FCC-hh electron cloud

L. Mether

I. Bellafont, E. Belli, G. Iadarola, R. Kersevan, K. Li, K. Ohmi,
A. Romano, G. Rumolo, D. Schulte

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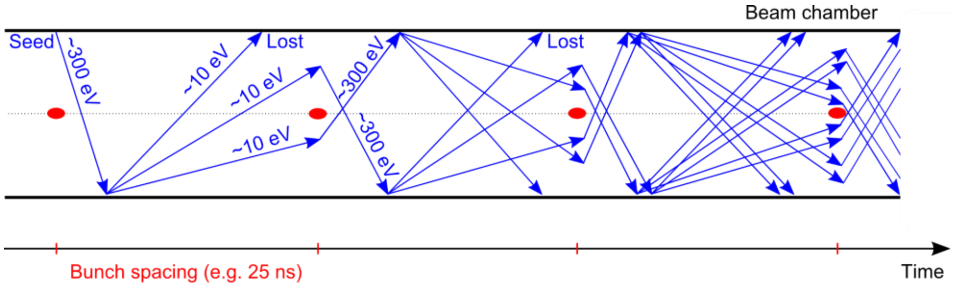
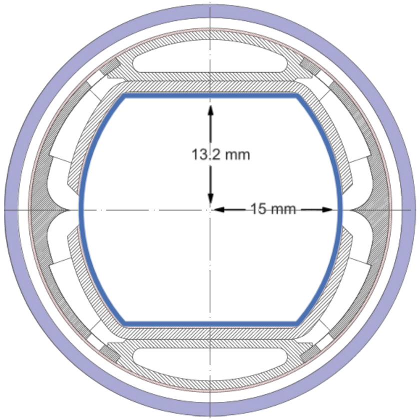
Introduction

Main concerns of electron cloud

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





Simulation studies

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

Electron cloud build-up for 25 ns and 5 ns beam
- Arc dipoles, quadrupoles, drifts
- Effect of photoelectrons

- 12.5 ns bunch spacing
- Instability simulation studies

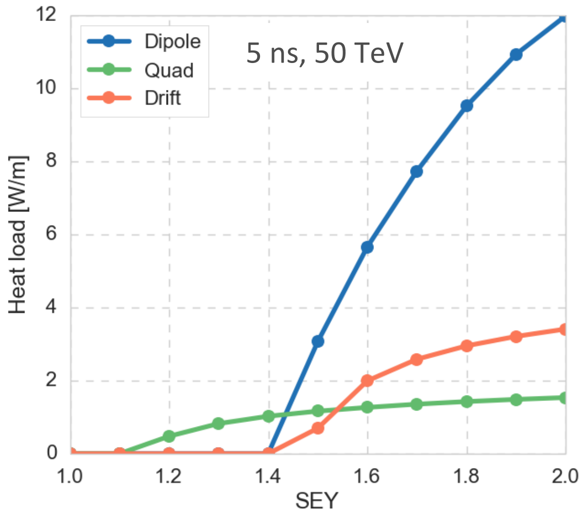
Multipacting threshold

Secondary electron yield (SEY) limit for electron cloud build-up

	25 ns		5 ns	
	3.3 TeV	50 TeV	3.3 TeV	50 TeV
Dipole	1.7	1.7	1.6	1.5
Q-pole	1.3	1.4	1.2	1.2
Drift	1.9	1.9	1.6	1.5

5 ns beam more challenging than 25 ns
- SEY = 1.1 required to keep arcs e-cloud free

