Synergia: A Modern Tool for Accelerator Physics Simulation

Συνεργεια

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Fermilab

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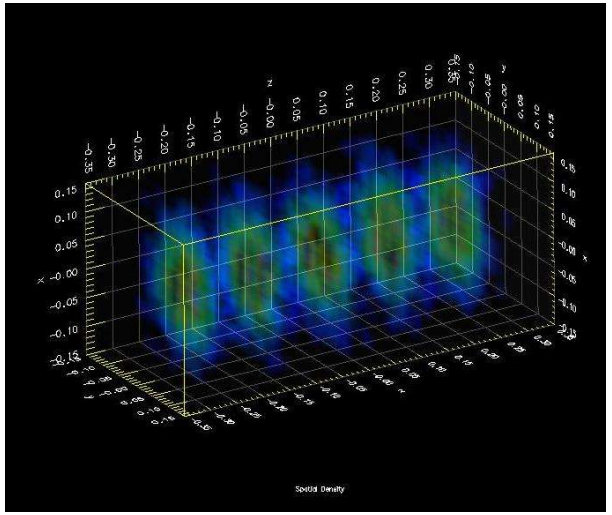

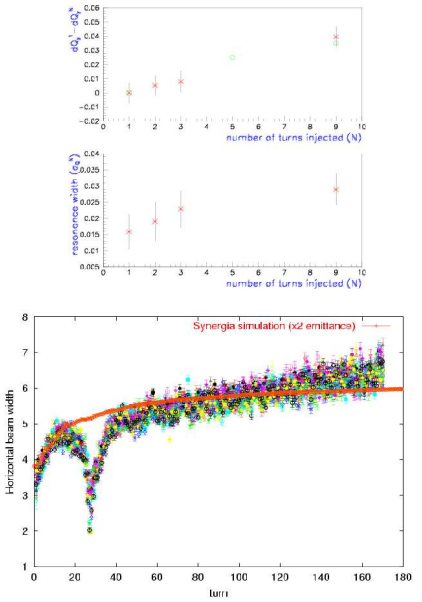

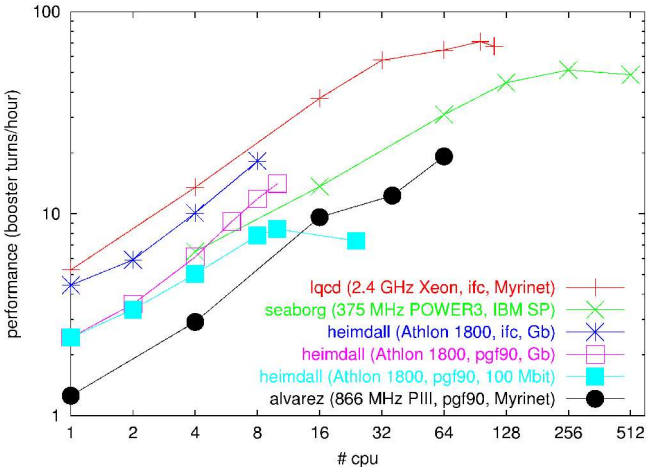

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Outline

- Accelerator modeling
  - the need for high-performance computing
- The Synergia framework
  - interfacing, extending, & encapsulating components
  - job management

http://cepa.fnal.gov/psm/aas/Advanced_Accelerator_Simulation.html

- Synergia applications
  - analysis tools & analysis

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Accelerator Modeling

- Beam line elements capture, contain & guide the beam
  - external forces; single particle optics
- Forces generated by the beam
  - collective beam effects; depend dynamically on the beam distribution

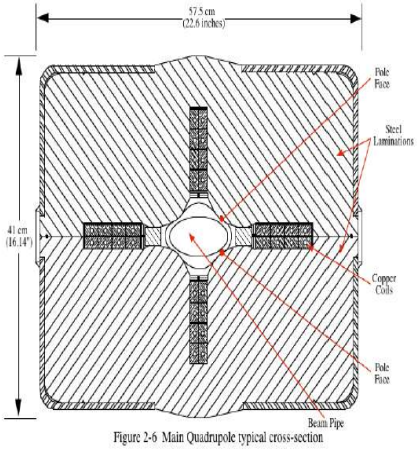
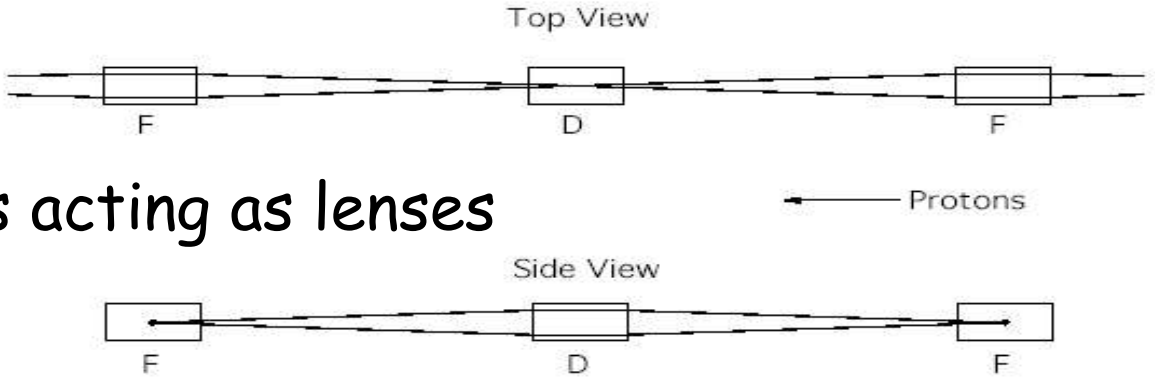


