

Electron Cloud in the Arcs

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Acknowledgments:

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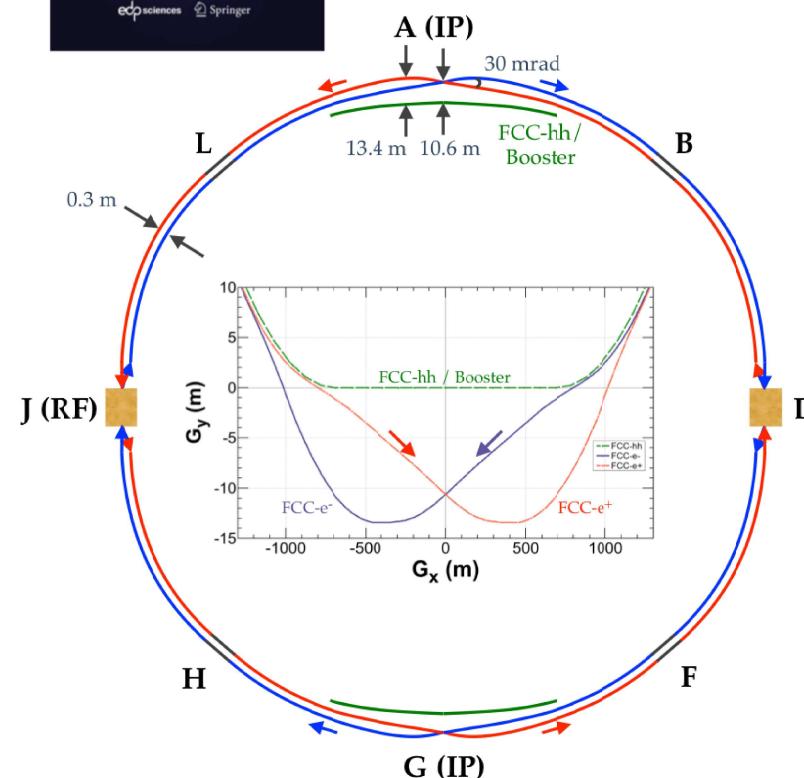
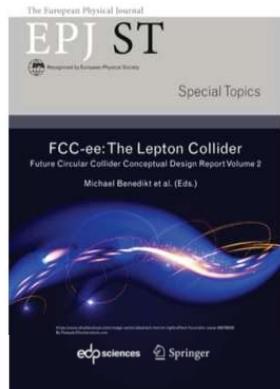


Outline

- FCC-ee machine & beam parameters, tools, SEY Models for the simulations
- Agreement on PyECLOUD & VSim results
- Comparisons for Dipole and Drift regions
 - e^- density vs. bunch spacings for various SEY values
 - Reference e^- densities
- Mitigation idea
- Conclusions

FCC-ee Collider Parameters

beam energy [GeV]	45.6
bunches per train	150
trains per beam	1
circular beam pipe radius [mm]	35
r.m.s. bunch length (σ_z) [mm]	3.5
h. r.m.s. beam size (σ_x)	120 [μm]
v. r.m.s. beam size (σ_y)	7 [μm]
number of particles / bunch	1.7×10^{11}



parameter scope for simulations

bunch spacing [ns]	10, 12.5, 15, 17.5, 20
SEY model	Furman-Pivi , ECLOUD
total SEY	1.1, 1.2, 1.3, 1.4
bent field [T]	0.01415, 0
Photoelectron generation rate ($n_{e(\gamma)}'$) [1/m]	
number of photoelectrons to be generated per positron per unit length	1e-3, 1e-6

Furman-Pivi & ECLOUD SEY Models

M.A. Furman and M.T.F. Pivi, 'Probabilistic Model for the Simulation of Secondary Electron Emission', SLAC-PUB-9912, 2003

TABLE I: Main parameters of the model.

	Copper	Stainless Steel
Emitted angular spectrum (Sec. II C 1)		
α	1	1
Backscattered electrons (Sec. III B)		
$P_{1,e}(\infty)$	0.02	
$\hat{P}_{1,e}$	0.496	
\hat{E}_e [eV]	0	
W [eV]	60.86	
p	1	0.9
σ_e [eV]	2	1.9
e_1	0.26	0.26
e_2	2	2
Redifused electrons (Sec. III C)		
$P_{1,r}(\infty)$	0.2	0.74
E_r [eV]	0.041	40
r	0.104	1
q	0.5	0.4
r_1	0.26	0.26
r_2	2	2
True secondary electrons (Sec. III D)		
$\hat{\delta}_{ts}$	1.8848	1.22
\hat{E}_{ts} [eV]	276.8	310
s	1.54	1.813
t_1	0.66	0.66
t_2	0.8	0.8
t_3	0.7	0.7
t_4	1	1
Total SEY^a		
\hat{E}_t [eV]	271	292
$\hat{\delta}_t$	2.1	2.05

^aNote that $\hat{E}_t \simeq \hat{E}_{ts}$ and $\hat{\delta}_t \simeq \hat{\delta}_{ts} + P_{1,e}(\infty) + P_{1,r}(\infty)$ provided that $\hat{E}_{ts} \gg \hat{E}_e, E_r$.

$$\delta_e(E_0, \theta_0) = \delta_e(E_0, \theta_0 = 0)[1 + e_1(1 - \cos^{e_2} \theta_0)]$$

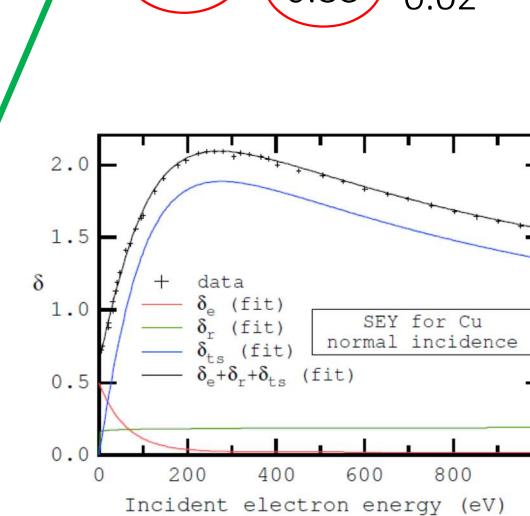
$$\delta_r(E_0, \theta_0) = \delta_r(E_0, \theta_0 = 0)[1 + r_1(1 - \cos^{r_2} \theta_0)]$$

