SLAC BEAM LINE

Volume 6, Number 1 — January 1975

THE WHITE HOUSE

WASHINGTON

January 3, 1975

Dear Dr. Panofsky,

On behalf of the American people, I extend my congratulations to you and your dedicated staffs and those of the Brookhaven National Laboratory for the major discovery of a new, heavy, relatively long-lived particle described in your recent letter to me. I appreciate your succinct explanation of the importance of this highly technical achievement. It continues to be my hope that important advances in basic knowledge of this type may lead to a better scientific understanding that ultimately benefits all mankind.

I am sure that the new experiments dealing with these discoveries will be attacked with vigor, enthusiasm, and excitement, and I extend to scientists working in the field my best wishes for continued success in your endeavors.

Sincerely,

Gerald R. Ford

Dr. W. K. H. Panofsky
Director
Stanford Linear Accelerator Center
Stanford University
Stanford, California 94305

FROM THE EDITOR

This unusually thick issue of the *Beam Line* consists of a letter (above) and 27 other pages. Pages *1* through *8* are a typical grab-bag of people news, announcements, contributions from readers, and so on.

Pages *SSRP-1* through *SSRP-12* form a report on the Stanford Synchrotron Radiation Facility. It has separate page numbers so that it can be lifted out as a complete report.

Pages *Psi-1* through *Psi-8* also form a lift-out section which continues the story of the recently discovered psi particles.

We'd like to thank Janet W. Boatner for her permission to print the fine poem on Page 2 of this issue.

--Bill Kirk

CONTENTS OF THIS ISSUE

WANT ADS

For Sale: Franklin stove. Sears No. 8453 Model. 30" firebox. $200. Immediate delivery. Tony Roder, X2293.

For Sale: Trailer hitch and floor mats for Volkswagon. Motorcyclist's helmet, almost new, small size. Pool cue. Dan Nevius, X2336.

For Sale: AMF *Air Hockey* game. One-year old, in good condition. Cost $300 new, sell for $150. Bill Kirk, X2605.

GILBERT & SULLIVAN AUDITIONS

The Stanford Savoyards will be presenting Gilbert & Sullivan's *Ruddigore* on April 9, 11, 12 and 13 in Dinkelspiel Auditorium. Auditions for singing roles have already taken place, but they still need musicians, set crew, costume crew, plus various and sundry odd bods to do other things. If you are interested in joining an enthusiastic and dedicated theatrical group, please call Rita Taylor at SLAC ext. 2411 for information. (If they wish, prospective orchestra members may call music director Dan Robinson direct at 325-5428 or 321-8888 to leave a message.)

--Rita Taylor

TREE PLANTING AT SLAC

We hadn't realized how many trees have been planted on this beautiful 480-acre site--more than 3500--until Bob Gould of Plant Engineering sent along the following list to us:

Washington thorn	4
Eucalyptus	
Globulus	1286*
Rudis	6
Sideroxylon	24
Leucoxylon	684
Acacia	42
Oak	
Live	319
Cork	47
Pine	
Aleppo	181
Bishop	518
Magnolia	17
Gingko	125
Evergreen ash	12
Olive	1
Podocarpus	6
Redwood	106
Rose bottlebrush	172
Arbutus Unedo	28
Liquidambar	13
TOTAL	*3591*

*Plus 1164 seedlings

A physicist had a horseshoe hanging on the door of his laboratory. His colleagues were surprised and asked whether he thought it would bring luck to his experiments. He answered: 'No, I don't believe in superstitions. But I've been told that it works even if you don't believe in it.'

--*I.B. Cohen*
Harvard historian of physics

PSI (3105)

"We have observed a very sharp peak . . ."
(From SLAC to Dec. 2 *Physical Review Letters*.)

Upon this site we've sighted the unseeable,
Without whose whatness life would be unbeable.

Although unseen, we know it must be there;
It leaves its un-shape clearly in un-air.

To say "psi" is a "particle," a little
Suggests there's something solid in its middle--

A heresy--so, to cut short debate,
We may say "resonance," "excited state."

Its life a billionth billionth of a second;
So lengthy, sub-atomically reckoned,

That by the sub-atomic minds of some
Psi has been hailed a new Methusalum.

How to explain this absence of "decay"?
I can but echo what the wiser say,

Which is, but all such oracles are dark:
"Psi may be the bound state of a charmed quark."

Faith states, and our forebearers still do say
Quarks move upon the mystic "Eightfold Way."

And--I speak this within a Mystery--
Depend upon the Co-inherent Three,

Which in the selfsame "quantum state" do dwell;
(A thing too high for mortal tongue to tell)

Their "state" the same, their "color" ever new,
A trinity of "red" and "white" and "blue."

No site had seen a quark, yet be they must,
Or so much speculation is but dust.

And now, Lo, a new "resonance" appears!
A quark incarnate (almost) sigh the seers.

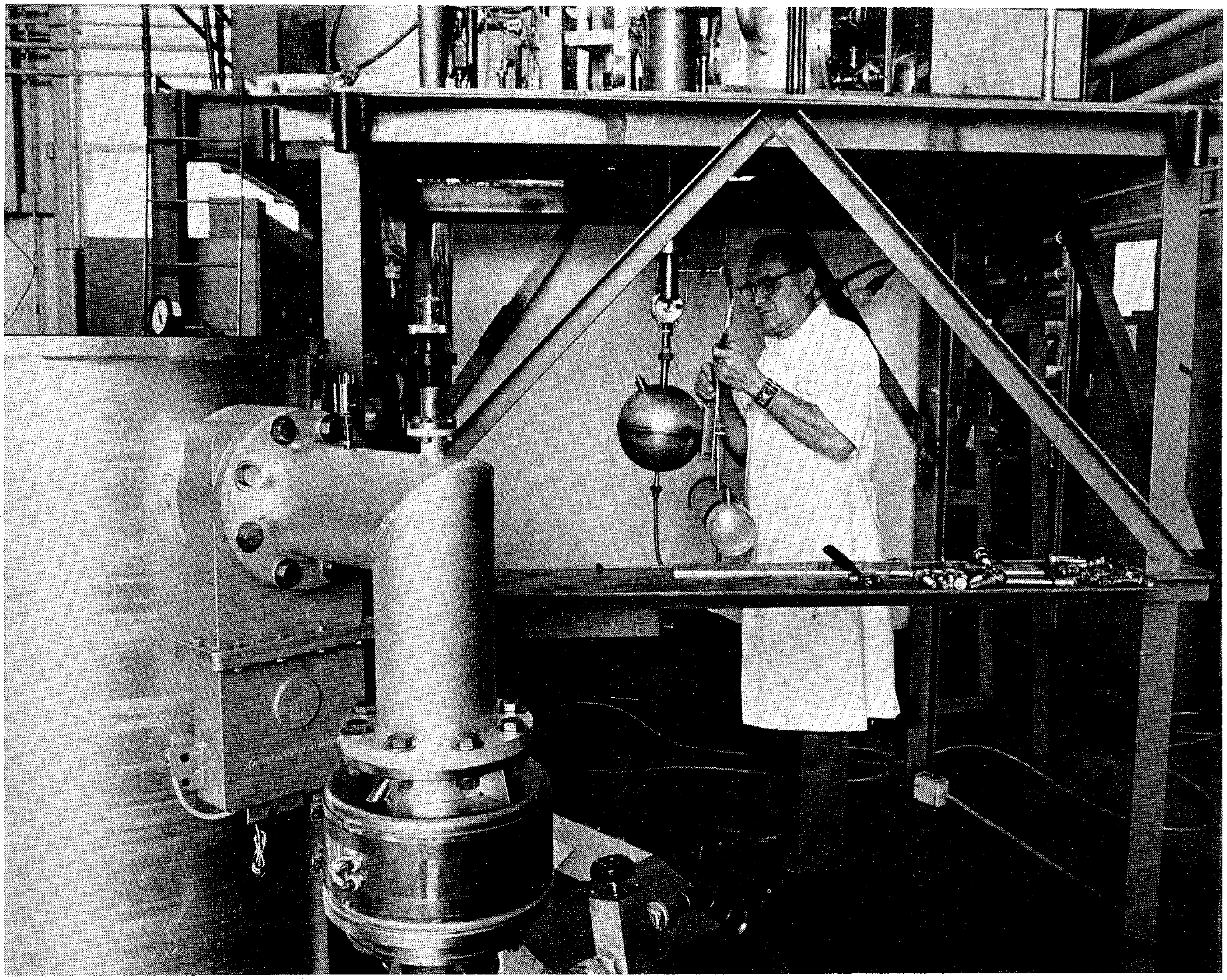
A "Mediator of weak interactions,"
Or else, perhaps, say other learned factions,

It has the "charm," a myth until today,
To keep doomed "hadrons" from destined "decay."

So Psi, whatever your advent may portend,
Accept this unlearned tribute I have penned.

Grant us "color" and "charm" before we die,
For our short lives are transient as a Psi.

--Janet W. Boatner



SLAC BUILDS TARGET FOR FERMILAB

Some months ago, the late Darrell Drickey of UCLA arranged for a liquid hydrogen target to be built at SLAC for use in an experiment at Fermilab. At that time the Target Group at Fermilab had a particularly heavy work load, so SLAC's Liquid Hydrogen Group was happy to help out by taking on this job. The photograph shows Al Koula of SLAC assembling the reservoir and liquid hydrogen flask for the target. The completed assembly will then go into the large cylindrical vacuum tank which appears in the left foreground.

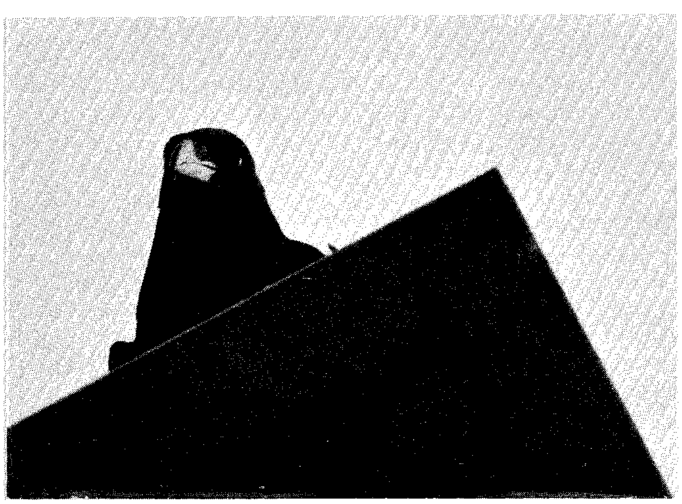
This target will be used in Fermilab Experiment #216: *Measurement of the pion form factor by direct pion-electron scattering*. In the experiment, a beam of pions produced by the 400 GeV Fermilab accelerator will pass through the small cylindrical vessel (the target flask) that Al is working on. The usual reason for using a liquid hydrogen target in experiments is to take advantage of the fact that the hydrogen atom has only a single proton as its nucleus, which simplifies the analysis of the interactions. In this case, however, the experimenters will study the interactions of pions with the hydrogen atom's single electron, rather than its proton. The result will be a measurement of the pion's "form factor"--that is, of how the pion's electric and magnetic properties are distributed within the particle. The SLAC-built target will be shipped out to Fermilab in January, in time for its first intended use in March.

Corvus Corax

--Photos by Gene Cisneros

At just about the time when the first psi particle was discovered at SPEAR, a mysterious visitor dropped out of the sky and took up residence at SLAC. With a little help from *A Field Guide To The Western Birds*, by Roger Tory Peterson, the visitor was eventually identified as a common Raven, *Corvus Corax*. The two main distinguishing features of the Raven can be made out in the accompanying photos: the "Roman nose," and the "goiter" (shaggy throat feathers). Note also the band on the bird's leg; we weren't able to determine whether the band was a part of an ornithological study, or whether it meant simply that the Raven was someone's pet.

The Raven spent a good deal of his time at SLAC perched on the roof of the Fabrication Building, near the Shop Lunch Room. He seemed fairly tame and would accept scraps of food from friendly humans. After about a month, he apparently left SLAC and headed off toward parts unknown. Before he blew town, however,



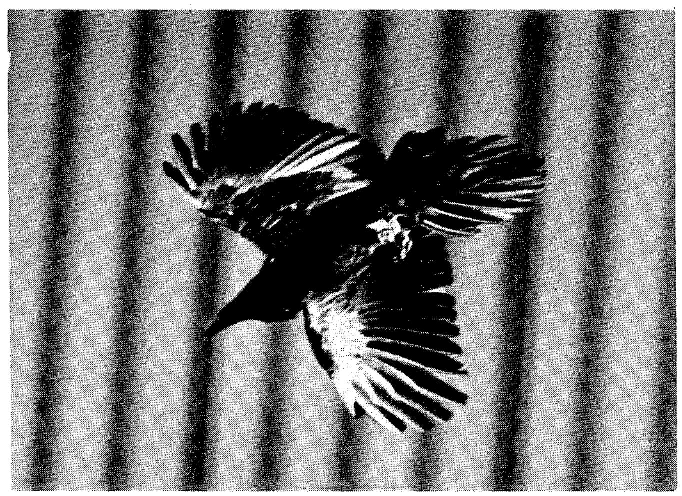
we sent one of our bird-brained *Beam Line* reporters out to try and get an in-depth interview. This attempt didn't work out too well, since the Raven was not only hard to understand but also kind of nasty. For what it's worth, however, the interview went something like this:

Beam Line: Well, Professor, to what do we owe the pleasure of your visit?

C. C. Raven: Awwk! Physics! Awwwk! Bring paper! Awwwk! Bring ink! Awwwk!

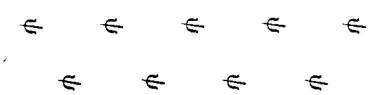
BL: Pardon? Did you say "ink"?

CCR: Ink, dummy! Awwwk! Bring paper and ink! Awwwk!



BL: Uh, OK. Hold on a minute. . . . OK, here's paper and ink. Now what? Umm. We see that you're dipping your feet into the ink. And now we note that you're walking across the paper. Umm.

CCR:



BL: Say, Professor, those tracks look a lot like--Holy Cow! Is *that* the "physics" you were talking about?

CCR: Awwwk! Psichology! Awwwk!

BL: But didn't you say--never mind. Now just one more question, Professor. We've already discovered two psi particles. Will there be any more?

CCR: Count, dummy! Awwwk!

BL: Count? Count what? Listen, Professor, if you know the answer, we'd love to quote you on it. Can you tell--

CCR: Awwwk! Quoth the Raven, "Seven more!"

RED CROSS BLOOD BANK NEEDS HELP NOW!

