measurement of the μ lifetime

to measure it we need to

detect muon and decay electron/positron

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

measure the time interval T between muon arrival and
e+/e- detection in several decays

extract the muon lifetime from a fit of the T distribution

- bring at rest as many muons as possible in an absorber (**)
- detect as many electrons/positrons from muon decay as possible (**)
- reduce as much as possible the background

measurement of the μ lifetime

decay $\mu^+ \rightarrow e^+ \, \nu_e \, \bar{\nu}_\mu$ $\mu^- \rightarrow e^- \, \bar{\nu}_e \, \nu_\mu$

- **three body decay**

- **forward-backward asymmetry in the positron emission**

muon capture

electron/positron detection

PHYSICAL REVIEW LETTERS VOLUME 14 1965

MEASUREMENT OF THE MOMENTUM SPECTRUM OF POSITRONS FROM MUON DECAY*

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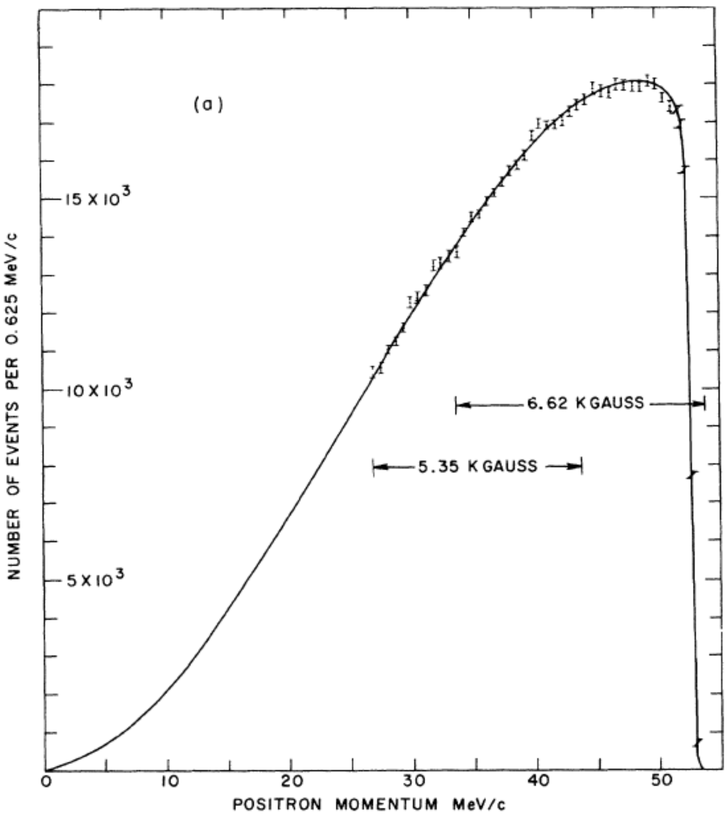
(Received 16 February 1965)



normalised distribution function:

$$f(E) \cong a \cdot E = \frac{2 \cdot E}{E_{max}^2}$$

$$E_{max} \cong 52\,\mathrm{MeV}$$

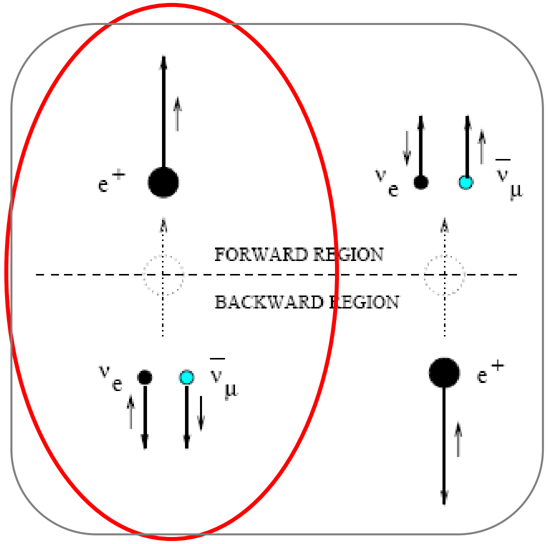
not all the e will be detected

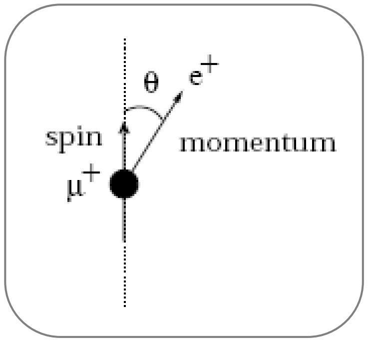
range of electrons: R (g/cm²) ~ 0.54·E (MeV)

