Computational Physics at PBPL

Sven Reiche - UCLA

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Areas of Research

- Beam Generation and Transport
  - Beam dynamics in space charge dominated regime of rf gun, beam transport, including non-linear optic, bunch compression.
- Radiation Interaction
  - Coherent Synchrotron Radiation (CSR) effects in a bend, transition and edge radiation as diagnostic, undulator as modulator and Inverse Free-Electron Laser.
- Plasma
  - 3D plasma waves, electron beam generation by wave breaking.
- Electro- and Magnetostatic 3D Calculation
  - Deflector cavity, Plane Wave Transformer (PWT) Design, permanent magnet quadrupole design, Undulator design for IFEL.

Resources

- Beowulf Cluster
  - Low cost 16 node cluster of Linux computers. Parallel architecture supported by some codes. Enhanced capability of parameter studies by running single processor codes simultaneously on different nodes. Unrestricted access and unlimited CPU time.
- Programming Expertise
  - Code development in C++, C and Fortran. Scripting and post-processing with Python, Tcl/TK, IDL, Mathematica. Support of MPI (parallel computation) and HDF5, SDDS and XML (common file formats)
- Software
  - Spans over code development (e.g. Parmela and Genesis), free-available scientific codes (e.g. Elegant or Radia), commercial software (e.g. Ampere).

Beam Generation and Transport (Start-End Simulation)

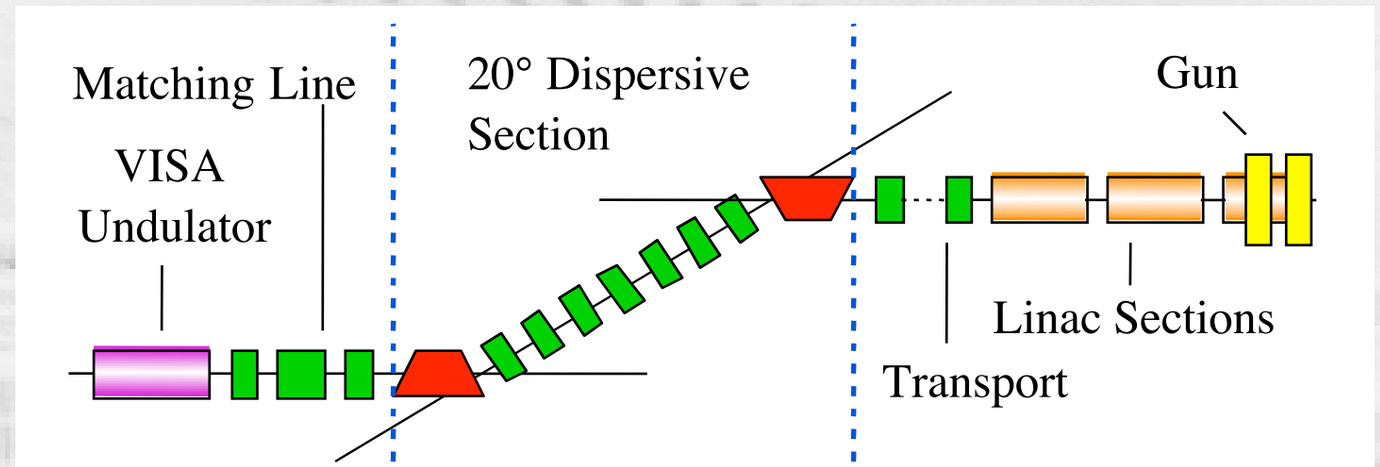
- The generation, acceleration and transport of photo-electron beams implies various effects, which have impact on the beam quality (emittance, energy spread and peak current).
- No single code can cover all these effects and would result in a highly inefficient code.
- Instead a chain of codes, each highly specialized on certain effects.

Start-End Simulation

- Successful modeling of the VISA experiment at ATF/BNL, resulted in a profound understanding of the beam transport.

