Update on heat load estimates

P. Dijkstal, G. Iadarola and G. Skripka

Thanks to: G. Arduini, R. De Maria, L. Mether, E. Metral, G. Rumolo

HLLHC-WP2 Meeting, 3 October 2017

Overview

The **goal** is to have a **complete survey** of the beam-induced heat loads on **all beam screens** including the effect of impedance, synchrotron radiation and e-cloud effects

Present status

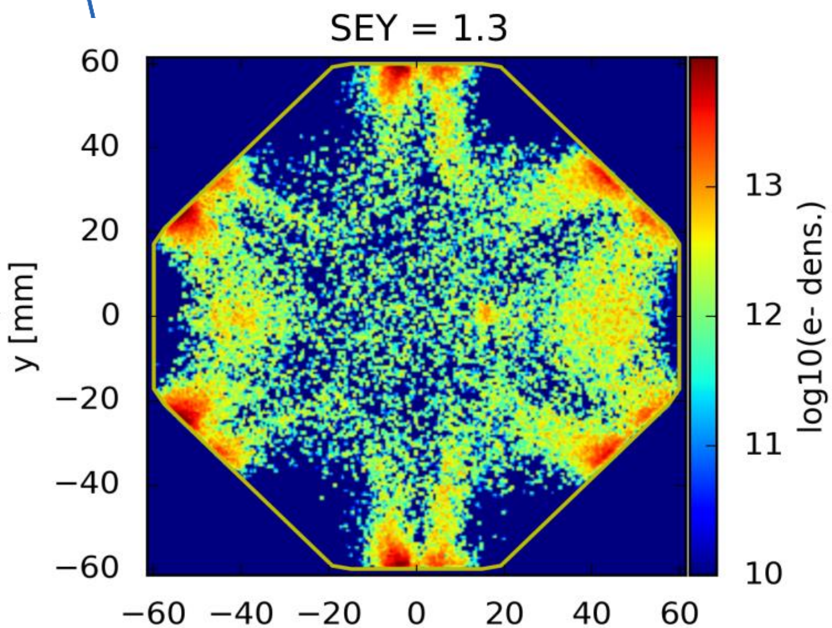
Machine part	Status
IR twin bore magnets	Estimates were made and documented in CERN-ACC-2016-0112
Inner triplets the four experimental IRs	Estimates were made and documented in a report presently being circulated (present version here)
Arcs	In progress (see next slides), to be completed and documented…

Update on heat loads in the inner triplets

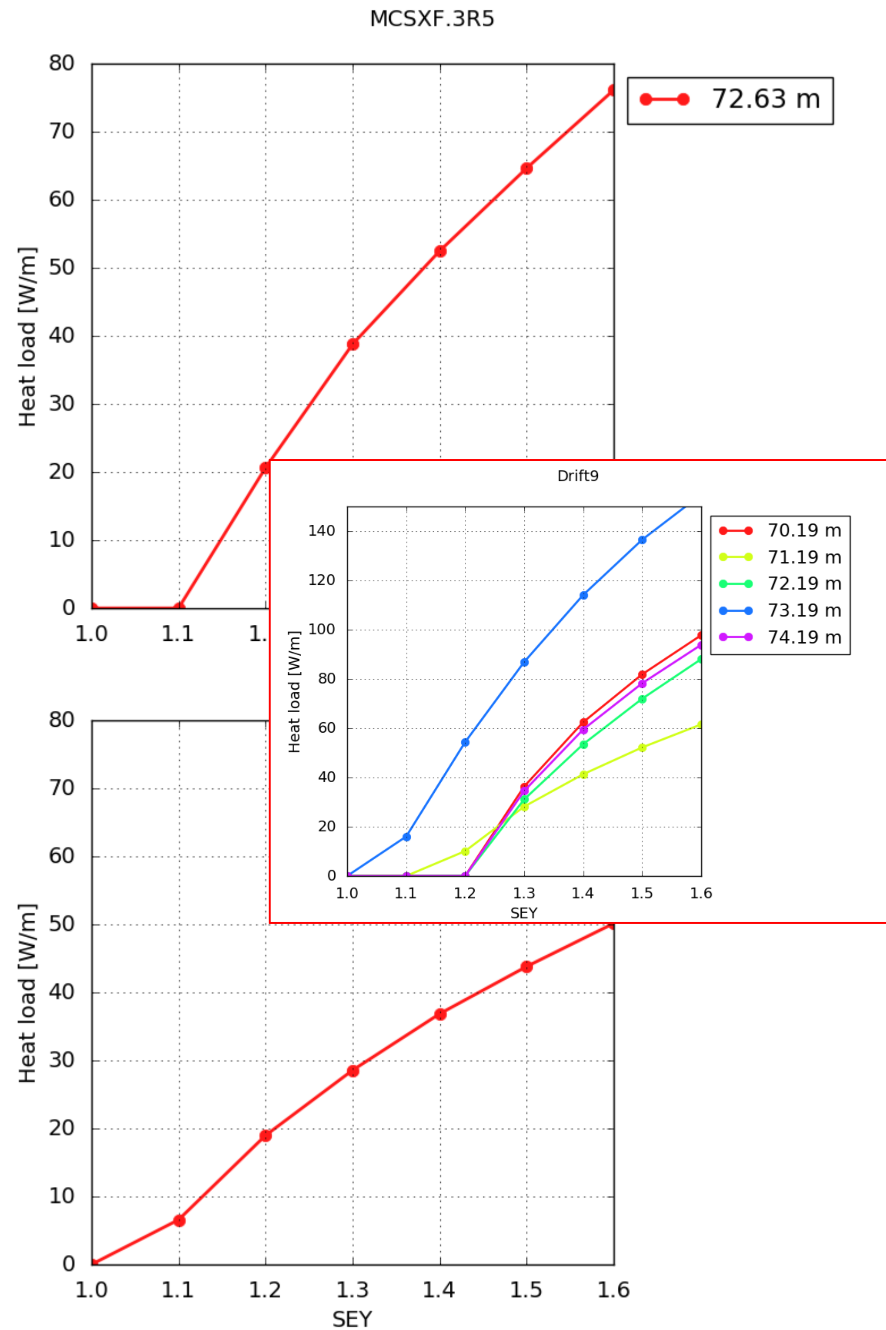
(for previous work see presentation given on 29 June)

Simulations for the corrector package

Update on the triplets – corrector package



- **No significant heat load expected with the coating** in place (SEY<1.1)
- Compared to the **corresponding drifts**:
  - Multipoles have **slightly lower threshold**
  - Multipoles show **lower heat loads** above threshold



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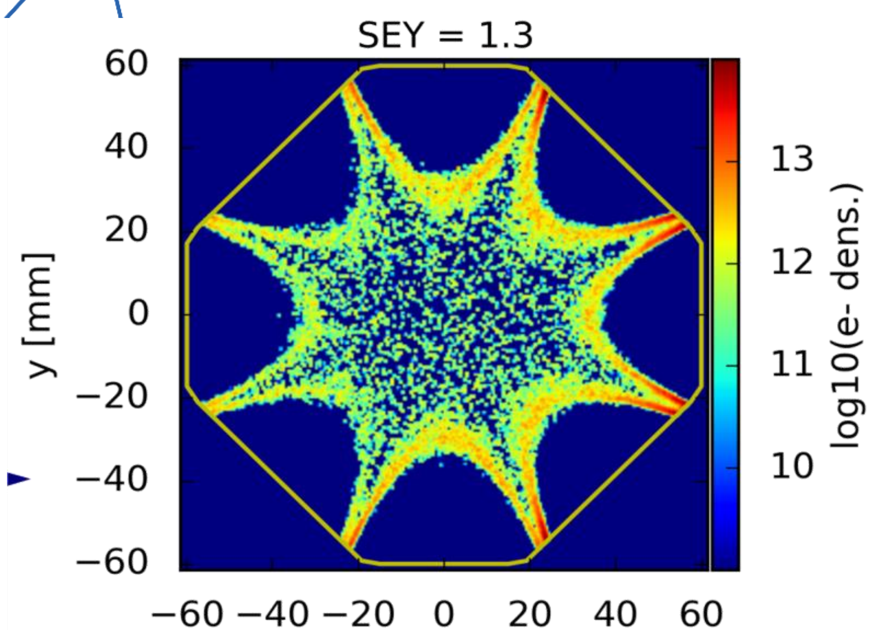

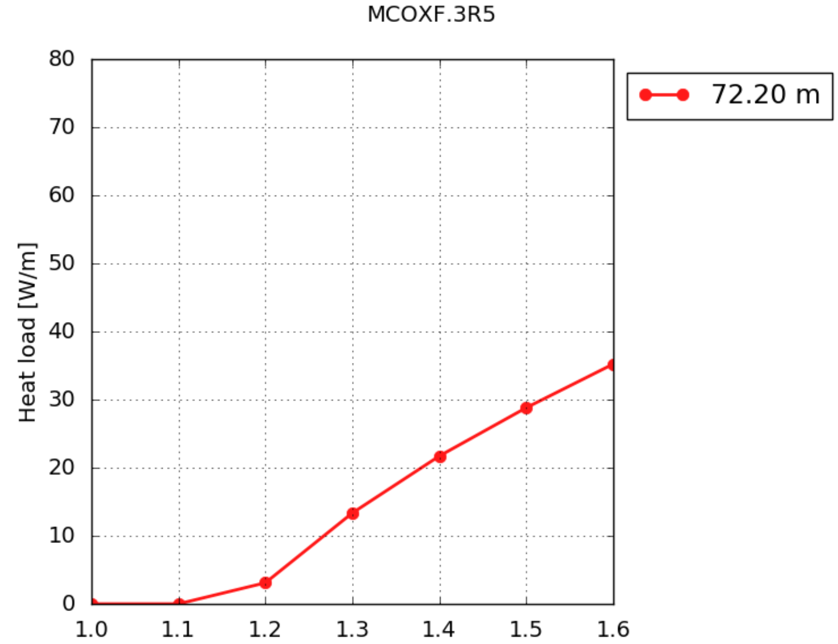

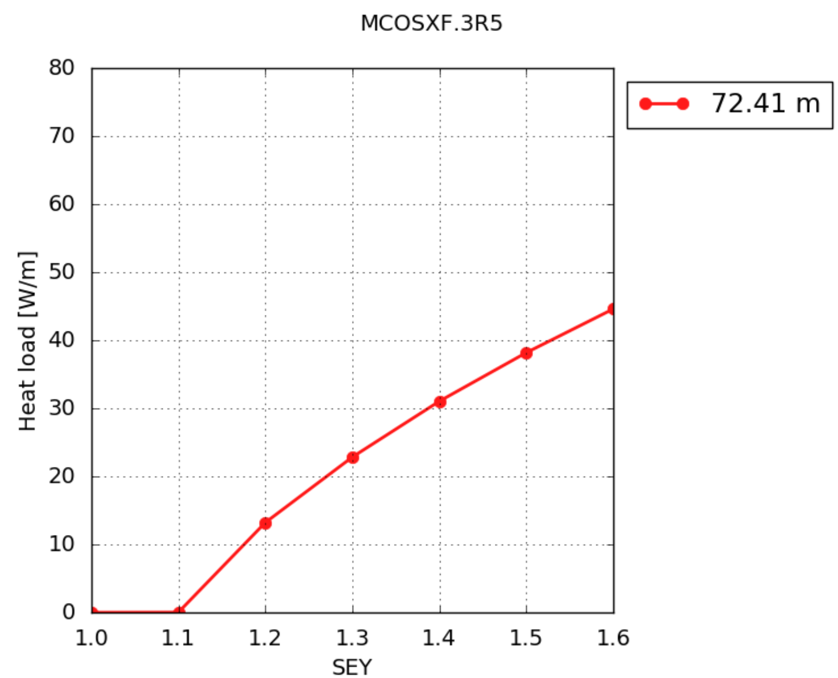

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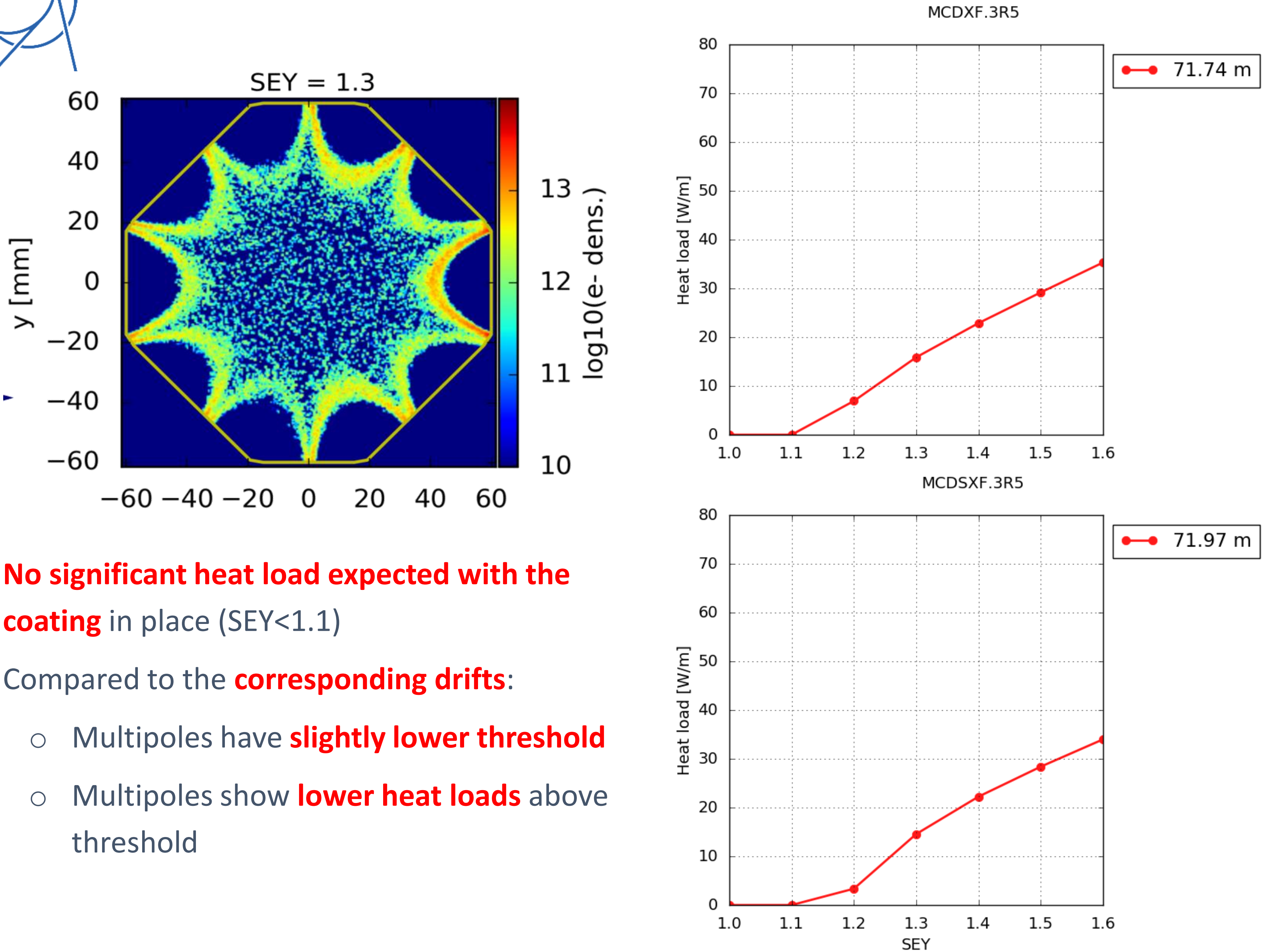

