Motivation for crystal collimation for HL-LHC

R. Bruce on behalf of WP5

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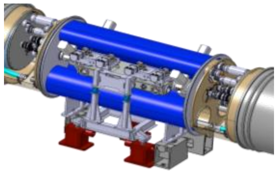
Outline

- HL-LHC collimation baseline upgrades for betatron cleaning
- Cleaning efficiency with Run 3 and Run 4 layouts for protons and Pb ions
- Outcome of energy deposition studies
- Performance concerns for Pb ion collimation

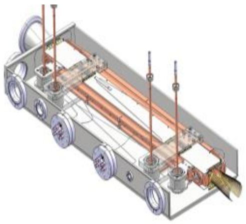
HL-LHC collimation upgrades

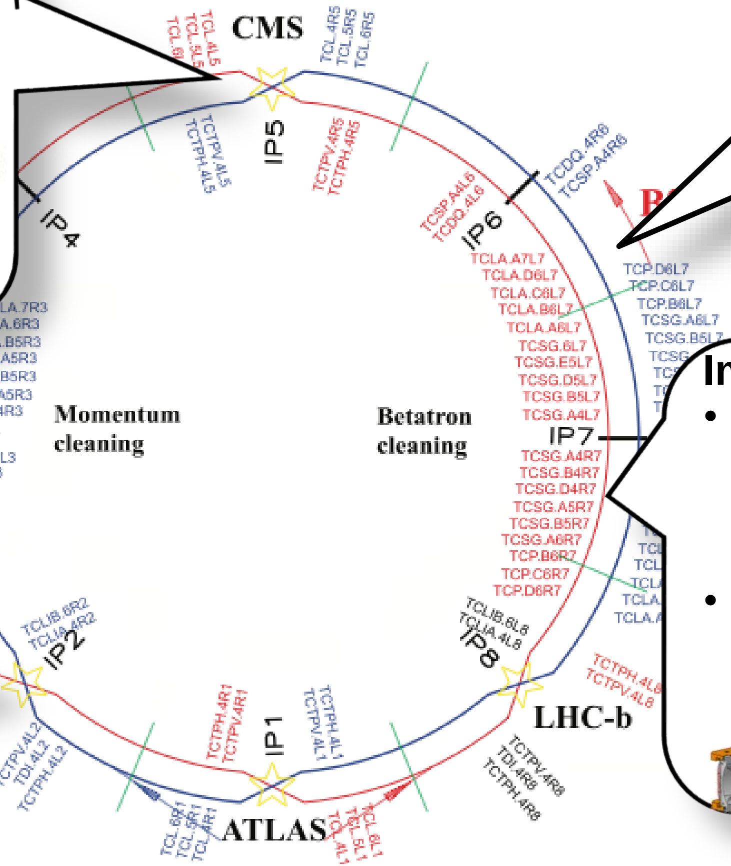
New IR layout (total IR1+IR5):
- New robust tertiary collimators (CuCD)
- physics debris collimators
- fixed masks


Cleaning: DS collimator + 11T dipoles

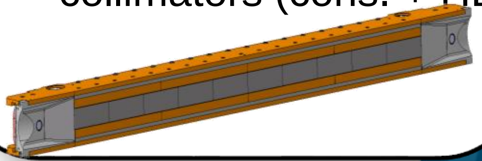


Ion physics:
Dispersion suppressor (DS) collimators





Impedance:
- New low-impedance, high robustness secondary collimators; coated MoGr
- New primary MoGr collimators (cons. + HL)



