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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

HE-LHC electron cloud

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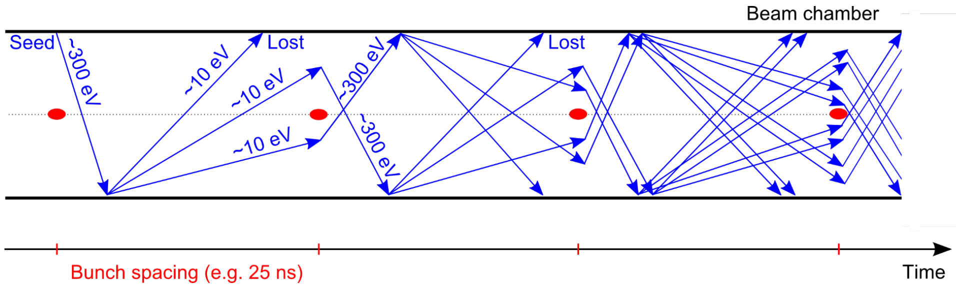
Introduction

Electron clouds can cause transverse instabilities, tune shift and spread, emittance growth, losses, heat load and vacuum degradation

- Effects can effectively be mitigated by preventing the build-up of electron clouds
- Need to identify required conditions to sufficiently suppress electron cloud build-up



Previous studies

Electron cloud build-up for 25 ns, 12.5 ns and 5 ns beam:

- Arc dipoles and quadrupoles
- Simple photoelectron model based on ray tracing results
- Flat top and 1.3 TeV injection energy

Studies performed using

- Main chamber of beam screen (2015 version)
- Cu surface

New results

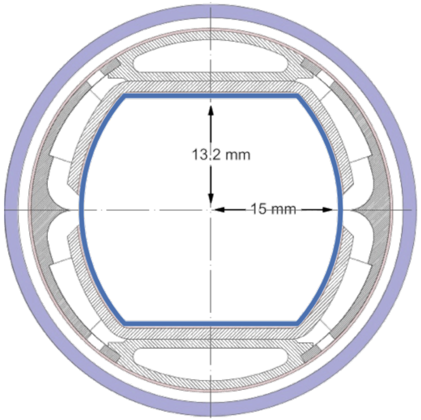
- Scaling with intensity and emittance
- Injection energy
- Beam screen geometry
- Field free regions

Overview of previous studies

Simulation studies of e-cloud build-up for different bunch spacing options

Electron cloud build-up for 25 ns, 12.5 ns and 5 ns beam:
- Main chamber of beam screen (2015 version), Cu surface
- Arc dipoles, quadrupoles

Main chamber of FCC beam screen (2015 version), with Cu surface



Machine parameters		
	Injection	Flat top
Energy	1.3 TeV	13.5 TeV

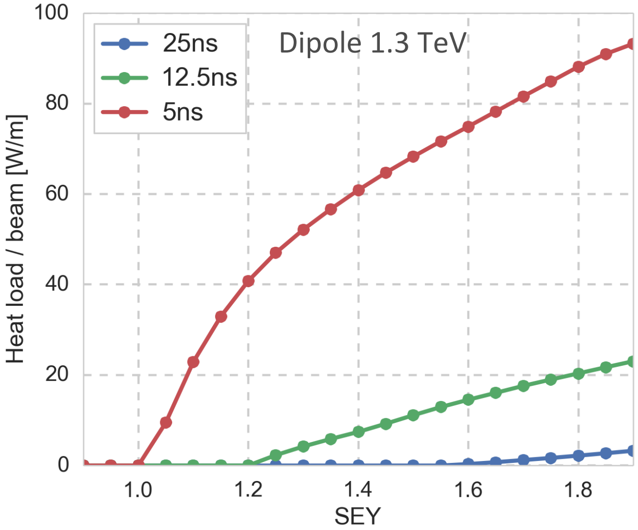
Arc elements		
	Dipole	Quad
Field	16 T	216 T/m

