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Measuring speed of light in laboratory using Na-22 source and $LaBr_3$ detector.

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Introduction:

The speed of light is represented by the letter "c". Before the seventeenth century it was generally thought that light is transmitted instantaneously. Nowadays, we know that light is just too fast for the human eye to determine its speed. We do know that our eyes can detect the radiation, which is why we see. Galileo doubted that light speed is infinite and he described an experiment to measure light's speed by covering and uncovering lanterns observed at a distance of a few kilometers. We don't know if he really attempted the experiment, but "c" is too large value for such a method to work. Today science accepts the speed of light is a fixed value of 299792458 m/s in vacuum and that nothing that we know of can travel faster than speed of light. Although the speed of light is already measured accurately to a value given before, it is a fascinating and quite beautiful project to measure the above said "speed of light" in laboratory using a Na-22 source. In this project we used two lanthanum bromide detector coupled with Photo multiplier tube's and coincidence between two 511 gamma rays produced by the decay of Na-22 source. Here in this experiment we are determining the speed of 511 keV gamma ray, Since all electromagnetic waves travel with speed of light we can take the speed of gamma ray to be the speed of light.

The Na-22 source mainly undergoes β^+ decay to produce positron this positron annihilates with electron to produce two gamma rays at an angle of 180 degree. The Decay modes were given in the diagram (fig-1) and also by the equation given below

$$_{11}Na^{22} \Rightarrow {}_{10}Ne^{22} + \beta^+ + \nu_e + \gamma$$

$$\beta^+ + \beta^- \Rightarrow 2\gamma \ (511\ keV)$$

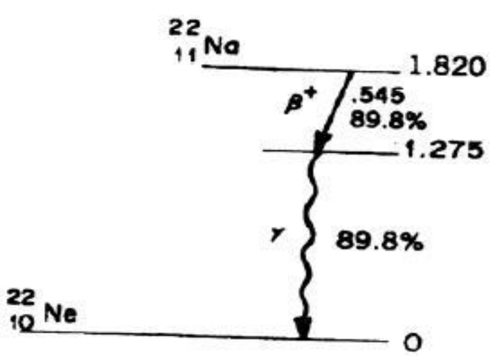

Fig-1: *Decay modes of Na-22 source.*

Experimental Details:

In this project we used two lanthanum bromide (III) scintillation detector (at opposite sides) to detect the two oppositely emitting 511 keV gamma rays from the Na-22 source. The working or principle of the lanthanum bromide (III) detector is described in this part. When a gamma ray strikes a LaBr3 detector its electron present in atom gets excited to higher energy levels and while returning back to ground state it produces visible light. This light signal is then amplified and converted into electrical signal using a photomultiplier tube connected to each LaBr3 Detector. This Photo Multiplier tube output is then connected to other signal processing electronics to acquire data. Recent advances in scintillator material have resulted in the development of cerium activated lanthanum bromide (LaBr3) detectors. These detector offer improved energy resolution, fast emission and excellent temperature and linear characteristics. The size of the detector we used is 1.5 x 2 inch.

In order to get started with the experiment we first need to setup the circuit as shown below,

