U.S. University-Based Linear Collider Accelerator R&D

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Can university groups do accelerator physics?

Accelerators are BIG, EXPENSIVE devices.

Many university HEP groups have concentrated on detector projects, perhaps because they believe these are:

• more suitable in scale for a university group
• more practical, given their prior experience in detector development.

Is this really true? Should university groups stay away from accelerator physics projects?
Of course university groups can do accelerator physics!

There are interesting, important projects whose scope is ideal for a university group.

The (inter)national labs welcome our participation and will help us get started, as well as loaning us instrumentation.

Many projects involve applications of classical mechanics and classical electrodynamics. These are perfect for bright, but inexperienced undergraduate students.

The projects are REALLY INTERESTING. (Also, it’s fun to learn something new.)
Most U.S. high energy experimentalists are employed either by national labs (Fermilab, SLAC, Argonne, Brookhaven, Lawrence Berkeley,...) or by universities.

Working at a U.S. university is different from working at a lab:

• We teach, develop new course material, serve on university committees. Unscheduled interactions with students are time consuming (and also rewarding).

• We can enlist the help of eager, talented undergraduates who are able to work productively on a wide range of laboratory projects.

• We have liberal access to the expertise (and sometimes hardware) of colleagues in other departments: engineering, for example.
U.S. university career path

- **University undergraduate**: 4 years; BA or BS
- **Graduate school**: 5-7 years; PhD
- **University postdoc**
- **National lab postdoc**: 3-5 years
- **Assistant professor**
- **National lab staff**
- **Associate professor**
- **National lab senior staff**
- **Professor**

- **Out**
- **Out**
- **Out**

- Green box: = permanent position
U.S. university career path

University postdoc positions are not expected to lead to permanent (faculty) positions at the same university.

Postdoc → assistant professor step is toughest: there are not very many university faculty jobs available.

Candidates for assistant professor positions are expected to have

• shown considerable leadership in their HEP collaboration
• played a major role in producing physics from recent data.

∴ U.S. postdocs (and grad students) do not devote more than a fraction of their time to future experiments (LHC, LC).

This plays a significant role in how U.S. universities participate in LC.
U.S. HEP funding

Two independent agencies: Department of Energy and National Science Foundation.

- DOE funds Fermilab, SLAC, ... and ~2/3 of the university groups.
- NSF funds CESR (CLEO) and ~1/3 of the university groups.

Though initially created as a DOE panel, HEPAP advises both agencies.

DOE and NSF cooperate, but they do not follow a “unified” national HEP policy. An example: the two agencies’ different interactions with university-based Linear Collider R&D initiatives in the U.S.

U.S. funding levels are strongly influenced by political currents.
Tensions

Graduate students and postdocs must work on near-term projects which yield particle physics results in order to advance professionally.

University faculty want to preserve autonomy and independence from administrative control by national labs. This is significant to us.

We receive mixed messages from DOE and NSF regarding LC funding (DOE is supportive, but NSF is less so).

We have various responsibilities in our currently-running/analyzing experiments.

So it’s complicated (but also very interesting)!
Engaging the university HEP community

January, 2002:

• FNAL was focused on Run II problems. LC wasn’t on the lab directorate’s radar.

• most university LC groups were already affiliated with SLAC; most were doing detector simulations.

• there was little planning underway to attract new groups (for example, with Fermilab orientations).

That’s not good!
Engaging the university HEP community

Fixing this: we’re professors, we’re not lab employees, we can do things without asking permission, they can’t fire us.

April - May, 2002 workshops at FNAL, Cornell and SLAC:
• meetings focused largely on concrete R&D topics
• Purpose: introduce university physicists to R&D issues suitable for university groups. (We really like doing lab work!)
• almost no Higgs sensitivity vs. stuff talks (at least not at FNAL).
Tom Himel (SLAC) was the hero of the workshops: he assembled a list of accelerator projects for us to consider. “The List” included NLC and TESLA projects.

These workshops ultimately led to a 50% increase in university participation in LC R&D.

About half of the new participants took on accelerator projects!
An example from Himel’s list...

ID 61  project size Medium  skill type physicist
short project description Acoustic sensors for structure and DLDS breakdown

Detailed project description understand the acoustic emissions from breakdowns and how the sounds propagate so that the use of acoustic sensors can improved in diagnosing breakdowns.

