Senior Year Project

Uzair Abdul Latif
Department of Physics
LUMS SBASSE

- Title: Developing Nuclear and Particle Physics Laboratory Experiments

- Supervisor: Dr. Imran Younas

- Aim: To help in the development of experiments, related to particle physics, for physics undergraduates.

- Target:
  - To setup at least two fully functional and developed experiments during the academic year.
    - Measure muon lifetime.
    - Measure muon velocity.

What is a muon?

- Muons are basically a more massive copy of electron with mass 105.66 MeV.
- Spin-1/2 particles.
- They are a part of the cosmic rays and are formed the decay of pions in the atmosphere:

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

- Are able to reach the ground at speeds nearing the speed of light.

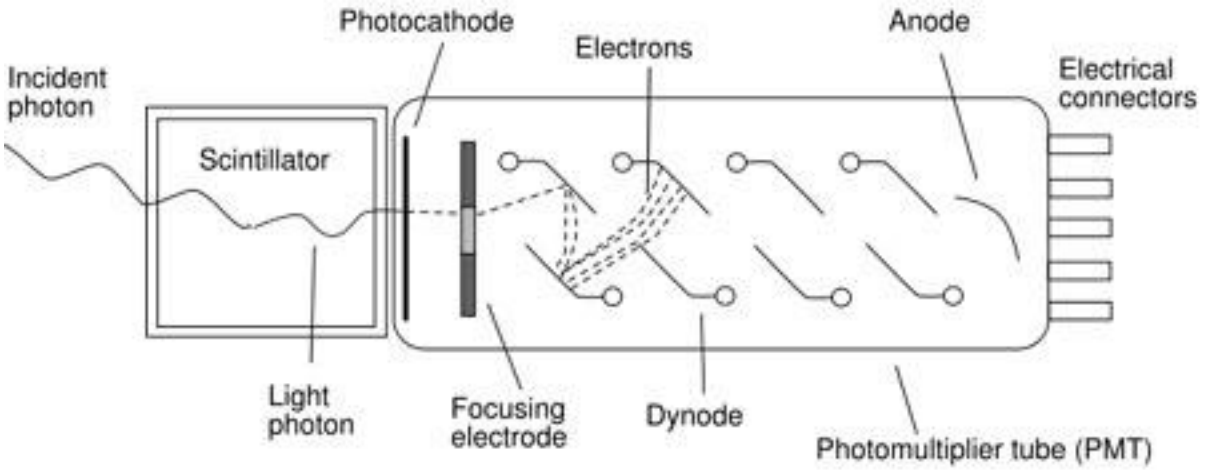
- Once caught they decay in the following way:

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

- Mean lifetime(+ve muons) ≈ 2.2μs
- Mean lifetime(-ve muons) ≈ 1.7μs
- Cosmic rays produce +ve to –ve muons in the ratio 56% to 44%.

A few things before we start…

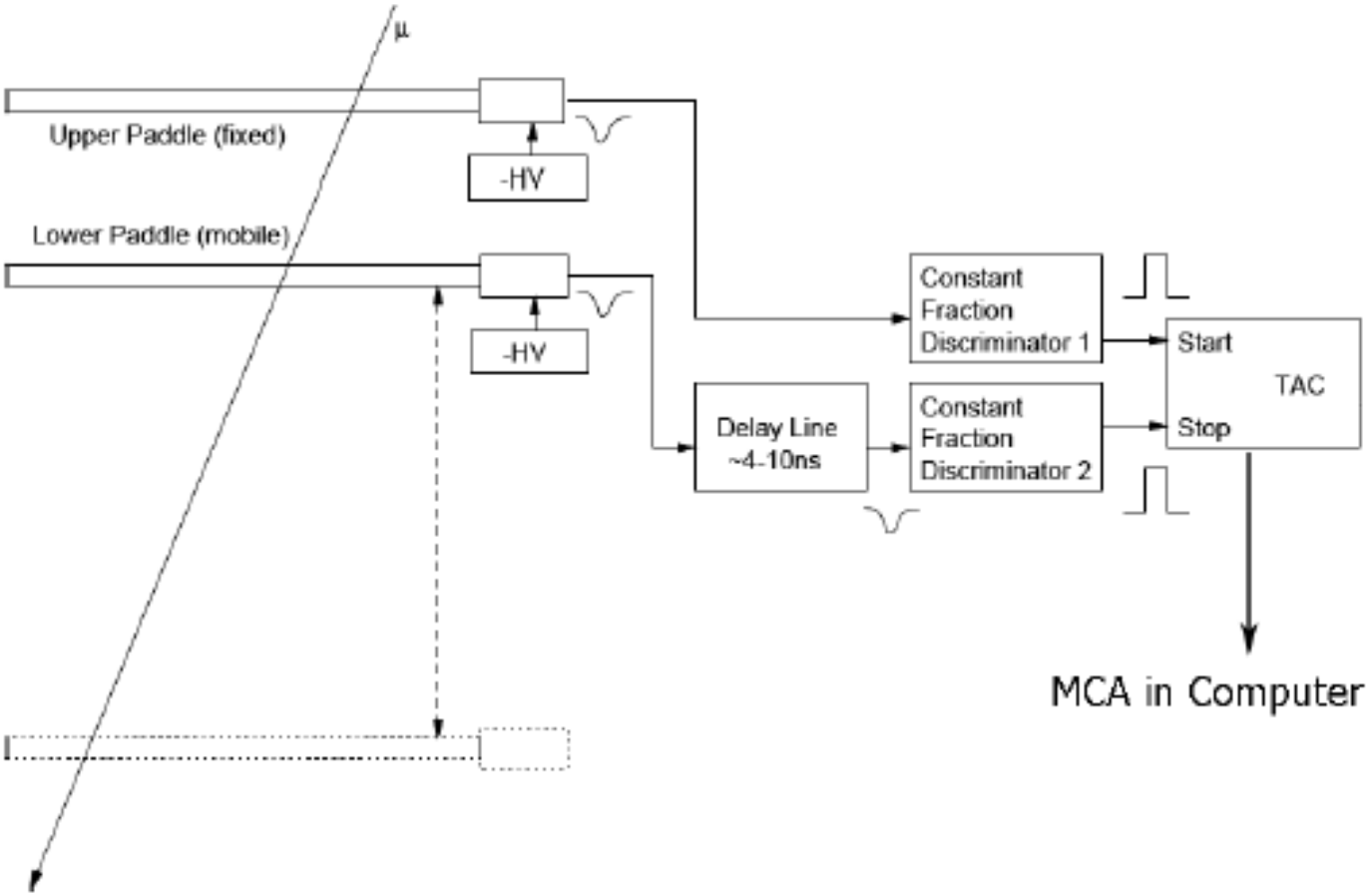
- A detector is the combination of plastic scintillators and PMTs(Photomultiplier tubes).
- Plastic scintillators have fairly high light output and a relatively quick signal, with a decay time of 2–4 nanoseconds.
- The biggest advantage of plastic scintillators is their ability to be shaped into anything with a high degree of durability.



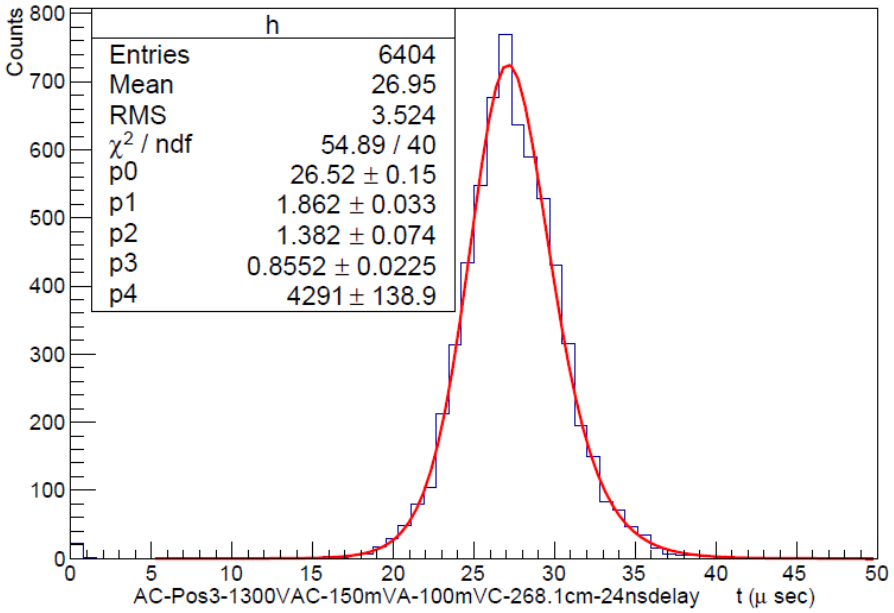
- A photocathode is coated with a photosensitive compound which emits electron when struck with a photon.
- Each dynode has a more +ve potential than its predecessor.
- Multiple dynode stages enable in the detection of single photons when flux of incident light is low.
- PMTs can amplify a single photon crystal by as much as 100 million times.

