Synergia: Release and Benchmarking

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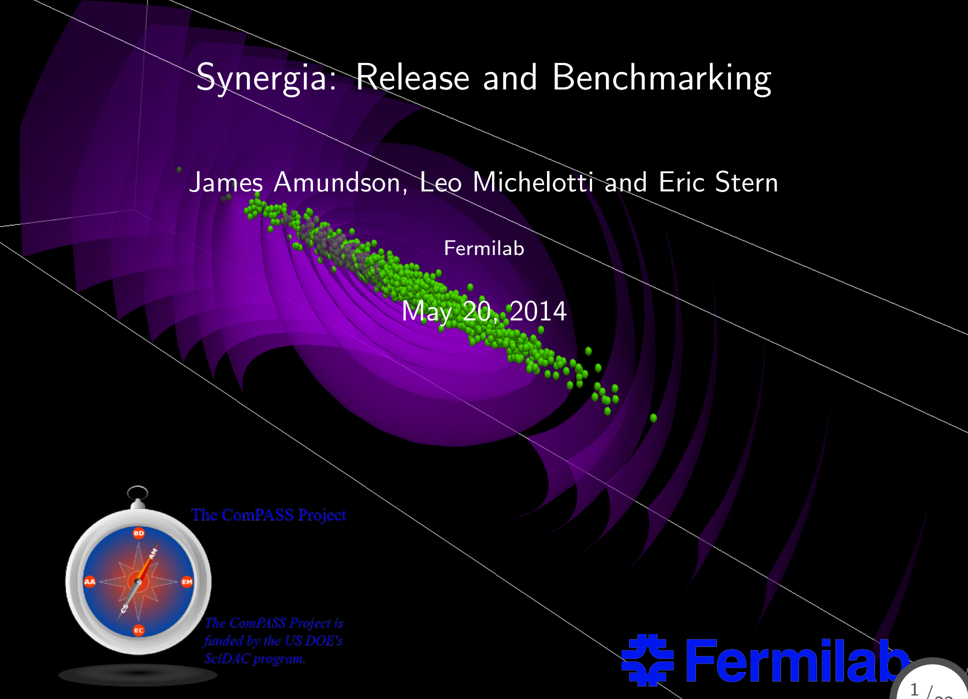
Fermilab

May 20, 2014



The ComPASS Project

The ComPASS Project is funded by the US DOE's SciDAC program.

Fermilab

Synergia

- Accelerator simulation package
  - independent-particle physics
  - collective effects
- Designed for range of computing resources
  - laptops, desktops, clusters and supercomputers
    - scales to over 100,000 cores
- Open source
  - We welcome collaborators
- Developed and maintained by the Accelerator Simulation group in Fermilab's Scientific Computing Division
  - James Amundson, Paul Lebrun, Qiming Lu, Alex Macridin, Leo Michelotti (CHEF), Chong Shik Park, Panagiotis Spentzouris and Eric Stern

General information:

`https://web.fnal.gov/sites/synergia/`

Source code, etc.:

`https://cdcvs.fnal.gov/redmine/projects/synergia2`

Synergia Physics

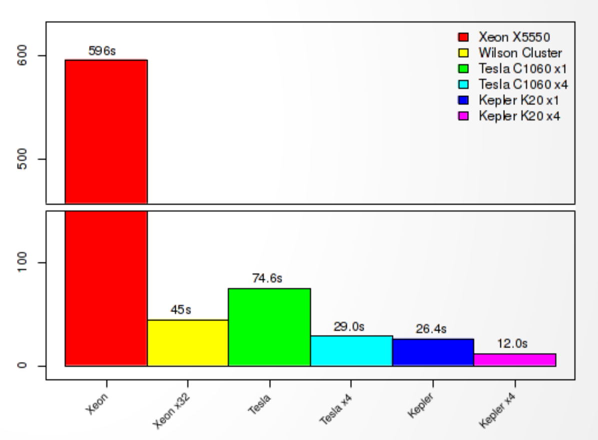
- Single-particle physics are provided by CHEF
  - details later in talk
- Apertures
- Collective effects (single and multiple bunches)
  - space charge (3D, 2.5D, semi-analytic, multiple boundary conditions)
  - wake fields
    - can accommodate arbitrary wake functions
  - electron cloud (proof of principle only)
- Space charge
  - 3D open transverse boundary conditions
    - Hockney algorithm, open or periodic longitudinally
  - 3D conducting rectangular transverse boundary
    - periodic longitudinally
  - 3D conducting circular transverse boundary
    - periodic longitudinally
  - 2.5D open boundary conditions
    - 2D calculation, scaled by density in longitudinal slices
  - 2D semi-analytic
    - uses Bassetti-Erskine formula, σs calculated on the fly
  - New space charge models can be implemented by the end user

