SLD 2001

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Improved Direct Measurement of Leptonic Coupling Asymmetries with Polarized Z Bosons

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(The SLD Collaboration)

$$\sin^2\Theta_W = 0.23098 \pm 0.00026$$

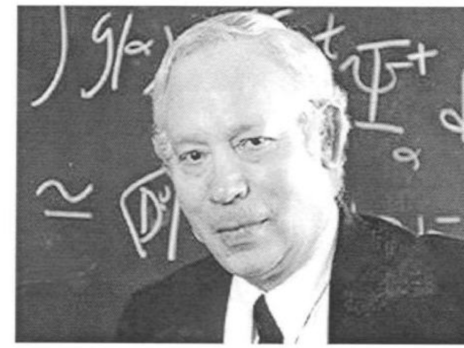
POLARIZATION
Highlights

- The PRE-SLD Era
- The SLC
- Looking Ahead – The Future Linear Collider

A Model of Leptons

Steven Weinberg - 1967

The first to unify the weak and electromagnetic forces, in 1967 Weinberg wrote down the most general form for an interaction for leptons, which included the concept of mixing, mass generation, and couplings to a heavy neutral gauge boson, the Z.



Steven Weinberg

The model assigned the electron and its neutrino to a left-handed doublet, while the right-handed electron was alone as a singlet. The neutral coupling that resulted was

$g_l = T_{3l} - q\ sin^2\ {}_w$ *and* $g_r = T_{3r} - q\ sin^2\ {}_w$

Thus the left-handed and right-handed couplings were different.

This choice preserved the purely left-handed charged currents.

While in the neutral currents parity violation was predicted, but was not maximal.

Polarized Electrons come to SLAC

Fixed Target Experiment E80 proposed

1970

Vernon Hughes and collaborators propose a polarized beam/polarized target experiment to validate the quark model of the proton

"the SLAC – Yale experiment E80"

The polarized electrons were from a ^{6}Li atomic beam ionized by a UV flash lamp

E80 was the first of a highly successful Spin Structure program at SLAC, CERN, DESY and elsewhere

Bill Ash, Dave Sherden and Jym Clendenin were collaborators who later worked on SLD/SLC

Vernon W. Hughes

End Station A Experiments

In 1972 **E95** was proposed to look for parity violation in inelastic scattering – using the SLAC-YALE "PEGGY"source

The source was too low in intensity, and the proposal stated E95 was "insensitive to the weak interactions".

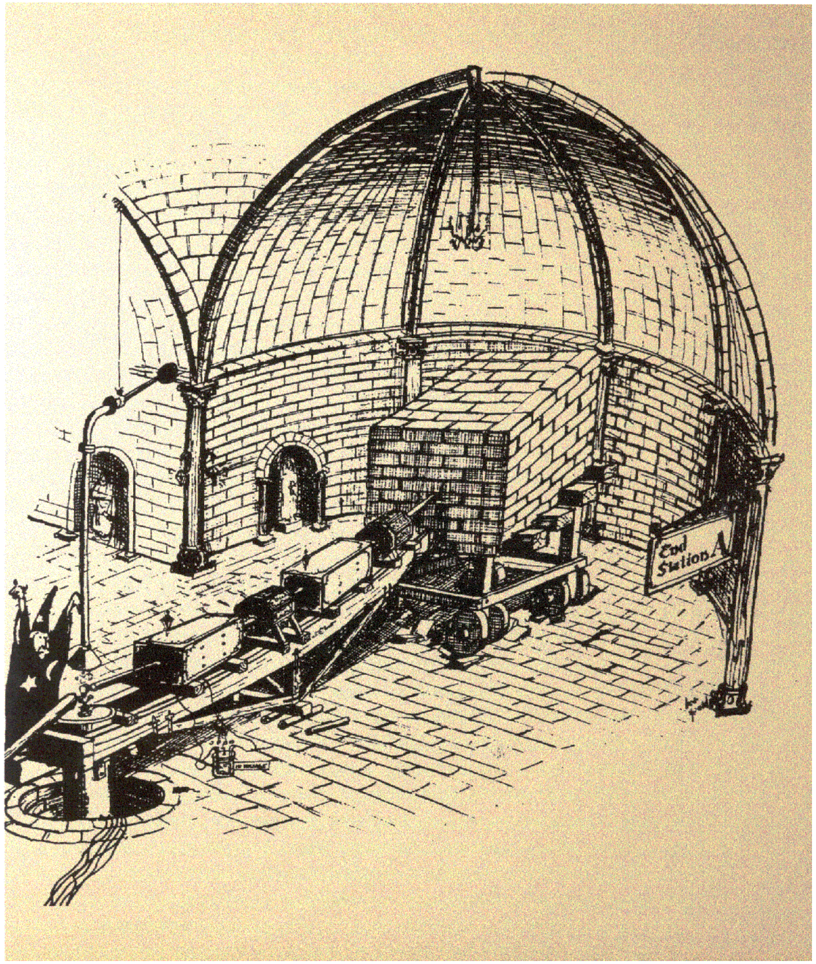
E95 published a limit in 1978

$A_{LR} < 2 \times 10^{-3}$ at $Q^2 = 1.2$ GeV/c^2

While E95 was underway, Charlie Sinclair and I were discussing ways to reach the weak level, as defined in the Weinberg-Salam model.

We needed an intense polarized electron source, and considered developing a laser-driven Fano source using a cesium vapor.

We proposed a new experiment, E122, which was approved, but we never built the Fano source.



Bob Gould's End Station A

Neutral Currents Discovered!

Gargamelle

CERN - 1973

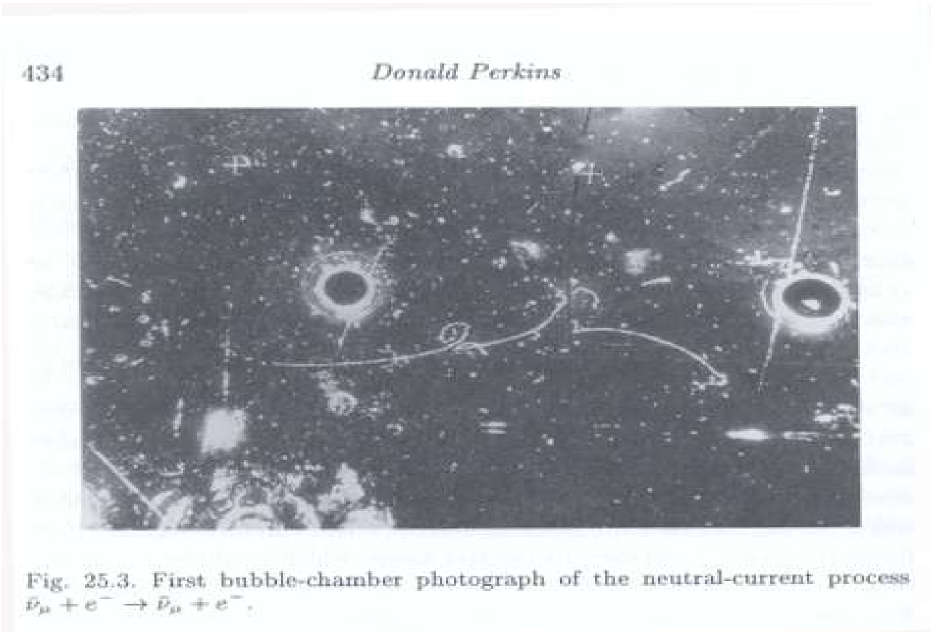

434 Donald Perkins

Fig. 25.3. First bubble-chamber photograph of the neutral-current process $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$.


