Dinamica dell'Electron Cloud: Calcolo dei Coefficienti della Mappa

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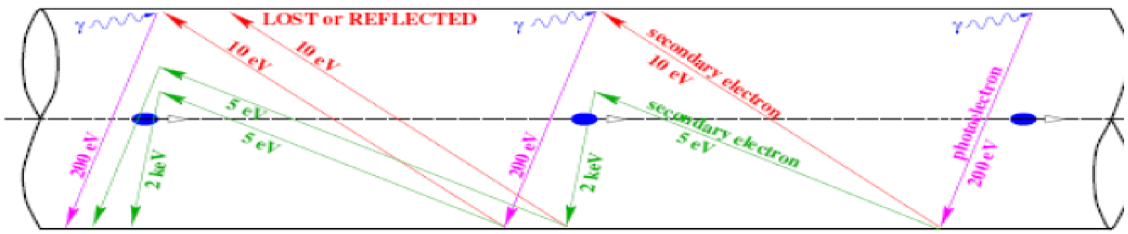
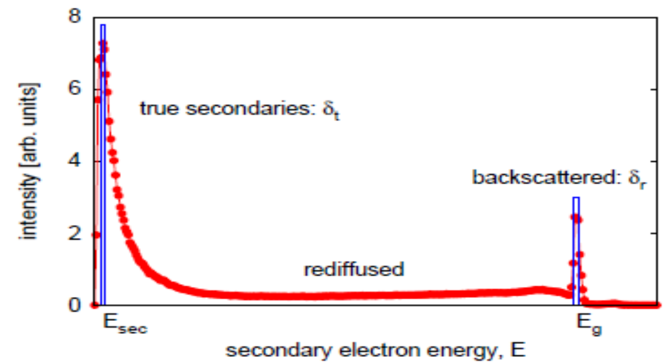
Plan of Talk

- Electron Cloud Effect
- Cubic Map Formalism
- Saturation Condition and the Quadratic Coefficient
- Conclusions and Outlook

Electron Cloud Effect and Secondary Emission Yield





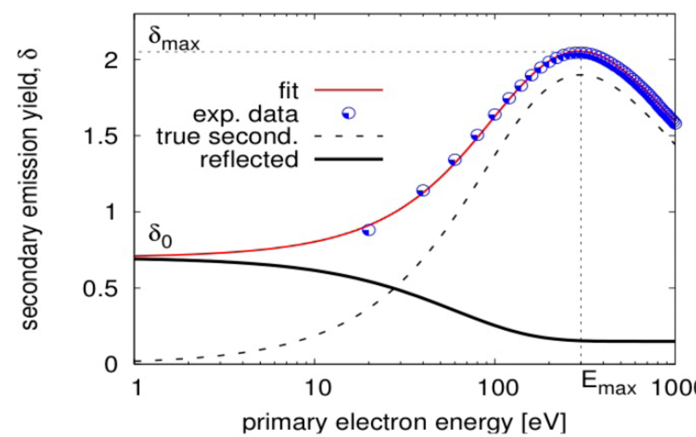
The electron cloud develops quickly as photons striking the vacuum chamberwall knock out electrons that are then accelerated by the beam, gain energy, and strike the chamber again, producing more electrons.

The interaction between the electron cloud and a beam leads to the electron cloud effects such as single- and multi-bunch instability, tune shift, increase of pressure and so on.

