Run III Layout and Performance for Protons

A.Mereghetti, on behalf of the LHC Collimation Team

2018 HL-LHC Annual Meeting – CERN (CH) – 15-18 Oct 2018

Outline

- Recap of Run III Layout:
  - TCSPM design and 2017 measurements with beam
  - Removal of MQWA.E5[L,R]7 and installation of shielding
  - TCLDs and load on downstream cold elements
- Expected performance in Run III:
  - Possible Run III optics
  - Outlook to HL-LHC v1p4
- Conclusions

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Overview of the Upgrade of the LHC Collimation System

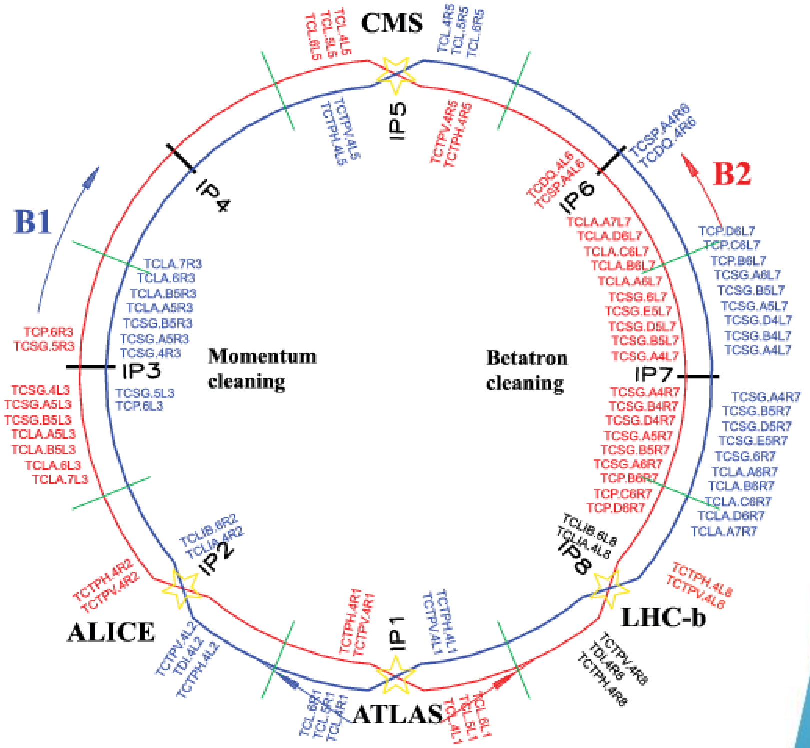
- Partial HL-LHC Upgrade* (during LS2):
  - Exchange of 2 IR7 TCPs (60cm): from CFC to MoGr;
  - Addition/Exchange of 4 IR7 TCSs (1m): from CFC to Mo-coated MoGr;
  - A single module MBH(11T)+TCLD+MBH(11T) in IR7 (p+ions) and a single TCLD in IR2 (ions only);
  - Exchange MQWA.E5[L,R]7 with shielding (reduce dose to MQW coils and spacers);

- Run III

- Full HL-LHC Upgrade* (during LS3):
  - Exchange remaining TCSGs (7);
  - IR1/IR5 TCTPs (1m):
    - Cell 4: from Inermet180 to CuCD (4);
    - Cell 6: TCTPHs in CuCD (2) + re-use TCTPVs in Inermet180 (2);
  - New TCLs (6);

New design of TCTPH.4 and TCL.4, with two beams in same tank!

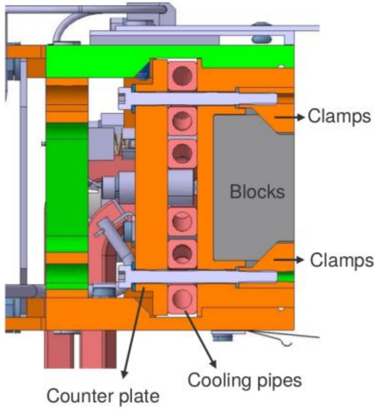
* Units are given ***per beam***.



A good fraction of the HL-LHC collimation hardware already available in Run-III, for gaining experience with LIU Beams!

Recap of TCSPM Design

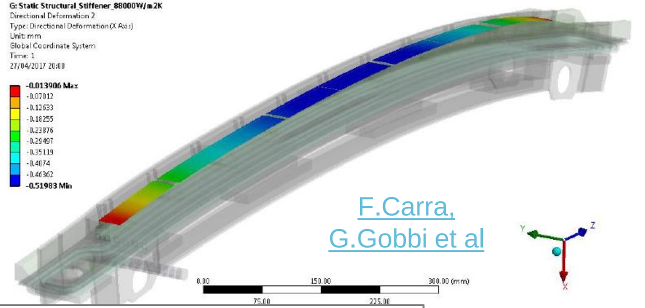
- TCSPM: new design of TCS collimators:
  - addition of in-jaw BPM monitors
  - "metallic" jaw, i.e. lower impedance
  - MoGr jaws should stand the same BLT minima as for the nominal LHC:
    - 1MW in case of 0.2h beam life time over 1-10s (Nominal LHC: 500kW);
    - 200kW in case of 1h beam life time in steady state (Nominal LHC: 100kW);
  - Mo-coated jaws: reduce impact on machine impedance budget (spare octupole current);



Courtesy of F. Carra

- TCSPM flatness not granted for 12m beam lifetime:
  - Estimation done looking at the most loaded secondary collimator in IR7 (i.e. immediately downstream of the TCPs);
  - Deformation computed linearly combining (pessimistic) thermal expansion, self-weight (V) and tolerances → check performance in simulations in presence of jaw deformations;
  - Gap at concerned collimator is not the smallest among all TCSs → 100μm specs may be taken not exactly strictly;

	1h beam lifetime			0.2h beam lifetime (DESIGN GOAL)		
	$TCSP_{CFC}$ (LHC)	$TCSPM_{CFC}$ (HL-LHC)	$TCSPM_{MoGr}$ (HL-LHC)	$TCSP_{CFC}$ (LHC)	$TCSPM_{CFC}$ (HL-LHC)	$TCSPM_{MoGr}$ (HL-LHC)
Stresses	OK	OK	OK	OK	OK	OK
Total sagitta	+83	-110	+76	+96	+300	+505

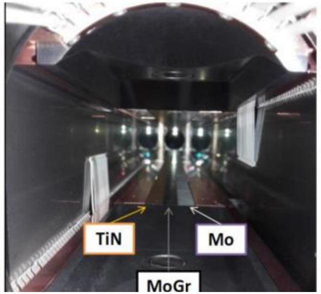


F.Carra, G.Gobbi et al

Staged implementation, avoiding the most loaded slot and giving further time to optimize eng. design

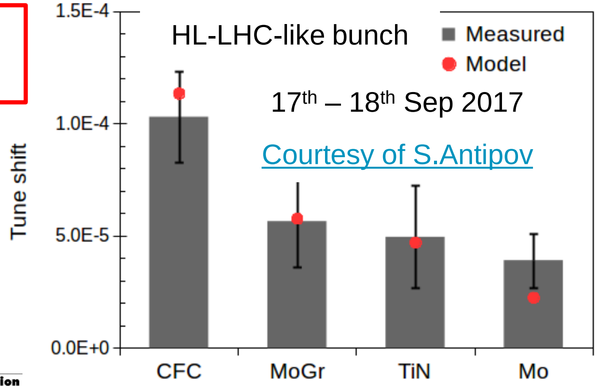
Validation of Design: Installation of TCSPM Prototype and measurements with beam

