FUTURE CIRCULAR COLLIDER
Innovation Study

FCCIS 2022 Workshop

Dec 5 – 9, 2022

Electron cloud simulations for the FCC-ee

Fatih Yaman, IYTE & STFC – ASTeC, Daresbury Lab.

Frank Zimmermann, CERN

Many Thanks: M. Zobov, D. Shatilov, G. Schiwietz and the FCC-ee optics team

December 7, 2022

FCC-ee Collider Arc Dipole Parameters

Parameters	
beam energy [GeV]	45.6
bunches per train	150
trains per beam	1
r.m.s. bunch length (σ_z) [mm]	4.32
h. r.m.s. beam size (σ_x) **[µm]**	207
v. r.m.s. beam size (σ_y**) [µm]**	**12.1**
number of particles / bunch (**10^{11}**)	2.76
bend field [T]	**0.01415**
circumference *C* [m]	**91.2**
synchrotron tune Qs	**0.037**
average beta function $\boldsymbol{\beta}_y$ [m]	**50**
threshold density (**10^{12} [m^{-3}]**)	**0.043**

- bunch spacings, BS : (25, 30, 32) ns
- circular beam pipe radii, r : (30, 35) mm
- SEY Models: ECLOUD, Furman-Pivi
- Total SEY : (1.1, 1.2, 1.3, 1.4)
- PE generation rates , $n'_{(\gamma)}$: (1e-3, 1e-4, 1e-5, 1e-6) m^{-1}
- threshold density (single-bunch instability) :

PyECLOUD

Drift region is included

$$\omega_e = \left(\frac{N_b r_e c^2}{\sqrt{2\pi}\sigma_z \sigma_y (\sigma_x + \sigma_y)} \right)^{1/2}$$

$$Q = \min(\omega_e \sigma_z / c, 7) \quad K = \omega_e \sigma_z / c$$

$$\rho_{\rm thr} = \frac{2\gamma Q_s \omega_e \sigma_z / c}{\sqrt{3} K Q r_e \beta_y C}$$

K. Ohmi, Beam-beam and electron cloud effects in CEPC / FCC-ee, Int. Journal of Modern Physics A, 31(33), 1644014 (2016).

K. Ohmi, F. Zimmermann and E. Perevedentsev, Wake-field and fast head-tail instability caused by an electron cloud, Phys. Rev. E 65, 016502 (2001).

F.Yaman, G.Iadarola, R. Kersevan, S. Ogur, K. Ohmi, F. Zimmermann and M. Zobov, Mitigation of Electron Cloud Effects in the FCC-ee Collider, EPJ Tech. and Inst. 2022 9:9, Accelerating the design of the future circular collider, 2022. (preprint arXiv:2203.04872)

Furman-Pivi & ECLOUD SEY Models

in this study
Total SEY = {1.1, 1.2, 1.3, 1.4}

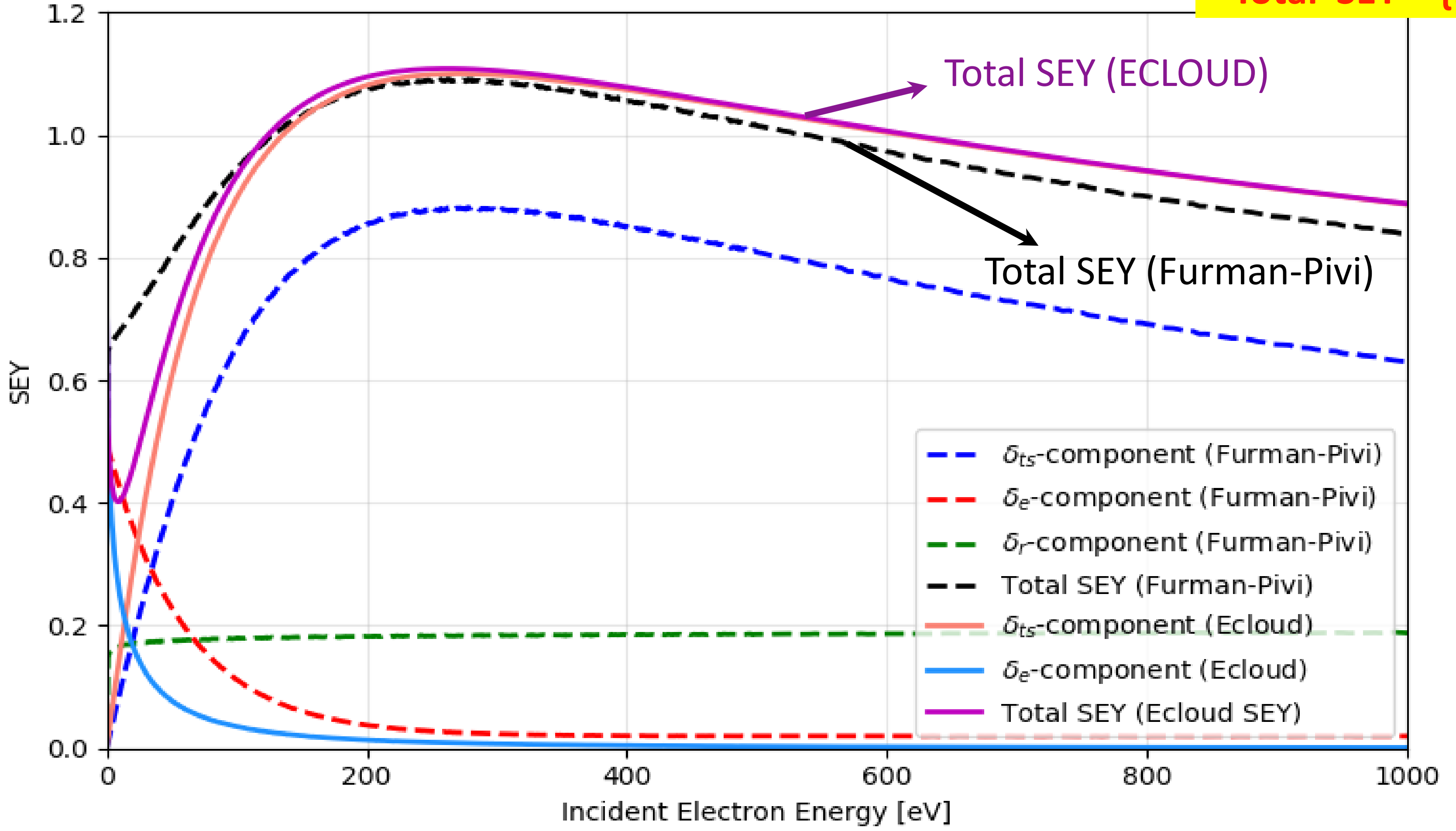


TABLE I: Main parameters of the model.

	Copper	Stainless Steel
Emitted angular spectrum (Sec. II C 1)		
α	1	1
Backscattered electrons (Sec. III B)		
$P_{1,e}(\infty)$	0.02	0.07
$\hat{P}_{1,e}$	0.496	0.5
$\hat{E}_e$ [eV]	0	0
W [eV]	60.86	100
p	1	0.9
σ_e [eV]	2	1.9
e_1	0.26	0.26
e_2	2	2
Rediffused 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

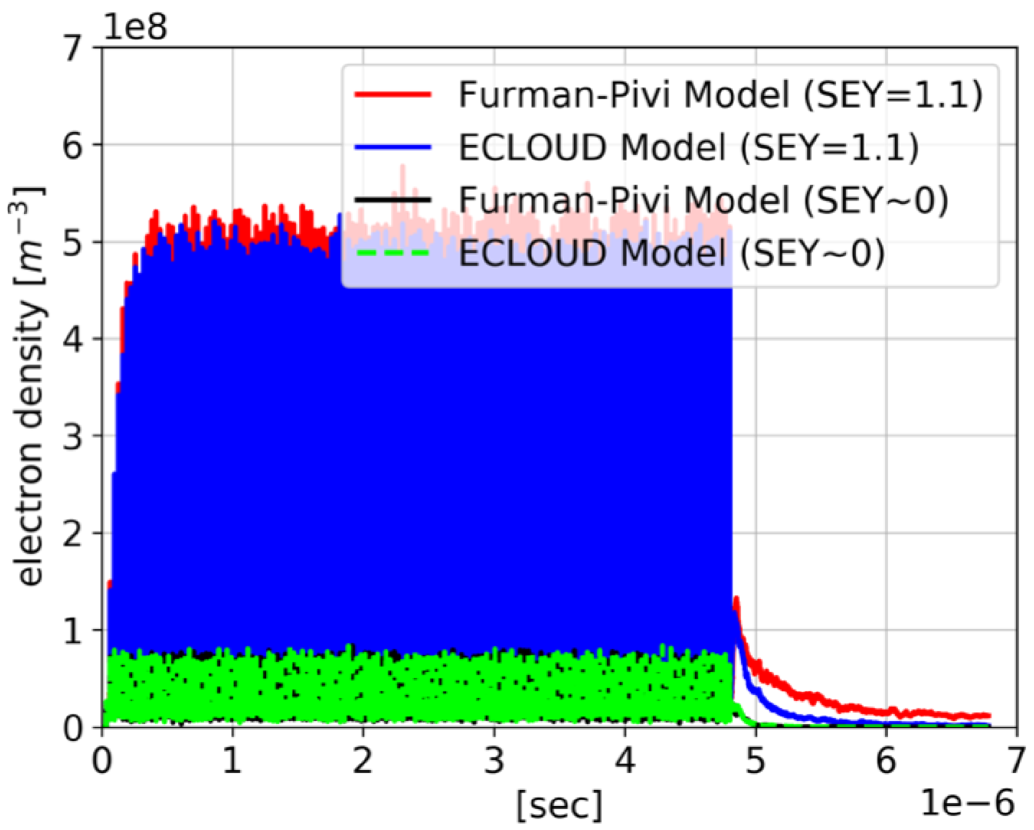
[a]Note that $\hat{E}_t \simeq \hat{E}_{ts}$ and $\hat{\delta}_t \simeq \hat{\delta}_{ts} + P_{1,e}(\infty) + P_{1,r}(\infty)$ provided that $\hat{E}_{ts} \gg \hat{E}_e, E_r$.

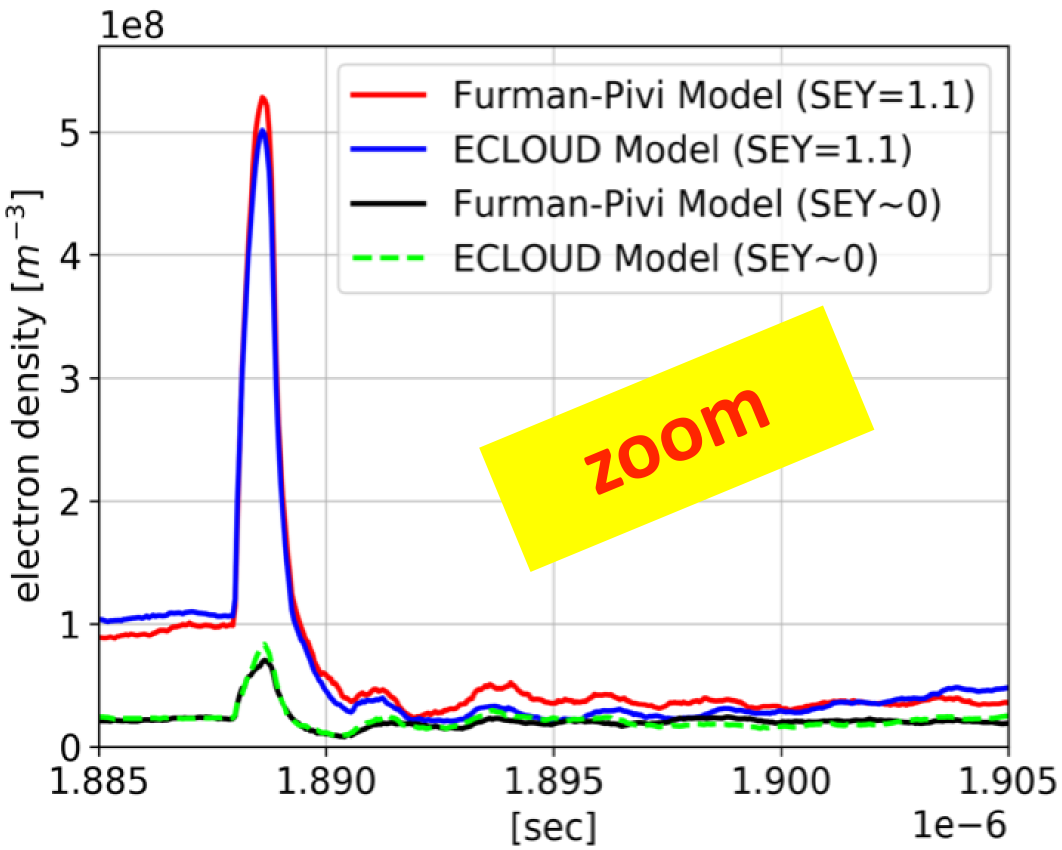
[a]Note that $\hat{E}_t \simeq \hat{E}_{ts}$ and $\hat{\delta}_t \simeq \hat{\delta}_{ts} + P_{1,e}(\infty) + P_{1,r}(\infty)$ provided that $\hat{E}_{ts} \gg \hat{E}_e, E_r$.