Have you opened an account at the Red Cross Blood Bank? If not, this is an especially good time to do so. Your pint of blood may help save a life, and it will also provide free blood for the members of your own family, should they ever need it. The Red Cross supply of blood is always depleted at holiday time, so this is the time to help replenish their supplies. It will only take about an hour of your time, and it is virtually painless. The nearest Red Cross Blood Bank is located at 3330 Hillview Way, Palo Alto. For an appointment, please phone 493-1363. Your help will be much appreciated.

A GLOSSARY FOR RESEARCH REPORTS

WORDS	*MEANING*
It has long been known that . . .	*I haven't bothered to look up the reference*
. . . of great theoretical and practical importance	*. . . interesting to me*
While it has not been possible to provide definite answers to these questions . . .	*The experiments didn't work out, but I figured I could at least get a publication out of it*
High purity . . . Very high purity . . . Spectroscopically pure . . .	*Composition unknown except for the exaggerated claims of the supplier*
Three of the samples were chosen for detailed study . . .	*The rest didn't make sense and were ignored*
. . . accidentally strained during mounting	*. . . dropped on the floor*
. . . handled with extreme care throughout	*. . . not dropped on the floor*
Typical results are shown . . .	*The best results are shown*
The agreement with predictions is excellent	*fair*
good	*poor*
satisfactory	*doubtful*
fair	*imaginary*
as good as could be expected	*non-existent*
The most reliable results are those of Jones	*He was a student of mine*
It is suggested that . . .	*I think*
It is believed that . . .	*I think*
It may be that . . .	*I think*
It is generally believed that . . .	*A couple of other guys think so too*
It might be argued that . . .	*I have such a good answer to this objection that I shall now raise it*
It is clear that much additional work will be required before a complete understanding . . .	*I don't understand it*
Unfortunately, a quantitative theory to account for these effects has not been formulated	*Neither does anybody else*
Correct within an order of magnitude	*Wrong*
It is hoped that this work will stimulate further work in this field	*This paper isn't very good, but neither are any of the others in this miserable subject*
Thanks are due to Joe Glotz for assistance with the experiments and to John Doe for valuable discussions	*Glotz did the work and Doe explained what it meant*

Editor's note: This Glossary, *written by C.D. Graham, Jr., first appeared in* Metal Progress *71 (1957) and was later reprinted in* A Random Walk In Science, *an anthology compiled by R.L. Weber, Crane, Russak & Co. (New York, 1973).*

PALO ALTO NURSE HEADS CONVENTION

Joan E. Gardner, a Palo Alto registered nurse, was named chairwoman of the 1975 annual convention of the American Association of Industrial Nurses to be held at the San Francisco Hilton Hotel April 13 to 17.

Mrs. Gardner, an employee of the Palo Alto Medical Clinic, is assigned to the Stanford Linear Accelerator Center.

More than 1,000 nurses working for U.S. industry, business and government are expected to attend the national meeting.

An eight-member committee of occupational health nurses from California will assist Mrs. Gardner. They will include Annettee B. Haag, Kemper Insurance, Menlo Park; Helen Hutson, Fairchild Camera and Instrument Co., Mountain View; and Carmel Turner, Hewlett-Packard, Mountain View.

--*Palo Alto Times,* Dec. 17, 1974

SPEAR's All Wet

'Twas the night before Christmas
And all throughout SPEAR
Not a creature was stirring,
Even no engineer!

A keg was set up
On the computer with care,
In hope that another psi
Soon would be there.

When from the positron source
There arose such a clatter,
Burton Richter exclaimed
"What the hell is the matter?"

"The vacuum is wet--
Water pressure's too high--
We're out of electrons,
But we'll have *steam* by and by."

"Drop that pressure!" said Burt,
"We'll have no more leaks.
This run must continue
For two final weeks!"

"There's nothing to do
But put in a funnel,
And let the hot water
Run out of the tunnel."

"The tunnel," said Burt,
"Takes two weeks to be full,
So turn on the beam
And cut out this bull!"

And I heard him exclaim,
As he switched on the red light,
"Merry Christmas to all,
And to all a Good Night!"

--*Charlie Hoard*

What They're Resolving For 1975

Stanford Linear Accelerator Center scientists resolve to stop trying to turn lead into gold. They'll work instead on turning water into oil.

--Editorial page
Palo Alto Times
Dec. 31, 1974

SOME INFORMATION ON HEART ATTACKS

In two medical journals which arrived recently on the same day, there were four articles and two editorials dealing with the problem of heart attacks. One article was directed primarily to cardiologists, but the other three were of sufficient general interest to make them worth summarizing here.

When I was in medical school we were taught that otherwise healthy women never experienced heart attacks. We now know, however, that that idea is not true, even though the incidence of heart attacks in women is still much lower than it is in men. In the December 16 issue of the *Journal of the American Medical Association* a study entitled "Coronary artery disease in young women" noted that in some women under 40 years of age such problems were present, and were nearly always associated with the same "risk factors" that are present in men who are particularly liable to heart attacks. These risk factors are: family history of heart attacks, high blood pressure, high blood fat (especially cholesterol), diabetes, and cigarette smoking.

The "coronary" arteries are the blood vessels which surround the heart like a crown, and which supply it with blood. When these vessels are partially obliterated with arteriosclerosis, then heart attacks (or "coronaries") are imminent. People with the positive "risk factors" noted above seem more prone to arteriosclerosis of the coronary arteries.

Another interesting paper in the same journal discussed high blood-fat levels (cholesterol and triglycerides) in the children of patients who have had heart attacks. More than 25% of these children had already accumulated abnormal blood fats even at their young age.

A third article in the *Lancet*, a British journal, is a study of coronary attack in men who had given up cigarette smoking. Those who had quit completely had reduced the risk of a heart attack by fully 50%.

These plus many other papers all point out the fact that coronary artery disease and subsequent heart attacks are largely preventable. The prevention begins in childhood and consists of good nutrition (particularly avoiding "over-nutrition"), good health habits, and regular medical check-ups.

--Dr. Charles Beal

Few phenomena are more remarkable, yet few have been less remarked, than the degree in which material civilization--the progress of mankind in all those contrivances which oil the wheels and promote the comfort of daily life--has been concentrated in the last half century. It is not too much to say that in these respects more has been done, richer and more prolific discoveries have been made, grander achievements have been realized, in the course of the 50 years of our own lifetime than in all the previous lifetime of the race. It is in the three momentous matters of light, locomotion and communication that the progress effected in this generation contrasts more surprisingly with the aggregate of the progress effected in all generations put together since the earliest dawn of authentic history.

--*Scientific American,* September 1868

SNEAKERS AT 3000 MILES

SLAC Whups Brookhaven In (Very) Long Distance Race

After almost a year of letter-writing and several transcontinental phone calls, the first Challenge Race between runners from SLAC and from Brookhaven National Laboratory (on Long Island) was recently held. It was a sort of Great Atlantic and Pacific Tea Party, with each team of runners negotiating a measured ten-mile course on their own home ground, and with the results exchanged by mail. SLAC Math whiz Charlie Hoard developed a formula whereby a runner's age and his time for the ten miles were weighted together to produce a number called the *speed index*. (It really isn't that complicated; just ask Charlie.)

After all the data were in, SLAC emerged as the winner of the first Challenge Race, with a slightly higher speed index than our colleagues on the east coast. Here are the runners and the pertinent statistics:

Runner	*Age*	*Time min.sec.*	*Speed Index*
C. Hoard	53	88:26	2.2854
E. Dally	43	60:19	3.1869
K. Moore	42	68:15	2.7927
G. Putallaz	33	63:35	2.8672
W. Divita	28	59:54	2.9552
SLAC Average			*2.8092*
BNL Average			*2.6826*

We need more runners to build up our team for next year. How about a New Year's resolution to start jogging and be in good shape for next September's Brookhaven Challenge Race?

--Ken Moore

BOOKMOBILE CALENDAR

The PUBLIC LIBRARY comes to SLAC every other MONDAY at NOON

Where?	*Volley ball court South Test Lab*
When?	*Every second Monday except holidays, NOON to 1:00 PM*
Who?	*Any SLAC employee can borrow books*
What?	*Adult and childrens' fiction & non-fiction, records & movies*

1975 SLAC BOOKMOBILE CALENDAR

Jan.	6, 20
Feb.	3
Mar.	3, 17, 31
Apr.	14, 28
May	12
Jun.	9, 23
Jul.	7, 21
Aug.	4, 18
Sep.	15, 29
Oct.	(none)
Nov.	10, 24
Dec.	8, 22

Copies of this calendar are available as bookmarks in the SLAC Library.

--Louise Addis

Mu, Pi, Lambda, Psi,
After all is said and done,
Watch the particles drifting by
From SLAC's injecting gun.

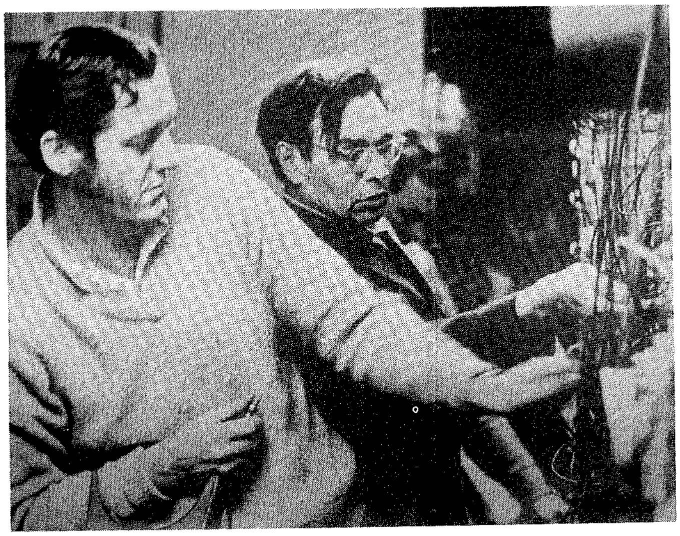
We at SLAC still lead the way
To new and better finds.
We do it all by night and day
While scratching our behinds.

The ring is just our special tool
For working in the dark.
We do it all while staying cool
And always hit the mark.

While other machines just snort and grope,
As on their guitars they strum,
We at SLAC are full of hope
Of greater finds to come.

--Les Horton

DARRELL DRICKEY



--Photo from *Soviet Life*

The late Darrell Drickey (left) is shown working with a Russian colleague at the 77 GeV proton accelerator at Serpukhov in the Soviet Union. Darrell was well known to many people at SLAC. Both as a physicist and as a friend, he will be missed.

Dr. Darrell Drickey, an internationally known elementary particle physicist, died of cancer on December 10 at the age of 40. Although Darrell had been a professor of physics at UCLA for the past few years, he was well known at Stanford and in the Palo Alto community.

After graduating from the South Dakota School of Mining in 1956, Darrell came to Stanford as a physics graduate student. In 1957 he married Martha Tomovick, and they lived for several years in College Terrace.

In 1963, Darrell completed his thesis work in experimental elementary particle physics at Stanford's High Energy Physics Laboratory. After a year spent working at the Linear Accelerator Center at Orsay, near Paris, he returned to Stanford as a member of SLAC's Experimental Group D. He worked on a series of photoproduction experiments at SLAC until 1968, at which time he joined the faculty at UCLA.

In 1970, Darrell became the leader of the first joint Soviet-American collaboration (sponsored by the USSR State Committee on Atomic Energy and the U.S. Atomic Energy Commission) working at the 77 GeV proton accelerator at Serpukhov in the Soviet Union, at that time the highest energy accelerator in the world. The group of American and Soviet scientists led by Dr. Drickey made the first measurement of the size of the pi-meson. Members of the same group, including many of the Soviet collaborators, are presently making even more accurate measurements at 400 GeV Fermilab accelerator, near Chicago. In addition to his experimental work at Fermilab, Darrell had taken on the important administrative task of heading the Fermilab Users Executive Committee.

Darrell was well known for the enthusiasm with which he approached life, whether it was a physics experiment or a clamming expedition. He was a superb experimental physicist, able to improvise with real genius during the frequently tense conditions that prevail at large accelerators. At the time of his death he was on leave of absence from UCLA to work at Fermilab on new methods for doubling the energy of the 400 GeV machine.

Survivors include Darrell's wife Martha, his son Roger, his daughters Sheryl and Linda, his mother Josephine Drickey, his brother Bruce, and his sister Shirley Drickey.

--Bob Mozley

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Published monthly on about the 10th day of the month. The deadline for material to appear in the next issue is the 1st day of the month.

Contributors

Herb Weidner, Bin 20, x2521: experimental area & facilities; general news.

Dorothy Ellison, Bin 20, x2723: want ads, clubs, sports, people; general news.

Harry Hogg, Bin 33, x2441: accelerator & related information.

Photographer

Joe Faust, Bin 26, x2429

Production

George Owens, Bin 82, x2411

Editor

Bill Kirk, Bin 80, x2605: letters, comments, articles; general news; whatever.

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	4-5	10-9	20-20	25-3	33-17	51-30	56-10	64-15	69-13	74-8	81-50	86-11	91-6	97-88

SSRP:
Stanford Synchrotron Radiation Project

The Stanford Synchrotron Radiation Project is a new national facility which makes use of the intense radiation produced by the SPEAR storage ring at SLAC to carry out important research in several fields of the physical and biological sciences. This article describes the SSRP facility and its early experimental program. It also gives some of the basic technical information needed to understand how the facility works and why its research program has already started to yield significant results.

Contents

A. INTRODUCTION

The Stanford Synchrotron Radiation Project (SSRP) is a new national facility for research in a variety of scientific disciplines, including physics, chemistry, biology, metallurgy and astrophysics. Although the Project is located at SLAC, adjacent to the SPEAR storage ring, it is funded by the National Science Foundation under a contract with the W. W. Hansen Laboratories of Physics on the Stanford campus. In addition to NSF support, contributions to the Project have been made by the U.S. Navy's Michelson Lab at China Lake, California; by Xerox Corporation; and by Bell Telephone Laboratories. The originators of SSRP are Professors Sebastian Doniach and William Spicer of Stanford (now the Director and Consulting Director, respectively), with much early help from SLAC's Gerry Fischer.

Experiments at SSRP make use of the intense synchrotron radiation that is given off as a "by-product" of the operation of the SPEAR storage ring. This "free" radiation has several remarkable properties: (a) high intensity, (b) a broad range of energies including some that are difficult to produce at useful intensities by other means, (c) natural collimation, (d) high polarization, and (e) pulsed time structure. (More information on these properties is given later.) Perhaps most important is the intensity, which is so high that even a very narrow band of energies will contain enough flux for a great variety of experiments. Before turning to a description of SSRP itself, we now want to review, in Section B, some physics background.

