Run 4 operational scenario

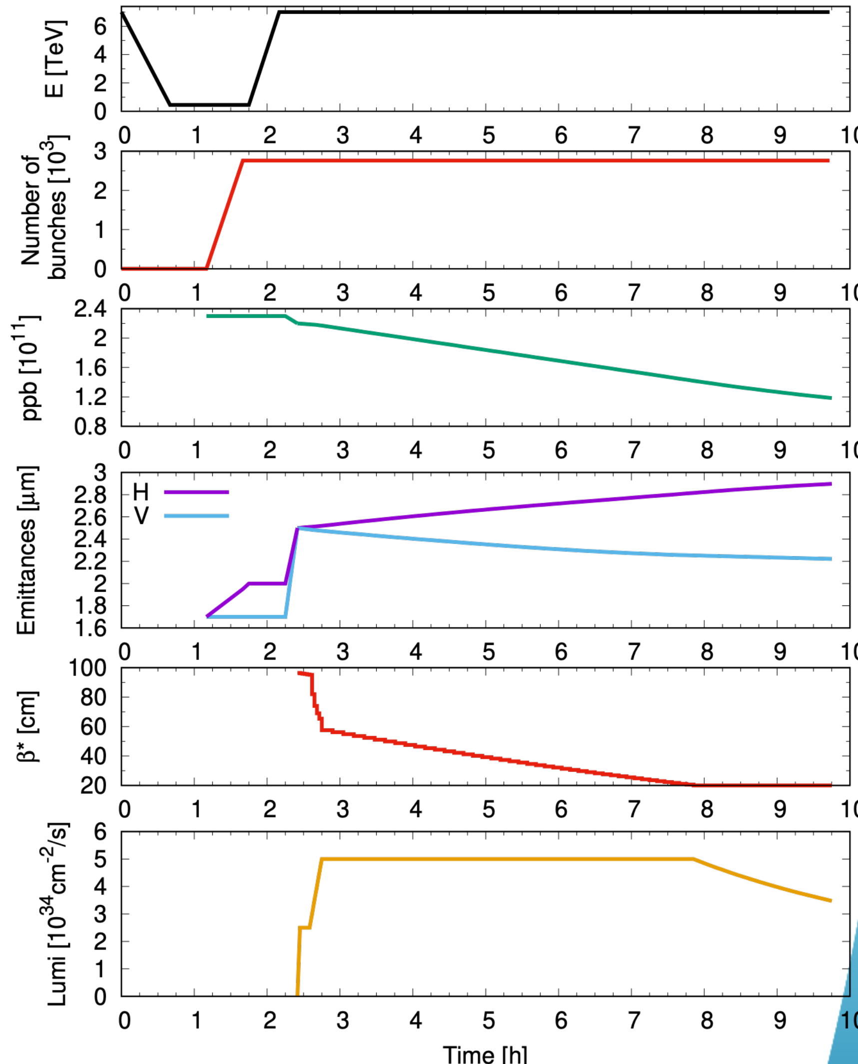
Nicolas Mounet and Rogelio Tomás, for WP2

With lots of input from C. Accettura, D. Amorim, C. Antuono, G. Arduini, H. Bartosik, P. Baudrenghien, B. Bradu, R. Bruce, O. Brüning, X. Buffat, R. Calaga, R. De Maria, J. Dilly, C. Droin, I. Efthymiopoulos, L. Fiscarelli, A. Foussat, L. Giacomel, M. Giovannozzi, G. Iadarola, P. Hermes, S. Izquierdo Bermudez, I. Karpov, S. Kostoglou, B. Lindström, E. Maclean, L. Mether, E. Métral, F.-X. Nuiry, Y. Papaphilippou, K. Paraschou, T. Pugnat, S. Redaelli, G. Rumolo, B. Salvant, L. Sito, G. Sterbini, H. Timko, E. Todesco, F. Van der Veken, A. Wegscheider, J. Wenninger, M. Zampetakis, C. Zannini, M. Zerlauth

14th HL-LHC collaboration meeting – 07/10/2024

Run 4 operational scenario: current baseline

	Standard	BCMS
Number of bunches	2760	2744
Pile up	130	132
Emittances [μm]	2.3/2.1 (2.5 in coll.)	2/1.7 (2.2 in coll.)
Octupole current [A]	380 (120 in coll.)	460 (120 in coll.)
β* [m]	**1 → 0.2**	
Intensity [10^{11} protons/bunch]	2.3 (2.2 in collisions)	
Levelled luminosity	**5.10^{34} cm^{-2}s^{-1}**	
Collimators	**Relaxed** (TCP IR7 8.5σ)	
Chromaticity Q’	15	
Half crossing anfle (crabbing angle)	250 μrad (-190 μrad) Hor. in IP1 / Ver. in IP5	



***R. Tomás et al**, HL-LHC Run 4 proton operational scenario,* CERN-ACC-2022-0001

Run 4 operational scenario: current baseline

- Assumptions on operational days (M. Zerlauth et al, EDMS 2902691):

year	ppb [1e11]	beta* [cm]	CC	Virt. Lumi	PU	YETS days	Commissionig	Scrubbing	MD days	Special runs	Int ramp-up	Proton physics	Ion physics	Int. Lumi [fb-1]
2029	1.8	30	off	3,9	101	189	80	10	12	5	**20**	**6**	**29**	9,6
2030	2.2	25	on	10.3	132	105	40	1	20	5	**15**	**136**	**29**	208
2031	2.2	20	on	13.5	132	105	25	1	20	7	**10**	**154**	**29**	238,8
2032	2.2	20	on	13.5	132	105	25	1	20	9	**10**	**152**	**29**	235,7

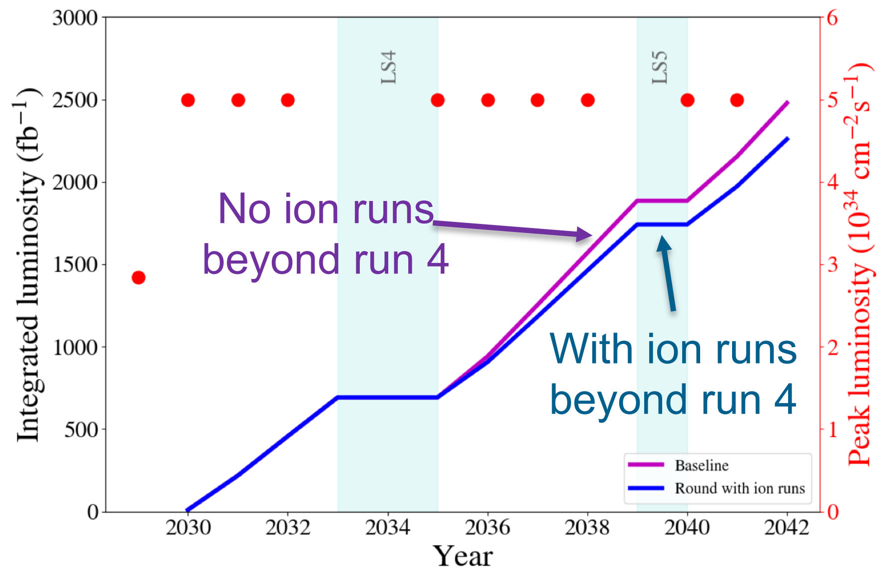
Insufficient for the bunch intensity ramp up in 1st year

Recent change of schedule shifts everything by one year (and removes one long shutdown) → **no change in integrated luminosity** (running 10 years)

Total integrated luminosity estimate:

+1% with **BCMS (IP1 & 5)** (also depending on several unknowns, e.g. emittance growth, transverse tails).

~460 fb^{-1} should be added for the **LHC** runs.



