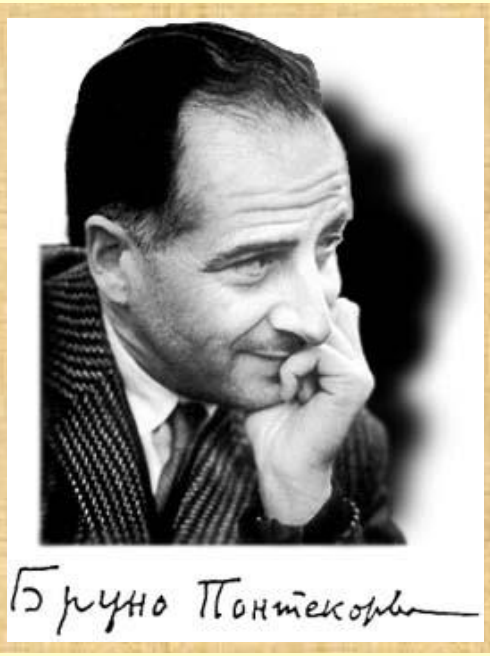
The early years of Bruno Maximovich Pontecorvo at Dubna



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.

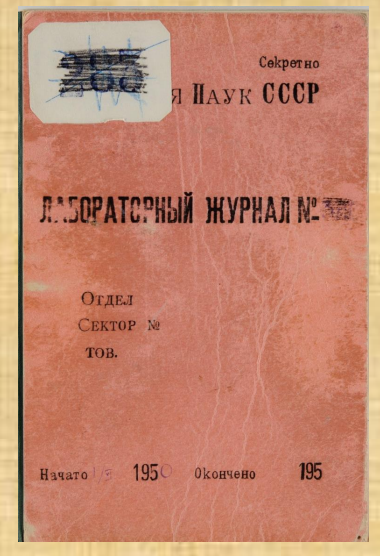

LA STAMPA

Tutte le accuse dell'on. Vinla giudicate infondate dalla commissione

Il giudizio e gli strascichi

Fuga a Mosca di uno scienziato atomico

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.


Секретно

Я Наук СССР

ЛАБОРАТОРНЫЙ ЖУРНАЛ №

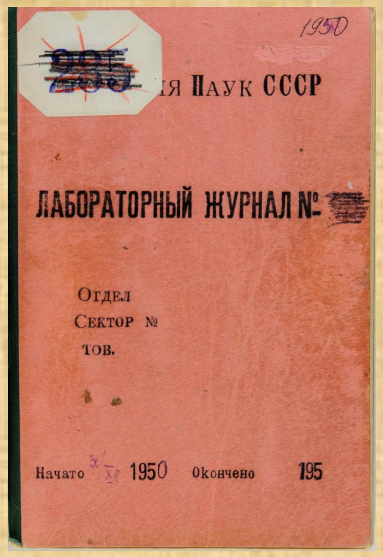
Отдел

Сектор №

тов.

Начато 195 Окончено 195

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.


1950

ія Наук СССР

ЛАБОРАТОРНЫЙ ЖУРНАЛ №

Отдел

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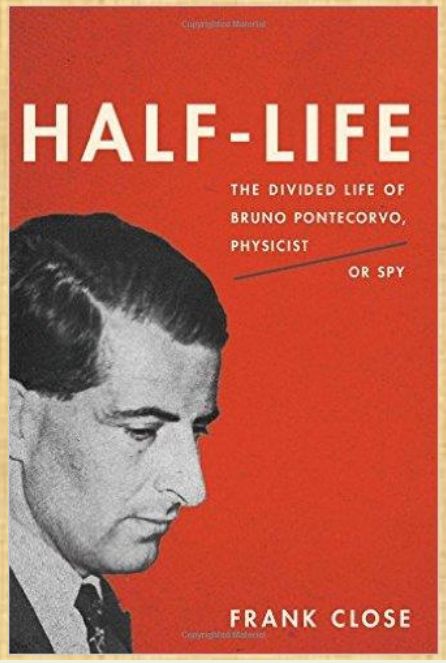
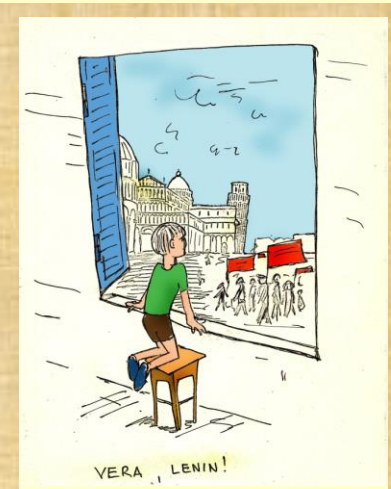
Начато 1950 Окончено 195



Published February 3rd 2015 by Basic Books

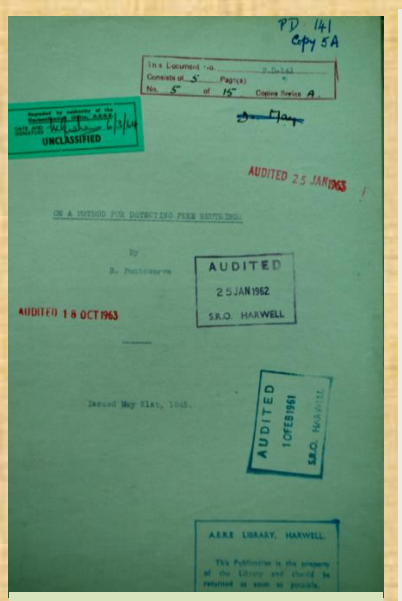
Who is Bruno Pontecorvo as man and scientist when, in late August 1950 at the age of 37 year old, he decided to give up everything and go to live in Russia ?

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



Bruno and the Communism as seen by Misha Bilenky

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



Report PD-205

Bethe e Peierls: neutrino has "*a penetrating power of 10 ^{16} km in matter*"

....."it is therefore impossible to observe free neutrinos".

Pontecorvo suggests to use the reaction:

$\nu + Cl^{37} \rightarrow Ar^{37} + e^-$

to detect the free neutrinos and prove its physical reality.

e-μ universality by Misha Bilenky

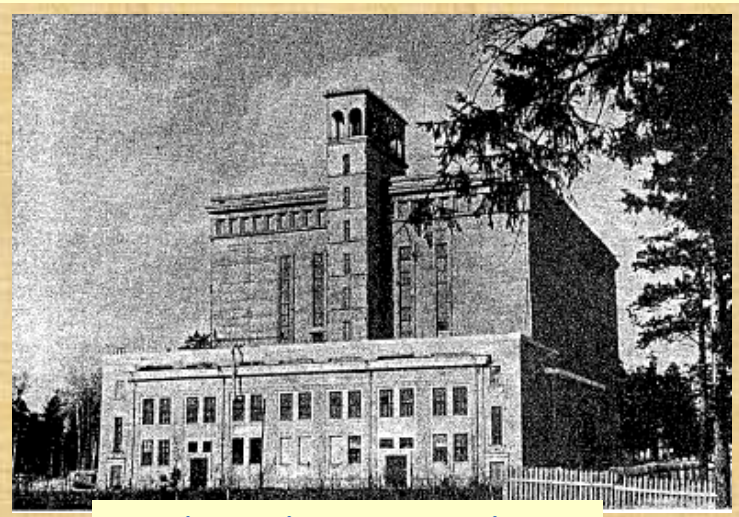
After the experiment of Conversi, Pancini and Piccioni and the interpretation given by Fermi, Teller and Weisskopf

Pontecorvo first had the intuition of the e-μ universality of weak interaction !

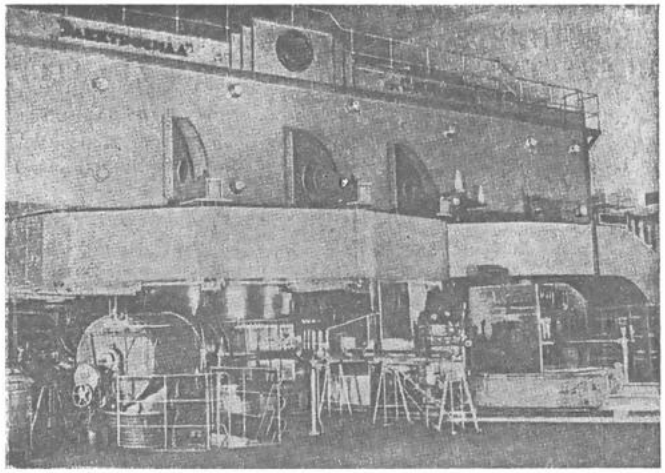
New life and new experiments in Dubna

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

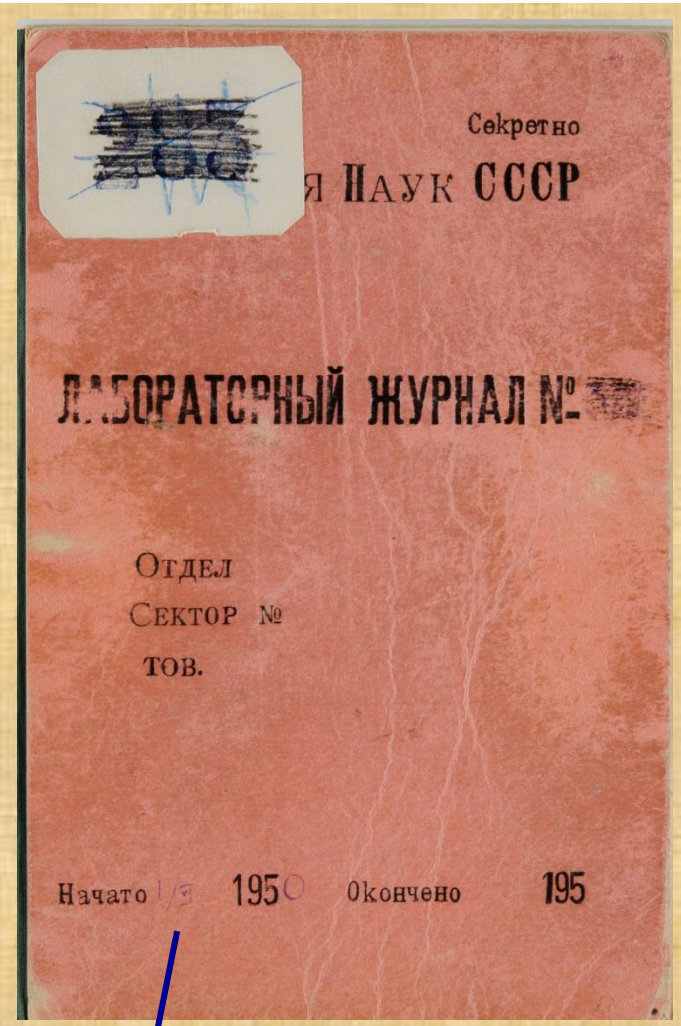


Synchrocyclotron building

	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 ($cm^{-2}\ sec^{-1}$)	—	—	$1 \cdot 10^8$ (E_p = 460 MeV)
Neutron flux at the maximum of the angular distribution 2 m from the internal target ($cm^{-2}\ sec^{-1}$)	$8 \cdot 10^7$	$2 \cdot 10^5$	$5 \cdot 10^6$
Neutron energy at the maximum of the energy 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

I/XI 1950 First Notebook: from 01/11/1950 to ≤ 30/11/1950
from 14/09/1950 to ≥ 24/03/1952

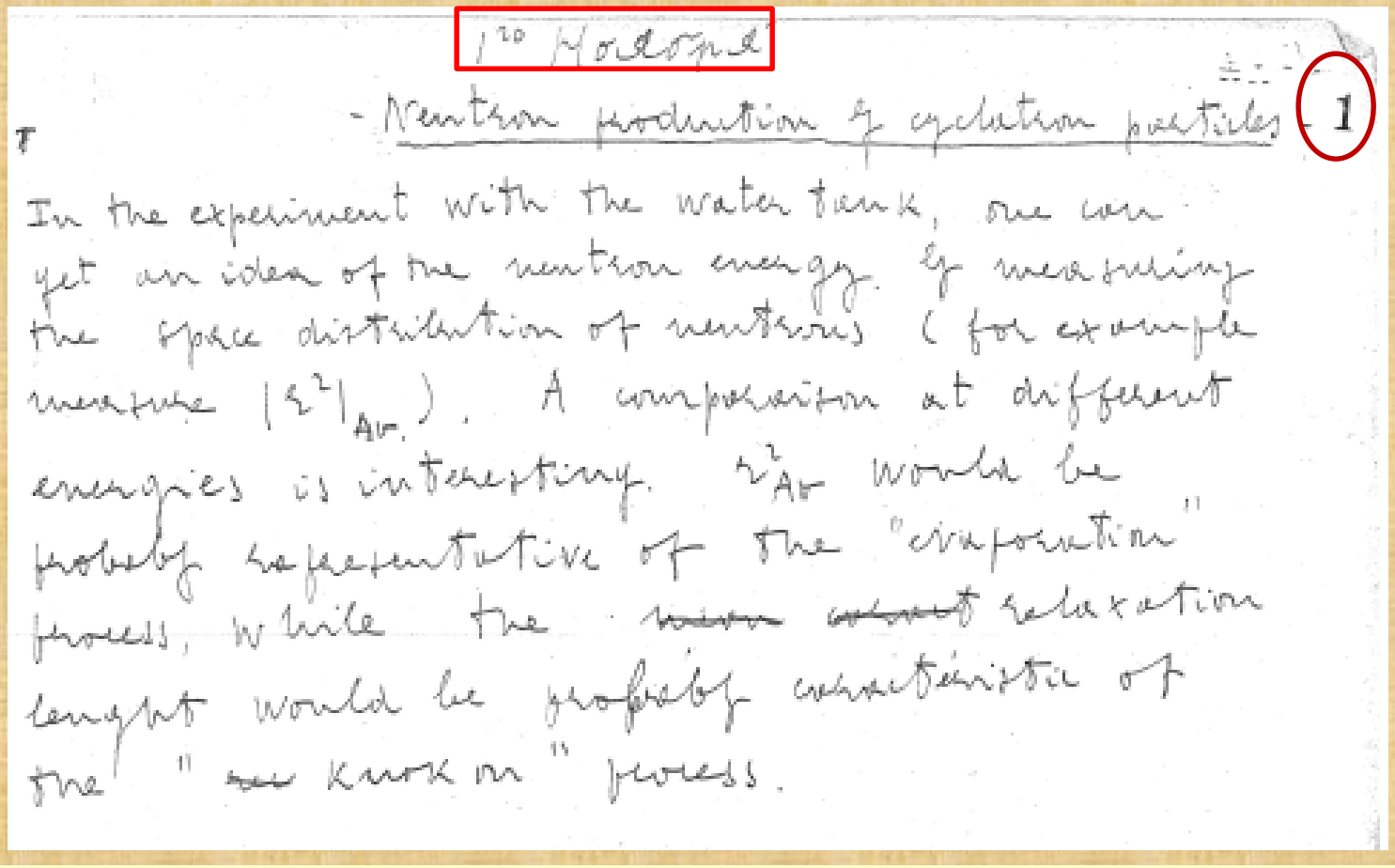


To commemorate the centenary of the birth of Bruno Pontecorvo have been organized in Pisa an exibition on the life and the scientific work of this great Italian physicist of the 20th century.
This Notebook was given from Gil Pontecorvo to Gloria Spandre and Elena Volterrani, both curators of this exibition 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)
- Neutron production by cyclotron particles -



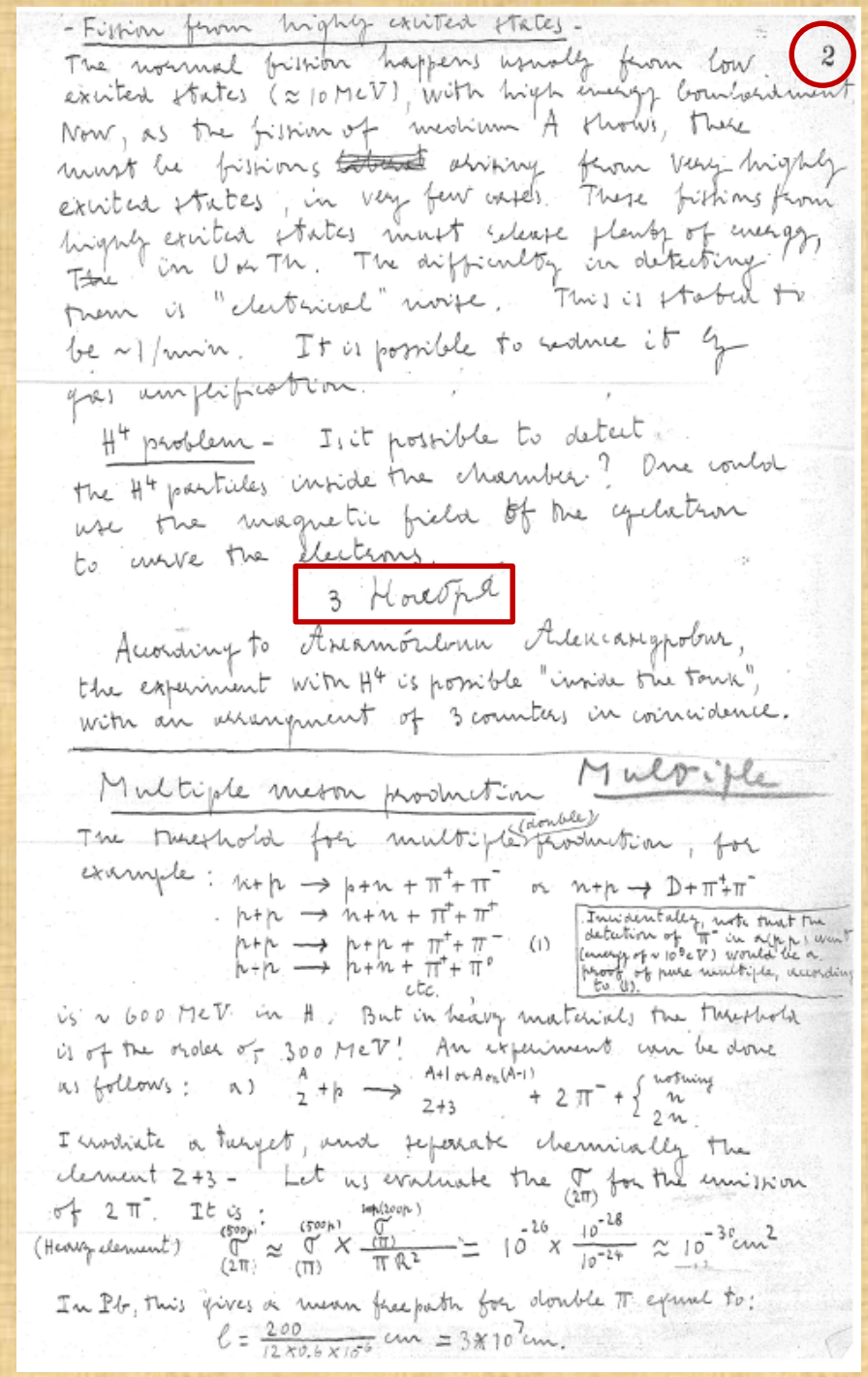
1st November

- Neutron production by cyclotron particles - 1

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 $|r^2|_{Av.}$). A comparison at different energies is interesting. r^2_{Av} would be probably representative of the "evaporation" process, while the ~~neutron~~ ~~energy~~ relaxation length would be probably characteristic of the "~~new~~ knock on" 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.)



- Fission from highly excited states -

The normal fission happens usually from low excited states (≈ 10 MeV), with high energy bombardment. Now, as the fission of medium A shows, there must be fissions ~~(about)~~ arising from very highly excited states, in very few cases. These fissions from highly excited states must release plenty of energy, like in U or Th. The difficulty in detecting them is "electrical" noise. This is stated to be ~1/min. It is possible to reduce it by gas amplification.

H^4 problem - Is it possible to detect the H^4 particles inside the chamber? One could use the magnetic field of the cyclotron to curve the electrons.

3 Ноября

According to Анатолию Александровичу, the experiment with H^4 is possible "inside the tank", with an arrangement of 3 counters in coincidence.

Multiple meson production

The threshold for multiple (double) production, for example:

$n+p \rightarrow p+n+\pi^+ +\pi^-$ or $n+p \rightarrow D+\pi^+ +\pi^-$

$p+p \rightarrow n+n+\pi^+ +\pi^+$

$p+p \rightarrow p+p+\pi^+ +\pi^-$ (1)

$n+p \rightarrow n+n+\pi^+ +\pi^0$

etc.

Incidentally, note that the detection of π^- in a $p+p$ event (energy of ≈ 10 BeV) would be a proof of pure multiple, according to (1).

is ≈ 600 MeV in H. But in heavy materials the threshold is of the order of 300 MeV! An experiment can be done as follows: a) $^{A}_{2} + p \rightarrow {}^{A+1 \text{ or } A-(A-1)}_{2+3} + 2\pi^- + \begin{cases} \text{nothing} \\ n \\ 2n \end{cases}$

I irradiate a target, and separate chemically the element 2+3 - Let us evaluate the $\sigma_{(2\pi)}$ for the emission of $2\pi^-$. It is:

(Heavy element) $\sigma^{(500\,\mu b)}_{(2\pi)} \approx \sigma^{(500\,\mu b)}_{(\pi)} \times \frac{\sigma^{\text{simple}(200\,\text{mb})}_{(\pi)}}{\pi R^2} \simeq 10^{-26} \times \frac{10^{-28}}{10^{-24}} \approx 10^{-30}\,\text{cm}^2$

In Pb, this gives a mean free path for double π equal to:

$l = \frac{200}{12 \times 0.6 \times 10^{23}}\,\text{cm} = 3 \times 10^{7}\,\text{cm}.$

Page 2: 3th November (1950)

Pontecorvo writes in this book some thoughts on which kind of experiments with what techniques can be done using the available cyclotron beams:

- Fission from highly excited states -

.....The difficulty in detecting them is "electrical" noise. This is stated to be ~1/min. It is possible to reduce it by gas amplification

H^4 problem - Is it possible to detect

the H^4 particles inside the chamber ? One could use the magnetic field of the cyclotron to curve the electrons.

3th November

According to Anatoly Alexandrovich, the experiment with H^4 is possible "inside the tank", with an arrangement of 3 counters in coincidence.

Multiple meson production

The threshold for multiple (double) production, for example:

$n+p \rightarrow p+n+\pi^+ +\pi^-$ or $n+p \rightarrow D+\pi^+ +\pi^-$

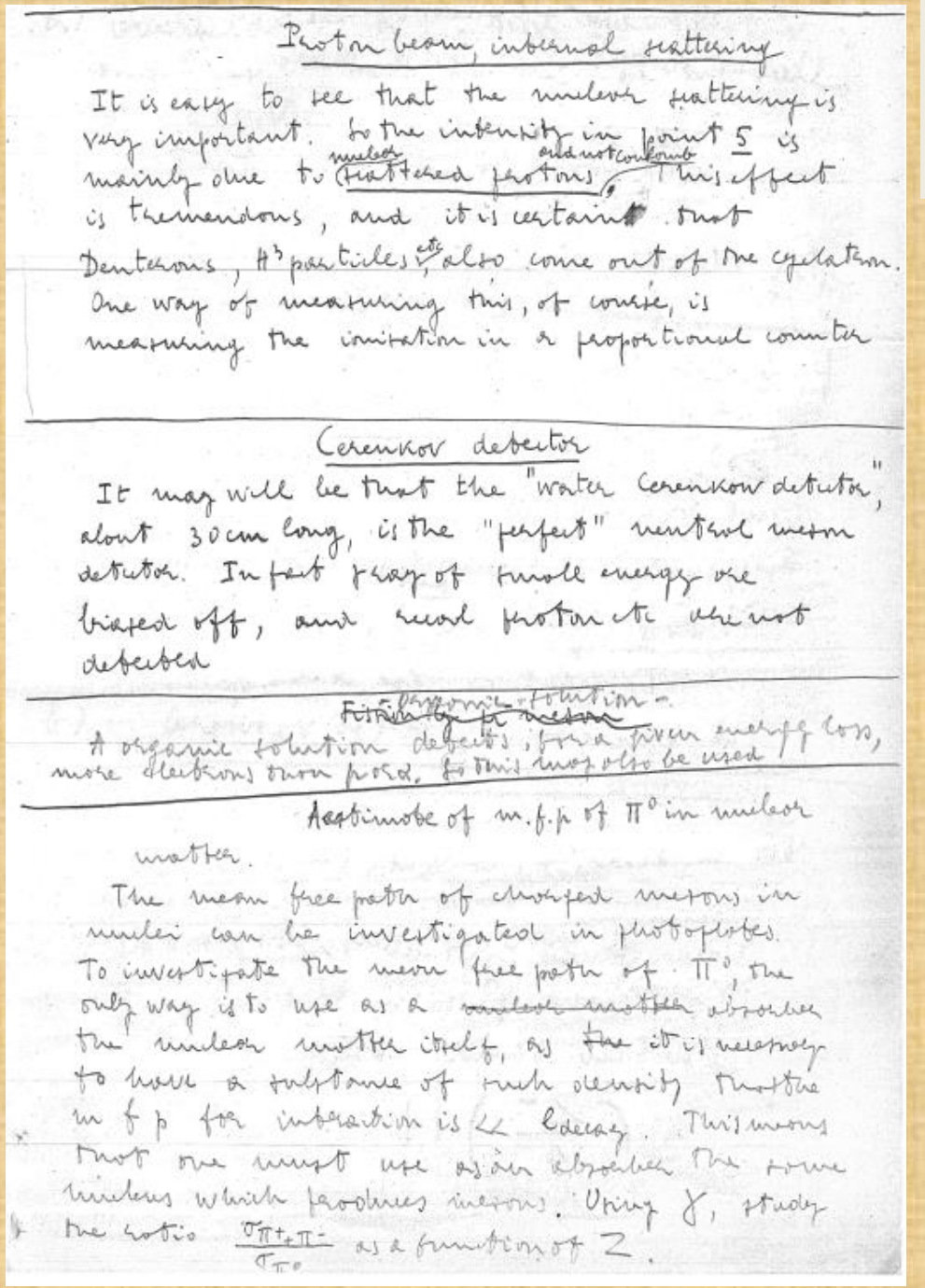
$p+p \rightarrow n+n+\pi^+ +\pi^+$

$p+p \rightarrow p+p+\pi^+ +\pi^-$

$p+p \rightarrow p+n+\pi^+ +\pi^0$

etc.

is ~ 600 MeV in H. But in heavy material the threshold is of the order of 300 MeV. An experiment can be done as follows: .....



Proton beam, internal scattering

It is easy to see that the nuclear scattering is very important. So the intensity in point 5 is mainly due to nuclear scattered protons (and not coulomb). This effect is tremendous, and it is certain that Deuterons, H^3 particles etc, also come out of the cyclotron. One way of measuring this, of course, is measuring the ionization in a proportional counter

Cerenkov detector

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

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

Stima del m.f.p di 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 m f p for interaction is $\ll l_{decay}$. This means that one must use as our absorber the same nucleus which produces mesons. Using γ, study the ratio $\frac{\sigma_{\pi^+ + \pi^-}}{\sigma_{\pi^0}}$ as a function of Z.

