SUMMARY SESSION 9 – ADDITIONAL LHC UPGRADE SCENARIOS

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Abstract

Session 9 of the 2010 Chamonix LHC Performance Workshop addressed "alternative" LHC luminosity upgrade scenarios. It covered the parameter space beyond nominal, implications of higher intensity, crab cavities, luminosity optimization and levelling, requests and wishes from the experiments, and a comparison of integrated luminosity evolutions for different upgrade scenarios.

INTRODUCTION

The 9th session featured 6 talks, on parameter space beyond 10^{34} $cm^{-2}s^{-1}$ by Frank Zimmermann, implications of higher intensities in the LHC by Ralph Assmann, crab cavities by Rama Calaga, luminosity optimization and levelling by Jean-Pierre Koutchouk, "what do the experiments want?" by Marzio Nessi, and comparison of integrated luminosities by Mike Lamont. In the following we report a few highlights from each presentation and we summarize the subsequent discussions.

PARAMETER SPACE BEYOND 10^{34}

Frank Zimmermann explored the parameter space for luminosities beyond 10^{34} $cm^{-2}s^{-1}$ [1]. The most important parameters are IP beta function, crossing angle, normalized emittance, bunch intensity, number of bunches, longitudinal bunch profile (Gaussian or flat), number of collision points, and turn-around time. Constraints include the total beam-beam tune shift, the long-range beam-beam effect imposing a crossing angle, the arc cooling capacity, the IR layout and optics limiting β^*, the event pile-up in the detectors and the luminosity lifetime. Beam intensity has been identified to be the most important parameter for higher luminosity. Reducing β^* does not significantly change the average luminosity unless it is complemented by crab cavities or by smaller emittance. Two strategies for levelling were presented, keeping either the luminosity or the beam-beam tune shift constant during a physics store.

Discussion:

Frank Zimmermann highlighted that a reduction of β^* might lower the maximum intensity, e.g. due to its impact on the collimator cleaning efficiency, collimator impedance effect, chromatic aberrations, or the long-range beam-beam interaction.

Roland Garoby pointed out that low emittance is an alternative to crab crossing.

Steve Myers asked about the beam-beam limit. All scenarios presented assumed a total beam-beam tune shift of 0.01 from two high-luminosity interaction points. This was a conservative value from the SPS collider, and less than half the value reached by the Tevatron.

Stephane Fartoukh commented that β^* could be further reduced with a beam of lower emittance. Frank Zimmermann asked if β^* was not limited by the chromatic aberrations as well as by aperture, and he argued that the former limit was not improved by the smaller emittance. Stephane Fartoukh replied that the 22 cm minimum value of β^* for Nb_3Sn assumed that the lattice defocusing sextupoles cannot exceed 600 A while their short sample limit is around 900A and while some of them have been tested mechanically up to about 700 A by industry. It assumes as well that one cannot use the b_3 spool piece to assist the defocusing sextupoles. Using the b_3 would degrade the situation in the horizontal plane but there is still more margin on the focusing sextupoles (these sextupoles are twice as efficient as the defocusing ones because the dispersion at the QF is twice higher). This limit also does not take into account that using IR2/8/4/6 we could envisage generating huge beta-beat to "simulate" or support the up and down excitation scheme of the sextupoles corresponding to the strategy he had presented for phase-I (but which will certainly require to re-equip IR4 and IR6 with a Q6 and a Q7). This list represented a series of measures amongst possibly others where creativity could help in pushing the β^* limit (contrary to the limit set by the aperture). Then, at the "not yet known matching section aperture limit" the gain in luminosity would be "2-fold" with $\beta^*=1/\varepsilon$ and with one over the luminosity loss factor (working at the also "not yet known beam-beam limit"). In this respect halving the emittance instead of doubling the bunch charge might be preferable (but of course not both which would be a "PS3" or an "SPL2")

Steve Myers asked about the limit on the total beam intensity. Frank Zimmerman replied that a major limit came from the limited cooling capacity of the beam screens and the pertinent heat load due to resistive-wall impedance, synchrotron radiation, electron cloud and luminosity debris (if the IR cryogenics would not be separated from the arc).

Oliver Brüning remarked that a turnaround time of 5 or 6 times the minimum value has been reached at other machines after years running [2].

IMPLICATIONS OF HIGHER INTENSITY IN THE LHC

Ralph Assmann surveyed the various intensity limits in the LHC [3]. After recalling the history of luminosity forecasts for the LHC, he demonstrated that the ultimate intensity is already challenging for the LHC. At ultimate intensity many systems are at the technological limits with little or no margin. He stressed that with regard to machine protection and damage survival, higher intensity and smaller emittance are nearly equivalent. Intensity limits around ultimate bunch charge come from a multitude of systems, such as the LHC RF, the beam dump, cryogenics, vacuum system, etc. Quench margin and radiation damage of magnets are other important constraints, as are protection devices and collimation. A coherent intensity upgrade plan should also address the LHC system limits. Beam tests in the new HiRadMat facility will give a clearer picture, e.g. with regard to machine protection and radiation protection.