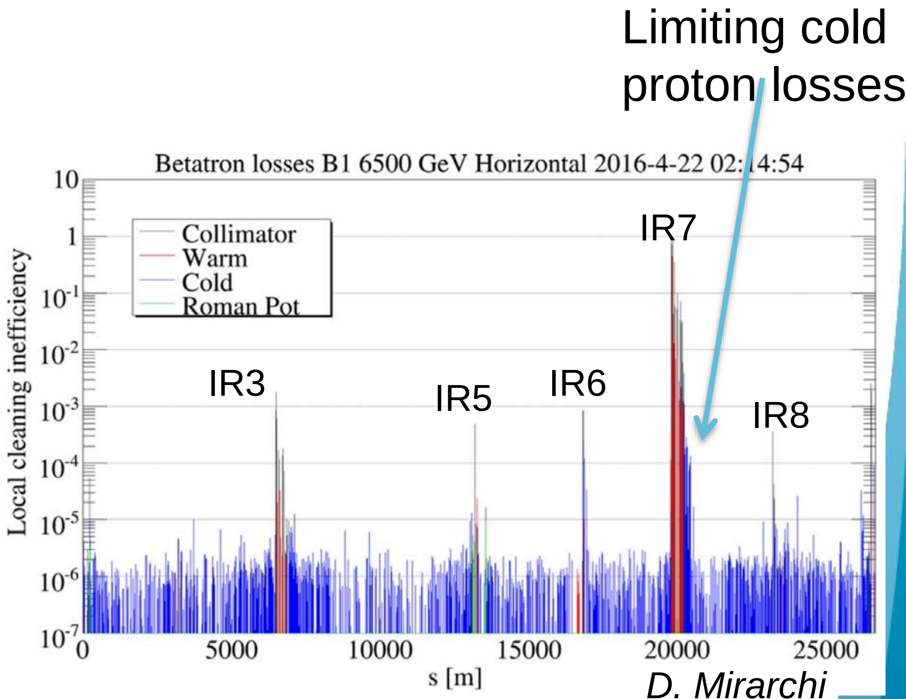
Baseline collimation upgrades

- LS2 collimation upgrades (per beam)
  - 2 low-impedance primary collimators (TCPPM) in IR7
  - 4 low-impedance secondaries (TCSPM) in IR7
  - 1 dispersion suppressor collimator (TCLD) downstream of IR7
  - 1 dispersion suppressor collimator (TCLD) downstream of IR2

- LS3 collimation upgrades (per beam)
  - 7 low-impedance secondaries (TCSPM)
  - 6 new tertiary collimators (TCTPM), 2 re-used (TCTPV)
  - 4 physics debris collimators (TCLP)
  - 6 fixed masks (TCLM)

Reminder: Why do we need a cleaning upgrade?

- Collimation system should safely dispose of unavoidable losses
- Small leakage of particles out of collimation system (cleaning inefficiency)
  - Main bottleneck: IR7 dispersion suppressor
  - Quench limit and inefficiency limit allowed loss rate
  - For given beam lifetime, limit on total intensity

