Status of Ecloud Build-Up Simulations for the ILC DR's

Miguel A. Furman

LBNL

ILCDR ecloud Webex mtg.

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Summary

- Essential simulation input parameters
- POSINST code features
- Results obtained for:
  - DC04 and DSB3
  - 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 seem consistent with Theo Demma's (15dec09), although an apples-to-apples 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
Bunch train	45 bunches (spacing t_b = 6.154 ns = 4 buckets)
Gap length between trains	15x4=60 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	$\delta(0)=0.31x\delta_{max}$

(*) 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

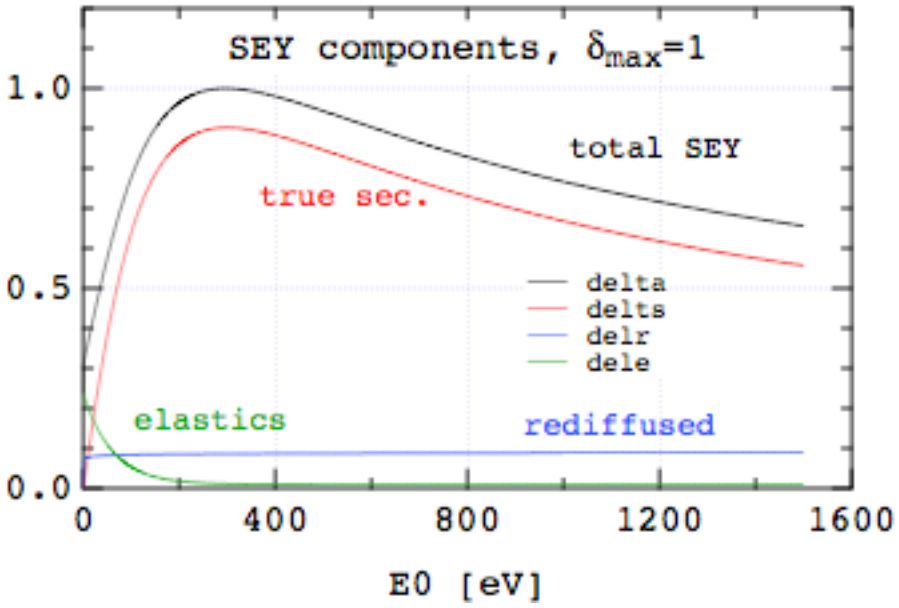
	DC04		DSB3	
Circumference [m]	6476.4		3238.2	
Harmonic number	14042		7021	
n'_γ [photons/e^+/m] (radiated γ's)	0.33		0.47	
n'_e [photo.-el./e^+/m] (without antech.)	0.033		0.047	
n'_e [photo.-el./e^+/m] (with antech.)	0.66×10^{-3}		0.94×10^{-3}	
	field-free	**bend**	**field-free**	**bend**
Tr. bunch 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–η), 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	$\Delta t = 1.25 \times 10^{-11}$ s (= 9 kicks/bunch)
Integration time step if no bunch present	$\Delta t = (2.4–2.5) \times 10^{-11}$ 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)

