Electron Cloud - Status and Plans

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Collaboration Mtg.
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Summary

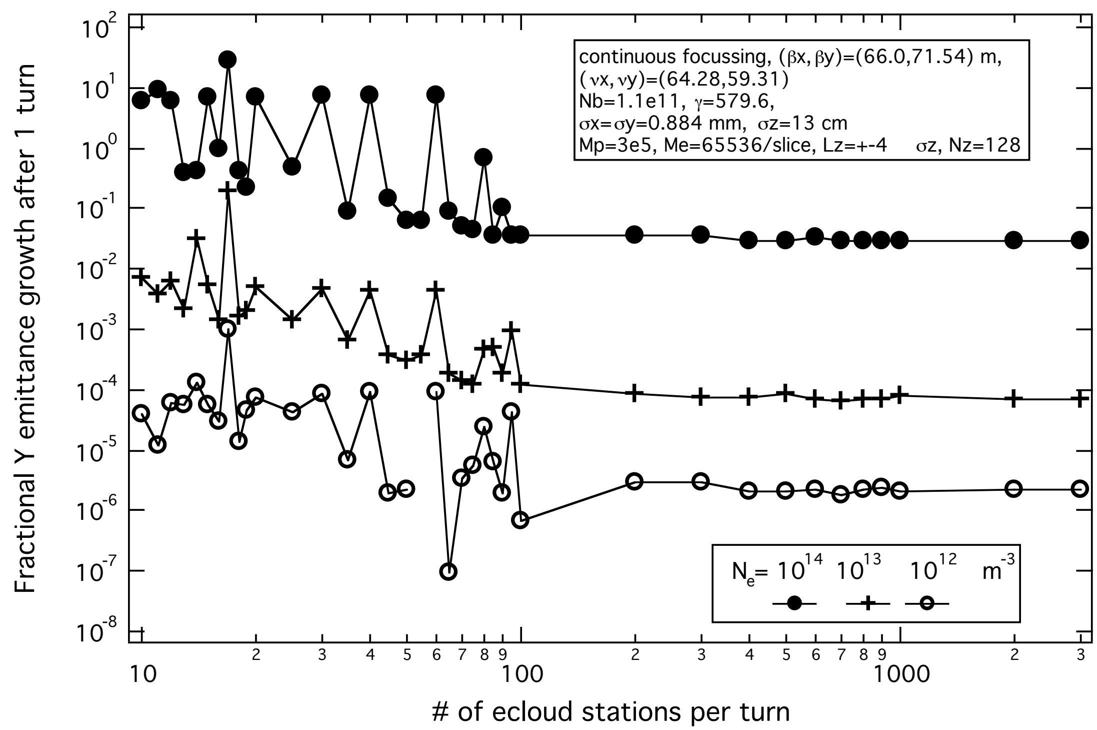
- Effects of ecloud on the beam
  - With code WARP/POSINST
    - Quasi-static mode “QSM”, and with
    - Lorentz-boosted frame method, fully self-consistent “FSC”
- Assessment of ecloud build-up for PS2
  - With build-up code POSINST (no effects on the beam)
- RHIC measurements
- Related ecloud R&D (non LARP)
- Status

Effects of ecloud: ε growth in LHC beam

code WARP (J.-L. Vay)

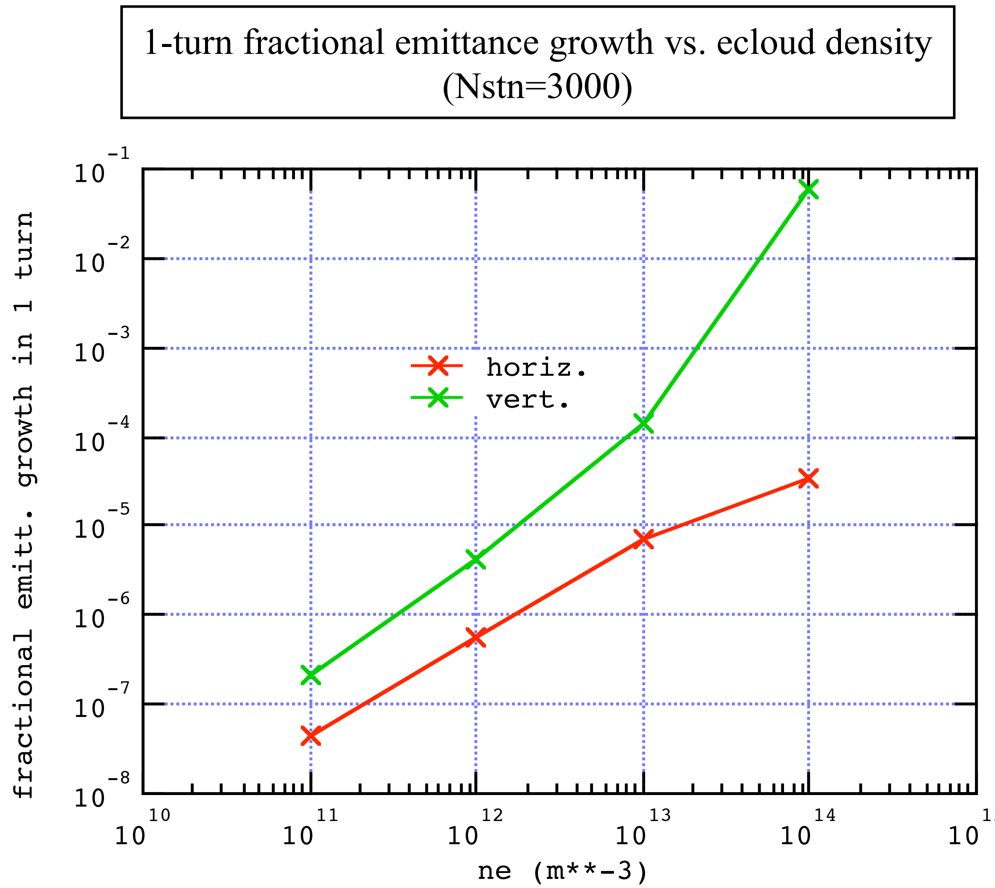
- one-turn ε growth simulation
- E=450 GeV, N_b=1.1x10^{11}, single bunch,
  - Code WARP, parallel, 3D calc.
    - Quasi-static approx. mode (QSM)
    - AMR, parallel 8 processors
  - Beam transfer maps from EC station to next
    - Up to 3000 stations
  - Actual LHC chamber shape
  - Constant focusing approx.
  - Electrons allowed to move vertically only
  - No synchr. oscillations
  - Beam launched offset by 0.1σ_y
- Conclusion: need to resolve λ_β to reach convergence, as expected (ie., # of EC stations > tune)

