ECLOUD in PS2, PS+, SPS+

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Summary

- New results for LHC (nominal case, t_b=25 ns spacing)
- Results for LHC upgrades (t_b=12.5, 25 & 75 ns)(*,**)
- Results for injector upgrades (SPS, SPS+,…)(**)

I am grateful for many discussions with F. Zimmermann and W. Fischer.

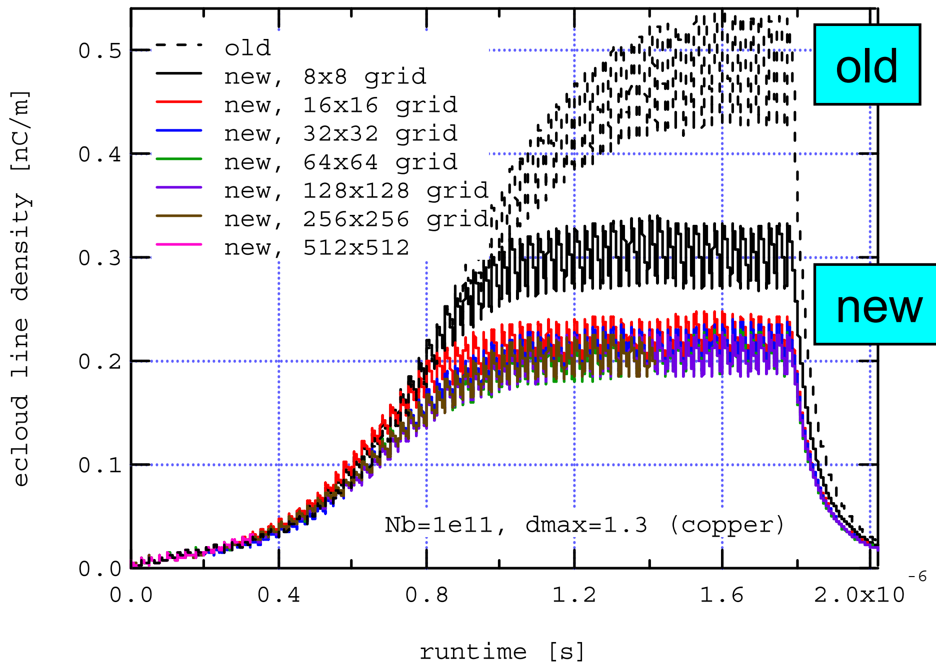
(*) In collaboration with summer student Michael Carrié (INP Grenoble, ENSPG).
(**) Very recent; not tested for numerical convergence, especially PS2 and PS+. Some cases yet to be done.

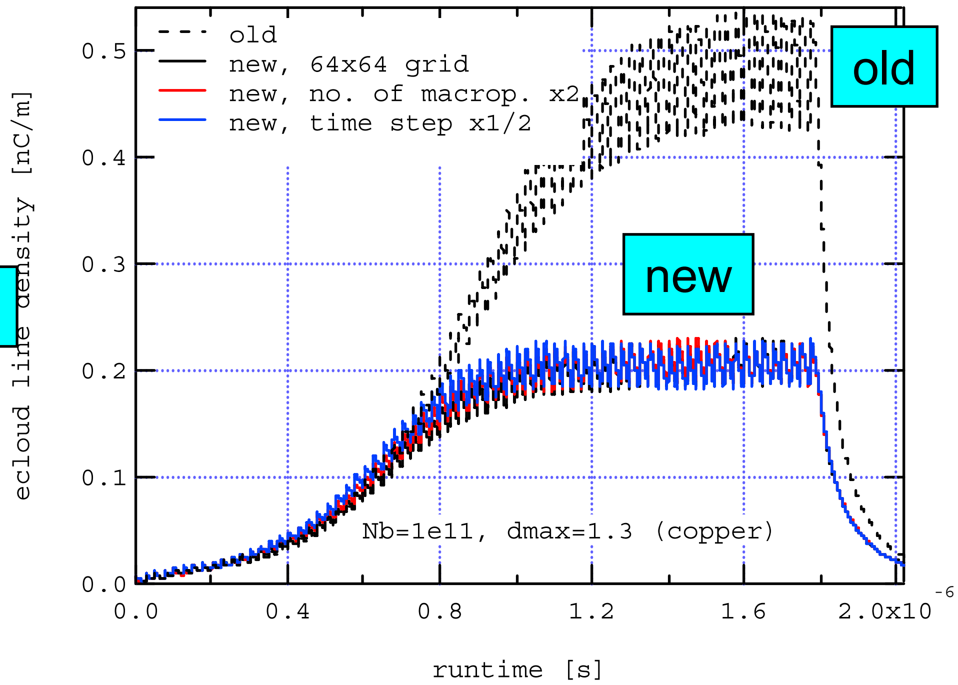
POSINST code fixes and improvements

- Error found ~2-3 months ago (M. Carrié, summer student)
  - When attempting first LHC upgrade simulations (t_b=12.5 ns)
    - Severe ecloud problem
    - Intermittent problem: exceedingly fast ecloud growth with gross violation of energy conservation, even in between bunch passages
- Traced to the Poisson solver subroutine
- Replaced with a new, multigrid solver (courtesy J. Qiang)
  - I have thoroughly tested it
    - In stand-alone mode
    - Convergence tests within LHC ecloud simulations
  - For 64x64 grid, it is ~as fast as old solver with 9x7 grid
  - New results show a more benign ecloud effect than the old ones
  - Most of the problem was due to the too-coarse grid used earlier
- I offer my embarrassed apologies

LHC nominal case (t_b=25 ns, E_b=7 TeV): old(*) & new results

Build-up of the ecloud in an arc dipole:
line charge density vs.time for 1 batch

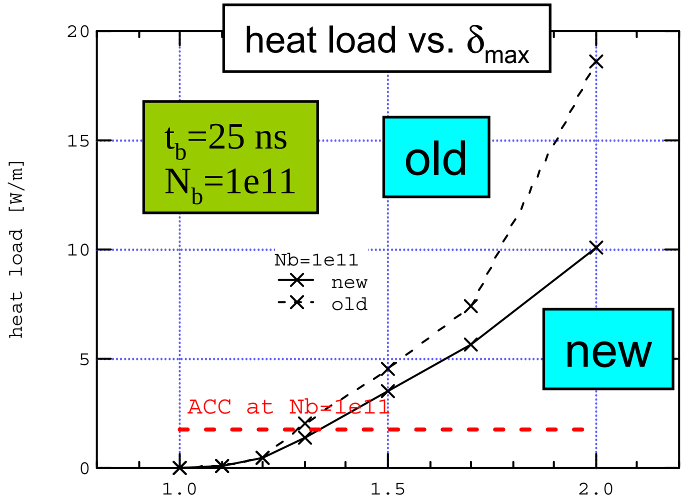


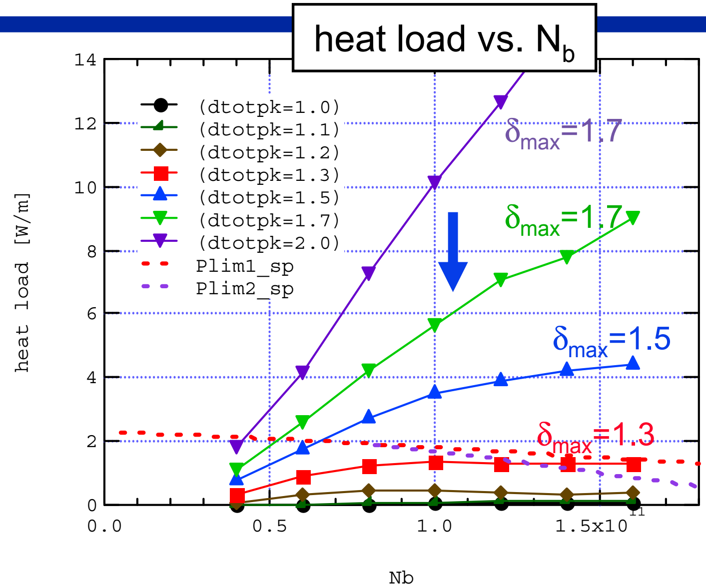


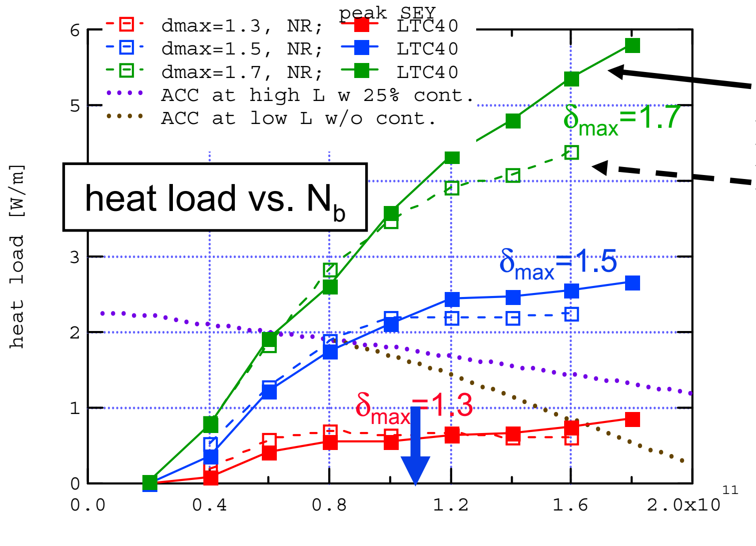
- Other convergence tests carried out, separately and in combination
- An erratum will be submitted to PRSTAB

(*) Old results: M. Furman and V. Chaplin, PRST-AB **9**, 034403 (March 2006)

LHC nominal case (contd.): ecloud heat load







Solid: LTC40: ECLOUD (F. Zimmermann, LTC mtg. #40, April 2005)

Dashed: new POSINST, SEY w/o rediffused

– New conclusion: ecloud less severe than before
– δ_{max} needs to be <1.3 (vs. <1.2 in the old calculation)
– Very good agreement with ECLOUD if same SEY model

▪▪▪▪▪▪ : cooling capacity available for EC power deposition (FZ, LHC MAC mtg. #17 (2005))

LHC upgrades

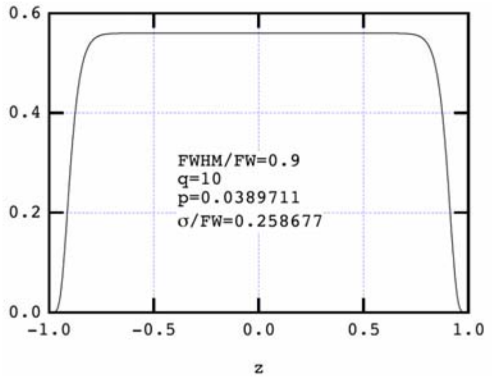
(from file lhcupgradeparams.pdf)

LHC, E_b=7 TeV	Nominal	Ultimate	Shorter bunch	Bigger bunch	Longer bunch
tb [ns]	25	25	12.5	25	75
Nb [1e11]	1.15	1.7	1.7	3.4	6
sigz [cm]	7.55	7.55	3.78	3.78	14.4
Longit. bunch profile	gaussian	gaussian	gaussian	gaussian	flat

Simulation conditions:

1. Look only at bending dipoles at E_b=7 TeV
2. Assume copper chamber
3. Primary electrons only from photoemission
   - Same photoelectric and SEY parameters as in "old case" (PRSTAB **9**, 034403 (2006))
4. Study ecloud during only one "batch", with a few spot checks to 2 and 3 batches
5. Definition of a "batch"
   - For t_b=12.5 ns, 144 bunches followed by a gap, for a total of 2 μs
   - For t_b=25 ns, 72 bunches followed by a gap, for a total of 2 μs
   - For t_b=75 ns, 24 bunches followed by a gap, for a total of 2 μs
6. For either nominal or short bunch cases, use 21 kicks per bunch. For longer bunches, use 41 kicks.
7. Always use the new Poisson solver with a 64x64 grid
8. For the long bunch case, use a generalized parabolic longitudinal shape,

$$\lambda(z) = K\left(1-|z/a|^{1/p}\right)^q\ ,\ |z|<a\ ,\ p,q\geq 0$$



NB: in this case, σ_z/FW=0.26 and FWHM/FW=0.9

Short bunch case (t_b=12.5 ns)

