Simulations of e-cloud in the SPS for feedback study

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with the participation of the SPS feedback team

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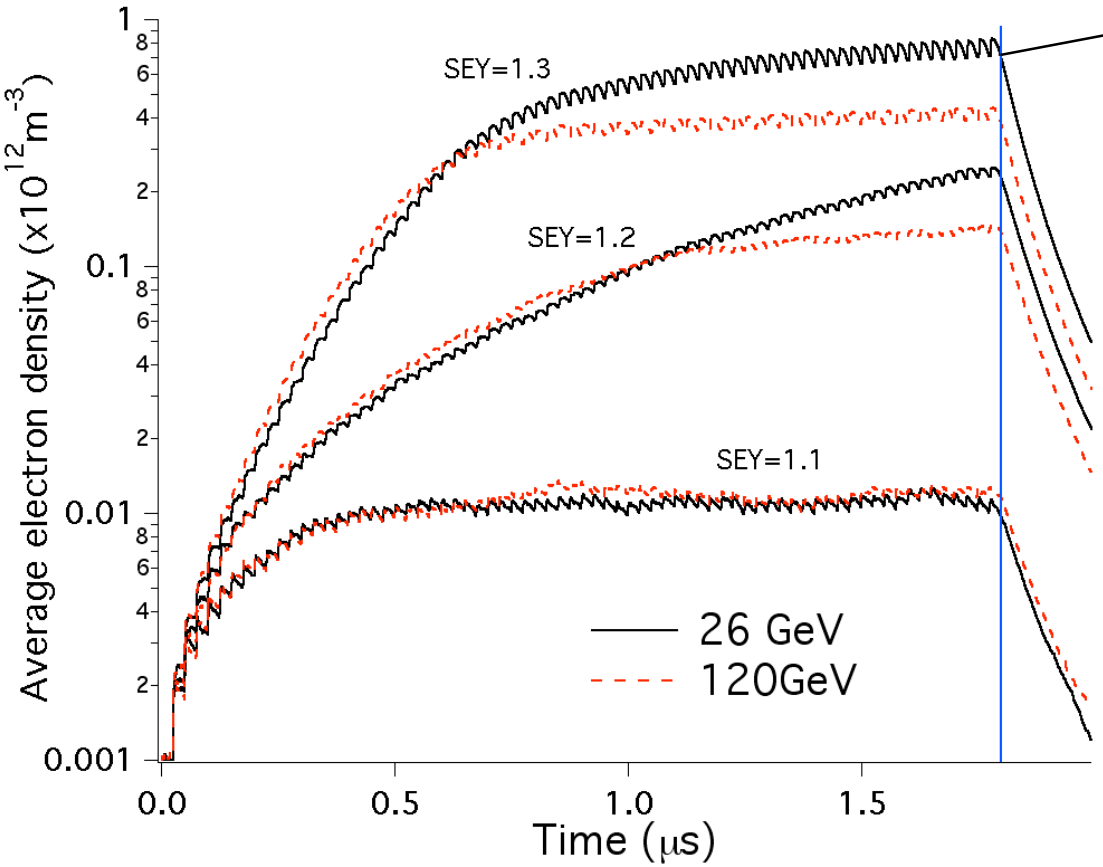
J. Thompson - Cornell Univ.

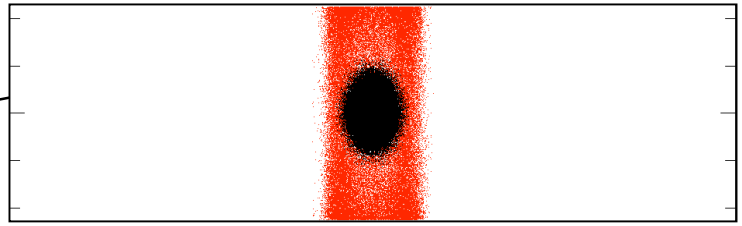
LARP CM12 collaboration meeting
Napa, CA - April 8-10, 2009

Content

- Comparison between Warp (LBNL-LLNL) and Headtail (CERN) simulations of e-cloud instability in SPS: emittance and tune shift,
- idealized models of feedback,
- damping of e-cloud driven instability with feedback models at “low” and “high” density of e-cloud,
- conclusion.

Posinst simulations of e-cloud build-up in SPS



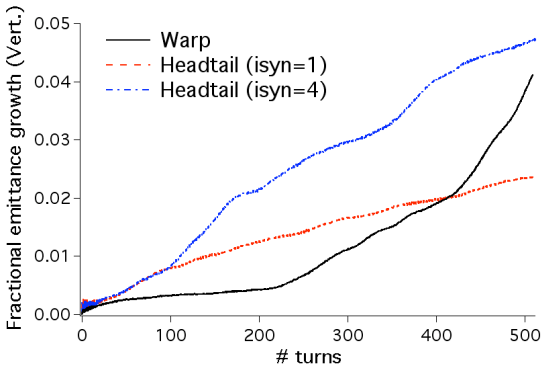


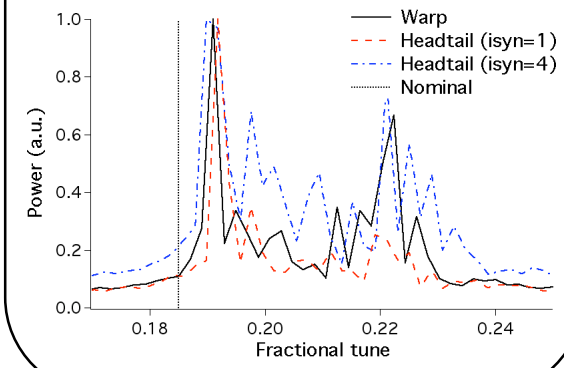
- Varying SEY between 1.1 and 1.3 leads to average density of electrons ranging between $10^{10}m^{-3}$ and $7.10^{11}m^{-3}$,
- electrons localized to small portion of chamber horizontally => local density ranging between $8.10^{10}m^{-3}$ and $5.10^{12}m^{-3}$.

