Electron Cloud Simulations with 75ns Bunch Spacing

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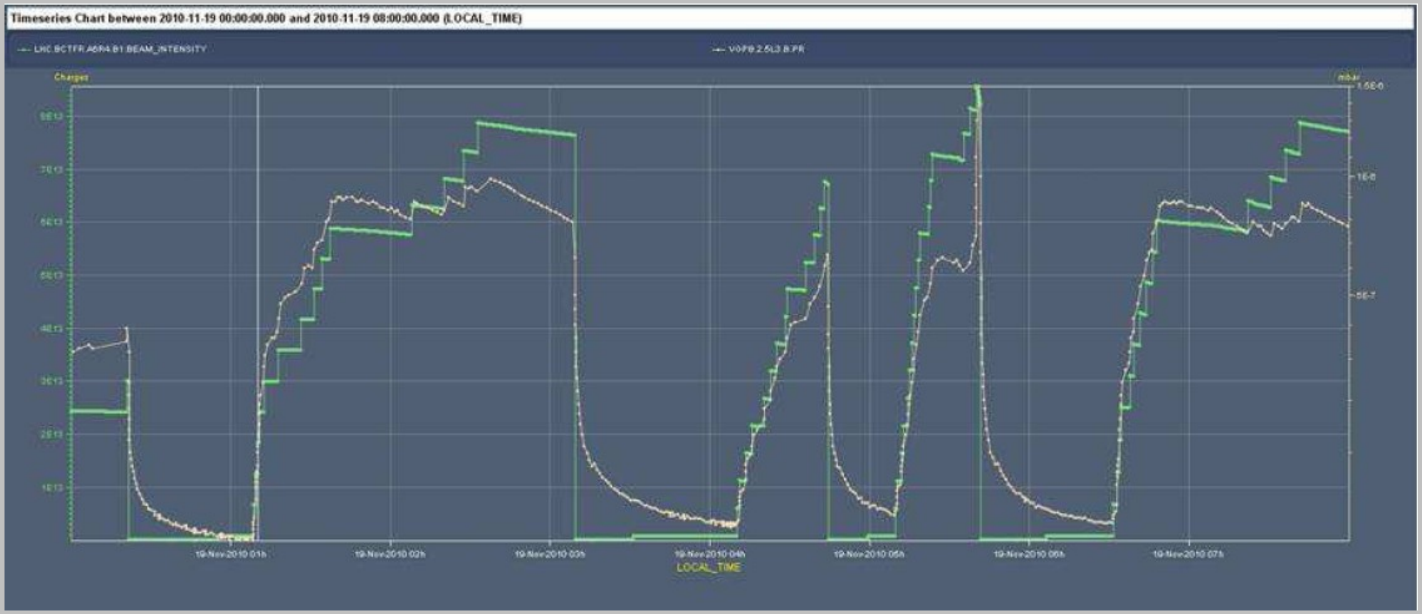
G. Rumolo, and F. Zimmermann

Introduction

➔OBSERVATIONS IN 2010:



Pressure rises with 75ns bunch spacing were observed in IR3
Even though P~10^-6mbar, 936 bunches could be filled in

➔PLAN FOR 2011: Scrubbing using 50ns bunch trains
Physics operation using 75ns

➔GOAL: Investigate SEY parameters such that e-clouds do not limit physics operation

Introduction

LIMIT: *ρ <1e11e-/m^3*** @IR3 (most critical warm location) @dipoles (~70% of LHC) (**limit for beam instabilities – see K. Li presentation)

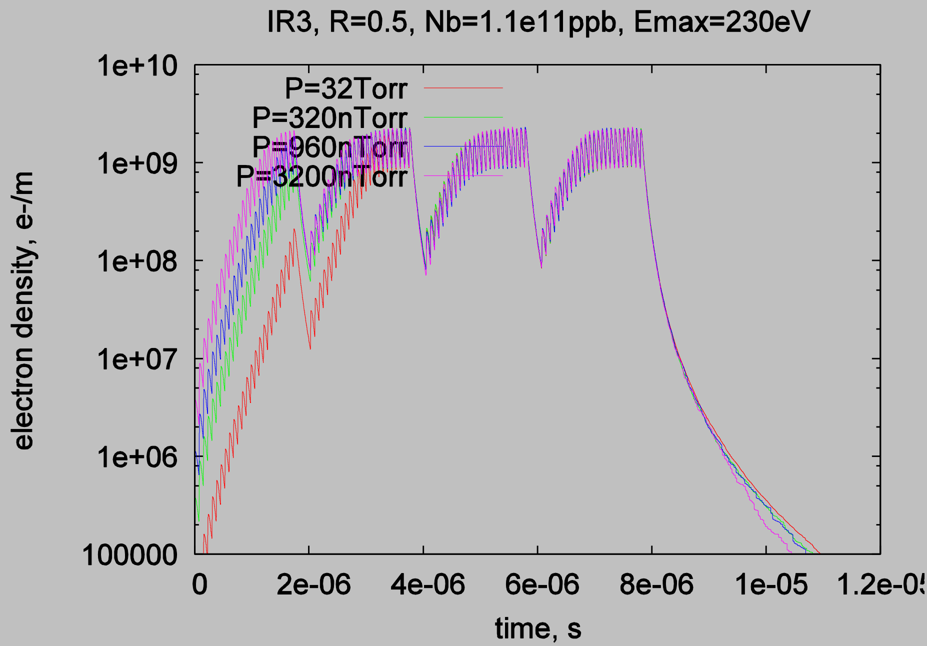
- Nominal LHC beam parameters & scan SEY parameters (SEY & R) to find ρ_limit

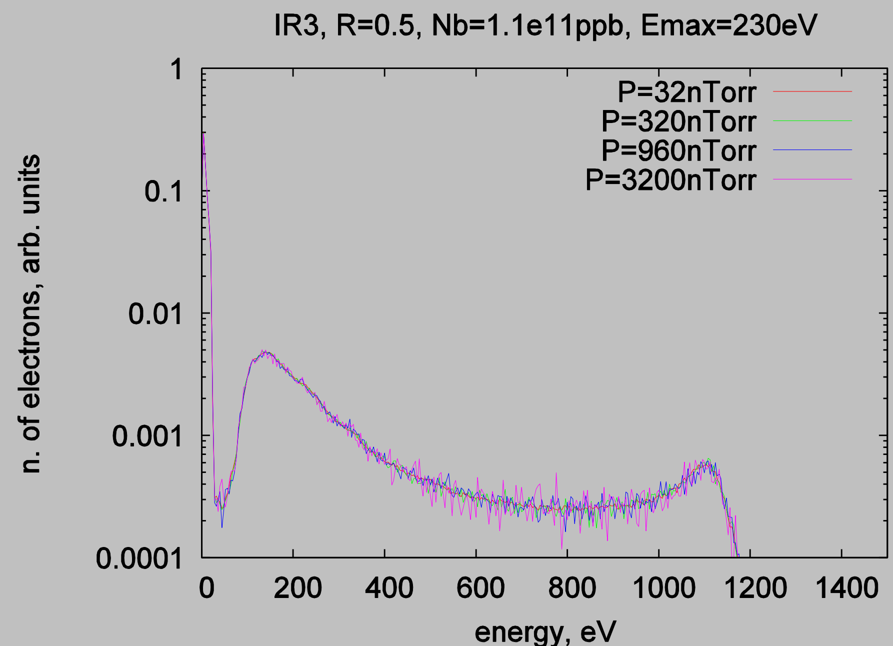
	Reference	Scan
Nb, protons	1.1e11	…
n. of batches	4	…
Bunch spacing (ns)	75	…
Batch Spacing (ns)	225	…
Emax (eV)	230	…
Reflectivity, R	0.5	[0.3 … 0.7]
Max SEY, SEY	2.5	[1.9 … 2.7]

… previously, some scan with beam pipe radius and pressure tests…

Simulations scanning initial pressure

INITIAL PRESSUREs: 32, 320, 960, and 3200nTorr
(FIELD FREE REGIONS)





→ With larger pressures, we reach the saturated value faster (but the saturated value does not change)
→ The pressure does not affect the e-energy spectrum

In general, we use 320nTorr
(However, we sometimes increase this pressure for CPU purposes)

