laboratorio di fisica nucleare e subnucleare

misura della vita media dei muoni

a.a. 2024-2025

25 novembre 2024

misura della vita media dei muoni

perchè

è una misura molto interessante da diversi punti di vista

occasione per approfondire/rivedere alcuni aspetti di

- teoria
  - decadimenti deboli
  - cattura nucleare dei μ^-
  - raggi cosmici: origine, caratteristiche

- "storia" della fisica delle particelle elementari
  - le origini, I primi esperimenti con i raggi cosmici

    Bruno Rossi, Cosmic rays, 1964
  - prima misura diretta della vita media dei muoni

    Bruno Rossi and Norris Nereson, "Experimental Determination of the Disintegration Curve of Mesotrons", Phys. Rev. 62 (1942) 417
  - le due componenti della radiazione penetrante

    M. Conversi, E. Pancini, O. Piccioni, "On the Decay Process of Positive and Negative Mesons", Phys. Rev. 68 (1945) 9-10, 232

misura della vita media dei muoni

perchè

è una misura molto interessante da diversi punti di vista

- è un esperimento completo, di cui si considerano tutte le fasi
  - obiettivi
  - metodo di misura
  - stima del tempo di misura necessario ad ottenere risultati significativi
  - progettazione e implementazione del sistema di acquisizione dati
  - acquisizione dati, e controlli per effetti sistematici
  - analisi statistica dei dati raccolti – stima de parametri e test d'ipotesi
  - conclusioni

come in tutti gli esperimenti … scala dei tempi diversa

o molto diversa!

misura della vita media dei muoni

perchè

è una misura molto interessante da diversi punti di vista

- non è necessaria strumentazione particolarmente sofisticata
  - non servono acceleratori o sorgenti

    i muoni sono una delle componenti dei raggi cosmici a livello del mare
  - fattibile con gli strumenti a disposizione

    ci saranno anche problemi, banali o meno, come in tutti gli esprimenti

- scelta: nulla di realmente nuovo

  applicazione di quanto sapete già

  bisogna mettere assieme le diverse conoscenze

i muoni

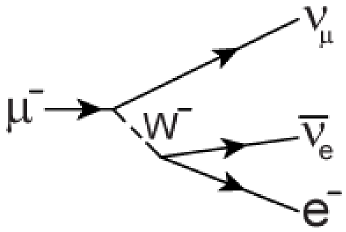
muoni

leptoni

	e^- / e^+	μ^- / μ^+	τ^- / τ^+
massa	0.511 MeV/c^2	**105.6 MeV/c^2**	1777 Mev/c^2
vita media τ_0	> $4.6 \cdot 10^{26}$ yr	**$2.2 \cdot 10^{-6}$ s**	$2.9 \cdot 10^{-13}$ s
	$\nu_e / \bar{\nu}_e$	$\nu_\mu / \bar{\nu}_\mu$	$\nu_\tau / \bar{\nu}_\tau$

$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$

$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$ ~100% dei casi



vita media: $\tau_0 = 2.2 \cdot 10^{-6}\ s$, $\Lambda_0 = 1/\tau_0$
a riposo

"lifetime: time elapsed between some reference time and the decay of a particle/nucleus"

se non a riposo

$$\tau = \gamma \tau_0 , \qquad \gamma = (1 - \beta^2)^{-1/2}$$

muoni

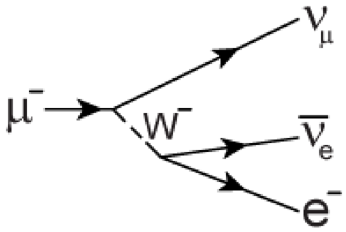
leptoni

	e^- / e^+	μ^- / μ^+	τ^- / τ^+
massa	0.511 MeV/c^2	**105.6 MeV/c^2**	1777 Mev/c^2
vita media τ_0	> $4.6 \cdot 10^{26}$ yr	**$2.2 \cdot 10^{-6}$ s**	$2.9 \cdot 10^{-13}$ s
	$\nu_e / \bar{\nu}_e$	$\nu_\mu / \bar{\nu}_\mu$	$\nu_\tau / \bar{\nu}_\tau$

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$

$$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$$

~100% dei casi



vita media: $\tau = 2.2 \cdot 10^{-6}\ s\ , \quad \Lambda = 1/\tau$

a riposo

$$\frac{\hbar}{\tau_\mu} = \frac{G_F^2}{(\hbar c)^6} \frac{(m_\mu c^2)^5}{192\ \pi^3}$$

$$\frac{\hbar}{\tau_\mu} = \frac{G_F^2}{(\hbar c)^6} \frac{(m_\mu c^2)^5}{192\ \pi^3} f\left(\frac{m_e^2}{m_\mu^2}\right) \left(1 + \frac{3m_\mu^2}{5m_w^2}\right) \left[1 + \frac{\alpha(m_\mu)}{2\pi} \left(\frac{25}{4} - \pi^2\right)\right]$$

$$\alpha^{-1}(m_\mu) = \alpha^{-1} - \frac{2}{3\pi} \log(m_\mu / m_e) + \frac{1}{6\pi} \cong 136$$

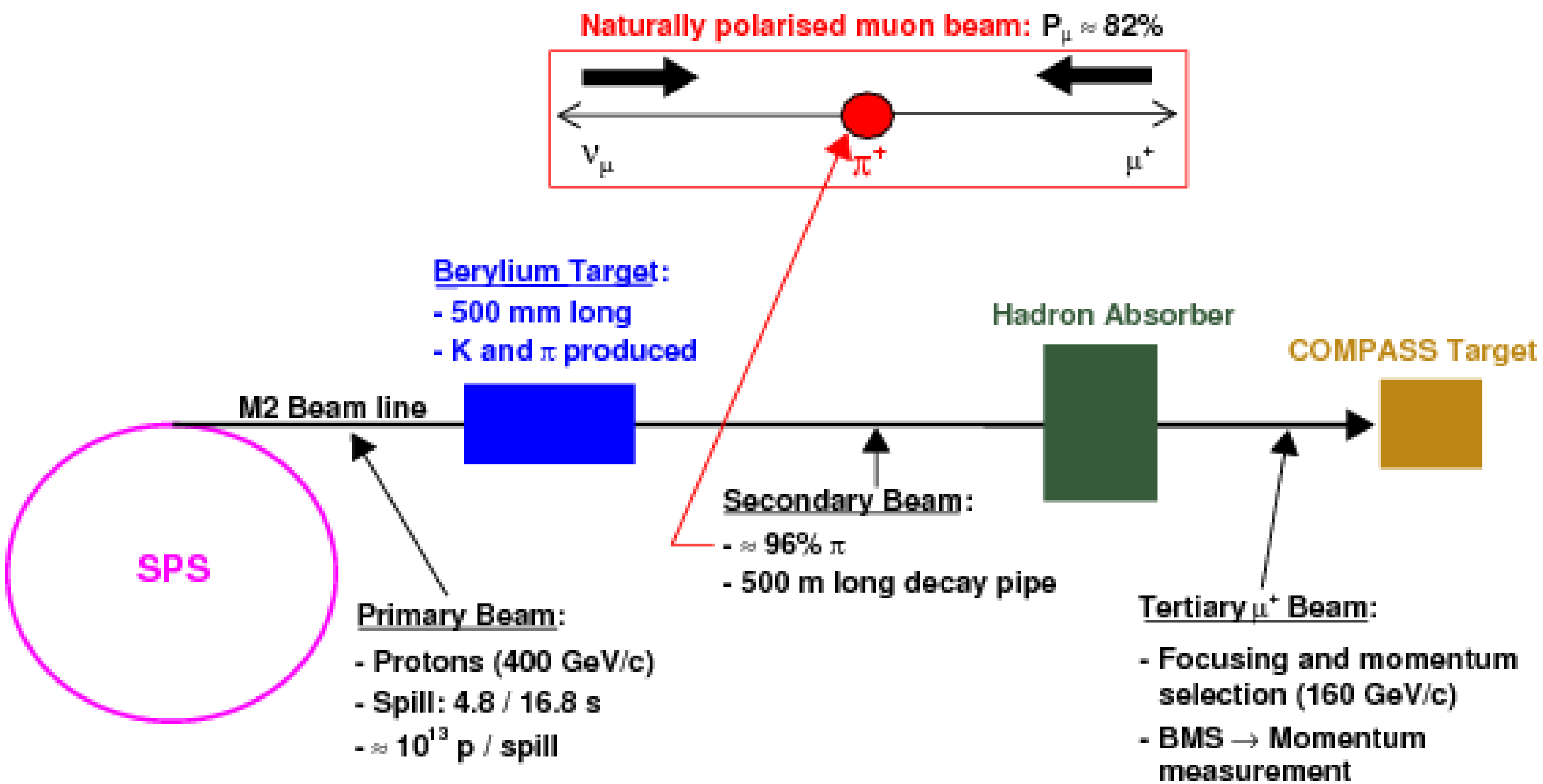
Mean life $\tau = (2.1969811 \pm 0.0000022) \times 10^{-6} s$

