High-quality Spin-polarized Beams Enable More Efficient Experiments at RHIC

The goal of the RHIC spin program is to improve our understanding of the origin of nuclear spin.
This goal is central to nuclear science:

> "*A fundamental challenge for modern nuclear physics is to understand the structure and interactions of nucleons ….*
> *The solution of the spin puzzle … remains incomplete.*"
> Source: *The Frontiers of Nuclear Science*, the Nuclear Science Advisory Committee's December 2007 Long Range Plan

Higher polarization yields better data,
because statistical uncertainties $\sim 1/Polarization^2$.
This means better data for a fixed cost.

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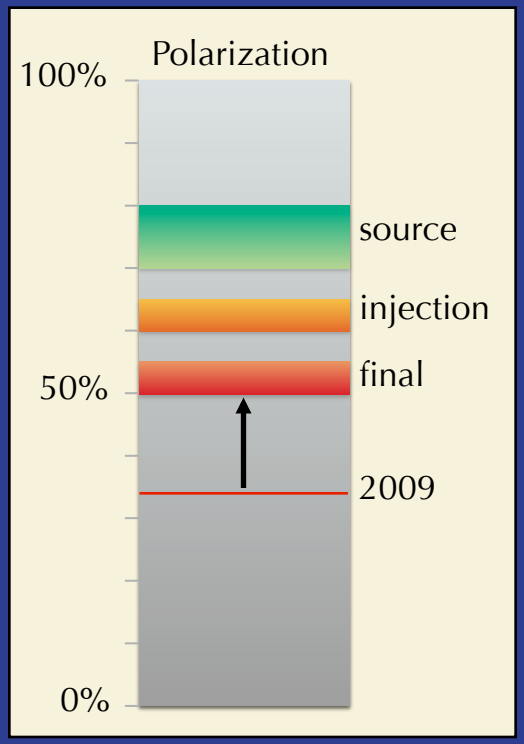
Collaborators at BNL: Mei Bai, Vahid Ranjbar

Optimization is Needed, But Trial and Error is Costly and Difficult



Statistical uncertainties ~1/*Polarization*^{2}
⇒Optimizing the beam is essential for efficient physics results.

Using machine time for optimization is expensive (RHIC is $150M/yr = $17k/hr, 20 cryoweeks/yr = $45k/hr).

APEX (accelerator physics experiments) *c.* 12h/wk over three years improved polarization from 34% to 52% ($15-33M).

New lattice configurations under consideration will also require optimization.

Simulation Provides a Faster, Less Expensive Route to Highly Polarized Proton Beams

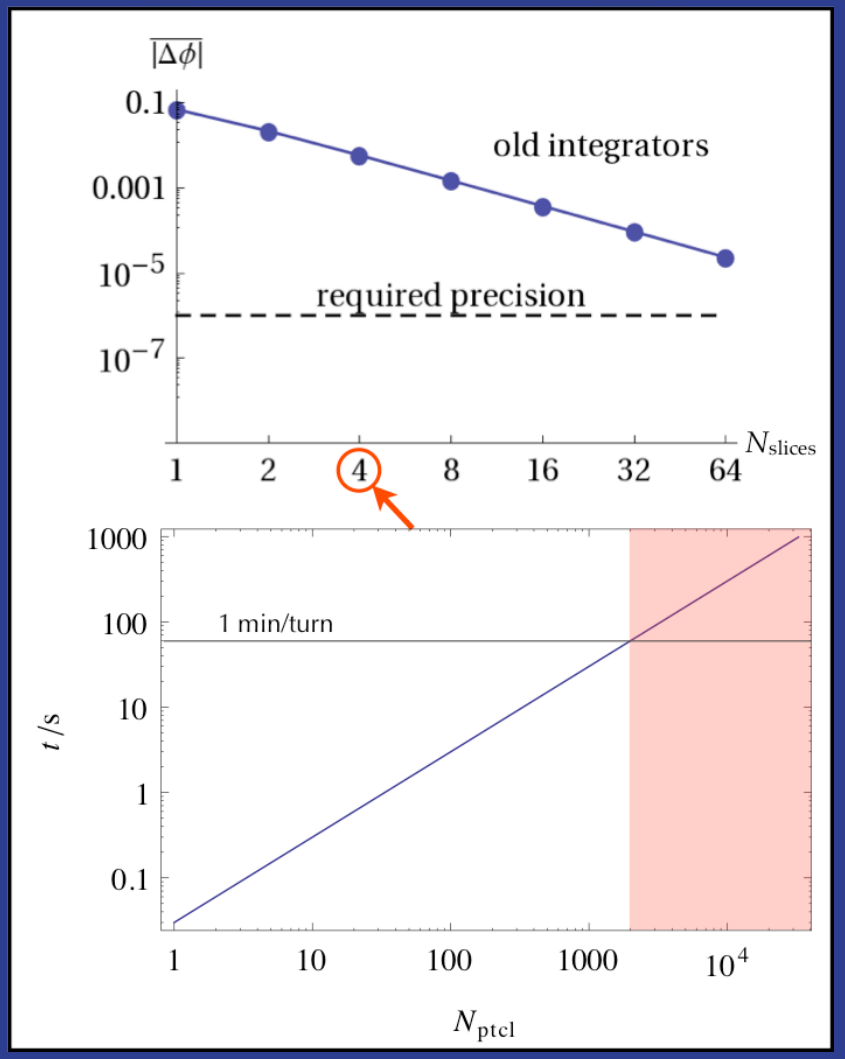
Beam simulations ...

