

## LHC RELATED PROJECTS AND STUDIES – PART(II)

L. Rossi (Chair), R. De Maria (Scientific Secretary), CERN, Geneva, Switzerland.

### *Abstract*

The session was devoted to address some aspects of the HL-LHC project and explore ideas on new machines for the long term future.

### INTRODUCTION

The session had two parts. The former focused on some of the key issues of the HL-LHC projects: beam current limits (R. Assman), evolution of the collimation system (S. Redaelli), R&D plans for the interaction region magnets (G. Sabbi) and crab cavities (R. Calaga). The latter explored the ideas for the long term future projects (LHeC and HE-LHC, F. Zimmermann) and how the current R&D program for magnets (L. Bottura) and RF structures (E. Jensen) could fit in the envisaged scenarios.

#### **BEAM CURRENT LIMIT FOR HL-LHC. R. ASSMAN.**

The speaker reminded the sources of the beam current limitations in the LHC and discussed their relevance in the final picture. Systems and topics were analyzed one by one: RF, vacuum, e-cloud, cryogenics, magnets, injection and protection, collimation, radiation to electronics, radiation protection. In summary a plot in the plane of bunch intensity and number of bunches was produced to show the accessible region of the parameter space, showing that the 25ns goal of the HL-LHC ( $2.2 \cdot 10^{11}$  ppb) is within reach with some effort.

#### *Discussions*

O. Bruening, asked what has to be invested on and with which priority to reach 1.1A, for instance the TAS and TAN for IR2 and IR8. R. Assman replied that definitely the IR cryogenics cooling capacity and the robustness of the protection devices is to be revised. J-P. Koutchouk asked whether the smaller than nominal emittances envisaged for the HL-LHC will reduce the damage limits. R. Assman replied that experiments using the HiRadMat facility are foreseen to address this issue.

P. Baudrenghien reminded that the control on transient beam loading, now enforced at the expenses of power, is not strictly required for operations and, in addition, it makes operations less sensitive to klystron failures. J. Tuckmantel observed that, at injection, the transient beam loading must be controlled although, as P. Baudrenghien repeated, requires less power.

R. Schmidt stressed that high current has an effect on the machine availability which is one the key ingredient for making luminosity levelling effective.

#### **DO WE REALLY NEED AN UPGRADE OF THE COLLIMATION SYSTEM FOR HL-LHC? S. REDAELLI.**

The speaker was asked to elaborate whether the collimation system needs to be upgraded to meet the HL-LHC goals. The affirmative answer was supported by an illustration of the goals of the upgrade plans on several fronts: collimation efficiency, extended lifetime, operational efficiency, safe maintenance, compliance with new layouts. An important question mark left was whether collimating in the dispersion suppressor is really needed or not. Today IP2 seems more critical, followed by IP1 and IP5 and then IR3 and IR7. In any case a strong program for renovation and renewal of the existing system is needed in view of the higher intensity and integrated luminosity. The talk concluded with an illustration of the recent and past experiences, the staged plans for the upgrade, their associated benefits and an overview on promising new directions.

#### *Discussions*

R. Steinhagen asked to comment on how the long range beam-beam compensation wires can contribute to the collimation efficiency. L. Rossi commented that the long range effects, as often mentioned by W. Herr, may provide a good cleaning mechanism for the tails. S. Redaelli recalled that one operational problem comes from the fact that the mechanism is responsible for big spikes because occurs all of a sudden when the two beams are put in collision. R. Assman reminded that in the tails there are still MJoules of energy that poses concerns for machine protections.

J. Wenninger reminded that BPM in collimator will be very useful also in the transfer lines for operational reasons.

J. Jowet commented to mind that during ions runs there are several MGy/nb-1 of losses in the dispersion suppressor area of the insertions.

#### **NEW MAGNETS FOR THE IR: HOW FAR ARE WE FROM HL-LHC TARGET? G. SABBI.**

The speaker illustrated the past, present and future of the Nb<sub>3</sub>Sn development for the LHC triplet quadrupoles focusing on the aspects related to the steps from prototypes to technology demonstrators, the choice of the conductor from available cables to optimized solutions for accelerators and the impact on HL-LHC specifications of aperture and length. The excellent performance reached in prototypes and models, 170T/m at 4.2K in 120mm aperture, is already 40% better than the NbTi reach. Big

efforts are underway in the US-LARP collaboration to further improve these results and establish accelerator quality magnets. The conclusions called for a stronger integrated effort among the collaborating institutes and CERN.