$$\delta_{ts}(E_0, \theta_0) = \hat{\delta}(\theta_0)D(E_0/\hat{E}(\theta_0)),$$

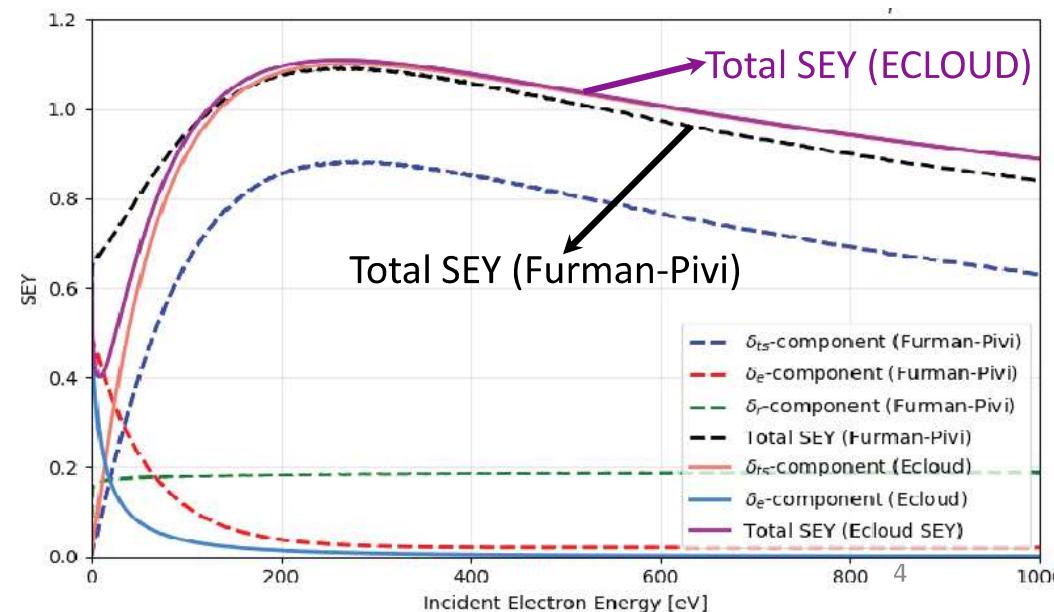
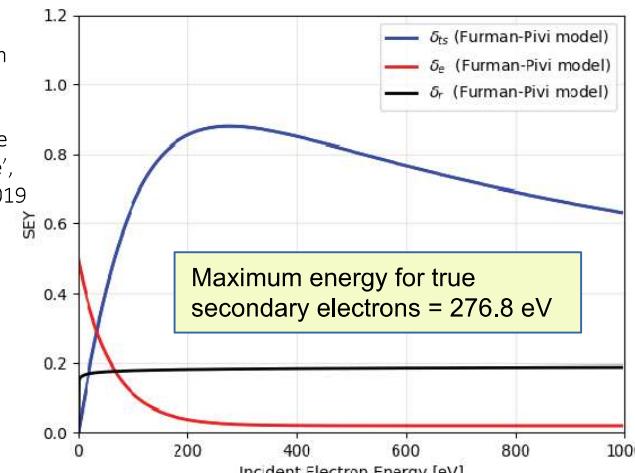
$$\delta(E_0, \theta_0) = \delta_e(E_0, \theta_0) + \delta_r(E_0, \theta_0) + \delta_{ts}(E_0, \theta_0)$$

^aNote that $\hat{E}_t \simeq \hat{E}_{ts}$ and $\hat{\delta}_t \simeq \hat{\delta}_{ts} + P_{1,e}(\infty) + P_{1,r}(\infty)$ provided that $\hat{E}_{ts} \gg \hat{E}_e, E_r$.

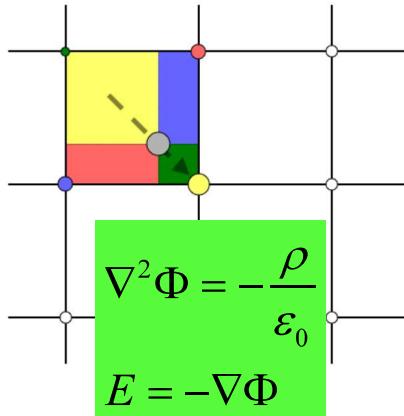
1.1 0.88 0.02



E.G. T. Wulff and G. Iadarola, 'Implementation and benchmarking of the Furman-Pivi model for Secondary Emission in the PyEcloud simulation code', CERN-ACC-2019-0029, 2019



Agreements on PyECLOUD & VSim Results for the Dipole & Drift



- 2D Electrostatic PIC simulation
- effects of space charge and secondary electrons are included
- total SEY = 2.1, Furman-Pivi Model
- Initial $e^- = 1e12$ [e^-/m^3], bunch spacing = 20ns, bunches per train = 20, no photoemission

PyECLOUD

- adaptive scheme to control the number of electrons per macro particle during the simulation
- ECLOUD and Furman-Pivi SEY models



G. Iadarola, "Electron cloud studies for CERN particle accelerators and simulation code development" CERN-THESIS-2014-047, (2014).



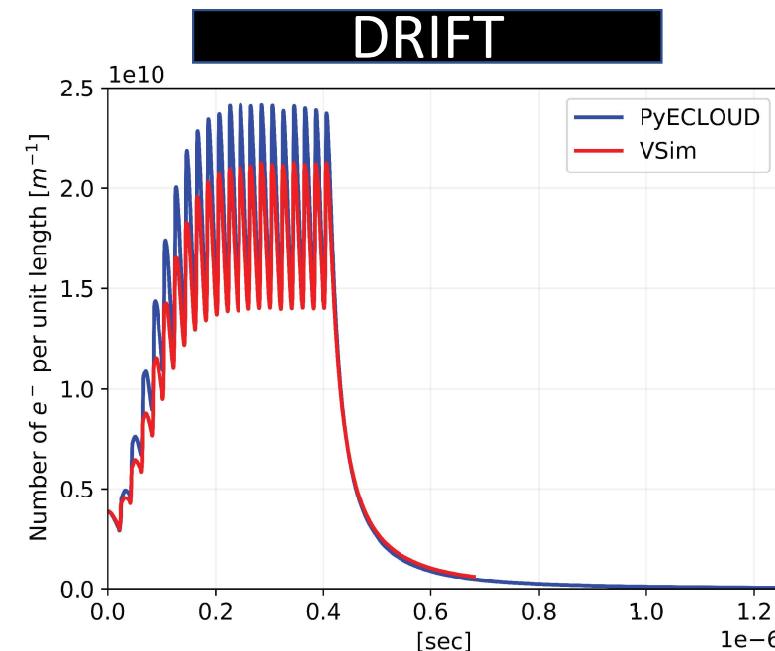
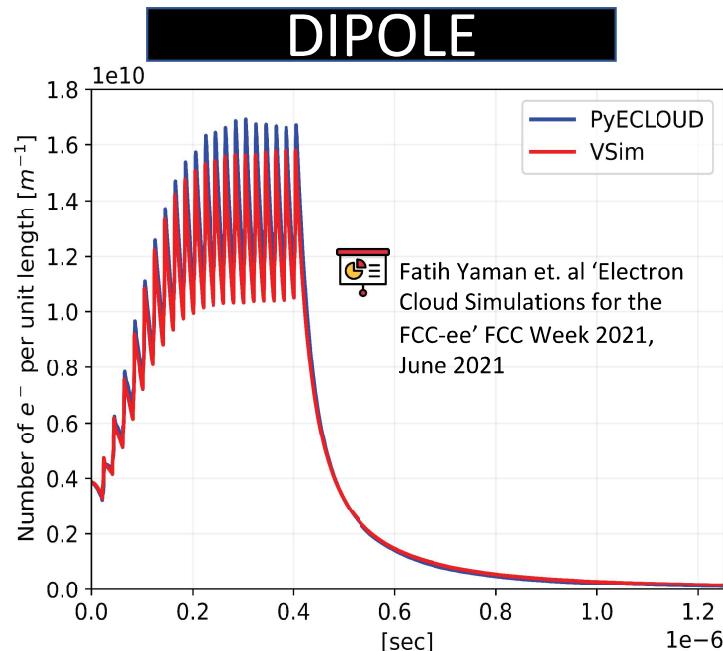
N. Hilleret et al., "Secondary electron emission data for the simulation of electron cloud", Proc. of ECLOUD'02, CERN-2002-001, (2002).

