Fast switching IDs and experience with the APS Circularly Polarizing Undulator

L. Emery and A. Xiao

Accelerator Systems Division
Argonne National Laboratory

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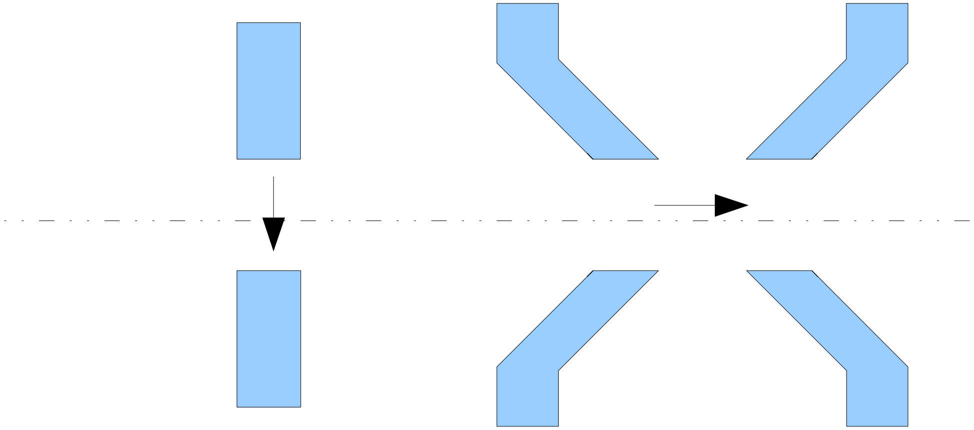
Perturbation from pulsed ID

- The perturbation from a change of the ID configuration is similar from that of a slowly changing polarizing undulator.
- Perturbations that are noticeable:
  - Orbit, i.e. angle and position
  - Normal quadrupole
  - Skew quardupole
  - Dynamic multipole only recently modeled! DA is OK in both reality and model.
- Correct by feedforward with correctors belonging to CPU
  - Time waveform are applied to seven correctors
  - Waveforms are interpolated from prepared table as a function of (I_v, t) where I_v is a main supply set point.

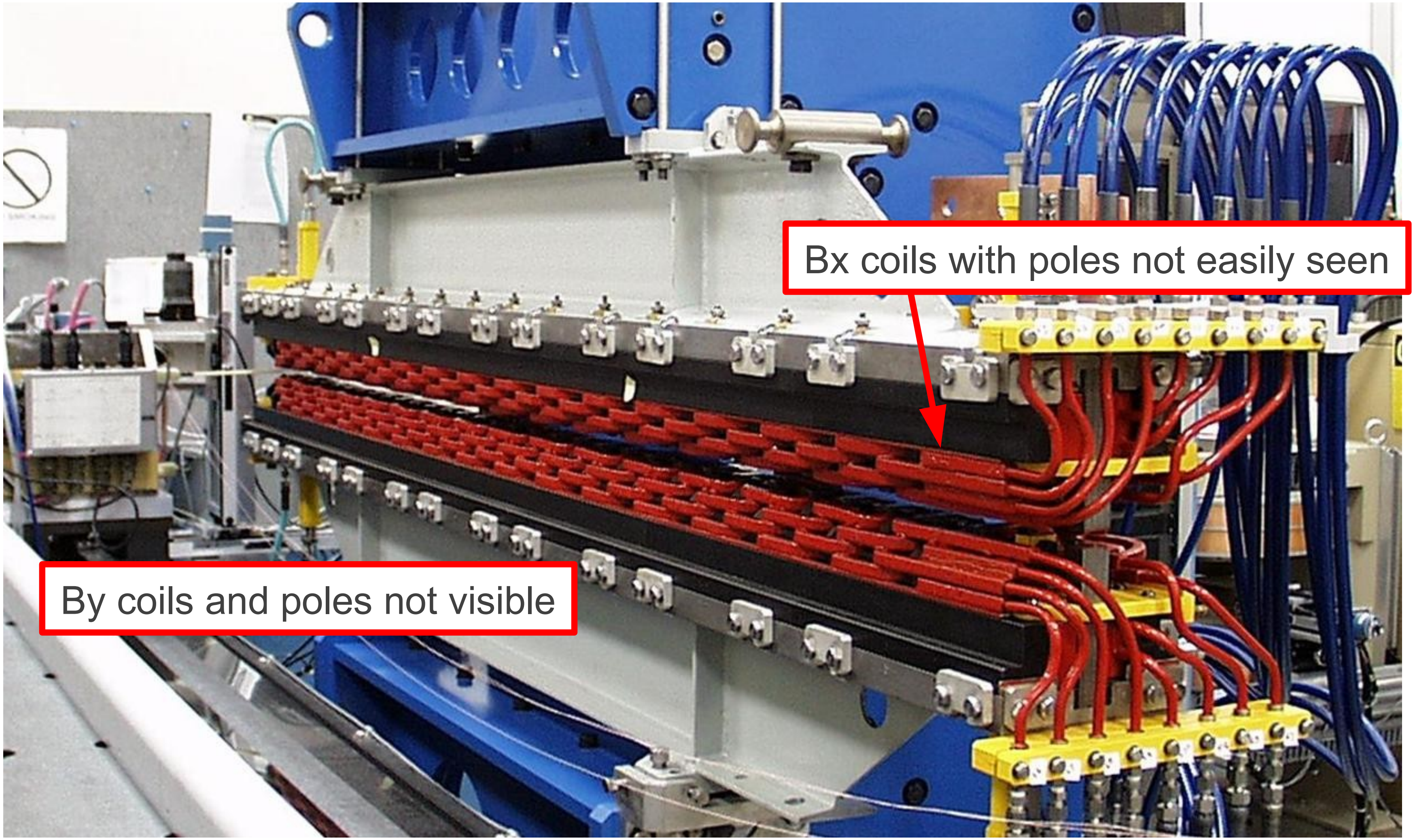
Circular Polarizing Undulator (CPU)

- Two sets of interleaved iron poles, fixed aperture.
  - Upright poles for By
  - Side poles for Bx
  - 12.8 cm period