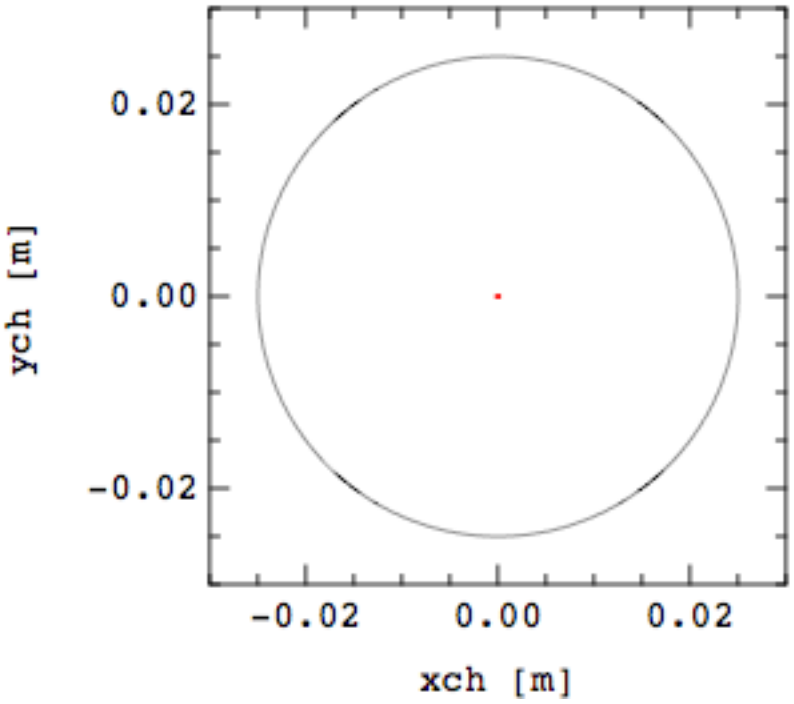
— Explored δ_{max}=0,0.9–1.4

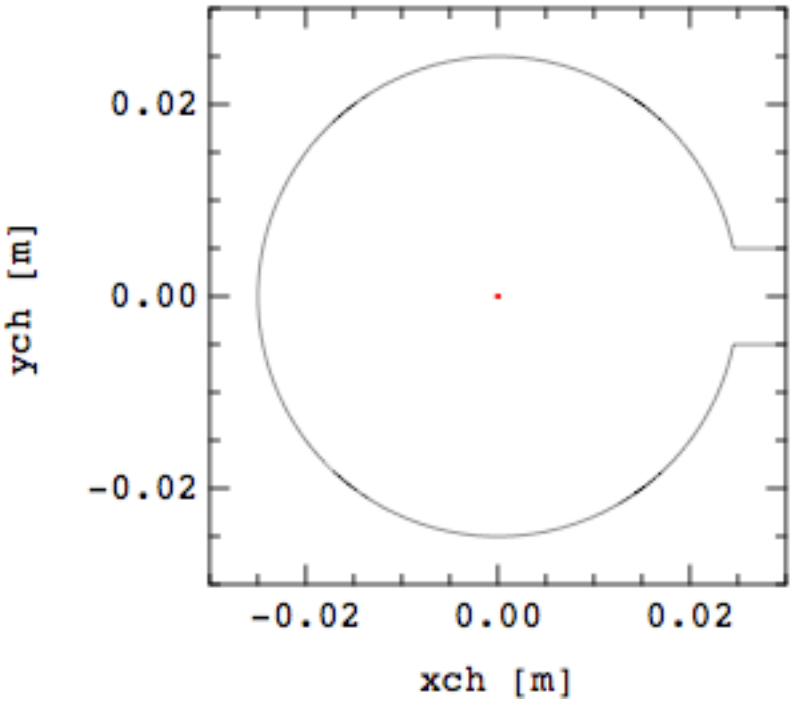
- keeping E_{max}=296 eV fixed while scaling $\delta(0) \approx 0.31 \times \delta_{max}$

— 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

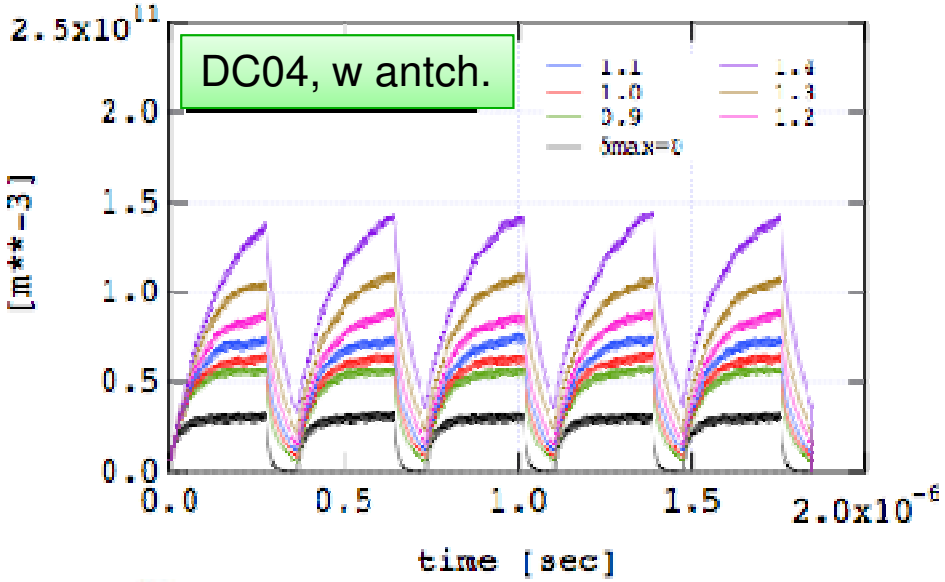
- Simulate individual sections of the ring, one at a time
  - —Field-free or dipole bend
    - Round pipe, a=2.5 cm, with/without antechamber of FH=1 cm
- Compute instantaneous and average ecloud density and many other quantities over 5 trains of 45 bunches each
  - —this is long enough for sensible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

