ComPASS SciDAC-3

Advanced Computation for High Intensity Accelerators

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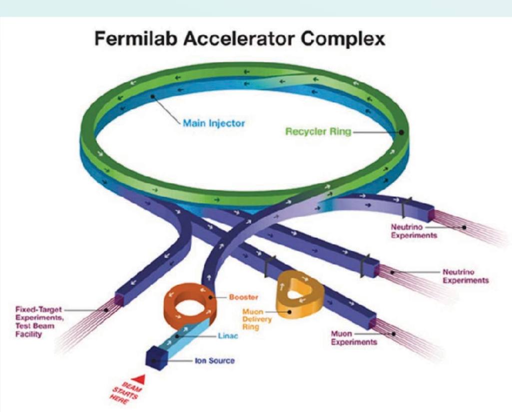
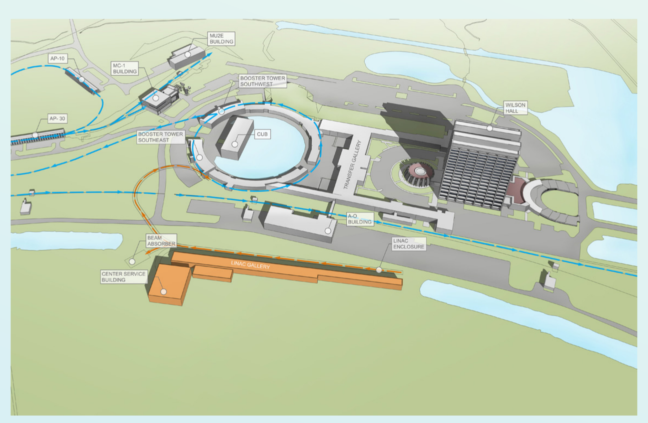
CONTEXT

The 2014 Particle Physics Project Prioritization Panel (P5) report identifies three accelerator-enabled science drivers. ComPASS is modeling high-intensity accelerators in support of all three.

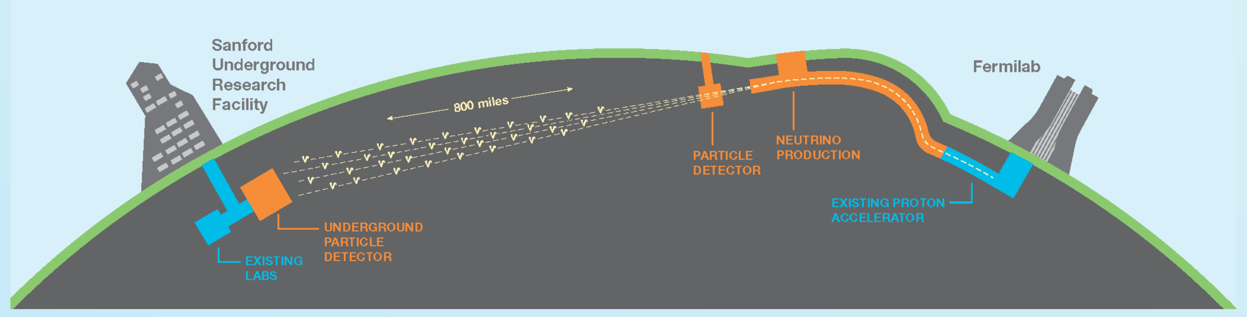
1. The physics of neutrino mass
   Fermilab Proton Improvement Plan (PIP)
2. New particles and interactions
   Fermilab Muon Delivery Ring (Mu2e), LHC injector upgrades
3. Higgs Boson as a tool for discovery
   LHC injector upgrades

