gpu-Accelerated Spin Tracking for Particle Accelerators

Tech-X
- a computational sciences company

Project Motivation & Initial Accomplishments
- DOE need; gpuSpinTrack; accomplishments

Production Phase – Improvements to Usability
- spin analysis; build system; interface; documentation; publications

Impact & Future
- gpuSpinTrack at BNL; future work; benefits to Tech-X

SBIR/STTR Exchange Meeting
6–7 August 2014, Gaithersburg, MD

PI: Dan T. Abell
Tech-X: Dominic Meiser (physics, GPU), Jacob King (GUI), Cory Perry (GUI)
BNL Collaborators: Mei Bai, Vahid Ranjbar

Tech-X Has a Long History of Addressing DOE Computational Needs

Tech-X has extensive experience with parallel computing, now in both MPI and GPU settings and on a range of platforms, from laptop to LCF.

Tech-X uses its computational expertise for scientific discovery.

Tech-X research covers a broad range: from fusion science to photonics to accelerator physics – including studies of electron cooling and our work on gpuElegant.

Tech-X has been one of the few companies to be included in and to have led SciDAC missions. These efforts include both ComPASS and FACETS.

High-quality Spin-polarized Beams Enable Efficient RHIC Operation

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 ~$1/\mathit{Polarization}^2$.
This means better data for a fixed cost.

Plenty of room for improvement: P_{source}≈70–80%, P_{final}≈50–55%

gpuSpinTrack: A Tool for Optimising Beam Polarisation

We are making gpuSpinTrack into a tool that helps scientists optimise beam polarisation more quickly and less expensively than using machine time.

Speed and Usability are critical. We therefore

- build on prior efforts of DOE scientists => Teapot + Spink;
- accelerate spin tracking by porting code to gpus;
- add a build system to make code easier to develop and install;
- develop documentation to make the code easier to use;
- implement better algorithms to achieve high-order accuracy;
- use canonical algorithms to preserve phase-space geometry.

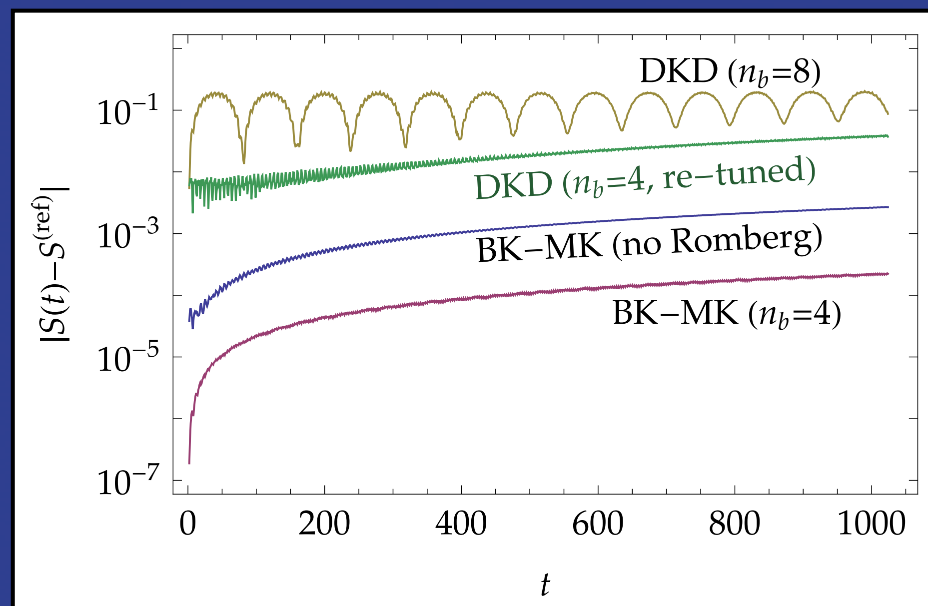
We Achieved Major Algorithmic Improvements in Year I

Separating the original monolithic gpu kernel into kernels for individual elements simplifies the logic and testing of each kernel, and also our implementation of dynamic lattices.

Implemented improved orbital tracking, which automatically improves spin tracking.

Simple “algorithmic add-on” improves spin convergence by orders of magnitude!

Initial improvements to build system simplify development.

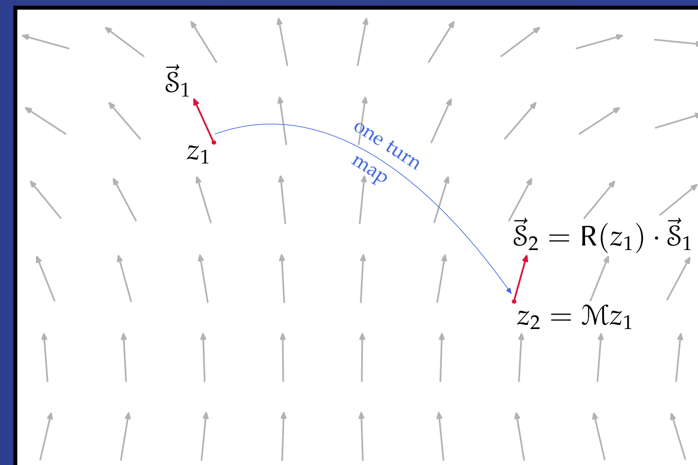


gpuSpinTrack Includes an Essential Tool for Optimising Spin Polarisation

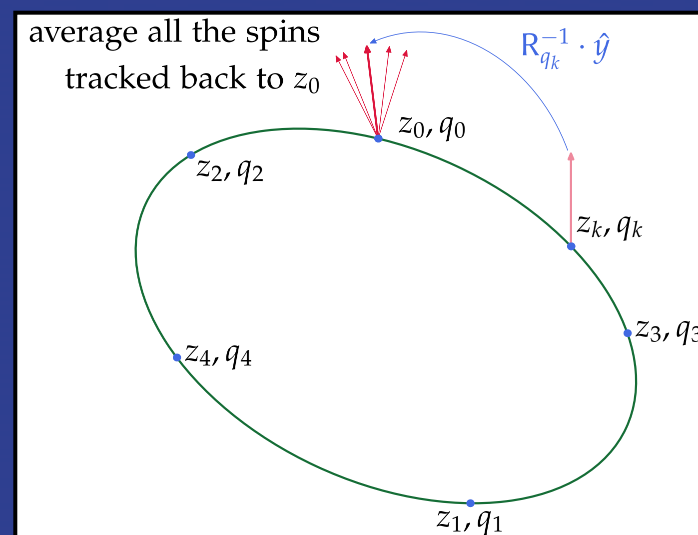
The Invariant Spin Field (ISF) places an important upper limit on the maximum attainable polarisation.

Optimising spin polarisation requires a knowledge of the ISF at a range of optical settings for a given lattice.

gpuSpinTrack now uses the *best known* algorithm for computing an ISF, so that on a GeForce GTX TITAN gpu, *computing a RHIC ISF using 10^3 turns for 10^4 phase-space locations now requires under 15 minutes of wall time.*

