HL-LHC layout and ATS optics building process

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Content and motivation

The HL-LHC project:

- aims at a peak luminosity of $5 \cdot 10^{34}\,\mathrm{cm}^2\mathrm{s}^-1$ and integrated luminosity of $250 - 300\,\mathrm{fb}$ per year and
- targets low-β^* in IP1 and IP5.

Therefore one needs:

- New triplets magnets to accommodate the aperture requirements with the necessary shielding for the additional radiation;
- A mitigation strategy for the geometric reduction factor;
- A new optics to be able to generate the squeeze low-β^* and control the enhanced aberrations, which in turns needs additional layout changes;

This talk will introduce these topics with an emphasis on the triplet layout and optics building.
The other topics will be address in the following talks.

Low β^* for HL-LHC

$$L = L_0 F_{\rm geo} F_{\rm hr} \qquad L_0 = \frac{N_b^2 n_b f_{\rm rev}}{4\pi\epsilon\sqrt{\beta_x^*\beta_y^*}} \qquad F_{\rm geo} = \frac{1}{\sqrt{1+\left(\frac{\sigma_z d_{\rm s}}{2\beta_x^*}\right)^2}}$$

$$\theta_{\rm c} = d_{\rm s}\sqrt{\epsilon/\beta_x^*} \qquad \sigma = \sqrt{\epsilon\beta}$$

quantity	unit	25ns	50ns
$f_{\rm rev}$	Hz	11245.5	11245.5
N_b	10^{11}	2.2	3.5
n_b		2808	1404
σ_z	cm	7.55	7.55
ϵ	μrad/γ	2.5	3.0
β^*	cm	15	15
$d_{\rm s}$		12.5	11.4
θ_c	μrad	590	590
$F_{\rm geo}$		0.3	0.33
L_0	$10^{34}/(\mathrm{cm}^2\,\mathrm{s})$	24.1	25.5
L	$10^{34}/(\mathrm{cm}^2\,\mathrm{s})$	7.3	8.4

Triplet options

NbTi and Nb_3Sn large aperture quadrupoles have been considered for LHC IR upgrade.
The following options have been proposed for the HL-LHC upgrade to be studied in the Task 2.2.

technology	aperture [mm]	gradient T/m
NbTi	140	100
NbTi	120	118
Nb_3Sn	140	150
Nb_3Sn	120	170

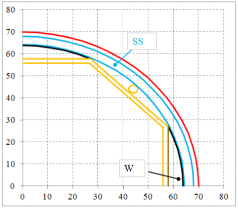
Recently it has been proposed under development:
150 mm and 140 T/m for Nb_3Sn.

Available aperture

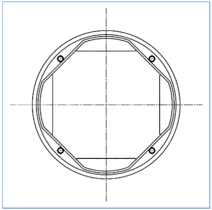
The aperture available for the beam is reduced by the presence of the beam pipe, shielding for radiation debris and the beams screen. A detailed layout is under development.

Vacuum Issues for the HiLumi Triplets – R. Kersevan – CERN – TE/VSC/IVM – 4Sept2012

2. Triplet Region Lay-out, Lattice and Vacuum Model



1/4th of 2D model showing the cross-section of the 140 mm ID cold-bore
(E. Todesco, private comm. 10/7/12)



Starting point: drawing LHCVSSX_0004 6/10/2009, **"Phase 1 Upgrade"**
(re-scaled to 140 mm cold-bore ID, and 6mm W shielding)

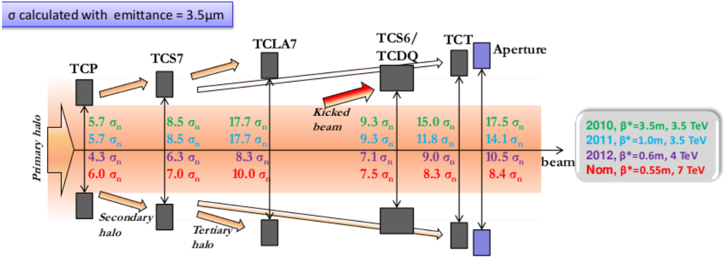
Conceptual 3D Model of 140 mm ID (cold bore, CD) Beam Screen (BS):

- W radiation shield is placed EXTERNALLY to the BS (see next slide)
- 4x4 Pumping Slots, racetrack-shaped like in the LHC arcs' BS have been added (see below), with a longitudinal spacing of 16 mm.