PIP-II will upgrade the Fermilab Accelerator Complex …

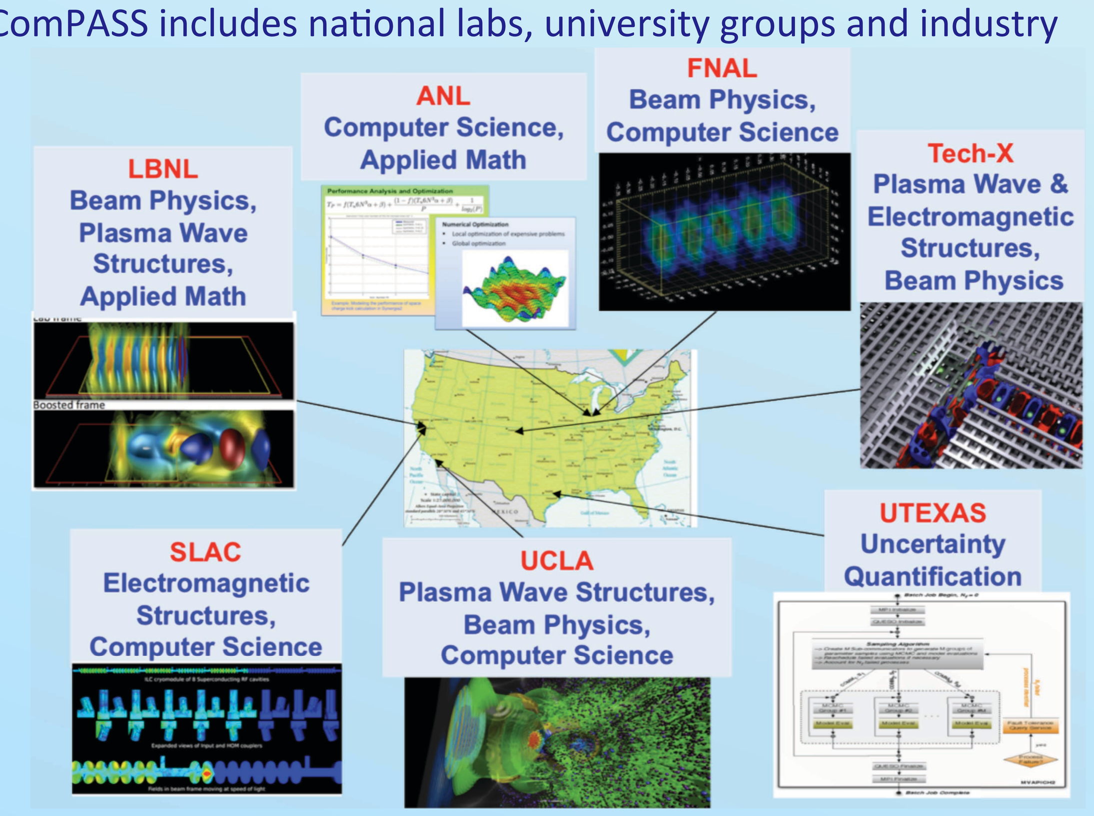




to send high –intensity neutrino beams to the Sanford Lab and the Deep Underground Neutrino Experiment (DUNE).



ComPASS includes national labs, university groups and industry



METHODS & TOOLS

***ComPASS SciDAC-3** is **advancing state-of-the-art modeling of Intensity Frontier accelerators**, using (developing if unavailable):*

- the most advanced algorithms & performance optimization tools
- cutting-edge non-linear parameter optimization and uncertainty quantification (UQ) methods.

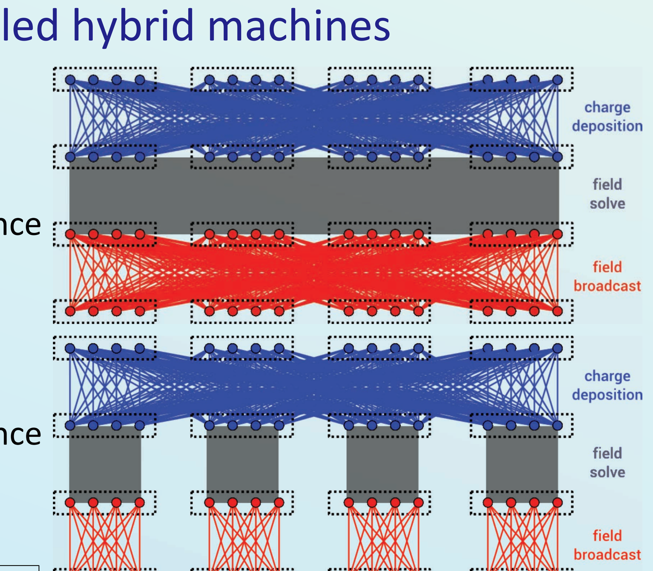
*Developing a **comprehensive set** of **codes** with **state-of-the-art electrostatic (ES) & electromagnetic (EM) field solvers:***