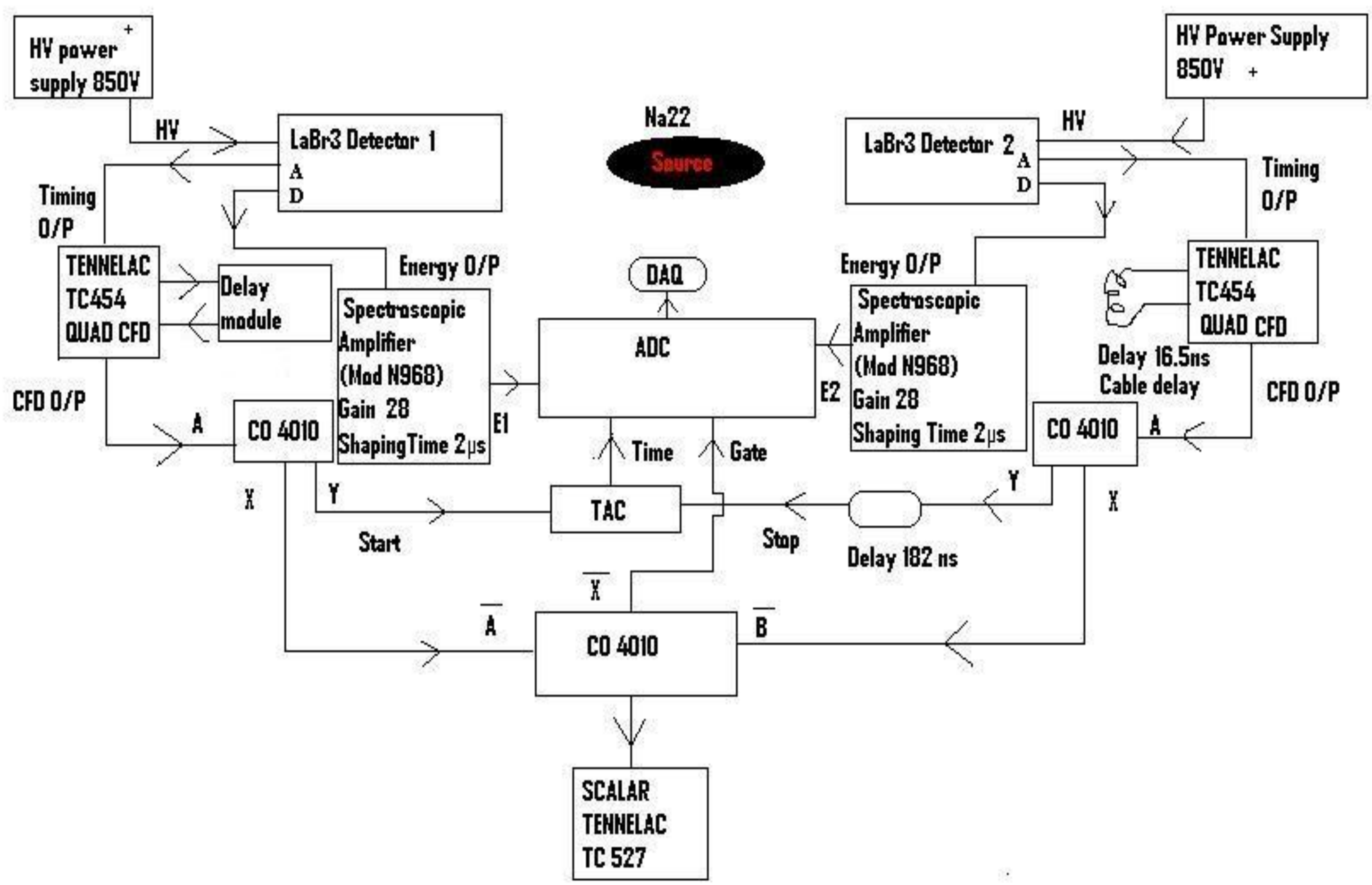

Fig-2: *Block diagram of the Circuit.*

In this section Constant fraction discriminator is discussed in detail in order to get some clear idea about its working. A discriminator circuit selects the minimum pulse height above threshold and when the input pulse height exceeds the discriminator preset level, the discriminator generates an output.

Anode → *TFA* → *Linear* → *Discriminator*

These random fluctuations superimposed on the signal pulses of identical shape and size may cause the generation of output pulses at somewhat different time leading to a time jitter, often referred to as amplitude walk. Even if the input amplitude is constant such a walk can still take place, if change occurs in the shape (i.e. rise time and the decay time) of the pulse. The CFD is used to overcome these problems. For this a constant faction of the total pulse irrespective of their amplitude reaches this point at the same time and hence pulses over a wide dynamic range can be accepted. This step involved in constant fraction timing (fig-3) is shown below.

