

Mixing of Particles Due to Noise in Synergia

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Fermilab

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The ComPASS Project

The ComPASS Project is funded by the US DOE's SciDAC program.



Introduction

- Working on 100,000 turn run for space charge induced trapping benchmark
- Kick placement study
- Statistical noise study
- Result
- Computational aspects

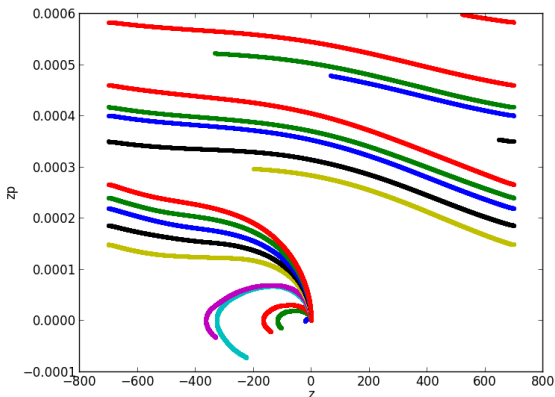
Kick Placement Study: The Problem

First:

- Longitudinal coordinates: $c\Delta t$ and $\frac{\delta p}{p}$
 - Often label these “z” and “zp”, respectively

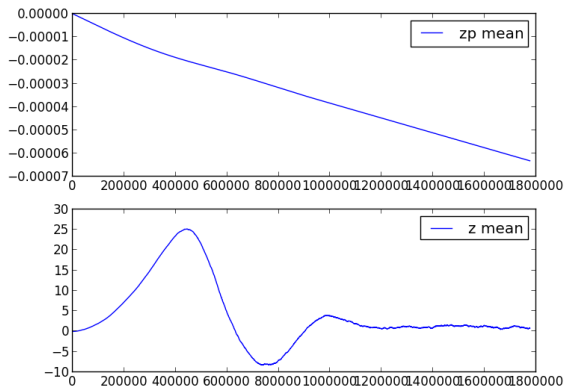
Observe:

- Instability in individual particle trajectories



The Problem 2

- Instability extends to means quantities

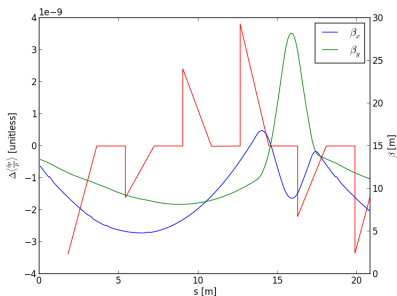


A Guess

- There is an art to choosing the frequency and placement of the space charge kicks around a ring.
 - Need to sample across a representative sample of the beam across the beam envelope.
 - Our default is usually to choose n kicks per cell, where $n \simeq 4$.
 - In early testing, $n = 5$ looked like a decent choice for SIS18.
 - 5 kicks per cell \times 12 cells = 60 kicks per turn.
- Speed is generally $\propto \frac{1}{\text{number kicks}}$
- Guess: maybe we need more kicks.
 - Double to 120 kicks per turn.
 - No improvement.

Space Charge Changes $\frac{\delta p}{p}$

- Magnets do not change the total kinetic energy of the particles in the bunch
 - Magnets do no work

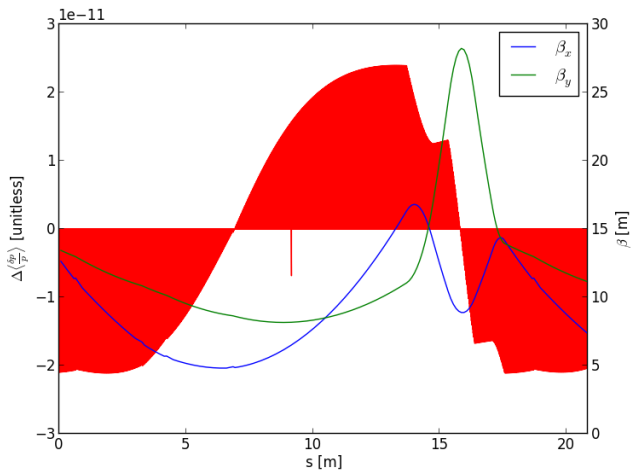


Changes in $\frac{\delta p}{p}$ in one SIS18 cell in the 5-kick scheme.