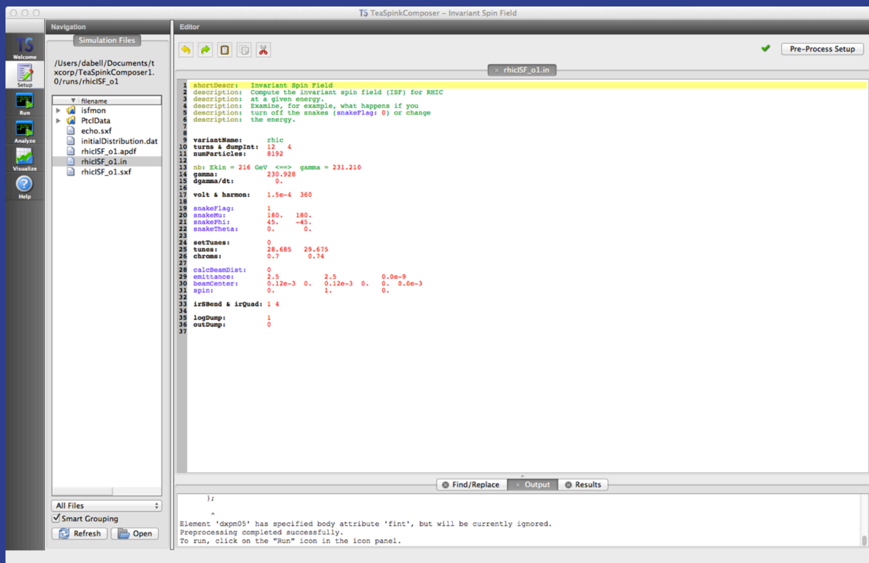


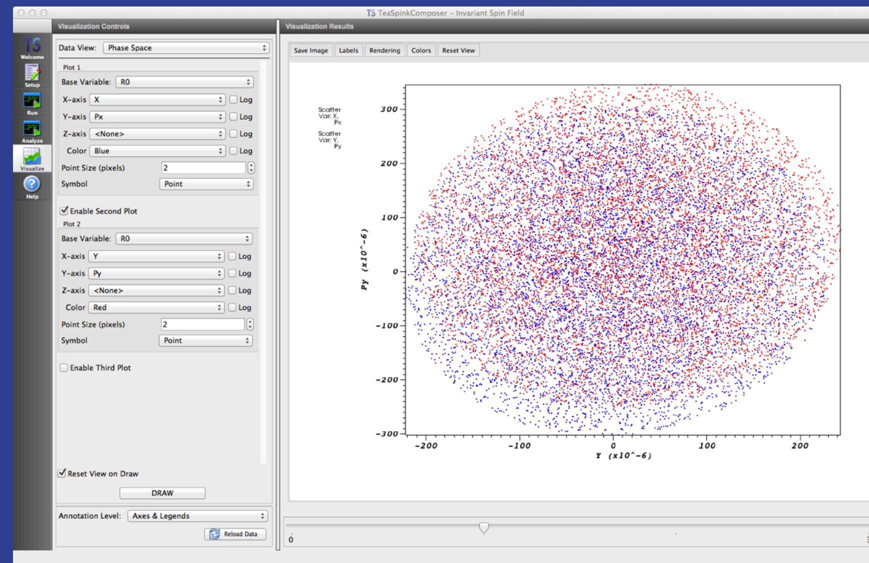
Schematic ISF

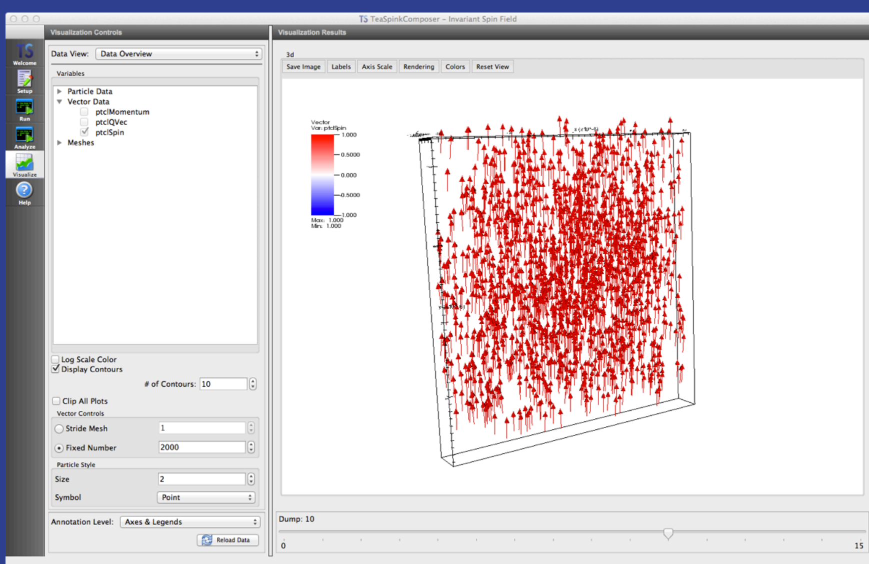


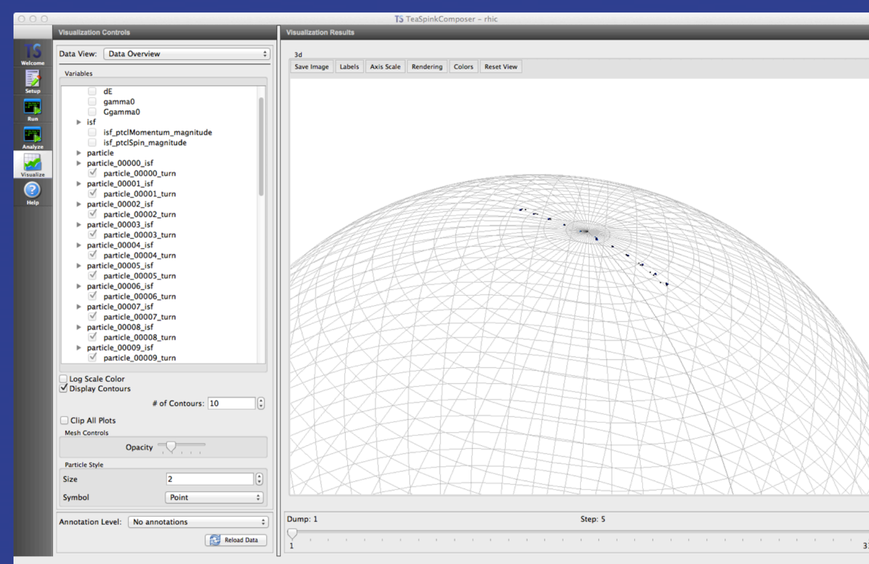
Computing the ISF

A Graphical Interface, *TeaSpink Composer*, Facilitates Data Exploration



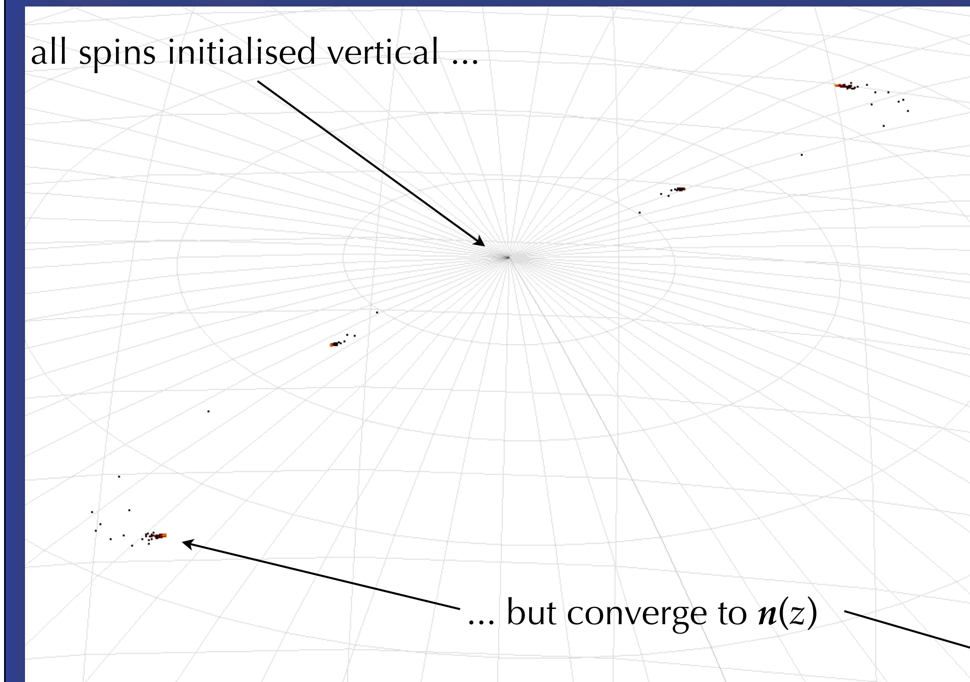


