Community Project for Accelerator Science and Simulation 4
ComPASS-4

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for

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Fermilab UCLA Argonne NATIONAL LABORATORY BERKELEY LAB

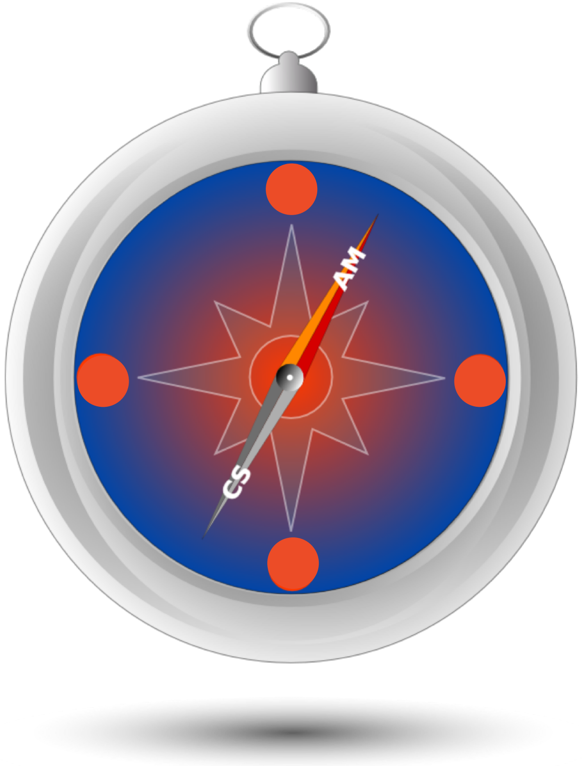
Driven By HEP Priorities from the P5 Report

The Particle Physics Project Prioritization Panel (P5) Report of 2014 reflects community-wide agreement on priorities

- Beam Dynamics
  - Conventional accelerator technology
  - Current technology
  - Intensity-dependent effects are most common limiting factor
- Plasma-based Acceleration
  - Next-generation accelerator technology
  - Could lead the way to higher energy accelerator

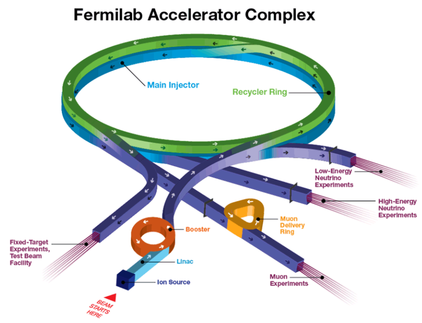
The ComPASS4 Collaboration

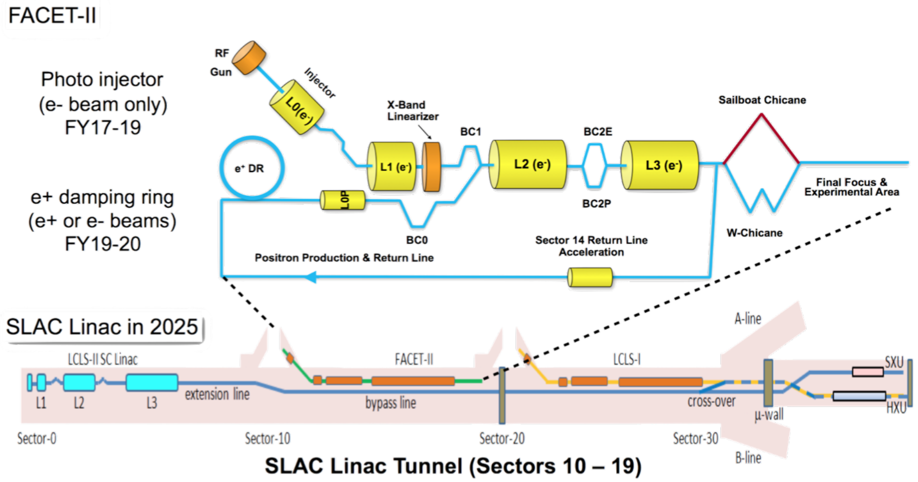
- Beam Dynamics
  - Fermilab
    - James Amundson, Coordinating PI
    - Eric Stern, Deputy PI
      - Synergia, MARS
- Plasma-Based Acceleration
  - UCLA
    - Warren Mori, Co-PI
      - QuickPIC, (Osiris), PIC methods
- Applied Math/Computer Science
  - LBL
    - Ann Almgren, Co-PI
      - Adaptive mesh refinement for solvers (ASAP/AMReX)
    - Esmond Ng, Co-PI
      - Linear algebra for Poisson solvers (ASAP)
  - ANL
    - Stefan Wild, Co-PI
      - Parameter optimization (POPAS)



