State of Art of Beam-Beam Simulations

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In Collaboration With

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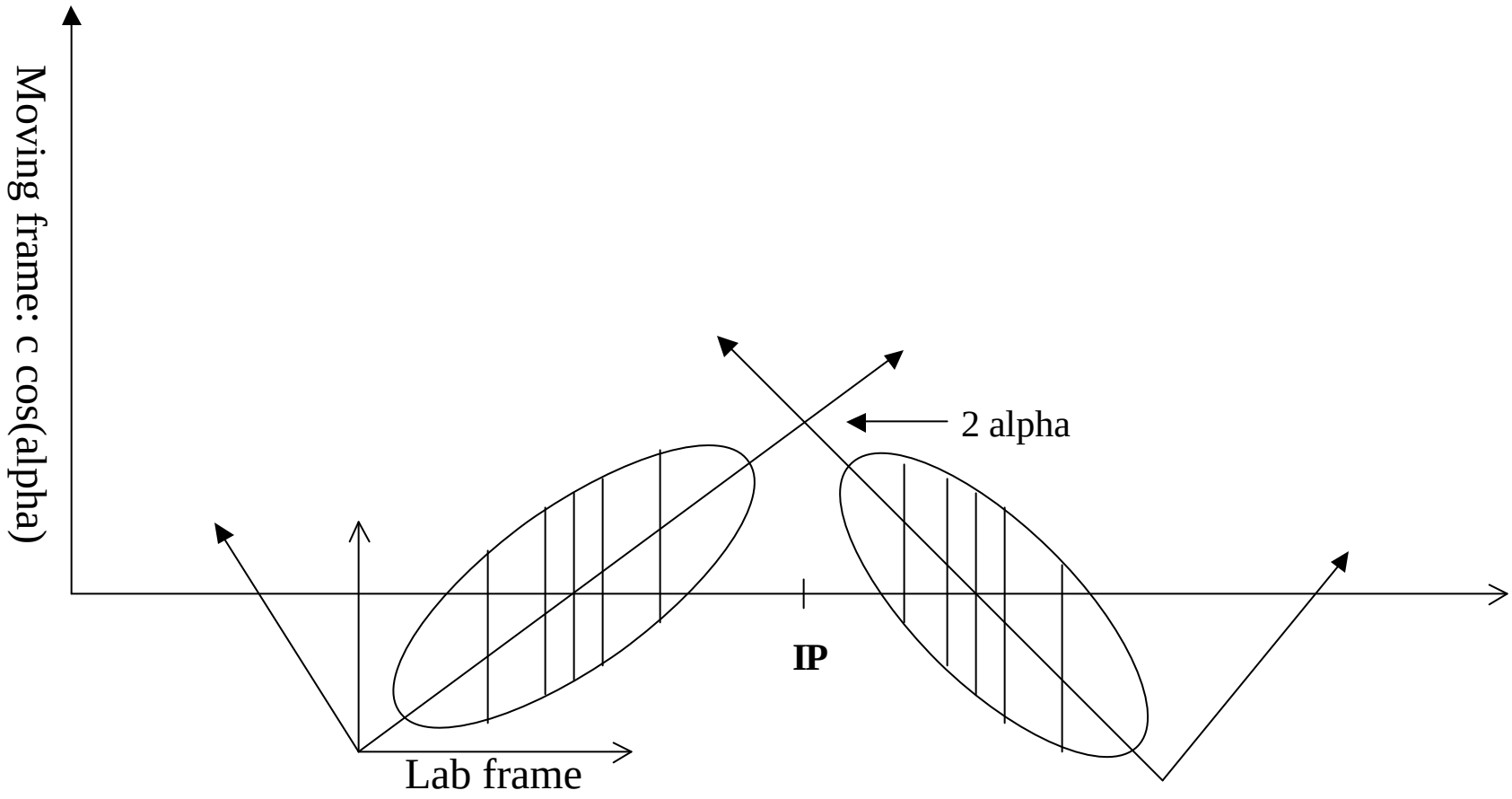
- W. Fischer – BNL
- T. Sen, M. Xiao – FNAL

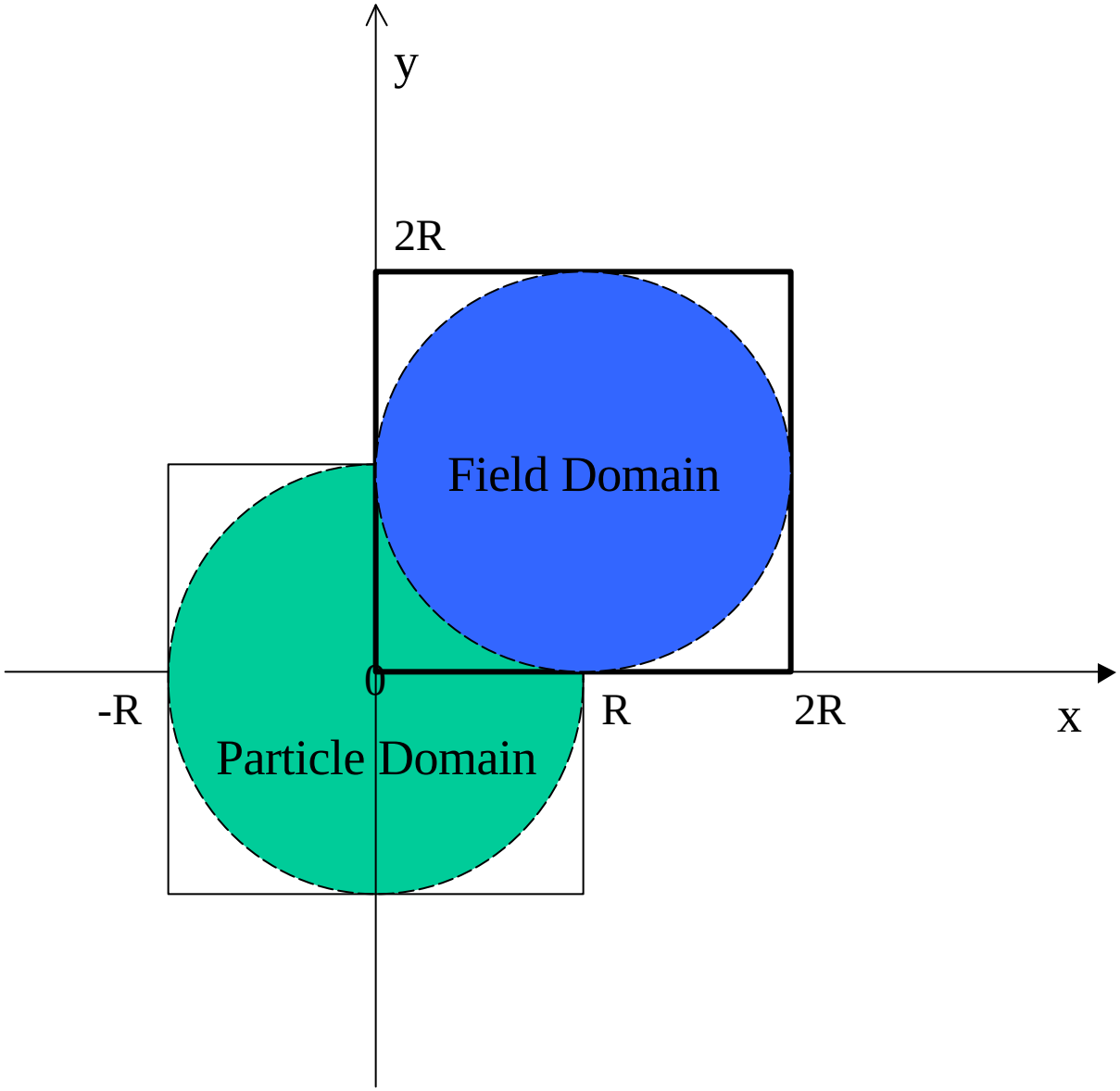
BeamBeam3D:
Parallel Strong-Strong / Strong-Weak Simulation Code

