The early years of Bruno Maximovich Pontecorvo at Dubna



It has been a great pleasure and a great honor for us to have the possibility to retrace the research activities done by Bruno Maximovich Pontecorvo at the Institute of Nuclear Problems during the early years of his stay in Dubna (from November 1, 1950 up to end of March 1952). This reconstruction was possible through the study of two notebooks where Bruno annotate his everyday research activity at the Dubna cyclotron. We are greatly indebted to Gil Pontecorvo, the oldest son of Bruno, who provided us the two notebooks.

> Rino Castaldi and Gloria Spandre INFN-Pisa

A new life of Bruno in Russia

At the end of August 1950, while on a short vacation in Italy with his family, Bruno Pontecorvo suddenly disappeared.

Nobody knew of him, his wife and his three children until 4th March 1955 when he gave in Moscow a press conference at the Academy of Sciences where he explained the motivations that have led him to leave the West and work in the Soviet Union. The next day the international press gave great prominence to the news. In many newspapers Pontecorvo was depicted as the Italian spy who fled to Russia with the American atomic secrets.

Still today Pontecorvo is depicted as the Italian physicist (or spy) who passed the secrets of the atomic bomb to the Soviets and collaborated to the construction of the Russian hydrogen bomb. Nothing could be further from the truth, as Bruno himself several times repeated in many occasions.



In these notebooks we find evidence that he hasn't worked to the Russian atomic program but he has only performed basic research in elementary particle physics.





HALF-LIFE

THE DIVIDED LIFE OF BRUNO PONTECORVO, PHYSICIST OR SPY

FRANK CLOSE

Published February 3rd 2015 by Basic Books

Who is Bruno Pontecorvo as man and scientist when, in late August 1950 at the age of 37 year old, he decided to give up everything and go to live in Russia ?

As man, Bruno is a deeply convinced communist who believes in a true socialist society inspired by a profound sense of justice and equality.

As scientist he is a theoretical and experimental physicist with genial ideas and profound intuitions



Bethe e Peierls: neutrino has "a penetrating power of 10¹⁶ km in matter"

....."it is therefore impossible to observe free neutrinos". Pontecorvo suggests to use the reaction: $v + Cl^{37} \rightarrow Ar^{37} + e^{-}$ to detect the free neutrinos and prove its physical reality.



 $e-\mu$ universality by Misha Bilenky



Bruno and the Communism as seen by Misha Bilenky

After the experiment of Conversi, Pancini and Piccioni and the interpretation given by Fermi, Teller and Weisskopf Pontecorvo first had the intuition of the $e-\mu$ universality of weak interaction !

New life and new experiments in Dubna

Certainly Bruno Pontecorvo must have been enthusiastic to arrive to the Institute of Nuclear Problems beginning of November 1950, and to have the possibility to work at the five-meter synchrocyclotron, the most powerful existing at that time in the world and, foremost, to live in a society that proclaims to build communism.

The reputation of brilliant assistant of Fermi precedes him and inspires great enthusiasm among the physicists of the Laboratory. It is customary among colleagues in the lab to call each other with name and patronymic therefore Bruno is renamed Bruno Maximovich, because his father's given name is Massimo. From that moment on, he will be Bruno Maximovich in all the scientific and social clubs of Russia.



Synchrocyclotron general view



	Kind of accelerated particles and their energy				
· .	280 MeV deuterons	560 MeV α's	480 MeV protons		
Internal target current (µA)	1	0,025	0,2-0,3		
Extracted proton flux at a distance of 10 m from the magnetic channel $({\rm cm^{-2}\ sco^{-1}})$	_		$(E_p = 10^{4})$		
Neutron flux at the maximum of the angular distribution 2 m from the internal target	0.403		460 MeV)		
(cm sec ^{-*})	8.10	$2 \cdot 10^{3}$	$5 \cdot 10^{6}$		
distribution (MeV)	120	120	380		
Halfwidth of the angular neutron distribution					
(radian)	0,17	0,35	0,55		
Process responsible for neutron production	Stripping	α-particle disintegration	charge exchange		

Parameters of available beams in 1950

Synchrocyclotron building

$\frac{|X| 1950}{\text{from } 14/09/1950 \text{ to } \le 30/11/1950}$



To commemorate the centenary of the birth of Bruno Pontecorvo have been organized in Pisa an exibition on the life and the scientific work of this great Italian physicist of the 20th century.

This Notebook was given from Gil Pontecorvo to Gloria Spandre and Elena Volterrani, both curators of this exibition in Pisa. That is a Notebook where Bruno, just arrived at the Institute for Nuclear Problems in Dubna, start annotate writing by hand, mostly in English, notes, ideas and considerations on the research program he intends to do.

This unpublished document is particularly interesting because until today little was known of the scientific work of Pontecorvo during his first early years in Russia. The date written on cover and on the first page of the Notebook is

1st November 1950.

Page 1 of the notebook

1st November (1950)
 <u>Neutron production by cyclotron particles</u> -

120 Howoond - Newtron production of cyclation posticles (1) In the experiment with the water tunk, one can yet an idea of the newtron energy of measuring the space distribution of newtrons (for example measure (21 Av.). A componention at different energies is interesting. The work be probably representative of the "crapoantion process, while the were about relaxation lengthe would be propolog what inistic of the " we know m " process.

"In the experiment with the water tank, one can get an idea of the neutron energy by measuring the space distribution of neutrons (for example measure $r^2|_{Av}$)."

(At the end of 1950 the neutrons are produced with the 560 MeV α -particles beam of the cyclotron colliding on internal targets of various substances and the energy is not very well known.)

- Fishion from highly excited states -The normal bristion happens usually from low (2) **Page 2:** 3th November (1950) excited states (≈ 10 MeV), with high energy bourloading Now, as the fishin of medium A thous, there Pontecorvo writes in this book some thoughts on must be fishions total advining from Very highly excited states, in very few cases. These fishing from which kind of experiments with what techniques linguly excited states must release plenty of everyof, The in Un Th. The difficulty in detecting can be done using the available cyclotron beams: men is " clusterical " movife, "This is stabil the be ~1/min. It is possible to reduce it y - Fission from highly excited states -ges unplification. "electrical" noise. This is stated to be ~1/min. It is H" problem - Is it possible to detect possible to reduce it by gas amplification the H+ particles inside the chamber? Due could use the magnetic field of the cyclictron H⁴ problem – Is it possible to detect to move the electrony. the H^4 particles inside the chamber? One could use the 3 Horeopa magnetic field of the cyclotron to curve the electrons. According to Arcamonloun Adexcangpobur, the experiment with H4 is possible "inside the touk", with an advangment of 3 counters in coincidence. 3th November According to Anatoly Alexandrovich, the experiment with H^4 is possible "inside the tank", with an arrangement of 3 Multiple meton production Multiple counters in coincidence. The tweehold for multiple production, for example: h+p -> p+n + T+T or n+p -> D+T+T Multiple meson production $\begin{array}{ccc} \mu + \mu & \longrightarrow & \mu + \mu + \pi^{+} + \pi^{+} \\ \mu + \mu & \longrightarrow & \mu + \mu + \pi^{+} + \pi^{-} \\ \mu + \mu & \longrightarrow & \mu + \mu + \pi^{+} + \pi^{0} \\ \end{array} \qquad \begin{array}{cccc} \text{Invitiant alley, units that find a detation of π^{-} in all μ of μ in a line μ of μ in all μ of μ of μ and μ of $\mu$$ The threshold for multiple (double) production, for example: $n+p \rightarrow p+n+\pi^++\pi^- \text{ or } n+p \rightarrow D+\pi^++\pi^$ is a 600 MeV in H. But in heavy materials the threshold $p+p \rightarrow n+n+\pi^++\pi^+$ is of the order of 300 MeV! An inperiment can be done as follows: a) $z + p \longrightarrow 2+3 + 2\pi^{-1} + \sum_{n=1}^{\infty} \frac{1}{n} + \sum_{$ $p+p \rightarrow p+p+\pi^++\pi^$ $p+p \rightarrow p+n+\pi^++\pi^0$ I undrite a turget, and separate chemically the etc. dement 2+3 - Let us evaluate the (20) for the emission is ~ 600 MeV in H. But in heavy material the threshold is $\begin{array}{cccc} & \sigma f & 2 \pi^{-}, & \text{It is} \\ (\text{Heaving element}) & & & \sigma \\ & & & \sigma \\ (2\pi) & \approx & & & \\ \end{array} \xrightarrow{(sopp)} & & & & \\ & & \sigma \\ (2\pi) & \approx & & \\ & & & \\ \end{array} \xrightarrow{(sopp)} & & & & \\ & & & \\ & & & \\ \hline & & & \\ & & & \\ \end{array} \xrightarrow{(sopp)} & & & \\ & & & \\ & & & \\ \hline & & & \\ & & & \\ \end{array} \xrightarrow{(sopp)} & & & \\ & & & \\ & & & \\ & & & \\ \hline & & & \\ & & & \\ \hline & & & \\ & & & \\ \end{array} \xrightarrow{(sopp)} & & & \\ & & & \\ & & & \\ & & & \\ \hline & & & \\ & & & \\ & & & \\ & & & \\ \hline & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ \end{array} \xrightarrow{(sopp)} & & \\ & & & \\$ of the order of 300 MeV. An experiment can be done as follows: In Pt, this gives a mean freepath for double TT equal to: $l = \frac{200}{12 \times 0.6 \times 10^6} \text{ cm} = 3 \times 10^{\circ} \text{ cm}.$

Inot in beam, internal seattering

It is easy to see that the nucleon frattening is very important. So the internity in point 5 is mainly one to that the factors This effect is tremendous, and it is certain this freet Denterous, to particles talks come out of the cyclation. One way of measuring this, of course, is measuring the imitation in a proportional counter

Cerenkov debertor

It may will be that the "water Cerenkow detutor, about 30 cm long, is the "perfect" ventered mean detutor. In fact pray of twole energy one biajed off, and record proton to whe not defected

A organic tolution debeits, fra hven energy lon, more devens our pord, to mis mos ollo be used of lon,

Acatimote of m. f. p of Tt in mileon

matter.

The mean free path of charged metors in mulei can be investigated in photoplates. To investigate the mean free path of TT, the only way is to use as a mulease mother abrocher the unlear mother itself, as the it is necessary to have a fulftame of much density that the m f p for interestion is 22 Ederay. This means that one unst use as an abrocher the some mindens which produces means. Using 8, study the notio <u>TT+T</u> as a function of 2. Pontecorvo continues writing, up to page 9, some thoughts on which kind of experiments with what techniques can be done using the available cyclotron beams:

- <u>Proton beam, internal scattering</u> -It is easy to see that the nuclear scattering is very important. So the intensity in point <u>5</u> is mainly due to nuclear <u>scattered protons (and not coulomb)</u>. This effect is tremendous, and it is certain that Deuterons, H³ particles etc, also come out of the cyclotron. One way of measuring this, of course, is measuring the ionization in a proportional counter

<u>Cerenkov detector</u>

It may well be that the "water Cerenkov detector", about 30 cm long, is the "perfect" neutral meson detector. In fact γ ray of small energy are biased off, and recoil proton etc are not detected

Organic solution -

A organic solution detects, for a given energy loss, more electrons than for α , so this may also be used

A estimate of m.f.p of π^0 in nuclear matter

The mean free path of charged mesons in nuclei can be investigated in photoplates. To investigate the mean free path of π^0 , the only way is to use as a absorber the nuclear matter itself, as it is necessary to have a substance of such density that the mfp for interaction is $\ll I_{decay}$. This means that one must use as our absorber the same nucleus which produces mesons. Using γ , study the ratio $\sigma_{\pi^++\pi^-} / \sigma_{\pi^0}$ as a function of Z.

