Bubble Chamber Physics at Columbia

Introduction.

The desire to identify the basic building blocks of matter and to identify the forces amongst them has long motivated people. In the 1930's this effort seemed to have succeeded. The proton (p), the electron (e), the neutrino (ν), and the Yukawa particle (needed to understand the nuclear force and originally identified as the particle we now call the muon μ) had been identifies and were thought to be sufficient to explain the structure of matter.

By the late 1940's it became obvious that this was not the case. First the muon was shown not to be the carrier of the nuclear force. The muon was shown to be the product of the Yukawa particle, now called the pion (π). (This prompted Professor Rabi's famous remark about the muon, "Who ordered that?")

The discovery of the pion was followed soon afterwards by the discovery of "V" and "K" particles in events initiated by cosmic rays. These experiments used emulsions and cloud chambers for their detectors. Looking at the results today one has to admire the skill and tenacity that the experimenters brought to their work. The results have stood the test of time, though of course they have been superseded by later experiments.

The properties of these new particles were strange, copious production yet long life times. Obviously they required much more investigation and the new particle accelerators then under construction, the Cosmotron at Brookhaven and the Bevatron at Berkley, seemed capable of producing large numbers of these particles. The problem was that the available detectors, cloud chambers and nuclear emulsions, while useful, would not be adequate for the investigations that people wanted perform to study the newly discovered particles. Fortunately, in 1953, the bubble chamber had been invented by Donald Glaser.

The bubble chamber had several advantages over both the cloud chamber and nuclear emulsions for the study of the new particles. The material in the bubble chamber acted as the target for the incoming beam, which meant that the point where the strange particles were produced could be observed. Most of the materials used in the bubble chamber had a long radiation length so that the secondary particles could be tracked through the bubble chamber and their momentum measured using the magnetic field in the chamber. The identity of the secondary particles could often be determined by the visual density of the tracks in the bubble chamber. The use of the bubble chamber yielded many of the discoveries from the 1950's until the 1970's that contributed to our current understanding of elementary particles.

The activities of the bubble chamber program at Columbia were centered at the Nevis Laboratories of the Columbia Physics Department though most of the early pictures analyzed were taken at BNL, first at the Cosmotron and then at the AGS. In its final experiments film from SLAC and FNAL was analyzed.

The program was initiated by Prof. Jack Steinberger in 1956. Unlike many other bubble chamber groups which used the film as a survey tool to search for new effects, the group under Prof. Steinberger focused its efforts in answering specific questions and the discoveries resulting from the group's work provided the answers to these questions.

Following his work on the 2*ν* experiment and the discovery of CP violation the problems that interested Prof. Steinberger could no longer be answered using the bubble chamber. He moved on to using other techniques, and eventually left Columbia for CERN, and the responsibility for leadership of the bubble chamber group was assumed by Prof. Charles Baltay. Prf. Baltay led the group until the effort was ended in the 1980's.

During the forty years of research using the bubble chamber many physicists and staff members contributed to the research. I will try to identify as many of them as I can at the conclusion of this essay. The fruits of their efforts resulted in many discoveries and other contributions to our understanding of particle physics. I have also collected the papers published by the group in *Physical Review* and *Physical Review Letters*. If I left some out, please let me know and I will add them to the list.

As I discovered early in my days with the bubble chamber group Prof. Steinberger preferred to be called Jack, and I will often refer to him by his preferred name in what follows.

The Early Years.

After the invention of the bubble chamber by Donald Glaser in 1953, Prof. Jack Steinberger recognized very quickly its potential use in studying strange particles.[1] With his graduate students, Jack Leitner[2], Nick Samios[3] and Melvyn Schwartz[4], he began in 1954 the design of an experiment using a bubble chamber to study strange particle production at the Cosmotron.

This required that they first learn how to make a bubble chamber able to do an experiment at an accelerator, for no such no such device then existed. One of the challenges was the recompression of the chamber, after the expansion that sensitized it to particles, that was fast enough so that the chamber could operate with the accelerator cycle of a few seconds. This was resolved when the Columbia group discovered the Barkesdale valve, which made it possible to recompress the chamber in a fraction of a second.

They then constructed a 6" chamber filled with propane. In this effort they collaborated with Glaser (who was then at BNL) and his graduate student David Rahm. This early collaborative effort was to characterize much of the work of the bubble chamber group over the next two decades; the experiments were done in collaboration with physicists from other institutions.

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[1] Much of the material in this section comes from Jack's book "Learning About Particles – 50 Privileged Years." (Steinberger, 2005)

[2] Jack Leitner joined the faculty at Syracuse University after receiving his degree. He started his own group there. His promising career was cut short by his death at an early age.

[3] Nick Samios left Nevis and joined the Shutt group at BNL. He led the effort that led to the discovery of the Ω^- baryon which completed the lowest lying decuplet in SU_3. He later became director of BNL.

[4] Mel Schwartz eventually joined the faculty at Columbia where he continued working with data from bubble chambers. His interest soon turned to ν physics. His insights and calculations led to the first accelerator neutrino beam and the discovery that there were (at least) two neutrinos. For this work he, along with Jack Steinberger and Leon Lederman were awarded the Nobel Prize.

The 6” chamber had operational difficulties and lacked a magnetic field but it permitted the measurement of the cross sections and angular distributions of the associated production reactions $\pi^- p \rightarrow \Sigma^- + K^+$ and $\pi^- p \rightarrow \Lambda^0 + K^0$. This experiment in 1956 with the 6" chamber was the first bubble chamber experiment ever! The experiment following the suggestion of T.D, Lee,, searched for parity violation in lambda decay in the angular correlation of the decay and production angle. , A 2 ½ σ parity violating effect was observed , some 6 months or so before parity violation was discovered by C.S. Wu et al.[5] Given the importance of the physics and the substantial uncertainty, no claim the discovery was made.

The early successes with the bubble chamber, despite its obvious deficiencies, led the group at Columbia to construct a new 12” Propane[6] Bubble Chamber with a 1.3T magnetic field which meant that the momentum of charged particles could be measured. This chamber also the first to use three rather than two cameras (which permitted simpler reconstruction of the tracks) to observe the particles. This innovation at Columbia was used in all future bubble chambers.

The first instance of a Σ^0 hyperon was seen in this chamber. The γ from the decay $\Sigma^0 \rightarrow \Lambda^0 + \gamma$ converted in the propane into an e^+e^- pair. Other neutral decays of hyperons and K^0 particles were also observed in the propane chamber along with rough estimates of the branching fractions.

A 12" Hydrogen chamber was also built and shared the magnet and optics with the propane chamber. Data from both chambers were used in the determinations of the spin and lifetimes of the Λ and Σ hyperons. Parity violation in the decay of the Λ was first observed by the Columbia group. There were in addition numerous systematic measurements of cross section and decay modes of Λ,Σ and K particles.

Among the other results of the group's efforts were discovery of the reduced rate in the leptonic Σ^- decay which contributed to the ideas that led to the Cabibbo angle.

This chamber was also used on a series of experiments using beam from the Nevis cyclotron. In 1959 there was a run of the 12-inch H_2 chamber at Nevis which yielded half a million pictures in one week! This rate was at least an order of magnitude greater than any chamber had taken previously.

The experiments included measurements on the decay of the μ, which yielded one of the early reliable and accurate measurements of the Michel rho value, and a definitive study of Dalitz pairs from the decay of the π^0 . The π^0decays with two Dalitz pairs yielded a definitive determination of π^0 parity.

Measurements at Nevis on the low energy scattering of of π^+p and π^-p were also performed using the chamber.

The discoveries and results from these early experiments using bubble chambers, both at Nevis[7] and elsewhere, led to a desire to have larger bubble chambers to study more and rarer

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[5] Wu, C.S., Ambler, E., Hayward, R.W., D.D. Hoppes, and Hudson, R.P., *Experimental test of parity conservation in beta decay*, Physical Review, **105**(4), 1957

[6] The methodology for use of liquid hydrogen in a bubble chamber was not fully developed at that time. Propane, while not without its dangers, could be used without cryogenic equipment, had a greater hydrogen density then did liquid hydrogen and its shorter radiation length made the observation of γ rays in the bubble chamber more likely.

[7] The experiments using beams from the Nevis Synchrocyclotron involved a determination of the parity of the π^0 meson and a search for the β decay of the π.

interactions as well as improving, with increased statistics, on the results already obtained. A bigger bubble chamber would produce more interactions for a given number of particles incident in the chamber, utilizing the accelerator that produced the particles initiating the reactions, more efficiently, allow more track length for more precise measurement of the momenta of the secondary particles, and convert more γ rays in the chamber.

The higher energy beams that would soon become available at the Brookhaven AGS seconded the need for larger chambers so that there would be more path length to measure the secondary particles with the necessary precision and to observe hyperon decays.

With this in mind work started at Nevis on the construction of two 30" bubble chambers, one filled with propane (which began operation in 1961)[8], the second with Hydrogen (which proably began operation in 1962). Physicists at BNL worked on the design and construction of these chambers. Among the people who contributed to the effort to design and build the chambers were Dr. Al Prodell (BNL) [9]and Dr. Derek Colley (Nevis)[10].

A Technology Aside.

The increased number of events anticipated from the larger chambers also necessitated a change in the way the pictures were studied and analyzed.

Whereas with the earlier chambers much of the scanning and measuring of the pictures was done by physicists now that work was to be done by trained technicians. Our scanners (technicians trained to scan the pictures and recognize event typologies of interest to the physicists doing the experiments) and measurers were excellent and very dedicated workers who were an essential part of the bubble chamber program.[11]

Initially the curvature of tracks was measured using templates. The development of computers and advances in electronics led to major changes in the way the events were analyzed.

To measure the coordinates of the tracks in the pictures, film projectors with moveable stages were constructed. The motion of the stage was digitized and coordinates of the measured points were punched on to IBM cards.

The IBM cards with the data were taken to an IBM 650[12] computer at Nevis and the spatial coordinates of the measured coordinates were reconstructed. Using these coordinates and measurements of the magnetic field in the chamber, the computer calculated the momenta of the measured tracks.[13]

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[8] There was an accidental spill of several hundred liters of propane from this chamber. Fortunately it evaporated into the air and did not cause an major incident.

[9] Al Prodell received his graduate education at Columbia and was a student of Prof. Polykarp Kusch.

[10] Derek Colley was a research associate, having received his degree from the University of Birmingham (UK). He was to return to Birmingham where he started his own successful bubble chamber group.

[11] Several of the scanners and measurers at Nevis were people who had escaped from the USSR.

[12] It is amusing to recall the specifications of the IBM 650. It had 4K words of 10 digits each. It could do a fixed point add in 0.4ms (that is 10^{-3}s).

[13] The primary reconstruction program, NP54, was developed by Richard J. Plano (later a professor at Rutgers) and Don Burd of the Nevis computing department. Other members of the department who contributed to

With the use of higher energy beams and the wider range of reactions being studied the topology of an event could not always be relied upon to identify the reaction. For example a simple two prong event in a π^-p of the following could correspond to any of the following final states;

the work of the Bubble Chamber Group were Fred Wuensch and Dot Palmer. There must have been others but their names escape me. My apologies to them.

$\pi^- p$
$\pi^- p\ \pi^0$
$\pi^-\ \pi^+ n$
$\pi^- K^+ \Lambda^0$
etc.

To help correctly identify the correct reaction topology computer programs were written first at LBL[14] and then at CERN to apply the constraints of energy and momentum conservation to the measurements assuming the identity, i.e. mass, of each track in the event. For each mass assignment hypothesis the program minimized a test function computed from the changes in the measured momenta that needed to be made to satisfy the energy and momentum constraints. A comparison of the values of the test function for each of the hypotheses meant that a assignment of the event to a particular reaction could often be made unambiguously. When an unambiguous identification was not possible visual estimates of the ionization of a track could be used to reduce the ambiguity. In most cases a unique identification of the particles in the final state, and hence the reaction, could be made.

The first event fitting program that we used at Nevis was the program GUTS developed at LBL. It was installed at the IBM 7090 of the Institute for Space Studies[15] by Sandy Wolf. The GUTS program could only fit one vertex at a time, a serious limitation in studying events with multiple vertices, such as were found in many events with strange particles. In addition we did not have the source code for GUTS which made its use awkward since it could not be easily adapted to the Nevis analysis system.

Fortunately CERN had developed a multi-vertex fitting program, GRIND. Rudy Bock of CERN came to Nevis and helped us install it on the computers used by the Bubble Chamber Group. We also had access to the source code so that we modify it to work with the Nevis programs.

The Middle Years

The 30" Propane Chamber.

The 30" propane chamber was finished before the 30" Hydrogen Chamber and used in an experiment using a 2GeV/c π^- beam at the BNL Cosmotron. The objective was to study the properties on the newly discovered Y*(1385)[16] resonance that had been discovered by the group

[14] The Lawrence Berkeley Laboratory.

[15] The Institute of Space Studies, a NASA facility, was at that time located in the Interchurch Center. The computer room was located on the top floor of the center with a great view of the Hudson River. Time on the Institutes 7090 was provided to us by its then director Robert Jastrow. The staff of the computing center there were very helpful to us. The Bubble Chamber Group continued to use the facilities of the ISS until Columbia opened its computing center with its own IBM 7090. Prior to sing the computers at the ISS members of the group could frequently be found after midnight, usually on a Friday , at the IBM computing center in the basement of the Time-Life building in Rockefeller Center where we had free use of the 7090 there.

