Damping Rings and Sources Summary

Cornell ALCPG meeting

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Damping Ring Reports

Damping Ring Design & Performance Goals	Andy Wolski
Recent Experimental Results from the LC Prototype DR – ATF	Marc Ross
A Complete Integration of Intrabeam Scattering Formulae for Asymptotic Beams	Sekazi Mtingwa
Damping Ring for NLC	Alexander Mikhailichenko
Damping Ring R&D Activities at Cornell and Minnesota	Joe Rogers
Investigation and Prototyping of Fast Kicker Options for the TESLA Damping Rings	Gerry Dugan
TESLA Fourier Series Kicker Update	George Gollin

presentations are here: http://www.lns.cornell.edu/~jtr/alcwdampingrings.html

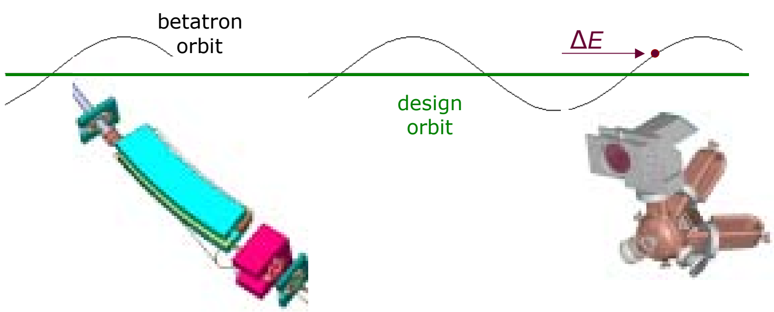
Andy Wolski: *Damping Ring Design & Performance Goals*

Nice presentation of general principles and issues in need of resolution.

Level of talk was well-suited to non-experts in the audience.

Transverse Oscillations and Damping

- Synchrotron radiation emitted in narrow cone (of width ~ $1/\gamma$) around instantaneous direction of motion
  - Particles receive a transverse momentum kick proportional to the amplitude of betatron motion
- Energy lost through synchrotron radiation is replaced in the RF cavities
  - RF field is such that there is no transverse momentum kick



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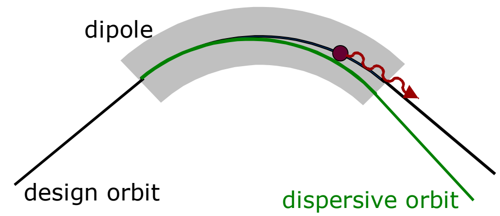
Some information was pedagogical…

Quantum excitation causes emittance growth

- If the synchrotron radiation were continuous (*h*? 0) then the six-dimensional emittance would damp to zero
- Emission of a photon will excite synchrotron and betatron oscillations



- Equilibrium emittance (longitudinal and transverse) is a balance between radiation damping and quantum excitation
- Injected emittance approaches equilibrium emittance exponentially:

$$\gamma\varepsilon(t) = \gamma\varepsilon_{\text{inj}} e^{-2t/\tau} + \gamma\varepsilon_{\text{equ}}\left(1 - e^{-2t/\tau}\right)$$

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Andy Wolski: *Damping Ring Design & Performance Goals*

…some conveyed the currently envisioned parameter sets for NLC and TESLA…

Damping Rings have challenging parameters

Experience at existing storage rings is useful, but Damping Rings will need to operate with lower emittance and larger energy loss

	Future Damping Rings			Operating Rings		
	NLC MDR	CLIC MDR	TESLA e^+	KEK-ATF	ALS	ESRF
Energy [GeV]	1.98	2.42	5	1.3	1.9	6
Circumference [m]	300	357	17,000	140	197	845
Normalized Natural Emittance [μm]	2.3	0.62	8.0	2.8	25	43
Charge/bunch [10^{10}]	0.75	0.42	2.0	1.1	0.61	0.53
Momentum Compaction [10^{-3}]	1.4	0.073	0.12	2.1	1.4	0.19
Natural Bunch Length [mm]	5.5	1.3	6.0	3.1	7.0	4.5
Natural Energy Spread [%]	0.1	0.14	0.13	0.055	0.1	0.1
Energy Loss per Turn [keV]	970	2,200	21,000	41	280	4.75
Energy Loss IDs/Total	0.86	0.83	0.95	0	0.2	0.2
Vertical Damping Time [ms]	4.0	2.6	25	29	8.9	7.0
RF Voltage [MV]	2.0	3.0	54	0.77	1.0	12
RF Frequency [MHz]	714	1500	500	714	500	352

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Andy Wolski: *Damping Ring Design & Performance Goals*

…and some described the challenges being addressed.

Acceptance

- Dynamic aperture is limited by nonlinear magnetic fields

Vertical emittance is sensitive to magnet alignment

Vertical emittance is also sensitive to stray fields

- Stray magnetic fields come from klystrons, cables, power supplies…

Collective effects can limit beam quality

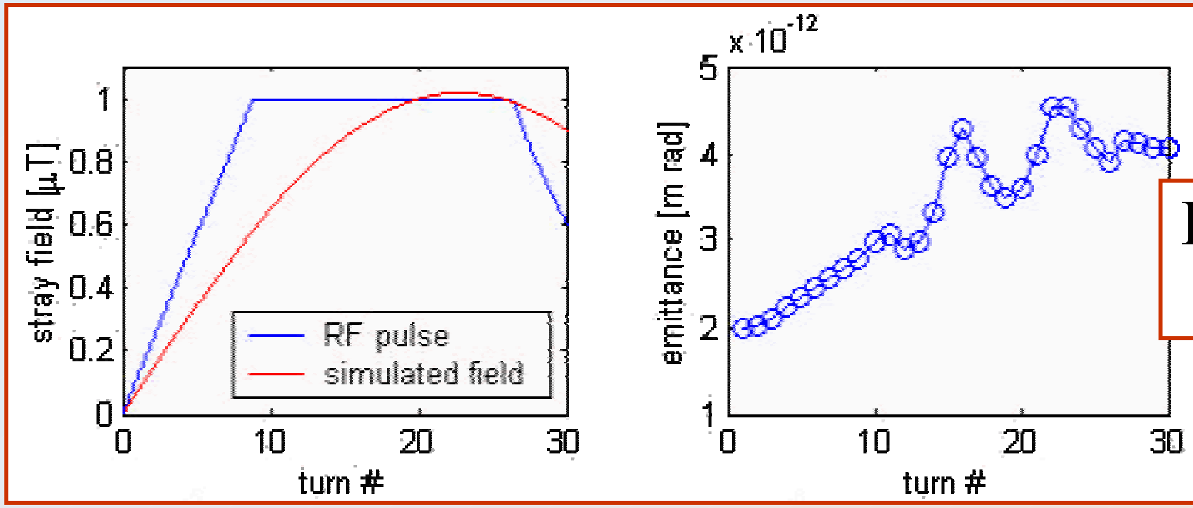
Classical instabilities include effects of wake fields

Space charge forces get stronger with lower energy, lower emittance

Electron cloud can destabilize positron beam

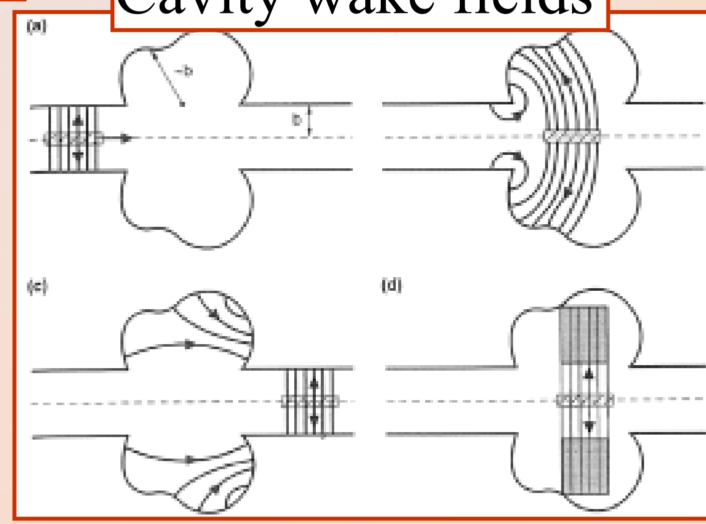
Intra-Beam Scattering

Andy Wolski: *Damping Ring Design & Performance Goals*



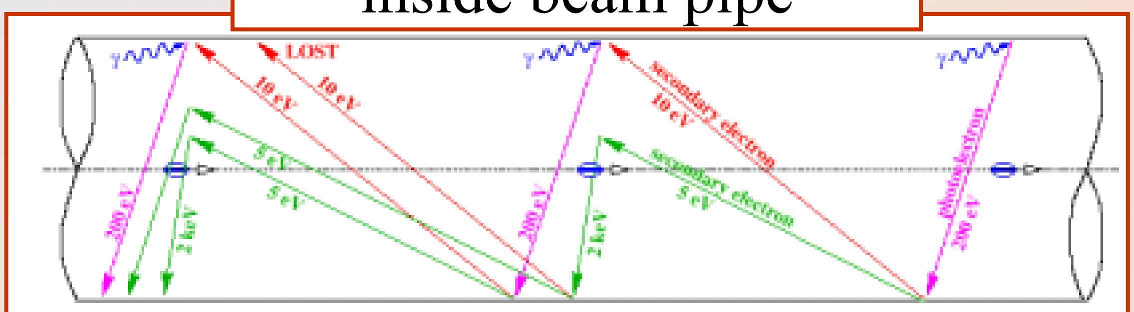
Emittance growth from stray fields

Cavity wake fields



Top: Resistive wall wake fields
Bottom: Trapped modes in a cavity
From A. Chao, "Physics of Collective Beam Instabilities"

creation of electron cloud inside beam pipe



Marc Ross: *Recent Experimental Results from the LC Prototype DR – ATF*

Lots of information about recent progress in improving emittance and also measurement instrumentation…

American Linear Collider Group

Topics:

- Emittance
- Beam Position Monitors
- Optics
- Beam-based Alignment
- Laserwire
- (Optical Diffraction Radiation)
- X-ray synchrotron Radiation
- Plans

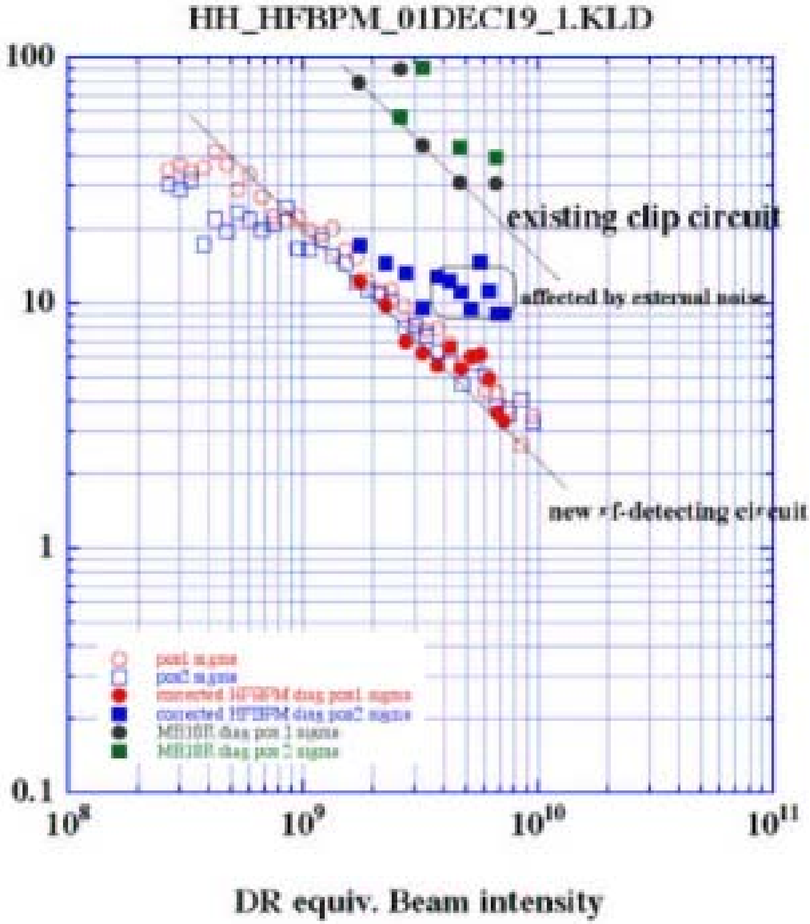
(Beam Position Monitors, Optics, Beam-based Alignment: Emittance tuning)