1-turn fractional emittance growth vs. Nstn
for 3 values of the ecloud density



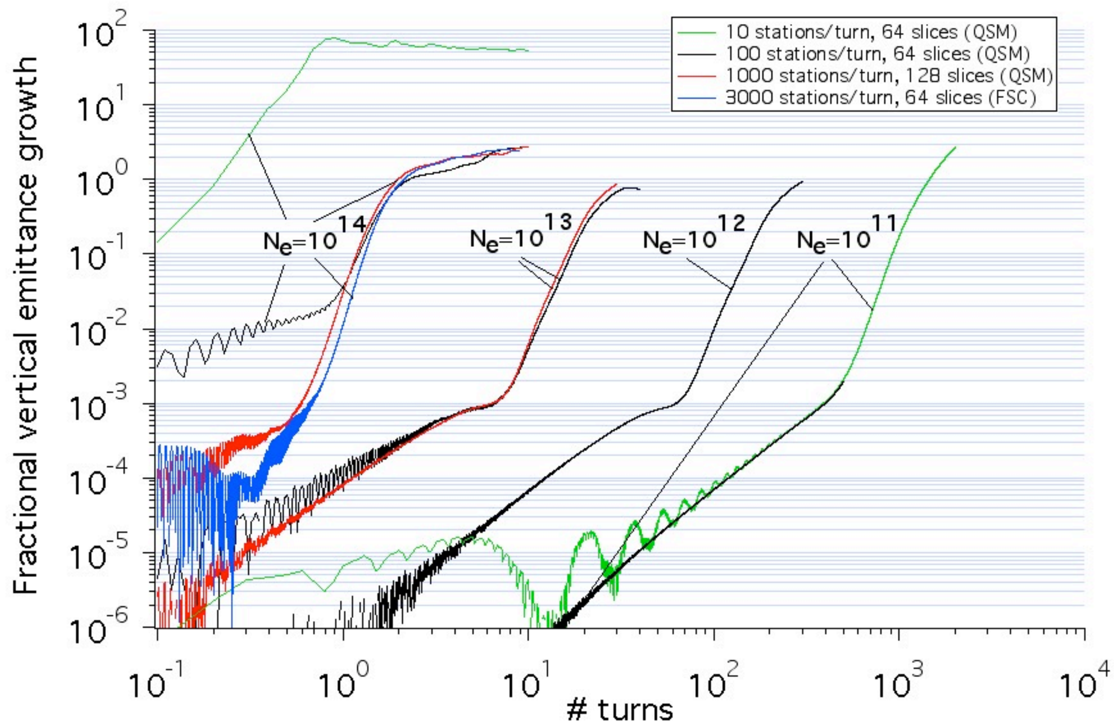
Effects of ecloud: ε growth in LHC beam
1-turn ε growth vs. n_e

- Emittance growth simul.
- Same conditions as previous slide
  - except N_{stn}=3000=fixed
- Conclusion:
  - $\Delta\varepsilon/\varepsilon \propto n_e$ as n_e-->0



Ecloud effects on the LHC beam: ε growth vs. time

- Same conditions as previous slides
- Conclusions:
  - Fully Self-Consistent (FSC) approx. in Lorentz-boosted frame agrees well with QSM
  - You can get away with much fewer ecloud stations if you are willing to wait for a while
    - Except at very high n_e
  - Emittance growth quite large; is this real?
  - Aggravating factors:
    - No synchr. osc., no E-spread
    - Continuous focusing (?)
    - Offset beam
    - ???



