# The Ψ Discovery

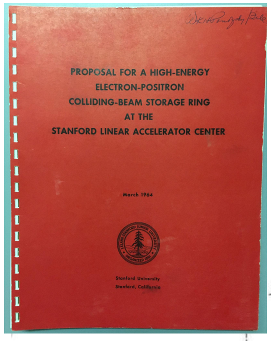
Martin Breidenbach

November 9 is the 50th anniversary of the $\Psi$ discovery and the beginning of the November Revolution.

Unfortunately, a 50th anniversary is a rather long time, and many of the principals are gone. More at the end of this.

Following are my recollections of that weekend in 1974 and the beginning of the "November Revolution".

# SPEAR - The first proposal - 1964   Led by Burton Richter


PROPOSAL FOR A HIGH-ENERGY ELECTRON-POSITRON COLLIDING-BEAM STORAGE RING AT THE STANFORD LINEAR ACCELERATOR CENTER

March 1964

Stanford University
Stanford, California

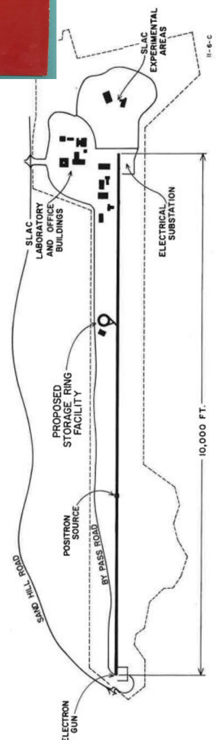
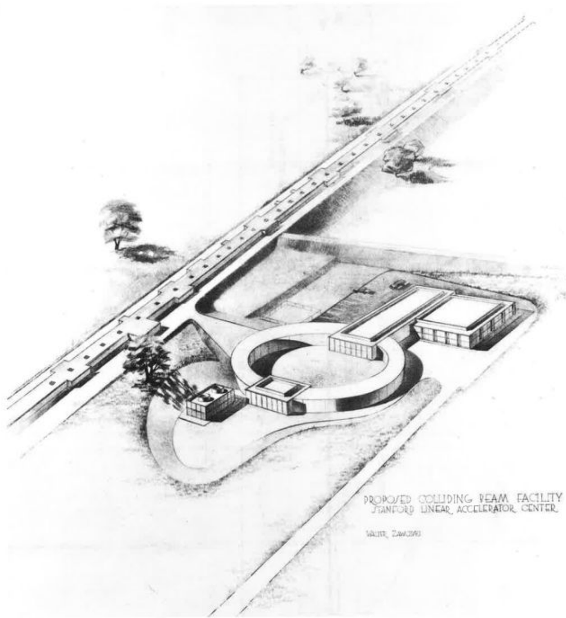



FIG. 12--Location of the proposed storage-ring facility on the SLAC site.

- 45 -

SLAC AHRO




PROPOSAL

It is proposed that the Atomic Energy Commission support the construction at Stanford University of a Colliding-Beam Facility (storage ring) for high-energy electrons and positrons. This facility would be located at the Stanford Linear Accelerator Center, and it would make use of the SLAC accelerator as an injector.

This proposal was prepared by the following persons:

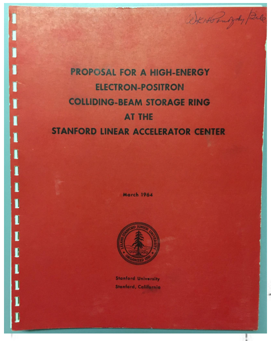
Stanford Physics Department

D. Ritson

Stanford Linear Accelerator Center

S. Berman
A. Boyarski
F. Bulos
E. L. Garwin
W. Kirk
B. Richter
M. Sands

# SPEAR - The first proposal - 1964



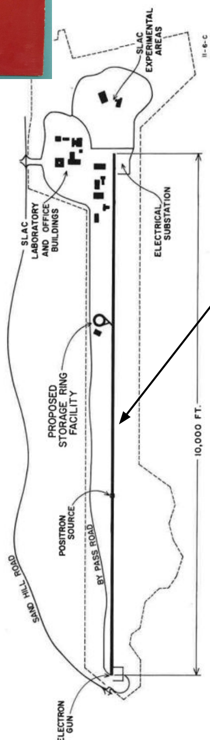
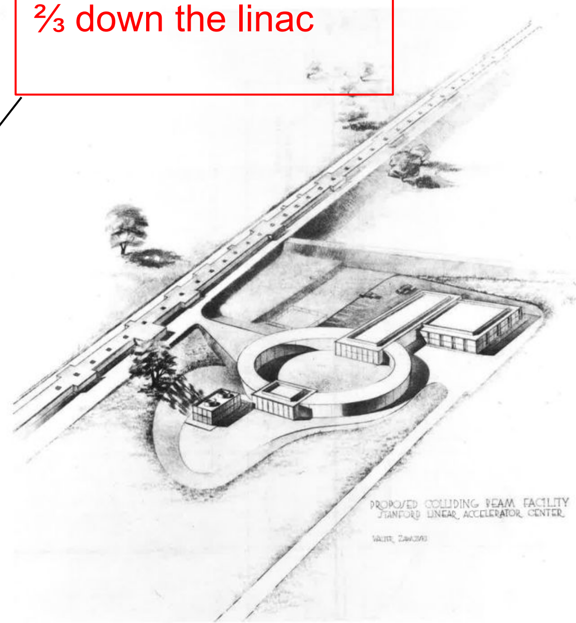




FIG. 12--Location of the proposed storage-ring facility on the SLAC site.