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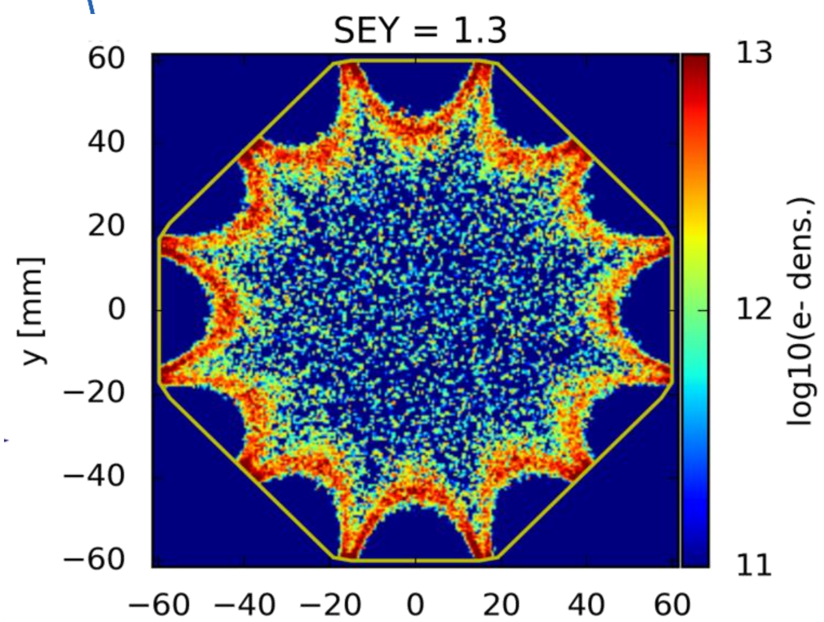

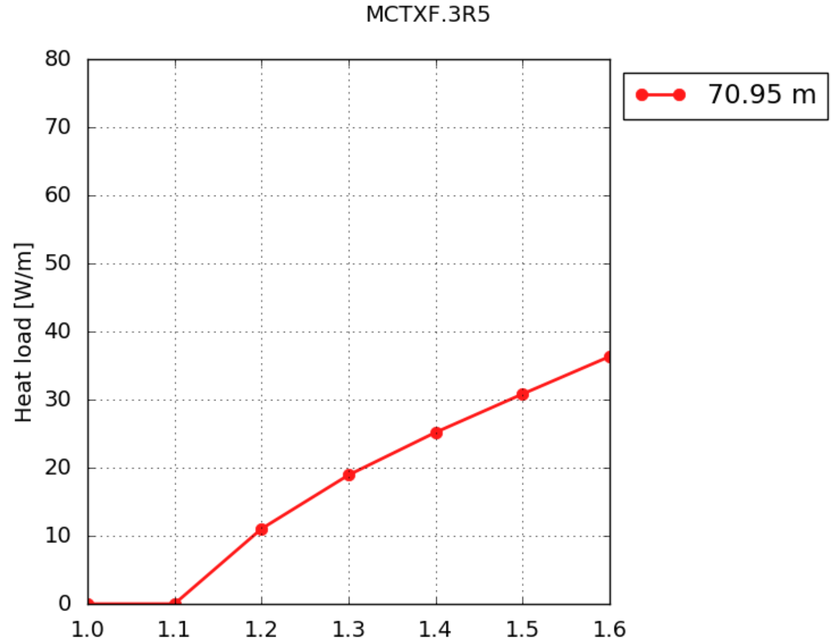

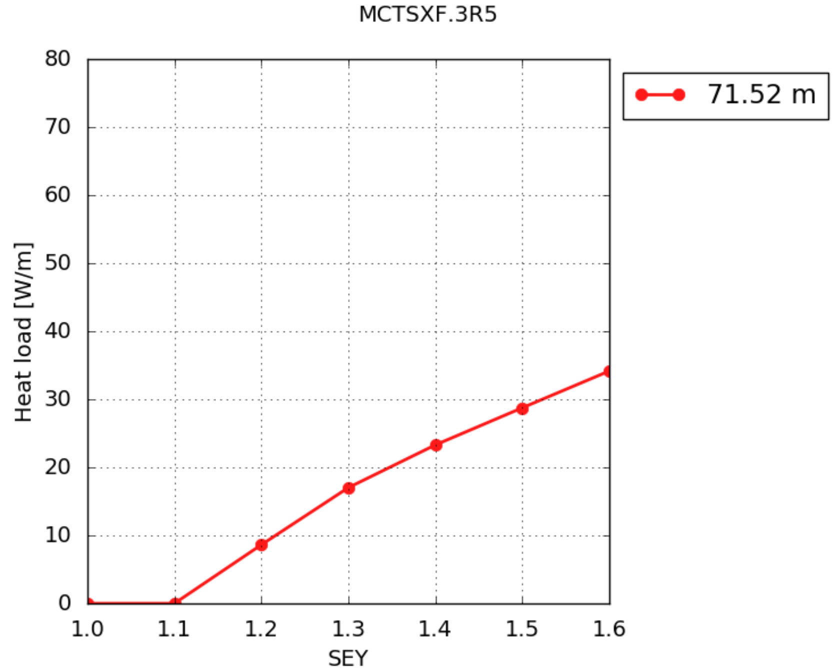

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Update on the triplets: heat load tables

Changes w.r.t. presentation given on 29 June:

- Included **corrector package**
- New nominal **bunch length** (9 cm)

Effect on the total smaller than 10%

See also G. Skripka and G. Iadarola, "Beam-induced heat loads on the beam screens of the inner triplets for the HL-LHC", to be published, draft available here

Triplets in IR1&5

Name	Length	Field config.	Chamber	Impedance (T_BS=70 K)	e-cloud (SEY=1.1/1.3(UncDrifts))	Total
ITQ1R5	11.6 m		BSHL_Q1	4.1 W	61.9 W	66.0 W
MQXFA.A1R5	4.2 m	quad	BSHL_Q1	1.5 W	19.0 W	
MQXFA.B1R5	4.2 m	quad	BSHL_Q1	1.5 W	24.7 W	
Drifts	1.7 m	drift	BSHL_Q1	0.6 W	0.1 W	
UncoatedDrifts	1.5 m	drift	BSHL_Q1	0.5 W	18.2 W	
ITQ2Q3R5	49.1 m		BSHL_Q23	15.3 W	338.0 W	353.3 W
MQXFB.A2R5	7.2 m	quad	BSHL_Q23	2.3 W	17.3 W	
MQXFB.B2R5	7.2 m	quad	BSHL_Q23	2.3 W	26.4 W	
MQXFA.A3R5	4.2 m	quad	BSHL_Q23	1.3 W	13.2 W	
MQXFA.B3R5	4.2 m	quad	BSHL_Q23	1.3 W	13.6 W	
MBXF.4R5	6.3 m	dip	BSHL_Q23	2.0 W	11.4 W	
MCBXFBV.A2R5 MCBXFBH.A2R5	1.2 m	dip	BSHL_Q23	0.4 W	0.0 W	
MCBXFBV.B2R5 MCBXFBH.B2R5	1.2 m	dip	BSHL_Q23	0.4 W	1.0 W	
MCBXFAV.3R5 MCBXFAH.3R5	2.2 m	dip	BSHL_Q23	0.7 W	1.5 W	
MCTXF.3R5	0.4 m	dodecap	BSHL_Q23	0.1 W	0.0 W	
MCTSXF.3R5	0.1 m	skew dodecap	BSHL_Q23	0.0 W	0.0 W	
MCDXF.3R5	0.1 m	decap	BSHL_Q23	0.0 W	0.0 W	
MCDSXF.3R5	0.1 m	skew decap	BSHL_Q23	0.0 W	0.0 W	
MCOXF.3R5	0.1 m	oct	BSHL_Q23	0.0 W	0.0 W	
MCOSXF.3R5	0.1 m	skew oct	BSHL_Q23	0.0 W	0.0 W	
MCSXF.3R5	0.1 m	sext	BSHL_Q23	0.0 W	0.0 W	
MCSSXF.3R5	0.1 m	skew sext	BSHL_Q23	0.0 W	0.7 W	
Drifts	8.6 m	drift	BSHL_Q23	2.6 W	21.1 W	
UncoatedDrifts	5.9 m	drift	BSHL_Q23	1.8 W	232.5 W	
Total IT R5						**419.4 W**

Update on the triplets: heat load tables

Changes w.r.t. presentation given on 29 June:

- New nominal **bunch length** (9 cm)

Effect on the total smaller than 10%

See also G. Skripka and G. Iadarola, "Beam-induced heat loads on the beam screens of the inner triplets for the HL-LHC", to be published, draft available here

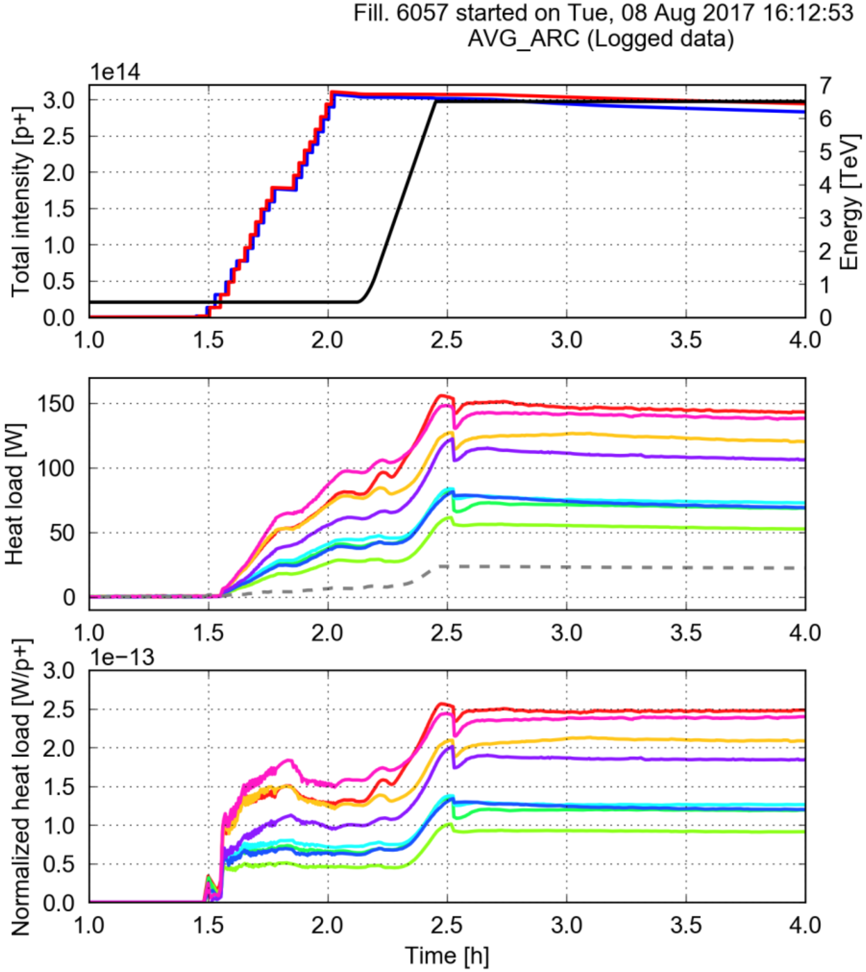
Triplets in IR2&8

Name	Length	Field config.	Chamber	Impedance (T_BS= 20 K)	e-cloud (SEY=1.1/1.3 (UncDrifts))	Total
ITQ1R8	9.8 m		BSMQ_Q1-R	5.2 W	9.5 W	14.7 W
MQXA.1R8	6.4 m	quad	BSMQ_Q1-R	3.5 W	0.7 W	
MCBXH.1R8						
MCBXV.1R8	0.5 m	dip	BSMQ_Q1-R	0.2 W	0.0 W	
Drifts	0.9 m	drift	BSMQ_Q1-R	0.4 W	0.0 W	
UncoatedDrifts	2.1 m	drift	BSMQ_Q1-R	1.0 W	8.8 W	
ITQ2Q3R8	23.7 m		BSMQ_2	9.3 W	43.1 W	52.4 W
MQXB.A2R8	5.5 m	quad	BSMQ_2	2.3 W	3.9 W	
MQXB.B2R8	5.5 m	quad	BSMQ_2	2.3 W	9.1 W	
MQXA.3R8	6.4 m	quad	BSMQ_2	2.6 W	7.4 W	
MCBXH.2R8						
MCBXV.2R8	0.5 m	dip	BSMQ_2	0.2 W	0.0 W	
MCBXH.3R8						
MCBXV.3R8	0.5 m	dip	BSMQ_2	0.2 W	0.0 W	
Drifts	2.9 m	drift	BSMQ_2	1.0 W	0.0 W	
UncoatedDrifts	2.5 m	drift	BSMQ_2	0.8 W	22.7 W	
ITD1R8	13.9 m		BSMB_1	4.2 W	10.4 W	14.6 W
MBX.4R8	9.5 m	dip	BSMB_1	3.0 W	9.7 W	
Drifts	4.4 m	drift	BSMB_1	1.2 W	0.8 W	
UncoatedDrifts	0.0 m	drift	BSMB_1	0.0 W	0.0 W	
Total IT R8						**81.7 W**