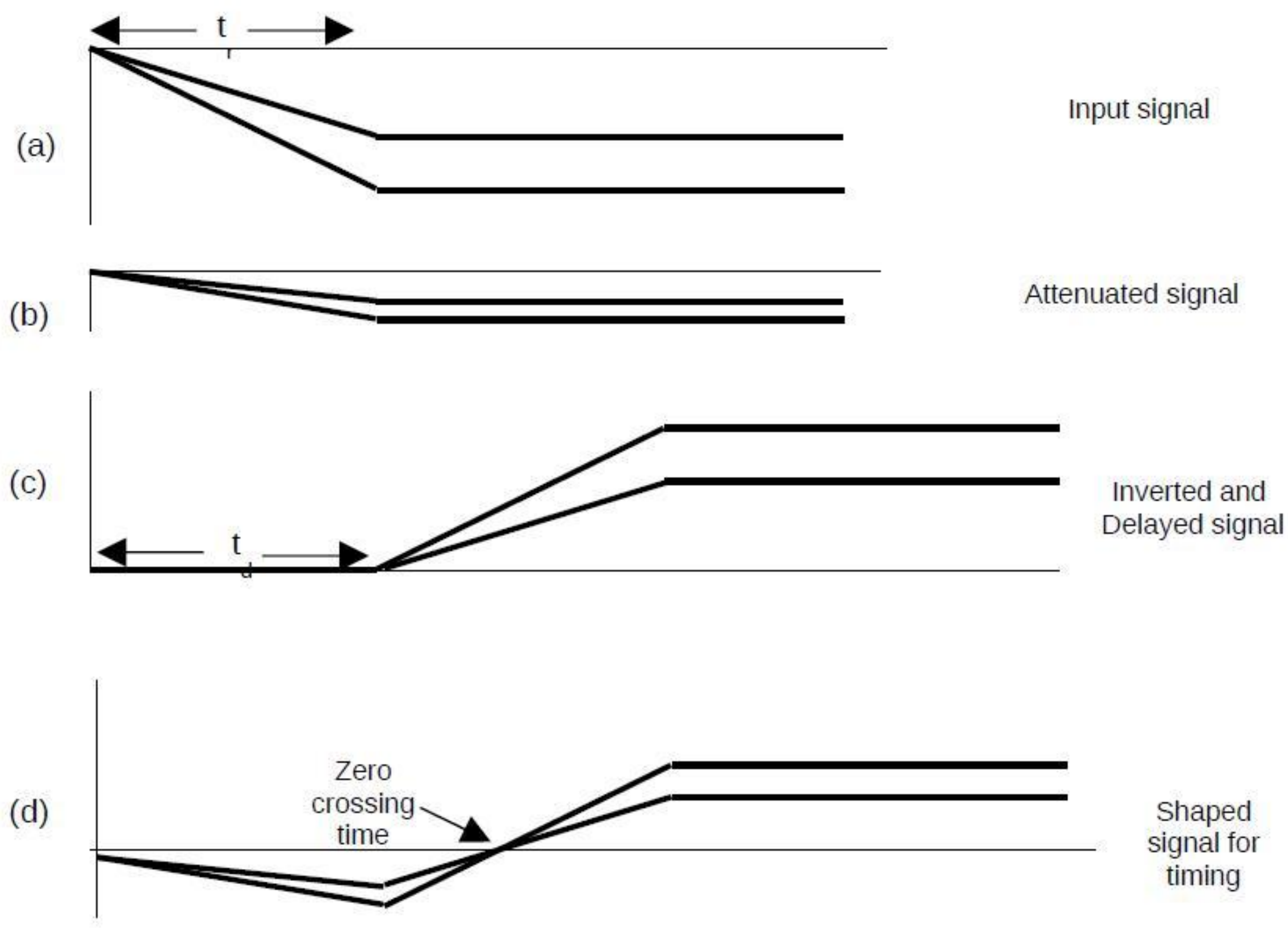

Fig 3: *Waveforms in the constant fraction timing pick-off method. Only the leading edges of the pulses are shown above.*

Before starting the actual experiment for collecting data's to measure "speed of light", the (TAC) Time to amplitude converter was calibrated using Time Calibrator (Ortec 462). We did this because the TAC produces an output which is proportional to the time interval between the arrival of start and stop, converted into amplitude. When the data's are acquired using LAMPS this TAC output will come as a peak within a range of channels. In order to get the time information from channel information, we Calibrated TAC using Time calibrator, so that now the time corresponding to one channel is obtained. From this we can calculate the TAC output in terms of time (i.e. seconds or nano seconds).Here the time calibrator range is 80ns and period is 10ns, since we set the TAC range as 50ns we got five time data's with a period of 10ns (if we choose 20ns period in time calibrator then we will get two time data's with a period of 20ns). The obtained data points for 10ns period (Table-1) and the TAC spectrum (Fig-4) were shown below,

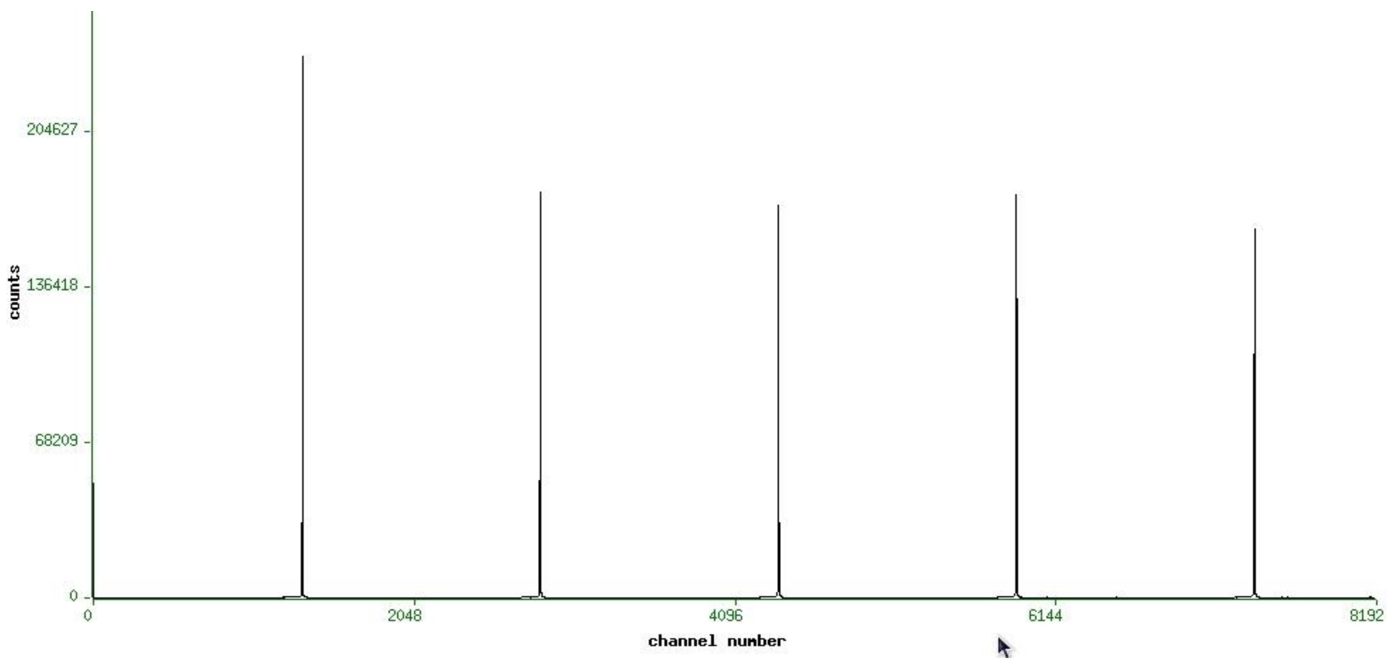

Fig-4: *TAC spectrum.*

Time	Peak position in Spectrum
10	1339.14
20	2856.10
30	4376.51
40	5896.94
50	7416.40