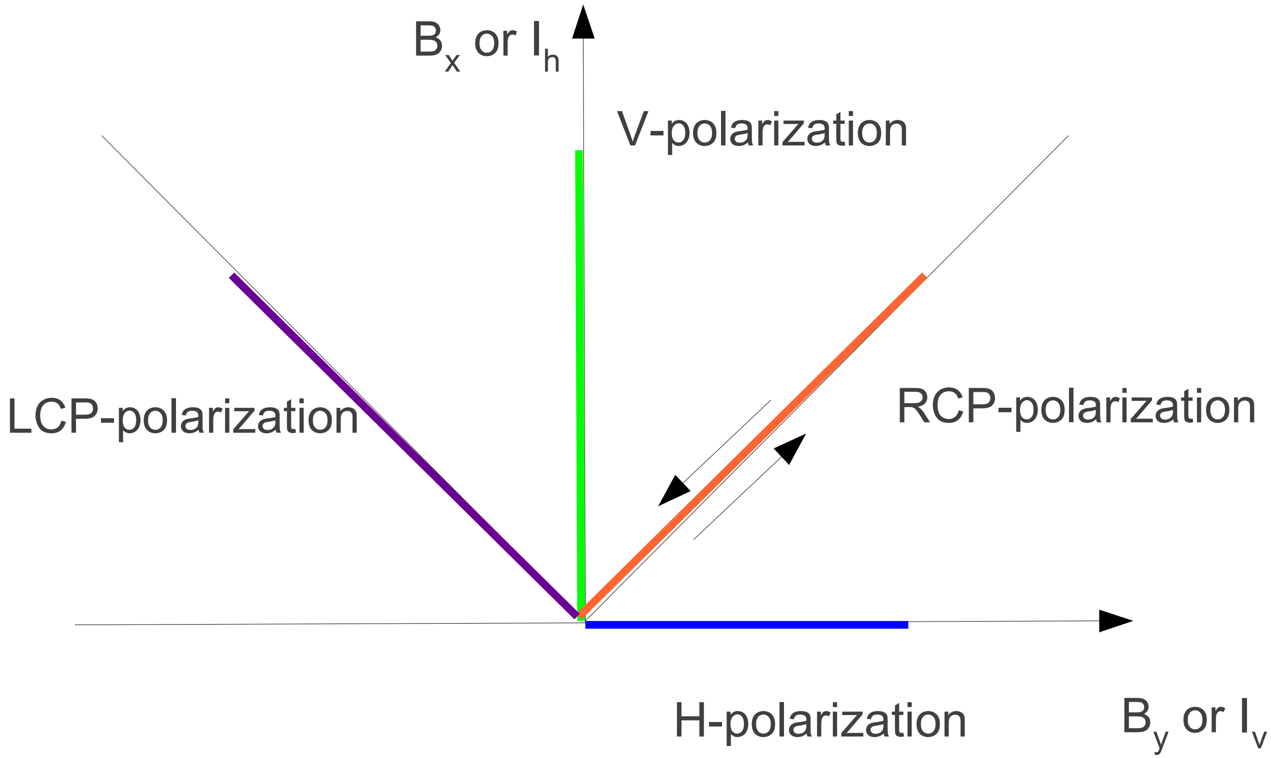
- Two main coils and power supplies
  - H-coil – produces Bx and V-polarized photons
  - V-coil – produces By and H-polarized photons
  - Power both, get RHP or LHP polarized photons
    - V-coil current is flipped for RHP↔LHP rapid switching
  - Operating modes: CW (RHP), CCW (LHP), H, V, and AC mode (CW/CCW)
    - Ramp from 0 to final set point, take data, then back to zero before changing modes

Circularly Polarizing Undulator



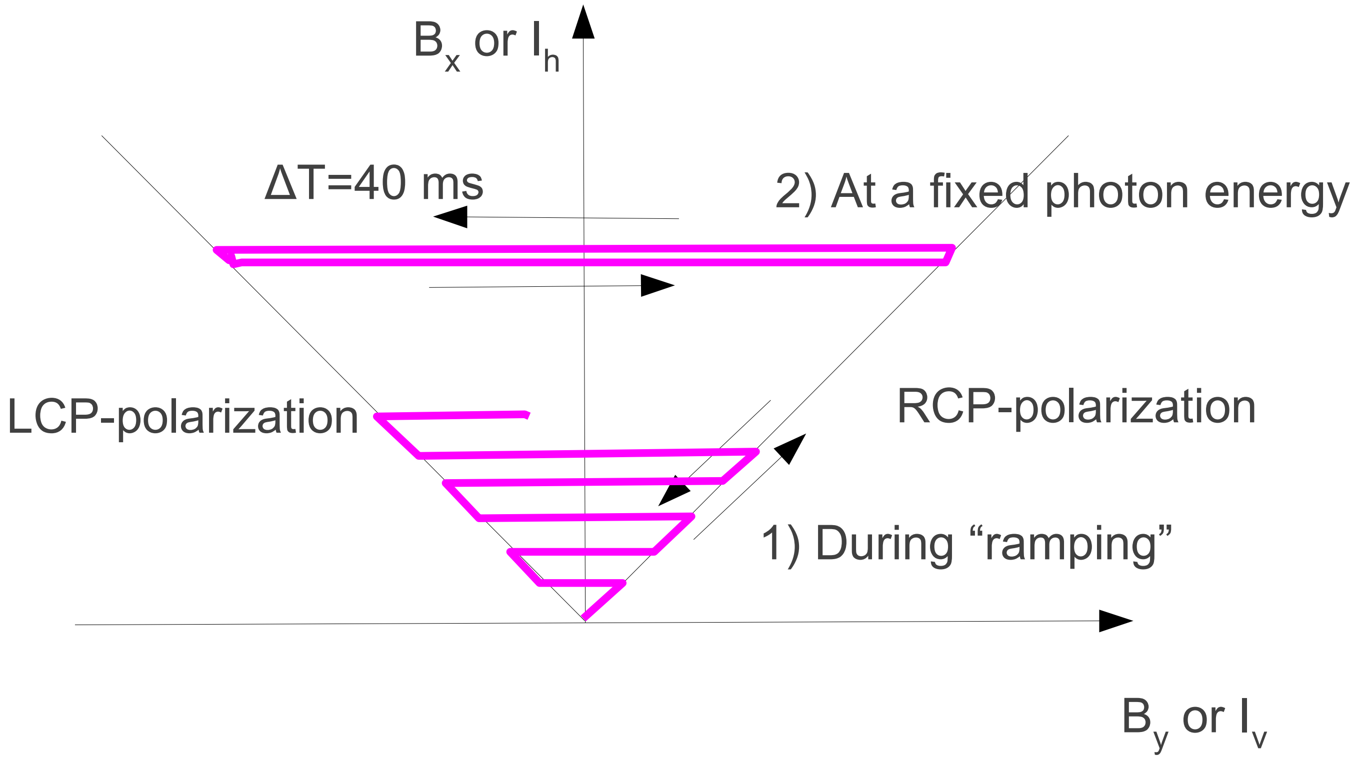
Circularly Polarizing Undulator

- Four “DC” modes where set points are ramped in a particular polarization starting from 0 A. Current set points are I_h and I_v



Circularly Polarizing Undulator

- One “AC” mode (switching mode) where sign of By is flipped at some interval (e.g. 2 second interval) while (Bx, |By|) is ramped along a line (taking 30 seconds). By-field settles in about 40 ms when switching.

