Muon Physics Prelab

Sunday, May 12, 2019 12:21 PM

Partner: Casteneda Angle, Moshirfatemi Nastazia

muon: basic particle, unsteable heavy charge, denote as μ

Source of muon:

cosmic rays collide with high energy particles in atomsphere.

$\pi^- \to \mu^- \bar{\nu}_\mu$, $\overset{\mu^-\text{ muon}}{}$ travel through atmosphere and lose kinetic energy

weak and electrodynamics interaction $\begin{cases}\text{neuclei}\\ \text{spontaneous decay}\end{cases}$

procheed: 15km/c 4 GeV 1/cm²·minute sea level

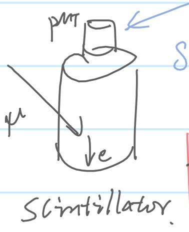
50μsec, 20 more than its rest lifetime time dilation.

muon decay math: exponential.

$$\begin{cases} \frac{-dN}{N_0} = \lambda \exp(-\lambda t)\, dt \\ \Rightarrow D(t) = \lambda \exp(-\lambda t),\ \tau = 1/\lambda \end{cases}$$

detector PMT photomultiplier

scintillator



↓ μ may particles that can excite the scintillator, not only muon

ionization, atomic excitation → emit blue/UV light

PMT: photo multiplier tube., decay: muon → electron neutrino, anti-neutrino

proton ← from any nuclei

$$\underbrace{\mu^- + p \Rightarrow n + \nu_\mu}$$

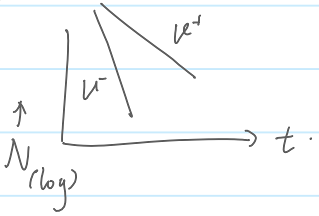
$\boxed{\mu^- \text{ life less than } \mu^+,}$ $\propto Z^4$.

stop → decay

↓ ↓

signal signal

Δt time interval



$$\tau_{obs} = \frac{\tau^- N^- + \tau^+ N^+}{N^+ + N^-}$$

$$\rho = \frac{\tau^+}{\tau^-}\left(\frac{\tau^- - \tau_{obs}}{\tau^+ - \tau_{obs}}\right)$$

Fermi Couple Constant G_F.

μ decay via weak effect

lifetime $\tau = \frac{192\pi^3\hbar}{G_F^2 m^5 c^{10}}$

G_F. (from PDG)

Muon Physics Prelab

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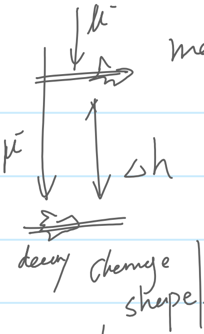
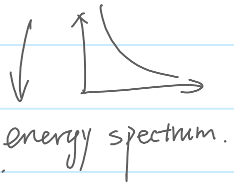


measure muon decay on different heights



a) typical muon energy for the detector size: 160 MeV

b) energy decay rate

$S = \rho x$ thickness g/cm^2.

Bethe-Bloch equation.

⇒ lose energy when travelling. vertically

$$\frac{dE}{dx} = -\frac{4\pi N_e}{mc^2\beta^2} Z^2 \left(\ln \frac{2mc^2\beta^2\gamma^2}{I} - \beta^2 \right) \approx 2\,MeV/(g/cm^2) \cdot \rho_{air}$$

energy loss: $2MeV/g/cm^2$.

here: $\rho_{air} = -\frac{dp}{dh}$, $P = p_0 \exp(h/h_0)$ $\begin{cases} p_0 = 1030\,g/cm^2. \\ h_0 = 8.4\,km. \end{cases}$

energy loss with height

N_e: electron density, Z: atomic number. β: velocity of projectile γ: $1/\sqrt{1-\beta^2}$ I: excitation energy of medium atom

$$\tau' = \int d\tau \quad \text{proper time}$$

$$= \int_H^0 \frac{dh}{c\beta(h)\gamma(h)}$$

$|\ d\tau = dt\sqrt{1-v^2} = dt/\gamma$.

