The Story of Parity Violation at SLAC

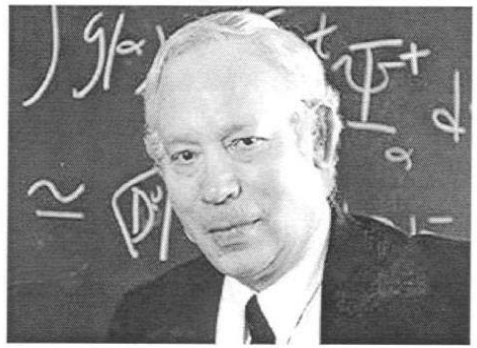
This story is about polarized electron beams at SLAC and the role Charlie played in bringing them into being.

I've had to do a lot of ARCHEOLOGY to find the good stuff…..

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

$$g_l = T_{3l} - q \sin^2\Theta_w \quad \text{and} \quad g_r = T_{3r} - q \sin^2\Theta_w$$

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.

Zel'dovich - 1958

PARITY NONCONSERVATION IN THE FIRST ORDER IN THE WEAK-INTERACTION CONSTANT IN ELECTRON SCATTERING AND OTHER EFFECTS

Ya. B. ZEL'DOVICH

Submitted to JETP editor December 25, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) 36, 964-966 (March, 1959)

WE assume that besides the weak interaction that causes beta decay,

$$g(\bar{P}ON)(\bar{e}^{-}O\nu) + \text{Herm. conj.}, \qquad (1)$$

there exists an interaction

$$g(\bar{P}OP)(\bar{e}^{-}Oe^{-}) \qquad (2)$$

with $g \approx 10^{-49}$ and the operator $O = \gamma_\mu(1+i\gamma_5)$ characteristic[1] of processes in which parity is not conserved.*

Then in the scattering of electrons by protons the interaction (2) will interfere with the Coulomb scattering, and the nonconservation of parity will appear in terms of the first order in the small quantity g. Owing to this it becomes possible to test the hypothesis used here experimentally and to determine the sign of g.

The matrix element of the Coulomb scattering is of the order of magnitude e^2/k^2, where k is the momentum transferred ($\hbar = c = 1$). Consequently, the ratio of the interference term to the Coulomb term is of the order of gk^2/e^2. Substituting $g = 10^{-5}/M^2$, where M is the mass of the nucleon, we find that for $k \sim M$ the parity nonconservation effects can be of the order of 0.1 to 0.01 percent.

In the scattering of fast ($\sim 10^9$ ev) longitudinally polarized electrons through large angles by unpolarized target nuclei it can be expected that the cross-sections for right-hand and left-hand electrons (i.e., for electrons with $\sigma \cdot p > 0$ and $\sigma \cdot p < 0$) can differ by 0.1 to 0.01 percent. Such an effect is a specific test for an interaction not conserving parity.

A magnetized iron plate can served as a source not expect an appreciable polarization of the emerging electrons, since the chemical potential of the electrons with spins parallel and antiparallel to the magnetization is evidently the same.

The interaction (2) leads to a displacement of the electron levels of different parities in the free atom.

In the hydrogen atom the probability of the metastable transition $2S_{1/2} \rightarrow 1S_{1/2}$, which appears on account of the admixture of $2P_{1/2}$ to the $2S_{1/2}$, still turns out to be even smaller that the transition probability on account of the magnetic moment of the electron, and is less than the probability of the two-quantum transition $2S \rightarrow 1S$ by a factor of more than 10^7. Finally, the interaction (2) leads to a rotation of the plane of polarization of visible light by any substance not containing molecules optically active in the ordinary sense of the words. The rotation of the plane of polarization also occurs because the weak interaction mixes atomic electronic states of different parity. A calculation of the effect gives an expression of the form

$$|n_{\text{right}} - n_{\text{left}}| \sim N_0(a^4/\lambda)g|\psi_S(0)||\psi_P(0)|/(E_P - E_S). \qquad (3)$$

where n is the index of refraction for circularly polarized light; $N_0 \sim a^{-3}$ is the number density of the atoms; a is the linear dimension of an atom; λ is the wavelength of the light; $|\psi_S(0)| \sim 1/a^{3/2}$; in $|\psi_P(0)|$ there are nonvanishing "small components" χ, given by $\chi \sim (\hbar/2mc)\sigma \text{ grad } \varphi$, where φ are the "large components"; $|\psi_P(0)| \sim (\hbar/mc)a^{-5/2}$, so that

$$|n_{\text{right}} - n_{\text{left}}| \sim (g/a^3\Delta E_{SP})(\lambda/mc\lambda) \sim 10^{-20}. \qquad (4)$$

Rotation of the plane of polarization by 1 radian occurs in a length of the order $\lambda/10^{-20} = 10^{15}$ cm, so that even in the first order in g the effect obviously cannot be observed.

How plausible is the assumption that the interaction (2) exists? Let us regard νe^- as a doublet

Trial Balloon - 1970

EXPERIMENTAL TEST FOR PARITY VIOLATING ADMIXTURE IN THE PROTON ELECTROMAGNETIC CURRENT

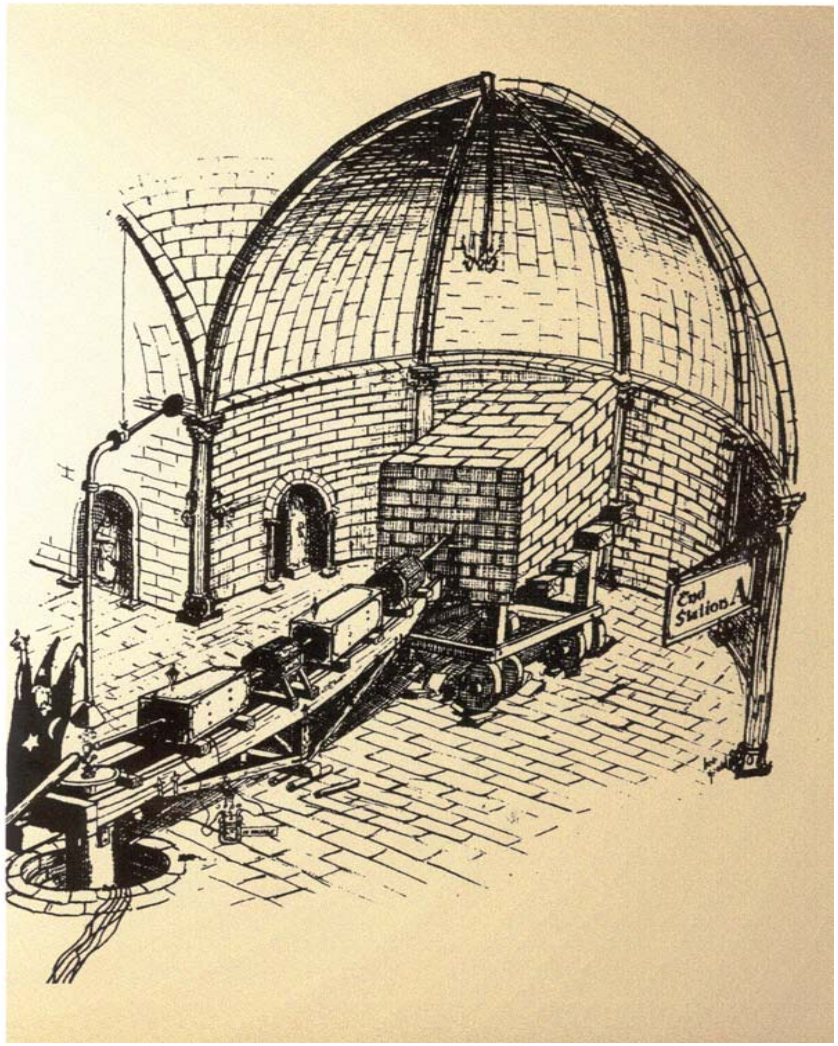
Recent experimental evidence for CP violation in weak decays has lead to considerable testing of basic invariance principles in particle interactions. A test for the invariance of the electromagnetic current of the proton under spatial inversion is proposed. It is emphasized that no direct experimental tests of significance exist at this time, but that indirect experimental tests as well as theoretical considerations, provide limits in the size of violation to be expected. Access to precision high energy spectrometers and high intensity electron beams make SLAC the ideal facility for performing this test.

BEAM TIME REQUESTED:

Two ~~one~~-week running periods, separated by 4-6 months; 180 pps at 11 GeV in end station A; 8 GeV/c and 20 GeV/c spectrometers will be used simultaneously.

PERSONNEL:

Richard Taylor, Elliott Bloom, et. al., (SLAC); Charles Prescott (Santa Cruz); Kirk McDonald (presently Caltech); M. Mestayer (STANFORD)



Early Photo of End Station A

Polarized Electrons come to SLAC

Fixed Target Experiment E80 proposed 1971

Vernon W. Hughes

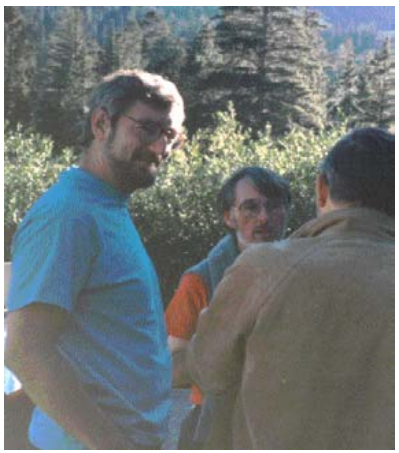
Vernon Hughes and collaborators propose a polarized beam/polarized target experiment to validate the quark model of the proton

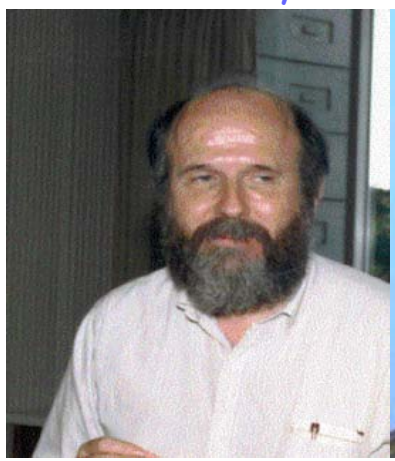
" the SLAC – Yale experiment E80 "

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, Dave Coward, and Paul Souder were some of your collaborators on E80





E95 Proposal - 1972

SLAC Proposal E95

EXPERIMENTAL TEST FOR AN ELECTROMAGNETIC AXIAL-VECTOR CURRENT OF HADRONS IN INELASTIC SCATTERING OF POLARIZED ELECTRONS

Experimenters: C.Y. Prescott (Spokesman); W. Atwood; E. Bloom; H. DeStaebler; S. Stein; R. Taylor; D. Trines: SLAC - Group A

and

D. Coward; D. Sherden: SLAC Spectrometer Facilities Group

and

G. Baum; R. Ehrlich; V. W. Hughes; M.Lubell; W. Raith; M. Zeller: Yale University

---

12°, an asymmetry of .004 corresponds to a parity violation of .03 of a maximal violation. This provides a good test of parity violation in electromagnetism, but is not sufficiently sensitive to observe parity violating effects arising from neutral weak currents.