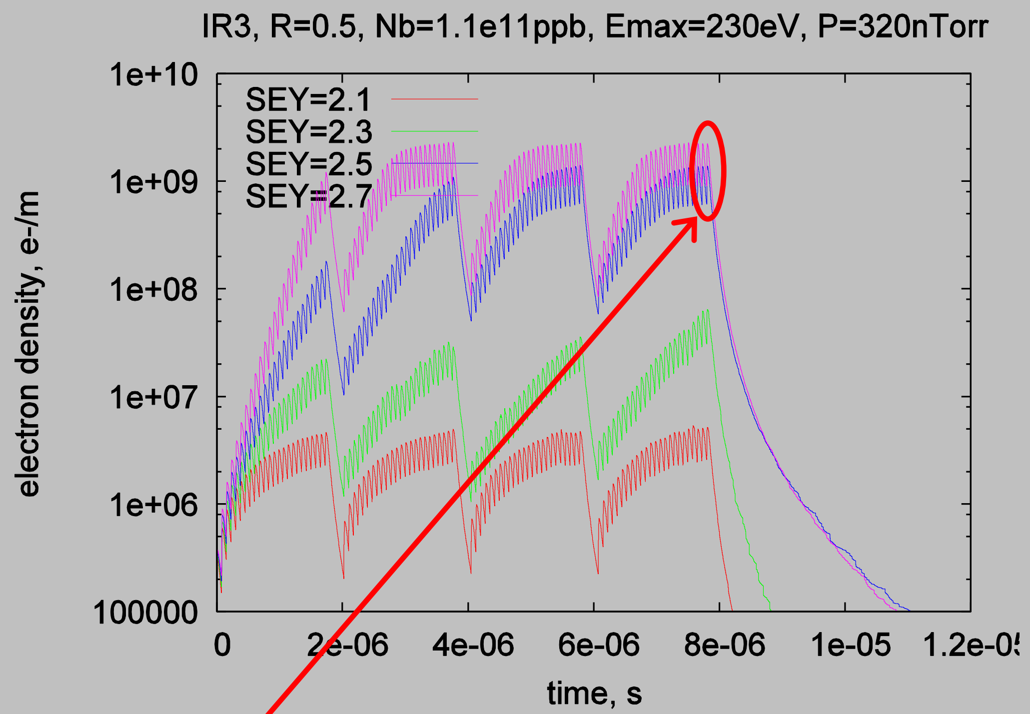
Simulations at IR3

ECLOUD simulations main input parameters

Parameter	symbol [unit]	IR3	Dipole
# pe-macroparticles/bunch	npepb	2000	2000
# of bunches	nbunch	128	128
# interm. steps/bunch	nbsteps	150	150
# interm. steps/interbunch drift	nisteps	300	5000
# particles per bunch	protons	1.1e11	1.1e11
bunch spacing	sb [m]	22.49	22.49
bunch length	σ_l [m]	0.118	0.118
Hor beam size	σ_x [mm]	1.50	1.51
Ver beam size	σ_y [mm]	1.13	6.58
particle energy	E [GeV]	450	450
circumference	C[m]	27000	2700
primary ph-e emission yield	peeff	0.001	0.001
bunch # until ph-e are emitted	nbini	128	128
max slice # until ph-e are emitted	nsini	150	150
angle cut for the emitted photons	...	.041	.041
energy ph-e, position of peak	epemax [eV]	7.	7.
energy ph-e (sigma distrb.)	epesig [eV]	5.	5.
energy sec. e- (sigma distrb.)	semax [eV]	1.8	1.8
secondary emission yield (yim)	SEY	[1.7 - 2.7]	[1.7 - 2.7]
secondary emission yield for $E \to 0$	R	[0.3 - 0.7	[0.3 - 0.7]
energy for max SEY (yemax)	E_{max} (eV)	230.	230.
Hor Aperture Limitation	xbound [m]	0.03	0.022
Ver Aperture Limitation	ybound [m]	0.03	0.018
Bending field	bfield [T]	1e-7	0.535 / 4.16
initial pressure	P [nTorr]	320.	320.

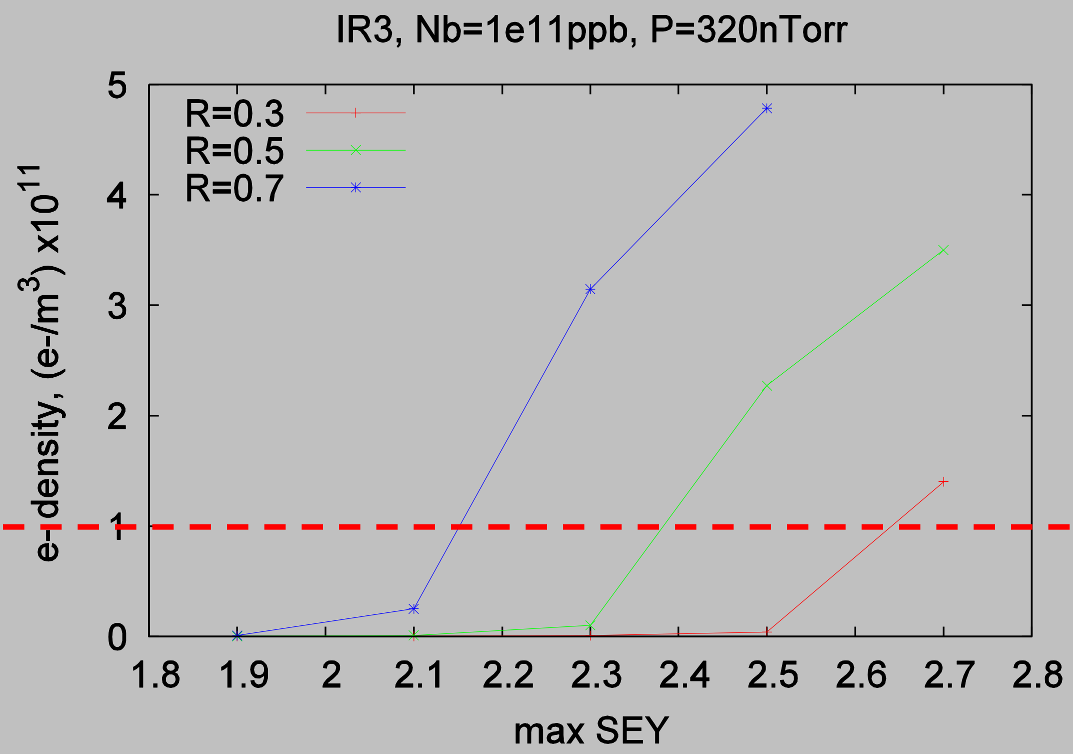
Simulations at IR3

Example of the linear e-density for R=0.5 and SEY = [2.1 ... 2.7]



The limit ***ρ <1e11e-/m^3*** refers to e-density before the bunch arrives
For all simulations, we take the value before the last bunch arrives at the end of the 4th batch.

Simulations at IR3



	SEY - threshold
R=0.3	~2.6
R=0.5	~2.4
R=0.7	~2.2

Simulations at Dipoles

- In this case, due care shall be taken in the "slicing"
- The ECLOUD slices shall properly sample the e- oscillations in presence of a magnetic field

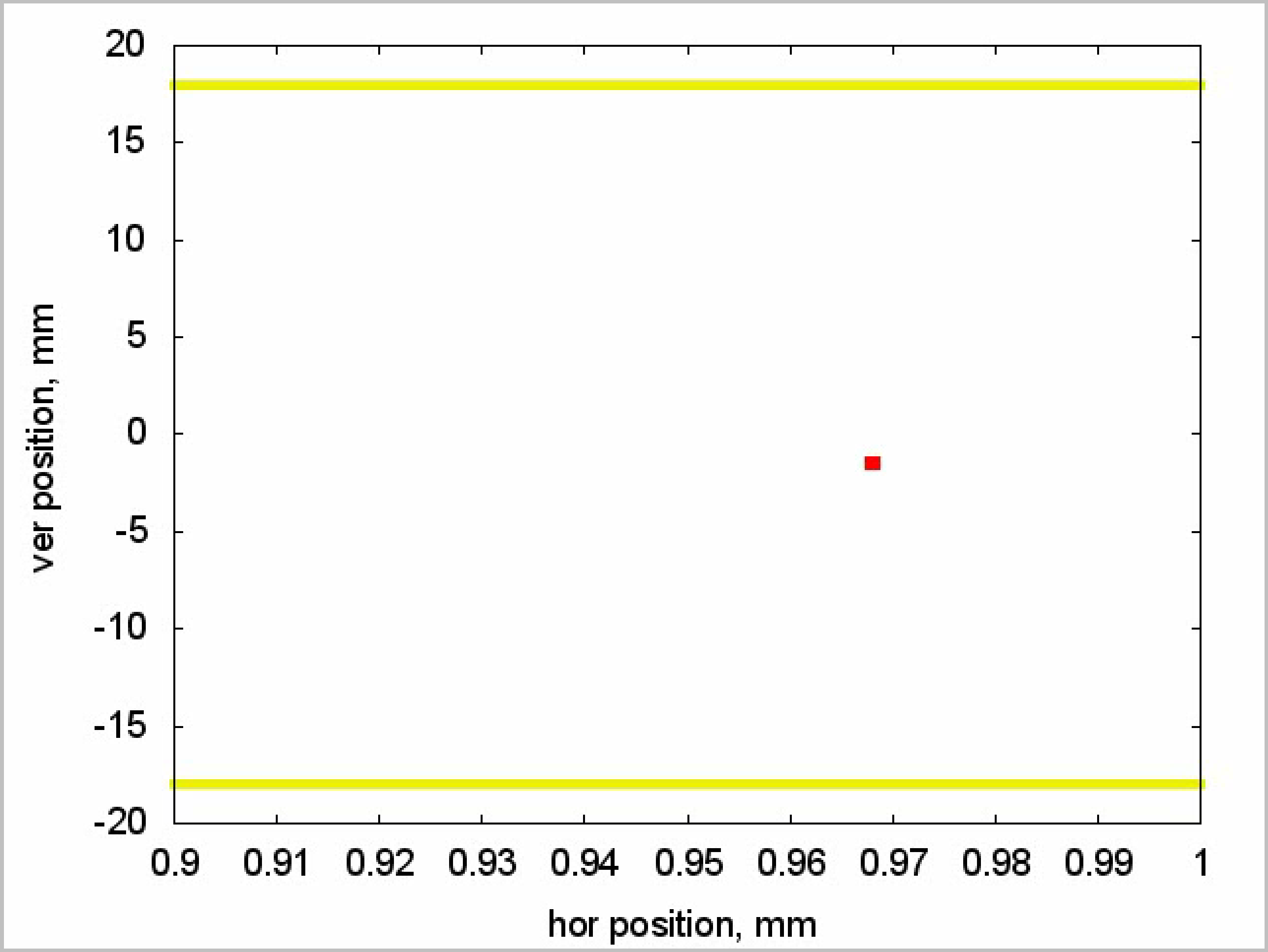
$$T_{Larmor} = 2*pi*m_e / (e*B)$$

	B(T)	T_{Larmor}(ps)	Interbunch slicing (nisteps @ECLOUD)
Injection	0.535	67	5000 (~4 samples/osc.)
Store	4.16	8.7	25000 (~3samples/osc)

- Ideally, the sampling should be ~8 samples/osc.
- But CPU time and huge output files are a big limitation, so we stayed between 3-4 (note also that Larmor radius decreases with B).