B. SOME BACKGROUND INFORMATION

1. Light And Other Radiation

Most people at SLAC have heard about the comparison that is often made between an accelerator and a microscope. With a conventional microscope, which uses visible light, we can see objects such as parts of living cells that may be less than .001 centimeter (10^{-3} cm) long. By using a more powerful kind of light (x-rays or electrons which have energies of some thousands of volts), we can get a picture of some of the smallest living things, such as viruses, that may be only 10^{-6} cm in size. And usually the next step we talk about at SLAC is the great leap inward that takes us all the way down to the realm of the elementary particles, such as the proton, whose size is about 10^{-13} cm. To illuminate protons we make use of a special kind of 'light' that is actually a beam of electrons which has been accelerated to billions of volts by the SLAC two-mile accelerator. Thus the 'resolving power' of the SLAC accelerator is about 10^{10} times greater than that of a conventional light microscope.

2. Atoms, Molecules And Angstroms

But hold on a minute. When we jumped from viruses all the way down to protons, we skipped right over a whole class of objects--atoms and molecules--that are almost completely responsible for making the world the way it is. So this time let's go back for a closer look at what we missed. To begin with, we'll need a new yardstick to give us a convenient unit of size for measuring atoms. This unit is called the *angstrom*. Its symbol is 'Å' and it is this big:

$$1\ \text{Å} = .00000001 \text{ centimeter} = 10^{-8} \text{ cm}$$

The angstrom is convenient* because it is close to the size of an atom: the radius of a hydrogen atom is about 0.5 Å, and the radius of a uranium atom is about 2.0 Å. Although those physicists who study the elementary particles have passed the atom by in their search for the smaller game that lives within the very small nuclei of atoms (about 10^{-4} Å, or 10,000 times smaller than the whole atom), it is worth remembering that the nucleus itself plays an almost totally insignificant role in the substance and activity of our everyday experience. But the whole atom, on the other hand, is definitely where it's at. It is because of the structure of atoms and their interactions with each other--and the tremendous variety of both --that steel is strong, water is wet, roses are red, and soap is slippery. In fact, it is because of atoms that almost everything is *anything*.

3. *What 'Size' Light Do we Need?*

Thus the realm of the atom and of the combinations of atoms that form molecules is the starting place for trying to understand any of the larger units of matter, both physical and biological, that occur in nature. In order to explore this realm successfully, we will need to select (as we did for viruses and for protons) just the right kind of light to shine on the atoms. The essential requirement is that the light be of a 'size' (wavelength) that matches the dimensions of the particular atomic or molecular structures we shall be studying. We can get an idea of the range of sizes that will be useful in this work by consulting Fig. 1, which shows some of the characteristics of electromagnetic radiation.

From this figure we see that the size of an atom, about 1 angstrom, is matched by radiation that lies in the x-ray region of the spectrum. For a wavelength of 1 Å, the corresponding x-ray energy is about 12,000 electron volts, or 12 keV. In order to study some of the inner electronic structure of atoms we will want to use x-rays that are somewhat 'harder' than 12 keV--say up to energies of 20 or 25 keV. In addition, structures up to several atoms in size will need 'softer' radiation from the ultraviolet portion of the spectrum. Ideally, then, our bag of radiation tricks should include the following range of energies and wavelengths:

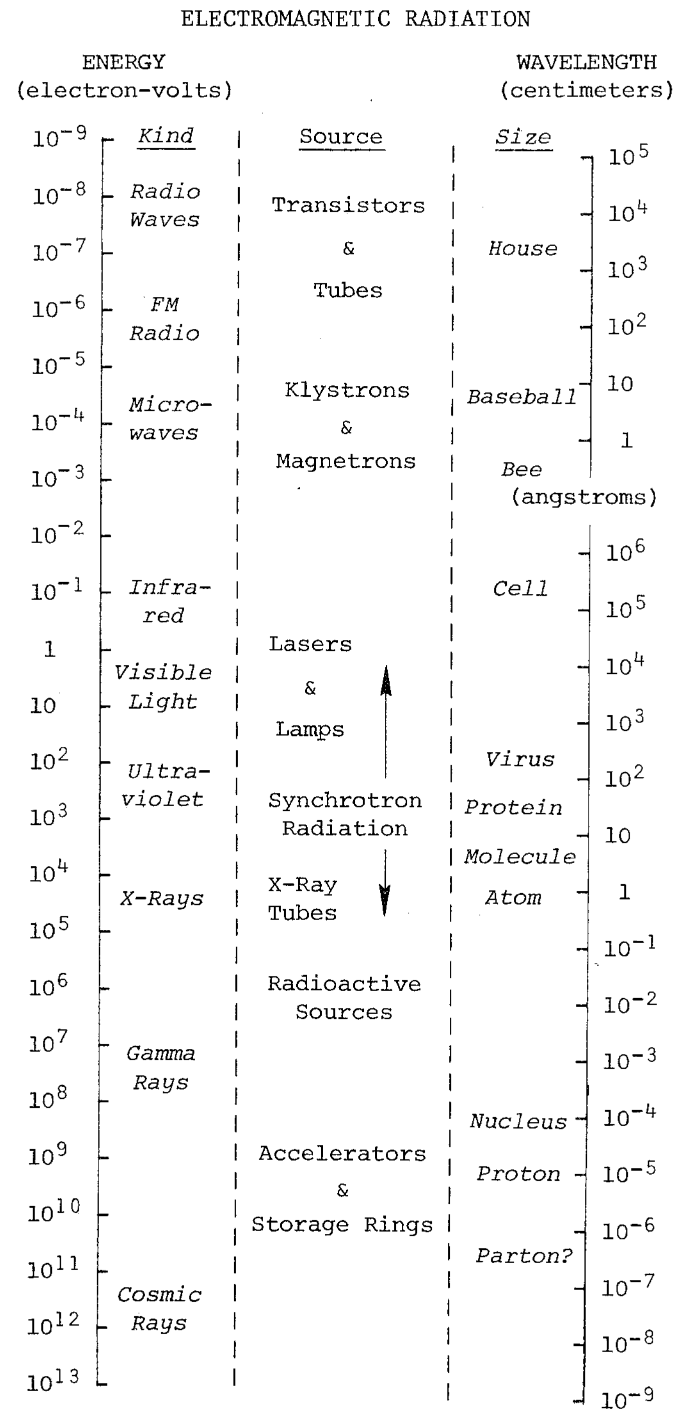


Fig. 1--Part of the spectrum of electromagnetic radiation. Longer wavelengths, such as very low frequency radio waves, lie off the top of the scale. Very energetic gamma rays produced by cosmic radiation (energies greater than 10^{20} electron-volts!) lie off the bottom of the scale. Although there is a vast range shown here, all electromagnetic radiation is fundamentally the same (same velocity, for example). When this radiation is used to probe the structure of matter (cells, atoms, protons), the wavelength chosen should be as small as, or smaller than, the dimensions of the structure being probed.

**Metrication note:* *In the International System of units (SI), the preferred unit of length for the sizes we're talking about is the nanometer, which 10^{-9} meter, or 10 Å.*

Wavelength: 0.5 to 100 Å

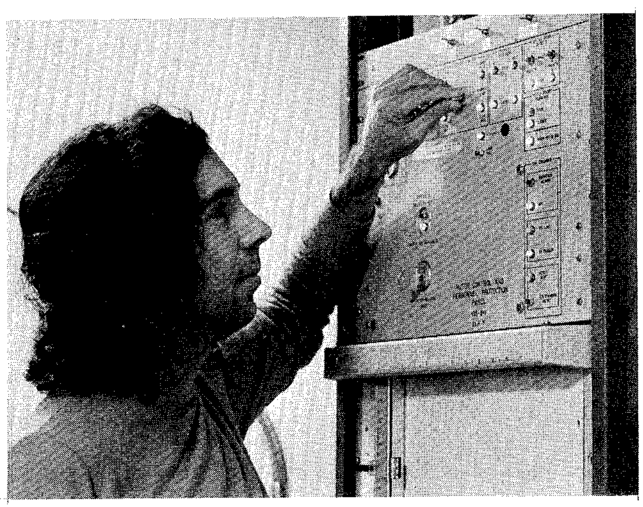
Energy: 0.12 to 25 keV

4. Speaking In Colors

All electromagnetic radiation comes in discrete "packets" or units called *photons*. We have already seen that there is a simple inverse relationship between the energy carried by a photon and its "size" or wavelength: the higher the energy, the shorter the wavelength. For the very narrow band of radiation that human beings can actually see (roughly between 4000 and 7000 Å), a change in wavelength or energy is also seen as a change is color. To us, radia- at 6500 Å is simply red light, while 4700 Å is seen as blue light. Because of this, scientists sometimes extend the idea of colors to describe radiation even when they are referring to parts of the electromagnetic spectrum that cannot actually be seen. Thus ultraviolet radiation is said to be *bluer* than visible light, and a beam of gamma rays which all have the same energy is sometimes described not only as *monoenergetic* but also as *monochromatic* (all of the same color). In general, then, the following rather loose talk is used:

bluer = harder = higher energy
redder = softer = lower energy

Which is probably a good place to stop the loose talk and get on with the subject at hand.



--Photo by Joe Faust

Visiting experimenter Steve Kowalzyk from Lawrence Berkeley Lab is shown opening shutters at the personnel protection control panel that was designed by Bruce Humphrey of SLAC. Radiation shielding, plus the gates, shutters and radiation monitors controlled by this system permit experimenters to control access to their individual research areas in complete safety, independent of the operation of SPEAR and of other SSRP experiments.

C. THE SSRP FACILITY

We turn now to a discussion of the SSRP facility itself, starting with the synchrotron radiation produced by SPEAR. We then follow this radiation from SPEAR into SSRP, describe the SSRP layout, and finally call attention to some of the special research apparatus at SSRP.

1. SPEAR's Rainbow Of Light

The SSRP facility is located at SPEAR in order to take advantage of the intense radiation that SPEAR gives off as a natural by-product of its normal operation. This radiation is caused by the fact that the electrons traveling in a curved path around the SPEAR ring lose a certain amount of their energy on each revolution. The radiation from SPEAR is emitted in the orbital plane of the electrons--flying off from the circular beam path in much the same way that mud flies off from a spinning automobile tire. This kind of centrifugal or "thrown-off" radiation is characteristic of the class of accelerators called "electron synchrotrons" (which includes SPEAR), and for this reason it has been given the name *synchrotron radiation*. For SLAC's purposes, the synchrotron radiation given off by SPEAR is more of a nuisance than a benefit, as Fig. 2 illustrates.

	Energy Of One 20-milliampere Beam (GeV)	*Radiation Loss (kilowatts)*
	1.5	0.7
SPEAR I	2.0	2.2
	2.5	5.4
	3.0	11.2
SPEAR II	3.5	20.8
	4.0	36.0
	4.5	57.8
PEP	15	500

Fig. 2--Synchrotron radiation energy loss at SPEAR and at (proposed) PEP. This synchrotron "mud" thrown off by the circulating beams heats up the inner walls of the SPEAR vacuum chamber and also knocks gas molecules out of the chamber walls. Thus both a water-cooling system and an elaborate vacuum-pumping system are required. In addition, a strong radio-frequency accelerating system is needed to give the beam particles a carefully timed "kick" on each revolution in order to make up for the energy lost by synchrotron radiation. These problems rapidly become more difficult as the energy of the beams is increased. For example, doubling the energy of one stored beam in SPEAR results in a 16-fold increase in the power lost to synchrotron radiation.

So synchrotron radiation is a natural by-product of the operation of SPEAR, and the next step in our investigation of SSRP is to find out a little more about this radiation--how many photons are given off per second, what energies do they carry, and so on. Information of this kind about a radiating source is called a *spectrum*. The spectrum of synchrotron radiation from SPEAR is shown in Fig. 3.

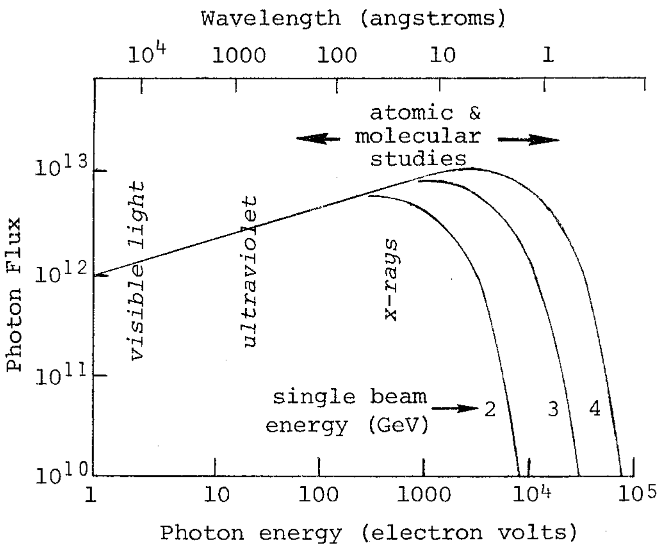


Fig. 3--The spectrum of electromagnetic radiation from the SPEAR electron beam at beam energies of 2, 3 and 4 GeV. The radiation intensity is at its peak in the region from 0.5 to 100 angstroms, which is an excellent match to the wavelengths needed for atomic and molecular studies. The vertical scale in the figure can be read simply as relative intensity. The actual numbers shown correspond (if you really care) to the following complicated units:

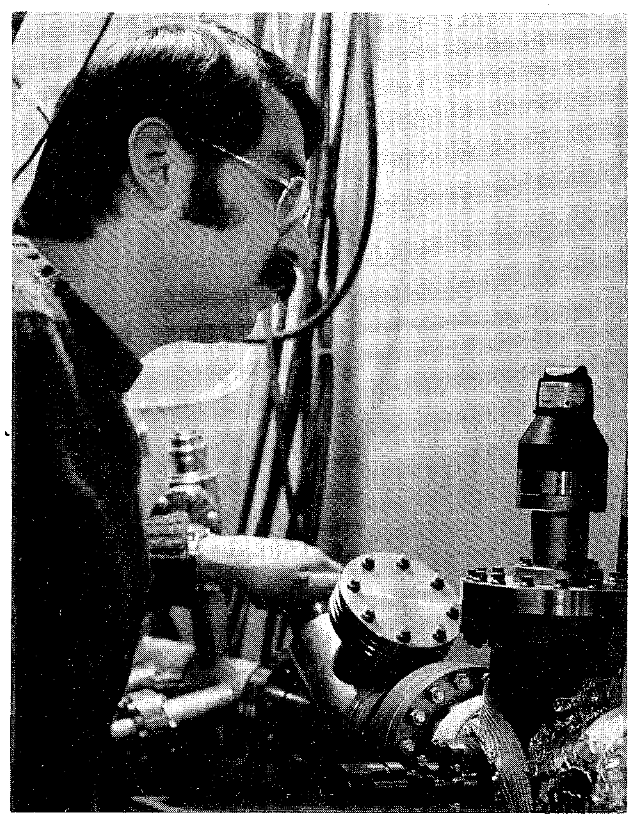
$$\frac{\textit{number of photons}}{\textit{second-milliampere-milliradian-10\% bandwidth}}$$

2. Some Practical Matters

We now turn to the practical problem of how to get the synchrotron radiation out of the SPEAR ring and into the SSRP facility. What we need is an opening or porthole in the SPEAR vacuum chamber that will let the radiation come out, but will *not* let the air get in. This particular requirement--maintaining the 'vacuum integrity' of SPEAR--is the single most important technical consideration in joining SPEAR and SSRP together. If SPEAR is to run satisfactorally, it needs a vacuum of less than 10^{-8} Torr--a level about 20 times better than that of the two-mile accelerator. If the pressure is higher than that, the SPEAR beams bump into so many gas molecules that they get frittered away to low intensity (few particles) too quickly. Materials selection and surface preparation are important for such low vacuum levels.

