$0_T @ \text{VLHC}$

**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, −π ≤ 0.01 GeV² for the first case; 5 μrad, −π ≤ 0.0006 GeV²) 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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>ε₂</td>
<td>5.03 × 10⁻¹⁰ m rad</td>
<td></td>
</tr>
<tr>
<td>β₂⁺</td>
<td>1100.0 m</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Performance of a total cross section experiment at the IP and at the detector place of Ring 1 for optics with β²⁺=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). |θymin| = √2y₄/M₄,12d with y₄ = 1.5 mm.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before D2</th>
<th>Q4 − Q5</th>
</tr>
</thead>
<tbody>
<tr>
<td>βy4</td>
<td>20.1</td>
<td>20.6</td>
</tr>
<tr>
<td>Δμy₄</td>
<td>0.250</td>
<td>0.250</td>
</tr>
<tr>
<td>M₄,12d</td>
<td>148.6</td>
<td>150.5</td>
</tr>
<tr>
<td></td>
<td>θymin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>θymin</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Performance of a total cross section measurement at the IP and at the detector place of Ring 1 for optics with β²⁺=3500, Version 6.0 at 7 TeV for nominal emittance and the Roman Pots between Q6 and Q7. |θymin| = √2y₄/M₄,12d with y₄ = 1.5 mm.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>ε₂</td>
<td>5.03 × 10⁻¹⁰</td>
<td>1.258 × 10⁻¹⁰ m rad</td>
</tr>
<tr>
<td>β₂⁺</td>
<td>3500.0 m</td>
<td></td>
</tr>
<tr>
<td>α₂⁺</td>
<td>0.0</td>
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</tr>
<tr>
<td>D⁺</td>
<td>0.0 m</td>
<td></td>
</tr>
<tr>
<td>M₄,11d</td>
<td>-253.4 m</td>
<td></td>
</tr>
<tr>
<td>y₄</td>
<td>-3.62 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>y₄/σ₄</td>
<td></td>
</tr>
<tr>
<td></td>
<td>θymin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>θymin</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Performance of a Coulomb measurement at the IP and at the detector place of Ring 1 for optics with β²⁺=3500, Version 6.0 at 7 TeV for different emittance values with the Roman Pots between Q6 and Q7. |θxmin| = √2x₄/M₄,12d with x₄ = 1.5 mm.
Fig. 2 Betatron phase advance from the IP (modulo 2π).

<table>
<thead>
<tr>
<th>Quad #</th>
<th>Lmagnet (m)</th>
<th>$\beta^* = 2000$ m $[\beta_{\text{max}} = 3.12$ km$]$</th>
<th>$\beta^* = 6$ m $[\beta_{\text{max}} = 575$ m$]$</th>
<th>$\beta^* = 0.30$ m $[\beta_{\text{max}} = 11.27$ km$]$</th>
<th>MAX,</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.90</td>
<td>-127.9</td>
<td>127.9</td>
<td>-301.5</td>
<td>301.5</td>
</tr>
<tr>
<td>2a &amp; 2b</td>
<td>9.22</td>
<td>160.2</td>
<td>-160.2</td>
<td>304.3</td>
<td>-304.3</td>
</tr>
<tr>
<td>3</td>
<td>10.90</td>
<td>-179.7</td>
<td>179.7</td>
<td>-301.5</td>
<td>301.5</td>
</tr>
<tr>
<td>4</td>
<td>12.19</td>
<td>-262.5</td>
<td>262.5</td>
<td>-51.11</td>
<td>51.11</td>
</tr>
<tr>
<td>5a &amp; 5b</td>
<td>12.19</td>
<td>96.20</td>
<td>-96.20</td>
<td>69.44</td>
<td>-69.44</td>
</tr>
<tr>
<td>6a &amp; 6b</td>
<td>12.19</td>
<td>-96.01</td>
<td>96.01</td>
<td>-62.00</td>
<td>62.00</td>
</tr>
<tr>
<td>7</td>
<td>7.62</td>
<td>49.55</td>
<td>-49.55</td>
<td>0.802</td>
<td>-0.802</td>
</tr>
</tbody>
</table>

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

4/17/01

J.A. Johnstone
In the transition from injection optics to high-beta* at no point does beta in the arc quads exceed 1000 m (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=1000 m, 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).
Transport Notation:

\[
\begin{pmatrix}
X \\
X'
\end{pmatrix} =
\begin{pmatrix}
M_{11} & M_{12} \\
M_{21} & M_{22}
\end{pmatrix}
\begin{pmatrix}
X_0 \\
X_0'
\end{pmatrix}
\]

\(X = M_{11}X_0 + M_{12}X_0'\)

Want:
\[
\begin{align*}
& \text{small} & \text{small} & \text{large} \\
& 0 & 0 & \beta^* \\
& \text{Left} & \text{large} & \psi = \left(2n + \frac{1}{2}\right)
\end{align*}
\]
Figure 9: Trajectories of protons scattered in the vertical plane at the same angle of 20 μrad, corresponding to \(-t=2\times10^{-2}\) GeV\(^2\), with two different vertical positions of the collision point, \(y^*=0\) and \(y^*\sigma^*\) (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 $\sigma_T$.

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

$$
\sigma_T^2 = \frac{1}{L} \left( \frac{16 \pi (hc)^2}{1 + \rho^2} \right) \frac{dN_{el}}{dt} \bigg|_{t=0}
$$

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

$$
\sigma_T = \frac{1}{L} (N_{el} + N_{inel})
$$

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

$$
\sigma_T = \frac{16 \pi (hc)^2}{1 + \rho^2} \left( \frac{dN_{el}}{dt} \right)_{t=0} \frac{1}{N_{el} + N_{inel}}
$$

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

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

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

$N_{el}$ is obtained by integrating the fit to elastic data from $t = 0$ to $t = -\infty$. 
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 $\beta^*$ were estimated assuming the nominal LHC emittance.
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.