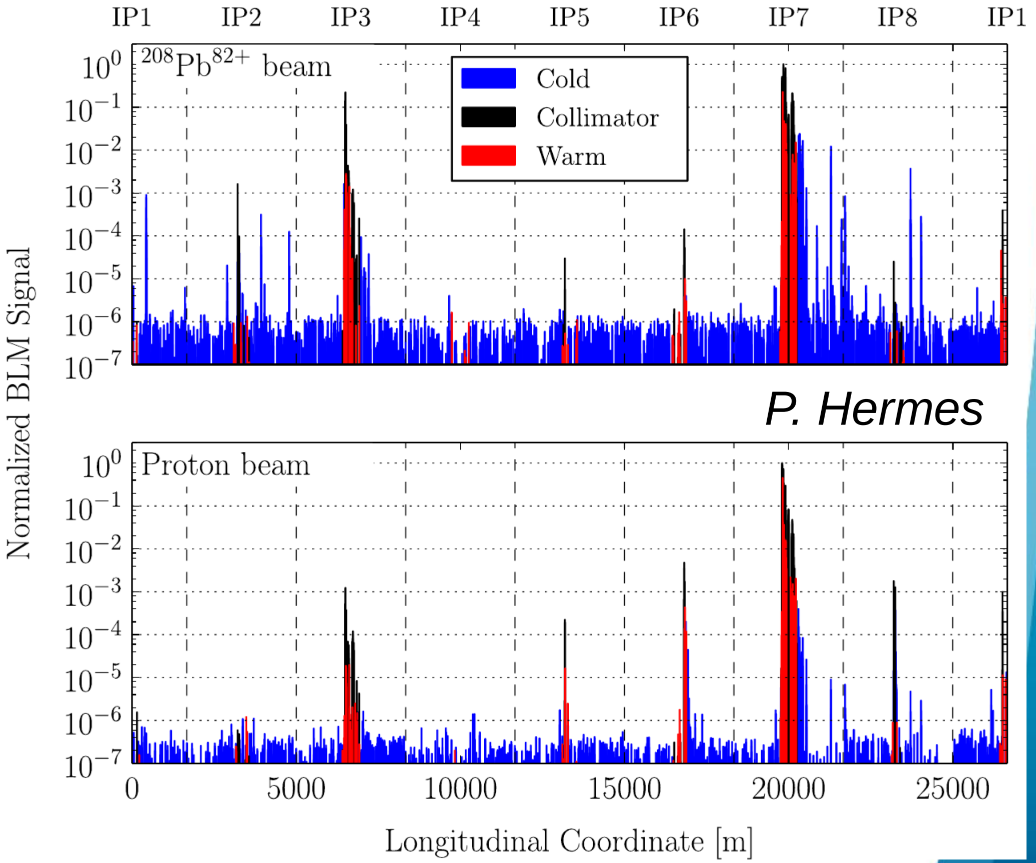


D. Mirarchi

Comparison of Pb ions and protons

- For both species, limit is in the IR7 DS

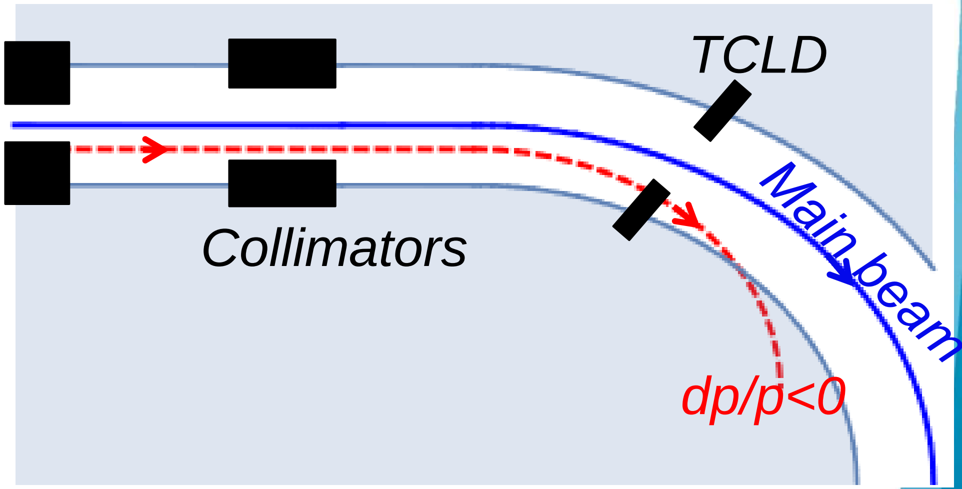
- Factor ~100 worse cleaning inefficiency for ions
  - Ion cleaning is critical, in spite of stored energy being much lower than for protons



P. Hermes

How to improve for HL-LHC

- Risk to be limited in intensity reach if nothing is done
- IR7 DS is the bottleneck, due to off-energy particles (or ion fragments) scattered out of primary collimator
- Solution: introduce extra collimators, TCLDs, in dispersion suppressor
  - Make space by replacing a standard dipoles by two shorter 11T dipole, with TCLD in between
- Present HL baseline: install 1 IR7 TCLD per beam in LS2
  - 2 TCLDs per side also studied (previous baseline – would give best performance)
  - Excluded to have more 11T units available in LS2