S. Kostoglou, 228th WP2 meeting, 02/07/2024, and WP2/5/7 session, Tu. 8/10 4 pm

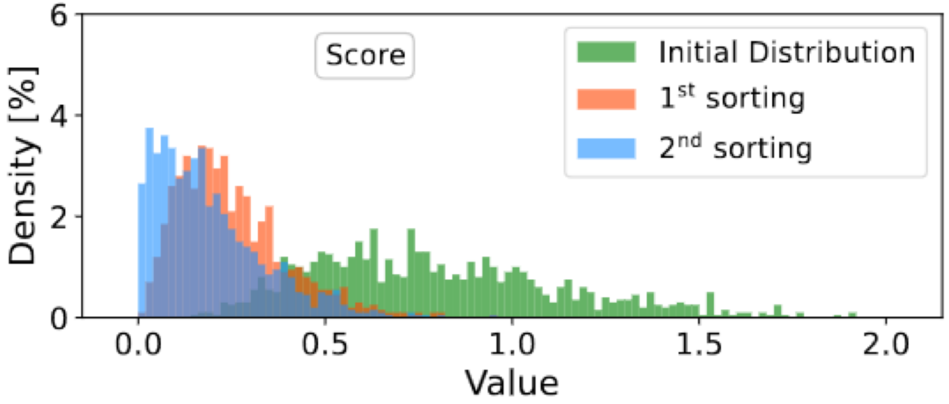
How robust is the current baseline?

- **Recent LHC achievements**:
  - ✓ **348 bunches of 2.3 10^{11} protons injected in the LHC**,
  - ✓ **full cycle (with collisions) for one train with 1.8 10^{11} protons** with 8σ long-range separation (beyond the requirements of HL-LHC) –even smaller separation achievable with wire compensation (see ***X. Buffat***, *WP2/5/7/10 session, Wed. 9/10 3pm*, and ***Long-range beam-beam wire compensation review*** *on Oct. 14-15th at CERN*)

- Still, a number of LHC observations require more studies:
  - **Hierarchy breakage** at the end of squeeze (see ***E. Maclean***, *WP2/5/7 session, Tu. 8/10 5:40 pm*, and ***C. E. Montanari***, *WP2/5/7/10 session, Wed. 9/10 2:40 pm*)
  - Unexplained **blow-up** (injection, ramp) – see ***S. Kostoglou***, *WP2/5/7 session, Tu. 8/10, 4 pm.*
  - Losses at injection (see ***S. Morales Vigo***, *WP13 session, Wed. 9/10 9:30am*)
  - Increased IBS for BCMS, and losses at start of ramp (see ***B. E. Karlsen-Bæck***, *WP2/WP4 session, Th. 10/10 9:10 am*)

How robust is the current baseline?

- **Magnets field quality**
  - **Voltage spikes** on MQXFAs**:** not too worrying (not occurring at steady nominal current), but field measurements ongoing at CERN (see ***G. Ambrosio*** *et al*, *WP2/WP3 meeting, 24/04/2024*, and ***J. Dilly***, *WP2/3 session, Wed. 9/10 10 am*)
  - Impact of **D2 multipole errors**:
    - b2 not problematic, a2 can be corrected but needs to be more studied (***J. Dilly***, *WP2/3 session, Wed. 9/10 10 am*),
    - **Dynamic aperture (DA) from b3 in D2 is ok** (***T. Pugnat***, *230th WP2 meeting, 03/09/2024*)
  - **MQXF sorting:** promising results on **beta-beating:**

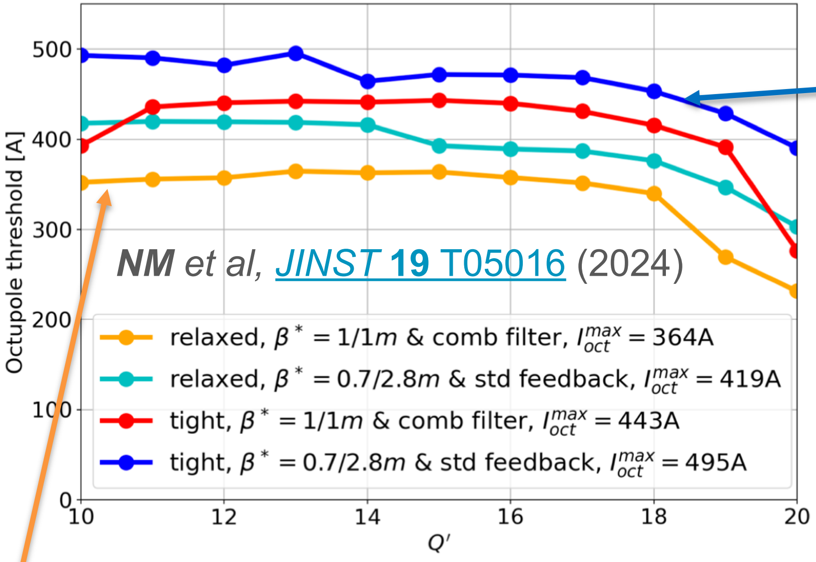


T. Pugnat, *WP2/WP3 meeting*, *30/04/2024, and THPC16, IPAC'24*
A. Wegscheider, *222nd WP2 meeting, 21/11/2023*
M. Giovannozzi,*WP2/3 session, Wed. 9/10, 9:30 am*

⟹ **Good progress with field quality** (more studies needed)**.**

Transverse impedance & stability (1/2)

- In general, **transverse stability is less critical** than past predictions, as **LIU beams** were observed to have **tails** (past predictions considered no tails) and **tails are beneficial for stability**.
- On the other hand, the fundamental mode of the crab cavity became a concern → a **comb filter** is required to mitigate it
- **Tight collimator** settings are also still on the table → **impedance increase**
- **Stability limits revised**: octupole threshold vs Q' (positive octupole polarity)



Tight collimator settings, no comb filter for crab cavities but **flat optics**

Baseline: **relaxed** collimator settings, **comb filter** for crab cavities

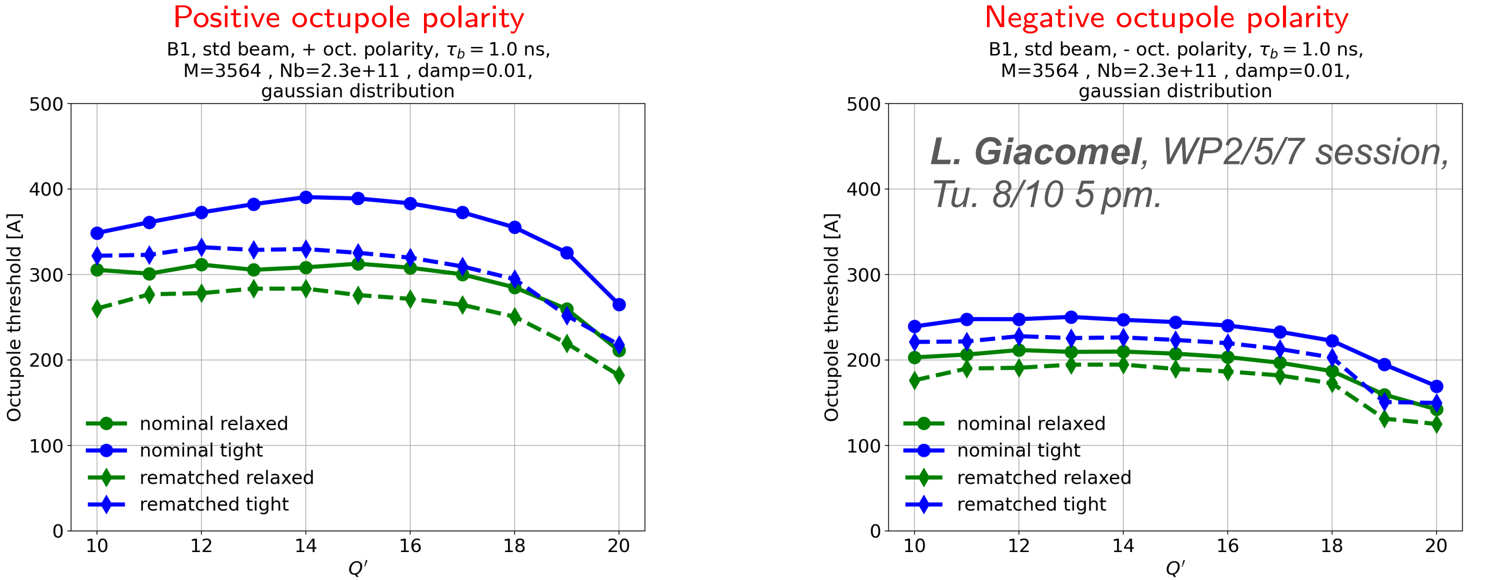
⟹ **Limit depends on CC and its mitigation**

In case comb filter has issues**, flat optics** is an efficient backup mitigation.