→ low-SEY surface treatment



Heat load scaled to device length in half-cell

Heat load due to e-cloud smaller than from synchrotron radiation

Multipacting threshold

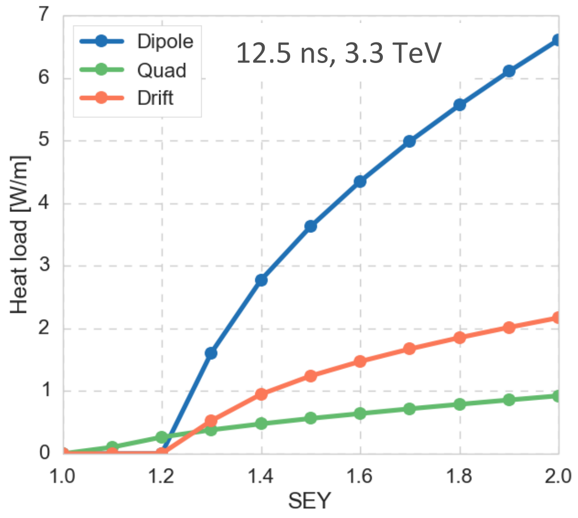
Secondary electron yield (SEY) limit for electron cloud build-up

	25 ns		5 ns		12.5 ns	
	3.3 TeV	50 TeV	3.3 TeV	50 TeV	3.3 TeV	50 TeV
Dipole	1.7	1.7	1.6	1.5	1.3	1.3
Q-pole	1.3	1.4	1.2	1.2	1.1	1.2
Drift	1.9	1.9	1.6	1.5	1.3	1.3

12.5 ns beam even more challenging than 5 ns beam

- At 3.3 TeV build-up in quadrupoles for SEY = 1.1

→ SEY ~ 1 required to keep arcs e-cloud free



Heat load scaled to device length in half-cell

Single bunch instability

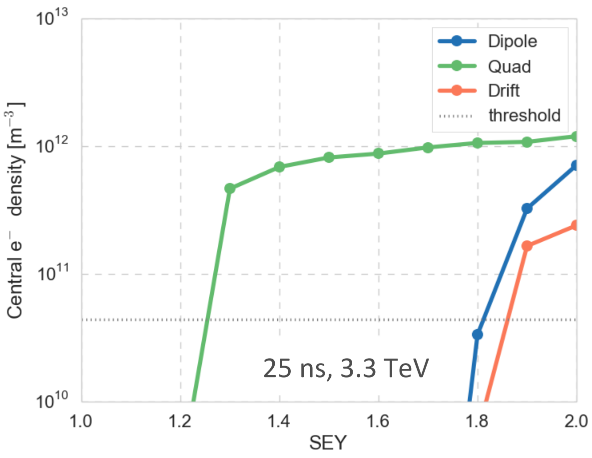
Analytical estimate of **threshold electron density** for instability

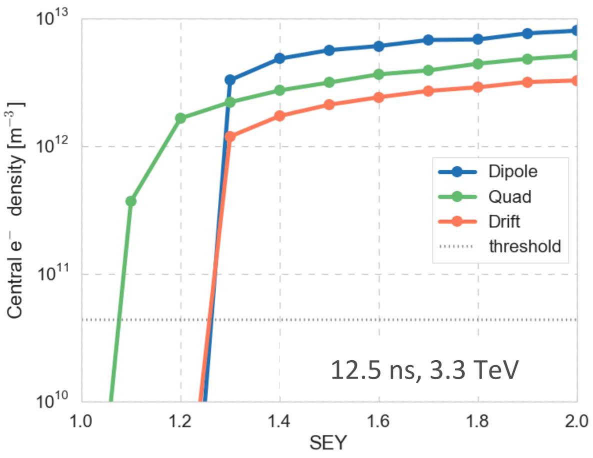
$$\rho_{e,th} = \frac{2\gamma\nu_s\omega_e\sigma_z/c}{\sqrt{3}KQr_0\beta L} \quad \text{with} \quad \omega_e = \sqrt{\frac{\lambda_p r_e c^2}{\sigma_y(\sigma_x+\sigma_y)}}, \quad K = \omega_e\sigma_z/c, \quad Q = \min(\omega_e\sigma_z/c, 7)$$