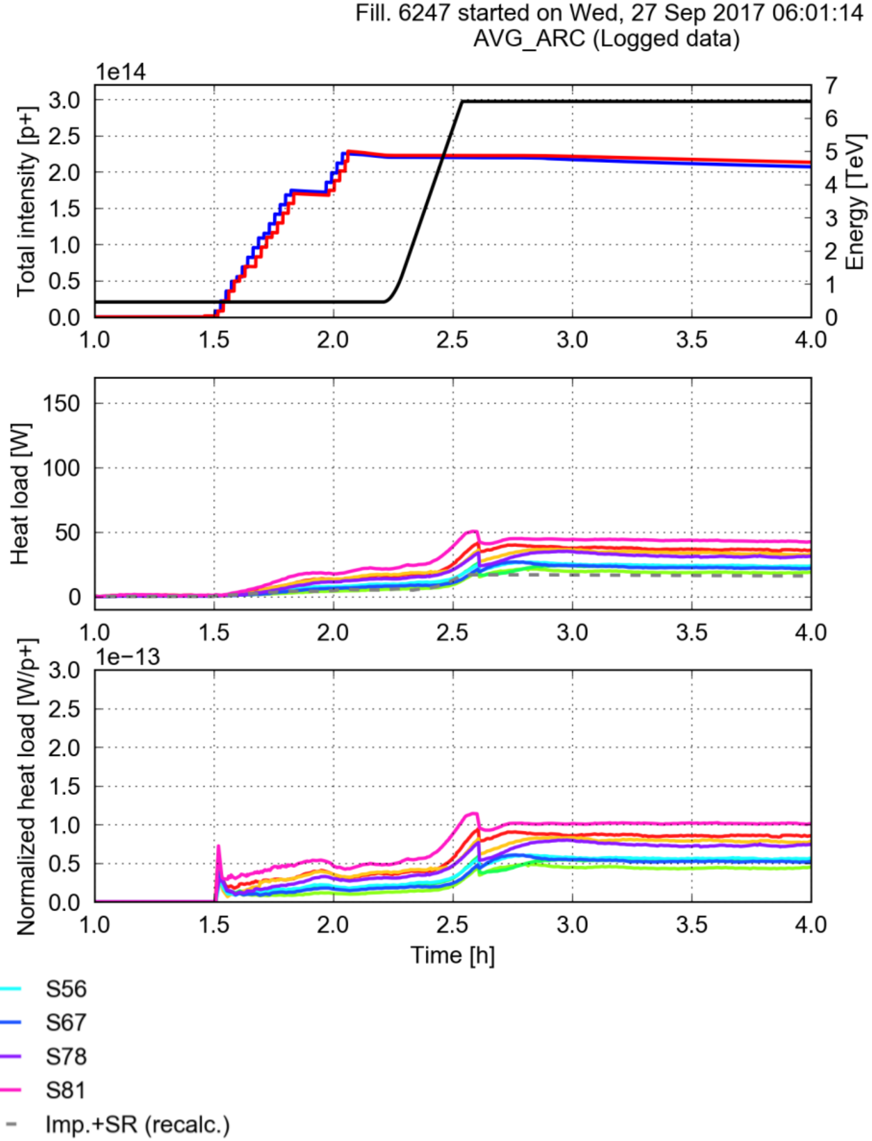
Heat load on the arc beam screen:
Status of ongoing work

Arc heat loads – 2017 status

25 ns (2556b)



8b+4e (1916b)



Arc heat loads – the model

Estimates are **more delicate** than for IRs due to the important **role of photoelectrons** generated by the beam **synchrotron radiation**

Decided to focus on the present LHC at first to develop a **solid model** (to be then applied for HL-LHC predictions):

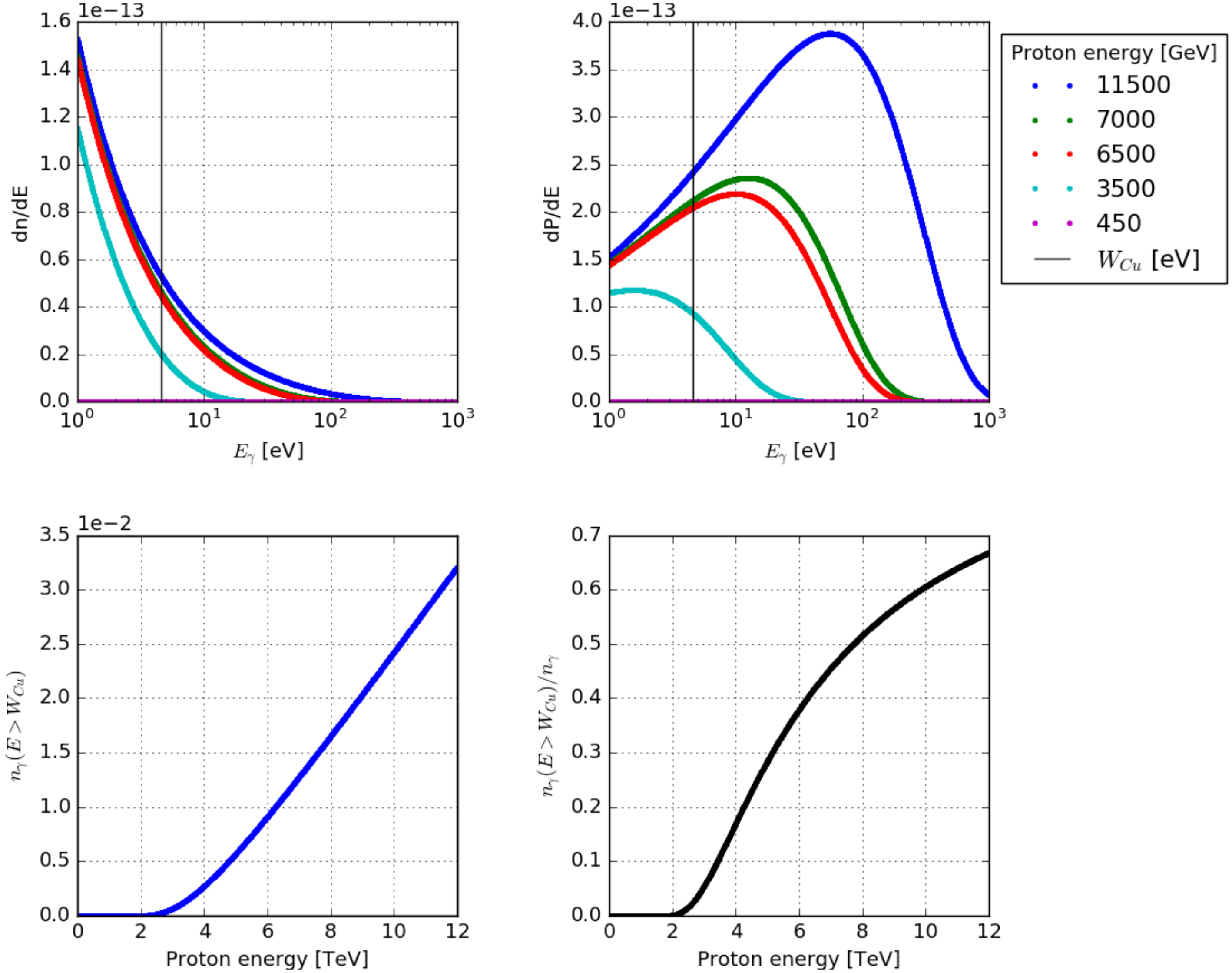
- Performed **literature review** to identify the best available knowledge on **photoelectron yield for the LHC beam screens** (correctly handling the effect of the saw-tooth)
- Defined the **correct "recipe"** to model the **effect of photoelectrons** from synchrotron radiation (implemented in a python tool):
  - Evaluate the **photon spectrum** for an arbitrary energy
  - Compute the number of **"direct" and reflected photoelectrons**
  - Translate the information into the **input parameters required by PyECLOUD**

Details in P. Dijkstal et al., "Simulation studies on the electron cloud build-up in the elements of the LHC Arcs at 6.5 TeV", to be published, draft available [here]

Arc heat loads – the model

Synchrotron radiation spectra

Number of photons above the Copper Work Function



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Arc heat loads – the model

- Estimates on the number of photons has to be combined with information **photoelectron yield** and **reflectivity** from lab measurements

  → Need to take into account the presence of the **sawtooth**

Available measurements show significant differences → Decided to compare **two sets of parameters**:

"Conservative"

Chamber type	R_i	R_r	Y_i	Y_r	Y_i^*	Y_r^*
Cu co-lam. with sawtooth	10.0	82.0	5.2e-02	2.2e-02	5.8e-02	1.2e-01
Cu co-lam.	82.0	82.0	2.3e-02	2.3e-02	1.3e-01	1.3e-01

Chamber type	N_i	N_r	N_t	n_γ	refl_frac	k_pe_st
Cu co-lam. with sawtooth	5.2e-02	1.2e-02	6.4e-02	1.1e-02	1.89e-01	7.00e-04
Cu co-lam.	2.3e-02	1.0e-01	1.3e-01	1.1e-02	8.20e-01	1.38e-03

"Optimistic"

(also accounting for photon conditioning)

Chamber type	R_i	R_r	Y_i	Y_r	Y_i^*	Y_r^*
Cu co-lam. with sawtooth	10.0	82.0	1.0e-02	4.6e-03	1.1e-02	2.6e-02
Cu co-lam.	82.0	82.0	4.6e-03	4.6e-03	2.6e-02	2.6e-02

Chamber type	N_i	N_r	N_t	n_γ	refl_frac	k_pe_st
Cu co-lam. with sawtooth	1.0e-02	2.6e-03	1.3e-02	1.1e-02	2.03e-01	1.39e-04
Cu co-lam.	4.6e-03	2.1e-02	2.6e-02	1.1e-02	8.20e-01	2.81e-04

Symbols:

Y_i, Y_i^*	Photoelectrons yields (defined by Eq. 20 and Eq. 21) in the region of direct impact of the synchrotron radiation (e.g. sawtooth region).
Y_r, Y_r^*	Photoelectron yields in the remaining part of the chamber.
R_i, R_r	Reflection rates in the region of direct synchrotron radiation impact and in the remaining part of the chamber, respectively.
N_i, N_r	Photoelectrons emitted in the region of direct impact of the synchrotron radiation and in the remaining part of the chamber, respectively.
N_t	Total number of emitted photoelectrons.
$n_\gamma(E > W_{\mathrm{Cu}})$	Number of photons with an energy above the copper work function, emitted per proton and per m in the LHC arc bending magnets (Eq. 16).

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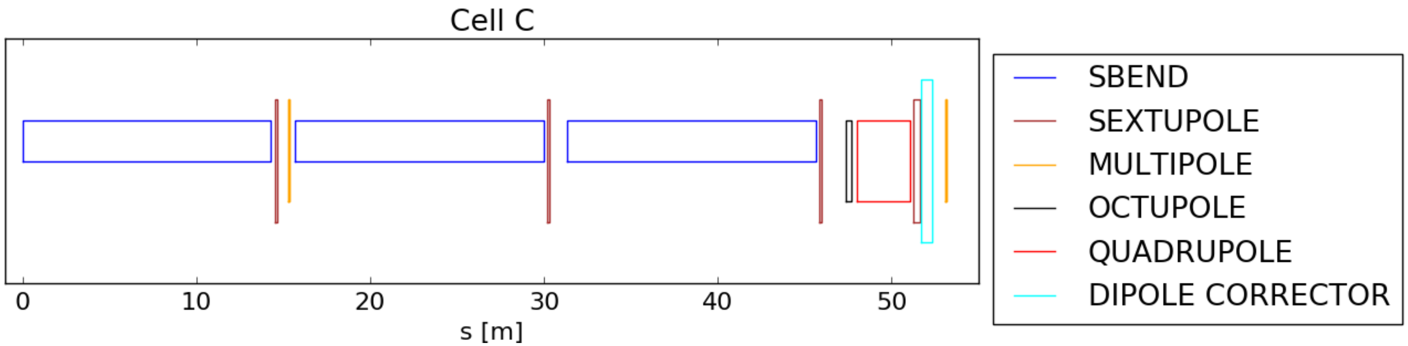
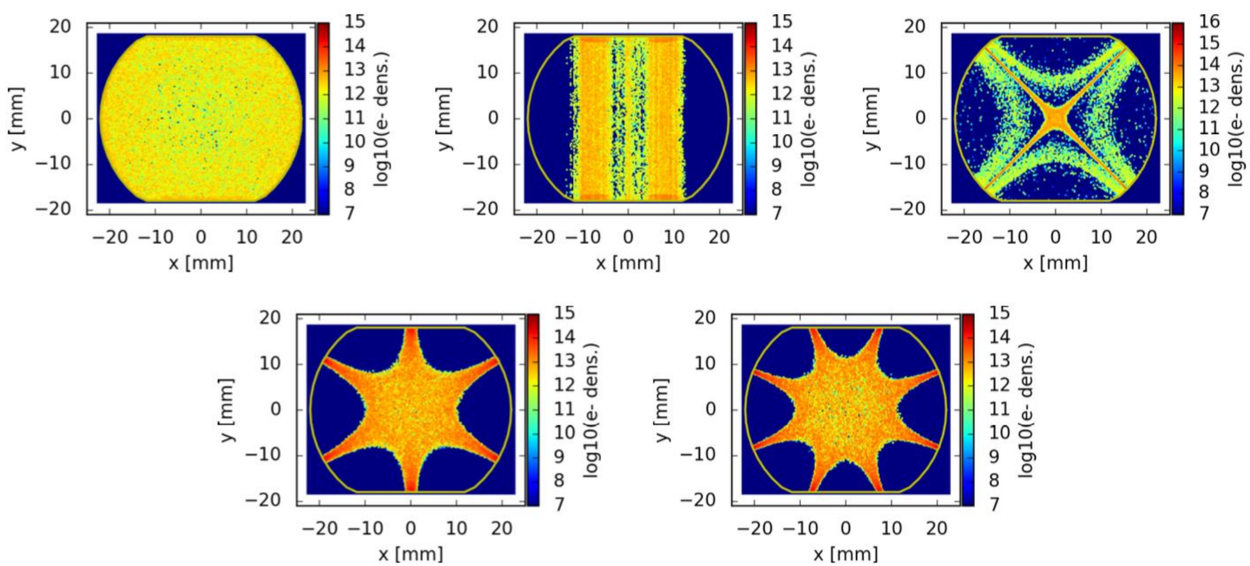
Arc heat loads – the model

The defined models have been used to simulate all the element of the arc half-cell





