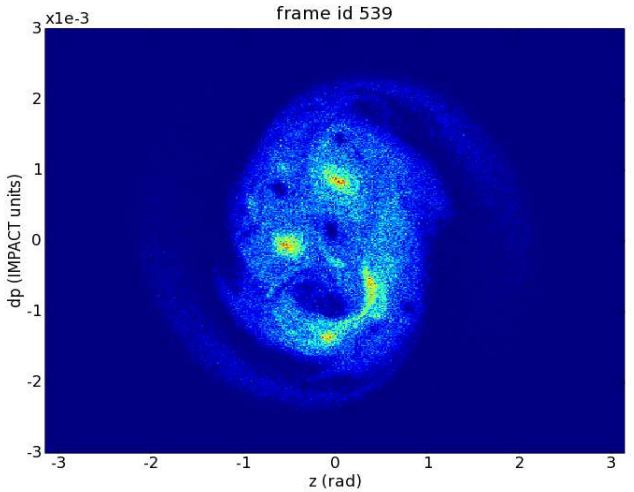
Συνεργεια

AMR/CPA ILC modeling

P. Spentzouris

1/24/06



http://cepa.fnal.gov/psm/aas/Advanced_Accelerator_Simulation.html

Outline

- Background on CPA
  - in house capabilities: people, codes, projects
  - other capabilities: collaboration
- ILC related modeling capabilies
  - DR design study @ FNAL

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CD AMR/CPA

- Currently 5 people
  - Leo M. (single-particle-optics) joined '06
  - Eric Stern (collective effects) joined '05
  - Doug Dechow (framework, TechX SBIR) '05
  - Jim Amundson and PGS (collective effects, framework, etc) since '01
- Members of multi-institution collaboration funded by SciDAC (LBNL, UCLA, TechX, SLAC, ...)

The FNAL Synergia project

Part of US DOE SciDAC program, with objectives:

- Develop accelerator simulation framework capable of 3D collective beam effect modeling, with realistic model parameters, in a time scale relevant for current operations.
  - tightly coupled parallel computing
  - flexible interface & analysis tools
  - re-use/integrate existing physics modules
- Develop necessary tools for modeling future accelerator designs

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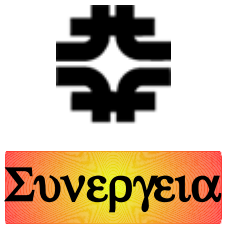
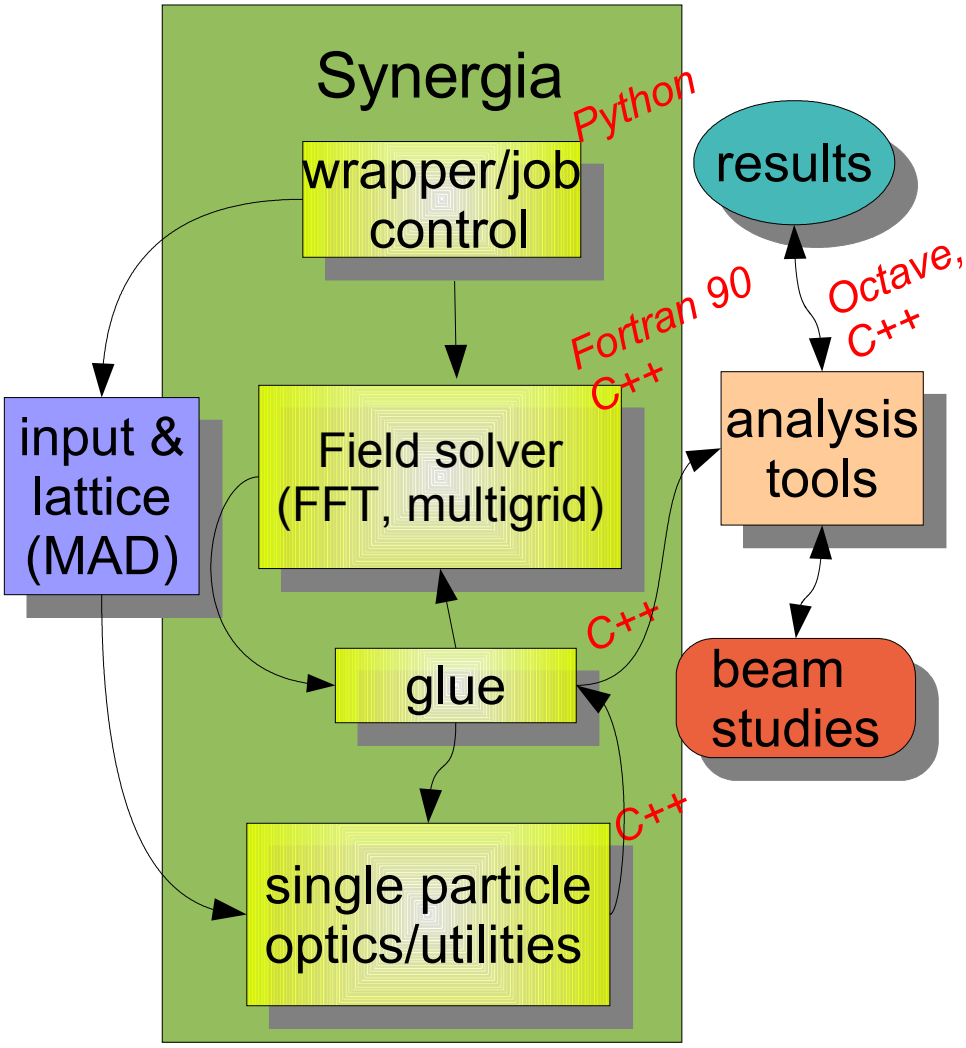
Or in plain English:

- Develop the expertise at FNAL to tackle interesting beam physics problems that require large scale computation
  - develop tools if necessary
  - install/learn tools
    - interface to our framework if desirable
- Leverage from SciDAC & SBIR program



The Synergia Framework

- Encapsulate & extend existing packages, develop new modules
  - single particle optics
    - arbitrary order maps (CHEF, C++)
  - Multi-particle effects
    - Poisson solver: FFT (Impact, F90), multigrid (PETSc libraries, C/C++)
- Physics utilities (Python, C++, Octave)



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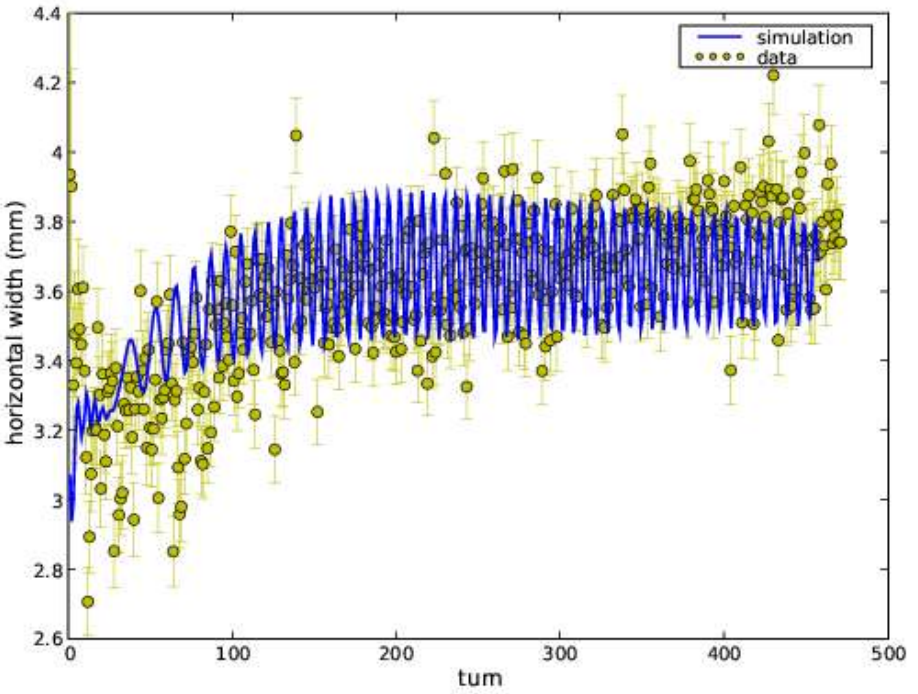
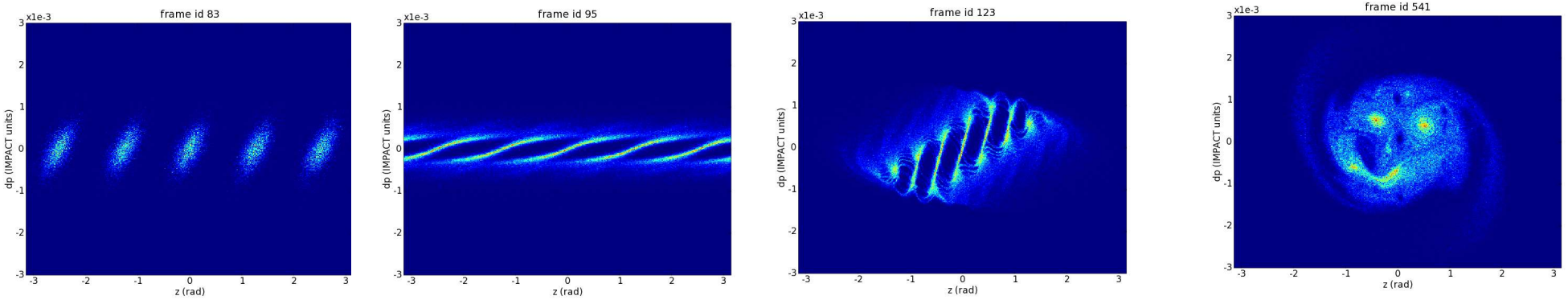


