University Contributions to the Linear Collider

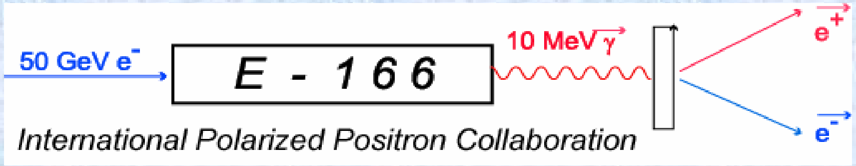
Milind V. Purohit

University of South Carolina, Columbia, SC

- **Introduction**
- **One Example from SC**
- **Two Examples from Univ. of Illinois**
- **Concluding Remarks**

Introduction

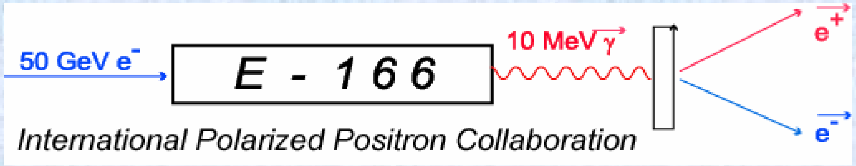
- Popular conception: The accelerator components such as magnets and RF are built by industry and national labs; large detector components are built by national labs, big university contingents.
- In this context, what can a university, particularly a small one, contribute to a large project such as the linear collider?



SLAC E-166 as Example for University Involvement

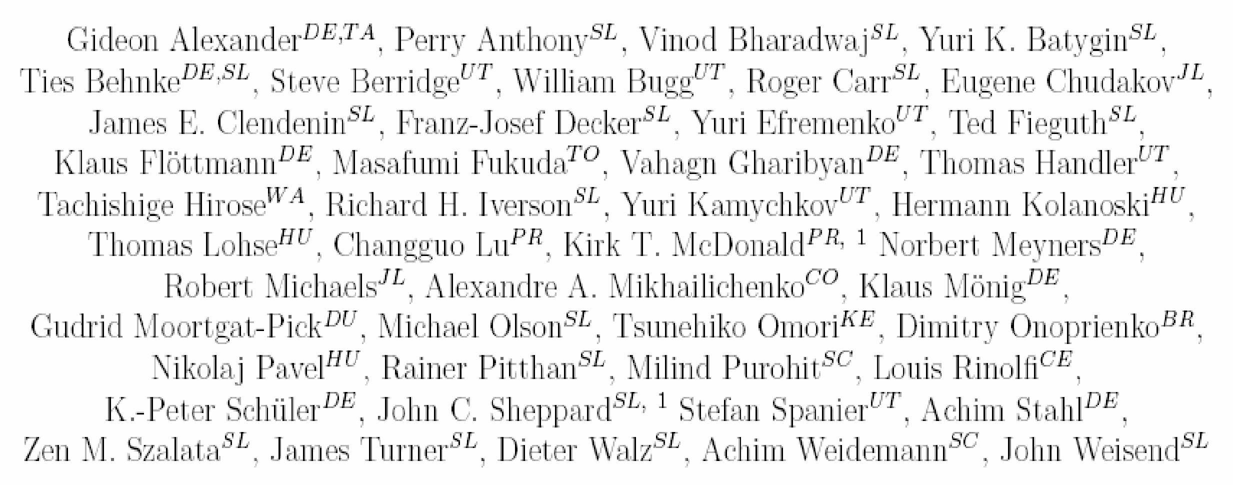
- Addresses important problem for accelerator (Positron Source, Positron Polarization)
- Test of new scheme requires experiment at a scale suitable for university involvement
- Small experiment gives hands-on experience with detectors, simulation to students

In the following: Motivation and short overview of E-166

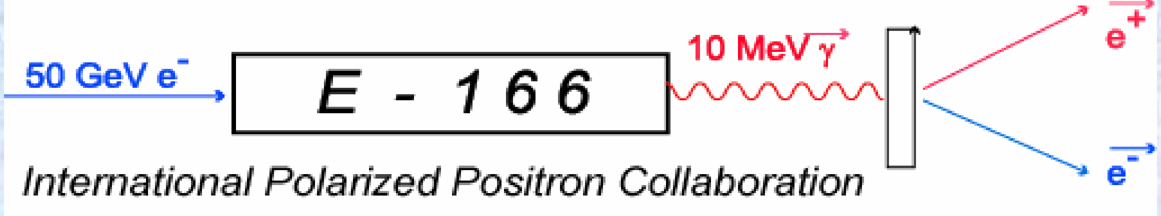


E-166: Undulator-Based Production of Polarized Positrons

E-166 Collaboration: (~ 45 Collaborators from ~15 Institutions)


Gideon Alexander^{DE,TA}, Perry Anthony^{SL}, Vinod Bharadwaj^{SL}, Yuri K. Batygin^{SL},
Ties Behnke^{DE,SL}, Steve Berridge^{UT}, William Bugg^{UT}, Roger Carr^{SL}, Eugene Chudakov^{JL},
James E. Clendenin^{SL}, Franz-Josef Decker^{SL}, Yuri Efremenko^{UT}, Ted Fieguth^{SL},
Klaus Flöttmann^{DE}, Masafumi Fukuda^{TO}, Vahagn Gharibyan^{DE}, Thomas Handler^{UT},
Tachishige Hirose^{WA}, Richard H. Iverson^{SL}, Yuri Kamychkov^{UT}, Hermann Kolanoski^{HU},
Thomas Lohse^{HU}, Changguo Lu^{PR}, Kirk T. McDonald$^{PR,\ 1}$ Norbert Meyners^{DE},
Robert Michaels^{JL}, Alexandre A. Mikhailichenko^{CO}, Klaus Mönig^{DE},
Gudrid Moortgat-Pick^{DU}, Michael Olson^{SL}, Tsunehiko Omori^{KE}, Dimitry Onoprienko^{BR},
Nikolaj Pavel^{HU}, Rainer Pitthan^{SL}, Milind Purohit^{SC}, Louis Rinolfi^{CE},
K.-Peter Schüler^{DE}, John C. Sheppard$^{SL,\ 1}$ Stefan Spanier^{UT}, Achim Stahl^{DE},
Zen M. Szalata^{SL}, James Turner^{SL}, Dieter Walz^{SL}, Achim Weidemann^{SC}, John Weisend^{SL}


^{BR} Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom
^{CE} CERN, CH-1211 Geneva 23, Switzerland
^{CO} Cornell University, Ithaca, NY 14853
^{DE} DESY, D-22603 Hamburg, Germany
^{DU} University of Durham, Durham DH1 3HP, United Kingdom
^{JL} Thomas Jefferson National Accelerator Facility, Newport News, VA 23606
^{HU} Humboldt University, Berlin, Germany
^{KE} KEK, Tsukuba-shi, Ibaraki, Japan
^{PR} Joseph Henry Laboratory, Princeton University, Princeton, NJ 08544
^{SC} University of South Carolina, Columbia, SC 29208
^{SL} SLAC, Stanford, CA 94309
^{TA} University of Tel Aviv, Tel Aviv 69978, Israel
^{TO} Tokyo Metropolitan University, Hachioji-shi, Tokyo, Japan
^{UT} University of Tennessee, Knoxville, TN 37996
^{WA} Waseda University, 389-5 Shimooyamada-machi,Machida,Tokyo 194-0202



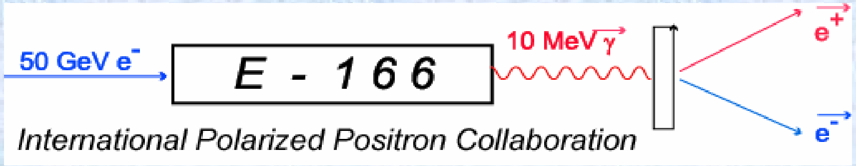
USC HEP
University of South Carolina
High Energy Physics Group

Polarized Positrons at a Linear Collider and FFTB (SLAC E-166)

Main Participant from USC:

Achim W. Weidemann

(Research Professor)

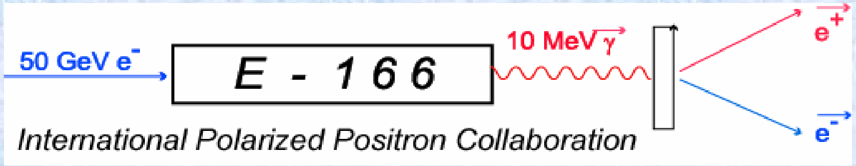


Physics Motivation for Polarized Positrons

Polarized e$^+$ in addition to polarized e$^-$ is recognized as a highly desirable option by the WW LC community (studies in Asia, Europe, and the US)

Having polarized e$^+$ offers:

- Higher effective polarization ⇒ enhancement of effective luminosity for many SM and non-SM processes
- Ability to selectively enhance (reduce) contribution from SM processes (better sensitivity to non-SM processes)
- Access to many non-SM couplings (larger reach for non-SM physics searches)
- Access to physics using transversely polarized beams (only works if both beams are polarized)
- Improved accuracy in measuring polarization.



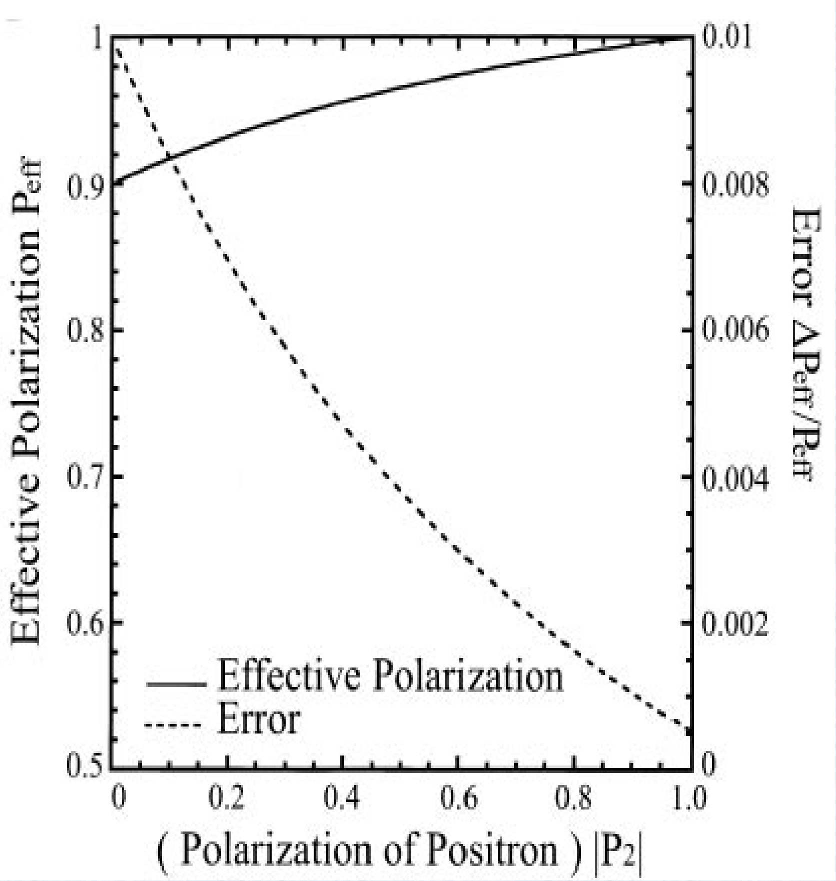
Physics Motivation for Polarized Positrons

- Electroweak processes $e^+e^- \rightarrow$ WW, Z, ZH couple only to $e^-_L e^+_R$ or $e^-_R e^+_L$ (but not $e^-_L e^+_L$ or $e^-_R e^+_R$).