1.1   0.88   0.02   0.2

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

Dipole Region: $n'_{(\gamma)}$ = 1e-6 m^{-1} , bunch spacing: 32ns, r = 35mm

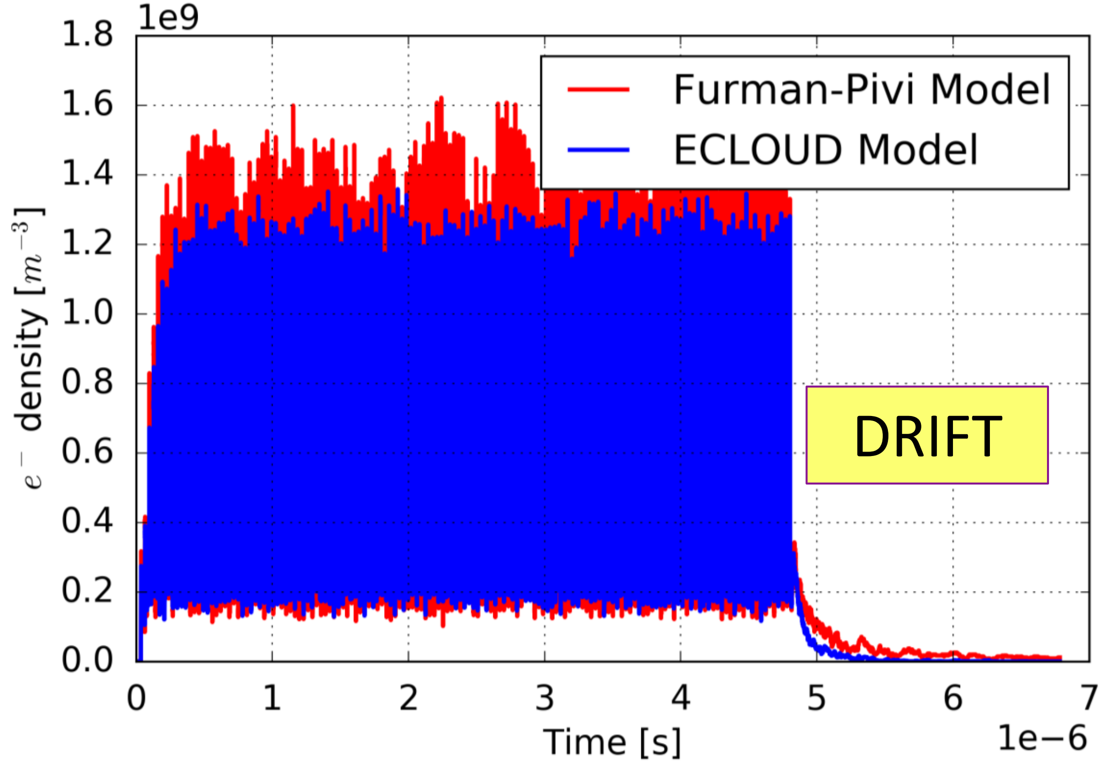


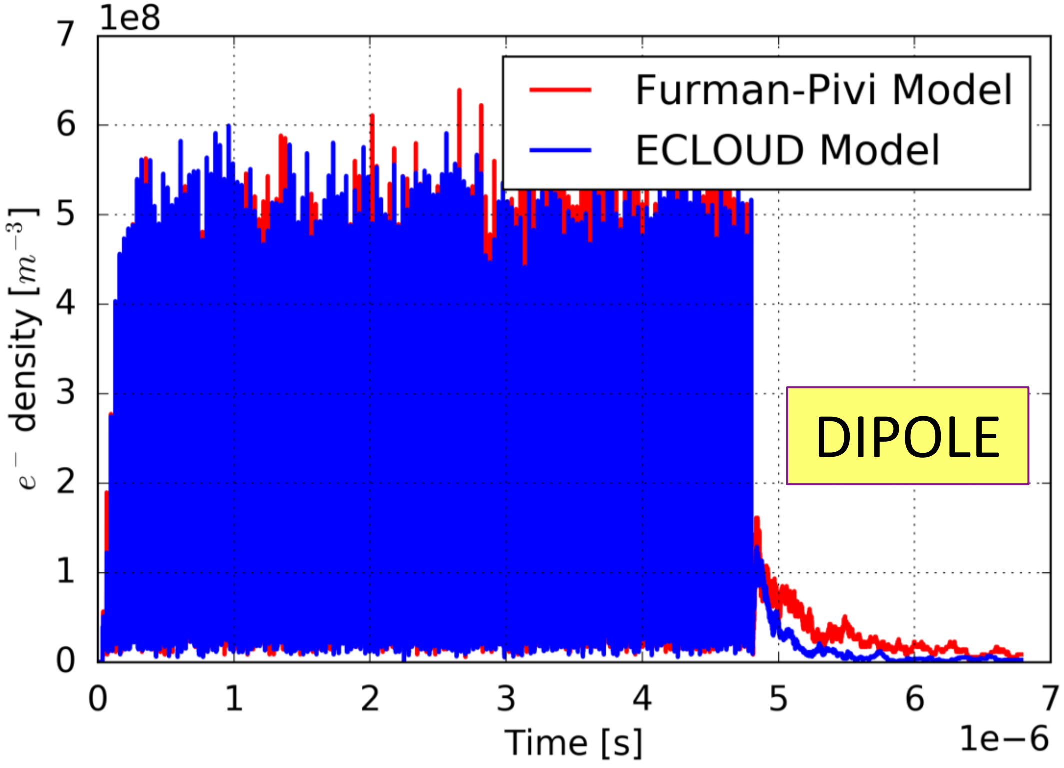


- results via two SEY models agree well for SEY ≃ 0 (min. ≃ 2e7 e^-/m^3)
- max. ≃ 5e8 e^-/m^3 is verified with both models for SEY = 1.1

Drift and Dipole regions

SEY =1.1 , $n'_{(\gamma)}$ =1e-6 m^{-1} , bunch spacing: 32 ns, r = 35mm

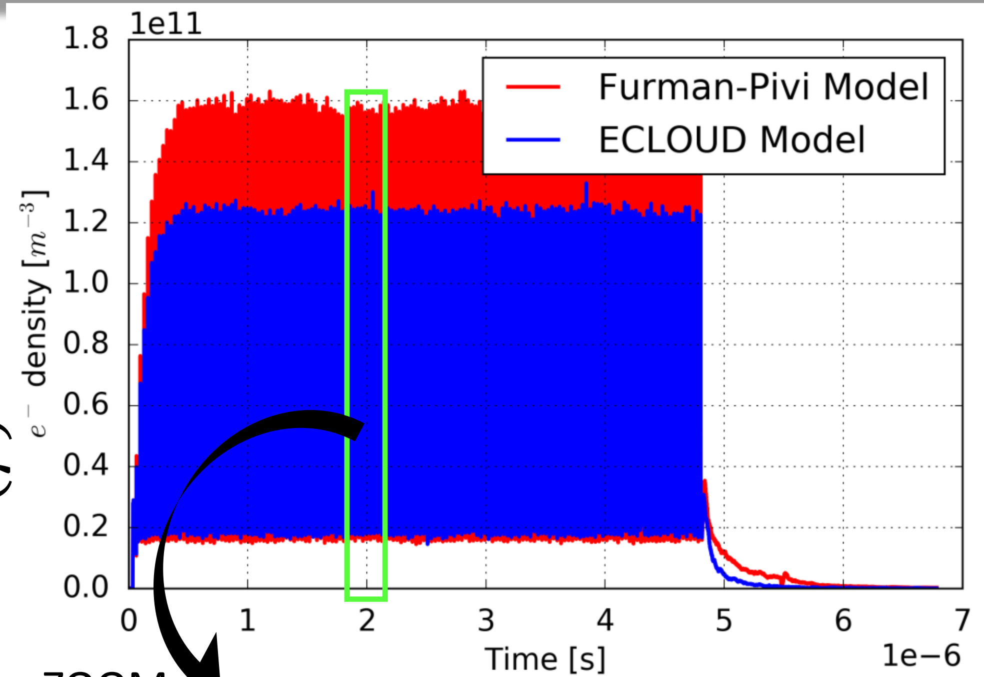




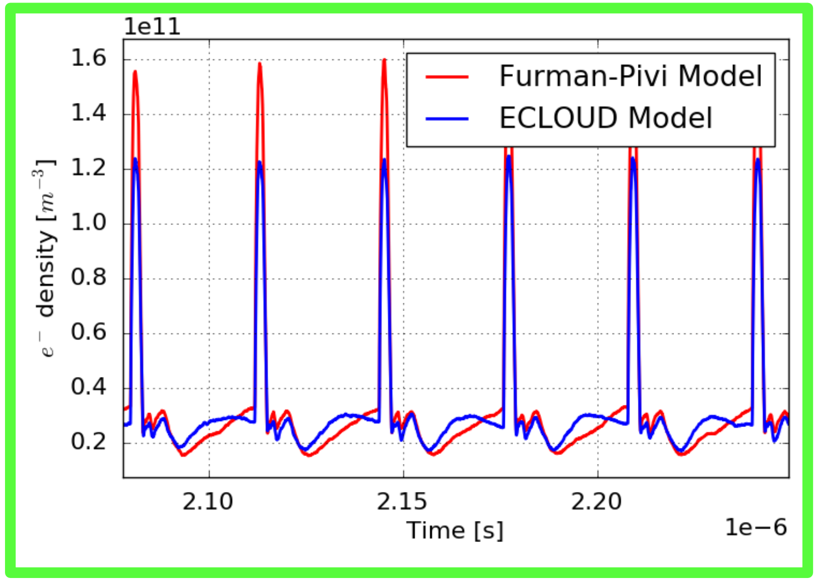
- both models yield similar results w.r.t. regions due to low SEY & PE (similar behaviours for 30ns bunch spacing)
- 0.01415 [T] external magnetic field ≃ 2.5 times lowers the densities for the weakest SEY & PE

Drift region: SEY =1.1 , bunch spacing: 32 ns, r = 35mm

$n'_{(\gamma)} = 1e\text{-}4\ m^{-1}$



ZOOM

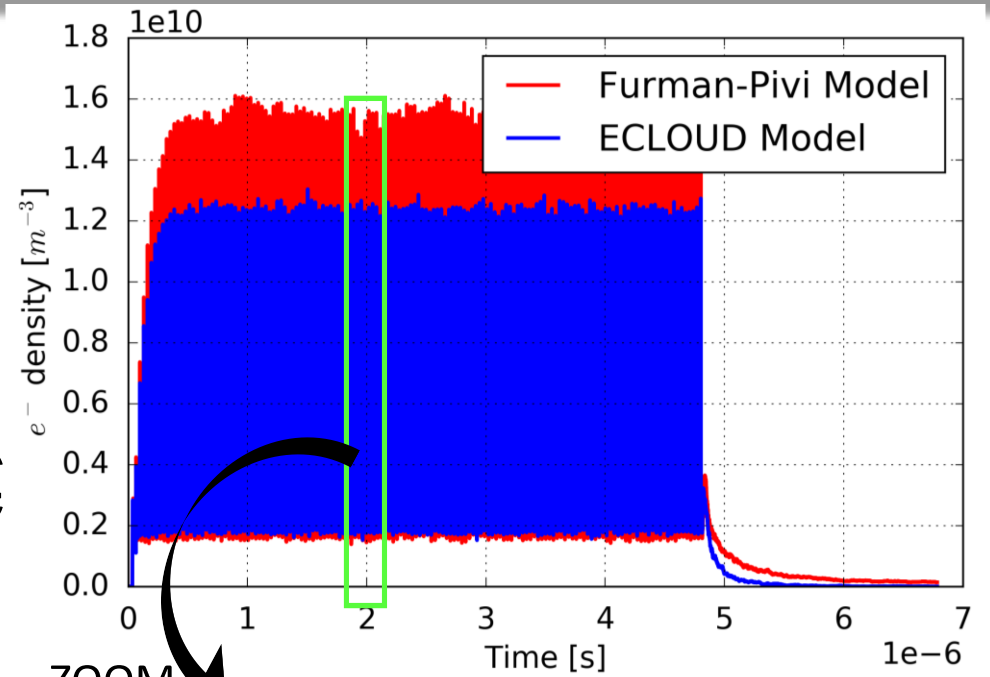


Average of min.

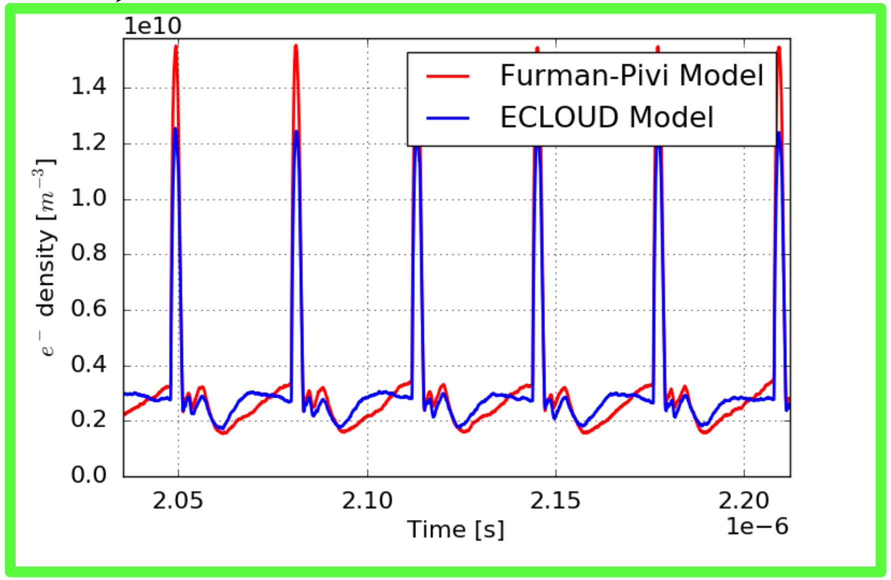
EC: 1.78e10 m^{-3}

FP: 1.50e10 m^{-3}

$n'_{(\gamma)} = 1e\text{-}5\ m^{-1}$



ZOOM



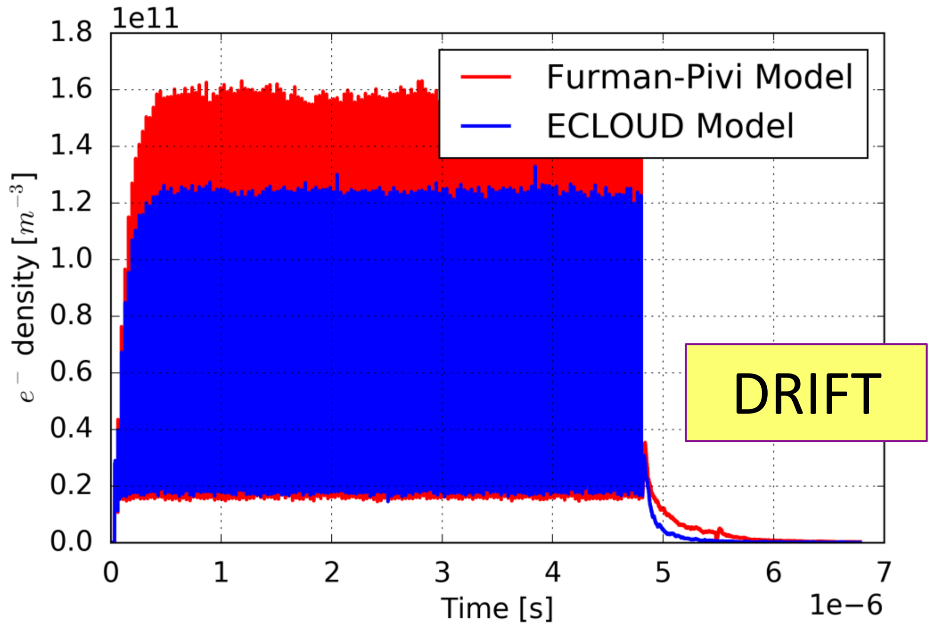
Average of min.

