Current Status of the AMAS code OPAL-T and its Application to the PSI-FEL 250 MeV Injector Design

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Outline

- What is OPAL-T
- Why do we need OPAL-T?
- What is the current status of OPAL-T? (i.e. What have I been doing?)
- Current results.
- The way forward.

OPAL-T

OPAL (Object oriented Parallel Accelerator Library) is a tool for charged-particle optics in accelerator structures and beam lines. Using the MAD language with extensions, OPAL is derived from MAD9P and is based on the CLASSIC class library, which was started in 1995 by an international collaboration. IPPL (Independent Parallel Particle Layer) is the framework which provides parallel particles and fields using data parallel ansatz. OPAL is built from the ground up as a parallel application exemplifying the fact that HPC (High Performance Computing) is the third leg of science, complementing theory and the experiment.

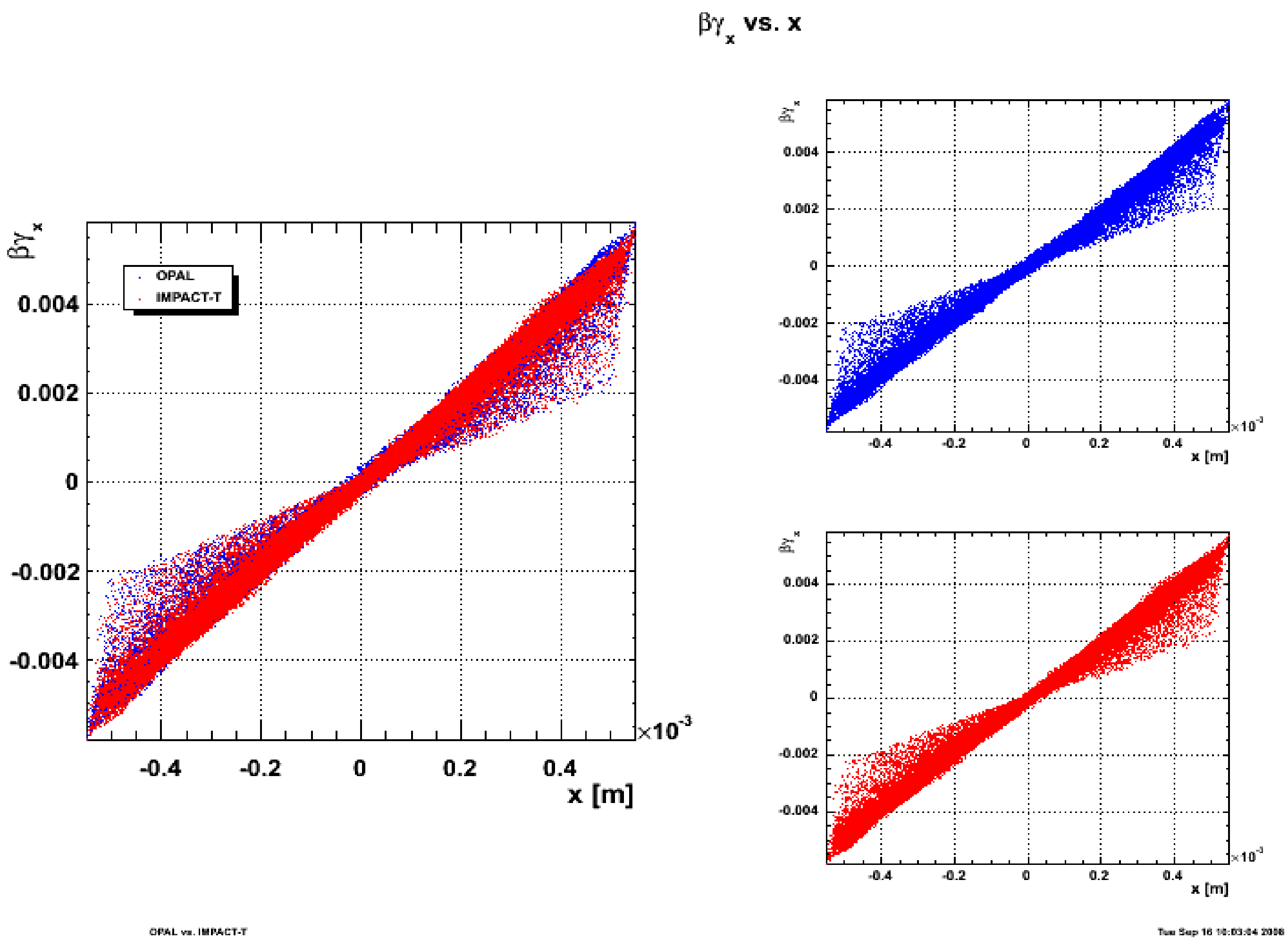
OPAL has four “flavours” or modes:

- OPAL-MAP (not yet released)
- OPAL-CYCL
- OPAL-T
- OPAL-Envelope (not yet released)

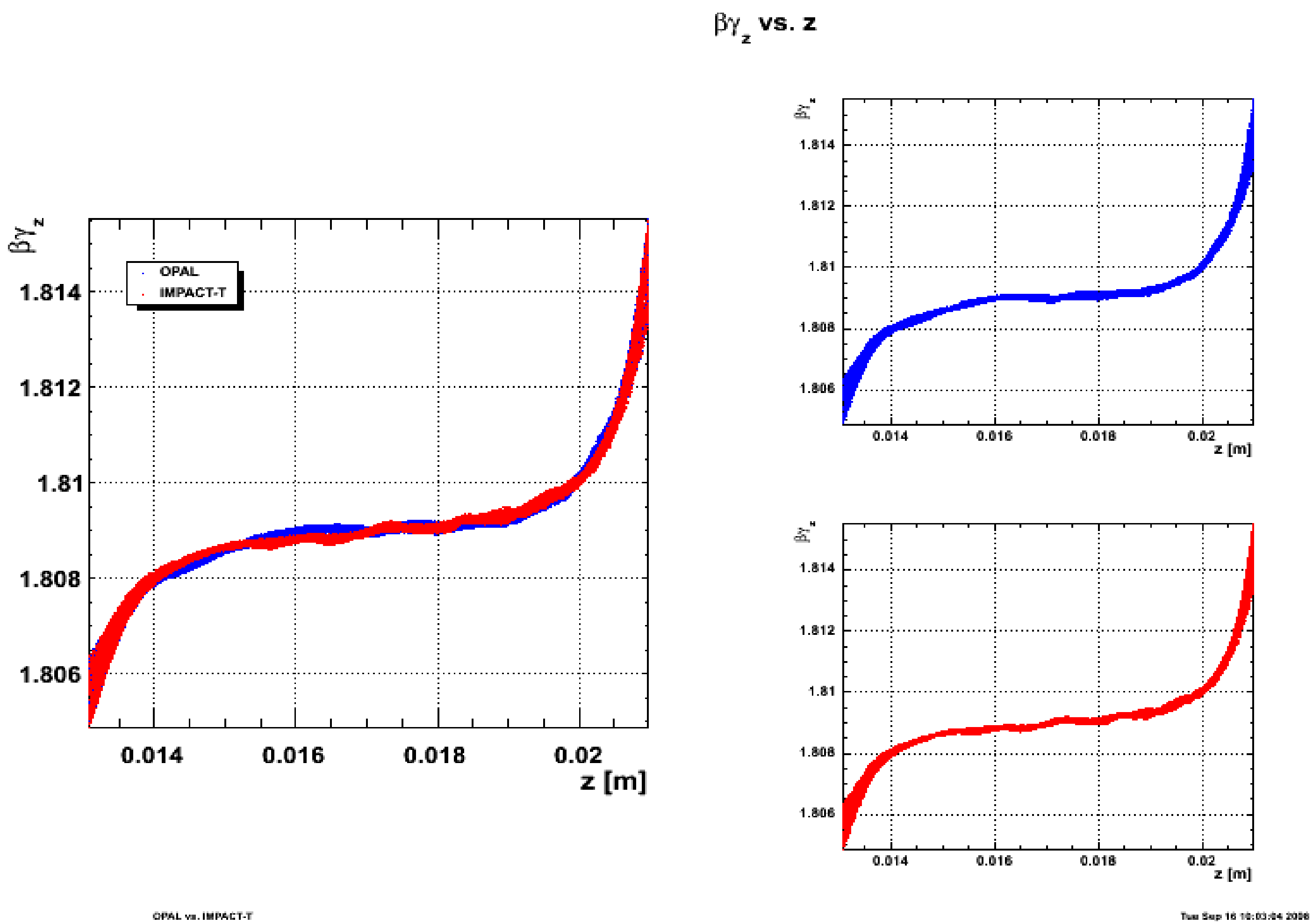
OPAL-T

- OPAL-T is a parallel time integration code that is numerically identical to IMPACT-T, but using an object oriented coding approach. This allows for much easier integration of new features and new numerical techniques. (It also makes use of a very powerful user interface library, something IMPACT-T largely lacks.)
- In the last year OPAL-T has progressed from almost nothing to a working code. A huge amount of effort, mostly from students, has gone into OPAL-T.
- OPAL-T and IMPACT-T are currently the only codes capable of massive 3D parallel simulations of particle accelerators in the time domain.
- My job, as it has turned out, was to be a beta tester and developer for OPAL-T. Lots of new features implemented over the last year required rigorous testing and debugging.

