ILC DR's: benefit of the antechamber
(or: antechamber vs. SEY)

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NOTE: the results presented here are the same as those I presented at Mauro's ecloud working group meetings on March 10 and September 22, 2010

Summary

- Essential simulation input parameters
- POSINST code features
- Results obtained for:
  - — DC04 (t_b=6 ns) and DSB3 (t_b=6 or 3 ns)
  - — peak SEY: δ_{max}=0, 0.9, 1.0, ..., 1.4
  - — field-free region and dipole bend
  - — with and without antechamber

  } in all combinations
- Conclusions

Results are consistent with Theo Demma's, although a detailed comparison remains to be carried out

THE FINE PRINT: this is work in progress. The results presented here are based on one set of input parameters, albeit believed to be realistic. Computational parameters have been only partially exercised to establish numerical stability.

Simulation input parameters for DC04 & DSB3
(mostly from M. Pivi, 17 Nov. 2009 et. seq.)

Beam energy	E_b=5 GeV
Bunch population	N_b=2x10^{10}
RMS bunch length	σ_z=5 mm
RF frequency	650 MHz
Bunch train for t_b=6.154 ns	45 bunches (spacing = 4 buckets)
Bunch train for t_b=3.077 ns	45 bunches (spacing = 2 buckets)
Gap length between trains	t_b=6 ns: 15x4=60 buckets; t_b=3 ns: 15x2=30 buckets
Fill pattern simulated	5 x (train+gap)
Chamber radius	a=2.5 cm
Antechamber full height (if present)	h=1 cm
Antechamber clearing efficiency	η=98%
Quantum efficiency of chamber surface	QE=0.1
Radiation vertical spot size at wall	σ_y=1 mm
Photon reflectivity	R=0.9 (*)
Peak SEY values explored	δ_{max}=0, 0.9, 1.0, 1.1, 1.2, 1.3,1.4
Electron energy at δ_{max}	E_{max}=296 eV
SEY at E=0	$\delta(0)$=0.31xδ_{max}

(*) This implies that, if there is no antechamber, a fraction 1–R=0.1 of the photoelectrons are generated localized at the right "edge" of the chamber. If there is an antechamber, a fraction 1–R=5.5x10^{-8} of the photoelectrons are generated localized at the right "edge" of the chamber (just above and below the antechamber opening).

Input parameters that vary from DC04 to DSB3

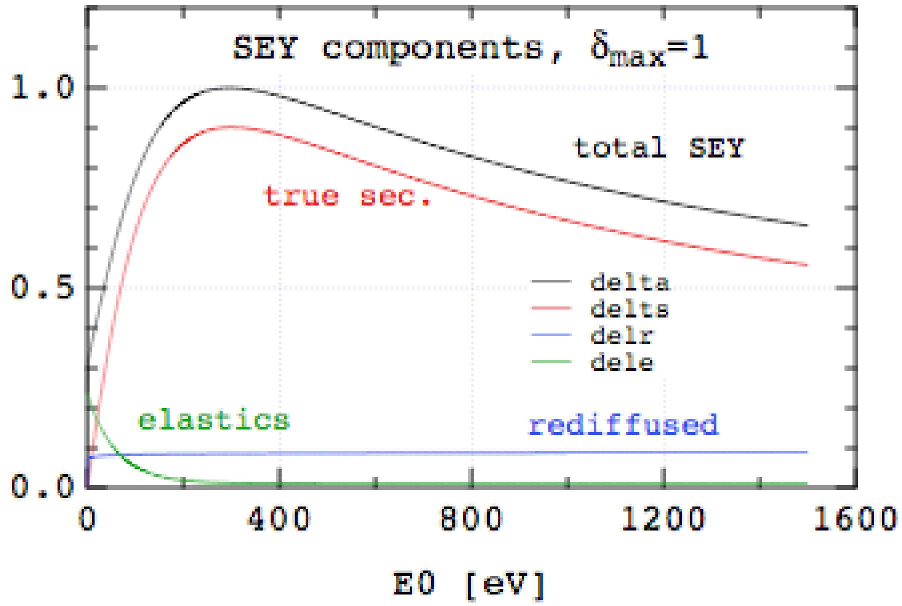
	DC04		DSB3	
Circumference [m]	6476.4		3238.2	
Harmonic number	14042		7021	
n'_γ [photons/e^+/m] (radiated γ's)	0.33		0.47	
n'_e [photo.-el./e^+/m] (without antech.)	0.033		0.047	
n'_e [photo.-el./e^+/m] (with antech.)	0.66×10^{-3}		0.94×10^{-3}	
	field-free	**bend**	**field-free**	**bend**
Tr. bunch size (σ_x,σ_y) [μm]	(360,6)	(260,6)	(270,6)	(110,5)
Dipole field B [T]	0	0.27	0	0.36

NB: $n'_e = n'_\gamma$ x (QE) x $(1-\eta)$, where η=0.98 is the antechamber clearing efficiency

Computational parameters for all cases

Bunch profile	3D gaussian
Full bunch length	$5\sigma_z$
Integration time step during bunch	$\Delta t = 1.25\text{x}10^{-11}$ s (= 9 kicks/bunch)
Integration time step if no bunch present	$\Delta t = (2.4–2.5)\text{x}10^{-11}$ s
Space-charge grid	64x64
Grid cell size	(5 cm)/64=781 μm
Macro-photoelectrons per bunch passage	1,000
Max. number of macroparticles allowed	20,000

SEY components



— Based on TiN fits (M. Pivi)

