MUON LIFE TIME MEASUREMENT:

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Abstract:

This experiment is to measure the life time of leptonic member muon. It is mainly measured as the time difference between the two pulses such as arrival of muon and muon decays to e^{-}. This is done by using a scintillator (where muons are stopped), PMT (where signal are converted into light pulse) and finally by the electrical circuit (which converts the signal as electrical signal). By plotting graph between life time and number of events and analyzing we can obtain lifetime of muon.

INTRODUCTION:

Muon was discovered by C.W. Anderson and S.H.Nedder meyer in 1937, when they exposed a cloud chamber to cosmic rays. In this project life time of cosmic ray muon is measured.

Actually muon comes under leptonic family and is one of the elementary particle. Its mass is about 105.7MeV/c^2. It participates in weak and electromagnetic interaction but not in strong interactions. The decay times of muon is similar to that of radioactive decay

$$N(t)=N(0)*\exp(-t/\tau)$$

Thus at time t only N muons will be there if N(0) muons are there initially with mean life time **τ**.

DECAYS OF COSMIC RAY PARTICLES:

Primary cosmic rays consist of 98% of protons. These particles will colloid with nuclei of the atmosphere air molecules and will produce shower of particles including pion (neutral and charged). Those produced pions are not stable and thus further decay into muon and neutrino in case of charged pions and as γ-rays in case of neutral pion. Their interactions are given as follows,

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

The cosmic ray shower is represented as diagrammatically as,

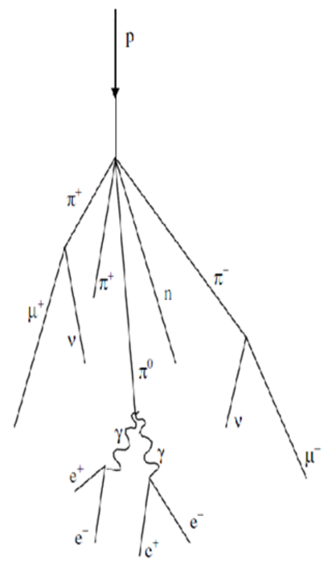

Fig 1. Cosmic ray shower

The interesting thing about muon is that though it has mean lifetime of 2.2μs and hence can travel only 650m (even when travel at the speed of light). Yet we can detect muon at ground level.

This is because of the phenomenon time dilation, whose expression is given as,

$$t = \frac{t'}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}} = \gamma t'$$

Where,

t – time in lab frame, **t'** – time in rest frame of the particle, **v** – Velocity of the particle, **c** – velocity of the light.

When muon travel at the speed of light, their lifetime 2.2µs get dilated to 15.6µs and hence can travel upto 4678.62 m and thus we are able to detect these particles at the ground level.

EXPERIMENTAL SET UP & WORKING:

In order to measure lifetime of muon we need a experimental arrangement which consists of the following components.

a) Scintillator
b) PMT
c) Electrical circuit (including PC)

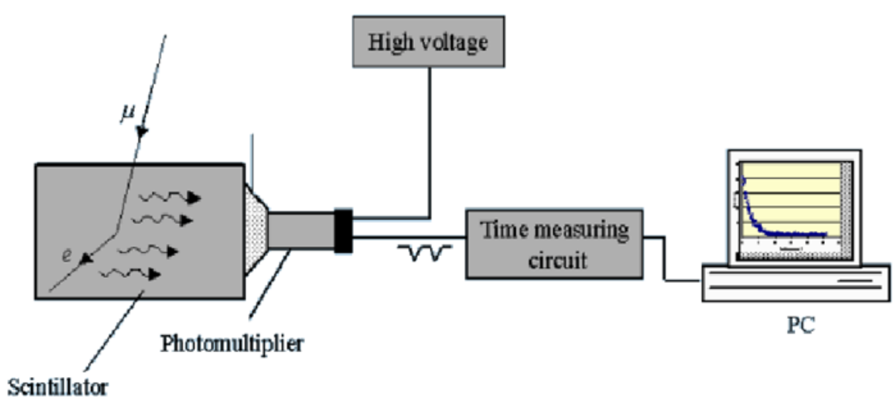

Fig 2. Experimental setup

SCINTILLATOR:

Scintillator are made of transparent material, which works on the principle that it produces visible light when charged particles passes through it. Scintillator mainly consists of molecules which get excited when charged particle passes through and again get de-excited by emitting photon in visible region.

