Accelerator Modeling

David Sagan
Cornell University

Cornell's CESR Storage Ring

- E+ / E- Collider. In operation since 1979.
- Used for both HEP and as an X-ray source.
- Beam energy:1.8 GeV - 5.5 GeV.
- 768 m circumference.
- ~100 BPM's.
- ~100 independently powered quadrupoles.
- ~50 horizontal correctors.
- ~50 vertical correctors.
- 3.51 meter interaction region solenoid running at 1.0 - 1.5 T.
- 22 skew quadrupoles for coupling compensation.
- 12 SC wigglers 1.6 m long, 2.1 T peak field.
- 82 sextupoles.
- 8 skew sextupoles.

Simulation Toolkit: Bmad

- Subroutine library for simulating relativistic charged particles.
- Written in Fortran90 in an object oriented fashion.
- C/C++ interface provides flexibility.
- MAD-like lattice file input format.
- A Plethora of element types:

  Quadrupole, Sextupole, LCavity, ElSeparator, Sol_Quad,
  Wiggler, BeamBeam, Patch, Taylor, Custom, etc…

- Various tracking routines:

  particles and macroparticles (full 6x6 σ matrices),
  Runge-Kutta integration, radiation damping and excitation,
  Lie algebraic symplectic integration, etc.

- Routines for:

  transfer matrices, Twiss parameters, Taylor map algebra,
  radiation integrals, long-range and short-range wakefields, etc…

- Easy simulation of "Control Room knobs".
- Superposition of elements on top of other elements.
- Documentation available.

CESR Simulation Program: CESRV

CESRV is a general purpose simulation tool which uses Bmad as the simulation engine:

- Calculates:
    - Orbits
    - Beta functions
    - Coupling
    - Dispersion
    - Emittances
    - etc.
- Simulates:
    - Magnet misalignments.
    - Magnet strength changes.
    - Multipole errors.
    - etc.

- Takes data:
    - Orbits
    - Betatron phase
    - Coupling
    - Dispersion
- Analysis:
    - Fitting of the lattice model to data.
      [Can handle multiple data sets.]
    - Correction of magnet errors.
    - Locating magnet errors.
    - Calibration of magnets.
    - "Knob" correction.
      [EG: Closing bump knobs.]

Twiss/Coupling Correction

1) Start with a design lattice:

Betatron phase:

Cbar12:

Cbar12 is a measure of the coupling.
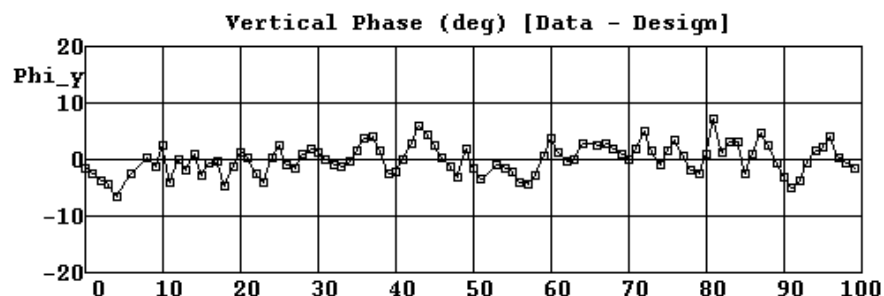Cbar12 = 0 -> No coupling.
Cbar12 ~ 1 -> Fully coupled.