- Multiple physics models:
  - strong-strong (S-S); weak-strong (W-S)
- Multiple-slice model for finite bunch length effects
- New algorithm -- shifted Green function -- efficiently models long-range parasitic collisions
- Parallel particle-based decomposition to achieve perfect load balance
- Lorentz boost to handle crossing angle collisions
- Multi-IP collisions, varying phase adv,…
- Arbitrary closed-orbit separation (static or time-dep)
- Independent beam parameters for the 2 beams

Two Beam Collision with Crossing Angle Alpha

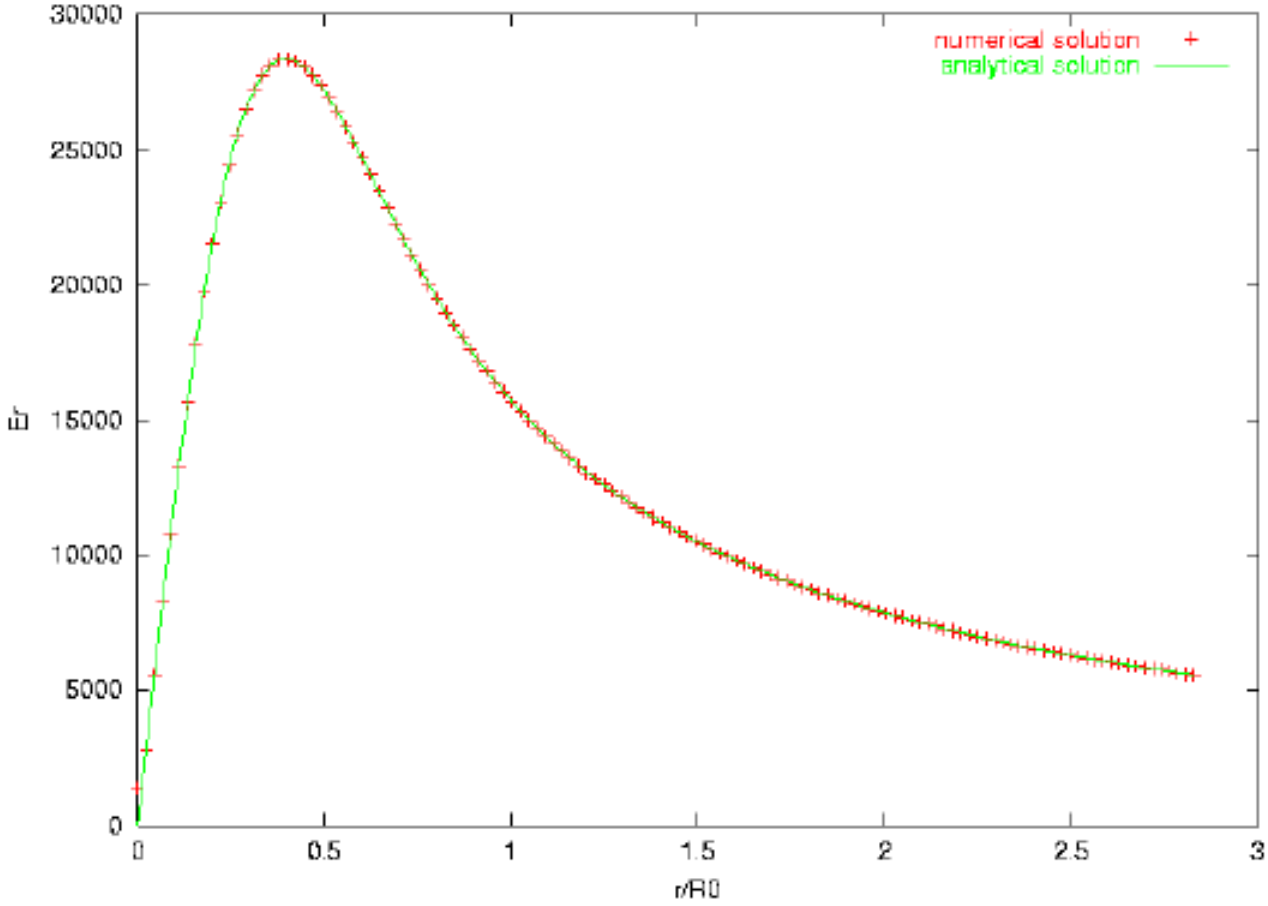


A Schematic Plot of the Particle Domain and the Field Domain



Comparison between Numerical Solution and Analytical Solution

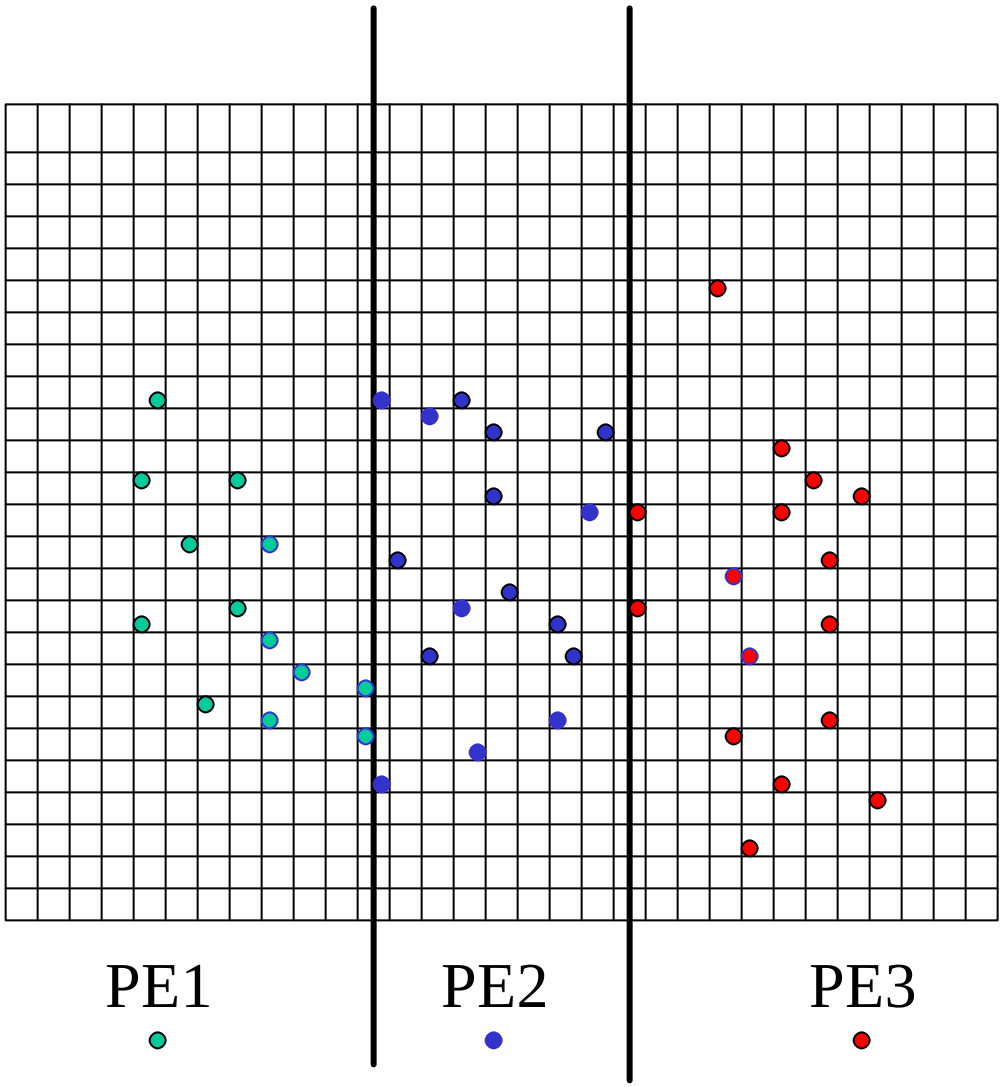
Radial Electric Field vs. Distance inside the Field Domain with Gaussian Density Distribution