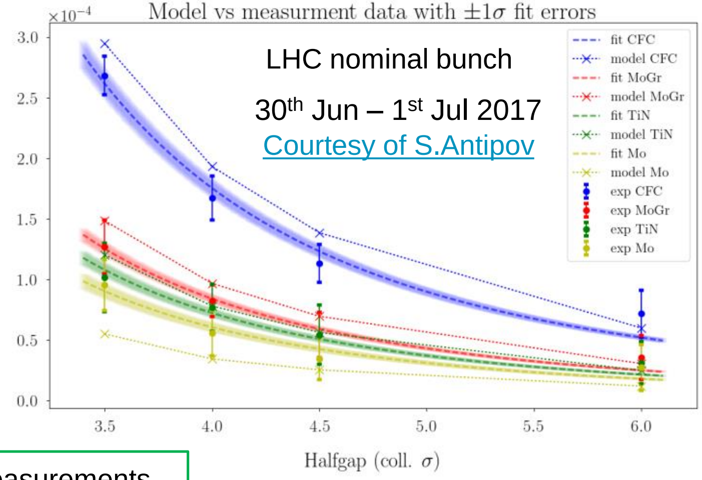
- During YETS 2016, a prototype of TCSPM was installed (LHC-TC-EC-0006) in slot D4R7.B2 (V TCSG) for tests with beam to finalise design:
  - Smallest beam σ among TCSGs → ideal for impedance measurements;
  - Presence of a regular TCS in CFC in same slot, for direct comparisons;
  - Three stripes of different materials, to assess effect of coating on impedance;
- Extensive MD campaign of tune-shift measurements in 2017, to benchmark expectations from impedance models;



…though measurements with Mo constantly x2 expectations

…possible explanation: surface roughness / non-regular column structure of Mo coating, with effects on impedance → ongoing investigations (G.Mazzacano, CERN, BE-ABP-HSC)

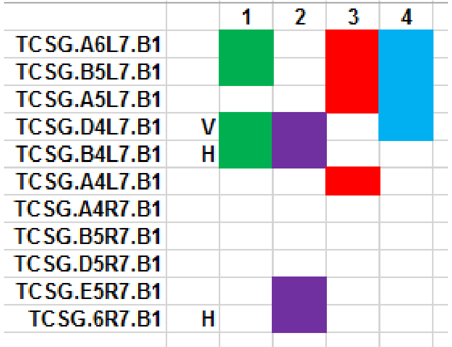




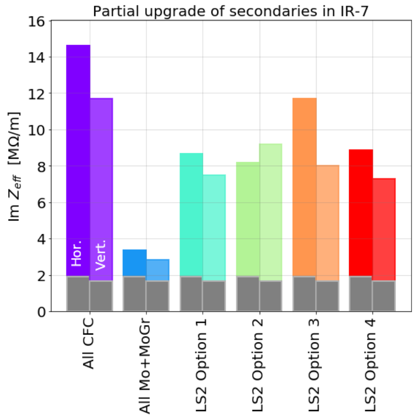
Challenging measurements, with sensitivity of $\Delta Q \sim 2\ 10^{-5}$!

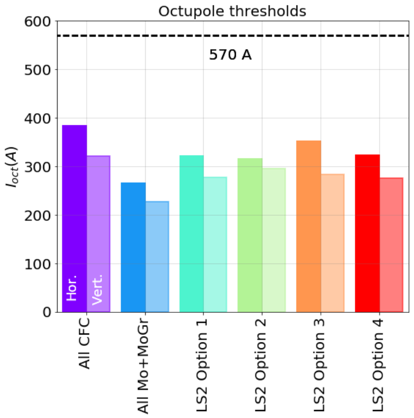
Installation Slots of TCSPMs

- Slots of installation of the 4 TCSPMs chosen among a pool of 4 possible ones (CERN-ACC-2017-0088, in preparation):
  1. Reduce impedance as much as possible – collimators with largest contribution on both H and V plane);
  2. Avoid first two skew collimators – most exposed to steady-state losses;
  3. Avoid H and V secondary collimators – ABD + inj. failures;
  4. Avoid H secondary collimators only – ABD;



Chosen one: option 2





Courtesy of S.Antipov

- 50% of the expected impedance reduction can be achieved exchanging only 4 collimators;
- Option 2 favored over the others since no TCSPM installed in most loaded location, giving time to further optimize design;
- Cleaning performance evaluated for each option, but no major differences found (A. Mereghetti, 2017 HL-LHC annual meeting);

Loading on coating layer still to be evaluated with detailed FLUKA simulations;

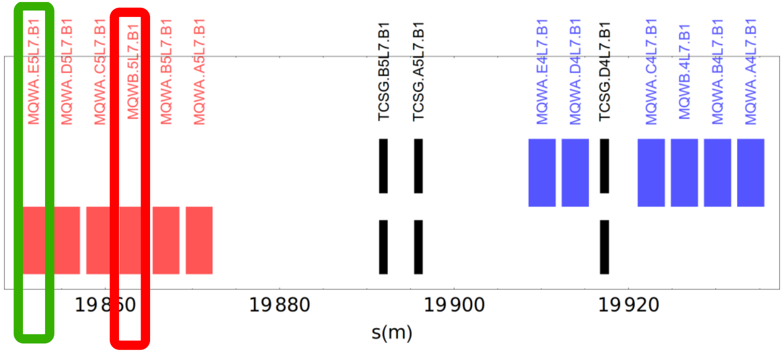
B1	B2	
TCSG.D4L7	TCSG.D4R7	*exchange*
TCSPM.B4L7	TCSPM.B4R7	*addition*
TCSPM.E5R7	TCSPM.E5L7	*addition*
TCSPM.6R7	TCSPM.6L7	*addition*

A.Mereghetti,

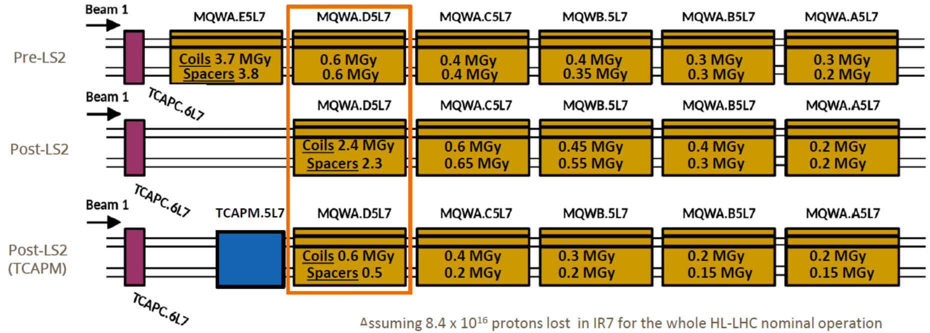
Removal of MQWA.E5[L,R]7 and Installation of Shielding