Synergia 2.1.0 General Release

- Ready for end-users
- Manual
  - Updating for MadX input
- Source release
- Binaries
  - SL6
  - Ubuntu (?)
  - Willing to consider requests
- End of May

Upcoming features for Synergia 2.2

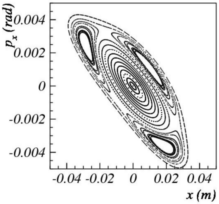
- SIMD vectorization optimizations
  - 2x - 8x+ speed improvement for particle propagation
- Production-ready GPU support
  - Probably Intel Phi (MIC) also
  - 100+ core performance from a few GPUs



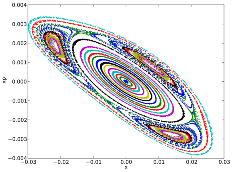
Space Charge Trapping Benchmark (recap and update)

- Space charge trapping benchmark in GSI SIS18
  - `http://web-docs.gsi.de/~giuliano/research_activity/trapping_benchmarking/main.html`
- *The aim of the code benchmarking is to confirm the space charge induced trapping of particles in a bunch during long term storage.*

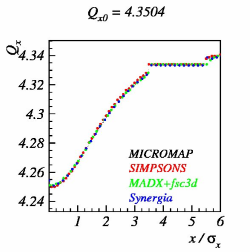
Benchmark phase space



Synergia phase space

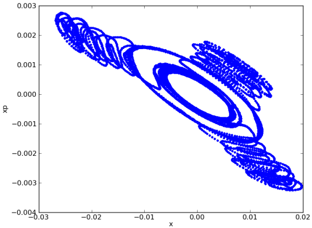


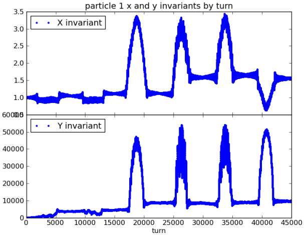
Tune vs. displacement



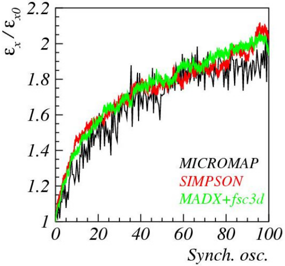
SIS18 Benchmarking: Successful Conclusion

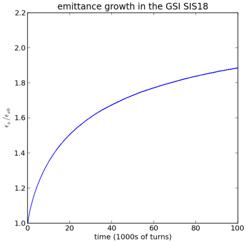
Single particle trapping



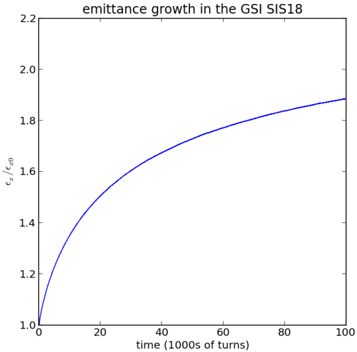


Emittance growth





A Very Large PIC Simulation (VLPS)



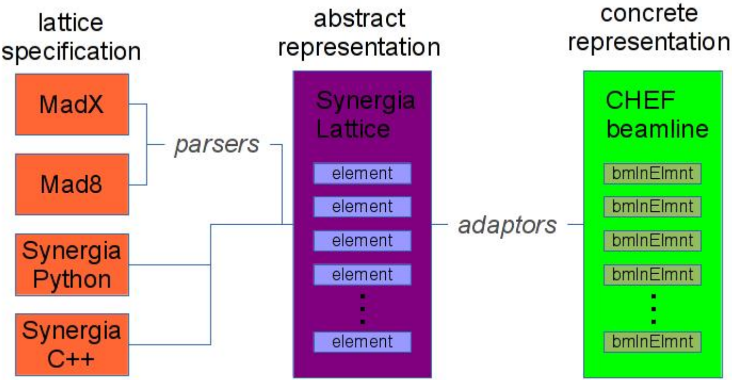
Details in tomorrow's talk.