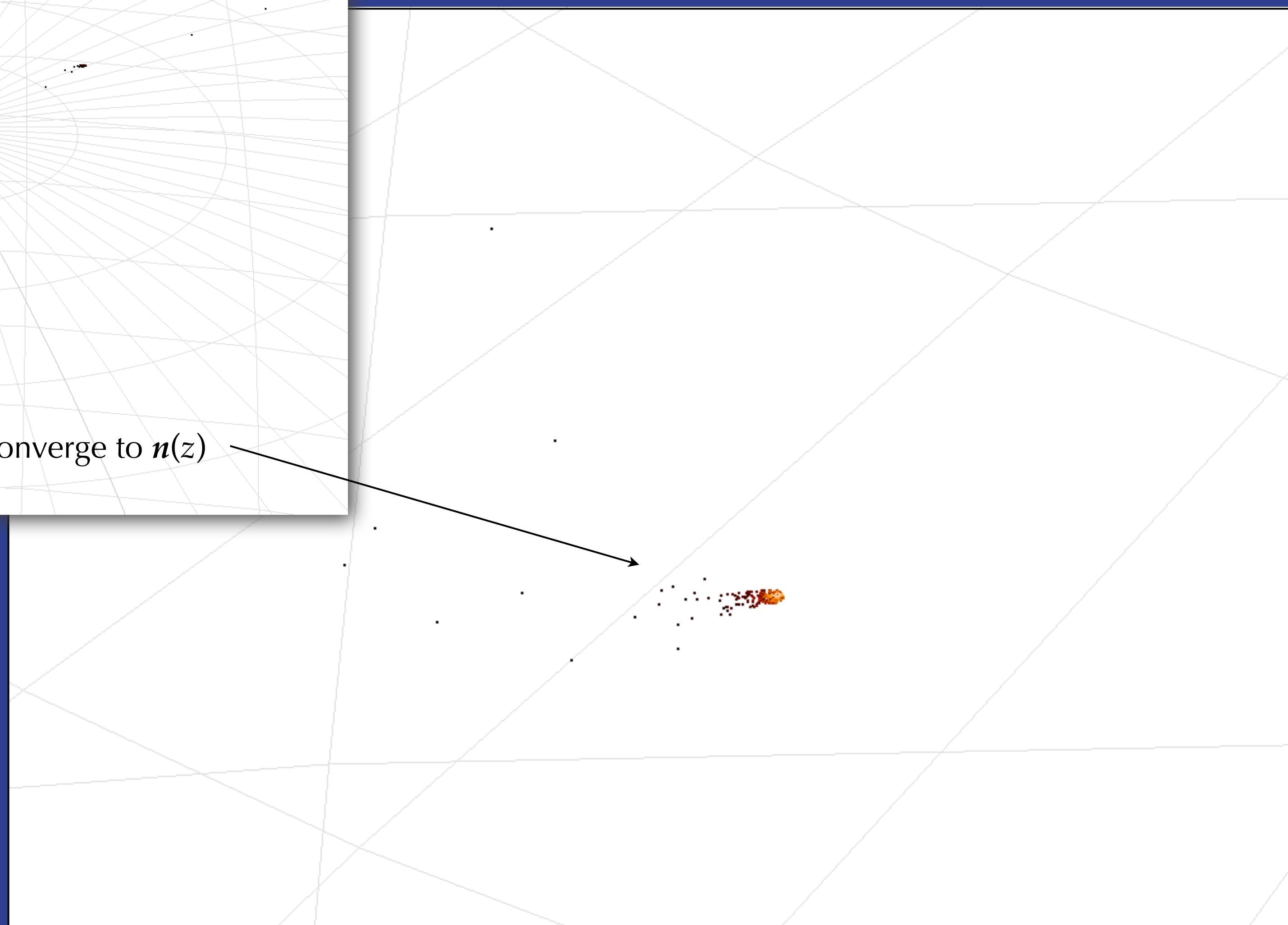




A Graphical Interface Enables Data Exploration (cont.)

... convergence of the ISF





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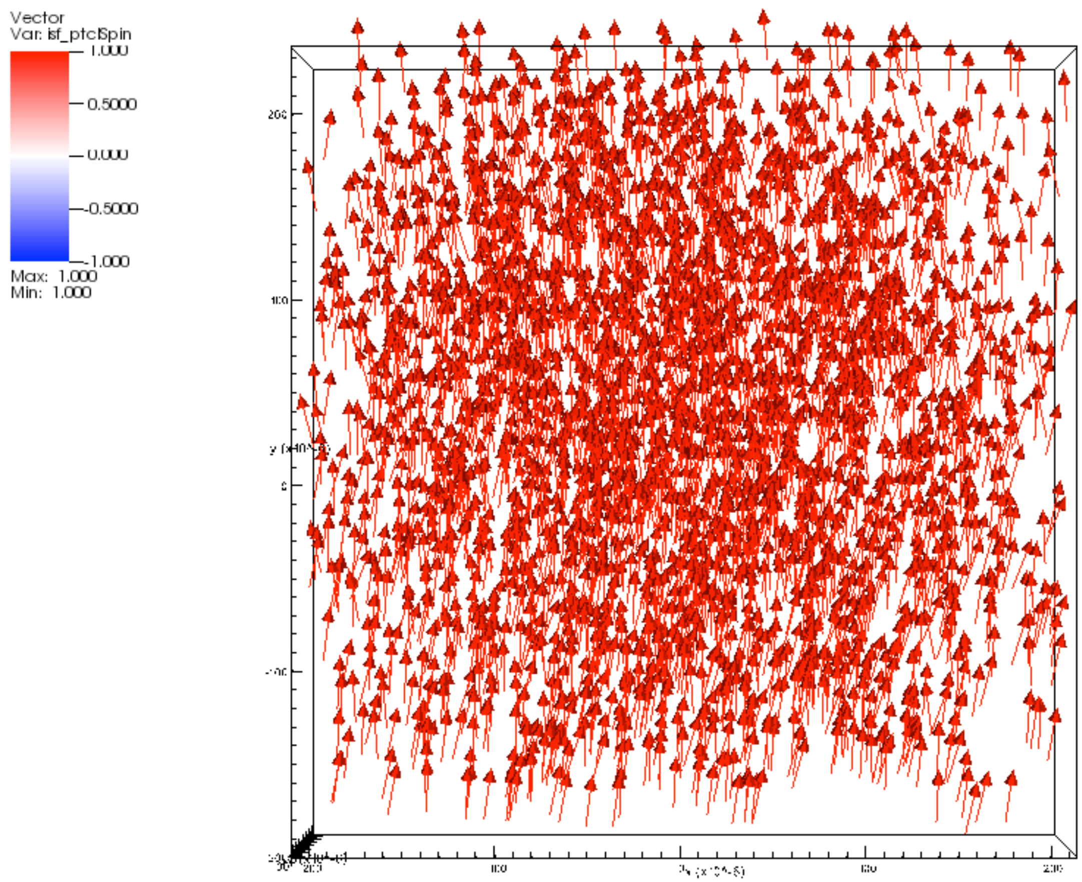
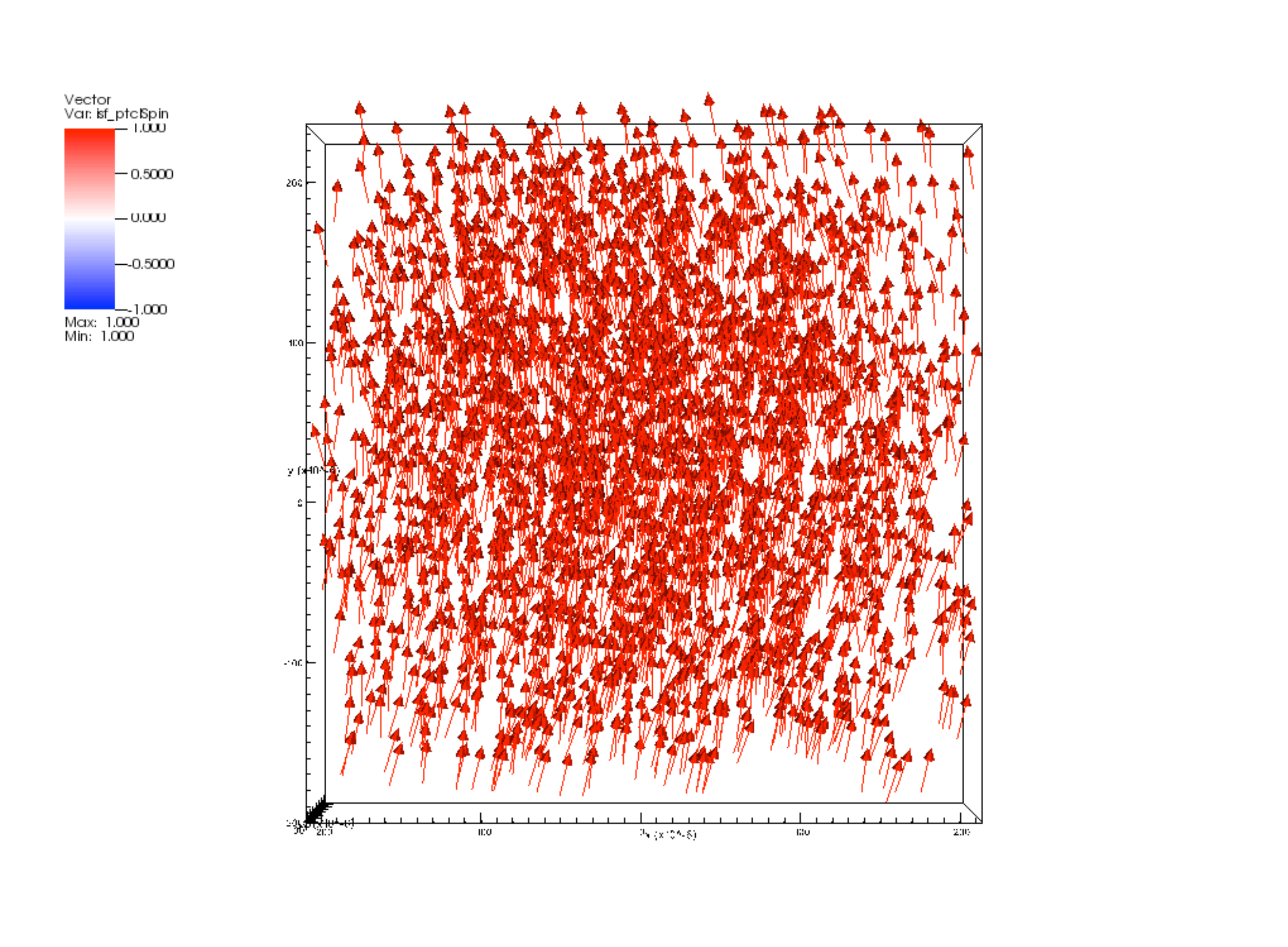


$$v_s = 414.286$$

A Graphical Interface Enables Data Exploration (cont.)