The Synergia 3D SC package has been used in Fermilab Booster modeling (JCP, PRSTAB, and PAC and HB04 conferences) and CERN PS (PAC), see:

http://cepa.fnal.gov/psm/aas/Advanced_Accelerator_Simulation.html

Longitudinal phase-space: injection, before bunching, start & end bunching



Other Synergia physics modules

- electron cloud generation
  - interface to cmee libraries -TechX- (SEY from M.Furman's POSINST)
  - electron tracking (GSL rk4)
  - field calculation from Synergia's Poisson solver (3D, arbitrary distribution) -under development
  - simple geometry
- impedance -implemented, model not tested

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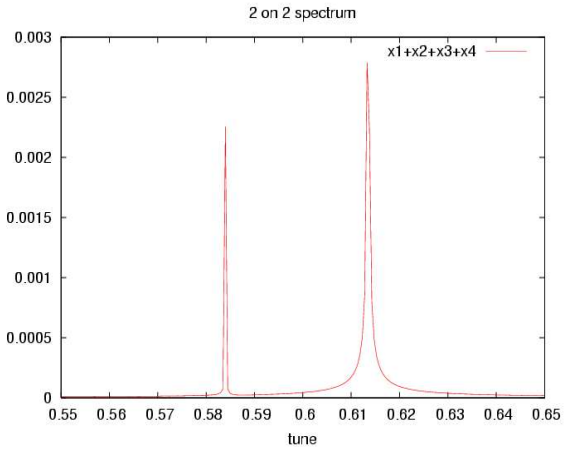
Available physics codes

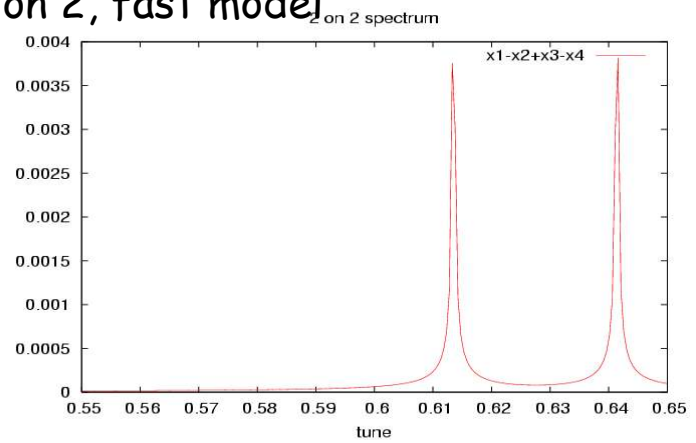
- BeamBeam3D: strong-strong 3D beam-beam capabilities (source LBNL)
  - TeV application in progress
  - code integration to Synergia in (slower) progress
- QuickPIC: electron cloud dynamics (source UCLA/USC)