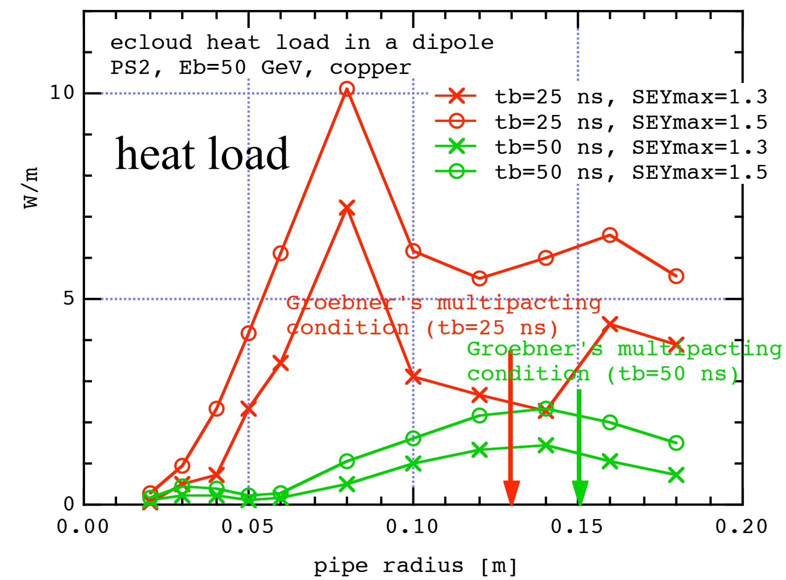
Ecloud build-up in PS2 at 50 GeV

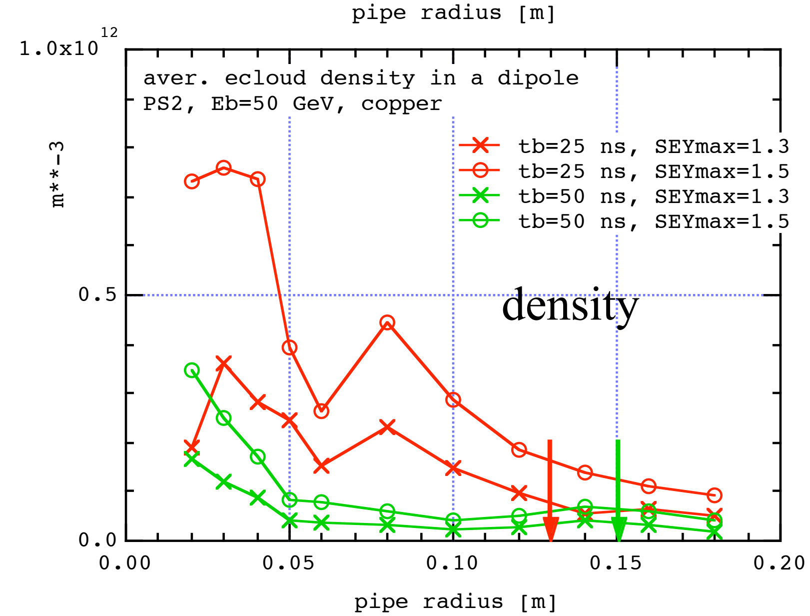
vs. chamber radius

- Looked only at a bending dipole
- Vary pipe radius keeping all else fixed

- N_b=4x10^{11} for t_b=25 ns, N_b=5.4x10^{11} for t_b=50 ns; other parameters as specified in LUMI06 by FZ
- Averages taken over 2 trains
- PS+ also looked at

- Conclusions:
  - Low heat load wants small radius
  - Low e$^-$ density wants large radius
  - Beam-induced multipacting condition broadens and gets shifted to lower radius relative to the impulse approximation (Gröbner, $r = \sqrt{N_b r_e s_b}$)