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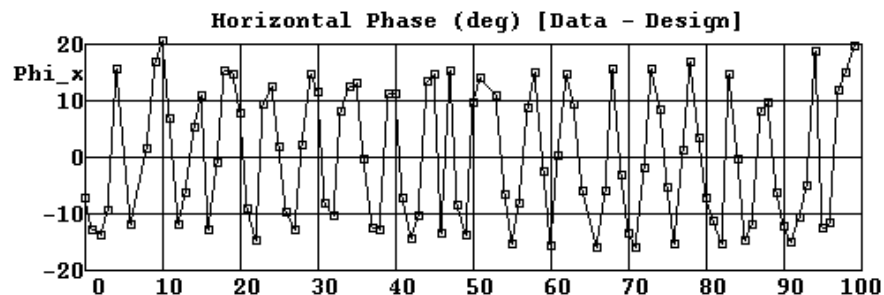LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS
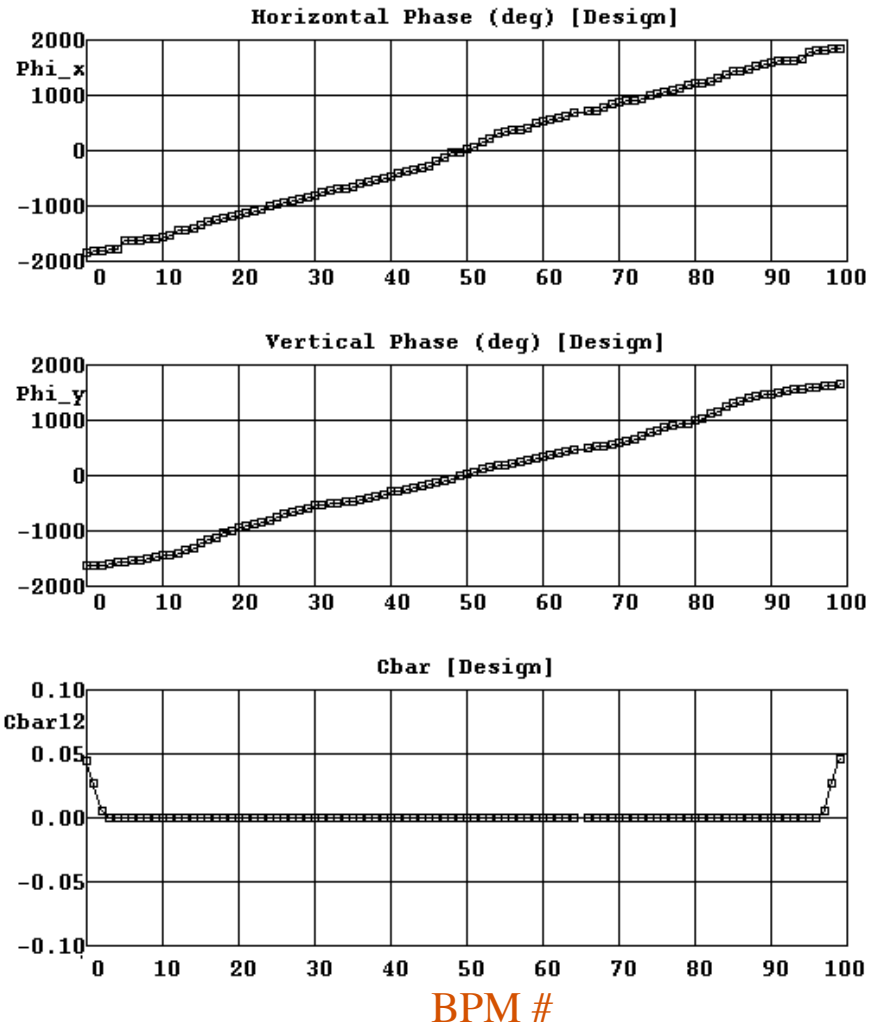
Twiss/Coupling Correction

2) Measure the betatron phase and coupling:

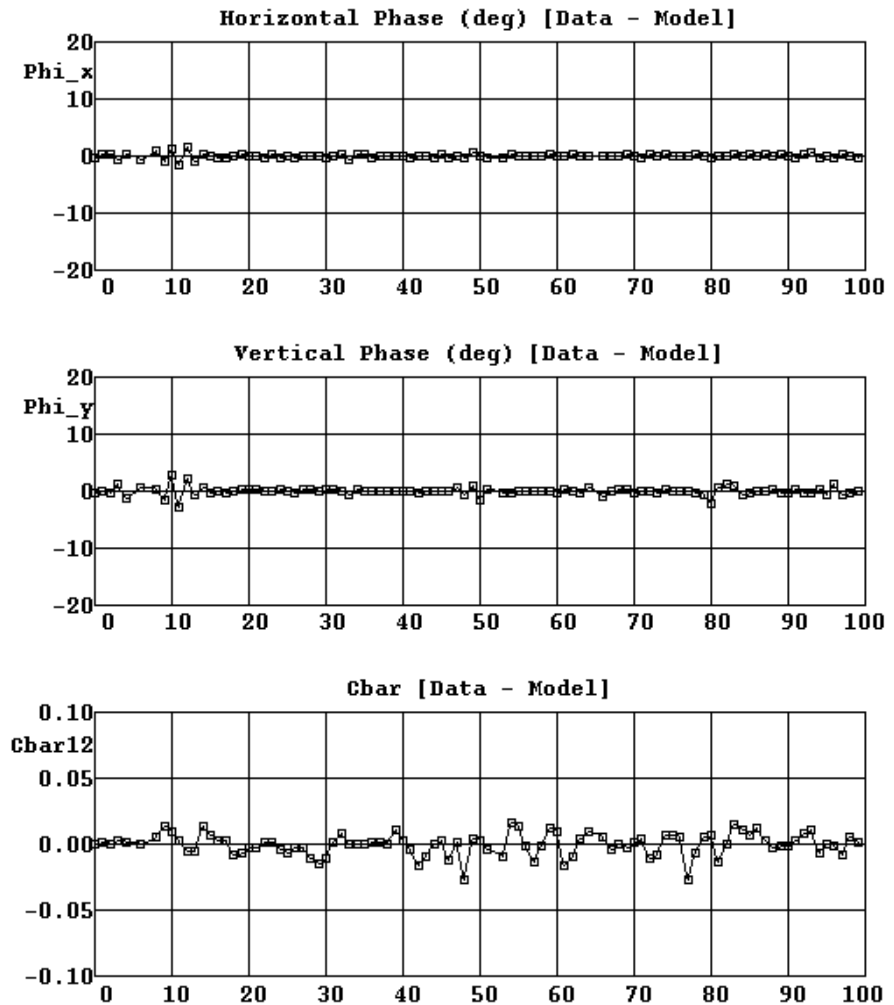Phase and coupling are measured by shaking the beam at "horizontal" and "vertical" betatron resonances and measuring the response at the BPM's.