The problem of getting the radiation out of SPEAR can be divided into two parts: (1) hard x-rays, with energies above about 3500 electron volts, and (2) all the rest of the lower energy x- and ultraviolet radiation. For the hard stuff, the solution is fairly simple. X-rays of 3.5 keV and higher will readily pass through a vacuum-tight 'window' which consists of a thin foil of beryllium metal. This window acts as a dependable barrier between SPEAR's good vacuum and the outside world. Once through the window, the hard x-rays continue in an atmosphere of helium to the experimental stations.

For the remaining, lower energy radiation, the solution that has been adopted is to extend SPEAR's vacuum system tangentially out in a 'finger' toward the SSRP facility (see next page). This extended vacuum system is potentially vulnerable to leaks that may occur in various pieces of SSRP experimental apparatus. For this reason, a special fast-acting vacuum



--*Photo by Joe Faust*

SSRP vacuum specialist Ralph Gaxiola is shown opening a high-vacuum valve on the 4° beam line at SSRP. Protection of the SPEAR vacuum and of the experimental vacuum systems is a prime concern of SSRP. Ralph gained much of his knowledge of ultra-high-vacuum systems while working in Norm Dean's SPEAR vacuum group. His responsibilities include interfacing with experimenters who want to connect their equipment into the extended SPEAR vacuum system.

valve (supplied by the CERN ISR group) has been installed near the SPEAR end of the extended finger. This valve can close in .03 second if triggered by any of several ionization gauges or other "gas sniffers" around the system. Care has also been taken to avoid contaminating either the SPEAR or SSRP systems with such materials as heavy hydrocarbons.

3. The Layout Of SSRP

The general arrangement of beams and experimental apparatus in the SSRP facility is illustrated in Fig. 4. Inside the vacuum chamber coming from SPEAR there are two special mirrors which split the narrow spray of synchrotron radiation into three separate beams: (1) The straight-ahead undeflected beam consists of hard x-rays with energies of 3.5 keV and above. (2) A second beam is reflected sideways through a 4^{o} angle; it consists of ultraviolet and x-radiation with energies less than about 2 keV. (3) The third beam is reflected upward through an 8^{o} angle; it consists of the softer ultraviolet radiation of 300 eV or less energy.

The straight-ahead, hard x-ray beam is simultaneously shared by three different experimental areas. If the need should arise, more elaborate switching and splitting systems can be added to provide additional experimental areas for any of the three main beams.

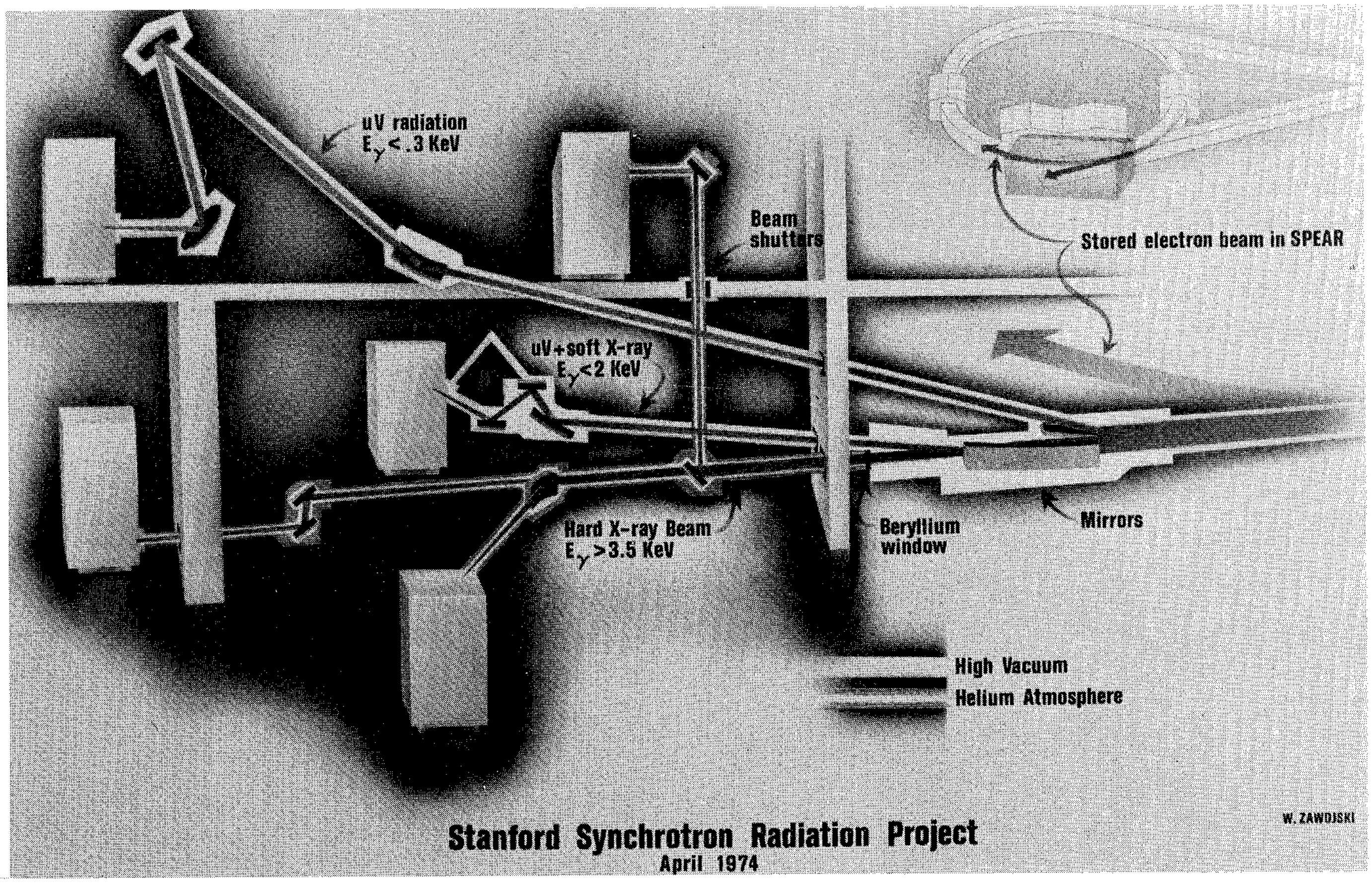
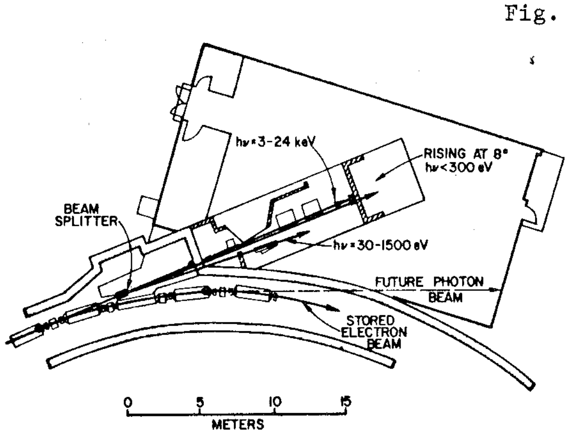
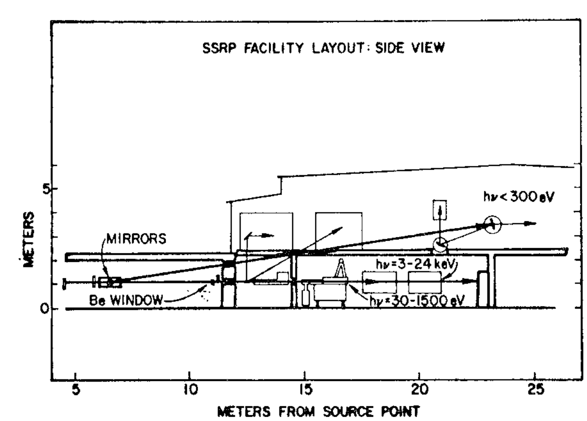
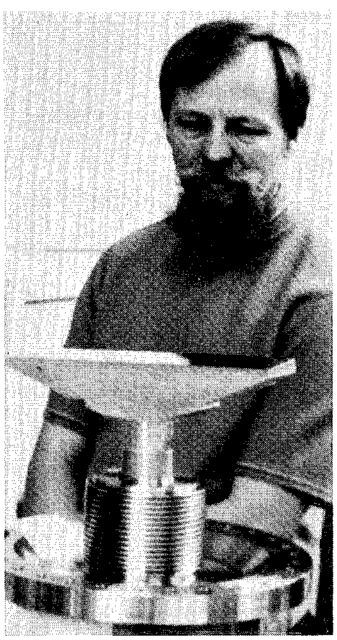


Fig. 4--SSRP Layout





The two beam-splitting mirrors at the front end of the SSRP beam system are particularly important and thus worth some special attention (see Fig. 5). Each is constructed of a thick copper block, polished to an exceptionally smooth finish, and plated with a thin layer of platinum. One of the mirrors is plane (flat), while the other has a very slightly concave cylindrical surface which focuses the radiation in the horizontal plane. The synchrotron radiation from SPEAR is sufficiently intense so that the mirrors must be able to dissipate something like 50 or 100 watts. Normally this heat load would be handled by a water-cooling system, but in this case it was decided that a rapid flow of water might cause a mechanical disturbance of the mirrors and thus affect the reflection of the synchrotron radiation beam. Since the alignment of of the beams is critical (they must be precisely directed to monochromator entrance slits that are only .001 centimeter wide), the cooling technique that has been adopted for the mirrors is the novel thermoelectric method.



--Photo by Herm Winick

Fig.5--Vic Rehn of the U.S. Navy's Michelson Lab at China Lake, California, is shown with one of the two beam-splitting mirrors that are used to separate the synchrotron radiation from SPEAR into high-, medium- and low-energy components. Vic's group has pioneered in the design and construction of such ultra-smooth mirrors. The mirror shown here has an average surface roughness of less than 30 Å, and is probably the smoothest piece of metal of this size ever made. Two such mirrors are used at SSRP.

4. Monochromators

As we noted earlier *monochrome* means 'one color,' so a *monochromator* is a device for getting radiation of a single color (or energy or wavelength). Perhaps it will come as a surprise that you are already familiar with a monochromator of a certain kind: a prism. As a reminder, Fig. 6 shows how the combination of a prism and a slit can be used to select one color of radiation from a mixed bag of colors.

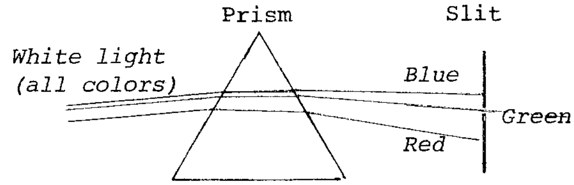
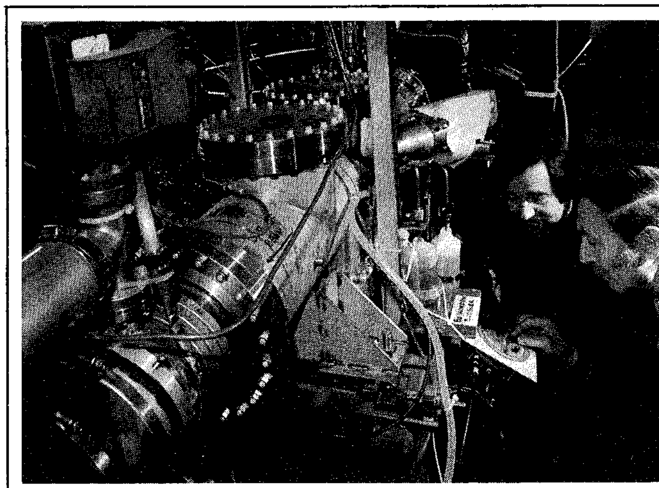


Fig. 6--Use of a prism and a slit to form a simple 'green-light' monochromator.

The fancier monochromators used at SSRP and elsewhere produce somewhat the same result as a prism, but they do it in a different way. The white light passing through a prism is spread out into its constituent colors by a process called *refraction*. This color separation can also be achieved by the *diffraction* of light from either of two kinds of special surfaces: (1) a man-made *diffraction grating*, or (2) any of a number of natural *crystal* materials. Let's look at these two monochromator possibilities in turn (next page).



--Photo by Joe Faust

Ben Salsburg (left) and Axel Golde of the SSRP staff are shown checking the helium flow in the straight-ahead x-ray beam line. This view is taken looking back toward SPEAR. Axel is responsible for mechanical facilities at SSRP. He works with experimenters to fit their equipment into the appropriate beam line, and also designs shielding, helium systems, beam shutters, and other mechanical components.

Diffraction gratings. The original form of diffraction grating, devised by a man named Fraunhofer, consisted of a series of parallel wires spaced an equal distance apart, as shown in Fig. 7.

