

MI/RR Space Charge Simulations with Synergia

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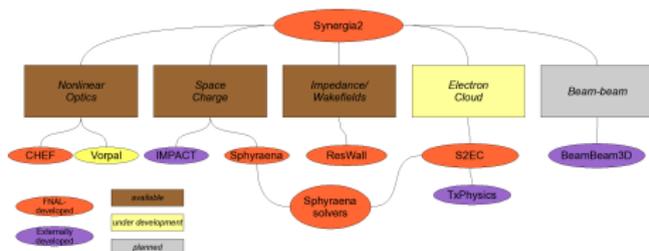
Project X Collaboration Meeting



- 1 Synergia
- 2 Single-particle Optics (CHEF)
- 3 Multiparticle/Collective Effects
 - Space Charge
 - Resistive Wall
 - Multibunch
 - Additions for Project X
- 4 Synergia Application examples
 - Booster
 - Mu2e
- 5 MI Simulation plans



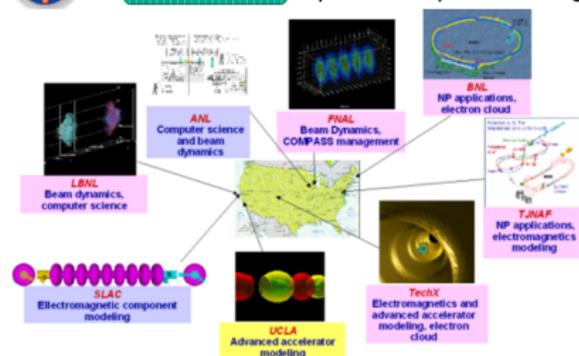
Overview



- Fully 3D PIC code
- Space charge included via split-operator technique
- Single-particle physics from CHEF
- Runs on desktops, clusters and supercomputers
- Fully dynamic simulations including ramping, feedback, etc.



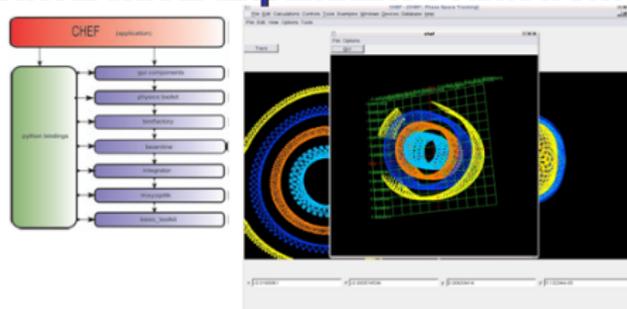
<https://compass.fnal.gov/>



- ComPASS collaboration includes most major accelerator simulation packages in the U.S., including all national labs
- Emphasis is on massively parallel computing



Collaborative Hierarchical Expandable Framework



- CHEF originally developed at Fermilab by Leo Michelotti starting in the early 90's
- Single-particle optics with full dynamics
 - Can be reduced to arbitrary-order maps
 - We have done demonstration calculations in Synergia to 15th order
- Customizable propagators
- MAD input
 - Internal representation not limited by MAD parameters



Space Charge and Resistive Wall Impedance

Space Charge

- Fully 3D space charge
 - Various boundary conditions: open, longitudinally periodic, conducting pipes
 - Utilizes (requires) large parallel computing resources
 - Extensively benchmarked against other codes
- 2D space charge
 - Useful in some limits, very fast

Resistive Wall Impedance

- Both intra-bunch and inter-bunch effects available
- Dipole and quadrupole effects implemented
- Benchmarked against theoretical values in various limits



Multibunch Physics

- Synergia can model multiple interacting bunches
- Strongly-coupled bunches
 - Space charge calculations include all bunches on a single grid
 - Scales to a few bunches
 - Example: 400 MHz bunch merging in the Fermilab Booster
- Weakly-coupled bunches
 - Bunches only communicate through resistive wall effects
 - Scales to many bunches



Additions for Project X

Complex apertures

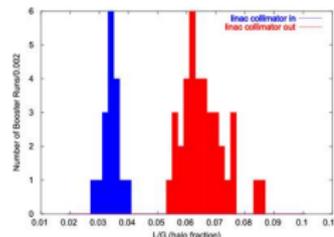
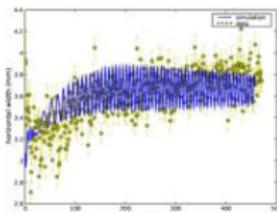
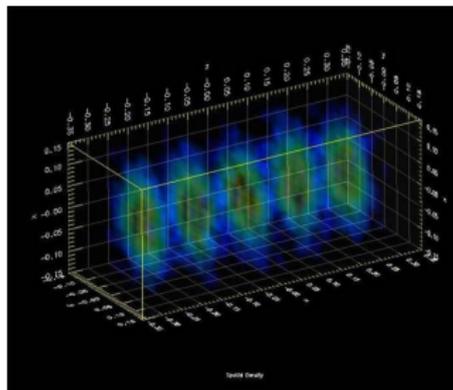
- Currently a single aperture is defined for the entire machine
 - We will add the ability to specify apertures on an element-by-element basis
- Only circular apertures are currently implemented
 - We will add other shapes as necessary