- Removal of MQWA.E5[L,R]7:
  - Module subject to highest load from IR7 losses (integrated dose);
  - Measurements and simulation campaign to estimate loads for present LHC and for HL-LHC (F.Cerutti and P.Fessia, HL-LHC TCC #14);
  - Proposal (P.Fessia et al): remove the module and propose solution to limit load on following module;
- New IR7 optics by R. Bruce (HSS Section Meeting, 12th Dec 2017):
  - MQWB.5 reconfigured as MQWA, in addition to MQWA module removal
  - Re-matching to arc optics;
  - Verification of cleaning performance (D. Mirarchi);
- Large simulation campaign (C.Bahamonde et al.), to propose shielding solutions – currently: tungsten masks at each magnet + iron shielding (2m);
- Final design presented by L. Gentini, ColUSM 31/08/2018;

Courtesy of R. Bruce, HSS section meeting (2017-12-06)



Total peak dose accumulated by the end of HL-LHC



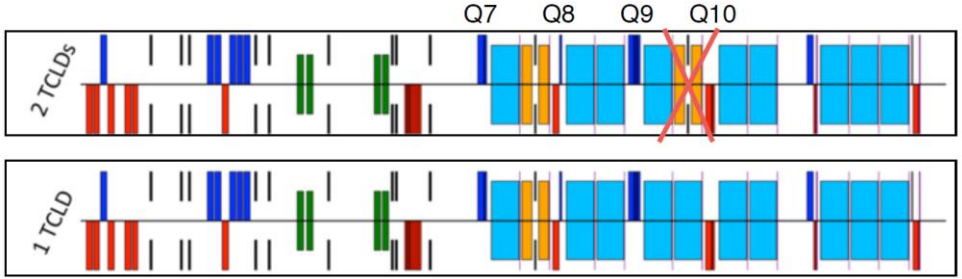
Assuming 8.4 x 10^{16} protons lost in IR7 for the whole HL-LHC nominal operation

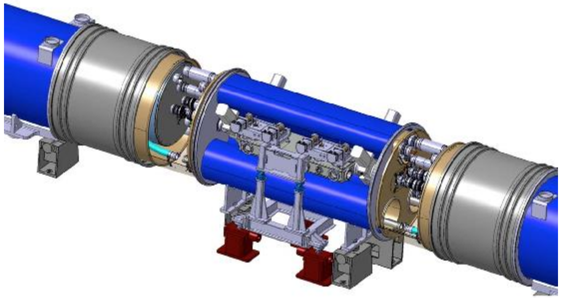
R. Garcia Alia, 7th HL-LHC Collaboration Meeting, 15/11/17

Courtesy of C. Bahamonde, ColUSM, 2018-06-01

TCLDs

- During LS2, it is planned to install a single module MBH(11T) + TCLD(Inermet180) + MBH(11T) in DS downstream of IR7 (protons / ions) per IR7 side:
  - Position currently considered: MB.B8x7 → Second unit (Q10) initially foreseen removed with 2016 re-baselining;
  - In IR2, only TCLD collimator in connection cryostat;





- Large simulation campaign (D.Mirarchi, P.D.Hermes, C.Bahamonde et al.), for optimizing position of TCLD package:
  - Cleaning performace (SixTrack);
  - Endep in magnets downstream of TCLD collimators (FLUKA):
    - Quench limit due to peak endep in SC coil;
    - Total endep in coils and cold bore tube (specific to 11T dipole);
    - Total power on cryogenics;

Input relevant for evaluations of cryogenics performance and adequacy to loss scenarios

TCLDs (II)

- Cryogenics experts have checked that thermal design of 11 T is sufficient – 1h BLT scenario is fine, and 0.2h BLT scenario can be tolerated only for short times;
- Limitations from the cryogenics system still need further investigations:
  - 1h BLT: cooling of cells 10 & 11 MB-dipoles could be critical with ions;
  - 0.2h BLT: adiabatic T-rise of 11-T-dipole coil (to be evaluated);

Intermediate 11T dipole specific summary for proposed beam-Lifetime scenarios (MBB.B8)

Continuous cooling <-> Blt 1h

	Peak power (mW/cm^3)	11T: coil + beam-pipe (W)	11T total (W)	comment
Protons	2	12	34	& (< 50 mW/cm^3 and < 41 W, total < 60 W)
Ions	4	21	66	& (< 50 mW/cm^3 and < 41 W total close to 60 W)

For the 1h Blt the 11T dipole thermal design is sufficient

Courtesy of R. van Weelderen, TCC meeting (2018-08-02)

Intermediate 11T dipole specific summary for proposed beam-Lifetime scenarios (MBB.B8)

Transient cooling <-> Blt 12min

	Peak power (mW/cm^3)	11T: coil + beam-pipe (W)	11T total (W)	10 s Energy (kJ)/(kJ/m)	comment
Protons	11	58	170	1.7/0.3	< 50 mW/cm^3 **coil > 40 W, total > 60 W**
Ions	21	105	330	3.3/0.6	< 50 mW/cm^3 **coil > 40 W, total > 60 W**

For the 12min Blt the 11T dipole thermal design is ok for peak power on coil - but overall temperature will drift during transient

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Expected Performance in Run III – 2017

- Expected performance of IR7 in Run III already presented in HL-LHC annual meeting in 2017:
  - Comparative assessment of IR7 cleaning inefficiency for the four possible post-LS2 configurations considered for installation;
  - IR7 settings: 2σ-retraction (i.e. TCPs@5.7σ, TCSGs@7.7σ);
  - Optics: v1p3:
    - β*=15cm, no TCLD installed → max η(s) at IR7 DS1;
    - β*=6m, TCLD installed + removal of MQWA.E5[R,L]7 → max η(s) at IR7 DS2;

Simulated Scenario	None $[10^{-6}]$	C–1 $[10^{-6}]$	C–2 $[10^{-6}]$	C–3 $[10^{-6}]$	C–4 $[10^{-6}]$	post–LS3 $[10^{-6}]$		
β^* =15 cm, B1H	6.19	5.77	6.38	6.11	5.73	6.23	6.07±4%	DS1
β^* =15 cm, B1V	5.33	5.12	5.17	5.32	5.07	5.34	5.23±2%	
β^* =6 m, B1H	2.47	2.41	2.45	2.34	2.35	2.25	2.38±3%	DS2
β^* =6 m, B1V	3.73	3.52	3.55	3.70	3.58	3.84	3.65±3%	

Very little impact on cleaning inefficiency from TCSPM installation layout for the same settings (as expected)

Expected Performance in Run III – 2018

- Present TCSPM installation foresees to actually replace only 1 TCSG (.D4[L,R]7) out of 4;
- The other 3 TCSPMs are added immediately downstream of respective TCSGs;
- It would be possible to run with TCSGs and installed TCSPMs at the same time or separately;

B1	B2	
TCSG.D4L7	TCSG.D4R7	*exchange*
TCSPM.B4L7	TCSPM.B4R7	*addition*
TCSPM.E5R7	TCSPM.E5L7	*addition*
TCSPM.6R7	TCSPM.6L7	*addition*

- Set of simulations aimed at assessing variations in cleaning performance if TCSPMs and/or TCSGs are used:
  - Studies focused on a first version of possible Run III optics, developed in the framework of the Run III Configuration WG;
  - Flat optics (50cm/15cm) considered – in MDs, found to be more challenging in terms of aperture margins;
  - 2018-like collimator settings (pushed performance) vs HL-LHC-like settings (more relaxed settings, especially on impedance);
  - CRDS beam process, i.e. telescope with tele-index at ~2.5 → increased effectiveness of octupoles in stabilizing the beam;
- Run III optics does not incorporate the new one of IR7;
  - Quick look also at HL-LHC v1p4, to focus mainly on new IR7 optics;

Simulation Settings

- optics:
  - Run III Flat (β*=50cm/15cm);
  - HL-LHC v1p4 (β*=15cm, with IR7 optics);
- 7 TeV, B1H / B1V only, 0.04σ halo;
- 2018 OP-like settings vs HL-LHC baseline;

New: aperture and offset directly from MADX when generating fort.2!
→ Preliminary results!

