GAMMA RAY PRODUCTION FROM NEUTRAL – CURRENT NEUTRINO – NUCLEUS INTERACTIONS

DISSERTATION

Submitted to SRM Institute of Science and Technology

In partial fulfilment of the requirement

for the award of the Degree of

Bachelor of Science

in

Physics

by

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SRM INSTITUTE OF SCIENCE AND TECHNOLOGY,
KATTANKULATHUR, CHENNAI – 603 203

MAY 2018

DECLARATION

I hereby declare that the dissertation entitled **"GAMMA RAY PRODUCTION FROM NEUTRAL – CURRENT NEUTRINO – NUCLEUS INTERACTIONS"** submitted for the degree of Bachelor of Science is my original work and the dissertation has not formed the basis for the award of any degree, diploma, associateship, fellowship of similar other titles. It has not been submitted to any other University or Institution for the award of any degree or diploma.

Place :

Date : Deepti Hariharan

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Submitted for university project viva-voce examination held at **SRM INSTITUTE OF SCIENCE AND TECHNOLOGY,** *Kattankulathur, Chennai – 603203*

Date

Internal Examiner

External Examiner

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ABSTRACT

A core – collapse supernova emits an enormous number of neutrinos and anti-neutrinos of all flavors. They have a mean energy of ~10-20 MeV and carry away nearly 99% of the total gravitational energy. They can be detected and analyzed by studying the charged-current inverse β-decay reaction, which is the largest contribution, or by the neutral-current (NC) inelastic scattering reactions, which is expected to be the second largest contribution in large-scale detectors like Super Kamiokande (water – based), KamLAND (liquid – scintillator based), etc.. The NC scattering reactions are dominated by reactions between ν_μ / ν_τ neutrinos (anti-neutrinos) with ^{12}C and ^{16}O. Therefore, to understand the mechanism of the core – collapse event, these NC events have to be understood well. ^{12}C and ^{16}O are excited to giant resonances through NC inelastic scattering with neutrinos. The gamma rays emitted during decay of these resonant states can be used to study underlying mechanism of NC events.

In the experiment E398, the Grand Raiden conducted at RCNP, Osaka University, Japan, a high – energy proton beam has been used to excite ^{12}C and ^{16}O to giant resonant states and study the gamma rays released to obtain systematic experimental data. The optical potential model can be used for the interaction potential and form factors, which in turn yields the nuclear matrix element for the decays. The nuclear form factors involve the contributions from the neutral-current as well as charged current dynamics.

In this work, we study the gamma ray emissions from proton – ^{12}C scattering data. The data for 15.1 MeV gamma rays from the giant resonance of ^{12}C has been analyzed. Aforementioned, these reactions are expected to be the second largest

contribution, thus data has to be analyzed for higher precision. The gain of the photomultiplier tubes decreases gradually on each run because of continuous gamma ray emission. This gives us information about the shift in the gain value for each counter. It is seen that the first three columns of detectors have a poor energy resolution. The last two columns have a stable gain and good resolution. These are reliable for accurate measurements. The stabilization of gain for each PMT is required to produce accurate results with target 5% uncertainty. This work has been done in collaboration with the E398 group in Okayama University, Japan.

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INTRODUCTION

1.1. INTRODUCTION

Neutrinos are charge-less leptonic particles that come under the standard model. They were first theorized by Pauli in 1930 to account for the continuous distribution of energy during beta decay. A model was developed by Fermi and later confirmed in the Cowan – Reines experiment.

During the core – collapse event of supernovae, extremely large number of neutrinos are released from the core. These neutrinos interact with the element present on the way out. Study of such neutrinos will help understand the event core – collapse event better.

During beta decay, beta particles are emitted with a range of energies instead of a sharp cross-section as in figure 1. Also, during emission, the beta particles came out with an angle instead of recoiling in a straight line relative to the incident particle which seemed to violate conservation of momentum [3]. To account for these abnormalities, Pauli suggested another highly-penetrating particle which was later named ‘neutrino’ by Fermi. Conservation of angular momentum requires it to be a fermion (spin 1/2).

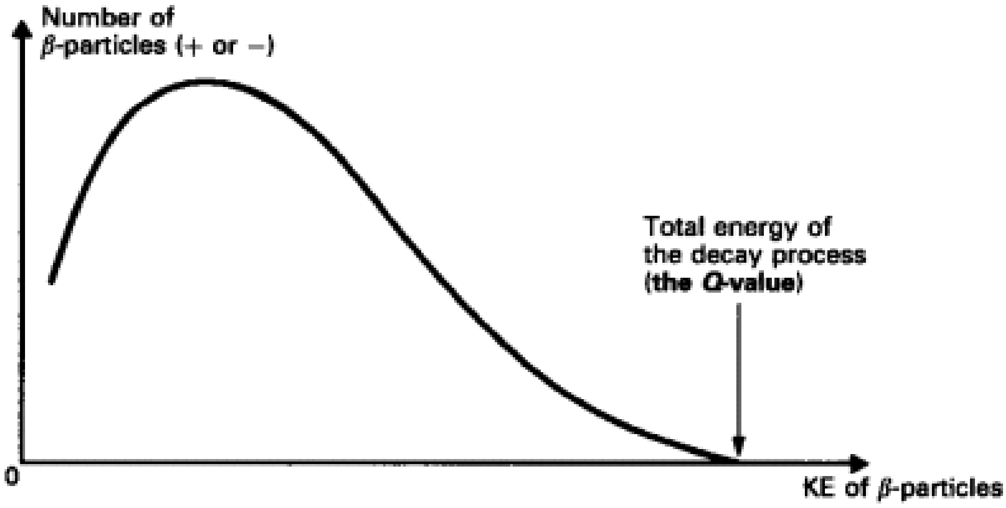


Figure 1: Beta spectrum – continuous spectrum instead of the expected discreet energies
Credits: R. Church, quantumdiaries.org

1.2. CORE – COLLAPSE SUPERNOVA

Supernova is the violent death of massive stars. The core – collapse event happens in type II supernovae and depending on the initial mass of the star, it can collapse into either a neutron star or a black hole.

Nuclear fusion is the main source of energy force to balance the star against its gravity. Initially, hydrogen burning takes place. When all the hydrogen is used up, the rate of fusion decreases thus decreasing the energy to act against gravity causing the star to fall inwards. The collapse of the star raises the temperature and helium fusion is started. This process of fusion, collapse and fusion of the next element continues progressively till iron stage is reached (figure 2). Iron is the most stable element and a tremendous amount of energy must be supplied to it for fusion. The energy produced by collapse is not enough to commence the fusion of iron and so the core continues collapsing beyond electron degeneracy limit. The temperature inside the core is very high and is released in the form of high-energy gamma rays. These photons disintegrate iron nucleus to lighter nuclei in a process termed photodisintegration. Beyond Chandrasekhar mass limit ($M_{star} > 1.4M_{\odot}$), electron degeneracy point is crossed and protons and electrons start combining to form neutrons and electron-neutrinos by electron capture:

$$p^{+} + e^{-} \rightarrow n + \nu_{e}$$

This release of energy in the form of gamma rays and neutrinos causes the star to contract further and cool down. The core starts detaching from the outer layers. The neutrinos rarely interact with matter and escape freely carrying away 99% of the gravitational energy [2].

