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ARIA 19

Development of the platform to calculate the cross section induced by the proton beam

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Outline

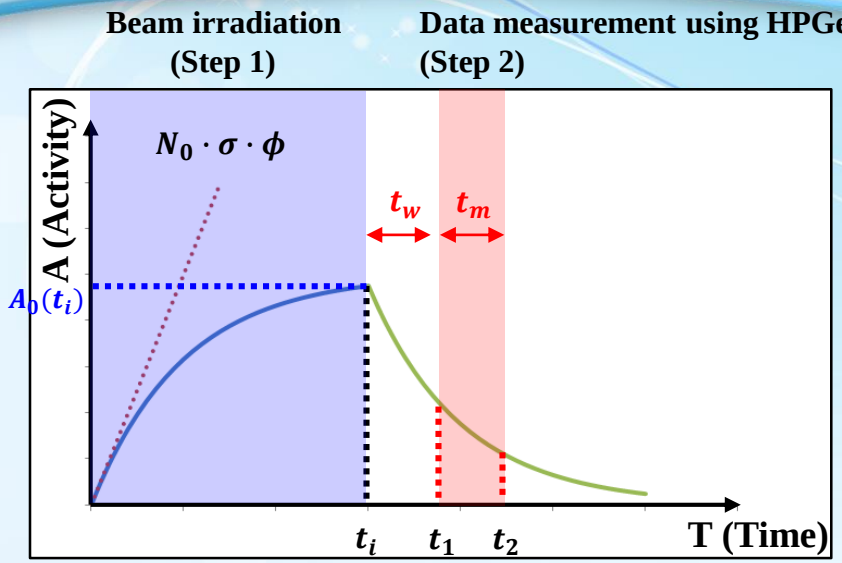
- **Introducing the platform to calculate the cross-section.**
- **Showing the example of the data analysis from the platform using the real data.**

KOrea Multi-Purpose Accelerator Complex

The cross-section

- **The cross-section** of a nucleus is defined as the probability that a nuclear reaction will occur.
- The cross-section measurements of the nuclear reaction interested are very important stage to understand **the production yield of the radioactive isotopes**.
- The process to calculate the cross section of a nuclear is not difficult. However, beginners can make a lot of mistakes during the calculation of the cross-section.
- If there is **some platform** to calculate the cross-section, beginners also can calculate the cross-section easily without mistakes.
- This is **the main motivation** to make some platform using the data analysis programs such as ROOT and C++. In the future, Qt.
- In this presentation, the algorithm of this platform to calculate the cross-section from the real beam irradiation data will be described.

Two steps to calculate the cross-section



- N : The number of radioactive nuclei
- N_0 : The initial number of nuclei
- σ : The cross-section in the reaction interested $[cm^2]$
- ϕ : The flux of incident particle $[\frac{\#}{cm^2 \cdot sec}]$

From S. C. Yang PhD thesis, p.18

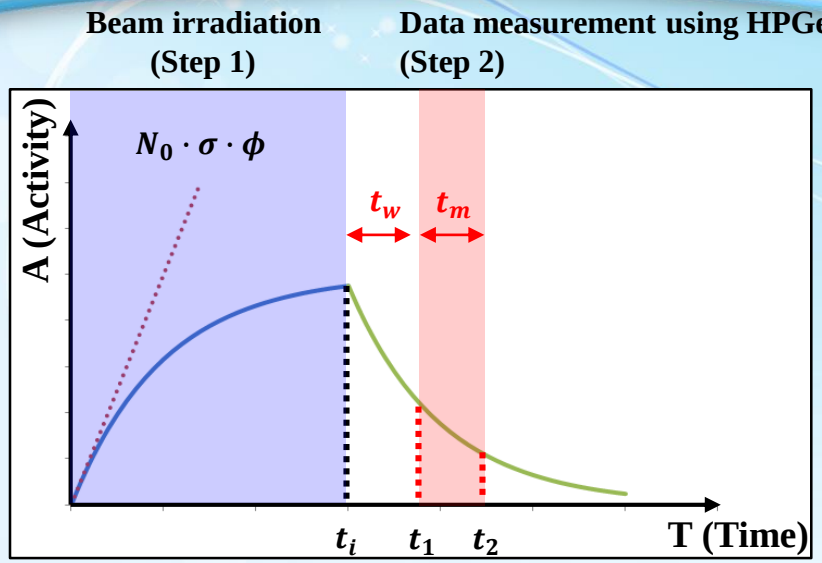
- There are two stages to calculate the cross-section : The first step is to irradiate the beam with the target. The second step is to measure the number of radioactive nuclei, N in the target using HPGe.
- The activity of the target after the beam irradiation is the following (Step 1) :

$$A_0(t_i) = N_0 \cdot \sigma \cdot \phi\left(1 - e^{-\lambda \cdot t_i}\right)$$

- The number of radioactive nuclei in the target is calculated using the following (Step 2) :

$$N = \varepsilon \cdot I_\gamma \int_{t_1}^{t_2} A_0(t_i)\, e^{-\lambda \cdot t} dt = \varepsilon \cdot I_\gamma \frac{N_0 \cdot \sigma \cdot \phi}{\lambda}\left(1 - e^{-\lambda \cdot t_i}\right) e^{-\lambda \cdot t_w}\left(1 - e^{-\lambda \cdot t_m}\right)$$

Two steps to calculate the cross-section



- N : The number of radioactive nuclei
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- ϕ : The flux of incident particles $[\frac{\#}{cm^2 \cdot sec}]$

From S. C. Yang PhD thesis, p.18

- The equation to calculate the cross-section is following :

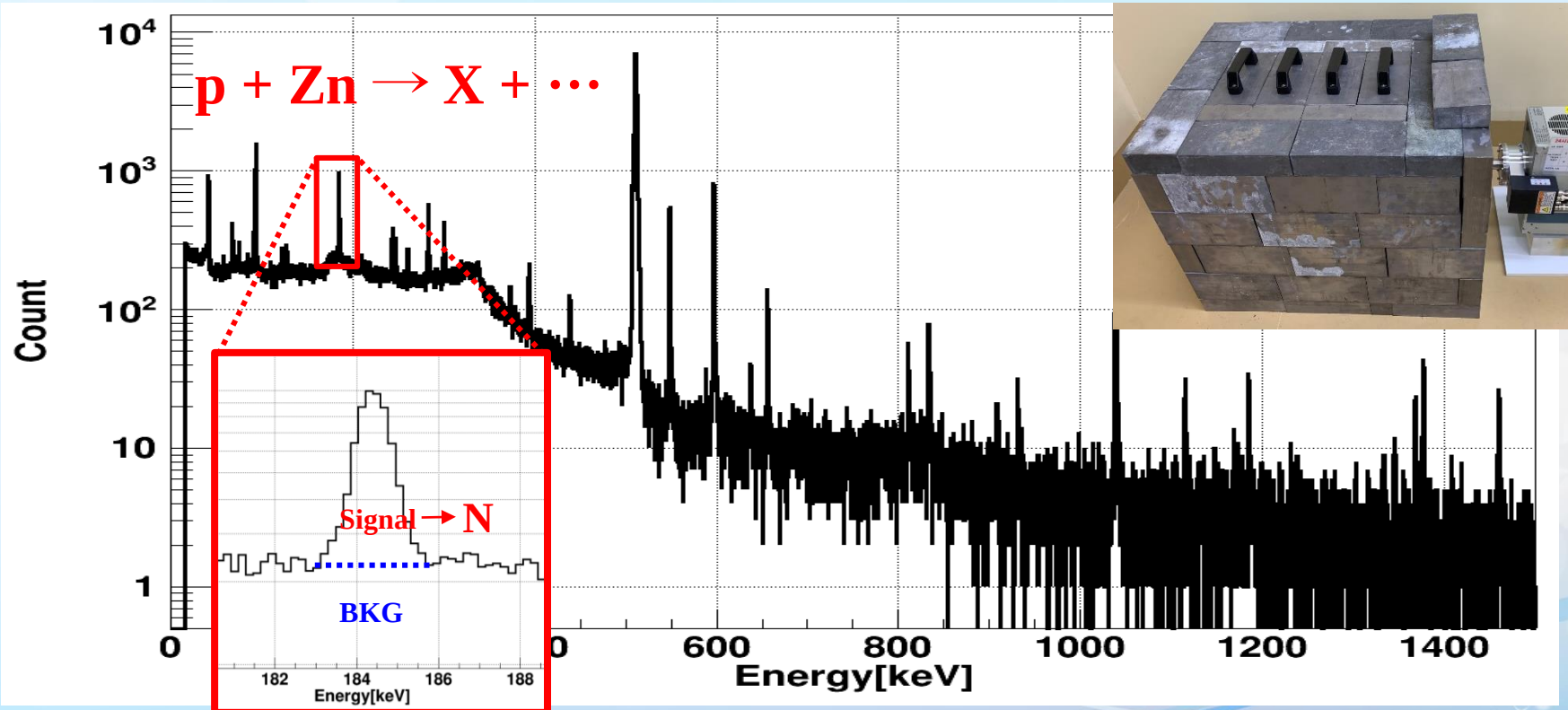
$$\sigma[cm^2] = \frac{N \cdot \lambda}{N_0 \cdot \phi \cdot \epsilon \cdot I_\gamma} \cdot \frac{1}{(1 - e^{-\lambda \cdot t_i}) e^{-\lambda \cdot t_w} (1 - e^{-\lambda \cdot t_m})}$$

