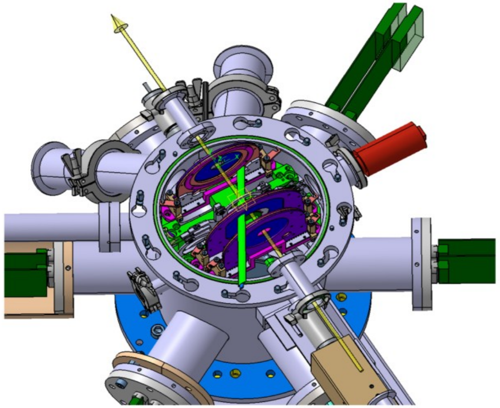
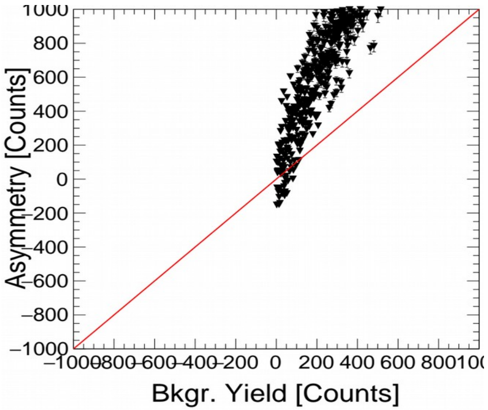
Study of Analysis Strategies for Target Induced Background in Fusion Measurements of Astrophysics Interest





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CONTENT

1. INTRODUCTION

1.1 Carbon fusion in nuclear astrophysics

- Heavy-ion fusion reactions involving ^{12}C nuclei such as the fusion $^{12}C + ^{12}C$ reaction is one of the most important reactions in nuclear astrophysics

- The rate of $^{12}C + ^{12}C$ reactions important in

  1. Evolution of massive stars (more than 8 M_{SUN})
  2. Explosive astrophysical scenarios such as type Ia supernovae
  3. Super-bursts in binary systems

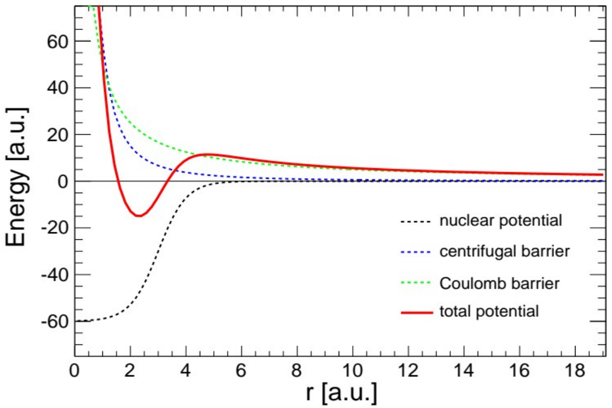
- These reactions take place at a typical temperature of 5×10^8 K and densities of $(2-5) \times 10^9 gcm^{-3}$ corresponds to an energy of E = (1 - 2) MeV

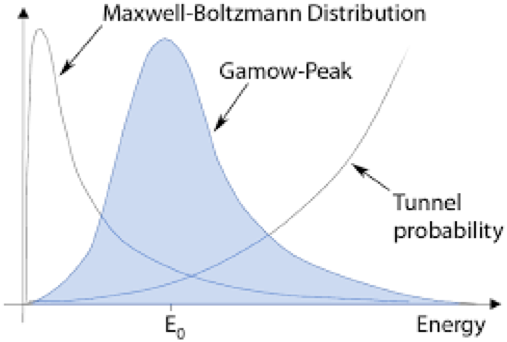
1.2 Fusion Reaction of Astrophysics interest

- To fusion reaction to occur, two positively charged nuclei must overcome the Coulomb potential barrier

Quantum tunneling Through coulomb barrier
Maxwell-Boltzmann distribution

Gamow Peak

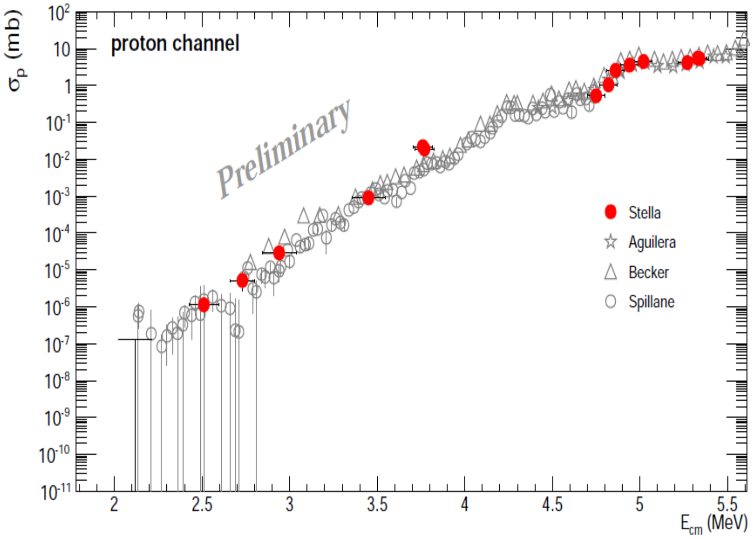


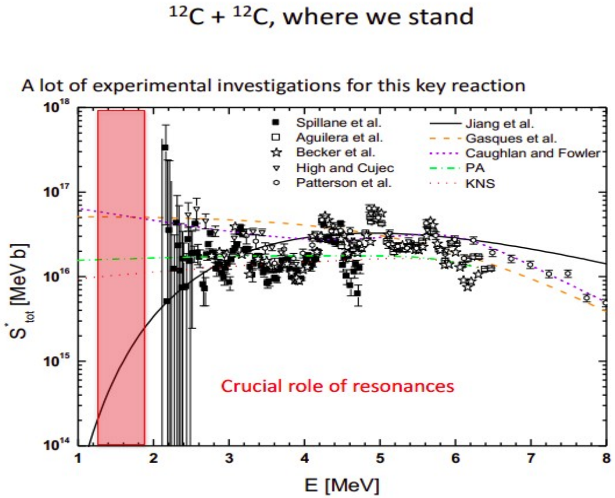


$$\sigma(E)=\frac{1}{E}.\exp(-2\pi\eta).S(E) \qquad \eta = summerfold\ parameter$$

- Cross section are well below ***nanobarn level (10^{-8} mb)*** . Therefore,it is extremely difficult to directly measure the $^{12}C+^{12}C$ fusion cross sections at stellar energies.(Nuclear hindrance plays some role !!!)