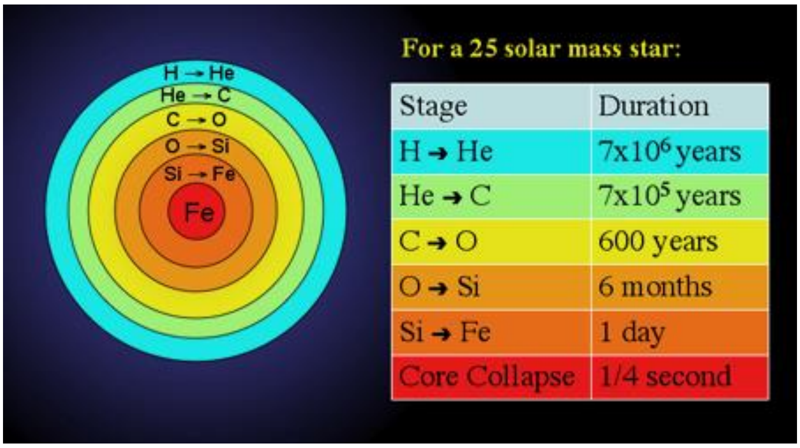


Figure 2: Life of a massive star
Credits: astronomy.swin.edu.au

The star cannot collapse beyond the neutron degeneracy pressure. At this point, the strong nuclear force becomes repulsive. The materials of the star rebound in a violent shock-wave which propagates outwards and dissociates the heavy element present in the core. The dissociation reduces the energy and halts the shock. The core, which now consists mostly of neutrons, is at an extremely high temperature and this energy is released in the form of neutrinos. These thermal neutrinos and anti-neutrinos come in all flavors and are several times more in number than the electron-capture neutrinos. The core is so dense that it is transparent only to neutrinos. The compression is so enormous that even iron starts fusing and all the higher elements like gold, silver, platinum, etc. are formed. The neutrinos produced interact with the matter present on the way out and imparts energy to the halted shock wave and resumes it. The materials are dissipated in space.

The process by which the neutrinos impart energy and momentum to the halted shock wave to resume it is not fully understood.

1.3. COMPOUND NUCLEUS REACTIONS

A nucleus excites to higher levels by energy transfer from the incoming particle. The excited compound nucleus formed has a relatively long life-span of 10^{-18} – 10^{-16} seconds and decays into products independent of how it was formed. This usually happens if the projectile has low energy. The de-excitation depends only on the energy, angular momentum and parity of the compound nucleus.

$$A + a \rightarrow X^{*} \rightarrow B + b$$

A compound nucleus may decay by emission of particles or gamma ray or by fission as in the case of heavy nuclei.

1.3.1. Hadronic Decay: -

Decay of the compound nucleus by emission of hadronic particles such as proton, neutron, alpha particle, etc. is termed as hadronic decay. Release of such particles may initiate a chain of other reactions in a cascade which will be discussed later.

$$X^{*} \rightarrow Y + b + \gamma$$

1.3.2. Electromagnetic Decay: -

Decay by emission of gamma rays with no intermediate hadronic state is termed direct / electromagnetic decay.

$$X^* \rightarrow X + \gamma$$

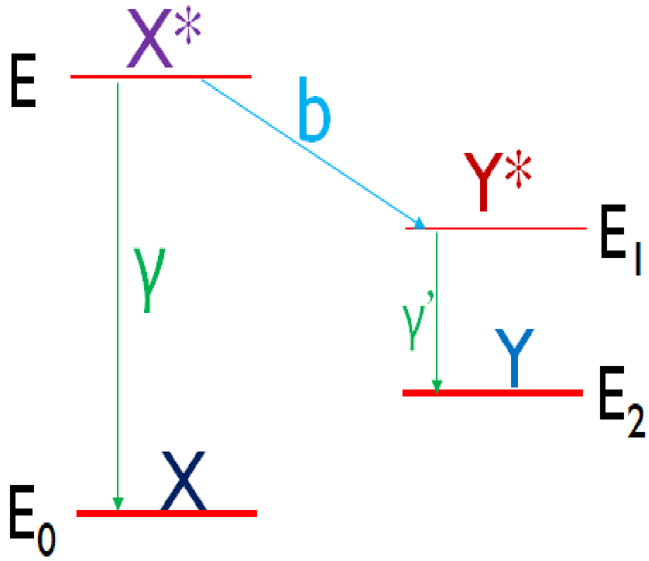


Figure 3: Types of decay

1.3.3. Cascade Reactions

Decay of compound nuclei sometimes leads to a sequence of reactions where a particle released by one nucleus is absorbed by the next nucleus and so on. This leads to a final product of multiple nuclei and particles. The cross-section of each reaction is therefore less and the overall spectral function has a large width.

The chain reaction in fission of uranium is one such example. The neutron released one nucleus is absorbed by another nucleus and the reaction continues.

Another example is that of ^{32}S decaying to ^{26}Al with intermediate ^{28}Si and ^{27}Al. ^{32}S decays by alpha decay into ^{28}Si. This undergoes β^+ decay to ^{27}Al. ^{27}Al decays by β^- decay into ^{26}Al.

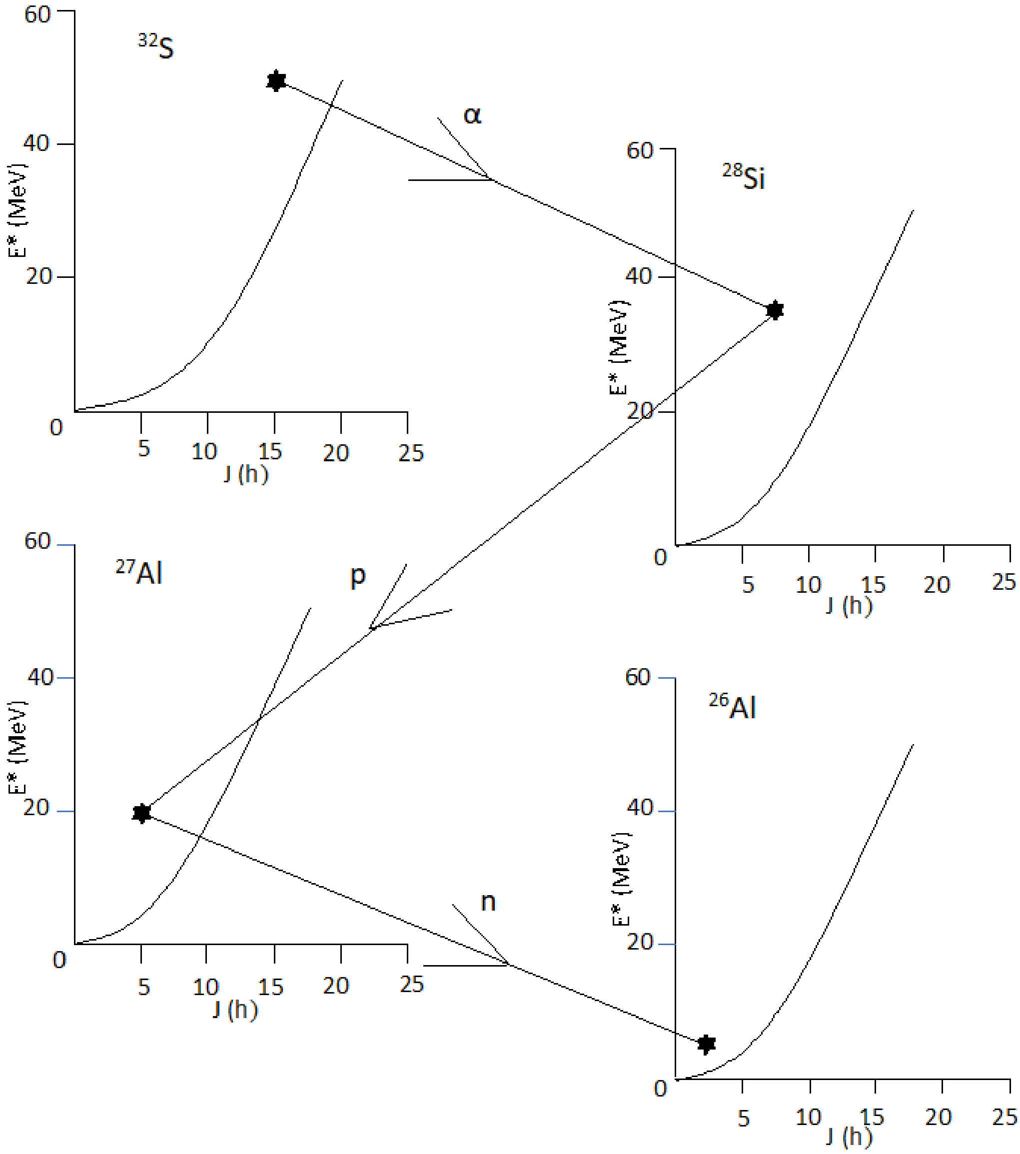


Figure 4: Stepwise α, neutron and proton decay of ^{32}S to ^{26}Al

1.4. GIANT RESONANCE

Inelastic scattering is of many types like quasi-elastic scattering, single – particle resonance, giant resonance, etc... Resonance is the oscillation of particles inside the nucleus when the external frequency matches the frequency of the particles inside. Depending on the available energy from the incident particle, resonance may take place for one or a few particles or all the particles in the nucleus. Collective oscillation (vibrations or rotations) of many or all the particles inside the nucleus is called giant resonance. The resonance corresponds to the transition between collective exited states and the ground state. The strength of the transition, given by the transition amplitude, depends upon he number of particles exited and the size of the system. Giant resonance can be described as a high – frequency, damped harmonic vibration around the mean shape of the system [6].

