MESUREMENT OF MUON LIFETIME

USING COSMIC MUON STOPPED IN PLASTIC SCINTILLATOR DETECTOR.

ASMITA REDIJ

SCIENTIFIC OFFICER.

AS A PART OF EXPERIMENTAL PHYSICS COURSE (I).

CONDUCTED FOR INO TRAINING SCHOOL .

UNDER THE GUIDANCE OF

DR. SATYANARAYANA BHEESETTE &

MR.   L.V. REDDY

Abstract :

Aim of this experiment is to measure lifetime of muon using cosmic ray muon. Muon produced on the interaction of cosmic ray particle with atmospheric nucleus travel through atmosphere to reaches the surface of earth. Muons which pass through the scintillation detector interact with matter in the detector, to loss all its energy by ionization and excitation of molecules in it and decay off giving two consecutive gamma rays signal, first by the slowed down muon and second on its subsequent decays. Time difference (t) between these two signals follow exponential distribution given by function $N = N_o \exp(-t/\tau)$, where lifetime τ is defined as time in which No/e particle decay. Data taken for 96hrs was analyzed to get lifetime of of muon 2.17 +0.02 microseconds.

Content

INTRODUCTION

Muon

Muon was first discovered in 1936 while studing cosmic radiation, by Carl D. Anderson and Seth Neddermeyer at Caltech. Later in 1937 J. C. Street and E. C. Stevenson's cloud chamber experiment confirmed the existence of muon. As electron it is a spin half negatively charged particle with mass 200 time that of electron. It was finally resolved to be a fundamental particle belonging to the family of leptons as per the standard model of particles.

In this experiment we intent to measure the lifetime of cosmic ray muon stopped

Source of muon

The only natural source producing muon is the cosmic ray. Neither any radioactive decay nor nuclear fussion is capable of producing such as larger rest mass energy required for muon production. Cosmic ray particle reaching upper layer of the Earth's atmosphere interact with atmospheric nuclei to produce pion. These pions decay to muons, which then penetrates through the atmosphere.

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

Muon because of it larger mass is not sharply accelerated and so do not loss by brehmstrlung as electron. Hence muon can penetrate over long distance. Muons lose energy at a constant rate of about 2 MeV per g/cm^2. Taking the vertical depth of the atmosphere to be about 1000 g/cm^2, muons will lose about 2 GeV to ionization before reaching the ground. The mean energy of muons at sea level is still 4 GeV. Therefore the mean energy at creation is probably about 6 GeV. Average flux of muon at sea level is about 1 muon /sq cm/ minute.

Muon Decay

Muon is an unstable particle and decays via weak interaction. Both muon and antimuon dominantly decay through

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

Muon(μ^-) also disappear due to its capture by a nucleus by weak interation. The probability of this capture is proportional to Z^4. Where μ^+ is strongly repelled by the nucleus, so they only undergo spontaneous decay. Though the lifetime of free muon and free antimuon is same, for muon the measured mean lifetime in matter is lesser and becomes shorter with increasing Z of the material.

The number of muon that survive at time t, N(t) given by

$$N(t) = N_0 \exp(-t/\tau)$$

Where, N_0 is number of muon at time t =0

τ is mean lifetime of muon.

Thus the distribution of decay of unstable particle falls of exponentially with time. The mean lifetime of the particle is the time required to reduce the initial number of particles by a factor of 1/e as measured in rest frame. Mean lifetime of free muon is 2.19703 +/- 0.0004 microsecond. This exponential distribution of muon decay time makes it makes no difference where we start our t=0 from.

Test for Relativistic Time Dilation

Range of muon traversing with the speed of light, with the mean lifetime of 2.197 micro-second would be only 660 m. However, at relativistic speeds, the lifetime of the muon, as perceived in lab frame is much longer. Given a minimal 2 GeV muon (rest mass = 0.1 GeV):

Kinetic energy is given by

$$K = \gamma mc^2 - mc^2$$

Where, $\gamma = (\sqrt{(1 - u^2 / c^2)})$, u = relative velocity.

m is the rest mass energy.

$$\gamma = (K + mc^2)/mc^2 = (2+0.1)\text{GeV}/0.1\text{GeV} = 21$$

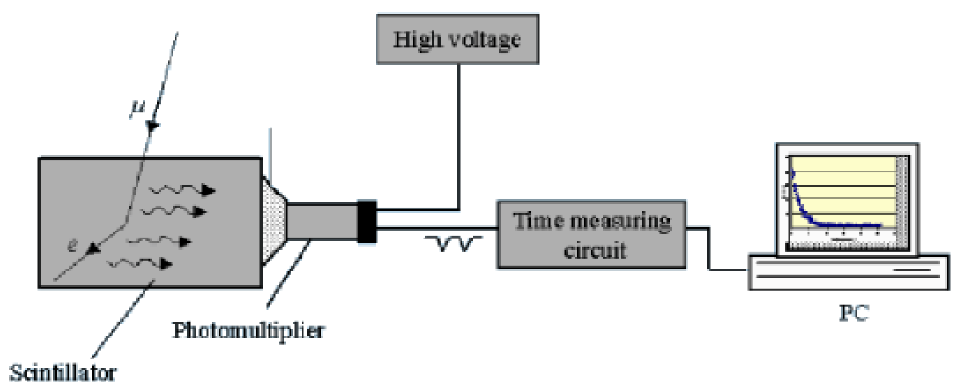
Using time dilation: $\Delta t = 21 * 2.197 * 10^{-6}$ s $= 4.6 * 10^{-5}$ s

