The Discovery of the Antiproton between Rome and Berkeley

Gianni Battimelli

Sapienza University, Roma

The Rise of Particle Physics

Rome, September 23-24, 2024

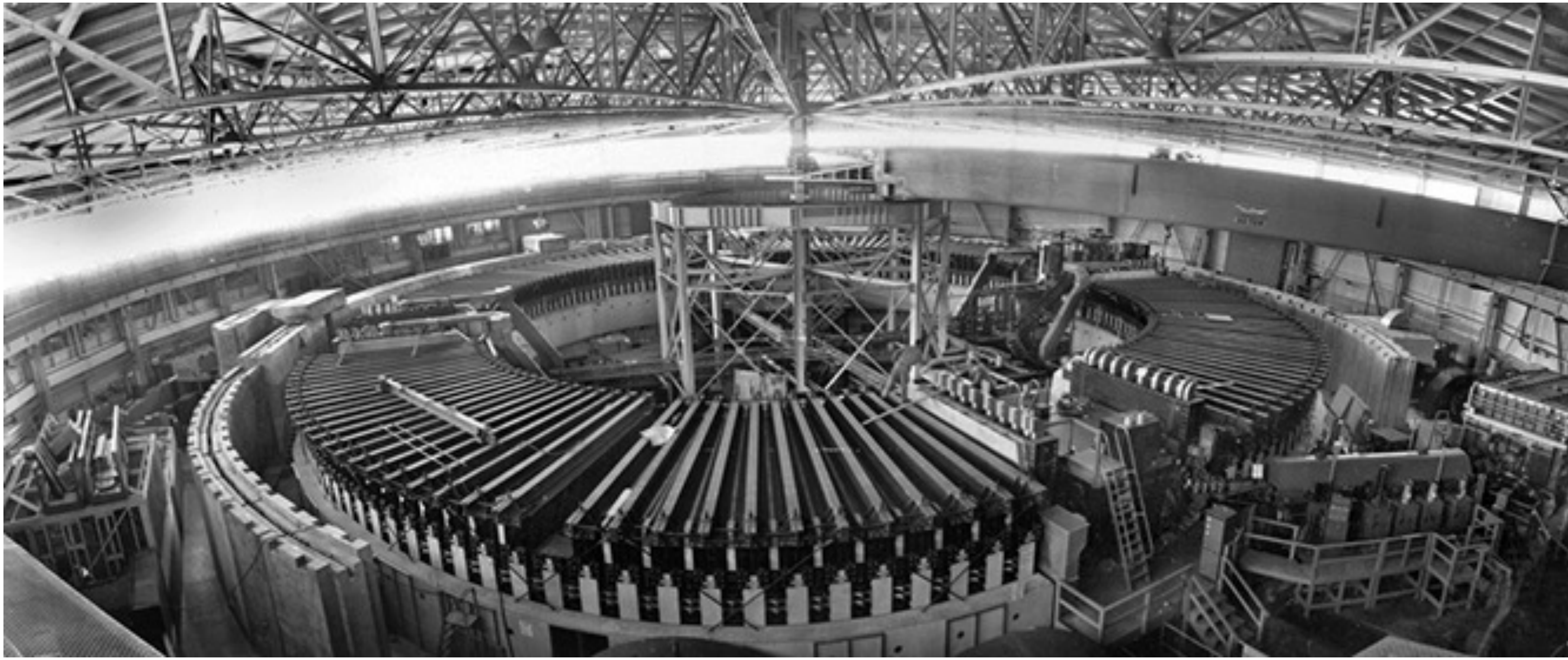
Cosmic rays and accelerators.

Pisa 1955

"A striking fact that emerged in Pisa was that the time for important contributions to subnuclear particle physics from the study of cosmic rays was very close to an end. A few papers presented by physicists from the U.S.A. showed clearly the advantage for the study of these particles presented by the Cosmotron of the Brookhaven National Laboratory (3 GeV) but even more by the Bevatron of the Lawrence Radiation Laboratory in Berkeley (6.3 GeV)". (Amaldi 1988, p. 117)

"... at the Pisa Conference in July 1955 ... the cosmic ray physicists could be proud; they had found just in time all possible decays of the heavy mesons, and made it very plausible that there was one and only one K particle. But their triumph was a swan's song. At the same conference the Berkeley physicists brought better proofs of that idea." (Peyrou 1989, p. 631)

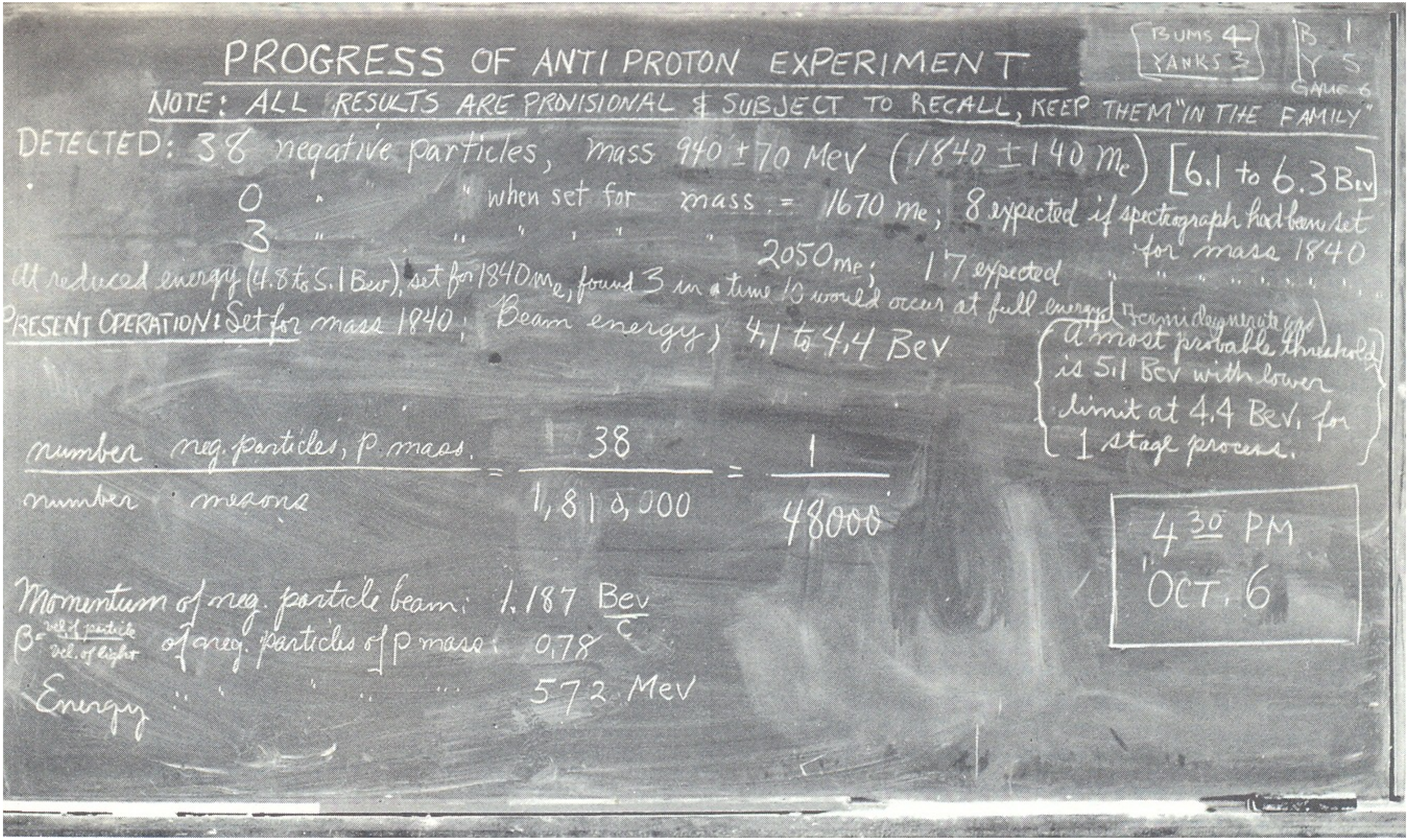
“better proofs” thanks to “better tools”