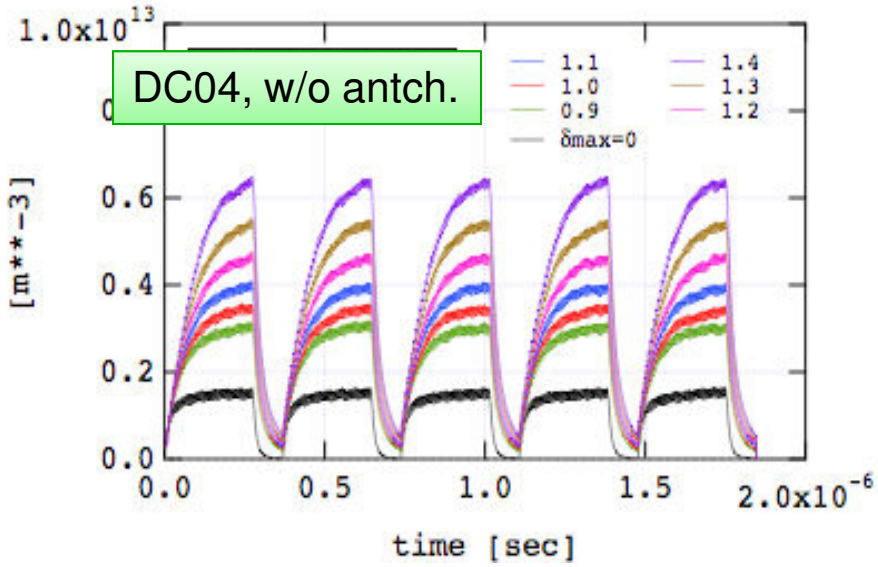
Results

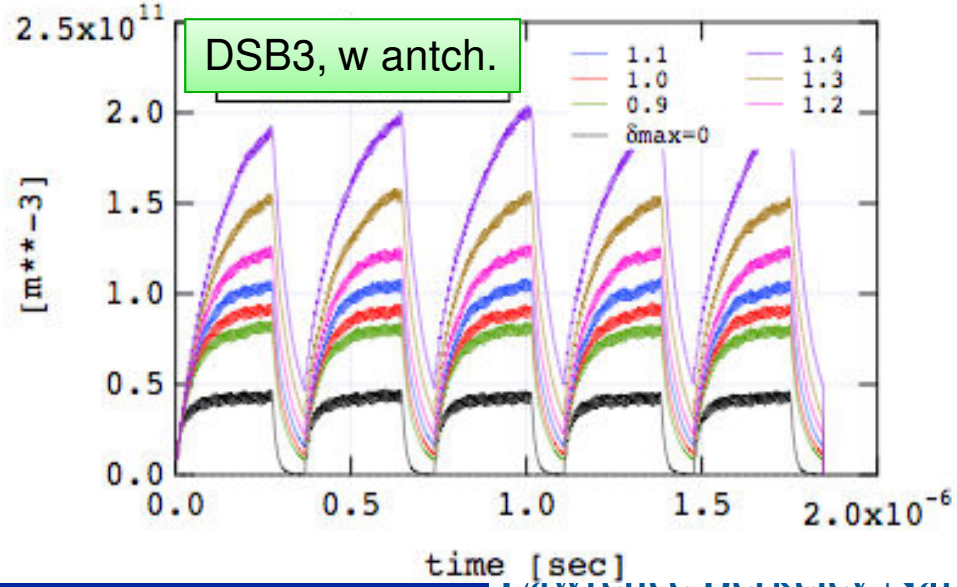
- Build up
  - Density vs. time
- Time-averages vs δ_{max}
  - Aver. density (time and space)
  - Density in front of bunch within the 10-σ beam ellipse
    - NB: "front of bunch" is defined to be $\Delta z=2.5\sigma_z$ from center
  - Aver. beam neutralization
- Everything else that POSINST computes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