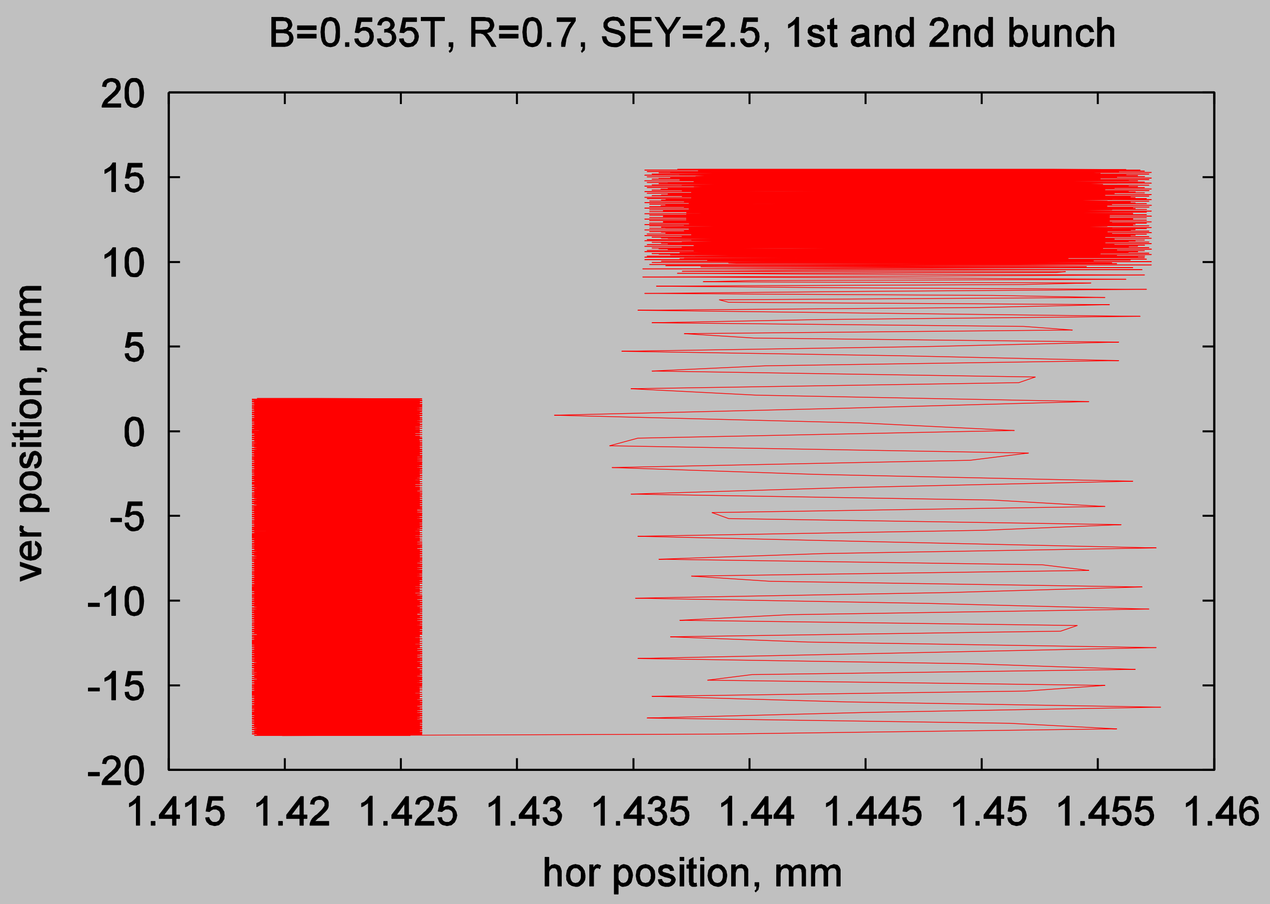
Simulations at Dipoles

Electron motion in a dipole



Simulations at Dipoles

Electron motion in a dipole



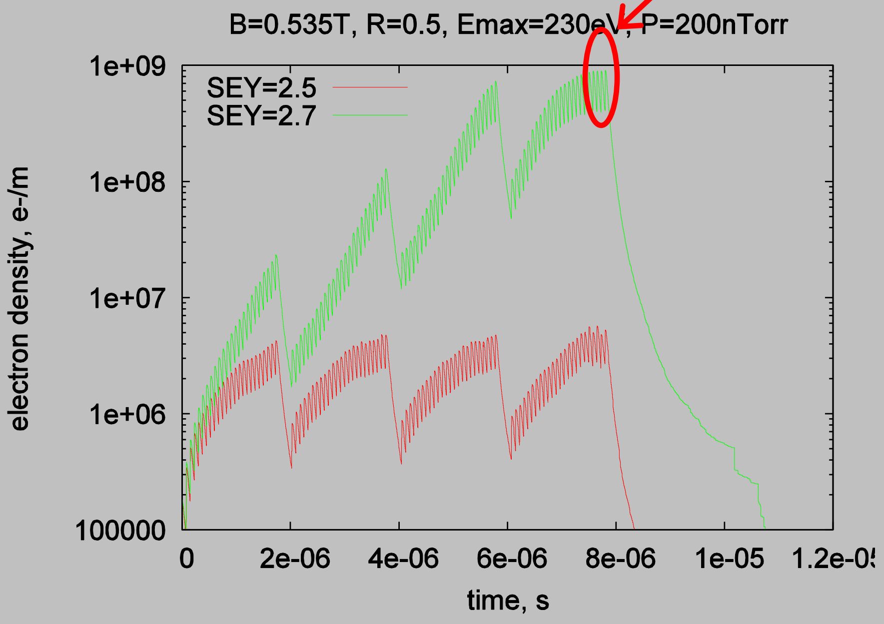
Simulations at Dipoles, Injection

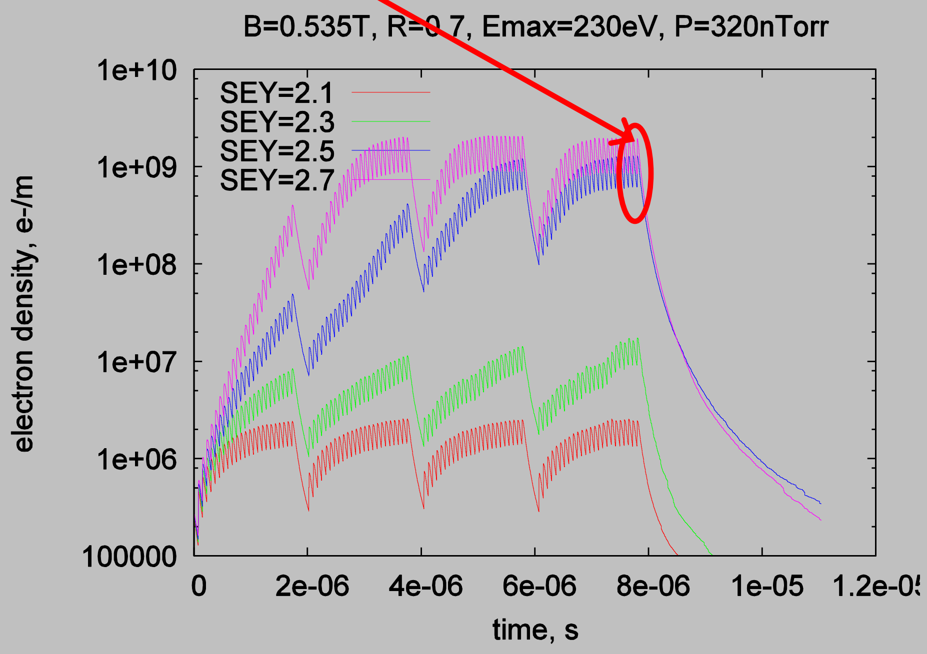
ECLOUD simulations main input parameters

Parameter	symbol [unit]	IR3	Dipole
# pe-macroparticles/bunch	npepb	2000	2000
# of bunches	nbunch	128	128
# interm. steps/bunch	nbsteps	150	150
# interm. steps/interbunch drift	nisteps	300	5000
# particles per bunch	protons	1.1e11	1.1e11
bunch spacing	sb [m]	22.49	22.49
bunch length	σ_l [m]	0.118	0.118
Hor beam size	σ_x [mm]	1.50	1.51
Ver beam size	σ_y [mm]	1.13	6.58
particle energy	E [GeV]	450	450
circumference	C[m]	27000	2700
primary ph-e emission yield	peeff	0.001	0.001
bunch # until ph-e are emitted	nbini	128	128
max slice # until ph-e are emitted	nsini	150	150
angle cut for the emitted photons	...	.041	.041
energy ph-e, position of peak	epemax [eV]	7.	7.
energy ph-e (sigma distrb.)	epesig [eV]	5.	5.
energy sec. e- (sigma distrb.)	semax [eV]	1.8	1.8
secondary emission yield (yim)	SEY	[1.7 - 2.7]	[1.7 - 2.7]
secondary emission yield for $E \to 0$	R	[0.3 - 0.7	[0.3 - 0.7]
energy for max SEY (yemax)	E_{max} (eV)	230.	230.
Hor Aperture Limitation	xbound [m]	0.03	0.022
Ver Aperture Limitation	ybound [m]	0.03	0.018
Bending field	bfield [T]	1e-7	0.535 / 4.16
initial pressure	P [nTorr]	320.	320.