The Berkeley Bevatron. In 1955 this was the only accelerator in the world where a beam of protons could reach the energy of 6.3 GeV, above the threshold for the production of proton-antiproton pairs

Rochester 1956

«I would say that the Sixth Rochester Conference (April 3-7, 1956) marked the transition from «little science» to «big science» in particle physics. Until the sixth conference, the decision to give equal treatment to accelerator physics, cosmic ray physics and particle theory had served its purpose. Indeed, during the first half-dozen Rochester conferences, it was a common experience for the cosmic ray experimentalists to describe qualitative features of some new discoveries at high energies, for the theorists to articulate these results into a set of model options and, finally, for the accelerator physicists to present at the same, or the very next conference, the quantitative data that enabled one to select the most likely theoretical model. But, at Rochester VI, it was clear that the stream of results from the Berkeley bevatron and the Brookhaven cosmotron would monopolize strange particle physics and Bob Leighton was led to remark that «next year those people still studying strange particles using cosmic rays had better hold a rump session of the Rochester Conference somewhere else -- that the machine work had been pretty hard on cosmic-ray people»…
It should be noted that 1956 was the year when the production of the antiproton was achieved with the Berkeley bevatron – after years of frustration with cosmic ray experiments.» (Marshak 1989, pp. 755-756)



Berkeley, October 6, 1955

Observation of Antiprotons*

OWEN CHAMBERLAIN, EMILIO SEGRÈ, CLYDE WIEGAND, AND THOMAS YPSILANTIS

Radiation Laboratory, Department of Physics, University of California, Berkeley, California

(Received October 24, 1955)

ONE of the striking features of Dirac's theory of the electron was the appearance of solutions to his equations which required the existence of an anti-particle, later identified as the positron.

The extension of the Dirac theory to the proton requires the existence of an antiproton, a particle which bears to the proton the same relationship as the positron to the electron. However, until experimental proof of the existence of the antiproton was obtained, it might be questioned whether a proton is a Dirac particle in the same sense as is the electron. For instance, the anomalous magnetic moment of the proton indicates that the simple Dirac equation does not give a complete description of the proton.

The experimental demonstration of the existence of antiprotons was thus one of the objects considered in the planning of the Bevatron. The minimum laboratory kinetic energy for the formation of an antiproton in a nucleon-nucleon collision is 5.6 Bev. If the target nucleon is in a nucleus and has some momentum, the threshold is lowered. Assuming a Fermi energy of 25 Mev, one may calculate that the threshold for formation of a proton-antiproton pair is approximately 4.3 Bev. Another, two-step process that has been considered by Feldman[1] has an even lower threshold.

TABLE I. Characteristics of components of the apparatus.

$S1$, $S2$	Plastic scintillator counters 2.25 in. diameter by 0.62 in. thick.
$C1$	Čerenkov counter of fluorochemical 0–75, ($C_8F_{16}O$); $\mu_D=1.276$; $\rho=1.76$ g cm^{-3}. Diameter 3 in.; thickness 2 in.
$C2$	Čerenkov counter of fused quartz: $\mu_D=1.458$; $\rho=2.2$ g cm^{-3}. Diameter 2.38 in.; length 2.5 in.
$Q1$, $Q2$	Quadrupole focusing magnets: Focal length 119 in.; aperture 4 in.
$M1$, $M2$	Deflecting magnets 60 in. long. Aperture 12 in. by 4 in. $B\cong 13\,700$ gauss.

There have been several experimental events[2–4] recorded in cosmic-ray investigations which might be due to antiprotons, although no sure conclusion can be drawn from them at present.

With this background of information we have performed an experiment directed to the production and detection of the antiproton. It is based upon the determination of the mass of negative particles originating at the Bevatron target. This determination depends on the simultaneous measurement of their momentum and velocity. Since the antiprotons must be selected from a heavy background of pions it has been necessary to measure the velocity by more than one method. To date, sixty antiprotons have been detected.

Figure 1 shows a schematic diagram of the apparatus. The Bevatron proton beam impinges on a copper target and negative particles scattered in the forward direction with momentum 1.19 Bev/c describe an orbit as shown in the figure. These particles are deflected 21° by the field of the Bevatron, and an additional 32° by magnet $M1$. With the aid of the quadrupole focusing magnet $Q1$ (consisting of 3 consecutive quadrupole magnets) these particles are brought to a focus at counter $S1$, the first scintillation counter. After passing through counter $S1$, the particles are again focused (by $Q2$), and deflected (by $M2$) through an additional angle of 34°, so that they are again brought to a focus at counter $S2$.

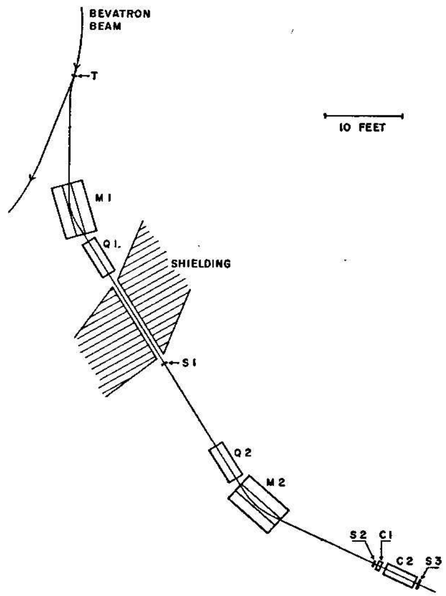


FIG. 1. Diagram of experimental arrangement. For details see Table I.

The particles focused at $S2$ all have the same momentum within 2 percent.