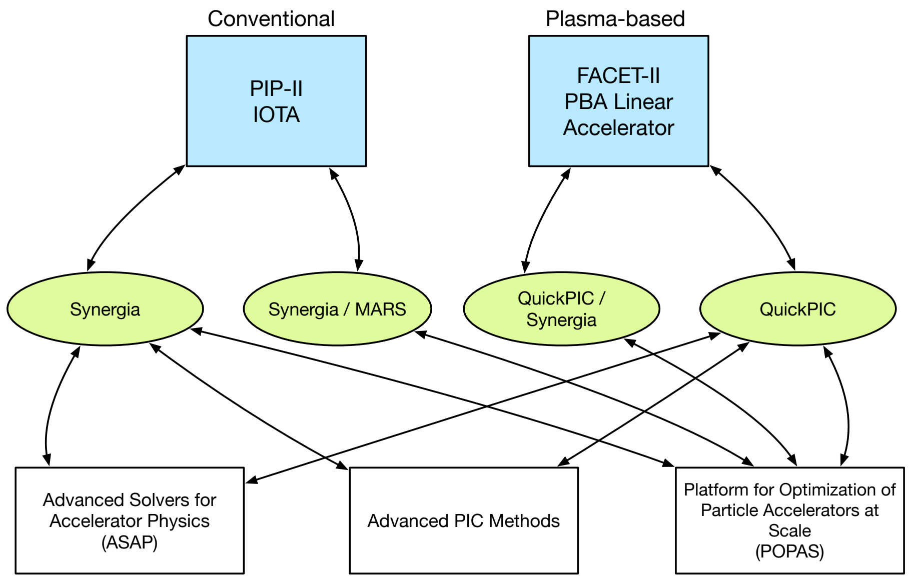
ComPASS4 Supports HEP Accelerator Science

- Conventional Beam Dynamics
  - The PIP-II project will increase the intensity of the beams produced by the Fermilab accelerator complex
  - The Fermilab Accelerator Science and Technology (FAST) facility includes the Integrable Optics Test Accelerator (IOTA) ring for beam dynamics experiments
- Plasma-based acceleration
  - The next-generation Test Facility FACET-II at SLAC Goals include
    - Completion of a single electron acceleration stage at higher energy
    - Demonstration and understanding of positron acceleration
    - Continuous, joint development of a comprehensive and realistic operational parameter set for a multi-TeV collider, to guide operating specifications for Advanced Accelerator.