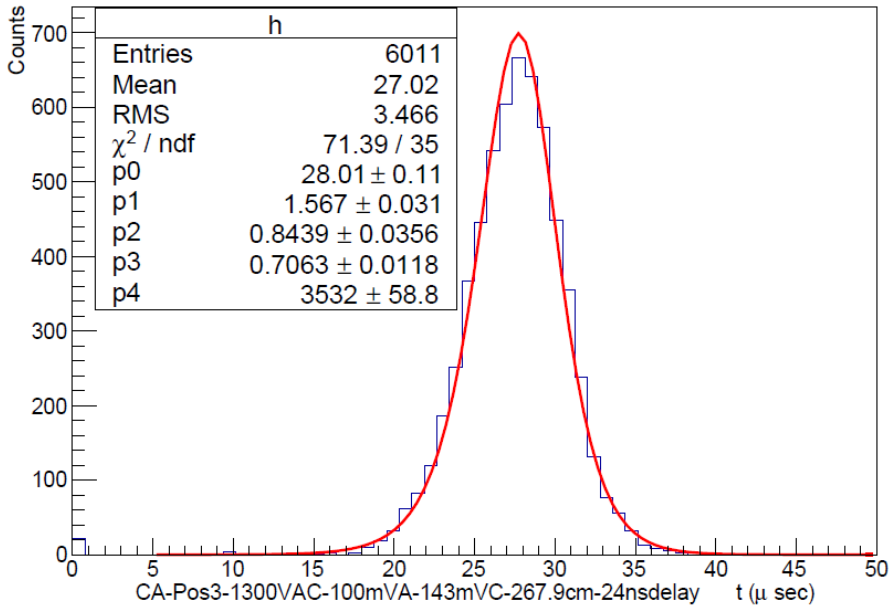
Velocity of the Muon

- Muons are approximately created around 30km up in the atmosphere.
- Speeds ranging up to around 0.998c .


μ
Upper Paddle (fixed)
-HV
Lower Paddle (mobile)
-HV
Constant
Fraction
Discriminator 1
Start
TAC
Stop
Delay Line
~4-10ns
Constant
Fraction
Discriminator 2
MCA in Computer

Measuring time



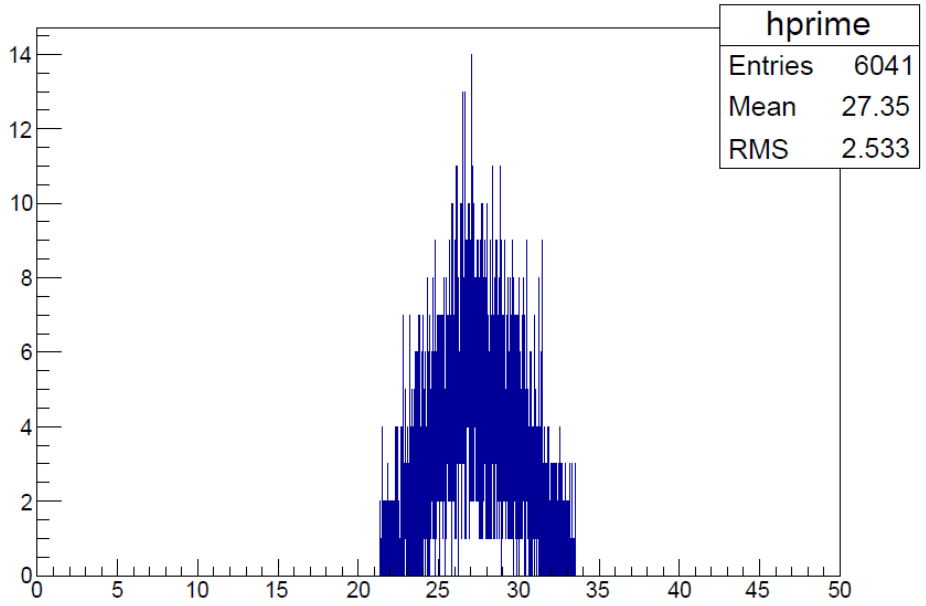


- Tail goes to left or right depending on the order of detectors
- Chi-square varies greatly and really bad in some cases!

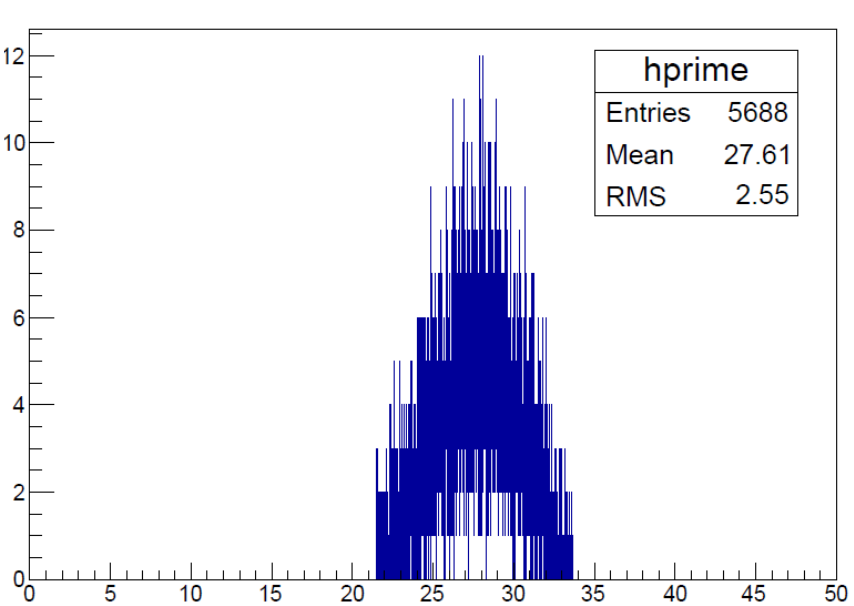
Finding the mean of the ‘actual’ data

- Need one consistent method to extract the mean of average time.
  - Fit types (left skewed and right skewed) with one function.
  - Calculate the mean of the function.
  - Take all the data points within ±2σ of the mean.
  - Calculate the the mean of the ‘actual’ data.