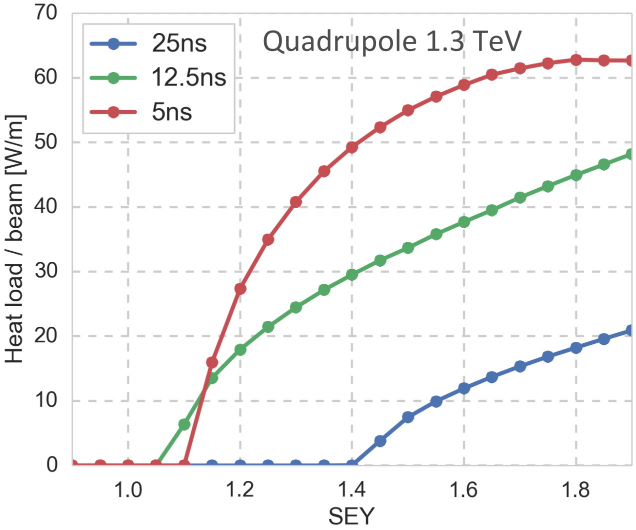
Beam parameters			
Bunch spacing [ns]	**25**	**12.5**	**5**
Bunch intensity [p^+]	2.2×10^{11}	1.1×10^{11}	4.4×10^{10}
Norm. emittance [m]	2.5e-6	1.25e-6	0.5e-6
Bunch length [m]		0.0755	
Bunch train pattern	(72b + 9e)*4	(144b + 18e)*4	(360b + 45e)*4

Heat load

The heat load must be within the cooling capacity of the cryogenic system

- The available cooling capacity is still to be defined
- For comparison, the load from synchrotron radiation is 4.6 W/m/beam





- The heat load of the 5 ns beam is very high above SEY = 1.0
- The heat load of the 12.5 ns beam is moderate below SEY ~ 1.2
- The heat load of the 25 ns beam is small for SEY < 1.4

Single bunch instability

Analytical estimate of **threshold electron density** for instability

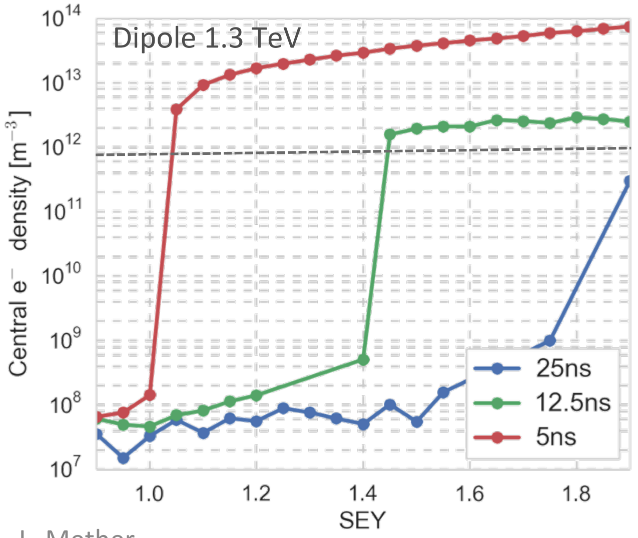
$$\rho_{e,th} = \frac{2\gamma\nu_s\omega_e\sigma_z/c}{\sqrt{3}KQr_0\beta L} \quad \text{with} \quad \omega_e = \sqrt{\frac{\lambda_p r_e c^2}{\sigma_y(\sigma_x+\sigma_y)}}, \quad K = \omega_e\sigma_z/c, \quad Q = \min(\omega_e\sigma_z/c, 7)$$