(Laserwire, (Optical Diffraction Radiation), X-ray synchrotron Radiation: Beam size monitors)

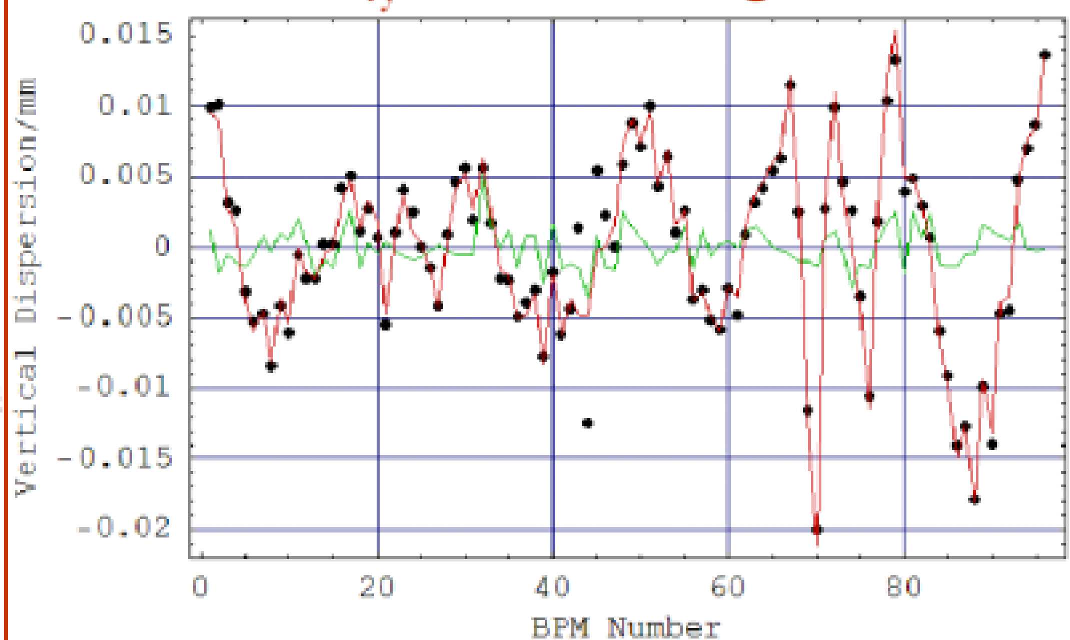
Marc Ross: *Recent Experimental Results from the LC Prototype DR – ATF*

Lots of information about recent progress in instrumentation…

New BPMs



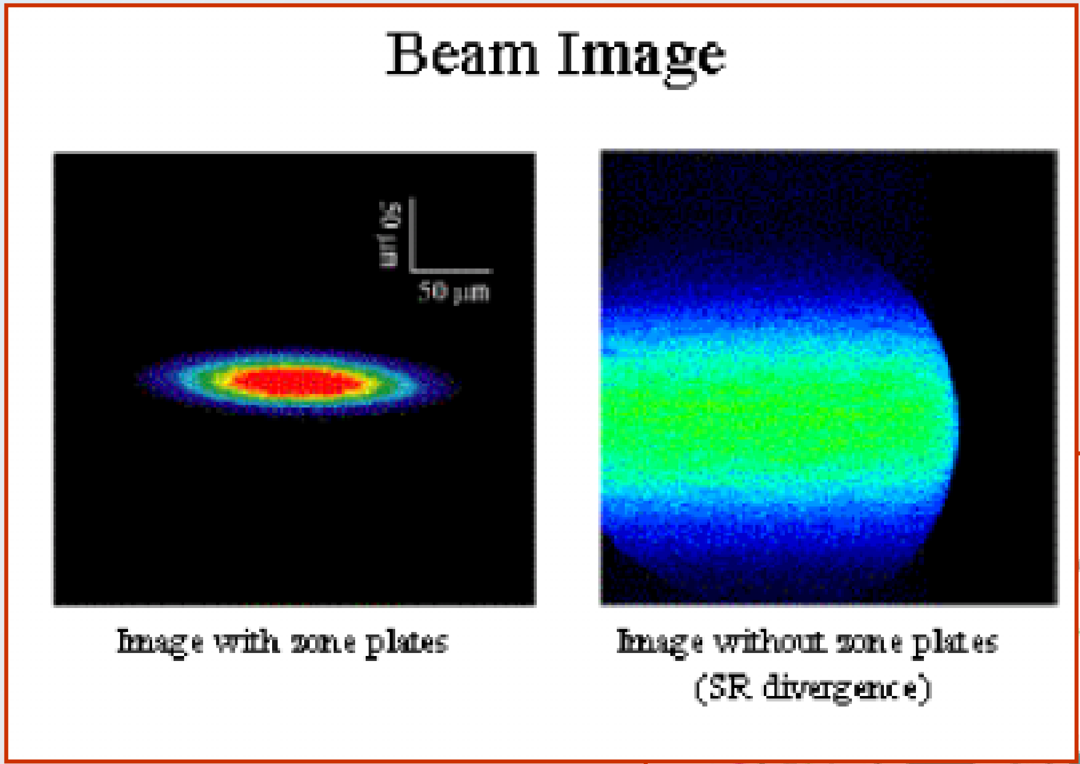
Test of η_y correction using skew trims



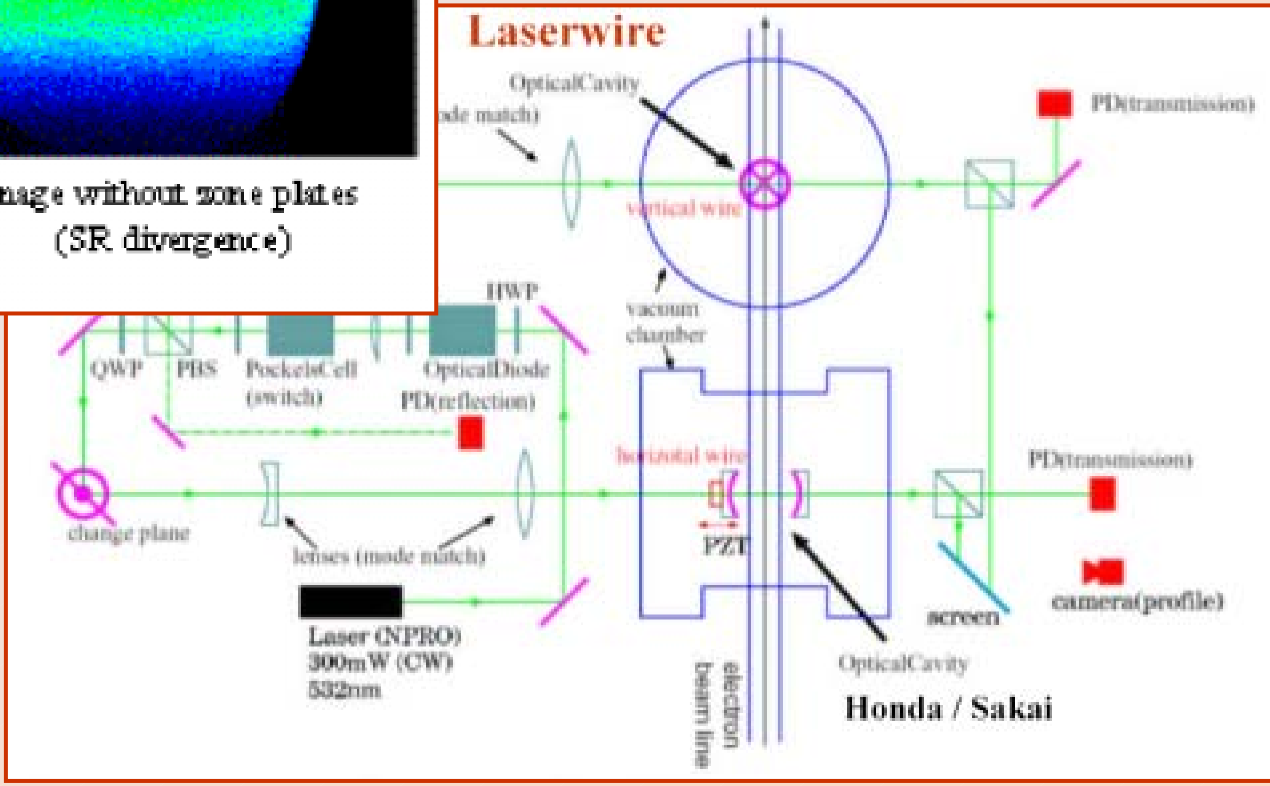
Black points = measured dispersion

Red line = predicted

Marc Ross: *Recent Experimental Results from the LC Prototype DR – ATF*



X-Ray Synchrotron imaging using Fresnel zone plates



Laserwire measurements

Lots more… (see Marc's talk)

Sekazi Mtingwa: *A Complete Integration of Intrabeam Scattering Formulae for Asymptotic Beams*

Mtingwa *et al*. have extended the analytic calculation of emittance growth due to intrabeam scattering.

As I understand it, earlier approaches to using "high energy modified Piwinski IBS theory" have involved a mix of analytic and numerical calculations. The necessary numerical integrations are time consuming to execute.

Results include analytic expressions for the time constants associated with horizontal and vertical emittance growth. The work should speed future calculations, obviating the need for (some) numerical integrations

Future plans include comparison of predictions with strong-focusing theory calculations for a variety of machines.

Alexander Mikhailichenko: *Damping Ring for NLC*

Mikhailichenko discusses NLC damping ring designs with and without wigglers. He comments that:

- intrabeam scattering analysis needs to be done with greater sophistication
- too many (unverified??) assumptions are used in wiggler dynamics calculations
- spin dynamics in damping ring has not been worked out yet.

He investigates a damping ring design without wigglers running at higher energy (~3 GeV), including intrabeam scattering and spin effects.

A.M. comments that it is important to consider simpler damping schemes than in the present NLC damping ring design.

Joe Rogers: *Damping Ring R&D Activities at Cornell and Minnesota*

The goals…

R&D goals over 3 years

- Studies of wiggler-related dynamic aperture limitations*
- Studies of beam-based alignment and emittance correction algorithms
- Studies of intrabeam scattering (IBS)
- Studies of space charge effects
- Investigation of collective effects relevant for damping rings
  (electron cloud and ion instabilities, impedance-driven instabilities)
- Development of simulation and modeling tools*
- Review of TESLA damping ring design and optics*
- Investigation of the superferric option for NLC and TESLA damping ring wigglers

These are a combination of experimental studies in CESR-c and simulation and design studies.