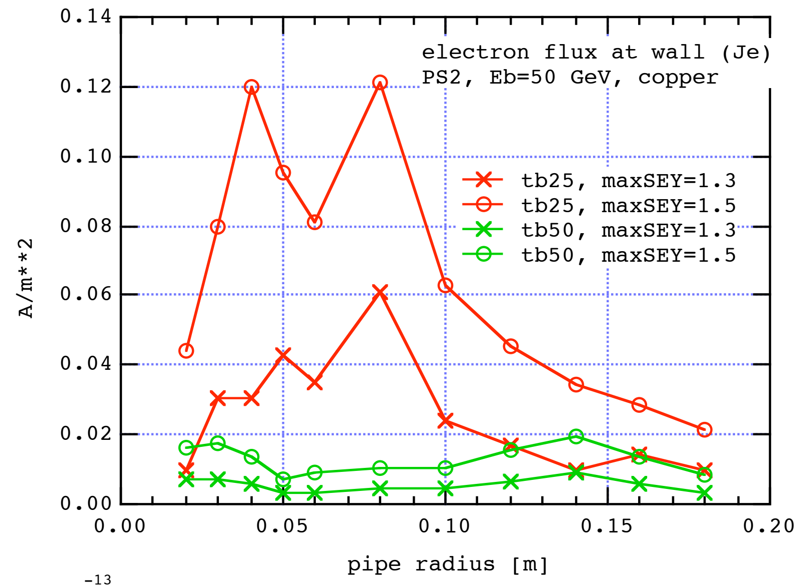


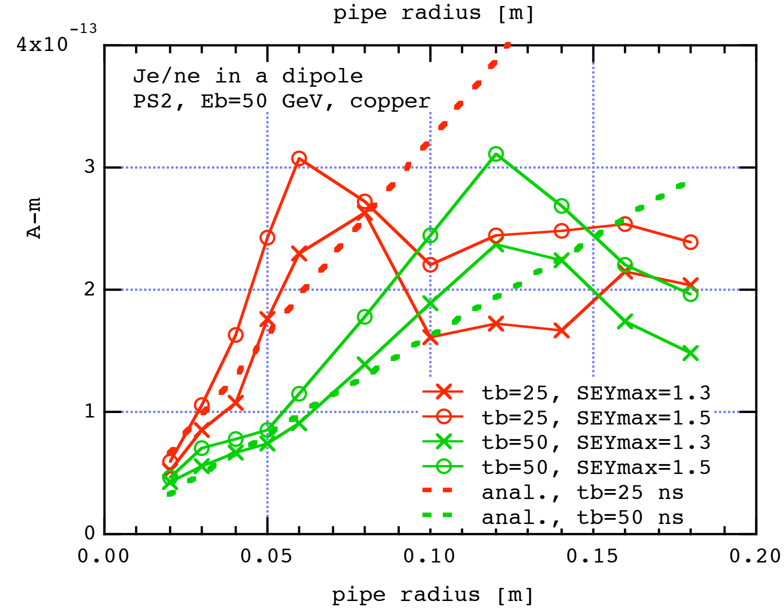
Ecloud build-up in PS2 at 50 GeV (contd.)

vs. chamber radius

- e^- flux at the walls (J_e)
- Conclusions:
  - Ratio J_e/n_e in good agreement with analytic expectation as r-->0:

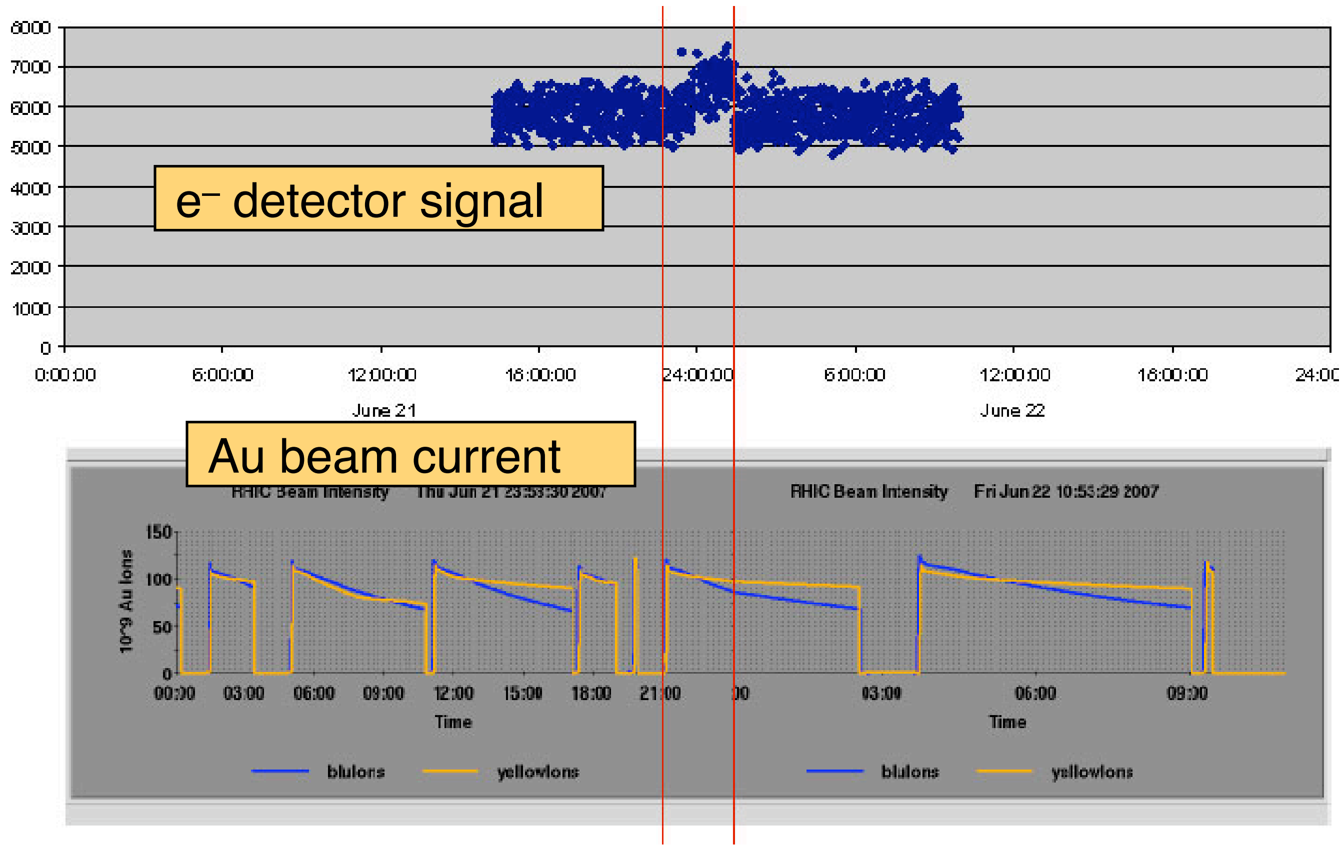
$$\frac{J_e}{e n_e} \rightarrow \frac{r}{2t_b}$$ (R. Zwaska)