AC-Pos3-1300VAC-150mVA-100mVC-268.1cm-24nsdelay



CA-Pos3-1300VAC-100mVA-143mVC-267.9cm-24nsdelay

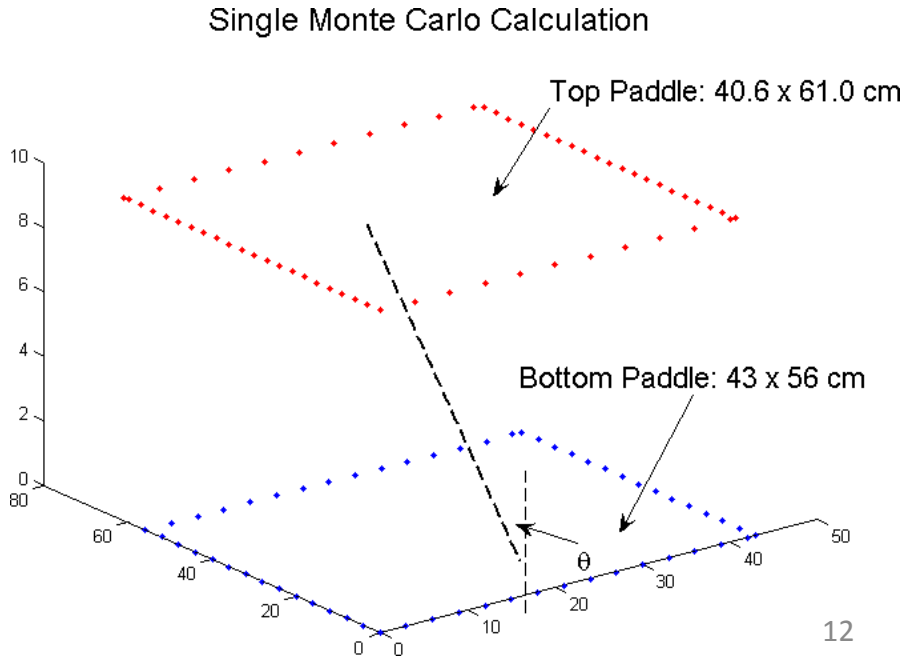


Measuring Distance

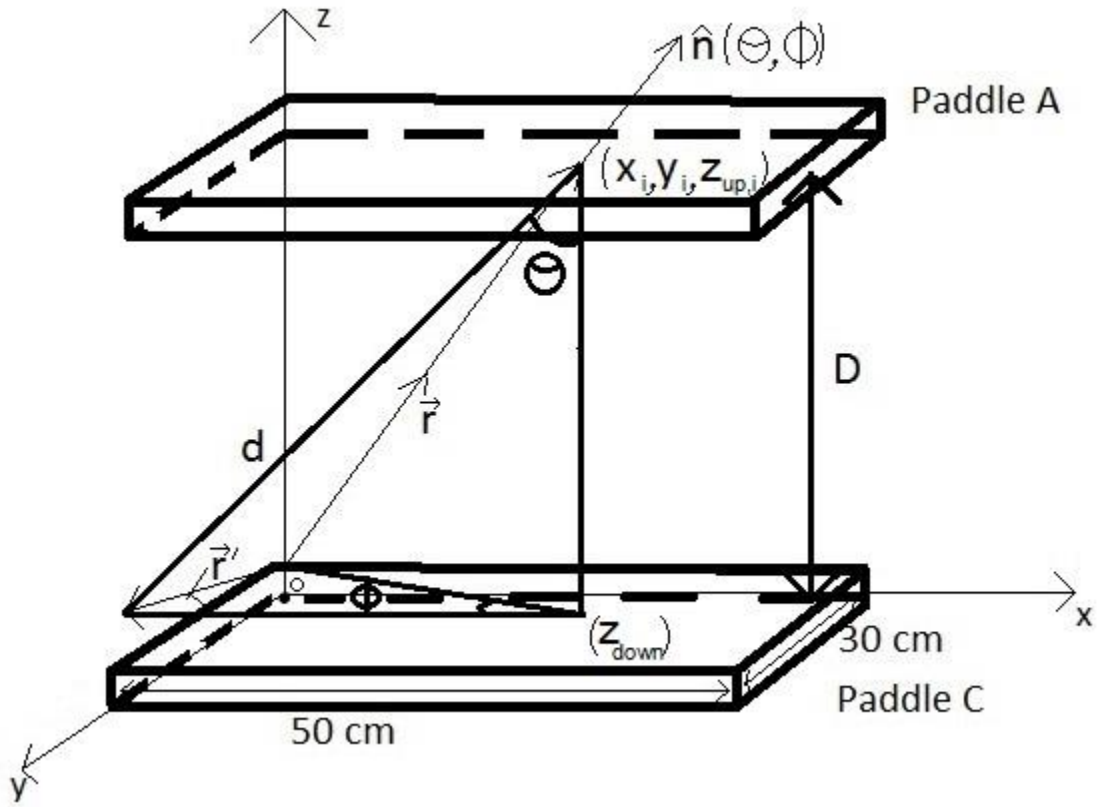
- Angular distribution of the muons:

$$I(\theta) \propto cos^2(\theta)$$

- We will have to run a Monte Carlo simulation to determine a mean slant range for any D between the paddles.



Simulation setup

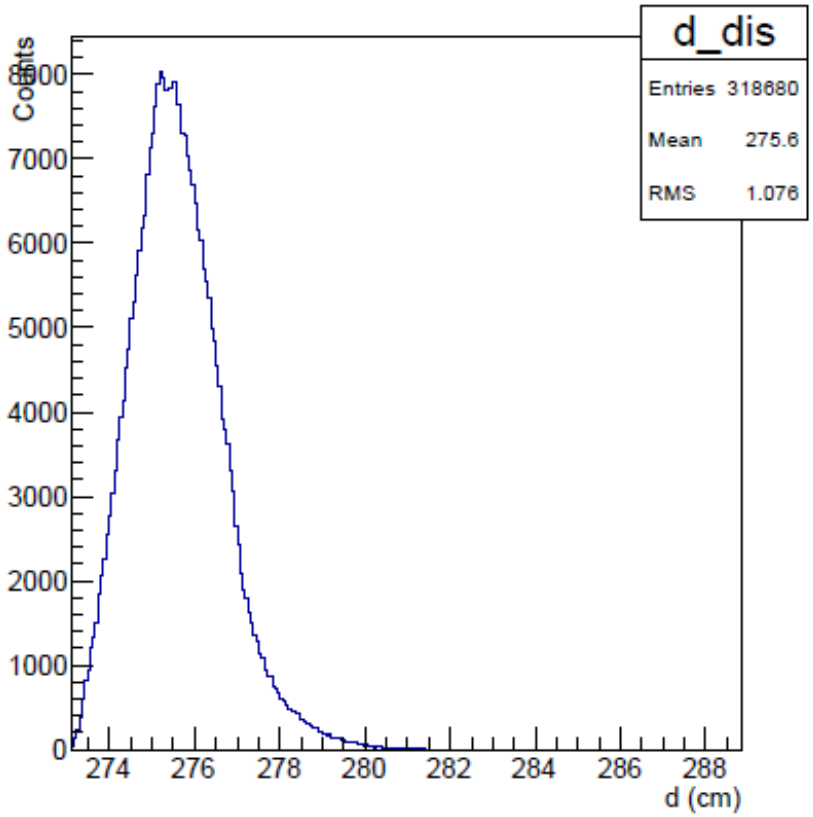


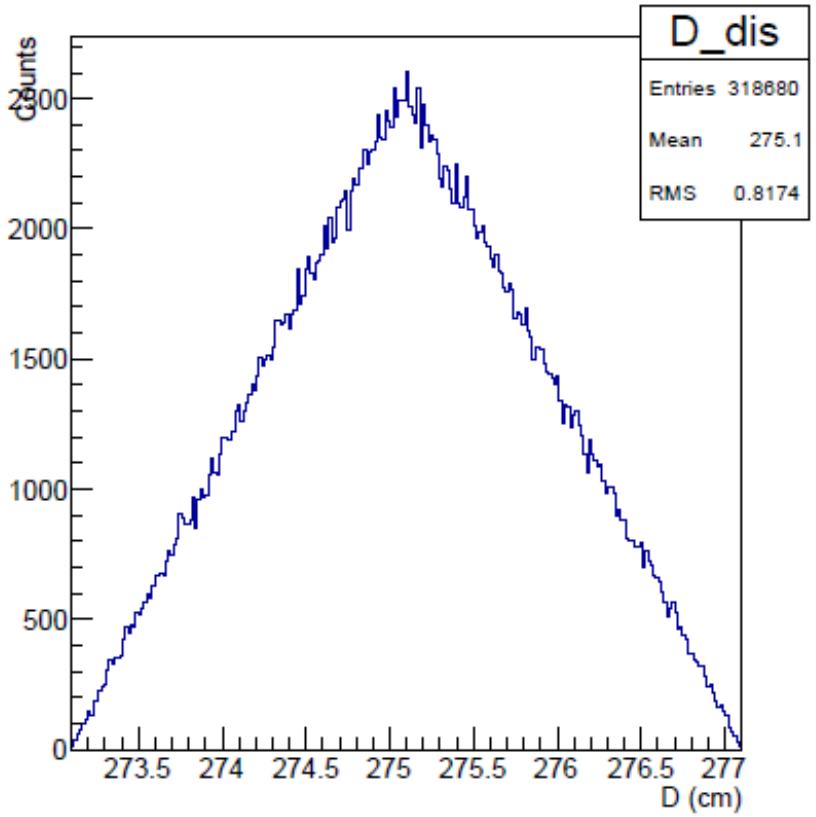
$$\vec{r}' = \vec{r} - d\hat{n}$$

d=D/cosΘ, where D=Zup-Zdown

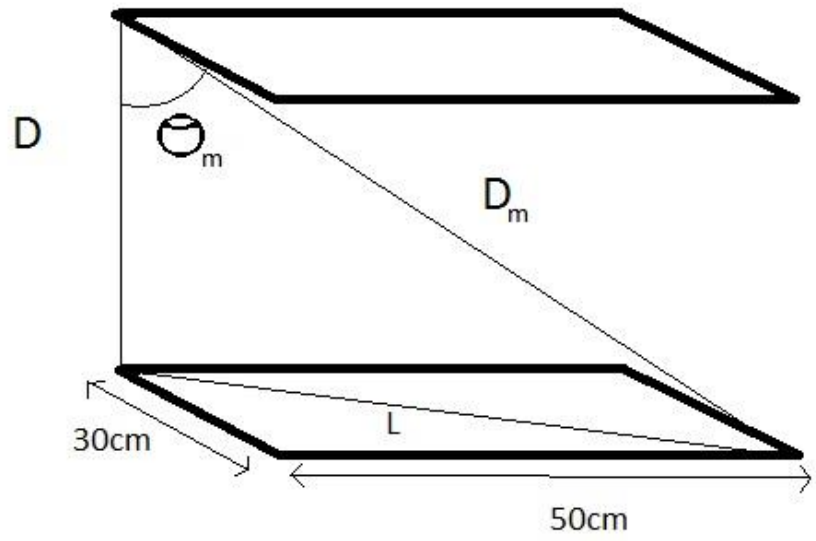
Simulation results

- The simulation was run for 1,000,000 events. Out of those 3,186,80 were HITs and rest were MISS. Dmax=277.1