- 45 -

SLAC AHRO

⅔ down the linac




RichterS6d_B12f2

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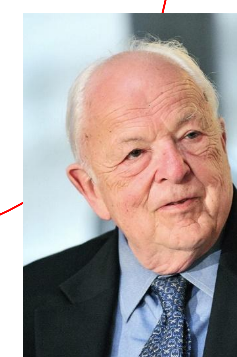
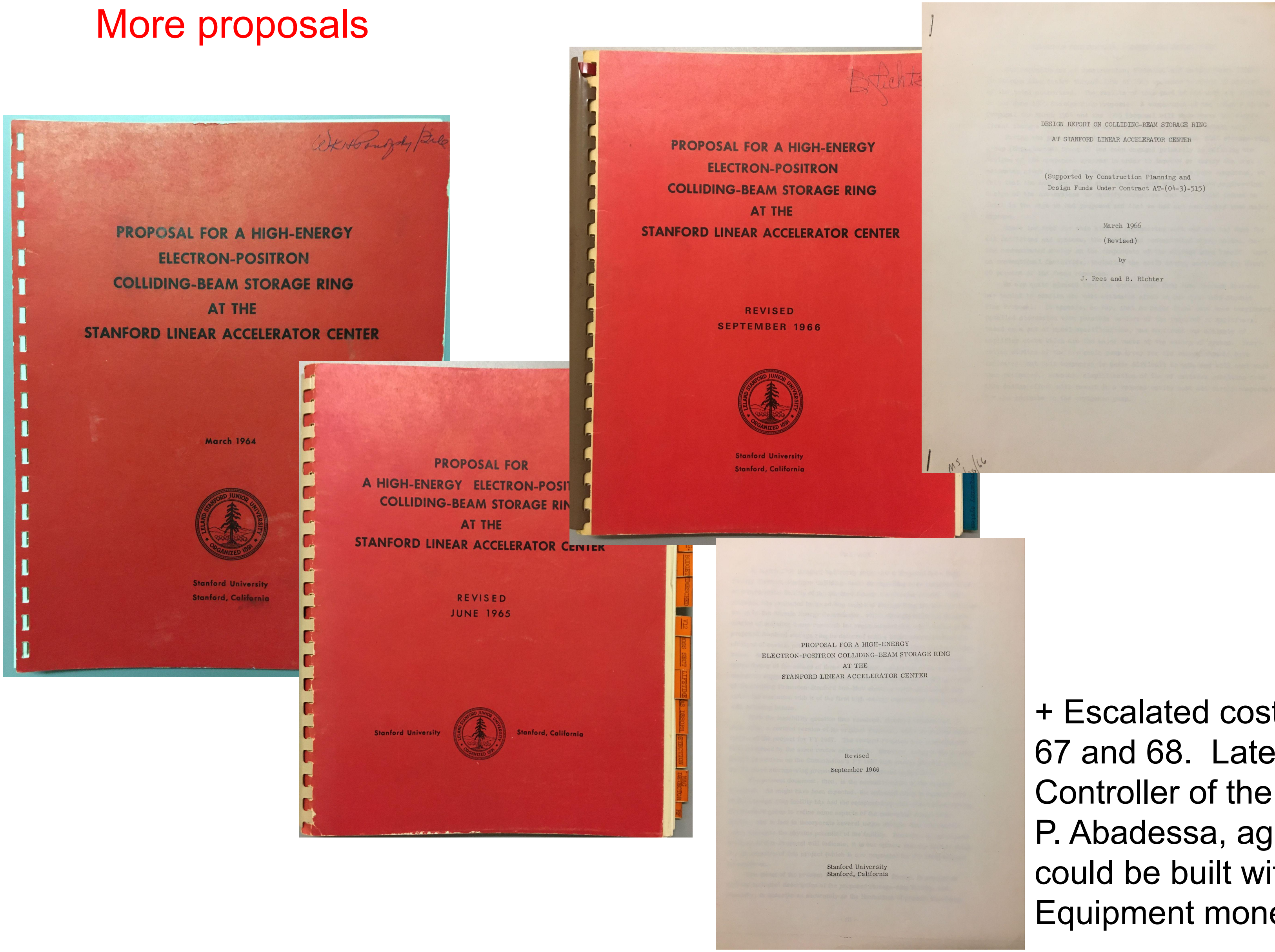


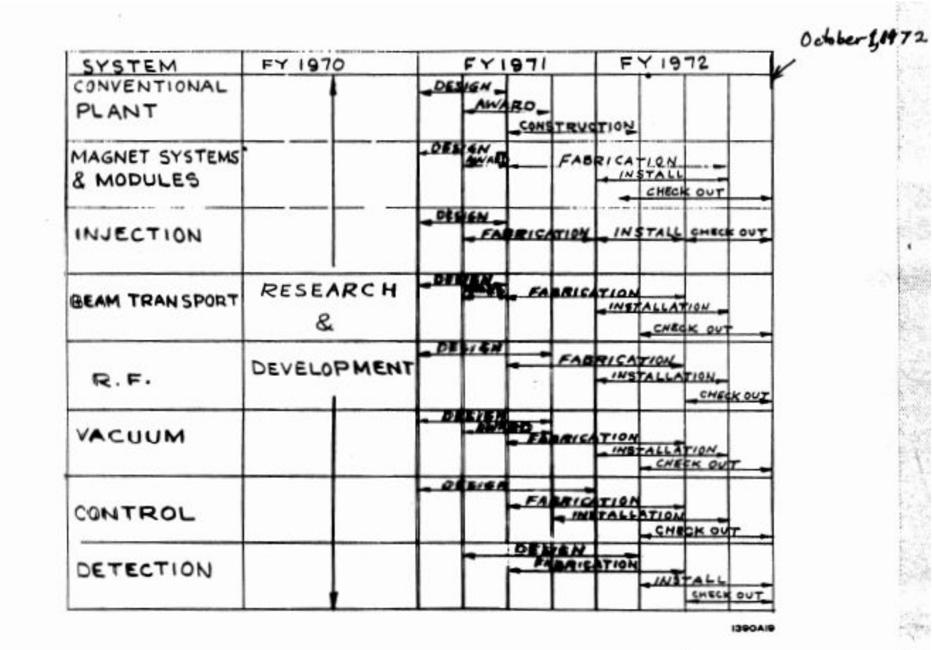
Relatively luxurious

# More proposals




+ Escalated cost estimates in 67 and 68. Late 69, the Controller of the AEC, John P. Abadessa, agrees SPEAR could be built with Equipment money

