Simulation Comparison Between an SVEA Code (MINERVA) and a PIC Code (PUFFIN) for SASE Free-Electron Lasers

Computational Nonlinear and Quantum Optics

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BACKGROUND

- FEL simulation codes: Slowly-Varying Envelope Approximation (SVEA) or a Particle-in-Cell (PiC) formulations.
- PiC Codes: PUFFIN - Computationally intensive
  - Both Maxwell's and the Lorentz Force equations are unaveraged – can model broad bandwidths and Coherent Spontaneous Emission
- SVEA Codes: Maxwell's equations are averaged over the fast time scale – faster than PiC codes
  - Wiggler-Averaged (KMR) Codes: GINGER, GENESIS, FAST, TDA3D
  - Unaveraged Codes: MEDUSA, MINERVA
    - Lorentz Force equations are not averaged over a wiggler period
- Codes comparison references shown below [1-3]

ABSTRACT

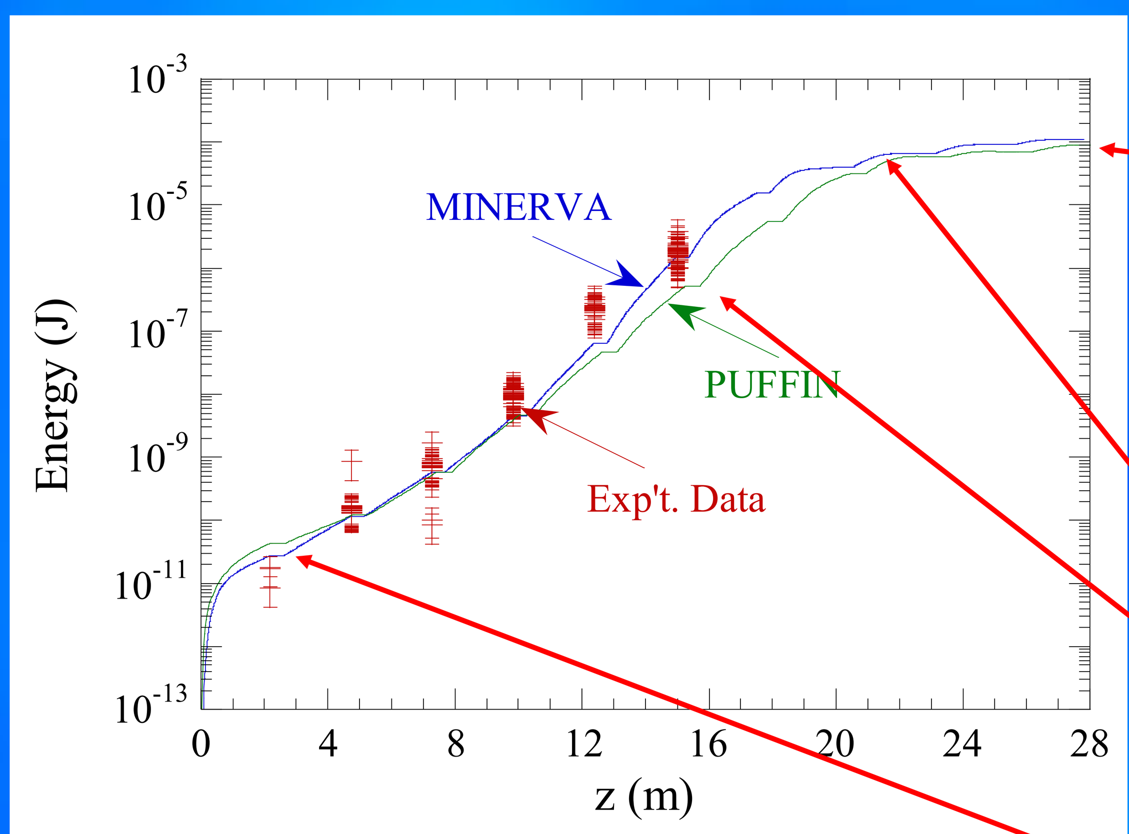
- We present a comparison between a PiC Code (PUFFIN) and an unaveraged SVEA Code (MINERVA) with experimental data taken at the SPARC SASE FEL experiment at ENEA Frascati [4].
- The only common feature of these two codes is that both integrate the complete Lorentz Force equations.
- We compare the codes predictions in the start-up region, the exponential gain region, and the post-saturation region.
- MINERVA uses an average over 15 noise seeds, PUFFIN uses an average over 5 noise seeds. Provides convergence to within about 5%.
- Important to note that the shot noise algorithms in the two codes are different.
  - MINERVA [5] uses an adaptation of the Fawley algorithm [6], while PUFFIN [3] uses a different algorithm [7].