EC: 1.76e9 m^{-3}

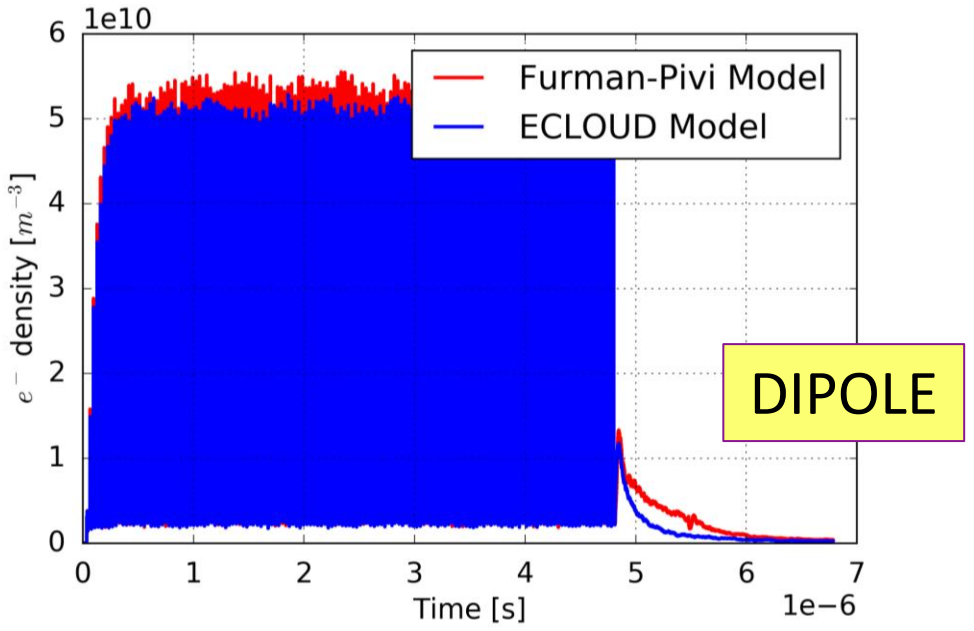
FP: 1.61e9 m^{-3}

Drift and Dipole regions: SEY =1.1 , bunch spacing: 32 ns, r = 35mm

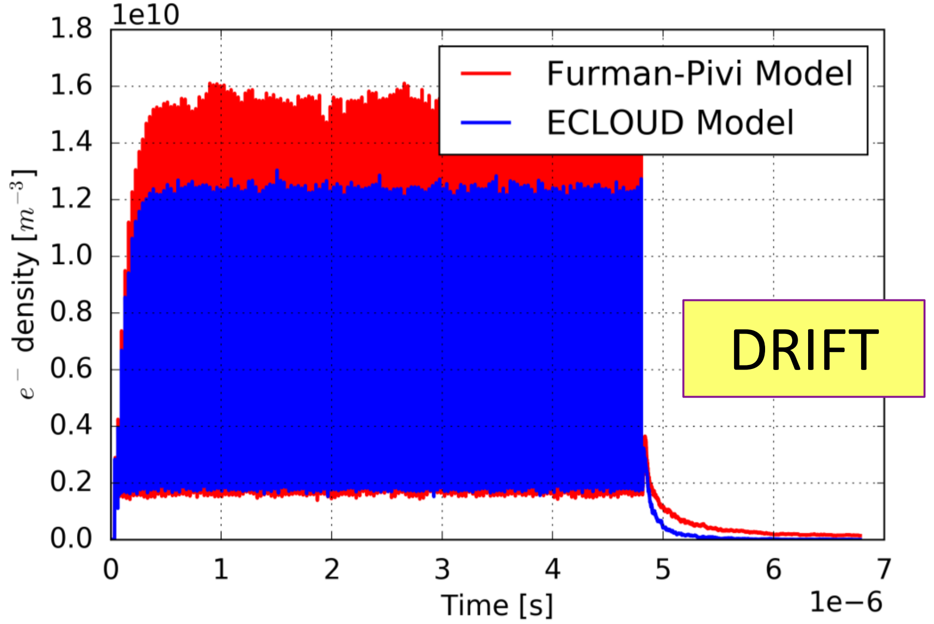
$n'_{(\gamma)}$ =1e-4 m^{-1}



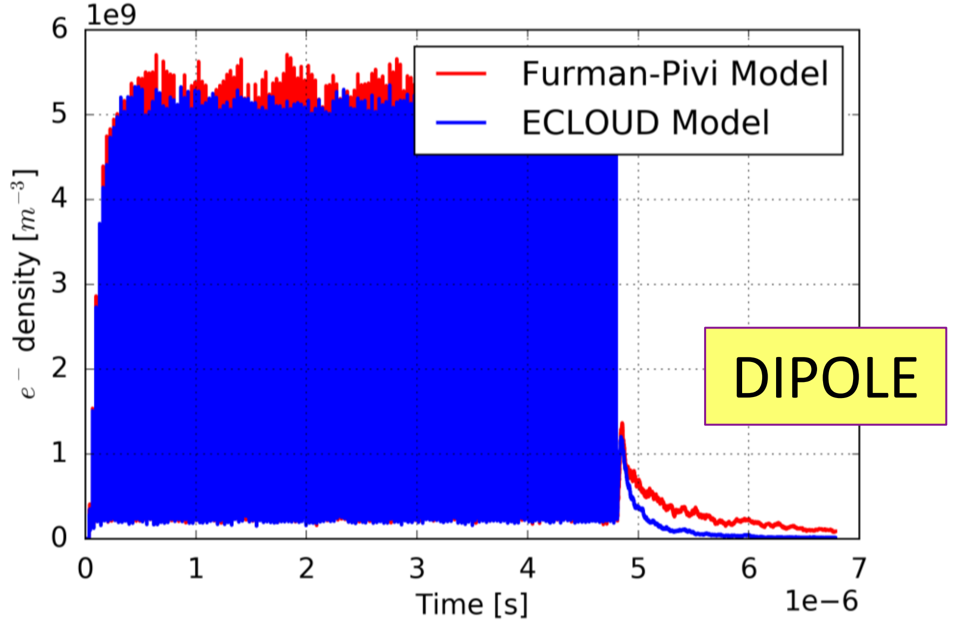
$n'_{(\gamma)}$ =1e-4 m^{-1}



$n'_{(\gamma)}$ =1e-5 m^{-1}

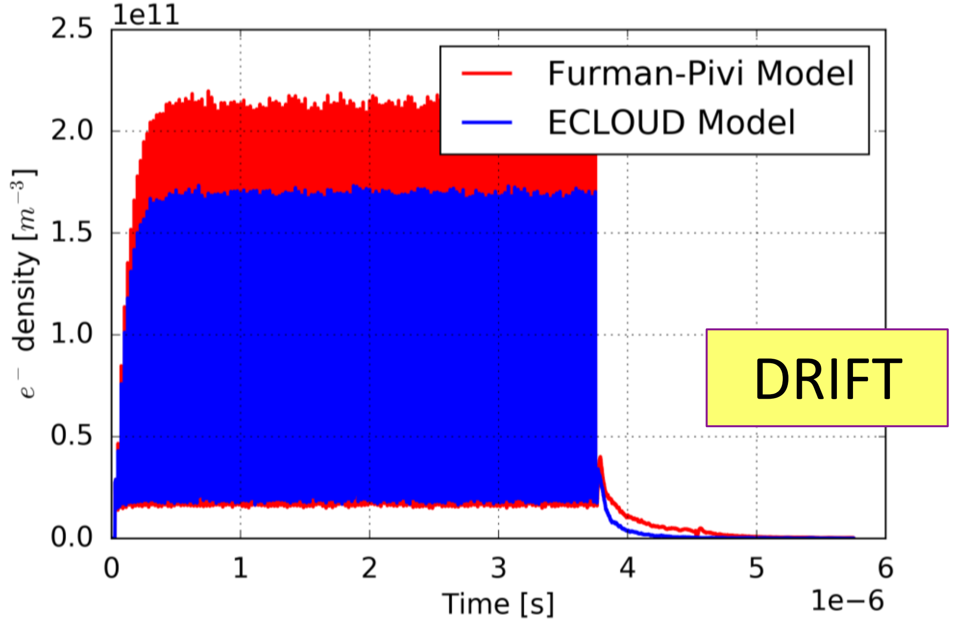


$n'_{(\gamma)}$ =1e-5 m^{-1}

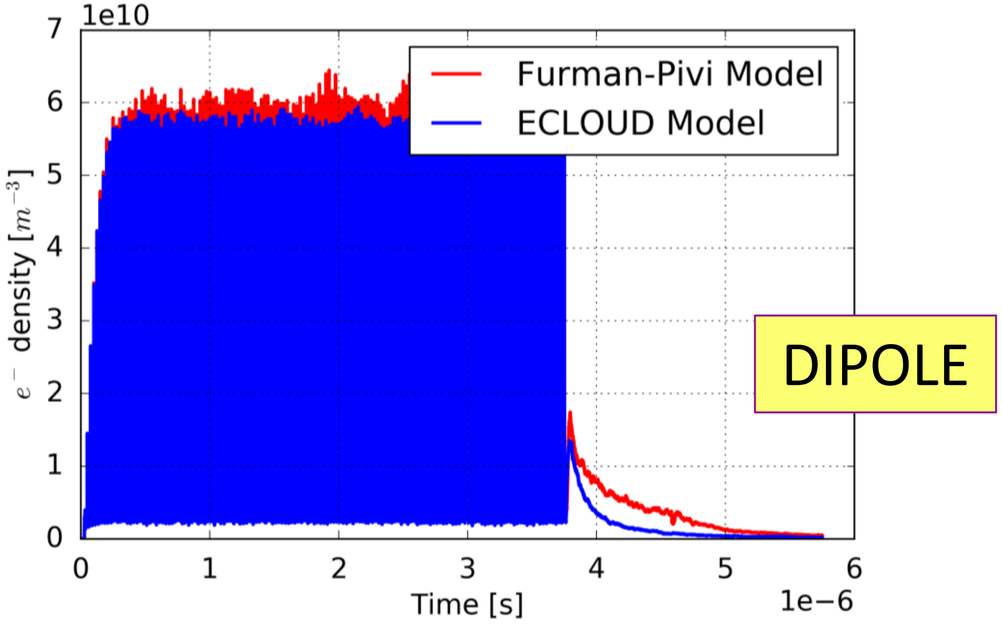


Drift and Dipole regions: SEY =1.1 , bunch spacing: 25 ns, r = 35mm

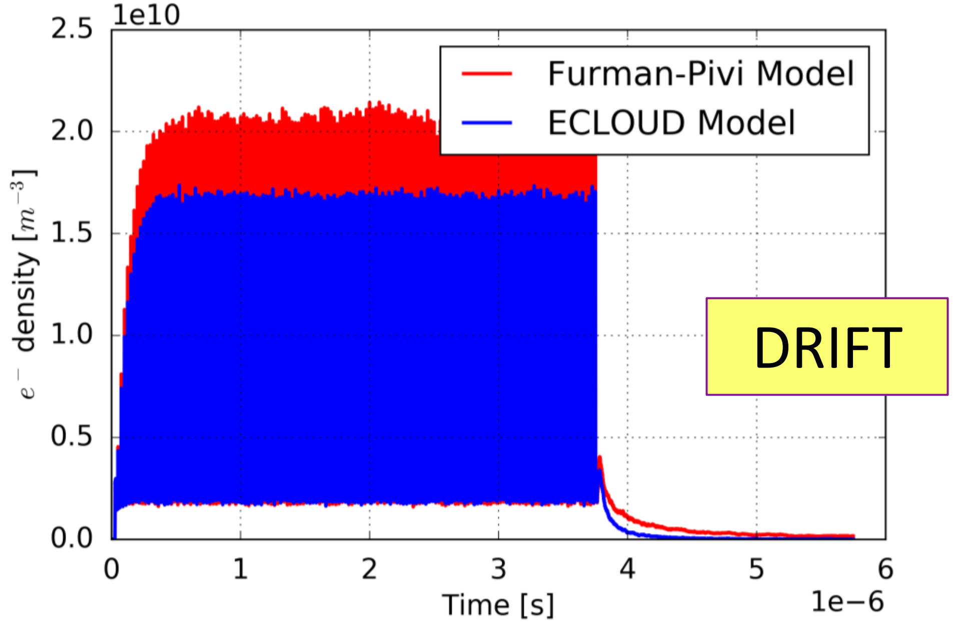
$n'_{(\gamma)}$ =1e-4 m^{-1}



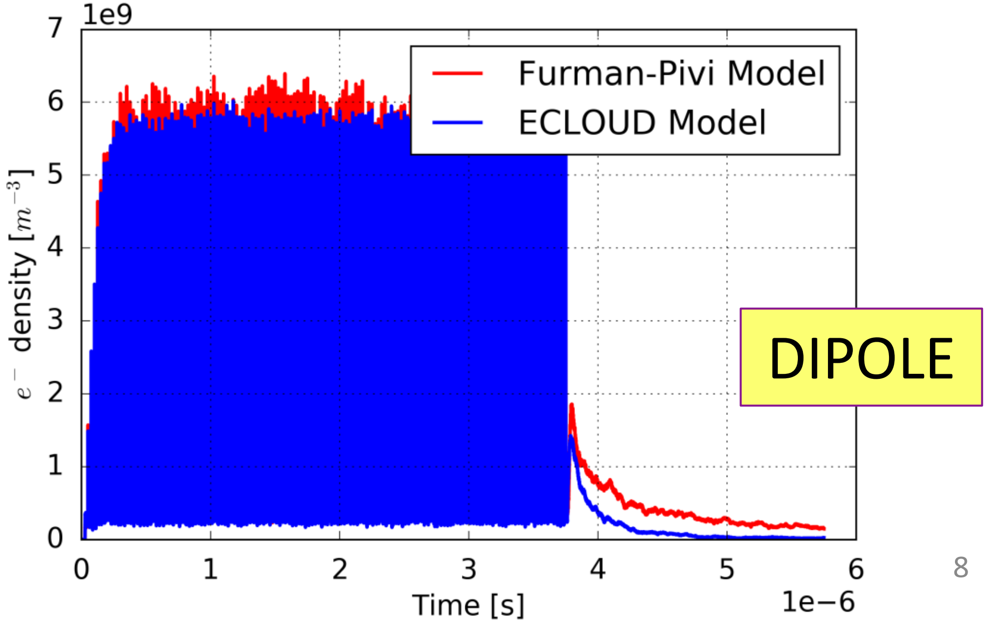