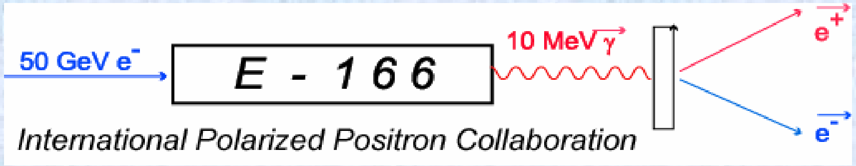
$\Rightarrow$ Can double or suppress rate using polarized positrons (in addition to polarized e^-).

- Effective polarization enhanced, and error decreased, in electroweak asymmetry measurements, $(N_L - N_R) / (N_L + N_R) = P_{eff} A_{LR}$, where $P_{eff} = (P_- - P_+) / (1 - P_- P_+)$.
- Improved accuracy in polarization measurement (Blondel scheme).

► Must have both e^+ and e^- polarization for Giga-Z project ($\sin^2\theta_W$)



(SUSY) Physics Motivation for Polarized Positrons



Slepton and squark produced dominantly via $\tilde{e}_L^-\tilde{e}_L^+$ (and not $\tilde{e}_R^-\tilde{e}_R^+$ or $\tilde{e}_R^-\tilde{e}_L^+$).

Separation of the (LL, LR) selectron pair

$\tilde{e}_L^-\tilde{e}_L^+$ $\tilde{e}_L^-\tilde{e}_R^+$

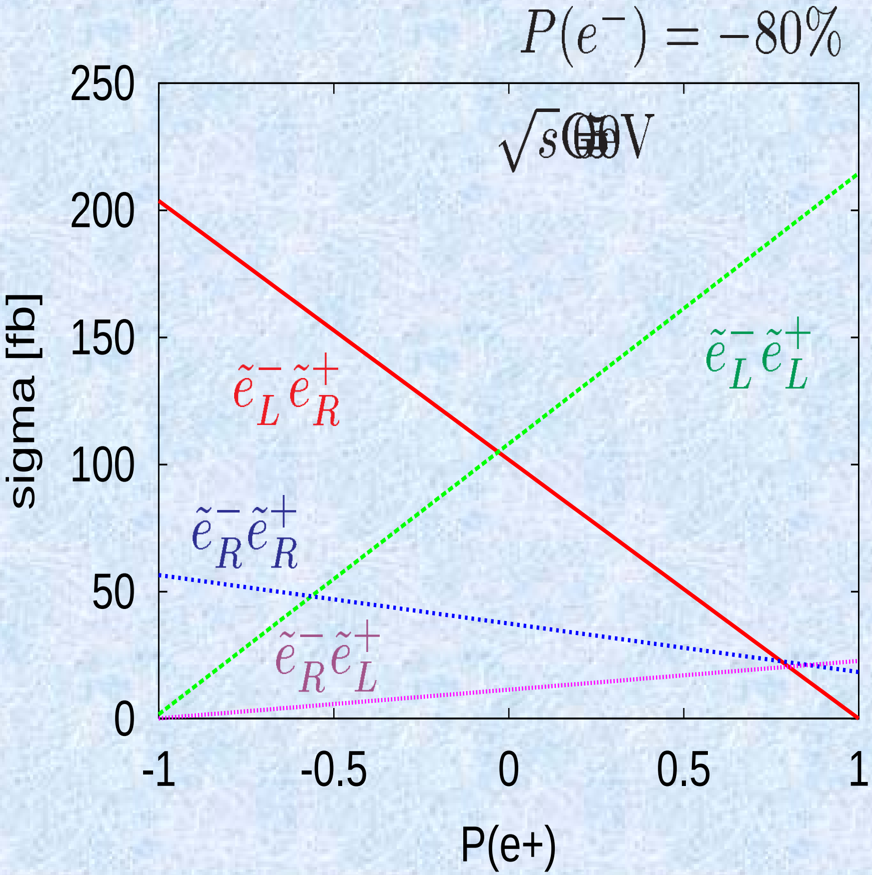
with longitudinally polarized beams to test association of chiral quantum numbers to scalar fermions in SUSY :

With P(e)=-80% and:

- P(e$^+$)= 0% $\Longrightarrow$ no separation!

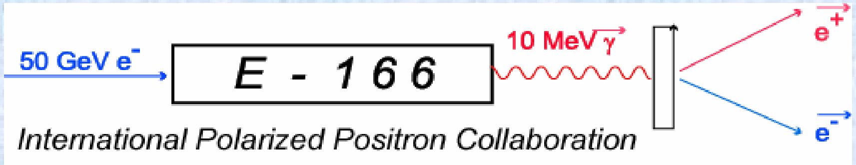
- P(e$^+$)= -40% $\Longrightarrow$ 163 fb vs 66 fb

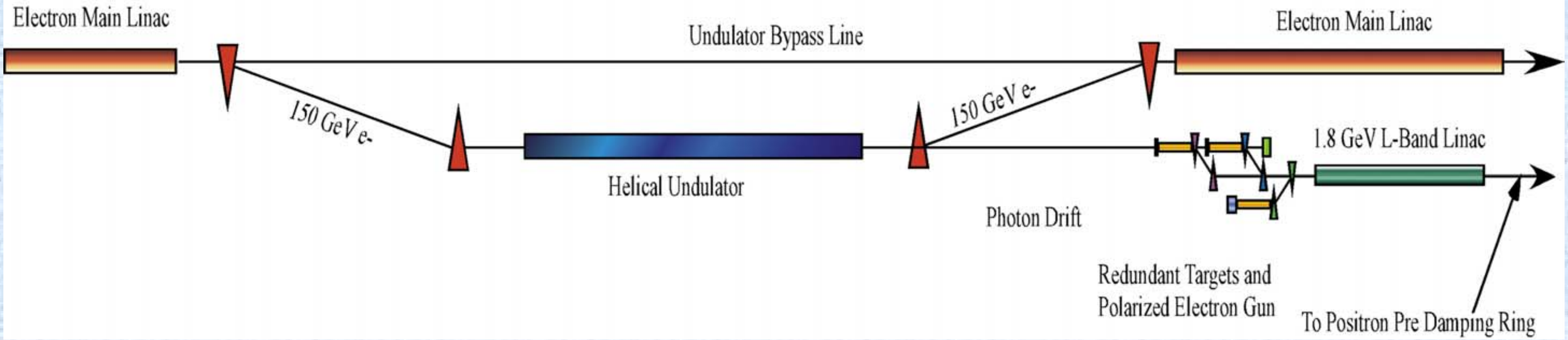
Can’t do without positron polarization!



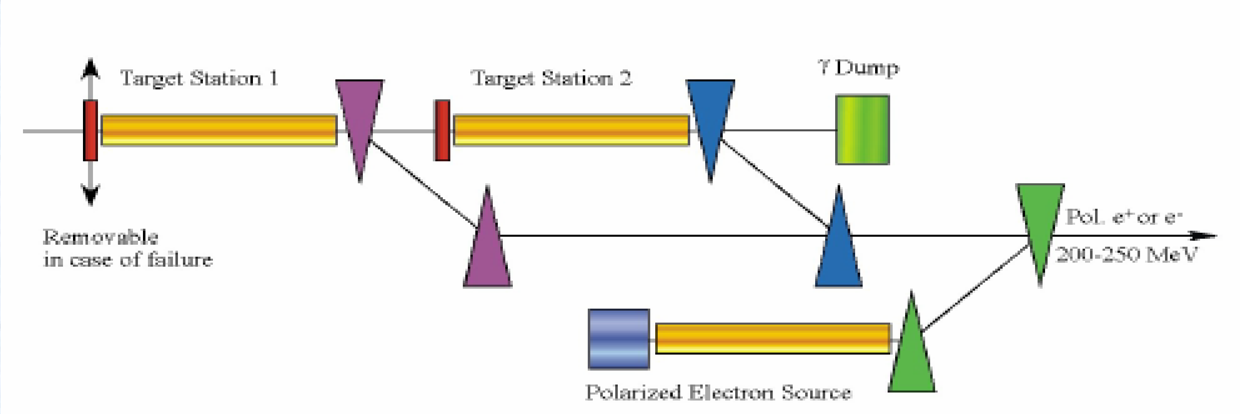
More examples in JLC, TESLA TDRs, Reviews, e.g. by G. Moortgat-Pick, http://www.ippp.dur.ac.uk/~gudrid/power