[16] I am using the nomenclature used at the time. This resonance is now known as the $\Sigma(1385)$ and is part of the lowest mass SU_3 decuplet.

at Wisconsin using the beam at the Berkeley Bevatron. Despite the small size of the exposure, as measured by later experiments, the experiment was a success.

The first discovery from the exposure was the first observation of the β decay of a Σ^- hyperon The event was analyzed and submitted for publication in less than a week. Additional results would take longer to obtain. The Y*(1385) was observed decaying into a $\Lambda + \pi$. When the Λ decay was analyzed it was discovered that it was polarized which could only occur if the Y*(1385) was also polarized in the production process. The size of the Λ polarization meant that the Y* must have spin 3/2 and not 1/2. This was the first determination of the spin of a hyperon resonance.

The exposure was also used to look for polarization of Λ^0 in the productions plane. If the Λ^0 were polarized it would indicate that parity was not conserved in the production process. No polarization was observed.

Experiments in the BNL 20" Chamber

While work progressed on the 30" Hydrogen chamber and the development of a low energy separated beam at the AGS there was a need for new pictures for the enlarged bubble chamber group to analyze. Therefore we obtained an exposure of the BNL 20" hydrogen BC to a separated π^+ beam at the AGS. Although we took pictures at three values of beam momentum most of the data were obtained at an incident momentum of 2.9 BeV/c. The primary result from these exposures was the first observation of simultaneous production of a boson resonance (in this case we observed principally the ρ, and the ω but also the η) along with the N*(1238) baryon resonance. We also found evidence, based on studying the decay of the ρ, that the reaction $\pi^+ + p \rightarrow \rho^0 + N^{*++}$ proceeded primarily via one pion exchange. The predictions of the model were not in complete agreement with the theoretical model which lead to the one pion exchange model with absorption.

The reaction $\pi^+ + p \rightarrow \omega + N^{*++}$ was hypothesized to proceed via ρ exchange though the angular distributions required significant absorption in calculations in order to obtain the observed decay distributions.

Another experiment in the 20" chamber, this time filled with D_2 measured the isotopic spin of the *f(1250)* meson to be 0.

The 30" Hydrogen Chamber

While rectangular chambers like the 20" at BNL or the 72" chamber at LRL were well suited to studies of high energy interactions where the produced particles come out close to the direction of the incoming beam, the circular 30" chamber had distinct advantages in the study of the interactions from stopped or low energy beams. A low energy/stopping beam was designed at Nevis and installed on the inside the ring of the AGS at BNL. With the chamber in place pictures were taken with stopped K^- and p-bar beams. (Later other groups obtained exposures using the beam and the chamber filled with D_2.)

The exposure of the 30 H_2 chamber to a stopped K^- beam was performed, among other things, to measure the Σ-Λ relative parity. The experiment was a success and the relative parity was found to be even.

The stopped p-bar exposure turned out to be very productive. The first measurements of the widths of the ω and ϕ mesons were obtained in this exposure. In addition the data were used to test charge conjugation invariance in the annihilation reaction. None was found.

These experiments ended Jack's active participation in bubble chamber experiments as he redirected his efforts towards understanding more about the recently discovered CP violation. The mantle of the leadership of the Columbia bubble chamber group devolved on to Charles Baltay.

The Latter Years.

Under Prof. Baltay's leadership the group continued to flourish. Work continued on the existing exposures while new exposures were obtained.

The stopping K^- film was used to determine the branching ratio of the Λ^0. Approximately 50 examples of the decay $\Sigma^{\pm} \rightarrow \Lambda e^{\pm} \nu$ in the exposure were used to measure the branching rates and more significantly a matrix element of a strangeness conserving weak current between baryon states. A precise measurement of the lifetime and decay branching ration of the Λ^0 was made using this exposure.

Multi-pion final states were studied in the film with the stopped p-bar. The frequency for annihilations into different final states, both resonant and non-resonant, were measured. The capture rates from the different p-pbar states were determined for several final state configurations. Charge conjugation invariance in the annihilation was tested and no violation was observed. The B meson at a mass of 1200Mev/c^2 was observed decaying into $\omega^0\pi^+\pi^-$.

The data from both stopping beams was combined in an unsuccessful attempt to find tachyons.

Measurement were made on the lifetimes and branching ratios of the Λ and the K_s.

New Exposures

Over the years additional film was obtained from Brookhaven, SLAC and Fermilab.

One of the first of these new experiments was an exposure of the 30" D_2 chamber to a π^+ beam at a momentum of 820MeV/c. In a study of the η^0 they observed and measured the rate of decay of the η^0 into neutral particles and in to the final state $\pi^+\pi^-\gamma$. Charge conservation in the decay of the η^0 was also tested in this exposure.

The 31" chamber at BNL (an enlarged version of the 20" chamber) was exposed to a 1.7GeV/c K^- beam and the properties and rare decay modes of the Ξ^- and Ξ^0 were studied. This exposure also yielded a measurement of the decay of the K_s into 2π. The η' was also observed and an inconclusive attempt was made to determine its spin and parity.

In an exposure of the BNL 80" bubble chamber to π^+ beams at 6.95 and 8.5 GeV/c multi-pion resonances were observed at masses of 1630 and 1720Mev/c^2. In another exposure of the 80" chamber, this time to a proton beam at 24.8GeV/c, resonant $p\pi^+\pi^-$ states were observed at 1423 and 1688 GeV/c^2.

The 82" hydrogen bubble chamber (the old LBL 72" chamber) at SLAC was illuminated by at 15GeV/c π^+ beam and an unsuccessful search for charmed particles decaying into a strange particle + pions. The exposure did reveal a new meson resonance at 2340Mev/c^2 which decayed primarily into $\rho\rho\pi$ with iso-spin of 1 or 2. The production of the A_1, A_3 and A_4 resonances was analyzed and these states were found to have properties usually associated with resonant states. A detailed study of the ω'(1675) was performed and compared with the A_2 produced where both where produced in the reaction $\pi^+p\rightarrow\Delta^{++}\pi^+\pi^-\pi^0$. The experiment, in the spirit of the times, also studied pion production in terms of the Feynman variable *x* and p_{perp}.

The interests of the Bubble Chamber group shifted after this experiment to studies of *ν* interactions. Interactions were observed at both BNL, in the 7' bubble chamber, and at FNAL in the 15' Bubble Chamber using both narrow band and broad band beams. The chambers were filled with a mixture of Ne and H_2.

An early experiment in the FNAL 15' chamber with a broad band *ν* beam failed to find evidence for a heavy lepton (such as the τ) but did observe production of the D^0 charmed meson. The cross section for the reaction $\nu_\mu e^-\rightarrow\nu_\mu e^-$ was measured and found to be in agreement with the Weinberg-Salam model with $\sin^2\theta_w = 0.2$. Cross sections and production distributions were also measured for strange particles in charged current interactions. The experiment confirmed the existence of the Σ_c^{++} and the Λ_c^+ charmed baryons. Observation of opposite sign dilepton production was consistent with expectations of charmed particle production in the *ν* interactions. An excess of Λ^0 events in the dilepton sample was evidence of charmed baryon production. Like sign dilepton events could all be assigned to the background of conventional sources. Evidence was also sought for *ν* oscillations but none was found and upper limits were set on the mixing angles and mass differences.

The 7' chamber at BNL was used to search for prompt neutrinos or other penetrating neutral particles, such as an axion, produced in a beam dump at BNL. None were found. the same chamber was exposed to a narrow band *ν* beam and both neutral and charged current *ν*-Nucleon interactions were studied.

With increasing intensity at the Fermilab accelerator and improved beams it was possible to use the 15' chamber in a narrow band neutrino beam. A series of successful measurements of cross sections and particle distributions was carried out. No evidence for neutrino oscillations was found in the data. The data also allowed the observation of neutral current single π^0 production.

Closing Comments

The experiments done with bubble chambers at Columbia spans 40 years and resulted in many significant contributions to both to our understanding of elementary particle physics and to the

list of accomplishments of the Columbia Physics Department. Many of the individuals who worked on these experiments either as student or as young researchers went on to illustrious careers at other institutions. They brought great credit to the Physics Department at Columbia.

As we learn and as technology advances, old techniques and questions are abandoned to be replaced by new ones. Such has been the case with bubble chambers but those of us who used them can be proud of what we accomplished.

If anyone reads this and wishes to add or modify anything here please contact me.
Norman Gelfand
nmg38@columbia.edu

Appendix A

Institutions Which Have Collaborated With the Columbia Bubble Chamber Group.

Bloomsburg State University at Bloomsburg, Pennsylvania
Brandeis University, Waltham, Massachusetts
Brookhaven National Laboratory, Upton, New York
Case Western Reserve University, Cleveland, Ohio
Institute for Advanced Study, Princeton, New Jersey
Institute for High Energy Physics, University of Heidelberg, Heidelberg, Germany
Institute for Space Studies, Goddard Space Flight Center, National Aeronautics and Space Administration, New
Istituto di Fisica, Bologna, Italy
Istituto di Fisica, Pisa, Italy
Louisiana State University, Baton Rouge, Louisiana
Max-Planck-Institut für Physik, D-8000 Munich 40, Federal Republic of Germany
Oak Ridge National Laboratory, Oak Ridge, Tennessee
Physics Department, State University of New York at Binghamton, Binghamton, New York
Princeton University, Princeton, New Jersey
Princeton-Pennsylvania Accelerator, Princeton University, Princeton, New Jersey
Rutgers, The State University, New Brunswick, New Jersey
State University of New York at Binghamton, Binghamton, New York
Stevens Institute of Technology, Hoboken, New Jersey
The City College of New York, New York, New York
The State University of New York at Stony Brook, Stony Brook, New York
The University of Tennessee, Knoxville, Tennessee
University of Bologna, Bologna, Italy
University of California, San Diego, La Jolla, California
University of Kentucky, Lexington, Kentucky
University of Maryland, College Park, Maryland 20742; and
University of Rochester, Rochester, New York
Yale University, New Haven, Connecticut

Appendix B- Members of the Columbia Bubble Chamber Group

Cynthia Alff-Steinberger
Charles Baltay
Naomi Barash
P. Bassi
Dave Berley
Enid Bierman
T. Böhringer
V. Borelli
M. Bregman
A. Bridgewater
G.L. Brown
E. B. Brucker
D. Caroumbalis
C. V. Cautis
L. D. Chen
Max Chretien
D. Cohen
Derek C. Colley
M. Conversi
W. A. Cooper
S. Csorna
Robert Ehrlich
Fred Eisler
Gary Feinberg
J. Feinman
G.E. Fisher
Paolo Franzini
H. French
Jean Marc Gaillard
Norman M. Gelfand
L. K. Gershwin
D. A. Glaser
C. Graves
M. Habibi
K. Han
S. W. Herb
M. Hibbs
R. Hylton
P. Igo-Kemenesa
G. Impeduglia

P. F. Jacques
E. W. Jenkins
M. Kalelkar
Joe Keren
Jewan Kim
Lawrence Kirsch
E. L. Koller
H. H. Kung
T. D. Lee
Juliet Lee
Jack Leitner
J. T. Liu
Gunther Lütjens
G. Mageras
I. Mannelli
Dave Miller
Uriel Nauenberg
R. Newman
H. Norton
Mike Nussbaum
J. Okamitsu
J. Okamitsuc
W. Orance
G. Ormazabal
D. Peterson
D. Pisello
Richard J. Plano
Al Prodell
G. Puppi
Joseph T. Ratau
E. Rice
Nick P. Samios
R. Santangelo
A. C. Schaffer
R. D. Schaffer
A. C. Schaffere
Peter Schmidt
"Jay" Schmidt
Jonas Schultz
Mel Schwartz
J. C. (Hans)

Severiens
K. Shastri
V. Silvestrini
J. Spitzer
P. E. Stamer
Jack Steinberger
Tai Ho Tan
H. Tanaka
Dan Tycko
A. Vogel
P. Waloscher
Sandy Wolf
N. Yeh
J. K. Yoh
Dino Zanello
V. Zomboli

Appendix C- List of Publications form The Columbia Bubble Chamber Group in the Physical Review, Physical Review Letters and Il Nuovo Cimento.

1956

Properties of Heavy Unstable Particles Produced by 1.3-Bev π^- Mesons

R. Budde, M. Chretien, J. Leitner, N. P. Samios, M. Schwartz, and J. Steinberger

Phys. Rev. 103, 1827 (1956) – Published September 15, 1956

A propane bubble chamber has been exposed to a π^- beam of 1.3-Bev kinetic energy. The reactions $\pi^-+p\rightarrow\Sigma^-+K^+$, $\pi^-+p\rightarrow\Lambda^0+\theta^0$, $\pi^-+p\rightarrow\Sigma^0+\theta^0$, can be experimentally distinguished from carbon events. Results based on the first 55 such events are presented. The center-of-mass production distribution of the Σ^- is peaked forward, that of the Λ^0 backward. No large anisotropies in the angular correlation of production and decay were found, so that we have no evidence for spin in excess of ½ for any of the three particles: Σ^-, Λ^0, or θ^0. A study of the relative abundance of single and double V production indicates that both Λ^0 and θ^0 have either long-lived "states" or neutral decay modes. A statistical analysis gives $\bar{\alpha}_{\Lambda^0}=0.3_{-0.12}^{+0.15}$, $\bar{\alpha}_{\theta^0}=0.3_{-0.12}^{+0.19}$, for the normal charged decay probabilities ($\Lambda^0\rightarrow\pi^-+p$; $\theta^0\rightarrow\pi^++\pi^-$) of the Λ^0 and θ^0, respectively. One event was analyzed to obtain the energy released in Σ^- decay. $\Sigma^-\rightarrow\pi^-+n+Q$; $Q=118\pm2.6$ Mev. The Σ^- lifetime on the basis of 16 decays is $(1.4_{-0.5}^{+1.6})\times10^{-10}$ sec.