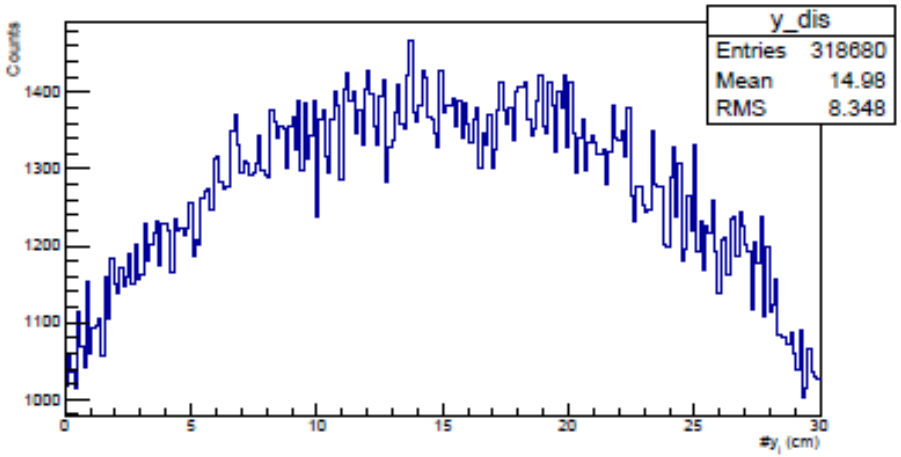


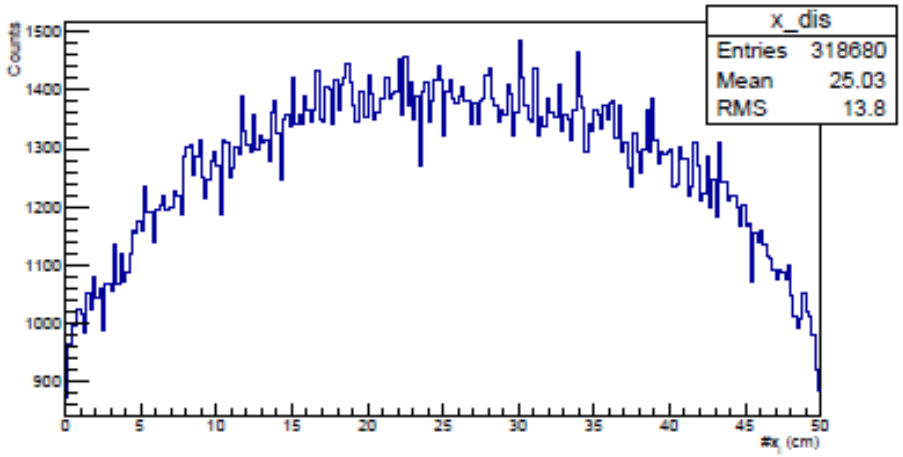


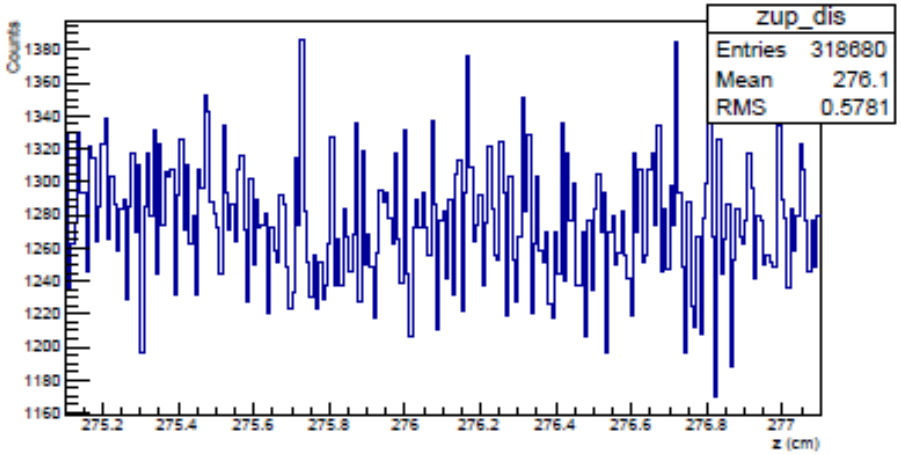
D_m and θ_m

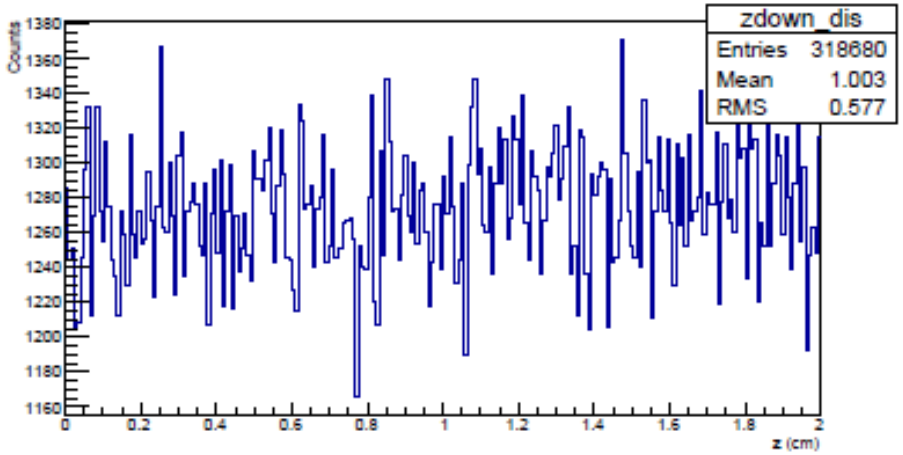


x, y, Z_{down}, Z_{up}

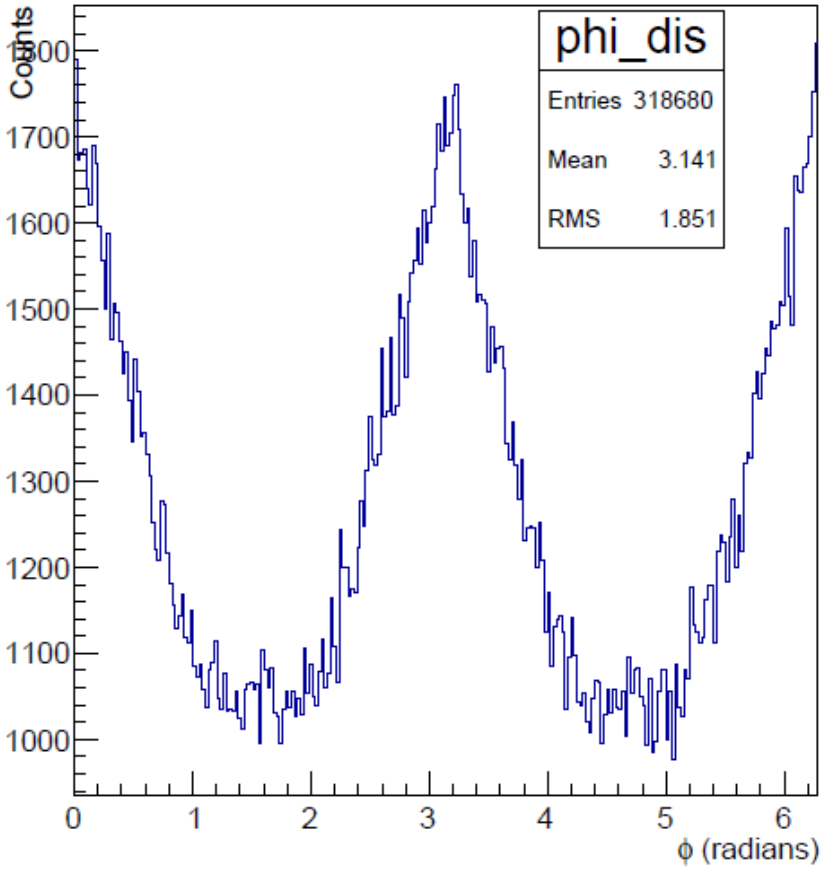

y_dis
Entries 318680
Mean 14.98
RMS 8.348
Counts
#y (cm)

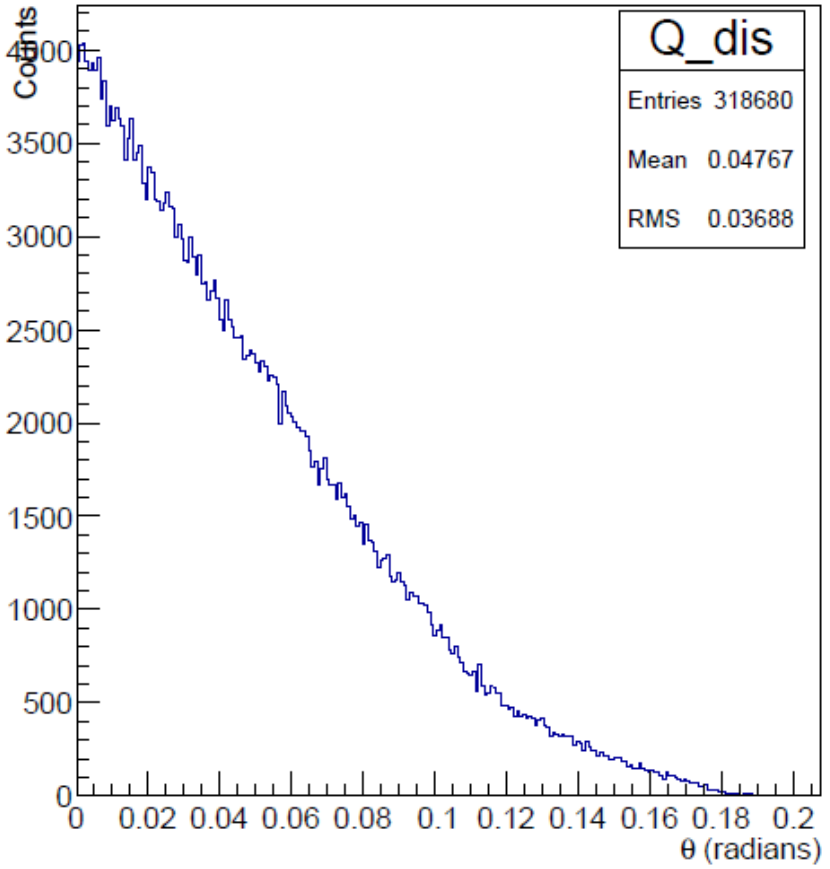

x_dis
Entries 318680
Mean 25.03
RMS 13.8
Counts
#x (cm)


zup_dis
Entries 318680
Mean 276.1
RMS 0.5781
Counts
z (cm)