### *Discussions*

J-P. Koutchouk asked whether the conductor stress sensitivity poses constraints on the aperture specifications. G. Sabbi replied that this is not a hard limit and that 150mm apertures are possible with appropriate design choices, such as wider cables to distribute the coil stress over a larger surface.

L. Rossi asked how much operating at 4.2K would compromise the performance. G. Sabbi replied that Nb<sub>3</sub>Sn performance is less sensitive than NbTi and changing the temperature from 1.9K to 4.2K drops the maximum gradient by about 10%. L. Bottura added that, at constant temperature margin, the enthalpy margin is bigger at 4.2K with respect to 1.9K.

S. Fartoukh asked what the status on field quality is, reminding that fractions of units are probably needed for the HL-LHC project. G. Sabbi replied that magnetic measurements performed on the latest 120 mm models indicate the geometric errors within a few units, which is a good starting point. E. Todesco added that the current models incorporate design variations among different coils and much better results can be expected during series production. The speaker also added that Nb<sub>3</sub>Sn technology suffers from persistent current and dynamic effects but they are less critical for the present application. L. Rossi reminded that also Nb<sub>3</sub>Sn does not suffer from snapback.

J-P. Koutchouk asked to comment concerning the low field instability shown in some early prototypes. The speaker answered that the instability issue can be addressed by proper design choices and construction processes.

## **CRAB CAVITIES: FROM VIRTUAL REALITY TO REAL REALITY?**

**R. CALAGA**

The talk illustrated the status and plan for crab cavities with emphasis on the hardware prototyping activities. The speaker reminded the justification for their installation, the proposed specifications, the operating principle and the hardware solutions. Among the many possibilities investigated in the last three years, the R&D is now converging on three compact cavity designs that look all very promising. Both in the UK (Lancaster) and in the US (LARP through ODU-SLAC and BNL) are building real prototypes that are advancing well. The plan is to have cryogenic test in late spring both in Europe and the US.

### *Discussions*

S. Fartoukh commented that 6MV per side per IP are not sufficient with the current optics and aperture constraints for full crab crossing with the present

HL-LHC proposed parameters and suggested for a third module to be foreseen in the layout. E. Chapochnikova added that one has to check for the total impedance budget.

L. Rossi asked whether operating at 4.2K is a viable option, but E. Jensen replied that 1.9K is much more preferable for many reasons including microphonics.

J. Wenninger wanted to remind that, as far as machine protection is concerned, the crab cavities are the most dangerous element after the beam dump. R. Calaga assured that the R&D program on these aspects has the top priority and in addition using multiple cavity modules mitigates dangerous effects.

## **LHEC AND HE-LHC: ACCELERATOR LAYOUT AND CHALLENGES.**

**F. ZIMMERMANN**

F. Zimmermann illustrated the layout, main accelerator-physics and technology challenges, required LHC modifications, global schedules with decision points for the proposed new machines LHeC and HE-LHC. For the LHeC important decisions need to be made in the close future, in particular the choice between the ring-ring and linac-ring option, the choice of the IP for the *e-p* collisions, and a ramp up of pertinent R&D (e.g. SC RF development and ERL test facility). For the HE-LHC, the priority is to decide by 2016 whether to base the magnets on high temperature superconductors or stay with a lower field provided by Nb<sub>3</sub>Sn. The speaker also reviewed other machines based on the exploitation of the LHC tunnel: a Higgs-factory (LEP3) which could share the storage ring with the ring-ring LHeC, and for the long-distant future combinations of options like HL-HE-LHC, and an HE-LHeC using CLIC technology for a 150 GeV straight energy recovery linac.

### *Discussions*

R. Garoby commented that also a new longer tunnel could be a viable option compared to the cost of high field magnets. F. Zimmermann agreed, although he cautioned about geological constraints. L. Rossi commented that all costs scale with the accelerator length including, beside the tunnel itself and the main magnets, cryogenics, vacuum, beam diagnostics, etcetera, and that, therefore, it is not granted that a larger tunnel will cost less.