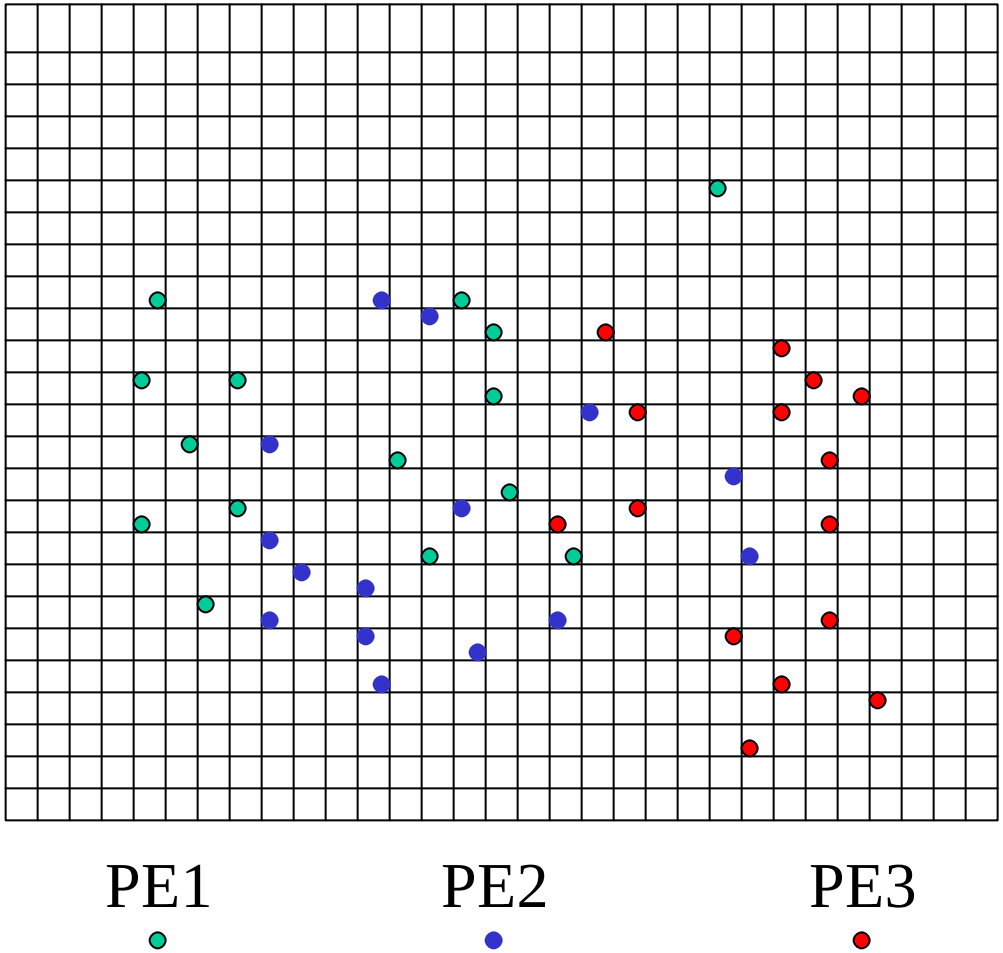
Parallel Implementation

- Uniformly distribute particles among processors
- Uniformly distribute the field domain among processors
- Exchange the local charge density among processors
- Solve the Poisson equation in parallel
- Collect the potential from the other processors