Very interesting what he writes on page 8! ! (beginning of November 1950)

on the frankformations of methis The 2 meter has a long life ? 10 the , and and supposed to decay into TT++TT+TT If this is to, it must be included that I does not interest with mulei, become, if the & induceds with mulin, then the lote of the second would be vie bost. (through the indication with uncloses of the vacuum) Let us suppose that it does not infusit Stingly, hime it is strongly produced, it must produced. as a bring promit of a strongly intracting metmalle But this Mo then would decoy who TT quicker thon in V. to there is a contradiction between the criptime of a strong inbroiting pointile, and its long lifetime. This contradiction, of counter, is repolved if the strong proticle is produced in poin. to from the very but the tay 2 merons have a long life, it ion be out 6) prot they are present in abundling we con combuse That there are metans curtinions Muchingsons) the theorigh for the for the fort with s prituke until wow would be whitent In -> C+2H TT-> W+Y culobin no other inesonthat $\mathcal{Z} = \mathcal{K} = \mathcal{V} \longrightarrow \begin{cases} \mu + i \\ \mu + i \end{cases}$ Therens tree been produced. Vount => TT+por TT+p Vo herris h+TT

On the transformations of mesons -

The τ meson has a long life >~ 10 -9 sec, and is supposed to decay into $\pi^++\pi^-+\pi^+$. If this is so, it must be concluded that τ does not interact with nuclei, because, if the τ interacts with nucleons then the rate of the disintegration would be very fast. (trough the interaction with nucleons of the vacuum) Let us suppose that it does not interact strongly. Since is strongly produced, it must produced as a decay product of a strongly interacting meson M. But this M then would decay into π quicker than in τ . So there is a contradiction between the <u>existence of a strong</u> <u>interacting particle and his long lifetime</u>. This contradiction, of **course**, is resolved if the strongly interacting particle is **produced** in **pair**.^(*) So from the very fact that a) τ mesons have a long life, b) that they are present in abundance, - we can conclude that there are mesons (not necessarily the τ mesons) which are strongly produced in pairs.

(incidentally these considerations explain the fact that until present day cyclotron no other mesons that π mesons have been produced.)

 $+\pi^{-}$

2

A consistent picture until now would be:

$$\mu \rightarrow e^{+}2\nu$$

$$\pi \rightarrow \mu + \nu$$

$$\tau^{+} = K = V^{*} \rightarrow \begin{cases} \mu^{+} + \pi^{+} \\ \mu^{+} + \pi^{0} \end{cases}$$

$$\mathsf{V}_{\mathsf{O}\mathit{light}} \!
ightarrow \! \pi^-\!\! + \mu^+ \, \mathsf{or} \, \pi^+\!\! + \mu^- \, ?$$

 $V_{Oheavy} \rightarrow p + \pi^{-}$



^(*) here, at the end of 1950, without the notion of strangeness, a deep intuition is needed to propose a production process in pair to solve this contradiction. ^(**)maybe just a coincidence! Two lines before he writes $\mu \rightarrow e+2\nu$ while here he writes $\mu \rightarrow e+\nu + \nu$ engraving the neutrinos with two different signs. Two profound intuitions in a single page ?! On page 9 he writes only the following few lines "On the multiple production of mesons", while the remaining part of the page, written in a reversed order, is the end of the draft of a paper.

- On the multiple production of menny-

In driftinsking the flowmenon of until fle feoduction, form an experimental point of view, it is necessary to member the forsibility that an approxime of multiple production may be given of the feoduction of heavy metrus (spin integer, there interestion with matter), which of course, decay into it metrus immediately piving the approxime of multiple production, while, in fact these maybe only me postile production, while, in fact these more one postile production while the interesting of the production while, in fact these more of the production while the matter of the system of the production where the matter of the system of the production where in fact these more of the production where the matter of the system of the production of the matter of the system of the production of the pro-

-On the multiple production of mesons -

In discussing the phenomenon of multiple production , from an experimental point of view, it is necessary to remember the possibility that an <u>appearance</u> of multiple production may be given by the production of <u>heavy</u> mesons (spin integer, strong interaction with matter), which of course decay into π mesons immediately, giving the appearance of multiple production, while, in fact there maybe only one particle produced per hit.

роцтэт

.... with a compensating filter of Al (2.5cm) in front of the collimator, equivalent (2.5cm) in... This method is preferable for small angle of detect(ion) to the (?)

Pontecorvo, after the first 9 pages, stops writing on this Notebook and he resumes writing only the following year (September 14^{th} , 1951, see next slide) turning the book on the opposite side, starting from the last page and writing in the Notebook until March $\geq 24^{th}$, 1952.

In diffusion the plannen of multiple fooduling the form on experiments, found of vision is is us meeter to comment the particles that and the plane of the fractulation of the plane of the integer of the plane the plane with mother, which of every into the plane intervertion with the equation of the property of the plane of the position with the subscript of the plane of the plane

- on the number a production of mermon -

.... with a compensating filter of Al (2.5cm) in front of the collimator, equivalent (2.5cm) in...This method is preferable for small angle of detect(ion) to the(?) method .

In discussing the phenomenon of multiple production, from an experimental point of view, it is necessary to remember the possibility that an <u>appearance</u> of multiple production may be given by the production of <u>heavy</u> mesons (spin integer, strong interaction with matter), which of course decay into π mesons immediately , giving the appearance of multiple production, while, in fact there maybe only one particle produced per hit.

- <u>snosam fo noitouborg algitlum ant nO</u>-

Pontecorvo resumes writing on the Notebook the following year, September 14, 1951, starting from the last page (n.100) turning the book on the opposite side. He has now decided what to do and he is ready to make an "Experiment on production of mesons by neutrons":

~** 0000 10000 500000 $T + h \rightarrow n + \gamma$ IT the a wtT? T+n-271+1+1 +h->T+h 2 N.N. 2=

hentems It is necessary : 1) The " having on 2) the "inverter" obsorber" 4) The absorber of y lodistion T Asy The codiator must be a phile of diameter It the Diometer Dum foraff. = m.f.h. fr. J. (> The invester must be I cm Ib, dea equal to the country they onea A > The aborber between compets must be 1 mm in x she cynol to the tray counter moll. T-> Must be about icon twin of It and I am thick of Cu to nee that the court in is wolly of), do a court to parte they counted The geomety as follows Converter -> Converter 000 Thisness VAA The detuting combers (for oway) one the hurde they to increase the outionuidence

Experiment on production of mesons by neutrons: 1) π^0 It is necessary: 1) the "radiator" R 2) the "converter" C 3) the "absorber" A between the 2 last counters 4) the absorber of γ radiation T $R \rightarrow$ The radiator must be a "sphere" $C \rightarrow$ The converter must be 1 cm Pb,.... $A \rightarrow$ The absorber between counters $T \rightarrow$ Must be about 1 cm thin of Pb,....

14 September

The geometry as follows:

And he continues writing what we could call today the "Technical Proposal" of the experiment...

30/XI 1950 Second Notebook: from 30/11/1950 to \geq 18/07/1951

1950

ГЯ ПАУК СССР ЛАБОРАТОРНЫЙ ЖУРНАЛ Nº 🐲 Отдел CEKTOP Nº TOB. Начато 🔭 1950 Окончено 195

30/x 1950

What Pontecorvo from November 1950 to September 1951 has been doing and why suddenly stopped writing in this first notebook only a few days after he started working at the Dubna synchrotron? Thanks to Gil we had the possibility to study a second notebook that describes the researches that Bruno has been doing during the months not reported in the first notebook. The starting date written in the cover is November 30, 1950 and the last date reported inside the notebook is July 18, 1951, just nine pages before the end of the notebook.

Page (1) of the second notebook

Ra ANS ra ANS A Herry dement · TR2 2 2=1 0 d Å A Light clements Twittim I meton E N+N { holiinin Te Matericolliung Fineton whitim M+N & Dirintegertim hh 10-28 cm2 TT Hippeneyes π++ MT+ P- AV+TTO ITT+ P -> N+2TT Carcable ITT+N -> P+TTo N+N-+ { scattering processes to P+TT ~> N+N T=TRZ frantiz + OCOLE(MUN) moz λ≪R 0,07 100 2 = E-200 -28

od A 2/3 Alevery lements

Pontecorvo starts the new notebook with geometric considerations on the order of magnitude of the total cross section for mesons production in nucleon-nucleon and nucleon-nuclei collisions.



Page (2) of the second notebook

in Tick 6 MATON C J << T (mc) when the I pretominout H will be 2) In a collation (that fuch that 2 TTV X b= W on top verter Then the collision will take place write must protochichty out if b is so small, there to Y waniformal Fo the helpbive my E 154TTA LL 350

Pontecorvo goes on for a few pages with these geometrical considerations, often scribbling numbers, formulas and graphics in a disorderly manner maybe just to fix thoughts and ideas that swirl in his mind.

1) $\sigma << \pi \hbar^2 / (mc)^2 \sigma << 6 \times 10^{-26} cm^2$ nucleon, nucleon,

when λ << ħ/mc

2) In a collision of parameter b the predominant v will be that such that $2\pi v \times b$ =u (relative velocity) Then the collision will take place with great probability only(?) if b is so small that v corrisponds to the relative energy $\hbar v/2\pi = E$ (?!! $\hbar v 2\pi = E \rightarrow v = E/2\pi \hbar$)

 $b \le u/2\pi v = u/2\pi (2\pi \hbar /E)=2\hbar/mu=2\hbar/p=2$ {E=1/2mu² $\rightarrow u/E=2/mu=2/p$ }

 $\sigma \leq \pi \boldsymbol{b}^2 \leq 4\pi \lambda^2 = 4\pi \,\hbar^2/(\mathrm{mu})^2 \rightarrow \sigma << 4\pi \,\hbar^2/(2\mathrm{mE})$

Page 4 of the second notebook

Pontecorvo very often uses the pages of these books just as a "rough draft" scribbling in a disorderly manner numbers, formulas and graphics, maybe just to fix the thoughts and ideas that swirl in the mind. It is therefore sometimes difficult to read what he is writing.



Pages 33-36: Draft "Measurement with a "star detector" of total cross sections for neutrons produced in the bombardment of Be with 475 400 Megavolt protons -"

Hepower will a to the bould with the 33 produced in the bould went of Re with 475 400 Hever Pryavet protons -Introduction - Total consultions tof mulei Los energies of the of the of the the our 280 Mit C . For Hour C she also avoitable measurments at 40 156 Hit. M. V. Jour 156 Me V. Total hon sections are would best measured of an attenuation method, in yood yearnety constitions, that is, with a great histome between the offerent and the detutor, monoto, out of fundor ant man Until now the following obtables hove been upen: u) Prophioritive findigertoes fourth u) CED (Friender un a n-2 neurotion. 2) Bi fishen chomber which but the fe (thistorich 2 50HeV) 3) A Telescope counting high weny revoils protons from or contraction way convits of perpentional atuntastant the the there of the articles

Measurement with a "star detector" of total cross sections for neutrons produced in the bombardment of Be with 400 Megavolt protons

<u>Introduction -</u> Total cross section of several nuclei have been measured for energies of ~ 40, 90 MeV () and ~ 280 MeV (). For H and C are also available measurements at 40 MeV () and 156 MeV ().