Figure 2-6 Main Quadrupole typical cross-section

magnets acting as lenses



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Problem Overview

- Model behavior of
  - ~10^{12} particles
  - through 100's of beam-line elements
  - 100's-1000's times
  - 6 degrees of freedom/particle (3D in configuration space)
- Collective effects depend on beam distribution
- Beam distribution affected by
  - external forces
  - collective effects

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Multi-particle dynamics

- Self consistent solution requires 3D modeling
- Use particle-in-cell (PIC) techniques
  - solve continuous equations on discrete grid
- Typical grid size: 65 x 65 x 65
- Large number of macroparticles (1-10M) required
- Parallel computers are necessary

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Additional issues

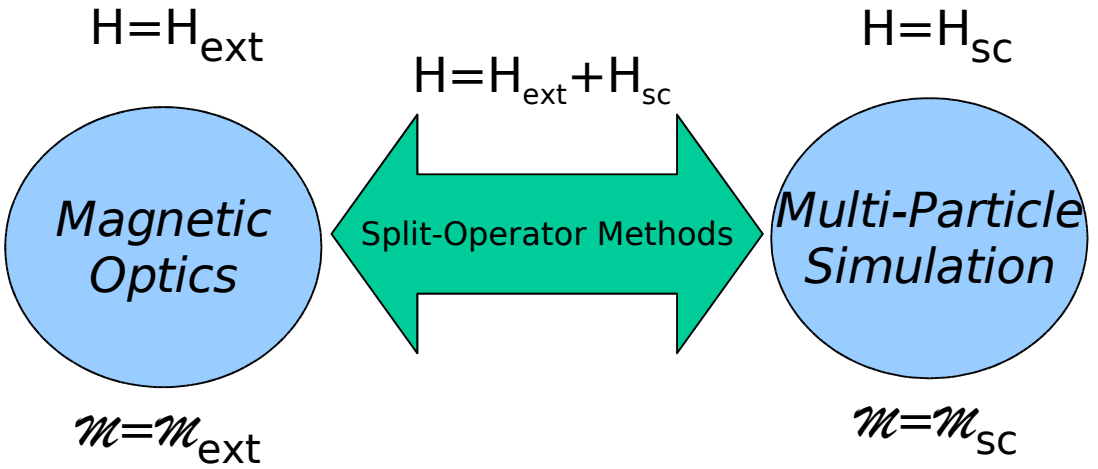
- Accelerators are complicated devices
- Simulations have complicated inputs and complicated running conditions
- Analysis of simulations come in many forms

Problem is more than just numerical!

Multi-particle dynamics modeling

- Split Operator Method
  - Magnetic optics: efficient particle transport, rapidly varying forces
  - Multi-particle: computationally expensive, slowly varying forces

minimize number of "expensive" steps



$$\mathcal{M}(t) = \mathcal{M}_{ext}(t/2)\,\mathcal{M}_{sc}(t)\,\mathcal{M}_{ext}(t/2) + O(t^3)$$

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Synergia Project

Developed as part of US DOE SciDAC program, with objectives:

- To create beam dynamics framework to model 3-D collective beam effects
  - The code should
    - Integrate/utilize existing packages
    - Be easily distributable & portable
- To model future and operating accelerators
  - benchmark code & help optimize machine performance