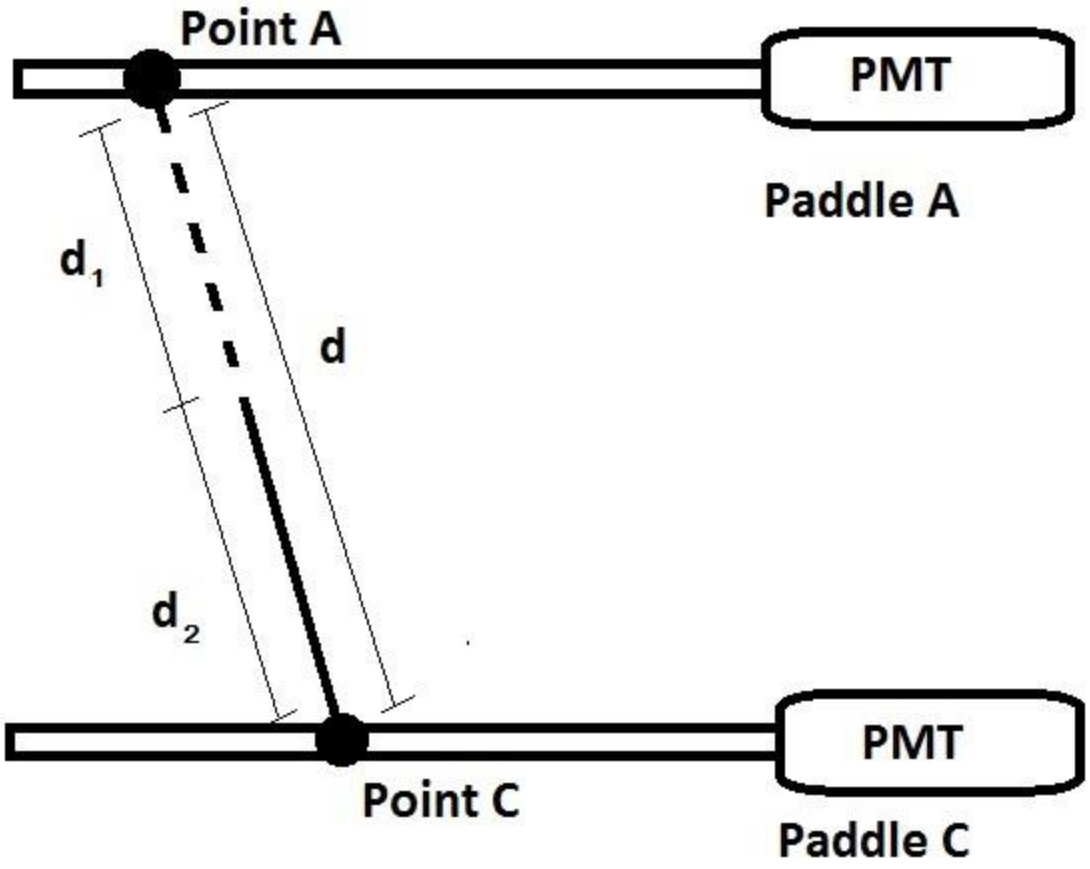

zdown_dis
Entries 318680
Mean 1.003
RMS 0.577
Counts
z (cm)

Θ,Φ

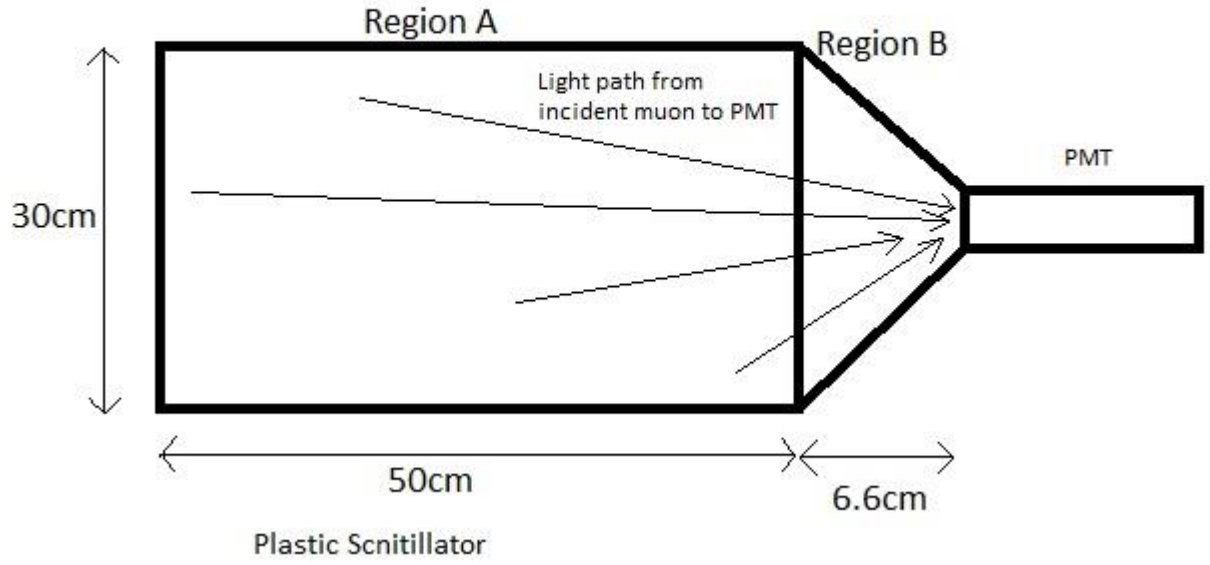

phi_dis
Entries 318680
Mean 3.141
RMS 1.851
Counts
ϕ (radians)


Q_dis
Entries 318680
Mean 0.04767
RMS 0.03688
Counts
θ (radians)

What exactly are we measuring?

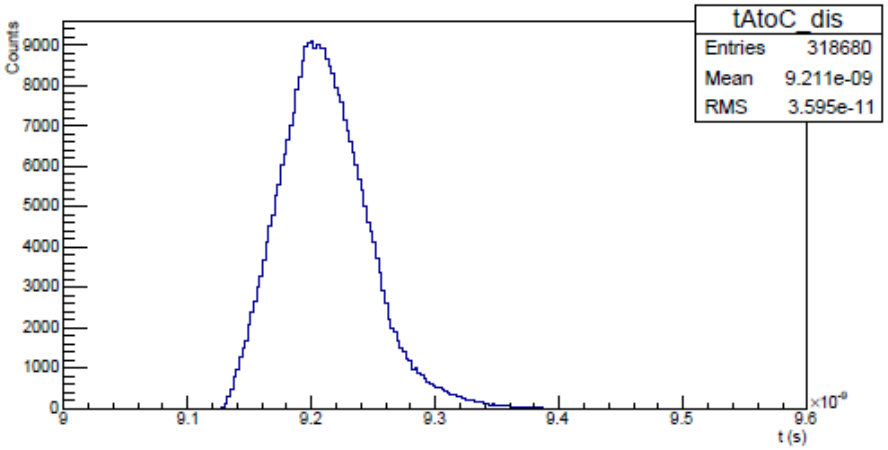


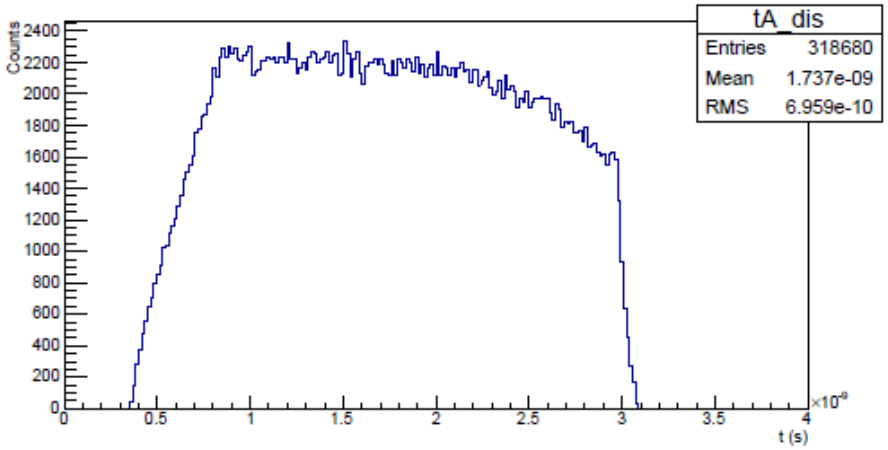
- Velocity of muon assumed to be constant and equal to 0.998c.

