FUTURE
CIRCULAR
COLLIDER

FCC-ee ELECTRON CLOUD & VACUUM

ELECTRON CLOUD SIMULATIONS FOR ARC QUADRUPOLES

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FCC-ee MACHINE AND BEAM PARAMETERS

FCC-ee machine and beam parameters

Parameter name	Value
Beam energy [GeV]	45.6
Bunch spacing [ns]	10, 12.5, 15, 17.5, 20
Bunches per train	150
Trains per beam	1
Secondary emission yield	1.1, 1.2, 1.3, 1.4
R.M.S. bunch length (σ_z) [mm]	3.5
R.M.S. beam size (σ_x) [μm]	120
R.M.S. beam size (σ_y) [μm]	7
Chamber type	Circular, circular with winglets
Beam pipe radius [mm]	35
Magnetic field [T/m]	5.65
Photoelectrons generation rate (n_γ)	3.5e-5, 1e-6

Table 1. Parameters used for simulations. Source: ‘Electron cloud buildup in the collider: towards lower density’, Yaman 2020.

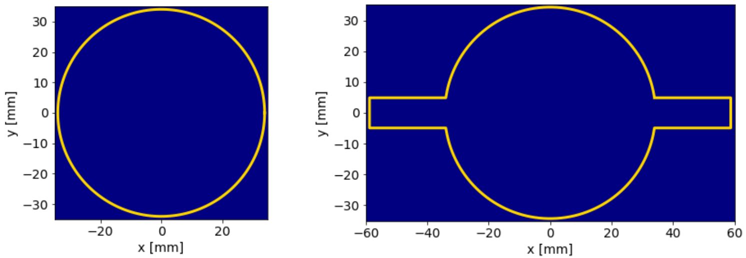


Figure 1. Circular chamber and chamber with winglets

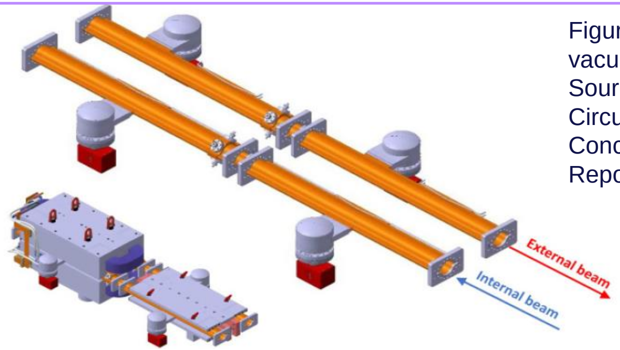
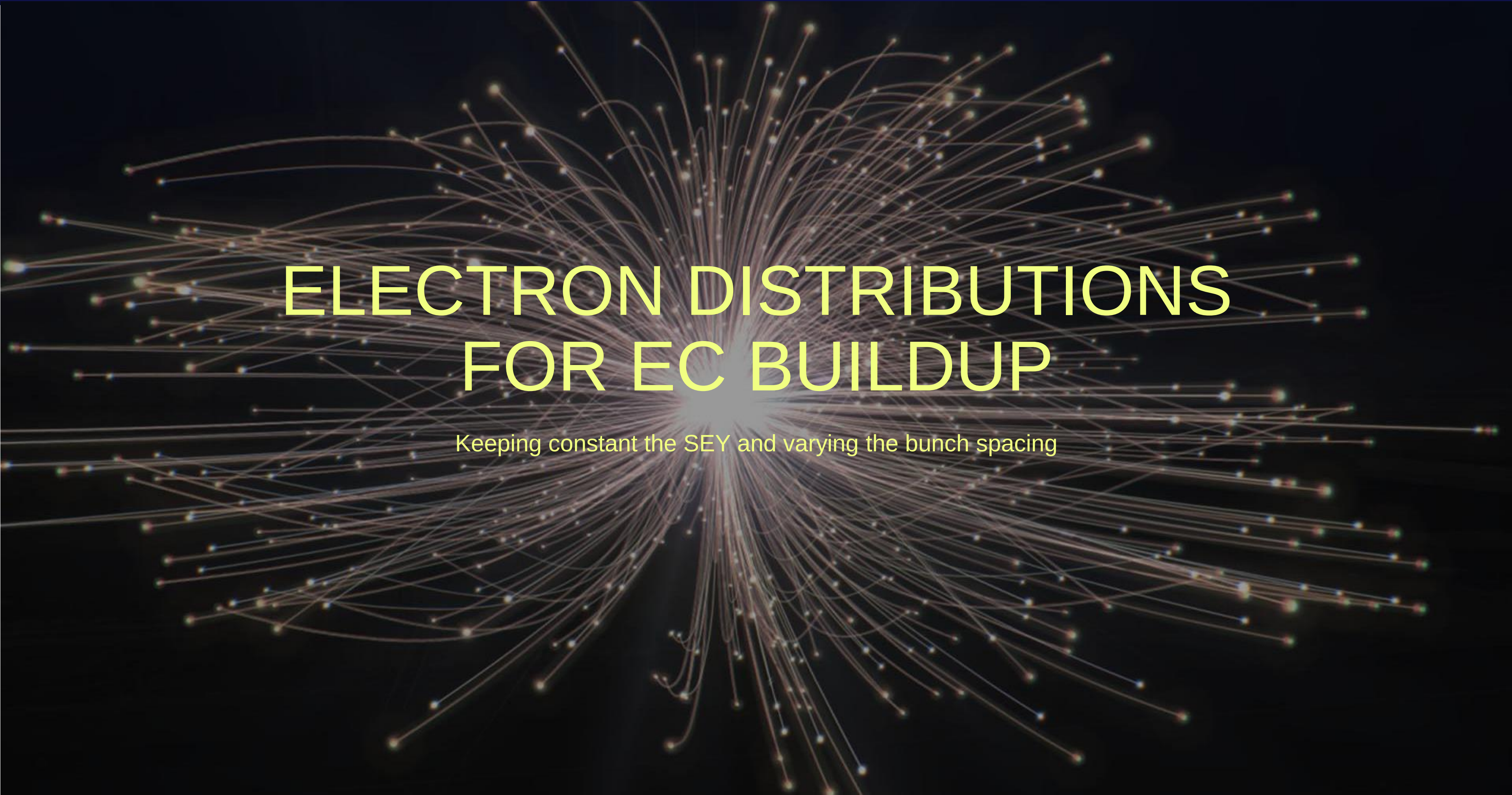


Figure 2. FCC-ee vacuum system. Source: ‘Future Circular Collider Conceptual Design Report’, CERN 2019.

Number of simulations → $5 \times 4 \times 2 \times 2 = 80$



ELECTRON DISTRIBUTIONS FOR EC BUILDUP

Keeping constant the SEY and varying the bunch spacing

Variation of bunch spacing using: SEY = 1.1 | $\eta_\gamma = 3.5e\text{-}5, 1e\text{-}6$

$\eta_\gamma = 3.5e\text{-}5$

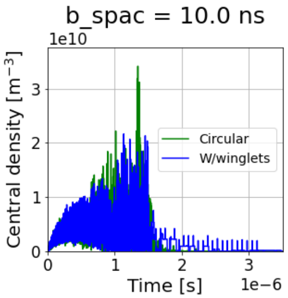
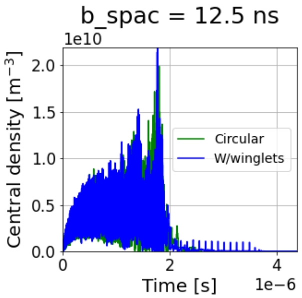


Figure 3



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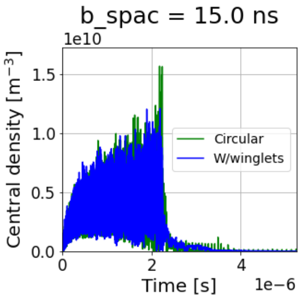

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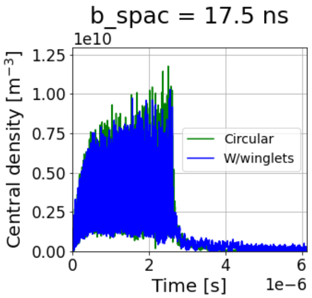

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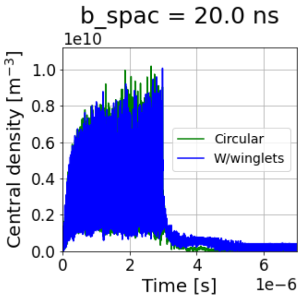
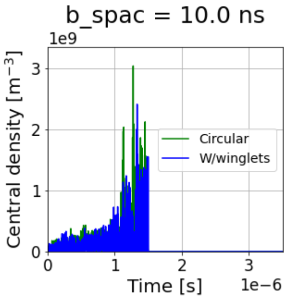


Figure 7

$\eta_\gamma = 1e\text{-}6$



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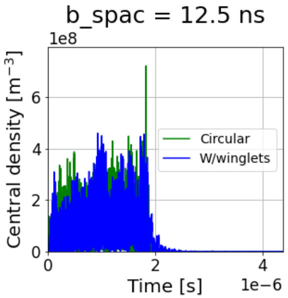

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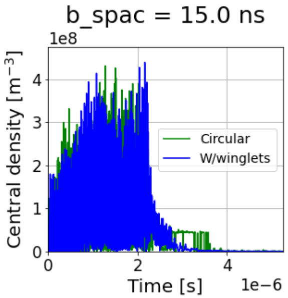