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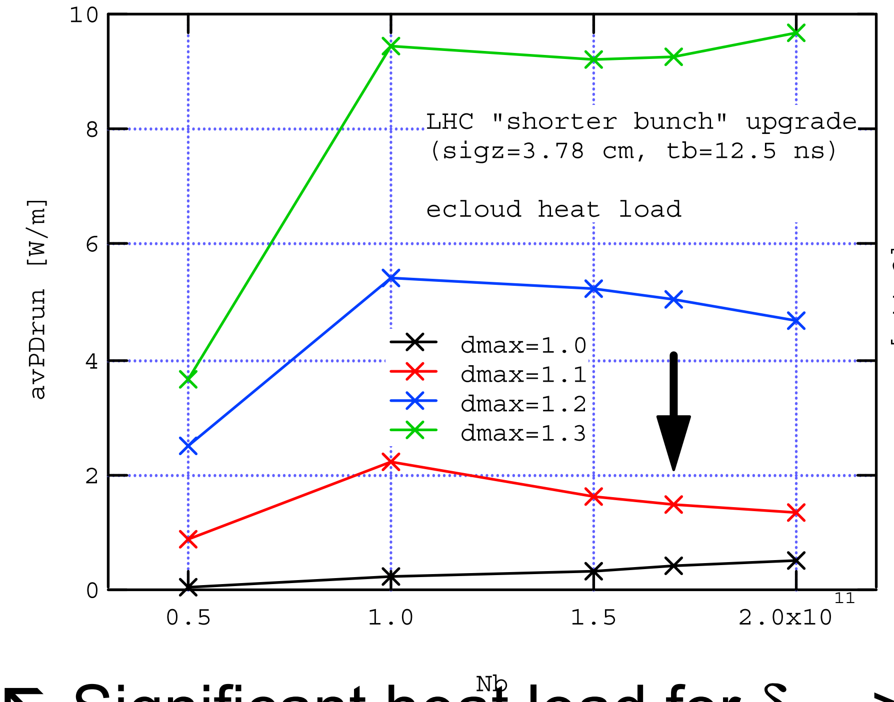
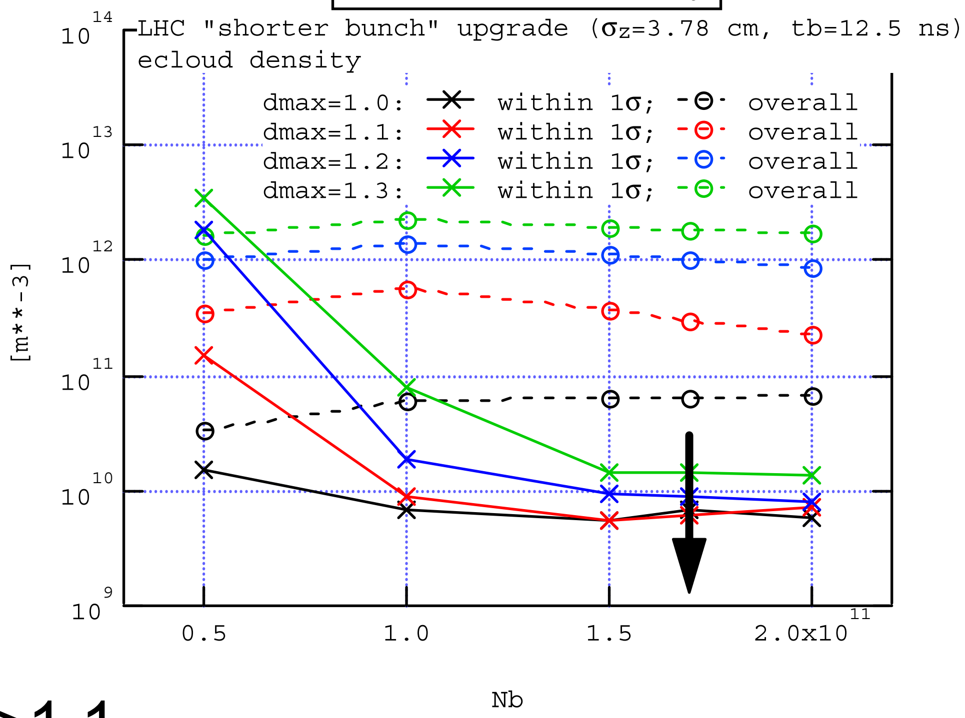
heat load vs. N_b

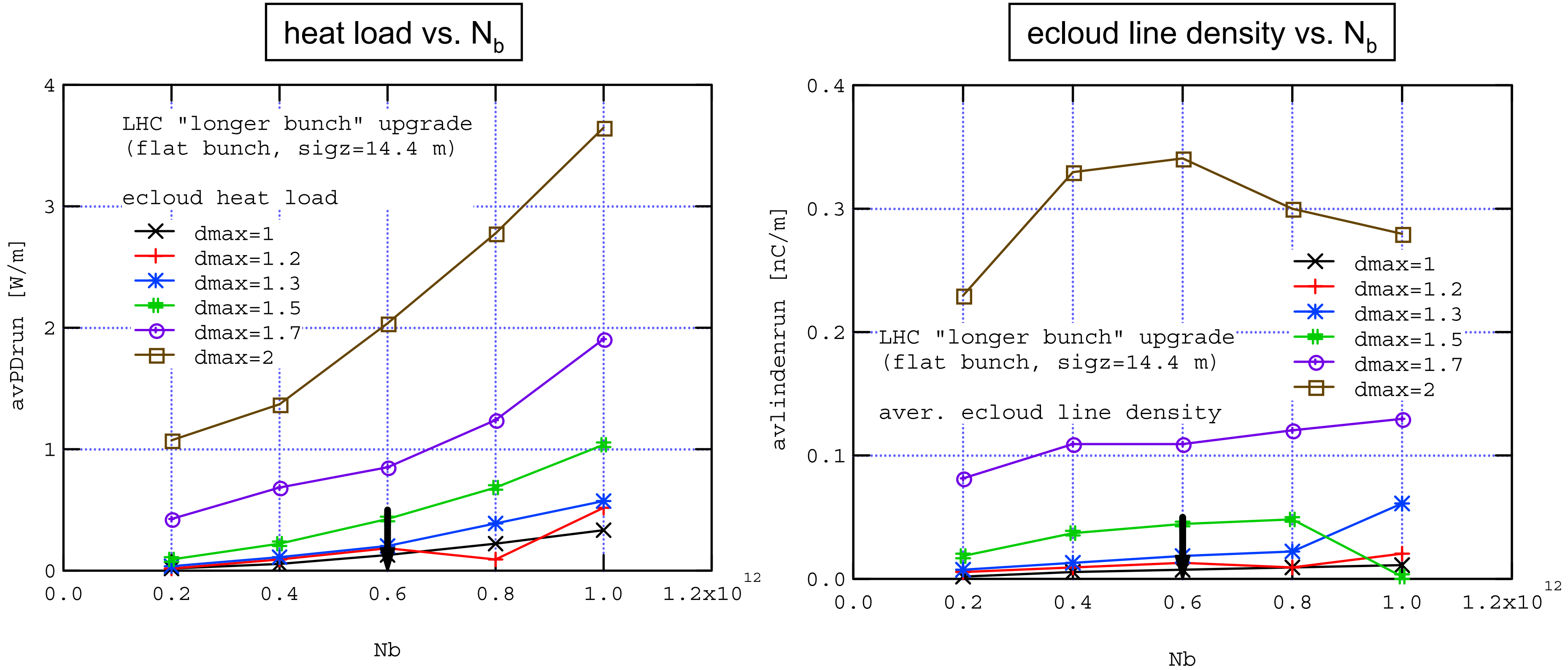


ecloud density vs. N_b



- Significant heat load for δ_{max}>1.1
  - Qualitatively consistent with ECLOUD results (file "LumiUpgrade-parameters-and-heat-loads.pdf")
  - What is the available cryo cooling capacity at t_b=12.5 ns?
- Significant difference in overall ecloud density vs. 1-σ density

Longer bunch case (t_b=75 ns)



- Insignificant heat load unless δ_{max} exceeds ~1.7
  - — Qualitatively consistent with ECLOUD results (file "LumiUpgrade-parameters-and-heat-loads.pdf", FZ and FR)
- ecloud dominated by photoelectrons, not by secondaries
- Density significantly below beam neutralization level

Injector upgrade

(parameters from file psplusetcparams.pdf)

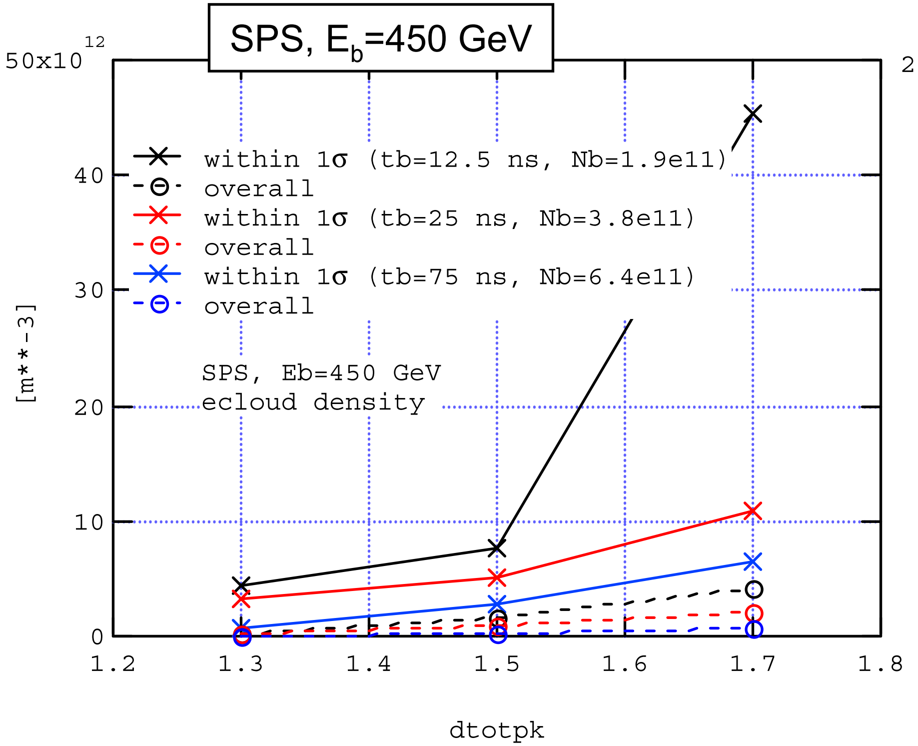
SPS	SPS, Eb=50 GeV			SPS, Eb=75 GeV			SPS, Eb=450 GeV			SPS+a, Eb=50 GeV			SPS+b, Eb=75 GeV			SPS+, Eb=1000 GeV		
tb [ns]	12.5	25	75	12.5	25	75	12.5	25	75	12.5	25	75	12.5	25	75	12.5	25	75
Nb [1e11]	1.9	3.8	6.4	1.9	3.8	6.4	1.9	3.8	6.4	1.9	3.8	6.4	1.9	3.8	6.4	1.8	3.6	6.2
sigz [cm]	14.3	23.4	23.4	12.6	20.9	20.9	12.0	12.0	12.0	14.3	23.4	23.4	12.6	20.9	20.9	12.0	12.0	12.0

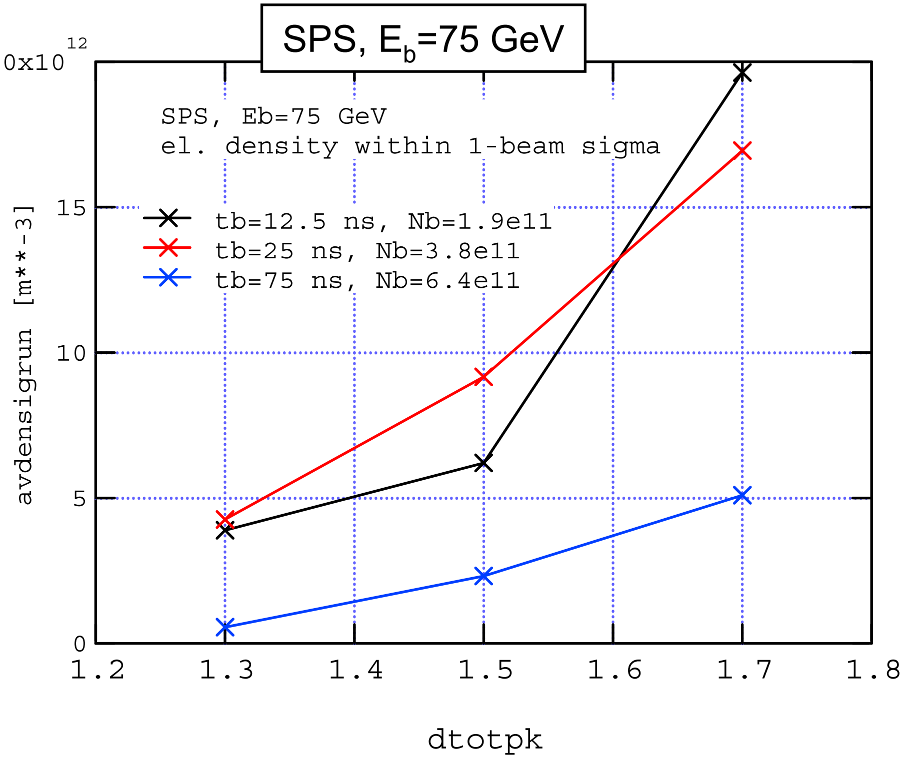
PS	PS2, Eb=50 GeV			PS+, Eb=75 GeV		
tb [ns]	12.5	25	75	12.5	25	75
Nb [1e11]	1.9	3.8	6.4	1.9	3.8	6.4
sigz [cm]	57.3	93.5	93.5	50.5	83.5	83.5

Simulation conditions:

1. Look only at bending dipoles
2. Look at one batch only
3. Identical “batch” definitions to those on slide 6
4. Assume stainless steel rectangular chamber
   - E_{max}=310 eV, independent of δ_{max}
   - Assumed δ_{ma} =1.3, 1.5 and 1.7
5. Primary electrons only from ionization of residual gas (assumed T=300 K and P=1e-5 Torr for simulation speed up and better numerical stability)
6. Bunch length divided into kicks such that, typically, Δt~0.1 ns (but Δt~0.3 ns for PS2 and PS+)
   - This is coarser than for the LHC by a factor ~3-5
7. New Poisson solver, 64x64 grid
8. NB: for all cases with 75 ns spacing, use long bunches with σ_z/FW=0.26 and FWHM/FW=0.9 (see p. 6)

