Summary of heat load estimates

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

HLLHC-WP2 Meeting, 29 June 2017

Outline

- Introduction and some reminders on previous results
- Heat load estimates for the Inner Triplets
  - IR1 and IR5
  - IR2 and IR8
- Progress status on arc heat loads
- Simulations for the TAXS absorber

Introduction

- In 2017 we continued **exchanging estimates on beam induced heat loads with WP9**
  - **HeatLoadCalculator tool** used regularly to evaluate impedance and synchrotron radiation contribution
  - Agreed on **conventions and file format**
  - Heat loads are provided **per cryostat**, separating the different sources
  - For the **arcs** we provide the **loads over the total length** (first to last bend, including dispersion suppressors)

heat_loads_estimation_LSS_HL_LHC.txt

```
# Heat load estimations for the LHC IR magnets
# Evaluated scenario: HL-LHC
# - Beam energy 7000.0 GeV
# - Bunch intensity: 2.20e+11 p
# - Bunch length (4*sigma): 1.20 ns
# - N. bunches: 2748
# - T = 70K assumed for the beam screens in the inner triplets
# - T = 20K assumed for the other beam screens
# The following values are for TWO beams.
# Component, Heat Load Impedance [W], Heat Load Synchrotron Radiation [W]
ITaL1,4.08e+00,0.00e+00
ITbL1,1.53e+01,0.00e+00
D2L1,2.72e+00,0.00e+00
Q4L1,2.36e+00,0.00e+00
Q5L1,3.20e+00,0.00e+00
Q6L1,4.01e+00,0.00e+00
ITaR1,4.08e+00,0.00e+00
ITbR1,1.53e+01,0.00e+00
D2R1,2.72e+00,0.00e+00
Q4R1,2.36e+00,0.00e+00
Q5R1,3.20e+00,0.00e+00
Q6R1,4.01e+00,0.00e+00
ITaL2,5.08e+00,0.00e+00
ITbL2,9.00e+00,0.00e+00
ITcL2,4.19e+00,0.00e+00
Q4L2,4.74e+00,0.00e+00
D2L2,3.99e+00,0.00e+00
Q5L2,4.84e+00,0.00e+00
Q6L2,6.94e+00,0.00e+00
ITaR2,5.08e+00,0.00e+00
ITbR2,9.00e+00,0.00e+00
ITcR2,4.19e+00,0.00e+00
D2R2,3.99e+00,0.00e+00
```

HL-LHC

heat_loads_estimation_LSS_LHC_DesignReport.txt

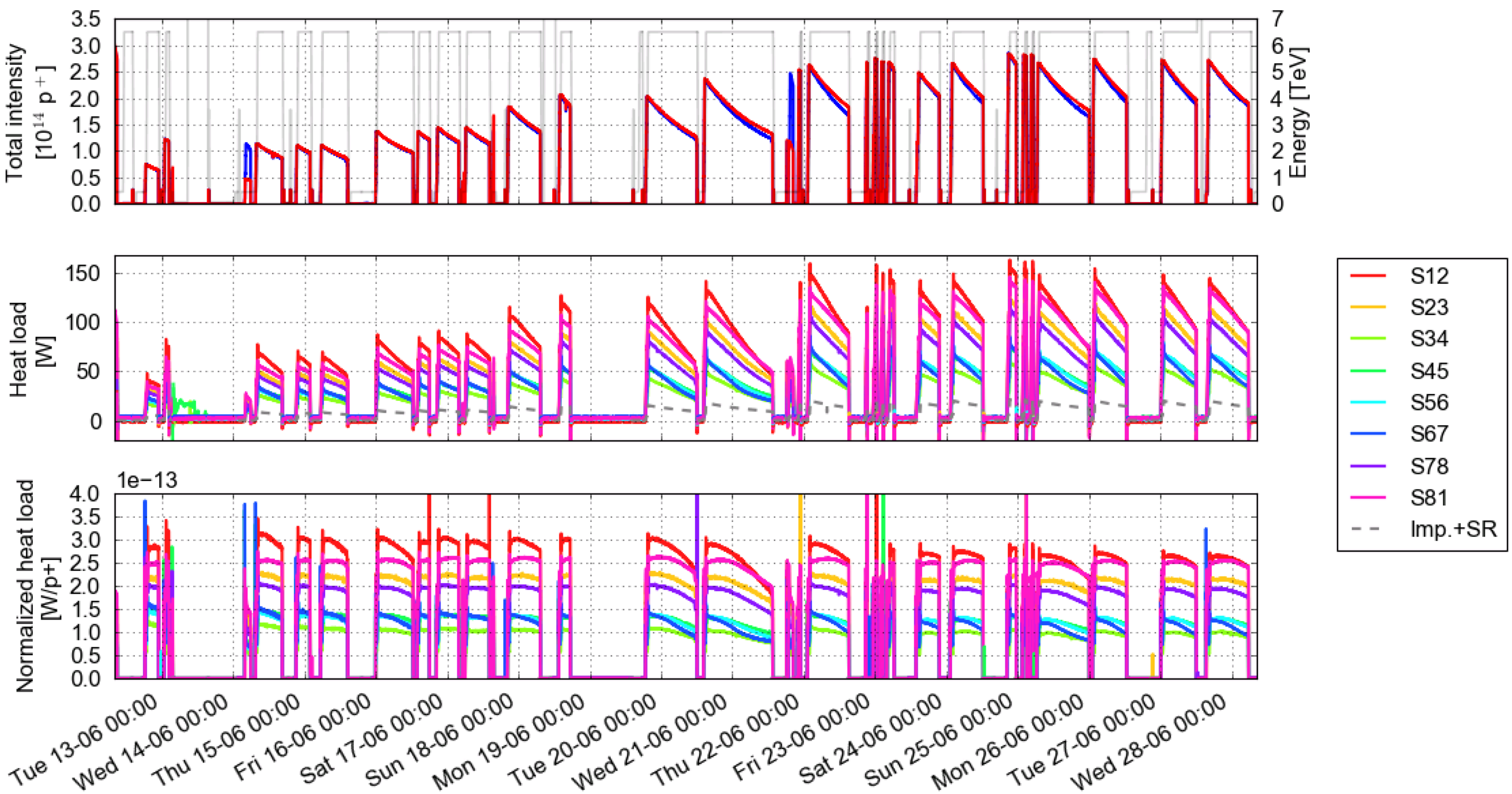
```
# Heat load estimations for the LHC IR magnets
# Evaluated scenario: LHC_DesignReport
# - Beam energy 7000.0 GeV
# - Bunch intensity: 1.15e+11 p
# - Bunch length (4*sigma): 1.00 ns
# - N. bunches: 2808
# The following values are for TWO beams.
# Component, Heat Load Impedance [W], Heat Load Synchrotron Radiation [W]
ITaL1,1.86e+00,0.00e+00
ITbL1,3.46e+00,0.00e+00
D2L1,1.46e+00,0.00e+00
Q4L1,1.25e+00,0.00e+00
Q5L1,1.73e+00,0.00e+00
Q6L1,1.73e+00,0.00e+00
ITaR1,1.86e+00,0.00e+00
ITbR1,3.46e+00,0.00e+00
D2R1,1.46e+00,0.00e+00
Q4R1,1.25e+00,0.00e+00
Q5R1,1.73e+00,0.00e+00
Q6R1,1.73e+00,0.00e+00
ITaL2,1.86e+00,0.00e+00
ITbL2,3.30e+00,0.00e+00
ITcL2,1.54e+00,0.00e+00
Q4L2,1.74e+00,0.00e+00
D2L2,1.46e+00,0.00e+00
Q5L2,1.78e+00,0.00e+00
Q6L2,2.55e+00,0.00e+00
ITaR2,1.86e+00,0.00e+00
ITbR2,3.30e+00,0.00e+00
ITcR2,1.54e+00,0.00e+00
D2R2,1.46e+00,0.00e+00
Q4R2,1.74e+00,0.00e+00
Q5R2,2.74e+00,0.00e+00
```

