# 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 $\mu$rad, $-t \leq 0.01$ GeV$^2$ for the first case; 3 $\mu$rad, $-t \leq 0.0006$ GeV$^2$) for the second one). In this paper a very high-$\beta$ 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.

## 1 A PRECISE MEASUREMENT OF TOTAL CROSS SECTION

To determine $\sigma_{tot}$ with good precision ($\leq$ 2%) we must reach $-t \simeq 0.01$ GeV$^2$ with an acceptance better than 50%.

### 1.1 Improving the standard layout: its limits

From the acceptance studies [1] of the standard high-$\beta$ optics described in [2] we could conclude that to have more than 50 % of acceptance for $-t$ = 0.01 GeV$^2$ we need to improve the optics, i.e. we need to increase the effective distance, $L_{z,eff}$ where $z = x, y$. If we have a parallel to point focusing optics, $(\phi_{z_d} - \phi_z^*) = \pi/2,\ 3\pi/2, ...$ the effective distance is given by: $L_{z,eff} = M_{z,12} = \sqrt{\beta_z^* \beta_{z_d}}$ Therefore the way to increase the effective distance for a given place, keeping the parallel to point focusing condition, is going far away from the IP. This is due to the fact that once you have fixed a place and the phase advance the effective distance keeps constant. This behavior is discussed in detail in [3].

Table 1 summarizes the performances of various high-$\beta$ optics with $\beta^*$=1100 m and different Roman pots positions, for Ring 1 calculated with MAD9 [4]. A slight improvement is observed for $M_{y,12_d}$ when we increase the distance between the IP and the Roman pots.

We could conclude from the table that to improve drastically the $L_{z,eff}$ is necessary to go far away from the IP. This implies changes in the standard layout.

| optics | standard | new | | |
|---|---|---|---|---|
| $\epsilon_z$ | $5.03\ \ 10^{-10}$ | | | m rad |
| $\beta_z^*$ | 1100.0 | | | m |
| measurement vertical | | | | |
| | before $D2$ | | $Q4 - Q5$ | |
| | | close $D2$ | close $Q4$ | |
| $\beta_{y_d}$ | 20.1 | 20.6 | 22.2 | m |
| $\Delta\mu_{y_d}$ | 0.250 | 0.250 | 0.250 | $2\pi$ |
| $M_{y,12_d}$ | 148.6 | 150.5 | 156.3 | m |
| $\|\theta_{y_{min}}\|$ | 14.3 | 14.1 | 13.6 | $\mu$rad |
| $\|t_{y_{min}}\|$ | 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 $\beta^*$=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.

## 2 A PRECISE MEASUREMENT OF COULOMB SCATTERING

The measurement of Coulomb scattering at LHC is important for at least two reasons: to use the coulomb amplitude for normalization of $d\sigma/dt$ nuclear and to determine the real part of the forward elastic scattering amplitude. The technique is through the interference between the nuclear and coulomb amplitudes whose maximum is reached at $-t_0 \simeq 8\pi\alpha/\sigma_{tot}$, where $\sigma_{tot}$ is the total cross section for hadronic $p-p$ interactions. At $\sqrt{s}\ =\ 14$ TeV, with $\sigma_{tot}$ predicted to be 110 mb [5], $-t_0 \simeq 6\times\ 10^{-4}$ GeV $^2$. Scattering angles, $\theta \simeq \sqrt{-t}/p$, are of the order of 3 $\mu rad$. These angles are smaller that the typical angular divergence of the beam in high luminosity operation, which is $\Delta\theta = \sqrt{\epsilon/\beta^*} \geq 35 \mu rad$.

### 2.1 Requirements for the insertion optics

Previously an optics for the measurement of total cross section (14 $\mu$rad, $-t \leq 0.01$ GeV$^2$) was found [6] and [2]. Scaling it down to the requirements of Coulomb scattering (3 $\mu$rad, $-t \leq 0.0006$ GeV$^2$) at the LHC energies gives us $M_{z,12} = L_{z,eff} \geq 707.6$ m taking a minimum approach distance of $\pm$1.5 mm.

* Work partially supported by contracts GVDOC99-01-8 and AEN98-1665-E

## 3 THE OPTICS

### 3.1 Hardware requirements for very high-$\beta$ optics

The layout of the right part of IR1 is shown in figure 1. There are in principle four possible locations for the detectors, one just before the dipole $D2$, the second one between $Q4$ and $Q5$, the third one between $Q5$ and $Q6$ and finally between $Q6$ and $Q7$. In these two last cases a warm section would have to be provided.