RHIC studies

- Two CERN e⁻ detectors installed in RHIC common-pipe region >1 yr ago
  - Inside a weak adjustable dipole magnet
- Electron detectors & installation was not a LARP-funded effort (M. Jiménez, CERN VAC)
- But LARP funds simulation & benchmarking activity
- Detectors now interfaced to the RHIC control system (Eric Blum, BNL)



LARP

Related developments (not LARP-funded, but synergistic)

BERKELEY LAB

- Microwave detection of ecloud
  - Recent experiments at PEP-II successful !
    - S. deSantis et. al., submitted for publication
  - Simulations at LBNL (K. Sonnad; TechX code VORPAL)

- ecloud at the FNAL MI intensity upgrade
  - Direct e^- measurements with RFA at the MI (I. Kourbanis, R. Zwaska)
  - Simulations at LBNL (M. Furman and K. Sonnad)
    - ecloud build-up studies (extensive and ongoing)
    - Effects on the beam (emittance growth, ...): newer effort

SLAC-LBNL ecloud R&D at SPS

NOTE: SLAC portion is funded by SLAC

Electron Cloud Studies for the SPS

•SINGLE-BUNCH INSTABILITY SIMULATION

- Code benchmarking and long term simulation runs for the SPS and LHC.
- Collaborators: K. Sonnad (LBNL), M. Pivi (SLAC), F. Zimmermann (CERN).
- CERN Contact: F. Zimmermann.

•SPS EXPERIMENTAL TESTS:

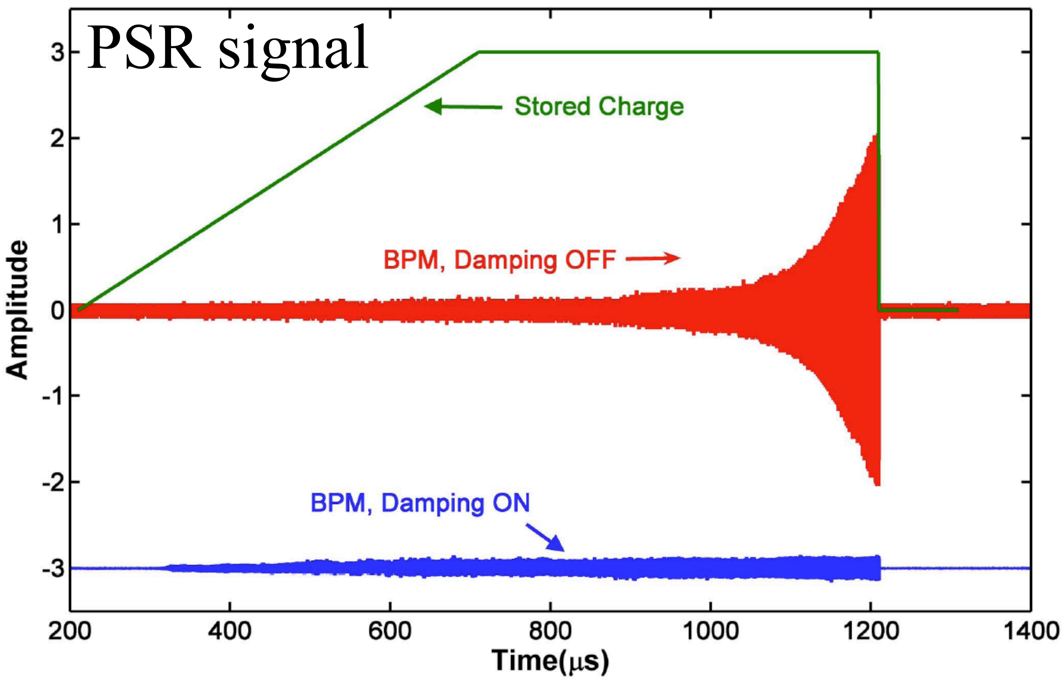
- groove insertion in the SPS 4-magnet dedicated experiment (grooved; clearing electrode; coated; plain SS)
- At SLAC we are working on manufacturing a groove insertion to fit in one of the 4 dipoles new installation of the SPS. This is part of a larger project to investigate mitigation techniques for the electron cloud in the SPS.
  Collaborators: M. Venturini, M. Furman, (LBNL), M. Pivi, M. Morrison, L. Wang, (SLAC) G. Arduini, E. Chapochnikova (CERN).
- CERN Contact: G. Arduini.