Polarized Positrons at LC

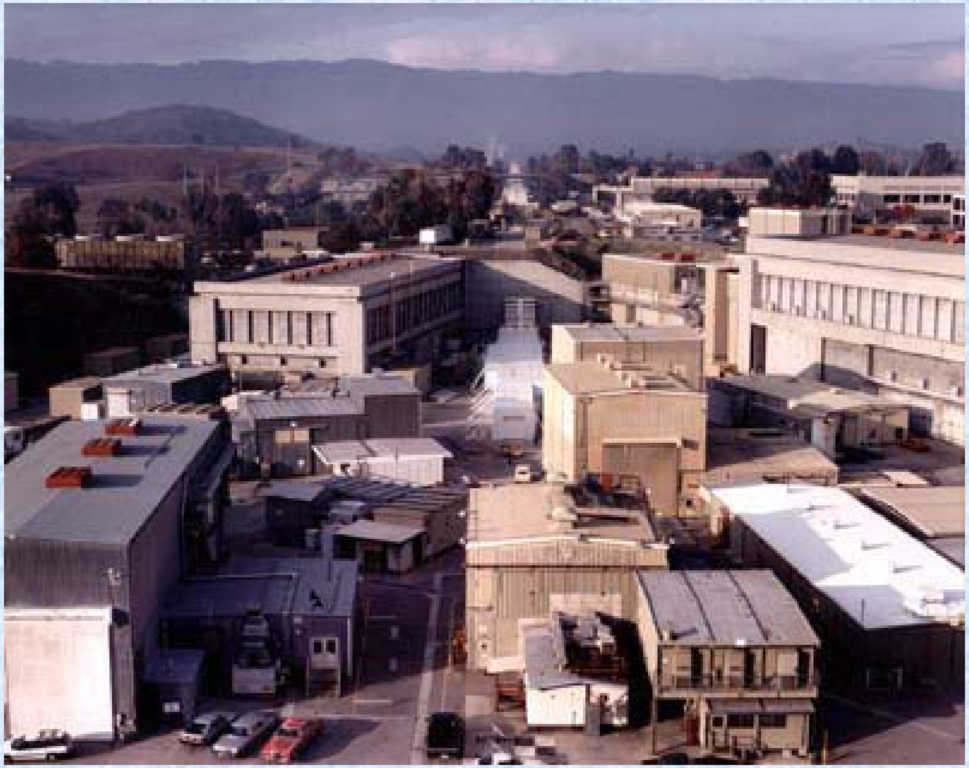




2 Target assemblies for redundancy (+ polarized e- source)



The FFTB



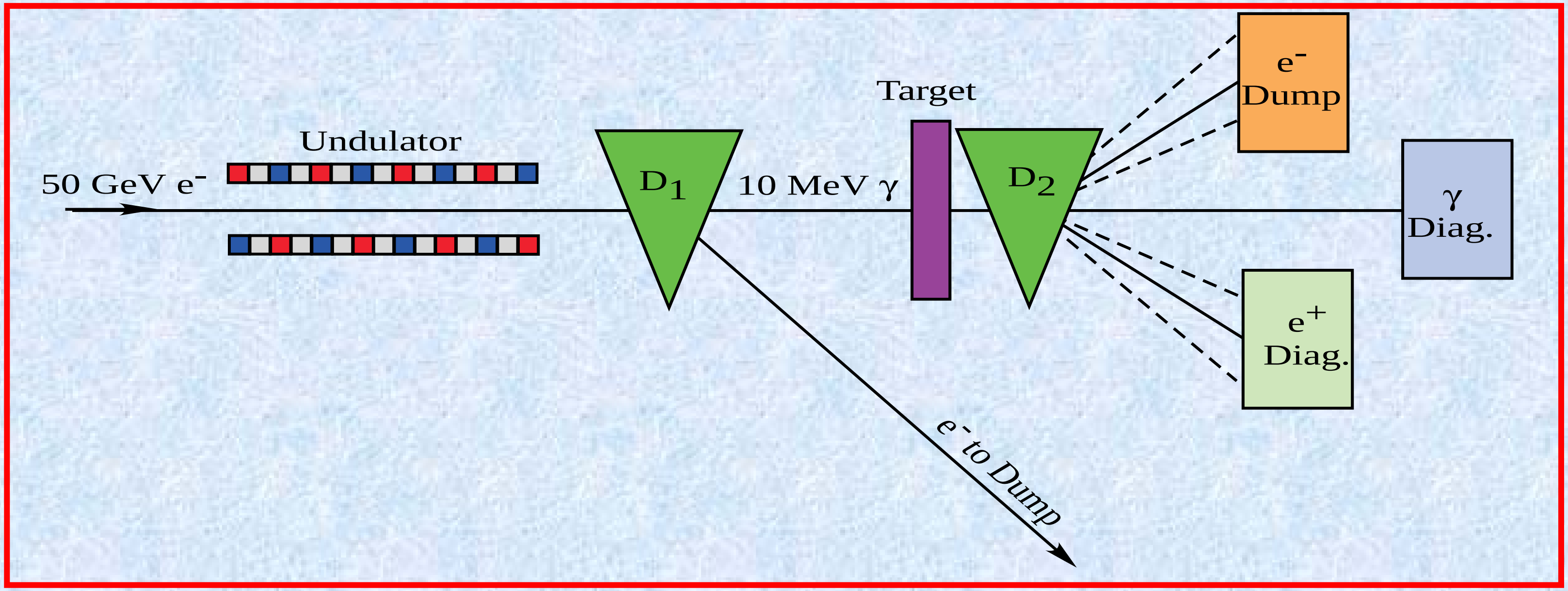
M. V. Purohit, U. of S. Carolina

50 GeV e$^-$ E - 166 10 MeV γ e$^+$ e$^-$

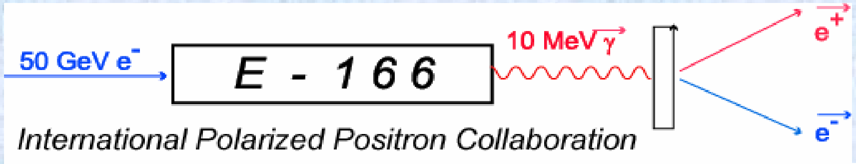
International Polarized Positron Collaboration

E-166 Experiment

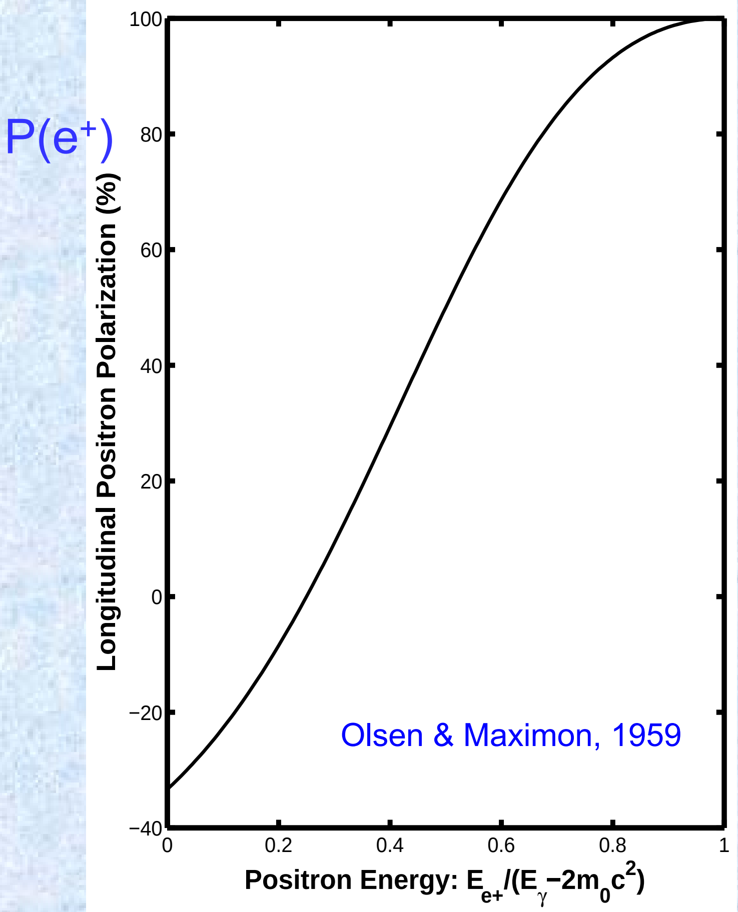
E-166 is a demonstration of undulator-based polarized positron production for linear colliders



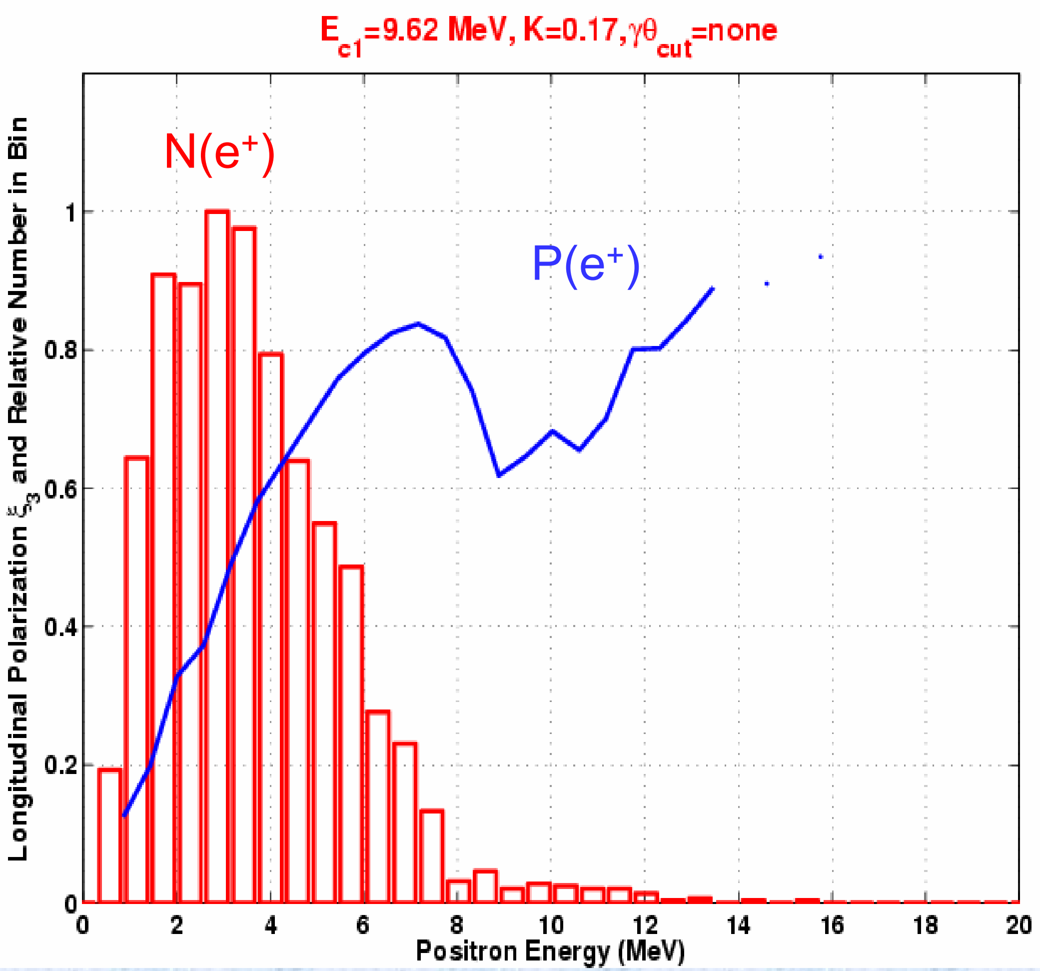
- E-166 uses the 50 GeV SLAC beam in conjunction with 1 m-long, helical undulator to make polarized photons in the FFTB.
- These photons are converted in a ~0.5 rad. len. thick target into polarized positrons (and electrons).
- The polarization of the positrons and photons will be measured.