Counters $S1$, $S2$, and $S3$ are ordinary scintillation counters. Counters $C1$ and $C2$ are Čerenkov counters. Proton-mass particles of momentum 1.19 Bev/c incident on counter $S2$ have $v/c=\beta=0.78$. Ionization energy loss in traversing counters $S2$, $C1$, and $C2$ reduces the average velocity of such particles to $\beta=0.765$. Counter $C1$ detects all charged particles for which $\beta>0.79$. $C2$ is a Čerenkov counter of special design that counts only particles in a narrow velocity interval, $0.75<\beta<0.78$. This counter will be described in a separate publication. In principle, it is similar to

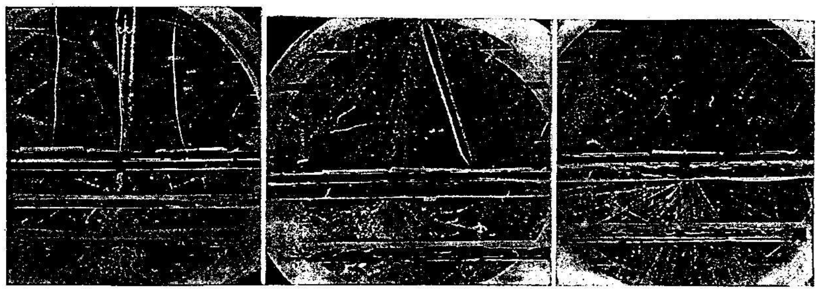
The Letter to the Physical Review announcing the discovery of the antiproton (October 24, 1955)

“The antiproton had been discovered by Segre` and Chamberlain and Clyde Wiegand and Ypsilantis but what they discovered was a negative particle of mass close to the proton. Within 5% of the protonic mass… As Owen Chamberlain and Clyde Wiegand were building the antiproton beamline where they had discovered these particles of negative charge and mass of the proton, they just went ahead and called it the antiproton.” (G. Goldhaber 2005)

“ By October 1955, the counter experiment had clearly demonstrated the following:
1. There were negative particles of protonic mass within an accuracy of 5 percent.
2. There was a threshold for the production of these particles at about 4 GeV of incident-proton-beam kinetic energy.
These were necessary conditions for the identification of antiprotons.
Then, in November 1955, our efforts in the emulsion experiment, despite the handicaps mentioned earlier, yielded one event, found in Rome, that came to rest and produced a star with a visible energy release of about 826 MeV. Again a necessary condition for antiprotons…”
(G. Goldhaber 1989)

E. Hayward, "Ionization of High Energy Cosmic-Ray Electrons", Physical Review 72 (1947)

COSMIC-RAY ELECTRONS 941



(a) (b) (c)

FIG. 5. Cloud-chamber photographs of unusual events, as described in the text.

"... is a photograph of the track of a particle that ionized above five times as much as an average mesotron and also seems to have produced a huge shower in the lead below.... Other possible explanations are that... it is a negative proton giving up all of its energy in interacting with the lead plate"

M. Schein, D.M. Haskin, and R.G. Glasser, "Narrow Shower of Pure Photons at 100000 Feet", Physical Review 95 (1954)

856 LETTERS TO THE EDITOR

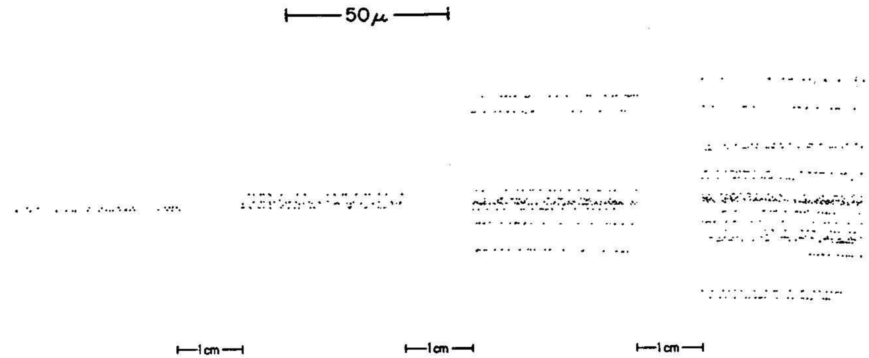


FIG. 1. Narrow shower of pure photons. Sections at arbitrary intervals to show development of shower. Note pair starting in last section.

" Such a phenomenon would appear to be incompatible with the production of these photons by any conventional electromagnetic process... One possibility... is that it may be produced by an annihilation process in flight at very high energy"

"Other possible explanations are that… it is a negative proton" (Hayward 1947)

"One possibility… is that it may be produced by an annihilation process" (Schein et al. 1954)

PHYSICAL REVIEW VOLUME 94, NUMBER 1 APRIL 1, 1954

A V-Decay Event with a Heavy Negative Secondary, and Identification of the Secondary V-Decay Event in a Cascade*

E. W. COWAN
California Institute of Technology, Pasadena, California

(Received December 31, 1953)

Two cosmic-ray decay events have been photographed in a cloud chamber under conditions that yield mass values from combined magnetic-field momentum measurements and ionization measurements from droplet counting. A method has been developed for assigning meaningful probable errors to the ionization measurements. The first event is interpreted as the decay of a neutral V particle into a positive π meson and a negative particle of mass $1850\pm250m_e$. On the assumption of a two-body decay, the Q value for the decay is 11.7 ± 4 Mev. The second event is a cascade decay that can be summarized by the following reaction:

$$Y^- \to 67\pm12 \text{ Mev} + \pi^- + \Lambda^0$$
$$\searrow 40\pm13 \text{ Mev} + \pi^- + p.$$

The proton of the Λ^0 decay is identified by a measured mass of $2050\pm350m_e$. On the assumption of a two-body decay, the mass of the primary V particle is $2600\pm34m_e$.

E. W. Cowan, "A V-Decay Event with a Heavy Negative Secondary, and Identification of the Secondary V-Decay Event in a Cascade", Physical Review 94 (1954)

"The mass of this particle is near or equal to that of a proton and is not consistent with the mass of any negative particle that has been identified… there is no clear evidence that the particle is actually an antiparticle to the proton. No annihilation phenomenon is observed…" (Cowan 1953)

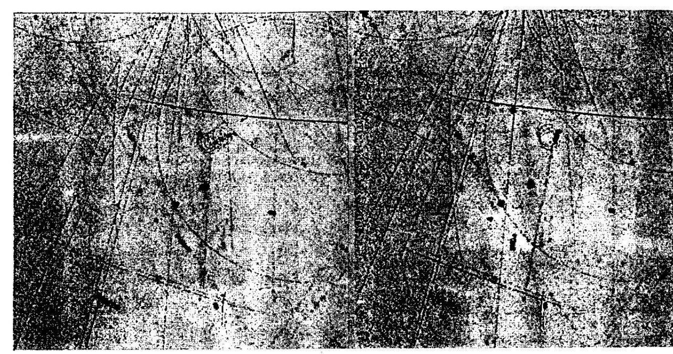


FIG. 1. A V-decay event with a heavy negative secondary.

"... The mass of this particle is near or equal to that of a proton and is not consistent with the mass of any negative particle that has been identified... there is no clear evidence that the particle is actually an antiparticle to the proton. No annihilation phenomenon is observed... "

Possible Example of the Annihilation of a Heavy Particle*

H. S. Bridge, H. Courant, H. DeStaebler, Jr.,† and B. Rossi
Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received June 21, 1954)

THE picture in Fig. 1 and the sketch in Fig. 2 show an unusual cosmic-ray event photographed with the M.I.T. multiplate cloud chamber at Echo Lake, Colorado. The chamber contained eleven brass plates, each 0.50 inch thick (11.1 g cm^{-2}) and was triggered by a penetrating-shower detector placed above it. Two additional views, taken at different angles, are available.

Three electron showers, *b*, *c*, *d*, appear to be associated with the stopping of a charged particle, *a*, in one of the plates. Within the experimental errors, the axes of the three showers and the direction of the last visible segment of track (*a*) intersect at one point in the plate.

From the number of small showers with no apparent origin occurring in our cloud chamber, we found an upper limit of 10^{-3} for the probability that either (*c*) or (*d*) may be a case of chance association. It is practically impossible to explain shower (*b*) in a similar way for a survey of about 10 000 pictures has not revealed a single shower of the size of (*b*), with no apparent origin and going upward.

