Preliminary simulations of e-cloud feedback in the SPS with Warp-POSINST

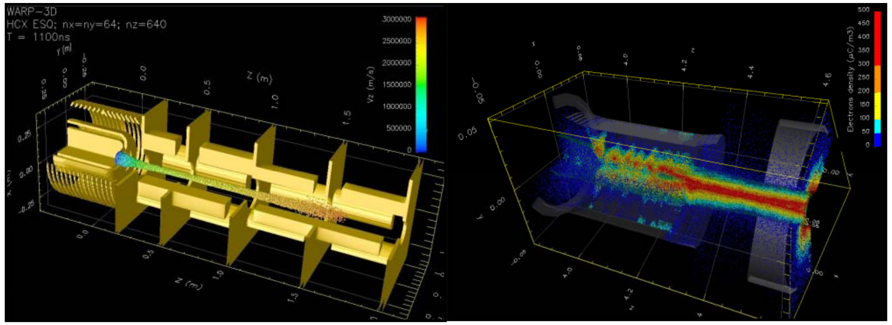
J.-L. Vay, M.A. Furman
LBNL
jlvay@lbl.gov,mafurman@lbl.gov

Presented by M. Venturini (LBNL)

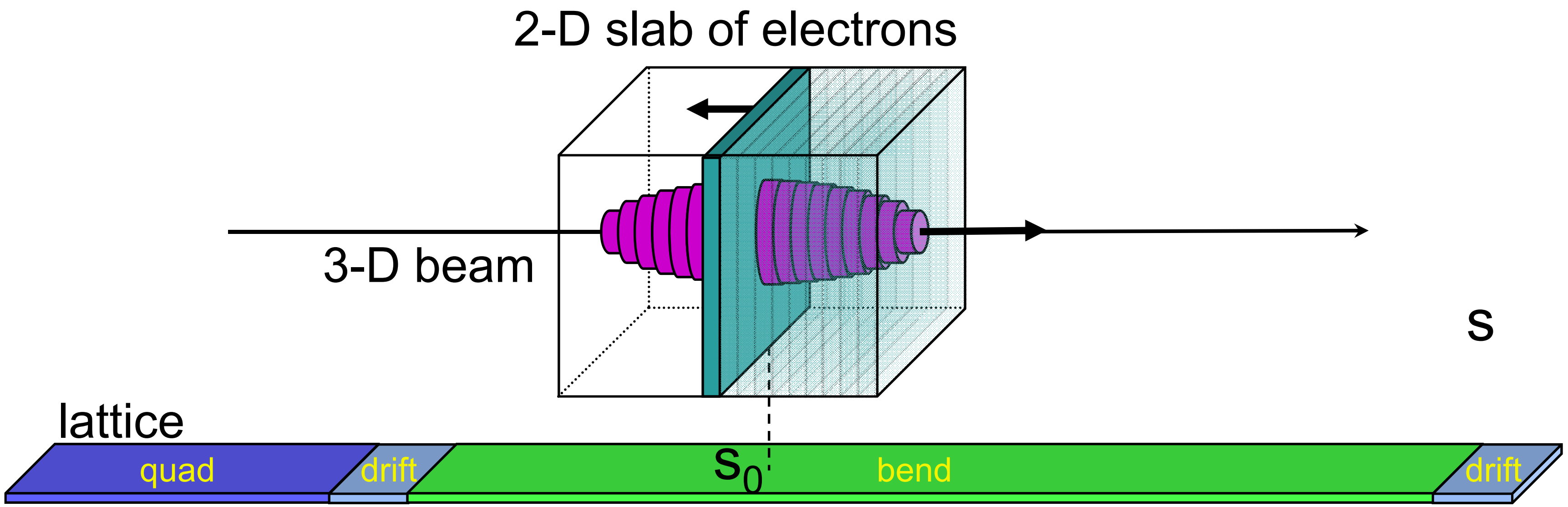
E-cloud mitigation mini-workshop
CERN - November 20-21, 2008

Warp - 3D accelerator/PIC code

- **Geometry:** 3D, (x,y), (x,z) or (r,z)
- **Field solvers:** electrostatic - FFT, capacity matrix, multigrid, AMR
  electromagnetic - Yee mesh, PML bc, AMR
- **Particle movers:** Boris, “drift-kinetic”, new leapfrog
- **Boundaries:** “cut-cell” --- no restriction to “Legos” (not in EM yet)
- **Lattice:** general; takes MAD input
  - solenoids, dipoles, quads, sextupoles, …
  - arbitrary fields, acceleration
- **Bends:** “warped” coordinates; no “reference orbit”
- **Diagnostics:** Extensive snapshots and histories
- **Python and Fortran:** “steerable,” input decks are programs
- **Parallel:** MPI
- **Misc.:** tracing, quasistatic modes,
  support for boosted frame

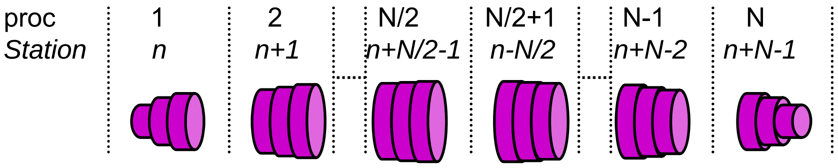


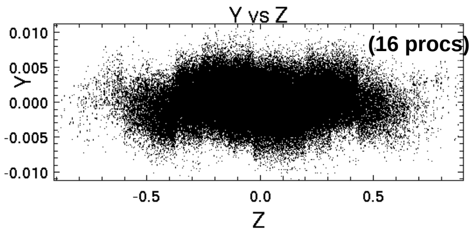
Warp: Quasi-Static Mode (“QSM”)



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).

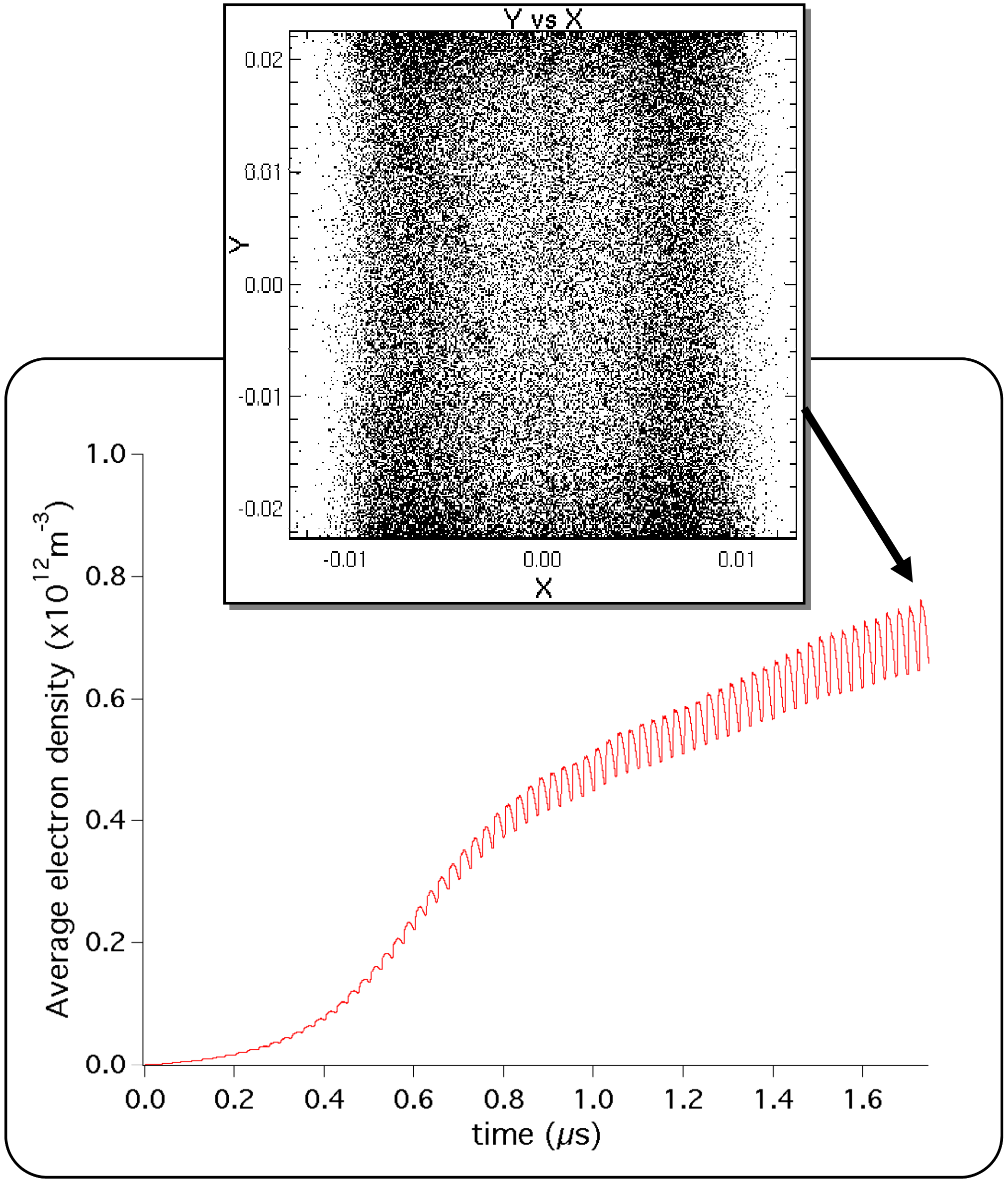
On parallel computers:





Study feedback of EC induced single-bunch instability in smooth SPS lattice

- SPS at injection (E_b=26 GeV)
  - γ=27.729
  - $N_p=1.1\times10^{11}$
  - continuous focusing
    - $\beta_{x,y}$= 33.85, 71.87
    - $\nu_{x,y}$= 26.12, 26.185
    - ν_z= 0.0059
  - N_{stn} ecloud stations/turn=100
  - Fresh e-cloud density as pre-computed by POSINST



Initial e-cloud distribution in a bend (POSINST)

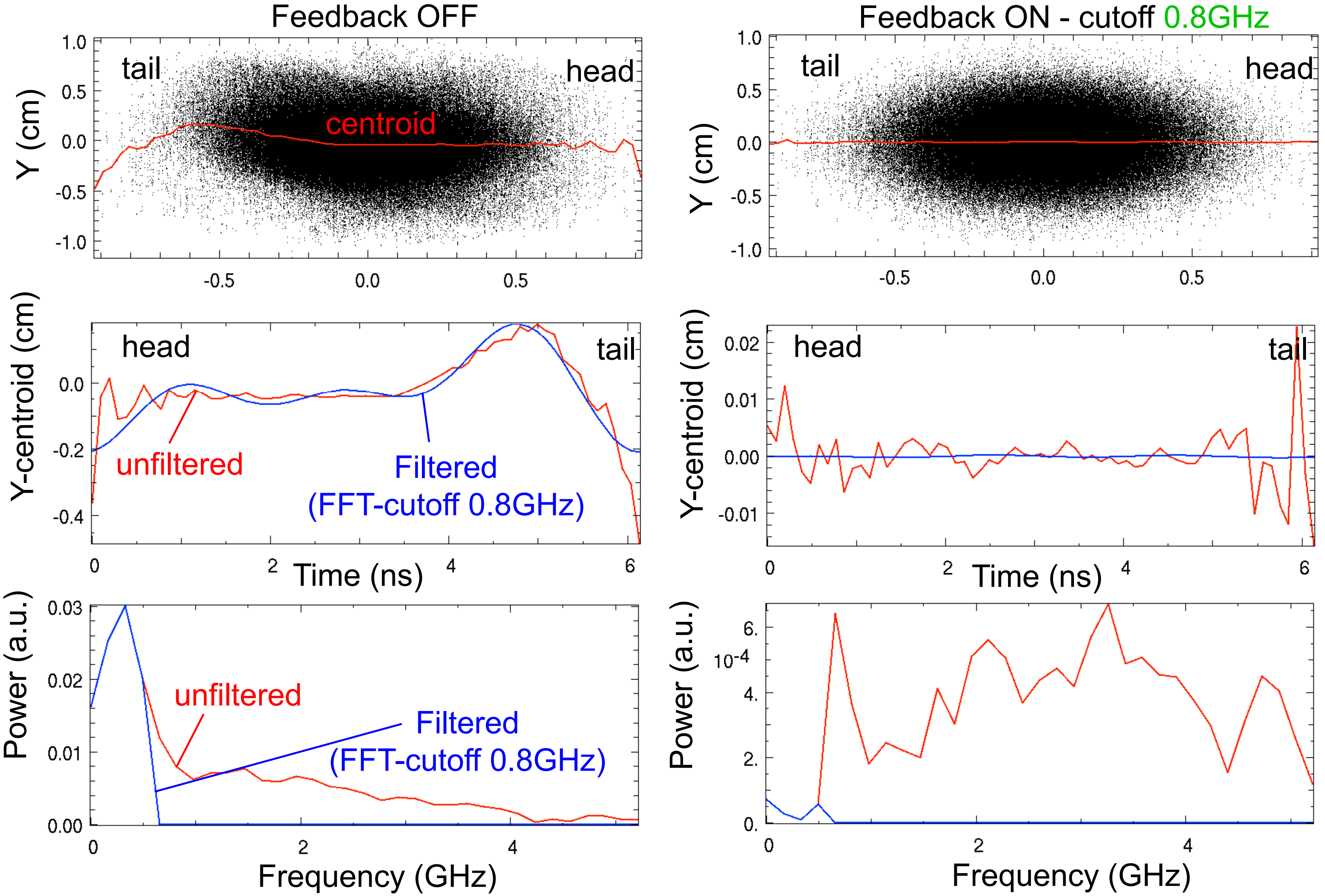
Feedback model 1

- Highly idealized model of feedback system.
- Record slice centroid $y_0(t)$ from every beam passage
- *apply low-pass FFT filter (sharp cutoff at 800MHz): $y_0(t) \Rightarrow \hat{y}_0(t)$
- scale transverse position $y \Rightarrow y - g \cdot \hat{y}_0$ (g=0.1 used in all runs)

*optional stage

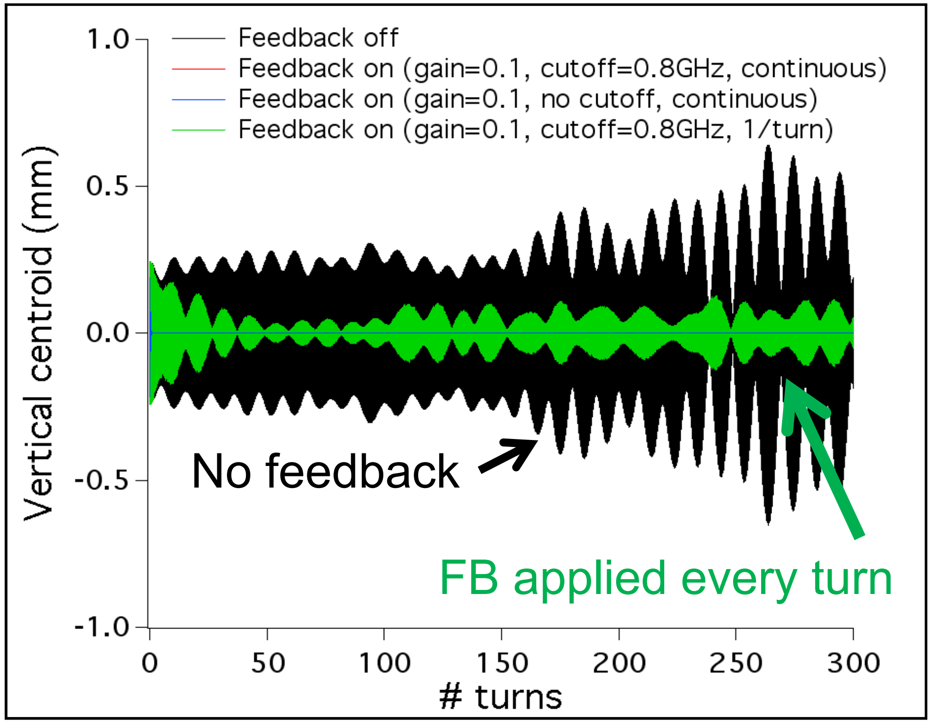
Preliminary simul. study of SPS EC feedback

Model 1 - beam distribution after 300 turns

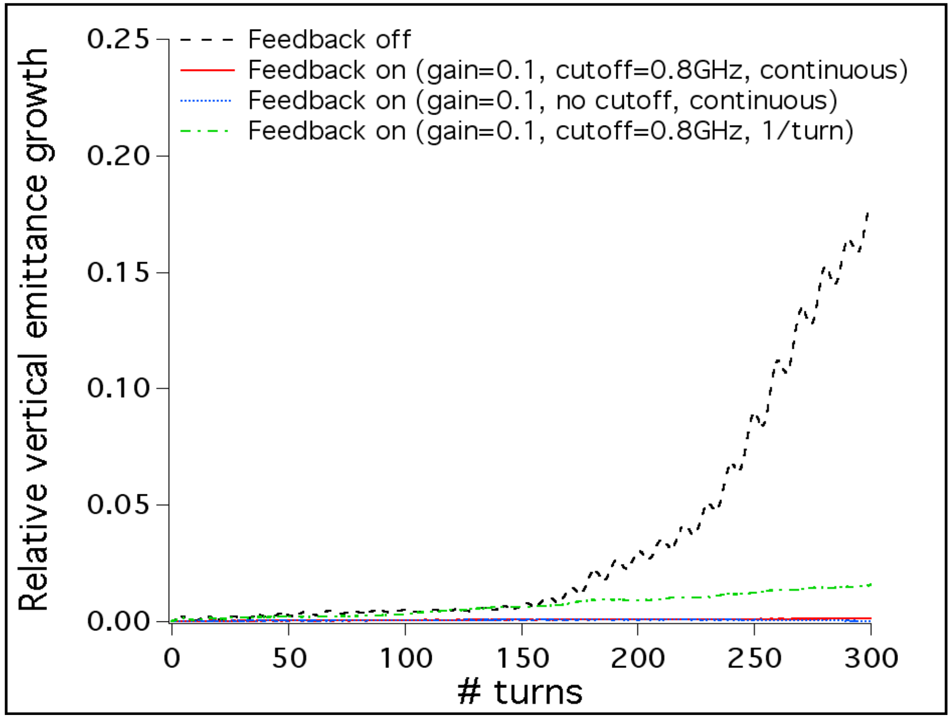


Controlling centroid motion reduces emittance growth

Centroid



Evolution of emittance



(disclaimer: all simulations done with same resolutions but no guarantee of numerical convergence)

