

# Status Report and Measurement of Total Cross Sections at Pohang Neutron Facility

**G. N. Kim**, H. Ahmed, M. H. Meaze, D. Son

*Institute of High Energy Physics, Kyungpook National University,  
1370 Sankyok-dong, Puk-ku, Daegu, 702-701, Korea*

V. R. Skoy, Y. S. Lee, M. H. Cho, H. S. Kang, I. S. Ko, W. Namkung  
*Pohang Accelerator Laboratory, Pohang University of Science and Technology  
San 31 Hyoja-dong, Nam-gu, Pohang, 790 - 784, Korea*



## History of Pohang Neutron Facility (PNF)

- ✓ May 1997: Pulsed Neutron Facility based on an electron linac was proposed.
  - ☛ 100 MeV, 300 mA, 1.0  $\mu$ s, 60 – 500 Hz
  - ☛ G.N. Kim et al., ND1997 (Trieste, Italy, May 1997) p.556.
- ✓ Aug. 1998~ Workshop on Nuclear Data Production and Evaluation was organized
- ✓ Dec. 1999: Pohang Neutron Facility was constructed.
  - ☛ 75 MeV, 40 mA, 1.8  $\mu$ s, 12 Hz
- ✓ March 2000 ~ : Experiment started (Test experiment)
  - ☛ 60 MeV, 30 mA, 1.5  $\mu$ s, 12 Hz
  - ☛ Measured TOF path length
- ✓ 2001 ~ : Started to measure total cross-sections
- ✓ 2002 ~: Scientists from Vietnam were joined experiment.  
(Nguyen Van Do, Pham Duc Khue. Phun Van Duan)
  - ☛ activation experiments
- ✓ 2003~: Scientists from Vietnam(3), India(2), and China(2) were joined.
  - ☛ activation experiments
  - ☛ total cross section measurements (Ta, Pb, Bi)



# Pohang Neutron Facility

- **Electron Linear Accelerator (Designed)**
  - **Energy : 60 MeV ( 100 MeV)**
  - **Beam Current: 100 mA (300 mA)**
  - **Pulse Width : 1.0  $\mu$ s ~2.0  $\mu$ s (1.0  $\mu$ s ~ few ns)**
  - **Repetition Rate: 10 Hz ~ 12 Hz (60 - 500 Hz)**
- **Target : Water cooled Tantalum**
- **Time-of-Flight System: 10.8 m**
- **Experimental Room : 1**



# Pohang Neutron Facility

## (1) Electron Linear Accelerator

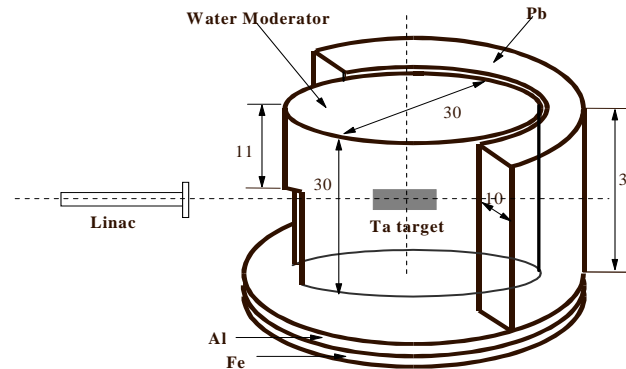




## (2) Target and Moderator System



- 10 Ta Plates
- 3 (40 mm $\phi$ x 2mm t)
  - 2 (40 mm $\phi$ x 3mm t)
  - 1 (40 mm $\phi$ x 4mm t)
  - 4 (40 mm $\phi$ x 6mm t)
- with 2 mm t Ti cover



