Stefano Redaelli, 03-05-2004

37$^{\text{th}}$ Meeting of the LHC Collimation Working Group, April 23, 2004

Present: Oliver Aberle, Ralph Assmann (chairman), Hans Braun, Markus Brugger, Oliver Brüning, Helmut Burkhardt, Bernd Dehning, Gianluca Guaglio, Barbara Eva Holzer, John Jowett, Verena Kain, Daniela Macina, Andreas Morsch, Igor Pshenichnov, Christian Rathjen, Stefano Redaelli (scientific secretary), Guillaume Robert-Demolaize, Rudiger Schmidt, Vasilis Vlachoudis.

1 AOB

Ralph Assmann (RA) open the meeting with an AOB on the super graphite material to be possibly used for the LHC collimator jaws. At the last APC meeting, this new material was suggested by Fritz Caspers as a possible candidate for the collimator jaws. It shows similar mechanical properties of the chosen graphite but a much smaller electrical resistivity, which could significantly reduce the collimator impedance. Due to lack of time, it is excluded to use the super graphite in the SPS collimator test. Nevertheless, RA said that it should be verified whether this material could be of some interest for us and, if this turns out to be case, a sample should be ordered to perform some tests. Rudiger Schmidt (RS) encouraged to discuss with him in case someone wants to perform some beam tests at TT40, like for instance to introduce a piece of super graphite (10 cm?) in the material test.

2 Proposed locations for tertiary collimators (V. Kain, S. Redaelli)

See slides at http://www.cern.ch/lhc-collimation/files/VKain_2004-04-23.pdf

Verena Kain (VK) presented a proposal for the locations of the LHC tertiary collimators (TCTs). She worked on that with Stefano Redaelli (SR), with support with Ralph Assmann and Rudiger Schmidt and inputs from other colleagues. Tertiary collimators are required in the LHC to (1) protect the superconducting triplets (MQXs) around the interaction regions and to (2) collimate the tertiary halo that escapes from the collimation regions. TCTs will be required only for the incoming beam at each interaction point. It is noted that, due to the large beta functions ($\beta >$4000 m), the superconducting triplets are the aperture bottlenecks of the LHC at collision energy with squeezed optics, in particular for the high-luminosity interaction points (IP1 and IP5). Ideally, one would shade the mechanical aperture of the triplets by placing collimators just upstream of these magnets, at a zero phase advance for the incoming beams at either side of the interaction point. In practice, this will not be possible in the LHC because upstream of the triplets there are the D1 magnets, used to kick the beams on the straight section around the IPs. The location of the tertiary collimators requires then dedicated studies.

Three metres were originally reserved upstream of each D1 magnet for the TCTs. However, upstream of D1 the two beams share a common vacuum chamber and therefore the incoming beam cannot be collimated on both horizontal sides due to the interference with the outgoing beam. The vertical collimation does not show basic limitations but a careful design of the jaws should nevertheless be carried out to avoid interference with the outgoing beams (collimator jaws must only be placed close to the incoming beam). The following possible locations for the horizontal TCTs have then be considered: (1) just downstream of the TAN (common beam pipe but large intra-beam distance); (2) space between D2 and TAN; (3) π phase advance upstream of the MQX. The option (1) has been excluded for the moment because the common vacuum chamber would require a special design of the collimator jaws (movable finger to be inserted between the two beams in the same chamber?). Option (3) is not adequate because the point at π from the MQX changes its longitudinal position by several metres during the betatron squeeze which prevents protecting the MQX magnets all through the squeeze nor in case of operation at larger β^* (see later). Hence, the only option considered in detail was option (2).

It is noted that any variation from the optimum zero phase advance between TCT and MQX reduces the collimation efficiency. At collision optics, there is virtually no phase advance between the MQX and D2 and any location would be suitable for placing the collimators. The variation of phase is an issue, in particular for IP1 and IP5 (high luminosity experiments), in case of operation at larger β^* than the nominal value of 0.55 m. For example, if $\beta^* = 2$ m the TCT-to-MXQ phase advance increases by approximately 8 to 9 deg with respect to the nominal case of $\beta^* = 0.55$ m (these values are based on the the optics for the beta squeeze provided by S. Fartoukh). By means of a simple model for the efficiency reduction due to a phase error, VK has verified that the reduced collimation efficiency from the aforementioned phase difference is acceptable.

