The Community Project for Accelerator Science and Simulation 4: Advancing Accelerator Physics through High-performance Computing

ComPASS4

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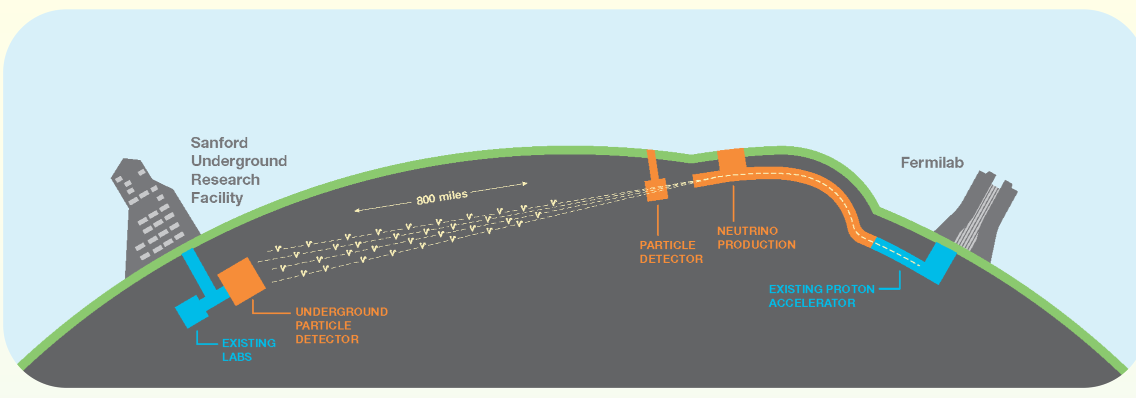
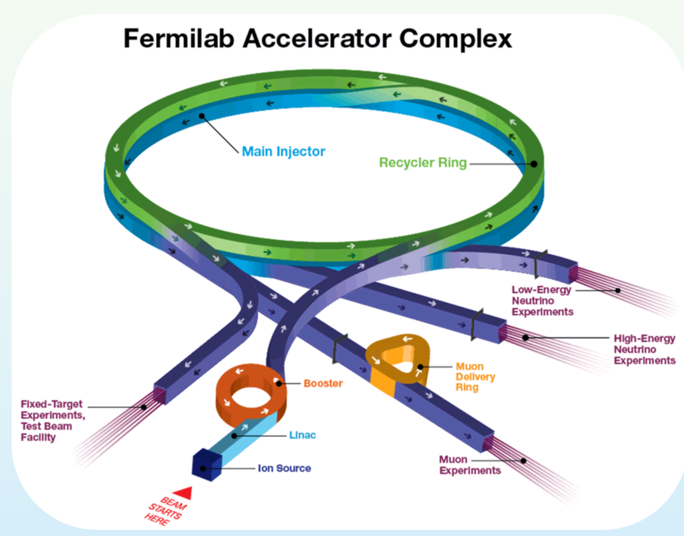
HEP Physics Drivers for Beam Dynamics