# The Spear Schedule




5. *CONSTRUCTION*

(a) Originally we thought it would take about two years to build, but we found that we were spending money too fast, so we did what any alert project managers would do: we shortened the schedule.

From John Rees - The Genesis of Spear 1990(?)

# SPEAR, before SSRP and SSRL,

## was a parking area

End Station A, deep inelastic scattering, pointlike structure in nucleons

Injection lines

West Pit, enclosing SLAC-LBL Magnetic Detector

SPEAR, 780 ns around

Power Supplies

Control Room, SPEAR and Detector

# SPEAR, ~1973

SPEAR was approved after a long struggle.
Built for $6M, with operations commencing 21 months after approval.

# SPEAR in 1973 - 1974

- We were working on an overdue paper on $R=\sigma_h / \sigma_{\mu\mu}$ vs $\sqrt{S}$
- R $= \sum_i q_i^2$ was strangely large in results from ADONE and the CEA, hinting at colored quarks.


- "Accepted Wisdom" was that resonances were unlikely, but if something was there it would be several hundred MeV wide and with an R increase of a few.
- At SPEAR, in 1973, we measured R from 2.4 to 4.8 GeV in 200 MeV steps, and the runs at 3.2 and 4.2 GeV seemed high. In June of 1974, we re-measured 3.1, 3.2, and 3.3 GeV- and 4.1, 4.2. and 4.3 GeV just before the summer shutdown. I did a quick analysis and left the logbook note " The Whiz-Bang Analysis Team says there is no bump at 4.2 Gev".

# 1974

- Several of us, led by Roy Schwitters, looked harder at the data around 3.1 GeV, and found that runs at the same nominal energy had statistically inconsistent values of R. Suspecting software, we went to the first video display at SLAC connected to the mainframe (a huge monstrosity that had to be reserved in advance), and we classified event pictures and made tallies by hand. Nothing could be found wrong with the analysis.

- That summer, SPEAR was upgraded to SPEAR 2, and planned to run above 5 GeV. Roy, Ewan Paterson, and I argued with Richter to go back to 3.1 GeV. Burton argued that it was more interesting to move forward into new territory. That Friday, Gerson Goldhaber reported (incorrectly as it turned out) that the high σ runs at 3.1 had an excess of $K_s$ . We were given the weekend "to waste".

# The Control Room Scene

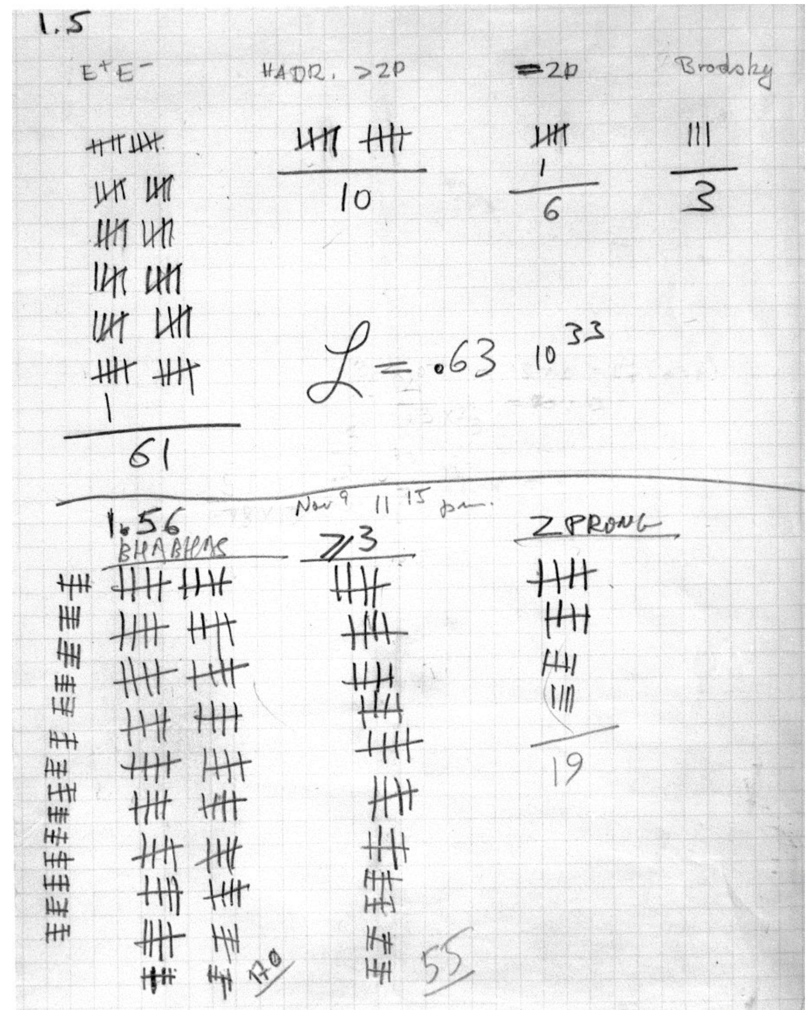
The epicenter of the Control Room.


