Overview of the Synergia 3-D Multi-Particle Dynamics Modelling Framework

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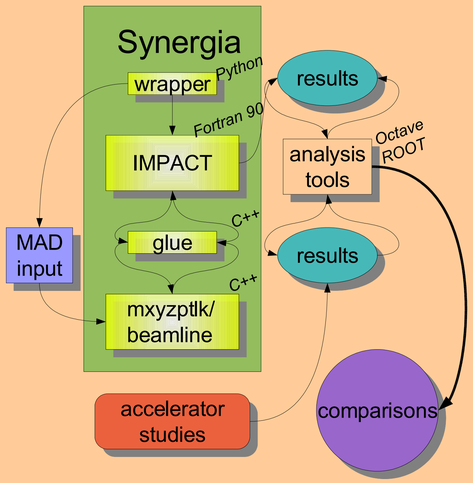
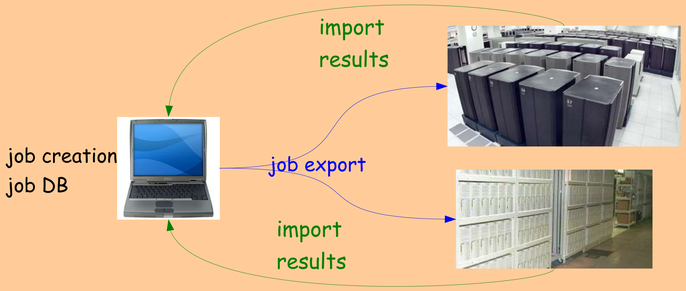
Synergia



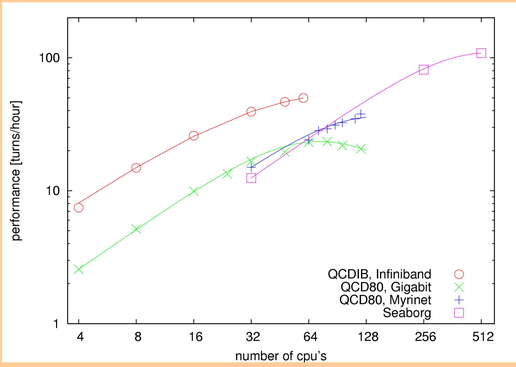
3D space-charge code with circular accelerator capabilities
Re-uses existing beam dynamics packages
Arbitrary order maps
Advanced parallel computing tools
- particle manger
- load balancing

Modern build system and code distribution tools
Human interface and standard accelerator lattice description (MAD)

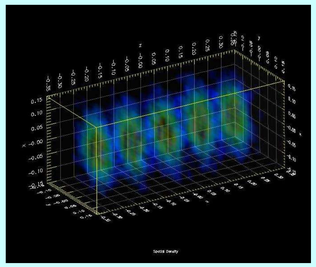
Complete and flexible job management system code ported both on super-computers and parallel commodity PC clusters



Performance, measured in FNAL Booster turns per hour, for 3M macro-particles



~100 turns/hr on 512 processors at NERC
~50 turns/hr on 64 2.0 Ghz Xeon processors with Infiniband network fabric



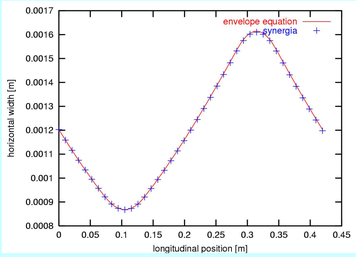
High-precision simulations use 33x33x257 grid and ~3,000,000 particles
Periodic boundary conditions – periodic/long beam
Multi-turn injection
6-D PhS matched beam generation utilities

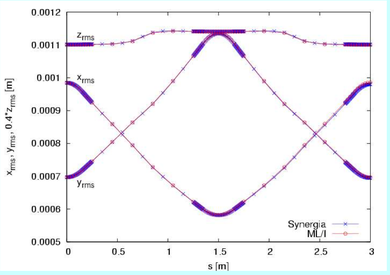
Model validation tests

0.5 Amp, 0.0067 GeV, matched, KV beam in a FODO. Comparison with the envelope equation prediction:

$$\sigma_x'' + K_x\sigma_x - \frac{\epsilon_{\rm rms}^2}{\sigma_x^2} = \frac{\xi}{4(\sigma_x+\sigma_y)}$$

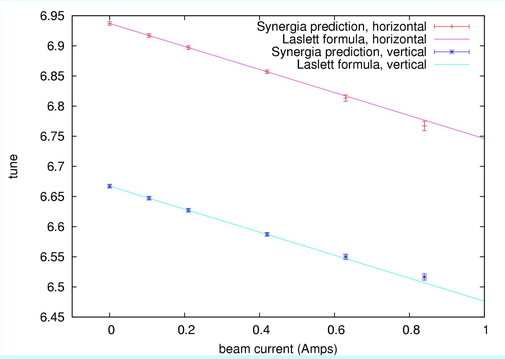
$$\sigma_y'' + K_y\sigma_y - \frac{\epsilon_{\rm rms}^2}{\sigma_y^2} = \frac{\xi}{4(\sigma_x+\sigma_y)},$$





