Neutron total Cross-sections and Resonance parameters of Dy at Pohang Neutron Facility

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The 1st Asian Nuclear Reaction Database Development Workshop

Total Cross Section Measurement of Pohang Neutron Facility

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1. Total Cross Section Measurement
2. Pohang Neutron Facility
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5. Signal and Noise separation
6. Neutron Energy Calibration
7. Flight Length and t_0 fitting
8. Dysprosium FADC TOF Spectra

1. Total Cross Section Measurement

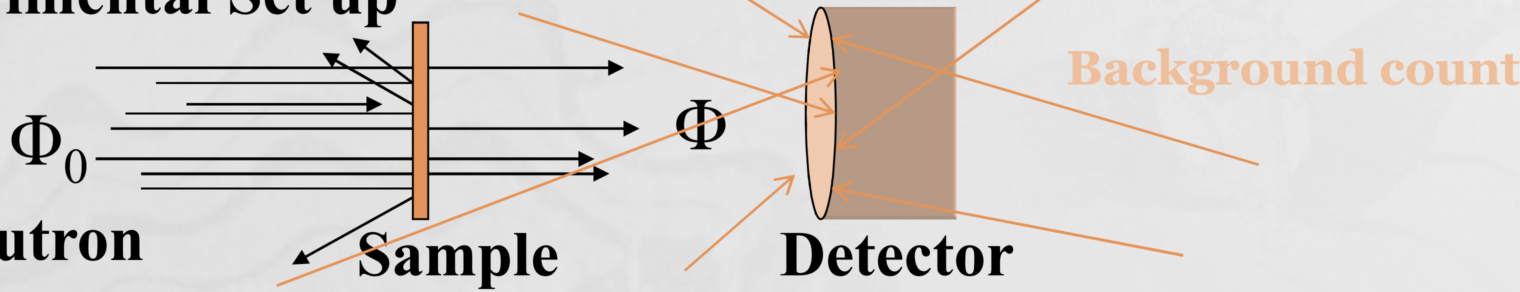
1. Neutron Energy E in eV corresponding to channel I in TOF

$$E[eV] = \left(\frac{72.3 \times L[m]}{T[\mu s]} \right)^2$$

L: flight path length

T: time of flight

2. Experimental Set up



3. Neutron Transmission rate

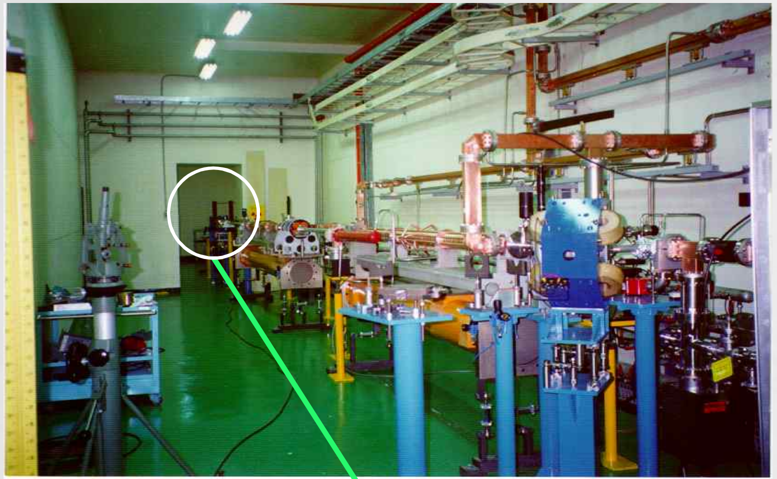
$$T(E_i) = \frac{Count\_with\_Sample}{Count\_without\_Sample} = \frac{\{In(E_i) - In^B(E_i)\}/M}{\{Out(E_i) - Out^B(E_i)\}/M^B} = \frac{C_{In}(E_i)/M}{C_{Out}(E_i)/M^B}$$

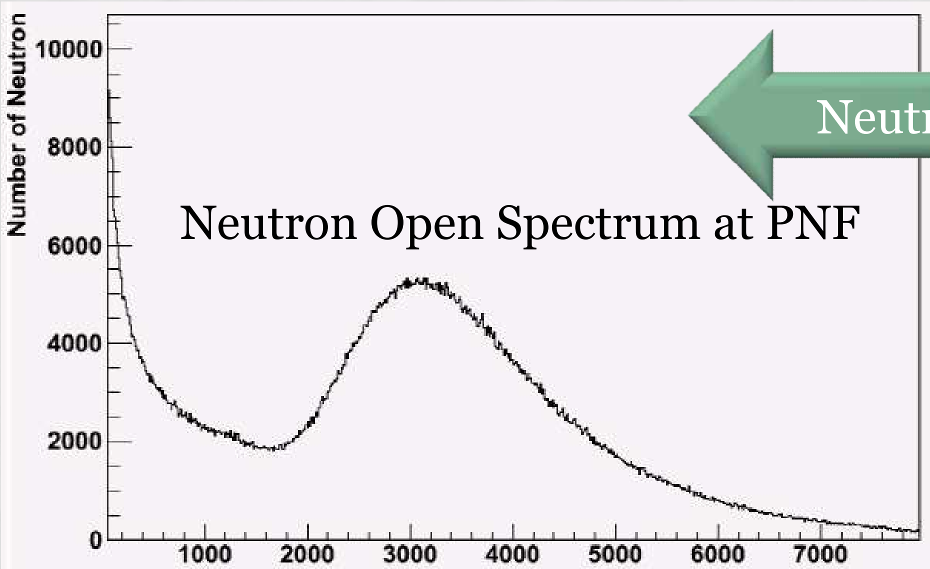
4. Total Cross Section

$$\sigma(E) = \frac{1}{N} \ln T(E)$$

2. Pohang Neutron Facility

- Electron accelerator based Time of Flight system
  - ✓ electron energy = 50 ~ 70 MeV
  - ✓ repetition rate = Below 30Hz
  - ✓ pulse width = 1 ~ 2 μs
  - ✓ peak beam current = 30 ~ 60 mA
  - ✓ TOF flight length = 11.5~12m
  - ✓
- Target + water moderator : to produce neutron pulse
  - ✓ Ta plates + cooling system

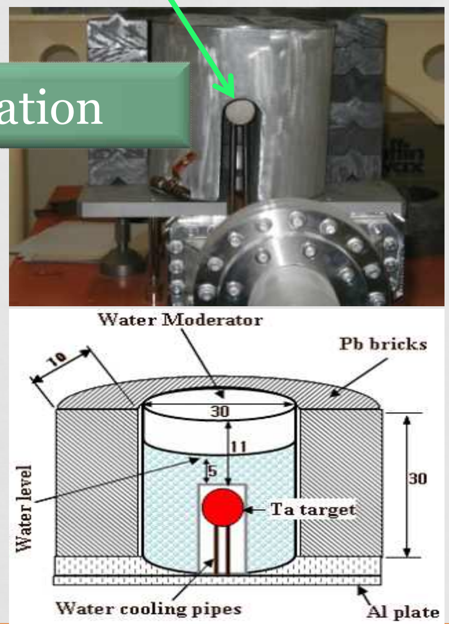




Neutron Open Spectrum at PNF

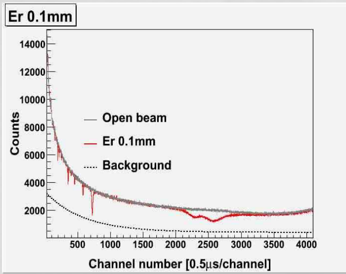
Neutron Arrival Time (us)

Neutron generation



3. Current TOF DAQ

Total Cross-section



BC702 Neutron Detector

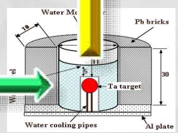
Neutron

Scattering, Capture, etc

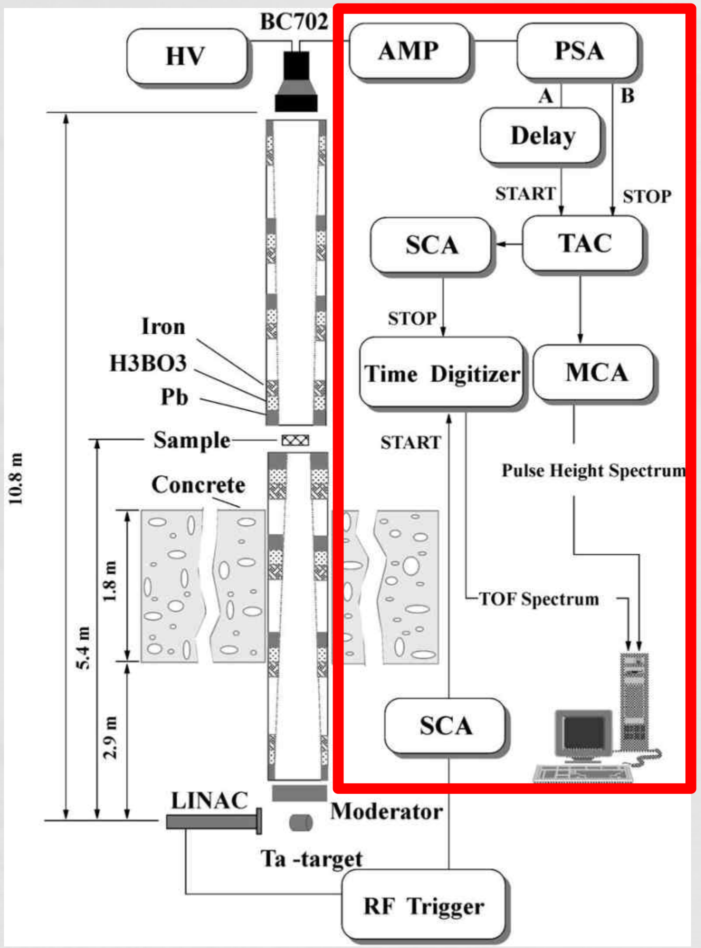
Sample Changer

Neutron

e⁻

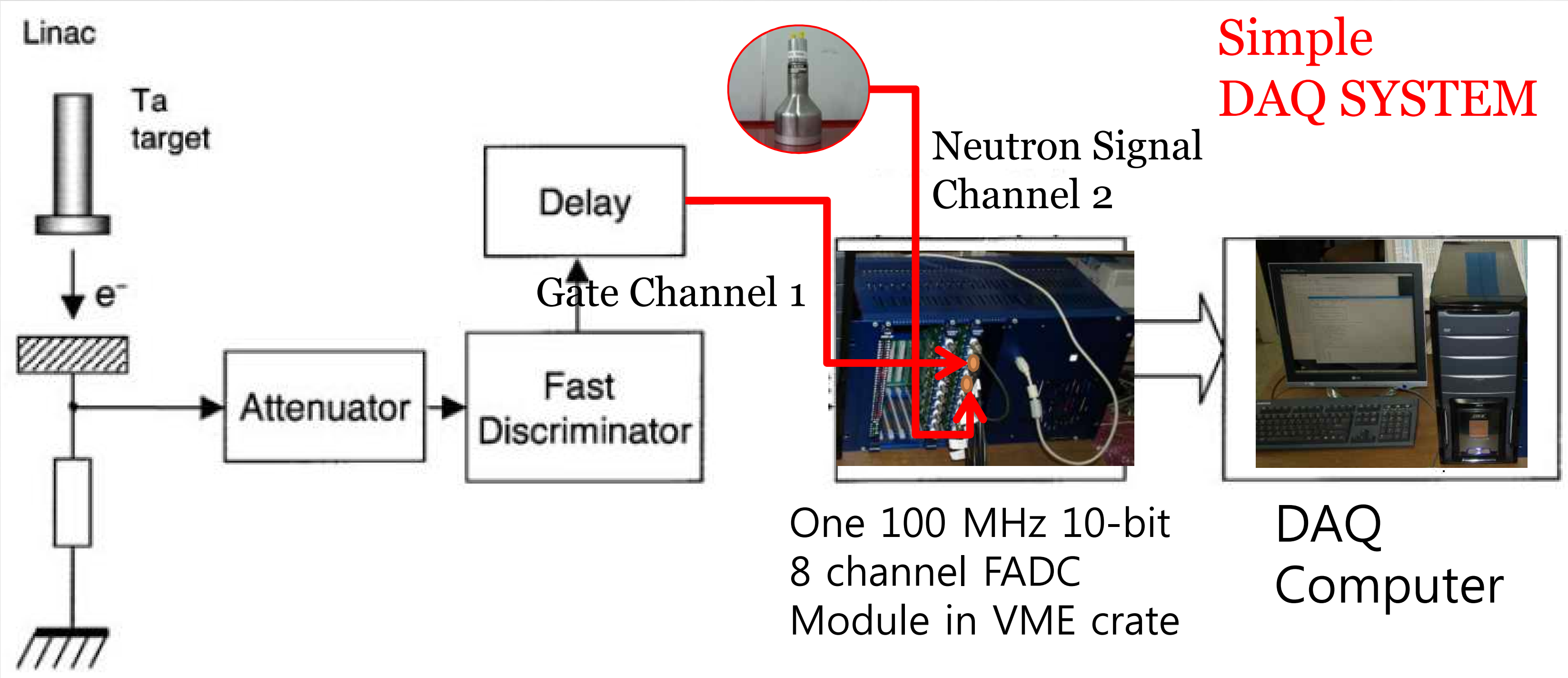


Current DAQ



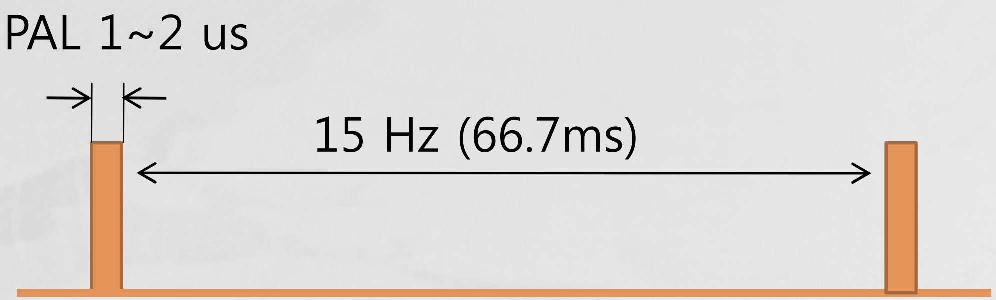
FADC DAQ

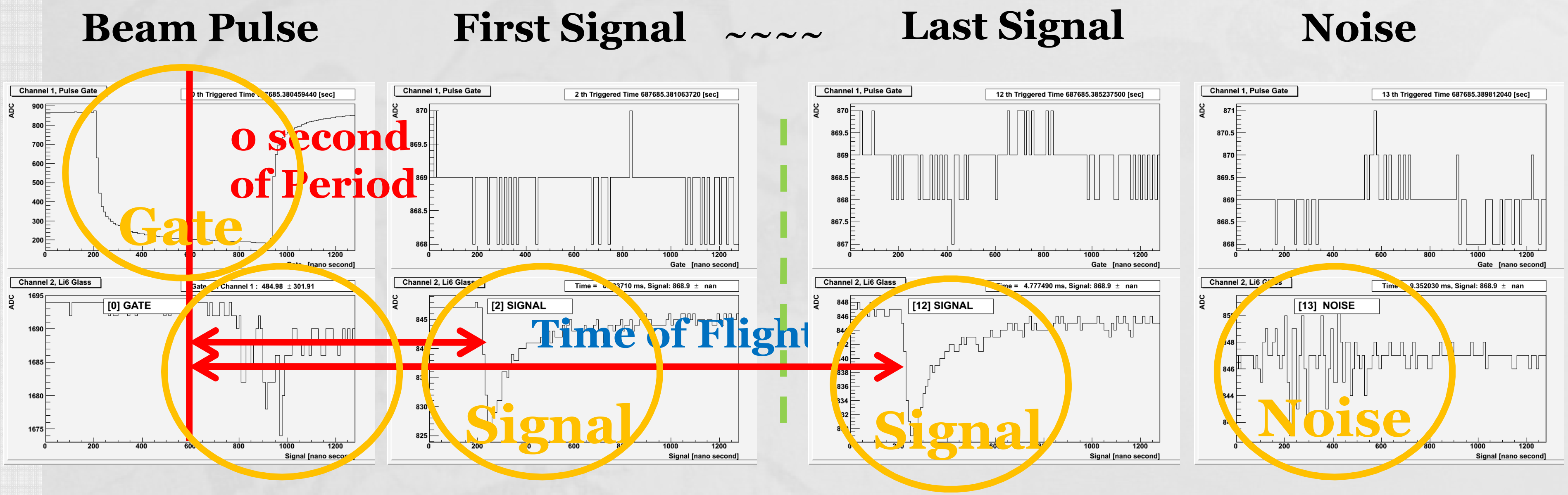
4. Flash ADC TOF DAQ (1)