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Arc heat loads – results for LHC beam parameters

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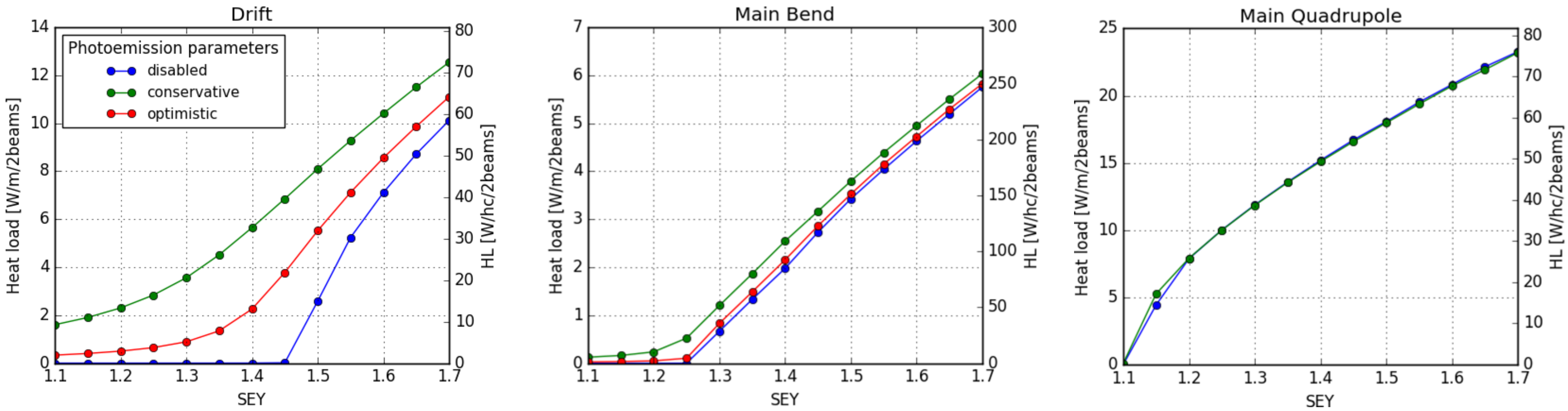
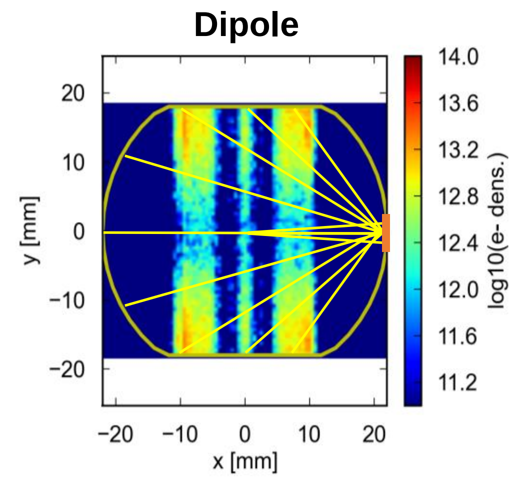


The **impact of the photoelectrons** is very **strong the drift sections**:

- For the other elements, in the presence of a vertical magnetic field, only photoelectrons from reflected photons (<10%) can be accelerated by the beam and contribute to the heat load



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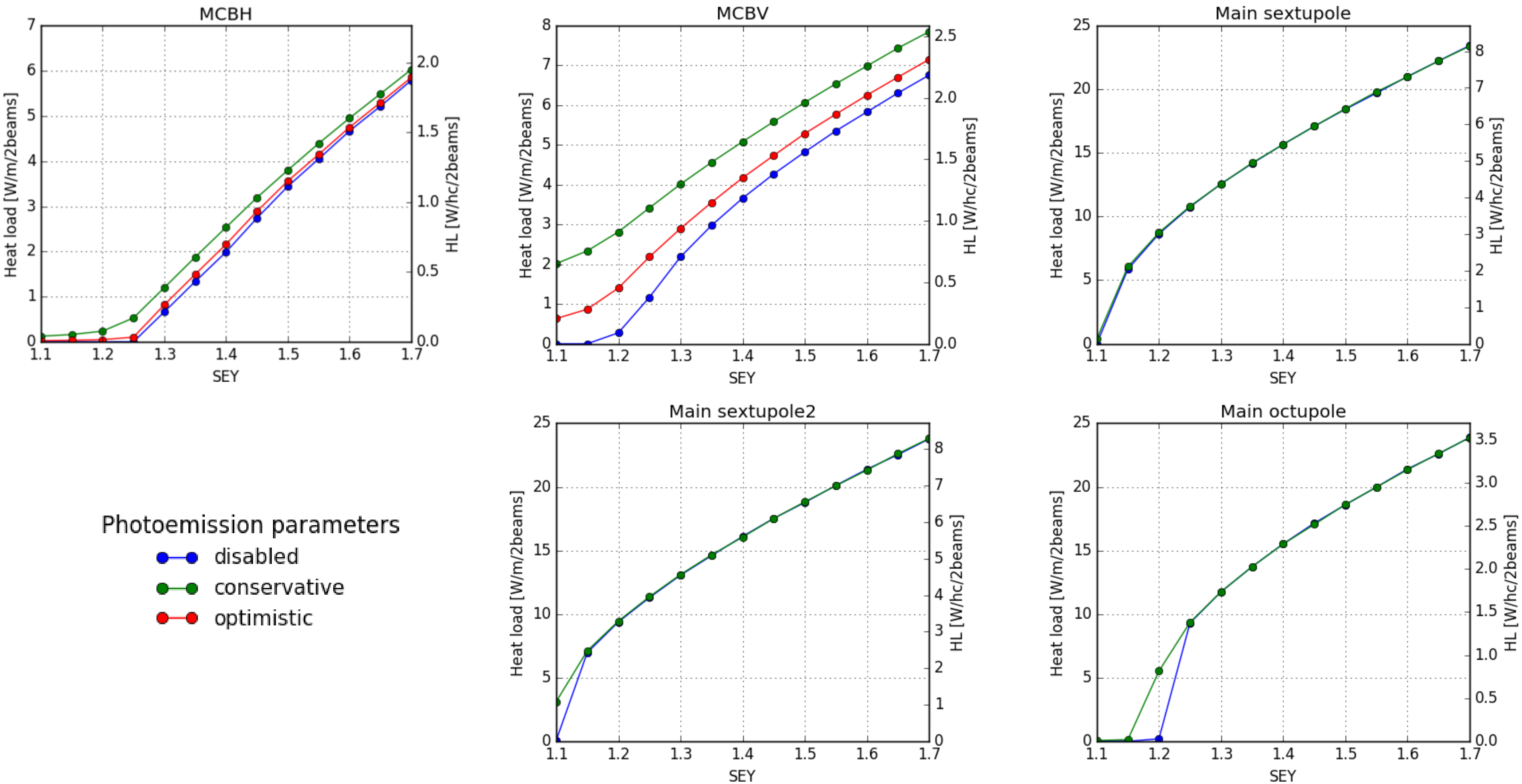

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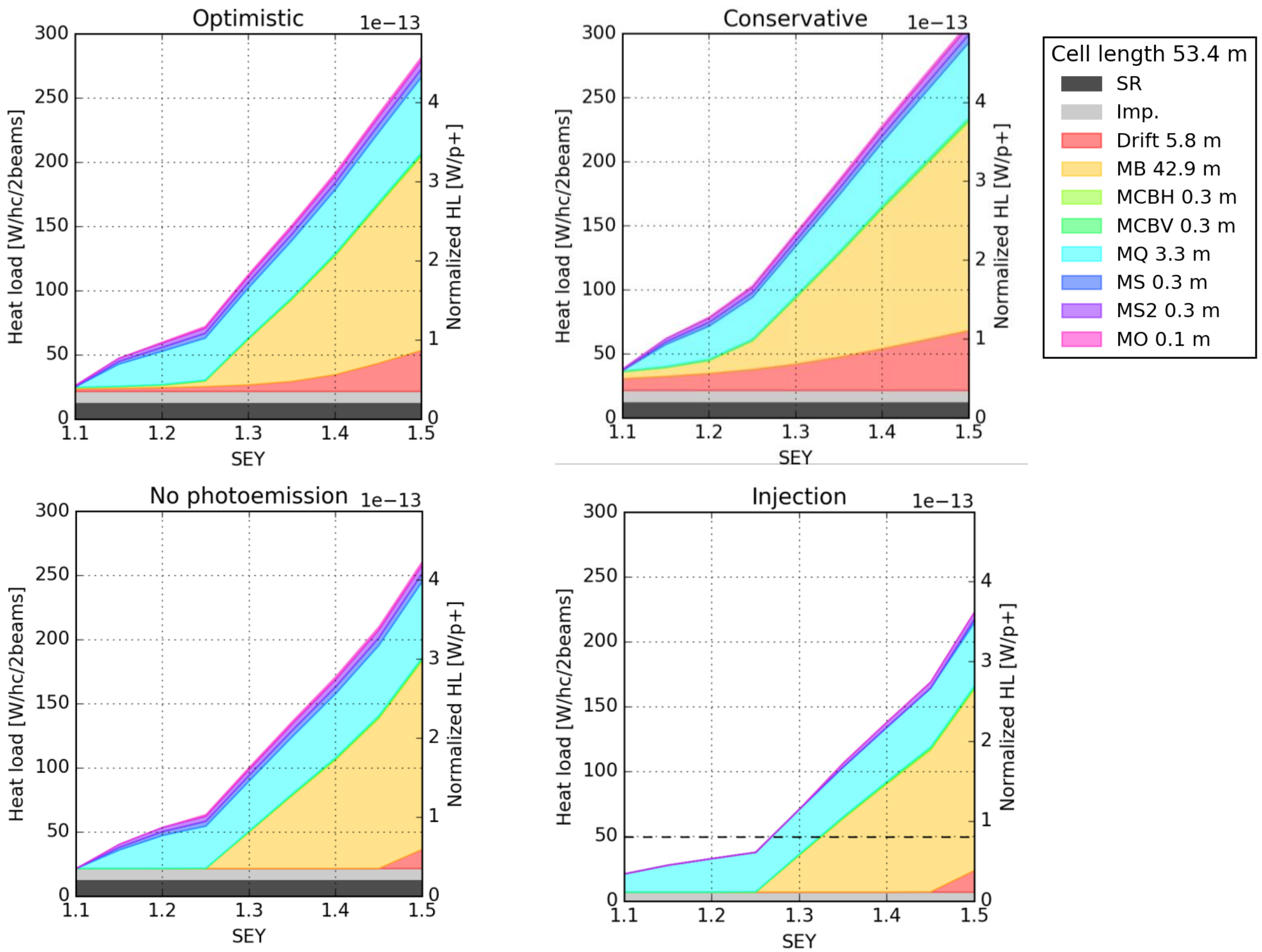
Arc heat loads – results for LHC beam parameters

Total loads (assuming SEY uniform in the cell)



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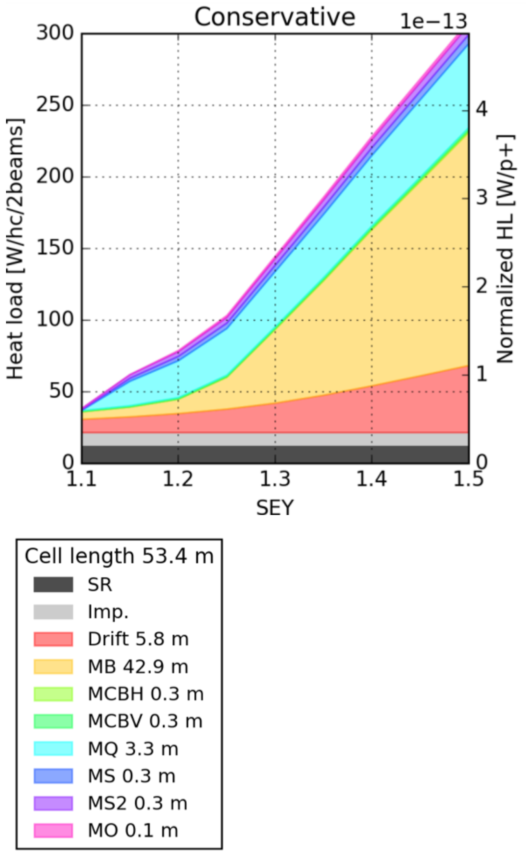
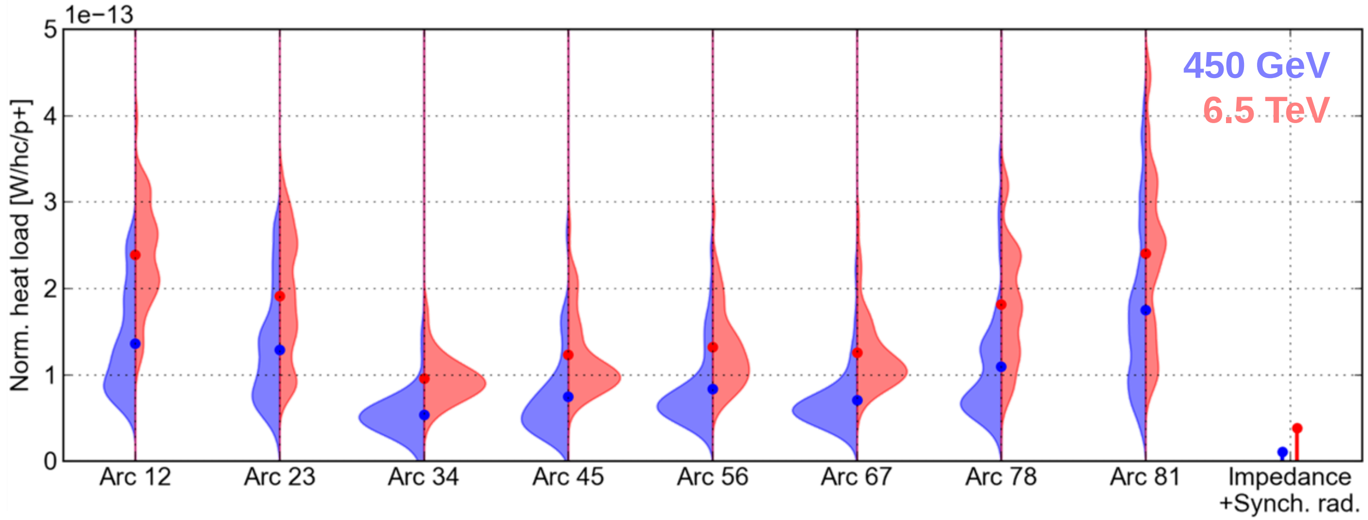
Arc heat loads: SEY estimate based on measurements

