PS2 Electron-Cloud Build-Up Studies: Status

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Miguel A. Furman
LBNL
mafurman@lbl.gov

- **Team:** M. Furman, M. Venturini, J.-L. Vay, G. Penn, J. Byrd, S. de Santis (LBNL); M. Pivi, L. Wang, J. Fox, C. Rivetta (SLAC); R. de Maria (BNL).
- **CERN contacts:** M. Benedikt, G. Rumolo, I. Papaphilippou, F. Zimmermann, J. M. Jiménez, G. Arduini, F. Caspers.

Summary

- Contents of this talk:
  1. Goals
  2. Assumptions
  3. Numerical convergence of simulations
  4. Sensitivity to transverse and longitudinal bunch profiles
  5. Sensitivity to beam energy (injection vs. extraction)
  6. Sensitivity to fill pattern (25 ns vs. 50 ns bunch spacing)
  7. Sensitivity to peak SEY
  8. Comparison of PS2 and MI upgrade
  9. Conclusions
  10. What next
  11. Tasks and effort level

- Results obtained with 2D build-up code POSINST
- All results here are for the ecloud build-up in a PS2 dipole bending magnet <u>only</u>
- Previous results presented at:
  - **LUMI2006** (Valencia, Oct. 2006); report LBNL-61925
  - **ECL2** (CERN, Mar. 2007); report LBNL-61925-update

Goals of PS2 ecloud studies

1. Predict as closely as possible the EC density n_e and its distribution
2. If a SC option is considered for the PS2, quantify the power deposition on the chamber walls from the EC
3. Use n_e and its distribution as inputs to understand effects on the beam
   - Coherent single- and multi- bunch instabilities
   - Emittance growth
4. Assess mitigation mechanisms if necessary
   - Low-SEY coatings
   - Grooved surfaces
   - Clearing electrodes
   - Feedback system (similar to SPS, if necessary and feasible) (*)
5. Possibly combine EC with space-charge studies
   - EC provides a local, dynamical, neutralization of the beam
6. Maintain an ongoing side-by-side comparison against MI upgrade
   - Measurements and code validation at the MI are likely to bolster PS2 studies

(*) See talks by J. Fox, R. de Maria, J.-L. Vay, M. Pivi

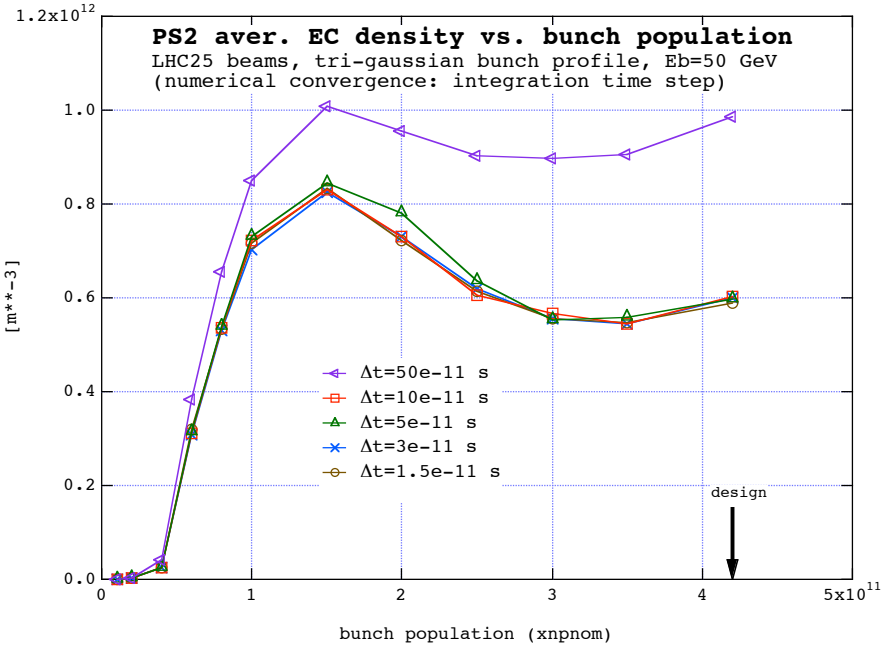
Assumptions

1. C=1346.4 m, h=180, f_{RF}=40 MHz
2. Elliptical chamber cross section, semi-axes (a,b)=(6,3.5) cm
3. Peak SEY=1.2, 1.3 or 1.4
4. Beam energy: KE_{inj}=4 GeV, KE_{extr}=50 GeV
5. Dipole bending magnet: B=0.136 T @inj., 1.7 T @extr.
6. Beam fill patterns:
   - "LHC25": 168 full consecutive + 12 empty buckets, s_b=25 ns, $N_b=4.2\times10^{11}$
   - "LHC50": 84 full every other + 12 empty buckets, s_b=50 ns , $N_b=5.9\times10^{11}$
7. Bunch length: σ_t=3 ns @ inj., σ_t=1 ns @ extr.
8. $\varepsilon_x=\varepsilon_y=6.5\times10^{-6}$ m–rad (RMS, normalized)
9. (β_x, β_y)=(30, 26) m at dipole magnet (neglect bunch dispersive width)
10. Bunch shape:
    - Transverse: gaussian, parabolic or flat
    - Longitudinal: gaussian or flat
      - but not in all combinations
11. Computational parameters:
    - Macroparticles=20,000 max.
    - Integration time step: $\Delta t=(1.5–50)\times10^{-11}$ s
    - Space-charge grid: 16x16, 32x32 or 64x64 [just enough to cover (2a)x(2b) area]