4) The orientation of the electron spin relative to the momentum

End Station A Experiments

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

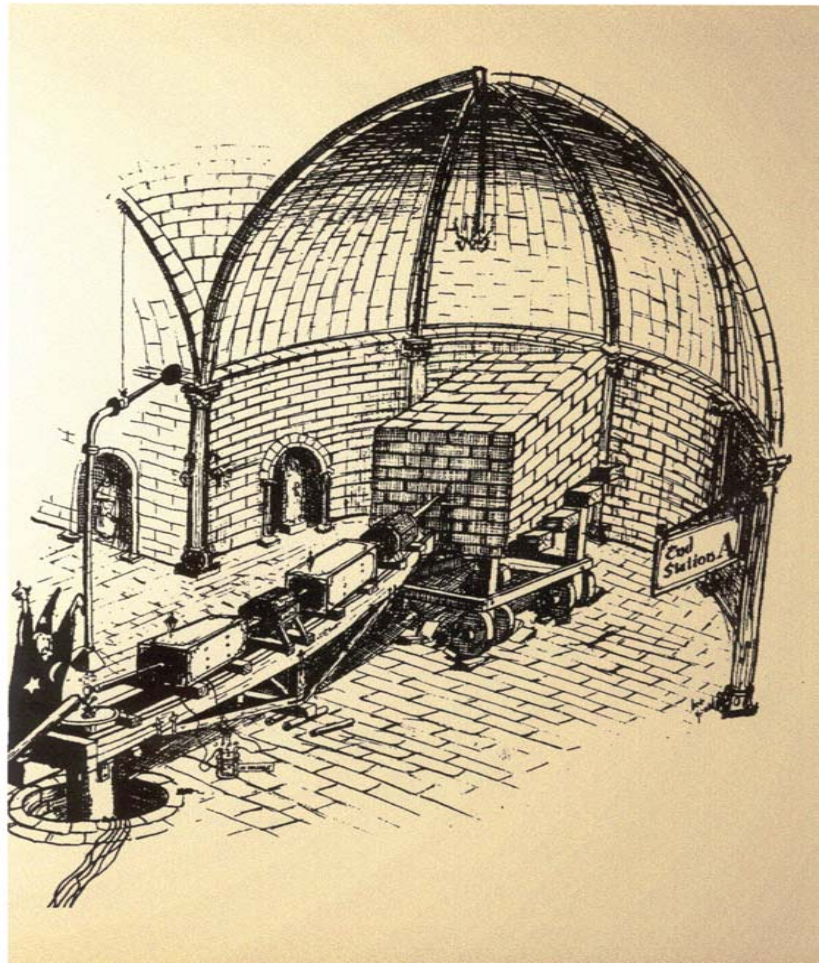
The source was too low in intensity, and the proposal stated E95 was "insensitive to the weak interactions".

E95 ran in 1976 and published a limit in 1978

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

Even before 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.



Bob Gould's End Station A

Neutral Currents Discovered!
Gargamelle
CERN - 1973

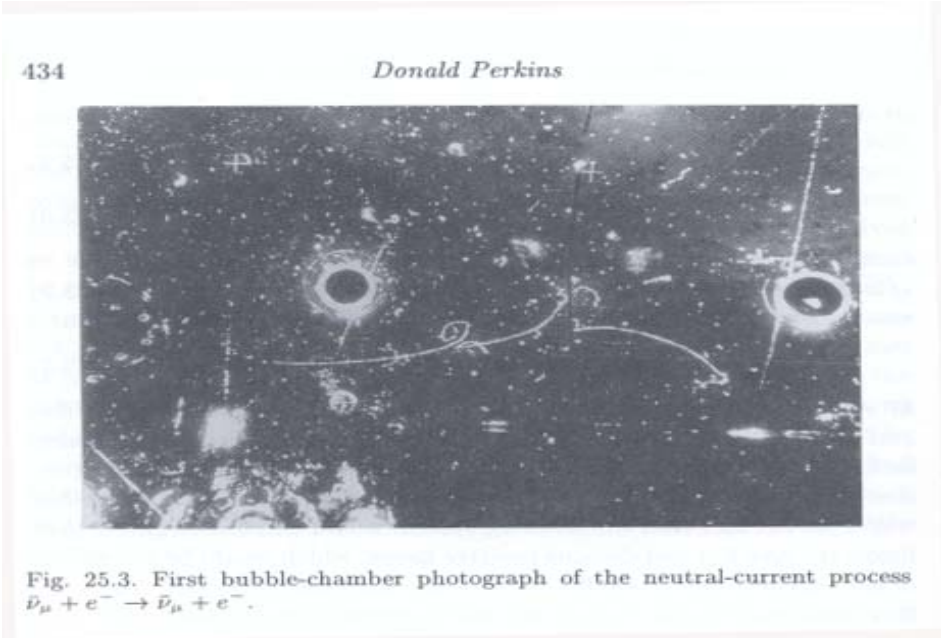


Fig. 25.3. First bubble-chamber photograph of the neutral-current process $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$.

Gargamelle finds one ν_μ e^- event!

(two more by 1976)

First Z^0 seen in UA1 in 1983

Charlie Baltay

Search for a new source

DATE: July 20, 1973

TO : Distribution

FROM : Charlie Sinclair

SUBJECT: Discussion of PEGGY Status and a Possible Alternative Polarized Electron Source.

A meeting was held on 18 July 1973 with D. Coward, E. Garwin, R. Miller, R. Koontz, R. Neal, W. Panofsky, and C. Sinclair in attendance. The status of the polarized electron source, PEGGY, presently in testing at Yale, was reviewed, and the possibilities of an alternative source were discussed.

Dave Coward reviewed the status of the PEGGY tests, as obtained from a phone conversation with Mike Lubell on 7/18. After an initial test in May, when a yield of 5×10^7 electrons of unknown polarization/pulse was obtained (a factor of 20 below design), a mirror misalignment was found

Roger Miller feels that a lower limit to the time between hardware arrival at SLAC and any possible accelerated beam is six weeks. The potential pitfalls in this time estimate are too numerous to list. Thus it was universally agreed that SLAC must operate on the presumption that there will be no polarized e- beam in 1973.

Given the realities of the PEGGY situation, it is prudent to imagine that PEGGY might not perform acceptably in the forseeable future, and investigate possible alternative methods of obtaining a polarized electron source.

These possible alternatives include photo emission from EuO or field emission from EuS covered W needles, as pointed out to Pief in a memo from W. Spicer.

These solutions, like the Yale source, involve a number of distinct technical difficulties, and if it were decided to pursue one of these methods, it would involve a sizeable commitment on SLAC's part. Among the possible problems with these sources, we noted the following:

1. The emittance is dominated by the large magnetic fields used. SLAC

E122 Letter of Intent – July 1974

DATE: July 26, 1974

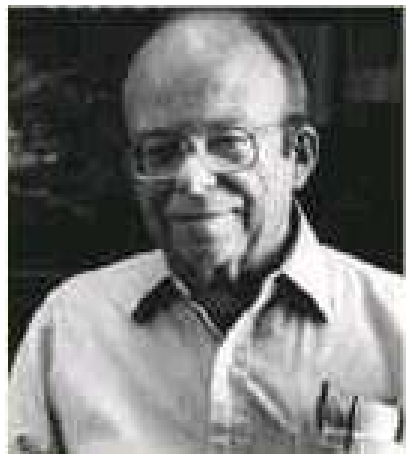
TO : W. K. H. Panofsky

FROM : Charles Sinclair, Charles Prescott

SUBJECT: INTENT TO SUBMIT PROPOSAL

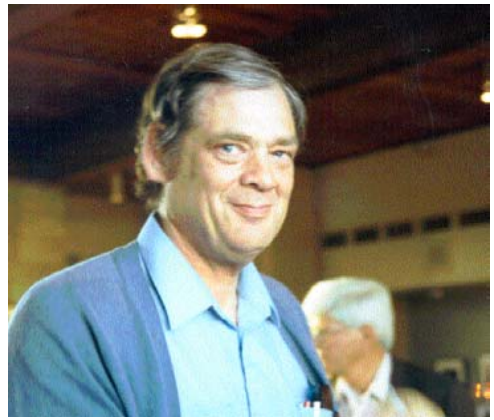
For some time, now, we have been studying the possibilities for observing parity violating $\vec{\sigma} \cdot \vec{p}$ terms in inelastic scattering of polarized electrons off unpolarized targets. Such experiments, if convincingly able to demonstrate asymmetries at the 10^{-4} level, are both timely and of fundamental importance. Measurement of such small asymmetries is an extremely difficult experimental task. Our studies of the prospects for seeing such small effects have led us to two conclusions.

First, proof of observation of parity violation requires elimination of systematic effects, correlated to spin reversal, which lead to false asymmetries. Checks must be carried out systematically on-line and will require running times comparable to those of the measurements of interest. Any proposal which counts individual electrons implies, at SLAC's duty cycle, lengthy runs to obtain sufficient statistical accuracy to reach the 10^{-4} level. A better approach is to achieve high counting rates for electrons so that 10^{-4} asymmetries



Pief

E122 Letter of Intent - 1974



George Chadwick

STANFORD UNIVERSITY

STANFORD LINEAR ACCELERATOR CENTER

Mail Address
SLAC, P. O. Box 4349
Stanford, California 94305

November 1, 1974

Program Advisory Committee
c/o George B. Chadwick
Stanford Linear Accelerator Center

Dear Sirs:

We are preparing a second proposal to continue the search for parity violation in e-p inelastic scattering. At the time E-95 was approved, there was little basis for predicting the strength of axial-vector terms in the interaction, but recent neutrino experiments from FNAL and CERN have demonstrated the existence of neutral current effects which are widely believed to be those predicted by the Weinberg-Salam model of weak and electromagnetic interactions. Observation of neutral current effects in reactions not involving neutrinos is an important piece of experimental evidence. It is our belief that the small parity violating asymmetries expected on the basis of Weinberg-Salam models will not be observable using the present polarized electron source, PEGGY. Systematic effects which are correlated to spin direction contribute false asymmetries which mask real parity violating effects. Experimental time must be provided for the investigation and elimination of spin reversal systematic effects. With the present PEGGY intensity, beam time required to study false asymmetries at the weak interaction level is prohibitive.

To overcome the systematic and statistical limitations imposed on us by the PEGGY source, we propose to develop and install a Fano-type polarized electron source driven by a dye laser. A prototype of this source has operated successfully at Bonn University at a level of 3×10^{9} electrons/pulse. We believe state-of-the-art techniques permit us to reach at least 10^{10} electrons per pulse. The polarization of the beam can be reversed by rotation of a quarter-wave plate in the laser beam, wh we believe promises us a beam essentially free of spin-reversal systemati effects, since all electron optics remain unchanged.

in Figure 1, where the statistical accuracy from a 200 hour run is compared to weak neutral current effects and to the results expected from E-95. The second part of the proposal will discuss a large solid angle detector for increasing counting rates. We will ask that no decision be made on the second part of the proposal at this time. We will return to the PAC for consideration of further running time with a large solid angle detector at a later date when more information on experimental conditions is in our hands.

Considerable interest in carrying out further parity violation experiments has been expressed by members of the E-95 proposal, and we expect to form a collaboration from the interested members of that experiment.

Charles Y. Prescott
SLAC

Charles K. Sinclair
SLAC

CKS Appendix to the LOI

DATE: October 31, 1974

TO : APPENDIX - Part I

FROM : Charles Sinclair CKS

SUBJECT: Summary of results achieved by the Bonn Fano Effect polarized electron source, and expectations for what might be achieved at SLAC with a Fano source.

1.) Physics of the Fano Effect.

The Fano Effect[1] is the production of longitudinally polarized electrons by ionization of alkali metal atoms (except Lithium) with circularly polarized light of wavelength near photoionization threshold.

The single valance electron of the alkali metals is in a $n^2S_{1/2}$ ground state. When photoionized (electric dipole transition) the final state may be either $\epsilon^2P_{3/2}$ or $\epsilon^2P_{1/2}$, where ϵ denotes a continuum state. In the wavelength region near threshold, the matrix elements for transitions to these two states cross zero, due to the strong cancelations between the S and P state wavefunctions. Spin orbit coupling causes the two matrix elements to cross zero at somewhat different wavelengths, thus making possible a region in which the signs of the two matrix elements differ. This spin orbit effect makes it possible to effect a cancellation such that circularly polarized photons of a particular wavelength produce electrons with 100% longitudinal polarization.

In practice, the wavelength region over which substantial photoelectron polarization is rather broad, some 200 Å or so in Cesium, the most practical alkali metal for Fano Effect sources. Polarization reversal is effected by changing the sense of the circularly polarized light, and thus can be done while leaving all electron optical conditions unchanged. This feature essentially

E122 Letter of Intent (cont.)

APPENDIX - Part 2 : A large solid angle detector for inelastic electron scattering.

Successful parity violation experiments at low energy have incorporated a technique we wish to use. To obtain sufficient counting rates so that weak parity violation effects can be seen, the flux or current of scattered particles is measured, rather than counting individual particles. To measure parity violation in electron scattering at SLAC, we propose to reach 10^{-4} asymmetry levels in $\sim$ 1 hour of beam time by installing a large solid angle gas Cerenkov detector in End Station A. A sketch of the detector is givn in Figure 2. The detector is basically a cone of revolution, subtending 4° to 10° in the lab. and segmented into 16 parts. The Cerenkov counter is filled with atmospheric N_2 (diluted somewhat with He to raise it Cerenkov threshold) and can be made thin-walled. Light output is collected onto 16 photo-multiplier tubes, whose output can be integrated and stored on a pulse-to-pulse basis. The highly directional response of gas Cerenkov counter rejects particles coming from directions other than those from the target.