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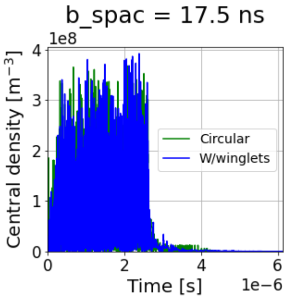

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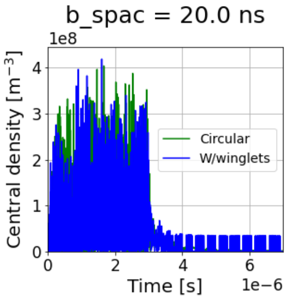
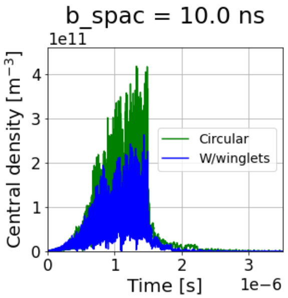


Figure 12

Variation of bunch spacing using: SEY = 1.2 | $\eta_\gamma = 3.5e\text{-}5,\ 1e\text{-}6$

$\eta_\gamma = 3.5e\text{-}5$



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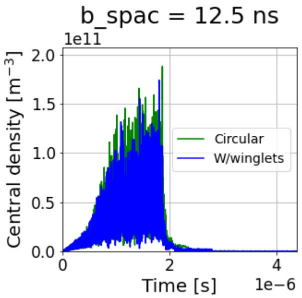

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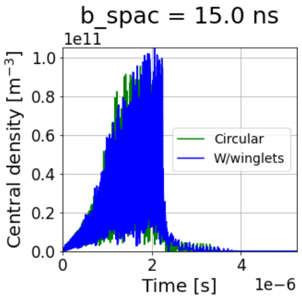

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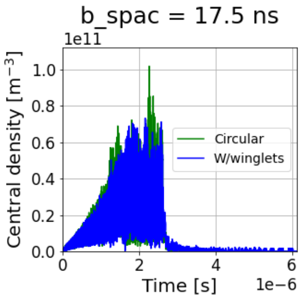

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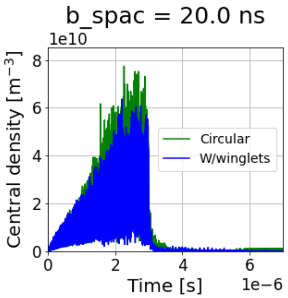
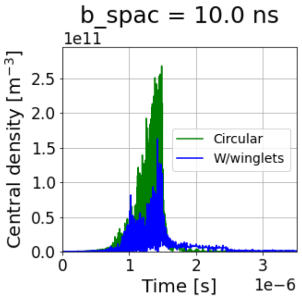


Figure 17

$\eta_\gamma =$ 1e-6



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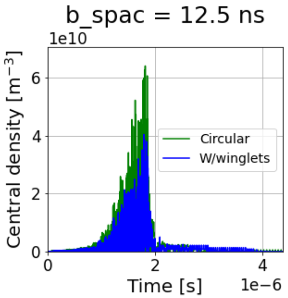

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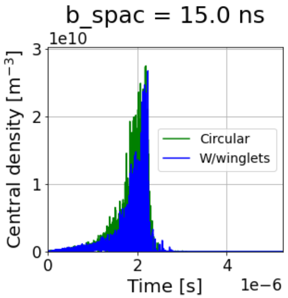

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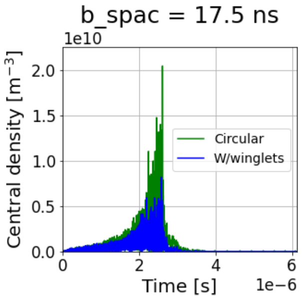

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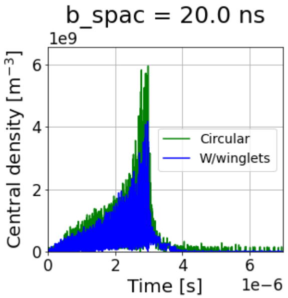
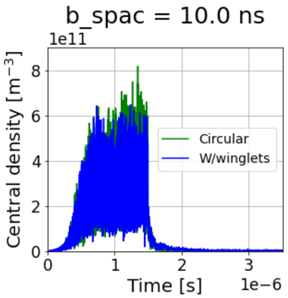


Figure 22

Variation of bunch spacing using: SEY = 1.3 | $\eta_\gamma = 3.5e\text{-}5, 1e\text{-}6$

$\eta_\gamma = 3.5e\text{-}5$



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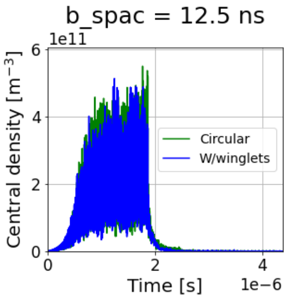

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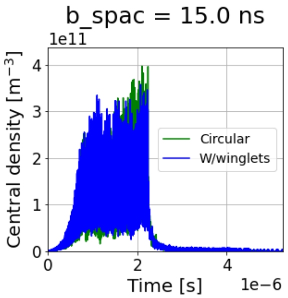

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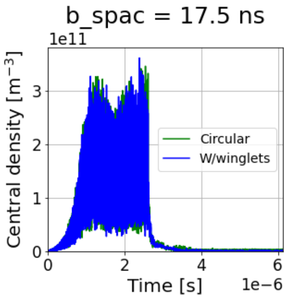

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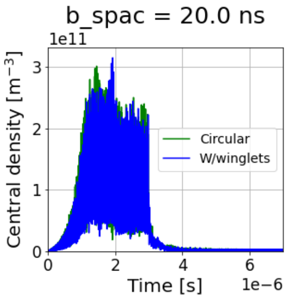
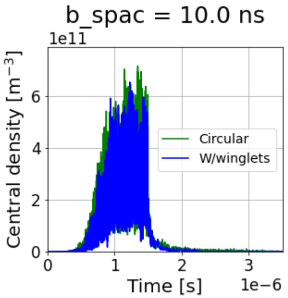


Figure 27

$\eta_\gamma = 1e\text{-}6$



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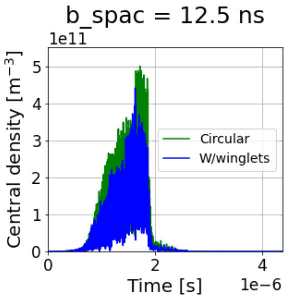

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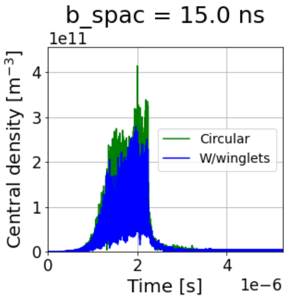

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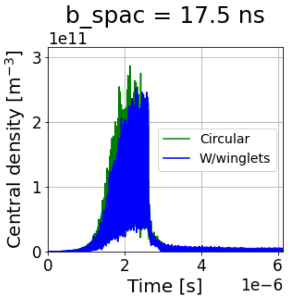

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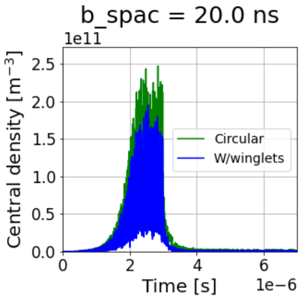
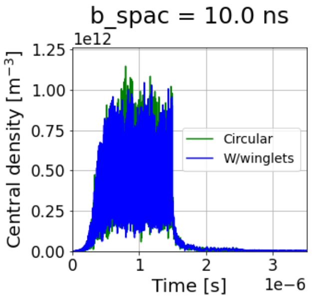


Figure 32

Variation of bunch spacing using: SEY = 1.4 | $\eta_\gamma = 3.5\text{e-}5$, 1e-6

$\eta_\gamma = 3.5\text{e-}5$



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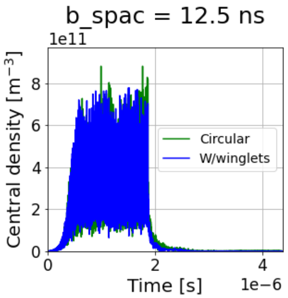

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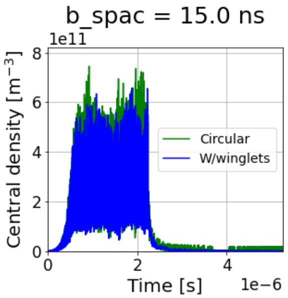

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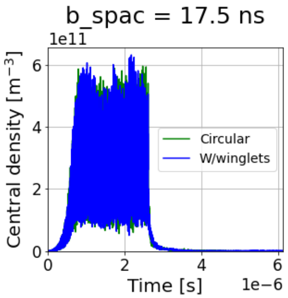

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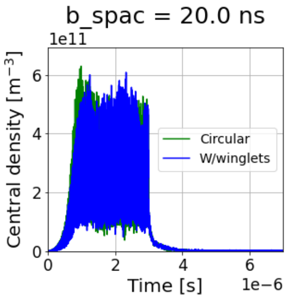
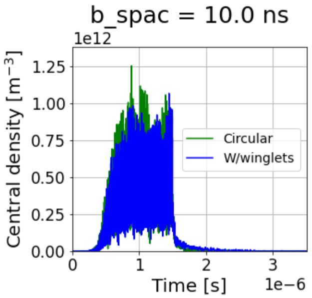