Charlie Baltay

Gargamelle finds one ν_μ e^- event!

(two more by 1976)

First Z^0 seen in UA1 in 1983

The Promise of Gallium Arsenide

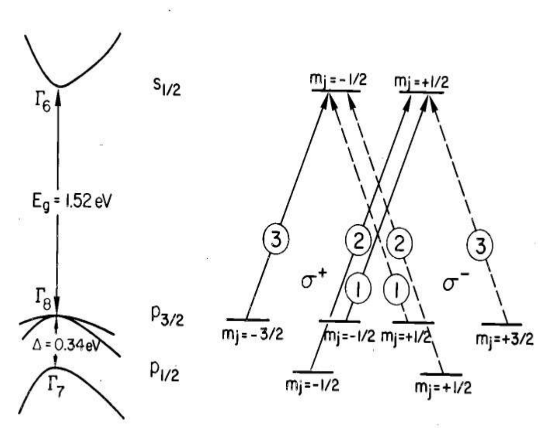
1974

Gallium Arsenide was well known to have polarized internal electrons when optically pumped by circularly polarized light

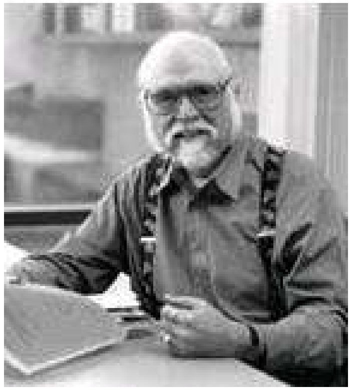
(Ekimov and Sakarov, JETP Letters 13, 495 (1971))

Bell and Spicer had shown that the conduction band electrons could be photoemitted by adding Cs-O monolayers to the surface.

Ed Garwin knew of these works and the need for a source at SLAC.



Ed Garwin



Bill Spicer

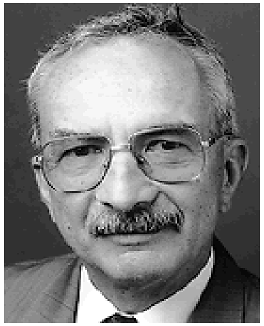
Gallium Arsenide proposed

Garwin, Pierce, and Siegmann

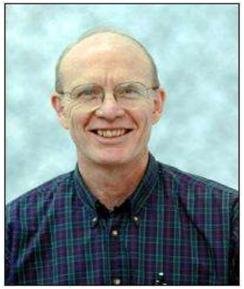
1974

Ed Garwin visited ETH Zurich in 1974, and while there proposed to develop a polarized electron source using gallium arsenide. The first source was built and demonstrated by Dan Pierce at ETH Zurich (now at NIST).

The density of electrons in GaAs is high, promising large available currents. GaAs as a source of polarized electrons appeared ideal for SLAC, but first, the principles had to be demonstrated.



H. C. Siegmann



Dan Pierce

E. L. Garwin

SLD

Parity Violation

1974-1978

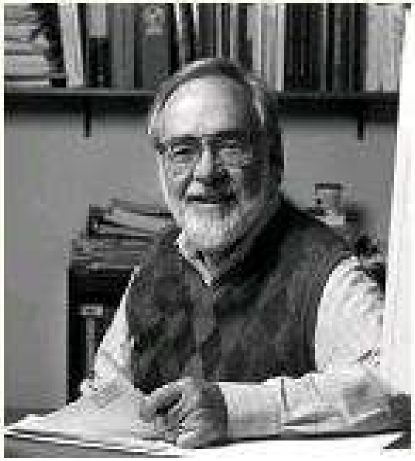
The prospect of a GaAs photoemission source for high beam currents triggered a new proposal….which could test the Weinberg-Salam model in the End Station. Charlie Sinclair and I proposed such a test to the SLAC EPAC in 1974.

This experiment was E122.

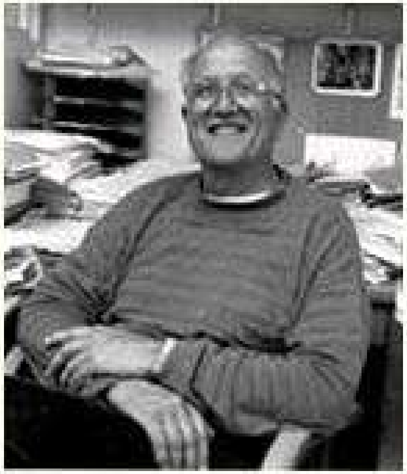
The proposal received conditional approval and we went to work on the source, with Ed Garwin and Roger Miller. That occupied us for 4 years.

Charlie Sinclair

Ed Garwin



Charlie Prescott



Roger *Miller*

1977 – The Drama Intensifies
Atomic Parity Violation lays an EGG

Two competing atomic physics groups eagerly pursue parity violation in bismuth vapor – Washington and Oxford

They hold noisy debates in conferences and reports – among themselves on the one hand, and with Weinberg and Salam on the other. They argued for the "hybrid" model which predicted no parity violation. They published back-to-back null results in PRL.

Zh. Eksp. Teor. Fiz. 71, 1665 (1976) [Sov. Phys. JETP (to be published)].

[6]I. P. Grant, N. C. Pyper, and P. G. H. Sandars, to be published.

[7]S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967).

[8]A. Salam, in *Proceedings of the Eighth Nobel Symposium*, edited by Svartholm (Almkvist and Wiksell, Stockholm, 1968).

[9]We use the optical convention that a positive rotation appears clockwise when looking toward the source.

[10]M. A. Bouchiat and C. C. Bouchiat, Phys. Lett. 48B, 111 (1974).

[11]Collisional broadening becomes noticeable for He buffer gas pressures above 100 Torr, but no observable collisional enhancement of the integrated absorption of this M_1 line occurs.

[12]A convenient parameter is the mean number of absorption lengths of the hfs components at their peaks.

[13]The central dip associated with the Faraday effect disappears in the average over the transmitted laser light for conditions of strong absorption as in Fig. 2(b).

[14]The average over the laser profile of any λ-dependent background rotation will change when the absorption line alters the transmitted laser profile.

[15]P. E. G. Baird *et al.*, follwing Letter [Phys. Rev. Lett. 39, 798 (1977)].

Search for Parity-Nonconserving Optical Rotation in Atomic Bismuth

P. E. G. Baird, M. W. S. M. Brimicombe, R. G. Hunt, G. J. Roberts, P. G. H. Sandars, and D. N. Stacey
Clarendon Laboratory, University of Oxford, Oxford, England
(Received 7 July 1977)

We report the results of a laser experiment to search for the parity-nonconserving optical rotation in atomic bismuth. We work at wavelengths close to the 648-nm $J=3/2 \to J=5/2$ M_1 transition from the ground state. We find $R = \mathrm{Im}(E_1/M_1) = (+2.7 \pm 4.7) \times 10^{-8}$, in disagreement with the theoretical value $R = -30 \times 10^{-8}$ predicted for this transition on the basis of the Weinberg-Salam model of the weak interactions combined with relativistic central-field atomic theory.

We report the results of an experiment to search for the parity-nonconserving (PNC) optical rotation[1-4] in atomic bismuth which has been predicted[5-7] on the basis of the Weinberg-Salam[8] ... ing the different approaches employed.