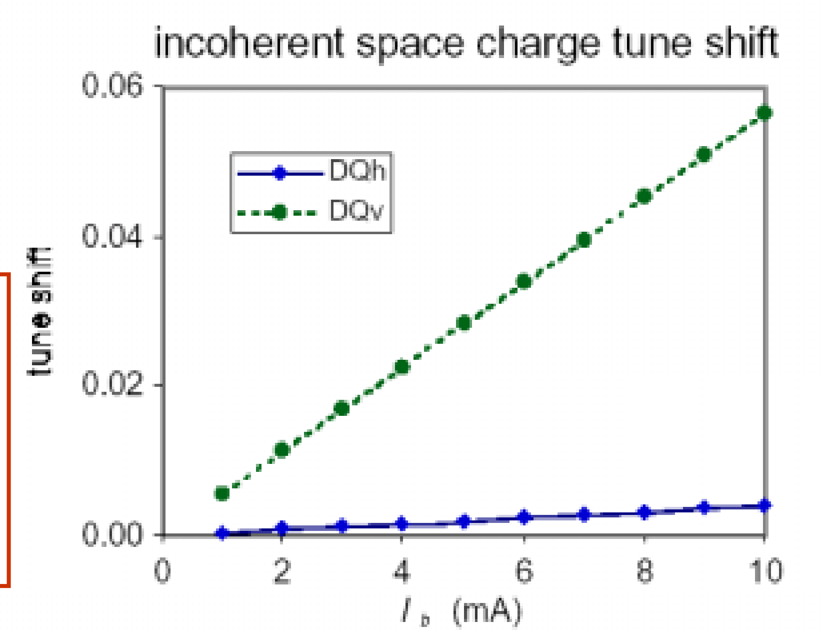
* primary areas of activity in FY03

Joe Rogers: *Damping Ring R&D Activities at Cornell and Minnesota*

The wiggler studies are especially sensible given the groups' CLEO-c (wiggler!!) involvement.

Activities include a large amount of simulation in order to compare actual wiggler results with predictions.

CESR-c
$E = 1.55$ GeV
emittance coupling ratio= 0.0045
$\eta_{y,rms} = 0.045$ m
$\sigma_s = 1.0$ cm
no wigglers



Joe Rogers: *Damping Ring R&D Activities at Cornell and Minnesota*

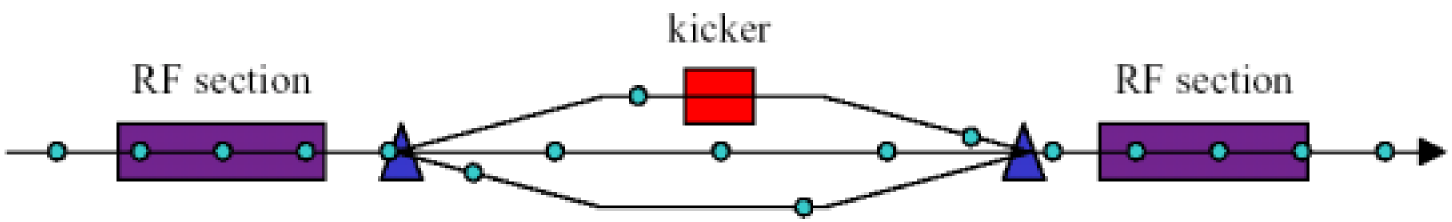
The effort includes exploration of alternative TESLA damping ring designs to the current dogbone layout. They're very interesting to consider…

Joe Rogers: *Damping Ring R&D Activities at Cornell and Minnesota*

Alternatives to the TESLA dogbone damping ring (1)

(R. Helms, D. Rubin)

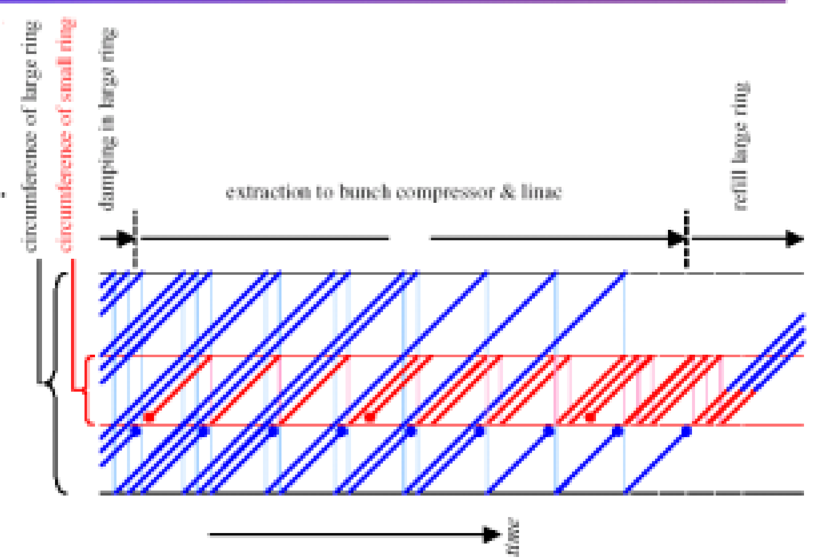
• A secondary RF system with a different frequency is used to separate the beam dispersively, bunch by bunch, into different channels.



Alternatives to the TESLA dogbone damping ring (2)

(J. Rogers)

• Uses two rings (one large, one small) with a common RF section.



Very cool.

Gerry Dugan: *Investigation and Prototyping of Fast Kicker Options for the TESLA Damping Rings*

First year goal: "…we will review fast kicker schemes which have been proposed in the past."

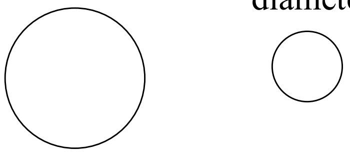
Requirements-

Energy: 5 GeV, kick angle: 600 microradians
=>Field integral 0.01 T-m
Bunch-to-bunch variation +/- 0.07%
Residual deflection 0.3-0.5%
Duration < 20 ns

Injected beam sizes at β=50 m:

Positrons: 17 mm diameter

Electrons: ~4 mm diameter



Extracted beam sizes at β=50 m:

Vertical: 40 μm

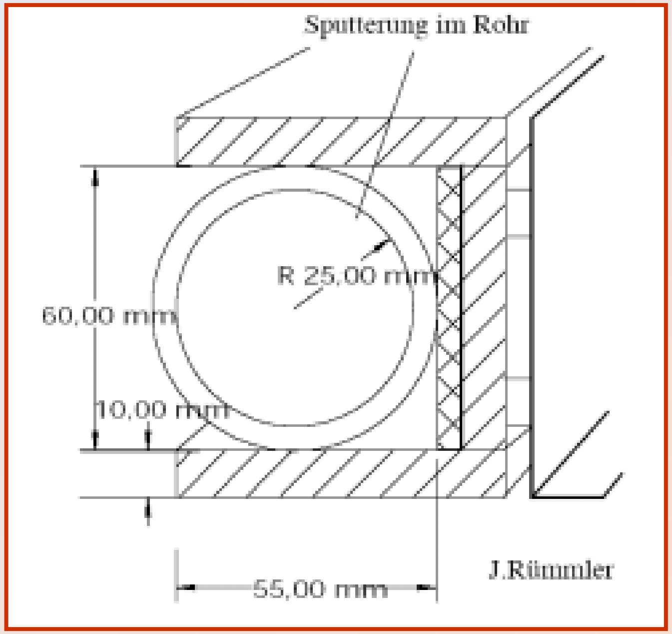
Horizontal: 800 μm

Gerry Dugan: *Investigation and Prototyping of Fast Kicker Options for the TESLA Damping Rings*

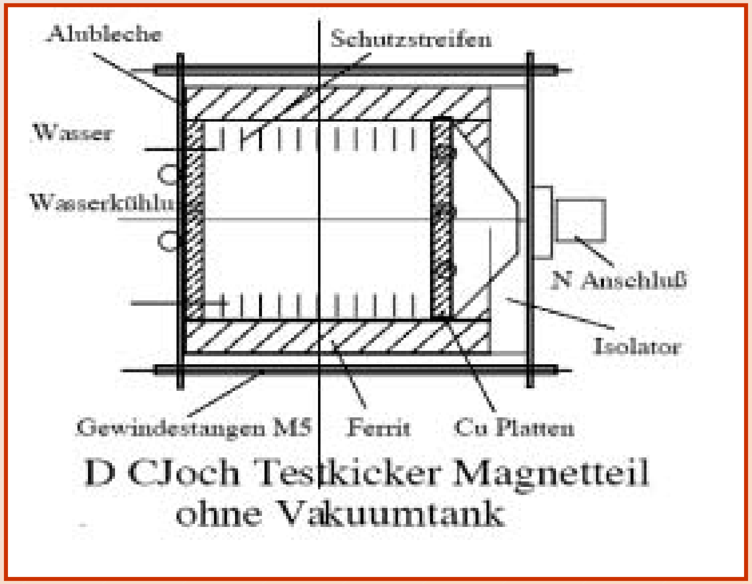
It is reasonable to aim for the same "line density" in TESLA as in NLC/JLC (~ 1.8×10^{10}/m).

This would require 3-4 ns kicker rise/fall time. Some of the designs:

Ferrite kicker with resistive coating on ceramic tube



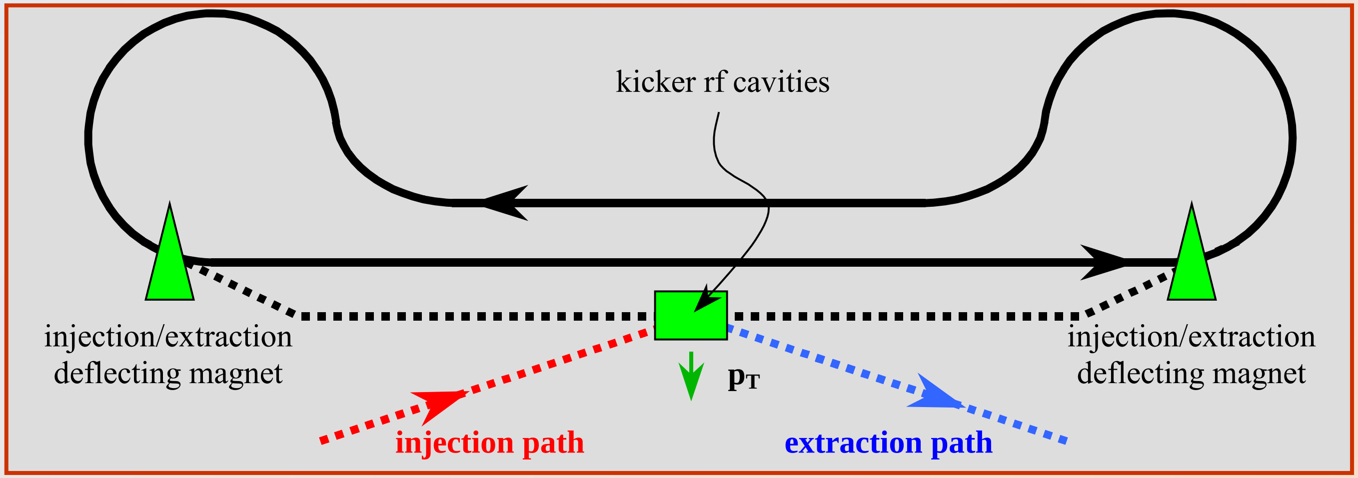
Ferrite kicker with strips

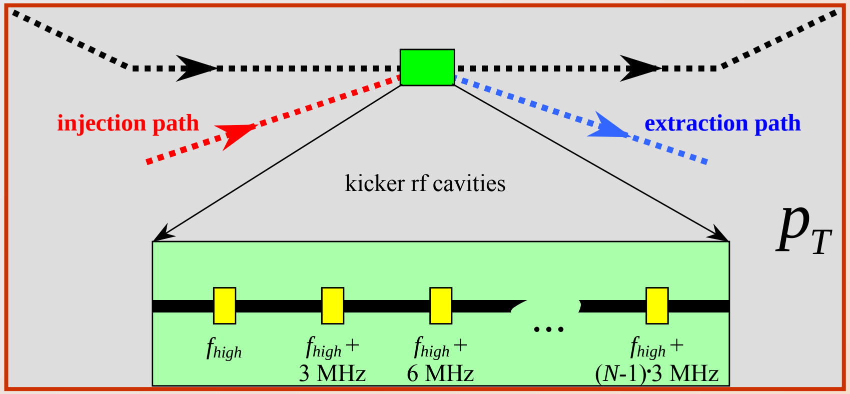


…or maybe a stripline kicker.