Total cross sections are usually best measured by(?) an attenuation method, in "good geometry conditions", with a great distance between the attenuator and the detector.

Until now the following detectors have been used:

- Radioactive indicators, such as C¹¹, (threshold ~ 20 MeV) () produced in a n-2n reaction (threshold ≈
- 2) Bi fission chamber (threshold \approx 50 MeV) ()
- 3) A telescope counting high energy recoils protons from a radiator placed in the beam () The telescope consists of proportional and a scintillating counters in coincidence (?) the threshold of the detector is

Pages 33–36: Draft "Measurement with a "star detector" of total cross sections for neutrons produced in the bombardment of Be with 475 400 Megavolt protons –"

without correction an average intensity of upstitue of mapelobian is free out free out the total pulse lunght is The punity of the ges, was not known to mis, boot must have been high become: 1) It was formble ato count ble B"initiation in prosence of schong plowingtion. 2) An inspection of the oscilloscope admay showed quite clearly the presence of two every promps construction of the distintigention to the person states one of the most first of Li a As a comptante of the integen his wine was very floop, as well as the curve ping The minh of pulses as a function of counter voltage at a given bias gatte The offorget us, was quest for the set of could be reproduced of within the stoket ever, and distance of several times,

without correction an average intensity of counts/min, when the frequency repetition of the cyclotron is /sec and the total pulse lenght is .

+ The BF³ counters.

The purity of BF³ was (?) not know to us, but must have been high because: 1) It was possible to count all B¹⁰ (?) protons in presence of strong γ radiation. 2) An inspection of the oscilloscope showed quite clearly the presence of two energy groups corresponding to the disintegration to the excited state and to the ground state of Li⁷.

The fact that the integral (?) bias curve was very flat, as well as the curve giving the number of pulses as a function of counter voltage, at a given bias, resulted in a good stability of the apparatus, permitting the reproducibility, within the statistical error, at distance of several hours.

The BF_3 neutron counters (pag. 17)

March 10, 1951

BF3 conters

No1, brass, 30m pressure BF3, unterins affecting. 20.8×1019 atomsof B" in total.

No2, phass, 10 cm pressing Btz, contains effectivez: 3.4×10's at mand 210 in the atoms of B10 in total

rampare cauter

2×64+44 828 64+60

3×67+28 29×64+4

March 10,1951

BF³ counters N. 1, brass, 30 cm pressure BF³, contains effectively: 20.8x10¹⁹ atoms of B¹⁰ in total N. 2, glass, 10 cm pressure BF³, contains effectively: 3.4x10¹⁹ atoms of B¹⁰ in total

kompare counter

glass 2x64+44 3x64+28

brass 32x64+60 29x64+4

Measurements in Cu of "Total σ with star detector" (pag.22) (Normalised) Results Notu, 26 cube with procobbetos 0. 544± 0.010 THE 行道 22 (Woundart) nefults. 0.04091 0.0018 Nocir, No Eb-aute "60 cm + Pb aube Cin 0.0405+0.0012 On Pers No Pb well 0.0413 1 0,0012 順 On 60cm , no Po-whe 0,0389 ± 0,0012 . On 20cm, No Pourse 0 0413+ 0,0012-MOF No Cui, no Bbunke 0.0438±0.006 1 20 priction or nortera of a tetate Berner No Cn, Ptroube Recurry linerated, However as close as formate 0,542 ± 0,010 No Cu, Please Cui 100m, 200 outre 0.214 + 0.004 P.555±0.008 (wir power forme) Carrown, Downe 0.106+ 0.002 0 NoCu, Struche Port 榆谷 高二酸 honofforman 36 contatt 0.352 \$ 4005 Cir som Pt ande 0.062 ± 0.0012 Windi Cu locin Boundie Profit Laton Blacole No Cu Pb cube 0.156 ±0.003 0.543 + 0.010 Culpin Pointe Pb wabe u Sun 后** 1. 0,151 + 0,002 0,235 ±0.0035 (ma power from) 0,405 1 0,006 vé Cu 5cm Bbank No Co. House 0.360±0.006 0,551± 0.012 Cn. 25cm Bbule 0.0845 10.002 Vit TAC soon, Pourbe En Joen Lbube 際で

0216 = 0.003

0,218 ± 0.004

Attenuation curve in Cu





Attenuation curve in Cu ** without paraffine filter * Point without paraffine filter o Point with paraffine filter X normalized to (The intensity is normalized ?? so that the intensity without absorber ?? X 3

 $C_{U\sigma\star}$

money its nopage theman

Cu σ with ~ 36 cm filter of paraffine O

Without paraffine filter

With paraffine filter ≈ 40 cm

This plot in semi logarithmic paper is inserted at the page where the previous measurements are reported The results of total cross section on Cu, Pb and Al are summarized on top of the page. In the central part of the page there is the draft of a letter for the request of soviet citizenship for the whole family. The letter is addressed to the Chairmen of the Presidium of the Supreme Soviet of the USSR, Nikolay M. Shvernik, President of USSR from 1946 to 1953.

For total σ meas. the attenuation plot vs the target thickness in a logarithmic paper will be used.

Summy of heralts 5 inte Total T' T = 1.19±0.02 TPG= 2,89±0,07 TAC = 0.60±0.02 Председателью Президина Зерховного Совета WBEPHUKU Thomas Baro Weepunk, uparts 76 подданство нета и ною сенью. Прошу Вас , т. Шверник, разрешить шне и шоей семье перейти в Советское подданство. then (Pag. 26)

Summary of results

Total σ :

 σ_{Cu} = 1.19 ± 0.02 σ_{Pb} = 2.89 ± 0.07 σ_{AI} = 0.60 ± 0.02

 President of the Presidium of the Supreme Soviet of the USSR Comrade Shvernik

I ask you, Tovarich Shvernik, to allow me and my family to become a Soviet citizen.

∧Log I

The total cross section measurements are done in many other complex nuclei

Proproven Cu? - m, E, U, C., Bougge A-Normoliter Total T I) Pb. us abroula. II) Nolt no absorber Pb, wo abroiber II) No Bb, 3on 4 abrilars \$ Sm, Fe, C * 0.612 ± 0.009 TI) It, we alsowled VI Ib +U No Pt, us algorles VI) Bb + Sm 0 0 413 ± 0.0016 VII) It + Fe MI) P6+U No Pb; Su 20 cm 0. 03 84 ± 0.0016 110) P6+0 X) PB+C No. 26, Fe 12 cm 0,0397±0,0020 XII. But Poerfe No Db, C 40m 0.0405± 0.0020 ETT) PB+ (m (5m) XTIA) Pin no elsore a Pb, no absorber 0.605+ 0.009 Til 2 Do + Doroff -The lo + propube: Pb, for Locan 0,166 ± 0.002 TY 5 Cm. 1211 XM Dan Cuit-Pb, Fe 12 cm 0.220± 0003 XVII No 26 moutron Pb, U 10em 0, 154± 0,002 Pag. 27 Pb; modrocca 0,537±0,006 0,034 ± 0,005 0013 0074 0,033 ±0,003 0,0463000 0,038 ± 0,002 15623 1270 Bi dur 1804 Pb, C40cm 0, 224+0,003 0. 325 ± 0.006 1.550 950 0.275± 0.004 1. 33024, 150. 288± 0.003 31 453 Ĉ 10.5551 0,008 Pb, Porofine Som 0, 200 ± 0.003 0.60 ± 0.02 1.12 0.500± 0.018 Al Fe 1.11 ± 0.03 柳 Pb, multorly 0, 603 ± 0,008 1.19± 0.02 proprint 1.15±0.02 1.145 20,0015 Cw Pb, Poroffen Soen 0,207± 0,003 Sn 2.02±0.04 328 3.8 1.83±0.03 1.87+0.03 Bb, C 40cm 1,22/± 0,002 2,89 + 0.07 453 (4)8 2,83 + 0,03 Pb 284±0,03 X Pb- Cu 5 em 0.360± 1.005 328+0.03 3.40+ 0.07 5.03 4.5 3.14+ 0.05 · () ·

Pag. 29

Pontecorvo interprets the measurements of the total cross section in terms of the "opaque nucleus model", a sort of optical model that take into account the reabsorption inside the nucleus

Pontecorvo interprets the measurements of the total cross section on complex nuclei in terms of the "opaque nucleus model"





Pag. 67

Pontecorvo follows the results on the measurement of the π^+/π^- ratio obtained in experiments done in the West.

Data on π^+/π^- Data on TT/TT-75, . (1467A-75,1467 A; 76,588, A; 77,526; 79,198 Mayer (?) et al, Aprile 1951, pp 15. p+p → no π⁰ 76,588,A 78, 497, 1950 - Chew and Steinberger Pauli principle, in normal interpretation, 2 effects: 77, 526,6 1) π^+/π^- increase at high meson energy, for a given proton 79,138 energy Myse madey Hilverbrouk, Knoble, Hales, Bullett. Am 2) π^+/π^- increase with decreasing proton energy And viceversa with neutron bombardment 78, 437, 1850 - Chew and Heinberger Bondi principle, in warmed integertation, 2 offerts: 78, 85, 1950, Richmon and Wilson -380 MeV protons: π^+/π^- in C = 5. ± 1.5 Entry 1) _ The coverse at high meron my, for a given proton Weissbluth, 78,86,1950 And Viceverta nion werden π^{+}/π^{-} = 1.5 ± 1 in Pb, p 340 MeV Brodner and Jones, 78,90,1950 π^+/π^- Be 2.7±2; C 4.8±5; Al 5.4±1; Cu 4.3±2 -78, 85, 1850, Michmon our Wilson -Brauner et al. Phys. Rev. 79, 720 3 potter from: $\frac{\pi^+}{\pi^-} \sim C = 5 \pm 1.5$ n 270 MeV $\pi^+/\pi^-=14$ Brauner, not published: Weissbluth, 78,86,1950 π^{+}/π^{-} , protons 260-270 MeV = ≈ 15 Browner Comel Routin -TT == 1.5±1 m. Pb, p 340Th2 Llip Der 78, 53720. Pag. 61 M 270Met. $\frac{\pi}{\pi + 2} = 14$ Brodner out Imes 78, 30, 1950 Bronner, not fublished; Be 27+2 protons 260.2701 C 4.8±5 AC 5.4+1 5,4+1 Ch 43t2

Some notes about a seminar that Pontecorvo is going to held on the measurements of the π^+/π^- ratio on nucleon nucleon collisions.