Our apparatus is illustrated schematically in Fig. 1. The Spectra-Physics 580A jet-stream dye laser produces approximately 2 mW of light in a

[5]R. E. Tribble, J. D. Cossairt, and R. A. Kenefick, Phys. Rev. C 15, 2028 (1977).

[6]J. C. Hardy, J. E. Esterl, R. G. Sextro, and J. Cerny, Phys. Rev. C 3, 700 (1971).

[7]P. M. Endt and C. van der Leun, Nucl. Phys. A214, 1 (1973).

[8]R. L. McGrath, J. Cerny, J. C. Hardy, G. Goth, and A. Arima, Phys. Rev. C 1, 184 (1970).

[9]J. C. Hardy and I. S. Towner, Nucl. Phys. A254, 221 (1975).

[10]A. H. Wapstra and K. Bos, At. Data Nucl. Data Tables 19, 175 (1977).

[11]E. G. Adelberger and D. P. Balamuth, Phys. Rev. Lett. 27, 1597 (1971).

[12]S. Fortier, H. Laurent, J. M. Maison, J. P. Schapira, and J. Vernotte, Phys. Rev. C 6, 378 (1972).

[13]S. Galès, M. Langevin, J. M. Maison, and J. Vernotte, C.R. Acad. Sci. 271B, 970 (1970).

Upper Limit on Parity-Nonconserving Optical Rotation in Atomic Bismuth

L. L. Lewis, J. H. Hollister, D. C. Soreide, E. G. Lindahl, and E. N. Fortson
Department of Physics, University of Washington, Seattle, Washington 98195
(Received 7 July 1977)

We have searched for optical rotation near the 8757-Å magnetic-dipole absorption line in atomic bismuth vapor. The experiment is sensitive to parity nonconservation in the weak neutral-current interaction between electrons and nucleons in atoms. We find $R \equiv \mathrm{Im}(E_1/M_1) = (-0.7 \pm 3.2) \times 10^{-8}$, which is considerably smaller than the value $R = -2.5 \times 10^{-7}$ obtained by central-field calculations for this bismuth line using the Weinberg-Salam theory of neutral currents.

We present here results of an experiment in which we search for parity-nonconserving (PNC) optical rotation in atomic bismuth vapor.[1,2] We selected the $J=\frac{3}{2} \to J=\frac{3}{2}$ absorption line at 8757 Å where there is no competing background absorption from Bi_2 molecular bands to limit the usable

At SLAC, the laser-driven GaAs source works; Polarized electrons are accelerated in December 1977.

E122 Announces Parity Violation
June 1978

In June 1978, in the SLAC Auditorium, E122 announced the evidence for parity violation in inelastic ep and ed scattering. The statistical significance exceeded 10 sigma. Consistency checks and null texts were fully satisfied.

In the Fall, E122 again ran, and the combined data agreed with the W-S Model and gave

$$\sin^2 \Theta_w = 0.224 \pm .020$$

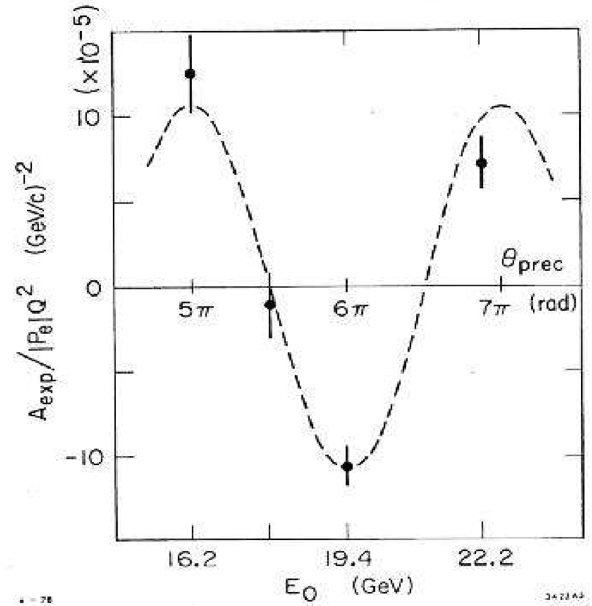
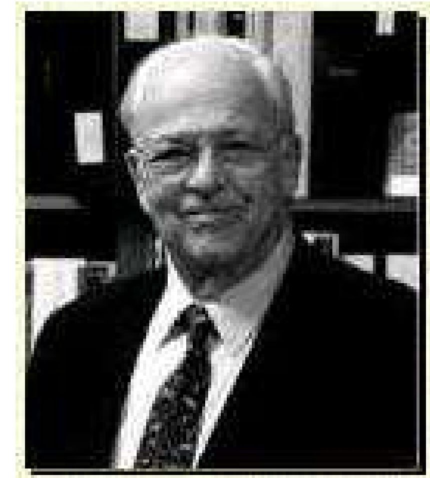


Fig. 3

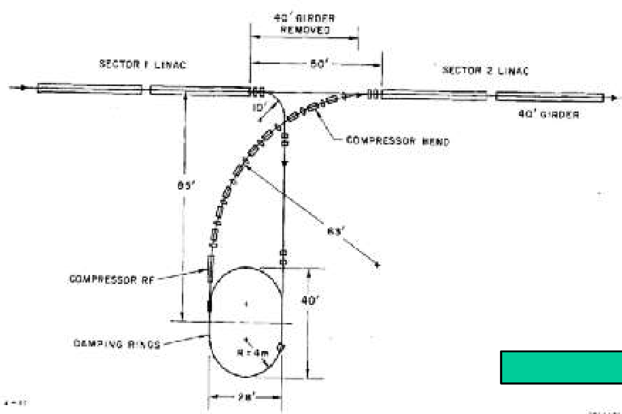
The SLC Era

By 1979, the ESA Parity Violation work was winding down. Richard Taylor and I were discussing the future program, and I argued for joining Group C's plans led by Burton. He was planning the SLC. I wanted to take polarized electrons to the SLC. Dick called a meeting in early 1980, to talk about the idea. Burton listened.

Burton also passed along to me an invitation to speak about this in Europe that summer.

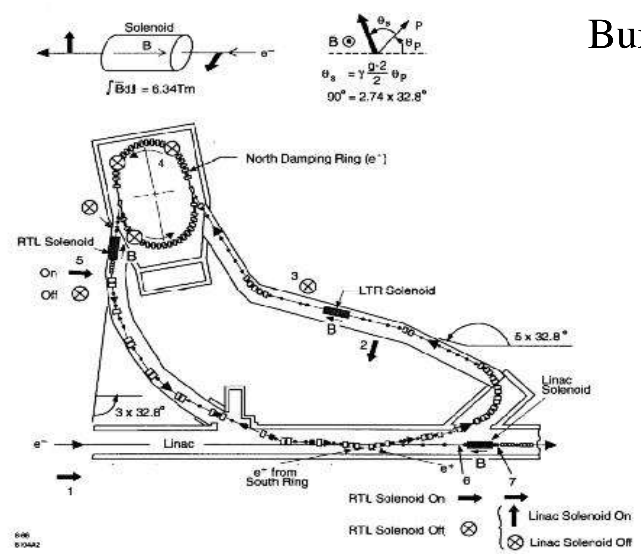


Burton Richter



The SLC Design Report

June 1980



The SLC DR's

As built

HEP Spin Physics Conference, Lausanne 1980

13th Erice Summer School, 1980

Burton received invitations to speak in 1980. He had two sent down to me, the Erice Summer School and the Lausanne HEP Spin Conference. I spoke on the physics of polarized electrons at the Z-pole.