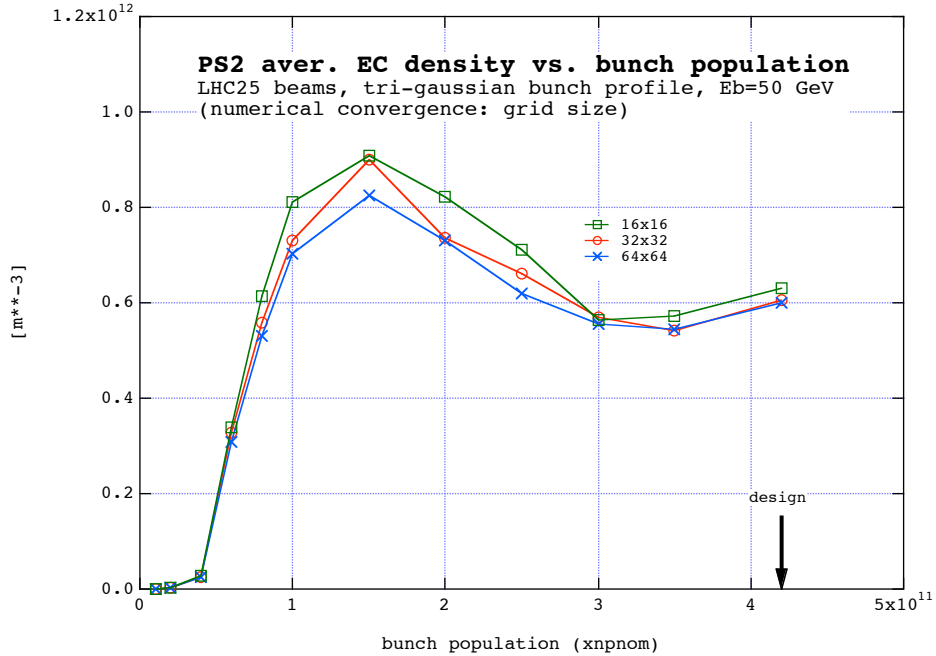
Numerical convergence: average n_e vs. N_b

LHC25 beam, E_b=50 GeV, trigaussian bunches, δ_{max}=1.3

integr. time step



space-ch. grid size

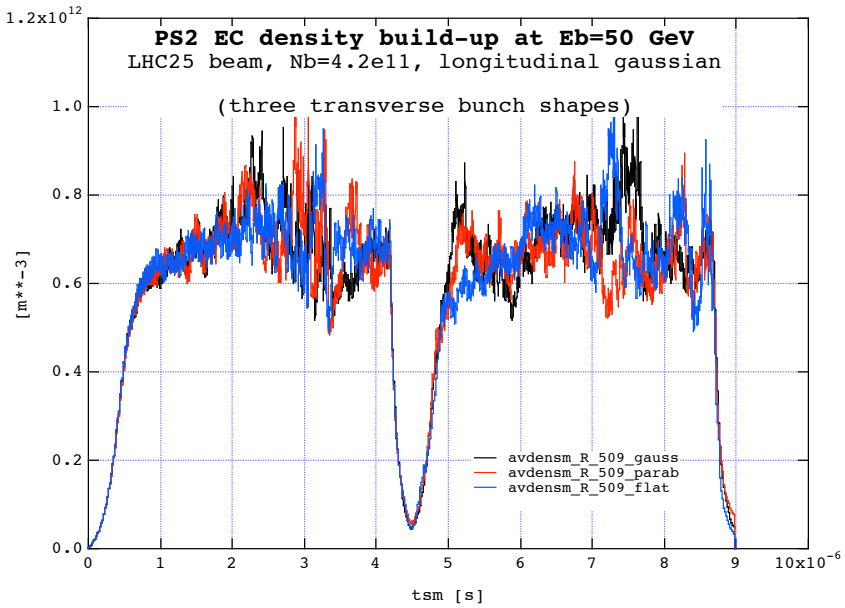


- Reasonable convergence for Δt<~1x10^{-10} s and grid size 16x16 or finer
- Above results, and all subsequent, are 2-turn averages
  - Most carried out with Δt=3x10^{-11} s and 64x64 grid
- N.B.: more detailed quantities than n_e, or higher values of δ_{max}, might require smaller Δt and finer grids

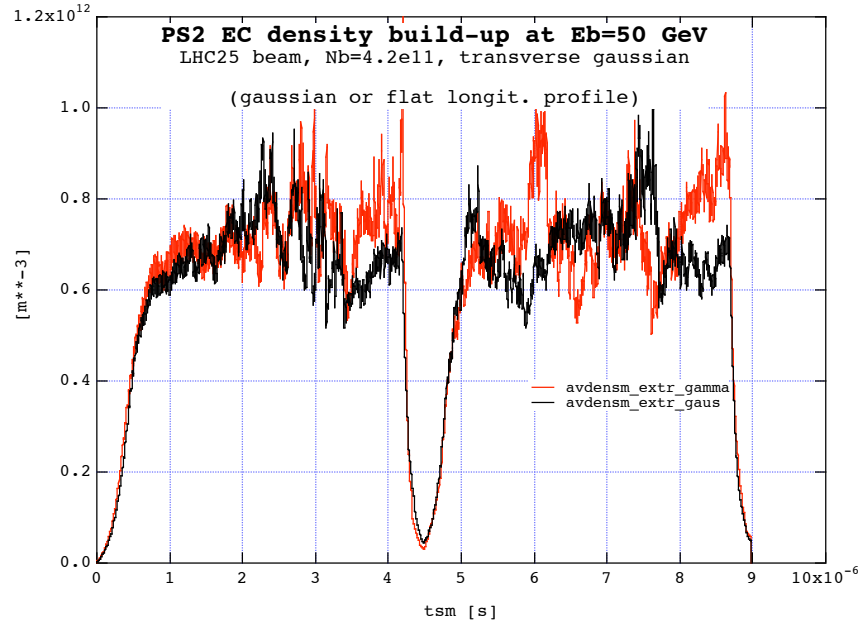
Sensitivity to trans. and long. bunch profiles