Needed by whom NLC and TESLA
present status In progress, help needed
Needed by date 6/1/2003
Contact Person Marc Ross, (650)926-3526, mcrec@slac.stanford.edu

www-conf.slac.stanford.edu/lcprojectlist/asp/projectlistbyanything.asp
...and what we’re doing with it.

more on this later...
Sample accelerator projects

Here are some of the ~110 items from Tom’s list:

- low level RF Digital Feedback Hardware
- Exception Handling for RF System
- TESLA Wave Guide Tuner Control
- Structure Breakdown diagnostics
- active vibration stabilization of Final Doublet
- Linac accelerator structure cooling without vibration
- Acoustic sensors for structure and DLDS breakdown
- beam profile monitor via Optical Transition Radiation
- Very fast injection/extraction kickers for TESLA damping ring
- RF BPM electronics, including tilt
- 5-10 kW magnet power supply
- flow switch replacement
- robot to replace electronic modules in tunnel
- Programmable Delay Unit
- linac movers: 50 nm step, rad hard
- Low Level RF 500 MHz digitizer
“Jump-starting” a university-based R&D program

How to organize something like this?

Desired outcome:

• broad range of projects without duplication of work.
• collaboration among university groups would be possible, even when one is DOE funded, one NSF funded.
• mechanism for informal oversight of progress (what’s working, what’s not?)
We organized ourselves

LCRD (DOE) proponents write short project descriptions

UCLC (NSF) proponents write short project descriptions

ALCPG working group leaders offer suggestions for revision, collaboration with other groups, etc.

LCRD proponents write “subproposals”

UCLC proponents write “project descriptions”

Proposal coordinators create one unified document combining LCRD and UCLC projects

Separate accelerator and detector committees review proposed work for both agencies

LCRD proponents revise subproposals

UCLC proponents revise project descriptions

Proposal coordinators create new document combining revised LCRD and UCLC projects, then transmit to DOE and NSF.
The result, first year

A University Program of Accelerator and Detector Research for the Linear Collider

University Consortium for Linear Collider R&D
and
Linear Collider Research and Development Working Group

October 22, 2002

...renewal submitted November, 2003

The result:
- 71 new projects
- 47 U.S. universities
- 6 labs
- 22 states
- 11 foreign institutions
- 297 authors
- 2 funding agencies
- two review panels
- two drafts
- 546 pages
- 8 months from $t_0$

Funded by NSF* and DOE

*planning grant only
**Who the “we” is**

**“Proposal coordinators”:**
- Dan Amidei (University of Michigan)
- Dhiman Chakraborty (Northern Illinois University)
- Dave Cinabro (Wayne State University)
- Gerry Dugan (Cornell University)
- Dave Finley (Fermilab)
- George Gollin (University of Illinois)
- Tom Himel (SLAC)
- John Jaros (SLAC)
- Usha Mallik (University of Iowa)
- Shekhar Mishra (Fermilab)
- Ritchie Patterson (Cornell University)
- Joe Rogers (Cornell University)
- Slawek Tkaczyk (Fermilab)

Background image: Big Doc author list
## Scope of U.S. university work in this initiative

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<td>it’s complicated</td>
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Here come the professors!

Faculty of the world unite!

Self-organizing efforts seem entirely possible.

participants

graphics from 15 of 68 projects
university R&D topics

• Beam simulations and other calculations: 6
• Kickers, magnet technologies, mechanical support systems: 4
• Instrumentation and electronics: 9
• Ground Motion: 1
• Control Systems: 1
• RF Technology: 5
• Non-$e^+e^-$ collisions: 1
• Electron and positron source technology: 2

Let’s look briefly at a handful of accelerator projects being pursued by U.S. university groups, then in more detail at one of mine.
Compact Wakefield Facility (Chicago, Argonne, FNAL)

A dedicated facility for high-resolution wakefield measurements of NLC structures. Work needed:

1. A 20 MeV, **high-brightness**, **Drive Beam** excites wakefield
2. A 5 MeV **Witness Beam** probes the wakefield
3. **Downstream Optics** measures the witness beam deflection
Investigation of novel schemes for TESLA damping ring kickers (University of Illinois)

Investigate a “Fourier series kicker”: a series of rf cavities creates a kicking function with periodic zeroes and an occasional spike.