M- ferminore-

I wont to take on mulen -unless columns out II (to trios_ Discussion of experimental institute - apulation in which are the colorism widness produce mayous-Vouolly htp -> TT+n+h nth -> TT + n+h + n+n VV (Breaked Sign berm (n+2) thest traber (h+2) Whother is the evidence? unotibe p+hi hince the most it ; not the proof, resource 2non my IT" 2 nn Too mole - No (Nulofment) Astron out un hime ment / R.2 is a big winder let us ropet, it is clear That this kyrotus urtoyount parts baulog from the but not n+2->17 vist fromble conclude mut up to the "Condumm. Dup times we know. TT ~ VIT

Seminaire -I want to talk on nucleon-nucleon collisions, and π^+/π^- ratios – Discussion of experimental method -Conclusion on what (??) are the collision which produce mesons Usually p+p $\rightarrow \pi^+$ +n+p n+n $\rightarrow \pi^-$ +n+p n+p $\rightarrow \pi^+$ +n+n (neutron beam (n+Z) π^- +p+p (proton beam (p+Z) What is the evidence? $p+Z \rightarrow \pi^$ $n+Z \rightarrow \pi^+$ Since $p+p \rightarrow no \pi^-$, must be p+n $n+n \rightarrow no \pi^+$, must be n+pNot true proof, reasonable Ζ p n,n Too small - No Assuming only (?) n n $\rightarrow \pi^-$, then $\sigma^{\pi^{-}}_{p,Z} = \sigma_{neut,recoil} \times \sigma^{\pi^{-}}_{n,Z} / \pi R^{2}$ since $\sigma_{\text{neut,recoil}}/\pi R^2$ is a big number, let us say ≅ 1/5, it is clear that this hypothesis not against facts. Similarly from the fact that $n+Z \rightarrow \pi^+$, not possible conclude that n+p etc. p p Conclusion: only ??? we know: $p+p \rightarrow \pi+$ $p+p \rightarrow no \pi^0$ $p+n \rightarrow \pi^0$

Possibility of performing an "H⁴ experiment"

-H resperimentdrevort; which will be of the order of Englist intrine; MV= E Ez= 1 ME Har= = 1 E2 -= 1 (20×106)2 -1 ×105 V~ ~ 50000 eV. This could be measured in a small prop. comter Lat us assume thathe H4 Know have 20 cm air hoinge, The mouth topping is the comoth will be of the oblice of Bu country doioune ber tumore) If we have a stream countri with A, Thin the tumber stopping it of the reader a tuikness= home inching mother, ic: in a volume = 2771 91 × 3

- H⁴ experiment -

Possibility of measuring α recoil which will be of the order of (neglect neutrinos) $Mv = E_{a}/c$ $E_{a} = \frac{1}{2}M_{a}E^{2}/(M_{a}^{2}C^{2}) = 1/2 E^{2}(M_{a})$ C^{2}) = $\frac{1}{2}$ (20×10⁶)² / 4×10⁹ = $\frac{1}{2}$ 10⁵eV pprox 50000 eV. This could be measured in a small prop. counter . Let us assume tat the H⁴ track have 20 cm avr (?) Range. The number stopping in the counter will be of the order of counter diameter(cm avr)/Range(cm avr). If we have a 0.1 cm counter with A, then the number of stopping is of the order of $1/200 \approx 1/1000$ of those produced in a thikness range, in solid matter, i.e.: in a volume = $2\pi \times 0.1 \times 3$



H⁴ an hypothetical bound state of three neutrons and one proton. Never observed !

Physics but also Poetry



$H^4 \rightarrow \beta$ +v+He ⁴	Li ⁴ $ ightarrow$ unstable probably				
$Li^8 \rightarrow \beta + \nu + Be^8 \times o$	x Be ⁸ \rightarrow β^+ +v+Li ⁸ o				
$B^{12} \rightarrow \beta + \nu + C^{12} \times o?$	x N ¹² \rightarrow β^+ +v+ \mathcal{C}^{12} o				
$N^{16} \rightarrow \beta + \nu + O^{16} x$	$ F^{16} \rightarrow unstable$				
$F^{20} \rightarrow \beta + \nu + Ne^{20} x$	x Na ²⁰ \rightarrow β^+ +v+Ne ²⁰ o				
-	For meson work -				
Delayed α emission ??? :					
1) $He^4+\pi^- \rightarrow H^4$ (fast)					
$ ightarrow eta^-$ and He ⁴ recoil					
2) (a) $C^{12}+\pi^{-} \rightarrow B^{12}$ (for	ast)? C^{13} + π ⁺ → N ¹² +n				
	$ C^{12}+\pi^+ \rightarrow N^{12}(fast)$				
$_{\rm B}$ C^{13} + $\pi^ \rightarrow$ B ¹² +n	Ne ²⁰ + π^+ \rightarrow Na ²⁰ (slow)				

Sormovo Lyrics (Сормовская лирическая) Love poem (which later becomes a song) of Yevgeniy Aronovich Dolmatovsky. It talks about a boyfriend who dresses up and goes in the town of Sormovo to find his beautiful girlfriend, but he is disappointed by her.

The Russian text of the poem

also unpriori, the Expedic calekon YAR O Heplagh ighton Sections unda, plaber unbould. cheole3 adirino. Hay apenson oundfue anteren to repton anoponenio

На Волге широкой, На стрелке далёкой Гудками кого-то зовёт пароход. Под городом Горьким, Где ясные зорьки, В рабочем посёлке подруга живёт. В рубашке нарядной К своей ненаглядной Пришёл объясниться хороший дружок: Вчера говорила — Навек полюбила,

А нынче не вышла в назначенный срок.

Свиданье забыто, Над книгой раскрытой Склонилась подруга в окне золотом. До утренней смены, До первой сирены Шуршат осторожно шаги под окном. Ой, летние ночки,

Ой, летние ночки, Буксиров гудочки... Волнуется парень и хочет уйти. Но девушки краше, Чем в Сормове нашем, Ему никогда и нигде не найти. А утром у входа Родного завода Влюблённому девушка встретится вновь И скажет: «Немало Я книжек читала, Но нет ещё книжки про нашу любовь».

http://poetryrain.com/authors/dolmatovskiyevgeniy/10919

https://www.youtube.com/watch?v=Ig0g5-2fK5k

Page 85; Summer 1951 (~ July 11): Pontecorvo is planning the group activities for next year.

Plan for the year 85 I) Aramol Clex + bloching. Investigation of the possibility of existence of Ht, out, in cose of crisburce of Ht, inverty of its peopleties. he interest of property particulation of a nor pupil cight printer that in the part of the start of view of the many of cight printer that in the part of the start of according to the many of the start of within the next lew months. The first experiment invites in any the (hypermetical) & forticles into any the meticities have the constructioned, placed at a distance of 210 cm from the cyclotion Jorged. This without though give a longer twismements of while a measurement of the firme (experiments) and the source of the produce on the If the first ferment is meenfull, it will take about a year to investigate the populas of H4 (nuture, lifetime), and wayledge to study in what contribut it is feadneed. If the texperiment is not meenfull, other mithods to the confidence one these these one approximation of the article of the prosting the country the country of the prosting of the country of the cou biased & about it does not require ouring to pochecked of En < 14 The V, and brufolded gittentern), proconfilled with the) b) Proportional country Debuton of delige Doe & posticles (~ few tens KV) collengancy to the recoil of B from #4 # 4-+ Het + B+ wenterins, In This experiment the 50 to T mom routh be used to peolice # accordy to T-+ Het > # #+ Het All the experiments above manihissed anog toot and now ou of aneworn cosult but Unfortunoted the interest of the feeblam

Plan of the year

85

I) <u>Anatol Alex +Vladimir</u> Investigation of the possibility of a stable state of H⁴, and, in case of existence of H⁴ investigating of its properties. The problem is interesting from the point of view of the ?? light number ?????? on the ?? β decay. Preliminary experiments should be done within the next few months. The first experiment consists in curving the (hypothetical) β particles in the cyclotron magnetic field and registering them in 3 counters in coincidence, placed at a distance of \geq 10 cm from the cyclotron target. This method should give a rough measurements of H_{ρ} , while a measurement of the lifetime (expected value $\approx 10^{-3}$ sec) is made by electronic methods. The H⁴ could be produced in the target by nuclear interactions (?): for example Li⁸ excite \rightarrow H⁴ + He⁴. If the first rough experiment is successful, it will take about a year to investigate the properties of H⁴ (spectrum, lifetime) and ?? also to study in what condition it is produced. If the first experiment is not successful, other methods are considered: these are a) detection of H⁴ in a long liquid organic scintillation counter, biased so that it does not register ?? β particles by Energy \leq 14 MeV, and ?? by high energy neutron. b) Detection (on a prop. count. filled with He) ? of delayed lphaparticles (\approx few tens KV) corresponding to the recoil of β from H⁴ $H^4 \rightarrow He^4 + \beta + neutrino$. In this experiment, the 50 MeV π^- meson should be used to produce H⁴ according to π^- + He⁴ \rightarrow H⁴ + He⁴

but unfortunately the interest of the problem

Page 85; Summer 1951 (~ July 11): Pontecorvo is planning the group activities for next year.

double meson person for This weight des a chemist timique). chemical technique). Supplication from Ivon talevon Prisodopo Beogentus of Inferenchine with II - Development of terriques capoble of detuny by neutrons. electronically atompt werons = for the Terristipohen the 2.2 μ s μ^+ – e⁺. The Investigation of The method counists in detecting the TT from the 2.2 ps fitet. The n-p has special inbarry, 寳 become until now there is no certain ??? Counters. evidence most chough meron she inturing Roberton in n-peoplitions. Direct detection of the worm beam (+an-) ΤĊ from the yelother with tothalis untrady. Application to pr wearin of IT /1- lotio. Application to change of II cotion with Z The method are might performed committee or feichtlation combes in connerdence. Development of Cohenser detectore, V for the study of calobivistor posticles

double meson production (this necessitates a

III Georgy Ivan Selivan -Development of techniques capable of detecting elettronically mesons . Investigation of π^+ production in hydrogen and other elements

The method consists in detecting the π^+ from

The n - p has special interest because until now there is no certain evidence that charged meson are intensively produced in n-p collisions

IV <u>Direct detection of the meson beam (+</u> and -) in the cyclotron, with electronic n

Application to the measure of π^+/π^- ratio. Application to change of π^+/π^- ratio with Z. The method will use small photoplates?(?) counters or scintillation counters in coincidence

Development of Cerenkov detectors, for the study of relativistic particles

Page 91: July 18 (1951), is the latest date on the notebook. Only 9 pages remain to the end. Pontecorvo describes the activities in preparation to the planned experiments with neutron beams that start simultaneously in the experimental Room 2 and 3.

たいむんい 91 les un from shell. ~ shipt nice wenter beren: 120+64 (But mere was apprentus!) - 2til necessary to ask spenial time, about 2 hours, To meanue confully Ef(E. 2 MERL=2 Conclusion: subtraining the beam hime the beam was very wide, but and the phildring of the big window poor, " but the cyclotion internety lost, The baingeound inditions de 2 like they will be : - Baing of a King 2 10000 /min -Calculations of bang on July 18 Experiment on IT -- Box No 1, in hoom 3 of yelotian building-Voltage: 830V- V Cajchation does not work: AB-(C, C') Triggers (CC') sulager 2222020 24×64 +25 /min 24×64 +50 Corelation works with intensity mariant 34×64+32 42+64 +28 AB-Bulseof 42×64 +24 Voliald С JUT 1- Ender helps 44264 +0 A -æ-Cat - Amin Critikan way wot work 23+64+ 49 Bach pome: Room No 2 With bention bear (AB-C) (AB-C) X Z , twoll - , buouse pathing Through 30830 ofen window, and fered fluidening very book with bring : Neve the wall close to shrinefa room: commic log back degreeped by mitron roder, copied \$ 70x64 /min 2 60 x64 min AB-Co and close mull and AB-C and close sheepithing pre-industrial bothiles from Maximum intensity mous "maximum" for the Lookistor. time being, ie ~ 1 - 1 times less throw upual; because the Voltop on Diment be trull

Pontecorvo resumes writing on the Notebook the following year, September 14, 1951, starting from the last page (n.100) turning the book on the opposite side. He has now decided what to do and he is ready to make an "Experiment on production of mesons by neutrons":

~** 0000 10000 500000 $T + h \rightarrow n + \gamma$ IT the a wtT? T+n-271+1+1 +h->T+h 2 N.N. 2=

hentems It is necessary : 1) The " having on 2) the "inverter" obsorber" 4) The absorber of y lodistion T Asy The codiator must be a phile of diameter It the Diometer Dum foraff. = m.f.h. fr. J. (> The invester must be I cm Ib, dea equal to the country they onea A > The aborber between compets must be 1 mm in x she cynol to the tray counter moll. T-> Must be about icon twin of It and I am thick of Cu to nee that the court in is wolly of), do a court to parte they counted The geomety as follows Converter -> Converter 000 Thisness VAA The detuting combers (for oway) one the hurde they to increase the outionuidence

Experiment on production of mesons by neutrons: 1) π^0 It is necessary: 1) the "radiator" R 2) the "converter" C 3) the "absorber" A between the 2 last counters 4) the absorber of γ radiation T $R \rightarrow$ The radiator must be a "sphere" $C \rightarrow$ The converter must be 1 cm Pb,.... $A \rightarrow$ The absorber between counters $T \rightarrow$ Must be about 1 cm thin of Pb,....