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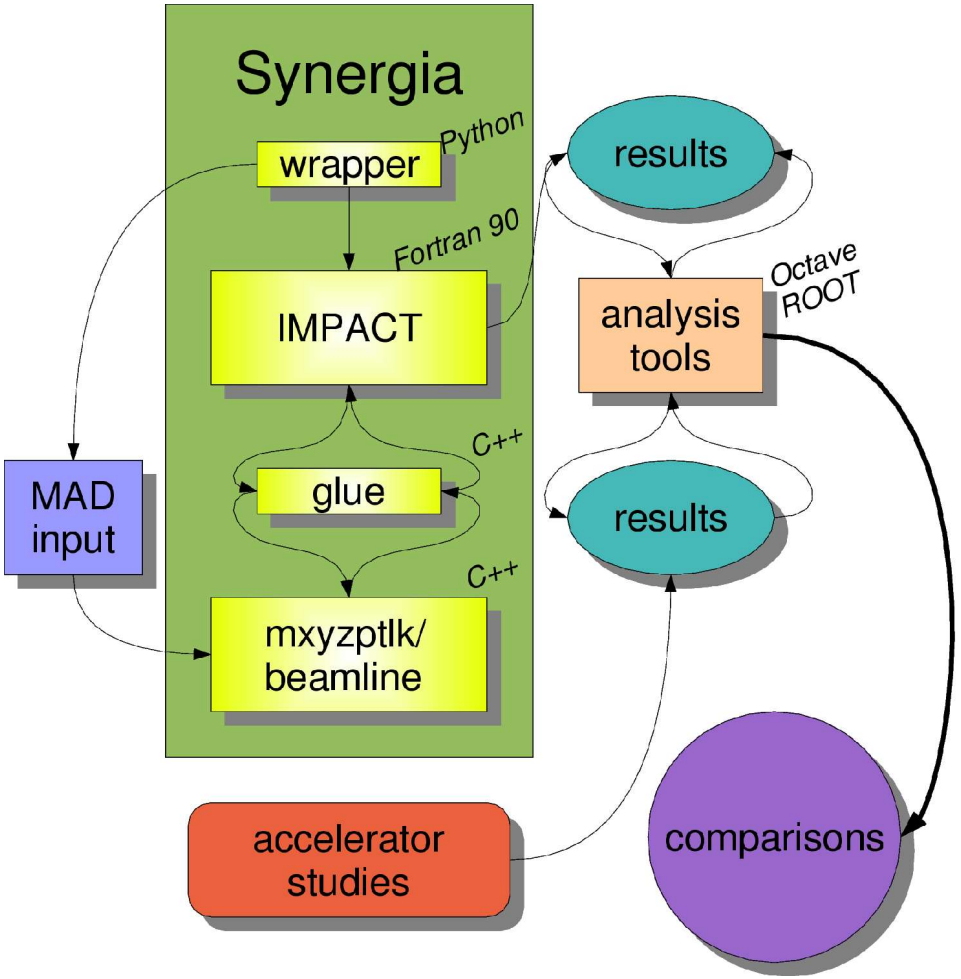
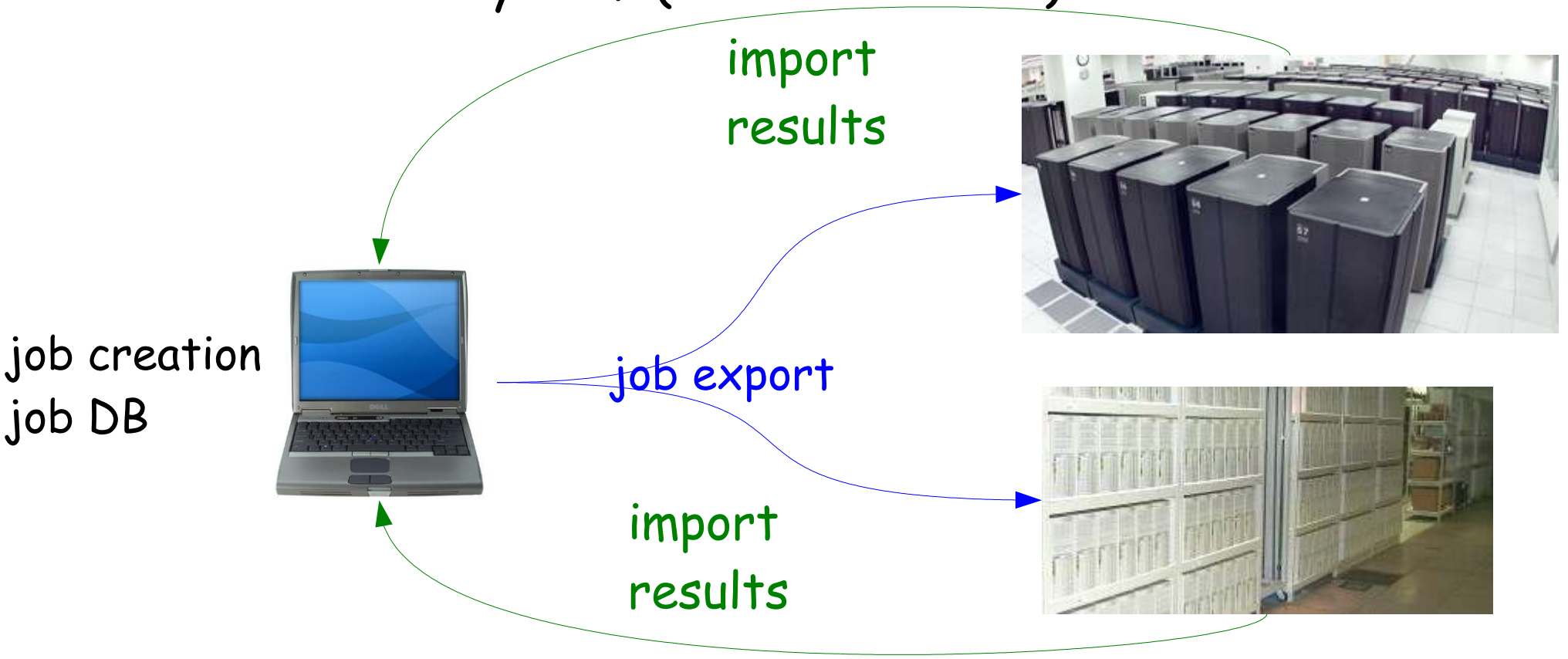
The Synergia Framework

- Modularize, encapsulate & extend existing packages
  - mxyzptlk/beamline libraries
    - arbitrary order single particle optics (C++)
  - Impact space-charge
    - Poisson solver; 3D parallel FFT using MPI (F90)
- Job management and physics utilities (Python, C++, Octave)



Synergia framework

- Fully functional job management system (Python)
- Portable build system (GNU Autotools)