R&D combined effort: SLAC FTEs, M&S and Travel (PRELIMINARY)

	FY08	FY09
FTEs	0.25	0.25
M&S	20.0 k$	---
Travel	5.0 k$	5.0 k$

New proposed initiative: active feedback damper of ecloud instability for SPS

- SPS has an ecloud instability for LHC beams
  - Single bunch in V, coupled bunch in H; spectrum ~700 MHz
- SLAC-LBNL proposed effort (J. Fox and J.Byrd)
- Similar system used for PSR ecloud instability
- CERN interested (O. Brüning's talk, this morning)



See J. Fox's talk tomorrow

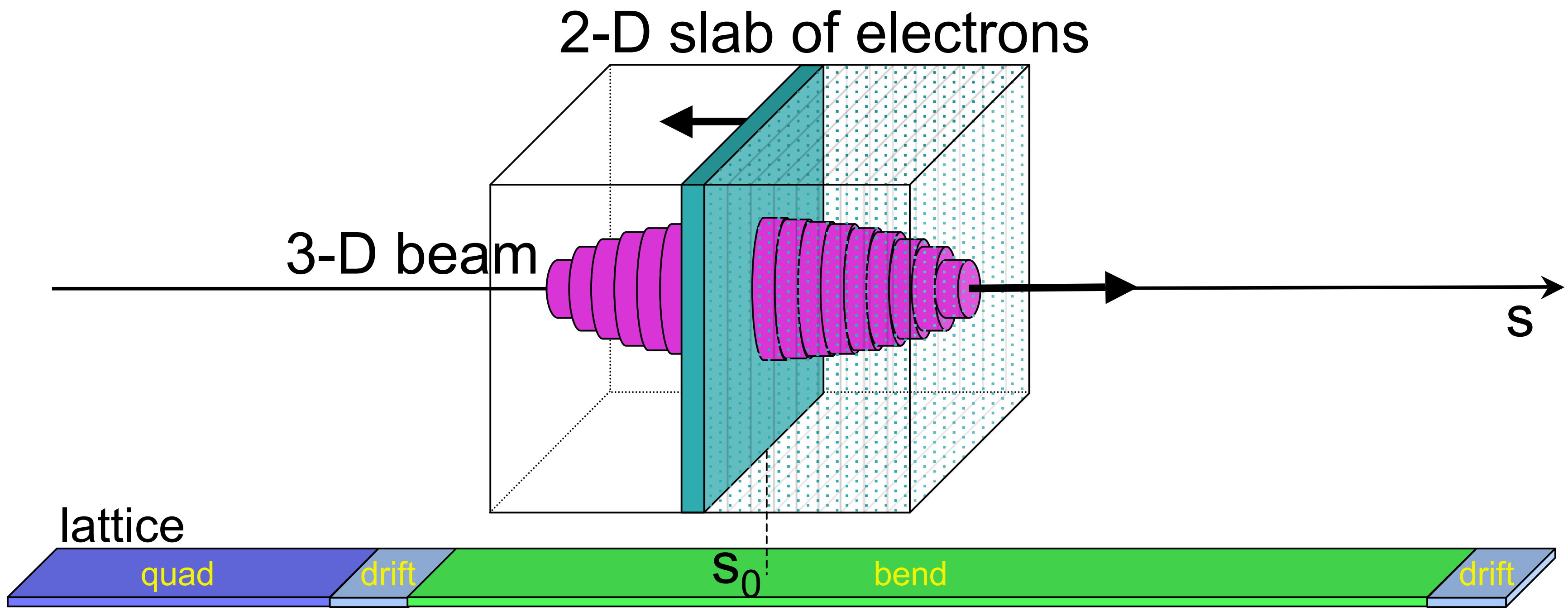
Status summary and future goals

1. Nominal LHC heat-load estimate and POSINST-ECLOUD benchmarking: (*) done
2. Upgraded LHC heat load: (*) done
3. Injector upgrade heat load: (*) continuing
4. Effects from ecloud on beam: (*)
   - AMR, QSM, adaptive time stepping, parallelization: implemented in code
     - Applications to LHC in constant-focusing approximation and other simplifying assumptions
   - 3D self-consistent simulations: challenging; continuing
   - Lorentz-boosted frame method: shows good agreement with QSM in benchmarks
   - Effects of ionized gas on heat load and beam: not started
5. Analyze SPS data, esp. measured heat load and e^- spectrum: (*) need to benchmark against expts.
   - will simulate effects on the beam
6. Help define optimal LHC conditioning scenario: (–) delayed or deleted
7. Apply Iriso-Peggs maps to LHC: (–) delayed or deleted
8. Simulate e-cloud for RHIC detectors and benchmark against measurements: (**) continuing
9. Simulate ecloud for LHC IR4 "pilot diagnostic bench:" not started
10. ecloud suppression at SPS:
    - 700 MHz feedback system: <u>new intiative</u> (SLAC-LBNL) (J. Fox, tomorrow afternoon)
    - Specialized chambers (grooved, coated, cl. electrodes): <u>new initiative</u>; SLAC portion is SLAC-funded

(*) endorsed by CERN AP group
(**) endorsed by CERN vacuum group
(–) no longer endorsed by CERN AP group

Additional material

Quasi-static mode ("QSM")



1. 2-D slab of electrons (macroparticles) is stepped backward (with small time steps) through the frozen beam field
   - 2-D electron fields are stacked in a 3-D array,
2. push 3-D proton beam (with large time steps) using
   - maps - "WARP-QSM" - as in HEADTAIL (CERN) or
   - Leap-Frog - "WARP-QSL" - as in QUICKPIC (UCLA/USC).