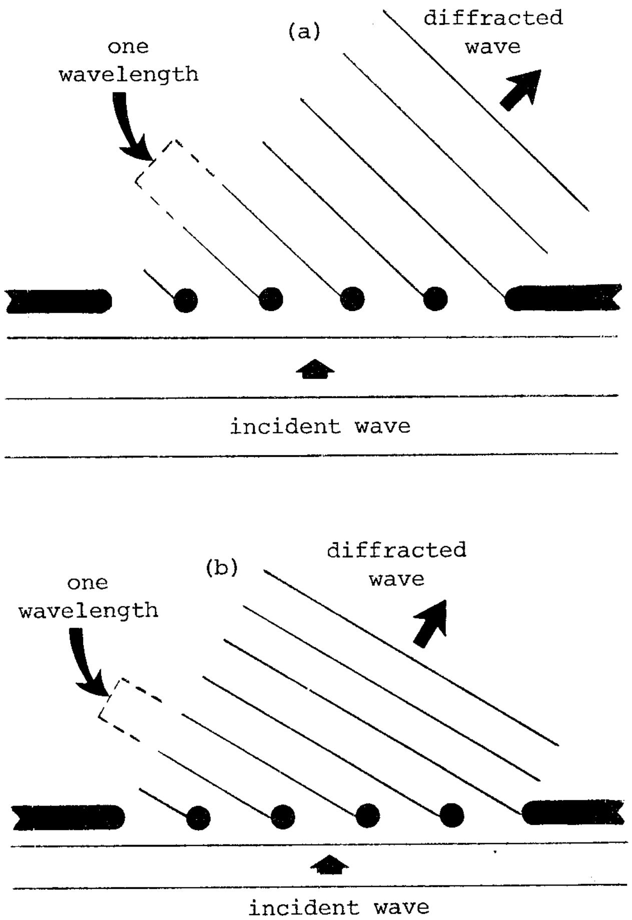
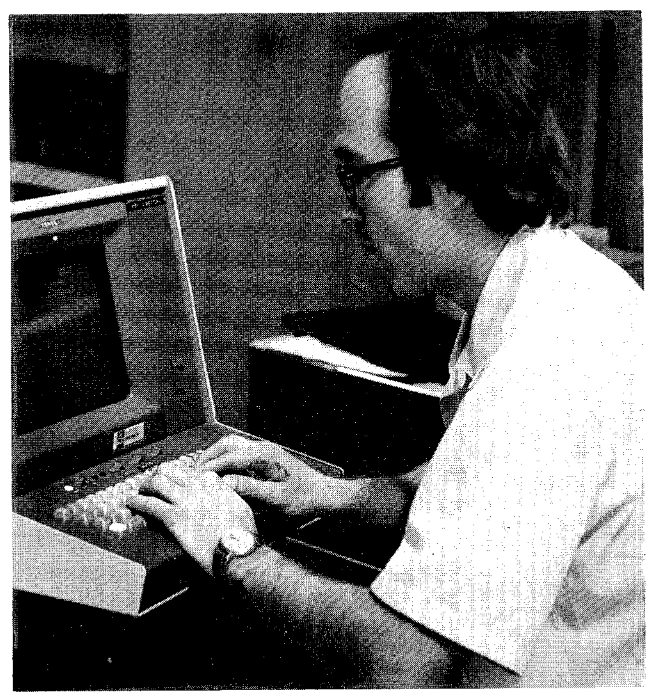


Fig. 7--A diffraction grating made of four parallel wires. The two sketches, (a) and (b) show how different wavelengths of radiation are diffracted at different angles by the wires. This is an example of a *transmission* grating, in which diffraction occurs as the radiation passes through the wire grid. The more common form, described in the text, is a *reflection* grating, in which the diffracted radiation reflects back from a grooved solid surface. All diffraction gratings serve the purpose of separating radiation into constituent 'colors' or wavelengths, and are thus the key elements in monochromators.

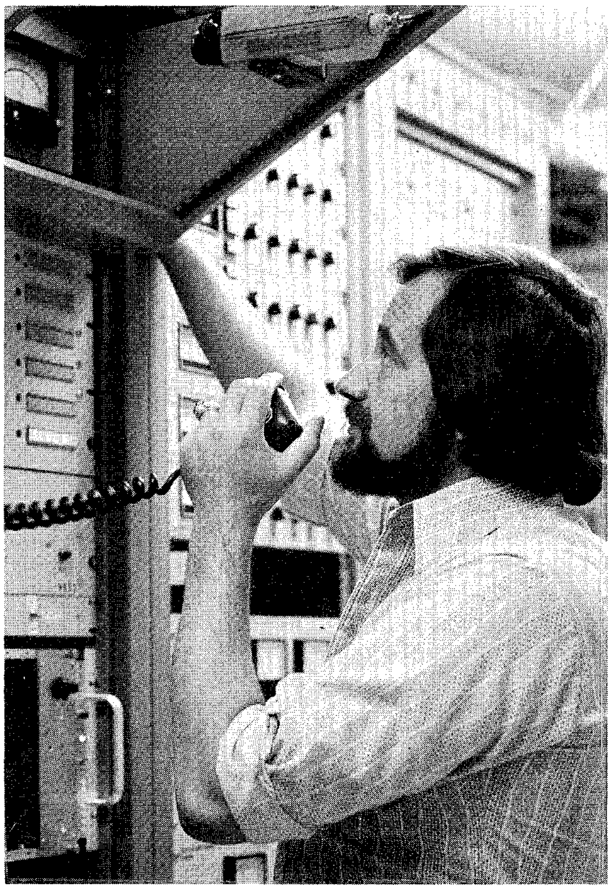
We used the parallel-wire form of diffraction grating to illustrate the principle because it is easy to draw. However, the more common form of grating is a smooth surface into which many parallel grooves have been cut by a sharp scribing instrument. Since the spacing between grooves (or wires) will determine the range of wavelengths that can be separated (or *dispersed*) by a grating, short wavelengths will require very close spacing. A machine called a 'ruling engine' is used to cut or scribe the grooves, and the most accurate of these machines can cut as many as several thousand grooves per centimeter on a suitable surface. If we recall, however, that our studies of atoms may require x-rays with wavelengths of less than a *millionth* of a centimeter, then it's obvious that even the best of man-made diffraction gratings will not be good enough, and we'll have to look elsewhere for a 'one-color-maker.'

Crystal monochromators. The ultimate diffraction gratings are those produced by nature. On the surface of such crystalline solids as quartz, for example, the regular spacing of the rows of atoms in the *crystal lattice* produces the same effect as the parallel grooves in a ruled grating. And since the distance between the parallel rows of atoms in a crystal is roughly a few angstroms, such crystals can be used to sort out x-ray wavelengths into their constituent 'colors.' As an example of the kind of resolution that can be achieved, there is a monochromator presently in use at SSRP which successively diffracts an x-ray beam from two separate crystals. This device yields an 8 keV x-ray beam in which the energies of the individual photons are the same to within about 0.2 electron-volts.



--*Photo by Joe Faust*

Visiting experimenter Gus Apai, from Lawrence Berkeley Laboratory, is shown at the teletype control for the ultra-high-vacuum, grazing-incidence monochromator, an instrument that was designed and built at Xerox Corporation and at the University of Wisconsin.



--Photo by Joe Faust

Ben Salsburg of SSRP is shown communicating with the SPEAR control room in order to adjust the position of the SSRP beam. Unlike charged-particle beams, which can be steered and focused magnetically, the synchrotron radiation beam emerges along a path that is tangential to the orbit of the circulating electrons in SPEAR. Thus the synchrotron radiation beam is steered by adjusting the orbit of the SPEAR electron beam. A simple and effective orbit-control circuit was designed by Ewan Paterson and was installed by the SPEAR operators working under Tom Taylor. This system has made it possible to position the synchrotron radiation beam with an accuracy of a fraction of a millimeter at a distance of 20 meters from SPEAR, thus eliminating the need for frequent realignment that is the norm at other synchrotron radiation labs.

Ben Salsburg is in charge of electrical systems at SSRP, working with experimenters to get their equipment set up and operating properly. He is presently designing a read-out system for a multi-wire proportional chamber array that will be used in x-ray diffraction studies--an example of high-energy-physics technology adapted to other research uses.

D. THE SSRP EXPERIMENTS

Although SSRP has only been in operation since May 1974, it has already achieved experimental results that have attracted a good deal of attention. Six papers based on work done at SSRP were presented at the International Conference on Ultraviolet Radiation Physics held in Hamburg, Germany, in July. In addition, about 80 scientists from all parts of the U.S. and from Western Europe recently attented an SSRP Users Conference at SLAC to discuss the research possibilities at SSRP.

In the following paragraphs we first describe the mechanism by which experimental proposals are acted upon at SSRP, after which we go on to a description of some of the actual experiments that have already been carried out or are presently planned.

1. *Proposals And Decisions*

Like SLAC, SSRP is a national facility for basic research. This means that SSRP's facilities are available to any qualified user. Experiments presently under way at SSRP include scientists from the University of Washington, from Caltech, from Xerox Corporation, from Bell Telephone Labs, from the University of Illinois, from UC-Berkeley, and of course from Stanford. More than a dozen new proposals have been received from these and other institutions, including Argonne National Laboratory, Harvard University, and the National Bureau of Standards.

Proposals for experiments are sent to SSRP's Director, Professor Doniach, who seeks advice from several different sources before reaching his decision. The proposals are reviewed for scientific merit by SSRP's Program Review Panel, a group that is similar to SLAC's Program Advisory Committee. In addition, outside referees (not football) are called upon for advice in their particular fields of expert knowledge. And SSRP's staff provides advice about technical feasibility in much the same way that SLAC's Experimental Facilities Department advises the Director of SLAC. The only role which SLAC itself plays in this process is to exercise control in safety matters--particularly radiation safety--and to set vacuum standards for those experiments that will be connected to the line leading to the SPEAR vacuum system. Once a proposal has been accepted, it is scheduled into the overall SSRP program, and is eventually carried out with the assistance of the SSRP staff.

The construction of SSRP was funded by the National Science Foundation, starting in June 1973. Because of the fact that the SPEAR designers had had the foresight to fit the ring with a small tangential 'spout' which merely had to be uncapped (the open spout lets out less than .002 of SPEAR's total synchrotron radiation) it was possible to begin some preliminary pilot studies with the radiation as early as July 1973. By May 1974 the facility was fully operational, thanks in large measure to the outstanding co-operation and assistance provided by SLAC (see separate box on this page). Thus SSRP was able to get in about 7 weeks of solid experimental running before the scheduled shutdown of the storage ring for conversion to SPEAR II. During this run there were three types of experiments of considerable interest carried out at SSRP, which we'll describe in the next three sections of this article.

2. *EXAFS: Extended X-Ray Absorption Fine Structure*

The apparatus used in the EXAFS experiments consists of a variable-energy monochromator that directs x-rays with a well-defined energy ($\pm$ 1 electron volt at about 10 keV) onto a target material at intervals of about one pulse second. Some of these x-rays knock loose inner-shell electrons (those closest to the nucleus) from the atoms in the material. That is, in the right circumstances an electron will absorb the energy of an incoming x-ray and recoil completely out of the atom. Ion chambers placed just in front of and just behind the target material are used to measure the x-ray flux that arrives at, and is transmitted through, the target. A computer calculates the ratio of these measurements (which is the absorption), steps the monochromator to a new energy setting, then makes a new measurement. Several thousand measurements, each of which lasts from 1 to 5 seconds, are made in rapid succession, and the results are plotted on-line as well as stored in the computer memory for later analysis.

The absorption of x-rays by matter follows the characteristic pattern shown in Fig. 8. The absorption peaks at a certain critical energy (different for each element), then tails off fairly slowly at still higher energies.

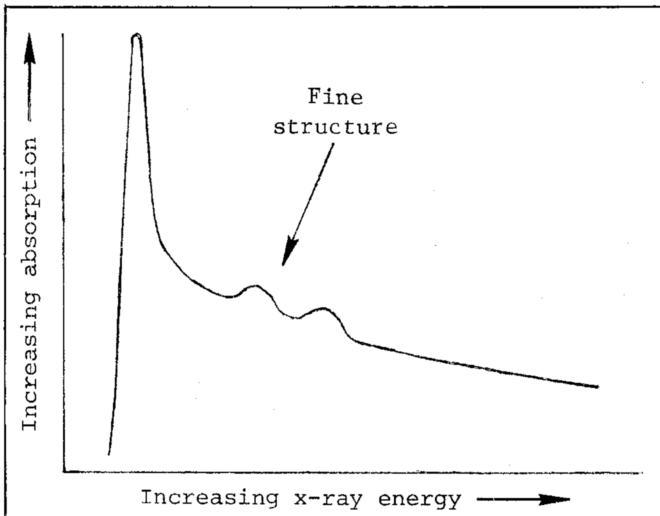


Fig. 8--Typical pattern of x-ray absorption by inner-shell atomic electrons. If the emitted electron interacts with neighboring atoms, the interactions will show up as fine structure in the absorption curve.

To understand what happens to the freed electron, we have to recall that electrons, like other elementary particles, are not only little bits of stuff but also that they can just as well be thought of as waves. And when an outgoing electron wave leaves its home atom it is quite likely to get scattered (bounced around) by the neighboring atoms. This scattering or interaction with the neighbors shows up in the absorption measurements as a series of small bumps or wiggles (that is, as *fine structure*) in the energy region just above the main absorption peak. Therefore--and this is the point--any change in the arrangement of the neighboring atoms will *show up as a change in the fine structure*.

Thus the EXAFS technique gives us a powerful tool for gaining detailed information about the local environment of an x-ray absorbing atom.

A SPECIAL VOTE OF THANKS

Although the original SSRP plans called for a construction schedule of 18 months, the facility actually began operating after only 10 months. We want to acknowledge this remarkable achievement by mentioning some of the people, both from SSRP and from SLAC, who made it possible.

Much of the individual credit goes to Axel Golde, Ray Dannemiller and Ben Salsburg of the SSRP staff. The vacuum system for SSRP was designed by Fred Johnson, and was built, assembled, tested and installed by Mark Baldwin (now replaced by Ralph Gaxiola); Norm Dean and Joe Jurow gave much valuable assistance in this work.

The special thin beryllium and carbon foils were developed by Earl Hoyt. Gary Warren defined the shielding requirements and also helped develop the access procedures; Gary now monitors SSRP activities for radiation safety. Bob Baker helped in designing and in supervising the installation of the cable plant.

Control logic for the vacuum and personnel protection systems was designed by Bob Melen, Bruce Humphrey and Jack Miljan, and was mostly constructed in Frank Generali's shop. Bill Savage, Alex Tseng, Morris Beck and Ray Robbers led the Plant Engineering effort in the design and in supervising the construction of the SSRP Building (No. 120). Ray Larsen and John Harris provided technical advice and liaison between SSRP and SLAC.

The SSRP staff would like to thank everyone who helped for a job well done.

This technique has been known for many years (it was first explained by Kronig in 1931), but there were practical problems connected with doing the experiments. When conventional x-ray tubes are used to produce the radiation, it is not uncommon for one complete energy scan of a single material to take a few *days*, or even *weeks*, to be completed. During such long running periods there are fluctuations in tube output and in detector sensitivity, with the result that the experiments were both painfully long and not very precise.

The high intensity and excellent collimation of SPEAR's synchrotron radiation makes it possible to measure a complete absorption spectrum with excellent accuracy in a typical period of about *25 minutes*, or roughly 1000 times faster than with earlier methods. An example of an EXAFS measurement done at SSRP is shown in Fig. 9. This experiment was a study of the copper-atom environment in the compound copper sulphate ($CuSO_4$). The first measurement was on the crystalline material itself, and the second after it had been dissolved in water. A completely different spectrum appeared for the second measurement, and it is now thought that the change resulted from a surrounding 'cage' of water molecules that had been established around the copper atom in solution. On a later measurement ammonia was added to the solution, and again the spectrum changed as a result of the formation of copper-ammonium ions. This experiment marks the first time that direct structural data of this kind has been possible in the field of solution chemistry.