LHC Design Report

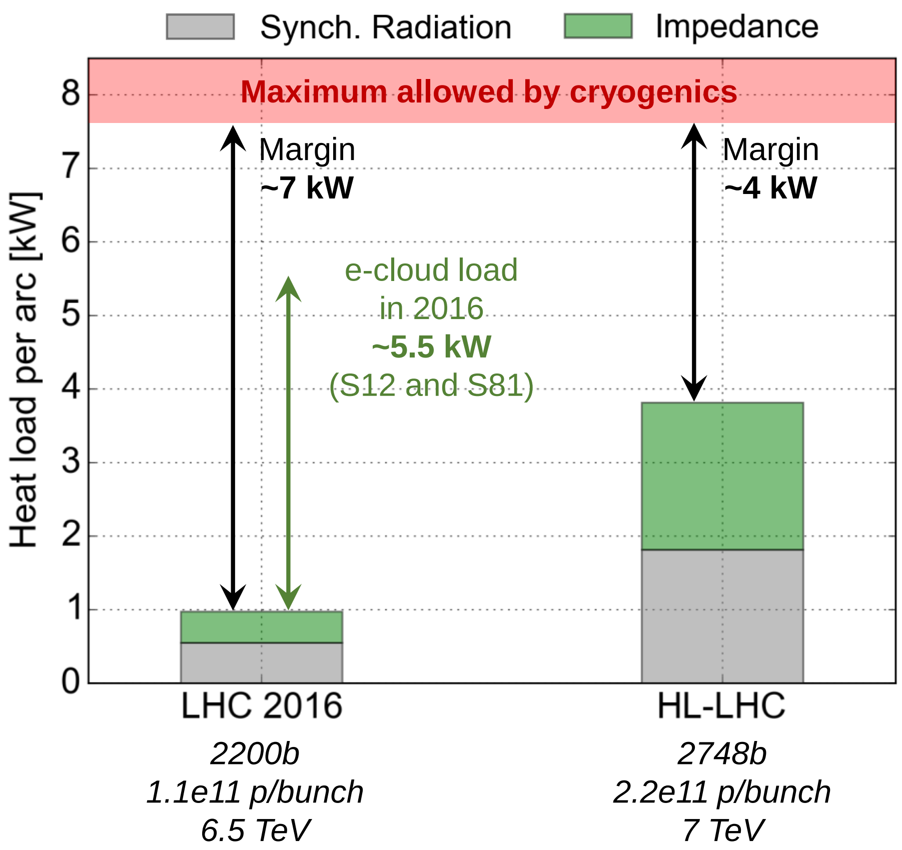
Introduction

- In 2017 we continued **exchanging estimates on beam induced heat loads with WP9**
  - **HeatLoadCalculator tool** used regularly to evaluate impedance and synchrotron radiation contribution
  - Agreed on **conventions and file format**
  - Heat loads are provided **per cryostat**, separating the different sources
  - For the **arcs** we provide the **loads over the total length** (first to last bend, including dispersion suppressors)
- **Strategy proposed by WP9**
  - In a first iteration **only estimates on impedance and synchrotron radiation** are required. These are combined with other heat load sources to compute the **remaining capacity available for e-cloud loads**
  - On the WP2 side we prepare e-cloud estimates for the full machine for comparison with the available margins

- Presently a **large difference beam induced heat load** is observed on the beam screen the arcs, with some of them **using a large fraction of the available capacity**
- The source of this extra heat load (presently unknown) **needs to be identified and suppressed** in order to reach the target HL-LHC performance

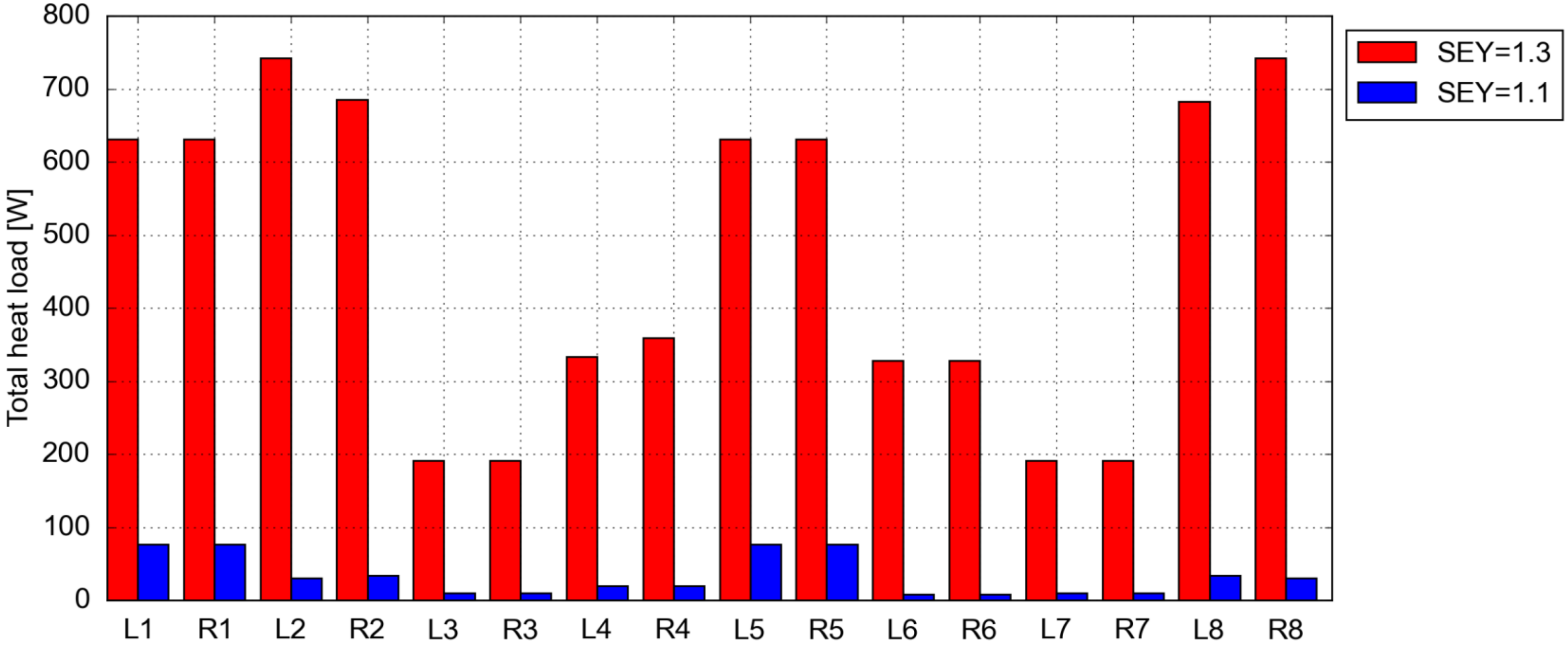


- The situation for HL-LHC will be **more critical as other heat load sources will be larger**



Twin bore magnets in the IRs

- Detailed heat load estimations have been made for twin-bore magnets all IRs. Results have been published in https://cds.cern.ch/record/2217217?ln=en



- Only **experimental IRs have a significant impact**
- In particular **S78 and S23 are the most critical** as they are cooled by less powerful cryoplants (ex-LEP)
- Additional margin for these arcs can be gained by **coating the beams screens in the adjacent matching sections (i.e. L8 and R2)**

For more info: S. Claudet and G. Iadarola @ 6th HL-LHC Collaboration Meeting, Paris

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- Heat load estimates for the Inner Triplets
    - IR1 and IR5
    - IR2 and IR8
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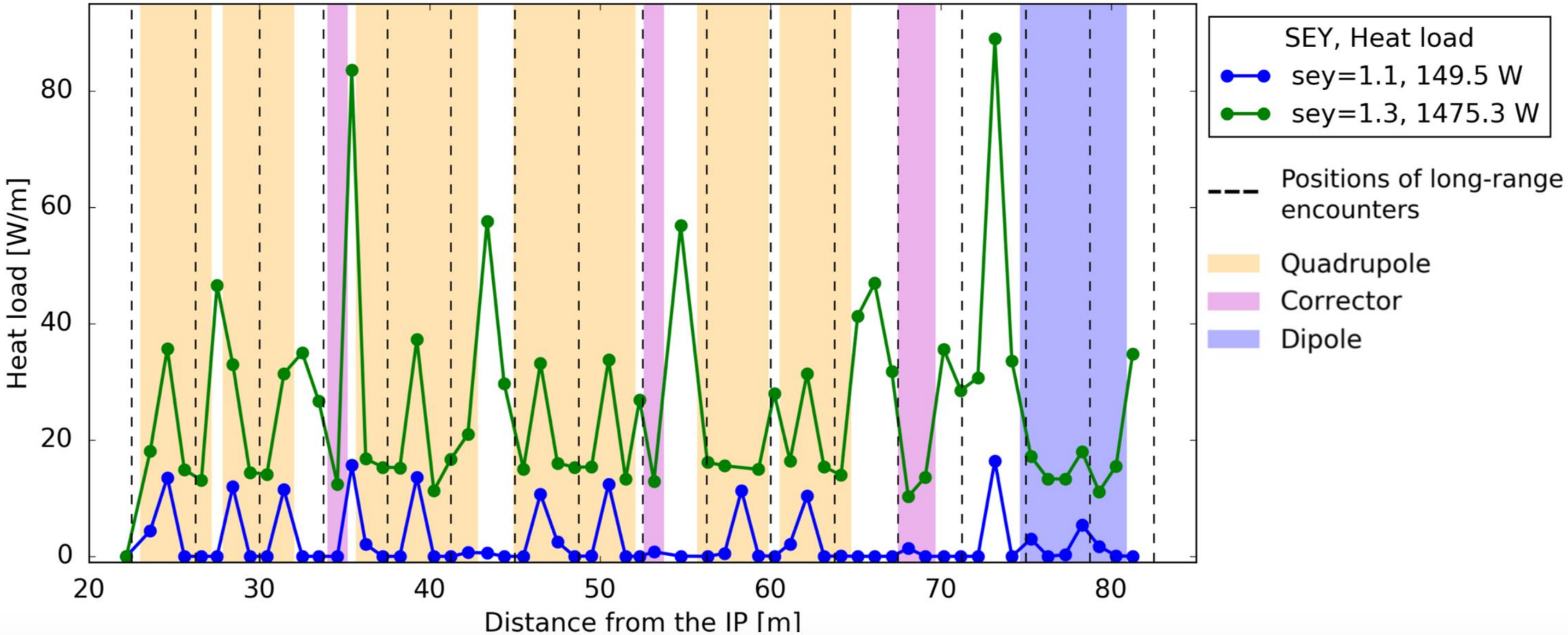
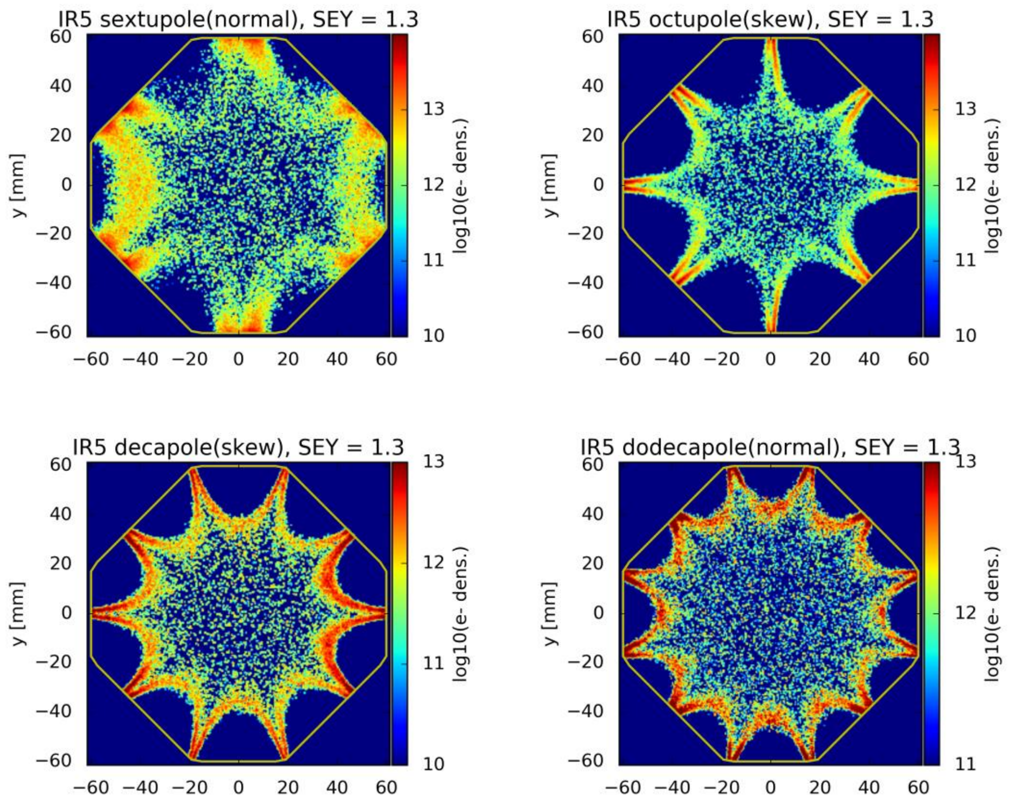
HL-LHC inner triplets: IR1 and IR5