(Segre', Nuclei and Particles)

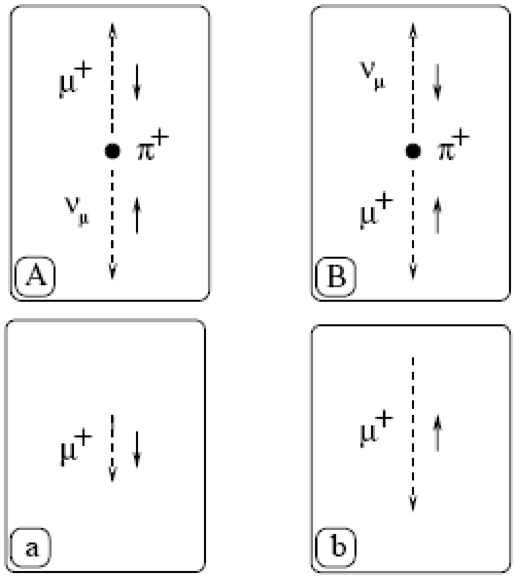
measurement of the μ lifetime

forward-backward asymmetry in the positron emission





$$N(\theta) \propto 1 + \alpha' \cos\theta$$



measurement of the μ lifetime

muon capture

A potential complication in this measurement is the fact that roughly half of the stopped muons are negative and therefore subject to capture in tightly bound orbits in the atoms of the scintillator. If the atom is carbon then the probability density inside the nucleus of a muon in a 1s state is sufficiently high that nuclear absorption can occur by the process (see Rossi, "High Energy Particles", p 186)

$$\mu^- + p \rightarrow n + \nu, \qquad (12)$$

which competes with decay in destroying the muon.

Muon capture in hydrogen is the most important from the theoretical point of view, but by far the hardest experimentally. First the rate is small ($\sim 460\,\mathrm{s}^{-1}$) in comparison to muon decay ($455 \times 10^3\,\mathrm{s}^{-1}$) a factor of a thousand which causes great difficulty in an experiment. Secondly

D.F. Measday / Physics Reports 354 (2001) 243–409

measurement of the μ lifetime

muon capture

D.F. Measday / Physics Reports 354 (2001) 243–409

Table 4.2
Some illustrative total capture rates for μ^- in nuclei. Also given is the mean lifetime. For the hydrogen isotopes, molecular formation complicates the situation. For other light elements (He, Li, Be, ^{10}B) the capture rate is the statistical average of the hyperfine states except for those marked (lhfs), i.e., lower hyperfine state. For $Z > 15$ the rate is always for the lower hyperfine state

Z (Z_{eff})	Element	Mean-life (ns)	Capture rate $\times 10^3 (\mathrm{s}^{-1})$	Huff factor	Ref.
	μ^+	2197.03 (4)	455.16		[14]
1 (1.00)	^{1}H	2194.90 (7)	0.450 (20)	1.00	[23]
	^{2}H	2194.53 (11)	0.470 (29)		[211]
2 (1.98)	^{3}He	2186.70 (10)	2.15 (2)	1.00	
	^{4}He	2195.31 (5)	0.356 (26)		
3 (2.94)	^{6}Li	2175.3 (4)	4.68 (12)	1.00	[250]
	^{7}Li	2186.8 (4)	2.26 (12)		[250]
4 (3.89)	^{9}Be	2168 (3)	6.1 (6)	1.00	[183]
5 (4.81)	^{10}B	2072 (3)	27.5 (7)	1.00	[183]
	^{11}B (lhfs)	2089 (3)	23.5 (7)	1.00	[183]
6 (5.72)	^{12}C	2028 (2)	37.9 (5)	1.00	[183]
	^{13}C	2037 (8)	35.0 (20)		[183]
					[183]
					[183]
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					[252]

the muon radius soon becomes comparable to that of the nucleus.