We are using plastic scintillator which is made by dissolving organic scintillator in a solvent containing styrene monomer, which is then polymerized to form solid plastic. These scintillator made by above technique in general covered with black sheets so that surrounding stray light will not interfere the experiment.

The typical dimension of scintillator (we are using) is about 24 X 24 X 14.5 cm^3. The efficiency of scintillator is the fraction of all incident particles that converted into visible light.

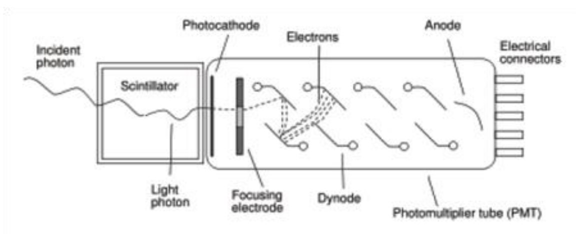

Fig 3. PMT coupled with scintillator

PHOTO MULTIFPLIER TUBE:

PMT consists of photocathode, several dynodes and anode enclosed in an evacuated glass tube. When the photons from the scintillator incident on photocathode of PMT e^- multiplier consists of number of electrodes called dynodes. Each dynode is held at a greater positive voltage than the previous one.

The e^- produced by photon from scintillator 1st move towards the 1st dynode, get accelerator by the electric field and will arrive at 2nd dynode with greater energy and so on. Mean while the number of e^-s also increased at each dynode by secondary emission. Finally the e^- will reach the anode the change get accumulated and results in sharp pulse which indicates the arrival of photon at the photocathode.

The sensitivity of photocathode is given by a ratio called Quantum Efficiency as,

QE = (no. of photoelectrons emitted / no. of incident photons on photocathode)

Though QE have to be 100% in ideal case, practically it is only 20-30%

Efficiency of dynode is given as, another ratio called overall multiplication factor(δ)

δ = (no. of secondary e^- emitted / no. of primary incident electron)

The type of PMT we use is 9807B whose tube's diameter is 1" with a 21 pin base.

WORKING PRINCIPLE:

The time difference between pulse given by muon when it passes scintillator and that by e^- (due to muon decay) gives the lifetime of muon.

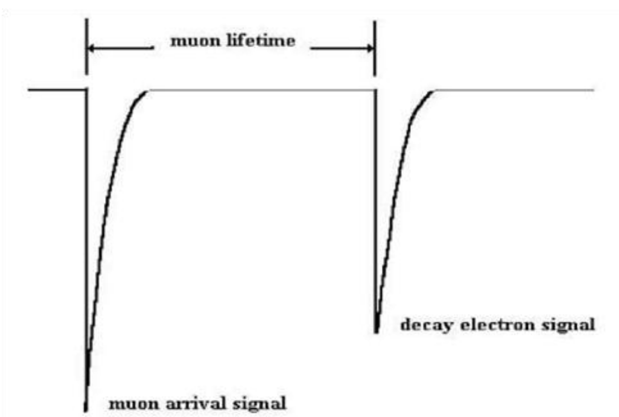

Fig 4. Pulses gives muon lifetime

MUON ELECTRONIC CIRCUIT:

The electronic circuit of muon life time measurement consists of the following components:

LM360 (8 PINS)	: Comparator
74LS74(14 PINS)	: D-Flipflop
74LS161(16 PINS)	: Counter
74LS541 (20 PINS)	: Buffer
74LS11(14 PINS)	: AND Gate
74LSLS04(3 PINS)	: NOT Gate
7805 (3 PINS)	: Positive voltage regulator
7905 (3 PINS)	: Negative voltage regulator
LM317	: Positive voltage regulator
DB103(4 PINS)	: Bridge rectifier

A constant threshold voltage is supplied to non-inverting terminal of the comparator. The negative pulse from the PMT is applied at inverting terminal of the comparator. When this pulse exceeds the threshold voltage results positive pulse in the o/p of comparator.

This positive pulse is given as clock to 1^{st} FF which makes Q o/p high and Q' o/p as low (as it is complementary o/p). Thus as Q o/p is connected ENT of the lower counter it starts counting at the rate of 10MHz as soon as Q is high. When the 4-bit counter reaches its maximum counting, its RC0 becomes high which is feed to ENT of the upper counter and the upper counter starts counting.

