
CERN

Update on comparison of MD data against simulations

Galina Skripka, Giovanni Iadarola and Eric Wulff

Many thanks to: Benjamin Bradu, Riccardo De Maria, Philipp Dijkstal, Lotta Mether, Annalisa Romano, Giovanni Rumolo and all the machine operators

Outline

- Recap
- Arc-to-arc heat loads
- Heat loads in instrumented cell

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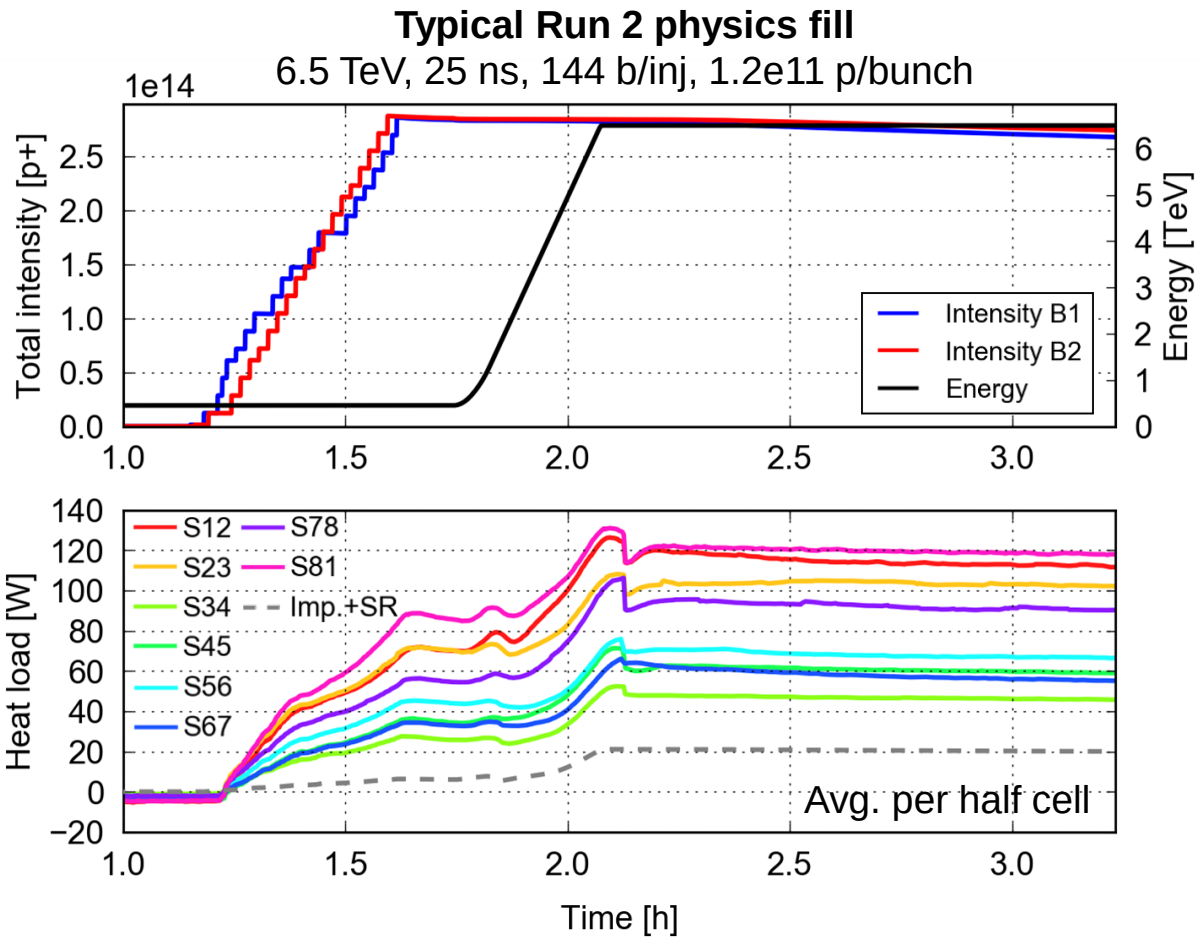
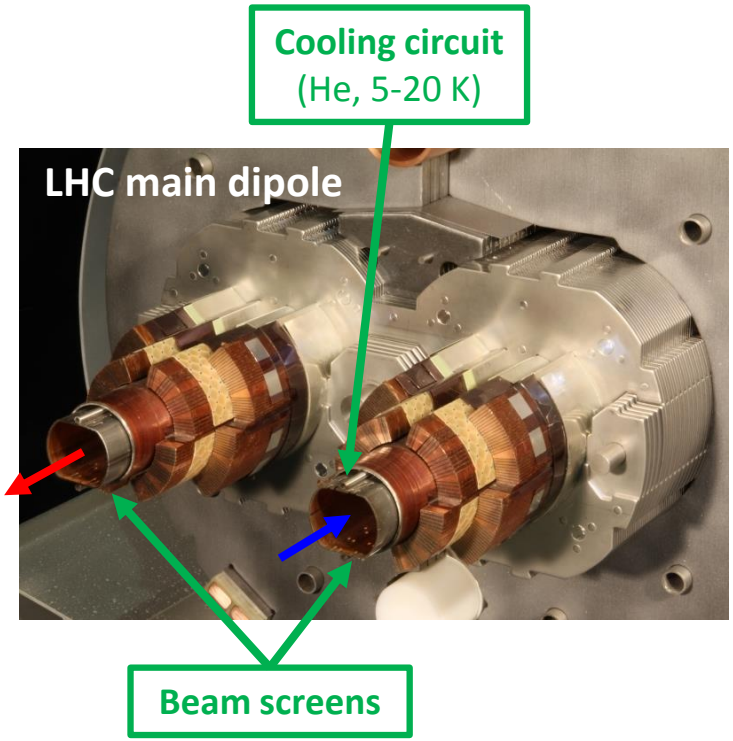
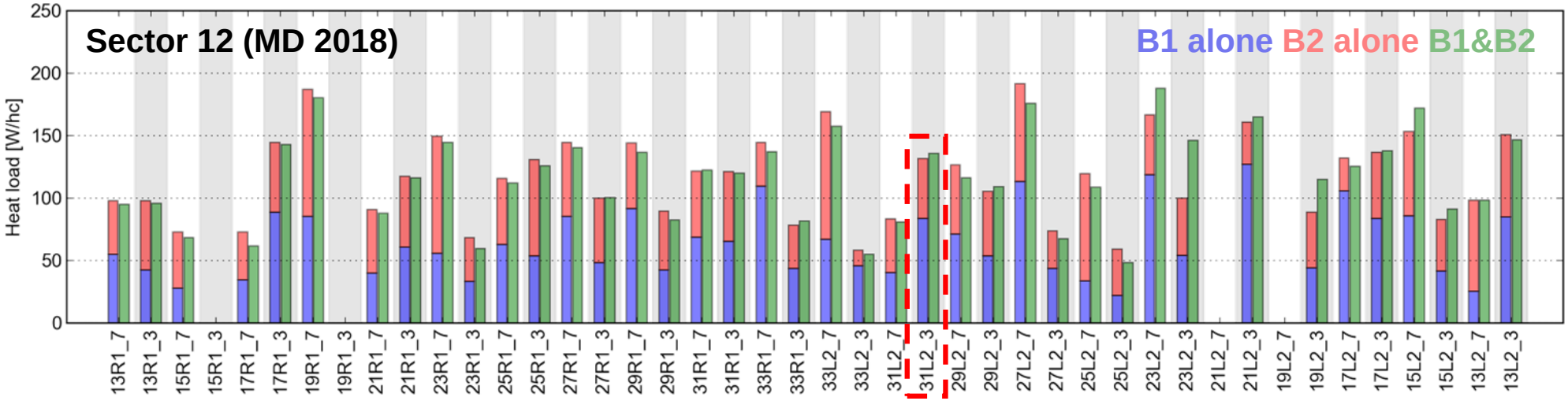
- In Run 2 **large beam-induced heat loads** (>100 W/hcell) are observed on **the beam screens** of the **LHC arcs** → Much larger than impedance and synchrotron radiation
- Very **large differences among the eight** arcs (up to a factor of 3), not at all expected!





Distribution along the ring

- Especially in the high load sectors, we observe **large differences from cell to cell**
- Heat loads can be different for the **two apertures of the same cell**
- **Differences** are present even **among magnets of the same cell**



Cell 31L2 (equipped with extra thermometers)

At 450 GeV:	25 W	20 W	50 W	3 W
	Q	Dipole	Dipole	Dipole
At 6.5 TeV:	5 W	30 W	70 W	8 W

Underlying mechanism

We are looking for a mechanism that **transfers energy from the beam to the beam-screen:**

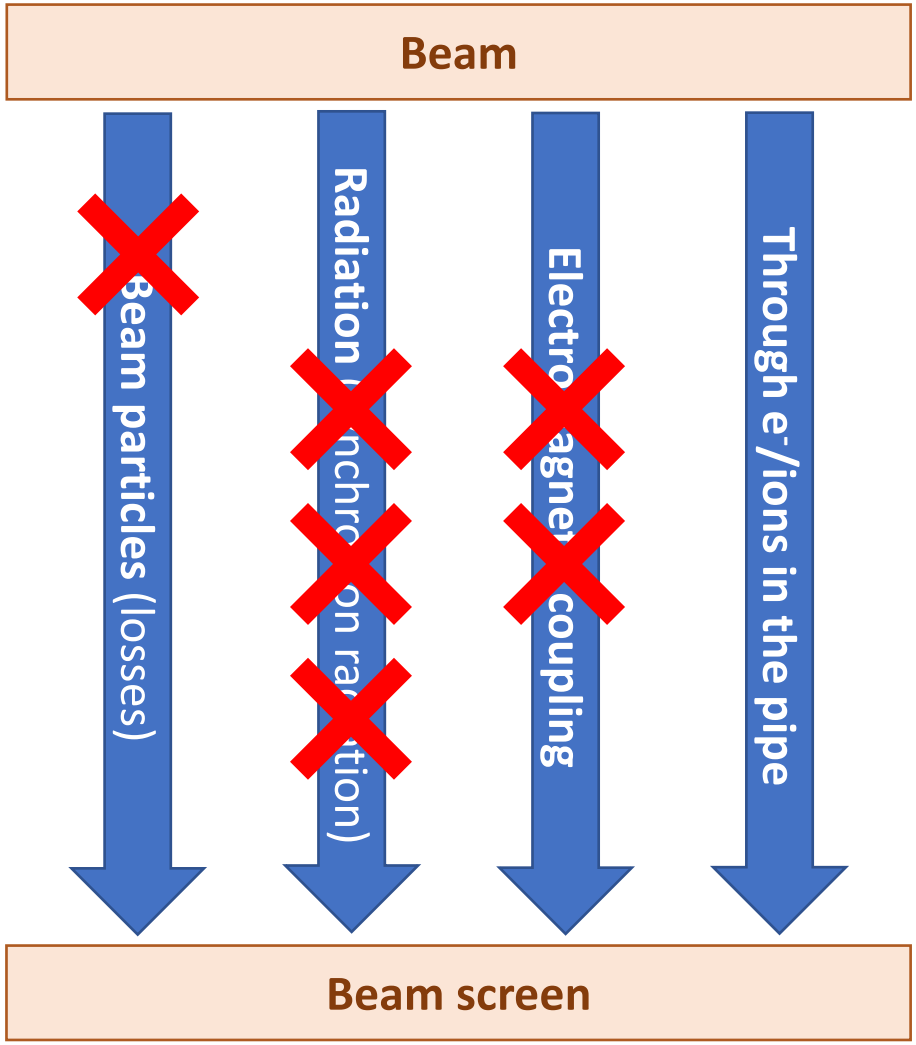
- Here are the possibilities that were identified