See ***L. Giacomel*** et al, [JINST 19 P05046](#) (2024) as well as *WP2/5/7 session, Tu. 8/10 5 pm,* and *WP2/4 session, Th. 10/10 9:50 am*

Transverse impedance & stability (2/2)

- **Negative octupole polarity can help** (particularly true with tails) → **tested** in MD
- **Collimator impedance** can be further optimised with **rematched optics** (IR7 + IR3 with the option to relax IR3 settings instead of rematching IR3)

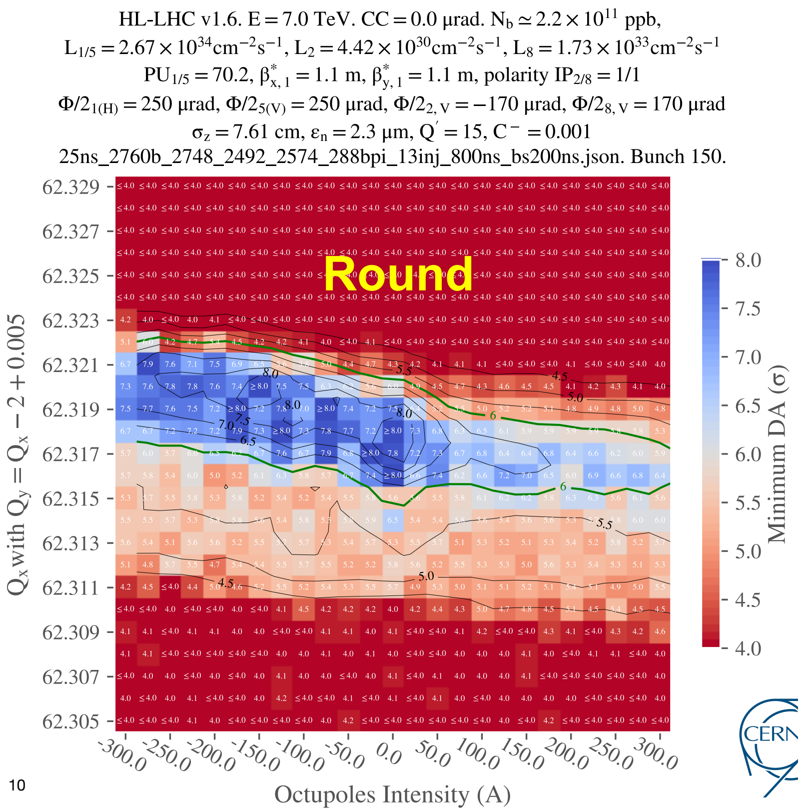


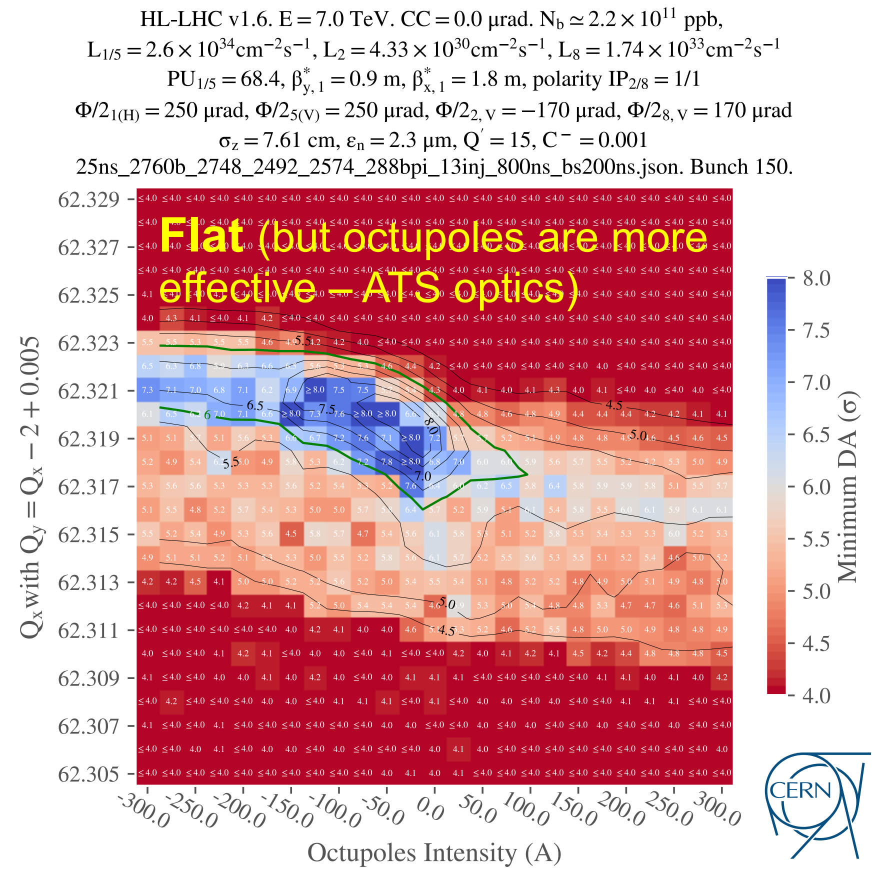
→ **IR3 & IR7 optics validated in MD** (see ***R. De Maria*** *and* ***B. Lindström***, *LSWG*, *02/07/2024*, and *WP2/5/7 session, Tu. 8/10, 4:20 & 4:40 pm*)

- Another potential reduction: **"sweet spot" found in MD, around Q'=20** (see ***X. Buffat***, *WP2/5/7/10 session, Wed. 9/10 3pm*)

DA potential bottlenecks (1/2)

- **End of collapse**, scanning octupole current:





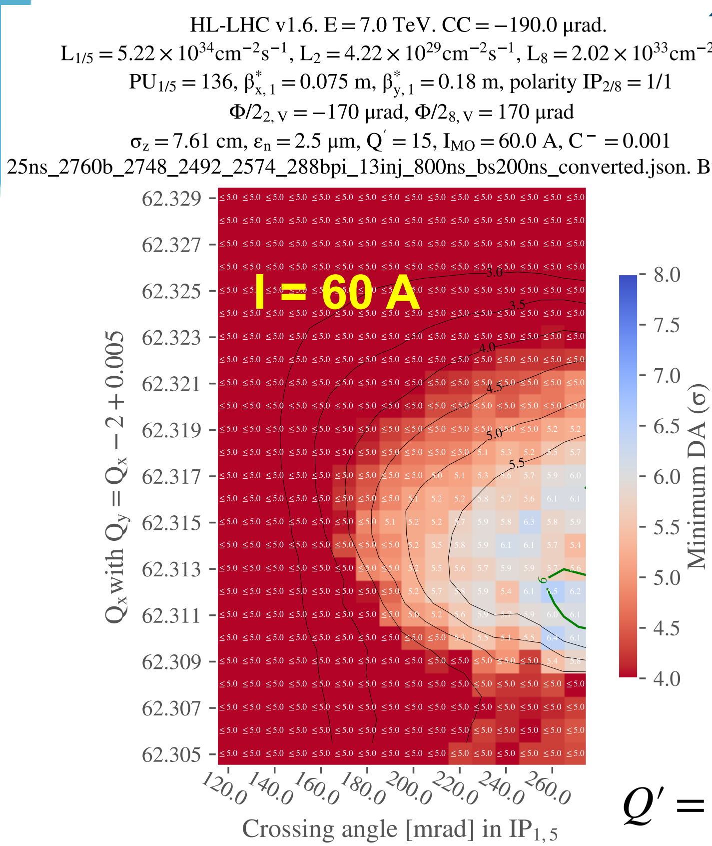
⟹ **DA remains tight** for octupoles >300 A (needed for stability).

⟹ but **negative octupole polarity** can help.