George Gollin: *TESLA Fourier Series Kicker Update*

Use a series of rf cavities kicking transversely; frequencies and amplitudes are chosen to kick every *N*th bunch, leaving other bunches undisturbed.

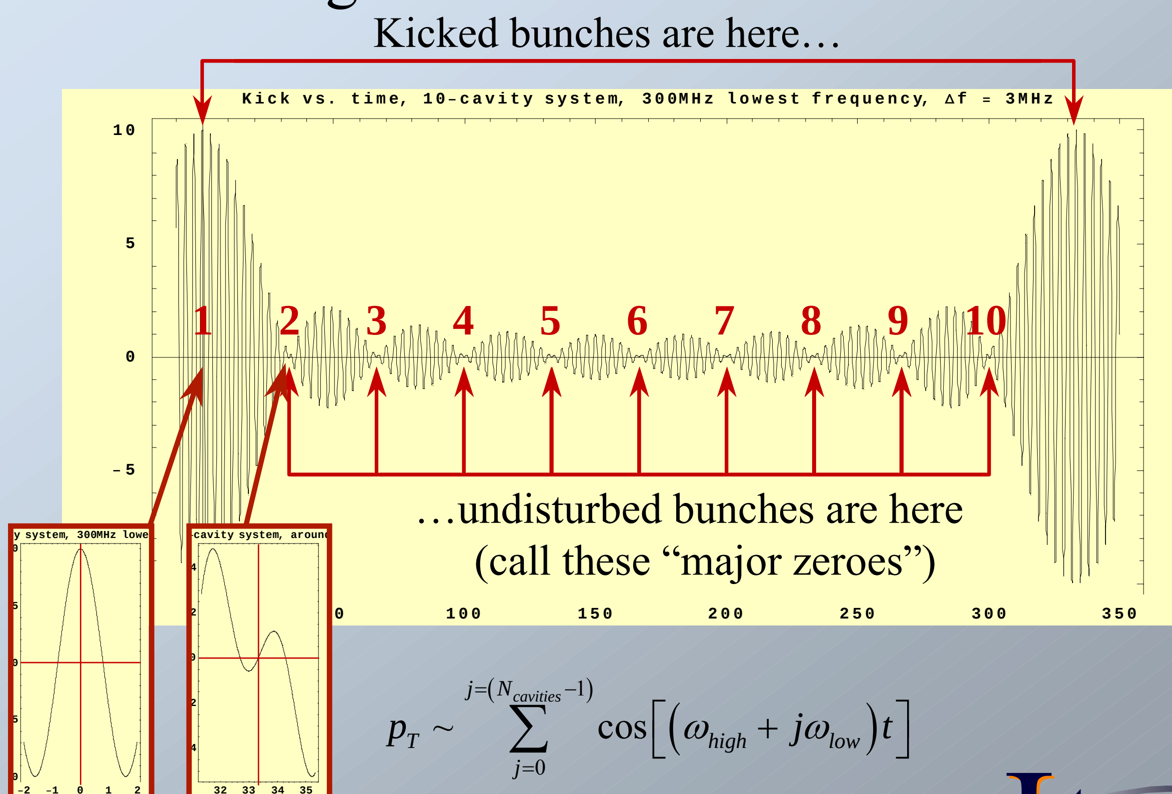




$$p_T = A\left[\sum_{j=0}^{j=N_{cavities}-1} A_j \cos\left[\left(\omega_{high} + j\omega_{low}\right)t\right]\right]$$

Both p_T and dp_T/dt can be made to be zero when not-to-be-kicked bunches pass through the kicker (this figure shows a configuration in which only p_T is zero).

Bunch timing



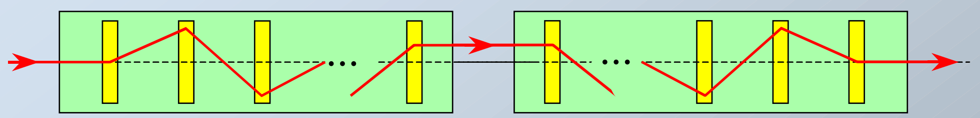
$$p_T \sim \sum_{j=0}^{j=(N_{cavities}-1)} \cos\left[\left(\omega_{high} + j\omega_{low}\right)t\right]$$

Interval between kick and adjacent “major zeroes” is uniform.

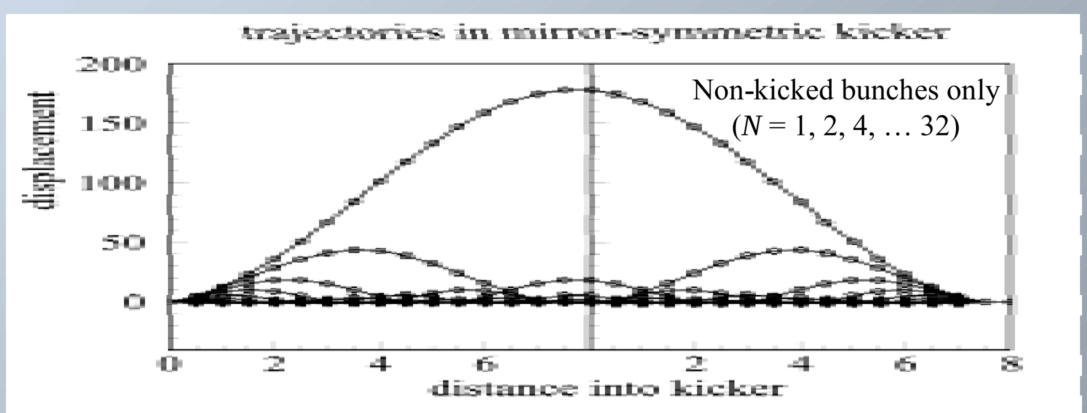
George Gollin: *TESLA Fourier Series Kicker Update*

It looks promising; perhaps it would allow the TESLA damping ring to be made considerably shorter. A variety of effects are being studied.

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.



Sources Reports

Electron and Positron Sources for Linear Colliders: Overview	John Sheppard
Undulator Based Polarized Positron Source	Kirk McDonald
Multivariate PreInjector Simulation with PARMELA/ROOT	Tom Schwarz
Inverse Compton Scattering Polarized Positron Sources	James Rosenzweig
Polarized Photocathode R&D Progress at SLAC: SLC to NLC	Richard Prepost
Polarized RF Gun R&D at Fermilab	Markus Huening

presentations are here: http://home.fnal.gov/~mhuening/alcwsources.html

John Sheppard: *Electron and Positron Sources for Linear Colliders: Overview*

Nice general discussion of what's going on now. As with Wolski's talk, level was well-suited to non-experts (me!).

John's main topics:

NLC - The Next Linear Collider Project

e^-e^+ Sources

- Polarized Electron Sources
- Conventional Positron Sources
- Undulator Based Positron Source

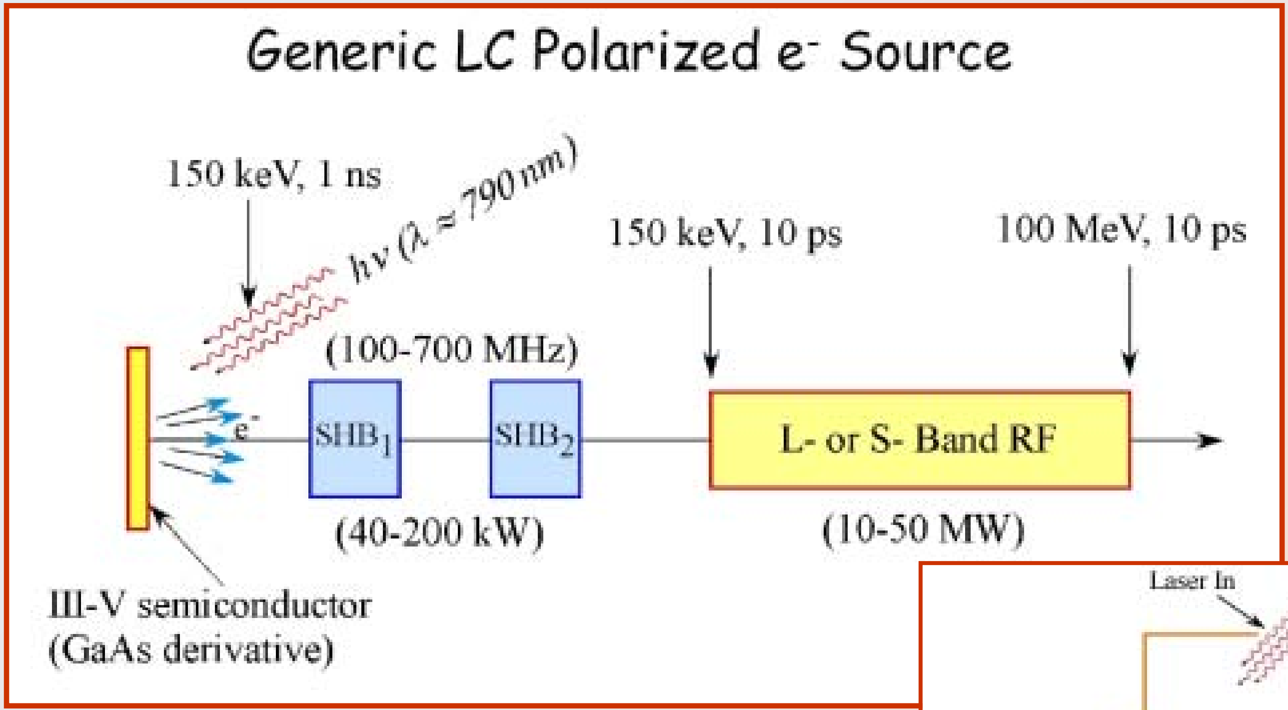
John Sheppard: *Electron and Positron Sources for Linear Colliders: Overview*

Electron sources:

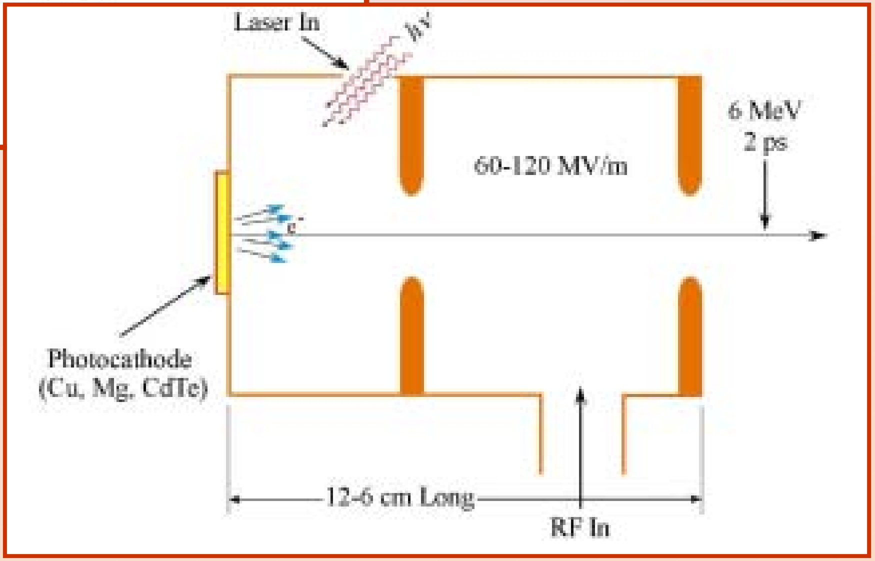
> At present, all linear collider polarized electron source designs (CLIC, GLC, NLC, TESLA) are based on the SLC polarized electron source: DC gun, GaAs derivative photocathode, 800 nm laser, SHB bunching, damping rings required.

Polarization goal ~90%; various approaches to achieving this presently under investigation.