0.1 Amp, 3-D cold beam of 250 MeV protons in a FODO with rf. Comparison with ML/I.

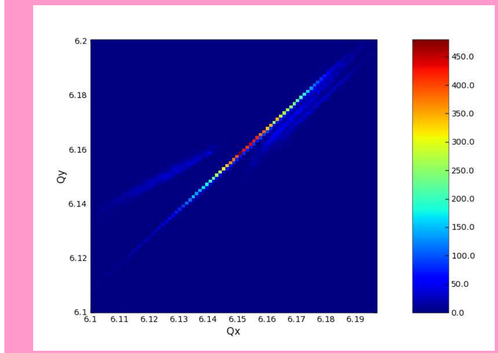
Calculate particle tunes in a FNAL Booster simulation using a KV beam



Compare with the Laslett formula

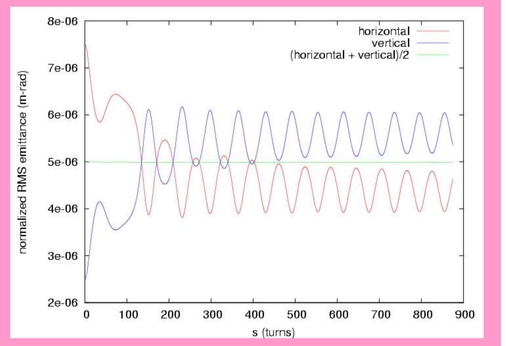
$$\delta\nu = \frac{-N r_0}{8\pi\beta^2\gamma^3\epsilon}$$

CERN PS simulations and comparisons with other codes

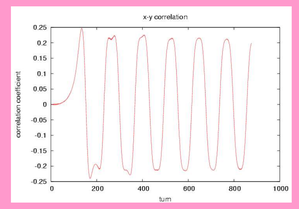


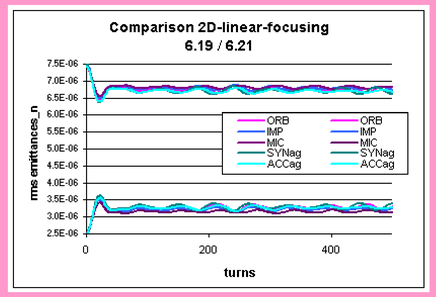
Tune density plot for a CERN PS simulation using a linear lattice with Qx = 6.207 and Qy = 6.190

Horizontal and vertical emittance and their average, versus turn. The Synergia simulation shows the expected Montague resonance exchange.



<x y> correlation coefficient . There is a strong correlation between the horizontal and vertical planes.





Synergia results compared to other simulation codes for a linear PS lattice with Qx=6.19, Qy=6.21 (see I. Hofmann, this conference)

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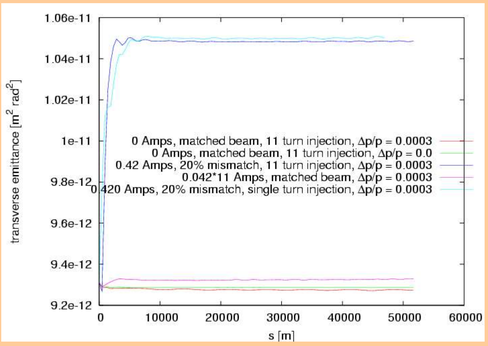
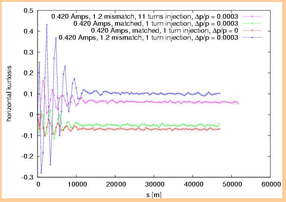
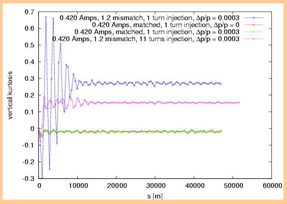
Fermilab Booster Modeling, no rf



3-D FNAL Booster modeling, using 2nd order maps, with the rf turned off. The simulation shows a 12% increase in transverse emittance due to space charge for 20% mismatch. This agrees well with the prediction (13%) from the free energy model:

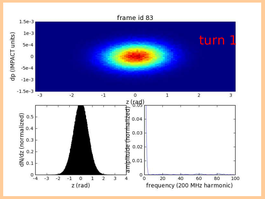
$$\frac{\epsilon_f^T}{\epsilon_i^T} = 1 + 4\left[(\mu-1)^2 - (\mu-1)^3\right] + \mathcal{O}((\mu-1)^4),$$

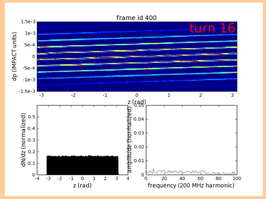


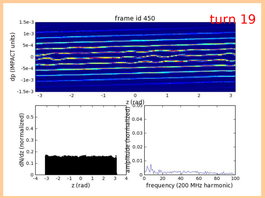


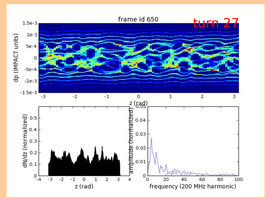
Kurtosis for the above simulations. The beam quickly converges to a Leptokurtic distribution, which signifies halo creation.