$\tau_{\mu^+} / \tau_{\mu^-} = 1.00002 \pm 0.00008$

da PDG - misure di precisione al PSI (MuLan), con acceleratori

muoni da decadimento dei pioni

- raggi cosmici
- acceleratori



muoni da decadimento dei pioni

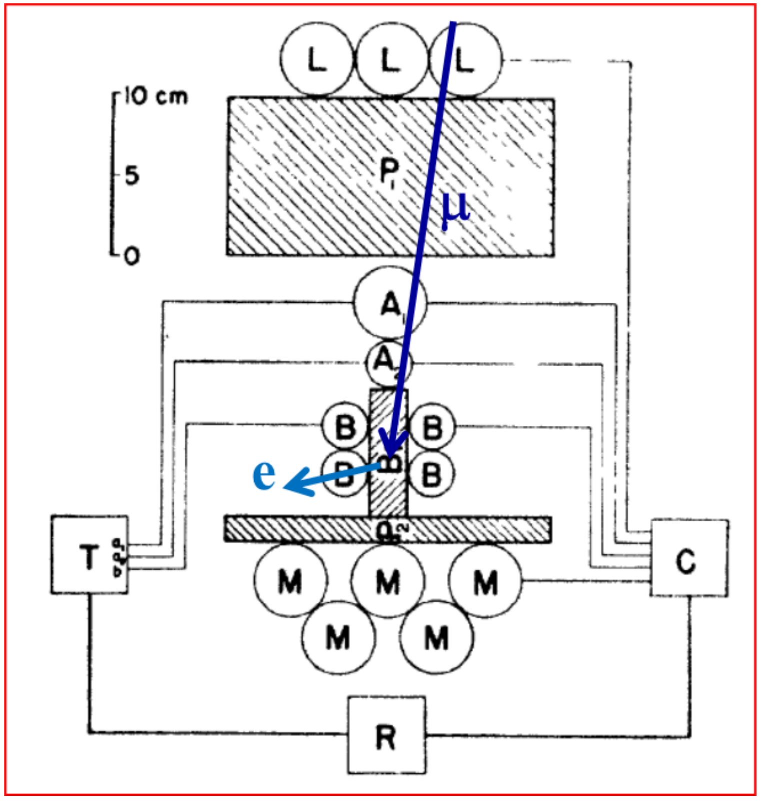
- raggi cosmici
- acceleratori – esperimenti
  - vita media (PSI)
  - decadimenti proibiti (PSI)
  - spettrospopia di atomi muonici, raggio del protone (Rutherford Lab, Psi, Riken)
  - momento magnetico anomalo, g-2 (CERN, BNL, Fermilab)
  - scattering elastic μe, μp (CERN)
  - (SI)DIS μp (n), struttura dei nucleoni (CERN)
  - future muon collider, frontiera dell'energia
  - ….
  - e molto altro https://www.asimmetrie.it/editoriale-23

ma torniamo alla nostra misura

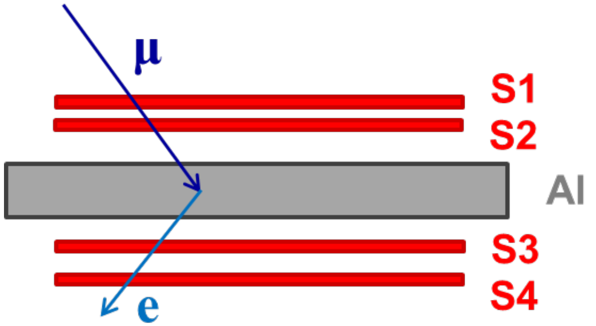
misura della vita media dei muoni

misura dell'intervallo di tempo t tra l'istante in cui il muone viene portato a riposo e l'istante in cui viene rivelato l'elettrone prodotto nel decadimento

esperimento molto simile a quello di Nereson e Rossi



apparato sperimentale piu' semplice



eventi utili:

μ incidente che si ferma nell'assorbitore

$START$: $S_1 \cdot S_2 \cdot \overline{S_3 \cdot S_4}$ oppure $S_1 \cdot S_2 \cdot (\overline{S_3} \cdot \overline{S_4})$

e di decadimento emesso verso il basso o l'alto e rivelato

$STOP$: $S_1 \cdot S_2 \cdot \overline{S_3 \cdot S_4}$ oppure $S_1 \cdot S_2 \cdot (\overline{S_3} \cdot \overline{S_4})$

$S_3 \cdot S_4 \cdot \overline{S_1 \cdot S_2}$ oppure $S_3 \cdot S_4 \cdot (\overline{S_1} \cdot \overline{S_2})$

eventi utili:

μ incidente che si ferma nell'assorbitore $L \cdot A \cdot \overline{M}$

e di decadimento rivelato in B ...

misura del ritardo nell'emissione

misura della vita media dei muoni

misura dell'intervallo di tempo t tra l'istante in cui il muone viene portato a riposo e l'istante in cui viene rivelato l'elettrone prodotto nel decadimento

probabilita' di decadimento in $(t, t+\delta t)$

$$\boldsymbol{P_d(t,t+\delta t) = P_0(t) \cdot p_d(t,t+\delta t)}$$

$$\boldsymbol{p_d(t,t+\delta t) = p_d(\delta t)} = \Lambda_0 \cdot \delta t$$

$$P_0(t+\Delta t) = P_0(t) \cdot \{1 - p_d(\Delta t)\} = P_0(t) - P_0(t) \cdot \Lambda_0 \cdot \Delta t$$

$$\frac{P_0(t+\Delta t) - P_0(t)}{\Delta t} = -P_0(t) \cdot \Lambda_0 \quad \rightarrow \quad \frac{dP_0}{dt} = -P_0 \cdot \Lambda_0$$

$$\frac{dP_0}{P_0} = -\Lambda_0 dt \qquad \ln P_0 = -\Lambda_0 t + c$$

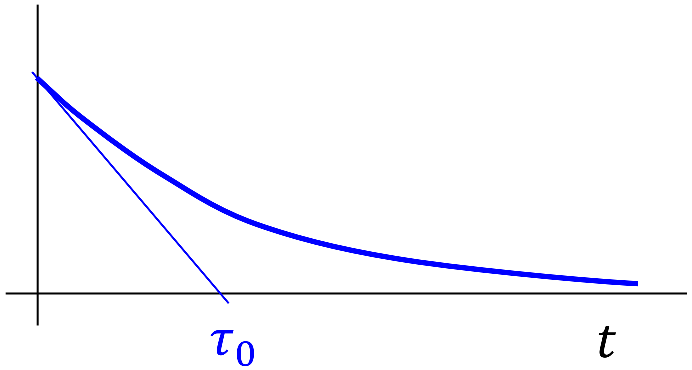
$$\boldsymbol{P_0\,(t)} = Ae^{-\Lambda_0 t} = e^{-\Lambda_0 t}$$

$$\boldsymbol{P_d(t,t+\delta t) = e^{-\Lambda_0 t}\Lambda_0 \cdot \delta t = f(t) \cdot \delta t}$$

$$\boldsymbol{f(t) = e^{-\Lambda_0 t}\Lambda_0 = \frac{1}{\tau_0} e^{-t/\tau_0}}$$

$$\Lambda_0 = \frac{1}{\tau_0} \simeq 0.45 \cdot 10^6\, s^{-1}$$

$\boldsymbol{\mu^+}$



misura della vita media dei muoni - μ^-

oltre a decadimento, anche cattura nucleare

muoni negativi possono formare atomi muonici con i nuclei atomici del materiale dell'assorbitore

il μ^- viene catturato dal campo di Coulomb del nucleo e legato nella shell K in un tempo molto breve, meno di 1 ns

il raggio medio di questo stato è ~ rapporto di massa tra l'elettrone e il muone (200), inferiore a quello degli atomi elettronici, e comporta una sovrapposizione delle funzioni d'onda del muone e nucleare

c'è quindi la possibilità che il muone venga assorbito dal nucleo

$$\mu^- p \rightarrow \nu_\mu n$$

$$\boldsymbol{\Lambda_C \propto Z^4}$$

misura della vita media dei muoni - μ^-

oltre a decadimento, anche cattura nucleare

muoni negativi possono formare atomi muonici con i nuclei atomici del materiale dell'assorbitore

il μ^- viene catturato dal campo di Coulomb del nu
molto breve, meno di 1 ns

il raggio medio di questo stato è ~ rapporto di mas
inferiore a quello degli atomi elettronici,
funzioni d'onda del muone e nucleare

c'è quindi la possibilità che il muone venga assorb

$$\mu^- p \to \nu_\mu n$$

$$\boldsymbol{\Lambda_C \propto Z^4}$$

Material	Λ_C [μs^{-1}]
Al	0.7054 ± 0.0013
Cu	5.676 ± 0.037
Pb	13.45 ± 0.18

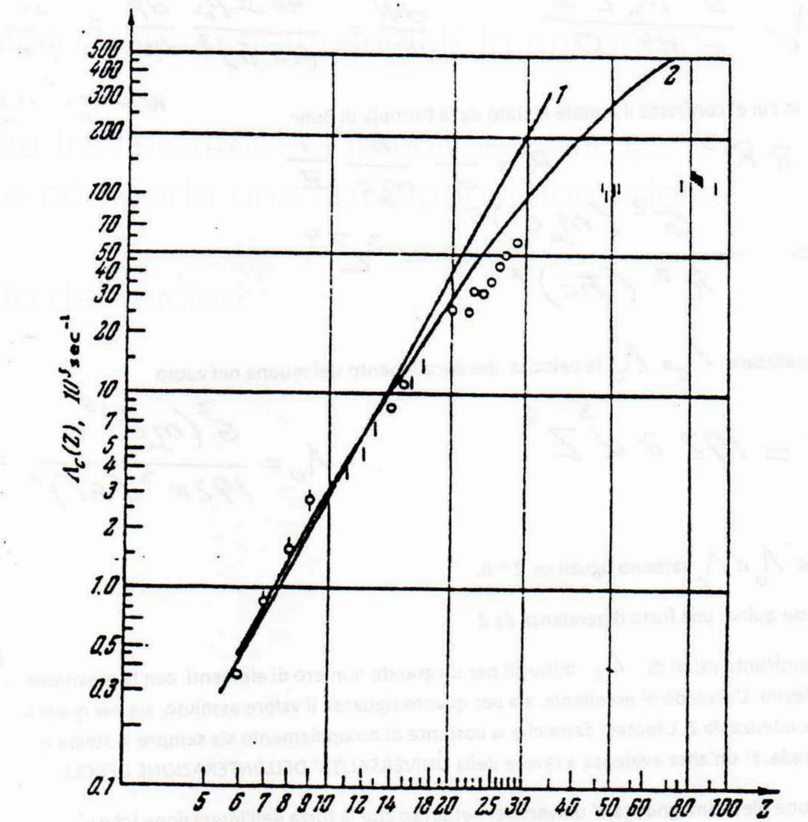


Fig. 3.16 Probability of capture of negative muons by different nuclei. Curve 1 shows $\Lambda_c(Z) \approx Z$, and curve 2 shows $\Lambda_c(Z) \approx Z_{eff}^4$. Open circles represent experimental data for which the error was less than the diameter of the circles