$n'_{(\gamma)}$ =1e-4 m^{-1}



$n'_{(\gamma)}$ =1e-5 m^{-1}

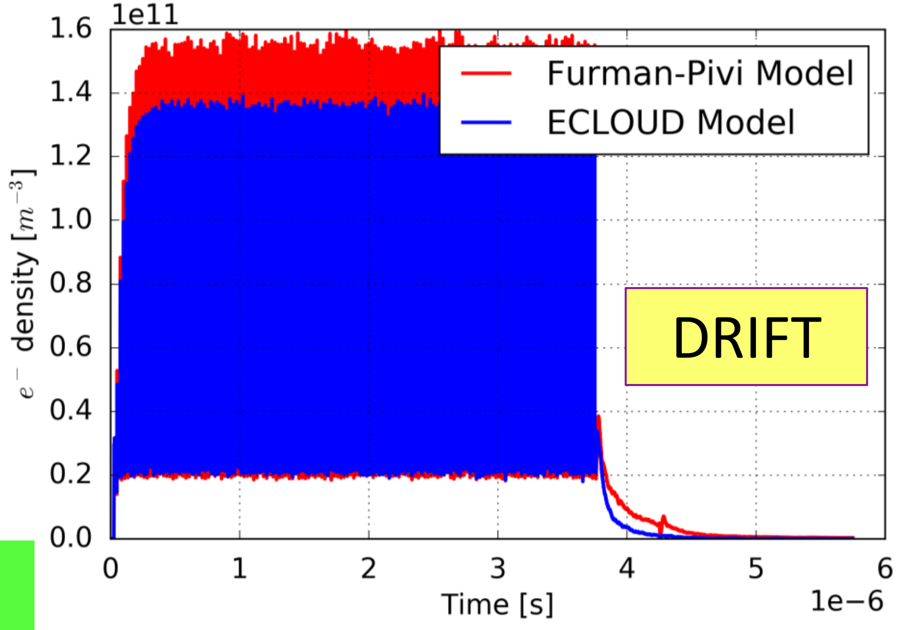


$n'_{(\gamma)}$ =1e-5 m^{-1}



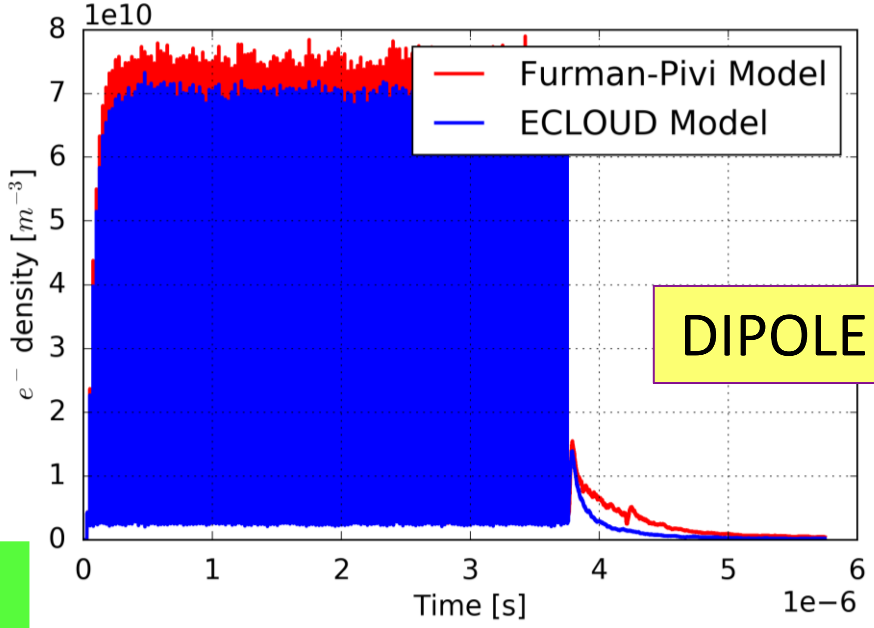
Drift and Dipole regions: SEY =1.1 , $n'_{(\gamma)}$ =1e-4 m^{-1} , bunch spacing: 25 ns

r = 30mm



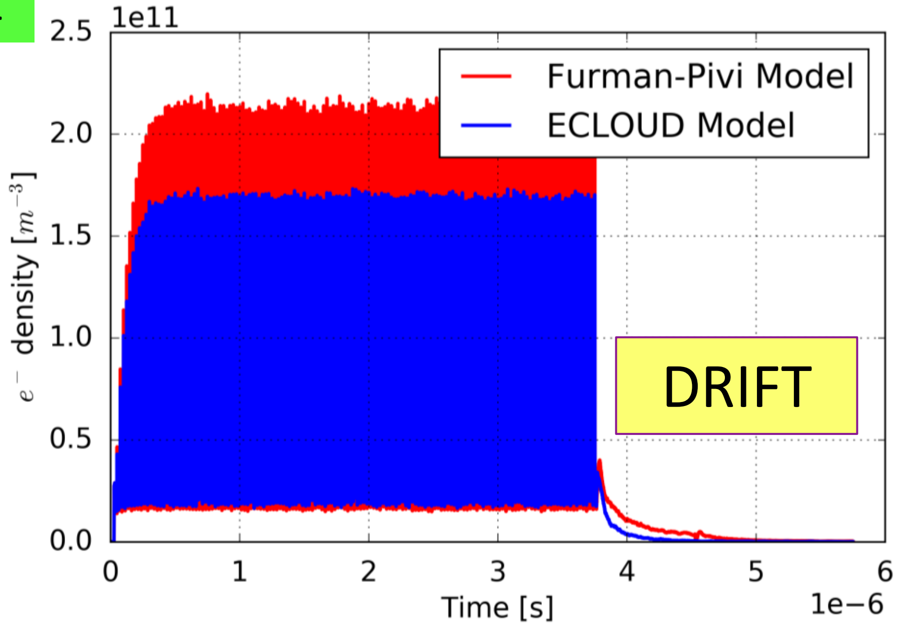
FP ~ 1.35
EC ~ 1.21

r = 30mm

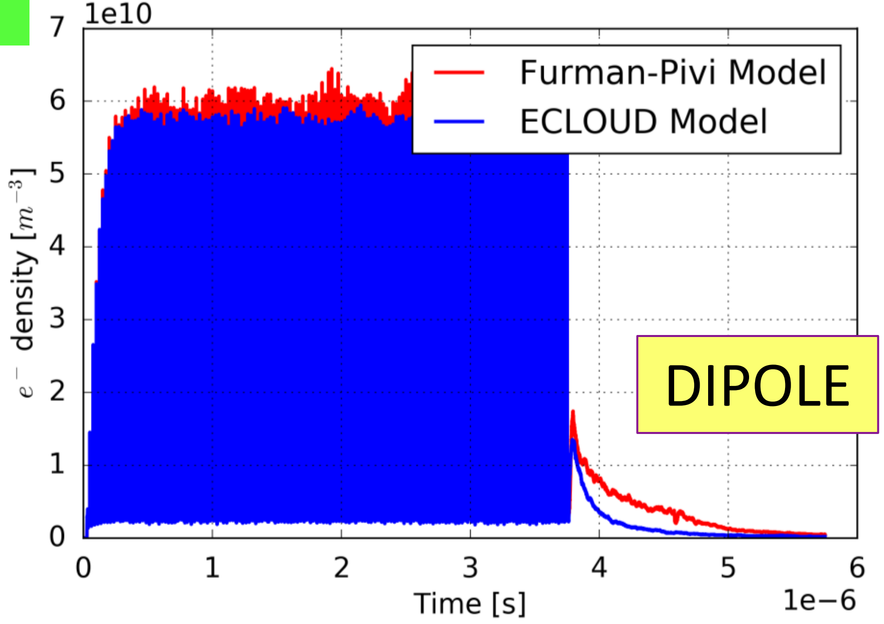


FP ~ 0.75
EC ~ 0.84

r = 35mm



r = 35mm

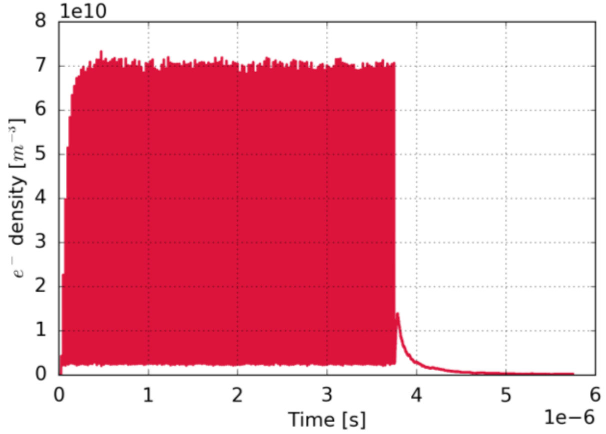


Dipole Region : ECLOUD Model

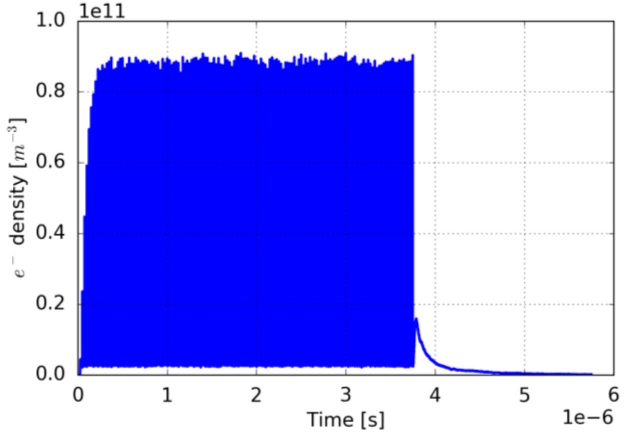
bunch spacing: 25 ns, $n'_{(\gamma)}$ =1e-4 m^{-1}

r = 30mm (first row) , r = 35mm (second row)