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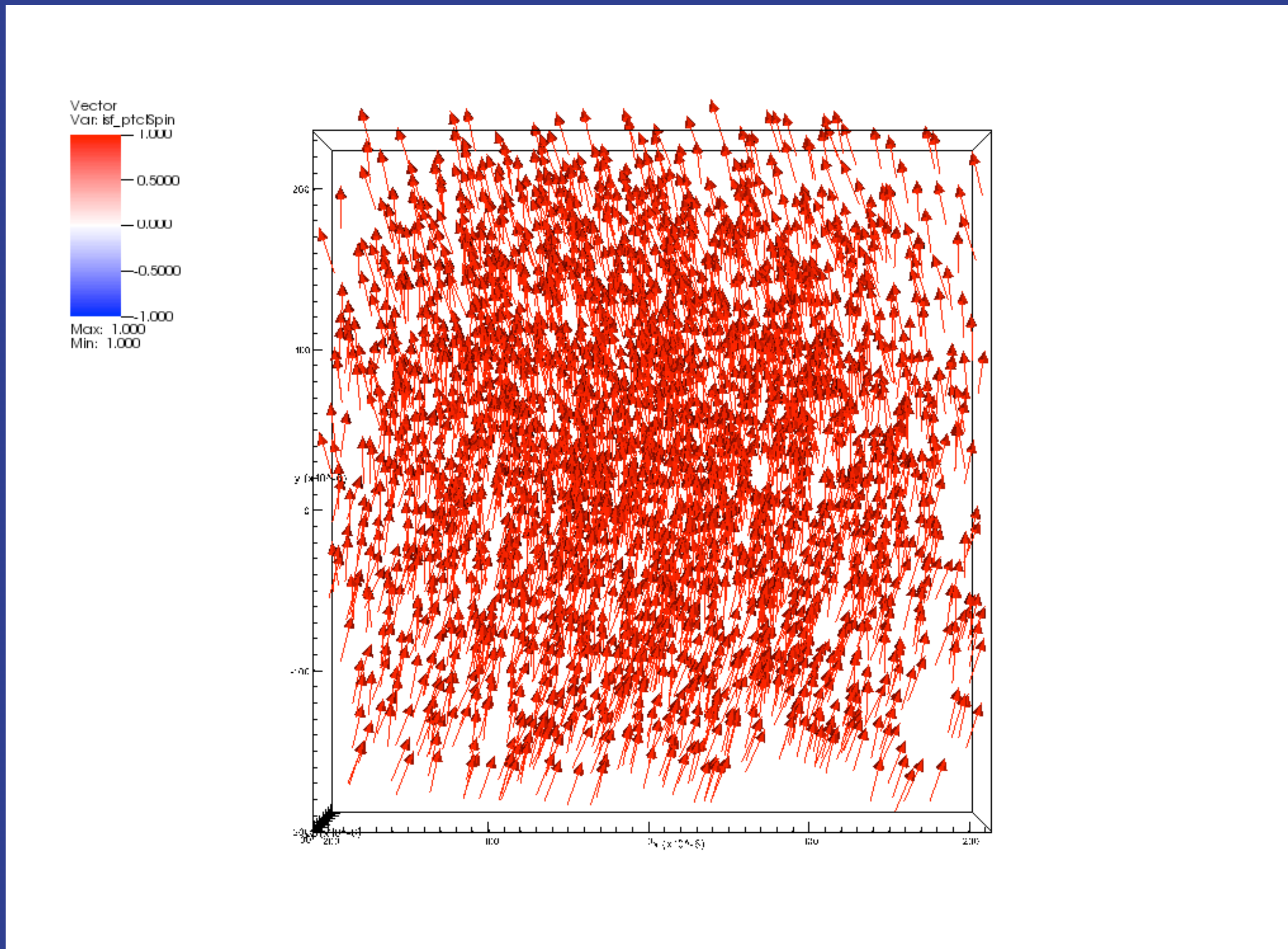

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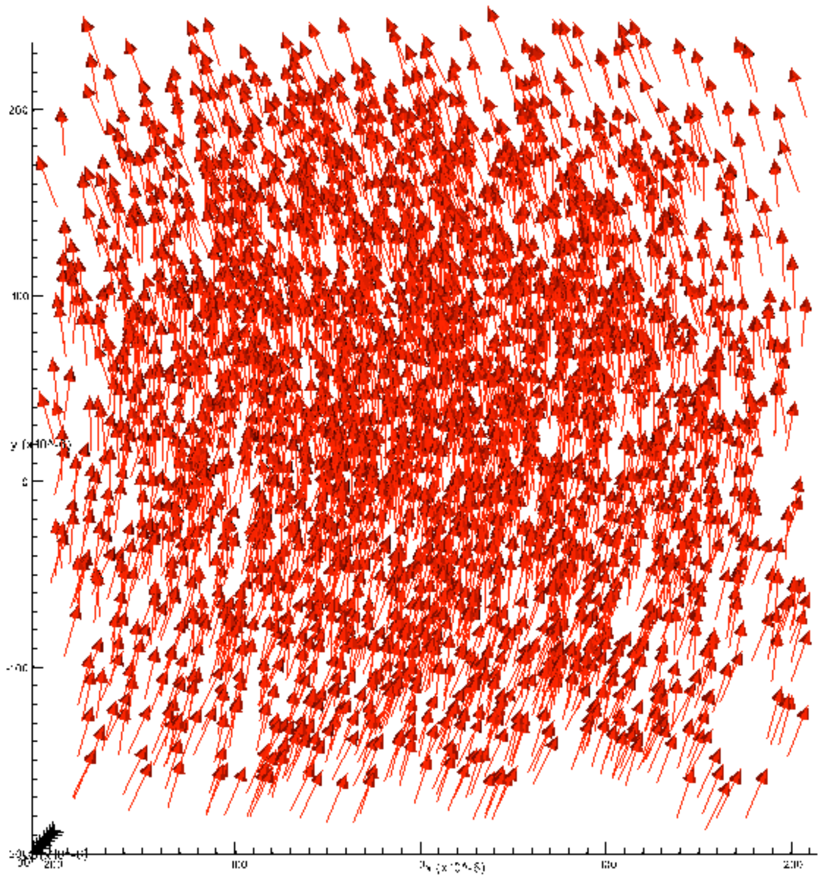