misura della vita media dei muoni - μ^-

oltre a decadimento, anche cattura nucleare

$$\boldsymbol{\Lambda_C \propto Z^4} \qquad \boldsymbol{\Lambda^- = \Lambda_0 + \Lambda_C}$$

probabilita' di decadimento in $(t, t+\delta t)$

$$\boldsymbol{P_d(t, t+\delta t)} = P_0(t) \cdot p_d(t, t+\delta t)$$

$$\boldsymbol{p_d(t, t+\delta t)} = p_\mathrm{d}(\delta t) = \Lambda_0 \cdot \delta t$$

$$P_0(t+\Delta t) = P_0(t) \cdot \{1 - \boldsymbol{p}(\Delta t)\} = P_0(t) - P_0(t) \cdot \boldsymbol{\Lambda^-} \cdot \Delta t$$

$$\frac{P_0(t+\Delta t) - P_0(t)}{\Delta t} = -P_0(t) \cdot \Lambda^- \qquad \rightarrow \qquad \frac{dP_0}{dt} = -P_0 \cdot \Lambda^-$$

$$\frac{dP_0}{P_0} = -\Lambda^- dt \qquad \ln P_0 = -\Lambda^- t + c$$

$$\boldsymbol{P_0(t)} = Ae^{-\Lambda^- t} = e^{-\Lambda^- t}$$

$$P_d(t, t+\delta t) = e^{-\Lambda^- t} \Lambda_0 \cdot \delta t = f_-(t) \cdot \delta t$$

$$\boldsymbol{f_-(t) = e^{-\Lambda^- t} \Lambda_0 = \frac{1}{\tau_0} e^{-t/\tau^-}} \qquad \boldsymbol{\tau^- = \frac{1}{\Lambda^-} < \tau_0}$$

misura della vita media dei muoni - μ^-

Material	Λ_C [μs^{-1}]
Al	0.7054 ± 0.0013
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Pb	13.45 ± 0.18

oltre a decadimento, anche cattura nucleare

$$\Lambda_C \propto Z^4 \qquad \Lambda^- = \Lambda_0 + \Lambda_C$$

in aria praticamente non ci sarebbe cattura, tutti i μ^- decadono
stessa distribuzione per μ^+ e μ^-

$$f(t) = \frac{1}{\tau_0} e^{-t/\tau_0}$$

in Pb praticamente tutti i μ^- vengono catturati
praticamente solo decadimenti dei μ^+

$$f(t) = \frac{1}{\tau_0} e^{-t/\tau_0}$$

in Al parte dei μ^- decade, parte viene catturato
entrambe le componenti

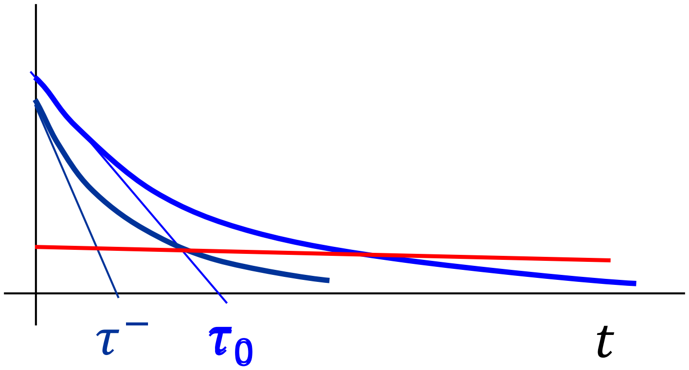
$$f(t) = \frac{1}{\tau_0} e^{-t/\tau_0} \qquad f_-(t) = \frac{1}{\tau_0} e^{-t/\tau^-}$$

con $\tau^- = \frac{1}{\Lambda^-} \simeq 0.86 \cdot 10^{-6}\ s$

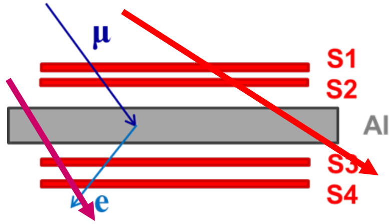
misura della vita media dei muoni

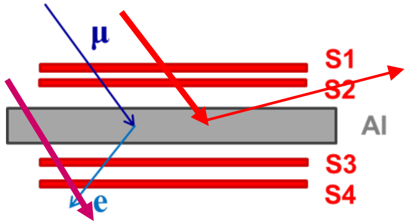
μ^+ $$f(t) = \frac{1}{\tau_0} e^{-t/\tau_0}$$

μ^- $$f_-(t) = \frac{1}{\tau_0} e^{-t/\tau^-}$$



piu' un fondo ….



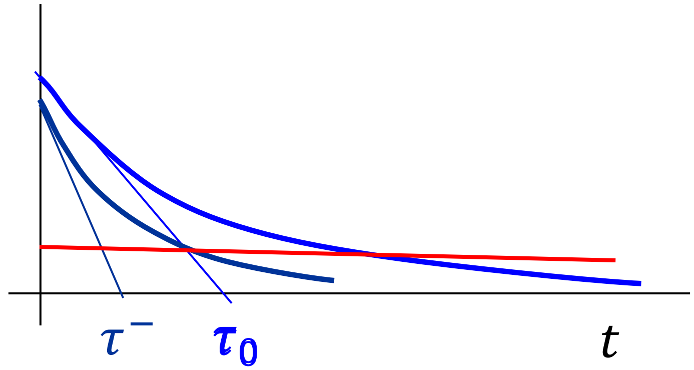


costante?
distribuzione dei tempi d'attesa

misura della vita media dei muoni

μ^+ $$f(t) = \frac{1}{\tau_0} e^{-t/\tau_0}$$

μ^- $$f_-(t) = \frac{1}{\tau_0} e^{-t/\tau^-}$$



vogliamo misurare questa distribuzione, con risoluzione e statistica sufficienti per stimare τ^- con incertezza ragionevole (<10%) e verificare l'ipotesi che ci sono veramente due componenti

misure di intervalli di tempo da 0 μs

a ~ $5\tau_0 \sim 10\ \mu s$ → esponenziali (TDC)

a $\sim 25\ \mu s$ → fondo (scala)

tempo di presa dati: da stimare, ma almeno due settimane

cominciamo con

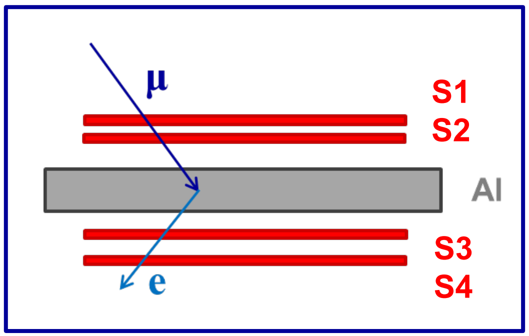
scintillatori

- tensioni di lavoro di S_1, S_2, S_3, S_4 e soglie
- coincidenze e anticoincidenze
- conteggi (in 2'?)

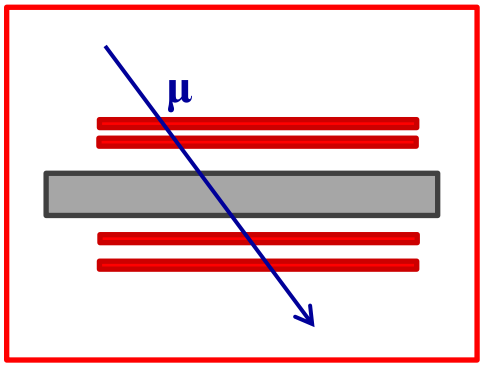
$$S_1, S_2, S_3, S_4$$
$$S_1 \cdot S_2, \qquad S_3 \cdot S_4$$
$$S_1 \cdot S_2 \cdot S_3 \cdot S_4$$
$$S_1 \cdot S_2 \cdot \overline{S_3 \cdot S_4}\ , \quad S_1 \cdot S_2 \cdot (\overline{S_3} \cdot \overline{S_4})$$
$$S_3 \cdot S_4 \cdot \overline{S_1 \cdot S_2}, \quad S_3 \cdot S_4 \cdot (\overline{S_1} \cdot \overline{S_2})$$

