Electron cloud scaling: from LHC to FCC-hh

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Electron cloud studies for FCC-hh

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Motivation and Aims of this study:

- Estimate build-up thresholds, SEYs, heat load
- Predict tune shifts, spreads and instability thresholds
- Estimate the effect of residual photoelectrons
- Compare LHC vs. FCC-hh, understand energy scaling.

Will electron cloud still be a concern in FCC-hh ?

FCC-hh vs LHC beam screen

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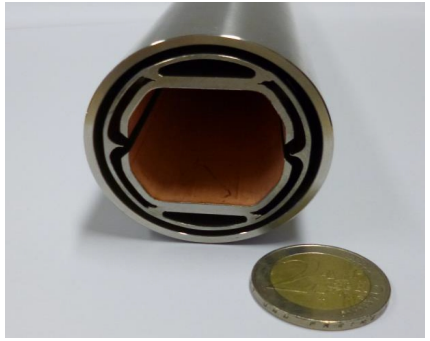
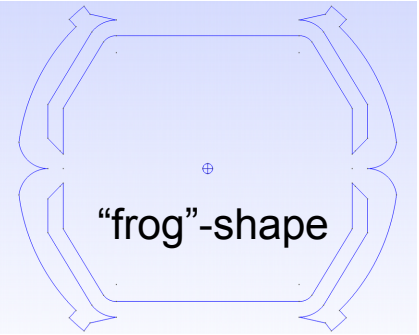
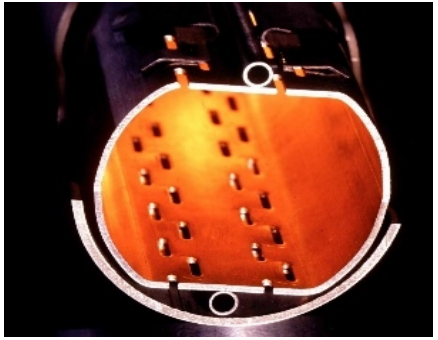
FCC-hh

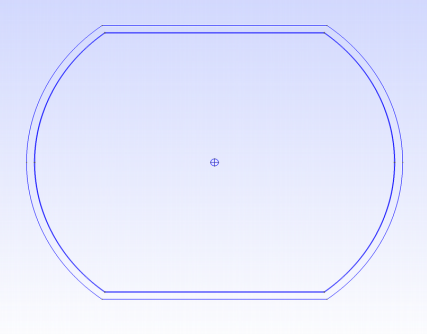




	LHC	FCC-hh
Circumference [m]	27×10^3	10^5
E_{inj} [TeV]	0.45	3.3
B_{inj} [T]	0.54	1.06
E_{top} [TeV]	7	50
B_{top} [T]	8.4	16
Beam screen Temperature [K]	20	50

LHC





Bunch length, σz [m]	0.1
Bunch radius, σr [m]	10^{-3}
Bunch population, N_i	10^{11}
Bunch spacing [ns]	25
Maximum total SEY δ_{max}	1.8

Electron cloud study

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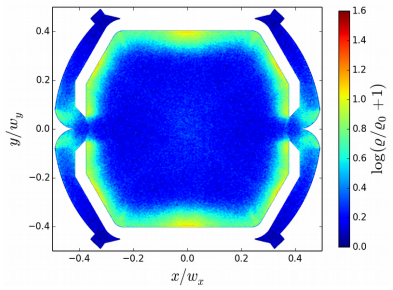
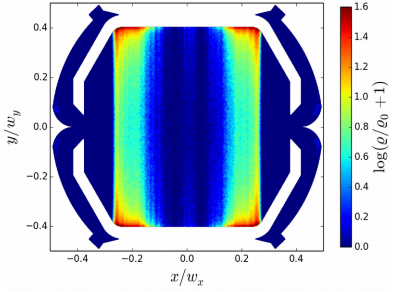
Assumptions:

1. Electrostatic field solver for electron space charge field
2. Ultra relativistic approximation of primary beam: Rigid bunch approximation
3. LHC/FCC bunches

Simulation 2D tool *openEcloud* for electron cloud studies:

- Finite Integration Technique (field solver)
- 2D LU Poisson Solver with arbitrary cut-cell boundaries
- Standard Particle-In-Cell for electrons
- Boundary interaction models for electrons





openEcloud : https://github.com/openecloud

e.g. F. Petrov, O. Boine-Frankenheim, O. Haas, PRAB (2014)