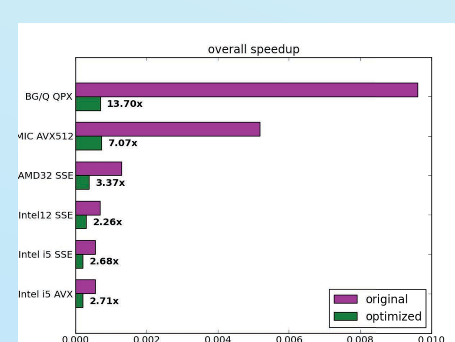
- ES-multigrid (**Synergia, Vorpal, Warp, FASTMath**), ES-AMR multigrid (**Warp, FASTMath**)
- EM-finite element (**ACE3P-FASTMath**),
- EM-extended stencil finite-difference (**OSIRIS, Vorpal, Warp**),
- EM-AMR finite-difference (**Warp, FASTMath**),
- EM embedded boundary (**Vorpal**) for both metals and dielectrics
- Darwin-finite-difference (**QuickPIC**).

*Working **with SciDAC institutes:***

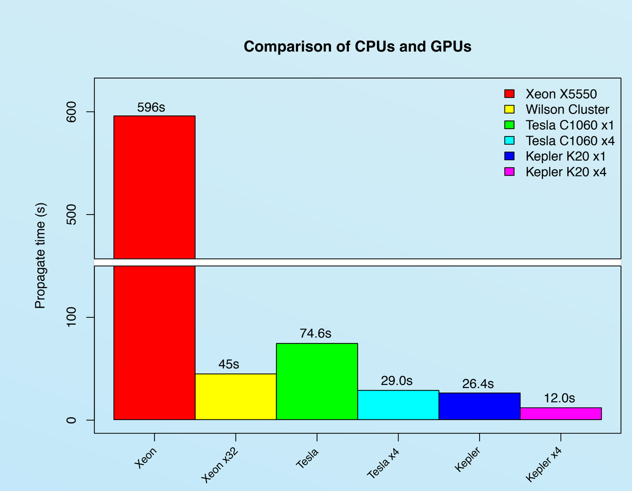
- **FASTMath:** field solvers (SuperLU, Chombo),
- **QUEST:** uncertainty quantification (QUESO),
- **SUPER:** performance analysis & optimization, non-linear parameter optimization.

Communication avoidance in Synergia enhances scalability on traditional architectures as well as GPU/MIC-enabled hybrid machines

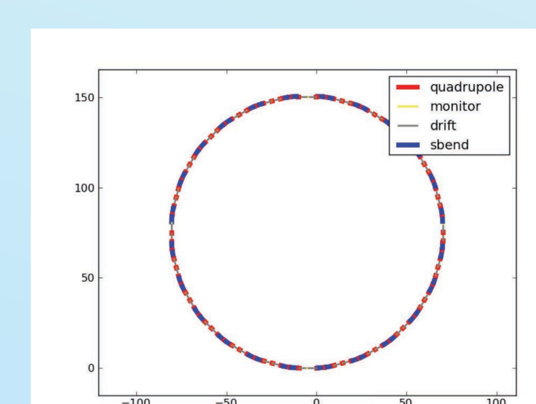




Explicit vectorization of Synergia single-particle routines leads to a large performance enhancement across architectures

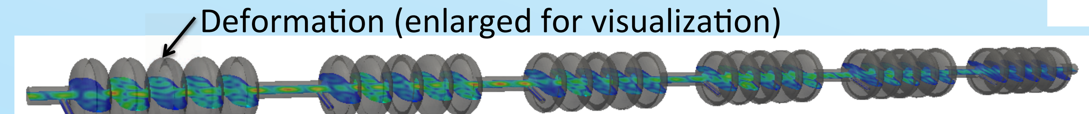


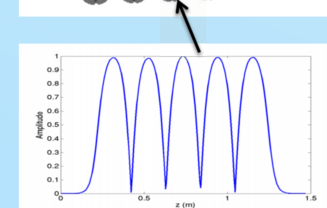
GPU-enhanced Synergia achieves better overall performance with 4 GPUs than an entire Linux cluster



ComPASS and SUPER are working together on optimization tools for new lattice designs

Deformation (enlarged for visualization)