e confronto tra i diversi gruppi e con quanto atteso

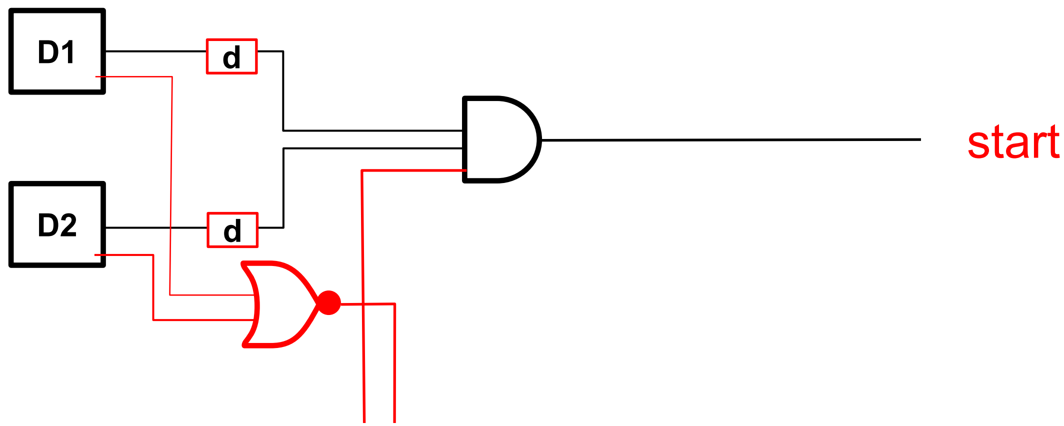
parentesi su coincidenze – tempi…

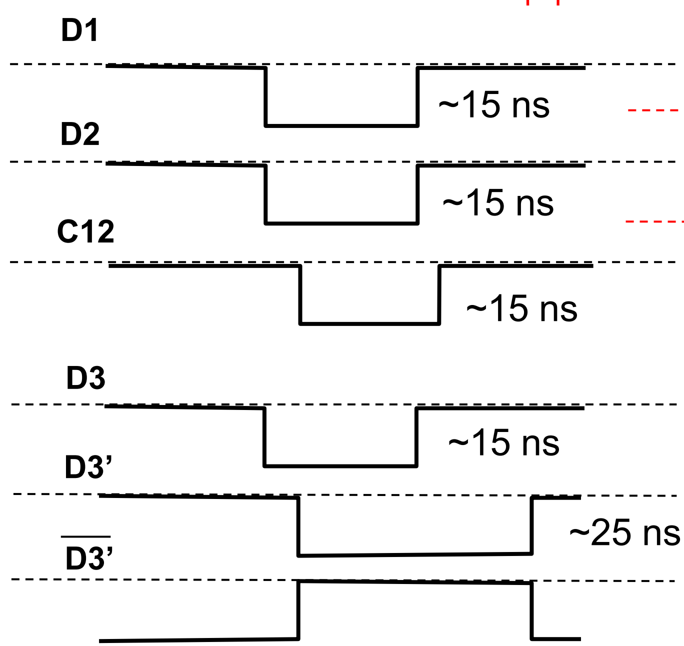


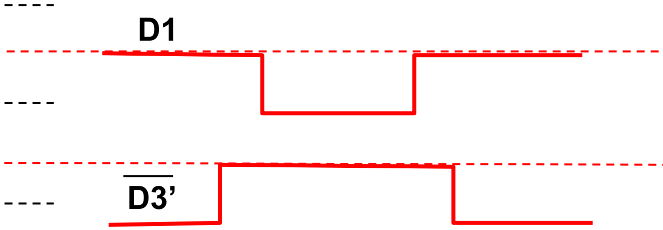
eventi utili



eventi da rigettare







cominciamo con

scintillatori

- tensioni di lavoro di S_1, S_2, S_3, S_4 e soglie
- tempi coincidenze e anticoincidenze
- conteggi (in 2'?)

$$S_1, S_2, S_3, S_4$$
$$S_1 \cdot S_2, \quad S_3 \cdot S_4$$
$$S_1 \cdot S_2 \cdot S_3 \cdot S_4$$
$$S_1 \cdot S_2 \cdot \overline{S_3 \cdot S_4}\,, \quad S_1 \cdot S_2 \cdot (\overline{S_3} \cdot \overline{S_4})$$
$$S_3 \cdot S_4 \cdot \overline{S_1 \cdot S_2}, \quad S_3 \cdot S_4 \cdot (\overline{S_1} \cdot \overline{S_2})$$

e confronto tra i diversi gruppi e con quanto atteso

conteggi attesi

- geometria dell'apparato
  dimensioni scintillatori e assorbitore
  posizioni relative
- stime approssimate del flusso di muoni attraverso l'apparato
  nell'assorbitore si fermano pochi muoni
  → muoni a livello del mare

raggi cosmici – alcune informazioni utili

Bruno Rossi, Cosmic rays, 1964   Particle Data Group, Cosmic rays

primary cosmic rays

“The cosmic radiation incident at the top of the terrestrial atmosphere includes all stable charged particles and nuclei with lifetimes of order 10^6 years or longer. When discussing the astrophysical origin of cosmic rays,
“primary” cosmic rays are those particles accelerated at astrophysical sources and “secondaries” are those particles produced in interaction of the primaries with interstellar gas” (→ atmosfera)

“… Apart from particles associated with solar flares, the cosmic radiation comes from outside the solar system … ”

raggi cosmici – alcune informazioni utili

Bruno Rossi, Cosmic rays, 1964   Particle Data Group, Cosmic rays

primary cosmic rays

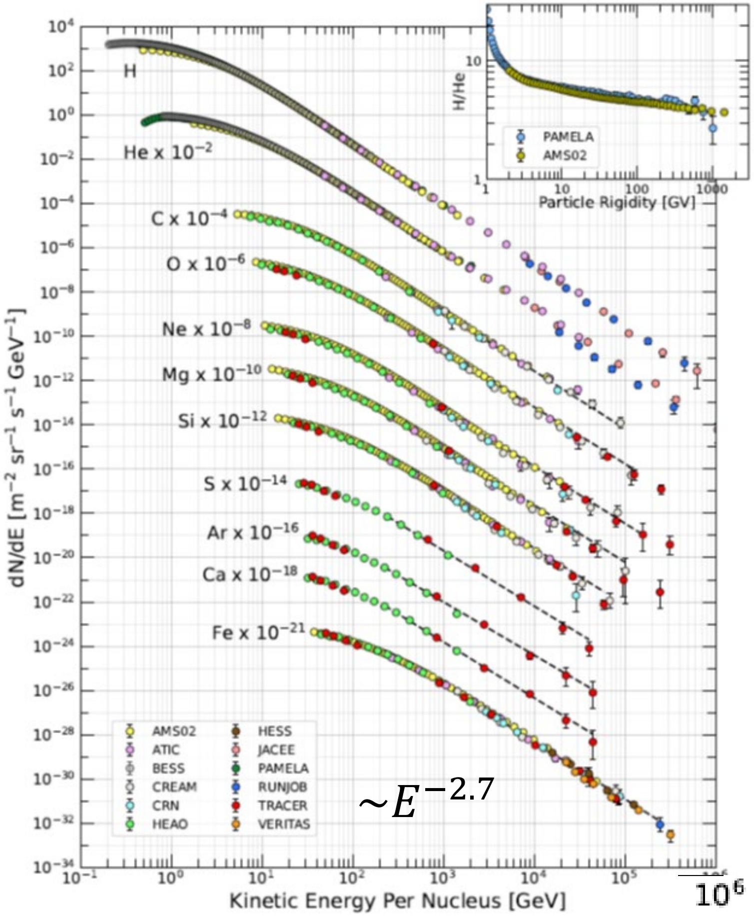


Figure 30.1: Fluxes of nuclei of the primary cosmic radiation in particles per energy-per-nucleus are plotted vs energy-per-nucleus using data from Refs. [1–15] The inset shows the H/He ratio as a function of rigidity [1,3].

Table 30.1: Relative abundances F of cosmic-ray nuclei at 10.6 GeV/nucleon normalized to oxygen ($\equiv 1$) [9]. The oxygen flux at kinetic energy of 10.6 GeV/nucleon is 3.29×10^{-2} (m^2 s sr GeV/nucleon$)^{-1}$. Abundances of hydrogen and helium are from Refs. [2–4]. Note that one can not use these values to extend the cosmic-ray flux to high energy because the power law indices for each element may differ slightly.

Z	Element	F	Z	Element	F
1	H	550	13–14	Al-Si	0.19
2	He	34	15–16	P-S	0.03
3–5	Li-B	0.40	17–18	Cl-Ar	0.01
6–8	C-O	2.20	19–20	K-Ca	0.02
9–10	F-Ne	0.30	21–25	Sc-Mn	0.05
11–12	Na-Mg	0.22	26–28	Fe-Ni	0.12