VSim

- Vorpal simulation engine (VSim 9.0.2, VSim 11)
- based on S.A. Veitzer & P.A. Stoltz IPAC2015 study



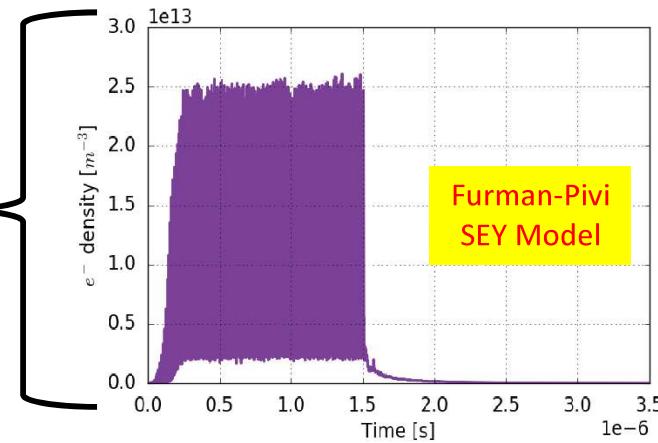
S.A. Veitzer and P.H. Stoltz, 'Electron Cloud Buildup and Dissipation Models for PIP II', Proc. IPAC2015



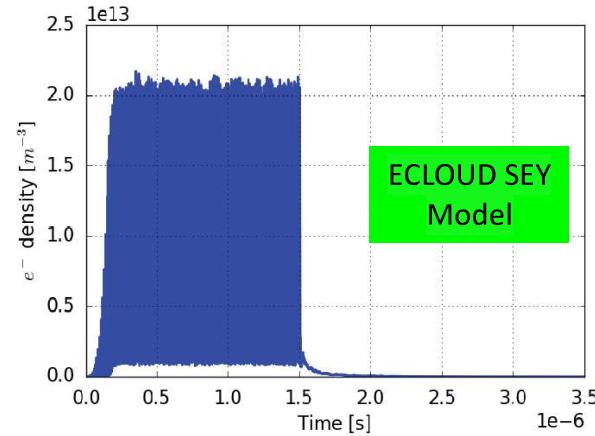
Strong Eccloud Effect for the Dipole & Drift Regions