No TCT design is available yet. It is preferred that a design similar to the one of the TCSs can be used. This assumption seems reasonable unless specific space constraints impose changes of the collimator design. For example, some space concerns arises because of the reduced intra-beam distance downstream of D2 (165 mm instead of 194 mm). For the moment, 2 m should be reserved per TCT.

In the following table, the proposed TCT locations for all IPs are summarized. The positions of of TCLIs and TCLPs are also given. Some concerns for each specific case are given below. It is noted here that at IR5 the interference with the TOTEM experiment prevent installing horizontal TCTs at D2. Only one jaw can then be installed at D1 due to the interference with the outgoing beam on the opposite side with respect to the other beam. Although the horizontal crossing at IP5 gives more margin on the unprotected side (the collimated side will be the most critical one), approximately 40 % of the dangerous horizontal phase space remains unprotected if an LHC arc aperture of 40 σ is assumed.

Coll. Type	Orientation	N. of jaws	Location	Dist. from IP [m]	BB separ. [m]	IP Side
TCT	H	2	IP1	148	0.172	Both
TCT	V	2	IP1	146	0.167	Both
TCT	H	2	IP2	117	0.165	Both
TCT	V	2	IP2	75	0.036	Both
TCT	H	1	IP5	86	0.032	Both
TCT	V	2	IP5	88	0.036	Both
TCT	H	1	IP8	73	0.030	Both
TCT	V	2	IP8	75	0.036	Both
TCLI	V	2	IP2	71	0.024	Right
TCLI	V	2	IP2, Q6	221	0.194	Right
TCLI	V	2	IP8	71	0.024	Left
TCLI	V	2	IP8, Q6	221	0.194	Left
TCLP	H	2	IP1	150	0.176	Both
TCLP	H	2	IP1, Q5	191.4	0.194	Both
TCLP	H	2	IP5	150	0.176	Both
TCLP	H	2	IP5, Q5	191.4	0.194	Both

It is noted that:

- In IP1, there are no major space limitation. It should be possible to install the horizontal TCTs downstream of D2 without interference with already installed equipment.

- In IP2, the available space between D2 and D1 is very small due to the presence of the luminometer and the ZDC. Notably, there is basically no space between D2 and the recombination chamber. The installation of TCT, which are needed only for the ion runs, requires then a discussion of the equipment to be installed in this region. Possible interference of the TCT with the measurements of luminometer and ZDC have also to be taken into account. These topics will be followed up by the people involved (RA, VK, C. Rathjen, SR, RS, Daniela Macina), in close connection with the experiment people.

- In the case of IP5, both horizontal and vertical collimators have to be place close to D1 because at D2 the Roman Pot of TOTEM is installed. This has an impact on the collimation efficiency because horizontal collimation with one jaw only will be allowed. This might imply a reduced luminosity at CMS then at ATLAS if the reduced collimation efficiency proved to increase the quench probability of the MQXs at IP5. A possible solution to that problem could be to combine the TCT with the already present TCL. The design implications of such a choice have not been carried out yet.

- TCTs at IP8 are only required for early collision and it has to be decided whether it is really necessary to install them. If this is the case, there is enough space to put the vertical TCTs close to D1 and the horizontal TCTs close to D2. Nevertheless, a ZDC might be installed at D2, which could interfere with the TCT. Even so, one could put a single-jaw horizontal TCT at D1: in IP8 the horizontal crossing would leave more margin on the unprotected side.

Discussion

There was full support from the collimation team to the proposed locations for the LHC tertiary collimators. However, some additional iteration will be required to make sure that the required space can be made available (in particular for IR2) and that the the TCTs do not significantly interfere with the already present equipment of the various IRs. (**Action**: RA, VK, D. Macina, Christian Rathjen). The most critical situation is found at IP5: the interference with the TOTEM experiment prevents a full horizontal protection of the triplet aperture. This might require a smaller luminosity in IR5 than in IR1 if the operation at top energy (ultimate luminosity performance) proved to be critical for the quench of the superconducting triplets.