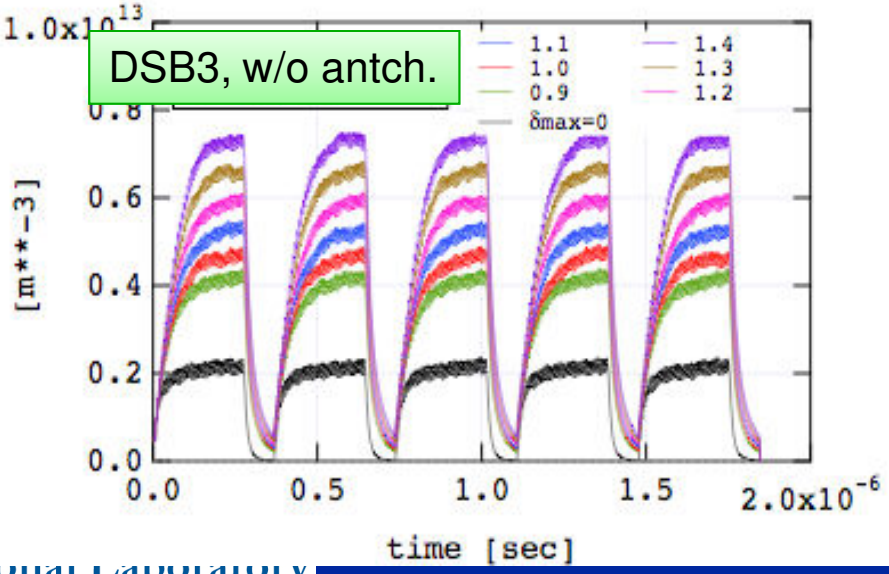
Field-free region build-up

space-averaged ecloud density



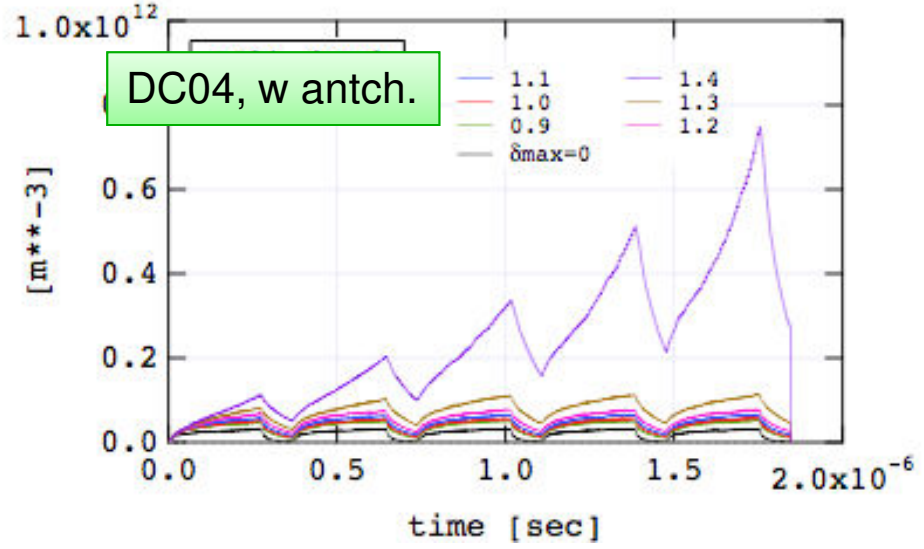


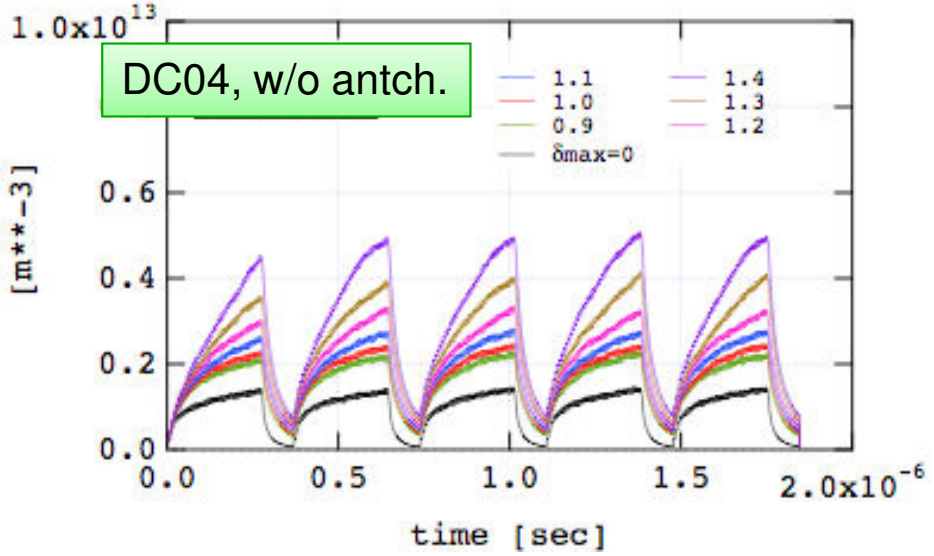


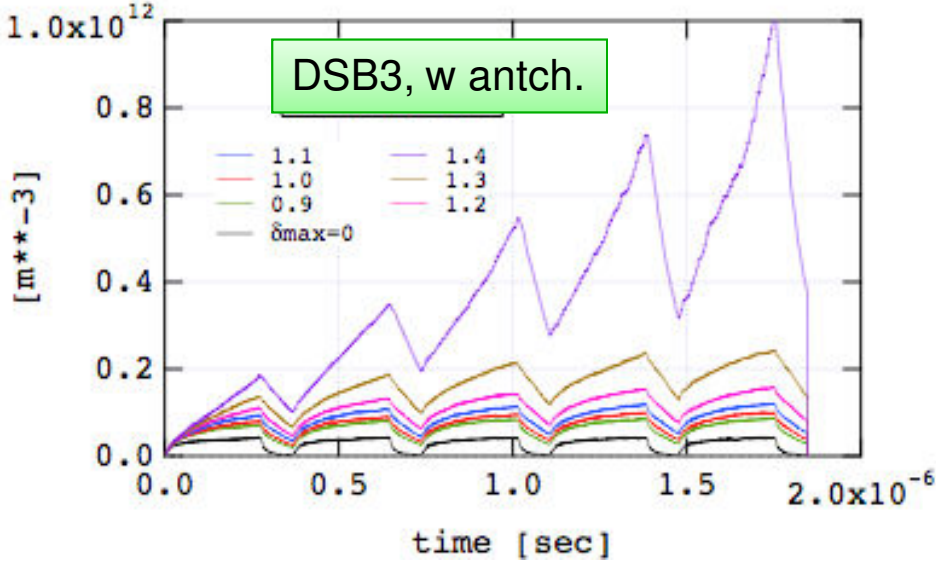