1.3 Nuclear hindrance effect on sub barrier energies

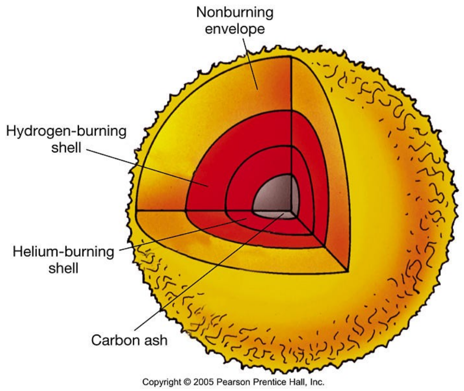




1. Fusion cross sections in the astrophysical low energy region are very small,
2. Background contributions can thus be a problem.
3. Even be worse in the case the fusion cross section is hindered .

“So it is essential to focus hard on background”

2. Carbon (C) Burning Reaction inside a star



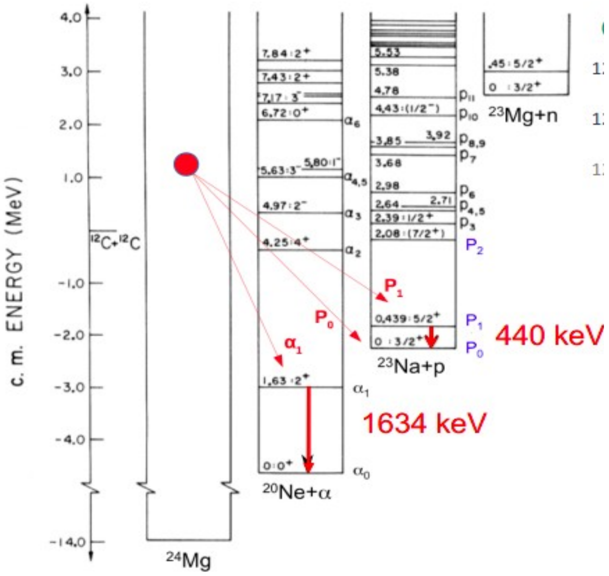
$$^{12}C + {}^{12}C \rightarrow {}^{24}Mg^{*} \rightarrow {}^{23}Na^{*} + {}^{1}p$$

$$^{12}C + {}^{12}C \rightarrow {}^{24}Mg^{*} \rightarrow {}^{20}Ne^{*} + {}^{4}\alpha$$

$$+\gamma$$

$$^{12}C\,({}^{12}C\,,p)\,{}^{23}Na$$

$$^{12}C\,({}^{12}C\,,\alpha)\,{}^{20}Ne$$



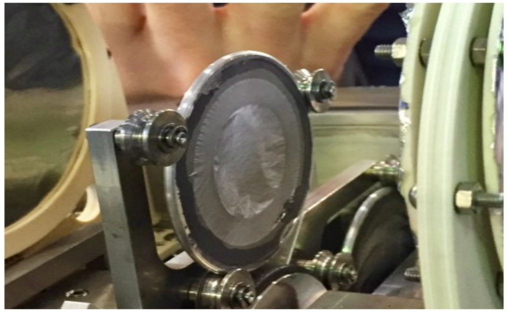
Which parameters affect Cross section ?

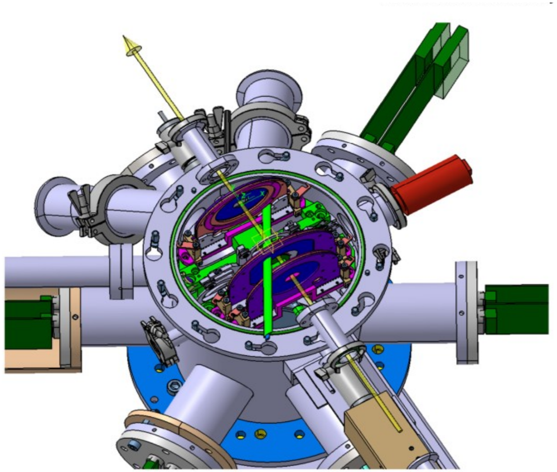
$$dN = \left(\frac{d\sigma}{d\Omega}\right).I.N_t.d\Omega.\Delta t$$

- #of Particle collected in Detector
- Differential cross section
- Intensity of beam
- Scattering centers
- Solid angle
- Measurement time

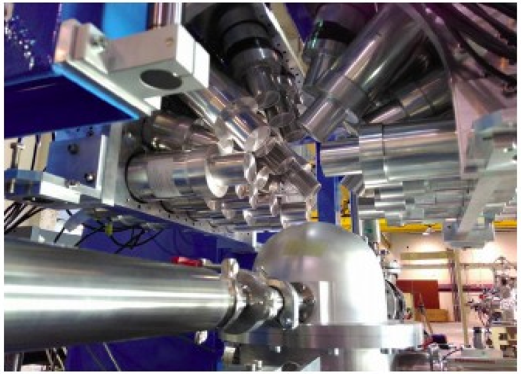
3. STELLA (STELlar LAboratory) Experiment

STELLA is an experiment dedicated to the measurement of reactions of astrophysical interest (low energies)





$$dN = \left(\frac{d\sigma}{d\Omega}\right).I.N_t.d\Omega.\Delta t$$



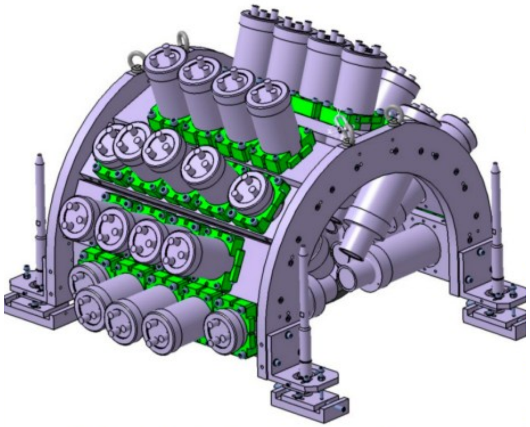
Key points,

1. Rotating targets which can sustain high beam intensities
2. High-efficiency particle and gamma-ray detection systems
3. Long data taking time
4. Nanoseconds timing for background reduction and determination of reaction channels