**Water level was fixed to 3cm above the target surface**



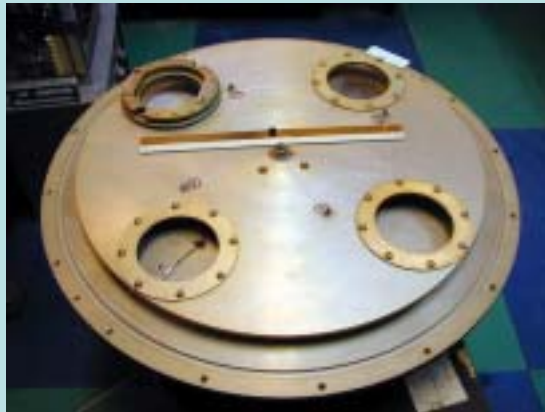


## (3) Time of Flight System

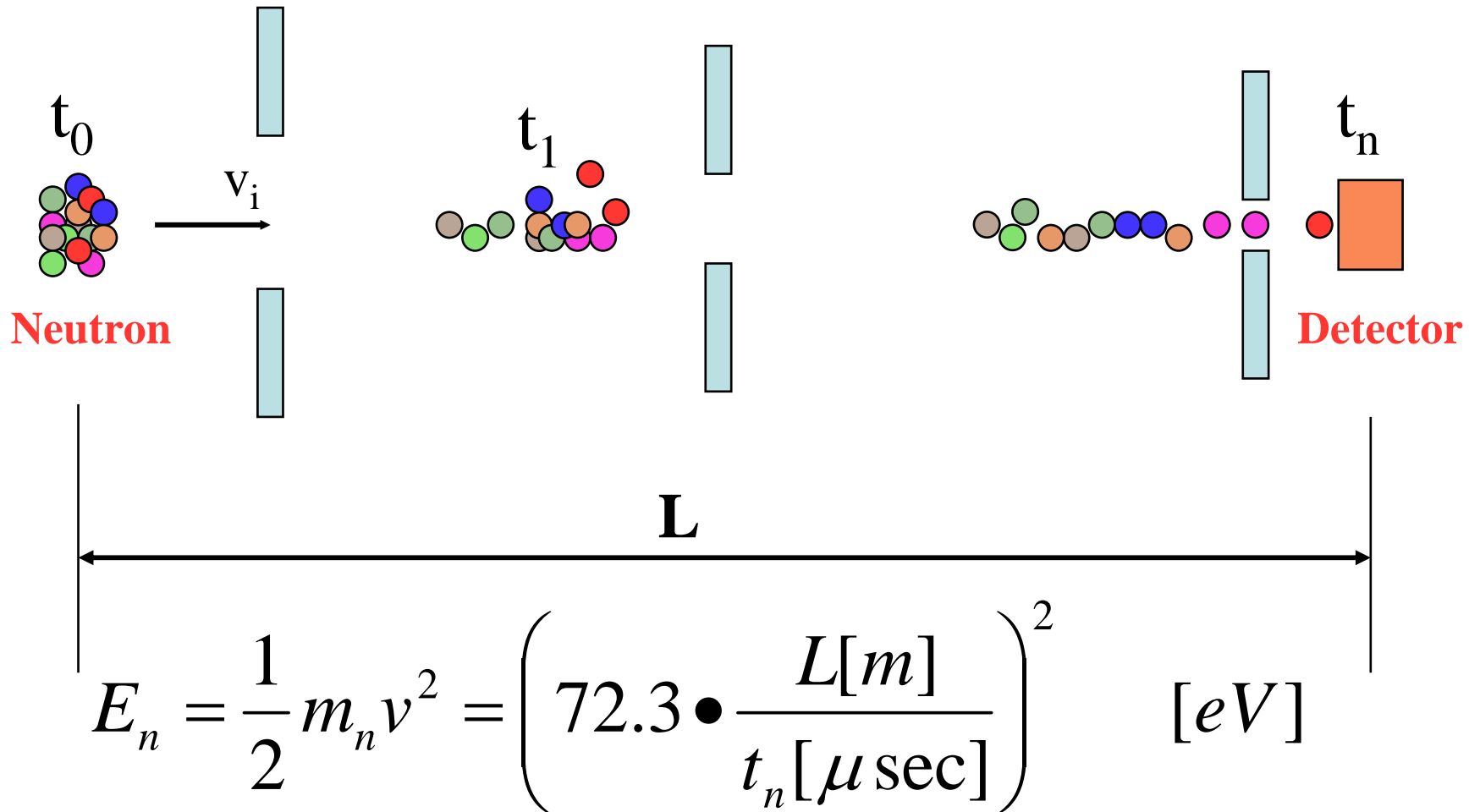
11 m TOF experimental Hall



Install Automatic Sample Changer



# Neutron Time-Of-Flight method





# Measurement of TOF path length

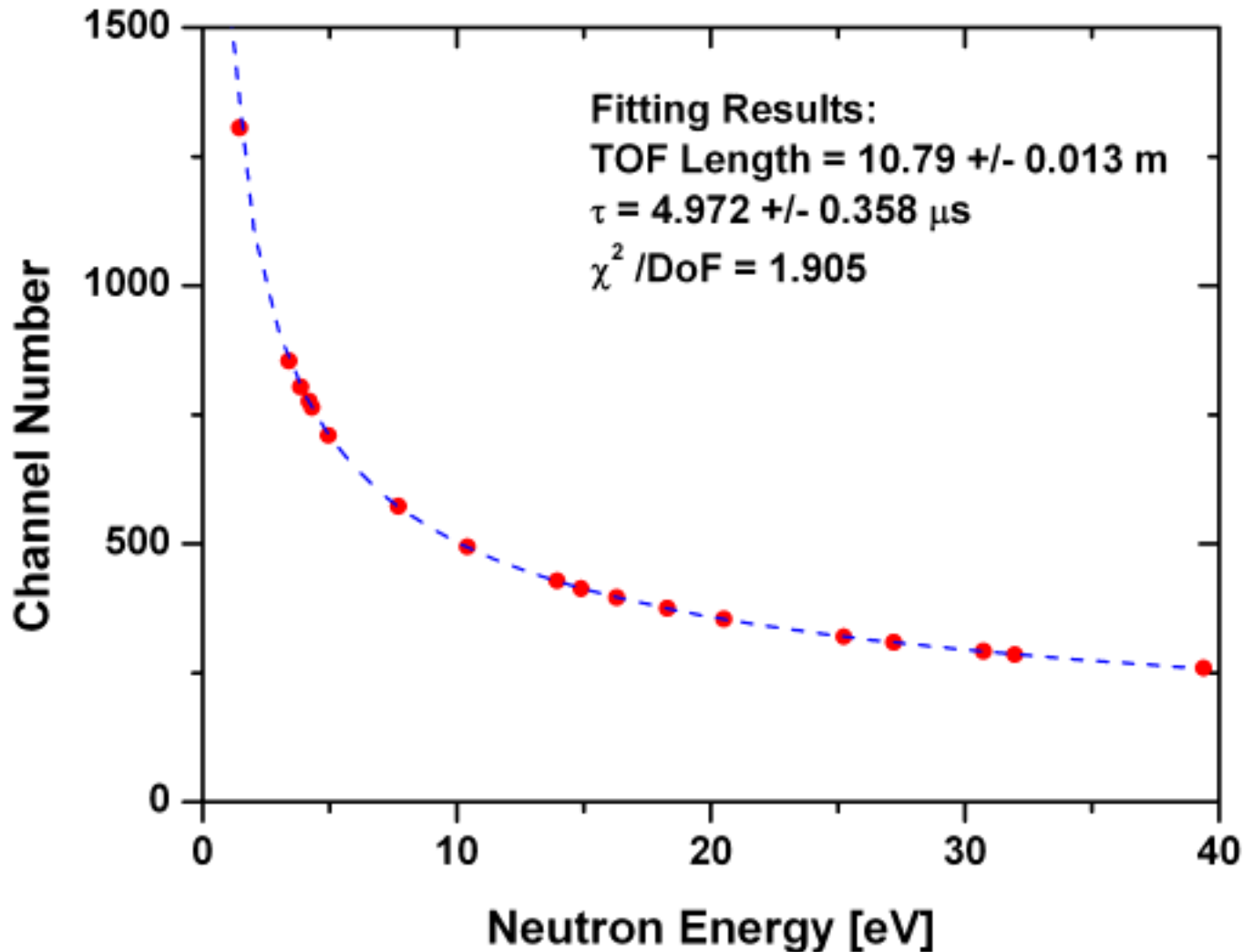
Isotopes	Neutron Energy [eV]	Channel Numbers	Isotopes	Neutron Energy [eV]	Channel Numbers
$^{115}\text{In}$	1.450	1306	$^{181}\text{Ta}$	13.96	428
$^{147}\text{Sm}$	3.397	854	$^{149}\text{Sm}$	14.89	413
$^{115}\text{In}$	3.859	804	$^{107}\text{Ag}$	16.30	396