Synergia framework

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```
mad_file = myopts.get_value("Mfile")
(D_x, D_y) = madcalc.dispersion_initial(mad_file,"bcelinj",
                                        myopts.get_value("energy"))
if myopts.get_value("matchcurrent") != None:
    match_current = myopts.get_value("matchcurrent")
else:
    match_current = ip.current()
[sigma_x,sigma_xprime,r_x,sigma_y,sigma_yprime,r_y] = envelope_match(
    myopts.get_value("emit"), match_current,mad_file)

mismatchx = myopts.get_value("mismatchx")
mismatchy = myopts.get_value("mismatchy")
ip.x_params(sigma = sigma_x * mismatchx, lam = sigma_xprime * pz / mismatchx)
ip.y_params(sigma = sigma_y * mismatchy, lam = sigma_yprime * pz / mismatchy)
```

job creation script

geometry discription in standard (MAD) language

beam generation "matching module"

key.csv - OpenOffice.org 1.1.1

File Edit View Insert Format Tools Data Window Help

	E	F	G	H	I	J	K	L	M
1	dist	dpop	scmatch	matchcurrent	madfile	mismatchx	mismatchy	maporder	injection turns
2	Input distribution is KV trans uniform long	3.00E-024	default	0	booster_skew2.mad	1	1	2	0
3	Input distribution is KV trans uniform long	3.00E-024	default	0	booster_skew3.mad	1	1	2	0
4	Input distribution is gaussian covariance	0	default	0	default	2	1	2	0
5	Input distribution is gaussian covariance	0	default	0	default	2	1	1	0
6	Input distribution is gaussian covariance	0	default	4.20E-011	booster_res-45.mad	1	1	2	0
7	Input distribution is gaussian covariance	0	default	4.20E-011	booster_res-45.mad	1.2	1.2	2	0
8									
9									
10	Input distribution is gaussian covariance	0	default	4.20E-011	default	1.2	1.2	2	0
11	Input distribution is gaussian covariance	0	default	4.20E-011	default	1.2	1.2	1	0
12	Input distribution is gaussian covariance	0	default	0.42	default	1.2	1.2	1	0
