

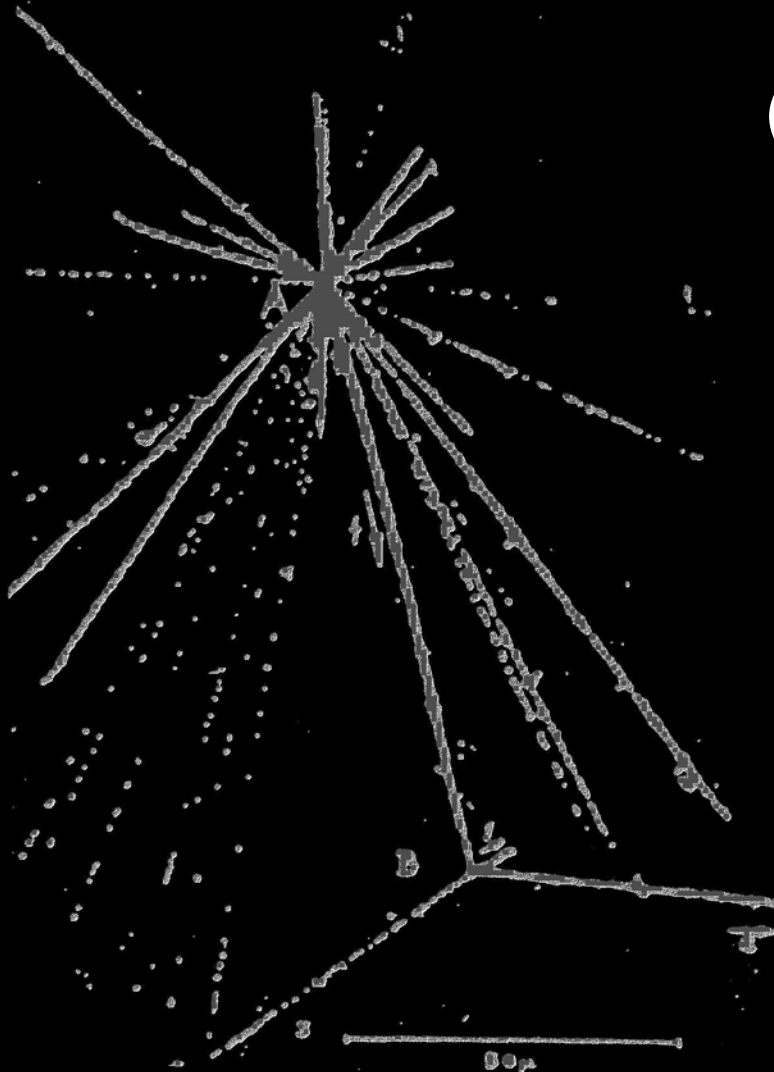
HYPERNUCLEI

(and strange particles)

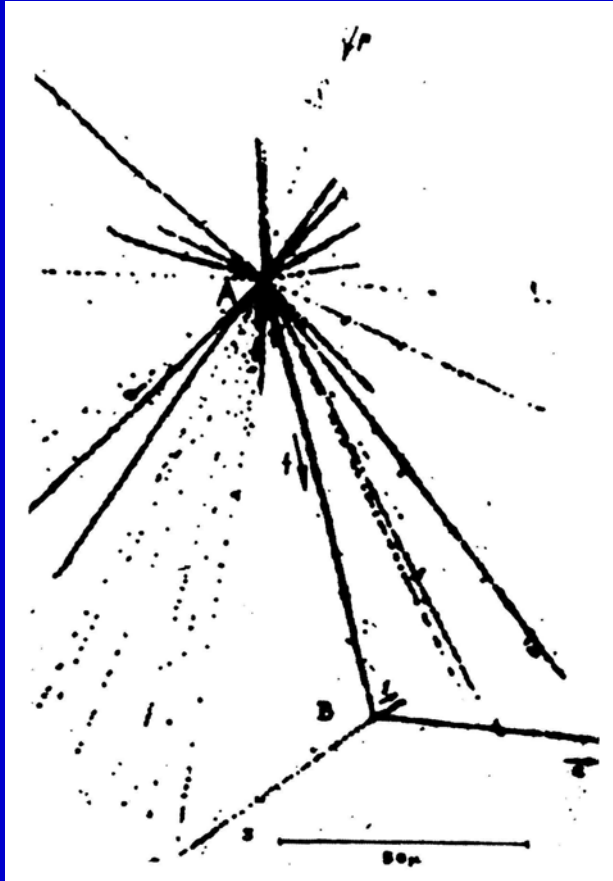
How

it all

began



Andrzej Kajetan Wróblewski
Warsaw University



In September 1952 Marian Danysz and Jerzy Pniewski (Warsaw University) discovered the first hypernucleus. It happened during a time of confusion concerning the newly detected heavy unstable particles. The study of hypernuclei was of considerable help in understanding the properties of strange particles.

Curious particles

A surprising discovery

In December 1947

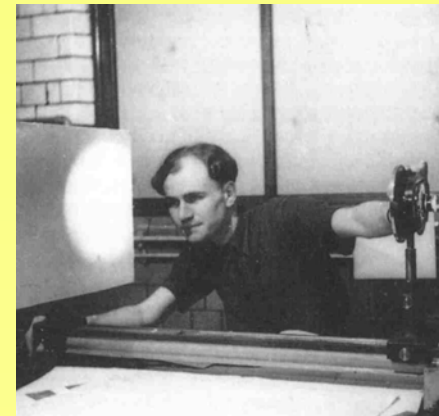
Rochester and Butler

in Manchester reported the first
photographs of forked tracks
(later called "V particles")

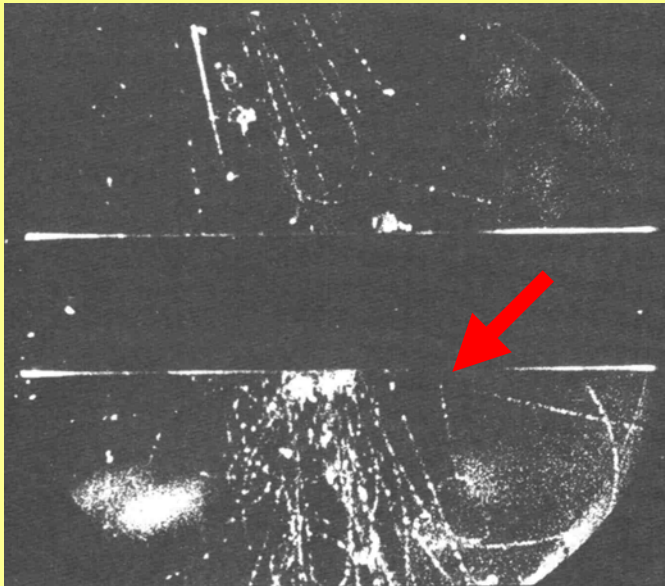
Nature 160, 855 (1947)



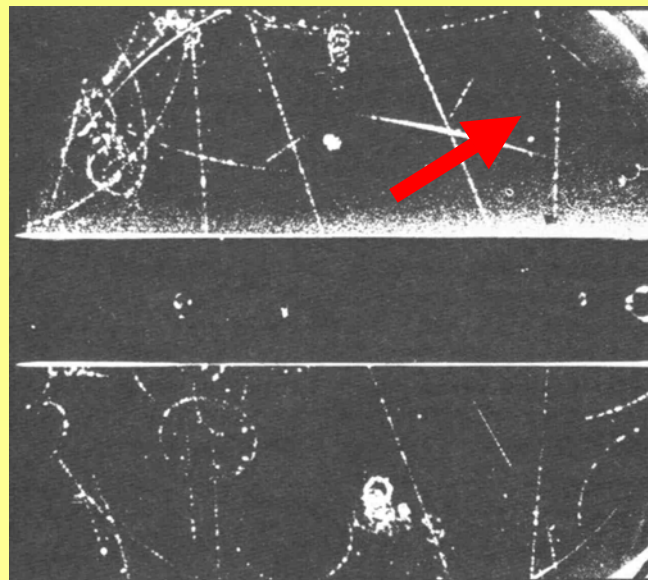
George Rochester



Clifford Butler



Neutral V particle



Charged V particle

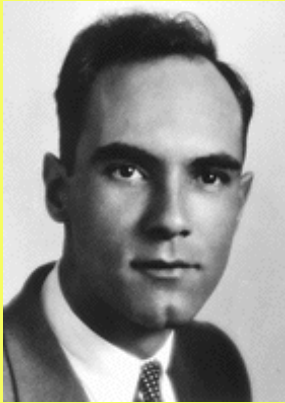


”After the early discoveries that promised so much, there followed several frustrating years, a period of strain for Butler and myself, when no further examples of the V particles were found.”

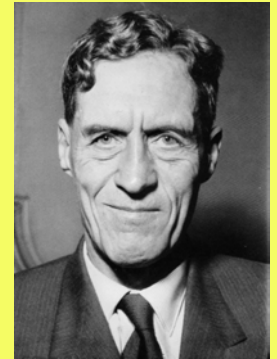
Rochester at Fermilab Symposium (1985)

1948

1949



**Carl Anderson
to Patrick Blackett,
28 November 1949**



”Rochester and Butler may be glad to hear that we have about 30 cases of forked tracks similar to those they described in their article in *Nature* about two years ago, and so far as we can see now their interpretation of these events as caused by new unstable particle seems to be borne out by our experiments.”

June 1950: ”V particles” (Blackett, Bohr, Anderson)

Meetings

1947 1948 1949 1950 1951 1952 1953 1954 1955 1956

Bagneres de Bigorre
Glasgow
Padova
Pisa

3rd Rochester

**I
D
E
A
S**

Tokyo Symposium
Gell-Mann isospin
Gell-Mann strangeness

Pais pair production
Gell-Mann Pais associated production

Cosmic rays

Accelerators

**F
A
C
T
S**

V's produced singly
V's in pairs ?