Range x=ct $x = (3.0 * 10^{8}$ m/s$) * (4.6 * 10^{-5}$ s$) = 13860$m

Detection of muon at sea level give evidence of time dilation predicted by special relativity.

EXPERIMENTAL SETUP

The Setup consists of Bicron-404 plastic scintillator of dimension 24cm x24cm x 14.5cm, wrapped with ‘Tyvec’ paper with high reflectivity and for refocusing of scintillation produced and then with ‘Tedlar’ paper to prevent ambient light from entering the detector. Scintillator slows down and stops the muon passing through it.



Block Diagram of Experimental setup

A Photomultiplier tube to pick up scintillation emitted when muon interacts with plastic scintillator and to convert this light signal into electric signal. A time measuring circuit to measure the time interval between two consecutive trigger.

Plastic Scintillator

Because of its good sensitivity, linear response to energy fast response and pulse shape discrimination, scintillation detector is the most widely used particle detector today.

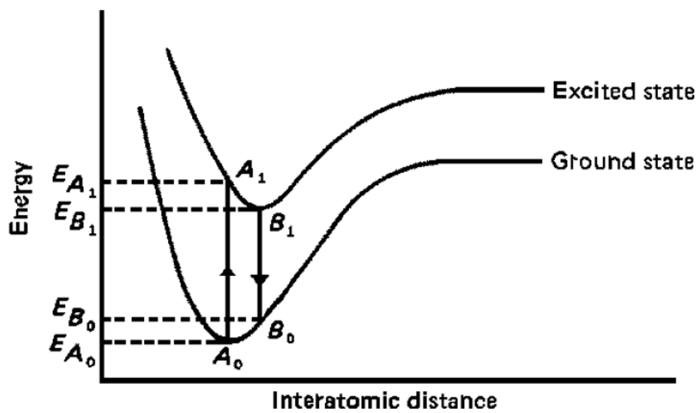
A good scintillation detector must also have:

1) High efficiency for conversion of excitation energy to fluorescent radiation.
2) Transparency to its fluorescent radiation so as to allow transmission of the light.
3) Emission in the spectral range consistent with the spectral response of the existing photomultipliers.

4) Short decay constant τ.

Plastic scintillators are solutions of organic scintillator with solid pastic solvent. Organic scintillators are aromatic hadrocarbon compound containing linked or condensed benzene-ring structures. When a charged particle passes through them the molecules in it are excited which de-excite emitting a photon.

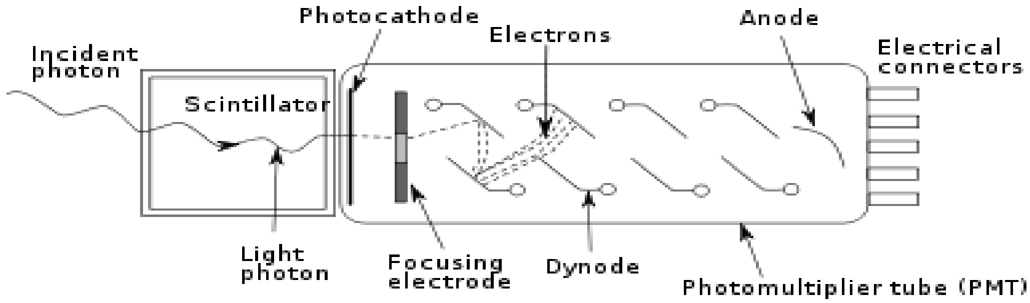
We used plastic scintillator from Bicron BC-404, Premim plastic scintillator, with Polyvinyltoluene base, Density 1.032 g/cc and refractive index 1.58. In Fluorescence the initial excitation take place via the adsorption of photon and de-excitation by emission of a longer wavelength photon. Fluors are used as 'waveshifters' to shift scintillation light to a longer wavelength photon.