1957

Possible Detection of Parity Nonconservation in Hyperon Decay

T. D. Lee, J. Steinberger, G. Feinberg, P. K. Kabir, and C. N. Yang

Phys. Rev. 106, 1367 (1957) – Published June 15, 1957

Cited 52 times

No abstract available.

Experimental Situation on Parity Doubling

F. Eisler, R. Plano, N. Samios, M. Schwartz, and J. Steinberger

Phys. Rev. 107, 324 (1957) – Published July 1, 1957

No abstract available.

π^--p Elastic Scattering at 1.44 Bev

M. Chretien, J. Leitner, N. P. Samios, M. Schwartz, and J. Steinberger

Phys. Rev. 108, 383 (1957) – Published October 15, 1957

An investigation of π^-+p elastic scattering, made in a liquid propane bubble chamber, is reported. Identification of events is made on the basis of kinematics. The problem of contamination by pion scattering from protons bound in carbon is considered in some detail; it is shown that the latter requires a correction of only 4±2.5% of the total number of events. The angular distribution is presented. It shows a large diffraction peak at small angles and an approximately isotropic plateau over the backward hemisphere. The forward peak is fitted to a black-sphere diffraction pattern with a radius of $(1.08\pm0.06)\times10^{-13}$ cm. The total elastic cross section is found to be σ_e=10.1±0.80 mb.

Demonstration of Parity Nonconservation in Hyperon Decay

F. Eisler, R. Plano, A. Prodell, N. Samios, M. Schwartz, J. Steinberger, P. Bassi, V. Borelli, G. Puppi, G. Tanaka, P. Woloschek, V. Zoboli, M. Conversi, P. Franzini, I. Mannelli, R. Santangelo, V. Silvestrini, D. A. Glaser, C. Graves, and M. L. Perl

Phys. Rev. 108, 1353 (1957) – Published December 1, 1957

No abstract available.

Demonstration of the Existence of the Σ^o Hyperon and a Measurement of its Mass

R Plano, N Samios, M Schwartz and J Steinberger

Il Nuovo Cimento (1955-1965), 1957, Volume 5, Number 1, Pages 216-219

Abstract
Three events, demonstrating the existence of the Σ^0 hyperon, have been found in a propane bubble chamber. The Q-value for the decay $\Sigma^0 \rightarrow \Lambda^0+\gamma+Q$ has been measured to be (73.0 ± 3.5) MeV.

Systematics of Λ^0 and θ^0 decay

- F. Eisler, R. Plano, N. Samios, M. Schwartz and J. Steinberger

Il Nuovo Cimento (1955-1965), 1957, Volume 5, Number 6, Pages 1700-1715

Systematic observations on 528 Λ^0-θ^0 production events in propane have yielded the following information: 1) There exists a neutral Λ^0 decay; $\Lambda^0 \rightarrow \pi^0 + n$ and the fraction of Λ^0's decaying in this mode is .32±.05. 2) The θ_1^0 component has a neutral decay mode, very probably $\theta_1^0 \rightarrow \pi^0+\pi^0$. The θ^0 therefore very probably has even spin. The fraction $P(\theta_1^0 \rightarrow \pi^0 + \pi^0) / P(\theta_1^0 \rightarrow 2\pi)$ is .14±.06. The branching ratio $P(\Lambda^0 \rightarrow \pi^0 + n) / P(\Lambda^0 \rightarrow \pi^- + p)$ is in good agreement with the $\Delta I = 1/2$ selection rule; the branching ratio $P(\theta^0 \rightarrow 2\pi^0) / P(\theta^0 \rightarrow \pi^+ + \pi^-)$ seems to be in disagreement. 3) (51±7.5)%, or just one half of the θ^0 mesons escape the chamber and are to be identified with the θ_2^0 -meson proposed by GELL-MANN and PAIS ([4]). The question of the existence of additional (parity doublet) decay modes is discussed. 4) The decays $\Lambda^0 \rightarrow \mu^- + p + \nu / e^- + p + \nu$ are not observed and the fraction of such decays is less than 2%. 5) The 3 particle decay modes of the θ_1^0 have not been observed and are therefore very unlikely to exceed 2% of all θ_1^0 decays. 6) Preliminary measurements yield lifetimes $\tau_{\theta 1}{}^0 = (.95 \pm .08) \cdot 10^{-10}$ s and $\tau_\Lambda{}^0 = (2.8 \pm .2) \cdot 10^{-10}$ s. 7) For the θ_2^0 we obtain a lower limit of the lifetime, which together with the results of LANDE et al. ([5]) brackets the θ_2^0 lifetime $(3 < \theta_2^0 < 10) \cdot 10^{-10}$ s.

1958

Associated Production of Σ^0 and θ_2^0; Mass of the Σ^0

F. Eisler, R. Plano, N. Samios, J. Steinberger, and M. Schwartz

Phys. Rev. 110, 226 (1958) – Published April 1, 1958

An event in which θ_2^0 and Σ^0 production and decay are both observed, is described. This event yields a mass value for the Σ^0 and demonstrates the associated production of the θ_2^0. Additional events yielding mass values of the Σ^0 are reported.

β Decay of the Pion

G. Impeduglia, R. Plano, A. Prodell, N. Samios, M. Schwartz, and J. Steinberger

Phys. Rev. Lett. 1, 249 (1958) – Published October 1, 1958

No abstract available.

Leptonic Decay Modes of the Hyperons

F. Eisler, R. Plano, A. Prodell, N. Samios, M. Schwartz, J. Steinberger, M. Conversi, P. Franzini, I. Manelli, R. Santangelo, and V. Silvestrini

Phys. Rev. 112, 979 (1958) – Published November 1, 1958 We have searched for the leptonic decay of the Λ^0 and Σ^-. The sensitivity of the experiment was such that 5-6 events

should have been found according to the predictions of the "universal" V-A model of β decay. No examples of leptonic decay were observed.

Experimental determinations of the Λ^0 and Σ^- spins

F. Eisler, R. Plano, A. Prodell, N. Samios and M. Schwartz, et al.

Il Nuovo Cimento (1955-1965), 1958, Volume 7, Number 2, Pages 222-230.

Abstract

We discuss the applicability of the argument of Adair (1) to the determination of the hyperon spins on the basis of the observed distribution in the production angle for the process $\pi+N\rightarrow Y+\theta$. Because of the pronounced backward and forward peaking of these distributions it is found possible to use a large fraction of the events without jeopardizing the validity of the argument. We find from measurement of the distribution in the correlation angles between incident and outgoing pions that the spins of both the Λ^0 and Σ hyperons are one half. The only assumptions necessary to this result are 1) that the θ spin is zero and 2) that the interaction radius for strange particle production is not pathologically large.

Bubble chamber study of unstable particle production in π^--p collisions at 910, 960, 1200 and 1300 MeV

F. Eisler, R. Plano, A. Prodell, N. Samios and M. Schwartz, *et al.*

Il Nuovo Cimento (1955-1965), 1958, Volume 10, Number 3, Pages 468-489

Abstract Results are reported on the total and differential cross-sections for the reactions $\pi^- + P \rightarrow \Lambda^0 + \theta^0$; $\Sigma^0 + \theta^0 \square \Sigma^- + K^+$ at 910, 960, 1200 and 1300 MeV using hydrogen and propane bubble chambers in a magnetic field of 13.4 kG. The chambers and their operation, as well as the method of analysis are described in detail.

Lifetime of Λ^0 ϑ^0, and Σ^-

F. Eisler, R. Plano, A. Prodell, N. Samios and M. Schwartz, et al.

Il Nuovo Cimento (1955-1965), 1958, Volume 10, Number 1, Pages 150-154

The lifetimes of the Λ^0 ϑ^0, and Σ^- observed in bubble chamber photographs have been calculated. The following values are obtained: $\tau_\Lambda°=(2.29\ -.13\ +.15\ )\cdot 10^{-10}$ s on the basis of 454 events; $\tau_\theta°=(1.06\ -.06\ +0.8\ )\cdot 10^{-10}$s on the basis of 259 events and $\tau_\Sigma-=(1.89\ -.25\ +.33\ )\cdot 10^{-10}$ s on the basis of 107 events. A comparison with previous values of the mean lives is presented.

1959

Search for Rare Decay Modes of the μ^+ Meson

Juliet Lee and N. P. Samios
Phys. Rev. Lett. **3**, 55 (1959) – Published July 1, 1959

No abstract available.

Scattering of 3.7-25 Mev Positive Pions by Hydrogen

G. E. Fischer and E. W. Jenkins
Phys. Rev. **116**, 749 (1959) – Published November 1, 1959

The Columbia University hydrogen bubble chamber was used to investigate the π^+-p scattering cross section in a laboratory energy range from 3.7 to 25 Mev. A total of 950 events were measured, of which 338 were caused by incident pions that would have come to rest in the chamber. Treating the small p-wave and large Coulomb contributions as known, the s-wave phase shift is found to deviate from a linear dependence on momentum only by one and a half standard deviations.

Parity of the Neutral Pion

R. Plano, A. Prodell, N. Samios, M. Schwartz, and J. Steinberger
Phys. Rev. Lett. 3, 525 (1959) – Published December 1, 1959
No abstract available.

1960

Panofsky Ratio

N. P. Samios

Phys. Rev. Lett. **4**, 470 (1960) – Published May 1, 1960

No abstract available.

Momentum and Asymmetry Spectrum of μ-Meson Decay

Richard J. Plano

Phys. Rev. **119**, 1400 (1960) – Published August 15, 1960

The beta decay of the positive μ meson was studied using a liquid hydrogen bubble chamber in a magnetic field of 8800 gauss. An analysis of 9213 events used in the momentum spectrum yielded ρ=0.780±0.025. This number includes the internal radiative corrections and is to be compared directly with the 0.75 predicted by two component theory. The analysis of 8354 events used in the asymmetry spectrum gave for the magnitude of the asymmetry $|\xi|$=0.94±0.07 and for the shape parameter δ=0.78±0.05.

π^0-π^- mass difference as determined from double Dalitz pairs

N. P. Samios

Il Nuovo Cimento (1955-1965), 1960, Volume 18, Supplement 1, Pages 154-159

Abstract
The π^0, π^- mass difference was determined by measuring the momenta of the two internally converted electron positron pairs from π0-decay.
A total of 119 events gave a value π^--π^0=(4.69±0.07) MeV

1961

Dynamics of Internally Converted Electron-Positron Pairs

N. P. Samios

Phys. Rev. **121**, 275 (1961) – Published January 1, 1961

The reactions studied were $\pi^-+p\rightarrow n+\pi^0$ ($\pi^0\rightarrow\gamma+e^+ +e^-$) and $\pi^-+p\rightarrow n+e^+ +e^-$. From a sample of ∼15 000 internally converted electron-positron pairs, 7000 were measured, of which 4200 were used in the detailed analysis. The differential distributions in y (the energy partition) and x^2 (the virtual mass of the photon) agree with the theoretical quantum electrodynamic calculations. A measure of the form factor for the $\pi^0\rightarrow 2\gamma$ reaction gave a value $\Gamma(x/\mu)$=1-(0.24±0.16)x^2/μ^2, where μ is the mass of the pion. It was further demonstrated that the number of events necessary

to determine the contribution of the longitudinally polarized virtual γ rays in the second reaction is of the order of 50 times that in the present experiment.

Leptonic Decay of a Σ^- Hyperon

Paolo Franzini and Jack Steinberger

Phys. Rev. Lett. 6, 281 (1961) – Published March 15, 1961

No abstract available.

Example of the Decay $\Lambda^0 \rightarrow p+\mu^-+\bar{\nu}$

F. Eisler, J. M. Gaillard, J. Keren, M. Schwartz, and S. Wolf

Phys. Rev. Lett. 7, 136 (1961) – Published August 15, 1961

No abstract available.

1962

Parity of the Neutral Pion and the Decay $\pi^0 \rightarrow 2e^+ + 2e^-$

N. P. Samios, R. Plano, A. Prodell, M. Schwartz, and J. Steinberger

Phys. Rev. 126, 1844 (1962) – Published June 1, 1962

Two hundred and six electronic decays of the π^0, $\pi^0 \rightarrow e^+ + e^- + e^+ + e^-$, have been observed in a hydrogen bubble chamber. The decay distributions of the electron pairs and the total rate for this process are shown to be in good agreement with theory. An examination of correlations of the e^+e^- pair decay planes on the basis of electrodynamic predictions is in agreement with the hypothesis that the π^0 is pseudoscalar, but disagrees for scalar pions by 3.6 standard deviations.