IR	Coll Family	HL-LHC [ε=2.5μm]	HL-LHC [ε=3.5μm]	2018 OP-like [ε=2.5μm]	2018 OP-like [ε=3.5μm]
IR7	TCP/TCS/TCLA/TCLD	6.7/9.1/12.7/16.6	5.7/7.7/10.7/14	5.9/7.7/11.8/16.6	5/6.5/10/14
IR3	TCP/TCS/TCLA	17.7/21.3/23.7	15/18/20	17.7/21.3/23.7	15/18/20
IR6	TCDQ/TCSP	10.1/10.1	8.5/8.5	8.6/8.6	7.3/7.3
IR1/5	TCT/TCL	10.4/14.2	8.8/12	9.5/17.7	8/15
IR2	TCT	43.8	37	35.5	30
IR8	TCT	17.7	15	35.5	30

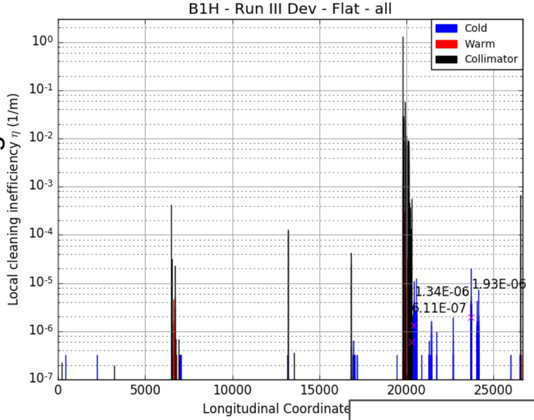
In 2018 operation we actually had: 8.5σ@30cm, 7.8σ@25cm

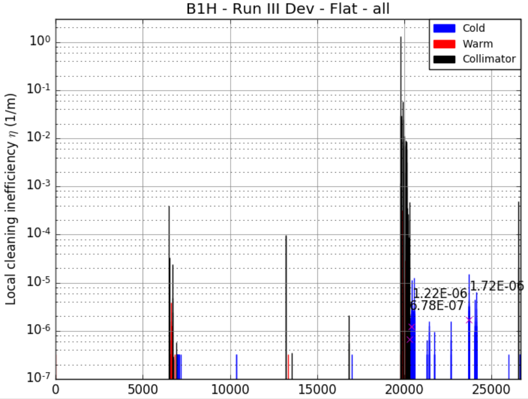
In 2018 operation we actually had: 37σ@IR2, 15σ@IR8

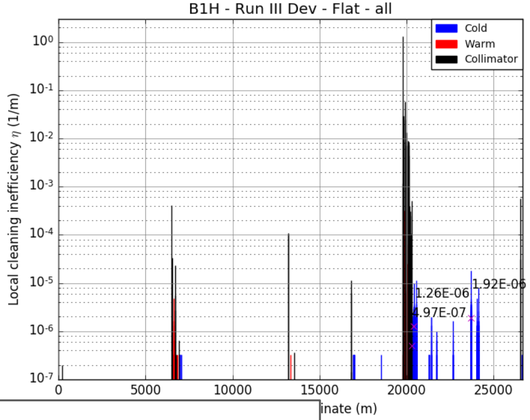
Results – LMs – Run III Flat, OP-2018 Like Settings, B1H

TCSGs only | TCSGs + TCSPMs | TCSPMs only

Entire ring

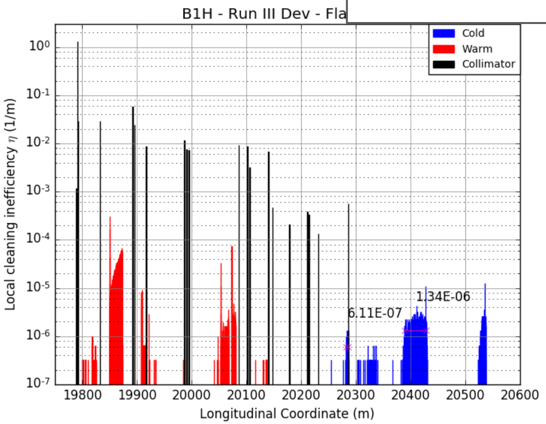


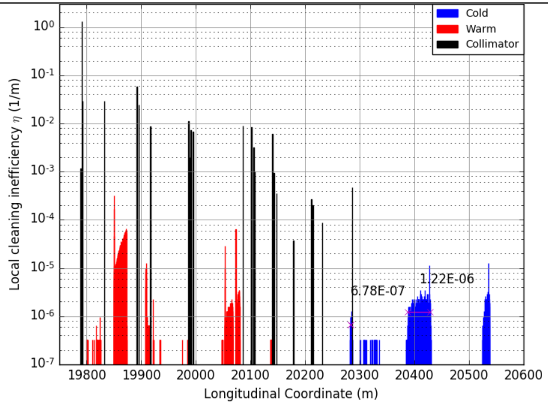


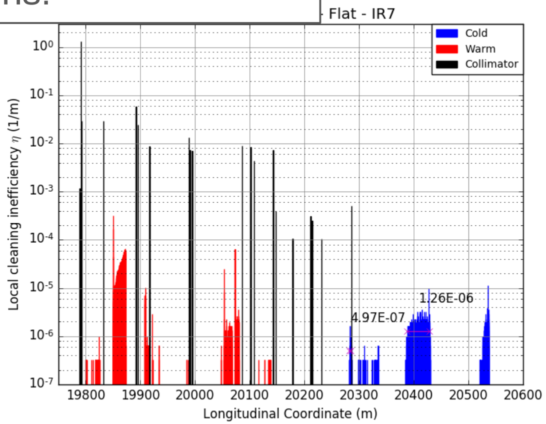


No major differences on patterns!