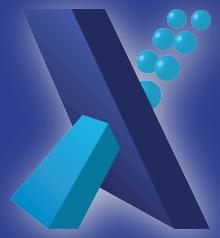
- don't interrupt machine operations;
- have much lower costs (labor & power);
- can explore a large range of possible parameters
  - close to the edge of operational safety
  - beyond limits of existing equipment (*e.g.*, to guide future upgrades)

Existing Computation Does Not Meet the Needs for RHIC Spin Tracking

The high-rate of spin precession in RHIC demands high-precision spin tracking simulations.

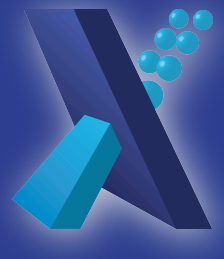
1–20 minutes per turn for inadequate precision … and useful simulations require *thousands* of turns
⇒ weeks of simulation time





Tech-X Domain Knowledge and Expertise to know and do what is needed

- Many years of experience with orbital tracking in accelerators
- Five years of experience with spin-orbit tracking
- Five years of experience in GPU development for scientific applications and consulting
- GPU acceleration of legacy codes: Elegant, PETSc, …
- GPU acceleration of core components of Vorpal
- Development of GPULib, a widely used library that gives scientists the power to use GPUs from high-level languages



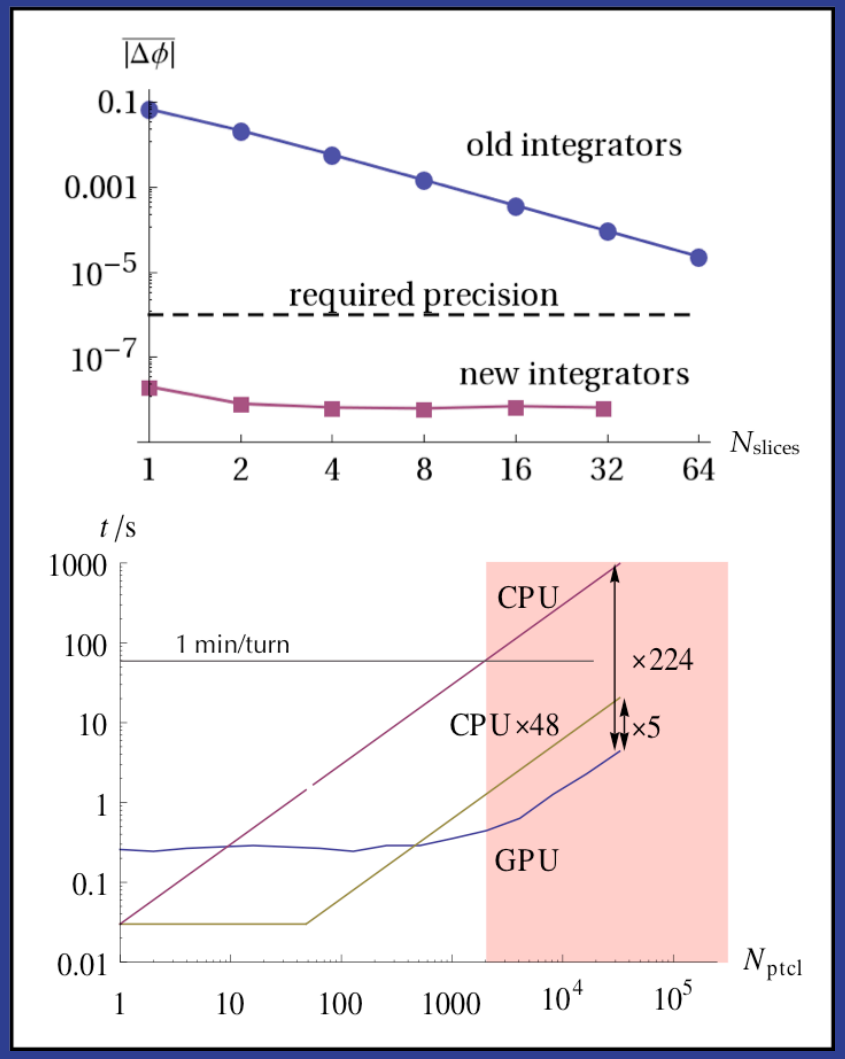
Tech-X has Improved the Speed and Usability of Spin Tracking Simulations