Benchmarking WARP-QSM vs. HEADTAIL

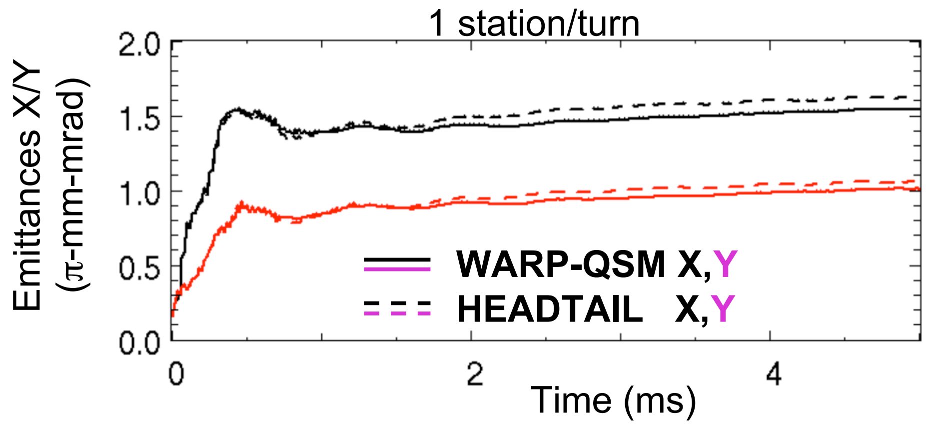
CERN code benchmarking website

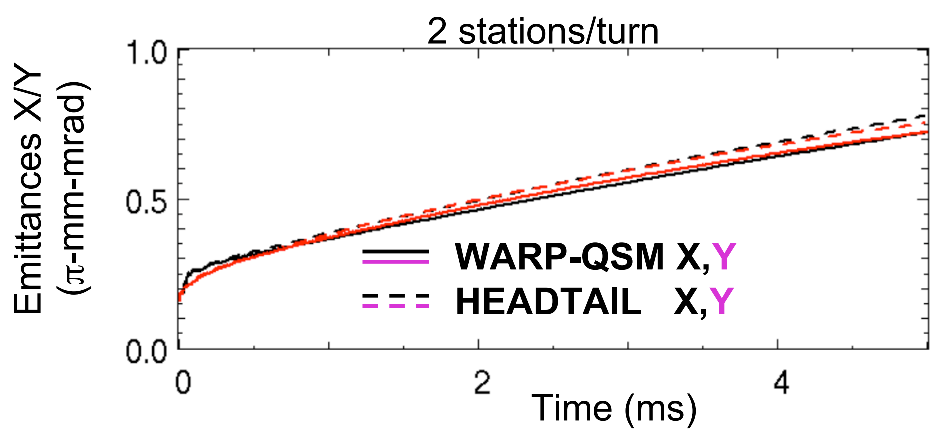
Proposed Model for Instability Simulations

round bunch in a round pipe: 1e11 protons
uniform electron cloud with density 1e12 m^-3
each bunch passage starts with a uniform cloud
chamber radius 2 cm
uniform transverse focusing for beam propagation
zero chromaticity, zero energy spread
no synchotron motion
energy 20 GeV
beta function 100 m
ring circumference 5 km
betatron tunes 26.19, 26.24
rms transverse beam sizes 2 mm (Gaussian profile)
rms bunch length 30 cm (Gaussian profile, truncated at +/- 2 sigma_z)
no magnetic field for electron motion
elastic reflection of electrons when they hit the wall

NEW: **with open and/or conducting boundary conditions (please specify boundary assumed), with 1 and/or several interaction points per turn or continuous interaction (please specify)**

result: plot of x&y emittances vs time





Towards "full self-consistency": Lorentz-boosted frame method

- "Fully self-consistency" (FSC)
  - Beam and ecloud affect each other
  - Beam-gas ionization, secondary electrons, lost protons striking wall, etc
- This is a formidable problem
  - We'll approach it step by step
  - In the end, probably use FSC only as spot-checks on simpler, faster calculations
  - But all necessary "modules" already in code WARP
- Essential computational problem in ecloud: wide disparities of time scales needed to resolve e^- motion, proton motion and lattice (eg., betatron wavelength)
- Found that self-consistent calculation has similar cost than quasi-static mode if done in a Lorentz-boosted frame (with γ>>1), thanks to relativistic contraction/dilation bridging space/time scales disparities (J. L. Vay, with partial LARP support)
- Computational complexity is not a Lorentz invariant (for certain problems)

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Noninvariance of Space- and Time-Scale Ranges under a Lorentz Transformation and the Implications for the Study of Relativistic Interactions