Discussion:

Lucio Rossi asked if the underlying assumption for the collimation limit was that the loss fraction remained the same. Ralph Assmann confirmed the basic assumption that relative losses are constant.

Vladimir Shiltsev commented that the loss models and the scenario presented indicated that the LHC beam intensity might be limited well below nominal. He recommended developing a strategy to get the maximum integrated luminosity in such a case. Steve Myers commented that at the moment the design parameters were still being considered. One would adapt the strategy later. Jean-Pierre Koutchouk emphasized that in case the intensity was limited below nominal one could reduce β^* to recover luminosity, which had indeed been one of the justifications for the IR upgrade phase I.

CRAB CAVITIES

Rama Calaga discussed the use of crab cavities [4]. The crossing angle reduces the luminosity. This geometric luminosity loss can be recovered by opposite deflection of the bunch head and the bunch tail, which may be achieved by so-called RF crab cavities, frst proposed in 1988 and in operation at KEKB since 2007. Rama Calaga addressed the two motivations for crab cavities in the LHC, the requirements, the concept and merits of compact crab cavities [4]. For a β^* of about 0.25 m, the gain in peak luminosity through the crab cavities is of order 50%. For the nominal LHC the gain is 10-15%. The main open issues are impact on collimation efficiency (which looks OK for a first implementation stage [5]), the effect of crab RF noise on the beam transverse emittance, impedance, and machine protection. Installation possibilities are “global” conventional crab cavities in IR4 or compact “local” cavities in IR1 and 5 based on a new technology. After the LHC-CC09 [5] workshop in September 2009, the LHC crab cavity advisory board issued a number of guidelines, which included the statements that following the success of KEKB, CERN must pursue the use of crab cavities for the LHC, since the potential luminosity increase is significant; that a final crab cavity implementation for the LHC has not yet been settled; with both “local” and“global” crabbing schemes still being under consideration; that future R&D should focus on compact cavities which are suitable for both schemes; and that one possible showstopper has been highlighted: machine protection, which is critical for the LHC. In particular, crab cavities can increase the LHC luminosity without an accompanying increase in beam intensity, thereby avoiding negative side effects associated with high intensity and high stored beam energy.

Discussion

Oliver Brüning commented that additional studies would be needed for the beam-beam interaction with a finite crab RF frequency.

Jean-Pierre Koutchouk asked if one could correct the second order chromaticity in case a horizontal-horizontal crossing scheme would be adopted for “global” crab cavities. Stephane Fartoukh commented that for such scheme and this purpose one would require a phase advance between IP1 and IP5 of about π on one side of the ring, and $\pi/4$ on the other side, which would constrain the tune to values close to the quarter integer. Jean-Pierre Koutchouk concluded that the simple global crab-cavity scheme is not likely to work.

Oliver Brüning commented on the doglegs in IR4 that could be prepared for a crab-cavity installation. Rama Calaga confirmed that with proper preparation global crab cavities could be installed in IR4 during a short stop.

LUMINOSITY OPTIMIZATION AND LEVELING

Jean-Pierre Koutchouk discussed complementary measures [7]. At a luminosity level of 10^{35} $cm^{-2}s^{-1}$, whatever the scenario, the luminosity lifetime becomes close to operations “time constants” (cycling and filling, travel time to remote buildings and repairs…). Hence, luminosity levelling could be raised as a requirement for all scenarios. Levelling is also useful for the machine: peak energy deposition, beam-beam effect, operation efficiency. Accordingly, the performance goal of Phase II would become <L> ∼ 5-6x10^{34} cm^{-2}s^{-1}, almost constant over the run (event multiplicity ∼ 100 for 25 ns spacing). Turn-around time and machine availability are two important parameters. As for the turnaround time, Jean-Pierre Koutchouk suggested that perhaps one should not use data from other places (ISR is a good example that short turnaround is possible). Levelling is possible by varying β*, or the crossing angle (with the side effect of reducing the luminous region), or the bunch length. The beam-beam effect requires special attention. The beam-beam tune shift varies during the store when levelling with the crossing angle [1,7]. In addition, the optimum tunes for head on and long-range collisions are not the same, as had been illustrated by a 2009 SPS MD result [8].

Levelling via the crossing angle appears to have the best potential (performance, complexity) but requires unexplored solutions (Crab Crossing) or some interference with detectors (Early Separation). Levelling via the bunch length is worth a detailed study to understand its feasibility. Levelling by β* has an inherent performance limit, is probably complex to implement, but it is cheap.