14 September

The geometry as follows:

And he continues writing what we could call today the "Technical Proposal" of the experiment... In September 1951, less than one year after his arrival in Dubna, Bruno Maximovich Pontecorvo is a respected group leader of a group of young physicists (Vladimir, Anatol, Alex, Adolph and George Selivanov). In group meetings he assigns the work to be done by each member, defines the program to be fulfilled, etc. as for instance is done in these three pages:

1) Vladimir : . Finish work on H4, in the Anotol. Alex. bresent variant, + report. Help of 2) Adolph : Finish work on metons with hordioactive indicators + report. Have B counters ready. Here a counter ready 3) Seonje 1) Finish work on duty frieton + report -2) Conclude on the work of production of Thin C by mentions * _ . 3) Initiate electronic detection of myons 4) Finish one Schound considence + rintillator (10⁸ sec), on the feitheriple of 1-2, 1-3, 2-3 double cannidence 10⁸, thiple 10⁶ 106 + 1 channel coincidor outi, externol. external, coincid, routicoincid. Armember dolog of 5×10⁻⁸to moosure widental. 100 auidental. 4) Anotol : finish work + white Preports a) onguloa b) total work on seconday neutrons

1) Measure the effective duty fritter of the gelation as follows - Fritmis: a) Measure the repolicing time of the system (using continous tources). b) Measure the accidental hotes when the gelation works. Experiment a: In the gulation building with a distance of two mags of about 15m, and with 2 sources, measure: 1) Single hotes, our coincidence: (D-A-Binovolo from this we get z tome without 2) four with no toucke for consting volues in subsequent experiment. Experiment b: Experiment 6: 1) When exclotion works, fingle hotes and enimidence hotes. Meaturment of d, duty factor. Take 2 pingle combins. + T) Put them on the beam, for eway, with from each other and measure A B (AB) Varify that Varify mot the cyclation is constant. 宜) 亚) offer phutdown, A, B (AB). \mathbb{I} Write all date about to the yelotion V) If cooperiments reorougly reproduce ble, VI they verious conditions of exclotion.

The activity of the group is rather well documented daily

-Workshop Time -15 Centralista Tey yourson. A 124/ 180 Telescope To test The volines coincidence and outicinitence officiency. Nobe: in this make the following experiments the new a: Rotat. *480 B 46/264 94 , m tens the yeartin Wes constant, but wel the monitor ! Toke me time, Big pinkbox: Q CD yatoge 560 By black box: 2 1263 55183 It was devided to could * To that the BLD-A 20 ferry willes hundle box: A 885 yuurom. other burdle they : B. time for is will be: 885 c non bepringolu - Ist experiment, testing a notucal printing Teleptope G.I 1801 1400 977 /3mg 514 4 264 В 180 other teleprope. Manar (AGBC') 669 CD 0000000-B-C fine but 656 fundle work 100 The christ Figl (ACBC')= 57884+0 | 5684+1 BLD-A 10×64 + 60 100 Small chaspi See non bepingen 2 ×4+3 (ABC-C)= 15x4+0 100 Rent + Verdimin 1436 A 660. Jantopina -605 35×4+2 5x64 (ABC'-C) 41+4+2 693 C 1000 /3m D Withno 700 Voltageon BCD-A 5 ×64 + 26 Of these: = Februar 16 2 24h felivour 3 Tochous a nojem abran in Sey horebeforega infinders I experiment 883 A 993/3m 421 B 13 core the bilande 643 CD 651 2) reports 000000000 BCD-A 2×64+27 3) 2 cmolotr Foyz Torboko c nogenicobron a c hope begingoen (AC'BC)= 119 /2m 4 4) Tonemour 57 Here 1 847 (ABC-C')= 53/2m A 371 B (A BL- C') = 140 1007/3~ 612 615 D 27 Febbraio - Wormshop time: wovallac BCD-A 4×64+17 mC 630. C Konbegniefold This is no good . Cu 1806 2 telesure - Repeat experiment, often change of electronic. -(AC'BC) = 54×4+1 51×4+3 982/3m 400 hs Foy2-534 Fe shield 634 25 hs 1 (ABC-C')= 15 x4+0 15 x4+3 677 Þ thati 86 (ABC-C')= 42 ×4+3, 43×4+2 30 41 BCD-A 6864+33

Workshop time requested and used to build support and mechanical structures Measurements to test the various coincidence and anticoincidence efficiencies

Data taking

The activity of the group is rather well daily documented



Final results on meson production by neutrons

The speech of the Group Leader

A close collaboration between the various members of an experimental group is vital for the success of one experiment. However it is not always easy to ensure that the group collaborate efficiently as it is well known to every group leader; and the Pontecorvo's group was not an exception. Here is the draft of what Pontecorvo says in the group meeting of March 6, 1952:

March 6, 1952 meen. This means that GIV. will belf, become & IV wonth to estimate in molen V Hype and not to been monoton the your We have this meeting in helption to some reoryouissti we with this expirience of electroms design and of our years. The first think is that there is a construction, other members of proup. This new addition. The second is that we must have internel colloloiothin must be finantly. This colloloidint must also be 2 ways, i.e. in the indust of all. alitentians more frequently. For this we will made a tennoise every week of ~14, a thinkday at 6 a. This tennine will be on informal organisations advice and be thanked withe oble the Of perficiely, what does this mean reacyonisation I That he will perhapped in experiments will have 2 points: a) Briefly sing memby of years meon: will describe the propress of the week I) G. I will help in jewed with advice not and B) There will be a hif mention other would of the poup and delethering peoblems of what boybunction prograss in the town is interesting II) The help soon he for by phelis in the week's new our our focuing found soft I) In addition to ordivice, these will be The trink is the most important thing hore concerte form, fire soluce that we have to childrense. In my opinion presented Appeartus, and even given the way of construction I una metrin' holotoms invite out youp were to not this besting in other words full collocation, sobisfactory, France When anang cramples Were members out yroup, for example, went That secons, that on a ger in trans, steeler for advice to other group, while there exist in our promp a very will guologica many the inferend 6 I will took make in this sile of the thereing one your, because of these heloting could not more the of the these belowing Benn word that on the word in the gold buildy Monitor III) The devotion This applies And find forms Thinness III) It is essental That, generally speaking, now whose is fould. And also we unertast ditures, in general, the parts, that the out ery theme that more on len his own think in which we must agree, is to forget the to aunt that the start of was not to high and (we must forget show it radicely, ofgodotas. This wear, severally not Mufting of on they inter a frem to other. IV) the work tother on the muse How con we change it wowirdly, for the ford of the total scientific production of the your for well of which is also Epertury, Cost on the continu to avoi only more had In ou This necessing that it is contaction Amore his own teine. This is newson of colloloustion in one poup. What does this 6 Esoluotin,

The speech of the Group Leader

March 6, 1952

We have this meeting in relation to some reorganization of our group. The first thing is that there is a new addition. The second is that we must have internal discussion more frequently. For this we will make a seminar every week, of $\approx 1^h$, on Thursday at 6^h ...omissis...

The third is the most important thing that we have to discuss. In my opinion personal relations inside our group were very bad not satisfactory. There were many examples where members of our group, for example, went for advice in electronics to other group, while there exists in our group a very well qualified man in electronics G.I. ...omissis..... the situation was not satisfactory and we must change it radically, for the interest of the total scientific production of the group. For this is necessary that it is established more collaboration in our group.



What does this mean? This means that G Iv. will help, with his experience of electronic design and contruction, other members of the group. This collaboration must also be 2 ways, i.e. in the interest of all. Specifically, what this reorganization means:

I) G.I. will help in general with advice other member of the group on electronic problems

II) In addition to advice, there will be more concrete form. Give scheme apparatus, and even of constructing and testing, in other words full collaboration on a scientific thema.

III) It is essential that, generally speaking, every thema has more or less his own apparatus. IV)....omississ,Cast (?) and Gean (?) continue to work only with George Ivan.. on his own theme. This is necessary because G Iv wants to work(?) in nuclear physics and not to be working on constructing apparatus.

V) The interest of other people in the group will be of course that will have advice and be trained, of G. I. that he will partecipate in experiments

VI) Rememberis good what is for everybody

The problem of non-collaboration in the group between the electronics expert and the other members is perceived by Pontecorvo as a general problem in experiments of particle physics, very much present today even to a much greater extent. He then writes a document on how he thinks this problem should be solved.

- Electronics and Nuclear Physics-Bactor day research in nuclear physics agains a great deal of modern distance apparents. Mutil a few years ago, those it (was the partice natural toot? The experimental physicits to produced himself all the electronic equipment necessary for his experiments. However notes this power is investing "standard be clear to everybody and electronic promps, producing "standard equipment" and developing new advances transpires is very derivable. Without an electronic years, the production of trientific usuality and infects the contraddiction between the forest of meetings. The form a developing way advances transpires is very derivable. Without an electronic years the production of trientific usuality and infects the contraddiction between the forest formed or and infects the contraddiction between the forest of meetings infects the contraddiction between the forest of necessary of the advance formed only is necessary to produce the borne of on electronic years for physic issocch. It is meeting also because it is not possible to expect that every physicit in the borne it is not possible to expect that every physicit in the borne it is not possible to expect that every physicit in the borne it is not possible to expect that every physicit in devery competent in the twice of course men which menage to be we prove the time the of course men which menage to be

physics, but there are exception: If we think there will be the men which can address one knowledge in the file of inder prephysics out of electronics. If we expect that every more in the laborton must be mab, we some of the " win fortor consistering of the present dy high productivity i.e the specialities. The speciality in prime out temposities speciality to have a unglionent it may be.