$^{180}\text{W}$	4.184	776	$^{147}\text{Sm}$	18.29	375
$^{171}\text{Ta}$	4.310	764	$^{150}\text{Sm}$	20.51	354
$^{149}\text{Sm}$	4.957	710	$^{149}\text{Sm}$	25.23	320
$^{183}\text{W}$	7.70	573	$^{183}\text{W}$	27.21	309
$^{115}\text{In}$	9.05	528	$^{109}\text{Ag}$	30.73	292
$^{181}\text{Ta}$	10.42	494	$^{147}\text{Sm}$	31.97	285
			$^{181}\text{Ta}$	39.39	259

Fitting Function: 
$$I = \frac{72.3 \times L}{\Delta t \times \sqrt{E}} + \frac{\tau}{\Delta t}$$





# Measurement of TOF path length





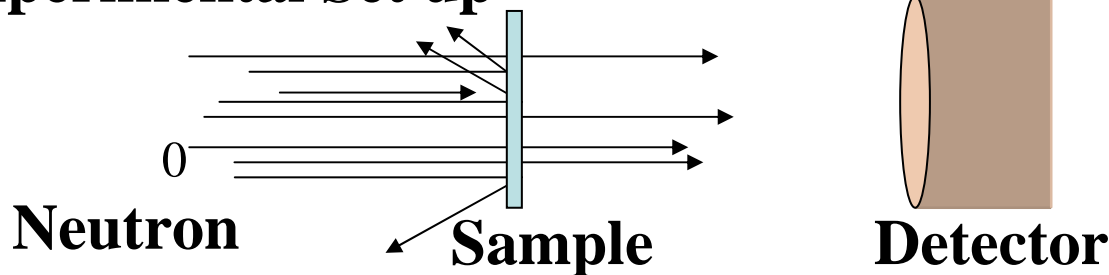
# Measurement of Neutron Total Cross Section