Beam stay-clear

Computed by finding the touch point of a scaled halo with the 2D vacuum cross section reduced by beam and mechanical tolerance (n_1 value). The LHC was designed for n_1=7.

In practice:

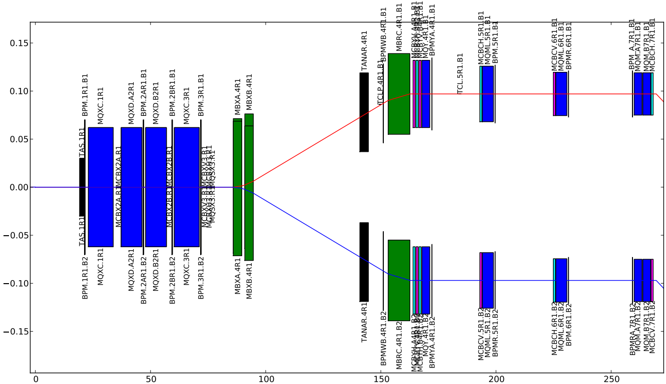


(R. Bruce, CERN MAC, 2012.08.06)

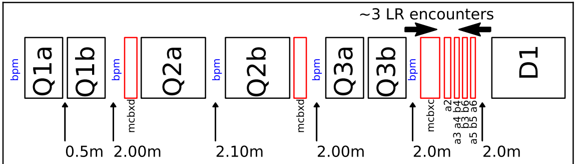
For the HL-LHC there are ongoing analysis counting of new BPMs in the collimators. Impedance budget, which has the impact on the settings of the collimators,is under investigation too.

Triplet layout structure and constraints

PhaseI like:



Triplet layout: new working hypothesis



Q1/3 a/b: 3.97m, 140 T/m, 150mm
Q2 a/b: 6.76m, 140 T/m, 150mm
D1: 7.7m, 40 Tm, 150 <-> 160mm
Q3-D1 distance (presently ~9m) is already critical

MCBXD: 1.3m, 1.8Tm, h/v nested orbit corrector
MCBXC: 2.00m, 4.5Tm in xing plane(for crab) and
1.8Tm in the other plane
MQSX3: 0.67m, skew quadrupole corrector
MCSTX3: 0.50m, (b3,b6) nested correctors
MCOSSX3: 0.50m, (a3,a4,b4) nested correctors
MCDTSX3: 0.50m, (a5,b5,a6) nested correctors

Crossing angle mitigation

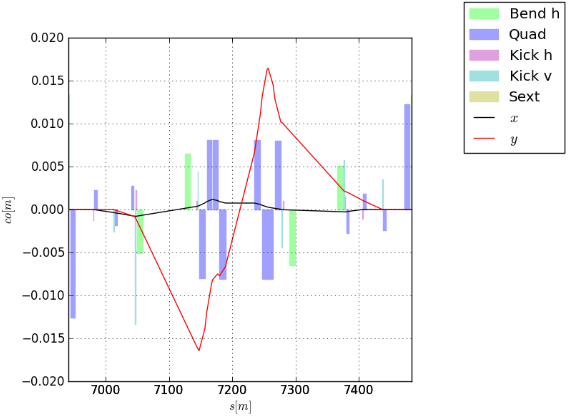
$$F_{\rm geo} = \frac{1}{\sqrt{1+\left(\frac{\sigma_z d_{\rm s}}{2\beta_x^*}\right)^2}} \sim 0.3 \text{ for } \beta^* = 15\text{cm},$$

Crab cavities restore the geometric reduction factor by tilting the beam at the IP only with some limits:

- Rf curvature effect
- Voltage available: about 10MV for the current optics

Implication for layout

The best compromise between large beta function and beam separation is between D2 and Q4:



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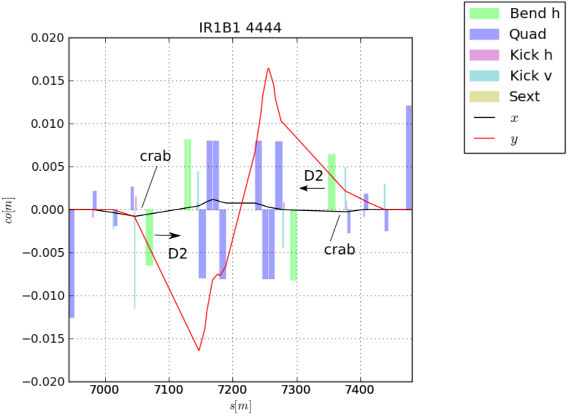