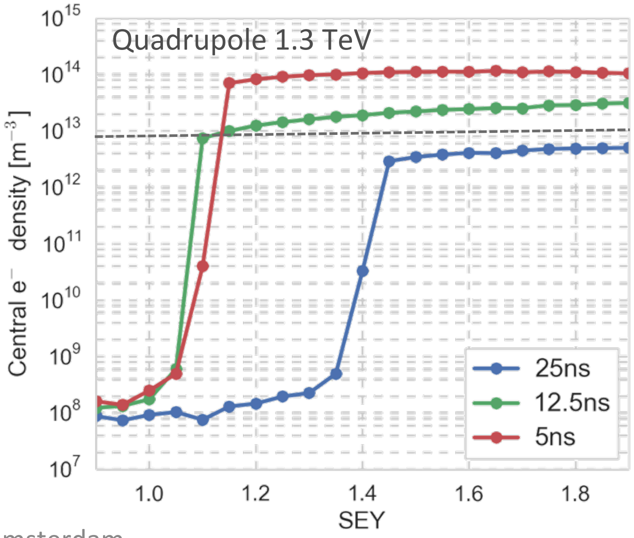
K. Ohmi

	450 GeV	13.5 TeV
Analytic	1.4×10^{11}	8.1×10^{11}
Simulation	3×10^{11}	6×10^{12}

- 25 ns beam well below instability threshold
- 12.5 ns beam around threshold for SEY > 1.4
- 5 ns beam unstable for SEY > 1.0

- 25 ns beam around threshold for SEY > 1.4
- 12.5 and 5 ns unstable at low SEY



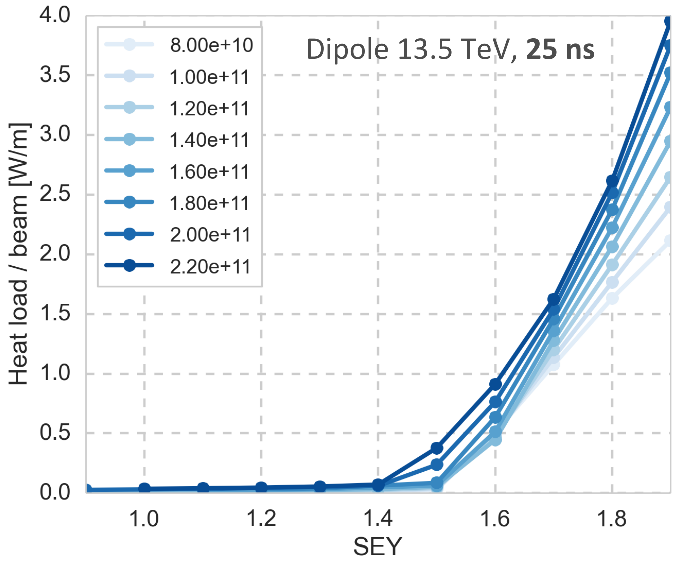


Evolution during fills

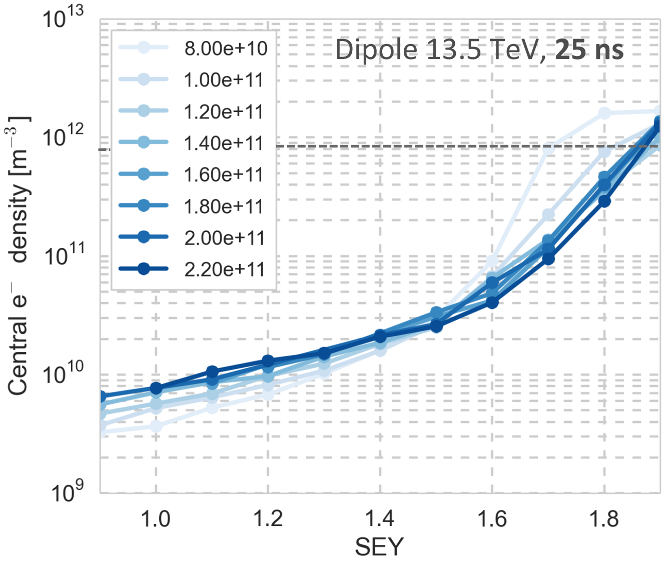
E-cloud effects don't scale linearly with intensity

- Some effects may get worse with the intensity burn-off during fills
- Scan decreasing intensity and emittance in uniform steps shows significant effect for the 12.5 and 25 ns beams, in particular in the quadrupoles (also dipoles for 12.5 ns)