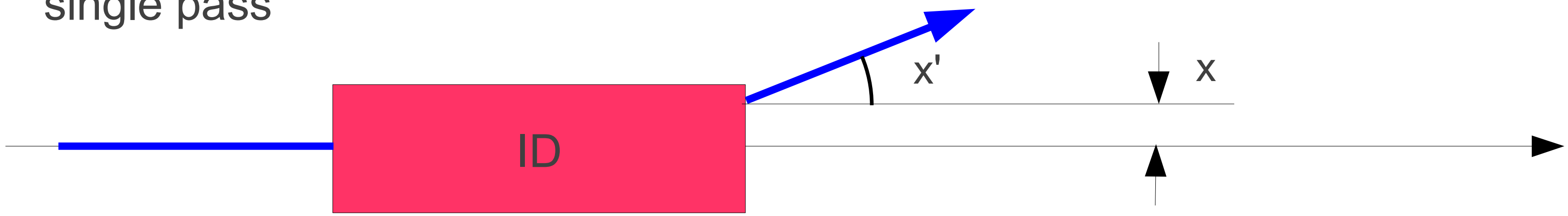


Possible Perturbation (beam stability)

- Trajectory error
  - Angle and trajectory, disturbs orbit at other light source points
  - Orbit readings and orbit “slow” and “fast” feedback
  - Pair of H and V dipole correctors
- Focusing error
  - Normal quadrupole and skew quadrupole, disturbs global vertical beam size
  - Tune measurements and beam size measurement
  - One normal and two skew quadrupole correctors
    - Normal quad is actually spare Bx poles
    - Skew quads are separate (small magnets) and have six poles.
- Need to correct higher-order multipoles first
- Mode of operations
  - “slow” DC modes (i.e. no fast switching), errors change slowly
  - “AC” mode, quickly changing errors. Harder to correct.

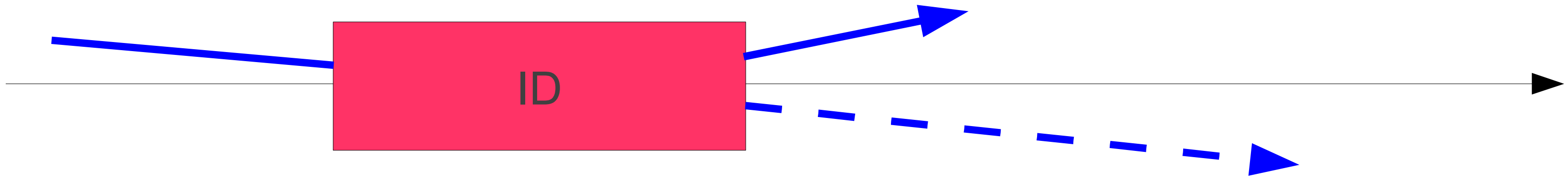
Angle and Trajectory Errors

single pass



first (angle) and second (position) integral errors of B_y cause orbit distortion everywhere

closed orbit (periodic trajectory)



Angle and Trajectory Error plus Correction

- Add two small corrections (~50 μrad) as a function of gap setting
  - through feedback on orbit error
  - through feedforward (what is normally done)
- Does not correct average photon direction within device itself
  - need four correctors in general to compensate both the orbit outside the ID and the average photon direction