- TOF Signal Data without Noise is possible due to the pulse shape analysis

4. Flash ADC TOF DAQ (2)





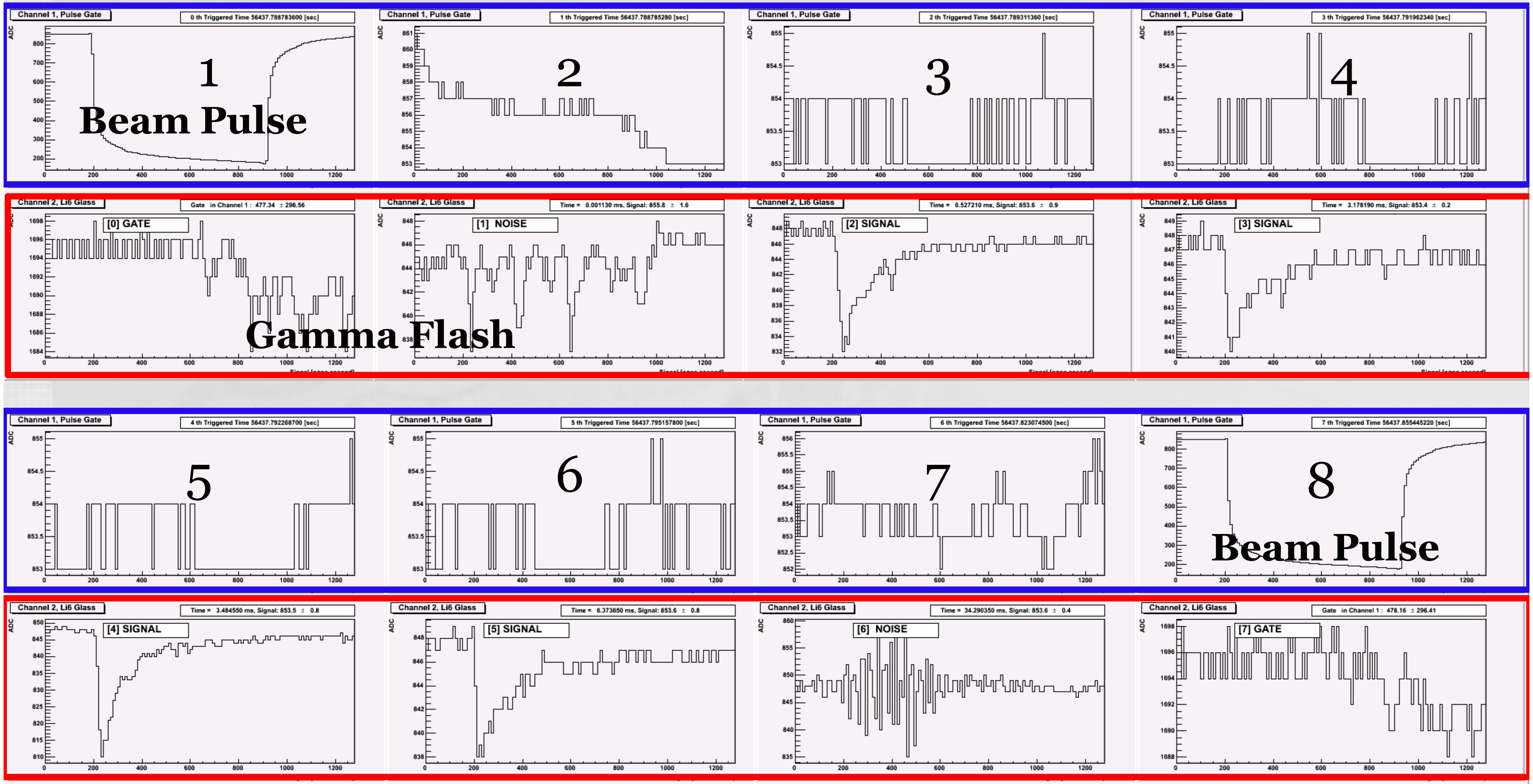
Gamma Flash due to Bremsstrahlung

Noise Rejection using a Software is possible and easy using FADC

4. Flash ADC TOF DAQ (3)

Recorded GATE channel

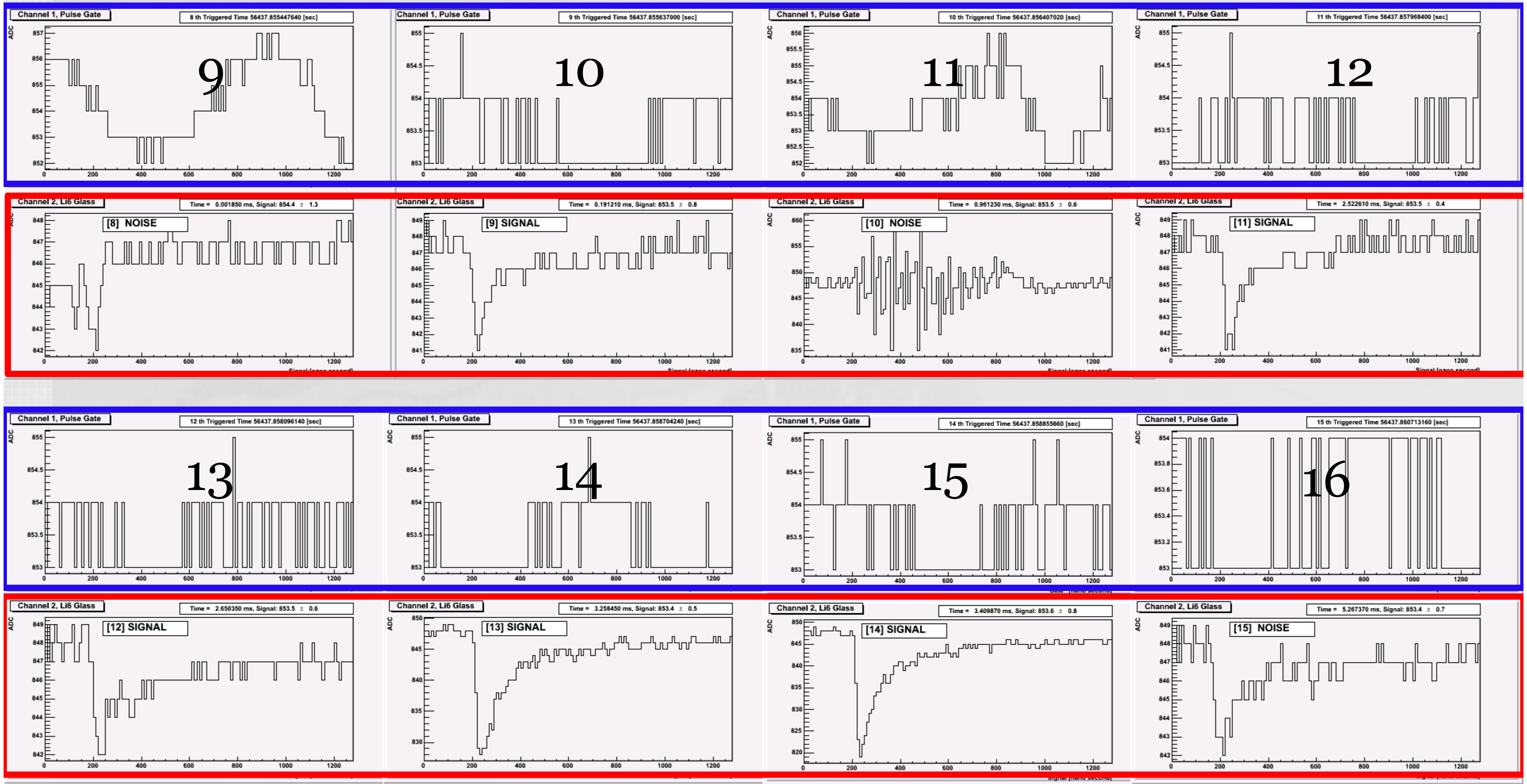
Recorded SIGNAL channel



4. Flash ADC TOF DAQ (4)

Recorded GATE channel

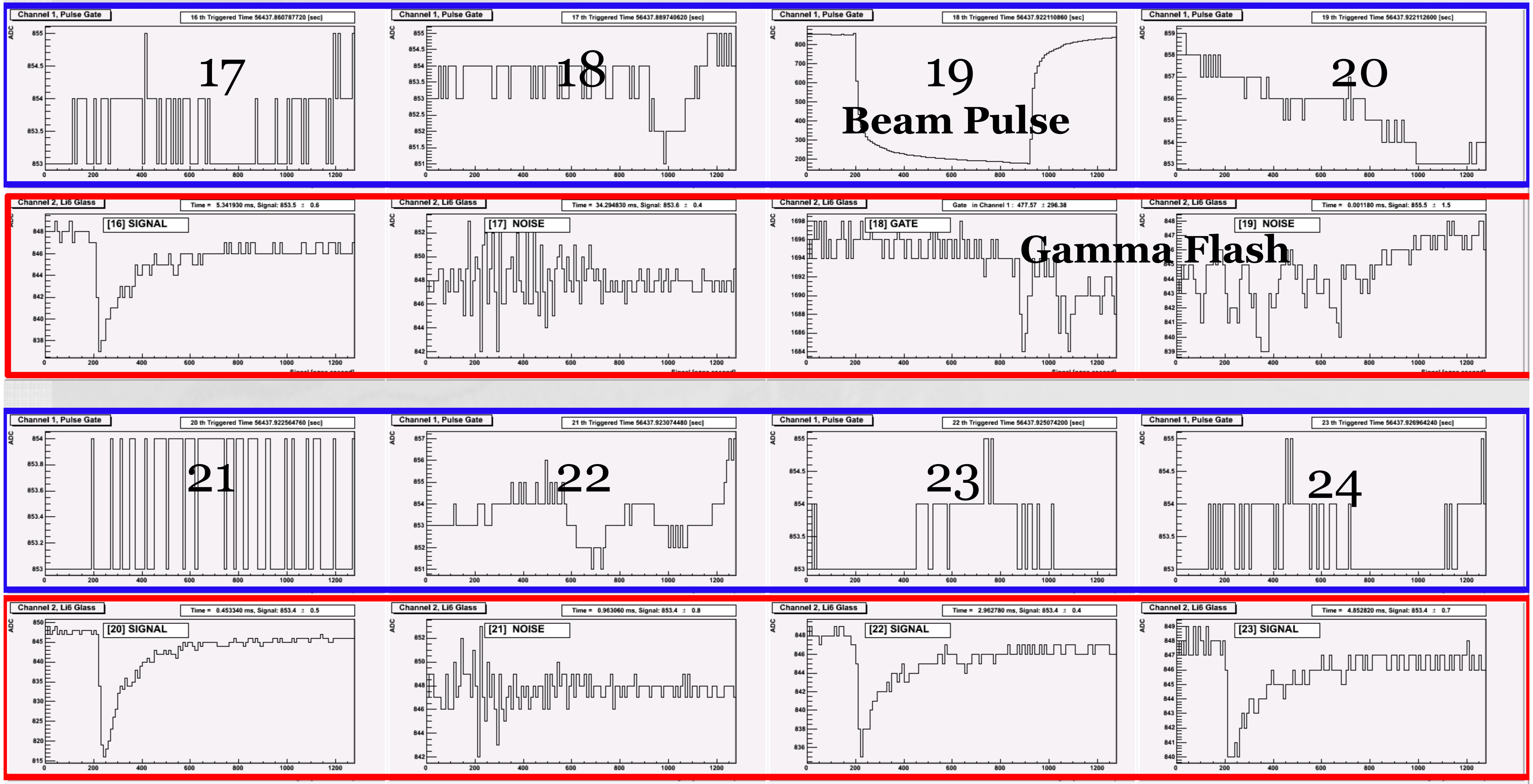
Recorded SIGNAL channel



4. Flash ADC TOF DAQ (5)

Recorded GATE channel

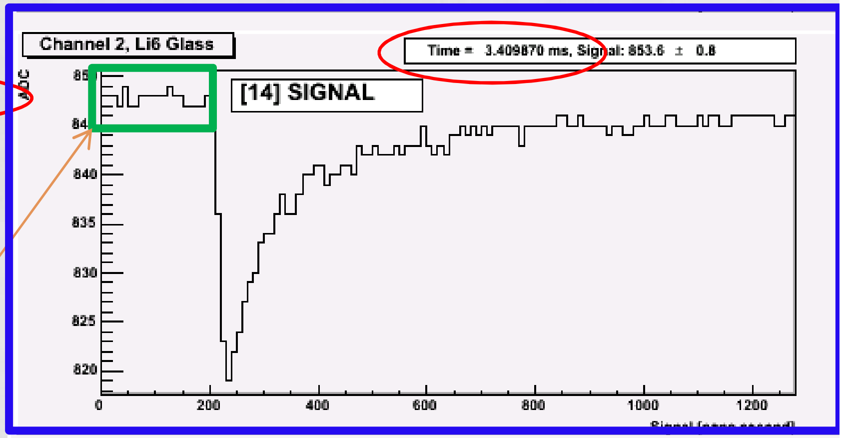
Recorded SIGNAL channel



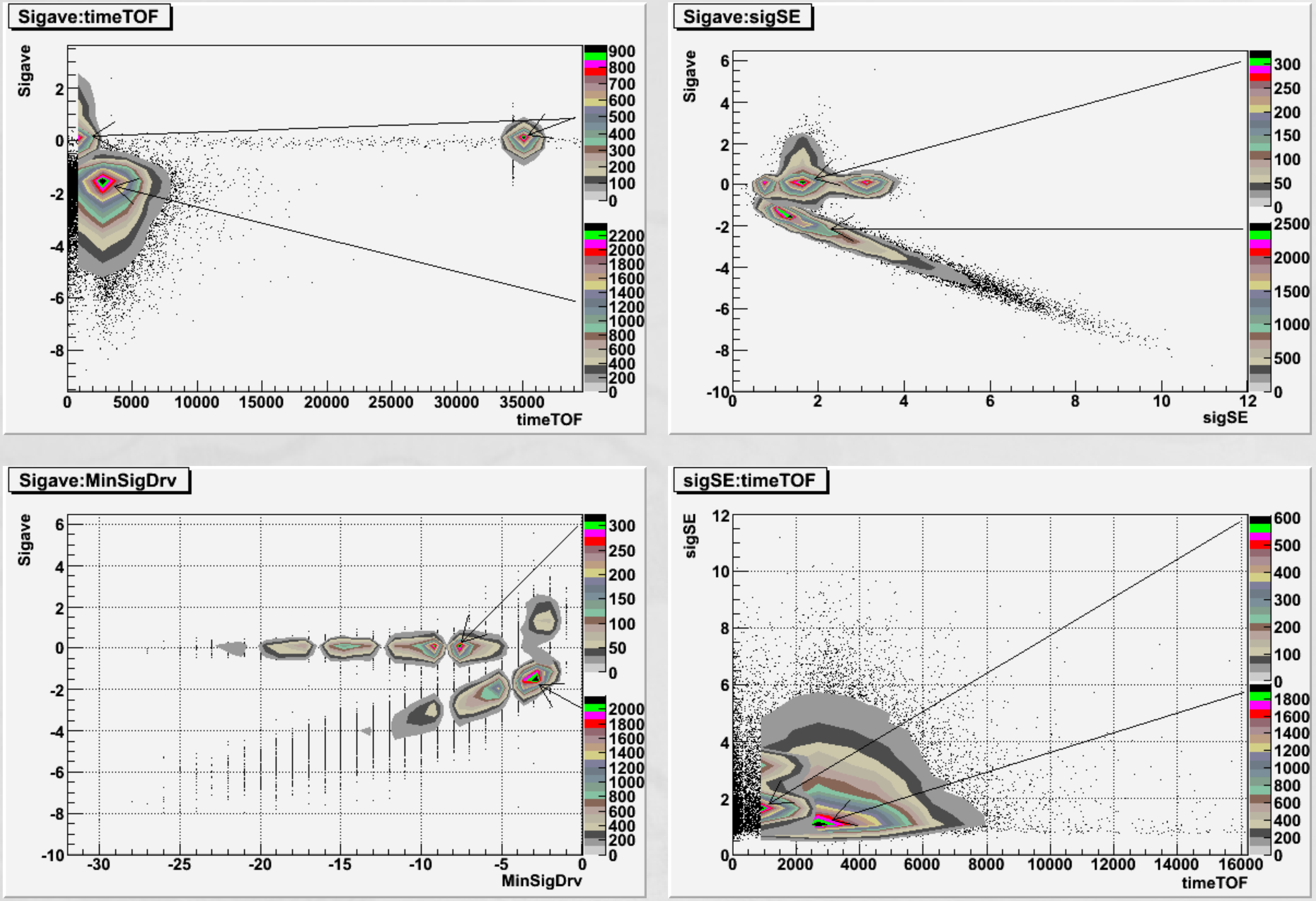
5. Signal and Noise separation (1)

- 7 Parameters are studied to find best cuts to separate Signal and Noise
- 21 cases are studied and 4 are selected as a best conditions for a better S/N

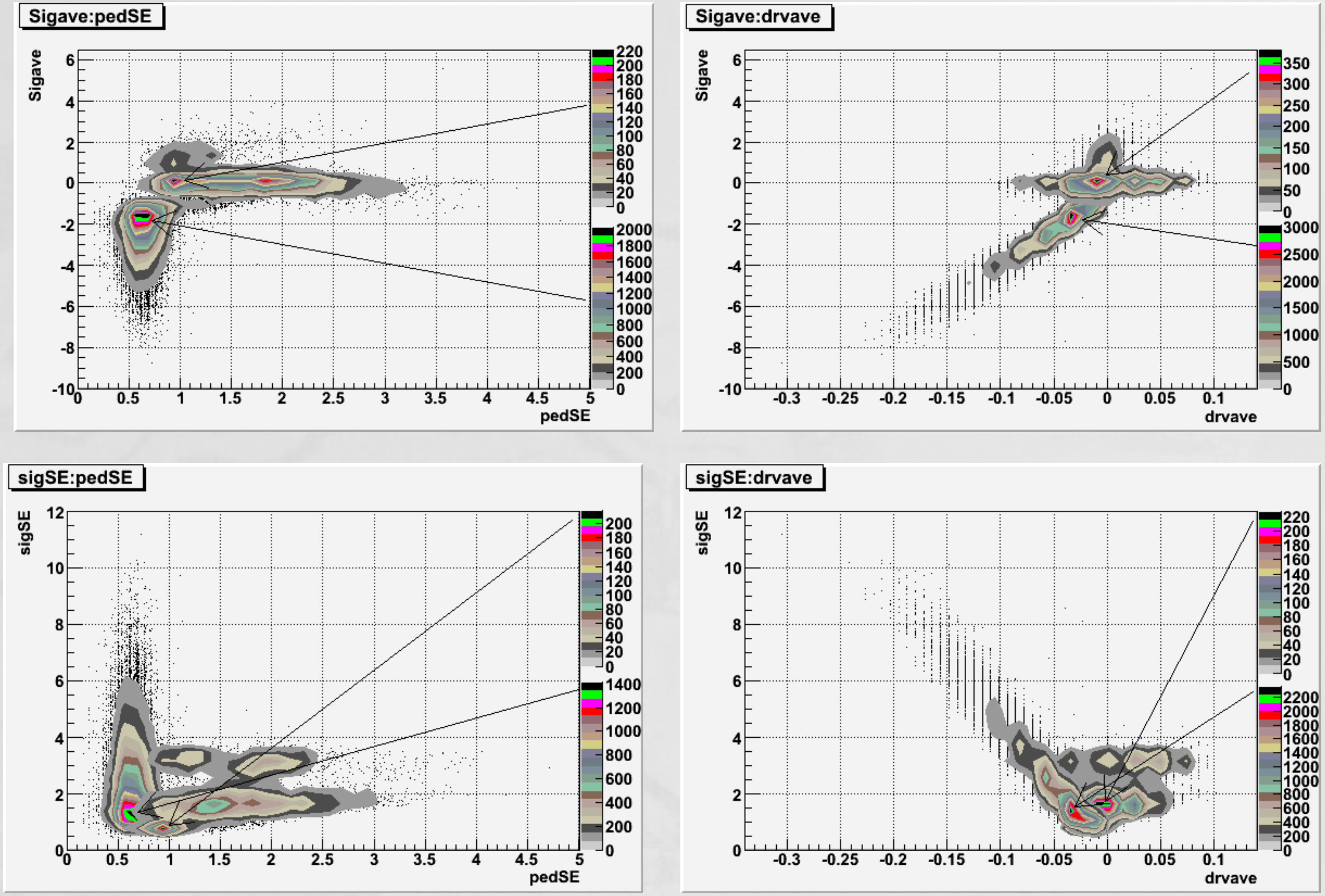
1. timeTOF : triggered time[us] from GATE
2. Sigave: Average ADC values
3. sigSE: Standard Error(SE) of Signals
4. **pedSE: SE of pedestal in first 20 bins**
5. **drvave: Average of first derivative of ADC**
6. **drvSE: SE of drvave**
7. **MinSigDrv: Minimum value of first derivative**



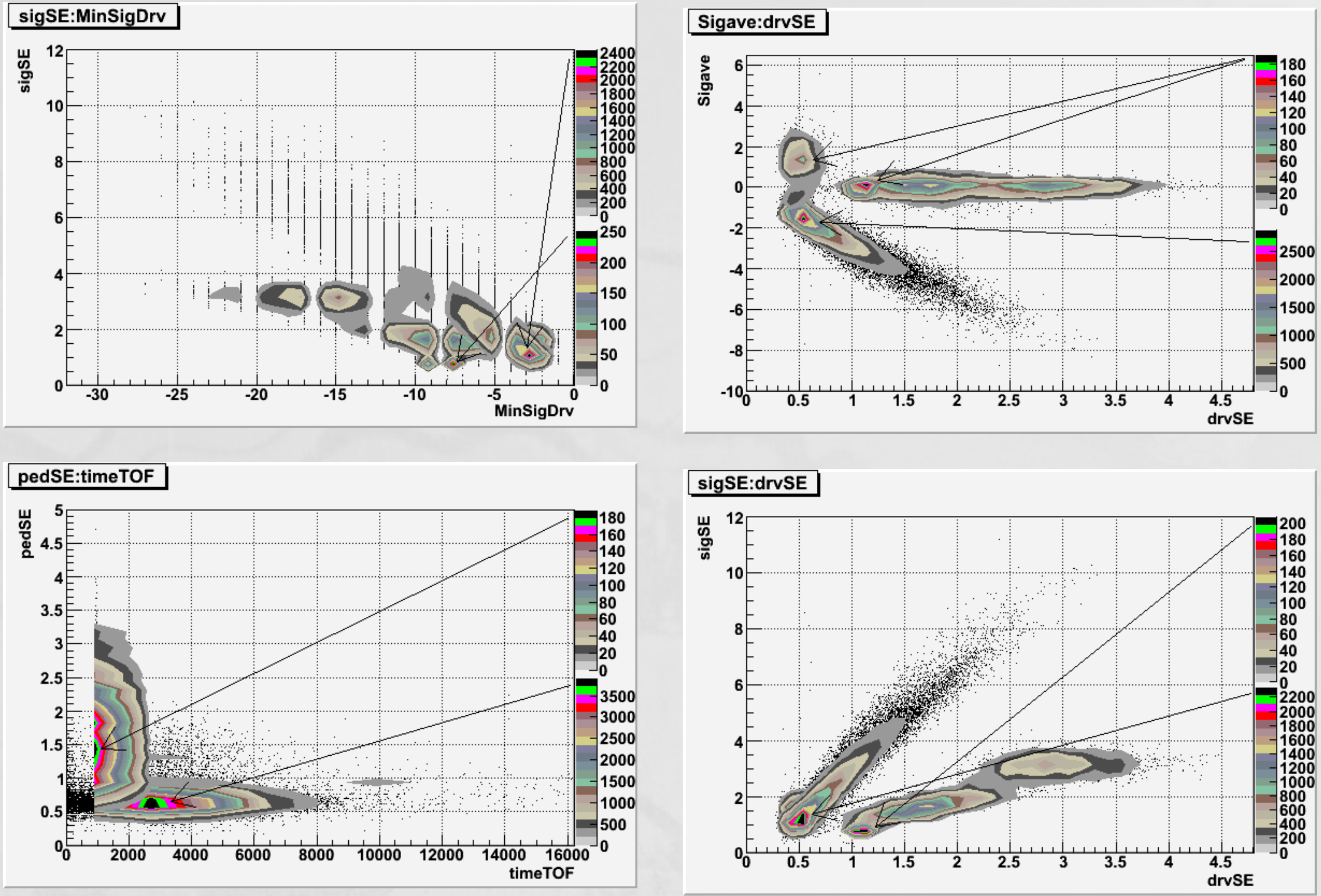
5. Signal and Noise separation (2)



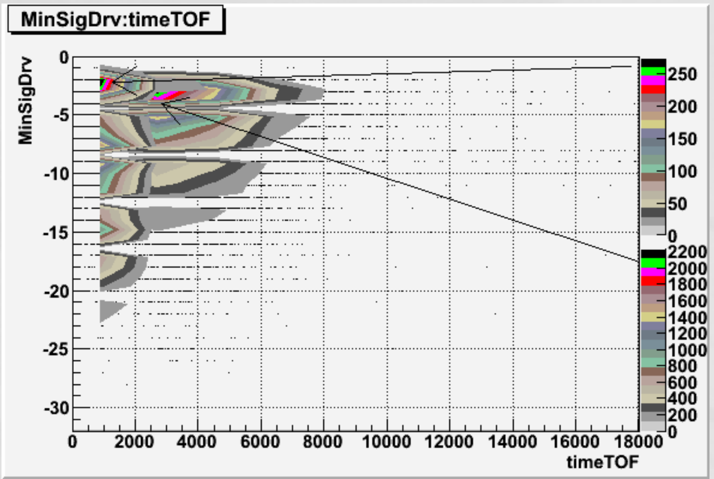
5. Signal and Noise separation (3)

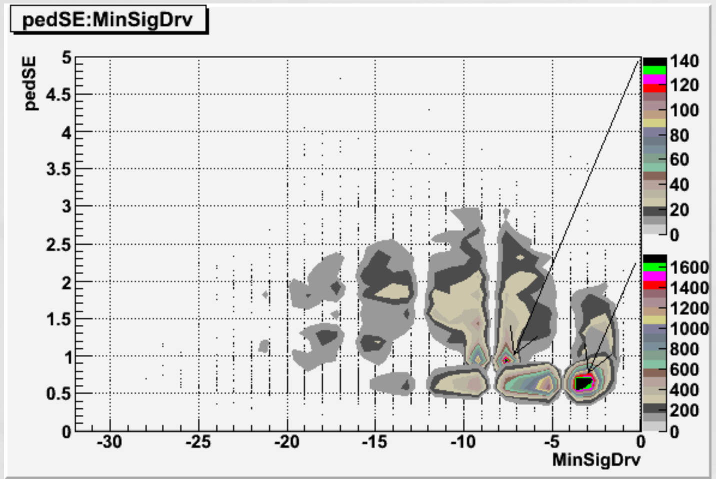


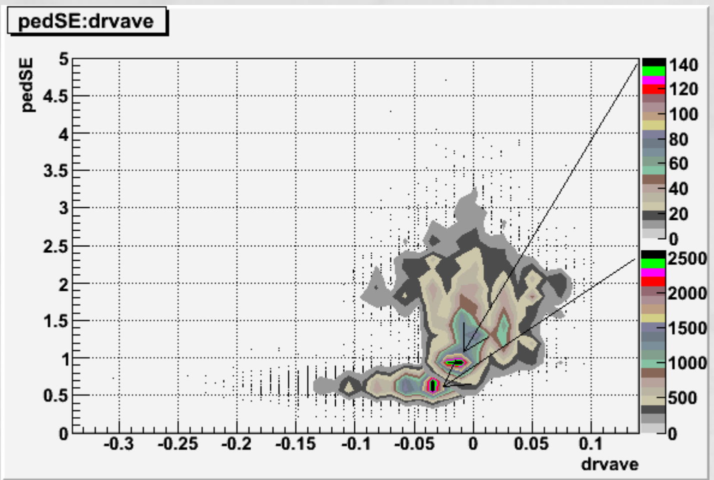
5. Signal and Noise separation (4)