Primakoff

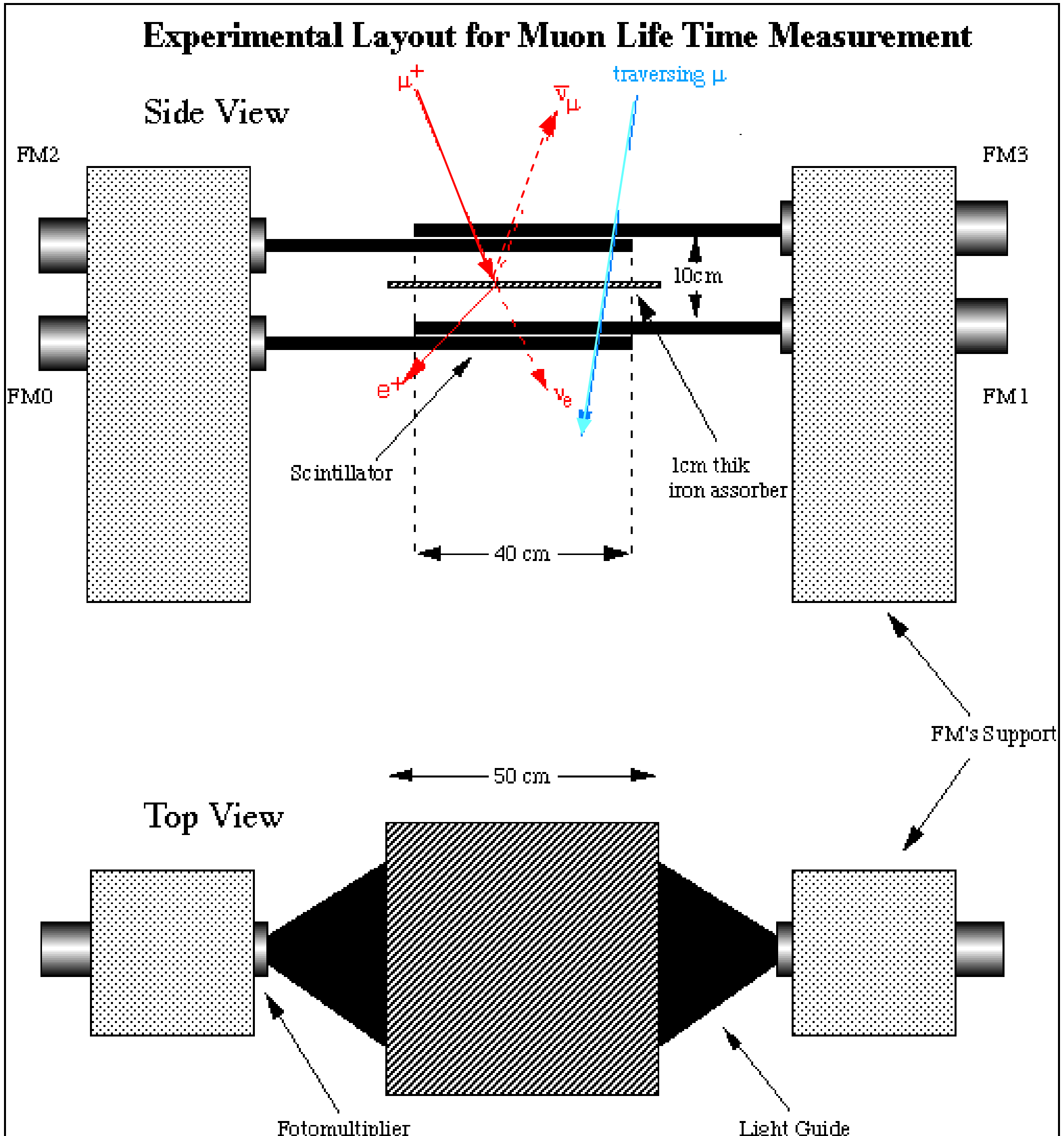
$$\Lambda_c(A,Z) = Z_{\mathrm{eff}}^4 X_1 \left[1 - X_2 \left(\frac{A-Z}{2A}\right)\right]$$

Pauli exclusion principle.