- 100,000 turns
- 71 steps/turn
- 7,100,000 steps
- 4,194,304 particles
- 29,779,558,400,000 particle-steps
- 1,238,158,540,800,000 calls to drift
  - *Yes, that's over a quadrillion*

Synergia and MadX

Detailed comparision of single-particle physics in Synergia and Madx

Lattices


lattice specification
MadX
Mad8
Synergia Python
Synergia C++
parsers
abstract representation
Synergia Lattice
element
element
element
element
element
adaptors
concrete representation
CHEF beamline
bmlnElmnt
bmlnElmnt
bmlnElmnt
bmlnElmnt
bmlnElmnt

CHEF

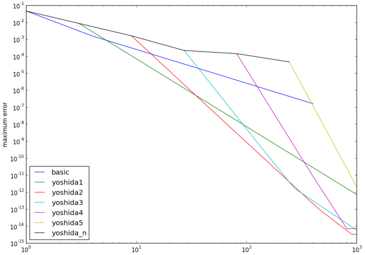
Two fundamental concepts in CHEF:

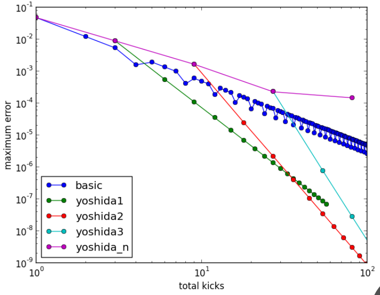
- Propagation and map analysis are fundamentally linked
  - The *same* code is used
    - Utilizes C++ templates
- CHEF Propagators provide a separation between propagators and geometry
  - Physical model for each element can be changed
- Basic CHEF model
  - exact drift
  - exact dipole
  - thin linear/nonlinear elements
    - including cavities, septa, monitors, etc., ...
  - thick elements are {drift, thin} elements
    - {} denotes sandwiching
- Bends in CHEF
  - simple bends: rbend, sbend
    - sbend = edge physics + dipole + edge physics
    - rbend = edge physics + dipole + edge physics
  - combined-function bends: CF_rbend, CF_sbend
    - CF = edge physics + {dipole, thin elements} + edge physics

CHEF Propagator Example: Thick Quadrupole

- CHEF defaults to 4 kicks per step
  - scheme is $\mathcal{O}(kL)^2$
  - Synergia used to default to 10 steps
- Yoshida arbitrary-order symplectic propagator
  - yoshida$n$ is $\mathcal{O}(kL)^{2n+2}$
  - Synergia now defaults to $n = 2$, 4 steps
- Can pick propagator and parameters at run time
  - Slow, accurate for map comparison
  - Fast, less accurate for tracking

Right: maximum fractional error for (exact) linear transfer matrix





Another CHEF Propagator: MADPropagator for CF_sbend

- Uses coefficients from tmsect.f90 a la Karl Brown
  - Unresolved issues with $x'(p_x/p_z)$ vs. p_x/p_0
  - Both MADX and CHEF use p_x/p_0
- Completely replaces the CF_sbend propagator, including edge effects

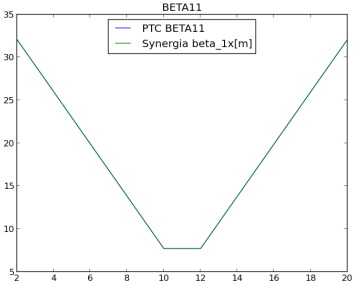
Propagation options in Synergia

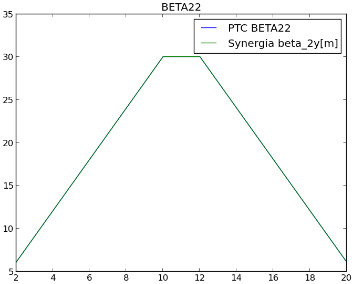
- Direct use of Chef propagators: explicitly symplectic
  - We now use this most of the time
- Linear maps: fast, symplectic, no non-linear effects
- Higher-order polynomial maps: not as fast, non symplectic, as non-linear as you like
  - Arbitrary order
    - We've done 15^{th}
- User can choose which propagation method on an element-by-element basis