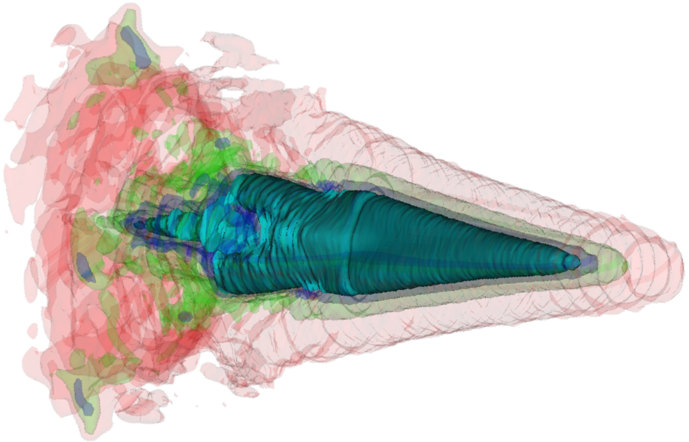
HEP/ASCR Collaboration in ComPASS4

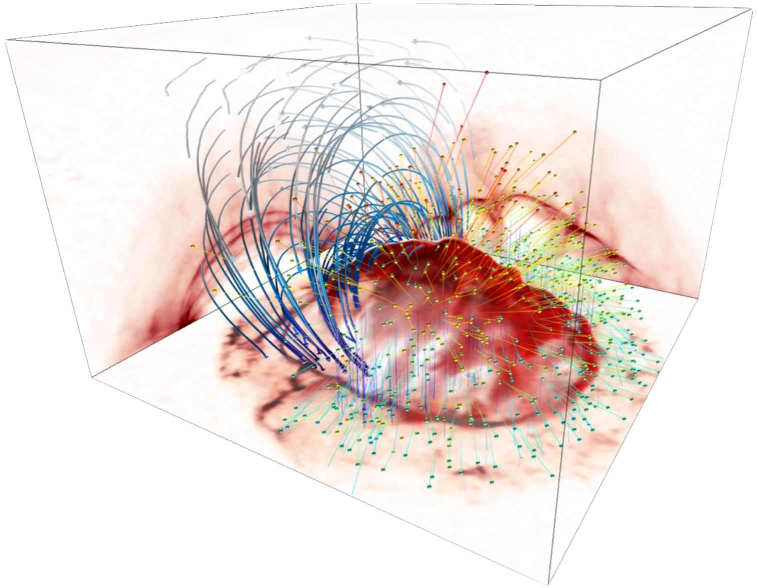


- ComPASS4 accelerator physics efforts are partnering with ASCR projects in three areas
  1. Advanced Solvers for Accelerator Physics (ASAP) are taking advantage of developments in linear algebra and automatic mesh refinement
  2. PIC methods are being refined for modern computing architectures
  3. Advanced optimization methods are being made available for general accelerator problems in the Platform for Optimization of Particle Accelerators at Scale (POPAS)

Plasma Accelerator Simulation: QuickPIC and Osiris

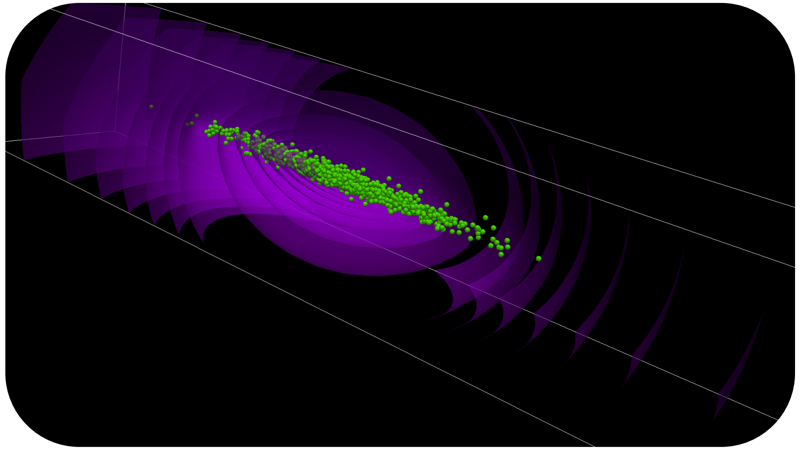
- QuickPIC will be enhanced as part of ComPASS4
  - QuickPIC is a 3D parallel Quasi-Static PIC code, which is developed based on the framework UPIC
    - Scalability to ~128 K cores
    - Pipeline Parallelization in z
    - MPI + OpenMP + Vectorization (For Intel Phi)
    - Laser Module and Field Ionization Module
    - Open Source on GitHub
- Some ComPASS4 physics simulations will utilize Osiris
  - Osiris is a full parallel PIC code with state-of-art relativistic EM-PIC algorithm.
    - Scalability to ~1.6 M cores
    - SIMD hardware optimized
    - Dynamic Load Balancing
    - QED module
    - Particle merging
    - GPGPU and Xeon Phi support

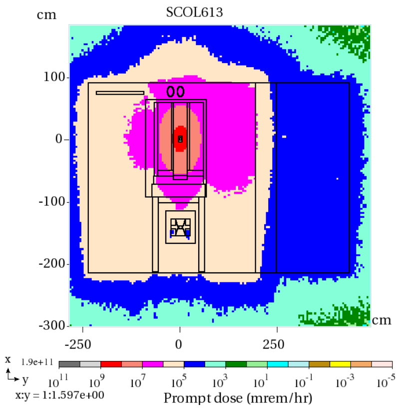


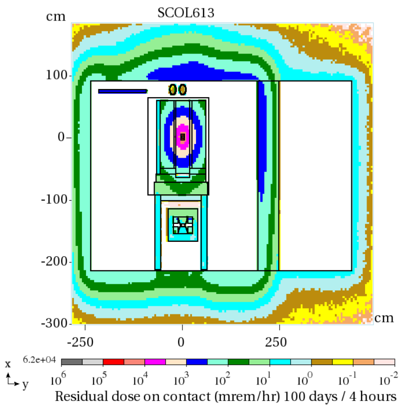


Conventional Accelerator Simulation: Synergia and Synergia/MARS

- **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
- **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