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

$$E[eV] = \left( \frac{72.3 \times L[m]}{(I - I_0) \times W[\mu s]} \right)^2$$

$L$ : flight path length  
 $W$ : channel width

## 2. Experimental Set up



## 3. Neutron Transmission rate

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

## 4. Total Cross Section

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



## Samples for Total Cross Section measurement

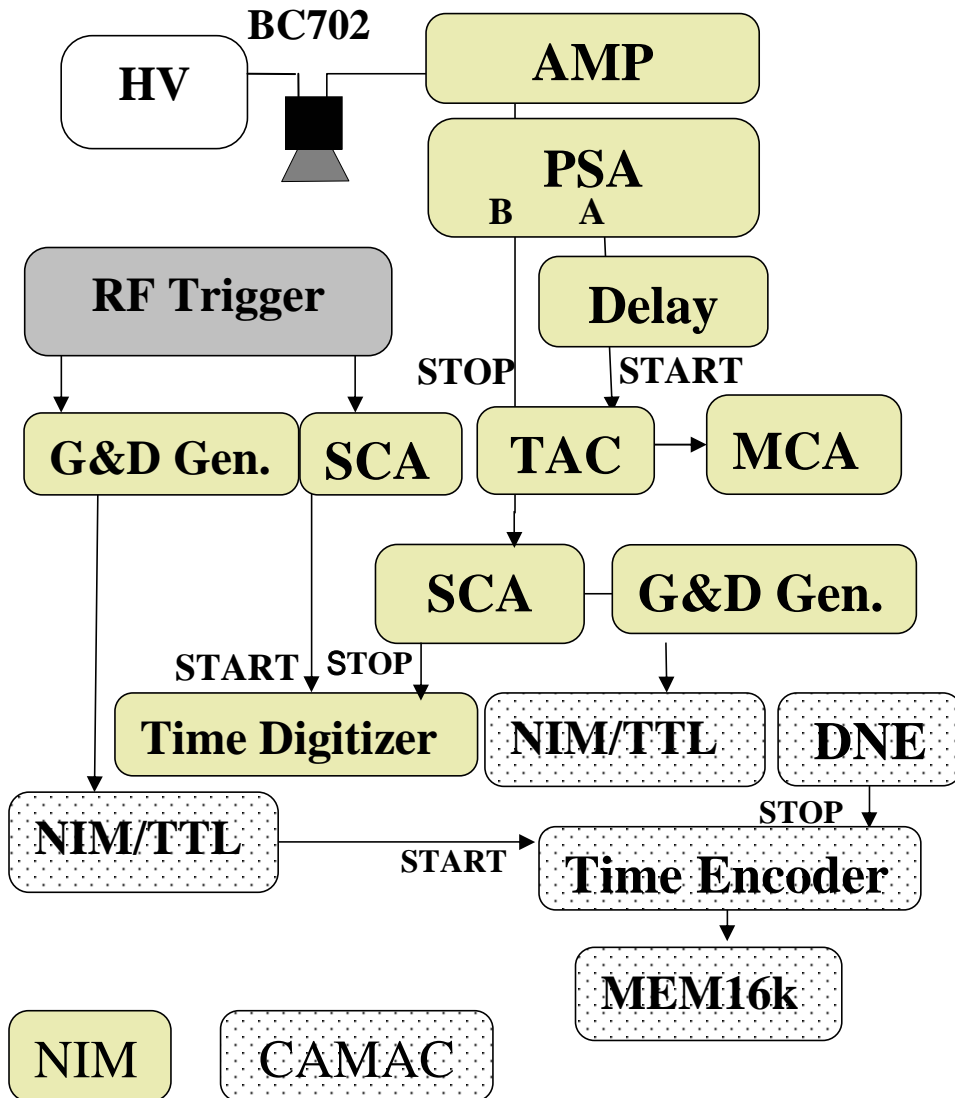
Sample	Size [mm <sup>3</sup> ]	Weight [g]	Purity [%]	Run Time [hr]	
				In	out
Sm	50x 50x1.0	20.254	99.9	65	65
Ag	100x100x0.5	53.036	99.98	65	65
Dy	100x100x0.5	37.945	99.9	18	16
In	100x100x0.2	9.84	99.99	21.5	21.5
W	100x100x0.2	19.3	99.98	48	48
Cu	100x100x1.5	134.4	99.96	31.25	31.25
Ti	100x100x0.5	4.5	99.99	43	43
				291.75	289.75



## Samples for Background measurement

Sample	Size [mm <sup>3</sup> ]	Weight [g]	Purity [%]	Resonance Energy [eV]
Co	100x100x0.5	47.467	99.9	132
Ta	100x100x0.2	33.889	99.95	4.3, 10.3
In	100x100x0.2	9.84	99.99	1.46
Cd	100x100x0.5	44.319	99.99	0.025