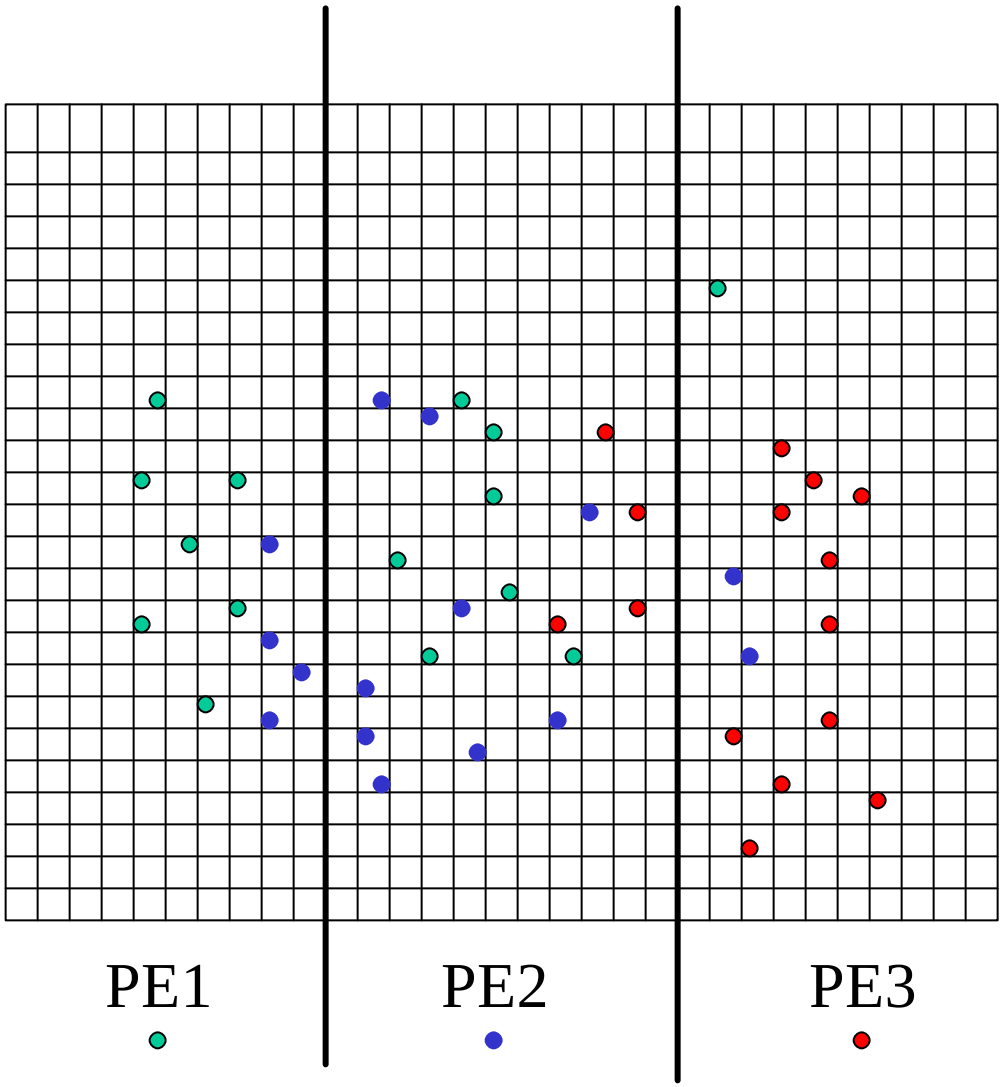
Domain Decomposition



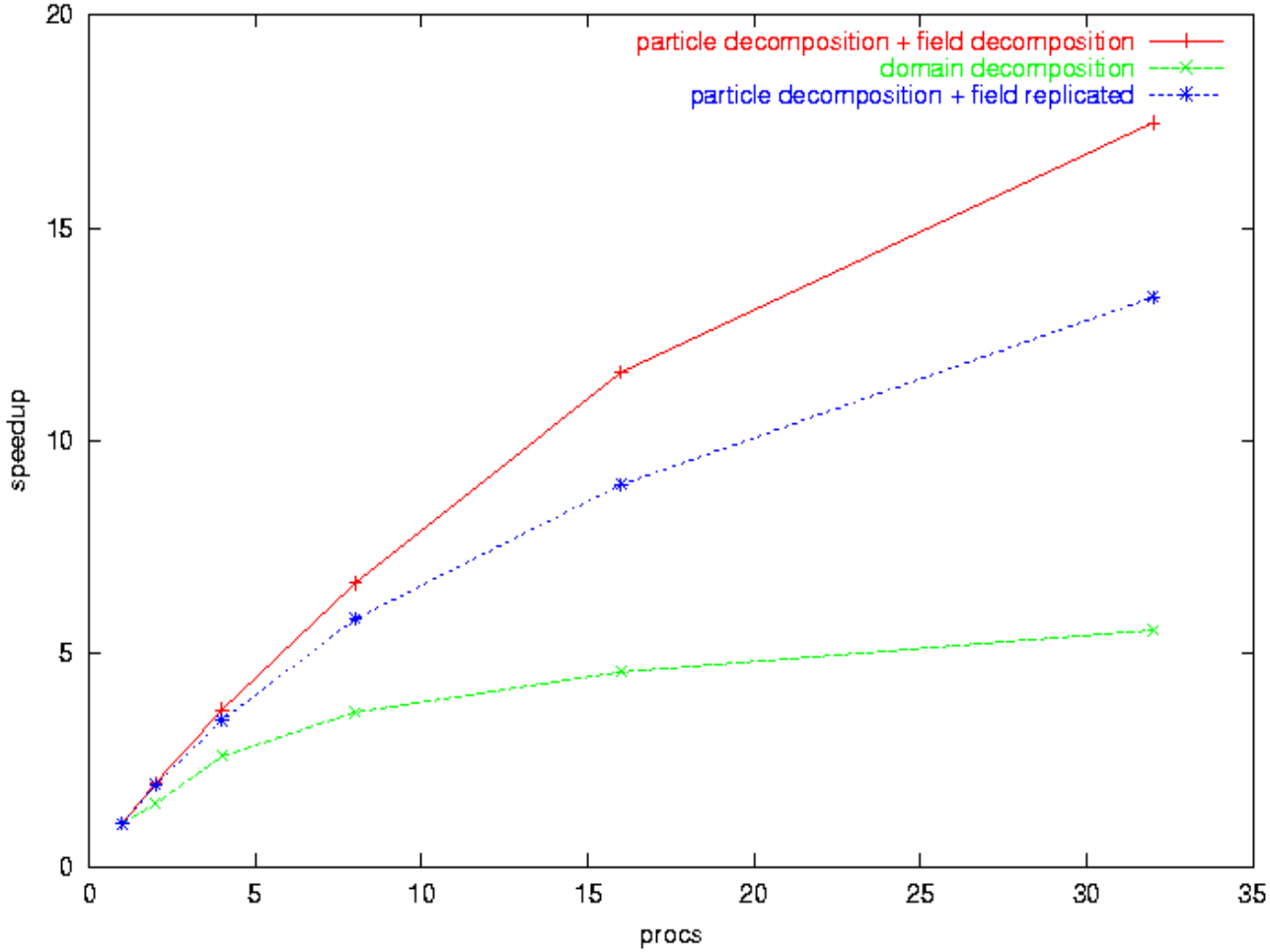
Particle Decomposition



Particle and Field Decomposition



A Comparison of Scalability of Parallel Implementation Using
a) Domain-decomposition b) Particle-Decomposition c) Particle+Field-Decomposition