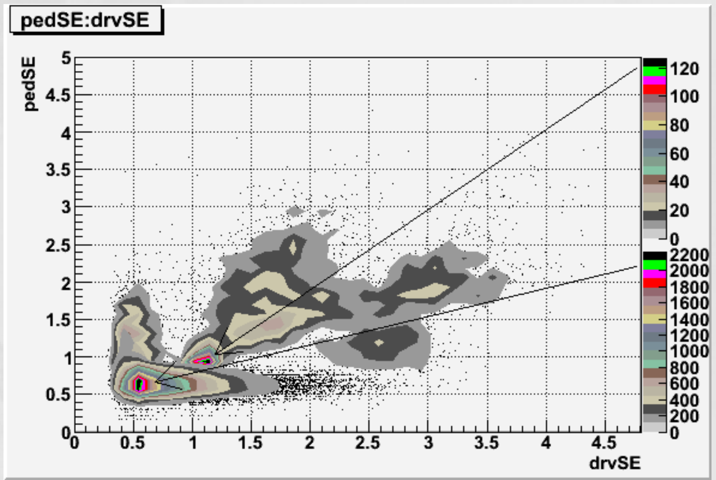


5. Signal and Noise separation (5)

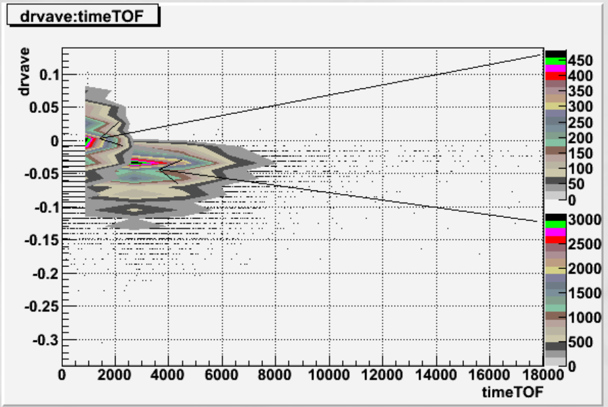


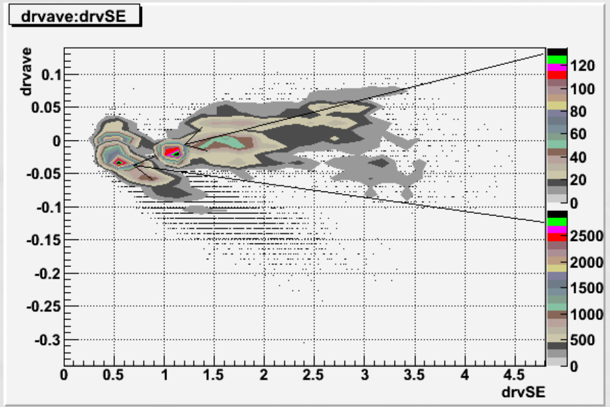


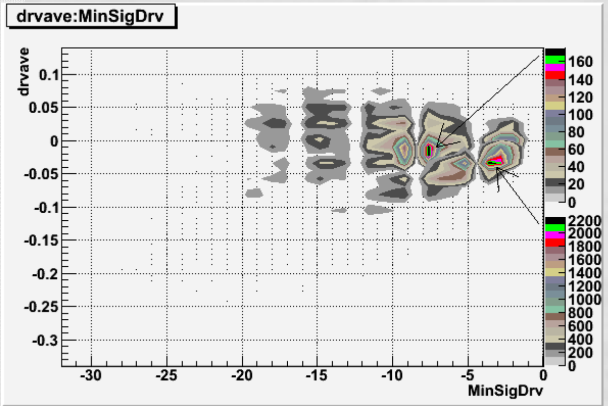


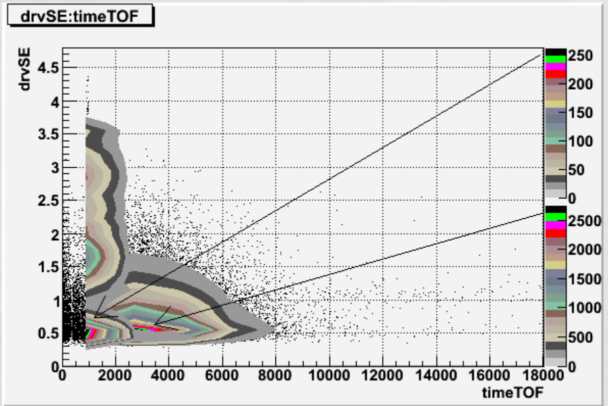


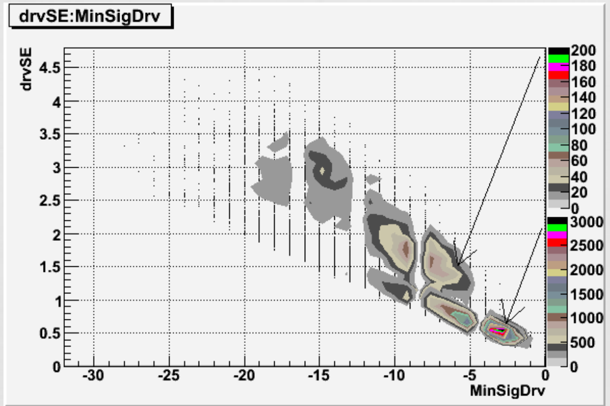
5. Signal and Noise separation (6)



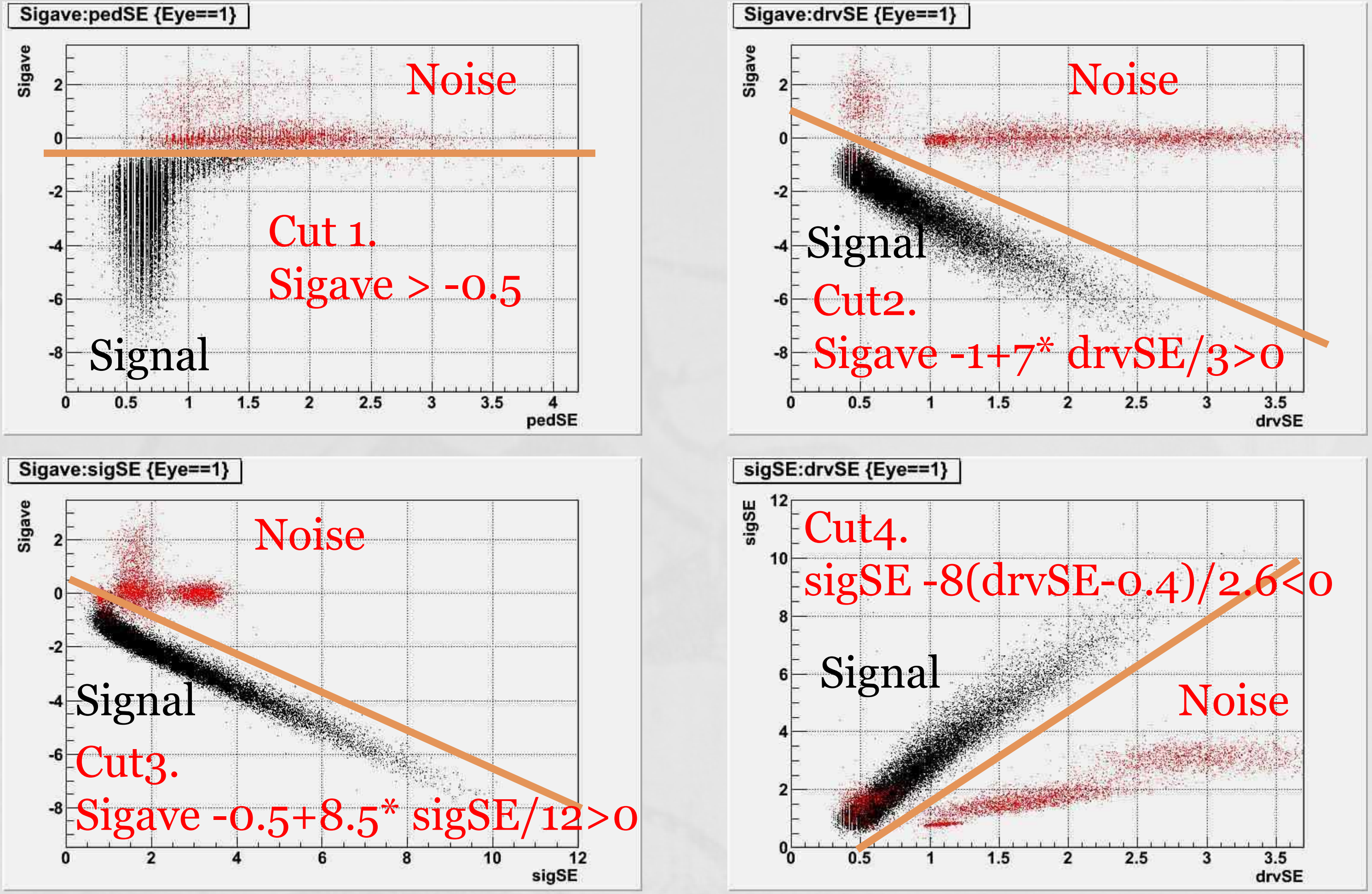








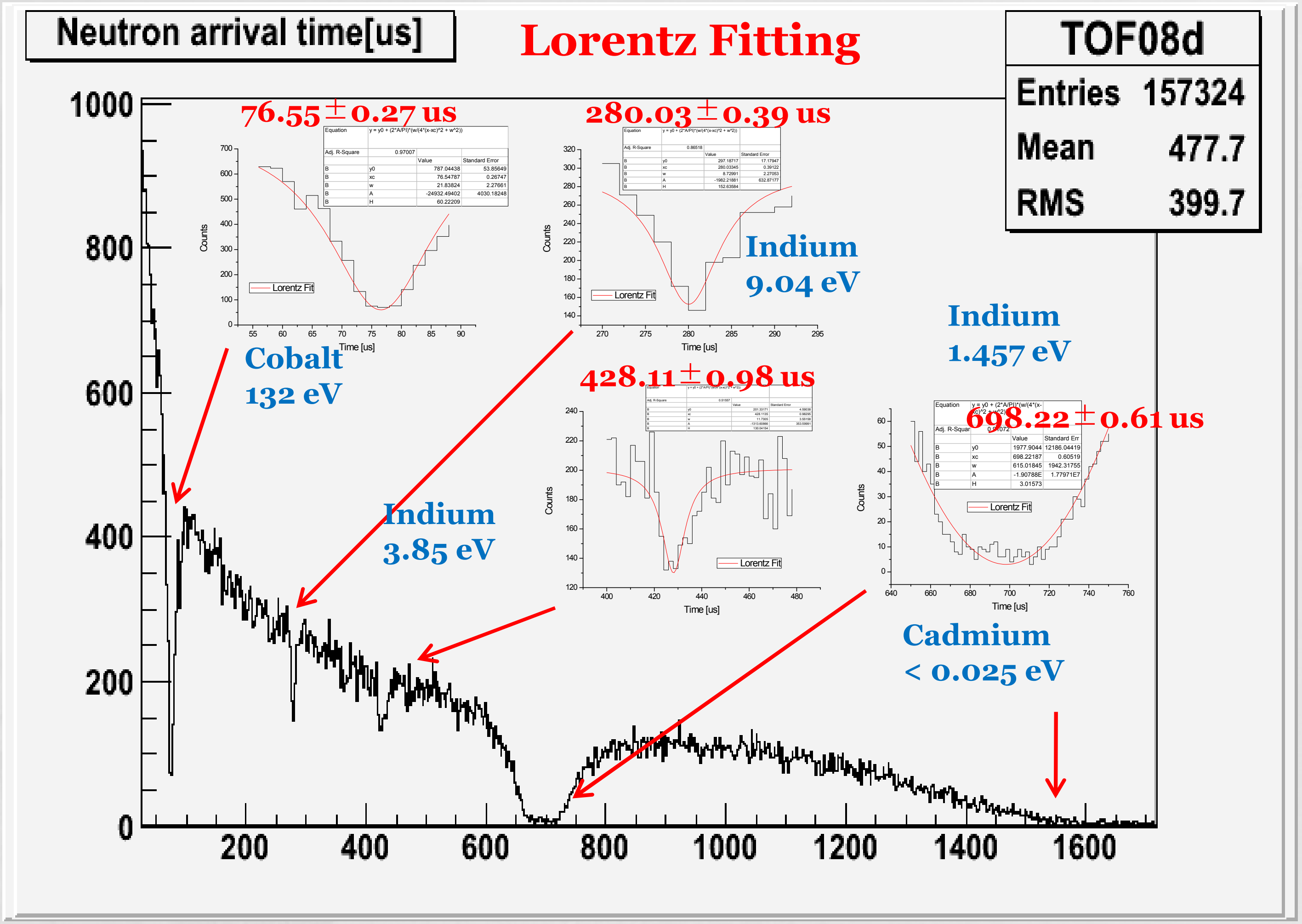
5. Signal and Noise separation (7)



4 cuts => S/N = 448.4, Signal Loss=1.19 %, Noise Rejection = 98.7 %

6. Neutron Energy Calibration

Using Notch Filter (Co, Cd, In)

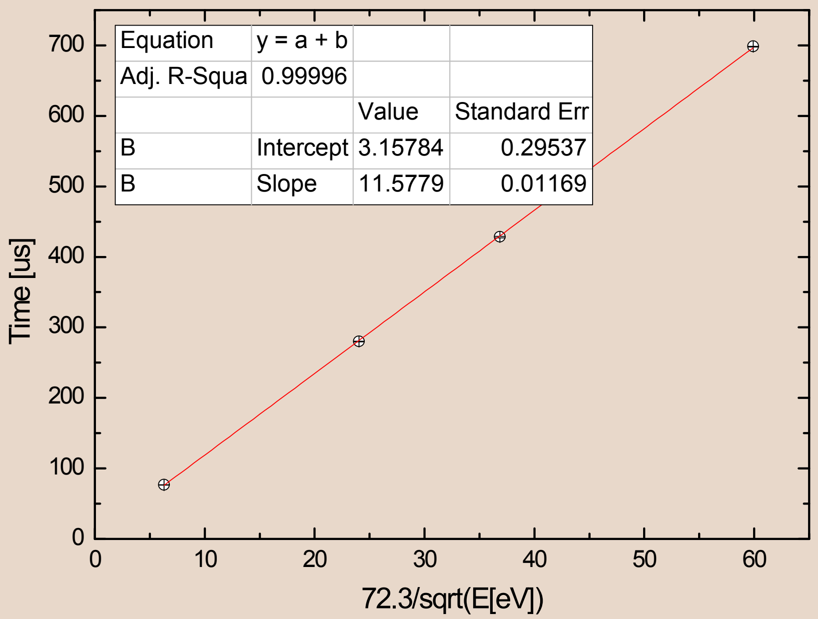


Time[us]

7. Flight Length and t_o Fitting

$$E = \left(\frac{72.3 \times L[m]}{t - t_0[\mu s]} \right)^2 [eV] \quad \Rightarrow \quad t[\mu s] = \frac{72.3 \times L[m]}{\sqrt{E[eV]}} + t_0$$

Using a linear fitting of four energies from Notch Filter, L and t_o are found

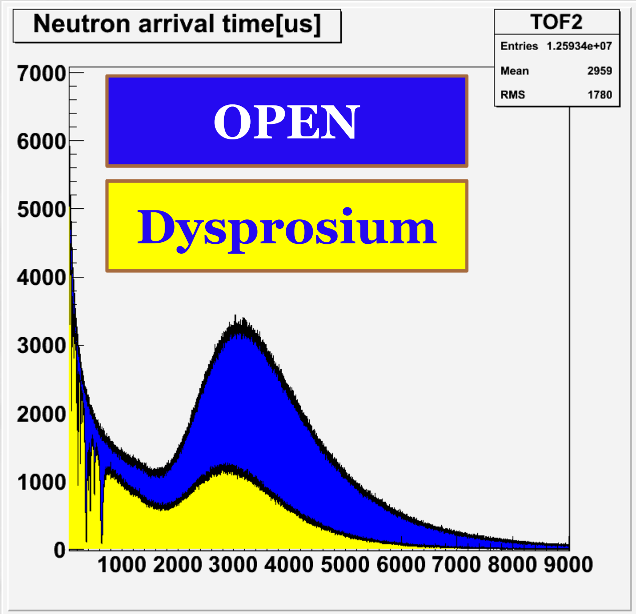


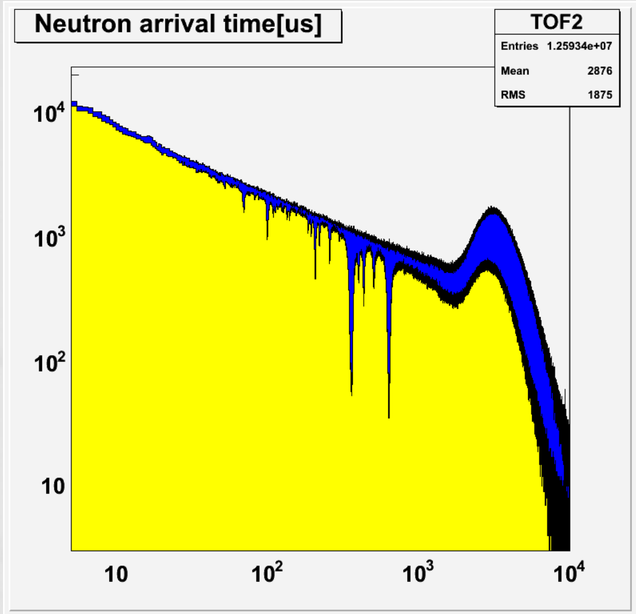
$L = 11.578 \pm 0.012$ [m]

$t_o = 3.158 \pm 0.295$ [us]

$$E = \left(\frac{72.3 \times 11.578}{t[\mu s] - 3.158} \right)^2 [eV]$$

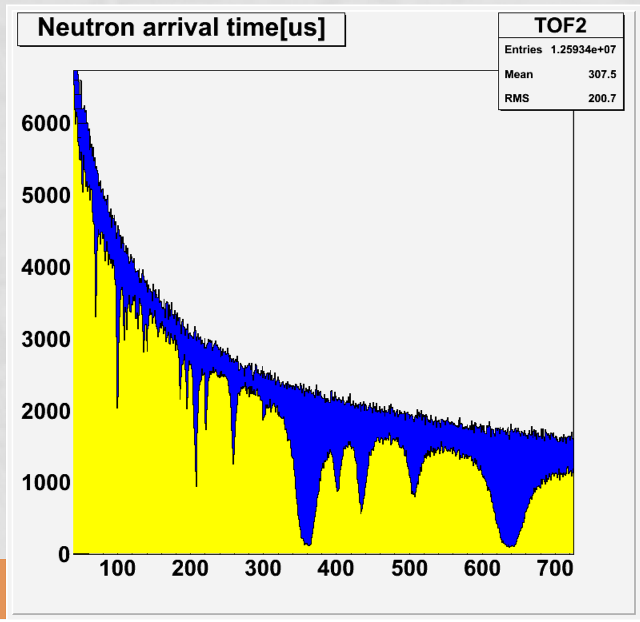
8. Dysprosium TOF Spectrum

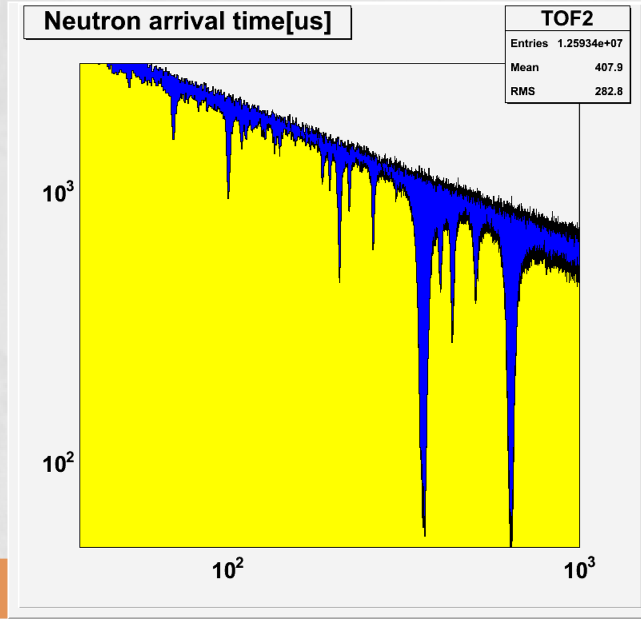




Linear

Log





Neutron Resonance Analysis using SAMMY

Contents 2

1. SAMMY-8 Introduction
2. Pre_SAMMY Run
3. Input Data Preparation
4. SAMMY fitting

1. SAMMY Introduction (1)

OAK RIDGE NATIONAL LABORATORY

managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY

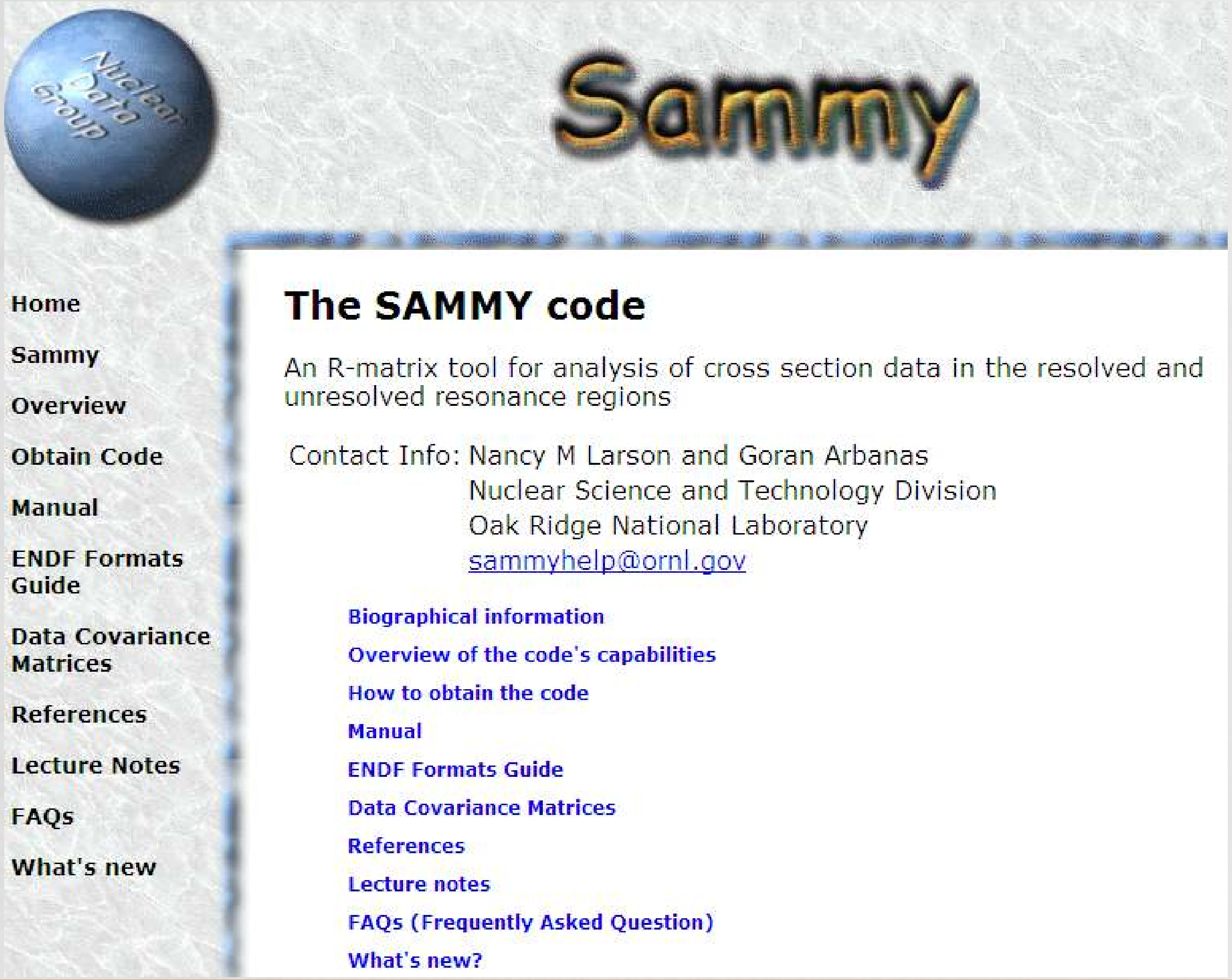
RSICC PERIPHERAL SCIENCE ROUTINE

SAMMY-8

Code System for Multilevel R-Matrix Fits to Neutron and Charged-Particle Cross-Section Data Using Bayes' Equations