Compatible with **measured intensity loss**

Compatible with **measured dependence on bunch spacing**

Compatible with **measured dependence on bunch intensity**

Compatible with **measured dependence on beam energy**



= Excluded

G. Iadarola, Update on the LHC heat-load and projection for HL-LHC, 8th HL-LHC Collaboration Meeting *More info here*

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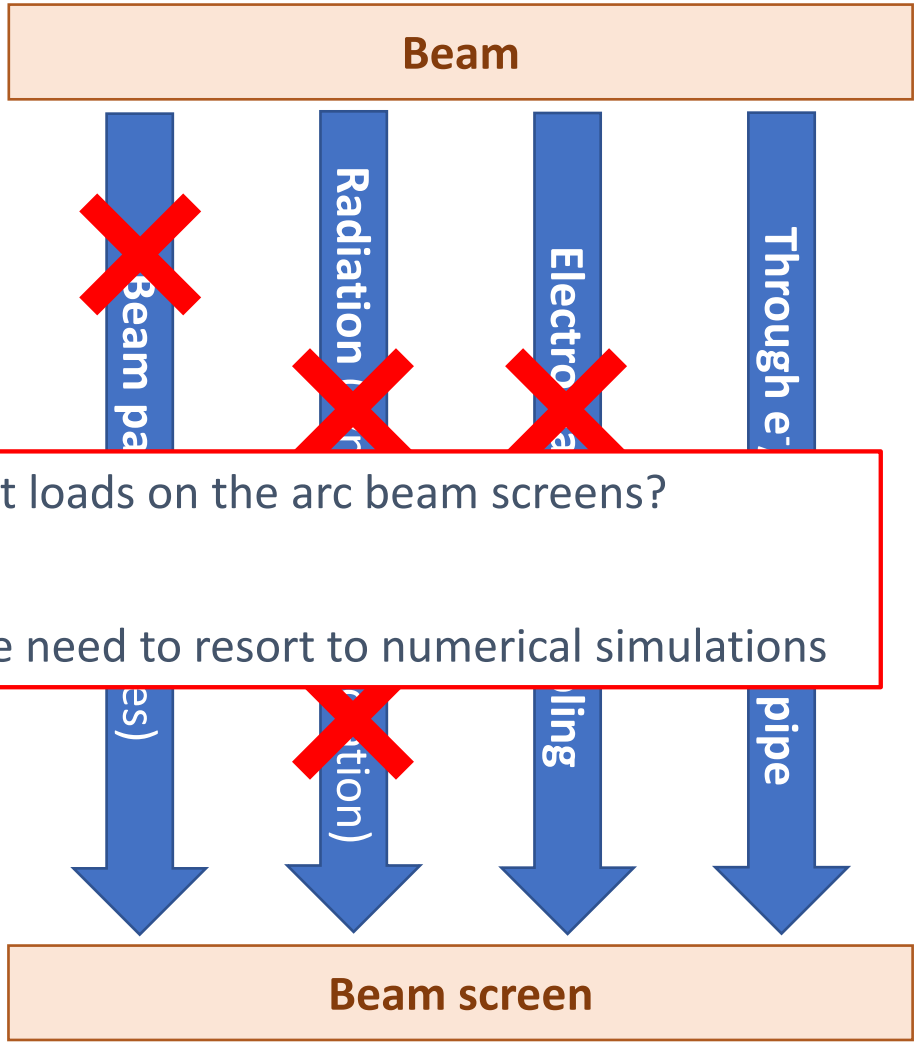


Compatible with **measured intensity loss**

Compatible with **measured dependence on bunch spacing**

Co
on

Compatible with **measured dependence on beam energy**

Can **e-cloud** be the **source** of the heat loads on the arc beam screens?

→ Qualitatively yes

→ For quantitative estimates we need to resort to numerical simulations

= Excluded

Could a nonuniform SEY in the LHC be responsible for the observed differences?

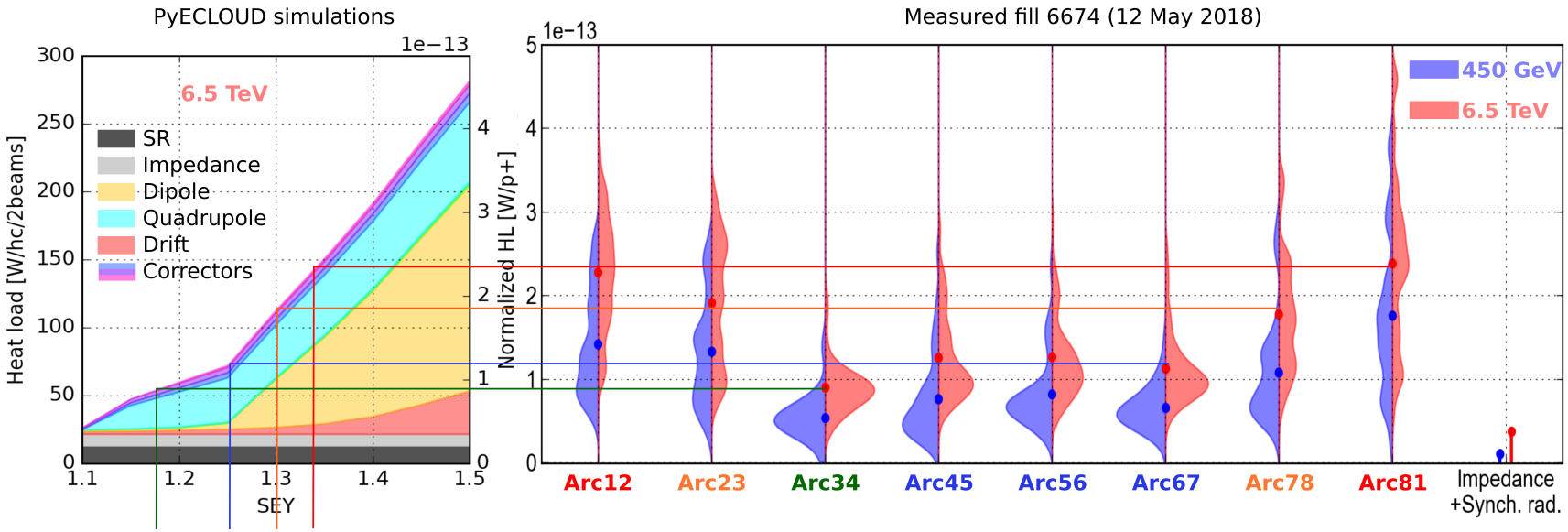
Outline

- Recap
- Arc-to-arc heat loads
- Heat loads in instrumented cell

Arc-to-arc: finding SEY values

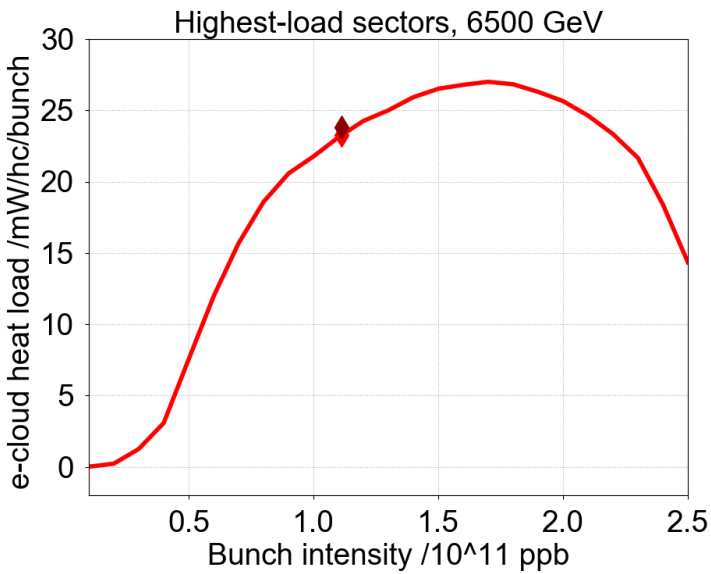
Hypothesis: the differences among sectors are caused by different SEY

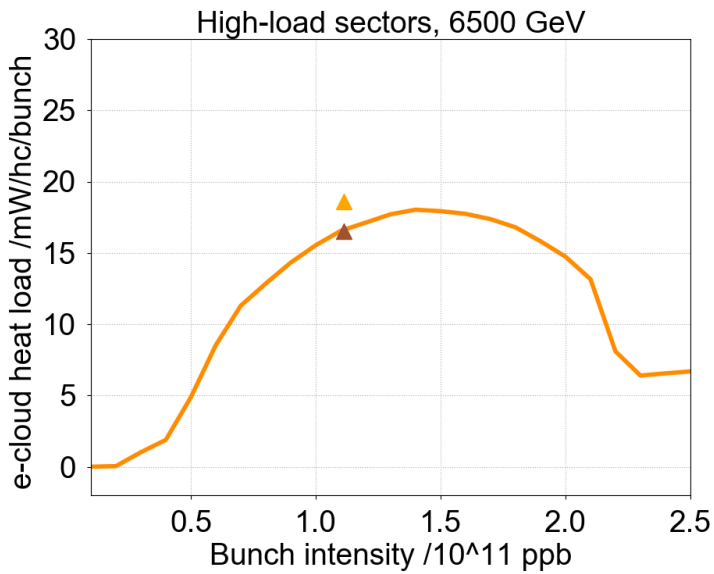
- Find modeled SEY corresponding to the average measured heat loads
  - assuming uniform SEY along the sector

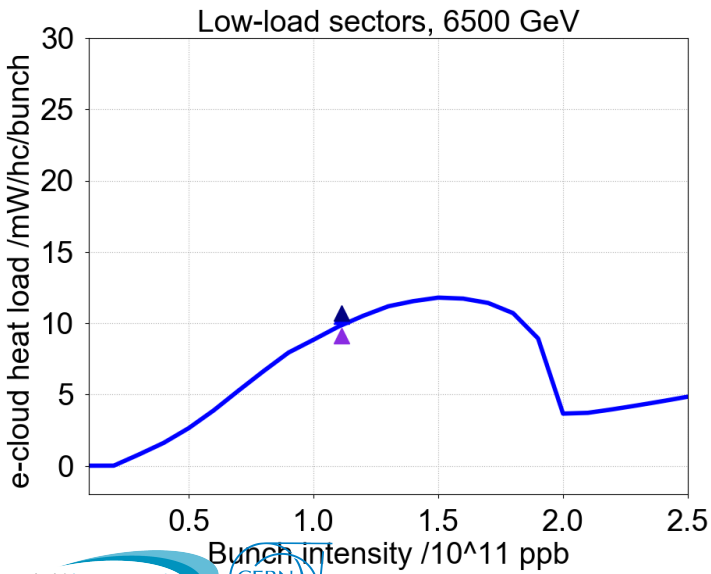


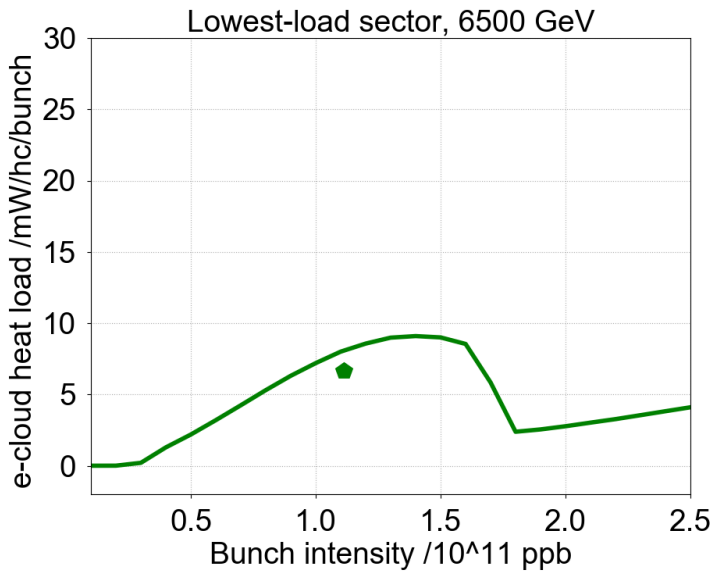
Sector	S34	S45/S56/S67	S23/S78	S12/S81
SEY	1.20	1.25	1.30	1.35

Arc-to-arc: std beam @6500 GeV









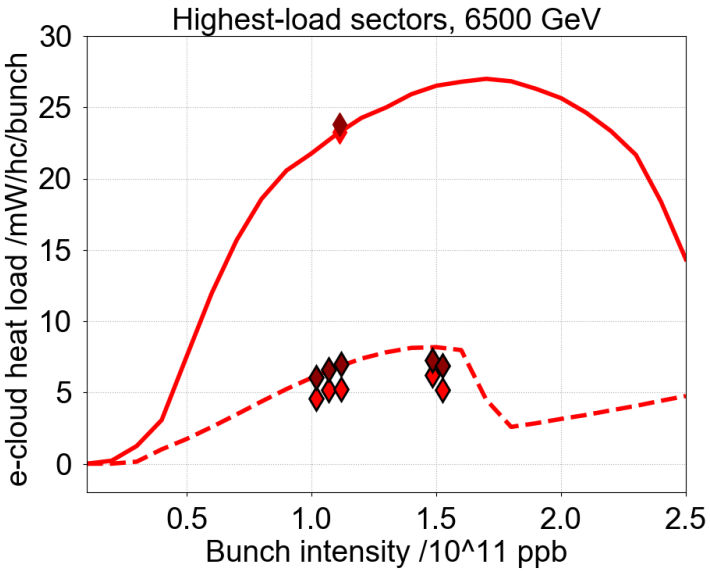
SEY 1.35 (std)
measured S12 (std)
measured S81 (std)