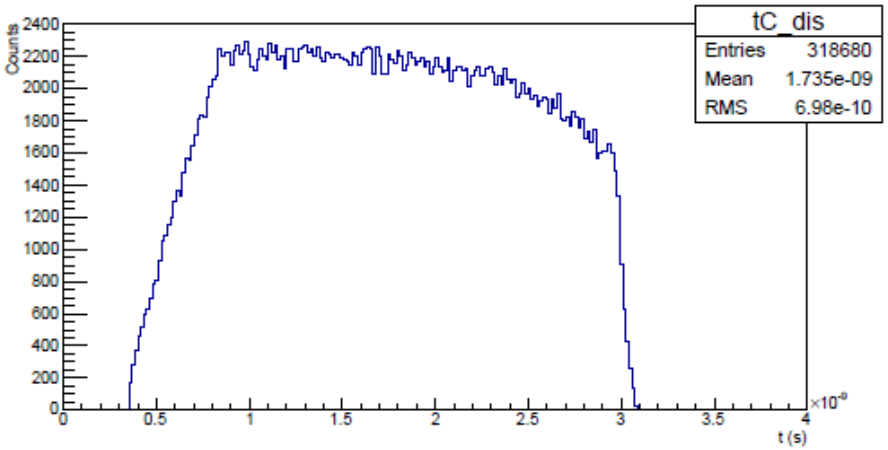


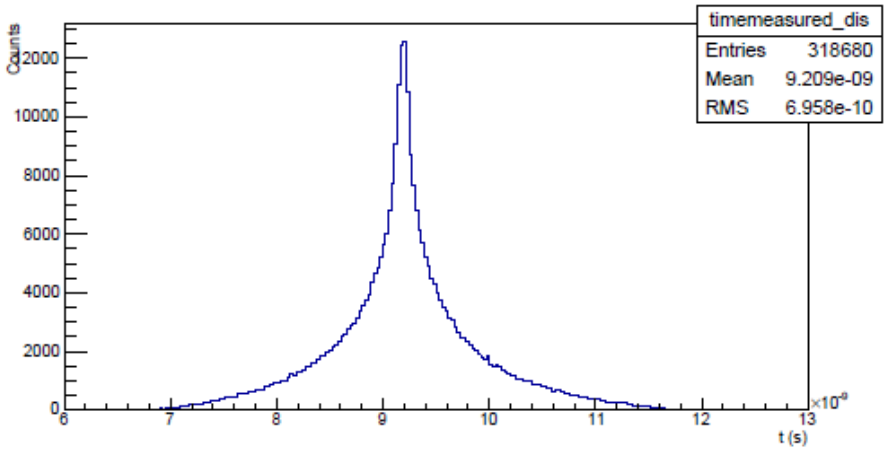
- t_A , t_B: The time taken for light to travel from the point where the muon is incident to the PMT.
- $v = \frac{c}{n}$
- t_{AC}: The time taken for the muon to travel from paddle A to C.

$v_\mu = 0.998c$ (assumed)