We started by using the **conservative** parameter set→ analysis will be repeated with the “optimistic” and cross-checked against measurements at injection energy…

Simulations



Measurements



Fill	6054	6054
Started on	07 Aug 2017 14:15	07 Aug 2017 14:15
T_sample [h]	2.58	3.10
Energy [GeV]	450	6499
N_bunches (B1/B2)	2556/2556	2556/2556
Intensity (B1/B2) [p]	2.94e14/3.03e14	2.91e14/3.01e14
Bun.len. (B1/B2) [ns]	1.27/1.29	1.07/1.07
H.L. exp. imped. [W]	6.47	10.15
H.L. exp. synrad [W]	0.00	12.61
H.L. exp. imp.+SR [W/p+]	1.08e-14	3.84e-14
T_nobeam [h]	1.90	1.90

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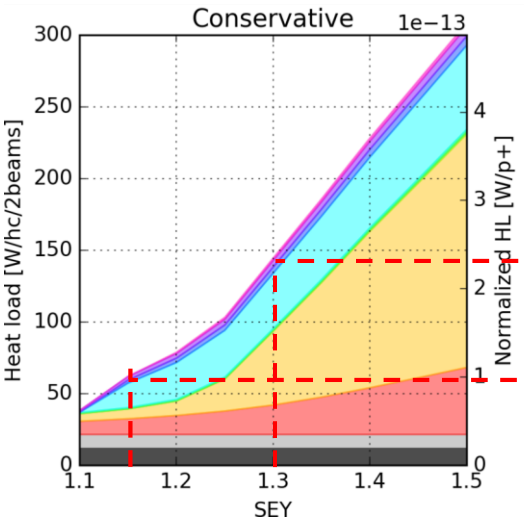

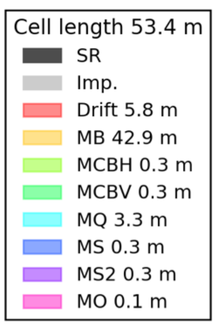

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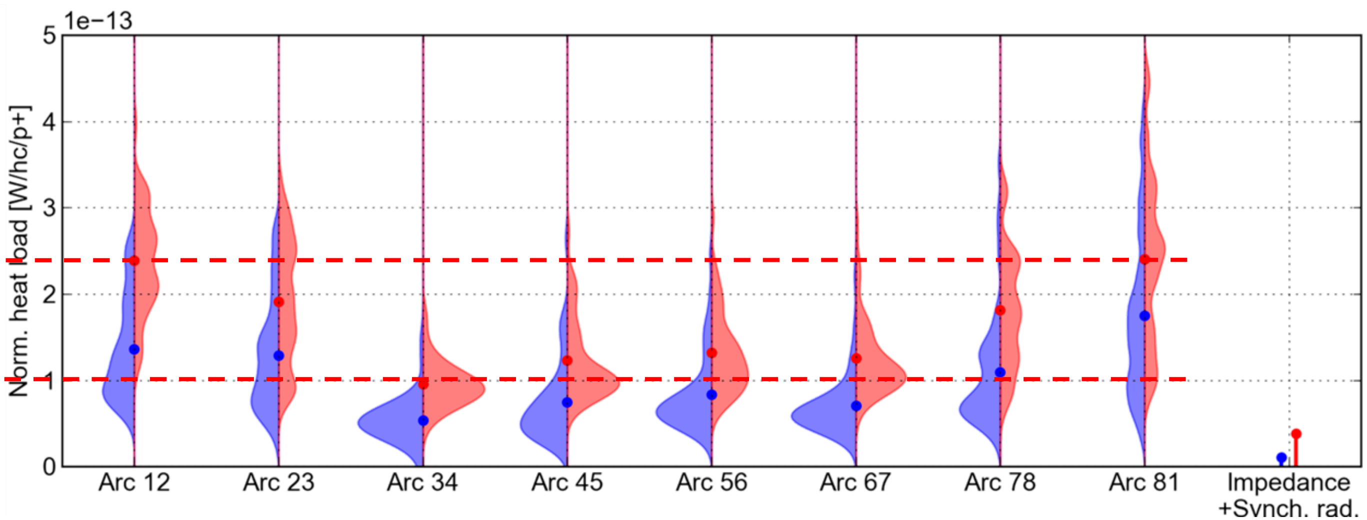
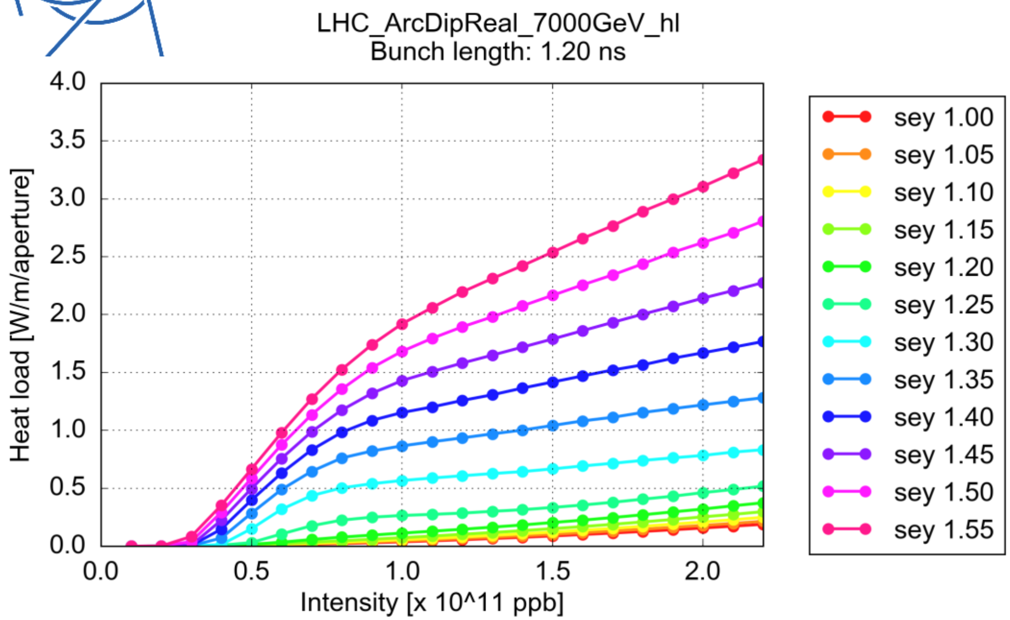
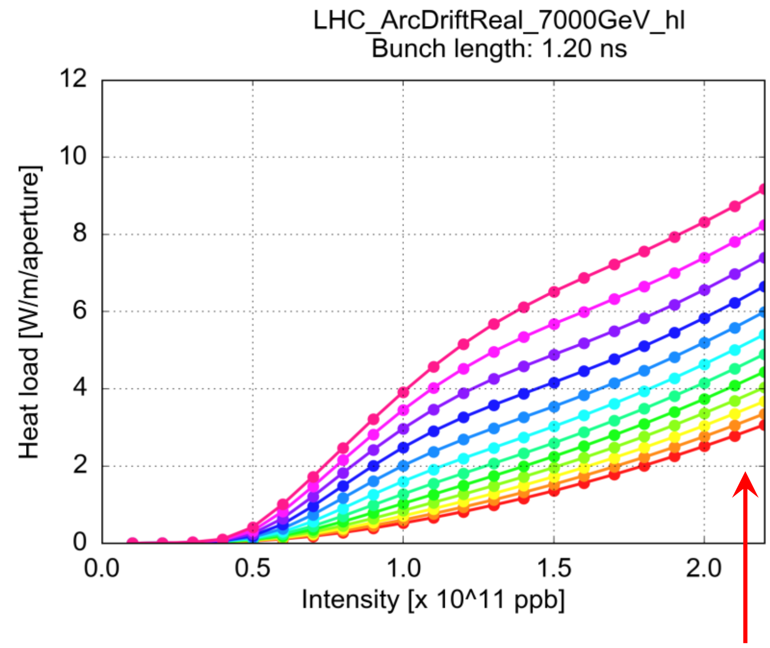


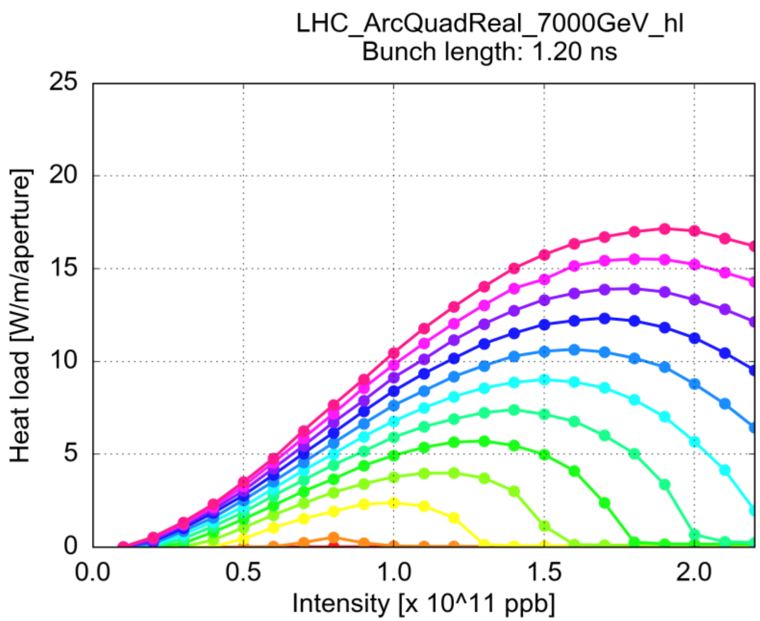
Based on these assumptions:

Avg. high load sectors (S12, S81):	**SEY = ~1.3**
Avg. low load sectors (S34, S45, S56, S67):	**SEY = ~1.15**
Worst cells in the ring:	**SEY = ~1.4**
Best cells in the ring:	**SEY = ~1.1**