H.S. Bridge, H. Courant, H. DeStaebler, Jr., and B. Rossi, "Possible Example of the Annihilation of a Heavy Particle", Physical Review 95 (1954)

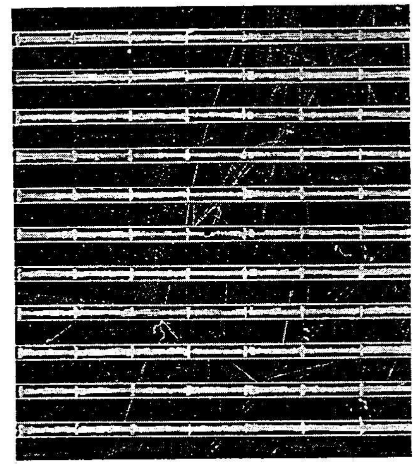


Fig. 1. Cloud-chamber photograph of the cosmic-ray event.

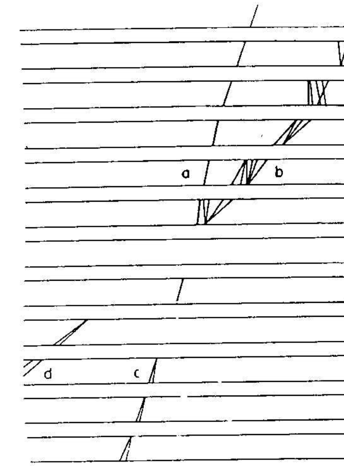


Fig. 2. Sketch of the cosmic-ray event.

"In view of the difficulties of interpreting the event as a decay or an absorption process, one should consider the possibility that the event represents the annihilation process of two heavy fermions. For example, the incident particle might be an antiproton (or an antihyperon) that undergoes annihilation with an ordinary proton. A large fraction of the energy liberated in such a process may well be changed into π^0 mesons and thus ultimately appear in the form of γ rays"

B. Rossi, Rochester Conference, 1956:

"... we used the photometric method to re-analyze the M.I.T. antiproton event, and found a value of 823 ± 155 Mev for the rest energy of this primary particle.... there is thus little doubt that the M.I.T. event was indeed the annihilation of an antiproton"

"… there is thus little doubt that the M.I.T. event was indeed the annihilation of an antiproton" (Rossi 1956)

International collaborations in cosmic ray research (1952-1954)

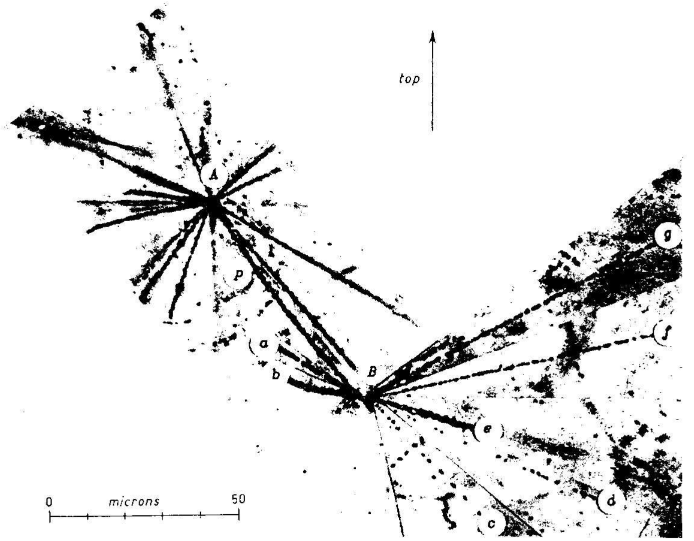
- **Sardinia, June-July 1952 (Bristol, Bruxelles, Glasgow, Gottingen, London, Lund, Milano-Genova, Padova, Paris, Roma-Cagliari, Torino)**

- **Sardinia, May-June 1953 (Bern, Bristol, Bruxelles, Caen, Catania, Copenhagen, Dublin, Gottingen, London, Lund, Milano-Genova, Oslo, Padova, Paris, Roma, Sydney, Torino, Trondheim, Uppsala, Warsaw)**

- **G-stack, October 1954 (Bristol, Dublin, Copenhagen, Milano-Genova, Padova)**

"Unusual Event Produced by a Heavy Particle at Rest"

"Unusual Event Produced by Cosmic Rays"



"... the interpretation of this track in terms of a high energy fragment... is very improbable. Such a conclusion is definitely confirmed by the fact that the deflection of a fast fragment through an angle of 90° should be associated with a rather long recoil track, even in the case of a target nucleus as heavy as silver. No recoil is observed in the present case.... the track is due to a low energy particle.

... the event could also be due to an accidental coincidence in space. Therefore we have evaluated the probability for such a coincidence... the value is sufficiently small to entitle us to look for an interpretation of the observed event in terms of a physical process... We are left to consider the star B as produced by the track p. Then the corresponding particle either has rest energy of the order of 1.5 $\div$ 2 GeV, or, being an antiproton, it has been annihilated by a nucleon, releasing $2\ m_p c^2$ = 1876 MeV.

One can conclude that the probability of an accidental coincidence can not be disregarded although it is rather small. If one excludes this possibility the more likely interpretation seems to be that of an annihilation process of a heavy particle... the many questions raised by the discussion of this event will obviously find their final answer only if other similar events will be observed."

IL NUOVO CIMENTO VOL. I, N. 3 1° Marzo 1955

Unusual Event Produced by Cosmic Rays.

E. AMALDI, C. CASTAGNOLI, G. CORTINI, C. FRANZINETTI and A. MANFREDINI
Istituto di Fisica dell'Università - Roma
Istituto Nazionale di Fisica Nucleare - Sezione di Roma

(ricevuto il 18 Febbraio 1955)

Summary. – The authors describe an event consisting of two stars respectively of about 5 and 1·2 GeV energy. The probable value of the number of accidental space coincidences that one expects to observe in the scanned volume, is about $4\cdot10^{-4}$. This value, although it does not allow us to exclude an accidental process, justifies the consideration of interpretations in terms of some physical process. Special attention is devoted to the production, capture and annihilation of a negative proton.

"Faustina", the «strange event» found in January 1955 by the emulsion group led by Amaldi in Rome in plates exposed to cosmic radiation during the 1953 Sardinia expedition

«This value [the expected number of similar events due to casual spatial coincidences in the volume explored] is sufficiently small to entitle us to look for an interpretation of the observed event in terms of a physical process and not of an acciodental coincidence.
We are left to consider the star B as produced by the track p. Then the corresponding particle either has a rest energy of the order of 1.5-2 Gev, or, being an antiproton, it has been annihilated by a nucleon, releasing $2\ m_p c^2 = 1876$ MeV. We do not have any argument in favour of one or the other of these two possibilities apart from the fact that unstable particles of rest energy of the order of 1.5-2 Gev have never been observed; nor has the antiproton, but this, at least, is expected to exist as a consequence of very general arguments based on symmetry with respect to the sign of the electric charge…

The many questions raised by the discussion of this event will obviously find their final answer only if other similar events will be observed.

We are glad to express our thanks to Prof. B. Ferretti, Dr. B. Touschek, Dr. G. Morpurgo and dr. R. Gatto for various criticisms, and enlightening discussions.»