Perhaps this will allow construction of a much smaller TESLA damping ring?
Beam Halo Monitor & Instrumented Collimators (Mississippi)

Progress in seeing signals from a diamond detector. (Diamond since radiation damage will be an issue.)

Other possibilities being considered: W-quartz fiber, for example.

Figure 1: Sketch of a proposed 2 stage collimator with upstream spoiler and final instrumented absorber.
Transverse Phase Space Measurements for a Magnetic Bunch Compressor by Using Phase Space tomography (UCLA, BNL, JLab)

A schematic diagram of the ATF beam line with bunch compressor is shown in the following figure. The first triplet is used to match different twiss parameters in the compressor. The second triplet is used for matching the compressor with other beam line.
Beam loss monitors for LC (Northwestern)

Secondary emission detectors, tested at CLIC test facility at CERN. Fast, rad hard, large dynamic range.
Uwe Happek: Bunch length interferometry

PATH DIFFERENCE: $2y\alpha$
Undulator Based Production of Polarized Positrons for Linear Colliders (Tennessee, Princeton)

• 50 GeV $e^-$ beam and 1 m-long, helical undulator to make 10-MeV polarized photons.

• Photons are converted into $e^+$, $e^-$ with ~ 50% polarization.

• Measure $e^+$, $e^-$ polarization


Concept: Balakin and Mikhailichenko (1978)
Development of Polarized Photocathodes for the Linear Collider (Wisconsin, SLAC)

“Bandgap engineering of strained GaAs.”
RF Beam Position Monitors for Measuring Beam Position and Tilt
(UC Berkeley)

Analysis of test beam data from KEK ATF using SLAC-built device.
Beam Test Proposal of an Optical Diffraction Radiation Beam Size Monitor at the SLAC FFTB (UCLA)

Simulation work so far.

ODR Yield in $0.1/\gamma$ angle range
$\sigma$: rms transverse beam size
Fast Synchrotron Radiation Imaging System for Beam Size Monitoring
(Cornell, SUNY Albany)

Exploring possible parameters, configuration for device.

Design for a Synchrotron Radiation Camera for Beamsize Measurement

Basic concept:
1. Refocus SR in the damping rings to make a projected image of the passing bunch.
2. Diffraction limit on source size forces us into the x-ray regime

Goals:
1. **definite:** Measure $\sigma_x$ and $\sigma_y$
2. **possible:** Single-bunch resolution
3. **optimistic:** Intrabunch measurement (i.e. z)
   - Don't yet know if this will be possible.
   - Still working on ideas for this.

Status:
Have started simple simulations for studying optics and detector choices:
1. Optics
   - point-to-point with sufficient magnification
   - Zone plates are one candidate
2. Detection
   - small pixel array is one candidate

Relevant times

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<th>Tesla</th>
<th>NLC</th>
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Ground Motion studies versus depth
(Northwestern)

Linear collider R&D: Preparing ground motion study in NUMI
noise versus depth

- Northwestern University joined the study, is providing equipment and will participate in the study
- Measurements needed to determine the best depth to locate the next linear collider
- Test at Aurora Mine already done
- Next… Numi Tunnel
  ➔ This was classified as a high priority project (1.5)

Szleper, Velasco, Serye

Equipment ordered by NU (will arrive ~ May 27)

Broadband Three-component Seismometers KS-2000

Portable Data Recorder DL-24
Ring-tuned, permanent magnet-based Halbach quadrupole (UCLA)

Progress, both in modeling and in fabrication of prototypes for studies.
Design and Fabrication of a Radiation-Hard 500-MHz Digitizer Using Deep Submicron Technology
(Ohio State)

Some of the circuit functional blocks have been designed, but none fabricated for test yet.

Figure 2. Schematic of a 3-bit cell.
Chirped waveform pulse compression kicker for TESLA damping ring (Cornell, Illinois)

Dispersive wave guide compresses chirped RF signal.

Commercial broadcast RF amplifier ~100kW, but compression generates large peak power for kicking pulse in low-Q cavity.
Fermilab/ Northern Illinois University photoinjector lab

A0 photoinjector lab at Fermilab produces a relativistic (16 MeV now, 50 MeV in a few months), bunched low-emittance electron beam. (It’s rather like a TESLA injector.)