bunch space = 10ns, $n'_{e(\gamma)} = 1e-3$, SEY= 1.4

DIPOLE

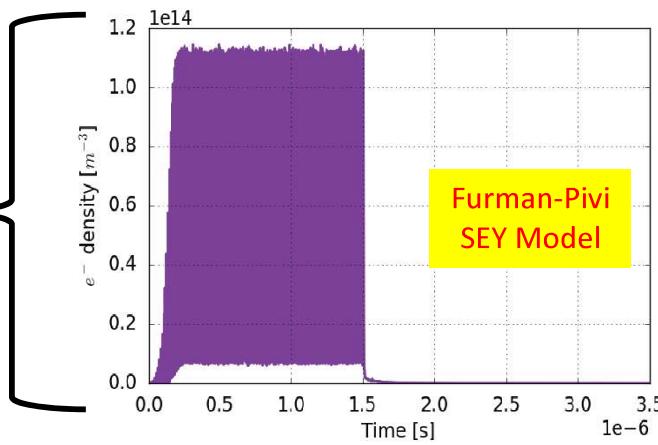


factor ≈ 1.25

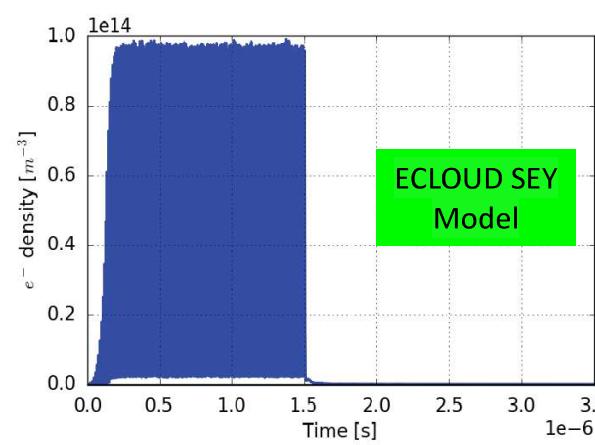


factor ≈ 4.6

DRIFT

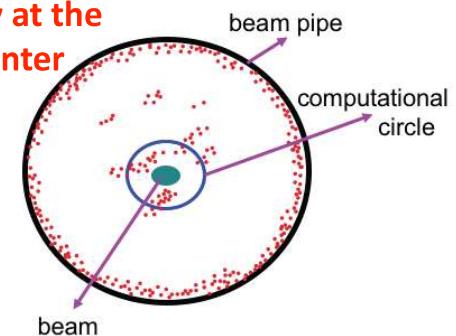


factor ≈ 1.17



factor ≈ 4.8

calculation of e^- density at the pipe center

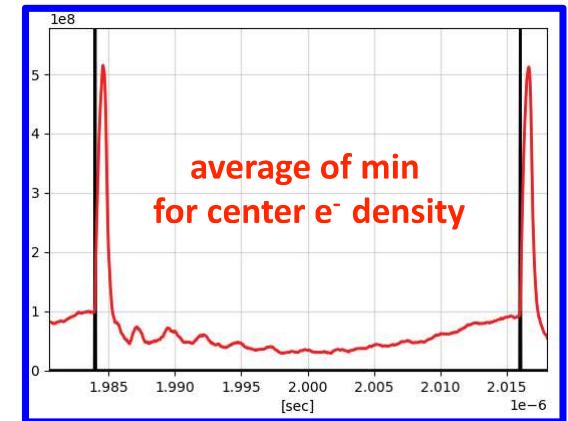
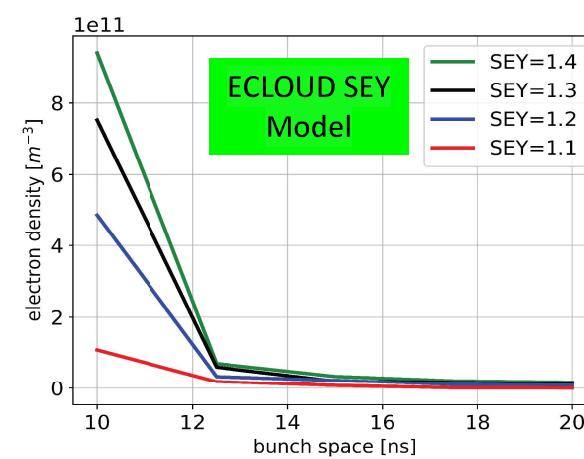
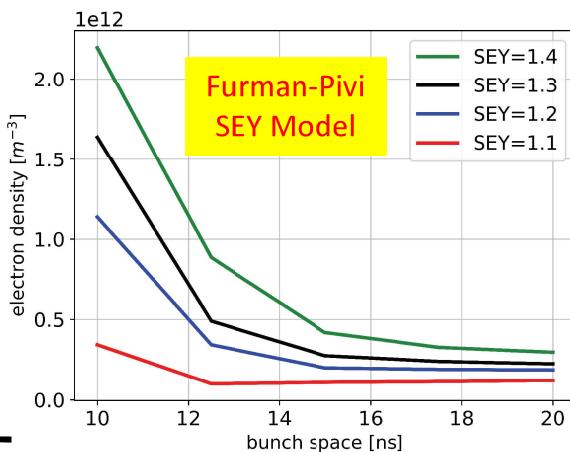