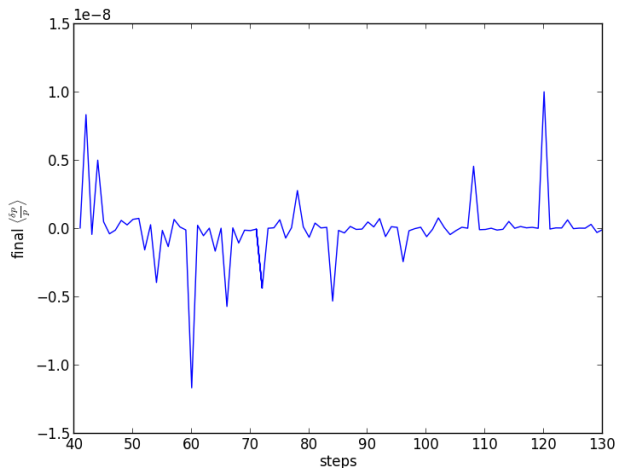
- Space charge can change the total kinetic energy of the bunch
 - Exchanges with the potential energy, which is a function (only!) of the shape of the bunch
 - For a *matched beam* space charge should not induce a net change in $\frac{\delta p}{p}$

A Brute Force Approach to the SIS18 Cell

- 800 kicks per cell

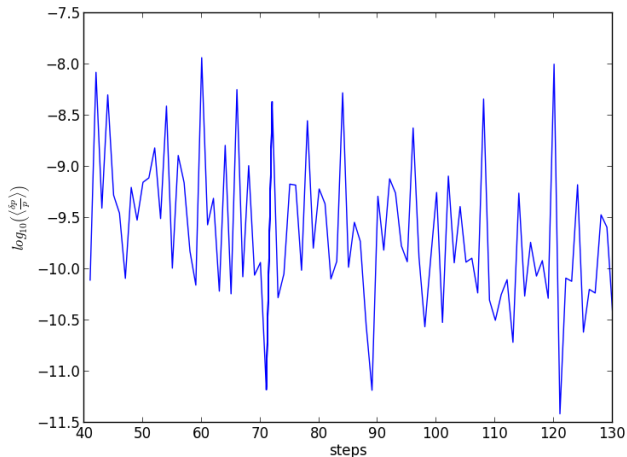


A Systematic Study



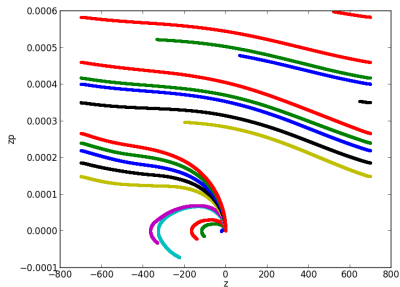
- Integer multiples of 12: bad
- My luck: bad

$\log_{10}(\text{abs})$ of Previous Slide

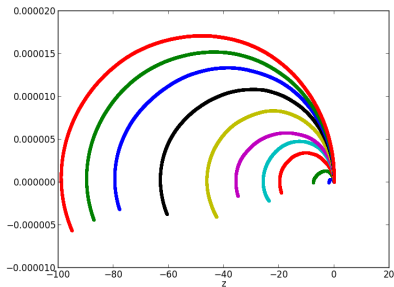


- (Relative) primes: good
 - 71 kicks/turn is a good choice
 - 1000 times smaller net change than from 60 kicks/turn