Once the final location of the TCTs will be decided in detail, a coherent proposal should be presented at the LTC for the management to take the final decision.

Other points discussed during the presentation of VK are listed below.

- Oliver Brüning (OB) noted that it has been asked to have ion runs at IP2 with reduced crossing angle. Since this has an impact on the BB separation at the proposed TCT location, it should be checked whether this has an impact on the installation of the TCT. **Action:** SR, VK.

- It was often mentioned that the TCTs are mainly required for the collimation of the tertiary halo with the squeezed optics. Andreas Morsch pointed out that with proton runs the experiments will acquire data even at larger β^*, when TCTs will be not be used. In this operation scenario, the showers may be induced in the (unprotected) triplet even if the the losses are not large enough to quench the magnets. Is this an issue for the background in the detectors? Will it be possible to acquire clean data without TCTs in the first LHC phase? OB answered that this should not be a problem because with the operation at $\beta^* = 10\,\mathrm{m}$ the triplets are basically arc-equivalent ($40\,\sigma$ margin) and should not induce a significant background. RA stressed that in any case, the primary scope of the TCT is to avoid MQX quenches and damage.

- When it was noted that a non optimum MQX protection at IP5 could impose a reduced luminosity with respect to IP1, OB commented that IP1 and IP5 have a symmetric optics to provide a compensation of the long-range beam-beam effects (crossing angles are inverted in the two IPs), which assumed the two experiments to have the same beam-beam kicks. Therefore, a change of β^* in one point must be complemented with a change in crossing angle to keep beam-beam compensation.
- Is was suggested to combine the TCT with the TCLP at IP5 since there the space constraints are a major issue for the TCT installation (DM). This option seems interesting but requires dedicated design studies. A potential problem comes from the fact that the TCL are required from day 1 whilst the TCT are required for the ultimate LHC performance and can then be installed later (RA).

3 Collimation of ion: locations of additional spoilers (H. Braun)

See slides at http://www.cern.ch/lhc-collimation/files/HBraun_2004-04-23.pdf

Hans Braun (HB) presented possible new locations of additional spoilers required for the LHC ion collimation. It is noted that the ion collimation is required only for the ultimate LHC ion performance and not for the "Early Ion Scheme". The two-stage betatron cleaning proposed for the proton beams is not suitable for the ion beams. The basic reason for that is that, when impacting on the 0.2 m long primary collimators, with high probability the ions would fragment before accumulation enough kick to hit the secondary collimators. If fragmented, the ions change the charge-to-mass ratio (q/A) which would cause them to be lost in the downstream dispersion suppressor.

It can be shown that for the kick $\delta x'$ experienced by an ion interacting with the collimator, the following relation applies:

$$\delta x' >> \sqrt{\frac{(n_2^2 - n_1^2)\epsilon_N}{\gamma_{\rm rel}\beta_{\rm twiss}}},$$

where n_1 and n_2 are the openings of primary and secondary collimators (unit σ), ϵ_N is the normalized emittance, $\gamma_{\rm rel}$ is the relativistic γ function and $\beta_{\rm twiss}$ the lattice betatron amplitude at the collimator location. For a given setting of collimator openings n_1 and n_2 (assumed to be the same as for the proton collimation system), the kick can only be increased by choosing a place with large beta functions and/or by choosing a material with higher Z numbers. HB calculated a figure of merit for collimator materials by taking into account all the ion-matter interaction relevant for the the LHC conditions. Detailed plots with the various conditions can be found in HB's presentation. The conclusion of HB is that the working point of the primary collimators of IR7 for proton beams is by far below the smaller limit of minimal beta function required for ions, both at injection and at collision energy.

