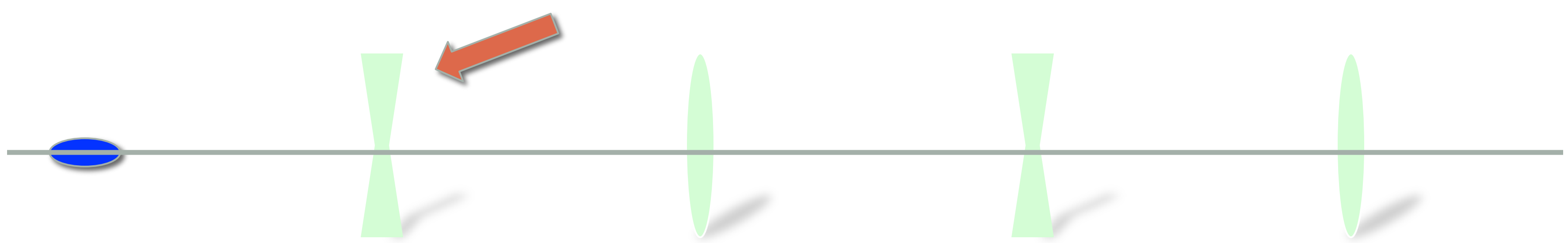
CONTROL ROOM ACCELERATOR PHYSICS

Trajectory/Orbit Correction Applications

Orbit Correction

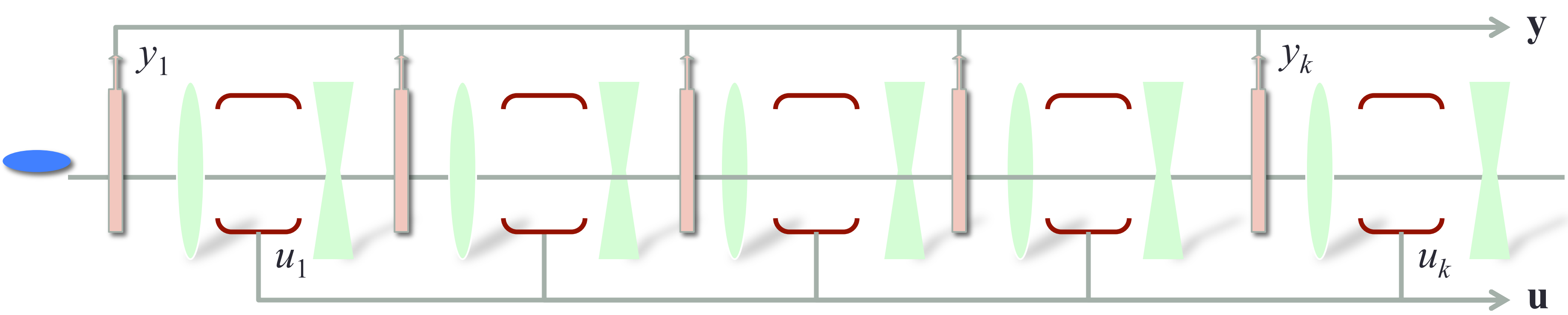
Objective

- Maintain the beam (bunch) propagation along its design trajectory
  - There are always errors from power supplies and magnetic misalignments
    - These errors cause deviations from design trajectory
  - Off-axis beam can cause a variety of issues
    - Increased beam loss
    - Decreased beam quality by sampling nonlinearities of magnets
    - Quadrupole steering



