Electron cloud studies

intermediate results for WP4

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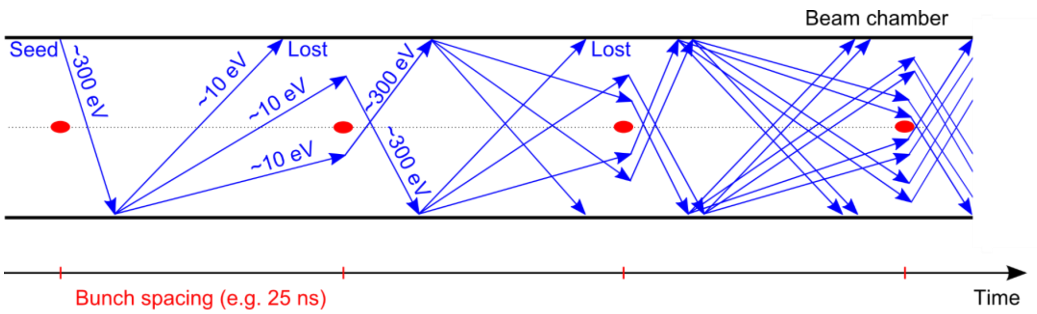
Outline

- Introduction
- Where is beam screen coating needed?
- Constraints on photoelectron (photon) flux
- Summary

Introduction

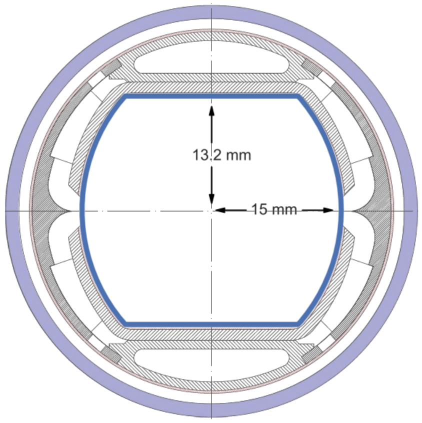
Secondary Electron Emission can drive an avalanche multiplication effect, filling the beam chamber with an electron cloud



Main concerns of electron cloud

- Transverse instabilities due to interaction between beam and electron cloud
- Emittance growth, tune shift and spread, beam losses
- Heat load and vacuum degradation due to electron flux on chamber wall

Constraints for beam screen and vacuum design?



Simulation studies

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

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

- Arc dipoles, quadrupoles and drifts
- Effect of photoelectrons

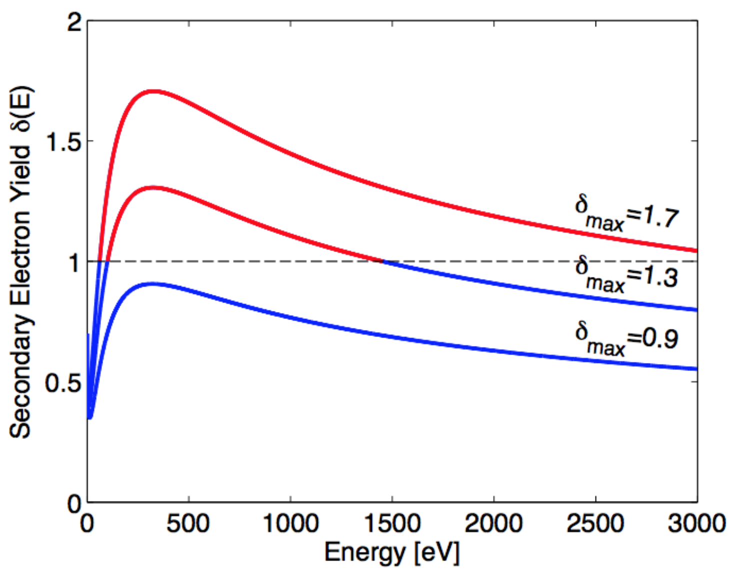
Secondary electron yield

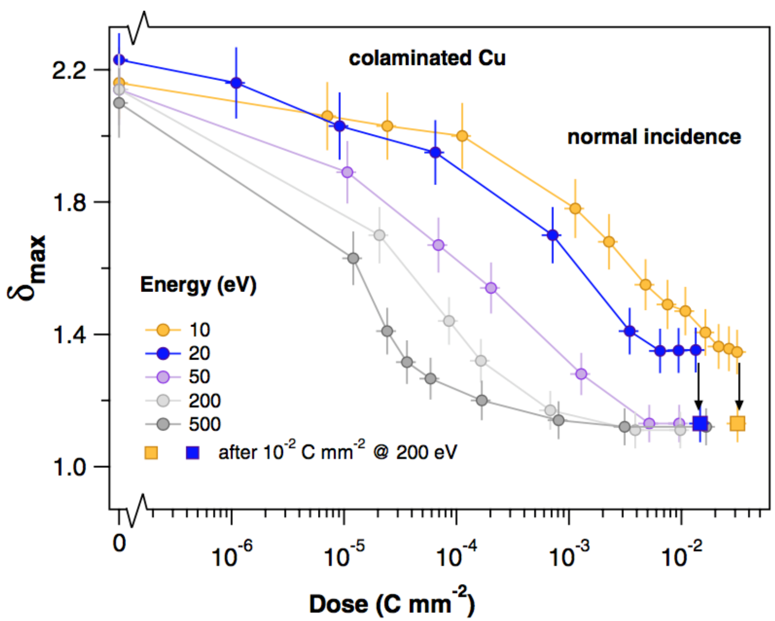
- E-cloud build-up depends crucially on the Secondary Electron Yield (SEY) :

$$\delta(E) = \frac{I_{\text{emit}}}{I_{\text{imp}}(E)}$$

Ratio between emitted and impacting electron current as a function of the energy of the impinging electrons

- It depends on surface properties and can be modified by surface treatments
- Also the history of the surface, in particular the accumulated electron dose
  - To a certain extent the e-cloud cures itself → beam induced scrubbing



