CORNELL UNIVERSITY LEPP
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

Cornell University

Accelerator Physics at Cornell

Jeff Smith

October 6th, 2006

What do Accelerator Physicists do?

- We design and build Particle Accelerators!
- Particle accelerators are *CENTRAL* to numerous scientific endeavors including
  - high energy particle physics
  - nuclear physics
  - x-ray crystallography
  - other x-ray imaging techniques
  - electron microscopy
  - mass spectroscopy
  - cancer treatement
- Accelerator physics is involved with a diverse range of studies (and we need many more people to go into the field!)

What do accelerator physicist use?

- We use many theoretical tools:
  - Hamiltonian non-linear single- and many-particle dynamics
  - Hamiltonian resonance theory and Hill's equations (i.e. coupled oscillatory systems)
  - Linear perturbation theory
  - Optics (chromatic aberrations, filamentation, multi-poles & etc...)
  - E&M field analysis
  - Synchrotron radiation
  - Superconductivity
  - Materials Science
  - Plasma studies

Areas of work at Cornell

- CESR
  - Beam lifetime
  - Beam-beam interactions and parasitic crossings
  - Increasing luminosity
  - Conversion into a ILC damping ring test facility
- SRF
  - Design fabricate and test new superconducting RF structures (you'll hear a talk on this in a couple weeks)
- ILC
  - Positron production
  - Damping ring / wiggler design and simulation
  - Main Linac, bunch compressor and spin rotator optics design
  - Beam emittance preservation and luminosity optimization
- ERL
  - All aspects of machine!
  - Everything done with the other three areas above!

Faculty, Staff and facilities

- 9 Faculty!
  - Gerald Dugan, Donald Hartill, Louis Hand, Georg Hoffstatter, Hasan Padamsee, Mathias Liepe, Raphael Littauer, David Rubin, Richard Talman, Maury Tigner
- At least 34 research staff (last I counted)
  - see www.lepp.cornell.edu/LeppDirectory.html for full directory
- Two laboratories on Campus
  - Newman Laboratory
  - Wilson Laboratory
- Resources:
  - GRID computing clusters
  - Extensive machine shops
  - magnet and RF cavity fabrication facilities
  - drafting office
  - large number of support and administrative staff
  - ~100 people total
- Work with numerous facilities around the world
  - Jefferson Lab.
  - KEK
  - SLAC
  - CERN

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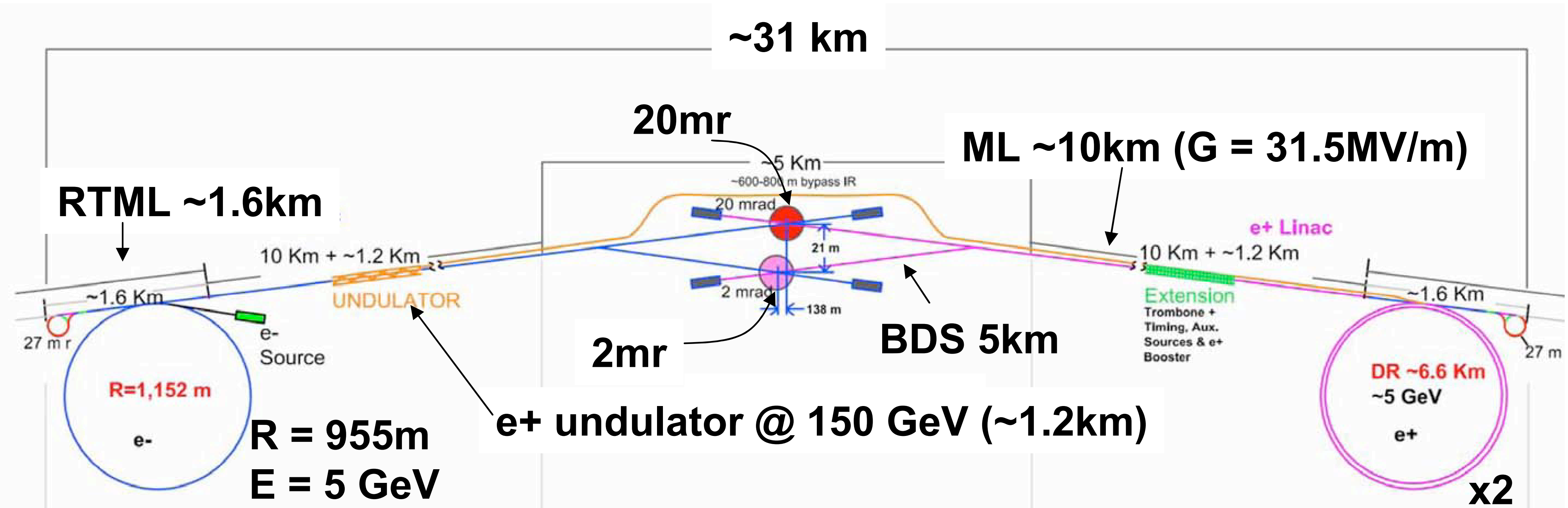
Grad Students