Booster Applications

We have done extensive modeling of the Booster with Synergia

- 400 MHz structure debunching
- 37.7 MHz capture
 - Including RF phase ramping
- Emittance growth
 - Including comparison with experiment
- Halo formation
 - Including comparison with experiment



We are currently working on space charge simulations of the Fermilab Debuncher for the proposed Mu2e experiment

- Beam to be extracted from Debuncher using resonant extraction
- Accumulator/Debuncher required to handle 10^5 times more particles than current operating conditions

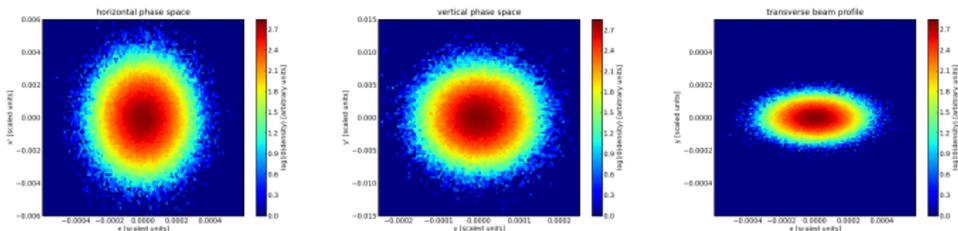
Beam parameters from proposal

- 8 GeV
- 1.2×10^{13} protons/bunch
 - lower intensity bunches under consideration
- 20π emittance
- 40 nsec longitudinal RMS
- (Laslett) space charge tune shift is ~ 0.08

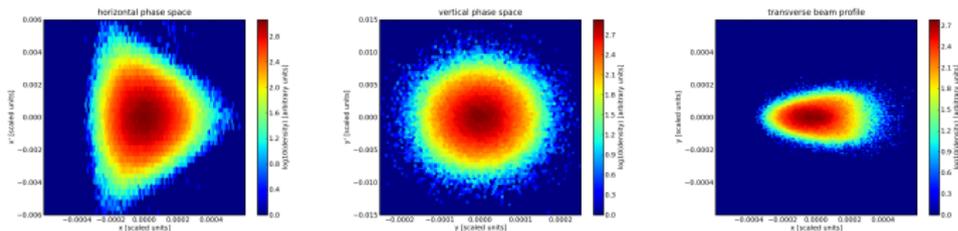


Mu2e Sextupole Ramping without Space Charge

Initial beam



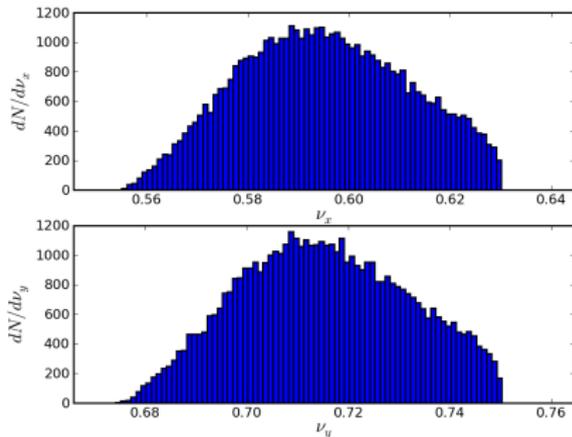
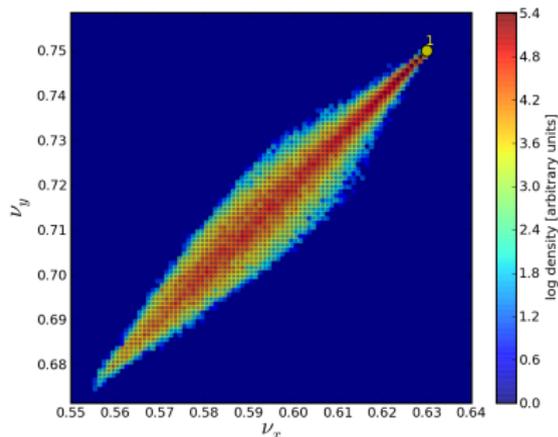
Final beam