This should be an excellent facility for all sorts of device tests as well as beam physics studies!
In more detail: “Investigation of acoustic localization of rf cavity breakdown” (Illinois)

Can we learn more about NLC rf cavity breakdown through acoustic signatures of breakdown events?

At UIUC (“UC” = Urbana-Champaign):

George Gollin (professor, physics)
Mike Haney (engineer, runs HEP electronics group)
Bill O’Brien (professor, EE)
Jeremy Williams (postdoc)
Erik Wright (graduate student)
Joe Calvey (UIUC undergraduate physics major)
Michael Davidsaver (UIUC undergraduate physics major)
Justin Phillips (UIUC undergraduate physics major)

Marc Ross is our contact person at SLAC.
A note concerning the warm/cold recommendation

The TESLA design for RF couplers is complicated: RF flows in one end (at room temperature), out the other end (at 2K).

Breakdown in the couplers may prove to be an issue.

What we have learned in studies of NLC structures should map into investigations of TESLA coupler breakdown.
This is what we were studying

Harry Carter sent us a five-cell structure from Fermilab’s NLC structure factory.

We need to understand its acoustic properties.

Start by pinging copper dowels with ultrasound transducers in order to learn the basics.
Harry Carter sent us a pair of copper dowels from their structure manufacturing stock: one was heat-treated, one is untreated.

NLC structures are heat-brazed together; heating creates crystal grains (domains) which modify the acoustic properties of copper.

#2 is heat-treated...

…#1 is not.
Transducer setup

We can listen for echoes returning to the transducer which fires pings into the copper, or listen to the signal received by a second transducer.
Transducer setup, on the bench
Scattering/attenuation at 1.8 MHz in copper

Piezoelectric transducer behaves like a damped 1.8 MHz oscillator.

A “ping” launched into a copper dowel will bounce back and forth, losing energy through

- absorption in the transducer
- scattering of acoustic energy out of the ping
- absorption of acoustic energy by the copper.

25 mm

~15 mm

69 mm

ping
dowel
Scattering is much more important than attenuation

Single transducer: ping, then listen to baseline “noise” as pulse travels in copper, pumping energy into acoustic baseline “glow.”

At ~5 mm per μsec, full scale corresponds to 12 m acoustic path inside the heat-treated (grainy) dowel. The “glow” lasts a long time.

Full scale ~2.4 milliseconds. Lots of round-trips!
Condensed matter, as done by folks in HEP

Our model: regular (rectangular, 2D, 3D) grids of mass points connected by springs. Transducer is an array of points driven in unison, with damping.

Speeds of propagation for pressure and shear waves are determined by $k_1$, $k_2$, and $k_1/k_2$. We use $k_2 = k_1/2$.

We can vary spring constants arbitrarily in order to introduce dislocations and grains: our grain boundaries have smaller spring constants.
Propagation of a 50% shear, 50% compression wave, copper **without** grains

Note the different propagation speeds.
Propagation of a 50% shear, 50% compression wave, copper without grains

Note the different propagation speeds.
Propagation of a 50% shear, 50% compression wave, copper with grains

Note the disruption of the wave fronts due to scattering!
Propagation of a 50% shear, 50% compression wave, copper with grains

Note the disruption of the wave fronts due to scattering!
Simulated transducer response, some months ago

Time Step 54

Time Step 156

Time Step 266

Simulated Scope Shot

Actual Scope Shot
3-D model we’re working with right now

4 “perfect” transducers, one acoustic excitation spot.

A flaw: transducers are TOO good.
The main difficulty…

Our general approach has been to assume “perfect knowledge” of the behavior of the copper at the transducers:

- transducer knows about individual motions of each of the individual mass points it touches (a real transducer returns a signal based on the average of all points)

- transducer returns velocity vector of surface points (ours don’t [though this kind exists]: we only measure the component normal to the transducer face

Discarding information degrades our naïve reconstruction algorithm’s performance considerably. (This is what we’re working on now.)

But here’s a look at our naïve approach anyway: it gives an idea of how surprisingly well things work with very limited information.
Acoustic excitation, viewed in one horizontal slice

We’ll record what the simulated transducers “hear” then try playing it back into the copper to see if we generate a peak in the intensity somewhere which corresponds to the original excitation.