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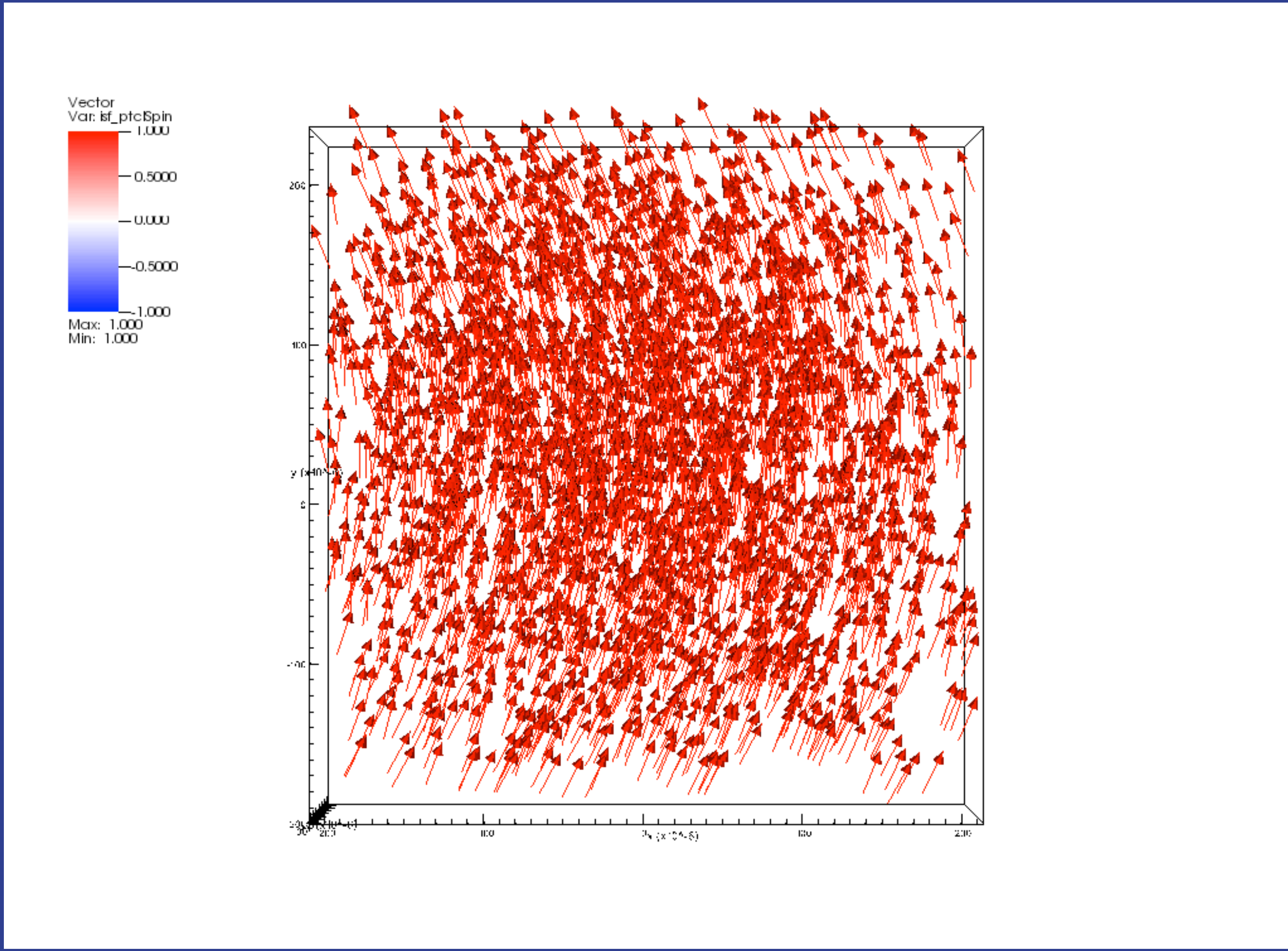

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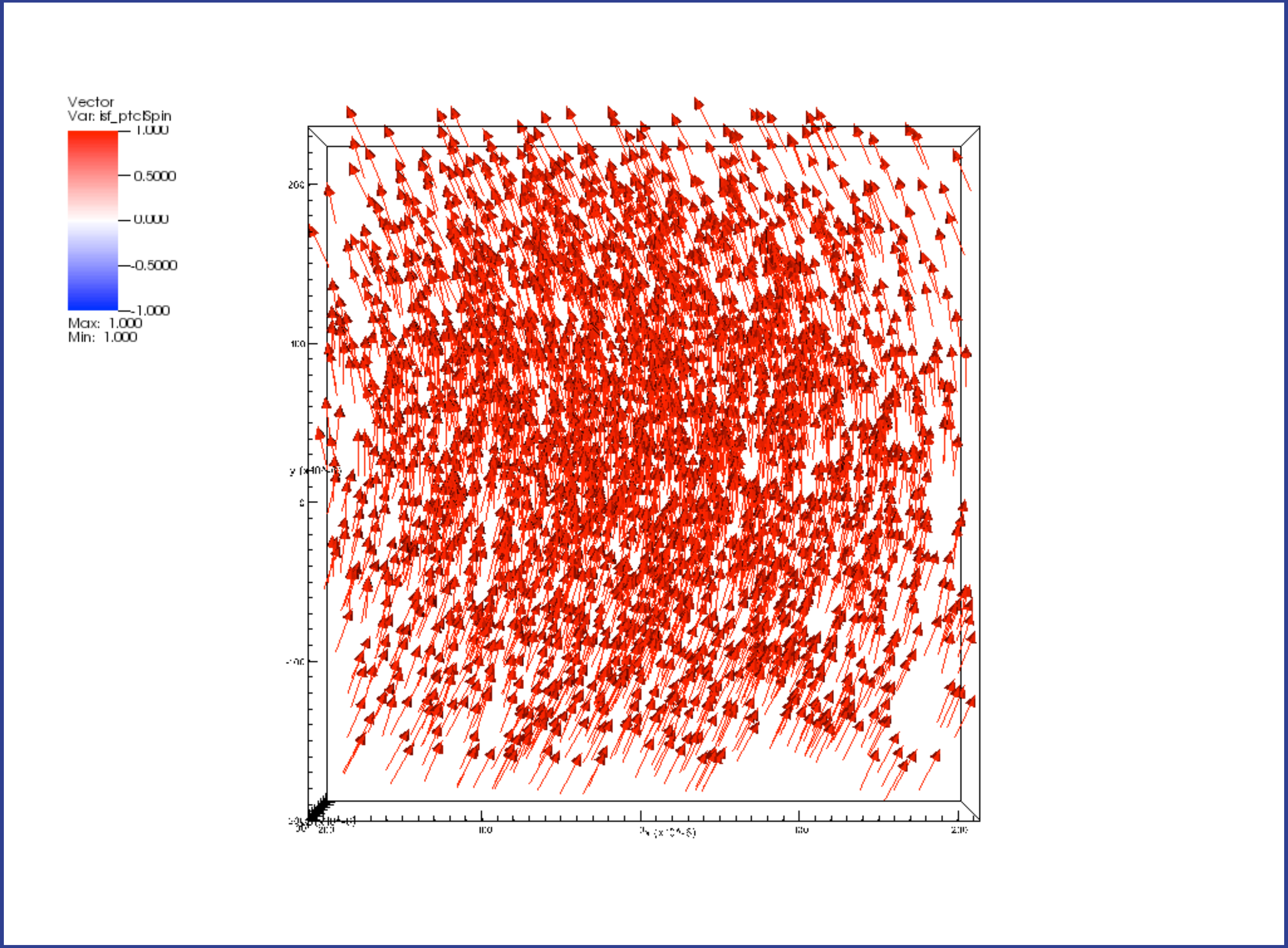

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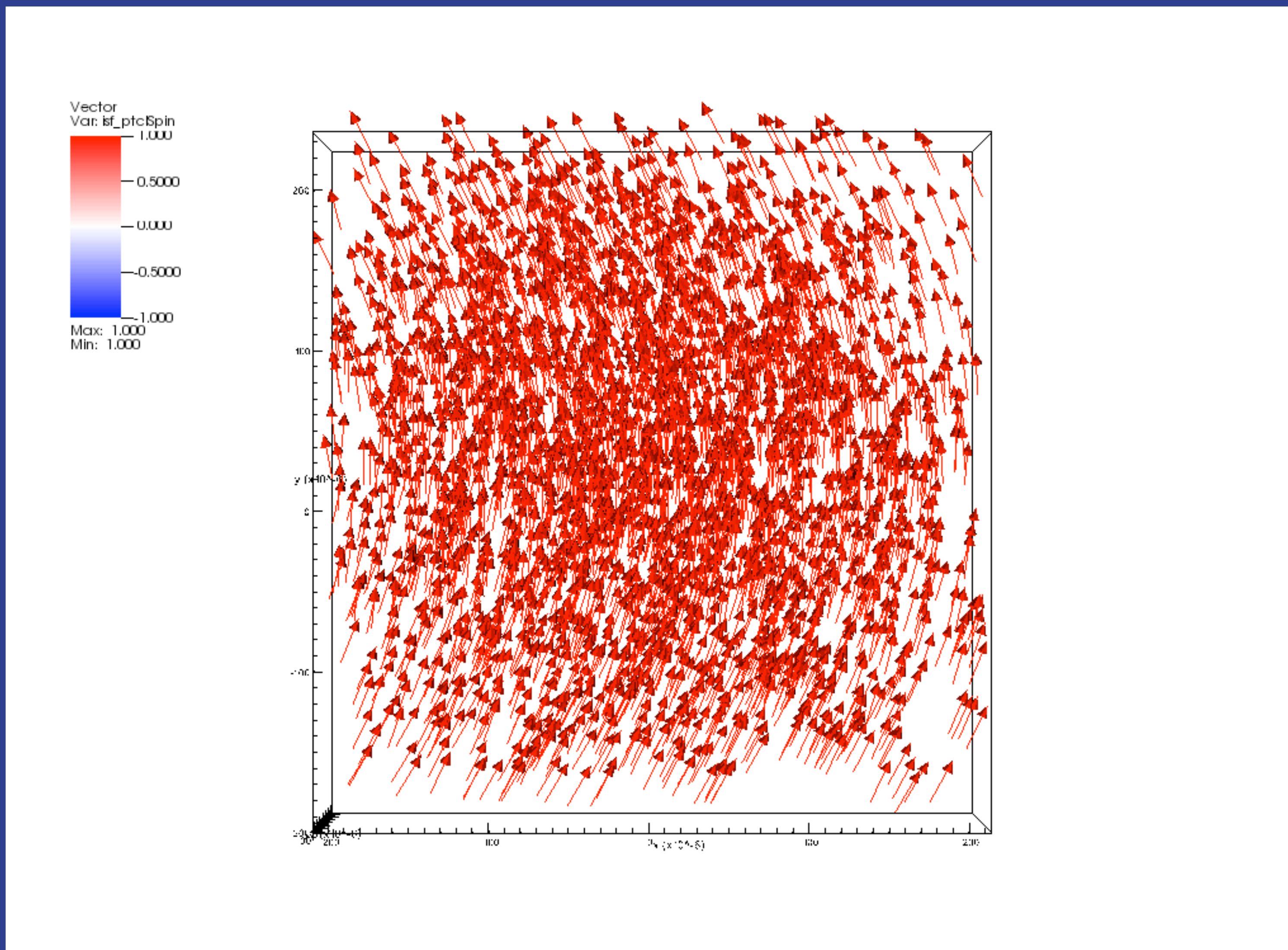