X_1 is the muon capture rate for hydrogen,

$X_1 = 170\,\mathrm{s}^{-1}$ and $X_2 = 3.125$

experimental set-up



not exactly this!!

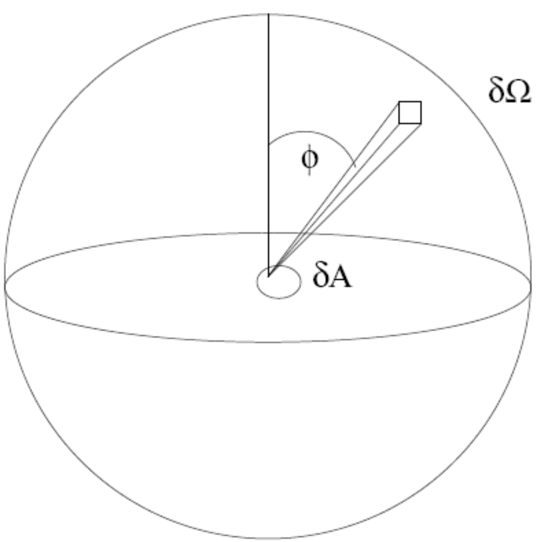
muon flux

$$I(\phi) = I_v cos^2(\phi)$$

$$I_v = 0.83 \times 10^{-2}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{str}^{-1}$$

From B. Rossi, Rev. Mod. Phys., **20**, 537 (1948)

$I(\phi)d\Omega dA dt$ number of particles incident upon an element of area dA during the time dt within the element of solid angle dΩ from the direction perpendicular to dA.



$$\delta\Omega = \sin\phi\delta\phi\delta\theta$$

$$\cos\varphi\ dA$$

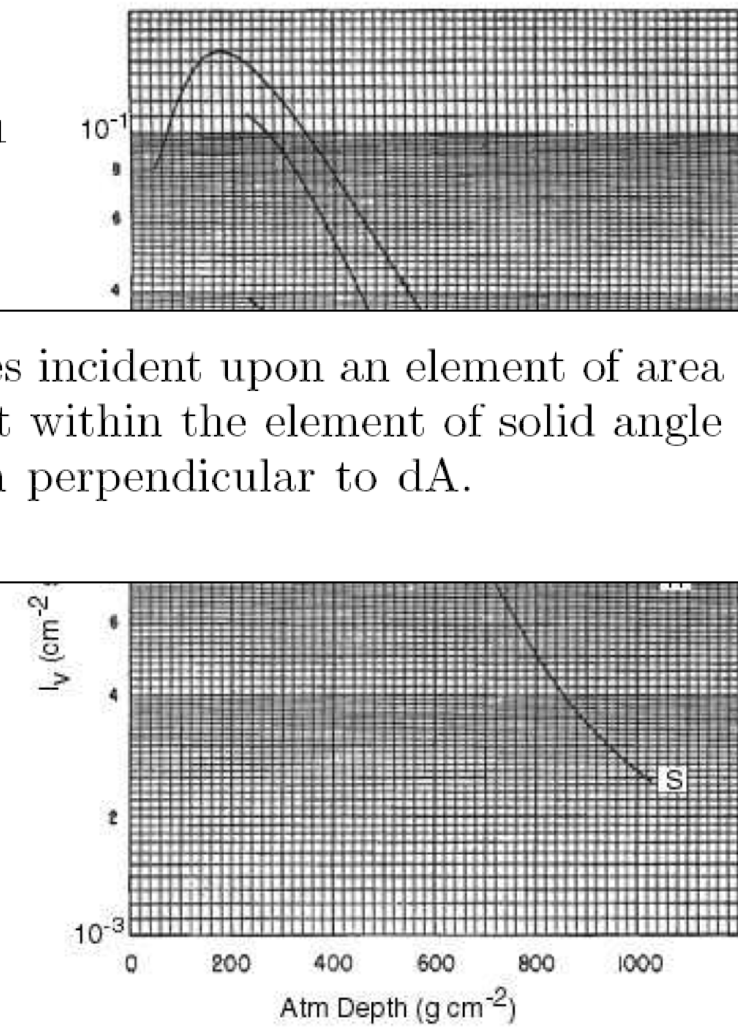


FIG. 9: The vertical intensities of the hard component (H), of the soft component (S), and of the total corpuscular radiation as a function of atmospheric depth near the geomagnetic equator.