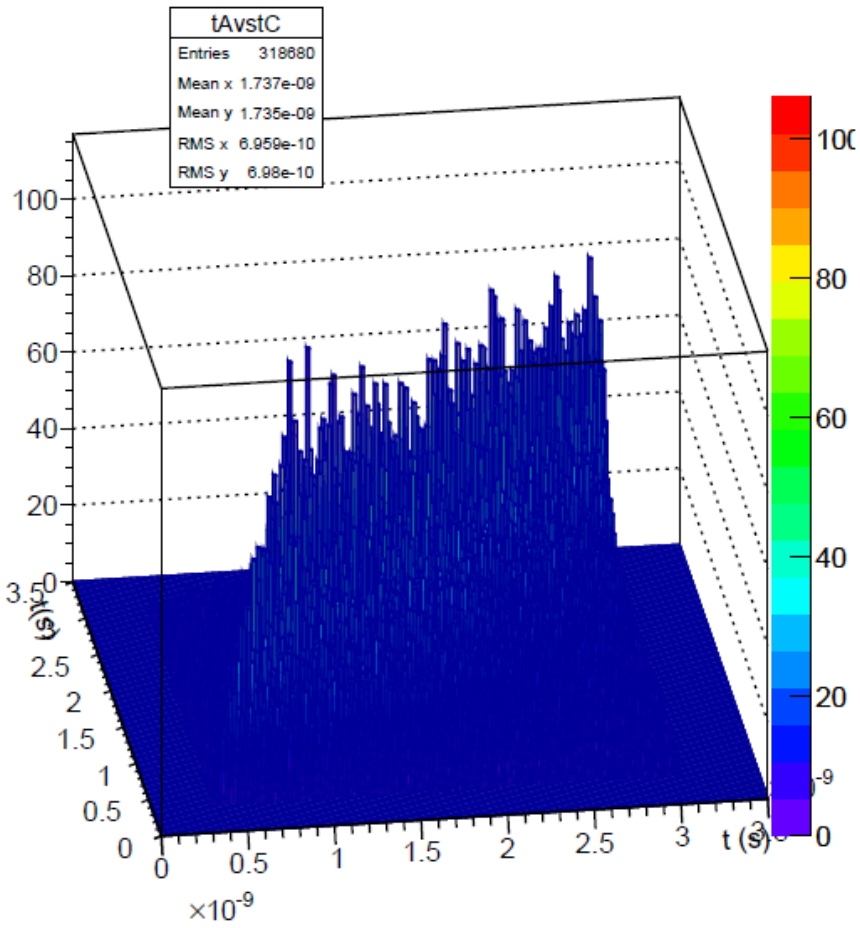


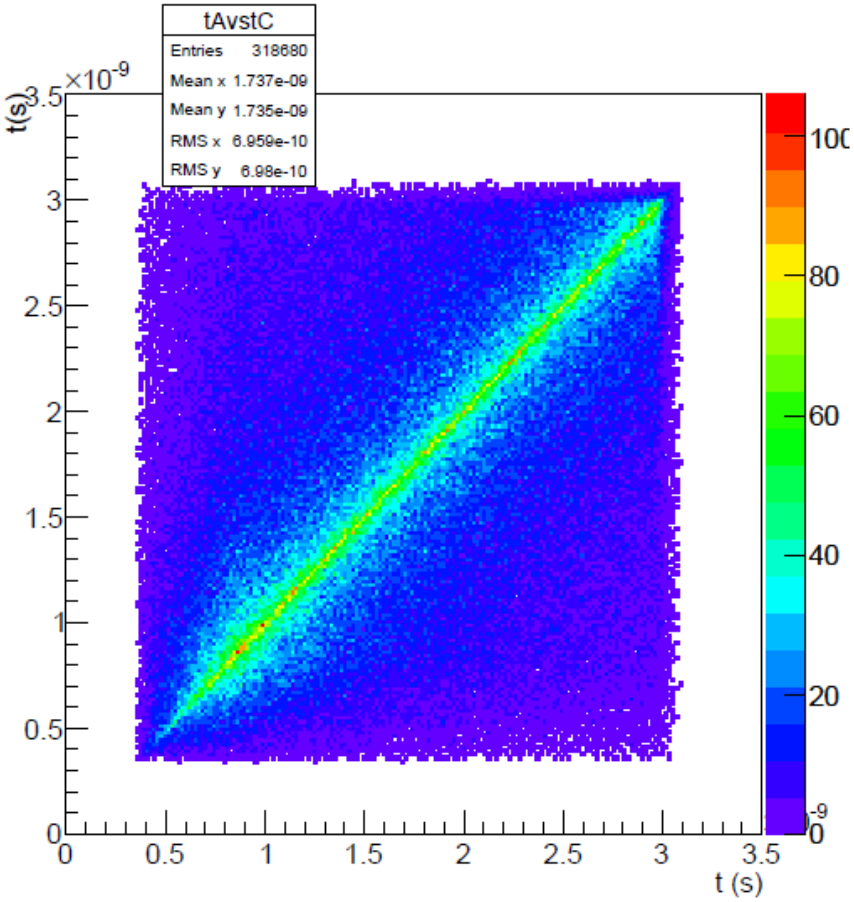


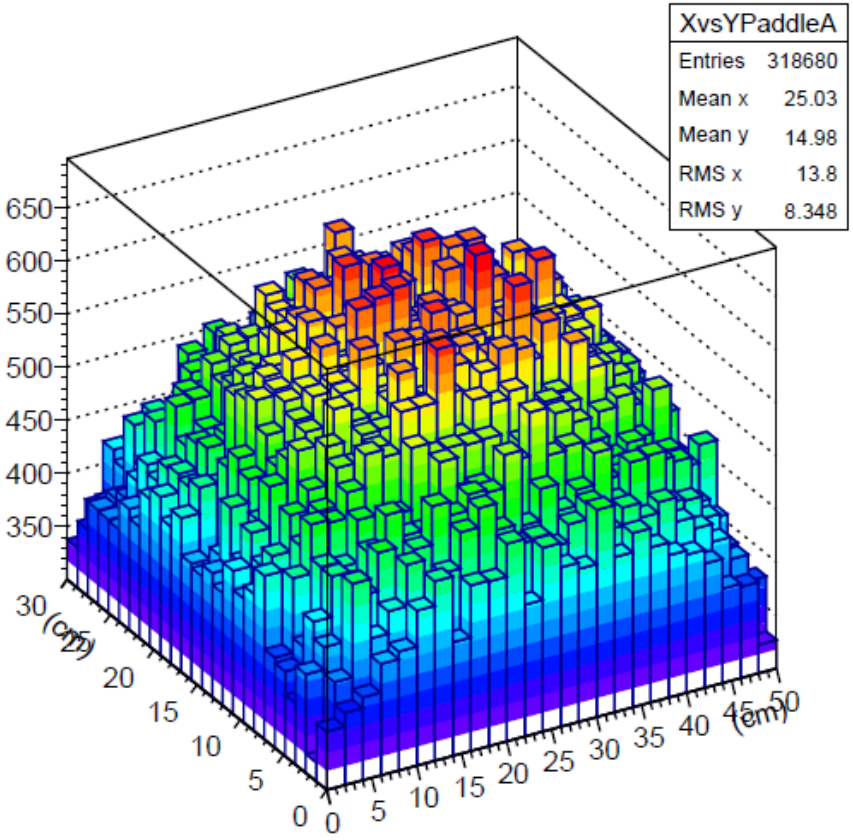


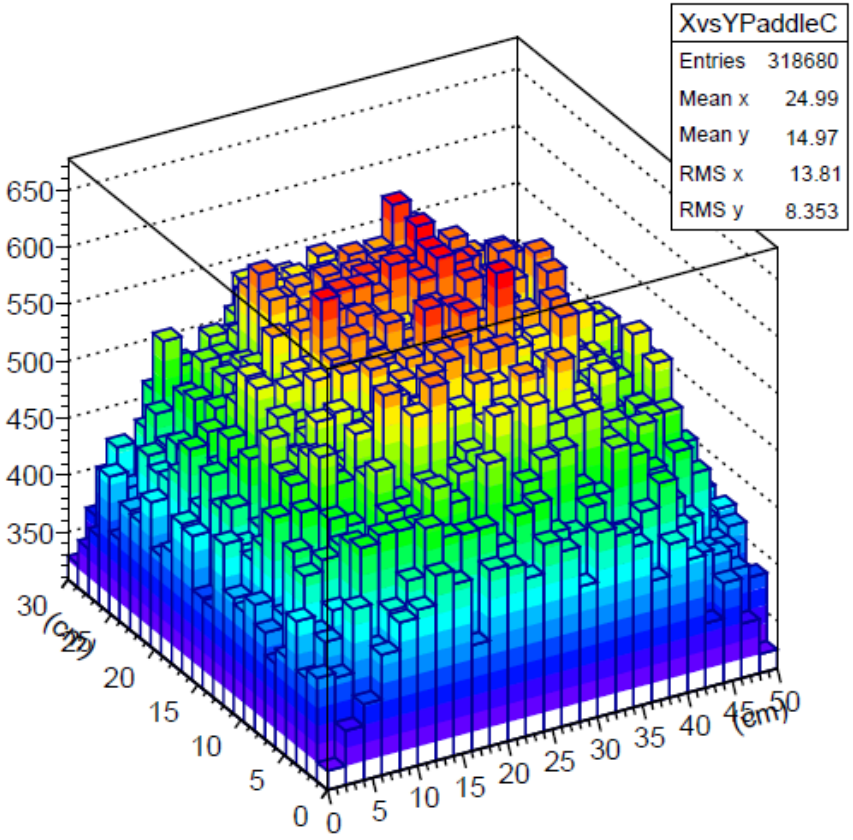


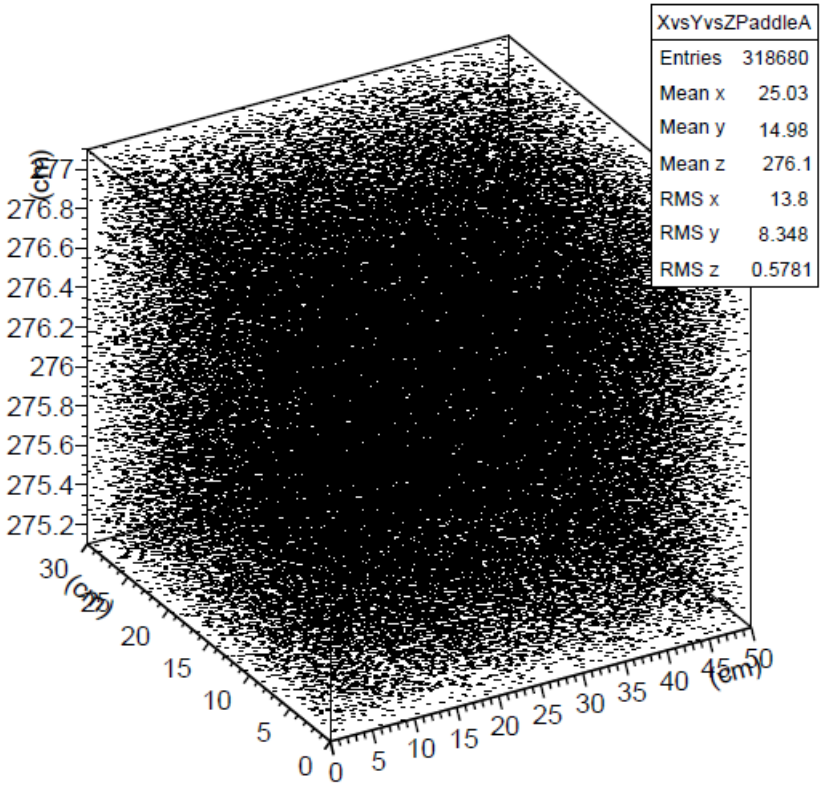
t_A vs t_C

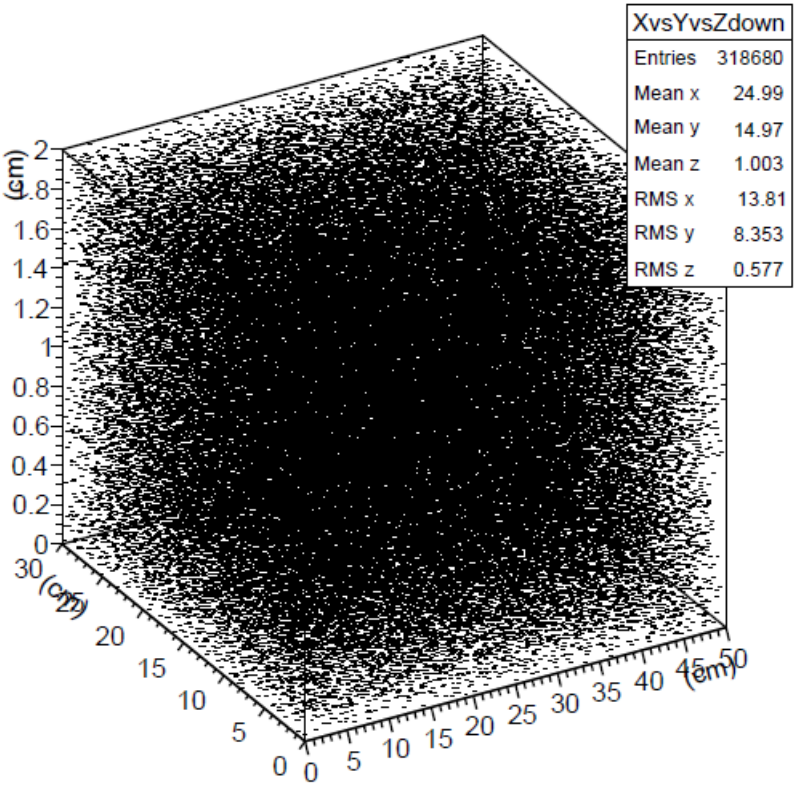

tAvstC
Entries 318680
Mean x 1.737e-09
Mean y 1.735e-09
RMS x 6.959e-10
RMS y 6.98e-10
t (s)
×10^-9


tAvstC
Entries 318680
Mean x 1.737e-09
Mean y 1.735e-09
RMS x 6.959e-10
RMS y 6.98e-10
t(s)
×10^-9
t (s)


XvsYPaddleA
Entries 318680
Mean x 25.03
Mean y 14.98
RMS x 13.8
RMS y 8.348
650
600
550
500
450
400
350
30
25
20
15
10
5
0
(cm)
0 5 10 15 20 25 30 35 40 45 50
(cm)