$d\tau = \frac{dh}{c\beta(h)}$

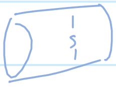
$\frac{dE}{dh} = \rho C_0 \Rightarrow \underline{dE = \rho C_0 dh}$.

$E = m_0c^2\gamma \quad dE = m_0c^2 d\gamma$.

$\Rightarrow dh = \frac{dE}{\rho C_0} = \frac{m_0c^2}{\rho C_0} d\gamma$.

↓

$\tau = \frac{mc}{\rho C_0} \int_{\gamma_1}^{\gamma_2} \frac{d\gamma}{\beta\gamma}$ $\begin{cases} \gamma_2: \text{before entering the detector.} \\ \gamma_1: \text{at height } H \text{ in atomsphere} \end{cases}$ $\gamma_2 \approx 1.5$ $E_1 = E_2 + \Delta E$, $E_2 = 160\,MeV$



average thickness of detector $s \simeq 10 g/cm^2$.

Hence the stoping rate R of muon is different at different height.

$R = \exp(-t'/\tau)$ τ = lifetime

Measurement 1: muon life time.

Measurement 2: flux of muon at sea level.

Lab Note Setup

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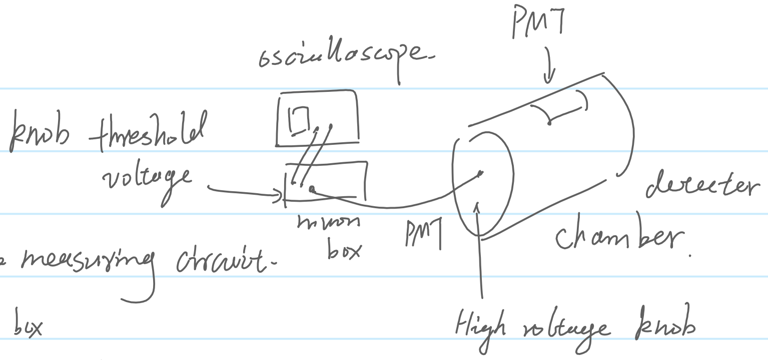
Partner: Moshirfatemi Nastazia



1) check all apparatus.

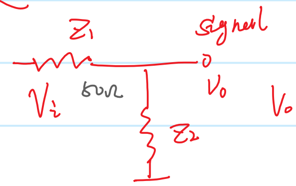
2) connect wires and tables to build the measuring circuit.

- connect PMT from detector to muon box
- connect the serial output to computer to collect data

3) set voltage, HV at 1100-1200 V, threshold at 180-220 mV

4) install terminator on the BNC table, set a 50Ω impedance

terminator is important



$$V_0 = V_i \frac{Z_2}{Z_1+Z_2}$$

$$\simeq V_i \ (Z_2>>Z_1)$$

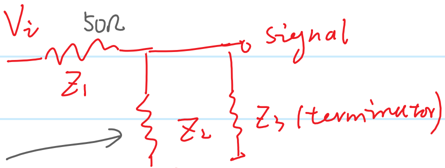
5) open muon_physics software and learn about the interface

6) set the configuration and start recording data.

-config: com3 port, 6uSec, 20 bins

$$\Downarrow$$

7) save data file and upload to google drive.



Some problem:

The muon detected frequency should be 6Hz at proper setting. However, the detected muon number are 0-3 every second. much less than expected

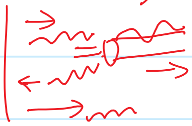
)possible reason: noise from cosmic rays and fluctuation of electronics

osillascop impandence $Z_2 = 1M\Omega$

$$Z' = (Z_2^{-1}+Z_3^{-1}),\ Z_3 = 50\Omega$$

$$Z' \simeq Z_3 \ (Z_2>>Z_3)$$

$$\Rightarrow V_0 = V_i \frac{Z_3}{Z_1+Z_3} \simeq \frac{1}{2} V_i$$



avoid signal oscillation

observation of pulse signal:

1) connect PMT cable to muon box

2) connect AMPLIFIER and DISCRIMINATE output to channel 1 and channel 2 of oscilloscope

3) make sure that CH1 and CH2 input cable are installed with terminator to achieve a 50Ω impedence.