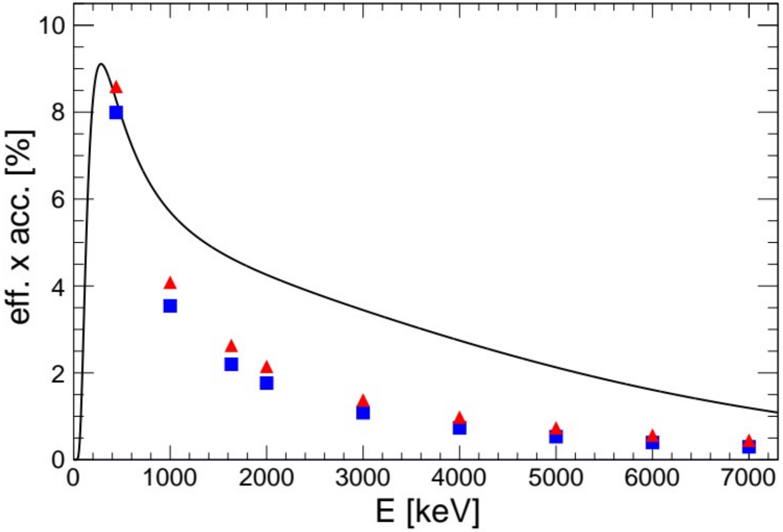
3.1 ɣ Particle Detection

36 LaBr3 detectors -(Cylindrical geometry IPHC designed mechanical support, Strasbourg + York construction)

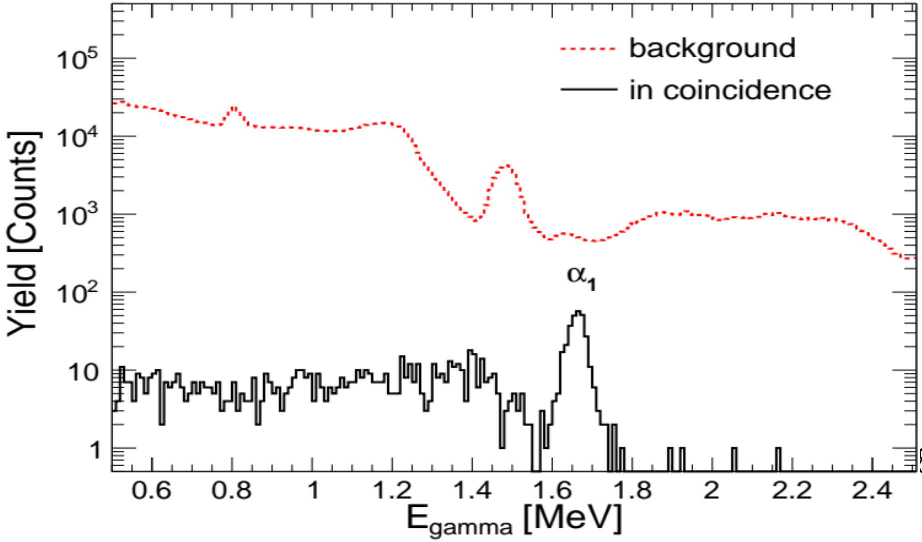
- (Energy resolution : 3% FWHM at 1333 keV (with Co-60 source)
- These detectors have sub-nanosecond timing resolution
- Photo peak efficiency
- e = 8% @ 440 keV
- e = 2-2.5% @ 1634 keV



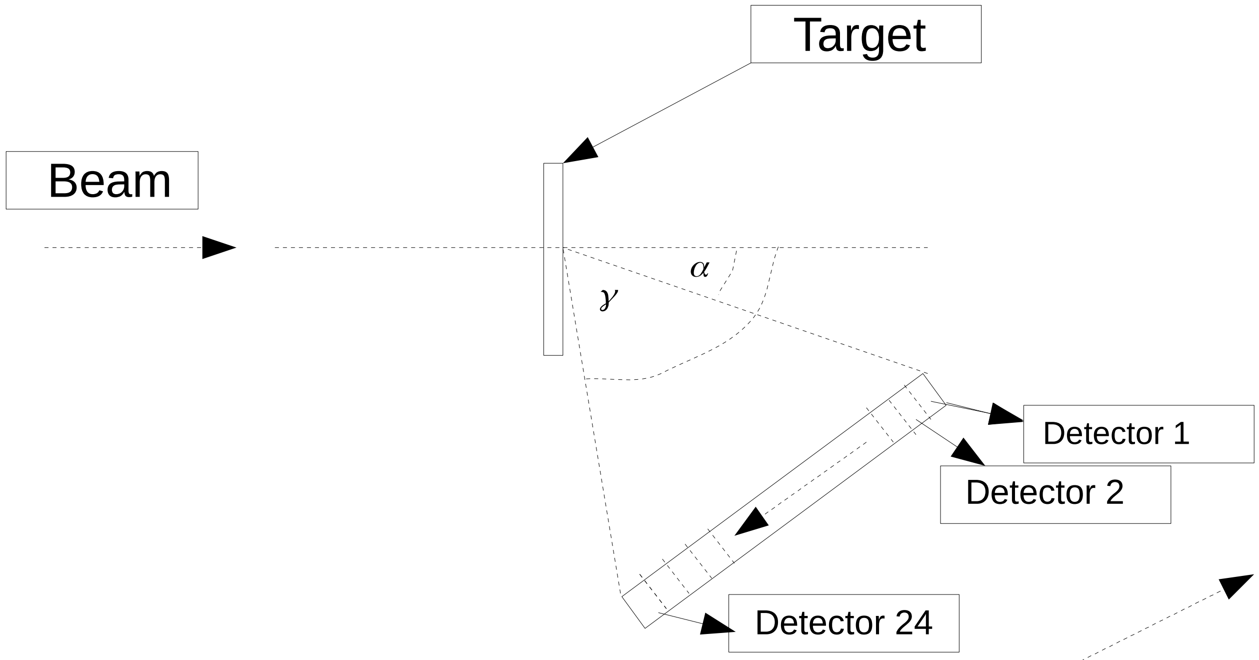
Comparison with "GAMMASPHERE"

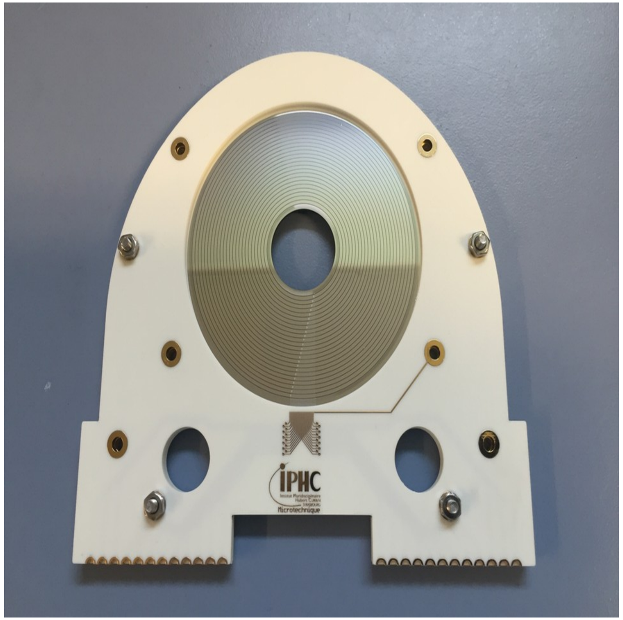


Alpha reaction channel



3.2 Charge Particle Detection





- ***DSSSD*** (Double-Sided Silicon Strip Detector)
- 24 single rings(one ring is detector) in one disk
- Angular coverage (per ring)= 10mrad – 28mrad