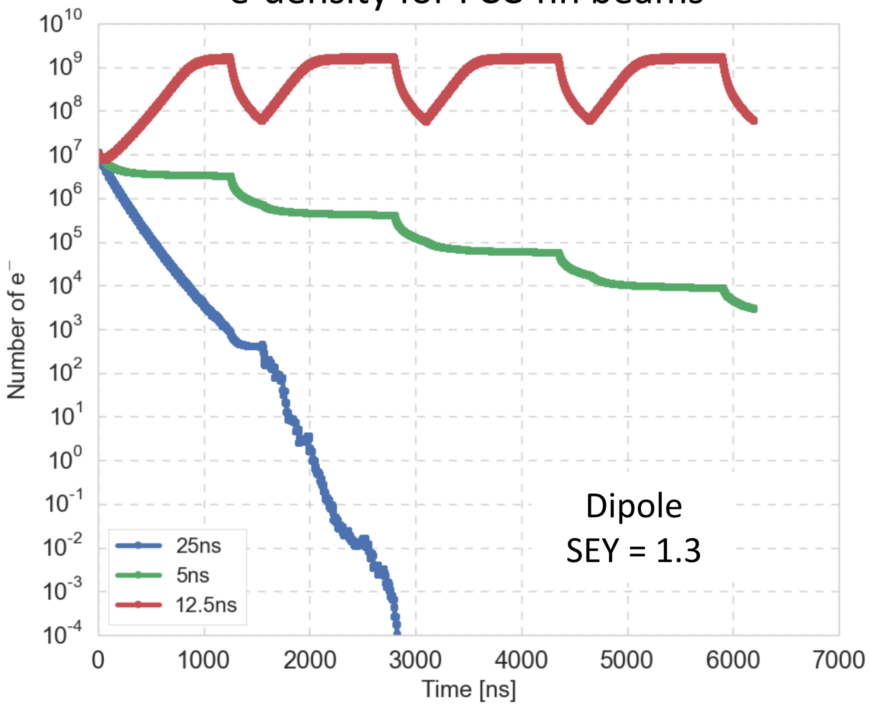


R. Cimino et al. Phys. Rev. Lett. **109**, 064801 – 2012

Multipacting threshold

- Multipacting threshold – threshold SEY for exponential electron multiplication
  - Depends on chamber geometry,
  - Magnetic fields,
  - Beam energy and intensity,
  - Bunch spacing, train pattern
  - Surface SEY …

E-cloud build-up starting from uniform e-density for FCC-hh beams



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

	25 ns		12.5 ns		5 ns	
E [TeV]	3.3	50	3.3	50	3.3	50
Dipole	1.6	1.6	1.2	1.2	1.5	1.4
Quadrupole	1.2	1.3	1.0	1.1	1.1	1.1
Drift	1.8	1.8	1.2	1.2	1.5	1.4

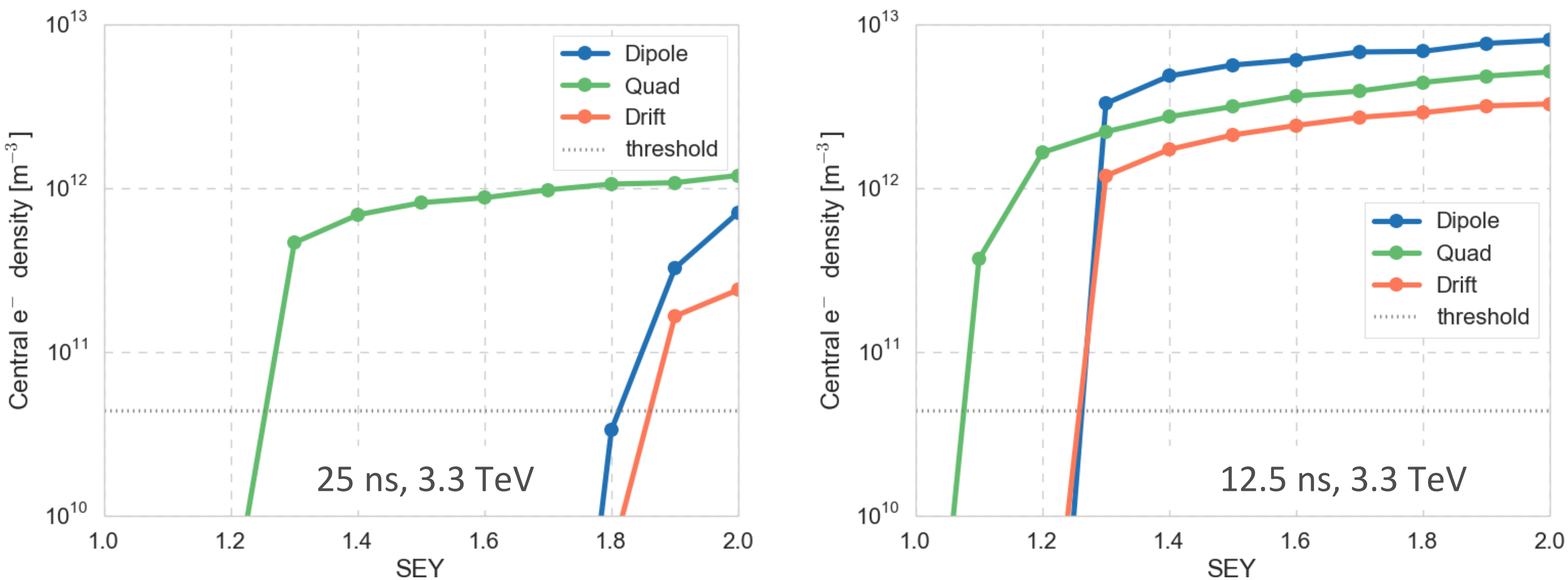
Threshold for e-cloud instability

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

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

  – Thresholds: 6×10^{10} m^{-3} at 3.3 TeV, 3.6×10^{11} m^{-3} at 50 TeV

Above the multipacting threshold, central electron densities are above the instability threshold in virtually all cases → need to stay below threshold