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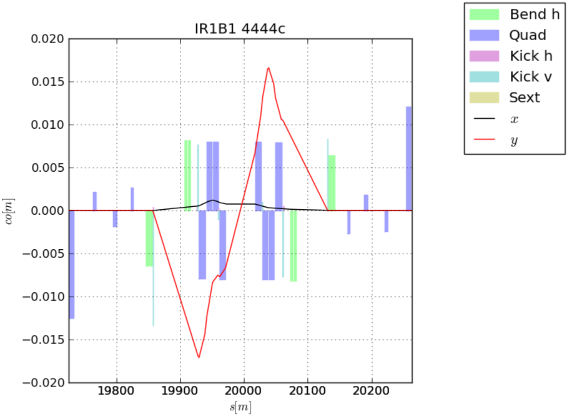


with new crossing scheme to avoid orbit excursions

Implication for optics

$$V_{\rm crab} = \frac{cE\theta_c/2}{\sqrt{\beta^*\beta_{\rm crab}}\omega_{\rm crab}}$$

High beta at the crab cavities is highly envisaged but the phase advance constraints and/or the mechanical aperture of D2/Q4 limit the beta functions.

See talk B. Dalena tomorrow for further investigations.

ATS motivation

Any optics will be limited by:

- aperture in the triplet
- field quality of the magnets around the triplet

Nominal-like optics are limited by:

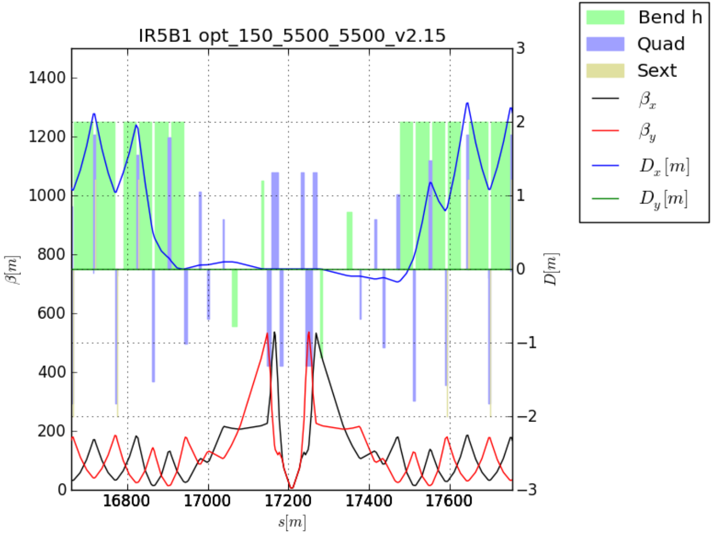
- chromatic aberration (beta', Q'', Q''', dispersion)
- optics flexibility

ATS optics are limited in β^* only by field quality in the arcs (max factor 8 w.r.t pre-squeeze beta*).

ATS optics sequence

- injection: offers the largest aperture margin in the straight sections

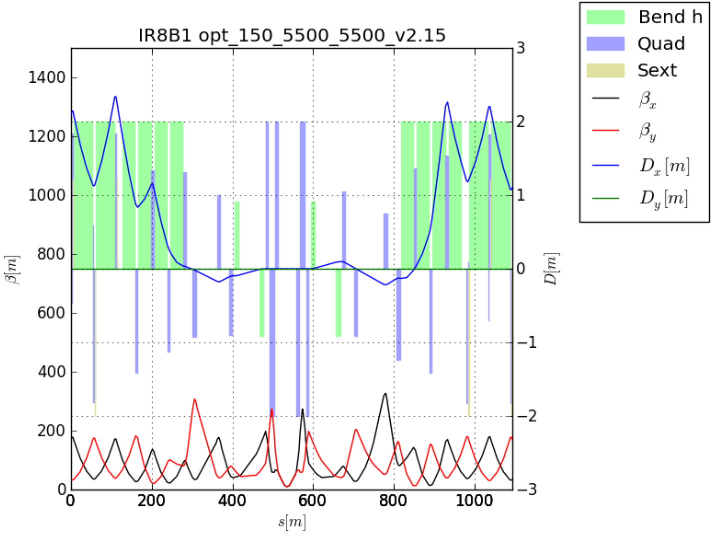
ATS optics sequence



ATS optics sequence

- injection: offers the largest aperture margin in the straight sections
- flattop: due to the injection constraints some of the strengths cannot be sustained at top energy (e.g. IR28 triplet strength), therefore different optics are needed

