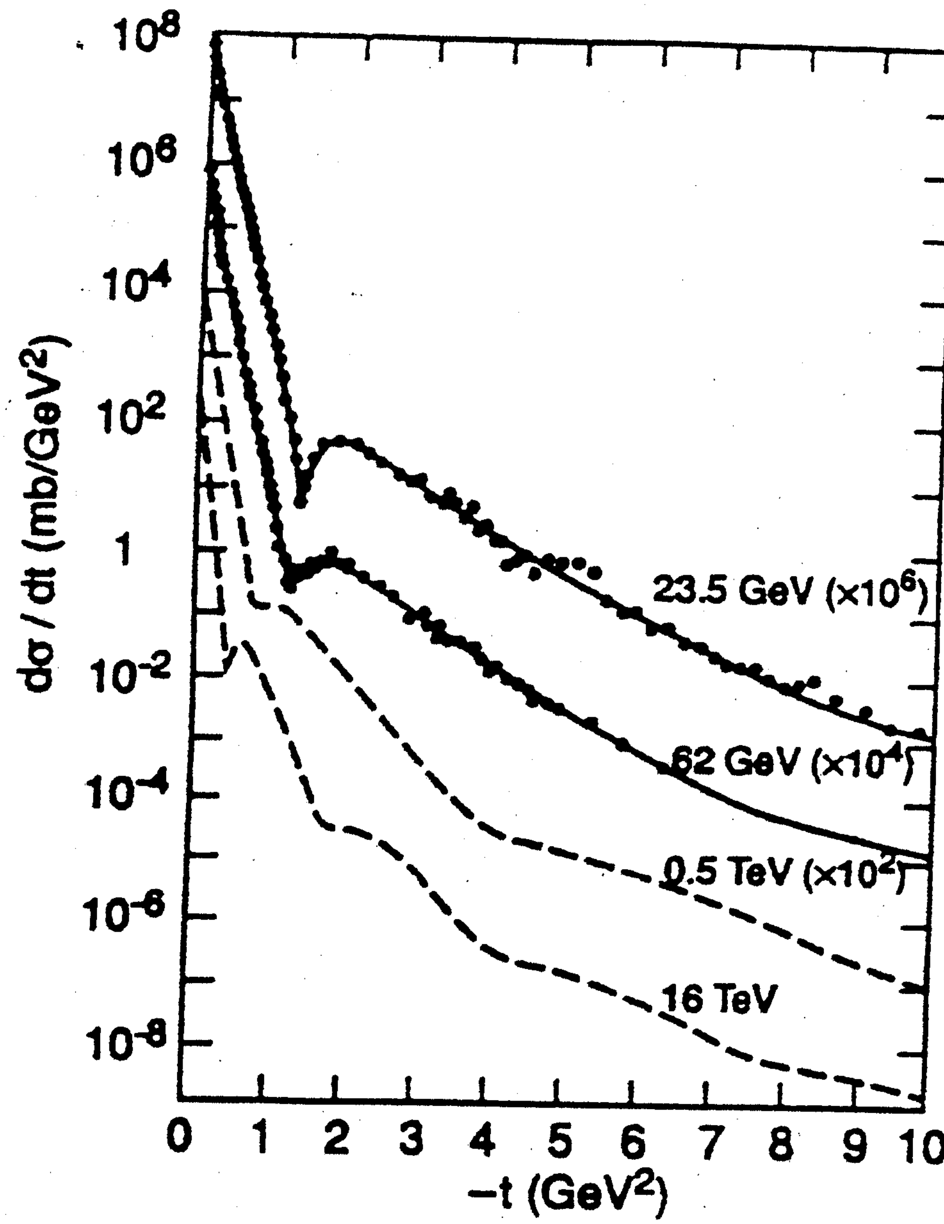


Figure 5: Proton-proton elastic scattering data are shown together with the predictions of the model of ref.[11].