With updated machine parameters

3.3 TeV	50 TeV
$6 \times 10^{10}\ m^{-3}$	$3.6 \times 10^{11}\ m^{-3}$

Above the multipacting threshold, central electron densities are in the instability regime





Central electron densities scaled to device length in half-cell

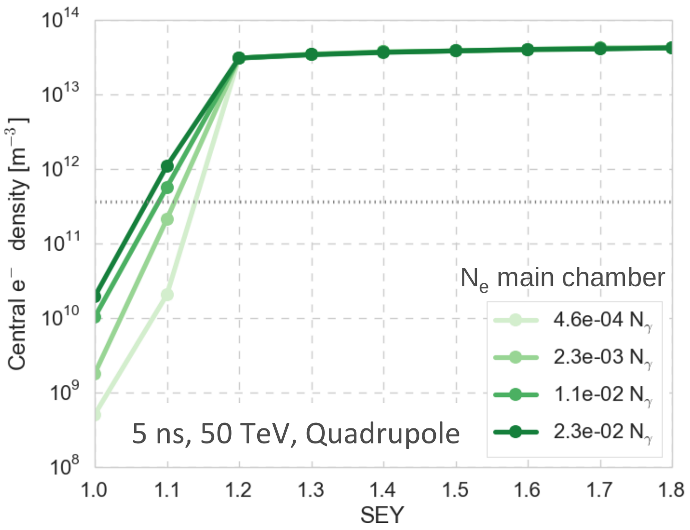
Effect of photoelectrons

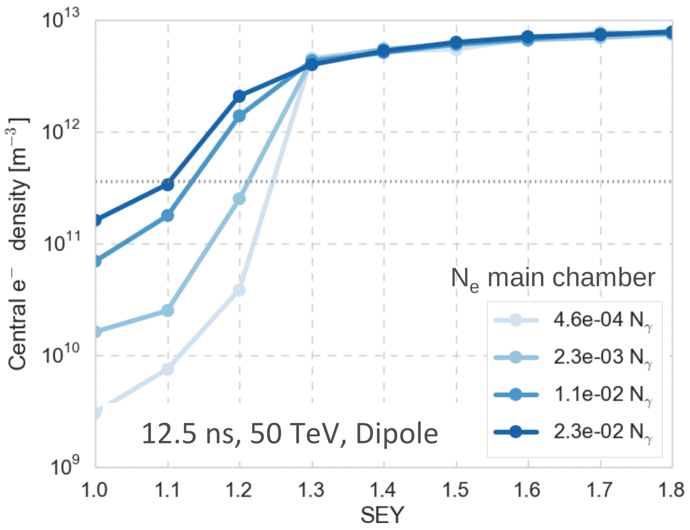
Even with SEY = 1-1.1, electron densities can reach instability threshold due to photoelectrons

- depending on the number photons that reach the main chamber and the photoelectron yield

- For 5 ns and, especially, 12.5 ns the threshold is approached for N_e ~ 1-5 % of photon number

→ For up to 5% photons in main chamber (vacuum group estimate) yields > 0.2 problematic





Central electron densities scaled to device length in half-cell

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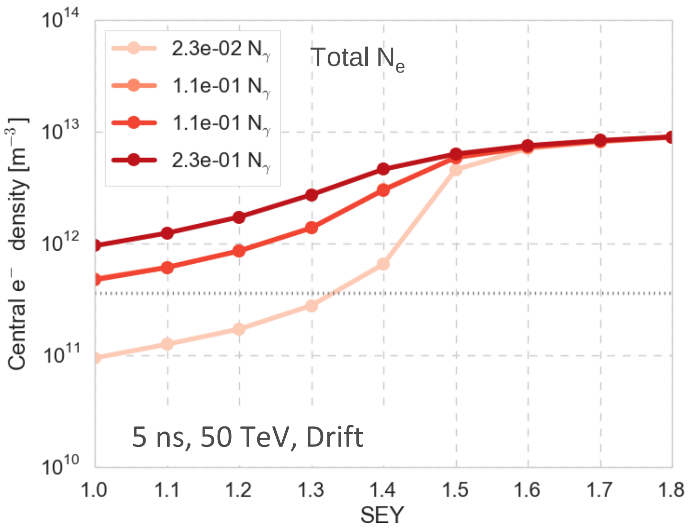