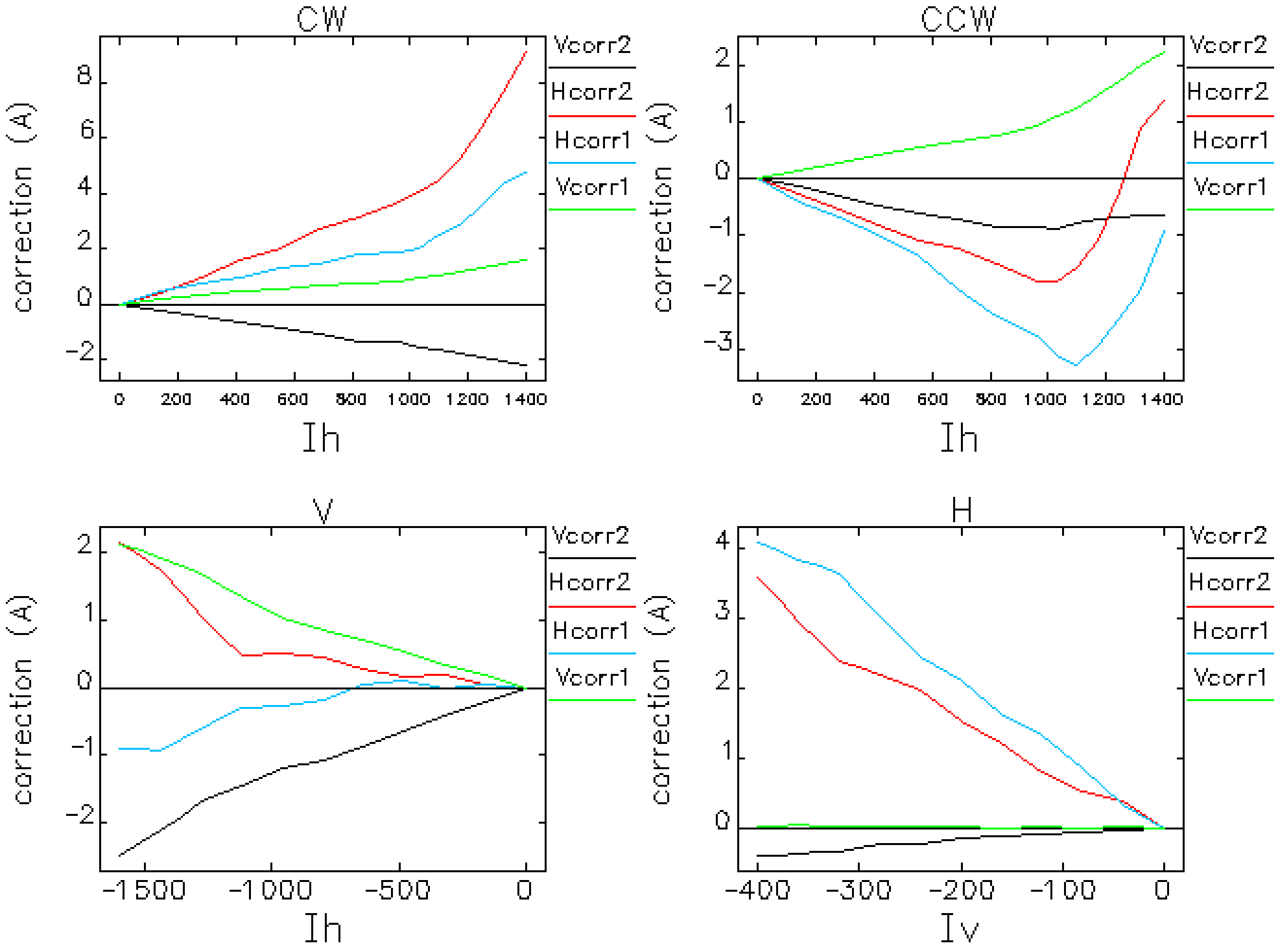
single pass and closed orbit

General Correction

- "DC" modes are relatively easy to correct
  - One parameter with CPU – Main current. Other types, e.g. Apple-II, has gap plus longitudinal displacement, i.e. Photon energy plus ellipticity
  - B_y-coil requires much less correction than B_x coil.
- AC modes involve matching a transient waveform with perturbation to use in feedforward
  - more complex procedure to arrive at accurate correction
  - 1.5 kHz orbit feedback system not sufficient to correct by "feedback" since it has bandwidth of 60 Hz.

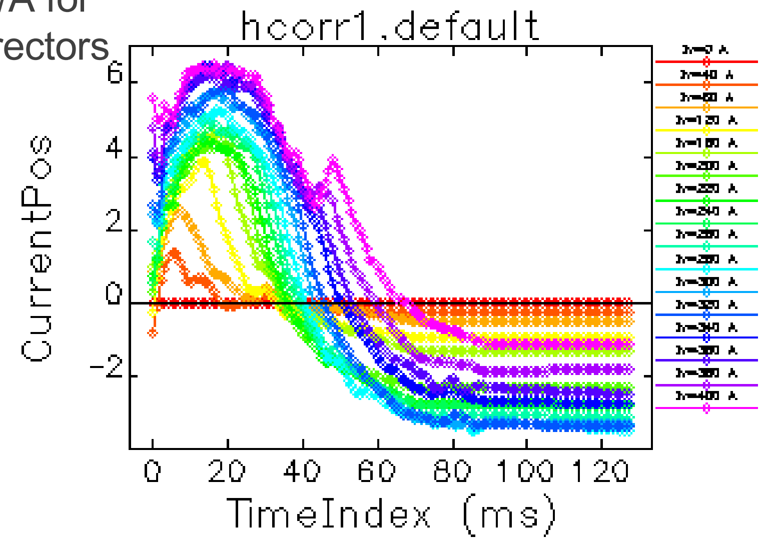
DC Mode Corrections

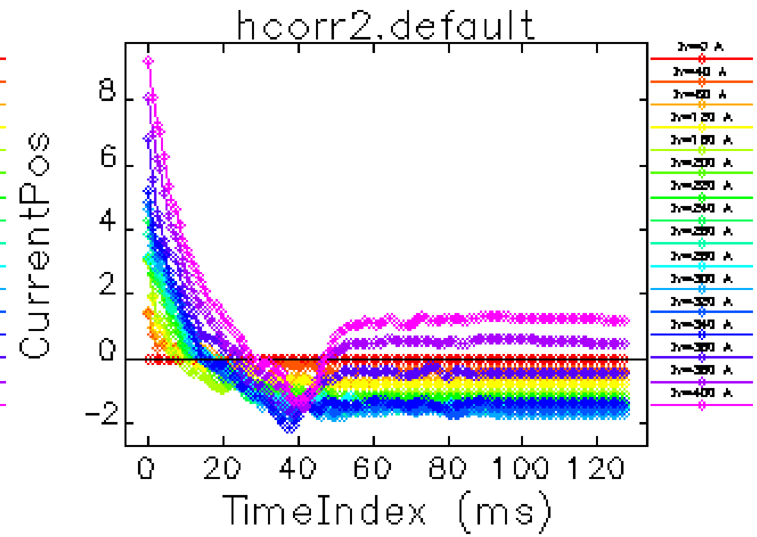
~60 microns/A for H and V correctors

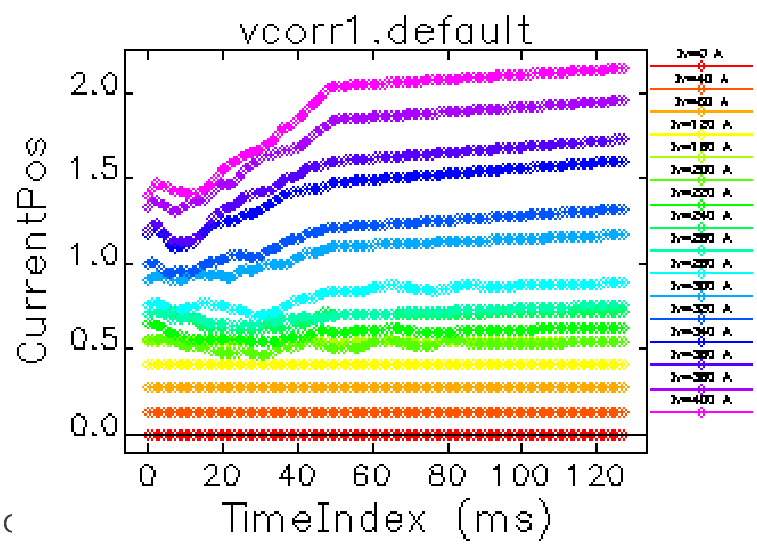


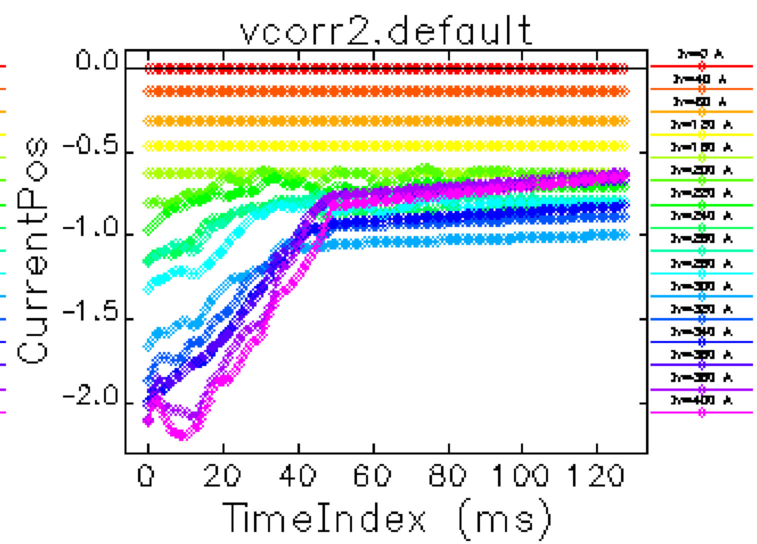
AC mode correction (four dipoles)