4) set vertical scale at about 50 mV, trigger level -17 mV, trigger type "pulse".

Fitting Method and Error

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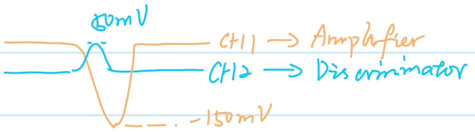
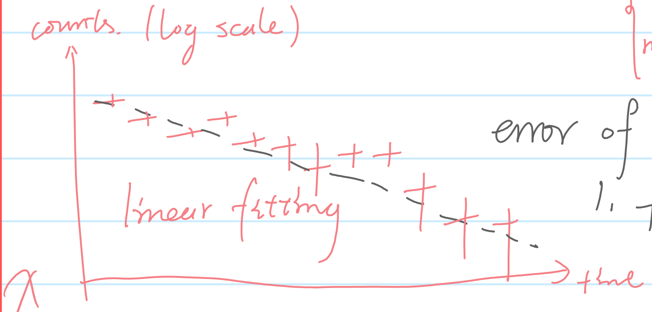


⇒ important

the actual peak value is 150 mV < 180 ~ 220 mV, Smaller

the recommended threshold from lab manual

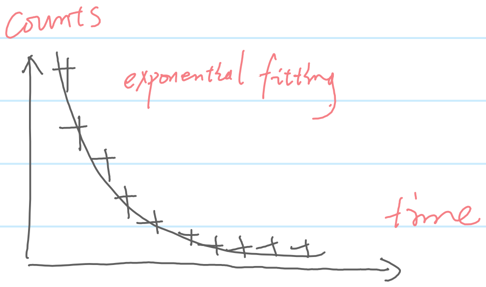
most muon events may be filtered out by the overestimated threshold value



error of histogram of decay time.

1. for each bin in histogram, if the count number in that bin is N. the uncertainty should be $\sqrt{N}$

2. horizontal error should be the standard deviation of the data allocated to the bin, plus the least resolution of measurement (20 nSec) $\left(\delta_{bin}^{2}(t) + \delta_{min\_e}^{2}\right)^{\frac{1}{2}}$



$f(t) = A\exp(-\lambda t) + B$

λ: decay rate B: offset value of noise. (should be 0 in ideal condition)

Spieee avearge

muon life time

$\boxed{T = 1/\lambda}$

3. two ways of fitting
   ① non-linear fitting with exponential decay model
   ② linear fitting on log scale data

The error bar in log scale is not symmetric, it actually looks shorter at larger value

First Data Analysis

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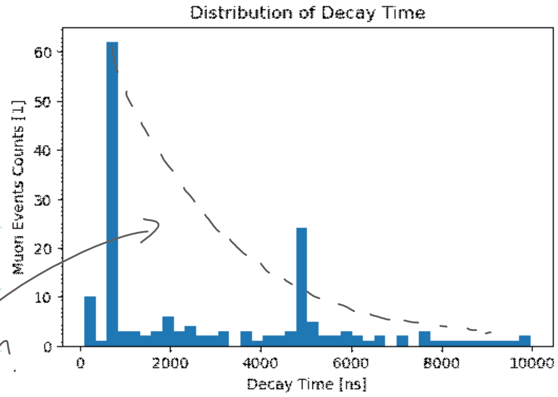