The multipacting threshold is slightly increased with decreasing intensity



A slight increase of the central density for lower intensities at high SEY



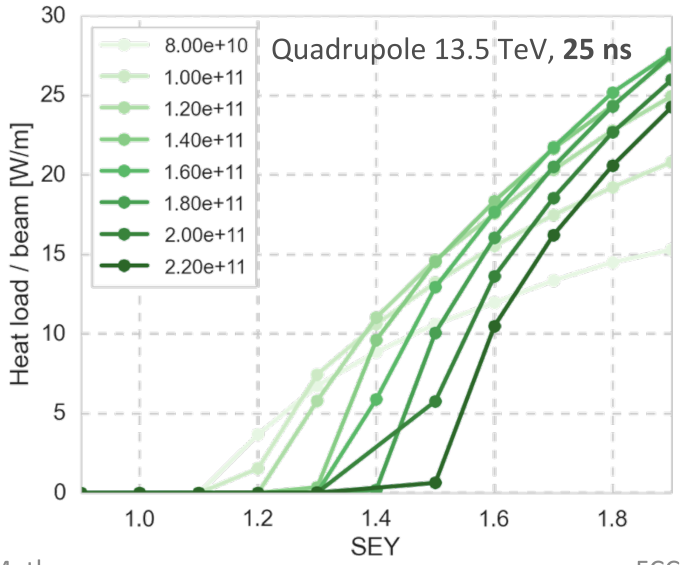
Evolution during fills

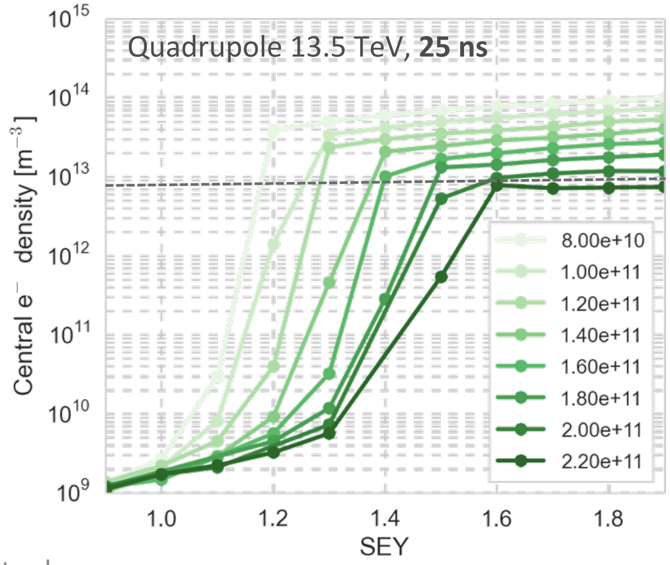
E-cloud effects don't scale linearly with intensity

- Some effects may get worse with the intensity burn-off during fills
- Scan decreasing intensity and emittance in uniform steps shows significant effect for the 12.5 and 25 ns beams, in particular in the quadrupoles (also dipoles for 12.5 ns)

The multipacting threshold decreases significantly with decreasing intensity

For lower intensities, the central density approaches the instability threshold at low SEY





Electron cloud build-up

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The multipacting thresholds, i.e. secondary emission yield (SEY) limits for electron cloud build-up, have been identified with build-up simulations

Multipacting thresholds from build-up simulation
(defined as highest SEY without build-up)

	5 ns	12.5 ns	25 ns	5 ns	12.5 ns	25 ns	5 ns	12.5 ns	25 ns
	Injection 1.3 TeV			Flat top 13.5 TeV			Intensity and emittance scan		
Dipole	1.0	1.2	1.55	1.0	1.15	1.45	1.0	1.1	1.4
Quadrupole	1.1	1.05	1.4	1.05	1.1	1.45	1.0	1.0	1.1

The 5 ns beam has very low thresholds, and would need a coating with an SEY no larger than 1.0 to be a viable beam option (also very high heat loads and central electron densities above SEY ~ 1)