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:

- Proton beam, internal scattering -

It is easy to see that the nuclear scattering is very important. So the intensity in point 5 is mainly due to nuclear scattered protons (and not coulomb). This effect is tremendous, and it is certain that Deuterons, H^3 particles etc, also come out of the cyclotron. One way of measuring this, of course, is measuring the ionization in a proportional counter

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Organic solution -

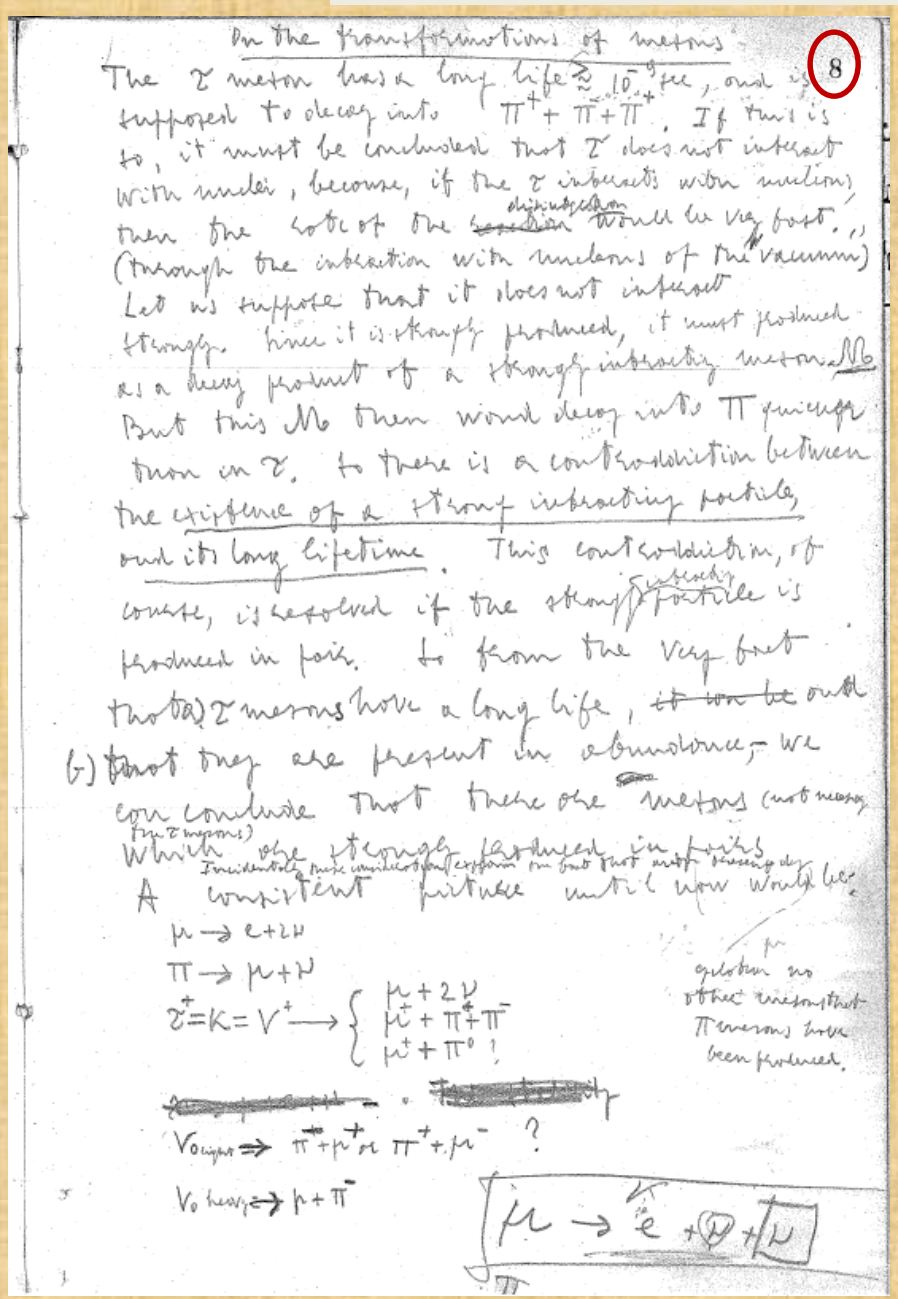
A organic solution detects, for a given energy loss, more electrons than for α, so this may also be used

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 $\ll l_{decay}$. 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 transformations of mesons

8

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. (through 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 existence of a strong interacting particle and his long lifetime. 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.

A consistent picture until now would be:

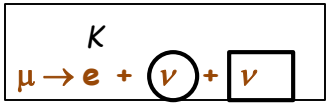
$\mu \to e + 2\nu$

$\pi \to \mu + \nu$

$\tau^+ = K = V^+ \to \{ \mu + 2\nu \;;\; \mu^+ + \pi^+ + \pi^- \;;\; \mu^+ + \pi^0 \; ? \}$

$V^0_{light} \to \pi^- + \mu^+$ or $\pi^+ + \mu^-$?

$V^0_{heavy} \to p + \pi^-$



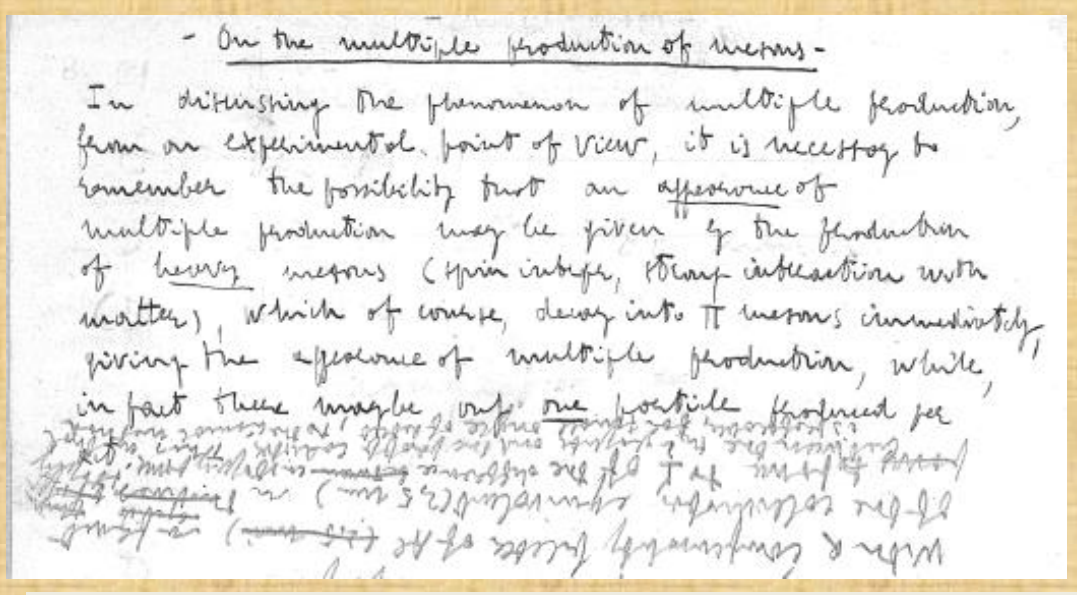
(**)

(*) 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 $\mu \to e + 2\nu$ while here he writes $\mu \to e + \nu + \nu$ 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.

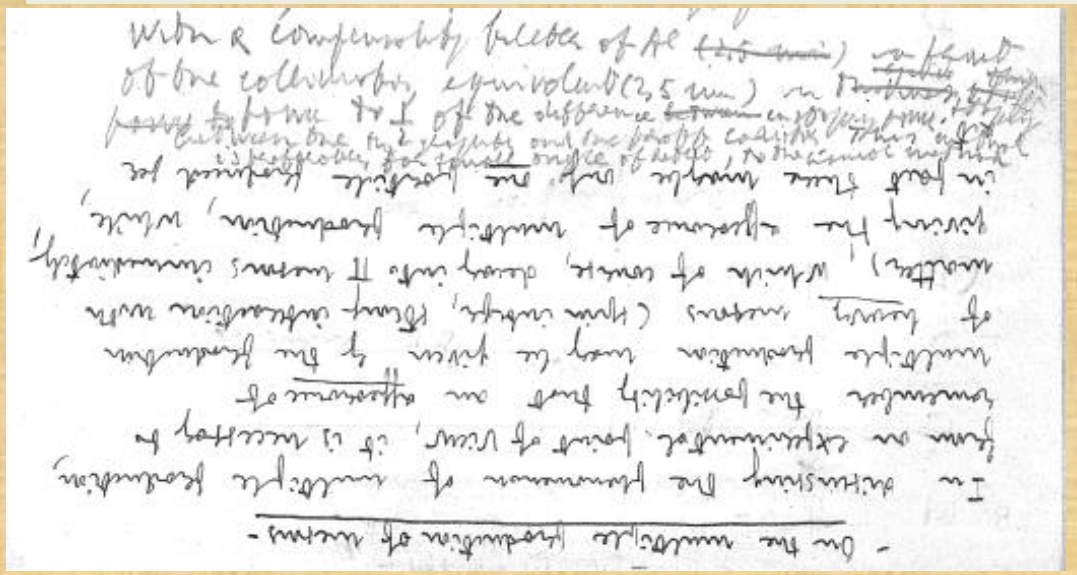


-On the multiple production of mesons -

In discussing the phenomenon of multiple production , from an experimental point of view, it is necessary to remember the possibility that an appearance of multiple production may be given by the production of heavy 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.

.... 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 .

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



-On the multiple production of mesons -

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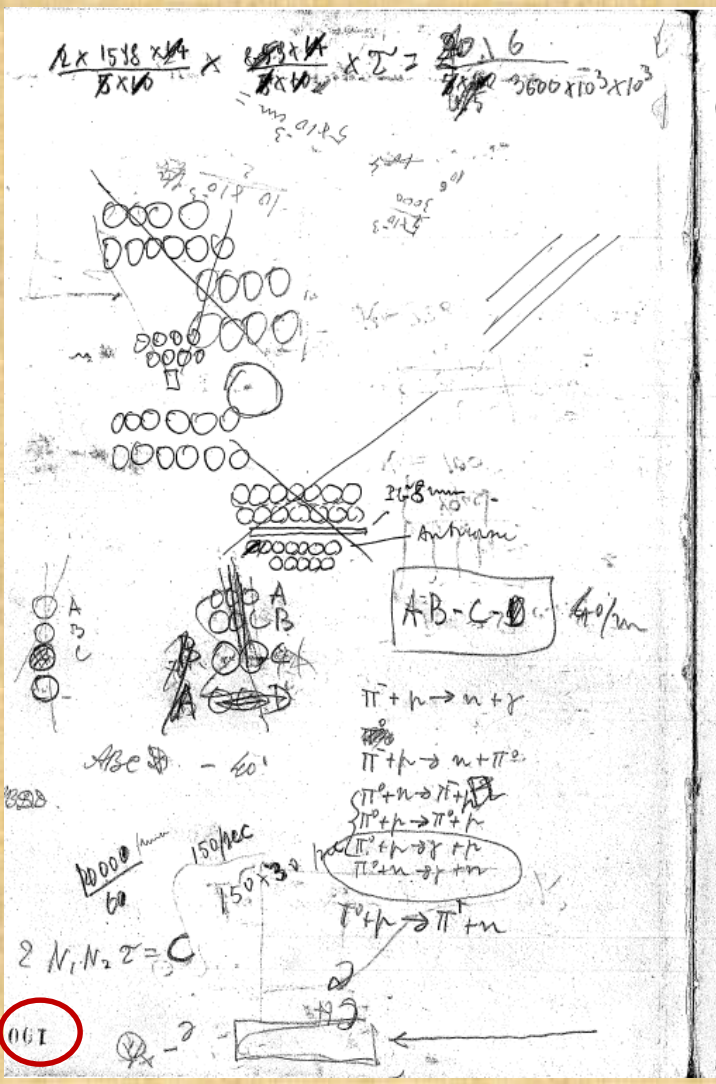
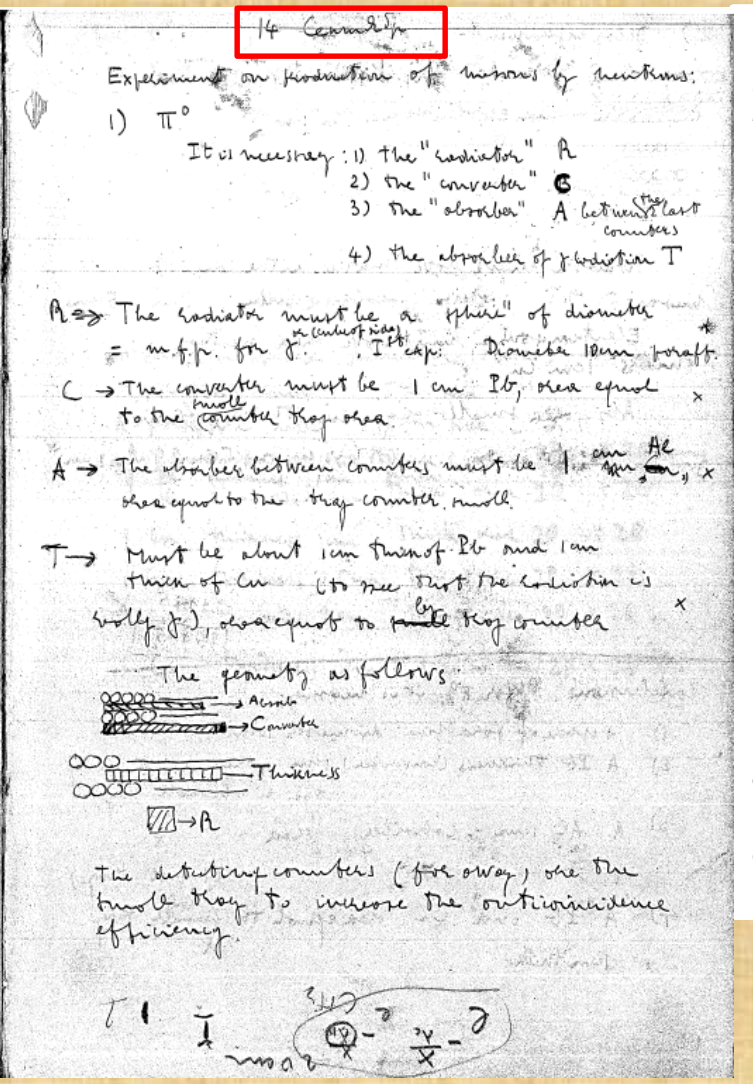
Pontecorvo resumes writing on the Notebook the following year, September 14, 1951, starting from the last page (n.100) turning the book on the opposite side.
He has now decided what to do and he is ready to make an "Experiment on production of mesons by neutrons":





14 September

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 → *The radiator must be a "sphere " ....*
.....

C → *The converter must be 1 cm Pb,....*
.....

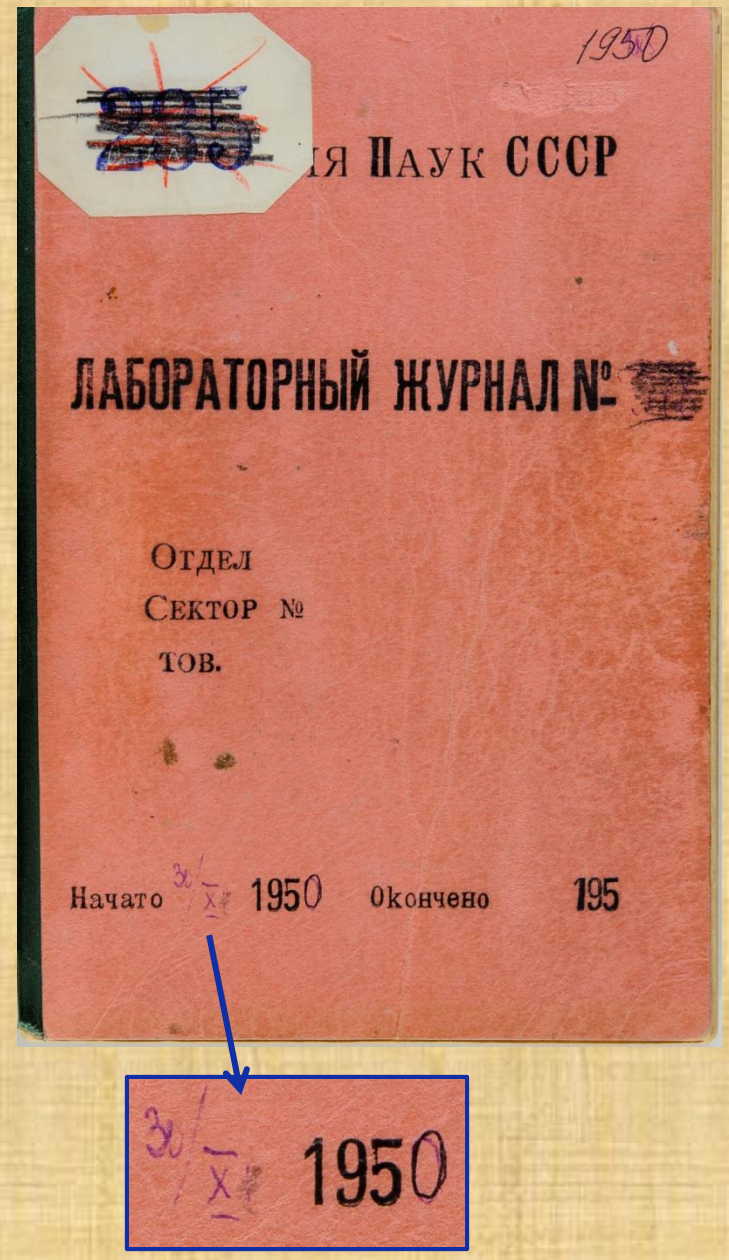
A→ *The absorber between counters ....*
.....

T→ *Must be about 1 cm thin of Pb,....*
.....

The geometry as follows:
.....
.....

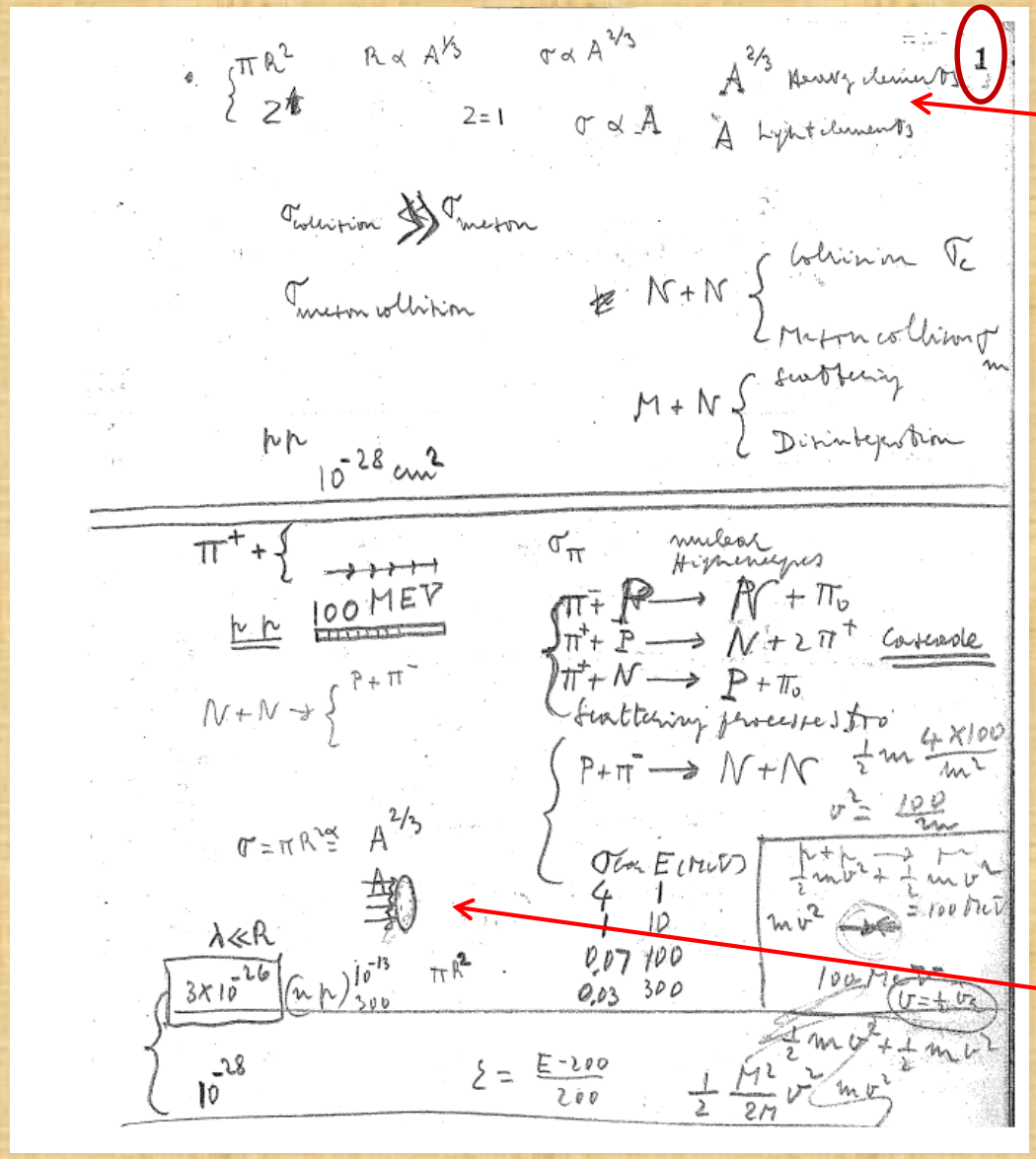
And he continues writing what we could call today the *"Technical Proposal"* of the experiment...

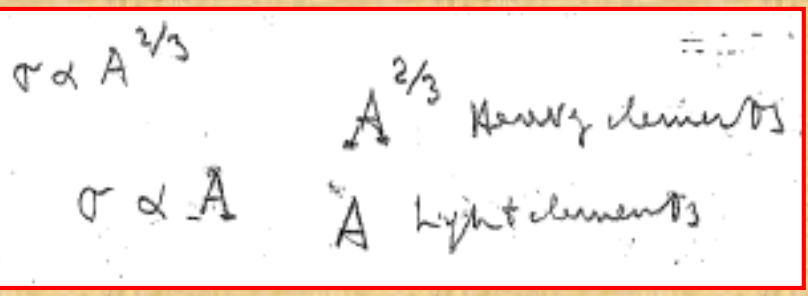
30/XI 1950 Second Notebook: from 30/11/1950 to ≥ 18/07/1951



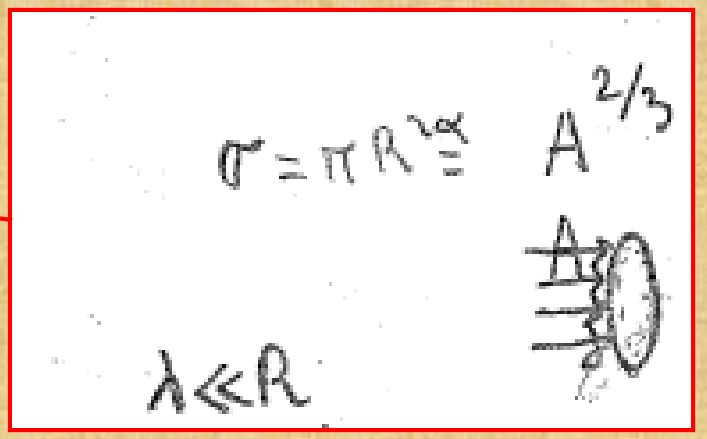
What Pontecorvo from November 1950 to September 1951 has been doing and why suddenly stopped writing in this first notebook only a few days after he started working at the Dubna synchrotron?
Thanks to Gil we had the possibility to study a second notebook that describes the researches that Bruno has been 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

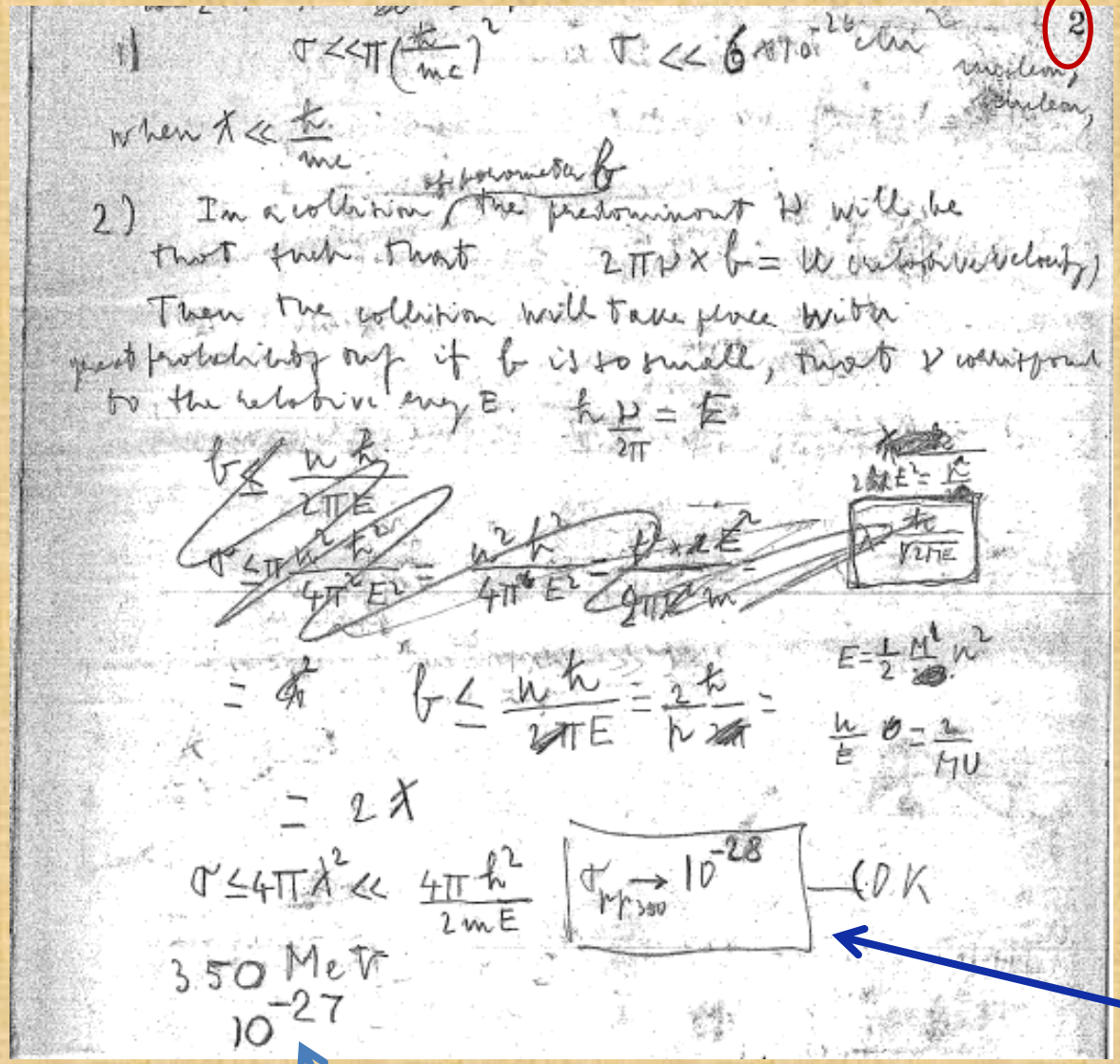




Pontecorvo starts the new notebook with geometric considerations on the order of magnitude of the total cross section for mesons production in nucleon-nucleon and nucleon-nuclei collisions.