Simulations at Dipoles, Injection

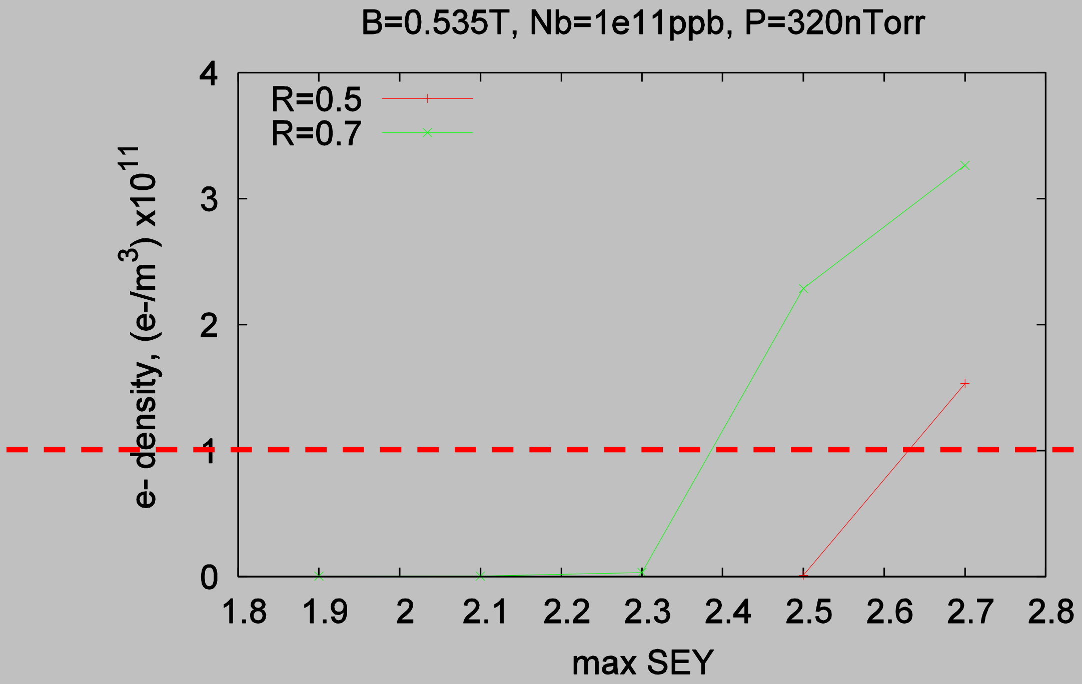
We follow the same procedure as in IR3 to get e-densities at last bunch passage in the 4th batch





Simulations at Dipoles, Injection

…and so we get a similar plot, but with higher thresholds wrt IR3. Presumably, due to smaller apertures (30mm vs (22,18)mm) – see next

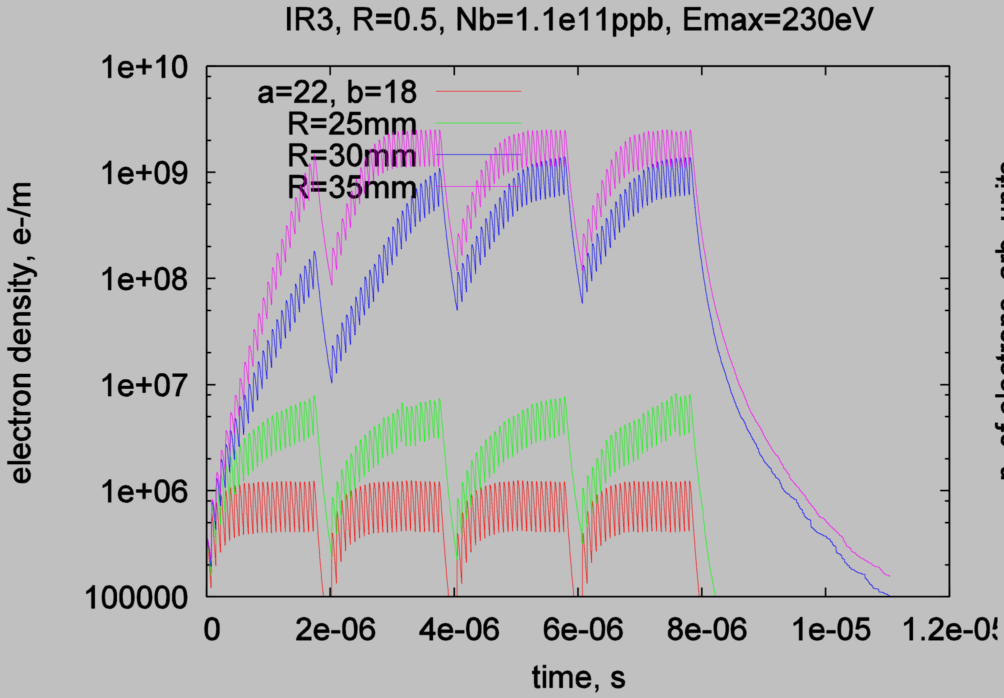


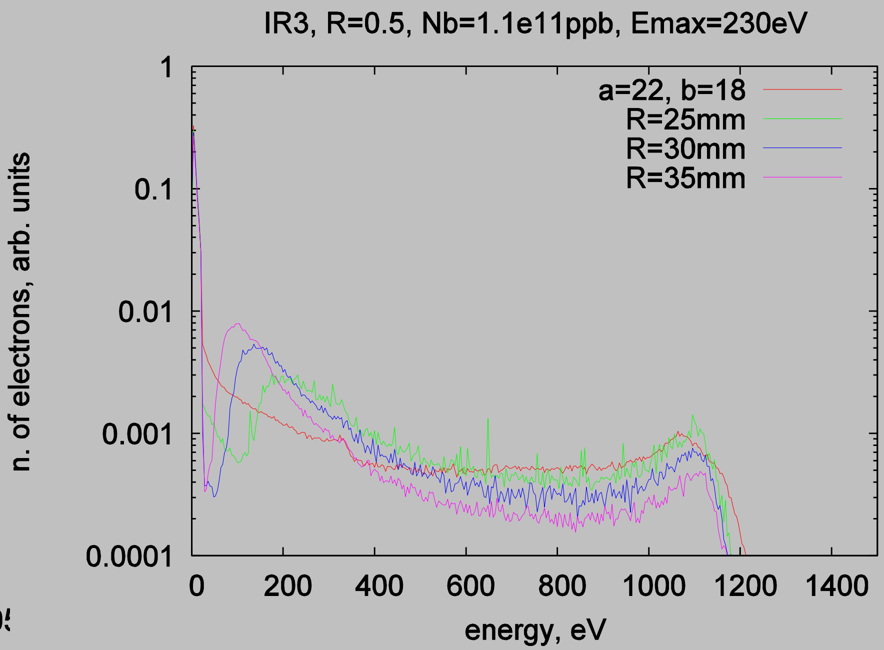
	SEY - threshold
R=0.3	…
R=0.5	~2.6
R=0.7	~2.4

Note that for R=0.3, SEY thresholds > 2.7, which is unrealistically high

Simulations scanning chamber aperture

Comparison between the beam screen geometry (a=22; b=18mm) with a round chamber of different beam pipe radius (from 20 to 35mm)





→Larger beam pipe radius results in a longer survival of low energy electrons
→So, IR3 (30mm) should have lower threshold than Beam Screen

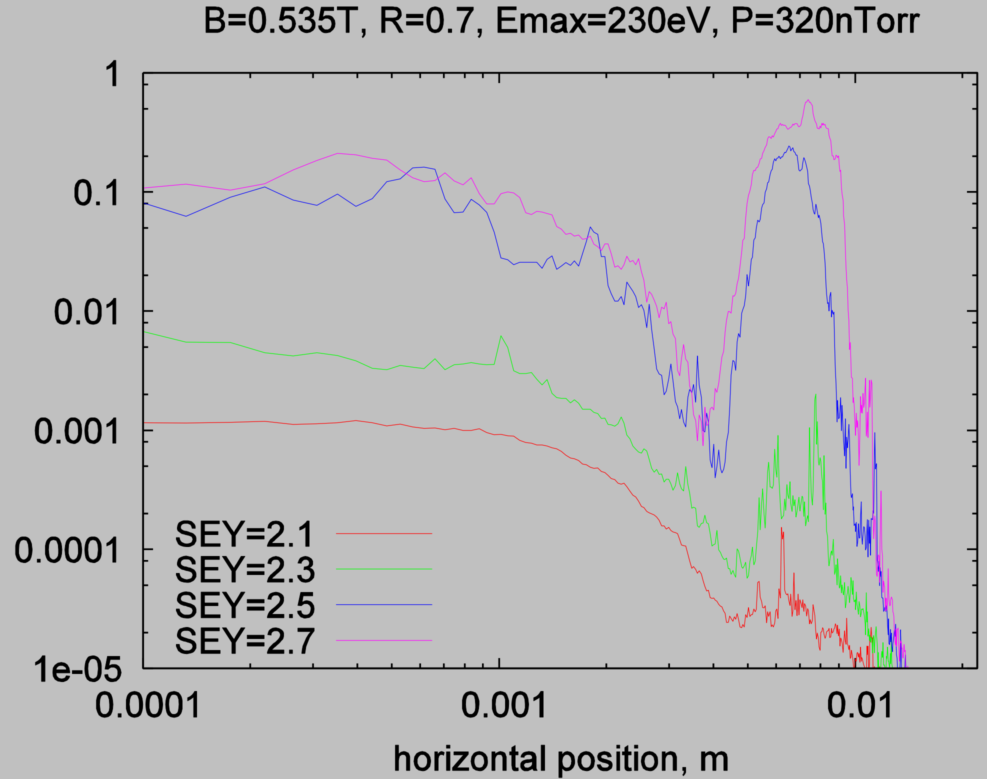
$$t_F = \frac{2b}{\sqrt{2E/m_e}}$$

TOF of an e- at energy E in a chamber of radius=b (neglecting external electric fields)