Table-1: *Data's for TAC Calibration.*

The calibration graph done by the data's collected are given below:

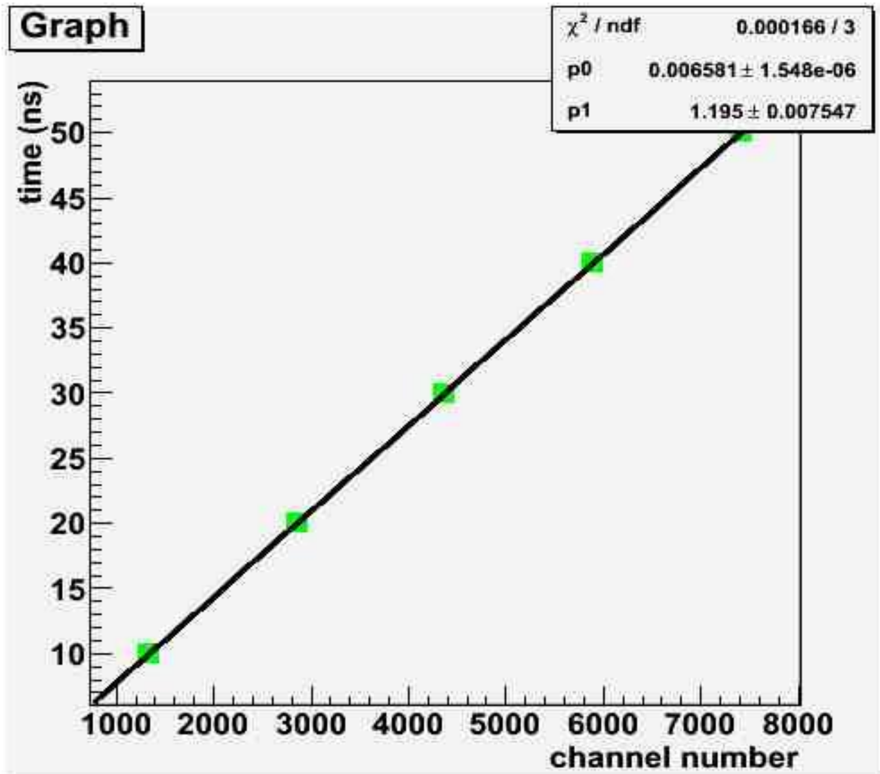

Fig-5: *Calibration graph for TAC.*

Here after fitting the above values with a first order polynomial (y=ax+b) we obtained the fit parameter for calibration as

a=0.006581 ± 0.000001548,
b=1.195 ± 0.007547.

In order to start collecting the data's we first made the circuit connection as shown in the block diagram (fig-2).

Once the connection was done, the next step to proceed is to adjust the initial settings. Here in this project we adjusted the pulse width of constant fraction discriminator (CFD), Checked Zero Cross over, energy threshold in order to eliminate unwanted noise (2/7 of 511 keV) and gain of amplifier. After checking each detector individually for output signals the coincidence logic was set using the coincidence unit CO-4010. According to the boolean algebra,

$$\overline{X} = \overline{\overline{A} + \overline{B}} = A \cdot B$$

Here in the coincidence unit we need to get output only when both the detectors detect 511keV gamma ray. For this we need the logic "A . B" this is generated from the available "OR" gate in CO-4010 using the above said boolean algebra.

After doing the initial settings, we kept both detectors at 100cm from the source at 180 degree and stated the data acquisition using the LAMPS software. Before starting data acquisition, as shown in block diagram the output of detector 1 is given as start signal to TAC after going through CFD and delay module. Similarly the output of detector 2 is given as stop signal to TAC after going through CFD and delay module. Now in order to make the coincidence logic, a part of both CFD outputs were connected to CO-4010 unit as shown in the block diagram. After doing this the Energy pulse of each detector after going through amplifier, TAC Output and coincidence output are connected to the DAQ as shown in block diagram. In the LAMPS software we made a Time spectrum gated on 511keV in both detectors. Data was collected for 100cm to 600cm in steps of 100cm repeated several times. Here one detector was kept fixed and we moved the other detector. Data's was recorded in list mode E1, E2, T.