Simulations of e-cloud instability in SPS comparison Warp-Headtail

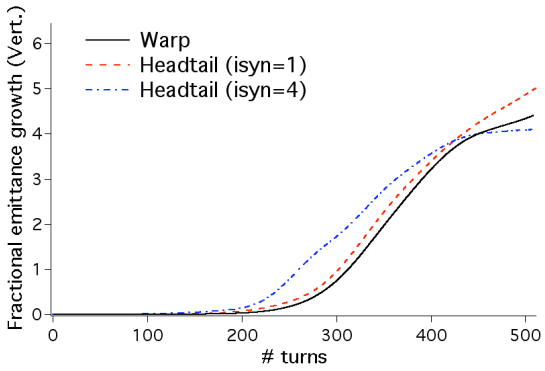
- SPS
  - N_p=1.1×10^{11}
  - n_e=1.×10^{12}m^{-3} (uniform)
  - ⊥ :continuous focusing
    - $\beta_{x,y}$= 33.85, 71.87
    - $\nu_{x,y}$= 26.13, 26.185
    - chrom.$_{x,y}$=0.1,0.1
  - // : ν_z= 0.00323
    - Warp/HT (isyn=1): continuous focusing
    - HT (isyn=4): focusing more localized
  - 10 stations/turns
  - 512 turns

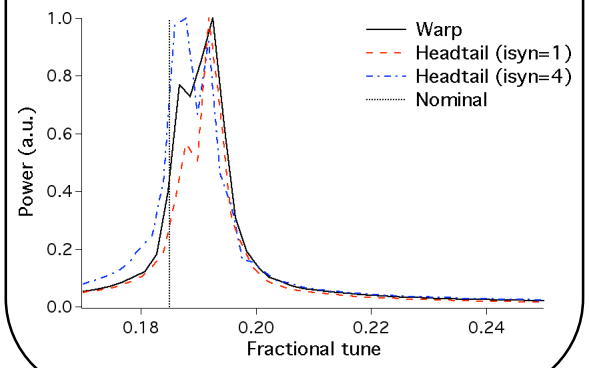
E_b=26 GeV (at injection)





E_b=120 GeV

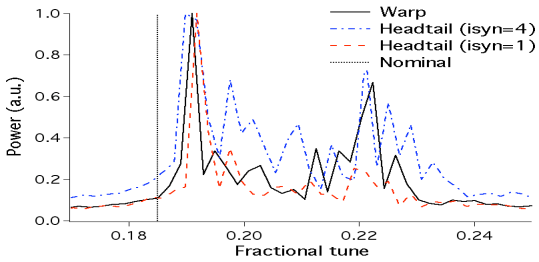




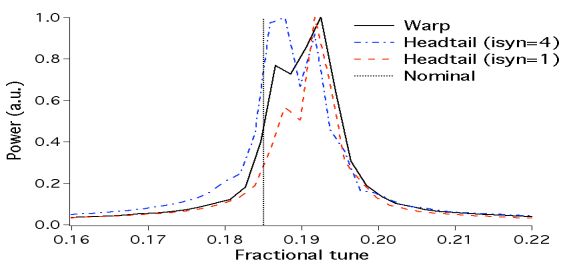
Good agreement between Warp and Headtail on emittance growth and tune shift using continuous focusing models at 26GeV and 120GeV.