- Simulated the **entire cryogenic length**
- Relevant **magnetic field map** is used for main dipoles and quadrupoles and for dipole correctors. Other sections (e.g. multipole correctors) are simulated as drifts
- **Conclusion: we rely on the presence of a low SEY coating** to keep heat loads on cryogenics at reasonable values
  - **SEYmax < 1.1** assumed for the coatings

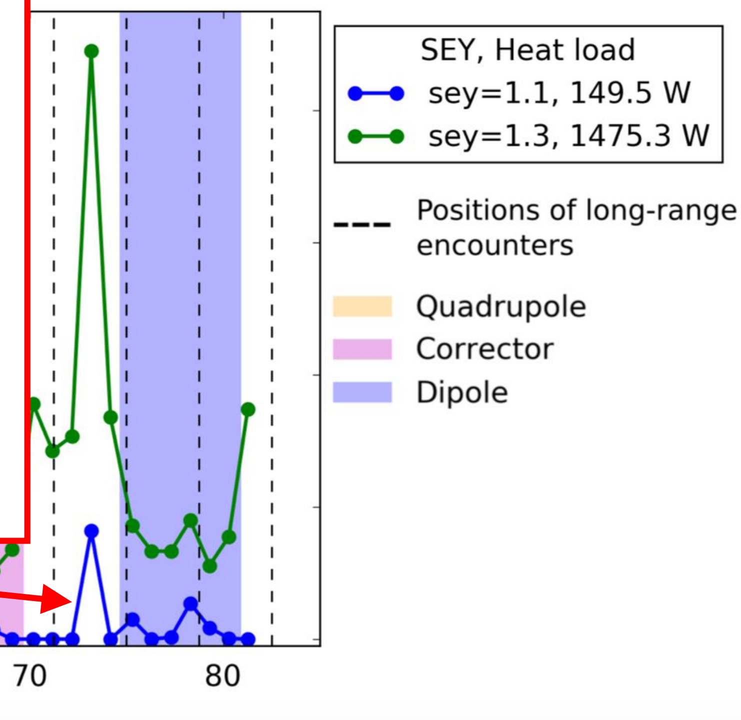


The **corrector package** is presently being simulated and will be added soon to the heat load estimates:



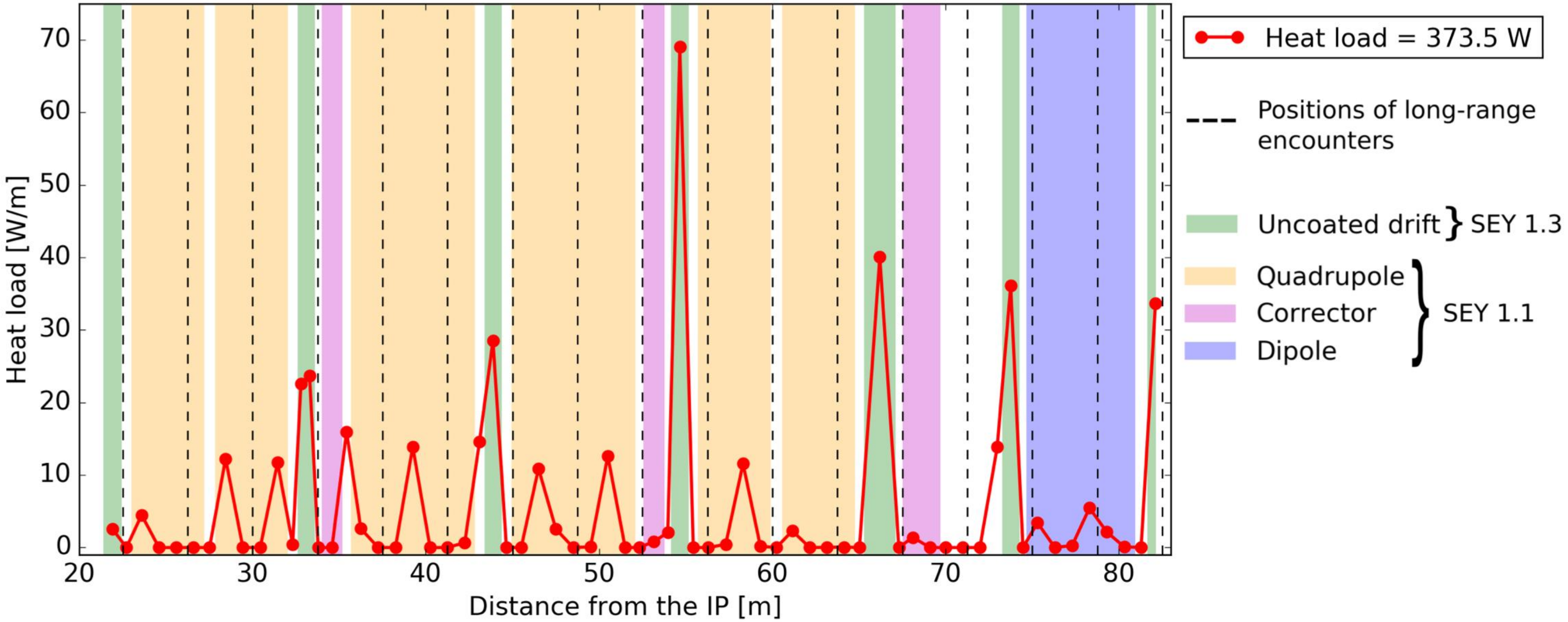
... dipoles and quadrupoles and for ...ole correctors) are simulated as drifts

... **SEY coating** to keep heat loads on



HL-LHC inner triplets: IR1 and IR5

- To asses the impact of having short uncoated sections (bellows, BPMs) we simulated the case in which **all sections outside the cold masses have SEY_{max} = 1.3**
- The heat load increases by **~220 W with respect to the fully coated case**
- Moreover, **impact on beam quality and stability needs to be assessed** as the effect on the beam is **amplified by the large beta functions**
- **Strategy proposed to WP12 (vacuum):**
  - Total length of **non-coated parts should be minimised** (as much as possible)
  - Once the the **"SEY profile" along the IR** is defined, we will perform detailed simulations to confirm that no problem is expected