Scattering of 6-24 MeV Negative Pions by Hydrogen

Enid Bierman

Phys. Rev. **127**, 599 (1962) – Published July 15, 1962

The scattering of negative pions at laboratory energies between 6 and 24 MeV has been observed in a liquid hydrogen bubble chamber. The energy of each scattering was deduced from the ranges and angles of the scattered pion and recoil proton. Flux was measured by direct count of tracks of stopped pions. A maximum likelihood analysis was performed treating the strength of the small *P*-wave contribution as known. Based on 246 scattering events at a median energy of 13 MeV, the *S*-wave scattering length $a=(2\alpha_1+\alpha_3)/3\eta$ is found to be 0.090 ± 0.005 when the large Coulomb contribution is assumed to be the nonrelativistic amplitude for pure Coulomb

scattering. Results are also presented with further Coulomb corrections. Values of α_1 are computed from the combination of this experimental result with experiments on π^+-p scattering.

Evidence for $\pi^+\pi^-$ Resonances at 395- and 520-MeV Effective Mass

N. P. Samios, A. H. Bachman, R. M. Lea, T. E. Kalogeropoulos, and W. D. Shephard

Phys. Rev. Lett. **9**, 139 (1962) – Published August 1, 1962

Production of Pion Resonances in π^+ p Interactions

C. Alff, D. Berley, D. Colley, N. Gelfand, U. Nauenberg, D. Miller, J. Schultz, J. Steinberger, T. H. Tan, H. Brugger, P. Kramer, and R. Plano

Phys. Rev. Lett. 9, 322 (1962) – Published October 1, 1962

No abstract available.

Decays of the ω and η Mesons

C. Alff, D. Berley, D. Colley, N. Gelfand, U. Nauenberg, D. Miller, J. Schultz, J. Steinberger, T. H. Tan, H. Brugger, P. Kramer, and R. Plano

Phys. Rev. Lett. 9, 325 (1962) – Published October 1, 1962

No abstract available.

Resonances in Strange-Particle Production

D. Colley, N. Gelfand, U. Nauenberg, J. Steinberger, S. Wolf, H. R. Brugger, P. R. Kramer, and R. J. Plano

Phys. Rev. 128, 1930 (1962) – Published November 15, 1962

In an exposure of propane to 2.0-BeV/c π^- mesons at the Cosmotron in the Columbia 30-in. chamber, reactions have been analyzed for resonances between the particles present in the final state. The reactions studied were sufficiently overdetermined to permit a separation of hydrogen events from carbon. We find definite evidence for resonances in the $\Lambda\pi$ system (Y_1^*) with M_0=1392±7 MeV and $\Gamma/2$=40±10 MeV; in the $K\pi$ system (K^*) with M_0=897±10 MeV and $\Gamma/2$=30±10 MeV. We also seem to see the 1404- and 1525-MeV $\Sigma\pi$ resonances. The data indicate that the Y_1^* has spin 3/2 and its parity is even.

1963

Experimental Study of Double-Charged Pion Production in (π^-,p) Collisions at 900 MeV

Derek C. Colley and Joseph T. Ratau

Phys. Rev. 130, 357 (1963) – Published April 1, 1963

Eight hundred and forty events of the kind $\pi^-+p\rightarrow\pi^-+p+\pi^-+\pi^+$ produced in the 20-in. BNL hydrogen bubble chamber by 900-MeV pions have been unambiguously identified using spatial reconstruction and kinematic fitting programs as well as ionization density estimates. The π^+,π^- and π^-,π^- combined mass distributions can be fitted by smooth curves, with no deviation beyond statistical fluctuations; no indication has been found of any prominent pion-pion resonance in this interaction, which covers a mass range up to 610 MeV. The π^+,p combined mass distribution differs markedly from the four-body phase-space curve, but can be well fitted by weighting the π^+,p total cross-section curve at each point according to the amount of phase space available for production of an isobar of corresponding mass. Assuming that the interaction proceeds exclusively via formation of the (π^+,p) isobar, one can get a good fit to the π^-,π^- mass spectrum. This isobar model is also consistent with all of the observed angle and momentum distributions for both pions and protons. The momentum distributions show no indication of any pion-pion-proton resonance in the range up to 1550 MeV, or of any three-pion resonance in the range up to 750 MeV. The cross section for the events studied was measured and found to be (0.33±0.04) mb.

Lifetime of the ω Meson

N. Gelfand, D. Miller, M. Nussbaum, J. Ratau, J. Schultz, J. Steinberger, T. -H. Tan, L. Kirsch, and R. Plano

Phys. Rev. Lett. 11, 436 (1963) – Published November 1, 1963

No abstract available.

Width of the φ Meson

N. Gelfand, D. Miller, M. Nussbaum, J. Ratau, J. Schultz, J. Steinberger, T. H. Tan, L. Kirsch, and R. Plano

Phys. Rev. Lett. 11, 438 (1963) – Published November 1, 1963

No abstract available.

1964

Experimental Study of Parity Conservation in Λ° Production in Carbon Nuclei Using Incident π^- of 2.0 BeV/c Momentum.

R. Ehrlich and J. K. Kim

Phys. Rev. 133, B132 (1964) – Published January 13, 1964

Parity conservation has been tested for the Λ° production processes: $\pi^-+N\rightarrow\Lambda^\circ+$anything, where the nucleon N is in a carbon nucleus. Approximately 120 000 pictures were taken of the Columbia-BNL 30-in. propane bubble chamber exposed to a π^- beam of 2.0 BeV/c momentum at the Cosmotron. On the basis of 486 events, of which all but 23 were identified without ambiguity as Λ°, no indication of parity nonconservation was found. This result rests on the fact that the

average Λ° polarization $\overline{P}$ in the production plane was found to be consistent with the value zero within the statistical error. The values found for two components of $\overline{P}$ in the production plane are: -0.08±0.12 and 0.00±0.12, using the value +0.63 for α, the asymmetry parameter.

Associated Production of ΛK at the ΣK Threshold

Joseph Keren

Phys. Rev. 133, B457 (1964) – Published January 27, 1964

The reaction $\pi^-+p\rightarrow\Lambda+K$ has been studied in the liquid-hydrogen bubble chamber at the threshold energy for the reaction $\pi^-+p\rightarrow\Sigma+K$. The differential cross section for Λ production has been found to be $d\sigma/d\Omega=50-10\cos\theta-25\cos^2\theta-51\cos^3\theta+56\cos^4\theta$ μb/sr with a total cross section of 0.67±0.04 mb. The Λ's produced are nearly completely polarized normal to the production plane, and their decay is characterized by $|\alpha\overline{P}|=0.60\pm0.05$. Two leptonic Λ decays have been identified giving a rate for the leptonic decay consistent with one in a thousand. An unsuccessful attempt has been made to detect cusp-like effects. This attempt has failed because of the presence of high angular momentum states in the ΛK production process.

Compilation of Results on the Two-Pion Decay of the ω

G. Lütjens and J. Steinberger

Phys. Rev. Lett. 12, 517 (1964) – Published May 4, 1964

No abstract available.

Neutral Decay and Isotopic Spin of the f^0

N. Gelfand, G. Lütjens, M. Nussbaum, J. Steinberger, H. O. Cohn, W. M. Bugg, and G. T. Condo

Phys. Rev. Lett. 12, 567 (1964) – Published May 18, 1964

No abstract available.

β Decay of the Σ^+ and Σ^- Hyperons and the Validity of the ΔS=ΔQ Law

U. Nauenberg, P. Schmidt, J. Steinberger, S. Marateck, R. J. Plano, Henry Blumenfeld, and Leo Seidlitz

Phys. Rev. Lett. 12, 679 (1964) – Published June 15, 1964

No abstract available.

Complication of Results on the Two-pion Decay of the ω

G. Lütjens and J. Steinberger

Phys. Rev. Lett. 12, 717 (1964) – Published June 22, 1964

No abstract available.

Test of the Validity of ΔS=ΔQ Rule in K^0 Decay

L. Kirsch, R. J. Plano, J. Steinberger, and P. Franzini

Phys. Rev. Lett. 13, 35 (1964) – Published July 6, 1964

No abstract available.

1965

Determination of Σ-Λ Relative Parity

Cynthia Alff, N. Gelfand, U. Nauenberg, M. Nussbaum, J. Schultz, J. Steinberger, H. Brugger, L. Kirsch, R. Plano, D. Berley, and A. Prodell

Phys. Rev. 137, B1105 (1965) – Published February 22, 1965

An experiment has been performed to determine the Σ-Λ relative parity, through a study of the decay mode $\Sigma^0 \rightarrow \Lambda^0 + e^+ + e^-$. The Σ^0 were produced by stopping K^- mesons in the Brookhaven National Laboratory-Columbia 30-in. hydrogen chamber, in the reaction $K^- + p \rightarrow \Sigma^0 + \pi^0$, and 314 events were identified. The experimental distribution of the combined mass of the electron-positron pair was compared to that predicted by Feinberg, by Feldman and Fulton, and by Evans. If it is assumed that the dependence of the form factors on the combined mass of the electron-positron pair can be neglected, and that the ratio of the electric form factor F_1 to the magnetic form factor F_2 is less than 6, then the data show that the Σ-Λ relative parity is even.

Strange-Particle Production in π^+-p Collisions

David Berley and Norman Gelfand

Phys. Rev. 139, B1097 (1965) – Published August 23, 1965

Strange particles produced in interactions of positive pions with protons have been studied with the Brookhaven 20-in. bubble chamber, which was exposed to π^+ beams of 2.35, 2.62, and 2.90 BeV/c. Cross sections are presented and the production of resonances is discussed. The outstanding feature of the multi-particle final states is that they are dominated by K-π, K-$\bar{K}$, and Y-π resonances. The isotopic spin of the φ is confirmed to be zero and no evidence is found for a φ decay into three pions.

Antiproton Annihilation in Hydrogen at Rest. I. Reaction $\bar{p} + p \rightarrow K + \bar{K} + \pi$

N. Barash, P. Franzini, L. Kirsch, D. Miller, J. Steinberger, T. H. Tan, R. Plano, and P. Yaeger

Phys. Rev. 139, B1659 (1965) – Published September 20, 1965

In a study of 735 000 antiproton annihilations at rest in the hydrogen bubble chamber, 182 examples of the reaction $K_1K_1\pi^0$ and 851 examples of the reaction $K_1K^{\pm}\pi^{\mp}$ were recorded. The distributions in the internal variables of these reactions are presented. A substantial fraction of the latter reaction proceeds through an intermediate K^* state; $\bar{p} + p \rightarrow K + K^*$. The theory of the interference effects in this reaction is presented and compared with the experimental result. It is concluded that the KK^* annihilation proceeds dominantly from the ^3S, I=1 state of the $\bar{N}$ N

system. The fraction of $\bar{p}$ p annihilations into KK^* is given as $f_{KK^*}=(2.1\pm0.3)\times10^{-3}$.

Annihilations of Antiprotons in Hydrogen at Rest Into Two Mesons

C. Baltay, N. Barash, P. Franzini, N. Gelfand, L. Kirsch, G. Lütjens, D. Miller, J. C. Severiens, J. Steinberger, T. H. Tan, D. Tycko, D. Zanello, R. Goldberg, and R. J. Plano

Phys. Rev. Lett. 15, 532 (1965) – Published September 20, 1965

No abstract available.

Annihilations of Antiprotons in Hydrogen at Rest into Two Mesons

C. Baltay, N. Barash, P. Franzini, N. Gelfand, L. Kirsch, G. Lütjens, D. Miller, J. C. Severiens, J. Steinberger, T. H. Tan, D. Tycko, D. Zanello, R. Goldberg, and R. J. Plano

Phys. Rev. Lett. 15, 597 (1965) – Published October 4, 1965

No abstract available.

Test of Charge-Conjugation Invariance in $\bar{p}$ -p Annihilations at Rest

C. Baltay, N. Barash, P. Franzini, N. Gelfand, L. Kirsch, G. Lütjens, J. C. Severiens, J. Steinberger, D. Tycko, and D. Zanello

Phys. Rev. Lett. 15, 591 (1965) – Published October 4, 1965

No abstract available.

Some Features of K^0 Decay: The $\Delta S=\Delta Q$ Rule, and the $|\Delta I|=1/2$ Rules for Leptonic and Three-Pion Decays

P. Franzini, L. Kirsch, P. Schmidt, J. Steinberger, and R. J. Plano

Phys. Rev. 140, B127 (1965) – Published October 11, 1965

In a sample of ~36 000 K^0 and $\bar{K}^0$ mesons produced in antiproton annihilations in a liquid-hydrogen chamber, the K^0 leptonic decay rate and the time distribution of K^0 leptonic decays as well as the $K^0\rightarrow\pi^+ +\pi^- +\pi^0$ decay rates were studied. These results permit tests of the $\Delta S=\Delta Q$ rule and CP violation in leptonic decays, as well as tests of the $\Delta I=1/2$ rule for both leptonic and nonleptonic decays when compared with published results on other charge channels. The data, within their experimental error, are found to be consistent with all three rules.