Fast 2D Poisson solver, PIC solver, SEY model, interfaces to PATRIC/pyORBIT

Secondary emission yield model

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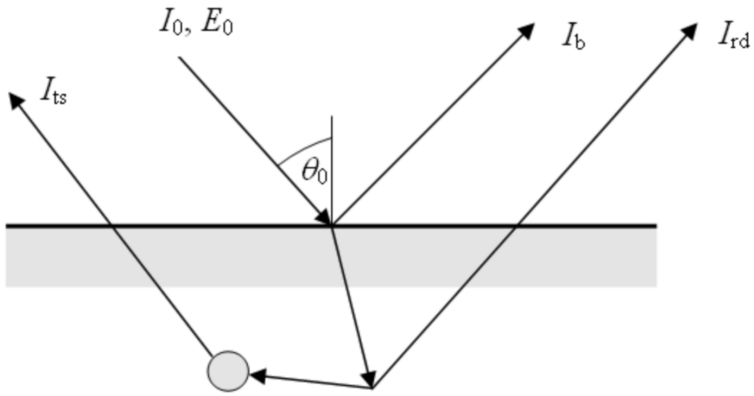
Furman model: $\delta = \delta_e + \delta_r + \delta_{ts}$

$$\delta_{ts}(E_0, \theta_0) = \hat{\delta}(\theta_0) D(E_0 / \hat{E}(\theta_0)) \qquad D(x) = \frac{sx}{s - 1 + x^2}$$

$$\hat{\delta}(\theta_0) = \hat{\delta}_{ts}[1 + t_1(1 - \cos^{t_2}\theta_0)]$$

$$\delta_{bs} = \hat{\delta}_{bs}(E_0, \theta_0)[1 + e_1(1 - \cos^{e_2}\theta_0)]$$

$$\delta_{rd} = \hat{\delta}_{rd}(E_0, \theta_0)[1 + r_1(1 - \cos^{r_2}\theta_0)]$$



Simple SEY model: $\delta = \delta_e + \delta_{ts}$

$$\delta_{elas}(E) = R_0 \left(\frac{\sqrt{(E)} - \sqrt{(E + E_0)}}{\sqrt{(E)} + \sqrt{(E + E_0)}} \right)^2$$

$$\delta_{true}(E, \theta_i) = \delta'_{max}(\theta_i) \frac{s \dfrac{E}{E'_{max}(\theta_i)}}{s - 1 + \left(\dfrac{E}{E'_{max}(\theta_i)} \right)^s}$$

$$\delta'_{max}(\theta_i) = \delta_{max} e^{\frac{1 - \cos\theta_i}{2}}$$

Main differences:

- δ_{max}
- angle dependence
- rediffused electrons
- free parameters

M. A. Furman and M. T. F. Pivi Phys. Rev. ST Accel. Beams 5, 124404
R. Cimino et al., Phys. Rev. Lett. 93, 014801
G. Iadarola's PhD Thesis; P. Dijkstal Master Thesis

Electron cloud study: Furman model vs Simple SEY model

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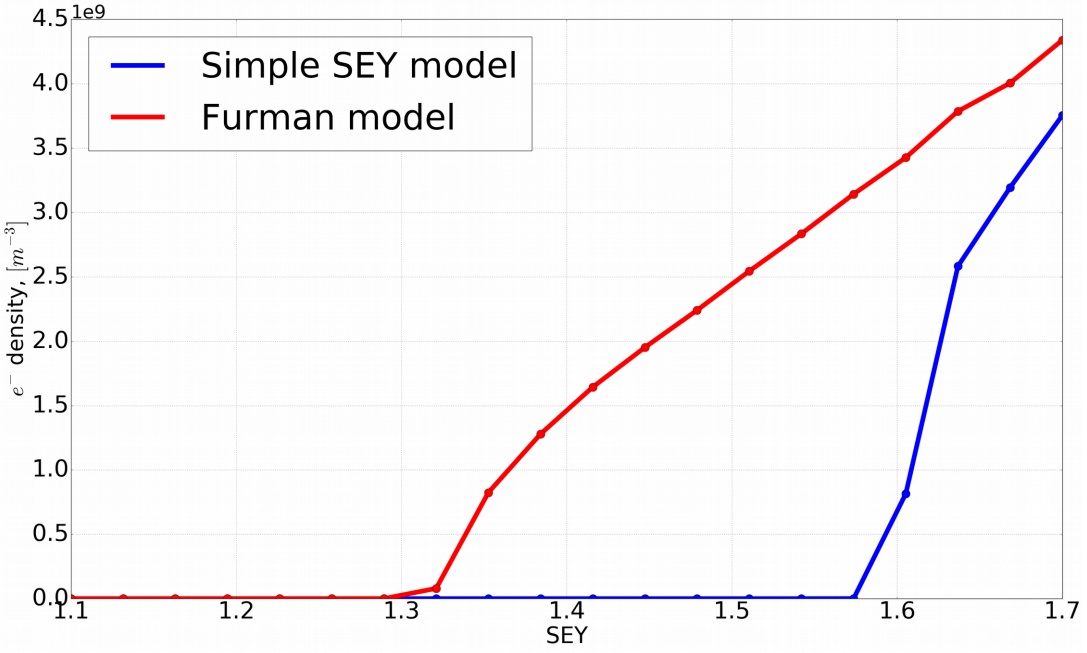
The threshold approaches SEY ~ 1.3 with Furman and ~1.6 with simple SEY models in FCC-hh in the absence of Bfield