~60 microns/A for
H and V correctors









Hysteresis

- Electromagnet CPU has iron
- Correction depends on history of cycling; our DC corrections assume previous continuous cycling
  - Corrections fails because User always change polarization after ramping main coils to 0 A
  - Skew quadrupole perturbation different on ramp down to 0 A
  - Orbit distortion ok on ramp down because of external orbit correction
- Fast errors (near the switching transition in AC mode) are not completely corrected by local correctors → use global orbit feedback system to compensate residual errors

Using Fast Orbit Feedback Channels

- Prepare orbit response matrix from calibrated model:

$$\Delta x = M \Delta c$$

  - c is the vector of (a reduced set) of correctors, including CPU dipole correctors
- Multiply BPM error readings vector with inverse response matrix to obtain “corrector error”, corrections required for setting orbit back to zero (note negative sign)

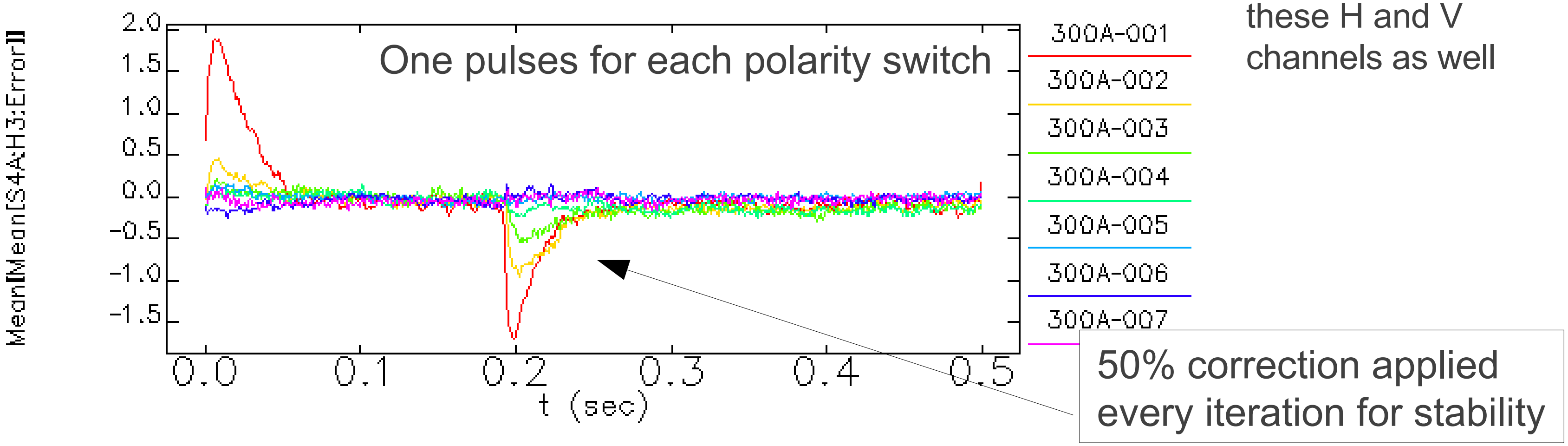
$$\Delta c_e = -M^{-1} x_e$$

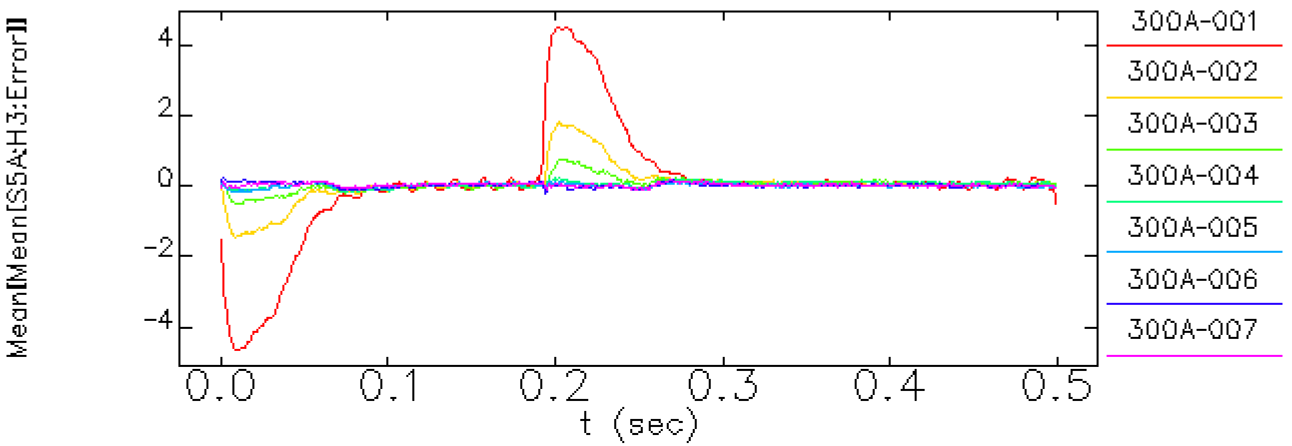
- Fast orbit feedback reads orbit error and makes a computation of Δc_e at a 1.5 kHz rate. Each element of Δc_e is called a channel.
- If CPU is the only source of orbit perturbation and the matrix is correct, then only two elements of the Δc_e is nonzero

AC Mode Perturbation of Orbit

- In practice the channels are not perfectly formed. But the main two orbit feedback channels have highest signal.