Analysis:

After collecting the data's in any experiment the next step is analysis. In this project also we did analysis by first obtaining the peak position for all the files and then clubbing all the 100cm files into one by taking weighted average for peak position. Similarly the other 200cm, 300cm, 400cm, 500cm, and 600cm files were also clubbed into single file. So that we obtained 6 peak positions corresponding to 6 distances (Table-2). After this we converted the peak positions into time with the help of calibration obtained for TAC (the time corresponding to one channel). Then we plotted the graph between distance (in x-axis) and time (in y-axis). Then we fitted the plotted point with a first order polynomial (y=m(x-100)+c) to get the slope. This slope corresponds to dt/dl, which is the inverse of speed of light. The fitted graph, TAC, energy spectrum of two detectors and TAC gated with energy are given below in fig-10, fig-6, fig-7, fig-8 and fig-9 respectively.

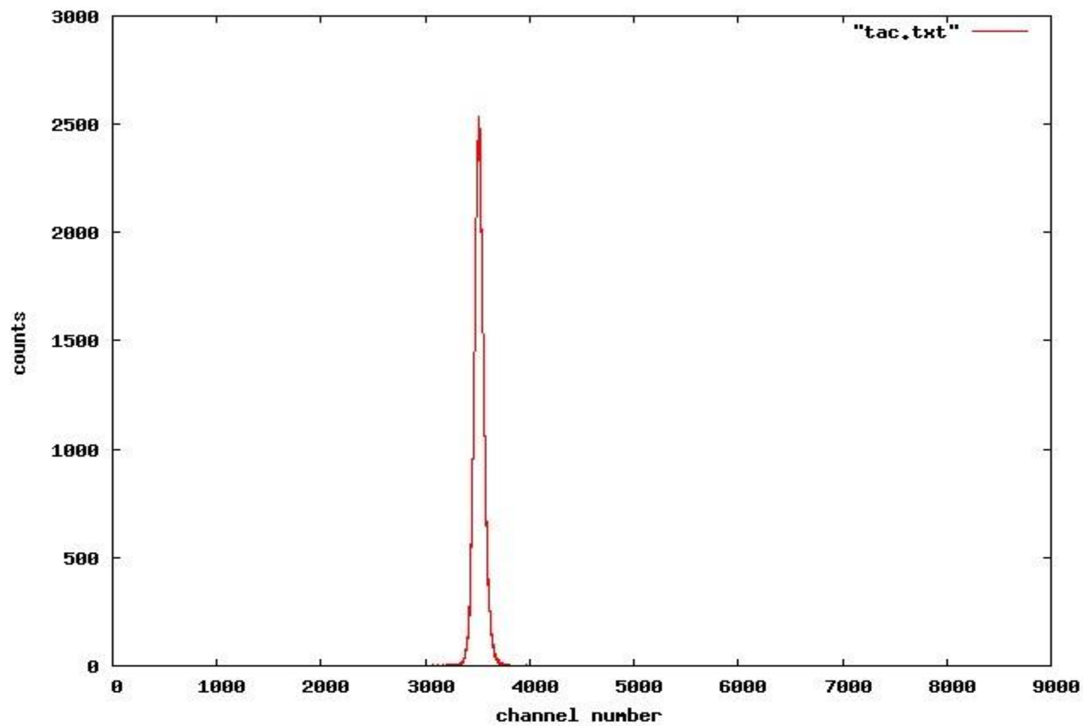

Fig-6: *TAC spectrum.*

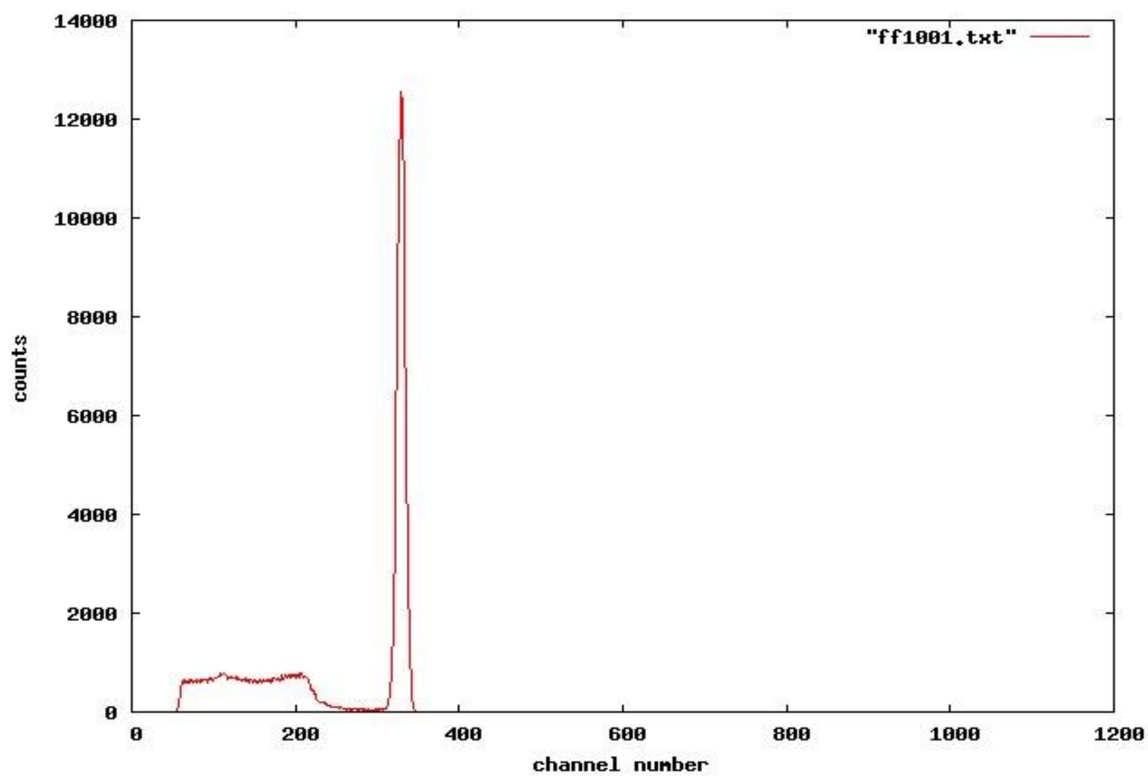

Fig-7: *Energy spectrum of detector 1.*

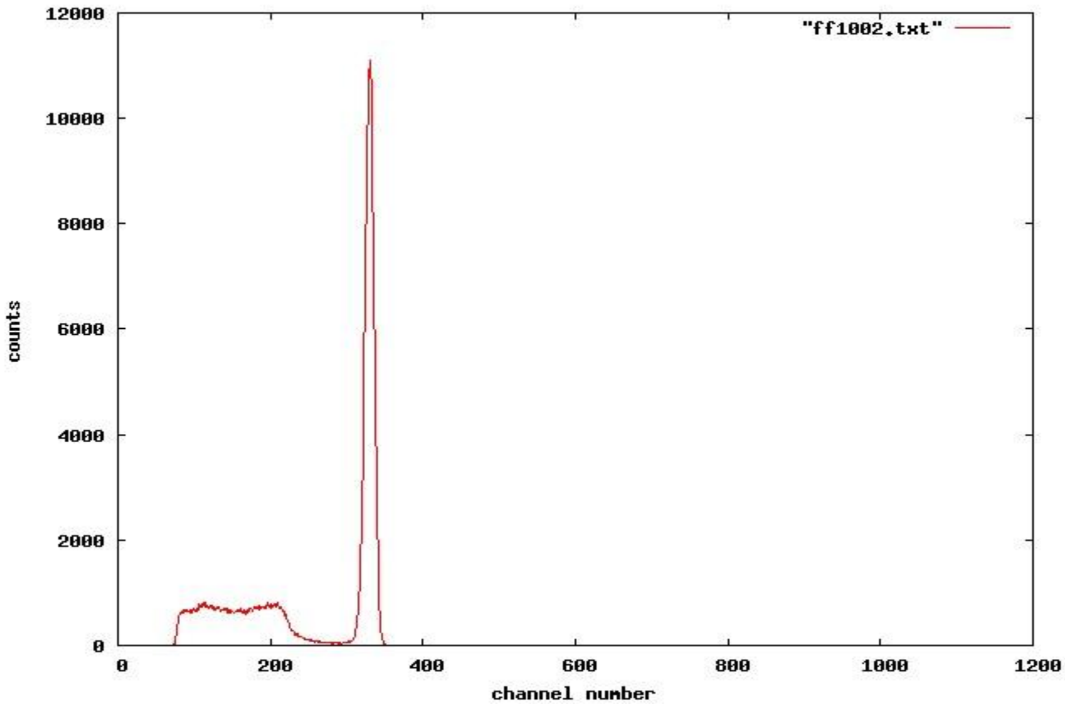

Fig-8: *Energy spectrum of detector 2.*

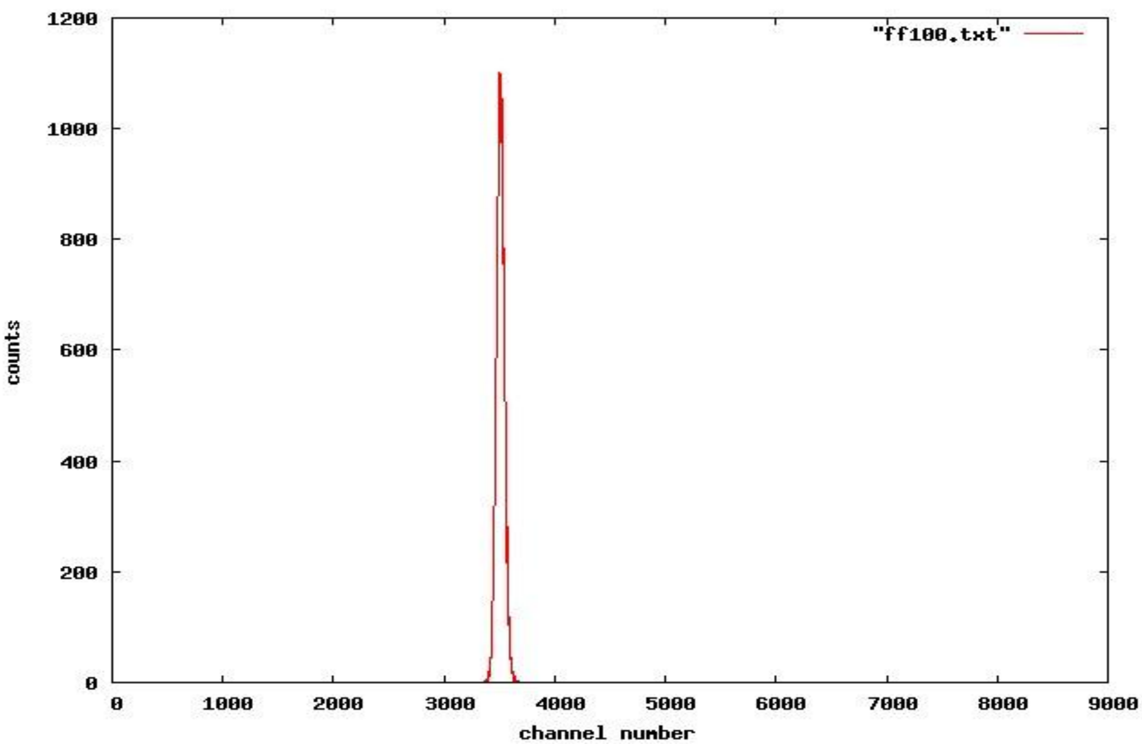

Fig-9: *TAC spectrum gated with energy of detector 1 and 2.*

Distance (cm)	*Error in distance (cm)*	*Time difference between start and stop (ns)*	*Error in time difference (ns)*
100	*0.1*	*23.069*	*0.0139*
200	*0.1*	*19.695*	*0.0077*
300	*0.1*	*16.363*	*0.0063*