Advanced Solvers for Accelerator Physics (ASAP)

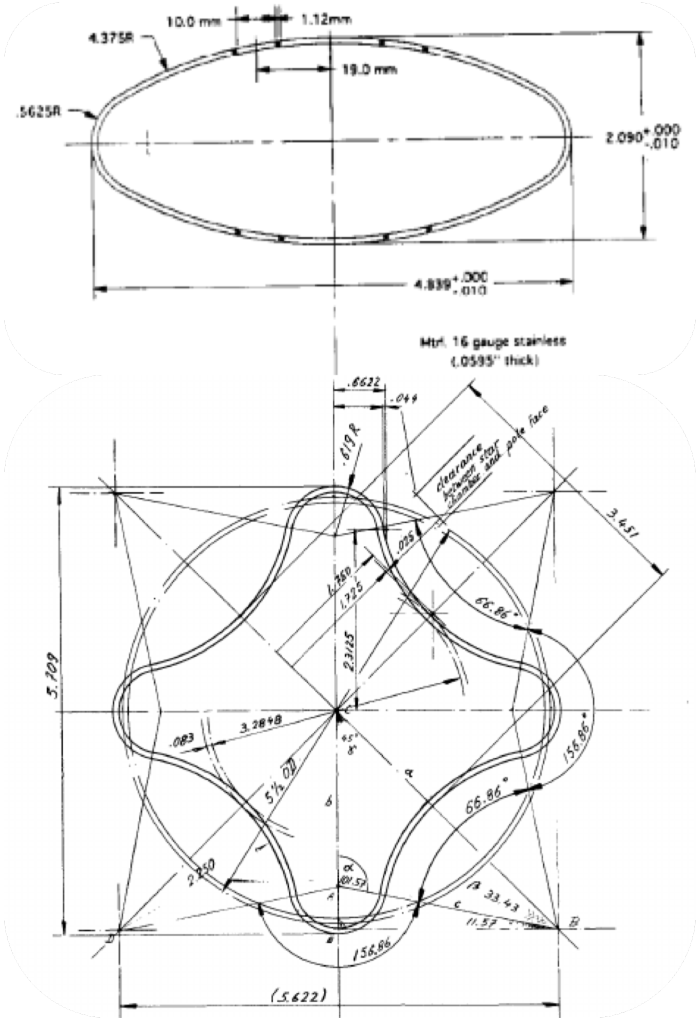
Existing Poisson solvers in Synergia and QuickPIC use FFT-based methods

- Fast
- Basic boundary conditions: open, rectangular

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

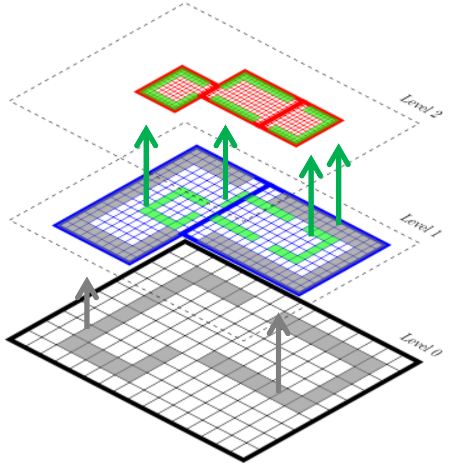
ASAP will incorporate advanced linear algebra solvers from FASTMath to handle arbitrary boundaries

