High field cavity studies for future linacs

- Re-entrant Shape Single Cell Cavity Reached 47 MV/m in May 05
- 2nd Re-entrant Cavity (built at Cornell) Treated and Tested at KEK Reached 50+ MV/m at KEK (Sept 05)

Graph showing the results of measurements with different temperatures and pressures.
200 MHz Nb/Cu Cavity built by CERN, tested at Cornell

Largest SRF Cavity

Max Eacc = 11 MV/m

Next step: Spinning a 1mm Nb on 4mm Cu cavity by Accel, testing at Cornell.

Nb/Cu cavities are relevant to ILC damping rings.
Energy Recover Linacs for colliders, light sources, and electron coolers
High loaded Q cavity control

- Run cavity at highest possible loaded Q for Energy recovery linac mode, i.e. without beam loading
- But: The higher the loaded Q, the smaller the cavity bandwidth!
Other SRF studies
Cornell has expertise and interest in other SRF studies of long ranging relevance that could be pursued with adequate funding:

- Crab cavities: 1st design at Cornell, relevant for LHC upgrade,
- light sources, and any high luminosity future collider with crossing angle.

- New materials for SRF: Nb3Sn, NbN, Nb3Al, HiTSC
- Films on substrates, bonds on substrates
- Relates to all future uses of SRF
From Cavity to Cyromodule
e.g. The Cornell x-ray ERL injector linac

Frequency tuner
Adjust cavity frequency

HOM absorber
Damp Higher-Order Modes

Input Coupler
Couple RF power into cavity

RF cavity
Inside He vessel

Cryogenic system
Bring cavity to 2K

15 feet

16 February 2006
Collider developments

1. Only wiggler dominated storage ring, 90% radiation from wigglers
   Requires advanced simulation of beam dynamics with nonlinearities, beam-beam force, ...

2. Advanced interaction regions require accurate accelerator simulation benchmarked against measurements, e.g. beam-based alignment
Collider Developments

- Phase space mapping through wigglers required for simulation of dynamical effects
- Mapping is based on detailed 3D modeling using Vector Fields Opera
- Symplectic and fast representation of nonlinear motion in measured wiggler fields.
Characterization of Wiggler Octupole Components

Measured and calculated dependence of vertical/horizontal tune versus vertical/horizontal amplitude

Vertical tune as function of vertical amplitude.

Horizontal tune as function of horizontal amplitude.

\[ dQ_v = m \cdot \Delta v [\text{mm}]^2 \]

- Meas: 0.0003024
- Model: 0.0003024
- Model wiggler OFF: -2.85e-05

\[ dQ_h = m \cdot \Delta h [\text{mm}]^2 \]

- Meas: 5.8937e-05
- Model: 2.2412e-05
- Model wiggler OFF: -6.5796e-06
• **Instrumentation Support**
  – General digitizer backbone for multiple instrumentation types
    • 72 MHz digitizers
    • On-board DSP for data processing
    • CESR Field Bus and Ethernet communications
    • I/O ports for custom hardware interfaces
  – **Multiple Front-End Options**
    • Beam Position Monitors
    • Synchrotron Light Beam Profile Monitors
      – *Visible light*
      – *X-ray*
    • Fast Luminosity Monitor
  – **Core Capabilities**
    • Parallel digitization of bunches
    • Turn-by-turn operation
    • >10K turn memory buffer for each bunch
    • Tight integration to CESR timing system (eg, multi-module synchronization, triggering, shaker phase information, etc)

• **Data Acquisition System**
  – **Large data sizes require on-board processing capability**
    • High level language (C or C++) programming of DSPs
    • Memory mapping of DSP memory to control system for debugging and monitoring utilizing dual-ported memory chips
  – **Detector operation utilizes on-board processing capability**
    • Calibration
    • Gain and timing control
    • Extensive data processing implemented, eg:
      – *Local betatron phase calculation*
      – *Bunch tunes (FFT)*
      – *Timing scans*
  – **User interface**
    • Flexible multi-user interface so that many different programs can operate devices
    • Device/system-level locking to prevent collisions between multiple requests
Interaction region optimization