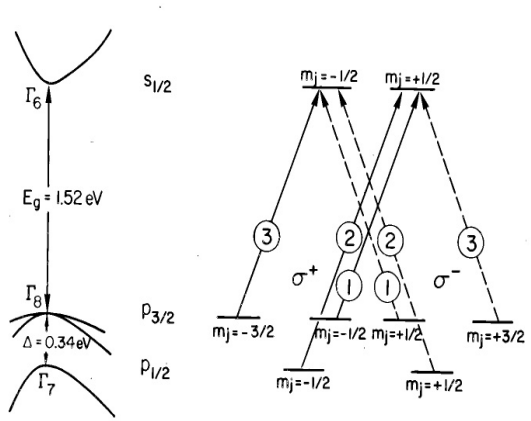
The gas Cerenkov detector resides downstream of a magnet of moderate $\int Bdl$ which shields the detector from soft electrons which emanate from the target.

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

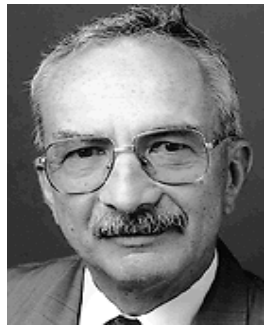
Bill Spicer

Gallium Arsenide proposed

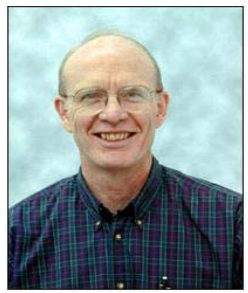
Garwin, Pierce, and Siegmann
1974

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

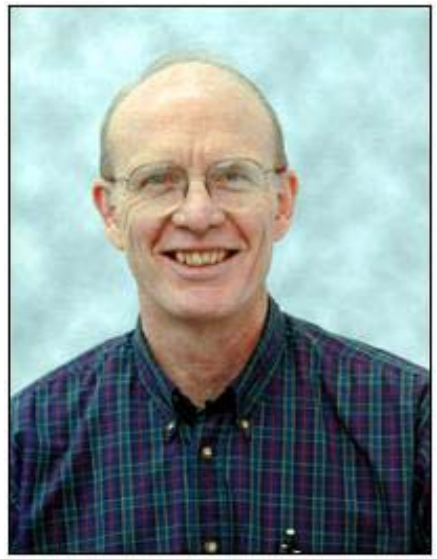


Dan Pierce

E. L. Garwin

First GaAs Test

Dan Pierce and Felix Meier were the first to demonstrate photoemission of polarized electrons from GaAs in H. C. Siegmann's lab in ETH Zurich



Dan Pierce

PHYSICAL REVIEW B VOLUME 13, NUMBER 12 15 JUNE 1976

Photoemission of spin-polarized electrons from GaAs

Daniel T. Pierce* and Felix Meier
Laboratorium für Festkörperphysik, Eidgenössische Technische Hochschule, CH 8049, Zürich, Switzerland
(Received 10 February 1976)

The spin polarization of electrons photoemitted from (110) GaAs by irradiating with circularly polarized light of energy $1.5 < \hbar\omega < 3.6$ eV was measured by Mott scattering. The GaAs surface was treated with cesium and oxygen to obtain a negative electron affinity (NEA). The spectrum of spin polarization $P(\hbar\omega)$ exhibits a peak ($P = 40\%$) at threshold arising from transitions at Γ, and positive ($P = 8\%$) and negative ($P = -8\%$) peaks at 3.0 and 3.2 eV, respectively, arising from transitions at L (Λ). Anomalous behavior, consisting of a depolarization at threshold and an increase and shift in the peak polarization to 54% at 1.7 eV, is attributed to a small positive electron affinity (PEA) characteristic of some samples. Restriction of the photoelectron emission angle by the PEA leads directly to the anomalously high P. Results of calculations show that P cannot be increased above 50% for emission arising from transitions at Γ in NEA GaAs. Our detailed interpretation of the spectra indicates how spin-polarized photoemission can be used to study the spin-dependent aspects of electronic structure. The outstanding qualities of NEA GaAs as a source of spin-polarized electrons are discussed and compared with other sources.

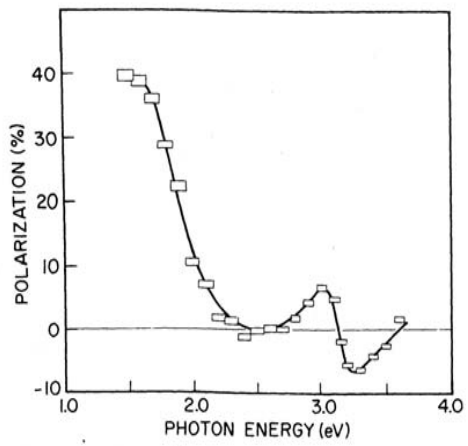


FIG. 6. Spectrum of spin polarization from GaAs + CsOCs at $T \leq 10$ K [the same sample and conditions as curve (a) of Fig. 5] . Note the high value of $P = 40\%$ at threshold ($\hbar\omega \sim 1.5$ eV) and positive and negative peaks

Parity Violation
1974-1978

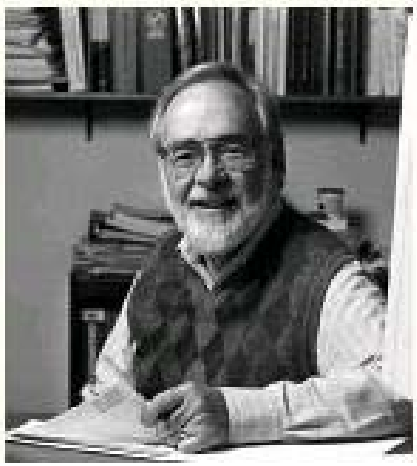
The prospect of a GaAs photoemission source for high beam currents triggered a new proposal….which could test the Weinberg-Salam model in the End Station. Charlie Sinclair and I proposed such a test to the SLAC EPAC in 1974.

This experiment was E122.

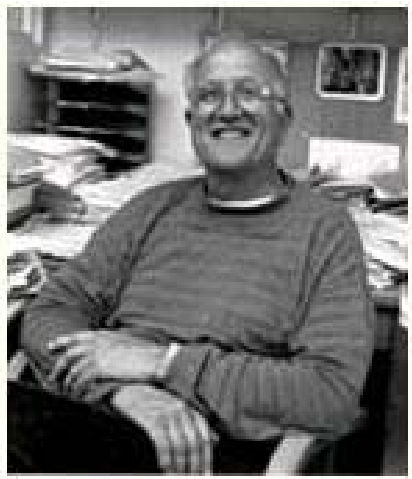
The proposal received conditional approval and we went to work on the source, with Ed Garwin and Roger Miller. That occupied us for 4 years.

Charlie Sinclair

Ed Garwin



Charlie Prescott



Roger Miller

E122 Proposal
June 1975

SLAC Proposal E-122

A TEST OF PARITY VIOLATION IN THE INELASTIC SCATTERING
OF POLARIZED ELECTRONS AT THE LEVEL OF THE WEAK INTERACTION

EXPERIMENTERS: SLAC, Groups A and SFG: W. Ash; W. Atwood; R. Cottrell; H. DeStaebler; H. Pessard; C. Prescott*; L. Rochester; D. Sherden; C. Sinclair*; R. Taylor
Yale University: M. Bergstrom; R. Ehrlich; V. Hughes; M. Lubell; K. Kondo; N. Sasao; P Souder
University of Bielefeld: G. Baum; B. Raith, P. Schuler

* Spokesman

BEAM: Solid State Polarized Electron Source, (under development)
10^{11} $\bar{e}$/pulse (10 ma peak 1.6 usec), 50% polarized, 180 pps.

TARGET: 30 cm LD_2.

EQUIPMENT: 8 GeV/c and 20 GeV/c spectrometers, modified for high counting rates; Counting House electronics and computers.

RUNNING TIME: 300 hours at 200 pps and 100 hours checkout at 30 pps
100 hours at 19.42 GeV
100 hours at 16.18 GeV
100 hours at 17.80 GeV

POLARIZED ELECTRON GUN

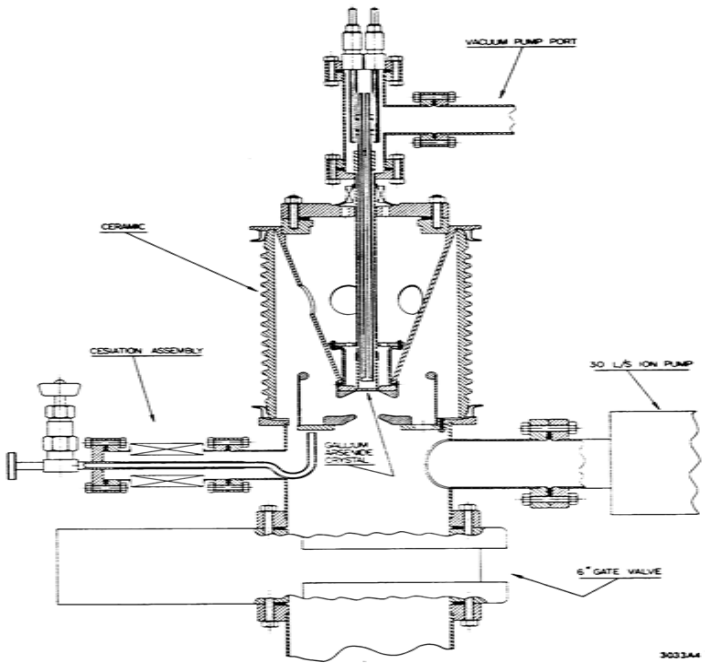
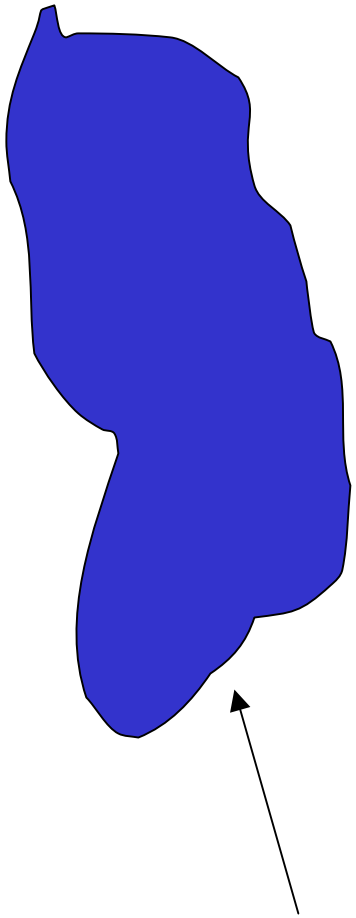


Fig. 4. View of the SLAC GaAs gun, with electron bombardment heater in place.



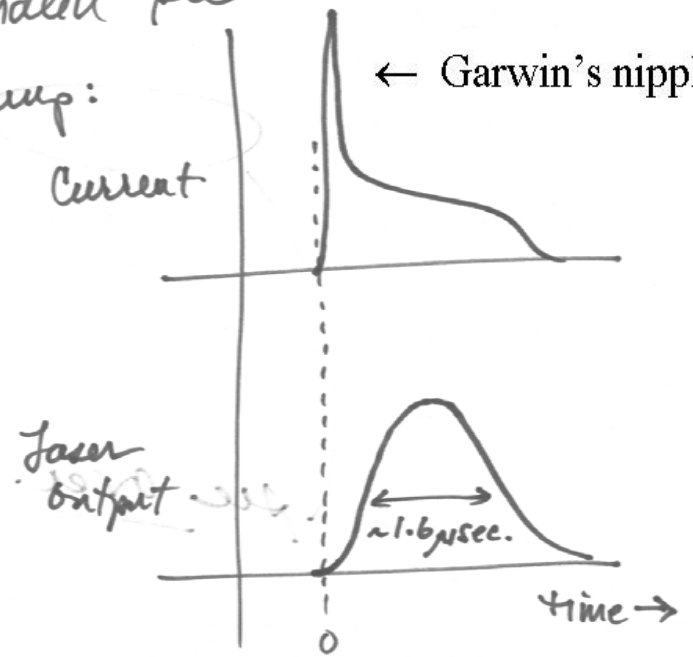
Dye stains everywh

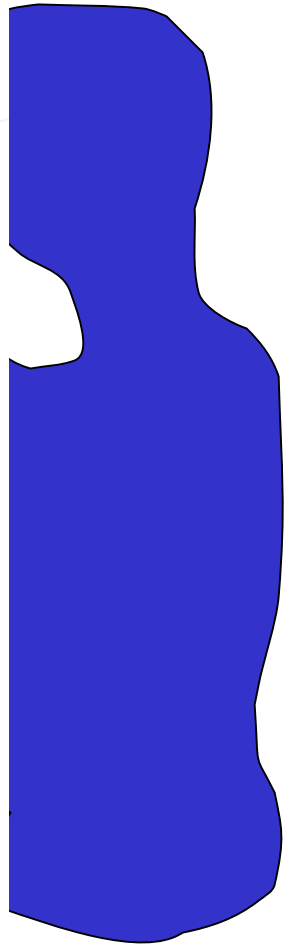
n.b. 1% Q.E. at our λ (710nm) $\Rightarrow$ 5.7 mA/W.