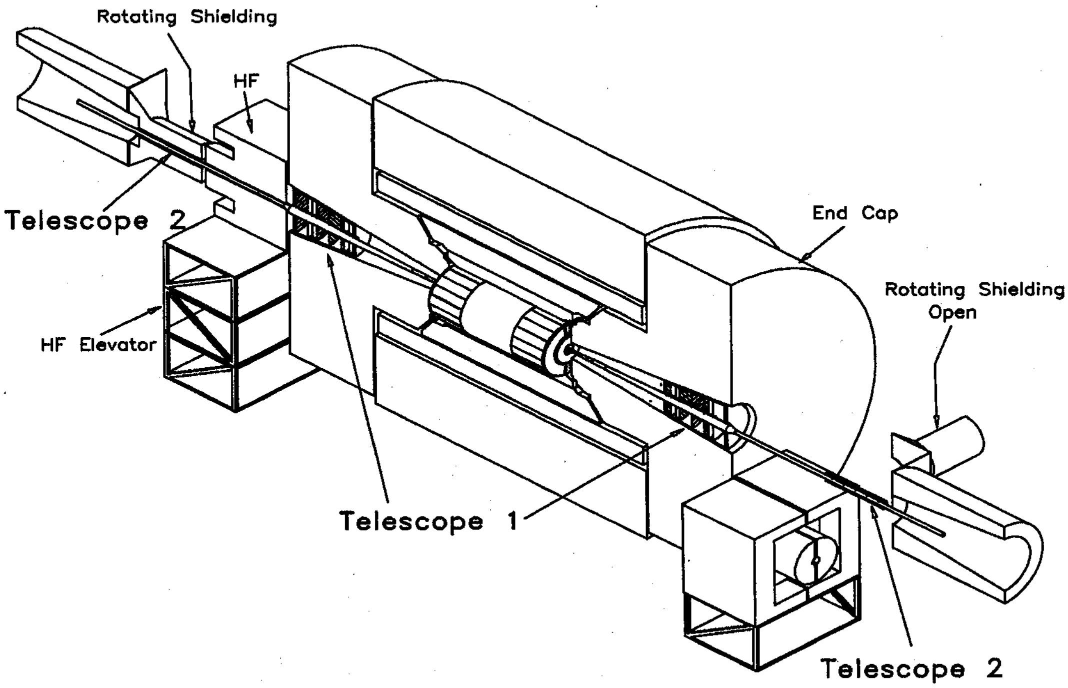


Figure 16: Sketch of the CMS / TOTEM layout.

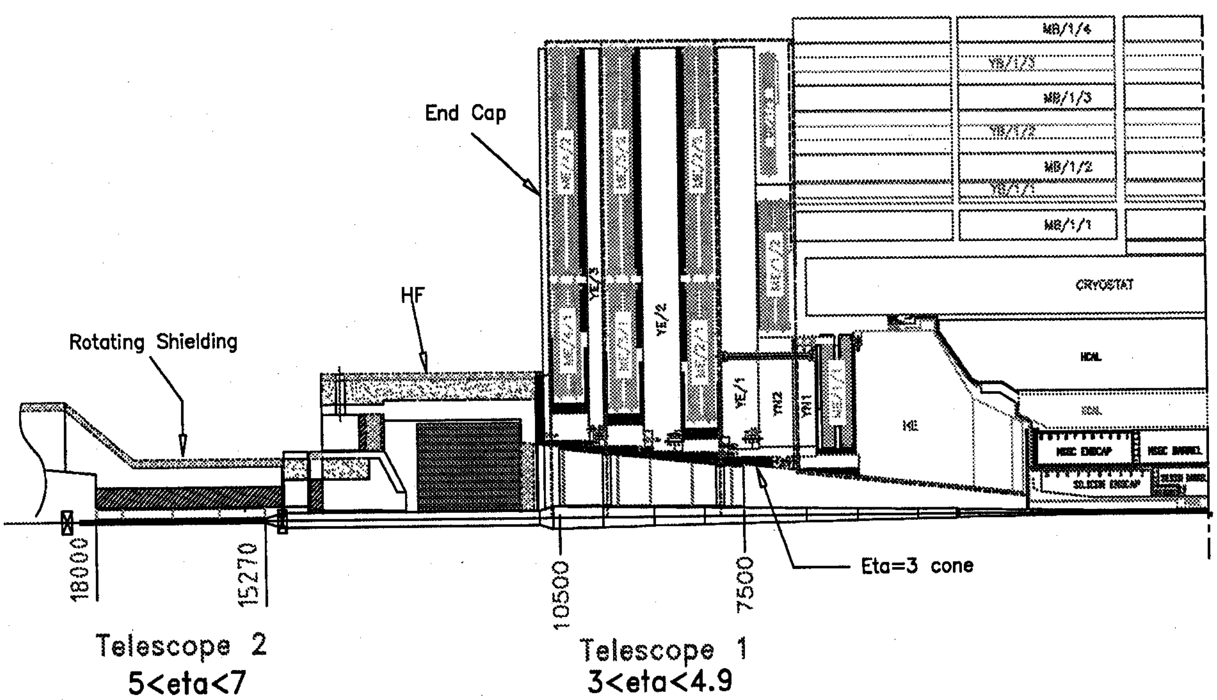


Figure 17: Section of the CMS experimental apparatus showing the integration of the TOTEM telescopes T1 and T2.