Page 2 of the second notebook



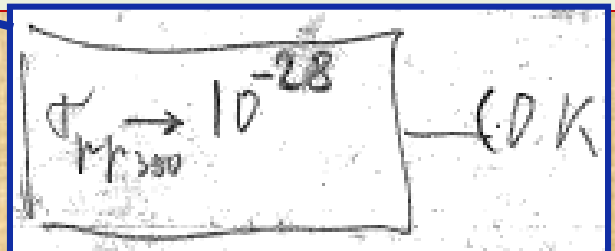
Pontecorvo goes on for a few pages with these geometrical considerations, often scribbling numbers, formulas and graphics in a disorderly manner maybe just to fix thoughts and ideas that swirl in his mind.

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

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

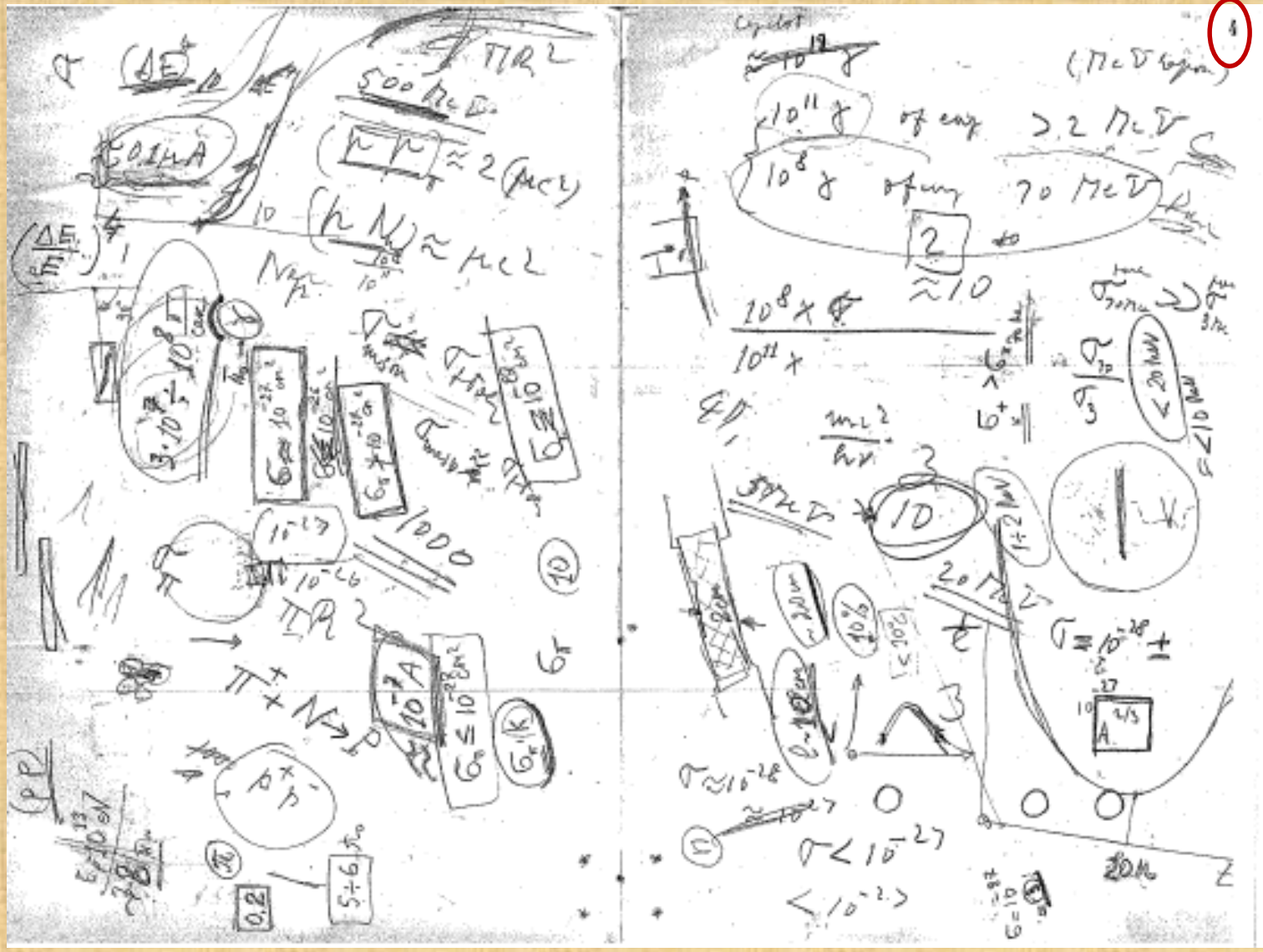
$b \leq u/2\pi\nu = u/2\pi(2\pi\hbar/E) = 2\hbar/mu = 2\hbar/p = 2\lambda$
{$E = 1/2mu^2 \rightarrow u/E = 2/mu = 2/p$}

$\sigma \leq \pi b^2 \leq 4\pi\lambda^2 = 4\pi\hbar^2/(mu)^2 \rightarrow$
$\sigma << 4\pi\hbar^2/(2mE)$

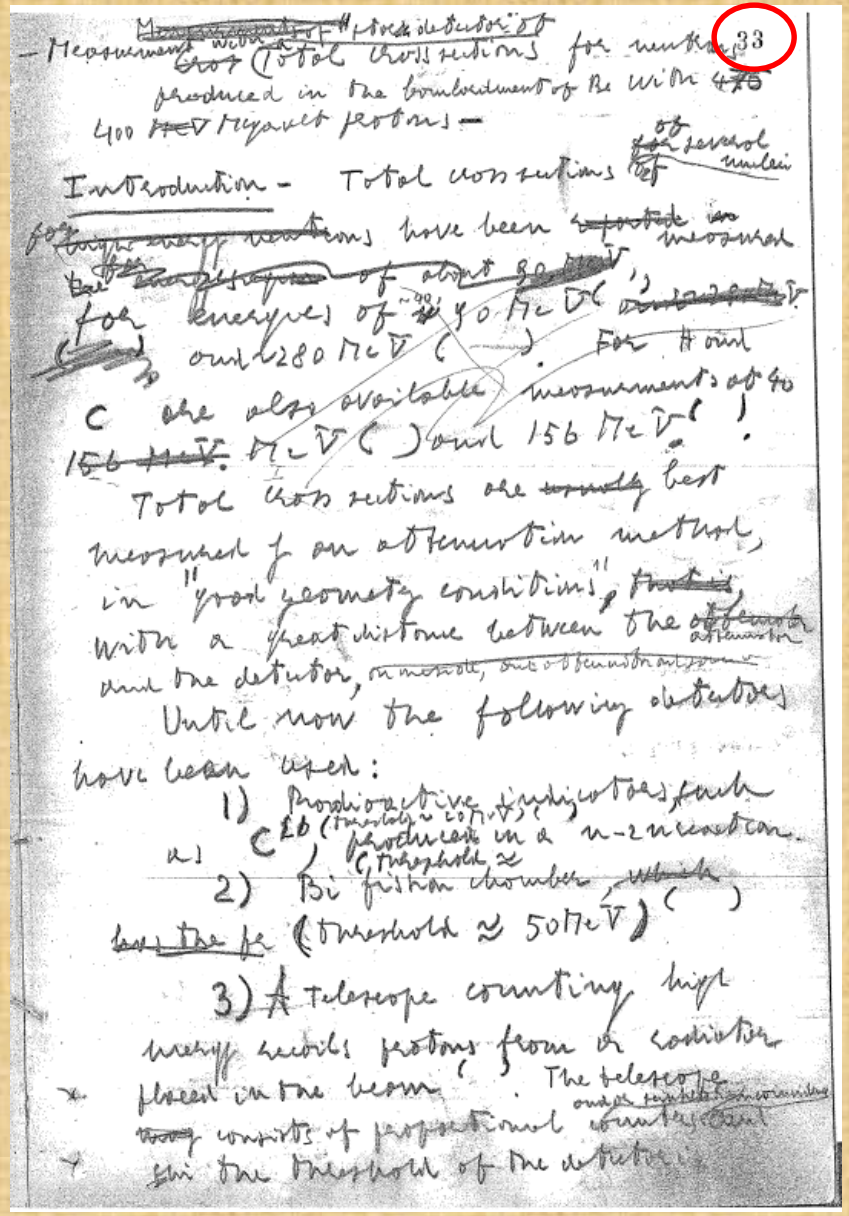


Page 4 of the second notebook

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 –"


33

– Measurement with a "star" detector of (Total cross sections for neutrons produced in the bombardment of Be with 475 400 Megavolt protons –

Introduction – Total cross sections of several nuclei 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:

1) Radioactive indicators, such as C^{11}, (threshold ~ 20 MeV) ( ) produced in a n-2n reaction (threshold ≈
2) Bi fission chamber (threshold ≈ 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

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

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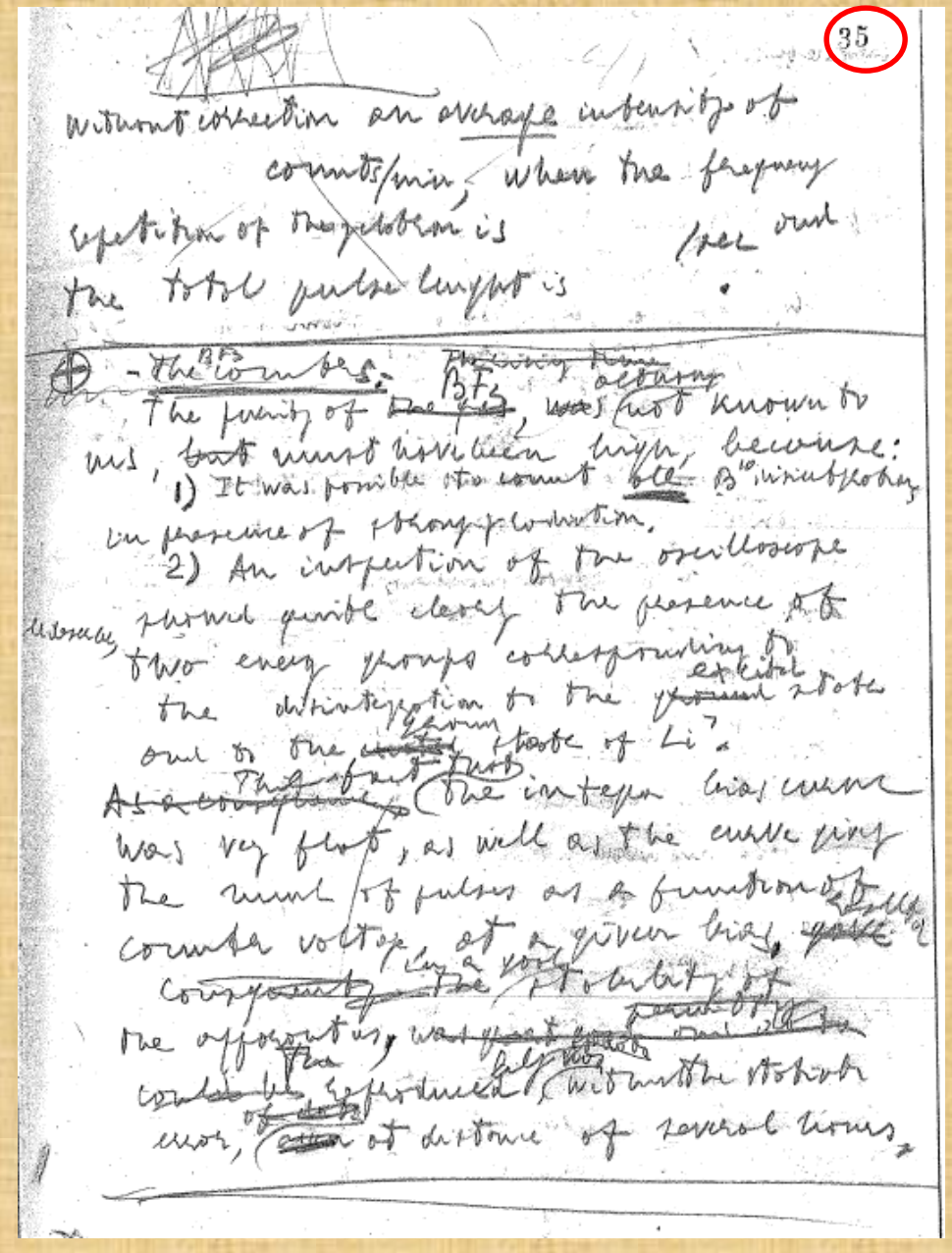

35

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

+ The BF^3 counters.

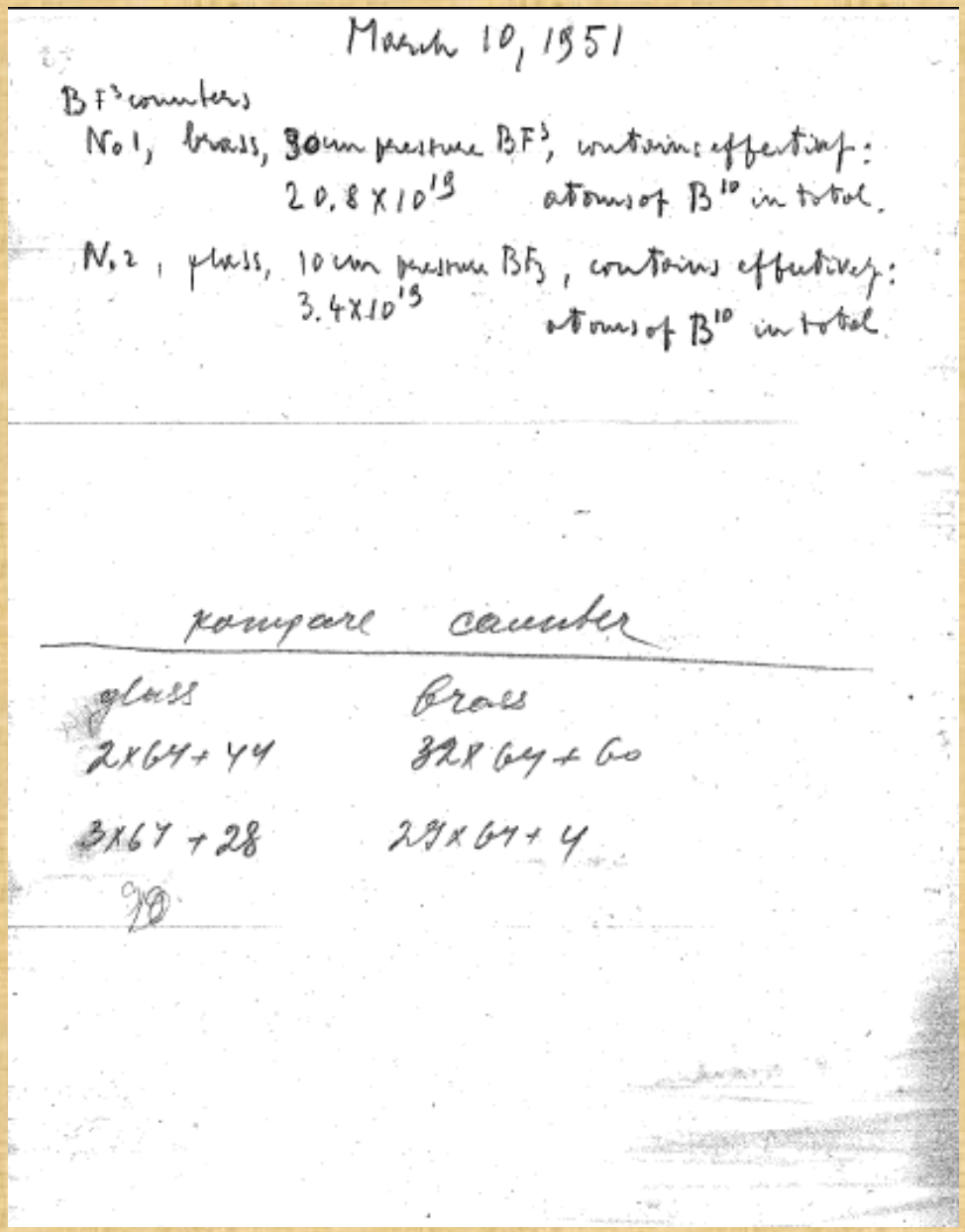
The purity of BF^3 was (?) not know to us, but must have been high because:

1) It was possible to count all B^{10} (?) 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 Li^7.

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

BF^3 counters
No 1, brass, 30 cm pressure BF^3, contains effectively:
20.8×10^{19} atoms of B^{10} in total.

No 2, glass, 10 cm pressure BF_3, contains effectively:
3.4×10^{19} atoms of B^{10} in total

kompare counter

glass	brass
2x64+44	32x64+60
3x64+28	29x64+4

March 10,1951

BF^3 counters
N. 1, brass, 30 cm pressure BF^3, contains effectively :
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3.4×10^{19} atoms of B^{10} in total

---

kompare counter

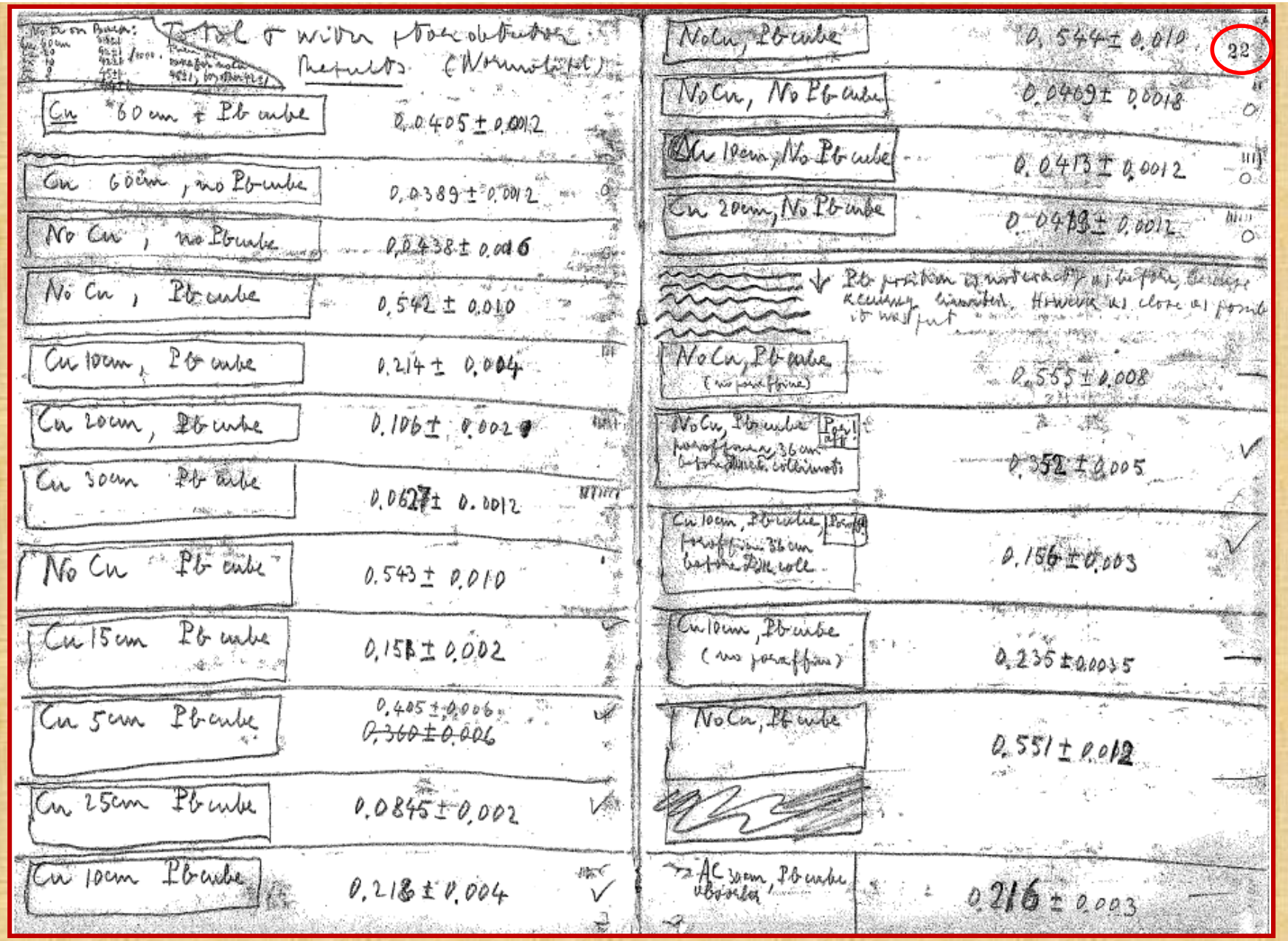
---

glass	*brass*
2x64+44	*32x64+60*
3x64+28	*29x64+4*

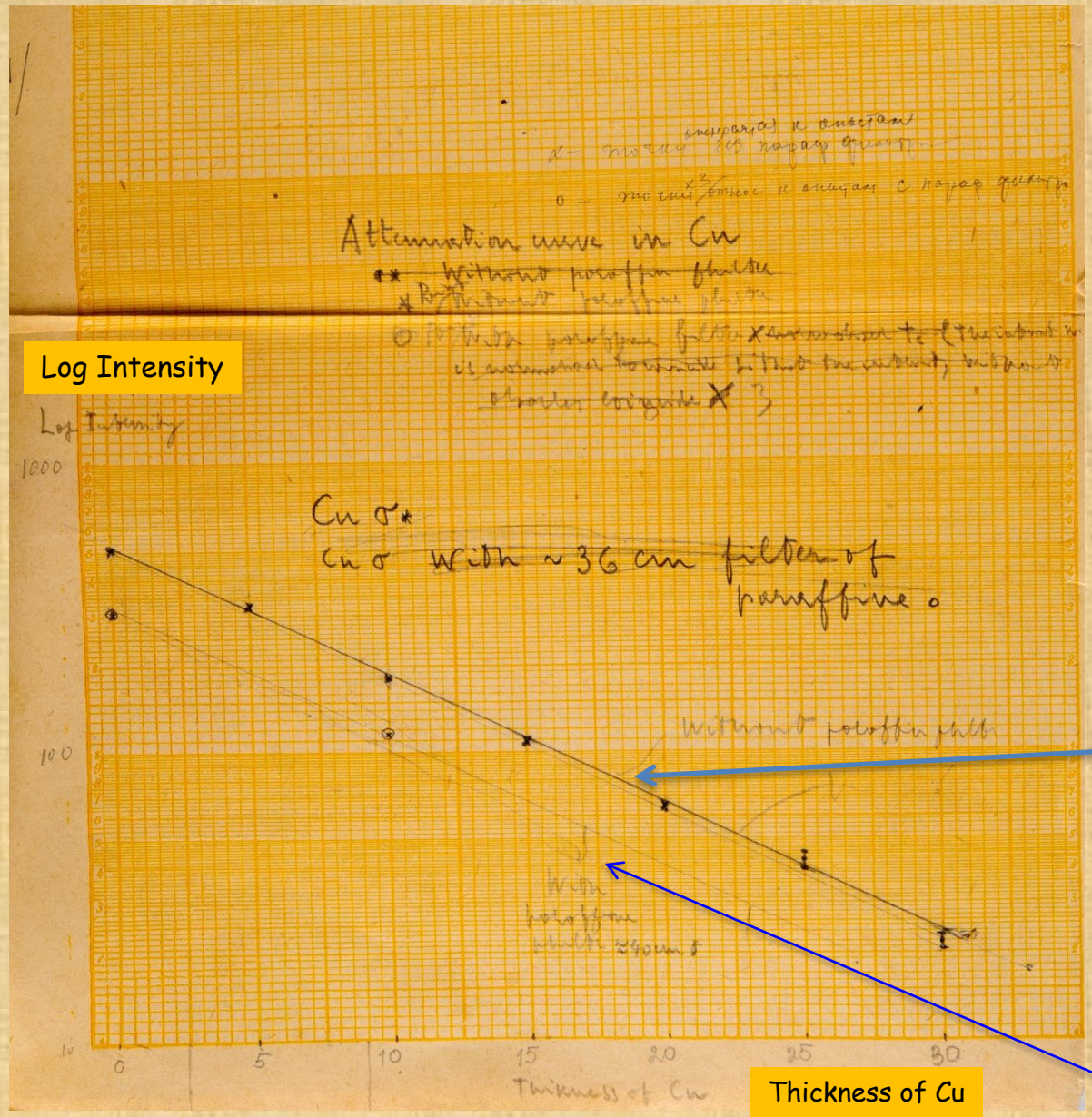
Measurements in Cu of "Total σ with star detector"

(pag.22)

Results (Normalised)



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

Cu σ *

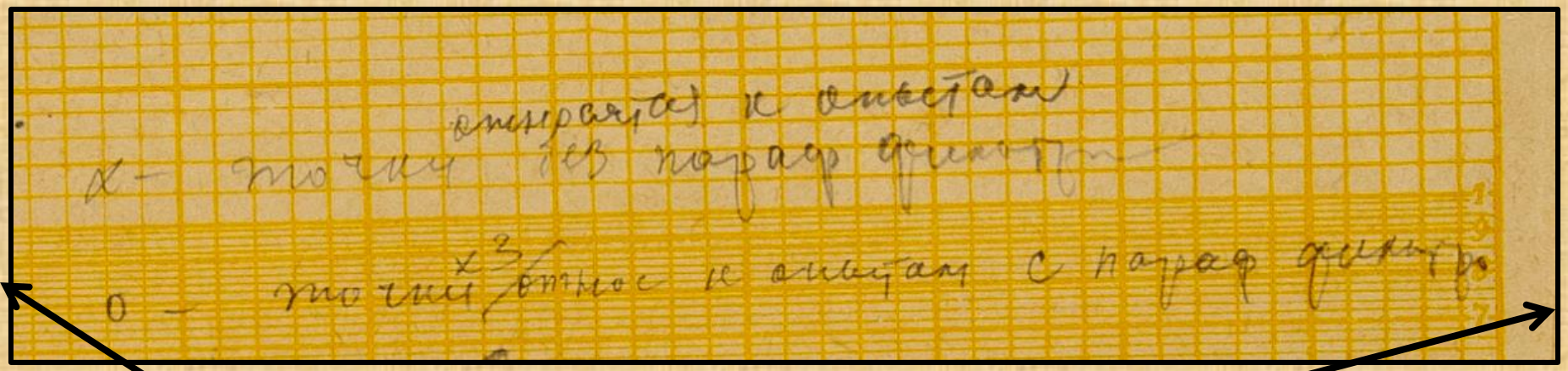
Cu σ with ~ 36 cm filter of paraffine o

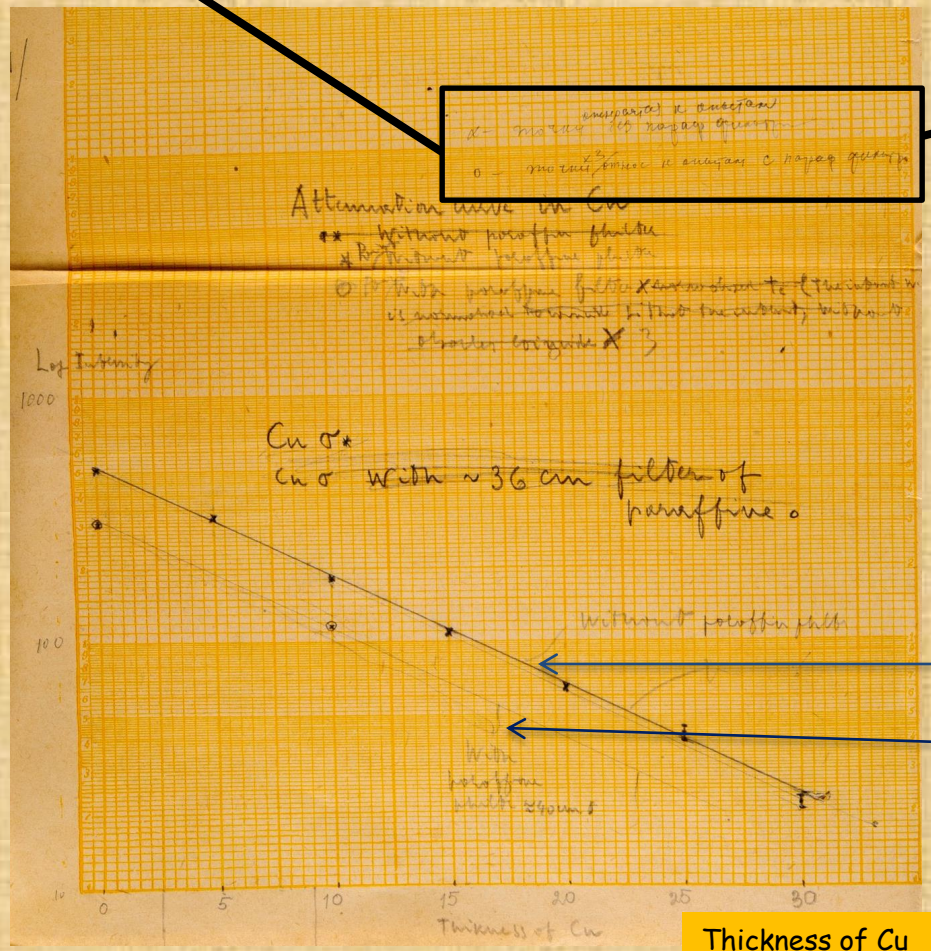
Without paraffine filter

This plot in semi logarithmic paper is inserted at the page where the previous measurements are reported