- The platform to calculate the cross-section needs and calculates the following variables :

Stage 0 : N_0, ϵ, I_γ, λ ⇨ **Stage 1 : t_i, ϕ** ⇨ **Stage 2 : N** ⇨ **Stage 3 : σ**

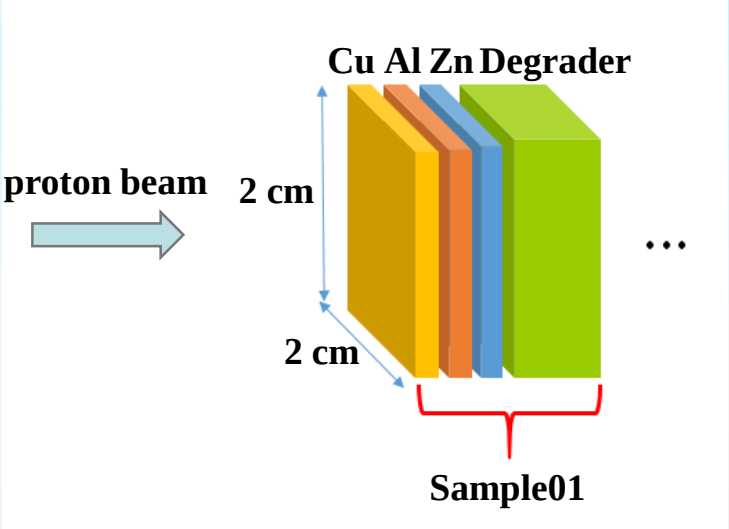
Measuring N of the target using HPGe detector.

- After the beam irradiation to the target, the HPGe detector is used in order to measure the number of radioactive nuclei in the target.
- The result measured by HPGe detector is shown as γ-spectrum with the counts per energies :



Calculating the cross-section using the real data

- The real data to measure the cross-section of the nuclear reaction, ^{nat}Zn (p, X) ^{67}Cu performed by Dr. Jun Kue Park(KOMAC) has been applied to this platform.
- The target used for this real data consists of 10 samples with Cu foil, Al foil, Zn foil, and degrader.



- The Al foil in the target is used to calculate the proton beam flux, ϕ using the nuclear reaction, ^{nat}Al (p, X) ^{24}Na
- The Zn foil in the target is used to calculate the cross-section of the nuclear reaction, ^{nat}Zn(p, X)^{67}Cu.

The output file made by HPGe detector.

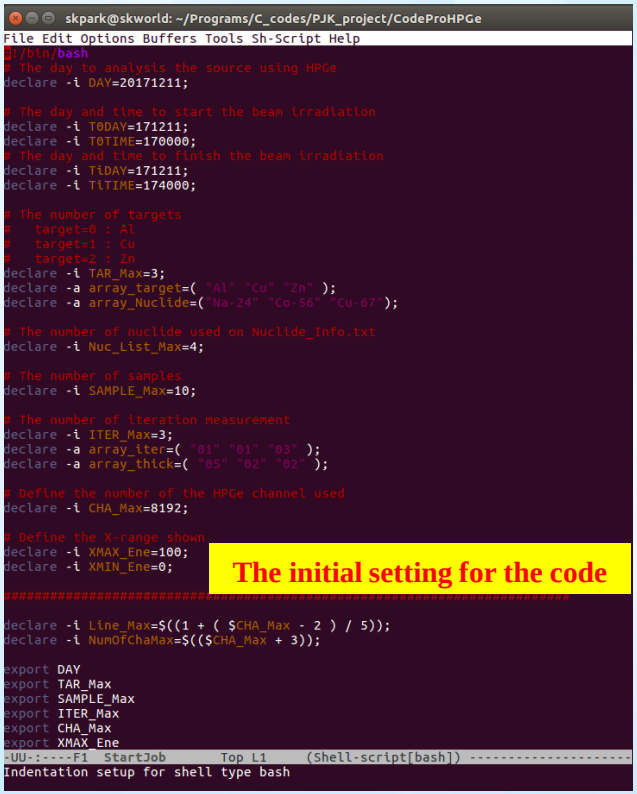
- The following is the output file made after measuring the target using HPGe detector.
- The platform get t_m, t_1, Energy calibration equation, and channel-count information from the output.

A004	t_m DET01	1	1	0 **The max channel**
A004	300.000000	327.256623	8192	
A004	12/12/17 14:08:04 **Measurement start time**			
A004	-0.115201	0.18314	0	0
A004	3.93308	0.00103019	-9.27595e-008	7.48049e-012 1
A004				
A004	**Energy calibration equation**			
A004	**Energy = 0.18314*Ch – 0.115201**			
A004				
A004	**The result of the energy and efficiency calibration**			
A004SPARE				
A004	121.78	665.614	244.693	1336.68
A004	344.272	1880.44	411.111	2245.51
A004	443.979	2424.69	778.89	4253.79
A004	867.32	4736.33	964.01	5264.45
A004	1085.78	5929.2	1112.02	6072.92
A004	1407.95	7688.72	0	0
A004	0	0	0	0
A004	0	0	0	0
A004	0	0	0	0
A004	0	0	0	0
A004	0	0	0	0
A004	0	0	0	0
A004	121.78	4.52992	244.693	5.2289
A004	344.272	5.54774	411.111	6.0331
A004	443.979	5.86901	778.89	7.64124
A004	867.32	6.50359	964.01	8.44569
A004	1085.78	8.51559	1112.02	8.30054
A004	1407.95	9.74416	0	0
A004	0	0	0	0
A004	0	0	0	0
A004	0	0	0	0