$\delta = I_s/I_p$ and $\delta = \delta_{ts} + \delta_{el} + \delta_{rdf}$

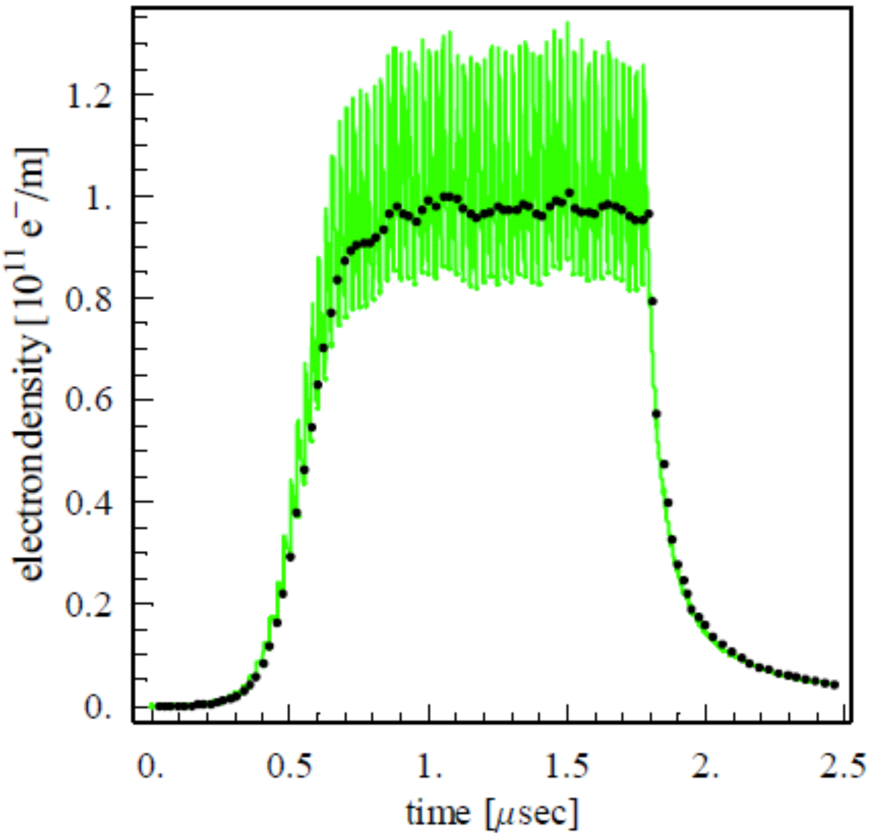
$\delta = \delta_{ts} + \delta_{el}$

Typical vacuum material have $\delta_{max} > 1$



Electron Cloud Buildup I

δ_{max} = 1.7 (72 f, 28 e)



LHC dipole parameters

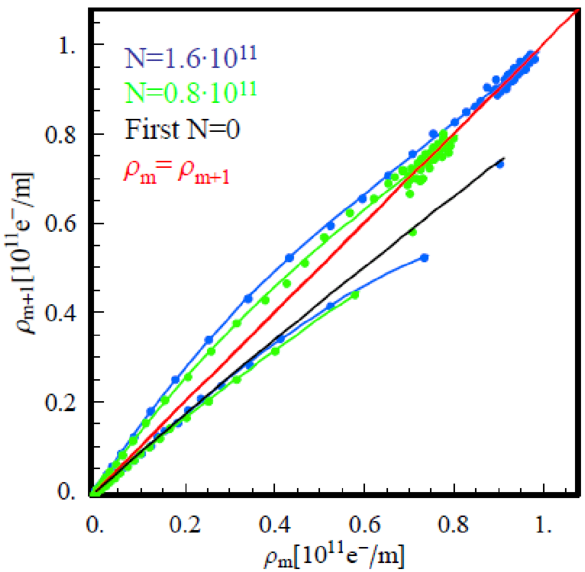
parameter	unit	value
beam particle energy	GeV	7000
bunch spacing	ns	25
bunch length	m	0.075
number of bunches N_b	–	72
number of particles per bunch N	10^{11}	0.8 to 1.6
bending field B	T	8.4
length of bending magnet	m	14.2
vacuum screen half height	m	0.018
vacuum screen half width	m	0.022
circumference	m	27000
primary photo-emission yield	-	$7.98 \cdot 10^{-4}$
maximum SEY δ_{max}	-	1.3 to 1.7
energy for max. SEY E_{max}	eV	237.125
energy width for secondary e^-	eV	1.8

— ECLOUD (CERN) output

- bunch to bunch average

Electron Cloud Buildup II
Bunch Filling Patterns

$\delta_{max} = 1.7$ (72 f, 28 e)

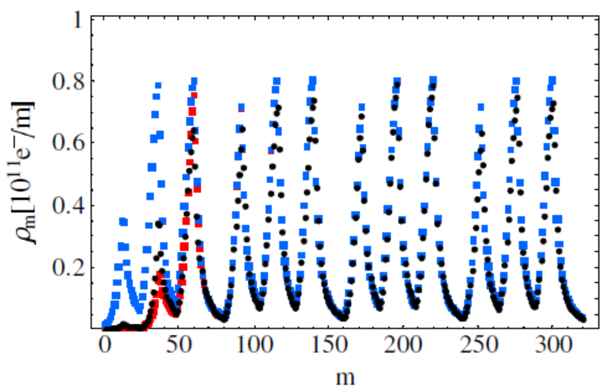


Lines corresponds to cubic fit of the form:

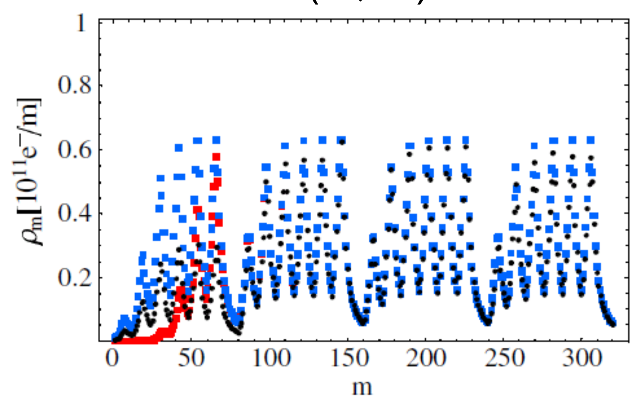
$n_{m+1} = \alpha\, n_m + \beta\, n_m^2 + \gamma\, n_m^3$

Three sets of coefficients are needed to describe the e-cloud density evolution

(12f,12e, 12f,12e,12f,12e)

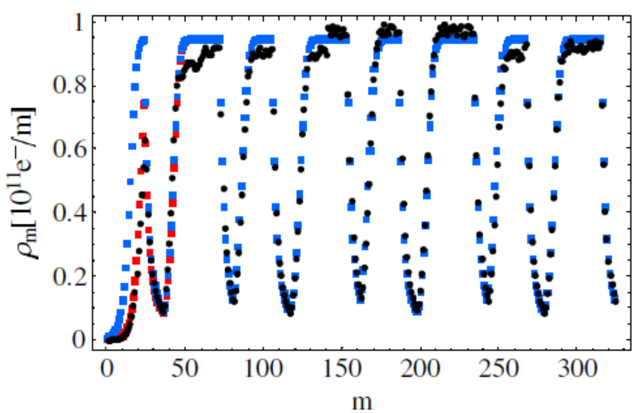


(6f,6e)



$\rho_0=10^{-2}[10^{11}e\text{-}/m]$, $\rho_0=10^{-4}[10^{11}e\text{-}/m]$

(24f,12e, 36 f)



Map results do not depends on the initial electron density

Relative error below 20%

Different bunch patterns can be described using the same Map coefficients

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Maps and Dynamics for Electron Clouds

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- For a given beam pipe characteristics (SEY, chamber dimensions, etc.) the evolution of the electron density is only driven by the bunch passing by,and the existing electron density before the bunch passage:

$$n_{m+1} = F(n_m)$$

- Simplify the e-cloud problem into a small number of mathematical parameters.
- The bunch-to-bunch evolution of the e-cloud density is represented by a cubic map:

$$n_{m+1} = \alpha\, n_m + \beta\, n_m^{\,2} + \gamma\, n_m^{\,3}$$

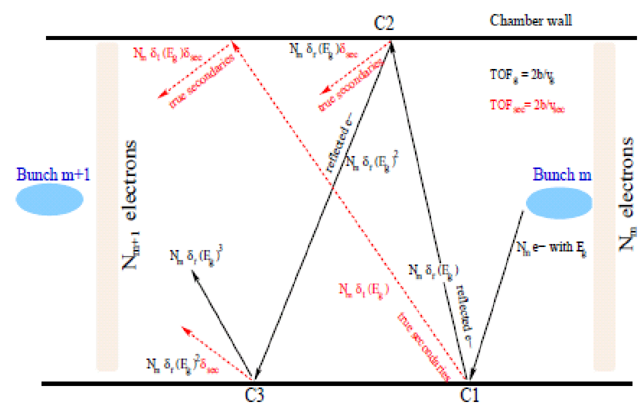
where n_m is the bunch to bunch average of the electron line density.

- The linear term a describes the exponential growth of the cloud density. For $n >> 1$

$n_1 = \alpha\, n_0,\ n_2 = \alpha\, n_1 = \alpha^2\, n_0$, and $n_m = \alpha\, n_{m-1} = \alpha^m\, n_0$

- The quadratic term b is related to the saturation due to space charge
- The cubic term is always very small and could be interpreted additional correction embodying small corrections.

$$a = \frac{N_{m+1}}{N_m} = \delta_r^n(\bar{E}_g) + \delta_t(\bar{E}_g)\delta_s^\eta(E_s)\cdot\frac{\delta_s^{n\eta}(E_s) - \delta_r^n(\bar{E}_g)}{\delta_s^\eta(E_s) - \delta_r(\bar{E}_g)}$$