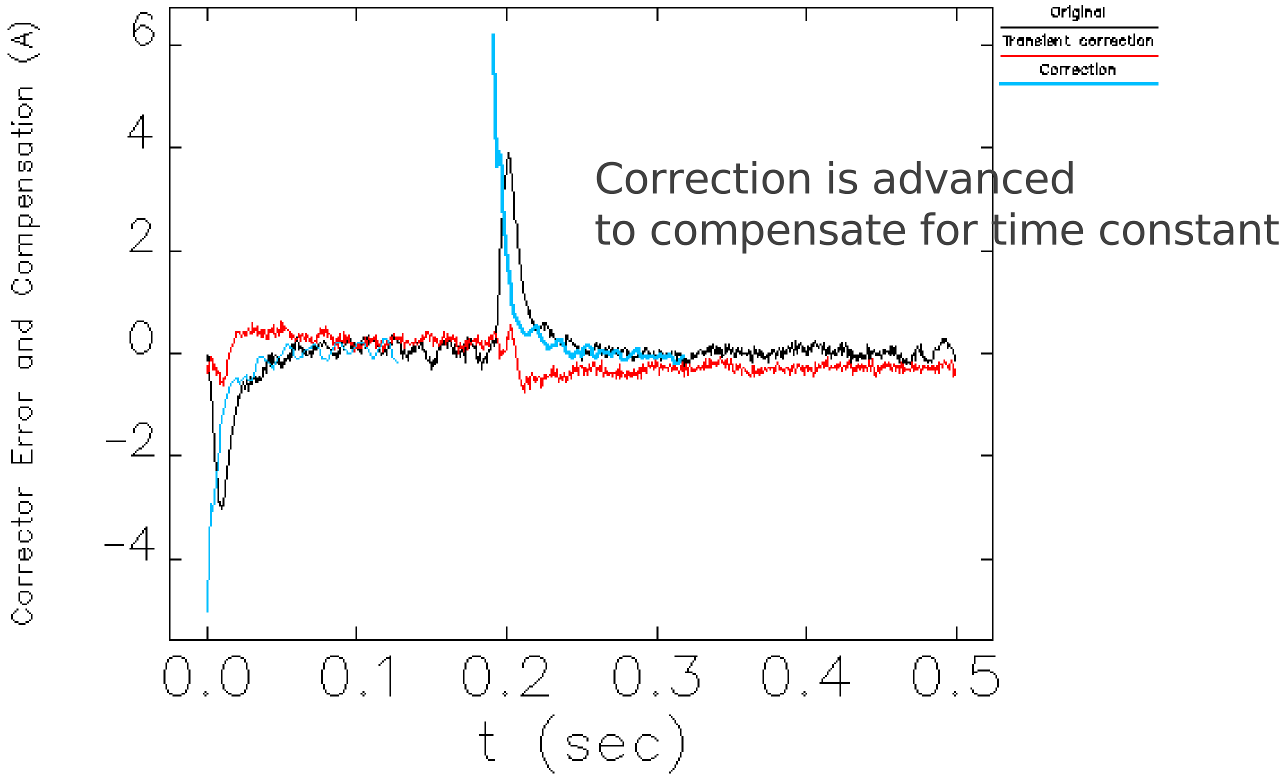
~60 microns/A for these H and V channels as well





AC Mode Correction

- Necessary processing to transform bpm signals to corrector signals:
  - Time constant (from vacuum chamber) for H-plane
  - Time delay for both part of waveform

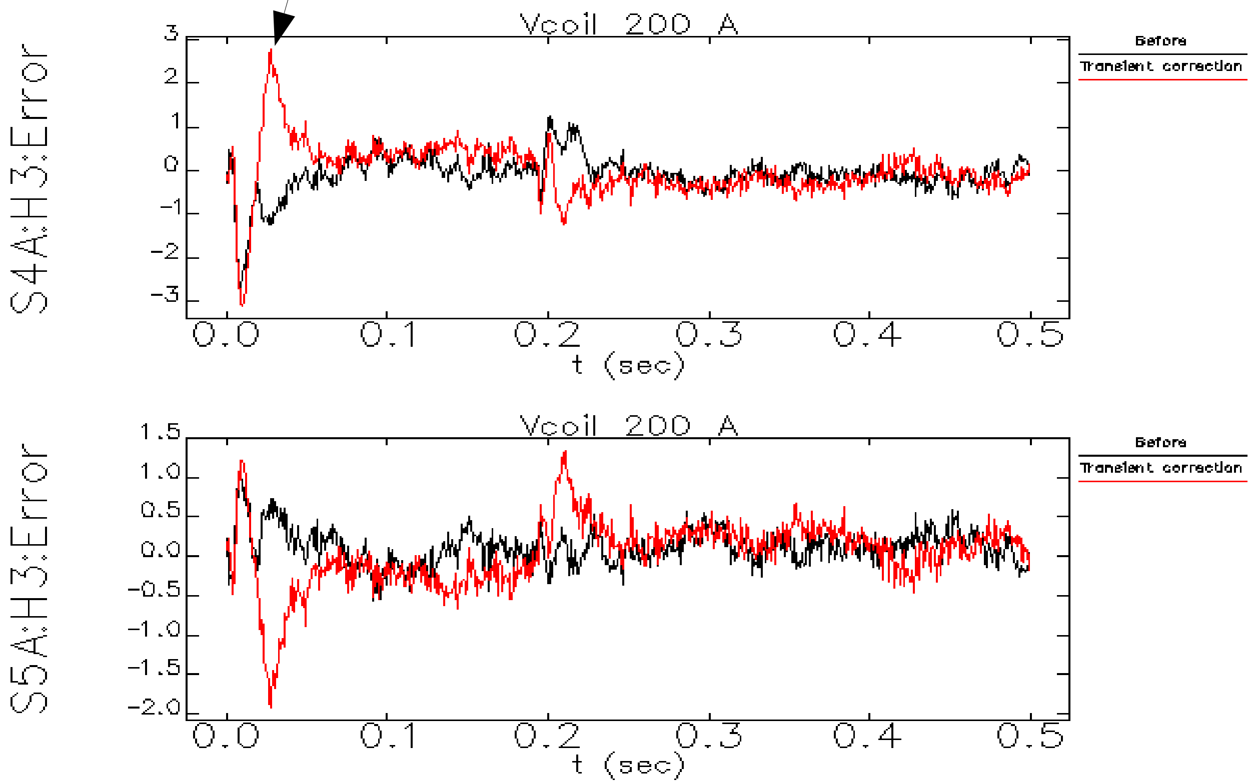


Pulsed CPU perturbation and correction

AC Mode Correction

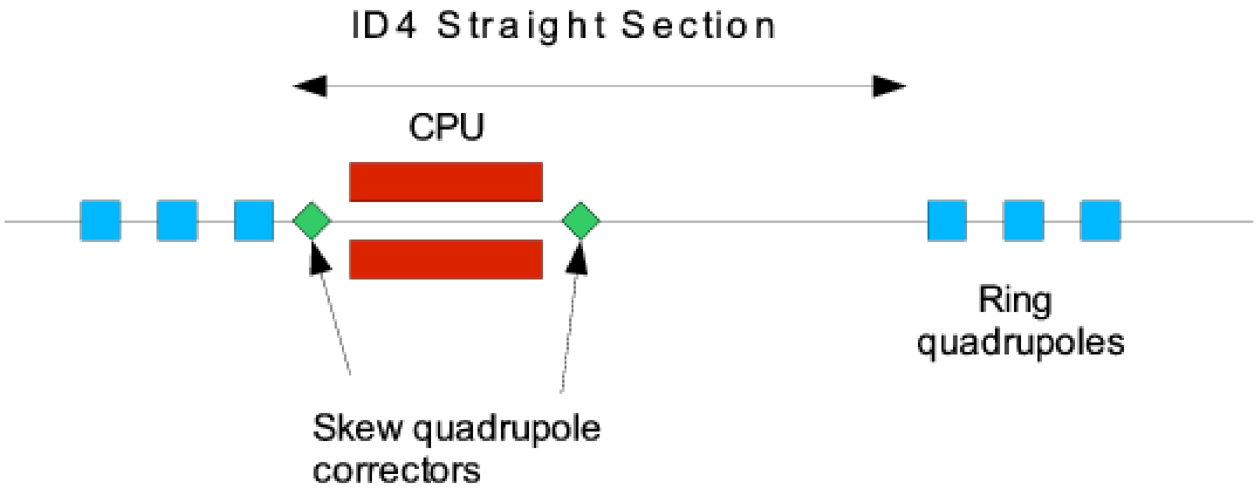
- A bad correction from slight error time delay