(grain-free “Cu”)
Acoustic excitation, viewed in one horizontal slice

We’ll record what the simulated transducers “hear” then try playing it back into the copper to see if we generate a peak in the intensity somewhere which corresponds to the original excitation.

(grain-free “Cu”)
Drive transducer signals back into copper

Now use measurements from perfect transducers to drive acoustic signals back into the copper... look for an intensity peak:

(grain-free “Cu”)
Drive transducer signals back into copper

Now use measurements from perfect transducers to drive acoustic signals back into the copper… look for an intensity peak:

(grain-free “Cu”)
Acoustic excitation, copper with grains

650 grains total; grain size is random, but typically one wavelength
Acoustic excitation, copper with grains

650 grains total; grain size is random, but typically one wavelength
Drive transducer signals back into grainy copper

It still works. BUT these transducers have unrealistic properties: model assumes perfect knowledge of movement of surface everywhere at transducer face. Real transducers don’t work this well.
Drive transducer signals back into grainy copper

It still works. BUT these transducers have unrealistic properties: model assumes perfect knowledge of movement of surface everywhere at transducer face. Real transducers don’t work this well.
What we are working on

• More realistic modeling of transducer performance
  real transducers are insensitive to shear waves, and only provide sums of amplitudes over entire transducer surface.

• Refinement of reconstruction algorithm. So far we find $t_0$ and initial position using something like an autofocus algorithm:
  use receiver transducers to “drive” signals backwards in time into copper; find time of maximum rms deviation from constant amplitude.
  a real transducer only reports average amplitude over sensor face: it doesn’t project sound backwards in a realistic manner (it produces a narrow beam)

• Measurements of real NLC structure properties
DOE support

DOE is funding LCRD 2.15!

• $25k FY04
• $35k FY05
• $35k FY06

• Support goes for a mix of instrumentation (more electronics, transducers,...) and student salaries
We are having a lot of fun (and you can too!)

This particular project is well suited for undergraduate participation.

The students are very good! All three undergraduate students will continue working after the summer ends.

We are finding it very natural to work in an area that is new to all of us.

If this summer is as productive as last summer, we will know how much information can actually be derived about breakdowns from acoustic data.
Fourier engineering: progress on alternative TESLA kickers

Here’s our other project…
The problem

Linac beam (TESLA TDR):
• 2820 bunches, 337 nsec spacing (~ 300 kilometers)
• Cool an entire pulse in the damping rings before linac injection

Damping ring beam (TESLA TDR):
• 2820 bunches, ~20 nsec spacing (~ 17 kilometers)
• Eject every $n^{th}$ bunch into linac (leave adjacent bunches undisturbed)

Kicker speed determines minimum damping ring circumference.

We are investigating a “Fourier series kicker”: use a series of rf cavities to create a kicking function with periodic zeroes and an occasional spike. Perhaps closer bunches/smaller damping ring will be possible?
Participants

This project is part of the US university-based Linear Collider R&D effort (LCRD/UCLC)

Fermilab
Leo Bellantoni
David Finley
Chris Jensen
George Krafczyk
Shekhar Mishra
François Ostiguy
Vladimir Shiltsev

University of Illinois
Guy Bresler
Keri Dixon
George Gollin
Mike Haney
Tom Junk
Jeremy Williams

Cornell University
Gerry Dugan
Joe Rogers
Dave Rubin
TRESLA damping ring kicker à la TDR

TDR design: bunch “collides” with electromagnetic pulses traveling in the opposite direction inside a series of traveling wave structures. Hard to turn on/off fast enough.

Fast kicker specs (à la TDR):

- \[ \int Bdl = 100 \text{ Gauss-meter} = 3 \text{ MeV/c} \, (= \, 30 \text{ MeV/m} \times 10 \text{ cm}) \]
- stability/ripple/precision \( \sim .07 \text{ Gauss-meter} = 0.07\% \)
Since it’s hard to turn on/off, why not leave it ON all the time?

Kicker field needs to be zero when unkicked bunches pass through.

Fields when kicker is empty of beam are irrelevant.

Synthesize kicker impulse from Fourier components of something with good peaks and periodic zeroes.