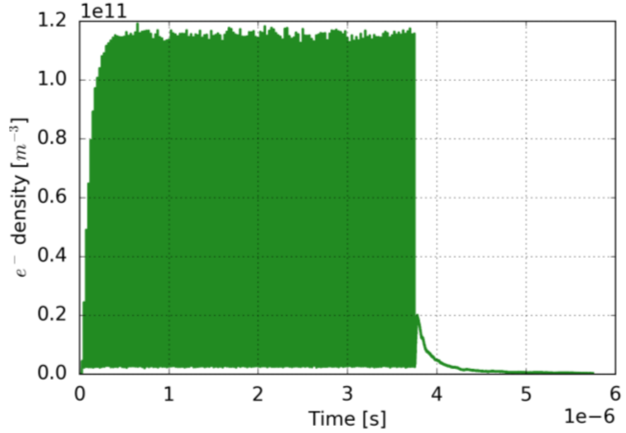
SEY=1.1



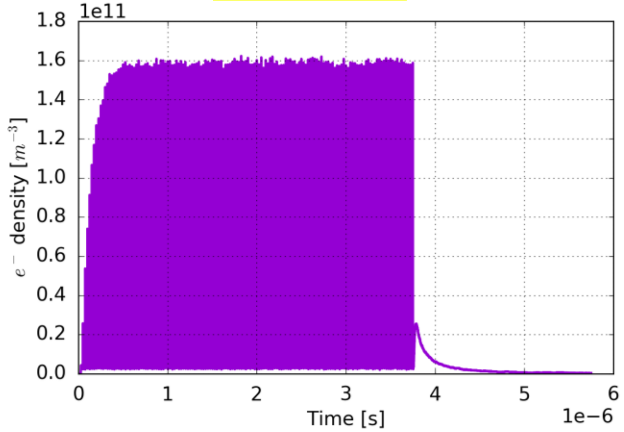
SEY=1.2



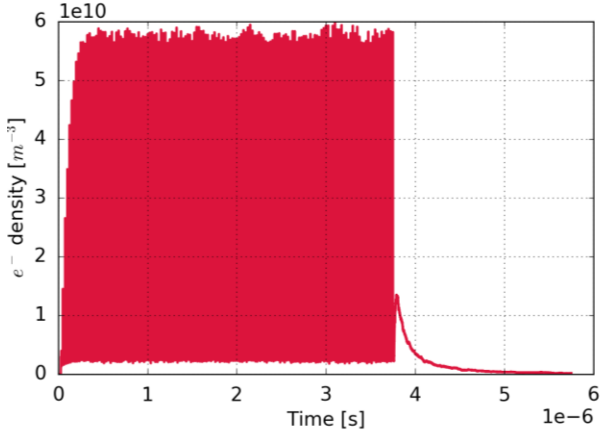
SEY=1.3



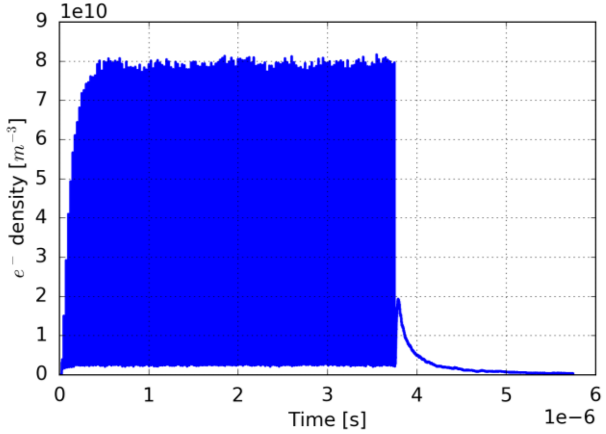
SEY=1.4



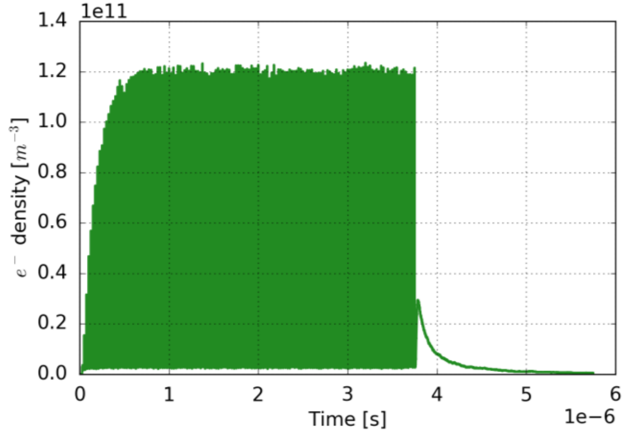
~0.84



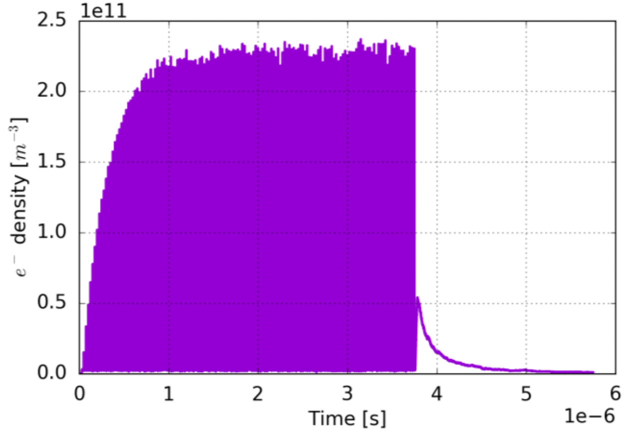
~ 0.88



~ 1



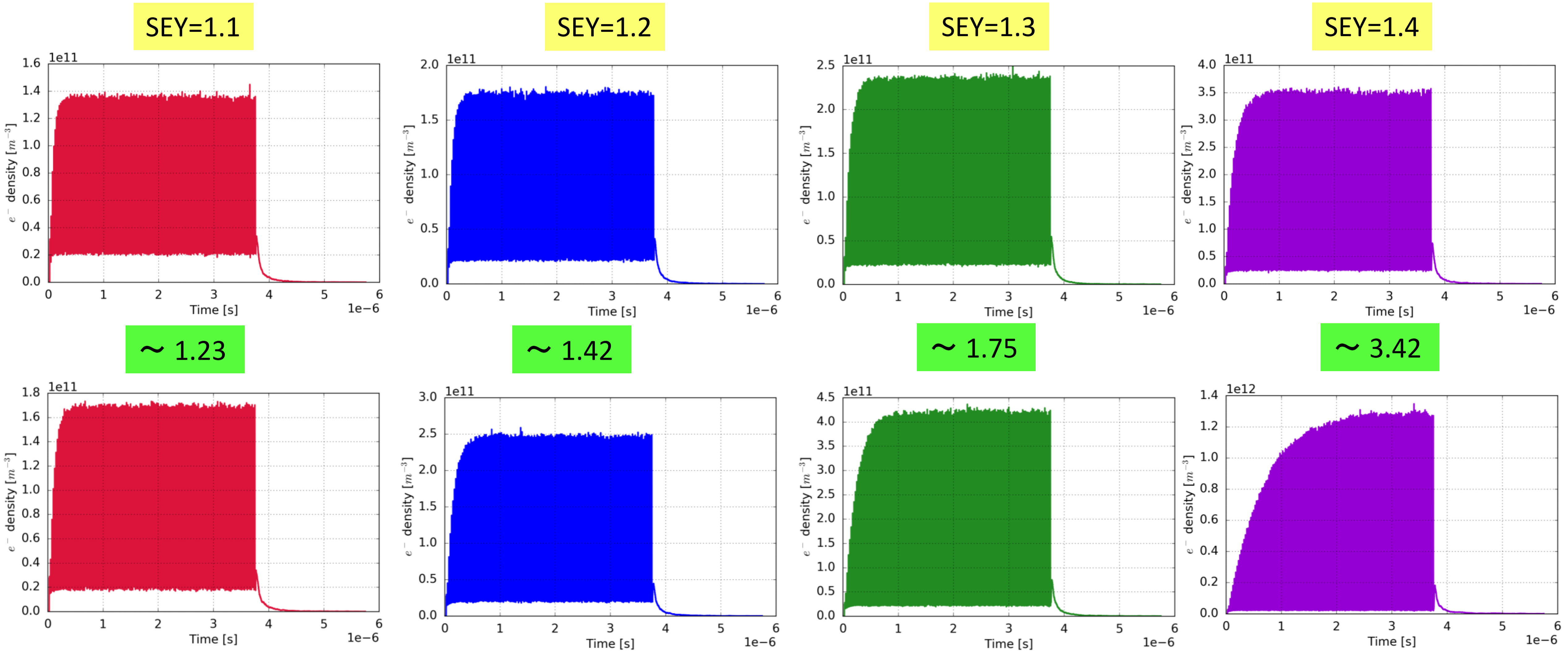
~ 1.37



Drift Region : ECLOUD Model

bunch spacing: 25 ns, $n'_{(\gamma)}$ =1e-4 m^{-1}

r = 30mm (first row) , r = 35mm (second row)

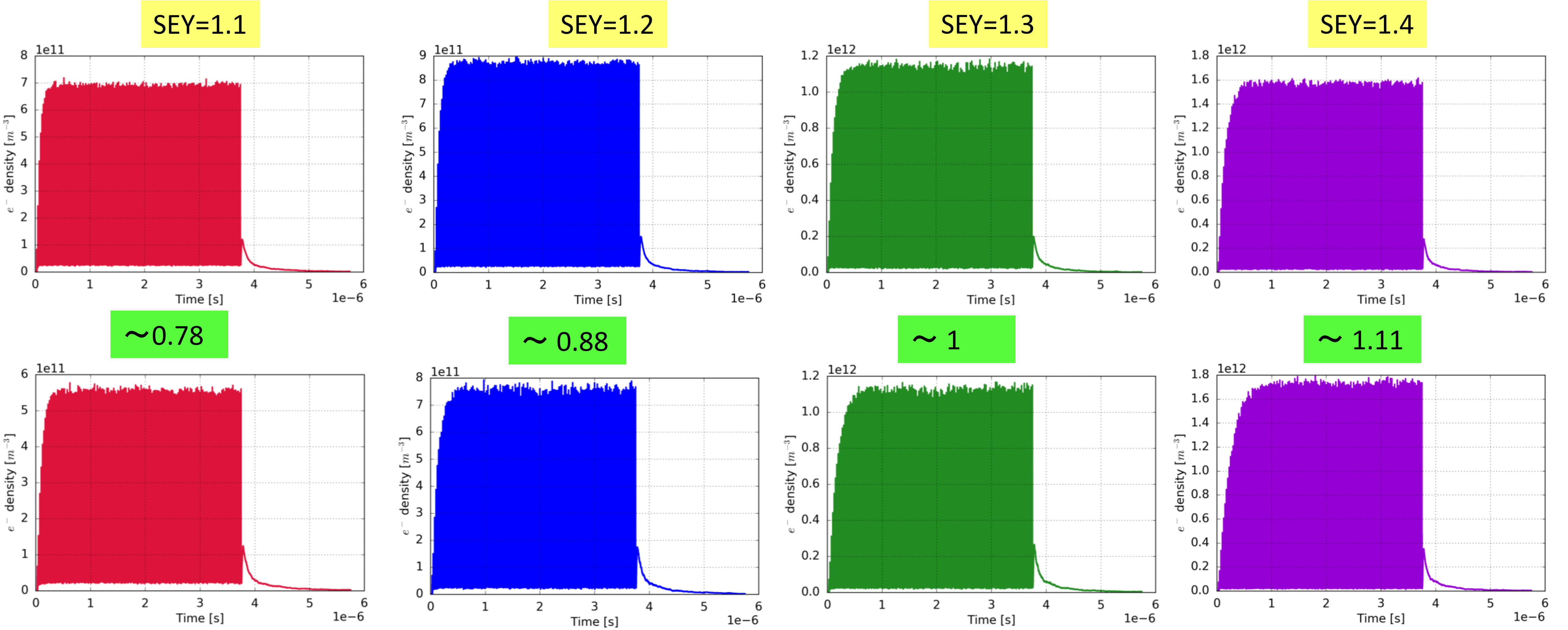


Dipole Region: ECLOUD Model

bunch spacing: 25 ns, $n'_{(\gamma)}$ =1e-3 m^{-1}

r = 30mm (first row) , r = 35mm (second row)

SEY=1.1 | SEY=1.2 | SEY=1.3 | SEY=1.4

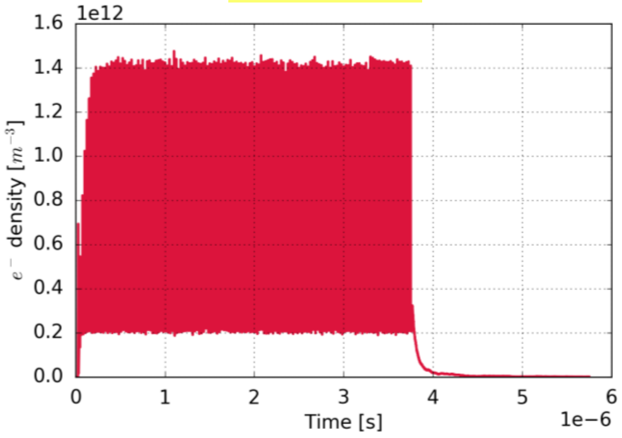


Drift Region : ECLOUD Model

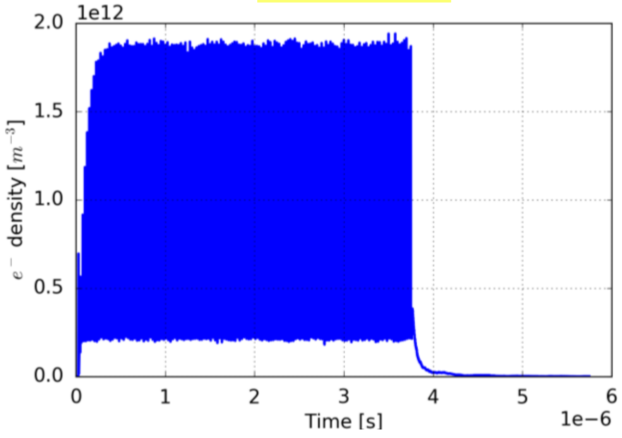
bunch spacing: 25 ns, $n'_{(\gamma)}$ =1e-3 m^{-1}

r = 30mm (first row) , r = 35mm (second row)