- Current graduate students (8):
  - Grigorii Eremeev, Richard Helms, Chrostopher Mayes, Alexander Romanenko, Chenshang Song, Jeff Smith, Jeremy Urban,Yi Xie
- Known world-wide for training accelerator physicists. Cornell graduates hold leadership positions at most accelerator laboratories in the world including:
  - Argonne, Cornell, DESY, Lawrence Berkeley, Fermilab, SLAC, Oak Ridge
  - Get a Ph.D. in accelerator physics at Cornell and you are pretty much guaranteed a good job in the field!

International Linear Collider

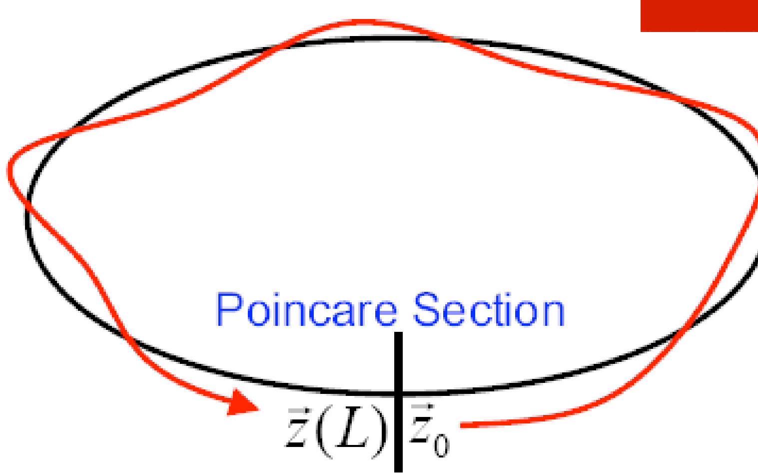
- Complentary to CERN's Large Hadron Collider (LHC).
- Crucial to completing the physics investigations at LHC on electro-weak symmetry breaking, Higgs studies, supersymmetry and other investigations.
- Somebody's got to build the machine, not just the detectors!
- Why not you? It'll be the largest machine human have ever built!