V particles discovered

V particles confirmed

Superprotons, cascade particles

π, μ

τ meson

V_1^0, V_2^0

HF

Λ, K

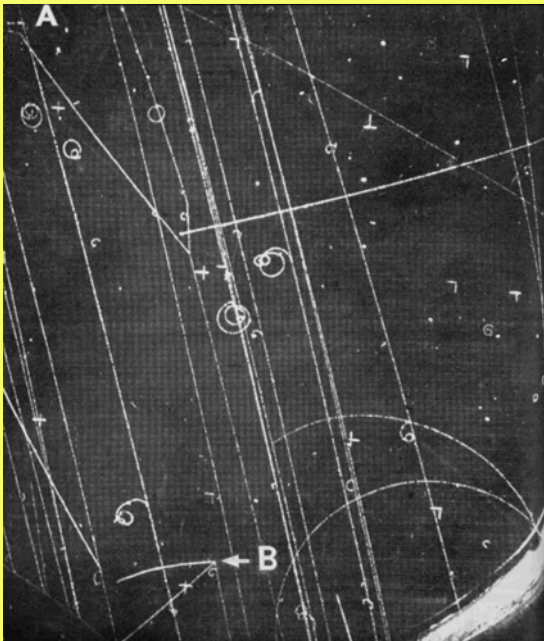
17 HF

120 HF

1947 1948 1949 1950 1951 1952 1953 1954 1955 1956

V particles at once showed unusual properties

- They were copiously produced in high energy collisions (with cross section of a few percent of that for pion production)
- Thus, if the same mechanism was responsible for their production and decay, their lifetime should be of the order of 10^{-21} s.
- The observed lifetime was $\geq 10^{-10}$ s.



7 July 1951 - Tokyo Symposium on new particles

Japanese theorists organized the meeting in order to present and discuss ideas about new particles. A strict selection rule needed to provide for the suppression factor of about 10^{11} .

Presented papers published in *Progress of Theoretical Physics*

vol. 6

Y. Nambu, K. Nishijima, Y. Yamaguchi, p. 615; p. 619;

K. Aizu, T. Kinoshita, p. 630;

H. Miyazawa, p. 631;

S. Oneda, p. 633



**A. Pais, Some remarks on the V-particles,
Phys. Rev. 86, 663
(subm. 22 Jan. 1952, publ. 1 June 1952)**

The abundance of V-particles can be reconciled with their long lifetime by using only interactions of a conventional structure, provided a V-particle is produced together with another heavy unstable particle.

The 'even-odd rule' of Pais allowed reaction $N + N \rightarrow \Lambda + \Lambda$

For several years the idea of production of V particles in pairs seemed to be yet another beautiful hypothesis slayed by ugly facts

For that reason Fermi and Feynman considered the possibility that the new particles have large spin (e.g. $13/2$ for the V_1^0)

Experimental evidence was against pair production of V^0 's

**W. B. Fretter et al.
(Berkeley)**

“Three pairs were observed. This frequency of observation contradicts the hypothesis that V^0 's are created only in pairs, unless one V^0 usually has a value of “betagamma” from 5 to 10 times as large as the other.”

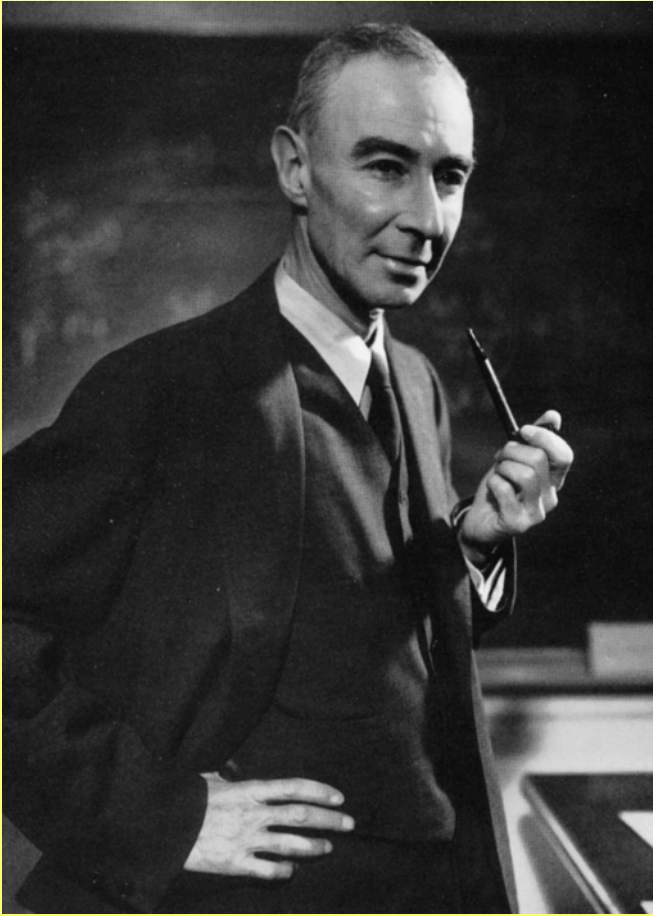
**R. B. Leighton et al.
(CalTech)**

”An analysis of the 152 examples leads to the following principal conclusions: (1) V -particles result from the impact of meson and probably also of nucleos, upon nuclei. (2) V -particles are generally produced singly and not in pairs...”

Both papers published in *Phys. Rev.* (January 1, 1953)
(submitted in September 1952)

V-particles and heavy mesons (December 1952)

Particle	lifetime (s)	Q (MeV)	Mass (m_e)	Spin
? $V_1^\pm \rightarrow p + \pi^-$ $\rightarrow (n + \pi^\pm)?$				half integral
$V_1^0 \rightarrow p + \pi^-$	$3 \cdot 10^{-10}$	40 ± 3	2190 ± 5	half integral
? $S^\pm, \chi^\pm, V^\pm \rightarrow \pi^\pm + ?$	$10^{-8} - 10^{-10}$		900-1500	-
? $S^\pm, \kappa^\pm, V^\pm \rightarrow \mu^\pm + (\gamma + \nu)?$	$10^{-8} - 10^{-10}$		1100	integral
$\tau^\pm \rightarrow \pi^\pm + \pi^+ + \pi^-$	$> 10^{-9}$	75.8	977 \pm 6	integral
? $V^\pm \rightarrow \pi^\pm + \pi^0 + \pi^0$				integral
$V_2^0 \rightarrow \pi^+ + \pi^-$ $\rightarrow (\pi^+ + \pi^- + ?^0)?$ $\rightarrow (\pi^\pm + \tau^\pm \text{ or } \zeta^0)?$	$2 \cdot 10^{-10}$		950	integral
? $\zeta^0 \rightarrow \pi^+ + \pi^-$			500?	
? ζ^\pm			500?	



**”I hope our grandchildren
when they attend the 2038
conference in Rochester will
take it for granted that they
know these things.”**

Oppenheimer at the Third Annual Rochester Conference,
December 18-20, 1952; *Proceedings* p. 74

Bagnères-de-Bigorre



185 participants from 22 countries

(France – 43, UK – 42, Italy – 27, USA – 20, Germany – 12, Belgium – 8, 4 each from India, Ireland and Switzerland, 2 each from Canada, Denmark, Israel, Japan, Sweden, and Turkey, 1 each from Brasil, Hungary, Mexico, Netherlands, Norway, Spain, and Yugoslavia)



CONGRÈS INTERNATIONAL
SUR LE
RAYONNEMENT COSMIQUE

ORGANISÉ PAR
L'UNIVERSITÉ DE TOULOUSE
SOUS LE PATRONAGE DEL'UIPPA
AVEC L'APPUI DE L'UNESCO

BAGNÈRES DE BIGORRE JUILLET 1953

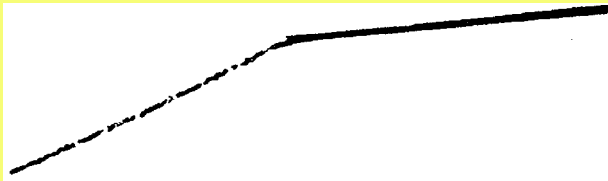
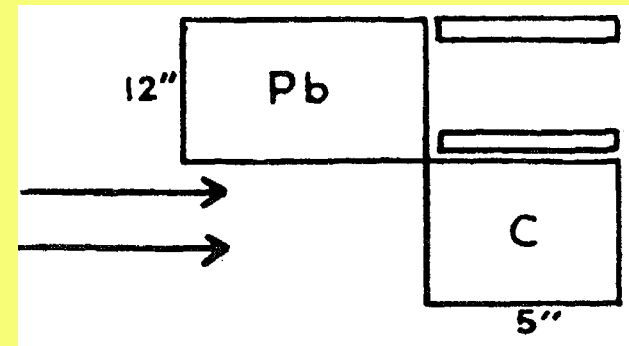
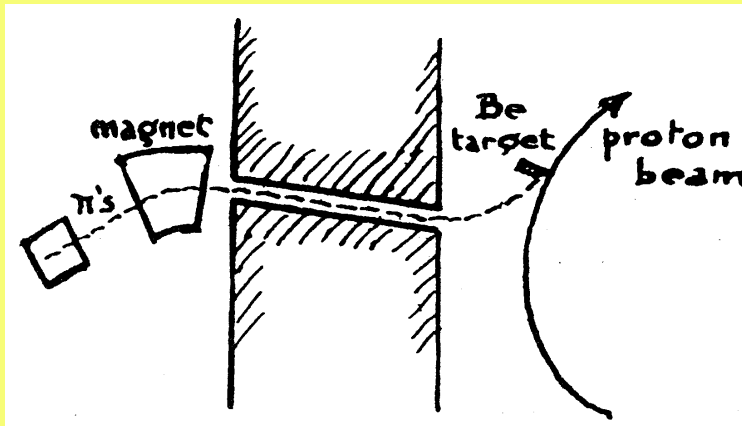
”The particles described in this conference are not entirely fictitious and every analogy with the particles really existing in nature is not purely coincidental”

By common consent one of the most remarkable conferences of the century

- The *Proceedings* are difficult to read by present day physicists because of nomenclature (different symbols used for the same particles)
- The existence of ‘Superprotons’ (now Σ) and ‘Cascade particles’ (now Ξ^-) well established
- New nomenclature for particles agreed upon:
H – hyperons, K – heavy mesons
 $V_1^0 \rightarrow \Lambda$; $V_2^0 \rightarrow \theta^0$
- The results presented by M. Schein et al. added to the confusion concerning the production of V_1^0 (now Λ)

M. Schein, D. Haskin, R. Glasser, F. Fainberg, K. Brown, On the artificial production of V^0 particles by 227 MeV pi-mesons generated in the Chicago cyclotron, *Proc. Bagnères de Bigorre*, p. 166

(Extension of the study reported in December 1952 at the Third Rochester Conference)



5 events observed, $\langle Q \rangle = 35 \pm 3$ MeV

Discussion (p. 287)

Fretter: Are the experiments of Schein consistent with the production of V_1^0 in pairs ?