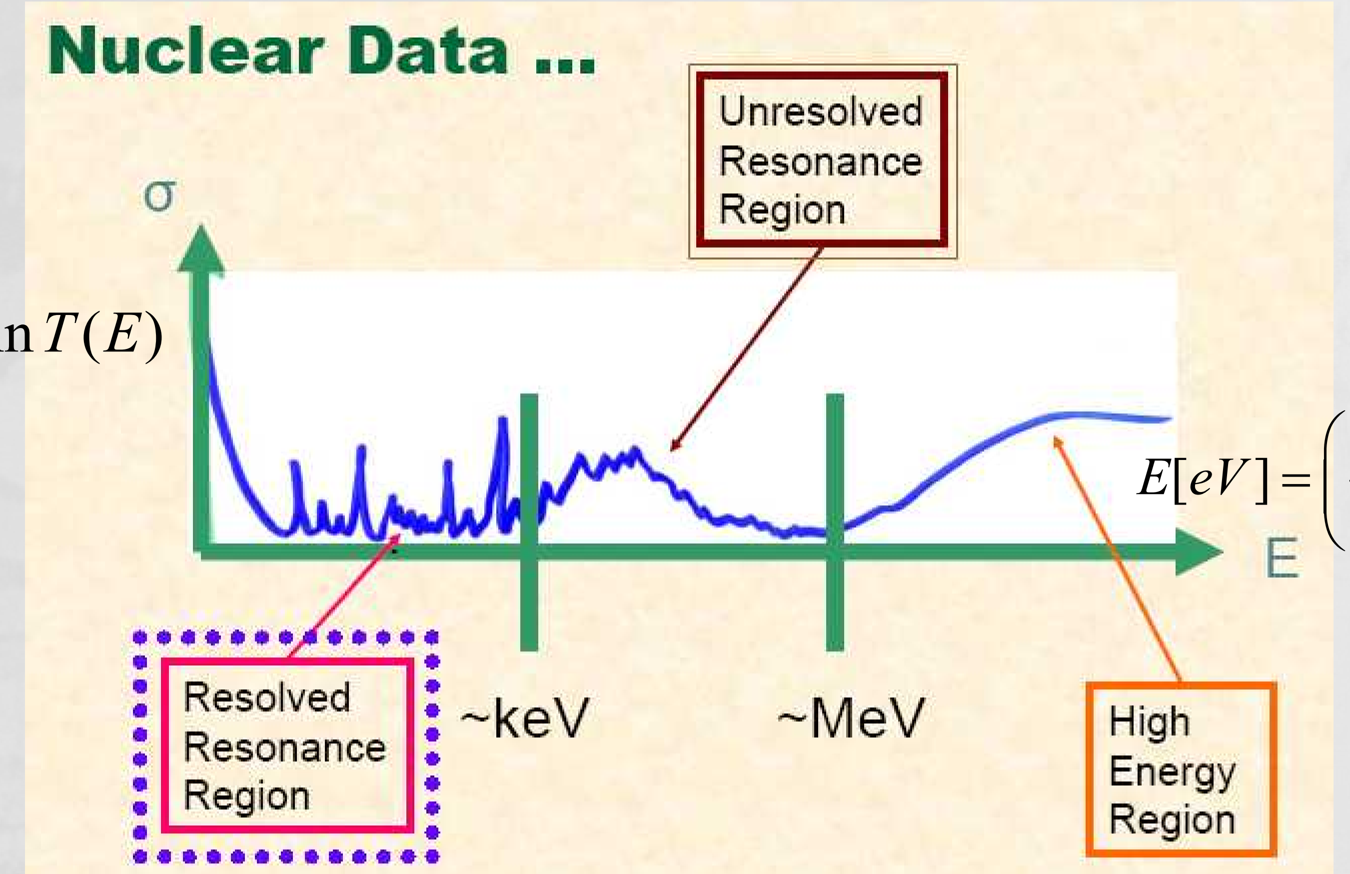
1. SAMMY Introduction (2)

http://www.ornl.gov/sci/nuclear_science_technology/nuclear_data/sammy/



1. SAMMY Introduction (3)

$$\sigma(E) = \frac{1}{N}\ln T(E)$$



$$E[eV] = \left(\frac{72.3 \times L[m]}{T[\mu s]}\right)^2$$

- Purpose: analyze time-of-flight cross-section data in the resonance region

1. SAMMY Introduction (4)

- *Types of data:*
  - total, elastic, capture, fission, inelastic, other reactions
    - Coulomb or not
  - angular distributions for elastic cross sections
  - certain types of integral data

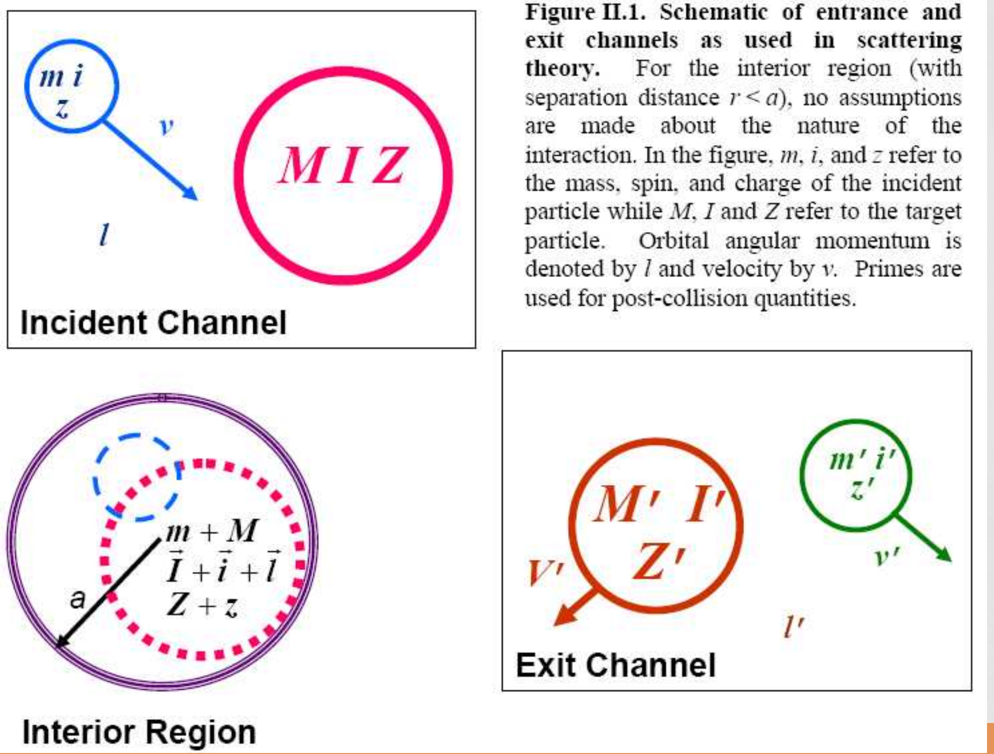


Figure II.1. Schematic of entrance and exit channels as used in scattering theory. For the interior region (with separation distance $r < a$), no assumptions are made about the nature of the interaction. In the figure, m, i, and z refer to the mass, spin, and charge of the incident particle while M, I and Z refer to the target particle. Orbital angular momentum is denoted by l and velocity by v. Primes are used for post-collision quantities.

1. SAMMY Introduction (5)

II.B.3.a. Single and multilevel Breit-Wigner cross sections

$$\sigma^{total} = \sigma^{elastic} + \sigma^{fission} + \sigma^{capture}$$

$$\sigma^{elastic} = \frac{\pi}{k^2}\sum_J g_J \sum_c \left\{ (1-\cos 2\varphi)\left(2 - \sum_\lambda \Gamma_{\lambda c}\Gamma_\lambda / d_\lambda\right) + 2\sin 2\varphi \sum_\lambda \Gamma_{\lambda c}(E-E_\lambda)/d_\lambda + \left(\sum_\lambda \Gamma_{\lambda c}(E-E_\lambda)/d_\lambda\right)^2 + \left(\sum_\lambda \Gamma_{\lambda c}\Gamma_\lambda / 2d_\lambda\right)^2 \right\}$$

$$\sigma^{fission} = \frac{\pi}{k^2}\sum_J g_J \sum_c \sum_{c'} \sum_\lambda \frac{\Gamma_{\lambda c}\Gamma_{\lambda c'}}{d_\lambda}$$

$$\sigma^{capture} = \frac{\pi}{k^2}\sum_J g_J \sum_c \sum_\lambda \frac{\Gamma_{\lambda c}\bar{\Gamma}_{\lambda\gamma}}{d_\lambda}$$

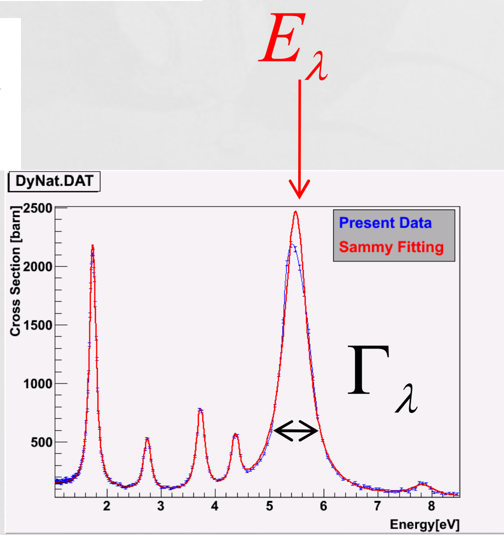
$$d_\lambda = (E - E_\lambda)^2 + (\Gamma_\lambda / 2)^2$$

$$\Gamma_\lambda = \sum_c \Gamma_{\lambda c} + \bar{\Gamma}_{\lambda\gamma}$$

$$\Gamma_{\lambda c}^{neutron} = 2\gamma_{\lambda c}^2 P_c$$

$$\Gamma_{\lambda c}^{fission} = 2\gamma_{\lambda c}^2$$

$$\bar{\Gamma}_{\lambda\gamma} = 2\bar{\gamma}_{\lambda\gamma}^2 .$$



SAMMY will calculate Resonance Energy, Gamma-Neutron, Gamma-Gamma, etc.

Resonance Parameters Deduced by SAMMY

- SAMMY is a multilevel R-matrix code for fitting neutron time-of-flight cross-section data using Bayes' method.
- The resonance analysis with SAMMY code provides complete information on the covariance for the resonance's parameters
- The main feature of SAMMY code is analysis of neutron resonance parameters based on neutron transmission and capture experimental data

R-matrix formula

$$R_{cc'} = \sum_{\lambda} \frac{\gamma_{\lambda c}\gamma_{\lambda c'}}{E_{\lambda} - E - i\gamma^2_{\lambda\gamma}}$$

c,c`: particle channel except for capture channel
γ : reduced-width amplitude

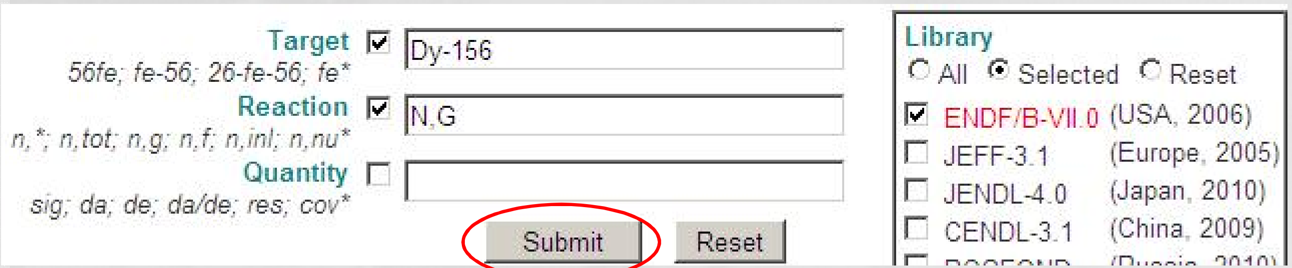
Γ : reaction width

- $\Gamma_{\lambda c} = 2P_l\gamma^2_{\lambda c}$ **for neutron channel**
- $\Gamma_{\lambda c} = 2\gamma^2_{\lambda c}$ **for fission channel**
- $\Gamma_{\lambda c} = 2\alpha^2_{\lambda}$ **for gamma channel**

P_l : penetrability(penetration factor)

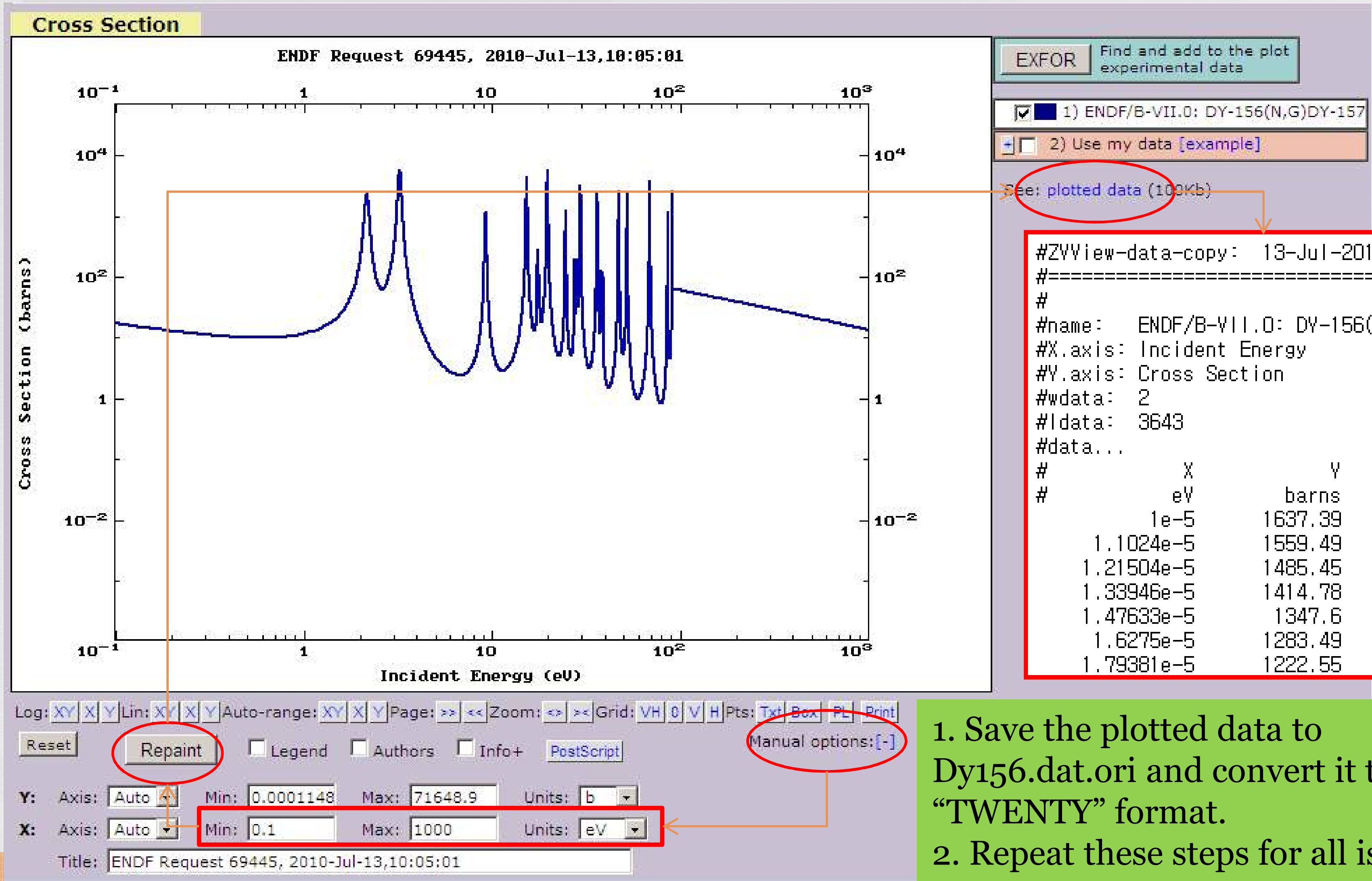
2. Pre_SAMMY Run(1)

- To make *.DAT, *.INP, *.PAR for Pre_Sammy run
- Pre_Dat file: (N, G)file_MT102 of ENDF_VII for Dy 156, 158, 160, 161, 162, 163, 164
- **http://www.nndc.bnl.gov**