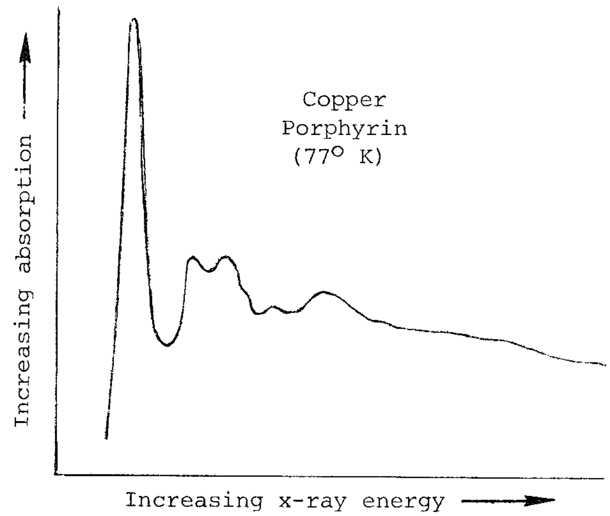
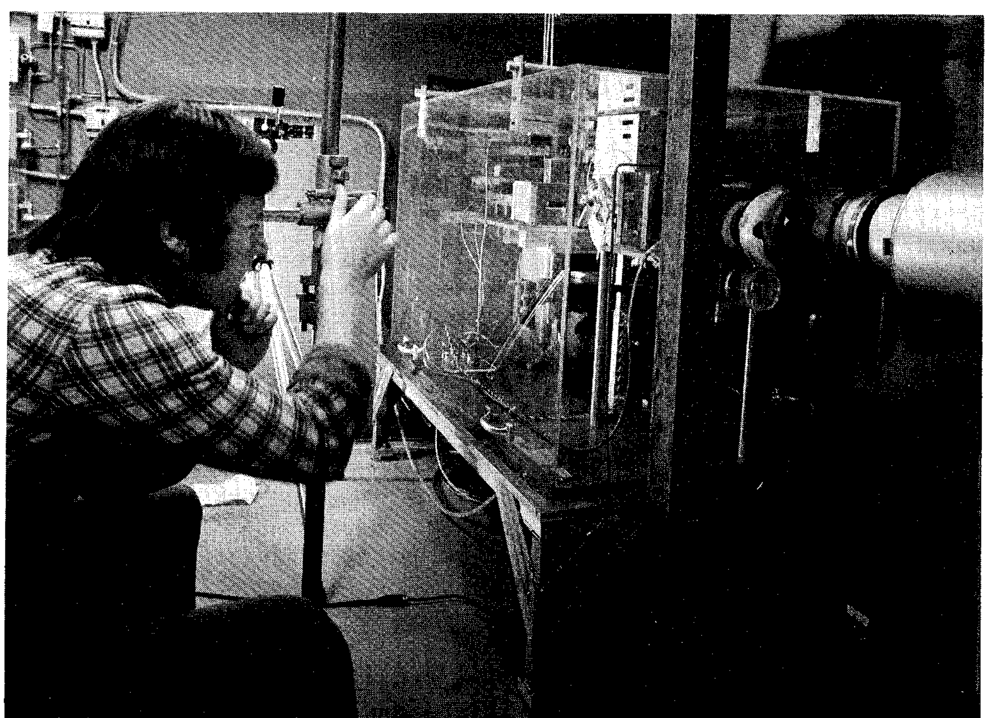


Fig. 9--EXAFS spectrum of tetraphenyl copper porphyrin at 77° K. The fine structure to the right of the peak indicates that the electron that was knocked out of the inner atomic shell of the copper atom is being interfered with by neighboring atoms.

One additional EXAFS application is worth noting. There are certain biological processes, in particular enzyme mechanisms, which depend critically on the precise location of a specific atom in a complex biological molecule. Since EXAFS probes the surroundings of a particular x-ray absorbing atom, the technique can be used, for example, to measure the slight shift in position that the iron atom in a hemoglobin molecule makes when the hemoglobin (in red blood cells) picks up or releases the oxygen it carries.



Visiting experimenter Pierre Lagarde, from the synchrotron radiation research center at Orsay, France, is shown aligning the crystal monochromator that is used in the EXAFS studies at SSRP.

--Photo by Joe Faust

3. *Photo-Electron Emission*

The process by which ultraviolet light or x-rays knocks an electron out of an atom is called the *photo-electric effect* (it was first explained by Einstein in 1905). By measuring the energies and angular distributions of the knocked-out electrons it is possible to learn a good deal about the electronic structure of the various elements. Some electrons in atoms are held tightly in an inner shell, while others wander more freely around the atom's outer periphery.

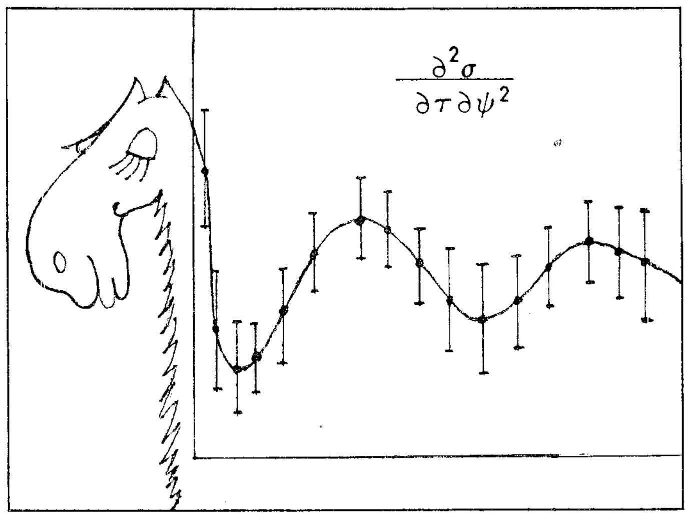
Three different experimental groups are presently pursuing studies of this kind at SSRP. Much of this work takes advantage of the fact that the synchrotron radiation from SPEAR has a unique time structure. Although the circumference of the SPEAR ring is about 800 feet, the machine is operated in the 'one-bunch mode,' which means that the single bunch of electrons circulating in the ring only takes up a space about 15 inches long (SPEAR II's new RF system reduces the bunch length to about 3 inches). Thus an observer standing in the SSRP facility and looking at SPEAR would see a flash of light that lasts for about 10^{-10} second, then darkness for about 10^{-6} second, and so on.

--Photo by Joe Faust

Vern Jones (left) and James Leland Stanford (yes, a direct descendant of the University's founder) are shown adjusting a mirror on the 8° beam line at SSRP. This beam line was built as a collaborative effort between SSRP and the U.S. Navy Michelson Lab at China Lake, California.

Experiments at SSRP take advantage of this comparatively long period of darkness between flashes to make time-of-flight measurements of the velocity of the knocked-out photo-electrons. This is done simply by measuring how long it takes the electron to travel from the target to the detecting apparatus. Knowing the velocity, the electron's energy and momentum can be calculated, and this information, together with the measured angular distribution patterns, is what is needed to infer the particular atomic structure from which the electron came.

Information about the way in which an atom's structure is determined by the particular configurations of its electrons is of paramount importance in trying to understand the properties of materials. SSRP's work in this field seems likely to be an important contributor to understanding the surface properties of metals, semiconductors and insulators, with applications to such practical areas as the fabrication of electronics components and the catalysis of chemical reactions.



4. *Biological X-Ray Diffraction*

The apparatus for using monochromatized synchrotron radiation to study the structure, and changes in structure, of biological systems has been used for some preliminary experimental work to date. X-ray diffraction patterns have been obtained from frog's-leg muscle and also from rat-tail collagen. (SSRPers are now in the habit of opening packages rather slowly, after several one-pound-size bullfrogs jumped out of one box.) The earliest exposures took several minutes, but recent apparatus improvements, coupled with the expected higher intensity from SPEAR II, make it likely that exposure times of less than one second will be feasible. So short an exposure time opens up the exciting possibility of studying the rapid changes that occur in many biological systems--for example, muscle and retinal tissue. Toward this end, there is work now being done on possible electronic detection techniques (e.g., wire chambers) to replace the film that is commonly used.

E. SPEAR II AND BEYOND

As far as SSRP is concerned, SPEAR II is even more of a good thing. We've already mentioned the increase in synchrotron radiation intensity that is expected. The combination of higher energy and greater beam current in SPEAR II will result in synchrotron radiation energy losses of up to 150 kilowatts per beam. This compares with the previous value of about 12 kW from SPEAR I. This roughly 12-fold increase in power also applies to the radiation that comes out to SSRP through the little peephole in SPEAR.

The prospective research potential of SSRP has already produced a great deal of interest among potential experimenters throughout the U.S. As we noted earlier, the physical facilities at SSRP are now set up to handle as many as 5 simultaneous experiments. In response to the expected demand, it may be possible to squeeze in another 1 or 2 set-ups in the present space. In the longer run, however, the better solution would be to have a second main beam run from SPEAR into the new part of an expanded SSRP facility. Plans for such a possible expansion are now being worked on.

For the even longer term, there has been some thought given to the relationship, if any, between SSRP and the proposed PEP storage ring facility at SLAC. Even if PEP is authorized for Fiscal Year 1976, as proposed, it will not be on the air until 1979 or 1980, so there is enough time to consider SSRP's lot in life in the meantime. Speculatively, however, we could imagine a situation in which SPEAR would eventually be operated solely for SSRP's purposes, after the high-energy physics interest had swung over to PEP. Equally imaginable is a revamped SSRP facility that would move over to PEP to capitalize on the higher energy and intensity, and other factors.

But then SSRP still has to learn to walk before it starts to run, since we've done little more than scratch the surface of the present exciting research possibilities. Once we have a few years of experimentation under our belts, the future will doubtless seem clearer.

We'll sign off here with an invitation: if anyone at SLAC would like to take a look around the SSRP facility, we'd be happy to arrange something. Just give a little advance notice by phoning SLAC Ext. 2874.

--Herm Winick & Bill Kirk

MORE ABOUT EXAFS AND SSRP

In their first experiments at Stanford, the [SSRP] experimenters studied some simple systems to check out the characteristics of the new source. They studied atoms, simple molecules, pure crystalline materials and simple compounds and confirmed earlier measurements made with traditional sources. With the krypton atom they showed there was no marked x-ray structure. Next, with the Br_2 molecule they measured the phase shifts the electrons experienced when scattered from the surrounding atoms. Then $GeCl_4$ and $Ni(CO)_4$ were studied to investigate the possible effects of multiple scattering and shadowing. They also studied semiconductor systems such as CuBr and GaAs and Ge to investigate the effect of ionicity of the band on the EXAFS structure.

The experimenters then wanted to demonstrate some of the potentialities of the technique. To show possible biological applications, they studied nickel and copper porphyrin and hemoglobin. In the porphyrins the metal atom is present to only one part in 50 or 100; the group was able to show that a good spectrum was still obtainable under these conditions. In hemoglobin, the iron atom in the porphyrin ring represents only about one part in 10,000; even in such a small proportion the experimenters found significant EXAFS structure. [They are] hopeful that the technique may be applied to oxygenation--by taking a spectrum of unoxygenated hemoglobin and then one for oxygenated hemoglobin one could learn how the immediate structure around the iron is affected by the presence of oxygen.

The technique has much potential in applications where the local environment around a given atom is of special interest, particularly for noncrystalline systems . . . . To demonstrate potential applications to chemistry, the experimenters compared spectra for bromine salts in solid form and in a water solution. The formation of hydrated bromine ions was demonstrated by the identity of bromine EXAFS structure for dilute solutions of different bromine salts . . . it should be possible to extract information on the structure of the hydrated ion by more detailed analysis of the spectra.

It might be possible to study a variety of chemical reactions . . . on a real-time basis by looking at reaction intermediates. To be feasible, one would like a factor of ten higher intensity (which will be available as a result of the upgrading program) for the x-ray source and measurement times in the 1-100 millisecond range.

--*Physics Today*, October 1974

MORE ON PSI

NO BLOCKBUSTERS THIS TIME, BUT A REPORT ON SOME RECENT ACTIVITIES

This eight-page section of the *Beam Line* contains the following parts:

Most of the information in Part A was provided by Roy Schwitters of SLAC's Experimental Group C. Part B is reprinted from the December 1974 issue of the *CERN COURIER*.

Although there is some new information to report this month about the psi particles, it's not the headline sort of stuff that we were happily beginning to get used to last month. The rumors you've been hearing about the discovery of a third new resonance at SPEAR are probably true (see page *Psi-2*), but better keep your shirt on because it's not all that big a deal. Since the discovery of the $\psi(3695)$, on November 20, there have not been any startling new developments either in the continuing experimental work or in theoretical interpretation of what it all means.

But this apparent lull after the storm doesn't really detract from the significance of the psi discoveries. The conversations in the Central Lab continue to have a kind of "once a decade" tone to them, and the physics literature continues to be inundated with a flood of papers on the subject. In addition, a remarkable number of people at SLAC have expressed a strong interest in following the psi story, even when it isn't making headlines. So we plan to try to make the most of a good thing by reporting often in the months ahead on what's happening, both here at SLAC and elsewhere, in the field of "ψchology" (the word is H. Harari's).

Several people at SLAC have sent us letters with kind words about the special December 5 issue of the *Beam Line* on the psi discoveries. We appreciate the encouragement. We'd also like to get any suggestions you may have about topics that need better explanation, new subjects that should be covered, and like that.

--BK

A. SPEAR EXPERIMENTS SINCE PSI

The last experimental running cycle for 1974 ended on December 15, and as the beams in SPEAR were shut down a semblance of calm finally returned to the control room. You may remember that SPEAR had been turned off early in the Summer of this year in order to go through the energy-upgrading modification called SPEAR II. When operation resumed, in mid-October, the plan was to work mainly on getting SPEAR II debugged and purring smoothly, with a little time left over for physics. So much for well-laid plans. The $\psi(3105)$ was discovered on November 9, and from that time on until December 15 experimentalists were crawling around SPEAR like so many ants, with the result that a good part of the SPEAR II debugging work and optimizing work has yet to be done. Next cycle, for sure.

The December 5 special issue of the *Beam Line* described the discoveries of the two psi particles. We report here on the experimental work that has been done at SPEAR since that time. Two kinds of studies were carried out: a search for additional particles, and measurements of some of the properties of the $\psi(3105)$ and $\psi(3695)$ particles.