Central electron densities scaled to device length in half-cell

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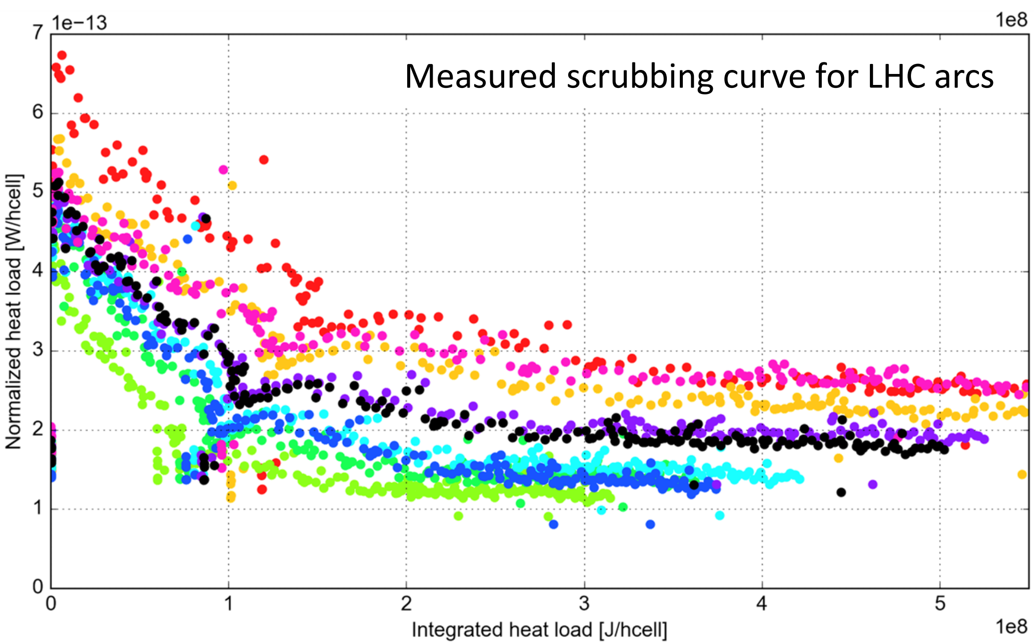
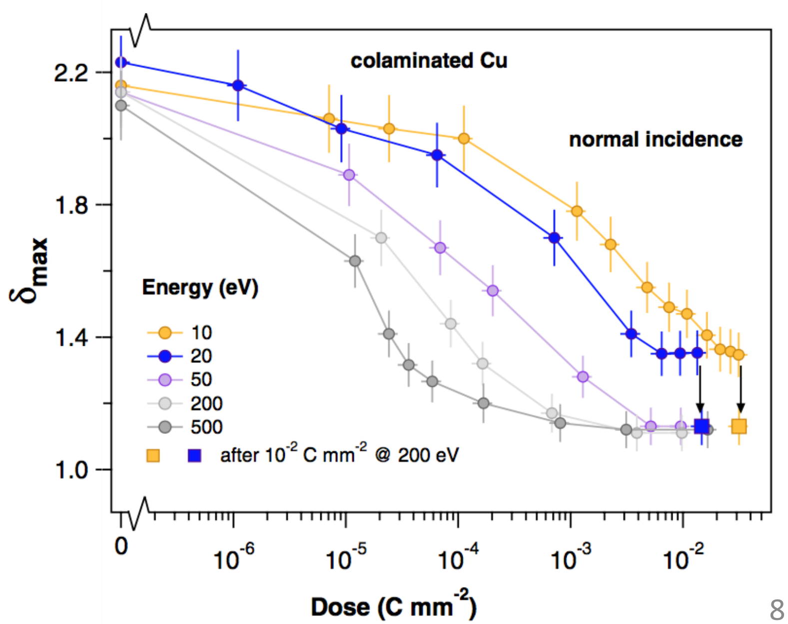
Which SEY can we assume?

- In the lab SEY decreases with e-dose down to values around 1.1 – 1.2
- Spending ~ 1 year of operation on lowering the SEY, can we reach SEY ~ 1.1?
  - Scrubbing becomes slower for lower SEY…
- LHC relies on this assumption → doesn't fully work!
  - Current understanding indicates that some beam screens have reached ~1.1
  - But others remain at 1.3 – 1.4 (after LS1), and are no longer improving
- We don't know why