2. Pre_SAMMY Run(2)

- Manual options:[-]➔Energy -> eV 로 변환➔ Repaint ➔ See: plotted data

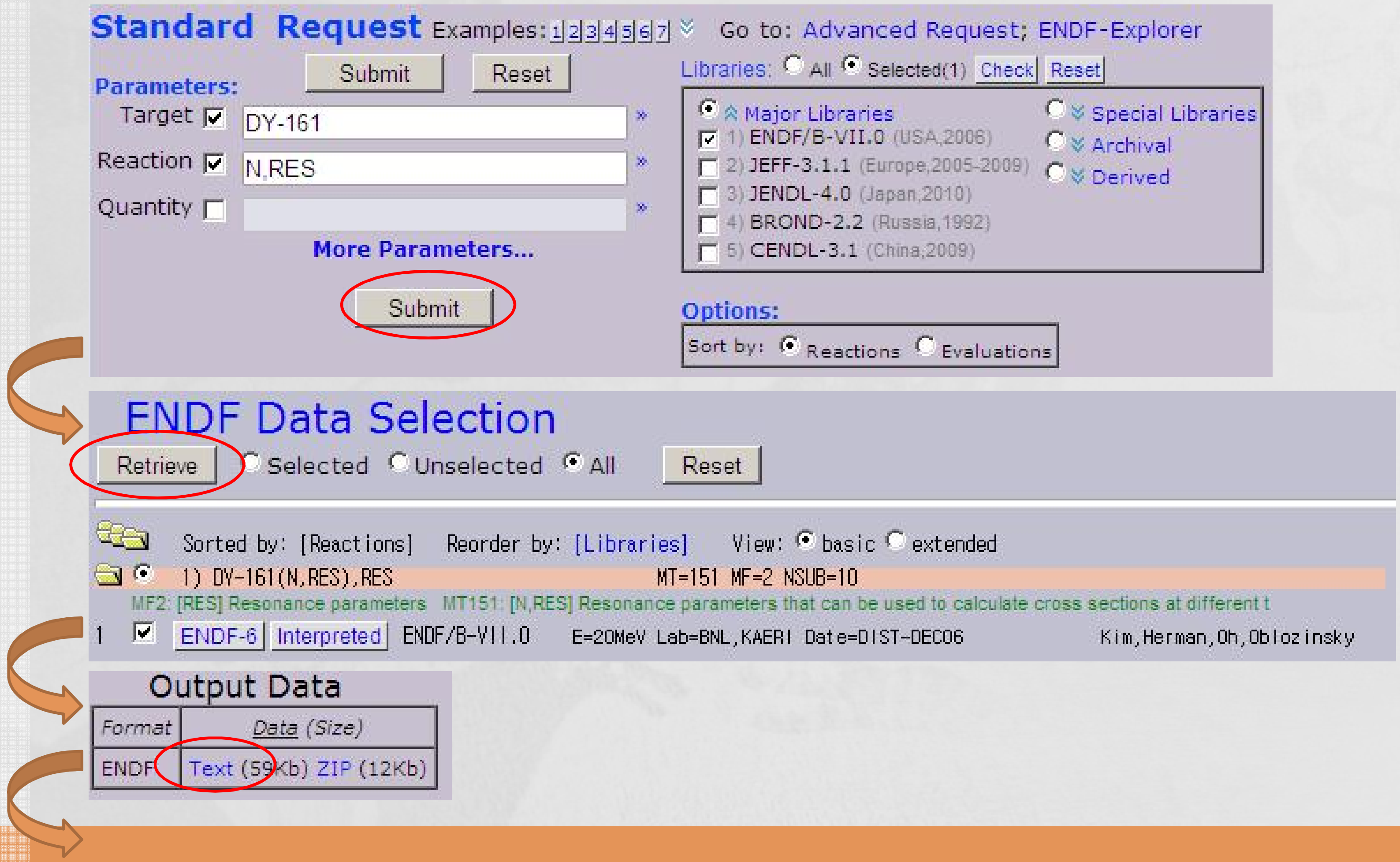


1. Save the plotted data to Dy156.dat.ori and convert it to "TWENTY" format.
2. Repeat these steps for all isotopes

2. Pre_SAMMY Run(3)

- *.PAR → Input for Variable Parameters

http://www-nds.iaea.org/exfor/endf.htm



2. Pre_SAMMY Run(4)

- *.PAR ➔ Input for Variable Parameters

```
[Ri03]                                                         6640 1451  226
   RIPL-2: Reference Input Parameter Library                   6640 1451  227
   IAEA, Vienna 2005, see                                      6640 1451  228
   http://www-nds.iaea.org/RIPL-2/                             6640 1451  229
                                                               6640 1451  230
************************************************               6640 1451  231
                                 1        451        459      16640 1451  232
                                 2        151        504      16640 1451  233
0.000000+0 0.000000+0            0          0          0      06640 1   099999
0.000000+0 0.000000+0            0          0          0      06640 0    0    0
6.616100+4 1.595440+2            0          0          1      06640 2151    1
6.616100+4 1.000000+0            0          0          2      06640 2151    2
1.000000-5 9.963000+2            1          2          0      06640 2151    3
2.500000+0 7.469997-1            0          0          1      06640 2151    4
1.595446+2 0.000000+0            0          0       1524    2546640 2151    5
1.890000+0 3.000000+0 1.176400-1 1.084000-2 1.068000-1 0.000000+06640 2151    6
2.710000+0 3.000000+0 1.195614-1 5.614285-4 1.190000-1 0.000000+06640 2151    7
3.680000+0 2.000000+0 1.261360-1 2.136000-3 1.240000-1 0.000000+06640 2151    8
4.330000+0 2.000000+0 8.137999-2 1.380000-3 8.000000-2 0.000000+06640 2151    9
        ⋮                   ⋮                   ⋮
1.125000+4 4.318060+0 0.000000+0 7.729327-4 1.068000-1 0.000000+06640 2151  497
1.250000+4 4.310188+0 0.000000+0 7.715236-4 1.068000-1 0.000000+06640 2151  498
1.375000+4 4.302328+0 0.000000+0 7.701166-4 1.068000-1 0.000000+06640 2151  499
1.500000+4 4.294486+0 0.000000+0 7.687130-4 1.068000-1 0.000000+06640 2151  500
1.750000+4 4.278844+0 0.000000+0 7.659130-4 1.068000-1 0.000000+06640 2151  501
2.000000+4 4.263261+0 0.000000+0 7.631237-4 1.068000-1 0.000000+06640 2151  502
2.250000+4 4.247738+0 0.000000+0 7.603450-4 1.068000-1 0.000000+06640 2151  503
2.581200+4 4.227266+0 0.000000+0 7.566806-4 1.068000-1 0.000000+06640 2151  504
0.000000+0 0.000000+0            0          0          0      06640 2   099999
0.000000+0 0.000000+0            0          0          0      06640 0    0    0
0.000000+0 0.000000+0            0          0          0      0    0 0    0    0
0.000000+0 0.000000+0            0          0          0      0   -1 0    0    0
```

1. Save the rectangular part as Dy156.ENDF to extract parameters using SAMMY.
2. Repeat these steps for all isotopes

2. Pre_SAMMY Run(5)

- *.INP ➔ Input for Pre-SAMMY Run

Dy156.inp (~₩바탕 화면₩2010-Kor...I₩pre_sammy₩Dy_sammy₩Dy156) - GVIM

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

```
Dy156
Dy156      155.924   0.00001   10000.0        5
PRINT THEORETICAL VALUES
USE NEW SPIN GROUP FORMAT
DO NOT SUPPRESS ANY INTERMEDIATE RESULTS
PRINT REDUCED WIDTHS
DO NOT SOLVE BAYES EQUATIONS
TWENTY
GENERATE PLOT FILE AUTOMATICAL
INPUT IS ENDF/B FILE 2

   293.0   25.5960   0.000000  0.0000000    .000   0.0        0.000
   6.5200  1.6485E-2
capture
```

0.samprerun.sh (~₩바탕 화면₩201...earData

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W

```
#!/bin/bash

rm -rf *SAM*
PWD=`pwd`
BASENAME=`basename $PWD`

sammy << EOF
$BASENAME.inp
$BASENAME.endf
$BASENAME.dat.ori_TWENTY.CNV $1 $2
EOF

if [ -f SAMMY.PLT ]; then

samplt << EOF
SAMMY.PLT
N
EOF

root -b -q 'SAMROOT.C("'$BASENAME'")'

fi
```

1. Only change name and atomic weight from Dy156.inp for all isotopes
2. Repeat these steps for all isotopes

Pre-SAMMY Run

[sammy@linux Dy156] 0.samprerun.sh 0.0001 1000.0

2. Pre_SAMMY Run(6)

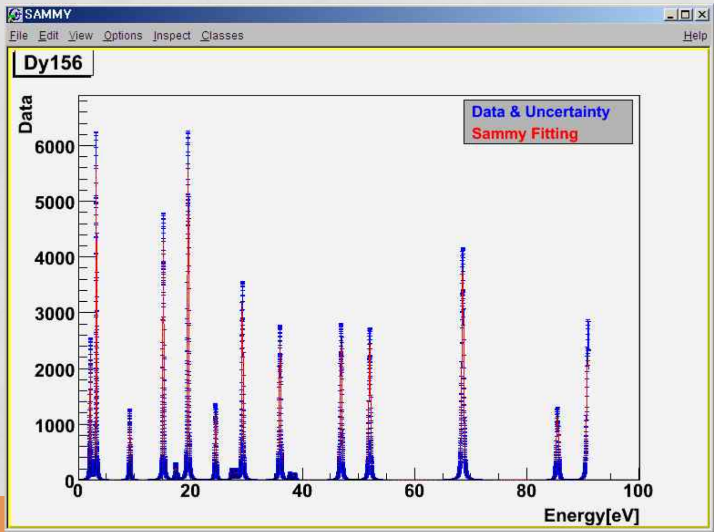
SAMNDF.INP (~₩바탕 화면₩2010-Ko...₩pre_sammy₩Dy_sammy₩Dy156) - GVIM2

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

```
Dy156
Dy156      155.924466  0.00001 1.0000E+04     0     5 0   0 0  0          0
PRINT THEORETICAL VALUES
USE NEW SPIN GROUP FORMAT
DO NOT SUPPRESS ANY INTERMEDIATE RESULTS
PRINT REDUCED WIDTHS
DO NOT SOLVE BAYES EQUATIONS
TWENTY
GENERATE PLOT FILE AUTOMATICAL
MLBW FORMALISM IS WANTED
PUT QUANTUM NUMBERS INTO PARAMETER FILE

  293.0    25.5960   0.000000  0.0000000      0.00000.0       0.000
  7.500000   0.016485                        0.00000
CAPTURE
  1       1     0   0.5       1.0   0.0
    1     1     0     0         0.5
```

- Result of Pre-SAMMY Run ➔
- SAMNDF.INP & PAR
- Repeat Pre-SAMMY Run for all isotopes
- Combine these result to make real DyNAT.PAR file



SAMNDF.PAR (~₩바탕 화면₩2010-Ko...₩pre_sammy₩Dy_sammy₩Dy156) - GVIM

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

```
2.150000000 83.6000000 .200000000                  0 0 0     1
3.210000000 83.6000000 .800000000                  0 0 0     1
9.190000000 83.6000000 .600000000                  0 0 0     1
15.20000000 83.6000000 4.60000000                  0 0 0     1
17.40000000 83.6000000 .320000000                  0 0 0     1
17.70000000 83.6000000 .100000000                  0 0 0     1
19.60000000 83.6000000 9.00000000                  0 0 0     1
24.50000000 83.6000000 2.40000000                  0 0 0     1
27.40000000 83.6000000 .400000000                  0 0 0     1
28.10000000 83.6000000 .400000000                  0 0 0     1
29.30000000 83.6000000 8.70000000                  0 0 0     1
36.00000000 83.6000000 9.00000000                  0 0 0     1
37.80000000 83.6000000 .400000000                  0 0 0     1
38.60000000 83.6000000 .400000000                  0 0 0     1
46.90000000 83.6000000 14.0000000                  0 0 0     1
52.00000000 83.6000000 16.0000000                  0 0 0     1
68.60000000 83.6000000 54.0000000                  0 0 0     1
85.50000000 83.6000000 15.0000000                  0 0 0     1
90.90000000 83.6000000 42.0000000                  0 0 0     1
```

3. Input Data Preparation (1)

- SAMMY Input Data: *.DAT, *.INP, *.PAR
- *.DAT ➔ Modify an experimental data using one of three data formats
- *.INP ➔ Input for FIXED Parameters
- *.PAR ➔ Input for Variable Parameters: Resonance Energy, Gamma-neutron, Gamma-Gamma, Gamma-Fission

3. Input Data Preparation (2)

Experimental Data Formats

1. "USE CSISRS FORMAT FOr data"
2. "USE TWENTY SIGNIFICAnt digits for experimental data"
3. "USE ENDF/B ENERGIES and cross sections MAT=abcd"

```
if ( format == "CSISRS" ) {
                    // Make CSISRS format [ E1  Y1  YE1 ]
                    //                    [ E2  Y2  YE2 ]
                    //                    [ ..  ..  ... ]
                    //                    [ 11f 11f 11f ] without blank space
   if (  (Energy > Emin) && ( Energy < Emax) ) {
     FORMAT = Form(" %10.4e %10.4e %10.4e", Energy, Barn, BarnError);
    out1 << FORMAT << endl;
   }
 }
 else if ( format == "TWENTY" ) {

                    // Make TWENTY format [ E1  Y1  YE1 ]
                    //                    [ E2  Y2  YE2 ]
                    //                    [ ..  ..  ... ]
                    //                    [ 20f 20f 20f ] without blank space
   if (  (Energy > Emin) && ( Energy < Emax) ) {
                     FORMAT = Form("%20.10f%20.10f%20.10f", Energy, Barn, BarnError);
     out1 << FORMAT << endl;
   }
 }
```

```
else {  // format == "ENDF/B"
// Make old default format [ E1 Y1 YE1/Y1 E2 Y2 YE2/Y2 E3 Y3 YE3/Y3 ]
//                 [ E4 Y4 YE4/Y4 E5 Y5 YE5/Y5 E6 Y6 YE6/Y6 ]
//                 [ ...................................... ]
//                 [ " "14f" "14f7.5f" "14f" "14f7.5f " "14f" "14f7.5f  ]
     if (  (Energy > Emin) && ( Energy < Emax) ) {
       FORMAT = Form(" %14.8e %14.8e%7.5f", Energy, Barn, BarnError/Barn);
       out1 << FORMAT;
        j++;
        if ( (j%3) == 0 ) { out1 << endl; }
     }
 }
```

0.1035080180	0.4333768189	0.0046054958
0.1037130877	0.4286459982	0.0046045193
0.1039187759	0.4333532155	0.0046566990
0.1041250527	0.4287957549	0.0046119601

3. Input Data Preparation (3)

- *.INP → Input for FIXED parameters
- DyNAT.INP

```
Dy EPITHERMAL TRANSMISSION - Dynat
Dynat    162.5    0.10000   6000.        5
PRINT THEORETICAL VALUES
PRINT ALL INPUT PARAMETERS
DO NOT SUPPRESS ANY INTERMEDIATE RESULTS
PRINT REDUCED WIDTHS
SOLVE BAYES EQUATIONS
TWENTY
EV
YIELD
FGM
GENERATE PLOT FILE AUTOMATICALLY
REICH-MOORE FORMALISM IS WANTED

   293.0  11.51727  0.002260 0.1500000  -0.01800
  0.01000    4
 6.47906 256.000   30.10087 128.000   75.09176  64.000
1000.07062  32.000
 7.500000 1.5824E-3             0.00100
TRANSMISSION
```

GROUPING part

Table VI A.1. Format of the INPut File

C:L	P,T	Variable name	Meaning (units)	Notes
1:1	1-80, A	TITLE		
2:1	1-10, A	ELMNT	Sample element's name	
	11-20, F	AW	Atomic weight (amu)	
	21-30, F	EMIN	Minimum energy for this data set (eV)	These values for EMIN and EMAX will be ignored if values are given in the interactive input (see Section VI.E)
	31-40, F	EMAX	Maximum energy (eV)	
	41-45, I	NEPNTS	1. Number of points to be used in generating artificial energy grid (default = 10001) 2. Maximum number of points to be analyzed at one time (default = 500). Use of this option is discouraged.	1. See Section V.A for a discussion of the artificial energy grid. 2. NEPNTS is the number of data points to be included in each region when "DIVIDE DATA INTO REGions" is specified in card set 3.

*SOLVE → Data Fitting

*<u>DO NOT SOLVE→</u>

<u>Theoretical Value Calculation</u>

<u>Using Parameter files</u>

3. Input Data Preparation (4)

- *.INP ➔ Input for FIXED parameters

Continued of DyNat.INP

```
1    1  0  0.5 0.0006    0.0  Dy156
  1  1  0  0       0.5
2    1  0  0.5 0.0010    0.0  Dy158
  1  1  0  0       0.5
3    1  0  0.5 0.0234    0.0  Dy160
  1  1  0  0       0.5
4    1  0  2.0 0.1891    2.5  Dy161
  1  1  0  0       2.0
5    1  0  3.0 0.1891    2.5  Dy161
  1  1  0  0       3.0
6    1  0  0.5 0.2551    0.0  Dy162
  1  1  0  0       0.5
7    1  0 -0.5 0.2551    0.0  Dy162
  1  1  0  1       0.5
8    1  0 -1.5 0.2551    0.0  Dy162
  1  1  0  1       0.5
9    1  0 -2.0 0.2490   -2.5  Dy163
  1  1  0  0      -2.0
10   1  0 -3.0 0.2490   -2.5  Dy163
  1  1  0  0      -3.0
11   1  0  0.5 0.2818    0.0  Dy164
  1  1  0  0       0.5
12   1  0 -0.5 0.2818    0.0  Dy164
  1  1  0  1       0.5
13   1  0 -1.5 0.2818    0.0  Dy164
  1  1  0  1       0.
```

Look for Dysprosium of Wiki
or Use Pre-SAMMY Run results

iso	NA	half-life	DM	DE (MeV)	DP
^{154}Dy	syn	3.0×10^{6} y	α	2,947	^{150}Gd
^{156}Dy	0,06%	1×10^{18} y	α	?	^{152}Gd
^{158}Dy	0,10%	^{158}Dy is stable with 92 neutrons			
^{160}Dy	2,34%	^{160}Dy is stable with 94 neutrons			
^{161}Dy	18,91%	^{161}Dy is stable with 95 neutrons			
^{162}Dy	25,51%	^{162}Dy is stable with 96 neutrons			
^{163}Dy	24,90%	^{163}Dy is stable with 97 neutrons			
^{164}Dy	28,18%	^{164}Dy is stable with 98 neutrons			

^{155m}Dy	234,33(3) keV			6(1) μs	11/2-	
^{156}Dy	66	90	155,924283(7)	STABLE [>1E+18 a]	0+	0,00056(3)
^{157}Dy	66	91	156,925466(7)	8,14(4) h	3/2-	
^{157m1}Dy	161,99(3) keV			1,3(2) μs	9/2+	
^{157m2}Dy	199,38(7) keV			21,6(16) ms	11/2-	
^{158}Dy	66	92	157,924409(4)	STABLE	0+	0,00095(3)
^{159}Dy	66	93	158,9257392(29)	144,4(2) d	3/2-	
^{159m}Dy	352,77(14) keV			122(3) μs	11/2-	
^{160}Dy	66	94	159,9251975(27)	STABLE	0+	0,02329(18)
^{161}Dy	66	95	160,9269334(27)	STABLE	5/2+	0,18889(42)
^{162}Dy	66	96	161,9267984(27)	STABLE	0+	0,25475(36)
^{163}Dy	66	97	162,9287312(27)	STABLE	5/2-	0,24896(42)
^{164}Dy	66	98	163,9291748(27)	STABLE	0+	0,28260(54)

2. Input Data Preparation (5)

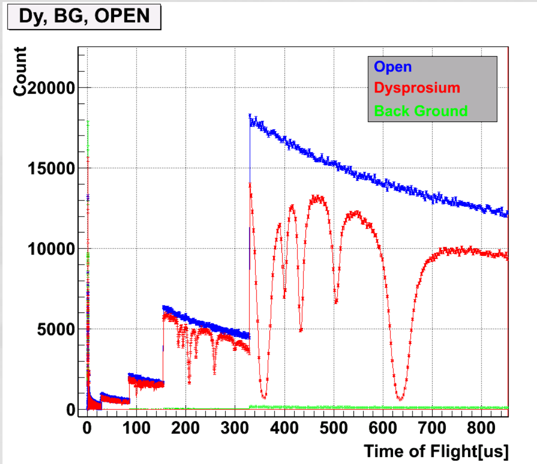
- DyNat.PAR ➔ Input for Variable Parameters

E_λ	Γ_γ	Γ_{c1}	Γ_{c2}	Γ_{c3}						
2.150000000	83.6000000	.200000000			0	0	0			01
3.210000000	83.6000000	.800000000			0	0	0			01
9.190000000	83.6000000	.600000000			0	0	0			01
15.20000000	83.6000000	4.60000000			0	0	0			01
17.40000000	83.6000000	.320000000			0	0	0			01
17.70000000	83.6000000	.100000000			0	0	0			01
19.60000000	83.6000000	9.00000000			0	0	0			01
24.50000000	83.6000000	2.40000000			0	0	0			01
27.40000000	83.6000000	.400000000			0	0	0			01
28.10000000	83.6000000	.400000000			0	0	0			01
3460.500000	114.200000	28.0000000			0	0	0			13
3520.300000	114.200000	71.0000000			0	0	0			12
3621.000000	114.200000	17.0000000			0	0	0			12
3911.600000	114.200000	17.0000000			0	0	0			13
4095.800000	114.200000	30.0000000			0	0	0			13
4348.800000	114.200000	25.5000000			0	0	0			13
4389.200000	114.200000	14.5000000			0	0	0			13
4916.000000	114.200000	42.0000000			0	0	0			13

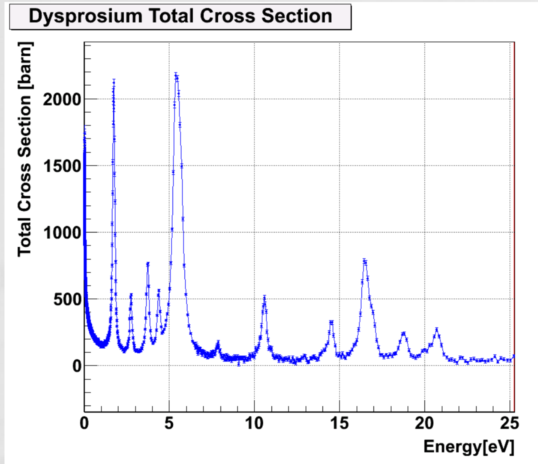
Table VI B.2. Format of the PARameter file

C:L	P, T	Variable Name	Meaning (units)
1:1	1-11, F	E_λ	Resonance energy E_λ (eV)
	12-22, F	$\Gamma\gamma$	Capture width (milli-eV)
	23-33, F	Γ_{c1}	Particle width for channel 1 (milli-eV)
	34-44, F	Γ_{c2}	Particle width for channel 2 (milli-eV)
	45-55, F	Γ_{c3}	Particle width for channel 3 (milli-eV)
	56-57, I	IS_E	Vary E_λ?
	58-59, I	IS_γ	Vary $\Gamma\gamma$?
	60-61, I	IS_{c1}	Vary Γ_{c1}?
	62-63, I	IS_{c2}	Vary Γ_{c2}?
	64-65, I	IS_{c3}	Vary Γ_{c3}?
	66-67, I	IGROUP	Quantum numbers for this resonance are those of group number IGROUP (card set 10.1 or 10.2 in Table VIA.1)

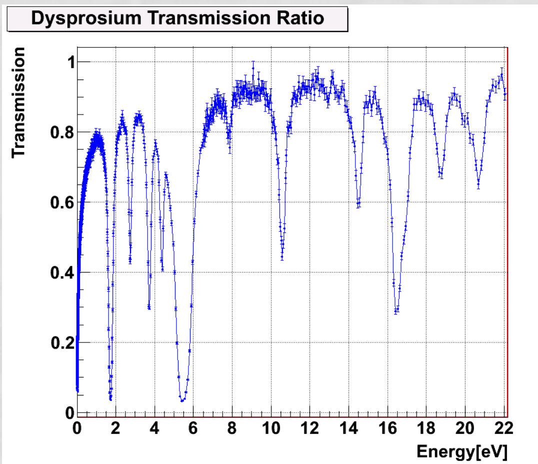
3. Sammy Fitting (1)