Reel to reel tape drives.
Reels mounted by hands!
140 Mbytes/Reel

A modern version of the Teletype, but still an important human interface

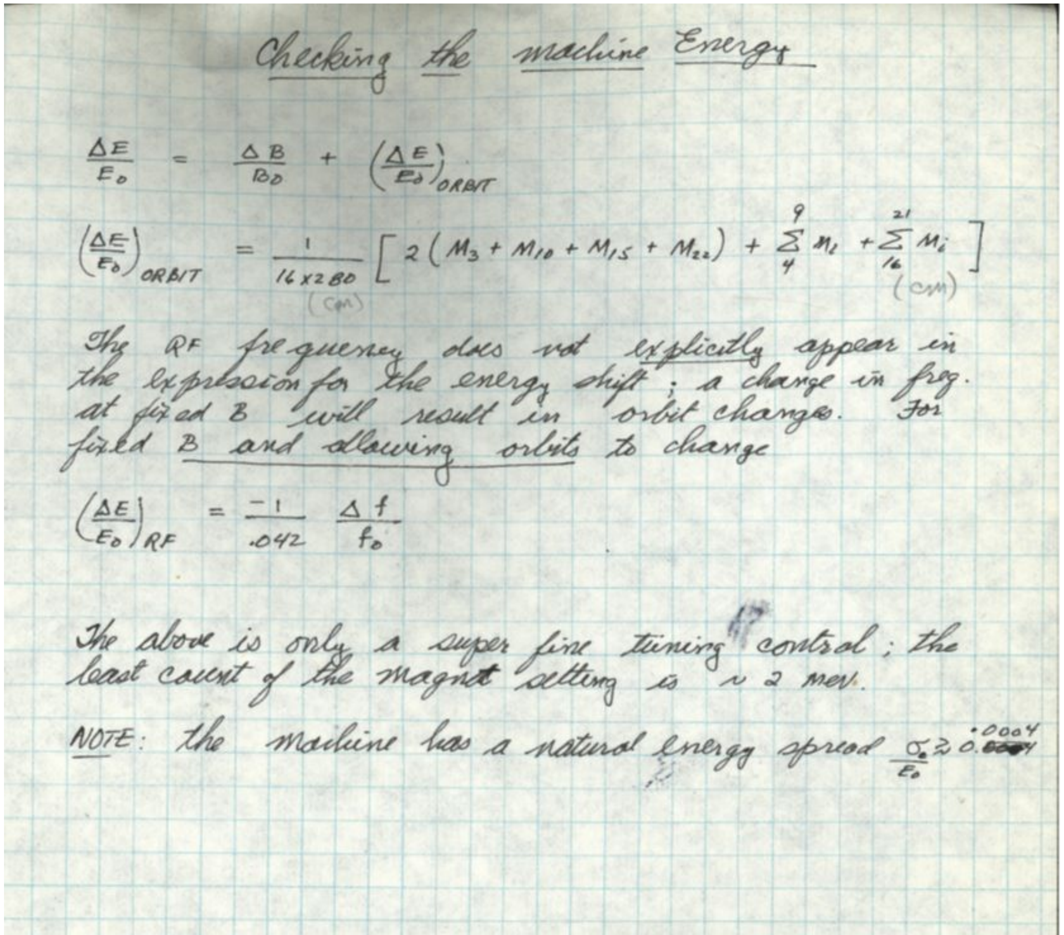
# Saturday Evening

mb, Gerson, Ewan, Herman Winick, Francois Vannucci




Rudy Larsen, Gerson Goldhaber

# SPEAR Beam Energy



Checking the machine Energy

$$\frac{\Delta E}{E_0} = \frac{\Delta B}{B_0} + \left(\frac{\Delta E}{E_0}\right)_{ORBIT}$$

$$\left(\frac{\Delta E}{E_0}\right)_{ORBIT} = \frac{1}{16 \times 280 \text{ (cm)}} \left[ 2\left(M_3 + M_{10} + M_{15} + M_{22}\right) + \sum_{4}^{9} m_i + \sum_{16}^{21} M_i \right] \text{(cm)}$$

The RF frequency does not explicitly appear in the expression for the energy shift; a change in freq. at fixed B will result in orbit change. For fixed B and allowing orbits to change

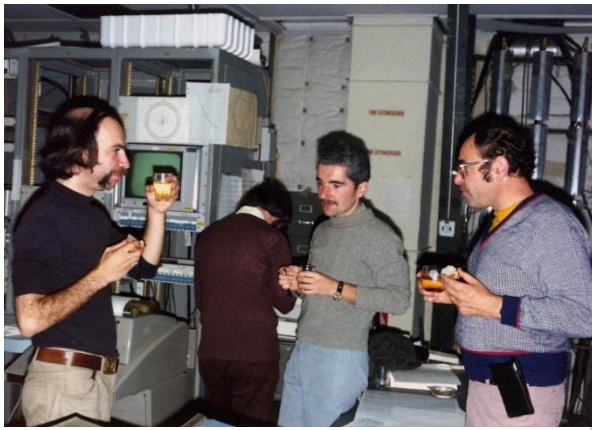
$$\left(\frac{\Delta E}{E_0}\right)_{RF} = \frac{-1}{.042} \frac{\Delta f}{f_0}$$