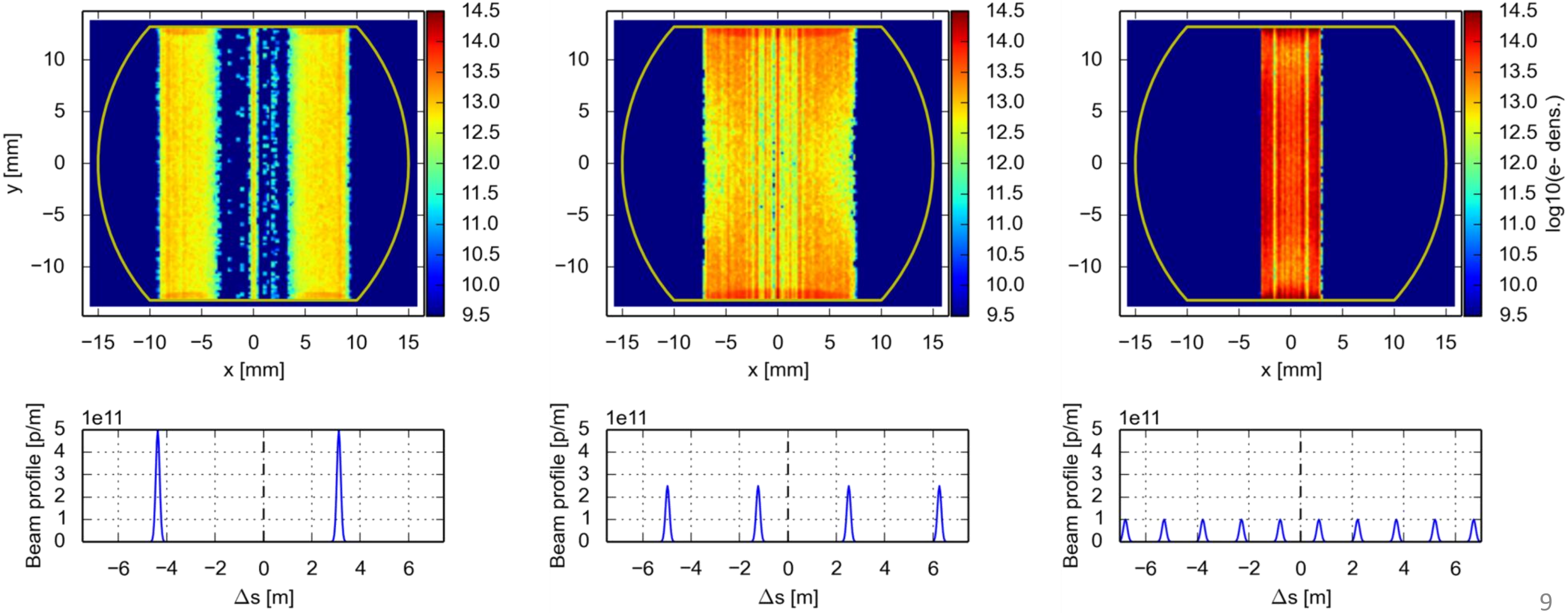




Dipoles

	25 ns		12.5 ns		5 ns	
E [TeV]	3.3	50	3.3	50	3.3	50
SEY threshold	1.6	1.6	1.2	1.2	1.5	1.4

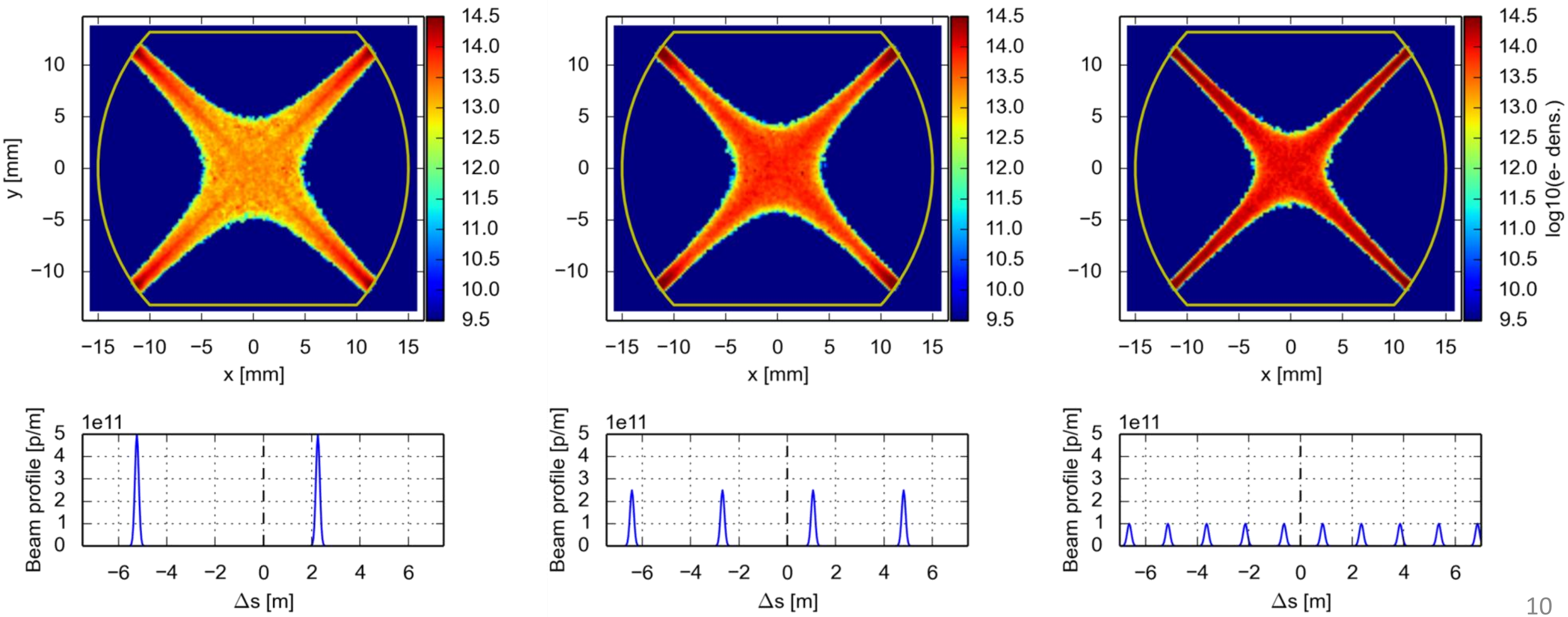
- SEY = 1.4 should be enough for both 25 ns and 5 ns beams, 1.2 for 12.5 ns
- A coating to avoid build-up for all beams should cover full top and bottom



Quadrupole

	25 ns		12.5 ns		5 ns	
E [TeV]	3.3	50	3.3	50	3.3	50
SEY threshold	1.2	1.3	1.0	1.1	1.1	1.1