Amaldi a Segrè, 29 marzo 1955

"... La mia proposta è però assai concreta e precisa. Ti mando a parte il preprint di un lavoro apparso nel Nuovo Cimento di marzo con la preghiera di leggerlo attentamente. Come vedrai c'è una buona probabilità che abbiamo osservato un antiprotone (l'evento viene chiamato Faustina ovverossia uno strano accidente). Se tale interpretazione non è corretta Faustina dovrebbe essere una coincidenza spaziale casuale, poichè tutte le altre interpretazioni possono essere escluse con sicurezza. Alla fine del lavoro diamo una buona ricetta per lo scanning in emulsioni esposte ai raggi cosmici e ciò è ora in corso a Roma, ed eventualmente in altri laboratori dalla fine di gennaio, ma si prevede che la ricerca possa dare una risposta significativa solo a lunga scadenza.

Ora il significato del nostro lavoro è il seguente: non si può escludere che Faustina sia una casuale, ma se essa fosse dovuta ad un vero antiprotone se ne dovrebbe concludere che la corrispondente sezione d'urto per produzione è grande (per esempio dell'ordine di 10^{-27} cm^2 per nucleone) ad una energia di circa 10 GeV quale è probabilmente l'energia del primario della stella A di Faustina. Si può allora pensare di provare a produrli anche con la vostra macchina. E' vero che l'energia è molto più bassa ma c'è ancora una buona probabilità di osservarli.

... Ora la mia proposta è la seguente: ci mettiamo d'accordo per lettera e voi montate l'esperienza e fate gli irraggiamenti... e noi facciamolo sviluppo e lo scanning; il lavoro viene pubblicato insieme, se viene fuori qualcosa che valga la pena. Per voi io penso a te Emilio Segrè, o se tu non puoi occupartene, a Gerson Goldhaber che lavora in lastre e sta con te, o a entrambi. Possibilmente non molte altre persone e non altre, essendo ben chiaro che questo ultimo punto è solo un mio desiderio personale non una condizione perchè sono disposto ad accettare qualunque tipo di combinazione da te proposta per ciò che riguarda la collaborazione da vostra parte."

Amaldi's proposal to Segrè, March 29, 1955

Amaldi to Segrè, March 29, 1955

“Now the meaning of our work is the following: we cannot rule out the possibility that Faustina be a casual coincidence, but in case it is due to a real antiproton one should conclude that the corresponding production cross section is large at an energy of about 10 GeV, which is likely the energy of the primary of Faustina’s A star. One can then think of trying to produce them also with your machine. True, the energy is much lower, but there is still a good probability to observe them…

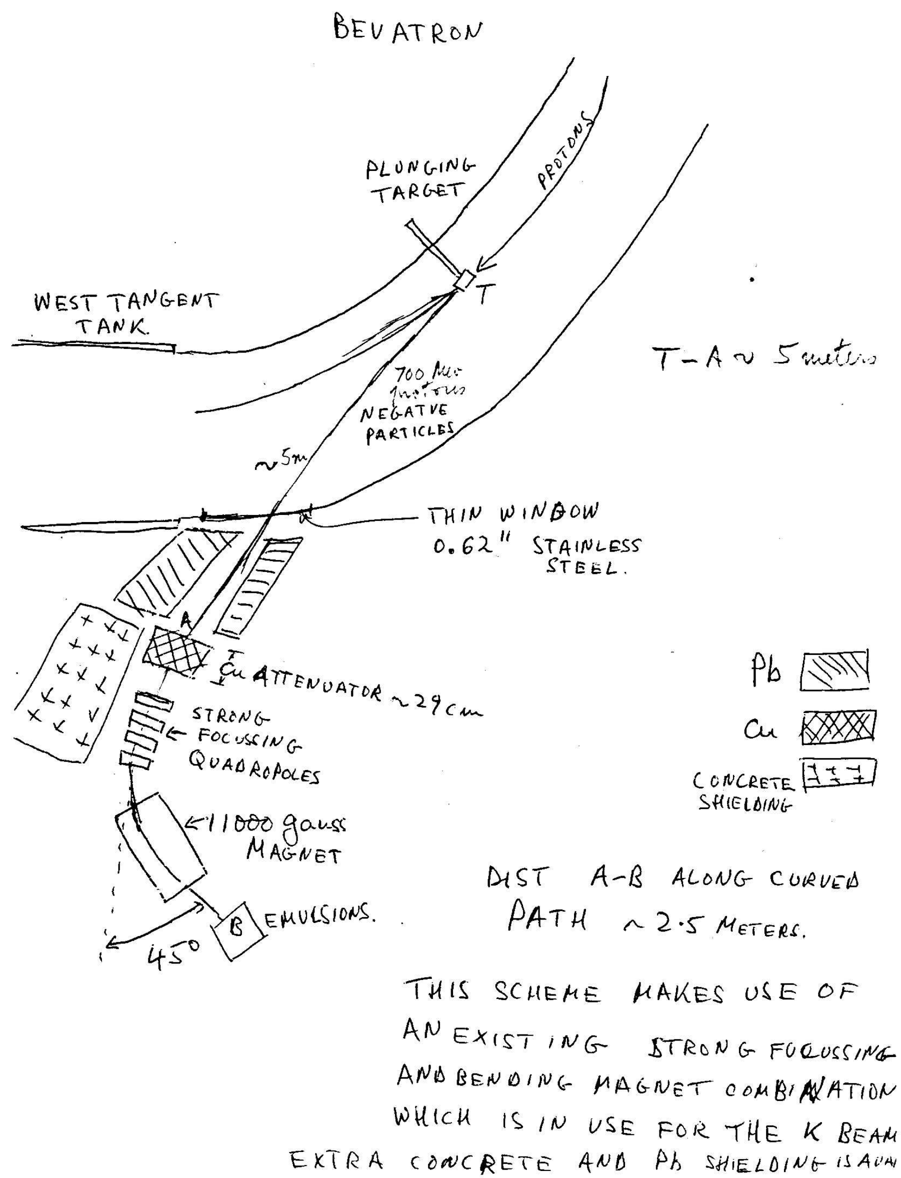
Now my proposal is as follows: we make an agreement that you set up the experience and make the irradiations, and we take care of development and scanning; if anything worth comes out of the work, we publish together. When I say «you», I mean you Emilio Segrè, or Gerson Goldhaber who works on emulsions and is with you, or both…”

Amaldi to Segrè, April 29, 1955

“ Here all the matter has been discussed extensively with our theoreticians (Ferretti and Touschek) and with the emulsions group”