Circ. $\gamma \to$ long. e^+ polarization



Olsen & Maximon, 1959

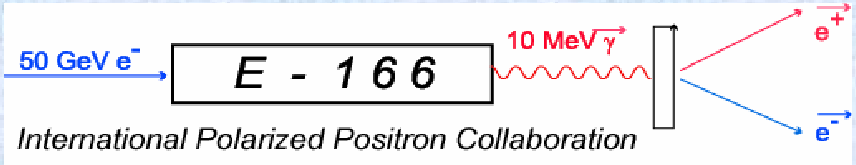


0.5 r.l. Ti Alloy target; 0.5% yield, **P(e^+)=54%** averaged over full spectrum

E-166 vs LC

E-166 is a demonstration of undulator-based production of polarized positrons for linear colliders:

- Photons are produced in the same energy range and polarization characteristics as in LC
- The same target thickness and material
- The polarization of the produced positrons is expected to be in the same range as in LC
- The simulation tools are the same as those being used to design the polarized positron system for a LC
- But: the intensity per pulse is low by a factor of 2000.



E-166 Outlook

- Experiment approved mid-June 2003;
- …with proviso: should study backgrounds first;
- doing backgrounds study now…mid-2004 (parasitical now, dedicated with thin-bored pipe in 2004)
- expect to run in early 2005 (….before end of 2005, after which FFTB will become LCLS)
- Hope to blaze the way for polarized positrons at a future LC!

References, details : See proposal and references at
`http://www.slac.stanford.edu/exp/e166`

Collaborators' Contributions

- SLAC: Beam Line, engineering, much support with engineering, construction, DAQ, Simulation,…
- Princeton: Positron Transport Line, Aerogel Counters
- DESY-DESY Zeuthen – Humboldt U.: Positron Polarimeter, incl. CsI (from BaBar), simulations
- U. of Tennessee: SiW Calorimeters
- U. of South Carolina: Support of background measurements (with detectors already installed), DAQ, simulation, organization,….

USC interest: Achim's fundamental interest, possibility to provide students with experience in hardware and running of an experiment.

Investigation of Acoustic Localization of rf Cavity Breakdown

George Gollin
Department of Physics
University of Illinois at Urbana-Champaign

LCRD 2.15

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

1. Who is participating
2. Studying the acoustic properties of Copper + transducer system
    - transducer response
    - speed of sound in Copper
    - scattering vs. attenuation at 1.8 MHz in Copper
3. Conclusions

Who is participating at UIUC

Joe Calvey (Undergraduate)

Michael Davidsaver (Undergraduate)

George Gollin (Professor, Physics)

Mike Haney (Engineer, runs HEP electronics group)

Justin Phillips (Undergraduate)

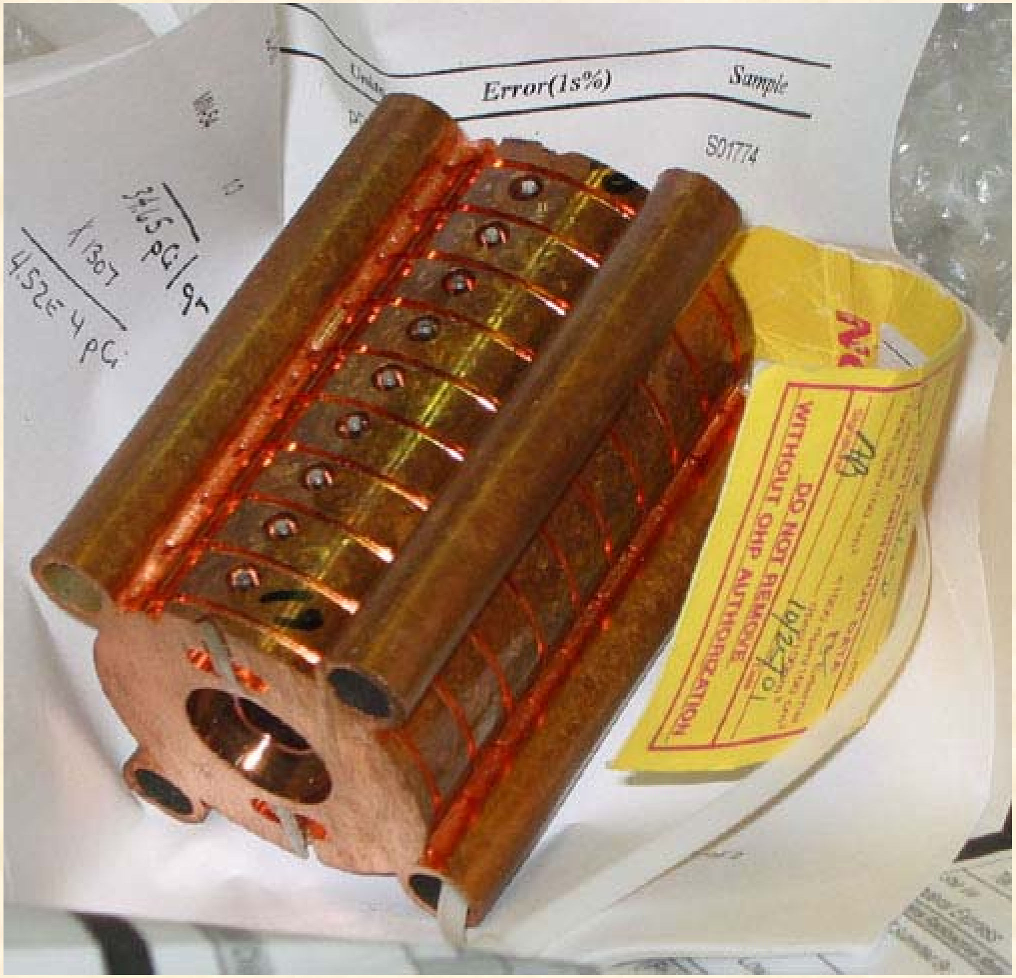
Bill O'Brien (Professor, EE)

Haney's PhD is in ultrasound imaging techniques; O'Brien's group pursues a broad range of acoustic sensing/imaging projects in biological, mechanical, … systems

We discuss progress and plans from time to time with Marc Ross at SLAC.

This is what we’re going to be studying

Ross sent us a short piece of NLC and some engineering drawings specifying the geometry.



We need to understand its acoustic properties.

Start by pinging copper dowels with ultrasound transducers in order to learn the basics.

The plan

1. Use ultrasound transducers to “ping” copper cylinders.
2. Learn about the acoustic properties of transducer + copper system
3. See how well we can model acoustic properties using *MatLab*
4. Develop an acoustic model for the NLC structure we have on hand
5. Ping the NLC structure and determine how well our model describes our measurements
6. Predict characteristics of the acoustic signature for various electrical catastrophes inside an NLC structure
7. Generate sparks inside cavity, measure what we can, then see how much information we can extract from the acoustic information.

So far we’ve been concentrating on items 1-3.

Copper dowels from Fermilab NLC Structure Factory

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.

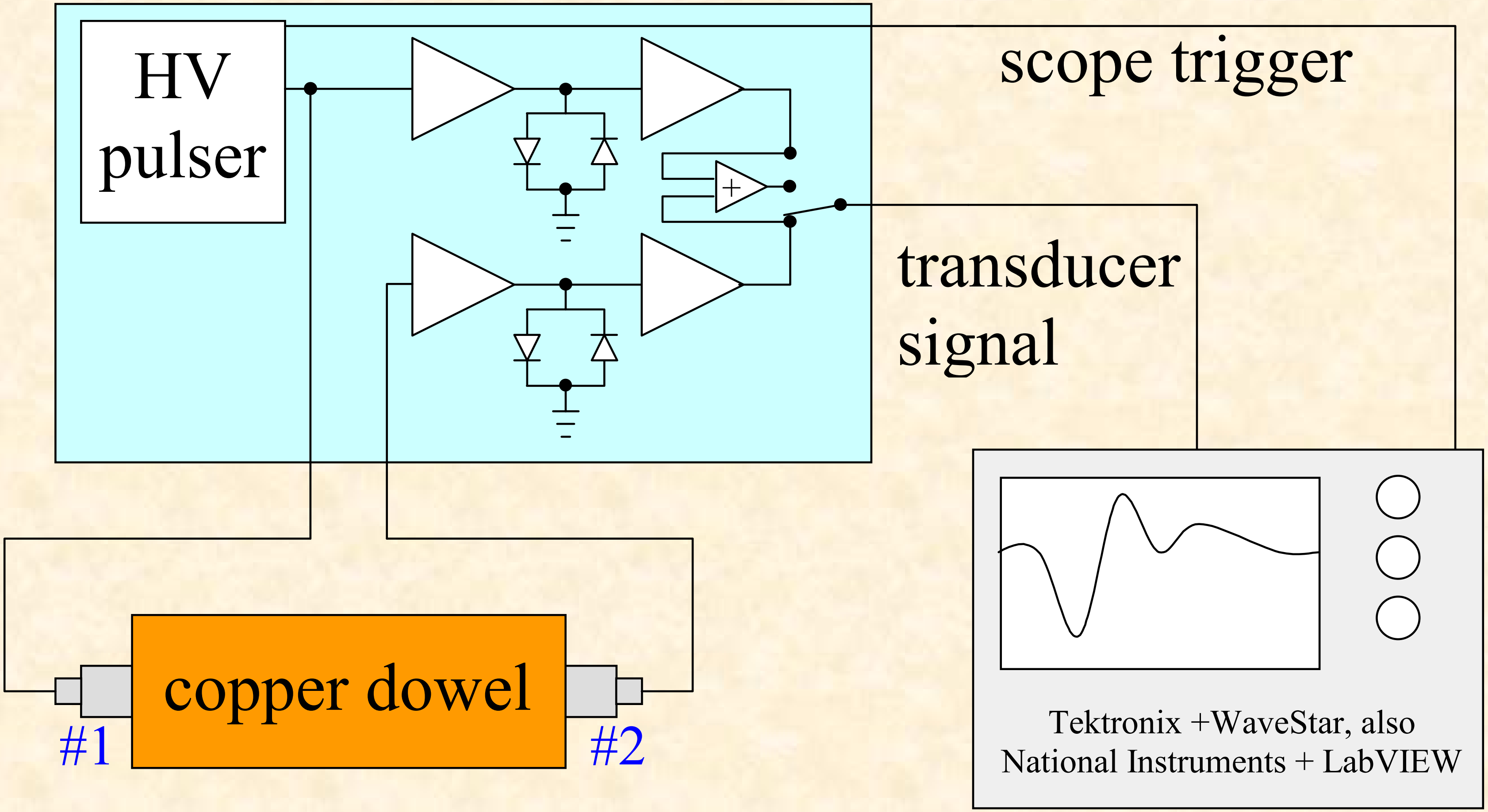
Ross also sent us a (small) single crystal copper dowel.