Activities

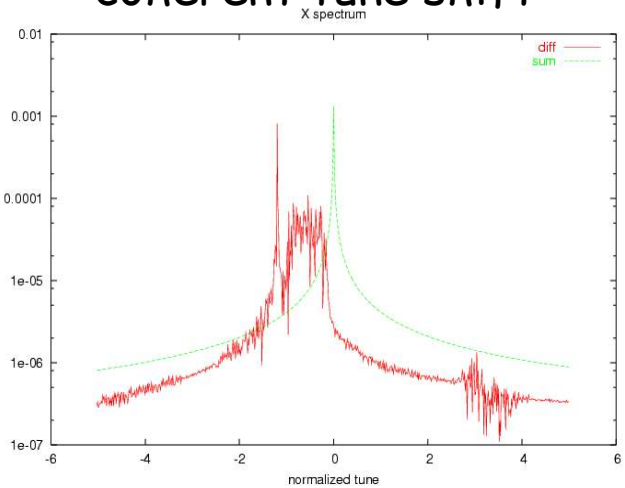
- Beam-beam using BeamBeam3D (Eric Stern)
  - 3D strong-strong model
  - implemented "fast" model, maps from measured lattice functions, diagnostics, etc
    - used for Tev modeling



2 on 2, fast model



TeV 1-on-1 head on collision coherent tune shift



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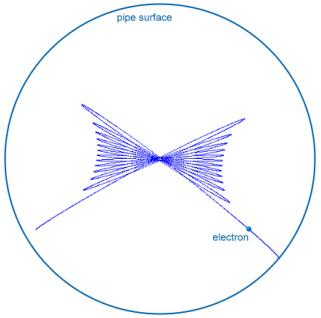
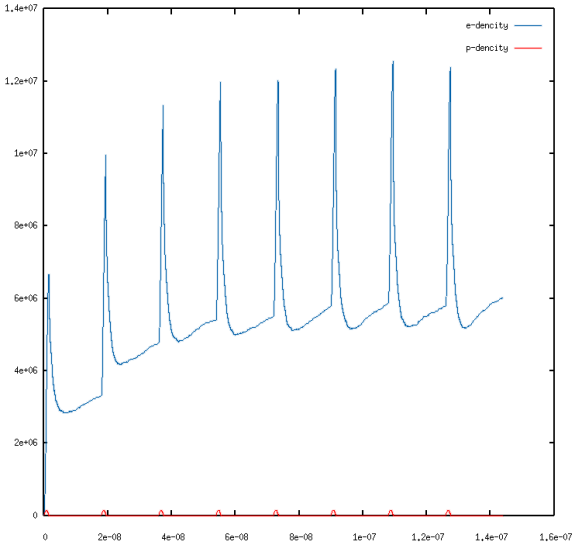
Activities

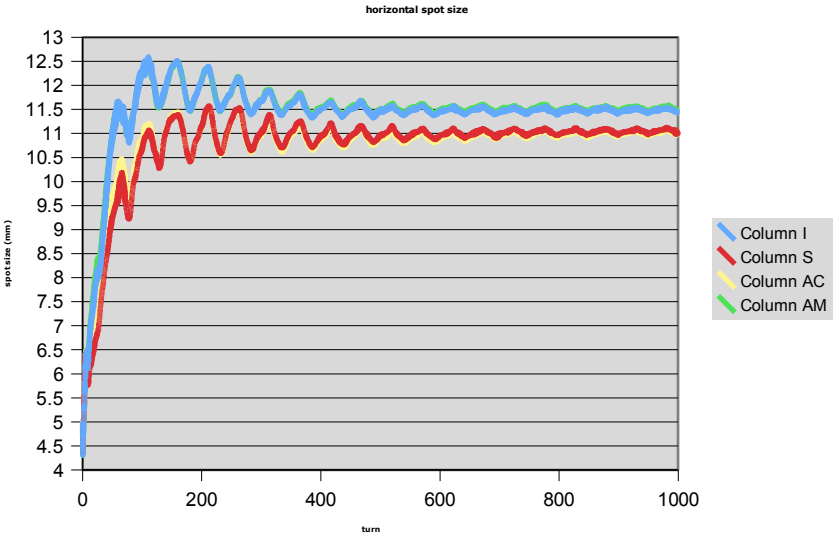
- Electron cloud. Currently implementing in framework and developing physics module for MI
  - use M. Furman's e-cloud generation code
    - tested vs other codes
  - field solver from Synergia
- Dynamics physics module
  - use QuickPIC