where Γ_f is the partial width into final state f. Figure 7 shows the ratio of σ/σ_{QED} versus $\sqrt{s}$, the center-of-mass energy, near the Z^0 mass. The cross section σ_{QED} is defined as $\sigma(e^-e^+\to\mu^-\mu^+)$ from single γ exchange only. In Fig. 7, single γ exchange has been included, but is negligible near the Z^0 mass. The curves are marked e_L, 0, e_R for $P_e = -1, 0 +1$, respectively. The experimental asymmetry

$$A_{exp} = (\sigma_R - \sigma_L)/(\sigma_R + \sigma_L) \qquad (14)$$

where $\sigma_R(\sigma_L)$ is the total cross section for right-handed (left-handed) electrons, has the value −.16 at the Z^0 peak, for $\sin^2\theta_W = .23$. In terms of the couplings

$$A_{exp} = \frac{2g_V^e g_A^e}{g_V^{e\,2} + g_A^{e\,2}} \quad . \qquad (15)$$

Measurement of the asymmetry, Eq. (14), and

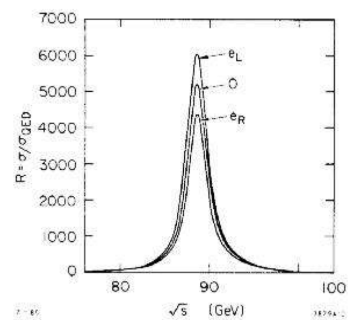
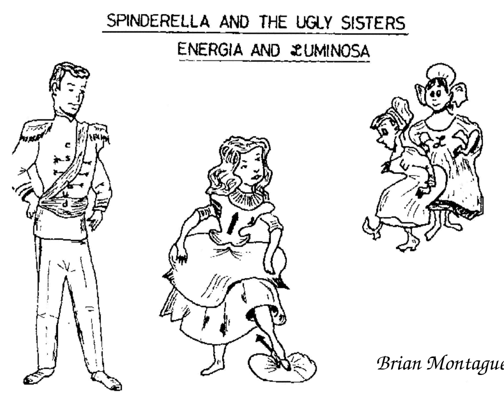


Fig. 7. $R = \sigma/\sigma_{QED}$ versus center-of-mass energy near the Z^0 pole for electron beams of positive helicity (e_R), negative helicity (e_L), or unpolarized beams (0).

Brian Montague, an accelerator theorist at CERN, also spoke at the Lausanne Conference. He worked in the LEP Machine group, and had a long standing interest in polarized electrons. He summarized his talk with the cartoon at the right.

Polarization at LEP was a difficult technical challenge. They eventually abandoned all serious efforts, leaving that physics to the SLC.



Brian Montague's cartoon

Energy first, then Luminosity, then Polarization



The Heroes

Nan Phinney
Marc Ross
Pantaleo
Tracy Usher
Morris Swartz
Mike Woods
Takashi Maruyama
Paul Emma
Bob Kirby
Tim Barklow

The Villians

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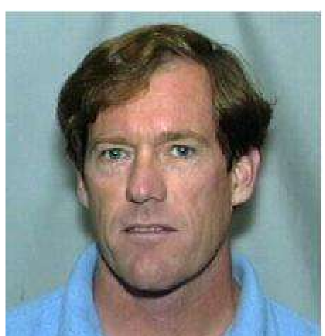
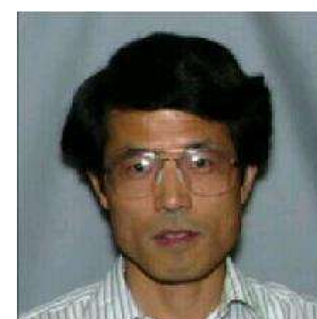
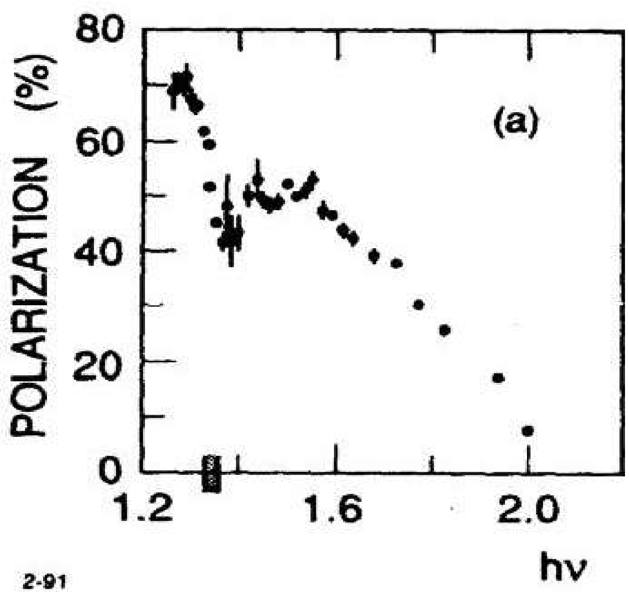


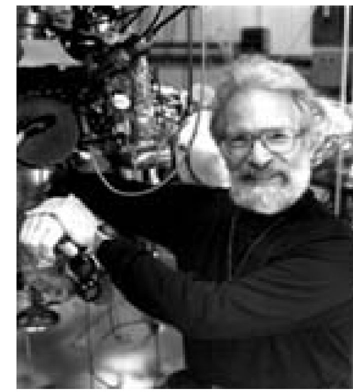
Strained GaAs

1991

A Collaboration between SLAC-Wisconsin-Berkeley achieved a major breakthrough in 1991. Through the application of MBE techniques, they demonstrated the first strained Gallium Arsenide cathode, which yielded 70% polarization at the bandgap edge.



Takashi Maruyama



Ed Garwin

Dick Prepost

Cathode Charge Limit

Mike Woods

SLAC-PUB-6268
April 1993
(A)

MEASUREMENT OF CHARGE LIMIT IN A STRAINED LATTICE GaAs PHOTOCATHODE*

P. Sáez, R. Alley, H. Aoyagi,+ J. Clendenin, J. Frisch, C. Garden, E. Hoyt, R. Kirby, L. Klaisner, A. Kulikov, C. Prescott, D. Schultz, H. Tang, J. Turner, K. Witte, M. Woods and M. Zolotorev

Stanford Linear Accelerator Center,
Stanford University, Stanford, California 94309

ABSTRACT

The SLAC Linear Collider (SLC) Polarized Electron Source (PES) photocathodes have shown a charge saturation when illuminated with a high intensity laser pulse.[1] This charge limit in the cesium-activated GaAs crystal seems to be strongly dependent on its surface condition and on the incident light wavelength. Charge limit studies with highly polarized strained lattice GaAs materials are presented.