13	Input distribution is gaussian covariance	0	default	0.22	default	1.2	1.2	1	0
14	Input distribution is gaussian covariance	1.00E-024	default	4.20E-011	default	1.2	1.2	2	0
15									
16									
17	Input distribution is KV trans uniform long	3.00E-024	default	0	booster_skew.mad	1	1	2	0
18	Input distribution is KV trans uniform long	3.00E-024	default	0.42	booster_skew3.mad	1	1	2	0
19									
20	Input distribution is KV trans uniform long	3.00E-024	default	0	booster_skew5.mad	1	1	2	0
21									

Sheet1

Sheet 1 / 1 Default 100% STD Sum=0

automatic job DB

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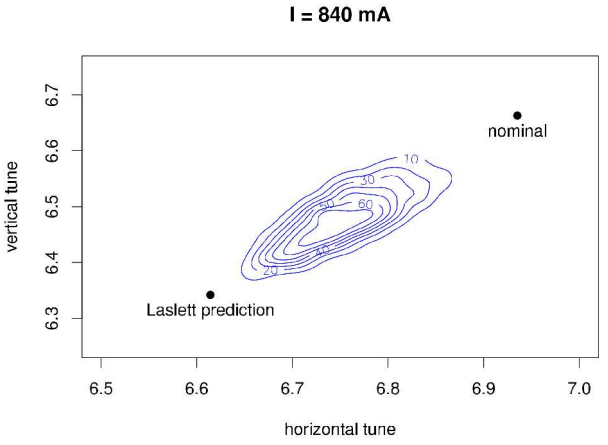
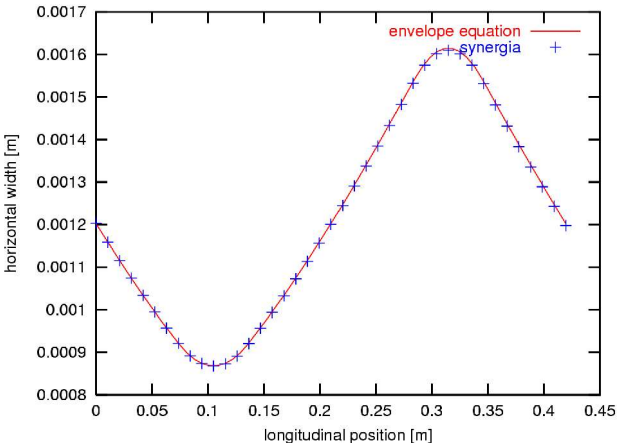
Synergia framework

- Test suite & documentation system
- Python utilities:
  - envelope equation solver (properly matched input beam)
  - Octapy: python to octave bindings
- Data persistency
  - utilizes HDF5