Possible reasons of the difference:
– rediffused electrons (only in Furman model)
– angle dependence
– free parameters
– etc.

Bunch population, N_i	10^{11}
Bunch spacing [ns]	25
Number of bunches	100

M. A. Furman and M. T. F. Pivi Phys. Rev. ST Accel. Beams 5, 124404
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SEY threshold: from LHC to FCC-hh

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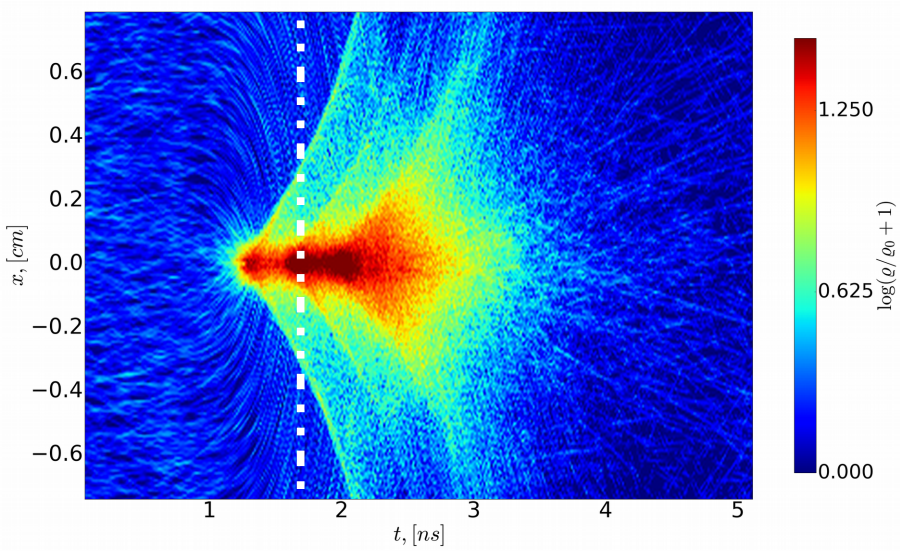
Possible reasons of the difference:
– rediffused electrons (only in Furman model)
– free parameters
– angle dependence
– etc.

	Furman model		Simple SEY model	
	LHC	FCC-hh	LHC	FCC-hh
Drift	1.23	1.3	1.3	1.6
Injection	1.1	1.25	1.25	1.42

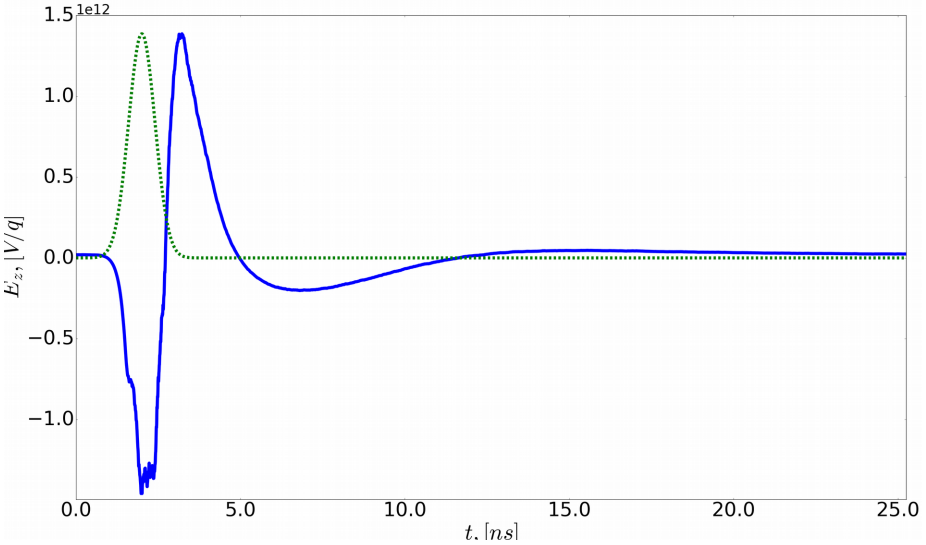
Bunch population, N_i	10^{11}
Bunch spacing [ns]	25
Number of bunches	100