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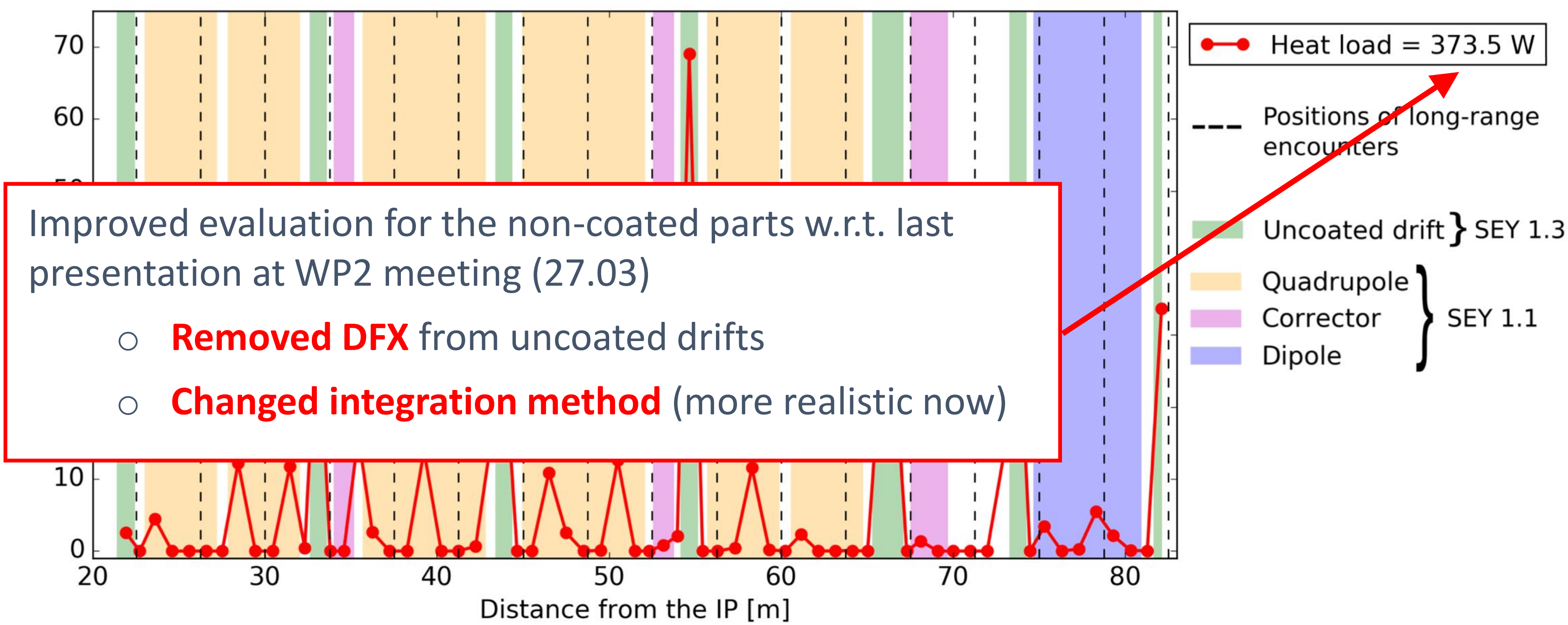

Improved evaluation for the non-coated parts w.r.t. last presentation at WP2 meeting (27.03)

- **Removed DFX** from uncoated drifts
- **Changed integration method** (more realistic now)

HL-LHC inner triplets: summary table

- A document has been drafted including detailed **tables for the beam induced heat loads in the different components**
- **Impedance heating** is included assuming that **beam screens are operated at 70 K**

Name	Length	Field config.	Chamber	Impedance (T_BS=70 K)	e-cloud (SEY=1.1/ UncDrifts1.3)	Total
ITQ1R5	11.6 m		BSHL_Q1	4.1 W	42.6 W	46.7 W
MQXFA.A1R5	4.2 m	quad	BSHL_Q1	1.5 W	4.8 W	
MQXFA.B1R5	4.2 m	quad	BSHL_Q1	1.5 W	25.9 W	
Drifts	1.7 m	drift	BSHL_Q1	0.6 W	0.2 W	
UncoatedDrifts	1.5 m	drift	BSHL_Q1	0.5 W	11.7 W	
ITQ2Q3R5	49.1 m		BSHL_Q23	15.3 W	330.9 W	346.2 W
MQXFB.A2R5	7.2 m	quad	BSHL_Q23	2.3 W	17.1 W	
MQXFB.B2R5	7.2 m	quad	BSHL_Q23	2.3 W	25.7 W	
MQXFA.A3R5	4.2 m	quad	BSHL_Q23	1.3 W	12.0 W	
MQXFA.B3R5	4.2 m	quad	BSHL_Q23	1.3 W	2.6 W	
MBXF.4R5	6.3 m	dip	BSHL_Q23	2.0 W	11.6 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	
Drifts	9.7 m	drift	BSHL_Q23	2.9 W	27.0 W	
UncoatedDrifts	5.9 m	drift	BSHL_Q23	1.8 W	232.5 W	
Total IT R5						**392.9 W**

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- A document has been drafted including detailed **tables for the beam induced heat loads in the different components**
- **Impedance heating** is included assuming that **beam screens are operated at 70 K**

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ITQ1R5	11.6 m		BSHL_Q1	4.1 W	42.6 W	46.7 W
MQXFA.A1R5	4.2 m	quad	BSHL_Q1	1.5 W	4.8 W	
MQXFA.B1R5	4.2 m	quad	BSHL_Q1	1.5 W	25.9 W	
Drifts	1.7 m	drift	BSHL_Q1	0.6 W	0.2 W	
MCBXFBV.B2R5	1.2 m	dip	BSHL_Q23	0.4 W	1.0 W	
MCBXFBH.B2R5						
MCBXFAV.3R5	2.2 m	dip	BSHL_Q23	0.7 W	1.5 W	
MCBXFAH.3R5						
Drifts	9.7 m	drift	BSHL_Q23	2.9 W	27.0 W	
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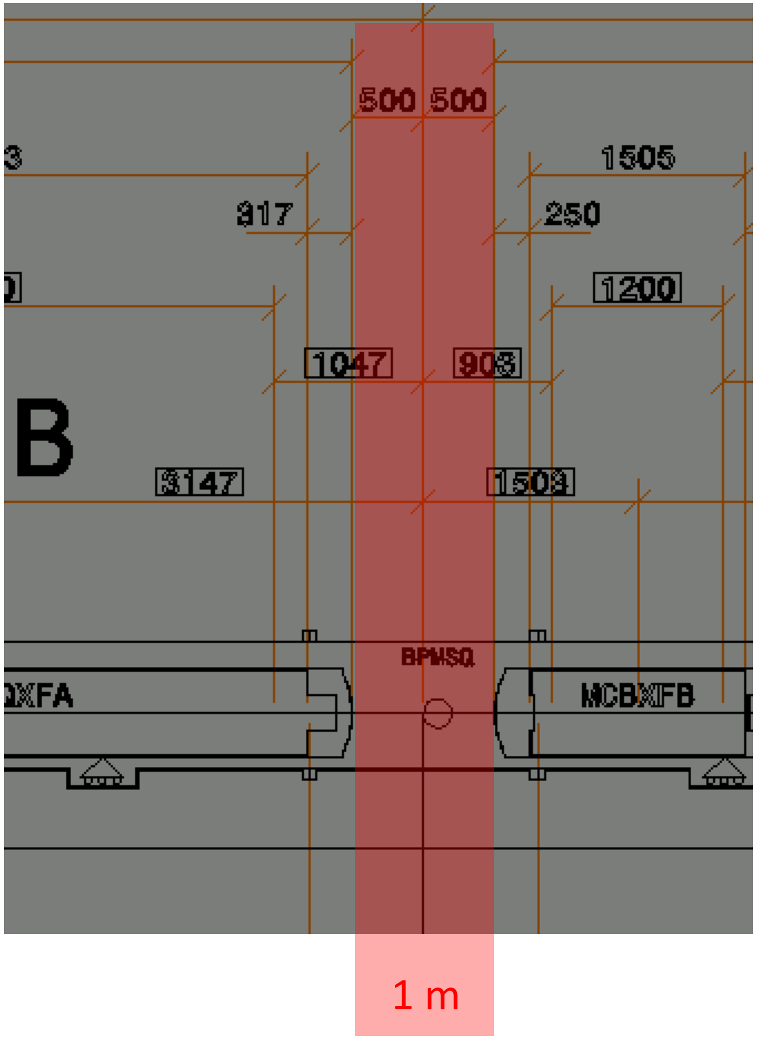
Total IT R5						**392.9 W**