Correction placed at wrong time



Quadrupole Component Error

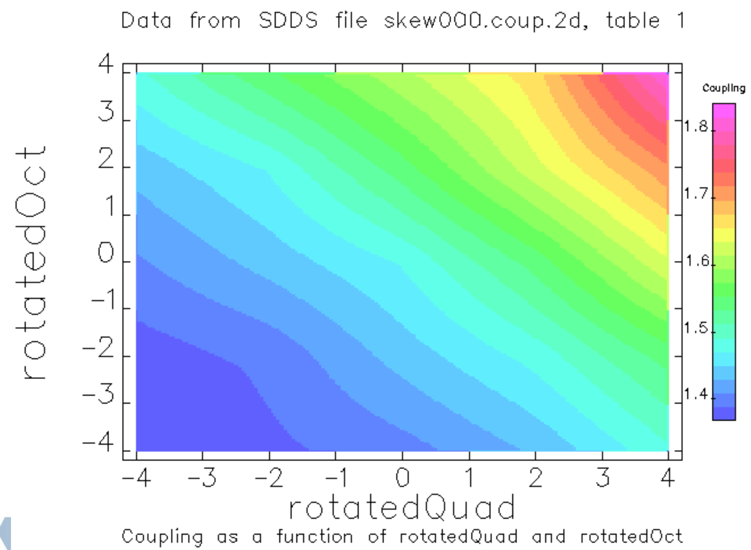
- Normal quadrupole error causes tune shift and coupling change
- Skew quadrupole error causes vertical dispersion change plus coupling change
- Perturbs vertical beam size to some extent everywhere in the ring
- Need two skew quadrupole magnets on each side to compensate skew quadrupole error symmetrically
- DC mode correction and DC level of AC mode

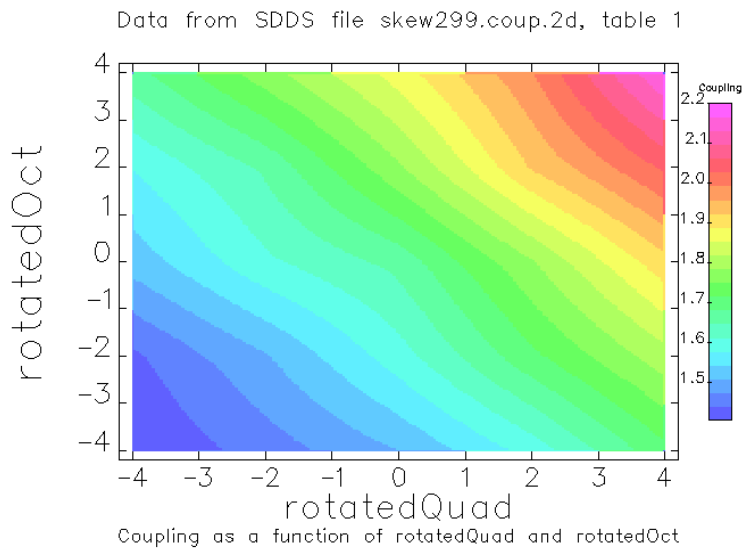


Local Quad corrections

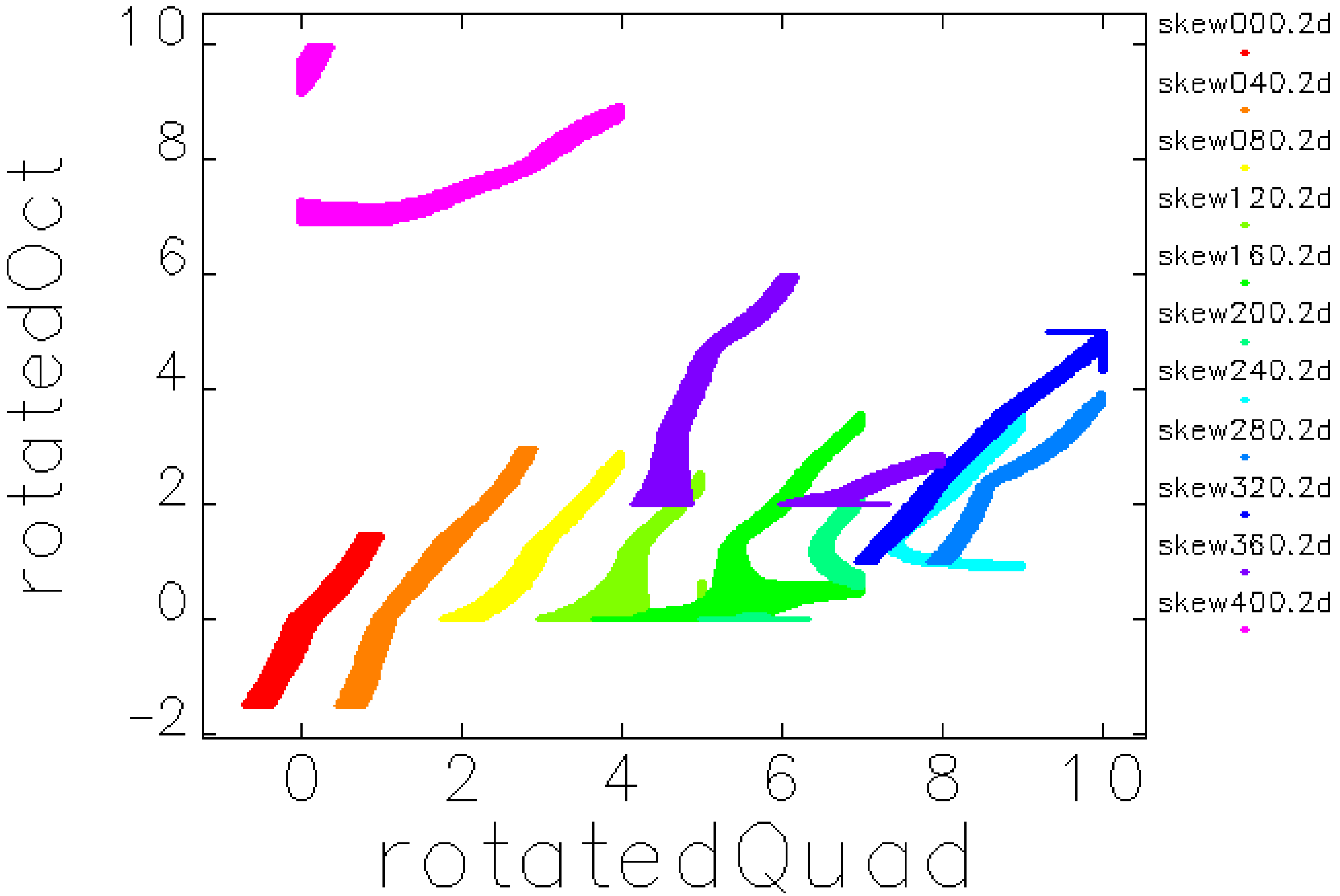
- Calibrated the quadrupole corrector for tune change
- Do tune measurements at different fixed set points (largest perturbation is 0.01 in nux)
- Apply correction. Use correction for DC level in AC mode.