ATS optics sequence



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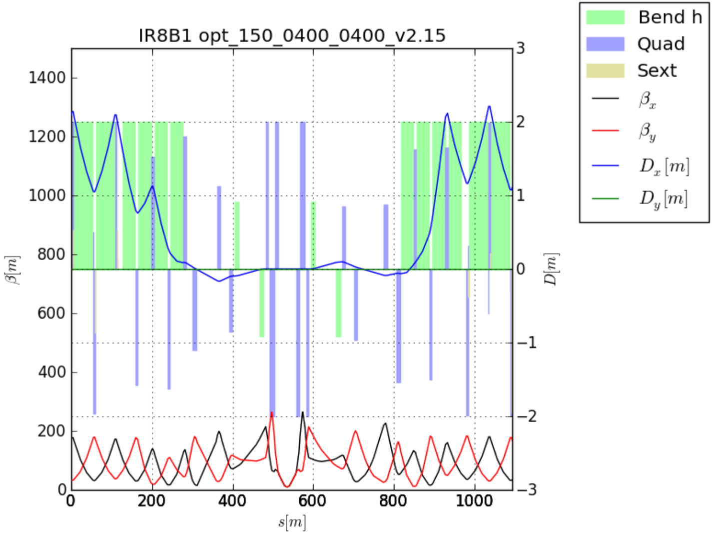

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- pre-squeeze: squeezing of beta star in the experimental insertions

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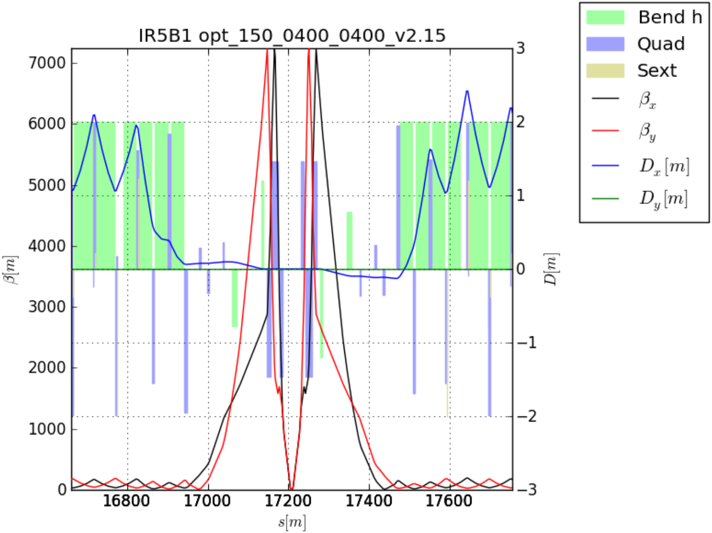
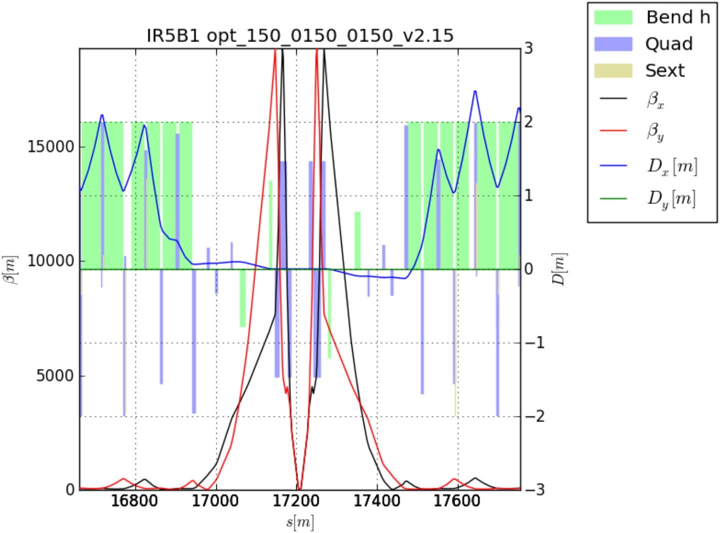