build-up at E_b=50 GeV in dipole bend, N_b=4.2e11, δ_{max}=1.3

three transverse profiles



two longitudinal profiles



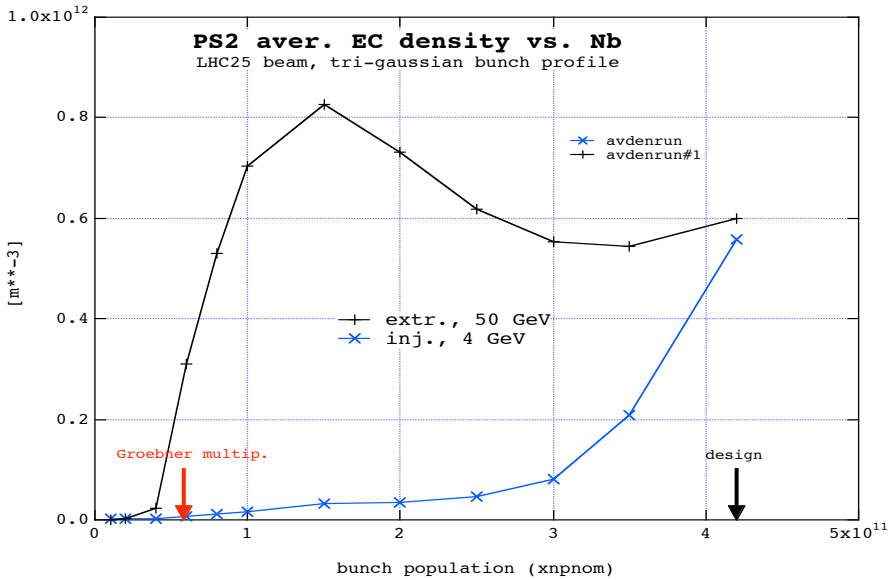
- Transverse: gaussian, parabolic or flat profiles
- Longitudinal: gaussian or flat profiles
- Conclusions:
  - E_b=50 GeV, bunch profile not a significant variable, either trans. or longit.
  - At E_b=4 GeV, flat longitudinal profile leads to ~20% smaller n_e than gaussian
  - EC density ~ 8×10^{11} m^{-3} at saturation, either at inj. or extr.

N.B.: deep fluctuations due to “virtual cathode” phenomenon; this needs work, although average n_e is probably okay

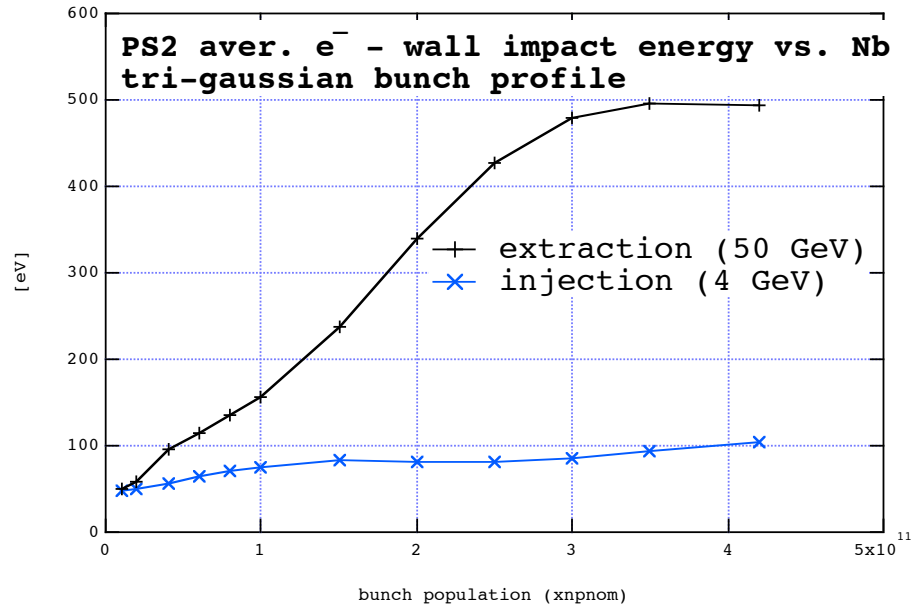
Injection vs. extraction: aver. n_e vs. N_b