Field flatness in cavity

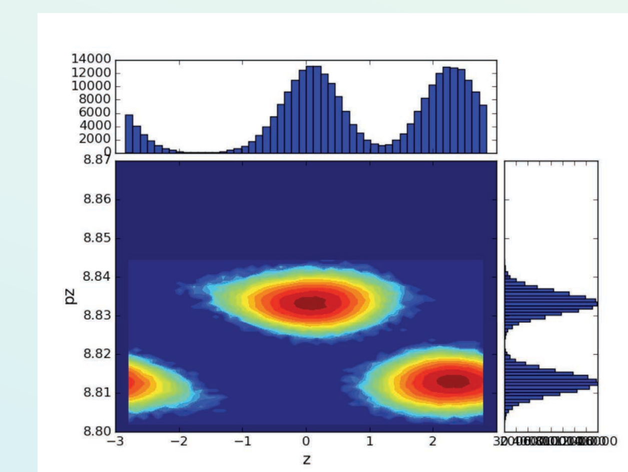
Higher-order mode (HOM) in the PIP2 650 MHz cryomodule (consisting of 6 superconducting cavities) with deformations at equators of cavity cells. The electric field pattern is shown on a cut plane.

APPLICATIONS

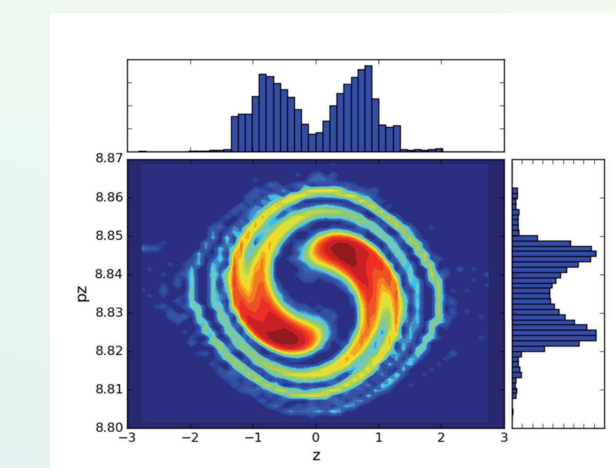
***ComPASS tools** provide **unique capabilities** that are being used for:*

- understanding and mitigating beam losses for existing accelerators,
- optimizing new accelerator designs
- understanding interaction with structures and generated plasmas

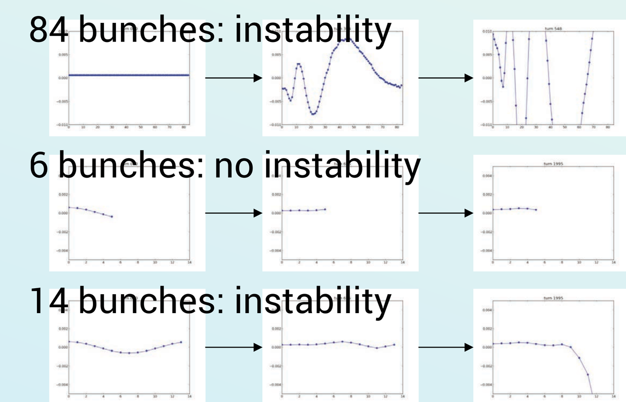
*The **ComPASS collaboration** has **extensive experience** in the modeling of **high-intensity proton drivers.** The focus is on **FNAL PIP-II** under **SciDAC3.***