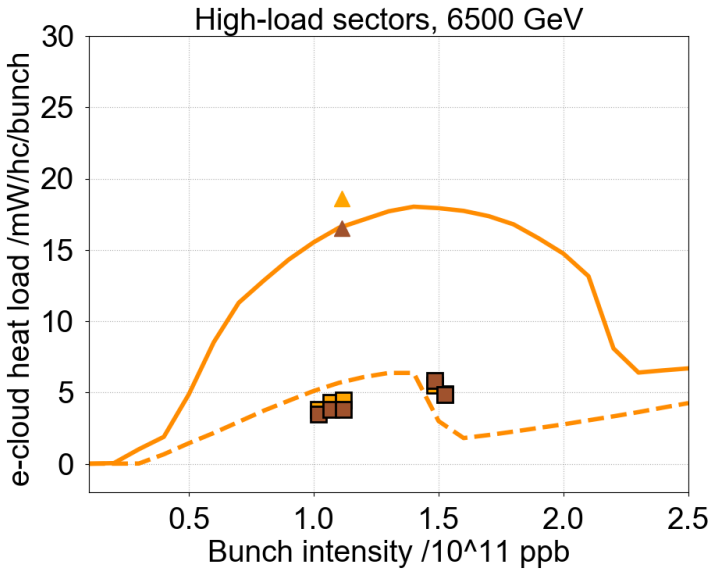
SEY 1.30 (std)
measured S23 (std)
measured S78 (std)

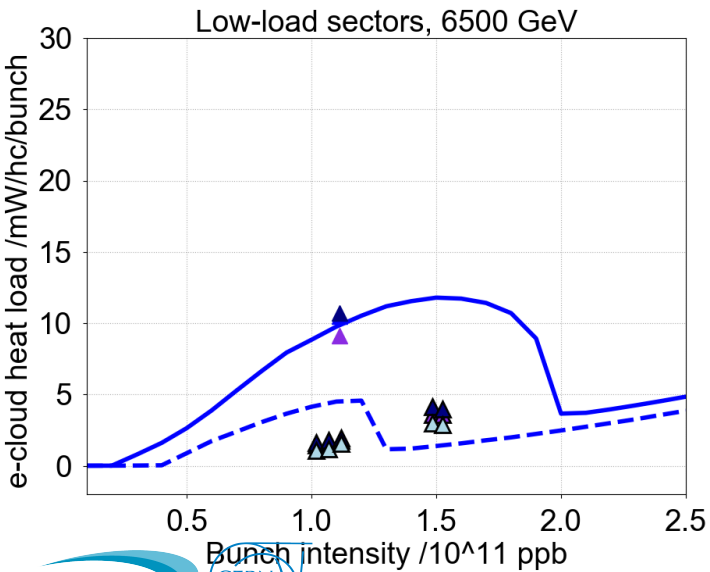
SEY 1.25 (std)
measured S45 (std)
measured S56 (std)
measured S67 (std)

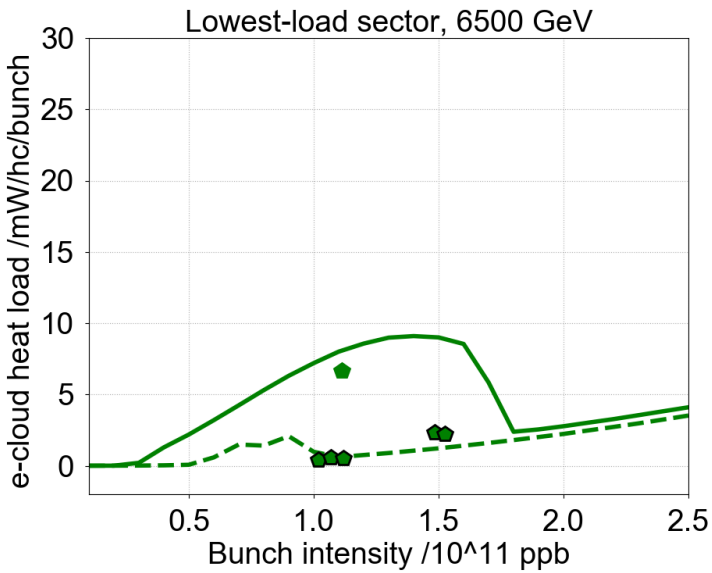
SEY 1.20 (std)
measured S34 (std)

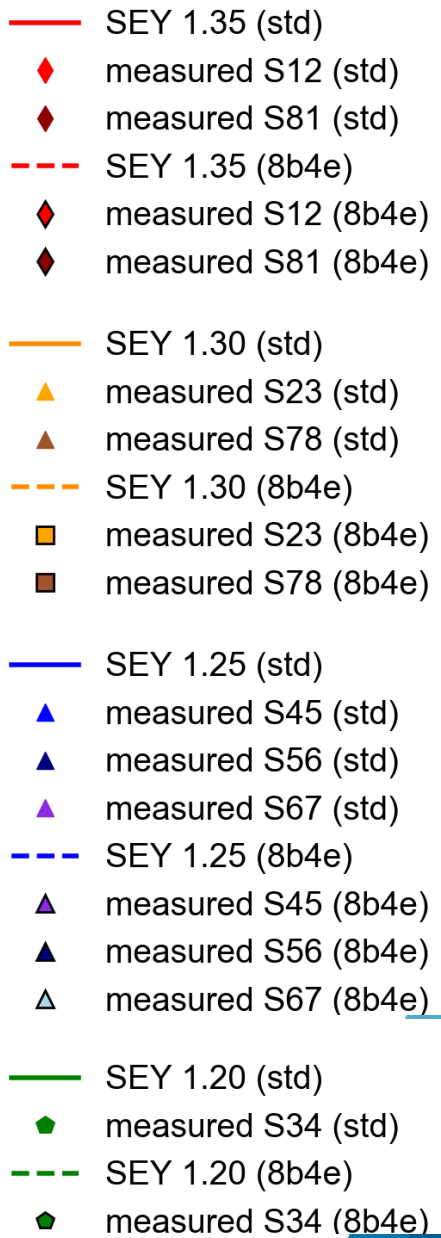
Arc-to-arc: std&8b4e @6500 GeV











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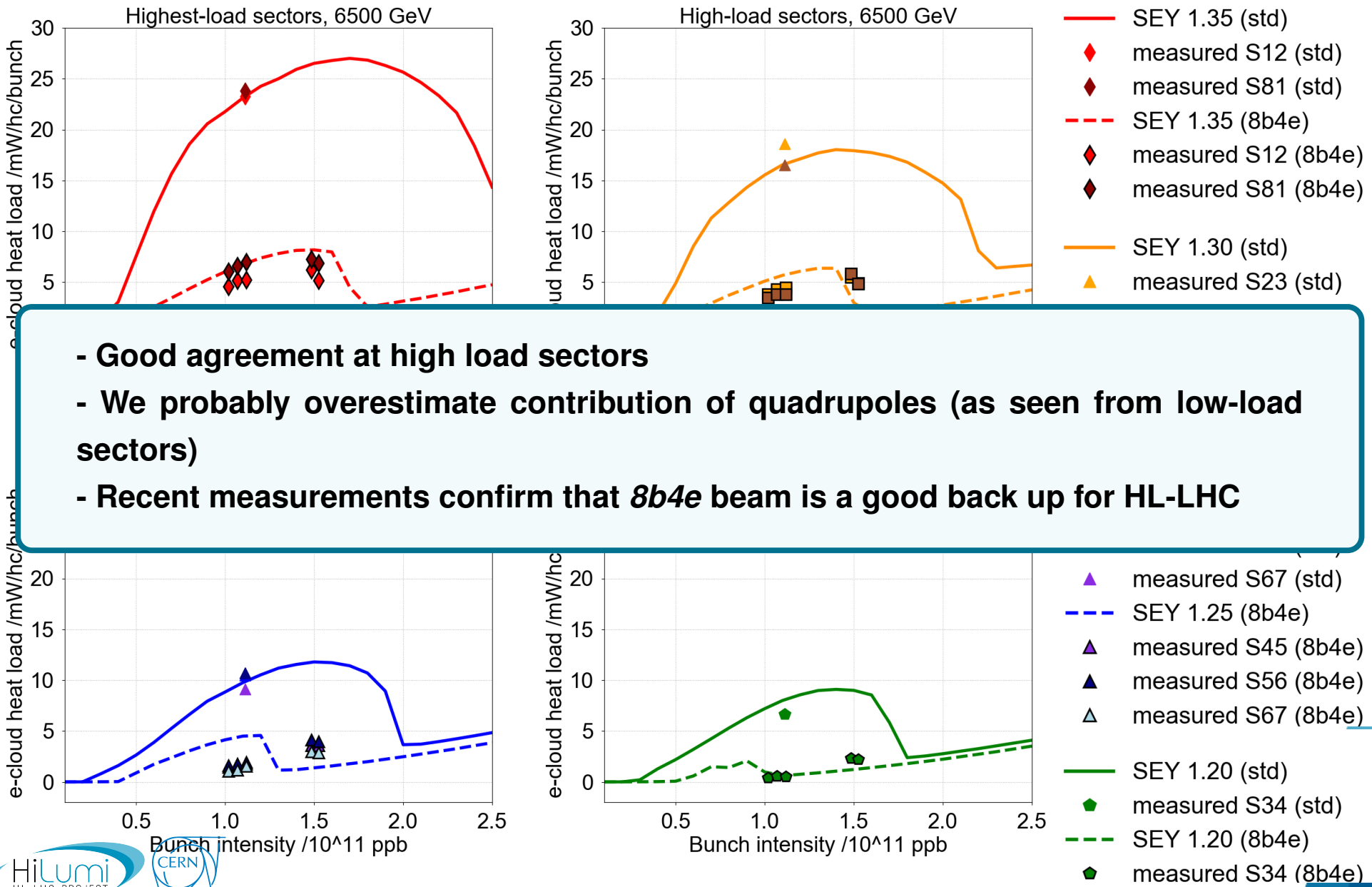
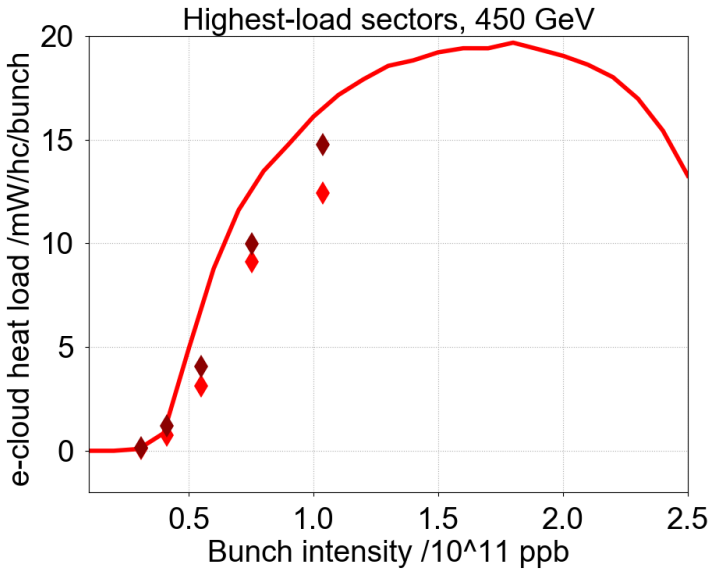