Mu2e Space Charge without Sextupole Ramping

Bare tune: 0.63 horizontal, 0.75 vertical (Point 1)

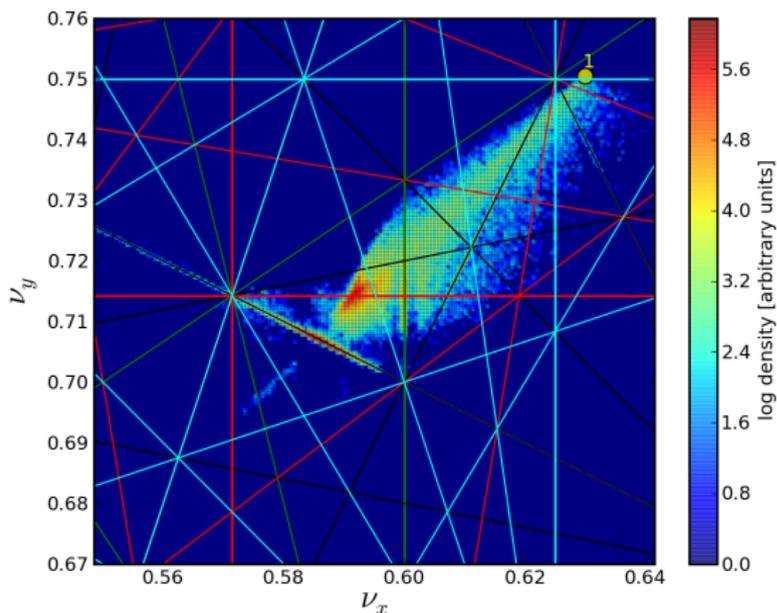
Tune footprint:



- Two-dimensional densities (colors) are plotted on a logarithmic scale
- One-dimensional densities are plotted on a linear scale
- Bin sizes are one unit of tune resolution