$\therefore$ 10 kW/cm^2 × $\frac{1}{3}$ cm^2 = 3.3 kW

$\Rightarrow$ 18.8 A emission per % Q.E.

But we saw $\lesssim$ 1 A. why? —
the temperature effect - not
understood by me, at leat. at
RT, we indeed see enormus currents -
at low temp:





CKS Memo – Jan 1976

DATE: January 6, 1976

TO : Joe Ballam

FROM : C.K. Sinclair

SUBJECT: Status of the new polarized electron source project.

This memo gives a brief overview of where we stand on the various aspects of the new polarized source project. Our immediate goal is to demonstrate that we can obtain large fluxes (ca. 10^{11}/μsec) of longitudinally polarized (ca. 50%) electrons from illumination of GaAs with circularly polarized light of the proper wavelengths. Certain aspects of this source which would make it suitable for use as a SLAC injector are being deferred, pending a successful demonstration of the principle.

The principal components, and their present status:

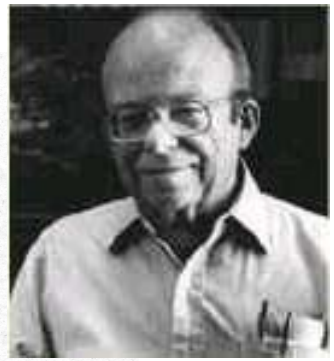
1.) Gun structures. Machining of all components for two complete assemblies is done, and all vacuum hardware has been ordered. Most is here. The system to cool the GaAs to 77°K has not been done, but will be quite simple. Only one gun will be assembled for the initial studies.

2.) GaAs. A number of samples are on hand, and Garwin believes the problem of preparing properly clean surfaces is under control. The apparatus for cesiating the surfaces, part of the gun assemblies, is complete. We will want ultimately to do optical measurements on the GaAs samples, as such measurements are fairly straightforward, and correlate well with polarized photoelectron emission. We are not yet set up to do these measurements, but most of the components are available.

3.) Beam line. Design is complete, and most components, including vacuum pumps, are on hand. The one special magnet has been constructed, and is being

Joe Ballam

CKS Memo – September 1976



WKHP

DATE: 17 September, 1976

TO : WKHP

FROM : Charlie Sinclair CKS

SUBJECT: Some remarks on the location for the new GaAs polarized electron source.

I would like to make several comments regarding the installation of the new GaAs polarized electron source on the linac, partly concerning what I feel to be very reasonable estimates of costs and schedules, and partly in rebuttal to Hughes' letter of September, which I feel does not fairly present the issues. My points, too hastily written, are presented in sort of random order.

1.) Were there no consideration but my personal pleasure, a separate room for the GaAs source would be much to my liking.

2.) I do not believe that the resolution of the question of a new room versus location of both sources in the present tunnel should await your return from China. Before an experimental program with the GaAs source can begin, we must undergo set-up, shakedown, and injection studies. Roger estimates that injection studies must begin by the end of the spring cycle, at the latest, for any reasonable hope of operation in the fall of 1977. The original anticipation, after the June 4th meeting, was that occupancy of the new room by the GaAs source would be in early December. Any possibility of that is already far past, and the presently discussed "time-early" dates are about February, were we to proceed with the new room immediately. Waiting until nearly the end of October will exacerbate this problem to what I feel is an intolerable level.

3.) The costs associated with the new room are substantial. To the present low bid of $128K must be added: i) Plant engineering work to install lights, power, air cooling, etc, estimated well in excess of $20K. Fred Hall has more precise numbers. ii)A new injection line between the GaAs source and the linac. Roger Miller has set aside $50K for this item, to include vacuum components, interlocking,

CKS Memo - November 1976

DATE: November 22, 1976

TO : J. Ballam

FROM : Charlie Sinclair CKS

SUBJECT: Estimated capital equipment costs to finish a dual gun polarized electron source, mated to the accelerator.

This memo contains a list of equipment which we feel is required to complete the dual gun gallium arsenide polarized electron source, and to completely instrument it as installed at the injector. The items marked with a single asterisk are currently in use on the present polarized source, PEGGY, and we anticipate that these will not be available to us due to their continuing development program. We have assumed, after talking with Roger Miller, that accelerator physics will take over the load of installing the source on the accelerator, and so with few exceptions do not include any components beyond the point where the beam leaves the source. I have, however, included some money for the required bending and focussing magnets, which we partially construct in our own shops. A number of the items listed are currently in use, and are borrowed from either Ed Garwin or the counting house (or, in the case of the transit, from Wade Milner). These items are indicated by double asterisks. In some instances, I feel that the items borrowed from the counting house can be essentially permanently transferred to use with the new source. Ed Garwin feels that it is unnecessary to exactly replace all of the various items we are

Crisis looms in early 1977

DATE: January 26, 1977

TO : George Chadwick, PAC

FROM : Charles Prescott

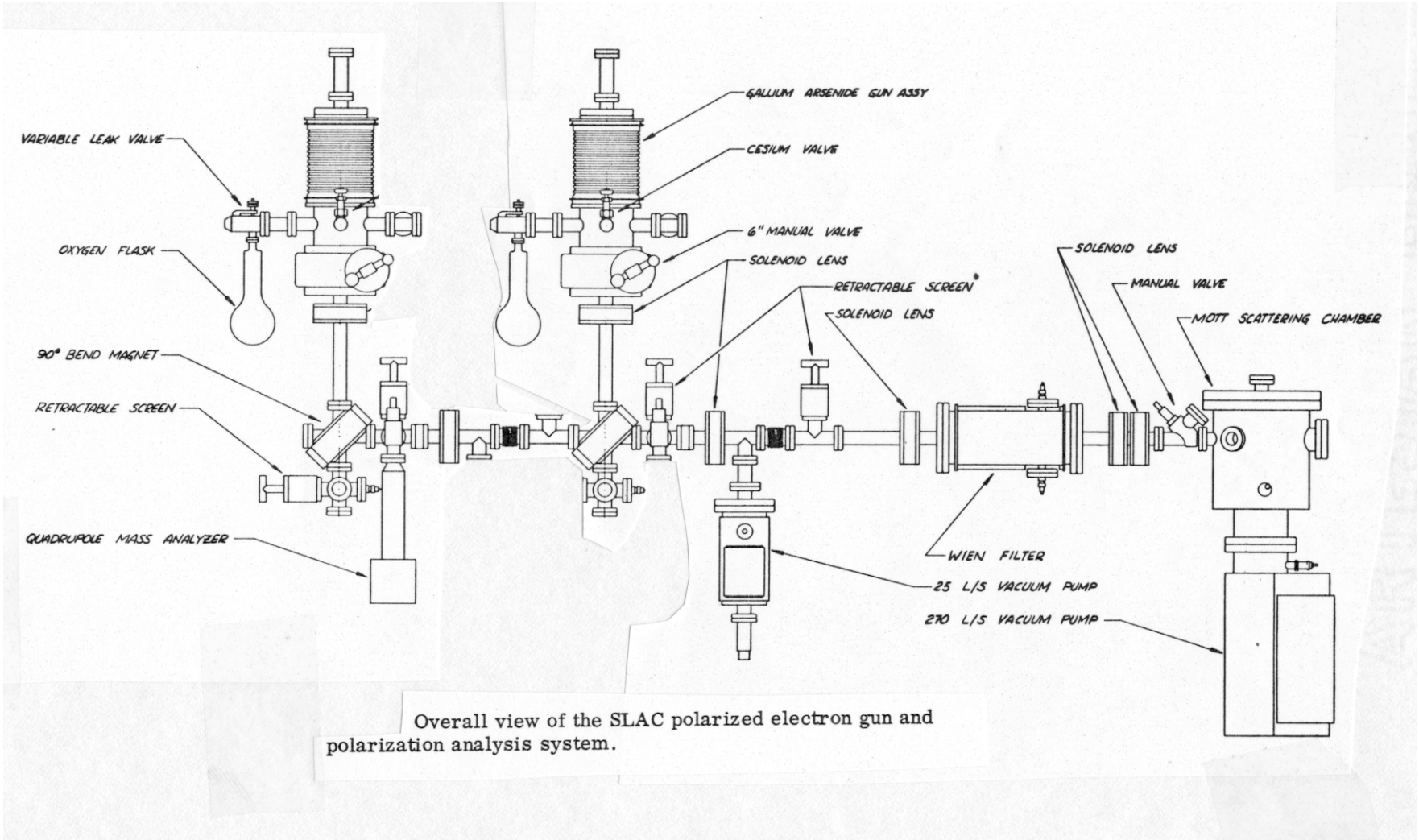
SUBJECT: CURRENT STATUS OF THE POLARIZED ELECTRON BEAM DEVELOPMENT FOR THE E-122 PROPOSAL

Last month, we asked you to reserve time for E-122 before the PAC. Development of the GaAs source for polarized electrons has been underway, and progress has been steady and rapid. It appeared at that time that successful operation of the source was imminent. We are anxious to achieve second-stage approval for E-122 to facilitate scheduling of the experiment. At this time, however, we have not met our design goals and are yet unable to request for second-stage approval.

In recent tests, we have achieved currents by photoemission from a cesiated GaAs surface, using a dye laser of the appropriate wave length, that are in excess of the 10ma peak current we stated as our design goals. This represents a major milestone in the development of the polarized electron beam. However, our measurements of the polarization yielded numbers substantially below the 50% design goal. The present cause or causes of the low polarization are unknown to us but are likely to be related to the preparation of the GaAs surface or the treatment of the GaAs during the in situ heat cleaning and cesiation process. We are actively undertaking steps to diagnose the problems. The delays we are presently encountering are mostly of a trivial nature having to do with changes in the vacuum system, laser components or test of other components of the system. We have recently installed a bench setup for testing the cesiation of GaAs wafers. This bench setup will allow us to quickly install, bake out, and test new GaAs surfaces. Previously, the testing was being performed in the gun structure of the source, and progress was slow, because vacuum bakeout was a week long process. We are optimistic that the final hurdles will be made in the near future.