Kicker is always on.
Three functions with good peaks and zeroes: #1

1. part of the series for a periodic $\delta$ function ($\omega$ is linac frequency):

$$1 + \sum_{k=1}^{N} 2 \cos (k\omega t) = \frac{\sin[(N + \frac{1}{2}) \omega t]}{\sin (\omega t / 2)}$$

"Features" (peaks and zeroes) are evenly spaced.

A problem: field has non-zero time derivative at the zeroes. Bunch head and tail experience different (non-zero) fields.
Three functions with good peaks and zeroes: #2

2. “square” of last page: this way zeroes also have zero slope…

\[
\text{kick} \sim \frac{\sin^2(N\omega t)}{\sin^2(\omega t)}
\]

Better… but frequencies range from 3 MHz to 180 MHz.

A 3 MHz RF device is very different from a 180 MHz device.
Three functions with good peaks and zeroes: #3

3. high-frequency modulate: this way fractional bandwidth is reduced.

$$\text{kick} \sim \frac{\sin^2(N\omega t)}{\sin^2(\omega t)} \cos(\Gamma N\omega t)$$

This is what we’re actually studying now, but with $N = 60$ and $\Gamma = 10$:
1.78 GHz ± 10% bandwidth

(Graph uses $N = 16$, $\Gamma = 4$.)

Fourier amplitudes

$k = \Gamma N$

$2N$
Damping ring operation with an FS kicker

We don’t want the beam to go through the kicker until we’re ready to extract.

Fourier series kicker would be located in a bypass section.

While damping, beam follows the upper path.

During injection/extraction, deflectors route beam through bypass section. Bunches are kicked onto/off orbit by kicker.
So what is it, actually?

Original idea: kicker would be a series of 60 “rf cavities,” each oscillating at one of the desired Fourier components. (60 cavities would allow the damping ring to fit into the Tevatron tunnel.)

A bunch “sums” the impulses as it travels through the system.

There are lots of cavities, but they’re all nearly the same.
Is there another way to sum the Fourier components?

Well yes, maybe…

Summing signals in a single cavity…

• **dumb**: build a 3MHz cavity and drive it so that multiple modes are populated. (cavity is huge, lots of modes to control…)

• **promising**: launch different frequencies down a long (dispersive) waveguide to a low-Q cavity. Send the frequency with slowest group velocity first, fastest last. Signals arrive at cavity properly phased to make a short pulse. \( Q \sim 25 \) cavity can support an acceptable range of frequencies. (This was originally Joe Rogers’ idea.)
Pulse compression kicker

Dispersive wave guide compresses chirped RF signal.

(Commercial broadcast?) RF amplifier $\sim 100$kW, but compression generates large peak power for kicking pulse in low-Q cavity.

![Diagram of pulse compression kicker system](image)

- Function generator
- RF amplifier
- (dispersive) wave guide
- Kicker cavity

- Waveguide group velocity vs. frequency
- 337 ns
- 20 ns
Trace the signal from kicker back to amplifier

Kicker cavity field for ~6 ns bunch spacing.

Cavity center-frequency is 600 times linac frequency, 10 times damping ring frequency.

Field inside cavity

±10 ns
Field at the downstream end of the wave guide

Wave guide field at cavity entrance.

Waveguide peak field is about 1/10 that inside the cavity. Note phase shift relative to cavity field.

Wave guide field at cavity entrance

$\pm 10 \text{ ns}$
Field 4/5 of the way down the wave guide

Wave guide field 90% down the length of the wave guide.

Note incomplete pulse compression at this point.

Wave guide field at $z = 45$ meters

$0 - 50$ ns
Field half-way down the wave guide

Wave guide field 50% down the length of the wave guide.

Wave guide field at $z = 25$ meters
Field at entrance to the wave guide

Field at upstream end of the wave guide.

Note that peak field is about .018 here, in comparison with 1.0 inside cavity.

Pulse compression, plus energy storage in the cavity!
Group velocity vs. frequency

1.3 GHz cutoff frequency wave guide

Into wave guide first

Into wave guide last
Pulse compression kicker

Unlike Fourier series kicker, in which bunches “sum” the effects of different frequencies, this design uses the cavity to form the sum.

System is linear, so low-power tests can be used to evaluate concept. (Fermilab is interested in pursuing this.)