not to scale

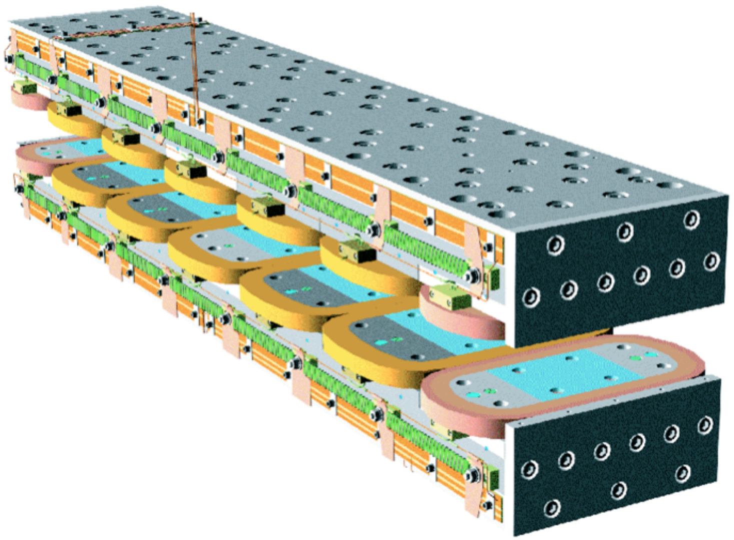
Grad Profile: Jeremy Urban

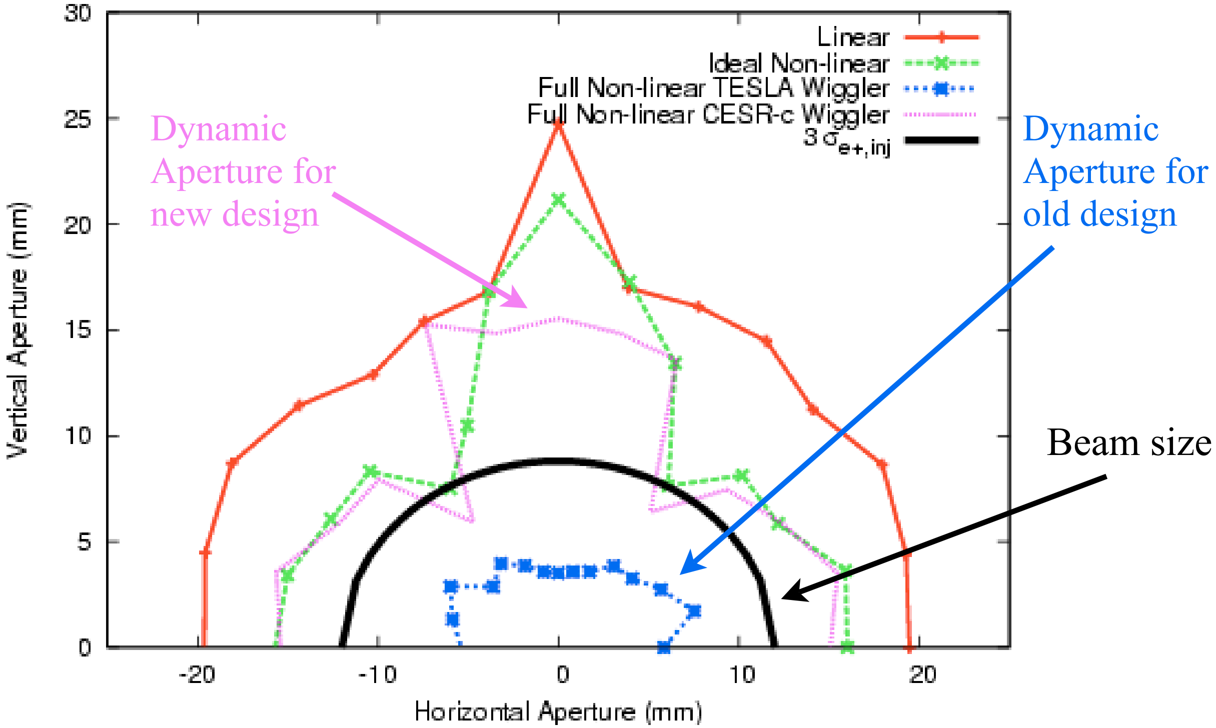
- In a circular accelerator with only linear beam dynamics, the beam transports through a periodic field and is described as a simple oscillatory system, however, there are nonlinear fields and field errors. So, the general equation of motion is

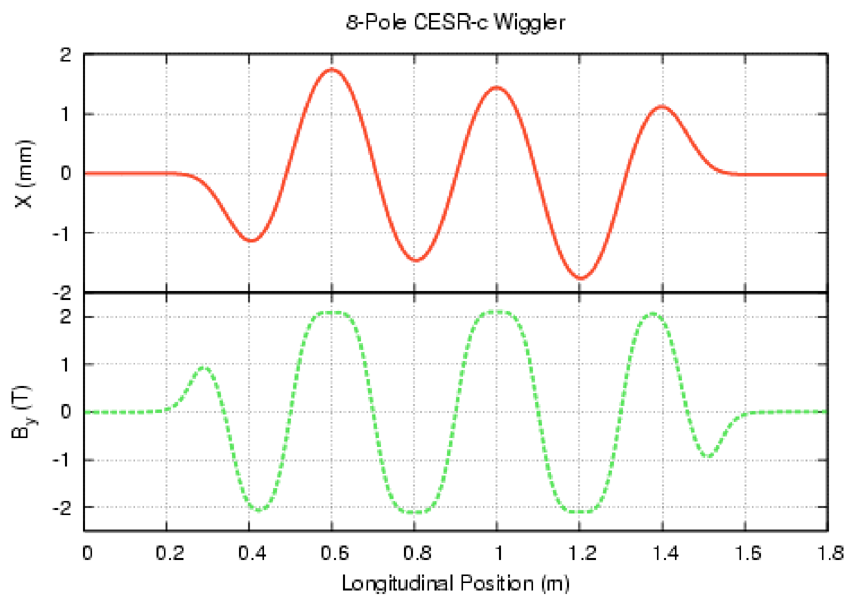


Grad Profile: Jeremy Urban

- Working on Wiggler Design for ILC Damping Rings
- Critical areas include:
  - DR dynamic aperture
  - Wiggler Field quality
  - optimize design for cost and construction