The 12.5 ns beam also has quite low SEY thresholds, and requires SEY < 1.1 in quadrupoles

The 25 ns beam has relatively high thresholds at nominal parameters, but build-up in the quadrupole is enhanced with decreasing intensity, occurring above SEY ~ 1.1

Beam screen design

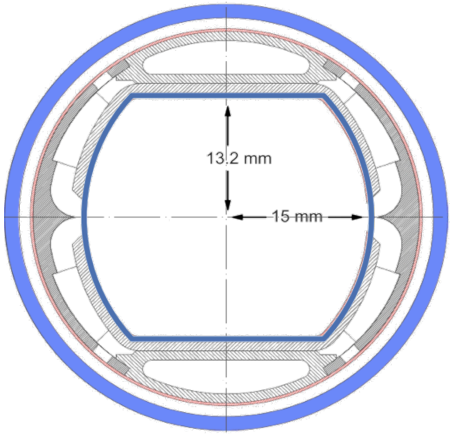
2015 → 2017

- Larger slit, saw-tooth surface, straight edges
- Impact expected mainly in the drifts, due to the cloud distribution in magnetic fields

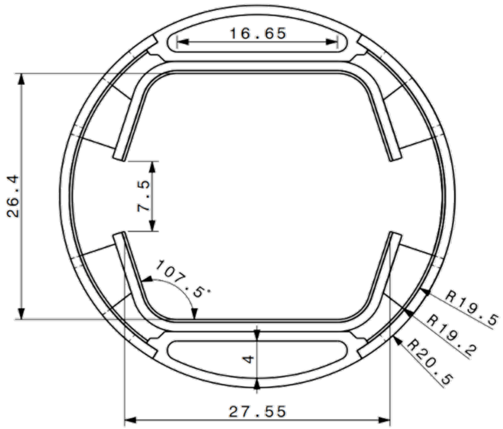
2017 → 2018

- Smaller vertical aperture (by 2 mm)
- Could impact results also in dipoles and quads

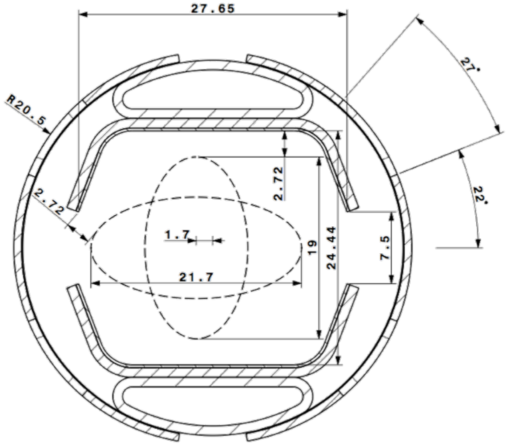
Local photoelectron production on individual surface segments implemented according to ray-tracing simulations *I. Bellafont, G. Guillermo*