- Do 2D scan of beam size with two skew quadrupoles
- Select set points which preserves the vertical beam size
  - Presently make settings of two correctors equal.





Solutions for skew quadrupoles



Applications Written for Checking Beam Stability

- Ramp CPU main currents and record
  - DC orbit for DC modes and AC mode for long periods
  - rms orbit for AC modes
  - Beam size for DC modes and AC mode for long periods
  - Takes a few hours

<table>
<tr><th rowspan="2"></th><th rowspan="2">DC mode</th><th colspan="2">AC mode</th></tr>
<tr><th>DC Level</th><th>Transient</th></tr>
<tr><td>Dipole</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Normal Quad</td><td rowspan="2">X</td><td rowspan="2">X</td><td rowspan="2">Not possible</td></tr>
<tr><td>Skew Quad</td></tr>
</table>

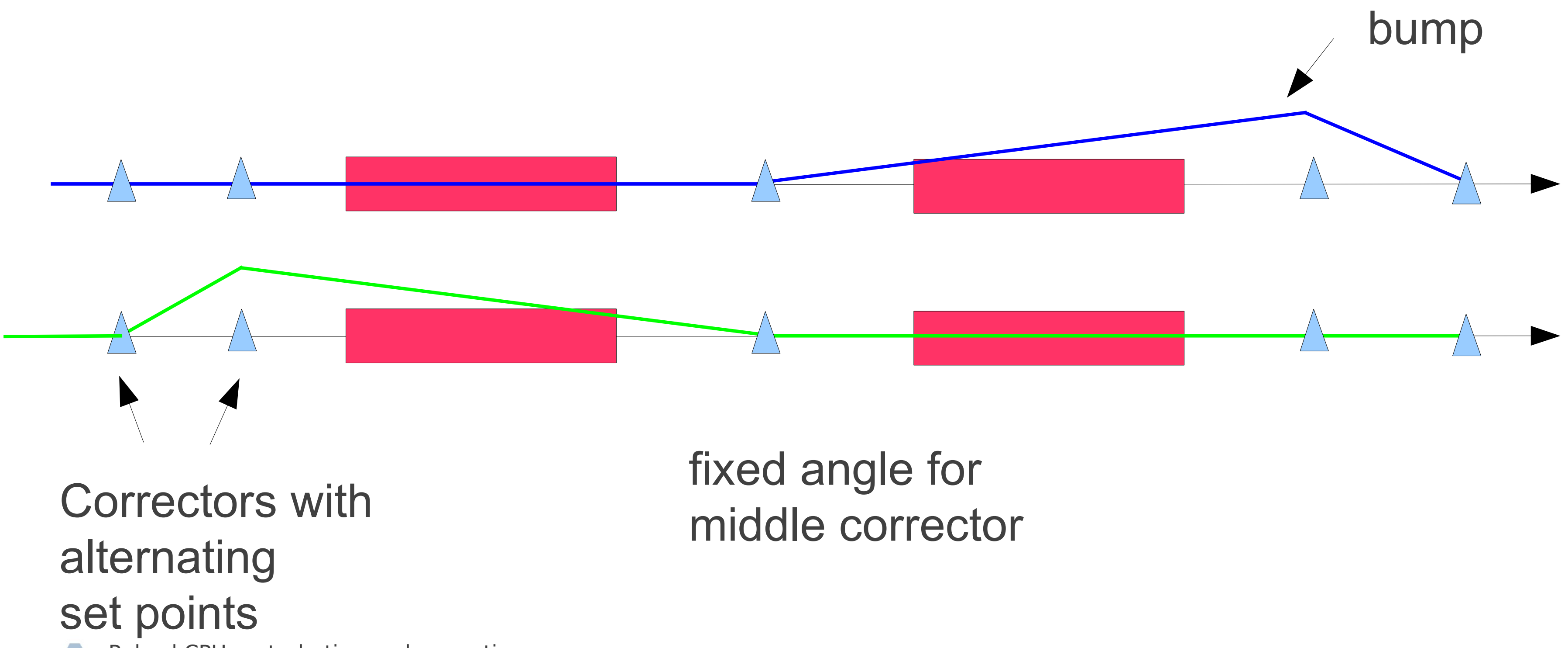
Applications Written for Correcting Beam Stability

- Ramp CPU main currents and record
  - DC orbit for DC modes and AC mode for long periods
  - rms orbit for AC modes
  - Beam size for DC modes and AC mode for long periods
  - Take several hours (8? if everything goes well)

	DC mode	AC mode	
		DC Level	Transient
Dipole	X	X	X
Normal Quad	X	X	Not possible
Skew Quad	X	X	

Double devices plus kicker bump

- Use corrector magnets to switch the beams of two undulators of fixed helicity (Spring8, T. Hara, NIM-A 2003)



Double devices plus kicker bump

- Pro: CPU no longer changing magnetic fields
- Con: Four correctors need to be synchronized and amplitude adjusted exactly
- This is easier. We already do this with orbit feedback in feed forward mode to compensate injection magnet leakage fields.
  - Limit is about 20 um peak orbit error during transition phase
  - Expect lower limit if kicker magnets are made the same and use the same timing system as orbit feedback system
- Still need “slow” DC compensation system if undulators are scanned