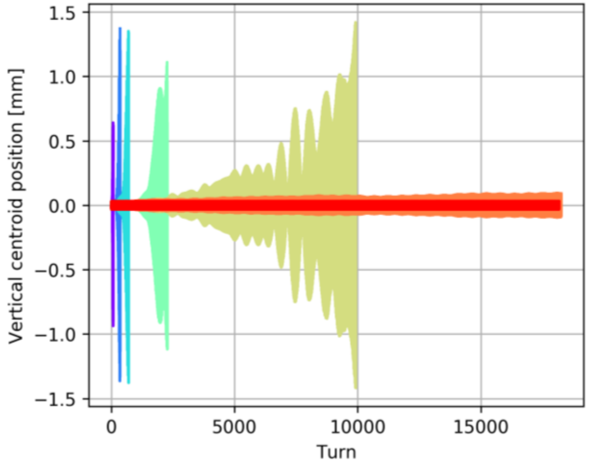
Central electron densities scaled to device length in half-cell

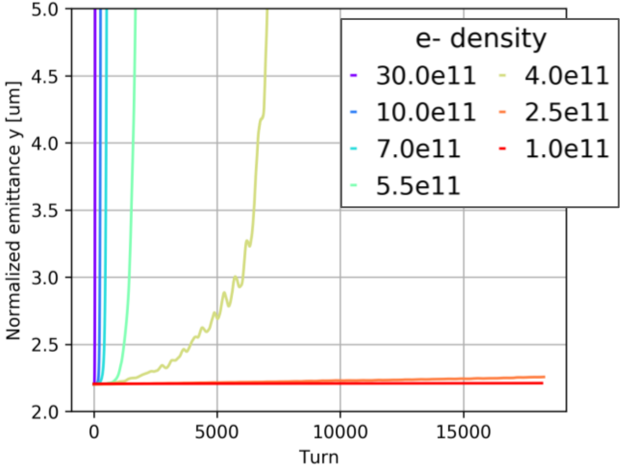
In drifts, also electrons potentially produced in ante-chamber may move into main chamber and lead to increased electron density

→ more detailed studies needed

Single bunch instability simulations

First instability simulation study: 25 ns beam at 3.3 TeV in dipole field – no stabilizing mechanisms





Ongoing studies:
- 5 ns at 3.3 TeV
- 25 ns at 50 TeV

→ seem to suggest similar scaling w.r.t. analytic estimate (TBC)