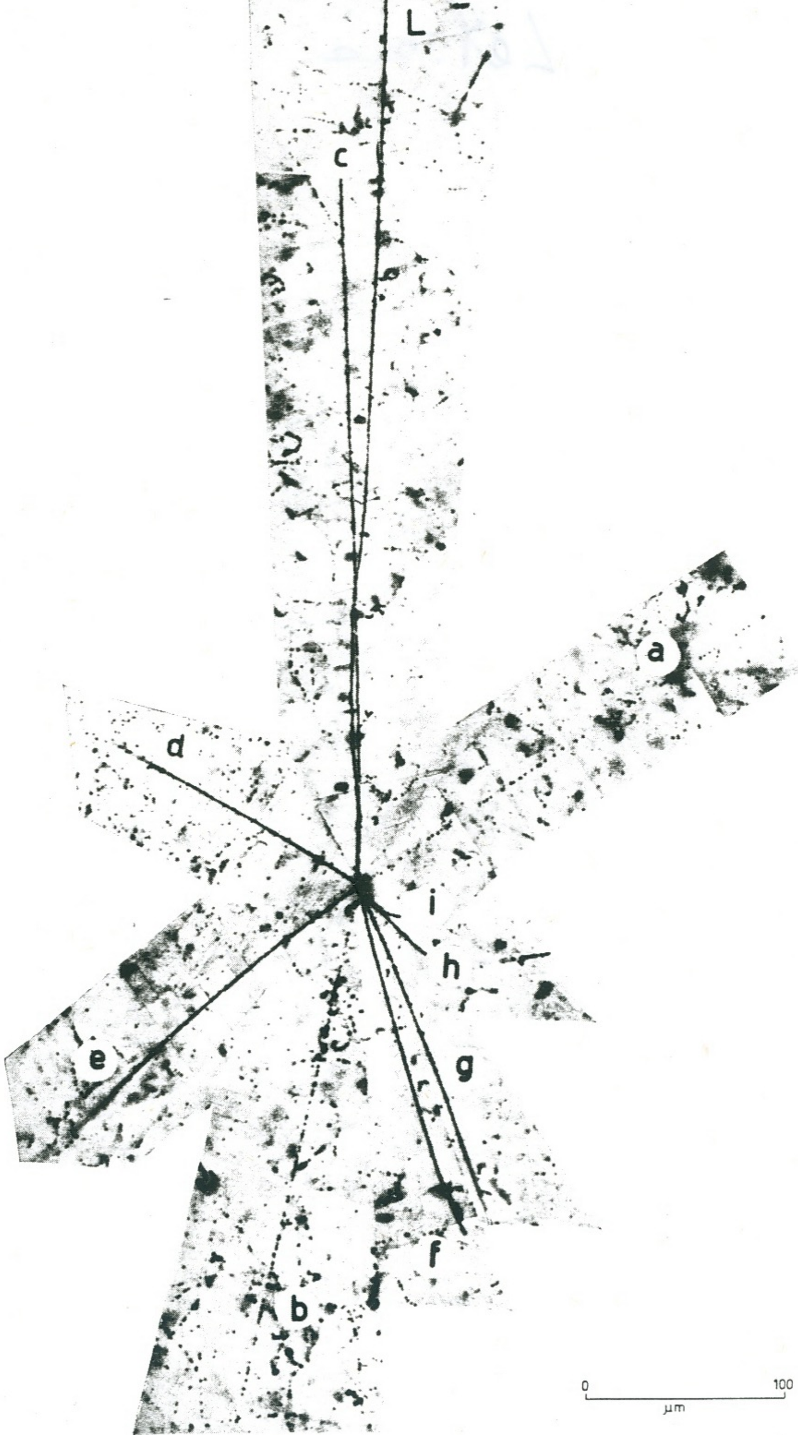
Segrè to Amaldi, April 15, 1955

«I have looked carefully to Faustina and I am also impressed by it. I would like to cooperate in the experiment you suggest; Goldhaber would also like to work on it, and Warren Chupp would almost certainly work on it…
Coming to the practical program: there are at least two programs, of which I know, for hunting the negative protons. One is a photographic one initiated by Rosen of Los Alamos, who has already made an exposure practically identical to your proposal, without the magnet…
The other method is based on a measurement of momentum and velocity, with a possible photographic check.»



Amaldi to members of his team in Rome, Berkeley, September 22, 1955

«There are 7 experiments to find the antiproton… [among them] one of the Segrè group based on a measurement of velocity from the time of flight between two scintillation counters and a measurement of momentum by deflection through a magnet. Yesterday this experiment started giving results that look positive: nothing is for sure yet, and therefore nothing should be circulated, but possibly a definitive answer will arrive in two or three days: should the thing be confirmed, there must be about one antiproton in 25.000-30-000 negative pions in the conditions of exposition A, that is in the conditions of the stacks 63 and 64 you are scanning…
Therefore, keep your eyes open and go ahead full force…»



Amaldi to Segrè, November 18, 1955

«Found Letizia similar Faustina particle protonic mass enters stack 62 left side leading edge comes to rest after 9.31 cm and produces star consisting 6 black particles 1 grey proton 1 pion 80 MeV 1 minimum ionization particle stop lower limit energy release 800 MeV stop measurements not yet finished letter follows Amaldi»

The first annihilation event found in Rome in the plates exposed to the Bevatron beam, November 1955

Rome, Saturday December 10, 1955

On the occasion of the monthly session of the Accademia dei Lincei, Dr. E. Amaldi from the University of Rome reported some preliminary results of a research on the annihilation of negative protons, by a collaboration between a team of the University of California, Berkeley, and a team of the University of Rome…

One can therefore come to the conclusion that this process is due to an antiproton and that it represents the first example of annihilation of this kind of particles produced by means of an accelerating machine. This observation is in a certain sense complementary to, and integrates, the discovery by Chamberlain, Segrè, Wiegand and Ypsilantis announced in mid-October by the Radiation Laboratory. On the other hand, the disintegration observed in the emulsions exposed to the Bevatron exhibits the same features as the one observed early in 1955 by the Roman team in emulsions exposed to the cosmic radiation, and one can therefore conclude that the interpretation of that event, proposed at the time, in terms of a process of an antiproton annihilation, was correct.

Physicists in Rome are looking for annihilation stars in order to confirm their interpretation of the dubious result they already have – Faustina, the uncertain annihilation star observed in the cosmic radiation;

Physicists in Berkeley are looking for annihilation stars in order to prove that the solid result they already have – the detection with counters of negative protons – is indeed the discovery of the antiproton

Physicists in Rome were looking for annihilation stars in order to confirm their interpretation of the dubious result they already had – Faustina, the uncertain annihilation star observed in the cosmic radiation;

Physicists in Berkeley were looking for annihilation stars in order to prove that the solid result they already had – the detection with counters of negative protons – was indeed the discovery of the antiproton

Amaldi to Wick, December 15, 1955

«We have actually found here in Rome a nice star due to a negative corpuscle with mass (1830 +- 55) m_e very similar to the one we found in January in the cosmic radiation. We are in the publication process but we have some small difficulties as to the final text. Judging from what is happening these days it seems that the big bosses in Berkeley are rather difficult to deal with. You might possibly tell me that you were already well aware of that!»

Amaldi to Segrè, December 12, 1955

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Segrè to Amaldi, December 14, 1955

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(Not fully) literal translations

Atti Accademia Lincei

“Questo evento conferma, anche se non in maniera definitiva, l'interpretazione... che le nuove particelle osservate al Bevatrone siano antiprotoni. Esso conferma anche l'ipotesi che la stella descritta in (5) (cioè Faustina, n.d.a.) fosse effettivamente dovuta ad un antiprotone.”

Physical Review Letters

"This event is corroborating evidence, but not final proof, for the interpretation... that the new particles observed at the Bevatron are antiprotons. It also gives support to the hypothesis that the star described in ref. 5 was indeed due to an antiproton."

a plausible theoretical estimate of 0.004 mb ($g^2/4\pi \approx 1$) for the antiproton production cross section,[3] we believe that the expected number of 2-Bev pion stars may be as high as 50 times the number of antiproton stars. Thus, combined with the probability factor from blob-density considerations, there may be roughly an equal probability that star B arises from the interaction of an antiproton as from a 2-Bev pion. However, since the momentum of a 2-Bev pion is 2140 Mev/c and the observed forward momentum of star B is visible only 840 Mev/c, there is again considerable doubt cast on the possibility that the incident particle could be a high-energy pion.