#2 is heat-treated…

…#1 is not.

We cut each dowel into three different lengths.

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.

Modeling the Copper + transducer system

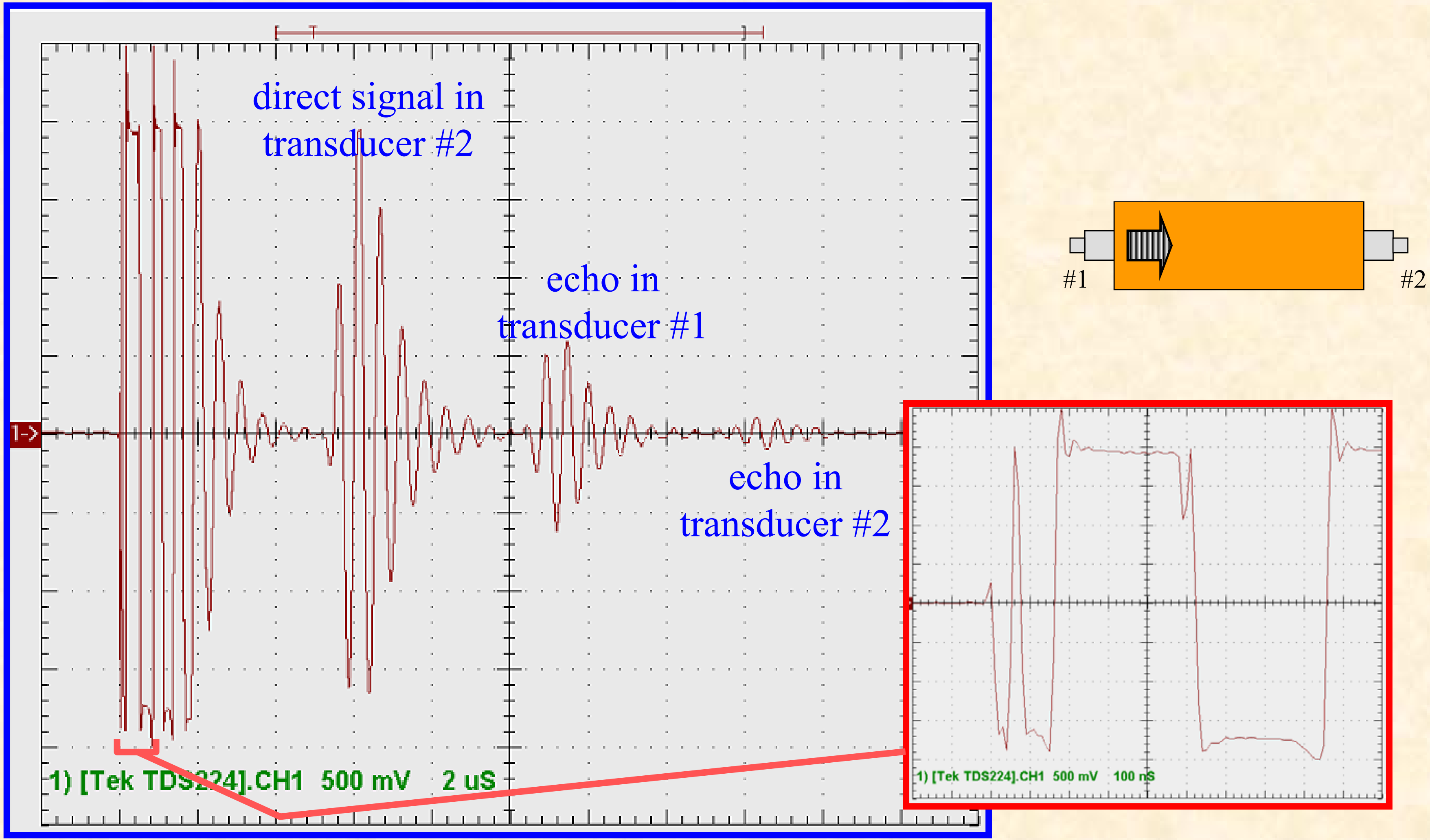
We want to understand this “simple” system in detail.

If we can model it accurately (using MatLab), we might be able to interpret acoustic information from the more complicated NLC structures.

HV pulses used to zap the transducer are short: ~10 nsec, ~1 kV, but there are reflections and other complicated effects which play a significant role in determining the actual excitation of the transducer.

Pinging the shortest heat-treated dowel

Two transducers: fire a ping, then listen for signals in both transducers. The initial excitation is complicated (note the the protection diodes)



Modeling the transducer

Model the Panametrics piezoelectric transducer as a (linear) damped oscillator

- response to a δ function: $x(t) \sim \frac{F_0 e^{-bt}}{\omega_1} \sin(\omega_1 t)$
- response to $F(t)$: $x(t) \sim \int_0^t \frac{F(t-t') e^{-b(t-t')}}{\omega_1} \sin[\omega_1 (t-t')] dt'$
- pressure generated by transducer ~ $a(t) = \frac{d^2 x(t)}{dt^2}$

Some equations

$x(t)$ in response to a $\delta(t)$ function

$$x(t) \sim \frac{e^{-bt}}{\omega_1}\sin(\omega_1 t)$$

$a(t)$ in response to a $\delta(t)$ function

$$a(t) \sim -v_0 e^{-bt}\left[\left(\frac{\omega_1{}^2 - b^2}{\omega_1}\right)\frac{\sin(\omega_1 t)}{\omega_1} + 2b\cos(\omega_1 t)\right]$$

$x(t)$ in response to $a(t)$ function above

$$x(t) \sim \frac{e^{-bt}}{\omega_1}\left[bt\sin(\omega_1 t) + \left(\frac{b^2 - \omega_1{}^2}{2\omega_1}\right)\left[t\cos(\omega_1 t) - \frac{\sin(\omega_1 t)}{\omega_1}\right]\right]$$

Transducer phenomenology

Try describing the excitation in terms of four δ functions applied to the piezoelectric crystal; adjust delays and amplitudes so that prediction for first echo signal looks reasonably good.

Accuracy of prediction for second echo's signal is a check.

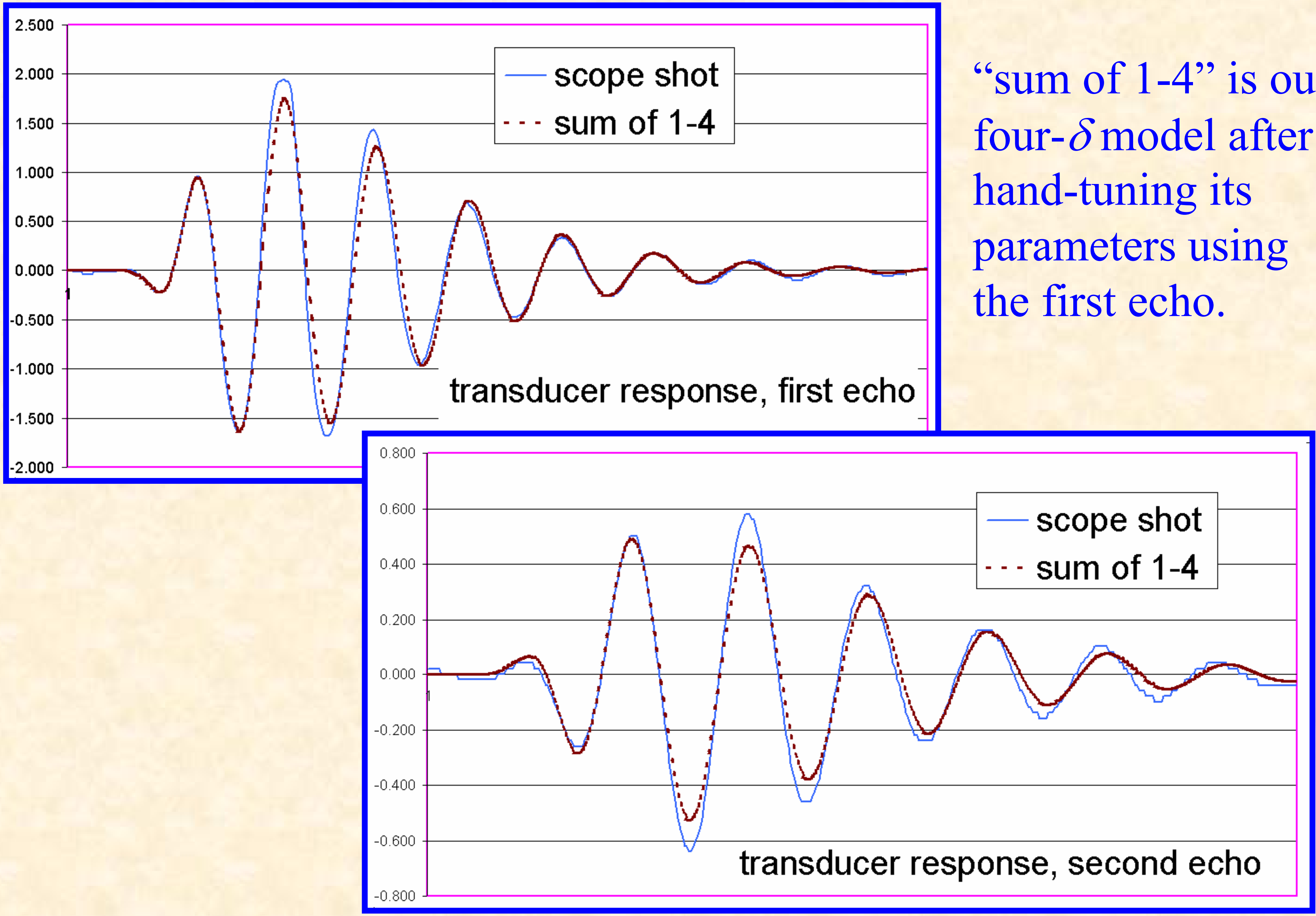
Looks pretty good, but not perfect (see plots on next slide).