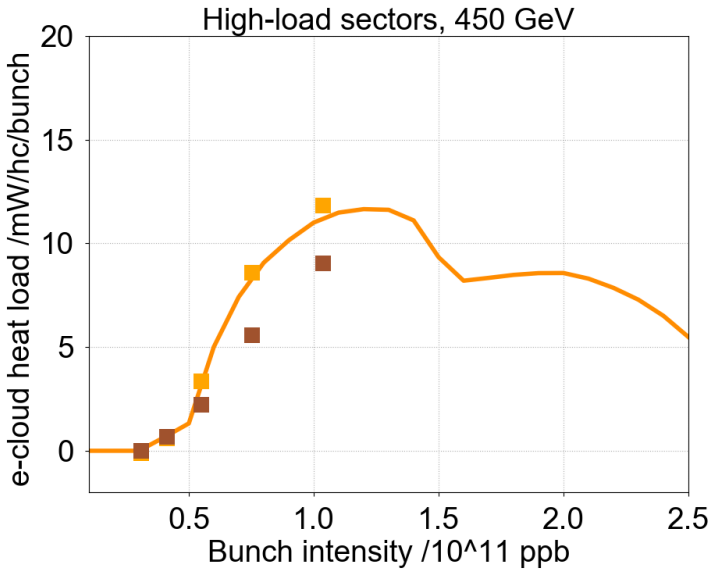
- Good agreement at high load sectors

- We probably overestimate contribution of quadrupoles (as seen from low-load sectors)

- Recent measurements confirm that *8b4e* beam is a good back up for HL-LHC

Arc-to-arc: std @450 GeV





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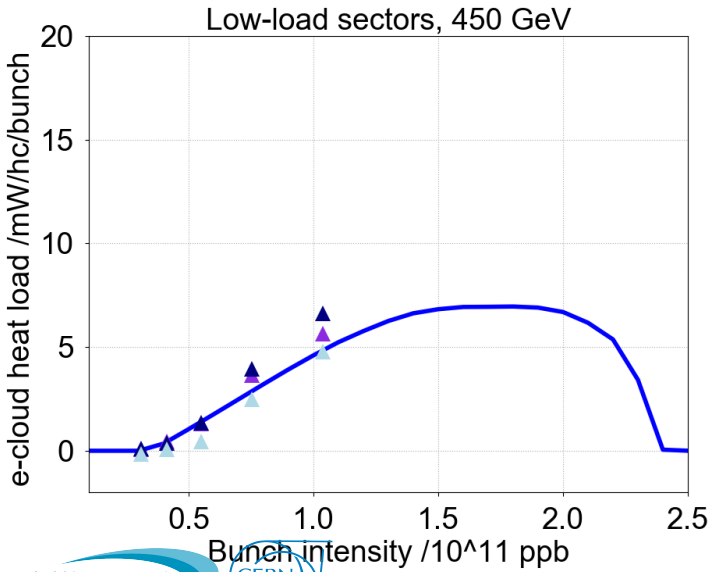

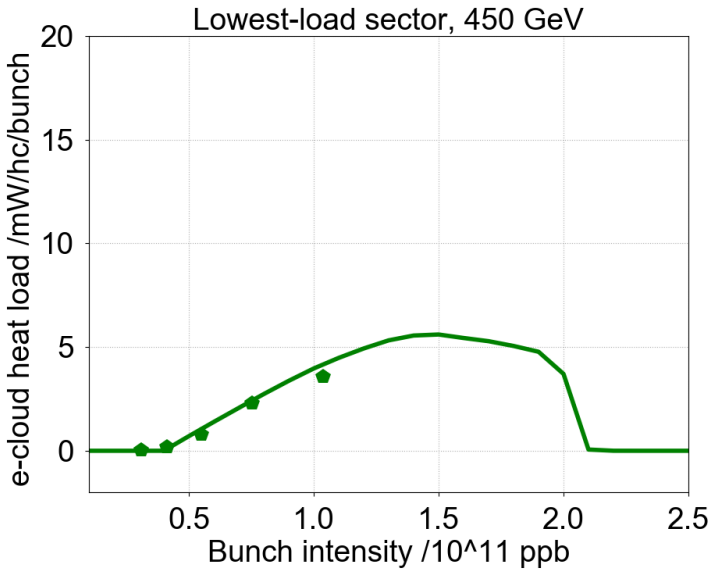

SEY 1.25 (std)
measured S45 (std)
measured S56 (std)
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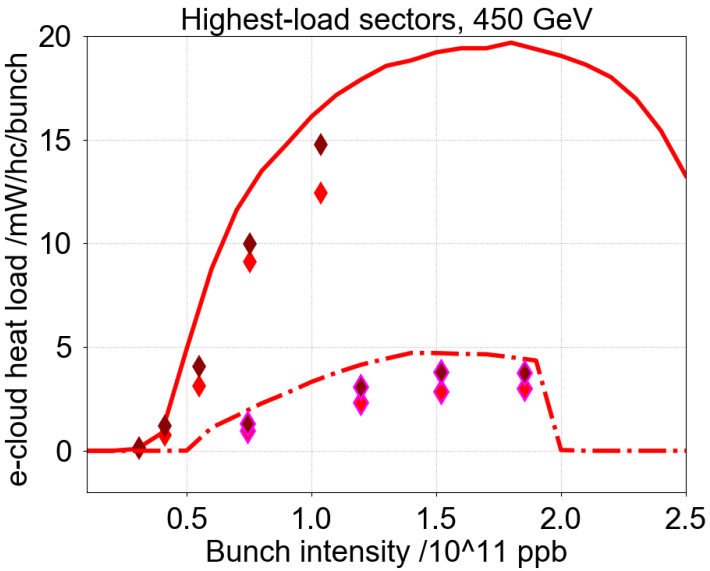
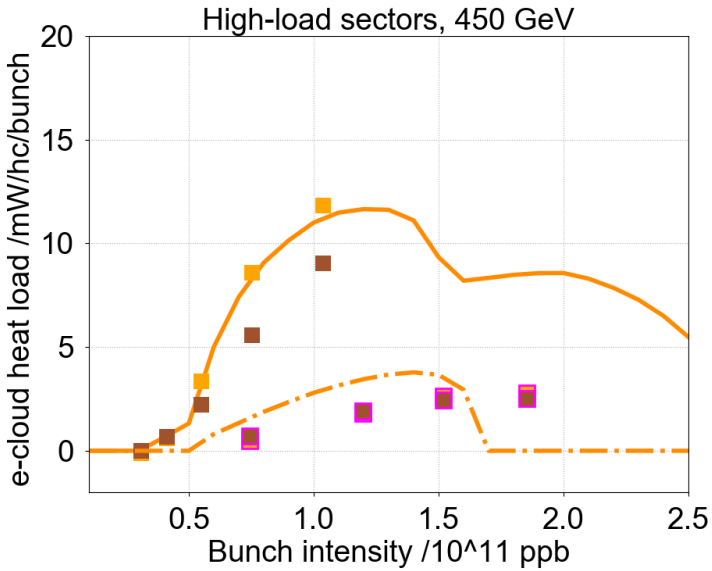
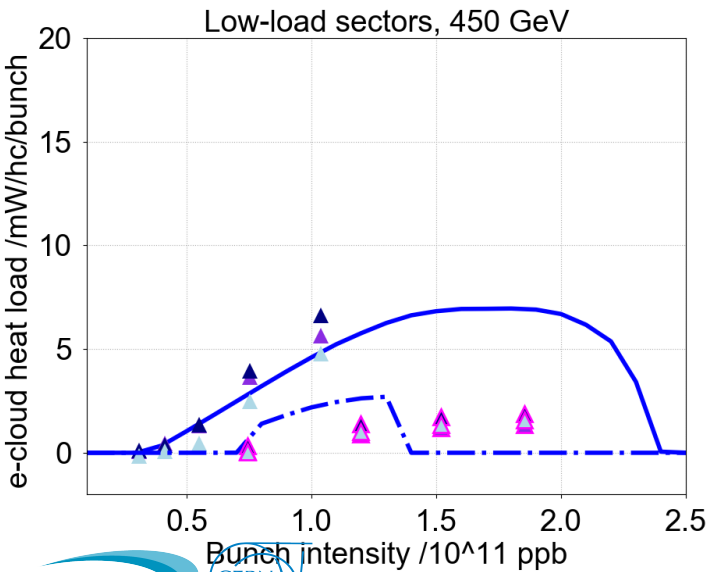
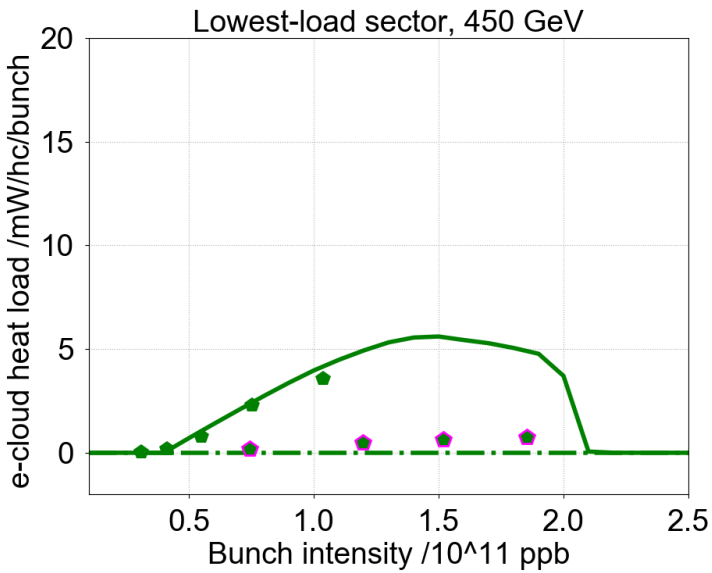
SEY 1.20 (std)
measured S34 (std)