There are many types of resonance modes classified according to their quantum numbers:

1. Isovector giant dipole resonance (IVGDR): collective nuclear vibration in which all protons vibrate against neutrons resulting in separation between the center of mass and center of charge resulting in a magnetic dipole.
2. Isoscalar giant monopole resonance (ISGMR): electric, isoscalar vibrations in which the protons and neutrons oscillate in phase.
3. Isovector giant monopole resonance (IVGMR): electric, isovector vibrations in which protons and neutrons oscillate out of phase against each other. This will be at a higher energy than the isoscalar one because more energy is required to separate the neutron and proton distribution.
4. Magnetic, isoscalar vibrations in which nucleons with spin ↑ vibrate with nucleons with spin ↓.
5. Magnetic, isovector modes in which protons with spin ↑(↓) oscillate against neutrons with spin ↓ (↑).

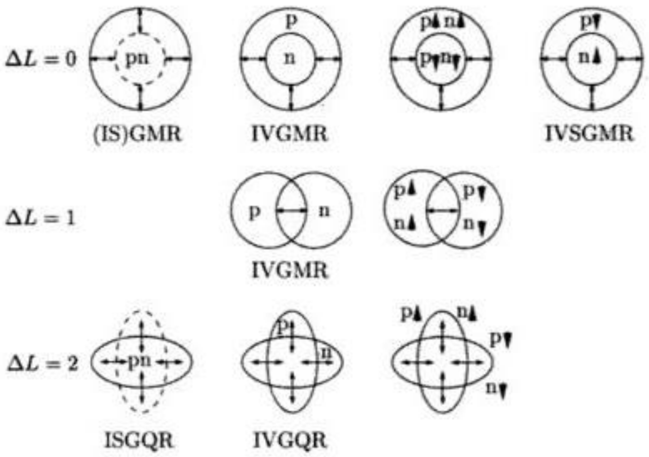


Figure 5: Various collective modes

1.5. WEAK INTERACTIONS

Weak interactions in one of the four fundamental forces besides strong force, electromagnetic force and gravitation. It occurs by exchange of intermediate vector bosons, W^+, W^- and Z^0. These are massive particles with mass ~ 80 GeV and exist virtually. The W^+ and W^- bosons are charged whereas the Z^0 boson is neutral. It is weaker than electromagnetic force and acts within one-thousandth the diameter of a proton.

Type of Interaction	Strength	Range	Experiencing Particles	Force Carrier Particle
Strong	1	10^{-15} *(diameter of nucleus)*	Nucleons	Gluon
Electromagnetic	$\frac{1}{137}$	∞	Charges	Photon
Weak	10^{-6}	10^{-18} *(0.1% diameter of proton)*	Sub-atomic Particles	Intermediate Vector Bosons
Gravity	10^{-39}	∞	Masses	?

Table 1: The four fundamental forces
Credits: hyperphysics.phy-astr.gsu.edu/hbase/Forces/funfor

Neutrino, being a charge-less leptonic particle can interact only via the weak force.

1.5.1. Charged – Current Interaction

These are reactions in which the W^+ and W^- bosons are involved. The interaction involves the transfer of charge like the absorption of an electron or positron.

$$n \xrightarrow{W^-} p + e^- + \nu_e$$

$$e \xrightarrow{W^+} \nu_e$$

1.5.2. Neutral – Current Interaction

Neutral – current interactions are mediated by Z^0 bosons. Transfer of energy, momentum and spin takes place but there will be no transfer of charge.

$$\nu + X^* \xrightarrow{Z^0} \nu' + X + \gamma$$

CHAPTER 2

THEORETICAL BACKGROUND

2.1. THE OPTICAL POTENTIAL MODEL

Analogous to refraction in optics, the optical potential model is a good approximation for calculating the energy averaged cross – section of reactions with large width [4]. The elastic scattering, in which energy is conserved is taken as the real part of the scattering and the other scattering effects which involve absorption of energy like inelastic scattering, resonances, etc. are taking as the imaginary part of the potential. As the energy increases, the number of non-elastic channels increase.

The absorption of energy by the nucleus can be described by adding an imaginary part to the potential [1]. It is a one body potential and can be written as:

$$U(r) = V(r) + \iota W(r)$$

$V(r)$ represents the nuclear shell-model potential and $\iota W(r)$ accounts for the absorption effects. Interaction with the incident particle also causes oscillations in the nucleus which leads to significant polarization [1]. Therefore, the polarization factor also has to be considered for more accuracy in calculating the potential. There may also be some electrostatic interaction between the nucleus and projectile. A general form for the potential is the sum of the central potential and the spin-orbit interaction potential,

$$U(r) = U_C(r) + \ U_S(r)\boldsymbol{\sigma} \cdot \boldsymbol{l}$$

with r being the distance between the particle and the center of mass of the nucleus, $\boldsymbol{\sigma}$ the spin and $\boldsymbol{l}$ the angular momentum.

The central potential is:

$$U_C(r) = V_C - Vf_o(r) - \iota Wf_v(r) + 4\iota W_s \frac{d}{dr} f_s(r)$$

V_C is the Coulombic potential of the form $\frac{Z_1 Z_2 e^2}{r}$ and $Vf_o(r)$ is the elastic potential. $\iota Wf_v(r)$ and $4\iota W_s \frac{d}{dr} f_s(r)$ give the absorption effect at the volume and surface of the nucleus, respectively.

The spin-orbit potential is:

$$U_S(r) = (\frac{\hbar^2}{mc})^2 \frac{1}{r} \; [V_s \frac{d}{dr} f_{vs}(r) \; + \; \iota W_s \frac{d}{dr} f_{ss}(r)]$$

The form-factor used here is of the Woods – Saxon form:

$$f(r) = \frac{1}{1 + \; e^{\frac{r - R}{a}}}$$

where $R = \; R_o A^{1/3}$ and a is the diffuseness parameter.

The optical potential model is limited to oscillations of large width and cannot describe sharp cross-sections. At higher energies, the resonances cannot be resolved and it appears as a continuous spectrum with a large decay width which can be explained well using the optical potential.

2.2. CROSS-SECTION

The cross-section of a reaction is defined as the probability of occurrence of the particular reaction. It is commonly measured as the differential cross-section ($\frac{d\sigma}{d\Omega dE}$) and the overall cross-section is obtained by integrating over the energies and solid angles.

Considering the incoming particle to be a wave, the Schrödinger equation is

$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + V_C(r)\right]\psi(r) = E\psi(r)$$

where μ is the reduced mass and E is the total energy [5]. It can be solved using the boundary condition:

$$\psi(r) \to e^{ikz} + f(\theta)\frac{e^{ikr}}{r}, (r \to \infty)$$

The first term is the incoming plane wave in the z-axis and the second term is the outgoing wave. $f(\theta)$ is the scattering amplitude from which the differential cross-section can be found:

$$\frac{d\sigma}{d\Omega} = |f(\theta)|^2$$

Solving the Schrödinger's equation mathematically is very challenging because the perfect form of the scattering amplitude (form-factor) is unknown. It can be found phenomenologically. The global optical potential, which considers the mass and energy dependence, is used to calculate the approximate shape of the form-factor, and the optimum parameters are found experimentally.