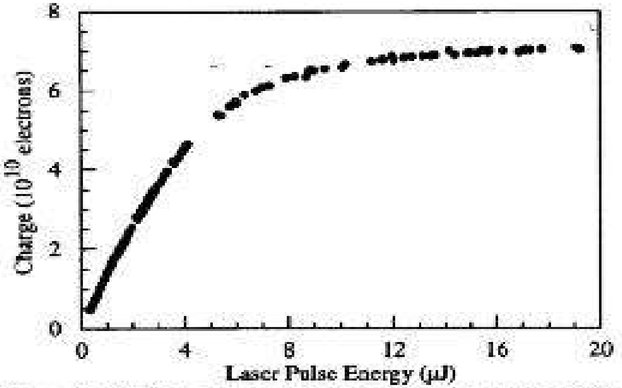


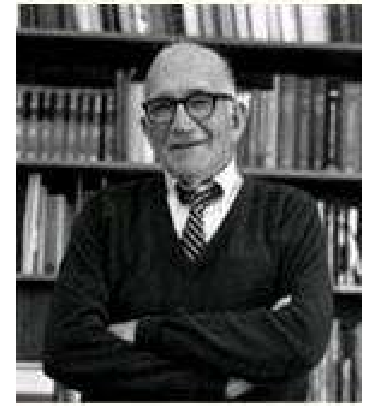
Figure 3. Typical photoemitted charge in the charge limit regime as a function of Ti:sapphire (850 nm) laser pulse energy. The photocathode QE was 1.51% and 0.57% at 750 nm and 833 nm, respectively. The cathode voltage was V = -120 kV.

SLD

February 1992

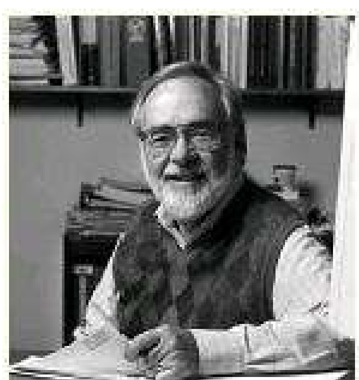
LEP turns on, and the SLC is in trouble

The polarized electron guns are now in deep trouble. They don't hold voltage, and no one knows why. Burton is under tremendous pressure to get the SLC running, so turns to Sid Drell to help figure out what to do for polarization. Sid talks to many SLACers. He decides to set up a task force and asks me to join. At first I refuse, but then agree. He asks Lowell Klaisner to join, and Bob Kirby. My job was the gun test lab… to figure out what is wrong. Lowell's job was to coordinate the Tech division support. Bob's was to build the load-lock system.



Sid Drell

We barely survived the 1992 turn on in May.

