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OPTICS STUDIES FOR DIFFRACTIVE PHYSICS AT THE LHC

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Abstract

Forward protons with momenta close to the beam-momentum arise either from elastic scattering or from single or double diffraction. These protons are very close to the beamline and can only be measured downstream using "beam close detectors". In this paper we present a complete study of the optics (low, medium and high beta), possible locations of the detectors and running scenarios for these measurements at insertions IR1 and IR5 of the LHC. These optics are compatible with the latest layout of the LHC insertions and the commissioning beam parameters.

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Abstract

Forward protons with momenta close to the beam momentum arise either from elastic scattering or from single or double diffraction. These protons are very close to the beamline and can only be measured downstream using "beam close detectors". In this paper we present a complete study of the optics (low, medium and high beta), possible locations of the detectors and running scenarios for these measurements at insertions $IR1$ and $IR5$ of the LHC. These optics are compatible with the latest layout of the LHC insertions and the commissioning beam parameters.

1 OPTICS DESIGN REQUIREMENTS FOR DIFFRACTIVE MEASUREMENTS

1.1 Elastic scattering

The optics requirements for a measurement of the elastic proton scattering at collision energy of 7 TeV in the LHC are derived from the physics requirements. Protons elastically scattered with a value of t equal to t_{min}= 0.01GeV^2 must be measurable [1].

These protons are emitted at the IP with an angle θ given by : $\theta = \sqrt{t_{min}/p}$ where p is the momentum of the proton beam. In order to be detected, their distance from the beam axis downstream of the insertion must be larger than n_σ r.m.s. beam size.

The value of n_σ is determined as follows. The edge of the detectors close to the beam must be at a distance from the beam centre such that an accidental triggering of the beam dump does not send the bunches into the detectors. The LHC is protected against such a misfunction by absorbers sitting in the insertion $IR6$ and placed at an horizontal phase of about $\pi/2$ from the dump kicker. These absorbers intercept particles with an action corresponding to more than 10 σ. As there can be a drift of the closed orbit of about 2σ before it is corrected, a safe position of edge of the Roman pots with respect to the beam is 14σ (2σ for the drift at the Roman pot and 2σ for the drift at the absorbers in $IR6$). Measurable particles are a little further so the the efficiency of the detector is sufficient. A minimum value of n_σ is then about 20.

A proton emitted from the IP with an angle θ will be at a distance from the beam axis equal to $L_{eff} = \theta\sqrt{\beta^*\beta}$ at a place where the betatron phase is $(n + 1/2)\pi$. Specifying that this distance is equal to n_σ r.m.s. beam size, we obtain the value of t_{min} : $t_{min} = n_\sigma^2 \epsilon_n m_0 cp/\beta^*$ where ϵ_n is the normalised r.m.s. emittance, m_0 the proton mass and c the speed of light. For the commissioning period the beam intensity will be reduced to 2.7 10^{10} p/bunch and ϵ_n will have the value of 10^{-6} m rad. Thus in order to obtain a maximum value of t_{min} of 0.01Gev^2, the minimum value of β^* has to be 263m. Actually it is interesting to measure elastic scattering down to the Coulomb region, this is why a larger value of β^* is foreseen. The nominal parameters are [2]:

- At the IP, $\beta^* \geq 1100$ m, $\alpha^* \ll 0.4$ and $D_x^{'*} \ll 0.13$. To this end the design parameters are : α^*=0, D_x^*= 0 and $D_x^{'*}$= 0.
- At the detector place supposing a vertical measurement, $(\mu_{y_d} - \mu_y^*) = \pi/2,\ 3\pi/2, ...$ and $\beta_{y_d} \geq 20$ m i.e. $M_{y,12} = L_{y,eff}$= 150 m. Furthermore it is very desirable to have the transfer matrix elements $M_{x,12} \approx M_{y,12}$.

1.2 Diffractive scattering

For this case protons having lost a fraction of their energy from some 10^{-3} to several 10^{-2} have to be detected outside the beam. Consequently what matters is the dispersion function. Unfortunately there is little which can be done in this direction. The dispersion function does not vary much in the region where the Roman pots sit, depending on the various LHC optics. It has a value of the order of 0.1m. In order to measure protons at 20σ, i.e. 1.2mm from the beam centre, the energy loss must be larger than 1%.

In order to measure protons having lost a part of their energy comprised between 0 and 1%, a solution consists of installing the detectors at the end of the dispersion suppressor where the dispersion has a value of 2m (with a value of β_x of 200m, i.e. an r.m.s. beam size of 0.18mm). However such a solution needs a modification of the machine hardware far from being straightforward.