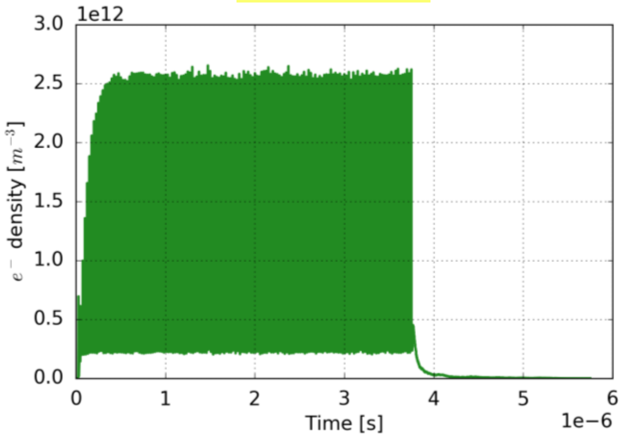
SEY=1.1



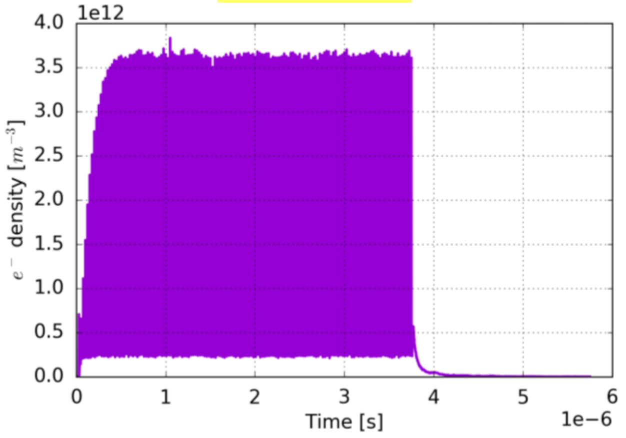
SEY=1.2



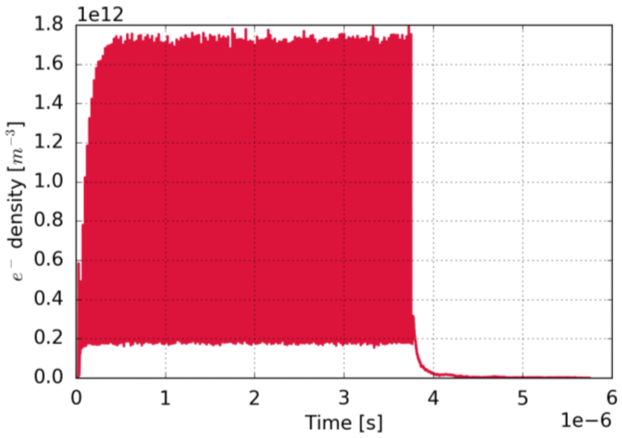
SEY=1.3



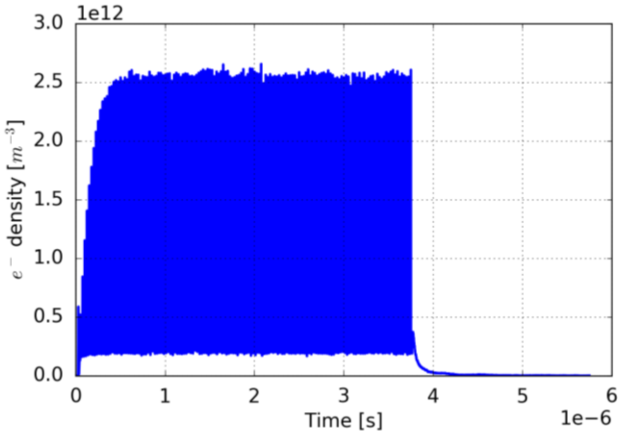
SEY=1.4



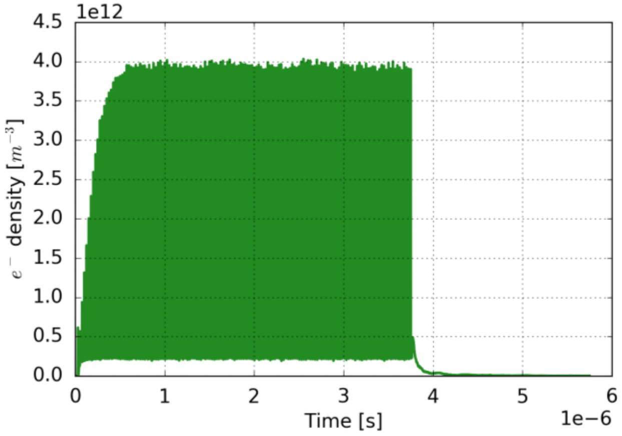
~ 1.21



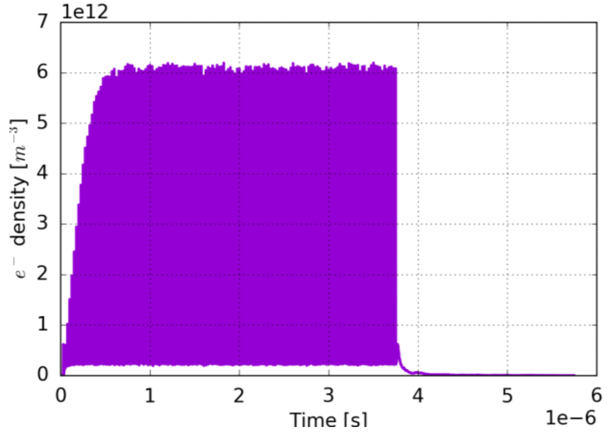
~ 1.38



~ 1.6



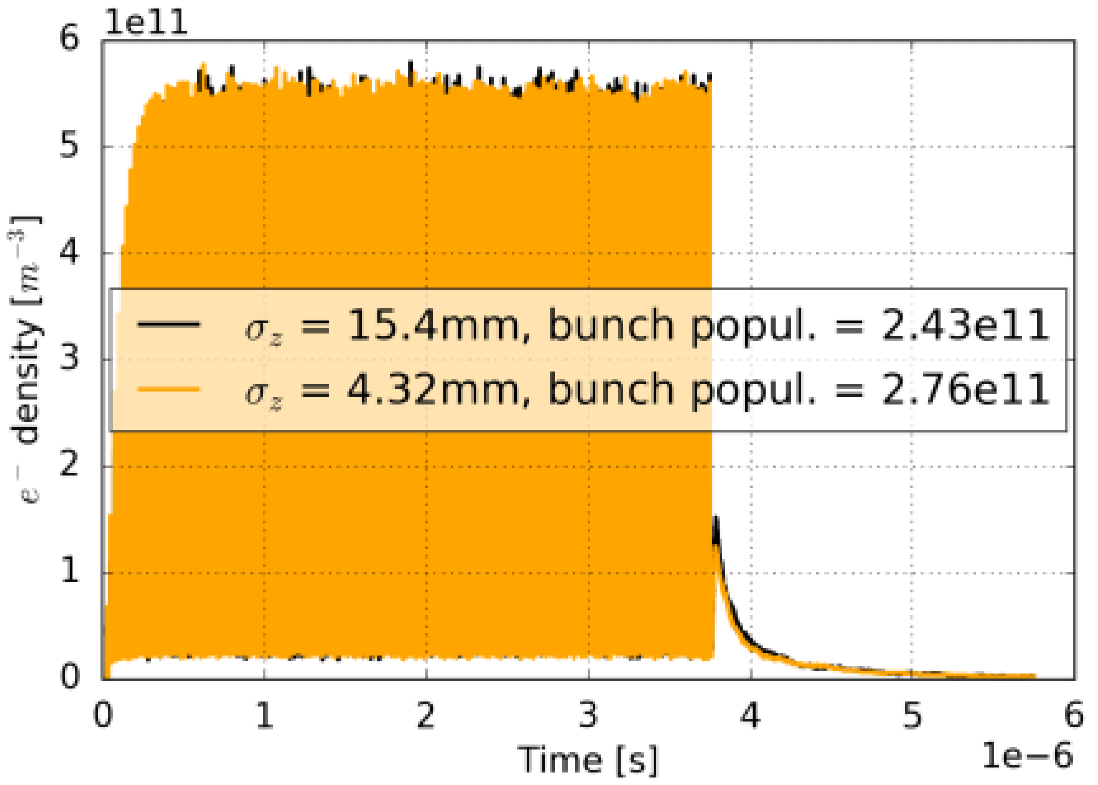
~ 1.69

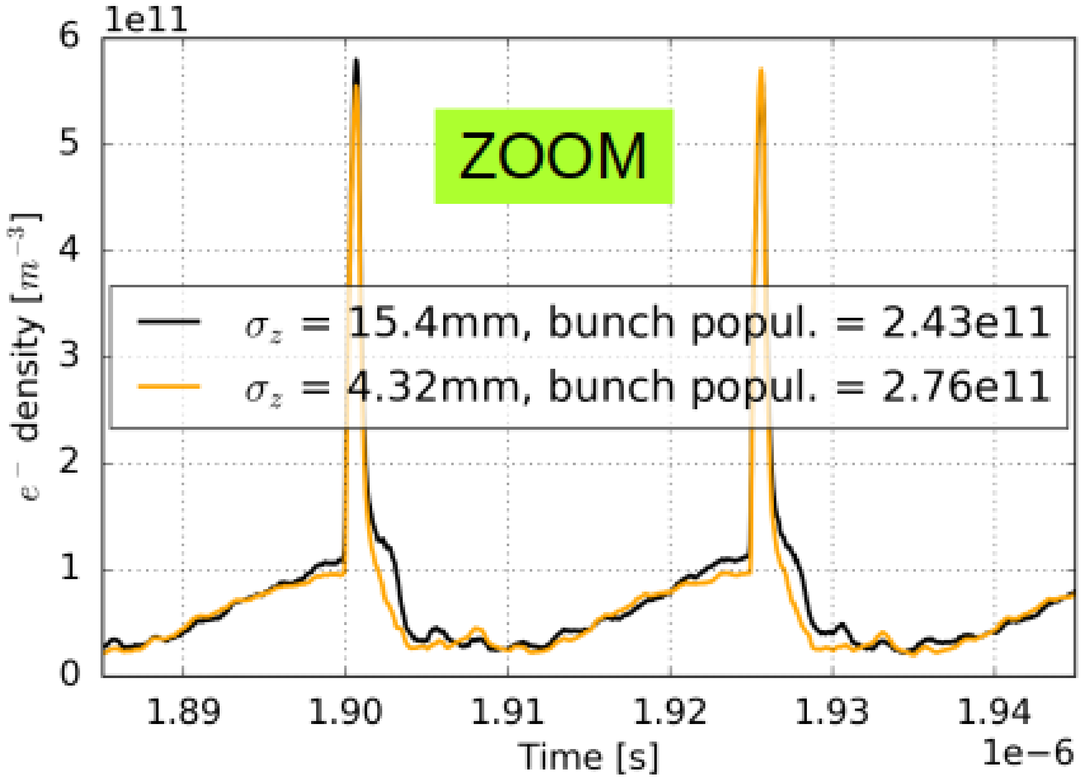


Dipole region

ECLOUD SEY Model

SEY =1.1 , $n'_{(\gamma)}$ =1e-3 m^{-1} , bunch spacing: 25 ns, r = 35mm

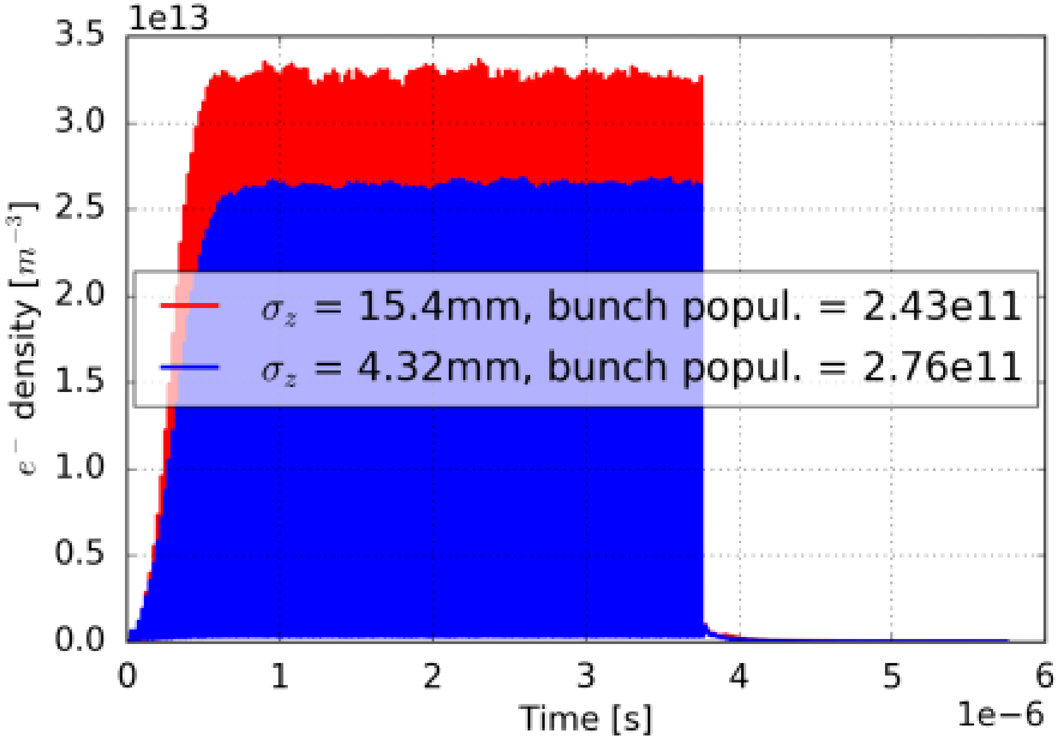


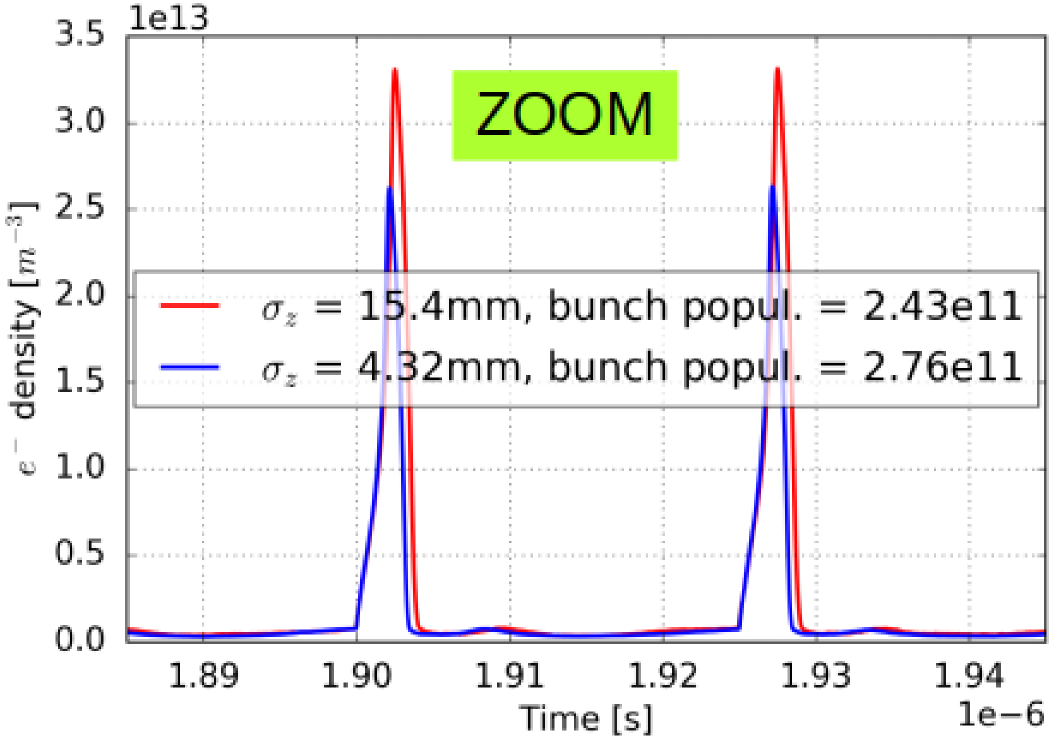


Drift Region

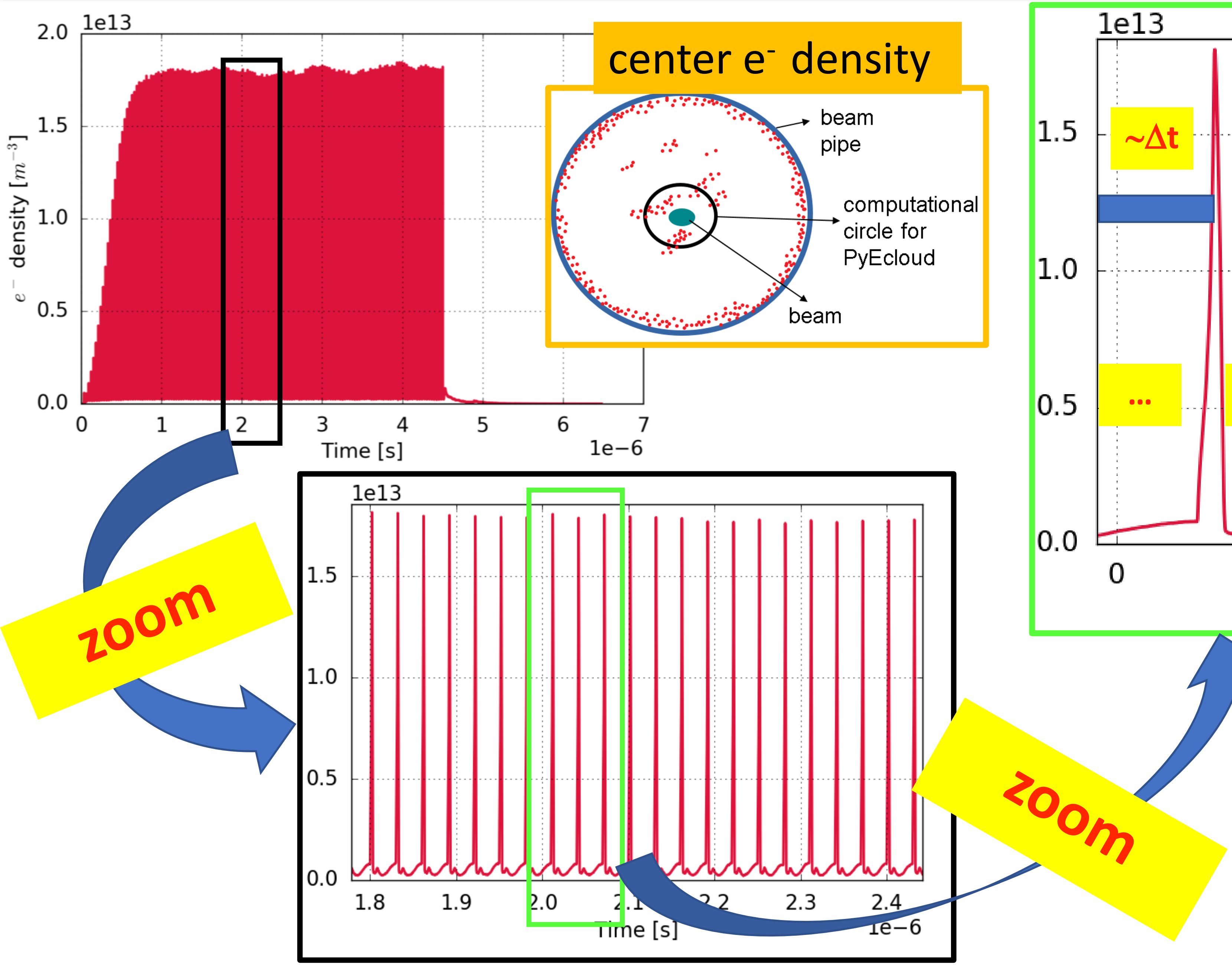