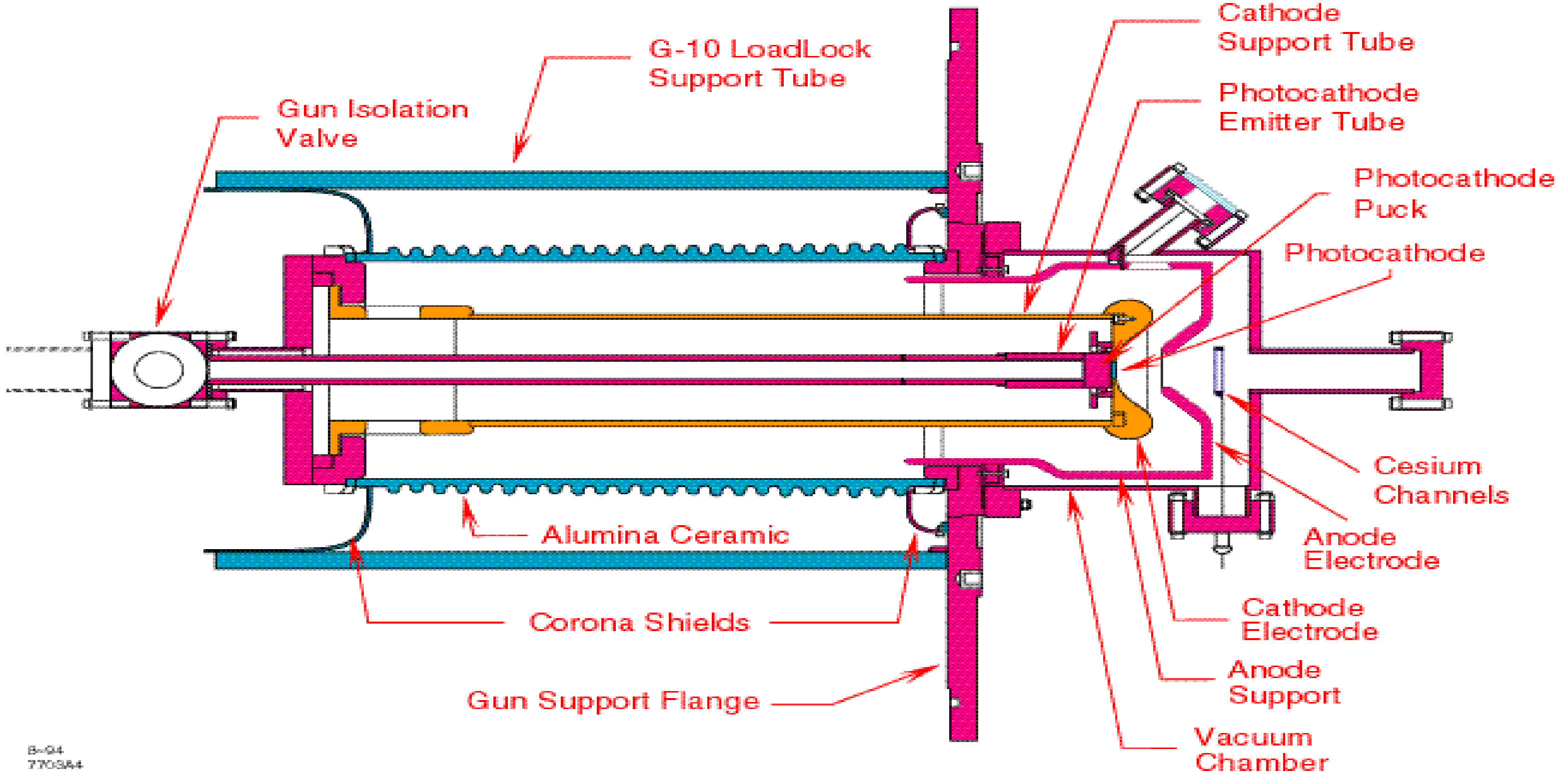


Charles Prescott

Bob Kirby

Lowell Klaisner

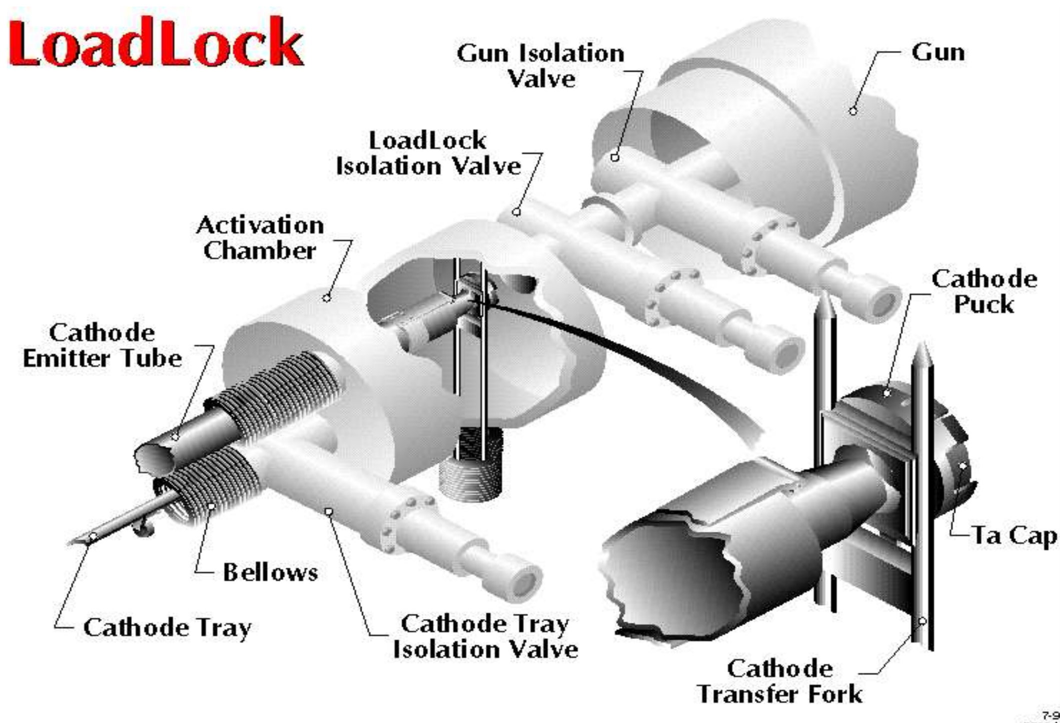
SLC Polarized Gun

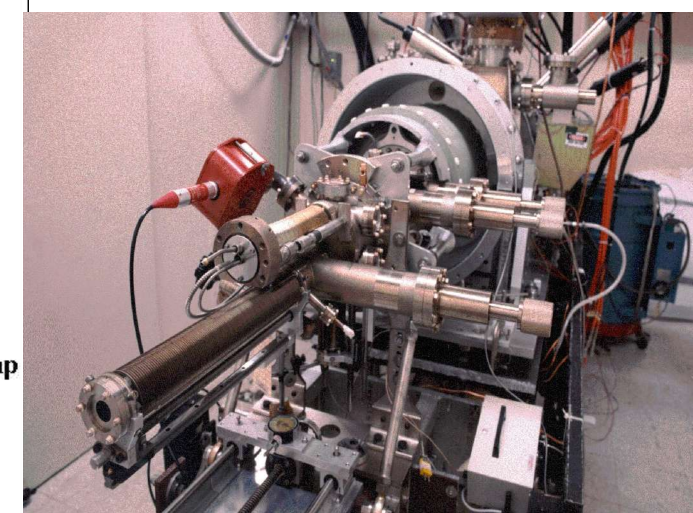


The Need for Load-Lock

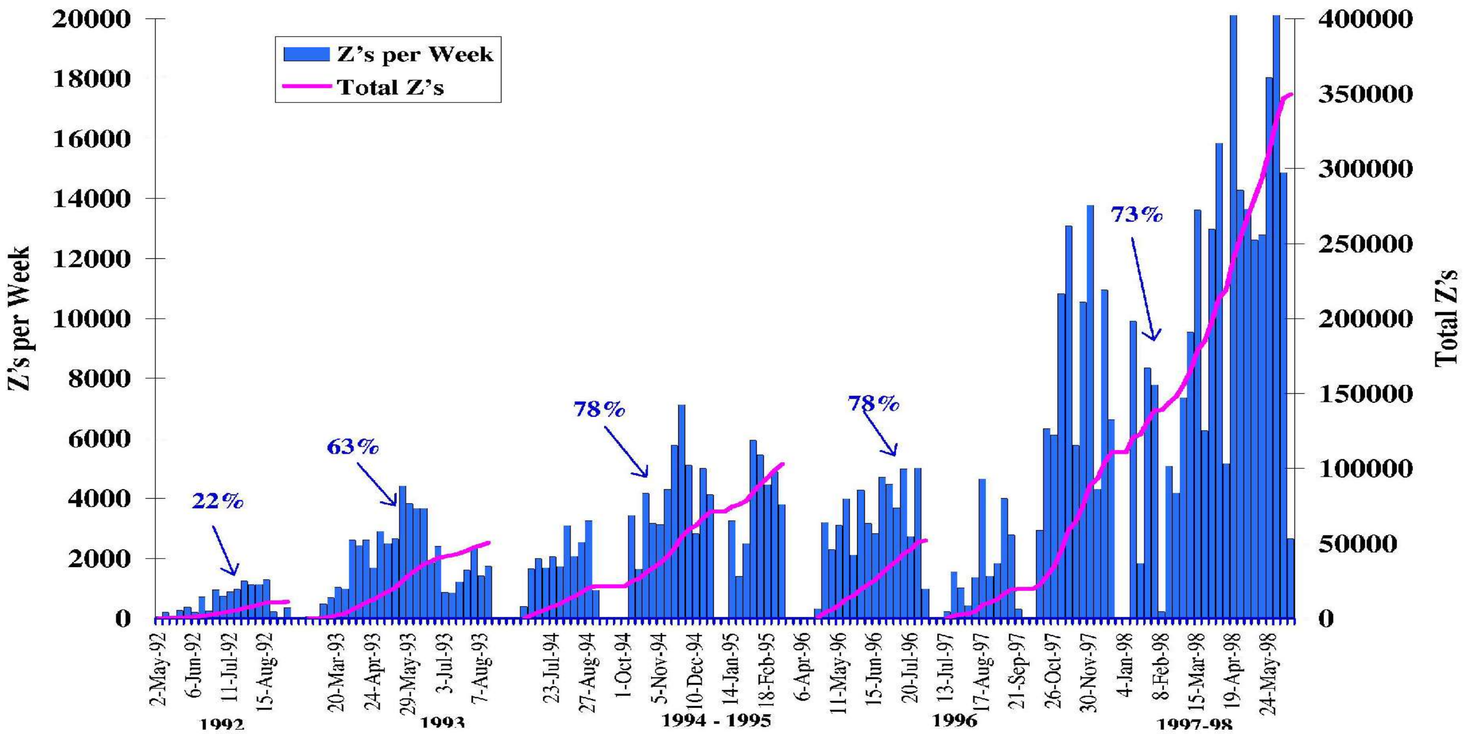
The Gun structure could not hold voltage…..unless "processed", which contaminated the clean cathode surface. The fix was to install the cleaned cathode through a valve system into the processed gun… a "load-lock" device, which had to be invented. Call in Bob Kirby to the rescue.