Simulations of e-cloud instability in SPS closer look at tune shift

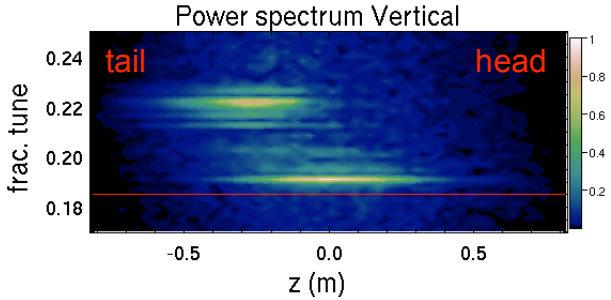
E_b=26 GeV

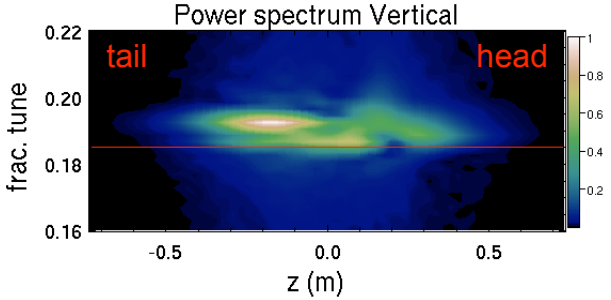


E_b=120 GeV

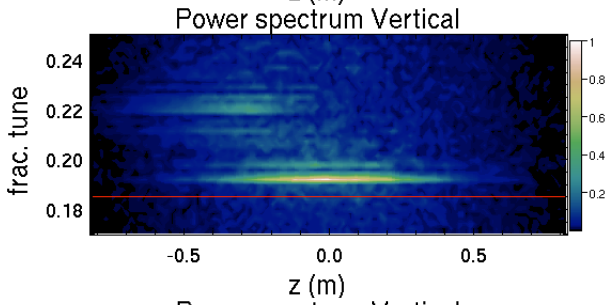


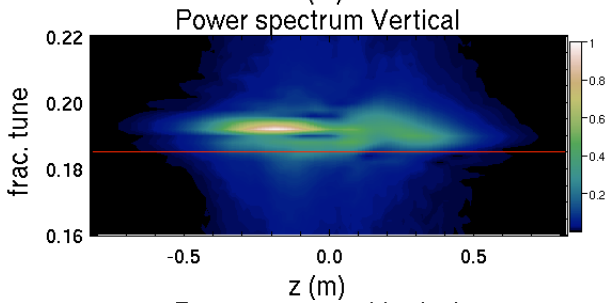
Warp



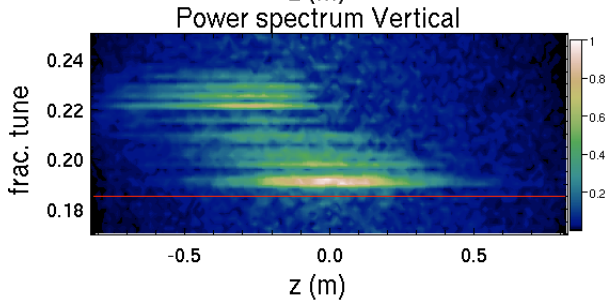


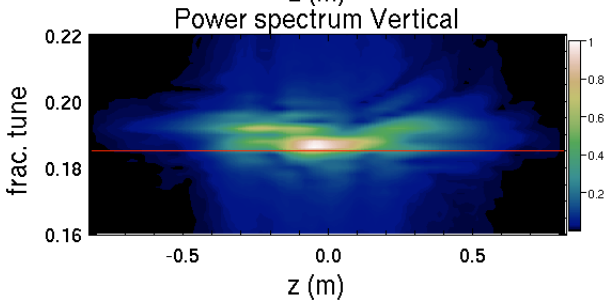
Headtail (isyn=1)





Headtail (isyn=4)

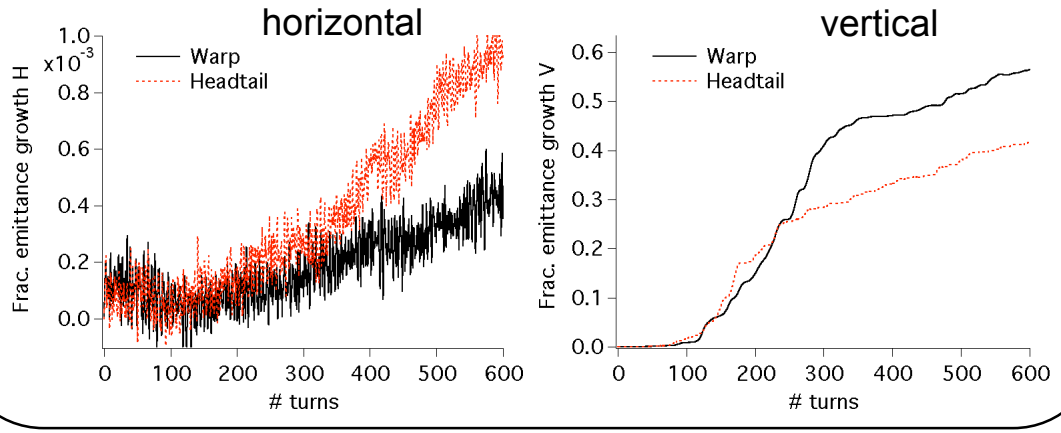




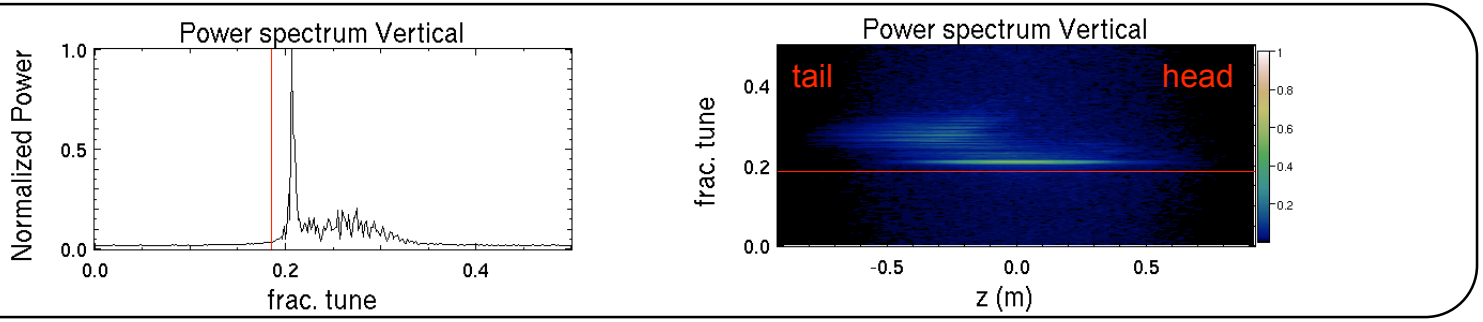
Simulations of e-cloud instability in SPS at injection - higher electron density