Feedback model 2 - prediction from two turns

- record centroid offset $y_0(t)$ and $y_1(t)$ from two consecutive beam passages

- predict $y_2(t)$ from $y_1(t)$ and $y_0(t)$ using linear maps, ignoring longitudinal motion and effects from electrons

$$\begin{pmatrix} y \\ y' \end{pmatrix}^{n+1} = \begin{pmatrix} C & \beta S \\ -S/\beta & C \end{pmatrix} \begin{pmatrix} y \\ y' \end{pmatrix}^{n} \quad \begin{matrix} C = \cos(\sigma) \\ S = \sin(\sigma) \end{matrix} \quad \Rightarrow \quad \begin{cases} y'_0 = \frac{y_1 - C y_0}{\beta S} \\ y'_1 = -\frac{S}{\beta y_1 + C y'_0} \end{cases} \quad \Rightarrow \quad \begin{pmatrix} y \\ y' \end{pmatrix}^{2} = \begin{pmatrix} C & \beta S \\ -S/\beta & C \end{pmatrix} \begin{pmatrix} y \\ y' \end{pmatrix}^{1}$$

- *scale according to line charge density λ: $y_2(t) \Rightarrow y_2(t) \bullet w_\lambda$

- *apply low-pass FFT filter (sharp cutoff at 800MHz): $y_2(t) \Rightarrow \hat{y}_2(t)$

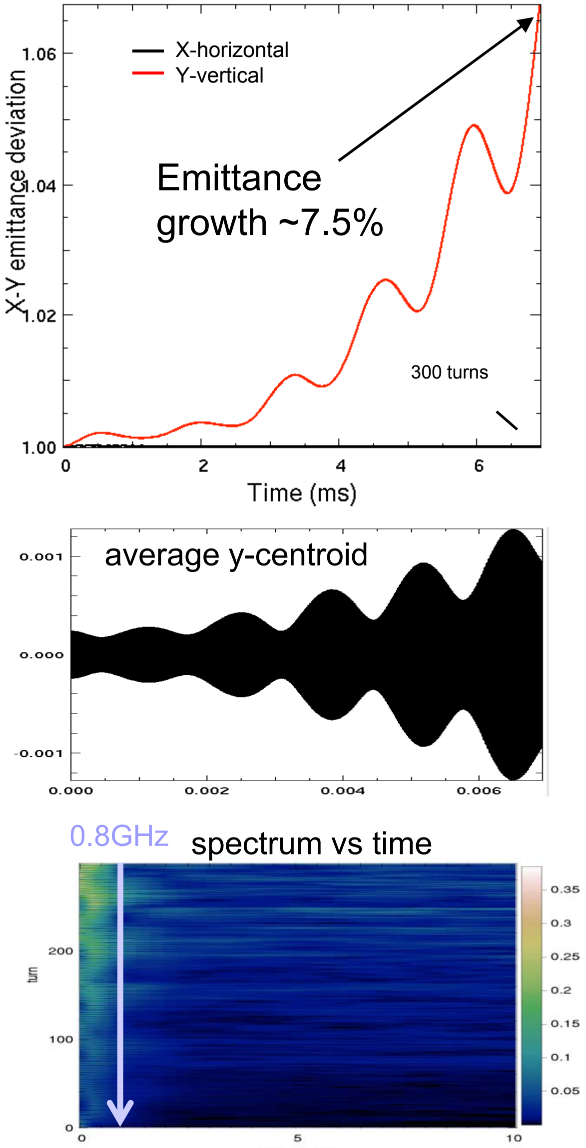
- one turn later, scale transverse position $y \Rightarrow y - g \bullet \hat{y}_2$ $(g=0.1)$