Electron cloud pinch in the FCC-hh



Electron cloud pinch in the absence of B-field

Bunch length, σz [m]	0.1
Bunch radius, σr [m]	10^{-3}
Bunch population, N_i	10^{11}
δ_{max}	1.8



The longitudinal electric field induced by a FCC-hh bunch in the saturated cloud

Stopping power

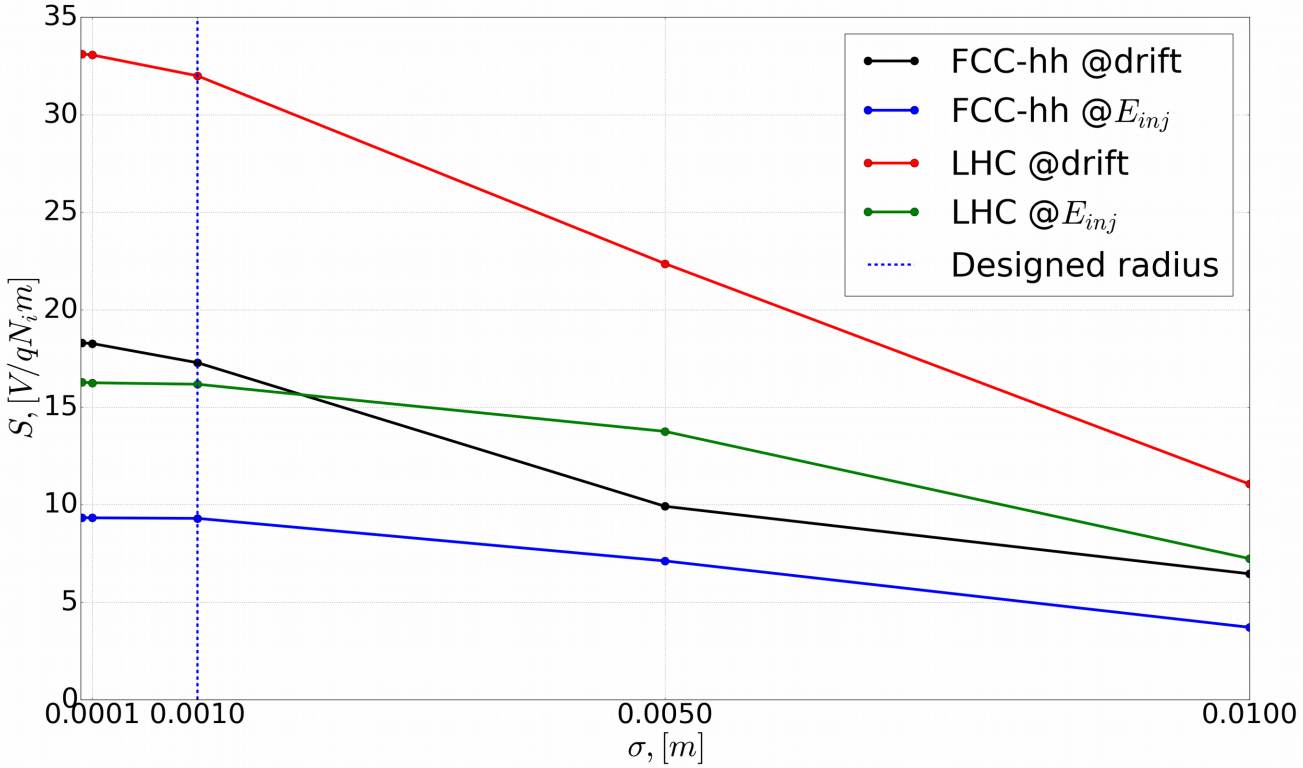
Stopping power – is a total energy loss of the bunch per length unit:

$$\frac{dW}{ds} = -\int \rho_i(\vec{r}) E_z(\vec{r}) d^3r \approx -q \int \lambda(z) E_z(z) dz$$

$$Heat\,load\,[W/m] = \frac{cS}{I_{bb}}$$

I_{bb} is the bunch distance

Bunch length, σz [m]	0.1
Bunch radius, σr [m]	$10^{-4}...10^{-2}$
Bunch population, N_i	10^{11}
δ_{max}	1.8