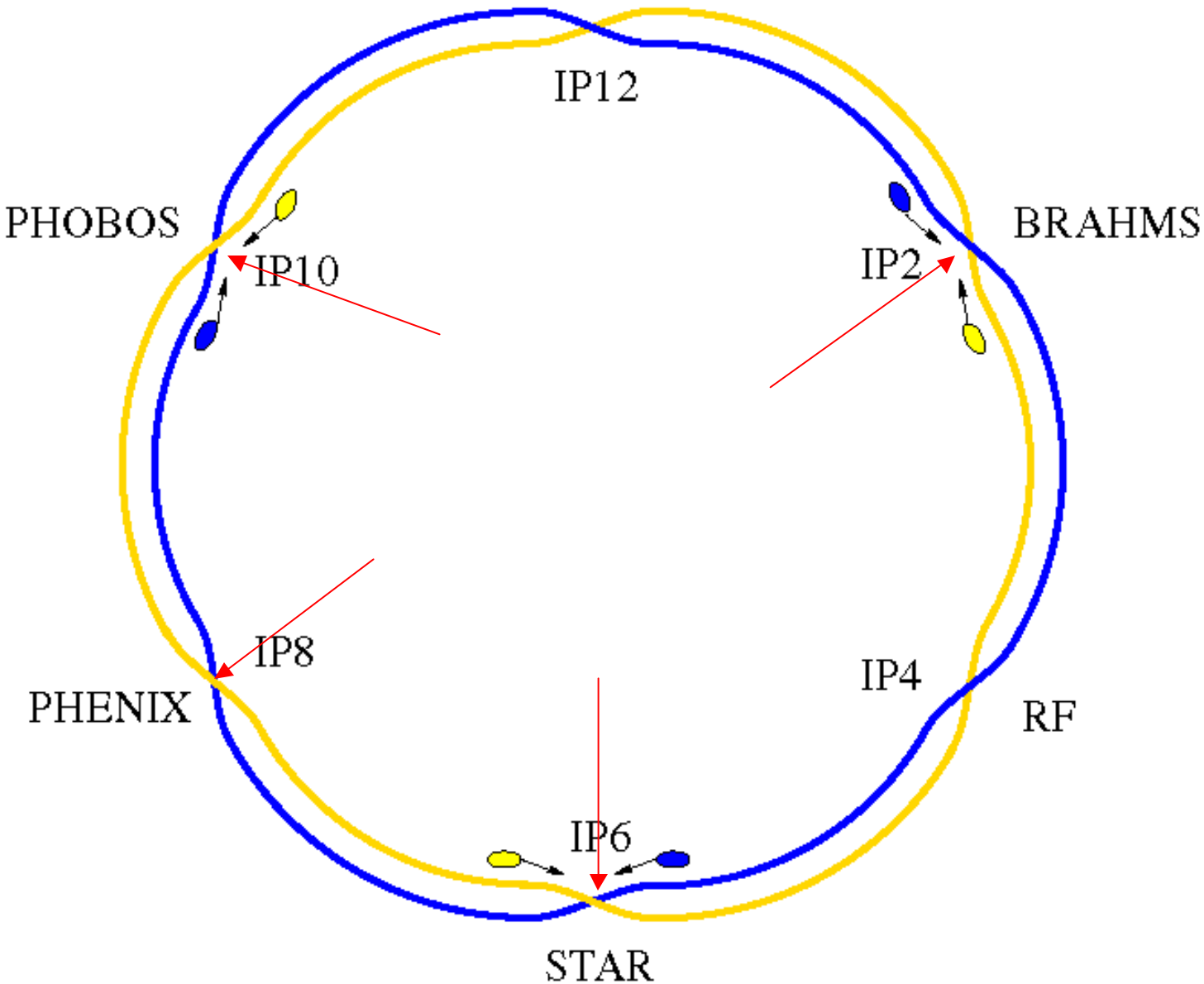


Applications

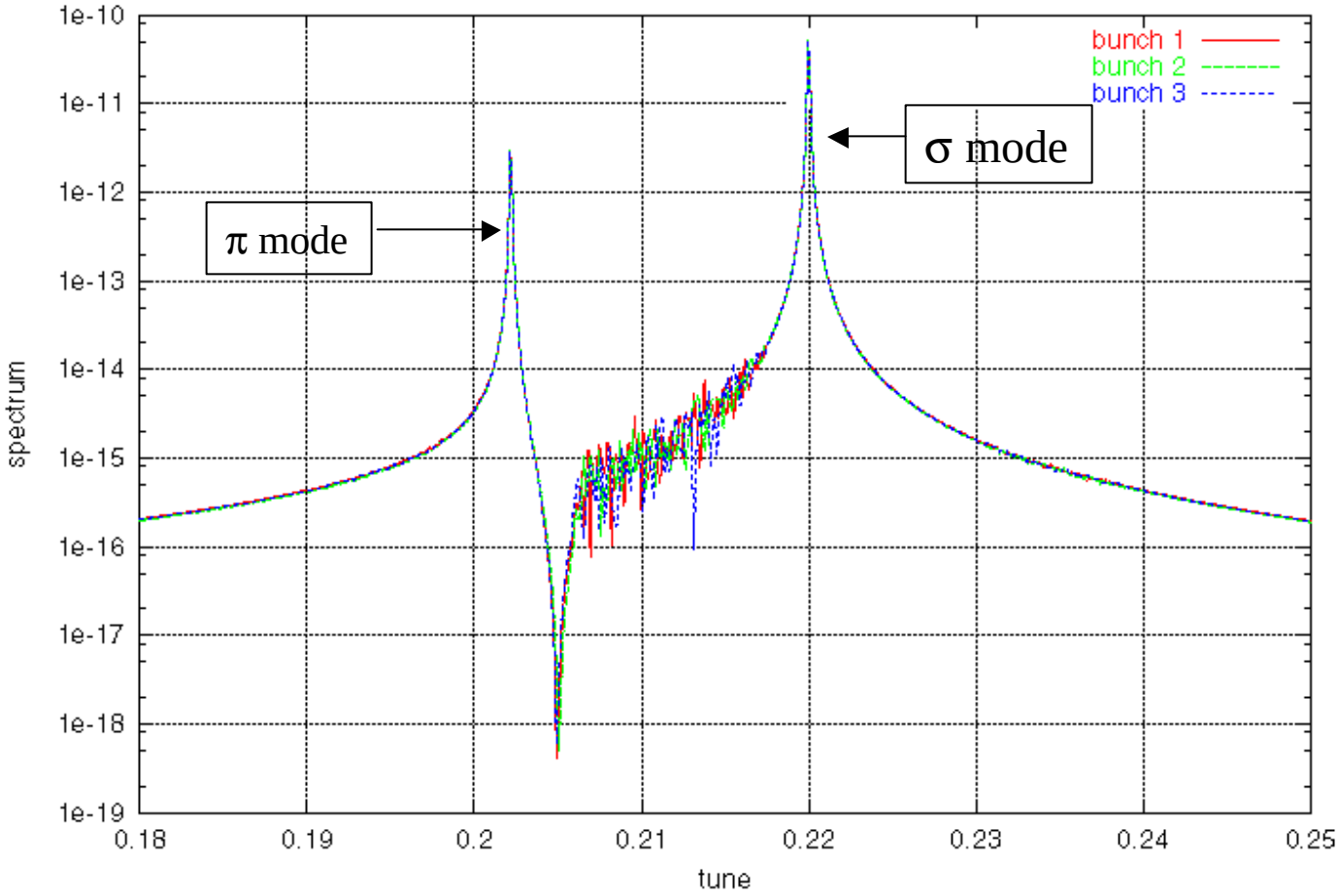
- Study the coherent mode of multi-bunch interactions at RHIC
- Study the antiproton lifetime at 150 GeV in the Fermilab Tevatron
- Study the LBNL sweeping detector for LHC

RHIC Physical Parameters for the Beam-Beam Simulations

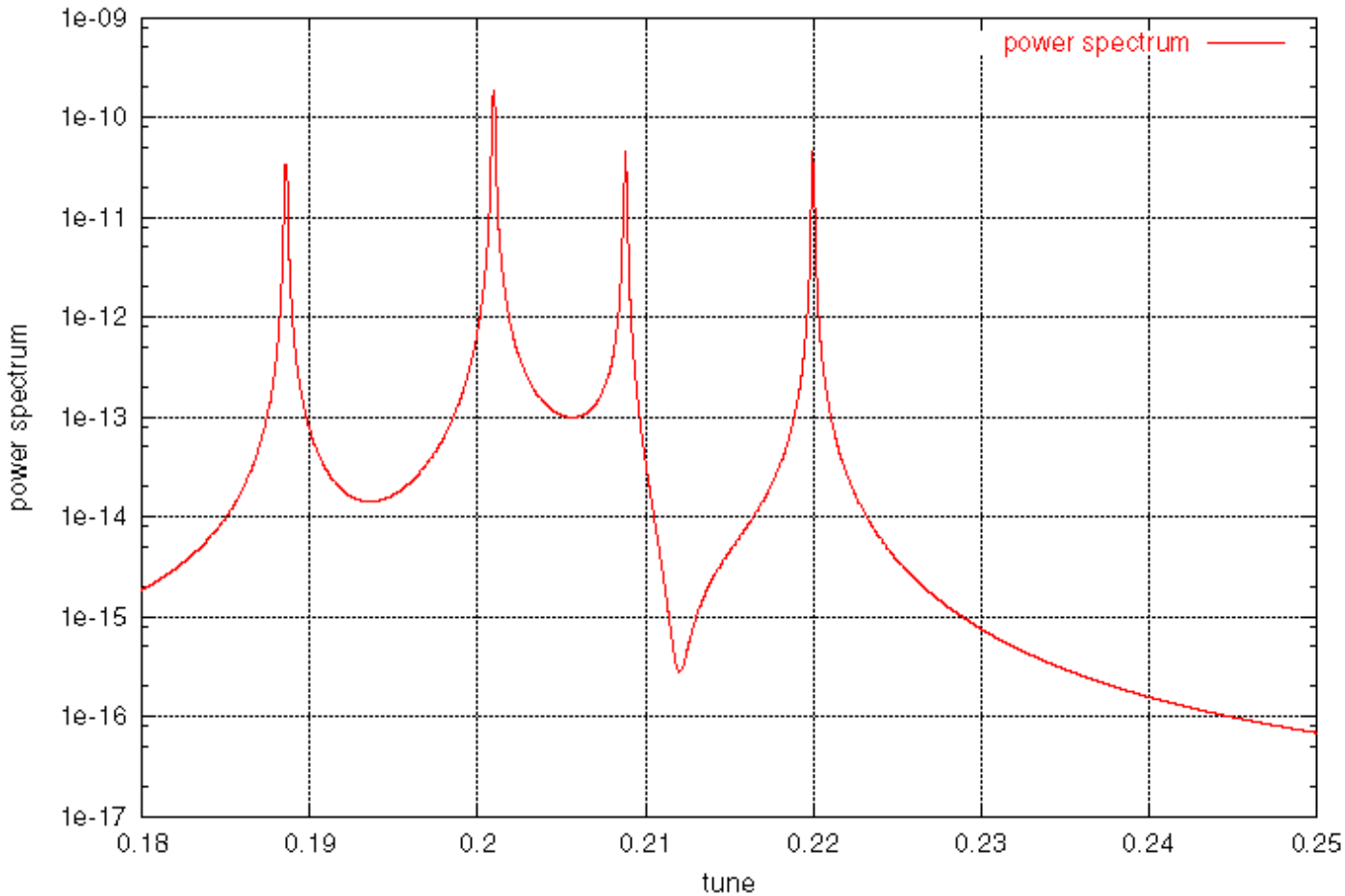
Beam energy (GeV)	100
Protons per bunch	10e10
β^* (m)	1
Rms spot size (mm)	0.176
Betatron tunes	(0.22,0.23)
Rms bunch length (m)	3.6
Synchrotron tune	3.7e-4
Momentum spread	1.6e-3
Beam-Beam Parameter	0.00366


IP12
PHOBOS
IP10
BRAHMS
IP2
IP8
PHENIX
IP4
RF
IP6
STAR

Power Spectrum of Horizontal Centroid Motion of Three Bunches (Self Consistent Strong-Strong Simulation)



Power Spectrum of Horizontal Centroid Motion of One Bunch (Rigid Beam Approximation)