Annihilation of Antiprotons in Hydrogen at Rest. II. Analysis of the Annihilation into Three Pions

C. Baltay, P. Franzini, N. Gelfand, G. Lütjens, J. C. Severiens, J. Steinberger, D. Tycko, and D. Zanello

Phys. Rev. 140, B1039 (1965) – Published November 22, 1965

Analysis of 823 events attributed to the reaction $\bar{p}$ +p(at rest)$\rightarrow\pi^+ +\pi^- +\pi^0$ yields the following results: (a) The channel accounts for 7.8% of the annihilations; (b) 0.55±0.05 of the channel proceeds via ρ production, and the capture to ρπ is from the $^3S_1$ state; and (c) 0.45±0.05

of the channel is nonresonant and this nonresonant production is from the $^1S_0$ state.

Annihilation of Antiprotons in Hydrogen at Rest. III. The Reactions $\bar{p}+p\rightarrow\omega^0+\pi^+\pi^-$ and $\bar{p}+p\rightarrow\omega^0+\rho^0$

C. Baltay, P. Franzini, G. Lütjens, J. C. Severiens, J. Steinberger, D. Tycko, and D. Zanello

Phys. Rev. 140, B1042 (1965) – Published November 22, 1965

The reactions (a) $\bar{p}+p\rightarrow\omega^0+\pi^+\pi^-(\pi^+\pi^-$ nonresonating), and (b) $\bar{p}+p\rightarrow\omega^0+\rho^0$ have been studied for antiprotons at rest. It is found that reaction (a) proceeds from the ^3S $\bar{p}$ p state, whereas reaction (b) is allowed only for the ^1S state. Reaction (a) accounts for 0.039±0.005 of all annihilations, and reaction (b) for 0.007±0.003 of all annihilations.

Measurement of the K0 Mass and the K0-K- Mass Difference

J. K. Kim, L. Kirsch, and D. Miller

Phys. Rev. 140, B1334 (1965) – Published December 6, 1965

From the decay of the K10 in a hydrogen bubble chamber, we have measured the mass of the K0 to be 497.44±0.33 MeV. From the reaction {K-p→K0,n}{↘}{$\pi^+\pi^-$} we have measured the K0-K- mass difference to be 3.71±0.35 MeV.

Σ Radiative Decay and the Angular Momentum of Σ Pionic Decay

M. Bazin, H. Blumenfeld, U. Nauenberg, L. Seidlitz, R. J. Plano, S. Marateck, and P. Schmidt

Phys. Rev. **140**, B1358 (1965) – Published December 6, 1965

We have studied the pion spectrum in the $\Sigma^\pm\rightarrow n+\pi^\pm+\gamma$ decay in order to determine the angular-momentum channel of the Σ pionic decay. We discuss the results from measurements of a sample of 14 800 $\Sigma^+\rightarrow\pi^++n$ decays and 25 000 $\Sigma^-\rightarrow\pi^-+n$ decays. After subtraction of the background, we find 26 Σ^+ radiative decays and 28 Σ^- radiative decays with $P_{c.m.}<166$ MeV/c. The combination $\Sigma^+\rightarrow\pi^++n$ decays via P wave and $\Sigma^-\rightarrow\pi^-+n$ decays via S wave is 45 times more likely than the combination $\Sigma^+\rightarrow\pi^++n$ decays via S wave and $\Sigma^-\rightarrow\pi^-+n$ decays via P wave. This means that our result is 2.7 standard deviations in favor of the first combination.

Search for a Neutral Scalar Meson

H. O. Cohn, W. M. Bugg, G. T. Condo, R. D. McCulloch, G. Lütjens, and N. Gelfand

Phys. Rev. Lett. 15, 906 (1965) – Published December 6, 1965

No abstract available.

The one-pion exchange model and an attempt to measure the spin of the f0

N. Gelfand and G. Lütjens

Il Nuovo Cimento A (1965-1970), 1965, Volume 40, Number 4, Pages 1034-1040

Abstract
We have compiled data on $\pi-\pi$ scattering distributions from the reaction $\pi^{\pm}+N\rightarrow\pi^{+}+\pi^{-}+N$. For each 50 MeV interval in $\pi\pi$ mass the $\pi\pi$ angular distribution is fitted to a polynomial in $\cos\theta_{\pi\pi}$. The simple one-pion exchange model fails to explain the $\pi-\pi$ angular distribution in the ρ^0 mass region. Using the calculations of Gottfired and Jackson a fair agreement is obtained. Above 1150 MeV in $\pi\pi$ mass $\cos4\theta_{\pi\pi}$ terms are needed. The coefficient of cos $\theta_{\pi\pi}$□□hows no evidence of a resonant shape in the f^0 region; it does not decrease until well past the f^0 mass.

1966

Nonstrange-Resonance Production in $\pi^{+}p$ Collisions at 2.35, 2.62, and 2.90 BeV/c

C. Alff-Steinberger, D. Berley, D. Colley, N. Gelfand, D. Miller, U. Nauenberg, J. Schultz, T. H. Tan, H. Brugger, P. Kramer, and R. Plano

Phys. Rev. 145, 1072 (1966) – Published May 27, 1966

In an exposure of the Brookhaven National Laboratory 20-in. hydrogen bubble chamber to a separated π^{+} beam at π^{+} momenta of 2.35 BeV/c (center-of-mass energy E^{*}=2.30 BeV), 2.62 BeV/c (E^{*}=2.41 BeV), and 2.90 BeV/c (E^{*}=2.52 BeV), we have observed production of the ω^0, ρ^0, and η^0 mesons. The production of the ω^0, ρ^0, and η^0 is often accompanied by simultaneous production of the N^{*++}. The momentum transfer in ω^0 and ρ^0 production is characteristic of peripheral collisions and suggests a single-particle exchange for the production mechanism. The decay distributions for the ω^0, ρ^0, and the ρ^{+} demonstrate the importance of modifying the single-particle-exchange model to include absorptive effects. An upper limit on the two-π decay of the ω^0 is set at 2%. The width of the η^0 is found to be less than 10 MeV. Elastic-scattering distributions are presented.

Annihilations of Antiprotons at Rest in Hydrogen. IV. $\bar{p}p\rightarrow\bar{K}K\pi\pi$

N. Barash, L. Kirsch, D. Miller, and T. H. Tan

Phys. Rev. **145**, 1095 (1966) – Published May 27, 1966

In a study of 735 000 antiproton annihilations at rest in the hydrogen bubble chamber, 3424 events of the reaction $\bar{p}+p \rightarrow K\bar{K}\pi\pi$ were observed. We present here the invariant-mass distributions and scatterplots for this reaction, separated according to the three channels $K_1K_1\pi^+\pi^-$, $K_1(K^0)\pi^+\pi^-$, and $K_1K^{\pm}\pi^{\mp}\pi^0$. Also presented are branching ratios into the various channels. K^* production is found to dominate in all cases. The fraction of $\bar{p}p$ annihilations into $K^*\bar{K}^*$ is $(4.5\pm0.9)\times10^{-3}$, and into $K^*K\pi$ is $(7.7\pm1.7)\times10^{-3}$.

Annihilations of Antiprotons at Rest in Hydrogen. V. Multipion Annihilations

C. Baltay, P. Franzini, G. Lütjens, J. C. Severiens, D. Tycko, and D. Zanello

Phys. Rev. 145, 1103 (1966) – Published May 27, 1966

Approximately 45 000 pionic annihilations of stopped antiprotons in hydrogen have been measured and analyzed. The relative annihilation rates into the various multipion final states are presented. The experimental distributions of the invariant masses of all the possible pion combinations have been obtained. Strong production of the ρ, ω, and η meson has been observed, and their production rates have been established. The rates for simultaneous production of $\rho^0\rho^0$, $\rho^0\omega^0$, and $\rho^0\eta^0$ are discussed.

Experimental Evidence Concerning Charge-Conjugation Noninvariance in the Decay of the η Meson

Charles Baltay, Paolo Franzini, Jewan Kim, Lawrence Kirsch, Dino Zanello, Juliet Lee-Franzini, Richard Loveless, John McFadyen, and Harold Yarger

Phys. Rev. Lett. 16, 1224 (1966) – Published June 27, 1966

No abstract available.

A Measurement of the K_1^0 Lifetime

L. Kirsch and P. Schmidt

Phys. Rev. **147**, 939 (1966) – Published July 29, 1966

On the basis of about 5000K^0 decays into two charged pions in a hydrogen bubble chamber, we have measured the K_1^0 lifetime to be $\tau_1=(0.843\pm0.013)\times10^{-10}$ sec.

Experimental Test of Time-Reversal Invariance in $\Sigma^0 \rightarrow \Lambda^0+e^++e^-$

R. G. Glasser, B. Kehoe, P. Engelmann, H. Schneider, and L. E. Kirsch

Phys. Rev. Lett. **17**, 603 (1966) – Published September 12, 1966

No abstract available.

$\Sigma^{\pm}$ Lifetime and the Branching Ratio $B_{\Sigma}{}^{+}\equiv(\Sigma^{+}\rightarrow\pi^{+}+n)/(\Sigma^{+}\rightarrow All)$

C. Y. Chang

Phys. Rev. 151, 1081 (1966) – Published November 25, 1966

Using 11 000 charged Σ's produced from $K^{-}+p\rightarrow\Sigma^{\pm}+\pi^{\mp}$ interactions taking place in the 30-in. Columbia-BNL hydrogen bubble chamber, we have determined the $\Sigma^{\pm}$ lifetimes and the branching ratio $B_{\Sigma}{}^{+}\equiv(\Sigma^{+}\rightarrow\pi^{+}+n)/(\Sigma^{+}\rightarrow all)$. By means of a least-squares fit to the differential decay distributions for the in-flight sigma decays, the following values were obtained: $\tau_{\Sigma}{}^{+}=(0.830\pm0.018)\times10^{-10}$ sec, $\tau_{\Sigma}{}^{-}=(1.666\pm0.026)\times10^{-10}$ sec, and $B_{\Sigma}{}^{+}=0.46\pm0.02$.

1967

Observation of the B Meson in the Reaction $\bar{p}+p\rightarrow\omega^{0}+\pi^{+}+\pi^{-}$

C. Baltay, J. C. Severiens, N. Yeh, and D. Zanello

Phys. Rev. Lett. 18, 93 (1967) – Published January 16, 1967

The B meson, decaying into $\omega^{0}+\pi^{\pm}$, has been observed in $\bar{p}$ p annihilations at rest in the reaction $\bar{p}+p\rightarrow\omega^{0}+\pi^{+}+\pi^{-}$. The mass and width of the B meson as observed in this reaction are M=1200±20 MeV and Γ=100±30 MeV.

Annihilations of Antiprotons at Rest in Hydrogen. VI. Kaonic Final States

N. Barash, L. Kirsch, D. Miller, and T. H. Tan

Phys. Rev. **156**, 1399 (1967) – Published April 25, 1967

We present here experimental results on the annihilation of stopped antiprotons into $K\bar{K}+3\pi$, $K\bar{K}_{\eta}$, and $K\bar{K}_{\omega}$. We find the branching ratios for $\bar{p}+p\rightarrow K_1K_1\eta$ and $\bar{p}+p\rightarrow K_1K_1\omega$ to be $(0.25\pm0.04)\times10^{-3}$ and $(1.08\pm0.16)\times10^{-3}$, respectively. From events of the latter reaction we find the width of the ω meson to be 12.3±2.0 MeV. The E^{0} meson is observed and evidence is seen for the assignment of even charge conjugation and even G parity to this resonance. In addition, we have used events from the reaction $\bar{p}+p\rightarrow K_1K^{\pm}\pi^{\pm}$ to measure the mass difference between the charged and neutral K^{*}. We find $M_{K^{*}{}_{0,K}}-M_{K^{*}{}_{0}}-M_{K^{*\pm}}=6.3\pm4.1$ MeV.

Neutral Decay Branching Ratios of the η^{0} Meson

C. Baltay, P. Franzini, J. Kim, R. Newman, N. Yeh, and L. Kirsch

Phys. Rev. Lett. 19, 1495 (1967) – Published December 25, 1967

The branching ratios for the decay of the η^0 meson into $3\pi^0$, $\pi^0\gamma\gamma$, and $\gamma\gamma$ have been measured. Under the assumption that no other neutral decays are significant, the results are $(\eta^0\to3\pi^0)/(\eta^0\to\gamma\gamma)=0.88\pm0.16$ and $(\eta^0\to\pi^0\gamma\gamma)/(\eta^0\to\gamma\gamma)<\sim0.28$ (95% confidence-level upper limit).

Partial Decay Rates of the η^0 Meson

C. Baltay, P. Franzini, J. Kim, L. Kirsch, R. Newman, N. Yeh, J. A. Cole, J. Lee-Franzini, and H. Yarger

Phys. Rev. Lett. 19, 1498 (1967) – Published December 25, 1967

We have measured the ratios $(\eta^0\to$neutral decay modes $)/(\eta^0\to$charged decay modes $)$ and $(\eta^0\to\pi^+\pi^-\gamma)/(\eta\to\pi^+\pi^-\pi^0)$ to be, respectively, 2.64 ± 0.23 and 0.28 ± 0.04. By combining these ratios with the results of the preceding Letter for the neutral modes, we obtain partial decay rates for the various η^0 decays. In particular, we obtain $(\eta^0\to3\pi^0)/(\eta^0\to\pi^+\pi^-\pi^0)=1.58\pm0.25$, in good agreement with the assumption that the three-pion final state has I=1.