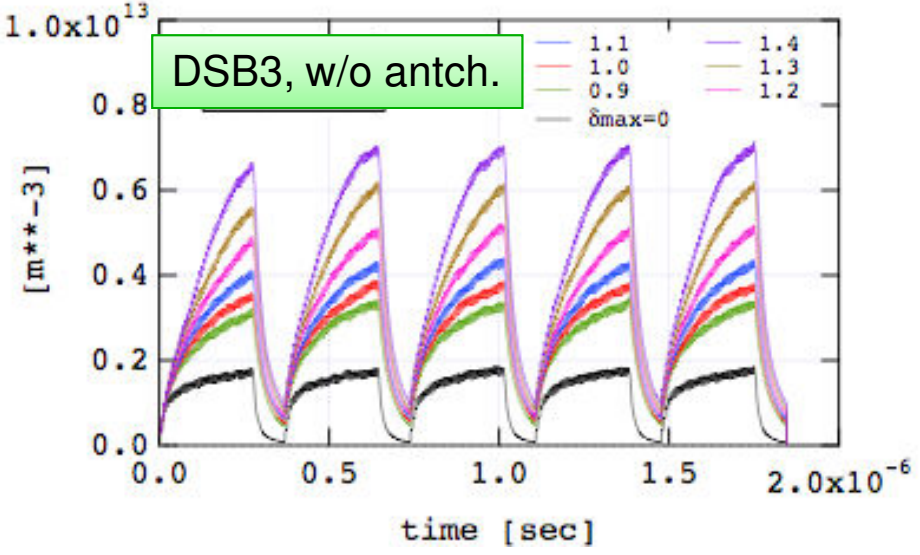
Bending magnet build-up

space-averaged ecloud density



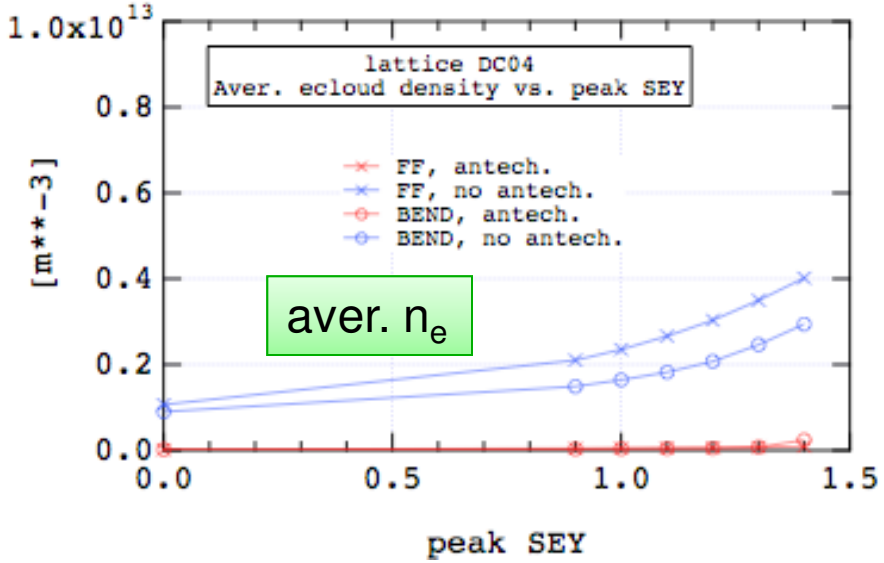


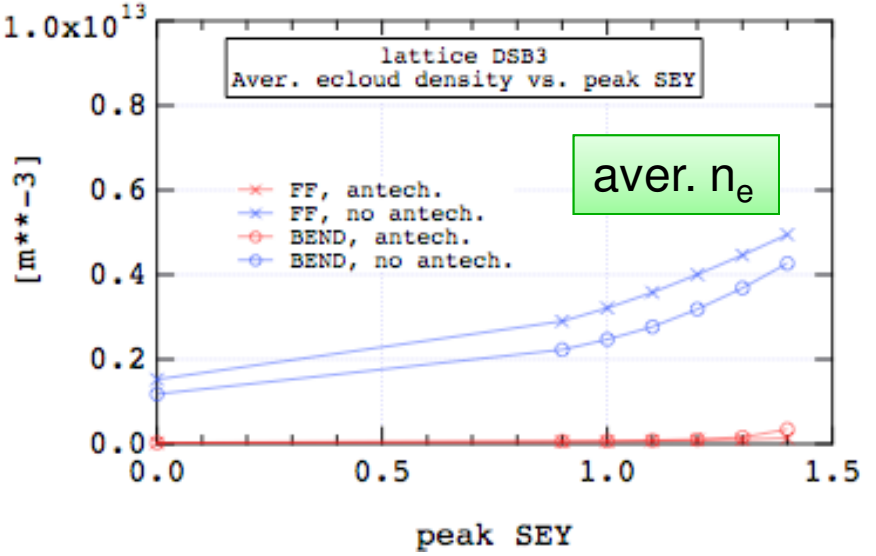


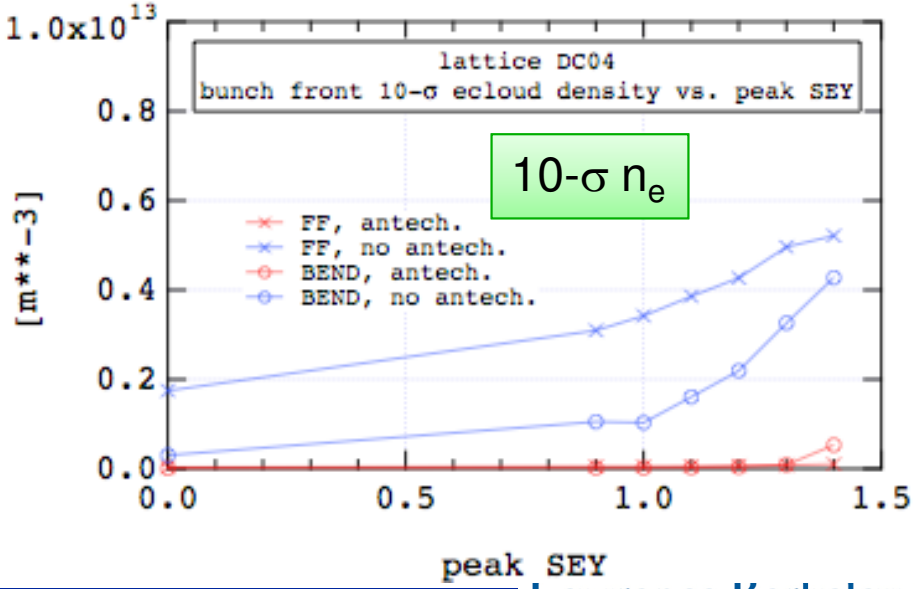


