Stefano Redaelli, 27-04-2006

68th Meeting of the LHC Collimation Working Group, April 3, 2006

Present: Ralph Assmann (chairman), Giulia Bellodi, Chiara Bracco, Hans Braun, Roderik Bruce, Markus Brugger, Bernd Dehning, John Jowett, Jacques Lettry, Manfred Mayer, Laurette Ponce, Stefano Redaelli (scientific secretary), Stefen Roesler, Mario Santana-Leitner, Maciej Sobczak, Vasilis Vlachoudis, Thomas Weiler.

1 A.O.B.

R. Assmann announced that we have received the first transfer line collimator produced by CERCA. The collimator is now at the building 252 and who wants to see it is welcome.

2 Status of LHC ion project (J. Jowett)

J. Jowett gave a review of the LHC ion project - see the slides of his presentation for details. The present schedule foresees to complete the initial LEIR commissioning by April 2006. At the end of 2006, ion beams will be tested in the PS. In 2007, ion beam tests will start at the SPS. The main goal for the LHC ion project is to have at least **4 weeks of ion physics run with the "early scheme" in 2008**. This "early scheme" foresees running Pb beams with less bunches than nominal (62 instead of 592) but with the nominal bunch intensity of 7×10^7. In addition, the β^* is larger. **Nominal ion runs are foreseen for 2009**. J. Jowett pointed out that the baseline is now that three experiments will take data with ion collisions, both during "early" and "nominal" schemes: ALICE, CMS and also ATLAS.

It was also mentioned that, as suggested at Chamonix2006, the four weeks of "early ion scheme" could be done after the 2008 proton run, during the cool down of the collimation sections.

J. Jowett reviewed the various issues related to operation of ion beams at the LHC, such as operational parameter space, nominal and early optics parameters at the various IP's, synchrotron radiation and beam and luminosity lifetime during a fill. John also pointed to the Chamonix2006 talk and paper by S. Maury for more details.

R. Assmann pointed out that, even with the early scheme, a few nominal bunches could damage the collimator. The peak temperature in the jaw due to impacting ion beams has not been calculated for the various failure scenarios but could be comparable to the one from proton beams. We should **repeat the robustness simulations for ions** and possibly envisage **robustness tests with ion beam**. J. Jowett and V. Vlachoudis commented that FLUKA **simulations** with ion beams are being setup and will be ready soon. We will then be able to decide whether robustness tests with beam will be required.

In his presentation, J. Jowett stated for the "early" ion scheme it is foreseen to operate at $\beta^* = 2$ m at IP2. R. Assmann commented that in IR2 we will delay the installation of TCT. So far, we worked with the assumption that IP2 and IP8 will work larger β^*, which does not require TCT's in early operation. The various optics configurations should be studied in order to figure out if the "early" ion scheme will require TCT's at IP2.

The issue of ion beam lifetime was also discussed. Simulations suggest that after a few hours of operation the beam intensity could go below the BPM visibility threshold. This issue has to be followed up because some critical system, such as e.g. the collimation and the beam dump, depend on the beam orbit measurements.

3 Simulations (G. Bellodi)

3.1 Updated ion collimation simulations

G. Bellodi reported on the status on ion collimation simulations. She has taken over the tools setup by H. Braun for ion collimation studies (ICOSIM code, see reports at the collimation working group meetings of June 27th 2005 and of May 23rd 2004).

The impacts on the various collimators are generated by tracking a uniform 4D distribution of particles (x, x', y, y') with amplitude of 6 sigmas, which corresponds to the nominal aperture of the primary collimators. Energy spread of the initial particle distribution is not included. The particle amplitude is increased every 100 turns to simulate the transverse beam diffusion. The corresponding average impact parameter is approximately 300 nm (can be changed as a simulation parameter). Impact locations at the TCP's are recorded as starting points for additional tracking campaigns for cleaning inefficiency studies (250 turns, 10^4-10^5 particles). At each collimator, for the particles that hit collimator jaws, the effective path length within the jaw material is calculated and a scattering routine is used to estimate absorption probability and the change of ion species.