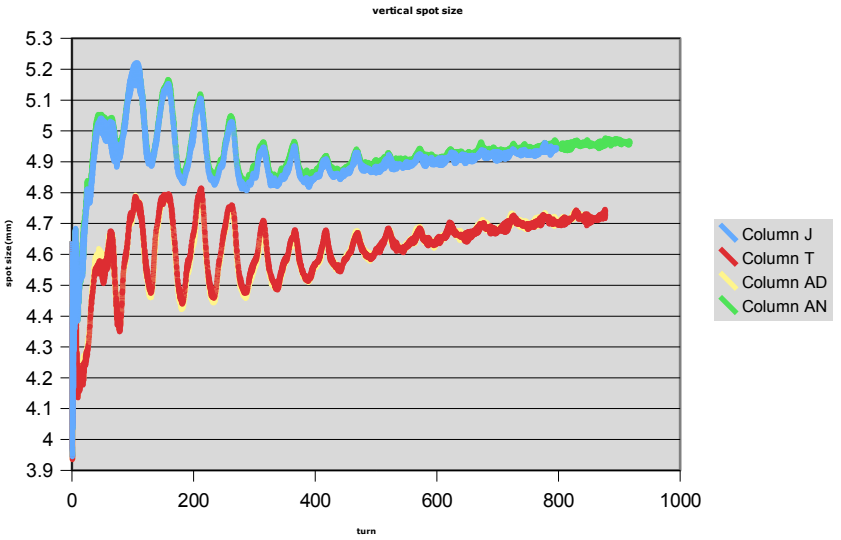




QuickPic MI results for MI @ 3E11 ppb

Model does not include fields





Work in collaboration with UCLA and USC

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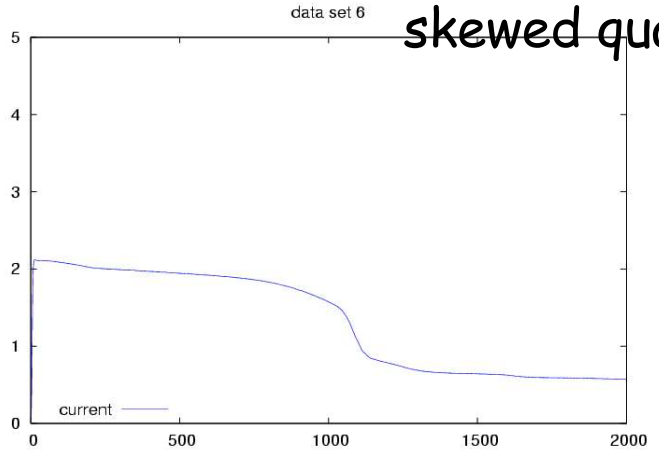
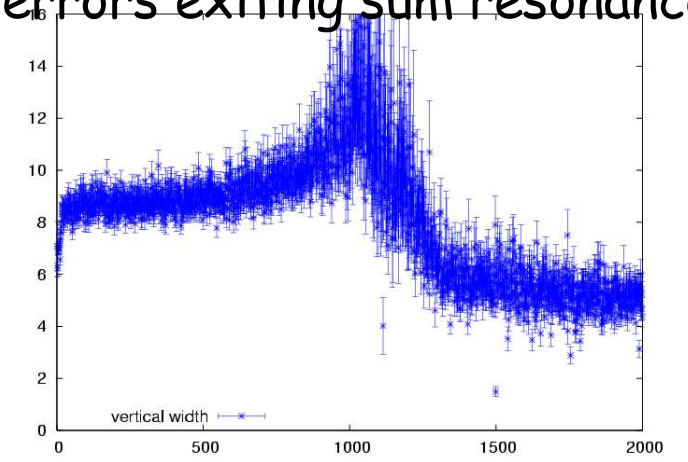
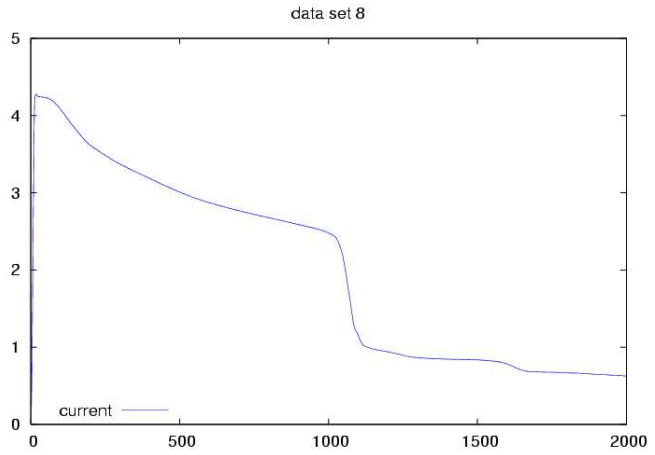
Activities