CHAPTER 3

EXPERIMENTAL DATA ANALYSIS

3.1. EXPERIMENT

An experiment was conducted at the Research Center for Nuclear Physics, Osaka under the project name E398 to study the gamma rays produced by giant resonance states of ^{16}O and ^{12}C.

The detector consists of an array of 25 NaI(Tl) counters each 2 inches in height and width and 6 inches in depth and a magnetic spectrometer "Grand Raiden". The target is neutral carbon and cellulose ($C_6H_{10}O_5$). A 392 MeV unpolarized proton beam was bombarded on the target. This excites the atoms to giant resonances which eventually decay by release of gamma rays. These gamma rays were measured by the

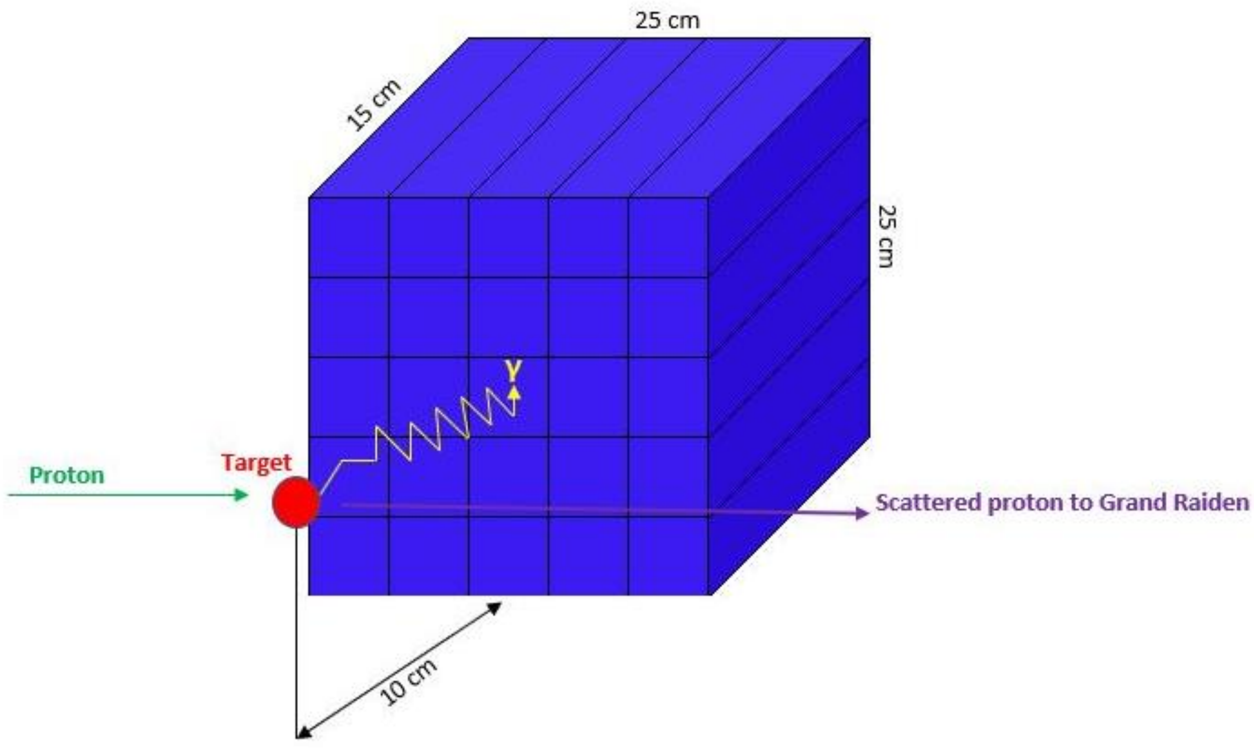


Figure 6: Target set-up

25 scintillation NaI(Tl) counters coupled with PMTs and placed 10 cm away from the target at $\theta_\gamma = 90°$ and the momentum of the scattered protons at scattering angle $\theta_p = 0°$ were analyzed by the Grand Raiden [5].

10	**11**	**12**	**13**	**14**
25	**1**	**2**	**3**	**15**
24	**8**	**9**	**4**	**16**
23	**7**	**6**	**5**	**17**
22	**21**	**20**	**19**	**18**

Table 2: Detector numbering – the first two columns receive radiation in the forward-angle and the last three receive radiation from the backward-angle relative to the beam

3.2. REACTIONS

The carbon atom, after interaction with the incoming proton, excites to giant resonance states which are peaked at 10 – 30 MeV:

$$^{12}C + p \rightarrow {}^{12}C^{*} + p'$$

This decays by release of gamma rays – electromagnetic decay

$$^{12}C^{*} \rightarrow {}^{12}C + \gamma,$$

or by release of a hadronic particle and subsequently a gamma ray – hadronic decay

$$^{12}C^{*} \rightarrow p + {}^{11}B + \gamma$$

$$^{12}C^{*} \rightarrow n + {}^{11}C + \gamma$$

$$^{12}C^* \rightarrow t + \ ^9B + \gamma$$

$$^{12}C^* \rightarrow d + ^{10}B + \gamma$$

$$^{12}C^* \rightarrow \alpha + \ ^8Be + \gamma$$

Among the hadronic decays, the proton and neutron channels are the dominant ones. For the 15.1 MeV resonance state of ^{12}C, only direct decay is possible.

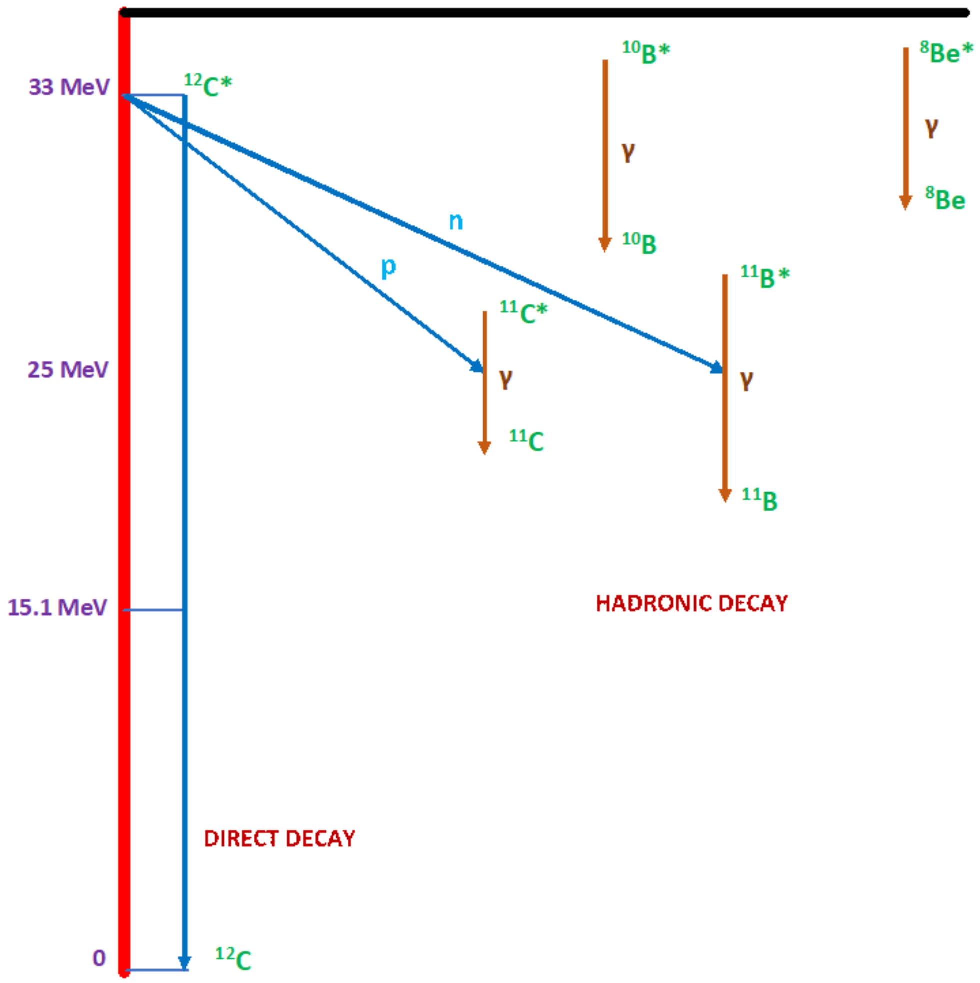


Figure 7: Decay modes of ^{12}C

The decay mode and energy of gamma ray is dependent on the Q-value for the reaction. These gamma rays are analysed to find the decay width of the reactions. The decay width for electromagnetic decay is $10^{-2} – 10^{-4}$ times the total decay width.