John Sheppard: *Electron and Positron Sources for Linear Colliders: Overview*



Accelerate electrons rapidly to avoid space-charge problems. RF gun:

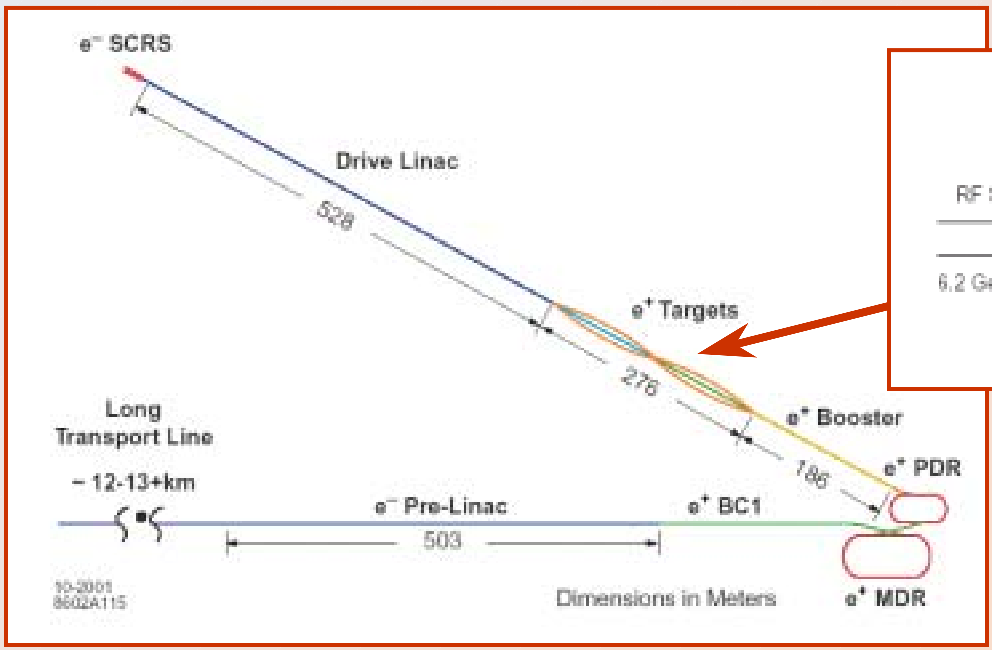


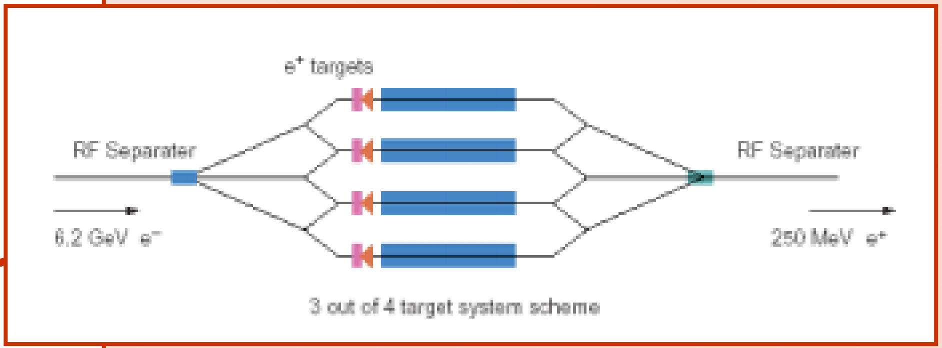
John Sheppard: *Electron and Positron Sources for Linear Colliders: Overview*

Conventional (unpolarized) positron sources:

Conventional Positron System: Multi-GeV electron beam incident to a thick, high Z target. System is followed by an SLC-like adiabatic matching device (flux concentrator of ~ 6-7 T peak field) and a high gradient L-band capture section for acceleration to 250 MeV, solenoidal focusing, followed by a L-band linac with quadrupole focusing

The positron target takes a beating.

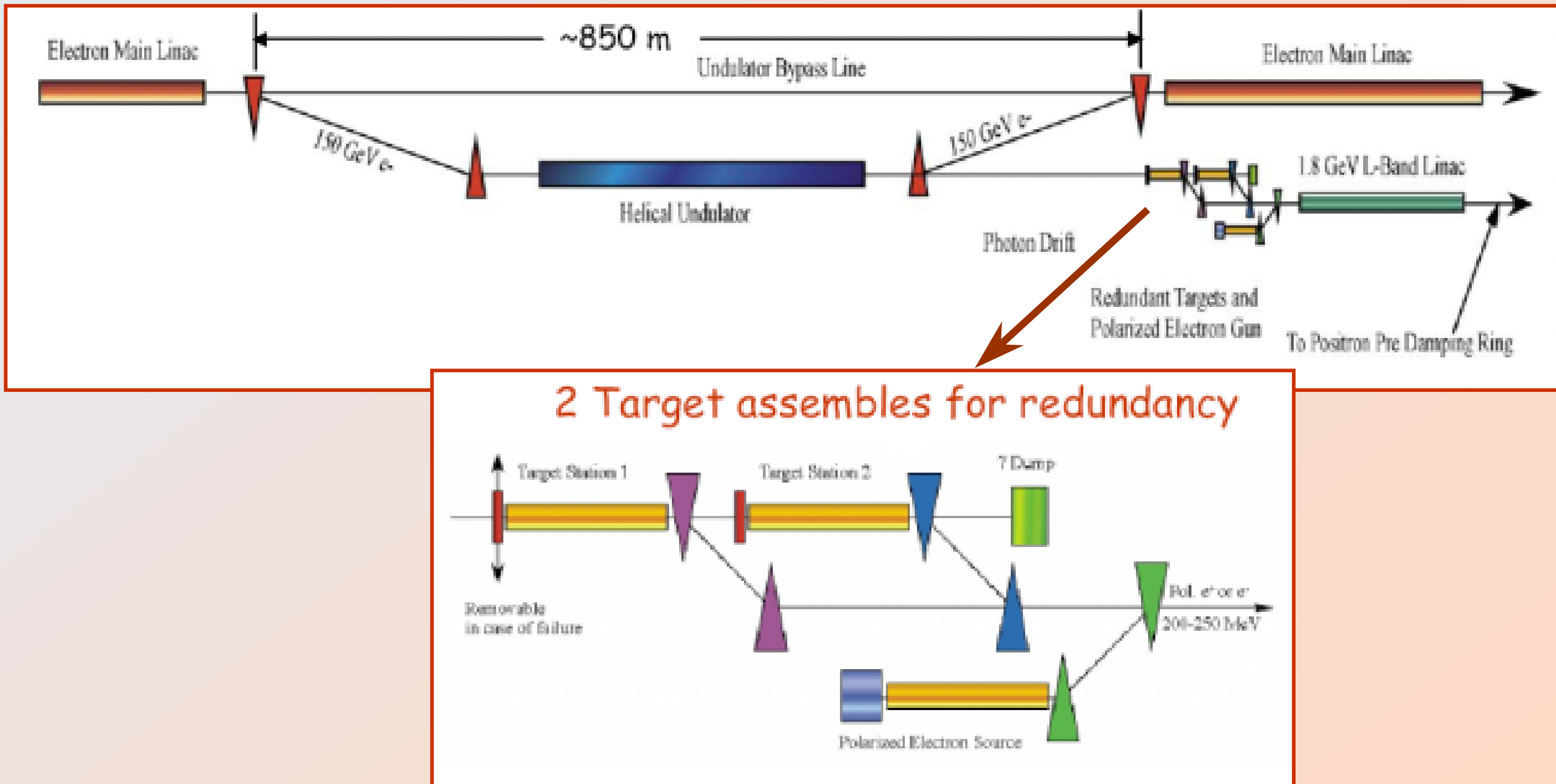




John Sheppard: *Electron and Positron Sources for Linear Colliders: Overview*

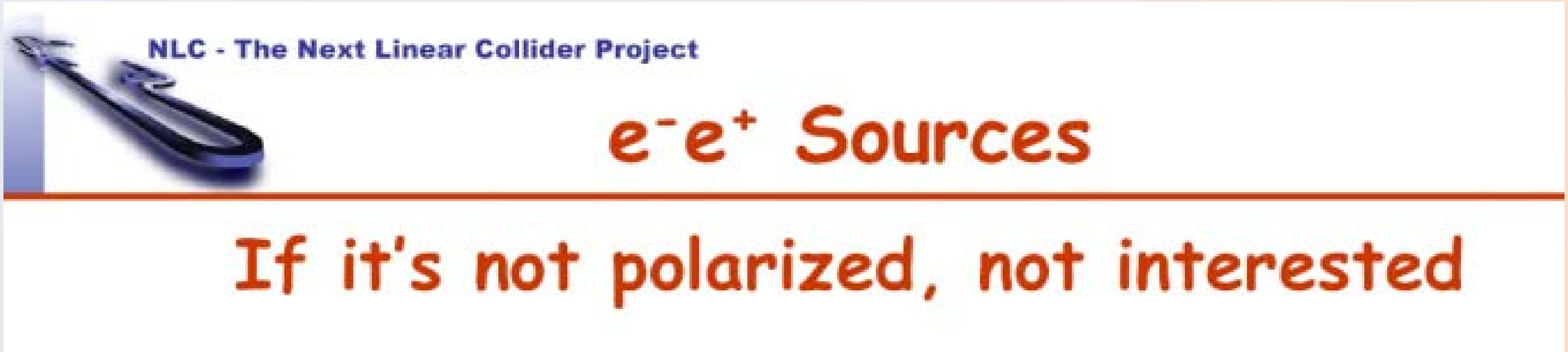
Undulator-based (polarized) positron sources: my understanding is that the undulator produces a beam of circularly-polarized γ which are converted to polarized e^+/e^-.

Idea originally from Balakin and Mikhailichenko (1979).



John Sheppard: *Electron and Positron Sources for Linear Colliders: Overview*

SLAC E166 (see McDonald's talk, immediately after Sheppard's) will study this.



Kirk McDonald: *Undulator Based Polarized Positron Source*

From Kirk's talk:

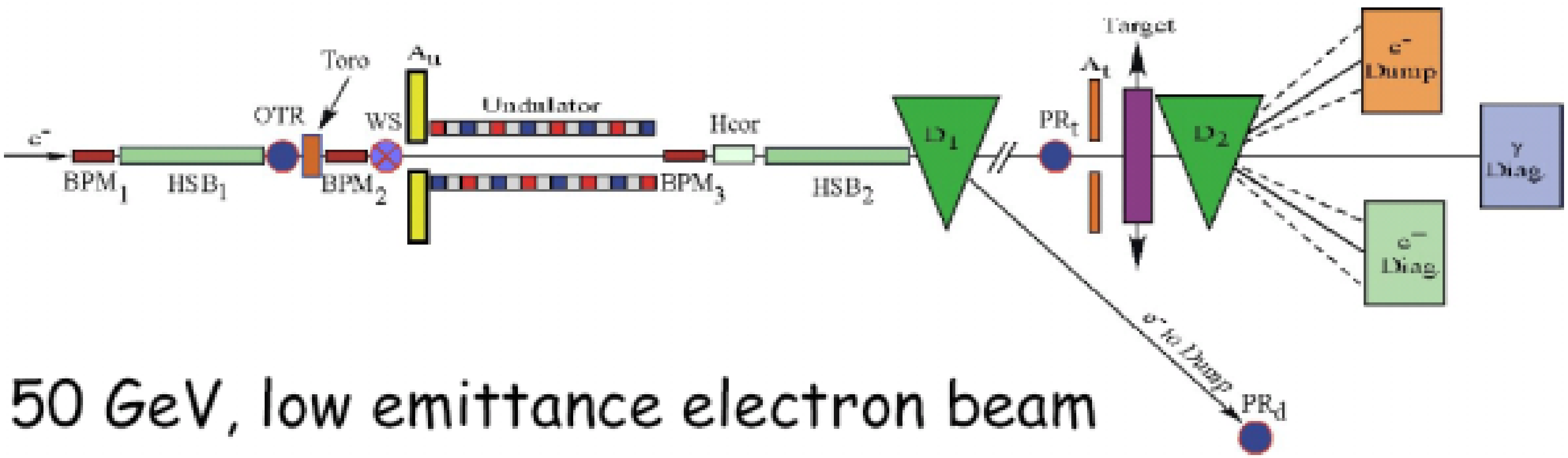
- E-166 uses the 50 GeV SLAC beam in conjunction with 1 m-long, helical undulator to make polarized photons in the FFTB.