- center density values are in the similar range for each model
- the ratio between the dipole and drift regions is ~ 4.7 for both models
- external magnetic field reduces the electron density at the center of the beam pipe

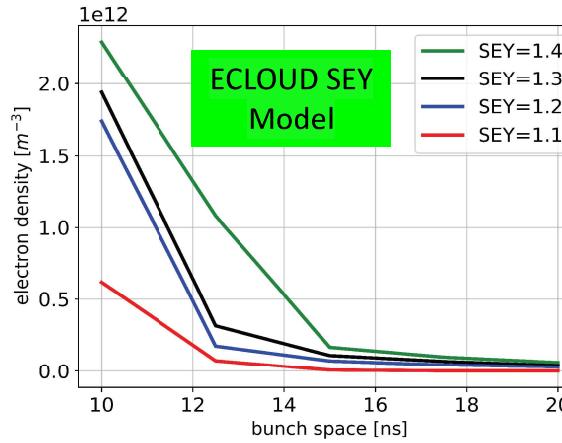
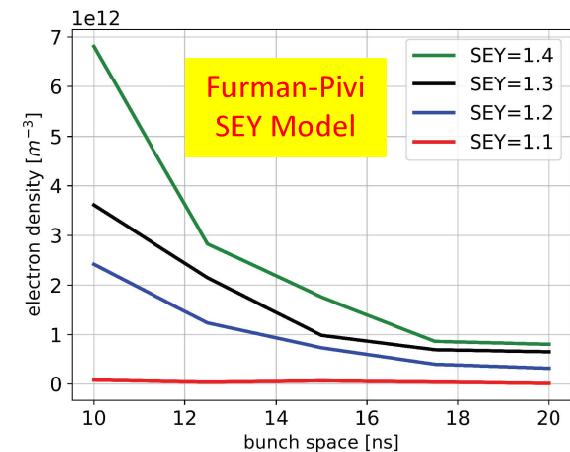
Center Density Comparisons

$$n'_{e(\gamma)} = 1e-6$$

DIPOLE



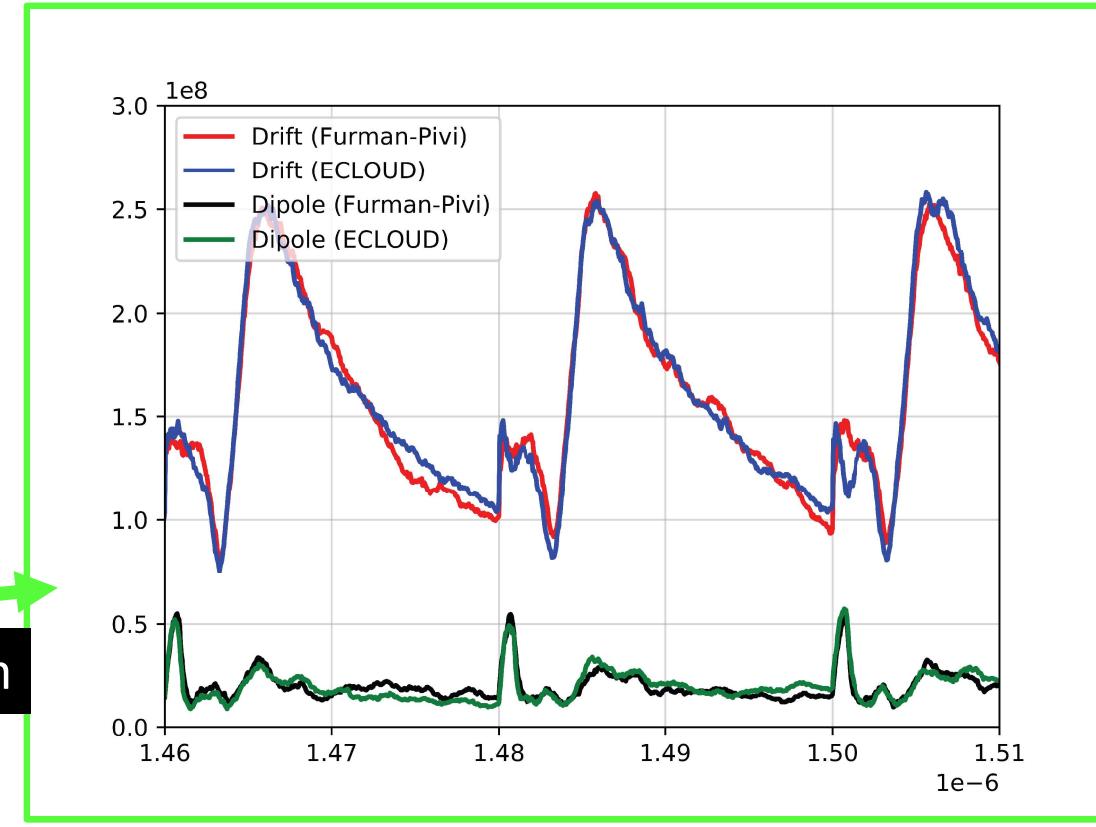
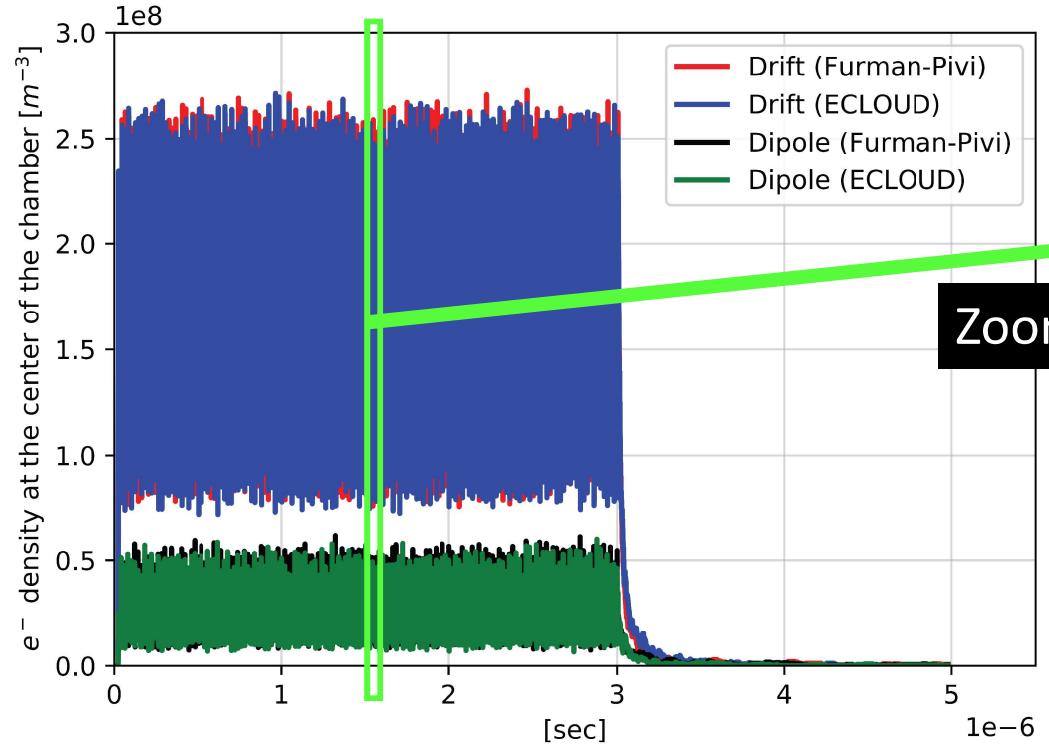
DRIFT