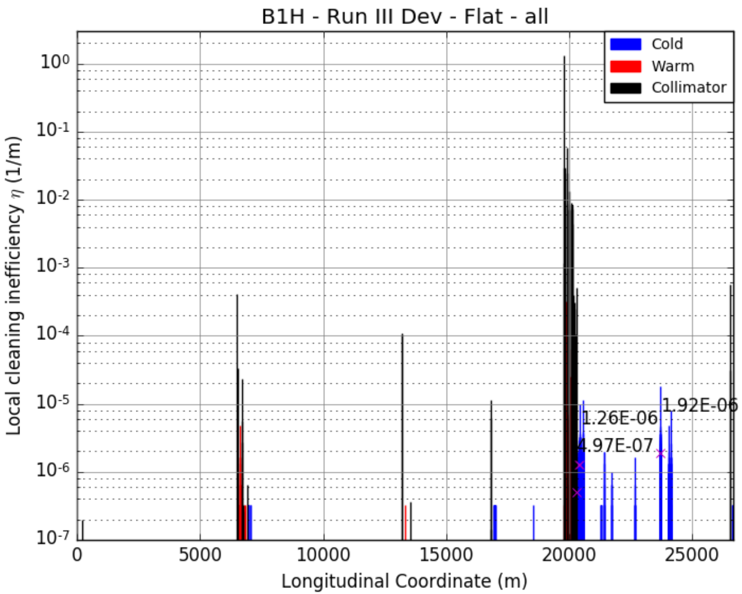


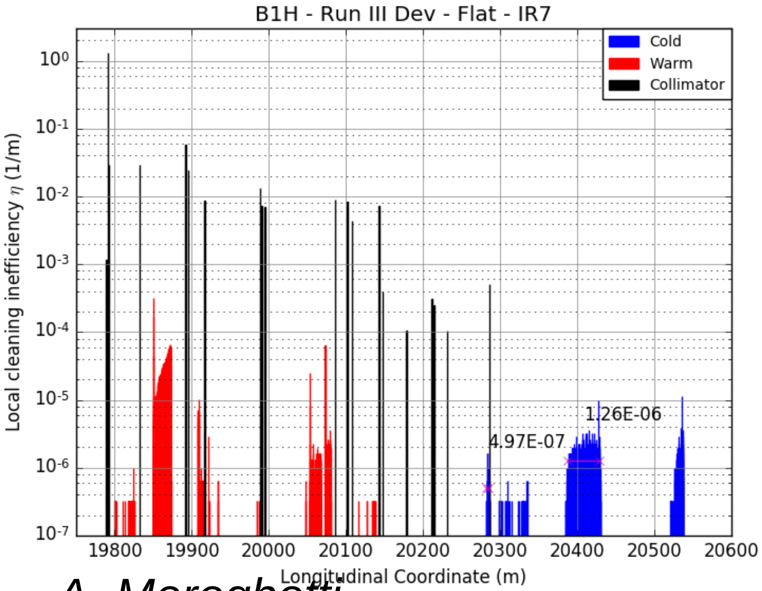
Performance with upgraded layouts

- Collimation cleaning inefficiency studied in tracking simulations
  - Using SixTrack-FLUKA coupling
  - Run 3 and Run 4 (HL-LHC) studied
  - See talks A. Mereghetti and N. Fuster Martinez on Tuesday

Proton cleaning – flat optics for Run 3

- Assumed similar collimator settings as 2018, β*= (50cm/15cm)
- TCLD shields well the first loss cluster