Grouping



Cross Section and Resonance Parameters



Transmission

Sammy Fitting using Input files

SAMMY Run

sammy DyNat.inp DyNat.par DyNat.dat 0.1 200

OUTPUT

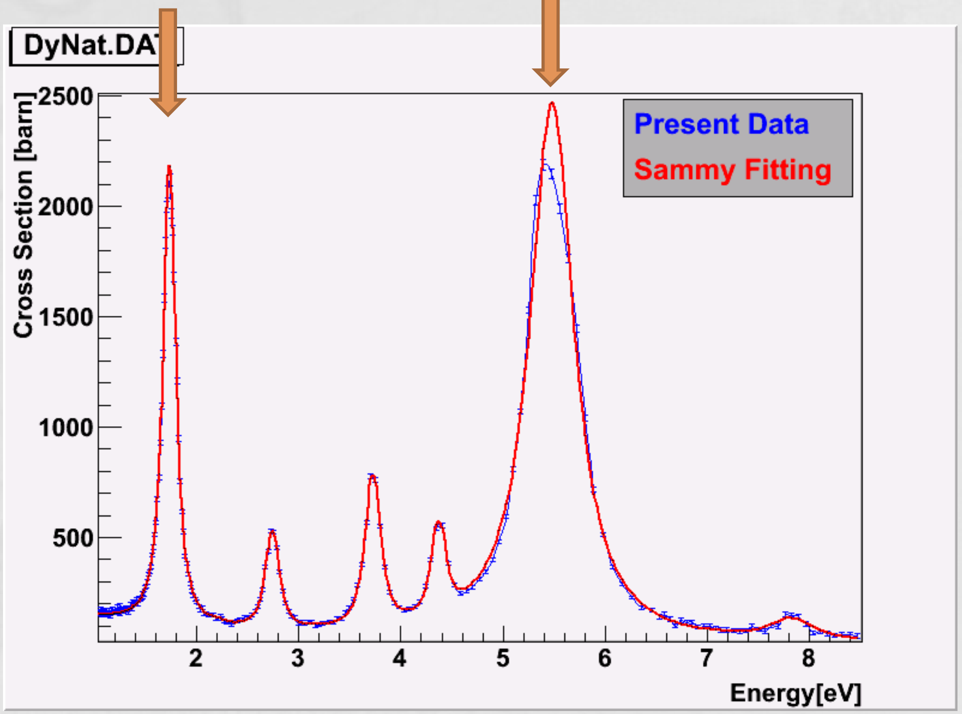
SAM_ASCII.PLT ➔ Fitted Cross Section
SAM_ASCII_2.PLT ➔ Fitted Transmission Rate
SAMMY.PAR ➔ Fitted variable parameters
SAMMY.LPT ➔ Total SAMMY Fitting Report

3. Sammy Fitting (2)

```
SPIN GROUP NUMBER  9  WITH SPIN= -2.0, ABUNDANCE=  0.2490, AND G= 0.4167
                     effective radius =  7.4975E+00
                         "true" radius =  7.4975E+00
       ENERGY             GAMMA-            GAMMA-
                          GAMMA            IncCha#6
                                           L=0  SPIN=-2.0
        (eV)            (MILLI-EV)        (MILLI-EV)
 1.73255E+00( 22) 1.2700E+02( 23)  1.8972E+00( 24)
 6.00296E+00( 25) 1.0690E+02( 26)  3.4801E-02( 27)
Expected              1.2692E+02        5.1430E-01
 Value         +/-    7.1022E-01  +/-   2.9020E-03
EV changed            1.2700E+02        1.8972E+00
parameters     +/-    7.1174E-01  +/-   5.7147E-03
```

```
SPIN GROUP NUMBER  6  WITH SPIN=  0.5, ABUNDANCE=  0.2551, AND G= 1.0000
                     effective radius =  5.9000E+00
                         "true" radius =  5.9000E+00
       ENERGY             GAMMA-            GAMMA-
                          GAMMA            IncCha#5
                                           L=0  SPIN= 0.5
        (eV)            (MILLI-EV)        (MILLI-EV)
 5.48424E+00( 19) 4.9728E+02( 20)  1.0262E+01( 21)
Expected              4.9728E+02        1.0262E+01
 Value         +/-    3.1652E+00  +/-   3.2261E-02
EV changed            4.9728E+02        1.0262E+01
parameters     +/-    3.1652E+00  +/-   3.2261E-02
```

First
SAMMY
Fitting
Result



3. Sammy Fitting (3)

First RESULTS of SAMMY

SAM_ASCII.PLT ➔ Fitted Cross Section

SAM_ASCII.PLT (~₩바탕 화면₩ND2010₩Dy₩sammy) - GVIM6

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

Energy	Data	Uncertainty	Th_initial	Th_final
1.3025376	181.30036	8.5137938	164.72168	164.65109
1.3117266	173.78704	8.4353505	166.51183	166.44314
1.3210131	179.57890	8.4119245	168.48514	168.41849
1.3303987	162.78007	8.4507571	170.66095	170.59646
1.3398849	180.73825	8.4653113	173.06178	172.99962
1.3494726	197.27698	8.4692367	175.71328	175.65362
1.3591636	177.34523	8.3897087	178.64514	178.58816
1.3689594	206.74253	8.4714438	181.89162	181.83752
1.3788614	196.01652	8.5047413	185.49237	185.44137
1.3888714	203.90112	8.5303637	189.49377	189.44611
1.3989906	201.16411	8.4983986	193.94981	193.90576

SAMMY.PAR ➔ Fitted variable parameters

SAMMY.PAR (~₩바탕 화면₩ND2010₩Dy₩sammy) - GVIM7

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

```
1944.300000 105.800000 240.000000            0 0 0     3
1994.300000 105.800000 250.000000            0 0 0     3
-1.89000000 106.800000 10.8400000            0 0 0     5
2.741176157 136.380489 .666679893            1 1 1     5
3.724688419 144.286082 2.16324484            1 1 1     4
4.368586984 113.451917 1.32007559            1 1 1     4
7.740000000 107.000000 .514285800            0 0 0     5
10.26000000 106.800000 .288000000            0 0 0     4
10.85000000 106.800000 .411428600            0 0 0     5
12.65000000 106.800000 .048000000            0 0 0     5
```

E_λ Γ_γ Γ_{c1}

SAM_ASCII_2.PLT ➔ Fitted Transmission Rate

SAM_ASCII_2.PLT (~₩바탕 화면₩ND2010₩Dy₩sammy) - GVIM9

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

Energy	Transmission	Uncertainty	Tr_initial	Tr_final
1.3025376	0.75092119	1.01012373E-02	0.77054626	0.77063234
1.3117266	0.75988853	1.01276832E-02	0.76836660	0.76845012
1.3210131	0.75296640	1.00075565E-02	0.76597106	0.76605186
1.3303987	0.77321935	1.03241764E-02	0.76333836	0.76341626
1.3398849	0.75158840	1.00526391E-02	0.76044388	0.76051868
1.3494726	0.73220289	9.79789530E-03	0.75725995	0.75733144
1.3591636	0.75562847	1.00164143E-02	0.75375487	0.75382283
1.3689594	0.72133386	9.65496800E-03	0.74989259	0.74995679
1.3788614	0.73366255	9.85858400E-03	0.74563198	0.74569215
1.3888714	0.72457951	9.76586430E-03	0.74092569	0.74098157
1.3989906	0.72771972	9.77143460E-03	0.73571963	0.73577091

SAMMY.LPT ➔ Total SAMMY Fitting Report

SAMMY.LPT (~₩바탕 화면₩ND2010₩Dy₩sammy) - GVIM8

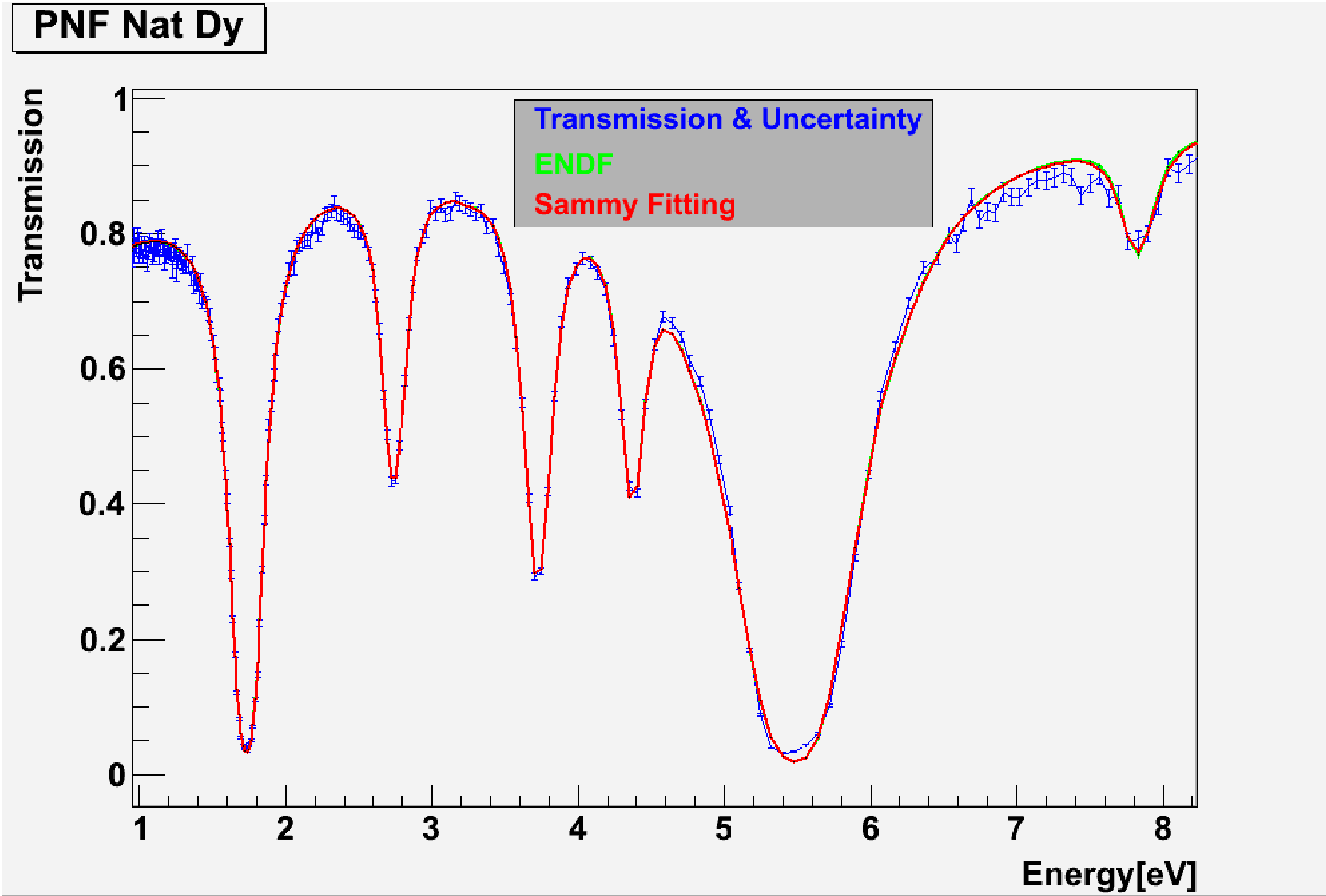
파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

```
( 51)1.915779 0.583301    (104)3.194038 0.844324    (157)6.357799 0.729370
( 52)1.932188 0.619759    (105)3.229429 0.842182    (158)6.457529 0.771010
( 53)1.948809 0.650835    (106)3.265412 0.840388
### Array size used for SAMMY-INT is      14066 ###
### Estimated array size for SAMMY-IPQ is      14182 ###

CUSTOMARY CHI SQUARED =     1015.76
CUSTOMARY CHI SQUARED DIVIDED BY NDAT =    6.42883
### Array size used for SAMMY-IPQ is      12128 ###
### Estimated array size for SAMMY-FIN is      11596 ###
### Array size used for SAMMY-FIN is      8351 ###
                             Total time =     0.37 seconds
Normal finish to SAMMY
```

3. Sammy Fitting (4)

Second SAMMY Fitting Result



3. Sammy Fitting (5)

Second RESULTS of SAMMY

SAM_ASCII.PLT ➔ Fitted Cross Section

SAM_ASCII.PLT (~₩바탕 화면₩SAPPORO) - GVIM5

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

Energy	Data	Uncertainty	Th_initial	Th_final
1.3025376	181.30036	8.5137938	165.28435	165.16002
1.3117266	173.78704	8.4353505	167.07284	166.94572
1.3210131	179.57890	8.4119245	169.04455	168.91443
1.3303987	162.78007	8.4507571	171.21931	171.08598
1.3398849	180.73825	8.4653113	173.61978	173.48301
1.3494726	197.27698	8.4692367	176.27173	176.13126
1.3591636	177.34523	8.3897087	179.20501	179.06057
1.3689594	206.74253	8.4714438	182.45407	182.30536
1.3788614	196.01652	8.5047413	186.05882	185.90550
1.3888714	203.90112	8.5303637	190.06591	189.90761
1.3989906	201.16411	8.4983986	194.52969	194.36602

SAMMY.PAR ➔ Fitted variable parameters

SAMMY.PAR (~₩바탕 화면₩SAPPORO) - GVIM6

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

```
1944.300000 105.800000 240.000000                      0 0 0     3
1994.300000 105.800000 250.000000                      0 0 0     3
-1.89000000 106.800000 10.8400000                      0 0 0     5
2.740993036 137.546784 .670462372                      1 1 1     5
3.724466930 143.806986 2.16238008                      1 1 1     4
4.368726402 114.377050 1.33812149                      1 1 1     4
7.829002600 212.322502 .838869818                      1 1 1     5
10.04930701 119.397391 .362273576                      1 1 1     4
11.02562238 120.660458 .345125992                      1 1 1     5
12.84177451 105.542074 .054033458                      1 1 1     5
```

E_{λ} Γ_{γ} Γ_{c1}

SAM_ASCII_2.PLT ➔ Fitted Transmission Rate

SAM_ASCII_2.PLT (~₩바탕 화면₩SAPPORO) - GVIM

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

Energy	Transmission	Uncertainty	Tr_initial	Tr_final
1.3025376	0.75092119	1.01012373E-02	0.76986050	0.77001197
1.3117266	0.75988853	1.01276832E-02	0.76768478	0.76783923
1.3210131	0.75296640	1.00075565E-02	0.76529332	0.76545091
1.3303987	0.77321935	1.03241764E-02	0.76266421	0.76282513
1.3398849	0.75158840	1.00526391E-02	0.75977272	0.75993718
1.3494726	0.73220289	9.79789530E-03	0.75659106	0.75675925
1.3591636	0.75562847	1.00164143E-02	0.75308739	0.75325953
1.3689594	0.72133386	9.65496800E-03	0.74922546	0.74940179
1.3788614	0.73366255	9.85858400E-03	0.74496393	0.74514469
1.3888714	0.72457951	9.76586430E-03	0.74025520	0.74044064
1.3989906	0.72771972	9.77143460E-03	0.73504483	0.73523523

SAMMY.LPT ➔ Total SAMMY Fitting Report

SAMMY.LPT (~₩바탕 화면₩SAPPORO) - GVIM4

파일(F) 편집(E) 도구(T) 문법(S) 버퍼(B) 창(W) 도움말(H)

```
(317)0.208697 0.549634    (634)0.678086 0.742931
### Array size used for SAMMY-INT is       34850 ###
### Estimated array size for SAMMY-NPV is      477421 ###

CUSTOMARY CHI SQUARED =    2316.83
CUSTOMARY CHI SQUARED DIVIDED BY NDAT =     2.43877
### Array size used for SAMMY-NPV is      930888 ###
### Estimated array size for SAMMY-FIN is       22844 ###
### Array size used for SAMMY-FIN is       8904 ###
                                Total time =     22.45 seconds
Normal finish to SAMMY
```

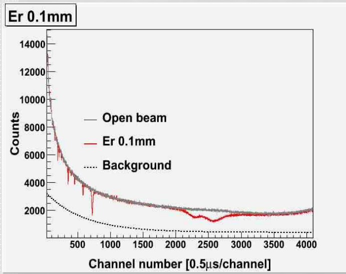
Development of Capture Cross Section Measurement System of Pohang Neutron Facility

Contents 3

- Neutron Capture Cross-section
- BGO Crystal Study
- 4π BGO Gamma Detector
- BGO detector modules
- BGO Temperature Compensation
- DAQ system using FADC
- Current Status

Neutron Capture Cross-section

Total Cross-section



Detector

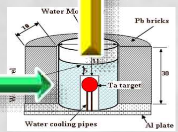
Neutron

Scattering ,
Capture, etc

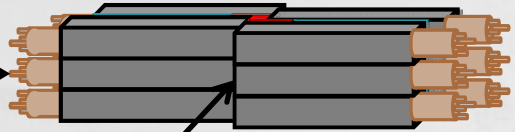
Sample
Changer

Neutron

e⁻

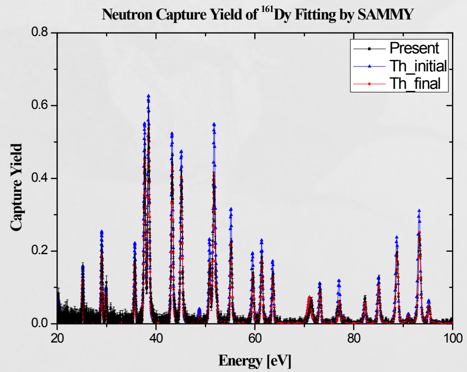


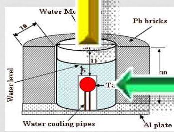
Capture Cross-section



Sample
In the middle

Neutron





e⁻

Measurement with a total energy absorption detector by TOF method

Relation between neutron capture yield and cross sections:

$$Y(E_i) = (1 - e^{-N\sigma_t(E_i)t}) \frac{\sigma_c(E_i)}{f_c(E_i)\sigma_t(E_i)}$$

Y(Ei): neutron capture yield
N: atomic density of sample
t: thickness of sample
σt(Ei): neutron total cross section
σc(Ei): neutron capture cross section
fc(Ei): correction function for neutron scattering and/or self-shielding in sample

If the thickness of sample is **thin** enough, capture cross section is

$$\sigma_c(E_i) = \frac{Y(E_i)}{Nt} f_c(E_i)$$

Neutron capture yield in sample:

$$C(E_i) = \varepsilon(E_i) Y(E_i) \phi(E_i) \longrightarrow Y(E_i) = \frac{C(E_i)}{\varepsilon(E_i)\phi(E_i)}$$

$C_S(E_i)$**:** Counting rate for the sample by the detector system
$\varepsilon_S(E_i)$: Gamma detection efficiency of the sample
$\phi(E_i)$: Neutron flux impinging on the sample as a function of neutron energy

w4

Characteristics of Crystal

Scintillator	BGO	NaI (Tl)	CsI (Tl)
Wave length of max. Emission [nm]	480	410	560
Decay constant [ns]	300	230	1000
Reflactive index	2.15	1.85	1.79
Scintillation efficiency [%]	8	100*	136.8 ~ 47.3
Specific Gravity	7.13	3.67	4.51
	Non-hygroscopic	Hygroscopic	Hygroscopic

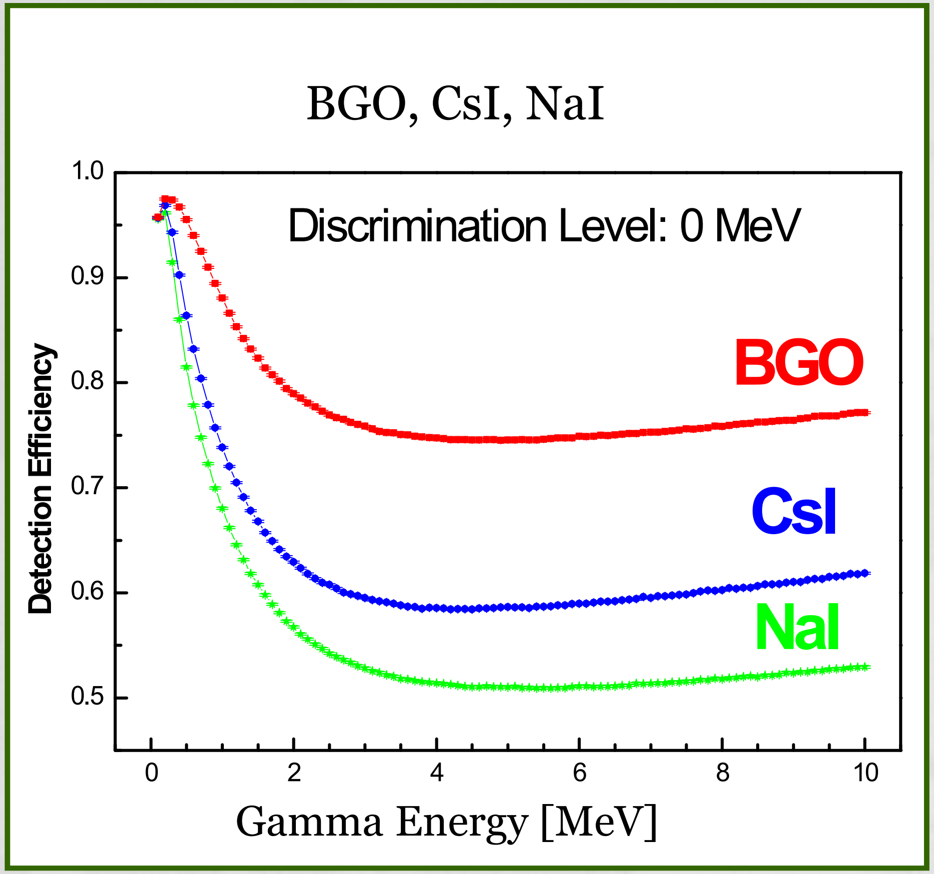
* The scintillator efficiency of NaI (Tl) is normalized to 100%