It should perhaps be pointed out that, since the visible energy evolution in star B is only 660 Mev in excess of the incident particle energy, the event is not incompatible with the absorption of a hypothetical boson of approximately protonic mass.

We are deeply indebted to the members of the Radiation Laboratory, University of California, and especially to Dr. E. J. Lofgren and Dr. G. Goldhaber, for the irradiation of the emulsions.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] B. Judek and E. Pickup (private communication); A. Husain and E. Pickup, Phys. Rev. 98, 136 (1955). Using electrons from $\mu - e$ decays, we have checked the ratio of plateau density to 6.2-Bev proton blob density and find a value of approximately 1.03, which, within experimental error, agrees with value of 1.05 used above. Although there is some disagreement [see Kaplon, Klarmann, and Yekutieli, Phys. Rev. 99, 1528 (1955)] as to the value of the plateau to minimum blob-density ratio, most observers are in agreement on the form of the blob-density curve above the plateau. Above the plateau, we have used a combination of the curves of Husain and Pickup and of J. R. Fleming and J. J. Lord [Phys. Rev. 92, 511 (1954)].

[2] The possibility that star B is created by an Eisenberg type of particle seems no more likely than in the case of a deuteron; unless perhaps the normally emitted K particle decays to pions or is converted directly into kinetic energy.

[3] D. Fox, Phys. Rev. 94, 499 (1954); R. N. Thorn, Phys. Rev. 94, 501 (1954); G. Feldman, Phys. Rev. 95, 1697 (1954).

Antiproton Star Observed in Emulsion*

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and

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(Received December 16, 1955)

In connection with the antiproton investigation at the Bevatron, we planned and carried out a photographic-emulsion exposure in a magnetically selected beam of negative particles. The magnetic system was identical to the first half (one deflecting magnet and one magnetic lens) of the system used in the antiproton experiment of Chamberlain, Segrè, Wiegand, and Ypsilantis.[1] The selected particles left the copper target in the forward direction with momentum 1.09 Bev/c.

Cosmic-ray events possibly due to antiprotons had been observed previously by Hayward,[2] Cowan,[3] Bridge, Courant, DeStaebler, and Rossi,[4] and (in nuclear emulsion) by Amaldi, Castagnoli, Cortini, Franzinetti, and Manfredini.[5] We were hopeful of finding events similar to the last one in our experiment as reported here.

When the antiproton concentration in the beam used was measured[1] (one for about 50 000 pions), it became possible to make a rough estimate of the number of antiprotons that should come to rest in the nuclear emulsion stacks. Since the range of antiprotons from the selected beam was considerably greater than the length of the stacks, it was necessary to slow the antiprotons in an absorber (132 g cm^{-2} of copper) before allowing them to enter the stacks in which they were to come to rest. The estimate of the number of antiprotons stopping in the stacks is hence rather drastically affected by the assumption made about their nuclear attenuation cross section in the copper absorber. If the attenuation cross section is assumed equal to that for protons we could expect about 7 antiprotons, while if it were twice that for protons we could expect only about 2.5 anti-

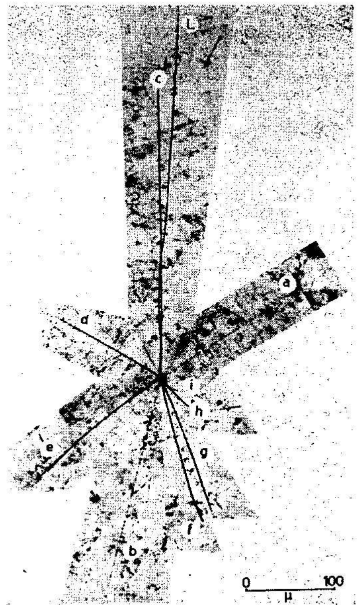

FIG. 1. Reproduction of the star. L is the incoming track (9.31 cm of range). For the explanation of the other tracks see Table I.

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On the Observation of an Antiproton Star in Emulsion Exposed at the Bevatron.

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(ricevuto il 5 Gennaio 1956)

Summary. — In connection with the antiproton investigation at the Bevatron several stacks of nuclear emulsions have been exposed in a magnetically selected beam of negative particles. The selected particles were produced in a copper target, bombarded with protons of 6.3 GeV, and had a momentum of 1.09 GeV/c. The experiments were designed to observe the annihilation process undergone by an antiproton brought to rest inside the emulsion. The details of the investigation are given in Section 2. Section 3 contains an estimate of the number of expected annihilation stars as obtained from previous measurements with counter experiments reported by Chamberlain, Segrè, Wiegand and Ypsilantis. Section 4 contains the description of the only event found so far. The mass of the primary particle responsible for it, as obtained from a weighted average using several independent methods is $(1824 \pm 51)\ m_e$. The star produced by it, is associated with a minimun release of « visible » energy of ~ 826 MeV while the corresponding unbalanced « visible » momentum amounts to ~ 520 MeV/c.

1. – Introduction.

Among the major research plans for the Bevatron was the investigation of the possible production of antiprotons and their study. This problem has been attacked in several ways and the first success has been the identification

The letter to Physical Review and the full length paper on Il Nuovo Cimento

ANTI-PROTON, NEW PARTICLE, SEEN FOR FIRST TIME 12/12/55

By SCIENCE SERVICE

BERKELEY, Calif., Dec. -- First visual evidence of the anti-proton, new subatomic particle, is reported by scientists of the Universities of California and Rome, Italy. They found one photo-emulsion "star," an explosion of the nucleus caused by an anti-proton.

This new particle was discovered at Berkeley in early October as the result of bevatron bombardment, after world-wide search by scientists for several years. The Berkeley discovery was made by precision measurements with counters.

Protons are the positively charged hearts of hydrogen atoms. Anti-protons are their opposite number, having the same mass, but negatively charged.

Annihilation of matter results when proton and anti-proton collide, turning the material particles into bursts of energy according to the famous Einstein theory equating mass and energy.