LHC25 beam, tri-gaussian bunch profile, δ_{max}=1.3

EC density



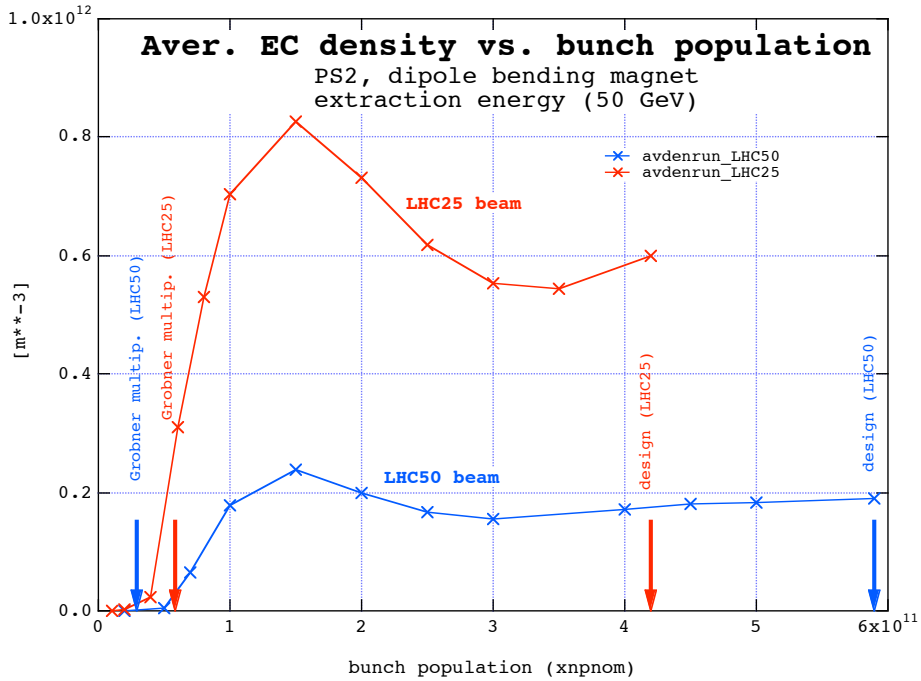
EC-wall collision energy



- Main variable vis-à-vis ecloud is bunch length
- At the nominal N_b=4.2x10^{11}, n_e is ~the same (injection or extraction)
- Strong nonlinear behavior of n_e vs. N_b
  - At E_b=50 GeV: partially explained by electron-wall impact energy: crosses E=300 eV (maximum SEY) at N_b~2x10^{11}
  - At E_b=4 GeV: I don't yet understand strong dependence of n_e for N_b < 4.2x10^{11}

Sensitivity to fill pattern: LHC25 vs. LHC50

average n_e vs. N_b, trigaussian bunch, E_b=50 GeV, δ_{max}=1.3

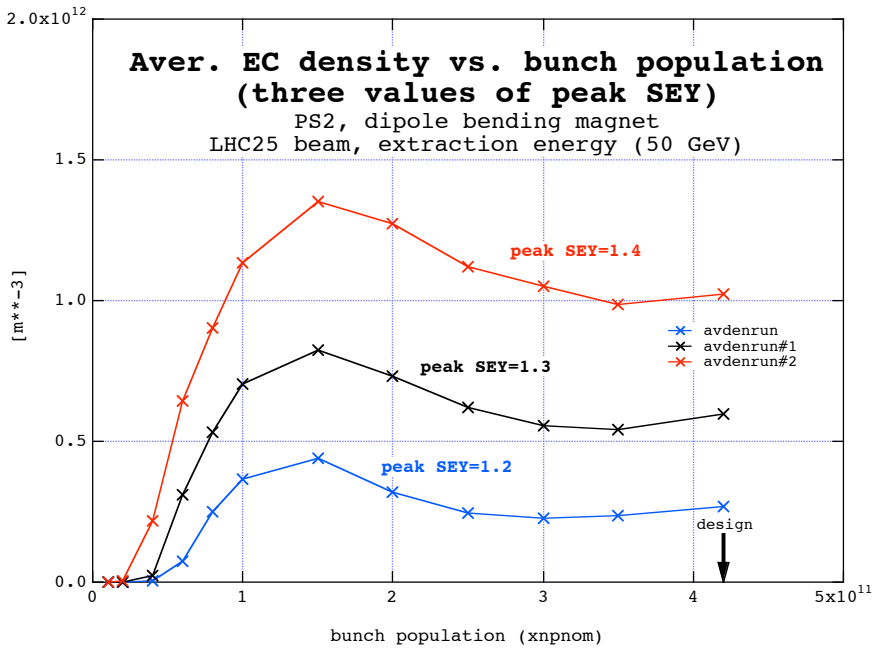


- LHC50 more favorable than LHC25 by factor ~3 in n_e
  - Reason: larger bunch spacing allows more time for the ecloud to dissipate between successive bunches

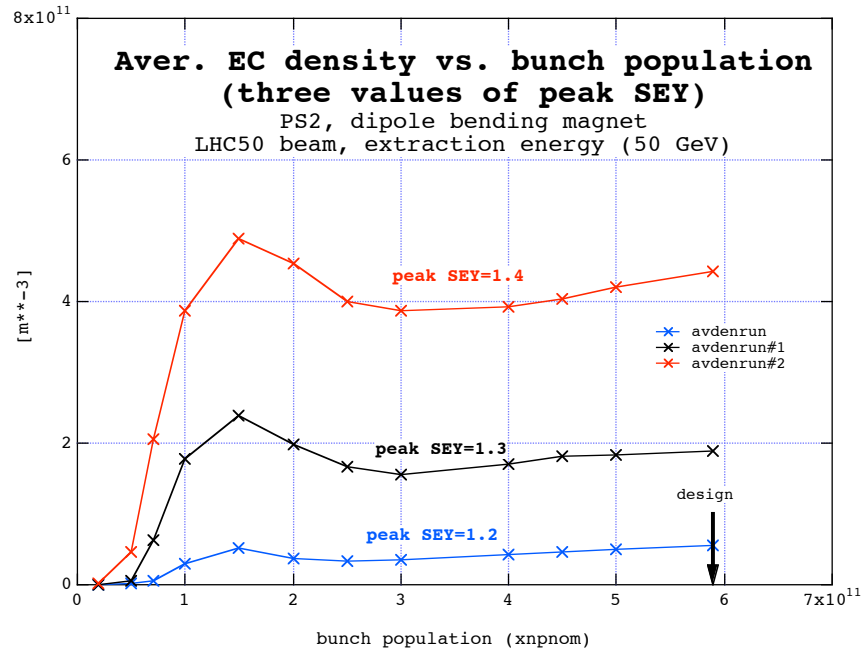
Sensitivity to peak SEY: aver. n_e vs. N_b