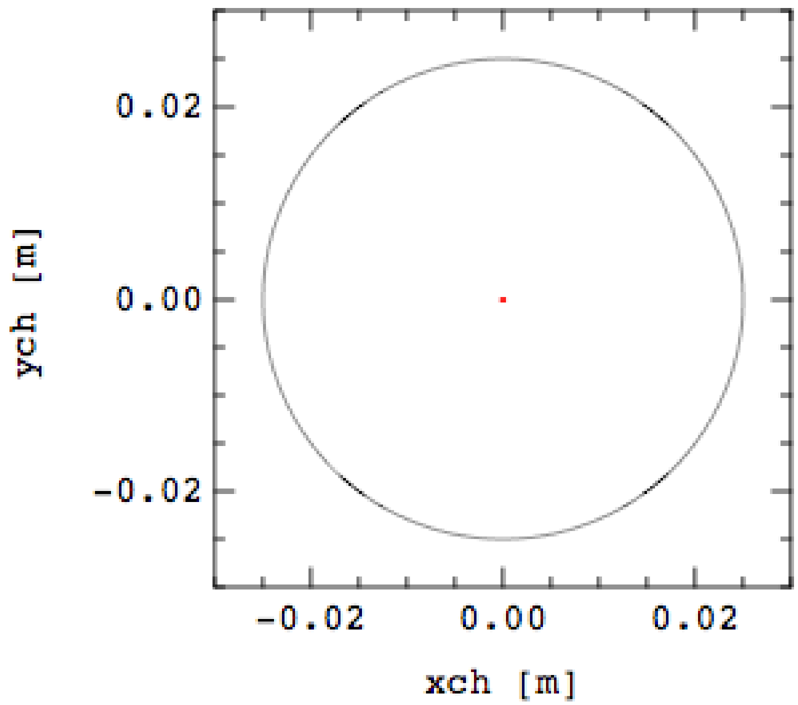
— Explored δ_{max}=0,0.9–1.4

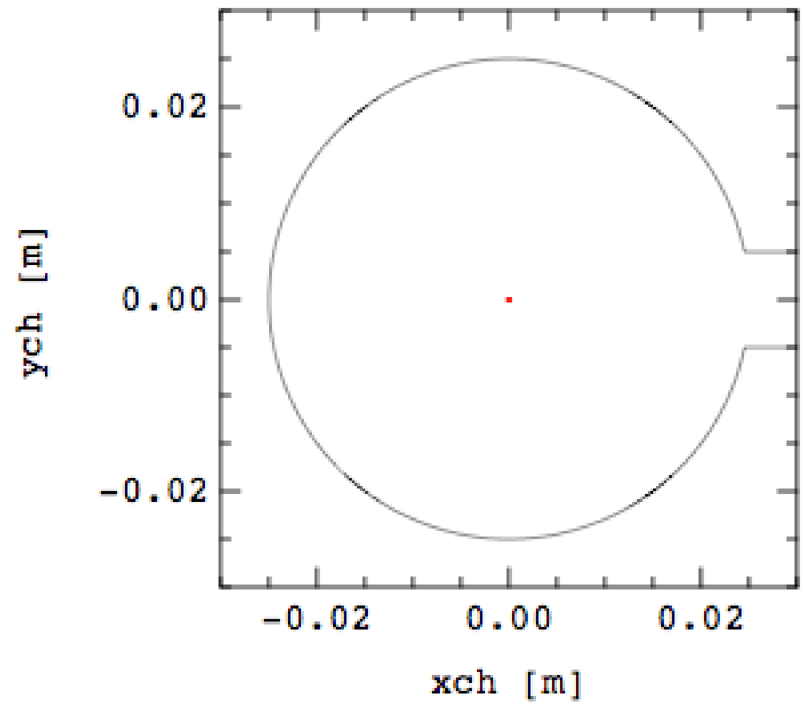
- keeping E_{max}=296 eV fixed while scaling $\delta(0)\approx0.31 \times \delta_{max}$

— NB: when changing δ_{max} away from δ_{max}=1, scale all 3 components (TS, R, E) by the same factor

- realism of this scaling is subject to debate

Chamber cross-section
without and with antechamber





"POSINST" code build-up simulations

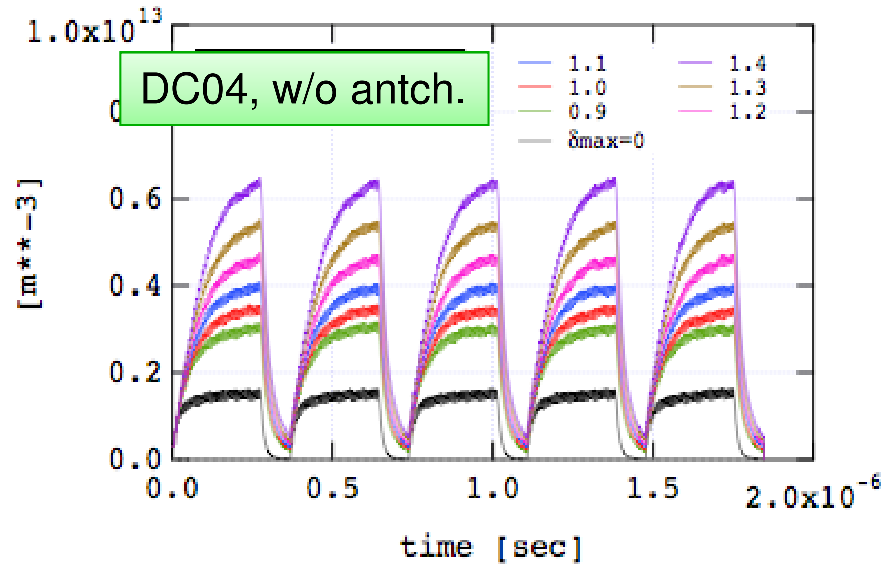
- Simulate individual sections of the ring, one at a time
  - —Field-free or dipole bend
    - Round pipe, a=2.5 cm, with/without antechamber of FH=1 cm
- Compute instantaneous and average ecloud density and many other quantities over 5 trains of 45 bunches each
  - —this is long enough for sensible time averages
- Use actual values for N_b, σ_x, σ_y, σ_z
- Use actual chamber geometry