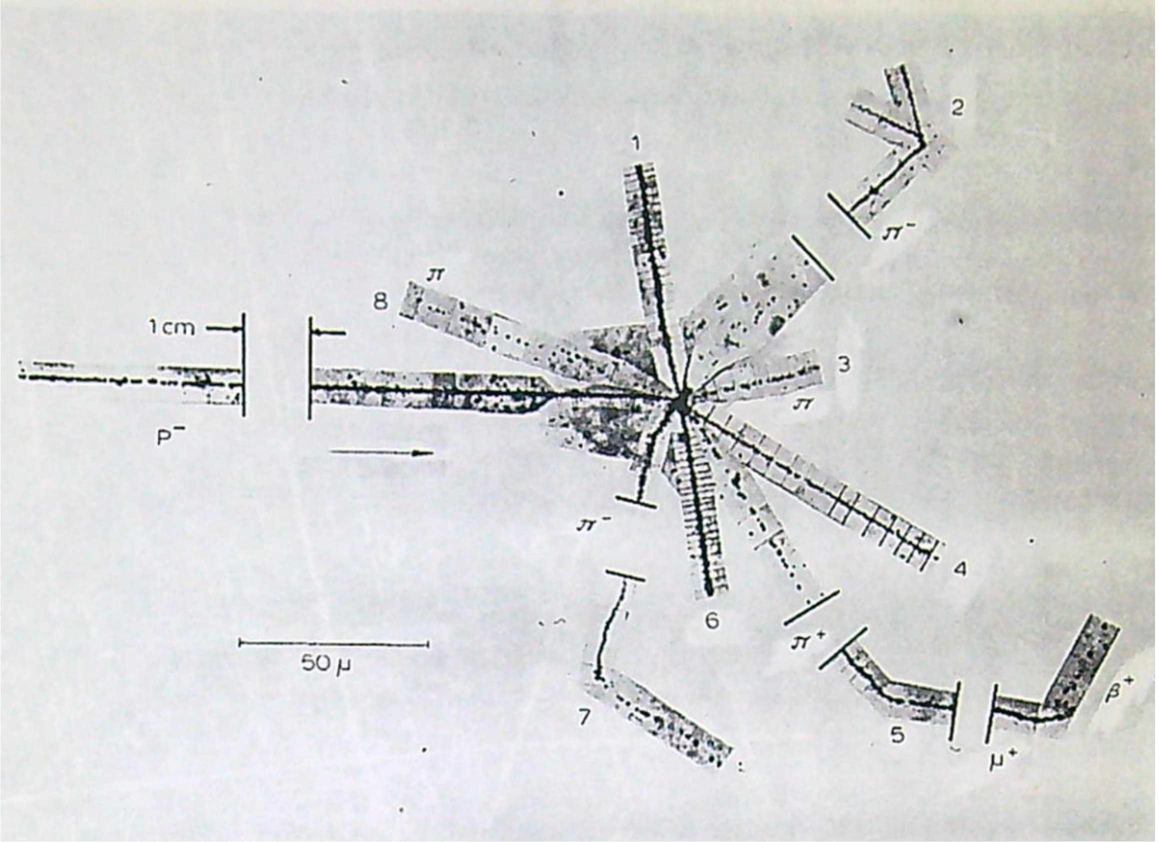
In collaborative research at the Universities of California and Rome, emulsion plates were bombarded in the bevatron anti-proton beam at Berkeley. Half the plates have been under study in Berkeley, the other half were taken to Italy for study by Prof. Eduordo Amaldi and colleagues.

One star was observed by the Amaldi group in mid-November and a joint paper describing the event, still unpublished, was written for the Physical Review, with names in the following order: Drs. Owen Chamberlain, Warren Chupp, Gerson Goldhaber, Emilio Segre, Claude Wiegand, all of Berkeley; and Eduordo Amaldi, C. Baroni, C. Castagnoli, C. Franzinetti and A. Manfredini of Rome.

This paper has been read to the Italian Academy of Sciences in Rome by Prof. Amaldi.

The star was made by an anti-proton entering either silver or bromine in emulsion. An eight-pronged star resulted, showing six

Press report of Science Service, December 12, 1955: "Antiproton seen for first time"



The annihilation star found in Berkeley, January 11, 1956

«This event turned out to be particularly important because it gave the conclusive proof ("sufficient condition" for those who were still in doubt) of the annihilation process. The visible energy release in this star was 1300 +_ 50 MeV. Clearly greater than the mass of the incident negative particle!
Chamberlain gave an invited talk at the 1956 New York meeting of the American Physical Society. There he reported on both the counter experiment and our annihilation event. He told me afterward that the proof supplied by the annihilation event was an important ingredient in the minds of the audience» (Goldhaber 1989)

Protagonists' recollections. Emilio Segrè (1993)

"My group had for some time studied the problem and prepared for it. I decided to attack the problem in two ways. One was based on the determination of the charge and mass of the particle. The other concentrated on the observation of the phenomena attendant on the annihilation of a stopping antiproton…
For the first attack, Chamberlain, Wiegand, Ypsilantis and I designed and built a mass spectrograph with several technically new features. For the second attack, Gerson Goldhaber, who was then in my group, exposed photographic emulsions in a beam enriched in antiprotons by our apparatus. Many other people were involved in the enterprise, and we had agreements on how to publish the results and give appropriate credit to everyone…
The mass-spectrograph experiment concluded on October 1, 1955, having proved the existence of the antiproton, and soon thereafter the emulsion work confirmed it…
At the time of the antiproton experiment, Amaldi and his wife Ginestra were at our home in Lafayette as our guests. He and I established a collaboration for the study of photographic emulsions exposed at Berkeley, taking advantage of the numerous well-trained scanners available in Rome."

Protagonists' recollections. Giulio Cortini (2005)

«The antiproton was in the air… A group of leading experimental physicists in Berkeley designed and performed an experience aimed at the f inal demonstration of its existence. The experiment was successful and was rewarded with a Nobel prize. Nonetheless, they wanted a more sensational confirmation: producing in their nuclear plates phenomena analogous to «our»…

Amaldi was in touch with the Berkeley group, and thanks to his prestige our group was associated to their «second» experiment: they sent us plates that had been exposed to the beam of antiprotons produced by their 6.3 GeV machine, and we found there the «first» event similar to «Faustina»: telegram, congratulations. But naturally the prestige of this new result, and of those who followed, fell largely on them…»

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(In 1956 Gilberto Bernardini proposed to the Accademia dei Lincei that the Feltrinelli Prize for Physics be awarded to the discoverers of the antiproton, listed as follows in alphabetical order: Owen Chamberlain, Giulio Cortini, Emilio Segrè)

CERNCOURIER

FEATURE

Fifty years of antiprotons

2 November 2005

Left: the first annihilation star imaged in the photographic-emulsion stack experiments, led by Gerson Goldhaber of the Segrè group, which confirmed the discovery of the antiproton. An antiproton enters from the top of the image and travels about 430 μm before meeting a proton. Nine charged particles emerge from the annihilation. Right: bubble-chamber image where an antiproton enters at the bottom. When it strikes a proton, four positive and four negative pions are created.

On protagonists' recollections. John Heilbron (1989)

"Insofar as historians may be said to have a particular goal, it is to understand the connection of events from a wider perspective than any of the historical actors, however well placed they were, could have attained. This aspiration does not imply a feeling of superiority to the actors, nor any special wisdom. It does imply the obligation and the patience to study a large quantity and broad range of sources from and about the past…

From the point of view just sketched, one can understand that most historians do not consider the unsupported recollections of former participants very good evidence about events in the distant past. The problem of partial observation is in this case compounded by failing and selective memory."

Two lessons of general character (like all general lessons, both are not exempt from exceptions)…

- Never trust scientists' recollections unless supported by independent documentary evidence

- Look at discoveries as processes spread over a period of time rather than as punctual events

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- Never trust scientists' recollections unless supported by independent documentary evidence

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… and a tentative conclusion, looking forward

The involvement of theoreticians in Rome in the discussion about the antiproton findings of their experimentalist colleagues most likely contributed to strengthen their confidence in symmetry arguments. And the actual making of the antiproton turned antimatter from a theoretical speculation into a manageable tool. It seems reasonable to suggest that in this respect the discovery of the antiproton contributed to pave the way in Rome for theoretical and experimental developments that followed, from the consequences of CPT theorem to matter-antimatter physics.

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