Not exactly innocent… **can this heat load be handled by the cryogenic system?**

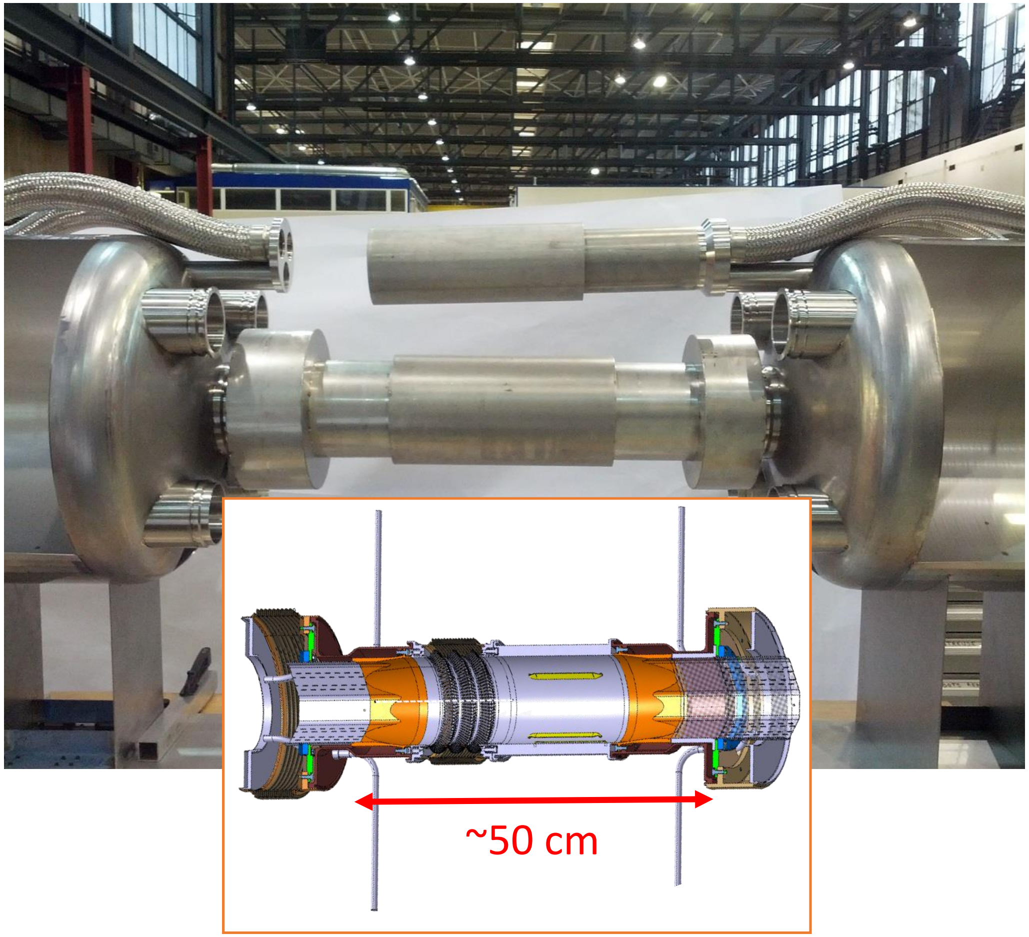
- **If not, no panic ☺ → the estimate is based on rather conservative assumptions:**
  - We can re-simulate using a **more realistic "SEY vs s" profile** to be provided by the vacuum team (see next slide…), guessing a gain of ~70W, to be verified
  - A feedback from Tuesday's meeting with the vacuum team is that **SEY_{max}=1.1 is quite pessimistic** → if needed we can tighten a bit this specification

HL-LHC inner triplets: assumptions on the interconnections

Simulation assumption



Preliminary design



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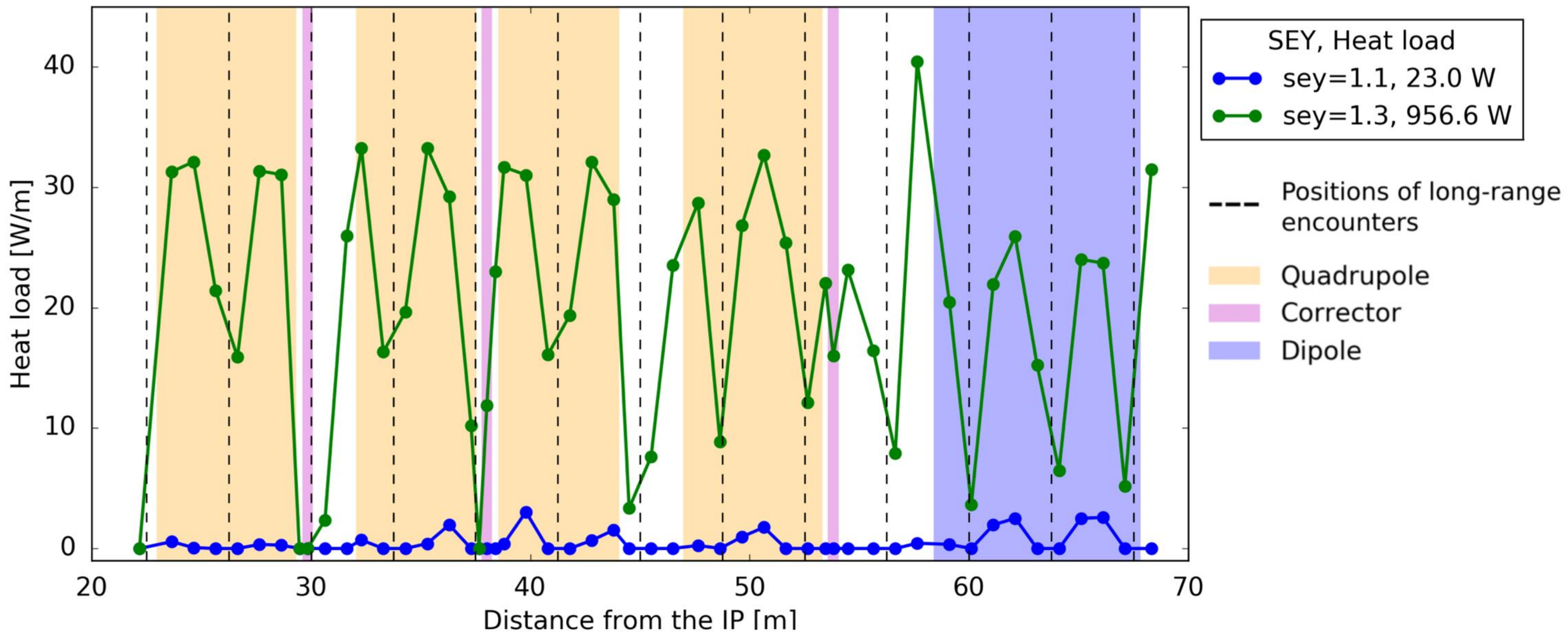
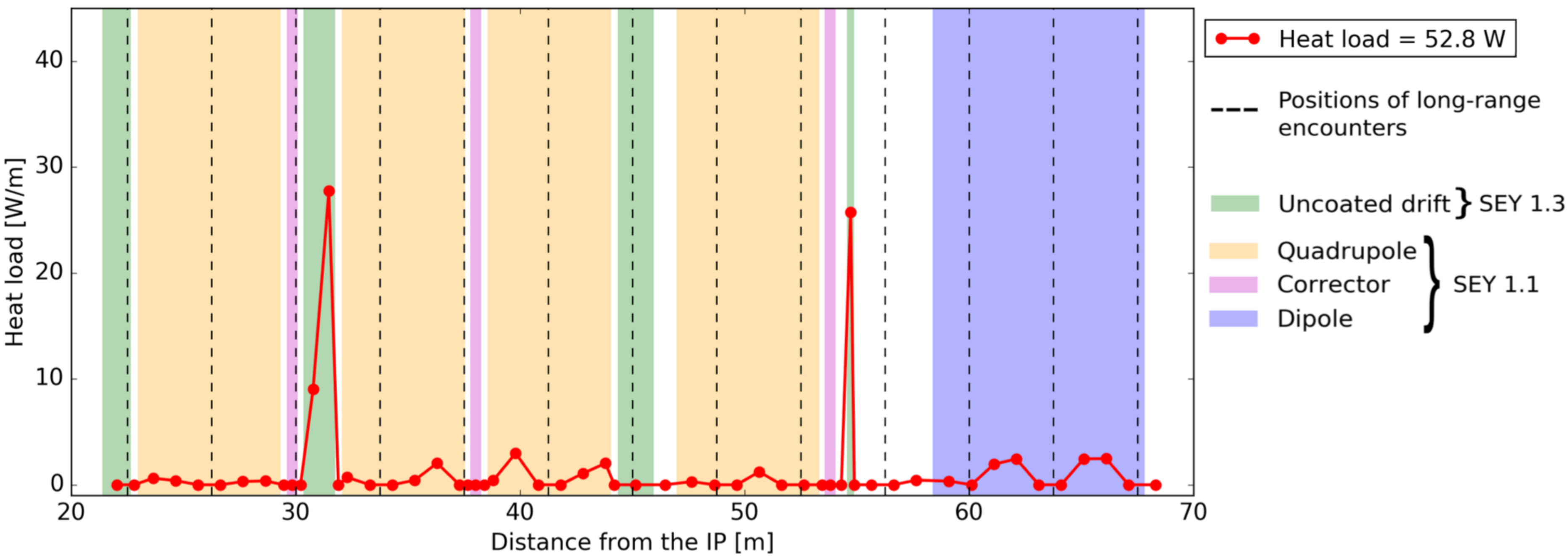
HL-LHC inner triplets: IR2 and IR8

- **Similar conclusions** as for Inner Triplets in IR1 and IR5
- We rely on the presence of a **low SEY coating** to keep heat load on cryogenics at reasonable values (here the treatment will have to be performed in situ)
  - **SEYmax < 1.1** assumed in the estimates provided to WP9 (cryogenics)