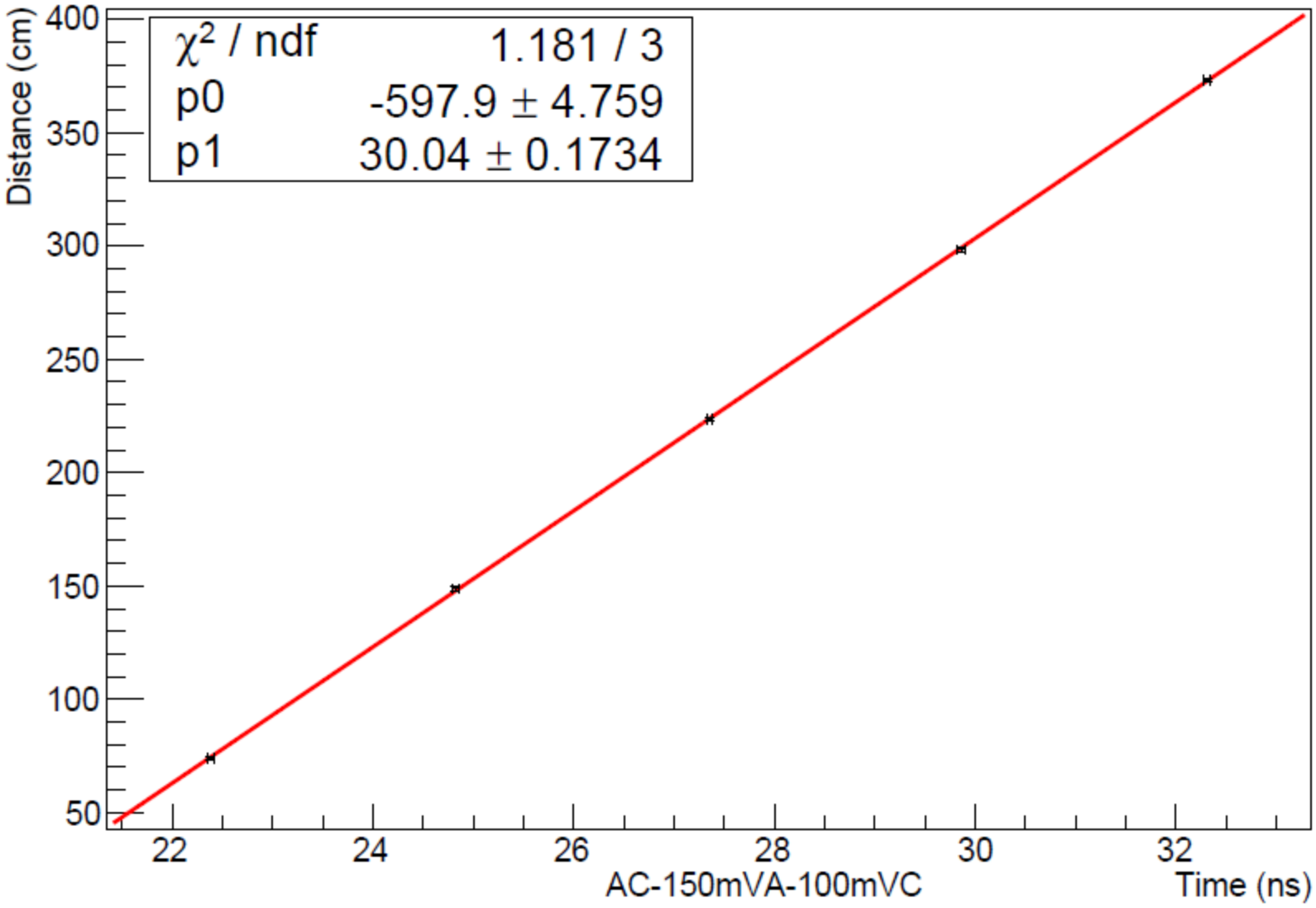

XvsYPaddleC
Entries 318680
Mean x 24.99
Mean y 14.97
RMS x 13.81
RMS y 8.353
650
600
550
500
450
400
350
30
25
20
15
10
5
0
(cm)
0 5 10 15 20 25 30 35 40 45 50
(cm)

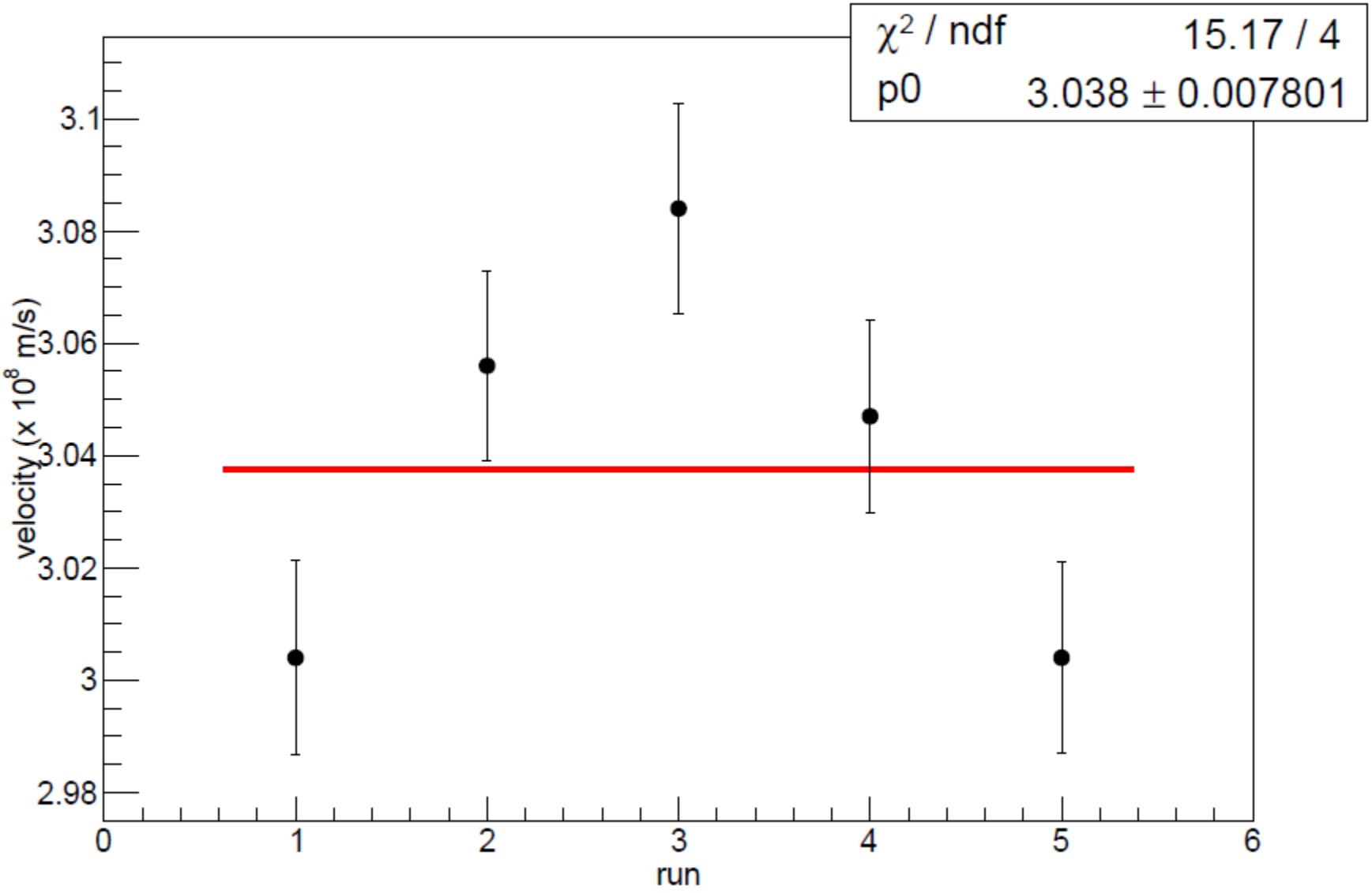

XvsYvsZPaddleA
Entries 318680
Mean x 25.03
Mean y 14.98
Mean z 276.1
RMS x 13.8
RMS y 8.348
RMS z 0.5781
(cm)
276.8
276.6
276.4
276.2
276
275.8
275.6
275.4
275.2
30
(cm)
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
50
(cm)


XvsYvsZdown
Entries 318680
Mean x 24.99
Mean y 14.97
Mean z 1.003
RMS x 13.81
RMS y 8.353
RMS z 0.577
(cm)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
30
(cm)
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
50
(cm)

Calculating the velocity (Finally!)

- Measure average time taken and average distance travelled (d2) for five different separations between paddle A and C.
- Plot a D vs T graph for those 5 points,
- Find the gradient(=velocity of muon!)


χ² / ndf 1.181 / 3
p0 -597.9 ± 4.759
p1 30.04 ± 0.1734
Distance (cm)
400
350
300
250
200
150
100
50
22
24
26
28
30
32
AC-150mVA-100mVC
Time (ns)



$< v >$=(3.04 $\pm$0.01 $\pm$ 0.08)$\times$ $10^8 ms^{-1}$

What next:

- Repeating the whole experiment with CFDs (Constant Fraction Discriminators).
- Using a self consistent method to assume velocity for the muon in the simulation:
  - Initial results:
  - expvMu1=3.01549e+08
    expvMu2=3.01531e+08
    expvMu3=3.01537e+08
    expvMu4=3.0152e+08
    expvMu5=3.01521e+08

Thank you!!