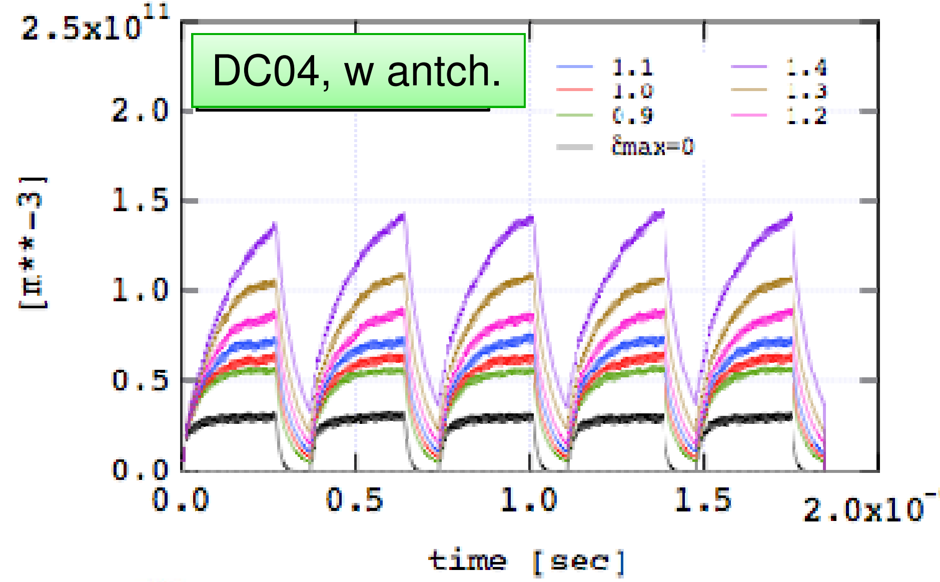
Results

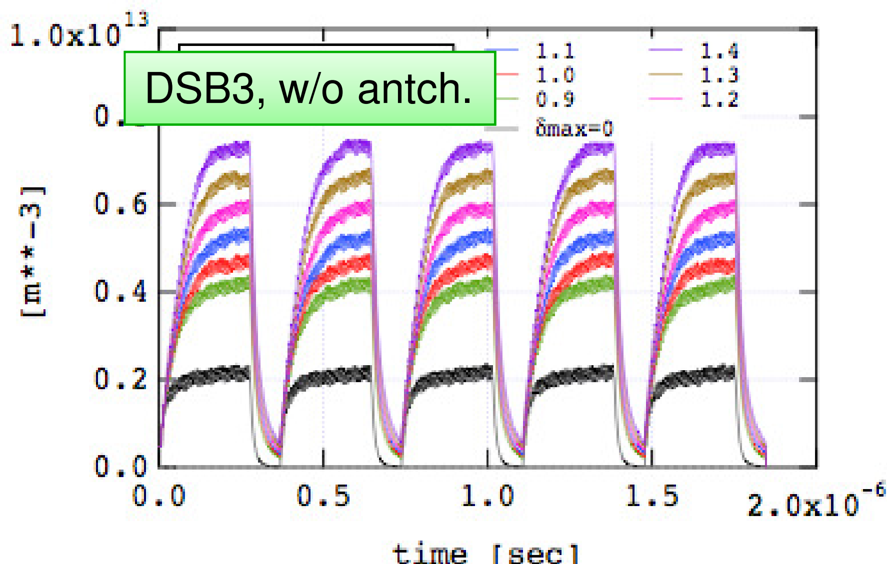
- Build up
  - —Density vs. time
- Time-averages vs δ_{max}
  - —Aver. density (time and space)
  - —Density in front of bunch within the 10-σ beam ellipse
    - NB: “front of bunch” is defined to be $\Delta z=2.5\sigma_z$ from center
- Everything else that POSINST computes (not shown here) is available by request