ATS optics sequence

- injection: offers the largest aperture margin in the straight sections
- flattop: due to the injection constraints some of the strengths cannot be sustained at top energy (e.g. IR28 triplet strength), therefore different optics are needed
- pre-squeeze: squeezing of beta star in the experimental insertions
- squeeze: squeeze of IR15 through the neighbouring insertions thanks to the phase advance choices. It can generate round and flat beams, up to a demagnification factor of 8.

ATS optics sequence



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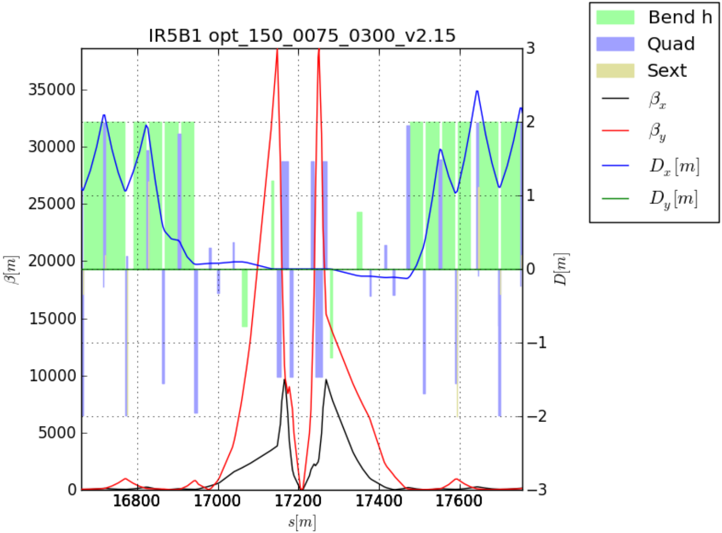

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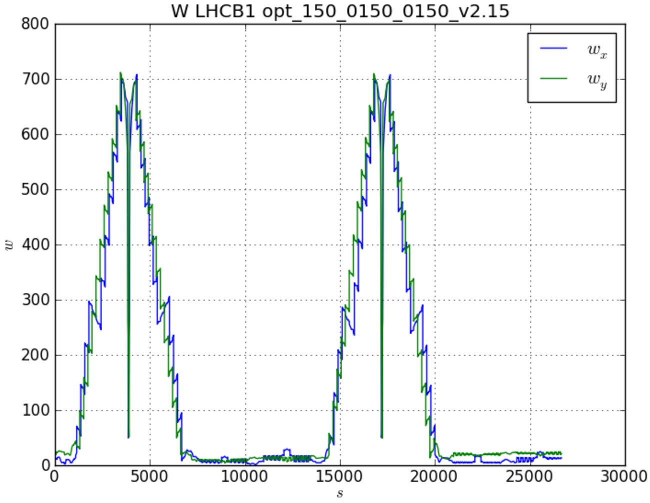

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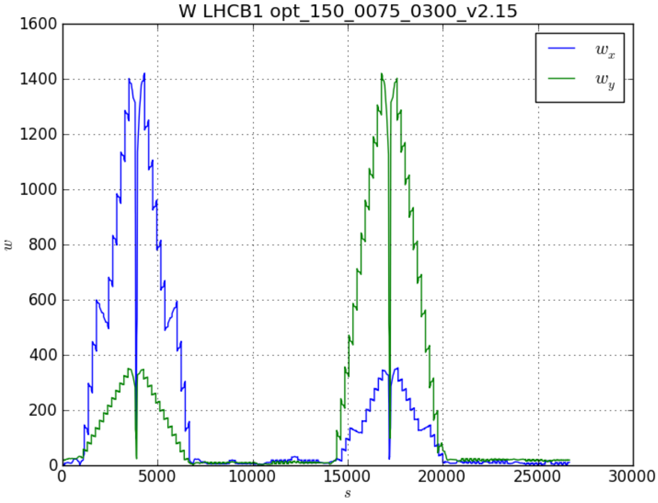