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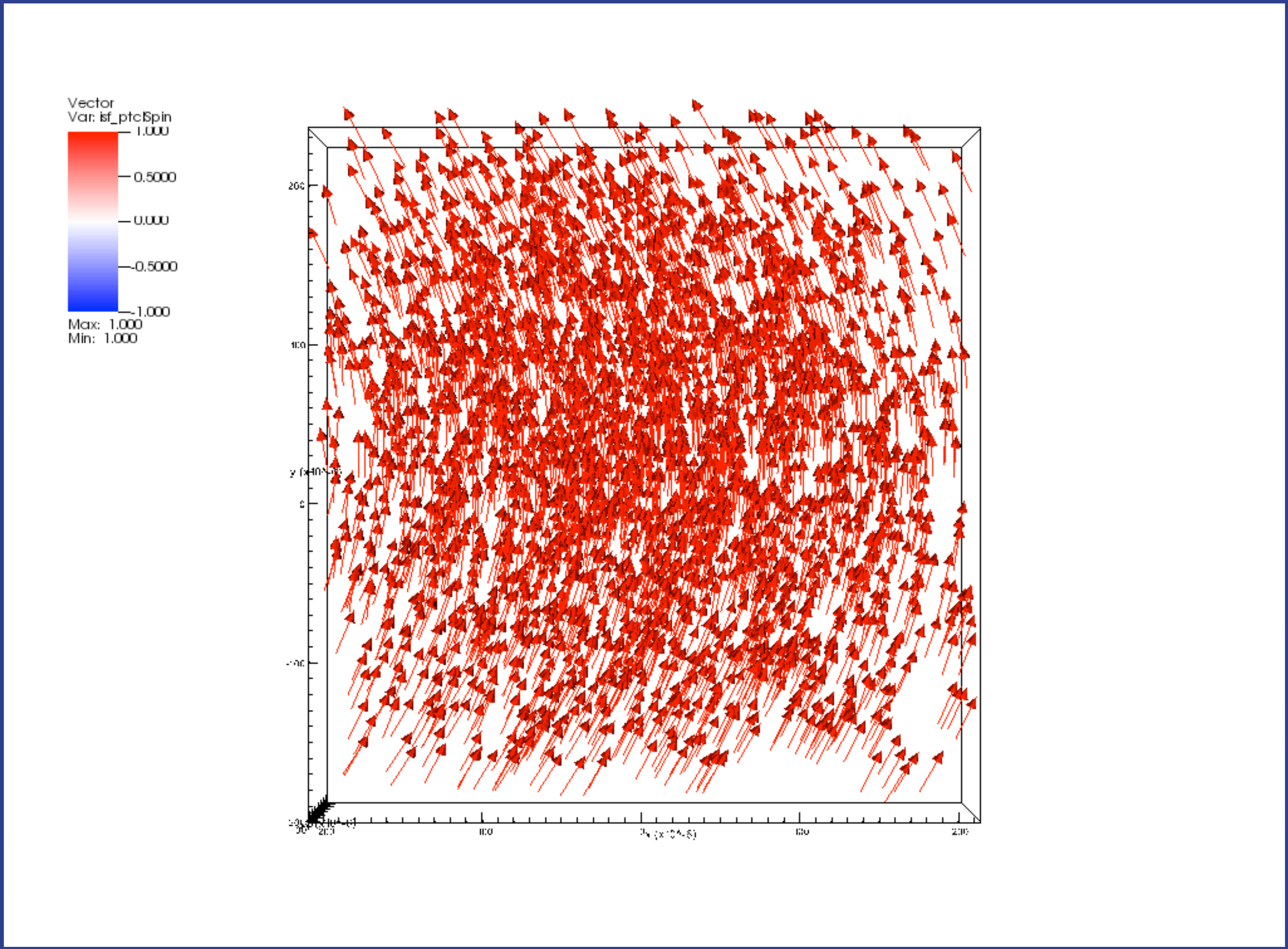

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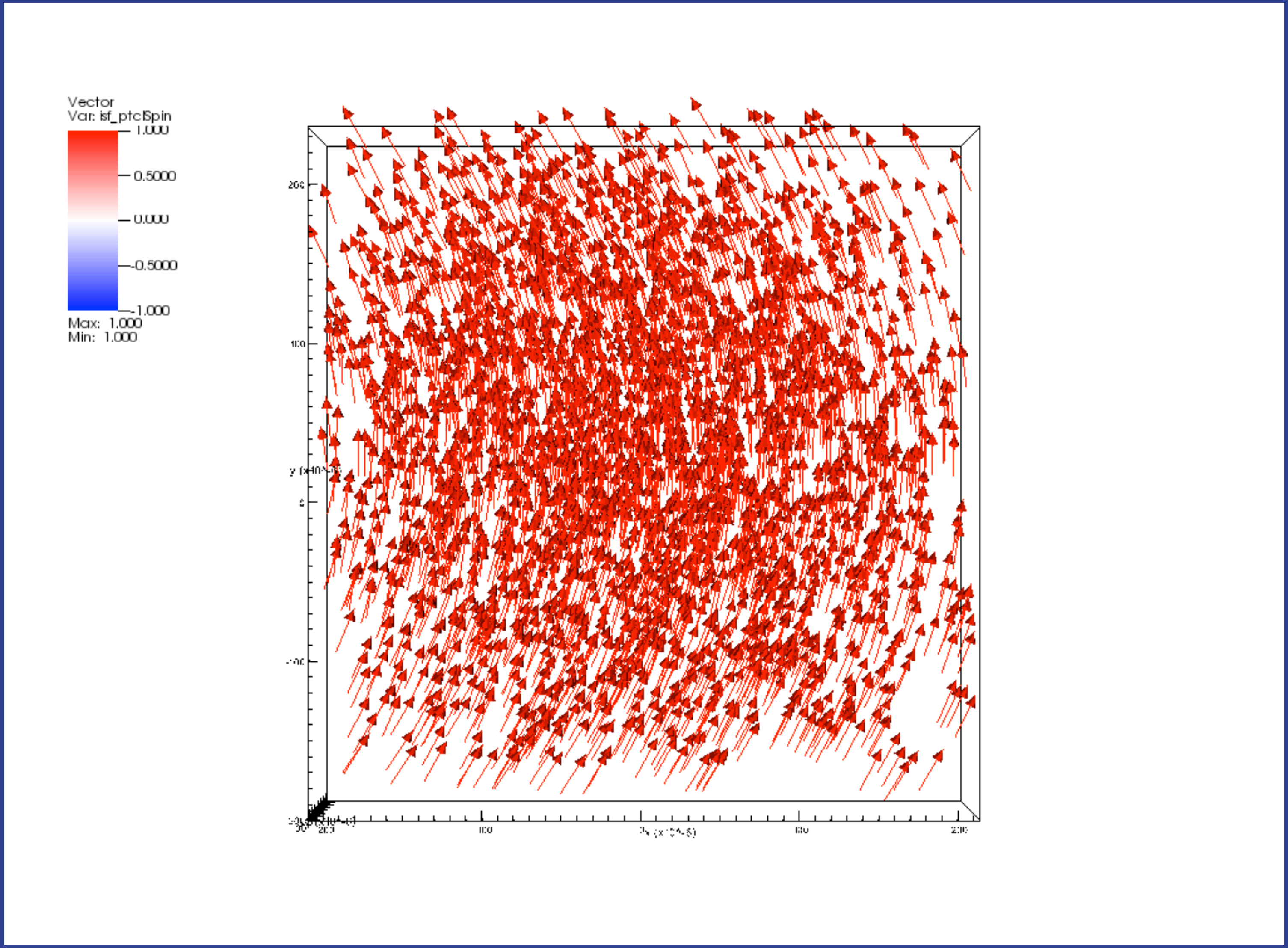