Our transducer: $\omega_1 = 2\pi \times 1.8$ MHz; $b = 1.70 \times 10^6$ sec^{-1}.

Recall that response to $F(t) = F_0\delta(t)$ is $x(t) \sim \dfrac{F_0 e^{-bt}}{\omega_1}\sin(\omega_1 t)$

Transducer phenomenology

“sum of 1-4” is our four-δ model after hand-tuning its parameters using the first echo.



transducer response, first echo

transducer response, second echo

Transducer phenomenology

The behavior of the transducer is influenced by how well it is coupled to the copper (acoustic loading, acoustic impedance [*Z*] mismatches, etc. etc.). We use a glycerin film to make transducer-copper contact.

It's a little tricky figuring out exactly what the transducer is pumping into the copper, and we may need to work up a different parameterization for each of the dowel/transducer combinations.

Reflection coefficient: $R \equiv \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right]^2 \; ; \; E_{reflected} = R \cdot E_{incident}$

Pulse shapes are <u>very</u> reproducible from shot to shot, but care is necessary in how the transducer is coupled to the copper.

Speed of sound at 1.8 MHz in copper

We have three different lengths of dowels and can make speed-of-sound measurements by timing the arrival of various reflections.

This way, effects related to transducer geometry cancel.

Dowel lengths	
Dowel 1: not heat-treated diameter: 6.907 cm	Dowel 2: heat-treated diameter: 6.908 cm
2.52 cm	2.56 cm
5.09 cm	5.09 cm
17.6 cm	17.6 cm

Speed of sound and grain structure…

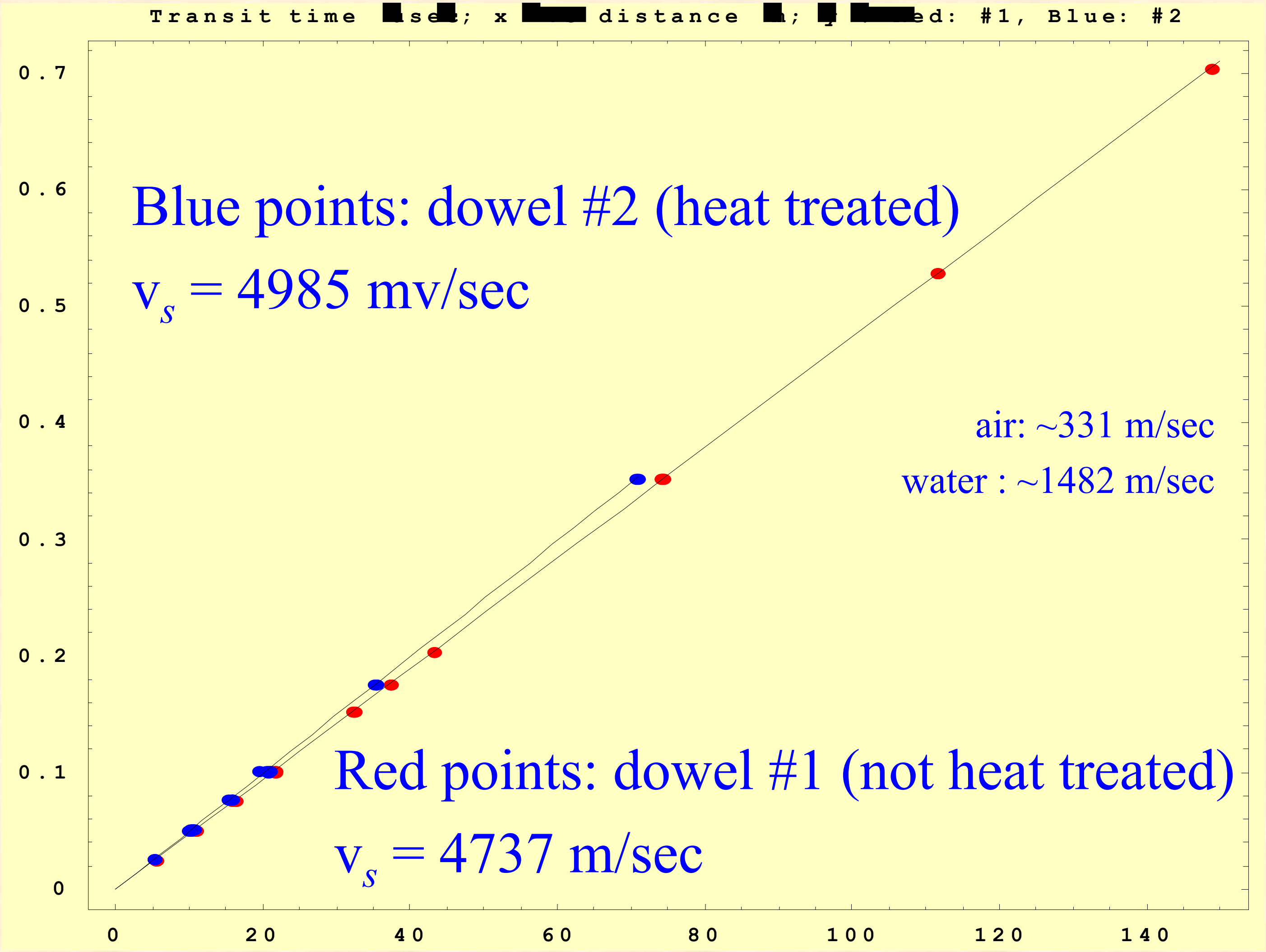
Closeup of one of the (heat-treated) dowel #2 sections.

Note that grain patterns visible at the copper’s surface.

Grain structure is not visible on the surface of dowel #1.

Speed of sound at 1.8 MHz in copper

The speed of sound is different in the two kinds of copper dowels. It's 5.2% faster in the grainy (heat treated) copper. (You can hear it!)



Blue points: dowel #2 (heat treated)

v_s = 4985 mv/sec

air: ~331 m/sec

water : ~1482 m/sec

Red points: dowel #1 (not heat treated)

v_s = 4737 m/sec

…so λ ~ 2.8 mm

Single crystal:

v_s = 4973 m/sec

(4.973 mm/µsec)

Measurements and modeling

We can measure acoustic signatures with good reproducibility, though coupling of transducers to copper is a little fussy.

We are using WaveStar and LabVIEW to acquire (and process) oscilloscope information.

Ongoing (parallel) effort: develop MatLab acoustic model for transducer + Copper system.

Wave equation:

$$\rho \frac{\partial^2 \vec{u}(\vec{x},t)}{\partial t^2} = \left(\mathrm{K} + \tfrac{4}{3}\mu\right)\vec{\nabla}\left(\vec{\nabla}\cdot\vec{u}(\vec{x},t)\right) - \mu\vec{\nabla}\times\left(\vec{\nabla}\times\vec{u}(\vec{x},t)\right)$$

ρ is density, K is bulk modulus, μ is shear modulus, P is pressure, V is volume.

Measurements and modeling

The plan: try to work up a simple phenomenological model (based on sensible physics) which includes scattering off grain (and other) boundaries and includes attenuation.

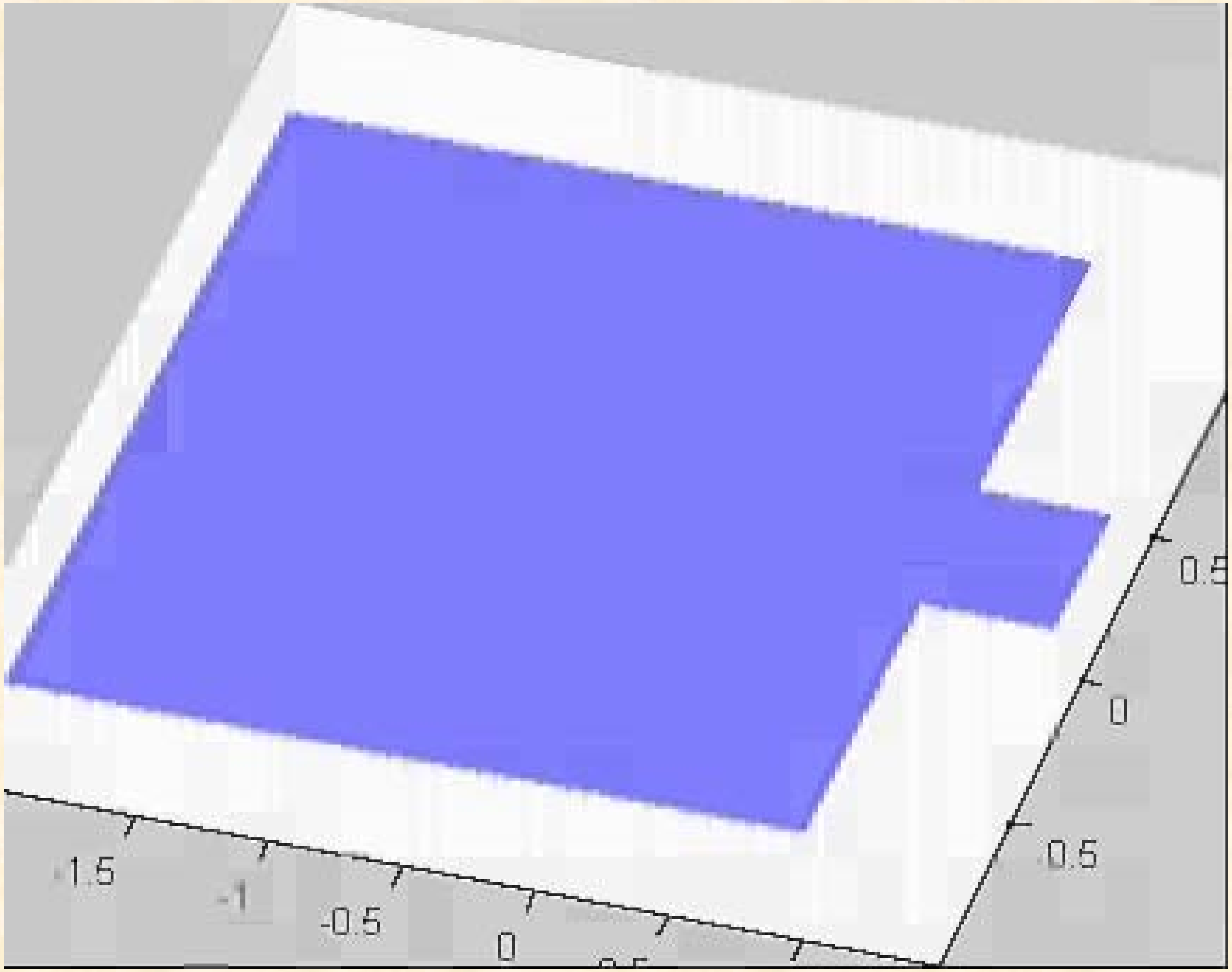
If we can model the copper cylinders adequately, perhaps we will be able to describe the NLC structure's acoustic properties.

