HL-LHC: Task Optics & Lattice Layout: Possible topics

status 2 March 2012

0.) Overview about the possible topics

A 1.) MAD-x optics calculations to establish the 120mm aperture / 180 T/m gradient ATS-optics versions: Barbara Dalena, CEA

B 2.) Study the robustness of the 4 standard HL optics with respect to longitudinal alignment errors and gradient errors within the boundary condition of 10% beta beat limit and /or re-"matchability": Catia Milardi

C 3.) Optics transition Injection / ATS-Lumi of 1.) : Maxim Korostelev, Cockcroft

C 4.) Redesign the matching section for optics flexibility:
* Shifting the position of the matching quadrupoles ... done ?
* Introducing additional quadrupoles Rob Appleby, Cockcroft
* Explore alternative phase advance IP / arc-sextupoles BJH / Rob

C 5a.) Optimisation / Flexibility of IR4 / 6 for ATS optics squeeze: Javier Resta & Angeles Faus-Golfe Uni Valencia

C 5b.) Optimisation / Flexibility of IR2 / 8 (10m, 5m, 3m) : Anton Bogomyagkov, Novosibirsk

C 6.) Introducing local sextupoles in the triplet region to improve the chromaticity correction: Jaques Payet & Antoine Chance, CEA

B 7.) Studying the flat beam option of 1.) ... work closely related to the beam-beam task: Catia / Anton / Javier

A 8.) Optics solutions for 140mm compatible gradients: Riccardo CERN

A 9.) Optics compatibility with IR collimations & Nb3Sn: Bernhard CERN

time schedule:
A -> short term: results needed until end of spring 2012 (mai)
B -> mid term: results needed until end of summer 2012 (summer)
C -> long term: results needed until end the year 2012

En Detail:

1.) MADX Optics Calculations:

The short term objective in the context of optics calculations is to establish four beam optics that will act as baseline for the magnet designers, and on the longer term will be our "Standards" for further considerations.
Riccardo summarised the present status of the work in a talk during the HL-LHC meeting in April 2011 and I cite the most important issues for you:
We want to develop 2 beam optics based on NbTi technology and 2 optics using Nb3Sn quadrupoles.
For both options we foresee at the moment two possible magnet apertures (coil inner diameter): 120mm and 140mm. In the table listed below these baseline options are marked by the arrows. [1]

ap. [9] [mm]	grad [10] [T/m]	lengths [11] [m]	β^* [cm]	N1 [12] [ppb]	N2 [13] [ppb]	t [14] [h]
150	144(83%Sn)	8.2 , 7.0	13.0	1.99E11	1.21E11	6.06
150	96(83%Ti)	10.8 , 9.0	17.0	2.03E11	1.36E11	5.24
→ 140	150(80%Sn)	8.00, 6.8	15.0	2.01E11	1.29E11	5.64
→ 140	100(80%Ti)	10.5, 8.8	19.0	2.05E11	1.42E11	4.89
→ 120	180(83%Sn)	7.1 , 6.1	18.6	2.05E11	1.42E11	4.96
→ 120	120(83%Ti)	9.3, 7.8	24.0	2.11E11	1.58E11	4.14
85	160(78%Ti)	7.7, 6.6	44.0	2.41E11	2.11E11	2.33
80	257(80%Sn)	4.8, 5.5	39.0	2.33E11	1.99E11	2.65

While Riccardo already developed a full matched version for the 140mm options the 120mm versions are only calculated until the beginning of the matching section and need further effort.
Here we need help to develop a fully matched solution, starting from the preliminary results, and including tolerance considerations to check the robustness of the optics and optimisation with respect to smallest beta star, achievable in the pre-squeeze optics, Q4-Q13 gradient margins and aperture needs in the complete straight section ad dispersion suppressor.
Goal: In the end we will need a first clear statement about the magnet parameters (length for the triplet magnets) in spring 2012.

2.) Robustness & Tolerance Considerations for the 4 Standard Optics

For the 4 baseline ATS optics mentioned above we will need estimates of the tolerances that can be accepted in the machine. Therefore these optics have to be studied under the influence of gradient errors and longitudinal misalignments.
The procedure will be to introduce focusing errors in the lattice and consider the resulting beta beat. We would like to know the maximum error that can be tolerated for a limit of $\Delta\beta/\beta$ =10% in the machine for the magnets in the high luminosity IRs (IR1 & 5) as well as in the neighboring matching sections (IR4,6 and 2,8).
For the studies on longitudinal alignment an error of 5mm is considered as a resonable number. Introducing this misalignment again the resulting beta beat is the key issue but may be in this case it could even be combined with a test to re-mathch the machine.
In a third study the influence of the fringe fields should be included. The "ideal" machine optics should be compared with the optics that results if the fringe fields of the large aperture magnets in the straight section are included. The goal again will be to get input of the resulting error and to conclude whether these effects can be tolerated or not.
Goal: we will need first results until end of summer 2012 to have a profound basis for the further planning.