XY at BPM0-W, file: cbpm0752.raw

$ax, ay [\text{mm}] = 2.007, 0.2357$

$\alpha(x/y), \theta = 22.05, 0.1063 \ (6.2055^\circ)$

XY projected to IP, file: cbpm0752.raw

$ax, ay [\text{mm}] = 1.038, 0.01357$

$\alpha(x/y), \theta = 136.1, -0.01081 \ (-0.6195^\circ)$

SCMATING 2 = -160

Compensating solenoid

Skew quad

CLEO solenoid

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Inter action region optimization

XY at BPM0-W, file:cbpm_q0751.raw

\[ ax, ay [\text{mm}] = 1.941, 0.09517 \]

\[ ar(xy), \theta = 69.91, 0.0469 (2.687^0) \]

XY at BPM0-E, file:cbpm_q0751.raw

\[ ax, ay [\text{mm}] = 2.009, 0.09637 \]

\[ ar(xy), \theta = 5696, 0.04798 (-2.7491^0) \]

XY projected to IP, file:cbpm_q0751.raw

\[ ax, ay [\text{mm}] = 0.9931, 0.01482 \]

\[ ar(xy), \theta = 162.3, -0.01359 (-0.7788^0) \]

SCMATING 2 = -120

Compensating solenoid

Skew quad

Q2

Q1

PM

CLEO solenoid
Interaction region optimization

**XY at BPM0-W, file:cbpm00750.raw**

- $ax, ay [mm] = 1.948, 0.03265$
- $ar(x/y), \theta = 119.7, 0.01454 (0.83293^0)$

**XY at BPM0-E, file:cbpm00750.raw**

- $ax, ay [mm] = 2.002, 0.176$
- $ar(x/y), \theta = 43.45, 0.08484 (-4.8612^0)$

**XY projected to IP, file:cbpm00750.raw**

- $ax, ay [mm] = 0.9808, 0.01582$
- $ar(x/y), \theta = 145.6, 0.01612 (-0.9235^0)$

**SCMATING 2 = -70**

- Compensating solenoid
- Skew quad Q2
- Q1
- PM
- CLEO solenoid
Inter action region optimization

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**XY at BPM0-W, file:cbpm0_0749.raw**

\[ ax, ay [\text{mm}] = 1.877, 0.04662 \]

\[ \text{ar(x/y),} \, \text{teta} = 41.71, -0.006508 (-0.37286^0) \]

---

**XY at BPM0-E, file:cbpm0_0749.raw**

\[ ax, ay [\text{mm}] = 1.946, 0.2202 \]

\[ \text{ar(x/y),} \, \text{teta} = 27.4, -0.1071 (-6.1367^0) \]

---

**XY projected to IP, file:cbpm0_0749.raw**

\[ ax, ay [\text{mm}] = 0.9495, 0.0159 \]

\[ \text{ar(x/y),} \, \text{teta} = 2507, -0.01674 (-0.9591^0) \]

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**SCMATING 2 = -40**

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Compensating solenoid

Skew quad

CLEO solenoid

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Inter action region optimization

SCMATING 2 = -70

Compensating solenoid
Skew quad

Q2
Q1
PM

CLEO solenoid
Interaction region optimization

SCMATING 2 = -40

Compensating solenoid

Skew quad

CLEO solenoid
Interaction region optimization

X\_Y at BPM0-W, file:cbpm\_0744.raw

\[ ax, ay \text{[mm]} = 1.859, 0.1025 \]

\[ \text{ar}(x/y), \theta = 93.0, 0.05407 (-3.0978^0) \]

X\_Y projected to IP, file:cbpm\_0744.raw

\[ ax, ay \text{[mm]} = 0.9352, 0.01978 \]

\[ \text{ar}(x/y), \theta = 85.72, 0.01764 (-1.011^0) \]