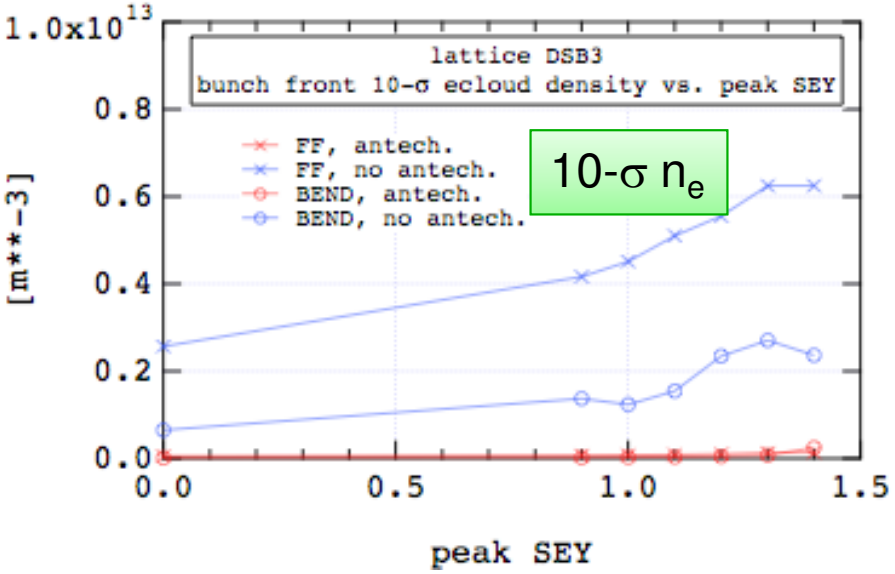
Time averages over 5 trains:
overall density and 10-σ front-bunch density

NB1: aver. $n_e \approx 0.7$ x (peak n_e). NB2: 10-σ n_e is very noisy w.r.t. aver.