Problems of the first-day data

1) completely not a exponential distribution

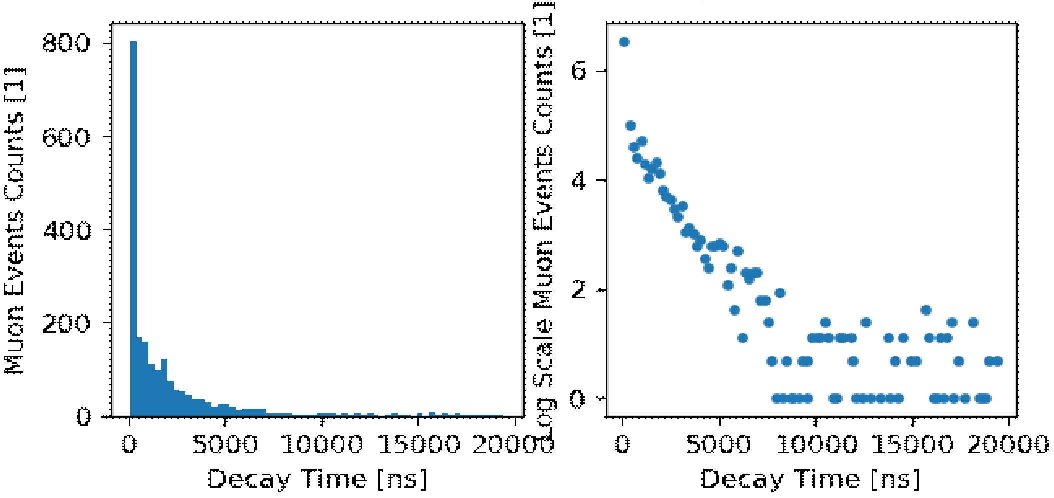
muon events: 171, total events: 47484

① most events are filtered out by the overestimated threshold

the remained data is something like noise or other kind of cosmis particles

solution: resest threshold voltage, set to 110~120mV

restart data record process, turn high voltage to 1200V (max)



A. The figure shows clearly that the impact of noise is more significant at larger time zone, where the effective count of muons is relatively smaller The Long-tail data make no sense because the minimum count of events is 1 and the probability of muon decay is very low. Thus even one noise event will result in high fluctuation

B. The peak at short time zone should be cut off. The anomaly here is caused by possible noise and the limited precision of apparatus. Since the resolution of measurement is 20nS. all the muons decay in 20nS are counted in the same bins And that's why the first bin is much higher than other part.

To correctly fit the exponential decay curve. the long tail and the first bin should be abandoned.

Flux Measurement Setup

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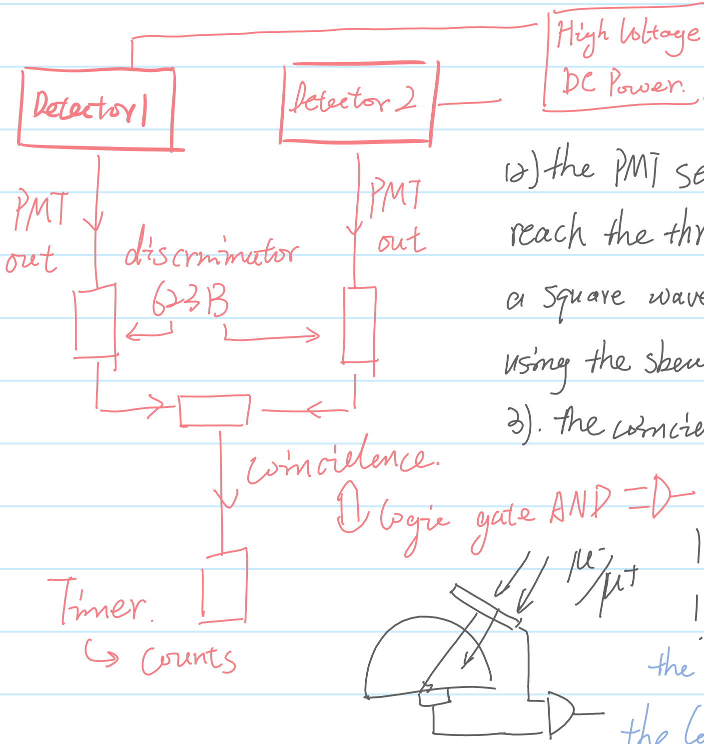
Measure muon flux using two detectors array.