Scintillation mechanism

Photo Multiplier tube

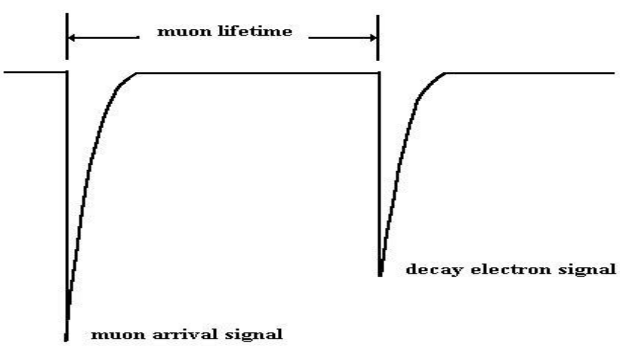
Photomultiplier tube is used to convert the light output from the scintillator to an electric signal. We used 21 pin 2" diameter PMT semitransparent bialkali photo-cathode. The biasing voltage required of about 1.8 kV. It is generated by means of a high voltage dc to dc converter (E20 – HVDCDC). The circuit is as shown in Figure Its (PMT's) biasing circuit receives AC input from a common step-down transformer which is connected to the general power supply (230 V, 50 Hz AC). The transformer gives input to both time measuring circuit and PMT biasing circuit.



Schematic of PMT

Detection Mechanism

For the measurement of muon life time we need to record the muon that enter the scintillator, slow down to stop and decay in the scintillator. As the muon slows down, losing it energy via ionization and by atomic excitation of solvent molecules. The excited scintillator molecules emit photon during de-excitation. These photons are seen by PMT and converted into an amplified electronic pulse. If this pulse amplitude is above threshold, a start trigger is sent to Timing circuit. Meanwhile the stopped muon after a short while decays into electron, neutrino and antineutrino. Neutrino and antineutrino take away small fraction of energy but escape through the detector unidentified. Electron takes away rest of the energy. Electron mass being much smaller than muon mass electrons emitter with sufficiently higher kinetic energy to produce scintillation. This second burst of scintillation produced is seen by the PMT and second trigger pulse is sent to the timing clock. The timing counter is stopped on receiving the second pulse. Timing between these consecutive signal is recorded as decay time of the detected muon.



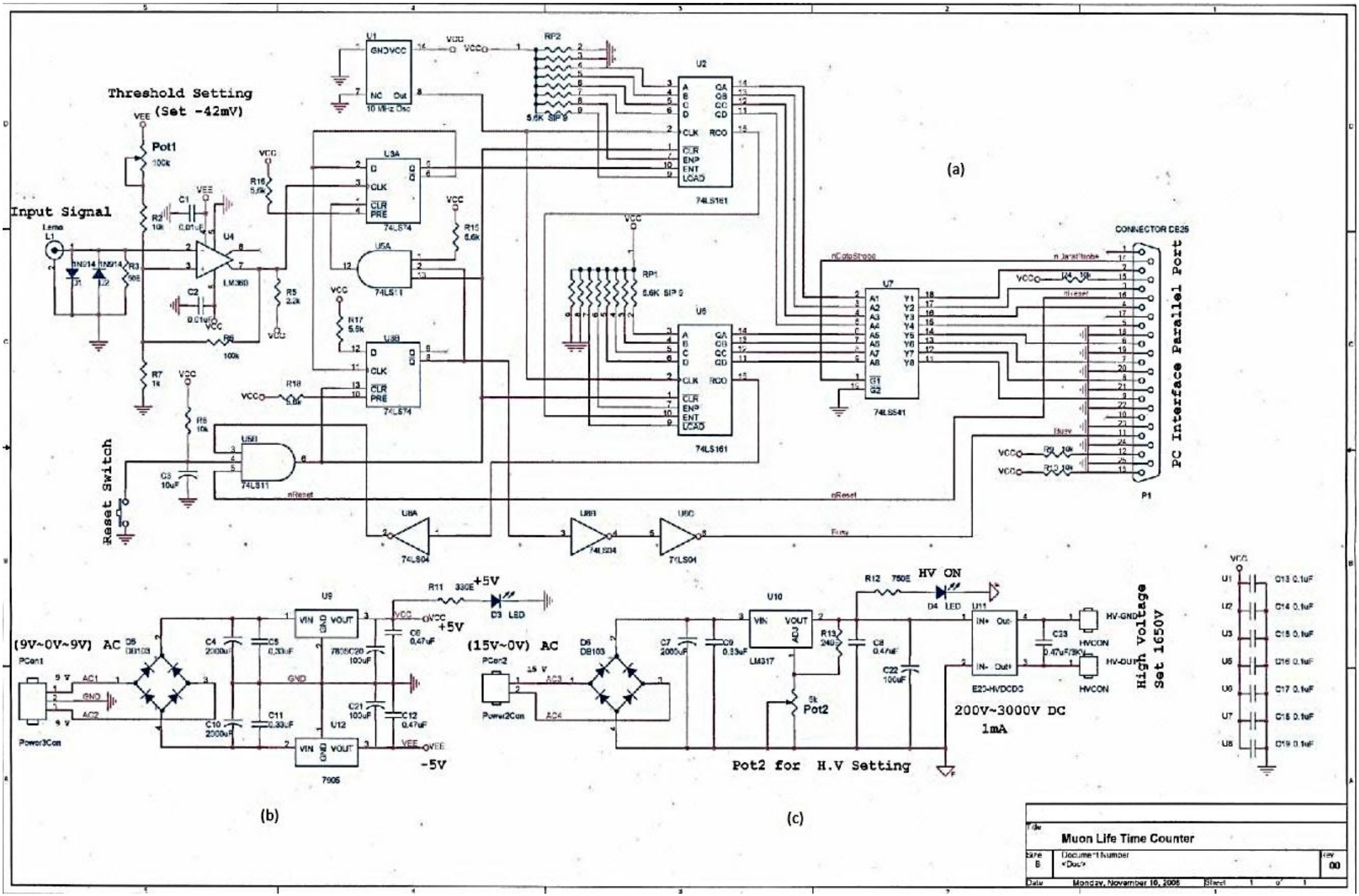
Scintillation Signature of stopped muon 1