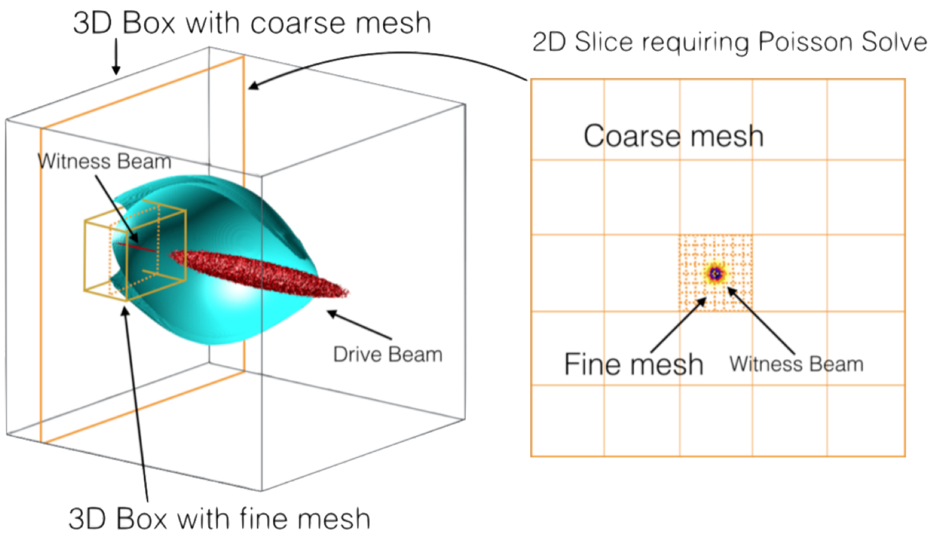
- Optimized for modern architectures



ASAP: AMReX Mesh Refinement

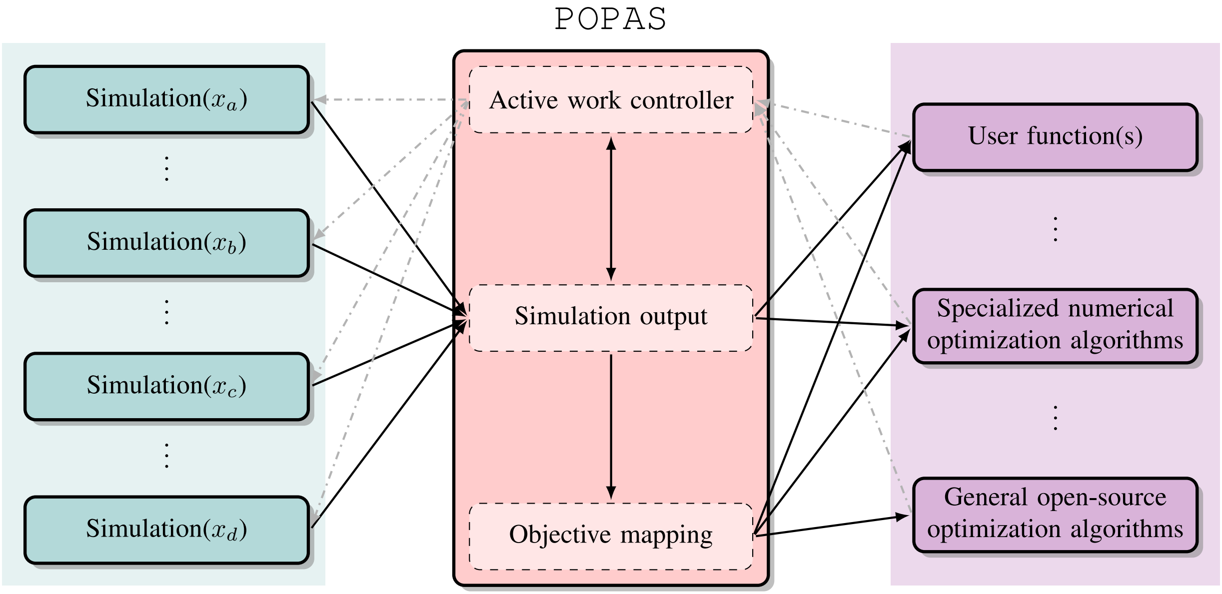
- AMReX is software framework to support the development of block-structured AMR applications for current and next-generation architectures.
- Mesh refinement – both static and adaptive – will be added to QuickPIC to enable faster, more efficient simulation.
- FASTMath support of AMReX provides source code and expertise to enable quick prototyping of multilevel algorithm and eventual optimization on new HPC architectures of the multilevel algorithm in the context of QuickPIC.
- Synergia applications of AMReX slated for later in the project





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
  - API design is the critical part of the project
- Take advantage of massively parallel systems
- Take advantage of automatic differentiation
  - Already present in Synergia

Highlight: Use of QuickPIC and OSIRIS for the design of FACET II Experiments

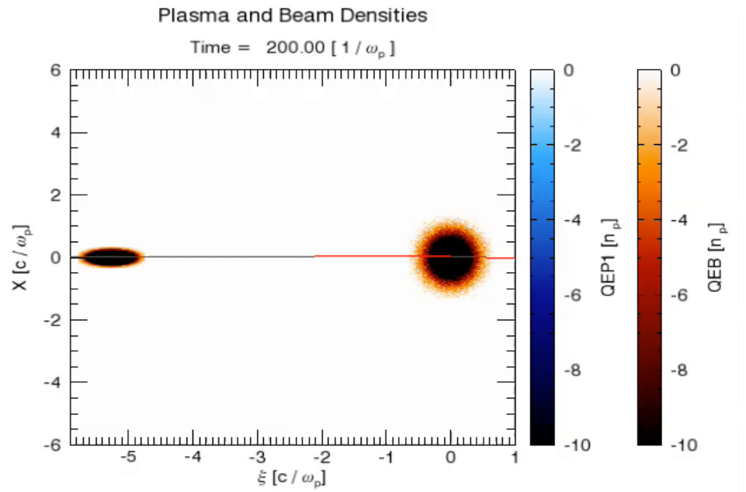
QuickPIC and OSIRIS are being used to design FACET II plasma wake field accelerator experiments and to explore key physics.