1. *The Search For Additional Particles*

Let's begin with a brief reminder of what the numbers *3105* and *3695* mean. Since Einstein ($E = mc^2$) it has been known that *energy* and *mass* are interchangeable things--that in some sense they are the same thing. Making use of this fact, physicists have found it convenient to express the mass of elementary particles in units of energy. It seems simpler to say that a proton's mass, for example, is 938 MeV rather than 1.67252×10^{-27} kilograms. So $\psi(3105)$ means the particle whose mass is 3105 MeV. Because of the special way in which SPEAR works, it also happens that this particular kind of particle is produced most copiously when the *sum* of the energies of SPEAR's electron and positron beams is exactly equal to 3105 MeV. This is because of the fact that the collision between two particles of equal energy (each 1552.5 MeV in this case) causes *all* of the energy carried by the two particles to be available for creating new particles. This is the case for SPEAR and for other equal-beam-energy storage rings, but not for conventional accelerators. In the Brookhaven experiment which observed the 3105 MeV resonance, for example, the energy of the proton beam was not related to the mass of the resonance and its actual value (about 28,500 MeV) was so unimportant that it was not even mentioned in the *Physical Review Letters* paper that announced the discovery.

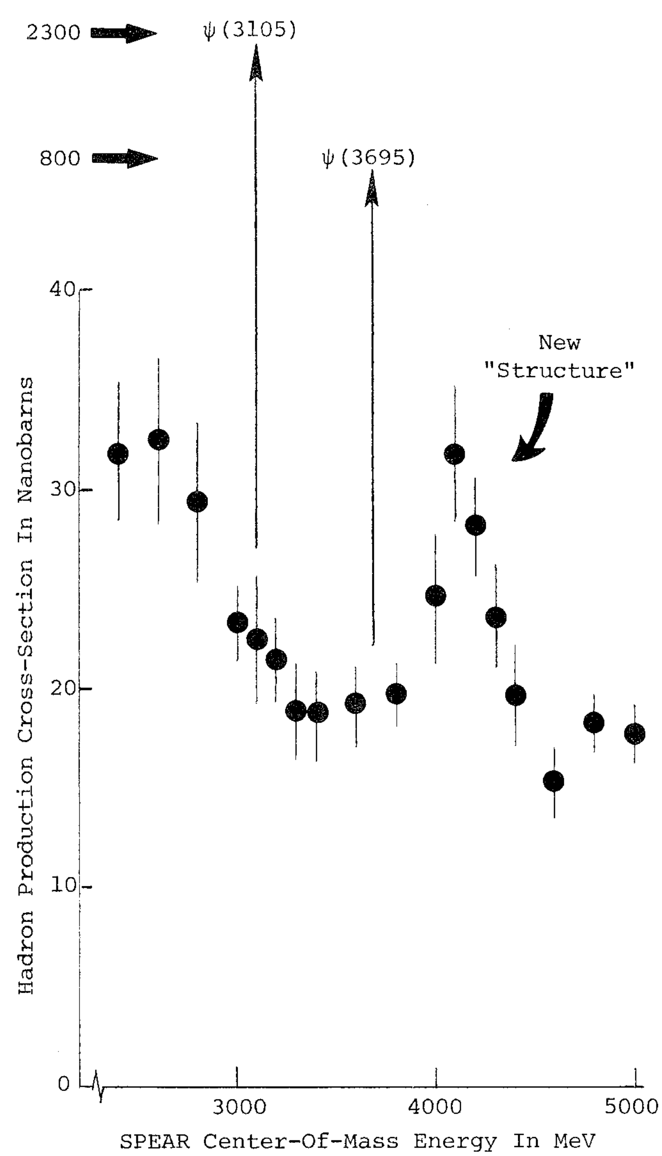
On to the search. Using the large magnetic detector in the West interaction region at SPEAR, the joint SLAC-LBL experimental team carried out a rather fine-toothed combing of the energy region from

3200 to 5900 MeV

(the same as 3.2 to 5.9 GeV, but we'll stick to MeV here because of the 3105 and 3695 names). The search was conducted by collecting data in a series of short runs, with the SPEAR energy being changed in 1 MeV steps from run to run, and with about two to five minutes spent at each energy setting. Under normal conditions (no resonances), the apparatus will detect perhaps one or two events during this short period of time. As described in the December 5 *Beam Line,* the events of interest here are those in which *hadrons* (strongly interacting particles, such as pi-mesons) are produced. If SPEAR's energy had just matched the mass of a new resonance during any of these short runs, the counting rate for hadronic events would have risen dramatically. As an example, the discovery of the second psi particle occurred during a series of short runs which averaged less than one event per run; but the run at 3695 MeV produced 9 events and thus delivered a loud message.

So what happened? Well, the answer is that no striking new resonances similar to the psi particles were found during the search. However, analysis of earlier SPEAR data did disclose a rather broad enhancement or "bump" at about 4100 MeV that is probably--but not certainly--a new resonance. The SLAC-LBL group has submitted a paper* which reports this finding, and in which they describe the bump as "structure," rather than as a resonance. The figure on the other half of this page describes the new thing, whatever it is, and also serves to illustrate the fact that it does not much resemble the two psi resonances.

In a more general vein, the energy scan from 3200 to 5900 MeV at SPEAR has pretty well ruled out the possibility of additional psi-like resonances in this energy region. Although more analysis will be required before precise statements can be made, the rough conclusion is that any resonances as sharp as the psi's would have been seen if they had a production cross-section (probability of creating them) that was greater than about 200 nanobarns--which is about 10 times lower than that of the $\psi(3105)$.



This figure is adapted from the paper by Augustin *et al*. noted below. It shows the evidence for "structure" in hadron production at an energy of about 4100 MeV. This structure is probably a broad resonance. A less likely explanation is that the bump represents a "threshold" effect, in which the cross-section rises when the energy becomes high enough to open up "new channels" of particle production. The $\psi(3105)$ and $\psi(3695)$ arrows have been added to the figure for comparison with the new bump, which has a width of about 250 or 300 MeV. In contrast, the psi resonance peaks are narrower than the arrow lines drawn on the figure. The new structure has a cross-section (probability for creation) of about 30 nanobarns, compared with 2300 and 800 nanobarns for the two psi particles. If the psi resonance peaks were drawn to the same scale as the rest of the figure, the arrow indicating $\psi(3105)$ would reach about 200 feet above the top of the page.

J.-E. Augustin et al, "Total cross-section for hadron production by electron-positron annihilation between 2.4 GeV and 5.0 GeV center-of-mass energy," submitted to Phys. Rev. Letters *(SLAC-Pub-1520).*

2. The Properties Of The Psi Particles

The second kind of experimental effort that has been going on at SPEAR since that reported in the December 5 *Beam Line* has been a more detailed study of some of the properties of the two psi particles. This work has been carried out with experimental apparatus in both the East and West interaction regions at SPEAR. In the West pit, the SLAC-LBL group has used the magnetic detector to study the decay of the psi resonances into several charged particles (those which have either a + or - electrical charge). In the East pit, a collaborating group* from the Stanford Physics Department, from the High Energy Physics Lab (HEPL) at Stanford, and from the University of Pennsylvania has used two large sodium iodide detectors to study psi decays into high-energy gamma rays and into muon pairs and electron-positron pairs. The two experimental groups accumulated data simultaneously while SPEAR was running.

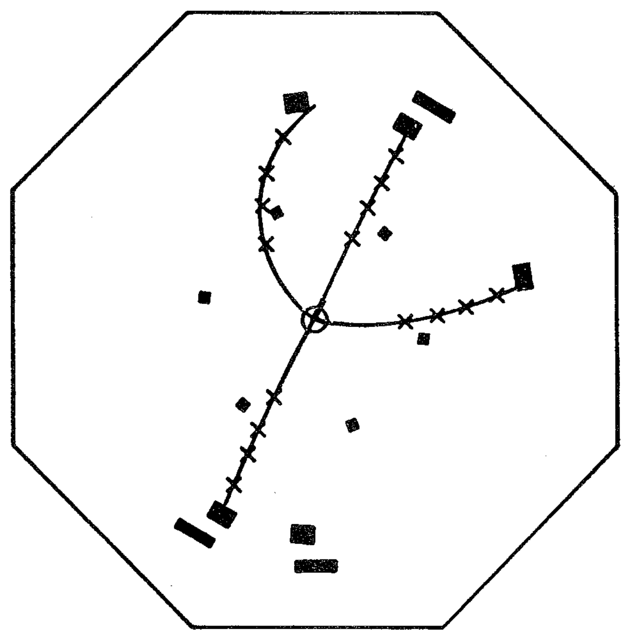
The experimental running time was divided between "sitting" on the resonance peaks of the two psi particles and running with SPEAR's energy set a few MeV below the 3105 MeV peak. With the energy set directly on the peak, the data corresponds to the decays of the psi's into ordinary particles; this kind of measurement is useful in trying to figure out why these ordinary decay processes are so strongly inhibited (why the psi's decay so slowly). The reason for taking data a few MeV off the peak involves some subtle physics that we can only touch upon briefly here. This has to do with an interference effect that is expected to occur between the decay of the $\psi(3105)$ into muon pairs and the production of muon pairs by the usual (non-psi) process. This interference effect, if confirmed, would provide an elegant way to determine two of the basic properties of the $\psi(3105)$: its *spin* and its *parity* (two of its intrinsic "quantum numbers"). The experimental data on this possible interference effect is presently being analyzed, and the results should be known fairly soon.

Information on the ψ(3105). Over 50,000 decays of the $\psi(3105)$ have been observed and recorded on magnetic tape by the SLAC-LBL group. One important result that has emerged so far is the fact that the $\psi(3105)$ appears to decay into an odd number of pi-mesons (pions) much more frequently than it does into an even number. This observation makes it likely that the $\psi(3105)$, which is an electrically neutral particle, does not have any charged (+ or -) sisters or brothers.

Information on the ψ(3695). The SLAC-LBL group has also accumulated about 20,000 decay events of the $\psi(3695)$. The most interesting fact learned so far is that the $\psi(3695)$ decays about 25% of the time into the $\psi(3105)$ plus two pions:

$$\psi(3695) \rightarrow \psi(3105) + \pi^- + \pi^+$$

This is a beautiful demonstration of the relationship between the two particles and is very important for discriminating between different theories which purport to explain them. When this particular kind of decay is observed at SPEAR, the computer reconstructs the event in the amusing way that is shown in the accompanying figure.



This is the sort of picture of events in the magnetic detector that is reconstructed from data fed into the computer at SPEAR. The particular event shown here (this exact topology is rather rare) is a reconstruction of of the decay process

$$\psi(3695) \rightarrow \psi(3105) + \pi^- + \pi^+$$

which is quickly followed by

$$\psi(3105) \rightarrow e^- + e^+$$

The two pions emerge back-to-back from the first decay, but since they have low momentum they are deflected by the magnetic field into oppositely curved paths. The $\psi(3105)$ then decays into an electron-positron pair which also emerges back-to-back but at high momentum, so that the tracks are essentially straight lines. The result of the four tracks is a pretty good picture of the letter "ψ".

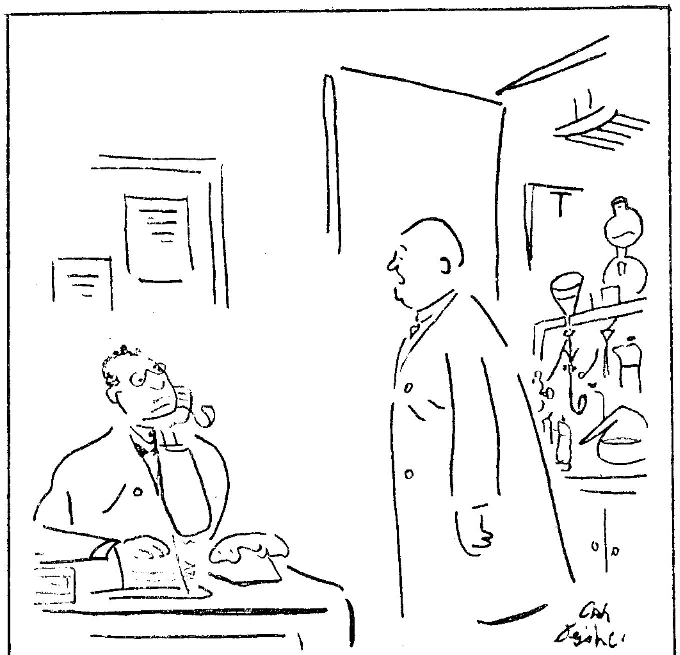
The Stanford-HEPL-Penn group includes the following persons: B. L. Beron, R. L. Ford, E. A. Hilger, R. Hofstadter, R. L. Howell, E. B. Hughes, A. D. Liberman, T. W. Martin, L. H. O'Neill and J. W. Simpson from the High Energy Physics Lab and the Department of Physics at Stanford; and L. K. Resvanis from the University of Pennsylvania.

3. The Stanford-HEPL-Penn studies

This group has been observing the decays of the two psi resonances into muon pairs and into electron-positron pairs. They have also searched for single high-energy gamma rays coming from the decay of the ψ(3695). This data is presently being analyzed, and when available it should have an important bearing on the theoretical understanding of the psi resonances. In particular, several theories make specific predictions about the existence of gamma rays of certain fixed energies that should be observed in the decay of the 3695 resonance. More generally, the sodium iodide detectors and their associated apparatus form an exceptionally effective system for detecting and measuring neutral particles, and as such they nicely complement the charged-particle analyzing power of the magnetic detector in the other interaction region at SPEAR. We hope to carry a more detailed description of the work of this group in a future issue of the *Beam Line*, shortly after the results of their experimental analysis become available.

That wraps up this month's report on SPEAR's experimental work. Since the accelerator is off for awhile now, we probably won't have much in the way of new experiments to report for another couple of months. However, this will give us a much needed opportunity to refine some of the SPEAR data and to sift through it in search of clues that may help to explain what these fascinating new particles are all about.

--Roy Schwitters



"I hate to say this, but, even under our brutally slashed research budget, I've made an important discovery."

--*Saturday Review*, June 12, 1971

B. THE NEW PARTICLES: THE VIEW FROM CERN

Note: This article is reprinted from the December 1974 issue of the CERN COURIER. *It was written by the* COURIER's *Editor, Brian Southworth. Although the article goes over some of the same ground that was covered in the December 5* Beam Line, *both the point of view and the detailed information are different enough to make it good reading for anyone who is interested in the continuing saga of psi. We have taken the liberty of adding a few section headings to the text just to ease the eye a bit. We'd be interested in any comments SLAC readers may have about this or any of the other articles we reprint in the* Beam Line.

Anyone in touch with the world of high energy physics will be well aware of the ferment created by the news from Brookhaven and Stanford, followed by Frascati and DESY, of the existence of new particles. But new particles have been unearthed in profusion by high energy accelerators during the past twenty years. Why the excitement over the new discoveries?