X\_Y at BPM0-E, file:cbpm\_0744.raw

\[ ax, ay \text{[mm]} = 1.859, 0.2815 \]

\[ \text{ar}(x/y), \theta = 10.72, 0.0193 (-6.8367^0) \]

SCMATING 2 = 70

Compensating solenoid

Skew quad

Q2

Q1

PM

CLEO solenoid

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Inter action region optimization

XY at BPM0-W, file:cbpm0746.raw

\[ ax, ay[mm] = 1.891, 0.06387 \]

\[ \ar(x/y), \theta = 130.5\degree, 0.03289 (1.8846^\circ) \]

XY projected to IP, file:cbpm0746.raw

\[ ax, ay[mm] = 0.9459, 0.01923 \]

\[ \ar(x/y), \theta = 100.9\degree, 0.01775 (1.0170^\circ) \]

XY at BPM0-E, file:cbpm0746.raw

\[ ax, ay[mm] = 1.902, 0.2487 \]

\[ \ar(x/y), \theta = 13.81\degree, 0.1089 (6.2381^\circ) \]

SCMATING 2 = 40

Compressing solenoid

Skew quad

CLEO solenoid

Q2

Q1

PM
Interaction region optimization

- X, Y at BPM0-W, file: cbpm0_0806.raw
  - $ax, ay [mm] = 1.656, 0.2776$
  - $ar(x/y), \theta = 0.002044 (-0.11709^0)$

- X, Y at BPM0-E, file: cbpm0_0806.raw
  - $ax, ay [mm] = 1.784, 0.226$
  - $ar(x/y), \theta = 9.077, 0.06253 (3.5827^0)$

- X, Y projected to IP, file: cbpm0_0806.raw
  - $ax, ay [mm] = 0.7943, 0.003986$
  - $ar(x/y), \theta = 456.8, -0.004516 (-0.2587^0)$

- Compensating solenoid
- Skew quad
- CLEO solenoid
- Q2
- Q1
- PM

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FNAL meeting on AARD
16 February 2006
Complete modeling of collision mode

Model includes:
- solenoids overlapping tilted quads,
- separator tilts
- differential coupling with skew sextupoles
- wigglers
- beam-beam force incl. parasitic interactions
- RF
- linear and nonlinear fields
- radiation
- crossing angle
- pretzel

1.89 GeV
Cornell LEPP ILC accelerator physics activities

- Damping ring to main linac design
- Low emittance transport & preservation studies
- Damping ring optimization:
  - studies of wigglers: electromagnetic design, impact on ring dynamic aperture
  - studies of fast kickers
- Positron source
  - undulator design
  - E166 participation
- Study of the use of CESR as an ILC positron damping ring test facility (after 2007)
1 Rearrangement of CESR wigglers

1 North and South Interaction Regions
   - South IR provides dispersion-free insertion region in standard optics
     • Remove CLEO $\Rightarrow$ South IR provides $\sim 18$ m of “free” space
     • Cryogenic support locally available
   - North IR can be configured similarly
     • Also $\sim 18$ m insert region
     • No cryogenic support so far

1 $\epsilon_x=2.5$nm, $\epsilon_y=5$pm
1 Disp and coupling correction
1 Analysis of adequate wigglers.
Wigger studies

e.g. for Damping Rings

Wiggler for the damping ring was described in 2000, also at LC02 Feb.4-8 SLAC. The Cornell wiggler served as a prototype. Lot of ideas introduced for the first time:

7-pole, **Wide** poles, Large aperture 90X50mm², Optimized coils shape, Recessed poles, Active field correction (end poles and central) for field adjustments, Tapering, Easy assembled cold mass...

Recently an **Ideal wiggler** was introduced. This wiggler has no nonlinearities. Field profile is **piecewise-linear** in this Wiggler. So the wiggler is not a problem anymore.