4.Reaction Kinematics

Beam energy : ***10.04 MeV***

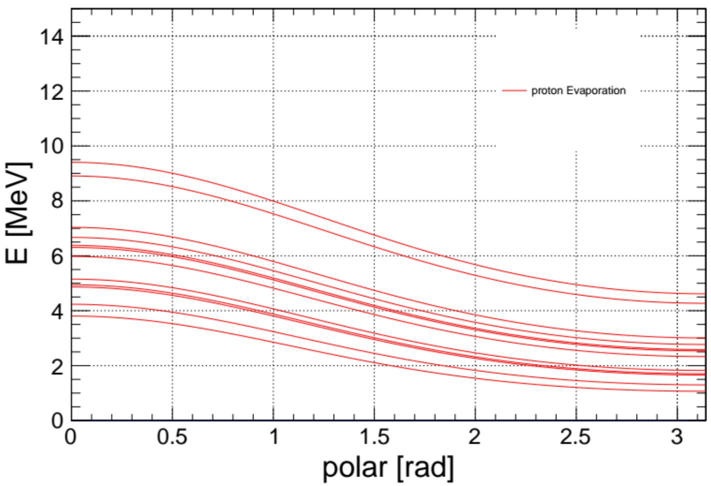
Elastic scattering (from water on targets) → $^{12}C(H,H)^{12}C$

Elastic scattering-(Deuterium form water) → $^{12}C(D,D)^{12}C$

Inelastic scattering-(Deuterium form water) → $^{12}C(D,P)^{13}C$

Main physics Channel → $^{12}C(^{12}C,p)^{23}Na$, $^{12}C(^{12}C,\alpha)^{20}Ne$

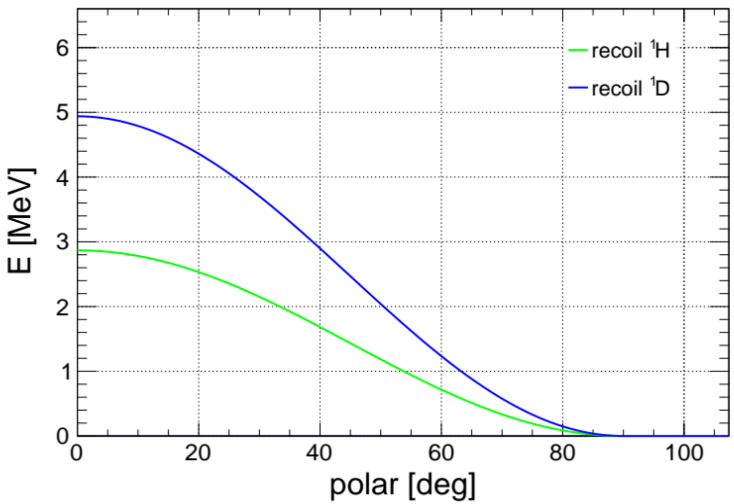
$^{12}C(^{12}C,p)^{23}Na$



Proton Evaporation

$^{12}C(H,H)^{12}C$

$^{12}C(D,D)^{12}C$



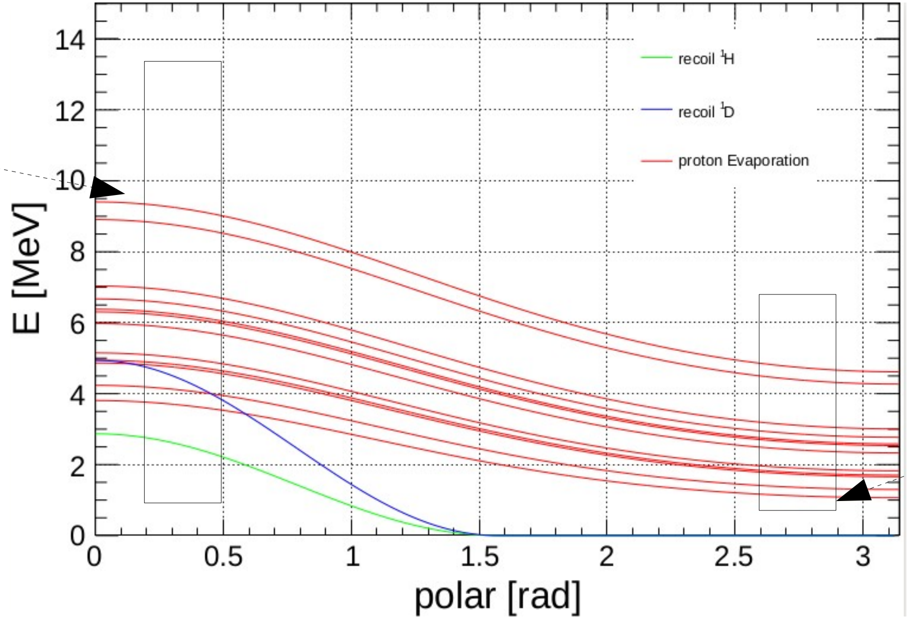
Elastic scattering

5. Data analyzing Procedure

```
gStyle->SetOptStat (0);
gStyle->SetOptFit (1);
const Double_t eneBeam = 10.04; // MeV


TF1 *f_eneVsPol[12];
// get kinematics ala bass1980.pdf
const Double_t v_inf = TMath::Sqrt (2*eneBeam/(A1*931.5));
const Double_t mu = (A1*A2/(A1 + A2))*m;
const Double_t eneCms = TMath::Power (v_inf, 2)*mu/2;
Double_t qVal[12], gam3[12];

const Int_t n_pol = 180;
double_t pol_mon[n_pol];
double_t ene_hydr[n_pol],ene_dut[n_pol];


for (Int_t i = 0; i < 12; i++)
     {
    qVal[i] = m*(A1 + A2 - A3 - A4) - eneEx[i];
    gam3[i] = TMath::Sqrt (A1*A3/(A2*A4)*(eneCms/(eneCms + qVal[i])));

    f_eneVsPol[i] = new TF1 (Form ("f_eneVsPol[%i]", i), ene_alpha, 0, TMath::Pi (), 5);
    f_eneVsPol[i]->SetParameters (eneCms, gam3[i], A1, A2, A3);
    f_eneVsPol[i]->SetNpx (1e3);
    }


  for (Int_t i = 0; i < n_pol; i++)
     {
    pol_mon[i] = i*TMath::Pi ()/180; // angle with the beam axis, rad
    ene_hydr[i]     = ene_reco (eneBeam, i*TMath::Pi ()/180, mass_hydr);     //for hydregen
    ene_dut[i]      = ene_reco (eneBeam, i*TMath::Pi ()/180, mass_dut);      //for duterium

    //std::cout << " " << pol_mon[i] << " " << ene_carb[i] << " MeV" << std::endl;
    }
```

Forward Detection
(0.2-0.5)