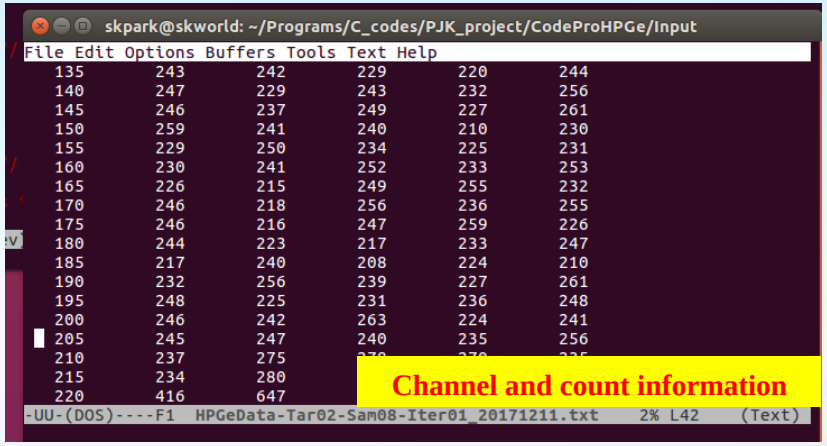
A004 **Channel**		**Count**							
A004USERDEFINED									
A004	0	0	**0**	0	**1**	0	**2**	0	**3**	0	**4**
A004	5	0	**5**	0	**6**	0	**7**	0	**8**	0	**9**
A004	10	0	**10**	0	0	0	0	0	
A004	15	0	**15**	0	0	0	0	0	
A004	20	0	0	0	0	0	0		
A004	25	0	0	0	0	0	0		
A004	30	0	0	0	0	0	0		
A004	35	0	0	0	0	0	0		
A004	40	0	0	0	0	0	0		
A004	45	0	0	0	0	0	0		
A004	50	0	0	0	0	0	0		
A004	55	0	0	0	0	0	0		
A004	60	0	0	0	0	0	0		
A004	65	0	0	0	0	0	0		
A004	70	0	0	0	0	0	0		
A004	75	0	0	0	0	0	0		
A004	80	284	263	288	259	269			
A004	85	275	277	265	285	286			
A004	90	276	275	291	263	253			
A004	95	250	262	277	214	251			
A004	100	245	249	268	250	267			
A004	105	246	242	244	235	273			
A004	110	255	242	248	264	244			
A004	115	243	247	267	219	230			
A004	120	271	236	251	255	246			
A004	125	275	256	251	224	217			
A004	130	242	249	267	224	261			
A004	135	243	242	229	220	244			
A004	140	247	229	243	232	256			

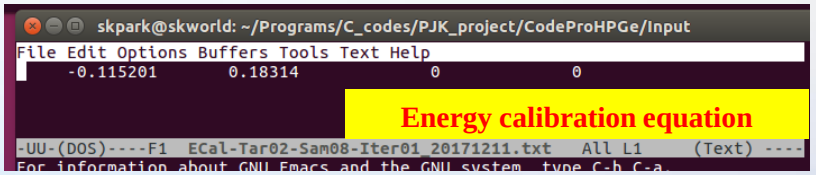
The programming language used in the platform

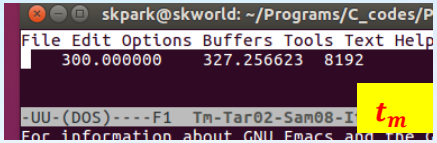
- The platform uses the following programming language :
  - Shell script : Setting the initial variables for the code
  - Perl and sed : Extracting several necessary information from the HPGe output file
  - ROOT and C++ : Analyzing the data after reading the input file made by Perl and sed

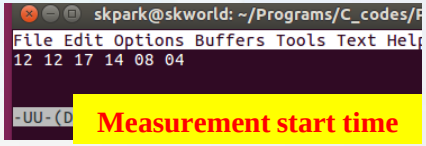


The shell script





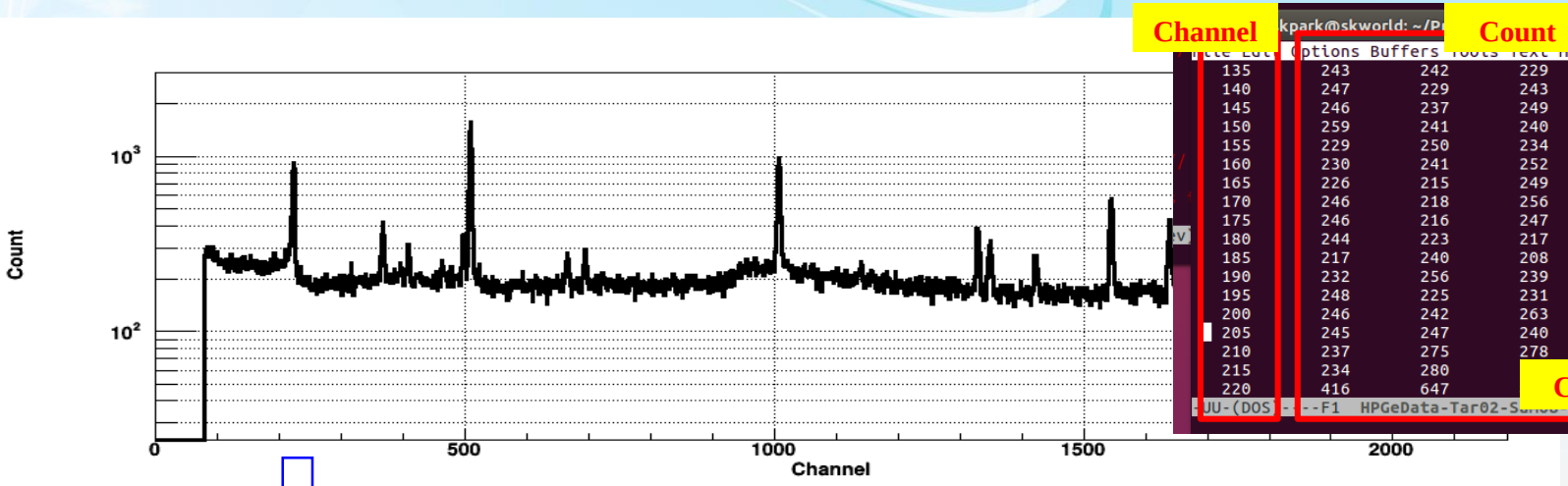




Several information extracted by Perl and sed

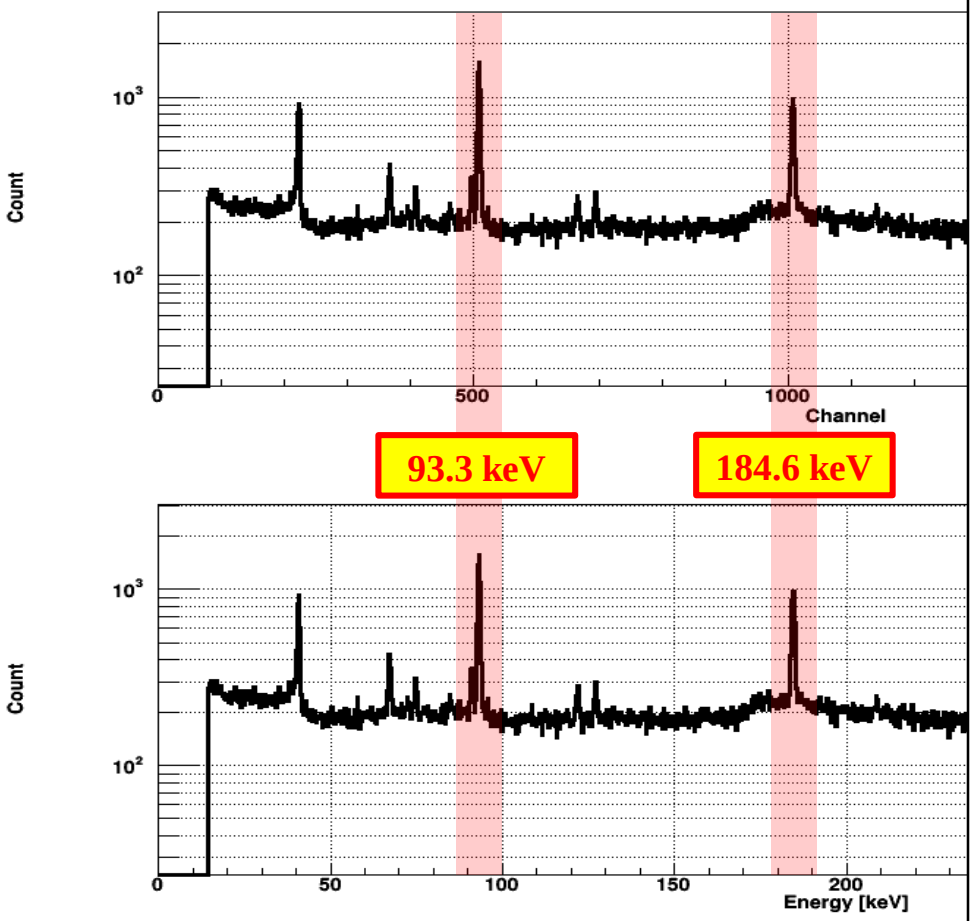
The γ-spectrum used as the basic histogram of the platform

- The platform has made the histogram with the channel as the x-axis and the histogram with the energy using the energy calibration equation.