Figure 37

$\eta_\gamma =$ 1e-6



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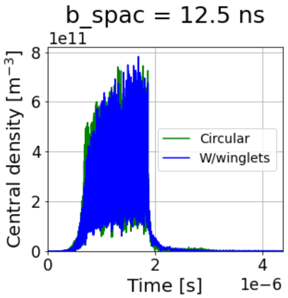

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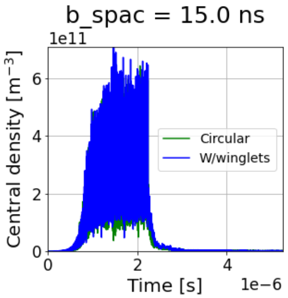

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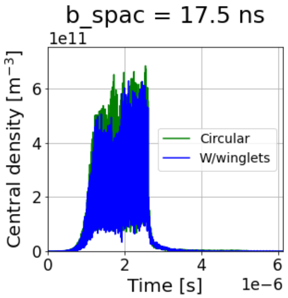

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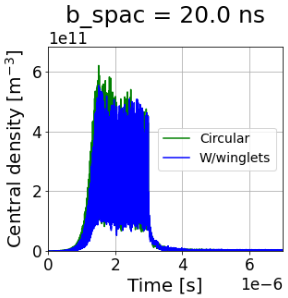


Figure 42

Summary

- Smaller bunch spacings produce higher values of electron density.
- Electron density is reduced when a circular profile vacuum chamber with winglets is used.
- There is a considerable reduction for the electron density when n_γ is decreased and SEY = 1.1, 1.2. But the form of the distribution is almost the same for both values of n_γ when SEY = 1.3, 1.4.

AVERAGE ELECTRON DENSITY

Keeping constant the SEY and varying the bunch spacing

Calculation of average electron density

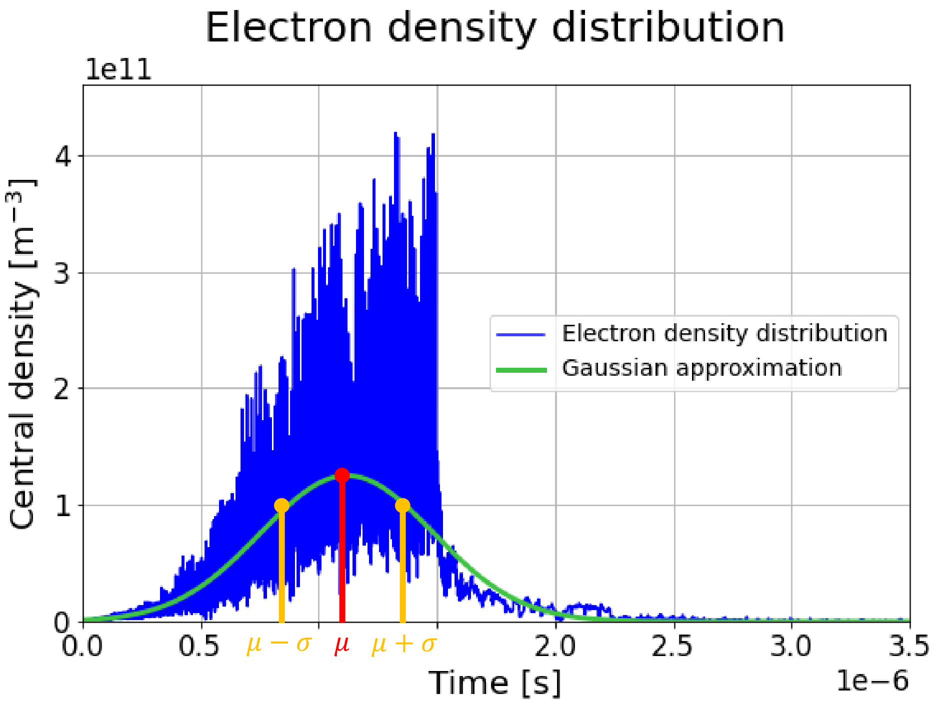


Figure 43

Gaussian approximation using a curve fit method:

$$\rho(t) = \frac{1}{2\sqrt{\sigma\pi}} \exp\left(\frac{t-\mu}{2\sigma}\right)^2$$

Where:

- $\rho(\mu) \rightarrow$ average e- density

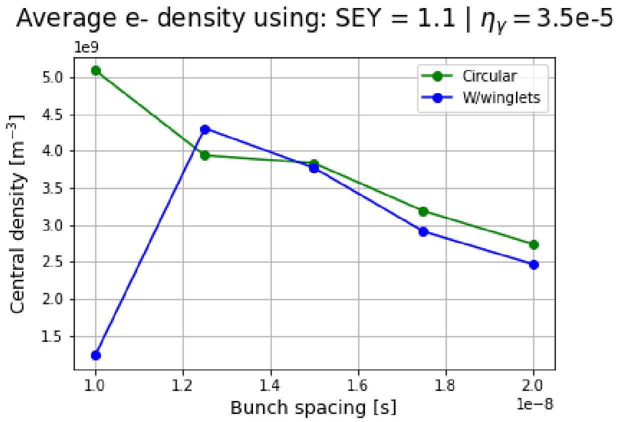


Figure 44. Average e- density for figures 3 to 7

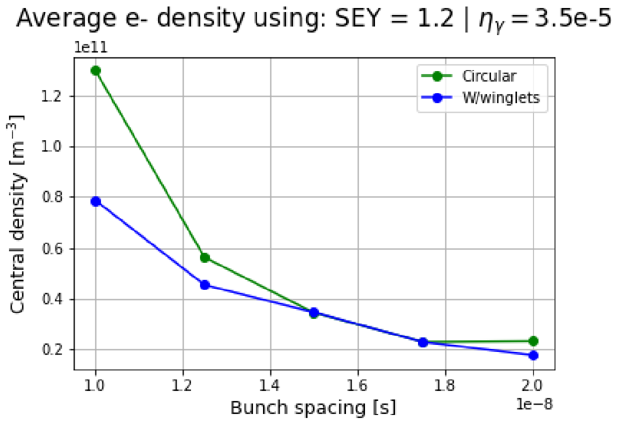


Figure 45. Average e- density for figures 13 to 17

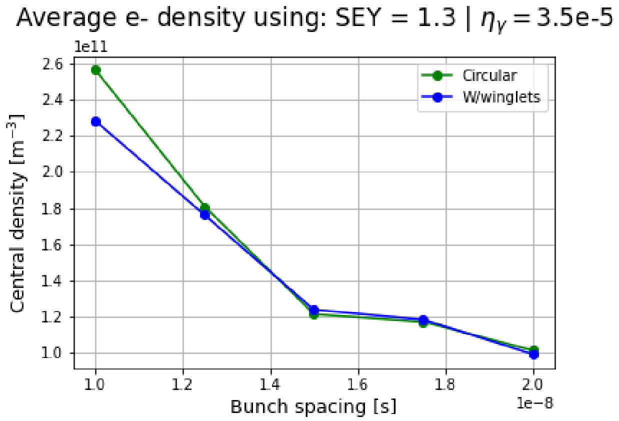


Figure 46. Average e- density for figures 23 to 27

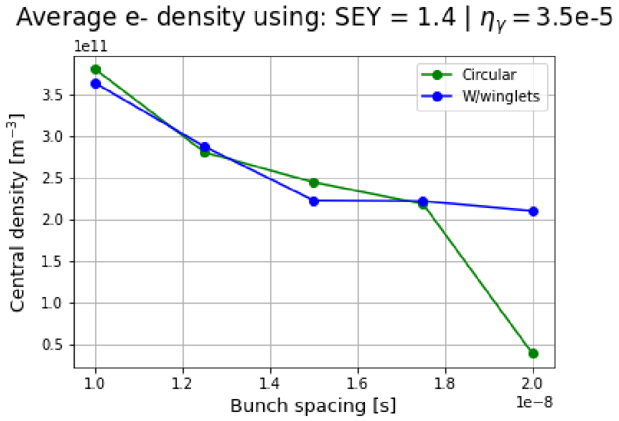


Figure 47. Average e- density for figures 33 to 37

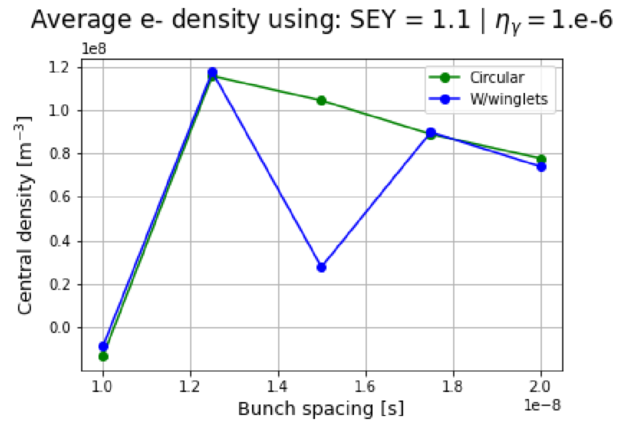


Figure 48. Average e- density for figures 8 to 12

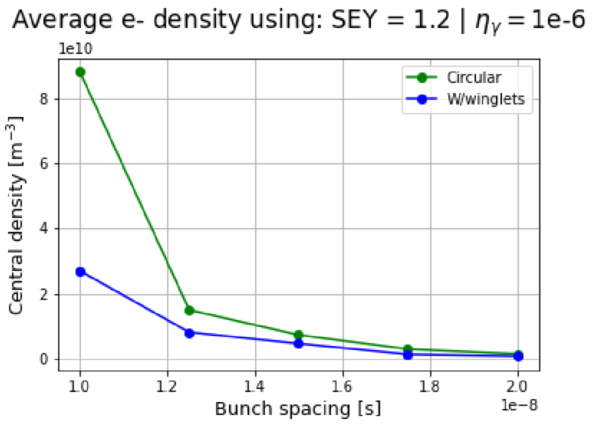


Figure 49. Average e- density for figures 18 to 22

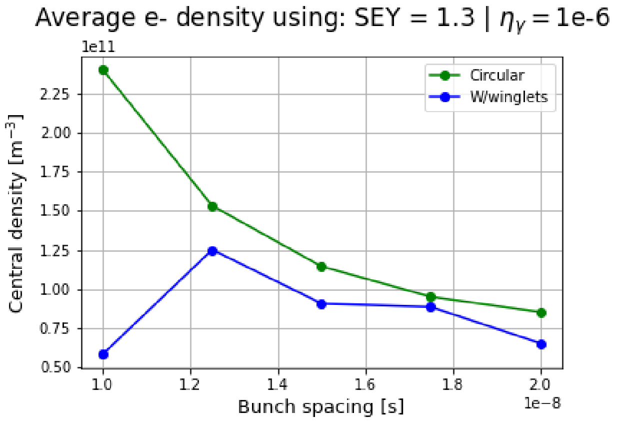


Figure 50. Average e- density for figures 28 to 32

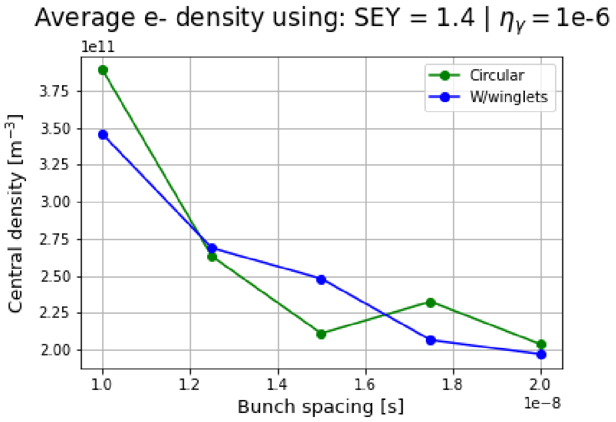


Figure 51. Average e- density for figures 38 to 42

Summary

The first two commentaries made in the previous section are corroborated with the calculation of average electron density for all the cases:

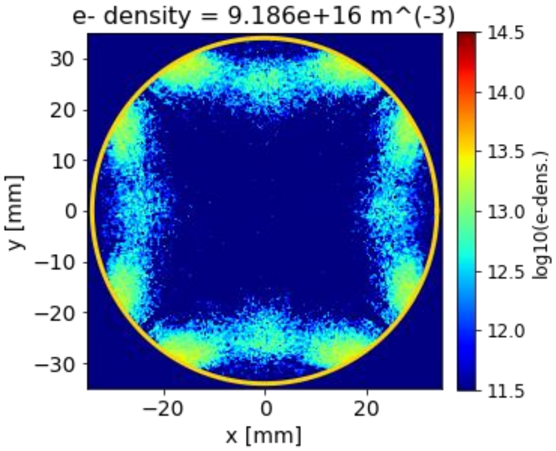
- Smaller bunch spacings produce higher values of electron density.
- Electron density is reduced when a circular profile vacuum chamber with winglets is used.

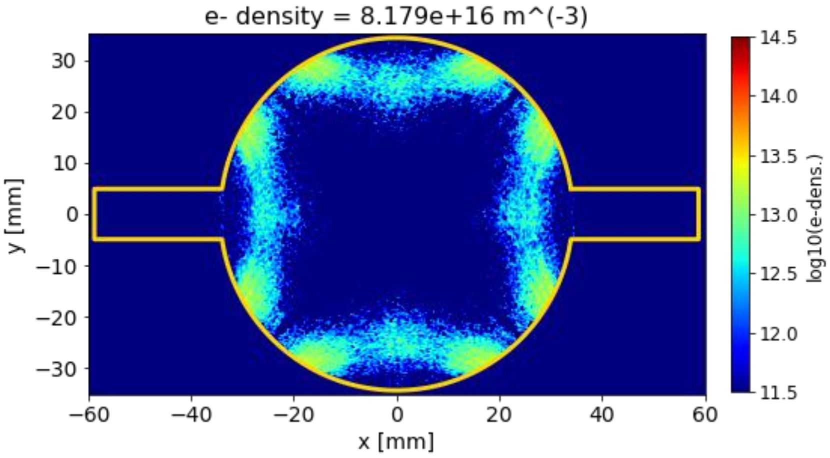
And it was proved that:

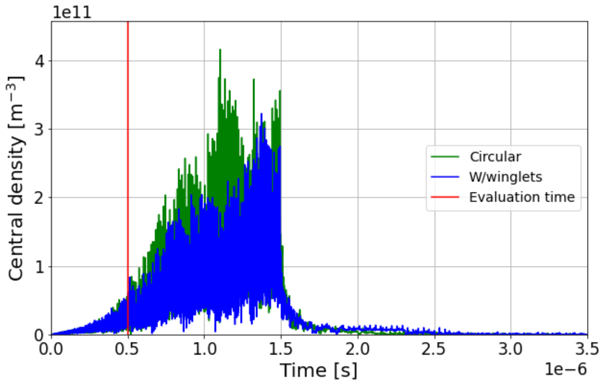
- There is a considerable reduction for the electron density when n_γ is decreased at every SEY value.

SPACE CHARGE ANALYSIS

Space charge evaluation at t = 0.5 µs

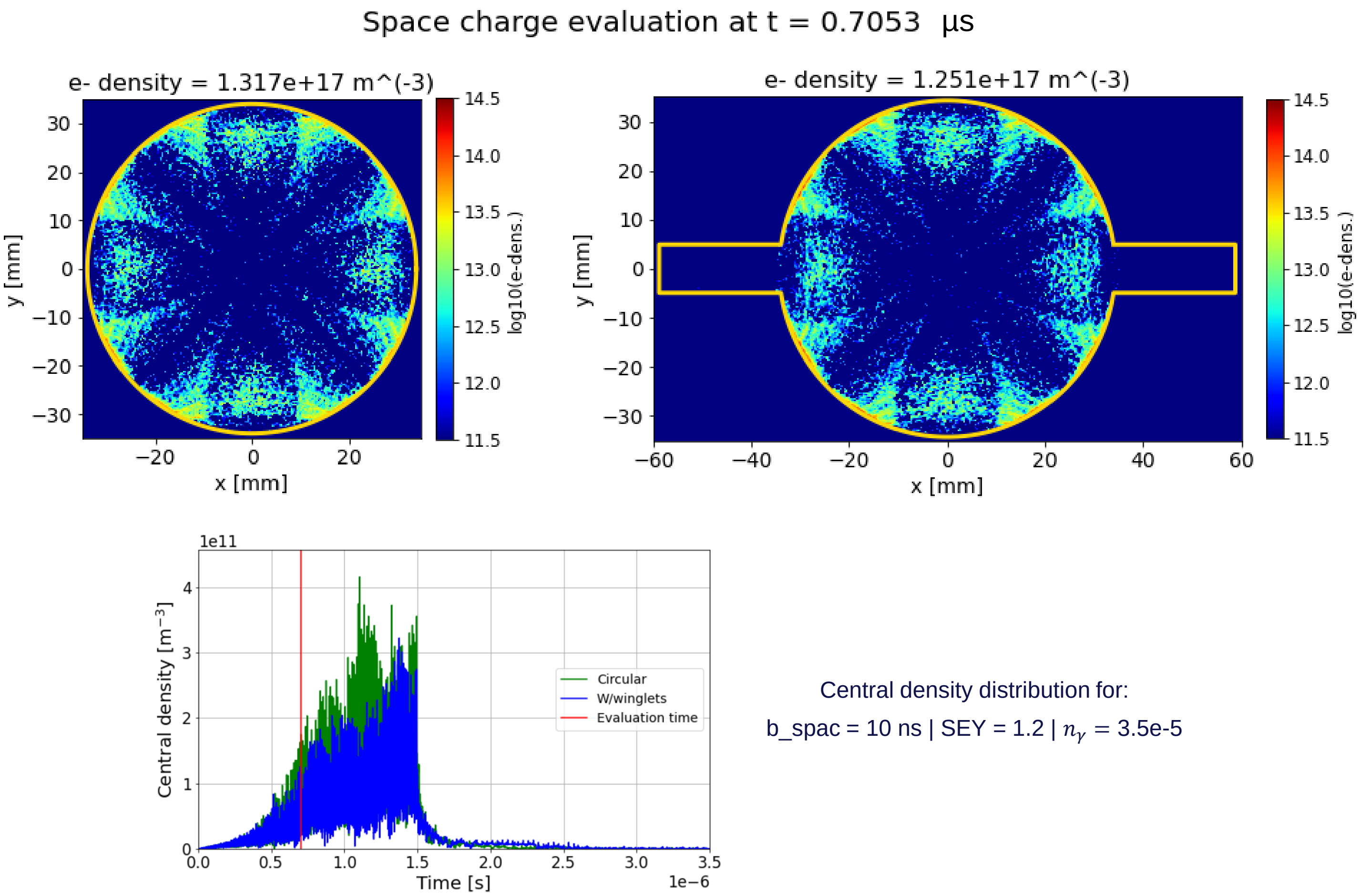






Central density distribution for:

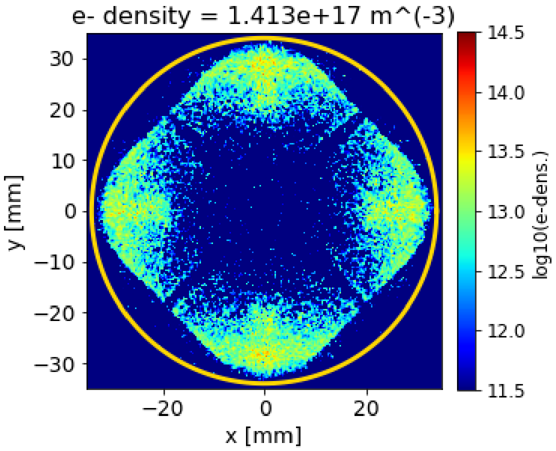
b_spac = 10 ns | SEY = 1.2 | n_γ = 3.5e-5

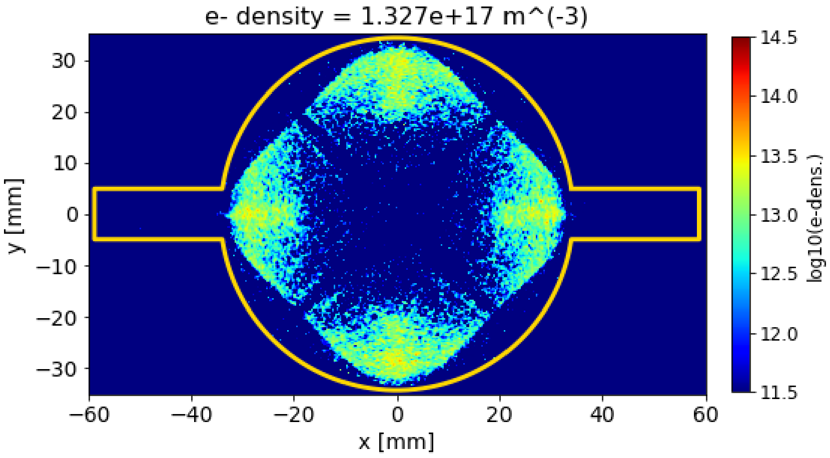


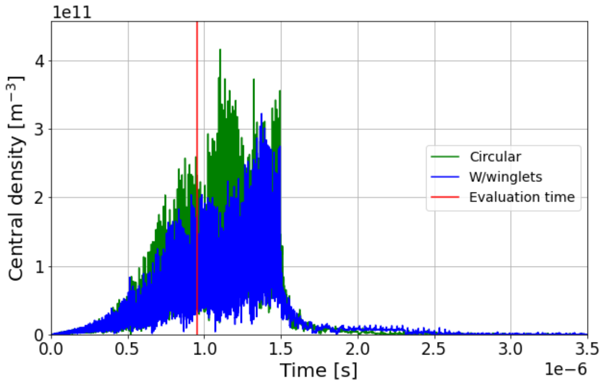
Central density distribution for:

b_spac = 10 ns | SEY = 1.2 | n_γ = 3.5e-5

Space charge evaluation at t = 0.953 µs



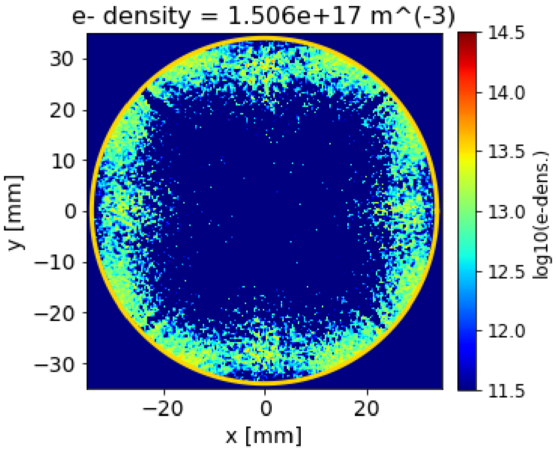


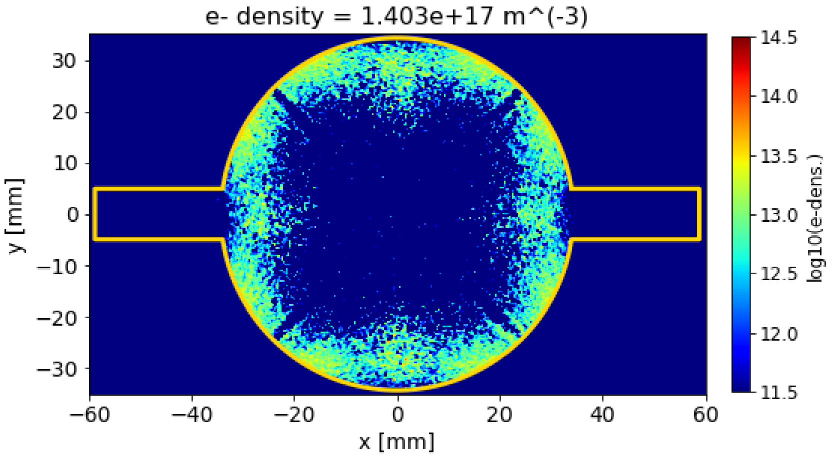


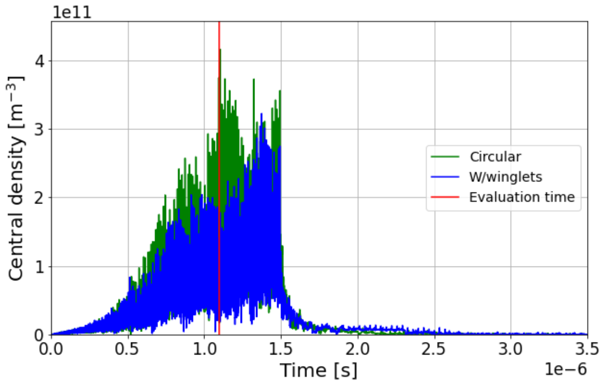
Central density distribution for:

b_spac = 10 ns | SEY = 1.2 | n_γ = 3.5e-5

Space charge evaluation at t = 1.1003 μs



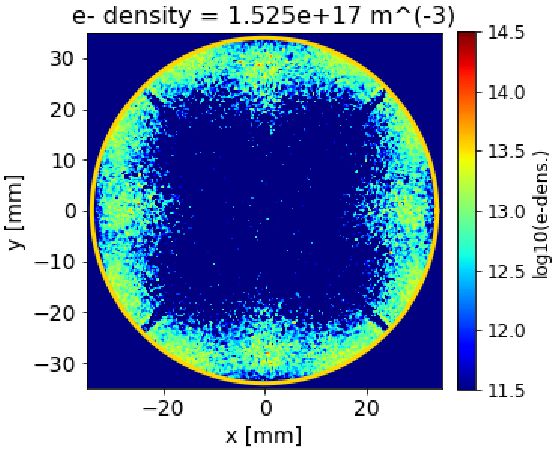


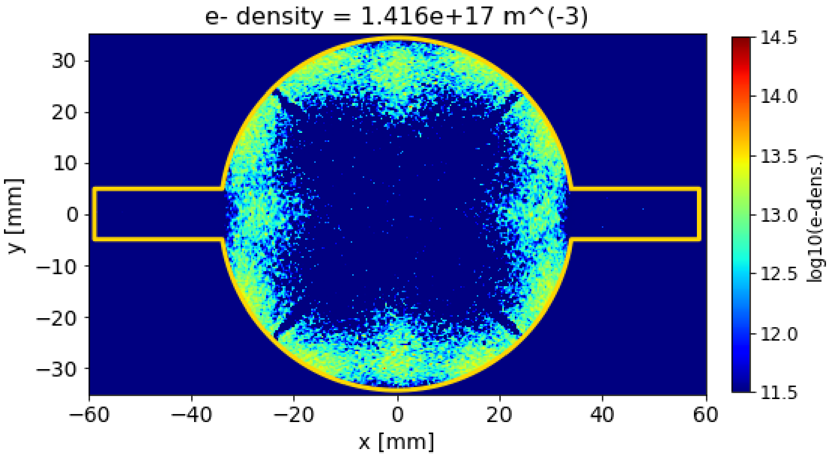


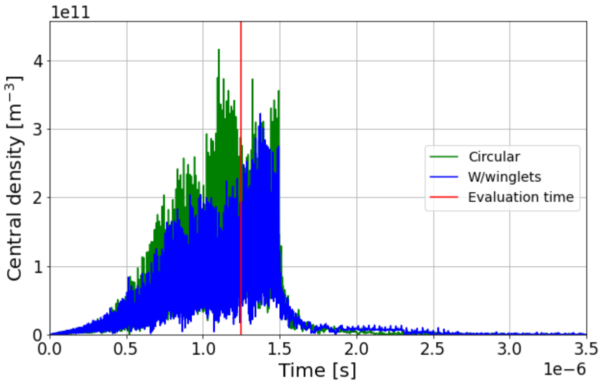
Central density distribution for:

b_spac = 10 ns | SEY = 1.2 | n_γ = 3.5e-5

Space charge evaluation at t = 1.2501 µs



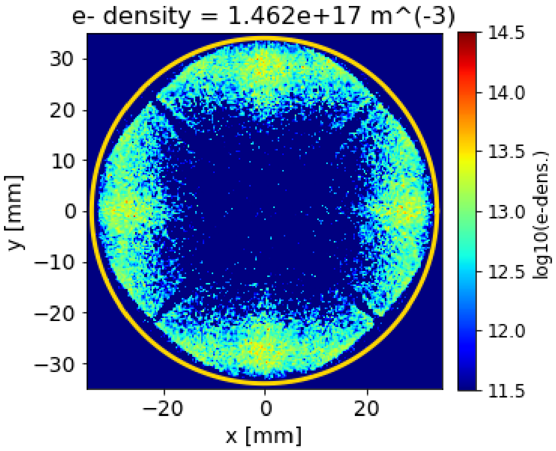


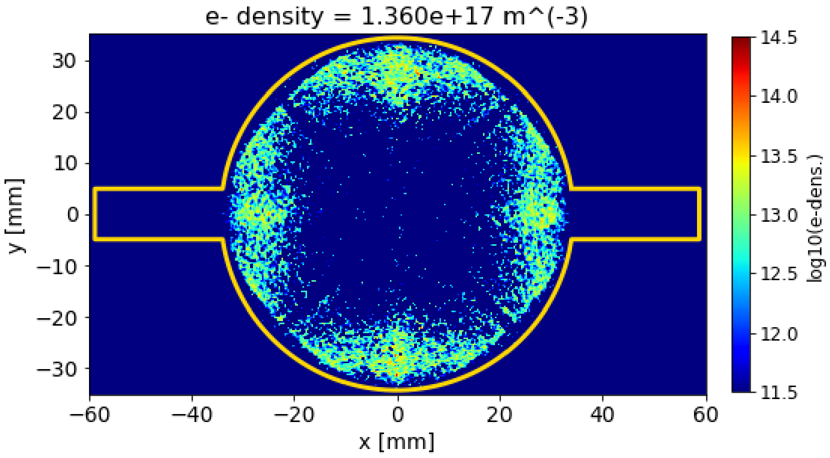


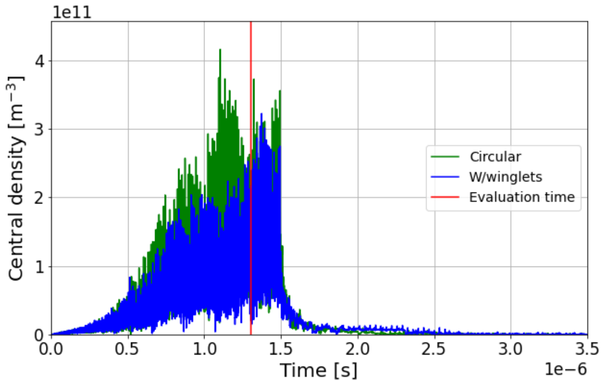
Central density distribution for:

b_spac = 10 ns | SEY = 1.2 | n_γ = 3.5e-5

Space charge evaluation at t = 1.3027 μs







Central density distribution for:

b_spac = 10 ns | SEY = 1.2 | n_γ = 3.5e-5

Summary

- Electron density is reduced when a circular profile vacuum chamber with winglets is used.
- The effect of the winglets is hardly noticeable in space charge plots, but the numbers show that there is a reduction of approximately 7% in electron density when this geometry is used.

Thank you for your attention.