- We Except Background in forward detector



Backward Detection

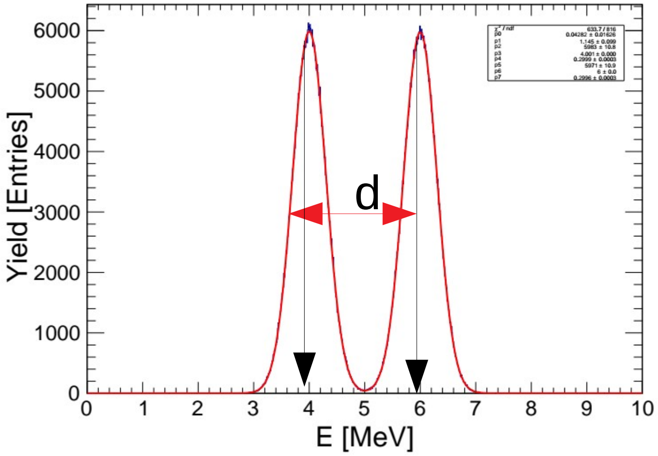
- We do not except Background in backward detector

- *Background from the target is affecting physics channel in forward detector*

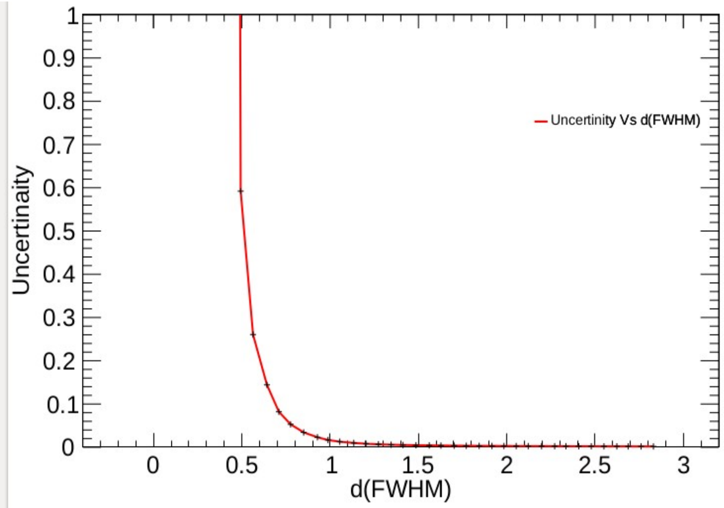
6. Symmetric Distribution

- First we discussed about Symmetric distribution in order to understand how the peaks influence themselves

$$\frac{\Delta U}{U} = \sqrt{\left(\frac{\Delta \mu_1}{\mu_1}\right)^2 + \left(\frac{\Delta \mu_2}{\mu_2}\right)^2}$$



Symmetric two Gaussian distribution

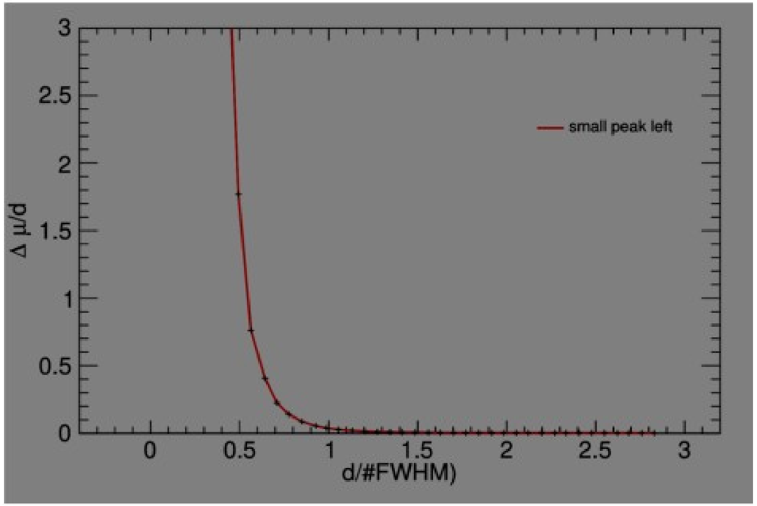


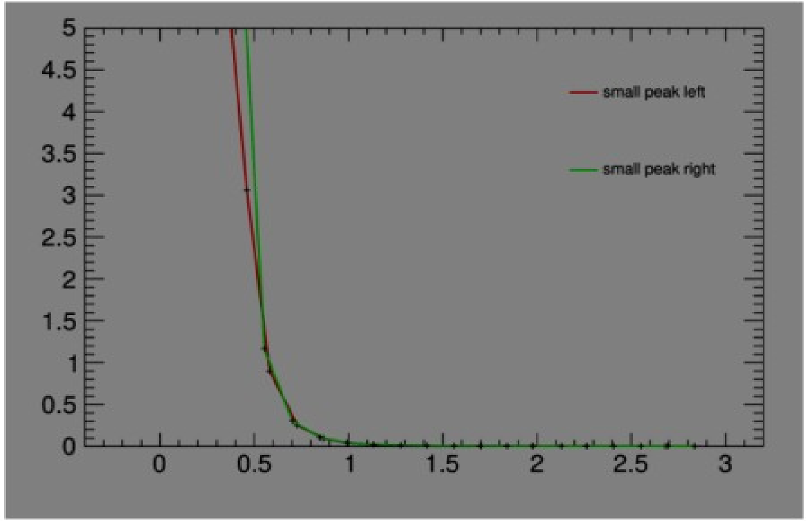
FWHM : minimum distance to separate two peaks with an approximate rule of thumb (Glenn F.Knoll)

7. New approach-(Using iteration procedure to fit values)

- The experimental spectra in neighboring detectors are very similar hence only slight change are noticed for the fit parameters when we going from detector 1 to 2.

Asymmetrical distribution:



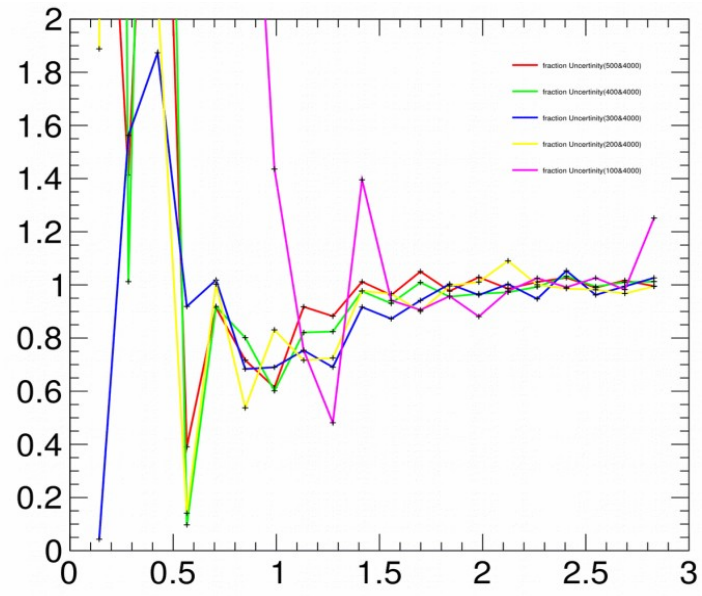


Pollution on the left side

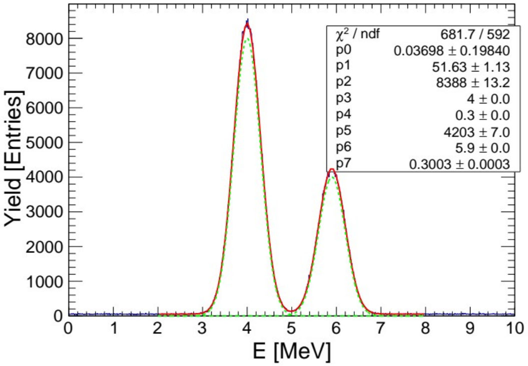
Difference between the pollution on the right (green curve) and on the right side (red curve)