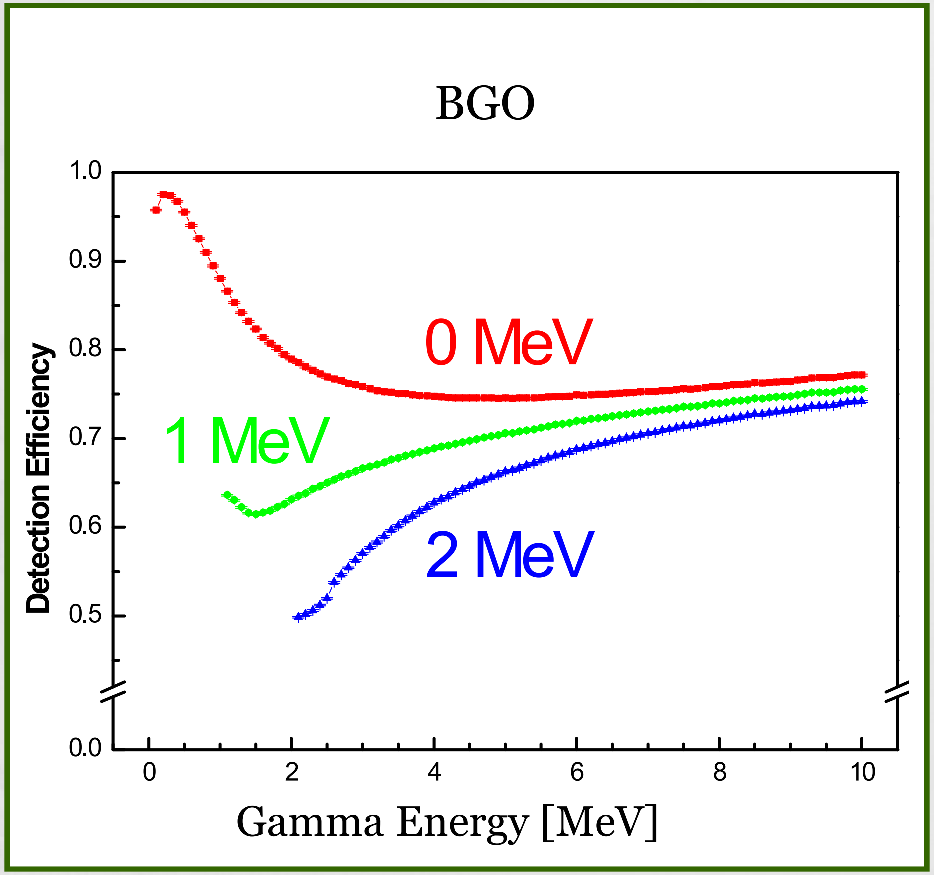
w4 in the simulation code, the physical processes include general physics process;electron magnetic process and optical process.em include photonelectron effect,compton effect and pair production,for electron ,there are ionization, multiscattering, anni.
wang, 2007-10-16

w5

Detection Efficiency using Geant4

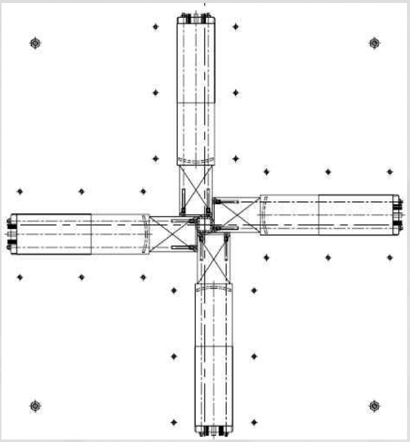
$$Detection\ Efficiency = \frac{N^{Accepted}_{>Threshold\ Energy}}{N_{Total}}$$





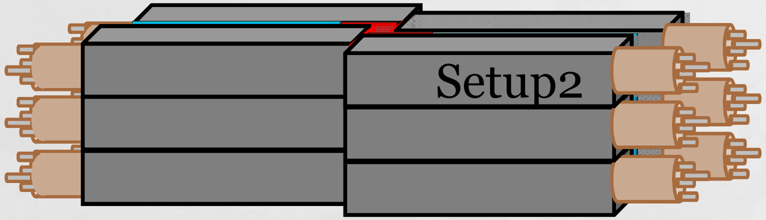
w5 we simulated the total intrinsic efficiency of detector array for different crystals materials under 15MeV.from comparison the highest efficiency were given by BGO crystal case.
wang, 2007-10-17

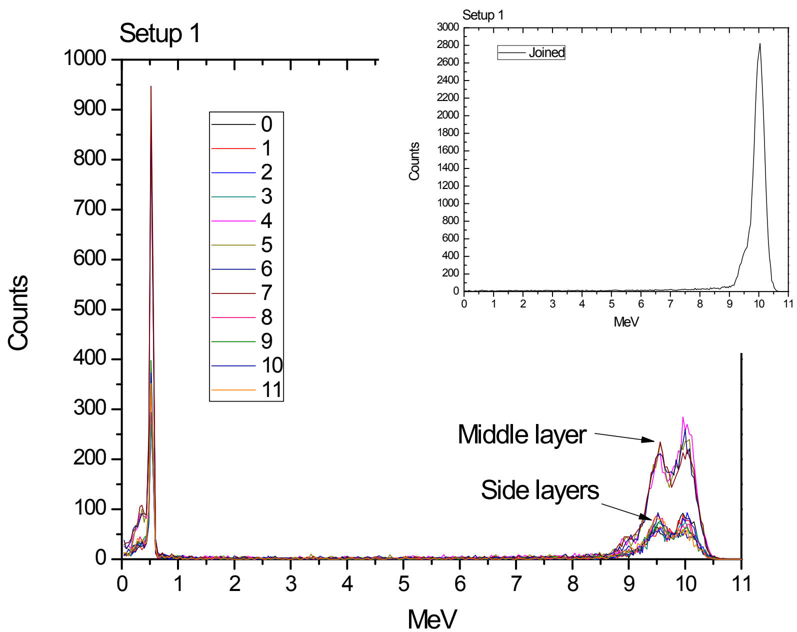
4π BGO Gamma Detector 1



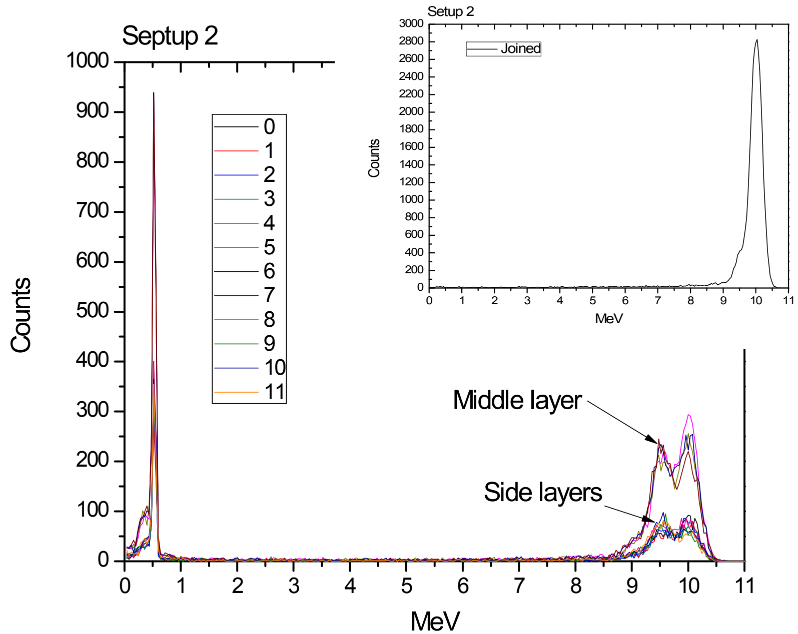
Setup1
98.25%
coverage

Setup2 : **98.21%** coverage



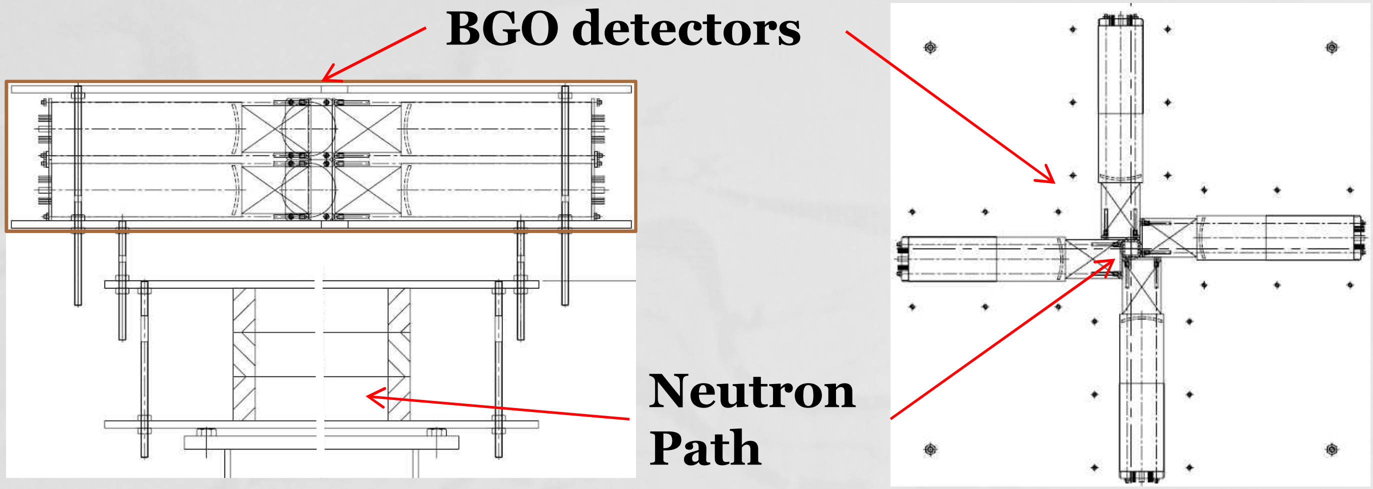


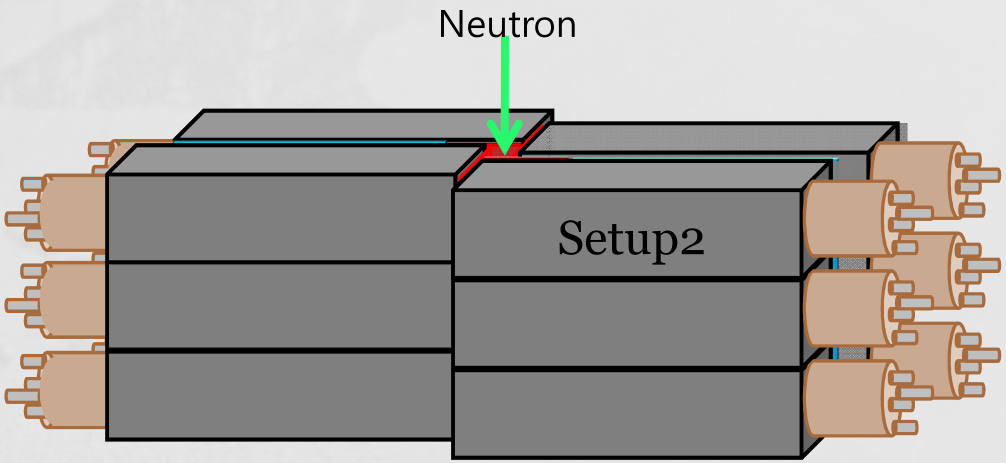
877/50000 initial particles did not hit any volume



894/50000 initial particles did not hit any volume

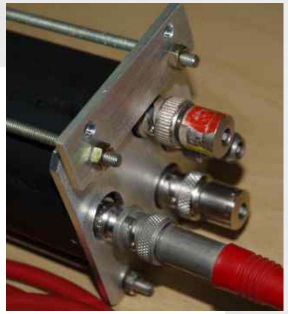
4π BGO Gamma Detector 2



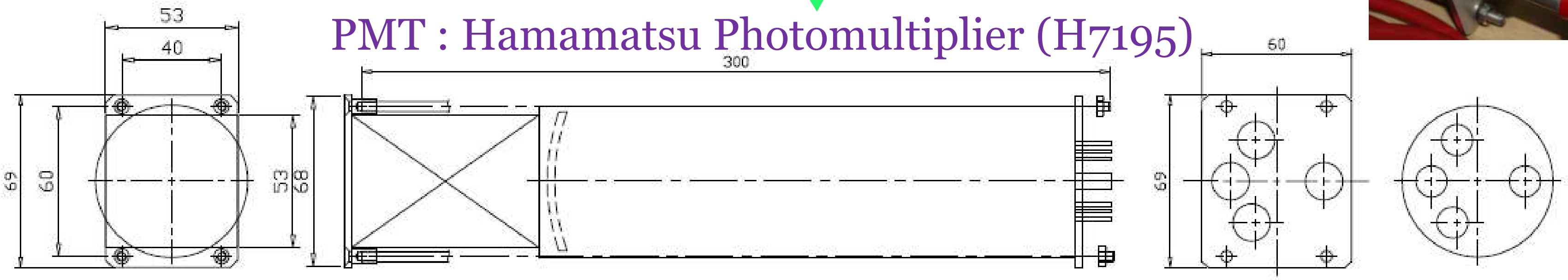


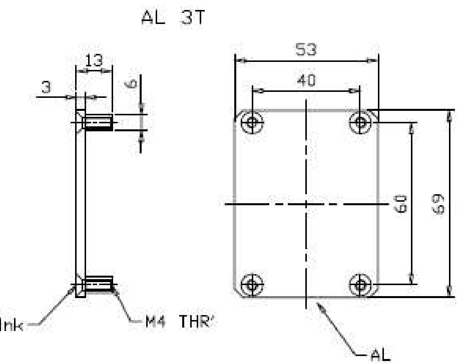
BGO detector modules 1

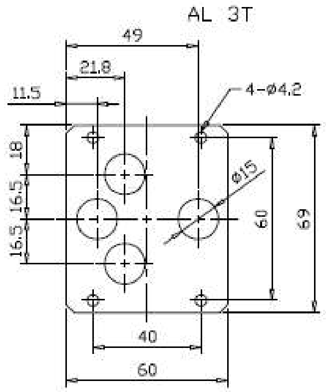
BGO made by SHANGHAI SICCAS HIGH TECHNOLOGY Corporation

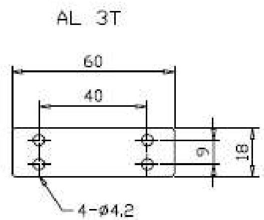


PMT : Hamamatsu Photomultiplier (H7195)





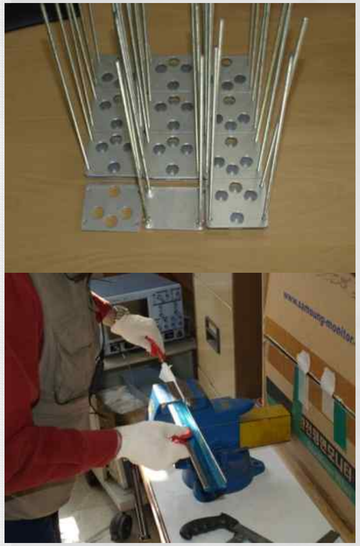




BGO detector modules 2

Assembly Process of a module of BGO gamma detector

Preparation of Module frame



Light Shield For BGO

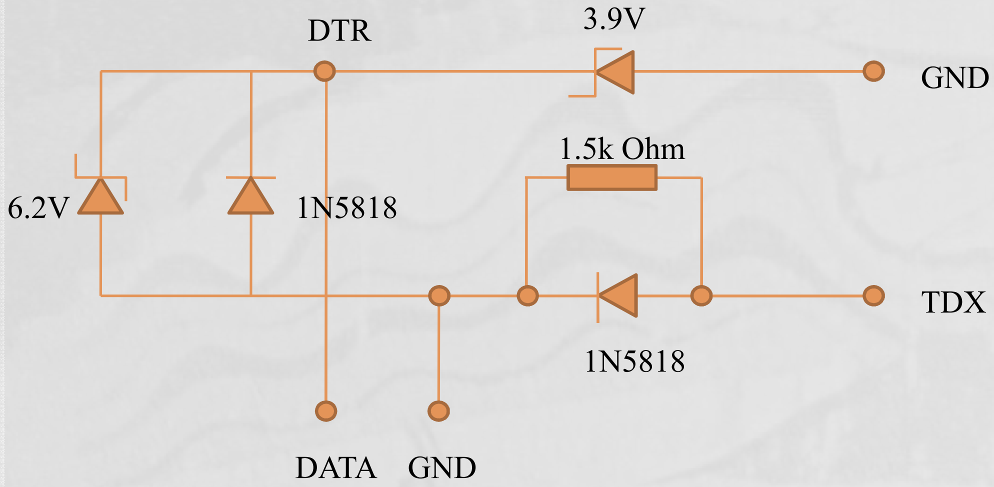
Cleaning BGO And PMT

Optical Connection

Fabrication Of a Module

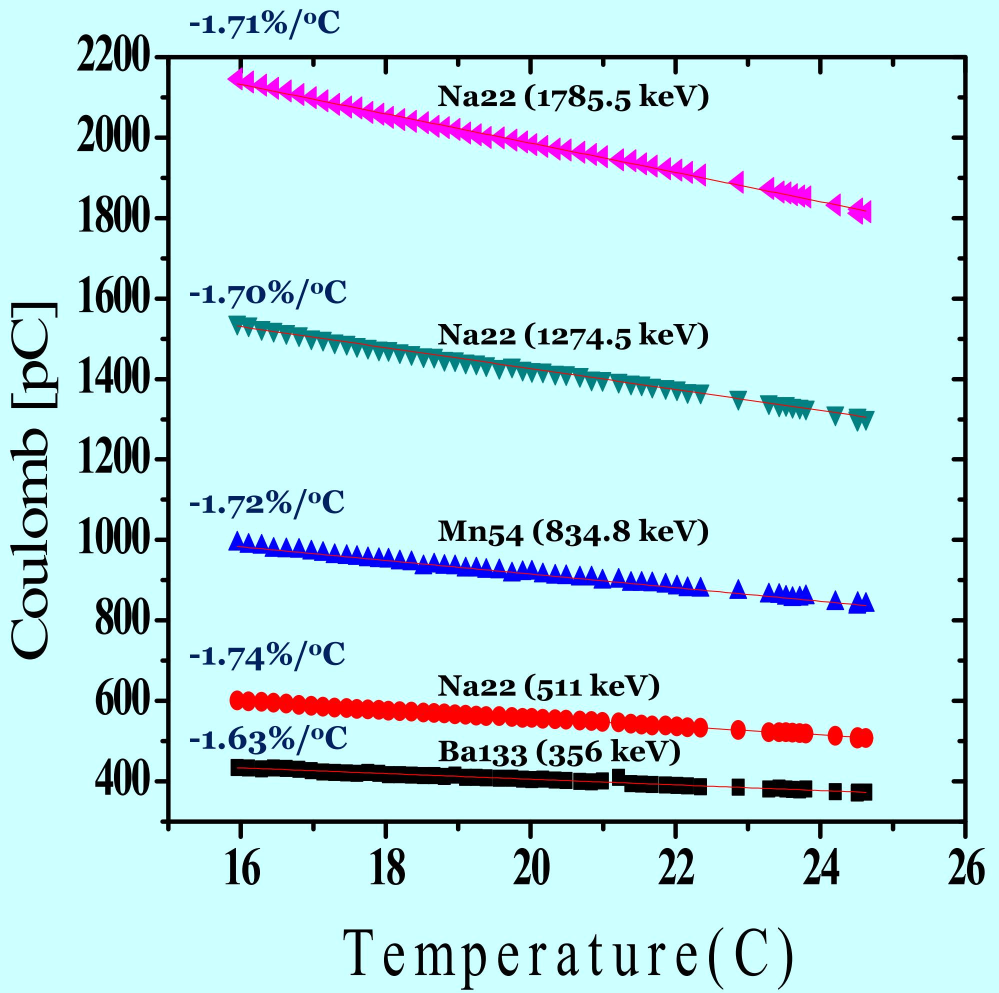
BGO Temperature & Energy 1

Temperature Sensor Using DS1820



Reference : Digital Temperature Sensor Module for Linux
http://www.digitemp.com

BGO Temperature & Energy 2



Temperature Calibration
Using Na22, Mn54, and Ba133

Our BGO Light Yield of Temperature Dependence From 16 °C to 26 °C

-1.7%/°C @ 16 °C
[-1.38%/°C @ 5 °C]

[REFERENCE]

Saint Gobain BGO :
[SGC_BGO_Data_Sheet.pdf]

-1.2%/°C

Naisen Zhang et al. :
[IEEE Trans. On Nuclear science Vol 37, No 2, April 1990]
From 5 °C to 40 °C