A brief answer is that the particles have been found in a mass region where they were completely unexpected with stability properties which, at this stage of the game, are completely inexplicable. In this article we will first describe the discoveries and then discuss some of the speculations as to what the discoveries might mean.

1. At Brookhaven

We begin at the Brookhaven National Laboratory where, since the Spring of this year, a MIT/Brookhaven team has been looking at collisions between two protons which yielded (amongst other things) an electron and a positron. A series of experiments on the production of electron-positron pairs in particle collisions has been going on for about eight years in groups led by Sam Ting, mainly at the DESY synchrotron in Hamburg. The aim is to study some of the electromagnetic features of particles where energy is manifest in the form of a photon which materializes in an electron-positron pair. The experiments are not easy to do because the probability that the collisions will yield such a pair is very low. The detection system has to be capable of picking out an event from a million or more other types of event.

It was with long experience of such problems behind them that the MIT/Brookhaven team led by Ting, J. J. Aubert, U. J. Becker and P. J. Biggs brought into action a detection system with a double arm spectrometer in a slow ejected proton beam at the Brookhaven 33 GeV synchrotron. They used beams of 28.5 GeV bombarding a beryllium target. The two spectrometer arms span out at 15^{o} either side of the incident beam direction and have magnets, Cherenkov counters, multiwire proportional chambers, scintillation counters and lead glass counters. With this array, it is possible to identify electrons and positrons coming from the same source and to measure their energy.

From about August, the realization that they were on to something important began slowly to grow. The spectrometer was totting up an unusually large number of events where the combined energies of the electron and positron were equal to 3.1 GeV. This is the classic way of spotting a resonance. An unstable particle, which breaks up too quickly to be seen itself, is identified by adding up the energies of more stable particles which emerge from its decay. Looking at many interactions, if energies repeatedly add up to the same figure (as opposed to the other possible figures all around it), they indicate that the measured particles are coming from the break up of an unseen particle whose mass is equal to the measured sum.

The team went through extraordinary contortions to check their apparatus to be sure nothing was biasing their results. The particle decaying into the electron and positron they were measuring was a difficult one to swallow. The energy region had been scoured before, even if not so thoroughly, without anything being seen. Also the resonance was looking 'narrow'--this means that the energy sums were coming out at 3.1 GeV with great precision rather than, for example, spanning from 2.9 to 3.3 GeV. The width is a measure of the stability of the particle (from Heisenberg's Uncertainty Principle which requires only that the product of the average lifetime and the width be a constant). A narrow width means that the particle lives a long time. No other particle of such heavy mass (over three times the mass of the proton) has anything like that stability.

By the end of October, the team had about 500 events from a 3.1 GeV particle. They were keen to extend their search to the maximum mass their detection system could pin down (about 5.5 GeV) but were prodded into print mid-November by dramatic news from the other coast of America. Sam Ting said that the Director of the Laboratory, George Vineyard, asked him how much time on the machine he would need--which is not the way such conversations usually go.

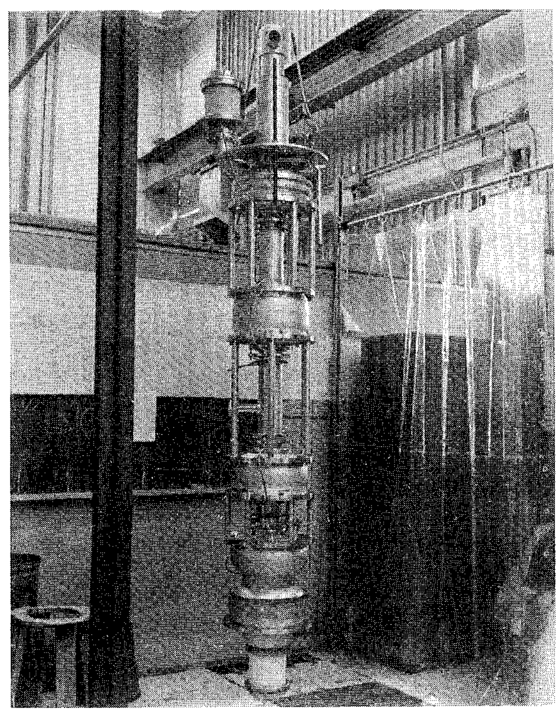
. . . Of what practical good is the discovery? That's unknown, save that it suggests a breakthrough in fundamantal knowledge--a pearl of pure science, which is what these laboratories were created to seek.

--Palo Alto Times
Nov. 19, 1974

2. At SLAC

The apparition of the particle at the Stanford Linear Accelerator Center on 10 November was nothing short of shattering. Burt Richter described it as 'the most exciting and frantic week-end in particle physics I have ever been through.' It followed an upgrading of the electron-positron storage ring SPEAR during the late Summer.

Until June, SPEAR was operating with beams of energy up to 2.5 GeV so that the total collision energy was up to a peak of 5 GeV. The ring was shut down during the late Summer to install a new r.f. system and new power supplies so as to reach about 4.5 GeV per beam. It was switched on again in September and within two days beams were orbiting in the storage ring again. Only three of the four new r.f. cavities were in action so that the beams could only be taken to 3.8 GeV. Within two weeks the luminosity had climbed to 5×10^{30} cm^{-2} sec^{-1} (the luminosity dictates the number of interactions



--Photo by Walter Zawojski

This is one of the high-power klystron amplifiers that were designed and built by SLAC's Klystron Group for use in the new radiofrequency system that is a part of the SPEAR II energy upgrading program. This tube stands about 10 feet high, and it is capable of about 300 kilowatts of average power output at the design frequency of 358 MHz. The rf power from these tubes is coupled to the circulating beams to compensate for the energy they lose through synchrotron radiation.

the physicists can see) and time began to be allocated to experimental teams to bring their detection systems into trim.

It was the Berkeley/Stanford team led by Richter, M. Perl, W. Chinowsky, G. Goldhaber and G. H. Trilling who went into action during the week-end 9-10 November to check back on some 'funny' readings they had seen in June. They were using a detection system consisting of a large solenoid magnet, wire chambers, scintillation counters and shower counters, almost completely surrounding one of the two intersection regions where the electrons and positrons are brought into head-on collision.

During the first series of measurements with SPEAR, when it went through its energy paces, the cross-section (or probability of an interaction between an electron and a positron occuring) was a little high at 1.6 GeV beam energy (3.2 GeV collision energy) compared with at the neighboring beam energies. The June exercise, which gave the funny readings, was a look over this energy region again. Cross-sections were measured with electrons and positrons at 1.5, 1.55, 1.6 and 1.65 GeV. Again 1.6 GeV was a little high but 1.55 was even more peculiar. In eight runs, six measurements agreed with the 1.5 GeV data while two were higher (one of them five times higher). So, obviously, a gremlin had crept into the apparatus. While meditating during the transformation from SPEAR I to SPEAR II, the gremlin was looked for but not found. It was then that the suspicion grew that between 3.1 and 3.2 GeV collision energies could lie a resonance.

During the night of 9-10 November the hunt began, changing the beam energy in 0.5 MeV steps. By 11:00 a.m. Sunday morning the new particle had unequivocally been found. A set of cross-section measurements around 3.1 GeV showed that the probability of interaction jumped by a factor of ten from 20 to 200 nanobarns. In a state of euphoria, the champagne was cracked open and the team began celebrating an important discovery. Gerson Goldhaber retired in search of peace and quiet to write the findings for immediate publication.

While he was away, it was decided to polish up the data by going slowly over the resonance again. The beams were nudged from 1.55 to 1.57 and eveything went crazy. The interaction probability soared higher; from around 20 nanobarns the cross-section jumped to 2000 nanobarns and the detector was flooded with events producing hadrons. Pief Panofsky, the Director of SLAC, arrived and paced around invoking the Diety in utter amazement at what was being seen. Gerson Goldhaber then emerged with his paper proudly announcing the 200 nanobarn resonance and had to start all over again, writing ten times more proudly than before.

3. The European Labs

Within hours of the SPEAR measurements, the telephone wires across the Atlantic were humming as information enquiries and rumours were exchanged. As soon as it became clear what had happened, the European Laboratories looked to see how they could contribute to the excitement. The obvious candidates, to be in on the act quickly, were the electron-positron storage rings at Frascati and DESY.

From 13 November, the experimental teams on the ADONE storage ring (from Frascati and the INFN sections of the Universities of Naples, Padua, Pisa and Rome) began to search in the same energy region. They have detection systems for three experiments known as *gamma-gamma* (wide solid angle detector with high efficiency for detecting neutral particles), *MEA* (solenoidal magnetic spectrometer with wide gap spark chambers and shower detectors) and *baryon-antibaryon* (coaxial hodoscopes of scintillators covering a wide solid angle). The ADONE operators were able to jack the beam energy up a little bit above its normal peak of 1.5 GeV and on 15 November the new particle was seen in all three detection systems. The data confirmed the mass and the high stability. The experiments are continuing using the complementary abilities of the detectors to gather as much information as possible on the nature of the particle.

At DESY [Hamburg, Germany], the DORIS storage ring was brought into action with the PLUTO and DASP detection systems [see page 427 of the December 1974 CERN COURIER for a description of these detection systems]. During the week-end of 23-24 November, a clear signal was seen in both detectors with PLUTO measuring events with many emerging hadrons and DASP measuring two emerging particles. The angular distribution of elastic electron-positron scattering was measured at 3.1 GeV, and around it, and a distinct change was seen. The detectors are concentrating on measuring branching ratios--the relative rate at which the particle decays in different ways.

Any subject, no matter how abstract, how inanimate, how remote from the ordinary affairs of men, remains lively and growing if taught to young children who are themselves growing by leaps and bounds, hungering and thirsting after knowledge of the world around them. To children, an understanding of the world around them is as essential as the tender loving care that, during this century, has been so exclusively emphasised in discussions of early childhood education. The language of science will then become--for everyday use--a natural language, redundant, wide in scope, deeply rooted in many kinds of human experience and many levels of human abilities.

--Margaret Mead

4. The Physics

In the meantime, SPEAR II had struck again. On 21 November, another particle was seen at 3.7 GeV. Like the first it is a very narrow resonance indicating the same high stability. The Berkeley/Stanford team have called the particles psi (3105) and psi (3695).

No one had written the recipe for these particles and that is part of what the excitement is all about. At this stage, we can only speculate about what they might mean.

Hadrons, Leptons & Quarks

First of all, for the past year, something has been expected in the hadron-lepton relationship. The leptons are particles, like the electron, which we believe do not feel the strong force. Their interactions, such as are initiated in an electron-positron storage ring, can produce hadrons (or strong-force particles) via their common electromagnetic features. On the basis of the theory that hadrons are built up of quarks [see the December 5, 1974 issue of the *SLAC Beam Line* and also page 332 of the October 1974 issue of the *CERN COURIER*], it is possible to calculate relative rates at which the electron-positron interaction will yield hadrons, and the rate should decrease as the energy goes higher. The results from the Cambridge [CEA] bypass and SPEAR about a year ago showed hadrons being produced much more profusely than these predictions.

What seems to be the inverse of this observation is seen at the CERN Intersecting Storage Rings and the 400 GeV synchrotron at the Fermi-Lab. In interactions between hadrons, such as proton-proton collisions, leptons are seen coming off at much higher relative rates than could be predicted. Are the new particles behind this hadron-lepton mystery? And if so, how?

New Quantum Numbers

Other speculations are that the particles have new properties to add to the familiar ones like charge, spin, parity . . . As the complexity of particle behaviour has been uncovered, names have had to be selected to describe different aspects. These names are linked, in the mathematical description of what is going on, to quantum numbers. When particles interact, the quantum numbers are generally conserved--the properties of the particles going into the interaction are carried away, in some perhaps very different combination, by the particles which emerge. If there are new properties, they also will influence what interactions can take place.

To explain what might be happening, we can consider the property called 'strangeness.'

> Now a number of theorists are persuaded that the new particles may consist of a fourth type of quark--one bearing charm--mated with its mirror image or antiparticle, a charmed antiquark. Such a combination would not outwardly display charm since the antiquark would cancel out the charm of the quark.
>
> If this is correct then charmed quarks should also combine with each of the three other types of quarks to produce a variety of heavy particles. Unlike the two psi particles some would be electrically charged and all would outwardly display charm. . . .
>
> --Walter Sullivan
> *New York Times*
> Dec. 15, 1974

This was assigned to particles like the neutral kaon [K-meson] and lambda to explain why they were always produced in pairs--the strangeness quantum number is then conserved, the kaon carrying +1, the lambda -1. It is because the kaon has strangeness that it is a very stable particle. It will not readily break up into other particles which do not have this property.

Colour & Charm

Two new properties have recently been invoked by the theorists--*colour* and *charm.* Colour is a suggested property of quarks which makes sense of the statistics used to calculate their existence. This gives us nine basic quarks --three coloured varieties of each of the three familiar ones. Charm is a suggested property which makes sense of some observations concerning neutral current interactions (discussed below).

It is the remarkable stability of the new particles which makes it so attractive to invoke colour or charm. From the measured width of the resonances they seem to live for about 10^{-20} seconds and do not decay rapidly like all the other resonances in their mass range. Perhaps they carry a new quantum number?

Unfortunately, even if the new particles are coloured, since they are formed electromagnetically they should be able to decay the same way, and the sums do not give their high stability. In addition, the sums say that there is not enough energy around for them to be built up of charmed constituents. The answer may lie in new properties, but not in a way that we can easily calculate.

The Intermediate Vector Boson

Yet another possibility is that we are, at last, seeing the intermediate boson. This particle was proposed many years ago as an intermediary of the weak force. Just as the strong force is communicated by passing mesons around, and the electromagnetic force is communicated by passing photons around, it is thought that the weak force could also act via the exchange of a particle rather than 'at a point.'

When it was believed that the weak force always involved a change of electric charge between the lepton going into the interaction and the lepton going out, the intermediate boson (often referred to as the W particle) was always envisaged as a charged particle. The CERN discovery of neutral currents in 1973 revealed that a charge change between leptons need not take place; there could also be a neutral version of the intermediate boson (often referred to as the Z particle). The Z particle can also be treated in the theory which has had encouraging success in uniting the weak and electromagnetic forces.

This work has taken the Z mass into the 70 GeV region, and its appearance at around 3 GeV would damage some of the beautiful features of the reunification theories. A strong clue could come from looking for asymmetries in the decays of the new particles because, if they are of the Z variety, parity violation should occur.

A Good Year For High Energy Physics

1974 has been one of the most fascinating years ever experienced in high energy physics. Still reeling from the neutral current discovery, the year began with the SPEAR hadron production mystery, continued with new high energy information from the FermiLab and the CERN ISR, including the high lepton production rate, and finished with the production of the new particles. And all this against a background of feverish theoretical activity trying to keep pace with what the new accelerators and storage rings have been uncovering.

--Brian Southworth, CERN