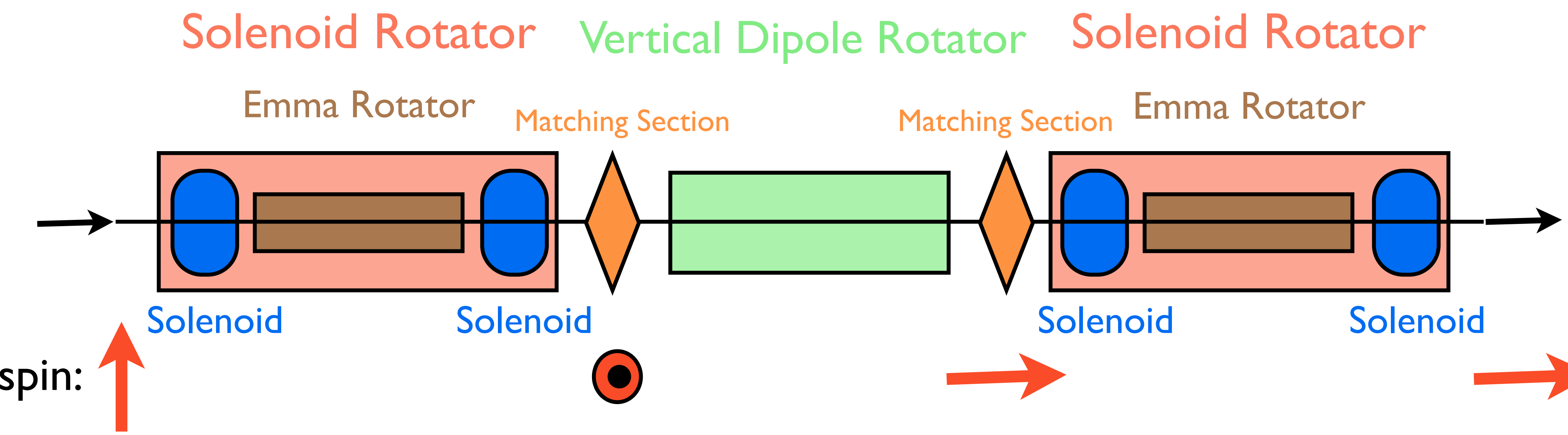


Grad Profile: Jeff Smith (me)

- Emittance preservation from Damping Ring to IP
  - Damping rings, via radiation damping, shrink the vertical beam emittance down to 20 nm (normalized)
  - Now beam must travel through 16 kilometers of beam line before reaching interaction point while preserving small beam size in the presence of
    - RF cavity wakefields, dispersive kicks due to misaligned magnets, Filamentation due to chromatic aberations, beam halo, stray fields
  - Sophisticated methods must be developed to compensate for these errors called Beam-Based Alignment and then tested using simulation tools

Grad Profile: Jeff Smith cont...

- ILC spin rotator design
  - Beam polarization must be vertical in damping rings, otherwise beam will depolarize
  - Polarization at IP should be variable for High Energy Experiments
  - Somehow, the beam polarization must be manipulated while preserving beam emittance



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Grad Profile: Jeff Smith cont...

- ## Current Layout:

Spin Tracking in BMAD has been implemented using a spinor-quaternion transfer map method. It is more efficient to use a SU(2) representation rather than SO(3) when describing rotations of spin. In spinor notation, the T-BMT equation describing spin motion can be written as