trigaussian bunch, E_b=50 GeV, δ_{max}=1.2, 1.3 and 1.4

LHC25 beam



LHC50 beam

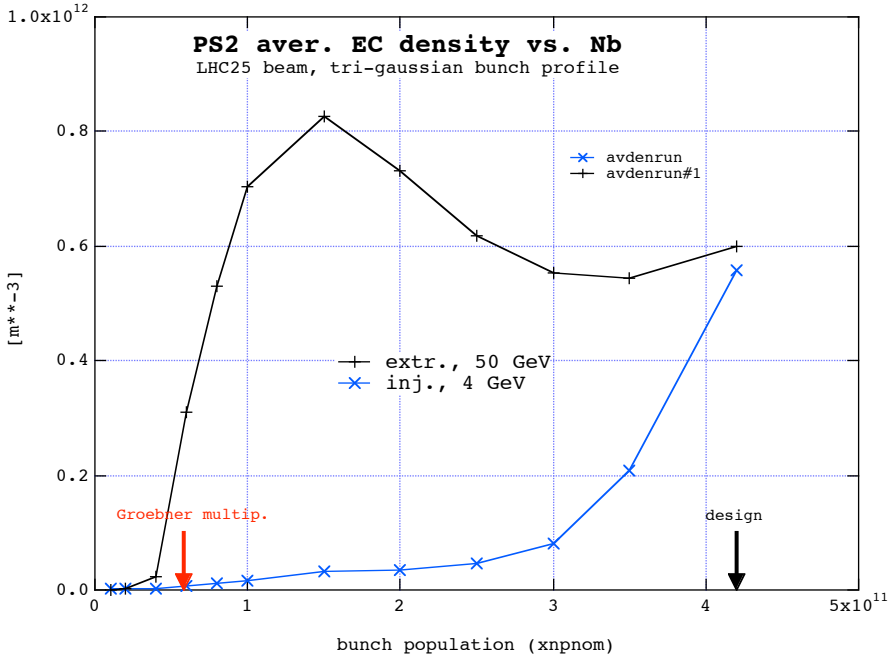


- Strong sensitivity to δ_{max}
  - Not a surprise
  - Used to calibrate EC build-up simulations against measurements at FNAL MI:
    - δ_{max}~ 1.3 is a reasonable value (after conditioning)
    - Awaits further confirmation, but various measurements are nicely consistent

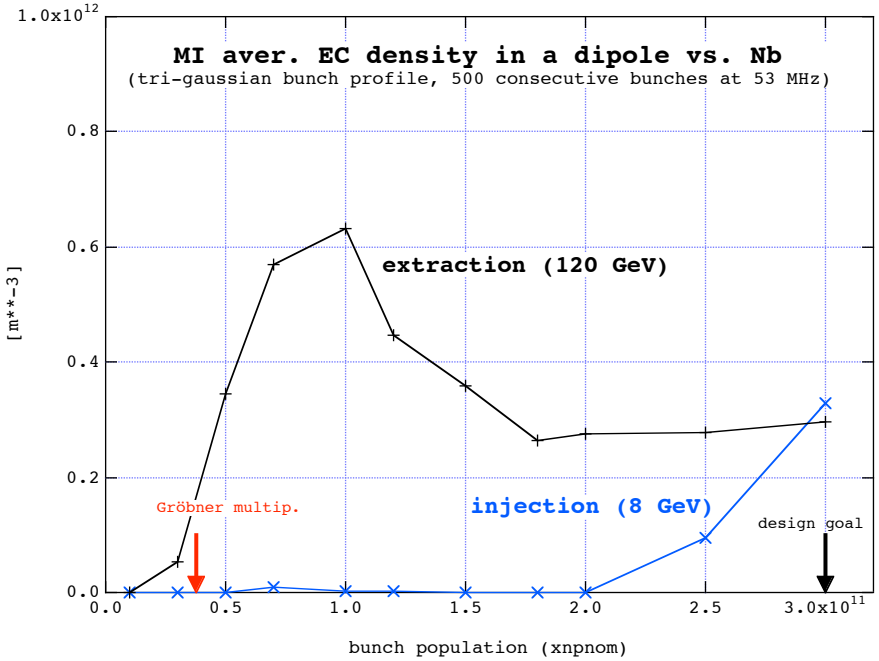
PS2 vs. MI upgrade: aver. n_e vs. N_b

trigaussian bunches, dipole bend, δ_{max}=1.3

PS2



MI upgrade



- Similar ecloud features in both machines
  - PS2 stands to profit from current ecloud program at MI
- See table on next page for parameters I actually used in the simulations

PS2 and MI upgrade

main parameters used in dipole ecloud simulations*

	PS2	MI upgrade
C [m]	1346.4	3319.419
h	180	588
(a,b) [cm]	(6, 3.5) (ellip.)	(6.15, 2.45) (ellip.)
f_{RF} [MHz]	40	53
K.E. [GeV]	4 – 50	8 – 120
B [Tesla]	0.136 – 1.7	0.1022 – 1.391
t_b [ns]	25 or 50	19
no. bunches	168 or 84	~ 500
N_b	4.2×10^{11}	3×10^{11}
$(\sigma_x, \sigma_y, \sigma_z)$ [mm]	(6.3, 5.9, 1000) @ inj. (1.95, 1.83, 330) @ extr.	(2.29, 2.81, 560) @ inj. (0.62, 0.76, 150) @ extr.
no. macropart.	20,000 max	20,000 max
Δt [s]	3×10^{-11} typ.	3×10^{-11} typ.
grid size	64 x 64 typ.	64 x 64 typ.