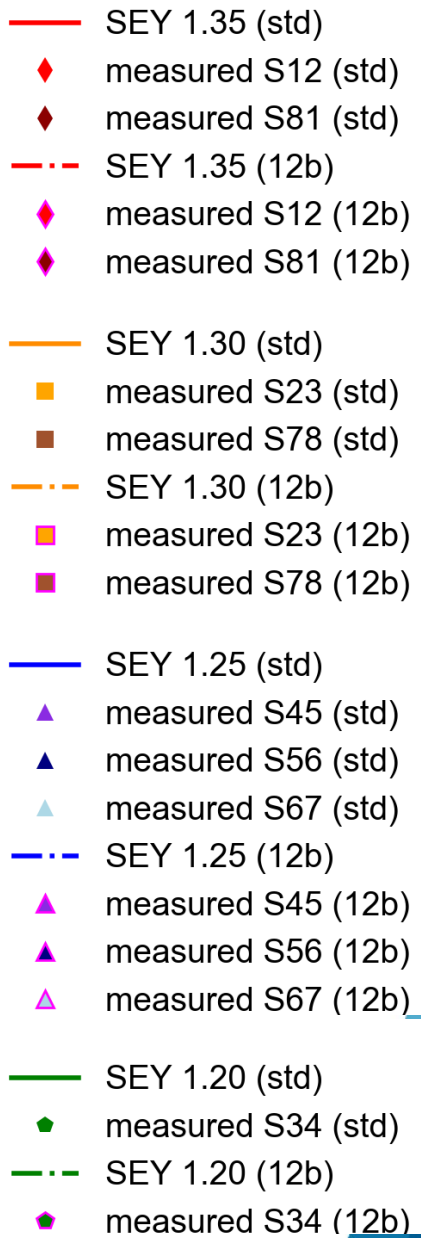
Arc-to-arc: std&12b @450 GeV











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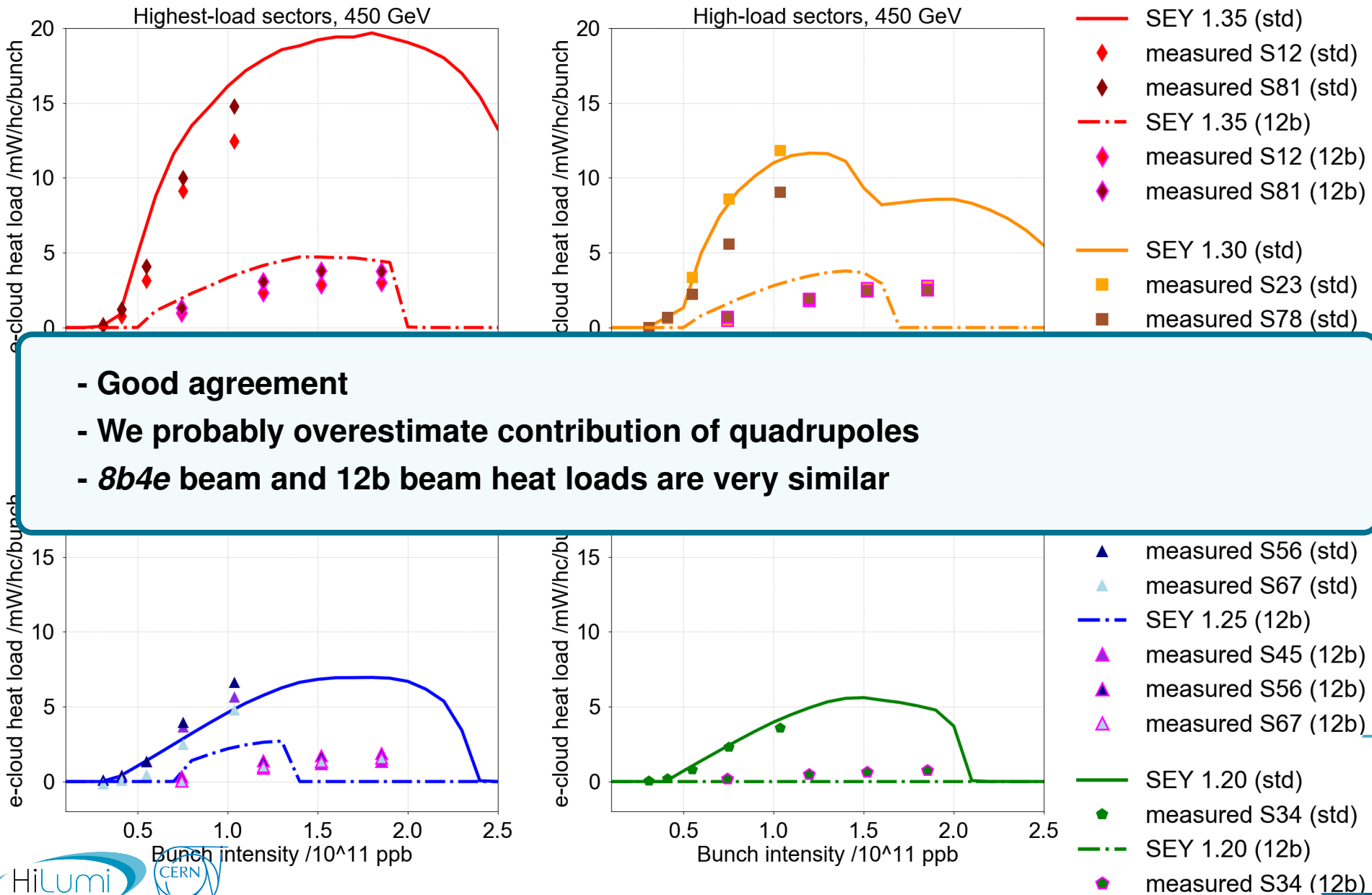

- **Good agreement**
- **We probably overestimate contribution of quadrupoles**
- ***8b4e* beam and 12b beam heat loads are very similar**

Outline

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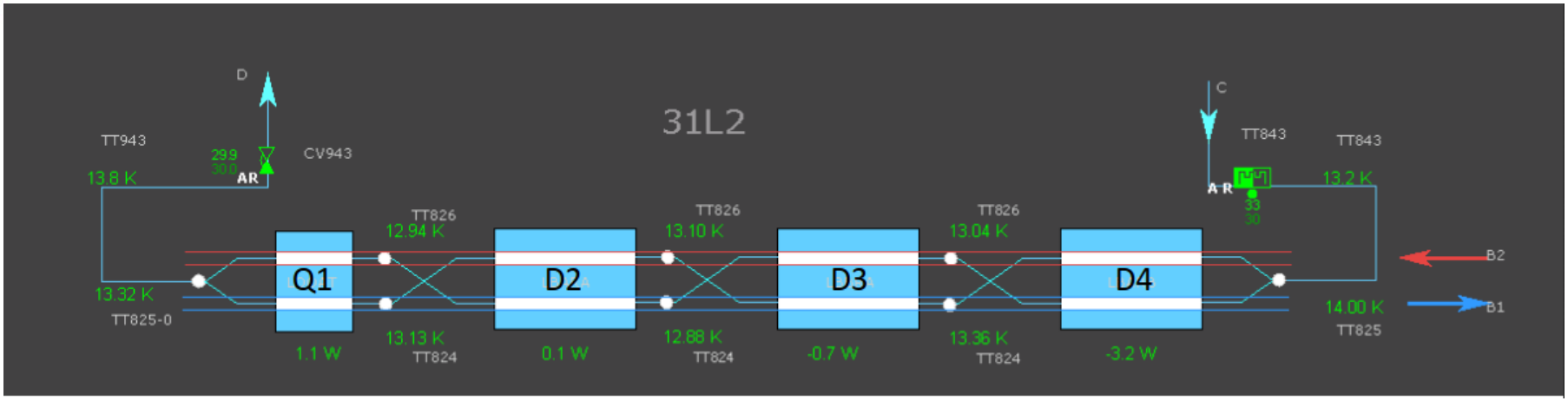
- Arc-to-arc heat loads
- Heat loads in instrumented cell (No data for 12b beam from MD4 analyzed yet)

31L2 instrumented cell



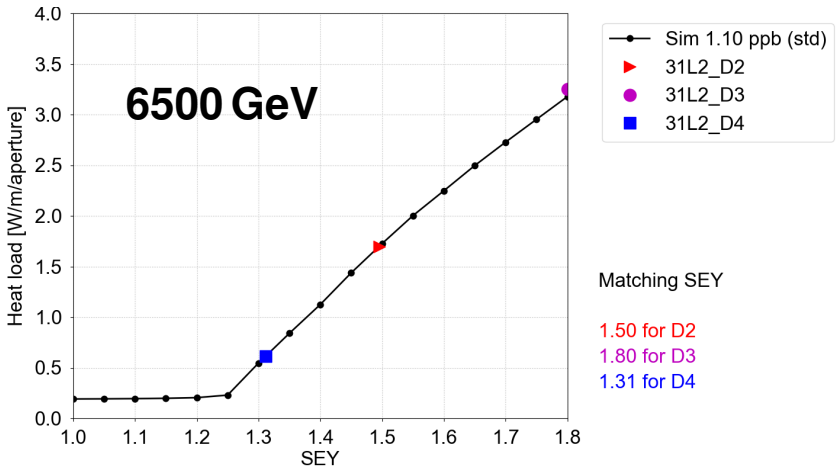
- Probes installed between magnets
- Possible to calculate heat loads on separate magnets
- We assume the flow splits equally between beam screens (which is not true...)

31L2 dipoles: finding SEY (guess # 1)

Guess: Measured heat load is only from 14.3 m dipole (in fact we measure some of the drift)

Fit individual dipole SEY for 72b@6500 GeV and check other energies and filling schemes

- SEY uniform along dipole and equal for beam screens one and two



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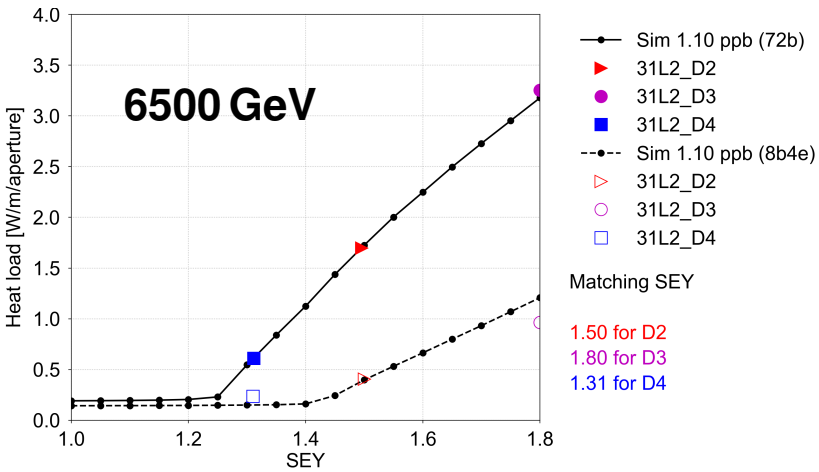

Fits well for high energy *8b4e* beam

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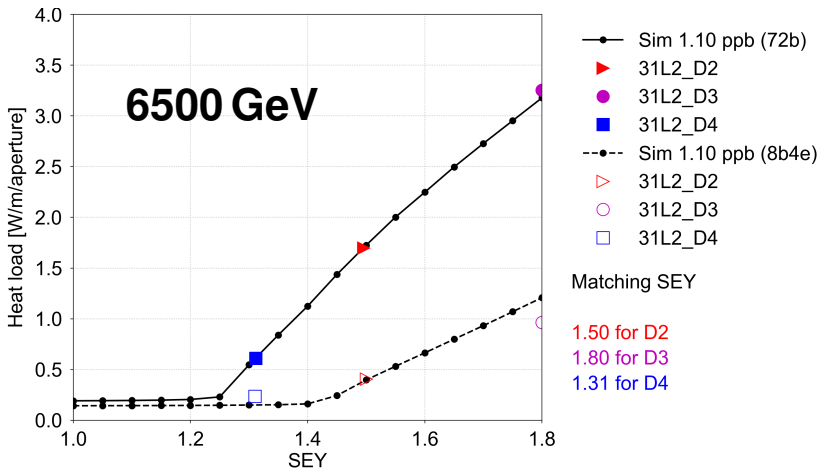
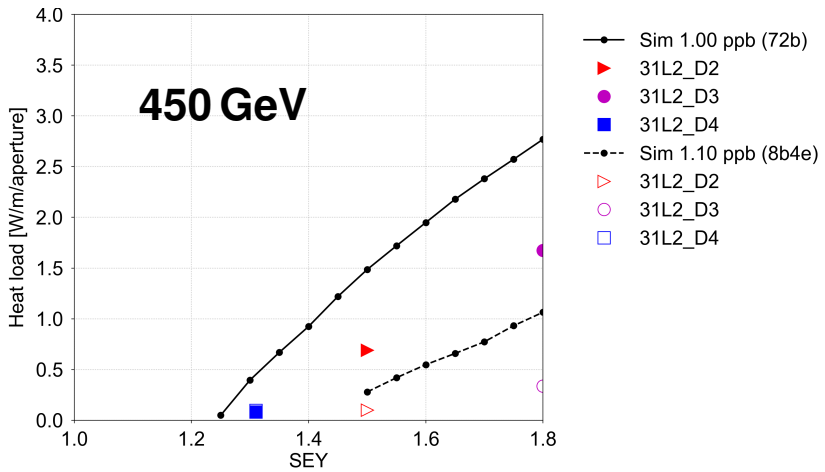




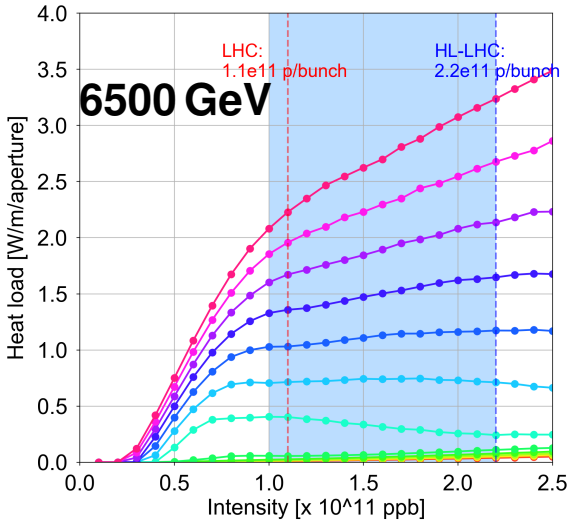
Fits well for high energy *8b4e* beam

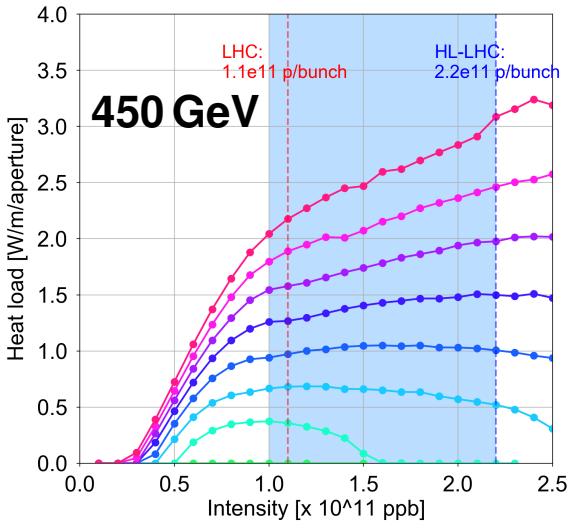
Fit breaks at injection energy

Which component is significantly different between 450 GeV and 6500 GeV?