- SPS at injection (E_b=26 GeV)
  - $N_p=1.1\times10^{11}$
  - $n_e=3\times10^{12}m^{-3}$ (uniform)
  - continuous focusing
    - $\beta_{x,y}$= 33.85, 71.87
    - $\nu_{x,y}$= 26.12, 26.185
    - chrom.$_{x,y}$=0.,0.
    - ν_z= 0.0059

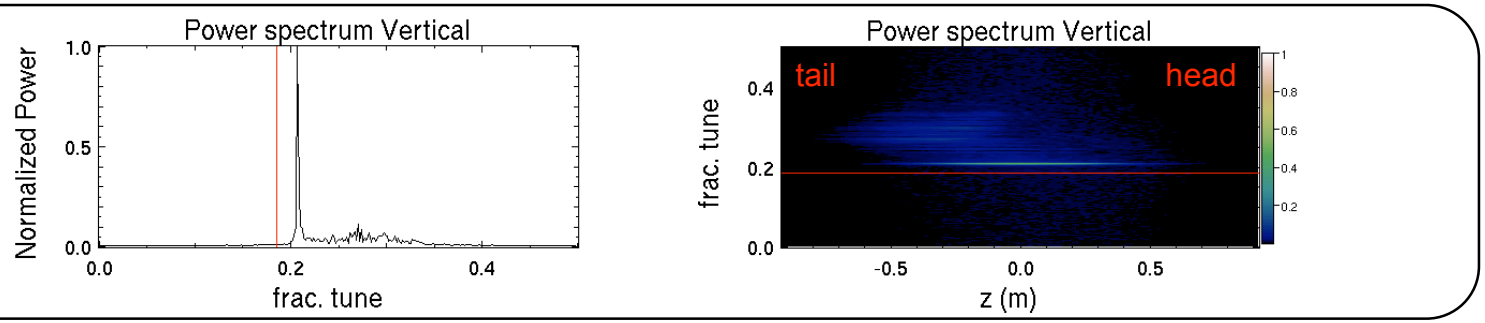
Fractional emittance growth



Warp



Headtail



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- conclusion.

Feedback model 1 - instantaneous

- record centroid offset $y_0(t)$ at station *n* for 1 beam passage
- *scale according to line charge density* λ: $y_0(t) \Rightarrow y_0(t) \cdot w_\lambda$ *optional*
- *apply low-pass FFT filter (sharp cutoff at 1GHz):* $y_0(t) \Rightarrow \hat{y}_0(t)$ *optional*
- scale transverse position $y \Rightarrow y - g \cdot \hat{y}_0$ (g=0.1 used in all runs)

Feedback model 2 - prediction from 2 turns

- record centroid offset $y_0(t)$ and $y_1(t)$ at station *n* for 1 beam passage for two consecutive turns

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

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

- *scale according to line charge density λ: $y_2(t)$ => $y_2(t) \cdot w_\lambda$*

  optional

- *apply low-pass FFT filter (sharp cutoff at 1GHz): $y_2(t)$=>$\hat{y}_2(t)$*

  optional

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

Feedback model 3 - prediction from 3 turns

- record centroid offset $y_0(t)$, $y_1(t)$ and $y_2(t)$ at station *n* for 1 beam passage for three consecutive turns

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

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

- *scale according to line charge density λ: $y_2(t)$ => $y_2(t)\cdot w_\lambda$*

  optional

- *apply low-pass FFT filter (sharp cutoff at 1GHz): $y_2(t)$=>$\hat{y}_2(t)$*

  optional

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

Content

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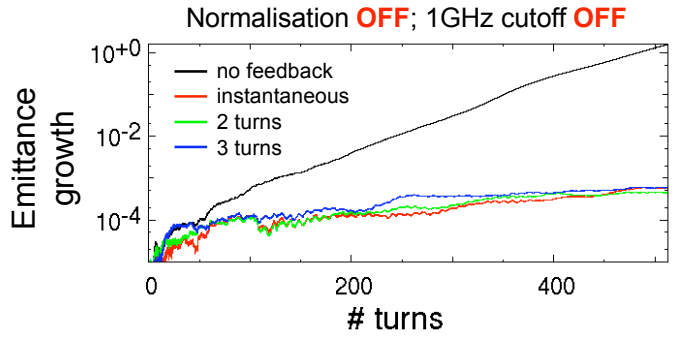
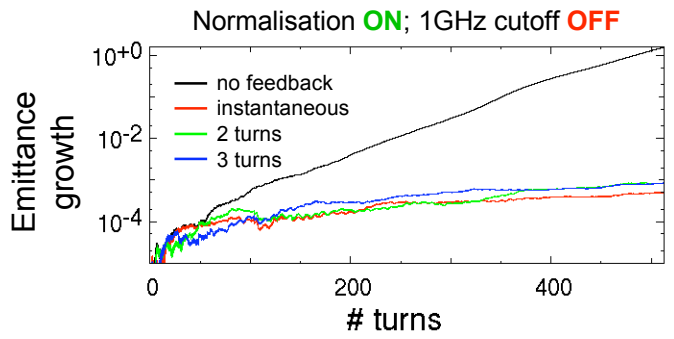
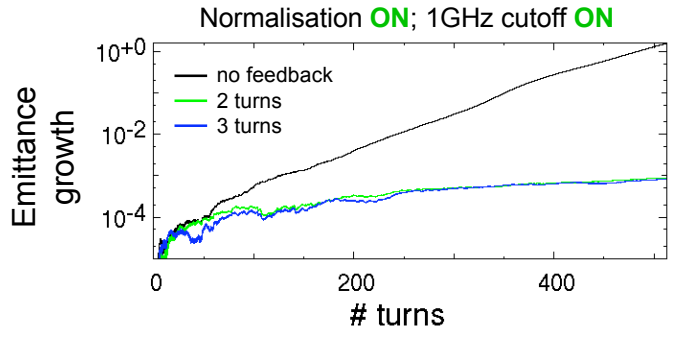
- idealized models of feedback,
- **damping of e-cloud driven instability with feedback models at "low" and "high" density of e-cloud,**
- conclusion.