The peak energies used in the γ-spectrum

- In the several kinds of energy peaks in the γ-spectrum, two peaks with the energy 93.3 keV and 184.6 keV are used to calculate the cross-section of the nuclear reaction, $^{nat}Zn(\mathrm{p,X})^{67}Cu$



- $^{nat}Zn(\mathrm{p,\ X})^{67}Cu$

Energy (keV)	Intensity (%)	Energy (keV)	Intensity (%)
91.266	7.00	208.951	0.115
93.311	16.10	300,219	0.797
184.577	48.7	393.529	0.220

- $^{nat}Zn(\mathrm{p,\ X})^{67}Ga$

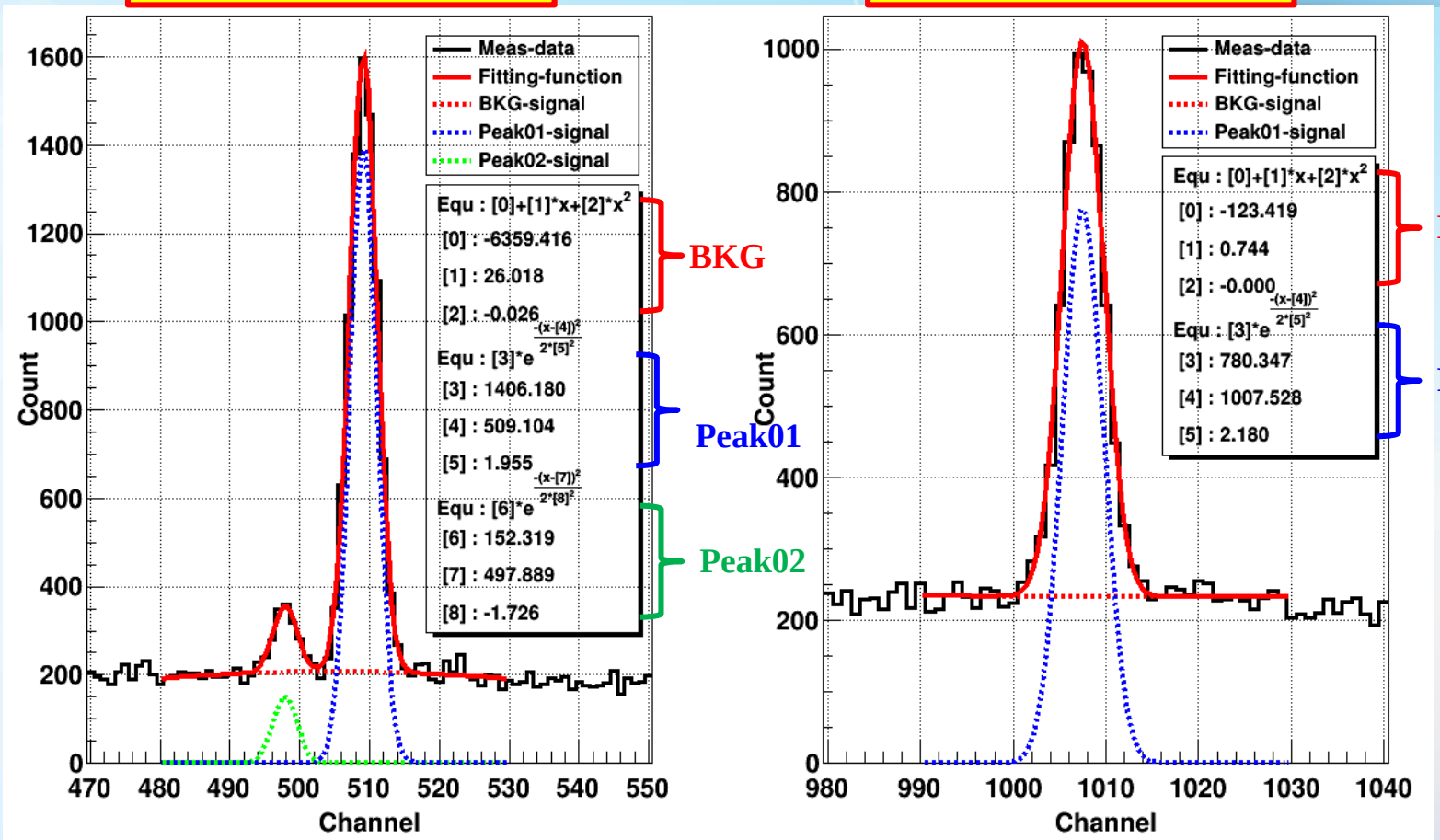
Energy (keV)	Intensity (%)	Energy (keV)	Intensity (%)
91.265	3.11	393.527	4.56
93.310	38.81	494.166	0.0684
184.576	21.410	703.106	0.0105
208.950	2.460	794.381	0.0540
300.217	16.64	887.688	0.148