3.) Optics transition Injection/Collision Optics

Having established a beam optics for luminosity we still will have to show that the beam that has been injected and accelerated to flat top can be squeezed down to the small betas. This optics transition has to be established without major impact on the beta beat during the interpolation steps and usually several intermediate steps are needed where the optics is re-matched to avoid problems.

4.) Re-Design of the Matching Section for Optics Flexibility

a) During the studies for the phase 1 upgrade, the position of the matching quadrupoles, namely Q4...Q6, had been untouched to keep the possible technical effort as low as possible. Meanwhile these restrictions have been withdrawn and we would like to know if we gain in flexibility if the locations of these magnets are varied.
Based again on one of the present well-matched optics (the 140mm versions e.g.) these magnets can be shifted one by one and after each step a re-match has to be done to see if the new solution obtained increases the optics flexibility defined in 1). First calculations are quite positive and so it is a worthwhile study.
As it is basically a re-tuning of present beam optics it might even be a good start for people that are not yet too familiar with the LHC and /or MAD-X.

b) A possible gain in performance of the optics could be achieved by introducing an additional quadrupole lens in the section between q3 and q7. Like in the previous case this would ideally start on the basis of one of our standards optics that is already available. As already mentioned before, the hope is to increase the optics flexibility in 1).
c) For an effective chromaticity compensation certain boundary conditions are needed for the phase advance between the IP and the arc sextupoles. $\pi/2$ modulo π are ideal values in the x and y plane. The question is whether we gain optics flexibility in IR1 & 5 by choosing different combinations of phase advances in horizontal and vertical plane.

5a.) Optimisation / Flexibility of IR4 / 6 for ATS optics squeeze:

The ATS scheme is based on the fact that the neighboring sectors are used to do the squeeze in the high luminosity IPs 1 & 5. By the nature of this scheme the boiundary conditions in these neighboring sectors are quite limited. A study will be needed to explore the flexibility that we still get there and to try to optimise the situation:
Keywords here are:

* study the phase advance over the straight sections 2 & 4 (e.ds.l to s.ds.r) to simplify the optics transitions while being compatible with nominal constraints in these IRs
* study the maximum β* lever arm offered by IR2, IR4
* Impact of changing the optics in IR4 (RF & beam instrumentation) and IR6 how flexible are we still in these regions ?

5b.) Optimisation / Flexibility of IR2 / 8 for ATS optics squeeze:

As in task 5a) the matching quadrupoles in IR 2&8 are used within the ATS scheme to squeeze the β* in IP1 to smallest values. At present the overall layout of the HL-LHC is based on a beam optics in IP8 that delivers 10m beta at LHCb. Recent discussions however show that the experiment is interested in smaller β* values.

* The task will be to establish a variety of optics in IR8 that guarantees the flexibility needed for the requests of LHCb experiment and at the same time still can guarantee the ATS scheme to get the design β* of 15cm in IP1.
* In addition the work will include considerations about the flexibility of the whole scheme in IR2&8 and the optimisation / variation of the phase advance within the long straight section 2&8.

6.) Local Chromaticity correction:

It has been proposed to use locally installed sextupoles in the triplet region to compensate at least a part of the chromaticity budget that is created by the HL-LHC insertion. As you might know the chromaticity is too high to be compensated by the LHC standard sextupole strengths. The ATS optics, introducing a strong beta beat in the arc, is used to increase the efficiency of our 6poles by artificially enhancing the beta values in the arc.
Based on one of the four standard optics local sextupoles could be introduced in the triplet region, trying to support the arc sextupoles without introducing significant geometric aberrations. (A little bit linear collider like approach ... so Andy/Rob does this sound attractive?)
A possible draw back might be the dynamic aperture, but exactly this needs to be studied in detail.

7.) Flat Beam Option

Due to the short bunch distance in LHC (50ns / 25 ns) a crossing angle is needed at the interaction points to avoid strong beam-beam effects at the parasitic bunch encounters. Due to this crossing angle the achievable luminosity is reduced, except crab cavities can be built and installed in the IR.
The size of this crossing angle and the requirements for crab cavitites can be reduced quite a bit if a beam optics is established that delivers flat beams at the IP. The plane with the larger β* will be the plane of crossing, as in this case the beam size at the parasitic encounters can be considerably reduced. ($\beta_s=\beta^*+s^2/\beta^*$).
The flat beam optics is considered as a possibility to reduce the beam beam problems in the upgrade and might even act as "plan B" in case that the use of crab cavities should turn out more demanding than expected. The goal will be to establish such an optics and to define the gradients for the triplet quadrupoles as an additional option to the four beam optics scenarios that are listed in table1. The beam parameters and the achievable luminosity have to be established and - in collaboration with the beam-beam team a consistent layout has to be found.

8.) Optics solutions for 140mm compatible gradients

see point 1)

9.) Optics compatibility with IR collimations

In order to improve the efficiency of the LJC collimation system and to handle the higher debris that is expected from the larger interaction rate additional collimators have to be installed in the dispersion suppressor part o the IR.
To gain space for these devices LHC standard dipoles will have to be replaced by stronger Nb3Sn types that have a large impact on the beam well being. Geometry, dynamic aperture and in the end magnet specifications are the keywords here.