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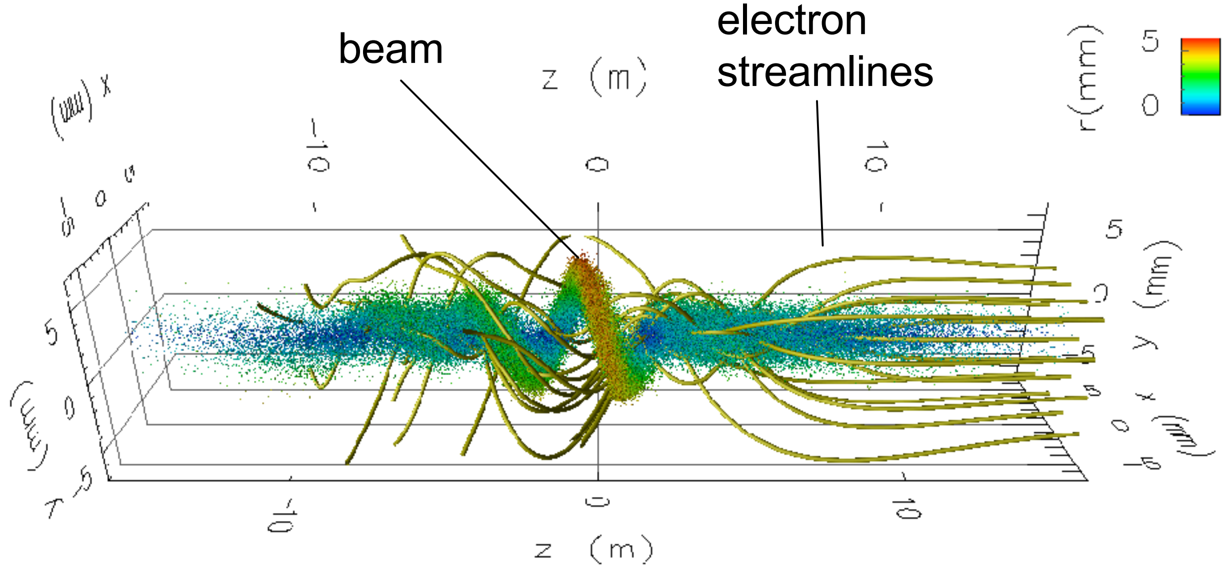
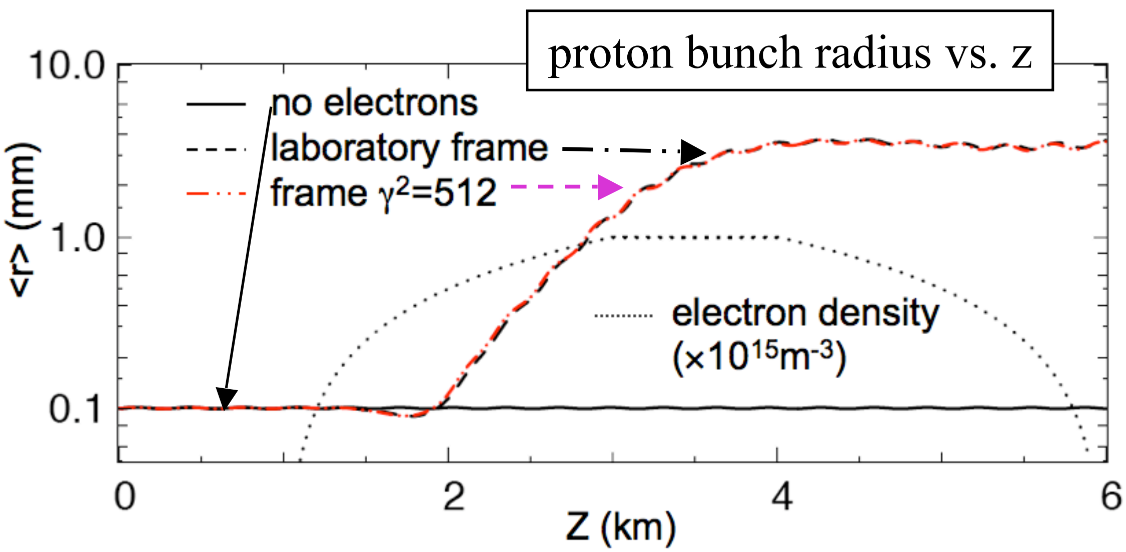
Boosted frame calculation sample:
proton bunch through a given e⁻ cloud

Hose instability of a proton bunch

- γ_b=500 in Lab
- L= 5 km, continuous focusing
    - Mag. field: B_θ=kr
- No chamber
- $N_b=10^{12}$
- $\rho_e=10^{13}$ m^{-3}





CPU time:
- **lab frame: >2 weeks**
- **frame with γ^2=512: <30 min**

Speedup x1000

J.-L. Vay, PRL **98**, 130405 (2007)

Lorentz-boosted method: my concerns

- Added complications:
  - moving boundary conditions
  - non-rectilinear moving frame (in curved trajectories)
  - sort out simultaneity of events for useful Lab frame diagnostics
  - …
- Need to be understood and implemented
- Real-life simulation case not yet available
- But clear indications of breakthrough in self-consistent simulations