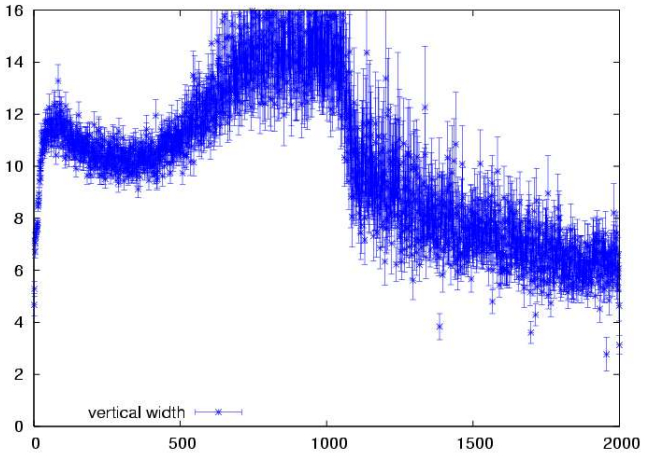
skewed quad errors exiting sum resonance?





Booster modeling and experiments.





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Current ILC related activities

- Optics (Leo Michelotti)
  - Implement electrons in CHEF ("Collaborative Hierarchical Expansible Framework"); "purify" relevant lattices for CHEF
    - understand/study DR lattices
    - work with Paul on linac lattices
- DR space-charge (Amundson, Spentzouris)
  - Fully 3D, self-consistent modeling for at least one DR case (all existing models "frozen-beam")
    - use new solver/framework (work in progress)
  - Compare with existing non-self consistent simulations
    - more cases if discrepancy

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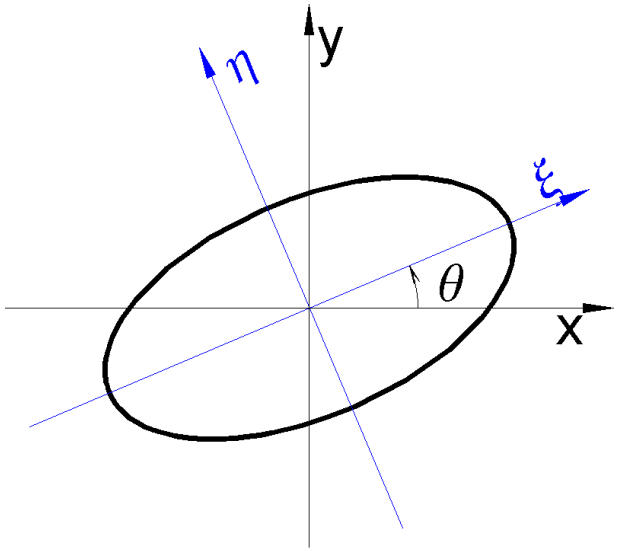
DR space-charge simulations

- Existing DR space charge simulations use weak-strong approximation
  - Force from a "frozen Gaussian" beam distribution (Bassetti-Erskine formula)



$$f_\eta + i f_\xi = 2\sqrt{\pi}\,\frac{r_e}{\gamma^3}\,\frac{\lambda(z)}{S}\left[w(a_1) - w(a_2)\exp\left(-\frac{\xi^2}{2\sigma_\xi^2} - \frac{\eta^2}{2\sigma_\eta^2}\right)\right]$$

$$S = \sqrt{2(\sigma_\xi^2 - \sigma_\eta^2)}; \quad a_1 = (\xi + i\eta)/S; \quad a_2 = \left(\xi\frac{\sigma_\eta}{\sigma_\xi} + \eta\frac{\sigma_\xi}{\sigma_\eta}\right)/S$$

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But really:

- Try to understand where our expertise is relevant, and where more modeling is needed in order to develop more expertise