Now let us see what will occur in this circuit if the muon decay into e^{-} and if it does not decay.

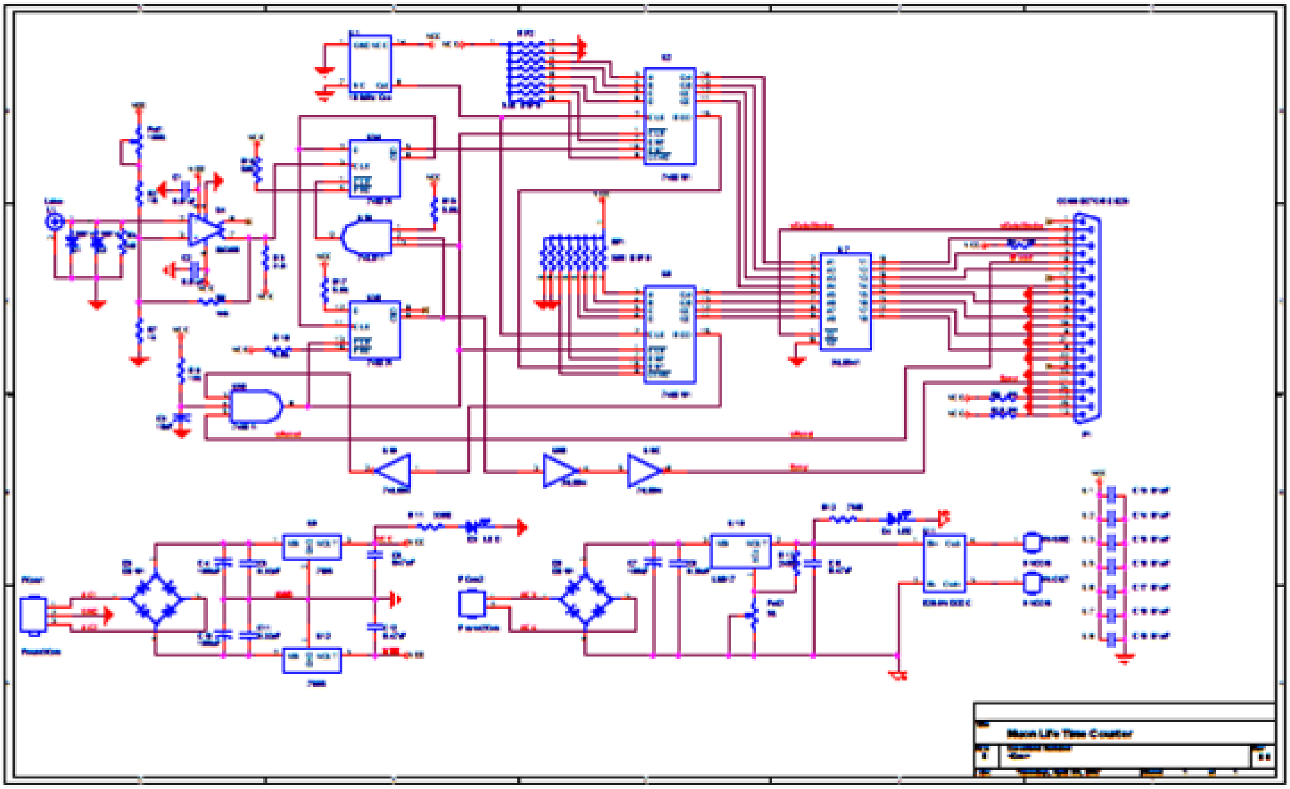

Fig 5. Electrical circuit

If the muon decays into e^-, the clock of 1st FF will obtain a pulse as D is low now (since Q' is low which is feed to D) the o/p Q will be low which will stop the counter. Now Q' of 1st FF is high makes c/k of 2nd FF high which in turn makes Q' of 2nd FF as low and the signal is sent to parallel port through BUSY PIN. After PC receives signal, it pulls DATA_STROBE low to enable data buffer. Thus now data buffer will pass the counts from counter to PC.