*optional stage

Feedback is effective at lower e-cloud density

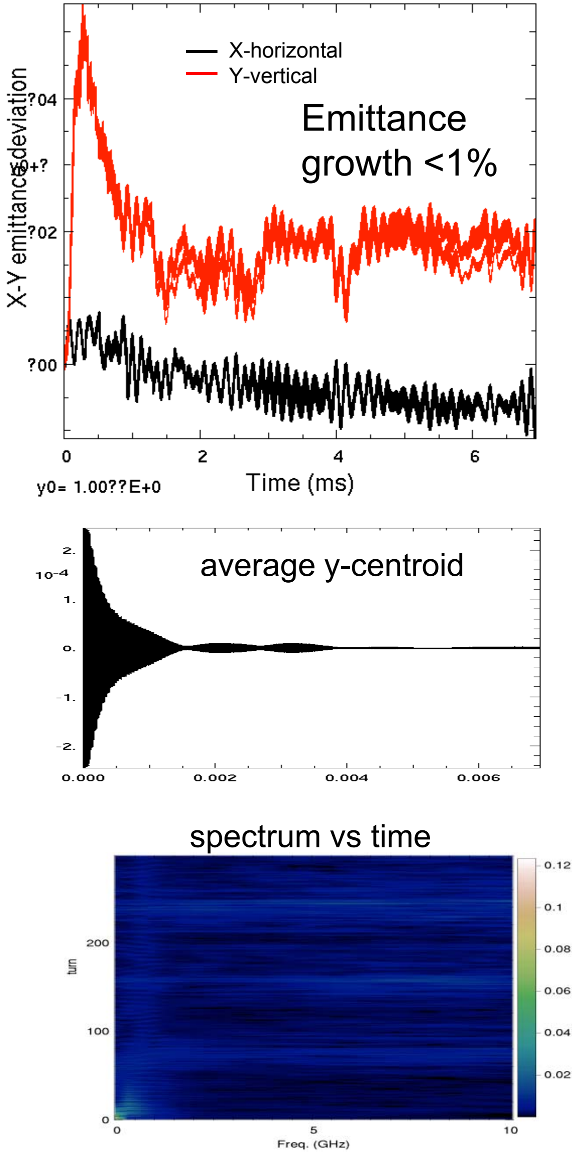
Model 2 - n_e~1.5×10^{12} m^{-3}

No feedback



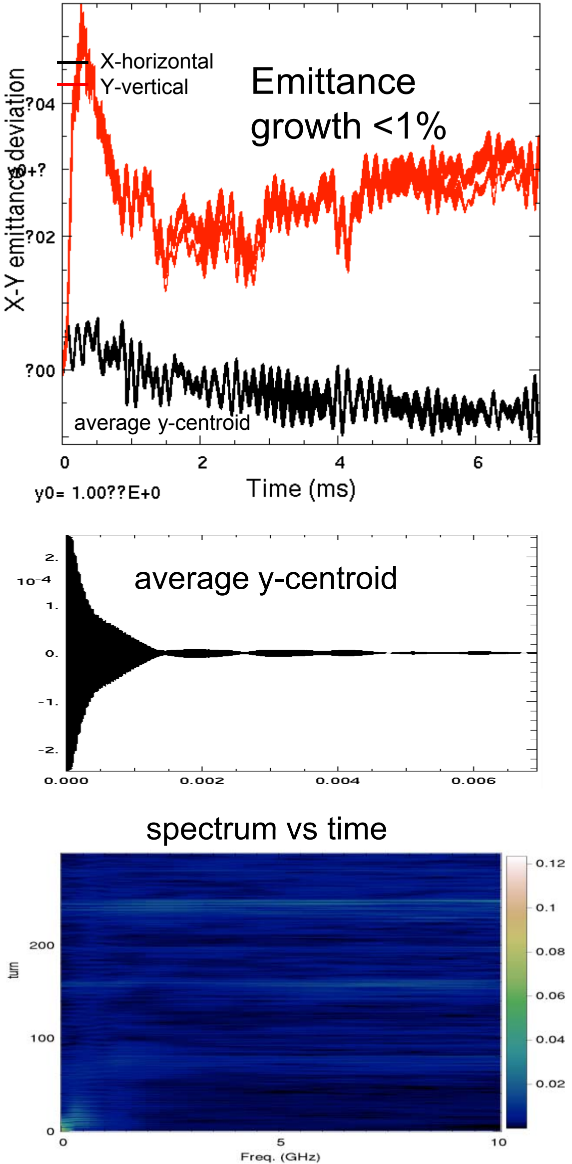
Emittance growth ~7.5%

filter off, w_λ off



Emittance growth <1%

filter on, w_λ off

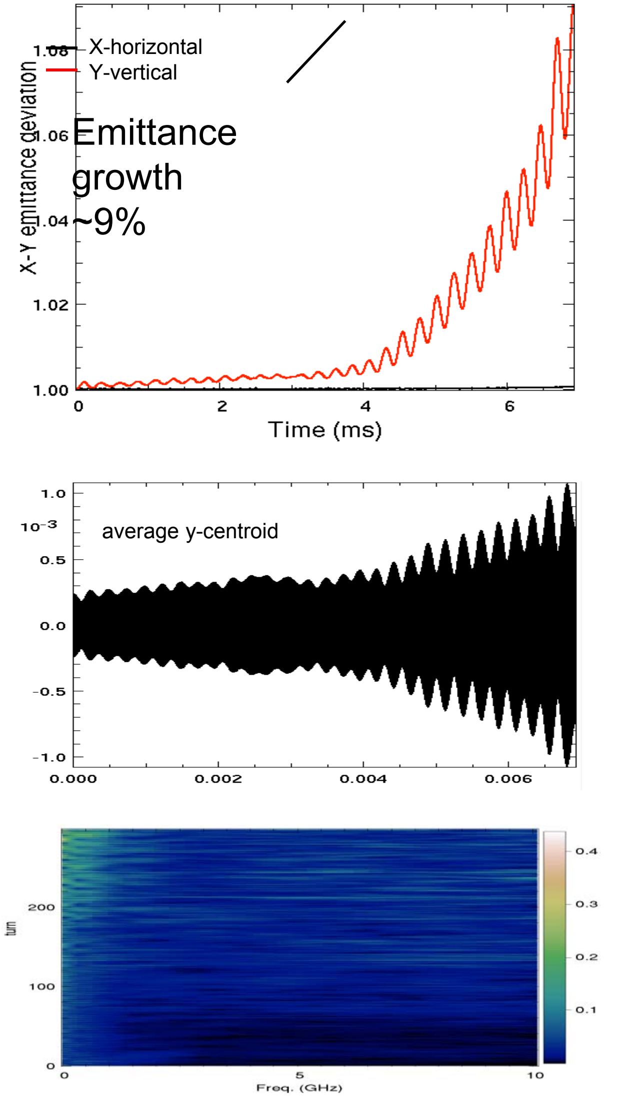


Emittance growth <1%

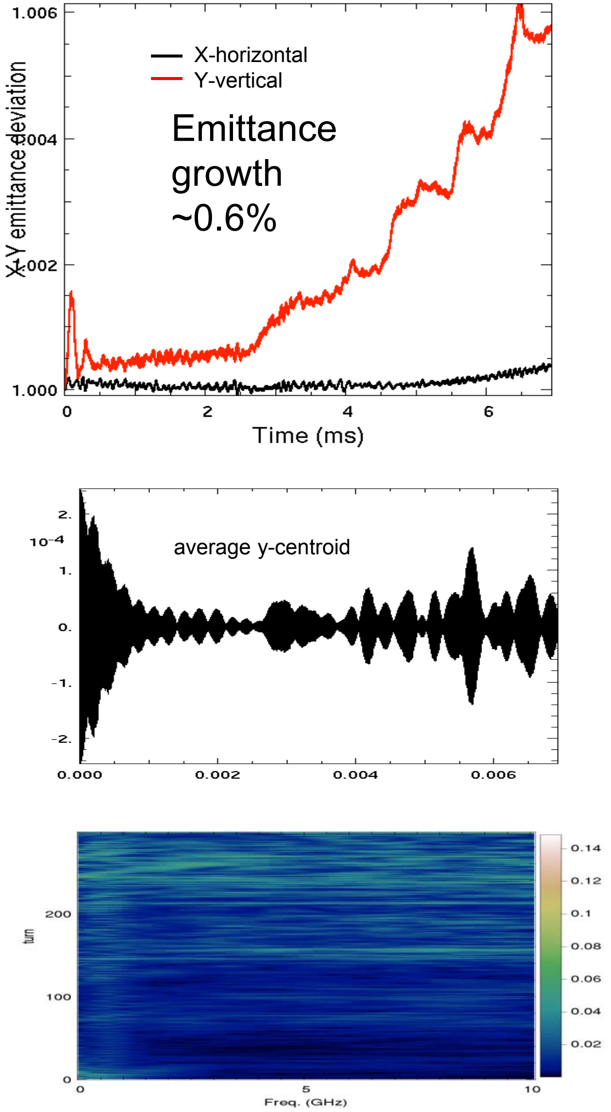
800 MHz bandwith too narrow at larger e-density

Model 2 - n_e~6x10^{12} m^{-3}

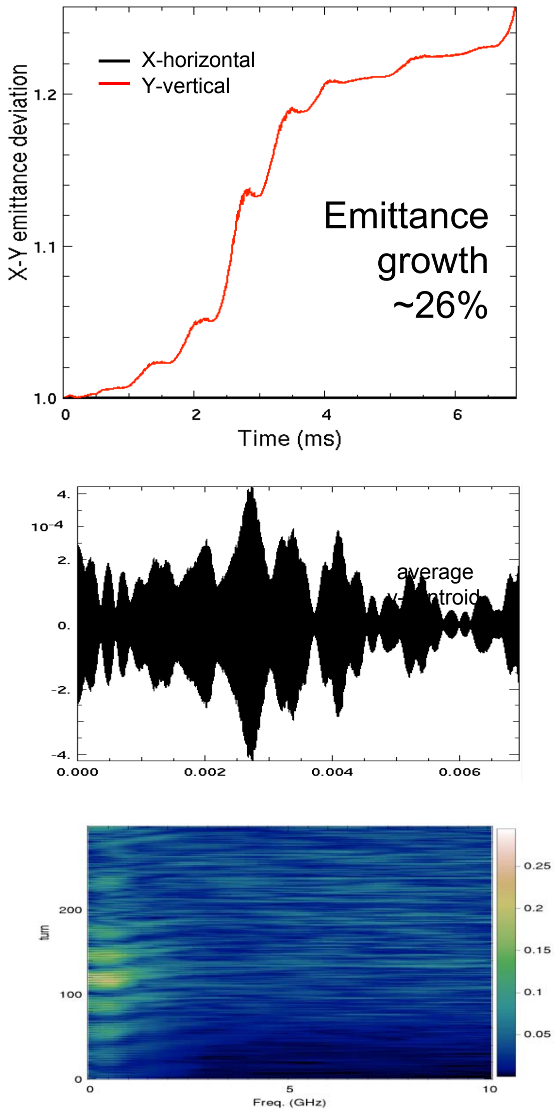
No feedback



filter off, w_λ off



filter on, w_λ off



Feedback model 3 – prediction from three turns

- record centroid offset $y_0(t)$, $y_1(t)$ and $y_2(t)$ from three consecutive beam passages

- predict $y_3(t)$ from $y_{0\text{-}2}(t)$ using linear maps, ignoring longitudinal motion and effects from electrons

$$\begin{pmatrix} y \\ y' \end{pmatrix}^{n+1} = \begin{pmatrix} C & \beta S \\ -S/\beta & C \end{pmatrix} \begin{pmatrix} y \\ y' \end{pmatrix}^{n} \Rightarrow \begin{cases} \sigma & = \arccos\left(\frac{y_0+y_2}{2y_1}\right) \\ y_2' & = \frac{-y_0\cos(\sigma)+y_1\cos(2\sigma)}{\beta\sin(\sigma)} \end{cases} \quad \begin{matrix} C = \cos(\sigma) \\ S = \sin(\sigma) \end{matrix} \Rightarrow \begin{pmatrix} y \\ y' \end{pmatrix}^{3} = \begin{pmatrix} C & \beta S \\ -S/\beta & C \end{pmatrix} \begin{pmatrix} y \\ y' \end{pmatrix}^{2}$$

- *scale according to line charge density λ: $y_2(t) \Rightarrow y_2(t) \bullet w_\lambda$

- *apply low-pass FFT filter (sharp cutoff at 800MHz): $y_2(t) \Rightarrow \hat{y}_2(t)$