[Diagram of wiggler magnets and field profile graph]
Beam Dynamics Studies for various accelerators

Advanced simulation tools have been developed:

**BMAD:** Beam dynamics library
**CESR-v:** Virtual CESR representation, experimentally benchmarked.
**Tao:** Virtual representation of general accelerators, used for ILC and ERL

**They include:**
- Linear and nonlinear fields
- Symplectic propagation through measured Wigglers
- Polarization propagation
- Beam-breakup instabilities
- CSR
- Space charge, and more

**They relates to:**
- ILC damping rings
- ILC linac
- Light sources
- Electron ion collider
- And any future accelerator
- Virtually all the depolarization is in the Final focus
- Haven’t looked at effects of misalignments
Low emittance transport for the ILC and ERL

Single failed BPM

This failed BPM is ignored in the BA algorithm.

Vertical Orbit (mm)

Vertical Normalized Emittance (nm)
Damping ring studies, e.g. dynamic aperture

Results from PAC2005 showed the TESLA TDR wiggler was unsatisfactory. All wiggler studies performed with the CESR-c wiggler.

The CESR-c wiggler has a large aperture which produces fields well approximated by the Ideal Non-Linear Wiggler Model = Single Mode Wiggler Model.
Undulators for polarized-positron production

6 mm in diameter

MEASURED LONGITUDINAL FIELD DISTRIBUTION IN LHE

Goal: Assemble and test working 4-m long prototype module for ILC
Aspects of x-ray ERL that are of general relevance for future accelerators

- Bright electron beams, gun developments for ILC and beyond.
- Component and technology development
- Space charge dominated beams
- Coherent Synchrotron Radiation
- Bunch compression

First quantitative CSR/bunch length measurements (A.Sievers et al. at Cornell)
- Ongoing measurement developments
500-750 kV Photoemission Gun with preparation, cleaning, and load lock chambers

Emittances: down to 0.1mm mrad
Current: up to 100mA
DC, 1.3GHz
Workforce enhancement

Graduate Students (currently 10, as many as for HEP)
Undergraduate Students (4 per year)
High School Interns through the learning web (2 per year)

Undergraduate Summer Students (2 per year)
Summer Students for the NSF’s REU program (15 per year)
Largely from underrepresented groups

US Particle Accelerator School 2005:
unique storage ring based experimental program.

Many Cornell alumni have gone on to dominant positions in accelerator physics.
Unique course of USPAS 2006 at Cornell University:
Experimental Accelerator Physics
With Control Room Experiences

Homework:
e.g. Phase space measurements in CESR

Horizontal pseudo phase space at $v = \frac{2}{3}$. Position at 10W vs position at 8W
Nonlinear Phase space dynamics for Students

**Homework:**
Horizontal and vertical pseudo phase space dynamics with
- damping
- tune shifts
- nonlinearities

Position at BPM 10 West vs position at BPM 8 West
Conclusion

- Cornell has a long and successful history of accelerator physics
- Cornell has facilities and scientific groups that allow participation in a wide range of accelerator physics and component developments
- Cornell is involved in several major ongoing accelerator R&D projects
- Cornell contributes to R&D that is relevant for particle accelerators in the near and far future by pushing system parameters at many fronts.

Thanks to the Accelerator Physics Group at Cornell University
Subjects esp. suitable for Cornell:
- Low emittance electron sources (as ERL)
- Undulator based positron sources (from CESR undulator expert)
- Damping rings (have wigglers like CESR)
- Beam dynamics simulation and accelerator modeling (based on codes for CESR and ERL)
- Bunch compressors (similar to ERL)
- Many superconducting RF subjects (as ERL)
- Crab cavities for the collision region (as in LHC)
• Mention which items are long term AARD, and which are mid and short term R&D: Most of our research is mid and short term R&D while keeping in mind that these mid term advances are the basis for a long term AARD impact.

• Other areas where we could contribute if the need comes up and we are supported are: LHC upgrade: crab cavities, accelerating cavities, interaction regions, optical acceleration.