VISA Start-End Simulation

- VISA Beamline at ATF

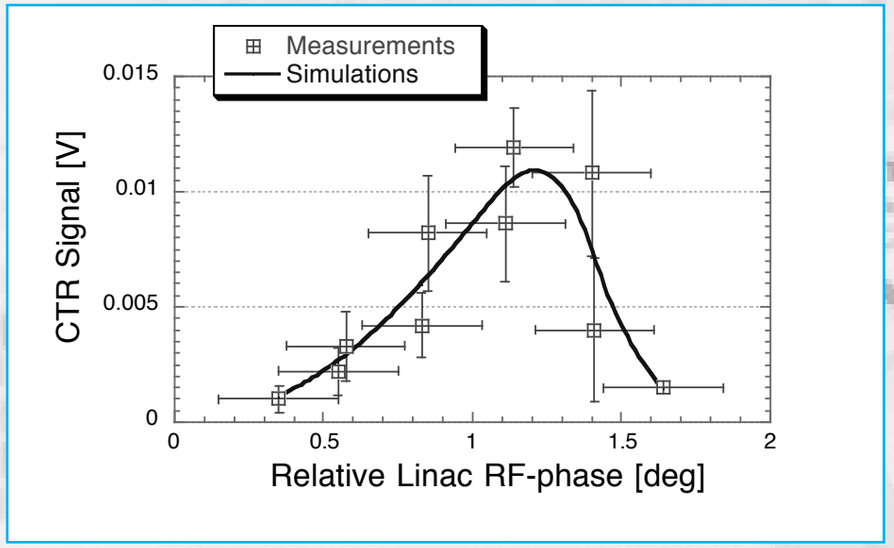


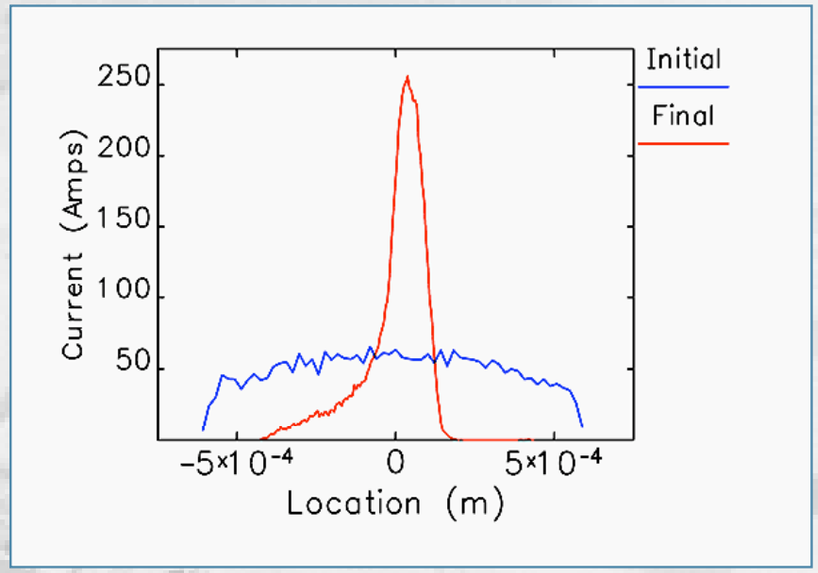
Codes: *Genesis 1.3* *Elegant* *Parmela*

Energy	71 MeV
Energy Spread	0.1%
Emittance	2.3 mm mrad
Current	250 A

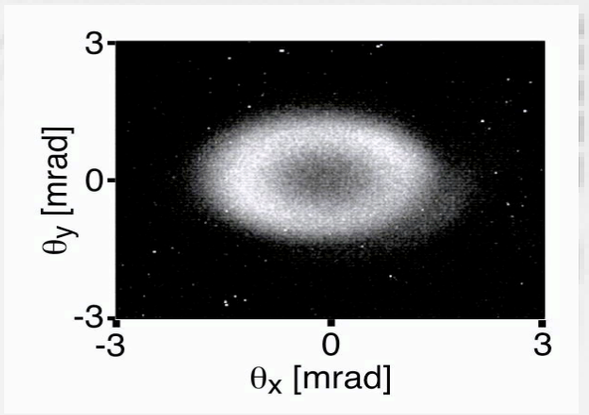
Understanding the Measurements

- Phase-dependent CTR-Signal
  - Non-linear contribution to bunch compression in dog-leg (Elegant).

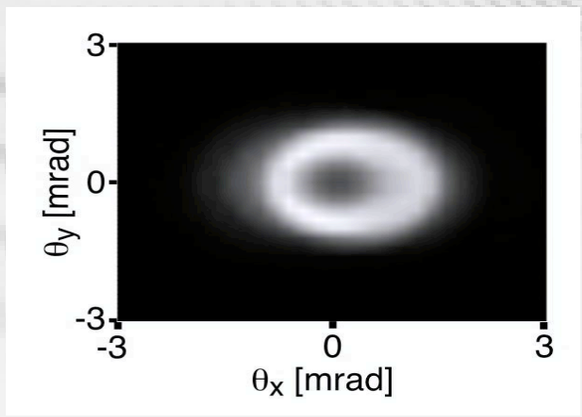




- Non Fundamental FEL mode (Genesis 1.3)
  - Asymmetric beam profile due to scraping and nonzero dispersion.