Schein: It is possible; however we have no positive evidence

Search for Λ^0 production

Authors	Reaction	Energy (MeV)	Result
Cocconi & Silverman (1951)	$\gamma + \text{C}$	≤ 310	negative
Schein et al. (1952)	$\pi^- + \text{C}$	227	positive
Hildebrand & Leith (1953)	$\text{p} + \text{C}$	345	negative
Garwin (1953)	$\text{p} + \text{C}$	450	negative
Rosenfeld & Treiman (1953)	$\text{p} + \text{CH}_2$	430	negative
Schein et al. (1953)	$\pi^- + \text{C}$	227	positive
Bernardini & Segrè (1954)	$\gamma + \text{Al}$	≤ 330	negative
Balandin et al. (1955)	$\text{N} + \text{N}$	670	negative



In 1953 W. B. Fowler, R. P Shutt, A. M. Thorndike, and W. L. Whittemore observed the first V particles in experiments at the newly commissioned Cosmotron at Brookhaven.

W. B. Fowler et al., *Phys. Rev.* **90**, 1126 (1953)

(subm. 29.4.1953, publ. 15.6.1953)

“Two definite examples of V^0 particles similar to those found in cosmic rays by many workers have been observed in a cloud chamber exposed to a neutron beam from the Cosmotron...”

(in about 4000 photographs scanned)

W. B. Fowler et al., *Phys. Rev.* **93**, 861 (1954)

(subm. 10.11.1953, publ. 15.2.1954)

Six pairs of V particles observed in pion-proton collisions

“Further work is required to determine whether production is *always* double in these and nucleon-nucleon collisions.”

“There seems to be no reason to doubt that the particles observed are the same as those observed in cosmic rays, but there is not much in the way of positive proof of it.”

Thorndike, *Proceedings* Glasgow Conference (1954), p. 332

W. B. Fowler et al., *Phys. Rev.* **98**, 121 (1955)

(subm. 9.12.1954, publ. 1.4.1955)

Five additional events with pairs of V particles

”In each case the observations are most naturally interpreted as due to the associated production of a hyperon and K-meson... In most cases, however, our interpretation is to be considered as an hypothesis which fits the observations rather than a demonstrated fact.”

G. D. James and R. A. Salmeron, *Phil. Mag.* **46**, 571 (1955)

(subm. 21.2 1955, publ. June 1955)

“The statistical analysis of the frequency of associated V-events in our cloud chamber does not provide evidence for or against the hypothesis that Y- and K-particles are always produced together. We interpret those associated V-events that we observe as examples of ‘plural’ production in separate reactions inside the same nucleus.”



Curious particles

”Now let me return to the paper that I did sent off in August 1953... Isotopic Spin and the New Unstable Particles. That was not my title, which was: Isotopic Spin and Curious Particles. Physical Review rejected ”Curious Particles”. I tried ”Strange Particles” and they rejected that too. They insisted on: ”New Unstable Particles”. That was the only phrase sufficiently pompous for the editors of the Physical Review. I should say that I have always hated the Physical Review Letters and almost twenty years ago I decided never again to publish in that journal, but in 1953 I was scarcely in the position to show around.”

M. Gell-Mann, 1982

Isotopic Spin and New Unstable Particles

M. GELL-MANN

*Department of Physics and Institute for Nuclear Studies,
University of Chicago, Chicago, Illinois*

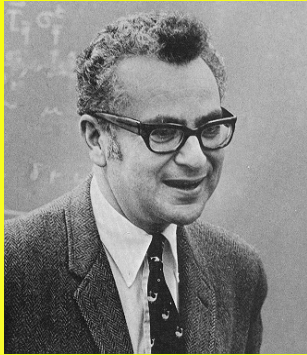
(Received August 21, 1953)

PEASLEE¹ has considered the interesting possibility that the principle of charge independence, now believed to hold for nucleons and pions, may extend to the new unstable particles as well. In order to discuss this suggestion, let us suppose that both “ordinary particles” (nucleons and pions) and “new unstable particles” (V_1 , V_4 , τ , etc.) have interactions of three kinds:

- (i) Interactions that rigorously conserve isotopic spin. (We assume these to be strong.)
- (ii) Electromagnetic interactions. (Let us include mass-difference effects in this category.)
- (iii) Other charge-dependent interactions, which we take to be very weak.

Peaslee inquires whether the quasi stability of the V_1^0 may be accounted for in this way if we assume it has isotopic spin $5/2$. With respect to (i) the decay into pion and nucleon is absolutely forbidden. Interactions of type (iii) are supposed to be weak enough to account for the long observed lifetime of $\sim 3 \times 10^{-10}$ second. However, he concludes that effects of type (ii) will cause transitions in a very much shorter time than this, since, for example, each electromagnetic interaction can change the isotopic spin of the system by one unit.

Recently Pais² has made the ingenious proposal that the new unstable particles differ from the ordinary ones in possessing one unit of “orbital isotopic angular momentum” and a negative “isotopic parity.” If we then re-interpret (i) as referring to conservation of total isotopic angular momentum and isotopic parity, we see that as far as (i) is concerned, the decay of new unstable particles into ordinary ones is forbidden. Also, these particles will always be produced in even numbers, as Pais had suggested earlier.³ Moreover, effects of type (ii) conserve isotopic parity, as Pais has introduced it, and so do not contribute to instability of



Murray Gell-Mann

”The interpretation of the new particles as displaced charge multiplets” – Gell-Mann’s paper at the 1955 Pisa Conference presented his scheme in a final form. New quantum number ‘strangeness’ officially introduced (but used in talks since September 1953)



Kazuhiko Nishijima

In Japan Nishijima proceeded along similar lines as Gell-Mann and also presented his results in the years 1953-1955; but his papers published in Japanese *Progress in Theoretical Physics* had less impact than Gell-Mann’s



Gell-Mann

”Strange particles...were not considered respectable, especially among the theorists. I am told... that when he wrote his excellent paper on the decay of the tau particle into three pions Dalitz was warned that it might adversely affect his career, because he would be known as the sort of person who worked on that kind of things.”

“Pion physics was indeed the central topic for theoretical physics in the mid 1950s, and that was what the young theoretician was expected to work on. The strange particles were considered generally to be an obscure and uncertain area of phenomena, as some kind of dirt effect which could not have much role to play in the nuclear forces, whose comprehension was considered to be the purpose of our research.”



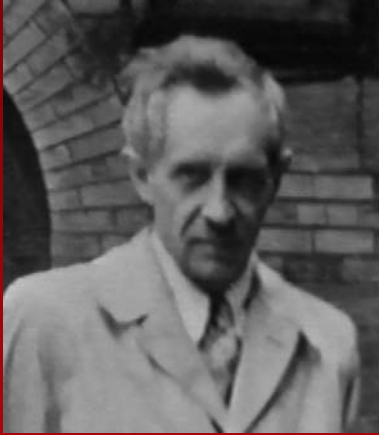
Dalitz

The discoverers

Marian Danysz



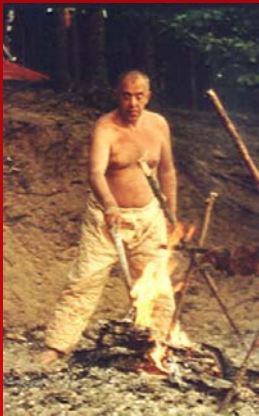
- born 1909 in Paris
- son of Polish-French physicist Jan (Jean) Kazimierz Danysz, who constructed the first β -spectrometer (1911)
- studied electrical engineering at Warsaw Polytechnic
- while still a student, worked in Warsaw Radiological Laboratory and co-discovered (1934) radioactive isotope of fluorine, published 3 papers
- 1937-39 worked as an electrical engineer
- 1950-1952 in Liverpool and Bristol, mastered nuclear emulsion technique in Powell's laboratory
- 1951 with Owen Lock and Gideon Yekutieli claimed discovery of a new particle (ζ^0)



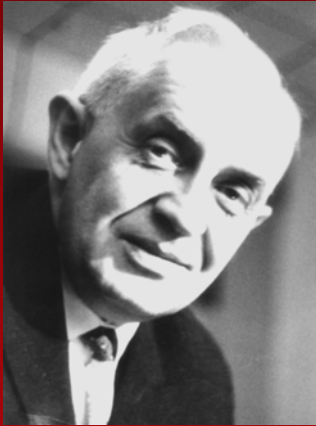
Jerzy Pniewski

- **born 1913 in Płock, son of a high-school teacher**
- **studied mathematics, and later physics, at Warsaw University**
- **started career in molecular optics; two papers (1938)**
- **1948-1950 in Liverpool to study β -spectroscopy**
- **1951 Ph.D. in nuclear spectroscopy**
- **persuaded by Danysz to join him (1952) in cosmic ray studies using nuclear emulsions**