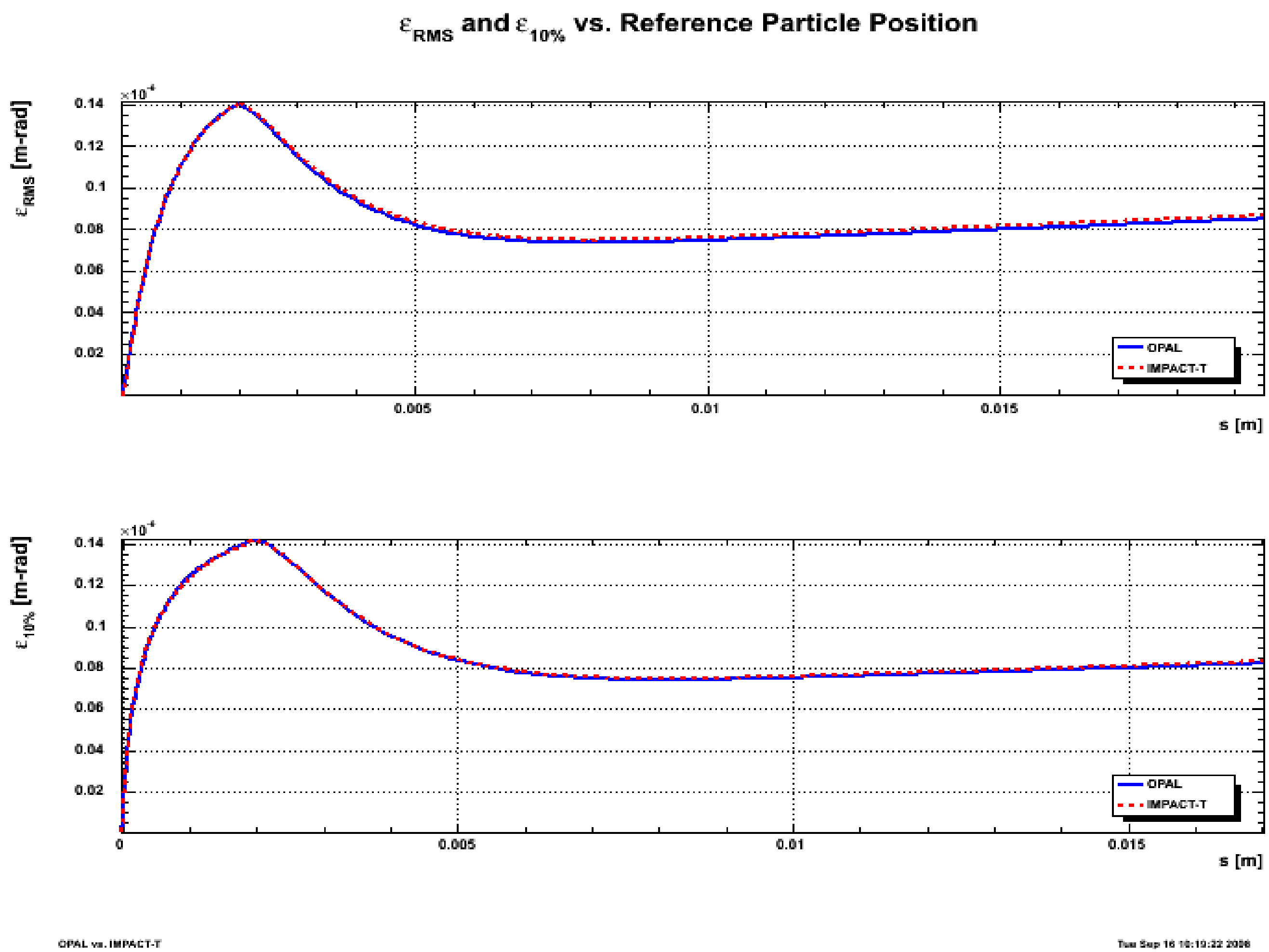
OPAL-T/IMPACT-T Results Comparison



OPAL-T/IMPACT-T Results Comparison



OPAL-T/IMPACT-T Results Comparison



Why is OPAL-T Necessary

- To investigate 3D effects in accelerator designs. In 3D we require lots of particles to reduce the numerical noise to acceptable levels.
- Examples:
  - Los Alamos APT and ATW projects.
  - PSI-FEL 250 MeV low emittance injector.

APT and ATW

In the 1990s, Los Alamos was working on two accelerator concepts:

1) Accelerator Production of Tritium (APT).
2) Accelerator Transmutation of Waste (ATW).