muons at rest

range usually given as $x \cdot \rho$ **, measured in** ***g/cm²***

"differential range spectrum" of the muons flux at sea level

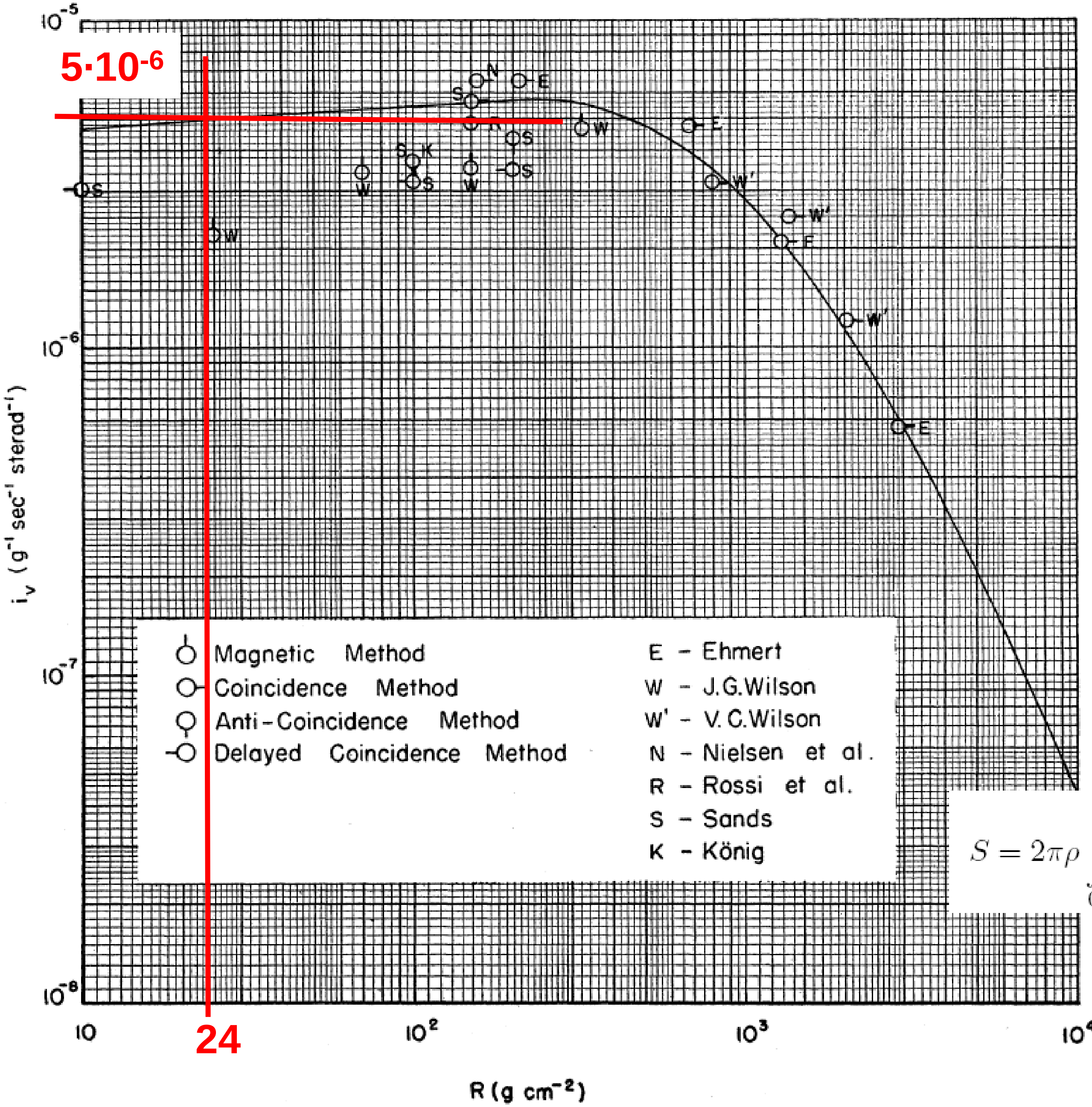
$$i_v(R) = \frac{dN}{dS\,dt\,d\Omega\,dR}$$