Measurement



Simulation

Status + Outlook of S-E Simulations

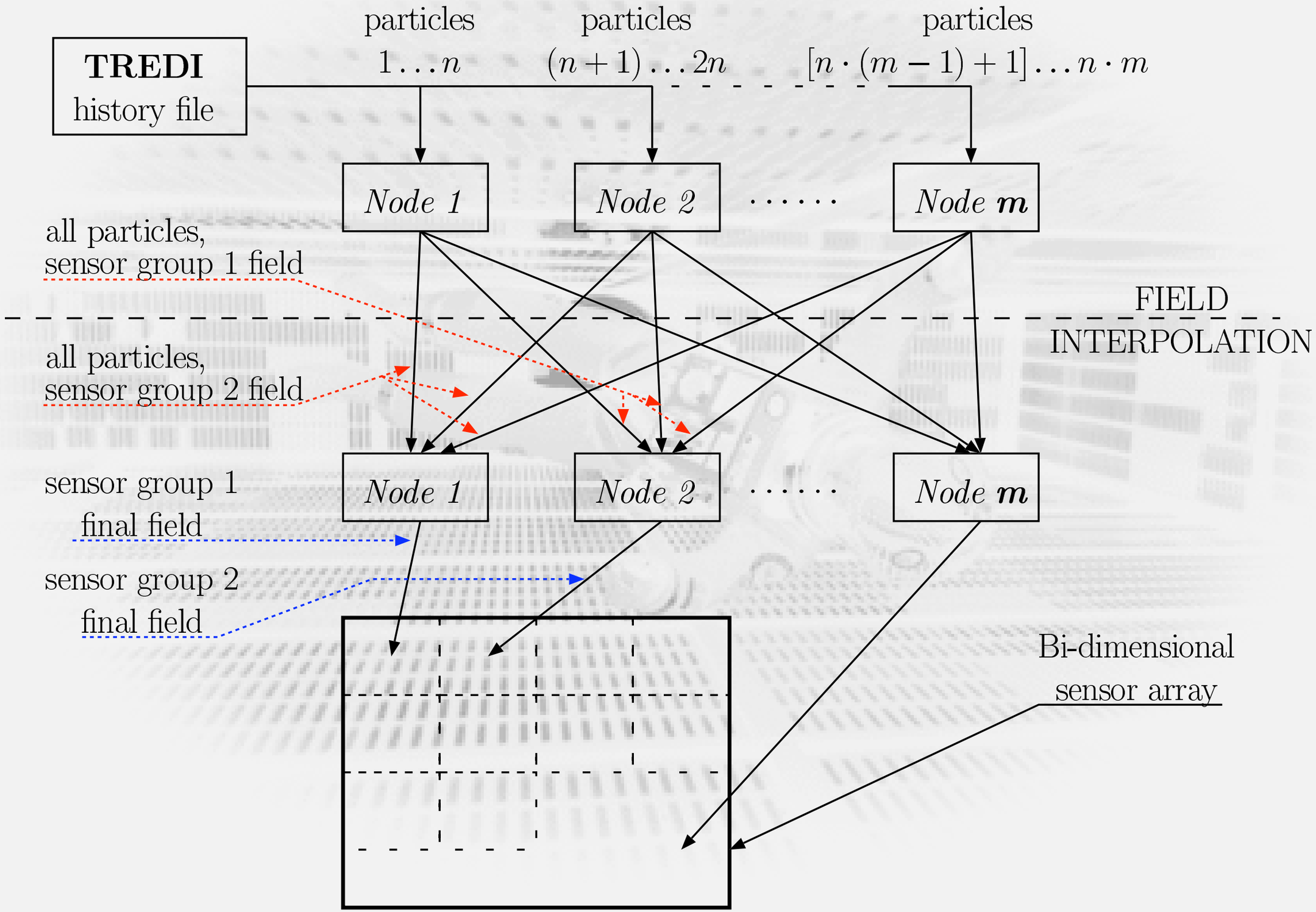
- Code suite of PARMELA, ELEGANT, GENESIS 1.3
- Add TREDI to code-suite for detailed CSR effects in bunch compressor to model strong compression in the ATF beam line.
- Modeling of CTR and CER (Coherent Edge Radiation) at ATF & Neptune.
- Negative R56 compression at the Neptune Dogleg beam line.
- Inverse FEL experiments at Neptune.