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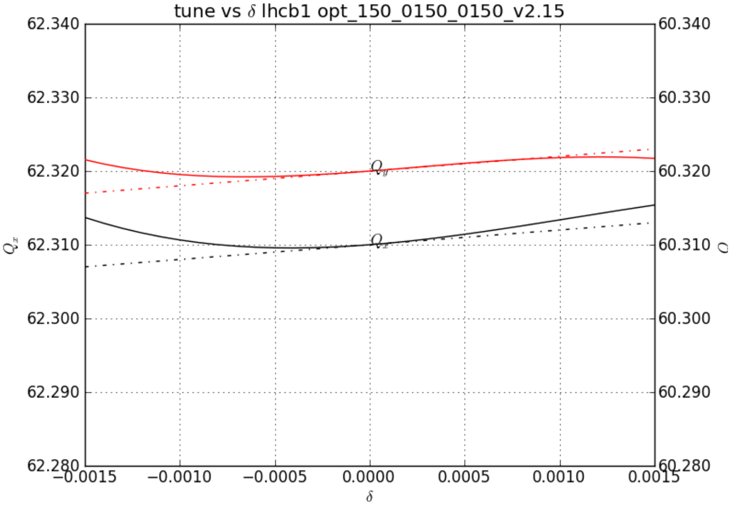

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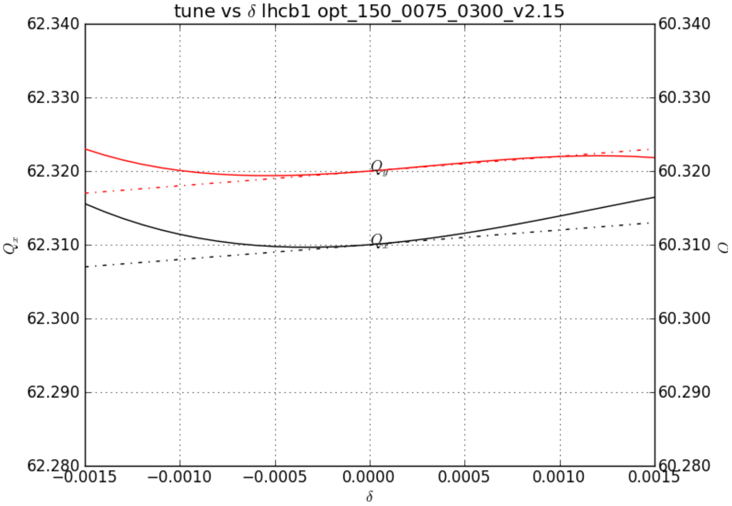

ATS building up (1)

- pre-squeeze beta*: iteration on layout and quadrupole strength margin: `mktripletv5.madx`, `slhc_sequence.madx`, `rematch_ir15_b12.madx`
- phase optimization: orthogonalization of the sextupoles effects on the x,y plane with the beta beating wave. Not very sensitive with the change of the IR15 triplet layout. Scripts: `rematch_betabeat.madx`, based on `PHASESHIFT` and `chromatic function matching`.
- arc rematching and IR37 rematching: `SHIFTPHASESECTORWEAK`, `rematch_ir[37]b[12].madx`
- IR2846 squeeze optics for different magnification ratio: generation of proper boundary conditions. For IR6 special care is used for the constraints of the dump system: Scripts: `selectIRAUX`, `rematch_ir[2846]b[12].madx`, `rematch_ir6b[12]m.madx`

ATS building up (2)

- for each squeezed beta*
  - rematch w: fine tune the sextupole to make chromatic beating vanishing in the collimation insertion. Scripts: `global_rematchw.madx`
  - crossing angle generation. Knobs generation for IR15 on arbirtrary planes and for IR28. Scripts: `rematch_xing_ir15.madx`, `xing.IP28.madx`
  - dispersion correction: compute orbit bumps in the arc to compensate for the dispersion induced by the crossing angle. Scripts: `rematch_disp.madx`;
- injection optics; iterates on apertures bottlenecks at injections. Scripts: `rematch_ir[12345678]b[12].madx`, `MK_APIR`.
- pretty printing of the optics: includes knobs generation and optics summary. Scripts: `save_optics.madx`;

Total of 20k lines of script built in 4 years!

Conclusions

... are in the rest of workshop