FCC-ee ELECTRON CLOUD & VACUUM
ELECTRON CLOUD SIMULATIONS FOR ARC QUADRUPOLES

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# FCC-ee machine and beam parameters

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<tr>
<td>Beam energy [GeV]</td>
<td>45.6</td>
</tr>
<tr>
<td>Bunch spacing [ns]</td>
<td>10, 12.5, 15, 17.5, 20</td>
</tr>
<tr>
<td>Bunches per train</td>
<td>150</td>
</tr>
<tr>
<td>Trains per beam</td>
<td>1</td>
</tr>
<tr>
<td>Secondary emission yield</td>
<td>1.1, 1.2, 1.3, 1.4</td>
</tr>
<tr>
<td>R.M.S. bunch length ($\sigma_z$) [mm]</td>
<td>3.5</td>
</tr>
<tr>
<td>R.M.S. beam size ($\sigma_x$) [µm]</td>
<td>120</td>
</tr>
<tr>
<td>R.M.S. beam size ($\sigma_y$) [µm]</td>
<td>7</td>
</tr>
<tr>
<td>Chamber type</td>
<td>Circular, circular with winglets</td>
</tr>
<tr>
<td>Beam pipe radius [mm]</td>
<td>35</td>
</tr>
<tr>
<td>Magnetic field [T/m]</td>
<td>5.65</td>
</tr>
<tr>
<td>Photoelectrons generation rate ($n_\gamma$)</td>
<td>$3.5e-5, 1e-6$</td>
</tr>
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Number of simulations $\rightarrow 5 \times 4 \times 2 \times 2 = 80$
ELECTRON DISTRIBUTIONS FOR EC BUILDUP

Keeping constant the SEY and varying the bunch spacing
Variation of bunch spacing using: $SEY = 1.1 | \eta_Y = 3.5e^{-5}, 1e^{-6}$

- $\eta_Y = 3.5e^{-5}$
  - Figure 3: $b_{spac} = 10.0$ ns
  - Figure 4: $b_{spac} = 12.5$ ns
  - Figure 5: $b_{spac} = 15.0$ ns
  - Figure 6: $b_{spac} = 17.5$ ns
  - Figure 7: $b_{spac} = 20.0$ ns

- $\eta_Y = 1e^{-6}$
  - Figure 8: $b_{spac} = 10.0$ ns
  - Figure 9: $b_{spac} = 12.5$ ns
  - Figure 10: $b_{spac} = 15.0$ ns
  - Figure 11: $b_{spac} = 17.5$ ns
  - Figure 12: $b_{spac} = 20.0$ ns
Variation of bunch spacing using: $\text{SEY} = 1.2 \ | \ \eta_y = 3.5\text{e-5}, 1\text{e-6}$
Variation of bunch spacing using: $\text{SEY} = 1.3$ | $\eta_Y = 3.5 \times 10^{-5}$, $1 \times 10^{-6}$

- $\eta_Y = 3.5 \times 10^{-5}$
  - Figure 23: $b_{\text{spac}} = 10.0$ ns
  - Figure 24: $b_{\text{spac}} = 12.5$ ns
  - Figure 25: $b_{\text{spac}} = 15.0$ ns
  - Figure 26: $b_{\text{spac}} = 17.5$ ns
  - Figure 27: $b_{\text{spac}} = 20.0$ ns

- $\eta_Y = 1 \times 10^{-6}$
  - Figure 28: $b_{\text{spac}} = 10.0$ ns
  - Figure 29: $b_{\text{spac}} = 12.5$ ns
  - Figure 30: $b_{\text{spac}} = 15.0$ ns
  - Figure 31: $b_{\text{spac}} = 17.5$ ns
  - Figure 32: $b_{\text{spac}} = 20.0$ ns
Variation of bunch spacing using: $\text{SEY} = 1.4 \mid \eta_Y = 3.5\text{e-5}, 1\text{e-6}$

![Graphs showing variation of bunch spacing](Figure 33 to Figure 42)

$\eta_Y = 3.5\text{e-5}$

$\eta_Y = 1\text{e-6}$
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 $n_\gamma$ is decreased and $SEY = 1.1, 1.2$. But the form of the distribution is almost the same for both values of $n_\gamma$ when $SEY = 1.3, 1.4$. 
AVERAGE ELECTRON DENSITY

Keeping constant the SEY and varying the bunch spacing
Calculation of average electron density

Gaussian approximation using a curve fit method:

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

Where:
- \( \rho(\mu) \rightarrow \) average e- density
Average e- density using: SEY = 1.1 | $\eta_y = 3.5 \times 10^{-5}$