Over 17 000 turns (~ 5 s): instability threshold around 1-2.5 x 10^{11} m^{-3}

- Compare to analytic estimate scaled to dipole length: 7.5 x 10^{10} m^{-3}

→ Analytic estimate slightly pessimistic, by factor 2-3

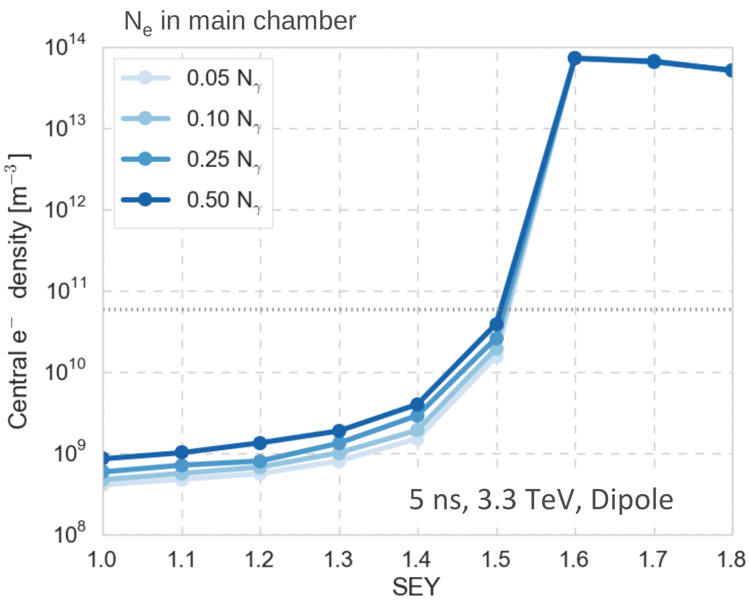
Stability at injection

Electron densities at 3.3 TeV much below instability threshold

- Due to smaller number of photons, and critical energy below Cu work function

	FCC	FCC Injection		
E [TeV]	50	1.5	3.3	5.5
E_c [eV]	4030	0.11	1.14	5.26
N_γ/p^+m	0.0497	0.00149	0.00328	0.00546
N_{eff}/N_{tot}	0.878	6.1e-20	2.5e-3	0.108
N_{eff}/p^+m	0.0436	9.1e-23	8.2e-6	5.9e-3

Most critical case for stability may be at some intermediate energy



Conclusions

Low-SEY coating is needed for stability

Based on first results of single bunch instability simulations:

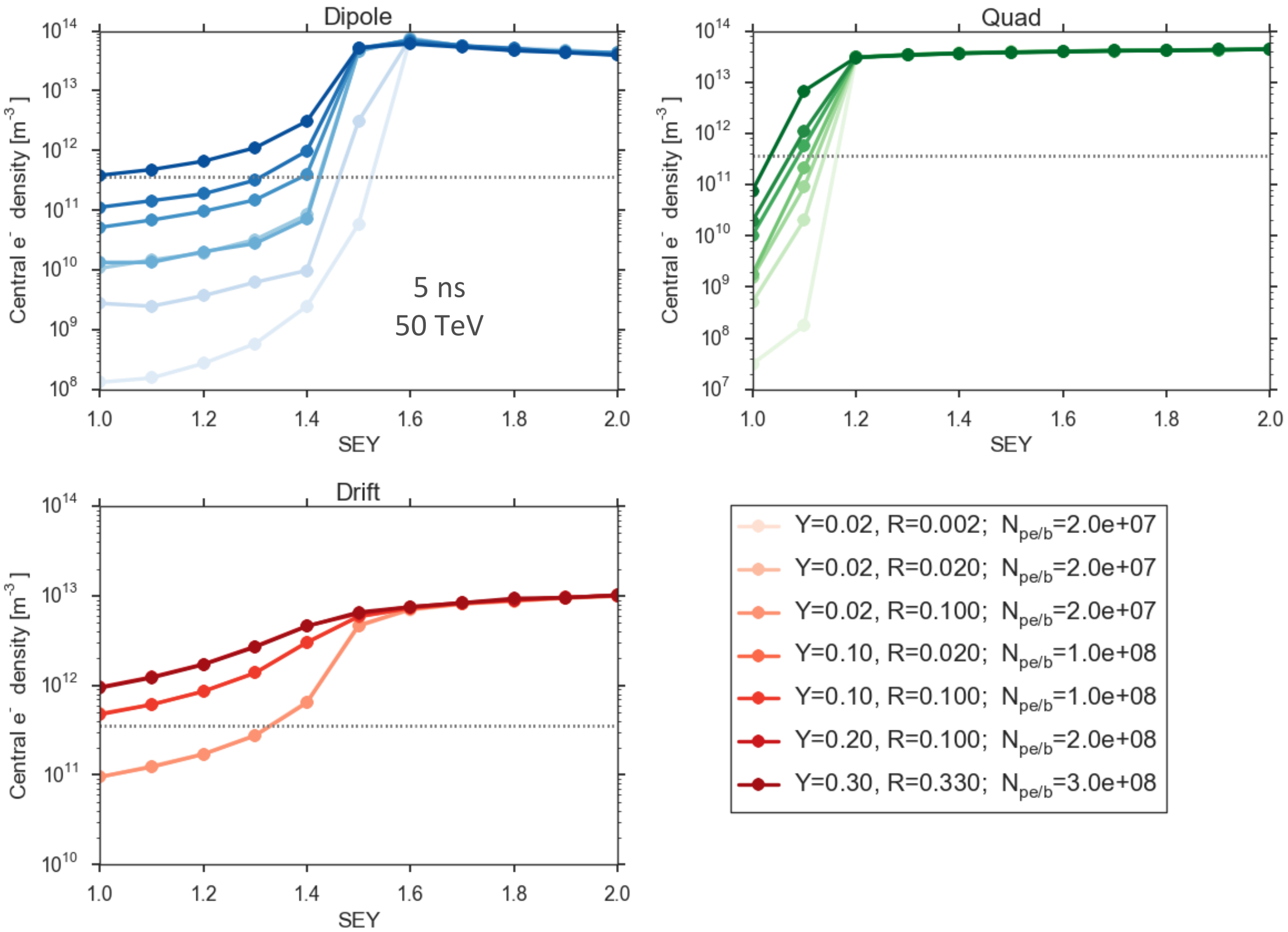
- Analytic threshold is slightly pessimistic, but correct order of magnitude
- Studies continuing: beam configurations, energy, arc elements and their combined effect, stabilizing mechanisms…