Simulations of e-cloud instability damping with feedback models in SPS - $n_e=1\times10^{12}m^{-3}$



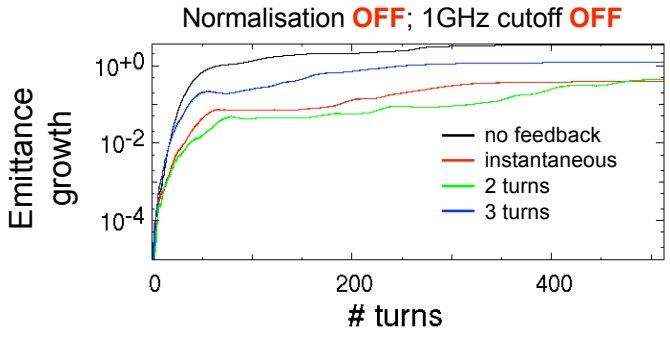


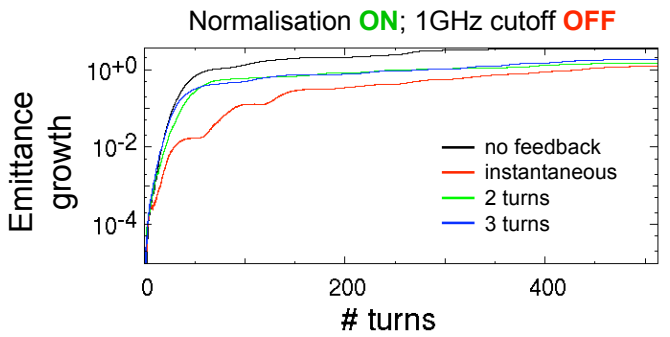


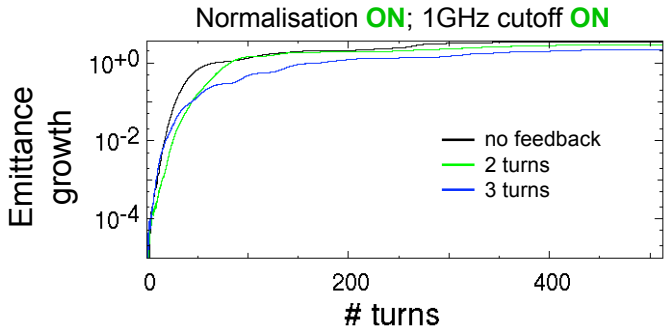
- SPS at (E_b=120 GeV)
  - $N_p=1.1\times10^{11}$
  - $n_e=1.\times10^{12}m^{-3}$ (uniform)
  - $\perp$:continuous focusing
    - $\beta_{x,y}$= 33.85, 71.87
    - $\nu_{x,y}$= 26.13, 26.185
    - chrom.$_{x,y}$=0.1,0.1
  - // : continuous focusing
    - ν_z= 0.00323
  - 100 stations/turns
  - 512 turns

All three feedback models suppressed instability very effectively.

Simulations of e-cloud instability damping with feedback models in SPS - $n_e=5\times10^{12}m^{-3}$







- SPS at (E_b=120 GeV)
  - $N_p=1.1\times10^{11}$
  - $n_e=5.\times10^{12}m^{-3}$ (uniform)
  - $\perp$:continuous focusing
    - $\beta_{x,y}$= 33.85, 71.87
    - $\nu_{x,y}$= 26.13, 26.185
    - chrom.$_{x,y}$=0.1,0.1
  - // : continuous focusing
    - ν_z= 0.00323
  - 100 stations/turns
  - 512 turns

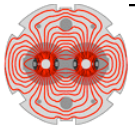
Effectiveness of feedback models greatly reduced for high density of e-clouds.