$$\frac{d}{dt}\Psi = -\frac{i}{2}(\sigma\,.\,\Omega)\,\Psi$$

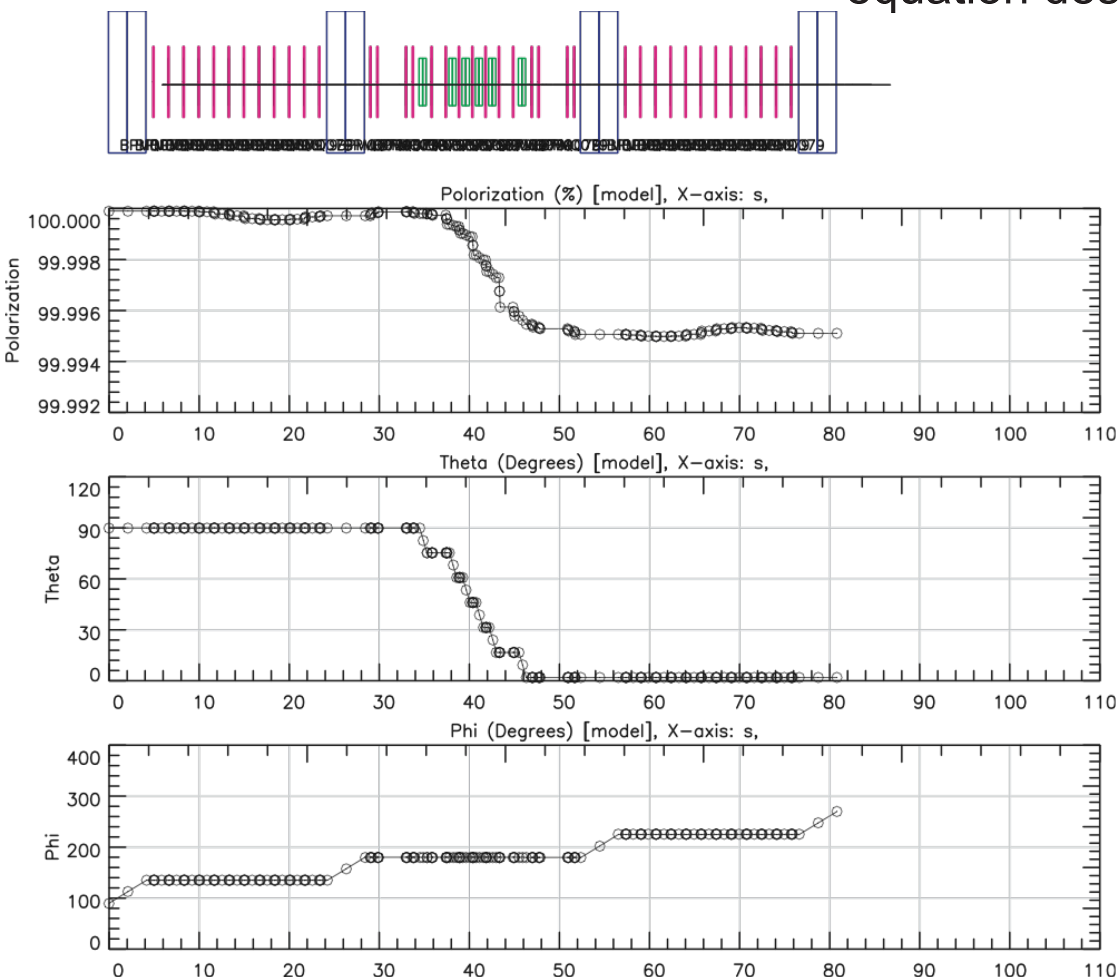
and the solution can be written as

$$\Psi(z;\theta) = (a_0\mathbf{1}_2 - \,\mathrm{i}\mathbf{a}\,.\,\sigma)\,\Psi(z_i;\theta_i)$$