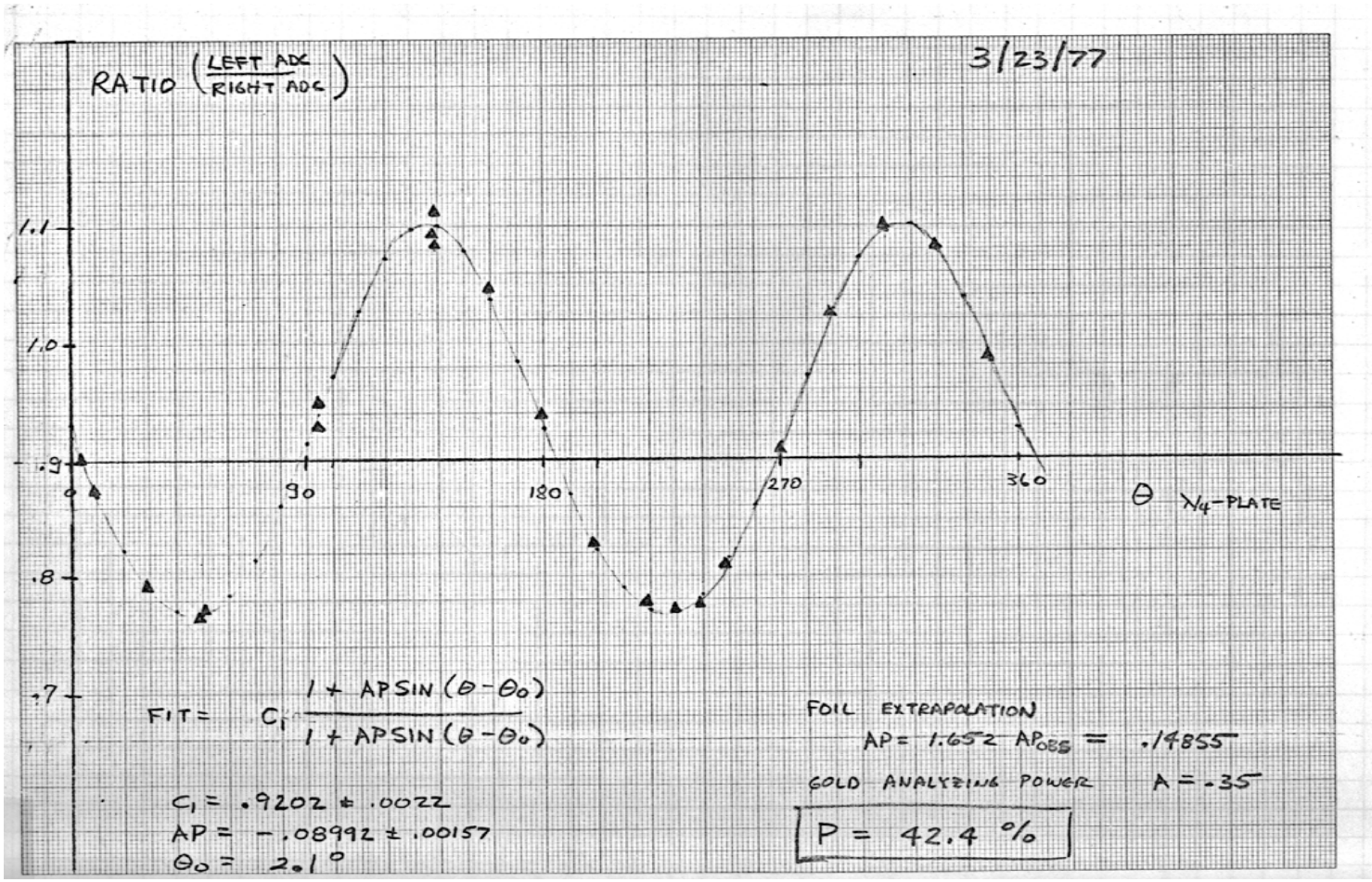
Therefore, I am asking you to cancel us from the PAC schedule on January 29. I realize this will leave a hole in your schedule and apologize for this. However, the PAC could probably put the time to better use on other matters, since they would take no action on E-122 yet. I hope these matters will be well sorted out for the next PAC meeting. Please pass this information along to the PAC.

The SLAC Injector

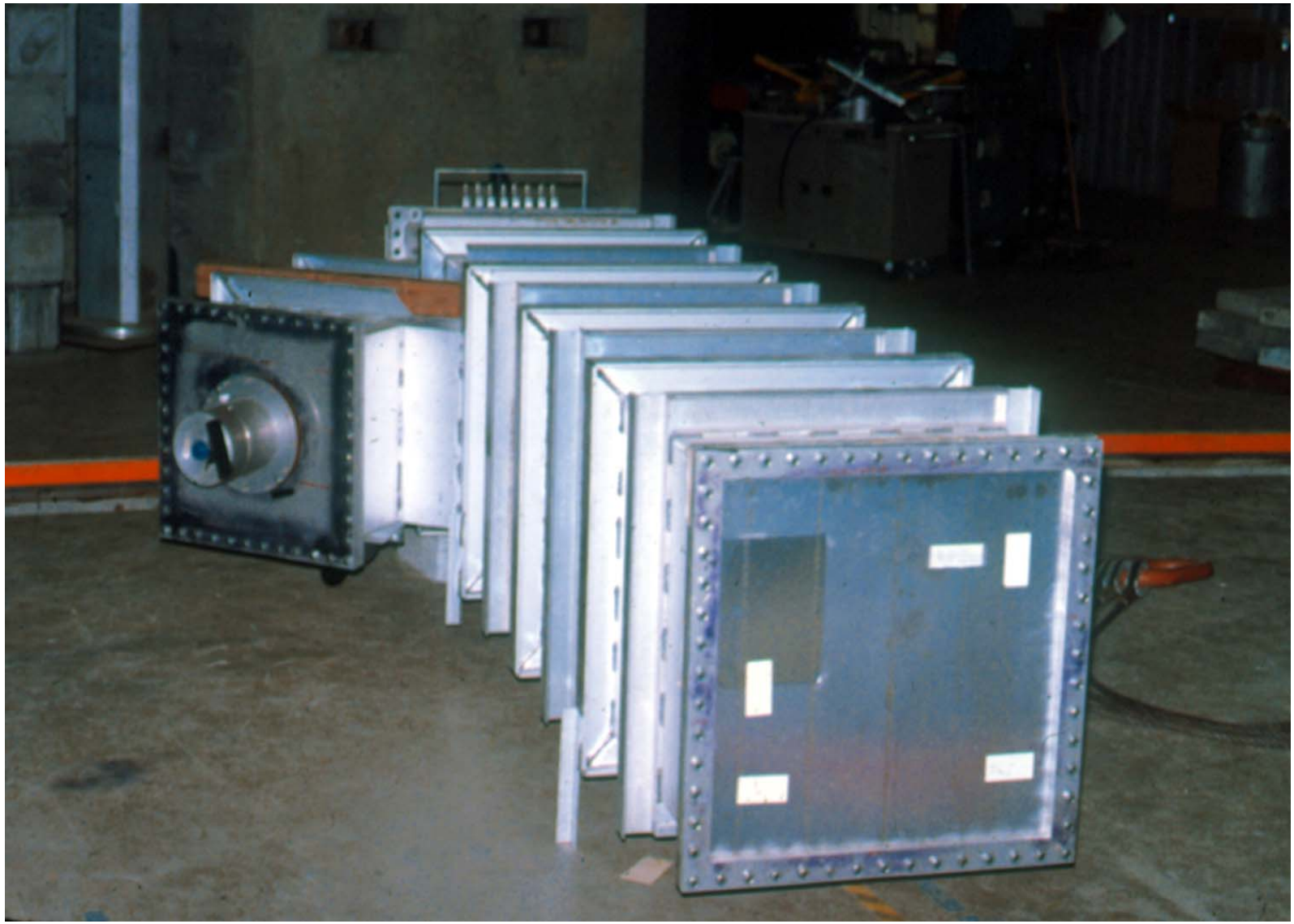


Overall view of the SLAC polarized electron gun and polarization analysis system.

Source Works!!