Furman-Pivi SEY Model

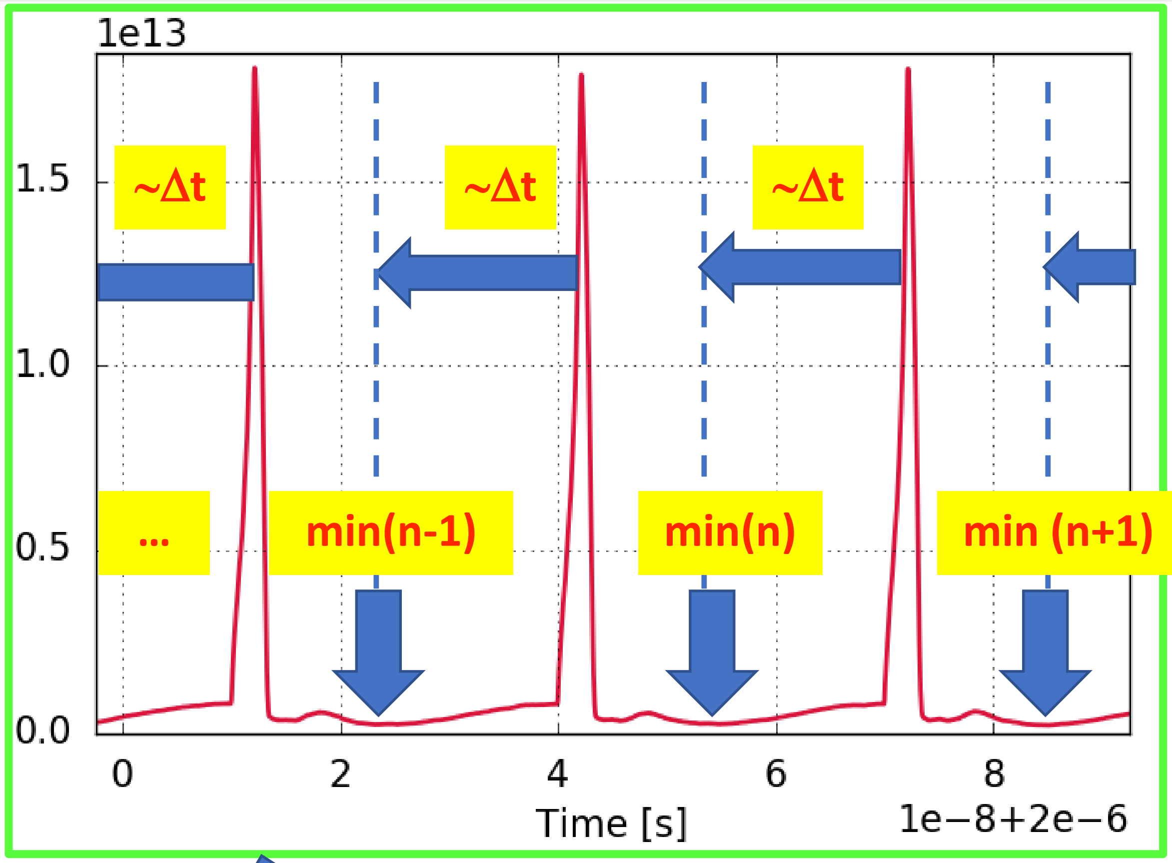
SEY =1.4 , $n'_{(\gamma)}$ =1e-3 m^{-1} , bunch spacing: 25 ns, r = 35mm





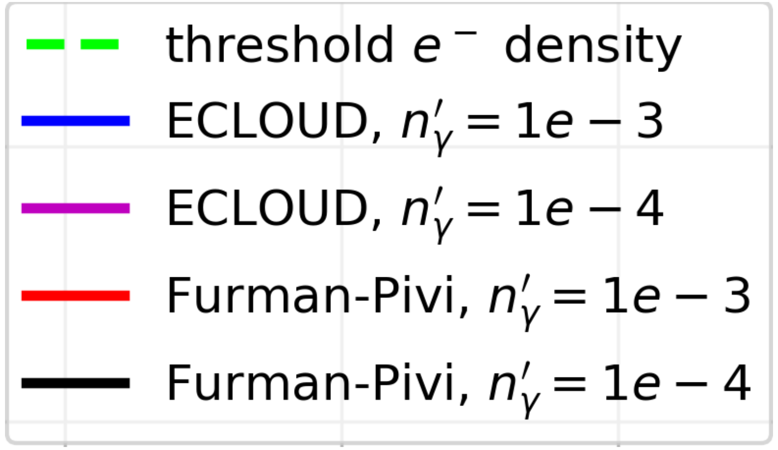
Average of min.'s for center electron density





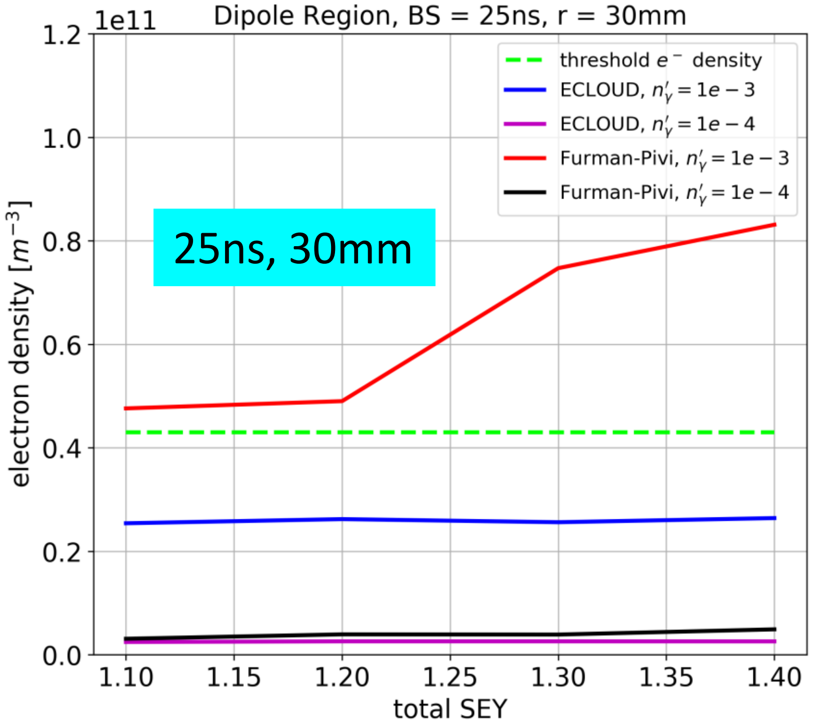
- max = 1.75e13 m^{-3}
- min = 2.25e11 m^{-3}
- average of min= 2.52e11 m^{-3} (Δt = 15.25 ns)

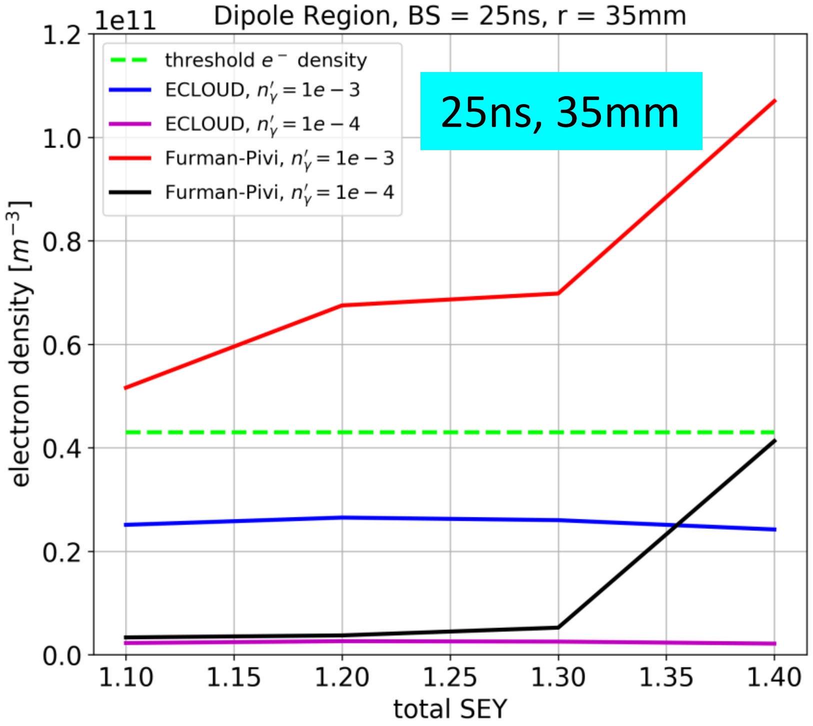
Dipole Region

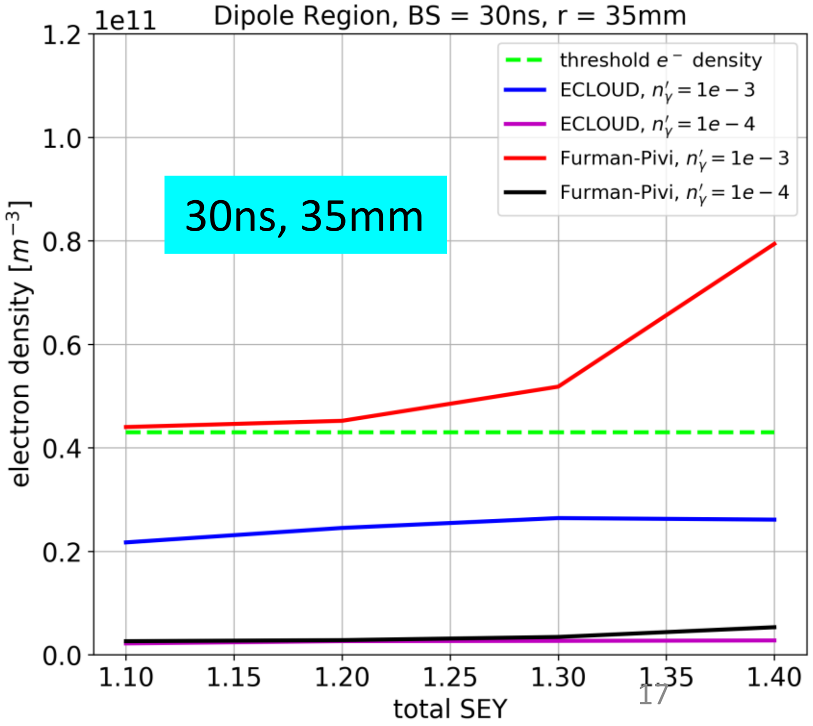


- Furman-Pivi Model
- $n'_{(\gamma)}$ = 1e-3 m^{-1}
- r = (30, 35) mm
- BS=(25, 30) ns
- SEY=(1.1,1.2,1.3,1.4)

- Furman-Pivi Model
- $n'_{(\gamma)}$ = 1e-4 m^{-1}
- r = 35 mm
- BS= 25 ns
- SEY= 1.4