1) the detectors are powered by high voltage DC power

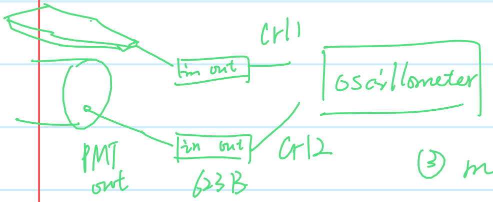
2) the PMT send signal to discriminators. when the signals reach the threshod voltage, the discriminator will send a square wave pulse. ⎍. width can be adjusted using the sbew driver.

3). the coincidence ← controller is actually a logical AND gate, that means only when both two detectors sending a signal above threshold will the final counter receive a counting signal.

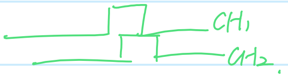
the PMT is triggered when particles excited a blue flash

the logical AND makes sure that only partcles crossing both detector can be counted, which filter out most of the random noise happened in the detectors (consider the probability that two irrelevant random noise happen simultaneously is very small)

- check discrmnator. ① set the threshold at minimum.



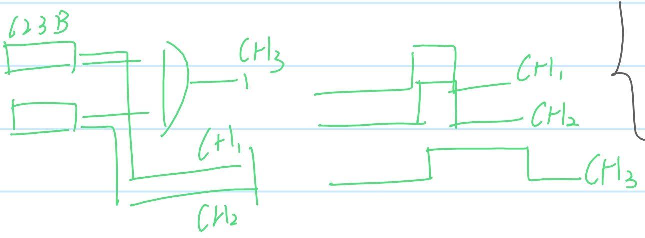
② PMT out → discrminator → oscillometer. check CH1 and CH2. edge trigger. DC coupling.



← result like this

③ measure minimum threshold, ground and the hole in panel, both 29.3mV

- check coincidence



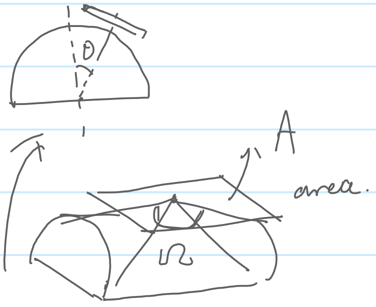
angle. $\theta_1, \theta_2, \theta_3$

count n_1, n_2, n_3.

time t_1, t_2, t_3.

$\boxed{n_i/t_i \cdot A \cdot \Omega}$

flux.

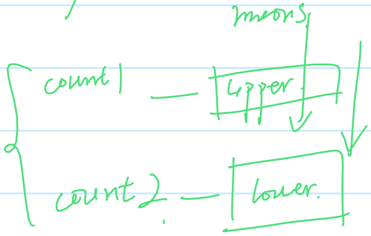


- check counts seperately

count2 > count1

↓

larger. detection area.



Set PMT I and PMT II parallel at zenith angle θ.

change location of the PMT II to to measure flux at different direction

Geometry and Solid Angle

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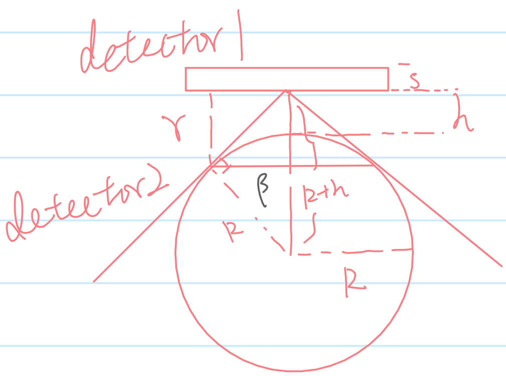
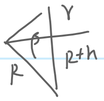
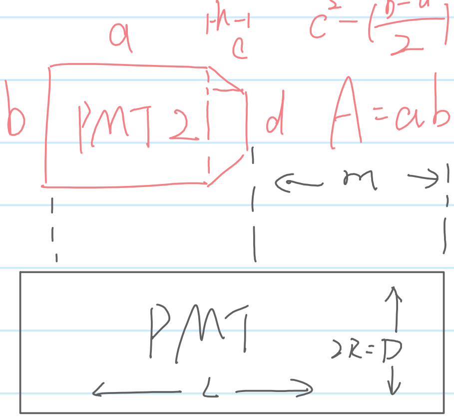
Measurement of muon flux



$$\begin{cases} \gamma = \frac{R}{R+h}\sqrt{(R+h)^2-R^2} \\ \beta = \frac{(R+h)^2-R^2}{R+h} \end{cases}$$