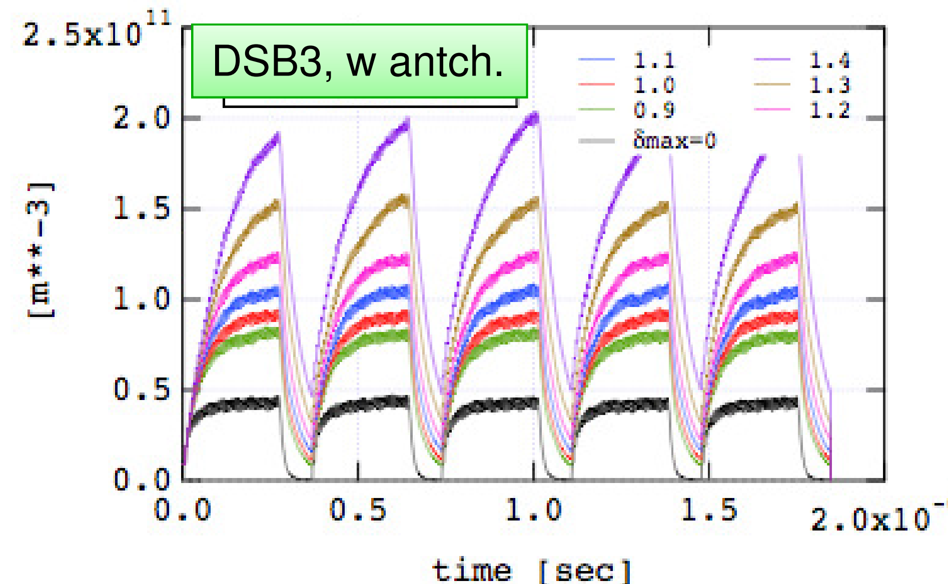
Field-free region build-up, t_b=6 ns

space-averaged ecloud density



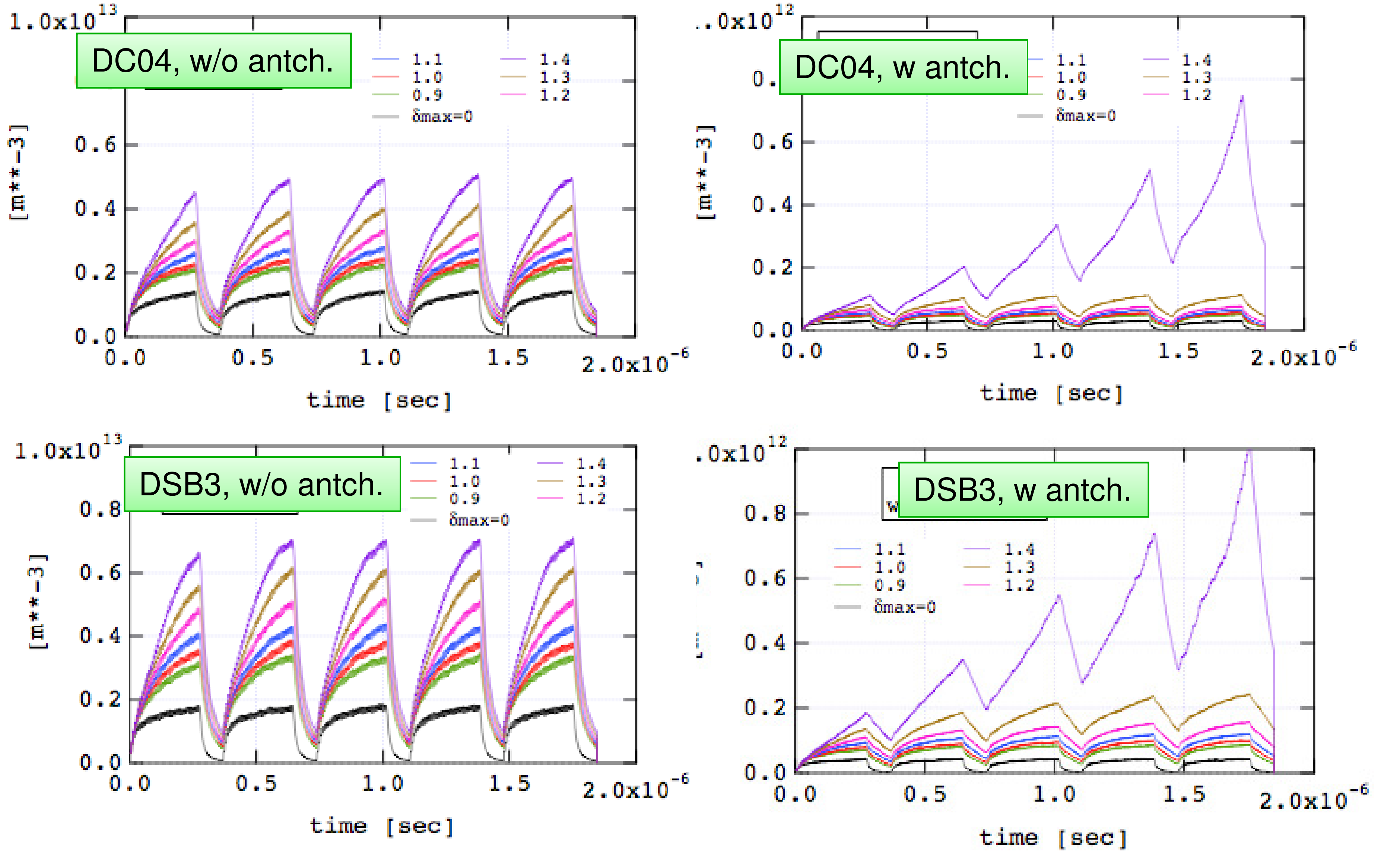






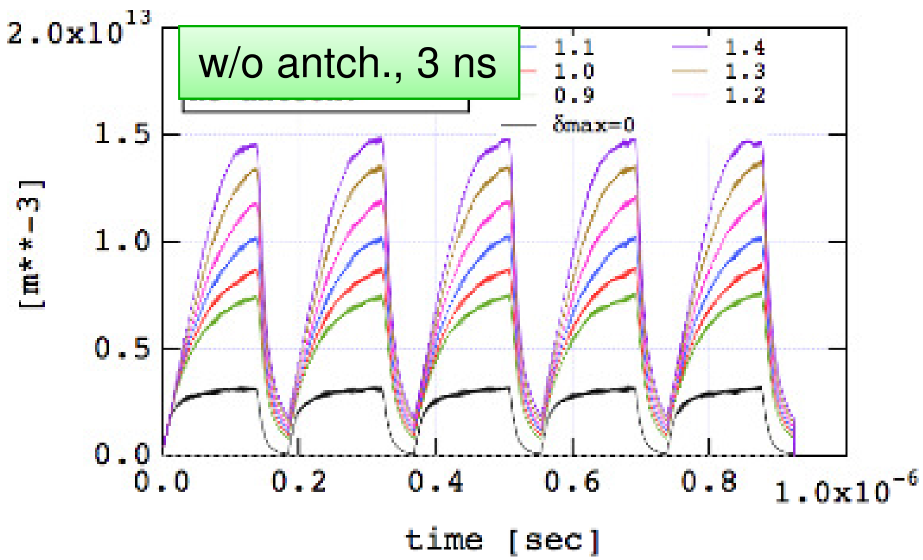
Bending magnet build-up, t_b=6 ns

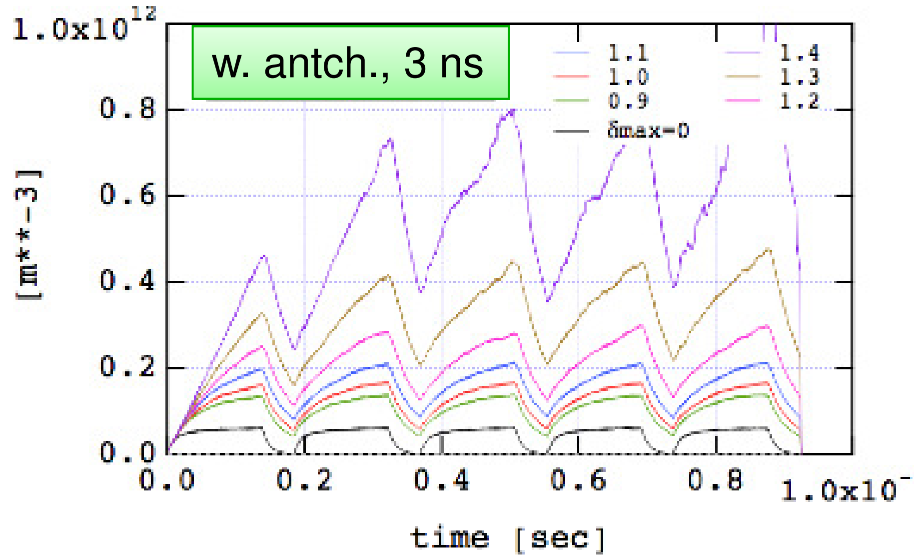
space-averaged ecloud density

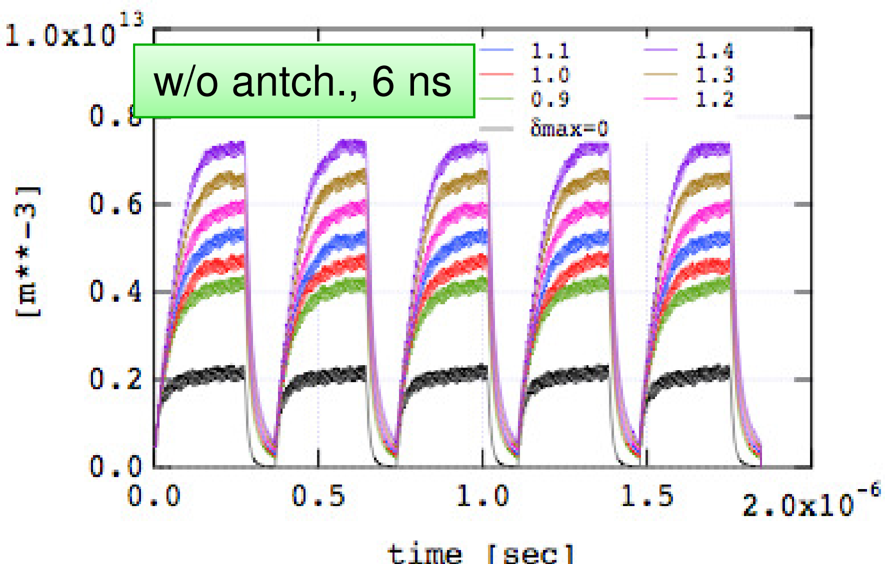


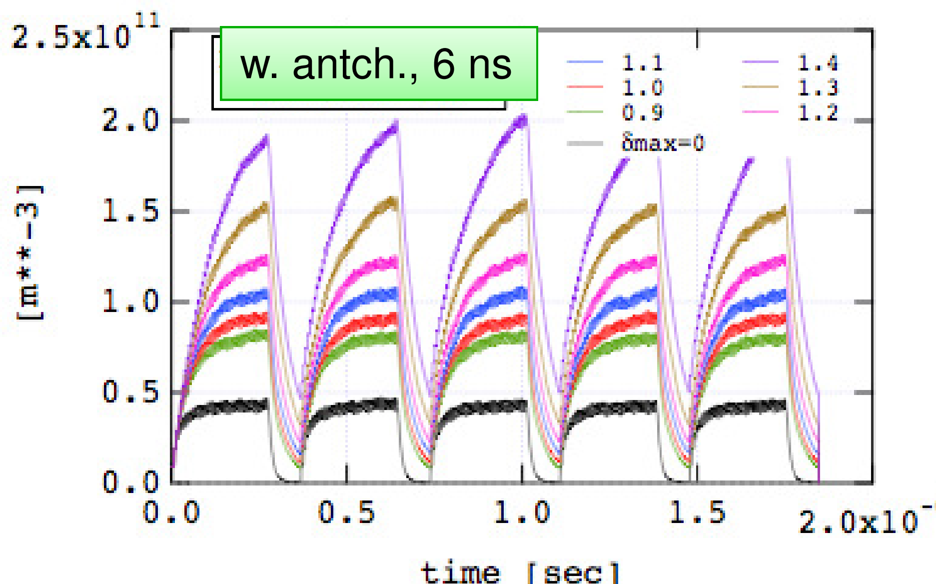
Field-free region build-up, DSB3

space-averaged ecloud density



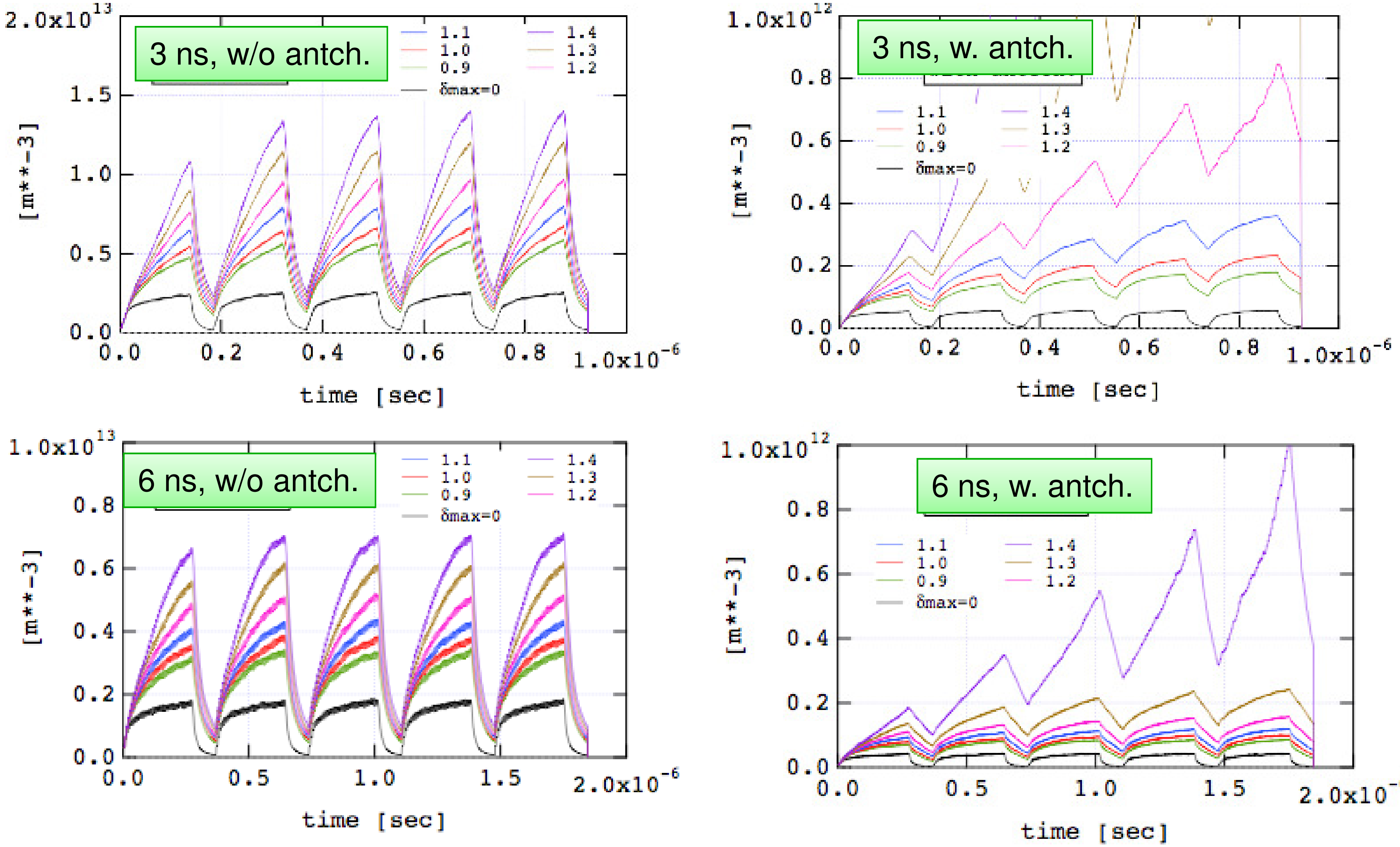






Bending magnet build-up, DSB3

space-averaged ecloud density



Overall n_e at saturation(*), t_b=6 ns

units: $10^{12}\ m^{-3}$

	DC04				DSB3			
	field-free		bend		field-free		bend	
δ_{max}	antch.	no antch	antch.	no antch	antch.	no antch	antch.	no antch
0	0.031	1.5	0.032	1.4	0.044	2.2	0.045	1.8
0.9	0.056	3.0	0.054	2.2	0.081	4.3	0.090	3.3
1.0	0.064	3.4	0.058	2.4	0.092	4.6	0.10	3.7
1.1	0.073	3.9	0.065	2.8	0.10	5.3	0.12	4.3
1.2	0.087	4.7	0.079	3.2	0.12	6.0	0.16	5.1
1.3	0.10	5.4	0.11	4.1	0.15	6.6	>0.2	6.1
1.4	0.14	6.3	>0.8	5.0	0.20	7.3	>1	7.0

(*) "Saturation" means here: "at the end of the last (5^{th}) train of bunches"

n_e within 10 beam σ's at saturation, averaged over bunch length, t_b=6 ns(*)