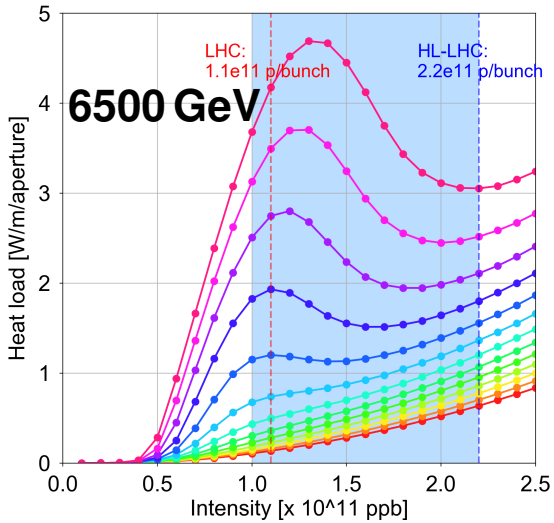
Heat loads vs bunch intensity with std beam

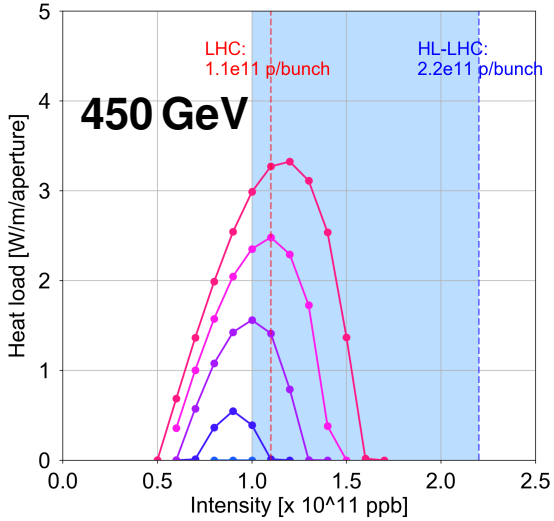
Dipole

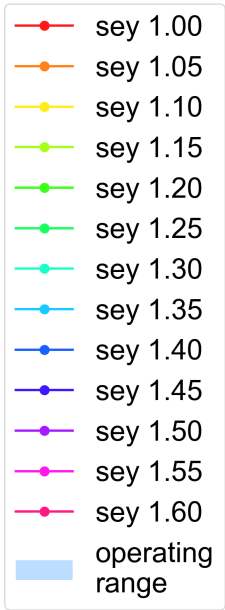




Drift



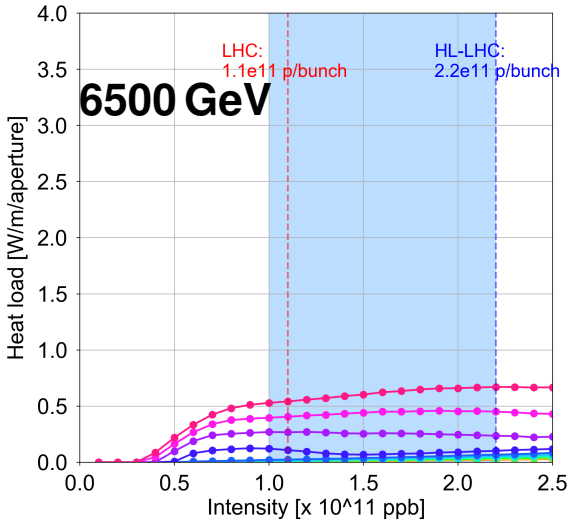


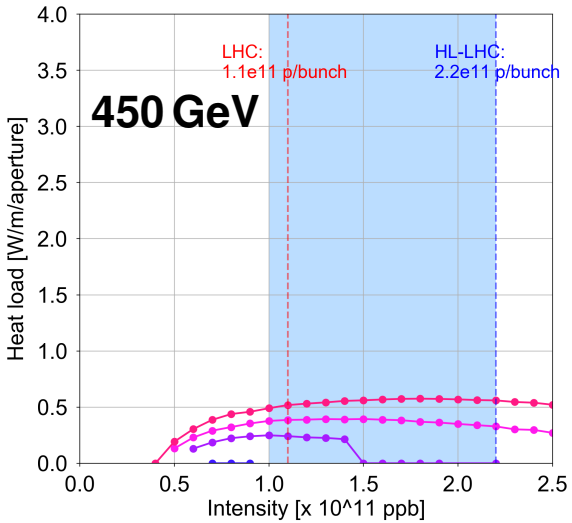


Drifts contribute significantly at high energy!

Heat loads vs bunch intensity with *8b4e* beam

Dipole





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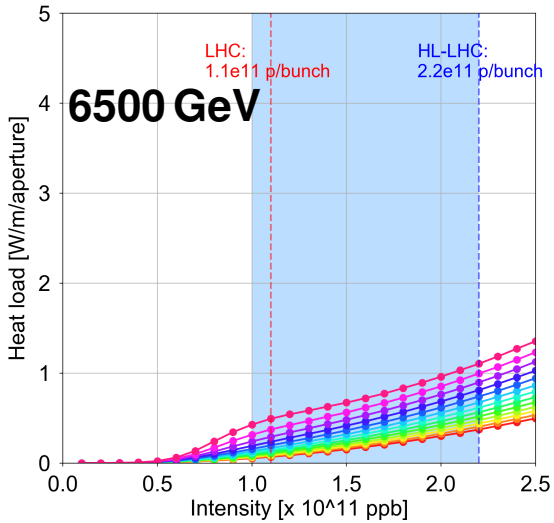

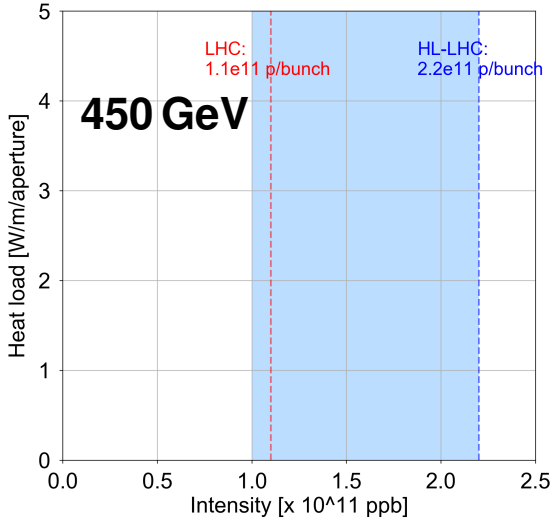

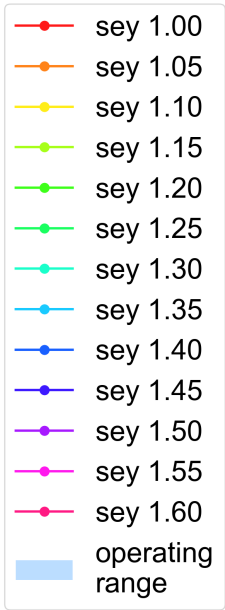

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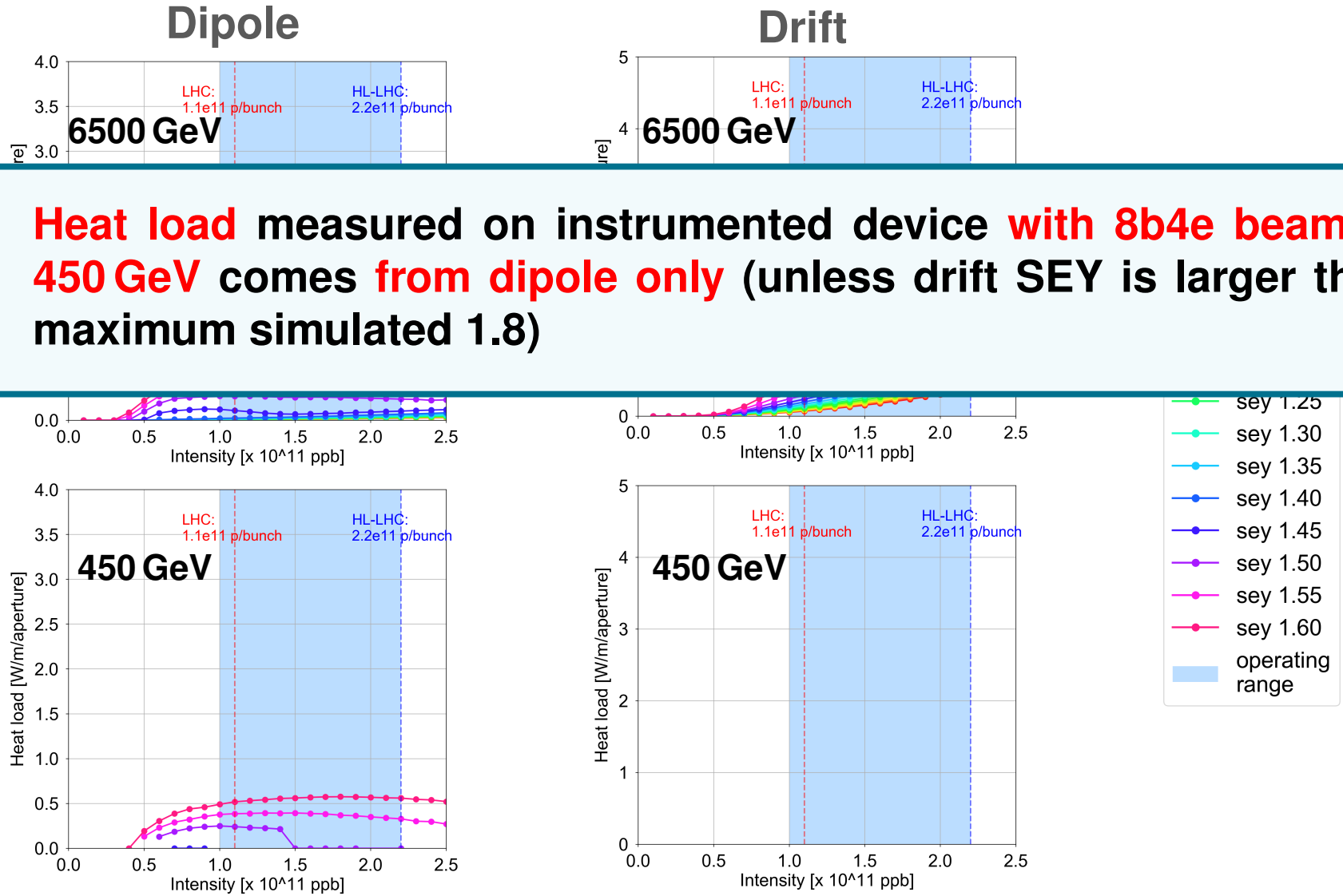
Heat loads vs bunch intensity with *8b4e* beam



Heat load measured on instrumented device with 8b4e beam at 450 GeV comes from dipole only (unless drift SEY is larger than maximum simulated 1.8)

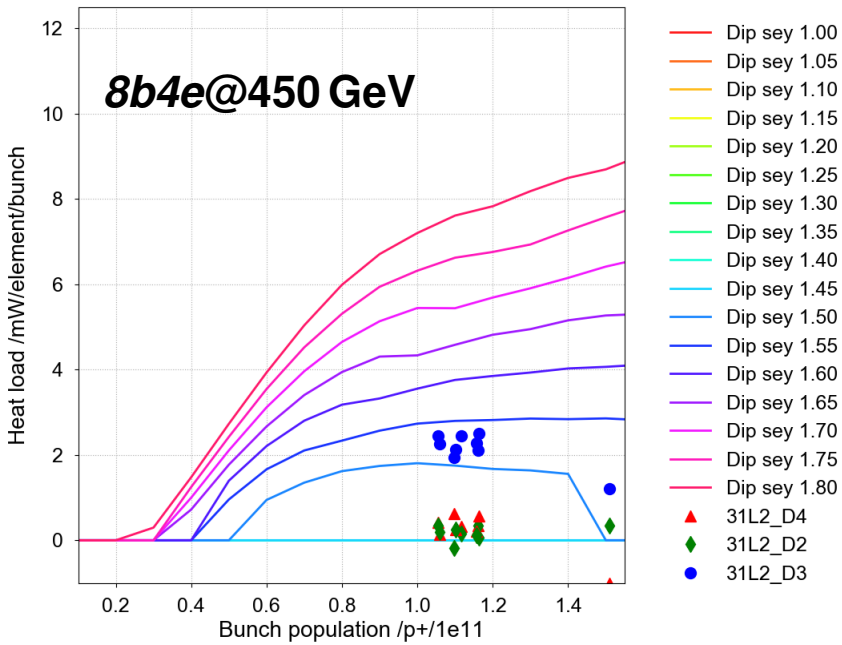
Drifts contribute significantly at high energy!