Latest simulations carried out by G. Bellodi include (1) Updated settings for injection, “early ion” and nominal optics; (2) updated aperture model (provided by S. Redaelli and adapted to ICOSIM by J. Jowett) and (3) Updated list of ring collimators according to the optics version V6.500 (only active absorbers TCLA are not included for the moment).

G. Bellodi carried out sensitivity studies of cleaning inefficiency as a function of the average impact parameter in the TCP's. She found that the locations of losses do not vary significantly (same s positions) but the amount of losses does change depending on the impact parameter. Notably, she found that at some locations, **the inefficiency gets worst for increasing impact depths** (average impacts below $\approx$ 500 nm). After a flat *plateau* at impacts between $\approx$ 500 nm and $\approx$ 1200 nm, surprisingly the inefficiency is further reduced for increasing impact parameter values (see page 12 of Giulia's slides). These results require more understanding.

Simulations performed with different values of Carbon jaw density show that **lower jaw density is beneficial for the cleaning**. The final simulations are carried out with the conservative assumptions that give worst cleaning efficiency (both for impact parameter and for jaw density).

Simulations are carried out for both beams at injection and at top energy. Details of the loss patterns can be found in the slides of G. Bellodi's presentation. Simulated loss locations are used to propose suitable **locations for the beam loss monitors** (BLM's). The longitudinal accuracy of simulations is assumed to be approximately 2 metres. To properly measure ion losses in the dispersion suppressor of IR7, it is proposed to place BLM's every **2.5 metres** along the first dipoles of the dispersion suppressor.

Follow-up the after meeting: Revised BLM locations were proposed (April 20th) and are being discussed among the concerned people (ABP, BI, Ion team). This will be discussed at the next meeting.

3.2 Discussion

There was a general agreement that, before fixing the BLM locations, the effect of **orbit errors** should be quantified. The ± 4 mm tolerance could change considerably the locations of losses with respect to what is expected for the nominal machine and hence this effect should be studied with high priority.

In addition, the following other issues came out from the discussion, which will be added into the pending action list of our web page (`http://lhc-collimation.web.cern.ch/lhc-collimation/action.htm`):

(1) R. Assmann proposed that the contributions of the **different halo types** (horizontal, vertical and skew) should be **treated separately**. It appears from the plots presented by G. Bellodi that the load on the skew primary collimator is larger than the others, which is not expected in reality (typically, lifetime reductions are seen in the horizontal or vertical directions).

(2) The **TCLA should be included in the simulations**. R. Assmann believes that they could have an important impact on the overall system efficiency because they are made of Tungsten. H. Braun does not actually agree with Ralph. He rather expects a small effect because the ions that are lost in the dispersion suppressor are still well below the 10 sigma betatron amplitude at the TCLA location (the betatron kick due to the interaction with the upstream TCP's and TCS's is very small). However, Hans agrees that they should be included in the simulations to systematically check their contribution.

(3) R. Assmann asked if the simulations are carried out until all the tracked particles are lost, as required to propserly calculate the cleaning inefficiency. Hans replied that this is indeed the case.

(4) R. Assmann also suggested to try to **reduce the length of the primary collimators**. This could improve the efficiency of the system (as also suggested by the fact that the cleaning efficiency improves for smaller impact parameters on the TCP's). In the LHC, a shorter TCP effective length could easily be achieved by using large jaw tilt angles.

(5) R. Assmann suggested to systematically study the effect of the tertiary collimators. Hans agree that they could definitely improve significantly the system performance.

(6) R. Assmann suggested that the ion collimation studies should be done with SixTrack, as it is done for the proton collimation studies. This would require (1) adding a scattering routine for ions and (2) implementing the knowledge of different ion species with in SixTrack.

(7) S. Redaelli asked if the crossing and separation schemes at the IR's are properly taken into account by ICOSIM. This does not seem to be the case for the moment.