(*) NB: actual parameters are evolving; see https://twiki.cern.ch/twiki/bin/view/Main/PS2Collaboration for PS2 current design, and http://projectx.fnal.gov for MI upgrade.

Conclusions for ecloud in a PS2 dipole

- Estimated EC average density is n_e~(0.1–1)x10^{12} m^{-3} if δ_{max}~1.3
  - "average" means: averaged both over time and space within the dipole chamber
  - Corresponds to <1% average beam neutralization
  - Beware: n_e has large fluctuations near the beam, and is strongly time dependent
    - Investigate necessity of including eclouds in space-charge studies
- Numerical convergence reasonably ascertained
- LHC50 beam clearly favored over LHC25 (factor ~3 in aver. n_e)
  - Confirms earlier calculations in 2006-07
- Surprisingly similar n_e at injection and extraction for nominal N_b
  - But dramatically different for lower values of N_b; why?
- Unsurprising strong sensitivity to peak SEY
  - Sensitivity to secondary emission spectrum remains to be studied
- Weak sensitivity to either transverse or longitudinal bunch profile
- Strong similarities with ecloud in MI upgrade
  - Affords a profitable synergy!
- Current results consistent with CERN results (G. Rumolo, talk Jan. 15, 2009)
  - Differences on the scale of a factor ~2
  - But there are qualitative differences as well (eg., injection vs. extraction results)
  - We have not (yet) done exactly the same calculation, so not a big concern at this point.
  - Need to understand differences

What next

- Complete assessment of numerical convergence
  - Especially no. of macroparticles
- Understand observed dependencies
  - Especially on N_b
  - Also injection vs. extraction energies
- Examine other regions of the chamber
- Revisit physical parameter values
- Simulate ecloud build-up during the ramp
  - Especially around bunch coalescing time
- Quantify sensitivity to secondary emission model details
  - Especially contribution from rediffused secondary electrons
- Maintain side-by-side comparison with MI upgrade
- Initiate exploration of effects of ecloud on the beam
  - Need other codes: WARP, HEADTAIL, …
- …

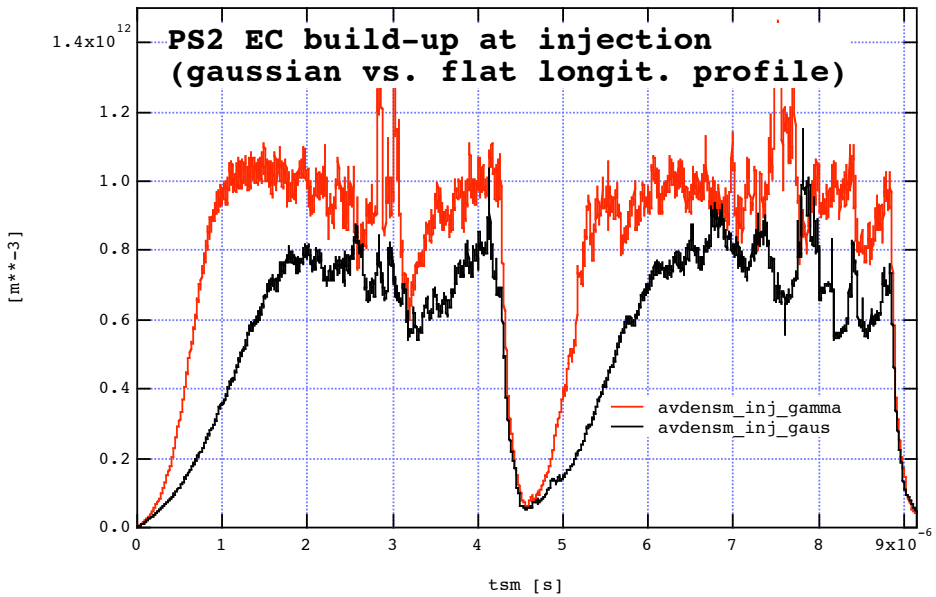
Tasks and effort level

1. Refine assessments of electron-cloud build-up (4 EPM(*)). Estimated completion: end of CY09
2. Compare electron-cloud build-up at the PS2 against MI upgrade (3 EPM). Commence in April 2009, complete at end of CY09.
3. Explore parameter space (4 EPM). Commence in Oct. 2009, complete in April 2010.
   - Secondary emission model
   - PS2 design parameters are changing
4. Assess ecloud mitigation mechanisms (4 EPM). Commence Jan. 2010, complete Oct. 2010.
5. Assess need to combine space charge with ecloud simulations (2 EPM). Commence in April 2009.
   - If yes, complete code augmentation/integration at end of CY2010, with final benchmarking validation in June 2011.
6. Assess impact of ecloud on the PS2 beam (12 EPM). Commence Oct. 2009. Initial assessment ready by June 2010. Final report Sep. 2011. Ongoing re-assessments to continue as needed.
7. If above indicate a single-bunch instability, design a BB FDBK system (4 EPM). Commence April 2011. Initial assessment Dec. 2011. Ongoing re-assessments to continue as needed.