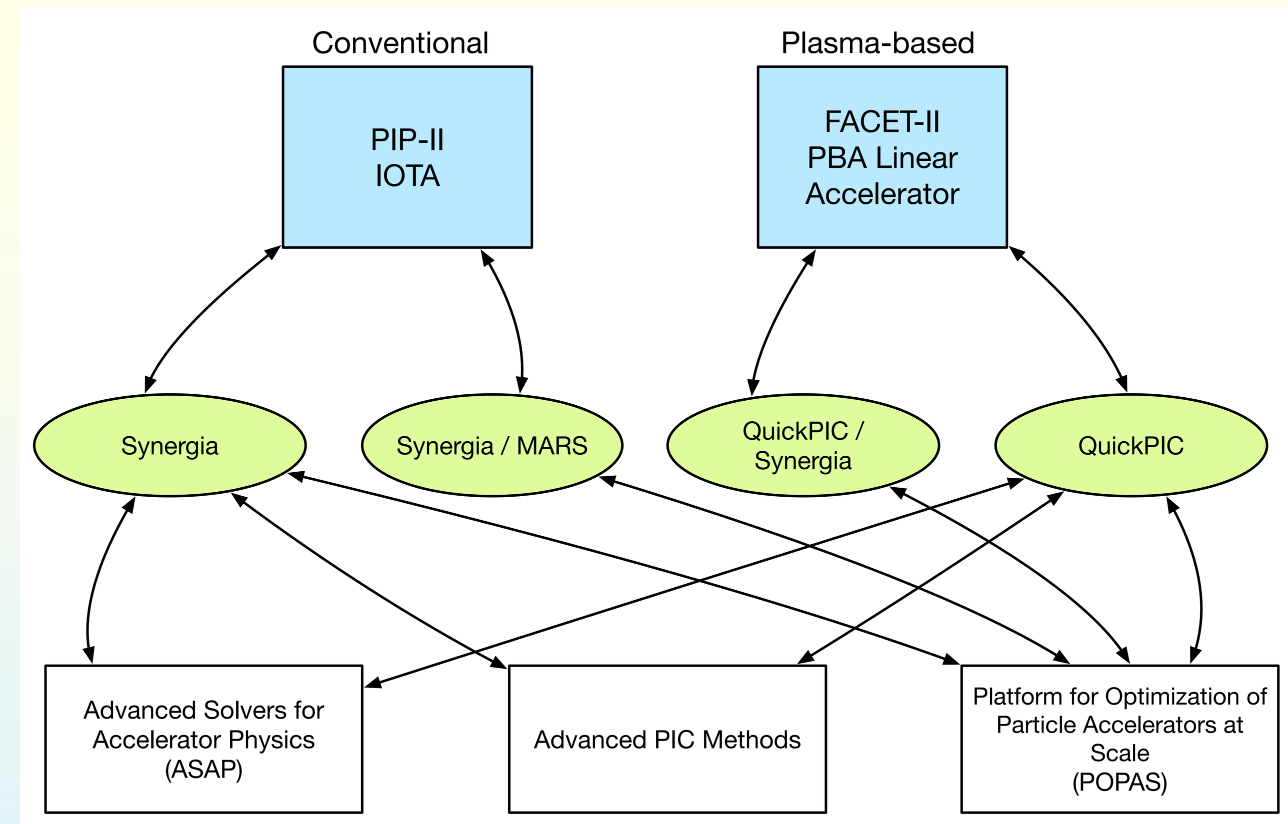
- The US High Energy Physics program is centered on high intensity physics
- The Deep Underground Neutrino Experiment (DUNE) will be the flagship experiment in the US program



- The PIP-II project will increase the intensity of the beams produced by the Fermilab accelerator complex
  - High-intensity beams are necessary for the success of DUNE
- Simulations of intensity-dependent beam dynamics are a critical part of the PIP-II design and implementation process
- ComPASS4 is enabling and performing intensity-dependent simulations for PIP-II

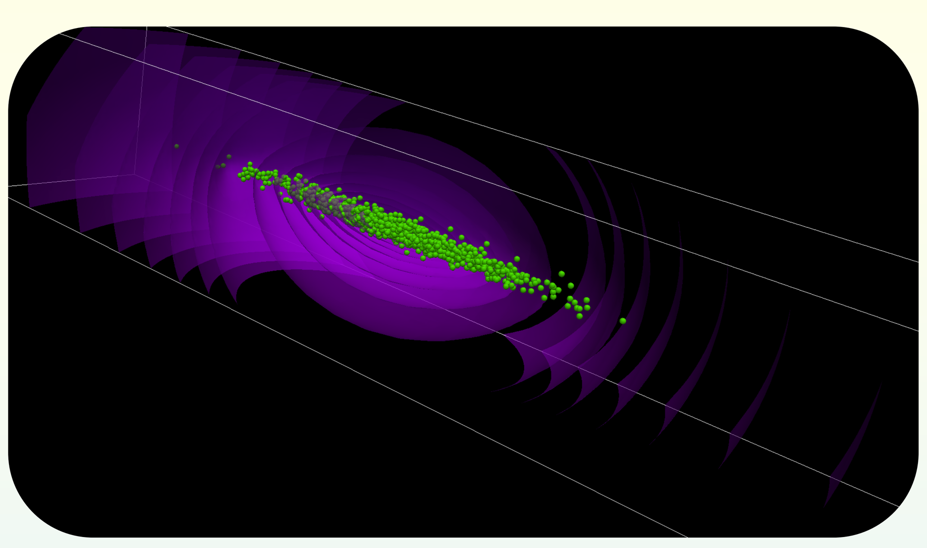
- The mission of the Fermilab Accelerator Science and Technology (FAST) facility is to develop a fully-equipped R&D accelerator chain intended to support research and development of accelerator technology for the next generation of particle accelerators
- The primary focus of this effort is the Integrable Optics Test Accelerator (IOTA) ring
- ComPASS4 simulations are part of the FAST/IOTA program