where

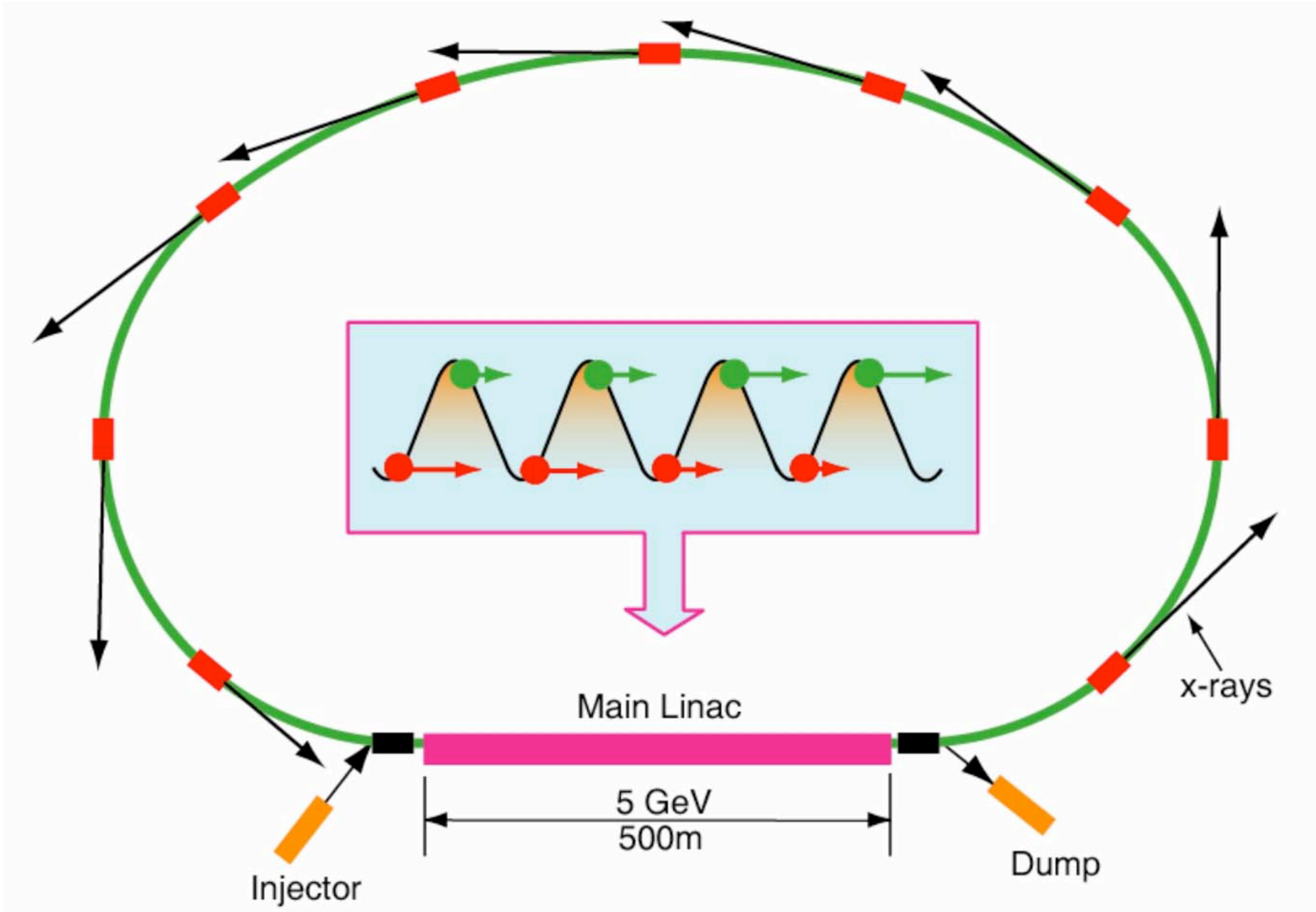
$$\text{Spinor} = \Psi = (\psi_1;\psi_2{}^T)$$