SIMULATION RESULTS AND EXPERIMENTAL COMPARISON

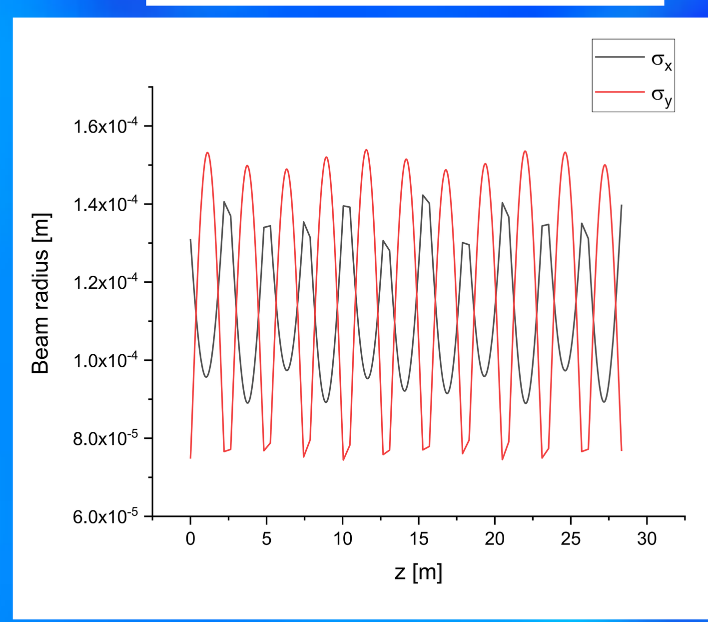
SPARC Parameters

Electron Beam	
Energy	151.9 MeV
Bunch Charge	450 pC
Bunch Duration	12.67 psec
x-Emittance	2.5 mm-mrad
y-Emittance	2.9 mm-mrad
rms Energy Spread	0.02%
rms Size (*x*)	132 microns
α_x	0.938
rms Size (*y*)	75 microns
α_y	-0.705
Undulators	11 segments
Period	2.8 cm
Length	77 Periods
Amplitude	7.8796 kG
K_{rms}	1.457
Gap Length	0.40 m
Quadrupoles	Centered in Gaps
Length	5.3 cm
Field Gradient	0.9 kG/cm

There was not enough charge to reach saturation in the 6 undulators used. We arbitrarily increased the number of undulators so we can compare the codes in the post-saturation regime