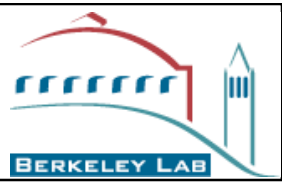
Conclusion

- Good agreement on emittance growth and tune shift between Warp and Headtail for simulation of e-cloud in SPS with continuous focusing model

- Idea seems, in principle, to work well with some restrictions
  - damping the coherent vertical motion has beneficial impact on emittance growth if the correction signal has the right modes and phases, which may be compromised by:
    - frequency response cutoff,
    - quality of prediction from pickup to kicker,
    - …

- What next:
  - model lattice with linear maps,
  - better modeling of the feedback system (bandwidth, gain, noise,…): ideally setup algorithm reproducing future experimental feedback system as closely as possible,
  - freq. cutoff: higher cutoff frequency?; smoother filter,
  - …

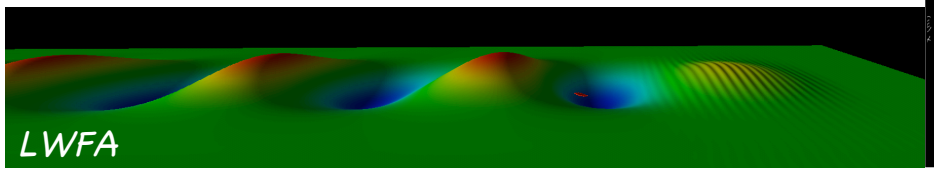


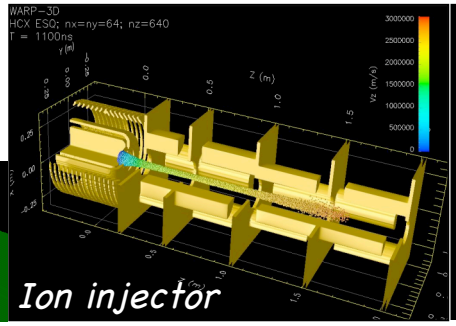


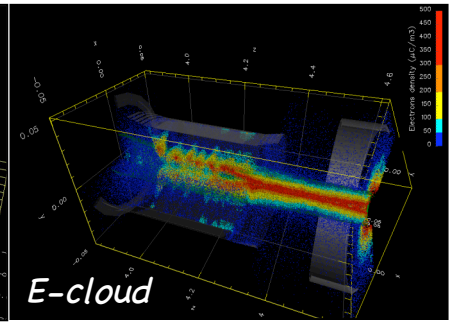
BACKUPS

Warp - 3-D accelerator PIC code

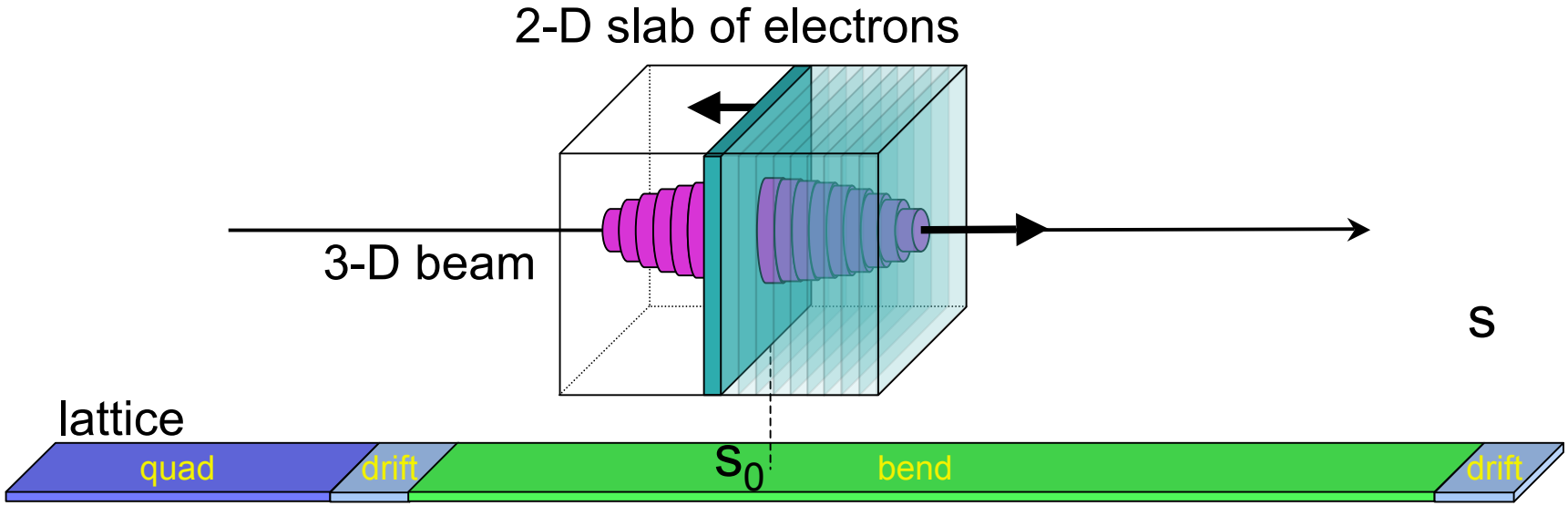
- **Geometry:** 3D, (x,y), (x,z) or (r,z)
- **Field solvers:** electrostatic - FFT, capacity matrix, multigrid, AMR
  electromagnetic - Yee mesh, PML bc, AMR
- **Particle movers:** Boris, "drift-kinetic", new relativistic leapfrog
- **Boundaries:** "cut-cell" --- no restriction to "Legos" (not in EM yet)
- **Lattice:** general; takes MAD input
  - solenoids, dipoles, quads, sextupoles, linear maps, …
  - 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





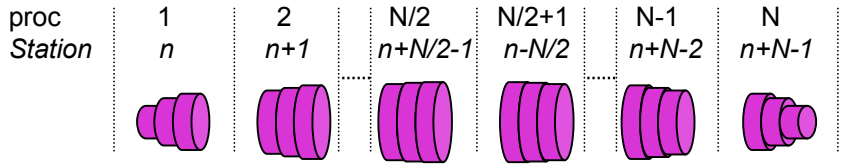


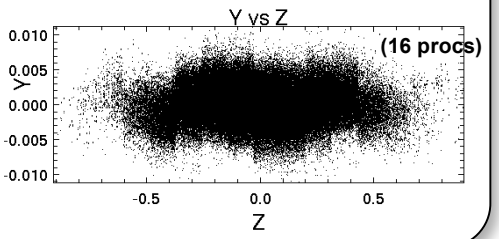
Warp - quasi-static mode ("QSM")



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).