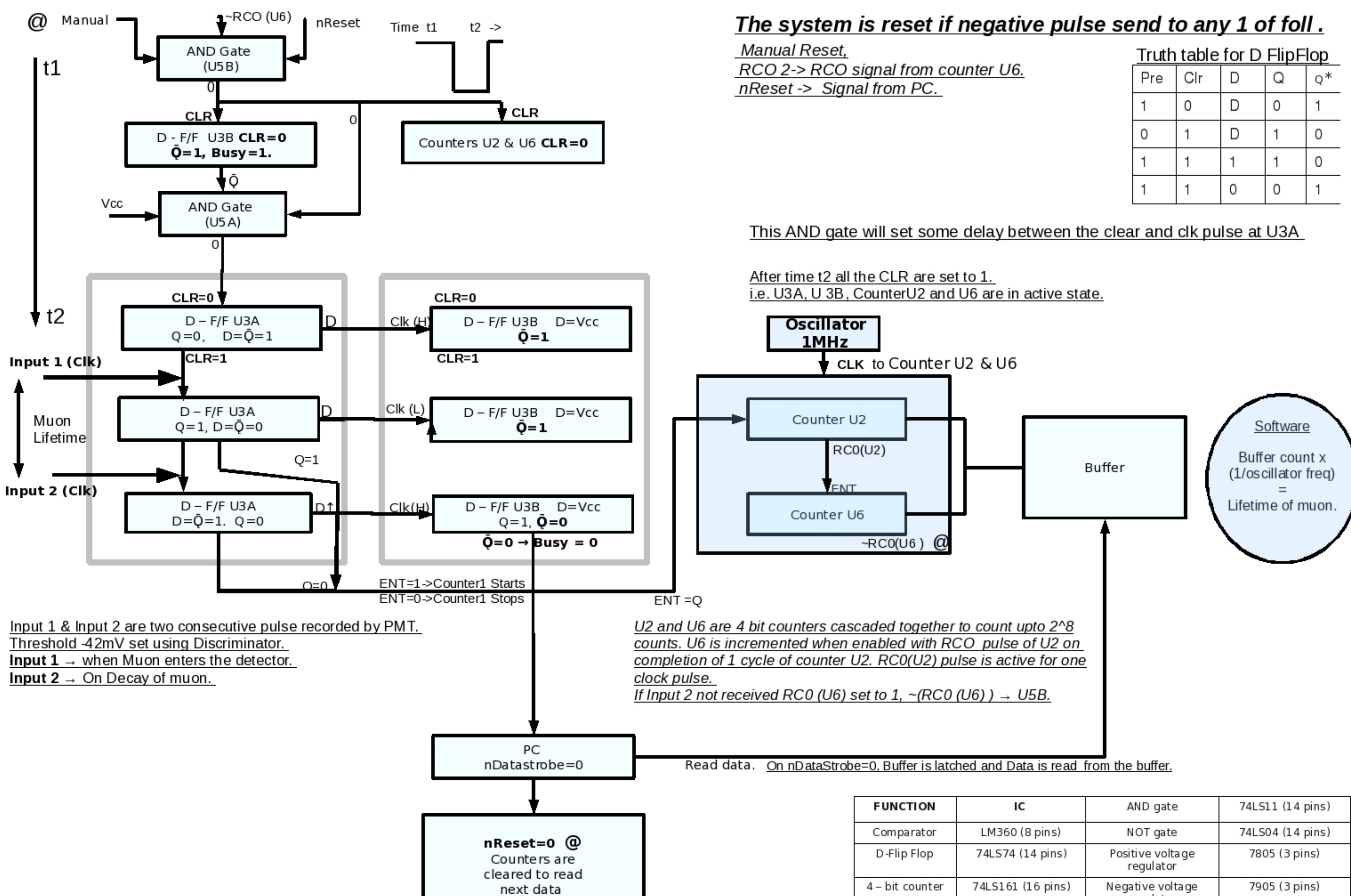
Time measuring circuit

Time measuring circuit is an electronic backend of the experimental setup interfaced with PC meant for measuring the time interval between the two consecutive trigger pulse marking the entry and decay of muons. It is interfaced with PC to so to record the data. On receiving the first trigger from the PMT the time measuring circuit, which ready to accept the trigger starts the counter. Counting is done by two cascaded 4 bit counter driven by clock of 10 MHz oscillator. On receiving the second trigger for PMT the circuit stops counting. If the second trigger is not received in 255 micro seconds. The circuit is reset and ready to recieve next muon trigger.