3.3. ANALYSIS OF GAMMA RAYS

3.3.1. ROOT

The analysis was done using ROOT, an object-oriented program and library developed by CERN originally for data analysis in particle physics designed for high computing efficiency. It contains several features specific to particle physics. It also has several applications in astronomy and data mining.

Development of ROOT was initiated by René Brun and Fons Rademakers in 1994. The program library is mainly built on C++ but is integrated with other languages such as Python and R. The version used here is C++.

3.3.2. Gain Calibration

The gain value and the peak value of the PMT gradually decreases over time due to continuous gamma radiation and radio-activation of the NaI(Tl) counters during the beam time as in figure 8. This results in a decrease in the energy resolution of the counters.

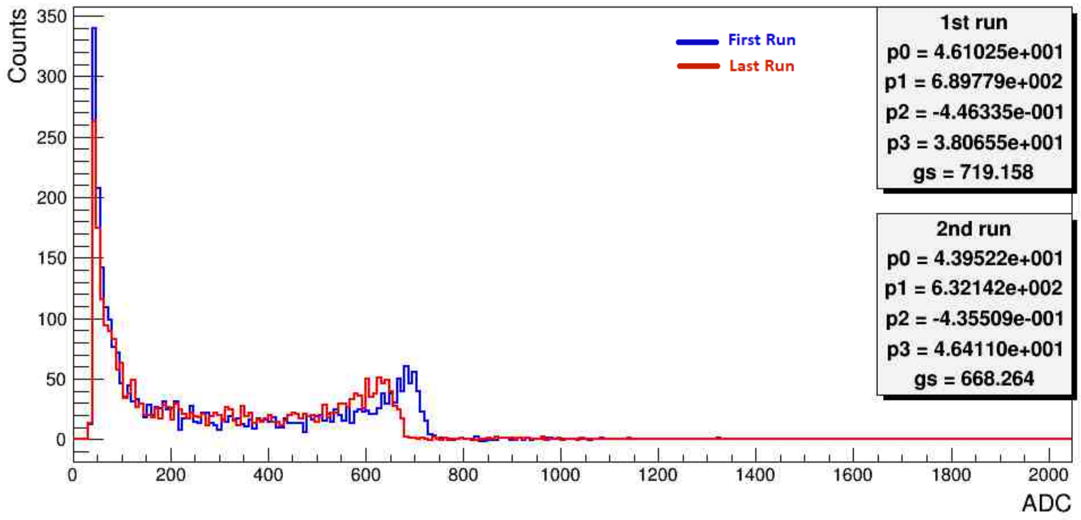


Figure 8: Gain shift from first to last run for a single counter – a clear decrease in gain is seen.

The gain calibration has been done using 15.1 MeV giant resonant state of ^{12}C. This shift in gain was corrected by first fitting the peak region with an asymmetric gaussian of the form:

$$f(ADC) = \ p_0 e^{-\frac{(ADC-p_1)^2}{2\sigma^2}}$$

$$\sigma = p_2(ADC + p_1) + p_3$$

where σ is the resolution, p_0 is the height, p_1 is the peak value and p_2, p_3 are asymmetric parameters. The parameters p_0, p_1, p_2, p_3 are obtained from the fit.

From this fit, the gain parameter can be determined:

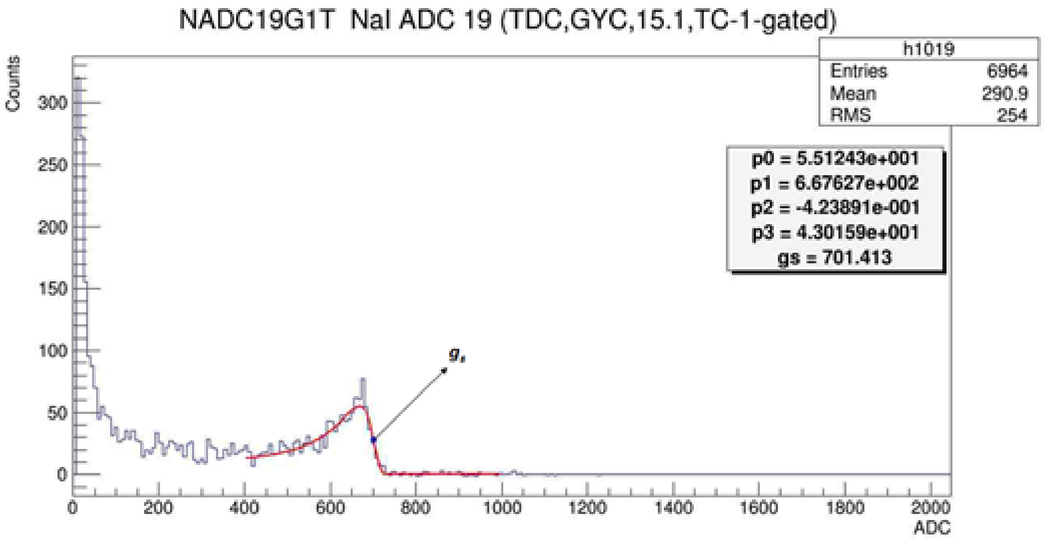


Figure 9: Gain parameter

The gain shift was corrected for each run with respect to the first run:

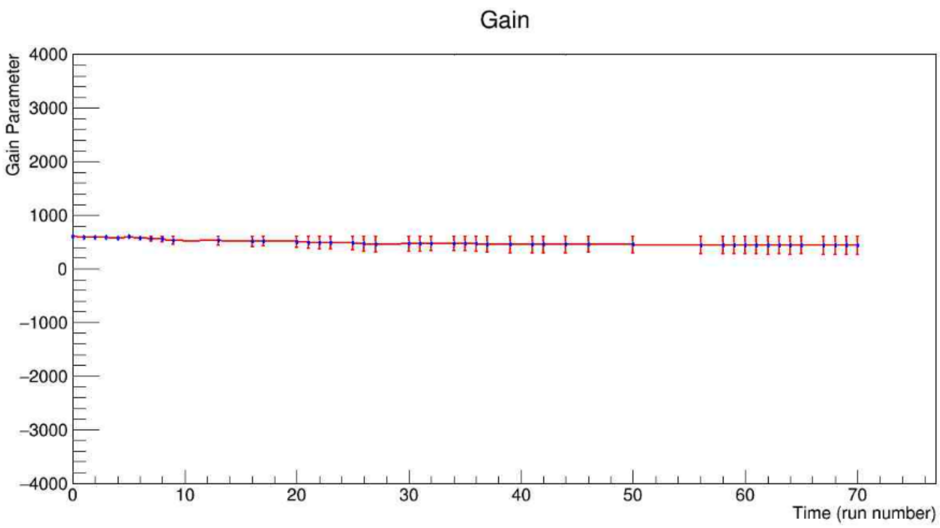
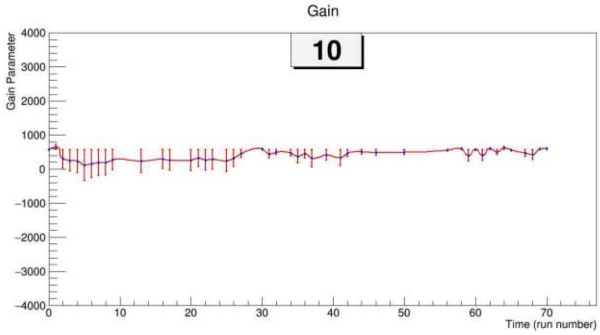