Early on in the project, it was recognized that they had a problem.

- Both APT and ATW required a powerful proton linear accelerator: ~1.6 GeV, ~250 mA (400 MW of true continuous beam power).
- It was recognized that a typical beam loss (≤0.1% of the beam) was potentially a major issue. (Lots of beam being deposited where you do not want it.)
- Simulation tools at the time used on the order of 1000 particles.
- Beam loss is mostly from beam halo formation. With 1000 total particles your halo is represented by 1 (maybe) particle?

IMPACT

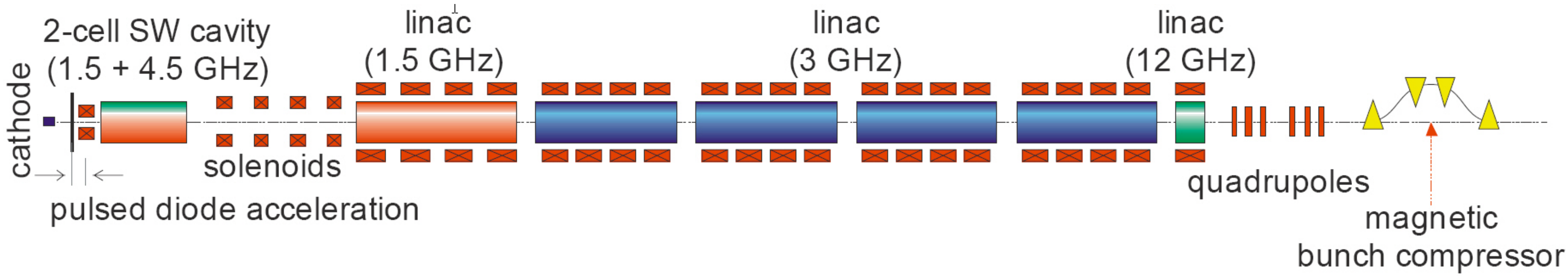
- Assuming that an accurate halo simulation requires at least 1000 particles in the halo, a low loss (1 part in 10^5) machine requires at least 100 million particles total in the simulation.
- Rob Ryne and Ji Qian developed the parallel code IMPACT (z integration) to solve this problem. (1 billion particle simulations)
- IMPACT led to the parallel code IMPACT-T (time integration) from Ji Qiang

How Many Particles for PSI-FEL Injector Simulations?

PSI has a similar problem with the FEL injector and the slice emittance calculation (~10% of the beam):

- Rule of thumb from LANL experience with PARMELA (in 2D space charge mode) is that you need at least 3000 particles in a simulation to get the numerical noise low enough for accurate RMS emittance numbers. (This number we expect to increase as the expected emittance decreases.)
- In 3D, this becomes: $(3000)^{3/2} \approx 165{,}000$ particles.
- Therefore, for an accurate 10% slice emittance calculation, we can estimate that we need on the order of 1.5 million particles.
- This number may need to be higher because of the very low emittance goal PSI hopes to achieve.