1968

Observation of Multipion Resonances at 1630 and 1720 MeV in High-Energy π^+p Collisions

C. Baltay, H. H. Kung, N. Yeh, T. Ferbel, P. F. Slattery, M. Rabin, and H. L. Kraybill

Phys. Rev. Lett. 20, 887 (1968) – Published April 15, 1968

No abstract available.

$p\pi^+\pi^-$ Enhancements in the Reaction $pp\to pp\pi^+\pi^-$ at 24.8 GeV/c

R. Ehrlich, R. Nieporent, R. J. Plano, J. B. Whittaker, C. Baltay, J. Feinman, P. Franzini, R. Newman, and N. Yeh

Phys. Rev. Lett. 21, 1839 (1968) – Published December 30, 1968

A study of the reaction $pp\to pp\pi^+\pi^-$ at 24.8 GeV/c, based on 3250 events, gives strong support for the production of resonant $p\pi^+\pi^-$ states at 1.423 ± 0.027 and 1.688 ± 0.023 GeV.

1969

THE DECAY $\Sigma^\pm\to\Lambda e^\pm\nu$

C. Baltay, P. Franzini, R. Newman, H. Norton, N. Yeh, J. Cole, J. Lee-Franzini, R. Loveless, and J. McFadyen

Phys. Rev. Lett. 22, 615 (1969) – Published March 24, 1969

We have observed 46 examples of the decay $\Sigma^-\to\Lambda e^-\nu$ and six of the decay $\Sigma^+\to\Lambda e^+\nu$. The branching ratios are, respectively, $(0.52\pm0.09)\times10^{-4}$ and $(0.16\pm0.07)\times10^{-4}$. A study of the

internal variables distribution yields G_V/G_A=-0.7±0.4 for the combined sample of $\Sigma^{\pm}\rightarrow\Lambda e^{\pm}\nu$.

1970

C. Baltay, G. Feinberg, N. Yeh, and R. Linsker

Phys. Rev. D 1, 759 (1970) – Published February 1, 1970

An experiment has been carried out to search for uncharged particles with spacelike four-momentum which presumably travel faster than light. No evidence for such particles has been found. The results can be expressed as upper limits on the production rates for such particles by stopped K^- and $\bar{p}$ compared to production rates of pions in similar reactions: $(K^-+p\rightarrow\Lambda^0+t^0)/(K^-+p\rightarrow\Lambda^0+\pi^0)\leq 2\times10^{-3}$, $(K^-+p\rightarrow\Lambda^0+t^0+\bar{t}^0)/(K^-+p\rightarrow\Lambda^0+\pi^0)\leq 2.5\times10^{-3}$, $(\bar{p}+p\rightarrow\pi^++\pi^-+t^0)/(\bar{p}+p\rightarrow 3\pi)\leq 2\times10^{-3}$, $(\bar{p}+p\rightarrow\pi^++\pi^-+t^0+\bar{t}^0)/(\bar{p}+p\rightarrow 4\pi)\leq 1\times10^{-3}$. Other sources of information placing limits on the interactions of tachyons are discussed.

1971

β Decay of the *Λ* Hyperon

J. Canter, J. Cole, J. Lee-Franzini, R. J. Loveless, and P. Franzini

Phys. Rev. Lett. **26**, 868 (1971) – Published April 5, 1971

We have obtained a sample of 141 kinematically determined $\Lambda\rightarrow pe\nu$ events. The internal-variable distribution for these events has been used to determine the magnitude of the ratio of the coupling constants, $|g_A/g_V|=0.75_{-0.15}^{+0.18}$. The branching ratio was also obtained as $(0.78\pm0.09)\times10^{-3}$.

Particle Momentum Distributions for 8.5-GeV/*c* π^+p Interactions

J. Cole, J. Lee-Franzini, R. J. Loveless, P. Franzini, and H. H. Kung
Phys. Rev. D **4**, 627 (1971) – Published August 1, 1971

We have measured two-, four-, six-, and eight-prong events from 8.5-GeV/*c* π^+p interactions and have prepared laboratory distributions of particle momenta both for the individual classes of events and for the combined sample.

Strangeness-Changing Leptonic Decay Rates for the $\Sigma^{\pm}$ Hyperons

J. Cole, J. Lee-Franzini, R. J. Loveless, C. Baltay, P. Franzini, R. Newman, H. Norton, and N. Yeh

Phys. Rev. D 4, 631 (1971) – Published August 1, 1971

The strangeness-changing leptonic branching ratios of the $\Sigma^{\pm}$ hyperon were determined from a stopping K^- exposure in the BNL-Columbia 30-in. hydrogen bubble chamber. The ratio $(\Sigma^-\rightarrow ne\nu)/(\text{all }\Sigma^-\text{ decays})$ is $(0.97\pm0.15)\times10^{-3}$, and the ratio $(\Sigma^-\rightarrow n\mu\nu)/(\text{all }\Sigma^-\text{ decays})$ is $(0.38\pm0.11)\times10^{-3}$. No evidence is found for $\Delta S=\Delta Q$ violations, and an upper limit for the ratio of

decay rates $[(\Sigma^+ \to n e \nu)/(\Sigma^- \to n e \nu)]$ is determined to be <12.6% with 95% confidence.

Precision Measurement of the Lifetime and Decay Branching Ratio of the Λ^0 Hyperon

C. Baltay, A. Bridgewater, W. A. Cooper, M. Habibi, and N. Yeh

Phys. Rev. D 4, 670 (1971) – Published August 1, 1971

A precision measurement of the Λ^0 lifetime τ_Λ and the branching ratio $R=(\Lambda \to p\pi^-)/(\Lambda \to \text{all})$ has been carried out. The results are $\tau_\Lambda=(2.54\pm0.04)\times10^{-10}$ sec and $R=0.646\pm0.008$. The errors include both the statistical errors and our estimate of the systematic errors.

Measurement of the $K_S^0 \to 2\pi$ Decay Branching Ratio

C. Baltay, A. Bridgewater, W. A. Cooper, L. K. Gershwin, M. Habibi, and N. Yeh

Phys. Rev. Lett. 27, 1678 (1971) – Published December 13, 1971

We have measured the branching ratio $(K_S^0 \to \pi^+\pi^-)/(K_S^0 \to \pi^0\pi^0)$ to be 2.22 ± 0.095, using a total of ~ 32 000 $\bar{K}^0$'s produced by K^- charge exchange.

1972

Measurement of the Ratio of the Axial-Vector to the Vector Coupling in the Decay $\Sigma^- \to n e^- \bar{\nu}$

C. Baltay, J. Feinman, P. Franzini, R. Newman, N. Yeh, J. Canter, J. Cole, J. Lee-Franzini, and R. J. Loveless

Phys. Rev. D 5, 1569 (1972) – Published April 1, 1972

From a sample of 393 $\Sigma^-\beta$ decays, we have selected 63 events in which a proton recoil from a neutron interaction in the chamber is observed. From the measured values of the electron-neutrino angle we conclude that for the $\Sigma^- \to n e^- \bar{\nu}$, $|g_A/g_V|=0.29_{-0.29}^{+0.28}$. This result is obtained from a maximum-likelihood calculation which includes the effect of a well-understood background of 27±6 events contained in our sample.

Decay $\Sigma^\pm \to \Lambda e^\pm \nu$

P. Franzini, R. Newman, F. Eisele, R. Engelmann, H. Filthuth, F. Föhlisch, V. Hepp, E. Leitner, V. Linke, W. Presser, H. Schneider, M. L. Stevenson, G. Zech, N. Barash, T. B. Day, R. G. Glasser, B. Kehoe, B. Knopp, B. Sechi-Zorn, G. A. Snow, J. A. Cole, J. Lee-Franzini, R. Loveless, and J. McFadyen

Phys. Rev. D **6**, 2417 (1972) – Published November 1, 1972

The ratio of the vector to axial-vector coupling constant for $\Sigma^\pm \to \Lambda e^\pm \nu$ decays using 186 events is determined to be -0.37±0.20. The branching ratio for $\Sigma^- \to \Lambda e^- \nu$ is $(0.62\pm0.07)\times10^{-4}$ and for $\Sigma^+ \to \Lambda e^+ \nu$ is $(0.21\pm0.05)\times10^{-4}$. An upper limit on the magnitude of the ratio of the axial-

magnetism to axial-vector coupling constants is 3.2.

1974

Properties of Ξ^- and Ξ^0 hyperons

C. Baltay, A. Bridgewater, W. A. Cooper, L. K. Gershwin, M. Habibi, M. Kalelkar, N. Yeh, and A. Gaigalas

Phys. Rev. D 9, 49 (1974) – Published January 1, 1974

We report a measurement of the Ξ^- and Ξ^0 weak-decay parameters, mean lifetimes, and spins, based on 4303 Ξ^- and 652 Ξ^0 decays. We find for the Ξ^-, $\alpha=-0.376\pm0.038$, $\varphi=11^\circ\pm9^\circ$, $\tau=(1.63\pm0.03)\times10^{-10}$ sec, and spin equal to ½ with higher spins excluded by more than 7 standard deviations; for the Ξ^0, $\alpha=-0.54\pm0.10$, $\varphi=16^\circ\pm17^\circ$, $\tau=(2.88_{-0.19}{}^{+0.21})\times10^{-10}$ sec, and spin equal to ½ with higher spins excluded by more than 4 standard deviations. The results are consistent with the requirements of T invariance, and they are in fair agreement with the $\Delta I=1/2$ rule.

Study of the decay distributions of the η' meson

C. Baltay, D. Cohen, S. Csorna, M. Habibi, M. Kalelkar, W. D. Smith, and N. Yeh

Phys. Rev. D 9, 2999 (1974) – Published June 1, 1974

We have carried out a study of the decay distributions of $\eta'(958)$ mesons produced in the reaction $K^-p\to\Lambda\eta'$ at 1.75 GeV/c, utilizing both the $\eta\pi^+\pi^-$ and $\pi^+\pi^-\gamma$ decay modes of the η'. A Dalitz-plot analysis of the $\eta\pi^+\pi^-$ decay channel rules out all spin-parity assignments except 0^- and 2^-, but is unable to distinguish between them. We find no evidence for the existence of anisotropies in the η' decay angular distributions, and thus our data do not support the recent conjecture, based on the observation of such anisotropies, that the η' has spin 2.

Observation of rare decay modes of the Ξ hyperons

N. Yeh, A. Gaigalas, W. D. Smith, H. Zendle, C. Baltay, A. Bridgewater, S. Csorna, W. A. Cooper, L. K. Gershwin, M. Habibi, and M. Kalelkar

Phys. Rev. D 10, 3545 (1974) – Published December 1, 1974

In an experiment based on the production of 8150 Ξ^{-1} and 2975 Ξ^0 hyperons, we have detected one example each of the decays $\Xi^-\to\Lambda\mu^-\bar{\nu}$ and $\Xi^0\to\Lambda\gamma$. The branching ratios of these hitherto unobserved decay modes are $\Gamma(\Xi^-\to\Lambda\mu^-\bar{\nu})/\Gamma(\Xi^-\to\Lambda\pi^-)=(3\pm3)\times10^{-4}$ and $\Gamma(\Xi^0\to\Lambda\gamma)/\Gamma(\Xi^0\to\Lambda\pi^0)=(5\pm5)\times10^{-3}$. One event of the decay $\Xi^-\to\Lambda e^-\bar{\nu}$ has also been observed. There is no evidence for $\Delta S=2$ decays; upper limits on these and other rare decay modes are presented.

1975

Search for Charmed-Particle Production in 15-BeV/c π^+p Interactions

C. Baltay, C. V. Cautis, D. Cohen, S. Csorna, M. Kalelkar, D. Pisello, E. Schmidt, W. D.

Smith, and N. Yeh

Phys. Rev. Lett. 34, 1118 (1975) – Published April 28, 1975

A search for the production of charmed particles in 15-BeV/c π^+p interactions has been carried out. The search was sensitive to charmed particles in the 1.5 to 4.0 BeV mass range, with lifetimes $\lesssim 10^{-11}$ sec, decaying into a strange particle with up to eight additional pions. No evidence for the production of such particles was found.

Search for Charmed-Particle Production in 15-BeV/c π^+p Interactions.

C. Baltay, C. V. Cautis, D. Cohen, S. Csorna, M. Kalelkar, D. Pisello, E. Schmidt, W. D. Smith, and N. Yeh

Phys. Rev. Lett. 34, 1205 (1975) – Published May 5, 1975

Evidence for a New Meson Resonance at 2340 MeV

C. Baltay, C. V. Cautis, D. Cohen, M. Kalelkar, D. Pisello, W. D. Smith, and N. Yeh

Phys. Rev. Lett. 35, 891 (1975) – Published October 6, 1975

Evidence is presented for a new meson resonance at 2340±20 MeV, with a width of 180±60 MeV, decaying primarily into ρρπ. The resonance, which is observed in 15-GeV/c π^+p interactions, has isotopic spin 1 or 2 and odd G parity. The cross section for production of the ρρπ state is 7.3±1.7 μb. Branching ratios into ρρπ and other decay modes are given.