units: 10^{12} m^{-3}

	DC04				DSB3			
	field-free		bend		field-free		bend	
δ_{max}	antch.	no antch	antch.	no antch	antch.	no antch	antch.	no antch
0	0.08	5.0	0.01	0.6	0.12	9	0.015	0.7
0.9	0.18	10	0.035	1.6	0.22	14	0.03	1.5
1.0	0.20	11	0.046	1.6	0.26	14	0.04	2.0
1.1	0.22	14	0.065	3.1	0.31	19	0.09	2.3
1.2	0.25	15	0.11	4.5	0.41	20	0.05	3.0
1.3	0.35	16	0.25	6.0	0.48	23	0.2	3.5
1.4	0.44	20	>4	8.0	0.62	24	>0.6	4.5

(*) "Saturation" means here: "at the end of the last (5^{th}) train of bunches." NB.: these data typically have large statistical errors, ~50%.

n_e at bunch front within 10 beam σ's, t_b=6 ns(*)

units: 10^{12} m^{-3}

	DC04				DSB3			
	field-free		bend		field-free		bend	
δ_{max}	antch.	no antch	antch.	no antch	antch.	no antch	antch.	no antch
0	0.024	1.2	0.023	1.0	0.034	1.7	0.031	1.3
0.9	0.044	2.3	0.038	1.6	0.063	3.2	0.063	2.4
1.0	0.050	2.6	0.042	1.8	0.070	3.6	0.073	2.6
1.1	0.057	3.0	0.048	1.9	0.081	4.0	0.086	2.9
1.2	0.066	3.4	0.056	2.2	0.94	4.5	0.10	3.4
1.3	0.080	3.9	0.079	2.6	0.11	5.0	>0.2	3.9
1.4	0.10	4.5	>0.3	3.1	0.14	5.6	>0.3	4.6

(*) Note: these simulated data have large errors (~40%) due to statistical noise. Within these errors, there is no difference between the time-averaged density and the instantaneous density at the last bunch in the train