- for bunch spacing > 15ns the density values do not change drastically
- ECLOUD SEY model is more optimistic as compared to Furman-Pivi Model
- with ECLOUD model sharper decrease for 12.5ns is observed

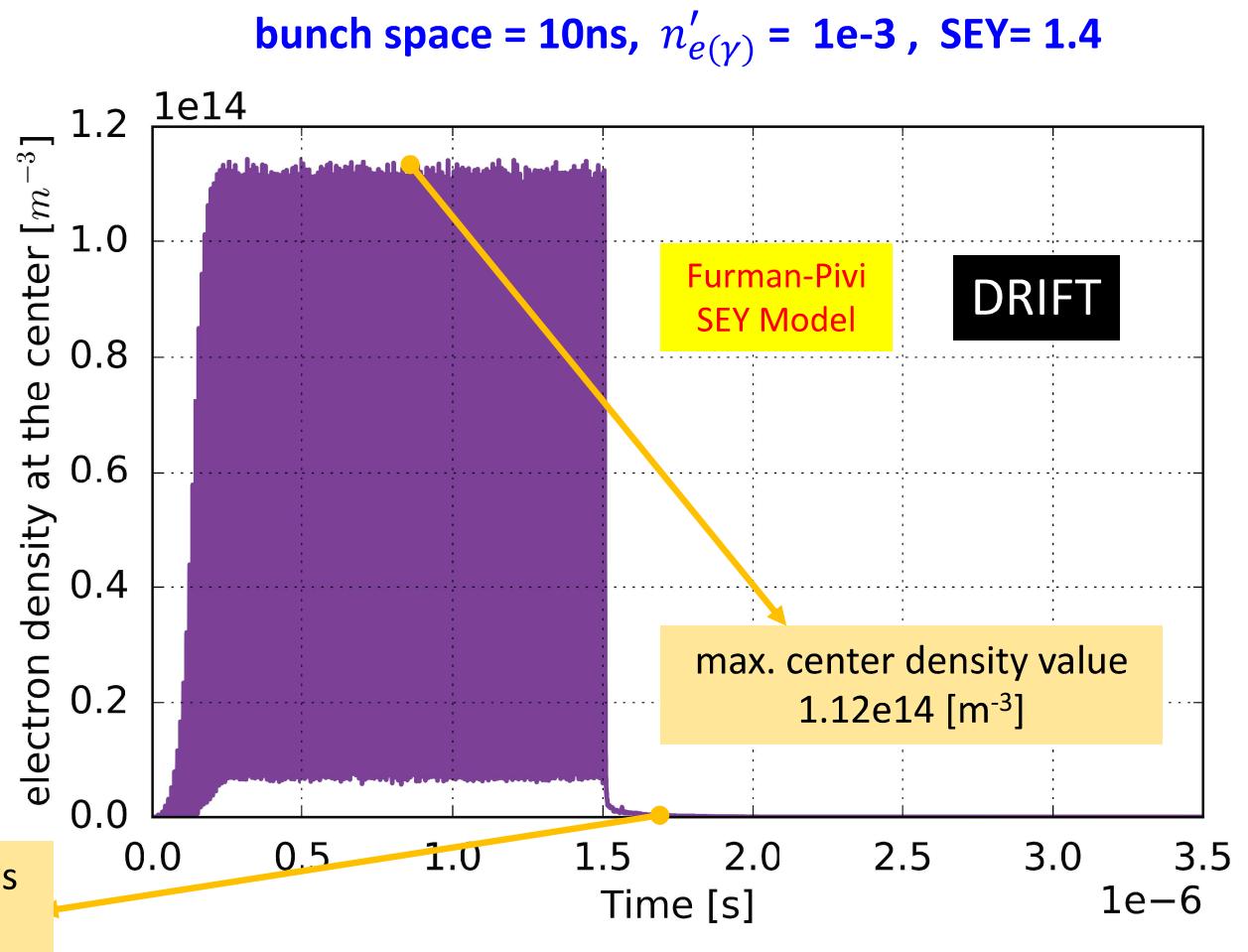
Reference densities for the two SEY models

- SEY = 0.0001 is used in the simulations.
- Two models agrees for the Drift and Dipole regions.
- Reference density value is ~ 5 times larger for the Drift



Mitigation: Preliminary Study

- cleaning the residual electrons with a single trailing bunch follows the main beam
- single bunch pass, various bunch populations, initial electron loading are considered
- among all cases the largest electron density value and the density at $1.75 \mu\text{s}$ are chosen