HL-LHC inner triplets: IR2 and IR8

- **Similar conclusions** as for Inner Triplets in IR1 and IR5
- We rely on the presence of a **low SEY coating** to keep heat load on cryogenics to reasonable values (here the treatment will have to be performed in situ)
  - **SEYmax < 1.1** assumed in the estimates provided to WP9 (cryogenics)
- Impact of having **non coated drifts** has been evaluated also for these devices
  - Less critical



Inner triplets in IR2 and IR8: summary table

- A document has been drafted including detailed **tables for the beam induced heat loads in the different components** (simulations of the high order correctors are ongoing)
- **Impedance heating** is included assuming that beam screens **are operated at 20 K**

Inner triplets in IR2&8:

Name	Length	Field config.	Chamber	Impedance (T_BS=20 K)	e-cloud (SEY=1.1/ UncDrifts1.3)	Total
ITQ1R8	9.8 m		BSMQ_Q1-R	5.2 W	9.3 W	14.5 W
MQXA.1R8	6.4 m	quad	BSMQ_Q1-R	3.5 W	1.8 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	7.5 W	
ITQ2Q3R8	23.7 m		BSMQ_2	9.3 W	33.4 W	42.7 W
MQXB.A2R8	5.5 m	quad	BSMQ_2	2.3 W	2.9 W	
MQXB.B2R8	5.5 m	quad	BSMQ_2	2.3 W	5.8 W	
MQXA.3R8	6.4 m	quad	BSMQ_2	2.6 W	1.5 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	23.1 W	
ITD1R8	13.9 m		BSMB_1	4.2 W	10.1 W	14.2 W
MBX.4R8	9.5 m	dip	BSMB_1	3.0 W	9.5 W	
Drifts	4.4 m	drift	BSMB_1	1.2 W	0.5 W	
UncoatedDrifts	0.0 m	drift	BSMB_1	0.0 W	0.0 W	
Total IT R8						**71.4 W**

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Arc heat loads: progress status

- 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.
- Drafted a **document** and **prepared a python** tool to:
  - 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**

Correct orientation

Inverted orientation

Work done together with P. Dijkstal, L. Mether and G. Rumolo

Arc heat loads: work in progress

...ify the best available knowledge on
...orrectly handling the effect of the

...trons from

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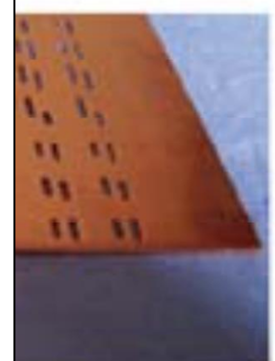
...tion



...Mether and G. Rumolo

3 Photons emitted by the beam

To estimate the...
by the beam ha...
Eq. (5.40) in thi...

P_s and ω_c are t...

An approximati...
radiation. The f...

The spectrum is...
$\dot{n}\hbar\omega$. Integratio...
of the material ...

The double inte...

The number of photons per...

n_γ = ...

Another interesting feature i...
of synchrotron radiation is ...

For energies corresponding ...

Figure 4 shows the properti...
script found in a python m...

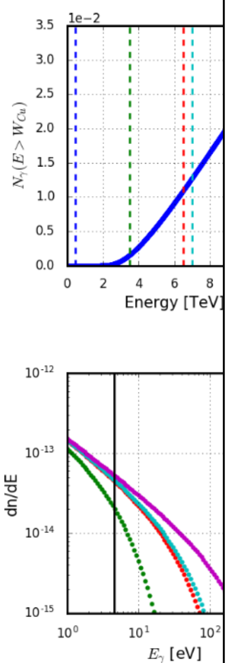


Figure 4: Top left: Number...
of photons above ...
beam energies. B...

6 Best estimates for photoemission simulations

It is explained how...
on the previously ...
The notation used...

Y_i (Y_i^*)
Y_r (Y_r^*)
R_i
R_r
N_i
N_r
N_t
n_γ

6.1 Obtaining k...

In case of uniform...

This is because al...
number of reflectio...

However in the ca...
are different at th...
at this point plays...
reflection have to b...

One simplification...
small portion relat...
and refl_frac are as...

For **alimit**, the crit...
0.36 mrad. For e_p...
macroparticles, 5 ...
photoelectrons are...
their kinetic energ...

For the angular dis...
(**inv_CDF_ refl_p**...
not available. This...
of multiple reflecti...
measured to be la...
any case be avoide...

6.2 Consistency of different measurements

The different published experimental results on photoelectron yields and reflectivities are compared in this table. If two values are stated for a photoelectron yield, they correspond to the measurements before and after photon scrubbing. The reflectivities colored in red only include the forward reflectivity. The yields in blue were not published but could be retrieved with the simple relation between R, Y and Y^* from Eq. (19).

Source	Cu co-lam.			with sawtooth		
	R [%]	Y [e/ph]	Y^* [e/ph]	R [%]	Y [e/ph]	Y^* [e/ph]
Baglin 1998	80.9	0.022	0.114	1.8	0.052	0.053
Cimino 1999	-	0.103/0.063	-	-	-	-
Baglin 2001	-	-	-	8	0.021/0.011	0.029/0.015
Mahne 2004	82	-	-	10	-	-

The differences between the Cimino and Baglin results can be explained with different "as-received" samples of Cu. Since only the two Baglin papers include results for sawtooth materials, these should be used for the simulation. The reflectivities from the Mahne paper should be used because of the superior measurement apparatus for reflected photons.

6.3 Parameters to use for the simulations

For a **conservative estimate**, the following table uses the high reflectivities from the Mahne paper and the high photoelectron yields Y from the first Baglin paper, retrieved from the values for Y^* as published in [4].

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

These yields and reflectivities, together with the number of photons from Eq. (15), finally lead to the needed parameters refl_frac and k_pe_st.

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

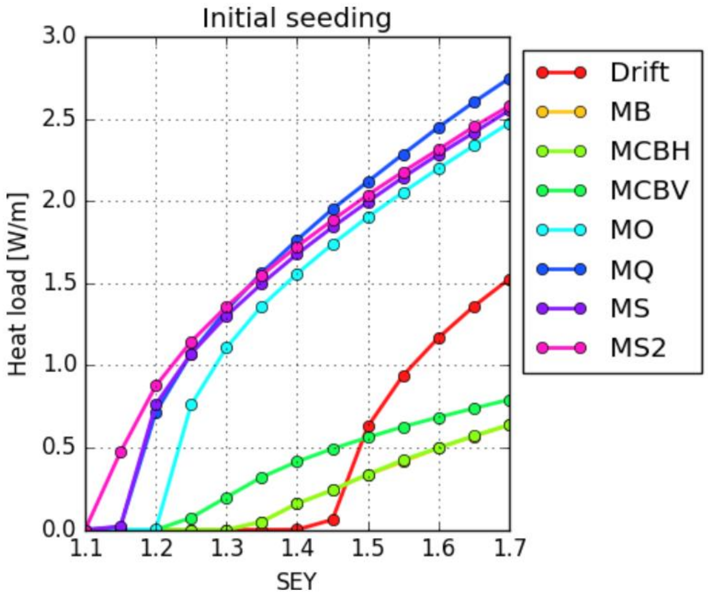
A **realistic estimate** would include scrubbing effects and a much lower yield, as measured in the second Baglin paper. With respect to the first, the yield of the sawtooth material is by a factor of $0.052/0.011 \approx 4.7$ lower. If this factor is also applied to the yield of the other material, the following input parameters should be used. In practise, mostly the value for N_r is relevant as it denotes the amount of photoelectrons that contributes to the stripes in e-cloud simulations for dipoles and quadrupoles.

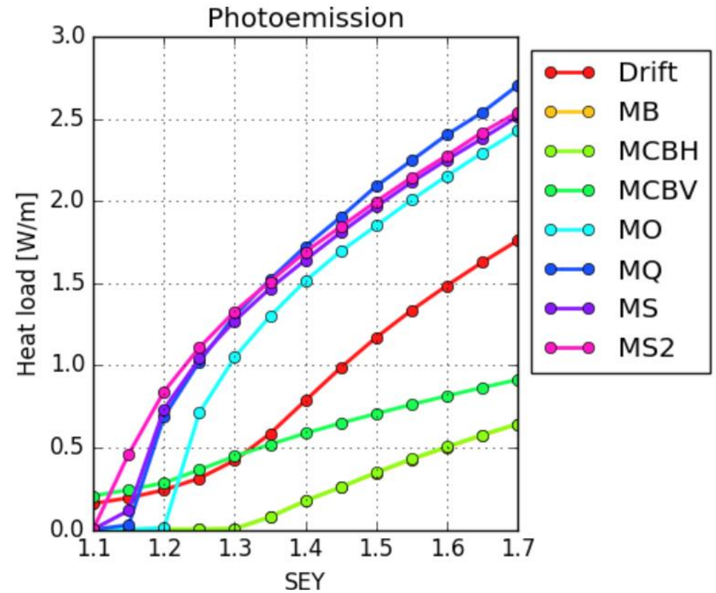
Chamber type	R_i	R_r	Y_i	Y_r	Y_i^*	Y_r^*
Cu co-lam. with sawtooth	10.0	82.0	1.0e-02	4.6e-03	1.1e-02	2.6e-02
Cu co-lam.	82.0	82.0	4.6e-03	4.6e-03	2.6e-02	2.6e-02