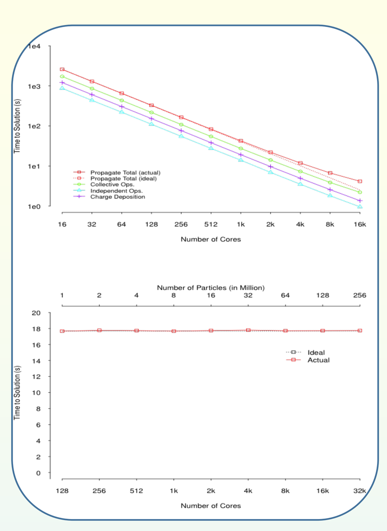
HEP/ASCR Relationships



- ComPASS4 is supporting the US HEP program through the conventional accelerator programs PIP-II and IOTA as well as plasma-based experiment at FACET-II
  - Synergia and Synergia/MARS for beam dynamics
  - QuickPIC for plasma-based acceleration
- ComPASS4 accelerator physics efforts are partnering with ASCR projects in three areas
  1. Advanced Solvers for Accelerator Physics (ASAP) are taking advantage of developments in linear algebra and automatic mesh refinement
  2. PIC methods are being refined for modern computing architectures
  3. Advanced optimization methods are being made available for general accelerator problems in the Platform for Optimization of Particle Accelerators at Scale (POPAS)
- ComPASS accelerator efforts in beam dynamics and plasma-based acceleration are being combined into a single simulation capable of handling a plasma-based linear accelerator stage with beam transport

Synergia and Synergia/MARS

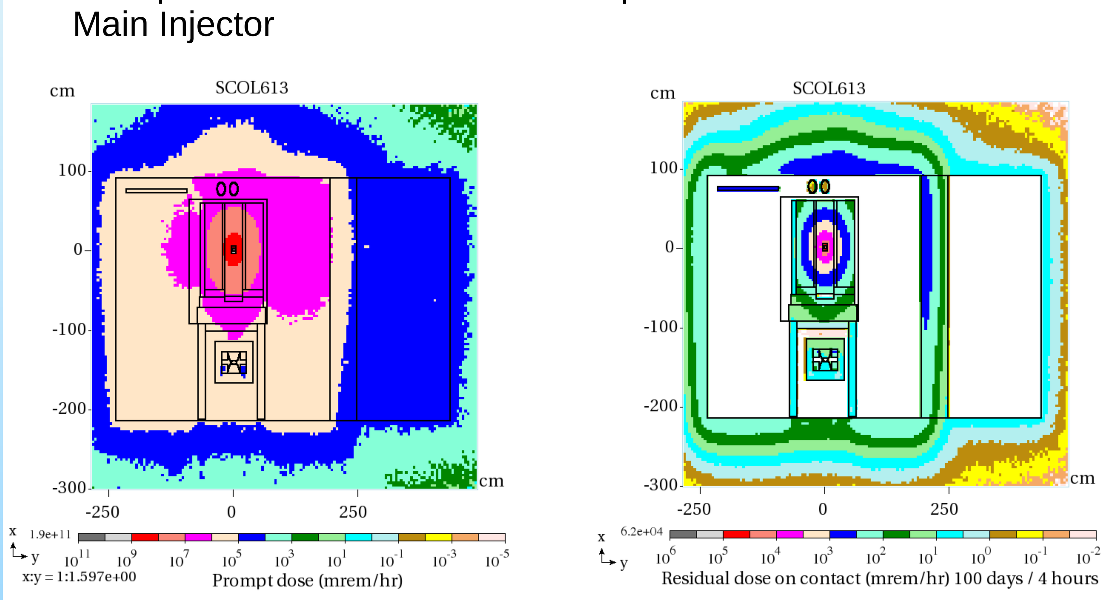




Synergia is the primary ComPASS4 package for conventional beam dynamics

- Linear and non-linear single-particle dynamics
- Space charge and general wakefields
- Tracking of single bunches, bunch trains, and overlapping bunch trains
- Strong scaling to 10k+ procs/bunch, 100k+ procs/train