# Data Acquisition System

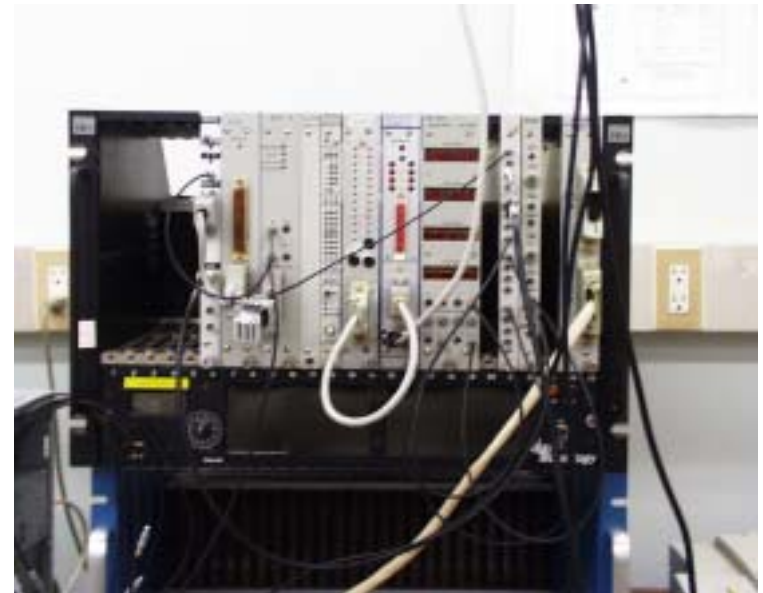


- **NIM Based System**

- ✓ n -  $\gamma$  separation
- ✓ Parallel data acquisition

- **CAMAC Based System**

- ✓ Control the sample changer