Following two pages show

1) Timing circuit diagram.
2) Flow chart to explain the working of Timing circuit.


Threshold Setting
(Set -42mV)
Pot1
Input Signal
Reset Switch
(a)
PC Interface Parallel Port
CONNECTOR DE25
74LS161
74LS74
74LS11
74LS04
74LS541
10 MHz Osc
LM360
(9V~0V~9V) AC
(15V~0V) AC
+5V
-5V
HV ON
High Voltage
Set 1650V
200V~3000V DC
1mA
Pot2 for H.V Setting
LM317
7805C220
7905
E23-HVDCDC
(b)
(c)
Muon Life Time Counter
Monday, November 10, 2008



The system is reset if negative pulse send to any 1 of foll .

Manual Reset,
RCO 2-> RCO signal from counter U6.
nReset -> Signal from PC.

Truth table for D FlipFlop

Pre	Clr	D	Q	Q*
1	0	D	0	1
0	1	D	1	0
1	1	1	1	0
1	1	0	0	1

This AND gate will set some delay between the clear and clk pulse at U3A

After time t2 all the CLR are set to 1.
i.e. U3A, U 3B, CounterU2 and U6 are in active state.

Input 1 & Input 2 are two consecutive pulse recorded by PMT.
Threshold -42mV set using Discriminator.
Input 1 → when Muon enters the detector.
Input 2 → On Decay of muon.

U2 and U6 are 4 bit counters cascaded together to count upto 2^8 counts. U6 is incremented when enabled with RCO pulse of U2 on completion of 1 cycle of counter U2. RC0(U2) pulse is active for one clock pulse.
If Input 2 not received RC0 (U6) set to 1, ~(RC0 (U6)) → U5B.

On nDataStrobe=0, Buffer is latched and Data is read from the buffer.

FUNCTION	IC	AND gate	74LS11 (14 pins)
Comparator	LM360 (8 pins)	NOT gate	74LS04 (14 pins)
D-Flip Flop	74LS74 (14 pins)	Positive voltage regulator	7805 (3 pins)
4 – bit counter	74LS161 (16 pins)	Negative voltage regulator	7905 (3 pins)
Buffer	74LS541 (20 pins)	Bridge rectifier	DB103 (4 pins)

DATA ANALYSIS

Measurement of muon lifetime

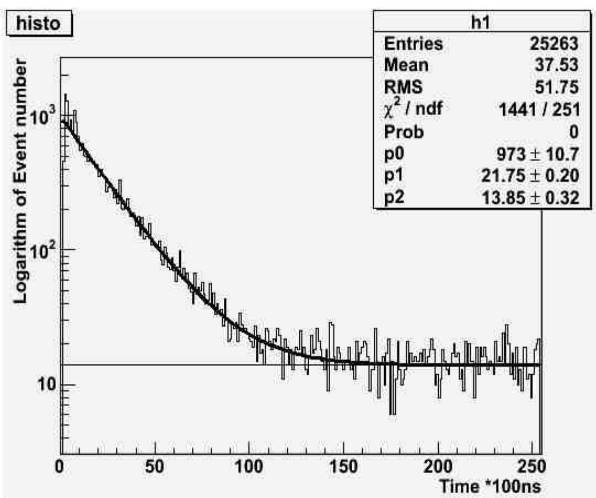
The experiment was run for 96hrs. The muon decay time for every stopped event was recorded. The muon decay time obtained for all the events were binned. The histogram was then fitted with the function

$$N(t) = N_0 \exp(-t/\tau) + b \quad \text{where } \tau \text{ is the lifetime of muon}$$

b correspond to background

Background

The detector responds to all type of particle which can produce scintillation in the detector. There is no way to distinguish between the through going and stopped muons which decay. So the two consecutive muons can also leave a record. But these time intervals will be uncorrelated and random. Background can be eliminated by selecting appropriate time interval and background level can be identified by looking at large time interval where less muon events are expected.