7.1 Further Discussion of asymmetric case

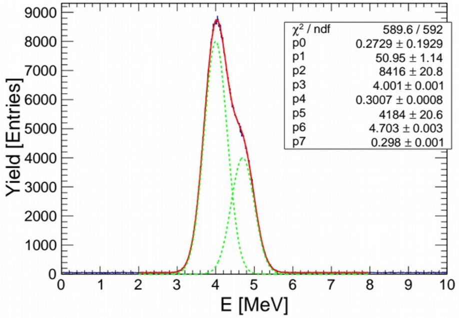
- Asymmetric Gaussian was set to different values (2000,1000,500,400,300,200,100,50)
- Individual plots looks same for every case . So we tried to plot more than one graphs in single canvas



Pollution fraction uncertainty vs Distance



Pollution at 2 FWHM



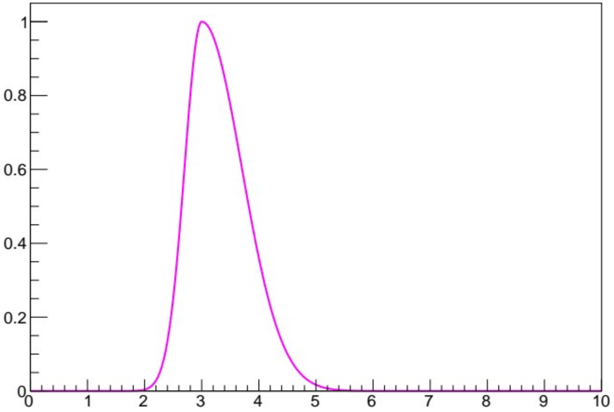
Pollution at 1 FWHM

8. Necessity of a Asymmetrical Gaussian

- When the pollution is very close to the unaffected side the fit with two Gaussian is no more efficient as we have seen with the uncertainties.
- We then need a new fit for the distance of one ***FWHM*** and lower cases:

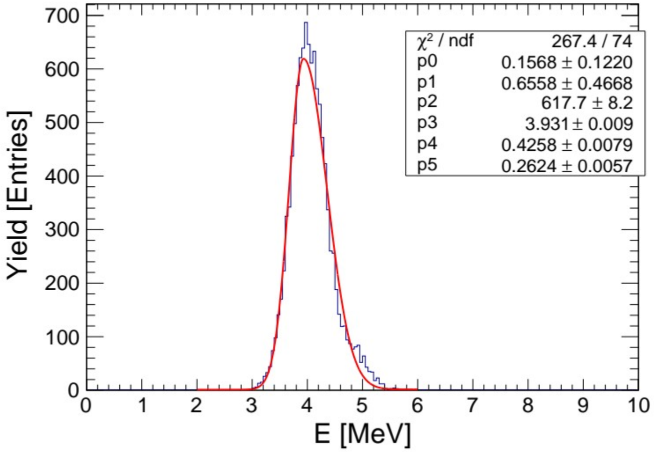
The asymmetrical Gaussian

$$f(x) = Aexp\left(\frac{x-\mu}{2\sigma_{1,2}}\right)$$



New set of parameters:

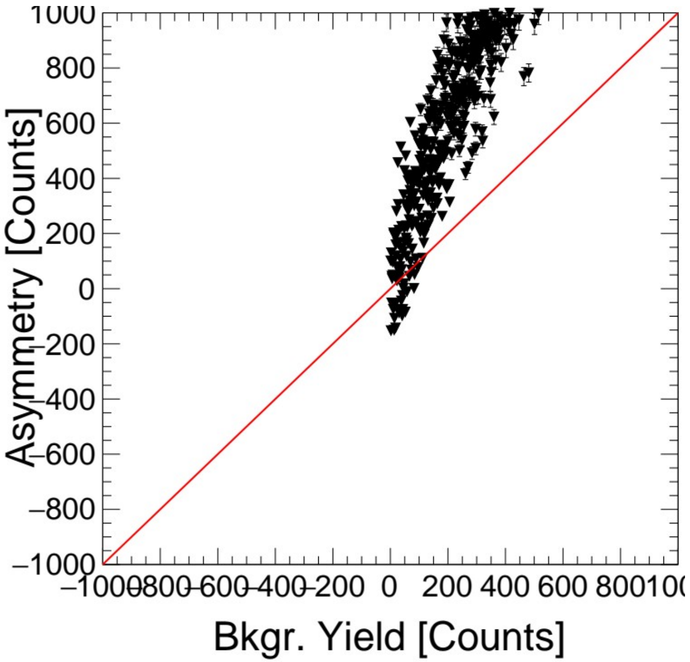
```
//The fit function
  TF1 *f_fit = new TF1 ("f_fit", my_resp2, 1., 9., 6);
  f_fit->SetParameter (0, Lin_Coeff);    //Itterated
  f_fit->SetParameter (1, Lin_Ordonee); // Itterated
  f_fit->SetParameter (2, Amp_I); // Itterated value taken estimated by looking the histogram
  f_fit->SetParameter (3, Mu_I); //value set maybe better fixed
  f_fit->SetParameter (4, Sig_L); //value set maybe better fixed
  f_fit->SetParameter (5, Sig_R); // Itterated
```



No background added : Simplest case

9. Lookup Tables from Simulations

- At a distance of a ***FWHM*** we have made statistical analysis on the importance of the pollution to evaluate the efficiency of our new fitting method:



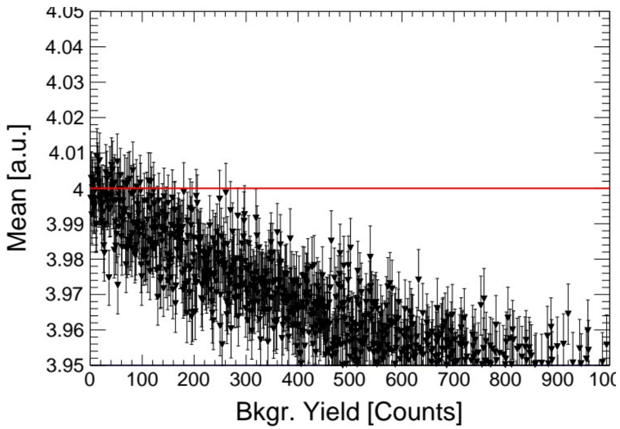
- Correlation without constraint on the fit