1976

Distribution of charge in π^+p interactions at 15 GeV/c

C. Baltay, C. V. Cautis, D. Cohen, M. Kalelkar, D. Pisello, W. D. Smith, and N. Yeh

Phys. Rev. D 14, 55 (1976) – Published July 1, 1976

Inclusive and semi-inclusive distributions of charge from a 15-GeV/c π^+p experiment are presented in terms of the Feynman variable x and the transverse momentum $p_\perp$. The charge distributions are found to have different n_{ch} and $p_\perp$ dependences in different kinematic regions. Our distributions are compared to similar ones calculated from published single-particle distributions in π^-p and pp experiments at several energies.

1977

Dilepton Production by Neutrinos in Neon

C. Baltay, M. Hibbs, R. Hylton, M. Kalelkar, W. Orance, E. Schmidt, A. -M. Cnops, P. L. Connolly, S. A. Kahn, M. J. Murtagh, R. B. Palmer, N. P. Samios, and T. T. Tso

Phys. Rev. Lett. 39, 62 (1977) – Published July 11, 1977

In an exposure of the Fermilab 15-ft bubble chamber filled with a heavy neon-hydrogen mixture to a broadband neutrino beam, we have observed 81 dilepton events of the type ν_μ+Ne→μ^-+e^++…. This corresponds to (0.5±0.15)% of the total charged-current neutrino

interactions. A total of fifteen neutral strange-particle decays ($K_s^0 \to \pi^+\pi^-$, $\Lambda^0 \to p\pi^-$) were found in these dilepton events. When corrected for detection efficiencies and unobservable strange particles, this is consistent with the production of approximately one strange particle per event.

Diffractive and Nondiffractive A_1, A_3, and A_4 Production in π^+p Interactions at 15 GeV/c

C. Baltay, C. V. Cautis, and M. Kalelkar

Phys. Rev. Lett. 39, 591 (1977) – Published September 5, 1977

We have studied the spin-parity structure of the 3π system produced opposite a proton or Δ^{++} in π^+p interactions at 15 GeV/c. Our results suggest that the broad enhancement at 1.1 GeV, traditionally associated with the A_1, does not have the properties usually associated with a resonant state. We obtain similar results for the A_3 and A_4 enhancements.

1978

Meson-resonance production in π^+p interactions at 15 GeV/c

C. Baltay, C. V. Cautis, D. Cohen, S. Csorna, M. Kalelkar, D. Pisello, W. D. Smith, and N. Yeh

Phys. Rev. D 17, 62 (1978) – Published January 1, 1978

We report on a study of 15-GeV/c π^+p interactions of all topologies using the SLAC 82-in. hydrogen bubble chamber. A description is given of the automatic pattern-recognition techniques used to measure the events. Cross sections are given for meson-resonance production in all topologies. Evidence is presented for a new resonance decaying to five pions. A measurement is made of the branching ratios of the g meson. A study is made of low-mass enhancements in the diffractively produced ρπ, fπ, and gπ channels, and a search is made for nondiffractive production of the A_1 meson.

Production of $\omega'(1675)$ in the Reaction $\pi^+p \to \Delta^{++}\pi^+\pi^-\pi^0$ at 15 GeV/c

C. Baltay, C. V. Cautis, and M. Kalelkar

Phys. Rev. Lett. 40, 87 (1978) – Published January 9, 1978

We present the results of a detailed study of $\omega'(1675)$ production in the reaction $\pi^+p \to \Delta^{++}\pi^+\pi^-\pi^0$ from a high-statistics bubble-chamber experiment at 15 GeV/c. We have measured the mass, width, and cross section as well as differential cross section and spin density matrix elements and compare then to A_2^0 production in the same reaction. We show clear evidence for the resonant phase increase of the 3^- $(\rho\pi)f_{I=0}$ amplitude with $\omega'(1675)$ production.

Experimental Limits on Heavy Lepton Production by Neutrinos

A. M. Cnops, P. L. Connolly, S. A. Kahn, H. G. Kirk, M. J. Murtagh, R. B. Palmer, N. P. Samios, M. Tanaka, T. T. Tso, C. Baltay, D. Caroumbalis, H. French, M. Hibbs, R. Hylton, M. Kalelkar, W. Orance, and E. Schmidt

Phys. Rev. Lett. 40, 144 (1978) – Published January 16, 1978

We present upper limits on the production of heavy leptons ($L^{\pm}$) by neutrinos via the process $\nu_\mu+Ne\rightarrow L^{\pm}+\cdots$, $L^{\pm}\rightarrow e^{\pm}+\nu+\bar{\nu}$. These limits imply that the L^- and L^+, if they couple in full strength to ν_μ, are heavier than 7.5 and 9 GeV, respectively. They also imply that the coupling strength ν_μ to the recently discovered 1.9-GeV heavy lepton τ is less than 0.025 of the normal ν_μ-μ coupling.

Charmed-D-Meson Production by Neutrinos

C. Baltay, D. Caroumbalis, H. French, M. Hibbs, R. Hylton, M. Kalelkar, W. Orance, E. Schmidt, A. M. Cnops, P. L. Connolly, S. A. Kahn, H. G. Kirk, M. J. Murtagh, R. B. Palmer, N. P. Samios, and M. Tanaka

Phys. Rev. Lett. 41, 73 (1978) – Published July 10, 1978

We have observed the production of the D^0 meson by neutrinos followed by the decay $D^0\rightarrow K_S{}^0+\pi^++\pi^-$. Correcting for detection efficiencies and K^0 decay branching ratios, we find that the production of the D^0 followed by decay into $K^0\pi^+\pi^-$ corresponds to (0.7 ± 0.2)% of all charged-current neutrino interactions.

Measurement of the Cross Section for the Process $\nu_\mu+e^-\rightarrow\nu_\mu+e^-$ at High Energies

A. M. Cnops, P. L. Connolly, S. A. Kahn, H. G. Kirk, M. J. Murtagh, R. B. Palmer, N. P. Samios, M. Tanaka, C. Baltay, D. Caroumbalis, H. French, M. Hibbs, R. Hylton, M. Kalelkar, and K. Shastri

Phys. Rev. Lett. 41, 357 (1978) – Published August 7, 1978

We have observed eleven events of the reaction $\nu_\mu e^-\rightarrow\nu_\mu e^-$ in a sample of 106 000 charged-current neutrino interactions in a heavy neon-hydrogen mixture in the 15-ft. bubble chamber at Fermilab. We obtain a cross section for this process of $[(1.8\pm0.8)\times10^{-42}\ cm^2/GeV]E_\nu$. This result is in good agreement with the prediction of the Weinberg-Salam model with $\sin^2\theta_W=0.2$.

1979

Confirmation of the Existence of the $\Sigma_c{}^{++}$ and $\Lambda_c{}^+$ Charmed Baryons and Observation of the Decay $\Lambda_c{}^+\rightarrow\Lambda\pi^+$ and $\bar{K}{}^0p$

C. Baltay, D. Caroumbalis, H. French, M. Hibbs, R. Hylton, M. Kalelkar, K. Shastri, A. Vogel, A. M. Cnops, P. L. Connolly, S. A. Kahn, H. G. Kirk, M. J. Murtagh, R. B. Palmer, N. P. Samios, and M. Tanaka

Phys. Rev. Lett. 42, 1721 (1979) – Published June 25, 1979

In a broadband neutrino exposure of the Fermilab 15-ft bubble chamber, we observe the production of the $\Sigma_c{}^{++}(2426)$ charmed baryon followed by its decay to $\Lambda_c{}^+(2260)$ and π^+. We find the mass of the $\Lambda_c{}^+$ to be 2257±10 MeV and the $m(\Sigma_c{}^{++})$-$m(\Lambda_c{}^+)$ mass difference to be 168±3 MeV. Previously unseen two-body decay modes of the $\Lambda_c{}^+(2260)$ are observed.

1980

Search for prompt neutrinos and penetrating neutral particles in a beam-dump experiment at Brookhaven National Laboratory

P. F. Jacques, M. Kalelkar, P. A. Miller, R. J. Plano, P. Stamer, E. B. Brucker, E. L. Koller, S. Taylor, C. Baltay, H. French, M. Hibbs, R. Hylton, K. Shastri, and A. Vogel

Phys. Rev. D 21, 1206 (1980) – Published March 1, 1980

Results are presented from a beam-dump experiment at Brookhaven National Laboratory using the 7-ft bubble chamber to search for prompt sources of neutrinos and the interactions or decays into $\gamma\gamma$ or e^+e^- of light, penetrating neutral particles (such as the axion). The observed events are all consistent with representing neutrinos from ordinary sources. We place upper limits on axion production that are below theoretical estimates. We also set upper limits on associated production of the charmed D meson.

Cross Sections and Scaling-Variable Distributions of Neutral- and Charged- Current Neutrino-Nucleon Interactions from a Low-Energy Narrow Band Beam

C. Baltay, H. French, M. Hibbs, R. Hylton, K. Shastri, A. Vogel, P. F. Jacques, M. Kalelkar, P. A. Miller, R. J. Plano, P. E. Stamer, E. B. Brucker, E. L. Koller, and S. Taylor

Phys. Rev. Lett. 44, 916 (1980) – Published April 7, 1980

This Letter compares neutral-current and charged-current scaling-variable distributions in neutrino-nucleon interactions induced by a narrow-band beam at Brookhaven National Laboratory; the x distribution of neutral-current events has been reported previously. The first measurement of flux-normalized neutrino cross sections from a narrow-band beam in the energy range E_ν=3-9 GeV is also presented.

1981

Cross-section ratio $\sigma(\nu n)/\sigma(\nu p)$ for charged-current and neutral-current interactions below 10 GeV

P. F. Jacques, M. Kalelkar, P. A. Miller, R. J. Plano, P. Stamer, E. B. Brucker, E. L. Koller, S. Taylor, C. Baltay, H. French, M. Hibbs, R. Hylton, K. Shastri, and A. Vogel

Phys. Rev. D 24, 1067 (1981) – Published September 1, 1981

We have measured the cross-section ratio $\sigma(\nu n)/\sigma(\nu p)$ for both charged-current and neutral-current interactions at low energy. The experiment used the wide-band neutrino beam at Brookhaven National Laboratory. The detector was the 7-foot bubble chamber filled with a 62% neon-hydrogen mixture. For charged-current events we find that the ratio reaches an asymptotic value of 1.80±0.19 for neutrino energies above 1 GeV. For neutral-current events we measure the ratio to be 1.07±0.24. Both of these results are in agreement with the quark model.

Experimental Limits on Neutrino Oscillations

N. J. Baker, P. L. Connolly, S. A. Kahn, H. G. Kirk, M. J. Murtagh, R. B. Palmer, N. P. Samios, M. Tanaka, C. Baltay, M. Bregman, D. Caroumbalis, L. D. Chen, H. French, M. Hibbs,

R. Hylton, J. T. Liu, J. Okamitsu, G. Ormazabal, R. D. Schaffer, K. Shastri, and J. Spitzer

Phys. Rev. Lett. 47, 1576 (1981) – Published November 30, 1981

A search for neutrino oscillations in a wide-band neutrino beam at Fermilab with use of the 15-ft bubble chamber is reported. No evidence is found for neutrino oscillations and upper limits are set on the mixing angles and neutrino mass differences in the transitions $\nu_\mu \rightarrow \nu_e$, $\nu_\mu \rightarrow \nu_\tau$, and $\nu_e \rightarrow \nu^{\sim}_e$, where ∼e denotes "not e."

1983

Measurement of the ν_μ Charged-Current Cross Section

N. J. Baker *et al.*

Phys. Rev. Lett. 51, 735 (1983) – Published August 29, 1983

The Fermilab 15-ft bubble chamber, filled with a heavy neon-hydrogen mix, was exposed to a narrow-band ν_μ beam. Based on the observation of 830 charged-current ν_μ interactions, the cross section was found consistent with a linear rise with the neutrino energy in the interval 10 GeV$<\sim E_\nu \lesssim$240 GeV. The average slope was determined to be $\sigma_\nu/E_\nu=(0.62\pm0.05)\times10^{-38}$ cm^2 GeV^{-1}.

1984

Measurement of the Bjorken x and y Distributions in Neutral- and Charged-Current ν_μ Interactions

C. Baltay *et al.*

Phys. Rev. Lett. 52, 1948 (1984) – Published May 28, 1984

Distributions of the Bjorken scaling variables x and y, and the structure function $F_+(x)$, are presented both for neutral-current and for charged-current ν_μ interactions. The data were obtained by use of the Fermilab 15-ft neon bubble chamber exposed to a narrow-band ν_μ beam. Results are based on 151 neutral-current and 683 charged-current events. An important feature of the neutral-current analysis is the event-by-event reconstruction of the outgoing neutrino.

1985

Opposite-sign dilepton production in ν_μ interactions

N. J. Baker, A.-M. Cnops, P. L. Connolly, S. A. Kahn, H. G. Kirk, M. J. Murtagh, R. B. Palmer, N. P. Samios, M. Tanaka, C. Baltay, M. Bregman, D. Caroumbalis, L. D. Chen, H. French, M. Hibbs, R. Hylton, M. Kalelkar, J. T. Liu, J. Okamitsu, G. Ormazabal, A. C. Schaffer, K. Shastri, and J. Spitzer

Phys. Rev. D 32, 531 (1985) – Published August 1, 1985

We report on a high-statistics bubble-chamber experiment using the Fermilab 15-ft

bubble chamber filled with a heavy neon/hydrogen mixture exposed to a wide-band neutrino beam. In a sample of 106 000 ν_μ &>0.3 GeV/c) and a negative muon were observed. After corrections, the rate for opposite-sign dilepton production for ν_μ charged-current events is (0.52±0.09)%. The E_ν dependence of this rate from threshold to ≅200 GeV is presented. The kinematic distributions and strange-particle content of the dilepton events are consistent with those expected from charm-particle production in neutrino interactions. A total of 58 neutral strange particles ($\Lambda \rightarrow p\pi^-$, $K_S^0 \rightarrow \pi^+\pi^-$) are observed in these events, where less than 16 are expected from conventional charged-current interactions. The presence of a significant excess of Λ's is evidence for substantial charmed-baryon production.