- ✓ Main data acquisition





# Neutron - Gamma Separation System and Result

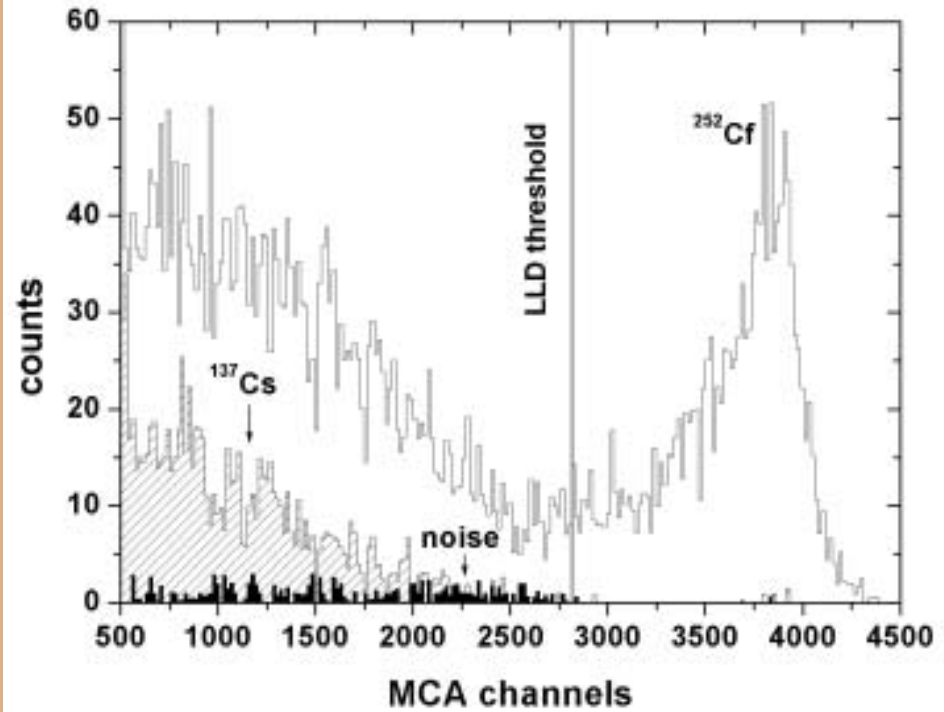
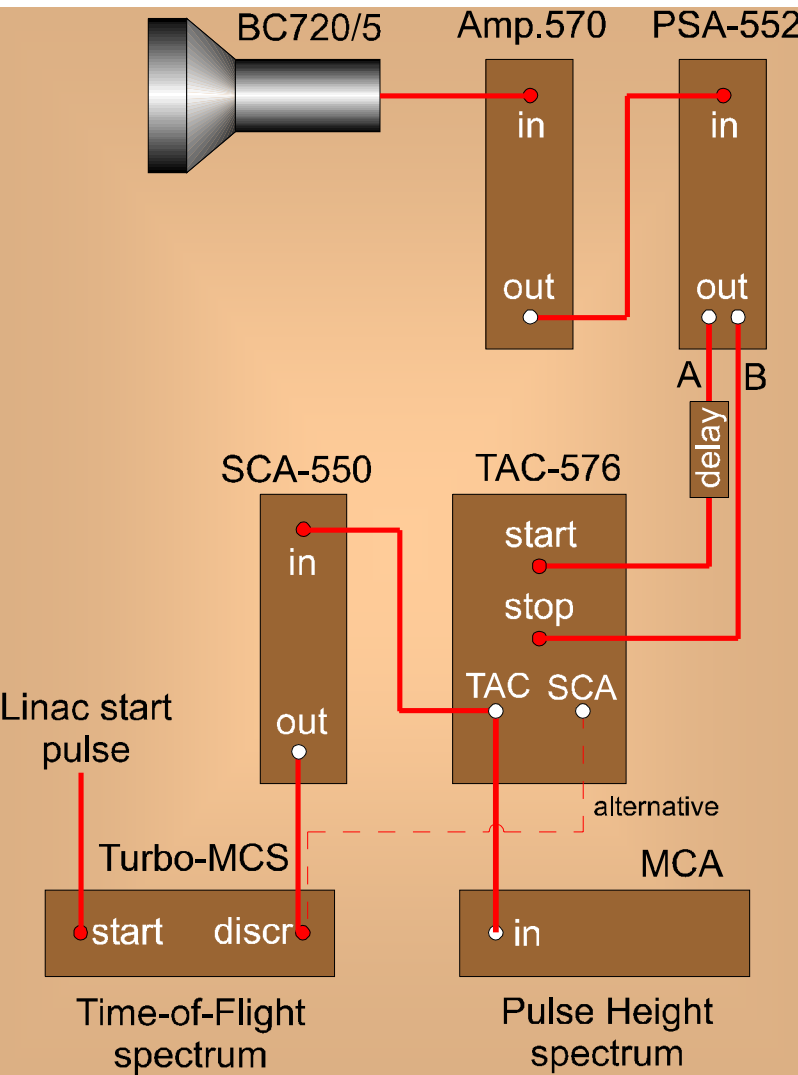
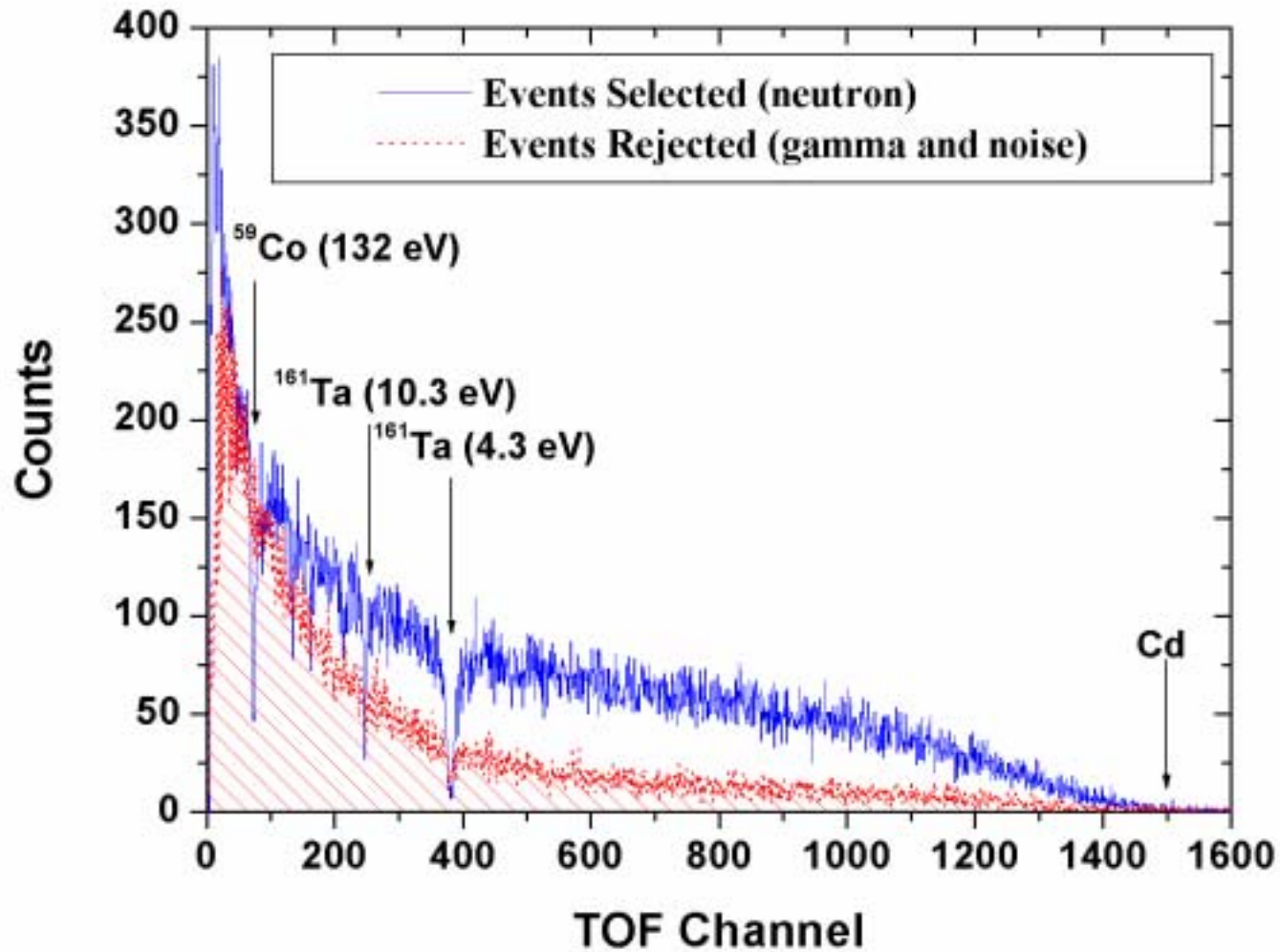