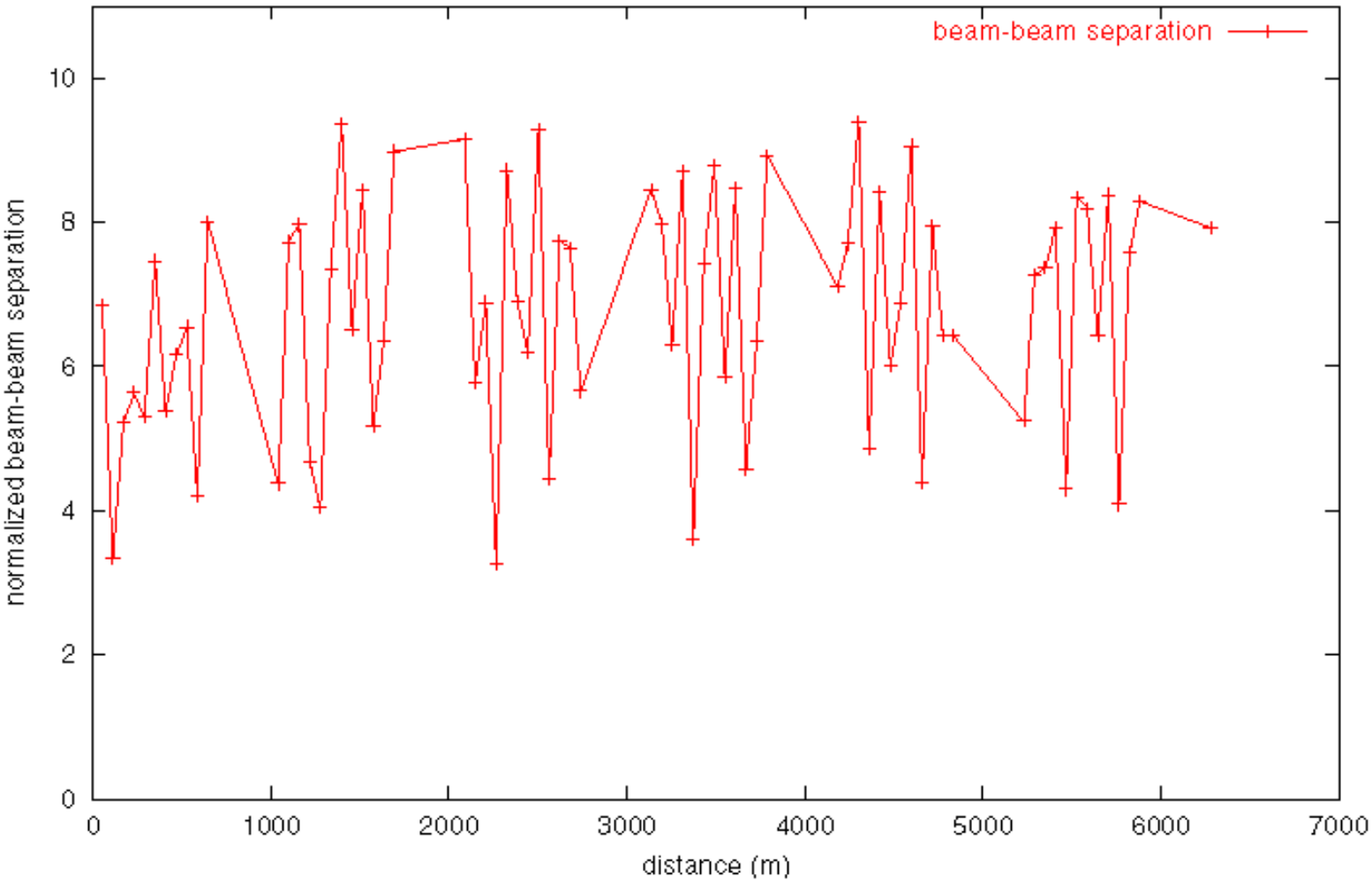
Computation Model for Pbar Lifetime Calculation At 150 GeV in the Tevatron

- Strong-weak model with soft-Gaussian approximation of beam-beam interaction
- 72 collision points
- 73 linear transfer maps from MAD output
- One linear chromaticity kick per turn
- One stochastic random kick per turn
- Weighted particle sampling
- Least-square fitting for the pbar lifetime
- 10^6 particles
- 100,000 turns

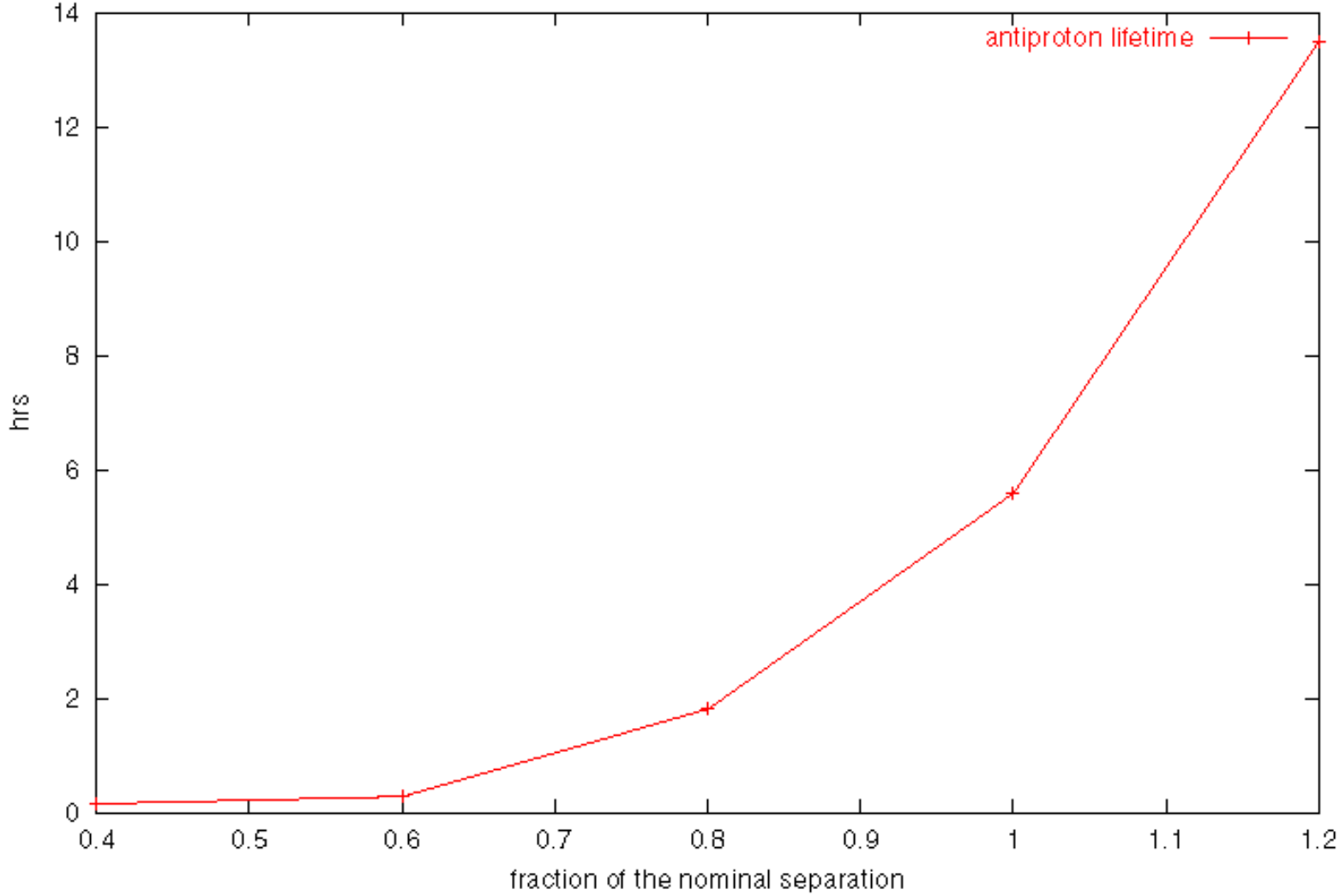
Reference Parameters

- Proton intensity: 2.2×10^{11} / per bunch
- Proton emittance: 25 pi-mm-mrad
- Proton momentum spread: 7×10^{-4}
- Proton rms bunch length: 0.9 m
- Antiproton emittance: 20 pi-mm-mrad
- Antiproton momentum spread: 4.31×10^{-4}
- Antiproton rms bunch length: 0.6 m
- Horizontal bare tune: 0.581
- Vertical bare tune: 0.576
- Horizontal chromaticity: 2
- Vertical chromaticity: 8
- Aperture size: 3.25 sigma

Proton – Antiproton Separation at 72 Collisio Locations (input to simulations)