IR7 only





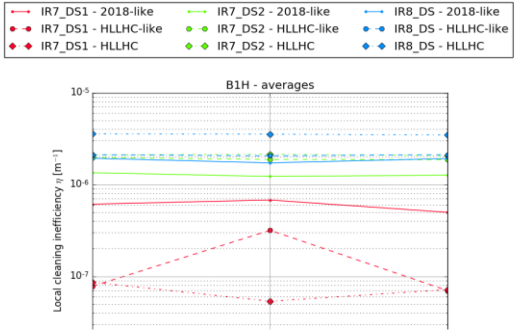


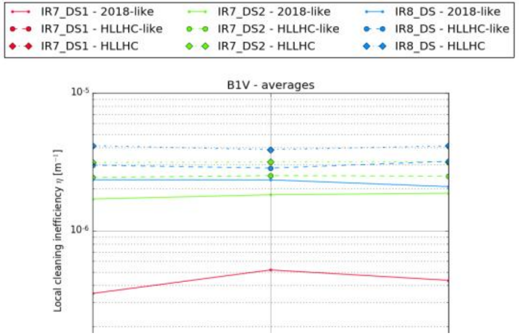
Results – Cleaning Inefficiencies

B1H

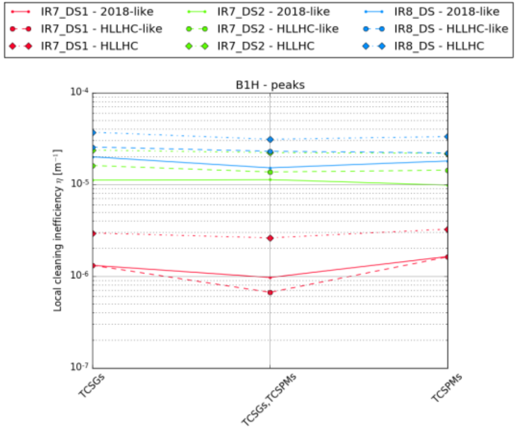
B1V

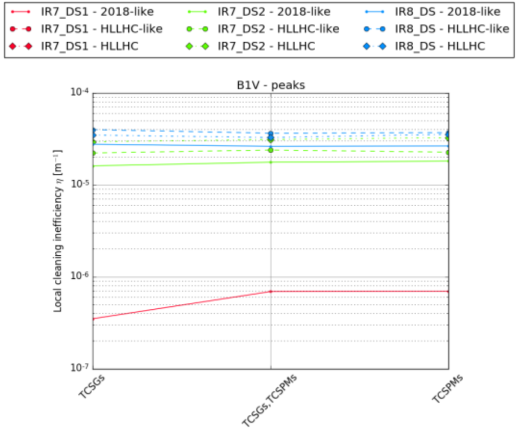
averages





peaks





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TCSPM.B4L7	TCSPM.B4R7	*addition*
TCSPM.E5R7	TCSPM.E5L7	*addition*
TCSPM.6R7	TCSPM.6L7	*addition*

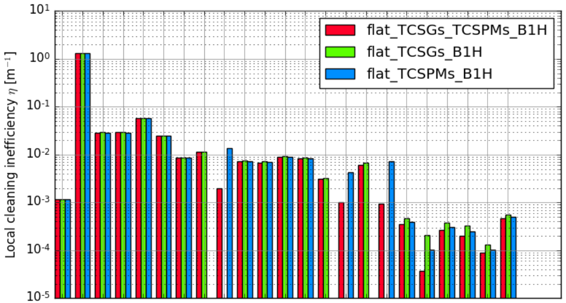
- 18 simulated cases:
  - TCSGs and TCSPMs vs only TCSGs vs only TCSPMs;
  - 2018-OP like settings vs HL-LHC settings;
  - B1H / B1V;
  - Run III Flat vs HL-LHC v1p4;
- Little variation in cleaning inefficiency when choosing between TCSGs and TCSPMs (as expected);
- Worse cleaning inefficiency with HL-LHC settings than with 2018-like settings (as expected);

HiLumi HL-LHC PROJECT

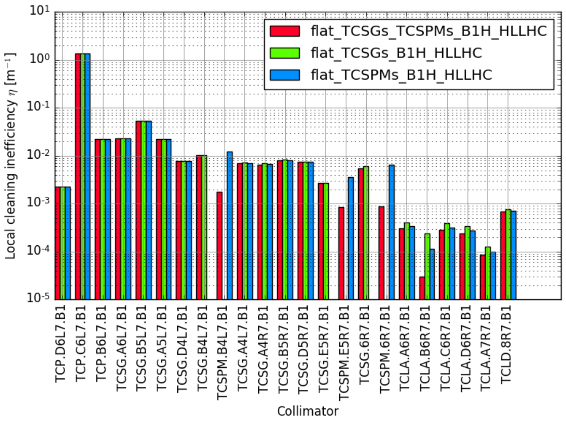
Results – Collimator Losses – B1H

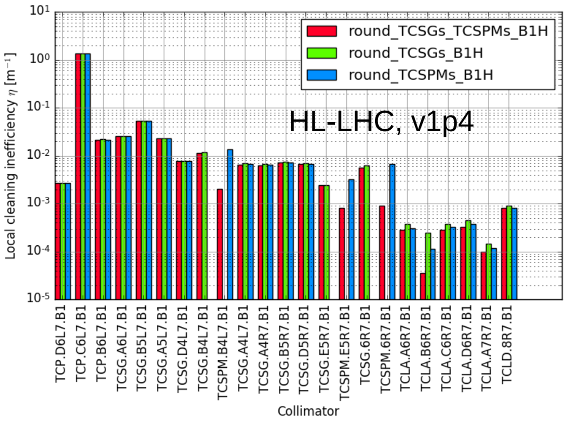
Run III Flat optics

2018-OP like settings



HL-LHC settings





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- 18 simulated cases:
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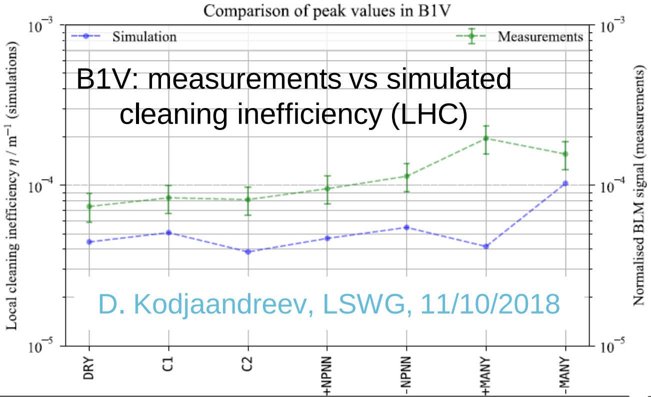
  - 2018-OP like settings vs HL-LHC settings;
  - B1H / B1V;
  - Run III Flat vs HL-LHC v1p4;

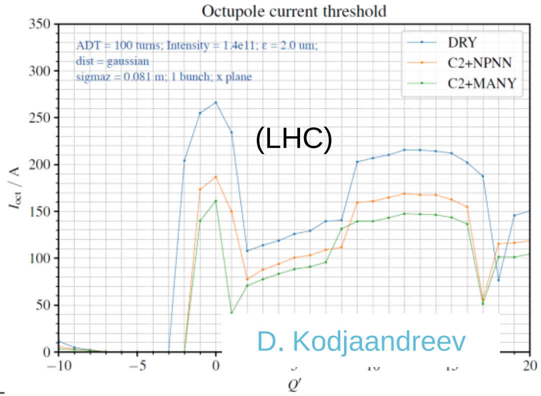
- TCSGs + TCSPMs:
  - TCSPMs in shadow of upstream TCSG;
  - Least load on TCLAs and TCLD;
- TCSGs only:
  - Highest load on TCLAs and TCLD;
- No major differences in patterns between 2018-OP-like and HL-LHC settings, or between Run III flat and HL-LHC v1p4;