***C. Droin** et al, THPC77, IPAC'24, and **C. Droin, S. Kostoglou & G. Sterbini**, WP2/5/7/10 session, Wed. 9/10 2pm*

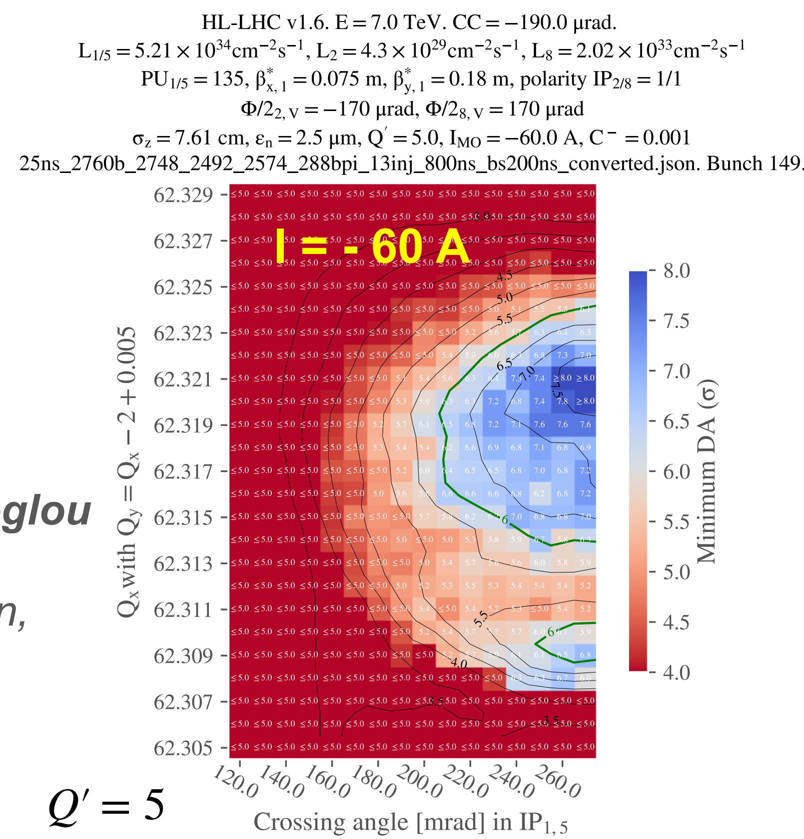
DA potential bottlenecks (2/2)

- **End of levelling**, scanning crossing angle (**flat optics** with β*=7.5/18 cm)



$Q' = 15$

C. Droin, S. Kostoglou & G. Sterbini,
WP2/5/7/10 session, Wed. 9/10 2pm



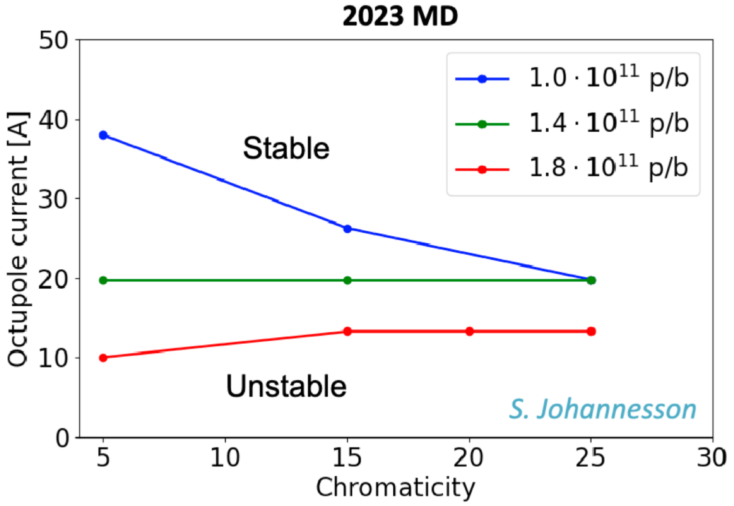
$Q' = 5$

⟹ With **low Q' and negative octupoles**, one could reduce further the crossing-angle. **Q'=6 is already operational** in the LHC during levelling.

e-cloud: LHC news

- **E-cloud situation degraded during LS1/LS2**, leading to **increased heat load.**
- **Cryo capacity estimates in several sectors have been lowered** (operation in S78 more limited than estimated in heaters measurements)
  ⟶ moved to **3x36 bunches** per train (2350 bunches with ~1.6 x 10^{11} p+/b).

- Still, some good news:
  - stability improvement with high bunch intensity
    → **lower Q' / octupole** at injection for HL intensity.
  - **Conditioning observed in 2024**
    → we may be able to **increase the number of bunches.**



- **Negative octupole polarity** remains to be tested at injection in the LHC.

L. Mether, HiLumi special joint WP2/WP3 Meeting, *23/01/2024*, and *WP2/5/7/10 session, Wed. 9/10 3:20 pm*

e-cloud: filling scheme mitigation

- The e-cloud situation in run 4 remains **largely unknown** (degradation in LS3).
- Filing schemes containing **8b+4e trains** (“**hybrid**”) are an effective means to reduce e-cloud:
  - absolutely necessary without beam screen treatment (BST)
  - could be necessary with BST if **significant further degradation occurs in sectors with little margin**

→ **depending on the situation, various options are envisaged**, with different impact on luminosity:

Scenario	Beam	N bunches	8b+4e	BST	LS3 degradation	Int. lumi/day [fb^{-1}]	
Baseline	4x72b	2760	-	Yes	No	3.4	ref
Degraded S56	Hybrid	2590	17%	Yes	~40%	3.2	-6%
Degraded S45	Hybrid	2460	32%	Yes	~70%	3	-12%
No BST	Hybrid	~~2320~~	~~47%~~	No	No	~~2.8~~	~~-18%~~
No BST	Hybrid	~~2470~~	~~30%~~	No	No	~~3~~	~~-12%~~
No BST	Hybrid	2260	54%	No	No	2.7	-21%
Worst case	8b+4e	1972	100%	No/Yes	Yes	2.4	-30%

Rough luminosity estimates with LPC calculator, assuming μ=130, n_b=2.3 x 10^{11} p, L_{lev}= < 5e-34 cm^{-2} s^{-1}

LS2 degradation of S78 was ~80%

With reduced cryo capacities

See also ***L. Mether***, *WP2/5/7/10 session, Wed. 9/10 3:20 pm*.

L. Mether, *228th WP2 meeting, 02/07/2024*

Aperture

Crossing:
V IP1 / H IP5

- **Aperture** updates with round and flat optics:

	TDR Round	New Round	Flat CC HV	Flat CC HV	Flat CC VH	Flat CC VH
β* Xing/Sep [cm]	15/15	15/15	18/9	18/7.5	18/7.5	18/8
Xing angle [μrad]	±295	±250	±240	±240	±240	±240
Crossing plane IP5	V (or H)	V (or H)	V	V	H	H
Aperture in Pt. 5	12.5	13.1	13.7	12.6	12.4	12.8
MKD-TCT [°] IP5 [B1/B2]	30/31	30/31	40/45	51/54	27/25	27/25
H Ap. Protected Ti./Re.	11.9/12.9	11.9/12.9	13.3/14.3	14.1/15.1	11.7/12.7	11.7/12.7
Ap. Margin [σ], Tight	0.6	1.2	0.4	-1.5	0.7	1.1
Ap. Margin [σ], Relaxed	-0.4	0.2	-0.6	-2.5	-0.3	0.1

TCT-TCDQ retraction (thus protected ap.) closely linked to MKD-TCT phase advance

R. De Maria

Round and flat (VH) are similar for aperture

- The choice of the **flat VH optics** implies **inverting the crab cavities**. Such an inversion was always assumed to be possible, even after LS3, but should be decided sufficiently well in advance.

Performance estimates for various options

Baseline (fb^{-1})	Round hybrid (2440 coll.)	Round BCMS	Flat 8/18 cm	Vbaseline extended ions	Round hybrid extended ions	Round BCMS extended ions	Flat 8/18 cm extended ions
2478.5	-10.55%	0.77%	3.28%	-8.85%	-18.45%	-8.13%	-5.79%

- In addition, if the **crossing angle is reduced** one would gain 1.6% with round optics (220 μrad), or 1% with flat optics (210 μrad).