The presence of on deatinic, group requires not our multing

the lettinic purp but dro

by one about equality of " status" between the men imposed experiment out me un injust is "unlear plynes". This kas indition is often about print is very

The telestionies important, because in some physics labor trics there is the tendency to put hunder place on a tright plane then elections. This "involve" is without foundation, and is not the the product of the matter physics. It is the protouper discovery of a new postile is use important that the Realisation of a Hickorolt, but it is equally the mot the introduction of negotive feed link, a tradevelopment of the travelling wave oughfir is uncho more important tum that the other stranger and the second of the stranger in I. " house and " is kept clock it is importable a collaboration between tecthance and timeter physics to become the formage twent to will don't profer to "dwinge profession" and the under plais. This ingener In this was then will la Right totology totoms the phofessional becouse &. electioner work will wont to make in experiments out The positulity of criptures of on clerkonic proup. as It, on the contrary the electronic mon will feel that his workers a precised, must be con your particle of the with development of new reporters, onen be will peneory continue to work in a full, and and the

Draft of the document on the problem of collaboration between experts on electronics and in nuclear physics

- Electronics and Nuclear Physics -

Until a few years ago, it was natural for the experimental physicist to produce himself all the electronics equipment necessary for his experiments. However nowdays the quantity of electronic equipment necessary for research is so great that an electronic group, providing "standard equipment" and developing new advanced techniques is very desirableomissis The presence of an electronic group not only is necessary to produce the large quantity of equipment necessary for physics research. It is necessary also because it is not possible to expect that every physicist in the laboratory can design and produce first class equipment as a "professional" man....omissis.. The specialization in science and techniques todays is a necessity, **however unpleasent it may be**. The presence of on electronic group requires not only continuous control and discussions between the nuclear physicists and the electronic group but also an absolute equality of "status" between the profession in "electronics" and the profession on "nuclear physics". This point is very important,

because in some physics laboratories there is the tendency to put nuclear physics on higher plane then electronics.....omissis.....It is true that the discovery of a new particle is more important that, for example, the realization of a stabilovolt (?), but it is equally true that the introduction of negative feed-back, or the development of the travelling (?) wave amplifier is much more important that for example, the study of a certain p , 3n reaction. Electronics and nuclear physics are 2 parts of physics of equal importance (?). If this artificial behaviour (?) is kept, clearly it is impossible a collaboration between professional electronic men and professional nuclear physicists: the professional electronic man will want to move (?) nuclear experiments, and consequently disappears the possibility of existance of an electronic group. If, on the contrary, the electronic man will feel that his work in electronics is appreciated, that he can gain prestige by the development of new apparatus, then he will generally prefers to work in such field.

The Teacher

At the end of February 1952 Pontecorvo is probably doing some teaching because he writes in the Book this memo in "Italian". In the three following pages he writes these formulae and evaluates the ranges for proton and deuteron in Cu and Al at various energies

1) Masse in Mit e, wermen, in D CHONMORE CANER BRIARY GROUDER FUR 22:10 2) Relegione two mounts (Aut), Total energ (in Mat) Kimbe every (in Mit), B 3) Istansimi un nomogrouma per konece A, momento, KE, Total Eng ground tim la massa di una borhullige una di 938, \$155 C.61 Naka flaren - purtequents honges 4) provi mito 5) 6) troments: autofivirtic 11 28 89

Dare formule approssimate for per:

- 1) Masse in MeV e, mesone π , mesone μ , p, D
- 2) Relazione tra momento (MeV/c), Total energy (in MeV), Kinetic energy (in MeV), β
- Istruzioni in monogramma(?) per trovare β, momento, KE, Total energy quando si sa la massa di una particella e una di queste quantità
- 4) Ranges
- 5) Rossi units
- 6) Momenta: relativistic

The Teacher

Around the end of February 1952 Pontecorvo is probably doing some teaching and he writes in these three pages few relativistic relations and evaluates the ranges for proton and deuteron in Cu and Al at various energies



and the second second	the second s	
-Units	Election	help bivirbics.
amentity	Symbol	Definition
1 Charge	e	charge of electron
Pobential	5	volt
J Velouity	С	velocity of light
Lenght	cm	centimeter
/ Tinue	(110)	time accurace for limit
10 mile	C C	to travel Im
Energy	w	energy of on electron
		accelerated of 1 volt.
Mass	eV	mais of a foctule whose
	Cre	best every is 1 ev
Kowentum	eV	momentum to e Lichide
	C	for which total man 2 -
		hest every 2 = 1 (or momentum
Electric field	K	of a porticle whose energy is I et
	an	oudring-
Force	ev	force acting on on electron
	cun	in a fulla of 1 V/cm.
Maynetic	V	Maquetic induction of a
(B)	c un	field in which a poeticle
		with unit unmention
	8	build unit change has a
		when twitching with his
mg	r r	to the field (10% en =
-		= 1 gouis)
. (1) erte and	
m B	CHP= mal-	
VEWAS	The R MIL	2



hange of protons and hange of Denterms -

Everyis (MCV)	$\iota \rightarrow$	10	20	30	40	50	60	70	80	90	100
Proton hance -	fin Cu	0.25	0.75	1.4	2.4	3.5	5.0	6.5	7.7	10.0	12
(qu/cut)	Lin Al	0,15	0.55	1,2	1.9	2.9	4.0	5.3	6.5	8.0	3,5
-											
(McV)		240	280	320	360	400	440	48D	520	560	600
Broton.	\rightarrow	53	68	86	104	122	142	/62	/83	204	226
(gh/um")	L	4 3	56	72	86	104	120	137	156	173	193
						· · ·					
		, š		·							
Re											
Energi (Mct	x ->	20	40	60	80	100	120	140	160	180	200
Dentum Rouse is	~ S ^{cu}	0,5	1.5	2.8	4.8	7	10	/3	15.4	20.0	24
(gh/and)	LAC	0.3	<i>.</i>	2.4	3.8	5.8	8	10.6	13	16.0	13
								Per	white of	h' ener	gia
ES	Cn	Ae	-						(MeV	19p/con	-)
200	3.03	3,5	8								
300	2,65	3.1	2								
350	2,21	2	59 +3								
500	1.89	2.	20								
1111											

In this book there is the story of some experiments on meson production by neutrons and protons both on complex nuclei and protons performed by Bruno Maximovich Pontecorvo and his small group of young physicists at the Dubna Cyclotron. He continues to use this book for drafts, sketchs, notes and mainly as logbook for data taking of the experiments performed during six months from 14 September 1951 until end of ($\geq 24^{th}$) March 1952. The last few pages are a draft of the paper "Production of neutral mesons by neutrons", which concludes the experiment proposed at the beginning of reversed side of the book, and published (see next slide) as internal report in Russian (B.M.Pontecorvo, G.I.Selivanov, RINP, 1951).

- Production of ventral mesons in a by ventions -

A) Introduction B) Appenditus C) Absolute experiment in Carlo D) Beladine magnetic Disconting in the time to protection of any reas E) Pelotin p measurements F) Discussions a Birchine main - - further

Introduction.

White the frontide amount of date have been published in the last years on the production of chart metans by matures to the production of charter metans by mentions has been to for only the object of a thout commission and the production of mentions by heading to been a properties to be for most in the production of presting to for the production of presting to be the production of the product of th

It is in the from this table that production of choryd and ventical mesons in the collinions had not got been appending and protion complet under the other of platents of ventice metors by vertice not spet her above of their two is corner, Becompe of the absence of darte on their tubert, it was matural presents the continuents The first work we report experiments the front most of our laboratory, we have investigated (and observed, for the first time), the front time of weather the first time), the front the is that the first time), the front is of the track mesons in Hydrogen and complex threlegi of neutrons. The contraction of the two for the two for the - Production of neutral mesons by neutrons -

Schema:

A) Introduction B) Apparatus C) Absolute experiment in Carb D) Relative measurements Discussion in relation to production of mesons E) Relative measurements F) Discussion a) production b) λ G) Conclusions - - Spectrum

Introduction -

While a considerable amount of data have been published $^{(1)}$ in the last years on the production of mesons by protons from accelerators, the production of charged mesons by neutrons has been so far only the object of a short communication $^{(2)}$ and the production of neutral mesons by neutrons so far had not been observed. The following table summarize the present day information on this subject.

Table I

It is clear may be seen from this table that production of charged and neutral mesons in elementary n-p collisions has not yet been observed, and not even in complex nuclei. The production of neutral mesons by neutrons has not yet been observed. For this reason, Because of the absence of data in this subject, it was natural presents some a considerable interests

In the present work we report experiments we have made utilizing the neutrons from the syncrocyclotron of our laboratory, we have investigated (and observed for the first time), the production of neutral mesons in Hydrogen and complex nuclei by neutrons.

First internal reports on π -mesons production

АКАДЕМИЯ НАУК СОЮЗА СОБЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПЛЕНИК

661. 647.562 Mpariba

"YTEEPAHAO"

Начальник Гидротехнической лаборатории Ай СССР доктор физико-матем. наук

/М.Г. Жецерянов/

иарта 1952 года.

отчет

попятка детектировать здерное рассвиние Л -мезоноз с обланом зарида при пожоци радиоактивных индикатороз.

> Руководитель: проф. Понтекорво Б. Исполнители: проф. Понтекорво Б. инд. Цухин А.И.

March 1952

 $\frac{\text{REPORT}}{\text{Detection of charge exchange scattering}}$ $\frac{\text{of } \pi \text{ mesons on nuclei by the method of}}{\text{radioactive indicators}}$

Leader: Prof. Pontecorvo B. Executors: Prof. Pontecorvo B. Eng. Mukhin A.I.

Internal Report in Russian dated March 1952 kindly provided to us by Gil Pontecorvo Attempt to detect the tractioning of The metons by

Introduction

The interaction of TT mesons with mucher was first investigated in the count way region, with conflictury on interestion membre for for the TI meters produced in survey of culotivishic forbieles of the order of the "genetical "win frepater, while Direin with wombe funiques, altorived in meon fee forth > 10 times the powetwich were fear forth. This description devicent the to the Current on couse ellon in the interprototion of Riterary, when work with outificial IT metros from acceleration was initiated. Perfort the repulting of B Truph (inpelaye) should definited pust To work interest Notes mulei with a non section of the order of permittion It occurred to us thist soon anon subiary of this order could be defected with the method of hodioschive indicators. In fact the internities () of the order of 104 /m /per , which are available ingaber form for galathan of our lalastory it can be from the galathan of our lalastory it can be existing the post in another in incontances it is possible to detect the postation of the formation will be work and the formation and for the formation will be and the method will be the formation of the formation of the the incontant formation and the the formation of the the the the formation to be and the formation of the start of the formation of the incontant formation of the formation of the formation of the incontant of the formation of the formation of the formation of the interval of the formation of the start of the formation of the form inja bear form 29 mons) I veloptic tolition of the weton ghe IR with non ener by given bethe unders inpostfur to pertince to

> Draft in English from the Notebook (~ October 5 - December 25, 1951)

<u>Attempt to detect the charge exchange</u> <u>scattering of π mesons by the method of</u> <u>radioactive indicators</u>

Introduction

The interaction of π mesons with nuclei was first investigated in the cosmic ray region, with conflicting results. Brown⁽¹⁾ found an interaction mean free path in photographic plates for the π mesons produced in showers of relativistic particles of the order of the "geometrical" mean free path, while Piccioni, with counter techniques, obtained a mean free path > 10 times the geometrical mean free path. This discrepancy was removed when work with artificial π mesons from accelerator was initiated....omissis... It occurred(?) to us that nuclear interaction with cross section of this order could be detected with the method of radioactive indicators. In fact with the meson intensities of the order of 10⁴- $10^{5}/\text{cm}^{2}/\text{sec}$, which are available in a beam from the cyclotron of our laboratory it can be estimated that in favorable circumstances it is possible to detect in light elements the production of radioelement with cross section only 10⁻²⁷ cm². This report will be mainly concerned with an attempt to detect the reaction $\pi^+ + B^{11} \rightarrow \pi^0 + C^{11}$ from the radioactive indicators.