Marian Danysz



- little formal physics background
- fantastic intuition
- unusual imagination
- hated administration, formalities and lecturing
- loved fast driving and hunting
- chain-smoker of cigars, cigarettes and pipe
- loved good food



Jerzy Pniewski



- **solid background in physics and mathematics**
- **well organized and systematic**
- **good lecturer**
- **competent and efficient administrator**
- **loved to entertain friends with magic tricks and puzzles**
- **never smoked but loved good cognac**



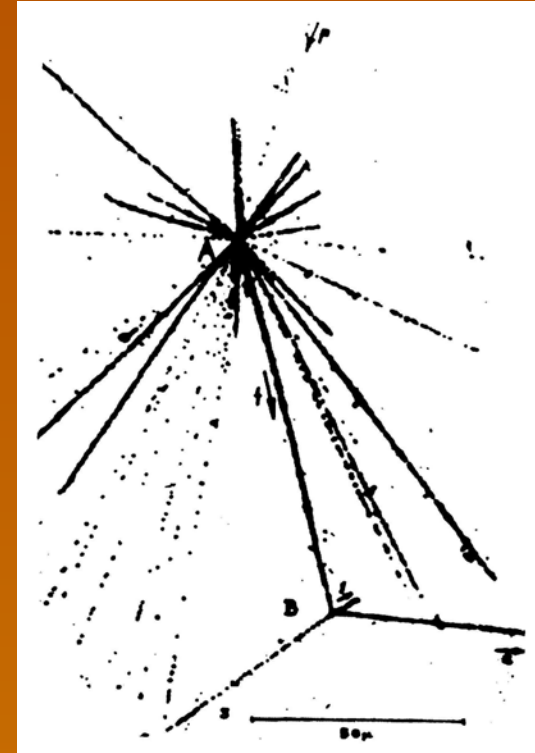
The discovery

The discovery



”Late in the evening of September 19 we began to analyse the recorded events one by one. Suddenly Marian exclaimed ‘Look, what

a strange animal’ and showed me two stars connected by a prominent and quite thick track. It was obvious that one of the stars was due to a disintegration of a heavy emulsion nucleus, silver or bromine, by a high energy cosmic radiation proton. The nucleus was split into small fragments and only one of them, distinct by its quite long track, seemed to have mass considerably larger than the others. Its track ended with a four prong star which indicated its spontaneous decay...”



Jerzy Pniewski, Autobiographical reminiscences

...We sent letters to...

W. C. Heisenberg,



C. F. Powell,



and D. Skobeltzyn...



J. Pniewski, Autobiographical reminiscences



Danysz to Powell on October 26, 1952

Dear Professor Powell,

It is more than four months as I am back in Warsaw...

From September the work has begun, and I hope we have

some prospects for the future. I have easily found people who are interested in emulsion work, three scanners are active since the end of September, problem of microscopes seems to find a satisfactory solution. At present the only base of our work are Bristol plates, they will be good as material for starting work, for teaching people the technique and may serve for some research – unfortunately, they are rather distorted...

With this letter I enclose a short note concerning a star of a rather exceptional character. We have worked on it with my friend J. Pniewski who will – I hope – continue to work with me in plate technique. If you find the whole problem not unreasonable we might send later a fuller account to Phil.Mag.

We would be very grateful for all suggestion and criticisms.

Yours most sincerely

M. Danysz

K. Gottstein to Danysz

Göttingen, 10th November, 1952.

Dear Danysz,

Thank you very much for your letter of October 26th and the preprint of your paper which, I think, is very interesting. Prof. Heisenberg has also read it with great interest. He agrees that the event cannot be explained as the delayed disintegration of an excited nucleus since the time 10^{-11} sec is much too long. On the other hand, the probability for the event being a "delayed σ -star" is extremely small, too. The binding energy of a π^- -meson in the K-shell is of the order of 1 MeV whereas the average energies of the mesons ejected in the disintegration at A are apparently much greater. So it is unlikely that a π^- -meson would have been captured by the fragment. But even if it had been captured, it would have to be expected to interact with the nucleus within a time much shorter than 10^{-11} sec.

K. Gottstein to Danysz (cont.)

Your suggestion that the event might be explained in connection with the V_1^0 or a similar particle seems to be very reasonable, however. The V_1^0 particles appear to be different from the nuclear force mesons in that they may be created and annihilated only in conjunction with their anti-particles. In your event the V_1^0 may have been separated from its anti-particle, which flew off in a different direction, and was left within the fragment where it decayed after its life-time had elapsed.

I wonder what the future will teach us about all these funny particles.

With best wishes,

Yours sincerely,

K. Gottstein



Powell to Danysz, November 19, 1952

Dear Danysz,

Thank you very much for your letter of the 26th October. The event is certainly most striking, but I feel that you would be well advised not to publish it at this stage. In spite of the most remarkable precision with which the heavy particle ends its range at the point of origin of the second star, you still have to meet the objection that you are dealing with a chance juxtaposition of unrelated events. Because of this, I think that it would be best, either to wait until a second example of the same phenomenon is found, or, to publish a photograph of it with a minimum of descriptive material. There seems to be no point, for example, in giving a detailed description of the big star from which the heavy particle was emitted....



UNIVERSITY OF BRISTOL

C. F. POWELL, M.A., F.R.S.
Melville Wills Professor of Physics.
Tel. No. Bristol 24161 Ext. 110.
Night Service 25027.

H. H. WILLS PHYSICAL LABORATORY,
ROYAL FORT,
BRISTOL 8.

November 19th, 1952.

Dear Danysz,

Thank you very much for your letter of the 26th October. The event is certainly most striking, but I feel that you would be well advised not to publish it at this stage. In spite of the most remarkable precision with which the heavy particle ends its range at the point of origin of the second star, you still have to meet the objection that you are dealing with a chance juxtaposition of unrelated events. Because of this, I think it would be best, either to wait until a second example of the same phenomenon is found, or, to publish a photograph of it with a minimum of descriptive material. There seems to be no point, for example, in giving a detailed description of the big star from which the heavy particle was emitted.

We are still working on the heavy mesons and several important questions are not yet solved. Perkins has shown that heavy mesons of mass about $1,200 \pm 200 m_e$ are emitted from stars produced by protons with an energy as low as 5 BeV, and possibly considerably lower. These heavy mesons absorb as much, or nearly as much, of the available energy as do the π -mesons. It is not yet decided whether they are kappas or chi's.

Menon and O'Ceallaigh now have 17 examples of kappa or chi-mesons at the end of their range. The recent measurements of the masses of chi's have been giving values between 900 and 1,000 m_e , and we wonder

The rise of hypernuclear physics

The second event

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF PHYSICS
IMPERIAL INSTITUTE ROAD
Telephone - - KENSINGTON 4861
PROF. SIR GEORGE F. THOMPSON, M.Sc., F.R.S.

ROYAL COLLEGE OF SCIENCE
SOUTH KENSINGTON
LONDON - - S.W.7

19 November 1952.

Dr. M. Danysz,
Hoza 69,
WARSAW. POLAND.

Dear Danysz,

We have recently observed the following event. A star of 19 heavy tracks and 1 shower particle emits a heavy fragment of charge about 12 units. This particle comes to rest in the emulsion as shown by its taper down. At the point where it comes to rest there is a small 3-prong star. I enclose a rough sketch of the event. Menon tells me that you have recently observed a very similar event and mentioned the possible explanation in terms of trapped π -mesons.

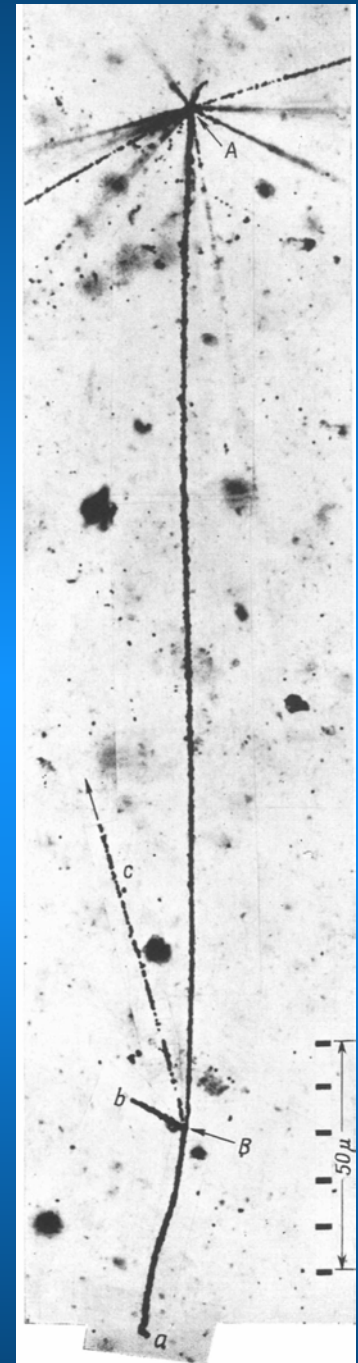
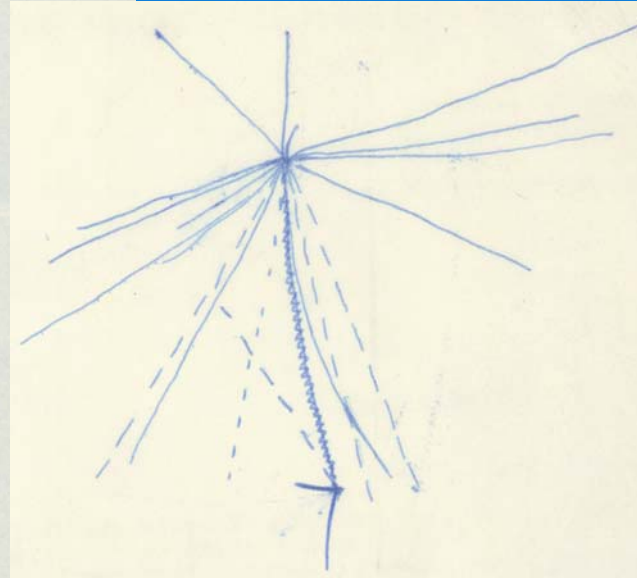
He suggested that we might publish a short note on this jointly. I would be glad to do this, if you think it is a good idea, two events being better than one. I would imagine a note or a letter in Phil. Mag. would be the thing. Would you let me know what you think. In any case, I would be glad to receive further details of your event.