which is the **vertical flux of muons which are brought to rest in dR after traversing a thickness R**

number of muons per unit S, t, Ω brought to rest after a thickness t:

$$\int_0^t i_v(R)\,dR$$

muons at rest in 3 cm of Fe



t=xρ = 3 · 7.87 g/cm²
~24 g/cm²

$$\Phi_v = \int_0^t i_v(R)\,dR$$

$$\cong 5\cdot 10^{-6}\cdot 20$$

$$= 1\cdot 10^{-4}$$

cm^{-2} s^{-1} sr^{-1}

stopping rate of muons

$$S = 2\pi\rho \int_0^A dA \int_0^b I(R',0)dx \int_0^{\pi/2} \cos^2\varphi \sin\varphi d\varphi$$

acceptance
μ^+ and μ^- !

electron/positron detection

range of electrons: R (g/cm²) ~ 0.54·E (MeV)

$$\left\langle E \right\rangle = \int dE\, E\, f(E) \cong 35\,\mathrm{MeV}$$

$$\left\langle R \right\rangle = 0.54 \cdot \left\langle E \right\rangle \cong 20\,\mathrm{g/cm^2} \cong 3\,\mathrm{cm\ of\ Iron}$$

$$R_{max} = 0.54 \cdot E_{max} \cong 30\,\mathrm{g/cm^2} \cong 3.5\,\mathrm{cm\ of\ Iron}$$

$$\left\langle t \right\rangle = 2\,\mathrm{cm\ of\ Iron} \cong 15\,\mathrm{g/cm^2} \rightarrow E_{min} \cong 15/0.54\ \mathrm{MeV} \cong 30\,\mathrm{MeV}$$

$$P_e = \int_{E_{min}}^{E_{max}} dE\, f(E)$$

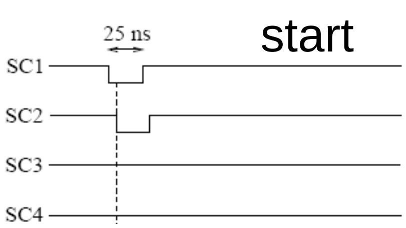
to maximise efficiency, compromise between maximum number of muons at rest and maximum number of detected e+/e-