With paraffine filter ≈ 40 cm

Thickness of 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

Cu σ *

Cu σ with ~ 36 cm filter of paraffine **O**

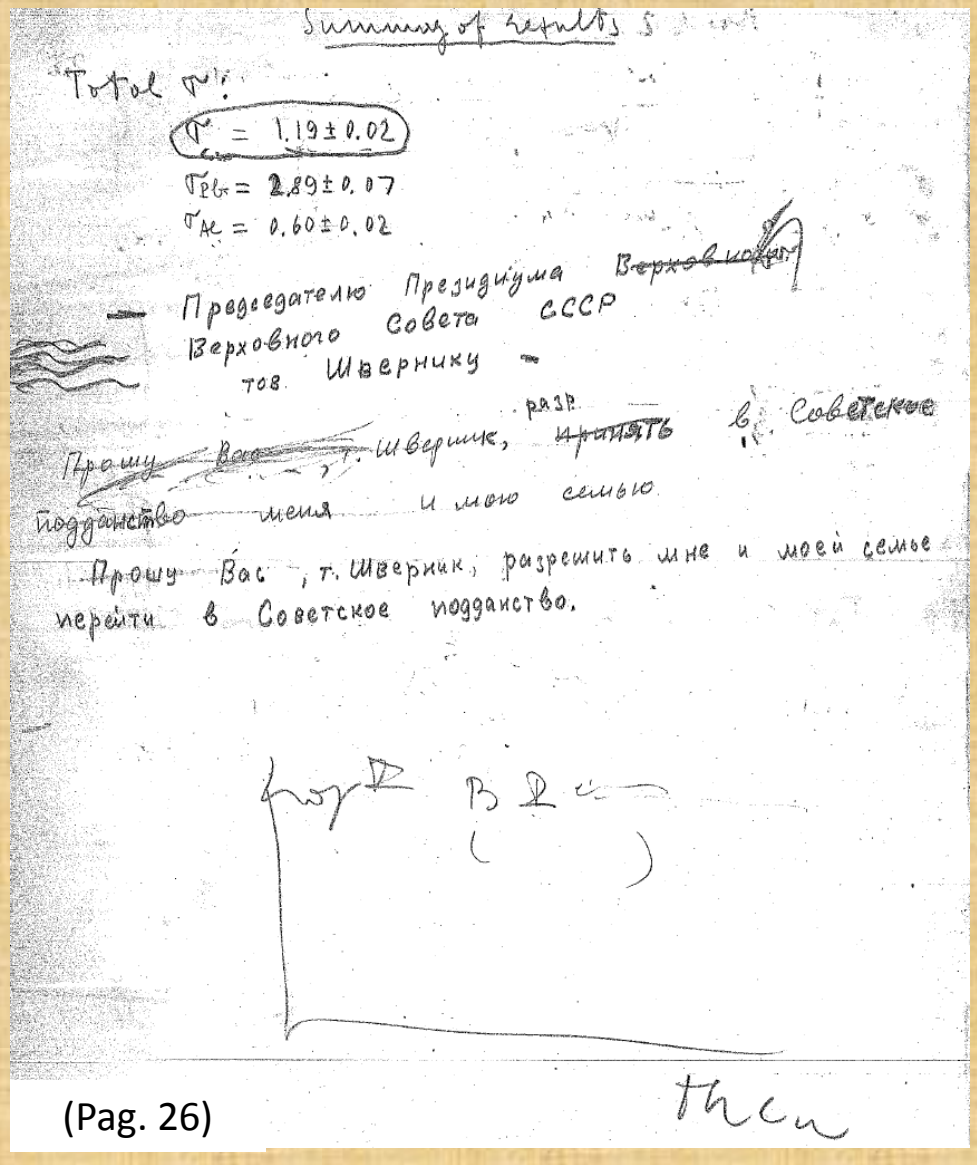
Without paraffine filter

With paraffine filter ≈ 40 cm

Thickness of Cu

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.



(Pag. 26)

Summary of results

Total σ :

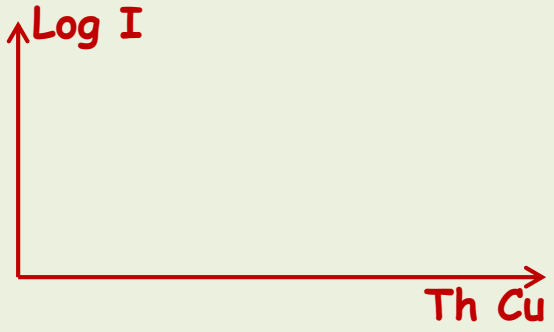
$\sigma_{Cu} = 1.19 \pm 0.02$

$\sigma_{Pb} = 2.89 \pm 0.07$

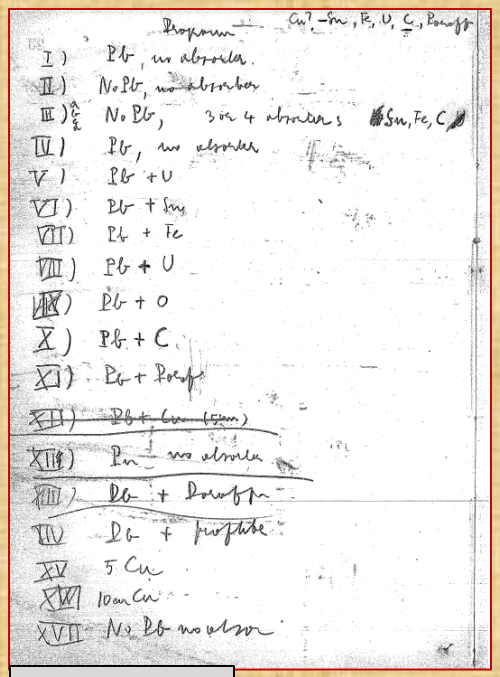
$\sigma_{Al} = 0.60 \pm 0.02$

— *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.



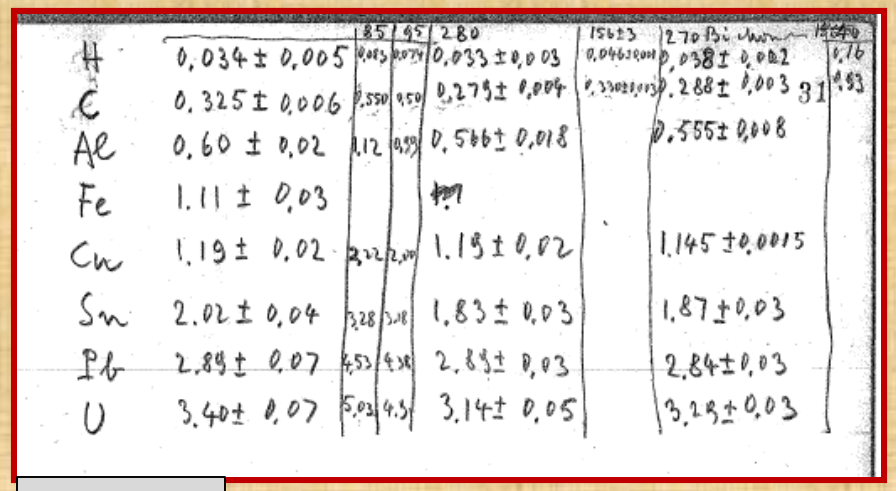
The total cross section measurements are done in many other complex nuclei



Programm — Cu? – Sn, Fe, U, C, Paraffin

I) Pb, no absorber
II) No Pb, no absorber
III) No Pb, 3 or 4 absorbers (Sn, Fe, C)
IV) Pb, no absorber
V) Pb + U
VI) Pb + Sn
VII) Pb + Fe
VIII) Pb + U
IX) Pb + O
X) Pb + C
XI) Pb + Paraffin
XII) ~~Pb + Cu (5cm)~~
XIII) Pb no absorber
XIV) Pb + Paraffin
XV) Pb + graphite
XVI) 5 Cu
XVII) 10cm Cu
XVIII) No Pb no absor

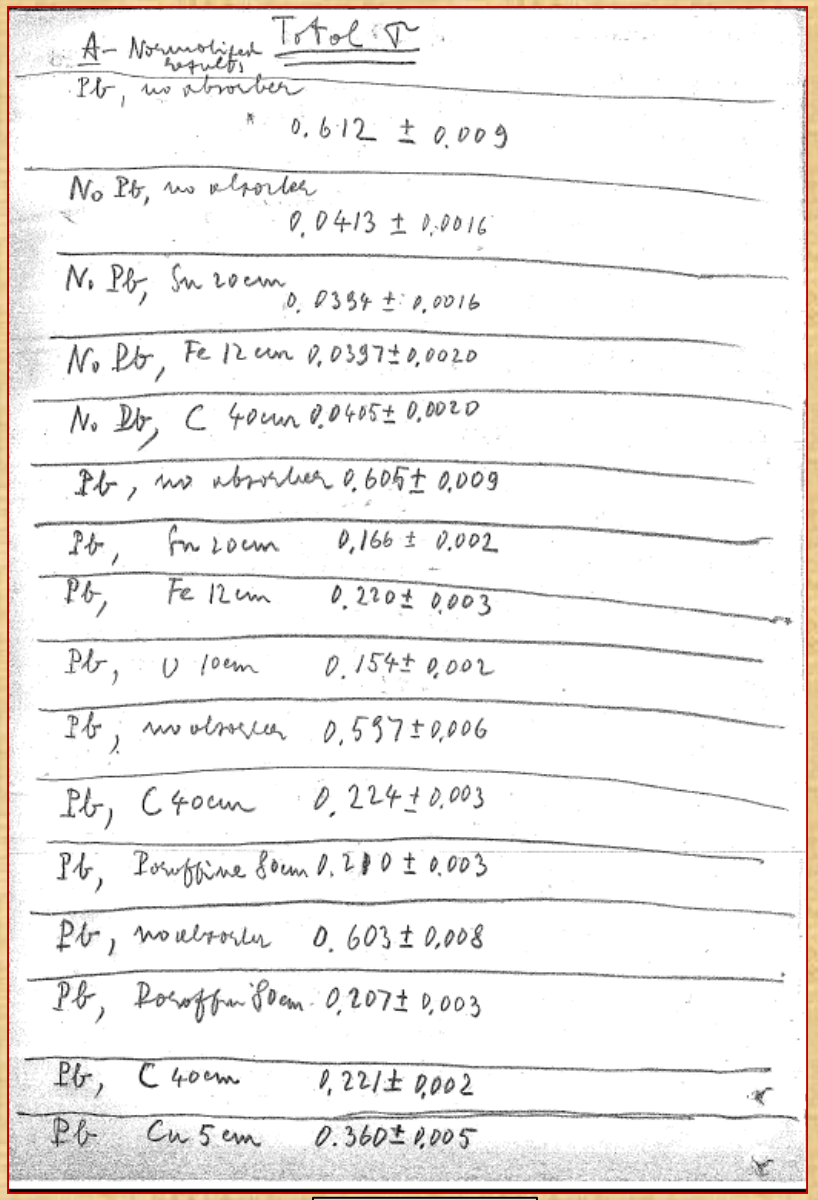
Pag. 27



		85	95	280	156±3	270 Bi	1240
H	0,034 ± 0,005	0,03	0,024	0,033 ± 0,03	0,046±0,004	0,038 ± 0,002	0,76
C	0,325 ± 0,006	0,550	0,50	0,279 ± 0,004	0,330±0,003	0,288 ± 0,003	0,93
Al	0,60 ± 0,02	1,12	0,99	0,566 ± 0,018		0,555 ± 0,008	
Fe	1,11 ± 0,03						
Cu	1,19 ± 0,02	2,22	2,10	1,13 ± 0,02		1,145 ± 0,0015	
Sn	2,02 ± 0,04	3,28	3,08	1,83 ± 0,03		1,87 ± 0,03	
Pb	2,89 ± 0,07	4,53	4,38	2,83 ± 0,03		2,84 ± 0,03	
U	3,40 ± 0,07	5,03	4,5	3,14 ± 0,05		3,23 ± 0,03	

31

Pag. 31



A – Normalized Total σ

Pb, no absorber 0,612 ± 0,009

No Pb, no absorber 0,0413 ± 0,0016

No Pb, Sn 20cm 0,0394 ± 0,0016

No Pb, Fe 12cm 0,0397 ± 0,0020

No Pb, C 40cm 0,0405 ± 0,0020

Pb, no absorber 0,605 ± 0,009

Pb, Sn 20cm 0,166 ± 0,002

Pb, Fe 12cm 0,220 ± 0,003

Pb, U 10cm 0,154 ± 0,002

Pb, no absorber 0,597 ± 0,006

Pb, C 40cm 0,224 ± 0,003

Pb, Paraffine 80cm 0,210 ± 0,003

Pb, no absorber 0,603 ± 0,008

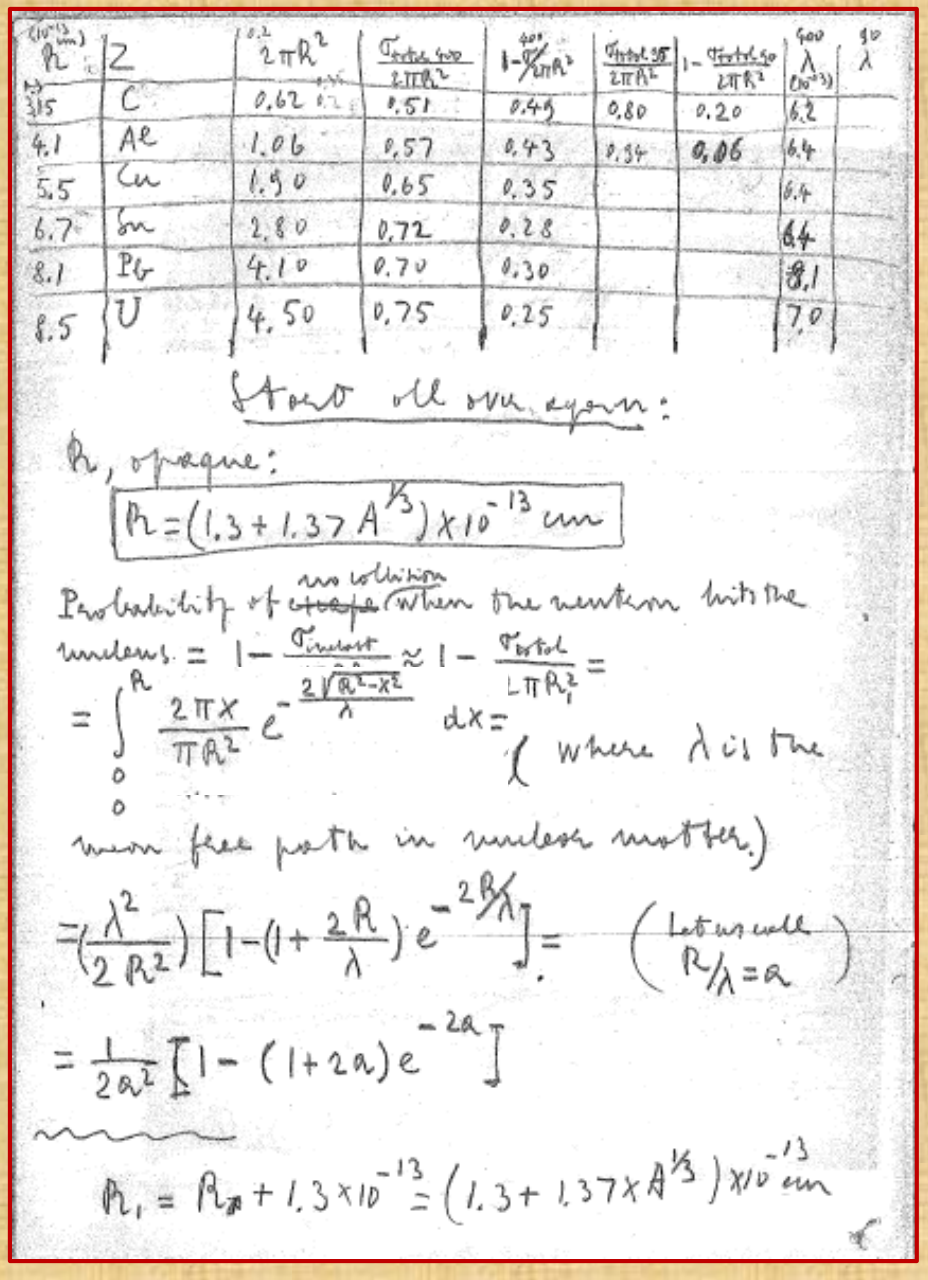
Pb, Paraffin 80cm 0,207 ± 0,003

Pb, C 40cm 0,221 ± 0,002

Pb Cu 5cm 0,360 ± 0,005

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



R (10^{-13}cm)	Z	$2\pi R^2$	$\sigma_{total400}/2\pi R^2$	$1-\sigma^{400}/2\pi R^2$	$\sigma_{total95}/2\pi R^2$	$1-\sigma^{90}/2\pi R^2$	λ^{400} (10^{-13})	λ^{90}
3.5	C	0.62	0.51	0.49	0.80	0.20	6.2	
4.1	Al	1.06	0.57	0.43	0.94	0.06	6.4	
5.5	Cu	1.90	0.65	0.35			6.4	
6.7	Sn	2.80	0.72	0.28			6.4	
8.1	Pb	4.10	0.70	0.30			8.1	
8.5	U	4.50	0.75	0.25			7.0	

Start all over again:

R, opaque:

$$R=(1.3+1.37A^{1/3})\times10^{-13}\ \text{cm}$$

Probability of no collision when the nucleon hits the nucleus $= 1-\frac{\sigma_{inel.}}{\pi R^2}\approx 1-\frac{\sigma_{total}}{2\pi R^2}=$

$$=\int_0^R \frac{2\pi x}{\pi R^2}\, e^{-\frac{2\sqrt{R^2-x^2}}{\lambda}}\, dx=$$ (where λ is the mean free path in nuclear matter)

$$=\left(\frac{\lambda^2}{2R^2}\right)\left[1-\left(1+\frac{2R}{\lambda}\right)e^{-2R/\lambda}\right]=$$ (Let us call $R/\lambda=a$)

$$=\frac{1}{2a^2}\left[1-(1+2a)e^{-2a}\right]$$

$$R_1=R+1.3\times10^{-13}=(1.3+1.37\times A^{1/3})\times10^{-13}\ \text{cm}$$

R (10^{-13}cm), Z, $2\pi R^2$, $\sigma_{total400}/2\pi R^2$, $1-\sigma^{400}/2\pi R^2$, $\sigma_{total95}/2\pi R^2$, $1-\sigma^{90}/2\pi R^2$, $\lambda^{400}(10^{-13})$, λ^{90}

Start all over again:

R, opaque :

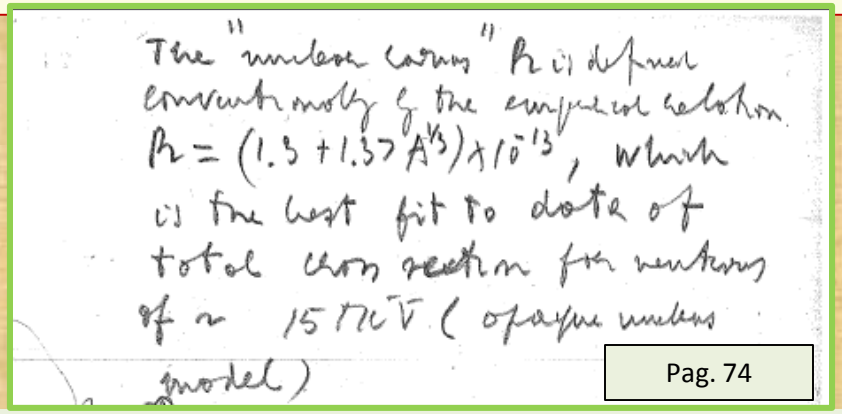
$$R_{(1)}=(1.3+1.37A^{1/3})\times10^{-13}\ \text{cm}$$

Probability of no collision when the nucleon hits the nucleus $= 1-\sigma_{inel.}/\pi R^2\approx 1-\sigma_{total}/2\pi R^2=$

$$=\int_0^R \frac{2\pi x}{\pi R^2}\, e^{-\frac{2\sqrt{R^2-x^2}}{\lambda}}\, dx=$$ (where λ is the mean free path in nuclear matter) $(R/\lambda=a)$

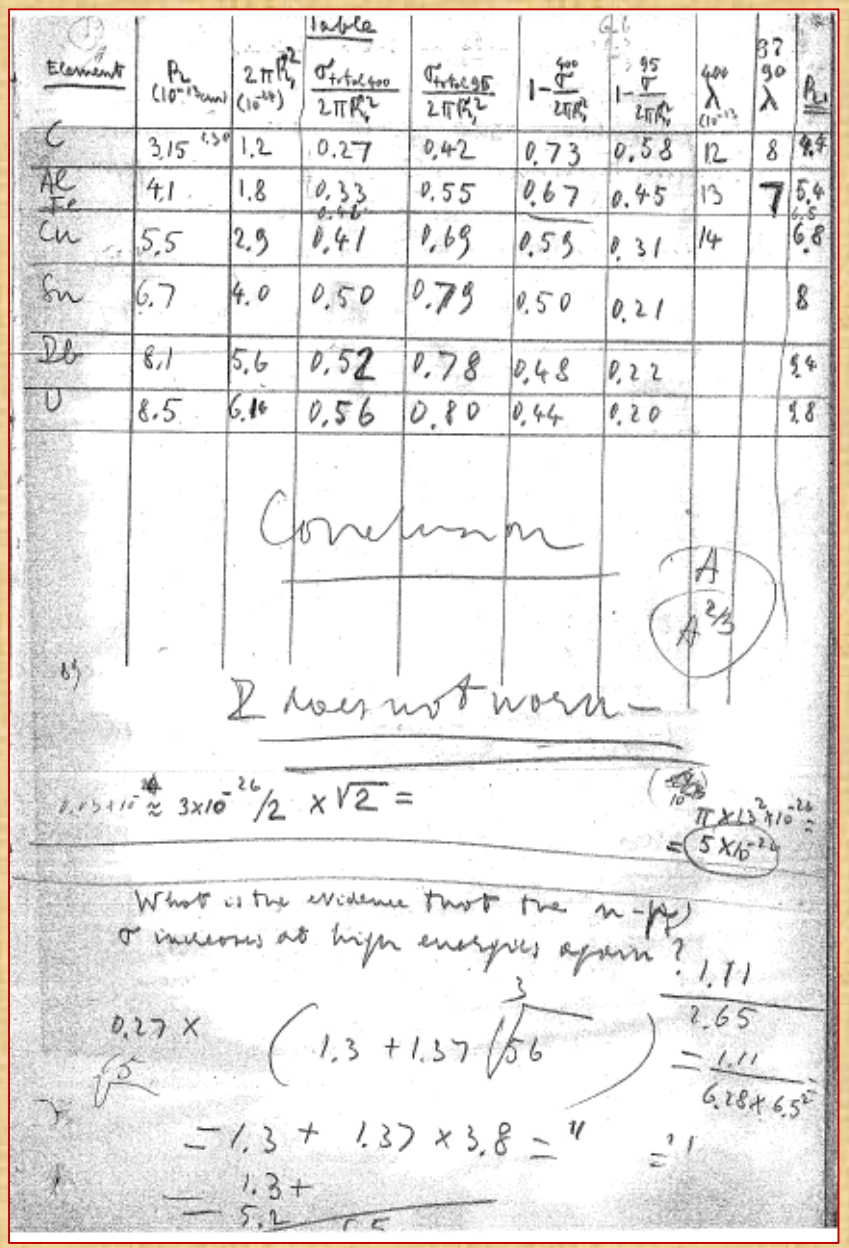
$= 1/(2a^2)[1-(1+2a)e^{-2a}]$

$$R_1=R+1.3\times10^{-13}=(1.3+1.37\times A^{1/3})\times10^{-13}\ \text{cm}$$



The "nuclear radius" R is defined conventionally by the empirical relation $R=(1.3+1.37A^{1/3})\times10^{-13}$, which is the best fit to data of total cross section for neutrons of ~ 15 MeV (**opaque nucleus model**)

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



Table

Element, R (10^{-13}cm), $2\pi R_1^2(10^{-24})$, $\sigma_{total400}/2\pi R_1^2$, $\sigma_{total95}/2\pi R_1^2$, $1-\sigma^{400}/2\pi R_1^2$, $1-\sigma^{95}/2\pi R_1^2$, $\lambda^{400}(10^{-13})$, λ^{90}, R_1

Conclusion

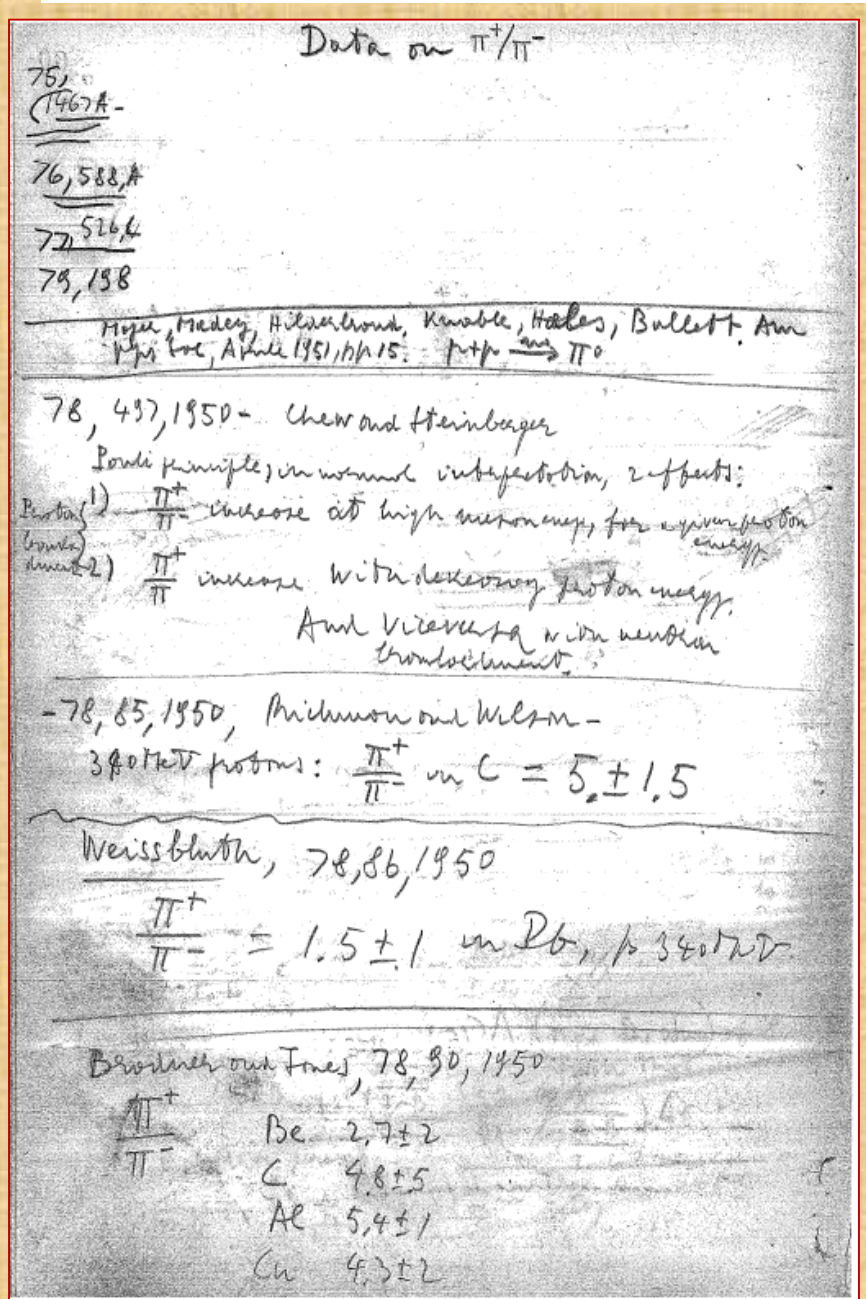
A

$A^{2/3}$

Z does not work -

What is the evidence that the n-p σ increases at high energy again ?