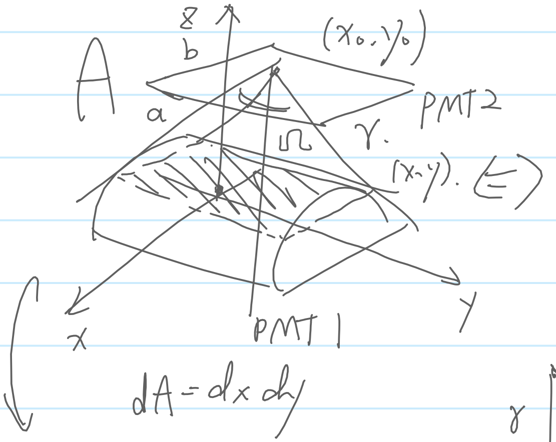


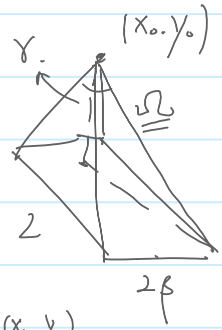


$$c^2-\left(\frac{b-d}{2}\right)^2=h^2$$

$$A=ab+\left(\frac{b+d}{2}\right)\sqrt{c^2-\left(\frac{b-d}{2}\right)^2}$$

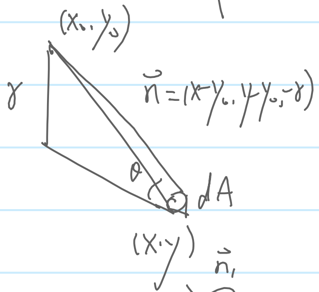
R[cm]	16.5	16.5	16.5	16.4
h[cm]	6.5	6.4	6.4	6.5
s[cm]	2.7	2.8	2.8	3
a[cm]	10.0	10.1	10.0	
b[cm]	10.0	10.2	10.0	
c[cm]	7.5	7.2	7.3	
d[cm]	5.5	5.3	5.0	
L[cm]	36.2	35.9	35.9	36.0
m[cm]	5.0	4.8	4.7	





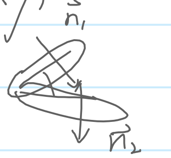
$$dA = dx\,dy$$

$$\gamma := \sqrt{(x-x_0)^2+(y-y_0^2)+\gamma^2}$$



$$dA_{eff} = dA\cos\theta$$

$$\cos\theta = \frac{|\vec{n}_1\cdot\vec{n}_2|}{|n_1||n_2|} = \frac{\gamma}{\sqrt{(x-x_0)^2+(y-y_0)^2+\gamma^2}}$$

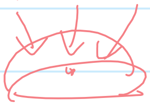


$n_2=(0,0,-1)$

$$\text{thus. } A\cdot\Omega = \int_{-\frac{b}{2}}^{\frac{b}{2}} dx_0 \int_{\frac{L}{2}-m+a}^{\frac{L}{2}-m} dy_0 \int_{-\frac{b}{2}}^{\frac{b}{2}} dy \int_{-\frac{L}{2}}^{\frac{L}{2}} dx \frac{\gamma}{[(x-x_0^2)+(y-y_0)^2+\gamma^2]^{\frac{3}{2}}}$$

$$\boxed{\text{Flux} = \frac{N_\mu}{\Delta t\cdot A\cdot\Omega}}$$

$\text{Flux}\cdot 2\pi \Rightarrow \boxed{s^{-1}cm^{-2}}$ $\quad \underline{\underline{\Omega < 2\pi}}$.