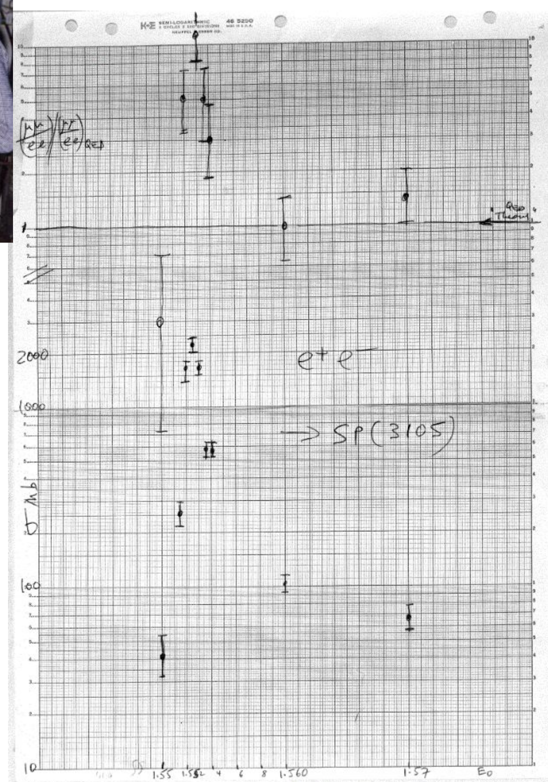
The above is only a super fine tuning control; the least count of the magnet setting is ~ 2 MeV.

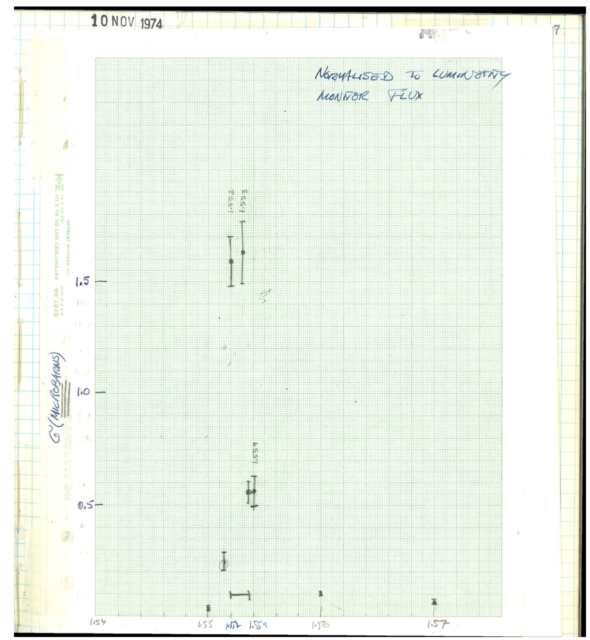
NOTE: the machine has a natural energy spread $\frac{\sigma_E}{E_0} \approx 0.0004$

The SPEAR bend magnets, and thus beam orbit – set the beam energy. The DAC that set the magnet current was too coarse, and one bit stepped over the resonance. We realized that changing the RF frequency slightly would change the beam radius, and could Vernier the energy.

# Sunday




e+e−
→ SP(3105)
1.55
1.560
1.57


10 NOV 1974
NORMALISED TO LUMINOSITY MONITOR FLUX
1.5
1.0
0.5

# Monday

**Discovery of a Narrow Resonance in $e^+e^-$ Annihilation***

J.-E. Augustin,† A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie,† R. R. Larsen, V. Lüth, H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl, B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum, and F. Vannucci‡
*Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305*

and

G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhaber, R. J. Hollebeek, J. A. Kadyk, B. Lulu, F. Pierre,§ G. H. Trilling, J. S. Whitaker, J. Wiss, and J. E. Zipse
*Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720*
(Received 13 November 1974)

We have observed a very sharp peak in the cross section for $e^+e^- \to$ hadrons, $e^+e^-$, and possibly $\mu^+\mu^-$ at a center-of-mass energy of $3.105 \pm 0.003$ GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

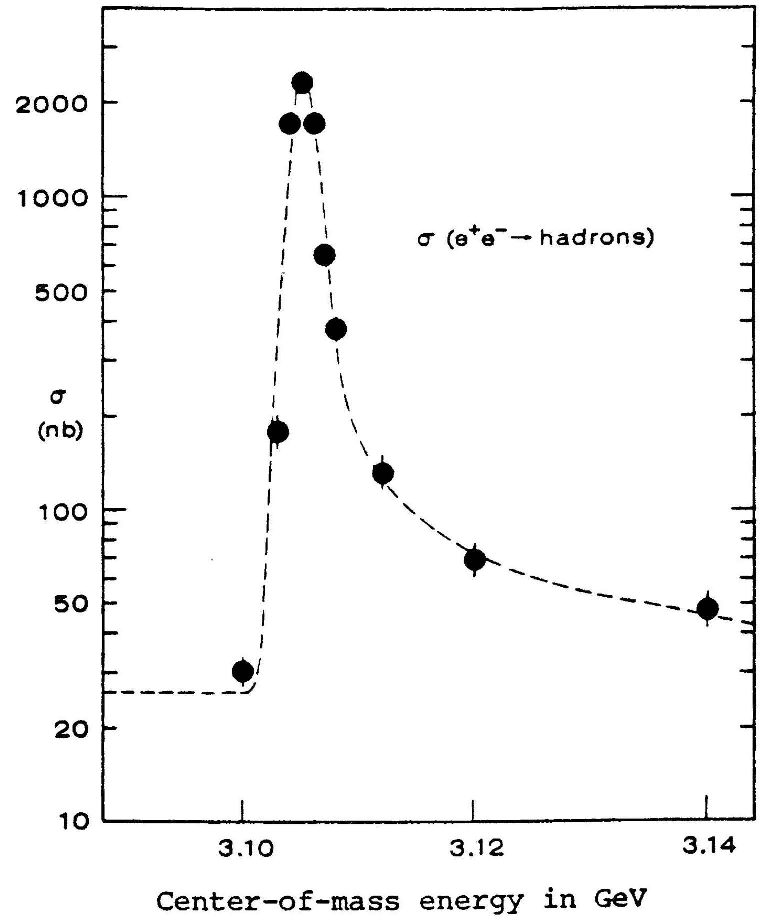
We have observed a very sharp peak in the cross section for $e^+e^- \to$ hadrons, $e^+e^-$, and possibly $\mu^+\mu^-$ in the Stanford Linear Accelerator Center (SLAC)–Lawrence Berkeley Laboratory magnetic detector[1] at the SLAC electron-positron storage ring SPEAR. The resonance has the parameters