Technical language: we would like to be able to understand how to describe the (acoustic) Green's function for our Copper structures.

We're still working on understanding our tools (MatLab and a home-grown version written in Visual C++)

Animation of acoustic waves

This is very cool, though it’s only 2-dimensional, and not completely correct yet. Even so, take a look…



What we’re working on now

- It feels like we’re largely done making measurements of acoustic properties of our Copper cylinders. We need to digest the data a little more.
- Learning to use MatLab, as well as debugging a home-grown acoustics algorithm, are our primary areas of concentration.
- Once we have more confidence in our ability to model very simple systems we’ll start developing a phenomenological model which can reproduce the main features of our Copper dowels.
- We’ll then begin seeing if what we’ve learned can be applied successfully to the NLC structure.

Comments on doing this at a university

- Participation by talented undergraduate students makes LCRD 2.15 work as well as it does. The project is well-suited to undergraduate involvement.
- We get most of our work done during the summer: we're all free of academic constraints (teaching / taking courses). The schedule for evaluating our progress must take this into account.
- Most support for students comes from our DOE base grant. We have borrowed PC's from the UIUC Physics Department instructional resources pool for them this summer.
- LCRD 2.15 requested $9k in support from DOE, which has decided to support us at the requested level.

Conclusions, etc. about Acoustic Wave Project

- We are able to make acoustic measurements of our Copper cylinders which are very reproducible from shot to shot.
- We observe significant differences in the acoustic properties of Copper which is, and is not, heat-annealed.
- We are working at understanding our modeling tools in order to develop a phenomenological description of Copper which can be used to predict/interpret acoustic signals in NLC structures. We don’t yet know how well this will work: the complications of scattering and absorption may make this difficult.
- This is a lot of fun.

A Fourier Series Kicker for the TESLA Damping Rings

George Gollin
Department of Physics
University of Illinois at Urbana-Champaign

LCRD 2.22

Introduction

- The TESLA damping ring fast kicker must inject/eject every n^{th} bunch, leaving adjacent bunches undisturbed.
- The minimum bunch separation inside the damping rings (which determines the size of the damping rings) is limited by the kicker design.
- We are investigating a novel extraction technique which might permit smaller bunch spacing: a "Fourier series kicker" in which a series of rf kicking cavities is used to build up the Fourier representation of a periodic δ function.
- Various issues such as finite bunch size, cavity geometry, and tune-related effects are under investigation.

Illinois participants in LCRD 2.22

Guy Bresler (REU student, from Princeton)

Note: REU = Research Experiences for Undergraduates

Keri Dixon (senior thesis student, from UIUC)

George Gollin (professor)

Mike Haney (engineer, runs HEP electronics group)

Tom Junk (professor)

We benefit from good advice from people at Fermilab and Cornell. In particular: Dave Finley, Vladimir Shiltsev, Gerry Dugan, and Joe Rogers.

Overview: linac and damping ring beams

Linac beam (TESLA TDR):

- One pulse: 2820 bunches, 337 nsec spacing (five pulses/second)
- length of one pulse in linac **~300** kilometers
- Cool an entire pulse in the damping rings before linac injection

Damping ring beam (TESLA TDR):

- One pulse: 2820 bunches, ~20 nsec spacing
- length of one pulse in damping ring **~17** kilometers
- Eject every n^{th} bunch into linac (leave adjacent bunches undisturbed)

17 km damping ring circumference is set by the minimum bunch spacing in the damping ring: Kicker speed is the limiting factor.

Overview: TESLA TDR fast kicker

Fast kicker specs (à la TDR):

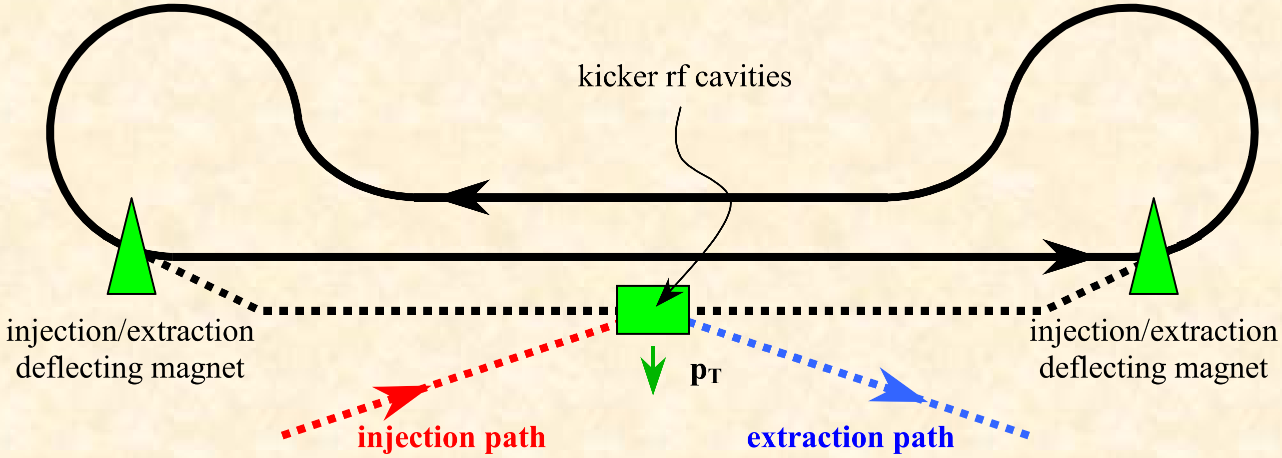
- $\int B\,dl = 100$ Gauss-meter = 3 MeV/c
- stability/ripple/precision ~.07 Gauss-meter = 0.07%
- ability to generate, then quench a magnetic field rapidly determines the minimum achievable bunch spacing in the damping ring

TDR design: bunch "collides" with electromagnetic pulses traveling in the opposite direction inside a series of traveling wave structures.

TDR Kicker element length ~50 cm; impulse ~ 3 Gauss-meter. (Need 20-40 elements.)

Structures dump each electromagnetic pulse into a load.

Something new: a “Fourier series kicker”

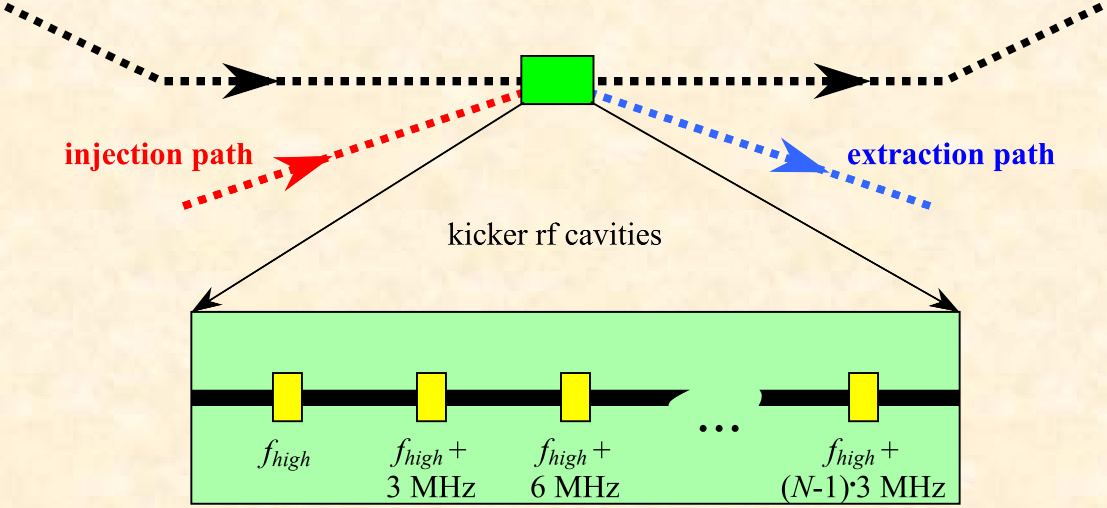


Fourier series kicker would be located in a bypass section.

While damping, beam follows the dog bone-shaped path (solid line).

During injection/extraction, deflectors route beam through bypass (straight) section. Bunches are kicked onto/off orbit by kicker.

Fourier series kicker

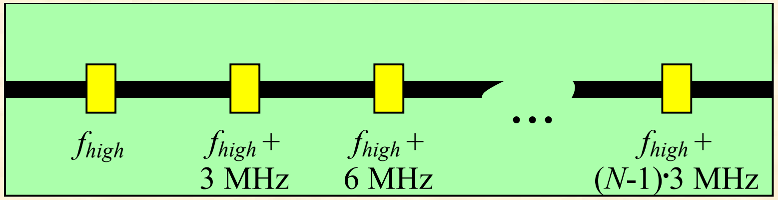


Kicker would be a series of *N* “rf cavities” oscillating at harmonics of the linac bunch frequency 1/(337 nsec) = 2.97 MHz:

$$p_T = A\left[\sum_{j=0}^{j=N_{cavities}-1} A_j \cos\left[\left(\omega_{high} + j\omega_{low}\right)t\right]\right]; \quad \omega_{low} = \frac{2\pi}{337\text{ ns}}$$

M. V. Purohit, U. of S. Carolina

Fourier series kicker



Run them at 3 MHz, 6 MHz, 9 MHz,… (original idea) or perhaps at higher frequencies, with 3 MHz separation: f_{high}, f_{high}+3 MHz, f_{high}+6MHz,... (Shiltsev's suggestion)

Cavities oscillate in phase, possibly with equal amplitudes.