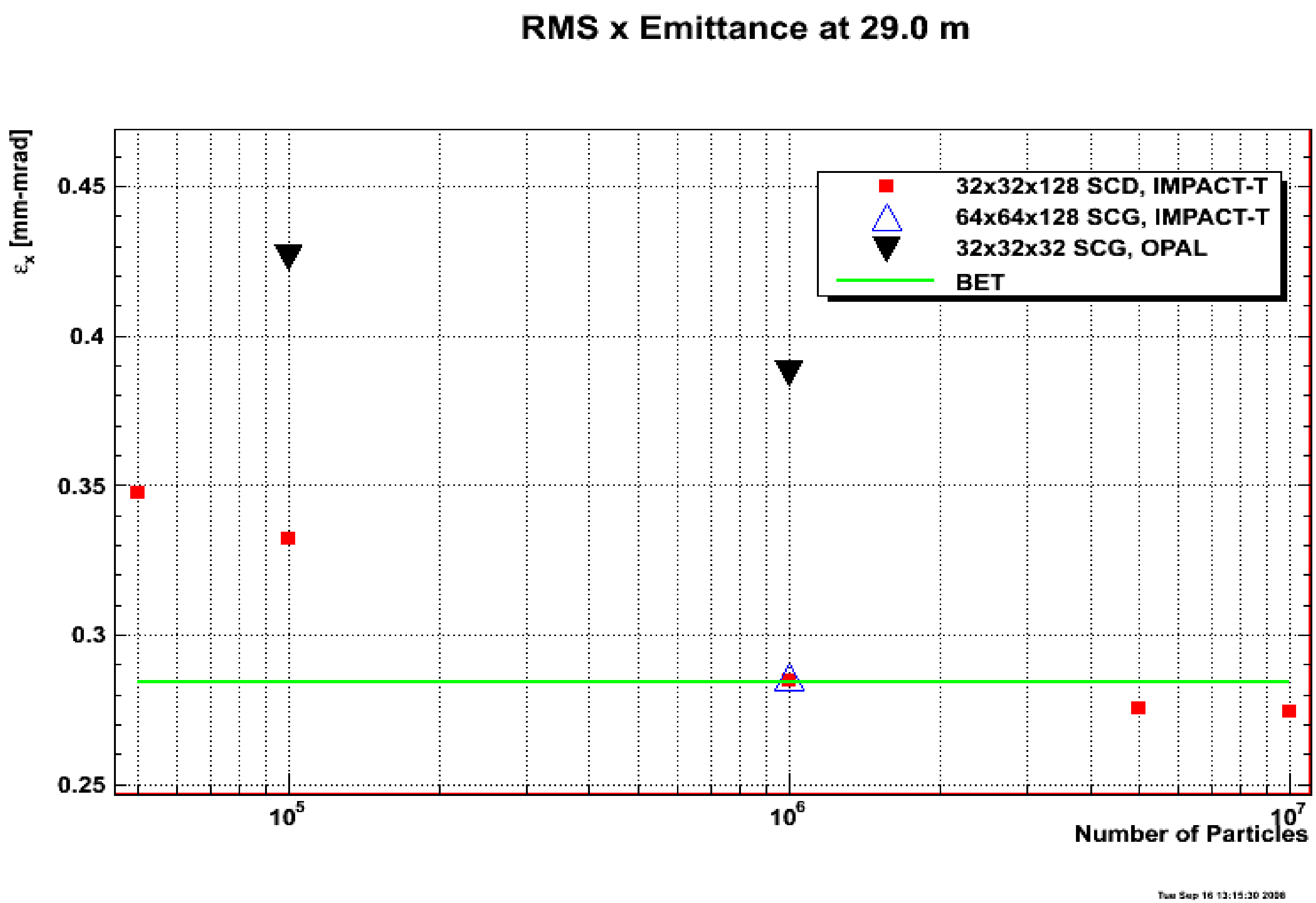
OPAL-T PSI-FEL 250 MeV Low Emittance Injector Simulation



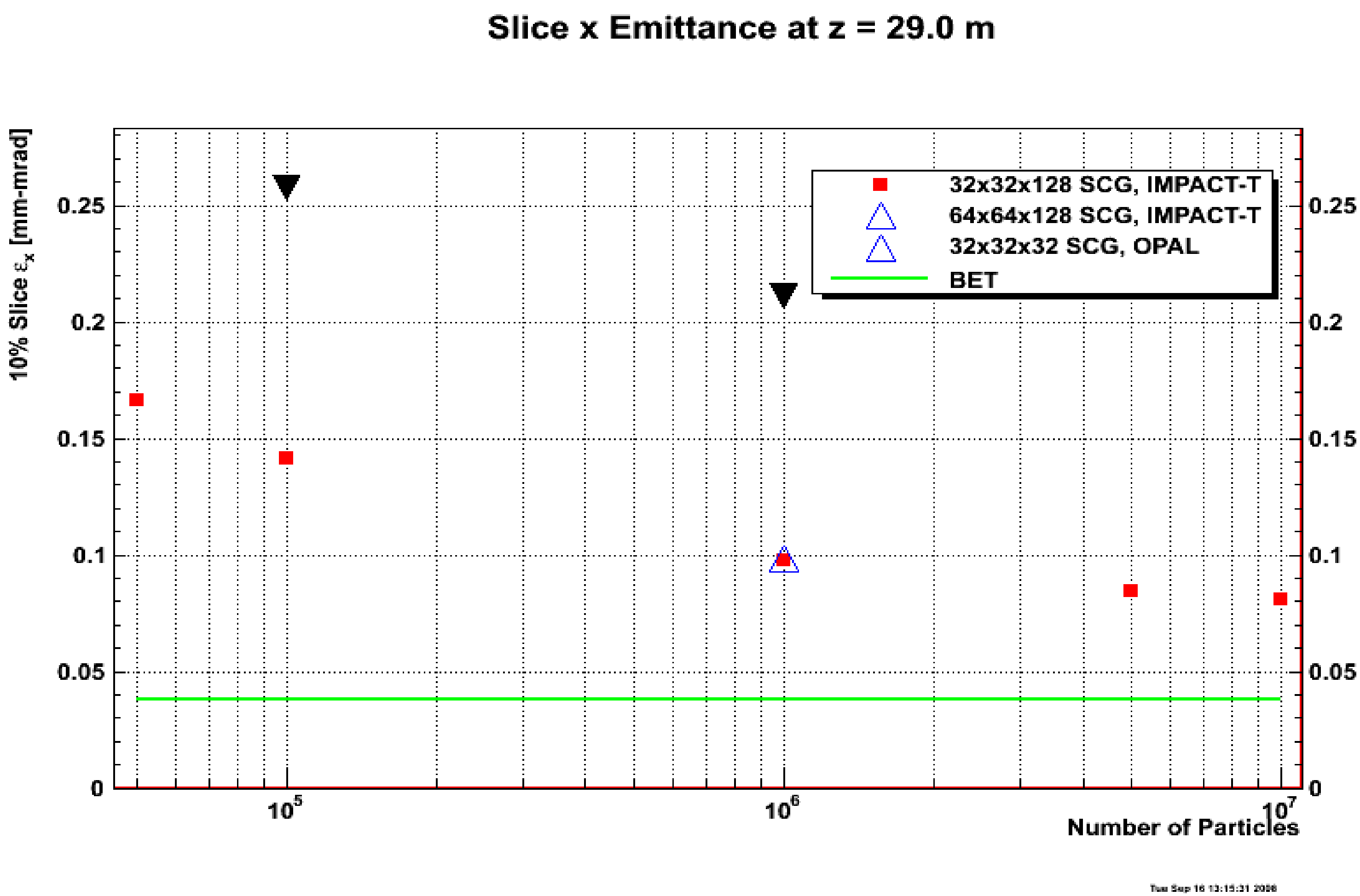
The current OPAL-T simulation is based on the original low emittance design from Rene Baker.