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



Data on π^+/π^-

75,1467 A; 76,588, A; 77,526 ; 79,198

Mayer (?) et al, ….. ….., Aprile 1951, pp 15. p+p ➔no π^0

78, 497, 1950 - Chew and Steinberger
Pauli principle, in normal interpretation, 2 effects:
1) π^+/π^- increase at high meson energy, for a given proton energy
2) π^+/π^- increase with decreasing proton energy
And viceversa with neutron bombardment

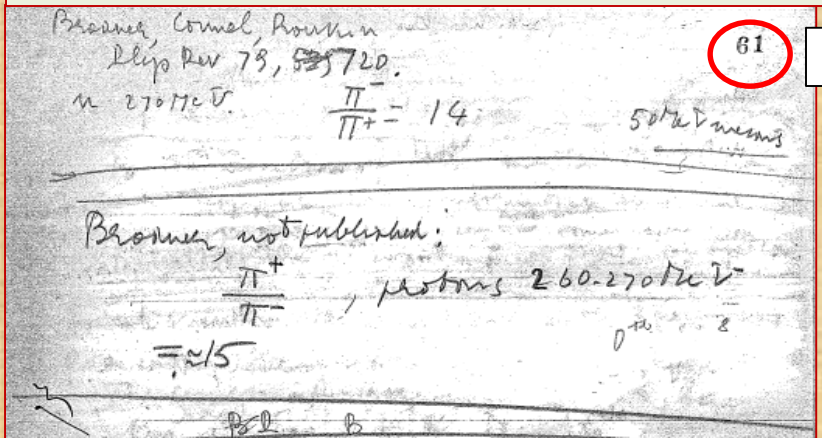
- 78, 85, 1950, Richmon and Wilson –
380 MeV protons: π^+/π^- in C = 5. ± 1.5

Weissbluth, 78,86,1950
π^+/π^- = 1.5 ± 1 in Pb, p 340 MeV

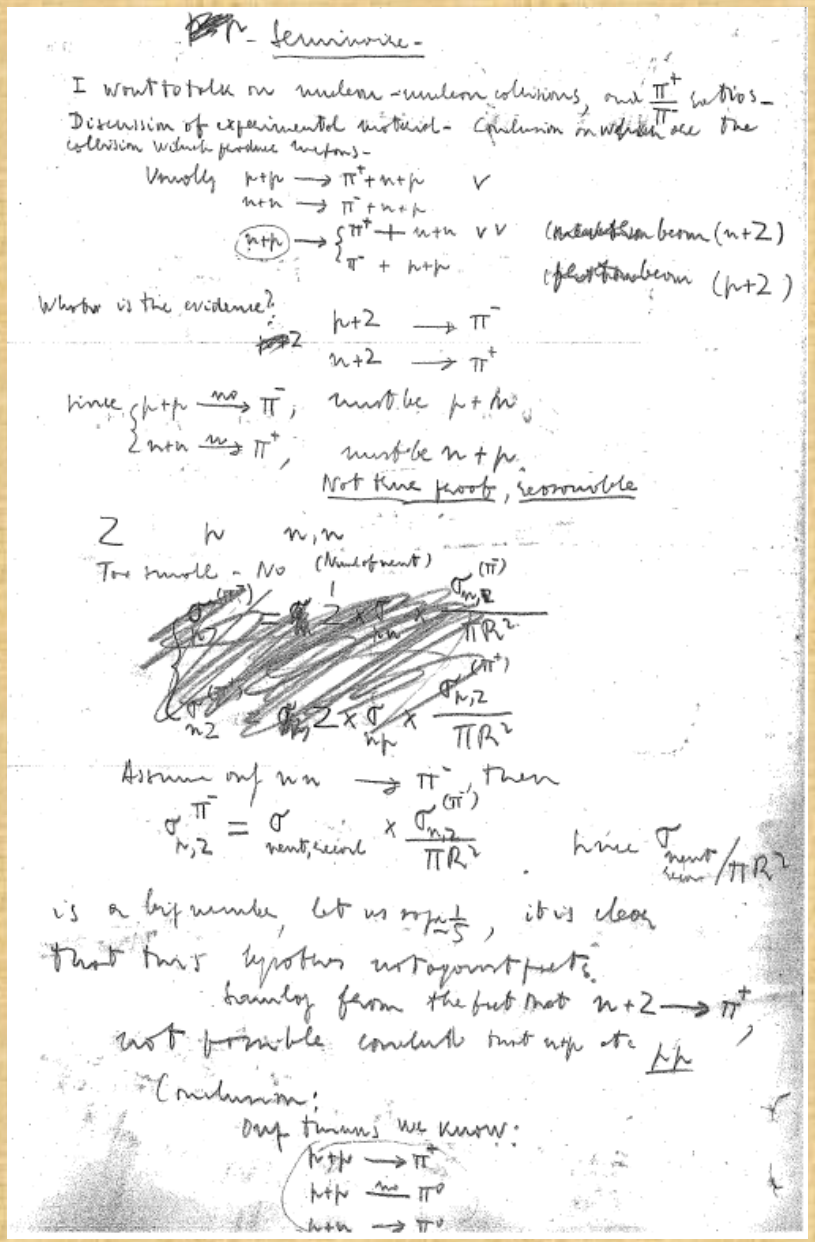
Brodner and Jones, 78,90,1950
π^+/π^- Be 2.7±2; C 4.8±5; Al 5.4±1; Cu 4.3±2

Brauner et al. Phys. Rev. 79, 720
n 270 MeV π^+/π^- =14

Brauner, not published:
π^+/π^-, protons 260-270 MeV = ≈15



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



- 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)
$\pi^- + p + p$ (proton beam (p+Z)

What is the evidence ?

$p+Z \rightarrow \pi^-$
$n+Z \rightarrow \pi^+$

Since $p+p \rightarrow$ no π^-, must be p+n
$n+n \rightarrow$ no π^+, must be n+p
Not true proof, reasonable

Z 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 $\sigma_{neut,recoil}/\pi R^2$ is a big number, let us say ≅ 1/5, it is clear that this hypothesis not against facts.

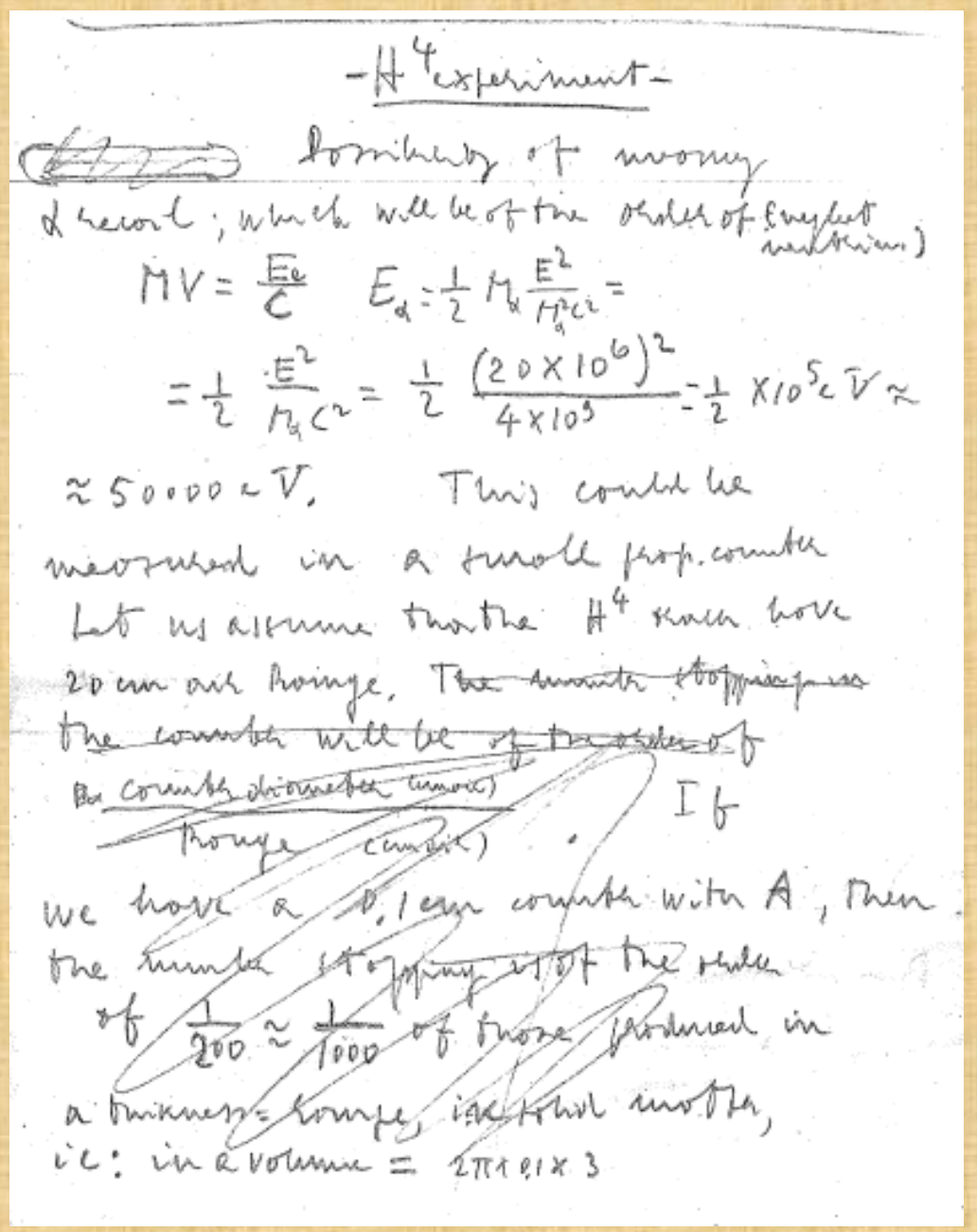
Similarly from the fact that $n+Z \rightarrow \pi^+$, not possible conclude that n+p etc. p p

Conclusion:

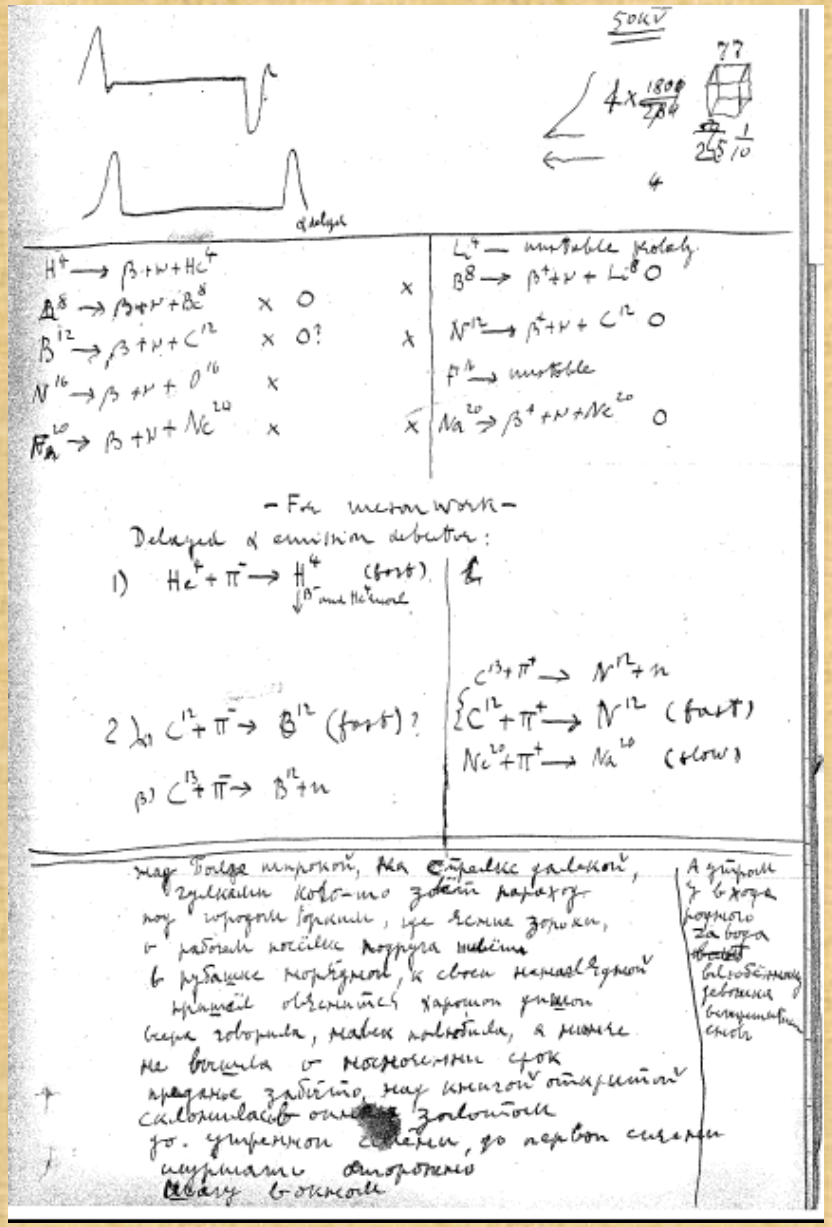
only ??? we know:

$p+p \rightarrow \pi^+$
$p+p \rightarrow$ no π^0
$p+n \rightarrow \pi^0$

Possibility of performing an "H^4 experiment"



Physics but also Poetry



$H^4 \rightarrow \beta + \nu + He^4$ | $Li^4 \rightarrow$ unstable probably

$Li^8 \rightarrow \beta + \nu + Be^8$ x o x | $Be^8 \rightarrow \beta^+ + \nu + Li^8$ o

$B^{12} \rightarrow \beta + \nu + C^{12}$ x o? x | $N^{12} \rightarrow \beta^+ + \nu + C^{12}$ o

$N^{16} \rightarrow \beta + \nu + O^{16}$ x | $F^{16} \rightarrow$ unstable

$F^{20} \rightarrow \beta + \nu + Ne^{20}$ x x | $Na^{20} \rightarrow \beta^+ + \nu + Ne^{20}$ o

-For meson work –

Delayed α emission ??? :

1) $He^4 + \pi^- \rightarrow H^4$ (fast)

$\rightarrow \beta^-$ and He^4 recoil

2) $_{\alpha)}$ $C^{12} + \pi^- \rightarrow B^{12}$ (fast) ? | $C^{13} + \pi^+ \rightarrow N^{12} + n$

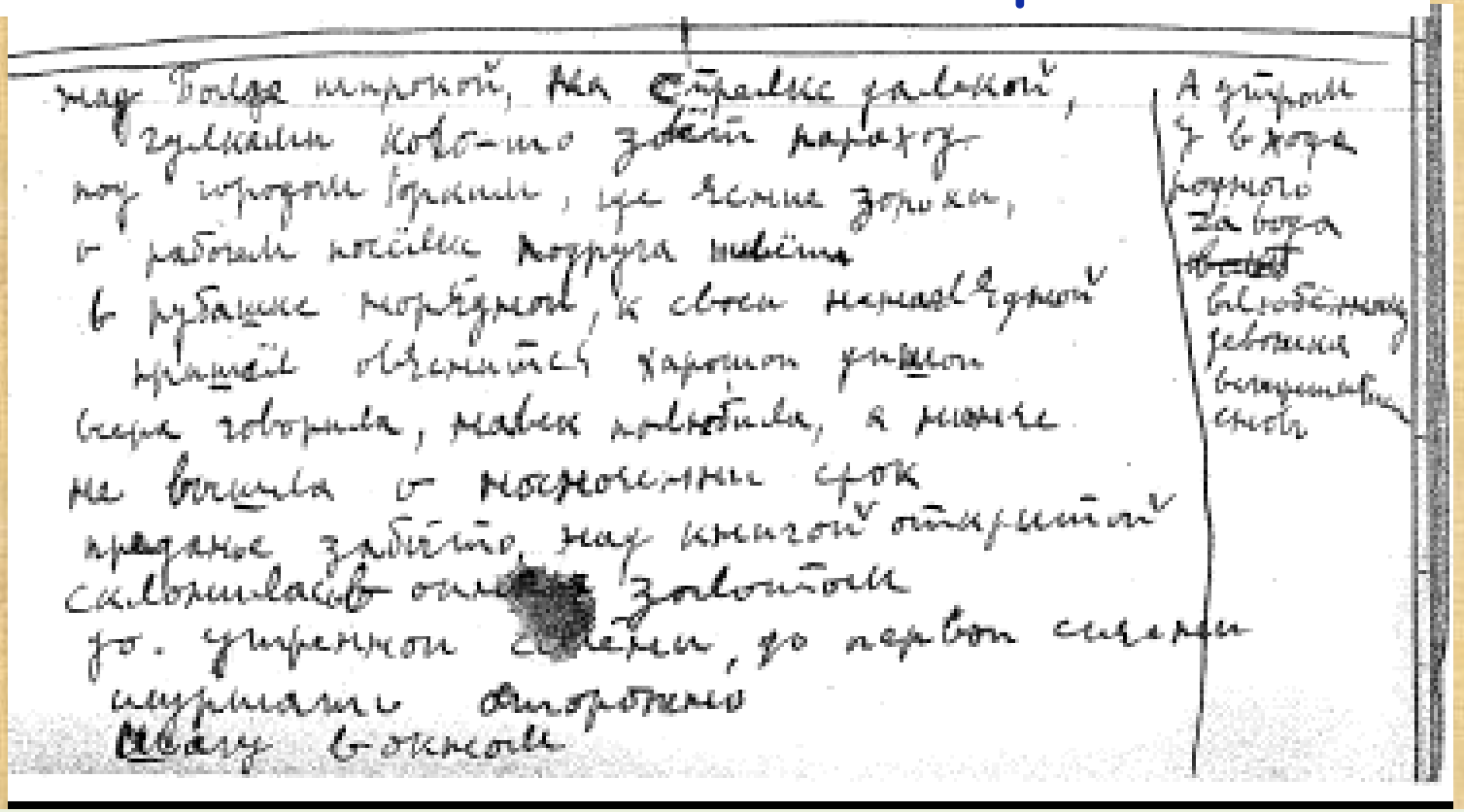
| $C^{12} + \pi^+ \rightarrow N^{12}$ (fast)

$_{\beta)}$ $C^{13} + \pi^- \rightarrow B^{12} + n$ | $Ne^{20} + \pi^+ \rightarrow Na^{20}$ (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



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.

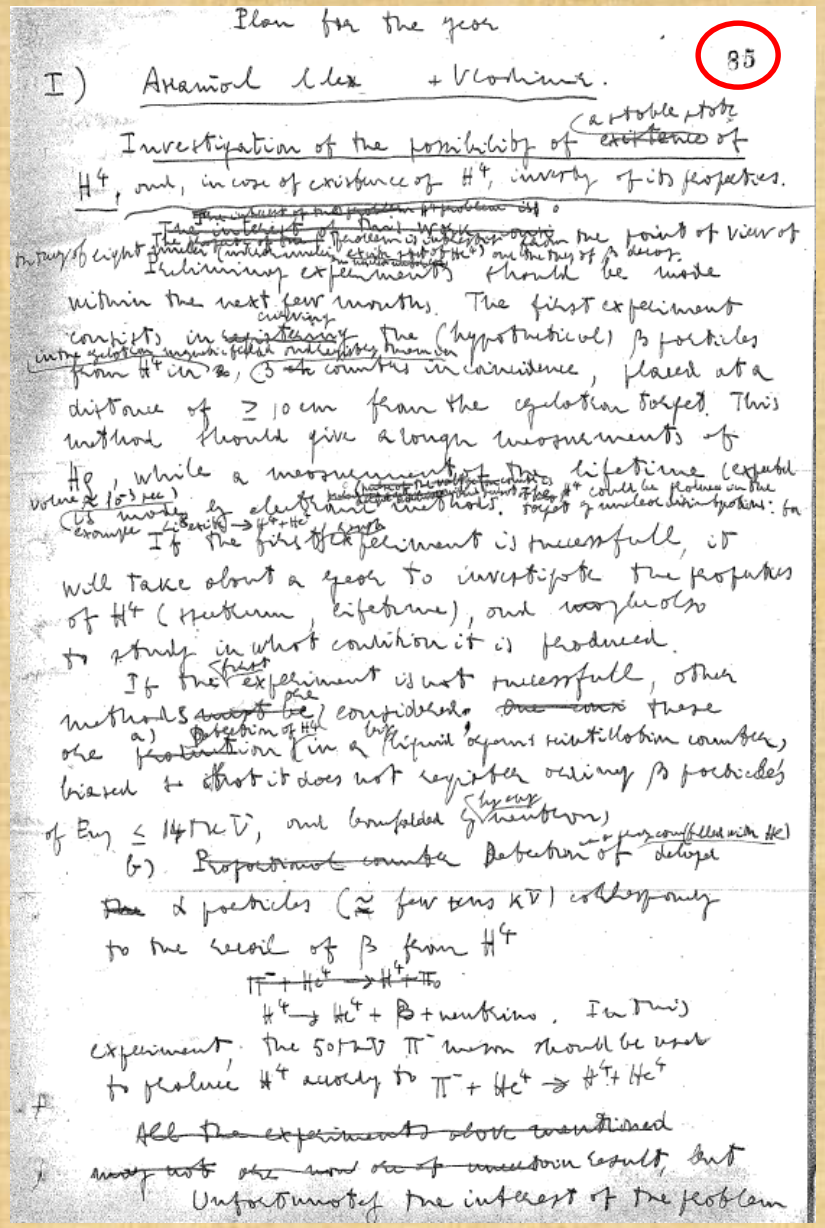
Ой, летние ночки,
Буксиров гудочки...
Волнуется парень и хочет уйти.
Но девушки краше,
Чем в Сормове нашем,
Ему никогда и нигде не найти.

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/dolmatovskiy-evgeniy/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) Anatol Alex + Vladimir.

Investigation of the possibility of (a stable state) existence of H^4, and, in case of existence of H^4, investigation of its properties.

The interest of this problem is ... 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 ≥ 10 cm from the cyclotron target. This method should give a rough measurements of $H\rho$, while a measurement of the lifetime (expected value ≈ 10^{-3} sec) is made by electronic methods. The H^4 could be produced in the target by nuclear interactions (?): for example Li^8 excite → $H^4 + He^4$.

If the first rough experiment is successful, it will take about a year to investigate the properties of H^4 (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 H^4 in a long liquid organic scintillation counter, biased so that it does not register ?? β particles by Energy ≤ 14 MeV, and ?? by high energy neutron.

b) Detection (on a prop. count. filled with He) ? of delayed α particles (≈few tens KV) corresponding to the recoil of β from H^4

$H^4 \rightarrow He^4 + \beta + \text{neutrino}$. In this experiment, the 50 MeV π^- meson should be used to produce H^4 according to $\pi^- + He^4 \rightarrow H^4 + He^4$ but unfortunately the interest of the problem

Plan of the year

85

I) Anatol Alex +Vladimir

Investigation of the possibility of a stable state of H^4, and, in case of existence of H^4 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 ≥ 10 cm from the cyclotron target. This method should give a rough measurements of $H\rho$, while a measurement of the lifetime (expected value ≈ 10^{-3} sec) is made by electronic methods. The H^4 could be produced in the target by nuclear interactions (?): for example Li^8 excite → $H^4 + He^4$.