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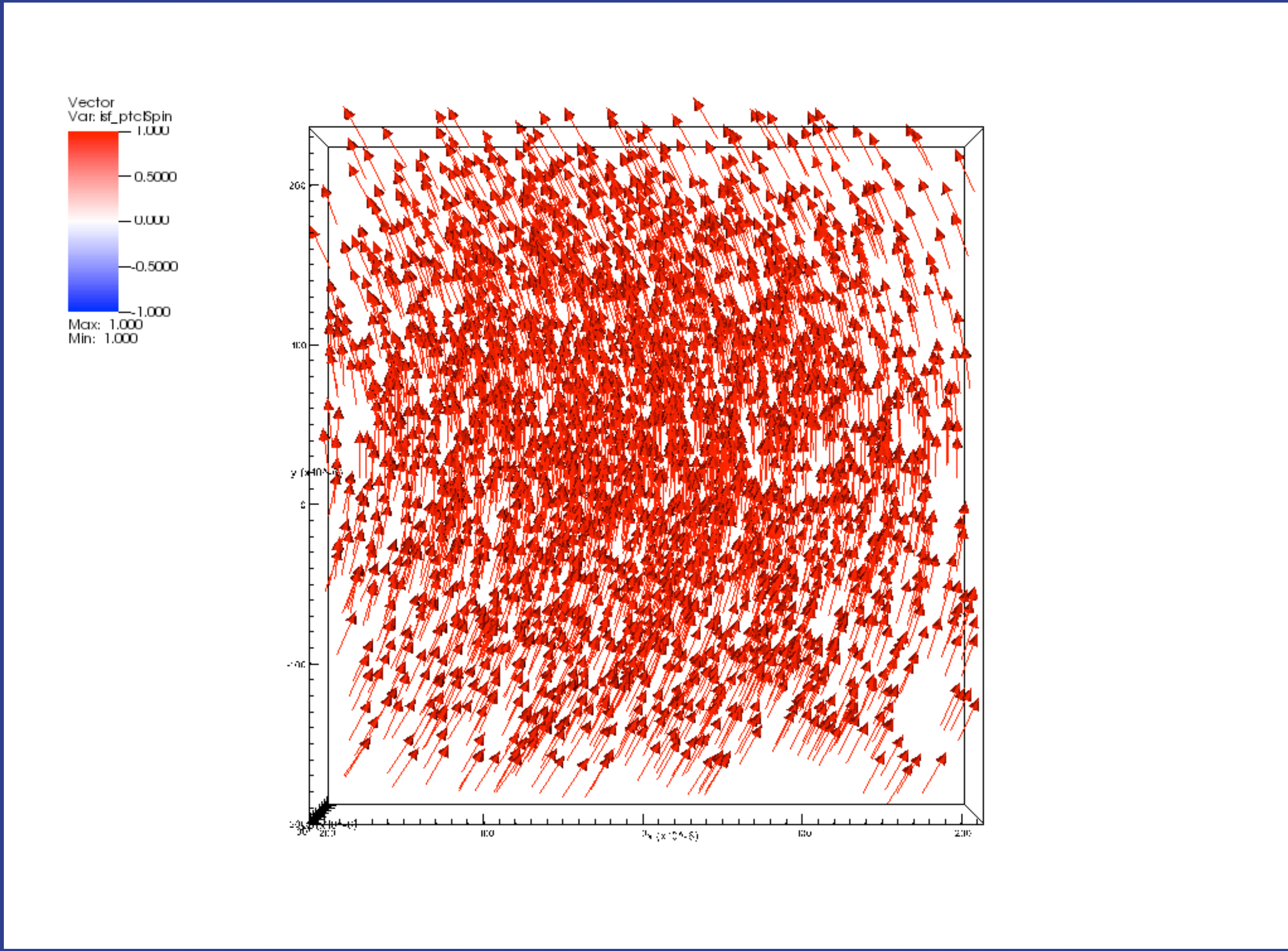

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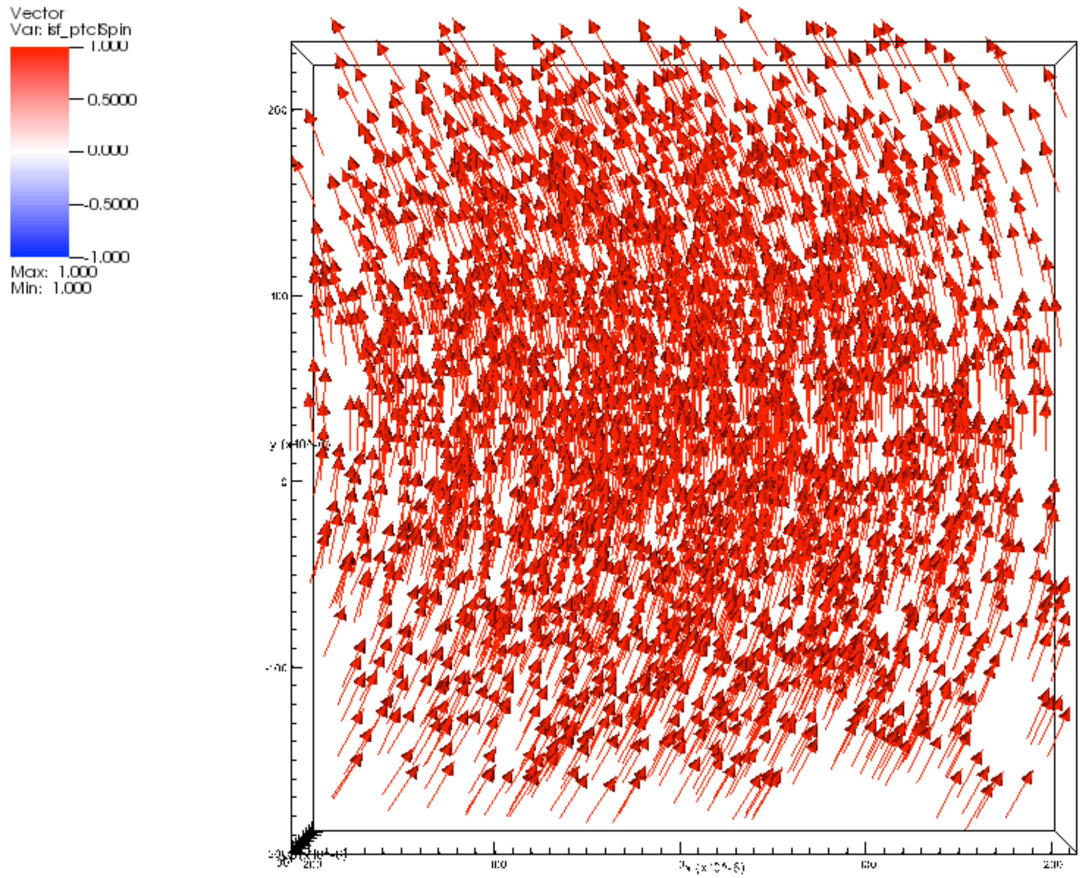


$$v_s = 415.286$$

Documentation Makes gpuSpinTrack Easier to Learn

The documentation now describes installation, input files, and parameters for all integrators. It also suggests best practices for running gpuSpinTrack.

We continue to update this document as we develop the code.

`gpuSpinTrack`: a manual

Dominic Meiser
Dan T. Abell

4 November 2013 at 12.45

Abstract

This document describes how to install and run `gpuSpinTrack`. These instructions discuss specifically how to run `gpuSpinTrack` on the NERSC GPU cluster DIRAC. Installing and running on other machines—including laptops with GPU cards—will be similar. A companion file, `gpuSpinTrack-template.tgz`, contains a sample workspace with all required input files, as well as sample shell scripts for queueing and running `gpuSpinTrack`.