Two peak energies used in the γ-spectrum

γ –spectrum : 93.3 keV

γ –spectrum : 184.6 keV

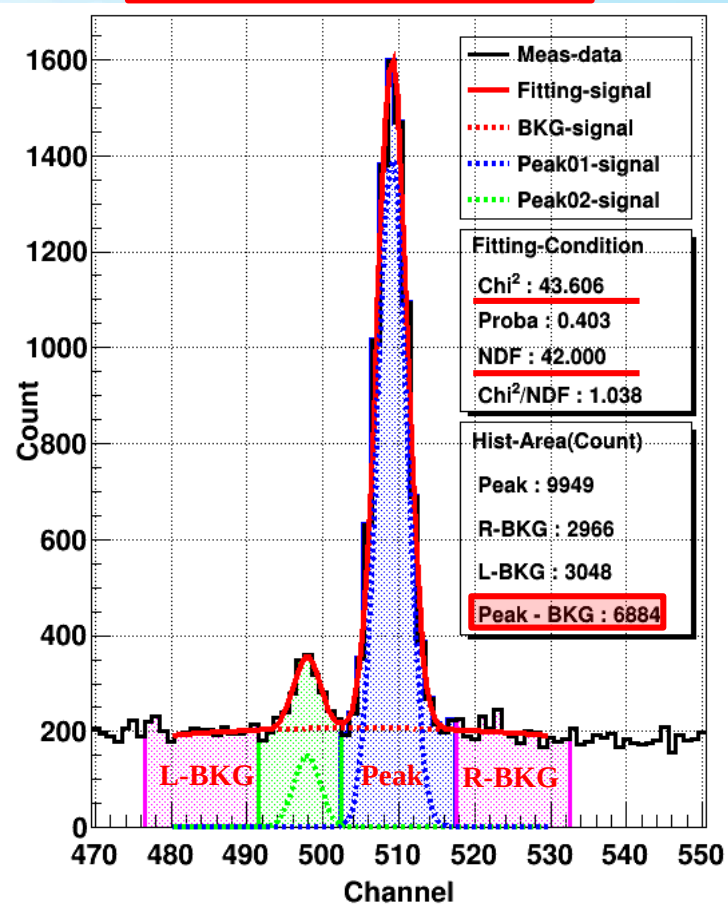
Sample08



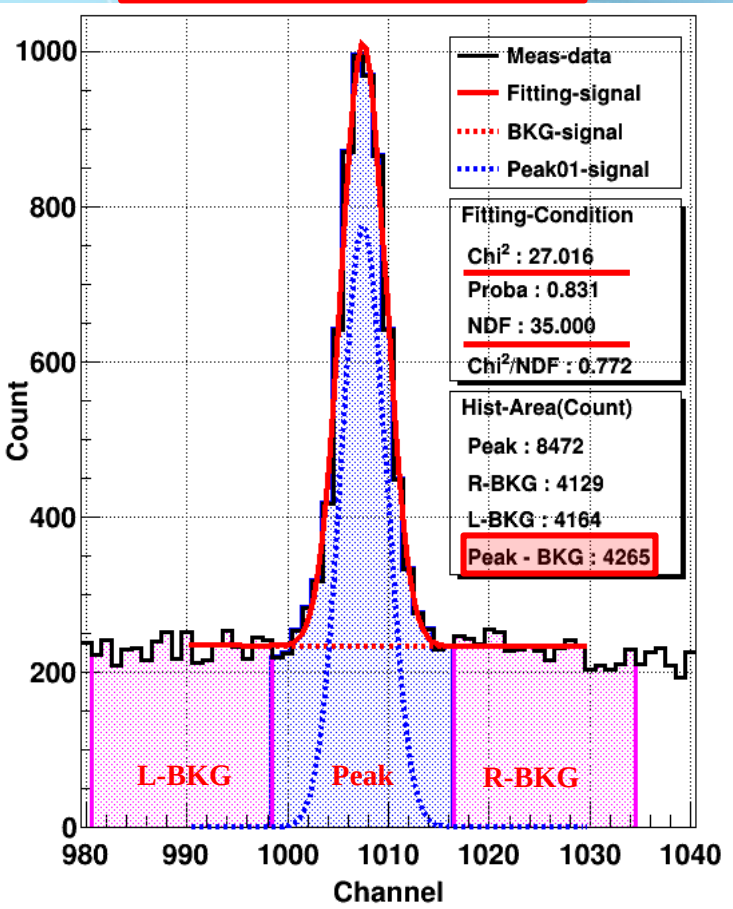
- Two peaks of the γ-spectrum are fitted by the function with a polynomial and Gaussian function.
- The number of radioactive nuclei from ^{67}Cu and ^{67}Ga are mixed together in both peaks.

Net peak area calculated from the fitting method

γ –spectrum : 93.3 keV



γ –spectrum : 184.6 keV

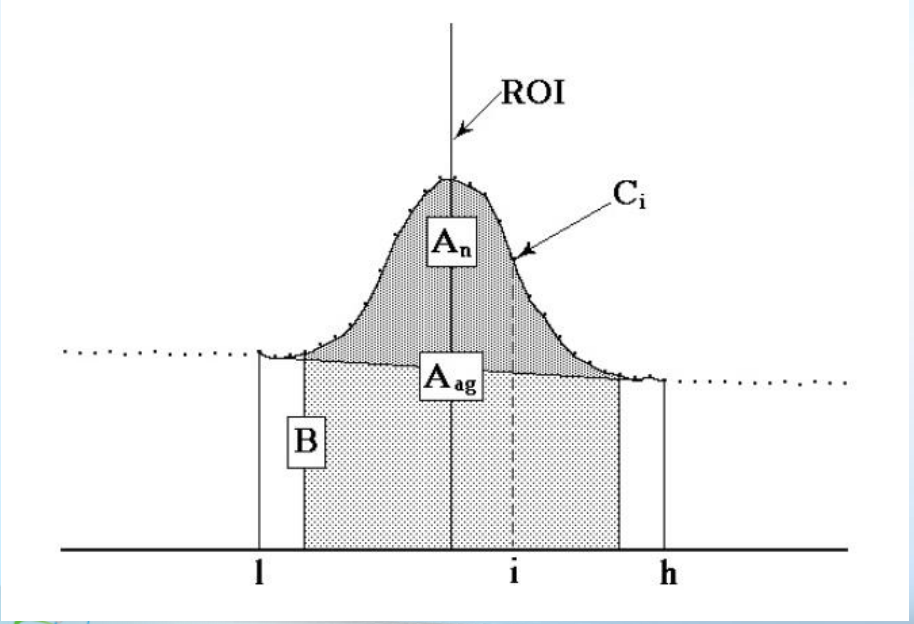


Sample08

- R-BKG and L-BKG around the peak are similar.
- As the result of the fitting, Chi² and NDF shown can be the condition to determine the state of fitting.

Net peak area calculated from another method

- Another method to calculate the net peak area is the automatic peak search method used in the gamma vision software.
- The background, B presented at the bottom of the peak is calculated from the middle point in the average for three channel of each side at the region of interest (ROI).
- The adjusted gross area, A_{ag} means the sum of all the channel marked by the ROI except the background of three channels on each side.



$$B = \left(\sum_{i=l}^{l+2} C_i + \sum_{i=h-2}^{h} C_i \right) \times \frac{h - l - 5}{6}$$

$$A_{ag} = \sum_{i+3}^{h-3} C_i$$

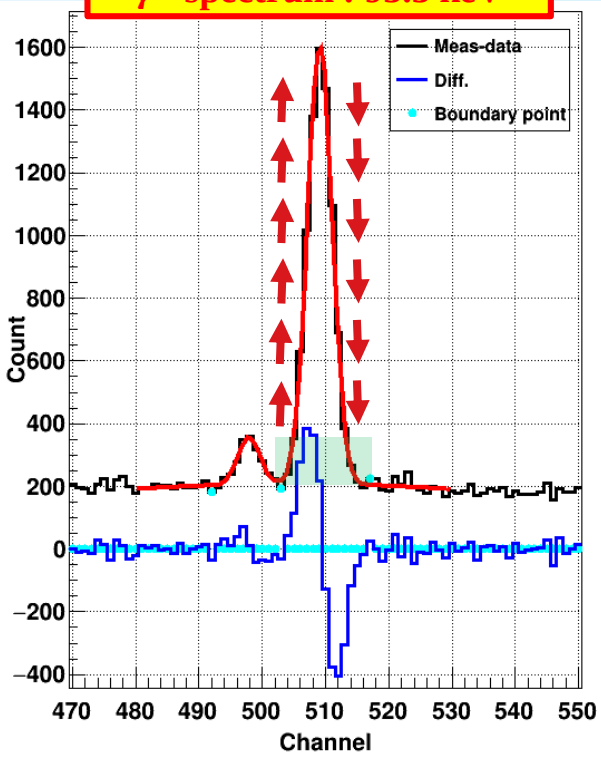
- The net area (signal) is the following :

$$A_n = A_{ag} - B$$

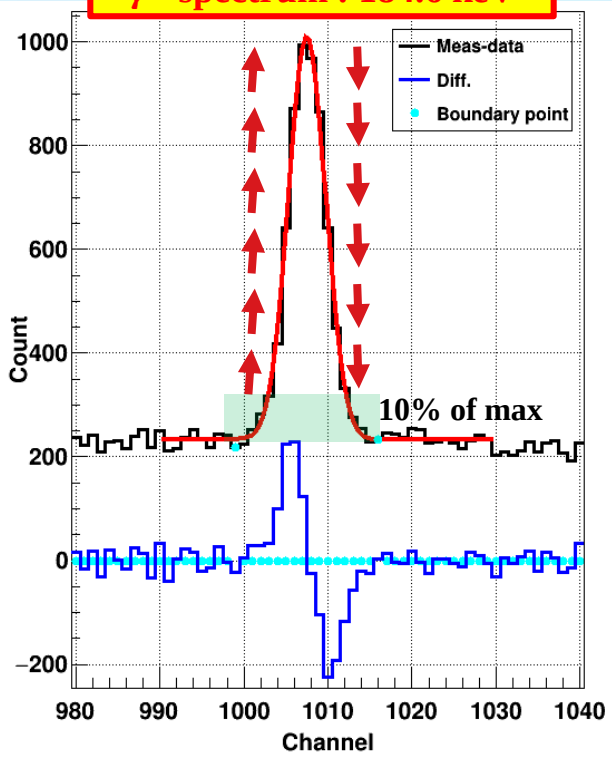
The boundary point between the signal and BKG

- In order to use the automatic peak search method, **the boundary point** between the signal and BKG should be determined on the γ-spectrum interested.
- How does the platform know where is the peak or BKG on the γ-spectrum?
- Near the peak, the slop is increased or decreased continuously.