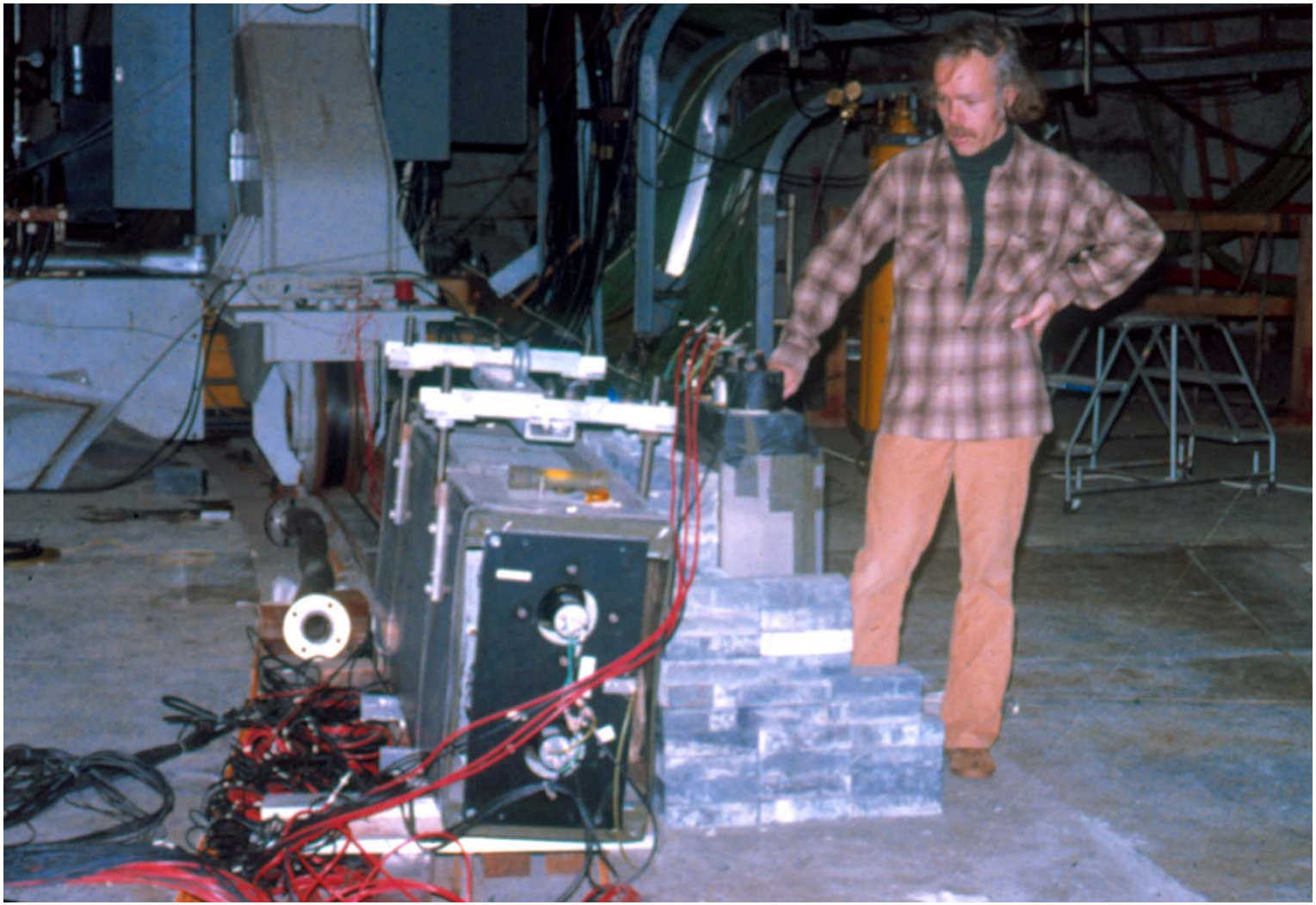


Building the Experiment



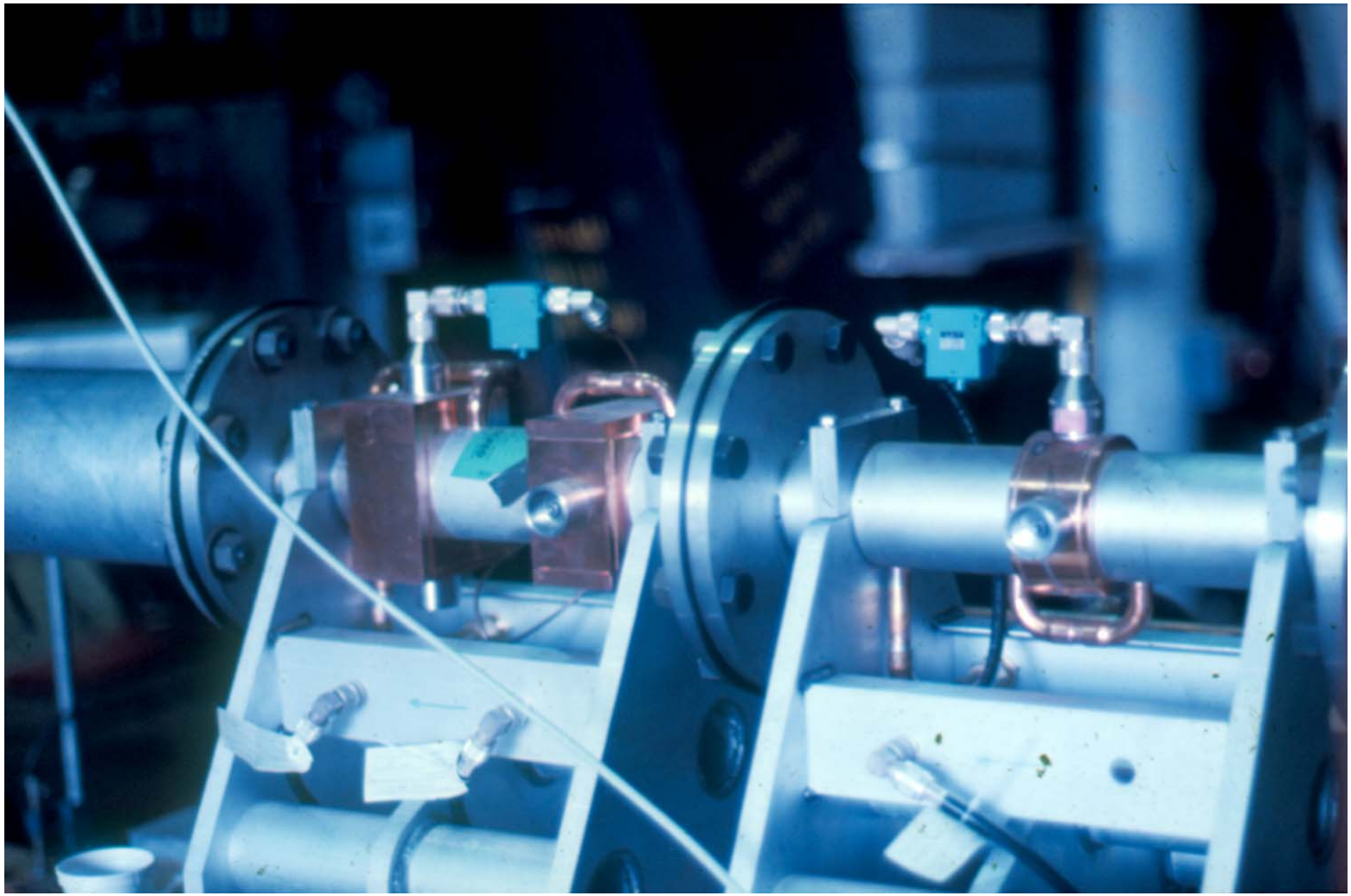
Cerenkov counter

Building the Experiment

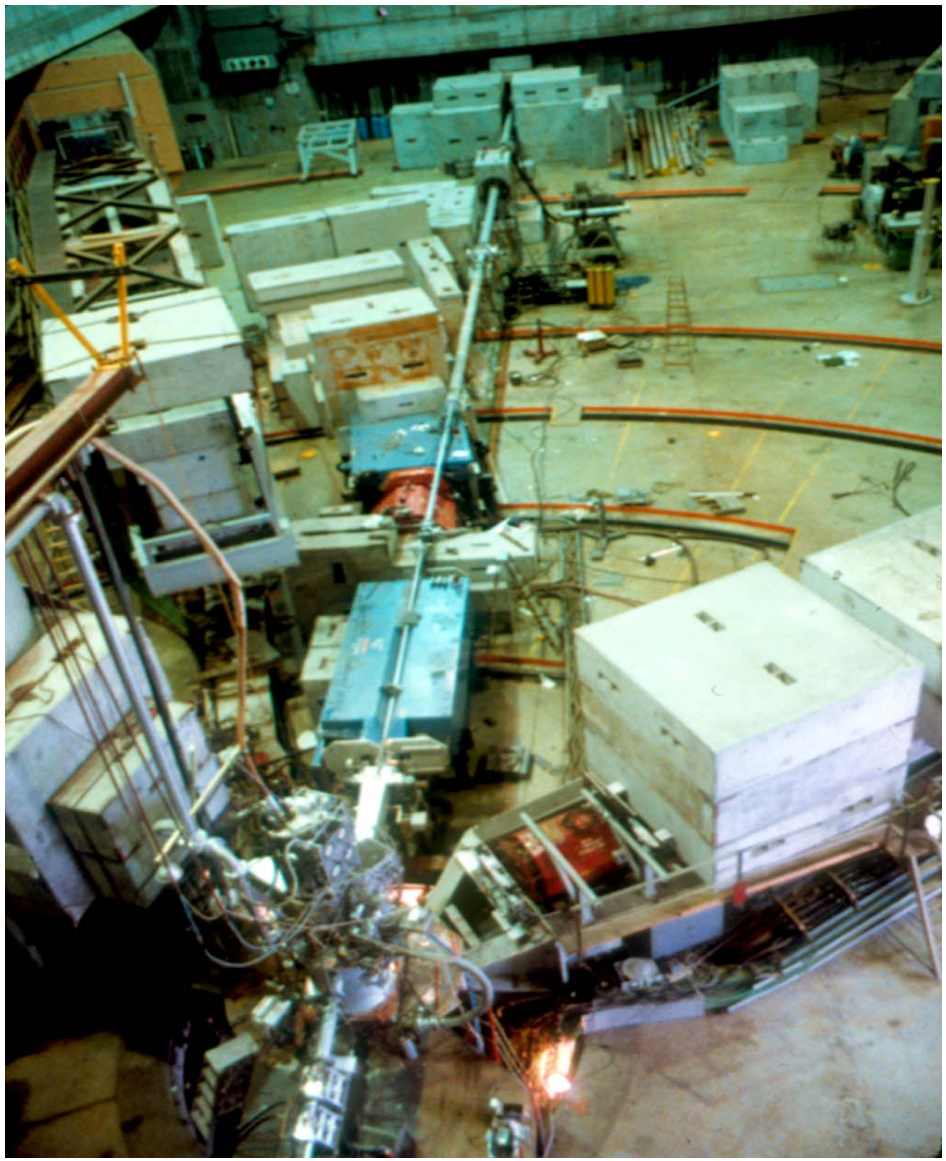


Lead Glass Shower Counter Pion Counter Bill Atwood

Building the Experiment



Building the Experiment



A Model of Leptons

Steve Weinberg - 1967

By 1977 many of the issues of neutral currents were being resolved in neutrino scattering. But one issue remained…. The assignment of the right-handed electron into a singlet or a doublet.

Parity violation distinguished the two choices.

$$\begin{pmatrix} \nu \\ e \end{pmatrix}_l \quad (e)_r$$

Parity is violated

or

$$\begin{pmatrix} \nu \\ e \end{pmatrix}_l \quad \begin{pmatrix} E^\circ \\ e \end{pmatrix}_r$$

Parity is conserved

Atomic Parity Violation to the rescue!!!!

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….the death knell for the W-S model!!!

VOLUME 39, NUMBER 13 PHYSICAL REVIEW LETTERS 26 SEPTEMBER 1977

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 $J=3/2$—$J=5/2$ M_1 transition from the ground state. We find $R=\mathrm{Im}(E_1/M_1)=(+2.7\pm4.7)\times10^{-8}$, in disagreement with the theoretical value $R=-30\times10^{-8}$ 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

VOLUME 39, NUMBER 13 PHYSICAL REVIEW LETTERS 26 SEPTEMBER 1977

[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 $R=\mathrm{Im}(E_1/M_1)=(-0.7\pm3.2)\times10^{-8}$, which is considerably smaller than the value $R=-2.5\times10^{-7}$ 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 $J=\frac{3}{2}\to J=\frac{5}{2}$ 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.

The Rest of the Bismuth PV Story

Atomic Parity Violation in bismuth still was unresolved. Novosibirsk had announced observation of PV in March 1978 (while we were running) but in 1980 Moscow reported a null result. Eventually the experiments settled down and the theory seemed to agree. Clear evidence didn't emerge in the bismuth system. The cesium work in the Commins group at Berkeley cleaned up the issues best.

Today Colorado has done the best atomic PV work with cesium, but their results don't make it on most S-T plots.

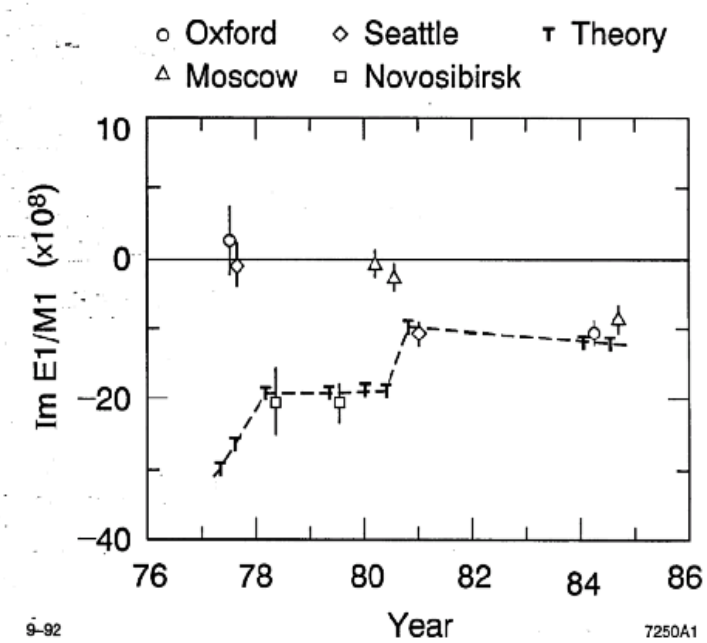
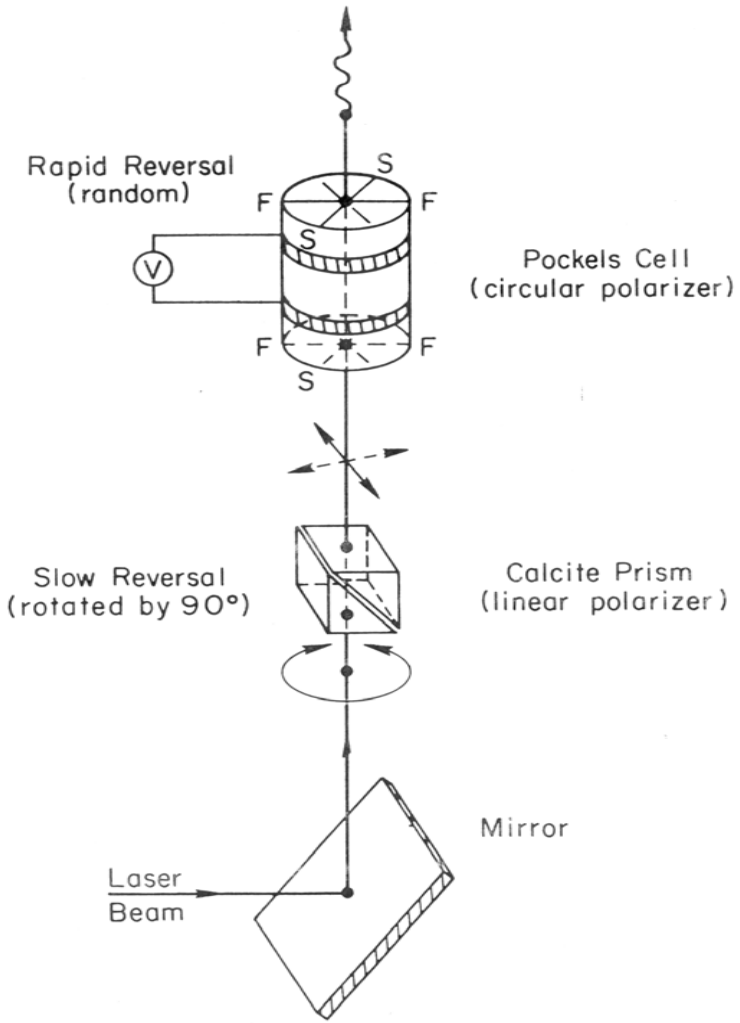
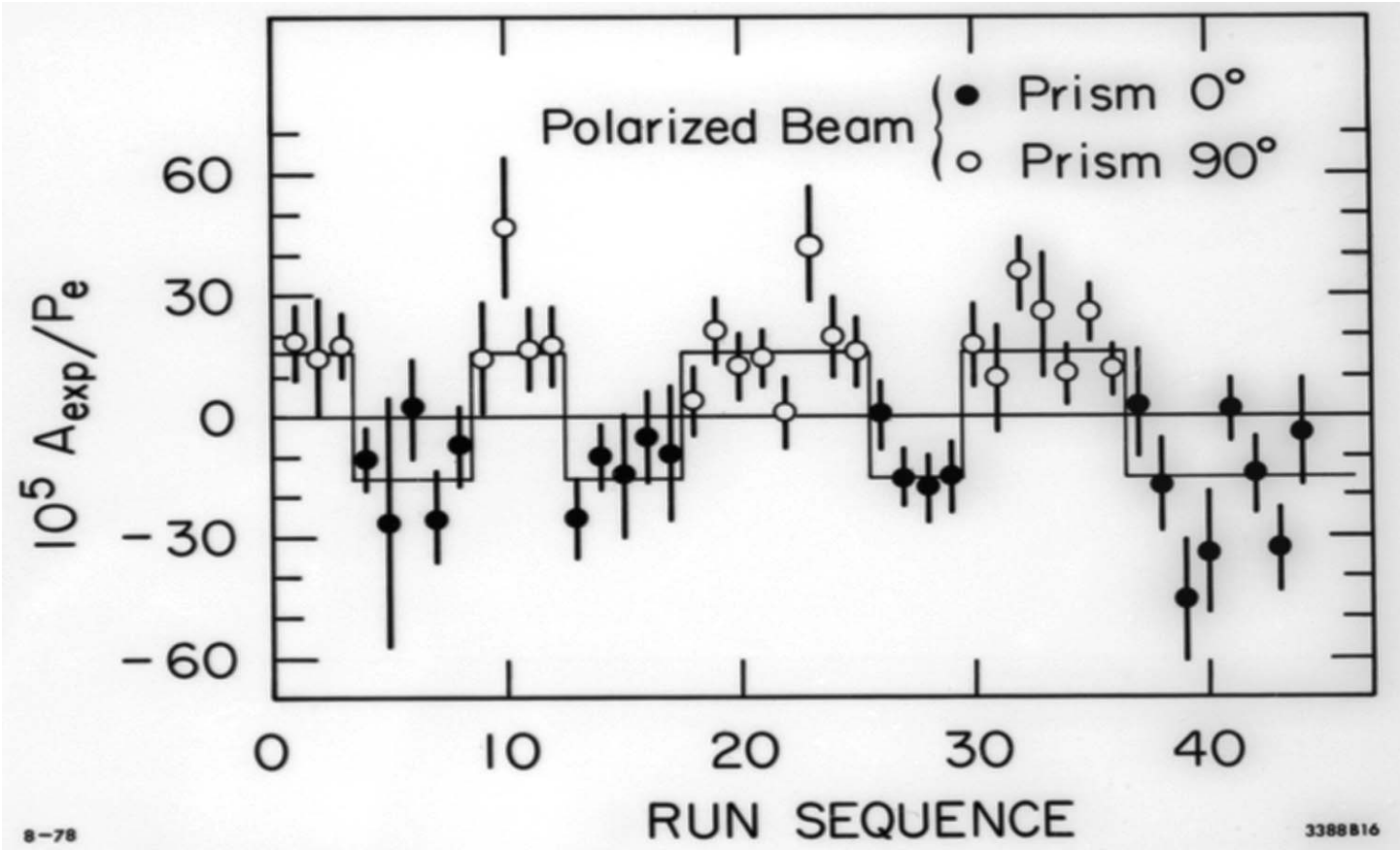