DSB3: overall n_e at saturation(*)

units: 10^{12} m^{-3}

	tb=3 ns				tb=6 ns			
	field-free		bend		field-free		bend	
δ_{max}	antch.	no antch	antch.	no antch	antch.	no antch	antch.	no antch
0	0.06	3.2	0.06	2.5	0.044	2.2	0.045	1.8
0.9	0.14	7.7	0.18	5.8	0.081	4.3	0.090	3.3
1.0	0.17	9.0	0.23	6.7	0.092	4.6	0.10	3.7
1.1	0.22	10.1	0.36	7.9	0.10	5.3	0.12	4.3
1.2	0.3	12.1	>0.85	9.6	0.12	6.0	0.16	5.1
1.3	0.5	13.8	>2.75	12	0.15	6.6	>0.2	6.1
1.4	>1.2	15	>5	14	0.20	7.3	>1	7.0

(*) "Saturation" means here: "at the end of the last, ie., 5th, train of bunches"

n_e within 10 beam σ's at saturation(*)

units: 10^{12} m^{-3}

	tb=3 ns				tb=6 ns			
	field-free		bend		field-free		bend	
δ_{max}	antch.	no antch	antch.	no antch	antch.	no antch	antch.	no antch
0	0.2	10	0.02	0.8	0.12	9	0.015	0.7
0.9	0.5	25	0.06	2	0.22	14	0.03	1.5
1.0	0.5	28	0.07	2.2	0.26	14	0.04	2.0
1.1	0.7	30	0.12	3	0.31	19	0.09	2.3
1.2	0.75	30	0.2	3.5	0.41	20	0.05	3.0
1.3	>1.4	35	>0.3	4	0.48	23	0.2	3.5
1.4	>3	40	>0.3	5	0.62	24	>0.6	4.5

(*) "Saturation" means here: "at the end of the last, ie., 5th, train of bunches." NB.: these data typically have large statistical errors, ~50%.