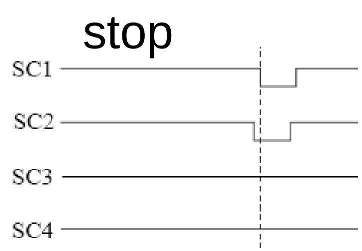
expected number of events

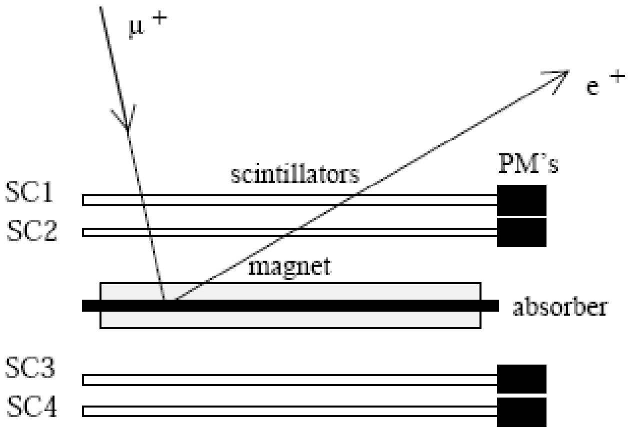
first order calculation

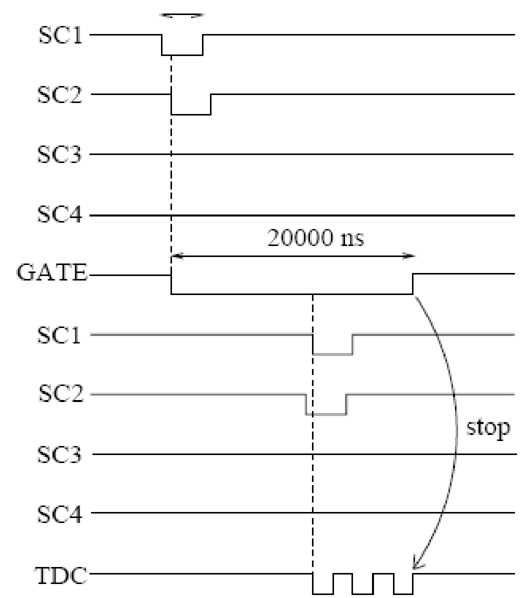
MonteCarlo ?