31L2 dipoles: finding SEY (smarter guess # 2)

Smarter Guess: Measured heat load is from 14.3 m dipole and 1.36m drift (assuming probes are centered between the dipoles)

Fit individual dipoles and adjacent drifts SEY for 8b4e@450GeV and check other energies and filling schemes

- SEY uniform along dipole and equal for beam screens one and two

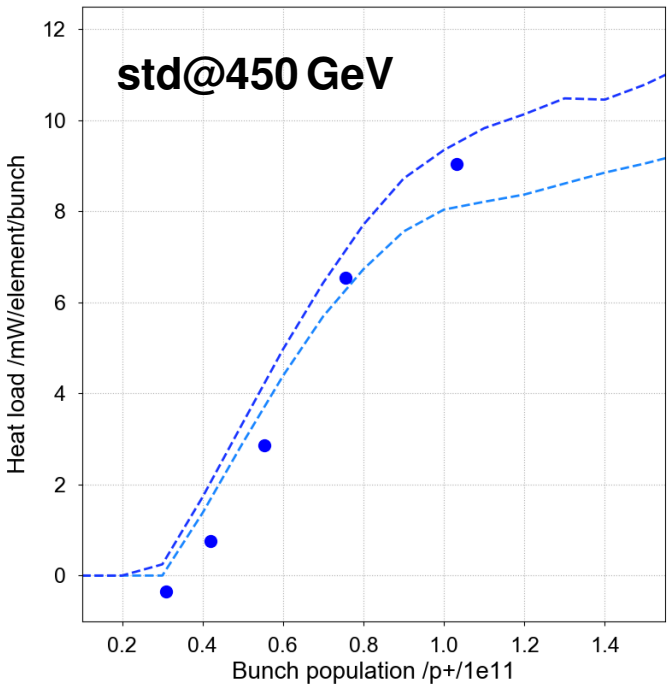


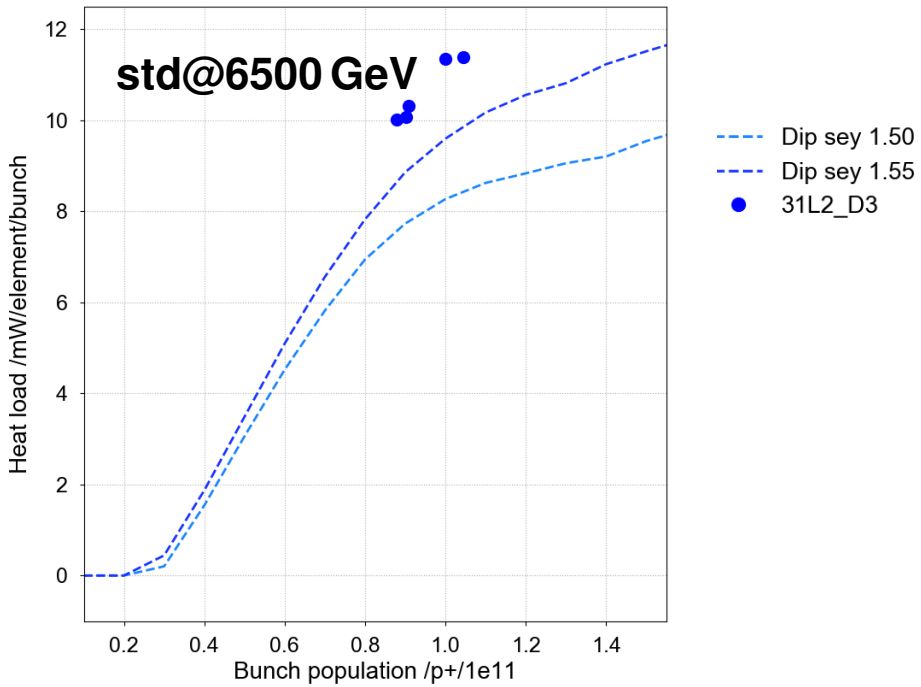
- D3: $SEY \approx 1.50 - 1.55$
- D2, D4: $SEY < 1.5$

31L2 dipoles: finding SEY (smarter guess # 2) (cont.)

D3 SEY model:

- Freeze D3: $SEY \approx 1.50 - 1.55$





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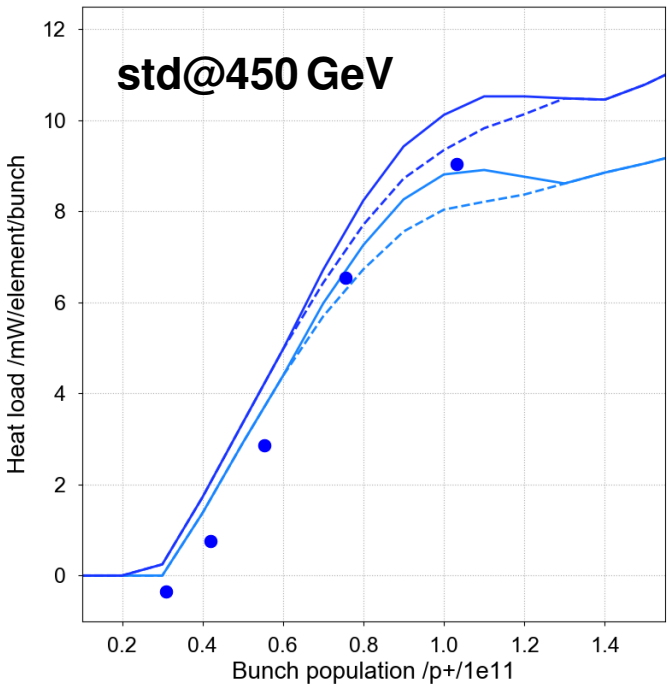
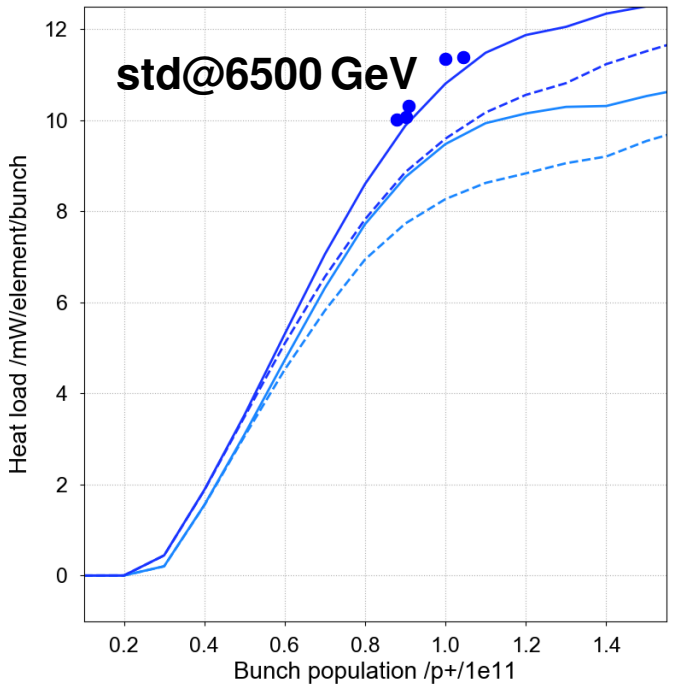
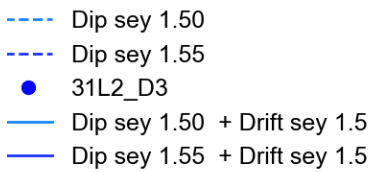
D3 SEY model:

- Freeze D3: $SEY \approx 1.50 - 1.55$
- Fit adjacent drift: SEY 1.5
  - improves intensity dependence @450 GeV
  - fits measurements @6500 GeV







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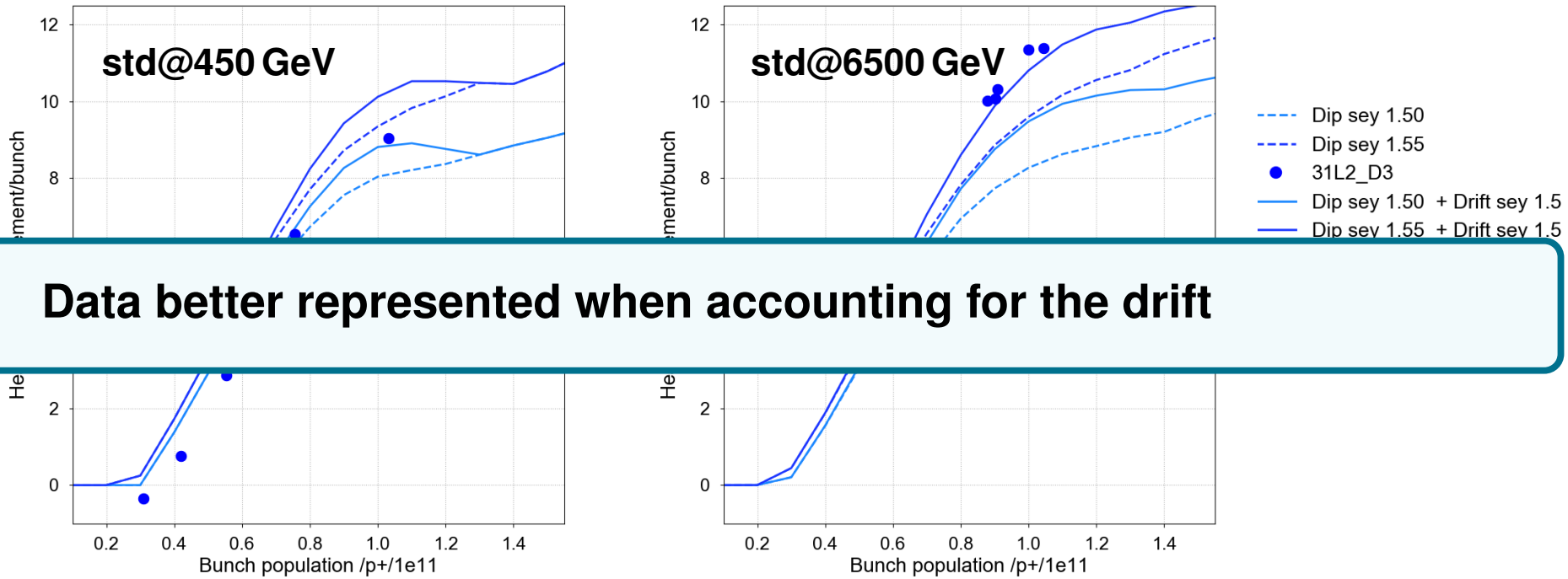
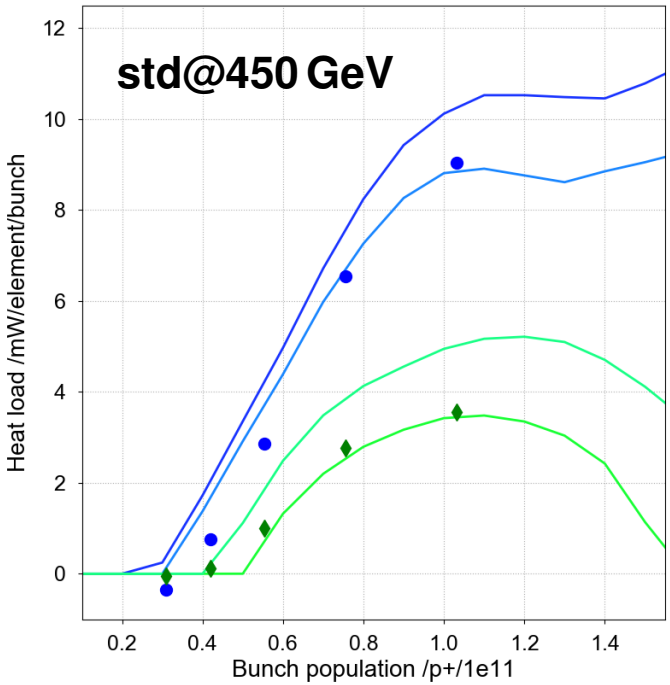
  - improves intensity dependence @450 GeV
  - fits measurements @6500 GeV