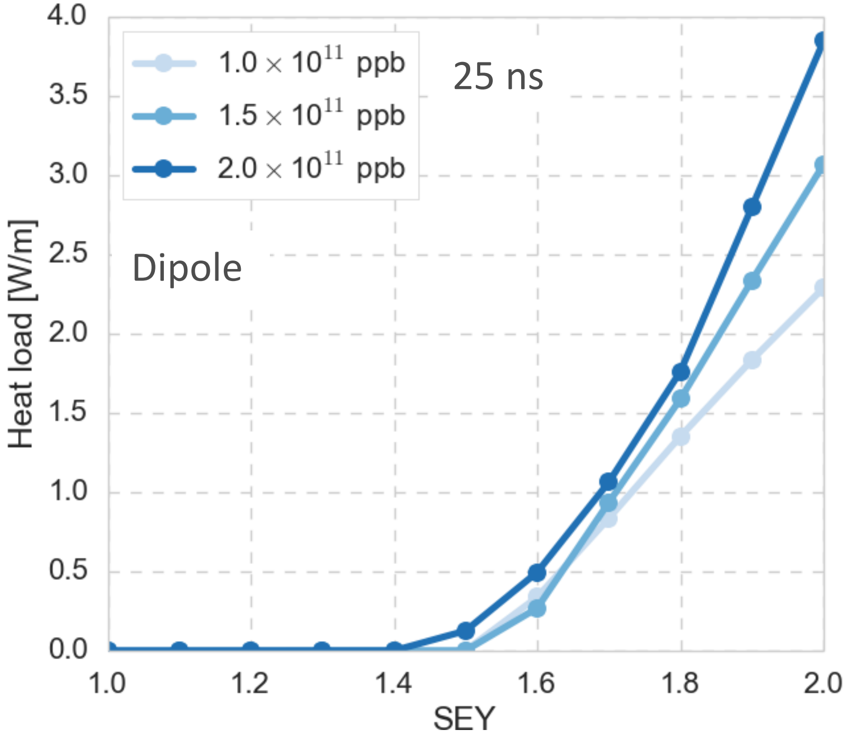
Enhanced electron densities due to photoelectrons at low SEY give some cause for concern