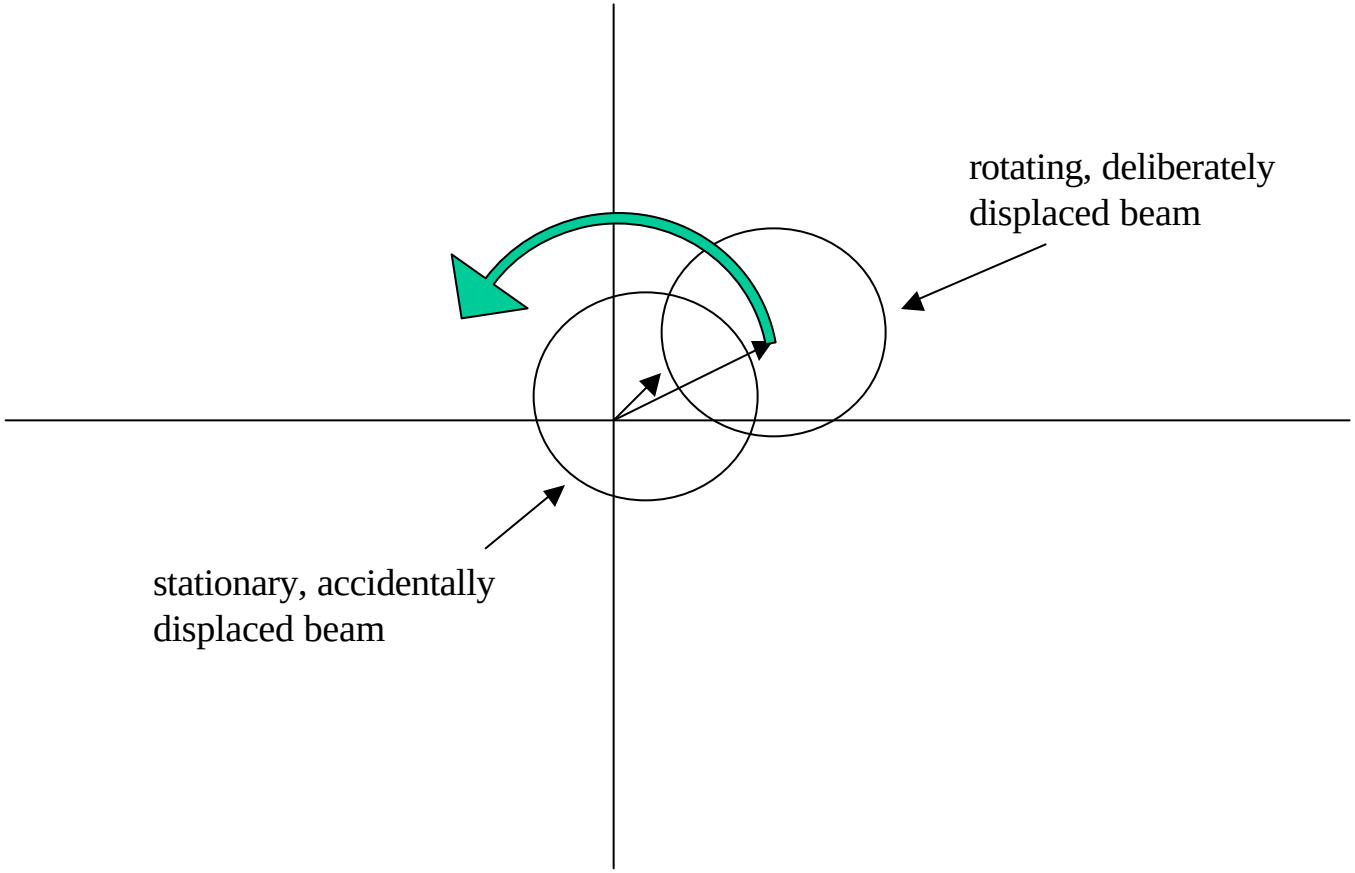
Antiproton Lifetime vs. Beam-Beam Separation



Nominal LHC Physical Parameters

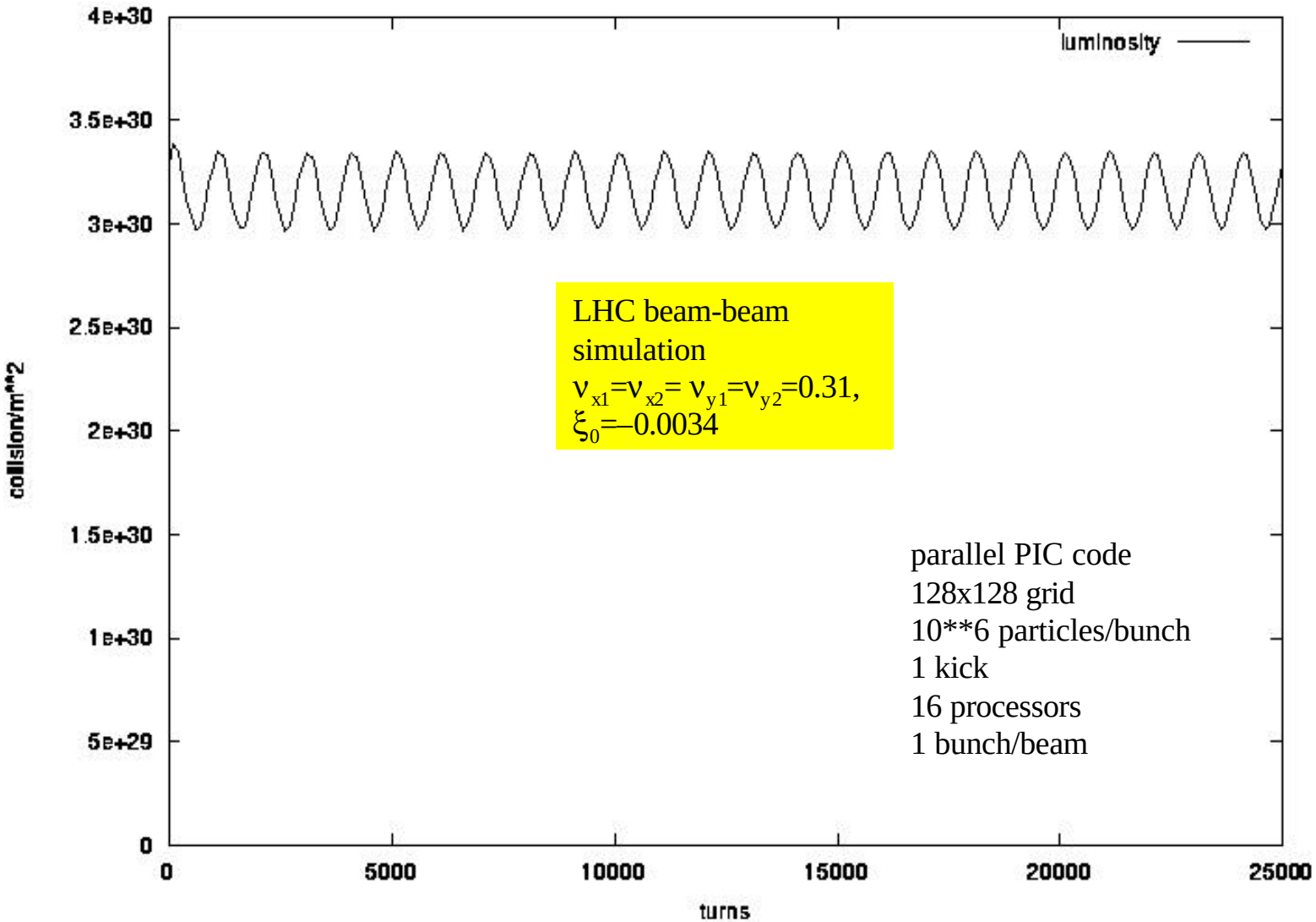
Beam energy (TeV)	7
Protons per bunch	1.05e11
Beta (m)	0.5
Rms spot size (um)	15.9
Betatron tunes	(0.31,0.32)
Rms bunch length (m)	0.077
Synchrotron tune	0.0021

LBNL sweeping detector schematics



$$L = L_0 + a\cos(2p\, t/T - a)$$

Simulated LHC luminosity signal (sweeping detector)



LHC beam-beam simulation
$\nu_{x1}=\nu_{x2}=\nu_{y1}=\nu_{y2}=0.31$,
$\xi_0=-0.0034$

parallel PIC code
128x128 grid
10**6 particles/bunch
1 kick
16 processors
1 bunch/beam