- 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.

Kirk McDonald: *Undulator Based Polarized Positron Source*

Also from Kirk's talk:



50 GeV, low emittance electron beam

2.4 mm period, K=0.17 helical undulator

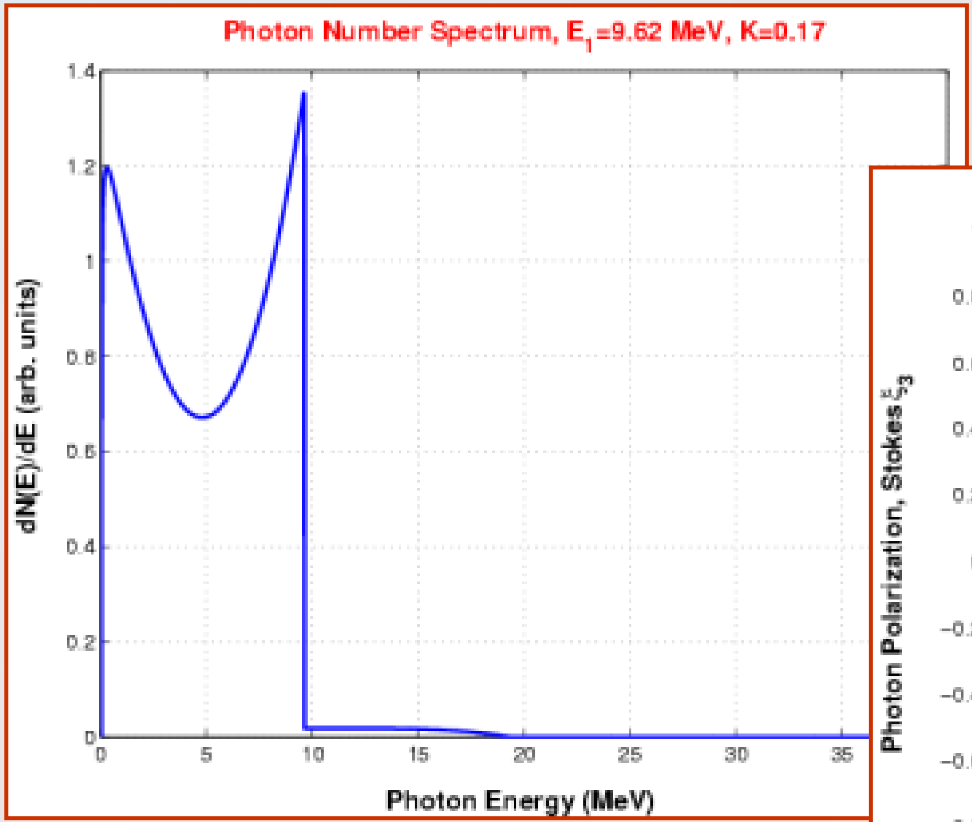
0-10 MeV polarized photons

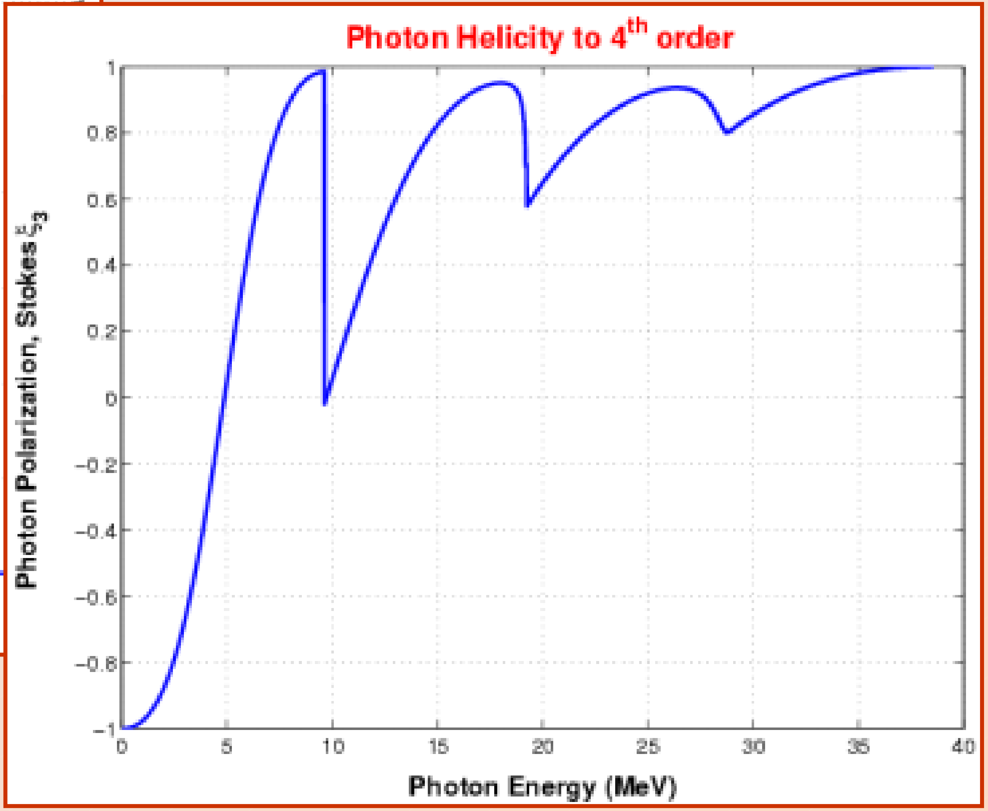
0.5 rad. len. converter target

51%-54% positron polarization

Kirk McDonald: *Undulator Based Polarized Positron Source*

Photon energy spectrum and polarization

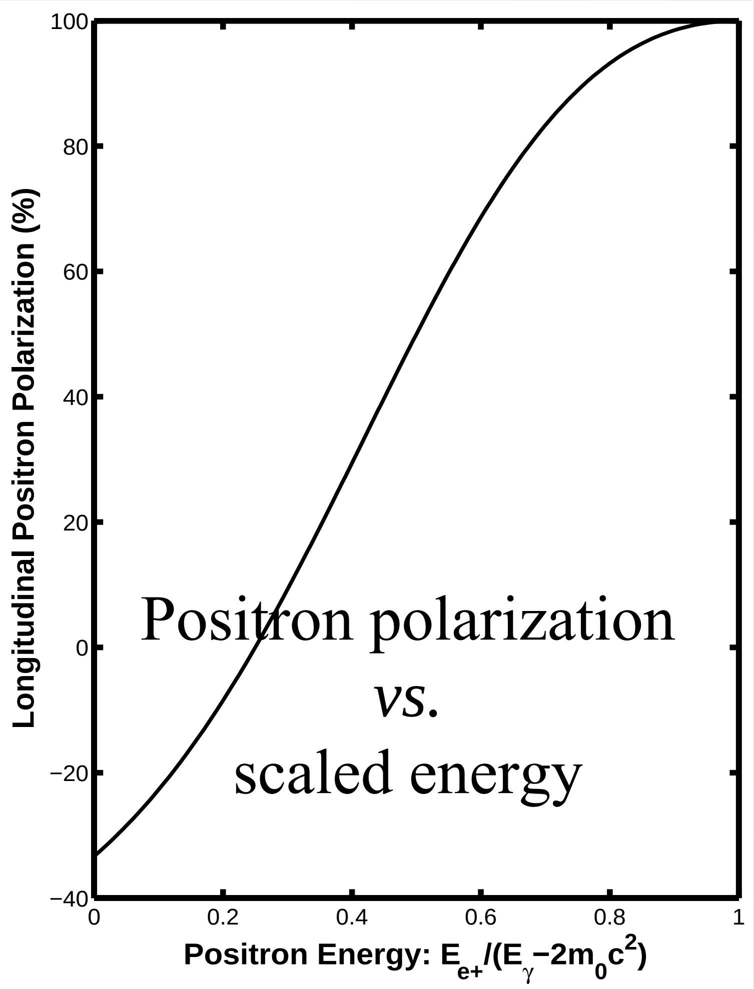




Kirk McDonald: *Undulator Based Polarized Positron Source*

Expectations from E166: measure polarization to about 3%

Positron Energy (MeV)	Positron Pol. P_{e^+} (%)	Positron Transport Eff. ϵ_{e^+} (%)	Photon Transport Eff. ϵ_γ (%)	Photon Asym. δ (%)	Analyz Powe A_{e^+} (		
3	42	1.5	0.045	0.55	18.6		
4	61	1.9	0.078	0.84	19.7		
5	69	2.1	0.12	0.82	17.0		
6	78	2.3	0.20	0.87	15.9		
7	84	1.7	0.28	0.93	15.8		
8	77	0.9	0.38	0.82	15.0	1.86×10^7	2.2
9	64	0.4	0.50	0.63	14.0	1.09×10^7	3.1
10	68	0.3	0.64	0.66	13.9	1.04×10^7	3.2



Tom Schwarz: *Multivariate PreInjector Simulation with PARMELA/ROOT*

There is a very large parameter space to explore when optimizing the design of a complex (accelerator) system.

This effort uses tools employed by HEP detector physicists to explore the behavior (as a function of the choice of parameters) of accelerator systems. It's a nice example of the benefits of cross-discipline collaboration.

The work uses a TESLA pre-buncher study as a benchmark (TESLA note 2001-22-2).

Tom Schwarz: *Multivariate PreInjector Simulation with PARMELA/ROOT*

From Tom's talk:

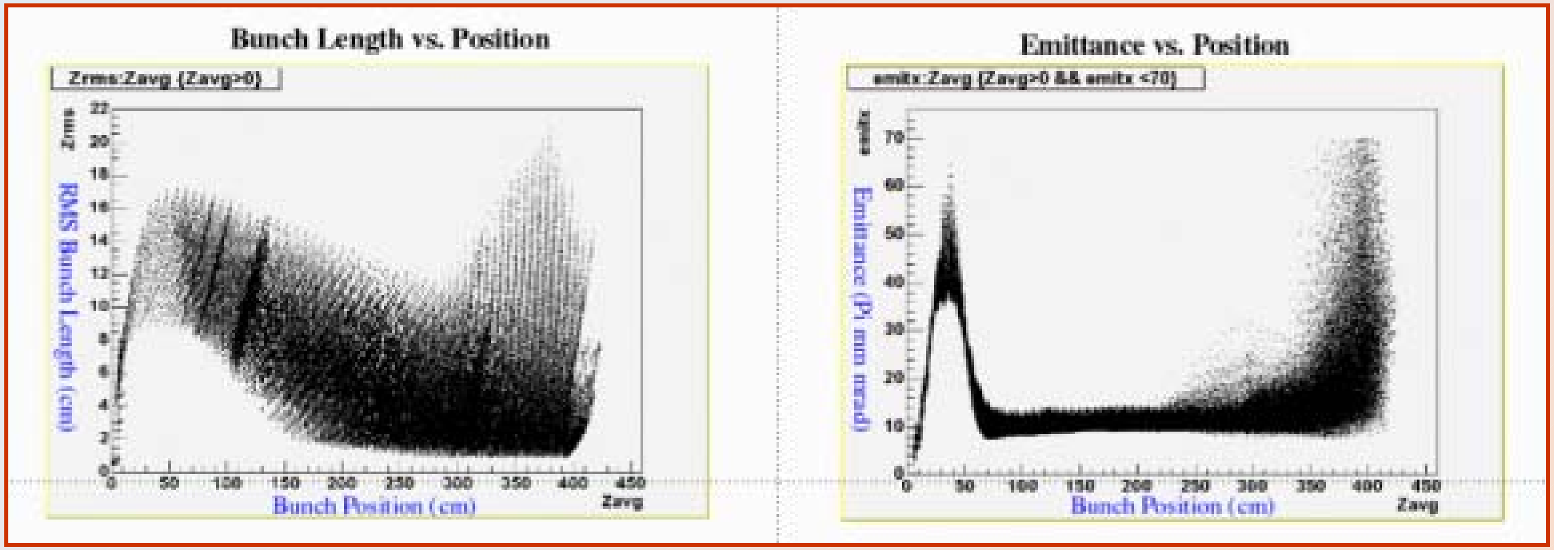
Example: What Range Of Input Parameters Is Compatible With Performance Tolerances