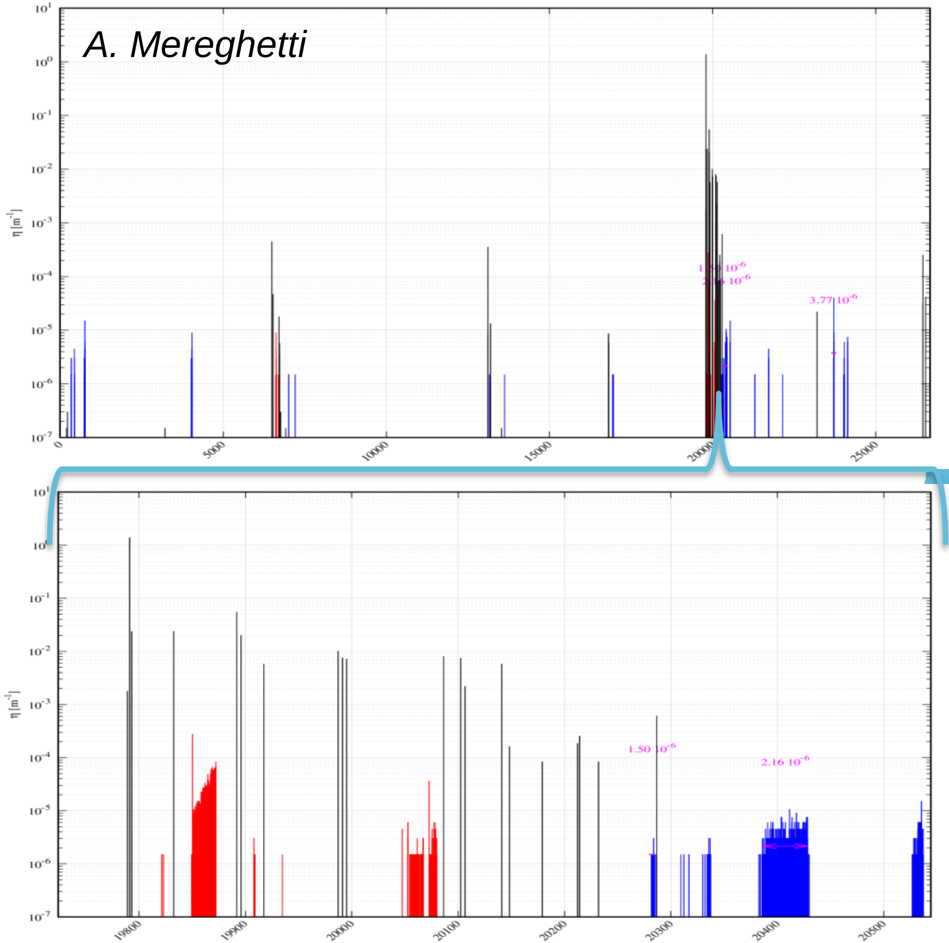




A. Mereghetti

Proton cleaning – HL-LHC v1.3

- Similar performance for HL-LHC v1.3, β*=15 cm
  - Slightly more open collimator settings assumed than for Run 3



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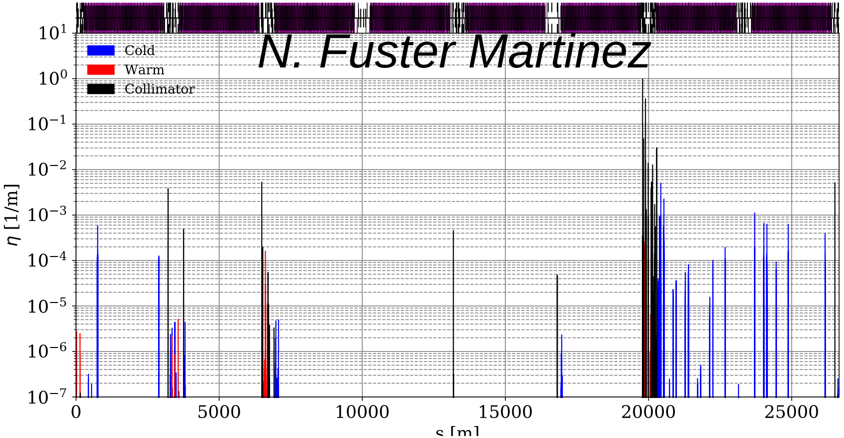
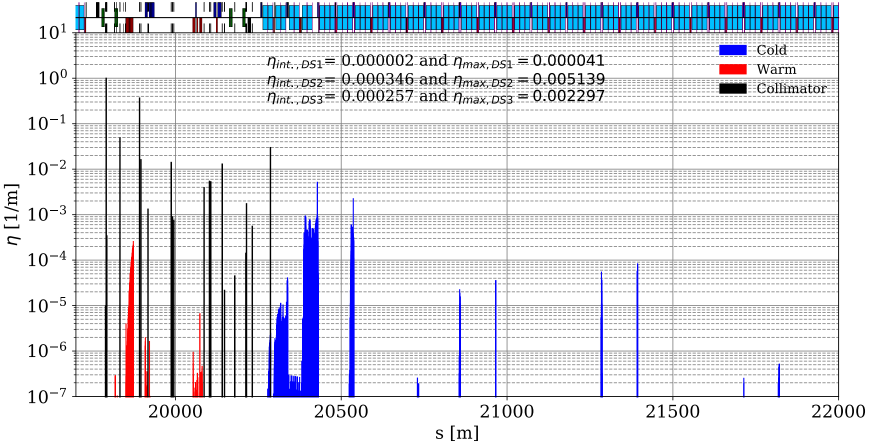
Pb ion cleaning – Run 3 layout