Prompt and residual dose above a particular location in the Main Injector

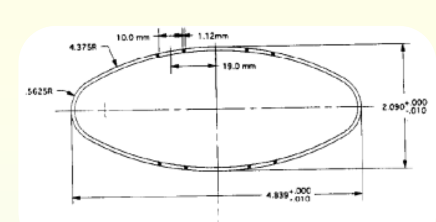


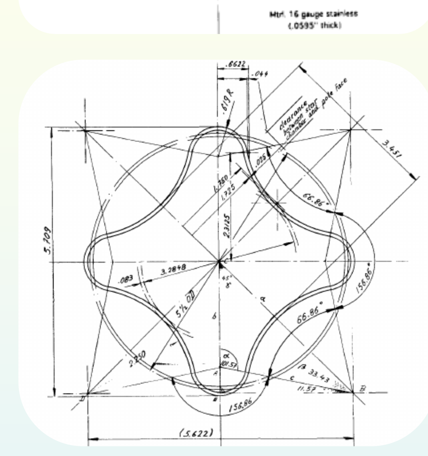
Synergia/MARS is being developed as part of ComPASS4

- MARS is a simulation package for energy deposition in matter
- Combined Synergia/MARS will allow full simulations of beam dynamics + losses + secondary radiation
- Includes MARS simulation of losses from Synergia as well as Synergia tracking of secondary particles from MARS

ASAP and POPAS

Advanced Solvers for Accelerator Physics (**ASAP**)





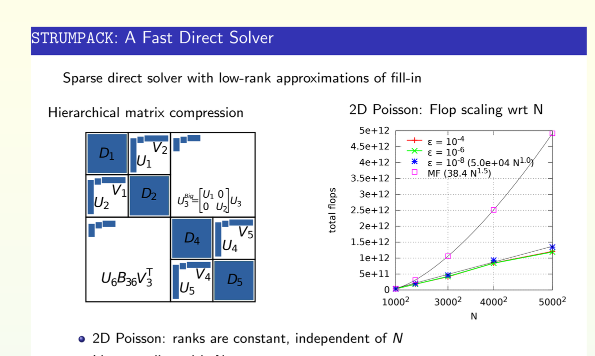
Existing Poisson solvers in Synergia and QuickPIC use FFT-based methods

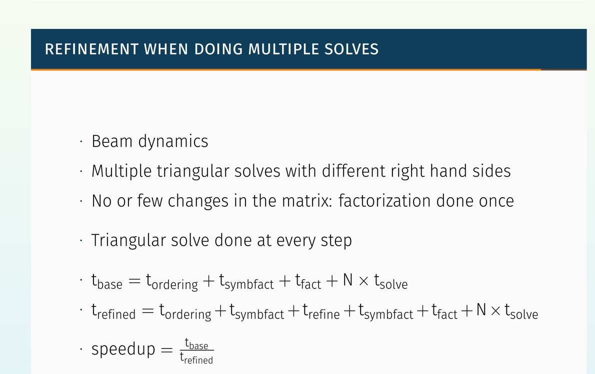
- Fast
- Basic boundary conditions: open, rectangular

Real machines often have non-trivial boundary conditions (left)

ASAP will provide linear algebra-based solvers for arbitrary boundaries

- Optimized for modern architectures





Platform for Optimization of Particle Accelerators at Scale (**POPAS**)

POPAS is being developed as a general solution to conventional and accelerator physics optimization problems on HPC platforms

- Creating an API to handle complex parameter and objective definitions
- Take advantage of massively parallel systems
- Take advantage of automatic differentiation
  - Already present in Synergia