-0.9%/°C @ 5 °C

BGO Temperature & Energy 3

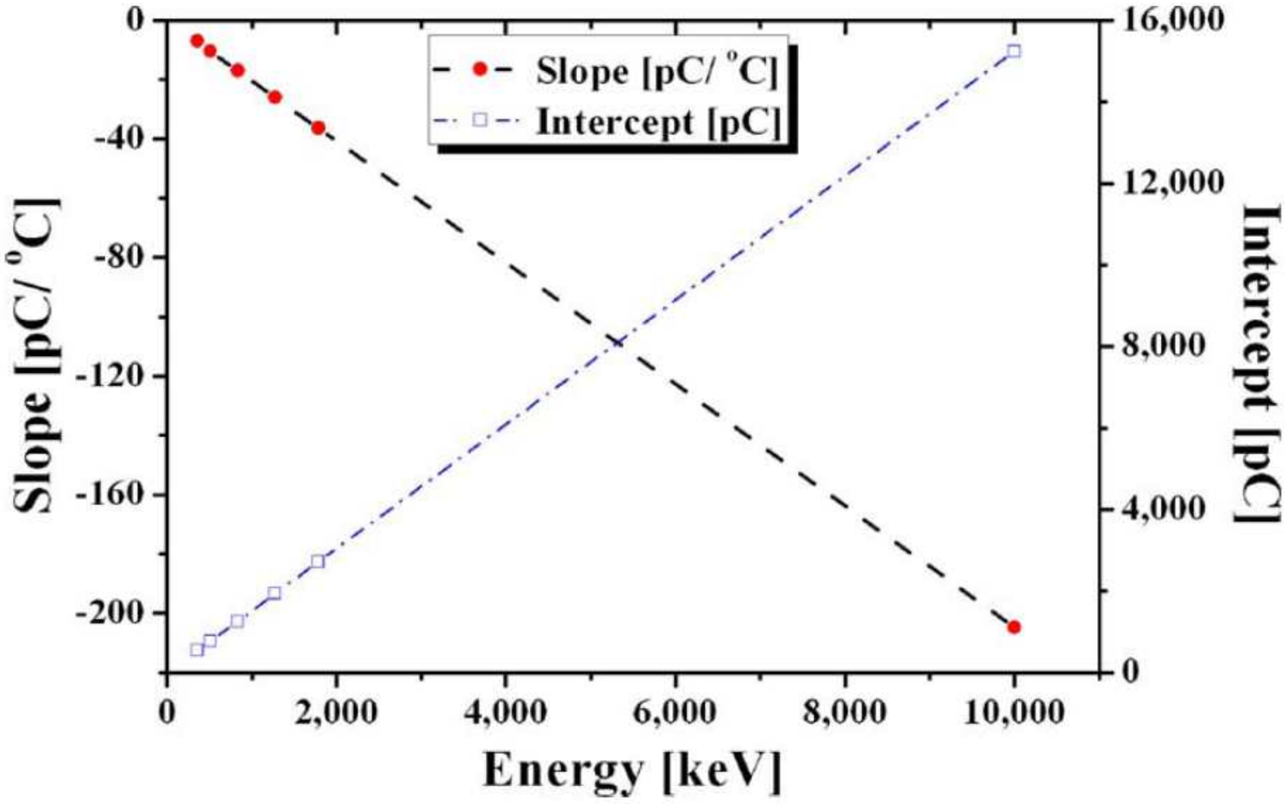
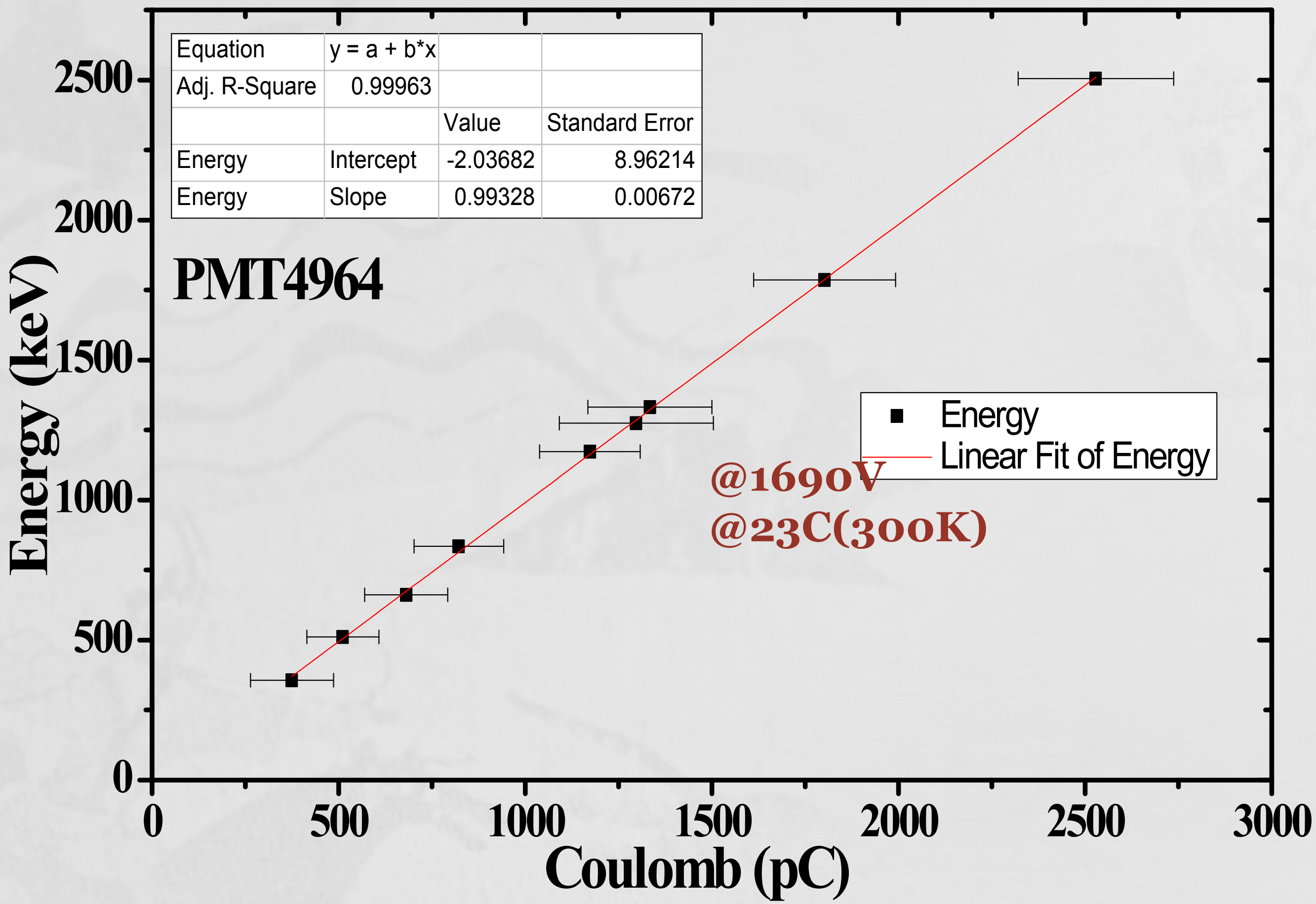


Fig. 7. Slope and the interception as a function of γ-ray energy.

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 57, NO. 3, JUNE 2010

Energy Linearity

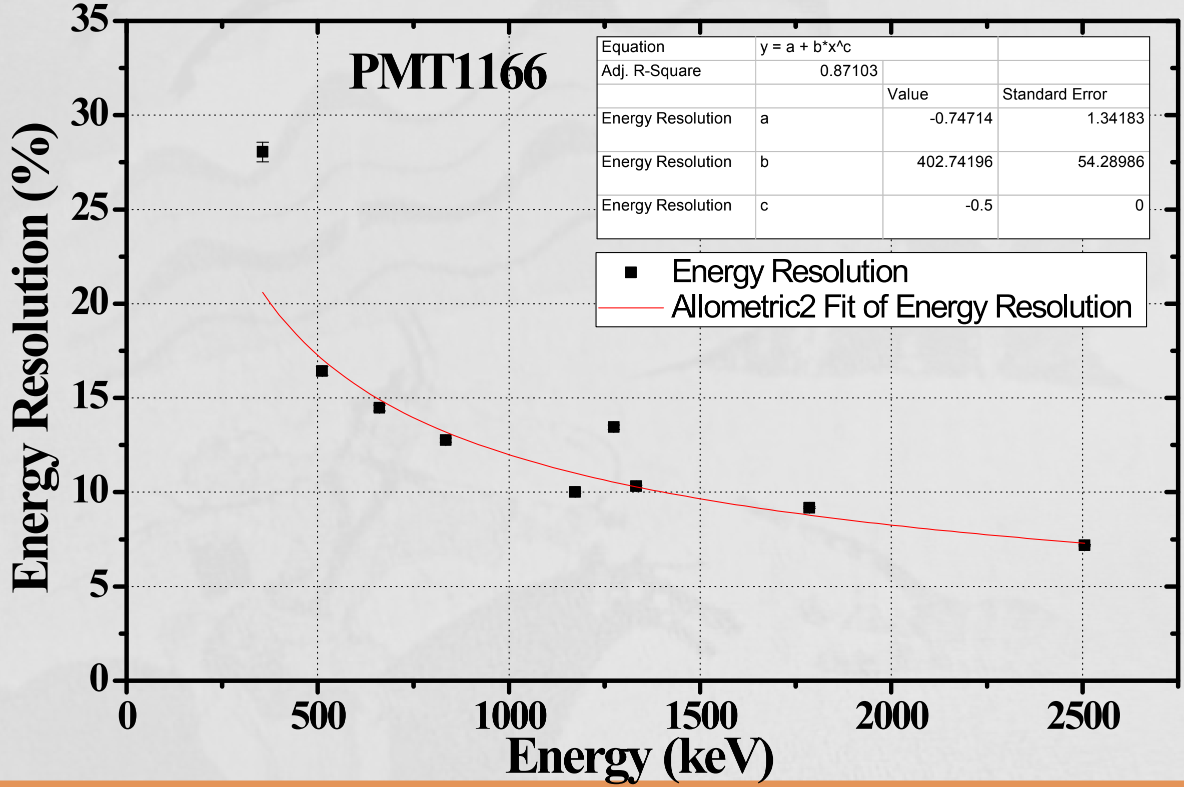
Energy Linearity compensated at 23°C



Energy Resolution

$$\frac{\Delta E}{E}[\%] = \frac{400}{\sqrt{E[keV]}} - 0.7 = \frac{12.65}{\sqrt{E[MeV]}} - 0.7$$

~20% @ 400 keV, ~12% @ 1 MeV, ~8% @ 2.5MeV

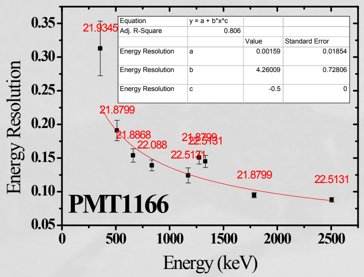


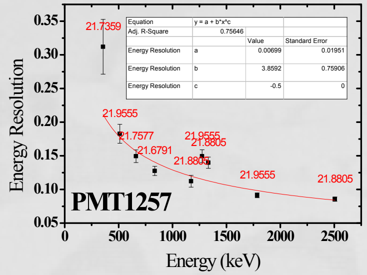
[REFERENCE]

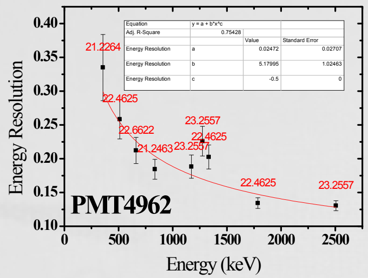
Naisen Zhang et al. :
[IEEE Trans. On Nuclear science Vol 37, No 2, April 1990]

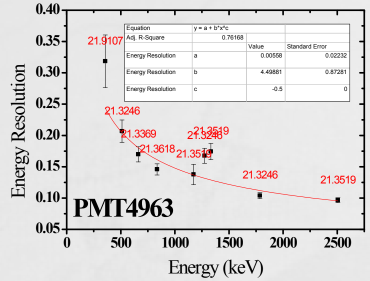
12% @ 1 MeV

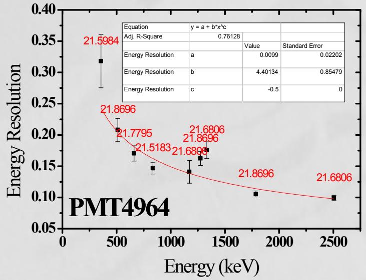
Final BGO Module Test Result

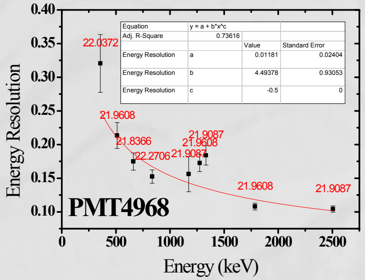


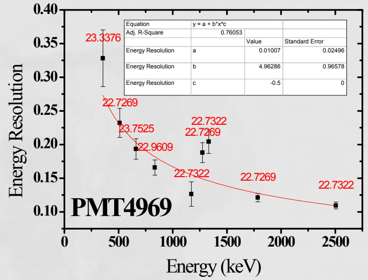


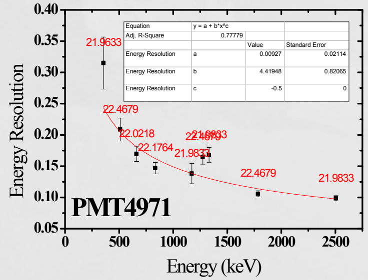


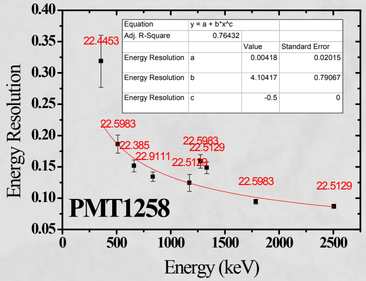


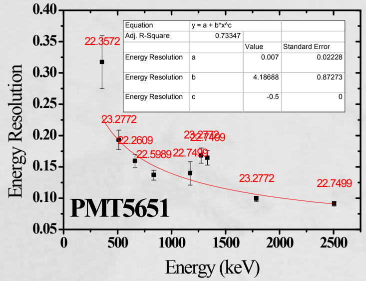


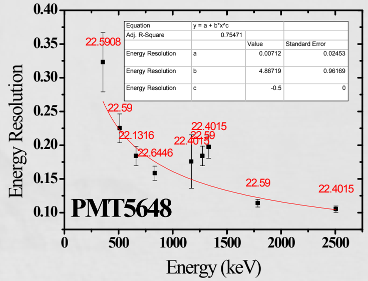


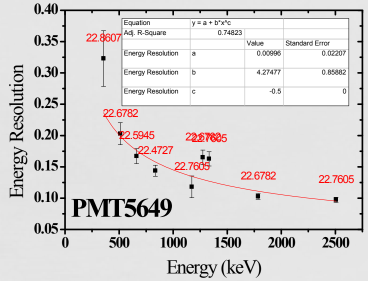




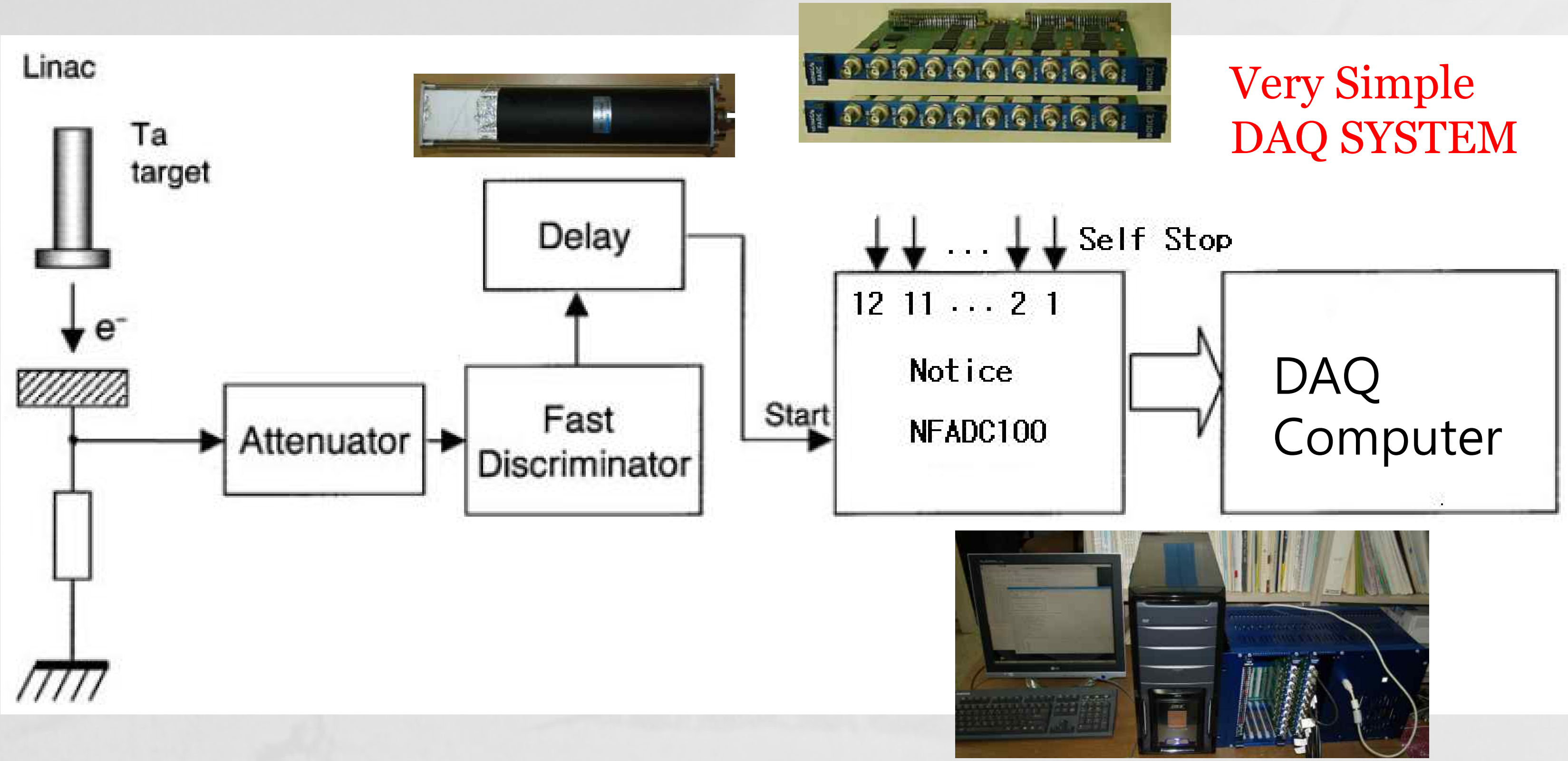








4π BGO γ-detector FADC DAQ 1



- TOF spectra (TIME) + Pulse Height spectra (Signal Shape)
- Possible for Pulse shape analysis

- It needs fast computing system

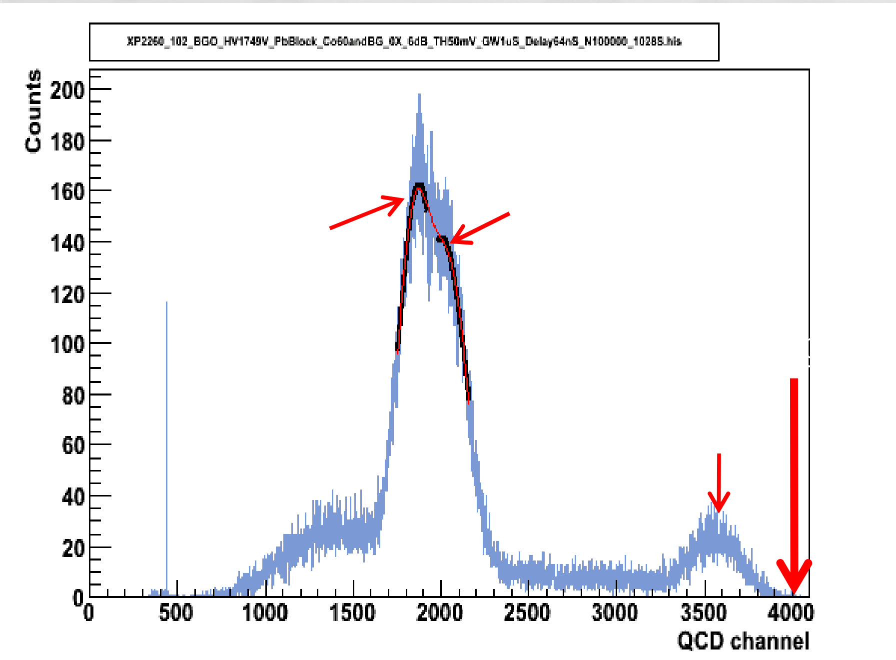
BGO γ-detector FADC DAQ 2

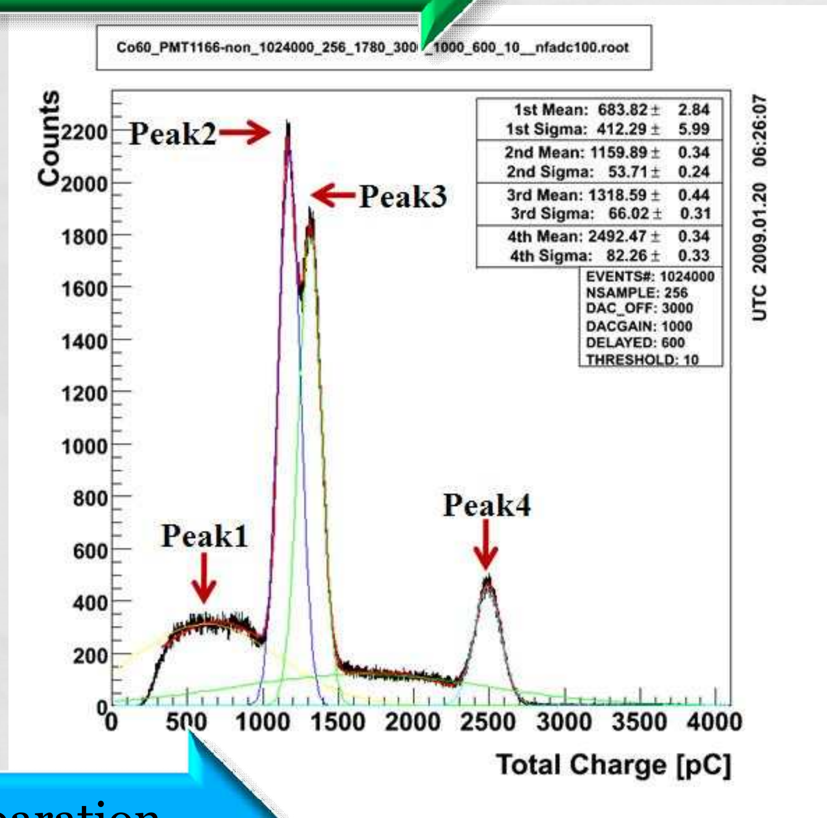
Different DAQ result using same BGO detector

VME ADC V792

Notice Korea 100 MHz FADC

More than 10 times better Charge Resolution





Better Peak Separation

Current Status

- 12 BGO detector modules are made and tested for Temperature, Linearity, and Resolution functions.
- Basic FADC DAQ system has been tested during Total Cross-section measurement and BGO module test.
- FADC DAQ system for Capture experiment will be arrived this year.
- The DAQ software to record 12 BGO signals will be tested next year.
- The on-line spectrum monitoring software will be developed next year.