raggi cosmici – alcune informazioni utili

Bruno Rossi, Cosmic rays, 1964   Particle Data Group, Cosmic rays

primary cosmic rays

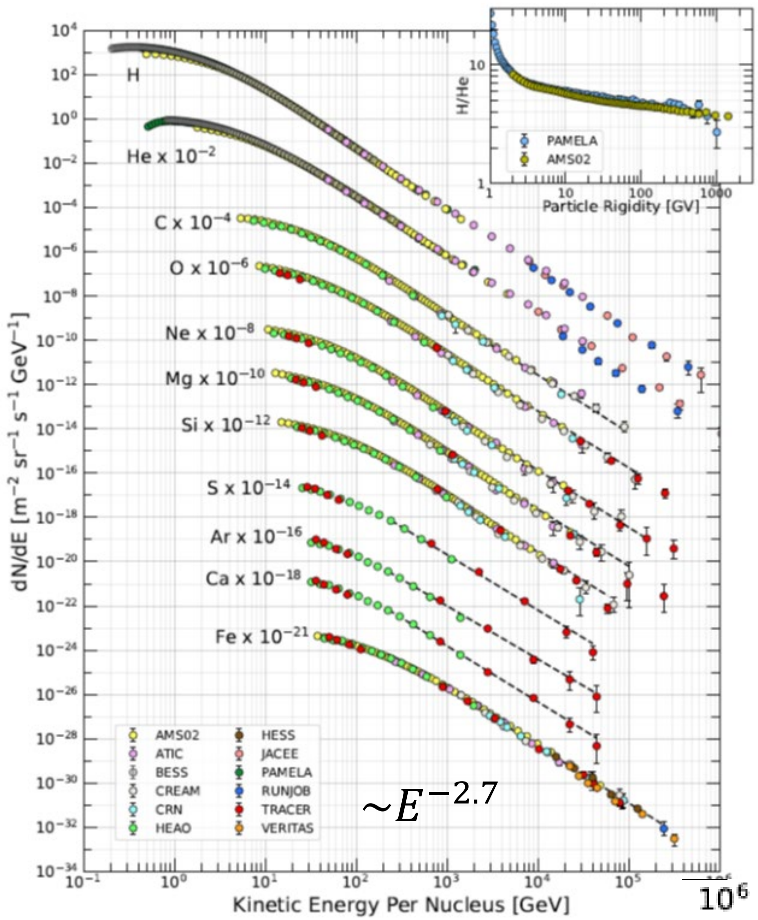
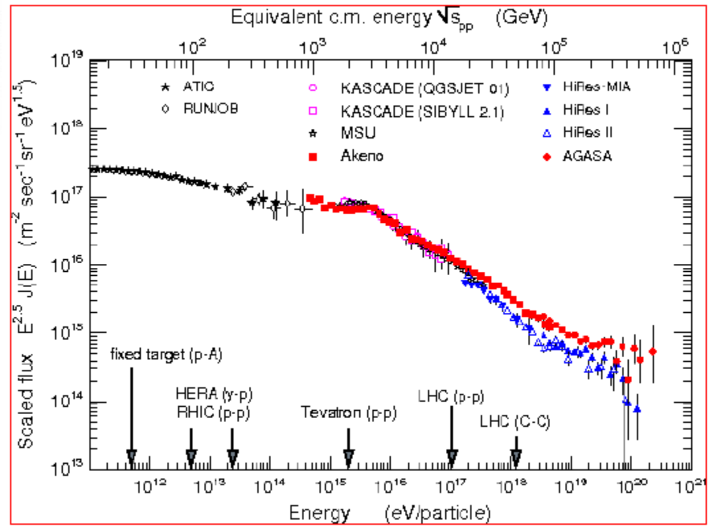


Figure 30.1: Fluxes of nuclei of the primary cosmic radiation in particles per energy-per-nucleus are plotted vs energy-per-nucleus using data from Refs. [1–15] The inset shows the H/He ratio as a function of rigidity [1,3].



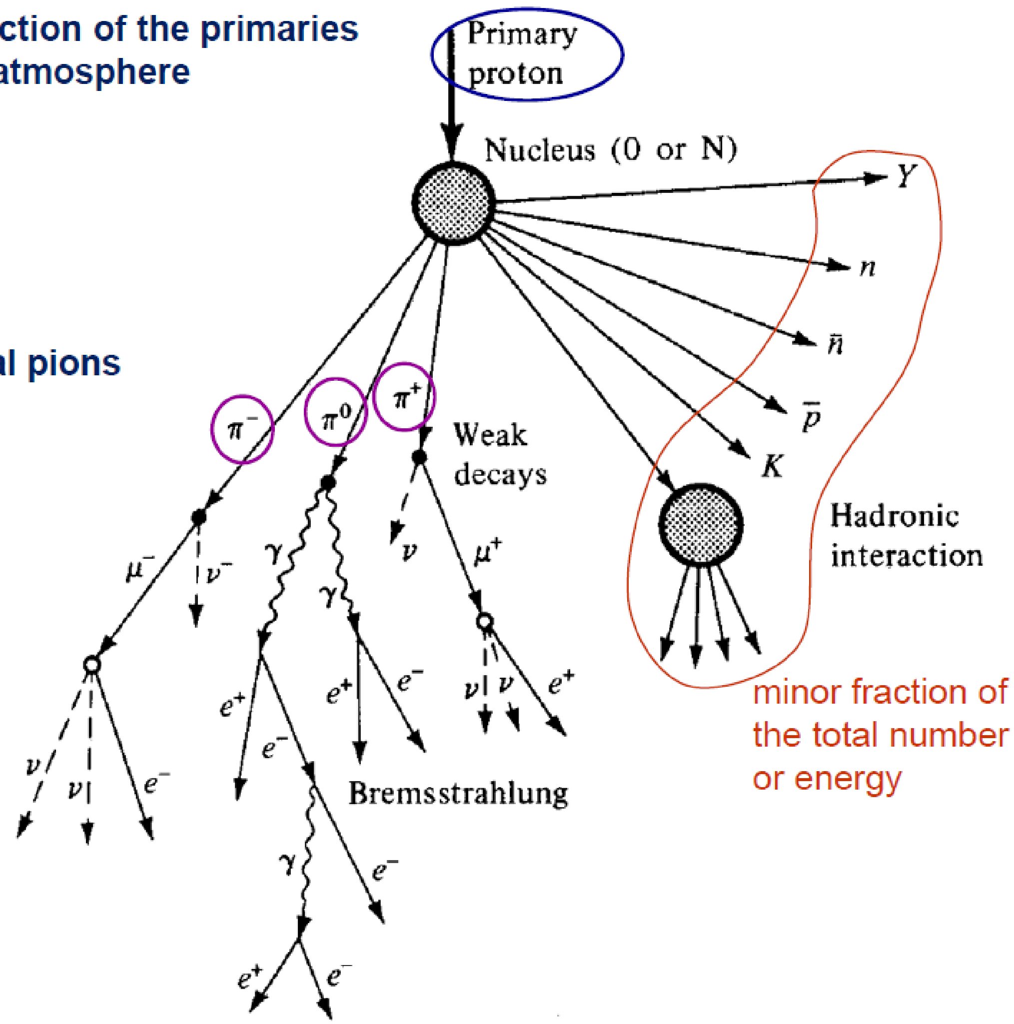
the *knee* could be due to the fact that most cosmic accelerators in the galaxy have reached their maximum energy…
for the *ankle*, one possibility is that an extragalactic flux beginning to dominate over the galactic flux …

raggi cosmici

Secondary Cosmic Rays

particles produced in interaction of the primaries with interstellar gas and atmosphere

mostly charged and neutral pions

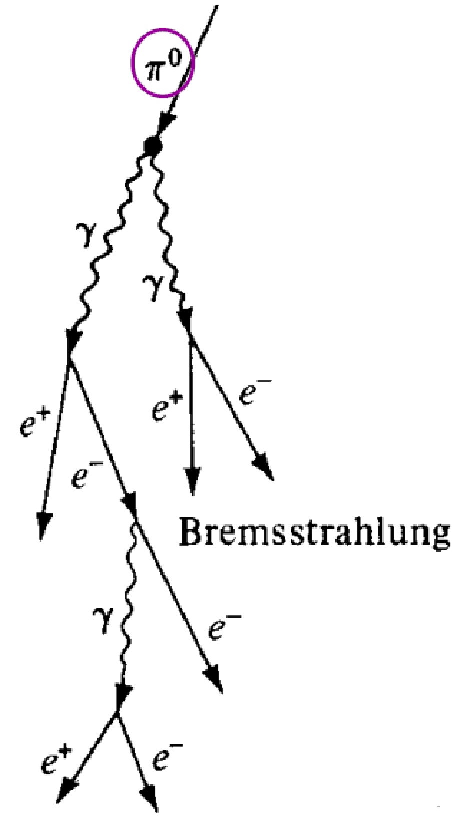


minor fraction of the total number or energy

raggi cosmici

Secondary Cosmic Rays

neutral pions $\pi^0 \rightarrow \gamma\gamma$ $\tau_{\pi^0} \cong 8 \cdot 10^{-17}$ s



in ~ one radiation length (37 g/cm^2 in air) an energetic photon interacts with the nuclear electric field of nitrogen or oxygen → e^+e^-

the electrons and positrons interact with air in ~ one radiation length to create bremmstrahlung photons again dividing the energy ....

e.m. SHOWERS **"soft" component**
this process comes to a halt as the average γ-ray energy drops below the pair creation threshold of 1 MeV, and normal ionization loss depletes the electron energies

raggi cosmici

Secondary Cosmic Rays

charged pions

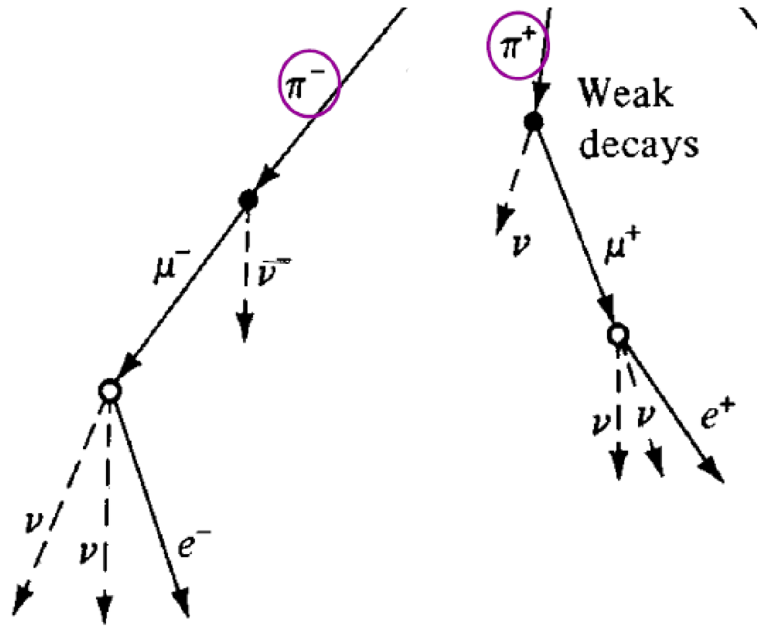
$$\pi^+ \rightarrow \mu^+ \nu_\mu$$
$$\pi^- \rightarrow \mu^- \overline{\nu}_\mu$$