Bob Kirby





1992 - 1998 SLD Polarized Beam Running



Vanda 6/22/98

Polarization at a Future Linear Collider

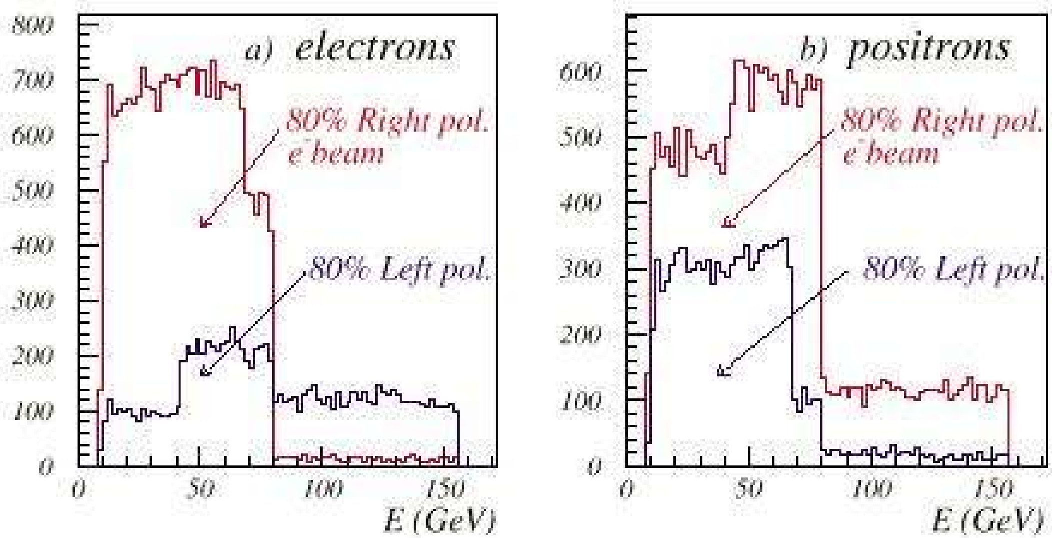


Figure 4.3: Electron and positron energy distributions for selectron pair production, with the indicated beam polarizations and integrated luminosity 50 fb^{-1} [157].

The case for electron beam polarization is clear.
What about the positrons?

The high price of polarized positrons

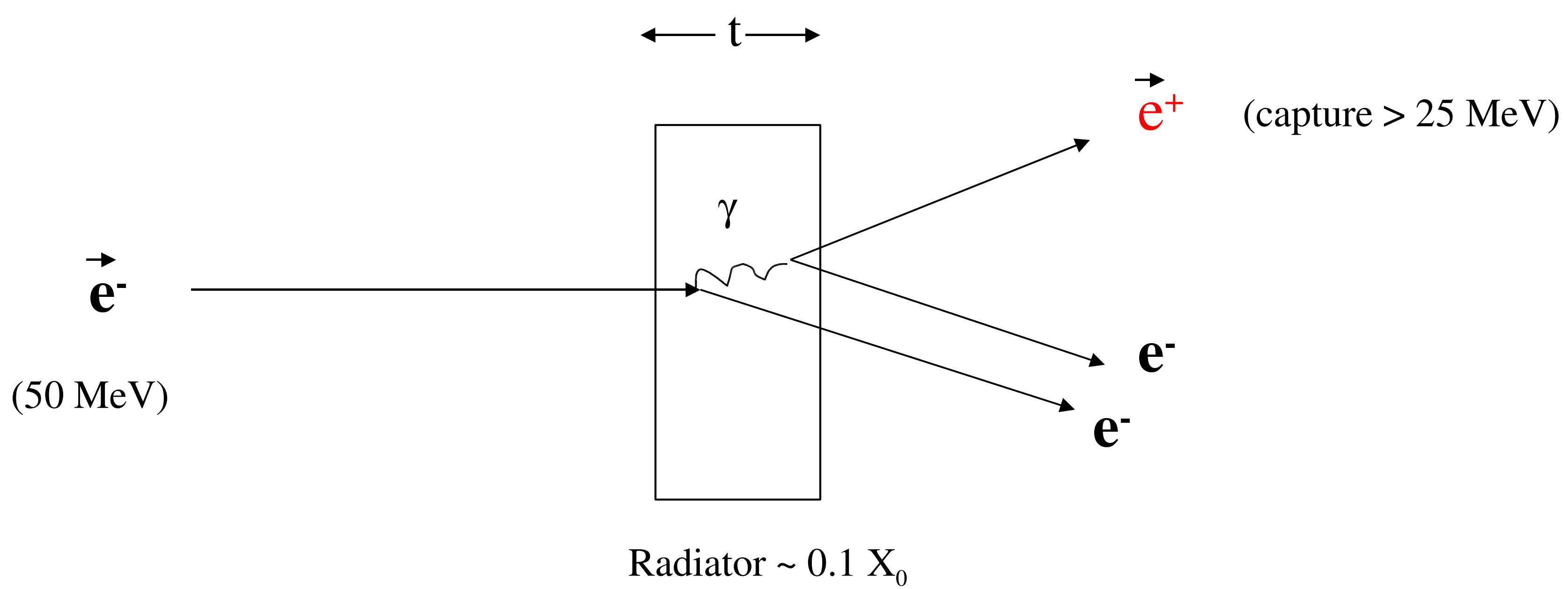
Photoemission sources give high yields of electrons. The quantum yield is in the range 0.1 % to 1.0 %, and the "cost" is 1.7 eV per electron. Polarizations as high as 80% are typical.

Positrons need 10-100 MeV photons each!
Yields of .01% to 0.1 % are typical

1) Bremsstrahlung/pair production
2) Compton backscattered photons
3) Helical Undulators

Bremsstrahlung

A. P. Potylitsin, NIM **A 398** 395 (1997)



Efficiency ~ .001

Polarization ~ 0.5

Beam Power ~ 1.5 MWatts (~ CEBAF)

Compton Source

T. Omori, KEK

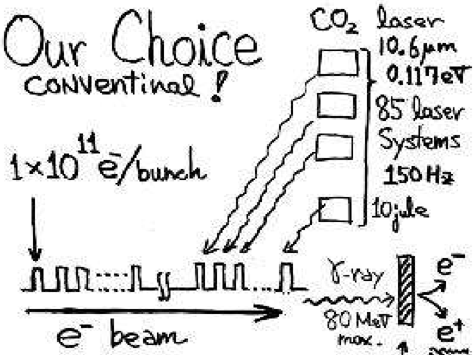
Trial to Design

Polarized Positron Source for Linear Colliders

5-Mar-1997 @SLAC
WS on Positron Source
Tsunehiko OMORI (KEK)

by KST Collaboration
[KEK
Sumitomo Heavy Industry
Tokyo Metropolitan Univ.]

Our Choice
conventional !



Low Energy 6.7 GeV
High Current
(1×10^{11} e^-/bunch)
× (85 bunch/train)
× (150 Hz)
time structure is the same as the main linac.

target
tangsten
t=3.5mm

Summary

(1) 85 CO_2 lasers
10 Jule, 150 Hz
6.7 GeV e^- linac, 150 Hz
1×10^{11} e^-/bunch, 85 bunch/train
→ positrons
0.7×10^{10} e^+/bunch,
85 bunch/train, 150 Hz
Pol. ≃ 50 %

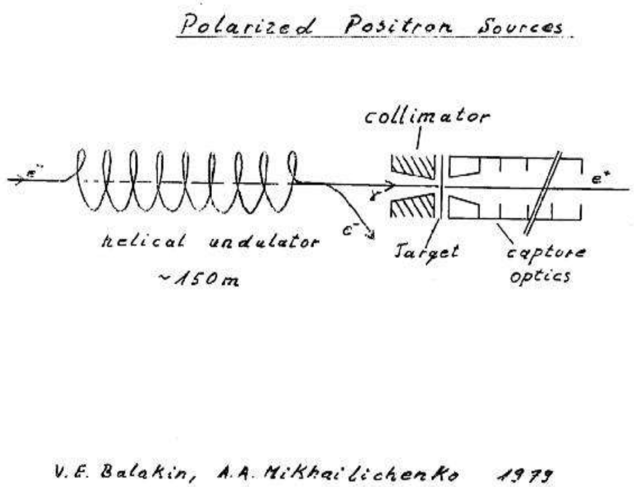
(2) Wall Plug Power ≃ 20 MW

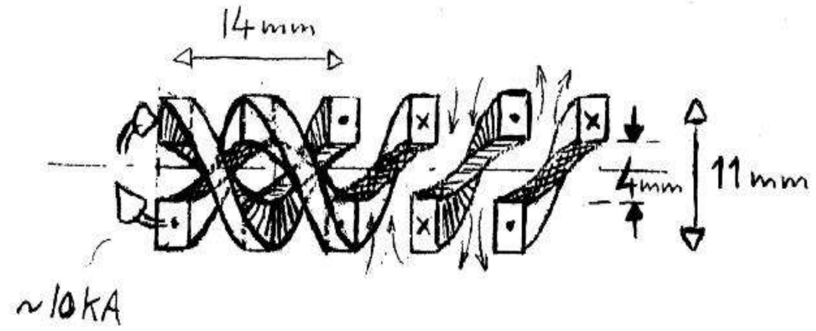
(3) Still Need R/D to get Conclusion.
(i) design: Capture Section
(ii) Simulation:
CAIN → Pair Creation on Target