Measurement time: ~20 sec.
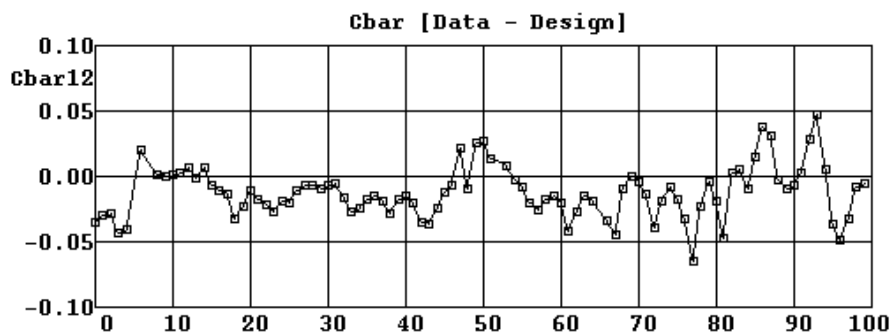
Twiss/Coupling Correction

3) Vary the quadrupole & skew quadrupole strengths in the model lattice until the phase and coupling as calculated from the model match the data.

Horizontal Phase (deg) [Data – Model]

Vertical Phase (deg) [Data – Model]

Cbar [Data – Model]

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Twiss/Coupling Correction

4) Make a correction:

After fitting the model to the data:

k_1 (model) <=> Present machine state

k_1 (design) <=> Desired machine state

Therefore:

dk_1 (correction) = k_1(design) - k_1(model)

First measurement: 11:33 am

Number of Corrections: 2

Final measurement: 11:51 am

Horizontal Phase (deg) [Data − Design]

Vertical Phase (deg) [Data − Design]