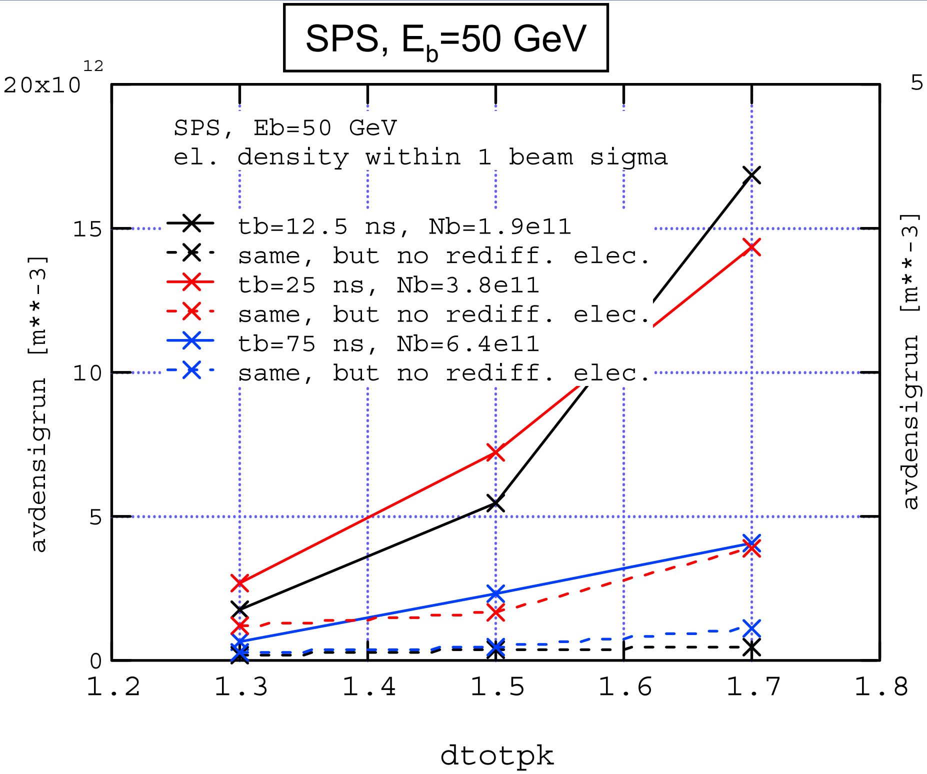
Ecloud density vs. δ_{max}

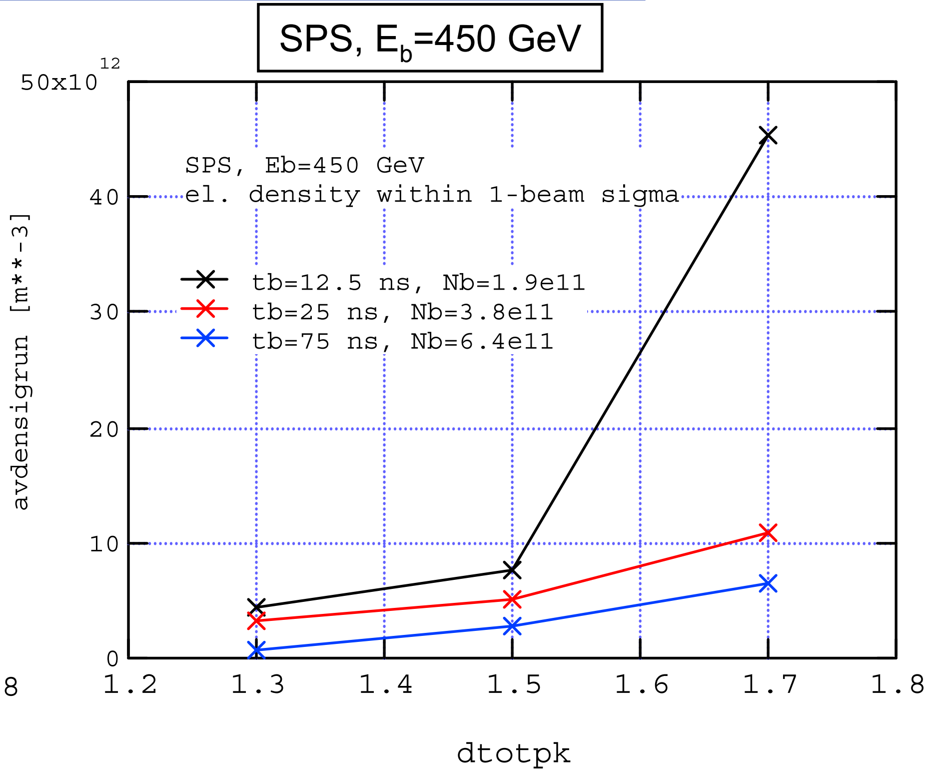




- Significant difference in overall ecloud density vs. 1-σ density
  - But $d_{1\sigma} >> d_{overall}$, exactly the opposite of LHC short bunch case (see slide 7)!!
    - Almost certainly due to longer bunches in the injectors

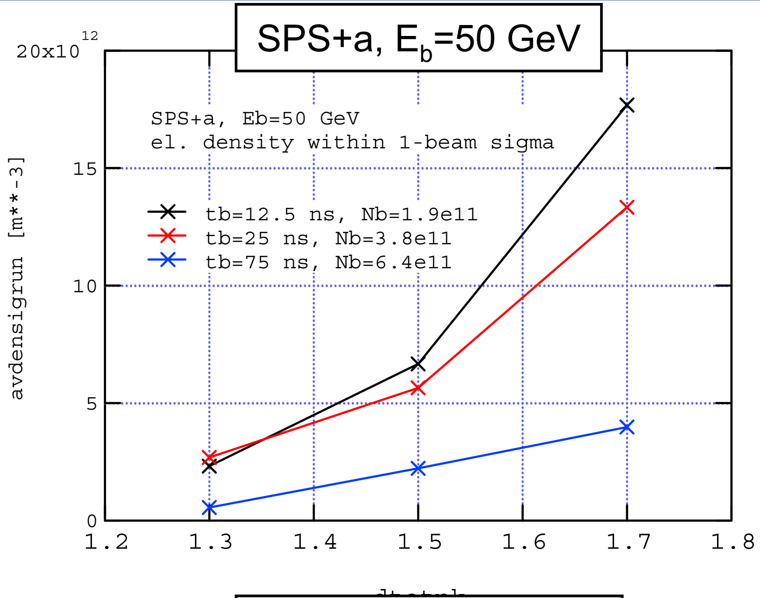
Ecloud density vs. δ_{max} (contd.)

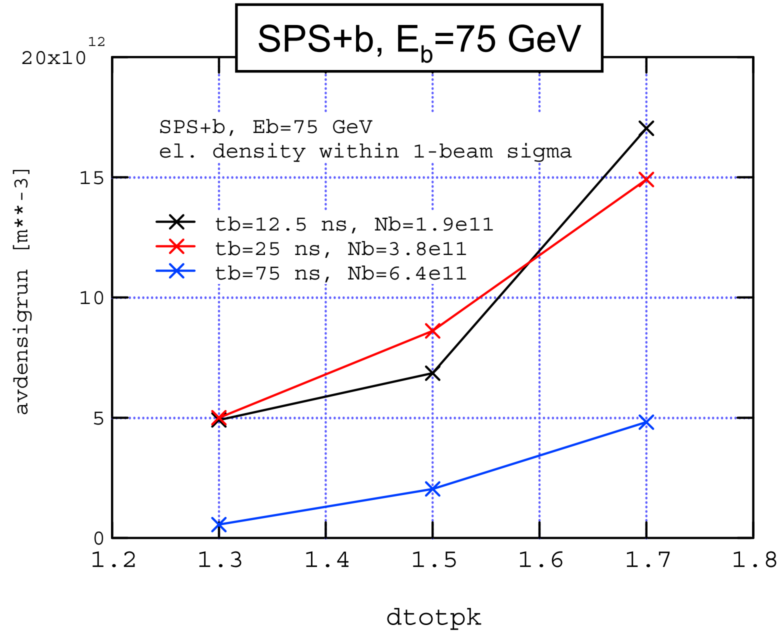


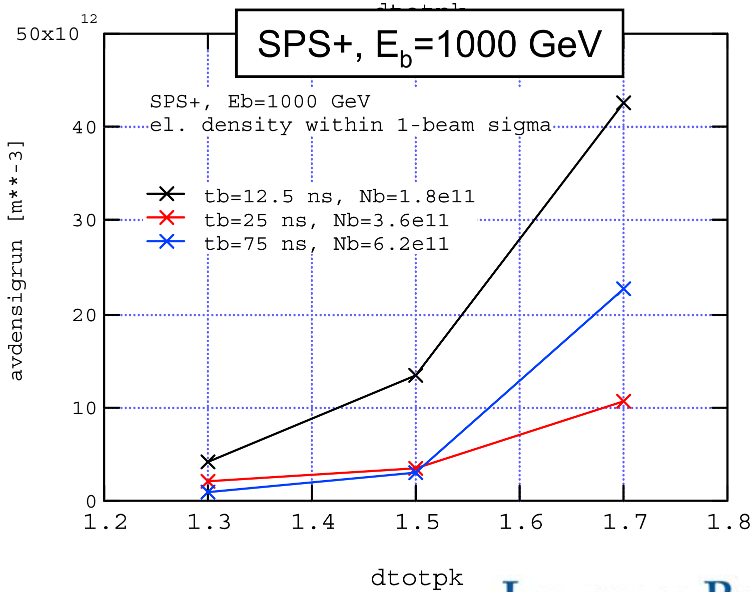


- Significant contribution of rediffused electrons
  - NB: stainless steel has a larger rediffused fraction than copper
    - But not many measurements available of the SEY components
    - It would be nice to have more

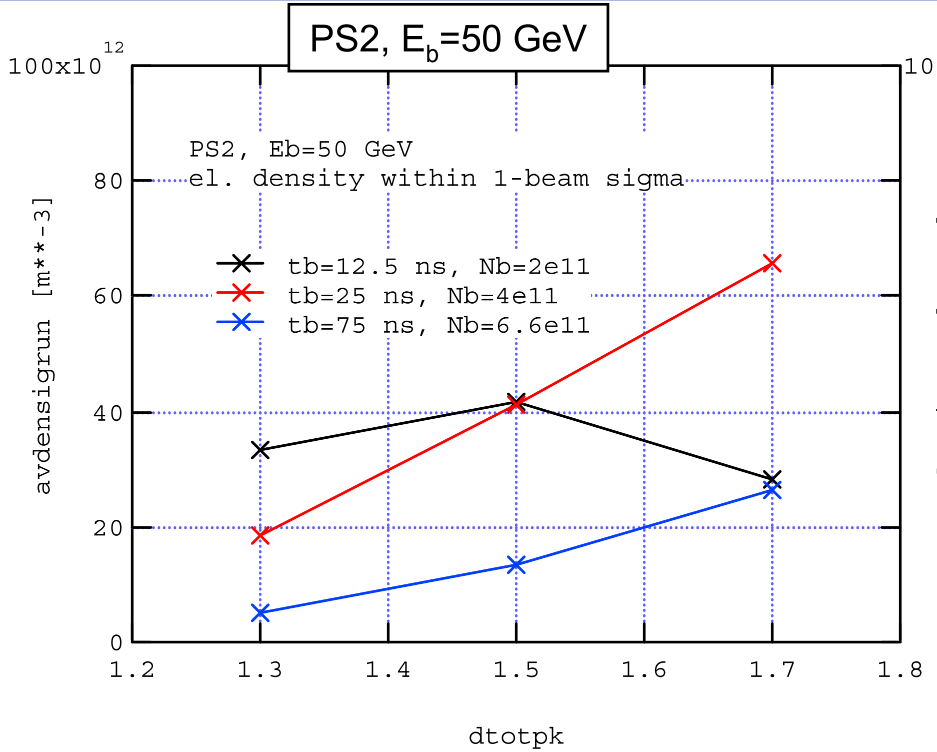
Ecloud density vs. δ_{max} (contd.)