γ –spectrum : 93.3 keV



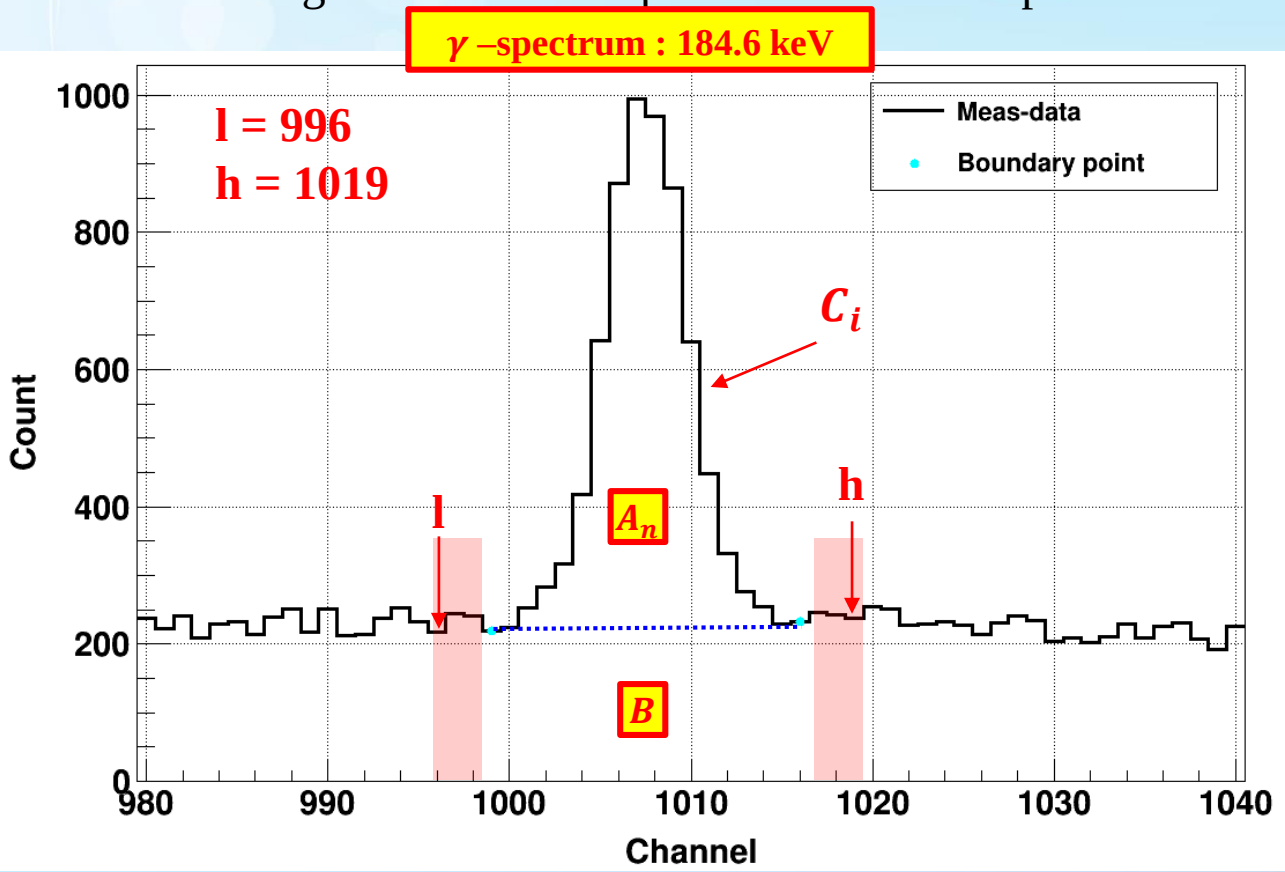
γ –spectrum : 184.6 keV



- In the left side of the peak, the slop is increased continuously.
- In the right side of the peak, the slop is decreased continuously.
- In the 10% range of the maximum, the slop <= 0 (in the left side) and the slop >= 0 (in the right side)

Net peak area calculated from another method

- After determining the boundary point, the net area of the signal can be calculated using the automatic peak search method.
- The following show the detail process done in the platform.



$$B_L = \sum_{i=l}^{l+2} C_i = 705$$

$$B_R = \sum_{i=h-2}^{h} C_i = 726$$

$$B = (B_L + B_R) \times \frac{h-l-5}{6} = 4293$$

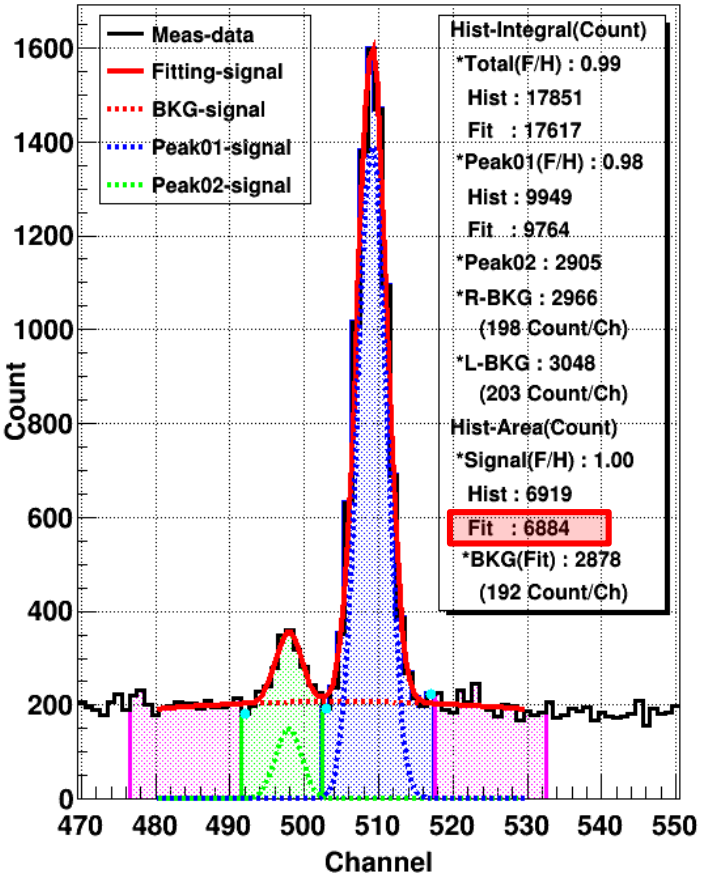
$$A_{ag} = \sum_{i=l+3}^{h-3} C_i = 8472$$

$$A_n = A_{ag} - B = 4179$$

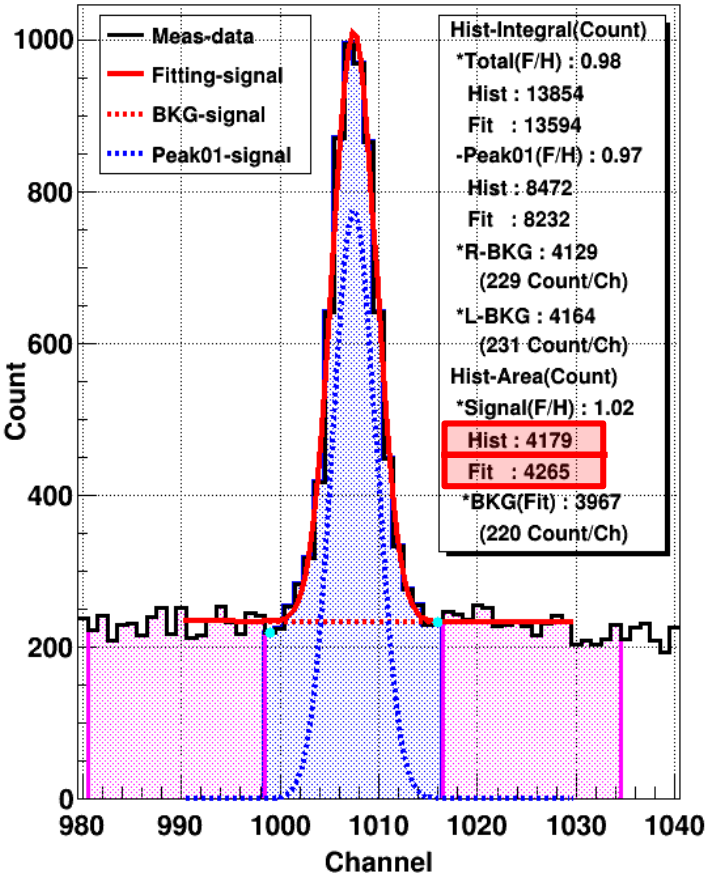
Calculating *N* from the peak mixed Cu-67 and Ga-67

- The net peak areas calculated by the fitting method and the automatic peak search method have the similar values. This fact shows the result of the data analysis done by this platform is reliable.