- New spin-orbit integrators are more accurate and much faster.
- The GPU implementation further boosts speed.
- Integrated analysis tools make it easier for scientists to examine results.
- Independent configuration of integrators simplifies the testing of approximations.
- The Bilder-ized build system streamlines development and testing of new ideas.

New integrators are *more* accurate and *much* faster

Improved orbital integrators and new spin-tracking techniques yield greatly improved accuracy.

< 10 secs per turn
at better than required precision
⇒ a few hours of simulation time



Department of Energy
Office of Nuclear Physics

DE-SC0004432 – Tech-X Corporation
gpuSpinTrack — GPU Acceleration of Spin Tracking in Colliding Beam Accelerators

DoE Need

The Nuclear Science Advisory Committee has identified the still mysterious origin of nuclear spin as one of the fundamental challenges for modern nuclear physics. RHIC is the only machine now capable of colliding polarized protons, which makes it a unique tool for exploring this important question.

Higher beam polarization will yield better data, at fixed cost, from experimental runs. Faster and more accurate spin-tracking simulations will help scientists understand how to improve the beam polarization in RHIC. Higher polarization will in turn help the RHIC spin program meet its goal of improving our understanding of the origin of nuclear spin.

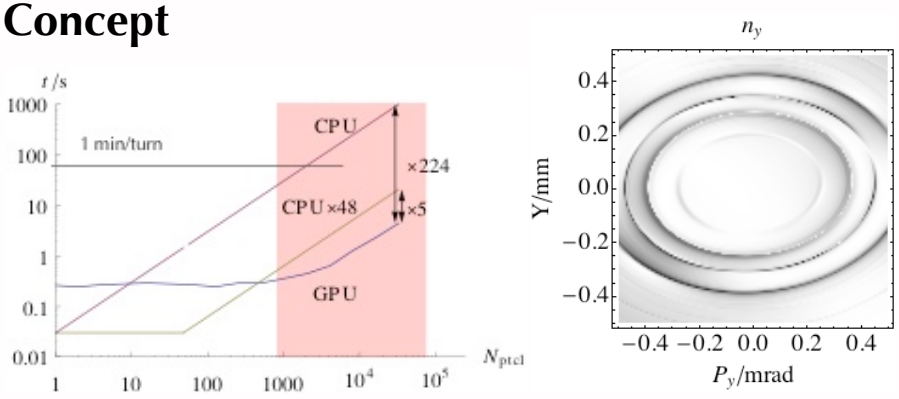
Approach for this Project

Newly developed spin-orbit integrators improve both accuracy and speed. We have implemented them for GPUs. As a result, the time to perform useful simulations has been cut from weeks to hours.

Our new, streamlined build system for gpuSpinTrack provides fast recompilation during development and testing. Newly developed infrastructure for synchronizing data between the CPU and GPU allows us to easily integrate important analysis tools into gpuSpinTrack. Moreover this analysis can be concurrent with simulation without compromising performance.

Tech-X is developing a graphical user interface that will make it easier to use gpuSpinTrack in the context of spin tracking projects.

Concept



Tech-X provides better and faster tools for tracking … and analysis.