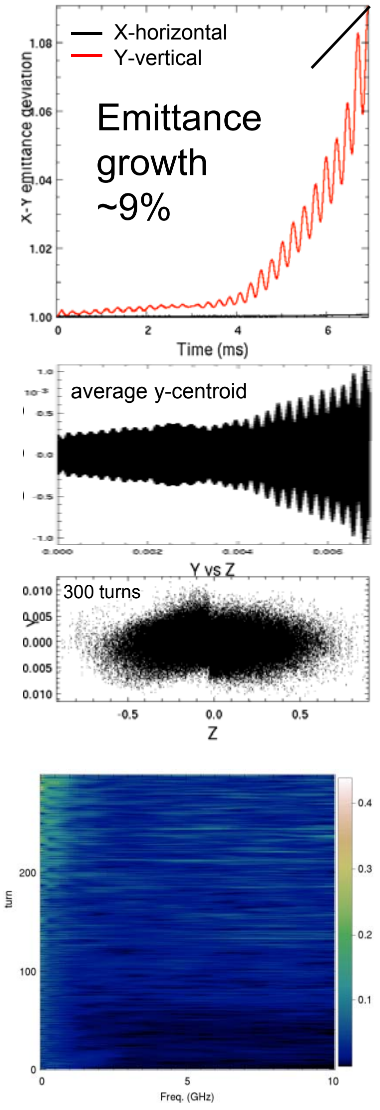
- one turn later, scale transverse position $y \Rightarrow y - g \bullet \hat{y}_2$ (g=0.1)

*optional stage

Preliminary simul. study of SPS EC feedback

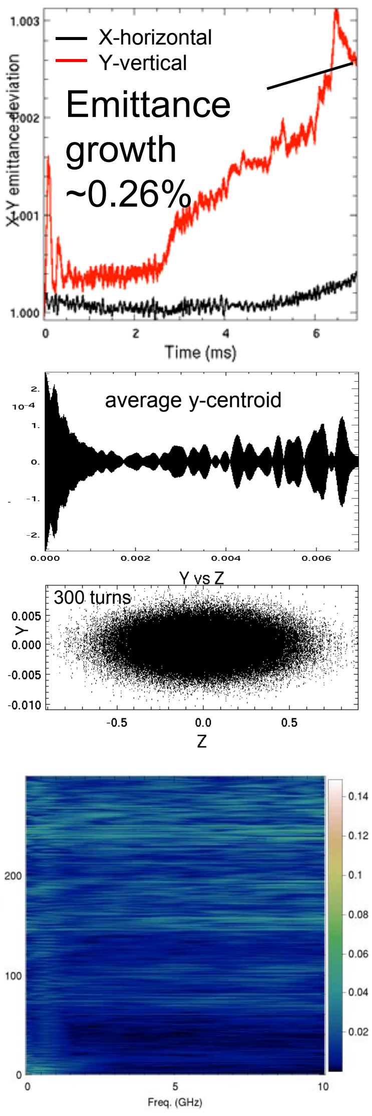
Model 3 - $n_e \sim 6 \times 10^{12}\ m^{-3}$

No feedback



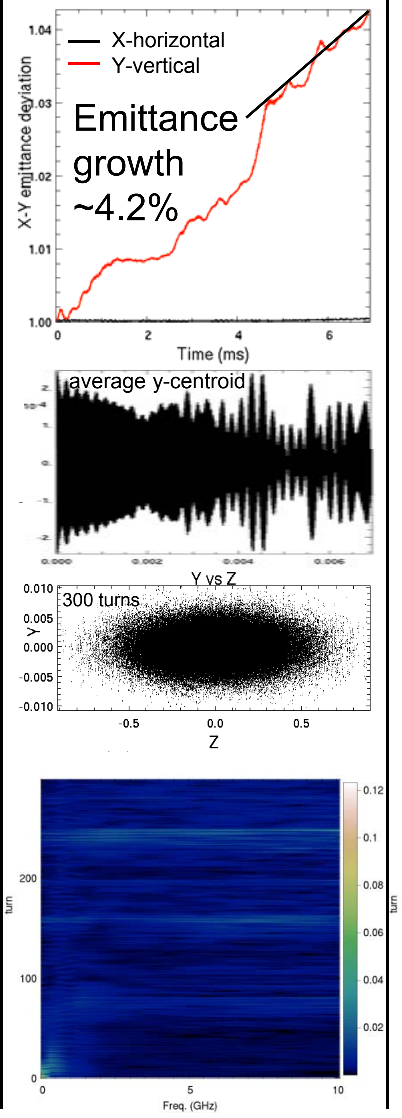
Emittance growth ~9%

filter off, w_λ off



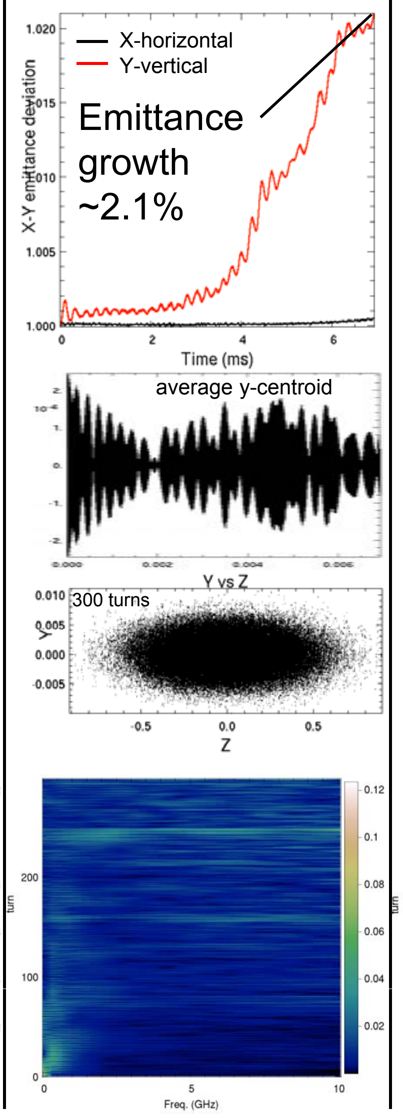
Emittance growth ~0.26%

filter on, w_λ off



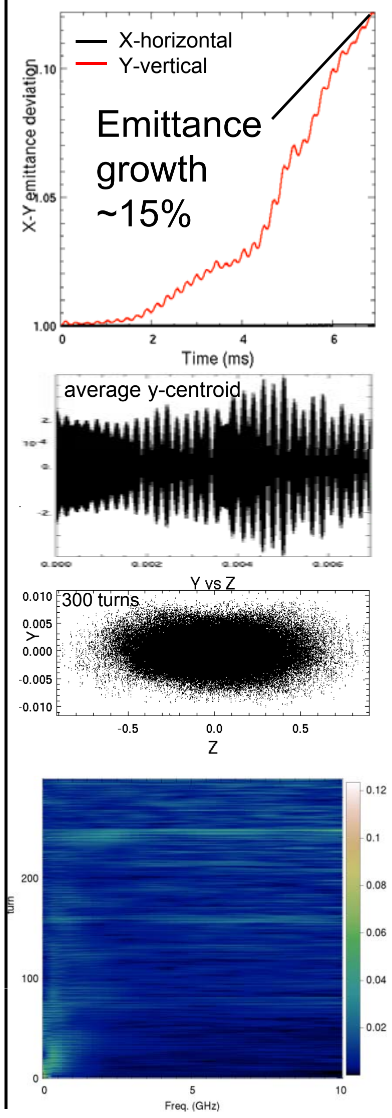
Emittance growth ~4.2%

filter off, w_λ on



Emittance growth ~2.1%

filter on, w_λ on



Emittance growth ~15%

Tentative Conclusions

- Work on determining the theoretical feasibility of a feedback system for e-cloud induced instability has just started.

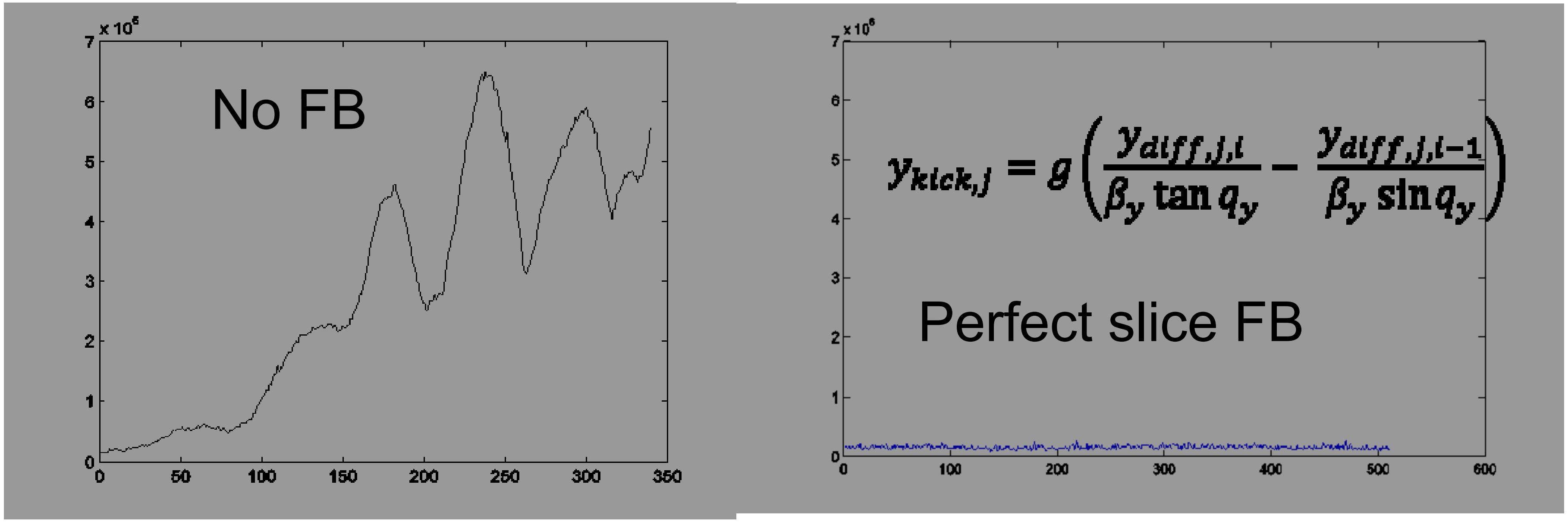
- A (demanding) 800 MHz bandwidth system has been shown to provide the desired damping (at least for not too-large e-density) for the SPS case study considered
    - damping the coherent vertical motion has beneficial impact on emittance growth
- More extensive study will be necessary to determine bandwidth requirement and should include
    - more realistic modeling of feedback systems (filter, time delays, noise …)
    - more complete modeling of beam dynamics (chromaticities …_