S. Kostoglou, *228th WP2 meeting*, *02/07/2024*, and *WP2/5/7 session, Tu. 8/10 4 pm this meeting*

- Summary of the luminosity options:
  - **Slight increase** with **BCMS (+1% in IP1 & 5)**
  - **+3%** with **flat optics** (**+4%** with **reduced crossing angle**)
  - **-9%** with **ions beyond run 4**
  - **-6 to -12%** with **hybrid scheme**

Conclusions

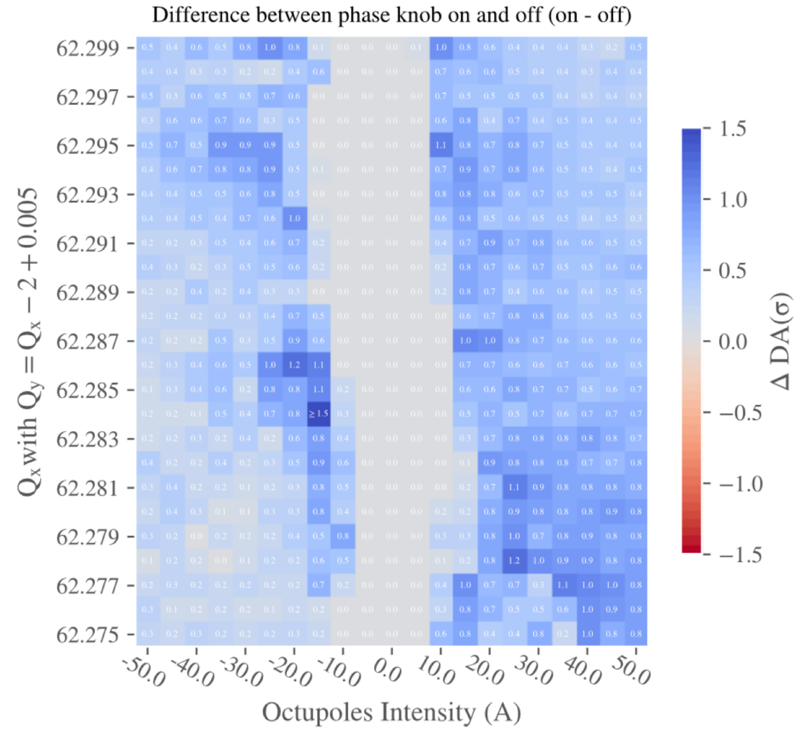
- **Current baseline** is **robust** in terms of stability, magnets field quality (studies on-going), aperture, and to some extent DA.
- Large unknowns remain regarding the **e-cloud issue**, with a possible impact on the filling scheme.
- A few **open questions** should be studied, including the comb filter for the crab cavities (to be tested), and the blow up at injection and ramp.
- Optimisations can be done:
  - for **stability and DA risk mitigation**:
    - rematched optics and/or IR3 collimator optimisation,
    - flat optics for crab cavity impedance,
    - negative octupoles & low chromaticity,
  - for **luminosity improvement (in IP1 and 5)**:
    - Flat VH optics,
    - BCMS beam,
    - crossing angle reduction.

Backup

Dynamic Aperture: various investigations

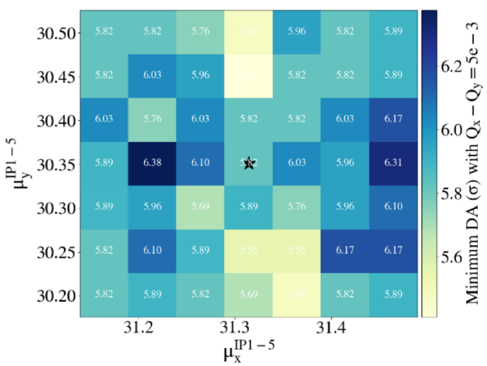
- Injection: **phase knob octupole compensation** (DA difference vs. oct.)

  C. Droin, 223rd WP2 meeting, 28/11/2023



- **Optimisation vs. phase advance** (start of levelling)

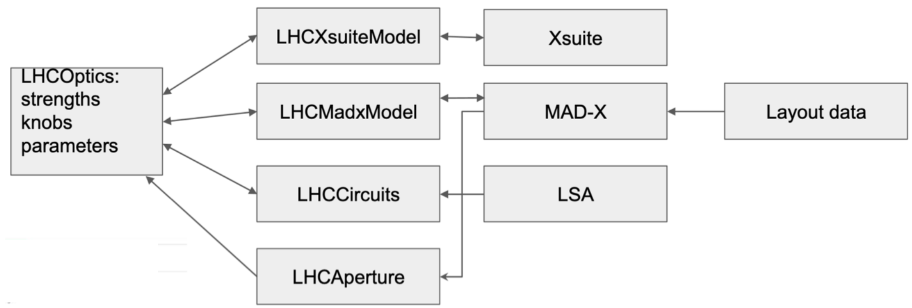
R. De Maria et al, *THBP21, HB'23*



- Single-particle DA with **flat optics and magnet errors** (*T. Pugnat, 220th WP2 meeting, 17/11/2023*) – marginally worse with flat, correction performance to investigate.
- **Impact of new IR3/IR7 optics** (see below) – DA minimally affected (***C. Droin***, WP2/WP3 meeting, *23/01/2024*).
- Assessing DA reproducibility (Xsuite) / exploring alternatives to min DA.
- **Beam-beam wire compensation: review** to take place on Oct. 14-15 (CERN), paper by **C. E. Montanari**, "Measurement of the nonlinear diffusion of the proton beam halo at the CERN LHC", under review

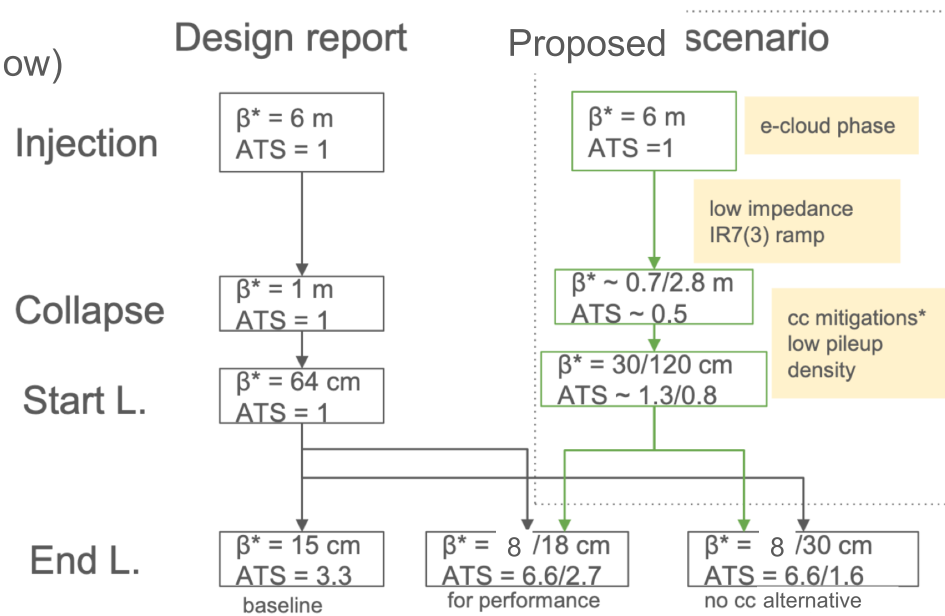
Optics and layout

- **New optics/layout version** (v1.8) – ***R. De Maria & Y. Angelis***, 227th WP2 meeting, *28/05/2024.*
  - PPS2 added
  - first layout using only layout database data
  - layout approval in ~September.