Saturation Condition

- In free field regions the distance (in units of beampipe radius *b*) passed by secondary electrons (with energy ε_0) before the next bunch arrives is

$$\xi = \frac{h}{b}\sqrt{\frac{2\mathcal{E}_0}{mc^2}}$$

- The density of the secondary electrons grows until the space-charge potential is lower than energy of the secondary electrons. For a gausslike distribution of electron cloud

$$V(r) = \int_r^b \vec{E}\cdot d\vec{l} = -\frac{\bar{N}_b\, e}{2\pi\epsilon_0 h}\ln\frac{r}{b} - \frac{N_{el}\, e}{2\pi\epsilon_0 h}\frac{1}{\int_a^b e^{-\frac{(y-r_0)^2}{2\sigma^2}}\, y\, dy}\int_r^b \frac{\int_a^y e^{-\frac{(z-r_0)^2}{2\sigma^2}}\, z\, dz}{y}dy =$$

$$g = \bar{N}_b/N_{el}$$

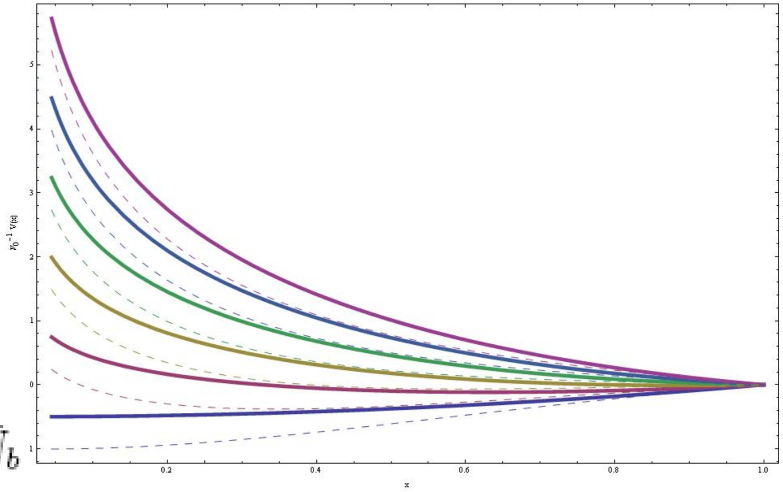
$$-\frac{\bar{N}_b\, e}{2\pi\epsilon_0 h}\ln x - \frac{N_{el}\, e}{2\pi\epsilon_0 h}\frac{G(x)}{F(1)} = -V_0\left[g\ln x + \frac{G(x)}{F(1)}\right]$$

- If the distribution is uniform

$$V_{ud}(r) = -V_0\left[g\ln x + \frac{1-x^2}{2}\right]$$

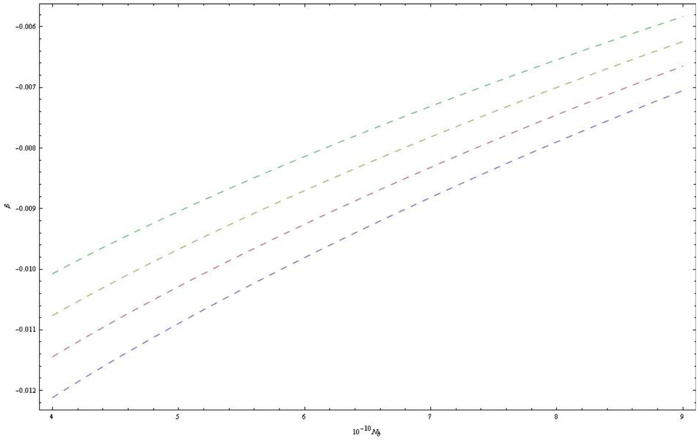
- The saturation condition can be obtained requiring

$$-e\,V(1-\xi) \sim \mathcal{E}_0 \qquad N_{el,sat} = \frac{2\pi\epsilon_0 h F(1)\mathcal{E}_0}{e^2 G(1-\xi)} - \frac{F(1)\ln(1-\xi)}{G(1-\xi)}\bar{N}_b$$