Stopping power as a function of the bunch radius in the saturated cloud

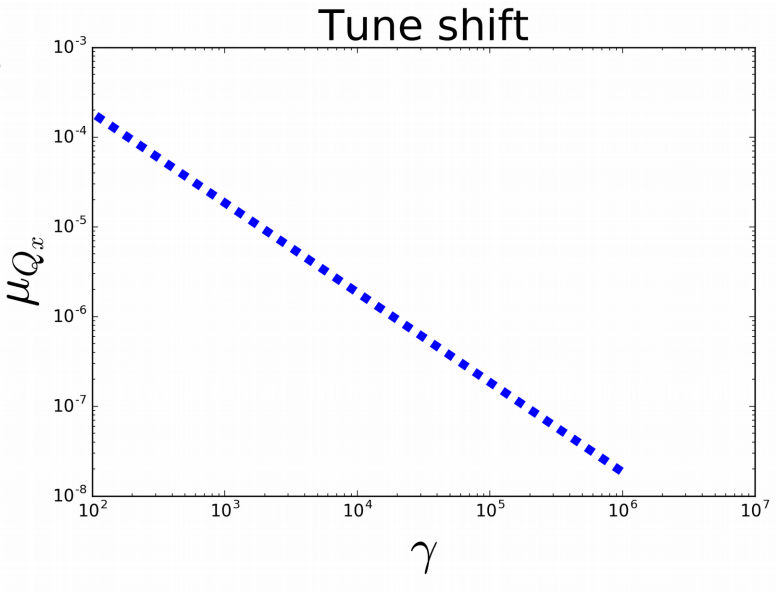
Tune shift at FCC-hh

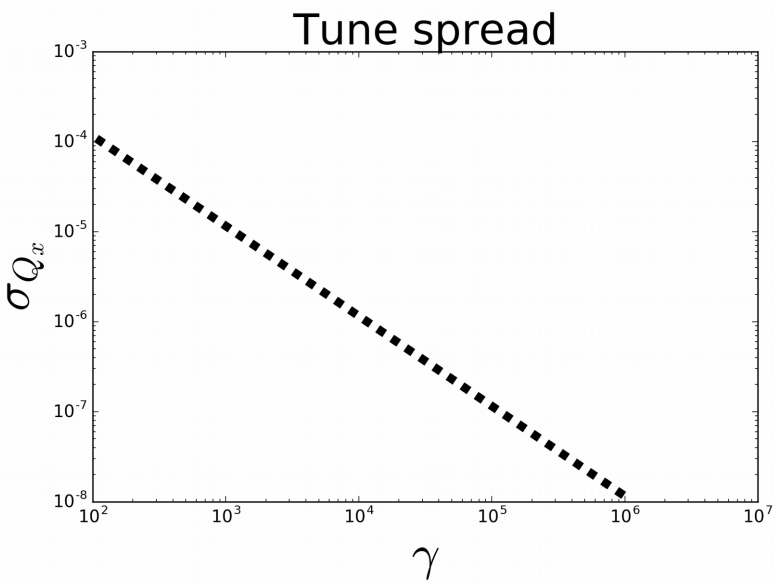
Higher gamma/energy → stronger electron cloud pinch → tune spread

Let's assume that the ecloud is the only source of tune shifts/spreads.

The kick due to an electron cloud:

$$\Delta x_e' = \frac{e E_x^e(x,y) L}{\gamma_0 m_p c^2}$$





Tune shift/spread depends strongly on gamma/beam energy - 1/ γ scaling

Conclusions and Outlook

	Furman model		Simple SEY model	
	LHC	FCC-hh	LHC	FCC-hh
Drift	1.23	1.3	1.3	1.6
Injection	1.1	1.25	1.25	1.42

Conclusions

- SEY threshold depends a lot on the chosen model
- Tune shift depends strongly on gamma/beam energy
- Stopping power: asymptotic limit is at beam radius = 1e-4 m

Next steps:

- electron cloud study with the bunch offset
- implementation of the electron cloud to tracking code (PATRIC/pyOrbit)
- electron cloud study w.r.t. instabilities, etc. in FCC-hh/LHC
- implementation of the photoelectrons

Thank you for your attention!