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

Average e- density using: SEY = 1.2 | $\eta_y = 3.5 \times 10^{-5}$

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

Average e- density using: SEY = 1.3 | $\eta_y = 3.5 \times 10^{-5}$

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

Average e- density using: SEY = 1.4 | $\eta_y = 3.5 \times 10^{-5}$

Figure 47. Average e- density for figures 33 to 37
Average e- density using: SEY = 1.1 | $\eta_f = 1.0 \times 10^{-6}$

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

Average e- density using: SEY = 1.2 | $\eta_f = 1.0 \times 10^{-6}$

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

Average e- density using: SEY = 1.3 | $\eta_f = 1.0 \times 10^{-6}$

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

Average e- density using: SEY = 1.4 | $\eta_f = 1.0 \times 10^{-6}$

Figure 51. Average e- density for figures 38 to 42
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 $n_\gamma$ is decreased at every SEY value.
SPACE CHARGE ANALYSIS
Central density distribution for:

- $b_{spac} = 10$ ns
- $SEY = 1.2$
- $\gamma = 3.5 \times 10^{-5}$

Space charge evaluation at $t = 0.5 \, \mu s$
Space charge evaluation at $t = 0.7053 \mu s$

Central density distribution for:

$b_{\text{spac}} = 10 \text{ ns} \mid \text{SEY} = 1.2 \mid n_\gamma = 3.5e-5$
Space charge evaluation at $t = 0.953 \ \mu s$

Central density distribution for:

$b_{spac} = 10 \ \text{ns} \ | \ SEY = 1.2 \ | \ n_\gamma = 3.5e-5$
Space charge evaluation at $t = 1.1003 \mu s$

Central density distribution for:

\[ b_{spac} = 10 \text{ ns} \mid \text{SEY} = 1.2 \mid n_y = 3.5e-5 \]
Space charge evaluation at $t = 1.2501 \, \mu s$

Central density distribution for:

- $b_{spac} = 10 \, \text{ns}$
- $\text{SEY} = 1.2$
- $n_y = 3.5e-5$

Electron cloud and vacuum conditions.

FCC-ee electron cloud and vacuum

Damian Ismael Ayim Canche
Space charge evaluation at $t = 1.3027$ $\mu$s

Central density distribution for:

$b_{\text{spac}} = 10$ ns | SEY = 1.2 | $\eta_y = 3.5 \times 10^{-5}$
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.

Summary
Thank you for your attention.
ELECTRON DISTRIBUTIONS FOR EC BUILDUP

Keeping constant the bunch spacing and varying the SEY
Variation of SEY using: $b_{\text{spac}} = 10.0$ ns | $\eta_{\gamma} = 3.5e^{-5}, 1e^{-6}$

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

$\eta_{\gamma} = 1e^{-6}$
Variation of SEY using: $b_{\text{spac}} = 12.5 \text{ ns}$ | $\eta_Y = 3.5\text{e-5}, 1\text{e-6}$
Variation of SEY using: $b_{spac} = 15.0$ ns | $\eta_y = 3.5e^{-5}, 1e^{-6}$
Variation of SEY using: $b_{spac} = 17.5 \text{ ns} \mid \eta_\gamma = 3.5\text{e-5, 1e-6}$

- $\eta_\gamma = 3.5\text{e-5}$
  - Figure 76: SEY = 1.1
  - Figure 77: SEY = 1.2
  - Figure 78: SEY = 1.3
  - Figure 79: SEY = 1.4

- $\eta_\gamma = 1\text{e-6}$
  - Figure 80: SEY = 1.1
  - Figure 81: SEY = 1.2
  - Figure 82: SEY = 1.3
  - Figure 83: SEY = 1.4
Variation of SEY using: $b_{spac} = 20.0 \text{ ns}$ | $\eta_Y = 3.5e-5, 1e-6$

\[ \eta_Y = 3.5e-5 \]

\[ \eta_Y = 1e-6 \]
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
Average e- density using: b_spac = 10.0 ns | $\eta_y = 1e-6$

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

Average e- density using: b_spac = 12.5 ns | $\eta_y = 1e-6$

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

Average e- density using: b_spac = 15.0 ns | $\eta_y = 1e-6$

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

Average e- density using: b_spac = 17.5 ns | $\eta_y = 1e-6$

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

Average e- density using: b_spac = 20.0 ns | $\eta_y = 1e-6$

Figure 101. Average e- density for figures 88 to 91
Space charge evaluation for a dipole magnet

Figure 102

e- density = 8.443e+16 m^(-3)