First internal reports on π -mesons production

The results of all experiments carried on by Bruno Maximovich Pontecorvo with his group of young researchers in the period 1951-1954 at the five-meter cyclotron were published as internal reports in Russian, some of those were also published later in 1955. In these early experiments the production of single charged and neutral π mesons with proton and neutron beams on proton and complex nuclei were performed: The production of π^0 with a neutron beam on protons and on complex nuclei was studied for the first time in the world (B.M.Pontecorvo, G.I.Selivanov, RINP, 1951) and (B.M.Pontecorvo, G.I.Selivanov,

RINP,1952; Dokl. Acad. Nauk SSSR,102,253 (1955)).

- Production of neutral metors ion or by neutrons -	"THEFT HAD"	
1) Introduction B) Appenditus () Abertuke experiment in Cech D) betakin meagenements Discossing in the time to productive of antropy E) Petertin 1 merror memory 5 F) Discussing all controlingions - full time	JORSOD MUMICO-MUTCHELIN HAYK Maurana (H. T. 1801 1895 1803)	
Introduction. Vetrike Winter Vetrike A considerable amount of date have been published	· St. = Clyf57. 2) 1952 .	25 September 1952
in the last years on the production of chose metrus by protony the temperate production of chosen and by mentions has been to for only the object of a short commission and the production of method techning by reactions to for have not been placed. The following telle	CENTOP F 62	
hummehing the parent-day information in this fubpert. Table I	$\frac{0 T 4 E T}{0 P A 30 B A HUE} \qquad \qquad$	<u>REPORT</u> Production of π^0 mesons in (n-p) and (n-d) <u>collisions</u>
It is the last the this tothe that we not get been offering and wented mesons in the colligions has not get been offering and have in quality that the other planter of remoted metrys by well when not get been observed. For this worm,	Начальник сектора # 62 профессор (Бей-Поктекорио)	Section leader Professor (B.M.Pontecorvo)
Because of the absence of decte in their subject, it was matured frequents and instructions The frequent Work we report experiments the how more utilizing the renting from the	Изполнителя: пробессор (Б.М.:Понтекорво) Ст.никиер (Селиников Г.И.)	Executors: Professor (B.M.Pontecorvo) Engineer (Selivanov G.I.)
inversessation of our laboratory, we have invertigated (and observe for the first time), the production of neutrol mesms in Hydrogen and complex under of neutrons. The concords on the during of neutrol	1952 r .	

Draft in English from the Notebook (~11/18 March 1952)

Internal Report in Russian dated September 25,1952 kindly provided to us by Gil Pontecorvo

Experimental and theoretical physicist

From the pages of these notebooks it emerges clearly the figure of a brilliant experimental physicist with extensive experience of the most advanced particle detectors and, at the same time, of a distinguished theoretical physicist.

The scientific interest of Pontecorvo goes far beyond the scattering experiments of nucleons and mesons on nuclei, although important. When he arrives in Dubna has already given fundamental contributions to the understanding of the weak interaction mechanism and therefore one should not wonder if many of his reflections concern the true nature of neutrinos and the study of the so-called strange particles.

Very interesting what he writes on page 8! ! (beginning of November 1950)

on the frankformations of methis The 2 meter has a long life ? 10 the , and and supposed to decay into TT++TT+TT If this is to, it must be included that I does not interest with mulei, become, if the & induceds with mulin, then the lote of the second would be vie bost. (through the indication with uncloses of the vacuum) Let us suppose that it does not infusit Stingly, hime it is strongly produced, it must produced. as a bring promit of a strongly intracting metmalle But this Mo then would decoy who TT quicker thon in V. to there is a contradiction between the criptime of a strong inbroiting pointile, and its long lifetime. This contradiction, of counter, is repolved if the strong proticle is produced in poin. to from the very but the tay 2 merons have a long life, it ion be out 6) prot they are present in abundling we con combuse That there are metans curtinions Muchingsons) the theorigh for the for the fort with s prituke until wow would be whitent In -> C+2H TT-> W+Y culobin no other inesonthat $\mathcal{Z} = \mathcal{K} = \mathcal{V} \longrightarrow \begin{cases} \mu + i \\ \mu + i \end{cases}$ Therens tree been produced. Vount => TT+por TT+p Vo herris h+TT

On the transformations of mesons -

The τ meson has a long life >~ 10 -9 sec, and is supposed to decay into $\pi^++\pi^-+\pi^+$. If this is so, it must be concluded that τ does not interact with nuclei, because, if the τ interacts with nucleons then the rate of the disintegration would be very fast. (trough the interaction with nucleons of the vacuum) Let us suppose that it does not interact strongly. Since is strongly produced, it must produced as a decay product of a strongly interacting meson M. But this M then would decay into π quicker than in τ . So there is a contradiction between the <u>existence of a strong</u> <u>interacting particle and his long lifetime</u>. This contradiction, of **course**, is resolved if the strongly interacting particle is **produced** in **pair**.^(*) So from the very fact that a) τ mesons have a long life, b) that they are present in abundance, - we can conclude that there are mesons (not necessarily the τ mesons) which are strongly produced in pairs.

(incidentally these considerations explain the fact that until present day cyclotron no other mesons that π mesons have been produced.)

 $+\pi^{-}$

2

A consistent picture until now would be:

$$\mu \rightarrow e^{+}2\nu$$

$$\pi \rightarrow \mu + \nu$$

$$\tau^{+} = K = V^{*} \rightarrow \begin{cases} \mu^{+} + \pi^{+} \\ \mu^{+} + \pi^{0} \end{cases}$$

$$\mathsf{V}_{\mathsf{O}\mathit{light}} \!
ightarrow \! \pi^-\!\! + \mu^+ \, \mathsf{or} \, \pi^+\!\! + \mu^- \, ?$$

 $V_{Oheavy} \rightarrow p + \pi^{-}$



^(*) here, at the end of 1950, without the notion of strangeness, a deep intuition is needed to propose a production process in pair to solve this contradiction. ^(**)maybe just a coincidence! Two lines before he writes $\mu \rightarrow e+2\nu$ while here he writes $\mu \rightarrow e+\nu + \nu$ engraving the neutrinos with two different signs. Two profound intuitions in a single page ?!

Strange Particles

The experiments on π meson-nucleon interaction performed at Dubna in the early 50s are certainly of great interest for Pontecorvo in understanding, at least phenomenologically, the strong interactions in the π meson-nucleon scattering.

However he was very excited by discovery in the 1947 of unstable new baryon and meson particles (the so called V particles) and, as we have seen at page 8 of his notebook, already at the end of 1950, he was puzzled by the

controduction between the cripture of a strong inbrouting portile, out its long lifetime. This controllibin, of course, is repolved if the strong protice is Cloud-chamber photograph of a V^0 particle decaying into two charged particles feadment in fact. (G.D.Rochester, C.C.Butler, Nature 160,855 (1947))

In the "Recollections on the establishment of the weak interaction notion" (B.Pontecorvo, JINR Preprint E1-85-583, Dubna, 1985) he writes: "Since 1947 I had been expecting new weak processes, so that I was very happy about all this. I felt that the notion of weak interaction became wider once again, but in new process. ...omissis.....On the basis of simple arguments I introduced (B.Pontecorvo, JETP, 1955, vol.29, p.140, with quotations on previous papers.), independently of Pais (Pais A., Phys.Rev., 1952, vol86, p.655) the idea of pair production of the new particles, more exactly the pair production of hyperons and kaons."

Strange Particles

In 1953, the fact that particles produced via strong interaction and decaying with a long lifetime must be produced in pair was not completely clear from an experimental point of view.

As usual, the theoretical physicist Pontecorvo, as brilliant experimenter, decides to clarify this point by himself :

an experiment was done trying to observe the formation of Λ^0 -particles in collisions of 670 MeV protons with carbon nuclei (Baladin M.P., Balashov B.D., Zhukov V.A., Pontecorvo B.M., Selivanov G.I. Report of the Inst.for Nuclear Problem, Acad. Sci. USSR, 1954). The conclusion of the experiment was that:

"The small value of the cross section for the formation of Λ^{0} particles in the interaction of protons with an energy of 670 MeV with complex nuclei agrees with the hypothesis of the fundamental transformation of a nucleon according to the scheme (N) \leftrightarrow (Λ^{0}) + (heavy meson)."

PHYSICAL REVIEW

VOLUME 93, NUMBER 4

Production of Heavy Unstable Particles by Negative Pions*

W. B. FOWLER, R. P. SHUTT, A. M. THORNDIKE, AND W. L. WHITTEMORE Brookhaven National Laboratory, Upton, New York

(Received November 10, 1953)

FEBRUARY 15, 1954

The production in pair of V-particles and heavy mesons was later observed in $\pi^- p$ collision with π^- of 1.5 BeV from the BNL Cosmotron by W.B.Fowler et al. (*Phys. Rev. 93, 861 (1954)*)

The important contributions given by Pontecorvo to the problem of understanding the properties of the "strange particles" are not enough acknowledged to him by the scientific community.

He was probably the first to have the intuition that the contradictory behavior of these strange particles can be explained if are produced in pair.

Unfortunately this idea remained hidden in internal reports written in Russian, not accessible for long time to the vast community of physicists outside the Soviet Union.

Maybe a second profound intuition in a single page! (beginning of November 1950)

on the frankformations of methis The 2 meter has a long life ? 10 the , and and supposed to decay into TT++TT+TT If this is to, it must be included that I does not interest with mulei, become, if the & induceds with mulin, then the lote of the second would be vie bost. (through the indication with uncloses of the vacuum) Let is suppose that it does not infinit Stingly, hime it is strongly produced, it must produced. as a driving product of a strongly interacting metanally But this Mo then would decoy who TT quicker thon in V. to there is a contradiction between the criptime of a strong inproceeding porticle, and its long lifetime. This contradiction, of counter, is repolved if the strong fortule is produced in poin. to from the very but the tay 2 merons have a long life, it ion be out 6) porot they are present in abundlonce, we con concluse That there are metand cust many Muchingsons) the theorigh for the for the fort with s prituke until wow would be whitent In -> C+2H TT-> W+Y culobin no other unexonstruct $\mathcal{Z} = \mathcal{K} = \mathcal{V}^+ \longrightarrow \{ \mathcal{H}^+ \}$ Therens tree been produced. VOLIMENT TT + M TT + M Vo herris h+TT

On the transformations of mesons -

The τ meson has a long life >~ 10 -9 sec, and is supposed to decay into $\pi^++\pi^-+\pi^+$. If this is so, it must be concluded that τ does not interact with nuclei, because, if the τ interacts with nucleons then the rate of the disintegration would be very fast. (trough the interaction with nucleons of the vacuum) Let us suppose that it does not interact strongly. Since is strongly produced, it must produced as a decay product of a strongly interacting meson M. But this M then would decay into π quicker than in τ . So there is a contradiction between the <u>existence of a strong</u> <u>interacting particle and his long lifetime</u>. This contradiction, of **course**, is resolved if the strongly interacting particle is **produced** in **pair**.^(*) So from the very fact that a) τ mesons have a long life, b) that they are present in abundance, - we can conclude that there are mesons (not necessarily the τ mesons) which are strongly produced in pairs.

(incidentally these considerations explain the fact that until present day cyclotron no other mesons that π mesons have been produced.)