ELECTRON DISTRIBUTIONS FOR EC BUILDUP

Keeping constant the bunch spacing and varying the SEY

Variation of SEY using: b_spac = 10.0 ns | $\eta_\gamma =$ 3.5e-5, 1e-6

$\eta_\gamma =$ 3.5e-5

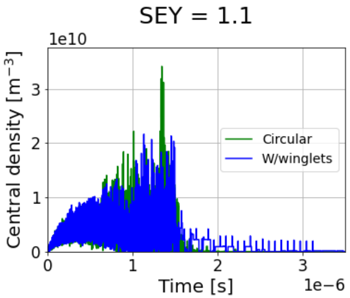


Figure 52

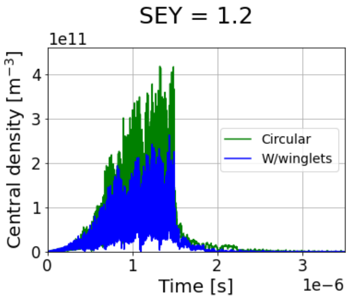


Figure 53

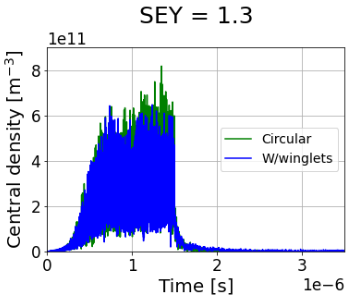


Figure 54

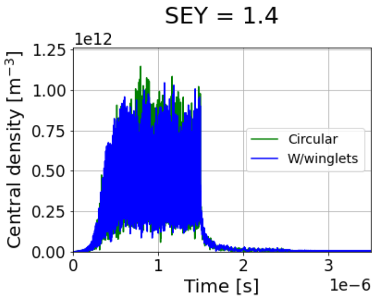


Figure 55

$\eta_\gamma =$ 1e-6

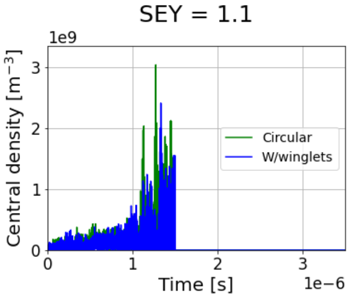


Figure 56

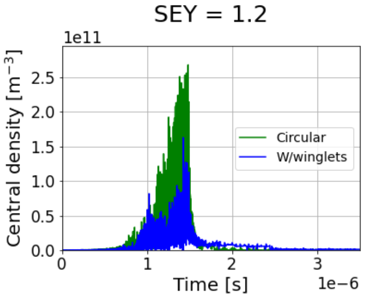


Figure 57

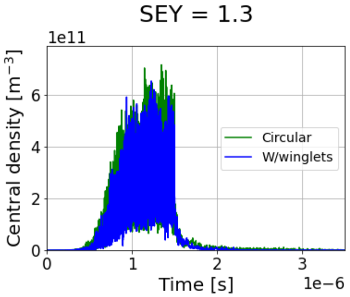


Figure 58

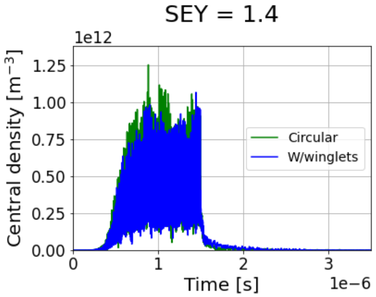


Figure 59

Variation of SEY using: b_spac = 12.5 ns | $\eta_\gamma =$ 3.5e-5, 1e-6

$\eta_\gamma = 3.5\text{e-}5$

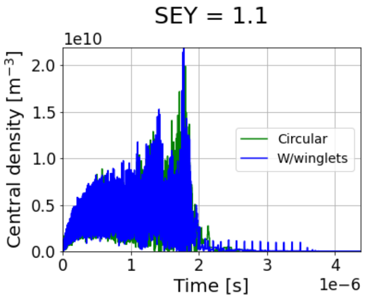


Figure 60

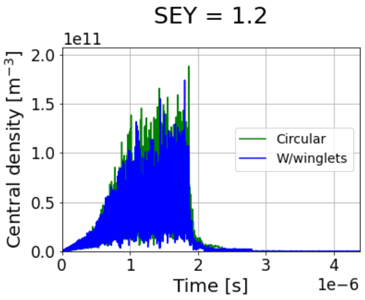


Figure 61

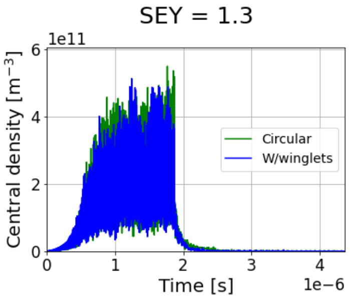


Figure 62

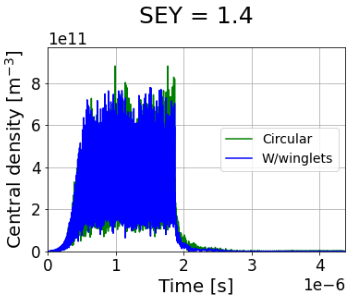


Figure 63

$\eta_\gamma = 1\text{e-}6$

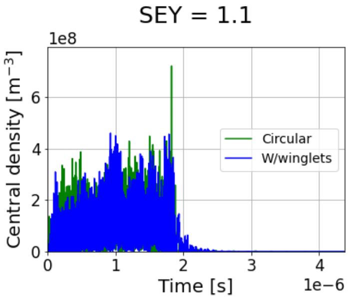


Figure 64

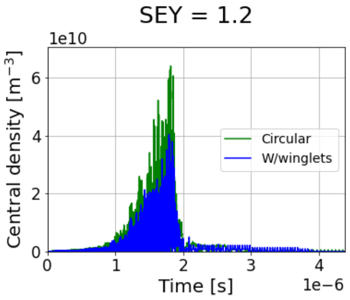


Figure 65

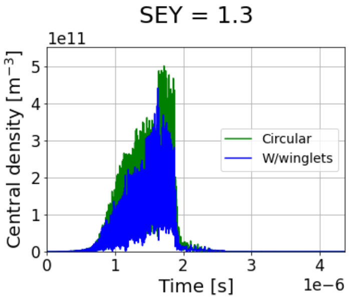


Figure 66

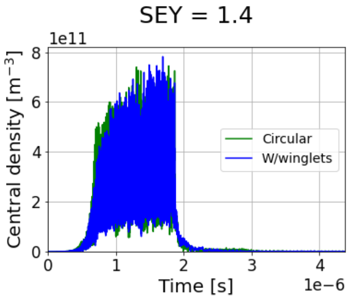


Figure 67

Variation of SEY using: b_spac = 15.0 ns | $\eta_\gamma =$ 3.5e-5, 1e-6

$\eta_\gamma = 3.5\text{e-}5$

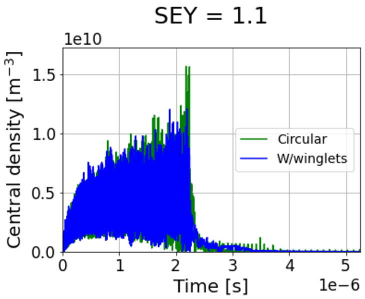


Figure 68

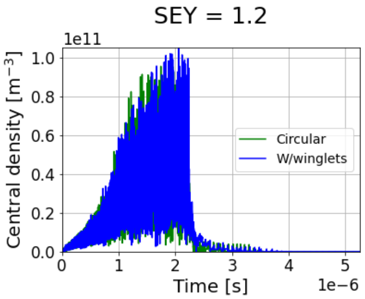


Figure 69

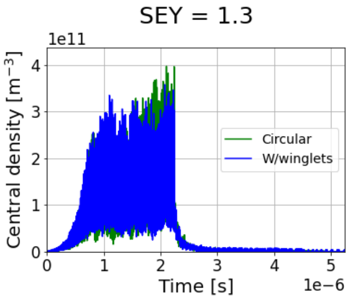


Figure 70

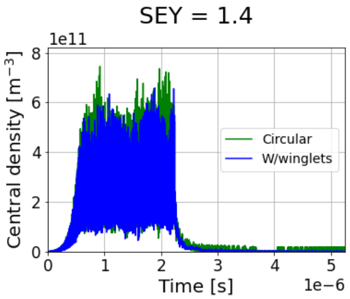


Figure 71

$\eta_\gamma = 1\text{e-}6$

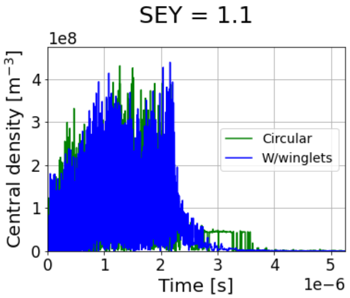


Figure 72

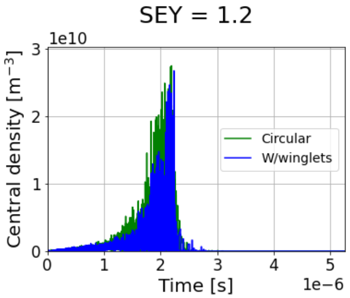


Figure 73

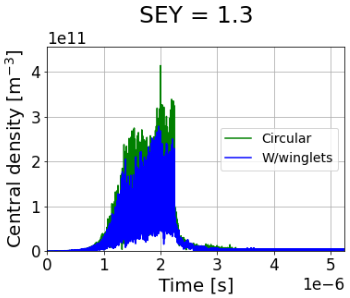


Figure 74

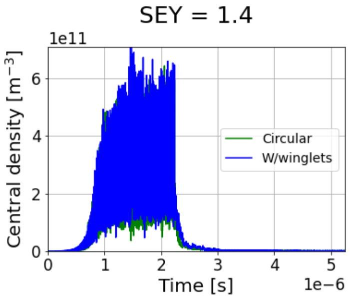


Figure 75

Variation of SEY using: b_spac = 17.5 ns | $\eta_\gamma =$ 3.5e-5, 1e-6

$\eta_\gamma = 3.5e\text{-}5$

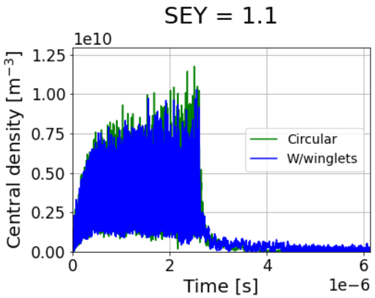


Figure 76

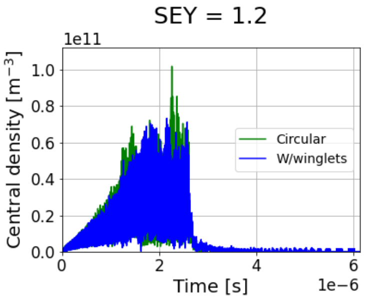


Figure 77

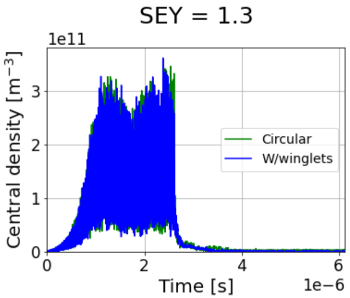