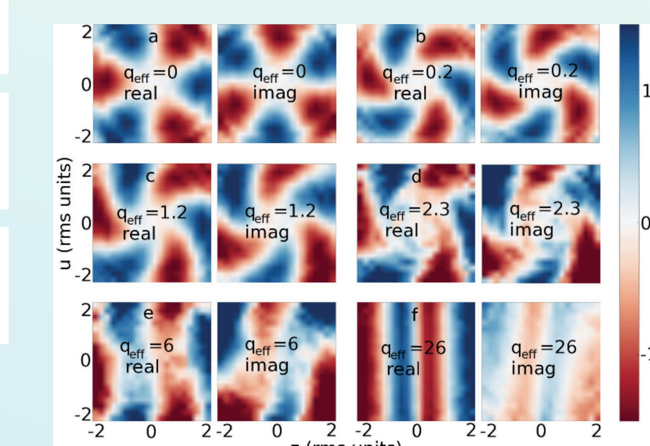


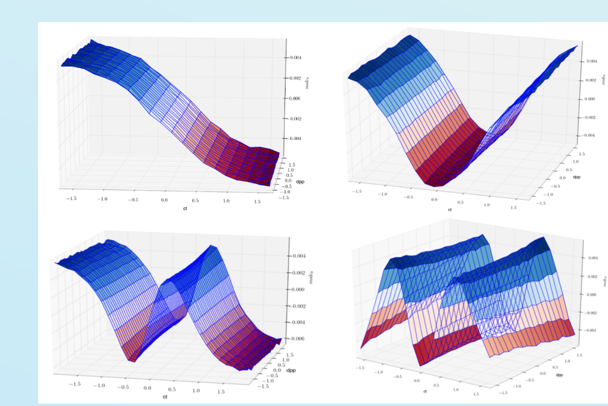
Synergia multi-bunch simulations of slip-stacking in the Fermilab Recycler are preparing for the higher intensities of PIP-II



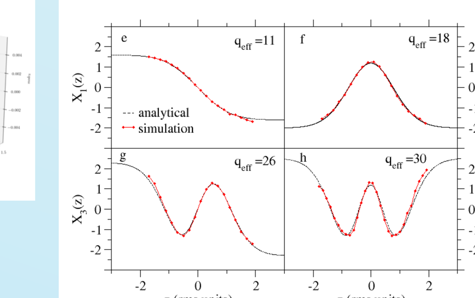
Large-scale Synergia multi-bunch studies of the Fermilab Booster have revealed the precise source of a wakefield-initiated instability



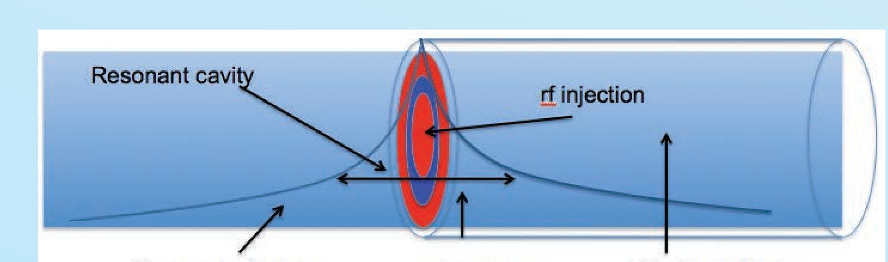




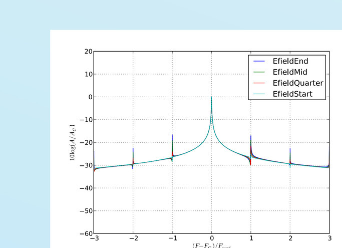
The first four modes of a 3D-G bunch in the strong space charge regime.



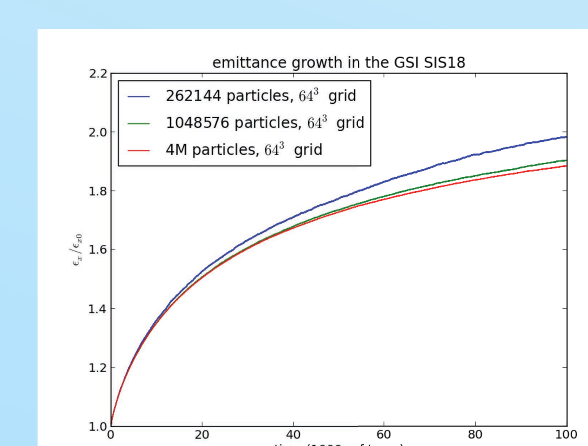
Synergia simulations of theoretically predicted space charge modes have advanced our understanding of the effects of space charge on beam dynamics in the Fermilab Booster and elsewhere



Multiphysics modeling with PIC/Plasma provides understanding of Dielectric Resonant Cavity rf Diagnostics of Electron Cloud Effect



Simulated spectrum showing side bands from frequency modulation, that are generated by harmonic modulation of electron cloud density (dielectric tensor)



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"

Simulations in support of the LHC Injector upgrades have lead to the largest-ever PIC beam dynamics simulations