Asymmetric Collimator Settings

- Impedance of collimation system is comfortably under control in Run III (N. Mounet, 5th Run III Config .WG meeting:
  - Partial IR7 collimator upgrade (4 TCSPMs/beam) introduces already 50% of gain from full upgrade (11 TCSPMs/beam);
  - CRDS with tele-index of ~2.5 enhances the octupole effectiveness;
  - Ok for pushed settings (as in 2018-OP) with beam brightnesses foreseen for Run III;
- In 2018, asymmetric collimator settings explored in simulations and MDs as a mean to further decrease collimator impedance at the expenses of limited worsening of cleaning inefficiency;



Measured inefficiency reasonably match expectations for B1, whereas discrepancies are found on B2;
→ To be understood;



Estimation of impedance reduction based on resistive wall term, dominant for LHC collimators;
→ To be refined, in view of Run III and (especially) HL-LHC, for having a final word;

- Considered asymmetric configurations (IR7):
  - TCPs (C1/C2);
  - The 4 TCSGs of the LS2 upgrade (NPNN/ANTI-);
  - Almost all IR7 TCSGs (MANY/ANTI-);

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Conclusions

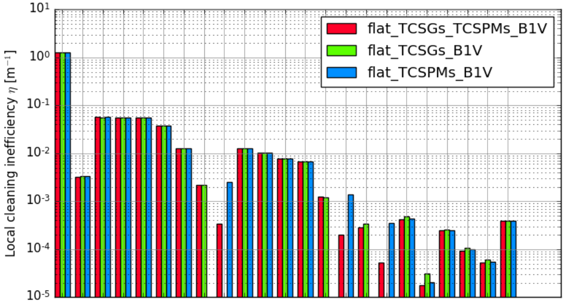
- LS2 will see the installation of the partial LHC Collimation Upgrade for HL-LHC:
  - Many changes already taking place during LS2;
  - Extended and detailed studies to converge on present baseline;
  - Different areas covered (e.g. cleaning performance, thermo-mechanics, cryogenics, radiation to equipment, …);
  - Many thanks to all teams involved!
- It will be possible to get acquainted to the new HL-LHC hardware already in Run III;
  - The staged installation of the TCSPMs (4/beam in LS2) will allow a further improvement of the design (e.g. to decrease the collimator sagitta for 0.2h BLT);
- Sound hardware for a good start-up in Run III:
  - More robust TCPs / TCSGs;
  - (Mo-coated) MoGr jaws will limit impact on impedance;
  - It should be possible to swallow the LIU beams once available in the LHC;

Thanks a lot!

Results – Collimator Losses – B1V

Run III Flat optics

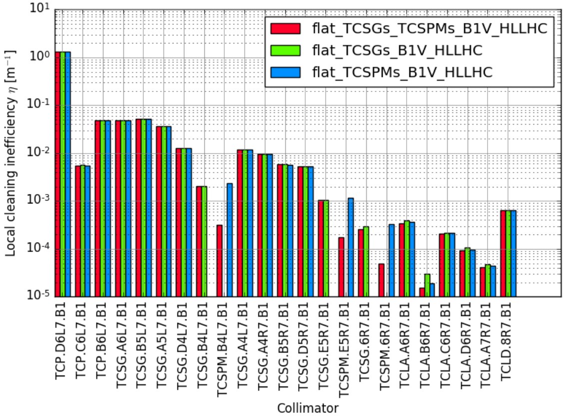
2018-OP like settings

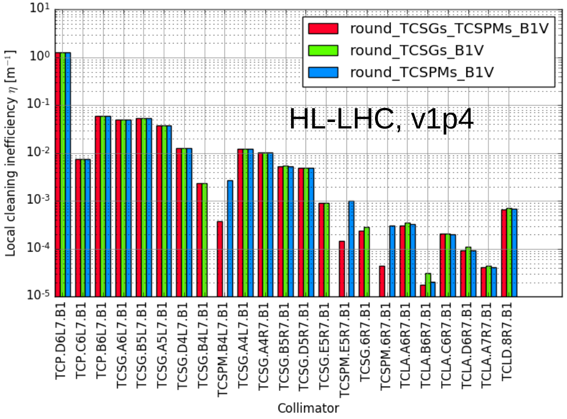


B1	B2	
TCSG.D4L7	TCSG.D4R7	*exchange*
TCSPM.B4L7	TCSPM.B4R7	*addition*
TCSPM.E5R7	TCSPM.E5L7	*addition*
TCSPM.6R7	TCSPM.6L7	*addition*

- 18 simulated cases:
  - TCSGs and TCSPMs vs only TCSGs vs only TCSPMs;
  - 2018-OP like settings vs HL-LHC settings;
  - B1H / B1V;
  - Run III Flat vs HL-LHC v1p4;

