Advanced Computation for High Intensity Accelerators

J. Amundson, P. Lebrun, Q. Lu, A. Macridin, L. Michelotti, C.S. Park, S. Sehrish, P. Spentzouris and E.G. Stern
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

***Abstract*—The ComPASS project is a US DOE SciDAC-funded collaboration of national labs, universities and industrial partners dedicated to creating particle accelerator simulation software. The future of particle physics requires high-intensity accelerators, whose planning, construction and operation require high fidelity simulations. We describe the methods and algorithms the ComPASS collaboration has employed to produce software capable of efficiently utilizing today's and tomorrow's high performance computing hardware. We also present the results of some key simulations and show how they are advancing accelerator science.**

I. Introduction

The future of particle physics requires particle accelerators capable of handling higher intensity beams than ever before achieved. Such high-intensity accelerators are typically limited by collective effects among the particles in the beams because these effects scale with the number of particles in the beam. The Community Project for Accelerator Science and Simulation (ComPASS) [1] is dedicated to creating software to support the design and operation of these machines. Since the accurate simulation of collective effects is a computationally demanding problem, we emphasize the efficient utilization of high-performance computing hardware.

We start by describing the particle physics context that defines the end goal of our accelerator physics efforts. We then discuss the methods and tools that go into creating scalable software that is capable of taking advantage of the current and future supercomputing hardware. Finally, we show some applications of our simulations to current and future accelerators including their implications for accelerator science.

II. Context

The context of our work is given by the recently released Particle Physics Project Prioritization Panel (P5) report [2], which worked to put together a unified plan for the future of the United States high energy physics program. The report identifies five scientific drivers: using the Higgs boson as a new tool for discovery, pursuing the physics associated with neutrino mass, identifying the new physics of dark matter, understanding cosmic acceleration and exploring the unknown through new particles and interactions. Three of the physics drivers (Higgs, neutrinos and new particles) require accelerator-based experiments, all of which require high-intensity accelerators.

III. Methods and Tools

Our poster displays several techniques we have used to obtain the best single-core and parallel performance from modern HPC hardware. We show how communication avoidance has improved our parallel scaling on distributed architectures. On GPU-based machines, we have combined communication avoidance with a CUDA-based implementation of our core beam dynamics application, Synergia [3], [4], to obtain better performance on a system of four Kepler GPUs than on a 128-core Xeon cluster. We also show how we have used explicit vectorization to obtain speedups ranging from $2x$ – $13x$ using several different SIMD instruction sets on Intel and POWER processors.

IV. Applications

We show select applications of our simulation software for machines that are part of the PIP program at Fermilab [5].

We show how the multiple-bunch capability in Synergia can be exploited to demonstrate *slip-stacking* in the Fermilab Recycler ring. In slip-stacking, two bunches separated in longitudinal phase space are merged to form a single high intensity bunch. We also show how we have used the multiple bunches to demonstrate the existence of a bunch-to-bunch instability in the Fermilab Booster synchrotron [6]. Our simulations demonstrate that this is a non-trivial effect requiring the simulation of many bunches.

In single-bunch simulations, we demonstrate third-integer resonant extraction from the Fermilab Delivery Ring for the Mu2e experiment [7]. This simulation required the combination of a collective effect (space charge) with the simulation of a nonlinear resonance in the beam optics system. Finally, we show the results of the longest-ever particle-in-cell beam dynamics simulation. The simulation modeled 100,000 turns in the GSI SIS18 lattice. It required 29,779,558,400,000 particle-steps.

Acknowledgment

This work was performed at Fermilab, operated by Fermi Research Alliance, LLC under Contract No. De-AC02-07CH11359 with the United States Department of Energy. It was also supported by the ComPASS project, funded through the Scientific Discovery through Advanced Computing program in the DOE Office of High Energy Physics. We also used resources of the Argonne Leadership Computing Facility at Argonne National Laboratory, which is supported by the

Office of Science of the U.S. Department of Energy under contract DE-AC02-06CH11357.

REFERENCES

[1] J. R. Cary *et al.*, "Compass, The Community Petascale Project For Accelerator Science And Simulation, A Broad Computational Accelerator Physics Initiative," J. Phys. Conf. Ser. **78**, 012009 (2007).

[2] "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context," report of the Particle Physics Project Prioritization Panel, http://usparticlephysics.org/p5/

[3] Amundson J, Spentzouris P, Qiang J and Ryne R 2006, *J. Comp. Phys.* **211** 229–248.

[4] https://cdcvs.fnal.gov/redmine/projects/synergia2

[5] S.D. Holmes, *et al.*, "Proton Improvement Plan-II," http://projectx-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1232.

[6] A. Macridin, J. Amundson, P. Spentzouris, V. Lebedev and T. Zolkin, "Transverse Impedance and Transverse Instabilities in Fermilab Booster," FERMILAB-CONF-13-431-CD.

[7] C.S. Park, *et al.*, "Non-linear Optimization Studies for the Resonant Extraction at Fermilab," in preparation.