Fig. 3. Pulse height spectra of  $\gamma$  rays from  $^{137}\text{Cs}$ , neutrons and  $\gamma$  rays from  $^{252}\text{Cf}$ , and noise from the neutron detector

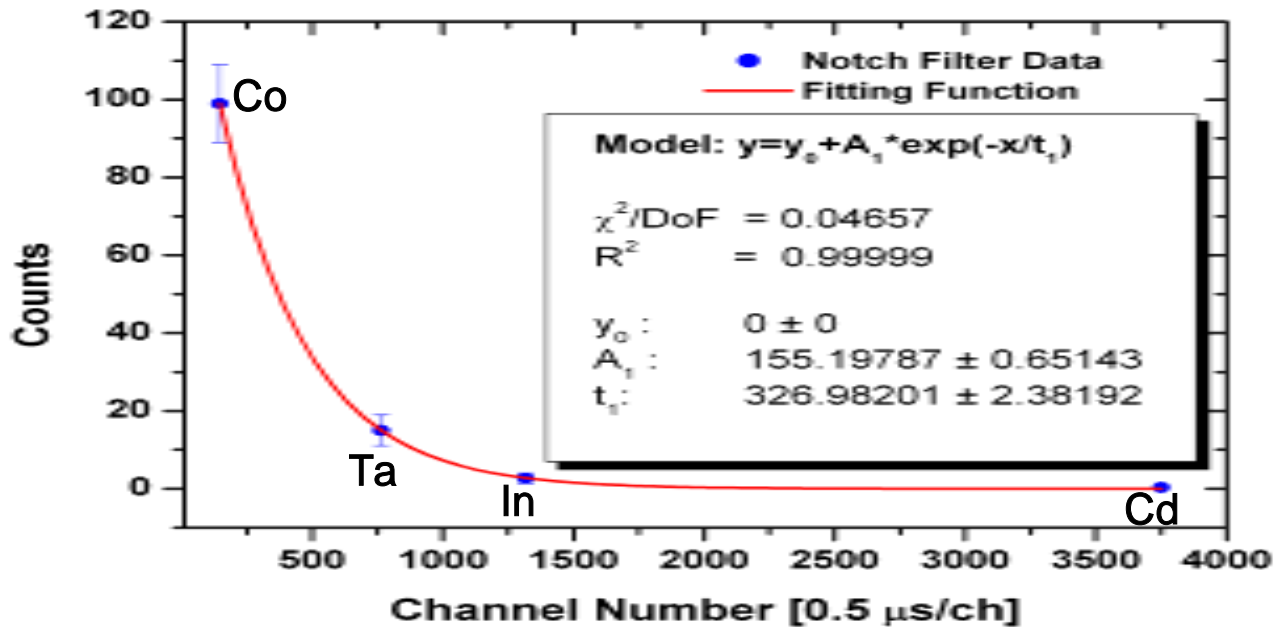
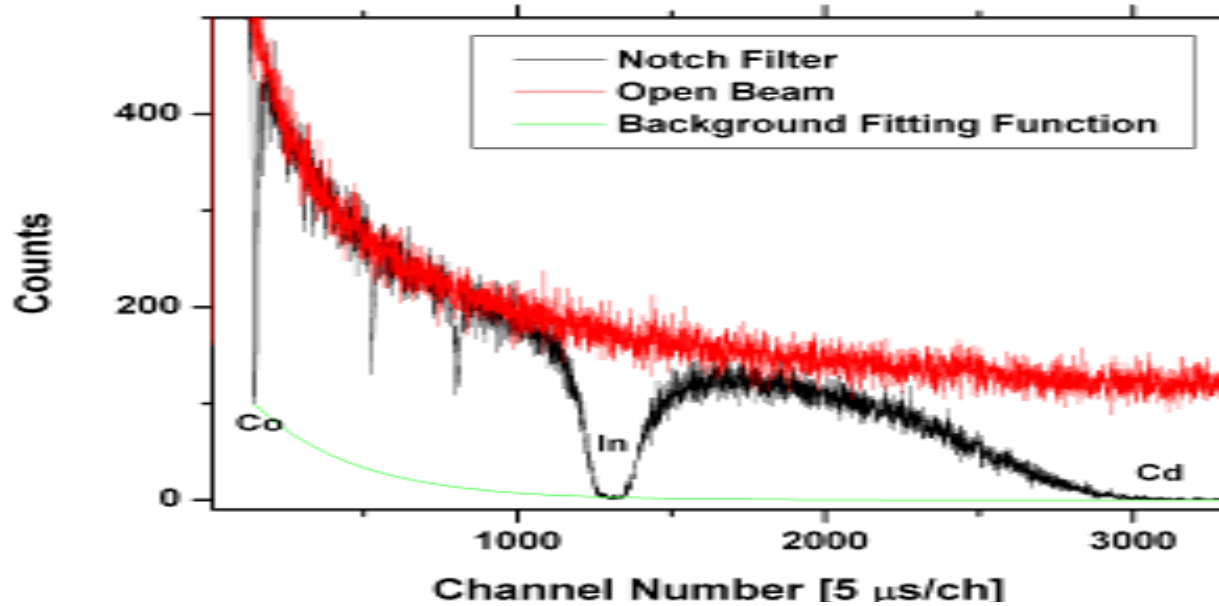