Radiation Interaction and Emission

Diagnostic

- Coherent Edge Radiation - fieldEye
  - Non-destructive diagnostic by the emission of transition radiation like radiation pattern at the edges of the bunch compressor magnets.
  - Based on the output of the self-consistent Lienard-Wichert code TREDI, particle trajectories are used to calculate the electric field at the detector position.
  - Frequency analyses to obtain spectrum in order to extract bunch length information.
  - Porting to multi-processor architecture to keep computational time within reasonable limits.

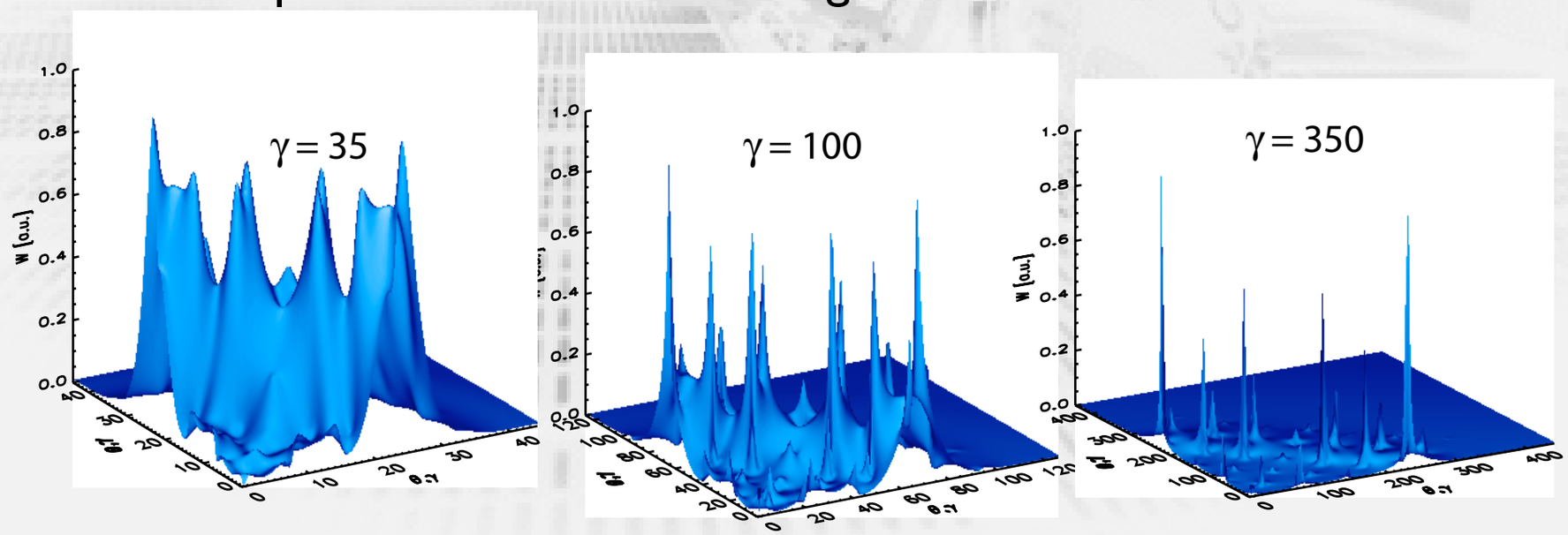
FieldEye - Program Structure



Diagnostic

- Transition Radiation (IDL Script)
  - Based on analytical equation, derived here at UCLA, calculation of the distortion of the transition radiation pattern for limited and non-even surfaces.
  - Determines total energy and transfer function for the collecting optics of the CTR measurement.

