Modeling of Accelerators for Next Generation Light Sources Using the IMPACT Code Suite

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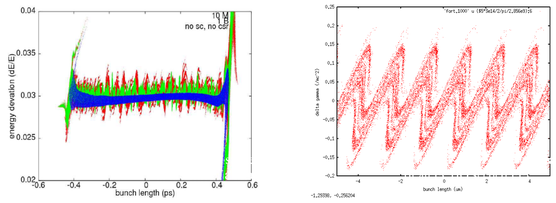
High-Resolution Multi-Physics Codes Are Required for State-of-the-Art Accelerator Design

For example
- The microbunching instability significantly degrades beam quality
- New seeding schemes (e.g. ECHO) demand production and transport of very fine beam structure
- High resolution modeling is needed to accurately model initial shot noise, resolve fine structure, and avoid numerical artifacts



IMPACT – **I**ntegrated **M**ap and **PA**rti**C**le **T**racking

- A high performance computing tool for large-scale accelerator beam dynamics modeling
  - **Multi-physics**
  - **State-of-the-art numerical algorithms**
  - **Advanced parallel implementation**
- Key features
  - —Detailed RF accelerating and focusing model
  - —Multiple 3D Poisson solvers
  - —Multi-charge state
  - —Machine error studies and steering
  - —Wakes
  - —CSR (1D)
  - —Monte Carlo gas ionization model
- Has been used by about 30 research institutes and universities around the world

Space-Charge Calculation Based on Integrated Green Function for Large Aspect Ratio Beams

$$\phi_c(r_i) = \sum_{i'=1}^{2N} G_i(r_i - r_{i'})\rho_c(r_{i'})$$

$$G_i(r,r') = \oint G_s(r,r')\,dr'$$

integrated Green function

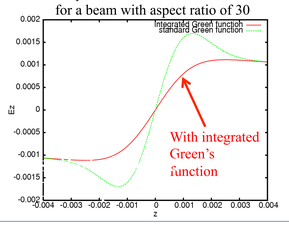
$$G_s(x,y,z) = 1/\sqrt{(x^2+y^2+z^2)}$$

standard Green function

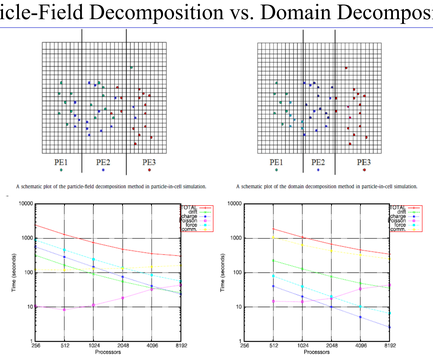
Integrated Green's function is needed for modeling large aspect ratio beams!

(O(N log N))

Comparison between the IG and SG for a beam with aspect ratio of 30



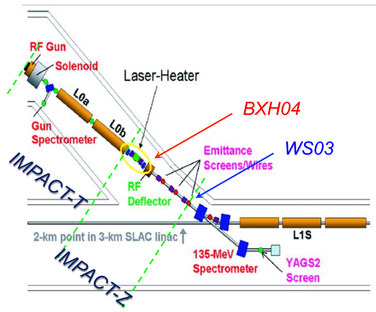
Parallel Performance Matters: Particle-Field Decomposition vs. Domain Decomposition

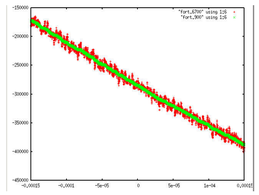


Particle-field decomposition out-performs the conventional domain decomposition

Some Application Examples

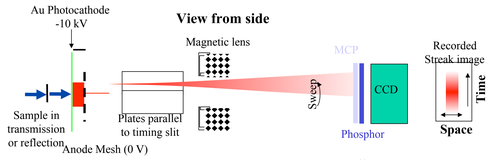
Application of the IMPACT Code to the **LCLS**



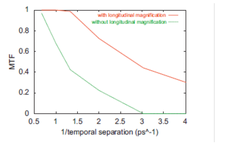


- *The red (at WS03) shows more microbunching than green (after BXH04), which indicates space charge amplified energy modulation*
- *BXH03 and BXH04 converts energy modulation built in undulator to density modulation*