Optics comparison: Toy lattices 1

- FODO cell

Compare: generalized lattice functions (Ripken) using MADX/PTC and Synergia





- Level of agreement is 10^{-12}

Optics comparison: Toy lattices 2

- FOBORODOBO32 Lattice
  - Circular, 32 cells, simple sbends
  - single RF cavity
  - $pc = 10\text{GeV}$
- Tunes (Synergia and MadX/PTC agree in all digits)
  - 0.603237761759 horizontal
  - 0.406213097186 vertical
- Chromaticity (Synergia and MadX/PTC agree in all digits)
  - -8.711359806 horizontal
  - -8.845639121 vertical
- We conclude that we have excellent agreement between Synergia and MadX/PTC up to and including simple bends and RF cavities

Optics comparison: Toy lattices 3

- KFOBORODOBO32 Lattice
  - Circular, 32 cells, simple sbends
  - single RF cavitiy
  - kicker
  - closed orbit not on zero
  - $pc = 10\text{GeV}$
- Tunes (Synergia and MadX/PTC agree in all digits)
  - 0.60886826 horizontal
  - 0.40920237 vertical
- Chromaticity (Synergia and MadX/PTC agree in all digits)
  - -8.823397 horizontal
  - -8.884926 vertical
- Level of agreement is 10^{-6} in generalized lattice functions

Optics comparison: Toy lattices 4

- cfoboobos Lattice
  - small lattice with combined function bends
  - magnifies issues

	h tune	h chrom
MADX-TWISS	2.541568195	0.5479383116
PTC-TWISS exact	0.5415681988	0.5479398011
PTC-TWISS inexact	0.5415681953	-2.800058545
Synergia/CHEF	0.5415665456	-2.2344878752
CHEF-MADlike-propagat	0.5415681953	0.5476584165

	v tune	v chrom
MADX-TWISS	1.680780993	-2.066730709
PTC-TWISS exact	0.6807809971	-2.066732481
PTC-TWISS inexact	0.6807809935	-1.971674502
Synergia/CHEF	0.680780711	-1.6762177921
CHEF-MADlike-propagat	0.6807809935	-1.2080765643

- Vertical chromaticity remains a mystery

Optics comparison: Toy lattices 5

- Replace combined function bending magnets with "Talman Sandwich" of 4 quadrupole kicks and pure sbends

	h tune	h chrom
PTC-TWISS exact	0.5381759729	-2.225755063
Synergia/CHEF	0.5381759729	-2.225755063

	v tune	v chrom
PTC-TWISS exact	0.6799606984	-2.064893011
Synergia/CHEF	0.6799606984	-2.064893011

- There are still issues we do not understand

Optics comparison: PS Lattice

- PS
  - has combined function magnets
- Tunes
  - 0.2532 horizontal (Synergia)
  - 0.2533 horizontal (MadX/PTC)
  - 0.3044 vertical (Synergia)
  - 0.3044 vertical (MadX/PTC)
- Chromaticity
  - -6.17 horizontal (Synergia)
  - -5.43 horizontal (MadX/PTC)
  - -7.15 vertical (Synergia)
  - -7.02 vertical (MadX/PTC)
- closed orbit agrees at the $\mathcal{O}(10^{-3})$ level or better

Optics comparison: PSB Lattice

- PSB
  - has quadrupoles with edge effects
    - implemented in CHEF, but not yet tested or turned on
- Tunes
  - 0.269999988062 horizontal (Synergia)
  - 0.269999988062 horizontal (MadX/PTC)
  - 0.420000013576 vertical (Synergia)
  - 0.420000013576 vertical (MadX/PTC)
- Chromaticity
  - -3.462330788 horizontal (Synergia)
  - -3.462330788 horizontal (MadX/PTC)
  - -7.248121275 vertical (Synergia)
  - -7.248121275 vertical (MadX/PTC)
- individual lattice functions show surprisingly large discrepancies

Conclusions

- Synergia 2.1.0 release slated for end of month
- Space charge trapping benchmark completed
  - including VLPS
- Synergia/CHEF can reasaonably reproduce MadX/PTC optics, but unresolved issues remain