Example: Resonant emission angle for a modulated surface

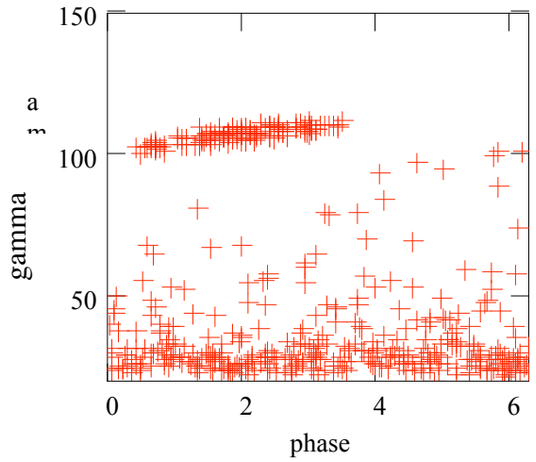


IFEL / Modulator

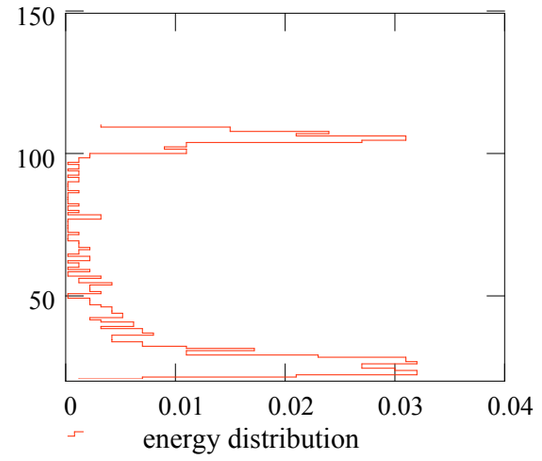
- Interaction between electron beam and a radiation field, coupled by the periodic magnetic field of an undulator.
  - Used to estimate efficiency of an Inverse Free-Electron Laser or the degree in the current modulator for plasma beat-wave experiments.
  - Modified, non official version of TREDI, supporting external radiation fields (Gauss-Hermite modes).
  - Official version of GENESIS 1.3 (maintained by UCLA) with self-consistent interaction, although period-averaged equations of motion impose a limit toward large accelerating gradients in an IFEL.

Example:
Neptune IFEL,
done with TREDI

Longitudinal phase space



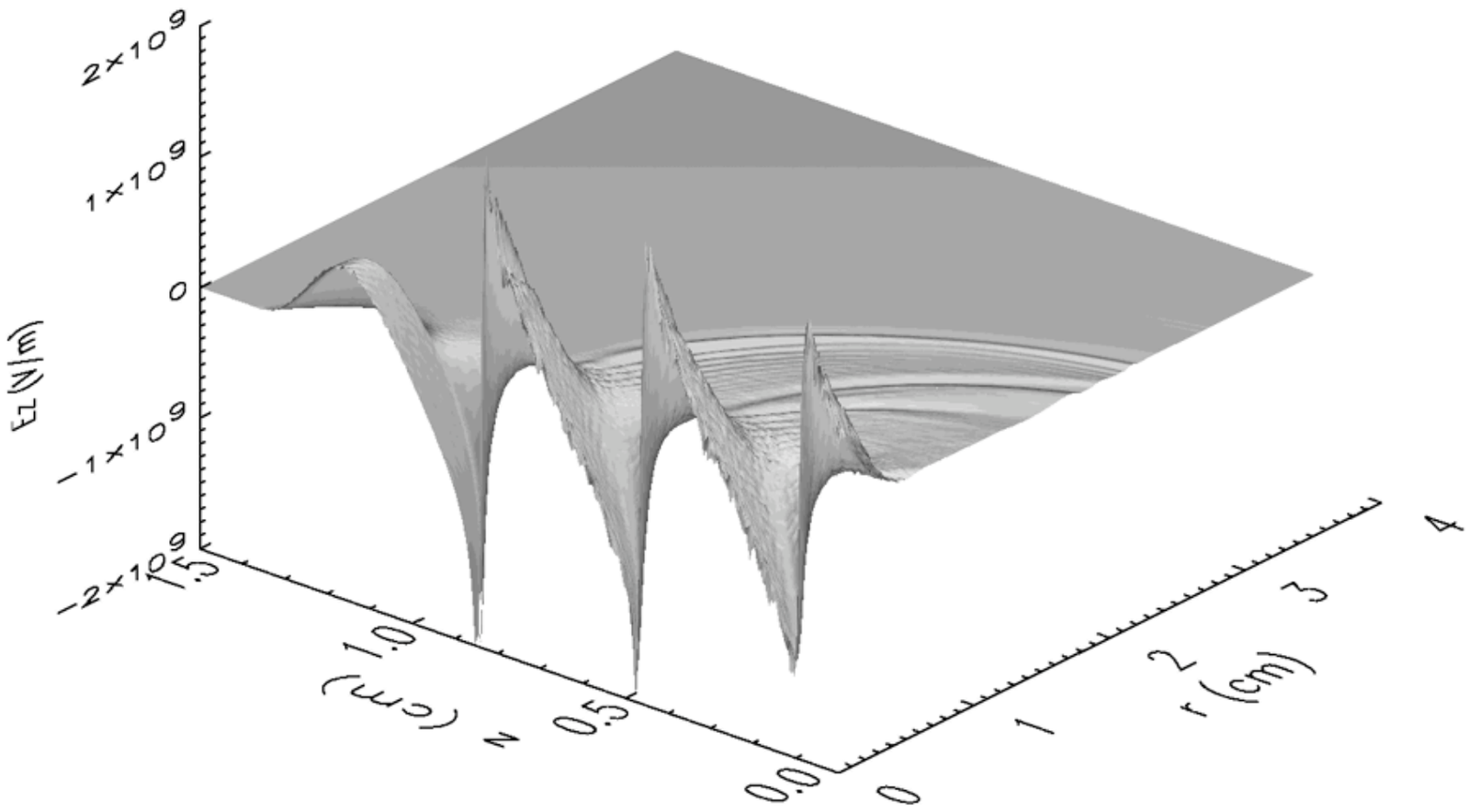
Energy population at the end of the undulator