- 1 MeV pulsed diode gun.
- 2-cell, dual frequency standing wave cavity.
- Quadrupoles turned off.
- 4-dipole bunching chicane (not yet included in OPAL-T simulation).

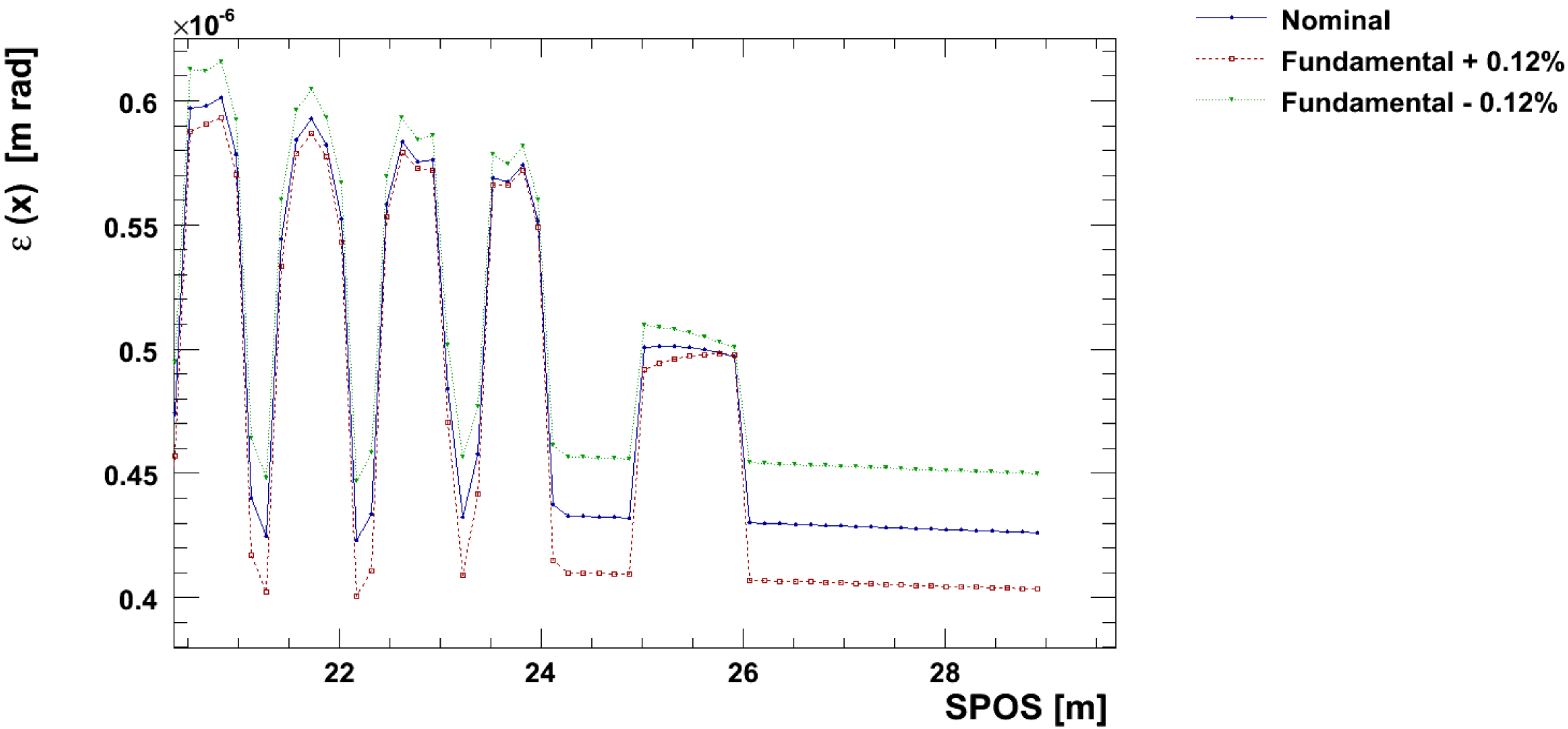
RMS Emittance Scaling with Number of Particles