Fig. 1

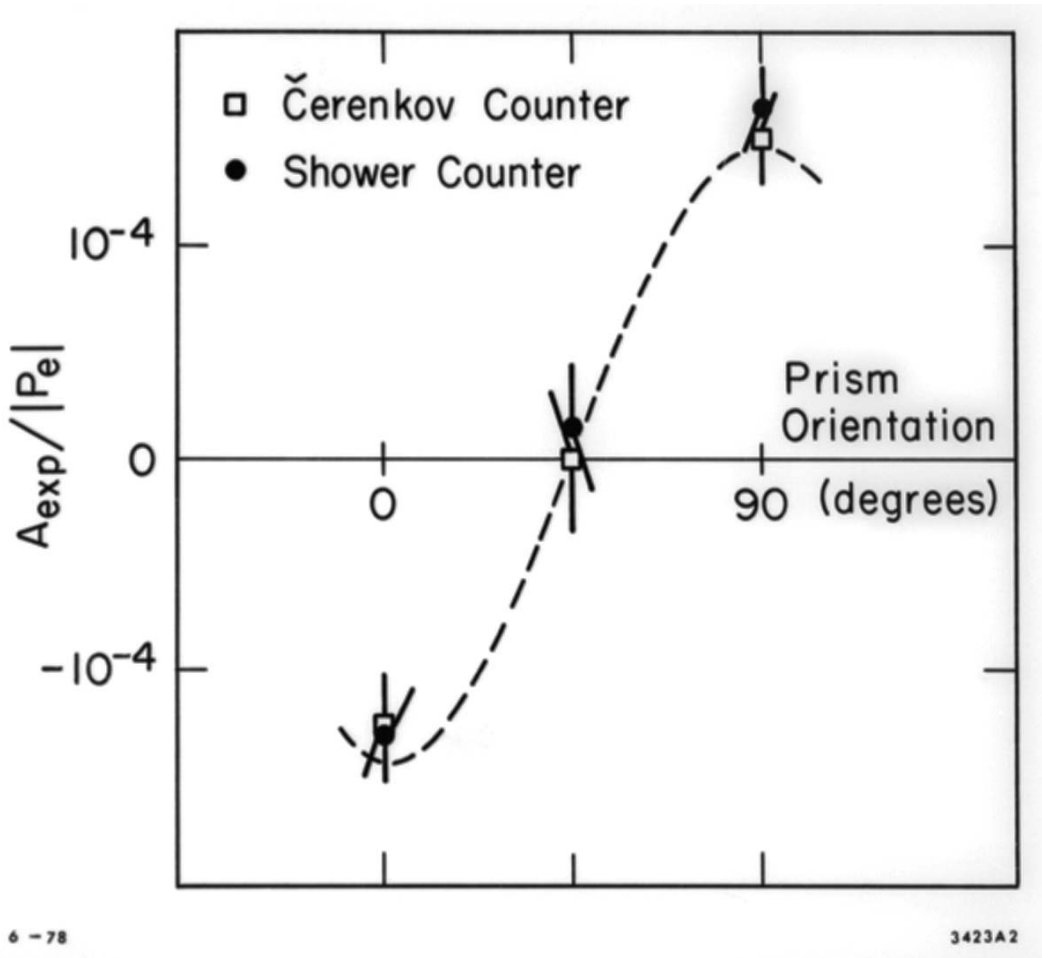
E122 Prism Rotation



Running E122



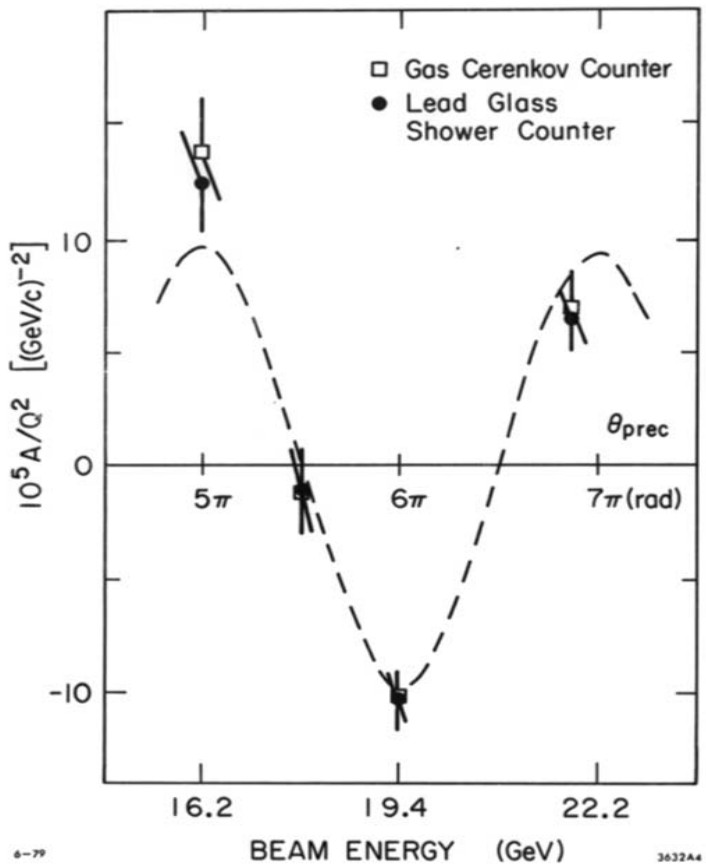
Prism Orientation



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.

$\sin^2 \Theta_w = 0.20 \pm .03$



Harvard, then Trieste

IL PICCOLO

GIORNALE DI TRIESTE

LO HA AFFERMATO L'AMBASCIATORE AMERICANO GARDNER

Trieste centro intellettuale

PARLANO GLI ESPONENTI

Rinaldi: la Dc è

DECADIMENTO RADIOATTIVO E FORZE ELETTROMAGNETICHE

La teoria Salam-Weinberg confermata dagli americani

L'importanza della scoperta viene paragonata a quella di Newton

Nell'ambito della sesta conferenza sulla fisica delle particelle al Centro internazionale di fisica teorica di Miramare, il risultato in assoluto di maggior interesse, non solo per gli ambienti scientifici mondiali ma anche per la cronaca cittadina, è emerso da una comunicazione fatta dal prof. Charles Prescott del laboratorio Slac (cioè dell'acceleratore lineare) di Stanford (California). Lo studioso americano ha annunciato il pieno successo di un esperimento (per il quale sono occorsi cinque anni di preparativi minuziosi e sei mesi per la realizzazione) che confermerebbe quella che il consulente scientifico del «Times» di Londra ha definito «una delle più importanti teorie della fisica dopo quella di Newton sulla forza di gravità».

La notizia riveste importanza particolare anche per Trieste in quanto la teoria è frutto degli studi del prof. Agdus Salam, direttore del Centro di fisica teorica di Miramare, e del prof. Steven Weinberg della Harvard University. L'esperimento («etremamente complicato e laborioso», ha ammesso il prof. Prescott) darebbe la conferma in maniera ufficiale, apre nuove prospettive per la comprensione delle proprietà e dell'interazione proprie delle particelle elementari del nucleo atomico.

«E' stato uno degli esperimenti più importanti degli ultimi anni — ha dichiarato il prof. Salam — dopo questo esperimento posso veramente dire di credere alla mia teoria».

Prof. Abdus Salam

Il cinquantaduenne direttore del Centro di Miramare si è complimentato con il prof. Prescott, che, a 39 anni, è uno dei più prestigiosi componenti dell'équipe del laboratorio californiano. Alle varie fasi dell'esperimento hanno preso parte 20 fisici e 40 tecnici di diversi laboratori, dalla Yale University al Cern di Ginevra, dalla Scuola superiore di Aguisgrana all'Istituto di fisica sperimentale di Amburgo. In sei anni di lavoro, le prove hanno impegnato numerosi esperti delle diverse branche della fisica, da quella dei laser alla fisica allo stato solido.

Prof. Prescott (Italfoto)

La teoria Weinberg-Salam (così, infatti, è conosciuta negli ambienti scientifici internazionali) afferma che le forze che presiedono al cosiddetto «radioactive decay» (letteralmente, «decadimento radioattivo») e quelle che tengono insieme gli atomi sono due aspetti di una medesima forza. Se questa teoria «unificante» («unifying theory») è corretta — questo è ciò che ha dimostrato, fino a prova contraria, l'esperimento di Stanford — l'importanza della scoperta è equiparabile a quella che fece Isaac Newton quando, grazie alla famosa mela, scoprì la legge di gravità, e successivamente dimostrò che la forza responsabile della caduta degli oggetti era la medesima che tiene la Terra in orbita attorno al Sole.

La verifica della teoria di portato a termine non adoperando gli atomi bensì particelle ancora più piccole, cioè gli elettroni e i neutroni, per «sondare» il nucleo dell'atomo di idrogeno, per accertare la consistenza della teoria Weinberg-Salam sull'unificazione delle interazioni deboli ed elettromagnetiche. Il successo che ha coronato l'esperimento sembra che abbia convinto anche i fisici più dubbiosi. Noi lo riferiamo in termini di cronaca (al di là della spiegazione «tecnica» della scoperta) per l'importanza della notizia in sé, augurandoci di poter annunciare presto un riconoscimento internazionale per il prof. Abdus Salam e il suo collega statunitense.

Messa di suffragio per mons. Fogar

Domani, sabato, alle ore 19.30, nella chiesa parrocchiale di San Giacomo, il vescovo mons. Belloni celebrerà una messa di suffragio per mons. Luigi Fogar, già vescovo di Trieste.

Il comitato per le onoranze a mons. Luigi Fogar, nell'intendimento di tenere sempre vivo il ricordo e l'insegnamento dell'indimenticabile presule, invita tutti i soci della Gioventù italiana di azione cattolica, i sacerdoti della diocesi, soci e simpatizzanti dell'Azione cattolica e quanti intendano onorarare la memoria di mons. Luigi Fogar ad intervenire al rito.