Plasma

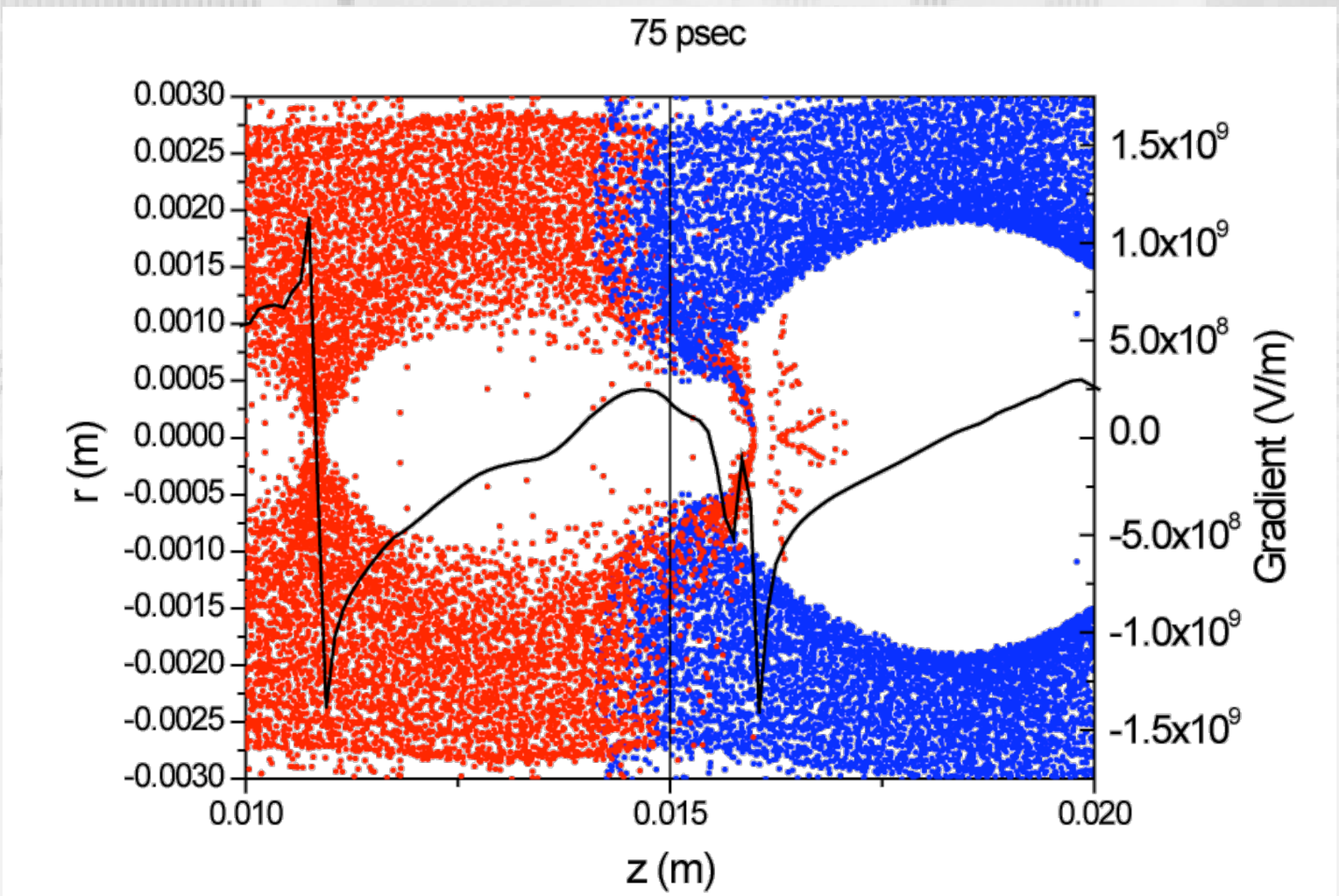
OOPICS Pro

- 2D Plasma simulations (Plasma beat wave)
- First parallel code in the lab.