that's why we need use solid angle to correct the result

$\Rightarrow \underline{\underline{s^{-1}\ sr^{-1}\cdot cm^{-2}}}$.

the seperation between two detectors lead to <u>less</u> observed muon events. prefer. a

Data and Some Error Estimation

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	Angle[Deg]	Start Time	End Time	Delta_T	Delta_T	Count
1	90	3:26:13 PM	4:33:05 PM	1:06:52	4012.00	600(err)
2	70	4:36:30 PM	5:01:23 PM	0:24:53	1493.00	281
3	90	5:05:21 PM	5:19:18 PM	0:13:57	837.00	170(con)
4	90	5:19:18 PM	5:35:12 PM	0:15:54	954.00	389
5	60	5:37:20 PM	5:46:55 PM	0:09:35	575.00	104(con)
6	60	5:46:55 PM	5:56:45 PM	0:09:50	590.00	219
7	60	11:40:45 AM	11:57:20 AM	0:16:35	995.00	177
8	50	11:59:55 AM	12:14:15 PM	0:14:20	860.00	104(con)
9	50	12:14:15 PM	12:29:55 PM	0:15:40	940.00	204
10	40	12:32:19 PM	1:01:39 PM	0:29:20	1760.00	140
11	30	1:03:11 PM	1:31:43 PM	0:28:32	1712.00	92

$$\begin{cases} count = N \\ \delta count = \sqrt{N} \end{cases}$$

$\delta_{\Delta t} = 1s.$

$$Flux = \frac{N}{\Delta t\, A\Omega}$$

$$\delta flux = Flux \cdot \sqrt{\left(\frac{\delta N}{N}\right)^2 + \underbrace{\left(\frac{\delta \Delta t}{\Delta t}\right)^2}_{\approx 0} + \left(\frac{\delta A\Omega}{A\Omega}\right)^2}$$

$I =$

```
NIntegrate[γ / ((x - x0)^2 + (y - y0)^2 + γ^2)^(3/2), {x, -L / 2, L / 2}, {y, -β / 2, β / 2}, {x0, L / 2 - m - a, L / 2 - m}, {y0, -b / 2, b / 2}]
83.0584
```

hard to do error propagation on Integral.

$$\begin{cases} \beta = \beta(R \cdot h) \\ \gamma = \gamma(R, h) \end{cases}$$

$$\frac{\partial I}{\partial h} = ???$$

$$\rightarrow \left(\frac{\partial I}{\partial L}\delta L\right)^2 + \left(\frac{\partial I}{\partial a}\delta a\right)^2 + \left(\frac{\partial I}{\partial b}\delta b\right)^2 + \left(\frac{\partial I}{\partial R}\delta R\right)^2 + \left(\frac{\partial I}{\partial h}\delta h\right)^2.$$

rough estimation: minimum presicion ~0.1cm. Typical deviation of length measurement ~0.3 m

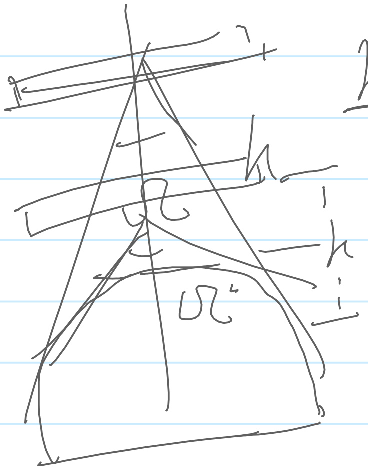
I dimension. cm^2·sr $S \cdot \boxed{\frac{A}{r^2}}$.

maximum (h)

error pertentage ≤ 10%. square → $\sqrt{2}$.

$$\boxed{\frac{\delta I}{I} \le \sqrt{2} \cdot 0.1}$$

θ.



h should be treated carefully!!

significantly affect the estimated value of solid angle Ω ~~θθ~~.