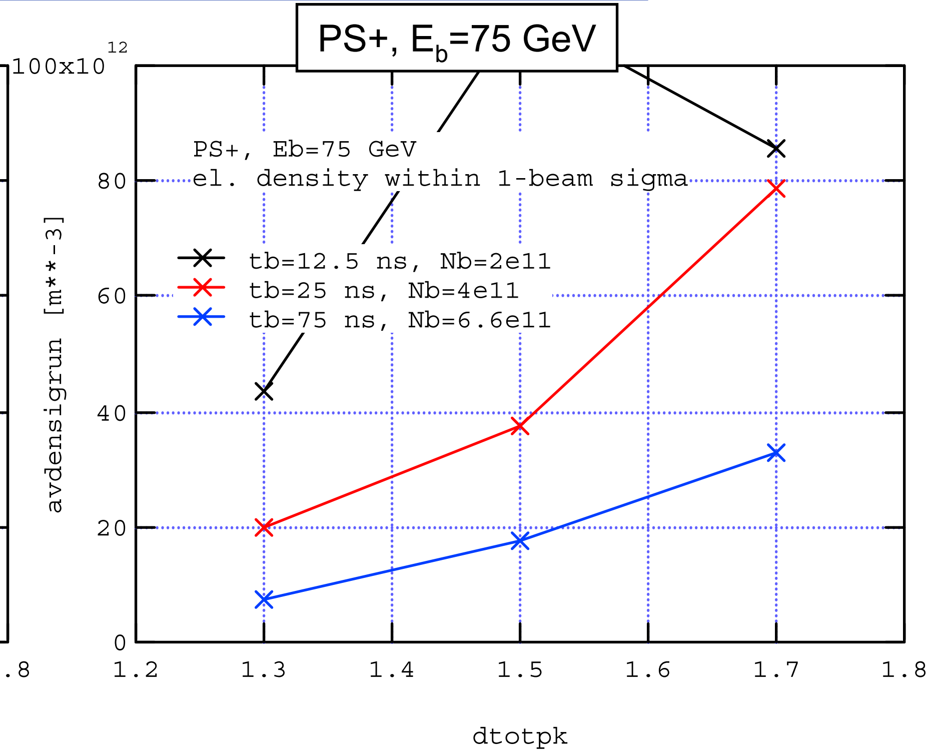






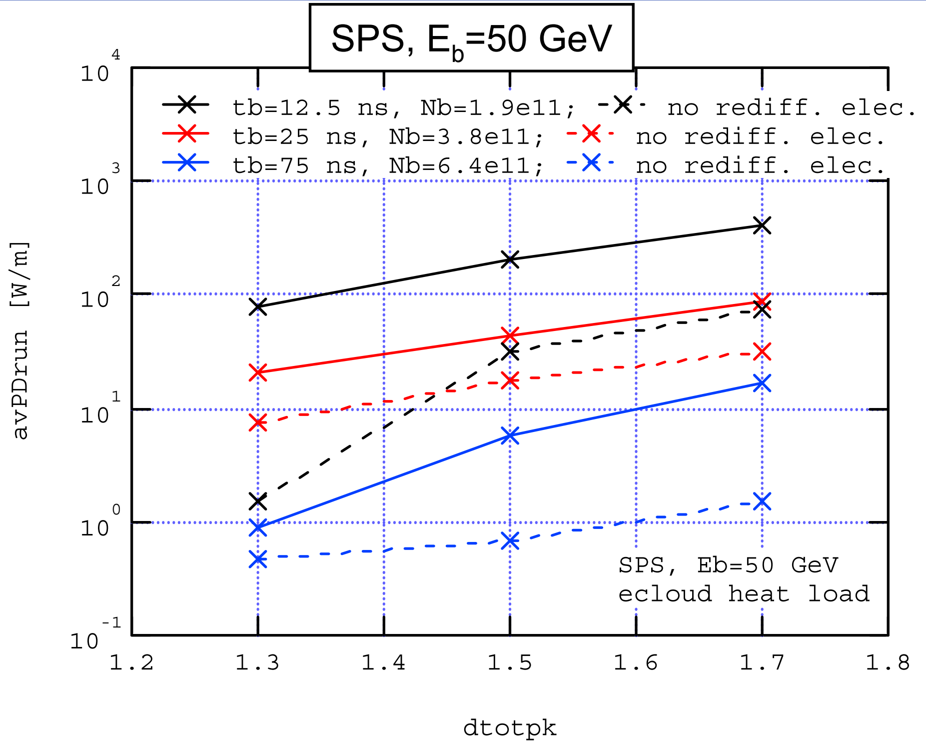
PS2 and PS+: $d_{1\sigma}$

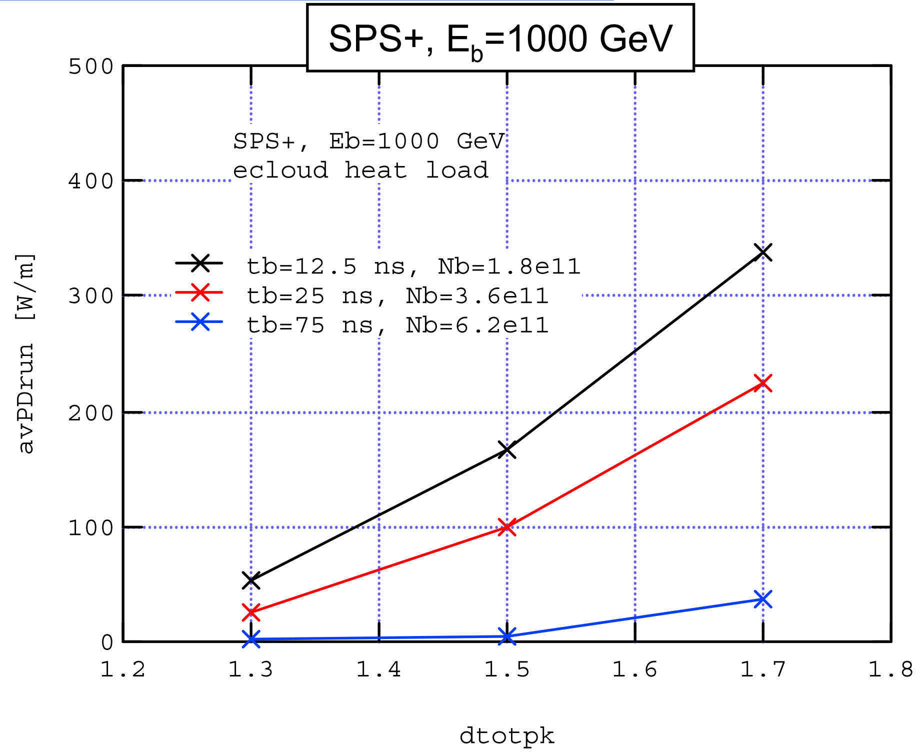




- PS2 and PS+ exhibit quite large $d_{1\sigma}$
  - Due to long bunches
- But clear evidence of lack of numerical convergence
  - Need to re-do with finer calculation

Heat load vs. δ_{max}

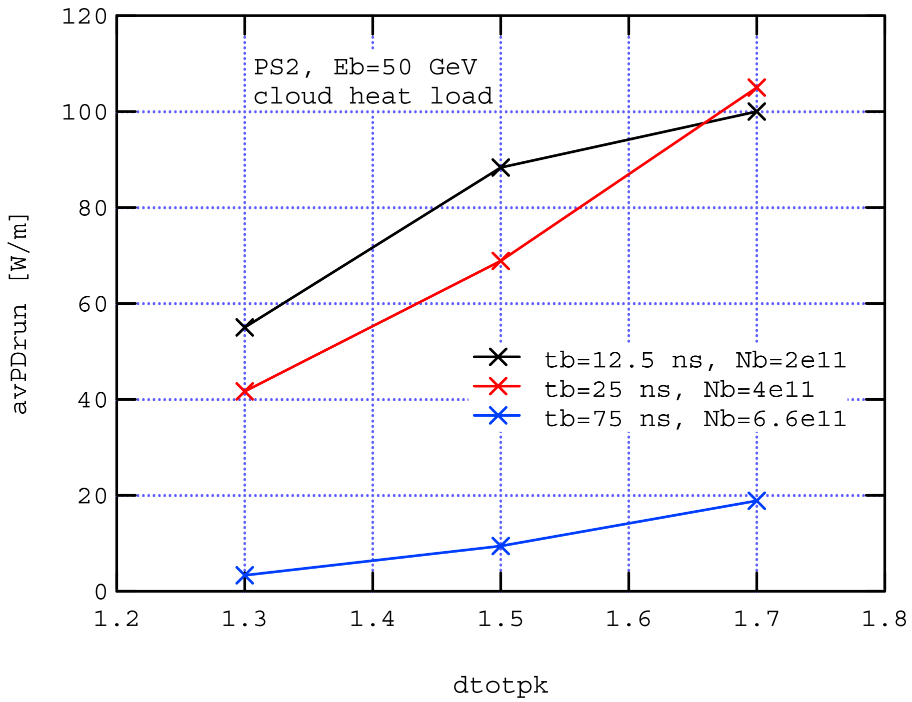


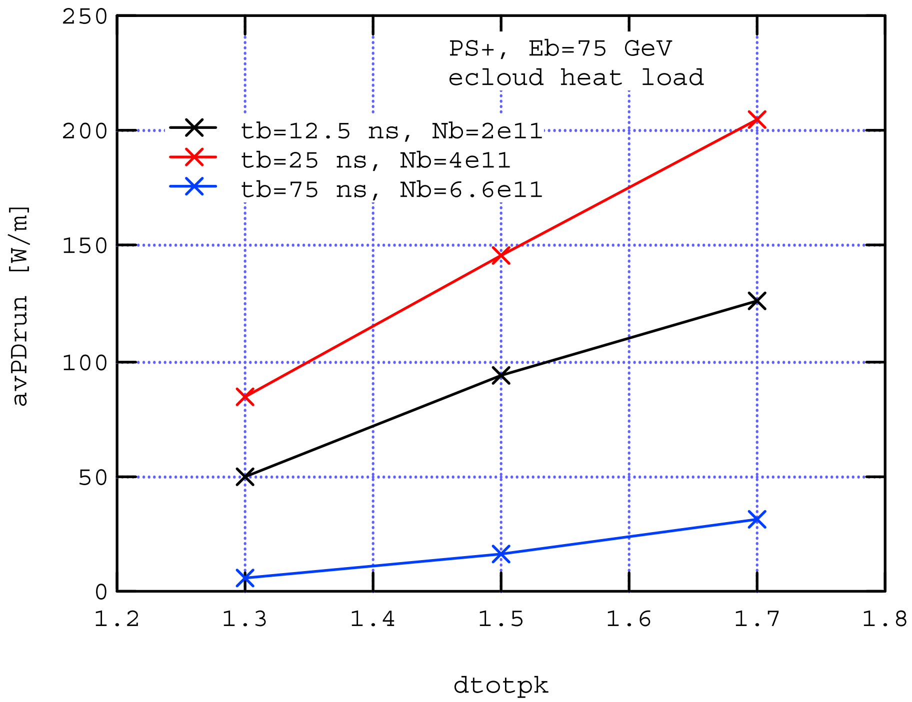


Heat load vs. δ_{max} (contd.)

PS2, E_b=50 GeV

PS+, E_b=75 GeV





- Heat load non-negligible (10's to 100's W/m)
  - Except for long bunches at 75 ns
  - Needs to be double-checked, esp. for PS2 and PS+

Conclusions

- Significant differences between electron density within the 1-σ ellipse ($d_{1\sigma}$) and the overall electron density ($d_{overall}$) for PS and SPS upgrades
  - $d_{1\sigma} >> d_{overall}$ (typ. for long bunches), or $d_{1\sigma} << d_{overall}$ (typ. for short bunches)
  - Keep this in mind for HEADTAIL-like instability simulations!
- Long bunches at t_b=75 ns lead to very low heat load in LHC
  - But may be just as sensitive to instabilities and/or ε growth as short bunches
  - I'll provide data for $d_{1\sigma}$ and $d_{overall}$ soon
- Heat load can be nontrivial in injectors
  - Is this an issue?
- This is a first look at ecloud for the upgraded LHC and its injectors
  - Not all cases studied
  - Numerical convergence not methodically checked
  - Parameter sensitivity minimally studied
- Shortcomings remain in SEY model in simulation code
  - Leads intermittently to "virtual cathodes"
  - I believe these are mostly (but not altogether) artificial, due to assumed independence of SEY on sp. ch. E-field
  - Iriso-Peggs maps seem not to have this deficiency (?)