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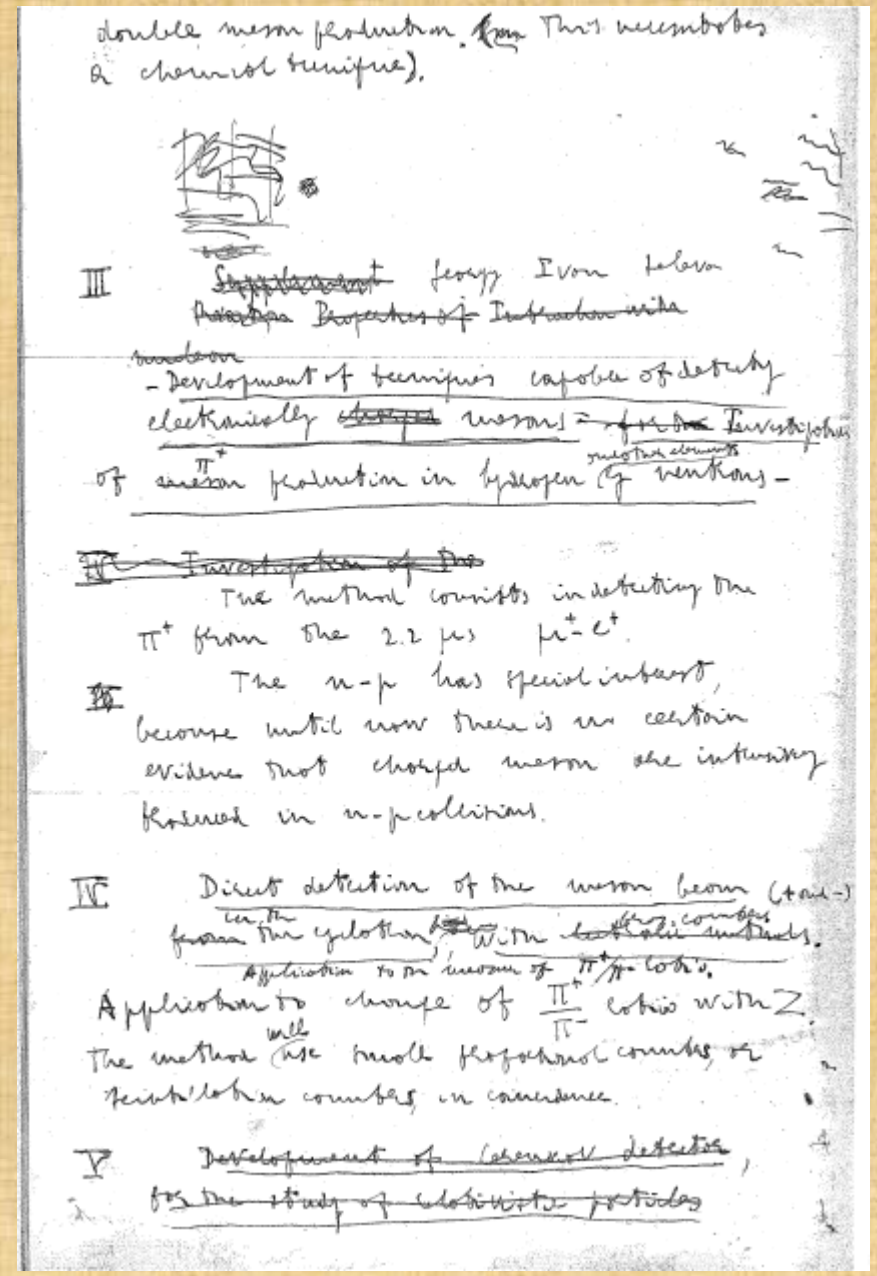
Page 85; Summer 1951 (~ July 11): Pontecorvo is planning the group activities for next year.



double meson production (this necessitates a chemical technique).

III Georgy Ivan Selivan

-Development of techniques capable of detecting elettronically mesons . Investigation of π^+ production in hydrogen and other elements by neutrons.

The method consists in detecting the π^+ from the 2.2μs $\mu^+ - e^+$.

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 Direct detection of the meson beam (+ and -) in the cyclotron, with ~~electronic methods~~ ??? Counters.

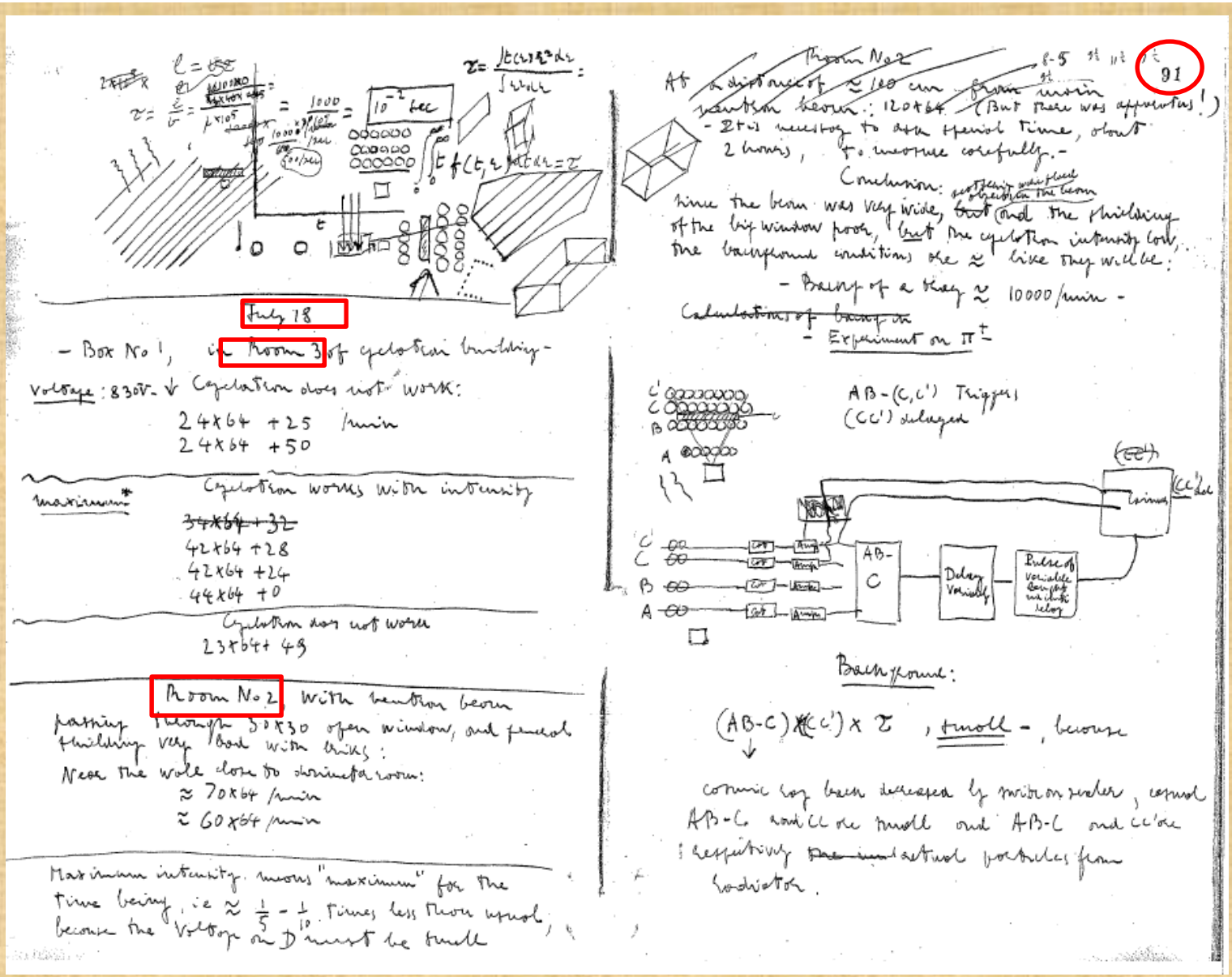
Application to the measure of π^+/π^- ratio.

Application to change of π^+/π^- ratio with Z.

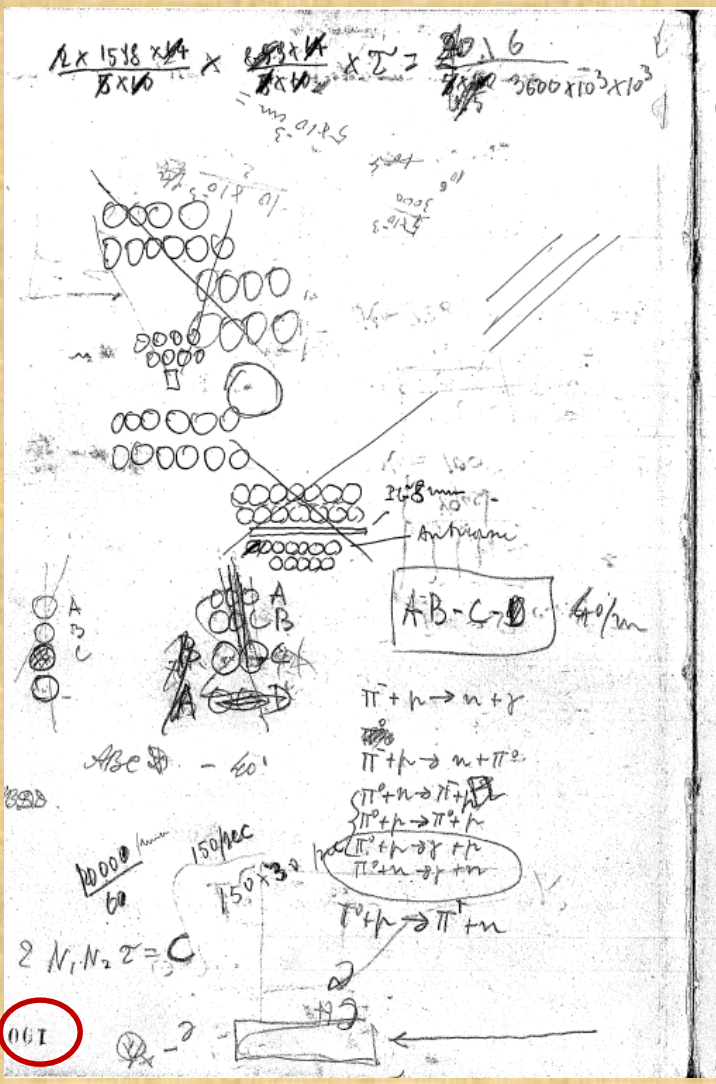
The method will use small photoplates?(?) counters or scintillation counters in coincidence

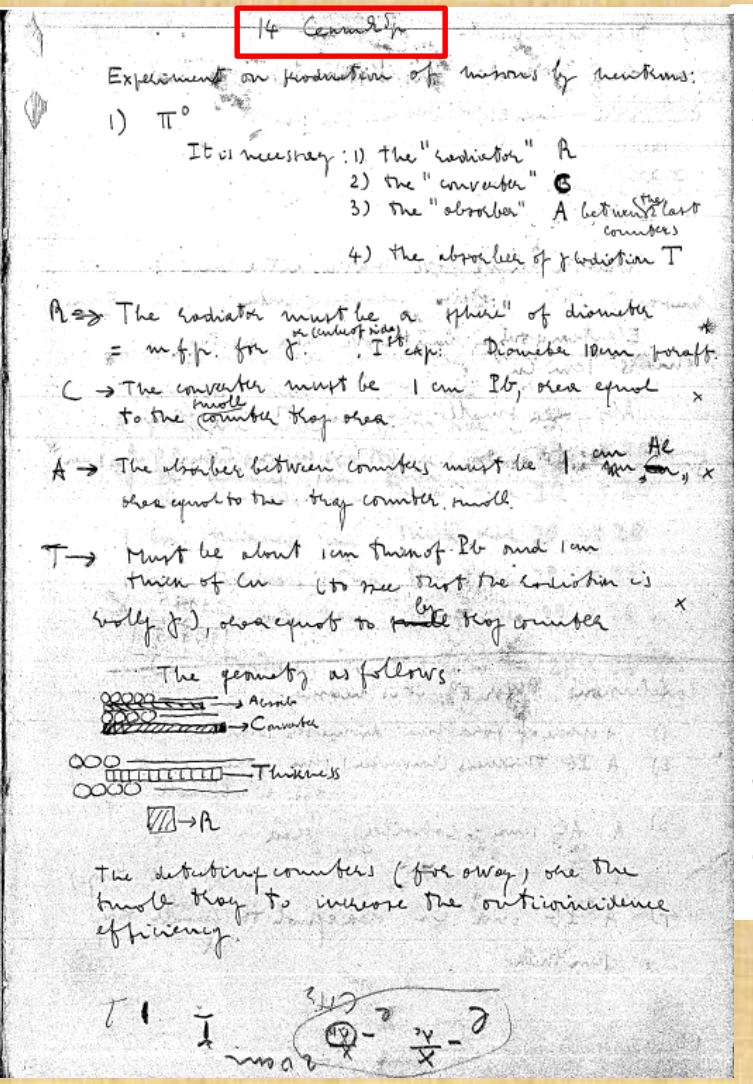
V ~~Development of Cerenkov detectors, for the study of relativistic particles.~~

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.



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":





14 September

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 → *The radiator must be a "sphere " ....*
.....

C → *The converter must be 1 cm Pb,....*
.....

A→ *The absorber between counters ....*
.....

T→ *Must be about 1 cm thin of Pb,....*
.....

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 + Anatol. Alex. Finish work on H^4, in the present variant, + report. Help of Irina.

2) Adolph: Finish work on mesons with radioactive indicators + report.
Have β counters ready.
Have α counter ready

3) George
1) Finish work on duty factor + report.
2) Conclude on the work of production of π^0 in C by neutrons*
3) Initiate electronic detection of mesons in forest
4) Finish ~~one~~ 3 channel coincidence + scintillator (10^{-8} sec), on the principle of
1-2, 1-3, 2-3 (10^{-8})
Double coincidence 10^{-8}, triple 10^{-6}
+ 1 channel coincid or anti, external
10^{-6}
external, coincid, or anticoincid.
Remember delay of 5×10^{-8} to measure accidental.

4) Anatol: finish work + write 2 reports
a) angular
b) total work on secondary neutrons

Program

1) Measure the effective duty factor of the cyclotron as follows - For this:
a) Measure the resolving time of the system (using continuous sources).
b) Measure the accidental rates when the cyclotron works.

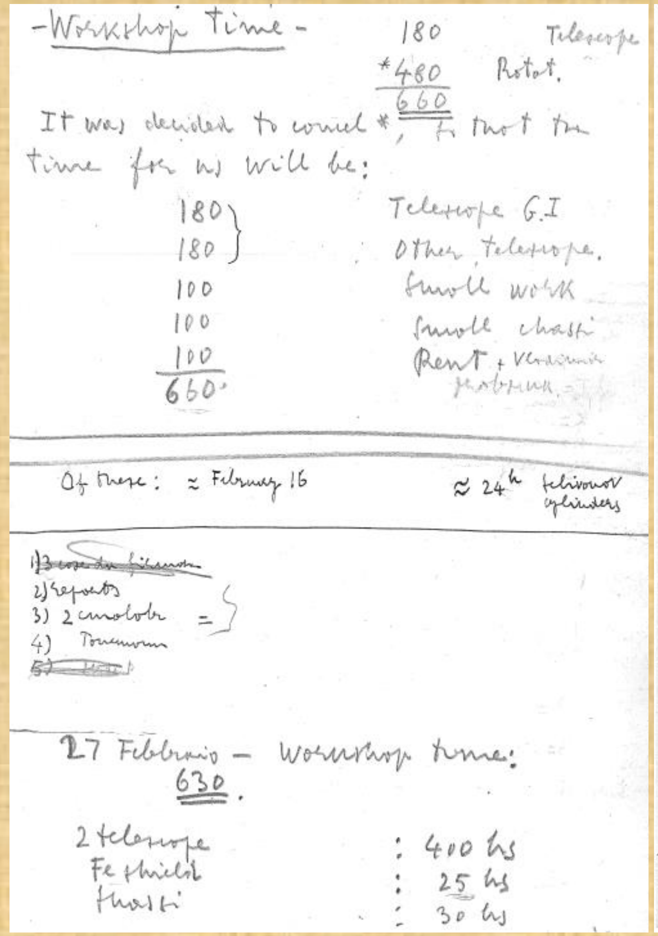
Experiment a: In the cyclotron building with a distance of two trays of about 10^m, and with 2 sources, measure:
1) Single rates, and coincidence: CD - A-B without, from this we get 2τ.
2) done with no source for correcting values in subsequent experiment.

Experiment b:
1) When cyclotron works, single rates and coincidence rates.

Measurement of α, duty factor.

I) Take 2 single counters. +
II) Put them on the beam, for away from each other, and measure A B (AB)
III) Verify that Verify not the cyclotron is constant.
IV) ~~Too various conditions of~~ Measure also after shutdown, A, B (AB).
V) Write all data relative to the cyclotron
VI) If the experiments are reasonably reproducible, for various conditions of cyclotron.

The activity of the group is rather well documented daily



-Workshop Time -	180 Telescope
*480 Rotat.
660

It was decided to cancel *, so that the time for us will be:

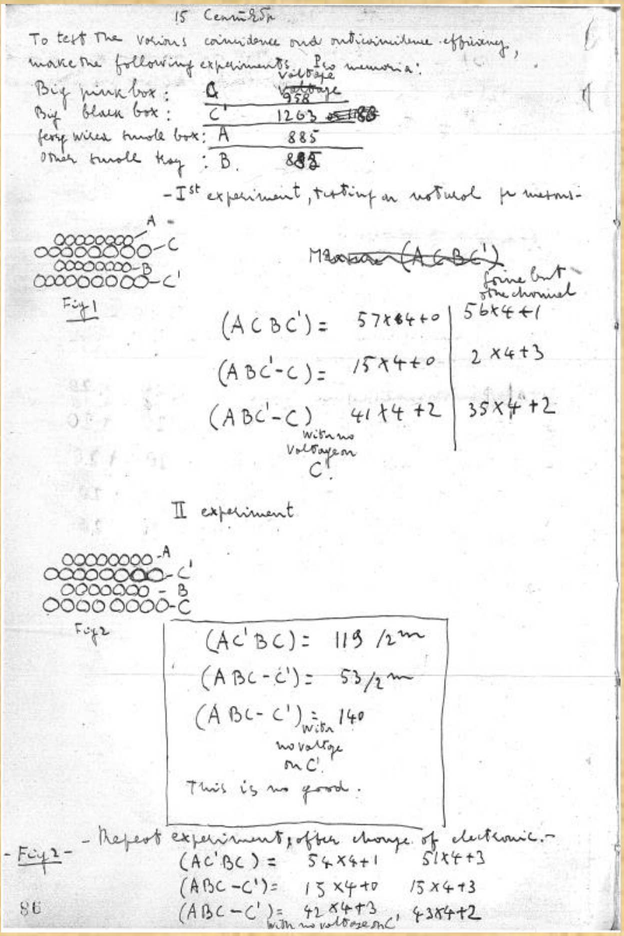
180 } Telescope G.I
180 } Other telescope.
100 Small work
100 Small chassis
100 Rent + ...
660.

Of these: ≈ February 16	≈ 24h ... cylinders

27 Febbraio — Workshop time:
630.

2 telescope : 400 hs
Fe shield : 25 hs
chassis : 30 hs

Workshop time requested and used to build support and mechanical structures



15 ...

To test the various coincidence and anticoincidence efficiency, make the following experiments. ...

Big pink box : C	958
Big black box : C'	1263
... : A	885
Other small ... : B	888

-Ist experiment, testing on natural ...

Fig 1

(ACBC') =	57x64+0	56x4+1
(ABC'-C) =	15x4+0	2x4+3
(ABC'-C) with no voltage on C'	41x4+2	35x4+2

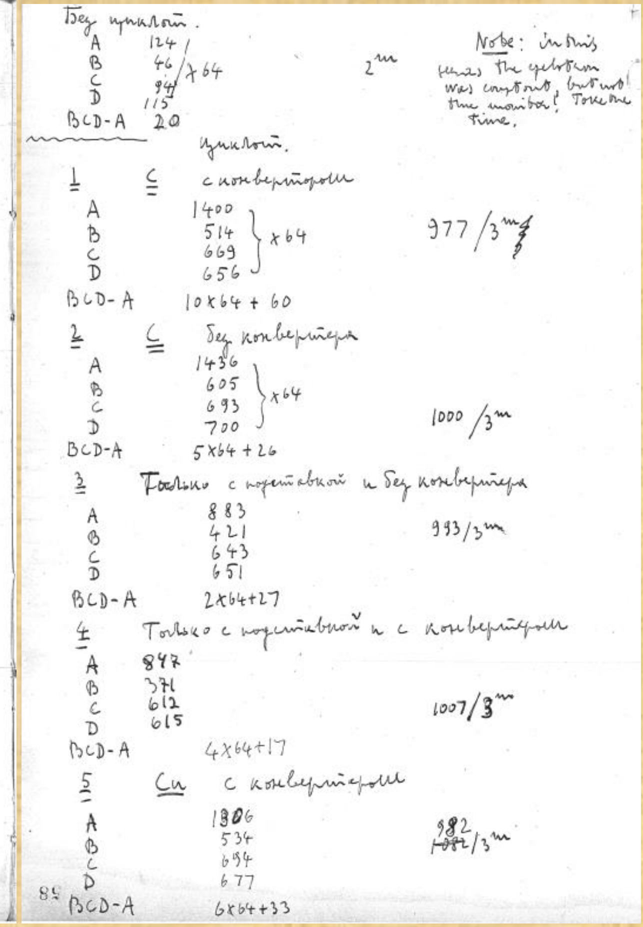
II experiment

Fig 2

(AC'BC) = 119 /2m
(ABC-C') = 53/2m
(ABC-C') with no voltage on C' = 140
This is no good.

- Repeat experiment, after change of electronic. -
(AC'BC) = 54x4+1	51x4+3
(ABC-C') = 15x4+0	15x4+3
(ABC-C') with no voltage on C' = 42x4+3, 43x4+2

Measurements to test the various coincidence and anticoincidence efficiencies



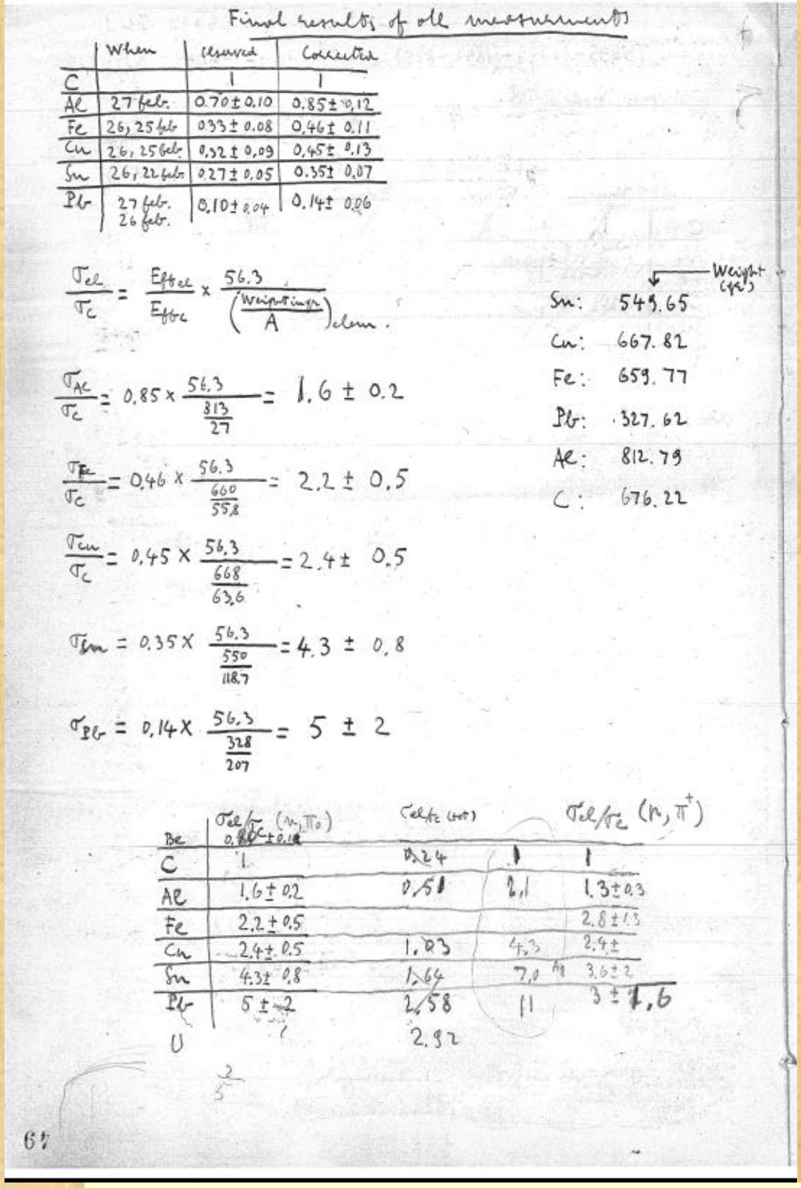
A	124	
B	46	x64
C	94	
D	115	
BCD-A	20	

Note: in this ... 2m

1 — A 1400, B 514, C 669, D 656 x64 — BCD-A 10x64+60 — 977/3m
2 — A 1436, B 605, C 693, D 700 x64 — BCD-A 5x64+26 — 1000/3m
3 — A 883, B 421, C 643, D 651 — BCD-A 2x64+27 — 993/3m
4 — A 847, B 371, C 612, D 615 — BCD-A 4x64+17 — 1007/3m
5 — A 1306, B 534, C 654, D 677 — BCD-A 6x64+33 — 982/3m

Data taking

The activity of the group is rather well daily documented



Final results of all measurements

	When	observed	Corrected
C		1	1
Al	27 feb.	0.70±0.10	0.85±0.12
Fe	26, 25 feb	0.33±0.08	0.46±0.11
Cu	26, 25 feb	0.32±0.09	0.45±0.13
Sn	26, 22 feb	0.27±0.05	0.35±0.07
Pb	27 feb. 26 feb.	0.10±0.04	0.14±0.06

$$\frac{\sigma_{el}}{\sigma_C} = \frac{Eff_{el}}{Eff_C} \times \frac{56.3}{\left(\frac{\text{Weight in gr}}{A}\right)_{elem.}}$$

Weight (gr):

Sn: 549.65
Cu: 667.82
Fe: 659.77
Pb: 327.62
Al: 812.79
C: 676.22

$$\frac{\sigma_{Al}}{\sigma_C} = 0.85 \times \frac{56.3}{\frac{813}{27}} = 1.6 \pm 0.2$$

$$\frac{\sigma_{Fe}}{\sigma_C} = 0.46 \times \frac{56.3}{\frac{660}{55.8}} = 2.2 \pm 0.5$$

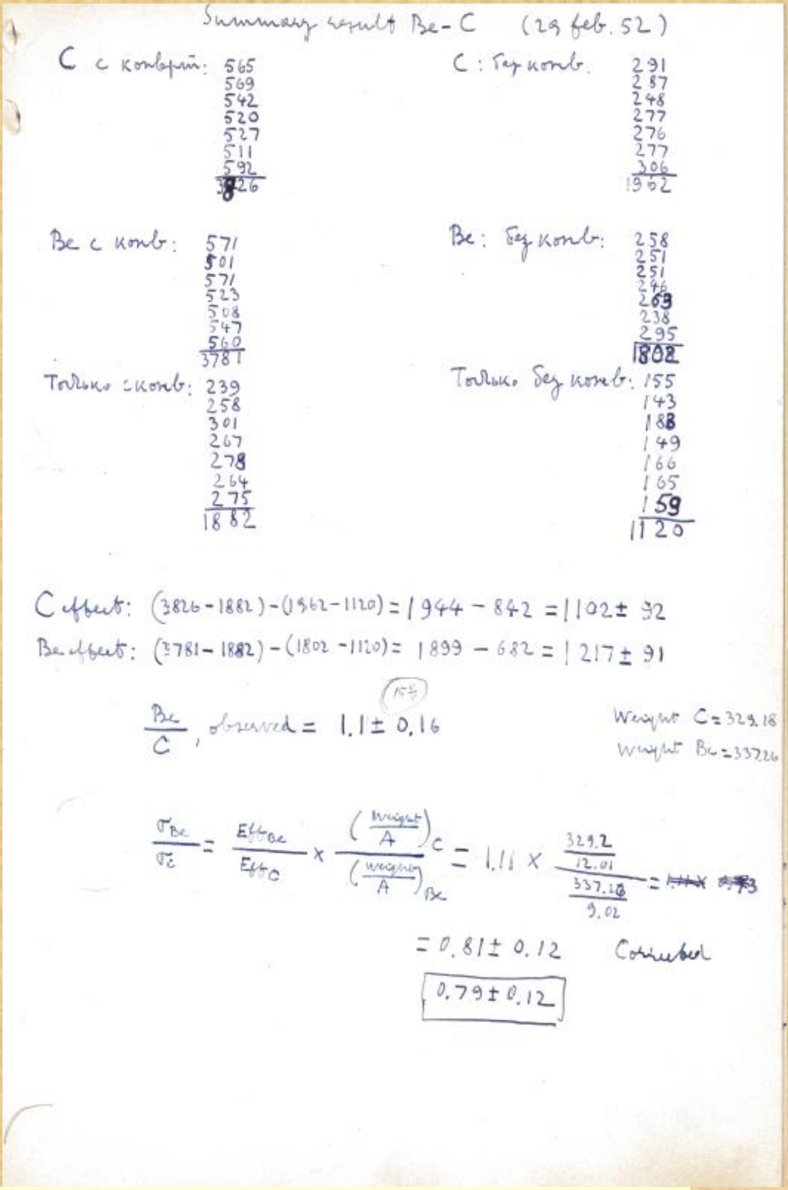
$$\frac{\sigma_{Cu}}{\sigma_C} = 0.45 \times \frac{56.3}{\frac{668}{63.6}} = 2.4 \pm 0.5$$

$$\sigma_{Sn} = 0.35 \times \frac{56.3}{\frac{550}{118.7}} = 4.3 \pm 0.8$$

$$\sigma_{Pb} = 0.14 \times \frac{56.3}{\frac{328}{207}} = 5 \pm 2$$

	σ_{el}/σ_C (n,π^0)	σ_{el}/σ_C		σ_{el}/σ_C (n,π^+)
Be	0.80±0.1			
C	1	0.24	1	1
Al	1.6±0.2	0.51	2.1	1.3±0.3
Fe	2.2±0.5			2.8±1.3
Cu	2.4±0.5	1.03	4.3	2.4±
Sn	4.3±0.8	1.64	7.0	3.6±2
Pb	5±2	2.58	11	3±1.6
U		2.92		

61



Summary result Be-C (29 feb. 52)

C с комбин.: 565, 569, 542, 520, 527, 511, 592 — 3826

C: без комб.: 291, 287, 248, 277, 276, 277, 306 — 1962

Be с комб.: 571, 501, 571, 523, 508, 547, 560 — 3781

Be: без комб.: 258, 251, 251, 246, 263, 238, 295 — 1802

Только с комб.: 239, 258, 301, 267, 278, 264, 275 — 1882

Только без комб.: 155, 143, 188, 149, 166, 165, 159 — 1120

C effect: (3826 − 1882) − (1962 − 1120) = 1944 − 842 = 1102 ± 92

Be effect: (3781 − 1882) − (1802 − 1120) = 1899 − 682 = 1217 ± 91

$\frac{Be}{C}$, observed = 1.1 ± 0.16

Weight C = 329.18
Weight Be = 337.26

$$\frac{\sigma_{Be}}{\sigma_C} = \frac{Eff_{Be}}{Eff_C} \times \frac{\left(\frac{\text{Weight}}{A}\right)_C}{\left(\frac{\text{Weight}}{A}\right)_{Be}} = 1.11 \times \frac{\frac{329.2}{12.01}}{\frac{337.10}{9.02}}$$

= 0.81 ± 0.12 Corrected

0.79 ± 0.12

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

We have this meeting in relation to some reorganisation of our group. The first thing is that there is a new addition. The second is that we must have internal discussions more frequently. For this we will make a seminar every week, of ~1h, on Thursday at 6h. This seminar will be an informal argument and will have 2 parts: a) Briefly ~~all~~ members of group will describe the progress of the week b) There will be a brief mention of what ~~has been the progress in the week~~ is interesting in the week's new own and foreign journals of physics.