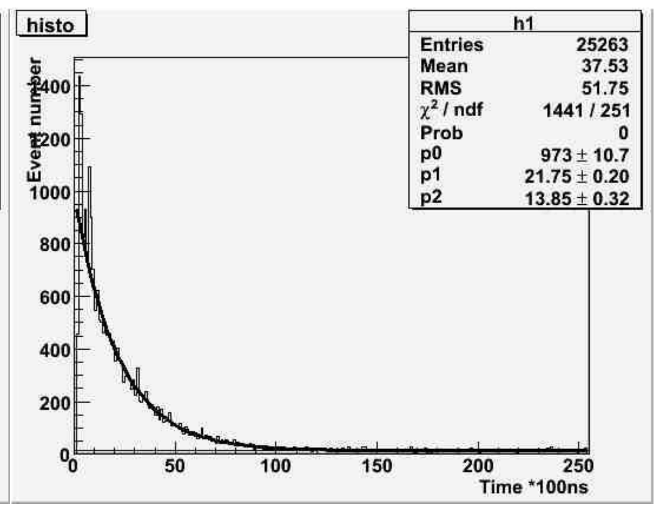


Figure 1 Muon Decay time histogram

Figure 2 Muon Decay time histogram(semi log)

Value of the fit parameter,

N_0 = 973 +/- 10.7

τ = 2.175 +/-0.020s

b = 13.85 +/- 0.32
The mean lifetime of muon is observed to be 2.175 +/-0.020s

Fermi constant

Fermi coupling constant G_F, gives the strength of Fermi's interaction. The most precise experimental determination of the Fermi constant comes fro measurements of the muon lifetime, which is inversely proportional to the square of G_F given as

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

$G_F = 1.1696 \times 10^{-5}\ GeV^{-2}$

CONCLUSION

The mean lifetime of the muon is was measured to be 2.175 micro second. Measured muon lifetime has an error of 1% from the free muon lifetime of 2.197 μs. This difference is due to the nuclear capture of muon.

APPENDIX

Datasheet 2" 9807B series

Datasheet Bicron BC-404 Premium Plastic Scintillator

51 mm (2") photomultiplier
9807B series data sheet

ET Enterprises electron tubes

1 description

The 9807B is a 51 mm (2") diameter, end window photomultiplier with blue-green sensitive bialkali photocathode and 12 high gain, high stability, BeCu dynodes of linear focused design for good linearity and timing. It is a plug-in replacement for the RCA 8575 and has a 21 pin base.

2 applications

- high energy physics studies

3 features

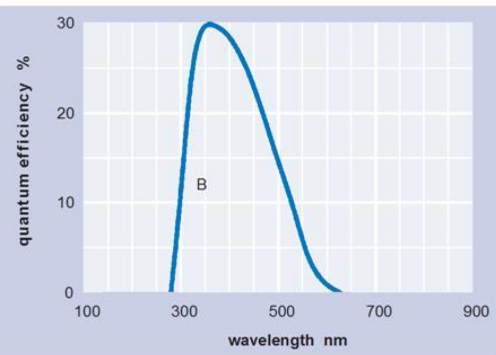
- good SER
- high pulsed linearity

4 window characteristics

	9807B borosilicate
spectral range** (nm)	290 - 630
refractive index (n_d)	1.49
K (ppm)	300
Th (ppb)	250
U (ppb)	100

*note that the sidewall of the envelope contains graded seals of high K content
** wavelength range over which quantum efficiency exceeds 1 % of peak

5 typical spectral response curves

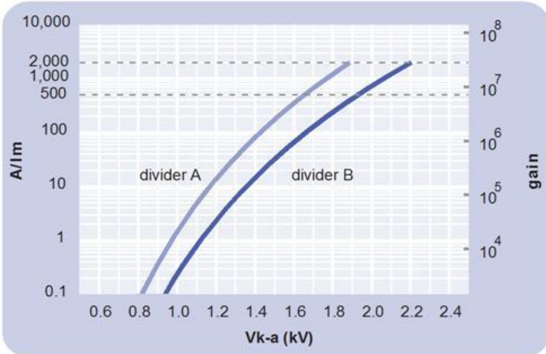


6 characteristics

	unit	min	typ	max
photocathode: bialkali				
active diameter	mm		46	
quantum efficiency at peak	%		30	
luminous sensitivity	µA/lm		70	
with CB filter		8	11.5	
with CR filter			2	
dynodes: 12LFBeCu				
anode sensitivity in divider A:				
nominal anode sensitivity	A/lm		500	
max. rated anode sensitivity	A/lm		2000	
overall V for nominal A/lm	V		1650	2300
overall V for max. rated A/lm	V		1900	
gain at nominal A/lm	x 10^6		7	
dark current at 20 ºC:				
dc at nominal A/lm	nA		3	20
dc at max. rated A/lm	nA		20	
dark count rate	s^{-1}		300	
pulsed linearity (-5% deviation):				
divider A	mA		50	
divider B	mA		150	
pulse height resolution:				
single electron peak to valley	ratio		2	
rate effect (I_a for $\Delta g/g$=1%):	µA		1	
magnetic field sensitivity:				
the field for which the output decreases by 50 %				
most sensitive direction	T x 10^{-4}		1	
temperature coefficient:	% ºC^{-1}		± 0.5	
timing:				
single electron rise time	ns		2	
single electron fwhm	ns		3	
single electron jitter (fwhm)	ns		2.2	
multi electron rise time	ns		3.2	
multi electron fwhm	ns		4.5	
transit time	ns		41	
weight:	g		150	
maximum ratings:				
anode current	µA			100
cathode current	nA			100
gain	x 10^6			30
sensitivity	A/lm			2000
temperature	°C	-30		60
V (k-a)(1)	V			2800
V (k-d1)	V			500
V (d-d)(2)	V			450
ambient pressure (absolute)	kPa			202