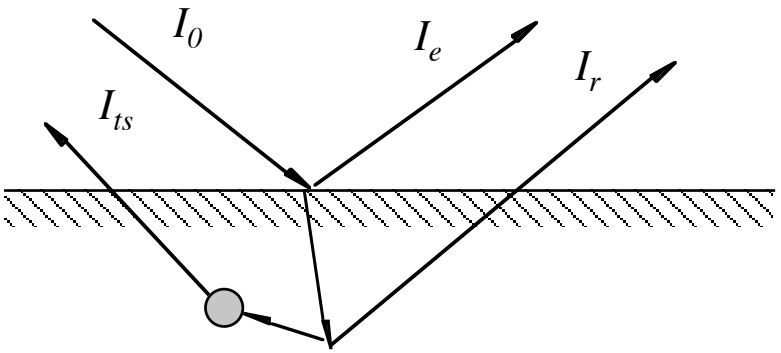
On parallel computers:





POSINST provides advanced SEY model.

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



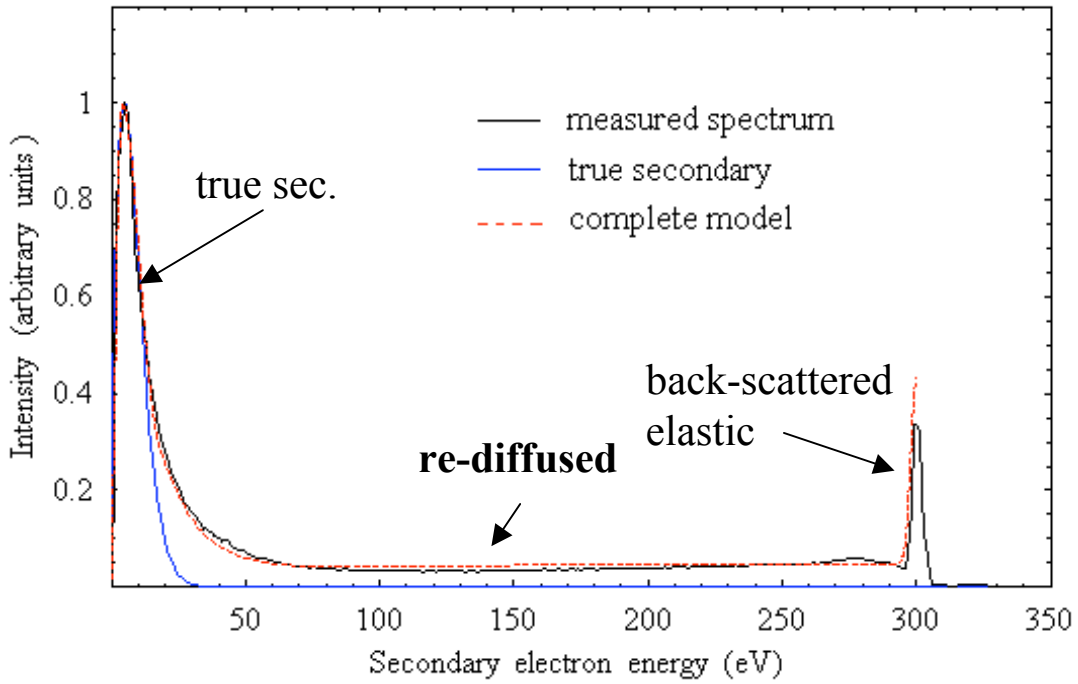
backscattered: $\delta_e = \frac{I_e}{I_0}$,

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

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

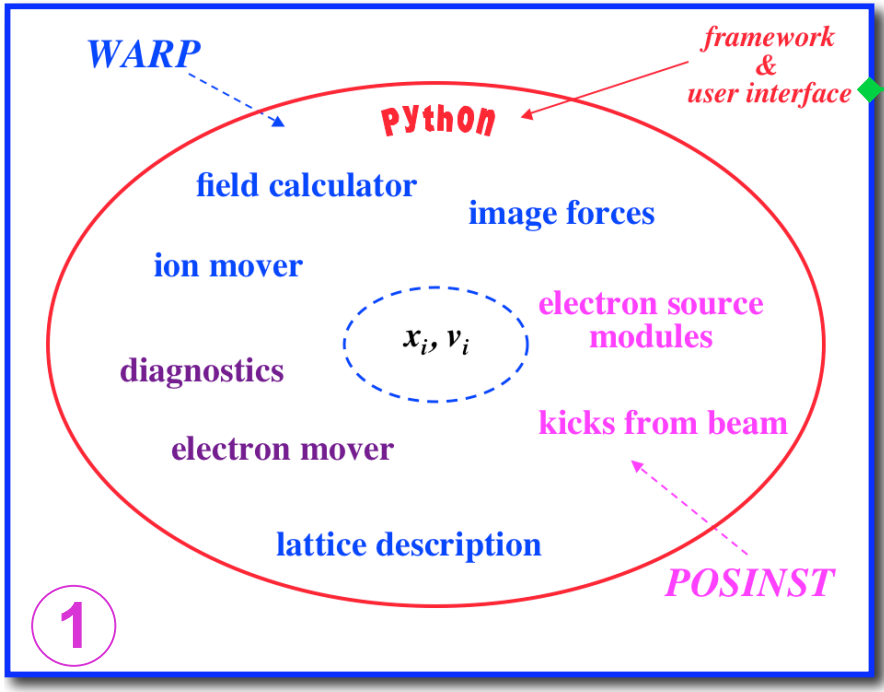
Phenomenological model:

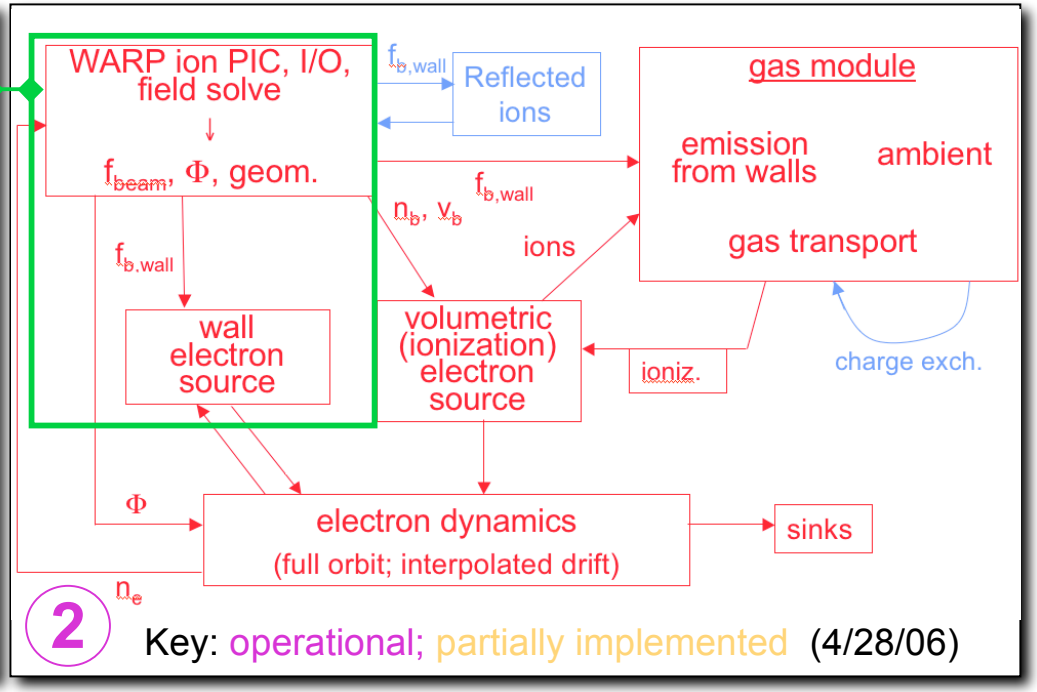
- based as much as possible on data for δ and $d\delta/dE$
- not unique (use simplest assumptions whenever data is not available)
- many adjustable parameters, fixed by fitting δ and $d\delta/dE$ to data



WARP-POSINST unique features

LARP merge of WARP & POSINST + new e⁻/gas modules

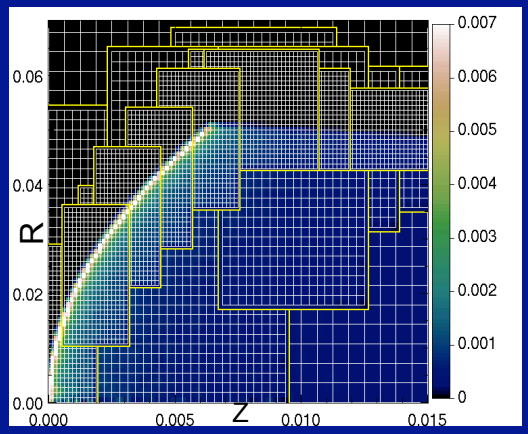




+ Adaptive Mesh Refinement

concentrates resolution only where it is needed

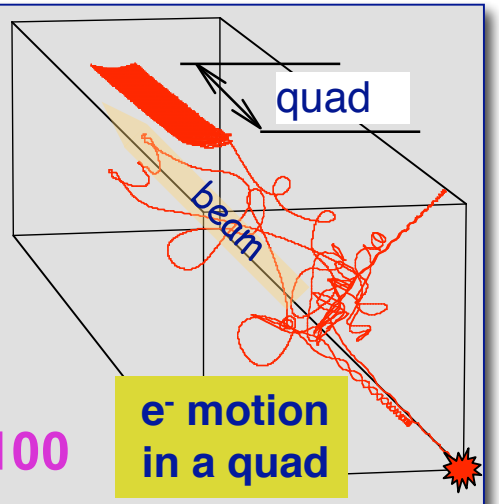
Speed-up 3 x10-10⁴



+ 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



Preliminary simul. study of SPS EC feedback*

Model 1 - beam distribution after 300 turns

*CM10, talk by furman