2015



2017



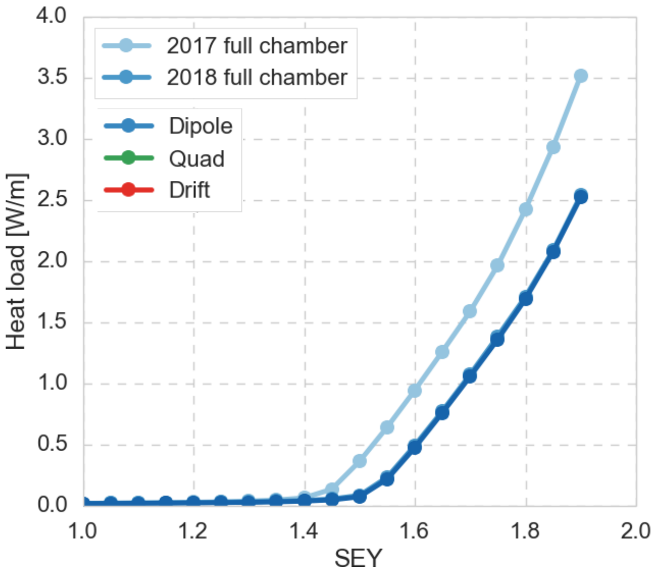
2018

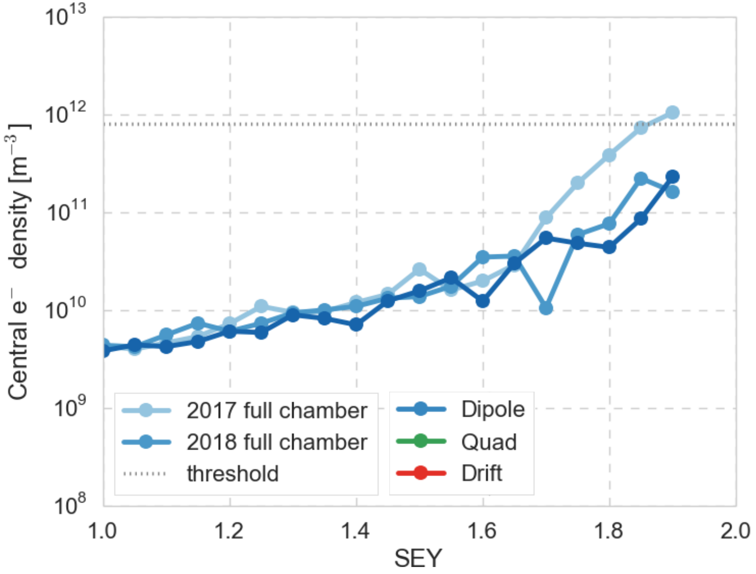
C. Garion, J. Fernandez Topham et al, *see talk of F. Perez*

Beam screen design

Simulations with full beam screen geometry for 2017 and 2018 beam screen models

- Build-up threshold in the dipole is slightly higher with the smaller vertical aperture





Beam screen design

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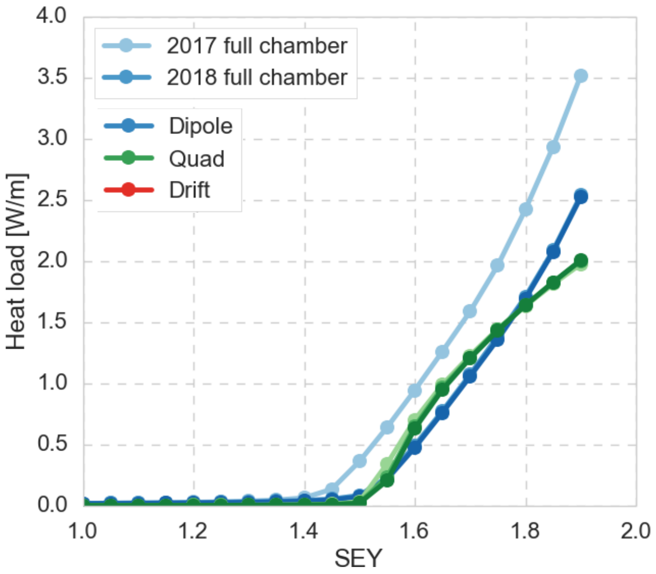
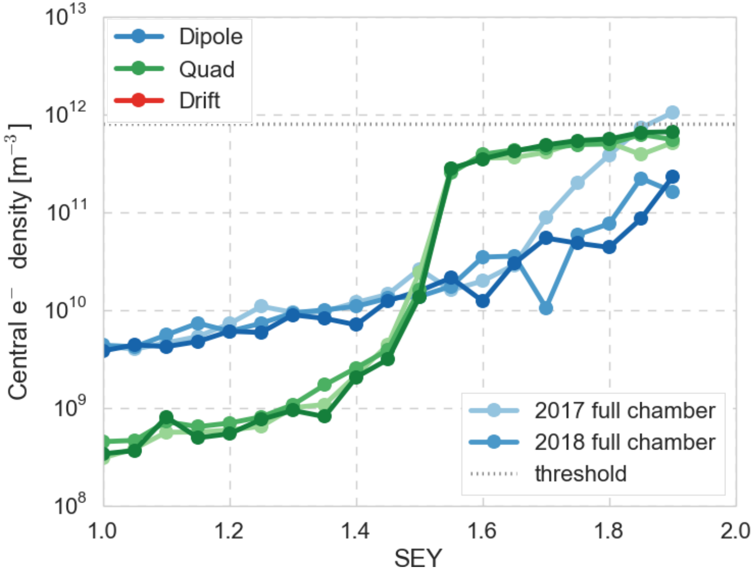
Simulations with full beam screen geometry for 2017 and 2018 beam screen models