ψ_1 and ψ_2 are complex numbers



Energy Recovery Linac

CHESS & LEPP



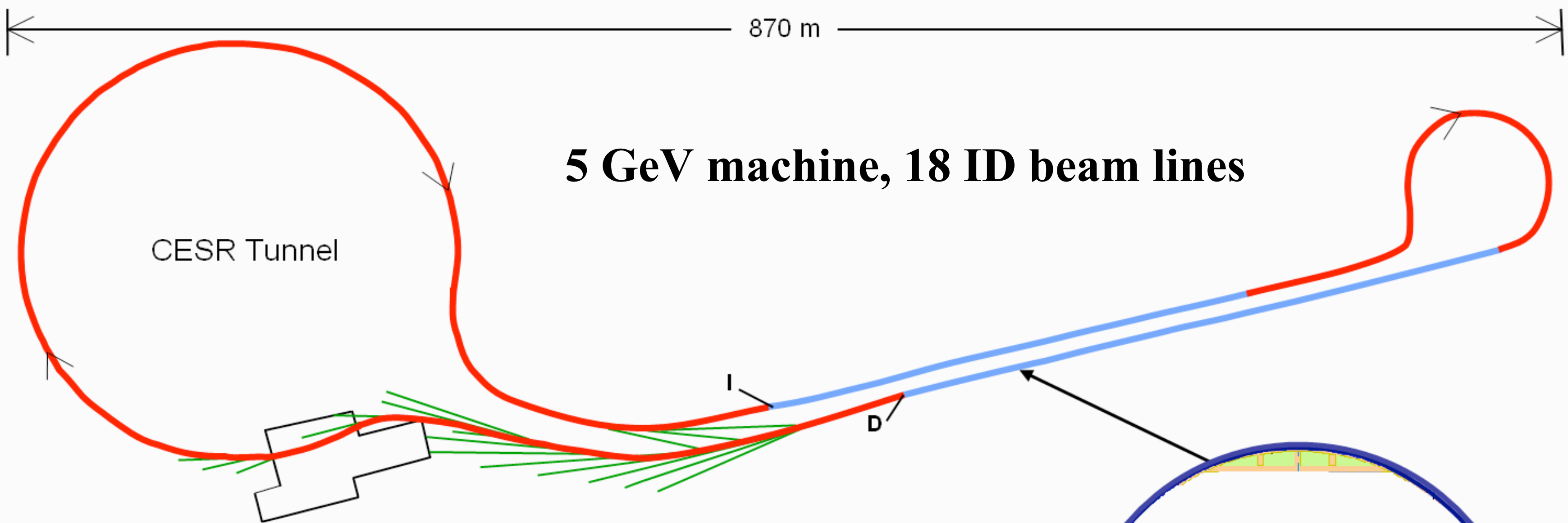
- Accelerating bunch
- Returning bunch

A superconducting linac is <u>required</u> for high energy recovery efficiency

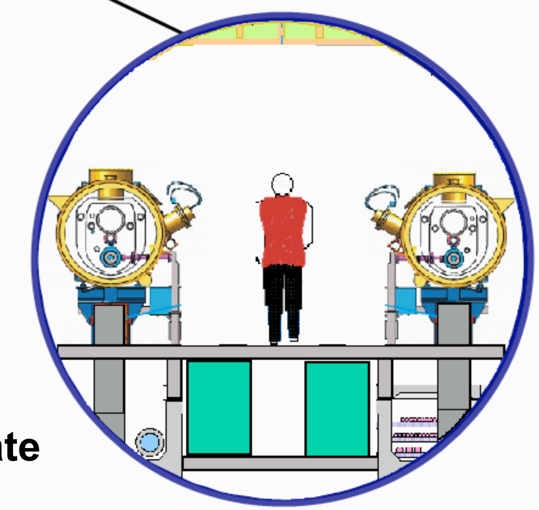
Cornell Phase II ERL Layout

(current version, layout still under development)

CHESS & LEPP



Preliminary layout view of an ERL upgrade to CHESS in the present CESR tunnel. A new tunnel with a return loop will be added to CESR. Electrons are injected into superconducting cavities at (I) and accelerated to 2.5 GeV in the first half of the main linac, then to 5 GeV in the second half. The green lines show 18 possible beamline locations. Electrons travel around the CESR magnets clockwise and re-enter the linac out of phase. Their energy is extracted and the spent electrons are then sent to the dump (D).



Two superconducting linacs in one tunnel accelerate the electrons to 5 GeV. Person shown for scale.