(1) subject to not exceeding max. rated sensitivity (2) subject to not exceeding max rated V(k-a)

7 typical voltage gain characteristics



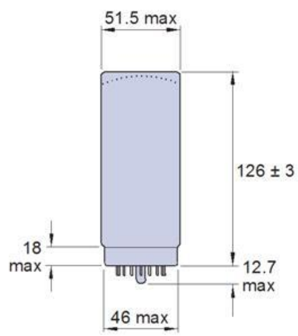
8 voltage divider distribution

	k	d_1	d_2	d_9	d_{10}	d_{11}	d_{12}	a	
A	300V	R	....	R	R	R	R	R	**Standard**
B	300V	R	....	R	1.25R	1.5R	2R	3R	**High Pulsed Linearity**

note: focus connected to d_1.

Characteristics contained in this data sheet refer to divider A unless stated otherwise.

9 external dimensions mm



10 base configuration (viewed from below)

'ic' indicates an internal connection

note: connect f to d_1

Our range of B21 sockets, available for this series, includes versions with or without a mounting flange, and versions with contacts for mounting directly onto printed circuit boards.

11 ordering information

The 9807B meets the specification given in this data sheet. You may order **variants** by adding a suffix to the type number. You may also order **options** by adding a suffix to the type number. You may order product with **specification options** by discussing your requirements with us. If your selection option is for one-off order, then the product will be referred to as 9807A. For a repeat order, **ET Enterprises** will give the product a two digit suffix after the letter B, for example B21. This identifies your specific requirement.

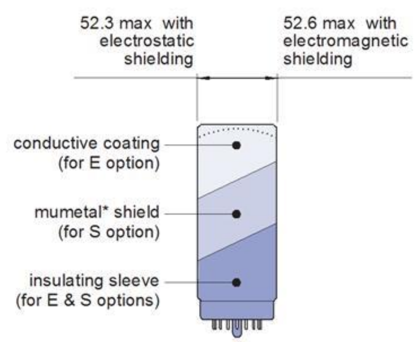
9807 ▢ ▢

options

E electrostatic shielding see drawing below
S electromagnetic shielding see drawing below
M supplied with spectral response calibration

specification options

B as given in data sheet
A single order to selected specification
Bnn repeat order to selected specification



12 voltage dividers

The standard voltage dividers available for these pmts are tabulated below:

	k	d_1	d_2	d_3	d_8	d_9	d_{10}	d_{11}	d_{12}	a
C628A	3R	R	R	....	R	R	R	R	R	
C628B	3R	R	R	....	R	1.25R	1.5R	2R	3R	
C628C	300 V	R	R	....	R	R	R	R	R	
C628D	300 V	R	R	....	R	1.25R	1.5R	2R	3R	

note: focus connected to d_1
R = 330 kΩ
*mumetal is a registered trademark of Magnetic Shield Corporation

ET Enterprises Limited
45 Riverside Way
Uxbridge UB8 2YF
United Kingdom
tel: +44 (0) 1895 200880
fax: +44 (0) 1895 270873
e-mail: sales@et-enterprises.com
web site: www.et-enterprises.com

ADIT Electron Tubes
300 Crane Street
Sweetwater TX 79556 USA
tel: (325) 235 1418
toll free: (800) 521 8382
fax: (325) 235 2872
e-mail: sales@electrontubes.com
web site: www.electrontubes.com

DS_ 9807B Issue 6 (20/09/10)

BC-400/BC-404/BC-408/BC-412/BC-416
Premium Plastic Scintillators

General Description The premium plastic scintillators described in this data sheet include the most economical (BC-416) as well as those with the highest light output.

General Technical Data

Base .... Polyvinyltoluene
Density .... 1.032 g/cc
Refractive Index 1.58
Coefficient of Linear Expansion .... 7.8×10^{-5}, below 67°C
Atomic Ratio, H/C .... ~1.1
Light Output Temperature Dependence .... At +60°C = 95% of that at +20°C; independent of temperature from -60°C to +20°C
Vapor Pressure .... May be used in a vacuum
Solubility .... Soluble in aromatic solvents, chlorine, acetone, etc. Insoluble in water, dilute acids, lower alcohols, silicone fluid, grease and alkalis.