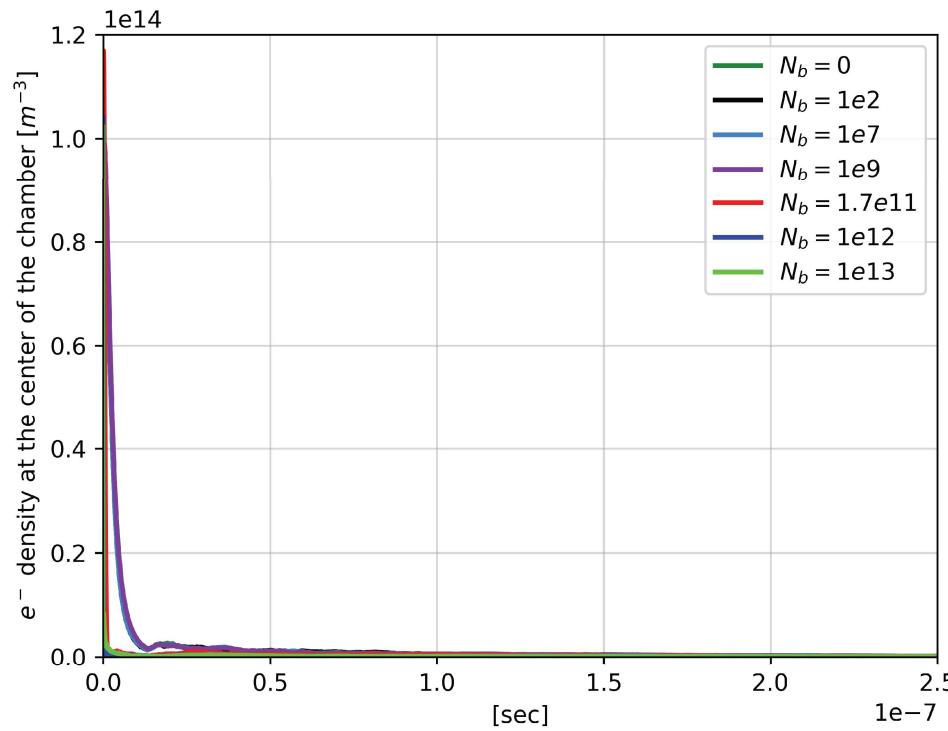


private communication with Seth Veitzer

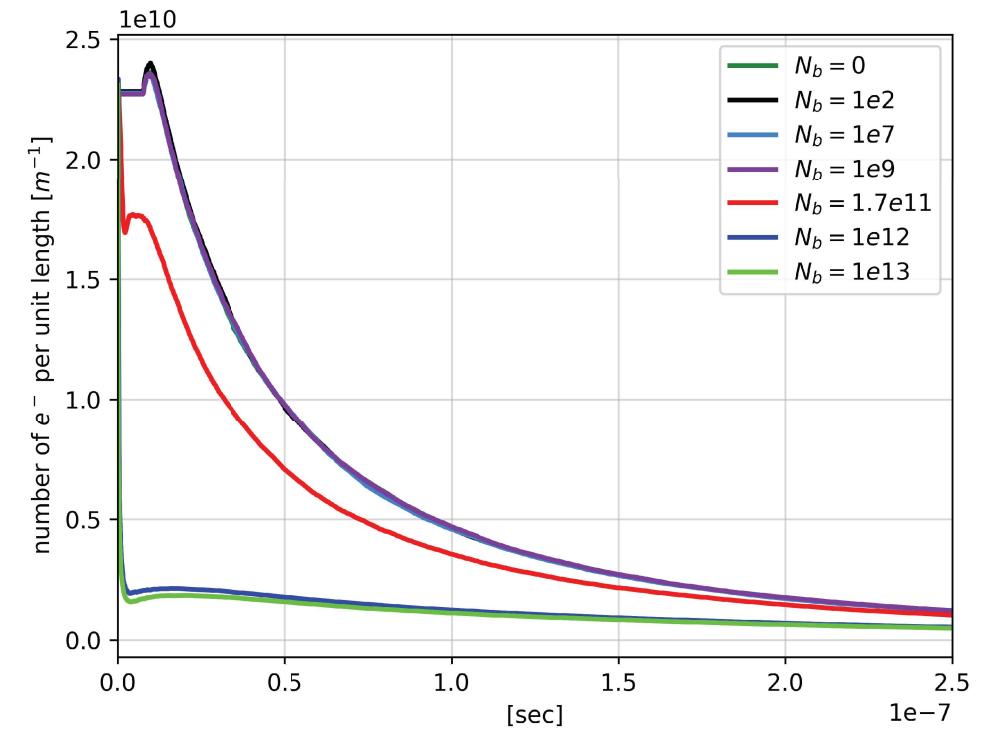
Mitigation: Preliminary Results

for center density value $1.12\text{e}14 \text{ [m}^{-3}\text{]}$

e⁻ density at the pipe center



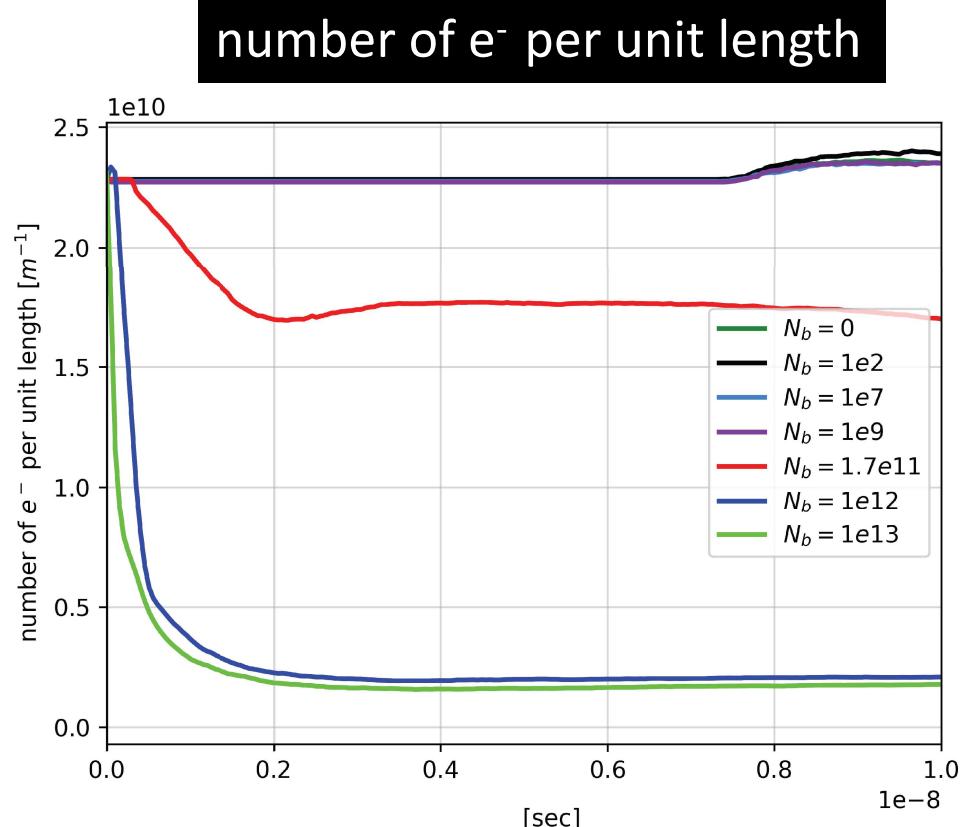
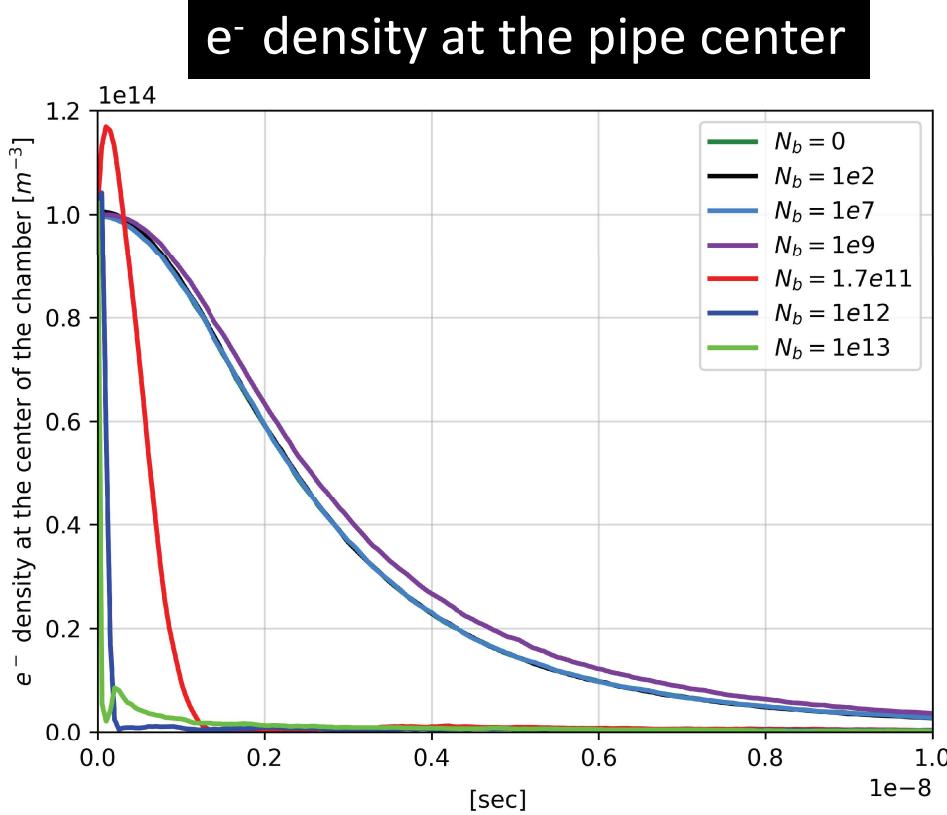
number of e⁻ per unit length