With best wishes,

Yours sincerely,



E.P. George.



Two papers or one?



Danysz to E. P. George (28 November 1952)

Dear George,

Thank you for your letter of the 19th November and the news concerning your case of a delayed disintegration of a heavy fragment. Obviously two events of such a kind are much better than one, and I quite agree that it is a good idea to publish this jointly in a note or letter in Phil. Mag...

Not to lose time we suggest that you would write a rough draft of the letter or note in question and send us a copy before publication as we may have some suggestions or remarks to make...

Two papers or one?



Danysz to A. J. Herz (9 February 1953)

Dear Herz,

...After receiving a letter from Menon, concerning Powell's proposition, we have sent the material related to our case to Bristol, and left all the decision concerning the publication to Powell. So I hope all is O.K.

Of course we are pleased to have another note in the same issue of the Phil. Mag. supporting our observation...

The first event published

BULLETIN DE L'ACADÉMIE
POLONAISE DES SCIENCES
Cl. III — Vol I, Nos 1—2, 1953

EXPERIMENTAL PHYSICS

Delayed Disintegration of a Heavy Fragment Emitted in Nuclear Explosion

by

M. DANYSZ and J. PNIEWSKI

Communicated by A. SOLTAN at the meeting of October 20, 1952

Introduction. A remarkable coincidence of two events recorded in a photographic emulsion was recently observed in this laboratory. It occurred in a G5 plate, 600 μ thick, which had been exposed at high altitude (85,000 feet)* to cosmic radiation, and concerns two stars marked *A* and *B* (Fig. 1). The centre of the star *B* coincides with the end of the track of a heavy fragment *f*, ejected from star *A*. If this coincidence is not accidental, it must be considered as an example of delayed disintegration of a heavy fragment. The probability of such a coincidence being very small, we thought it might be of interest to analyse the case more closely. It is clear, of course, that any conclusions drawn from a single observation should be treated with due caution.

Analysis. The disintegration referred to as star *A* represents the effect of a high energy interaction, presumably between a singly charged particle and a bromine or silver nucleus. The disintegration referred to as star *B* seems to be a case of delayed decay of a heavy fragment ejected from the star *A*.

Following the nomenclature of Brown *et al.* [1], star *A* may be described as a star of type 21+18*p*. The track *p* (see Fig. 1) — the only minimum track in the upper hemisphere, the direction of which coincides approximately with the direction of the »centre of gravity« of the emitted shower particles — apparently represents the incident particle, the primary of the disintegration *A*. Scattering measurements do not allow direct energy evaluation (length about 2 mm) but are not inconsistent with this assumption. Using statistical data, Camerini *et al.* [2], Daniel *et al.* [3] we estimate the energy of the primary to be about 30 Mev. Energy measurements on longer tracks of shower particles are also in agreement with this assumption.

From the analysis of the black and grey tracks of star *A* we could identify nine α -particles, one heavy fragment and eleven singly charged

* We are indebted to Professor C. F. Powell for the opportunity of exposing the plates in a balloon flight and processing them in the H. H. Wills Laboratory at Bristol.

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Correspondence

*Delayed Disintegration of a Heavy Nuclear Fragment: I**

By M. DANYSZ and J. PNIEWSKI

Institute of Experimental Physics, University of Warsaw †

[Received December 1, 1952]

A REMARKABLE coincidence of two events recorded in a photographic emulsion has recently been observed in this laboratory. It occurred in a G5 emulsion, 600 μ thick, which had been exposed to cosmic radiation at an altitude of 85 000 feet, ‡ and consists of two stars marked *A* and *B* in the photo-micrograph reproduced in Plate 13. The centre of the star *B* coincides with the end of the track of a heavy fragment ejected from the star *A*. If this coincidence is not accidental, it must be considered as an example of the delayed disintegration of a heavy fragment. The probability of a fortuitous coincidence is very small, and it therefore seemed appropriate to analyse the events more closely. It is clear, of course, that any novel conclusions drawn from a single observation should be treated with proper reserve.

The disintegration referred to as star *A* represents the result of a high-energy interaction, presumably between a singly-charged particle and a silver or bromine nucleus. In the nomenclature of Brown *et al.* (1949), the star *A* may be described as of type 21+18*p*. The track *p*—see Plate 13—is the only track in the upper hemisphere with minimum grain density, of which the direction coincides approximately with the 'axis' of the cone of the emitted shower particles. It therefore probably represents the incident particle which produced the disintegration *A*. Scattering measurements do not allow an accurate evaluation of its energy, but they are not inconsistent with the above assumption. Using statistical data of Camerini *et al.* (1951), and of Daniel *et al.* (1952), we estimate the energy of the primary particle to be about 30 bev. Energy measurements on some of the longer tracks produced by the shower particles are also in agreement with this estimate.

From the analysis of the 'black' and 'grey' tracks of star *A*, we could identify nine α -particles, one heavy fragment and eleven singly-charged particles. As no slow mesons were detected, the latter were probably due to protons, deuterons or tritons. The comparison of the shape of the track 'f' with those of other multiply-charged particles stopping in the emulsion allows a rough estimate of the charge of fragment *f*; the most probable value is about 5.

The initial kinetic energy of the fragment 'f', estimated from its range (90 μ) and charge (Perkins 1950), is of the order of 60 mev. The fragment appears to stop in the emulsion exactly in the centre of star *B*.

* A preliminary report of this observation was given by Professor A. Soltan at the meeting of the Polish Academy of Science held on 20th October 1952.

† Communicated by Professor C. F. Powell, F.R.S.

‡ We are indebted to Professor C. F. Powell for the opportunity of exposing the plates in a balloon flight and processing them at Bristol.

The second event

Delayed Disintegration of a Heavy Nuclear Fragment: II

By D. A. TIDMAN, G. DAVIS, A. J. HERZ and R. M. TENNENT
Imperial College, London, S.W.7*

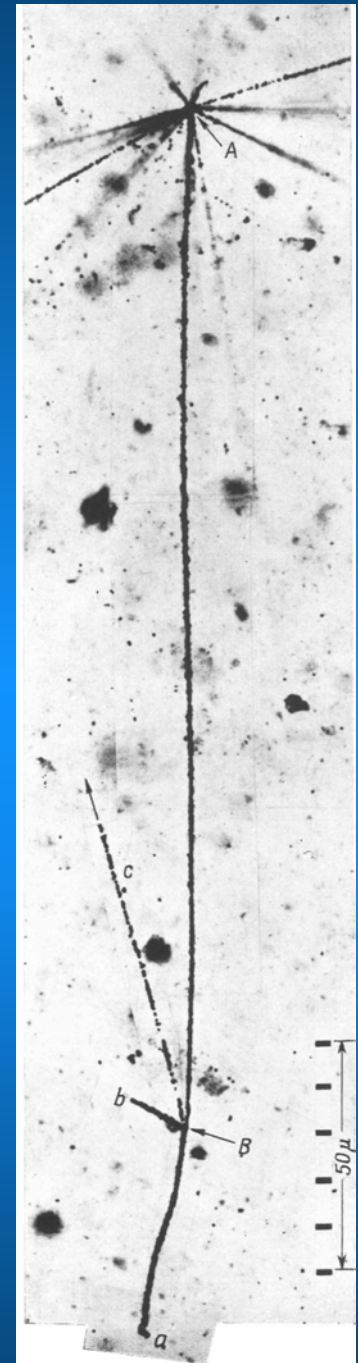
[Received December 15, 1952]

SOON after Dr. Menon of Bristol University had informed us about the event found by Danysz and Pniewski (see the preceding note), a similar observation was made in this laboratory. Photo-micrographs of the event are shown in Plate 14.

The event occurred in a G5 emulsion, $400\ \mu$ thick, exposed in a balloon flight at geomagnetic latitude 40°N . The balloon floated for eight hours at about 96 000 feet. The parent disintegration (star A) is of type $16+0p$, excluding the heavy fragment f. The track of the

* Communicated by Dr. E. P. George.

Phil. Mag. 44, 350 (March 1953)



The third event

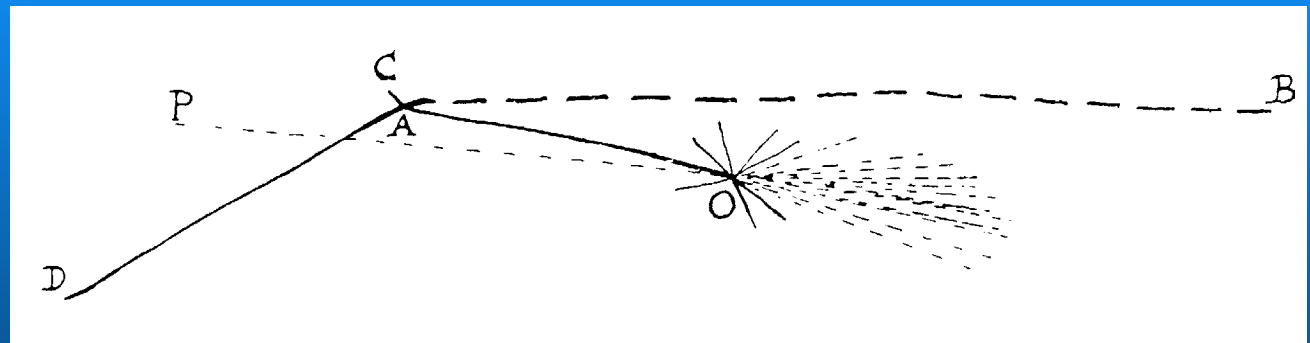
PHYSIQUE NUCLÉAIRE. — Émission probable d'un fragment nucléaire contenant une particule V^0 . Note de MM. JEAN CRUSSARD et DANIEL MORELLET, présentée par M. Louis Leprince-Ringuet.