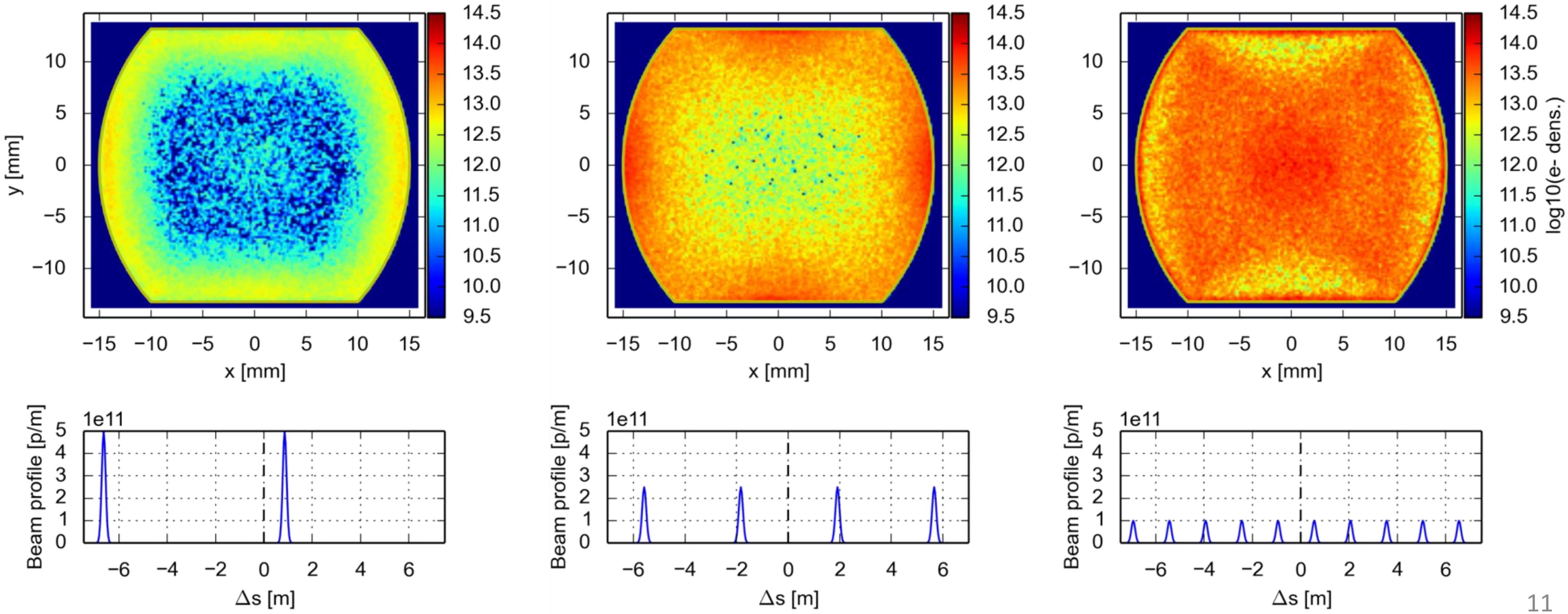
- For both 25 ns and 5 ns beams SEY = 1.1 OK, 12.5 ns beam requires SEY < 1.1
- Coating to avoid build-up would be needed on the sides (at 45°)



Drift

	25 ns		12.5 ns		5 ns	
E [TeV]	3.3	50	3.3	50	3.3	50
SEY threshold	1.8	1.8	1.2	1.2	1.5	1.4

- For 25 ns threshold is high → should be OK without coating (without photoelectrons)
- Multipacting on all sides → studies to determine necessary fraction of coating?



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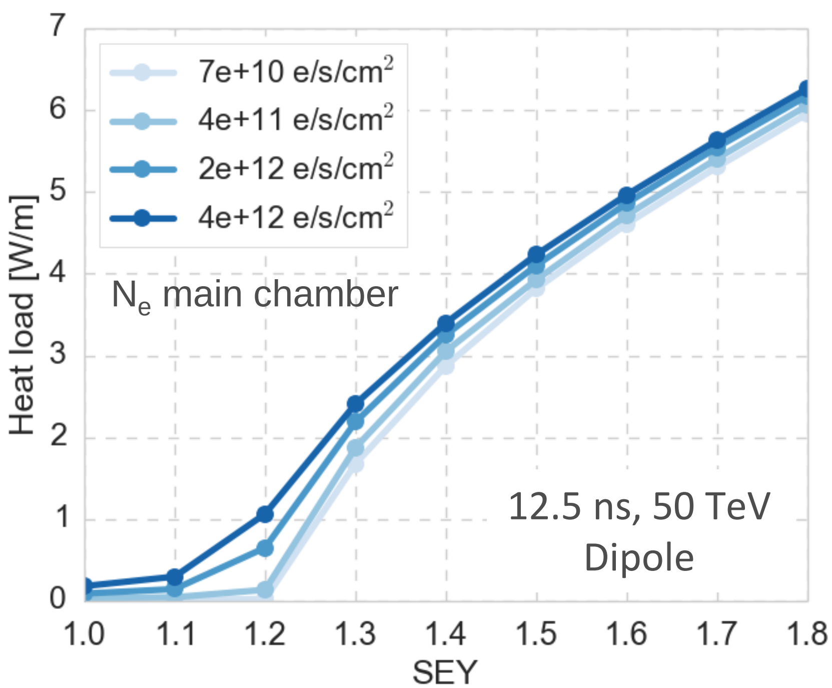
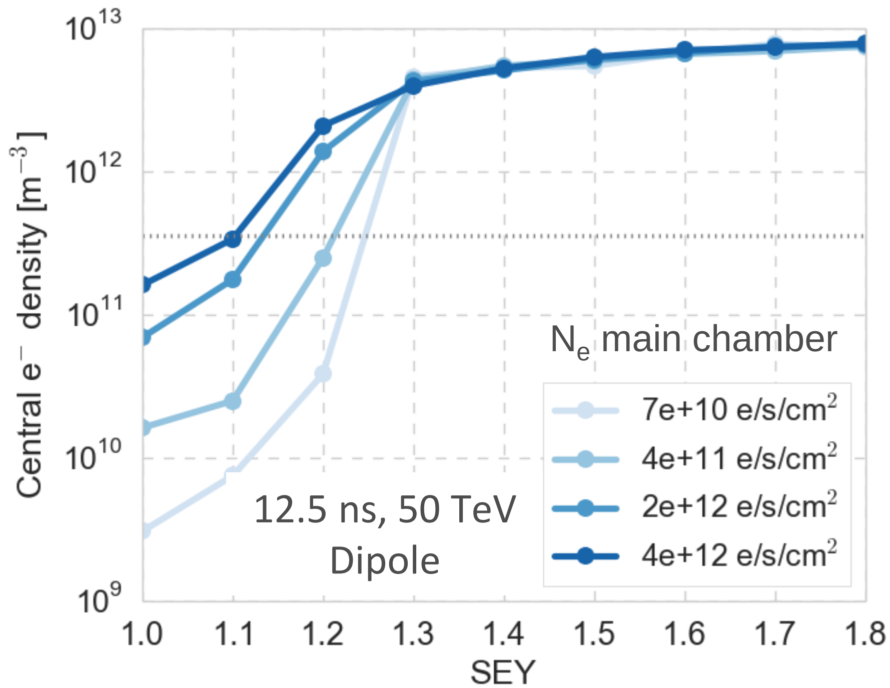
Effect of photoelectrons