Radiation Detected	Scintillator
< 100 keV X-rays	BC-404
100 keV to 5 MeV gamma rays	BC-408
>5 MeV gamma rays	BC-400 BC-416
Fast neutrons	BC-408 BC-412
Alphas, betas	BC-400 BC-404
Charged particles, cosmic rays, muons, protons, etc.	BC-408 BC-412 BC-416

Properties

	BC-400	BC-404	BC-408	BC-412	BC-416
Light Output, % Anthracene	65	68	64	60	38
Rise Time, ns	0.9	0.7	0.9	1.0	—
Decay Time, ns	2.4	1.8	2.1	3.3	4.0
Pulse Width, FWHM, ns	2.7	2.2	~2.5	4.2	5.3
Light Attenuation Length, cm*	160	140	210	210	210
Wavelength of Max. Emission, nm	423	408	425	434	434
No. of H Atoms per cm^3, $(x10^{22})$	5.23	5.21	5.23	5.23	5.25
No. of C Atoms per cm^3, $(x10^{22})$	4.74	4.74	4.74	4.74	4.73
Ratio H:C Atoms	1.103	1.100	1.104	1.104	1.110
No. of Electrons per cm^3, $(x10^{23})$	3.37	3.37	3.37	3.37	3.37
Principal uses/applications	general purpose	fast counting	TOF counters, large area	large area	large area economy

*The typical 1/e attenuation length of a 1 x 20 x 200 cm cast sheet with edges polished as measured with a bialkali photomultiplier tube coupled to one end

(continued over)

BICRON®
Saint-Gobain Industrial Ceramics, Inc.

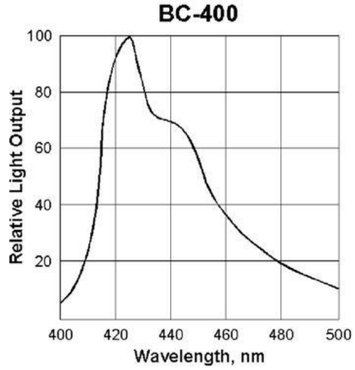
BICRON • 12345 Kinsman Road • Newbury, Ohio 44065 USA
Phone: (440) 564-2251 • Fax: (440) 564-8047 • Internet: http://www.bicron.com
Bicron FaxBack Information Access System: (800) 892-8708
European Office • P.O. Box 3093, 3760 DB Soest, The Netherlands
Phone: (31) 35 60 29 700 • Fax: (31) 35 60 29 214
Nippon Bicron • 8F Shinyokohama Station Building, 2-6-13 Shinyokohama
Kohoku-ku, Yokohama 222 Japan • Phone: (81) 45.474.5786 • Fax: (81) 45.474.5787

BC-400/BC-404/BC-408/BC-412/BC-416
Premium Plastic Scintillators

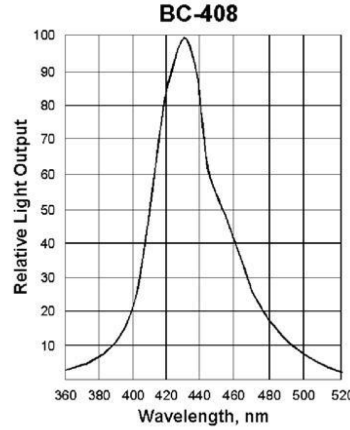
(continued from first page)

Emission Spectra

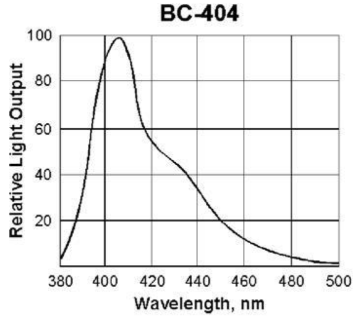
BC-400



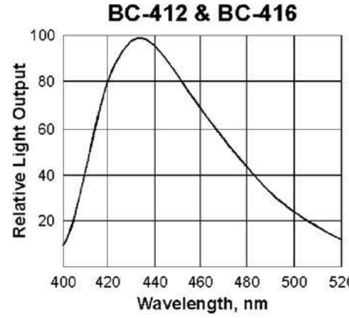
BC-408



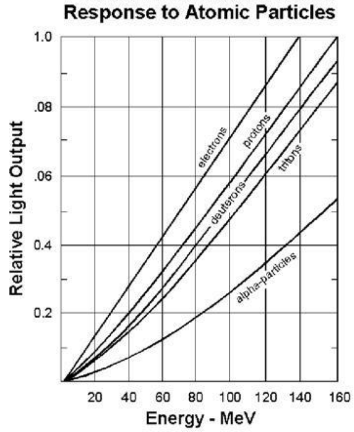
BC-404



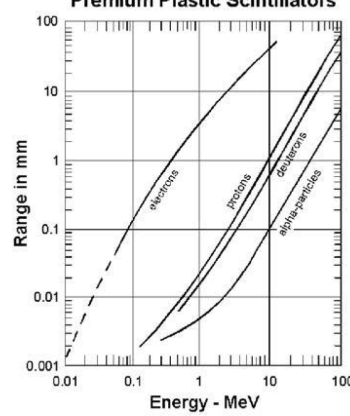
BC-412 & BC-416



Premium Plastic Scintillators Response to Atomic Particles



Range of Atomic Parlicles in Premium Plastic Scintillators



3/4/98

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