DSB3: n_e at bunch front within 10 beam σ's (*)

units: 10^{12} m^{-3}

	tb=3 ns				tb=6 ns			
	field-free		**bend**		**field-free**		**bend**	
δ_{max}	antch.	no antch	antch.	no antch	antch.	no antch	antch.	no antch
0	0.1	5	0.02	0.6	0.034	1.7	0.031	1.3
0.9	0.25	10	0.04	1.6	0.063	3.2	0.063	2.4
1.0	0.28	11	0.05	2.3	0.070	3.6	0.073	2.6
1.1	0.35	13	0.1	1.9	0.081	4.0	0.086	2.9
1.2	0.45	15	0.12	3.0	0.94	4.5	0.10	3.4
1.3	0.64	16	0.23	3.3	0.11	5.0	>0.2	3.9
1.4	>1.2	16	>0.7	4.4	0.14	5.6	>0.3	4.6

(*) Note: these simulated data have large errors (~50%) due to statistical noise. Within these errors, there is no difference between the time-averaged density and the instantaneous density at the last bunch in the train

Conclusions

- Generally, n_e in DSB3 is larger than in DC04 by 10–20%
- 10-σ front-bunch-density is comparable to aver. n_e (within factor 2 or less)
- If no antechamber:
  - — n_e has a generally smooth, monotonic dependence on δ_{max} in the range examined
  - — n_e is ~2x higher for t_b=3 ns than for t_b=6 ns
- With antechamber:
  - n_e has a 1st-order phase transition as a f(δ_{max})
    - critical value is $\delta_{max}\approx$1.0–1.3 (see table below)
    - If δ_{max} is below critical value, antechamber reduces n_e by factor ~40 relative to no-antechamber case
    - n_e is below instability threshold ~5x10^{11} m^{-3} (check w/Mauro) ???
    - if δ_{max} exceeds the critical value, antechamber offers no protection

Critical δ_{max}							
DC04				DSB3			
tb=3 ns		tb=6 ns		tb=3 ns		tb=6 ns	
f.f.	bend	f.f.	bend	f.f.	bend	f.f.	bend
(*)	(*)	>1.4	~1.3	~1.3	~1.1	>1.4	~1.2