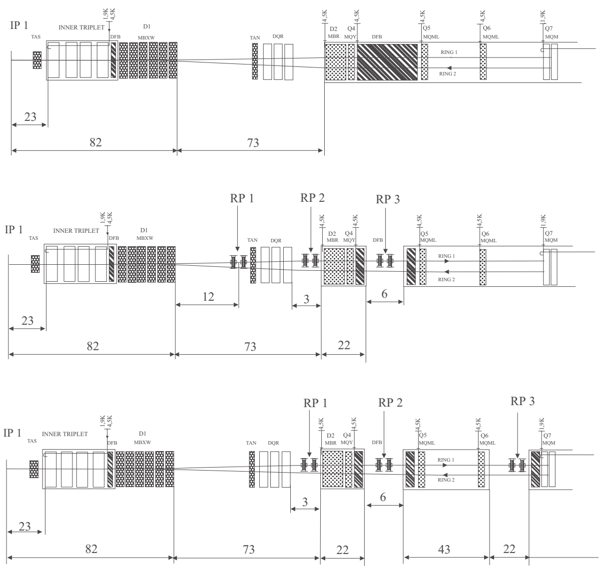


Figure 1: Layout of the insertion 1, Version 6.0. The upper part reproduces the standard insertion, the middle part shows the location of the three Roman pot stations $RP1$, $RP2$ and $RP3$ for the standard measurement of total cross section while the lower part shows the location of the three Roman pot stations $RP1$, $RP2$ and $RP3$ for a precise measurement of total cross section and Coulomb scattering. The layout is symmetric with respect to the IP.

### 3.2 Optics solution for very high-$\beta$ optics

Assuming the standard conditions of Version 6.0 described in [2] no solution could be matched which fulfills the requirements of parallel to point focusing optics.

A solution for measuring the total cross section in the vertical plane and the Coulomb scattering in the horizontal plane with the Roman pots stations between $Q6$ and $Q7$ ($RP3$ in the lower part of 1) could be found if $Q4$ is doubled in strength and $Q8$ is exceeding 7.6%. Figure 2 shows the solution for $\beta^*$=3500 m in Ring 1 calculated with MAD9. The most significant parameters for the total cross section and Coulomb experiments are summarized in tables 2 and 3 respectively. From table 3 we observed that $|x_d/\sigma_{x_d}|$ for nominal emittance is half of the required value to perform the measurement. The problem could be solved by reducing the emittance by four, i.e the emittance in the early days.

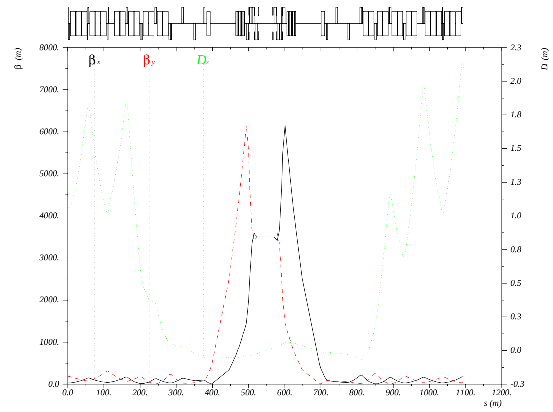


Figure 2: Very high-$\beta$ optics with $\beta^*$=3500 m in Ring 1 around IP1, Version 6.0.

| | | |
|---|---|---|
| $\epsilon_z$ | 5.03 $10^{-10}$ | m rad |
| $\beta_z^*$ | 3500.0 | m |
| $\alpha_z^*$ | 0.0 | |
| $D_x^*$ | 0.0 | m |
| $D_x^{'*}$ | 0.0 | |
| $\sigma_z^*$ | 1.33 | mm |
| $\sigma_z^{'*}$ | 0.38 | $\mu$rad |
| measurement vertical | | |
| detector between $Q6-Q7$ | | |
| $\beta_{y_d}$ | 18.4 | m |
| $\Delta\mu_{y_d}$ | 0.750 | $2\pi$ |
| $M_{y,11_d}$ | 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 | $\mu$rad |
| $\lvert t_{y_{min}}\rvert$ | 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 $\beta^*$=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.