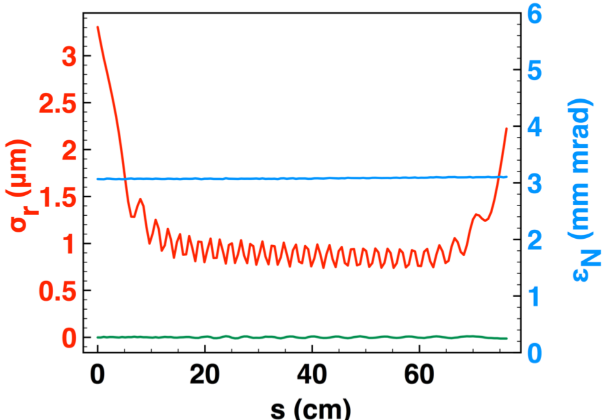
Significance and Impact

Simulations show that with FACET II two bunch and plasma parameters, an experiment is possible that simultaneously shows emittance preservation, low energy spread, high energy gain, and high efficiency.

Research Details

- The focal plane for the trailing beam should be located at a proper position to match the beam.
- For a He buffer gas in the plasma source, a 20 micron emittance can be preserved because the He is barely ionized.
- Asymmetric drive beam and/or ion motion can mitigate the trailing beam hosing in PWFA.





QuickPIC simulation for a two-bunch PWFA using FACET II beam parameters. The upper movie shows the beam and plasma densities evolution. The bottom plot shows the evolution of trailing beam's spot size, emittance band beam centroid.

UCLA

Highlight: Beam Simulation Combined with Lost Particle Tracking

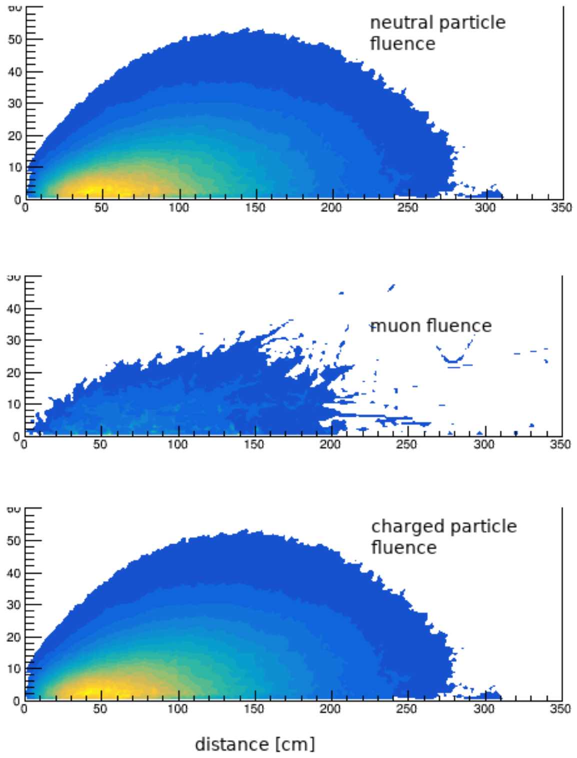
Synergia particles are transported through matter with MARS

Significance and Impact

The flux of lost beam particles and their energy deposition in matter can be simulated and so proposed accelerator designs may be evaluated.

Research Details

- Simulated particles were transported through a prototype rapid-cycling synchrotron with sextupoles. Large amplitude particles leave the aperture of the simulated machine.
- Lost particles are transported with the MARS energy deposition code into the wall of the building housing the accelerator.
- This kind of combined simulation will allow us to optimize accelerator design for maximized beam intensity and minimized harmful beam losses .



Fluences of particle types: Density map of fluences of neutral (top), muon (middle), and charged (bottom) particles resulting from particles lost in a accelerator simulation in accelerator enclosure wall.

The

ComPASS-4

collaboration thanks you for your attention

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