$\tau_\pi \cong 26$ ns

"hard" component

ionisation energy loss only

$$\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$$
$$\mu^- \rightarrow e^- \overline{\nu}_e \nu_\mu$$



raggi cosmici

Cosmic Rays: hard and soft components

1932, B. Rossi

$$\Phi_v = \frac{d^3N}{dS\,dt\,d\Omega} \qquad m^{-2}\,s^{-1}\,sr^{-1}$$

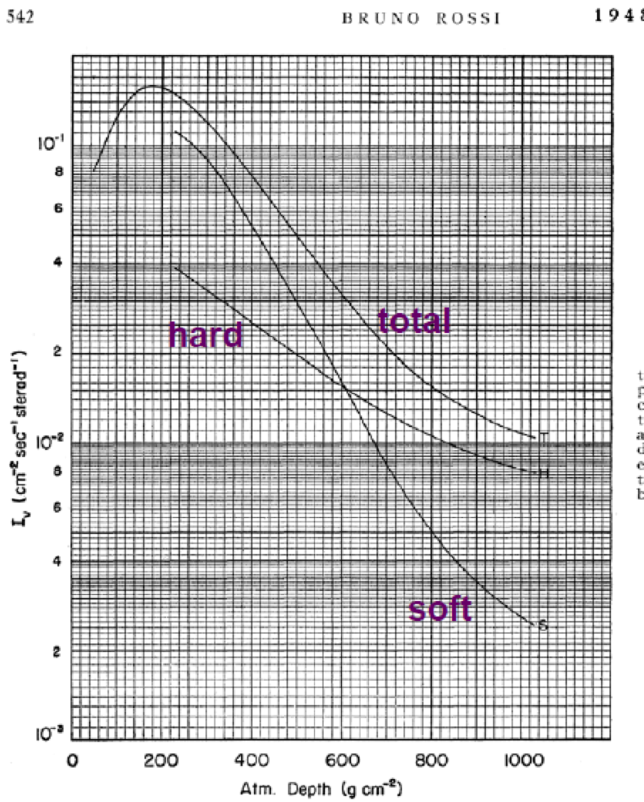
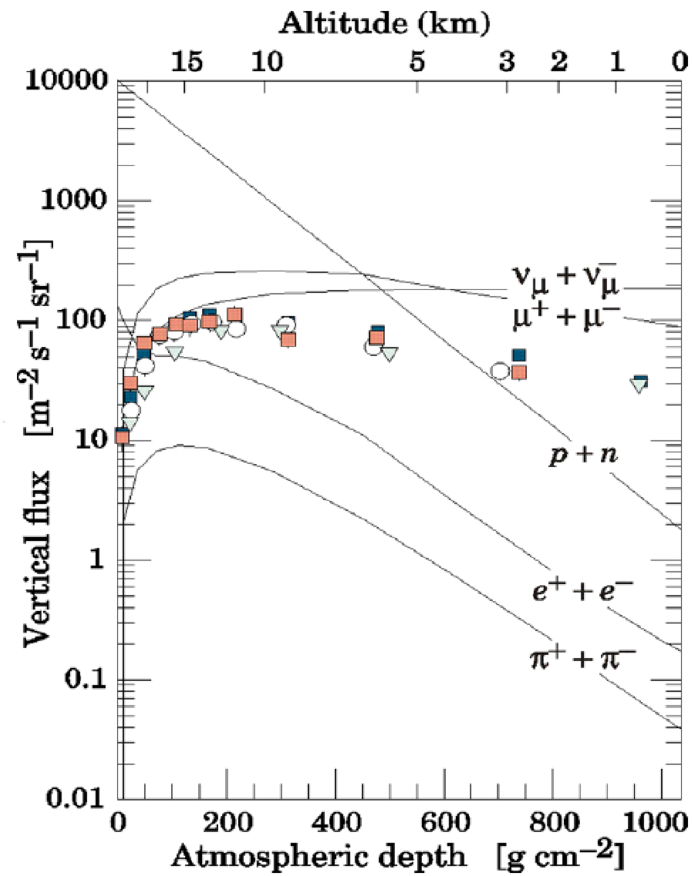


FIG. 3. The vertical intensities of the hard component (*H*), of the soft component (*S*), and of the total corpuscular radiation as a function of atmospheric depth near the geomagnetic equator. Minimum range of the soft particles: 5 g cm^{-2} of brass.



meas. negative muons with E>1GeV

PDG

raggi cosmici

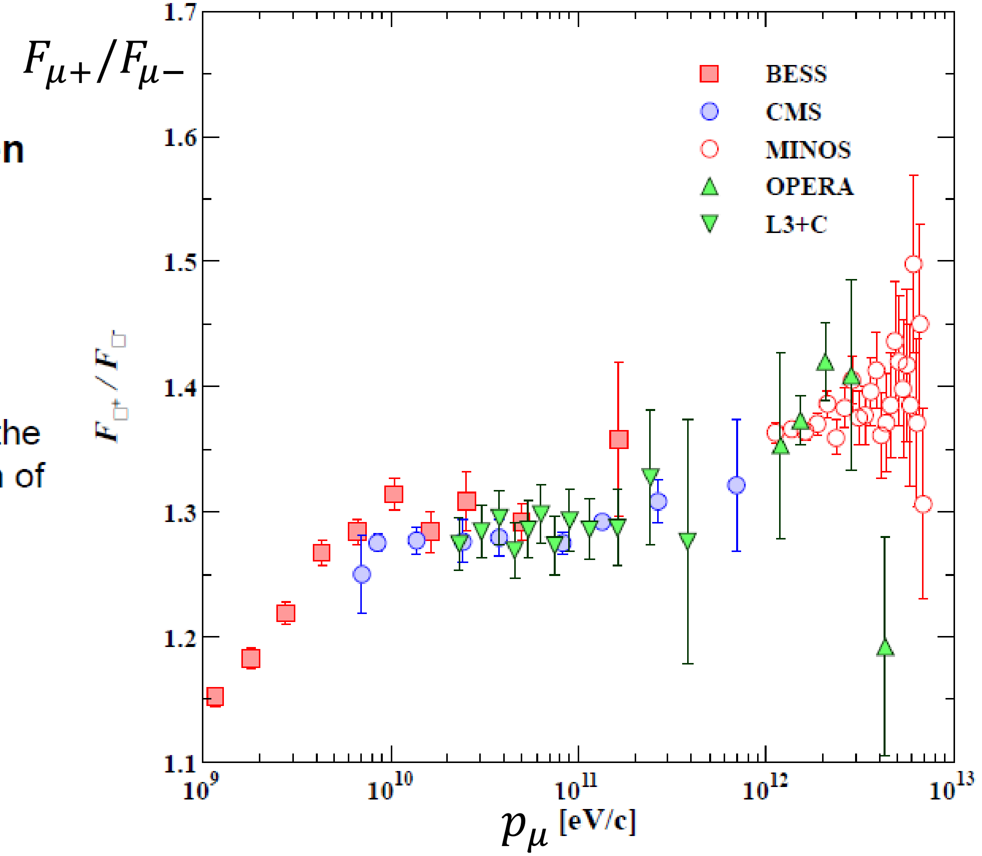
Cosmic Rays - sea level

MUONS

the charge ratio is between 1.1 and 1.4 from 1 GeV/c to 10^4 GeV/c

it reflects

- the excess of π+ over π− in the forward fragmentation region of proton initiated interactions



raggi cosmici

Cosmic Rays - sea level

MUONS

the mean energy of muons at the ground is ≈ 4 GeV

the energy spectrum is almost flat below 1 GeV, steepens gradually to reflect the primary spectrum in the 10–100 GeV range

$$\Phi = \frac{d^4N}{dS\,dt\,d\Omega\,dp}$$

B. Rossi

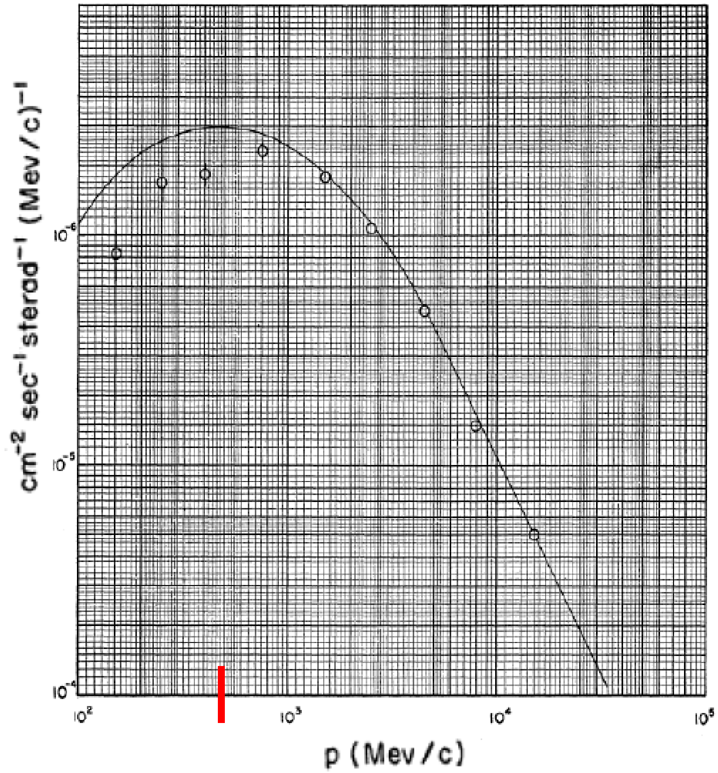
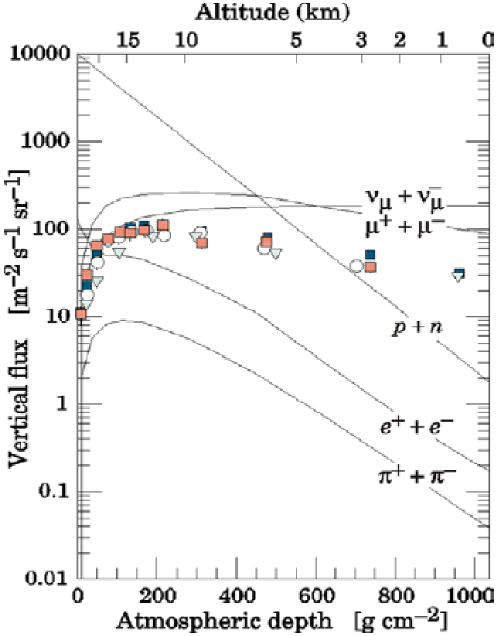