## 4 DETECTOR ACCEPTANCE

### 4.1 Total cross section

With the parameters of table 2, we have the results plotted in figure 3. The three curves correspond to 15, 20 and 25 $\sigma_{y_d}$ where $\sigma_{y_d} = 0.097$ mm is the vertical beam size (rms) at the detector place, ($RP3$ in lower part of figure 1). Adopting a conservative assumption (20 $\sigma_{y_d}$ = 2.0 mm)

| | | | |
|---|---|---|---|
| $\epsilon_z$ | $5.03\ 10^{-10}$ | $1.258\ 10^{-10}$ | m rad |
| $\beta^*_z$ | 3500.0 | | m |
| $\alpha^*_z$ | 0.0 | | |
| $D^*_x$ | 0.0 | | m |
| $D'^*_x$ | 0.0 | | |
| $\sigma^*_z$ | 1.33 | 0.66 | mm |
| $\sigma'^*_z$ | 0.38 | 0.19 | $\mu$rad |
| measurement horizontal | | | |
| detector between $Q6 - Q7$ | | | |
| $\beta_{x_d}$ | 177.4 | | m |
| $\Delta\mu_{x_d}$ | 0.250 | | $2\pi$ |
| $M_{x,11_d}$ | 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 | $\mu$rad |
| $\lvert t_{x_{min}}\rvert$ | 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 $\beta^*$=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.

for the approach distance, an efficiency better than $50\%$ is reached at $-t = 0.01$ GeV$^2$.

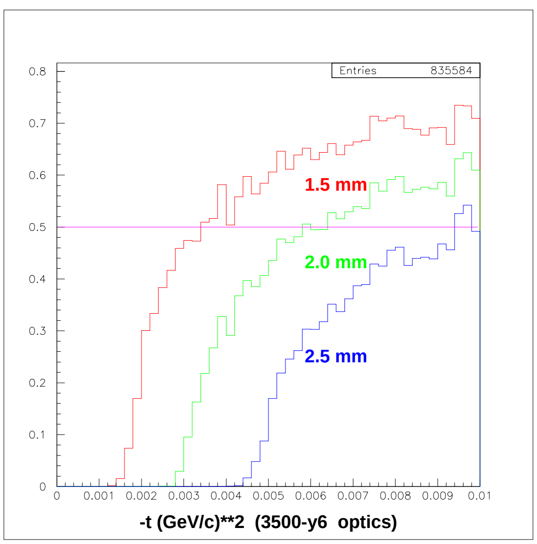


Figure 3: Acceptance for total cross section.

### *4.2 Coulomb scattering*

The crucial point for Coulomb scattering is to be able to reach down to -t values up to $-t_0$ and beyond. Figure 4 represents the geometrical acceptance of a detector 2.0 mm x 2.5 mm with the parameters of table 3, as a function of the minimal distance of approach to the beam: 10, 15 and 20 $\sigma_{x_d}$, where $\sigma_{x_d} = 0.149$ mm is the horizontal beam size (rms) at the detector place.

With a minimal approach distance of 2.2 mm (15 $\sigma_{x_d}$), an efficiency better than $40\%$ is reached at $-t = 6 \times 10^{-4}$ GeV$^2$.

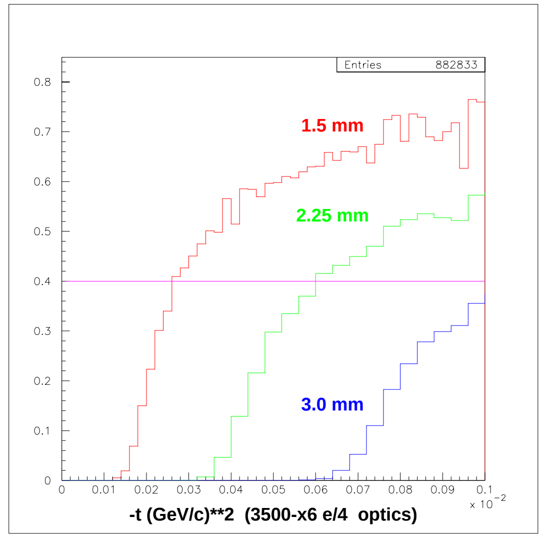


Figure 4: Acceptance for Coulomb scattering.

## 5 CONCLUSION

A very high-$\beta$ optics ($\beta^* = 3500m$), for a precise measurement of the total cross section and the Coulomb scattering at the LHC has been studied. It requires some minor hardware modifications of the present LHC set up. With realistic assumptions as to the minimum beam distance approach, an acceptance good enough is obtained in both cases.

## 6 REFERENCES

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