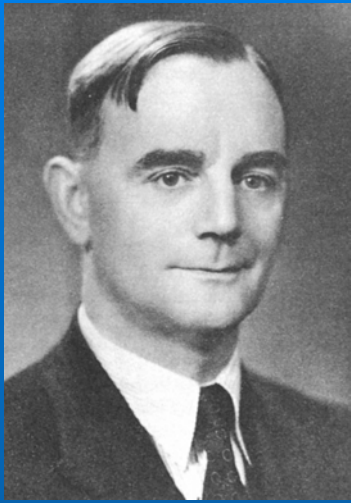
Le phénomène décrit ci-après a été observé dans une plaque photographique Ilford G₅ de 600 μ d'épaisseur, qui a été exposée au rayonnement cosmique en haute altitude sous 3 cm de cuivre, au moyen de ballons-sondes.

Il se trouve dans une grande étoile de 60 branches, dont environ 30 au minimum d'ionisation, produite par une particule de $Z = 1$ très énergétique. Le schéma ci-contre montre son aspect.

O est le centre de l'étoile, PO la particule incidente. La particule OA, qui paraît lente, produit une petite étoile secondaire ABCD.

Trace OA (longueur : 68 μ). — L'aspect et la mesure photométrique (1) sont compatibles avec une particule α en fin de parcours, ou également un noyau de lithium. Un proton est possible à la rigueur, mais beaucoup moins





Powell remained sceptical much longer

“Further examples have now been observed of the process, first observed by Danysz, in which a heavy nuclear fragment ejected from a nuclear explosion reaches the end of its range and disintegrates. It appears that π -mesons are frequently emitted as one of the products of the secondary disintegration. It is possible that these events are due to the presence, in the nuclear fragment, of a nucleon in an excited state; but alternative explanations cannot at present be excluded.”

Nature, September 12, 1953, p.477

”The original discovery suggesting that Λ^0 hyperons can exist not only as free particles but also bound within nuclei was due to Danysz and Pniewski... An excited hydrogen atom, to use the simplest example, consists of a proton and an electron in a state of higher energy than in the normal atom. The analogy might then suggest that the excited nucleon consists of a proton and an associated π^- - that the Λ^0 is a composite particle. Such a view could not have been finally excluded while our knowledge was confined to the decay of the free Λ^0 particle...

These considerations suggest that the Λ^0 particle is an excited nucleon in a different sense from that suggested by familiar analogies. We are entering a new field where basically new concepts remain to be established.”

C. F. Powell, Excited nucleons, *Nature* 173, 469 (14 March 1954)

„The hypothesis was made that the nuclear fragment contained a bound Λ^0 in a nucleus like an ordinary nucleon... It is an essential fact in the chain of reasoning which makes of hyperons just a new species of baryons, and hence leads to SU_3 , quarks etc.”

Ch. Peyrou (International Colloquium on the History of Particle Physics, Paris 1982)

Topics in the study of hypernuclei

Frequency of production

Mesonic and nonmesonic decays

Range distribution (GOK's)

Charge distribution

Heavy hyperfragments

Cryptofragments

Binding energy B_{Λ}

Lifetime

Spin

Λ -N interaction

Proposed names:

excited nuclear fragment

meson active fragment

unstable fragment

delayed disintegration of a nuclear fragment

V-nucleus

Λ -fragment

Λ -nucleus

Following a suggestion of M. Goldhaber, in February 1955 W. F. Fry, M. Schneps, and M. S. Swami first used the name "hyperfragment" and proposed the use of symbols such as ${}_{\Lambda}X^{\Lambda}$ (e.g. ${}_{\Lambda}\text{Be}^9$, ${}_{\Lambda}\text{He}^4$, ${}_{\Lambda}\text{Li}^8$). The symbols were later changed to ${}^{\Lambda}X_{\Lambda}$ and then to ${}_{\Lambda}^{\Lambda}X$

Binding energy of Λ in hypernuclei

$$B_{\Lambda} = (m_{\Lambda} + M_{\text{core}})c^2 - \sum m_f c^2 + Q$$

$$m_{\Lambda}c^2 = (m_p + m_{\pi^-})c^2 + Q_{\Lambda}$$

$$B_{\Lambda} = Q_{\Lambda} - Q + (M_{\text{core}} + m_p + m_{\pi^-} - \sum m_f)c^2$$

Padova Conference, April 1954

Summary of 17 known events by M. Grilli and R. Levi Setti

“In none of the cases the total energy release in the disintegration of the fragments is inconsistent with the hypothesis first suggested by M. Danysz and J. Pniewski, that a neutron in the fragment is simply replaced by a Λ^0 .”

Varenna July 1954

Summary of 28 known events by Levi Setti

“A first classification of these fragments into two classes: those which undergo mesonic and non-mesonic decay”

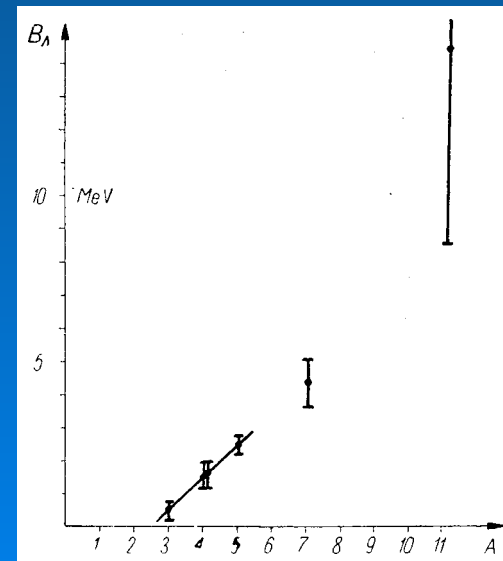
(8 mesonic, 14 non-mesonic, 6 doubtful)

„The fact that the binding energy of the Λ^0 in tritium and helium nuclei is definitely lower than that of the neutron would suggest that the interaction mechanism between the Λ^0 and nucleons is probably different from that of nuclear forces between nucleons, since, if the forces acting between the Λ^0 and nucleons are supposed to be ordinary nuclear forces, one should expect the binding energy of the Λ^0 in a nucleus to be greater than that of a neutron, due to the greater mass of the Λ^0 and the non-operation of the Pauli exclusion principle between the Λ^0 and the neutron.”

Cosmic Ray Conference, Budapest, September 1956

The first systematic review of hyperfragments
by A. Filipkowski, J. Gierula and P. Zielinski
A re-analysis of about 120 reported events and
careful selection left a "pure sample" of 72
hyperfragments

The binding energy B_{Λ}
in hypernuclei found
to increase linearly with A

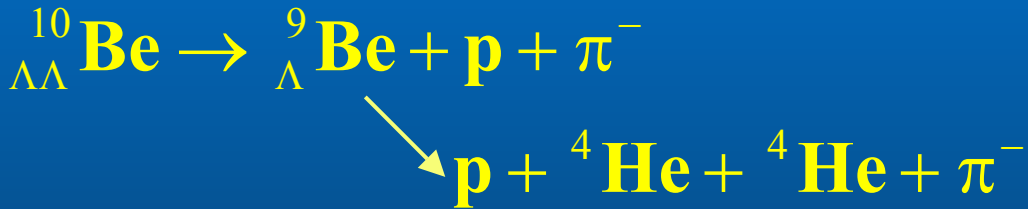


Frequency of hyperfragments

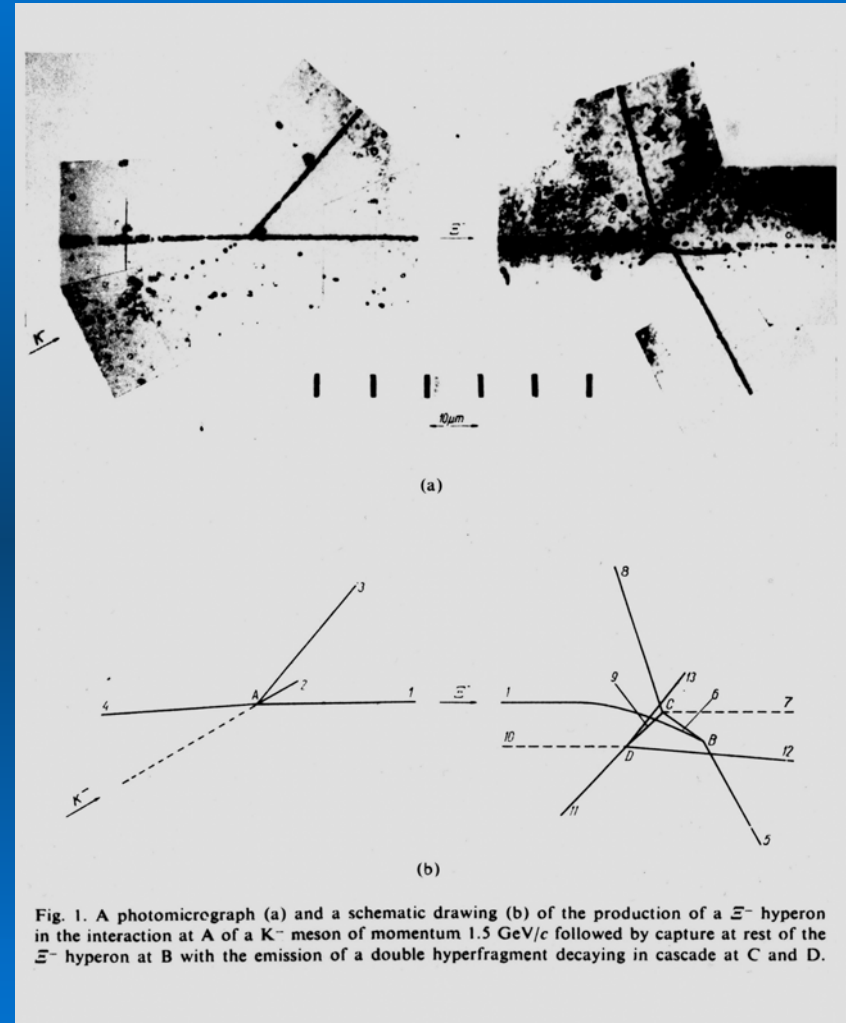
Experiment	Hyperfragments/stars
Cosmic rays	$61/119,000 = 5.1 \times 10^{-4}$
3 GeV π^-	$72/80,000 = 9 \times 10^{-4}$
3 GeV p	$33/34,480 = 9.1 \times 10^{-4}$
6 GeV p	$7/10,000 = 7 \times 10^{-4}$
K^- stars	$46/1001 = 4.6 \times 10^{-2}$