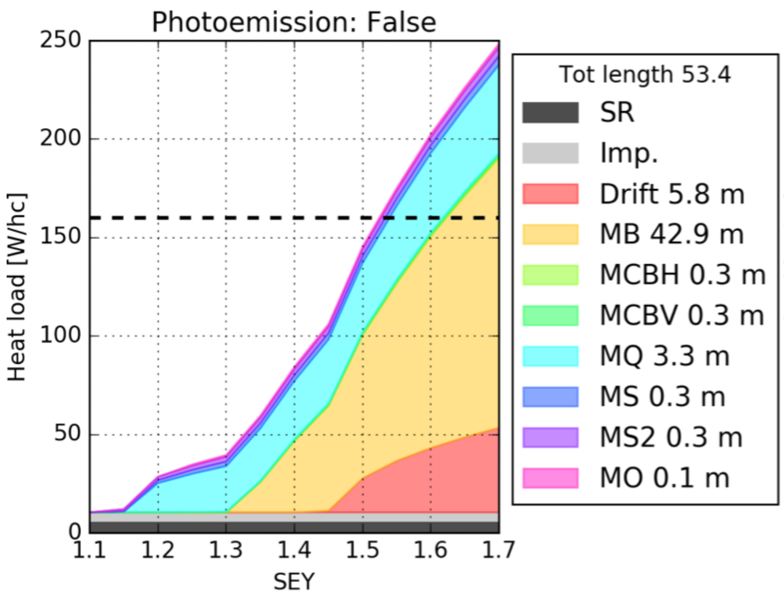
Chamber type	N_i	N_r	N_t	n_γ	refl_frac	k_pe_st
Cu co-lam. with sawtooth	1.0e-02	2.6e-03	1.3e-02	1.1e-02	2.03e-01	1.39e-04
Cu co-lam.	4.6e-03	2.1e-02	2.6e-02	1.1e-02	8.20e-01	2.81e-04

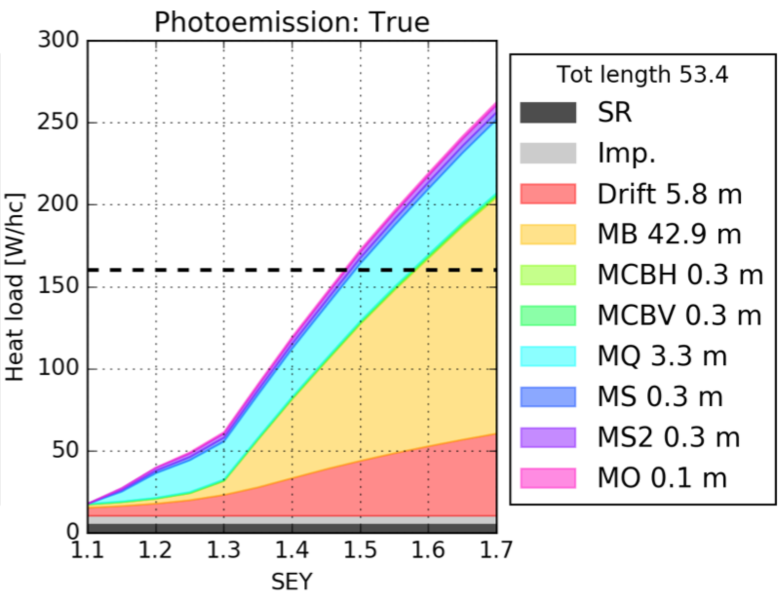
Arc heat loads: work in progress

- **Simulating all components. Preliminary** results for present LHC beam parameters:









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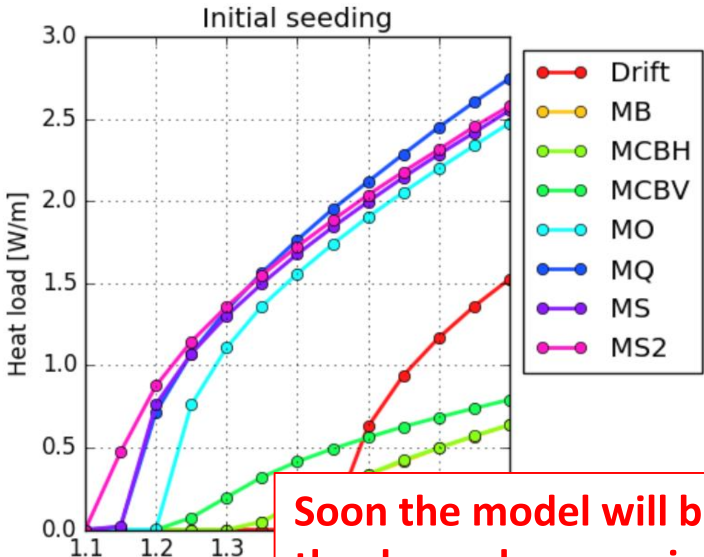
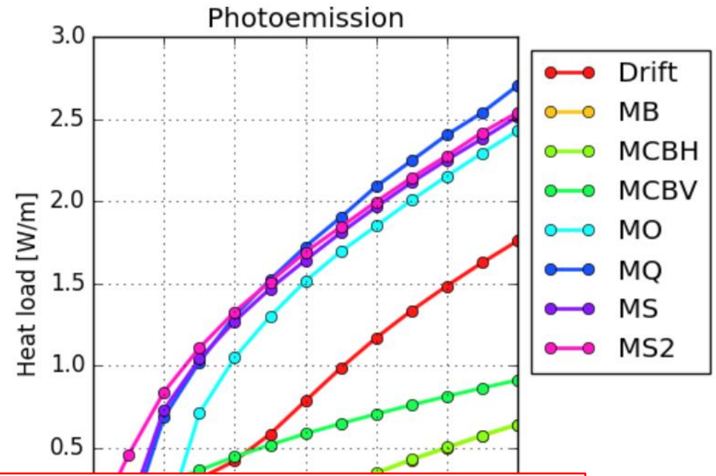
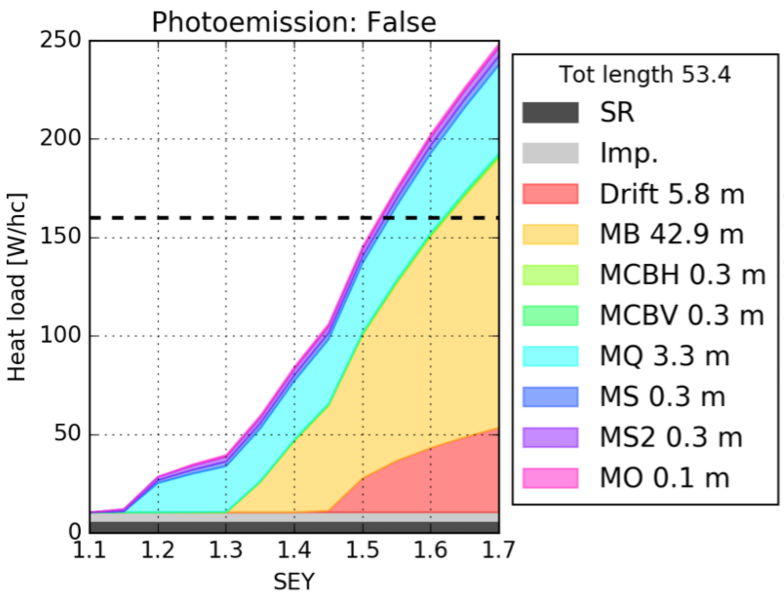
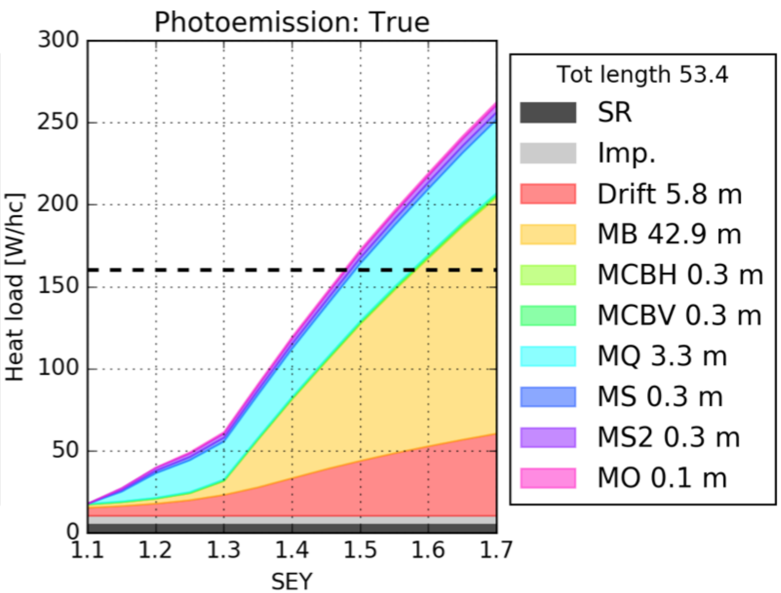