Figure 78

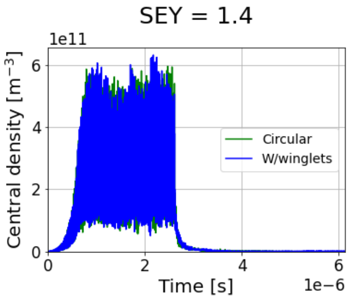


Figure 79

$\eta_\gamma =$ 1e-6

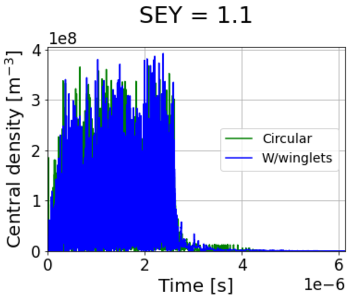


Figure 80

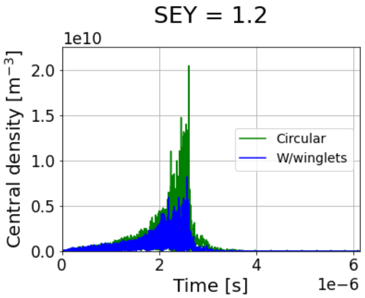


Figure 81

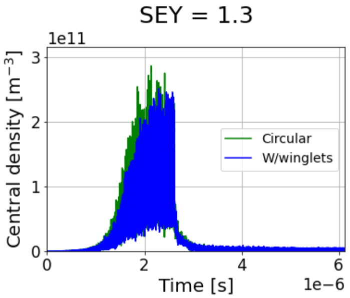


Figure 82

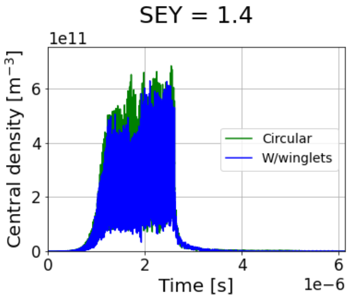


Figure 83

Variation of SEY using: b_spac = 20.0 ns | $\eta_\gamma =$ 3.5e-5, 1e-6

$\eta_\gamma = 3.5\text{e-}5$

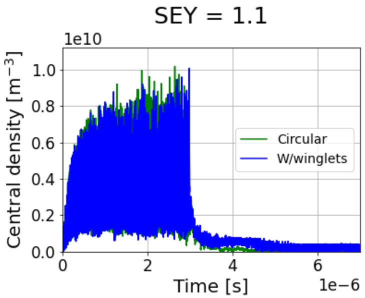


Figure 84

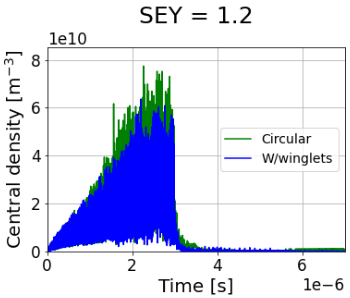


Figure 85

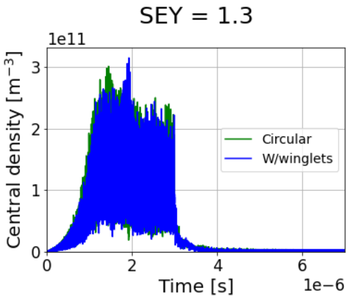


Figure 86

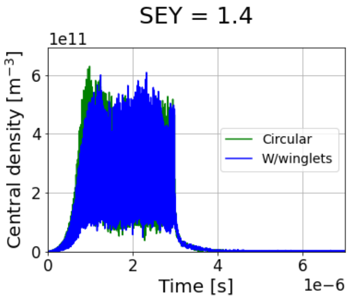


Figure 87

$\eta_\gamma =$ 1e-6

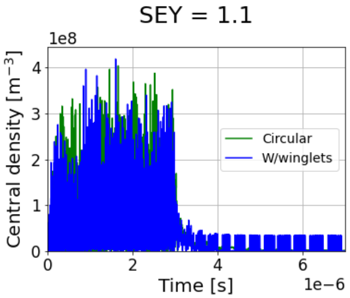


Figure 88

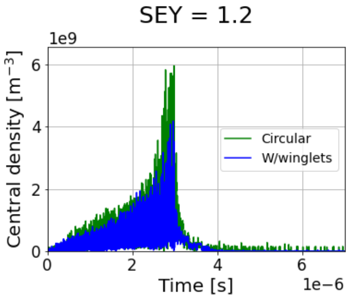


Figure 89

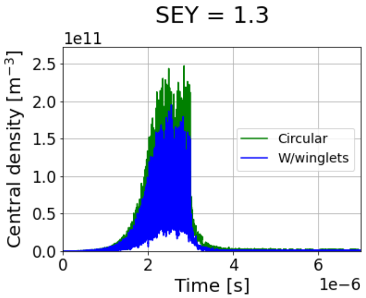


Figure 90

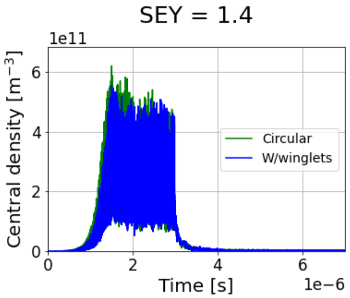


Figure 91

AVERAGE ELECTRON DENSITY

Keeping constant the bunch spacing and varying the SEY

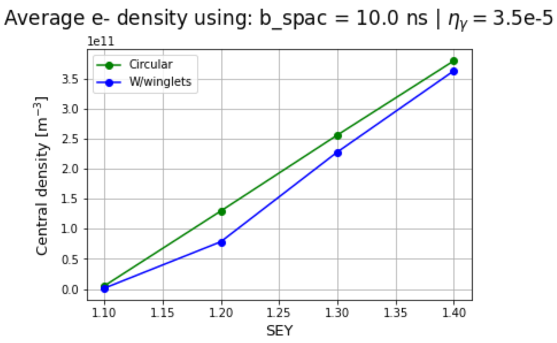


Figure 92. Average e- density for figures 52 to 55

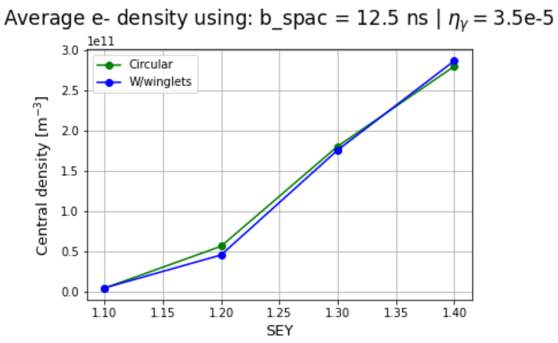


Figure 93. Average e- density for figures 60 to 63

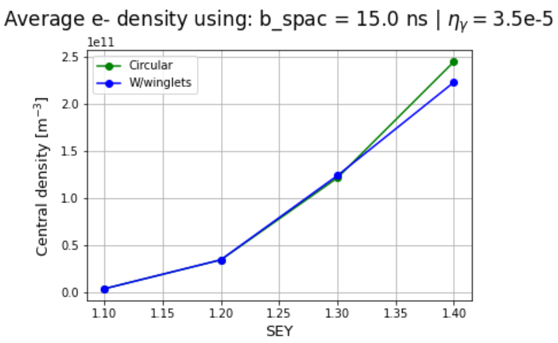


Figure 94. Average e- density for figures 68 to 71

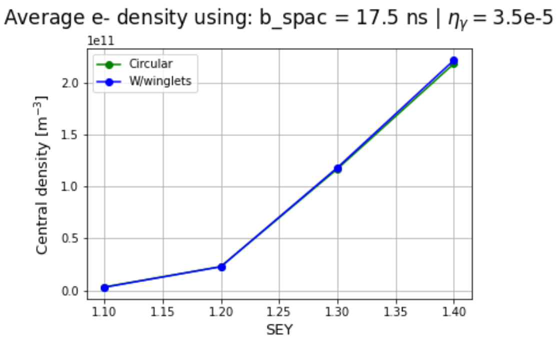


Figure 95. Average e- density for figures 76 to 79

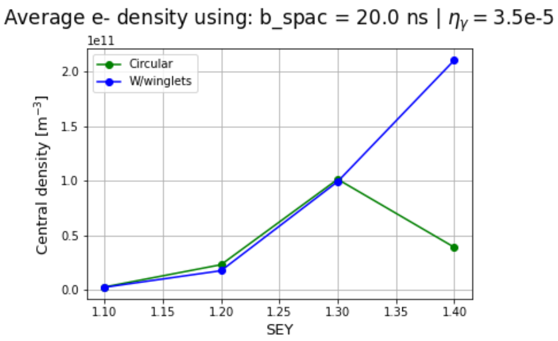


Figure 96. Average e- density for figures 84 to 87

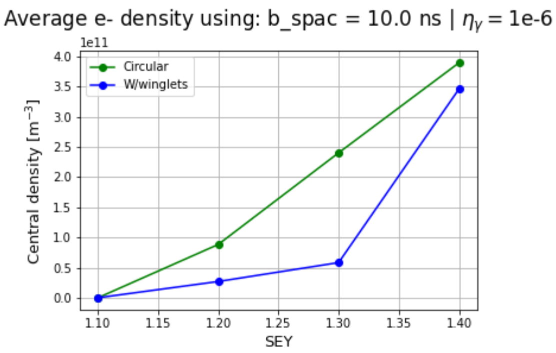


Figure 97. Average e- density for figures 56 to 59

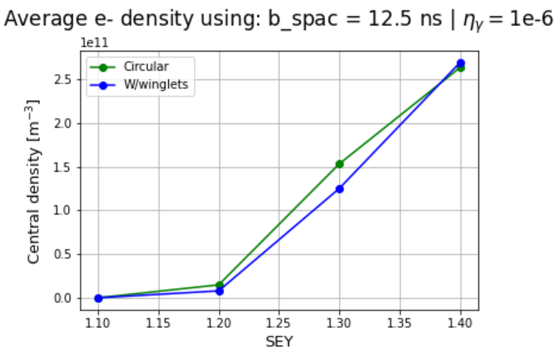


Figure 98. Average e- density for figures 64 to 67

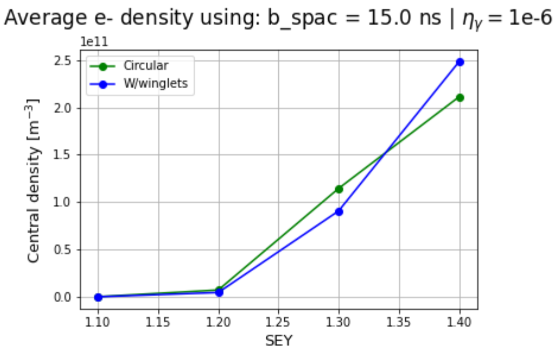


Figure 99. Average e- density for figures 72 to 75

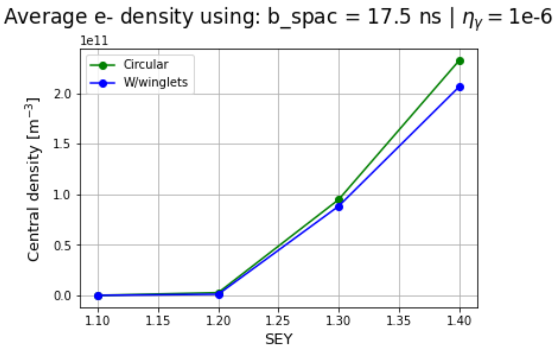


Figure 100. Average e- density for figures 80 to 83

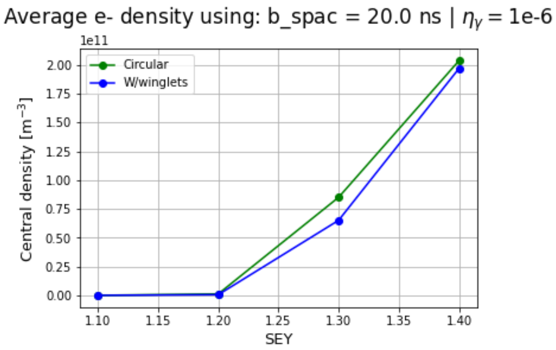


Figure 101. Average e- density for figures 88 to 91

Space charge evaluation for a dipole magnet

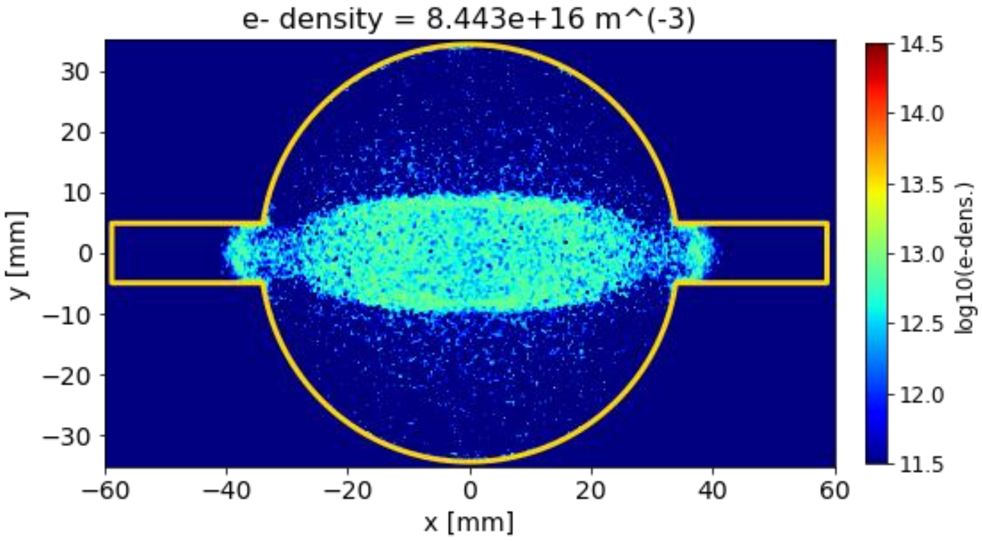


Figure 102