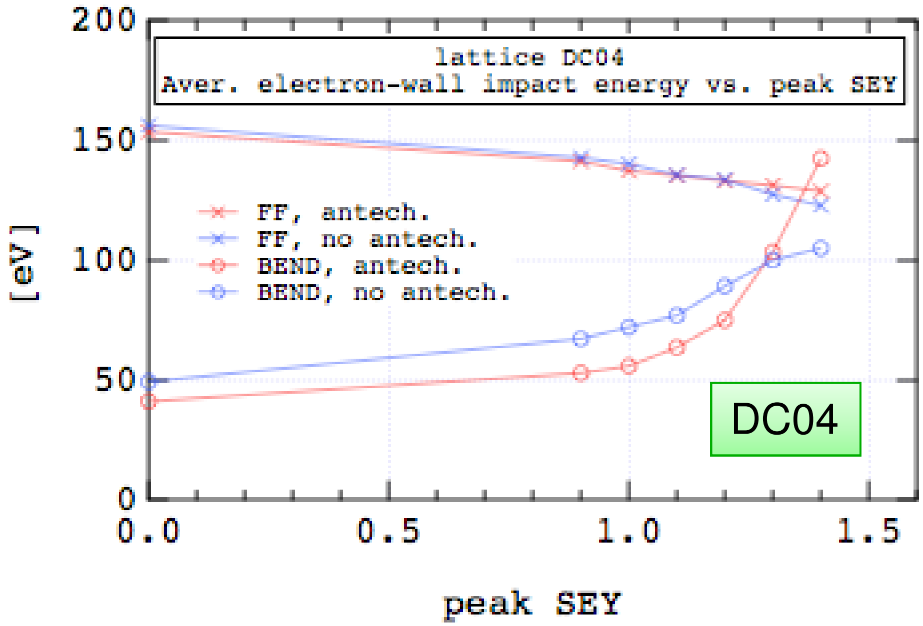
(*) not done

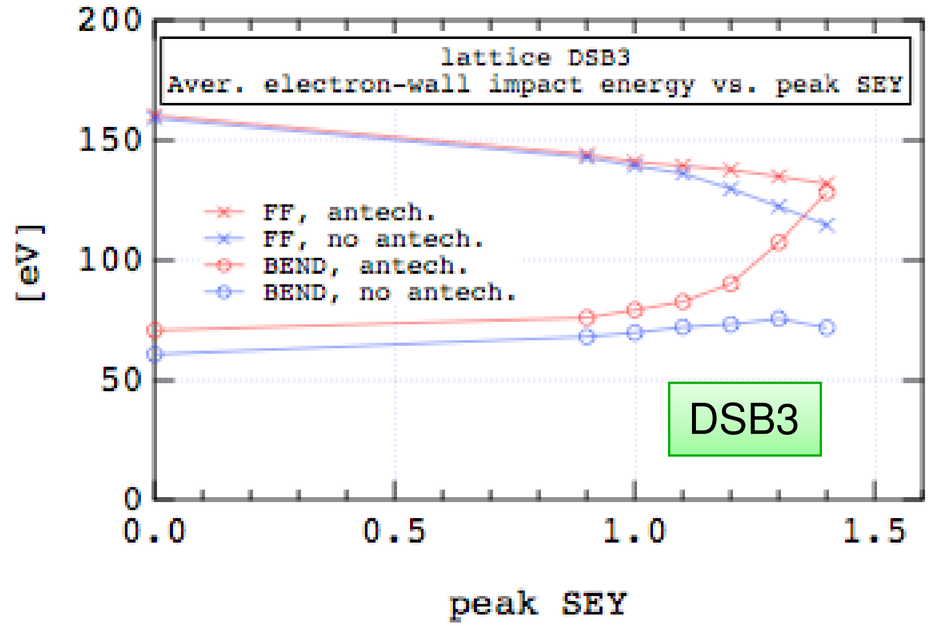
Caveats

- Sensitivity to details of SEY not explored, except for δ_{max}
  - — It seems desirable to at least vary E_{max} by ±20% and see what happens
  - — Ditto for the SEY relative composition TS/R/E
- Sensitivity to antechamber height (h) not explored
  - — Phase diagram (h-δ_{max}) would be interesting
- Numerical convergence partly checked
  - — If $\Delta t \rightarrow 3\Delta t$, results do not change much, except for bends with antechamber and large δ_{max} (these are the "runaway cases")
  - — Dependence on space-charge grid not checked
    - But 64x64 has given quite stable results in other cases
  - — Ditto for no. of macroparticles
- Reflectivity parameter R not exercised
  - — But high values (like R=0.9, used in all cases here) tends to yield pessimistic (ie. higher) values for n_e than low R, especially for bends
- <u>Not yet done</u>: quads, wigglers, and other regions of the machine

Extra material

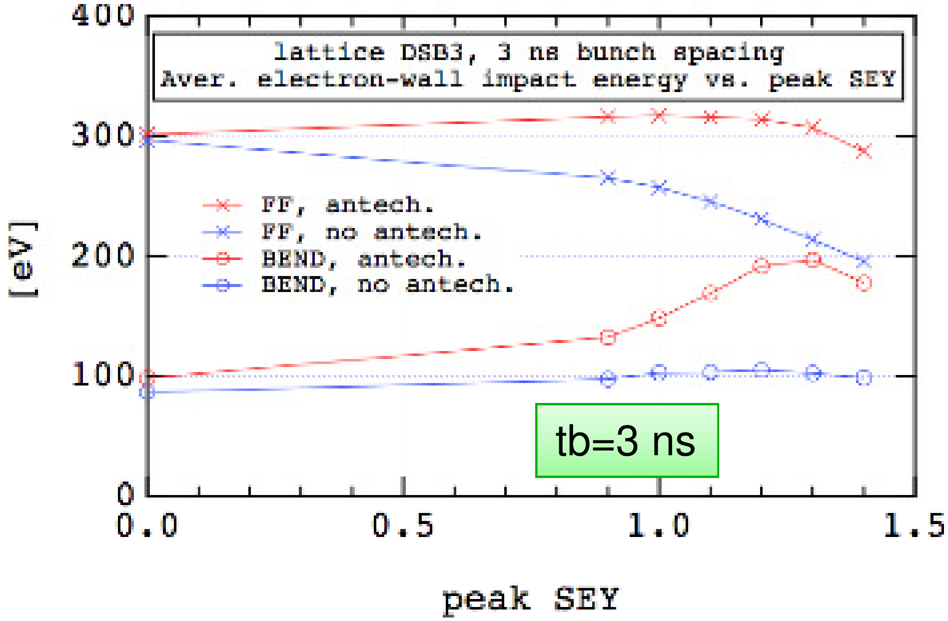
t_b=6 ns: aver. e^--wall impact energy E_w

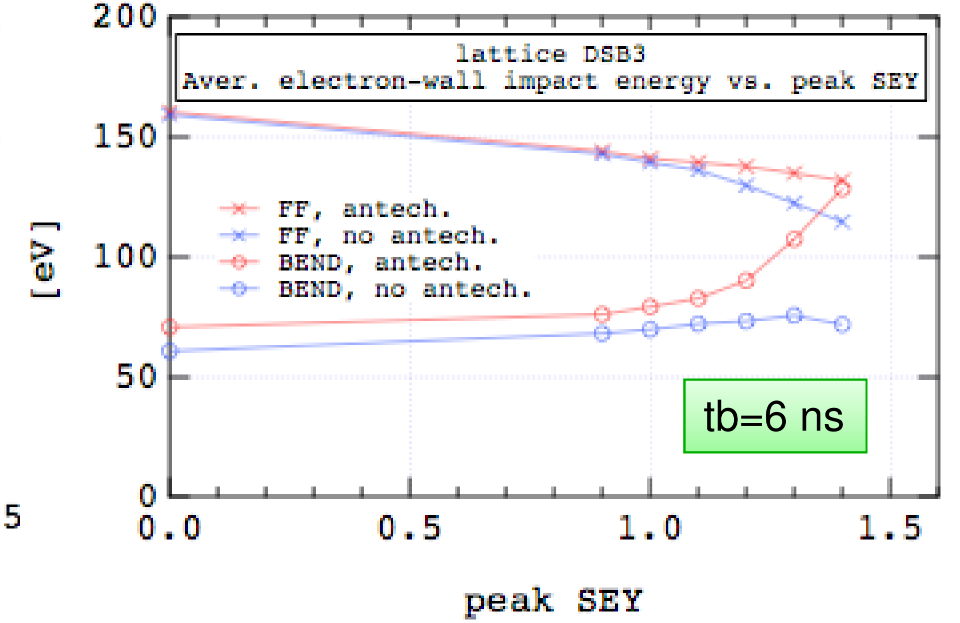




- Significantly below E_{max}=296 eV
- Tentative predictions:
  - If all else is fixed, ecloud density will be higher if E_{max} is lower than 296 eV, and viceversa
  - Ditto if N_b is larger than $2\text{x}10^{10}$
- Why does <E_0> depend strongly on δ_{max} in some cases?

DSB3: aver. e⁻-wall impact energy E_w





- E_w is ~2x larger for tb=3 ns than for tb=6 ns
- tb=6 ns: $E_w << E_{max}$=296 eV for both ff and bends
- tb=3 ns:
  - $E_w << E_{max}$=296 eV for bends
  - $E_w =\sim E_{max}$=296 eV for ff

- Tentative conclusion for tb=3 ns:
  - For ff, n_e is at its largest possible
  - For bends, if all else is fixed, n_e will be higher if E_{max} is lower than 296 eV, and viceversa
  - Ditto if N_b is larger than 2×10^{10}