Slice Emittance Scaling with Number of Particles



Preliminary Studies Varying Element Parameters



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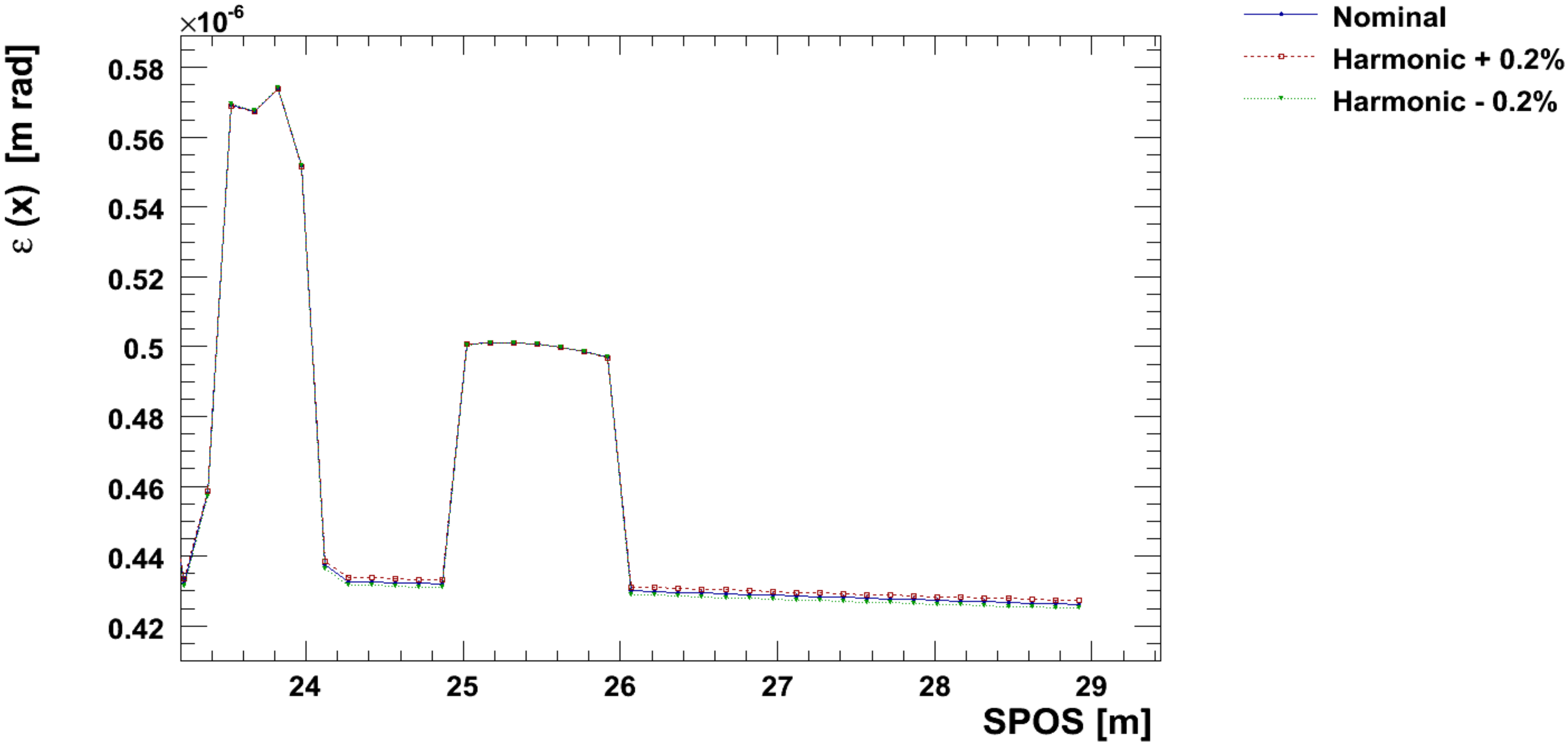