 $+\pi^{-}$

2

A consistent picture until now would be:

$$\mu \rightarrow e^{+}2\nu$$

$$\pi \rightarrow \mu + \nu$$

$$\tau^{+} = K = V^{*} \rightarrow \left\{ \begin{array}{c} \mu^{+} + \pi^{-} \\ \mu^{+} + \pi^{0} \end{array} \right.$$

$$\mathsf{V}_{\mathsf{O} \textit{light}} \rightarrow \pi^- + \mu^+ \, \mathsf{or} \, \pi^+ + \mu^- \, ?$$

 $V_{0heavy} \rightarrow p + \pi^{-}$



^(*) here, at the end of 1950, without the notion of strangeness, a deep intuition is needed to propose a production process in pair to solve this contradiction. ^(**)maybe just a coincidence! Two lines before he writes $\mu \rightarrow e+2\nu$ while here he writes $\mu \rightarrow e+\nu + \nu$ engraving the neutrinos with two different signs. Two profound intuitions in a single page ?!

ν_u≠

"At the Laboratory of Nuclear Problems of JINR in 1958 a proton relativistic cyclotron was being designed with a beam energy 800 MeV and a beam current 500 A... omissis.. At the beginning of 1959 I started to think about the experimental research program for such an accelerator....omissis... (one experiment) was intended to clear up the question as to whether $v_e \neq v_{\mu}$." Pontecorvo writes that in "The infancy and youth of neutrino physics: some recolletions" (Journal de Physique, 1982, n.12, vol 43, C8-221), and few lines later he asserts: "for people working on muons in the old times, the question about different types of neutrinos has always been present.

It seems to me that what he writes at page 8 of his Notebook at the beginning of November 1950

M-2 C+24



reinforces the fact that Pontecorvo had always the suspicion that the two neutrinos in the muon decay were two different type of particles.



 $v_{\mu} \neq v_{e}$ to acknowledge the Bruno's intuition

The new powerful cyclotron foreseen at Dubna could be for Pontecorvo the good occasion to answer that question. In the paper "Electron and Muon Neutrino" (J.Exptl. Theoret. Phys. 37 (1959) p.1751) he writes many possible reactions induced by neutrino (or antineutrino) beams that could be forbidden if $v_e \neq v_{\mu}$.

"There are no reasons for asserting that v_e and v_{μ} are identical particles" he writes just before to itemize the long list of possible interesting reactions, and continues:" the existence of two different types of neutrinos, which are not able to annihilate, is attractive from the point of view of the symmetry and the classification of particles and might help to understand the difference in nature of muons and electrons."

Finally, in the paper Pontecorvo proposes to use an anti- v_{μ} beam to look for the reaction anti- v_{μ} + p $\rightarrow \mu^+$ + n and to check that the anti- v_{μ} + p \rightarrow e⁺+n is forbidden.

Unfortunately the foreseen 800 MeV cyclotron was never built at Dubna !

The experiment was done three years later at the Brookhaven AGS For the experimental proof that $v_e \neq v_{\mu}$ L.M.Lederman, M.Schwartz and J.Steinberger Nobel Prize 1988.



Very interesting is what we found on page 76 of the (reversed) first Notebook ! This page was written between December 25,1951 and January 30,1952

Apponotus (1037+H-2/ASH-C c (10° un c (10¹⁶ Km) (*) $Cl^{37}+v \rightarrow Ar^{37}+e$ 3) the the description to on the diverse simmely-3) On the charge symmetry - On the charge symmetry Appointus for the determination of a seventh for a phole probe of Hr (Rent 7 Very) A. Alex -A. Alex.-Average The Happenered Observation Observations tobe of H4 Noble vapar emina of heavy In the course of this year several tomorghs on proposed In the course of this year several remarks or hoolivarbue with emilian of experiments whe more in the 62 ponto of which proposed experiments were made in the 62 group, of it is possible to mention tome. to portilest the experiments plarmed is comether dange which it is possible to mention some. with to take a period of chagrobetre Ht in the underseen At the ferritraile another was objected Neutrino -The dra with charithin of the pockets of by inside the problem of the distribution of flee, i is nev. The appeartus consut copole of cycolog 1) At the seminaire a method was discussed in rela neutrinos, i e of Bectevinof neutrin much to forticles count of 3-country incorrelence the problem of the detection of free neutrinos, i.e. of is not connected with the est of a Bohrmut C a detection of neutrino, a method which is not likefore chonsail expern of Leipum per The conclusion connected with the act of a β disintegration (like in -Future work is that fuch possibility in not too fee Them the classical experiment of Leipunski) The conclusion from present day fowlines, Afort on is that such possibility is not too far from present day to we we li facilities, A short report on this subject was written Provention of metros my (2) Lifetime of *t* mes Heavy mesons- - Possible The metant spad experiment on Induction of metons wi experiment on τ meson. In photophaphic plates it was Them In photographic plates it was placevil observed τ henren - my peoply ingoing one think 1) - On the to of the Z metms - Kouch (3) Lifetime etc. hiptime etc (3) -On the charge symmetry hypothesis -(4)expenser A discussion Remarks and

 Proposal for experiments 1) -<u>On the lifetime transformations lifetime of</u> the τ mesons heavy mesons and their

transformation -

^(*) H.Bethe and R.Peierls in Nature 133,532-532 (07 April 1934) evaluated an upper limit for the cross section of the neutrino interaction with matter and they wrote "For an (neutrino) energy of $2*3x10^6$ volts.... $\sigma < 10^{-44}$ cm²(corresponding to a penetrating power of 10^{16} Km in solid matter) It is therefore absolutely impossible to observe process of this kind with neutrinos created in nuclear transformation."

An experimental physicist with brilliant ideas and genial intuitions

In 1934, Bethe e Peierls (Nature 133,532,1934) showed that the cross section of neutrino interaction with nuclei is extremely low, $<10^{-44}$ cm² at MeV energies, "corresponding to a penetrating power of 10^{16} km in solid matter", as the authors wrote in this paper. Then the authors conclude the paper saying "it is therefore absolutely impossible to observe processes of this kind with neutrinos created in nuclear trasformations".

For Pontecorvo this conclusion was too drastic! In two reports (1945,1946) of the Chalk River Laboratories Pontecorvo suggests to use the reaction: $v + Cl^{37} \rightarrow Ar^{37} + e^-$ to capture neutrinos and prove its physical reality despite its trifling chance of interacting with anything.

This method is an absolutely genial idea that many years later will be used by other physicists awarded the Nobel Prize for that.



Internal reports PD-141 e PD-205

Free neutrino detection

I guess that when Pontecorvo is writing, at the end of 1951, in the top right corner of the page 76 (reversed) of the Notebook:

destrad!

he is evaluating in his mind the neutrino flux and the amount of Chlorine needed to detect a such elusive particle that can travel through 10^{16} Km of solid matter without interact !

At the end of 1951 Pontecorvo is seriously hoping to be able to do the Chlorine/Argon experiment.

liketine climial cipen of Leipum per The condumn is that fuch prinklity in not to fee from present doing fourtiches, Afterfat on this tupict was welten

It should be very interesting to find this "short report" to know how and where such possibility to perform the experiment existed for him in Russia. Unfortunately this possibility didn't realize, may be simply because the access to a nuclear reactor was not allowed to him.

Three years later, in 1954, R. Davis tried to use the Cl^{37} - Ar^{37} method in an attempt to detect reactor neutrinos exposing a 3900-liter tank of carbon tetrachloride (CCl_4) at the Brookhaven Research Reactor. And only in 1967, 21 years after the original Pontecorvo proposal, R. Davis used the Cl^{37} - Ar^{37} method to detect the neutrinos emitted by the sun, thus showing a deficit in the predicted solar neutrino flux.



Dreaming to detect neutrinos from the sun ! by Misha Bilenky

R. Davis

Nobel Prize

2002

N18

Neutrino Oscillations



Nobel Prize 2015 T. Kajita A. B. McDonald The more revolutionary idea of Bruno Pontecorvo is certainly the "neutrino oscillations". The first Bruno's intuition of this process can be found in a paper of 1957 "Mesonium and antimesonium. In various papers from 1957 to 1967 Pontecorvo anticipates of more than ten years the phenomenon of the deficit of the solar neutrinos and introduces the concept of sterile neutrinos

As the artistic vein of Misha Bilenky explains the phenomenon of the neutrino oscillations.



 $v_e \leftrightarrow v_\mu$ as seen by Misha Bilenky





Nobel Prize 2015 T. Kajita A. B. McDonald

Mechanism of neutrino oscillations as seen by Misha Bilenky A great Magic by Bruno Pontecovo



Bruno Pontecorvo Lenin Prize in 1963

ЛАУРЕАТУ ЛЕНИНСКОЙ ПРЕМИИ



ПРИ СОВЕТЕ МИНИСТРОВ СССР от 21 АПРЕЛЯ 1963 ГОДА ПРИСУЖДЕНА ЛЕНИНСКАЯ ПРЕМИЯ

НОНТЕКОРВО Брупо Максимовичу, членукорреснойденту Академии наук СССР, руководителе группы Обвединенного института дертых последований,—зя экспериментальные и теоретические исследованик филики нейтрипо и славых засимодействий.

ОСТАНОВЛЕНИЕМ КОМИТЕТА ПО ЛЕНИНСКИМ ПРЕМИЯМ

В ОБЛАСТИ НАУКИ И ТЕХНИКИ

на прожная в областия гая и техняция пе Манастров СССР



Комишеша по Аснинским премиям в области тауки и техники при Совете Министров Союза ССР от 21 апреля 1963 Сонтекорво Удруно Максимович

I guess that many of us would agree that Bruno Pontecorvo probably missed a couple of Nobel Prizes. The lack of enough resources and facilities (powerful accelerators, nuclear reactors, underground caverns) available to him in Russia denied to the experimental physicist Pontecorvo the possibility to realize his prophetical theoretical ideas in successful experiments. On the other hand possible collaborations of with international communities (CERN, USA, etc.) were at that time unthinkable, since he wasn't allowed to go outside the Soviet Union with the pretext of his safety ! More than that, as S.S.Gershtein affirms in the Recolletions on B. Pontecorvo, "he was not granted access to any reactor"

Nonetheless Bruno Maximovich Pontecorvo was awarded the Lenin Prize in 1963 for his work on physics of weak interactions and neutrino physics. In 1964 he become full member of the USSR Academy of Sciences and he was awarded many of the highest USSR orders.

Conclusions



A historical reconstruction of the experimental work, the scientific interests and also some great insights of Bruno Pontecorvo during his first year and a half in Russia is done through the pages of these two unpublished Notebooks.

These Documents are particularly interesting because until today little was known of the scientific work of Pontecorvo during his early years in Russia and even recently speculations on his possible involvement in the atomic program of the Soviet Union were raised.

From the pages of these notebooks it emerges clearly the figure of a brilliant experimental physicist with extensive experience of the most advanced particle detectors and, at the same time, of a distinguished theoretical physicist whose work strictly concerns basic researches in elementary particle physics only.

Acknowledgments



We gratefully acknowledge Gil Pontecorvo, the eldest son of Bruno, that provided us these unpublished documents. We would like to thanks V. Cavasinni, M.M.Massai and E. Volterrani for helping us at every stage of this work. We thank Andrei Ryskalin for having translated a few pages written in Russian of these notebooks. We also thank Bruno Sereni and Antonio D'Agnelli of the Documentation Office of the University of Pisa for the careful work done to photograph in high resolution all the pages of these notebooks.

Thanks for your attention