(*) EPM=experienced-person-month

Sensitivity to long. bunch profile at E_b=4 GeV

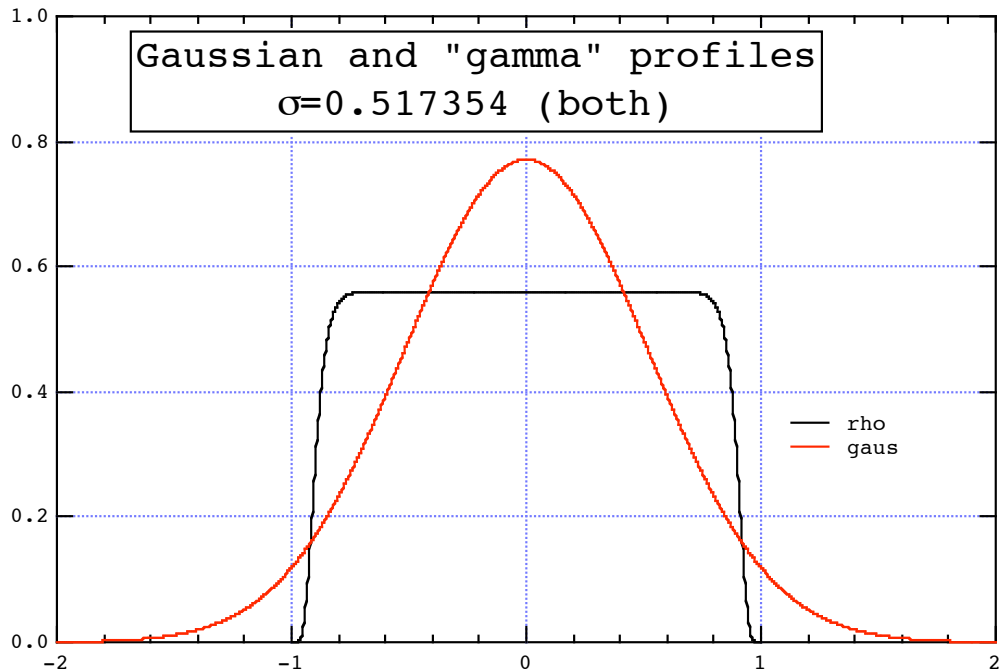
build-up for N_b=4.2e11, δ_{max}=1.3



- Flat long. profile leads to ~20% smaller n_e than gaussian

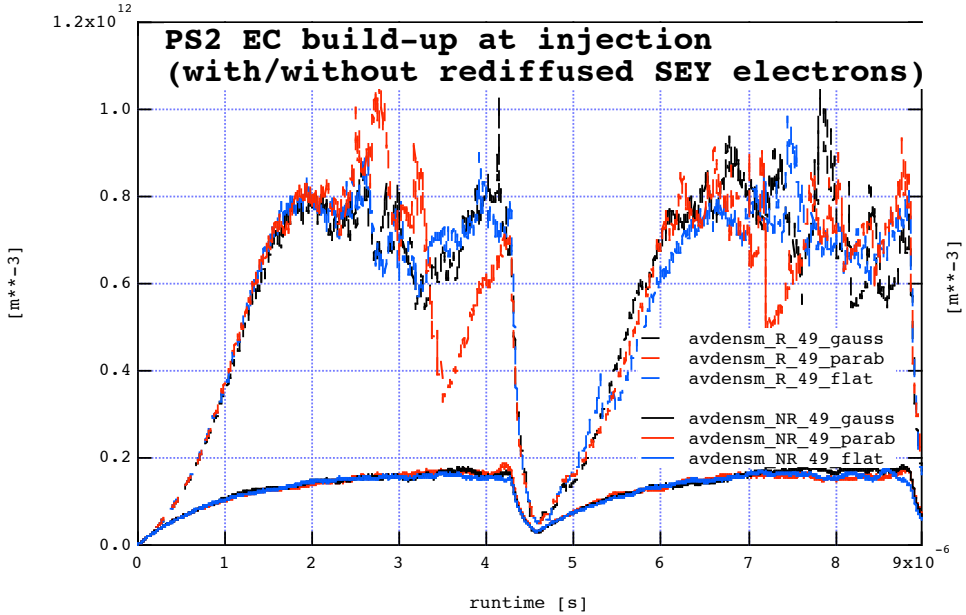
Flat and Gaussian longitudinal beam profiles

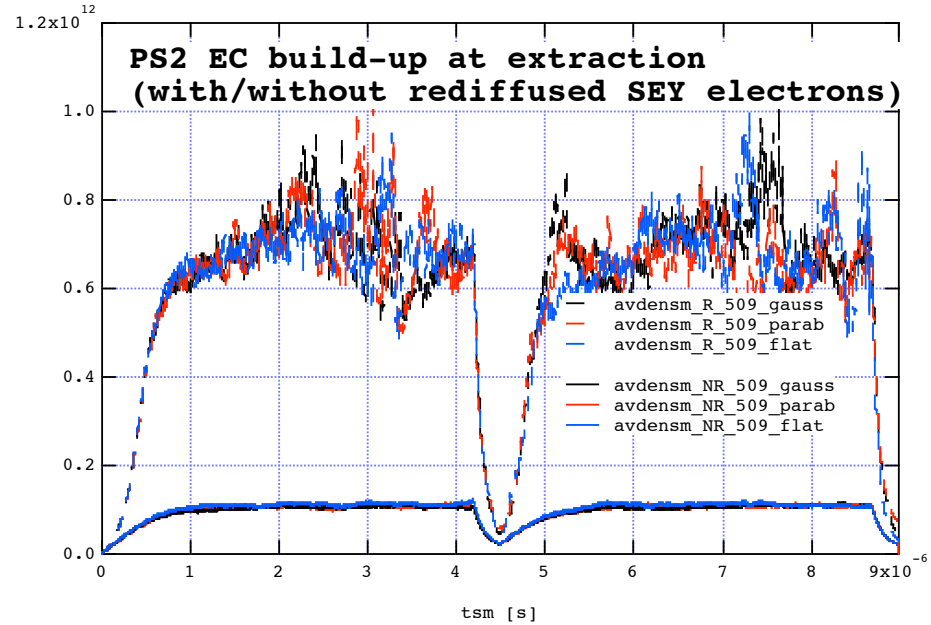
- The “gamma” flat profile is defined in LBNL-61925
- NB: for the *transverse* flat profile, I used a truly flat density function



Build-up at inj. and extr. in dipole bend, N_b=4.2e11

sensitivity to transverse bunch profile and SEY spectrum





- Gaussian, parabolic or flat tr. profile
- Gaussian long. profile
- Conclusions:
  - Transverse profile not a significant variable
  - Rediffused vs. no-rediffused secondary electrons: significant variable
    - We don't know exactly what is the % of rediffused in the actual vac. ch.
  - EC density ~(7-8)x10^{11} m^{-3} at saturation, either at inj. or extr.