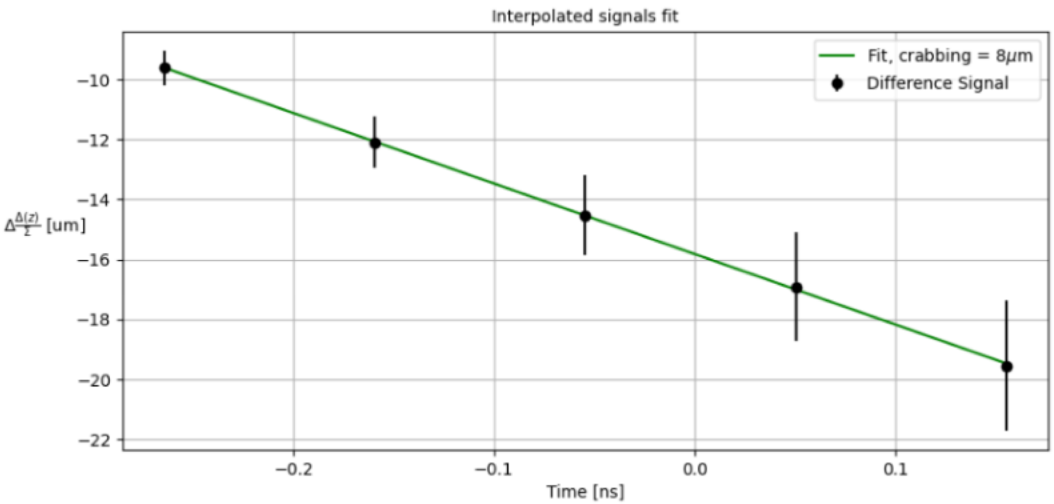
- **IR3/7 new optics** – ***B. Lindström*** (see next talk)
  - **tested in MDs**
  - promising impedance mitigation (see below)

- **New cycle proposal**:



Crabbing measurements & commissioning

- MDs in the LHC (2024) with **residual crabbing** from head-on beam-beam (inj.):



⟹ LHC residual crabbing **measurable** & conform to expectations

A. Fornara, LSWG, *02/07/2024*

- **Commissioning** and **conditioning** plans reviewed (***R. De Maria / R. Calaga (WP4) / D. Wollmann (WP7)***, WP2/WP4/WP7 joint meeting, *25/06/2024*):
  - Conditioning during hardware commissioning, continuing in operation
  - Proposal: first year with 1 MV, counter phased.
  - Impedance & noise measurements almost parasitically obtained
  - MD (or beam commissioning) tests to check full RF-ON sequence + CC-specific machine protection tests foreseen: interlocks, switch off cavities on one IP side, etc.

Update of performance estimates

- Baseline assumptions
  - intensity ramp-up included
  - **physics days** (***M. Zerlauth*** et al, EDMS 2902691, in preparation):

Run	Year	Efficiency	Bunch intensity (1e11 ppb)	β_x^* (cm)	β_y^* (cm)	CC	PU_{max}	Days Intensity ramp-up	Days Proton physics [1]	# colliding IP1/5 bunches [2]	# colliding IP8 bunches	Emit start of SB (μm)	IP1/5 crossing plane	IP1/5 φ/2 (μrad)	LHCb L_{peak} (1e33 Hz/cm²) [3]
4	2029	0.5	1.8	30	30	off	101	20	6	2748	2574	2.5	H/V	250	2
	2030	0.5	2.2	25	25	on	132	15	136	2748	2574	2.5	H/V	250	2
	2031	0.5	2.2	20	20	on	132	10	154	2748	2574	2.5	H/V	250	2
	2032	0.5	2.2	20	20	on	132	10	152	2748	2574	2.5	H/V	250	2
5	2035	0.5	2.2	15	15	on	132	15	152	2748	2574	2.5	H/V	250	2
	2036	0.5	2.2	15	15	on	132	10	195	2748	2574	2.5	H/V	250	2
	2037	0.5	2.2	15	15	on	132	10	198	2748	2574	2.5	H/V	250	2
	2038	0.5	2.2	15	15	on	132	10	198	2748	2574	2.5	H/V	250	2
6	2040	0.5	2.2	15	15	on	132	15	165	2748	2574	2.5	H/V	250	2
	2041	0.5	2.2	15	15	on	132	10	203	2748	2574	2.5	H/V	250	2

Extended ions after run 4
⟶ 22-24 less days

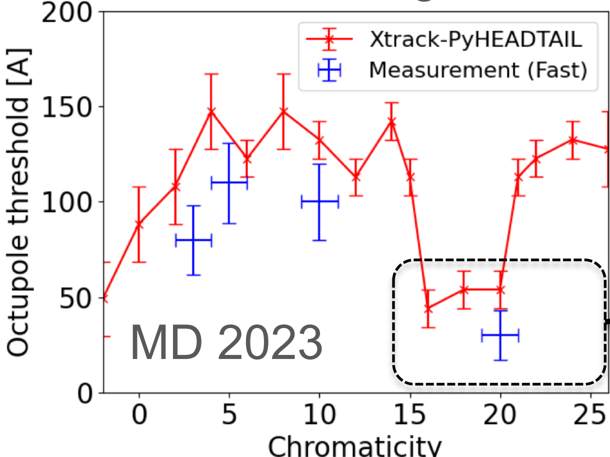
Hybrid: 2440 / 2240
BCMS: 2736 / 2370

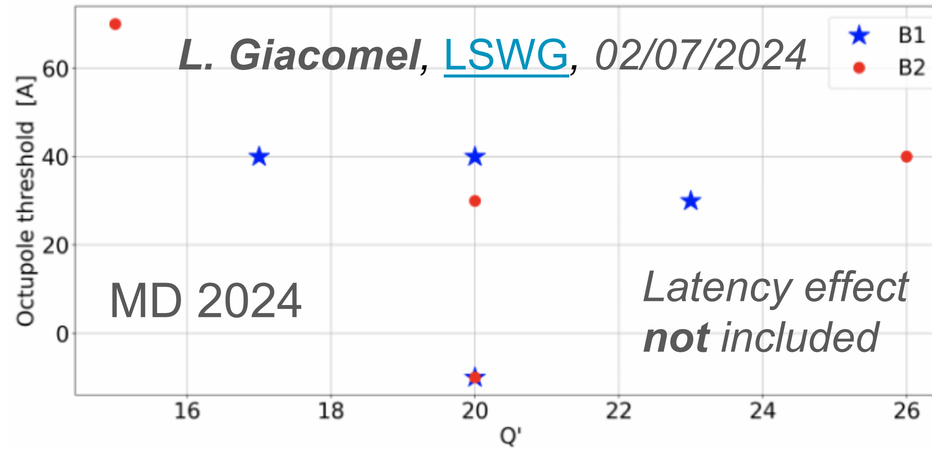
BCMS: 2.2

S. Kostoglou, *228th WP2 meeting*, *02/07/2024*

Transverse impedance & stability

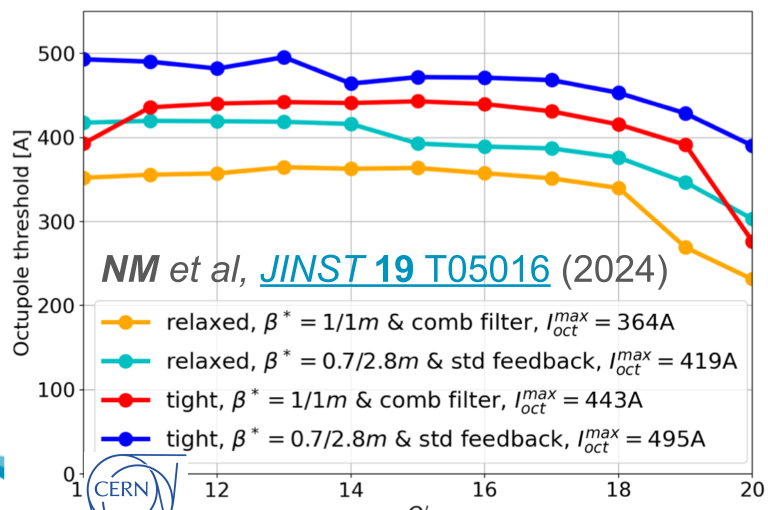
- **LHC MDs on octupole threshold:** potential large improvement at very high Q' from non-linear longitudinal motion





X. Buffat, 2024 LHC Chamonix workshop, *31/01/2024,* and this meeting

- **Stability limits revised**: octupole threshold vs Q'



Assumptions: Gaussian transverse **tails**, positive octupole polarity, latency effect included