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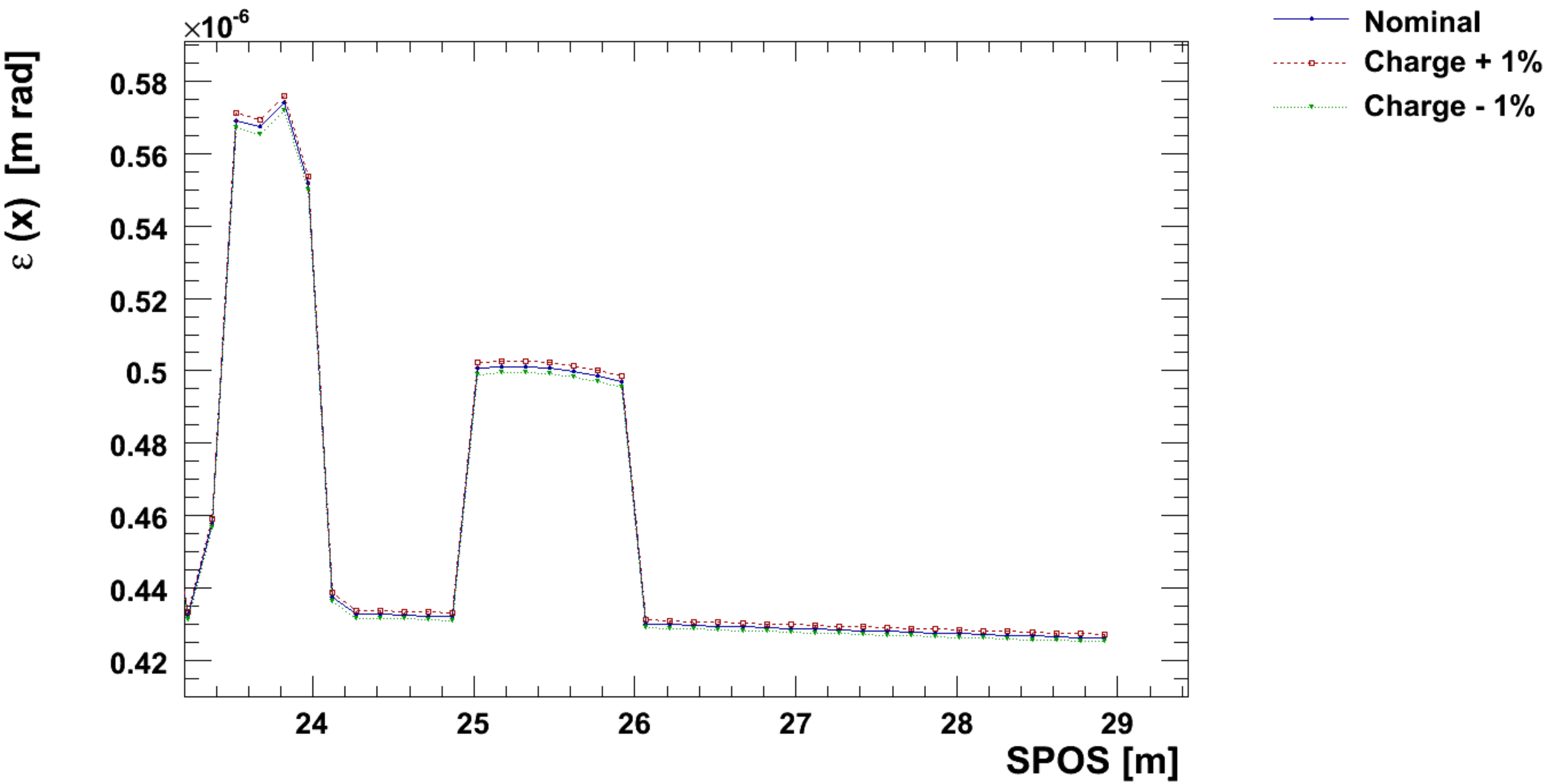

The Way Forward

- Implement first magnetic beam buncher in model.
- Establish simulation parameter requirements for useful (i.e. accurate) results:
  – Minimum number of particles needed.
  – Minimum time step required in various injector sections.
  – Minimum space charge grid.
  – Include wake fields where necessary (including CSR in buncher).
- Begin systematic error study of beam line components.