(8) The ICOSIM simulations are carried out by checking the losses at the end of each magnetic element. S. Redaelli commented that this does actually underestimate the losses in the quadrupoles: for a perfect machine, beam losses are expected in the first half of the quadrupole because the beta function is maximum in the middle. In the Twiss files used as ICOSIM inputs, magnet should be split in half to check the losses also in the middle of the elements and not only at the end.

(9) B. Denhing asked the proton collimation team to cross-check the proposed BLM locations.

(10) R. Assmann suggested to take into account the beam energy spread of the initial particle distributions.

4 BLM signal at the SPS (H. Braun)

H. Braun presented a model that he setup to understand the measured beam loss tails at the SPS. In the 2004 beam tests with the collimator, it was found that when a jaw is moved into the beam and left at a constant distance from the beam core, the beam loss monitor (BLM) signal shows slowly decaying tails, which last for several minutes. What physics mechanism can explain such a long time-scale of losses within the collimator?

The synchrotron frequency sets the slowest characteristic beam time-scale. However, at the SPS the synchrotron motion can only explain phenomena with typical times up to milliseconds, which is still orders of magnitude smaller that the observed BLM tail decay times.

H. Braun tried to explain the experimental observation with the following model: The image currents induced by the beam on the collimator material have always the effect of attracting particles toward the collimator surface. This is a wake-field effect that would ultimately drive beam particles onto the collimator jaw material. One can calculate the collimator kick for a particle passing close to the collimator. Single particle incoherent effects can become relevant for particles close to the collimator surface. Motion becomes unstable independently of the tune value (if you wait for a long enough time). See Hans slides for details.

Hans setup a simplified tracking model to estimate the effect of this collimator kick on the particle dynamics. He could calculate the required time until a particle touches the collimator and worked out a scaling law for the typical beam losses time-scale. E.g., with a jaw at about 2 mm from the beam core, it would take approximately 25 minutes to clean up all the protons lying within the first micron from the collimator jaw surface. In addition, the tail of beam losses is expected to vary like the inverse square root of time.

A detailed analysis of the SPS data shows that the distribution of loss tails presents indeed a large number of tails with $1/\sqrt{t}$ behaviour, as predicted from theory. However, in most of the cases the tails decay as $1/t^2$, which suggests that the proposed theory does not explain all the experimental observation. In addition, the measured times are a factor 5 larger than what is predicted. The collimator kick could be larger due to the surface roughness? Nevertheless, the observation of the $1/\sqrt{t}$ scaling law seem very encouraging.

Hans claims that the effect of the collimator wake-field should vary linearly with beam energy and therefore it should be easy to experimentally verify this prediction at the 2006 tests with beam. There was agreement that we should try to perform more measurement during this year's tests at the SPS.

If the theory is confirmed, one could actually use this effect to improve the cleaning efficiency: Hans launched the idea that this "mirror kick" could be used to drive proton or ions into the collimator jaw even before the particles actually touch the jaw surface. The required kick would be approximately 0.5 Tm. A magnetized collimator plate could amplify this effect but however have the drawback that the field would leak out of the collimator and could possibly perturb the circulating beam. This is "crazy" idea could prove to be useful for the LHC but certainly requires additional followup!

The next meeting will be announced.

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Action Items:

- ▷ FLUKA simulations with ion beams: collimator damage/survival for various accident scenarios (FLUKA and ion teams).
- ▷ Are TCT's required at IP2 for the early ion scheme? (LHC ion team).
- ▷ Ion collimation studies: (1) Increase particle diffusion speed every tracked turn instead than every 100 turns; (2) separate load contributions from different halo types (horizontal, vertical and skew); (3) Include TCLA's at IR3 and IR7;
- ▷ Improve the efficiency by reducing the length of the primary collimators? (LHC ion team)
- ▷ Setup ion collimation with SixTrack (proton and ion collimation teams).
- ▷ Take into account crossing and separation bumps (LHC ion team).
- ▷ Check the losses in the middle of the quadrupoles and not only at the magnet end (LHC ion team).