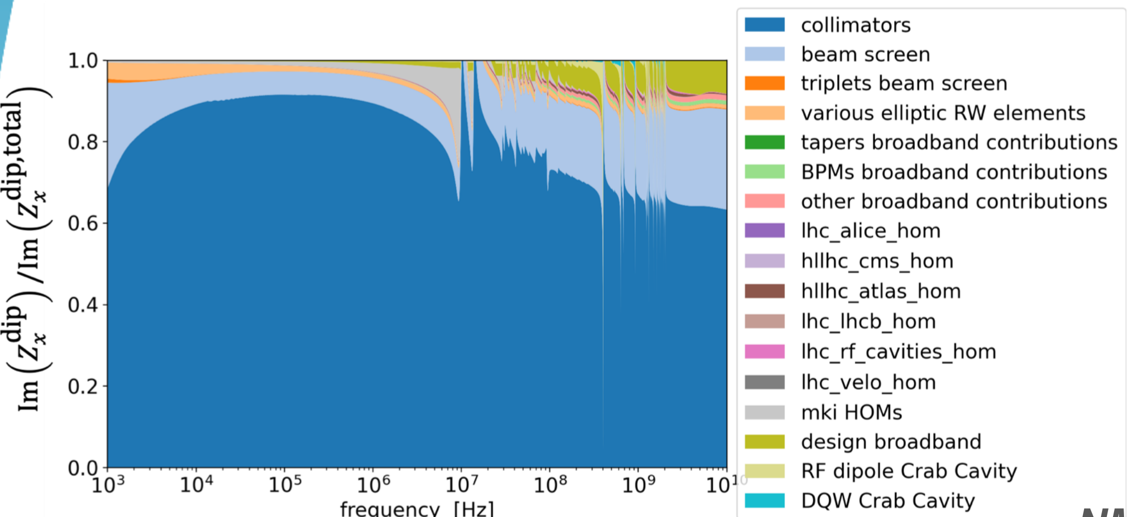
$\Longrightarrow$ **Limit depends on CC and its mitigation** (flat optics, comb filter)

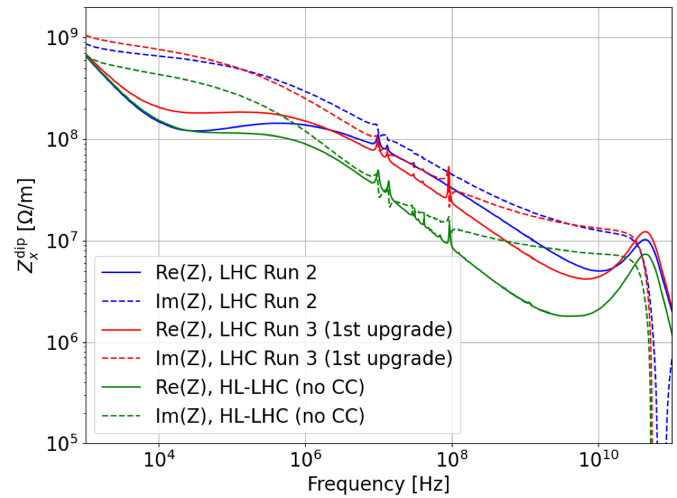
$\Longrightarrow$ A few factors might help and are studied: **new optics + non-linear RF**

See also ***L. Giacomel***, this meeting

Transverse impedance & stability

- **Collimators** dominate transverse impedance ⟹ coll. upgrade beneficial:



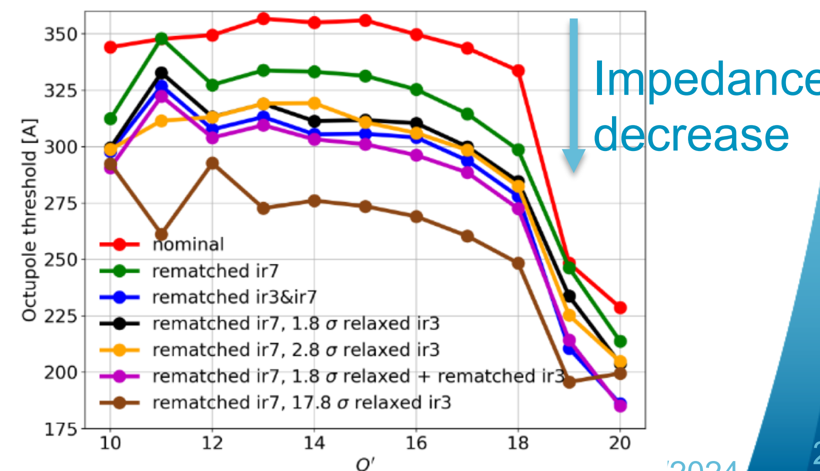


***NM** et al, [JINST **19** T05016]* (2024)

- **New optics for IR7** (see ***B. Lindström***, next talk), and in **IR3,** would decrease even further the impedance:

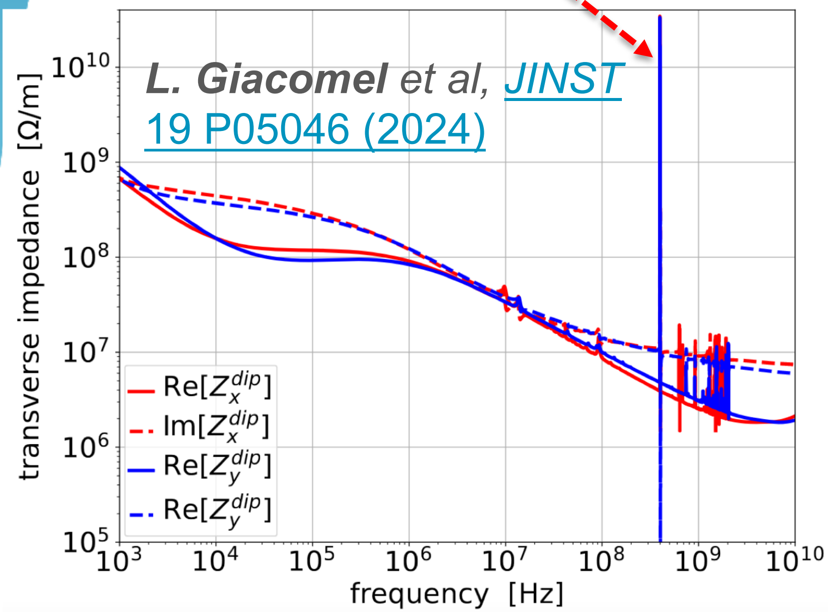
  ⟹ IR3 & IR7 optics validated in MD (see R. De Maria and B. Lindström, [LSWG], 02/07/2024)

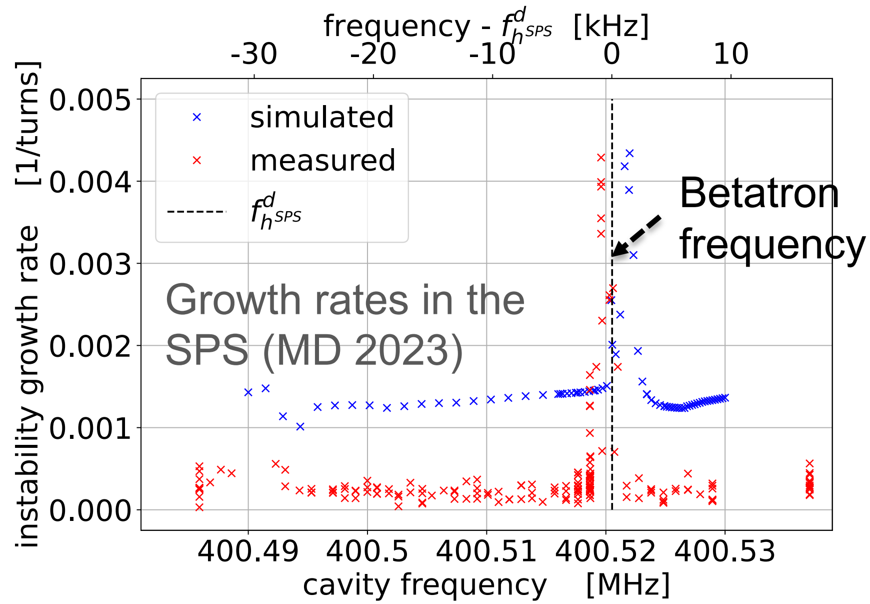
***L. Giacomel**, [224th WP2 meeting], 11/12/2023*
***L. Giacomel / B. Lindström**, [WP2/WP5 meeting], 27/02/2024; this meeting*