The third is the most important thing that we have to discuss. In my opinion personal relations inside our group were ~~[illegible]~~ not satisfactory. ~~[illegible]~~ There were many examples were members of our group, for example, went for advice (on electronics) to other groups, while there exist in our group a very well qualified man (in electronics) G.I., in general speaking our group, because of these relations, could not make use of the full possibilities of the group workers. I think that we must not discuss now whose is fault. And also we must not discuss, in general, the past. The only thing in which we must agree, is ~~to forget the~~ to admit that the situation was not satisfactory and that we must ~~forget~~ change it radically. How can we change it radically, for the interests of the total scientific production of the group? For this is ~~[illegible]~~ it is necessary that it is established a more collaboration in our group. What does this mean? This means that G.I. will help, with his experience of electronic design and construction, other members of group. This collaboration must be friendly. This collaboration must also be 2 ways, i.e. in the interest of all.

Specifically, what this reorganisation mean:

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

~~II) The help may be [illegible]~~

II) In addition to advice, there will be more concrete form. ~~[illegible]~~ Give scheme of apparatus, and even ~~given the way~~ of construction and testing, in other words full collaboration ~~[illegible]~~ on a scientific team. ~~Actually that means, that on a given team, G.I. will look more on this side of the work that on the work in the [illegible]~~

~~III) [illegible] This applies [illegible]~~

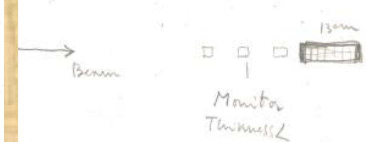
III) It is essential that, generally speaking, every theme has more or less his own apparatus. This mean, generally, not shifting of apparatus from a team to other, on this rule there will be exceptions.

IV) Between collaborators, generally speaking, can one continue to work only with G.IV on his own theme. This is necessary [illegible] production, because G.IV wants to [illegible] in order physics and not to become [illegible] constructor.

V The interest of people in the group will be of course that will have advice and be trained, of G.I that he will participate in experiments not only.

~~VI [illegible]~~

Tema mesoni



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 ≈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) Remember …..is 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 -

Until a few years ago, it was natural for the experimental physicists to produce himself all the electronic equipment necessary for his experiments. However nowadays the quantity of electronic equipment necessary for research is so great that electronic groups, producing "standard equipment" and developing new advanced techniques is very desirable. Without an electronic group, the production of scientific results will suffer from the contradiction between the large scale character and industrial organization of the laboratory and the small scale and individual character of the search for research.

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" electronic man. There are of course men which manage to be very competent in the science of electronics and in the science of nuclear physics, but these are exception: these will be the men which can advance our knowledge in the field of nuclear physics out of electronics. If we expect that every man in the laboratory must be such, we cancel one of the main factor of the basis of present day high productivity, i.e. the specialization. The specialization in science and techniques is today a necessity, however unpleasant it may be.

The presence of an electronic group requires not only

a) continuous contact and discussions between the nuclear physics and the electronic group but also

b) an absolute equality of "status" between the men engaged in "professional" electronics and the men engaged in "professional" nuclear physics". This point is very

important, because in some physics laboratories there is the tendency to put nuclear physics on a higher plane than electronics. This "[illegible]" is without foundation, and is usually the effect of the "[illegible]" of the nuclear physicists. It is true that the discovery of a new particle is more important than, for example, the realisation of a [illegible], but it is equally true that the introduction of negative feed back, or the development of the travelling wave amplifier is much more important than, for example, the study of a certain [illegible] reaction. Electronics and nuclear physics are 2 parts of physics of equal standing. If this artificial "hierarchie" is kept, clearly it is impossible a collaboration between professional electronic men and professional nuclear physicists: In this case there will be [illegible] the professional electronic man will want to make nuclear experiments, and because the possibility of existence of an electronic group disappears. If, on the contrary, the electronic man will feel that his work is understood and appreciated, that he can gain prestige by the development of new apparatus, then he will generally prefer to work in a [illegible] field.

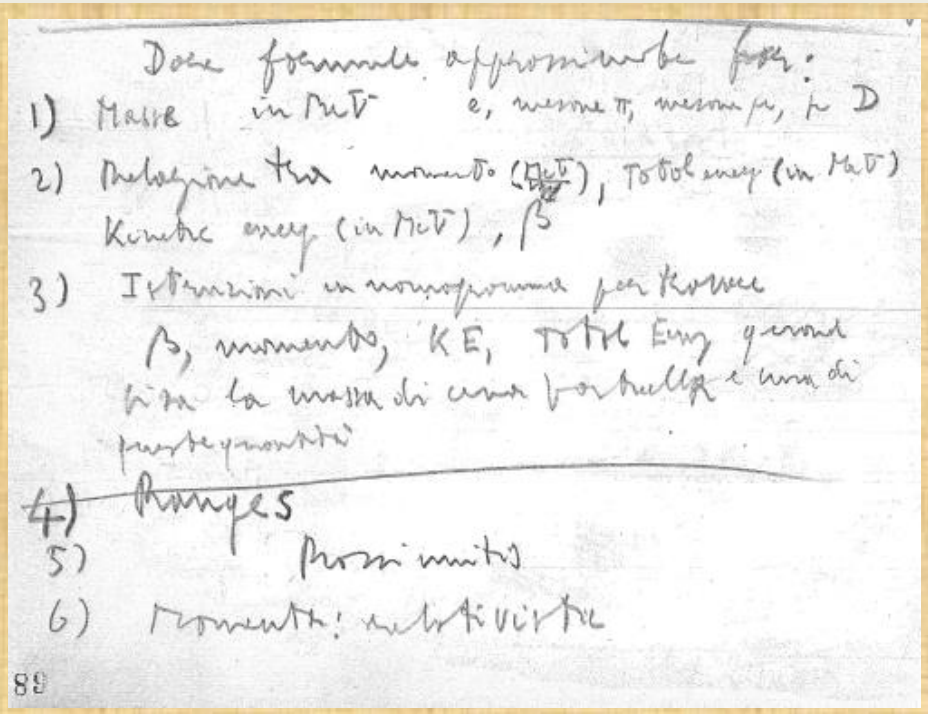
Draft of the document on the problem of collaboration between experts on electronics and in nuclear physics

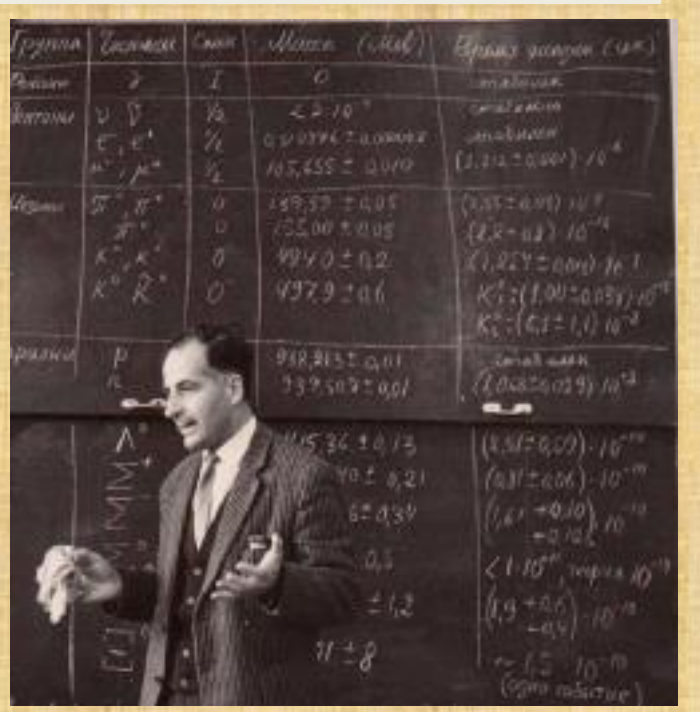
- **Electronics and Nuclear Physics** -

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 desirable** .....omissis ....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

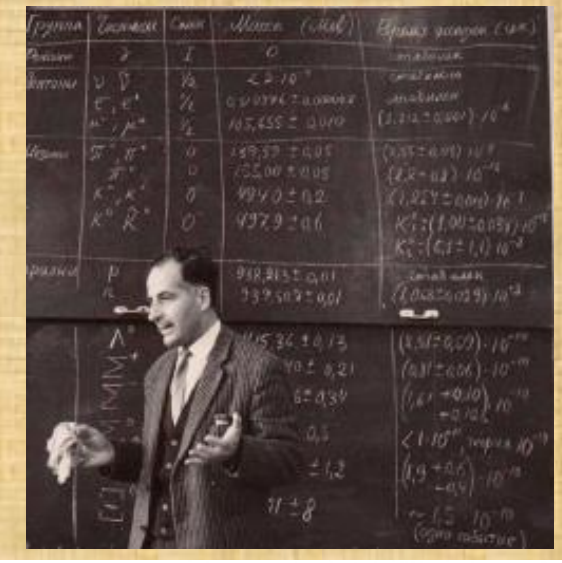

Dare formule approssimate per:
1) Masse in MeV
2) Relazione tra momento (MeV), Total energy (in MeV), Kinetic energy (in MeV), β
3) Istruzioni in monogramma per trovare β, momento, KE, Total Energy quando si sa la massa di una particella e una di queste quantità
4) Ranges
5) Rossi units
6) Momenta: relativistic
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
3) 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



- Useful relativistic formulae in C.G.S. -

E_{tot} ; E_{kin} ; m_0 ; v = velocity ; p = momentum.

$E_{kin} = m_0c^2\left(\frac{1}{\sqrt{1-\beta^2}} - 1\right)$; $E_{tot} = \frac{m_0c^2}{\sqrt{1-\beta^2}}$; $\frac{m_0c^2}{E_{tot}} = \sqrt{1-\beta^2}$

$p = \frac{m_0 v}{\sqrt{1-\beta^2}}$; $\frac{pc}{E_{tot}} = \beta$; $\frac{pc}{m_0c^2} = \frac{\beta}{\sqrt{1-\beta^2}}$

$E = \sqrt{m_0^2c^4 + p^2c^2} - m_0c^2$ $\qquad p = \frac{\sqrt{E(E+2m_0c^2)}}{c}$

If we express energy, momenta, and mass in MeV, $\frac{MeV}{c}$, $\frac{MeV}{c^2}$, or, briefly, in Me V, theory and denote in those units:

m = mass in MeV
T = Kin. E in MeV
Total energy = m + T = E_{tot}
K = Momentum in MeV
Hg = rigidity in gauss-cm.

then, simply by placing c = 1 in the above formulae

$T = m\left(\frac{1}{\sqrt{1-\beta^2}} - 1\right)$ $\qquad K = \frac{m\beta}{\sqrt{1-\beta^2}}$ $\qquad T \leq K \leq T + m$ (= will be for ultrarelativistic particles.)

$E_{tot} = \sqrt{m^2 + K^2}$

$T = \sqrt{m^2 + K^2} - m$ $\qquad Hg = \frac{K \times 10^6}{300}$ (charge 1)

$K = \sqrt{T + 2m}\ \sqrt{T}$ $\qquad K = 300\, Hg \times 10^{-6}$

$\beta = \frac{K}{T+m}$ $\qquad \beta = \frac{\sqrt{T+2m}\sqrt{T}}{T+m}$ $\qquad \frac{\beta}{\sqrt{1-\beta^2}} = \frac{K}{m}$ $\qquad \frac{T+m}{m} = \frac{1}{\sqrt{1-\beta^2}}$

Masses (MeV):

	electron	μ	π	p	D
m	0,5108		140	931	

- Units - - Electron relativistics -

Quantity	Symbol	Definition
Charge	e	charge of electron
Potential	V	volt
Velocity	C	velocity of light
Lenght	cm	centimeter
Time	$\frac{cm}{c}$	time necessary for light to travel 1 cm
Energy	eV	energy of an electron accelerated by 1 volt
Mass	$\frac{eV}{c^2}$	mass of a particle whose rest energy is 1 eV
Momentum	$\frac{eV}{c}$	momentum of a particle for which total energy² − rest energy² = 1 (or momentum of a particle whose energy is 1 eV and velocity c)
Electric field	$\frac{V}{cm}$	
Force	$\frac{eV}{cm}$	force acting on an electron in a field of 1 V/cm.
Magnetic induction (B)	$\frac{V}{c}\,cm$	Magnetic induction of a field in which a particle with unit momentum and unit charge has a radius of curvature of 1 cm when travelling perpendicul. to the field (1 V/c cm = $\frac{1}{300}$ gauss)

Range of protons and Range of Deuterons -

Energia (MeV) →	10	20	30	40	50	60	70	80	90	100
Proton Range (gr/cm²) in Cu	0.25	0.75	1.4	2.4	3.5	5.0	6.5	7.7	10.0	12
Proton Range (gr/cm²) in Al	0.15	0.55	1.2	1.9	2.9	4.0	5.3	6.5	8.0	9,5

Energia (MeV) →	240	280	320	360	400	440	480	520	560	600
Proton Range (gr/cm²) Cu	53	68	86	104	122	142	162	183	204	226
Proton Range (gr/cm²) Al	43	56	72	86	104	120	137	156	173	193

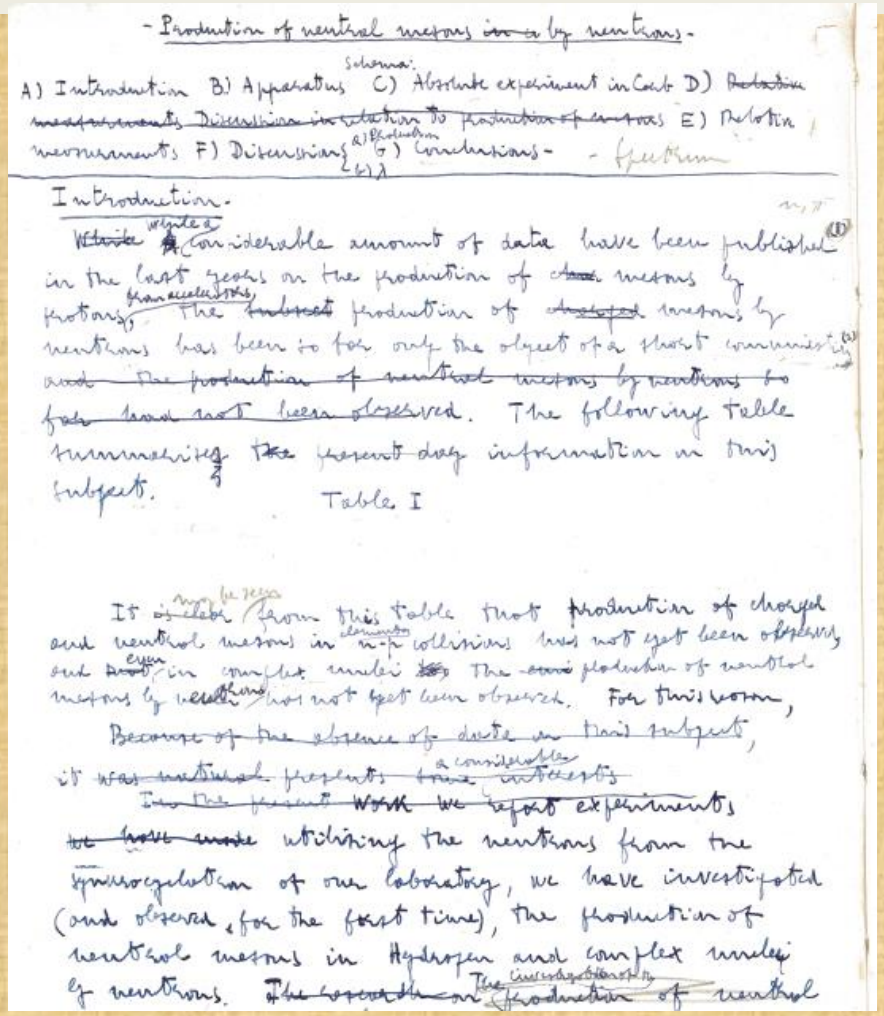
Range

Energia (MeV) →	20	40	60	80	100	120	140	160	180	200
Deuteron Range (gr/cm²) Cu	0.5	1.5	2.8	4.8	7	10	13	15.4	20.0	24
Deuteron Range (gr/cm²) Al	0.3	1.1	2.4	3.8	5.8	8	10.6	13	16.0	19

Perdita di energia (MeV / gr/cm²)

E (MeV)	Cu	Al
200	3,03	3,58
250	2,65	3,12
300	2,40	2,81
350	2,21	2,59
400	2,08	2,43
500	1,89	2,20
600	1,76	2,05

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 (≥ 24th) 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 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 СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПУБЛИК

661. 6/7 16г.
Прага

"УТВЕРЖДАЮ"

Начальник Гидротехнической
лаборатории АН СССР
доктор физико-матем. наук

/М.Г.Мещеряков/

" марта 1952 года.

ОТЧЕТ

ПОПЫТКА ДЕТЕКТИРОВАТЬ ЯДЕРНОЕ РАССЕЯНИЕ π -МЕЗОНОВ С ОБМЕНОМ ЗАРЯДА ПРИ ПОМОЩИ РАДИОАКТИВНЫХ ИНДИКАТОРОВ.

Руководитель: проф. Понтекорво Б.
Исполнители: проф. Понтекорво Б.
инж. Мухин А.И.

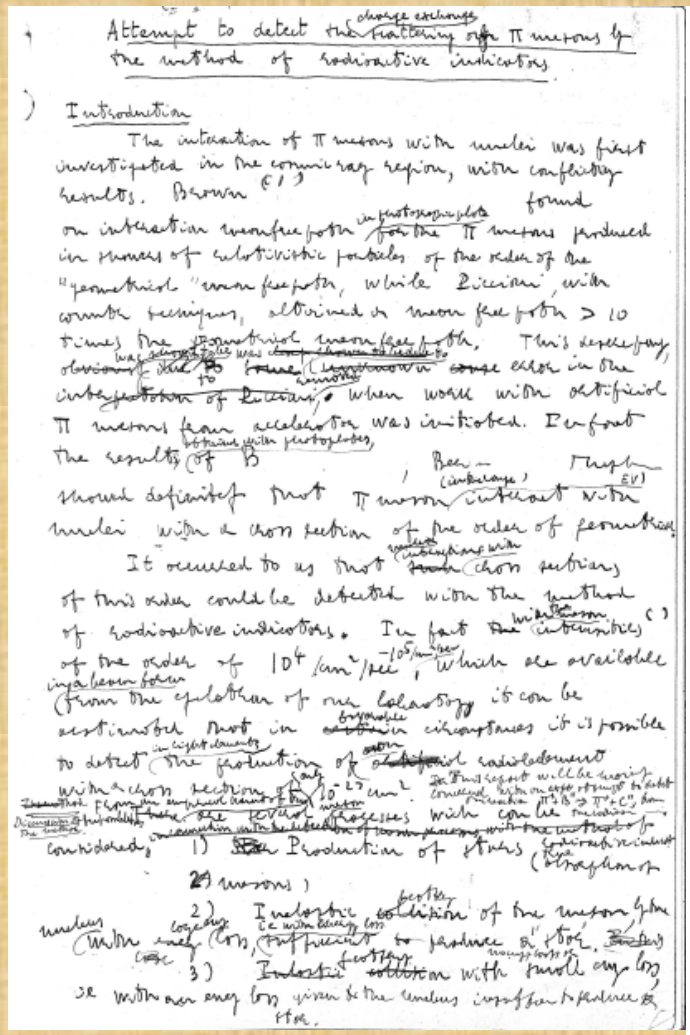
March 1952

REPORT

Detection of charge exchange scattering of π mesons on nuclei by the method of 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 charge exchange scattering of π mesons by the method of radioactive indicators

I 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.... 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 10^4-10^5/cm²/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.

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

Attempt to detect the charge exchange scattering of π mesons by the method of radioactive indicators

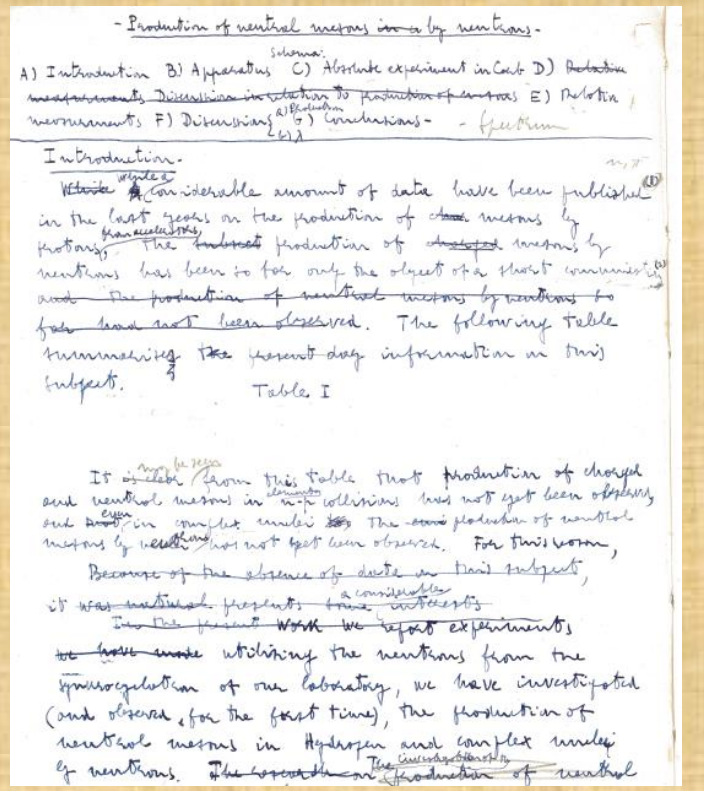
Introduction

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 10^4-10^5/cm²/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.

($^{11}C \rightarrow {}^{11}B + e^+ + \nu + 0.96$MeV with 20.3 min. half-life)

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 mesons by neutrons -

A) Introduction B) Apparatus C) Absolute experiment in Carb D) Relative measurements E) Relativ measurements F) Discussion G) Conclusions -

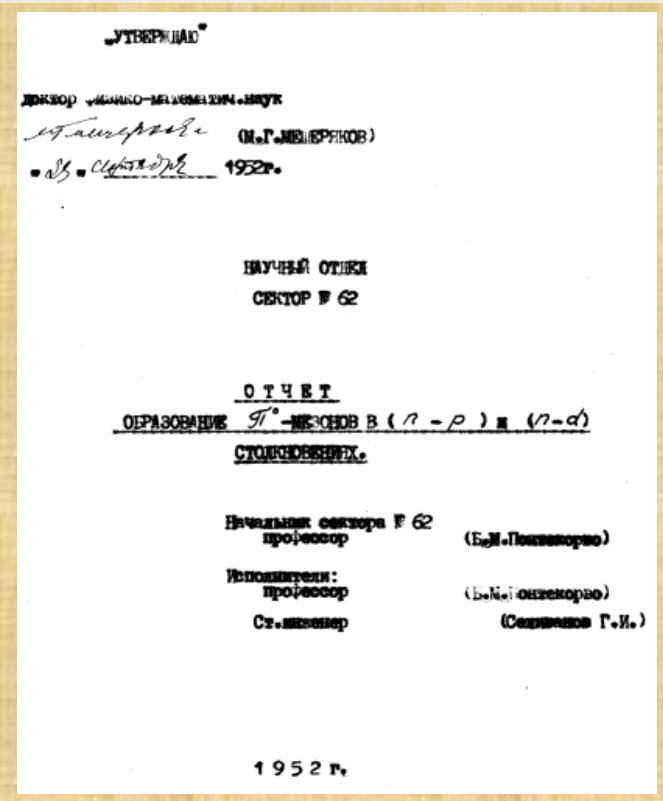
Introduction.

Considerable amount of data have been published in the last years on the production of mesons by protons. The production of mesons by neutrons has been so far only the object of a short communication. The production of neutral mesons by neutrons has not been observed. The following Table summarizing the present day information in this subject.

Table I

It is clear from this table that production of charged and neutral mesons in n-p collisions has not yet been observed and in complex nuclei. The coherent 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 interests. In the present work we report experiments, we have made utilizing the neutrons from the synchrocyclotron of our laboratory, we have investigated (and observed, for the first time), the production of neutral mesons in Hydrogen and complex nuclei by neutrons. The investigation on production of neutral

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



УТВЕРЖДАЮ

ДИРЕКТОР ФИЗИКО-МАТЕМАТИЧ. ИНСТ

(И.Г.МЕЛЬНИКОВ)

"25" сентября 1952г.