$E = 3.105 \pm 0.003$ GeV,

$\Gamma \leq 1.3$ MeV

(full width at half-maximum), where the uncertainty in the energy of the resonance reflects the uncertainty in the absolute energy calibration of the storage ring. [We suggest naming this structure $\psi(3105)$.] The cross section for hadron production at the peak of the resonance is $\geq 2300$ nb, an enhancement of about 100 times the cross section outside the resonance. The large mass, large cross section, and narrow width of this structure are entirely unexpected.

Our attention was first drawn to the possibility of structure in the $e^+e^- \to$ hadron cross section during a scan of the cross section carried out in 200-MeV steps. A 30% (6 nb) enhancement was

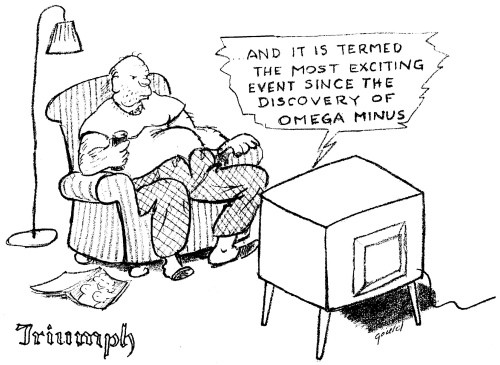



3 PRL's published on 2 December – SLAC, BNL, and ADONE.

Visible width dominated by SPEAR energy spread. True width extracted from Breit-Wigner shape : Γ = 91.0±3.2 keV (later result)

# How we learned of the J

Remarkably, Sam Ting was at SLAC that Monday for a meeting of the SLAC PAC. Roy, Vera, and I were in a tiny conference room editing the latest draft of the PRL, when Pief summoned Roy to his office. Roy returned, white as a sheet, and announced that "Sam has the same thing". A joint seminar by Roy and Sam was held that afternoon.




# Next Week

The obvious question was were there more narrow resonances. Bob Melen changed the DAC and SPEAR controls so that the energy could be controlled in fine steps, and Len Shustek and I invented a way to turn the IBM mainframe into a useful realtime computer.

Terry Goldman and I concocted a positronium model of the ψ, and predicted 3.7 GeV for the $_2$S state, so a little below that is where we started the scan.

# Richter & Ting Share 1976 Nobel Prize

***"for their pioneering work in the discovery of a heavy elementary particle of a new kind"***

2 years after the November Revolution

# Discovery

Most “discovery” in physics is a painstaking process:

- Hints from theory
- Extensive data taking
- Careful analysis to extract a signal
- Is it > 5 $\sigma$?
- Careful review
- Well planned announcement

……

The LHC Higgs discovery at the LHC is a rather good example of this.

# The Ψ and the Ψ’ were different, and different from each other.

- The Ψ was totally unexpected. Perhaps a broad bump, but nothing vaguely like this.
- Statistical significance was never a thought. We could (quite literally) hear the peak.
- The “announcement” was by chaotic telephone calls, resulting in PRL waiving their news embargo.
- The interval from discovery to publication submittal was 3 days!

“Nothing so strange and unexpected had happened in particle physics for many years,” - Richter - Nobel Prize lecture.

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- The Ψ’ mass was “suspected” via a crude positronium model by Terry Goldman and me.
- There was a systematic search that took a few hours to find it.
- Again, there was no question of statistics.

CALENDARR

# November 1974

www.calendarr.com

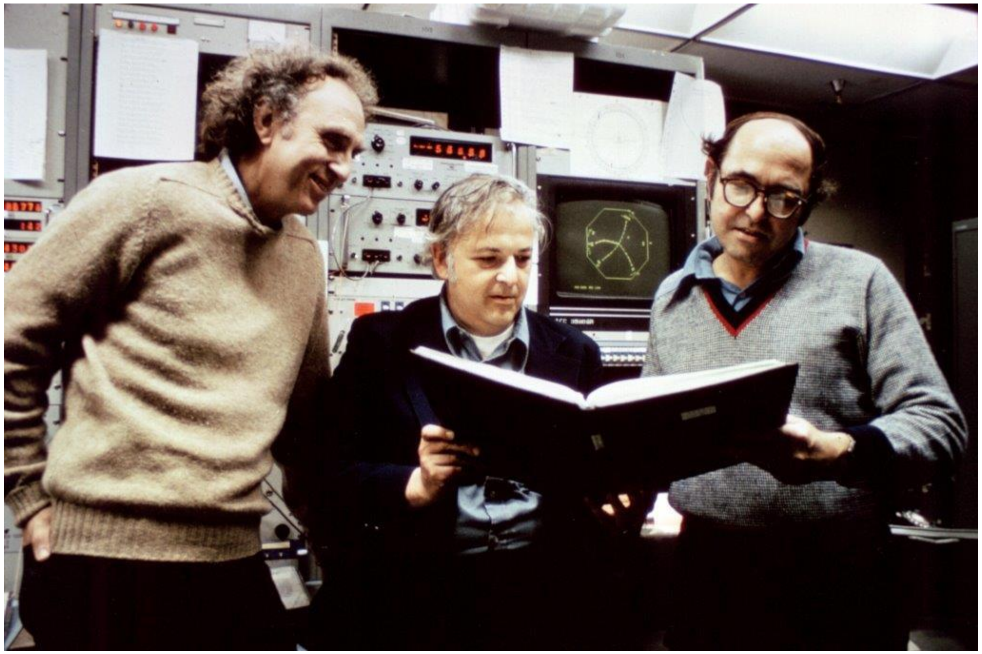
| Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|---|---|---|---|---|---|---|
| 28 | 29 | 30 | 31 | 1 | 2 | 3 |
| 4 | 5 Melbourne Cup | 6 | 7 | 8 Agreement to run at low energy | 9 Sharp resonance found | 10 Rescan, start paper, answer phone calls! |
| 11 Veterans Day Learn about J, finish paper, colloquia by Roy Schwitters and Sam Ting | 12 Dhanteras | 13 Ψ paper received at PRL. | 14 | 15 Rather frantic press release, Frascati confirms Ψ/J | 16 | 17 NYT Front page |
| 18 | 19 | 20 | 21 Discover Ψ' at 3:20 am, colloquium by mb | 22 | 23 | 24 |
| 25 Ψ' paper received at PRL | 26 | 27 | 28 Thanksgiving Day | 29 | 30 | 1 |