HL-LHC settings

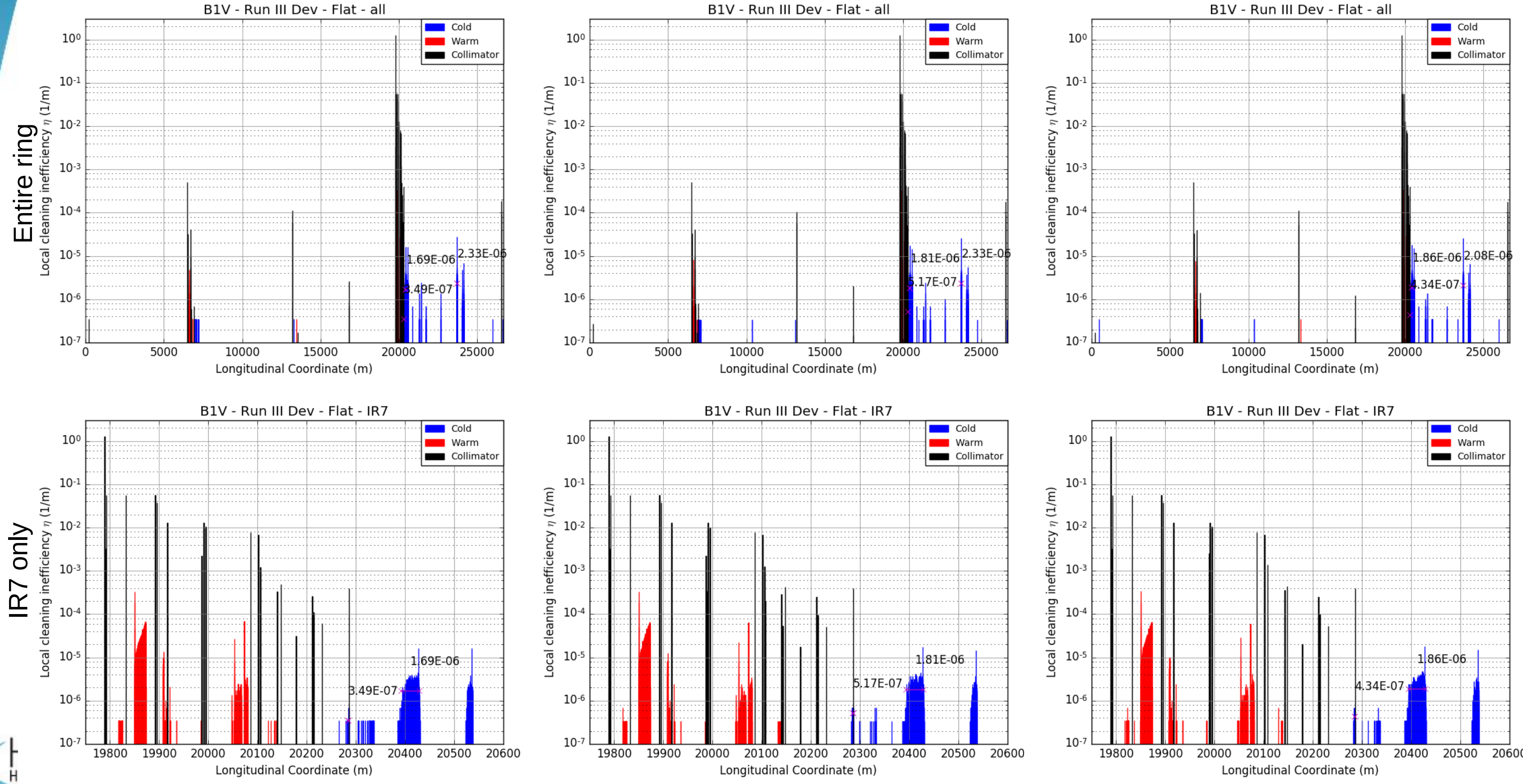




- TCSGs + TCSPMs:
  - TCSPMs in shadow of upstream TCSG;
  - Least load on TCLAs and TCLD;
- TCSGs only:
  - Highest load on TCLAs and TCLD;
- No major differences in patterns between 2018-OP-like and HL-LHC settings, or between Run III flat and HL-LHC v1p4;

Results – LMs – Run III Flat, OP-2018 Like Settings, B1V

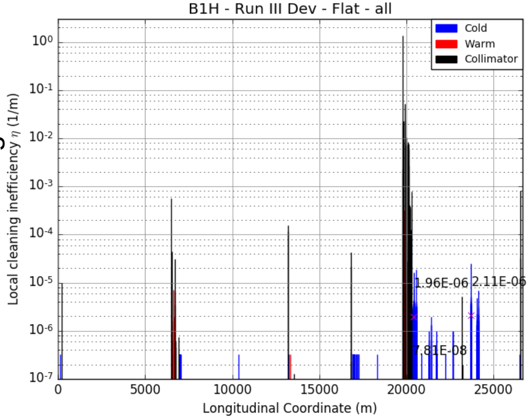
TCSGs only | TCSGs + TCSPMs | TCSPMs only



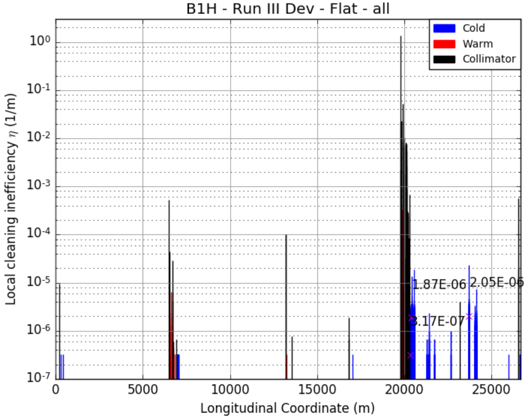
Results – LMs – Run III Flat, HL-LHC Settings, B1H