Simulations at Dipoles, Injection

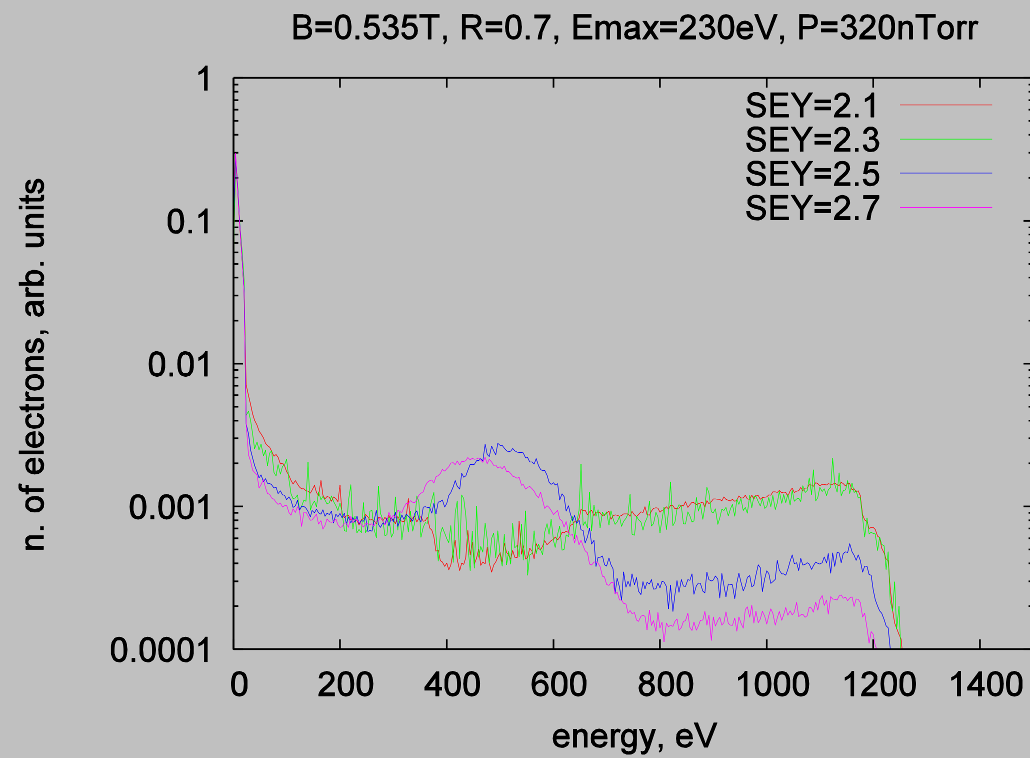
…but that's not all…

In Dipole regions, e- distribution is important because of the scrubbing
In these simulations, we assumed that primary e- are created by gas ionization 90% within the beam core and 10% outside beam core.



Simulations at Dipoles, Injection

…and an interesting situation at the energy spectrum…



The energy spectrum between (400-600)eV shows:

- hump when e-clouds occur
- dip when e-clouds no occur

Does the hump corresponds to the presence of the stripes?

Simulations at Dipoles, Store

ECLOUD simulations main input parameters
Few parameters changed wrt to dipoles @injection

Parameter	symbol [unit]	IR3	Dipole
# pe-macroparticles/bunch	npepb	2000	2000
# of bunches	nbunch	128	~~128~~
# interm. steps/bunch	nbsteps	150	150
# interm. steps/interbunch drift	nisteps	300	~~5000~~
# particles per bunch	protons	1.1e11	1.1e11
bunch spacing	sb [m]	22.49	22.49
bunch length	σ_l [m]	0.118	0.118
Hor beam size	σ_x [mm]	1.50	~~1.51~~
Ver beam size	σ_y [mm]	1.13	~~6.58~~
particle energy	E [GeV]	450	450
circumference	C[m]	27000	2700
primary ph-e emission yield	peeff	0.001	0.001
bunch # until ph-e are emitted	nbini	128	128
max slice # until ph-e are emitted	nsini	150	150
angle cut for the emitted photons	...	.041	.041
energy ph-e, position of peak	epemax [eV]	7.	7.
energy ph-e (sigma distrb.)	epesig [eV]	5.	5.
energy sec. e- (sigma distrb.)	semax [eV]	1.8	1.8
secondary emission yield (yim)	SEY	[1.7 - 2.7]	[1.7 - 2.7]
secondary emission yield for $E \to 0$	R	[0.3 - 0.7	[0.3 - 0.7]
energy for max SEY (yemax)	E_{max} (eV)	230.	230.
Hor Aperture Limitation	xbound [m]	0.03	0.022
Ver Aperture Limitation	ybound [m]	0.03	0.018
Bending field	bfield [T]	1e-7	0.535 / 4.16
initial pressure	P [nTorr]	320.	~~320.~~

64bchs (only 2 batches) @store

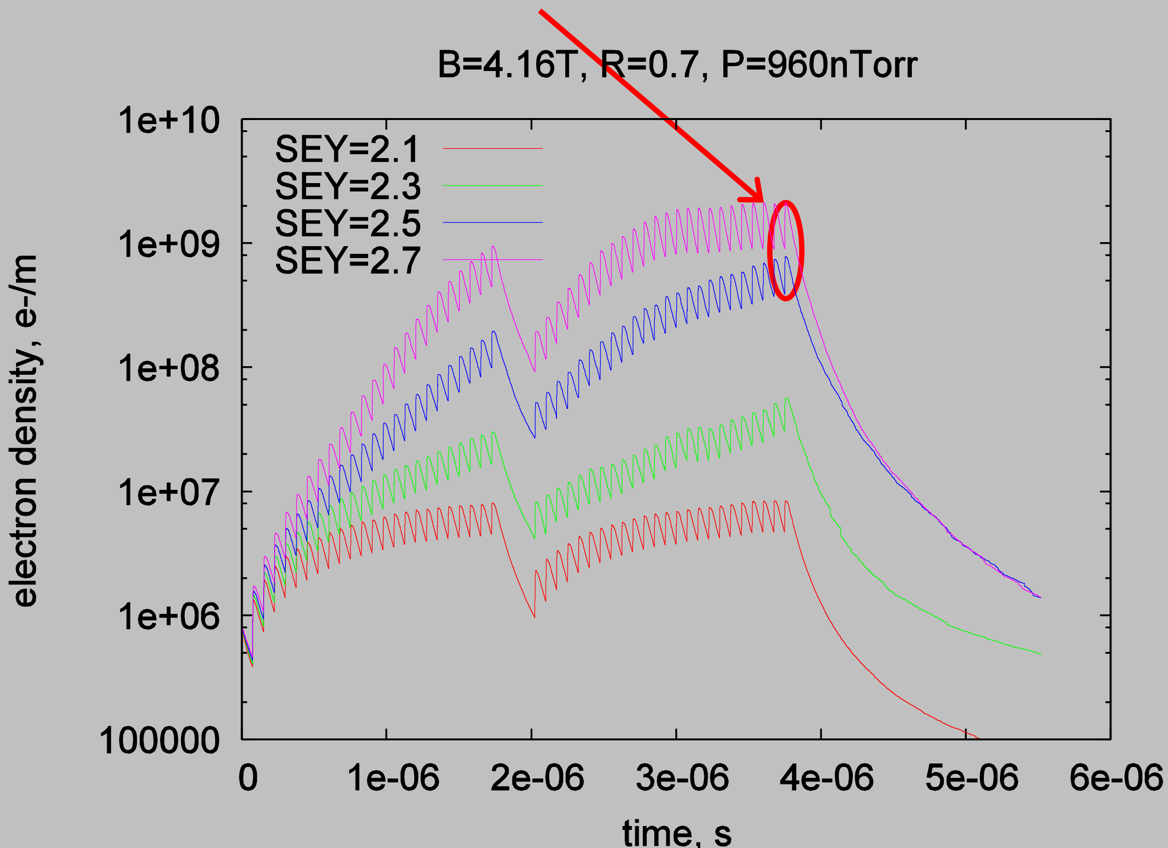
25000 @store

1.39 @store
0.238 @store

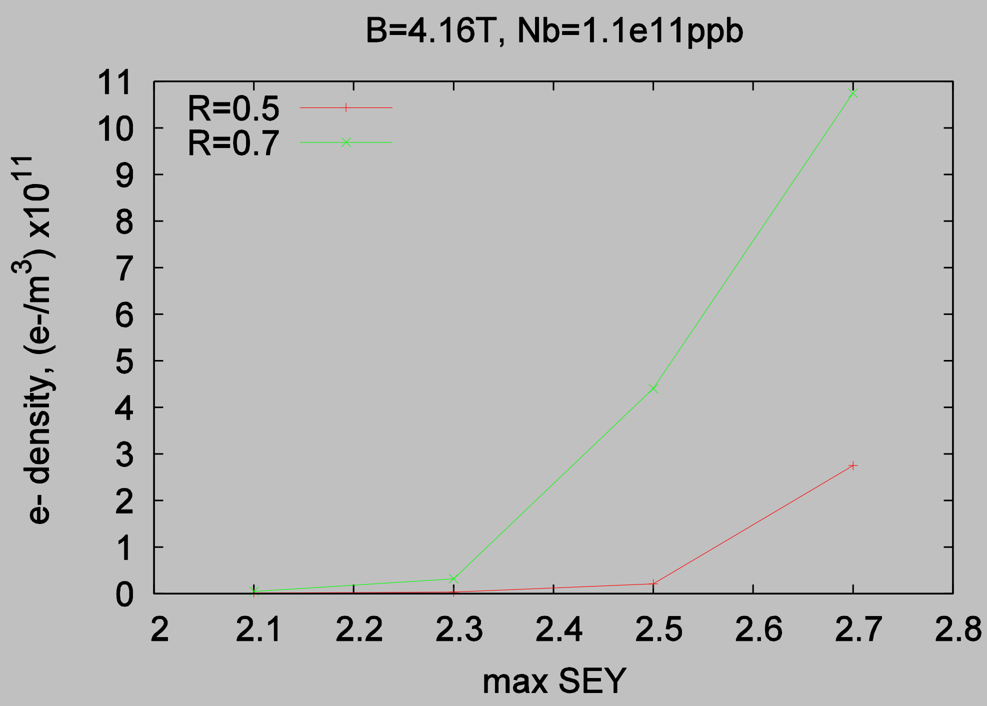
960nTorr @store

Simulations at Dipoles, Store

We follow the same procedure as in IR3 to get e-densities at last bunch passage in the 2nd batch