Arc heat loads: simulations for HL-LHC

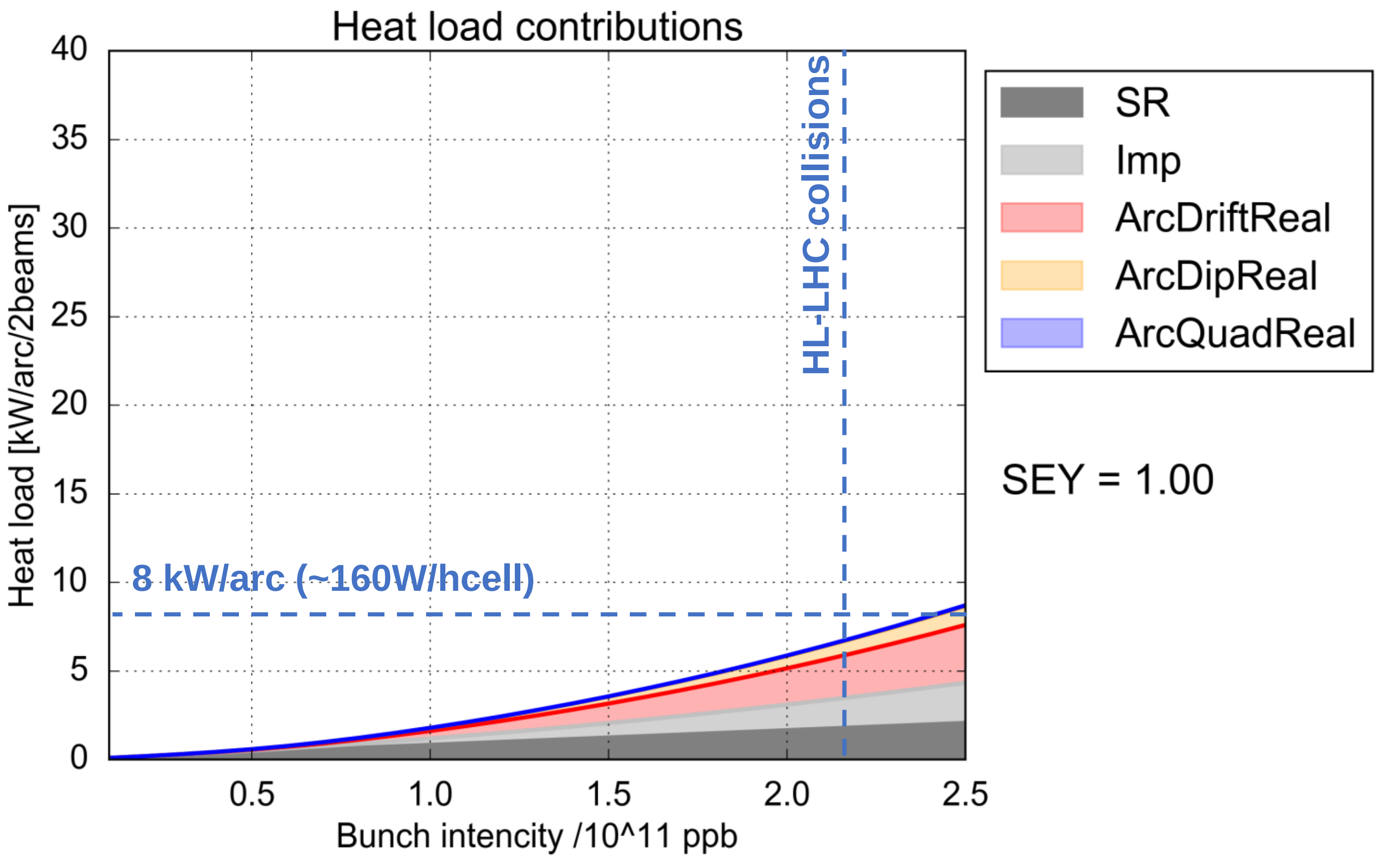






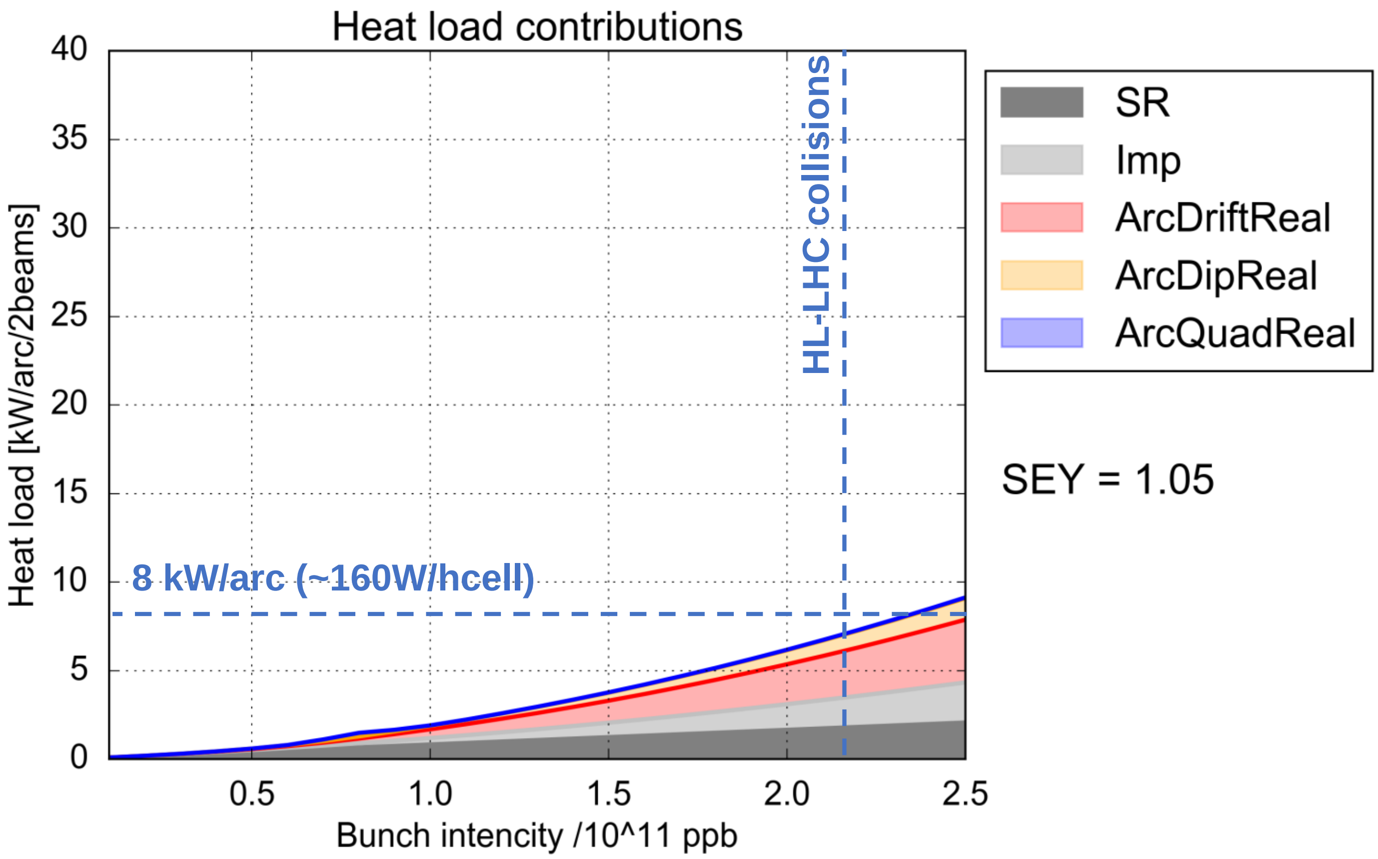
- **Conservative parameter set** used for the photoelectrons
- **Different trends** with bunch intensity observed for dipoles, quadrupoles and drifts
- **Significant heat load** from the **drifts** even for **low SEY**

Arc heat loads: simulations for HL-LHC



- For high bunch intensity **significant heat load is observed already for low SEY** (from impedance, synchrotron radiation, photoelectrons in the drifts)

Arc heat loads: simulations for HL-LHC



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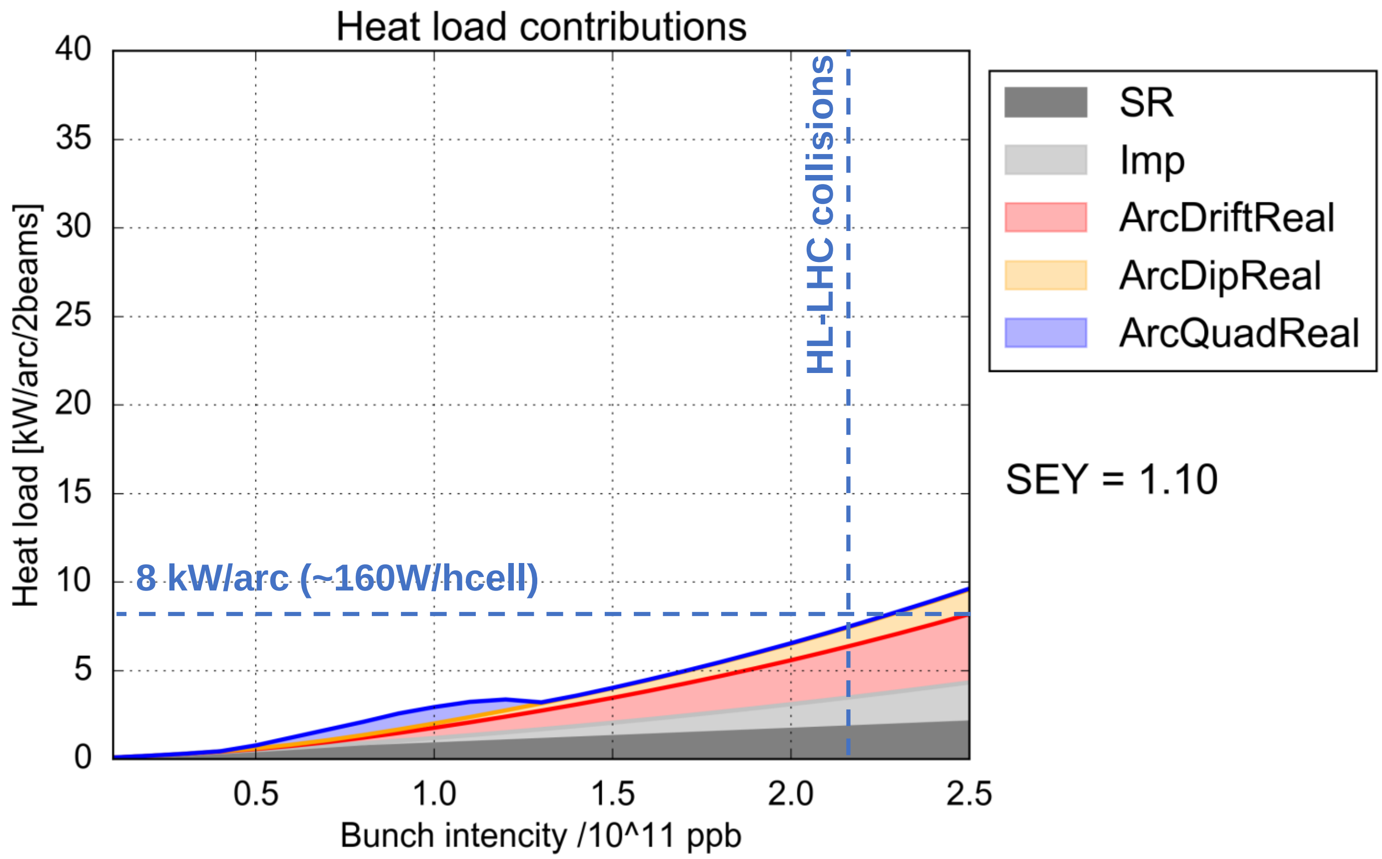

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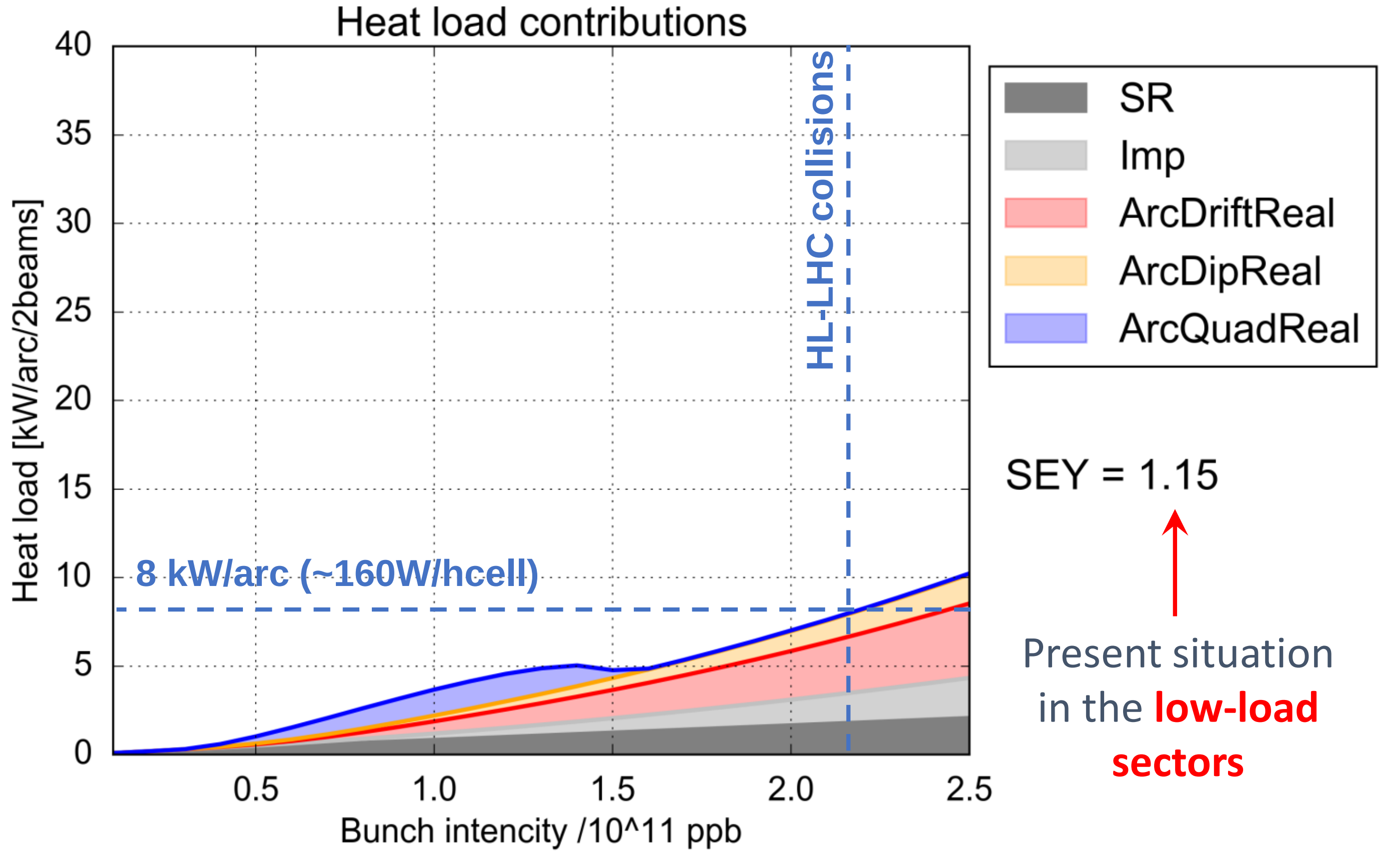
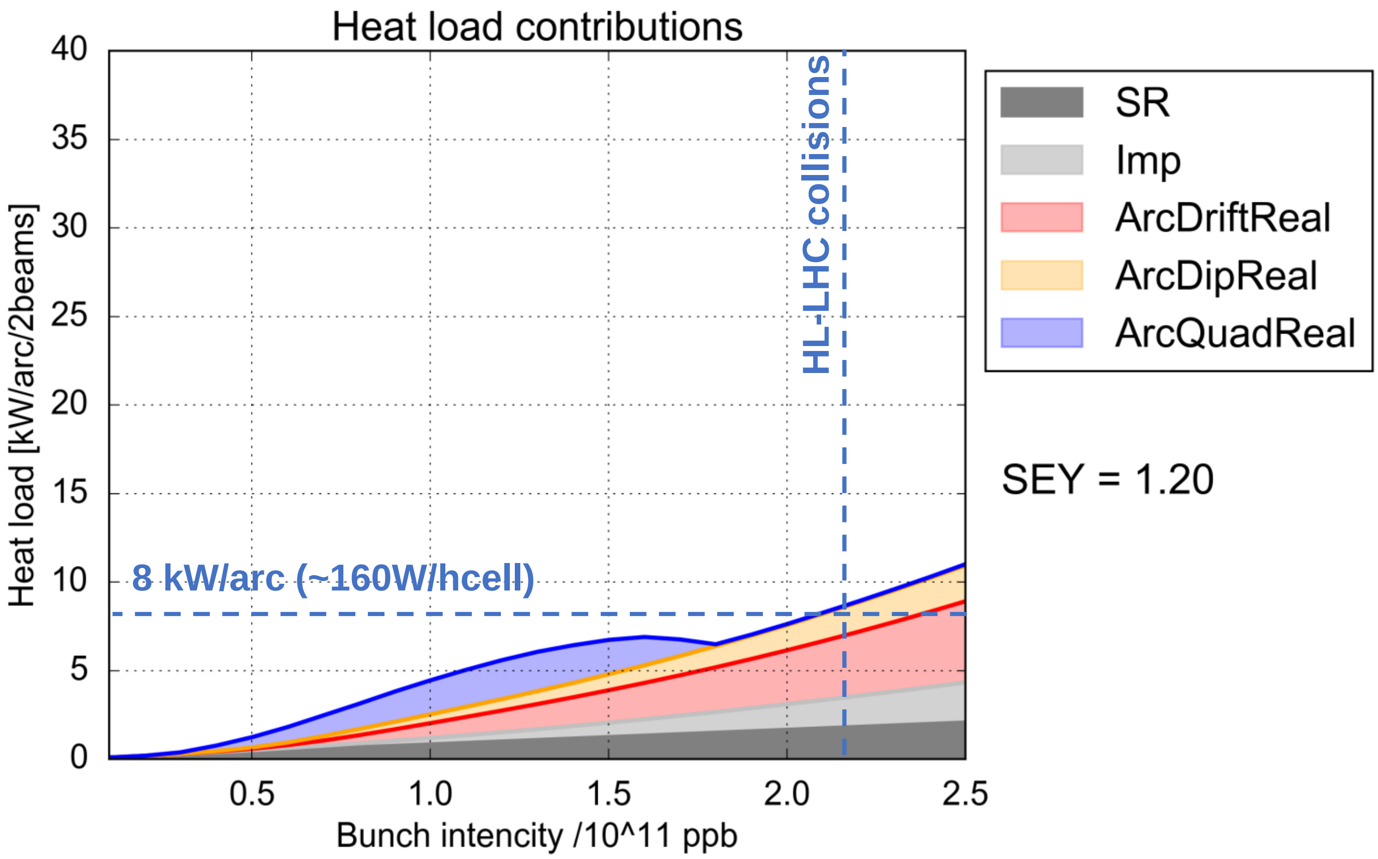