Soon the model will be "frozen" we will investigate the dependence on intensity





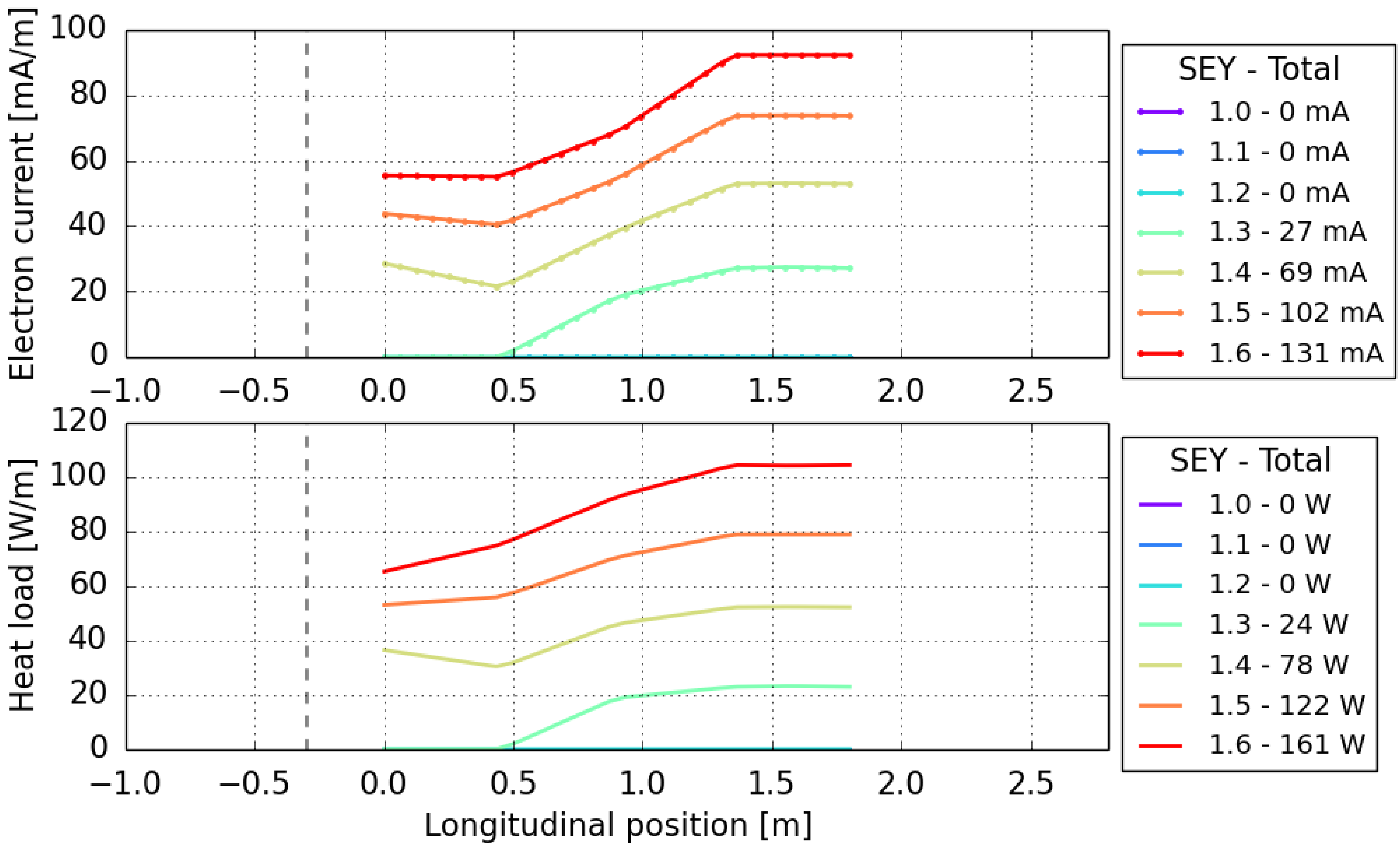
Outline

- Introduction and some reminders on previous results
- Heat load estimates for the Inner Triplets
    - IR1 and IR5
    - IR2 and IR8
- Progress status on arc heat loads
- Simulations for the TAXS absorber

TAXS absorber

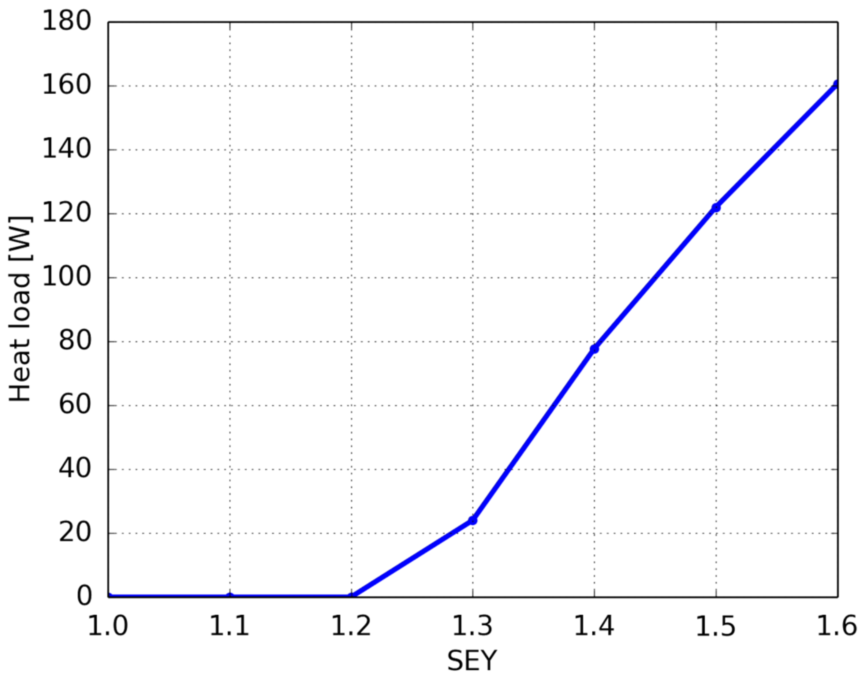
- Electron cloud build-up simulations have been performed for the TAXS absorber
- **Two beam device** → multipacting **depends on the distance w.r.t. the long range encounters**

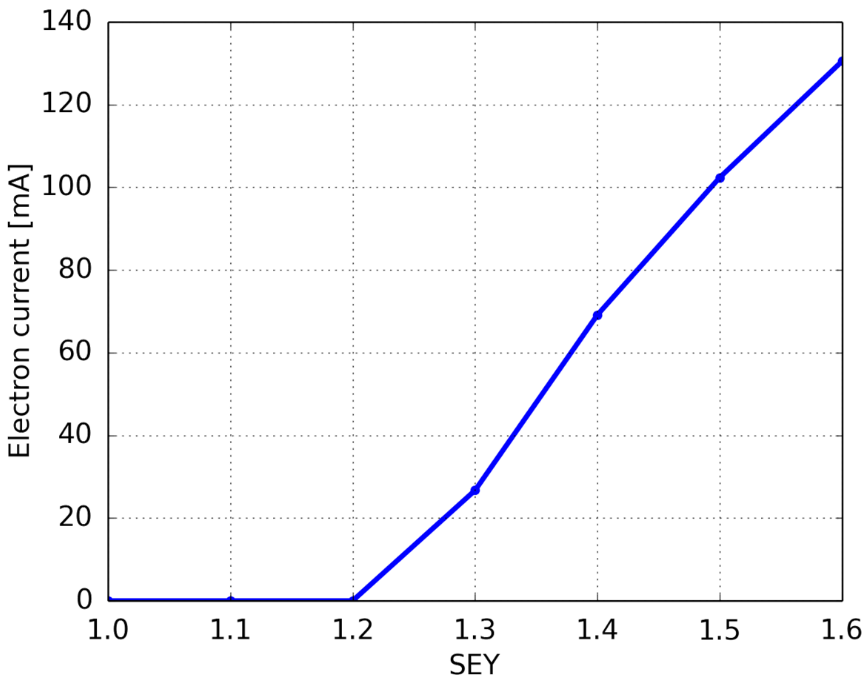
Length = 1.8 m, circular chambers, diameter = 60 mm



- Electron cloud build-up simulations have been performed for the TAXS absorber
- **Two beam device** → multipacting **depends on the distance w.r.t. the long range encounters**
- **Multipacting thresholds** are above **SEY_{max} = 1.2**
- **NEG coating** not possible there, **a-C coating under investigation**

Length = 1.8 m, circular chambers, diameter = 60 mm





Summary and conclusion

- **"WP2-WP9 interface"** for exchanging data on heat load estimates has been defined(conventions, requirements)
- Evaluations for **twin bore magnets** performed in 2016. Main outcomes:
  - **Experimental IR** are the most critical
  - IR1 and IR5 will be equipped with dedicated cryoplants
  - Load **IR2 and IR8 will affect the neighboring arcs** → **Low SEY coating of the matching sections is desirable**
- Heat loads in the **Inner Triplets** have been estimated **IR1&5** and for **IR2&8**
  - → We **rely on low SEY surface treatments (SEY_{max}<1.1)** to have reasonable heat loads on cryogenics
  - → A first analysis of the **impact of having un-coated drift sections** outside the cold masses has been performed
- Work for the definition of **a detailed e-cloud model of the arc half-cell** is almost complete→ soon to be applied to HL-LHC beam
- **TAXS simulations** are available to be folded in heat load and vacuum estimated

Thanks for your attention