- Build-up threshold in the dipole is slightly higher with the smaller vertical aperture
- Essentially no difference between the two chambers in quadrupoles

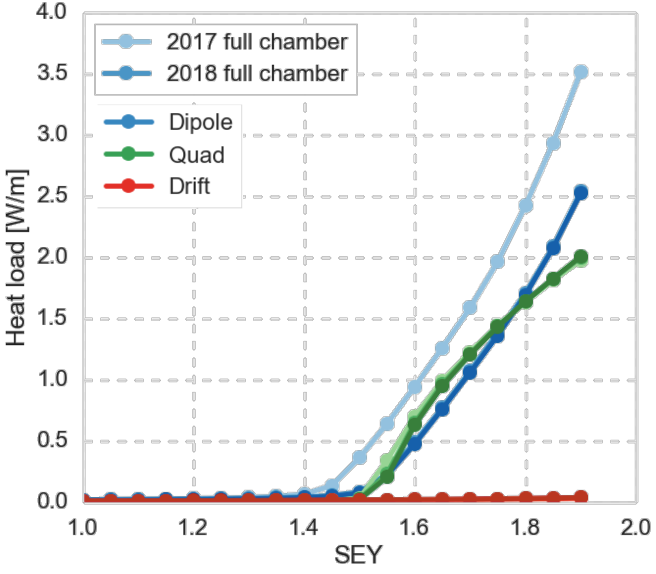


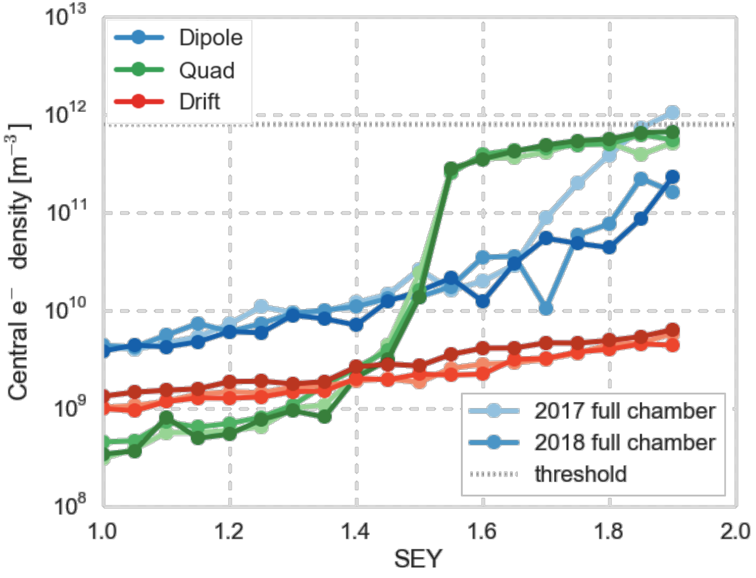


Beam screen design

Simulations with full beam screen geometry for 2017 and 2018 beam screen models

- Build-up threshold in the dipole is slightly higher with the smaller vertical aperture
- Essentially no difference between the two chambers in quadrupoles
- No build-up occurs up to SEY ~ 1.9 in the field free regions, here considering a 10^{12} e/cm^2/s flux of photoelectrons on the saw-tooth surface (build-up is suppressed by large aperture at the slits)