Coherent noise due to space charge:







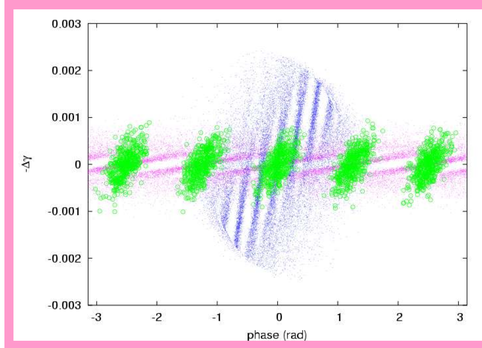


The injected beam has 200 Mhz structure. It debunches for ~10 turns and shows no structure for ~20 turns. In ~30 turns the longitudinal phase-space develops "holes."

The effect does not depend on the size of the computational grid or number of macroparticles. It goes away when space charge is turned off.

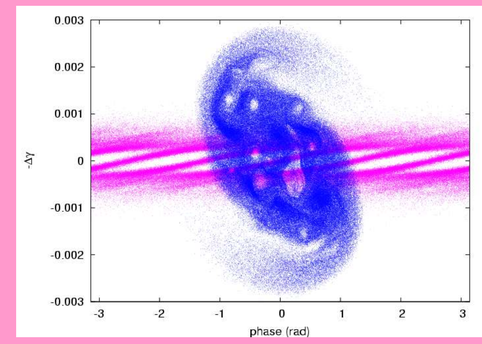
Fermilab Booster Modeling, including rf

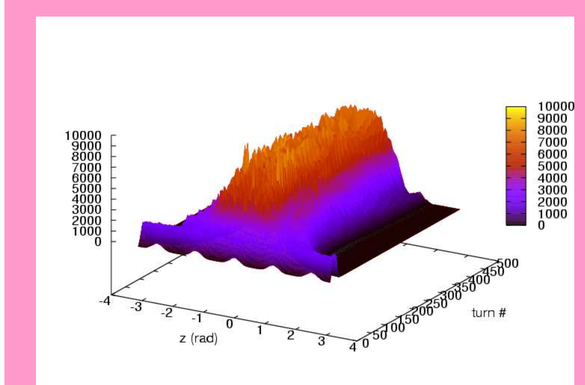
3-D model, using 2nd order maps. Ten turns of Linac beam (200 Mhz structure) is injected and debunched for 20 turns. The Booster rf (37.8 Mhz) is paraphased and ramped over 200 turns to full strength bunching.



Simulation with space-charge turned off, for injection (green), after 15 turns (purple), and after 400 turns (blue).

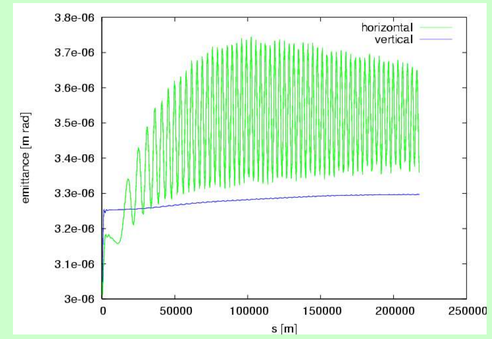
Space-charge tuned on, after 15 turns (purple) and 400 turns (blue)





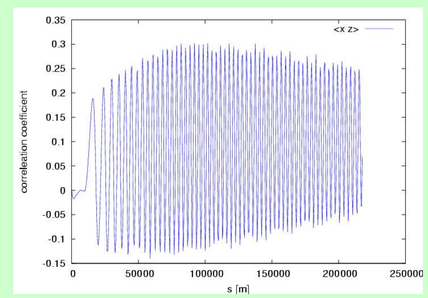
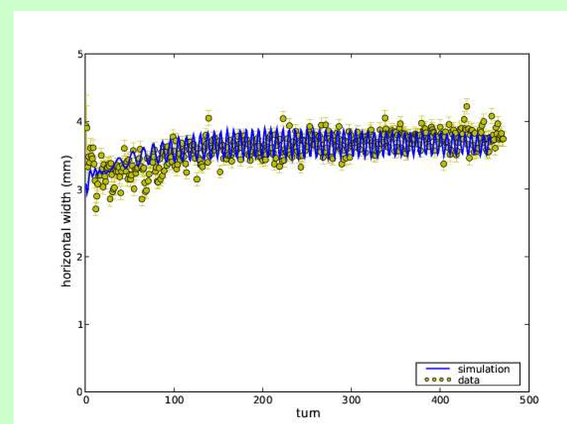
Waterfall plot, space charge on.

Horizontal and vertical emittance versus s



The bunching process introduces a correlation between the horizontal (bending) plane and the longitudinal plane.

<x z> correlation coefficient versus s. The variation matches the horizontal emittance variation.



Comparison of the predicted horizontal width the measurement obtained with the Booster IPM, on a turn-by-turn basis. The agreement is very good.