November 1974 has **19 work days**.

3rd Quarter - 06 · New Moon - 13 · 1st Quarter - 21 · Full Moon - 29

Holiday · Celebrations

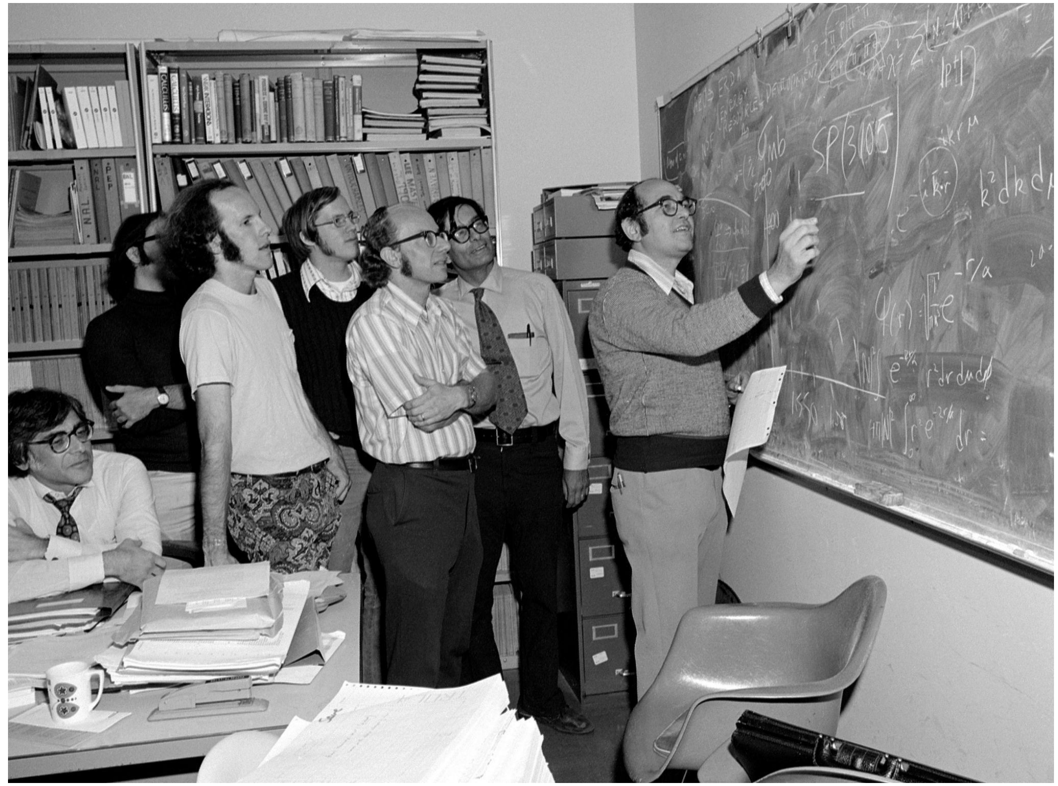
*In Memoriam*



Martin Perl, Burt, Gerson Goldhaber

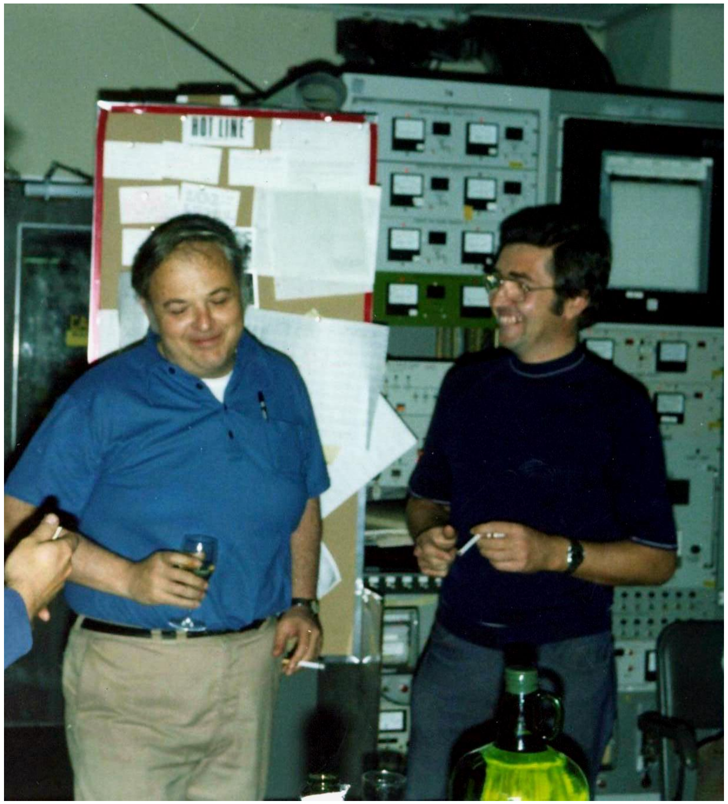
Rudy Larsen, Ewan Paterson, Burt

Norm Dean - SPEAR Vacuum Engineer



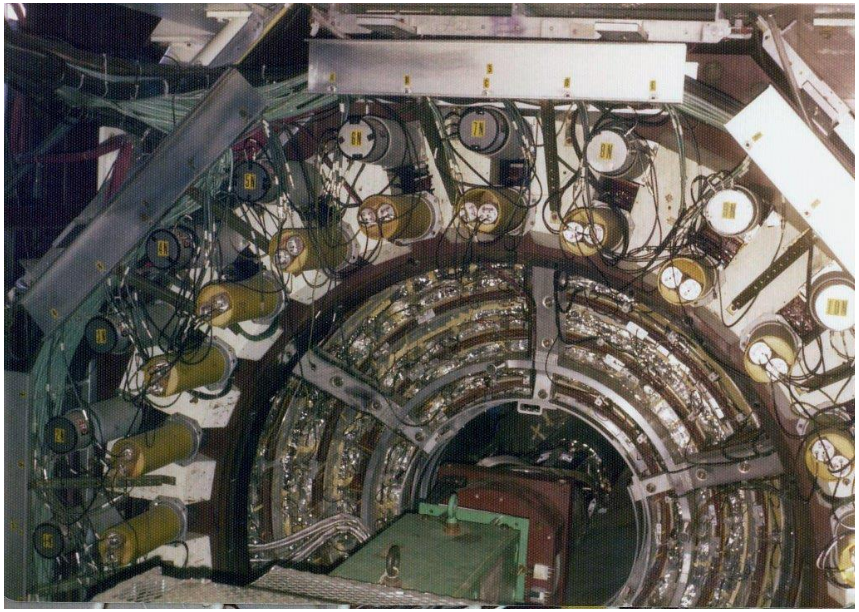
Gerson Goldhaber, George Trilling, John Kadyk

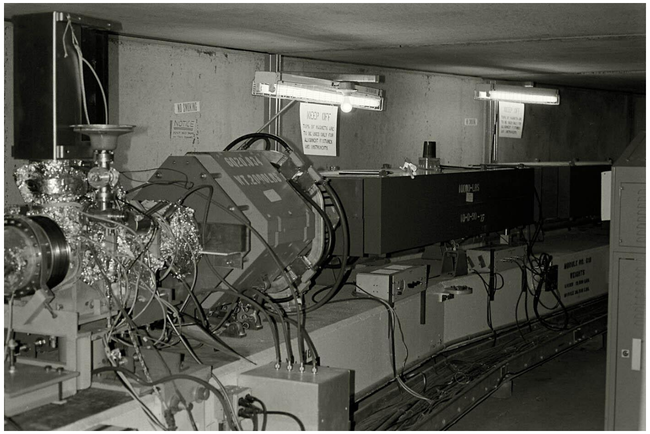
Pief, John Rees




Burton, Ewan

Roy Schwitters





Richter likened SPEAR (and MK-I) to a character in *Alice in Wonderland*. “It’s like the Cheshire cat, there’s nothing left but its grin.”

# Summary

- In the late 60’s to early 70’s, the SLAC-MIT deep inelastic experiments provided the experimental evidence first for partons and then their identification as quarks.

- The discovery of charm in 1974 convinced any last doubters and established the Standard Model.

- In the early days of quarks and the standard model, SLAC was a good place to be!


## Acknowledgments

B. Richter Nobel Lecture
H.L. Lynch Photographs
V. Lüth Photographs
SLAC Archives
M. Riordan *The Hunting of the Quark*