- Developing a simplified model of beam-e-cloud interaction may be helpful for the process of optimizing feedback design (John Byrd)
    - is modeling of e-cloud using effective wake-potential a viable option?

to follow is a short summary of recent work done by Joel Thompson with Wolfgang Hofle, Giovanni Rumolo, and John Byrd

EC Feedback with HEADTAIL

- Goal: add simple active feedback module to HEADTAIL code to explore gain and bandwidth required to damp SPS ECI.
-



$$y_{kick,j} = g\left(\frac{y_{diff,j,i}}{\beta_y \tan q_y} - \frac{y_{diff,j,i-1}}{\beta_y \sin q_y}\right)$$

FB Simulation Results

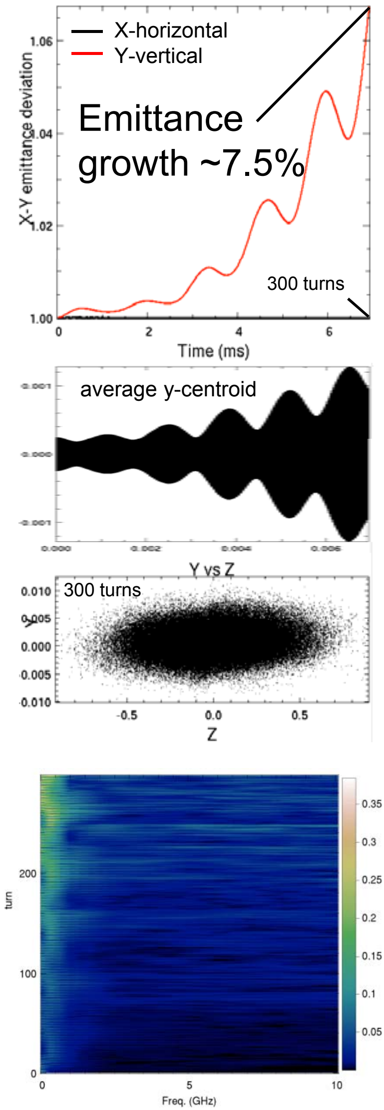
- FB on average vertical position ineffective (i.e. dipole FB)
- FB Bandwidth limitation implemented as a simple windowing function
  - FB effective for bandwidths as low as 300 MHz
  - Bandwidth below 500 MHz appears to require very large gain
- Proper kick phase determined from combination of position measurement from two consecutive turns.
- **Summary: good initial results. Significantly more effort required.**

BACKUPS

Preliminary simul. study of SPS EC feedback

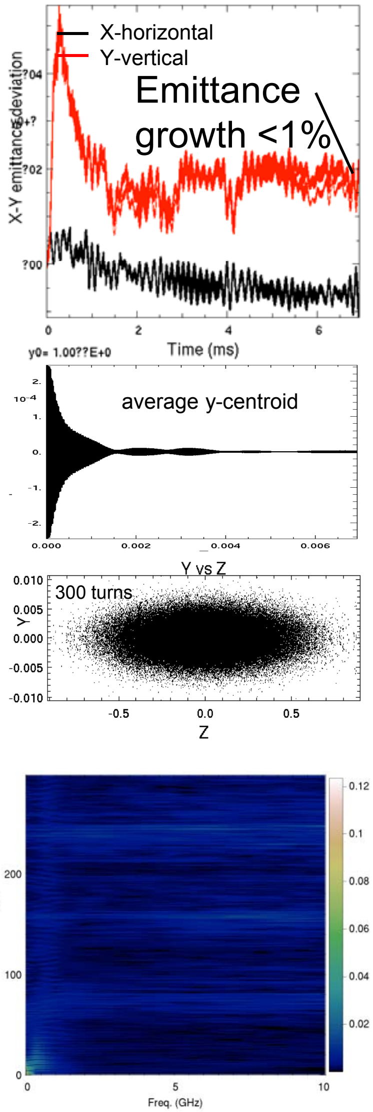
Model 2 - $n_e \sim 1.5 \times 10^{12}$ m^{-3}