Figure 10: Gain shift correction

This was done for all counters: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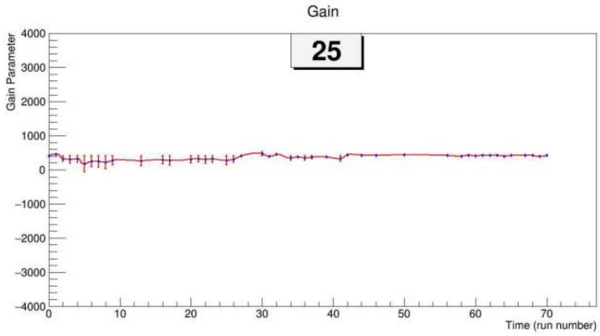
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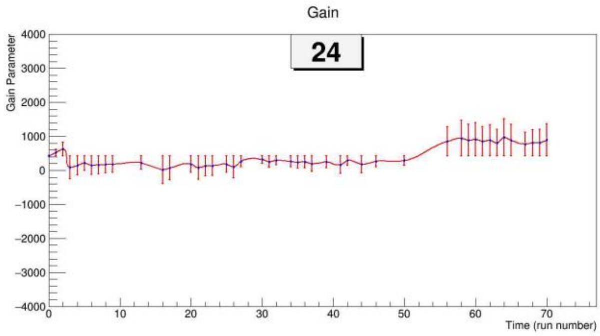
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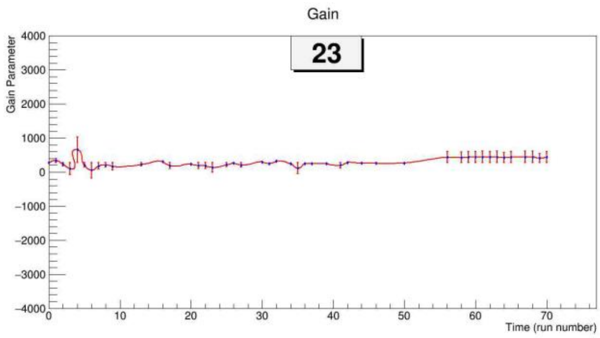
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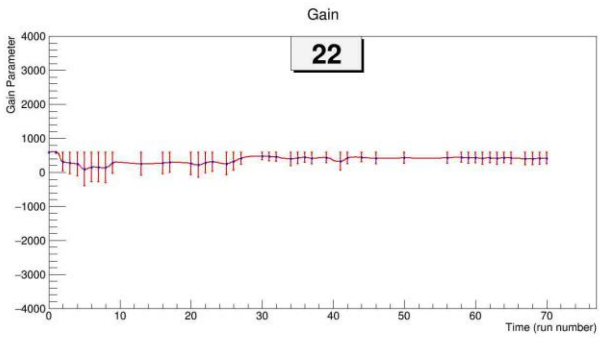
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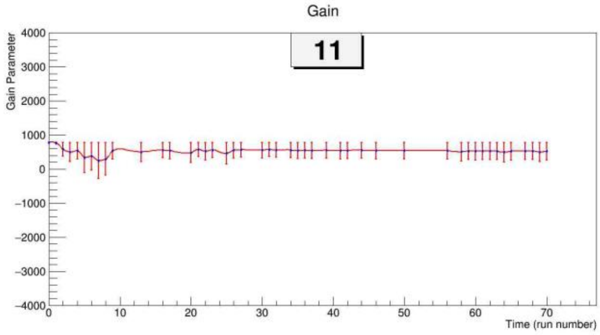
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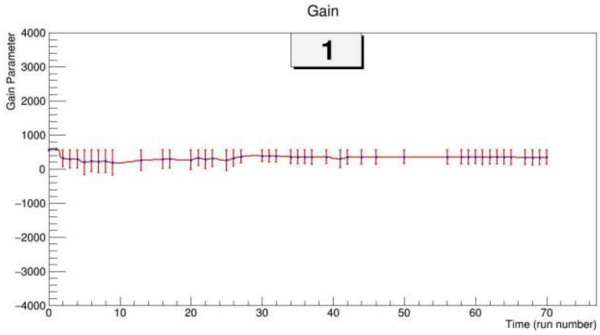
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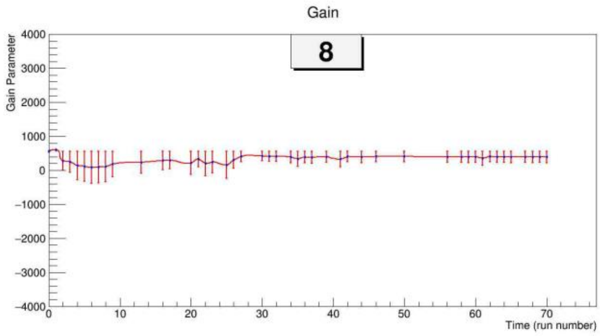
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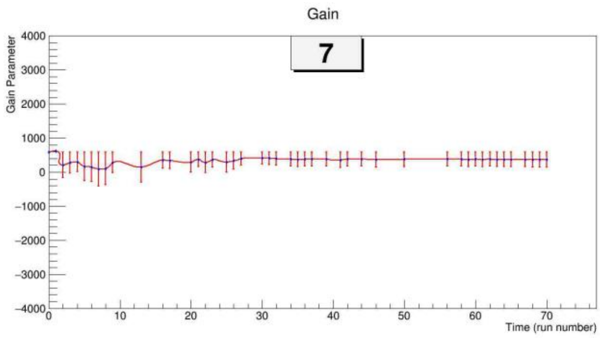
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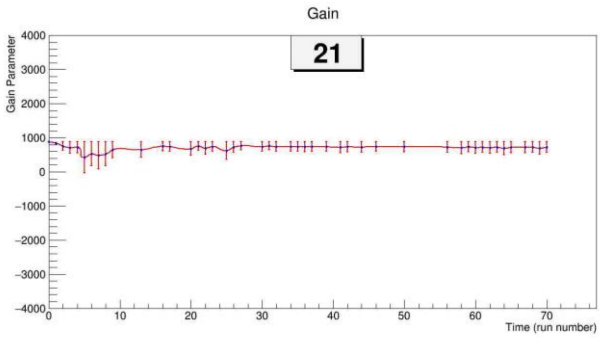
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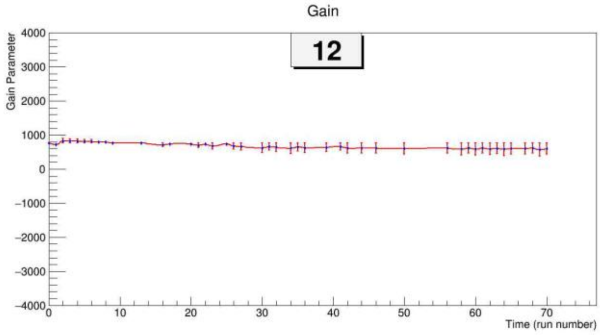
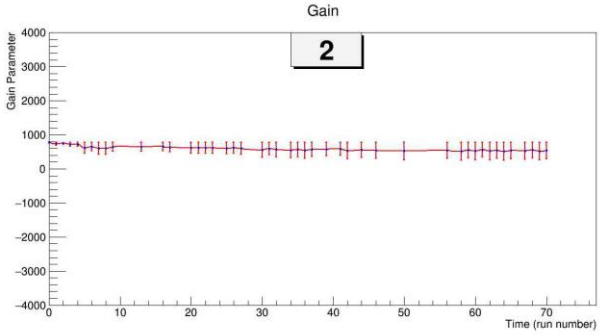
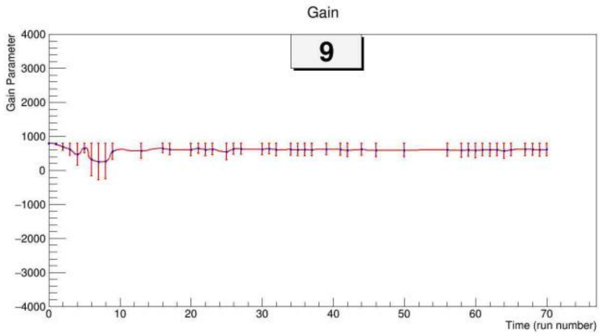
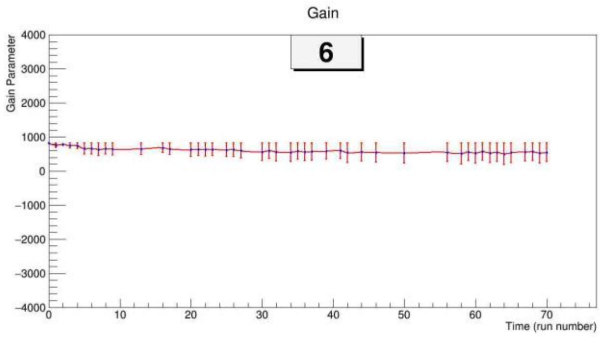
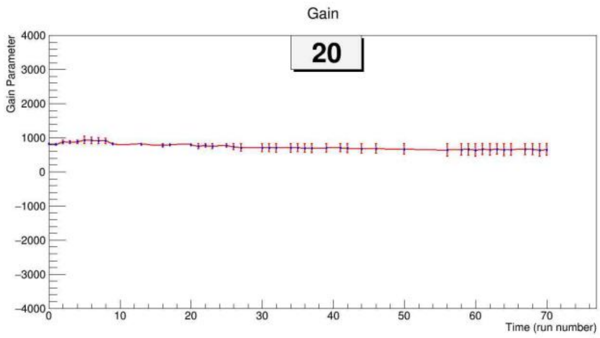
70
Time (run number)