Cbar [Data − Design]
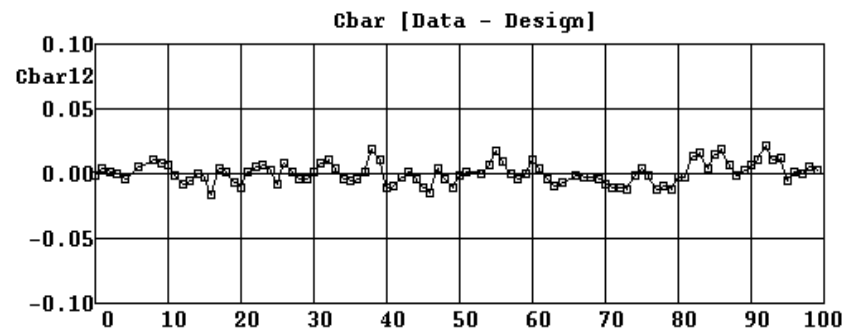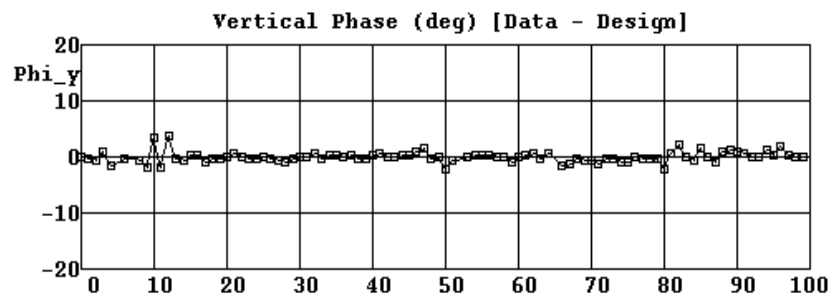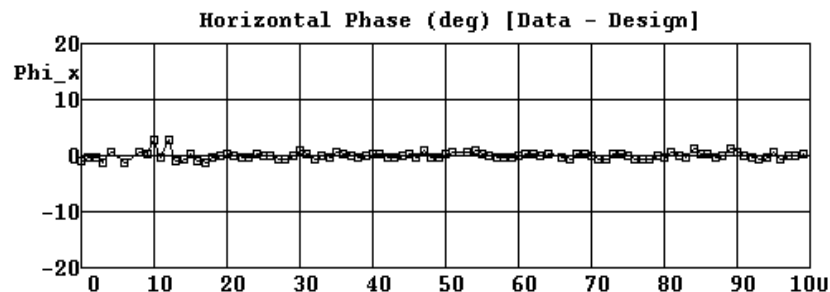
Calibration

Cbar12 difference due to change in
a skew quadrupole.

Steerings, quadrupoles, skew
quadrupoles, sextupoles, anad
skew sextupoles can all be
calibrated by varying magnet
strengths, taking orbit, phase
or coupling differences, and
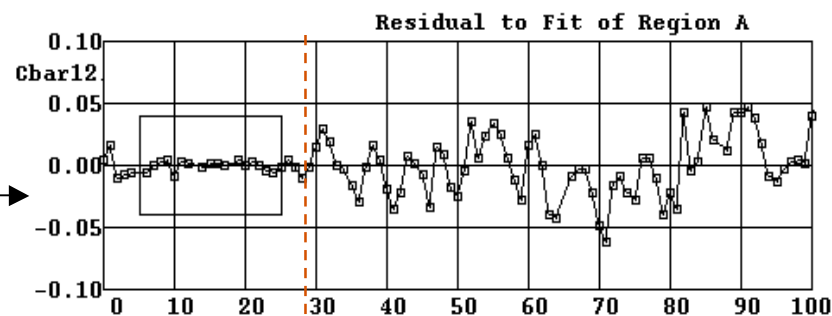fitting the results.

The Cbar12 difference - the model fit

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Locating Errors
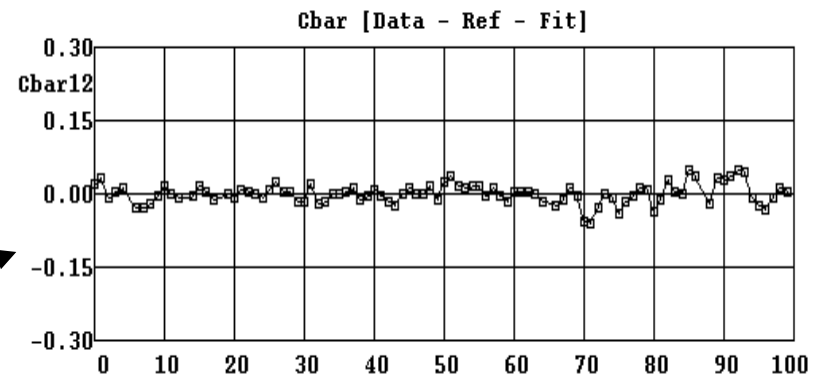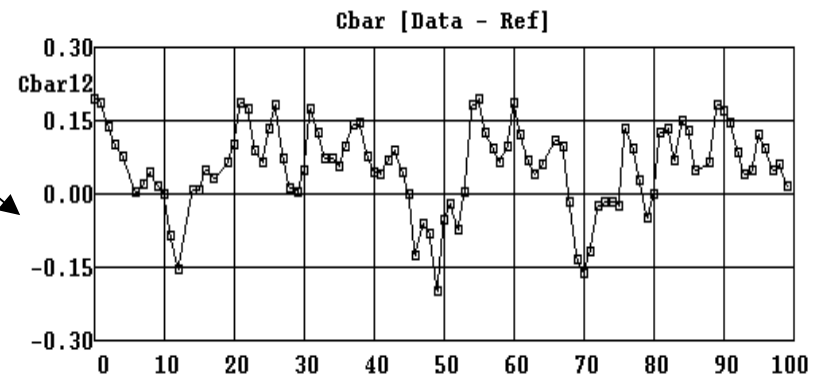
Original Cbar12 data:

Steering, quadrupole, and skew quadrupole errors can be located.
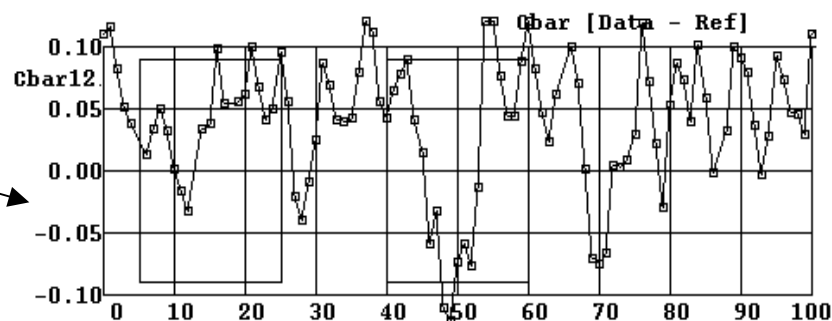
Fit to a region to the left of the error:

Fit to a region to the right of the error:
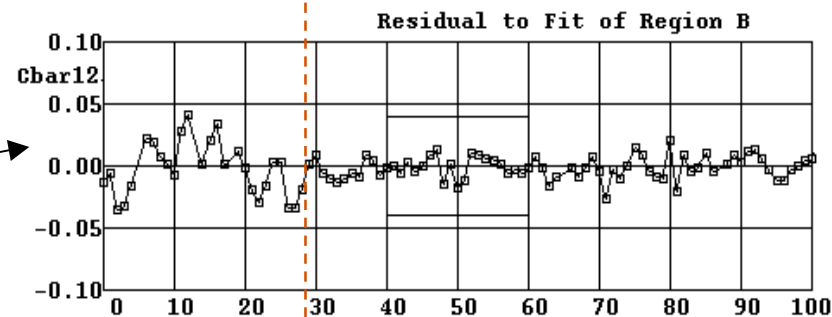
Simulation Tool: Tao

CESRV is specifically geared for the CESR storage ring.

For simulation of other machines a new program has been developed.

- Tao (Tool for Accelerator Optics): A generalized CESRV.

- Tao has been designed to be modular and easily customizable.

- Tao has been applied to:
    * ERL design & simulation
    * International Linear Collider design & simulation
        Storage ring
        Main LINAC
        Bunch compressor
    * JLab FEL

JLab FEL Simulator: FELV

$$\text{FELV} = \begin{bmatrix} \text{Tao} \\ + \text{Routines for reading in FEL data files} \\ + \text{Routines for BBU calculations} \end{bmatrix}$$

Purpose: To simulate the BBU instability so as to guide data taking
during BBU machine studies.

Procedure:
1. Take orbits for various steering settings.
2. Simultaneously fit the data sets to get the actual quadrupole strengths.
3. Calculate the transfer matrices between cavities.
4. Use the transfer matrices in the BBU routines to make predictions.

FELV Data

1) Take orbits for various steering settings:

Data:

10 horizontal corrector orbits.
10 vertical corrector orbits.

Initial Model:

Data - Model:

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FELV Fit

2) Simultaneously fit the data sets to get the actual quadrupole strengths.
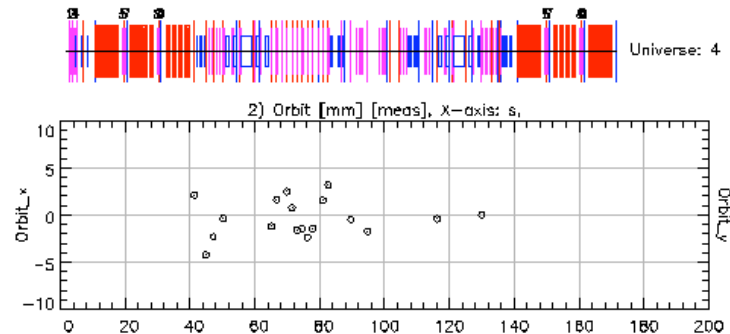
Common variables:
  • 54 Quadrupoles
Individual variables:
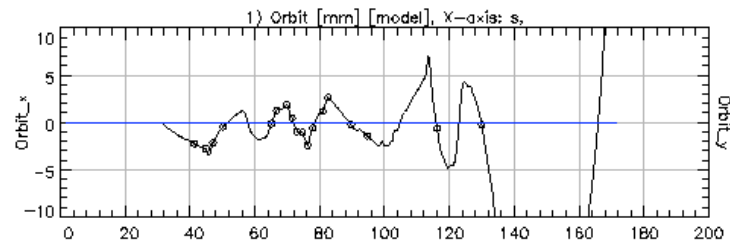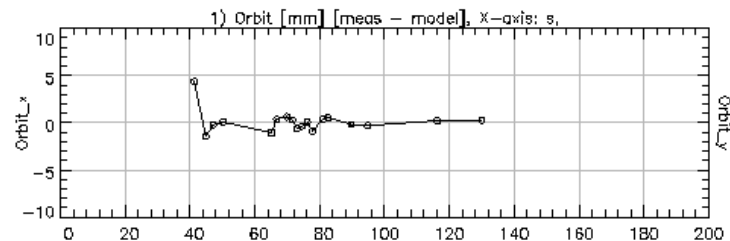 • 20 Steerings

Data:

Final Model:

Data - Model:

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FELV in General

FELV inherits from Tao the full capability of modeling the FEL including simulating magnet strength errors and misalignments, etc.
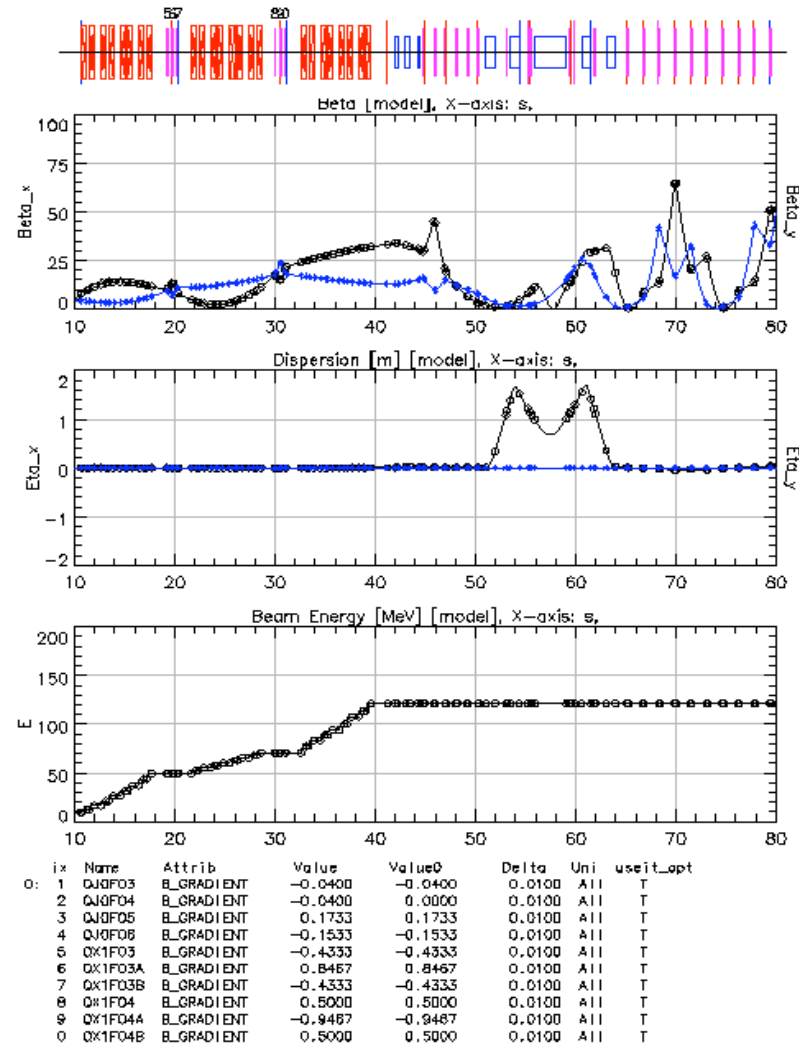
Bmad Plans

Near Future:

- Benchmarking the tracking of particles with energies below 5 Mev.
- Space charge module development (ImpactT).

Far Future:

- CSR module
- Spin tracking module
- …

Conclusion

- Fast, accurate, online modeling & correction substantially increases productivity.

- The importance of modular, extensible, modeling software cannot be over emphasized.