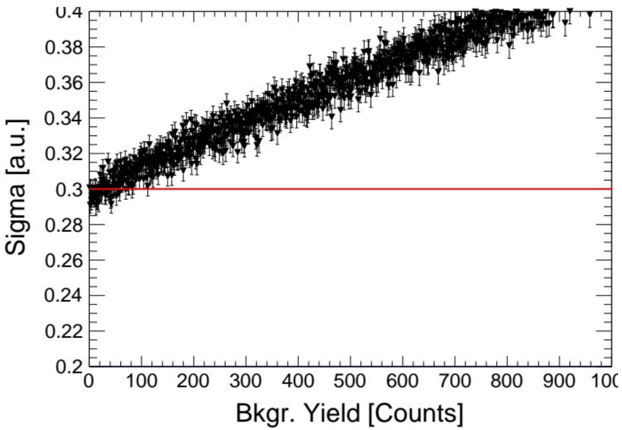
- X-axis : It is the number of counts in the Side polluted of the histogram

- Y-axis : One have defined the asymmetry as the difference of the integral of the healthy side and the pollution

9.1 What about the fitted parameters?

- Another thing to check for the validity of the fit is the difference between the input values and the iterated values, are they still the same?





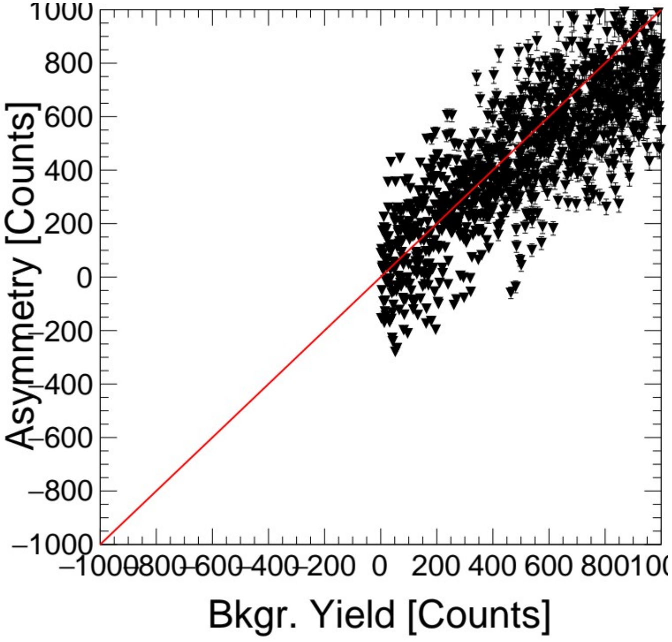
The red line corresponds to the input value

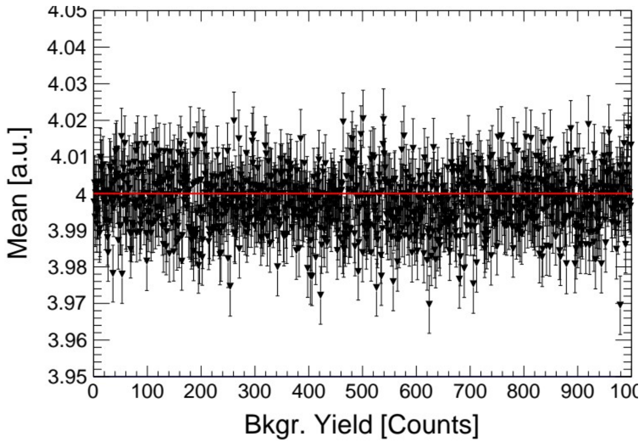
- We can notice from the graph that the pollution widens faster than it moves from the clean side

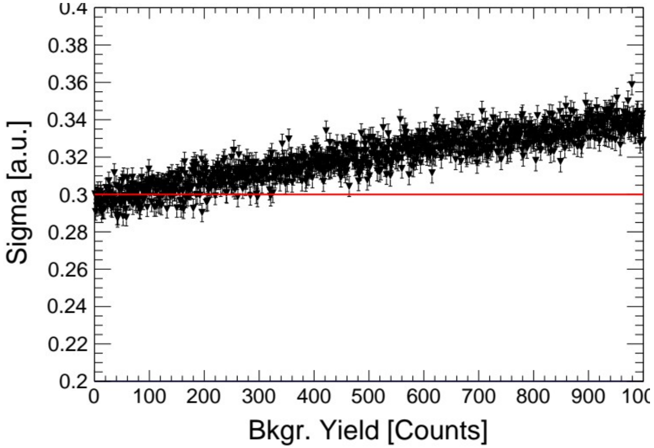
9.2 Closer cases

- Now what happen when the pollution get closer to the clean side?

One of the best result is at 0.5 FWHM :

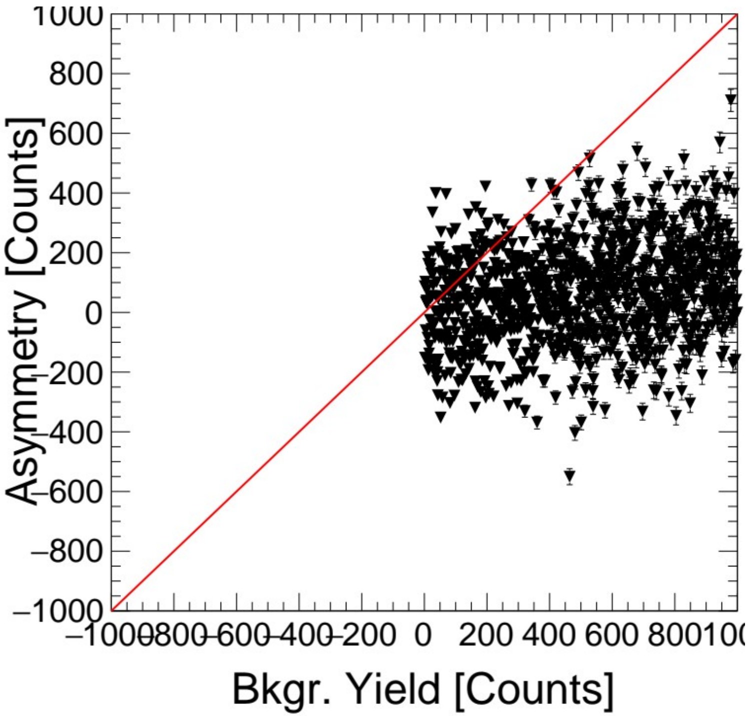






9.3 Limitations of the Fit

- There is a limit where the method of the Asymmetrical Gaussian become invalid.
- Indeed let’s take the case where the distance between the peaks is 0.3 FWHM :