No feedback



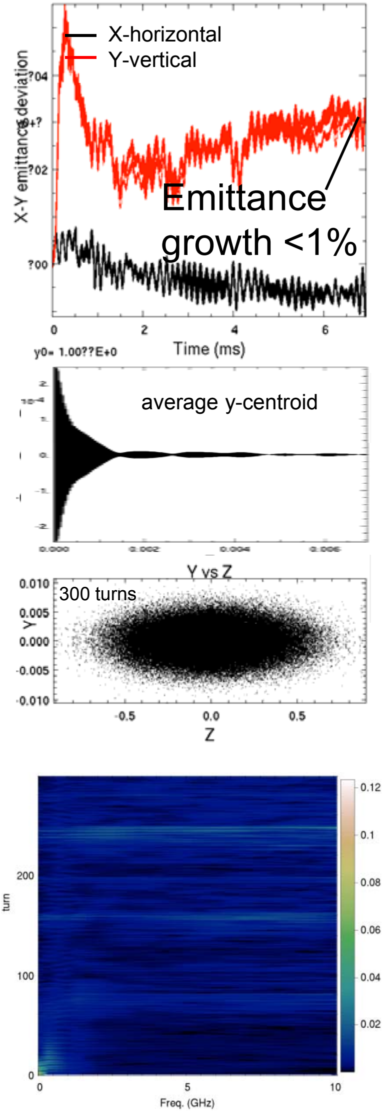
Emittance growth ~7.5%

filter off, w_λ off



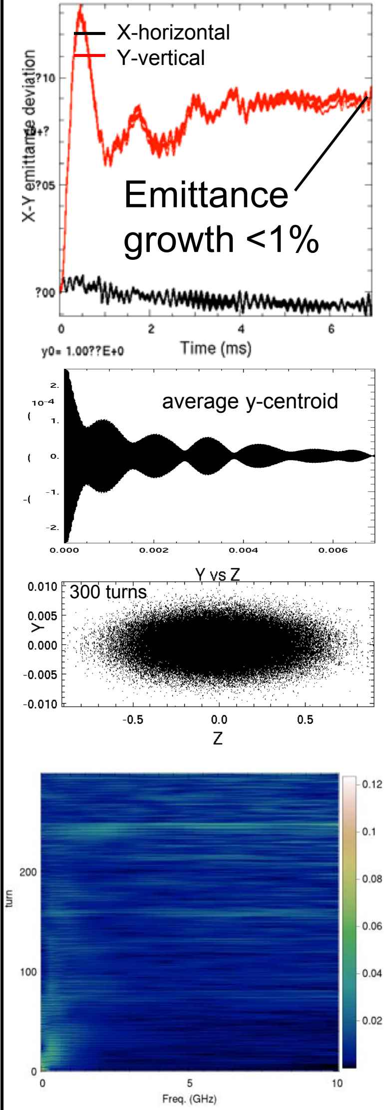
Emittance growth <1%

filter on, w_λ off



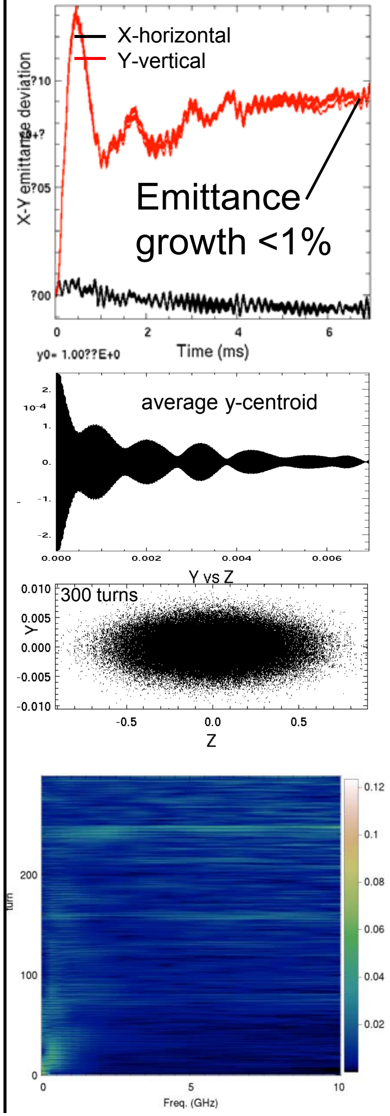
Emittance growth <1%

filter off, w_λ on



Emittance growth <1%

filter on, w_λ on

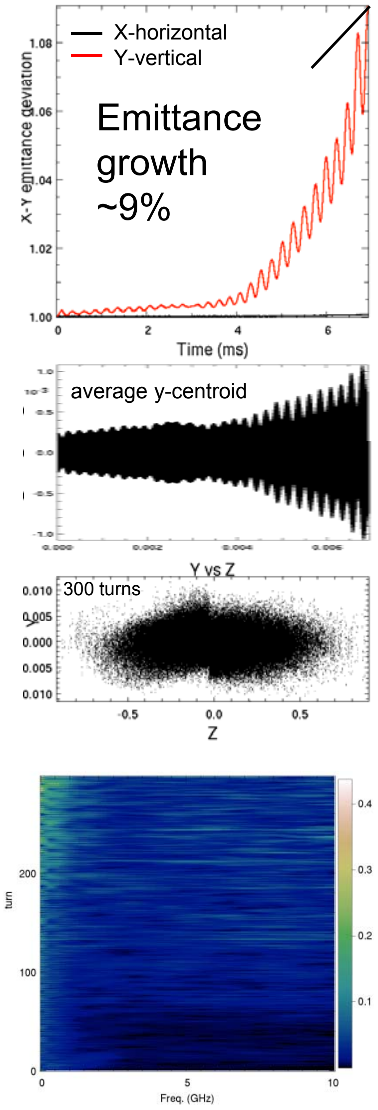


Emittance growth <1%

Preliminary simul. study of SPS EC feedback

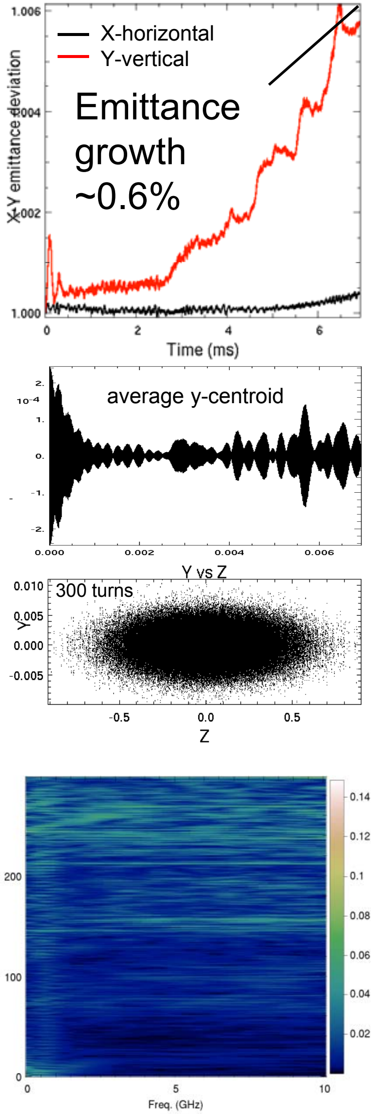
Model 2 - n_e~6x10^{12} m^{-3}

No feedback



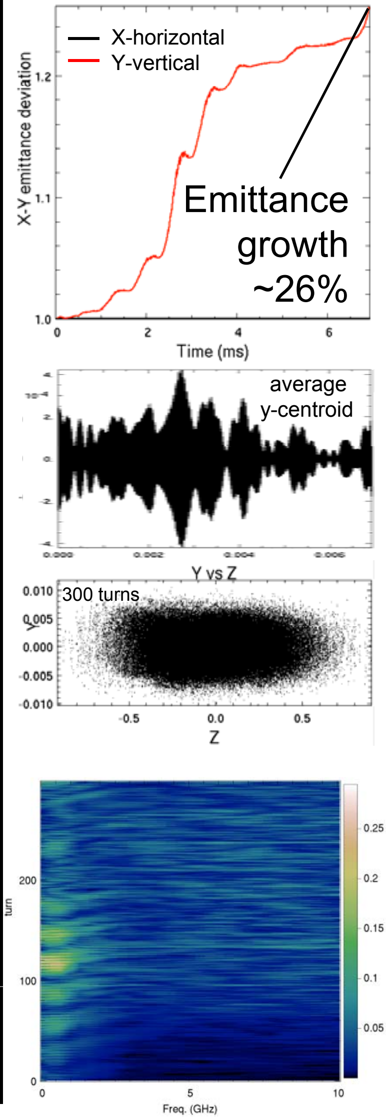
Emittance growth ~9%

filter off, w_λ off



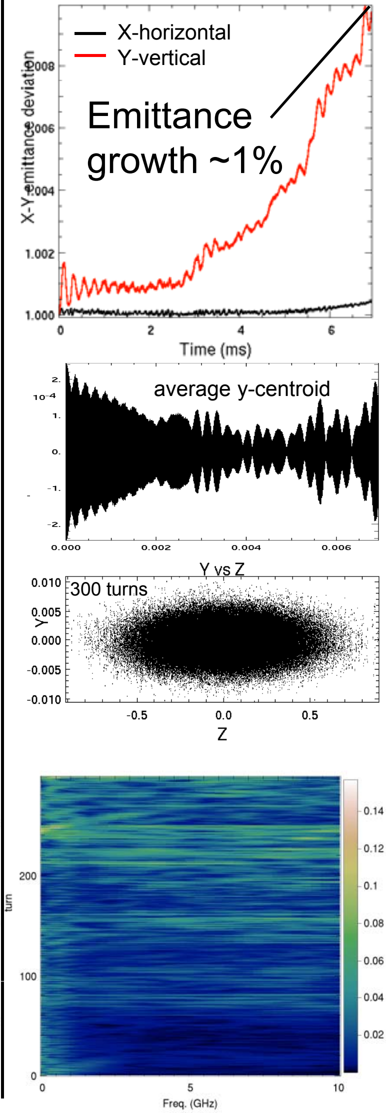
Emittance growth ~0.6%

filter on, w_λ off



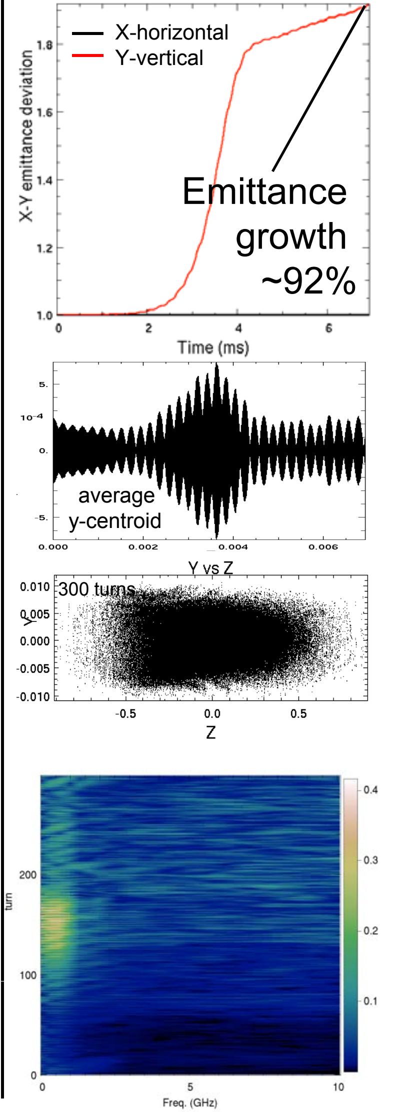
Emittance growth ~26%

filter off, w_λ on



Emittance growth ~1%

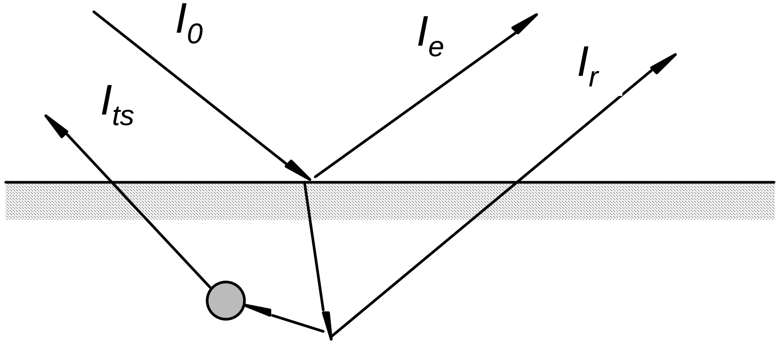
filter on, w_λ on



Emittance growth ~92%

POSINST provides advanced SEY model.