- The photoelectrons have a marginal effect on heat loads, but a significant effect on central densities below the multipacting threshold
  - Even with low SEY, electron densities can reach instability threshold due to photoelectrons, especially for the 12.5 and 5 ns beams



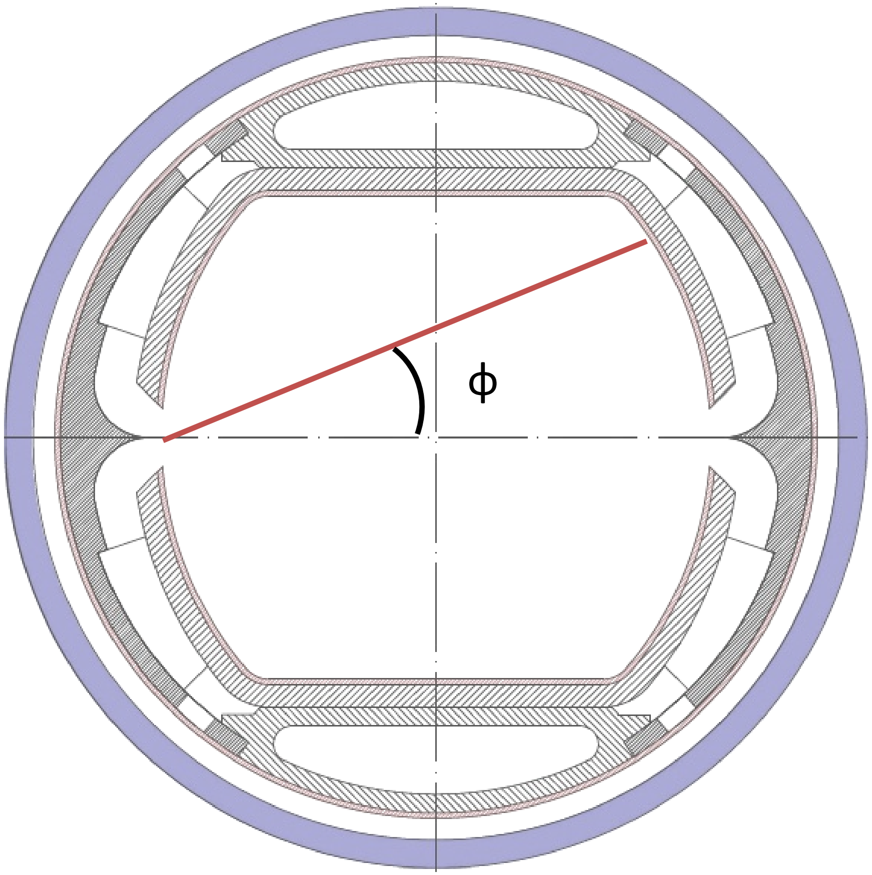


Heat load and central electron densities scaled to device length in half-cell

Photoelectrons in simulations

- In the build-up simulations, a given number of photoelectrons are generated for every bunch
- These electrons are initialized around the chamber with a $\cos^2$ distribution w.r.t. the angle ϕ from the SR impact point

- Modifications of the code to allow for e.g. a fixed number of electrons per chamber surface is on the list of things to do, but not yet implemented