Project Progress & Impact

Milestone	Date
Develop infrastructure for data synchronization	Nov 2011
Develop build system and regression tests	Feb 2012
Complete improved spin-orbit integrators	June 2012
Complete spin analysis tools	late 2012
Implement realistic Snakes and rotator models	early 2013
Complete GUI implementation	spring 2013
Write documentation	mid 2013

Technology Designed for DOE Needs Faces Commercial Challenges

DOE considers a single machine when funding projects.

DOE needs extreme solutions to extreme problems.

Specifically:

- no commercial entities produce 250 GeV/nucleon beams;
- no commercial entities design or operate colliders;
- no commercial applications for spin-polarized beams.

Unlike DOD and NASA, DOE does not generally procure developments made through the SBIR program. (But this could be changed!)

New commercialization mandates require rethinking from the start

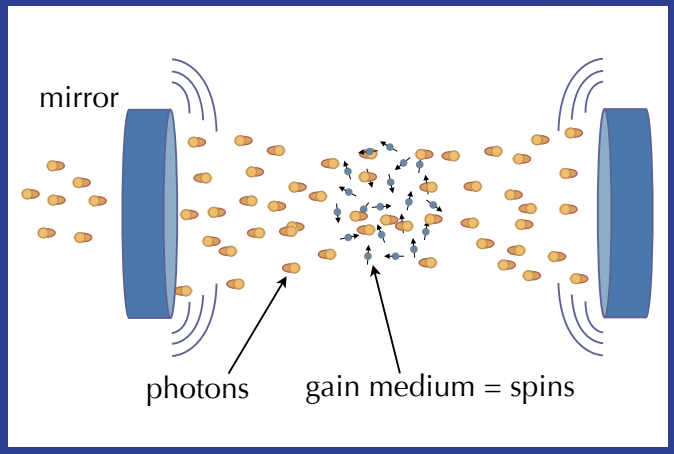
- 10-proposal limitation requires greater discrimination at the start
  - All Tech-X proposals now have a significant, commercialization part (usability, modeling within our framework)
  - We will work hard to figure out what the commercialization angle is.
- Tech-X is spending significant internal funds on marketing
  - Research
  - Branding
  - Publicity
  - Consultants for branding, releasing, research
- Tech-X has established software resellers in Asia and Europe
- Projects presented here start prior to new commercialization emphasis

gpuSpinTrack Technology Allows Us to Add Laser Device Simulations to Vorpal

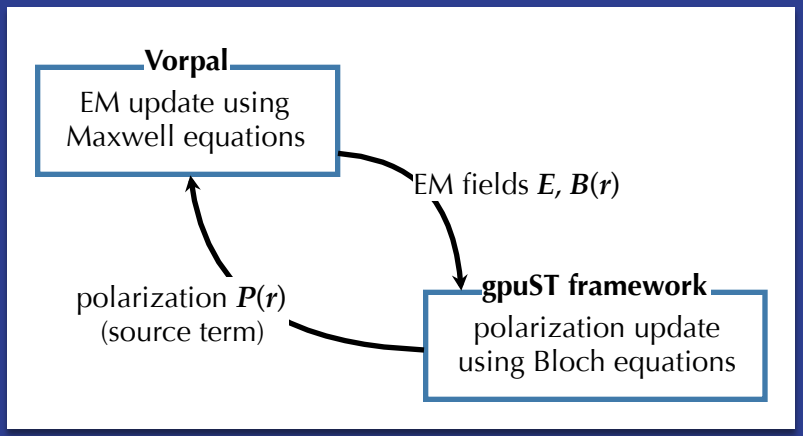
The dynamics of the laser gain medium is formally equivalent to spin dynamics:

$$\frac{\mathrm{d}\mathcal{S}}{\mathrm{d}t} = \Omega(E, B; t) \times \mathcal{S}.$$

Our GPU framework for spin tracking can be re-used for laser simulations.