Monte-Carlo generation of electrons with energy and angular dependence.
Three components of emitted electrons:



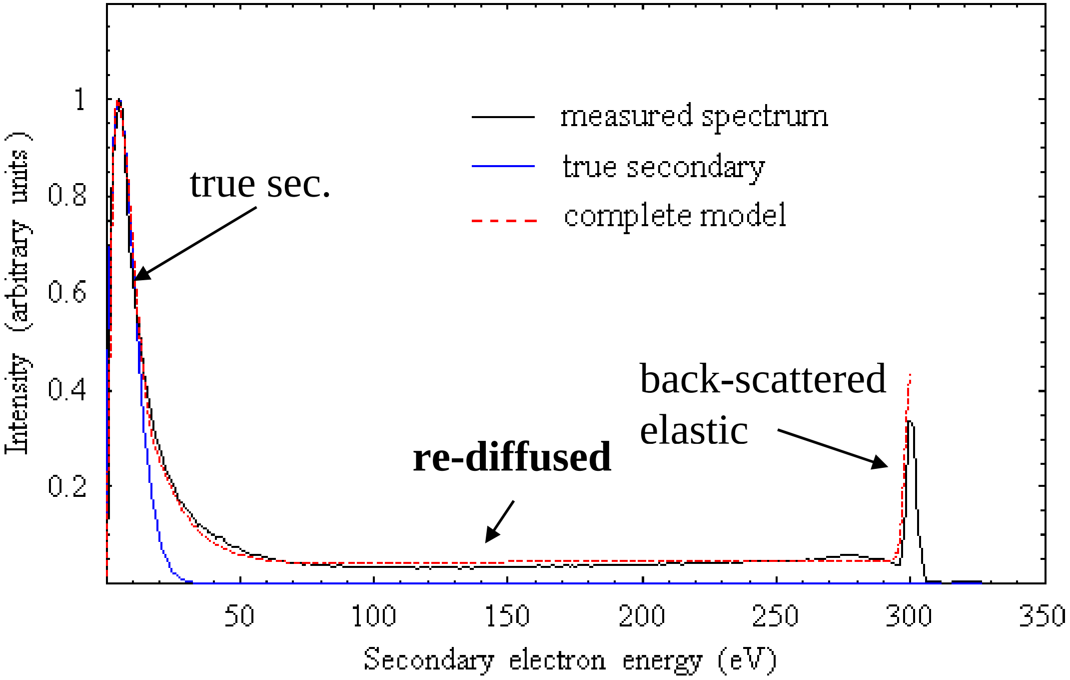
backscattered: $\delta_e = \frac{I_e}{I_0}$,

rediffused: $\delta_r = \frac{I_r}{I_0}$,

true secondaries: $\delta_{ts} = \frac{I_{ts}}{I_0}$

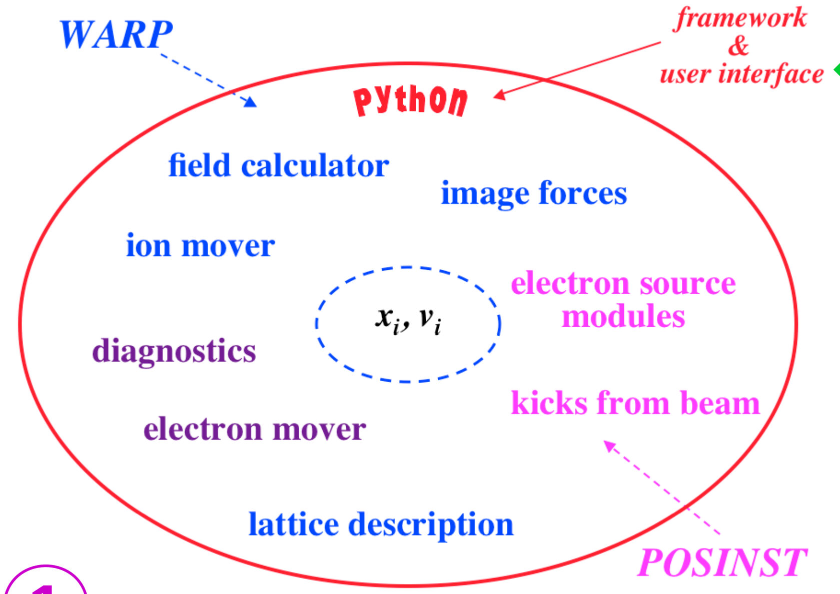
Phenomenological model:

- based as much as possible on data for δ and $d\delta/dE$
- not unique (use simplest assumptions whenever data is not available)
- many adjustable parameters, fixed by fitting δ and $d\delta/dE$ to data

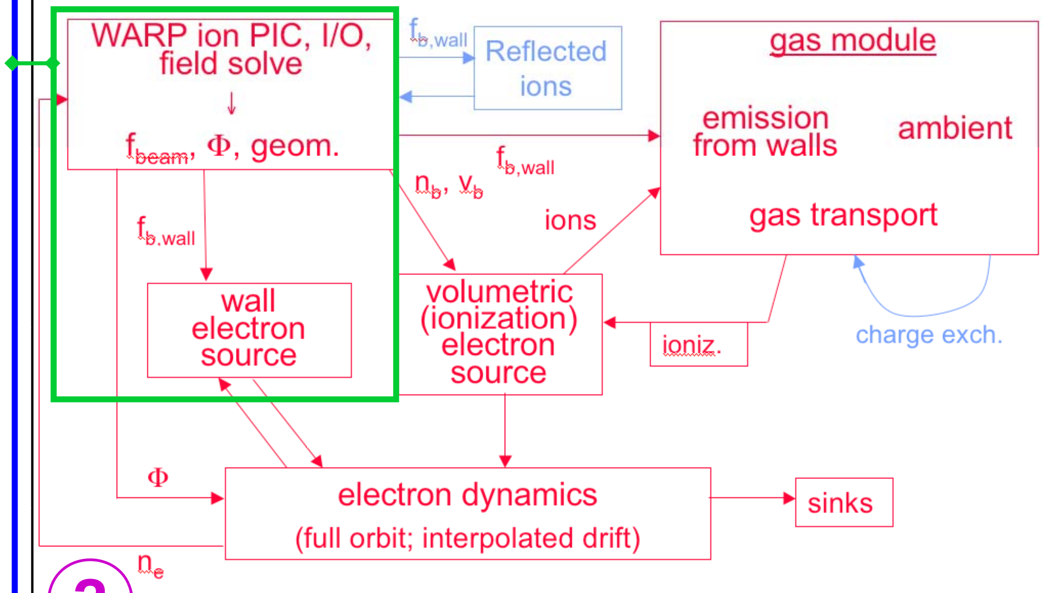


WARP-POSINST unique features

merge of WARP & POSINST + new e^-/gas modules



①

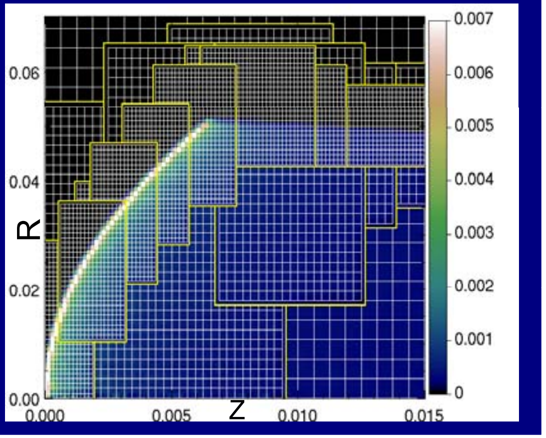


②

Key: operational; partially implemented (4/28/06)

+ Adaptive Mesh Refinement

concentrates resolution only where it is needed

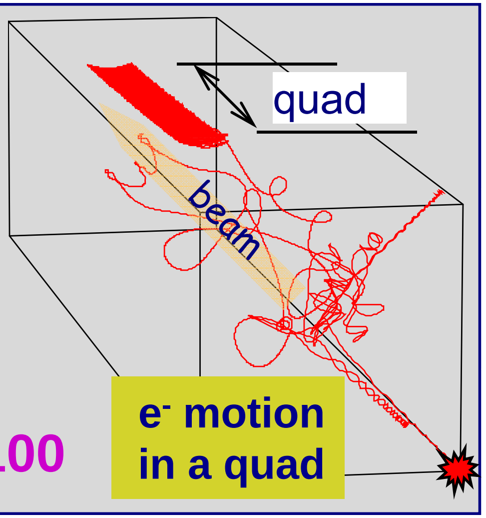


Speed-up

③ **x10-10^4**

+ Novel e^- mover

Allows large time step greater than cyclotron period with smooth transition from magnetized to non-magnetized regions



④ **Speed-up x10-100**