- Assuming the 2018 ion optics, but with the Run 3 layout
  - including TCLD and the foreseen low-impedance collimators

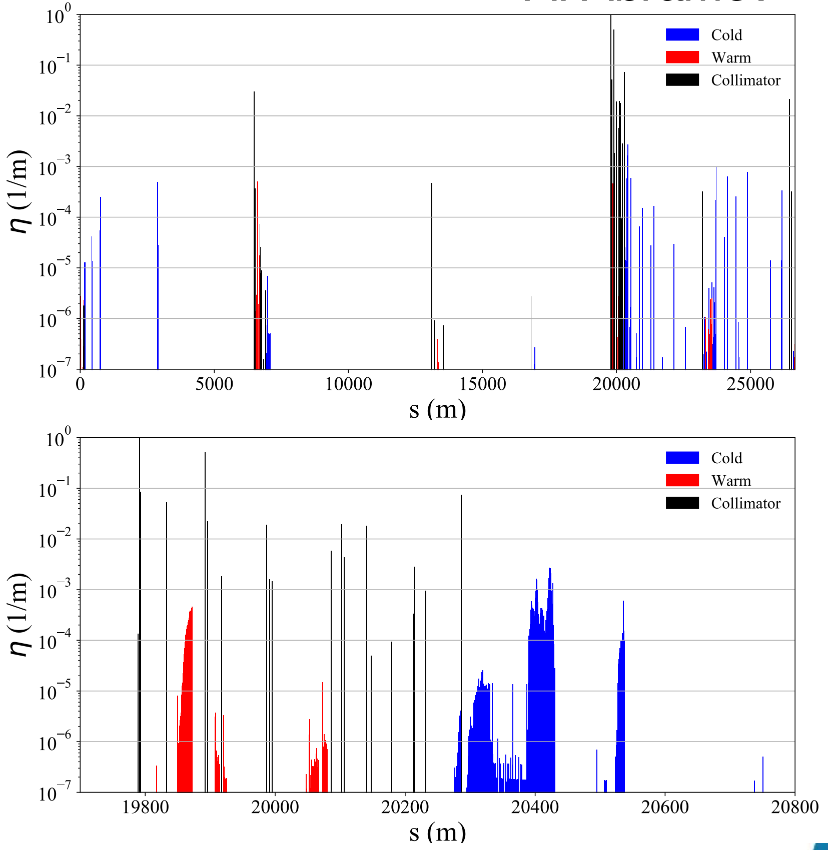




Pb ion cleaning – HL-LHC v1.2

A. Abramov

- Using optics HL-LHC v1.2 – ion version for v1.4 under development (R. de Maria)
- TCLD shields well the first loss cluster, but the second one remains almost unchanged
- Pb ion cleaning remains a factor ~100 worse than proton cleaning