FIG. 4. Differential momentum spectrum of mesons at sea level. The circles represent experimental determinations by Wilson (W7). (*Note:* In the ordinate scale 10^{-4} and 10^{-5} should read 10^{-6} and 10^{-7}, respectively.)

raggi cosmici

Cosmic Rays - sea level

MUONS



the integral intensity of vertical muons above 1 GeV/*c* at sea level is I_V ~ 80 m^{-2} s^{-1} sr^{-1}

(I ≈ 1 cm^{-2} min^{-1} for horizontal detectors)

the overall angular distribution of muons

$$I \sim I_V \cos^2\theta$$

at low energy the angular distribution becomes increasingly steep

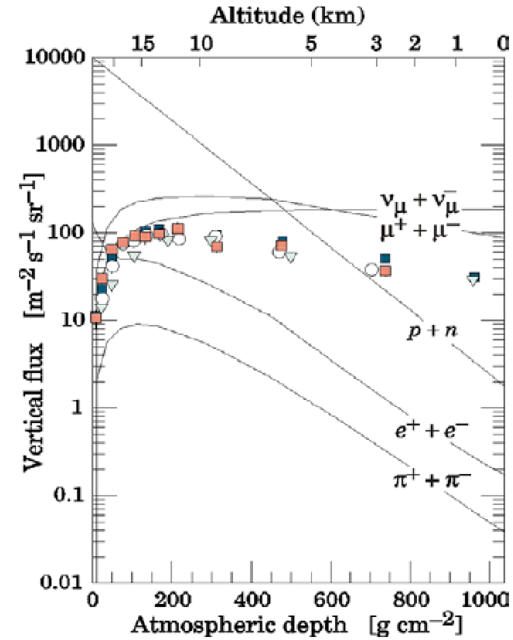
(at large angles low energy muons decay before reaching the surface)

their energy and angular distributions reflect a convolution of production spectrum, energy loss in the atmosphere, and decay

raggi cosmici

Cosmic Rays - sea level

MUONS



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lecay before reaching the surface)

ions reflect a convolution of
ss in the atmosphere, and decay

The integration over all solid angles in the range $0<\theta<\pi/2$ and $0<\phi<2\pi$ then read

$$\begin{aligned}\int_{2\pi} j(\theta,\phi)\cos\theta\, d\Omega &= 0.66 \cdot \int_{\theta=0}^{\pi/2}\int_{\phi=0}^{2\pi} \cos^3\theta\, \sin\theta\, d\theta\, d\phi \\ &= -0.66 \cdot \int_{\theta=0}^{\pi/2}\int_{\phi=0}^{2\pi} \cos^3\theta\, d\cos\theta\, d\phi \\ &= 1.04\,\mathrm{cm}^{-2}\,\mathrm{min}^{-1} = 173.3\,\mathrm{m}^{-2}\mathrm{s}^{-1}\,. \end{aligned} \tag{19}$$

The additiona cosθ- Term from the fact that a cosmic particle which is at an angle θ runs in, sees the horizontal surface of the detector shortened by this same factor.

cominciamo con

scintillatori

- tensioni di lavoro di S_1, S_2, S_3, S_4
  e soglie
- tempi coincidenze e anticoincidenze
- conteggi (in 2'?)

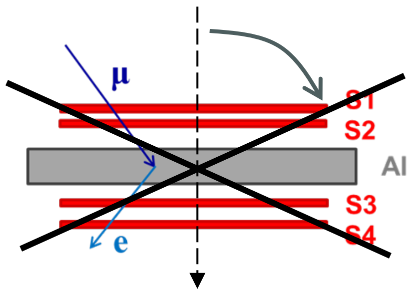
$$S_1, S_2, S_3, S_4$$
$$S_1 \cdot S_2, \quad S_3 \cdot S_4$$
$$S_1 \cdot S_2 \cdot S_3 \cdot S_4$$
$$S_1 \cdot S_2 \cdot \overline{S_3 \cdot S_4}\ , \quad S_1 \cdot S_2 \cdot (\overline{S_3} \cdot \overline{S_4})$$
$$S_3 \cdot S_4 \cdot \overline{S_1 \cdot S_2}, \quad S_3 \cdot S_4 \cdot (\overline{S_1} \cdot \overline{S_2})$$

e confronto tra i diversi gruppi e con quanto atteso

questa settimana

conteggi attesi

- geometria dell'apparato
  dimensioni scintillatori e assorbitore
  posizioni relative
- stime **approssimate** del flusso di muoni attraverso l'apparato
  nell'assorbitore si fermano pochi muoni
  → muoni a livello del mare



… entro il 6/12

… solo se resta tempo!

operazioni iniziali - stima degli eventi necessari

vorremmo

- misurare della vita media dei μ^- con un errore <5%, assumendo τ_0 noto
- **rigettare l'ipotesi che ci sia una sola componente,** che la distribuzione dei tempi misurati sia un singolo esponenziale **quanti eventi servono?**
  - generare N eventi con $\mathrm{f(t)} = \frac{1}{\tau} e^{-t/\tau}, \;\; \tau = 2 \;\; (\mu s)$
  - generare N/2 eventi con $\tau = 1$
  - riempire un istogramma ad es (0,10) con 50 bin
  - assumendo $n_1(t) = c_1 \, e^{-t/\tau}$ stimare c_1, τ e calcolare il χ^2
  - assumendo $n_2(t) = c_2 \left(e^{-t/\tau_1} + e^{-t/\tau_2}\right)$ stimare $\mathrm{c}_2, \tau_1, \tau_2$ e calcolare il χ^2

solo questa volta, con "ROOT"

ripetere molte volte (500?) → **distribuzioni di χ^2**
per diversi N, cominciando da N=3000

$$E[\chi^2_\nu] = \nu, \sigma_{\chi^2_\nu} = \sqrt{2\nu}$$

raccomandazioni…

- tra i gruppi
  - collaborazione (un unico apparato) e confronti

- in ogni gruppo
  - logbook accessibile a tutti con descrizione di tutto il lavoro fatto e dei problemi
  - lavoro parzialmente in parallelo, ma e’ molto importante che tutti seguano tutto e partecipino alle decisioni:
    sia il successo della presa dati che l’analisi dei dati e la relazione sono responsabilita’ di tutti

e soprattutto

non avere fretta ! controllate tutto in calma

Cosmic Rays

1800: “atmospheric electricity” an electroscope is “spontaneously” discharged
1896, Henri Becquerel: discovery of radioactivity
→ atmospheric electricity is caused by radiation from radioactive elements in the ground
1900-1910: measurements of ionization rate at increasing heights from ground : it decreases, as expected

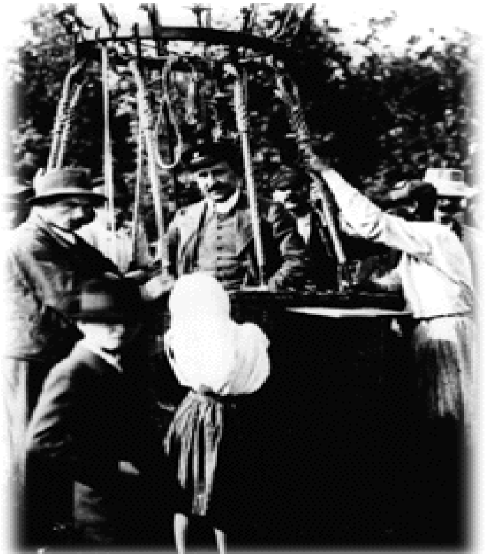
1912, V. Hess: carried three electrometers to an altitude of 5300 meters
in a balloon flight and found that the ionization rate
increased approximately four-fold over the rate at ground level

“The results of my observation are best explained by the assumption that a radiation of very great penetrating power enters our atmosphere from above.”

COSMIC RAYS

Nobel Prize in Physics in 1936

remarkable progress, in a few years
theory
experiments (could chambers → counters)



Cosmic Rays - muons

1932, B. Rossi: soft and hard components

1932, C. Anderson: positron

1936, S. Nedermeyer and **C. Anderson:** **muon**

1937, J. C. Street and **E. C. Stevenson:** with a cloud chamber measured $\mathbf{m_\mu = 207\ m_e}$

1935, H. Yukawa: an intermediate mass "meson" is responsible for the nuclear strong force mass of about 100 MeV/c^2: the muon (mesotron) ?
→ "mesone", e non leptone, μ

1939-40, B. Rossi et al.: study of absorption in air and graphite → muon decay, $\tau_\mu \sim 2\ \mu s$

1940, Williams and **Roberts:** **observation of the decay of a muon in e^+**

.....

