HL-LHC Optics MD

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Motivation for optics studies for HL-LHC

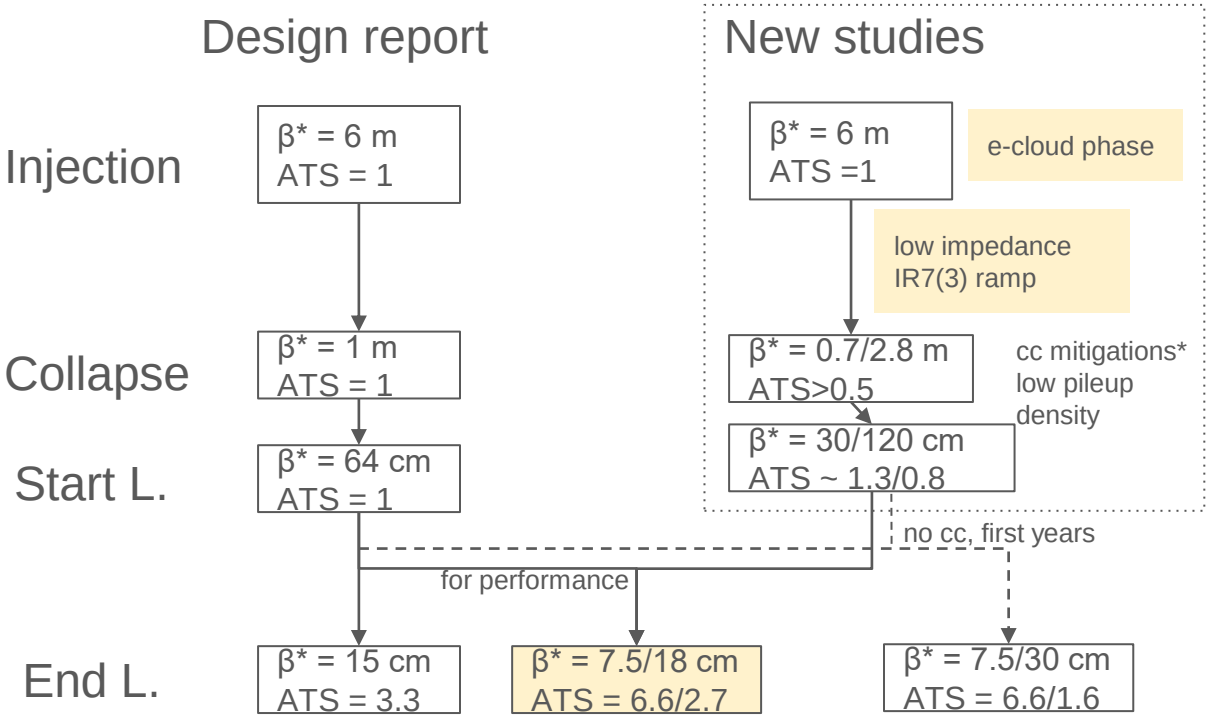
Despite missing HL-LHC triplets, it is still possible to deploy most of the HL-LHC optics in the LHC:

- e.g. IR1/5 presqueezed at β*~2.5m to reach β*= 38 cm for large ATS factors (6.6 compared to 2 operations in 2023 and 4 in MDs).

While we are very confident on linear optics:

- HL-LHC optics pushes limits on optics correction and aperture at flat top in the arcs.
- We can test the impact of orbit/tune stability (e.g. 10 Hz) for large ATS factor. Compare the impact of PC regulators from 2024 and 2025.
- Alternative optics configurations (such as collapse in flat) to the baseline are being studied to prepare for mitigating potential limitations related to impedance, emittance growth, failure scenarios. Useful to gain experience.
- Synergies with beam-beam and collimation studies.

Nominal cycle vs new proposals for HL-LHC



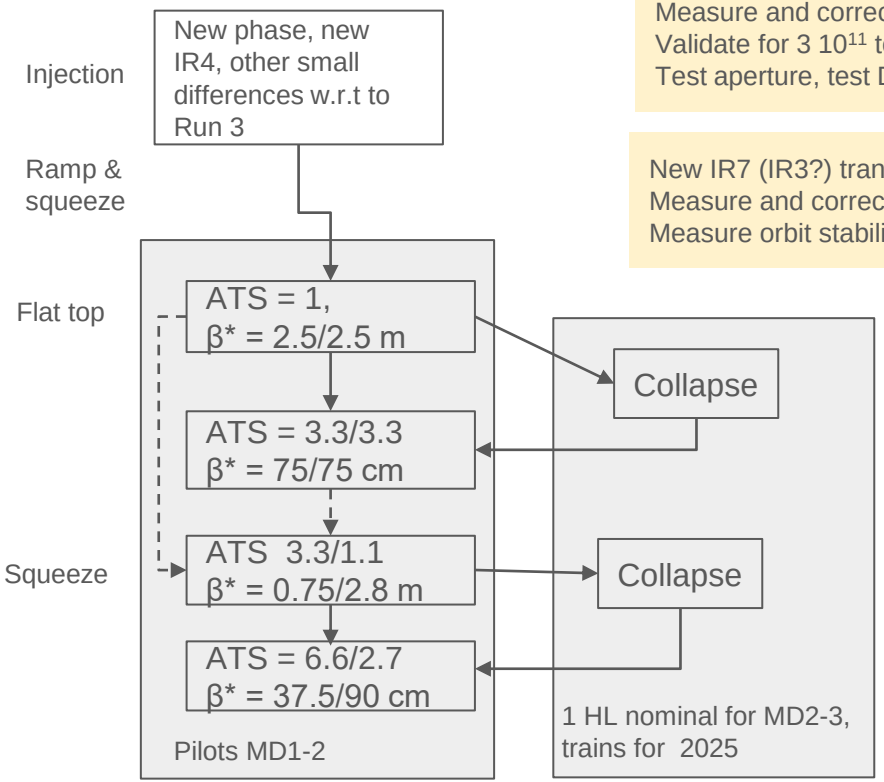
Several decisions pending for new studies:

1. crossing plane VH better β* reach (MKD-TCT)
2. detailed β*, ATS steps

MD to focus on new studies and extremes cases.

* cc impedance, emittance growth, fast failure

HL-LHC Optics, BB, Noise MDs



Measure and correct orbit and optics,
Validate for 3 10^{11} total (1 or 2 bunches)
Test aperture, test DA with negative octupole polarity

New IR7 (IR3?) transition in the ramp.
Measure and correct orbit and optics,
Measure orbit stability at collimators.

Round collapse for impedance mitigation, benchmark case.

Equivalent HL β* = 15 cm, measure and correct orbit and optics.

Flat collapse for impedance mitigation and comparison with round.

Equivalent HL β*=7.5/18 cm
Measure and correct orbit and optics, measure orbit stability and aperture.
Collapse one nominal with a small crossing angle at some convenient stage.

Crossing planes VH: additional crossing plane rotation (not needed in HL) adds complexity (no TCDQ/SMP control upgrade available).

Injection MDs

Injection	Time
Improved phase advance without phase knob, new phases overall.	4h: setup orbit, OMC 4h: one or two corrections
IR4: higher beta at instrumentation, slightly smaller aperture margins	
Test the minimum acceptable aperture at injection: 12.6@2.5um (Note) instead of 13.1@2.5um (Run3)	4h: global aperture checks

In 2024, we focus on pilots and 1-2 nominal large intensity (<3 10^{11} total).

Negative octupole polarity will be used.

For 2025 we propose to move to train to study loss maps, cleaning efficiency (~16h).

This requires +8h for a full MP validated setup.

MD Request: https://asm.cern.ch/md-planning/lhc-requests/11243?mode=b&query=HL-LHC

Ramp&Squeeze MDs

Ramp&Squeeze	Time
IR7 transition to low impedance optics	12h orbit, OMC, β*~2.5m/1 ATS
IR3 transition to low impedance optics?	

In 2024 we focus on pilots and 1-2 nominal large intensity (<3 10^{11} total).

Test operational feasibility, orbit stability in collimators.

For 2025 we propose to move to train to study beam-beam effects, loss maps, cleaning efficiency.

This requires +8h for a full MP validated setup.

MD Request: https://asm.cern.ch/md-planning/lhc-requests/11243?mode=b&query=HL-LHC

Squeeze/Levelling MDs

Flat top	Time
Test arc optics correction up to 6.6 tele-index optics, impact 10 Hz	4h+4h to OMC
Implement a collapse at flat top	4h (BB MD)
Measure arc aperture up to 6.6 tele-index optics	+2h if AC dipole works +4h if not
Study ideal MKD-TCT phased optics at 3.3 and/or 6.6x tele-index, off-momentum beta-beating impact on cleaning efficiency, IR3 settings	2025 synergy with collimation studies
Low-beta in Point 8 for Run 5, β*=0.5/1.5 m	synergy with ion run

In 2024 we focus on pilots and 1 nominal. negative octupole polarity will be used.

For 2025 we propose to move to train to study beam-beam effects and collimation test loss maps.

This requires +16h for a full MP validated setup.

In 2025 we considere to add other aspects related to HL-LHC options, future projects, other optimizations.

MD Request: https://asm.cern.ch/md-planning/lhc-requests/11243?mode=b&query=HL-LHC

Conclusion

MD plan for 2024 and 2025 to answer questions HL-LHC optics challenges for optics, noise, BB and collimation, coming from

- large beta functions and aperture in the arcs,
- more complex ramp&squeeze,
- different collpase process,
- negative polarity through the cycle.