Beam Propagation

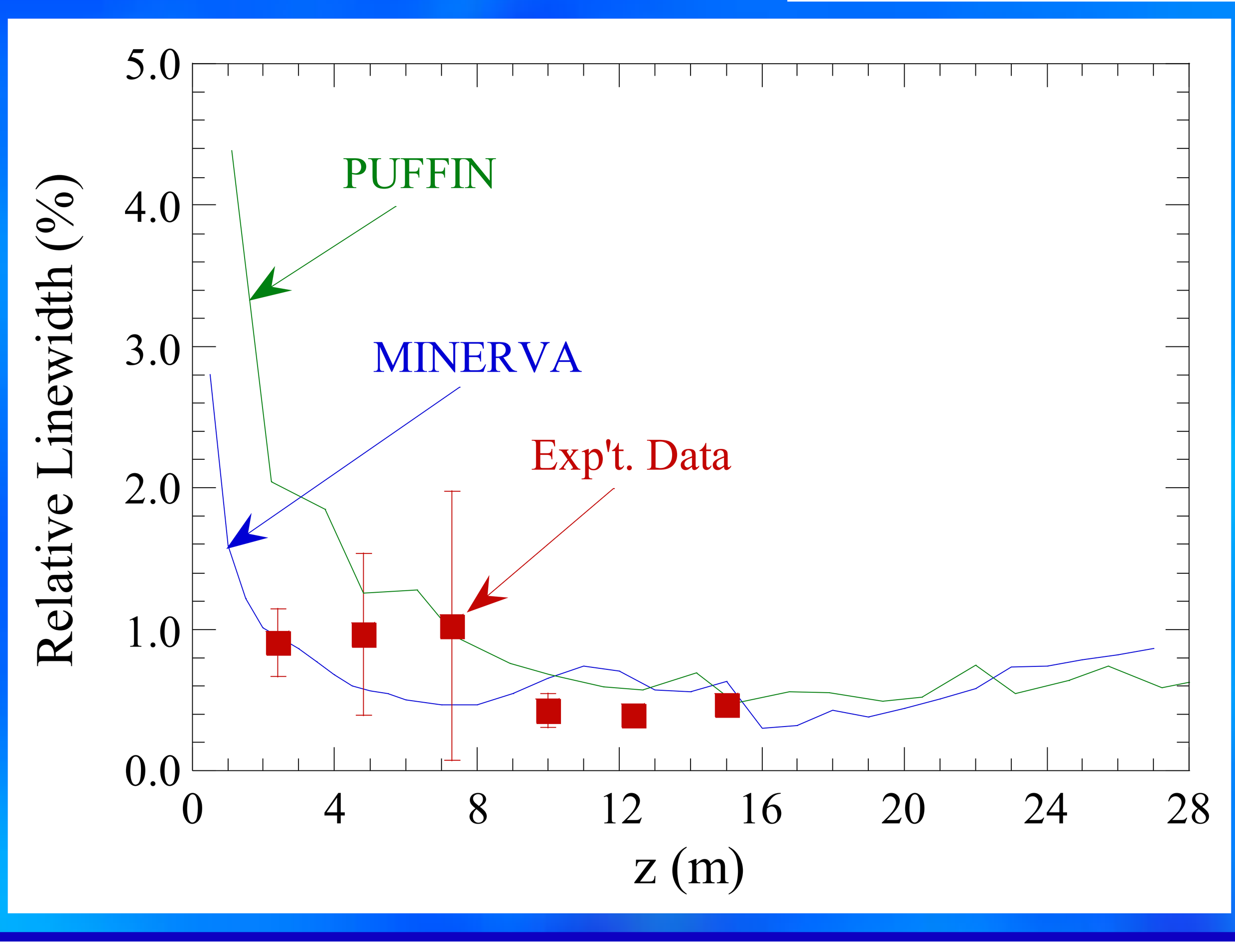


Post-Saturation: 19% difference
PUFFIN predicts 90 μJ
MINERVA predicts 111 μJ

Both codes predict saturation after about 20 m

Exponential Regime: Both codes are within experimental uncertainty

Start-Up Region: Within the First Undulator
Experiment Measured - 8.4 x 10^{-12} – 1.74 x 10^{-11} J
MINERVA predicts - 2.52 x 10^{-11} J
PUFFIN predicts - 4.02 x 10^{-11} J



The evolution of the relative linewidth as determined from PUFFIN and MINERVA and by measurement. It is clear that PUFFIN predicts a significantly wider initial spectrum than MINERVA. This is consistent with the wider bandwidth modelled by PUFFIN and the fact that, unlike MINERVA, it models the generation of the wider bandwidth CSE.

CONCLUSIONS

Good agreement found between (MINERVA and PUFFIN and the experimental measurements. **This is significant because these two formulations have virtually no elements in common, and we can conclude from this that they both faithfully describe the physics underlying FELs.** In particular, the agreement between the codes and the experimental measurements regarding the start-up regime in the SPARC FEL validates the different particle loading algorithms in both codes.

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