Mu2e Sextupoles and Space Charge Combined



white 3rd-order

orange 4th-order

green 5th-order

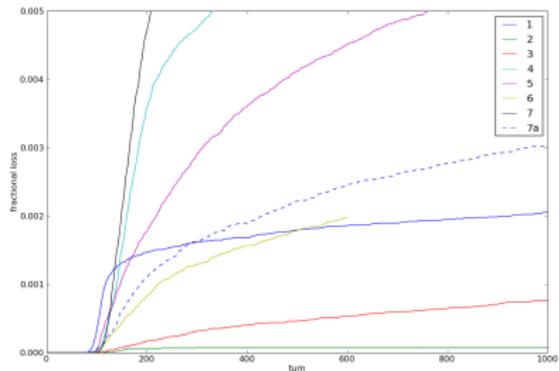
black 6th-order

red 7th-order

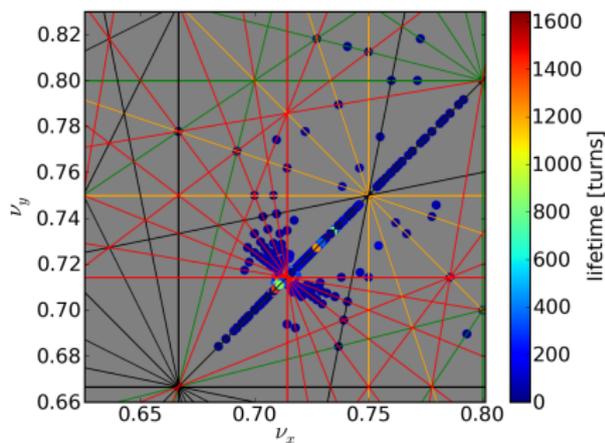
cyan 8th-order



We have studies aggregate losses in tune scans

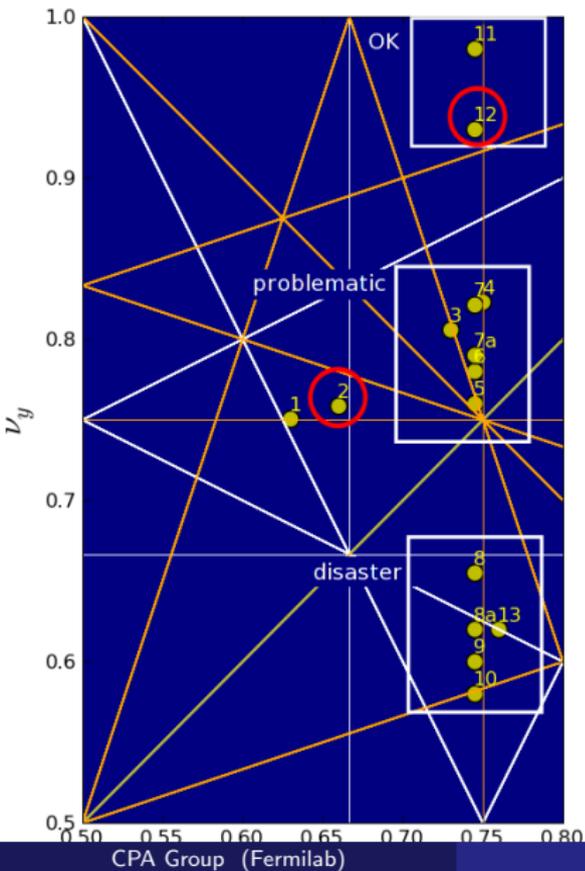


We can also perform detailed studies of individual losses

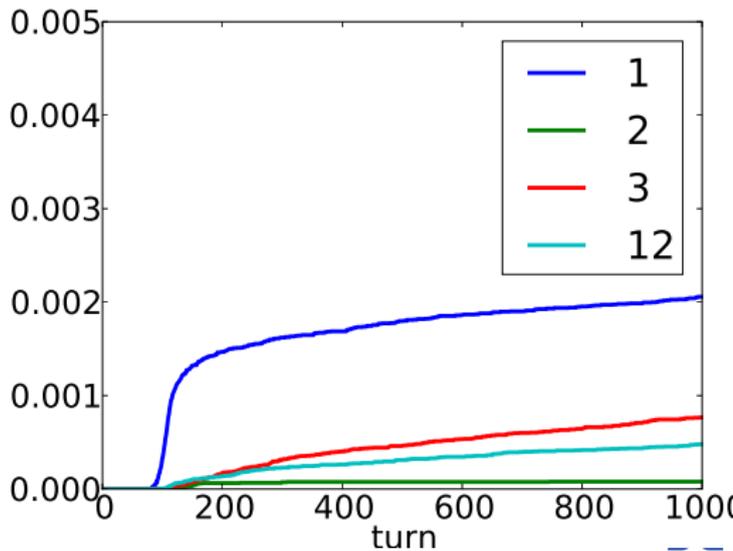


Mu2e Parameter Scan Summary

Tune Scan

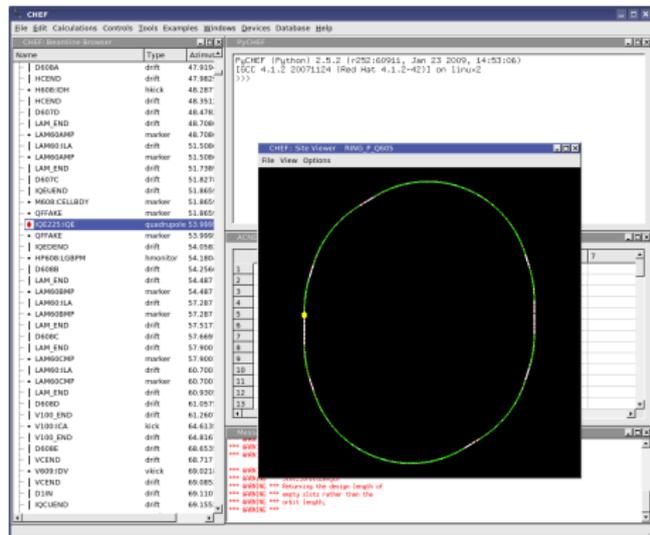


Losses for best points



MI Simulation plans. Available information:

- MI MAD lattice which we can process with CHEF and Synergia
- MI loss simulation using STRUCT from A. Drozhdin
 - Converter program to import MAD8 format lattice and add apertures for individual elements and beampipes
 - Fortran code implementing apertures
 - Code that implements particle transport through magnets including hardcoded multipole elements with errors
- Access to aperture, alignment, and field measurement data



Plan for Synergia MI simulations

- Synergia and CHEF use MAD8 input for the lattice description
- High order multipoles and errors for the magnets will be modeled by adding appropriate multipoles to base values.
 - Discuss with B. Brown and A. Drozhdin on using more accurate description of individual magnets.
- Individual apertures for different elements will need to be added to Synergia. This is straightforward (but tedious!).
- Model validation: perform comparisons with STRUCT (apertures) and IMPACT (space-charge). Compare with measurements for current operational parameters.
- Model space-charge effects for a single bunch at injection for Project-X parameters.
 - Study emittance dilution and losses.
- If desirable, extend simulations to include multi-bunch effects