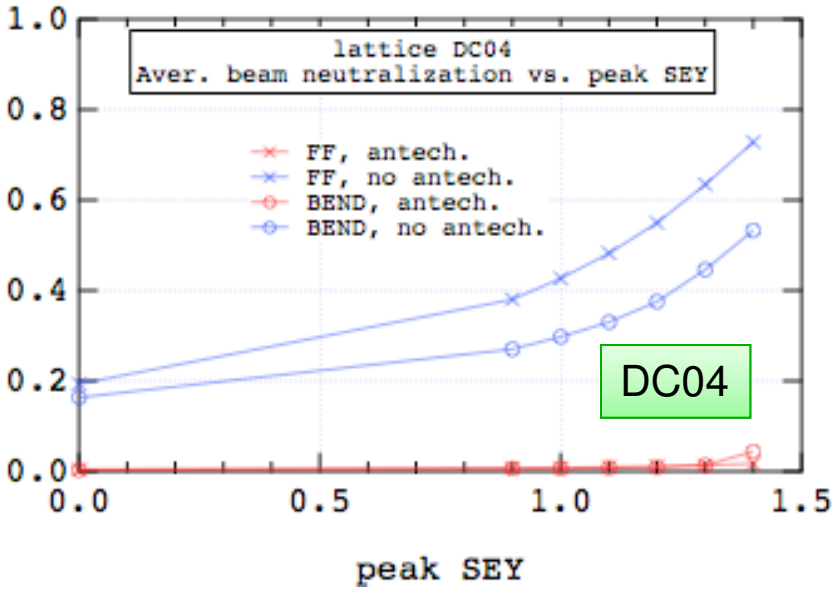


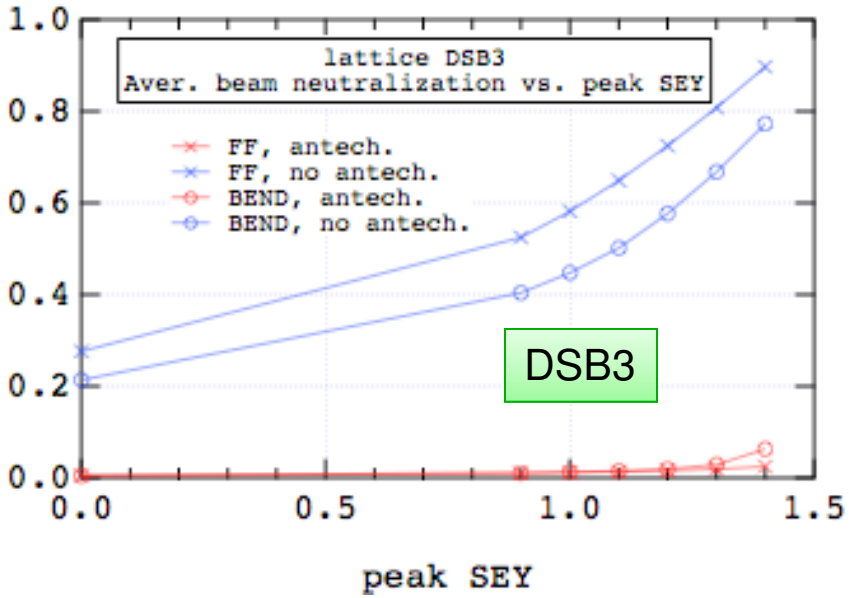






Time averages over 5 trains:
beam neutralization





- Neutralization is significant if there is no antechamber

Overall n_e at saturation(*)

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(*)

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%.

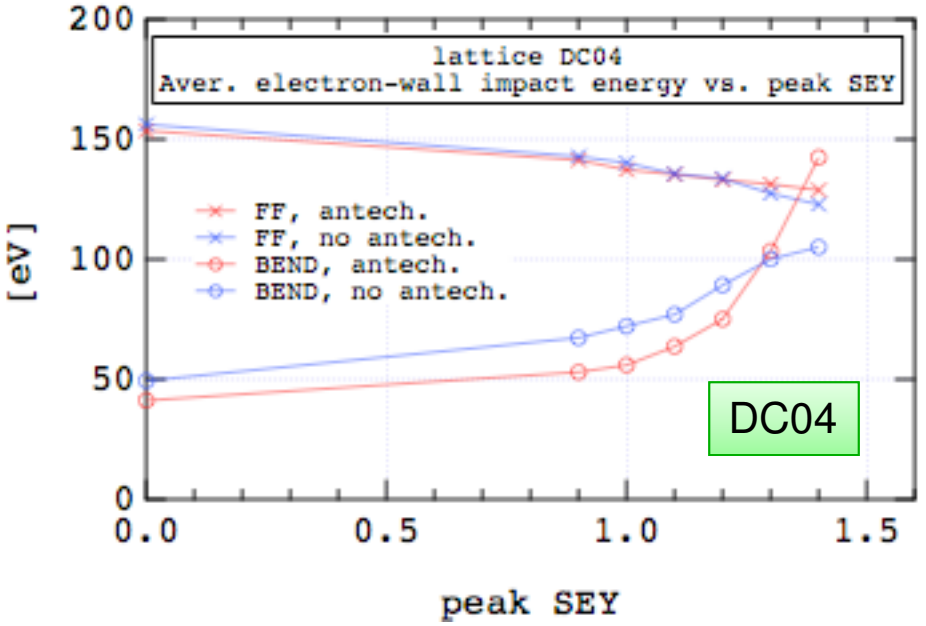
n_e at bunch front within 10 beam σ's (*)