Entire ring

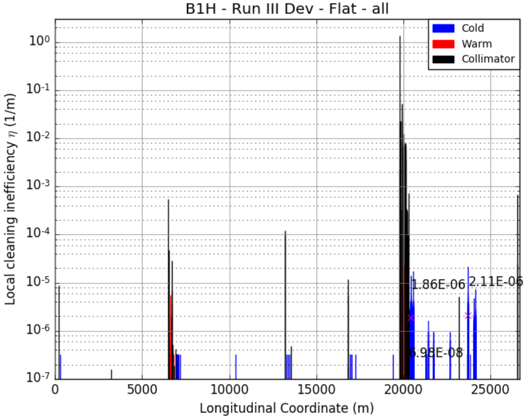
TCSGs only



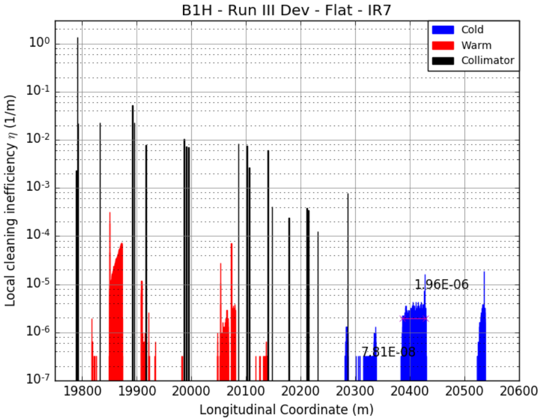
TCSGs + TCSPMs

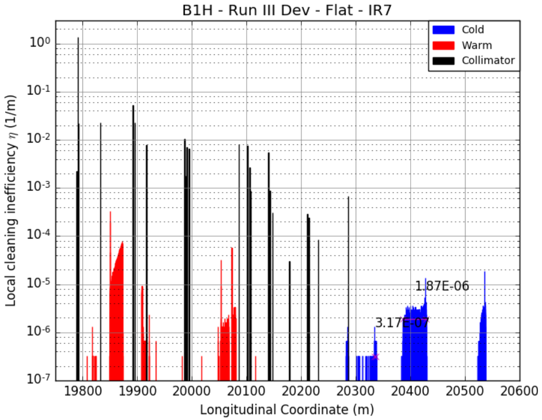


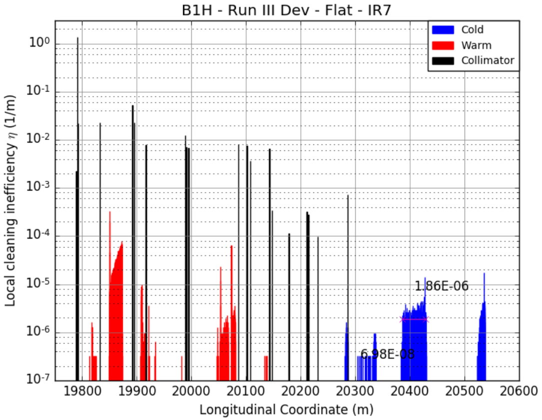
TCSPMs only



IR7 only





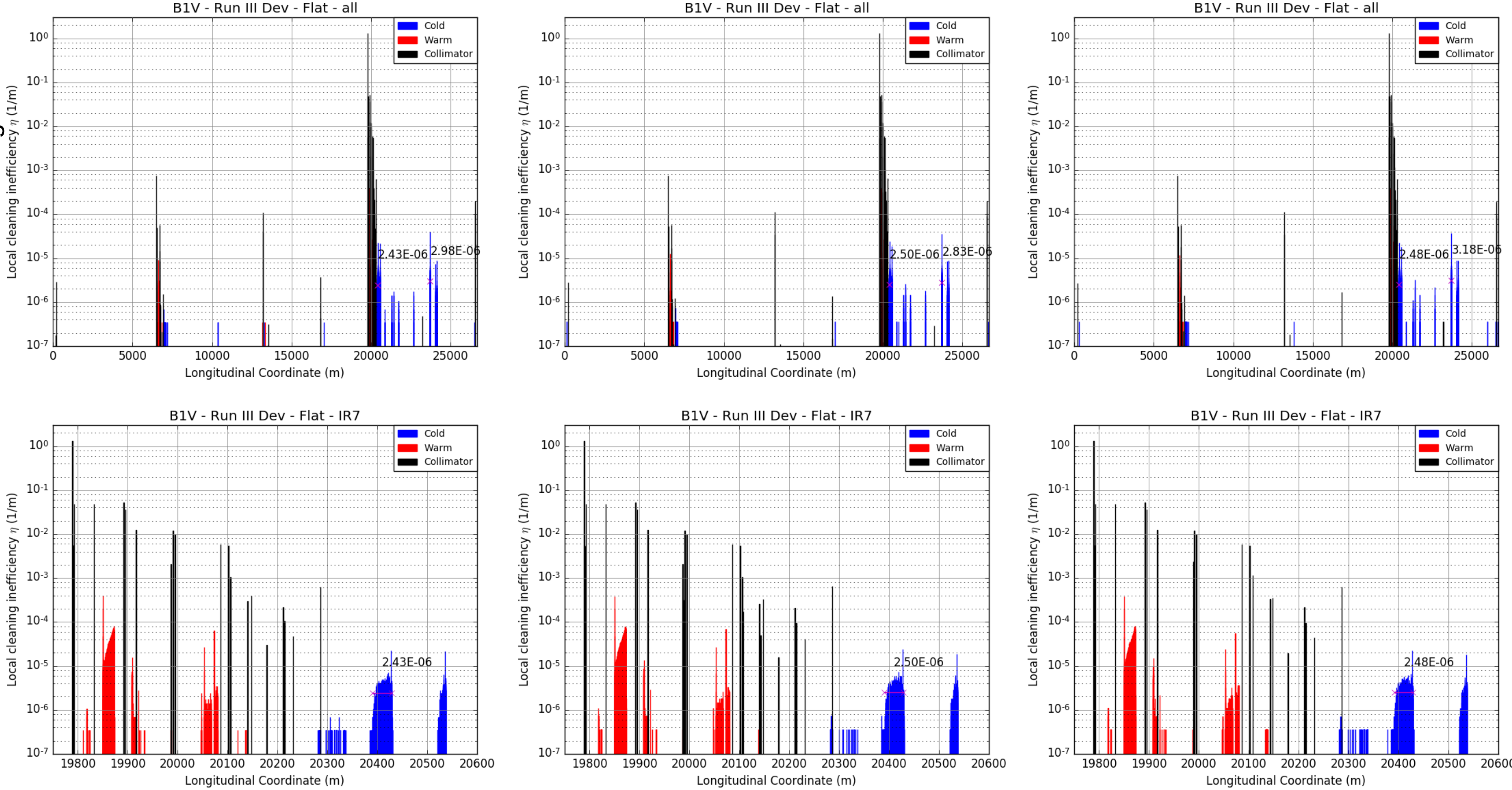


Results – LMs – Run III Flat, HL-LHC Settings, B1V

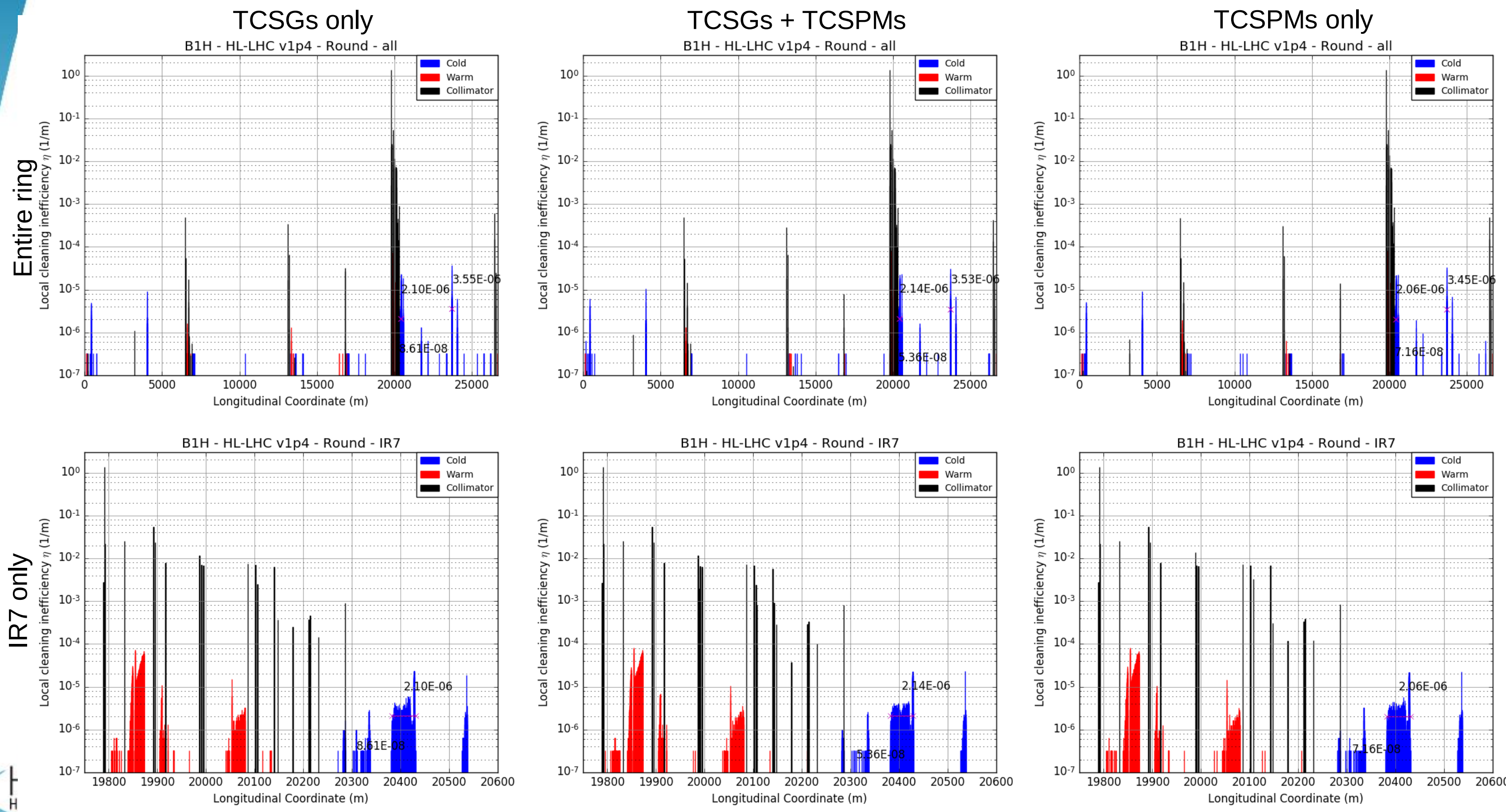
TCSGs only | TCSGs + TCSPMs | TCSPMs only

Entire ring

IR7 only



Results – LMs – HL-LHC v1p4, B1H



Results – LMs – HL-LHC v1p4, B1V

TCSGs only | TCSGs + TCSPMs | TCSPMs only

Entire ring / IR7 only