The long-range beam-beam compensation addresses a fundamental LHC performance limit; it appears effective and robust from several simulations, experiments and one implementation in DaΦne. It is mature for implementation at the LHC. An early dc implementation would allow the study of the beam-beam limits well before the LHC can reach this performance level.

Discussion

Stephane Fartoukh commented that the preferred location for the wire shifted towards D2 for the phase-I upgrade. Jean-Pierre Koutchouk replied that this might be uncritical. Stephane Fartoukh observed that one could also do levelling by varying the beam-beam separation, either longitudinally or transversely.

Massimiliano Ferro-Luzzi asked for the location of the wire compensator and an electron lens.

Jean-Pierre Koutchouk answered that the wire would be installed between D1 and D2, not close to the experiment proper; the same would be true for the electron-lens if used for long-range beam-beam compensation.

Lucio Rossi asked for the compatibility of the early-separation scheme with the experiments. Jean-Pierre Koutchouk responded that a strategy was needed for this point; the experiments would prefer crab cavities because these are outside the detector.

WHAT DO THE EXPERIMENTS WANT?

Marzio Nessi reviewed the requirements from the experiments [9]. The ultimate goal is to accumulate 3000 fb^{-1} on tape, 100 fb^{-1} for LHCb, and 10 nb^{-1} with *PbPb* collisions for ALICE. A luminosity evolution forecast was presented, and detector limitations discussed. Some detectors will age at a given integrated luminosity between 200 fb^{-1} and 1000 fb^{-1} (different case by case). Some detectors will become inefficient or problematic at a given peak luminosity, between 1 and 3x10^{34} cm^{-2}s^{-1}. Detector simulations assume certain evolutions of the accumulated dose, and of the peak luminosity. The first change for ATLAS would be the installation of new forward beam pipes. An additional pixel layer for ATLAS would be ready in 2014. The ATLAS forward calorimeters are sensitive to the peak luminosity, and would need to be replaced some time later. Then both ATLAS and CMS would request a long shutdown (>18 months), after ~600-700 fb^{-1} has been collected, to install new inner detectors. A large fraction of the front-end electronics and trigger electronics will need to be upgraded before going to sLHC Luminosity. For a pile-up of 400 events, the inner tracker gets 15,000 tracks per bunch crossing, and trigger considerations become ever more important. The experiments require a detailed base plan & scenario for the shutdown and beam periods. The compatibility between running CMS and ATLAS at sLHC and at the same time colliding at point 2 and 8 should be urgently clarified. At the time of the sLHC, LHCb would like to operate at 5x10^{33} cm^{-2}s^{-1} (after 2020). Full compatibility of the LHC and LHC-IR upgrades with the LHCb plan should be ensured. ALICE would request low luminosity <5x10^{31} cm^{-2}s^{-1}. Important conclusions were summarized. The experiments are strongly behind the idea of luminosity leveling. The machine experiment interface should have a proper level of organization and visibility.

Discussion

Oliver Brüning asked if the upgrade schedule is driven by luminosity or by collaboration timing. Marzio Nessi replied that it was driven by a combination of the two, and by a risk assessment.

John Jowett asked if from a certain date onward, ATLAS & CMS would not require heavy ion luminosities anymore. Marzio Nessi answered that this had not yet been discussed.

Ralph Assmann asked what determined the goal of 3000 fb^{-1}. Marzio Nessi answered that going from 1000 to 3000 fb^{-1} would increase the discovery reach for heavy “objects” by about 0.5 TeV. Above 3000 fb^{-1} further gain would not be significant.

Caterina Biscari inquired if there was a request for running at lower energy. Marzio Nessi replied that indeed there was another discussion ongoing on the energy for the nearer term, aimed at optimizing the discovery reach for the next couple of years.

Vladimir Shiltsev asked if the maximum acceptable number of events/crossing depends on the bunch spacing. Marzio Nessi answered that 200 was the number of events selected per second; some of the sub-detectors are working with longer integration times (60-80 ns instead of 25 ns).

Simon Baird commented that it was not only the experiments but also the machine which needed a planning.

COMPARISON OF INTEGRATED LUMINOSITIES

Mike Lamont reviewed the luminosity forecast [10]. Three hours was the absolutely minimum possible turnaround time. At LEP the best turnaround time had been 1 h compared with a theoretical minimum of 20 minutes. Assuming 60% machine availability and 4 h turnaround time, the luminosity forecast was 1 fb^{-1} at the end of 2011 and 100 fb^{-1} per year from about 2020 onward.

Discussion

Tiziano Camporesi asked if the forecast was optimistic.

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