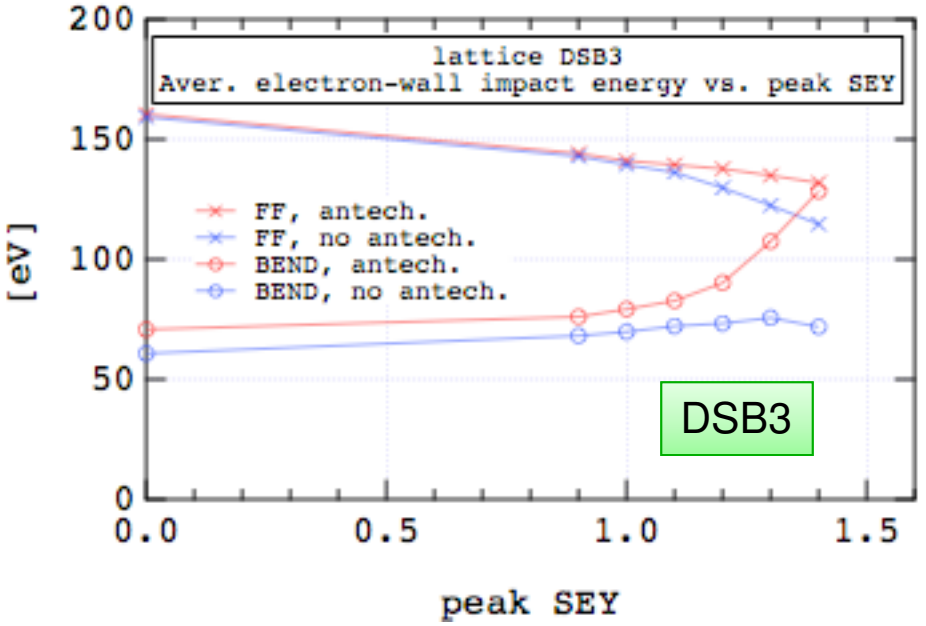
units: 10^{12} m^{-3}

	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 (~30-40%) 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

Aver. e^--wall impact energy $<E_0>$





- 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 $2x10^{10}$
- Why does $<E_0>$ depend strongly on δ_{max} in some cases?

Conclusions

- Significant no. of photoelectrons in all cases
  - ~20% (or more) of the ecloud density, depending on δ_{max}
  - Amplification effect from secondary emission is a factor ~ a few
    - This is very small, in my experience (?)
- n_e: generally smooth, monotonic dependence on δ_{max} in the range examined
  - Exception: n_e has a 1st-order phase transition in bends with antech. at $\delta_{max} \approx 1.2$-1.3
- ecloud density in DSB3 is larger than in DC04 by 10–20%
- Antechamber:
  - in field-free regions: ecloud density is lower by factor ~30-40 relative to all no-antechamber cases explored
  - in bending magnets: ecloud density lower by factor ~30-40 relative to no-antechamber cases unless δ_{max} exceeds ~1.3 (DC04) or ~1.2 (DSB3)
    - in these exceptional cases our results are inconclusive
    - but it looks looks to me like antechamber won't provide much protection, if any, in these cases
  - Aver. density: with ant.: $n_e \sim (1\text{-}2)\times10^{11}$ m^{-3} (aver. beam neutralization ~1-2%)
  - without ant.: $n_e \sim (2\text{-}4)\times10^{12}$ m^{-3} (aver. beam neutralization ~50-100%)
  - 10-σ front-bunch-density comparable to aver. density
    - within a factor of less than 2
- For DC04 dipole with antechamber and $\delta_{max}=1.2$, $n_e \approx 1\times10^{11}$ m^{-3}, consistent with T. Demma's result (15dec09); but he used R=0.5 and assumed η=97%

Caveats

- 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
- 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
- Not yet done: quads, wigglers, and other regions of the machine