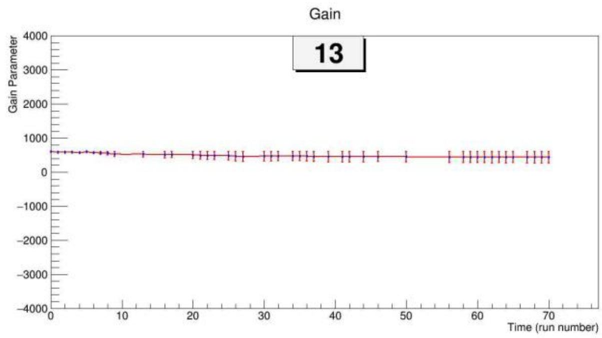

Gain
12
Gain Parameter
4000
3000
2000
1000
0
−1000
−2000
−3000
−4000
0
10
20
30
40
50
60
70
Time (run number)

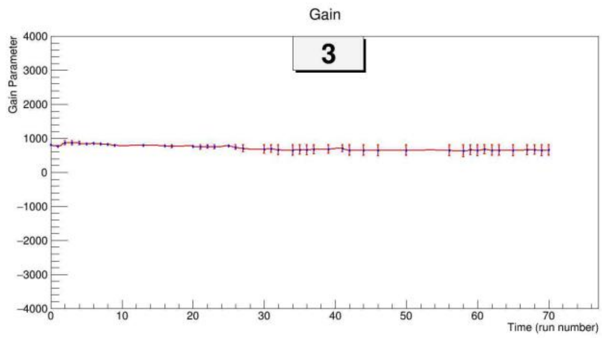

Gain
2
Gain Parameter
4000
3000
2000
1000
0
−1000
−2000
−3000
−4000
0
10
20
30
40
50
60
70
Time (run number)

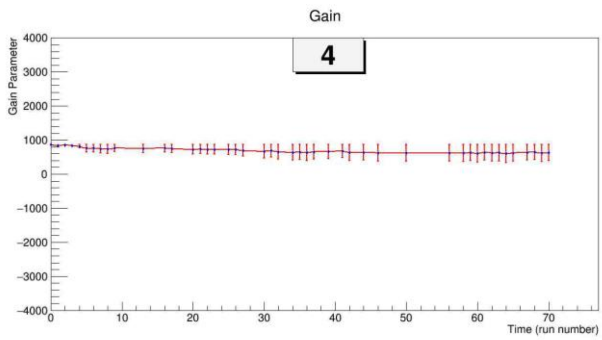

Gain
9
Gain Parameter
4000
3000
2000
1000
0
−1000
−2000
−3000
−4000
0
10
20
30
40
50
60
70
Time (run number)

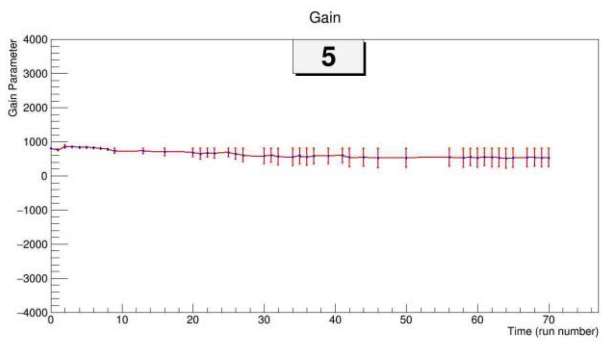

Gain
6
Gain Parameter
4000
3000
2000
1000
0
−1000
−2000
−3000
−4000
0
10
20
30
40
50
60
70
Time (run number)

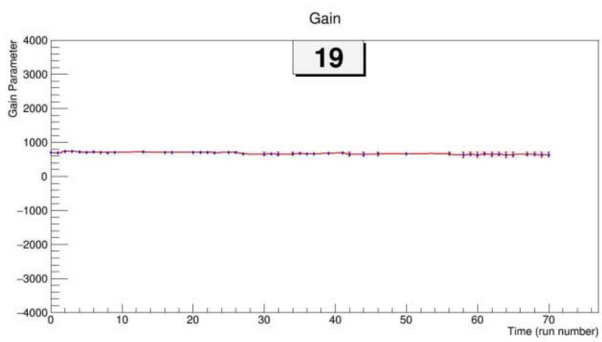

Gain
20
Gain Parameter
4000
3000
2000
1000
0
−1000
−2000
−3000
−4000
0
10
20
30
40
50
60
70
Time (run number)

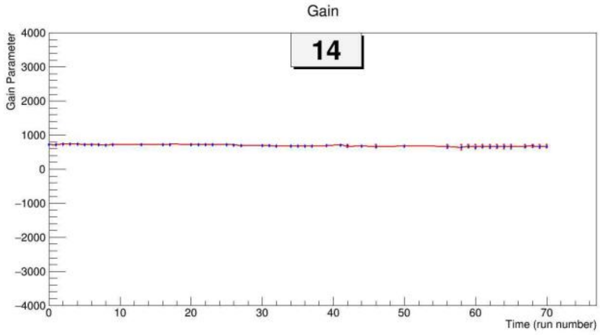

Gain
13
Gain Parameter
Time (run number)

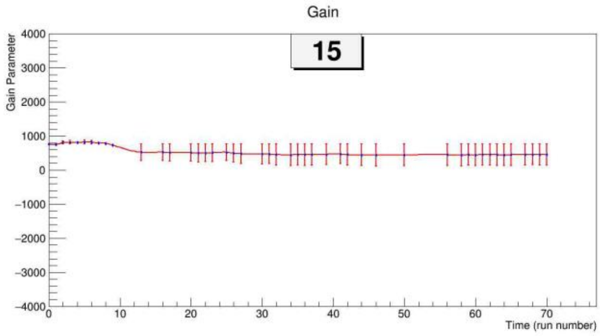

Gain
3
Gain Parameter
Time (run number)

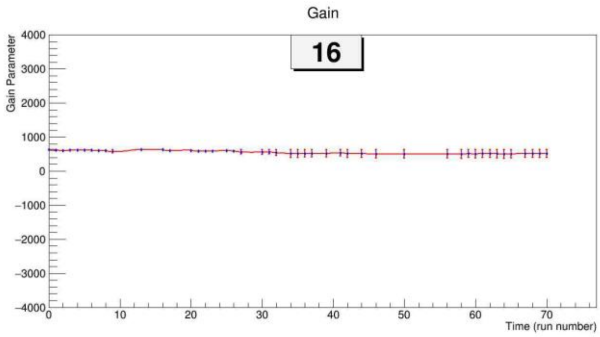

Gain
4
Gain Parameter
Time (run number)