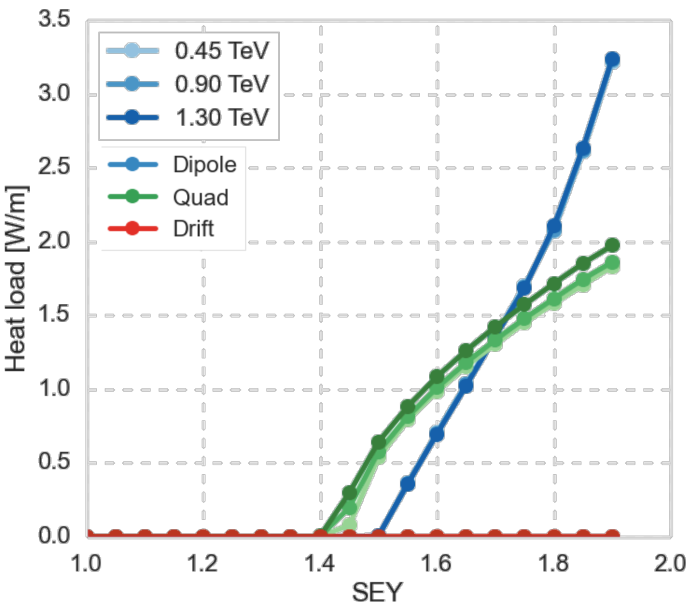


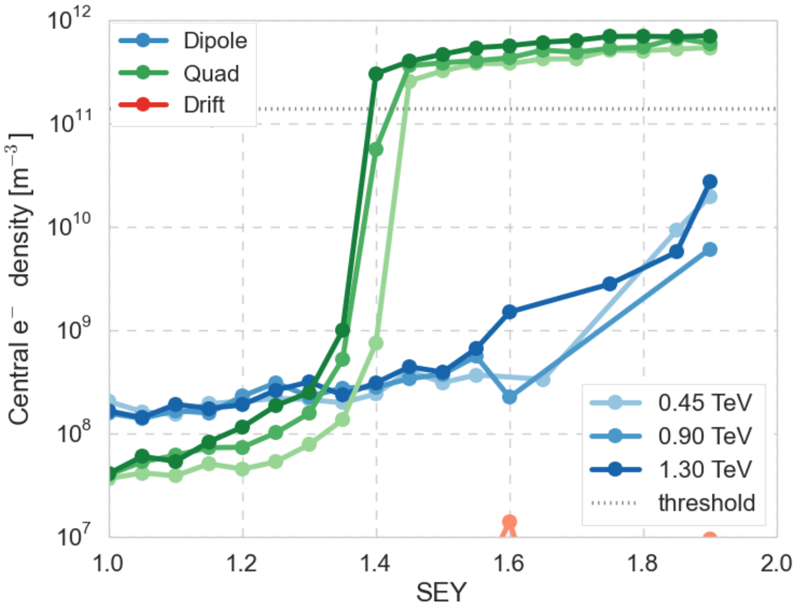


Injection energy

The effect of the injection energy on e-cloud build-up was studied

- A higher energy slightly enhances build-up in quadrupoles, but the effect is marginal
- No effect of the energy observed in dipoles
- No build-up occurs up to SEY ~ 1.9 in the field free regions at any injection energy





Conclusions

E-cloud build-up with the full FCC-hh beam screen geometry has been studied for 2017 and 2018 models

- No significant difference between the two proposed models
- The slit effectively mitigates build-up in field free regions, at least for moderate photoelectron production at the saw-tooth surface

The effect of the injection energy on build up has been studied

- No significant difference between injection energies was observed

The SEY threshold for e-cloud build-up has been determined for different bunch spacing

- The 5 ns bunch spacing is an option only with a coating with SEY = 1.0 or less
- The 12.5 ns requires SEY ~ 1.0 – 1.1 in dipoles and quadrupoles
- The 25 ns bunch spacing has relatively high thresholds at nominal parameters, but build-up in the quadrupole is enhanced by intensity burn-off, requiring SEY ~ 1.1