The two-stage collimation for ions could work in the LHC only if high-Z materials where used for the primary collimators and if they were placed at locations with beta functions larger than approximately 1000 m. These values can only be found in the interaction regions, in the vicinity of the superconducting triplets. In addition, the primary collimators must be very short, in the order of some millimetres, in order to avoid ion fragmentation. HB proposed the following location:

	Primary coll.	Secondary coll.
Beam 1	Downstream of IP2	IR3
	Downstream of IP5	IR7
Beam 2	Downstream of IP5	IR3
	Downstream of IP2	IR7

The locations of the primaries is chosen such that the beam passed through a collimation section before reaching an interaction region with squeezed optics. It is assumed that the secondary collimators used for proton beam can also be used to collimate the ion beams. For beam 2, if IP1 is squeezed, the primary collimator could be placed downstream of IP1 instead than IP2. Note that the scraped halo of beam two would have to pass through IP8, which should not have a squeezed optics during ion runs. RA pointed out that in the beam damp region (IR6) there are also location with large beta functions (up to around 400 to 600 m, according to OB). HB should consider these locations as possible candidate for the ion primary collimators.

HB pointed out that the work on the ion collimation is on-going and several things remain to be checked. In particular, (1) the available space have to be checked; (2) tracking simulations have to be setup to estimate efficiency of the system, loss maps and heat load; (3) the optimum jaw length and material have to be chosen. Another relevant concern is that the proposed solution only works for the squeezed optics at top energy, when the beta functions at the triplet are large (remark by RA and OB). A working solution to be applied all through the betatron squeeze remains to be found. Even if the final solution requires much additional work, HB proposed to reserve the space for ion scrapers in any case, before it is too late. Otherwise, the only option would be to reduce the nominal luminosity for ions. Initial ion runs should not be limited.

Discussion

The main concern about the presentation of HB was that the proposed approach for the two-stage ion collimation does not provide a solution at top energy before the betatron squeeze, when the required large beta functions are not yet achieved. Operating high-intensity LHC beams before squeeze would be prevented (OB). This seems a major problem to RA, since the collimation during squeeze is particularly difficult. If we are able to go through the squeeze without protection, this probably means that we do not need protection at all at collision energy! RA encouraged to work with high priority on this issue. As a possible solution, the location at primary collimators at IR6 ($\beta \approx$400-600 m) should be considered as a possible option.

In any case, it was decided to tentatively reserve space for the ion collimators at the proposed locations. In parallel, studies to improve the system and to find a solution for ion collimation before squeeze should continue with high priority.

RS asked whether a one-stage collimation system could be envisaged for ion. The objection by HB was that short spoilers + secondary collimators are required: the beam must hit the collimator jaws with large impact parameters to be absorbed. With a one-stage collimation, the halo ions would slowly approach to the collimator and eventually interact with its surface only, which would cause the to loose some nucleons and to change the q/A ratio. Maybe one could solve this problem by placing strong dipoles downstream of the collimators to kick out of the beam core the ions with different unmatched q/A ratio. RS argued that the strong kick from the D1 and D2 dipoles might be sufficient. Can we take profit of that? This option requires anyway further feasibility studies. As another possibility to improve the ion collimation could be to change the value of n_1 and n_2, which for the moment have been assumed to have the same ratio as for the proton case. **Action:** HB.

OB noted that there is no ion physics foreseen at IP8. One could possibly operate this region with a squeezed optics to generate the large beta functions required for the ion primary collimators. This option is interesting for the primary collimation of beam 2 and should be taken into account.

John Jowett pointed out that, if the collimation problems limit the total intensity of lead ions, then luminosity would be maximised by reducing the number of bunches and keeping the highest possible bunch intensity consistent with other limits. Thus, a filling scheme with about 200-300 bunches would allow the requirement on the efficiency of ion collimation to be relaxed.

D. Macina said that a primary collimator downstream of IP2 would intercept most of the spectator protons to be detected by the ZDC placed further downstream. This should be kept in mind for future discussions. Before deciding the final location for the ion spoiler, the people in charge of this detector should be contacted.

4 Information on International Collimation Review (A. Assmann)

RA announced that an International Collimation Review will take place at CERN from June 30th to July 2nd, shortly before EPAC2004. This meeting was approved by Steve Meyers, who agreed to invite about eight international expert on collimation with the goal of reviewing the LHC phase 1 collimation (physics, engineering, technical and operation issues) before entering series production. A side meeting on the involvement of SLAC/US-LARP into the LHC phase 2 collimation is also being discussed even though the main goal of the Review remains the discussion of the LHC phase 1 collimation. A list of people to invite is being prepared. RA encouraged to send him proposal/suggestion of collimation experts who we might take profit from.