Total for 2024: 48 h

Total for 2025: 48 h

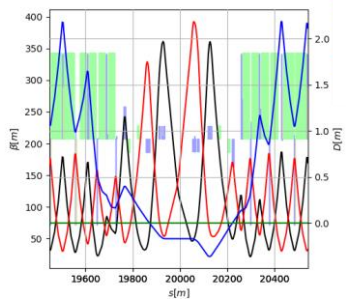
Study	**Block**	**Time**	**Beam**
Injection OMC, Aperture	MD1-2	12h	Pilots/ IND/ 2-3 10^{11}
Ramp with IR7 transition, OMC, orbit and tune stability	MD1-2	12h	
Squeeze, OMC, Aperture	MD3-4	12h	
Inj, Ramp, Collapse for BeamBeam studies, Noise	MD3-4	12h	2-3 10^{11}
Inj, Ramp, Coll Alignment and MP Validation, tune stability	2025	16h	1 Train
Inj, Ramp, Squeeze, Loss maps, cleaning	2025	16h	
Inj, Ramp, Squeeze, Loss maps, cleaning	2025	16h	

OP contact: T. Persson.

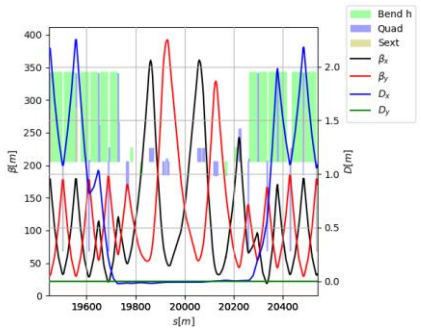
Preparation

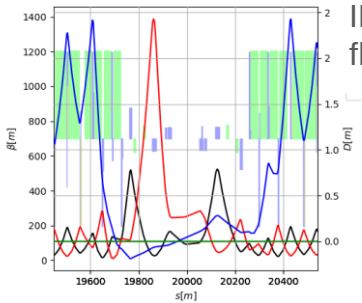
- Completed MD procedure.
- Full Python reimplementation of the optics factory: xsuite based!
- Optics cycle preparation for MD1/MD2: what is the hard deadline
  a. Integrate optimized HL-LHC IR7 and IR3 at flattop: done
  b. Integrate phase knobs as built-in phase at injection: done
  c. Decide on beta* in IR1/5 at the end of the ramp to be compatible with TCDQ settings (see later): done
  d. Make the ramp&squeeze: done
  e. Finalize MAD-X optics files with operational knobs for LSA for Matteo: expected today.
  f. Choose to time in the ramps and prepare settings and corrections: to do next week.
  g. Check ADT settings with experts for new optics: to do!
- Prepare for MD3-4-5:
  a. Prepare a squeeze for 6.6x preserve the TCDQ settings in 3.6 mm (limitation will be lifted in HL)

HL-LHC IR7 optics

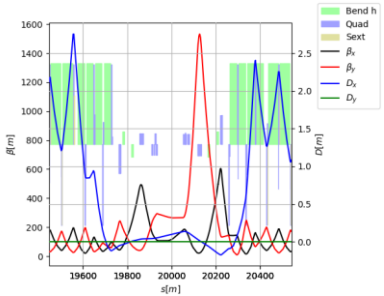


IR7 injection





IR7 flat top

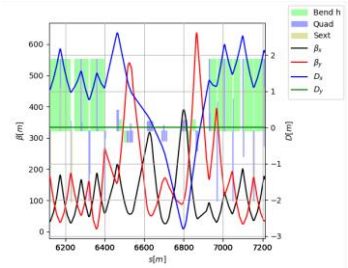


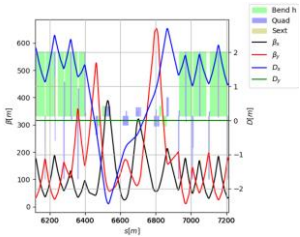
The original IR7 for HL-LHC used RQTL8.L7B1 at 240A, since Arjan said it would be possible, in principle.

Presently, the circuit is commissioned at 200A:

- it is impractical to recommission it now
- It is not needed for the MD that aims at proving the operational feasibility of the optics transitions
- Hardware commissioning test at 240A to be scheduled sometime late 2024 - start 2025.

IR3 flat top





MD Collimation settings [σ at ε=3.5 μm]

Coll	Inj	Flat top (ATS 1x) beta15=2.5m	End of squeeze (ATS 6.6x) beta15=37 cm
TCP7	5.7	5.0	5.0
TCSG7	6.7	6.5	6.5
TCDQ/TCSP	7.5	7.3 (3.6 mm)	6.8-8.3 (tbc, 3.6 mm constant)
TCP3	8.0	15	15
TCSG3	9.3	18	18
TCLA7	10.0	10	10
TCLA3	12.0	20	20
TCT15	13.0	20	10 (ok with good TCT-MKD)
TCT8	13	18	18
TCT2	13	37	37
TCL4	park	park	park
TCL5	park	park	park
TCL6	park	park	park

Gap of TCDQ in mm cannot be changed without access, excluded for the MD.

Squeezing V plane in IP5 is easier: Constant beta at TCDQ and good TCT-MKD phase.

H plane is more limited. Beta at TCDQ tends to increase TCDQ gap approaching secondaries. MKD-TCT getting worse, loosing margin between TCDQ-TCT.

If we want ATS in V plane, squeeze would require increase beta* at flat-top to gain in TCDQ-TCT margin, but there is a limit somewhere around 3 m.

Work in progress...

Ramp and squeeze function normalized gradient!