Undulator Source

Balakin and Mikhailichenko, Novosibirsk

(1979)





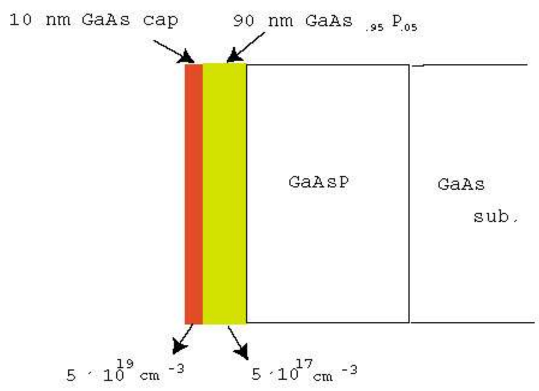
	undulator with iron	undulator without iron
undulator period λ	10.0 mm	10.0 mm
inner radius r_i	2.0 mm	2.0 mm
coil width w	2.8 mm	3.3 mm
coil height h	5.5 mm	4.0* mm
yoke height y	5.0 mm	–
on-axis field B_r	1.3 T	0.62 T
required undulator length	100m	150m

Cathode Charge Limit Solved
SLAC 2001

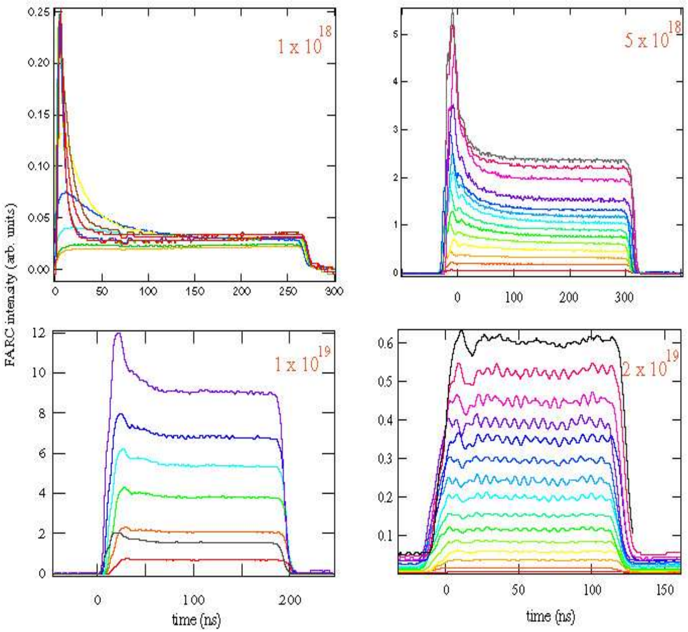
Takashi has worked diligently on the cathode charge limit problem. He has a new design under test, that looks promising for the NLC.

Takashi Maruyama

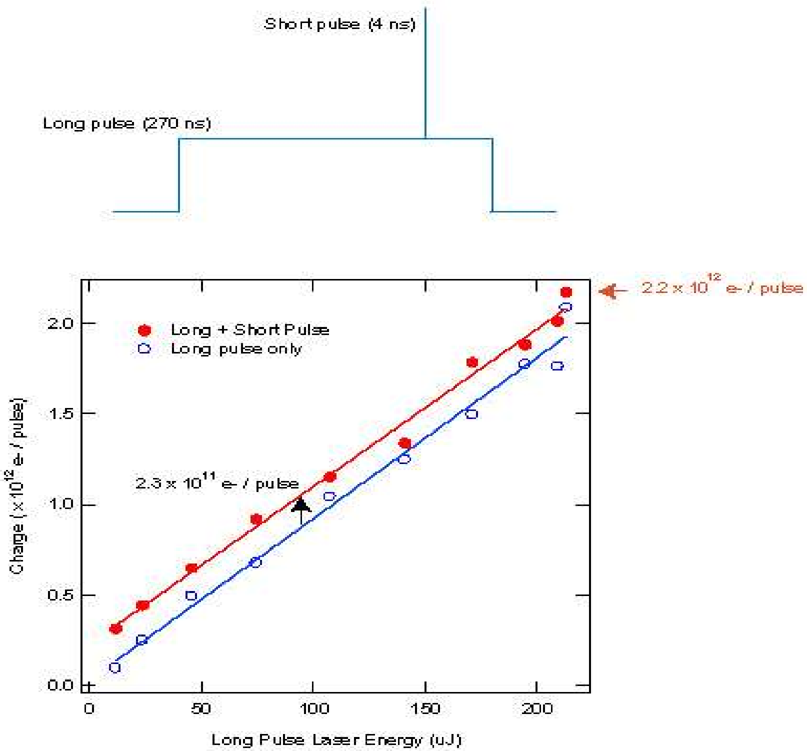
High Gradient Doped Strained GaAsP

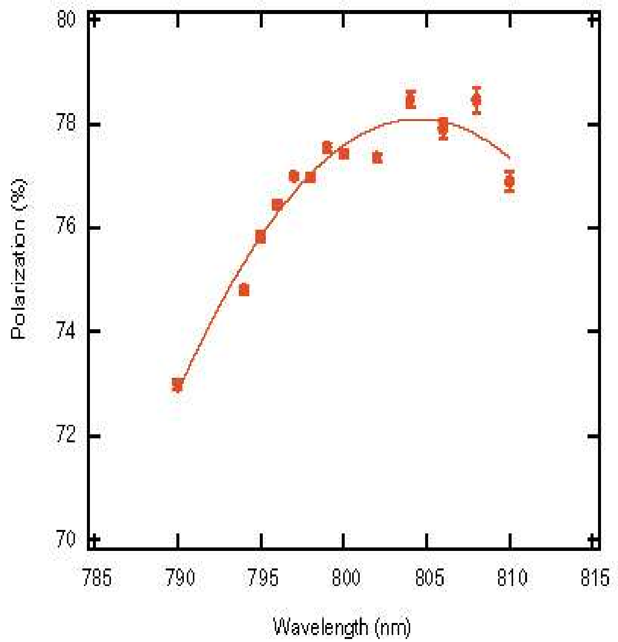


Faraday Cup Signal



The Cathode Charge Limit solved (continued)





SLD 2001

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Improved Direct Measurement of Leptonic Coupling Asymmetries with Polarized Z Bosons

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(The SLD Collaboration)

$$\sin^2\Theta_W = 0.23098 \pm 0.00026$$