RA also mentioned that a SLAC/US-LARP effort is being defined now to help us in the studies of the LHC collimation phase 2. Funds for LHC collimation studies have been allocated. The responsibility of building the system will remain to the CERN LHC collimation project but the colleagues from USA will take the responsibility n building prototypes of advanced collimators. RA strongly encouraged to prepare some specific proposals for collaborations, in particular with RHIC (Steve Peggs was here this week and had several discussions with OB and RA). For example, it was mentioned that shower studies with TCTs might be performed in collaboration with Mokhov, from Fermilab. OB said that it would be extremely useful to organize a test at RHIC to assess the validity of the simulation tools for the LHC collimation studies.

5 Status of SixTrack simulations with collimators (G. Robert-Demolaize)

See slides at http://www.cern.ch/lhc-collimation/files/GRD_2004-04-23.pdf

Guillaume Robert-Demolaize (GRD) presented the status of SixTrack simulations with collimators. The SixTrack tracking code is being adapted to include the collimation routines written by RA and J.-B. Jeanneret. The final goal is to have both a Windows and a Linux version of the code for studying in detail the efficiency of the proposed collimation system and scenarios for the collimator operation. In order to obtain reliable results, about 1 million particles should be tracked by using a realistic model for the LHC errors (field errors, misalignments, etc.). The CPU resources required for this tracking studies is of major concern and the speed of the program must be optimized. Indeed, the interaction of each beam particle with the collimators is treated individually.

The required number of particles to track imposes a technical problem because SixTrack can run at most 64 particles per time. In order to have an equivalent number of tracked particles larger than 10^5, the tracking routine is looped over a large number of tracking runs. This enables increasing the statistics required for efficiency studies: at least 15000 loops of 64 particles each (equivalent to 9.6×10^5 particles) are required since the expected collimation inefficiency is in the order of 10^{-4}. The estimated time of one simulation is approximately

30-40 hours. Additional CPU time have been asked for in ABP to meet this requirements and to achieve reliable predictions.

For the time being, beta version of SixTrack with collimators is available on Windows. The Linux version is being finalized. GRD has setup the block the the input definition in SixTrack. This has to be integrated into the standard SixTrack input file to allow a definition of tracking parameters such as the number of tracking loops, the collimator openings and the beam distributions (radial or pencil beams). Other details of collimator material, length, orientation tilt and offset are instead loaded from a separate data base files.

GRD showed some examples of simulated inefficiency for the LHC optics V6.4. The new optics V6.5 could not be used because a thin-lens version, required for the tracking in SixTrack, is not available yet. The obtained results are consistent with the previously estimated LHC inefficiency. The required calculation time is also compatible with what has been asked for the collimation studies. First results for the LHC optics V6.5 will come in the forthcoming weeks.

OB said that it could be very interesting to include into these simulations also the long range beam-beam effects. This option has to be taken in consideration.

Bernd Dehning asked whether the simulations will provide beam loss patterns along the magnets or only the magnet end (like in standard MADX runs). RA answered that in the final aperture model that SR is setting up, the LHC aperture will be defined with a 1 m accuracy along the LHC ring. This will enable producing loss patterns in any location of the machine to be used for instance for quench studies or FLUKA simulations.

6 New location of the collimator for the SPS test (O. Aberle)

In the discussions at the last APC meeting, it was found that the location foreseen for the collimator installation in the SPS ring is not suitable for the present collimation design because the aperture there is too small. A fast reaction was taken to find another location. It was decided to move the collimator to the SPS sector 51934, three quadrupoles upstream of the original location. The space allocated for the collimator is presently occupied by another experiment, which will be removed in June. An eight hour intervention should be required to install the collimator. Cables for electrical powering and cooling have been already prepared. The main difference with respect to what originally foreseen is that an horizontal collimator will be used instead than a vertical. The TT40 collimator has also changed orientation.

The next meeting will be announced.