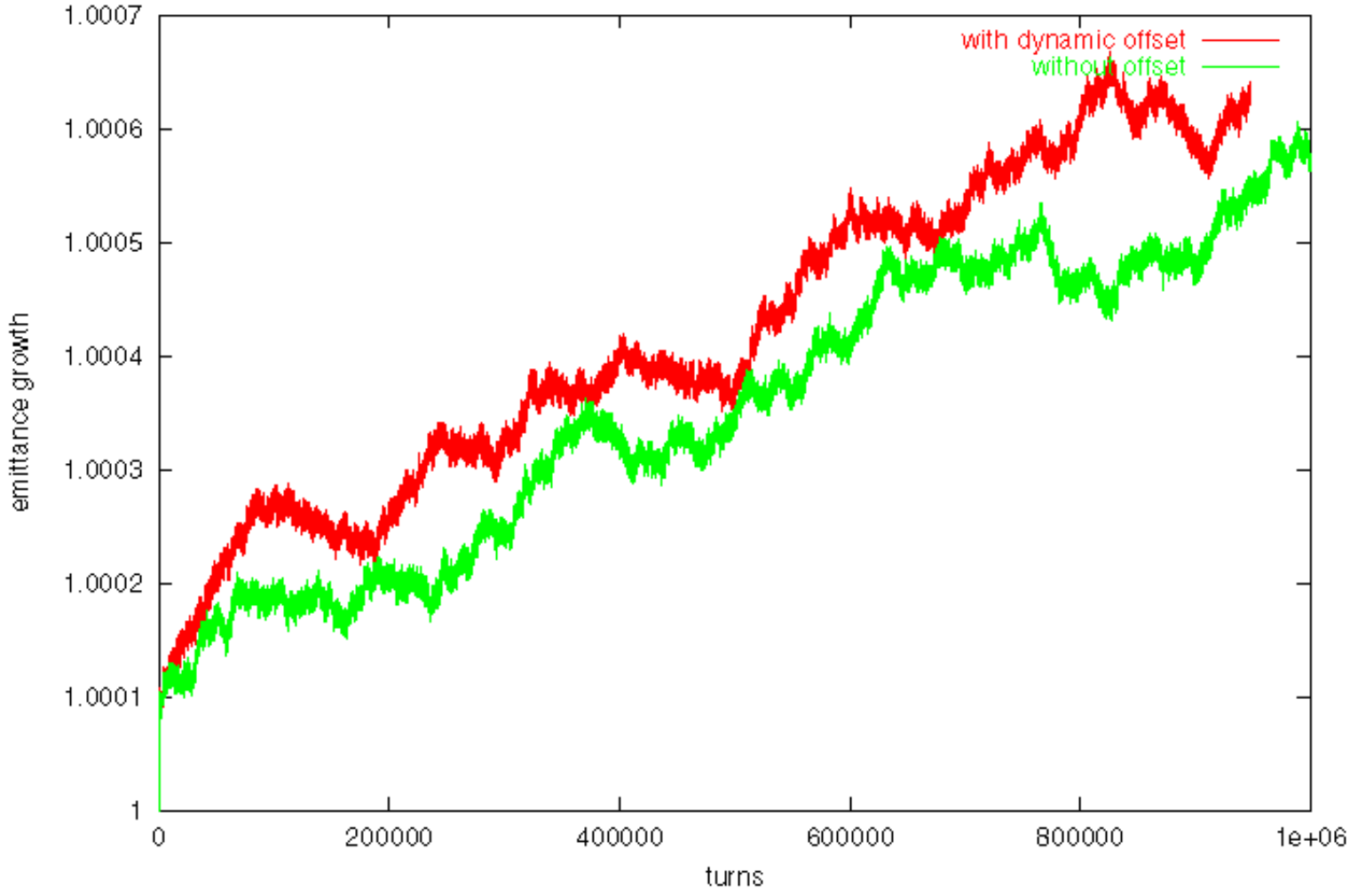
Conclusions

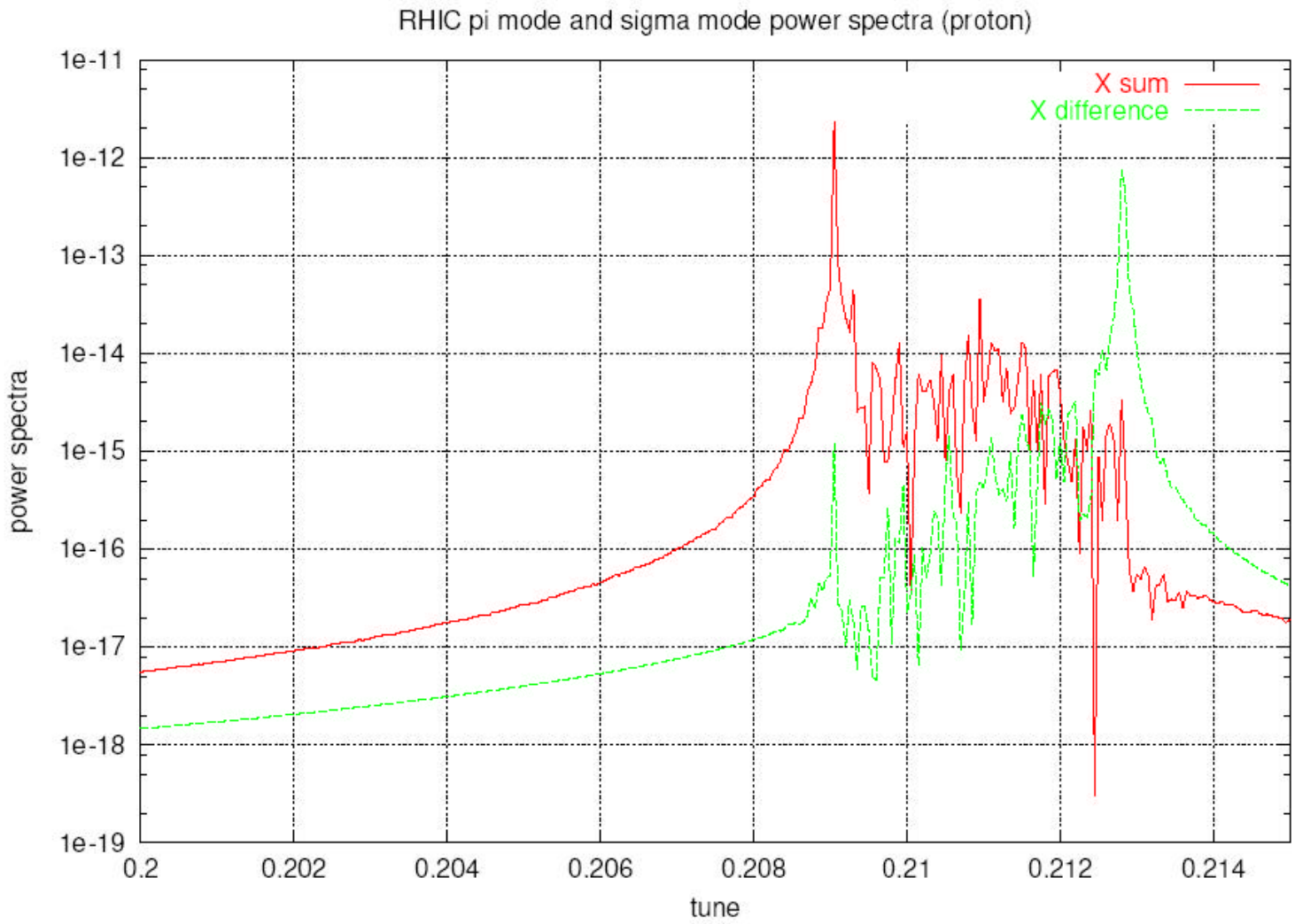
- We have developed a state of the art strong-strong/strong-weak parallel beam-beam simulation code
- We have applied the code to the studies:
  - RHIC: good agreement with coherent mode spectrum for single bunch collisions
  - Tevatron: qualitative agreement with the measured antiproton lifetime
- We have demonstrated long-term strong-strong simulation of LHC up to 10^6 turns

Future Work

- Study multi-bunch coherent modes using more realistic RHIC simulations and experimental comparison
- Study the antiproton lifetime using new lattice parameters
- Further assess LHC sweeping luminosity detector:
  - With crossing angle
  - With realistic amplitude and period
- Further assess long-term strong-strong beam-beam dynamics for LHC including crossing angle and parasitic collisions

Appendix 1: Averaged Emittance Growth with/without 0.1 sigma dynamic offset (LHC)



Appendix 2: RHIC (proton) simulations: beam-beam spectrum

– in agreement with measurements (Fischer et. al.)