LARP

SPS and PS upgrades

case	input_file	dtotpk	tb	xnpnom	beamen	avekrun	avek0run	avWCrun	avdensigrun	avdenrun	avlinedenrun	avPDrun
SPS, 50 GeV, tb=12.5 ns	SPS50_tb12p5_d1p3_hiP_dip	1.30	12.5	1.90E+11	50	2.434E+02	3.897E+02	6.998E-01	1.719E+12	1.832E+12	1.808E+00	7.908E+01
	SPS50_tb12p5_d1p5_hiP_dip	1.50	12.5	1.90E+11	50	2.462E+02	3.356E+02	2.924E+00	5.472E+12	5.073E+12	5.007E+00	2.023E+02
	SPS50_tb12p5_d1p7_hiP_dip	1.70	12.5	1.90E+11	50	2.836E+02	3.189E+02	7.987E+00	1.688E+13	9.027E+12	8.909E+00	4.124E+02
SPS, 50 GeV, tb=25 ns	SPS50_tb25_d1p3_hiP_dip	1.30	25.0	3.80E+11	50	1.745E+02	2.158E+02	3.128E-01	2.672E+12	1.217E+12	1.201E+00	2.040E+01
	SPS50_tb25_d1p5_hiP_dip	1.50	25.0	3.80E+11	50	1.838E+02	1.929E+02	9.222E-01	7.207E+12	2.436E+12	2.404E+00	4.355E+01
	SPS50_tb25_d1p7_hiP_dip	1.70	25.0	3.80E+11	50	1.886E+02	1.707E+02	2.484E+00	1.438E+13	4.501E+12	4.442E+00	8.652E+01
SPS, 50 GeV, tb=75 ns	SPS50_tb75_d1p3_hiP_dip	1.30	75.0	6.40E+11	50	3.113E+02	5.270E+02	3.943E-03	6.142E+11	3.476E+10	3.430E-02	8.724E-01
	SPS50_tb75_d1p5_hiP_dip	1.50	75.0	6.40E+11	50	2.389E+02	3.606E+02	4.919E-02	2.335E+12	3.577E+11	3.530E-01	5.719E+00
	SPS50_tb75_d1p7_hiP_dip	1.70	75.0	6.40E+11	50	2.173E+02	2.723E+02	2.668E-01	4.098E+12	1.196E+12	1.180E+00	1.660E+01
SPS, 75 GeV, tb=12.5 ns	SPS75_tb12p5_d1p3_hiP_dip	1.30	12.5	1.90E+11	75	5.123E+02	9.432E+02	6.681E-01	3.854E+12	1.572E+12	1.551E+00	1.098E+02
	SPS75_tb12p5_d1p5_hiP_dip	1.50	12.5	1.90E+11	75	4.982E+02	8.669E+02	2.826E+00	6.179E+12	4.359E+12	4.302E+00	3.115E+02
	SPS75_tb12p5_d1p7_hiP_dip	1.70	12.5	1.90E+11	75	5.782E+02	7.795E+02	8.238E+00	1.960E+13	8.873E+12	8.757E+00	7.448E+02
SPS, 75 GeV, tb=25 ns	SPS75_tb25_d1p3_hiP_dip	1.30	25.0	3.80E+11	75	1.780E+02	2.550E+02	1.834E-01	4.275E+12	7.730E+11	7.629E-01	1.677E+01
	SPS75_tb25_d1p5_hiP_dip	1.50	25.0	3.80E+11	75	1.888E+02	2.366E+02	6.397E-01	9.180E+12	1.844E+12	1.820E+00	4.196E+01
	SPS75_tb25_d1p7_hiP_dip	1.70	25.0	3.80E+11	75	2.091E+02	2.208E+02	1.809E+00	1.694E+13	3.411E+12	3.366E+00	8.604E+01
SPS, 75 GeV, tb=75 ns	SPS75_tb75_d1p3_hiP_dip	1.30	75.0	6.40E+11	75	9.794E+01	1.919E+02	3.236E-03	5.530E+11	2.925E+10	2.887E-02	4.167E-01
	SPS75_tb75_d1p5_hiP_dip	1.50	75.0	6.40E+11	75	1.104E+02	2.121E+02	2.845E-02	2.270E+12	2.162E+11	2.133E-01	2.966E+00
	SPS75_tb75_d1p7_hiP_dip	1.70	75.0	6.40E+11	75	1.194E+02	1.913E+02	1.446E-01	5.112E+12	7.024E+11	6.932E-01	9.517E+00
SPS, 450 GeV, tb=12.5 ns	SPS450_tb12p5_d1p3_hiP_dip	1.30	12.5	1.90E+11	450	4.185E+02	7.624E+02	1.257E-01	4.458E+12	3.404E+11	3.359E-01	3.691E+01
	SPS450_tb12p5_d1p5_hiP_dip	1.50	12.5	1.90E+11	450	4.475E+02	6.139E+02	8.113E-01	7.566E+12	1.538E+12	1.518E+00	1.559E+02
	SPS450_tb12p5_d1p7_hiP_dip	1.70	12.5	1.90E+11	450	4.723E+02	4.991E+02	3.391E+00	4.544E+13	4.138E+12	4.084E+00	3.788E+02
SPS, 450 GeV, tb=25 ns	SPS450_tb25_d1p3_hiP_dip	1.30	25.0	3.80E+11	450	3.783E+02	8.186E+02	7.774E-02	3.150E+12	3.165E+11	3.123E-01	3.030E+01
	SPS450_tb25_d1p5_hiP_dip	1.50	25.0	3.80E+11	450	4.169E+02	7.410E+02	3.547E-01	5.039E+12	9.956E+11	9.826E-01	9.854E+01
	SPS450_tb25_d1p7_hiP_dip	1.70	25.0	3.80E+11	450	4.642E+02	6.860E+02	1.081E+00	1.092E+13	1.988E+12	1.962E+00	2.090E+02
SPS, 450 GeV, tb=75 ns	SPS450_tb75_d1p3_hiP_dip	1.30	75.0	6.40E+11	450	2.105E+02	4.734E+02	2.690E-03	8.078E+11	2.056E+10	2.029E-02	1.118E+00
	SPS450_tb75_d1p5_hiP_dip	1.50	75.0	6.40E+11	450	2.034E+02	4.571E+02	2.203E-02	2.884E+12	1.573E+11	1.552E-01	6.179E+00
	SPS450_tb75_d1p7_hiP_dip	1.70	75.0	6.40E+11	450	1.991E+02	3.891E+02	1.334E-01	6.385E+12	6.128E+11	6.048E-01	2.001E+01
SPS+a, 50 GeV, tb=12.5 ns	SPSpa50_tb12p5_d1p3_hiP_dip	1.30	12.5	1.90E+11	50	2.120E+02	3.471E+02	7.814E-01	2.276E+12	2.260E+12	1.738E+00	7.114E+01
	SPSpa50_tb12p5_d1p5_hiP_dip	1.50	12.5	1.90E+11	50	2.437E+02	3.260E+02	3.003E+00	6.679E+12	5.747E+12	4.420E+00	1.901E+02
	SPSpa50_tb12p5_d1p7_hiP_dip	1.70	12.5	1.90E+11	50	2.668E+02	2.950E+02	9.586E+00	1.769E+13	1.177E+13	9.050E+00	4.182E+02
SPS+a, 50 GeV, tb=25 ns	SPSpa50_tb25_d1p3_hiP_dip	1.30	25.0	3.80E+11	50	1.599E+02	1.890E+02	3.686E-01	2.717E+12	1.536E+12	1.181E+00	1.621E+01
	SPSpa50_tb25_d1p5_hiP_dip	1.50	25.0	3.80E+11	50	1.585E+02	1.610E+02	1.093E+00	5.684E+12	3.162E+12	2.432E+00	3.346E+01
	SPSpa50_tb25_d1p7_hiP_dip	1.70	25.0	3.80E+11	50	1.653E+02	1.423E+02	2.780E+00	1.334E+13	5.367E+12	4.128E+00	6.146E+01
SPS+a, 50 GeV, tb=75 ns	SPSpa50_tb75_d1p3_hiP_dip	1.30	75.0	6.40E+11	50	3.277E+02	5.115E+02	3.658E-03	5.501E+11	3.421E+10	2.631E-02	7.258E-01
	SPSpa50_tb75_d1p5_hiP_dip	1.50	75.0	6.40E+11	50	2.328E+02	3.587E+02	3.861E-02	2.250E+12	3.194E+11	2.456E-01	4.335E+00
	SPSpa50_tb75_d1p7_hiP_dip	1.70	75.0	6.40E+11	50	2.076E+02	2.669E+02	2.311E-01	3.944E+12	1.226E+12	9.430E-01	1.434E+01
SPS+b, 75 GeV, tb=12.5 ns	SPSpb100_tb12p5_d1p3_hiP_dip	1.30	12.5	1.90E+11	75	4.649E+02	8.392E+02	9.360E-01	4.897E+12	2.342E+12	1.801E+00	1.239E+02
	SPSpb100_tb12p5_d1p5_hiP_dip	1.50	12.5	1.90E+11	75	4.297E+02	7.365E+02	3.603E+00	6.853E+12	6.089E+12	4.683E+00	3.086E+02
	SPSpb100_tb12p5_d1p7_hiP_dip	1.70	12.5	1.90E+11	75	6.141E+02	7.715E+02	8.338E+00	1.701E+13	9.753E+12	7.500E+00	7.514E+02
SPS+b, 75 GeV, tb=25 ns	SPSpb100_tb25_d1p3_hiP_dip	1.30	25.0	3.80E+11	75	1.621E+02	2.253E+02	2.044E-01	4.980E+12	9.330E+11	7.175E-01	1.312E+01
	SPSpb100_tb25_d1p5_hiP_dip	1.50	25.0	3.80E+11	75	1.650E+02	2.009E+02	7.661E-01	8.651E+12	2.367E+12	1.821E+00	3.305E+01
	SPSpb100_tb25_d1p7_hiP_dip	1.70	25.0	3.80E+11	75	1.758E+02	1.861E+02	2.107E+00	1.491E+13	4.281E+12	3.292E+00	6.599E+01
SPS+b, 75 GeV, tb=75 ns	SPSpb100_tb75_d1p3_hiP_dip	1.30	75.0	6.40E+11	75	9.268E+01	1.859E+02	3.123E-03	5.193E+11	2.973E+10	2.287E-02	3.546E-01
	SPSpb100_tb75_d1p5_hiP_dip	1.50	75.0	6.40E+11	75	1.072E+02	2.248E+02	2.233E-02	2.063E+12	1.910E+11	1.468E-01	2.374E+00
	SPSpb100_tb75_d1p7_hiP_dip	1.70	75.0	6.40E+11	75	1.164E+02	2.082E+02	1.339E-01	4.784E+12	7.537E+11	5.797E-01	9.177E+00
SPS+, 1000 GeV, tb=12.5 ns	SPSp1000_tb12p5_d1p3_hiP_dip	1.30	12.5	1.80E+11	1000	4.843E+02	9.778E+02	1.931E-01	4.246E+12	5.256E+11	4.042E-01	5.357E+01
	SPSp1000_tb12p5_d1p5_hiP_dip	1.50	12.5	1.80E+11	1000	5.042E+02	8.332E+02	8.893E-01	1.343E+13	1.731E+12	1.332E+00	1.656E+02
	SPSp1000_tb12p5_d1p7_hiP_dip	1.70	12.5	1.80E+11	1000	5.962E+02	7.611E+02	2.552E+00	4.259E+13	3.199E+12	2.460E+00	3.373E+02
SPS+, 1000 GeV, tb=25 ns	SPSp1000_tb25_d1p3_hiP_dip	1.30	25.0	3.60E+11	1000	4.070E+02	9.670E+02	7.615E-02	2.035E+12	3.354E+11	2.579E-01	2.612E+01
	SPSp1000_tb25_d1p5_hiP_dip	1.50	25.0	3.60E+11	1000	4.341E+02	8.553E+02	4.072E-01	3.526E+12	1.214E+12	9.340E-01	9.914E+01
	SPSp1000_tb25_d1p7_hiP_dip	1.70	25.0	3.60E+11	1000	5.271E+02	8.633E+02	1.184E+00	1.075E+13	2.293E+12	1.763E+00	2.254E+02
SPS+, 1000 GeV, tb=75 ns	SPSp1000_tb75_d1p3_hiP_dip	1.30	75.0	6.20E+11	1000	6.364E+02	1.232E+03	1.593E-03	9.246E+11	9.862E+09	7.584E-03	1.717E+00
	SPSp1000_tb75_d1p5_hiP_dip	1.50	75.0	6.20E+11	1000	5.267E+02	1.121E+03	5.139E-03	3.093E+12	3.451E+10	2.654E-02	4.578E+00
	SPSp1000_tb75_d1p7_hiP_dip	1.70	75.0	6.20E+11	1000	5.043E+02	9.966E+02	6.653E-02	2.268E+13	3.581E+11	2.754E-01	3.811E+01
SPS, 50 GeV, tb=12.5 ns, no	SPS50_tb12p5_d1p3NR_hiP_dip	1.30	12.5	1.90E+11	50	1.46E+02	2.78E+02	6.40E-03	2.12E+11	2.986E+10	2.95E-02	1.486E+00
	SPS50_tb12p5_d1p5NR_hiP_dip	1.50	12.5	1.90E+11	50	1.31E+02	2.23E+02	2.96E-01	3.86E+11	8.659E+11	8.55E-01	3.229E+01
	SPS50_tb12p5_d1p7NR_hiP_dip	1.70	12.5	1.90E+11	50	1.33E+02	2.01E+02	1.08E+00	4.65E+11	2.018E+12	1.99E+00	7.529E+01
SPS, 50 GeV, tb=25 ns, no re	SPS50_tb25_d1p3NR_hiP_dip	1.30	25.0	3.80E+11	50	1.29E+02	1.71E+02	8.30E-02	1.16E+12	4.820E+11	4.76E-01	7.696E+00
	SPS50_tb25_d1p5NR_hiP_dip	1.50	25.0	3.80E+11	50	1.28E+02	1.42E+02	2.57E-01	1.71E+12	1.043E+12	1.03E+00	1.774E+01
	SPS50_tb25_d1p7NR_hiP_dip	1.70	25.0	3.80E+11	50	1.28E+02	1.20E+02	6.45E-01	3.85E+12	1.770E+12	1.75E+00	3.204E+01
SPS, 50 GeV, tb=75 ns, no re	SPS50_tb75_d1p3NR_hiP_dip	1.30	75.0	6.40E+11	50	4.03E+02	7.14E+02	1.14E-03	2.83E+11	1.260E+10	1.24E-02	4.767E-01
	SPS50_tb75_d1p5NR_hiP_dip	1.50	75.0	6.40E+11	50	2.97E+02	5.60E+02	2.03E-03	4.81E+11	2.313E+10	2.28E-02	6.732E-01
	SPS50_tb75_d1p7NR_hiP_dip	1.70	75.0	6.40E+11	50	1.96E+02	3.62E+02	6.57E-03	1.10E+12	7.374E+10	7.28E-02	1.516E+00
PS2, 50 GeV, tb=12.5 ns	PS50_tb12p5_d1p3_hiP_dip	1.30	12.5	2.00E+11	50	2.47E+02	2.82E+02	6.57E-01	3.31E+13	1.540E+12	3.16E+00	5.503E+01
	PS50_tb12p5_d1p5_hiP_dip	1.50	12.5	2.00E+11	50	1.88E+02	2.17E+02	1.75E+00	4.17E+13	3.362E+12	6.90E+00	8.818E+01
	PS50_tb12p5_d1p7_hiP_dip	1.70	12.5	2.00E+11	50	1.82E+02	1.47E+02	3.07E+00	2.80E+13	4.208E+12	8.63E+00	9.982E+01
PS2, 50 GeV, tb=25 ns	PS50_tb25_d1p3_hiP_dip	1.30	25.0	4.00E+11	50	3.18E+02	4.06E+02	4.00E-01	1.83E+13	1.223E+12	2.51E+00	4.169E+01
	PS50_tb25_d1p5_hiP_dip	1.50	25.0	4.00E+11	50	2.97E+02	3.40E+02	1.02E+00	4.12E+13	2.059E+12	4.22E+00	6.890E+01
	PS50_tb25_d1p7_hiP_dip	1.70	25.0	4.00E+11	50	3.11E+02	3.12E+02	2.20E+00	6.56E+13	2.904E+12	5.96E+00	1.050E+02
PS2, 50 GeV, tb=75 ns	PS50_tb75_d1p3_hiP_dip	1.30	75.0	6.60E+11	50	1.62E+02	2.69E+02	2.86E-02	5.07E+12	1.658E+11	3.40E-01	3.258E+00
	PS50_tb75_d1p5_hiP_dip	1.50	75.0	6.60E+11	50	1.70E+02	2.38E+02	1.25E-01	1.36E+13	4.651E+11	9.54E-01	9.588E+00
	PS50_tb75_d1p7_hiP_dip	1.70	75.0	6.60E+11	50	1.81E+02	2.17E+02	3.64E-01	2.65E+13	8.488E+11	1.74E+00	1.866E+01
PS+, 75 GeV, tb=12.5 ns	PS75_tb12p5_d1p3_hiP_dip	1.30	12.5	2.00E+11	75	3.05E+02	3.70E+02	4.64E-01	4.38E+13	1.059E+12	2.17E+00	5.009E+01
	PS75_tb12p5_d1p5_hiP_dip	1.50	12.5	2.00E+11	75	2.53E+02	3.04E+02	1.43E+00	1.10E+14	2.588E+12	5.31E+00	9.379E+01
	PS75_tb12p5_d1p7_hiP_dip	1.70	12.5	2.00E+11	75	2.26E+02	1.94E+02	3.12E+00	8.57E+13	4.058E+12	8.32E+00	1.259E+02
PS+, 75 GeV, tb=25 ns	PS75_tb25_d1p3_hiP_dip	1.30	25.0	4.00E+11	75	7.94E+02	8.83E+02	3.53E-01	2.00E+13	1.025E+12	2.10E+00	8.393E+01
	PS75_tb25_d1p5_hiP_dip	1.50	25.0	4.00E+11	75	7.17E+02	6.88E+02	9.78E-01	3.75E+13	1.866E+12	3.83E+00	1.461E+02
	PS75_tb25_d1p7_hiP_dip	1.70	25.0	4.00E+11	75	6.41E+02	5.47E+02	2.27E+00	7.86E+13	2.798E+12	5.74E+00	2.053E+02
PS+, 75 GeV, tb=75 ns	PS75_tb75_d1p3_hiP_dip	1.30	75.0	6.60E+11	75	2.83E+02	4.47E+02	2.96E-02	7.40E+12	1.597E+11	3.28E-01	5.825E+00
	PS75_tb75_d1p5_hiP_dip	1.50	75.0	6.60E+11	75	2.77E+02	3.70E+02	1.32E-01	1.75E+13	4.584E+11	9.40E-01	1.645E+01
	PS75_tb75_d1p7_hiP_dip	1.70	75.0	6.60E+11	75	2.76E+02	3.14E+02	4.09E-01	3.29E+13	8.753E+11	1.80E+00	3.180E+01