From W. F. Fry (1958)

Double hyperfragment



Event found in Warsaw during
the work of the
Warsaw-Bristol-Bruxelles-
CERN-Dublin (IAS and UC)-
London (UC and WC)
Collaboration



M. Danysz et al. *Phys. Rev. Lett.* **11**, 29 (1963)

Hypernuclear physics came of age

Saint-Cergue, 28-30 March, 1963

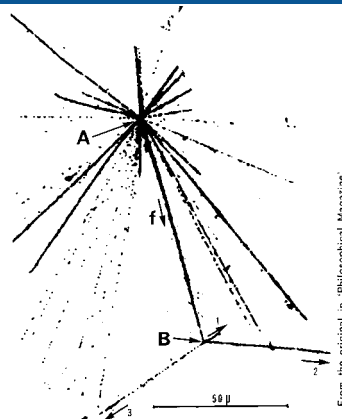
International Conference on Hyperfragments

by E.H.S. BURHOP and W.O. LOCK

Background to the Conference

In the early fifties, soon after the discovery of the so-called 'strange particles', two Polish physicists, M. Danysz and J. Pniewski, observed that nuclei could be formed in which a lambda hyperon was trapped. These 'hypernuclei' were unstable and, of course, broke up when the trapped hyperon decayed into a pi meson and a nucleon after a time of the order 10^{-10} second. Such hypernuclei may be produced as a result of the break-up of a nucleus after an interaction, and their life-time is still long enough to enable them to produce a track of length from a few microns (thousandths of a millimetre) up to several millimetres in a nuclear photographic emulsion. Because they are usually produced as a result of the breaking up or 'fragmentation' of a larger nucleus, hypernuclei produced in this way are commonly referred to as 'hyperfragments'.

The fact that hyperfragments can be formed at all shows that the interaction between a lambda hyperon and a nucleus must be one of attraction, at least under some conditions. From an estimate of the binding energy of the hyperon (that is, the amount of energy needed just to remove the lambda hyperon from the rest of the nucleus), some information about the force between the lambda and a nucleon can be obtained. This is very important information for elementary-particle physics and very hard to obtain in other ways. For example, the most direct way of obtaining such data is to study the scattering of lambda hyperons by nucleons. These studies are very difficult, however, because of the short life of the hyperon, which means



The first hyperfragment, discovered by Danysz and Pniewski in 1952. A cosmic-ray particle (ρ) causes a nuclear disintegration at A; one of the particles (f) emitted in the 'star' comes to rest at B and disintegrates with the emission of three charged particles. This particle (f) is the hyperfragment. Recent exposures of emulsions to beams of 1.5-GeV/c negative kaons at CERN have already produced several possible examples of 'stars' in which two hyperfragments are produced.

that there is usually a path length of only a few millimetres before the decay, and an enormous number of hyperons need to be studied in order to obtain just a few examples of scattering.

On the other hand, many hundreds of examples of hyperfragments have now been identified and their binding energies measured. This is possible if all the products resulting from the break-up of the hyperfragment are charged, so that their individual kinetic energies can be measured. From the sum of these, the energy available from the break-up of the hypernucleus is obtained, and this is equal to the energy released in the decay of the trapped hyperon (the Q-value, known quite accurately as 37.57 MeV) less the binding energy of the hyperon in the hypernucleus. In practice, accurate values of the binding energy can be estimated only if the pi meson resulting from the lambda decay escapes from the fragment (mesonic decay). In many cases the pi meson is absorbed before leaving the fragment (non-mesonic decay).

A whole new branch of nuclear physics is in process of being built up around the properties of hypernuclei. A start has been made in the determination of the spins and isospins of their ground states, and methods are being considered for the study of their excited states.

In these circumstances it seemed timely to organize a conference to review the present state of knowledge in this field. Further, since most hyperfragments have short ranges, the technique that is best suited to study them is usually that of nuclear emulsions. It was therefore very appropriate that the conference should have been organized on behalf of the CERN Emulsion Experiments Committee. Other techniques are beginning to show their value in the field, however, and some

68 participants from
14 countries

17 talks published in
the Proceedings

From time to time in CERN COURIER, reference has been made to 'hypernuclei' and 'hyperfragments' and, although some kind of explanation was usually appended, many readers no doubt remained with only a vague idea of their real significance. In the present article, the authors have first described in general terms the nature and properties of these special kinds of nuclei, and then reviewed the major topics discussed at the recent international conference on this subject.

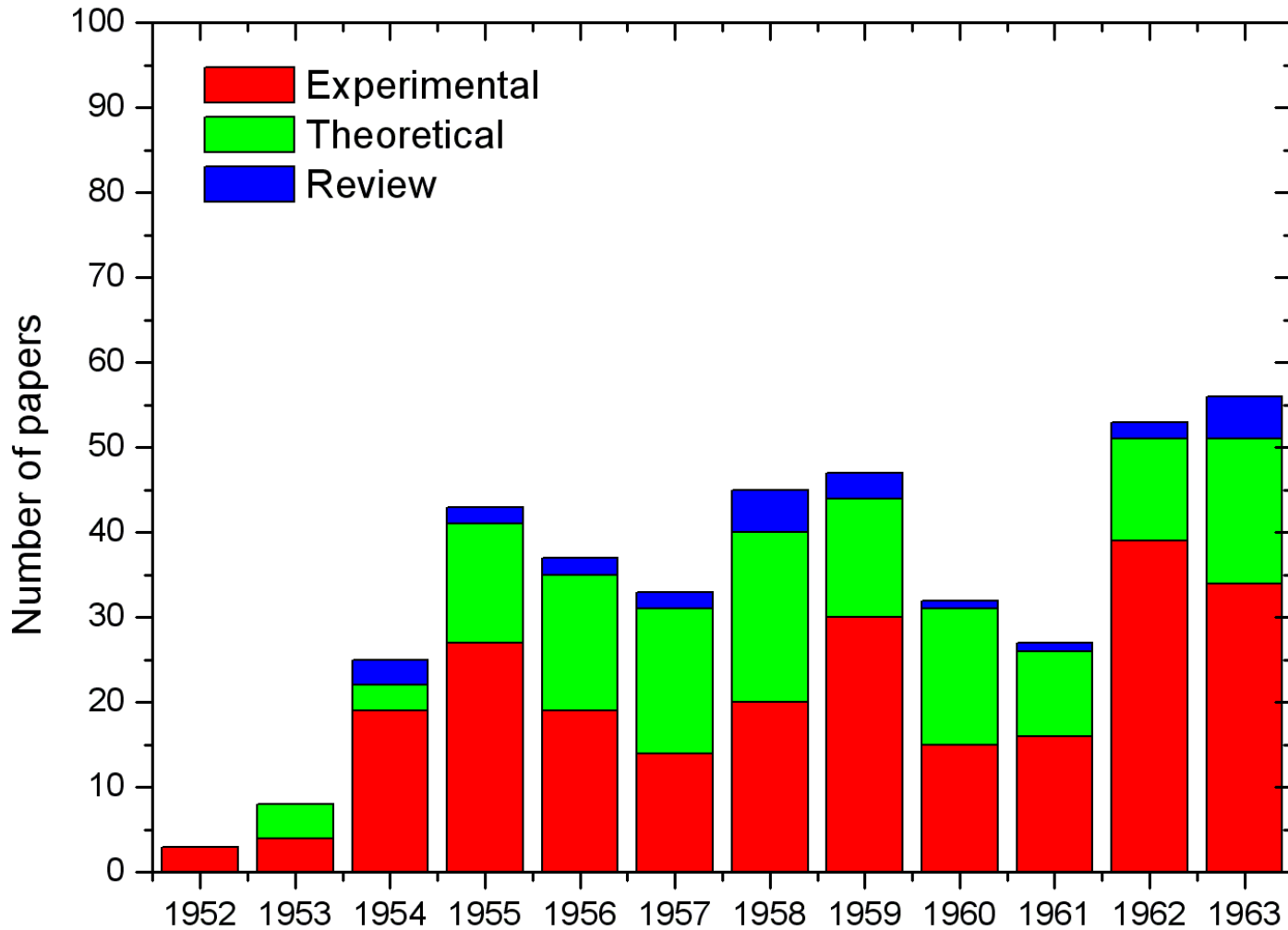
Prof. E.H.S. Burhop, of University College, London University, has been particularly interested in this field for some time, and for the last two years has been responsible for the 'European K⁻ Collaboration' which co-ordinates the efforts of eight different laboratories for the analysis of nuclear emulsions exposed at the CERN proton synchrotron to beams of K⁻ mesons. He is at present at CERN for a year, as a CERN Visiting Scientist, concerned chiefly with the study group on new accelerators. W.O. Lock has worked with nuclear emulsions for many years, and is joint Leader of the Nuclear Emulsion Group in the Nuclear Physics Division at CERN. He is also at present secretary of the Nuclear Physics Research Committee.