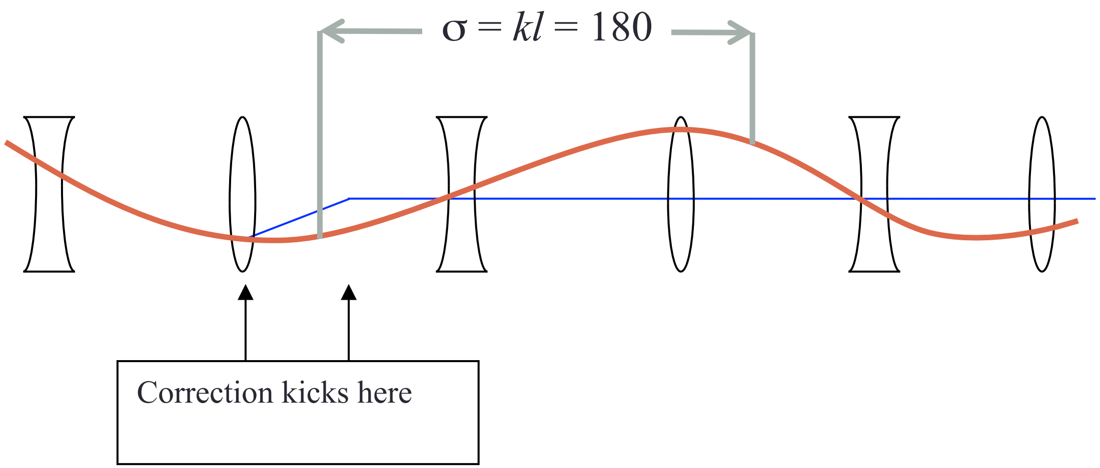
Orbit Correction
Problem Domain

- Can view this as a "dead beat" regulator problem
  - (**Dead beat control** problem consists of finding the input signal bringing the output to steady state in the smallest number of time steps.
    We can do this in one step without measurement errors, but…)
  - The beam oscillates about the design trajectory as it passes down the beamline
    - Measurement errors
    - Magnet offset errors
  - Sensors
    - Beam Position Monitors (BPMs) - Provide beam location at given beamline positions
    - No beam velocity information is available (is this an observable system?)
  - Actuators
    - Dipole corrector magnets - act like impulses or "momentum kicks"
    - Occasionally other magnets (quadrupoles)



Orbit Correction

Design of the Actuators and Sensors



- In initial state the beam is not on the design trajectory
  - Design orbit typically defined by the middle of the quadrupoles
- BPM separation depends upon betatron phase advance σ of beamline
  - Must sample more than the Nyquist rate (avoid 180 degree phase advance!)
- Ideally, 2 dipole correctors will center beam
  - Separation depends upon the dipole strength