НАУЧНЫЙ ОТЧЕТ

СЕКТОР № 62

ОТЧЕТ

ОБРАЗОВАНИЕ π^0-МЕЗОНОВ В (n-p) И (n-d) СТОЛКНОВЕНИЯХ.

Начальник сектора № 62
профессор (Б.М.Понтекорво)

Исполнители:
профессор (Б.М.Понтекорво)
Ст.инженер (Селиванов Г.И.)

1952 г.

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

25 September 1952

REPORT
Production of π^0 mesons in (n-p) and (n-d) collisions

Section leader
Professor (B.M.Pontecorvo)

Executors:
Professor (B.M.Pontecorvo)
Engineer (Selivanov G.I.)

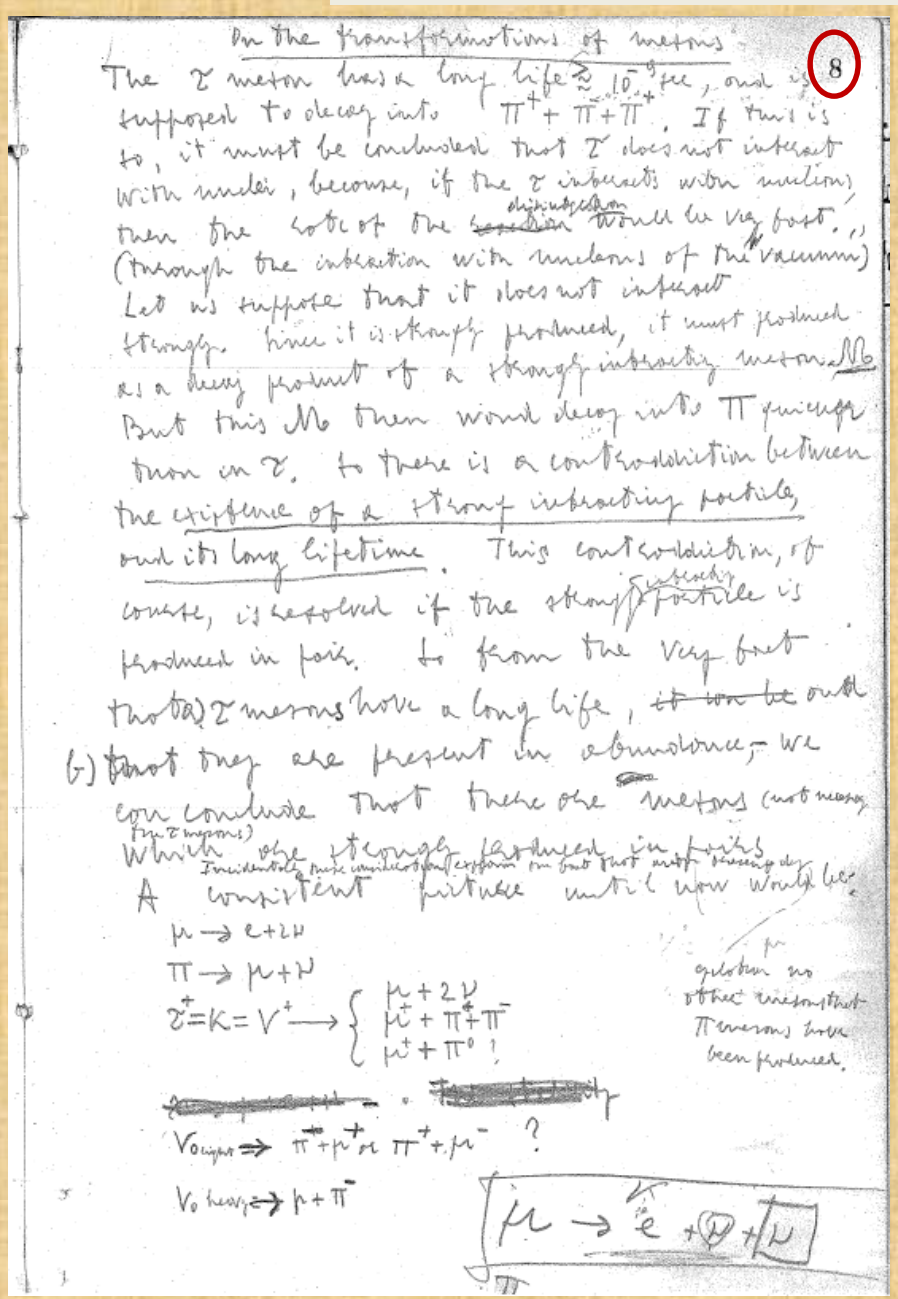
Experimental and theoretical physicist

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 transformations of mesons

8

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. (through 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 existence of a strong interacting particle and his long lifetime. 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.

A consistent picture until now would be:

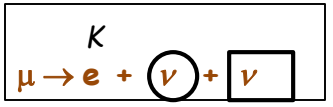
$\mu \to e + 2\nu$

$\pi \to \mu + \nu$

$\tau^+ = K = V^+ \to \{ \mu + 2\nu \;;\; \mu^+ + \pi^+ + \pi^- \;;\; \mu^+ + \pi^0 \; ? \}$

$V^0_{light} \to \pi^- + \mu^+$ or $\pi^+ + \mu^-$?

$V^0_{heavy} \to p + \pi^-$



(**)

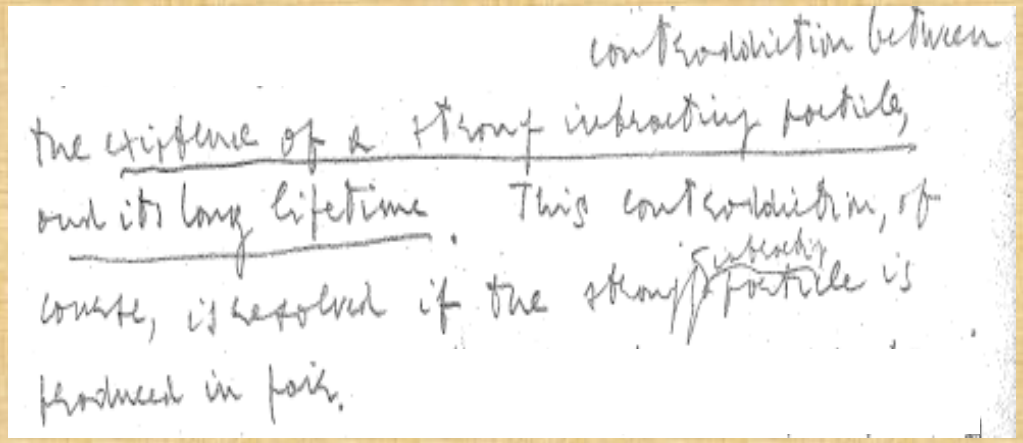
(*) here, at the end of 1950, **without the notion of strangeness**, a deep intuition is needed **to propose a production process in pair** to solve this contradiction.

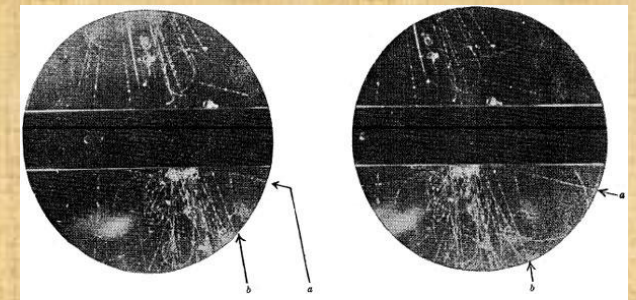
(**) maybe just a coincidence! Two lines before he writes $\mu \to e + 2\nu$ while here he writes $\mu \to e + \nu + \nu$ engraving the neutrinos with two different signs.

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





Cloud-chamber photograph of a V^0 particle decaying into two charged particles
(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

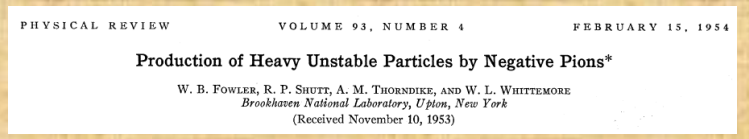
In 1953, the fact that particles produced via strong interaction and decaying with a long lifetime must be produced in pair was not completely clear from an experimental point of view.

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)."***

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



PHYSICAL REVIEW VOLUME 93, NUMBER 4 FEBRUARY 15, 1954

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)

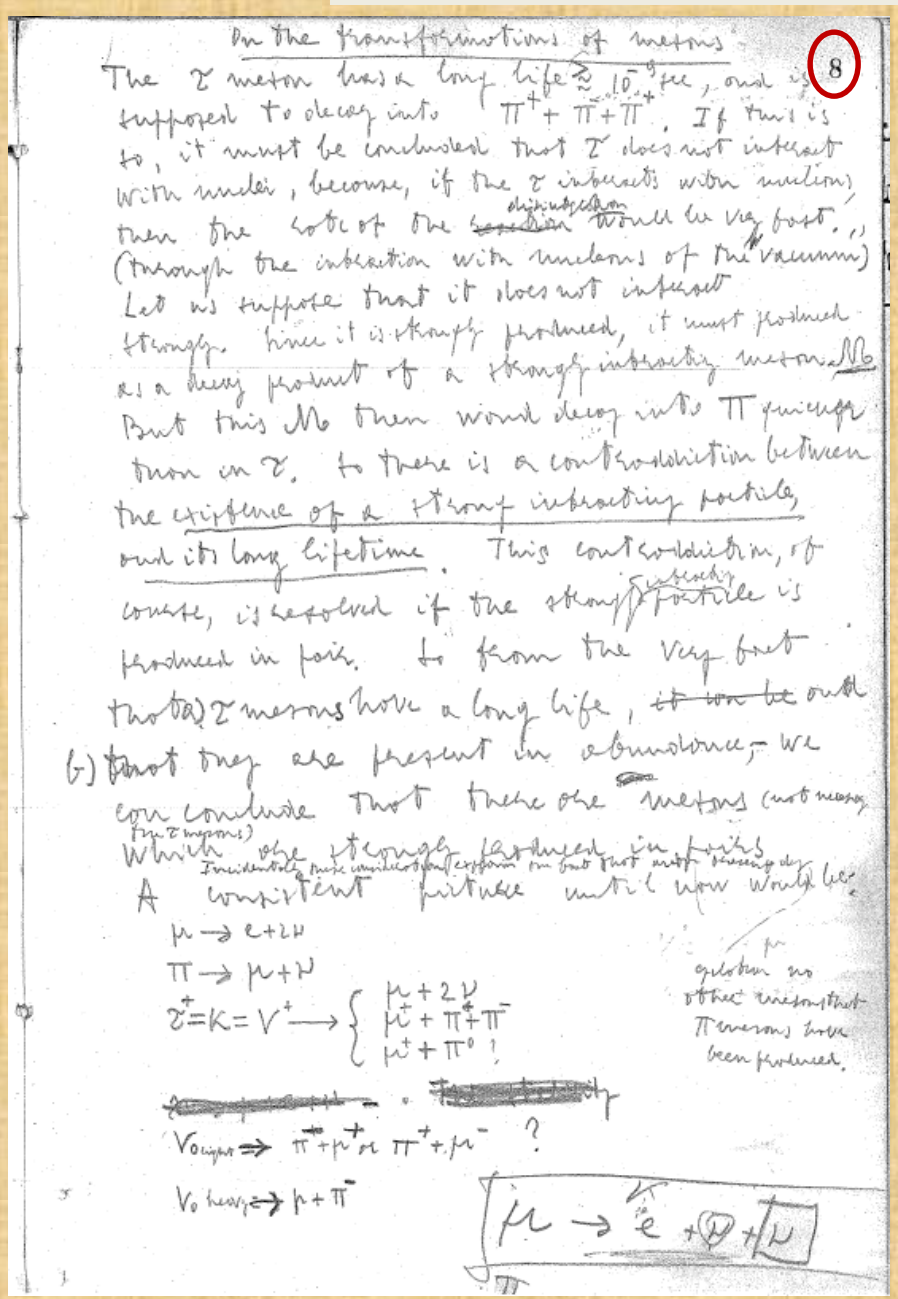
The important contributions given by Pontecorvo to the problem of understanding the properties of the "strange particles" are not enough acknowledged to him by the scientific community.

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)



(*) 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 $\mu \to e+2\nu$ while here he writes $\mu \to e+\nu+\nu$ engraving the neutrinos with two different signs.

Two profound intuitions in a single page ?!

$\nu_\mu \neq \nu_e$

"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 $\nu_e \neq \nu_\mu$ *."* 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

and few lines later

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

On the tombstone $\nu_\mu \neq \nu_e$ 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 $\nu_e \neq \nu_\mu$.
"There are no reasons for asserting that ν_e *and* ν_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- ν_μ beam to look for the reaction anti-ν_μ + p → μ^+ + n and to check that the anti-ν_μ + p → 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

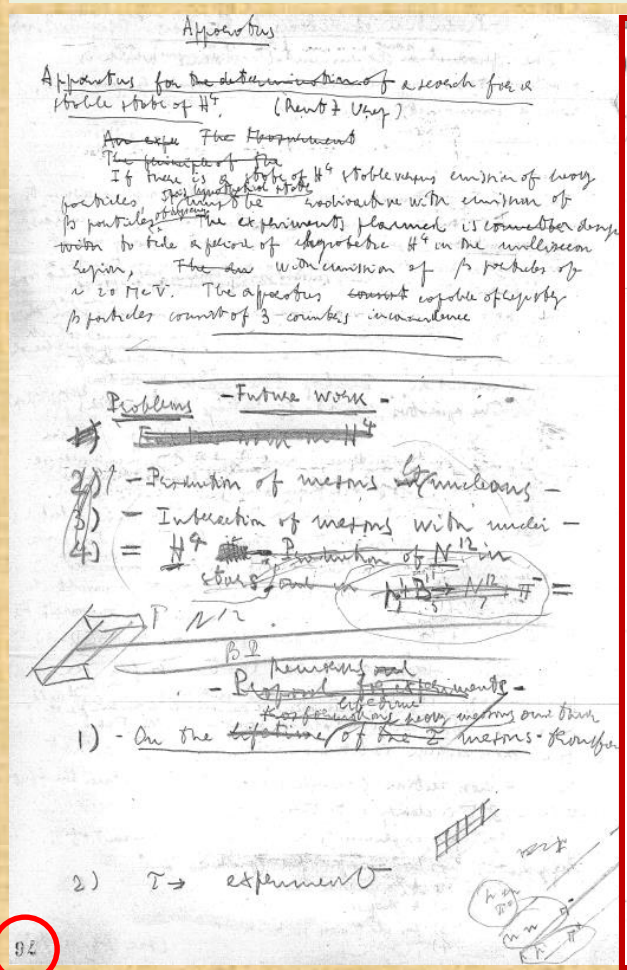
For the experimental proof that $\nu_e \neq \nu_\mu$

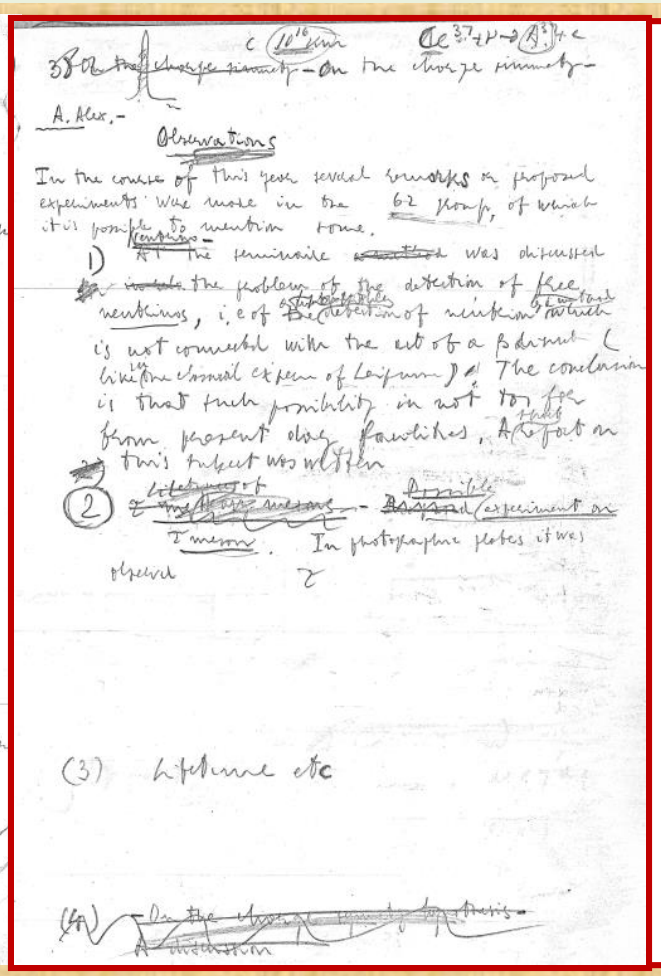
L.M.Lederman, M.Schwartz and J.Steinberger

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





c 10^{16} Km (*) $Cl^{37}+\nu \rightarrow Ar^{37}+e$

~~3) On the charge symmetry~~ -On the charge symmetry

A. Alex.-

Observations

In the course of this year several remarks or proposed experiments were made in the 62 group, of which it is possible to mention some.

Neutrino –

1) *At the seminaire ~~a method~~ was discussed ~~in rela~~ the problem of the detection of free neutrinos, i.e. of a ..... detection of neutrino, a method which is not connected with the act of a β disintegration (like in the classical experiment of Leipunski) The conclusion is that such possibility is not too far from present day facilities, A short report on this subject was written*

(2) ~~Lifetime of τ mes Heavy mesons~~ - Possible experiment on τ meson.

In photographic plates it was observed τ

(3) *Lifetime etc.*

~~(4) – On the charge symmetry hypothesis A discussion~~

Remarks ~~and~~ ~~Proposal for experiments~~ -

1) -On the ~~lifetime transformations~~ lifetime of ~~the τ mesons~~ heavy mesons and their transformation -

2) $\tau \rightarrow$ experiment

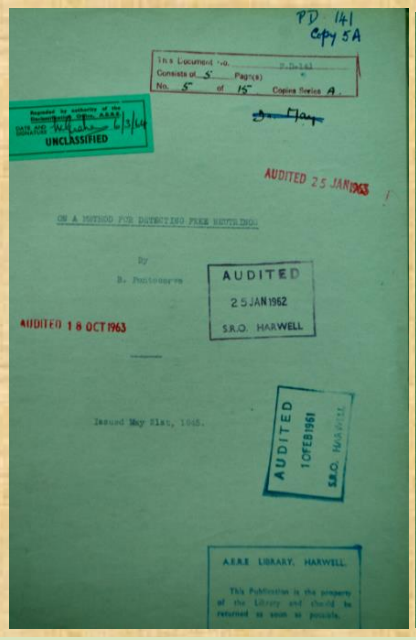
(*) **H.Bethe and R.Peierls in Nature 133,532-532 (07 April 1934) evaluated an upper limit for the cross section of the neutrino interaction with matter and they wrote "For an (neutrino) energy of $2*3x10^6$ volts….$\sigma < 10^{-44}$ cm ^{2}(corresponding to a penetrating power of 10^{16} Km in solid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

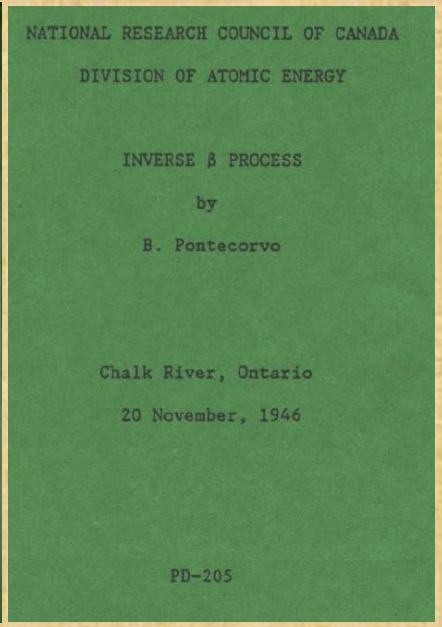
An experimental physicist with brilliant ideas and genial intuitions

In 1934, Bethe e Peierls (Nature 133,532,1934) showed that the cross section of neutrino interaction with nuclei is extremely low, $<10^{-44}$ cm^2 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: $\nu + Cl^{37} \rightarrow Ar^{37} + e^-$ 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.





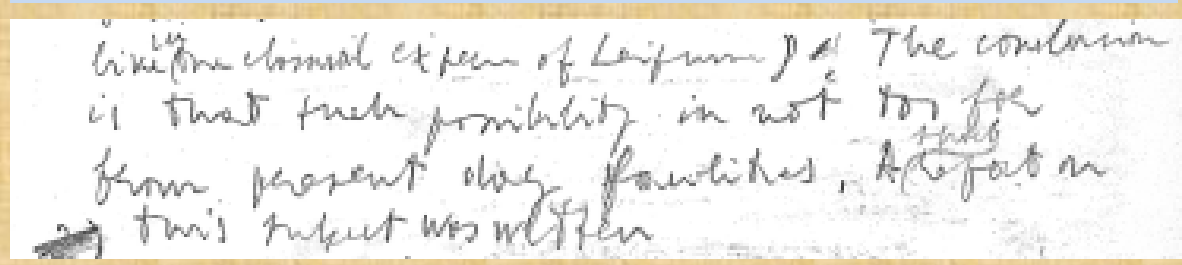
Internal reports PD-141 e PD-205

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:

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.



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

Neutrino Oscillations

Nobel Prize 2015

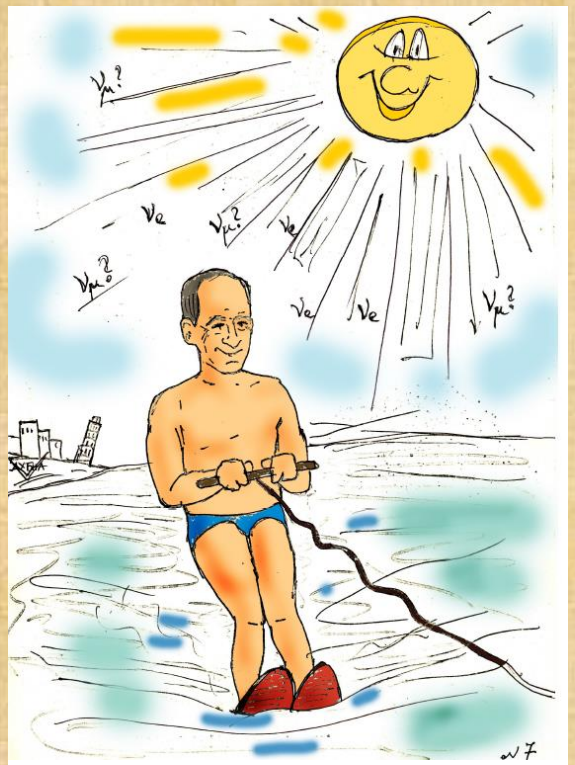
T. Kajita

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.

$\nu_e \leftrightarrow \nu_\mu$ as seen by Misha Bilenky



Tanning in the Sun
as seen by Misha Bilenky

Neutrino Oscillations

Nobel Prize 2015

T. Kajita

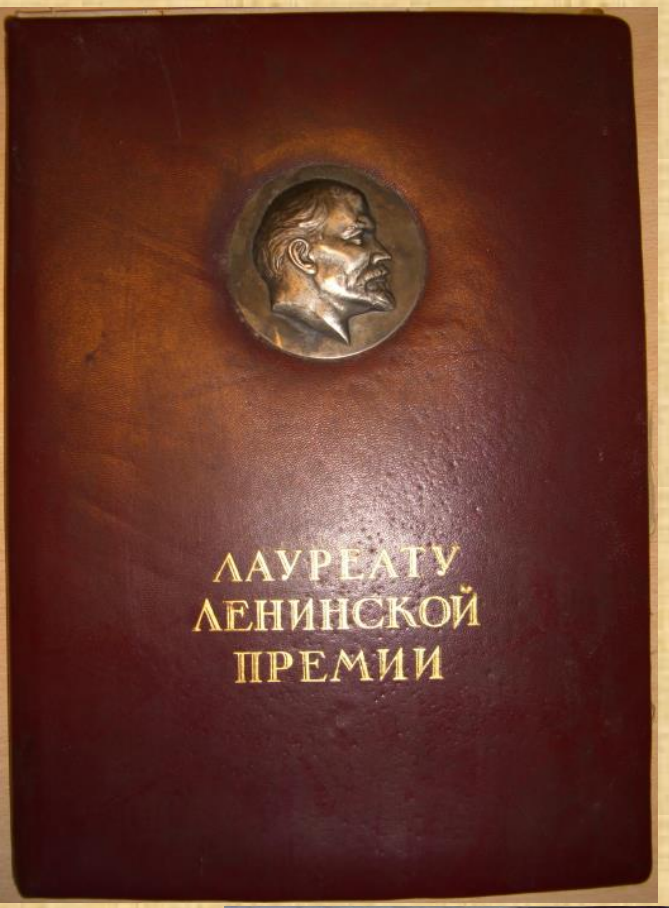
A. B. McDonald

Mechanism of neutrino oscillations as seen by Misha Bilenky

A great Magic by Bruno Pontecovo

ν_e → ν_μ

Bruno Pontecorvo Lenin Prize in 1963

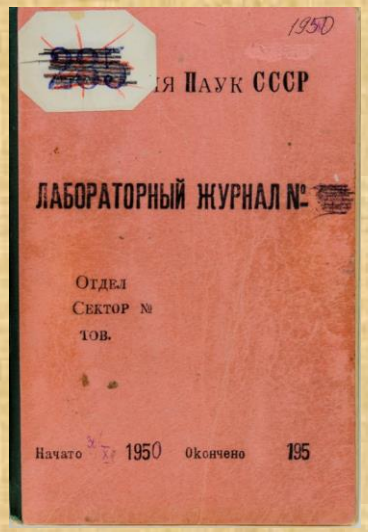


I guess that many of us would agree that Bruno Pontecorvo probably missed a couple of Nobel Prizes. The lack of enough resources and facilities (powerful accelerators, nuclear reactors, underground caverns) available to him in Russia denied to the experimental physicist Pontecorvo the possibility to 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

01/11/1950 – ≤ 30/11/1950
14/09/1951 – ≥ 24/03/1952



30/11/1950 – ≥ 18/07/1951

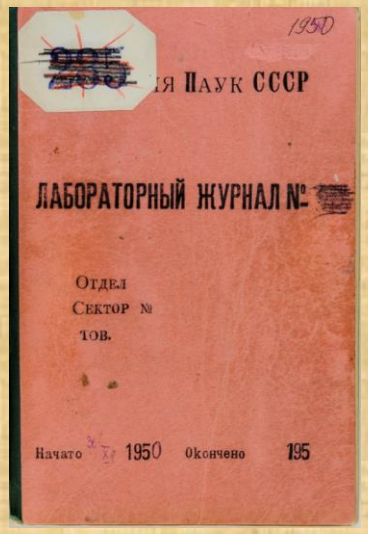
A historical reconstruction of the experimental work, the scientific interests and also some great insights of Bruno Pontecorvo during his first year and a half in Russia is done through the pages of these two unpublished Notebooks.

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

01/11/1950 – ≤ 30/11/1950
14/09/1951 – ≥ 24/03/1952



30/11/1950 – ≥ 18/07/1951

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