experimental set-up

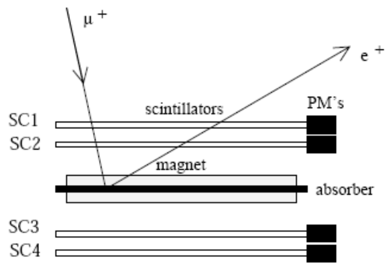


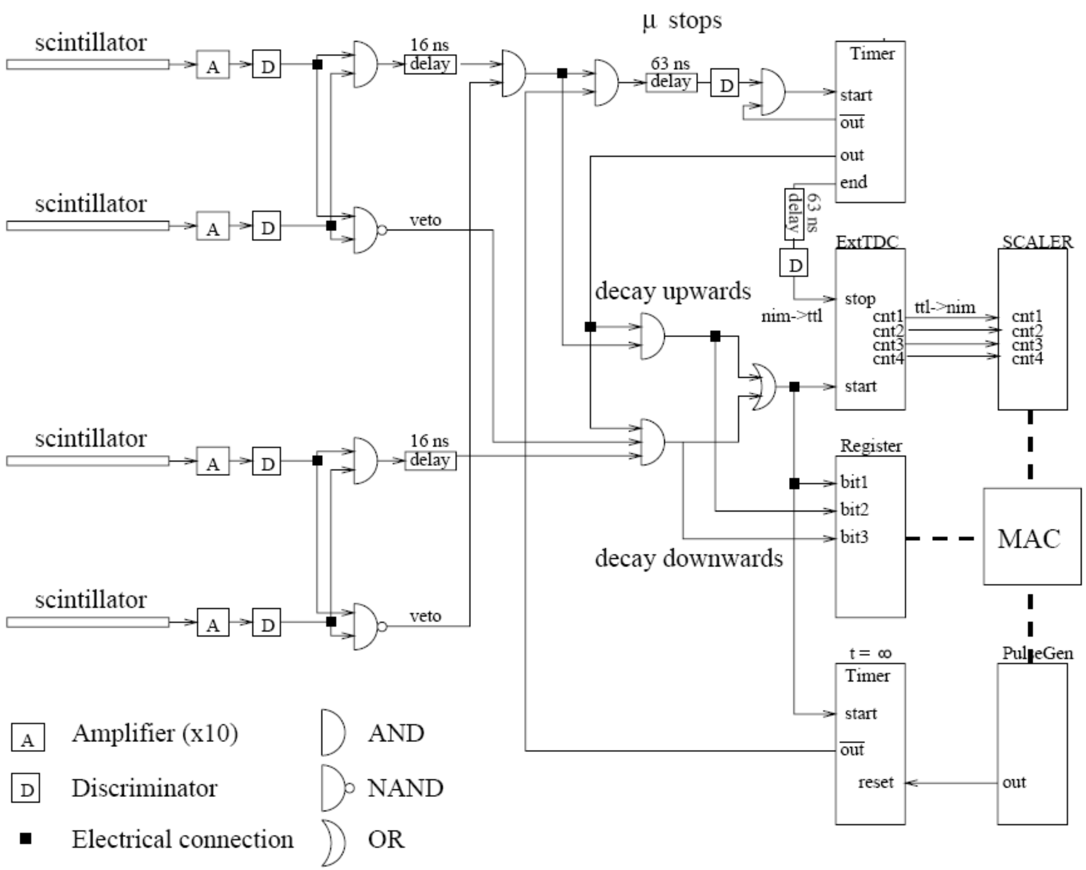




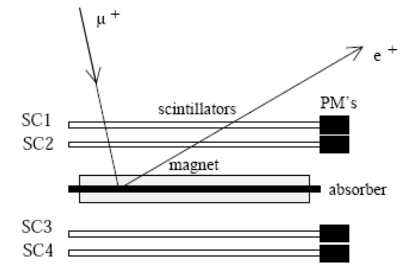


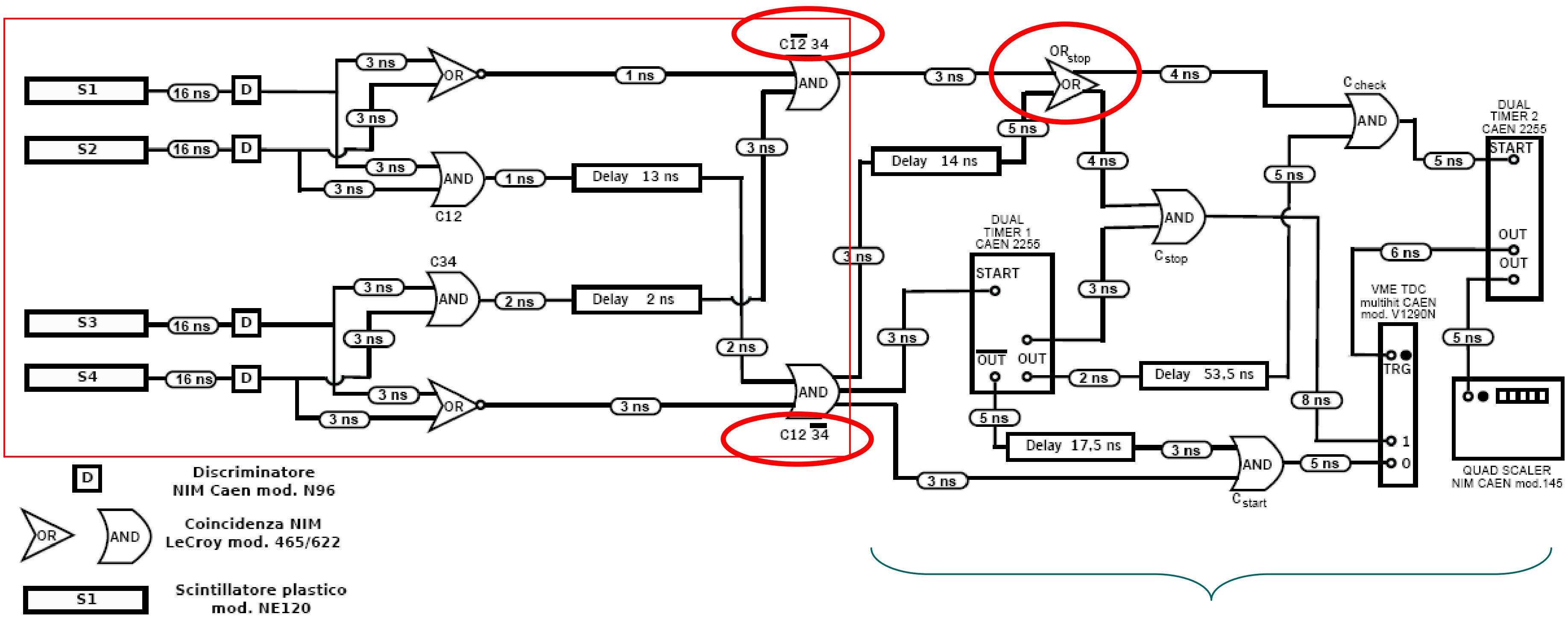
experimental set-up





experimental set-up





programma di acquisizione

experimental set-up