Simulations at Dipoles, Store



e- density is larger than at injection, but thresholds are roughly the same

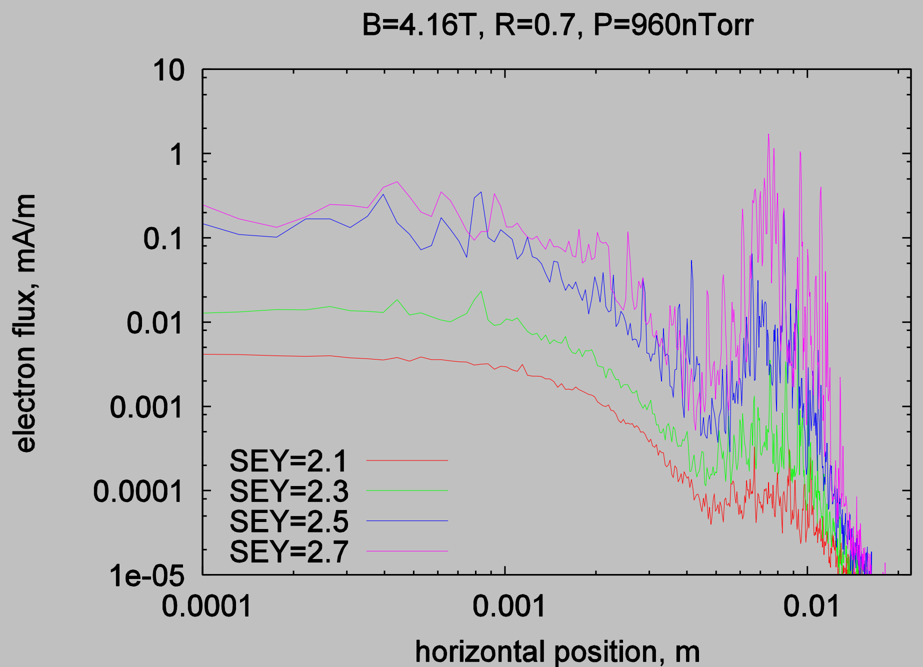
	SEY - threshold
R=0.3	…
R=0.5	~2.6
R=0.7	~2.4

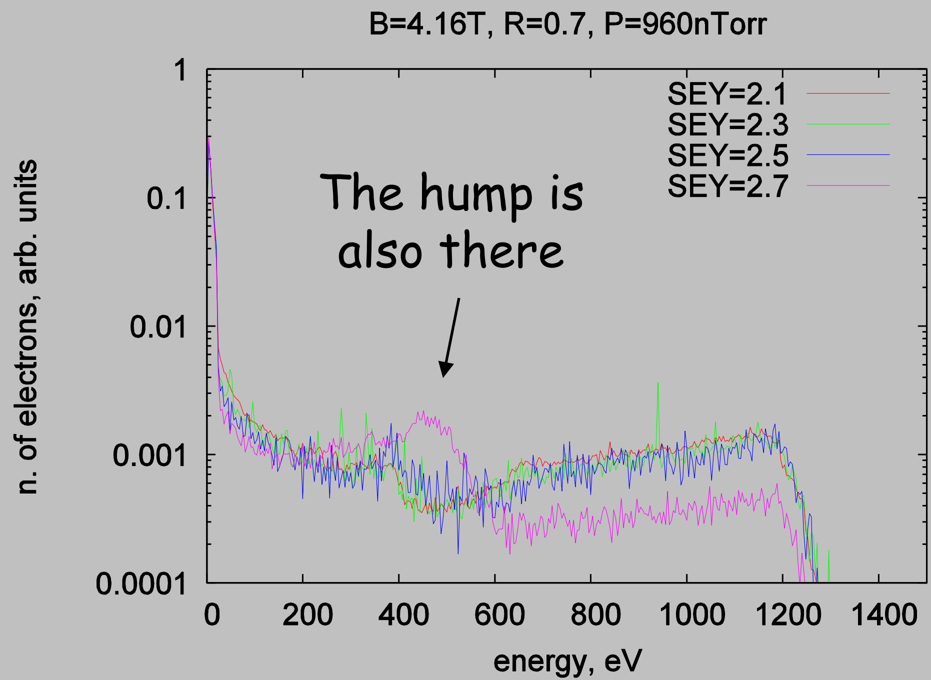
Due to smaller beam size?

Sigma_x,y=(1.51, 0.658) @injection
Sigma_x,y=(1.39, 0.236) @store

Simulations at Dipoles, Store

Hor flux Distribution: stripes are located at similar places wrt to injection conditions





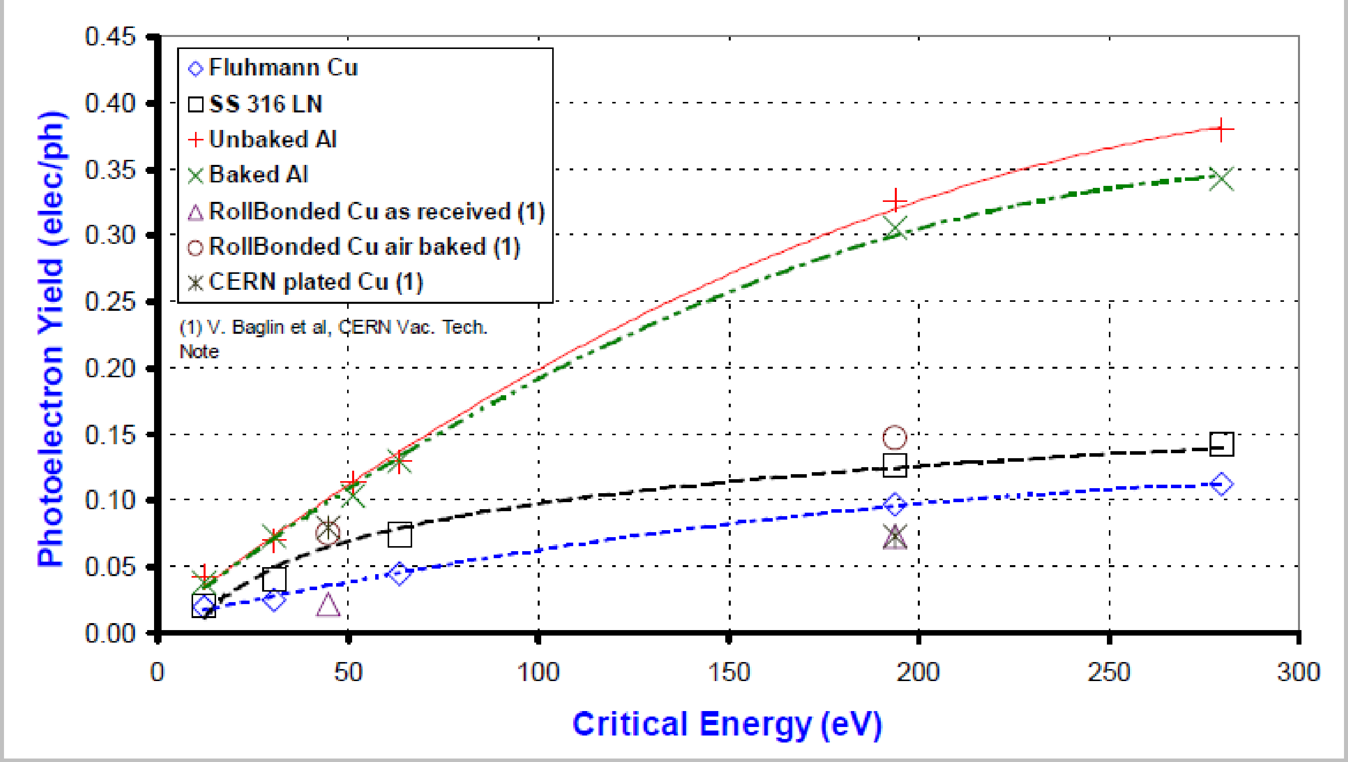
However, recall these simulations have different pressures and only two batches

Dipoles @Store: icoll=0 vs icoll=2

Typically, ECLOUD simulations assume primary electrons from:

gas ionization at injection (at 450GeV, Ec = 0.01eV)
synchrotron radiation at designed store (at 7TeV, Ec=45eV)

At 2011 store (3.5TeV), critical energy = 5.4eV, for which Y*~0.02:



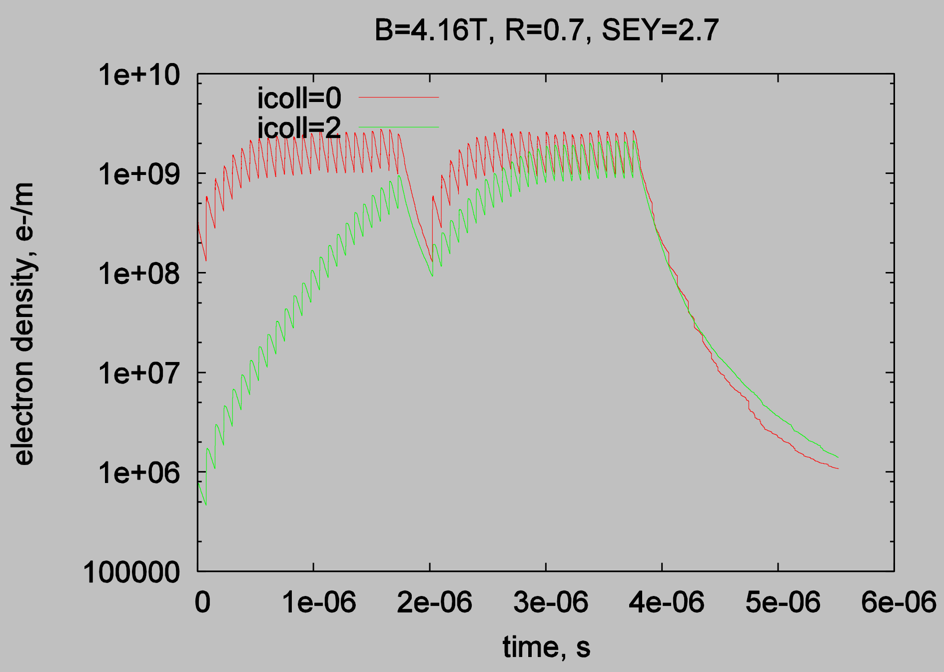
(J. Gomez-Goni, ASEVA Summer School 1999)

Simulations at Dipoles, Store

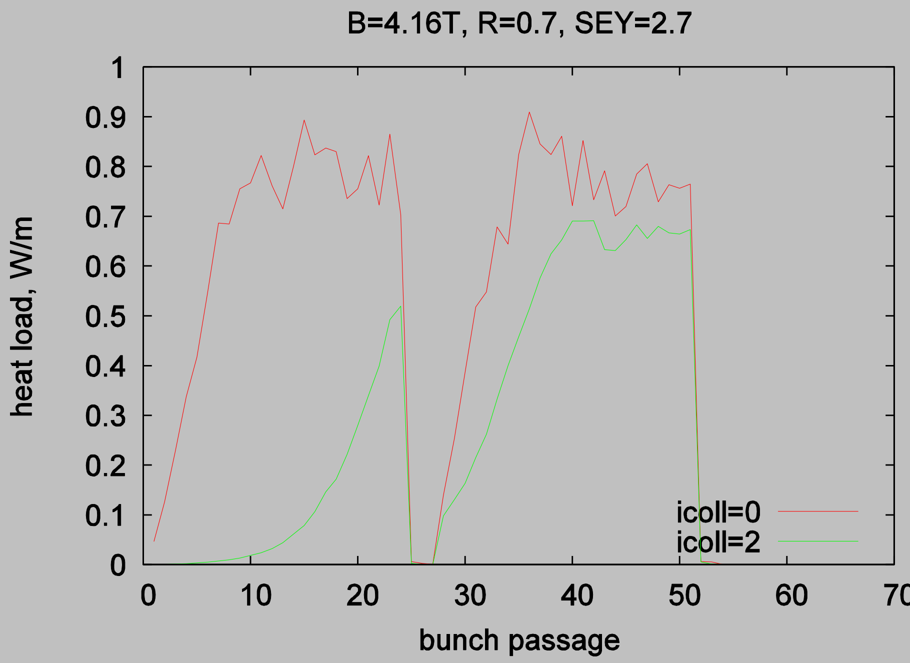
Comparison between primary e- assumed by:

- gas ionization (icoll=2)
- synchrotron radiation (icoll=0, with peeff=0.0016)

e-line density:

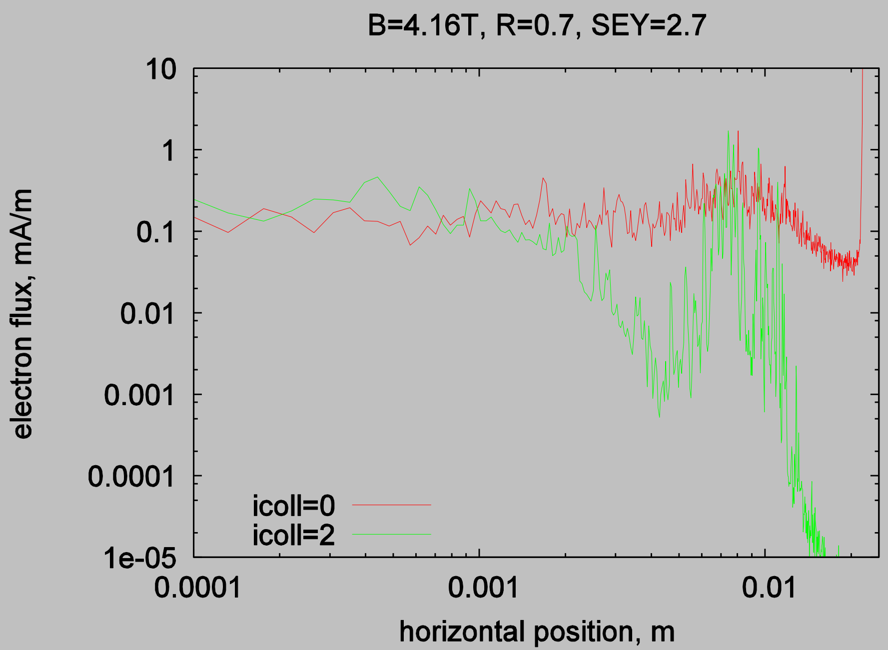


Heat Load:



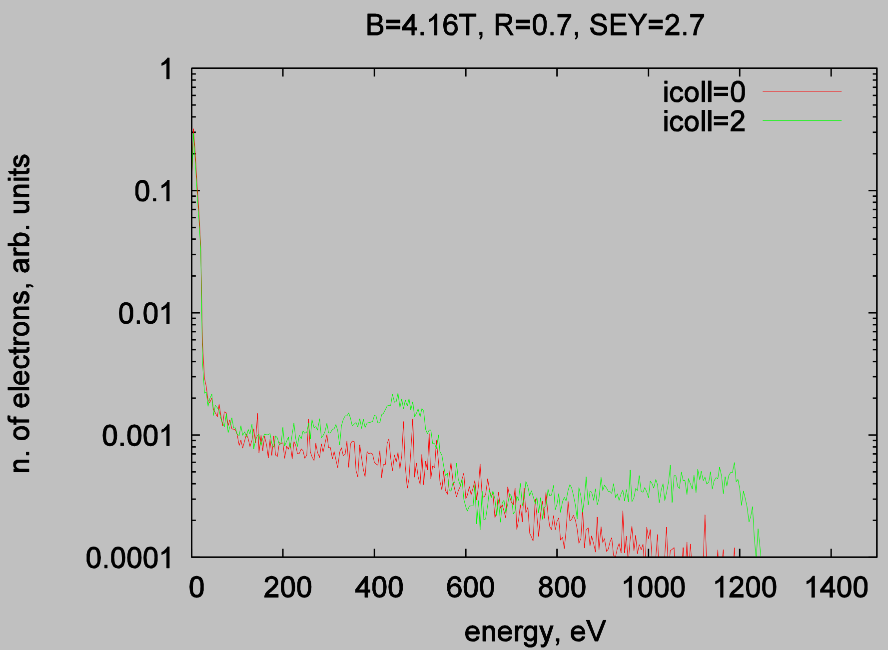
Simulations at Dipoles, Store

Hor flux:



The stripes with sync radiation are less clear (see next)

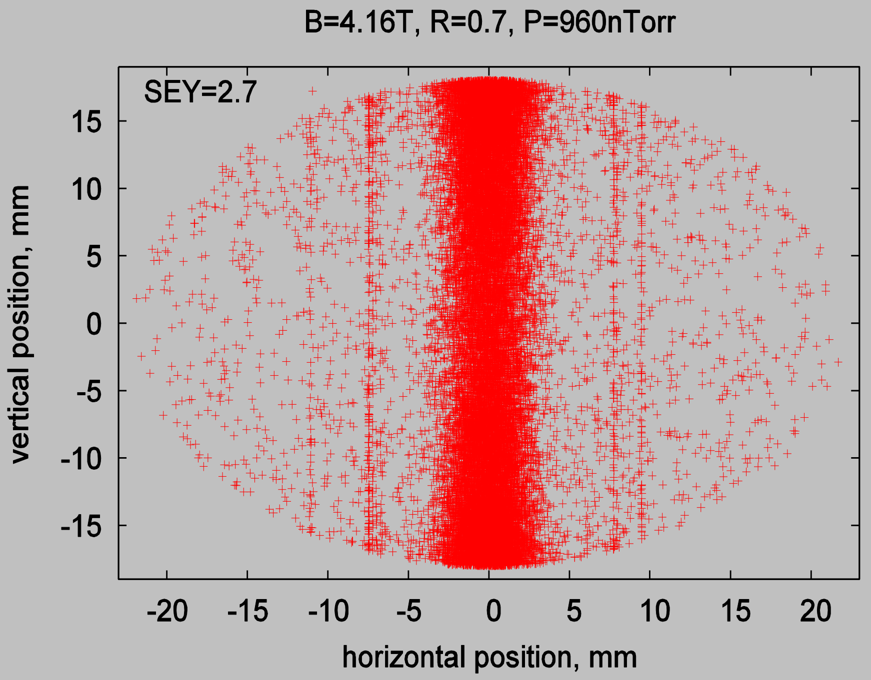
Energy spectrum:



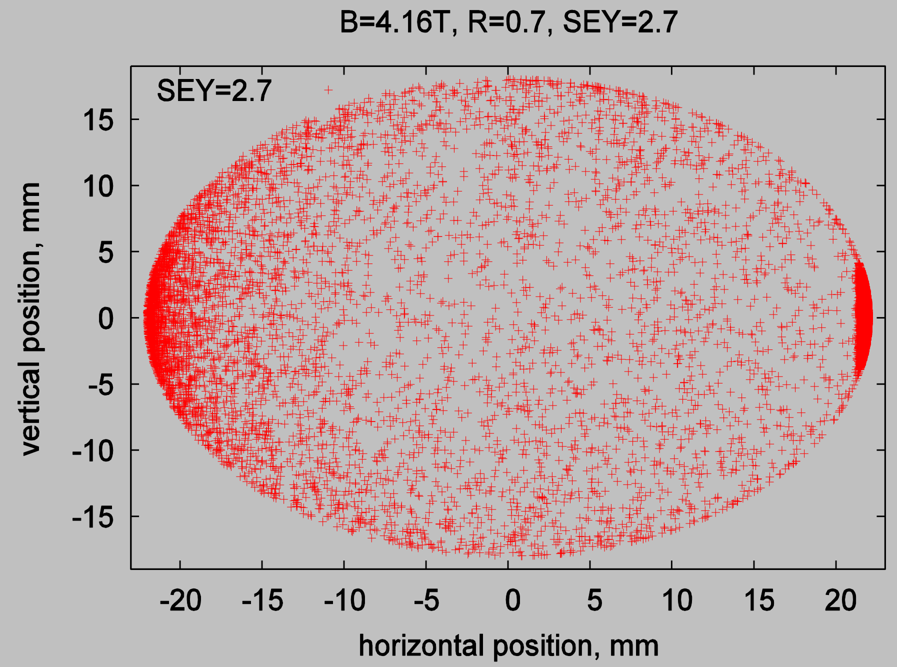
The hump disappears when primary e- are generated by sync. radiation

Simulations at Dipoles, Store

Icoll=2 - Gas ionization



Icoll=0 - Synchrotron Radiation



➔ Scrubbing at injection conditions will be efficient for store conditions?

Conclusions

• SEY thresholds for 75ns bunch spacing were found for feel free regions and dipole at injection and store conditions:

	IR3	Dipole 450 GeV	Dipole 3.5 TeV
R=0.3	~2.6	…	…
R=0.5	~2.4	~2.6	~2.6
R=0.7	~2.2	~2.4	~2.4

• Larger thresholds at dipoles than IR3 (presumably due to smaller apertures)

• Dipole simulations show a hump in the energy spectrum between (400-600) eV, not clear whether these corresponds to the presence of stripes

Conclusions

- Horizontal distribution at dipoles are similar at injection and store, provided that in both cases primary e- are due to gas ionization.

- However, using sync rad as primary source show a different electron distribution in the vacuum chamber. This points out that e-cloud at injection and 50ns might scrub diffs. regions inside the vacuum chamber.

Acknowledgements

- I wish to thank
  - all ABP Section for their invitation to participate in the Workshop and the EuCard/ACCNET for their support
  - D. Einfeld and F. Perez (CELLS) for their comprehension

Extra slides

Decay of an e-cloud

This Annex analyzes the electron density decay after an electron cloud formation. Neglecting the self electric fields, the number of remaining electrons in a *monoenergetic jet* of N_0 electrons after n wall collisions is expressed by

$$N_n = N_0 e^{-nt_F/\tau_d} \ , \tag{B.1}$$

where τ_d refers to the decay time, and t_F is the time of flight between two consecutive wall collisions. Assume now the energy of the "jet" is low (around 2 eV), such that, as shown in Sect. 3.3, the SEY can be interpreted as the elastically reflected probability. The number of electrons after n collisions is then

$$N_n = \delta^n N_0 \ , \tag{B.2}$$

where δ refers to the SEY for low energy electrons. Equating Eqs. B.1 with B.2 leads to

$$\tau_d = \frac{t_F}{-\ln \delta} \ . \tag{B.3}$$

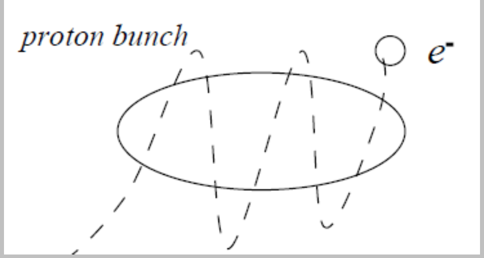
To calculate the time of flight t_F, consider the electron jet only moves in the transverse plane and in the radial direction. In a cylindrical beam pipe with radius b, it then follows that

$$t_F = \frac{2b}{\sqrt{2E/m_e}} \ , \tag{B.4}$$

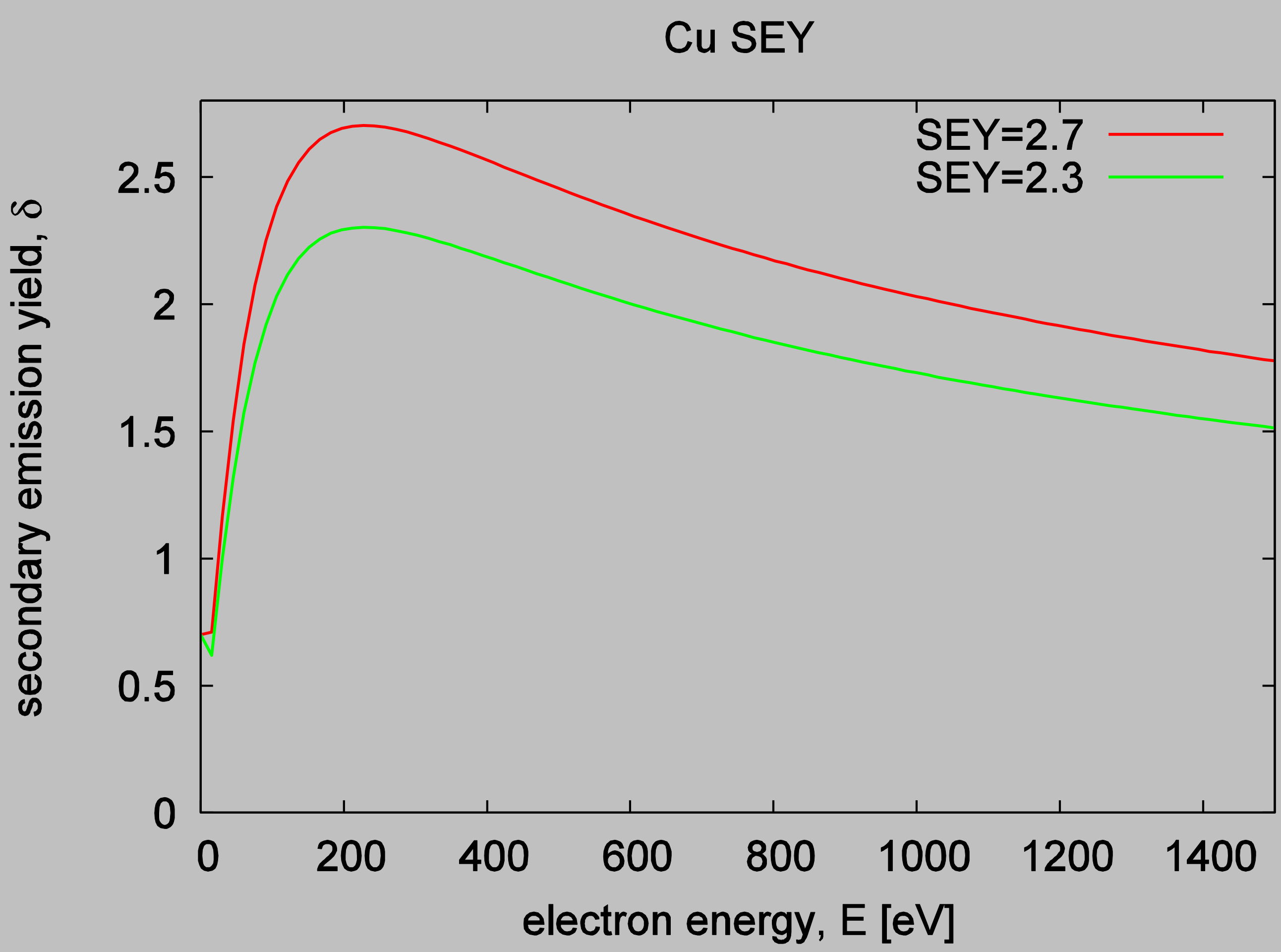
where E is the electron energy, and m_e is the electron mass. Using Eq. B.4, the decay time as a function of the low electron energy is

$$\tau_d = \frac{-\,2b}{\ln \delta \sqrt{2E/m_e}} = \frac{-\,b}{c \ln \delta} \sqrt{\frac{2m_e c^2}{E}} \ . \tag{B.5}$$

Slices during bunch passage shall be enough to follow e- oscillations inside bunch:



$$\omega_e = c\sqrt{\frac{2\pi Z r_e N_b}{\sigma_r^2 \sigma_z}}$$



Cu SEY
SEY=2.7
SEY=2.3
secondary emission yield, δ
0
0.5
1
1.5
2
2.5
0
200
400
600
800
1000
1200
1400
electron energy, E [eV]