Once the PC read the data, DATA_STRODE is again taken high and reset line is pulled low for a µs. Then this resets will clear FFs and counters and makes the circuit ready for the next pulse. If the muon does not decay, the upper counter will reach its maximum count of 255 bits (25.5µs) is reached which makes RC0 high, which is inverted and fed to NAND gate which in turn clears FF and hence the counter. Now it is ready for the next signal.

DATA ANALYSIS:

After obtaining the computerized data, which consists of number of events and the time difference between arrival of muon and decay of muon, they binned and then fitted.

Inorder to avoid background events due to stray light, arrival of another muon before a muon decay the curve obtained has been corrected. This is done by considering the background as constant and the function consider is given by,

$$N(t) = N(0) * \exp(- t / \tau) + b$$

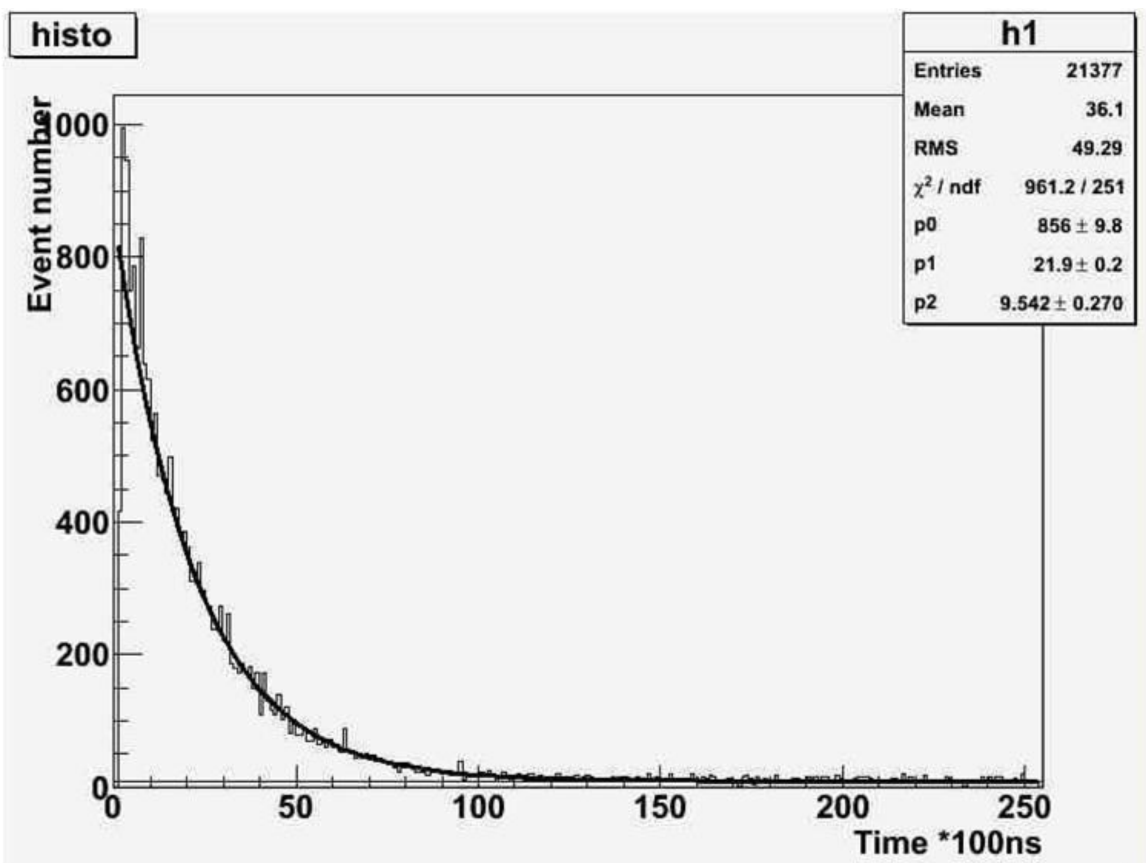

Fig 6. Event no. vs decay time with exponential fitting

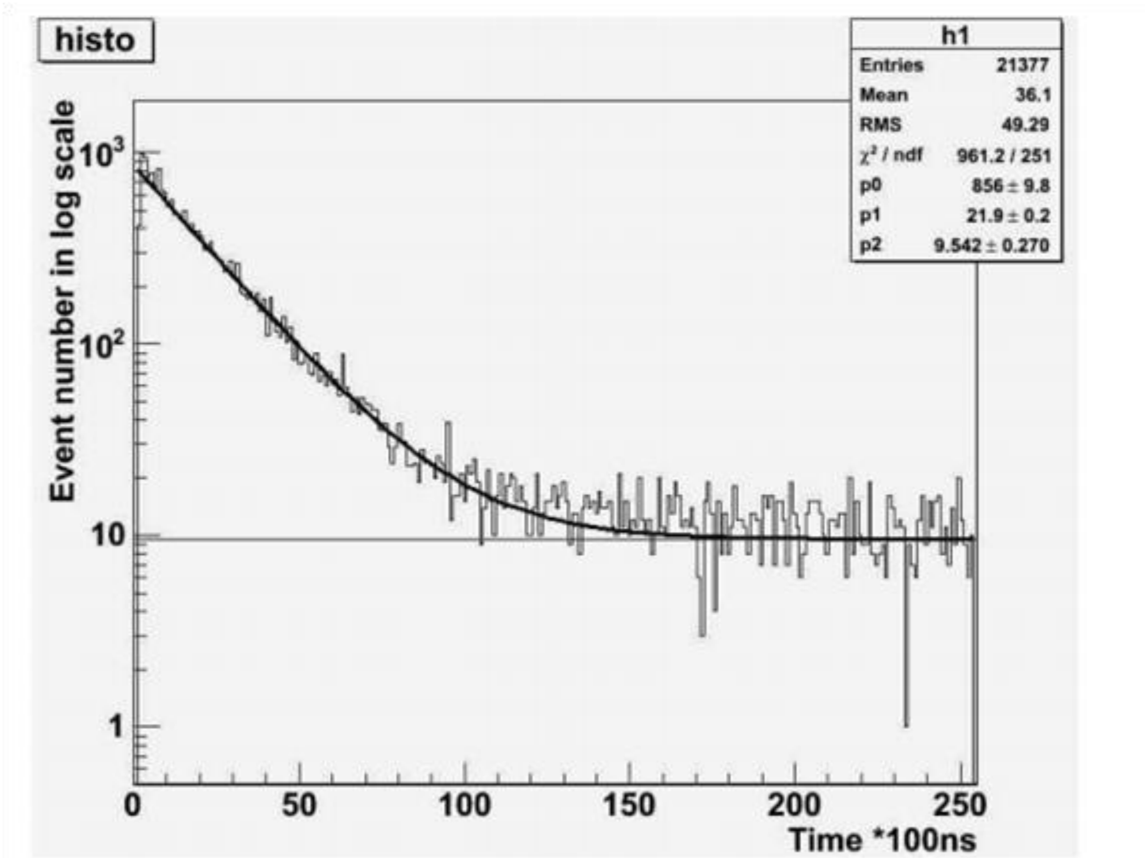

Fig 7. In logarithmic scale