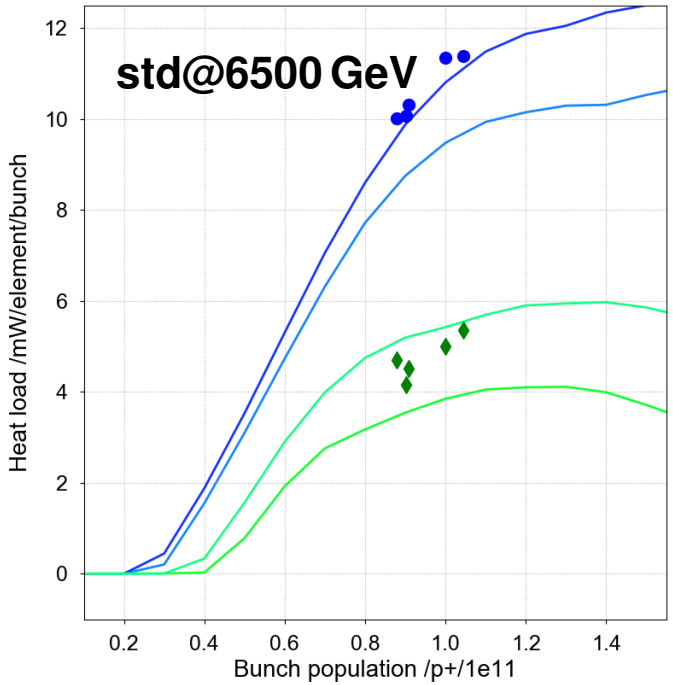


Data better represented when accounting for the drift

31L2 dipoles: models with std beam

Similar procedure for 31L2_D2 dipole was followed



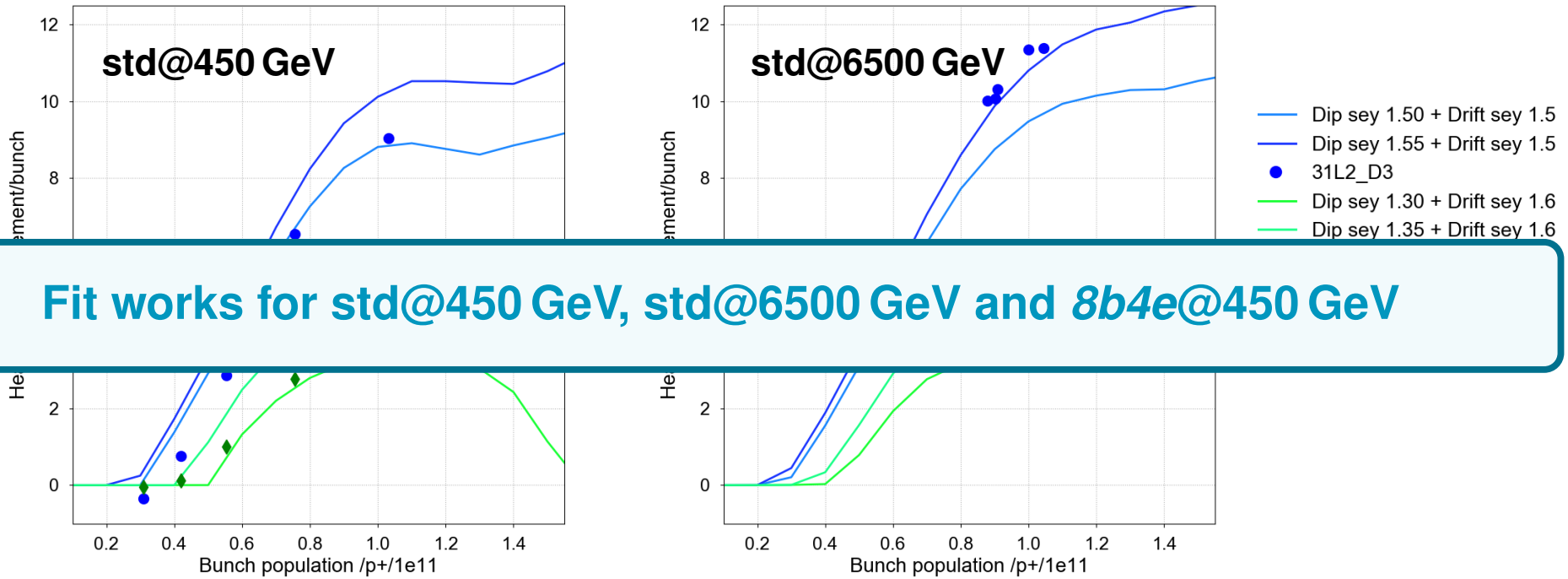


Best models found so far

	SEY_{dip}	SEY_{drift}
31L2_D2	1.5-1.55	1.5
31L2_D2	1.3-1.35	1.6

31L2 dipoles: models with std beam

Similar procedure for 31L2_D2 dipole was followed

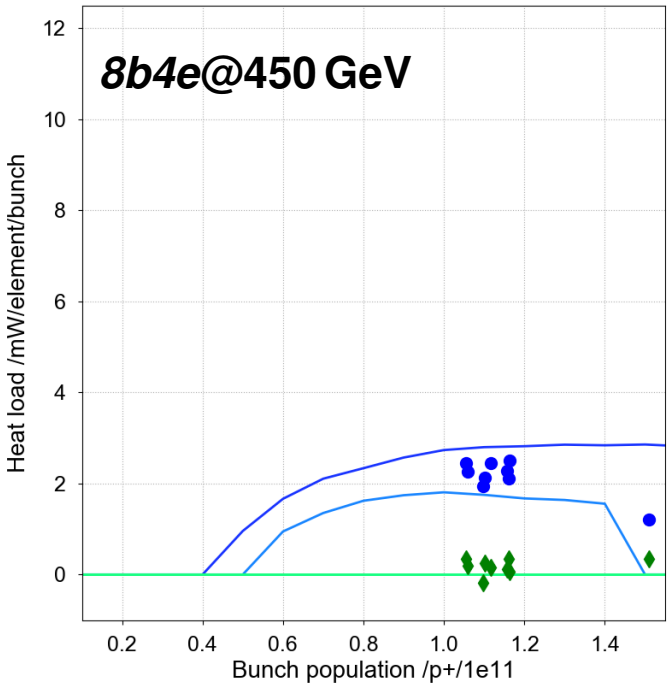


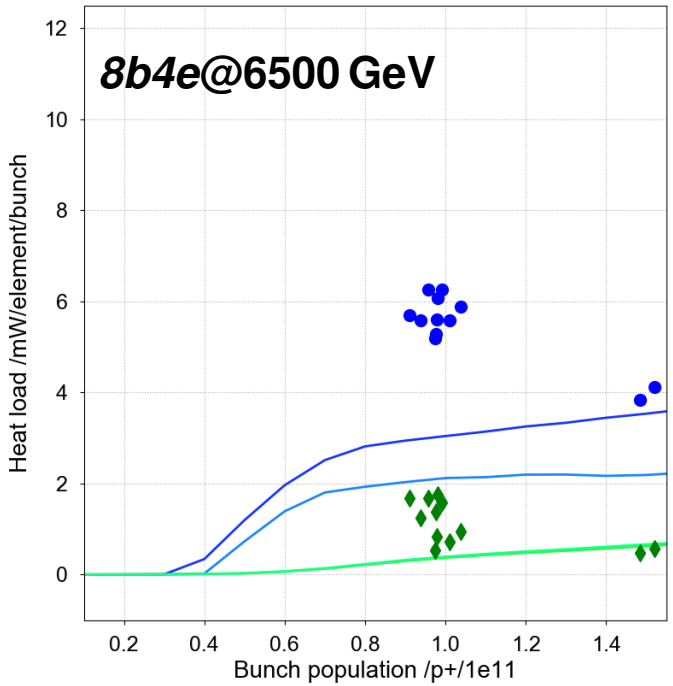
Fit works for std@450 GeV, std@6500 GeV and *8b4e*@450 GeV

Best models found so far

	SEY_{dip}	SEY_{drift}
31L2_D2	1.5-1.55	1.5
31L2_D2	1.3-1.35	1.6

31L2 dipoles: fits with *8b4e*

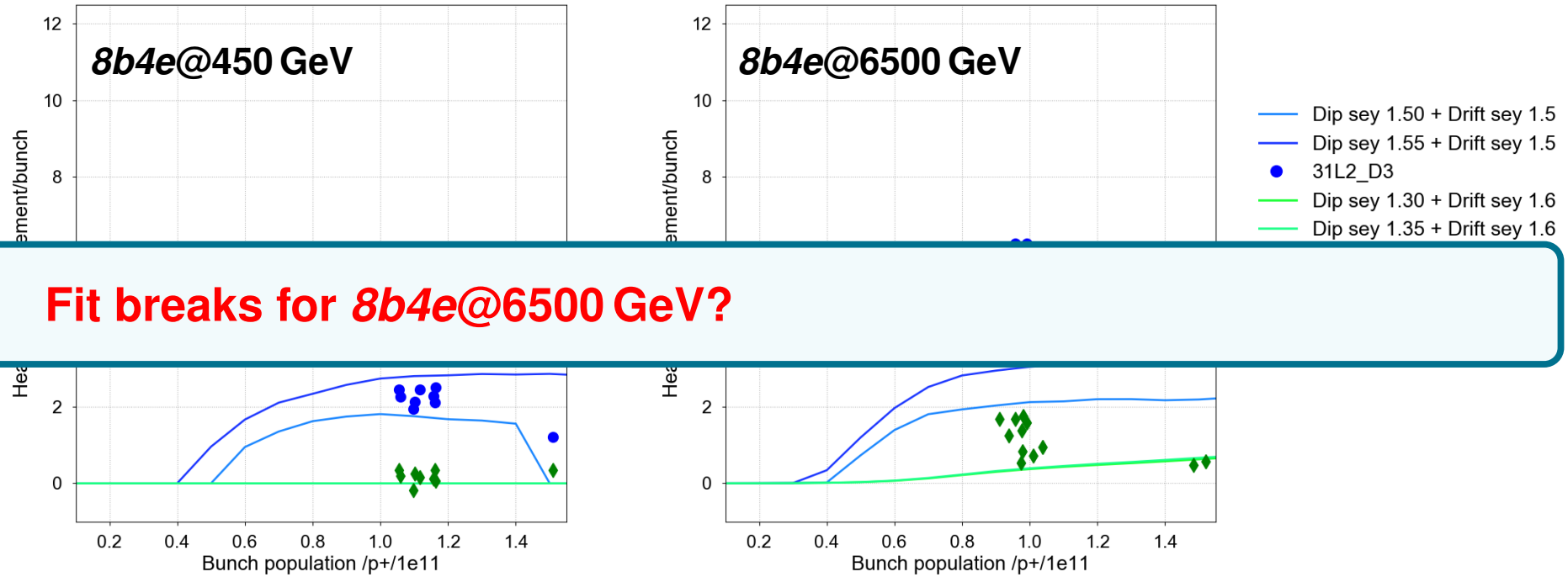




Best models found so far

	SEY_{dip}	SEY_{drift}
31L2_D2	1.5-1.55	1.5
31L2_D2	1.3-1.35	1.6

31L2 dipoles: fits with *8b4e*



Fit breaks for *8b4e*@6500 GeV?

Best models found so far

	SEY_{dip}	SEY_{drift}
31L2_D2	1.5-1.55	1.5
31L2_D2	1.3-1.35	1.6

Summary: arc-to-arc

Observed differences in heat loads in LHC sectors were analyzed

- The following SEY distribution in LHC fits the numerical results (assuming unifrom SEY within the sector)

Sector	**S34**	**S45/S56/S67**	**S23/S78**	**S12/S81**
SEY	1.20	1.25	1.30	1.35

- SEY models show good agreement for all tested filling schemes and energies
- Models tend to overestimate the contribution of quadrupoles
- Latest MD with high intensity 8b4e beams proved them to be a good back-up filling scheme for high-intensity

SEY fitting on cell-by-cell level is in progress

Summary: individual dipoles

Observed differences in heat loads in LHC individual magnets inside the 31L2 cell were analyzed

- SEY models found so far describe three of four tested filling schemes and energies

	SEY(dip/drift)	std@450	8b4e@450	std@6500	8b4e@6500
D3:	(1.50-1.55) / 1.5	✓	✓	✓	✗
D2	(1.30-1.35) / 1.6	✓	✓	✓	✗

- The challenges are
  - number of unknown parameters (measurable drift length, dipole SEY, drift SEY)
  - SEY of each separate beam screen in the dipole is different
  - Nonuniform SEY (confirmed in the dipoles) (see B.Bradu for Task Force on LHC Beam-Induced Heat Loads, 3 Oct.,2018)

Parameter optimization code needed to find general model Check model with 12b@450 GeV (MD4 data)

Thank you

Arc-to-arc: std&12b&8b4e @450 GeV