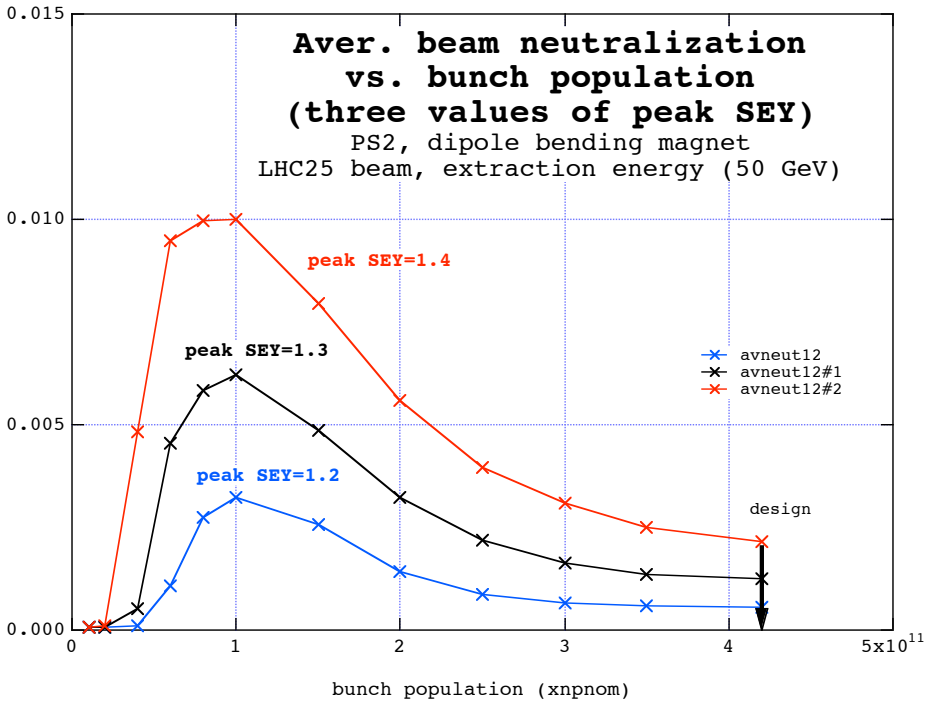
N.B.: deep fluctuations due to "virtual cathode" phenomenon;

Needs fixing, although average n_e is probably okay

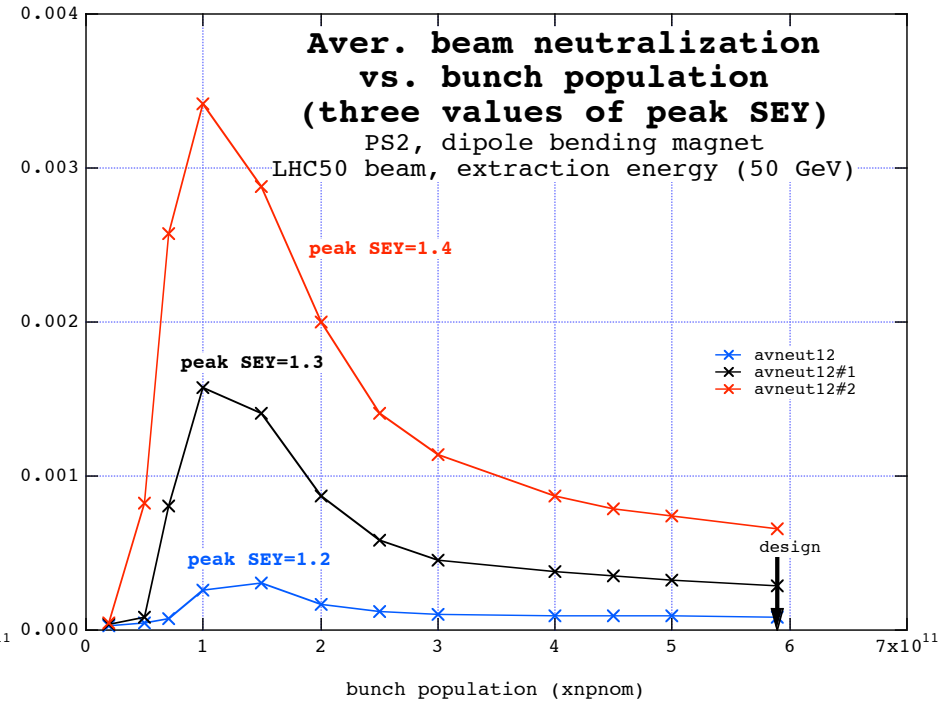
Average beam neutralization

LHC25 and LHC50 beams at 50 GeV, for 3 peak SEY

LHC25 beam



LHC50 beam



- Small neutralization factor, on average
  - NB: “average” means over time (2 turns) and space (entire dipole chamber volume)
  - For beam dynamics effects, you need to look <u>within</u> the beam, not on average