MAGIC - 2D

- Plasma density trapping as a source of very bright electron mean, overcoming the limitation by the thermal emittance
  - Experiment at the A0 injector, FNAL
  - Simulations done with the commercial code MAGIC-2D



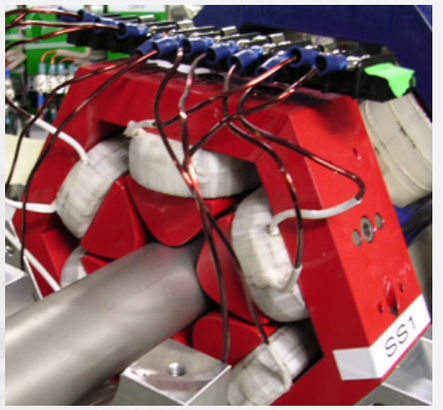
Electro-Magnetostatic Calculation

Codes for Magnet Design

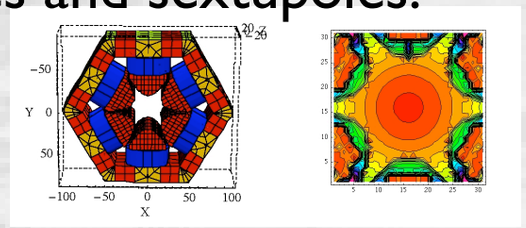
- POISSON (2D) for initial design and parameter optimization. Output can be inmported into PARMELA for rf gun simulation.
- AMPERE (3D, commercial program) for electro magnets. Weak support for permanent magnets. Estimate of heat load.
- RADIA (3D, free program, but requires MATHEMATICA to run) for permanent magnets. Highly flexible due to the MATHEMATICA scripting language. Limited support for electromagnets.

Magnet Design

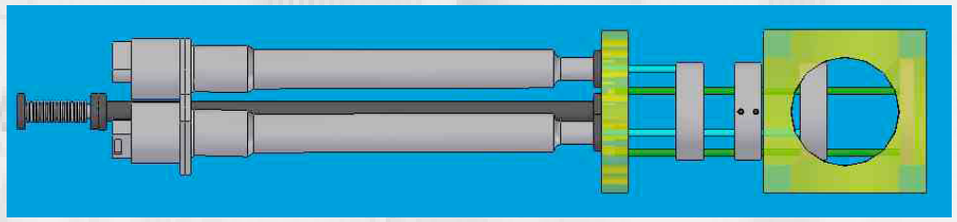
- Expertise in designing and building magnets for various beam lines and experiments



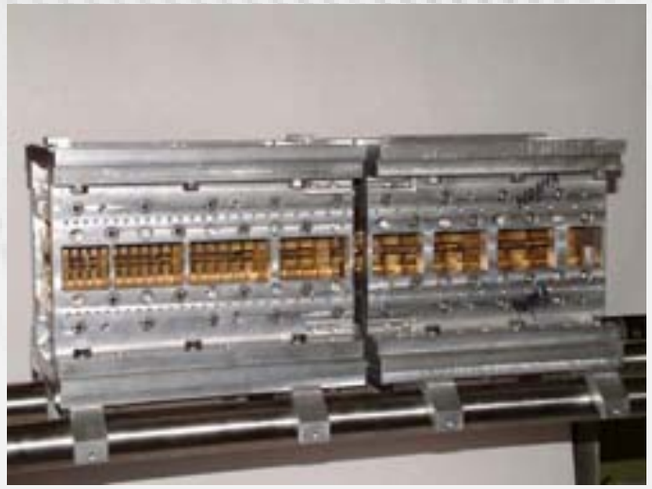
  - Electric solenoids, dipoles, quadrupoles and sextupoles.



  - Permanent magnet quadrupoles and control of focal strength by variable spacing of a triplet.



  - High precision undulator for Free-Electron Laser experiments.
  - Strongly tapered undulator for Inverse Free-Electron Laser experiments.