2 LHC OPTICS STUDIES FOR $IR1$ AND $IR5$ AT 7 TEV

2.1 High-β optics for small angle scattering (β^*= 1100 m)

A solution which does not requires new equipment could be found with the new layout of the LHC insertions. Figure 1 shows the optics functions for high-β optics with β^*=1100 m, for Ring 1. The calculation was done with MAD8 [3]. The measurement in the vertical plane is feasible without serious disturbances for the cryogenics by placing the Roman pots in front of $D2$. The most significant parameters for the experiment in Ring 1 are summarized in table 1. The beam sizes are calculated taking the commissioning emittance $\epsilon_n = 1.0$ μm rad. The displacement at the detectors place y_d has been calculated taking $y^* = \sigma_y^*$

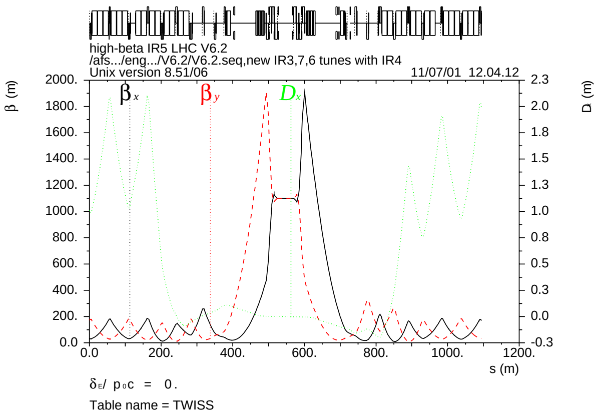

Figure 1: High-β optics with β^*=1100 m in Ring 1 around $IP5$, Version 6.2.

and $\theta_y^* = 14\mu$rad. The minimum acceptable value for y_d given by mechanical constrains of the detectors is of 1.5 mm. The $\theta_{y_{min}}$ has been calculated as $n_{y,\sigma}^2 \epsilon_n m_0 cp/\beta_y^*$, with $n_{y,\sigma}$ = 20, p= 7000 GeV and m_0 = 0.9383 GeV/c. The $\theta_{y_{max}}$ has been calculated as $r^2p^2/\beta_y^*\beta_y$, with r= 25.0 mm that corresponds to the radius of the vacuum chamber from [4].

An example of trajectories simulating an elastic event are shown on figures 2 and 3. The 10σ beam profile, also shown, is the closest transverse distance to which detectors can be placed. It is obvious that the measurement at t of 0.01 GeV^2 can only be done in the vertical plane. The largest displacement in the accessible zone occurs at 150 m just before $D2$, where the Roman pots are.

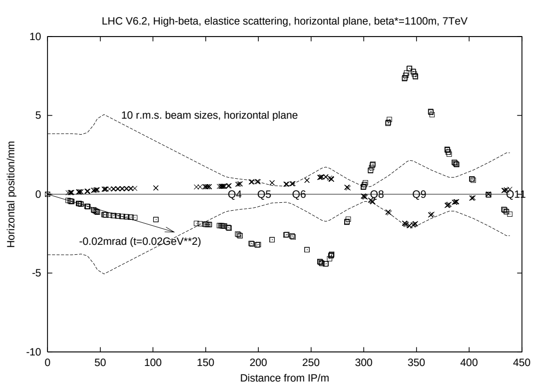

Figure 2: Horizontal 10σ beam profile and on momentum trajectories starting from the IP with : a) a value of t to arrive at the limit of the secondary halo (upper curve), b) a value of t of 0.026 GeV^2 to arrive far from the secondary halo (lower curve), vs. the distance to the IP for the commissioning emittance and β^*=1100 m.

We have calculated the geometrical acceptance at collision energy around $IR1$ and $IR5$ as follows. For a given

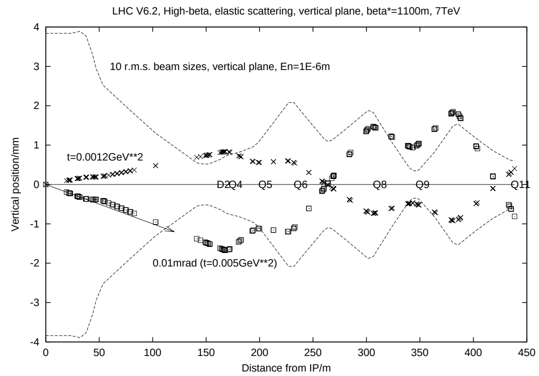

Figure 3: Vertical 10σ beam profile and on momentum trajectories starting from the IP with : a) a value of t of 0.0012 GeV^2 (upper curve), b) a value of t of 0.005 GeV^2 (lower curve), vs. the distance to the IP for the commissioning emittance and β^*=1100 m.

shape of the vacuum chamber, the inscribed secondary halo is estimated and the position of the associated primary collimator is deduced. If this position is larger than n_1=7σ, the situation is safe as the primary collimators in the cleaning insertion are at n_1=6σ[4].

The minimum value of n_1 for the high-β optics at commissioning emittance occurs in $TAS1$ absorbers and is equal to 17.0 as shown on figure 4. On the other hand, from the measurement point of view this element $TAS1$ does not set an unacceptable upper limit to the maximum value of t which is in the range of 1.4 GeV^2.