- Accelerator Needs To Perform Within Certain Tolerances
  PARMELA/ROOT Used To Find Range Of Input Parameters For Operation
- DC Gun, prebunching cavity, and two solenoids
- ~ 8000 PARMELA Simulations Run

PARAMETER	Min	Max	UNITS
Gun Voltage	120	200	KV
Bunch Length	0.5	2	ns RMS
Beam Radius	5	5	mm RMS
Pre-Buncher Freq.	108	432	Mhz
Charge	1.0E+10	2.50E+10	Electrons
Buncher Efield	40	60	KV

Tom Schwarz: *Multivariate PreInjector Simulation with PARMELA/ROOT*

From Tom's talk:



Performance and Input Constraints:

Position ~ 250 to 260 cm

Emittance < 12 Pi mm-mrad

Bunch Length < 200 ps

Charge < 1.6e10 e-'s

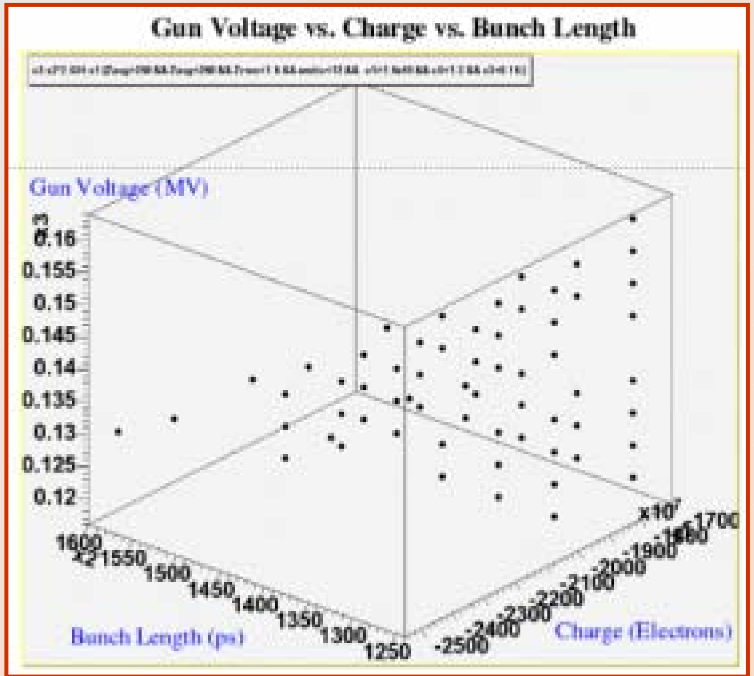
Buncher Voltage < 44 kV

Gun Voltage < 150 kV

Tom Schwarz: *Multivariate PreInjector Simulation with PARMELA/ROOT*

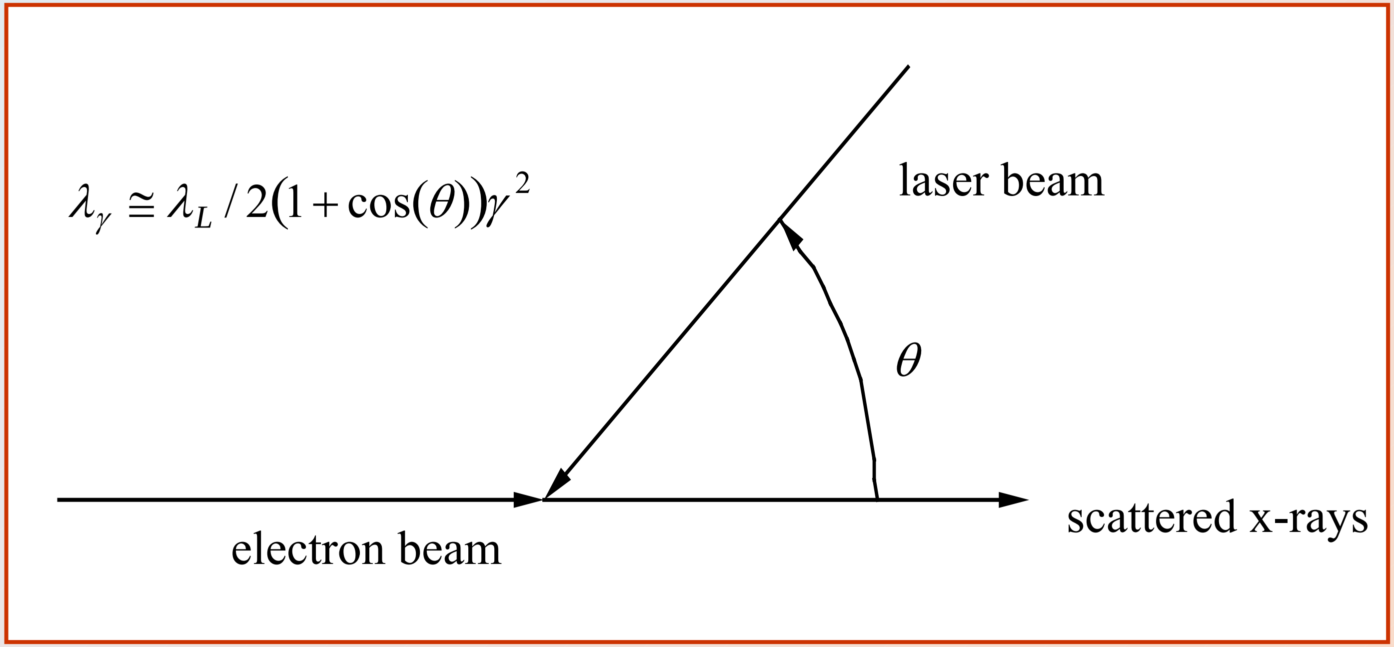
It looks like a nice approach.

- We've Developed Code To Perform Multiple Variable Input Scans In UCLA PARMELA And Use The Data Handling Capabilities Of ROOT For Analysis
- PARMELA/ROOT Allows You To Perform Large Simulations That Scan Over Several Variables Once, Then Analyze The Data However You Wish



James Rosenzweig: *Inverse Compton Scattering Polarized Positron Sources*

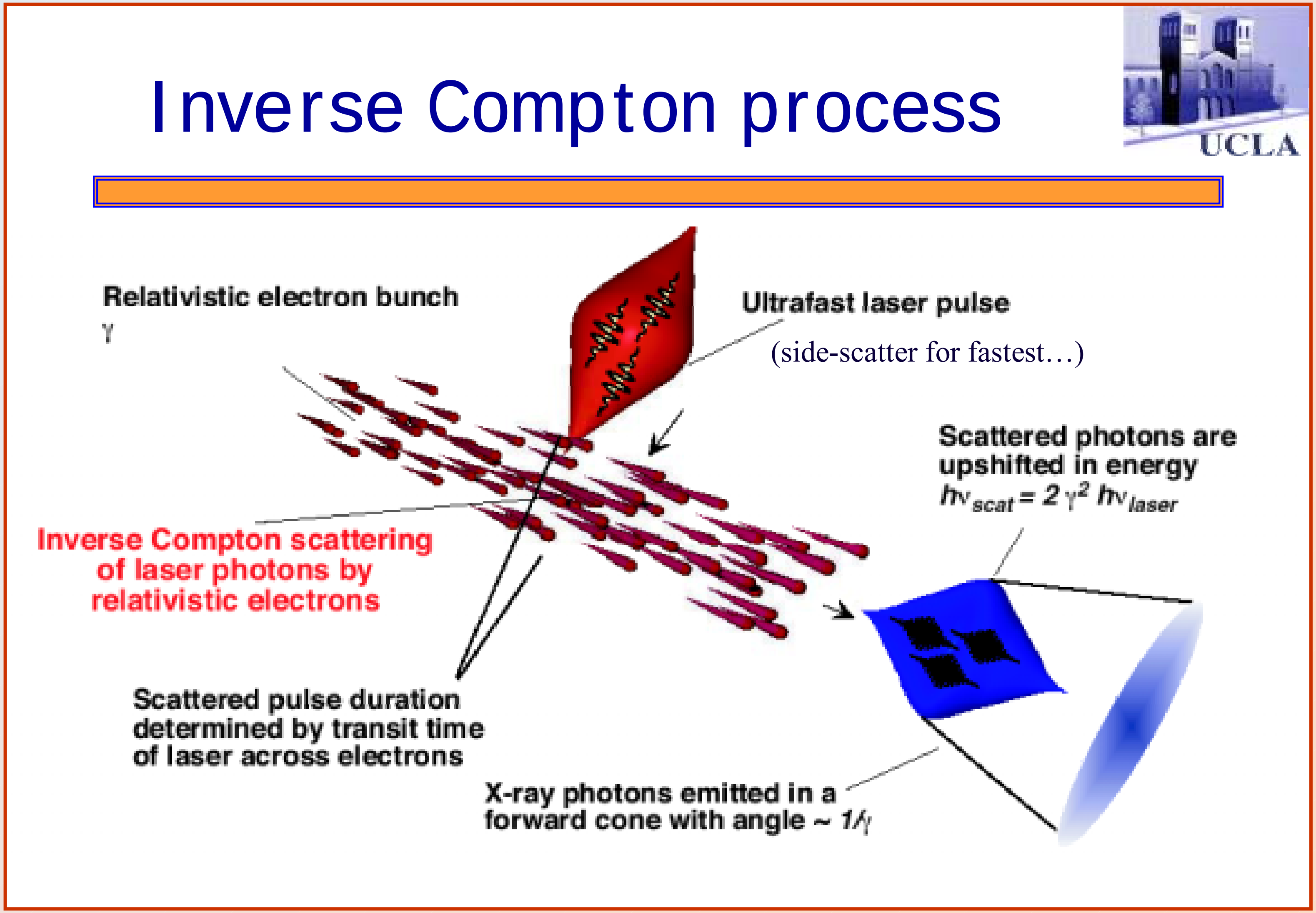
The process…



- Doppler upshifting of intense laser sources; “monochromatic” source
- Very intense electron and laser beams needed

James Rosenzweig: *Inverse Compton Scattering Polarized Positron Sources*

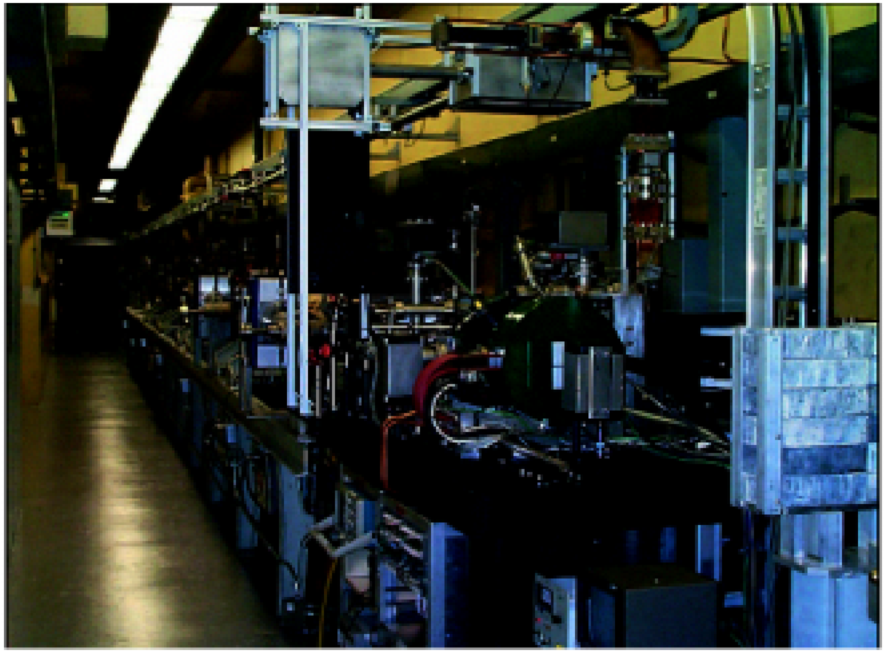
Circularly polarized photons will stay polarized