1941, Rasetti: $\mathbf{\tau_\mu = 1.5 \pm 0.3\ \ \mu s}$, first direct measurement

1942, Rossi and **Nereson:** with time-to-amplitude converter,
$\mathbf{\tau_\mu = 2.3 \pm 0.2\ \ \mu s}$

1947-1948, Conversi, Pancini, Piccioni: muon capture

from muon decay in different materials, the capture in light materials is not as relevant as in case of strong interactions

the muon does not interact strongly with nuclei, **it can not be the Yukawa particle**

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ci torniamo piu’ avanti

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Nereson Rossi

NOVEMBER 1 AND 15, 1942 PHYSICAL REVIEW VOLUME 62

Experimental Determination of the Disintegration Curve of Mesotrons

BRUNO ROSSI AND NORRIS NERESON
Cornell University, Ithaca, New York
(Received September 17, 1942)

The disintegration curve of mesotrons has been experimentally determined by investigating the delayed emission of disintegration electrons which takes place after the absorption of mesotrons by matter. Within the experimental errors, the disintegration curve is exponential and corresponds to a mean lifetime of 2.3 ± 0.2 microseconds.

THE purpose of the experiment described in the present paper was to determine the disintegration curve of mesotrons at rest. The experiment was performed by investigating the delayed emission of the disintegration electrons, which takes place after the absorption of mesotrons by matter.

at rest

We have succeeded in increasing the selectivity and the statistical accuracy of the method considerably by recording all decay electrons and measuring the time interval between the arrival of each mesotron and the emission of the corresponding electron. The circuit used for this measurement will be referred to as the *time circuit*.

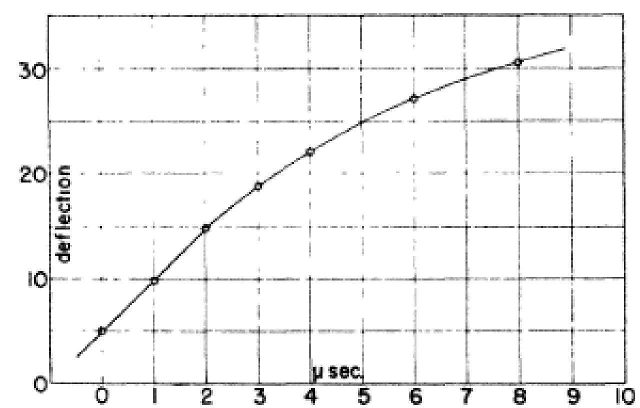
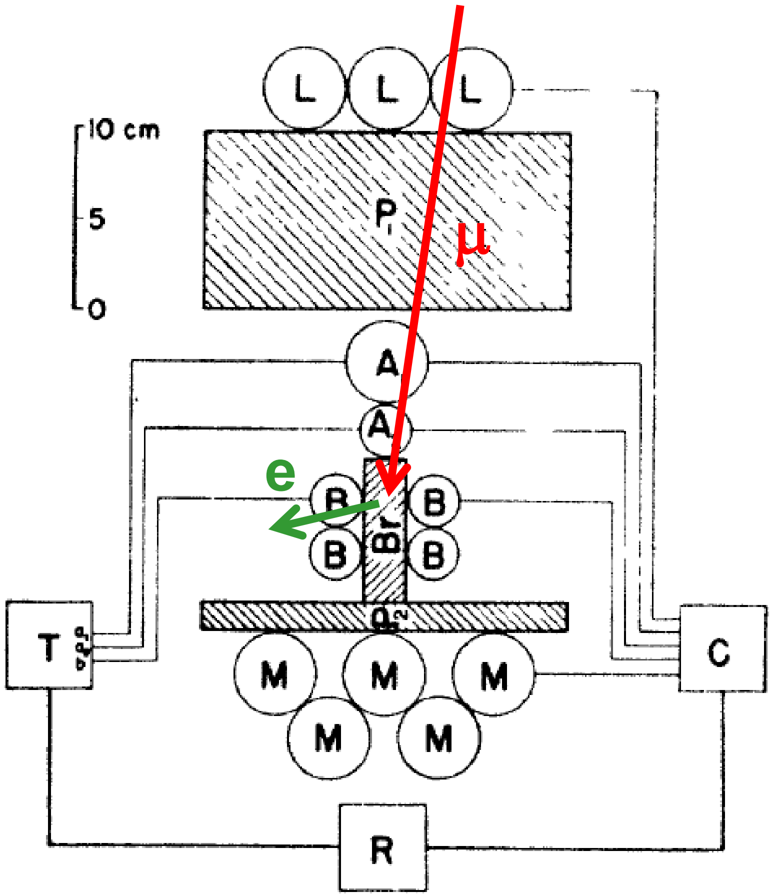


FIG. 1. Calibration curve of the time circuit.

Nereson Rossi



L, A, B, M: Geiger-Muller counters

the 4 counters L are connected in parallel (OR)

the same for the 4 counters B and the 5 counters M

Br: brass plate 25.5x8x2.3 cm

compromise: rate of stopped muons vs probability of detecting the electron

good event:

muon gives signal in L, A1, A2

decays in Br → no signal in M, B

decay electron gives a signal in B

P1: 9 cm of lead

to cut the electron component

P2: lead plate 1.4 cm thick

to decrease the probability of having a decay electron signal in M

C gives a signal which activates R if

$L \cdot A1 \cdot A2 \cdot B \cdot \overline{M}$ (10^{-4} s)

R registers the amplitude of the signal from T proportional to Δt between A and B

Nereson Rossi

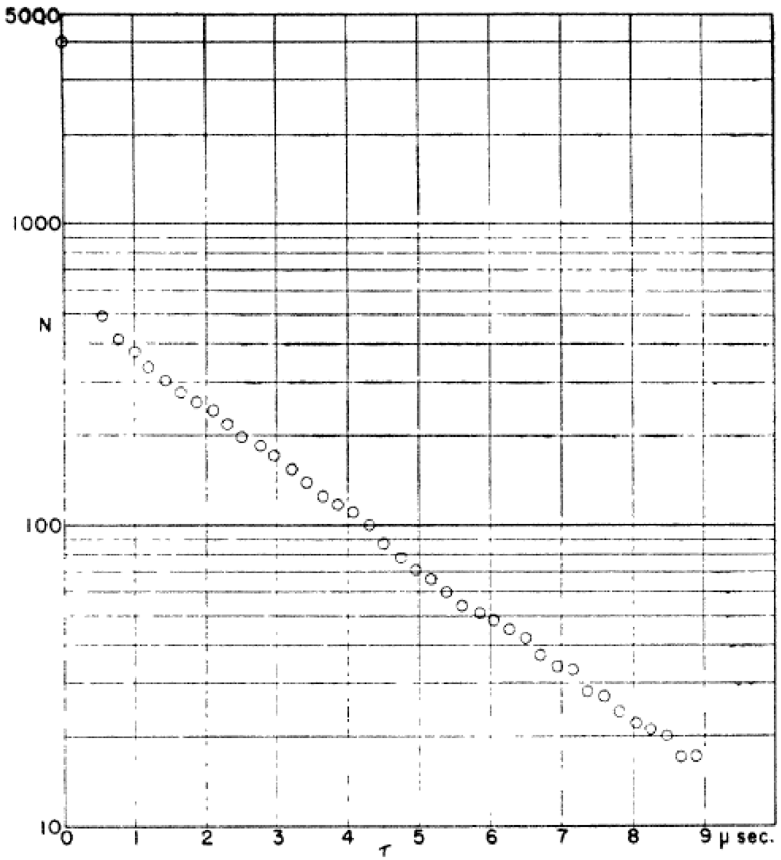


FIG. 5. Experimental disintegration curve of mesotrons. The abscissa τ is the delay recorded by the time circuit, the ordinate is the logarithm of the number N of anti-coincidences accompanied by delays larger than the corresponding abscissa (Exp. A).

$\tau_\mu(\text{MuLan}) = 2196980.3(2.2)$ ps

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semi-logarithmic scale in Fig. 5. The experimental points lie on a straight line as closely as one can expect considering the statistical fluctuations, with the exception, of course, of the point at $\tau=0$ and possibly the one at 0.55 μsec. Hence the disintegration of mesotrons follows an exponential law as does any ordinary disintegration process.

For the evaluation of the lifetime τ_0 we shall use the following equation:

$$\begin{aligned}\rho&=[N(\tau_1)-N(\tau_2)]/[N(\tau_2)-N(\tau_3)]\\&=[\exp(-\tau_1/\tau_0)-\exp(-\tau_2/\tau_0)]/\\&\quad[\exp(-\tau_2/\tau_0)-\exp(-\tau_3/\tau_0)],\qquad(1)\end{aligned}$$

where $N(\tau)$ is the number of mesotrons surviving at the time τ after their absorption in the brass plate. If we take $\tau_1=0.99$ μsec., $\tau_2=4.95$ μsec., $\tau_3=8.91$ μsec., then $\tau_2-\tau_1=\tau_3-\tau_2=\Delta\tau=3.96$ μsec. Equation (1) reduces to

$$\rho=\exp(\Delta\tau/\tau_0),$$

and the experimental data set forth in Table I yield

$$\tau_0=2.3\pm0.2\ \mu\text{sec.},$$

where the error indicated is the standard statistical error.