Limits on Like-Sign Dilepton Production in ν_μ Interactions

C. Baltay, M. Bregman, M. Hibbs, J. T. Liu, J. Okamitsu, A. C. Schaffer, K. Shastri, N. J. Baker, P. L. Connolly, S. A. Kahn, M. J. Murtagh, R. B. Palmer, N. P. Samios, M. Tanaka, E. B. Brucker, P. F. Jacques, M. Kalelkar, E. L. Koller, R. J. Plano, and P. E. Stamer

Phys. Rev. Lett. 55, 2543 (1985) – Published December 2, 1985

We have searched for the production of like-sign dilepton events ($\nu_\mu + Ne \rightarrow \mu^- + e^- + \ldots$) in a wide-band neutrino beam at Fermilab using the 15-ft bubble chamber. We observe no signal above the background arising from conventional sources. We set 90%-confidence-level upper limits for the production rates of $(\nu_\mu + Ne \rightarrow \mu^- + e^- + \ldots)/(\nu_\mu + Ne \rightarrow \mu^- + \ldots) < \sim 0.76 \times 10^{-4}$ and $(\nu_\mu + Ne \rightarrow \mu^- + e^- + \ldots)/(\nu_\mu + Ne \rightarrow \mu^- + e^+ + \ldots) < \sim 5.3 \times 10^{-2}$.

1986

Evidence for a new state produced in antiproton annihilations at rest in liquid deuterium

D. Bridges, H. Brown, I. Daftari, R. Debbe, A. deGuzman, W. Fickinger, L. Gray, T. Kalogeropoulos, R. Marino, D. Peaslee, Ch. Petridou, D. K. Robinson, G. Tzanakos, and R. Venugopal

Phys. Rev. Lett. **56**, 211 (1986) – Published January 20, 1986

Inclusive charged-pion spectra from $p\bar{d}$ annihilations at rest have been measured in a high-statistics experiment in search of broad states. Analysis of these spectra reveals an enhancement of the π^- spectrum at 315 MeV/c. This may be interpreted as a production of a new state of mass 1485 MeV/c^2 and width at most 200 MeV/c^2 recoiling against the π^-. This quasi two-body final state accounts for a large fraction of the $p\bar{n}$ annihilations.

Strange-particle production in neutrino-neon charged-current interactions

N. J. Baker, P. L. Connolly, S. A. Kahn, M. J. Murtagh, R. B. Palmer, N. P. Samios, M. Tanaka, C. Baltay, M. Bregman, L. Chen, M. Hibbs, R. Hylton, J. Okamitsu, A. C. Schaffer, and M. Kalelkar

Phys. Rev. D 34, 1251 (1986) – Published September 1, 1986

We report a study of strange-particle production from 61?0 charged-current ν_μNe interactions in the Fermilab 15-ft bubble chamber. The observed sample consists of 2279 K^0, 1843 Λ (including 94 Σ^0), 93 $\bar{\Lambda}$, and 4 Ξ^-. We give inclusive production rates for each of these, as well as the rates for specific single-, double-, and triple-vee channels. From these we derive the rates for associated production of $s\bar{s}$ quark pairs, and for single-s-quark production via charm decay. The dependence of K^0 and Λ production on E_ν, Q^2, W^2, x_B, and y_B are given. Normalized distributions of Feynman x, rapidity, fragmentation variable z, and transverse momentum squared are obtained for K^0 and Λ, and compared with those for charged pions. QCD predictions on the behavior of $\langle P_T{}^2 \rangle$ are tested.

Limits on neutrino oscillations in the Fermilab narrow-band beam

E. B. Brucker, P. F. Jacques, M. Kalelkar, E. L. Koller, R. J. Plano, P. E. Stamer, N. J. Baker, P. L. Connolly, S. A. Kahn, M. J. Murtagh, M. Tanaka, C. Baltay, M. Bregman, D. Caroumbalis, L. D. Chen, M. Hibbs, P. Igo-Kemenes, J. T. Liu, J. Okamitsu, G. Ormazabal, A. C. Schaffer, K. Shastri, and J. Spitzer

Phys. Rev. D 34, 2183 (1986) – Published October 1, 1986

A search for neutrino oscillations was made using the Fermilab narrow-band neutrino beam and the 15-ft bubble chamber. No positive signal for neutrino oscillations was observed. The 90%-C.L. upper limits for $\nu_\mu \rightarrow \nu_e$, $\nu_\mu \rightarrow \nu_\tau$, and $\nu_\mu \not\rightarrow \nu_e$ were found to be $R_{\mu\rightarrow e}<0.56\times10^{3}$, $R_{\mu\rightarrow\tau}<4.4\times10^{-2}$, and $R_{e\not\rightarrow e}<0.27$.

Evidence for Coherent Neutral-Pion Production by High-Energy Neutrinos

C. Baltay, M. Bregman, D. Caroumbalis, L. D. Chen, M. Hibbs, J. T. Liu, J. Okamitsu, G. Ormazabal, A. C. Schaffer, K. Shastri, N. J. Baker, P. L. Connolly, S. A. Kahn, M. J. Murtagh, N. P. Samios, and M. Tanaka

Phys. Rev. Lett. 57, 2629 (1986) – Published November 24, 1986

We have observed a signal of 55 isolated γ-conversion pairs produced in a wide-band neutrino beam using the Fermilab 15-ft bubble chamber filled with a heavy Ne-H_2 mixture. The signal is consistent with coherent neutral-current single-π^0 production followed by decay of the π^0 with one of the decay γ's being lost. This signal corresponds to a rate of $(2.0 \pm 0.4) \times 10^{-4}$ of the total ν_μ charged-current cross section at our average E_ν of 20 GeV. From this result, we obtain a value of $\beta=0.98\pm0.24$ for the weak-neutral-current isovector axial-vector coupling.

1989

Measurement of muon-neutrino—electron elastic scattering in the Fermilab 15-foot bubble chamber

N. J. Baker, P. L. Connolly, S. A. Kahn, M. J. Murtagh, R. B. Palmer, N. P. Samios, M. Tanaka, C. Baltay, M. Bregman, M. Hibbs, M. Kalelkar, J. Okamitsu, and A. C. Schaffer

Phys. Rev. D 40, 2753 (1989) – Published November 1, 1989

A total of 22 muon-neutrino-electron elastic-scattering events ($\nu_\mu e \rightarrow \nu_\mu e$) have been observed in an exposure of the Fermilab 15-foot bubble chamber filled with a heavy neon-hydrogen mixture to a wide-band neutrino beam. The elastic-scattering cross section is measured to be $1.67 \pm 0.44 \times 10^{-42} E_\nu$ cm^2 GeV^{-1}. The value of the weak mixing angle ($\sin^2\theta_W$) determined from this cross section, which is consistent with other measurements of this angle, is $0.20_{-0.05}^{+0.06}$.

Appendix D Early Articles Published in Il Nuovo Cimento

Experimental determinations of the Λ^0 and Σ^- spins

F. Eisler, R. Plano, A. Prodell, N. Samios and M. Schwartz, et al.
Il Nuovo Cimento (1955-1965), 1958, Volume 7, Number 2, Pages 222-230

We discuss the applicability of the argument of Adair (1) to the determination of the hyperon spins on the basis of the observed distribution in the production angle for the process $\pi + N \rightarrow Y + \theta$. Because of the pronounced backward and forward peaking of these distributions it is found possible to use a large fraction of the events without jeopardizing the validity of the argument. We find from measurement of the distribution in the correlation angles between incident and outgoing pions that the spins of both the Λ^0 and Σ^- hyperons are one half. The only assumptions necessary to this result are 1) that the θ spin is zero and 2) that the interaction radius for strange particle production is not pathologically large.

Bubble chamber study of unstable particle production in π^--p collisions at 910, 960, 1200 and 1300 MeV

F. Eisler, R. Plano, A. Prodell, N. Samios, M. Schwartz, J. Steinberger, P. Bassi, V. Borelli, G. Puppi and H. Tanaka, et al.
Results are reported on the total and differential cross-sections for the reactions $\pi^- + P \rightarrow \Sigma \Lambda^0 + \theta^0$; $\Sigma^0 + \theta^0$; $\Sigma^- + K^+$ 'at 910, 960, 1200 and 1300 MeV using hydrogen and propane bubble chambers in a magnetic field of 13.4 kG. The chambers and their operation, as well as the method of analysis are described in detail.

Lifetime of Λ^0 ϑ^0, and Σ^-

F. Eisler, R. Plano, A. Prodell, N. Samios and M. Schwartz, et al.
Il Nuovo Cimento (1955-1965), 1958, Volume 10, Number 1, Pages 150-154
The lifetimes of the Λ^0, ϑ^0, and Σ^- observed in bubble chamber photographs have been calculated. The following values are obtained: $\tau\Lambda° = (2.29 -.13 +.15) \cdot 10^{-10}$ s on the

basis of 454 events; $\tau\theta^\circ=(1.06\ -.06\ +0.8\ )\cdot10^{-10}$s on the basis of 259 events and $\tau\Sigma^\circ=(1.89\ -.25\ +.33\ )\cdot10^{-10}$ s on the basis of 107 events. A comparison with previous values of the mean lives is presented.

π^0-π^- mass difference as determined from double Dalitz pairs

N. P. Samios
Il Nuovo Cimento (1955-1965), 1960, Volume 18, Supplement 1, Pages 154-159
Abstract
The π^-, π^0 mass difference was determined by measuring the momenta of the two internally converted electron positron pairs from π^0-decay. A total of 119 events gave a value $m\pi^- - \pi^0 = (4.69 \pm 0.07)$ MeV

Demonstration of the existence of the Σ^0 hyperon and a measurement of its mass

R. Plano, N. Samios, M. Schwartz and J. Steinberger
Il Nuovo Cimento (1955-1965), 1957, Volume 5, Number 1, Pages 216-219
Three events, demonstrating the existence of the Σ^0 hyperon, have been found in a propane bubble chamber. The Q-value for the decay $\Sigma^0 \rightarrow \Lambda^0+\gamma+Q$ has been measured to be (73.0 ± 3.5) MeV.

Il Nuovo Cimento (1955-1965)
Volume 5, Number 6, 1700-1715, DOI: 10.1007/BF02856062

Systematics of Λ^0 and θ^0 decay

F. Eisler, R. Plano, N. Samios, M. Schwartz and J. Steinberger
Systematic observations on 528 Λ^0-θ^0 production events in propane have yielded the following information: 1) There exists a neutral Λ^0 decay; $\Lambda^0 \rightarrow \pi^0 + n$ and the fraction of Λ^0's decaying in this mode is .32±.05. 2) The θ_1^0 component has a neutral decay mode, very probably $\theta_1^0 \rightarrow \pi^0+\pi^0$. The θ^0 therefore very probably has even spin. The fraction $P(\theta_1^0 \rightarrow \pi^0 + \pi^0)\ /P(\theta_1^0 \rightarrow 2\pi)$ is .14±.06. The branching ratio $P(\Lambda^0 \rightarrow \pi^0 + n)\ /P(\Lambda^0 \rightarrow \pi^- + n)$ is in good agreement with the $I = 1/2$ selection rule; the branching ratio $P(\theta^0 \rightarrow 2\pi^0)\ /P(\theta^0 \rightarrow \pi^+ + \pi^-)$ seems to be in disagreement. 3) (51±7.5)%, or just one half of the θ^0 mesons escape the chamber and are to be identified with the θ_2^0 -meson proposed by GELL-MANN and PAIS ([4]). The question of the existence of additional (parity doublet) decay modes is discussed. 4) The decays $\Lambda^0 \rightarrow \mu^- + p + \nu$ / $e^- + p + \nu$ are not observed and the fraction of such decays is less than 2%. 5) The 3 particle decay modes of the θ_1^0 have not been observed and are therefore very unlikely to exceed 2% of all θ_1^0 decays. 6) Preliminary measurements yield lifetimes $\tau_{\theta_1^0} = (.95 \pm .08) \cdot 10^{-10}$ s and $\tau_{\Lambda^{0\backslash}} = (2.8 \pm .2)\cdot10^{-10}$ s. 7) For the θ_2^0 we obtain a lower limit of the lifetime, which together with the results of LANDE *et al.* ([5]) brackets the θ_2^0 lifetime $(3 < \theta_2^0 < 10)\cdot10^{-8}$ s.

Appendix E- Scanners and Measurers.

The work of the bubble chamber group was dependant on the work of our talented and dedicated measurers and scanners. I will list the names of those I can recall and encourage others to send me the names that I have forgotten.

Alex Rytov
Margaret-Anne Lewis
Ann Therrien
Cecile Margolis
Irene Yozdez
Fran Joyce
Alex Wosney
Alice Sttewart
Gerry Mauk