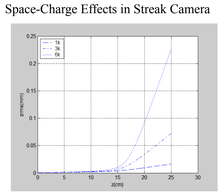
Modeling of the **ALS** Streak Camera Using IMPACT



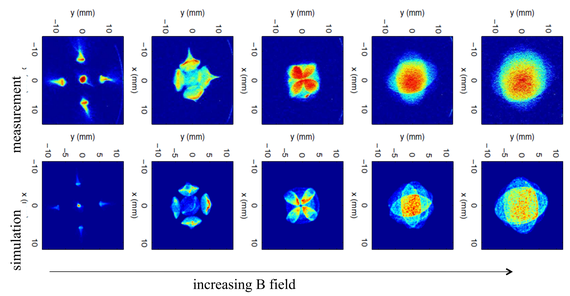
Space-Charge Effects in Streak Camera



X-ray streak camera temporal reslution improvement using a longitudinal time-dependent field

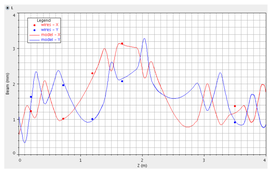


Application to the **ANL** Phase Space Manipulation (measurement vs. simulation)

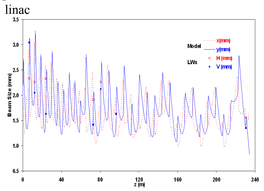


SNS Beam Dynamics Studies: Details of Space-Charge and RF Nonlinearities

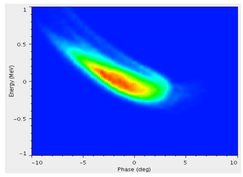
IMPACT model and measurement at the MEBT



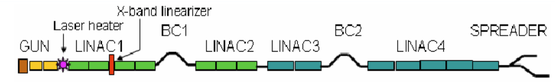
IMPACT model and the LWs measurements in SC linac



IMPACT model of DTL6 phase shifted by 6°.

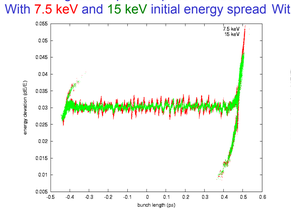


High Resolution Modeling of the **FERMI@Elettra** FEL Linac with IMPACT

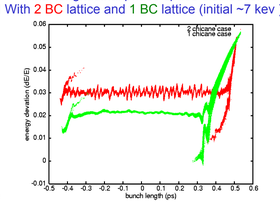


- Beam energy at the entrance of laser heater ~100 MeV (peak current ~70A), at the exit of Linac 4 E ~ 1.2 GeV (peak current 500A or 800A depending on configuration)

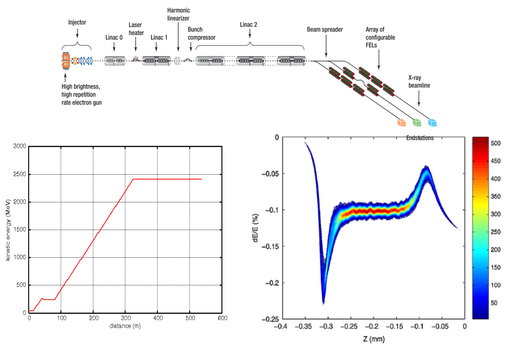
Final longitudinal phase space distribution With 7.5 keV and 15 keV initial energy spread



Final longitudinal phase space distribution With 2 BC lattice and 1 BC lattice (initial ~7 kev)



Billion-Particle Simulation of a FEL Linac Concept (5 Billion macroparticles, ~5 hour computing time on 1024 processors)



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Future Work

- Advancing the state-of-the-art in start-to-end, accelerator modeling for BES applications
- Development of new parallel, multi-scale methods for modeling phenomena in future light sources that cannot currently be modeled adequately (e.g. COTR)
  - High-resolution – sub-micron
  - Multi-scale
  - Multi-physics
  - 3-D
  - Parallel
- Allows for rapid accelerator system design, and performance optimization, while minimizing technical risk and cost

Publications

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