400	*0.1*	*13.062*	*0.0052*
500	*0.1*	*9.685*	*0.0041*
600	*0.1*	*6.40*	*0.0332*

Table-2: *Time difference between start and stop corresponding to different distances.*

The Fitted graph with data points are shown below,

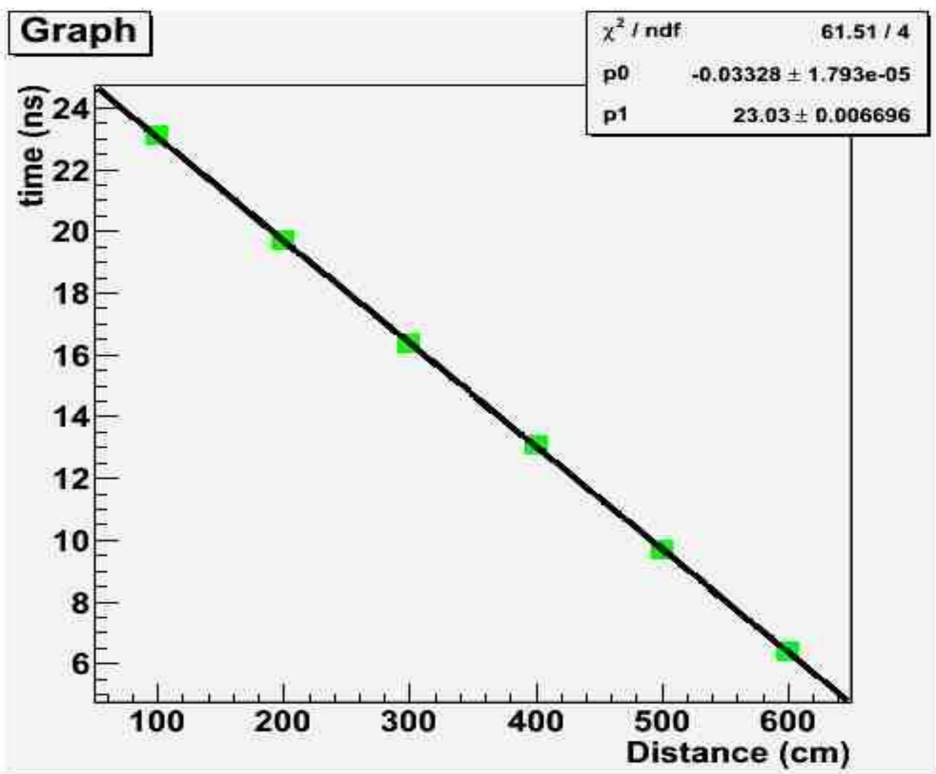

Fig-10: *Fitted graph with data points.*

The fit parameters were,

$m = -3.32829 \times 10^{-2} \pm 1.79334 \times 10^{-5}$,

$c = 23.030 \pm 6.69619 \times 10^{-3}$.

The speed of light is given by inverse of slope = 1/m

= 1/3.32829 x 10 $^{-2}$

=30.045 cm/ns.

The error for this speed is calculated by the formula,

$$\sigma_c{}^2 = (c/m)^2 * \sigma_m{}^2$$

Error in speed of light =0.0162 cm/ns.

Where

$\sigma_c{}^2$ *= Error in speed of light,*

$\sigma_m{}^2$ *= Error in slope measurement,*

m = slope.