SEY = 1.15

Present situation in the **low-load sectors**

- For high bunch intensity **significant heat load is observed already for low SEY** (from impedance, synchrotron radiation, photoelectrons in the drifts)
- Present conditioning achieved in the **low-load sectors** is **compatible with HL-LHC**

Arc heat loads: simulations for HL-LHC



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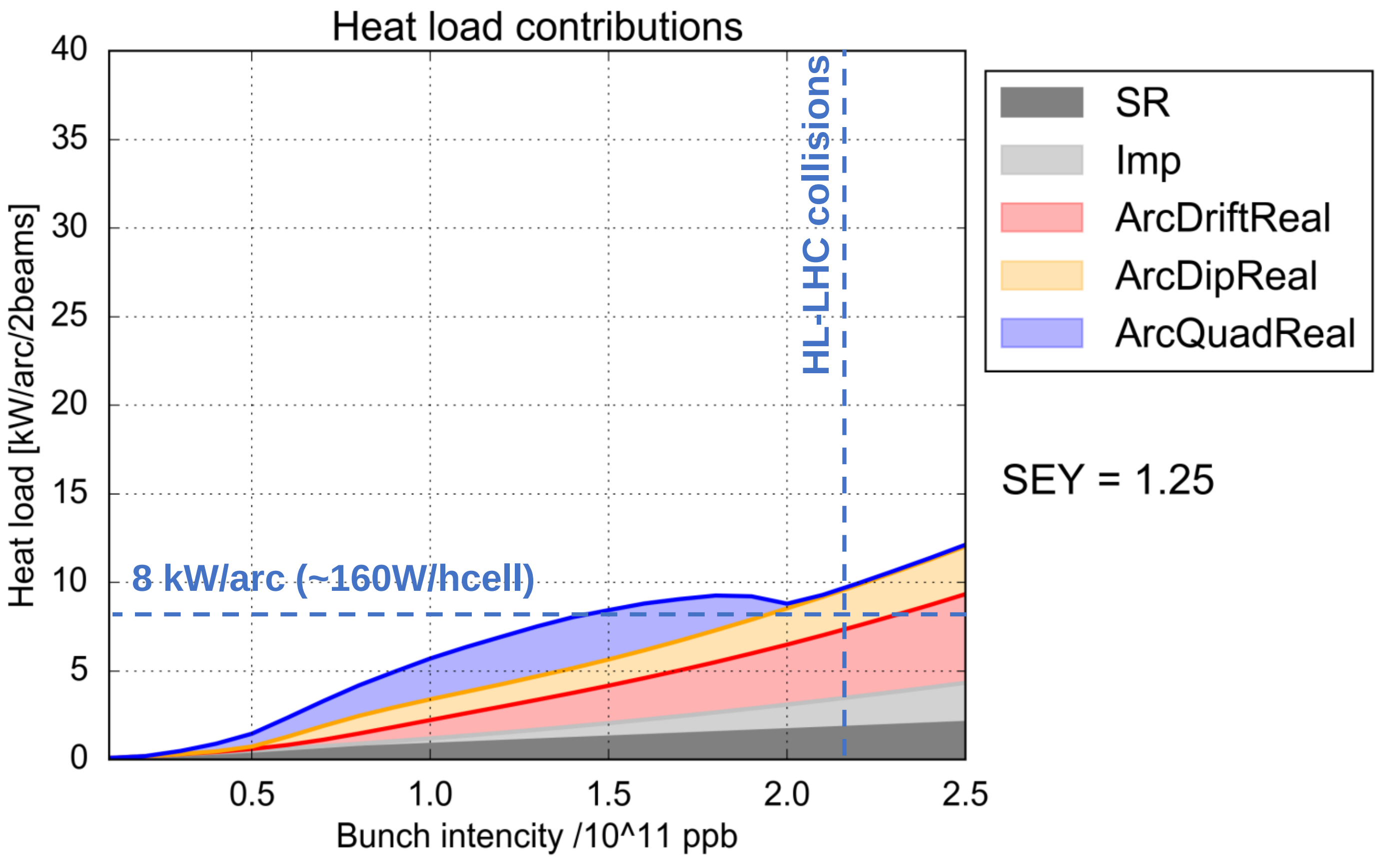

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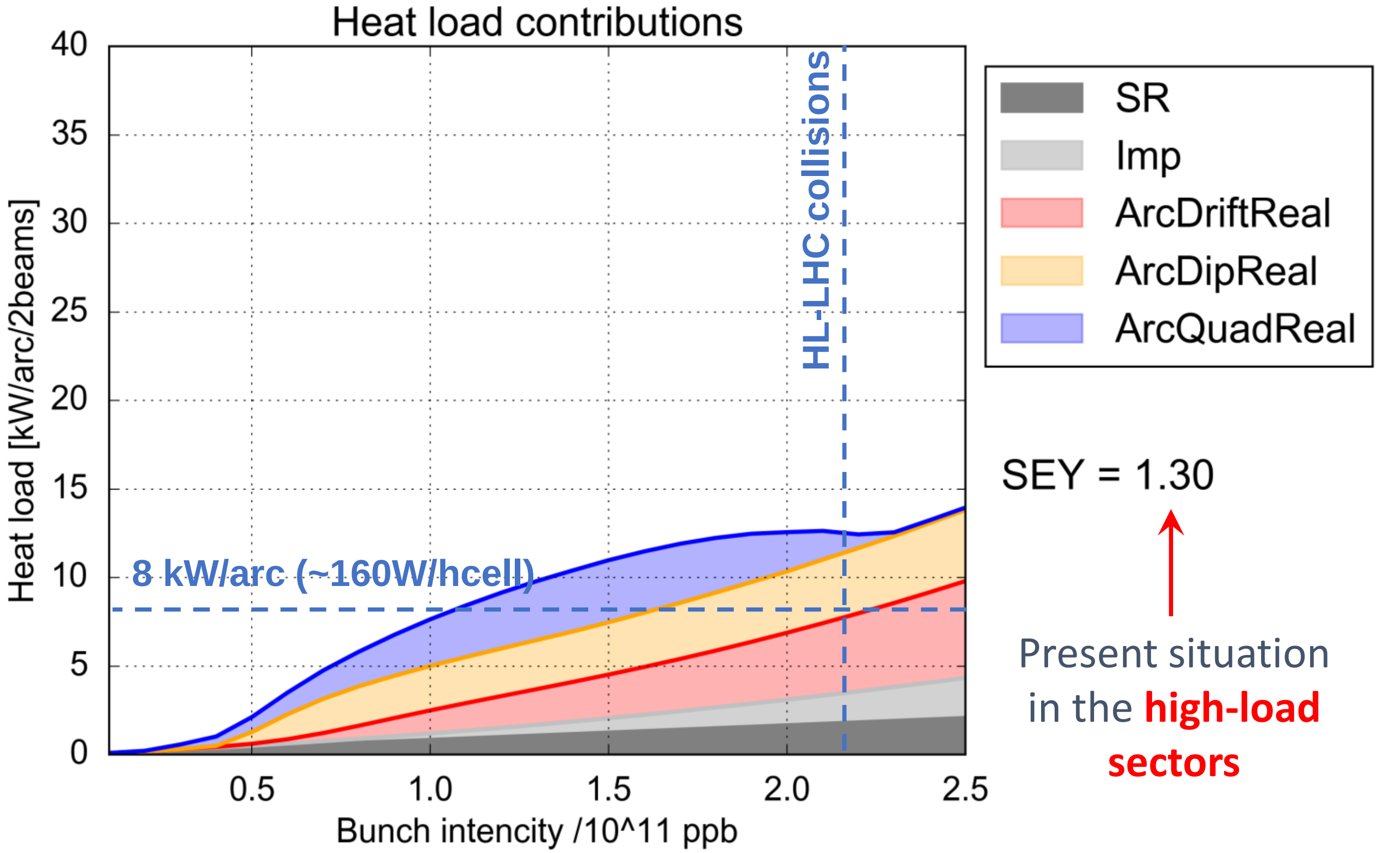
Arc heat loads: simulations for HL-LHC



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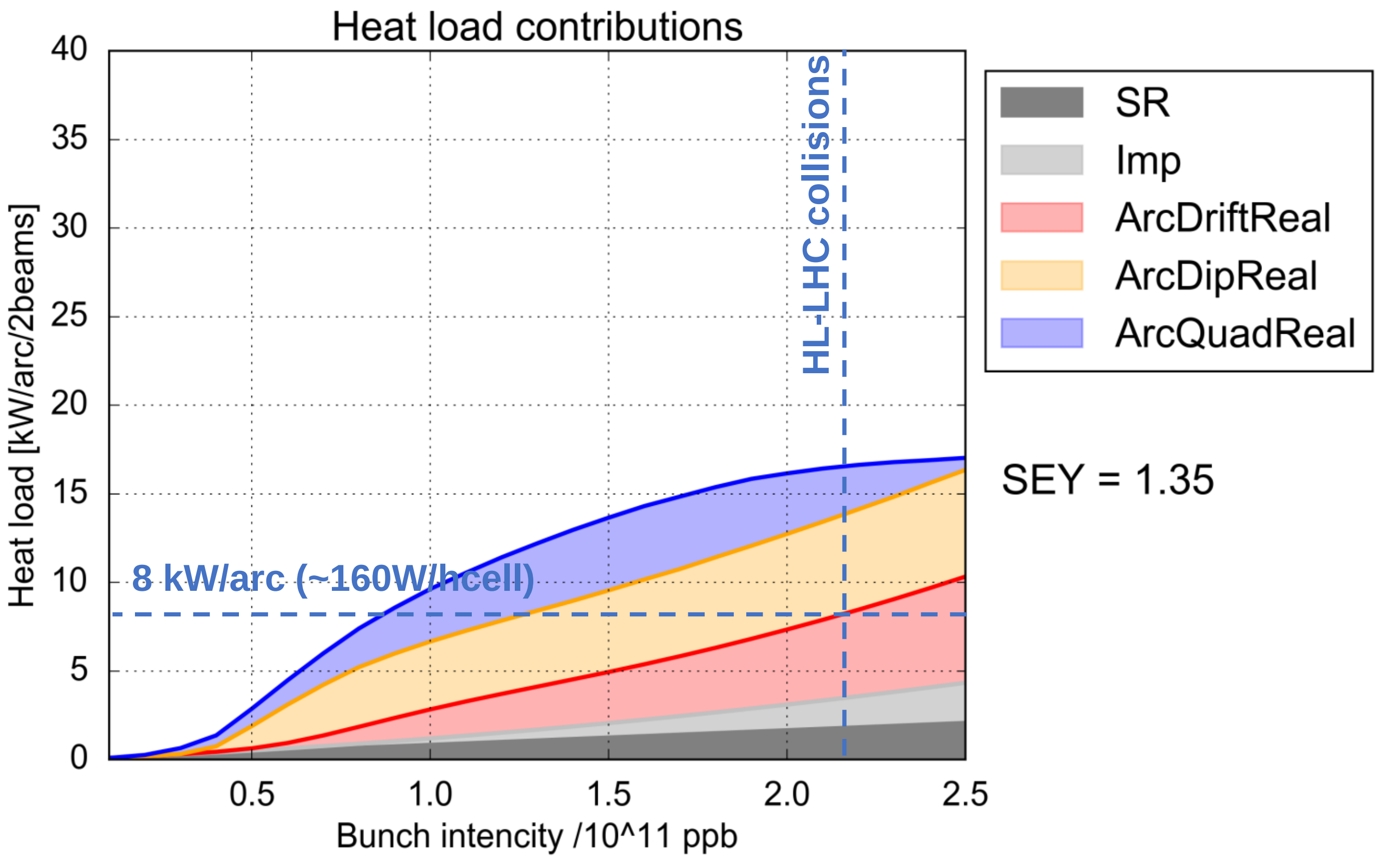

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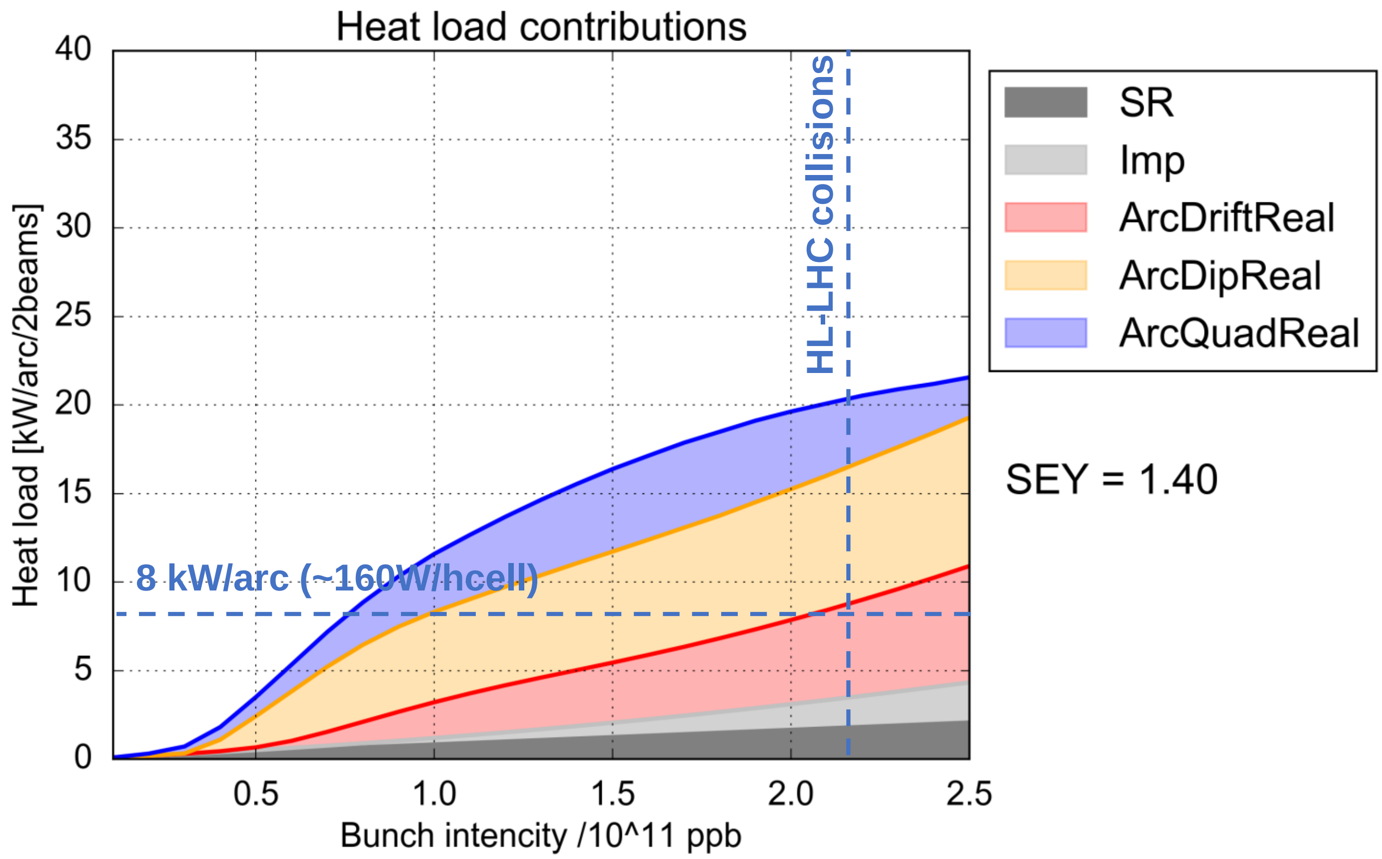