Mitigation: Preliminary Results

for center density value $1.12\text{e}14 \text{ [m}^{-3}\text{]}$

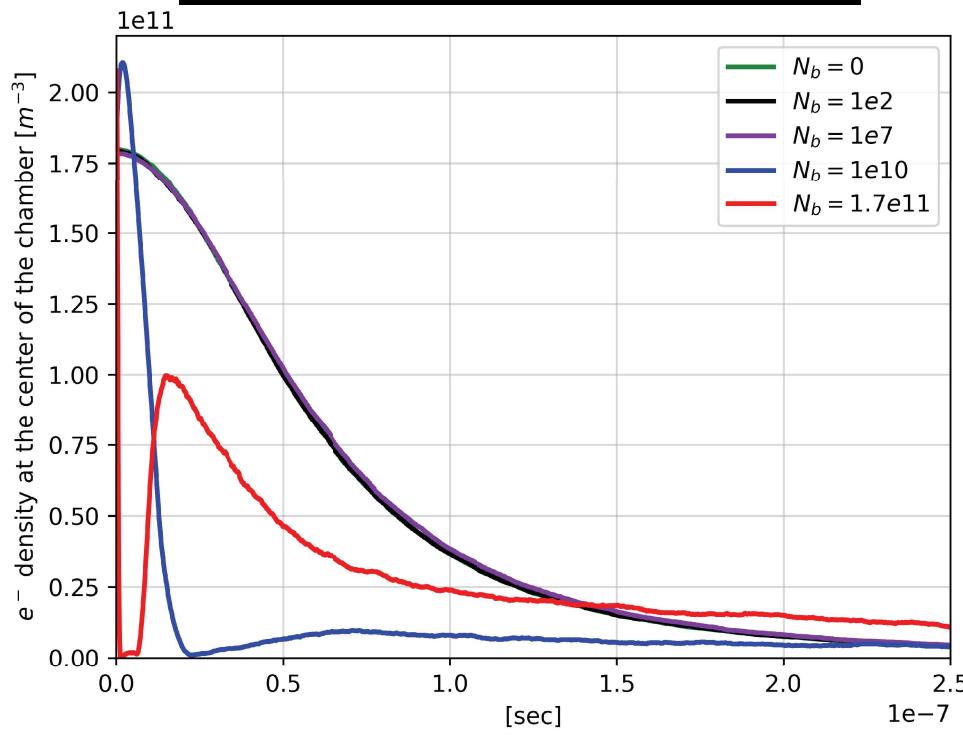
Zoom



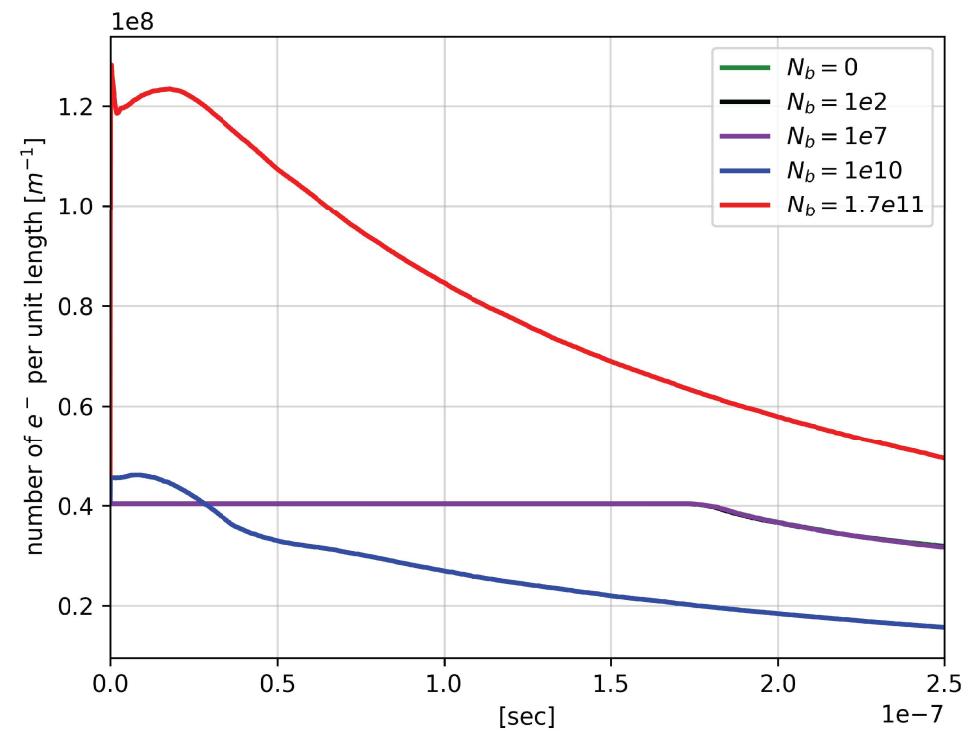
Mitigation: Preliminary Results

for center density value $1.8\text{e}11 \text{ [m}^{-3}\text{]}$

e⁻ density at the pipe center



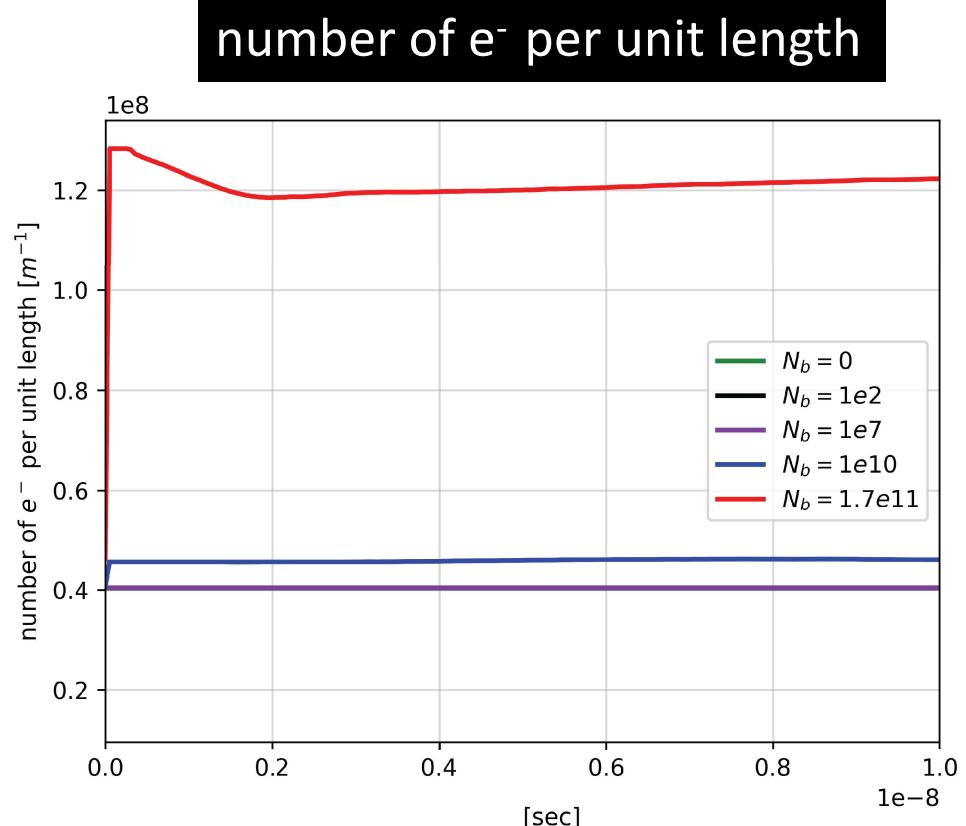
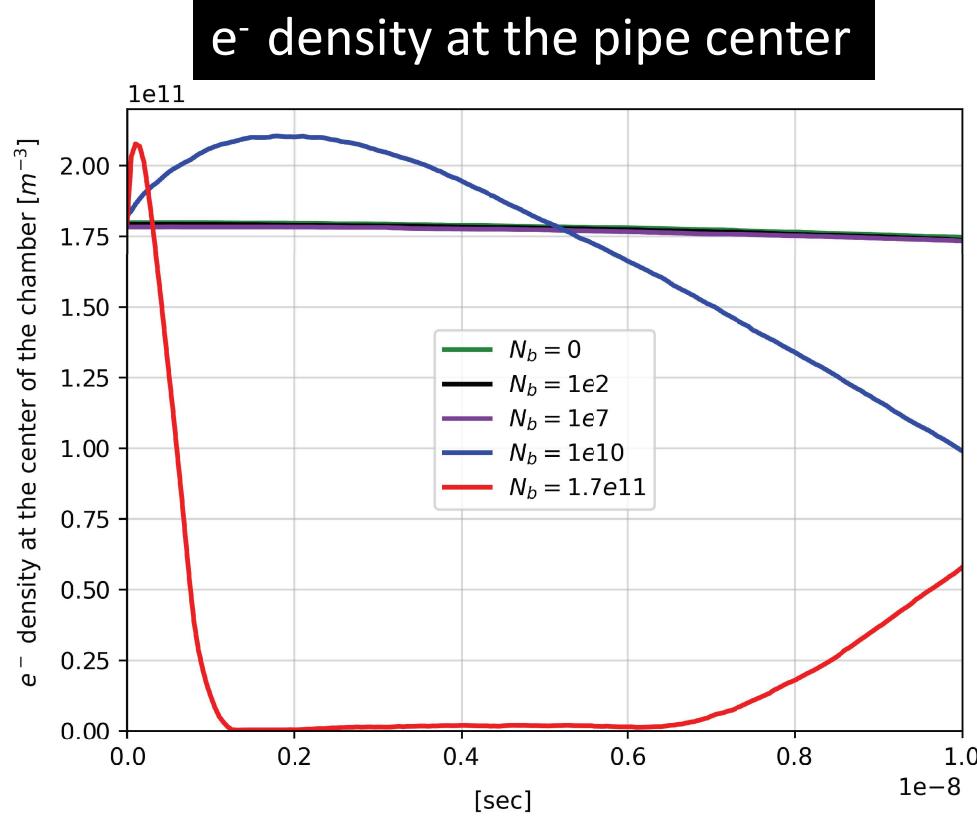
number of e⁻ per unit length



Mitigation: Preliminary Results

for center density value $1.8\text{e}11 \text{ [m}^{-3}\text{]}$

Zoom



Conclusions

- Electron cloud simulation results for the FCC-ee Collider dipole & drift regions (a similar study was done by G. Bellodi for the LHC)
- Simulations are performed in the realistic photon flux regimes
- The effects of SEY and n'_e decrease significantly for larger than 15ns bunch spacings
- e^- density values ~ 5 times larger for the same parameters in drift region
- SEY has a more significant effect on Ecloud center density as compared to n'_e
- Considering total SEY ~ 0 , the reference center e^- density values for the dipole region max. = $5e7$ [m^{-3}], for the drift region max.= $2.5e8$ [m^{-3}]
- Single trailing bunch can be used to clean residual electrons left behind the beam



Future Plans, Discussions, Comments, Ideas..

- simulations with the measured SEY data..
- similarities, differences between LHC and FCC-ee beam pipes from SEY points of view..
- new simulations for the build-up?
- impedance and wakefield calculations of the electron clouds..

THANK YOU FOR ATTENTION!



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