Energy deposition studies

- Tracking simulations show the lost primary beam protons
- FLUKA energy deposition studies needed to assess the risk to quench magnets (C. Bahamonde, A. Lechner)
  - Using output from tracking as starting conditions
  - See talk C. Bahamonde in Wednesday's session
- Output: energy deposition, per lost primary proton or Pb ion on the collimation system
  - scaled up by factor 3 to compensate discrepancy with LHC measurement

Normalization of energy deposition studies

- Normalizing loss power to the two design loss scenarios:
  - 12 minute beam lifetime, to be sustained for 10 s
  - 1 h beam lifetime, to be sustained "infinitely"

- Assumptions on beam conditions for HL-LHC

	# bunches	# particles/bunch	Loss rate 12 min.	Loss rate 1 h.	Loss power (12 min.)	Loss power (1 h)
Protons	2760	2.3e11	8.81e11 p/s	1.76e11 p/s	988 kW	198 kW
Pb Ions	1248	2.1e8	3.64e8 Pb/s	7.28e7 Pb/s	33 kW	6.7 kW

Simulated peak power load on DS magnets (HL-LHC)

C. Bahamonde - Wednesday's talk

TCLD position		PROTONS (mW/cm³)					IONS (mW/cm3)				
		Cell 8/9			Cell 11		Cell 8/9			Cell 11	
		*MB**	*MQ*	*11T*	*MB**	*MQ*	*MB**	*MQ*	*11T*	*MB**	*MQ*
No TCLD	0.2h	**21**	9.9	-	12	13	**57**	27	-	**57**	36
	1h	**4.2**	2	-	2.4	2.6	**11**	5.4	-	**11**	7.2
MBB.8	0.2h	6.6	8.1	11	8.7	13	5.4	15	21	**36**	33
	1h	1.3	1.6	2.2	1.7	2.6	1.1	3	4.2	**7.2**	6.6
MBA.9	0.2h	6.0	8.1	**48**	<0.3	<0.3	6.0	3.6	**33**	<0.003	<0.003
	1h	1.2	1.6	**9.6**	<0.06	<0.06	1.2	0.7	**6.6**	<0.0006	<0.0006

*Quench limit for MB could be ~20 mW/cm³ for steady state losses at 6.37Z TeV)

Outcome of energy deposition study

- Numbers shown already in Madrid 2017 (see talk C. Bahamonde)
- The installation of the TCLD always improves the situation
- For protons, the HL-LHC baseline is solid and shows good performance
  - Some margin up to quench limit
- For Pb ions, even with the TCLD, peak energy deposition on standard dipole in cell 11 above estimated quench limit
- Unless typical beam lifetime drops stay significantly above 12 minutes, risk for availability issues due to beam dumps on losses

Conclusions

- Baseline collimation layouts for Run 3 and Run 4 presented

- Cleaning performance with protons and Pb ions estimated through tracking studies and energy deposition
  - Collimation system meets requirements for protons
  - For Pb ions, estimated peak energy deposition is above quench limit during 12 minute lifetime drop – risk to introduce operational bottlenecks

- Other alternative means of improving cleaning efficiency for Pb ions should be investigated
  - Crystals?

Backup

Total power in cryogenic cells (W)

C. Bahamonde - Wedensday's talk

TCLD position		PROTONS Half-cells						IONS Half-cells					
		8	*9*	*10*	*11**	*CC*	*12*	*8*	*9*	*10*	*11**	*CC*	*12*
No TCLD	0.2h	50	**740**	15	**280-310**	100	10	10	**985**	35	**910-1015**	270	25
	1h	10	**148**	3	**56-62**	20	2	2	**197**	9	**182-203**	54	5
MBB.8	0.2h	210	100	10	230-265	85	10	351	135	20	569-635	115	20
	1h	42	20	2	46-53	17	2	70	27	4	112-127	23	4
MBA.9	0.2h	51	475	3	2.1-2.2	<1	<1	9	758	<1	<1	<1	<1
	1h	10	95	<1	<1	<1	<1	2	152	<1	<1	<1	<1