Phase Space Trajectories Before and After

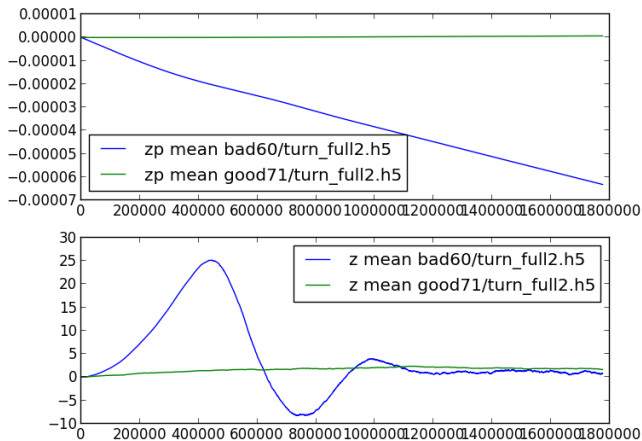


60 kicks/turn



71 kicks/turn

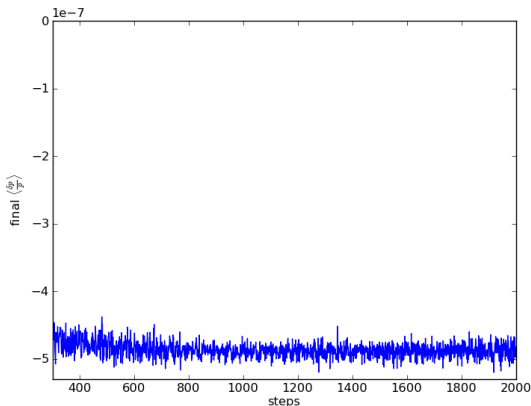
Mean Values Before and After



Comments

- Not satisfying: large numbers add to (near) zero
- Should be a way to make the cancellation happen automatically
 - I have not found one, yet
- Not a typical feature!

Fermilab Main Injector

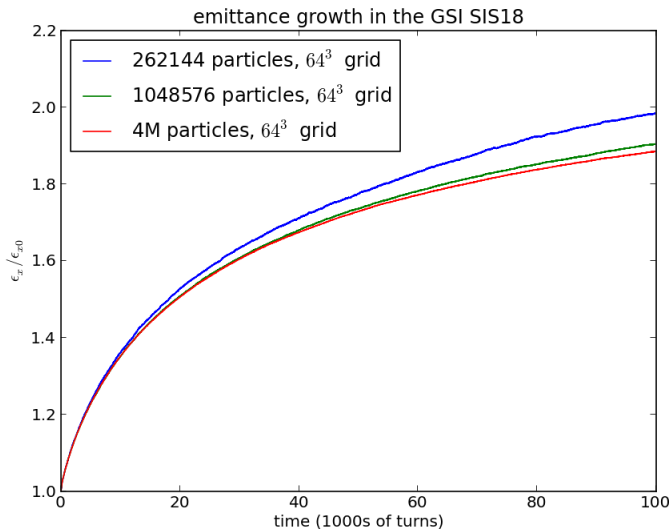


Statistical Noise Study

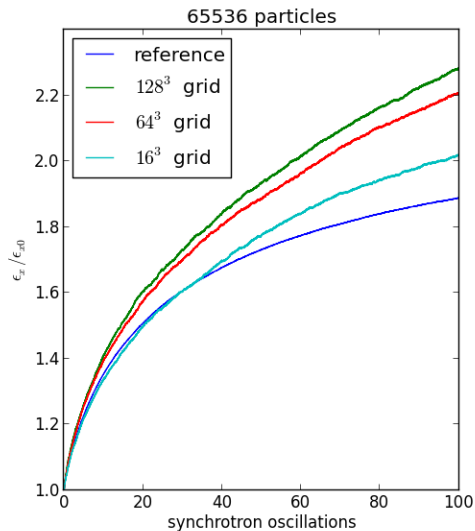
Several issues depend on grid size in PIC calculation:

1. Accuracy of field calculation as a whole improves as grid spacing is reduced
2. Grid spacing must be small enough to resolve any structure in the underlying beam
3. Statistical noise in charge density calculation increases as grid spacing is reduced
 - (2) is only an issue for non-Gaussian beams
 - In the past, we have typically handled (3) by keeping the number of particles *per grid cell* fixed as we varied the grid spacing

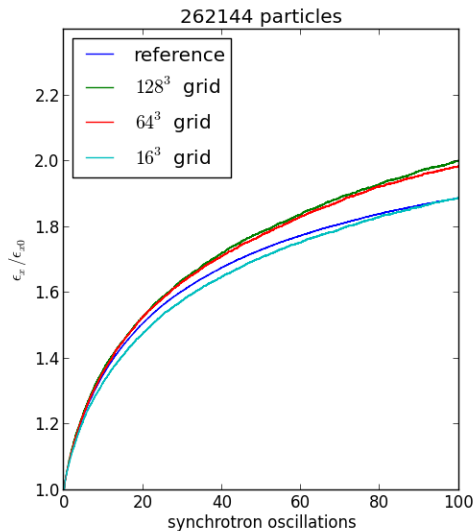
Best Answer First



Not Enough Particles

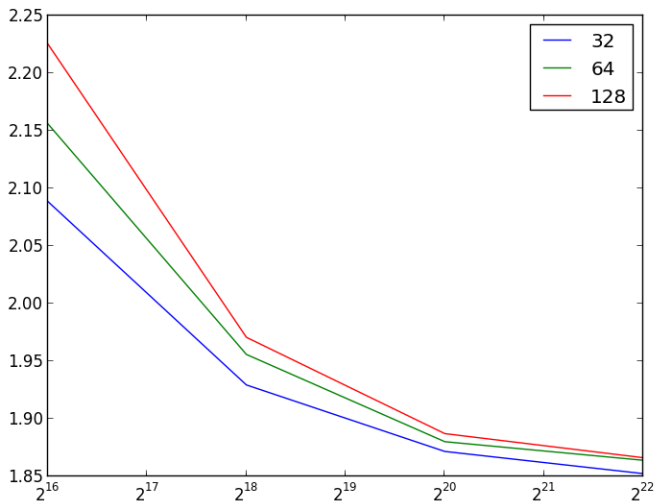


Bigger Is Not Always Better



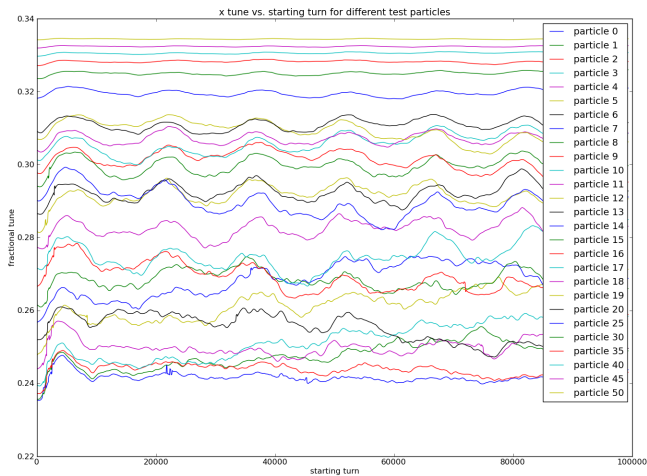
Evidence That 32^3 Is Not Enough

Final emittance as a function of $\log(\text{number})$



Tune Evolution over 100,000 Turns

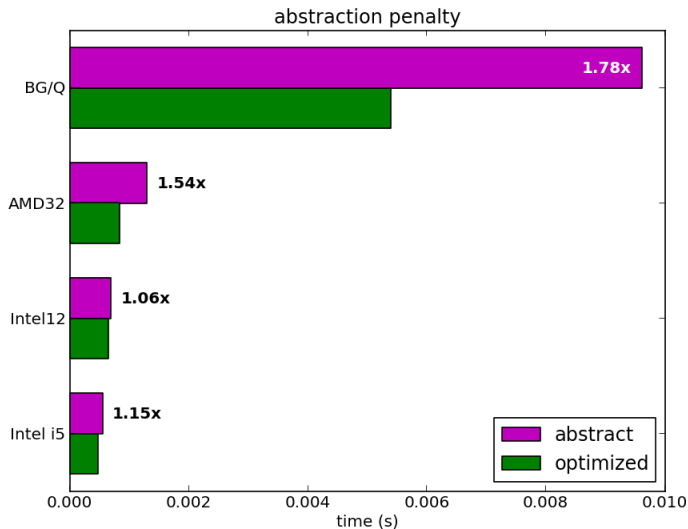
Test particle tunes in a 1024 tune moving window



Optimizing Particle Propagation

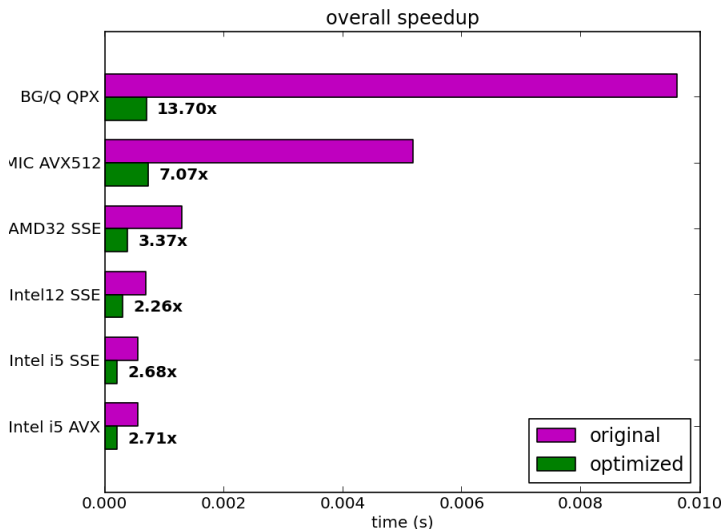
- Efficient tracking of many particles is now a higher priority in Synergia than ever before
- Independent-particle calculations (including drift) in Synergia provided by CHEF
 - C++, predates Synergia by over a decade
- Designed for deep analysis of single-particle physics
 - The genius: the same code propagates particle coordinates and polynomials in particle coordinates
- Synergia has to convert each of its particles to a CHEF particle (and back) each half step
 - 60 trillion conversions each way
- This overhead is our abstraction penalty

Optimizing Particle Propagation 2



Optimizing Particle Propagation 3