The error in this experiment comes from various sources.
These include:

1) *The finite extent of sensitive volume of* $LaBr_{3,}$
2) *The size of Na-22 source,*
3) *The jitter in the rise time and transit time spread of the photomultiplier,*
4) *The linearity of various electronics used in the experiment including the delay unit, TAC, discriminator and the DAQ,*
5) *The accuracy of length measurement.*

The first four sources of error combine together and reflect themselves in the time resolution of the coincidence peak during time calibration. However we need to minimize the last source of error. So, in order to reduce that we took data's for each position several times and then we clubbed all the data's for the same position into one value by taking average out of those data's. In this way we reduced the systematic error given by the fifth source of error. Still there will be some sort of uncertainties present in the measurement and those uncertainties were reflected as errors in the calculated values.

Samarium 121keV energy level life time measurement:

At the concluding day of this project we did samarium 121 energy level life time by taking coincidence spectra of 1408 keV and 121 keV energy lines of europium lines. The reason for choosing 1408 keV and 121 keV lines were whenever there is a 1408 keV line there will be 121 keV line. So it's easy for us to set the coincidence between these two lines. Then we calibrated the TAC for this experiment as discussed above. Next the data's were obtained and fitted with the polynomial (log(y)=-ax+b) Here a=1/τ. The fitted graph (fig-11) and the calculations were shown below,

TAC calibration =0.0131 ± 0.000005 ns/channel.
Slope of the fitted function =0.0263 ± 0.0001018.
The decay constant of 121keV energy level = TAC calibration/slope.

=0.4981 ± 0.0019374.

Therefore the half life time of 121 keV energy level is calculated from the relation,

Half life time = 0.693/Decay constant.

= 1.3913 ± 0.005412 ns.

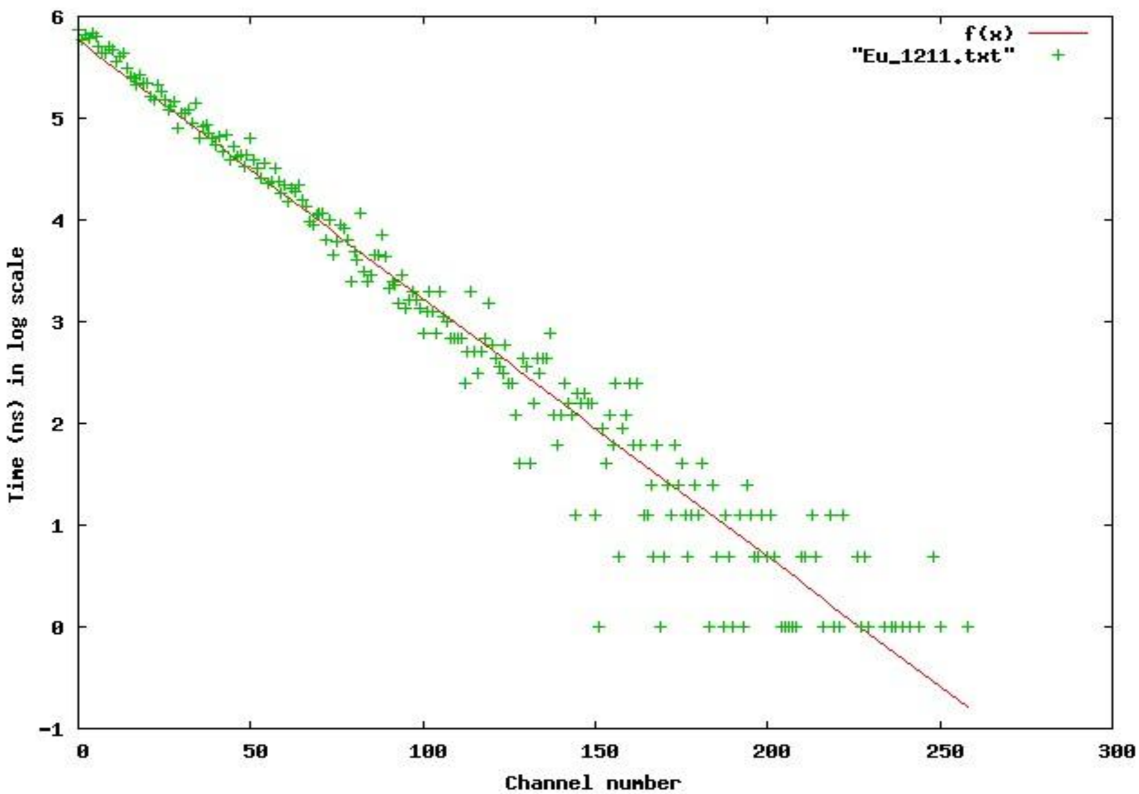

Fig-11: *Fitted graph with data points for europium life time.*

Conclusion:

From the analysis done on the collected data's we found the speed of light as 30.045 ± 0.0162 cm/ns. On the concluding day of "measuring speed of light" experiment we did samarium 121keV energy level life time measurement also as a part of this experiment and the life time of the samarium 121keV energy level was measured as 1.3913 ± 0.005412 ns.

Teams:

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4) *Maulik nariya.*

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