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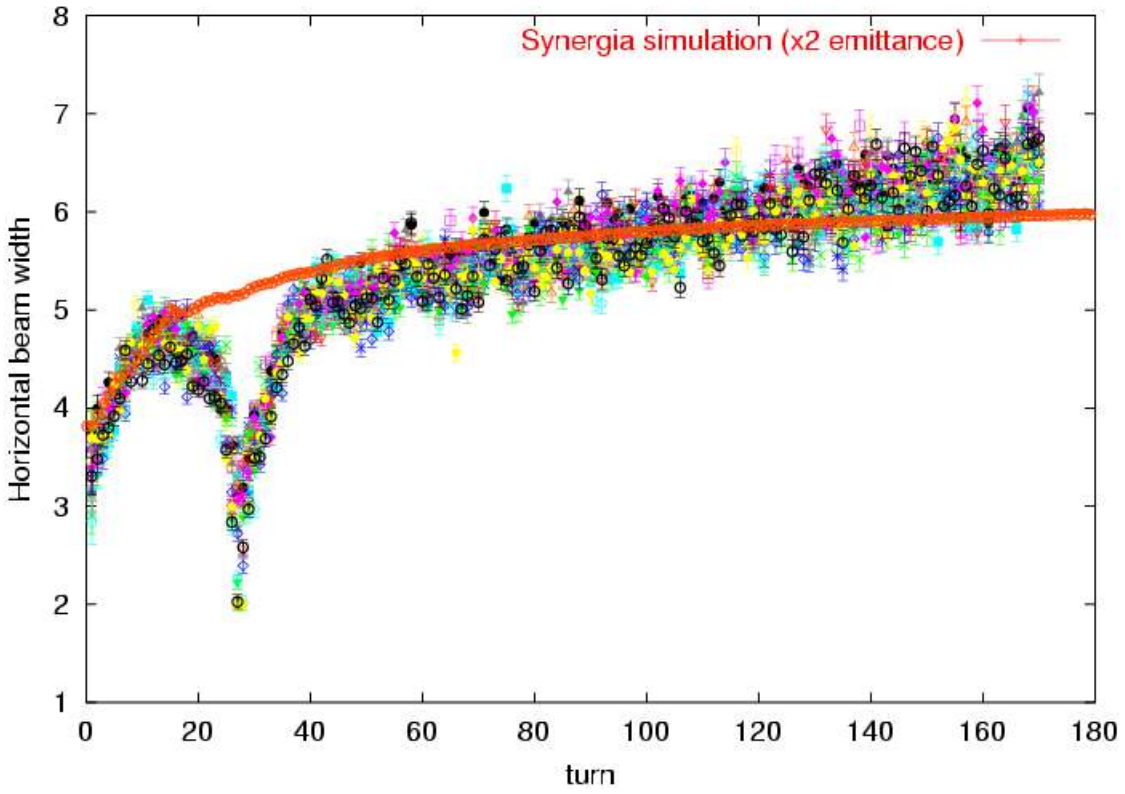
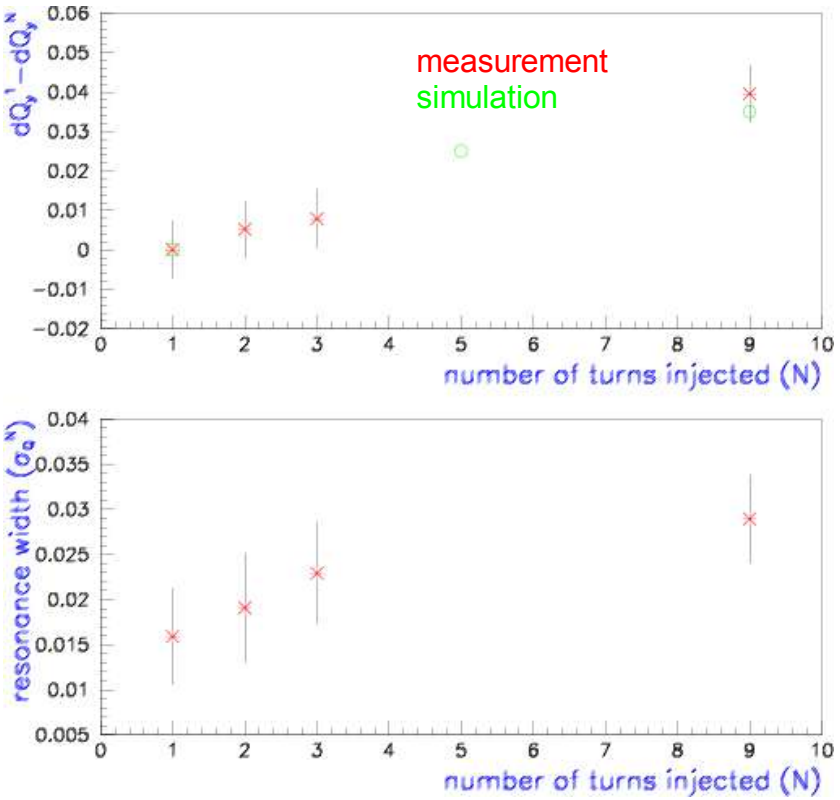
Fermilab Booster studies

beam width evolution, compared to experiment





coherent tune shift

Studying Halo Formation

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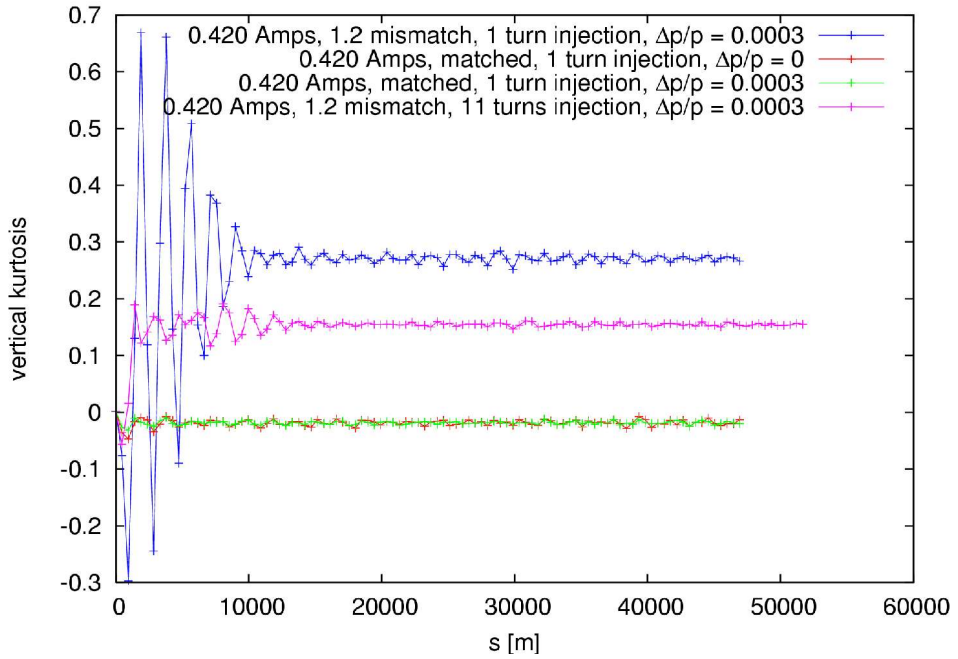
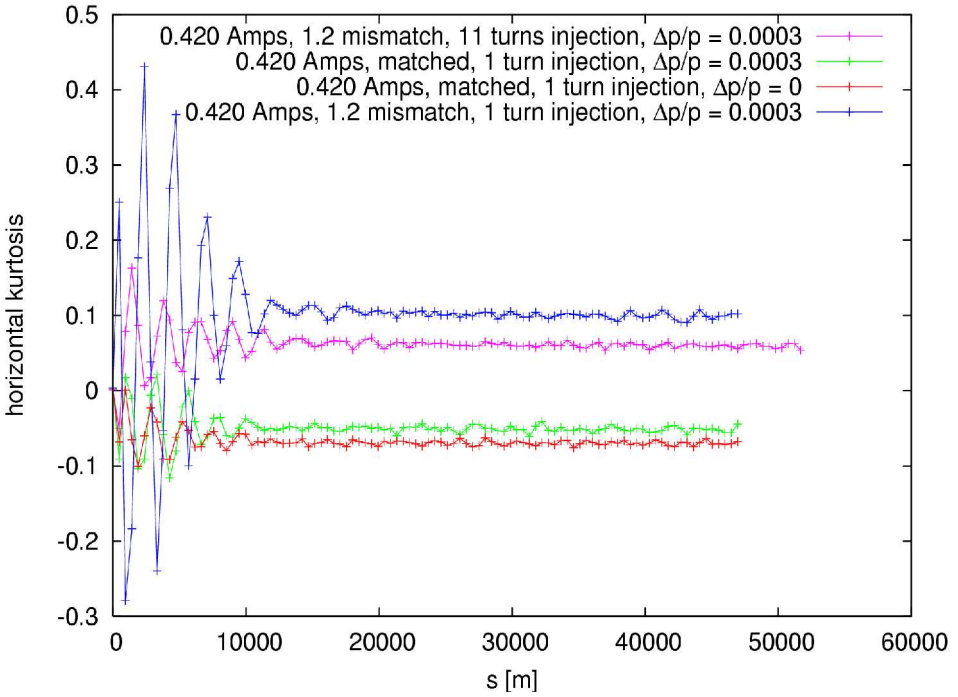
kurtosis $k \equiv \frac{\left\langle (x - \langle x \rangle)^4 \right\rangle}{\left\langle (x - \langle x \rangle)^2 \right\rangle^2} - 3$

horizontal



vertical



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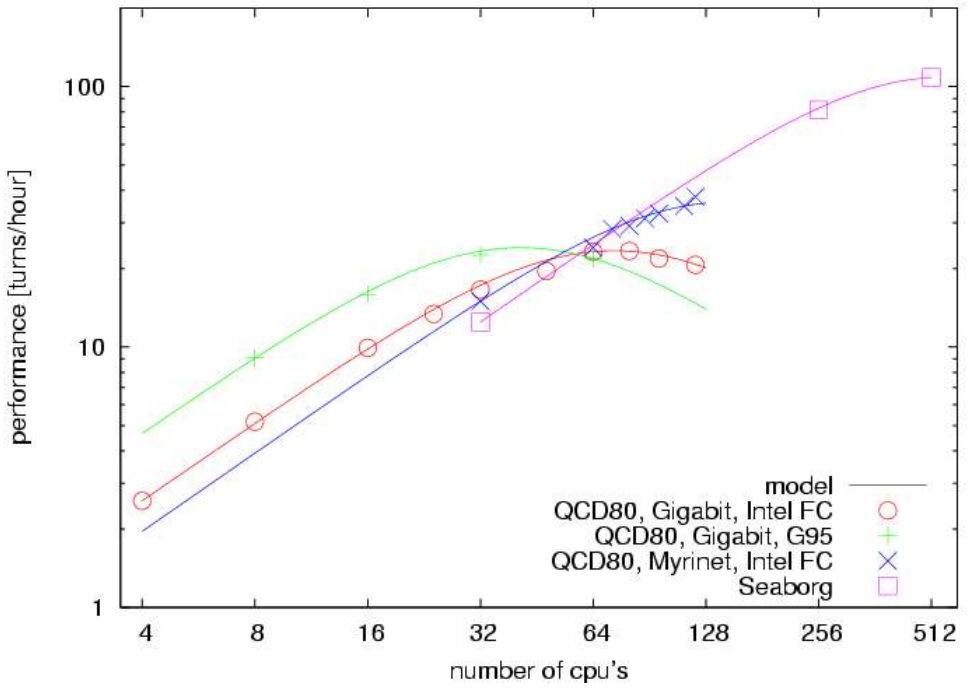
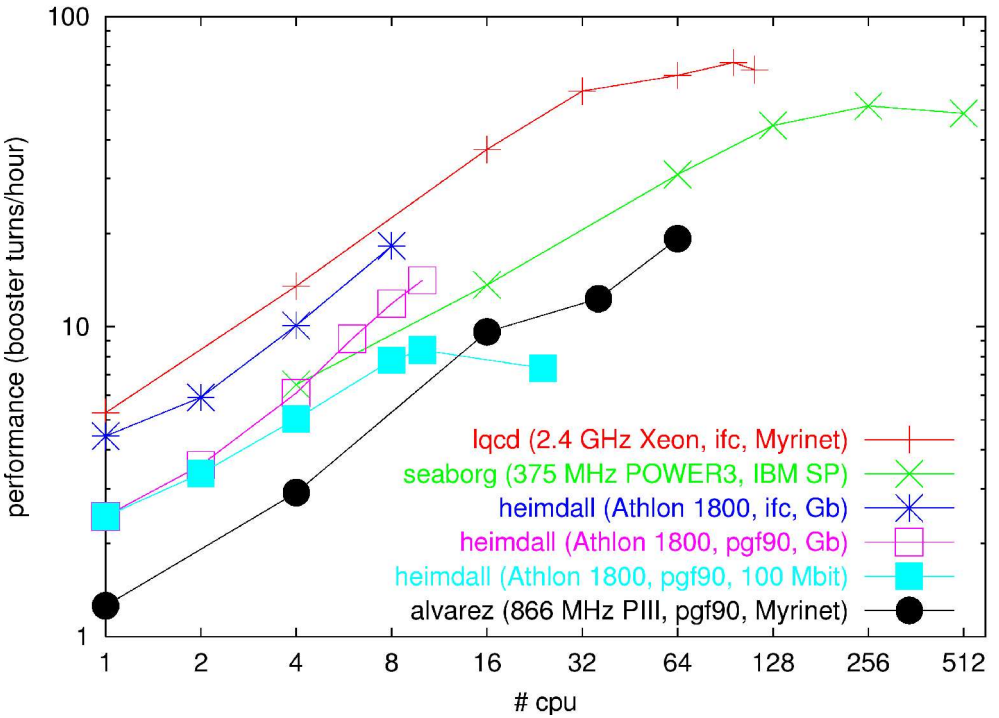
Performance



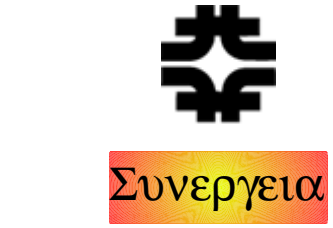
Use both linux clusters and super computers.



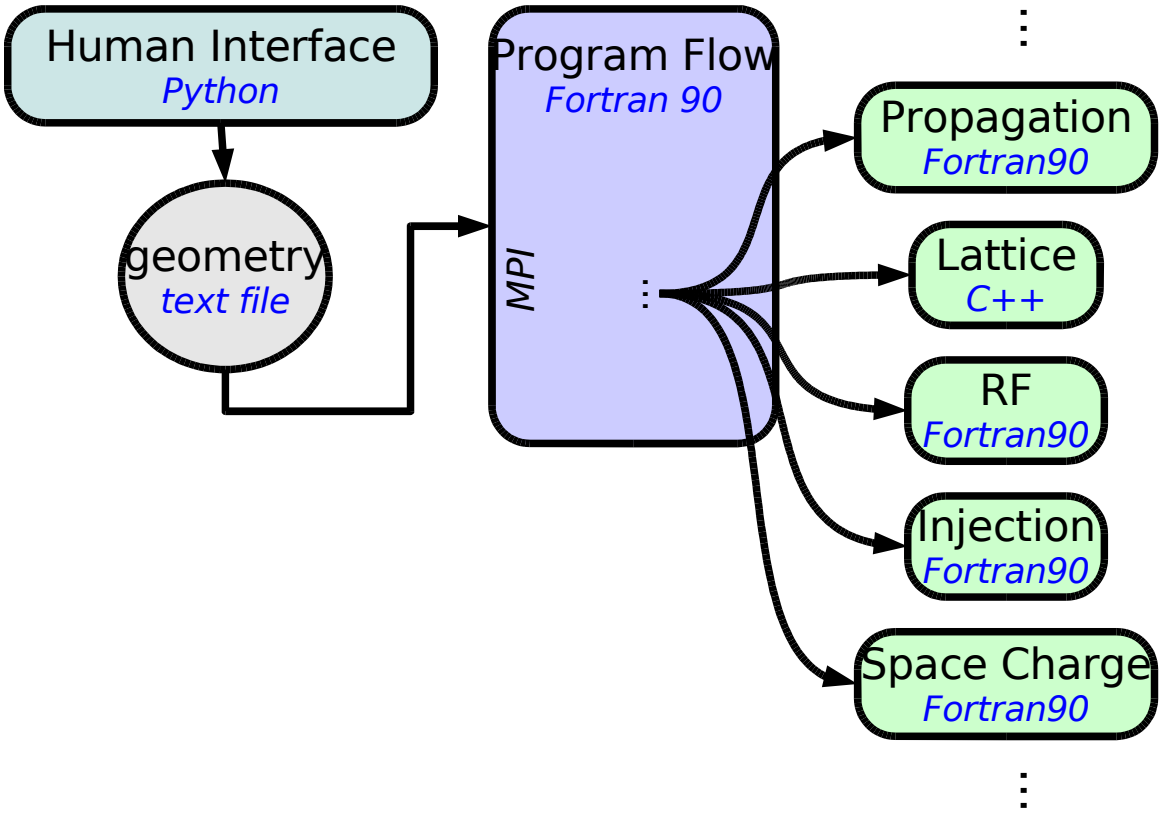
Performance model:

$$t = \frac{A}{N} + B N$$