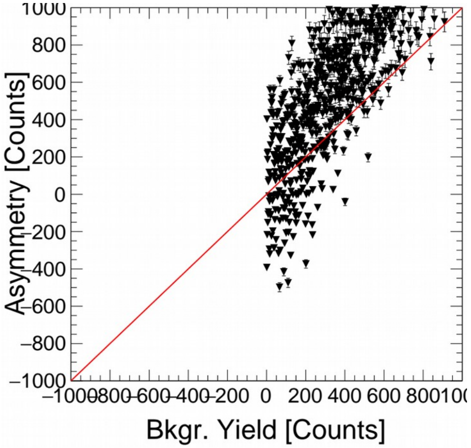


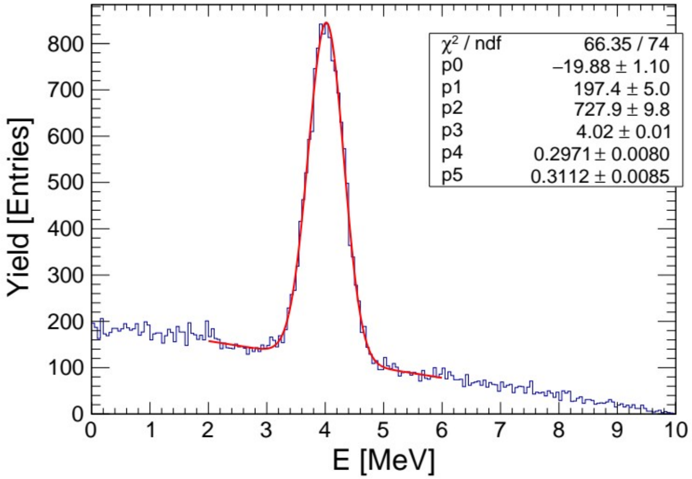
- The correlation is not relevant anymore

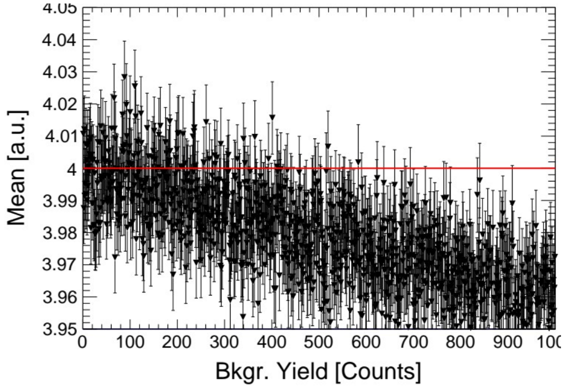
- So adding the case above 1 FWHM as a limit, there is actually two boundaries

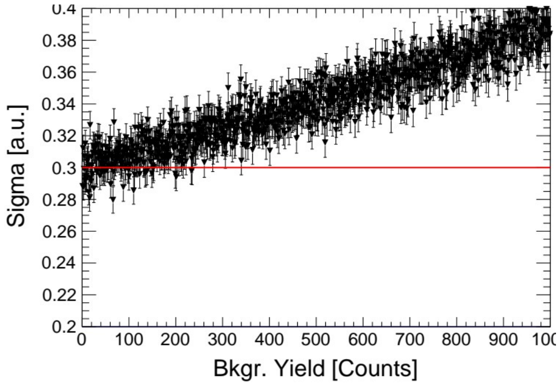
9.4 Adding a Linear Background

- Now we turn to more realistic situation









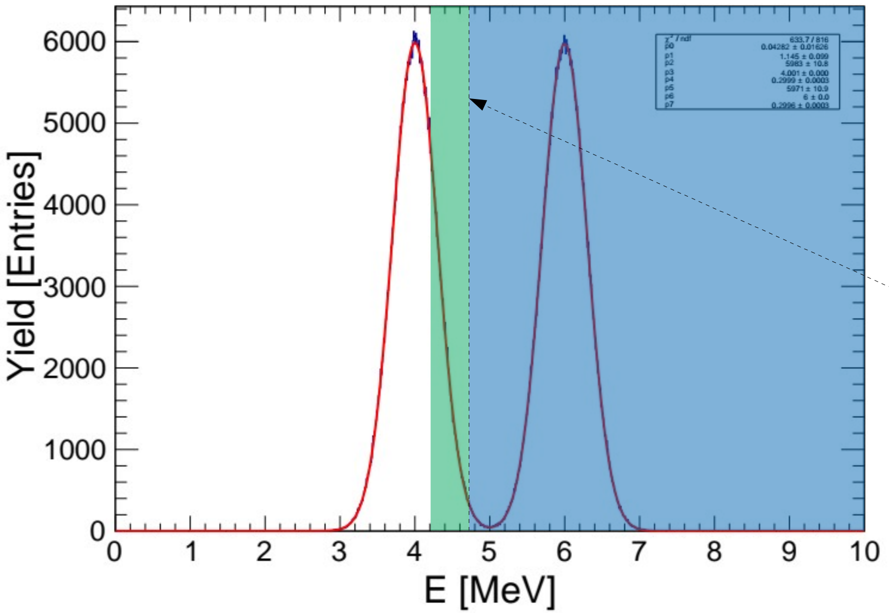
- The points are spread on a larger area

Conclusion & Discussion

- The full behavior of the pollution can be find with two different method of fitting that depend on the distance between the peaks.
- In further works we could study algorithm with constraint on parameters (deconvolution algorithms)

: Asymmetrical fit

: Symmetrical fit



1 FWHM

What we have learnt

- A new language frame work : Root
- How to fit and analyses qualitatively a graph
- Current experimental works about nuclear astrophysics
- Application of nuclear physics equations that we learn on class .

APPENDIX 1-(Reaction Kinematics)

$$A_1 + A_2 \rightarrow A_3 + A_4$$

$\boldsymbol{Laboratary\ energies, Angles:}\ E_1, E_3, \theta_3, d\,\omega_3$

$\boldsymbol{Center\ of\ mass\ energies, Angles:}\ E_i, E_f = E_i + Q, \Theta, d\Omega$

$$\left(\gamma_3 = \frac{A_1 A_3 . E_i}{A_2 A_4 . (E_i + Q)}\right)^{1/2}$$

Inelastic scattering

$$E_3 = \frac{A_1 A_3 E_i}{A_2 (A_1 + A_2)} \frac{[\gamma_3 \cos(\vartheta_3) \pm ((1 - \gamma_3^2 \sin^2(\vartheta_3))^{1/2})^{1/2}]^2}{\gamma_3^2}$$

Elastic scattering

for Elastic scattering, $A_4 = A_1, A_3 = A_2, \gamma_3 = 1$

$$E_3 = \frac{4 A_1 E_i}{A_1 + A_2} \cos\left(\frac{\Theta}{2}\right)^2 = \frac{4 A_1 A_2 E_1}{A_1 + A_2^2} \cos\left(\frac{\Theta}{2}\right)^2$$

$^{12}C(H, H)^{12}C$

$^{12}C(D, D)^{12}C$

$^{12}C(D, P)^{13}C$

$^{12}C(^{12}C, p)^{23}Na$

$^{12}C(^{12}C, \alpha)^{20}Ne$