- Not extremely critical, but close enough that many details matter:
  surface properties, their accurate implementation in simulations, understanding of quantitative effect of model assumptions
  - Synergy with needs for LHC and HL-LHC

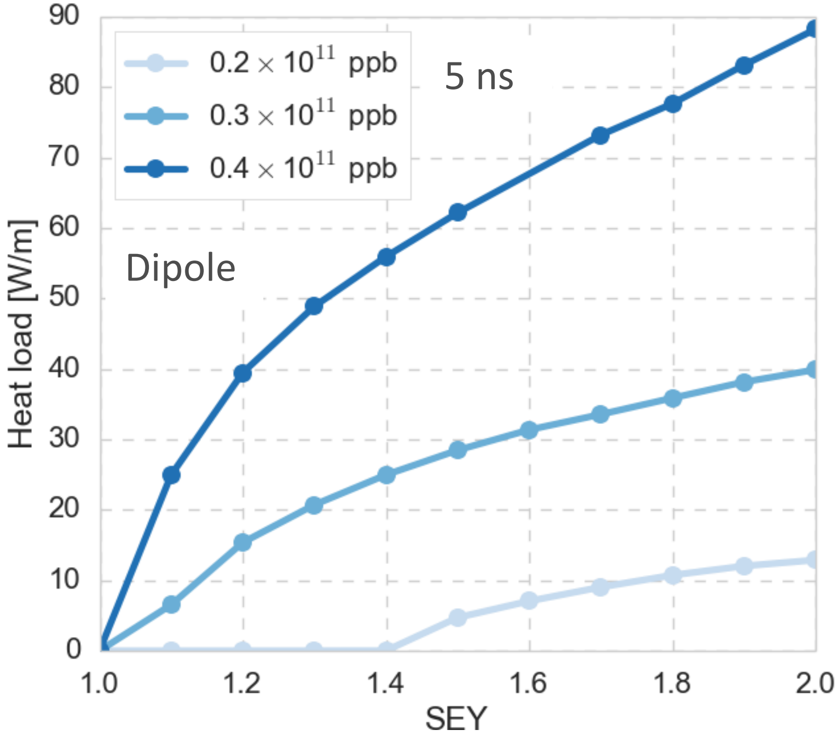
Spares

Simulation parameters		
Bunch spacing [ns]	25	5
Bunch intensity [p^+]	10 x 10^{10}	2 x 10^{10}
Norm. emittance [m]	2.2e-6	0.44e-6
Bunch length [m]	0.08	
Bunch train pattern	(50 b + 12 e)*4	(250 b + 60 e)*4
Arc elements considered (FODO, L = 213.9 m)	**Dipole** 16 T, L = 171.6 m	
	Quadrupole 444 T/m, L = 12.6 m	
	Drift L = 26.6 m	


Dipole
Quad
Drift
Central e⁻ density [m⁻³]
SEY
5 ns
50 TeV
Y=0.02, R=0.002; N_pe/b=2.0e+07
Y=0.02, R=0.020; N_pe/b=2.0e+07
Y=0.02, R=0.100; N_pe/b=2.0e+07
Y=0.10, R=0.020; N_pe/b=1.0e+08
Y=0.10, R=0.100; N_pe/b=1.0e+08
Y=0.20, R=0.100; N_pe/b=2.0e+08
Y=0.30, R=0.330; N_pe/b=3.0e+08



4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Heat load [W/m]
1.0 × 10^11 ppb
1.5 × 10^11 ppb
2.0 × 10^11 ppb
25 ns
Dipole
1.0
1.2
1.4
1.6
1.8
2.0
SEY



90
80
70
60
50
40
30
20
10
0
Heat load [W/m]
0.2 × 10^11 ppb
0.3 × 10^11 ppb
0.4 × 10^11 ppb
5 ns
Dipole
1.0
1.2
1.4
1.6
1.8
2.0
SEY