Programmable function generator can be reprogrammed to compensate for drifts and amplifier aging.

Underway: studies of how sensitive kicker is to parameter errors:
  • What if Q isn’t exactly 25?
  • What if amplitude, phase, losses in wave guide,… drift?
An example: what if $Q \neq 25$?

Cavity response to drive fields delivered by wave guide depends on $Q$. If $Q$ is different from nominal value, cavity fields are not as expected.

$Q$ differs from nominal by 0.1%
kicked bunch: $6.3 \times 10^{-4}$ error

$p_T$ error vs. bunch number ($< 7 \times 10^{-4}$)
EOI submitted to Fermilab to begin tests

A0 photoinjector lab at Fermilab produces a relativistic (16 MeV now, 50 MeV in a few months), bunched low-emittance electron beam. (It’s rather like a TESLA injector.)

This should be an excellent facility for kicker studies!
Simple kicker for initial tests

Start with a simple kicker whose properties are calculable and can be measured independently of its effects on the A0 electron beam.

Most important: how well can we measure a device’s amplitude and timing stability with the A0 beam?

BPM’s are separated by about a meter.
Simple kicker

Driving kicker with ±750 volt pulse from FNAL linac chopper pulser will deflect 16 MeV beam by 3.3 mrad. (See EOI for calculations.)

Two pairs of 50 µ resolution BPM’s determine deflection to ± 100 µrad
Small Damping Ring Studies at Fermilab

What might a damping ring, small enough to fit into the Tevatron or HERA or tunnels, actually look like?

We had a small workshop in March at Fermilab to think about this.

Participants: ANL, LBNL, SLAC, Cornell, DESY, FNAL…

6 kms, 6 straight sections, 25 wigglers.
Comparison of the two designs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Small ring ((e^+ / e^-))</th>
<th>Dogbone ((e^+ / e^-))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>5 GeV</td>
<td>5 GeV</td>
</tr>
<tr>
<td>Circumference</td>
<td>6.12 km</td>
<td>17 km</td>
</tr>
<tr>
<td>Horizontal emittance (\gamma e_x)</td>
<td>8 mm·mr</td>
<td>8 mm·mr</td>
</tr>
<tr>
<td>Vertical emittance (\gamma e_y)</td>
<td>0.02 mm·mr</td>
<td>0.02 mm·mr</td>
</tr>
<tr>
<td>Transverse damping time (\tau_d)</td>
<td>28 ms / 44 ms</td>
<td>28 ms / 50 ms</td>
</tr>
<tr>
<td>Current</td>
<td>443 mA</td>
<td>160 mA</td>
</tr>
<tr>
<td>Energy loss/turn</td>
<td>7.3 MeV / 4.7 MeV</td>
<td>21 MeV / 12 MeV</td>
</tr>
<tr>
<td>Radiated power</td>
<td>3.25 MW / 2.1 MW</td>
<td>3.2 MW / 1.8 MW</td>
</tr>
<tr>
<td>Tunes (Q_x, Q_y)</td>
<td>62.95, 24.52</td>
<td>72.28, 44.18</td>
</tr>
<tr>
<td>Chromaticities (\xi_x, \xi_y)</td>
<td>-112, -64</td>
<td>-125, -68</td>
</tr>
</tbody>
</table>
Comments about damping rings

It will be interesting to see how various optimizations turn out if it is possible to remove the 20 ns minimum bunch spacing requirement.

A small damping ring could be built and tested before linac construction was complete. (Independent tunnels) This is an appealing idea! It could allow beam to be injected into the linac as soon as the main linac was under construction.

Exploration of technical issues associated with damping rings is becoming a major focus of LC activity at Fermilab.
Fermilab damping ring studies

• Lattice design
• Dynamic aperture studies
• Instability studies
• Kicker work...

...all are underway.
Summary/conclusions

Linear Collider accelerator R&D is a fertile area for university groups. It is too much fun to leave to the accelerator physicists.

Spontaneous organization, without waiting for structure to be imposed from external sources (administrations of large labs, for example), can be an effective way to start a new, large, coherent, national R&D effort based at universities.

Realization of the Linear Collider will proceed most smoothly if detector physicists participate actively in the machine design. The accelerator and detector are closely coupled.