Orbit Correction

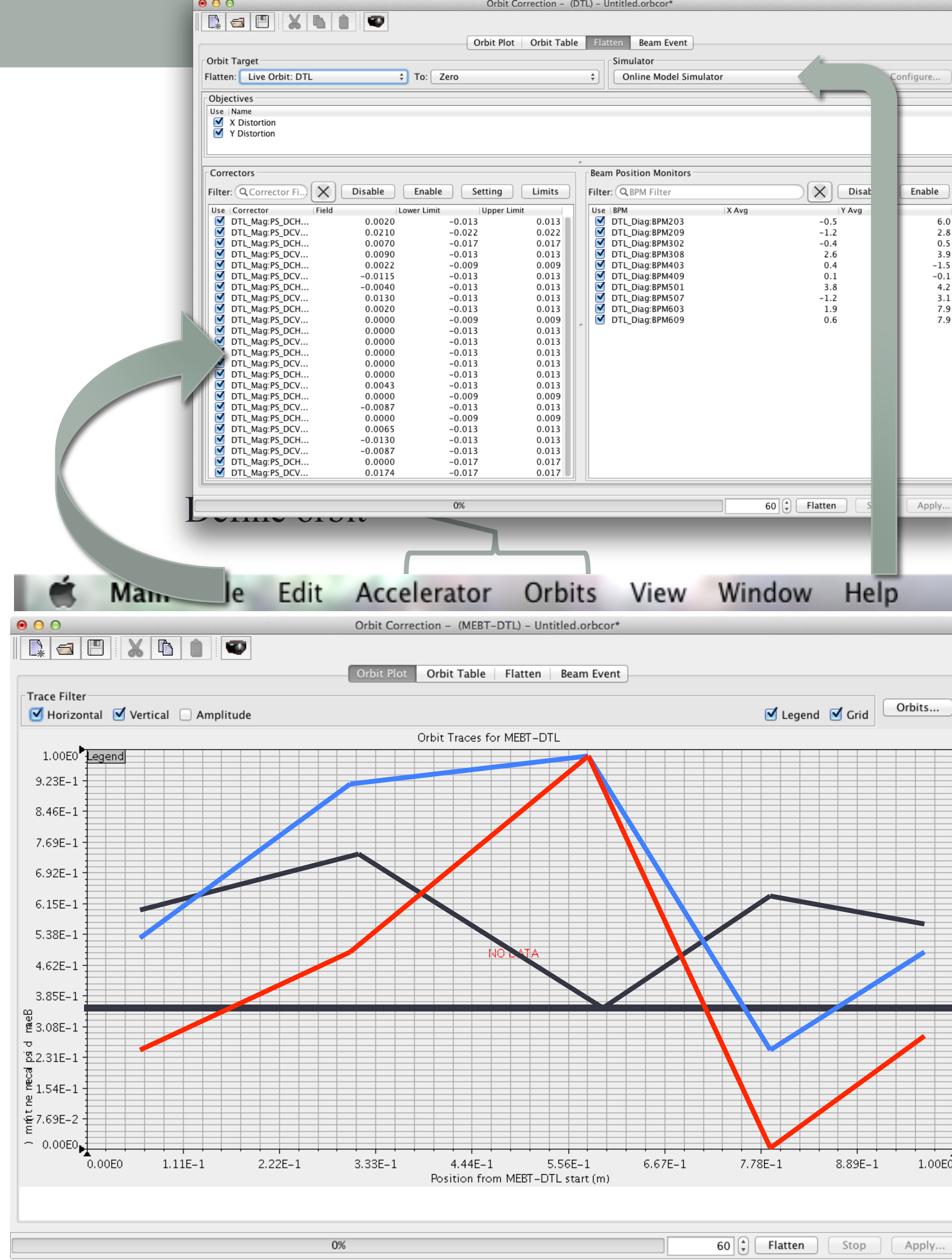
Strategies

- Model Independent Correction
  - Compute beam-based response matrix $[\partial \mathbf{y}/\partial \mathbf{u}]$
    - Provides incremental change in positions $\Delta\mathbf{y}$ given change $\Delta\mathbf{u}$ in correctors
    - $\Delta\mathbf{y} = [\partial \mathbf{y}/\partial \mathbf{u}]\ \Delta\mathbf{u}$
  - Compute a BPM response vector $\partial \mathbf{y}/\partial u_k$ for each corrector k
    - Need average over multiple samples ∂u_k to get clean responses
    - Also needs input for BPM offsets
- Model Reference Correction:
  - Use a model to predict change in beam position $\Delta\mathbf{y}$ for corrector change $\Delta\mathbf{u}$
    - Compute an approximate response matrix $[\partial \mathbf{y}/\partial \mathbf{u}]$
  - Need accurate $B(I)$ field functions for the quadrupole and correctors
  - Need good knowledge of magnet and BPM offset errors
    - beam-based techniques are required to refine these much below 1 mm
  - Fast

Orbit Correction

XAL Application

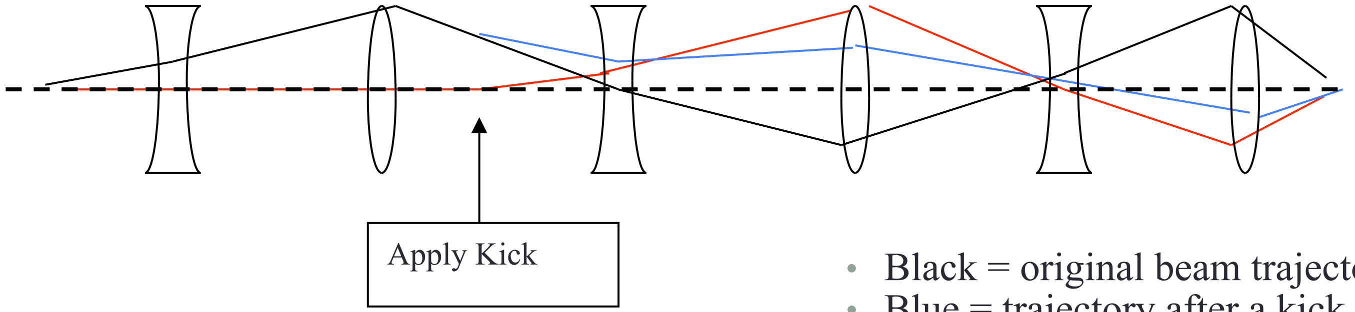
- Display orbit for an accelerator sector
  - Current, past, ideal
- Mark a reference orbit and save.
  - Restore to saved reference orbit at a later date
  - Orbit difference
- Select problem domain [phase plane(s)], BPM set, and corrector set
- Provides options for both model reference and model independent methods
  - Response matrix methods



Diagnostics

Orbit Difference: Locating Beamline Errors

- Perturb the initial trajectory of the beam at some point (i.e., change a dipole corrector)
- Subtract the initial trajectory from the perturbed trajectory
  - There should be no change in model or BPM upstream of the perturbation (independent of initial conditions)
  - Downstream of the perturbation the model and BPM changes should agree
  - When disagreement occurs the nature of differences yields clues to problem



- Black = original beam trajectory
- Blue = trajectory after a kick is applied
- Red = difference orbit (black – red)

Orbit Difference Diagnostics

Example: Beamline Hardware Polarity Confirmation

- Start with initial orbit – perhaps it will not flatten
- Do orbit perturbation and observer downstream **difference** between measured trajectory and model trajectory
  - If **one** BPM response has a sign error, then it is likely the BPM polarity is reversed.
  - If **all** observed BPM responses are off by -1, the dipole corrector likely has a polarity problem
  - When more complex behavior is observed there is possibility that a combination of BPMs and correctors have polarity issues.
    - Do perturbation farther downstream until one of the above conditions is seen
    - Obtain additional measurements from complimentary diagnostic devices, such as a wire scanner (provides position information).

Summary
Orbit Correction

- Orbit difference analysis is a standard technique
  - Commissioning new beamlines - One of the first tasks once beam is well transmitted
  - Diagnosing BPM and corrector errors

- There are robust methods for orbit correction
  - Highly automated
  - Both Model Reference Correction (MRC) and Model Independent Correction (MIC)
  - Need good agreement between the beam model and observation (in orbit-difference), otherwise MRC will not work