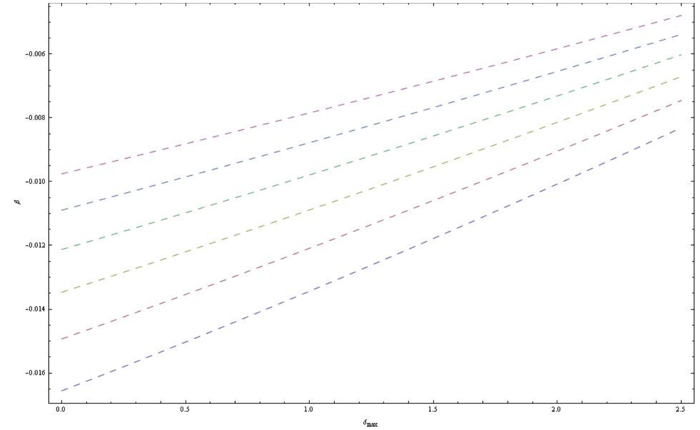


Electron density and quadratic coefficient

- The critical density is given by relation $$n_{sat} = \frac{N_{el,sat}}{\pi h b^2[(\tilde{r}_0 + p\,\tilde{\sigma})^2 - \tilde{a}^2]}$$
- The saturation condition satisfies the equation $$n_{sat} = \alpha\, n_{sat} + \beta\, {n_{sat}}^2 \quad \rightarrow \quad \beta = \frac{1-\alpha}{n_{sat}}$$
- The quadratic map becomes $$n_{m+1} = \alpha\, n_m + \frac{1-\alpha}{n_{sat}}\, {n_m}^2$$



Analytical prediction of coefficient for values δ_{max} = 1,4 - 2 and p = 2.

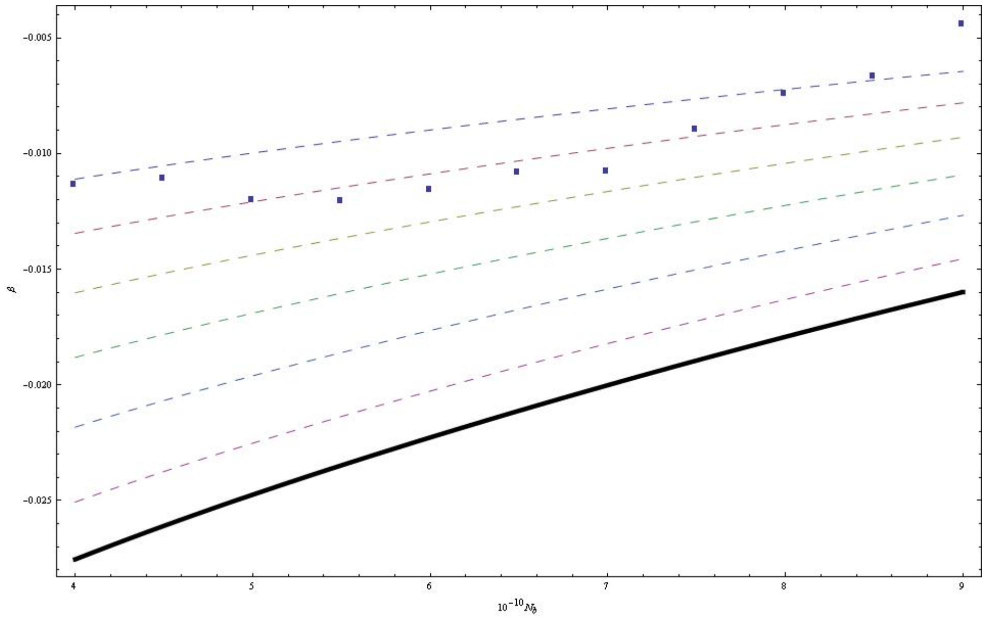


Analytical prediction of coefficient for values N_b = (4 - 9) *10^{10} and p = 2.

Quadratic coefficient

Comparison of the quadratic coefficient derived using ECLOUD simulations (points) and using the analysis of previous slides (dashed lines) with *p* = 2 - 3. The solid line is the result by assuming an uniform density.

Parameter	Quantity	Unit	Value
Beam pipe radius	b	m	.045
Beam size	a	m	.002
Bunch spacing	s_b	m	1.2
Bunch length	h	m	.013
Energy for δ_{max}	$\mathcal{E}_{0,max}$	eV	300
-	$\mathcal{E}_r$	eV	60
Particles per bunch	N_b	10^{10}	$4 \div 9$
SEY (max)	δ_{max}	-	1.7
SEY ($\mathcal{E} \to 0$)	δ_0	-	.7
SEY ($\mathcal{E} \to \infty$)	δ_∞	-	.15
-	ζ	-	1.83



Conclusions and Outlook

- The electron-cloud buildup can be described by a cubic map.
- Remarkably, if all other parameters (namely, the bunch charge *N*, the SEY, and the pipe parameters) are held fixed, the map coefficients basically *do not* depend on the filling pattern.
- An approximate formula has been derived for the quadratic coefficient in the map. The results are in acceptable agreement with numerical simulations obtained from ECLOUD.
- The analytical result could be useful to determine safe regions in parameters space where to minimize the electron clouds.
- Furthermore we would extend our results for the quadratic coefficient in order to include the presence of a magnetic field.
- Work is in order to calculate the higher order terms in the map.

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