<u>3 Basic Operating Modes</u>

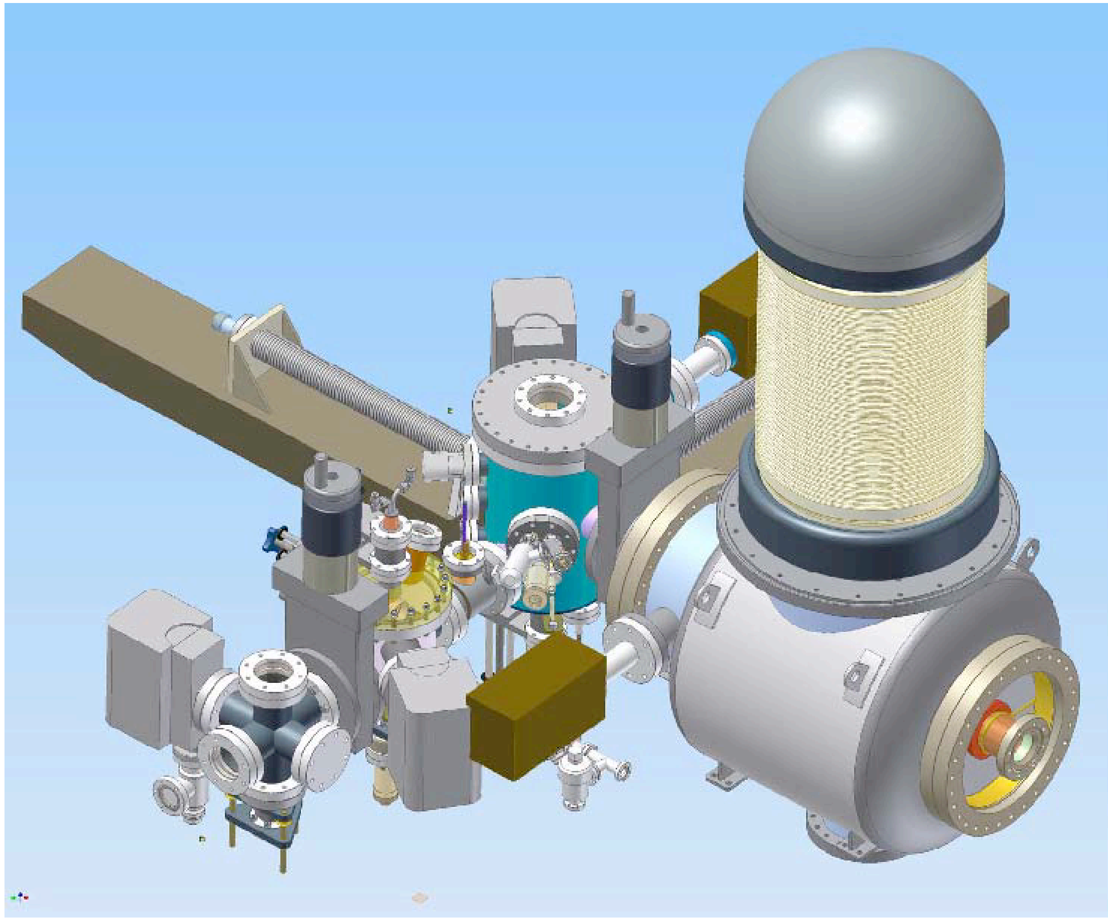
Hi-flux: 30 pm emittance, 100 mA, 77 pC, 1300 MHz repetition rate electron energy spread of 2E-4

Hi-coherence: 8 pm, 25 mA, 19 pC, (5 pm, 100 mA long-term goal)

Ultra-fast: 500 pm, 1 mA, 1 nC, 1 MHz repetition rate (10 nC, 20 fs long-term goal)

ERL DC Electron Gun

- To produce 100 mA ultra low emittance beams
- Very demanding requirements for an electron gun
- Space-charge dominated
- Hear more about the design, challenges and opportunities on the Wilson tour next week (October 10th).



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SRF Cavity Design and Fabrication

- Numerous machine around the use superconducting RF technology as the source of acceleration.
- Cornell leads this area and has one of the best facilities in the world for SRF studies
- Here more about this with Grigorii's talk Nov. 3rd.

Possible Thesis Projects

- ILC damping ring instabilities
- ILC 650 Mhz RF system design
- ILC low emittance tuning
- ILC DR-RTML feed-forward system
- ILC positron production (work at SLAC!)
- CESRTF low emittance tuning
- CESRTF electron cloud (theory and experiment)
- ERL Space charge effects (theory and experiment)
- ERL photocathode physics and technology
- ERL Emittance tuning
- ERL laser design for photogun
- ERL "flying carbon wire" design and experimentation
- ERL fast orbit feedback
- ERL beam diagnostics
- Undulators as X-ray sources
- SRF Cavity design and fabrication

I count 15 thesis topics here and this is just a quick list I came up with. There's certainly many others. And yes, we have the money to support this many students too!

There's also plenty of opportunities for students to "check things out" with summer appointments.

We also welcome Undergraduates to join our group. Many of the topics to the right can be worked on by undergrads.

Grad work environment

- Funding up the Wazoo
- Go to conferences all over the world
- Plenty of money for hardware and experiments
- An experienced and extensive support staff and excellent facilities
- Field is GROWING and very few students are entering the field
  - you'll essentially have your pick as to where you want to work.
- Please contact me (or someone else in the group) if you have any questions: js344@lepp.cornell.edu