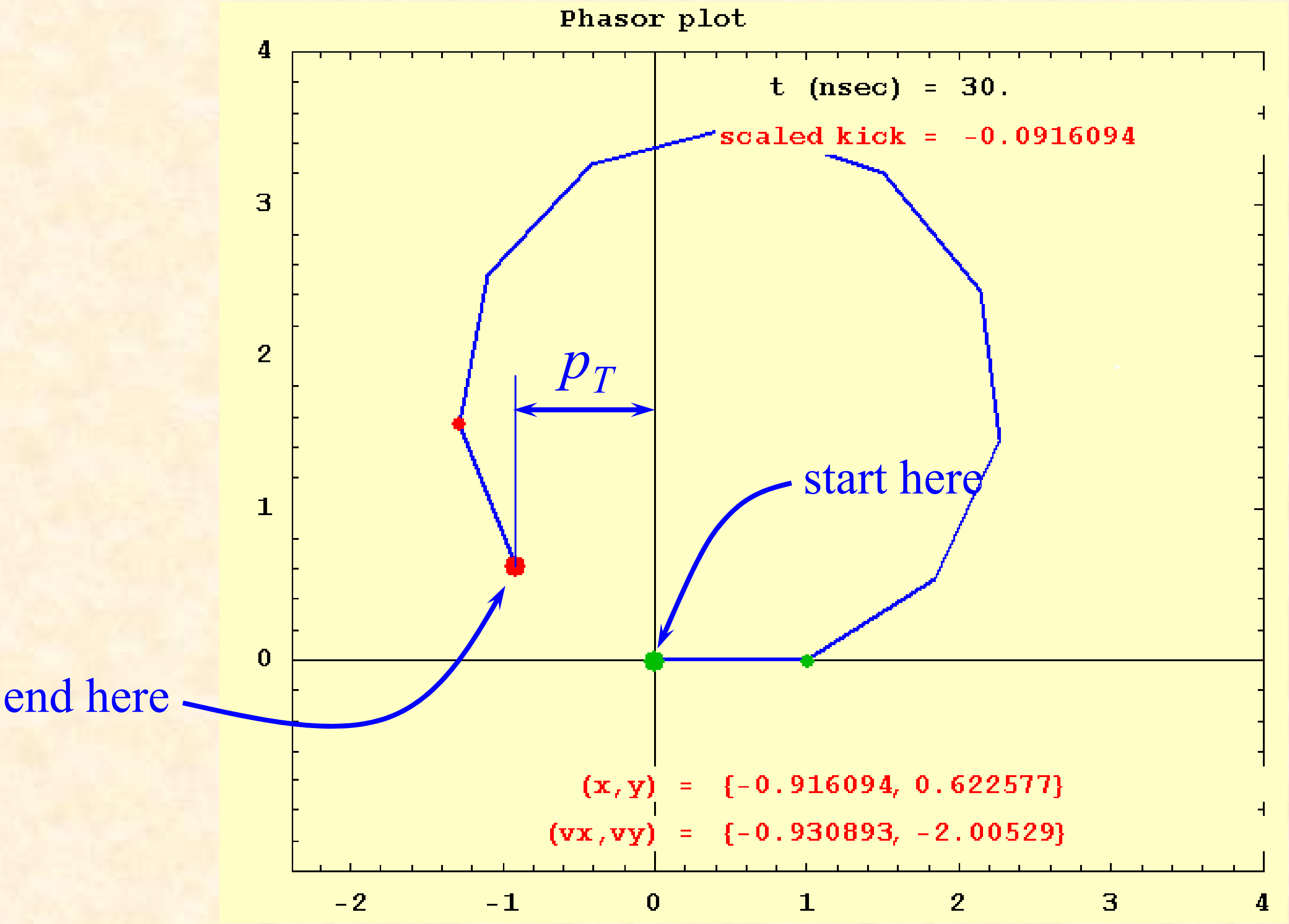
They are <u>always</u> on so fast filling/draining is not an issue.

Kick could be transverse, or longitudinal, followed by a dispersive (bend) section (Dugan's idea).

High-Q: perhaps amplitude and phase stability aren't too hard to manage?

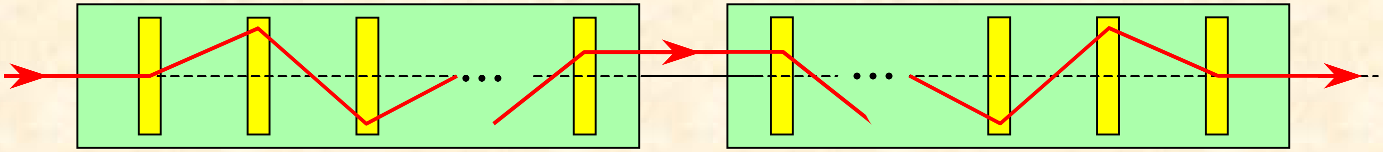
Phasors: visualizing the p_T kick

Here’s a 10-cavity phasor diagram for equal-amplitude cavities…

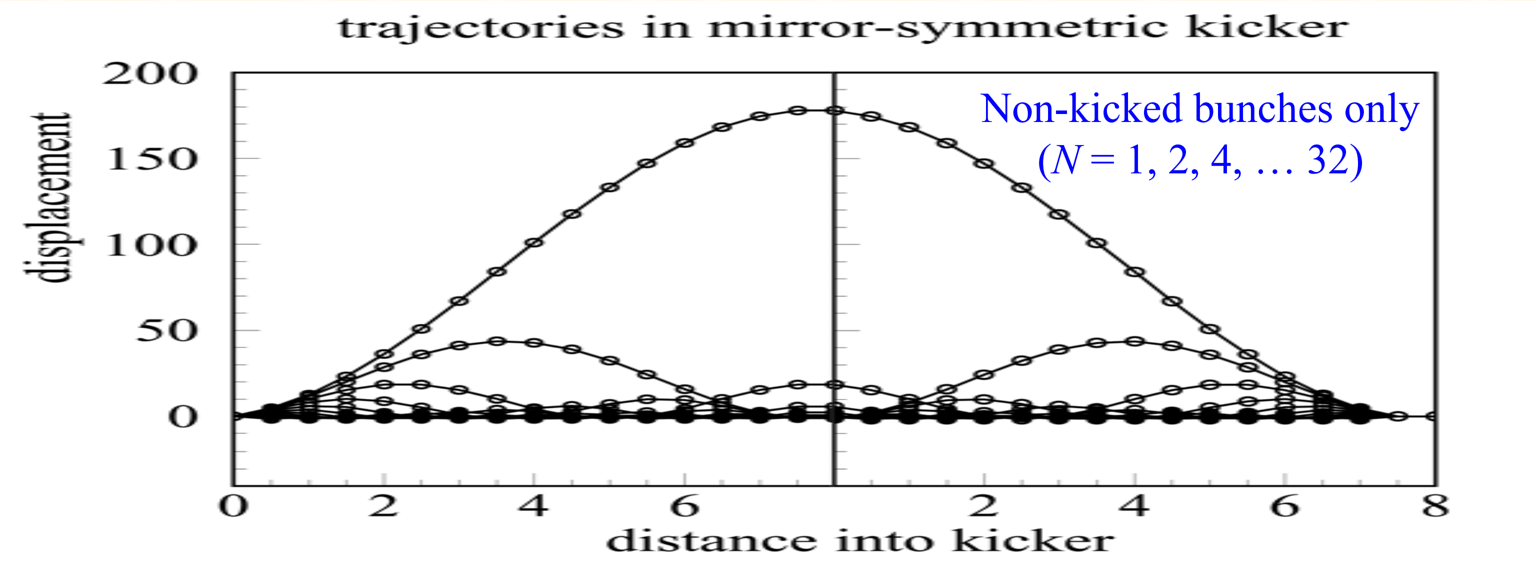


…and 30-cavity animations (30, A, B, C).

Finite separation of the kicker cavities



Compensating for this: insert a second set of cavities in phase with the first set, but with the order of oscillation frequencies reversed: 3 MHz, 6 MHz, 9MHz,… followed by …, 9 MHz, 6 MHz, 3 MHz.



Non-kicked bunches only
(N = 1, 2, 4, … 32)

Some of our other concerns

1. Effect of finite separation of the kicker cavities along the beam direction (George)
2. Arrival time error at the kicker for a bunch that is being injected or extracted (Keri)
3. Inhomogeneities in field integrals for real cavities (Keri)
4. What is the optimal choice of cavity frequencies and amplitudes? (Guy)

What we’re working on now

- Lately we’ve been working with models using high-frequency cavities, split in frequency by multiples of the linac bunch frequency.
- We want to better understand how to select the best set of cavity frequencies an geometries.
- We are in the process of incorporating tune effects into our models.
- We will investigate the kinds of corrections necessary to compensate for tune and cavity-related effects.
- We will look into the relative merits of horizontal and longitudinal kicks.

Comments on doing this at a university

- Participation by talented undergraduate students makes LCRD 2.22 work as well as it does. The project is well-suited to undergraduate involvement.
- We get most of our work done during the summer: we're all free of academic constraints (teaching / taking courses). The schedule for evaluating our progress must take this into account.
- Support for students comes from (NSF-sponsored) REU program. We have borrowed PC's from the UIUC Physics Department instructional resources pool for them this summer.
- LCRD 2.22 requested $2,362 in support from DOE (mostly for travel). In spite of a favorable review by the Holtkamp committee, DOE has rejected the proposal. (We don't know why.) We're continuing with the work, in spite of this.

Linear Collider R & D

At last count, there were:

Accelerator physics (31 proposals)

Luminosity, energy, polarization (9 proposals)

Vertex detector (3 proposals)

Tracking (10 proposals)

Calorimetry (12 proposals)

Muons and particle identification (3 proposals)

Funding for these proposals

- Funding came from both DOE & NSF
- In FY 2003:

Accelerator	Detector
$400 K 21 proposals	$400 K 23 proposals

FY 2004 status

- Requests already exceed previous year's funding by a large margin!

	Accelerator	Detector
DOE	$816K req. 19 proposals	Similar req. 22 proposals
NSF	$355K req. 12 proposals	$828K req. 15 proposals

US – India Collaboration (at the scientist level)

- University faculty visiting from the US are eager to collaborate with faculty and students from India on the Linear Collider.
- We are:
  - Usha Mallik (Univ. of Iowa)
  - Sanjib Mishra (Univ. of S. Carolina)
  - Milind Purohit (Univ. of S. Carolina)
- We represent a resource for experimentalists – for students who wish to visit and for faculty who wish to send their students to get practical experience. We would also, of course, enjoy faculty level visits.

Concluding Remarks

- University groups can:
  - Make intellectual contributions
  - Get students involved in smaller projects
- Collaborate with existing expertise
- Can be a very rewarding experience

⇒ Start by picking a project from web links shown earlier and seek collaborators, funding!

- Grow project(s) into larger involvement with LC, including simulations and (eventually) physics analyses.