And many, many conversations and experiences with colleagues and friends

# The machine and detector collaborations

## SLAC - LBL Magnetic Detector Collaboration

SLAC

- J.E. Augustin
- A.M. Boyarski
- M. Breidenbach
- ***F. Bulos***
- J.T. Dakin
- G.J. Feldman
- ***G.E. Fischer***
- D. Fryberger
- G. Hanson
- B. Jean-Marie
- ***R.R Larsen***
- V. Luth
- H.L. Lynch
- D. Lyon
- C.C. Morehouse
- ***J.M. Paterson***
- ***M.L. Perl***
- ***B. Richter***
- P. Rapidis
- ***R.F. Schwitters***
- W.M. Tanenbaum
- F. Vanucci

LBL and UC Berkeley

- ***G.S. Abrams***
- D. Briggs
- W. Chinowsky
- C.E. Friedberg
- ***G. Goldhaber***
- R.J. Hollebeek
- ***J.A. Kadyk***
- B. Lulu
- F. Pierre
- ***G.H. Trilling***
- J.S. Whittaker
- ***J. Wiss***
- ***J.E. Zipse***

## SPEAR Storage Ring Group -1972

- M. Allen
- J. E. Augustin
- A.M. Boyarski
- ***B. Richter***
- ***N. Dean***
- ***G.E. Fischer***
- ***J. Haissinski***
- J. L. Harris
- L. Karvonen
- M. J. Lee
- ***J. Rees***
- ***R. R. Larsen***
- R. McConnell
- ***P. Morton***
- A. Sabersky
- R. Scholl
- ***J. Voss***
- ***W. Davies-White***
- ***H. Wiedemann***

***deceased***