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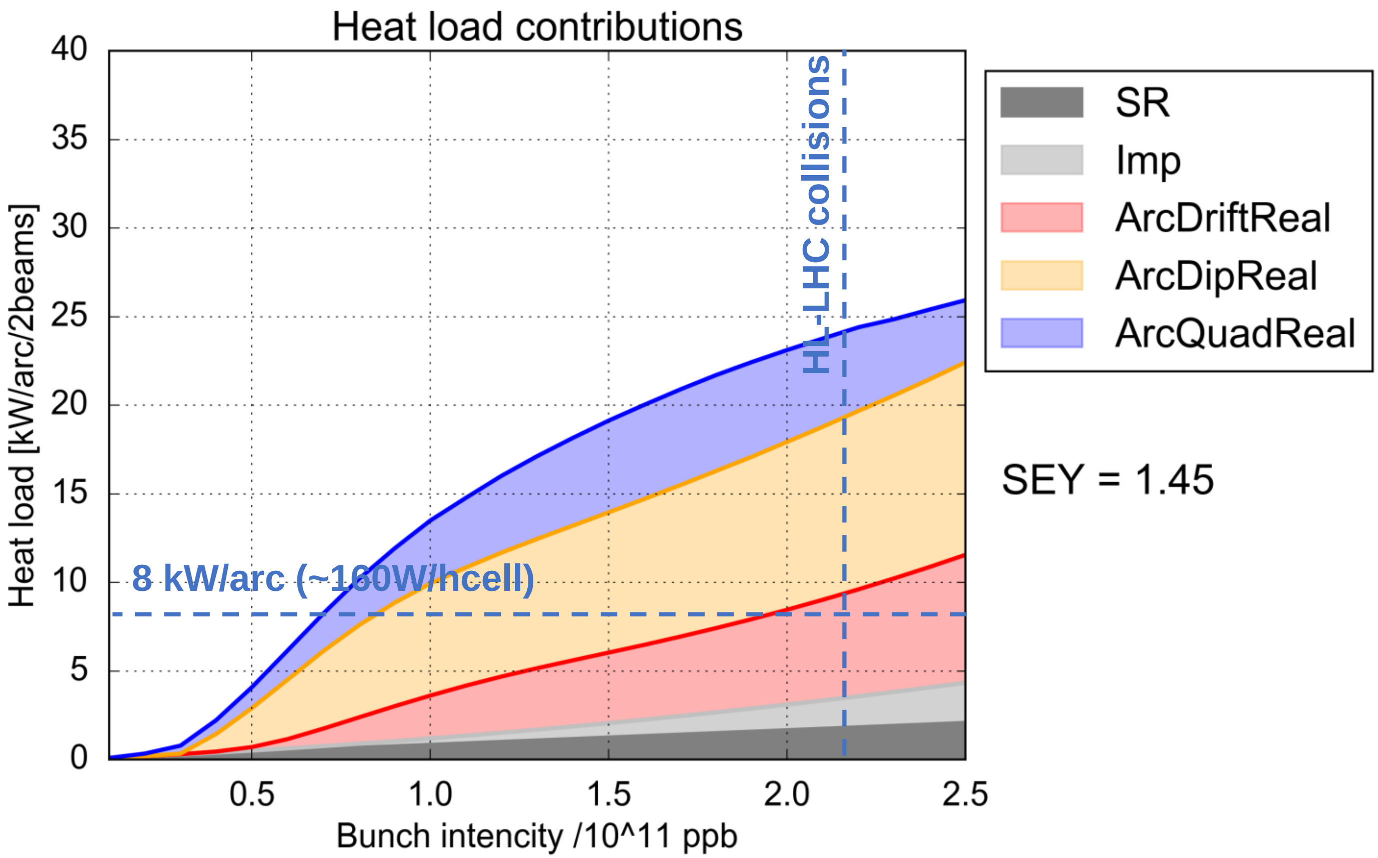

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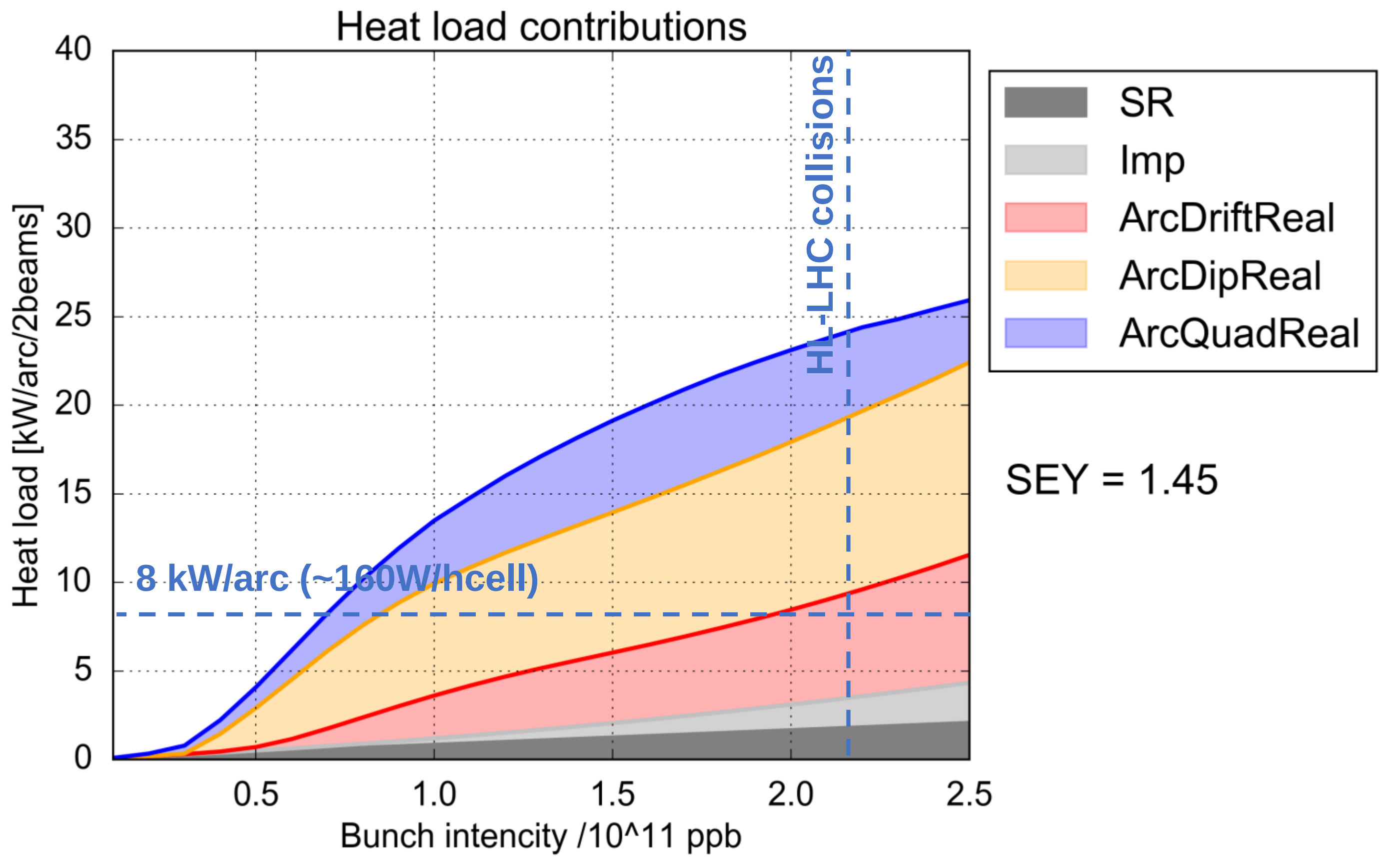

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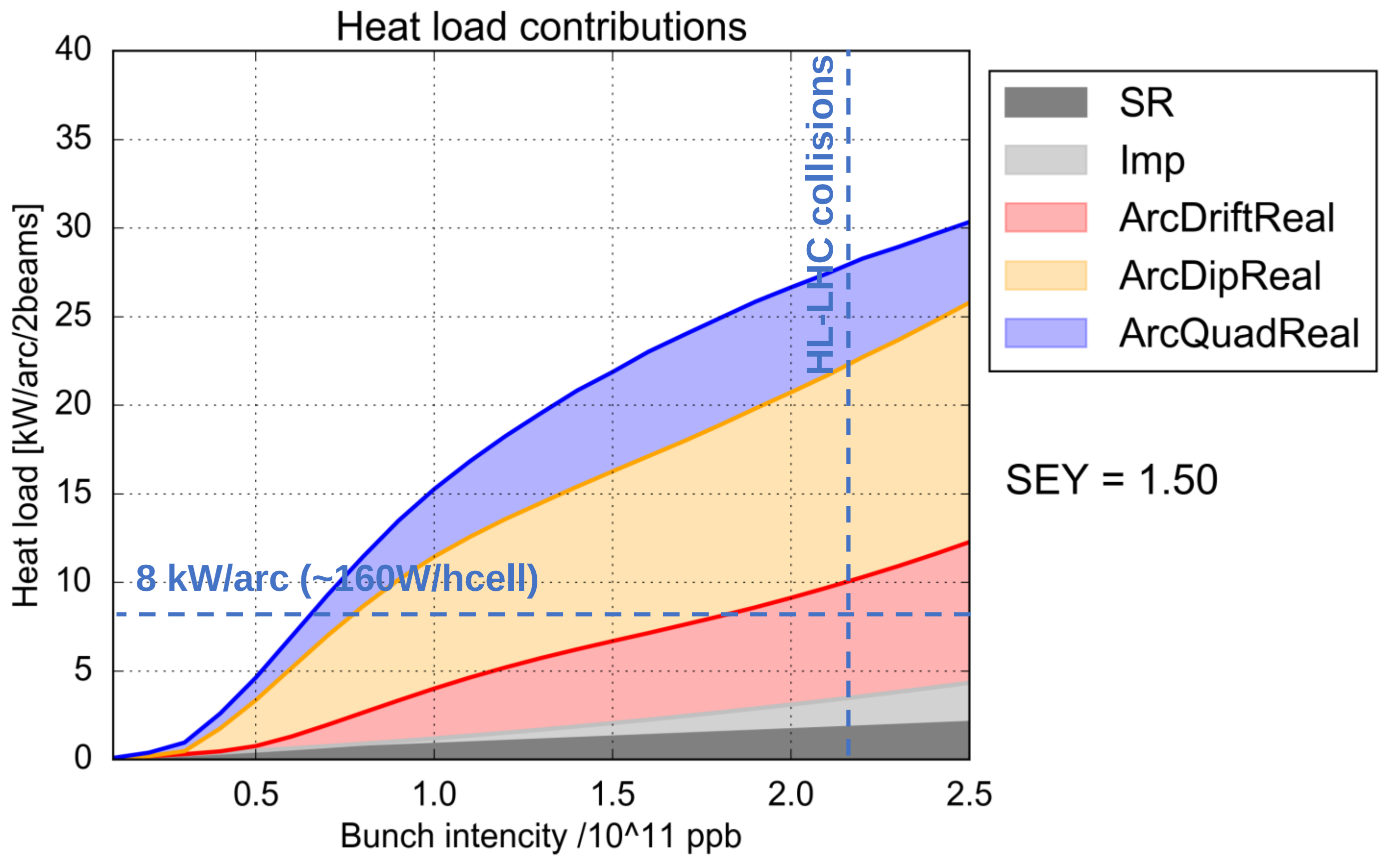

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Summary and conclusions

- Heat load **estimates for Inner Triplets and other magnets in the IR** have been **finalized** including the effect of impedance and e-cloud effects
- **Ongoing work** to estimate HL-LHC heat loads on the **arcs beam screens** (more complicated due to the effect of photoelectrons generated by synchrotron radiation)
  - Developed a **detailed model** including all elements of the arc half-cell and taking into account the **effect of photoelectrons**
  - **Simulations for LHC beam parameters** compared with heat load measurements to quantify the present conditioning state of the machine (SEY values) → Large **differences** observed between different arcs
  - With these values we made **first extrapolations for HL-LHC** (using a "conservative" parameter set for photoelectrons → to be refined):
    - For the **low-load sectors**, the present conditioning state would be **sufficient to operate with HL-LHC beam parameters** (with little margin…)
    - This is not the case for the **high-load sectors**, where the expected load goes **beyond 10 kW/arc**
  - It is **necessary to identify and suppress source of large heat loads** in S12, S23, S78, S81 in order to allow operation with HL-LHC beam parameters
  - Still margin on available **cooling capacity will be quite limited**
    - Heat load on LSS magnets in **IR2 and IR8 will affect the neighboring arcs** → **Low SEY coating of these matching sections is desirable**

Thanks for your attention!

25 ns (2556b)

8b+4e (1916b)