Some statistics

1952 - 1963

- * Database of papers on hypernuclear physics has been compiled using *Physics Abstracts* and some *Proceedings* of important conferences**
- * 409 papers in the years 1952 – 1963 (using submission dates)**
- * 504 authors from 23 countries**
- * Papers on related subjects (e.g. the Q_Λ value, the Λ -N force) listed in another database.**

Papers on hypernuclear physics



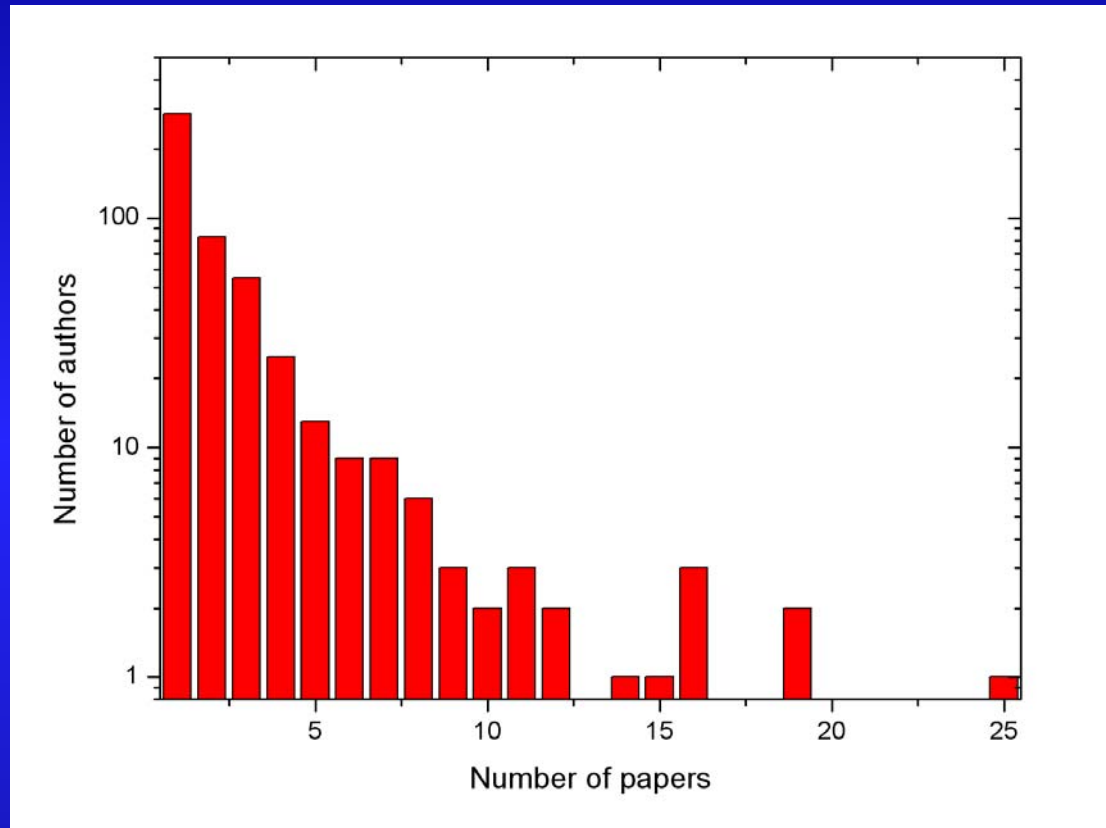
Statistics of papers and authors

	Papers	Authors
USA	153	166
UK	55	74
ITALY	47	83
USSR	39	52
POLAND	31	15
FRANCE	19	19
BELGIUM	17	8
INDIA	14	16
GERMANY*	13	28
JAPAN	11	18
SWITZERLAND	10	15
NORWAY	8	7
IRELAND	7	13

* including the DDR

Also 19 papers by 30 authors from Australia, Austria, Canada, Czechoslovakia, Denmark, Israel, Netherlands, Pakistan, Sweden, and Yugoslavia

Distribution of papers among the authors



369 authors (73.2%) published only 1 or 2 papers

Number of authors with 3 or more papers

	USA	41
	UK	23
	ITALY	22
	POLAND	12
	USSR	11
	BELGIUM	5
	FRANCE	5
	IRELAND	5
	SWITZERLAND	4
	NORWAY	3
	INDIA	2
	GERMANY	1
	JAPAN	1

353 papers published in journals

<i>Il Nuovo Cimento (and its Suppl.)</i>	146	(41.4%)
<i>Physical Review</i>	64	
<i>Zhurnal Eksp. Teor. Fiziki</i>	29	
<i>Physics Letters</i>	21	
<i>Nuclear Physics</i>	17	
<i>Physical Review Letters</i>	14	
<i>Comptes Rendus Acad. (Paris)</i>	9	
<i>Progress in Theoretical Physics</i>	8	
<i>Philosophical Magazine</i>	7	
other 22 journals	38	

Most prolific authors

25 R. Levi-Setti



19 R. H. Dalitz



19 D. H. Davis

16 R. G. Ammar, W. F. Fry, J. Zakrzewski

15 O. Skjeggstad

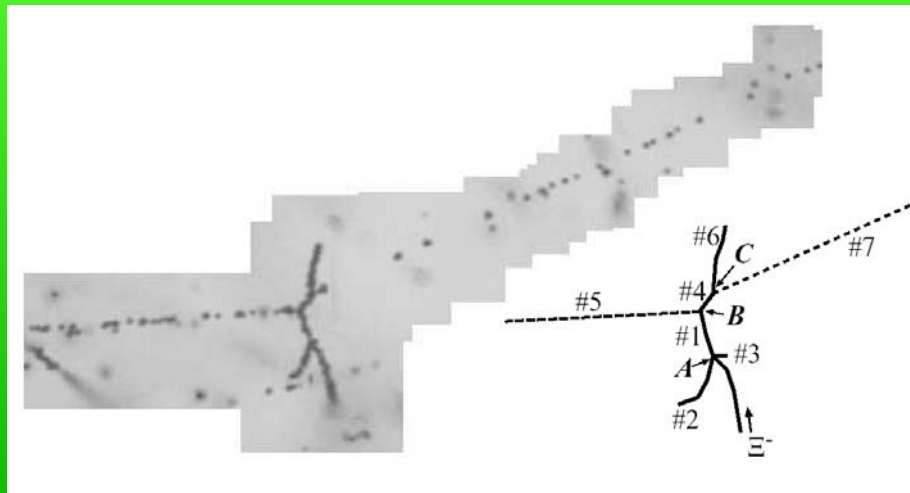
14 J. Sacton

The renaissance of hypernuclear physics

Renaissance for hypernuclear physics

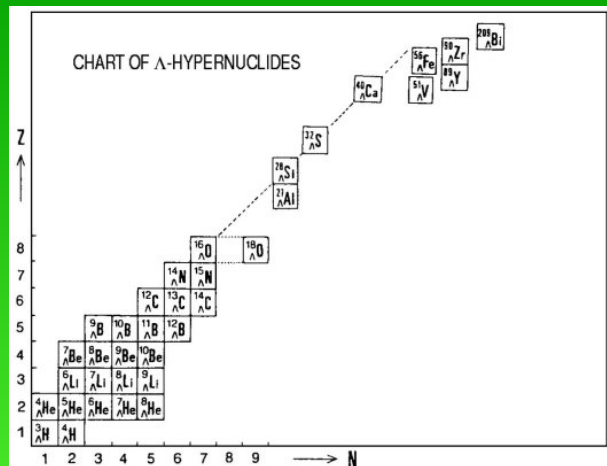


Hypernuclear physics program in Jülich in Germany (COSY), Newport News in USA (TJNAF), BNL in USA, Dubna in Russia (Nuclotron), KEK in Japan, Frascati in Italy (FINUDA at DAΦNE)



**New double
hyperfragments
observed in
experiments at KEK**

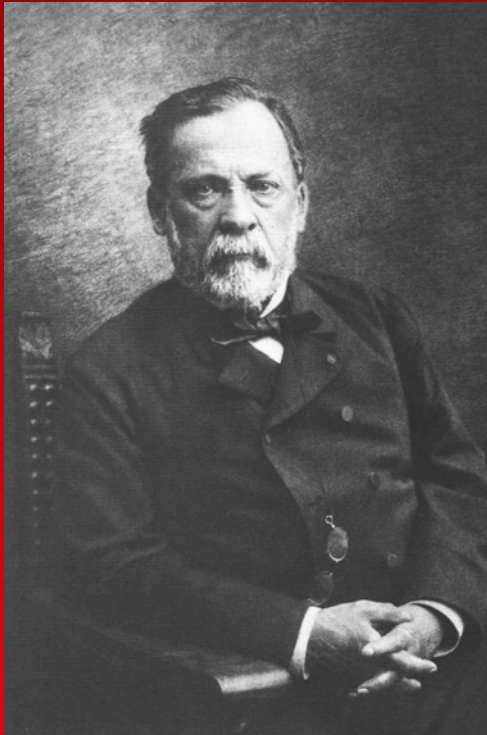
(From H. Takahashi et al.)



FINUDA at DAΦNE

**From Aldo Zenoni & Paola Gianotti,
Europhysics News, 33, 5 (2002)**

**Concluding
remarks**



Louis Pasteur

**”In the field of
observation, chance
only favours those
minds which
have been prepared”**

“I am reminded of a famous remark of Napoleon. Whenever he was presented with a young man for military advancement, he invariably asked the question: ‘Is he lucky?’ This was by no means a casual inquiry. The important quality for which he was seeking was – does this man put himself in a situation where he can be lucky? If you fail to put yourself in a situation where it is possible to have good fortune then you cannot have any success; if you do, you may.”

Powell in after-dinner talk at St. Cergue

Lucky and well prepared

- **The first hyperfragment found just after the start of scanning of new emulsion plates in a new laboratory of little experience – incredible piece of luck or a miracle**
- **The first (and only) double hyperfragment again found in Warsaw (one of the eight collaborating labs) – incredible piece of luck or another miracle**

Danysz and Pniewski were lucky and well prepared (later they first discussed hypernuclear isomerism and Pniewski initiated hypernuclear spectroscopy)

Two lucky physicists