Concerning LEP3, F. Giannotti pointed out that the Higgs-Higgs coupling will be out of reach. M. Nessi recalled that detectors need 20 years to be constructed. F. Zimmermann replied that large parts of the existing ATLAS and CMS might conceivably be reused for the *e+e-* collisions. L. Rossi asked whether pipetron magnets could be used for LEP3 as well. F. Zimmermann replied that this is not necessary since a much smaller field of only 0.2 T would be needed. W. Sylvain asked whether the Hirata-Keil limit is a hard limit. H. Burkhardt commented that studies are possible to explore this limit. M. Mangano commented that high energy p-p collider does not need a strong physics case due to the exploratory

nature of the investigation. F. Giannotti agreed on the general statement, but she suggested that at least some indication for physics to explore at the planned c.m. energy would be needed, as had been the case for the LHC the energy that had been decided based on fundamental reasons for new physics.

## **ACCELERATOR MAGNET R&D IN THE PERSPECTIVE OF A LHeC AND A HE-LHC: SYNERGY OR COMPETITION?** **L. BOTTURA**

L. Bottura illustrated how the current R&D activities on accelerator magnets can contribute to the LHeC and the HE-LHC project. For the LHeC the magnets of the ring option present the challenges of low field, low mass, low cost magnets to be installed in the LHC tunnel while running an aggressive accelerator programme. Moreover the mechanics of fly-by half IR quadrupoles and the heat extraction are not trivial. For the HE-LHC, the focus was given not only to the 20T dipole but also to the 500T/m quadrupoles. As a general remark the competition with the scheduled LHC activities was stressed.

### *Discussions*

S. Fartoukh asked whether single bore larger aperture dipole for p-pbar collisions can make the design of dipoles easier with respect to the twin apertures. L. Bottura replied that limitations are really related to the cold bore aperture, which is especially true when increasing the field and L. Rossi added that luminosity maybe limited by the pbar total intensity as in the Tevatron.

E. Todesco reminded that field quality and beam dynamics are easier at 20T. L. Bottura wanted to stress that the first question is still whether the magnets can be built or not. L. Rossi asked why NbTi was considered for the LHeC IR magnets (with high field). As discussed after the presentation, the values quoted are the envelope of the requirements for the IR quadrupoles, and should not be considered simultaneously.

## **SC CAVITY R&D FOR LHeC AND HE-LHC. E. JENSEN**

E. Jensen placed the LHeC and HE-LHC SC RF needs in the general landscape of SC cavity R&D activities. Emphasis was given to the energy recovery linacs option for the LHeC, which represents a very exciting frontier for the SC accelerator cavity technology with synergies either with the 700 MHz (SLS, ESS, eRHIC, SPL) or the 1.3 GHz (ILC, X-FEL) technologies. Beam stability requirements seem to favour the lower frequency. For the LHeC ring-ring option and HE-LHC, the RF requests are standard although any improvement carried out for the LHC (e.g. 800MHz cavities for bunch length manipulations) will have immediate benefit for the future projects. The HE-LHC RF system is essentially identical to the existing LHC RF system; the synchrotron radiation losses are still small, and the RF system requirements are dictated by beam stability.

### *Discussions*

M. Jimenez commented that the NbCu coating program needs resources for infrastructure. L. Rossi added asking why CERN is pushing the copper coated technologies for the high gradient cavities, a road that has been abandoned by others (ILC and proton drivers) in favour of the bulk Nb. E. Jensen replied that CERN will gain a lot in restoring the leadership in a technology with promising potential reach and whose limits have not been asserted. R. Losito added that Nb on copper is a no-back technology, simply has not so developed and pursued as the bulk technology.

## **CONCLUSION**

In summary there are no outstanding issues with the beam current and collimation system for the HL-LHC goals. The development of the key hardware elements for the HL-LHC is well in progress, although 10 years for R&D and construction is a relatively short time for a program that has to run in parallel with the LHC consolidation and many other interesting projects. The LHC tunnel demonstrates to be the cross-road for any foreseeable machine even beyond 2040, with many collaborating and or competing projects.