Dopo la messa, mons. Belloni si incontrerà con tutti gli ex soci della Giac, promotori dell'iniziativa, nella sala parrocchiale di campo San Giacomo 10.

FINANZA STA RICERCANDO TRE TRIESTINI

RECRUDESCENZA DEGLI ATTI

A test of electroweak unification

THE NEW YORK TIMES, TUESDAY, JULY 11, 1978

New Support Is Reported for Unified Force Theory

By MALCOLM W. BROWNE
Special to The New York Times

By ricocheting spinning electrons off the nuclei of atoms, a group of physicists from Stanford and Yale Universities and other institutions have discovered convincing new support for a theory that would unify two of nature's fundamental forces.

Most nuclear physicists familiar with the work believe, partly as a result, that the possibility is greater than ever that all of nature's four known forces will soon be unified by a common theory—a dream shared by Albert Einstein with many other scientists.

A unified field theory, scientists believe, would go far toward explaining the structure and origin of the universe, as well as crystallizing man's knowledge of physical law into a coherent whole.

The Stanford-Yale experiment, which was carried out using Stanford's powerful linear atomic particle accelerator, measured precisely the degree of "right-handed" or "left-handed" spin of electrons scattered by the nuclei with which they collided. It was found that there was a slight but vitally significant difference in the number of right-handed and left-handed electrons scattered.

A Violation of 'Parity'

This was a clear violation of what scientists call "parity"—the even-handed symmetry that governs the more familiar atomic and electromagnetic interactions. But just such a violation had been exactly predicted by a theory propounded a decade ago by an American, Steven Weinberg, a physicist, of Harvard University, and a Pakistani, Abdus Salam of Imperial College, London.

The work of Drs. Weinberg and Salam, which was conducted independently, resulted in a theory of the type known to mathematicians as a "gauge theory." The gauge theory in this case related the familiar force known as electromagnetism with one that operates only inside atoms—the "weak force."

The weak force is part of the radioactive decay of atomic nuclei and helps explain how the sun burns its hydrogen fuel to helium, among other things.

Besides electromagnetism and the weak force, scientists are aware of two other forces: gravity, and the "strong force"—the force that holds atomic nuclei together.

There is evidence that the strong force may, with the aid of some new gauge theory yet to be developed, be related to both electromagnetism and the weak force. This would leave the integration of gravity with the first three forces as the most perple
rists.

But even
hints of sol
in the form
gravity.

The exp
Stanford-Y

seminar June 12 by Dr. Richard Taylor of the Stanford accelerator staff.

Dr. Taylor said in a telepho interview: "Our experiment is probal as significant in demonstrating th idity of the Weinberg-Salam theory a is an experiment performed in 197 the European Nuclear Research Ce near Geneva, Switzerland. But this n work of ours is impressive enough, we k, to convince virtually all the re ning doubters."

Beginning of Experimen

The Stanford-Yale experime began with a mineral known as galli arse-nide, Dr. Taylor said, which is c e of emitting a beam of spinning rons when energized by circularly larized light.

"We get a beam intense enou h for an

SCIENCE NEWS OF THE WEEK

July 8, 1978

A Giant Step Toward Unified Field Theory

The use of field theory, which connects forces to characteristics of space and describes them by means of equations with geometrical content, is an old tradition in physics. We speak of the earth as being in the gravitational field of the sun. In school most people have seen the demonstration of a magnetic field using iron filings; textbooks represent electric fields with bundles of lines in the manner of Michael Faraday.

This geometrizing tendency has yielded many dividends from philosophy to practical technology. Among theoretical physicists it has aroused the long-standing hope of a unified field theory—essentially one description uniting all kinds of force. At the moment there are four known kinds of force (or interaction, as physicists prefer to say): gravity, electromagnetism and the weak and strong interactions of the subatomic domain.

The modern unified field theory, often called the Weinberg-Salam model after Steven Weinberg of Harvard University and Abdus Salam of Imperial College, London, begins with the weak and electromagnetic interactions. An experiment recently done at the Stanford Linear Accelerator Center has confirmed some key

for left or right. This principle of space-reflection symmetry or parity was one of three symmetry principles — the other two are time-reversal symmetry and symmetry of positive and negative electric charges or matter and antimatter — that all physical processes had to respect.

It is now known that for parity at least, some respect it and some do not. Processes governed by the weak interaction are particularly notorious for disrespect to the principle of parity, and what is relevant for the present case is that the formulations of Weinberg and Salam increase the possibilities for such violations and make them a likely means of testing whether this theory is a good description of what's going on. The Weinberg-Salam formulation provides a whole new class of weak-interaction processes, the neutral-current processes.

A neutral-current process is one in which two particles interact without exchanging a unit of electric charge. If a neutrino strikes a proton and bounces off, and the neutrino remains a neutrino and the proton remains a proton, that's a neutral-current interaction. (Before Weinberg and Salam the weak interaction had only charged-current interactions, those

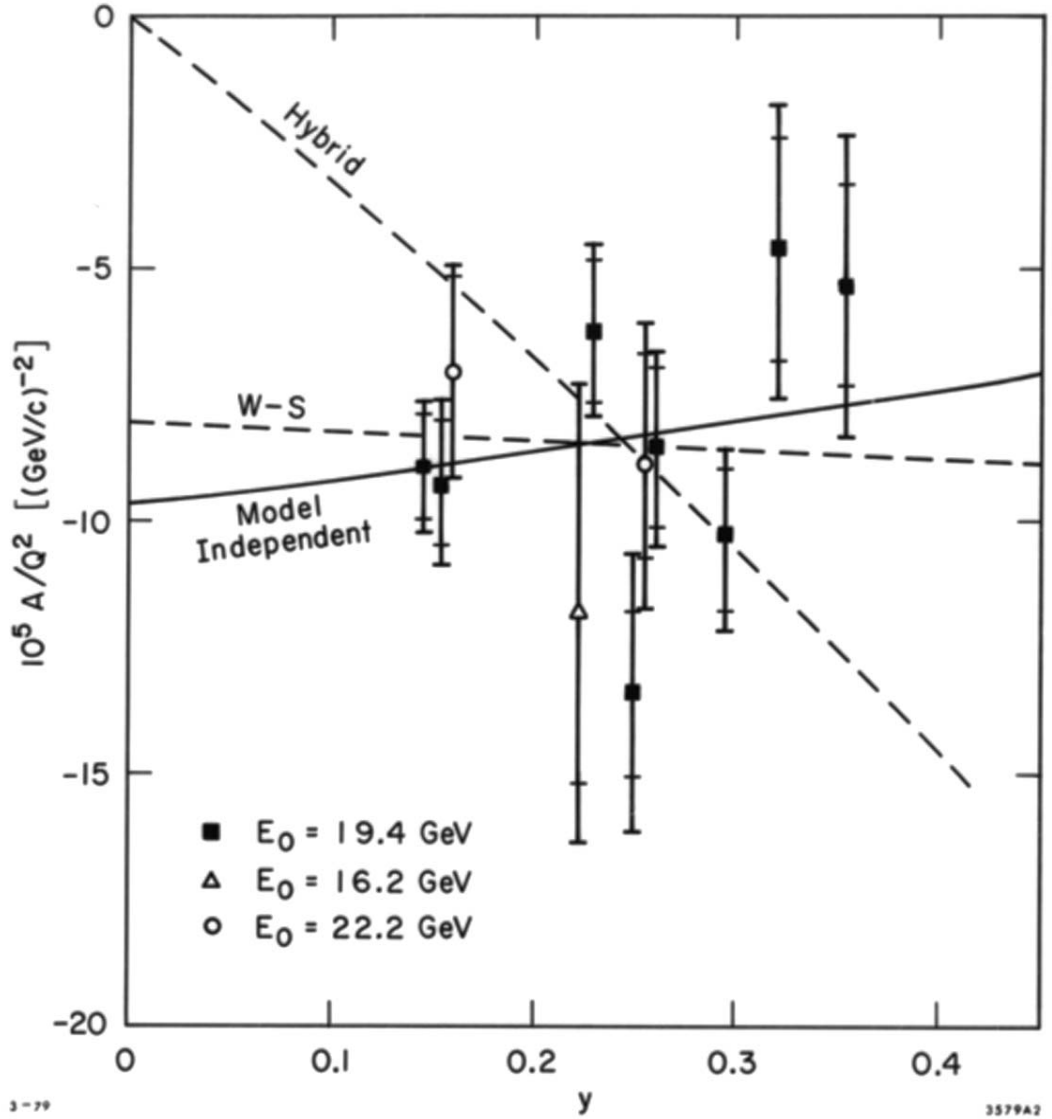
Harvard Univ

The ten-year-old unified field theory of Weinberg and Salam (bottom) gets an experimental shot in the arm.

other force is the weak interaction. "That's an assumption," says Richard Taylor, one of the experimenters, but it's a plausible one. The weak interaction exists; nothing else is known that might be causing the effect. If it is the weak interaction, then it is a neutral-current process, because no charge is exchanged between the electron and the proton. So it must be a neutral

E122 Models

E122 resumed running in the Fall of 1978. This time around, we shared the beam with SPEAR…we ran during the stores, and shut down during the fills, which were quick and efficient due to our control of the beam.
We studied the y-dependence…



E122 Final Result

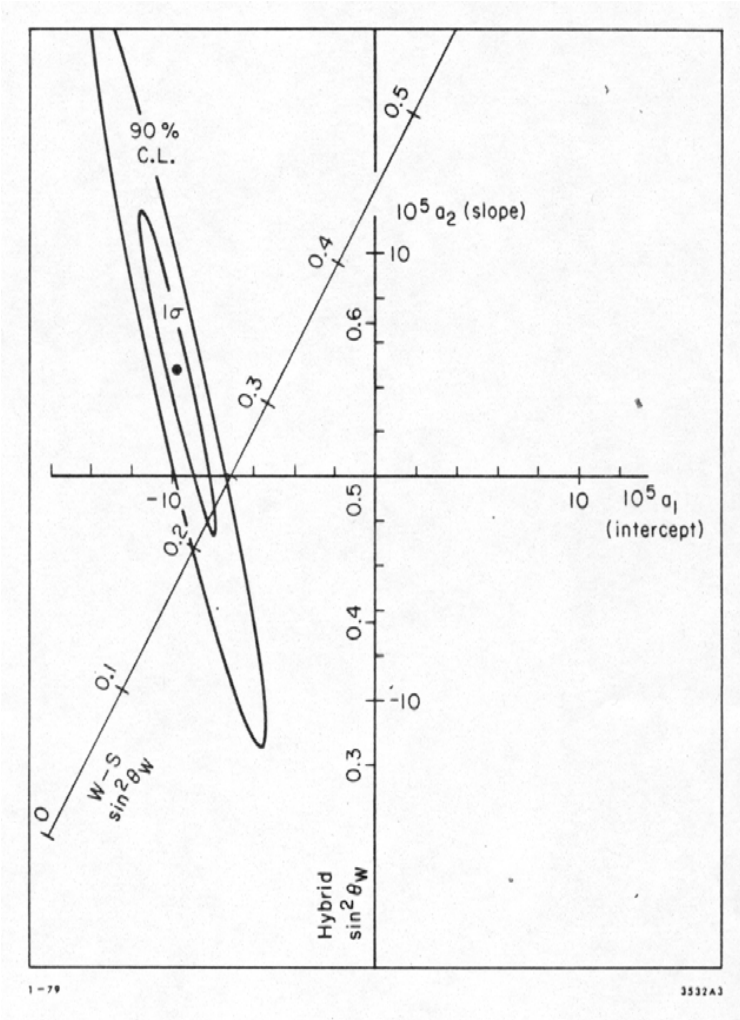
The final E122 results were published in Physics Letters B In 1979

$$\mathbf{\sin^2\Theta_W = 0.224 \pm 0.020}$$

(PL **B84**, 524 (1979))

Today's values from global fits gives

$\sin^2\Theta_W = 0.23156 \pm 0.00017$



SEQUEL

Subsequently……

SLAC went on to a series of spin structure experiments for the proton, deuteron, and He-3
and
To precision electroweak measurements with polarized electrons at the Z-pole

Jefferson Lab has developed an extensive program using polarized electrons as a probe of the nucleon…..

So, advice as you look toward the future
A quote from a famous philosopher

`` I don't want to achieve immortality through my work…

I want to achieve it through not dying''

Woody Allen