Thus by using root we obtain the above plots, where the horizontal straight line indicates the background effect.

The important parameters we obtain using these plots are given as,

$$\boldsymbol{\tau} = (2.19 \pm 0.2)\mu s$$

$$\boldsymbol{N_0} = (855.9 \pm 9.8)$$

$$\boldsymbol{b} = (9.54 \pm 0.27).$$

CALCULATION OF FERMI COUPLING CONSTANT:

We can cross check the measured lifetime (**τ**) by calculating Fermi coupling constant G_F of the weak interaction using

$$\boldsymbol{\tau = 192\,\pi^3 / G_F^2 m_\mu^5}$$

where,

τ – meanlife time, $\mathbf{G_F}$ – Fermi coupling constant, $\mathbf{m_\mu}$ - mass of muon.

Thus by using above formula the obtained G_F value is **1.16533 X 10^{-5} GeV^{-2}**, where we are taking m_μ as 105MeV.

References:

1) "*Introduction to Elementary particle physics" by D.J. Griffiths*
2) *"Muon Physics" by T.E.Coan and J.Ye*
3) *"Muon Life time Measurement" by Dr. Franz Muheim*
4) *"The CRESCERE Muon's Lifetime Experiment" by J.Santos, J.Augusto, A. Gomes, L.Gurriana, N.Lourenco, A.Maio, C.Marques, J.Silva*
5) *"Measurement of the muon Lifetime" in Advanced Physics Laboratory Experiment 4, January 2005.*