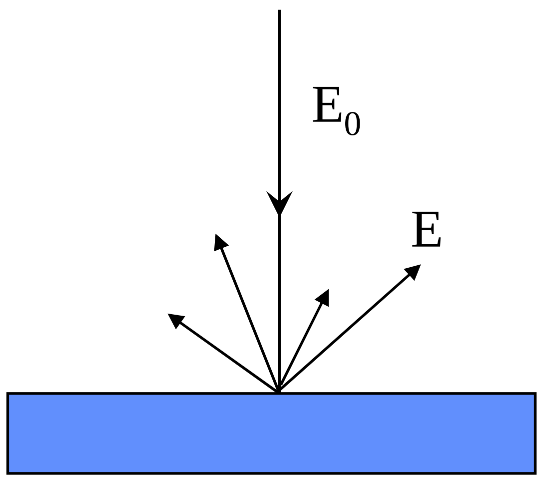
LHC, t_b=12.5 ns, σ_z=3.78 cm

case	xnpnom	dtotpk	avekrun	avek0run	avWCrun	avdensigrun	avdenrun	avlinedenrun	avPDrun
LHC_12p5_0p5_1p0	5.00E+10	1	2.42E+01	6.52E+01	5.50E-03	1.56E+10	3.29E+10	6.56E-03	4.19E-02
LHC_12p5_1p0_1p0	1.00E+11	1	4.31E+01	1.01E+02	1.33E-02	6.70E+09	5.95E+10	1.19E-02	2.14E-01
LHC_12p5_1p5_1p0	1.50E+11	1	4.47E+01	1.17E+02	1.73E-02	5.42E+09	6.31E+10	1.26E-02	3.32E-01
LHC_12p5_1p7_1p0	1.70E+11	1	4.62E+01	1.27E+02	1.90E-02	6.99E+09	6.51E+10	1.30E-02	4.04E-01
LHC_12p5_2p0_1p0	2.00E+11	1	4.79E+01	1.38E+02	2.14E-02	5.69E+09	6.69E+10	1.33E-02	5.08E-01
LHC_12p5_0p5_1p1	5.00E+10	1.1	4.62E+01	1.21E+02	4.68E-02	1.49E+11	3.52E+11	7.02E-02	9.02E-01
LHC_12p5_1p0_1p1	1.00E+11	1.1	5.61E+01	1.28E+02	9.03E-02	8.84E+09	5.82E+11	1.16E-01	2.21E+00
LHC_12p5_1p5_1p1	1.50E+11	1.1	5.30E+01	1.41E+02	6.18E-02	5.51E+09	3.63E+11	7.23E-02	1.61E+00
LHC_12p5_1p7_1p1	1.70E+11	1.1	5.36E+01	1.53E+02	5.39E-02	6.15E+09	2.97E+11	5.93E-02	1.50E+00
LHC_12p5_2p0_1p1	2.00E+11	1.1	5.25E+01	1.62E+02	4.70E-02	7.10E+09	2.30E+11	4.58E-02	1.35E+00
LHC_12p5_0p5_1p2	5.00E+10	1.2	4.83E+01	1.29E+02	1.49E-01	1.83E+12	1.03E+12	2.05E-01	2.49E+00
LHC_12p5_1p0_1p2	1.00E+11	1.2	5.94E+01	1.39E+02	2.34E-01	1.83E+10	1.39E+12	2.77E-01	5.40E+00
LHC_12p5_1p5_1p2	1.50E+11	1.2	5.85E+01	1.49E+02	1.93E-01	9.32E+09	1.13E+12	2.26E-01	5.21E+00
LHC_12p5_1p7_1p2	1.70E+11	1.2	5.75E+01	1.58E+02	1.79E-01	8.70E+09	1.03E+12	2.06E-01	5.05E+00
LHC_12p5_2p0_1p2	2.00E+11	1.2	5.67E+01	1.67E+02	1.56E-01	7.79E+09	8.75E+11	1.74E-01	4.69E+00
LHC_12p5_0p5_1p3	5.00E+10	1.3	4.77E+01	1.16E+02	2.72E-01	3.55E+12	1.69E+12	3.36E-01	3.66E+00
LHC_12p5_1p0_1p3	1.00E+11	1.3	6.26E+01	1.64E+02	4.28E-01	7.90E+10	2.29E+12	4.57E-01	9.45E+00
LHC_12p5_1p5_1p3	1.50E+11	1.3	6.09E+01	1.53E+02	3.63E-01	1.45E+10	1.95E+12	3.88E-01	9.19E+00
LHC_12p5_1p7_1p3	1.70E+11	1.3	5.95E+01	1.59E+02	3.54E-01	1.43E+10	1.87E+12	3.73E-01	9.24E+00
LHC_12p5_2p0_1p3	2.00E+11	1.3	6.06E+01	1.74E+02	3.30E-01	1.39E+10	1.74E+12	3.47E-01	9.67E+00

Backup material

Three components of secondary emission:
sample spectrum at E_0=300 eV

LARP



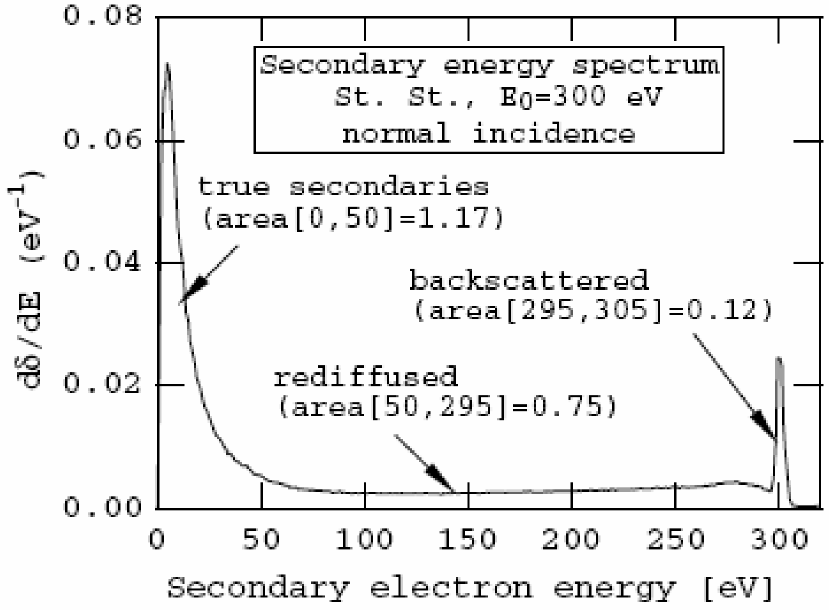
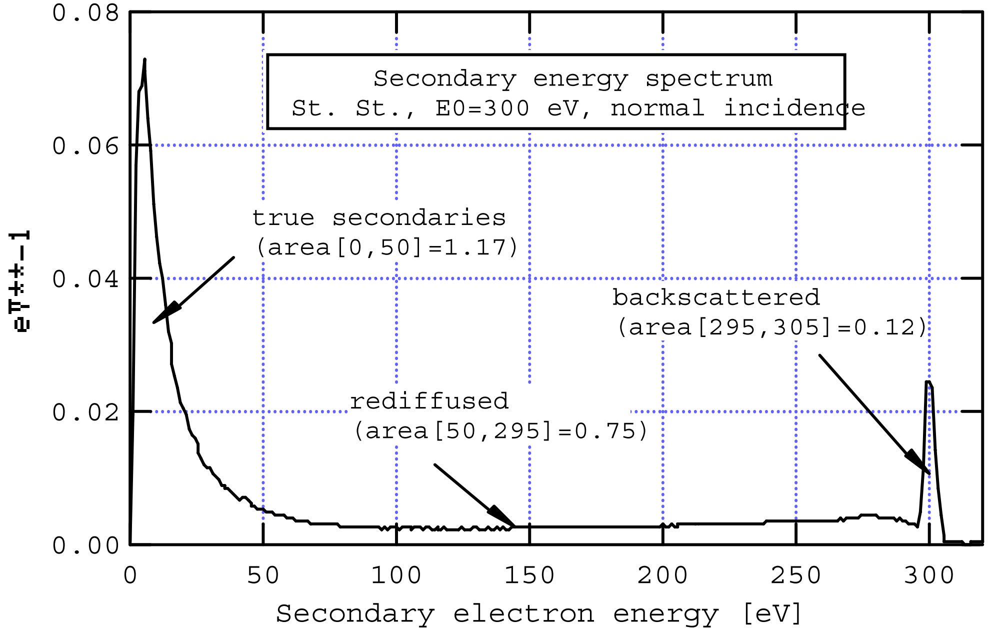


FIG. 2. A sample of the measured energy spectrum $d\delta/dE$ for an unconditioned sample of stainless steel at $E_0 = 300$ eV, normal incidence. The three components of the secondary yield are given by the values of "area $[E_1, E_2]$," each of which represents the integrated spectrum between E_1 and E_2. Thus for this case, $\delta_{ts} = 1.17$, $\delta_r = 0.75$, and $\delta_e = 0.12$, for a total SEY $\delta = 2.04$. The upper energy cutoff for the true secondaries is somewhat arbitrarily, but conventionally, chosen to be 50 eV. Data courtesy of R. Kirby.

from M. F. and M. Pivi, PRST-AB **5**, 124404 (2002)

Secondary emission spectrum

- Depends on material and state of conditioning
  - —St. St. sample, E_0=300 eV, normal incidence, (Kirby-King, NIMPR A469, 1 (2001))



st. steel sample	Cu sample
δ= 2.04	δ= 2.05
δ_e= 6%	δ_e= 1%
δ_r= 37%	δ_r= 9%
δ_{ts} =57%	δ_{ts} =90%
$\delta_e+\delta_r$ =43%	$\delta_e+\delta_r$ =10%

– Hilleret's group CERN: Baglin et al, CERN-LHC-PR 472.