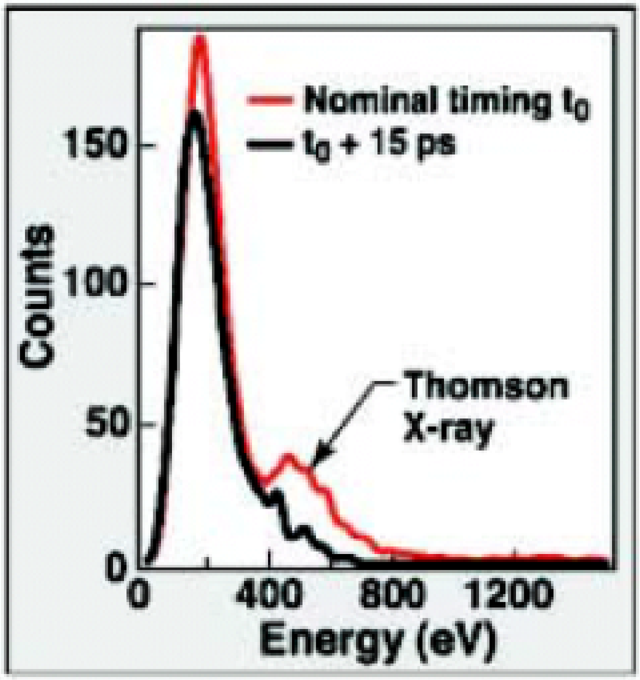
James Rosenzweig: *Inverse Compton Scattering Polarized Positron Sources*

Electrons made here… …produce X-ray photons.

35 year old 120 MeV travelling wave linac



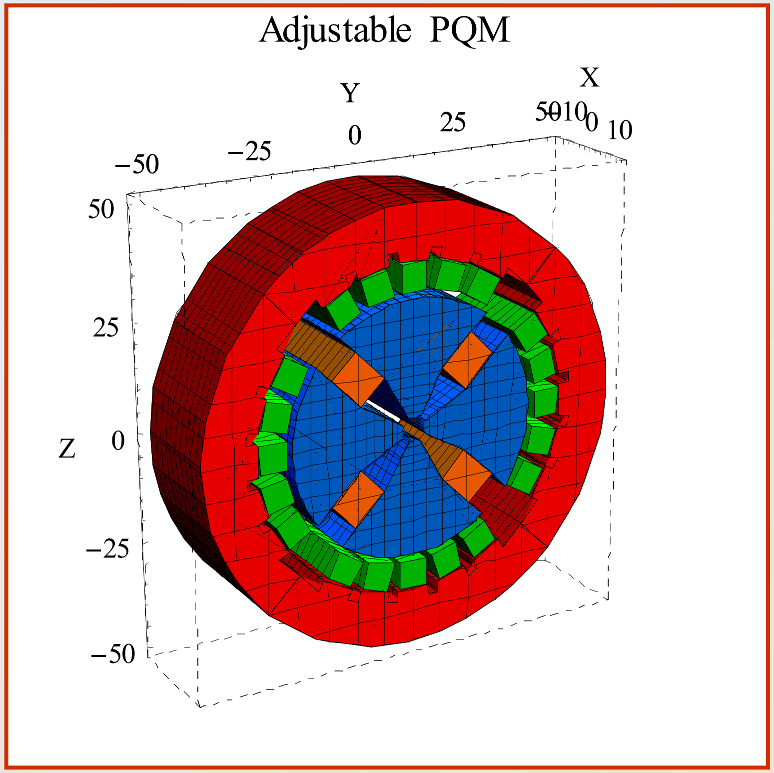
First light results

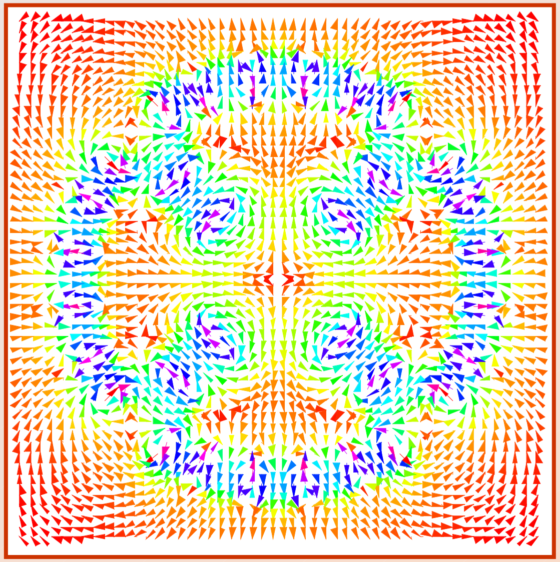


Timing worked out with gun only…

James Rosenzweig: *Inverse Compton Scattering Polarized Positron Sources*

Final focus improvements to get smaller beams, higher luminosity…





Halbach ring-tuned quad for NLC
(UCLA/FNAL/SLAC project), with field map

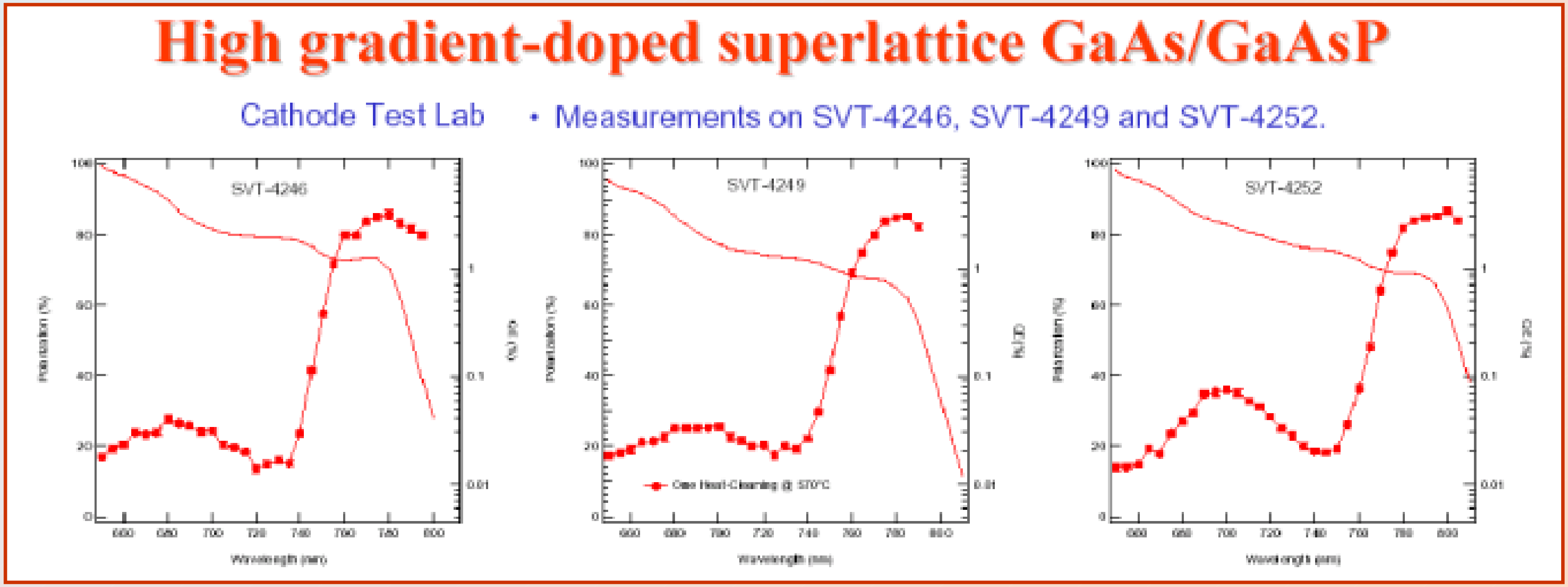
Richard Prepost: *Polarized Photocathode R&D Progress at SLAC: SLC to NLC*

- Technique is Bandgap Engineering of Strained GaAs.
- Polarization will be < 100% - But 90% possible.

Circularly polarized light leads to polarized photoemission.

Improving yield involves tradeoffs among various parameters: doping, photocathode thickness, Richard Prepost: *Polarized Photocathode R&D Progress at SLAC: SLC to NLC*

SBIR grant supports some of the work; results look promising.



Markus Huening: *Polarized RF Gun R&D at Fermilab*

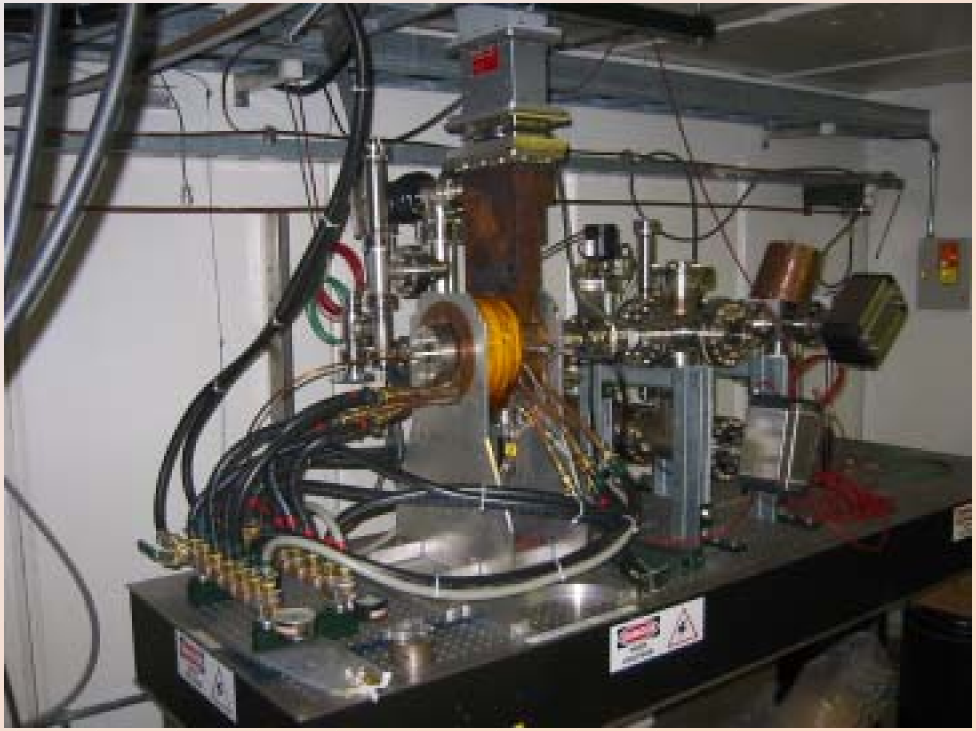
Investigate RF gun, flat beam, spin polarization…

Need GaAs cathode; very good vacuum (~10^{-12} Torr) is required.

Run a copper gun at liquid nitrogen temperature.

Prototype gun:

1.6 cell L-band
(1.3 GHz)



Markus Huening: *Polarized RF Gun R&D at Fermilab*

Vacuum test underway now. Future work to follow!

Summary of summary

Lots going on, lots to do.

Stay tuned!