N number of cpu's, 1/A ~ processor speed, B ~ networking speed



Synergia framework status



- User interface: flexible geometry and program flow
- Internal geometry representation constrained by F90 program flow module
  - complicates addition of new physics modules

Synergia framework design goal

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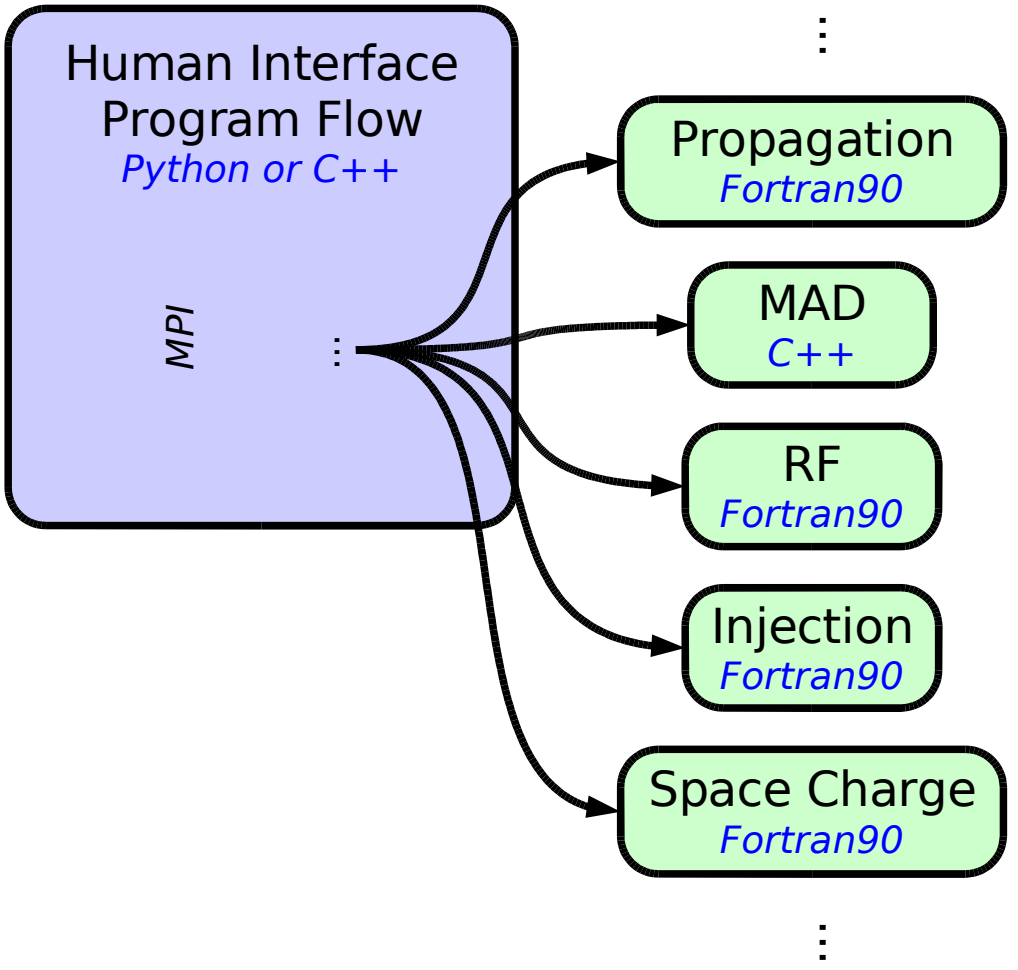
- Eliminate F90 control flow module
- Advantages
  - enhanced flexibility
    - new physics modules can be trivially added
    - dynamic loading possible
- Requires: better module interface definition



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Summary

- Synergia is a distributable beam dynamics framework
  - incorporates and extends existing codes
  - provides job management system
  - documentation & test suite
- Already used for beam studies
- Will be extended to include more physics
  - requires some framework development