– Other measurements: Cimino and Collins, 2003)

Electron-wall collision energy
comparison w/wo rediffused electrons

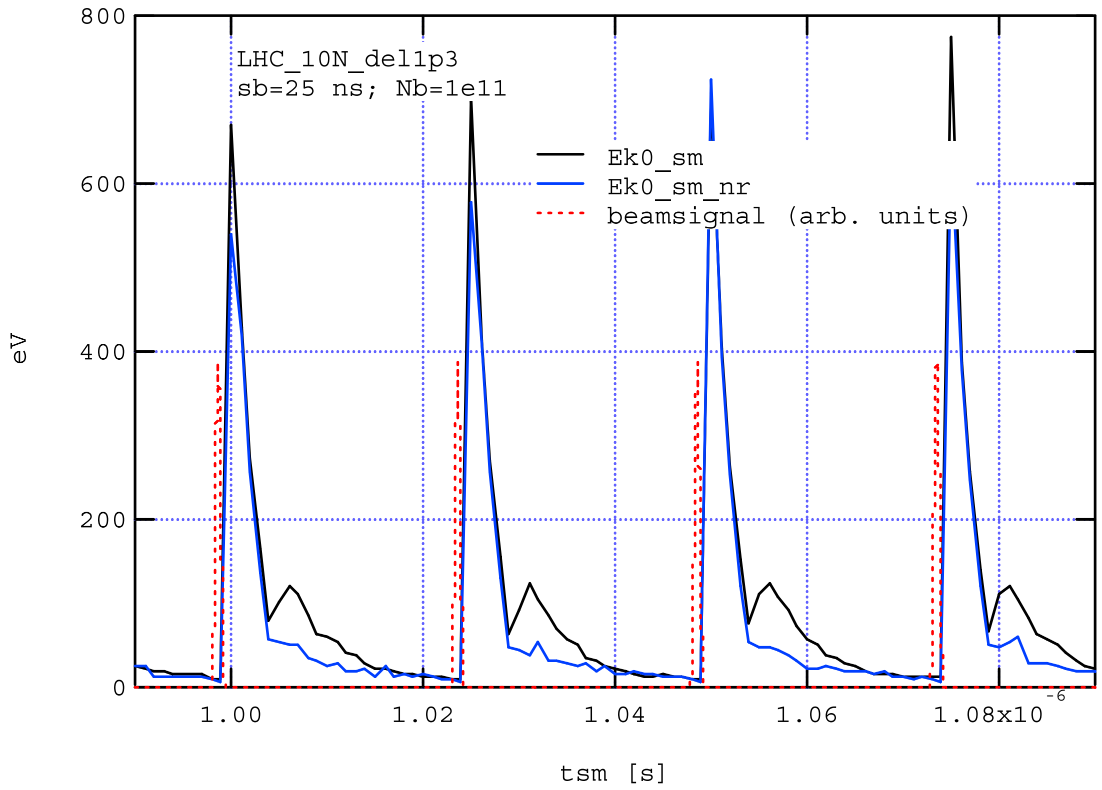
LARP

Four successive bunches in a 25-ns batch

~5 ns after bunch passage: 1st wave of electrons hits the wall (were kicked by the beam)

~5 ns later: second wave of electrons hits the wall; these were mostly rediffused electrons created when the 1st wave hit the wall

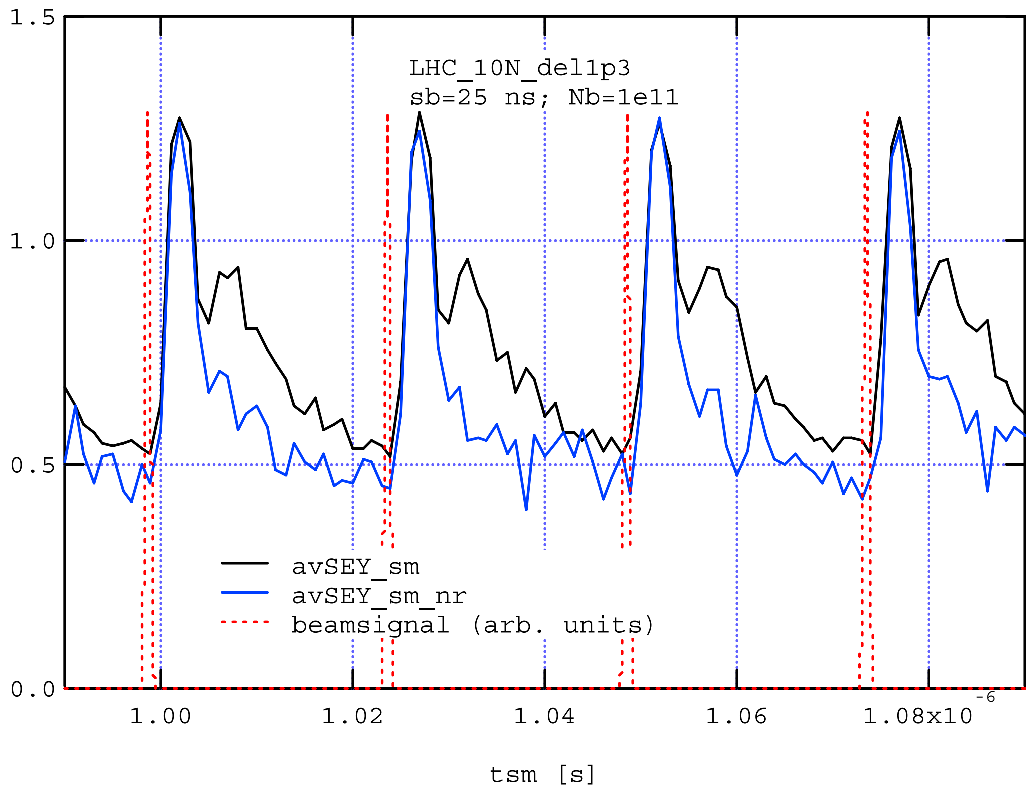
NB: the 2nd wave is absent in the “NR” case (“no rediffused”)



Effective SEY
comparison w/wo rediffused electrons

LARP

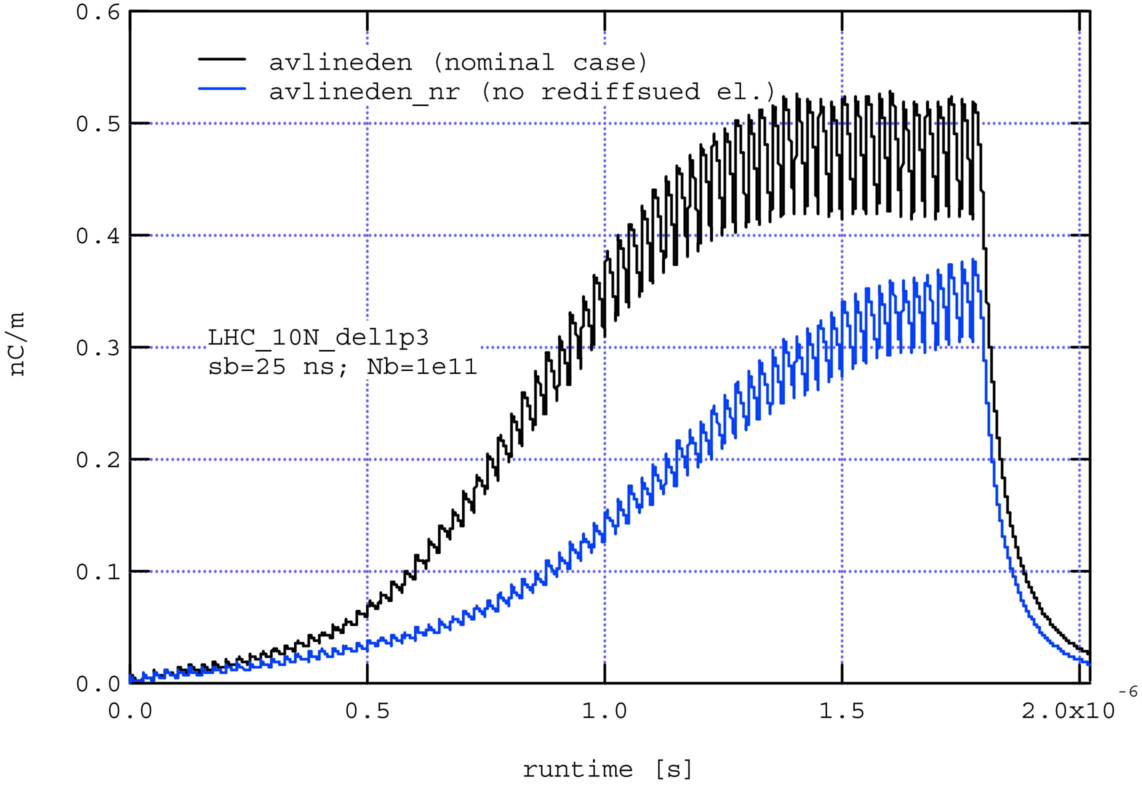
The 2nd wave leads to a higher effective SEY (δ_{eff}) than in the "NR" case…



[definition: δ_{eff}= (no. of emitted electrons)/(no. of incident electrons) averaged over all electron-wall collisions anywhere on the chamber wall, over any given time interval]

Average electron line density
comparison w/wo rediffused electrons

LARP



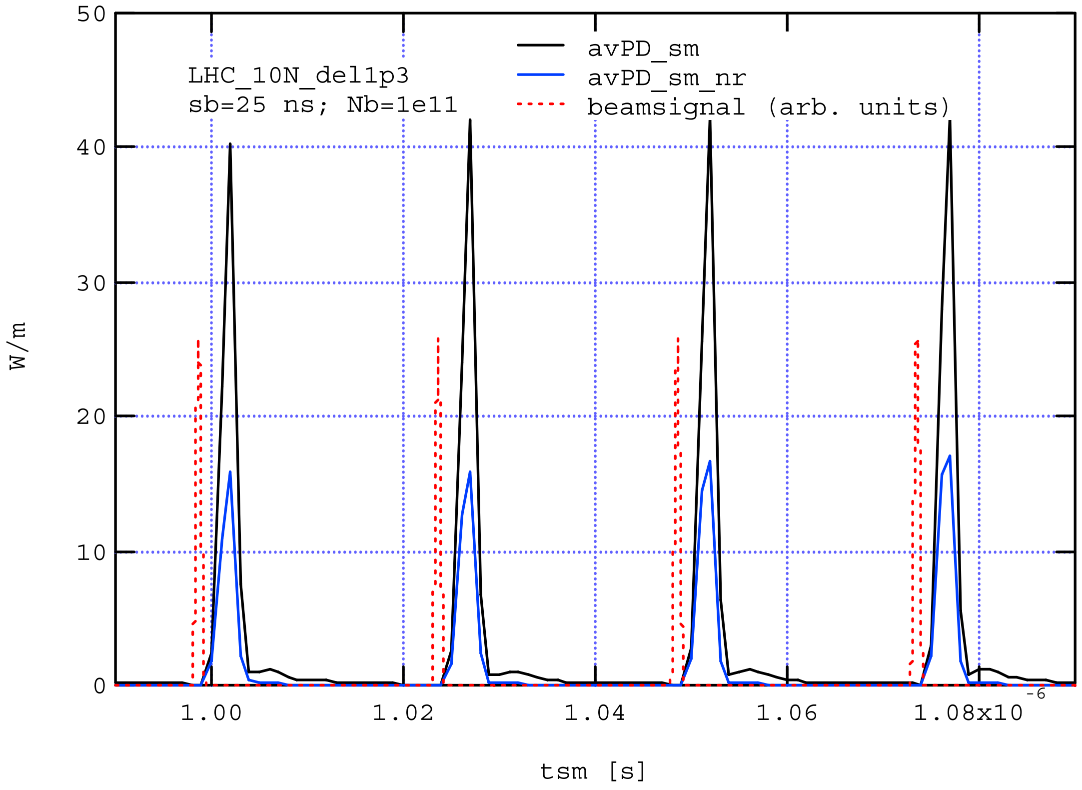
…which leads to ~twice the number of electrons…

Average power deposition
comparison w/wo rediffused electrons

…which, in turn, leads to ~twice the power deposition.

Most of the power deposition comes from the 1st-wave electrons. The factor ~2 is mostly because there are ~twice the number of electrons.