Contents

1 Installing gpuSpinTrack **1**

2 Input files **3**
2.1 Simulation parameters: the .in file 3
2.2 Lattice description: the .sxf file 6
2.3 Propagator description: the .apdf file 6
2.4 Particle distribution file (optional) 8

3 Running gpuSpinTrack **8**
3.1 Recommended directory structure 8
3.2 Shell scripts for running and queueing gpuSpinTrack 12

4 Data analysis for gpuSpinTrack **14**
4.1 Data layout 14
4.2 Analysis tools 14

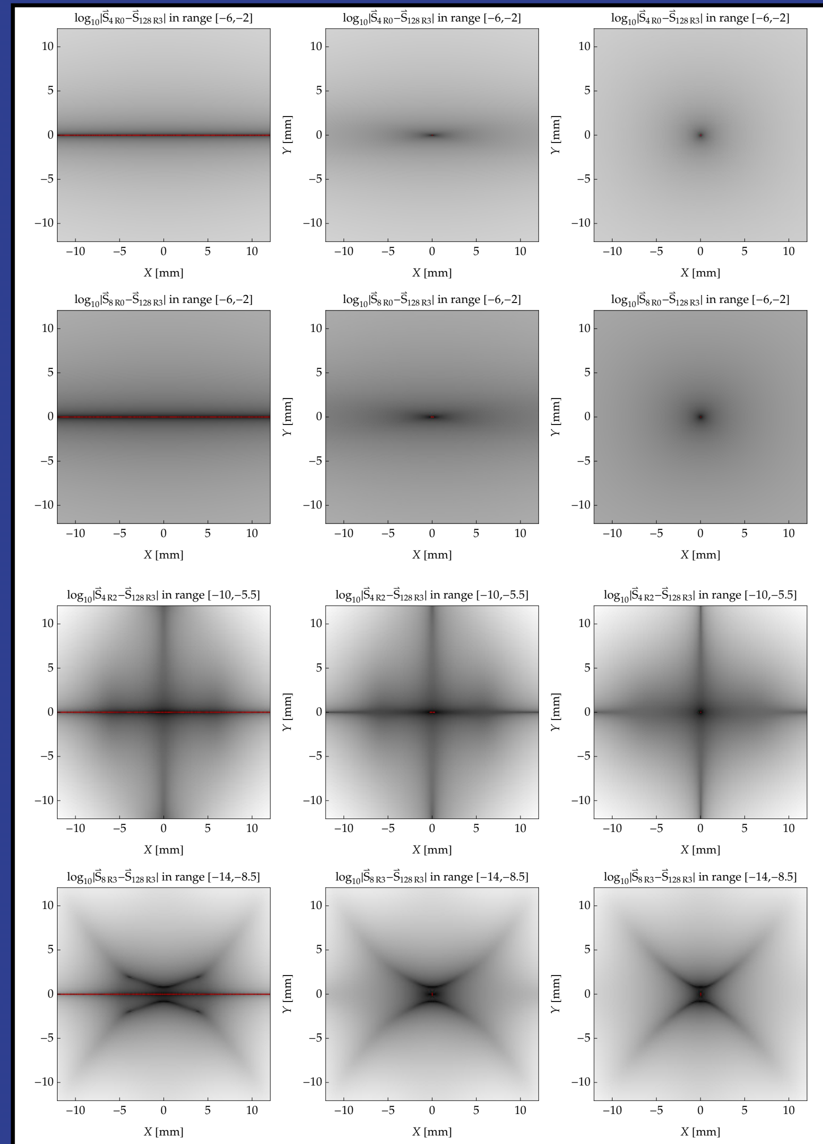
gpuSpinTrack Accomplishments Recognised through Publications

“Accurate and efficient spin integration for particle accelerators”, D.T. Abell, D. Meiser, Vahid Ranjbar, and D.P. Barber, re-submitted to PRST-AB; currently undergoing final revisions in response to referees.

This reports on an extensive study of the errors associated with our new approach to spin tracking.

“GPU-accelerated spin dynamics and analysis for RHIC”, D.T. Abell, D. Meiser, M. Bai, V.H. Ranjbar, and D.P. Barber, IPAC’13 Proceedings.

Posters presented at IPAC’12 and ICAP’12.



gpuSpinTrack Contributes to RHIC Run Decisions at BNL

Our collaborators at BNL are currently using gpuSpinTrack to analyse data from the most recent polarised beam runs at RHIC.

A decision made during the last RHIC run to return to using the standard lattice was based, in part, on gpuSpinTrack results.

That decision led to a significant improvement in the beam polarisation.

We Are Wrapping Up the Project

In the last ten months we have:

- implemented the capability to change the lattice dynamically;
- added new elements; in particular, a more realistic snake, and electro-static elements for EDM lattices;
- written more documentation;
- written the Graphical User Interface (GUI).

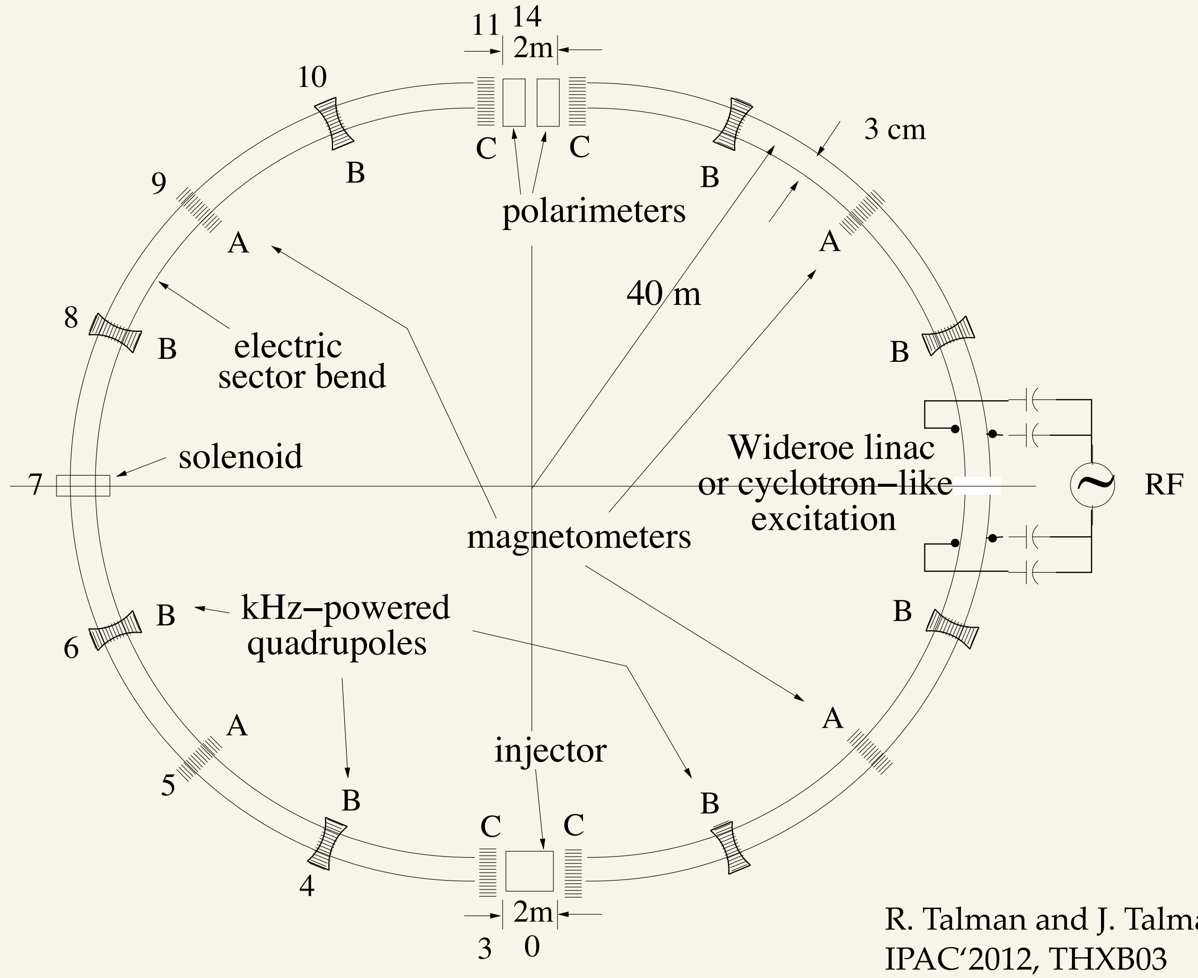
To finish up, we are

- testing the electro-static elements;
- and moving the documentation into the GUI.

What Next? Study Systematic Effects in Proposed EDM Measurements

The nuclear EDM, if present, must be extremely small.

Very accurate spin tracking is needed to "calibrate" this experiment.



R. Talman and J. Talman, IPAC'2012, THXB03

Future Work

Do some design and evaluation work (i.e. science) with this tool; in particular, for EDM and/or an electron-ion collider.

Implement electro-static fringe fields.

Implement a more accurate treatment of misalignments.

Extend the code to include synchrotron radiation effects so that we can also model electron spin dynamics (e.g. EIC / MEIC).

For Commercialisation, Tech-X Benefits From Its Expertise

Spin tracking is not inherently commercializable.

Our extensive HPC experience and our successful collaborations with DOE labs make us a strong candidate for contributing to an NP-SciDAC.

Our work on *TeaSpink Composer* builds on, and contributes to, our underlying *Composer* GUI for commercial Tech-X products.

Our expertise in gpu programming has led to numerous contracts and grants in other areas, mostly in applied math: gpuPETSc is one example.

Because of the mathematical similarities, our work on this project brings us closer to modeling active laser gain media.