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DR design @ Fermilab (M. Church)

- DR which can fit in the Tev tunnel
- consistent with using PD as injector
- consider using permanent magnets
- use "nominal" ILC parameters:
  - 5 GeV energy, 2E10 epb, 2820 bunches/train

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Physics issues

1) linear optics

2) tracking and dynamic aperture

3) vertical emittance preservation

4) space charge effects

5) instabilities and beam loading

6) polarization preservation

7) trapped ions

8) electron cloud

9) IBS

AMR/CPA will contribute if project goes ahead

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But first

- Evaluate current status of work/studies.
  - Marco Venturini (LBNL) SciDAC collaborator for SC
  - will need similar contact for e-cloud

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Ecloud @ ILC DR M.Pivi, Snowmass '05

The electron-cloud effect (ECE) in a nutshell:

- Beam residual gas ionization and photons produce primary e-
- Number of electrons may increases/decreases due to surface secondary electron yield (SEY)
- Bunch spacing determines the survival of the electrons

Especially strong effect and possible consequences:

- Single- (head-tail) and coupled-bunch instability
- Transverse beam size increase directly affecting the Luminosity
- Vacuum pressure and excessive power deposition on the walls

In summary: the ECE is a consequence of the strong coupling between the beam and its environment:

- many ingredients: beam energy, bunch charge and spacing, secondary emission yield, chamber size and geometry, chromaticity, photoelectric yield, photon reflectivity, …

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Working plan from Snowmass

- Pertinent parameters for three different rings (17 km, 6 km and 3 km circumference) [: “For some studies (e.g. electron-cloud build-up) it probably is not necessary to study every lattice in detail, but pick one in each circumference.”]
- Electron cloud build up is simulated for the different regions (arcs, wigglers, straights) considering different secondary emission yields.
- For the wigglers simulations the field can be modeled at various levels of sophistication, and the importance of refined models has to be explored;
- Single-bunch wake fields and the thresholds of the fast single-bunch TMCI-like instability are estimated;
- Multi-bunch wake fields and growth rates are inferred from e-cloud build up simulations;
- Electron induced tune shifts will be calculated and compared;
- Predictions of electron build up from different simulation codes are compared;
- Implemented in the simulations will be countermeasures which may be proposed as the ILC DR design evolves.

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Other possibilities

- Beam-beam @ IP
  - need to add quantum effects
    - leverage from SciDAC (LBNL also will participate in development)

More ambitious possible activities

- Implement realistic wakefields based on detailed geometry of cavities
  - simple implementation (for the beam dynamics part), but
    - need to run 3D EM codes (need local manpower)
  - the rest is simpler
    - parameterize result (moments)
    - implement as a "kick" in tracking

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Even more ambitious activities

- Utilize available EM structure design tools (through SciDAC):
  - VORPAL (Tech-X)
    - parallel, self-consistent (particles and fields), 3D EM code, with non-trivial surface boundary capabilities
  - Does it make sense to develop such expertise at Fermilab?

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SBIR with TechX

- Introduce arbitrary order rf maps from field measurements on the surface of the cavity. Could be a useful ILC application.

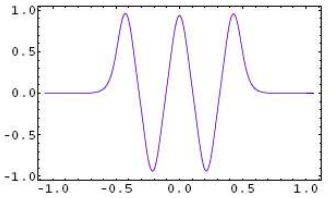

FIG. 5: Comparison of on-axis longitudinal field values computed analytically (blue) and from data with 10% relative noise (red). The latter curve is just barely visible above the left-most peak.

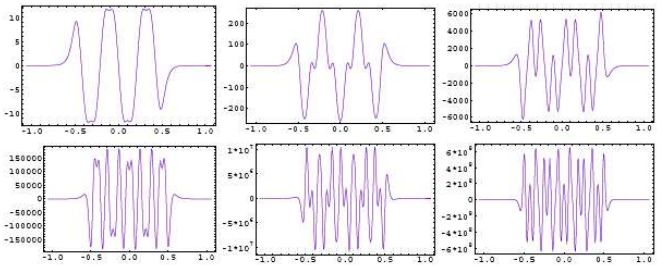

FIG. 6: Comparison of the first six derivatives (right-to-left, then top-to-bottom) of the on-axis longitudinal field computed analytically (blue) and from data with 10% relative noise (red).

D. Abel, TechX

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