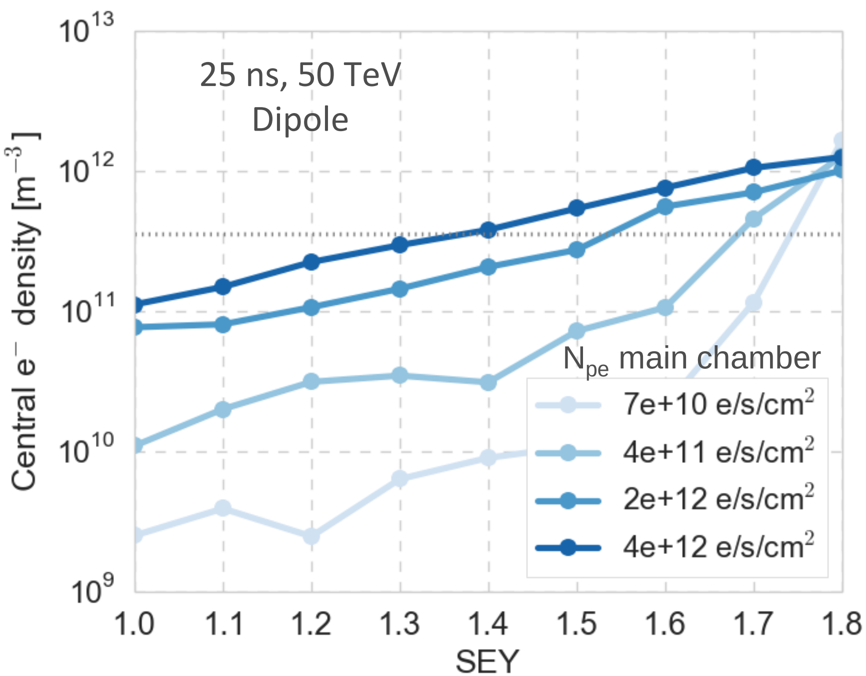


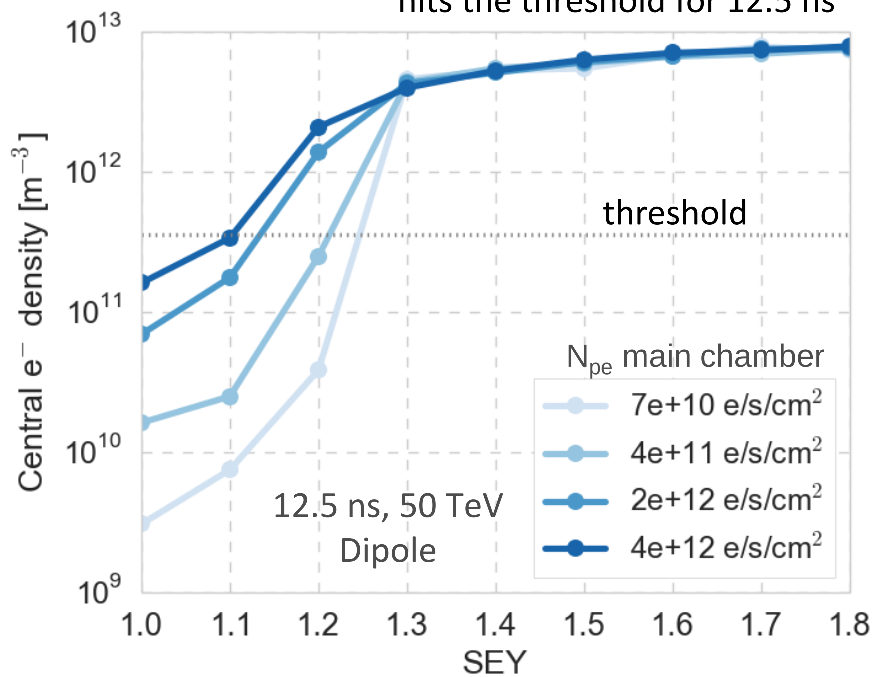
Dipoles

- Effect of the number N_{pe} of initialized photoelectrons on central electron densities compared to the analytical threshold density for instability
- The corresponding photon flux N_γ into the chamber is determined by the photoelectron yield Y:

$$N_{pe} = Y * N_\gamma \qquad N_\gamma = N_{pe} / Y$$

E.g for SEY = 1.1 and Y = 0.2 a photon flux of 2e13 p/s/cm² hits the threshold for 12.5 ns