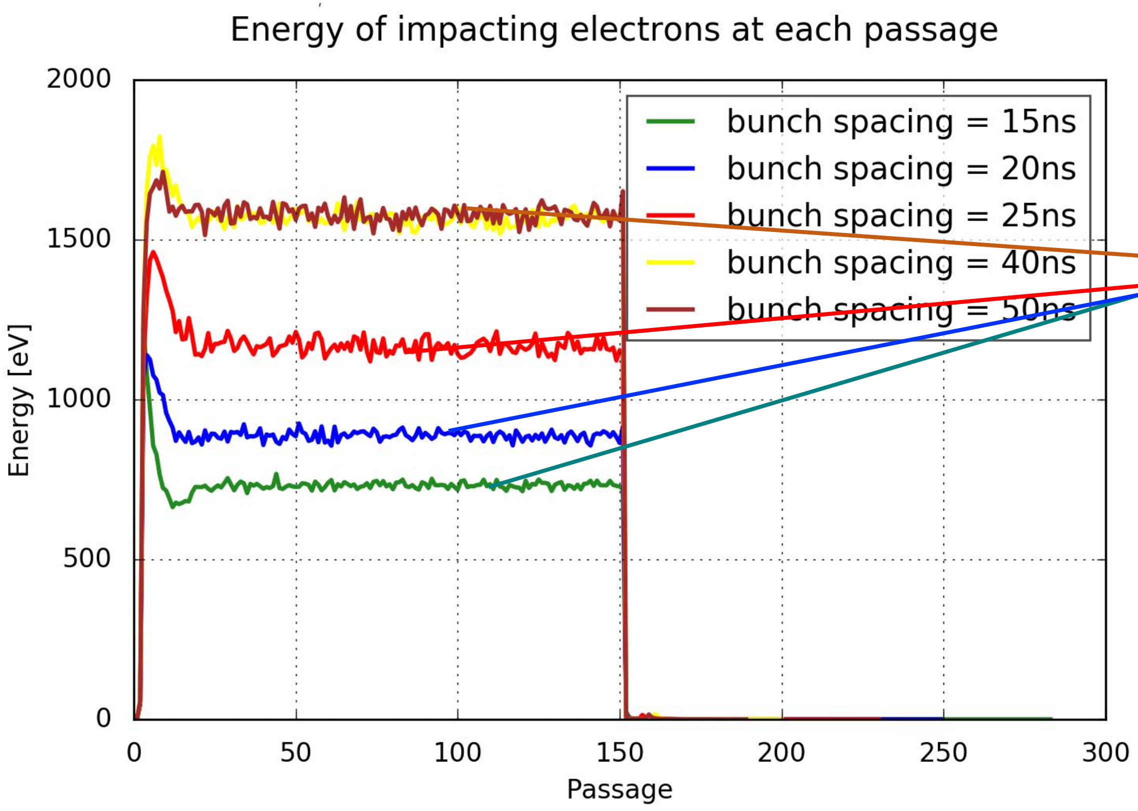


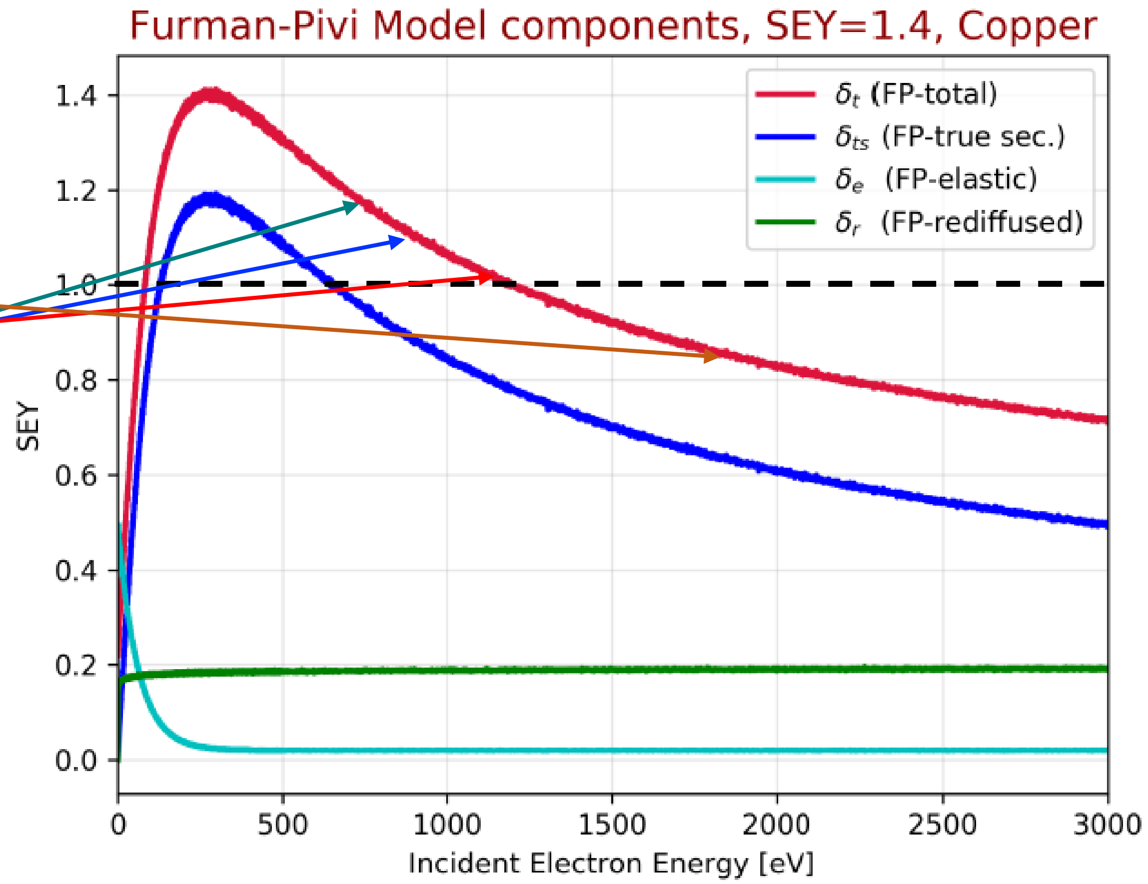
Drift Region

Furman-Pivi SEY Model

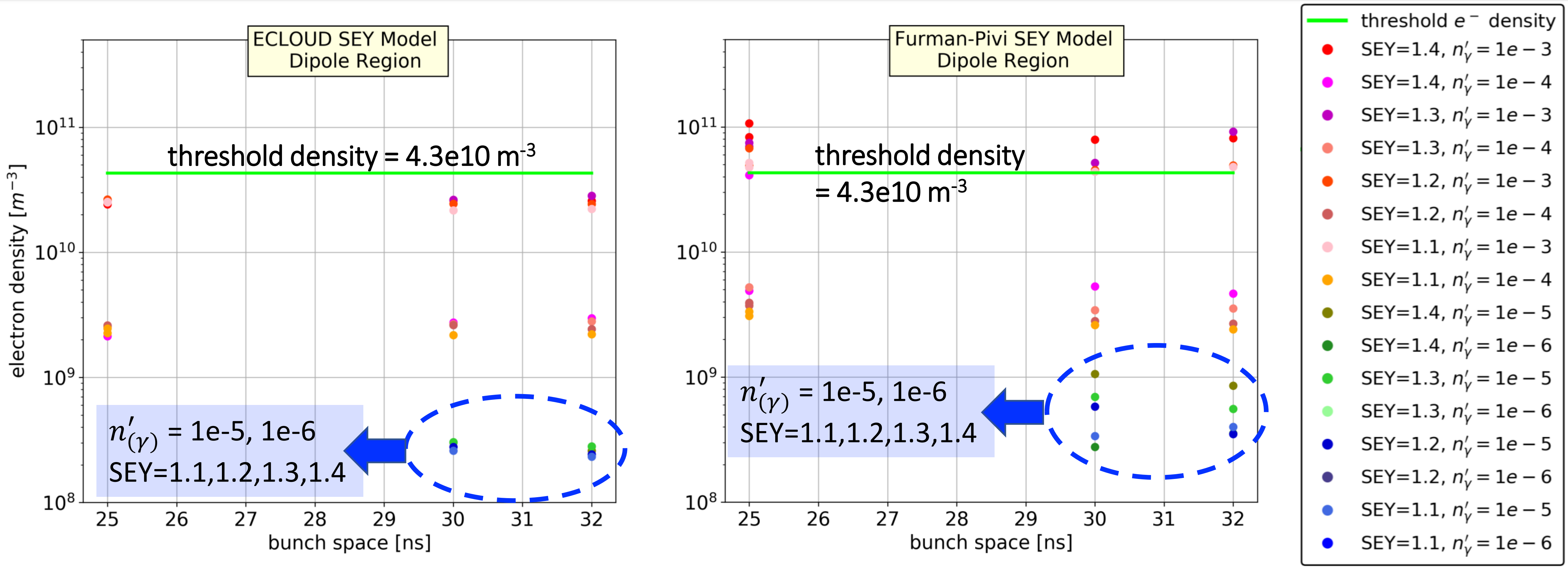
SEY =1.4 , $n'_{(\gamma)}$ =1e-3 m^{-1} , $\sigma_z = 15.4$ mm, $N_b = 2.43e11$

bunch spacing: 25 ns, r = 35mm





Dipole Region

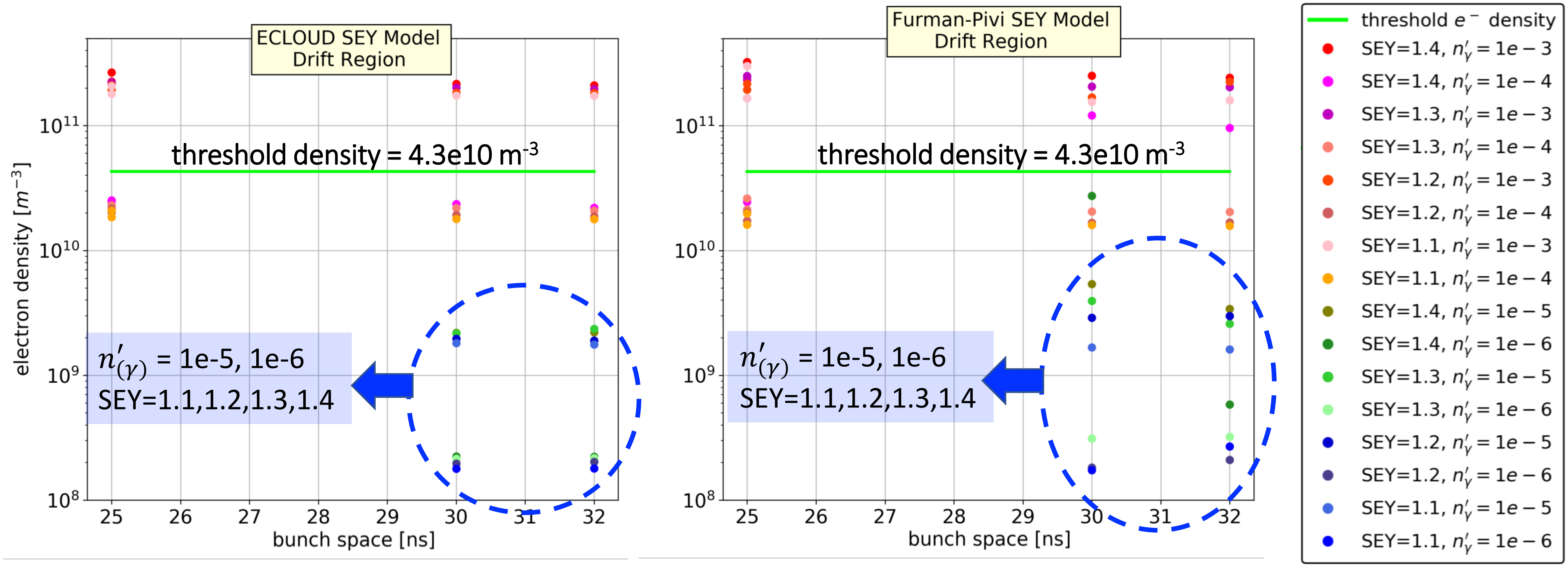


ECLOUD Model, $n'_{(\gamma)}$ = (1e-3, 1e-4, 1e-5, 1e-6)m^{-1}, r = (30, 35)mm, BS=(25, 30, 32)ns, SEY=(1.1,1.2,1.3,1.4) ☺

Furman-Pivi Model, $n'_{(\gamma)}$ < 1e-3 m^{-1}, r = (30, 35)mm, BS=(25, 30, 32)ns, SEY=(1.1,1.2,1.3,1.4) ☺

Furman-Pivi Model, $n'_{(\gamma)}$ = 1e-3 m^{-1}, r = (30, 35)mm, BS=(25, 30, 32)ns, SEY=(1.1,1.2,1.3,1.4) ☹

Drift Region



(ECLOUD, Furman-Pivi) Model, $n'_{(\gamma)}$ < 1e-3 m^{-1} , r= (30, 35)mm, BS=(25, 30, 32)ns, SEY=(1.1,1.2,1.3,1.4)

(ECLOUD, Furman-Pivi) Model, $n'_{(\gamma)}$ = 1e-3 m^{-1}, r = (30, 35)mm, BS=(25, 30, 32)ns, SEY=(1.1,1.2,1.3,1.4)

Furman-Pivi Model, $n'_{(\gamma)}$ = 1e-4, r= 35mm, BS=(25, 30, 32)ns, SEY=1.4

Conclusions and Future Plans

- reference center e- density ≌ 2e7 e-/m^3 (SEY ≌ 0 and $n'_{(\gamma)}$ = 1e-6 m^{-1})

- bunch spacing = 32ns, SEY = 1.1, $n'_{(\gamma)}$ = 1e-6 m^{-1}:
  - e- density ≌ 2.5 times lower in dipole compared to drift
  - max. density ≌ 5e8 e$^-$/m^3 is verified with both models

- In Drift region e- density increases with the increase of pipe radius for SEY=1.1, 1.2, 1.3, 1.4
- In Dipole region
  - e- density decreases with the increase of pipe radius for SEY=1.1 and 1.2
  - e- density increases with the increase of pipe radius for SEY=1.3 and 1.4

- For SEY=1.1 photoelectrons dominates the Ecloud formation

- $n'_{(\gamma)}$ < 1e-3 m^{-1} is necessary to keep average minimums lower than the estimated threshold for considered scope of parameters in dipole & drift regions

- $n'_{(\gamma)}$ < 1e-5 m^{-1} leads to 'safe-zone'

- Wake & Impedance calculations due Electron Clouds

- Simulations with the measured SEY data

THANK YOU FOR ATTENTION!

fatihyaman@iyte.edu.tr
Fatih.Yaman@stfc.ac.uk