γ –spectrum : 93.3 keV



γ –spectrum : 184.6 keV

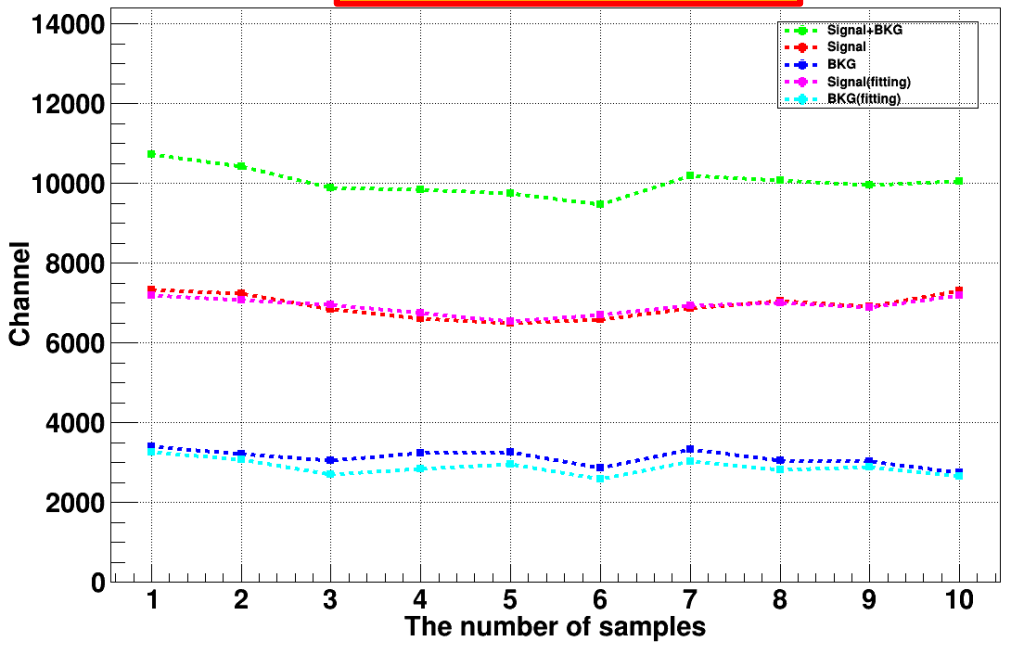


Sample08

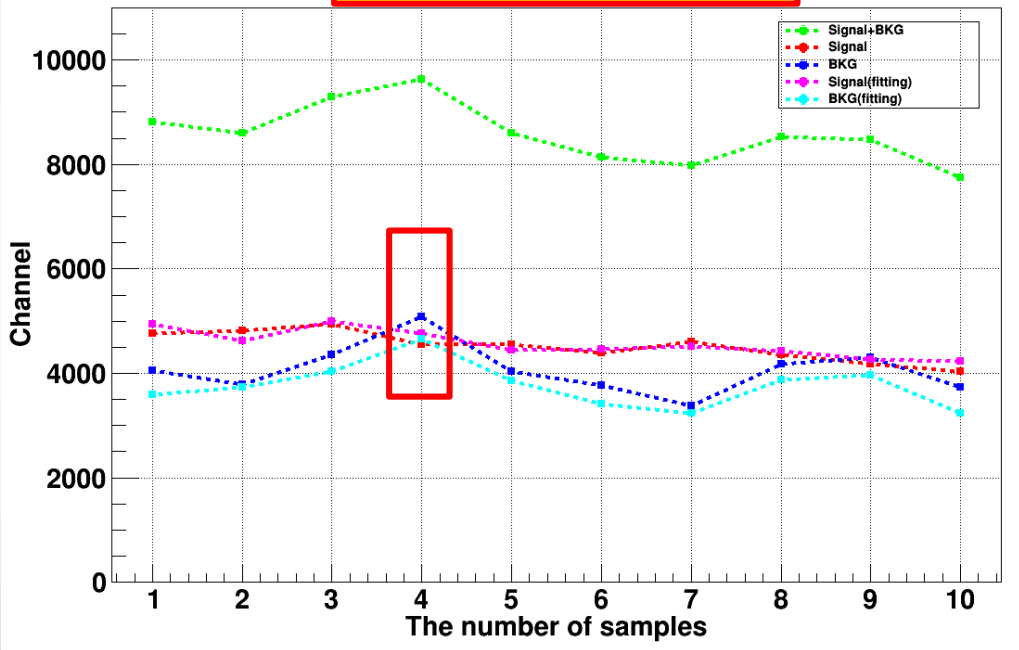
Checking the results made from 10 samples

- The net peak areas calculated by the fitting method and the automatic peak search method have also the similar values in the result made from 10 samples.
- There is the unusual data area at the sample04 with the energy 184.6 keV.