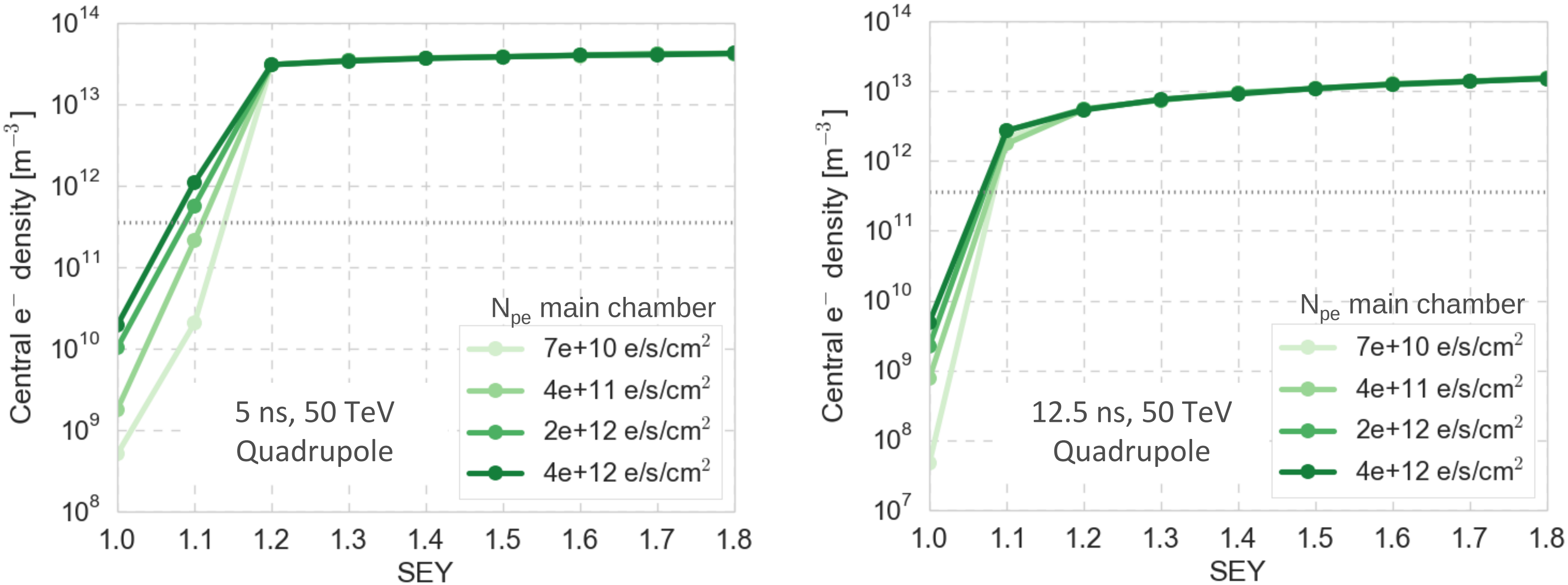




Central electron densities scaled to device length in half-cell

Quadrupoles

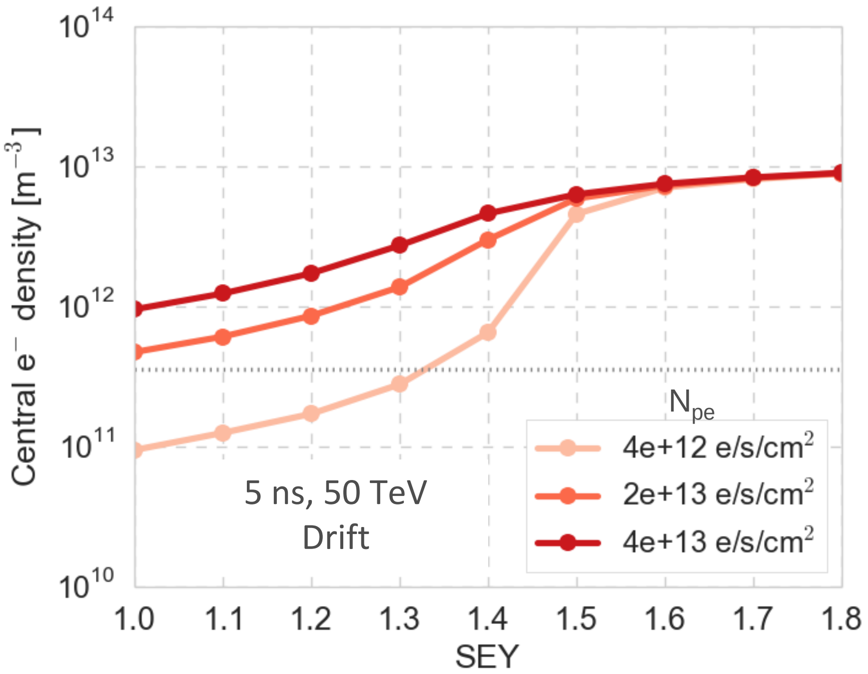
- In the quadrupole the multipacting thresholds are already very low
- It is mainly for the 5 ns beam that the photoelectrons could be a danger
  - E.g. for SEY = 1.1 and Y = 0.2, a photon flux of 1e13 p/s/cm² is too high, and 2e12 p/s/cm² is very close

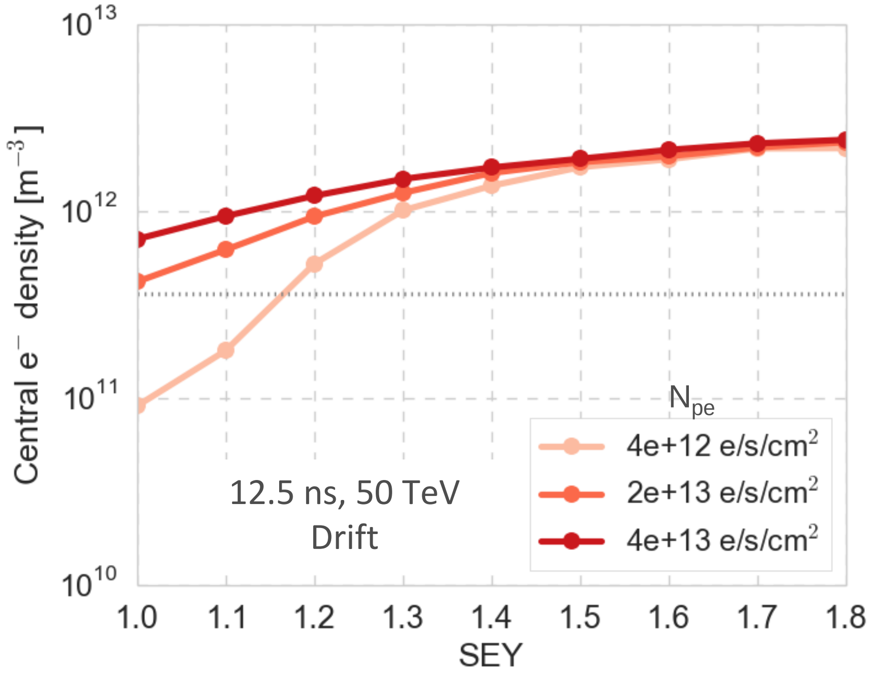


Central electron densities scaled to device length in half-cell

Drift

- In drifts, also photoelectrons produced in ante-chamber may move into main chamber and lead to increased electron density
  - Here electrons are initialized at the slit to mimic this effect (the electron numbers include these electrons)
  - Eventually simulations including the slit should be done to study the effect dynamically





Central electron densities scaled to device length in half-cell

Summary

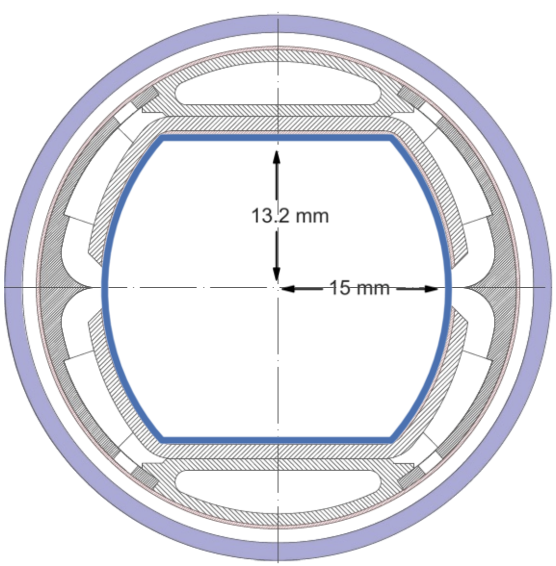
- Which parts of the beam screen need to be coated to avoid electron cloud depends strongly on the assumptions of the SEY behavior
  - In all cases, the 12.5 ns beam sets the most stringent constraints → relevant to know if this beam option is excluded
- In the quadrupoles SEY <= 1.1 is required in any case (SEY < 1.1 for 12.5 ns)
  - This would require a coating on the sides of the beam screen (at 45 degrees)
- Constraints on photoelectrons/photons depend on the photoelectron yield
  - For most cases about 1% of SR photons in the chamber should be acceptable
  - The dipoles with 12.5 ns beam, and quadrupoles with 5 ns beam set the strongest constraints
  - The drifts require further studies (also chamber shape etc should be known)
- The results depend on many assumptions, and are not final

Thank you

Simulation overview

Beam parameters			
Bunch spacing [ns]	25	12.5	5
Bunch intensity [p^+]	10×10^{10}	5×10^{10}	2×10^{10}
Norm. emittance [m]	2.2e-6	1.1e-6	0.44e-6
Bunch length [m]	0.08		
Bunch train pattern	(50b +	(100b + 24e)*4	(250b + 60e)*4

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



Arc elements			
	Dipole	Quad	Drift
Field	16 T	444 T/m	-
Length [m]	171.6	12.6	26.6