Speedup for removing overhead + adding SIMD + fiddling



Computing Resources

- 2014 INCITE Award
- Simulations of Fermilab and CERN machines
- 50 million core-hours on BlueGene/Q
 - underspent so far this year
- Next round of proposals will be in June...

Intensity-Dependent Dynamics in Fermilab and CERN Accelerators

Researchers are using ALCF resources to perform complex accelerator simulations for the world's two largest accelerator facilities, Fermilab and CERN. The results will assist in upgrades at both facilities, enabling the next generation of particle accelerator research.

Upgrades for these facilities follow two paths. In the U.S., Fermilab is pursuing the Intensity Frontier, which will create intense proton beams for measurements of ultra-rare processes in nature and neutrino experiments, such as the Long Baseline Neutrino Experiment. In Europe, CERN is pursuing the Energy Frontier by operating the Large Hadron Collider, the highest energy accelerator in the world.

Although the Fermilab and CERN accelerators support disparate areas of particle physics research, both upgrade efforts require an accurate understanding of intensity-dependent effects in their low- to medium-energy accelerators to move forward. Such understanding requires detailed numerical modeling that goes beyond the capabilities of desktop machines and simple clusters. This project combines state-of-the-art accelerator simulation software with petascale hardware to simulate the accelerators with unprecedented fidelity.

James Amundson | Fermilab
50 Million Core-Hours
Physics



INCITE 2014