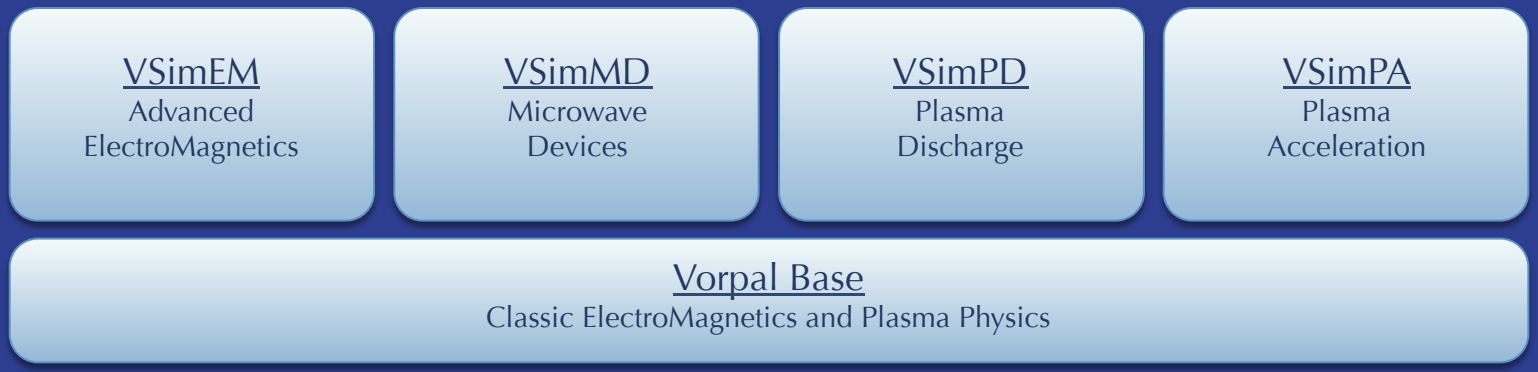
By coupling Vorpal's EM to a modified version of our gpuSpinTrack framework, we can develop a fast and accurate simulation tool for industrial lasers.



Dual Use

Tech-X Uses Vorpal Modules as Part of its Commercialization Strategy

Previous 5 years: $13M in non-SBIR revenue



New library created as part of gpuSpinTrack includes

- fast integrators for spin
- infrastructure for data transfers and synchronization
- gpu tools for data analysis

We can now develop a new, uniquely capable, Laser Device module for Vorpal.

VSimLD
Laser
Device

Market Potential for Laser Simulations

Total Market Size: $7.5 billion
Market for Simulations: ~1% = $75 million
A 2% market share yields ~$15 million

This is a realistic goal, because Vorpal will have uniquely strong capabilities in both optics and electromagnetics.

Source: Laser Focus World, "Annual Review and Forecast"
http://www.laserfocusworld.com/articles/print/volume-48/issue-01/features/economic-aftershocks-keep-laser-markets-unsettled.html

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Market Opportunity & Impact

Lasers have a wide variety of applications: telecommunications, data storage, metal processing, semiconductor and microelectronic manufacturing, excimer lithography, medical and surgical applications, instrumentation and sensors, scientific research, and military applications. Continued improvements and innovations in laser technology will benefit from accurate, detailed simulations.

Because of the similarities between the dynamics of a laser gain medium and spin, we can leverage gpuSpinTrack technologies into a uniquely capable framework for laser simulation.

These new capabilities will be packaged into a proprietary software module, VSimLD, for the commercial software package Vorpal. We estimate our potential market share as about $15M.

Technology and IP Position

A major challenge for widely applicable laser simulation software is the large variety of gain media and cavity geometries, and the many approximations suitable for different types of lasers. By incorporating technologies developed as part of this project, and leveraging the existing Vorpal application framework for electro-magnetics, we are in a unique position to provide a comprehensive, accurate, and easy-to-use tool for simulating lasers.

Tech-X protects its intellectual property through proprietary software license agreements and consulting contracts. Commercially available software is also protected by registered copyrights. The technology is protected under copyright law, though no copyright has been registered at present. We employ an external legal counsel provided by Faegre & Benson.

Product Devolopment Milestones

Milestone	Date
Develop infrastructure for data synchronization	Nov 2011
Develop build system and regression tests	Feb 2012
Complete improved spin-orbit integrators	June 2012
Complete spin analysis tools	late 2012
Complete GUI implementation	spring 2013
Implementation of VSimLD	mid 2013
Release of Vorpal 7.0	late 2013

Company/Team & Business Model

Tech-X, founded in Boulder, CO, in 1994, now has staff of more than 70 employees, about two-thirds of whom have a Ph.D. in a relevant technical discipline. The company has strong expertise in computational physics (plasma physics, accelerator modeling, fusion theory, fluid dynamics, multi-physics simulations), middleware (CORBA, DDS, GRID), scientific visualization and data analysis, climate modeling, as well as high-performance and distributed computing (including GPU computing) applied to engineering and scientific applications.

Development of the Vorpal VSimLD module will enable targeted marketing of Vorpal to the laser optics community.