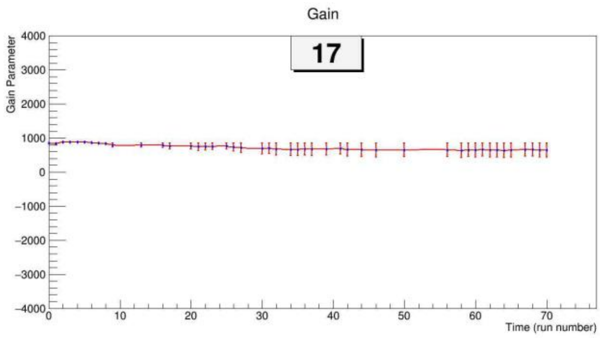

Gain
5
Gain Parameter
Time (run number)

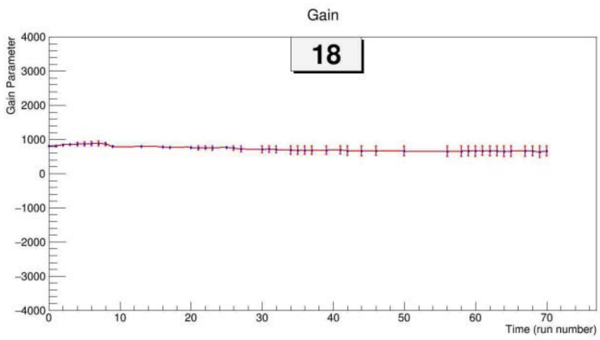

Gain
19
Gain Parameter
Time (run number)


Gain
14
Gain Parameter
Time (run number)


Gain
15
Gain Parameter
Time (run number)


Gain
16
Gain Parameter
Time (run number)


Gain
17
Gain Parameter
Time (run number)


Gain
18
Gain Parameter
Time (run number)

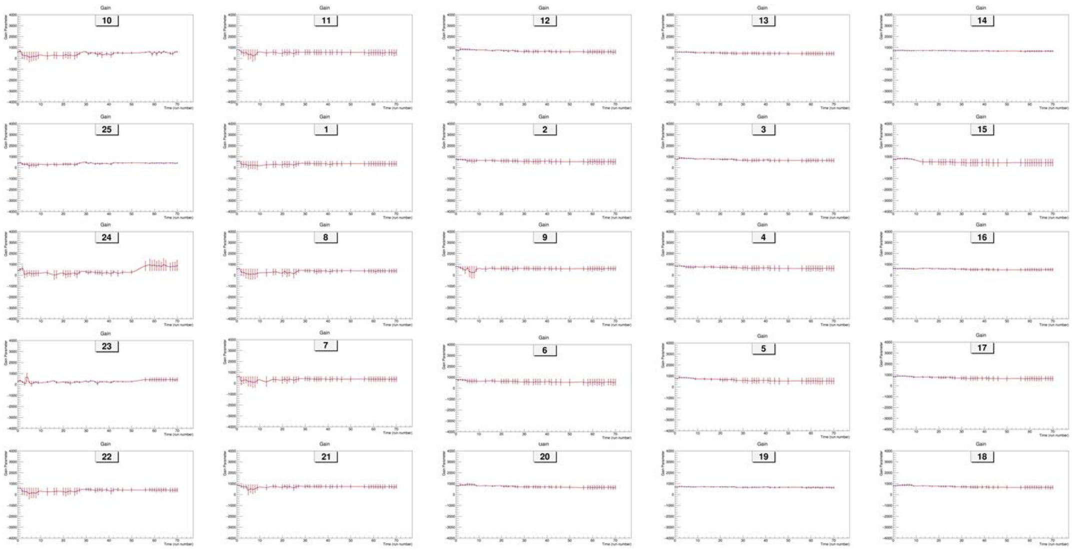


Figure 11: Gain for all 25 counters – a stable curve with smaller error bars indicate a better detector

Clearly, the gain value for the first three columns is not stable, the larger and irregular error bars indicate larger uncertainties. The resolution of these counters is poor. The first two counters receive the forward-angle high for energy gamma rays which tend to decrease the resolution of these counters. The third column is also located closer to the forward-angle gamma rays. The last two columns have a better parametric fit to the gain shift curve which indicate good resolution. Therefore, the 15 detectors located downstream to the beam have poor resolution as compared to the 10 detectors located upstream.

CHAPTER 4

CONCLUSION

The relative uncertainty reflected in the error bar and the stability of the gain shift curve measure the performance of the detector. A stable gain shift curve with smaller uncertainties indicate a good detector and better calibration. A better parametric fit for detector with smaller and constantly increasing error bars is considered more reliable. From the analysis, we can observe that the first three columns of the detector assembly, which are upstream to the beam, is unstable with irregular and bigger error bars. These detectors receive the forward-angle radiation which of considerably high energy and damage the scintillators. These are not reliable to get precise measurements and has to be excluded from further analysis. The last two rows of PMTs are located upstream to the beam and receive the backward-angle gamma rays. These are of lower energy and do not damage the scintillators and are thus more reliable for precise measurements.

Supernovae are rare events in the universe and waiting for one to happen is not a feasible endeavour. So, such events are simulated on earth and the systematic experimental data obtained from experiments like E398 will help understand the data from neutrino experiments by offering a background comparison. The present study will prove to be useful in understanding supernova neutrino-nucleus interactions, to resolve the neutrino mass hierarchy problem and consequently, an insight to physics beyond the Standard Model.

REFERENCES

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APPENDIX

COMPUTER CODE

1. Obtaining Gain – Fitting

```
{
   TFile *f = new
TFile("G:\\root_v5.34.36\\macros\\calibration\\macro\\old_data\\run1041.root",
"h1001");


   double p0, p1, p2, p3;
   p0 = 1;  p1 = 1; p2 = 1; p3 = 1;
   int xmin = 350;
   int xmax = 700;

   TF1 *fit = new TF1("fit", "[0]*exp(-(x-[1])**2/(2*([2]*(x - [1]) + [3])**2))", 0, 2000);
   fit.SetParameters(p0, p1, p2, p3);
   int i;
   fit.SetParameters(p0, p1, p2, p3);
   h1001.Fit("fit", "","", xmin, xmax);

   p0 = fit.GetParameter(0);
   p1 = fit.GetParameter(1);
   p2 = fit.GetParameter(2);
   p3 = fit.GetParameter(3);

   float a1 = fit.GetMaximum()/2;
   float b2 = fit.GetX(a1, p1, xmax);
   float gs = b2;
```

```
  std::ofstream data("G:\\root_v5.34.36\\macros\\Parameters.dat", std::ios::app);


  data<<1041-1041;
  data<<"         "<<gs<<endl;


  data.close();
}
```

2. Error

```
int main() {
   ifstream in;
   in.open("G:\\root_v5.34.36\\macros\\Detectors\\Parameters\\25.dat",
fstream::in);
   ofstream out("G:\\root_v5.34.36\\macros\\Detectors\\Errors\\25.dat", ios::app);
   int i; float x; float y;
   for(i=0; i<92; i++) {
      in>>x;
      if(i%2==0) {
         y = 0;
         out<<y;
      }
      else {
         y = x - 417.434;
         out<<"     ";
         out<<fabs(y)<<endl;
      }
   }
}
```

3. Gain vs. Time

```
{
   TCanvas *c1 = new TCanvas("c1", "Gain");
   TGraphErrors *ge = new
TGraphErrors("G:\\root_v5.34.36\\macros\\Detectors\\Gain Error\\1.dat");


        ge.GetYaxis().SetRangeUser(-4000,4000);
        ge.GetXaxis().SetTitle("Time (run number)");
        ge.GetYaxis().SetTitle("Gain Parameter");
        ge.SetTitle("Gain");


        ge.SetLineColor(2);
        ge.SetLineWidth(2);
        ge.SetMarkerColor(4);
        ge.SetMarkerStyle(33);
        ge.SetMarkerSize(0.8);


        ge.Draw("ACP");


        TPaveText *p = new TPaveText(44, 3000, 34, 4000);
        p.AddText("1");
        p.Draw();
}
```