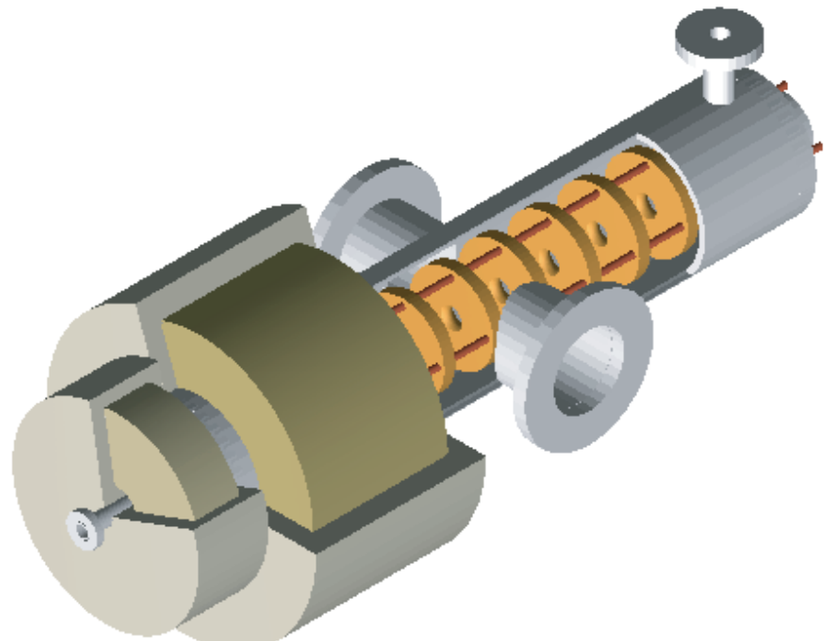


Codes for RF-Structure Design

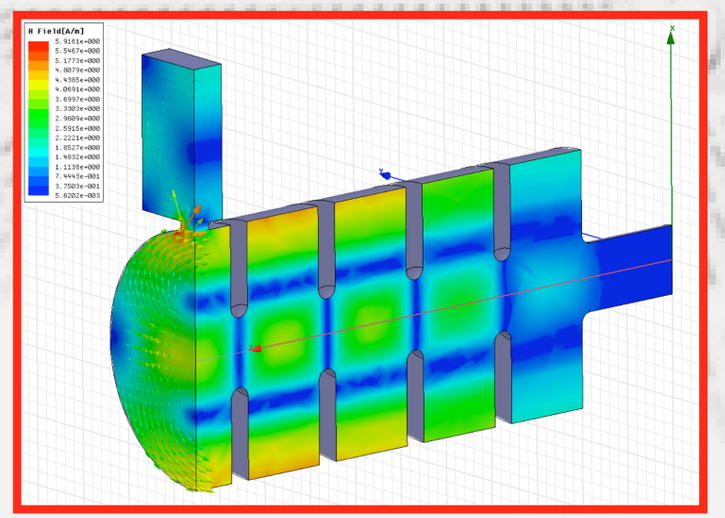
- SUPERFISH (2D) for initial design and parameter study. Supported by PARMELA.
- GDFIDL - 3D MAFIA-like field solver. UCLA has the source code for beta version. No further support by the GDFIDL development team, unless we upgrade to commercial version (with no access to source code)
- HFSS - Commercial, currently the primary program for 3D cavity design.

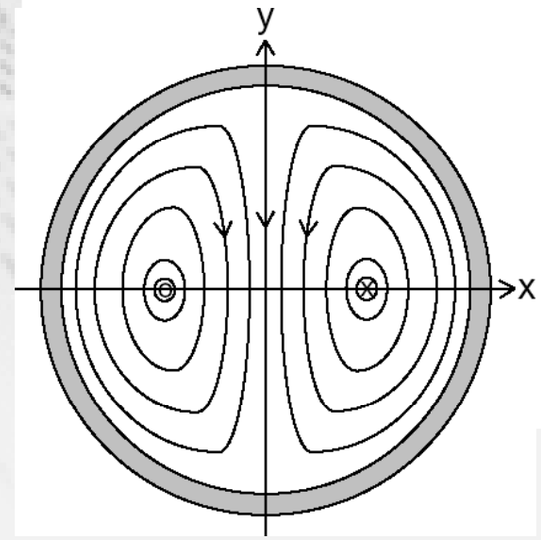
RF-Structure Design

- Design and construction of rf cavities for S- and X-band.
  - 1.6 BNL-type rf photo-electron gun
  - PWT linac and injected, designed at UCLA



- Deflecting cavity for bunch length measurement (X-band due to space limitation in the Neptune beamline)





Conclusion

- Growing expertise in designing and constructing magnets and rf-structures. Mostly 3rd party or commercial software.
- Leading in start-end simulation efforts to model complex beam lines.
- Source code development, mainly for radiation processes, which cannot be simulated with commercial software.
- Profound knowledge in high-performance computation by exploiting parallel architecture and modern file formats.