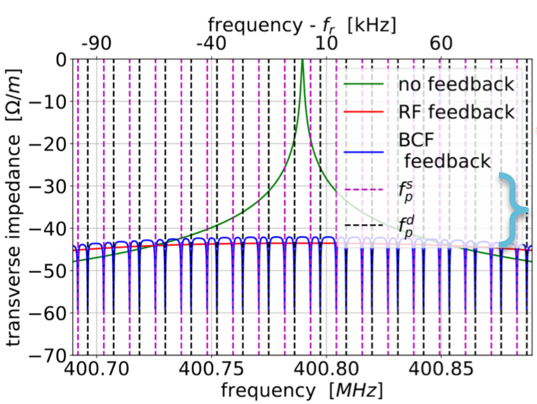
Crab cavities (with WP4) – impedance

- Fundamental mode has a strong effect on transverse impedance:





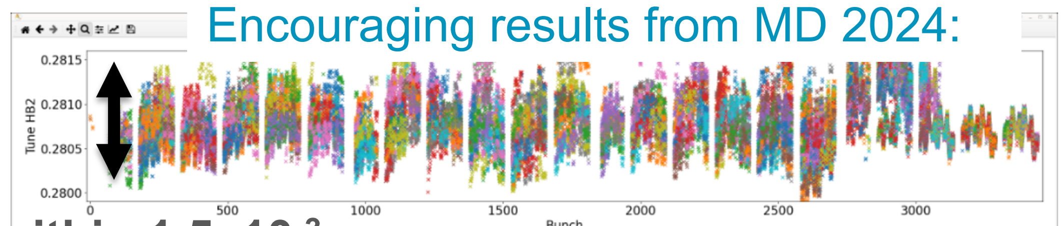
- Mitigations: **RF feedbacks** (std, **betatron comb filter**), **optics** (flat)



Lowering impedance at betatron frequencies

Tune acceptance (~5 10^{-3}) can be an issue.
⟶ Need to check multibunch tune shifts.

Encouraging results from MD 2024:



within 1.5x10^{-3}

L. Giacomel, *LSWG, 02/07/2024*

Reports, publications and proceedings

- M. Carlà, F. Carlier, R. Calaga, R. Tomás, S. Kostoglou, H. Bartosik, *Status of the Beam-based Measurement of the Skew-sextupolar Component of the Radio Frequency Field of a HL-LHC-type Crab-Cavity*, IPAC'23, MOPL001, https://doi.org/10.18429/jacow-ipac2023-mopl001.
- R. De Maria, R. Bruce, X. Buffat, G. Iadarola, S. Kostoglou, M. Giovannozzi, B. Lindström, L. Mether, E. Métral, N. Mounet, S. Redaelli, G. Sterbini, R. Tomás, *High Luminosity LHC Optics Scenarios for Run 4*, IPAC'23, MOPL034, https://doi.org/10.18429/jacow-ipac2023-mopl034.
- S. Kostoglou, H. Bartosik, R. De Maria, G. Iadarola, G. Sterbini, R. Tomás, *Dynamic aperture studies for the first run of High Luminosity LHC*, IPAC'23, WEPL102, https://doi.org/10.18429/jacow-ipac2023-wepl102.
- G. Sterbini, A. Bertarelli, Y. Papaphilippou, A. Poyet, A. Rossi, P. Bélanger, *Potential and Constraints of a Beam-Beam Wire Compensator in the HL-LHC Era*, IPAC'23, WEPL103, https://doi.org/10.18429/jacow-ipac2023-wepl103.
- A. Fornara, G. Sterbini, R. Appleby, Impact of Crab Cavity RF noise on the transverse beam profiles in the HL-LHC, IPAC'23, WEPL119, https://doi.org/10.18429/jacow-ipac2023-wepl119.
- C. Accettura, N. Biancacci, R. Bruce, F. Carra, N. Mounet, A. Kurtulus, F.-X. Nuiry, A. Perillo Marcone, S. Redaelli, Overview of Material Choices for HL-LHC Collimators, IPAC'23, WEPA148, https://doi.org/10.18429/jacow-ipac2023-wepa148.
- C.E. Montanari, A. Bazzani, M. Giovannozzi, A. Poyet, G. Sterbini, *Modelling the Experimental Data for Long-Range Beam-Beam Wire Compensators at the CERN LHC with Diffusive Models*, IPAC'23, WEPA021, https://doi.org/10.18429/jacow-ipac2023-wepa021.
- C.E. Montanari, A. Bazzani, M. Giovannozzi, P. Hermes, S. Redaelli, *Recent Measurements and Analyses of the Beam-Halo Dynamics at the CERN LHC using Collimator Scans*, IPAC'23, WEPA022, https://doi.org/10.18429/jacow-ipac2023-wepa022.
- B. Lindström, R. Bruce, X. Buffat, R. De Maria, L. Giacomel, P.D. Hermes, D. Mirarchi, N. Mounet, T.H.B. Persson, S. Redaelli, R. Tomás García, F.F. Van der Veken, A. Wegscheider, *Mitigating Collimation Impedance and Improving Halo Cleaning with New Optics and Settings Strategy of the HL-LHC Betatron Collimation System*, HB'23, TUC4C2, https://doi.org/10.18429/JACoW-HB2023-TUC4C2.

Reports, publications and proceedings

- R. De Maria, Y. Angelis, C.N. Droin, S. Kostoglou, F. Plassard, G. Sterbini, R. Tomás, *Increasing High Luminosity LHC Dynamic Aperture Using Optics Optimizations*, HB'23, THBP21, https://doi.org/10.18429/JACoW-HB2023-THBP21.
- L. Giacomel, P. Baudrenghien, R. Calaga, X. Buffat, N. Mounet, *Mitigation strategies for the instabilities induced by the fundamental mode of the HL-LHC Crab Cavities*, 2024 JINST 19 P05046, https://iopscience.iop.org/article/10.1088/1748-0221/19/05/P05046/pdf.
- N. Mounet at al, *High intensity beam dynamics assessment and challenges for HL-LHC*, 2024 JINST 19 T05016, http://dx.doi.org/10.1088/1748-0221/19/05/T05016.
- T. Pugnat, A. Wegscheider, E. Todesco, M. Giovannozzi, R. Tomás, *Sorting strategies for the new superconducting magnets for the CERN HL-LHC*, IPAC'24,THPC16, https://www.jacow.org/ipac2024/doi/jacow-ipac2024-thpc16/index.html.
- C. Droin, G. Sterbini, I. Efthymiopoulos, N. Mounet, R. De Maria, R. Tomás, S. Kostoglou, *Status of beam-beam studies for the high-luminosity LHC*, IPAC'24, THPC77, https://www.jacow.org/ipac2024/doi/jacow-ipac2024-thpc77/index.html.
- L. Giacomel, B. Lindstrom, G. Iadarola, G. Rumolo, N. Mounet, R. Bruce, X. Buffat, *Assessment of the real part of the impedance of the LHC collimators with instability growth rate measurements*, IPAC'24, THPC57, https://www.jacow.org/ipac2024/doi/jacow-ipac2024-thpc57/index.html.
- A. Fornara, G. Trad, G. Sterbini, H. Bartosik, N. Triantafyllou, P. Baudrenghien, R. Calaga, S. Kostoglou, T. Levens, X. Buffat, R. Appleby, Emittance growth studies due to Crab Cavity induced amplitude noise in the SPS, IPAC'24, THPC63, https://www.jacow.org/ipac2024/doi/jacow-ipac2024-thpc63/index.html.
- L. Mether, G. Iadarola, G. Rumolo, K. Paraschou, L. Sabato, S. Johannesson, *The electron cloud and its impact on LHC and future colliders*, IPAC'24, WEZD2, https://www.jacow.org/ipac2024/doi/jacow-ipac2024-wezd2/index.html.
- K. Paraschou, G. Iadarola, L. Mether, *Simulations of incoherent effects driven by electron clouds forming in the inner triplets of the Large Hadron Collider*, IPAC'24, WEPR57, https://www.jacow.org/ipac2024/doi/jacow-ipac2024-wepr57/index.html.
- …