The 2nd wave contributes an additional ~5-10% of “direct” power deposition (small bump ~10 ns after the bunch passage)

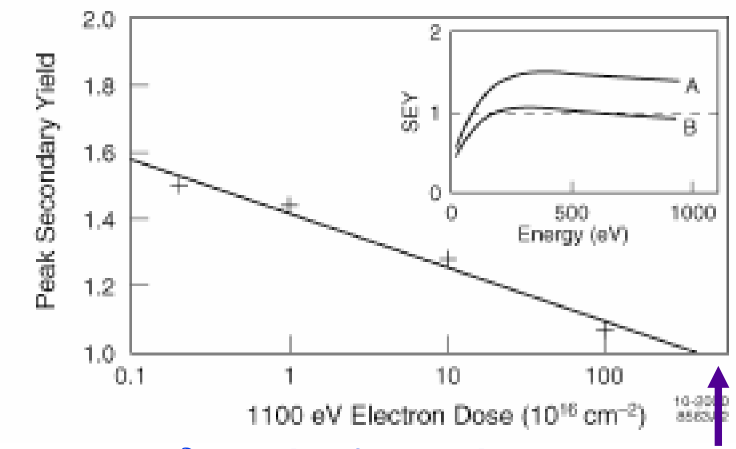


Conditioning

- Peak SEY δ_{max} vs e^- dose:

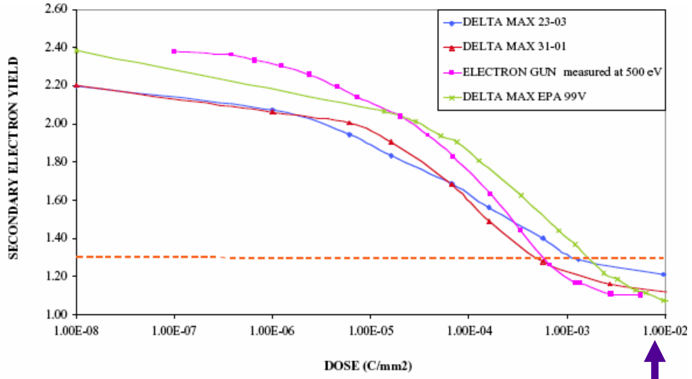
$$\delta_{\max} \simeq a - b\ln(D)$$
$$\text{for } 10^{-4} \lesssim D \lesssim 1\ \text{C/cm}^2$$

- δ_{max}~1 when D~1 C/cm²
  - — under vacuum and steady e^- current
- ECE is a self-conditioning effect
  - — Beam conditioning observed at SPS, PSR, PEP-II, RHIC…



δ_{max} vs. dose for TiN/Al
Kirby & King, NIMPR A469, 1 (2001)

~1 C/cm²



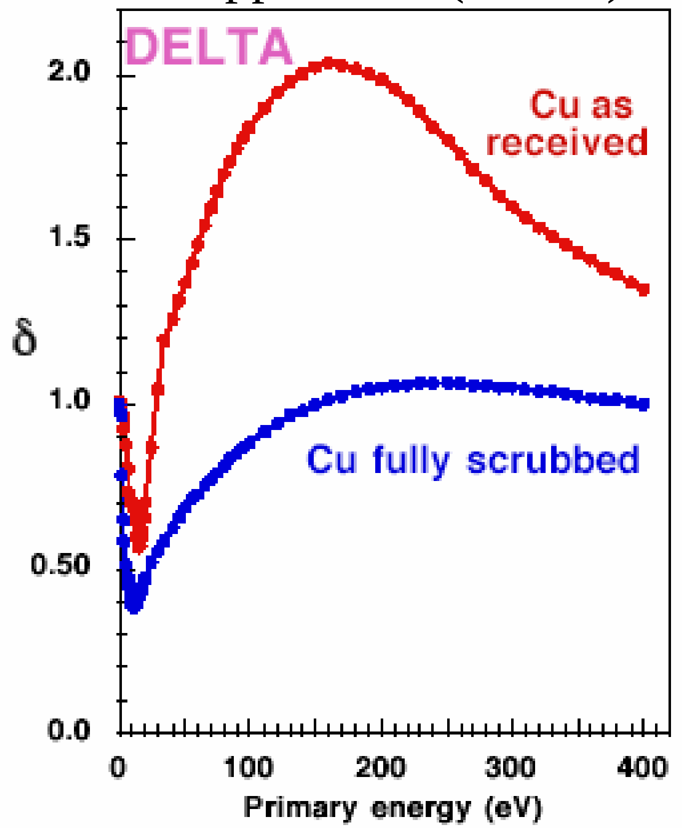
δ_{max} vs. dose for Cu
Hilleret, 2stream2001 (KEK)

1 C/cm²

Conditioning effects–contd.

- Consistent with bench results for Cu found at CERN!
  - the result $\delta(0)\approx 1$ seems unconventional
  - if validated, it could have a significant unfavorable effect on the EC power deposition in the LHC
    - because $\delta(0)$ controls the *dissipation rate* of the EC
    - large $\delta(0)$ ← electrons survive longer in between bunches

Copper SEY (CERN)



R. Cimino and I. Collins,
Appl. Surf. Sci. **235**(1), p. 231 (2004)

Code features

LARP

POSINST

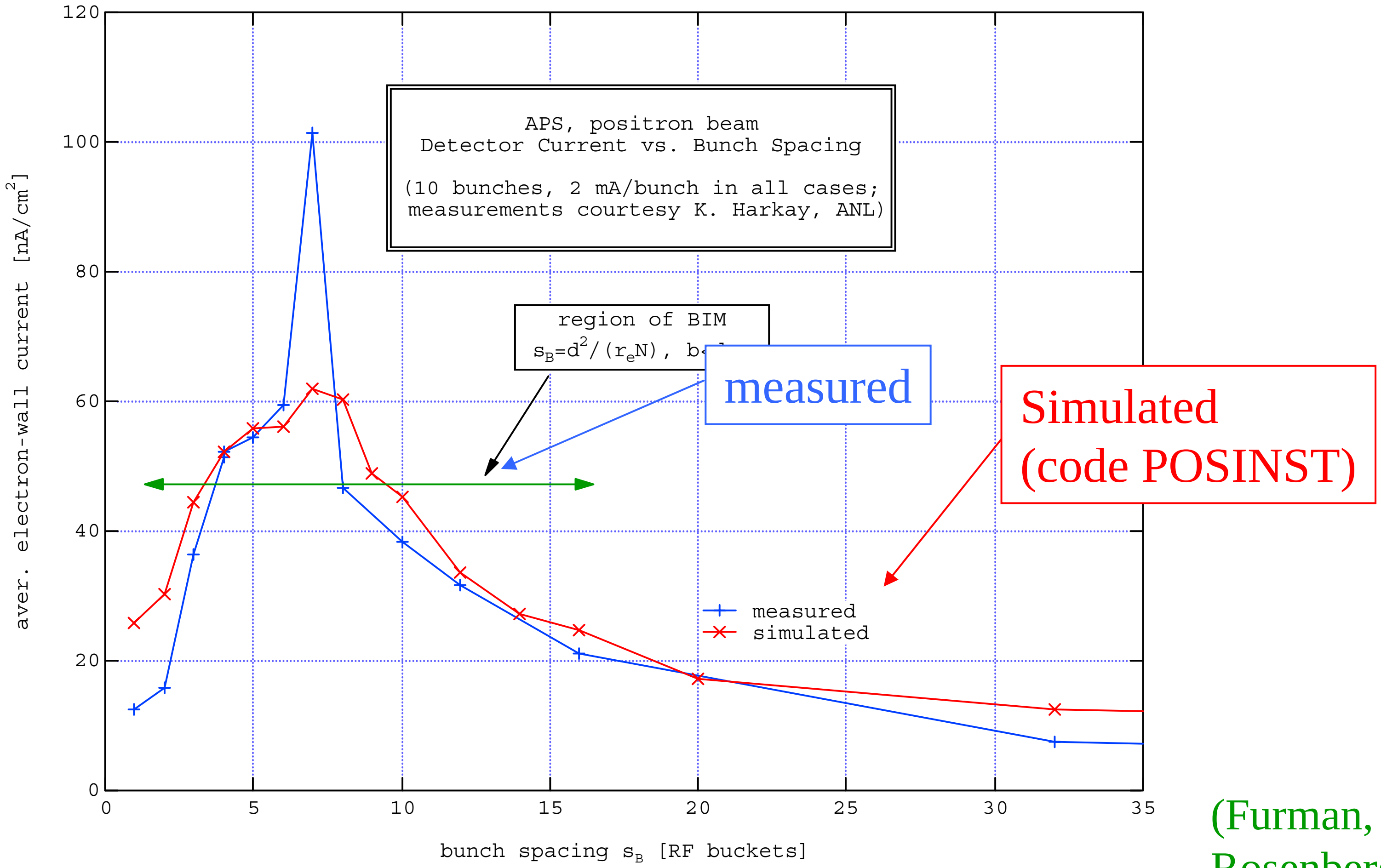
- Detailed SEY model
  - distributed by Tech-X
- 2D, not self-consistent
  - electrons are dynamical, beam is prescribed
  - geared towards determining EC build-up and e^- distribution in time, space and energy
- Basic ionization, photoelectric and ion-e^- generation models
- Space-charge (2D grid)
- Arbitrary beam fill pattern
- Field free or dipole fields
- Chamber rectangular or elliptical
- Arbitrary longitudinal bunch profile
- Transverse bunch profile: selectable from several choices
- Simple kick-drift e^- mover
- Serial computation

WARP/POSINST

- All of POSINST, plus:
- 3D, beam-cloud self-consistent
- Detailed ionization, ion-e^- generation models and gas desorption
- Space-charge: AMR 3D (2D x-y and r-z modes available)
- MAD input for lattice
- Arbitrary external fields (EM or B)
- Arbitrary chamber shape
- Arbitrary 3D bunch distribution
- PIC solver
- Hybrid Boris/drift mover for e^- in B fields
- Parallel computation (MPI)
- GUI

BIM in the APS: benchmark code POSINST

Time-averaged e⁻ flux at wall vs. bunch spacing
(e^+ beam, 10-bunch train, field-free region)

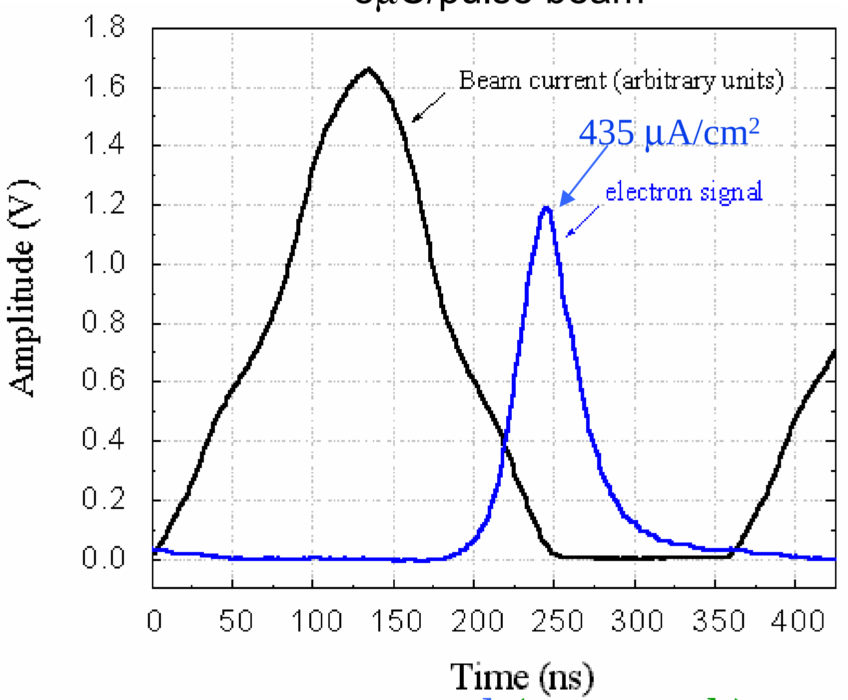


(Furman, Pivi, Harkay, Rosenberg, PAC01)

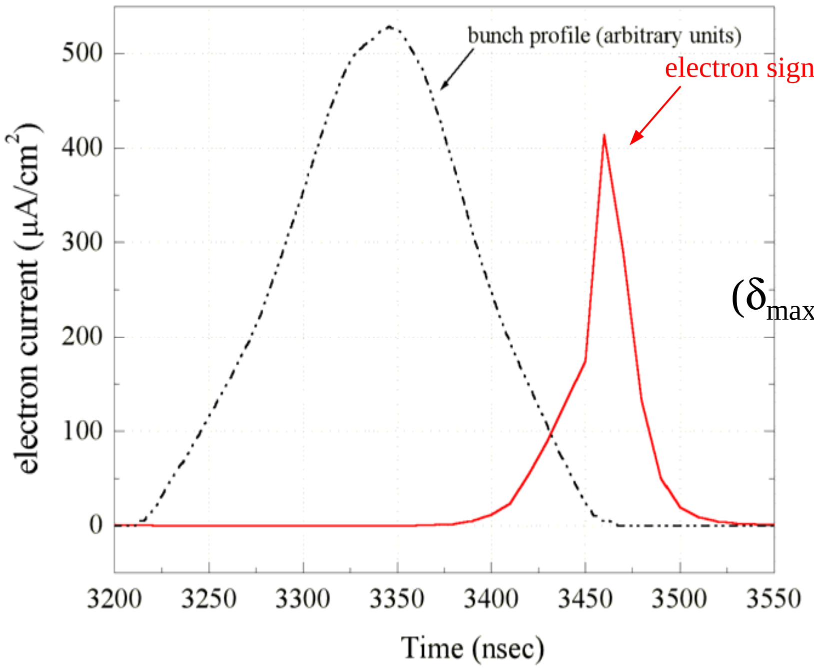
PSR: benchmark code POSINST

- Bunch length >> Δt
  - — a portion the EC phase space is in resonance with the "bounce frequency"
  - — "trailing edge multipacting" (Macek; Blaskiewicz, Danilov, Alexandrov,…)

ED42Y electron detector signal
8μC/pulse beam



measured (R. Macek)



(δ_{max}=2.05)

simulated (M. Pivi)