γ –spectrum : 93.3 keV

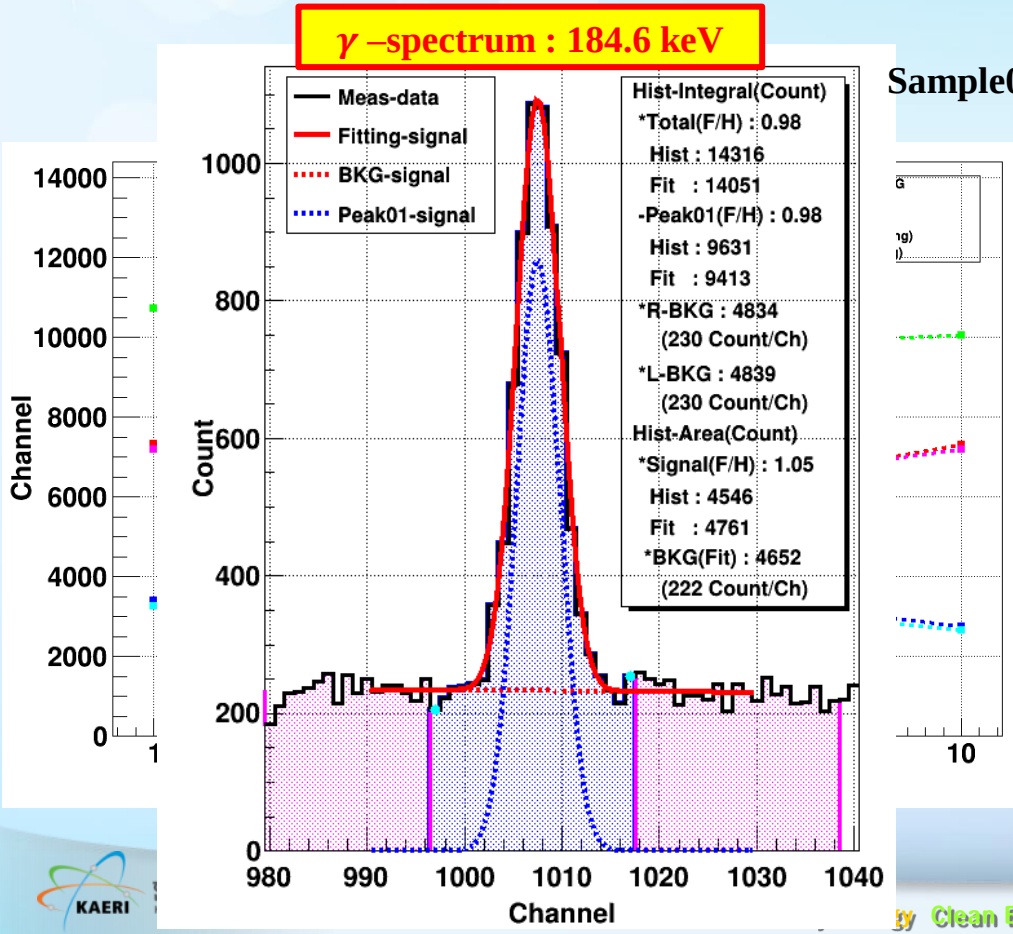


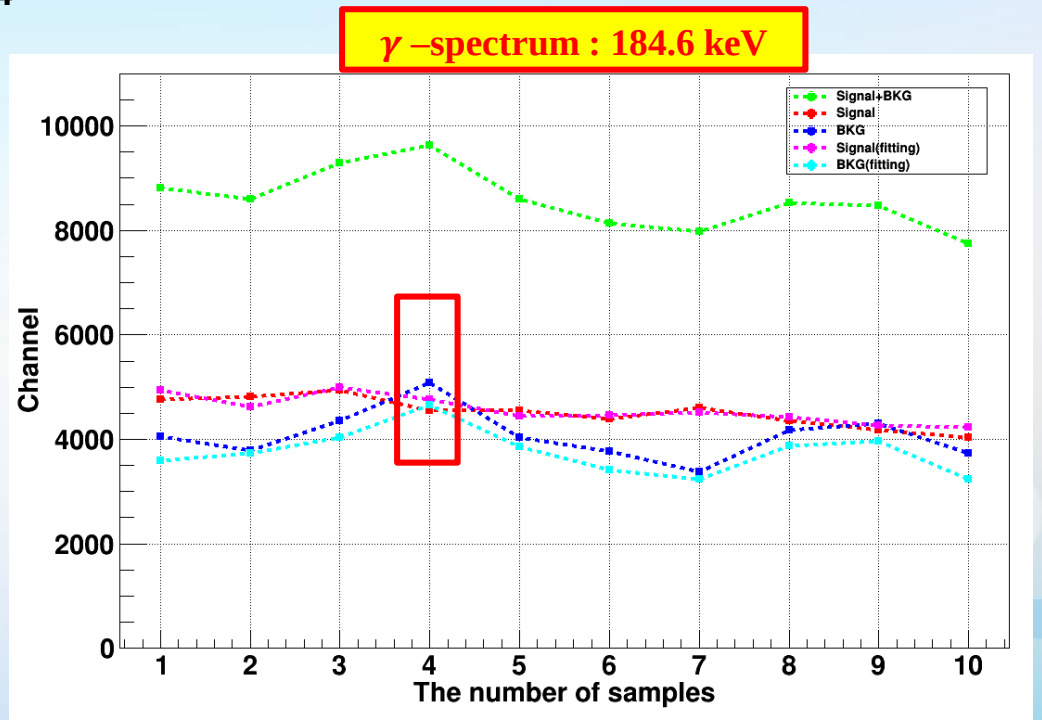
γ –spectrum : 184.6 keV



Checking the results made from 10 samples

- The net peak areas calculated by the fitting method and the automatic peak search method have also the similar values in the result made from 10 samples.
- However, there are no singularity found in the histograms fitted.



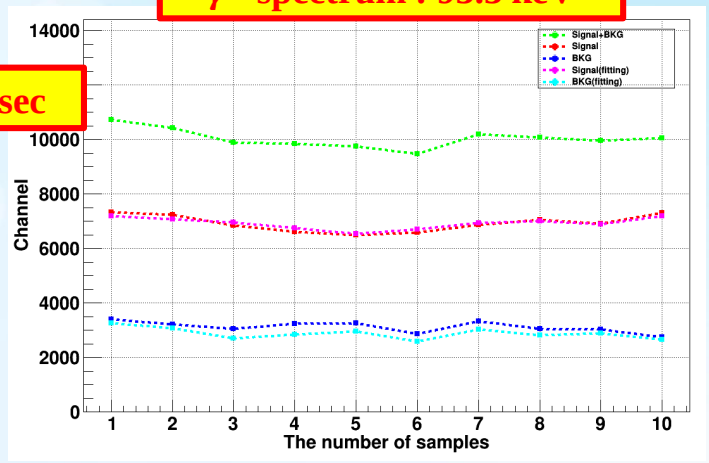


Checking the results in the different t_m

- When t_m is increased, there are no unusual data area found. This mean that the BKG has some fluctuation and if the data size is small, the BKG and signal can be ovepped.

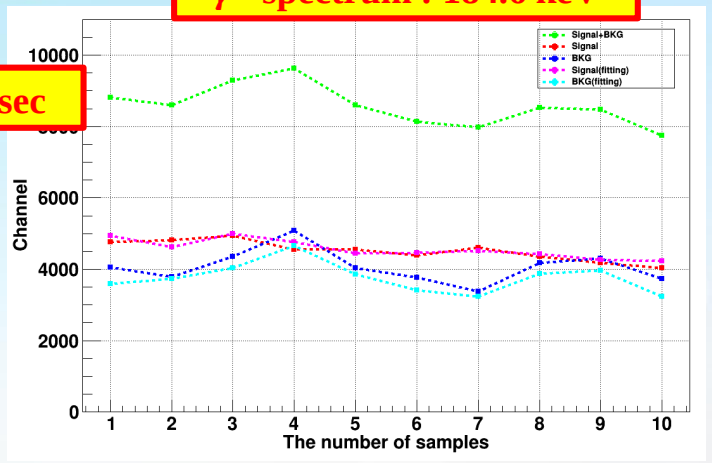
γ –spectrum : 93.3 keV

t_m : 300 sec

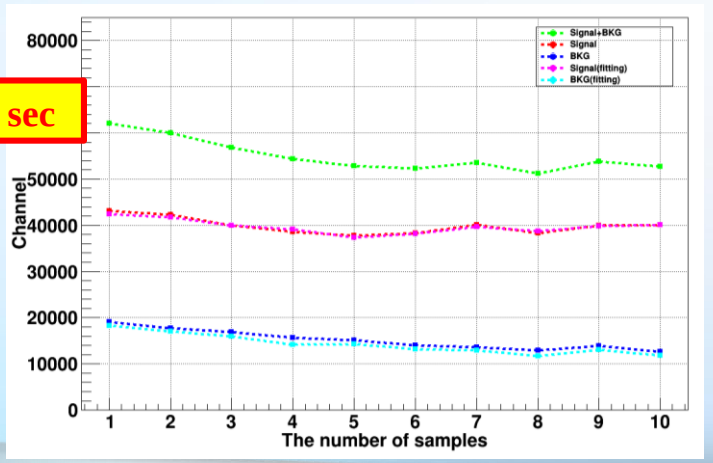


γ –spectrum : 184.6 keV

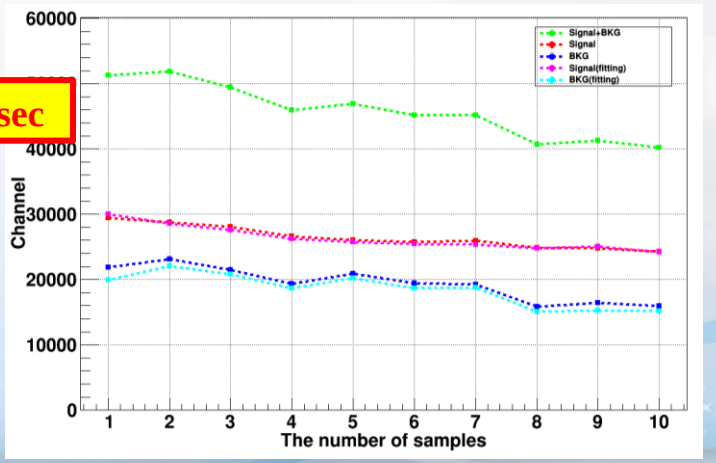
t_m : 300 sec



t_m : 3600 sec



t_m : 3600 sec



Summary and future plan

- The platform to calculate the cross section is still developed.
- The good agreement of the net peak areas calculated from two kinds of methods shows that the process of the data analysis of the platform can be reliable.
- Any criteria to determine the fitting condition done in the platform is needed like a chi-square test for goodness of fit.
- The platform should be upgraded to use the different kinds of input files.

My goal is that everyone can understand the process to calculate the cross-section easily.

```
$SPEC_ID:
No sample description was entered.
$SPEC_REM:
DET# 1
DETDESC# COM-PC MCB 129 Input 1
AP# GammaVision Version 8.10.02
$DATE_MEA:
12/12/2017 19:19:50
$MEAS_TIM:
1800.00 1802.98
$DATA:
0 8191
      0
      0
      0
      0
      0
      0
      0
      0
      0
      0
      0
      0
```