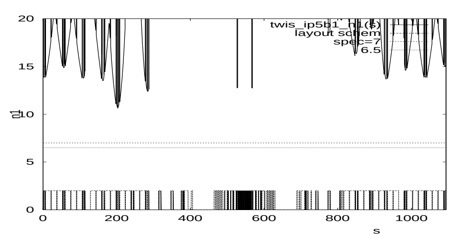

Figure 4: Geometrical acceptance at collision energy for high-β optics with β^*=1100 m in Ring 1 around $IP5$, Version 6.2.

2.2 Transition optics (β^* going from 1100 m to 150m)

A continuous transition in quadrupole excitation from β^* = 1100 m to 150 m could be found by keeping the same powering constrains for the low-β trim power supplies and the possibility of measuring elastic scattering in the full range of β^*.

Some quadrupoles exceed the nominal maximum gradients by less than 3 %, but the values are acceptable without requiring new equipment.

ϵ_n	1.0		μm rad
β^*	1100.0	150	m
α^*	0.0		
D_x^*	0.0		m
$D_x^{'*}$	0.0		
σ_ϵ	0.111		10^{-3}
σ^*	0.38	0.14	mm
$\sigma^{'*}$	0.35	0.95	μrad
detector in front of $D2$			
β_{y_d}	20.4	56.4	m
$\Delta\mu_{y_d}$	0.25		2π
$M_{y,11_d}$	0.0		
$M_{y,12_d}$	149.7	147.4	m
$M_{x,12_d}$	95.8	86.9	m
y_d	2.14	2.11	mm
$\lvert y_d/\sigma_{y_d}\rvert$	40.9	15.1	
$\lvert t_{y_{min}}\rvert$	0.0024	0.018	GeV^2
$\lvert t_{y_{max}}\rvert$	1.39	3.62	GeV^2

Table 1: Performances of the experiment at the IP and at the detector place in Ring 1 for high-β optics (β^*=1100 m) and medium-β (β^*=150 m), Version 6.2 at 7 TeV.

The geometrical acceptance is sufficiently large and does not impose any limit in the measurement.

2.3 *Medium-β optics (β^*= 150 m)*

A solution could be matched by keeping the same power constrains for the low-β trim power supplies, by exceeding $Q8.L5B1$ by 11% and $QTL11.L5B1$ by 6%. An optics could be matched without increasing the strength of these quadrupoles by relaxing the conditions $\alpha^* = 0$ and $Dx^* = Dx^{'*} = 0$. Figure 5 shows the solution for medium-β optics with β^*=150 m, for Ring 1 calculated with MAD8 [3].

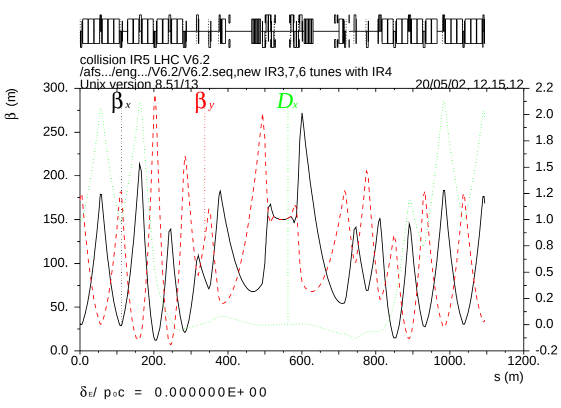

Figure 5: Medium-β optics with β^*=150 m in Ring 1 around $IP5$, Version 6.2.

The measurement in the vertical plane is also feasible by placing the Roman pots in front of $D2$. The most significant parameters for the experiment in Ring 1 are summarized in table 1.

The aperture restriction at collision energy for comissionig emittance occurs in quadrupole $MQM.9L5.B1$ and the associated value of n_1 is equal to 42.9.

2.4 *Injection Optics (β^*= 150 m)*

A continuous transition in quadrupole excitation from β^* going from 150 m to 18 m could be found by keeping the same powering constraints for the low-β trim power supplies, although the slope of the gradient transition changes its signs. These problems could be avoided by injecting with the medium-β optics β^* = 150 m, described above. For this injection optics the aperture restriction occurs in quadrupole $MQM.9L5.B1$, n_1=10.35 for the commissioning emittance, which is quite good.

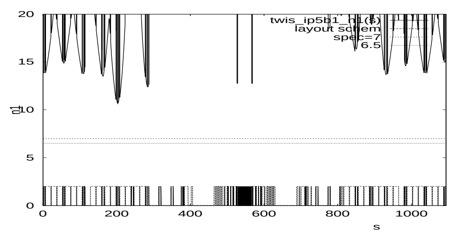

Figure 6: Geometrical acceptance for a beam with the nominal emittance at injection energy for medium-β optics with β^*=150 m in Ring 1 around $IP5$, Version 6.2.

3 CONCLUSION

The modifications of the insertion layout for version 6.4 of LHC were not dramatic. Optics solutions could be found for all possible measurements of elastics scattering in the conditions of LHC commissioning. If the same measurements have to be done with a nominal beam, there are injection problems. This has to be discussed further.

4 REFERENCES

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