# Spectra of events selected and rejected by the LLD value

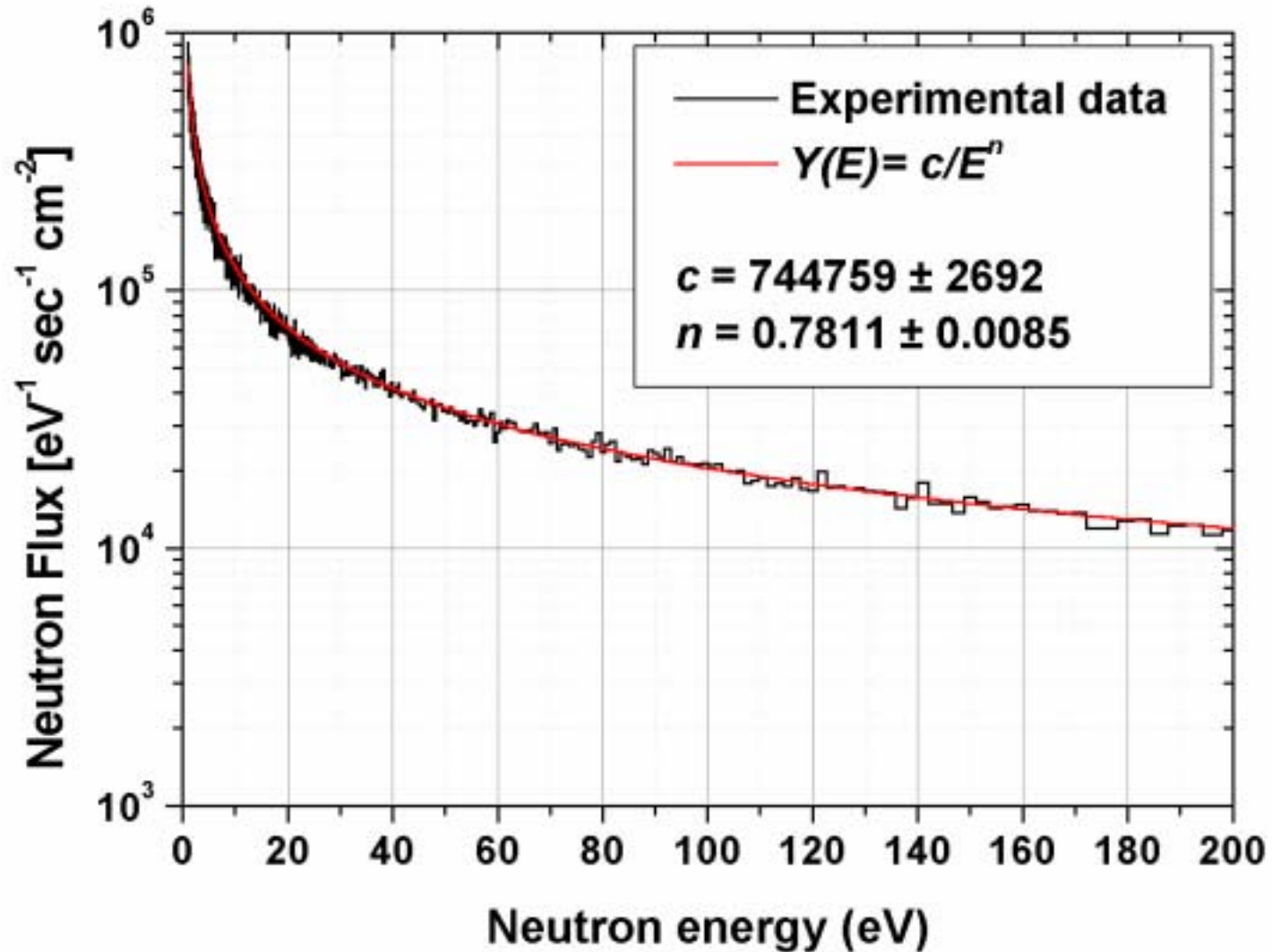


# Background Estimation





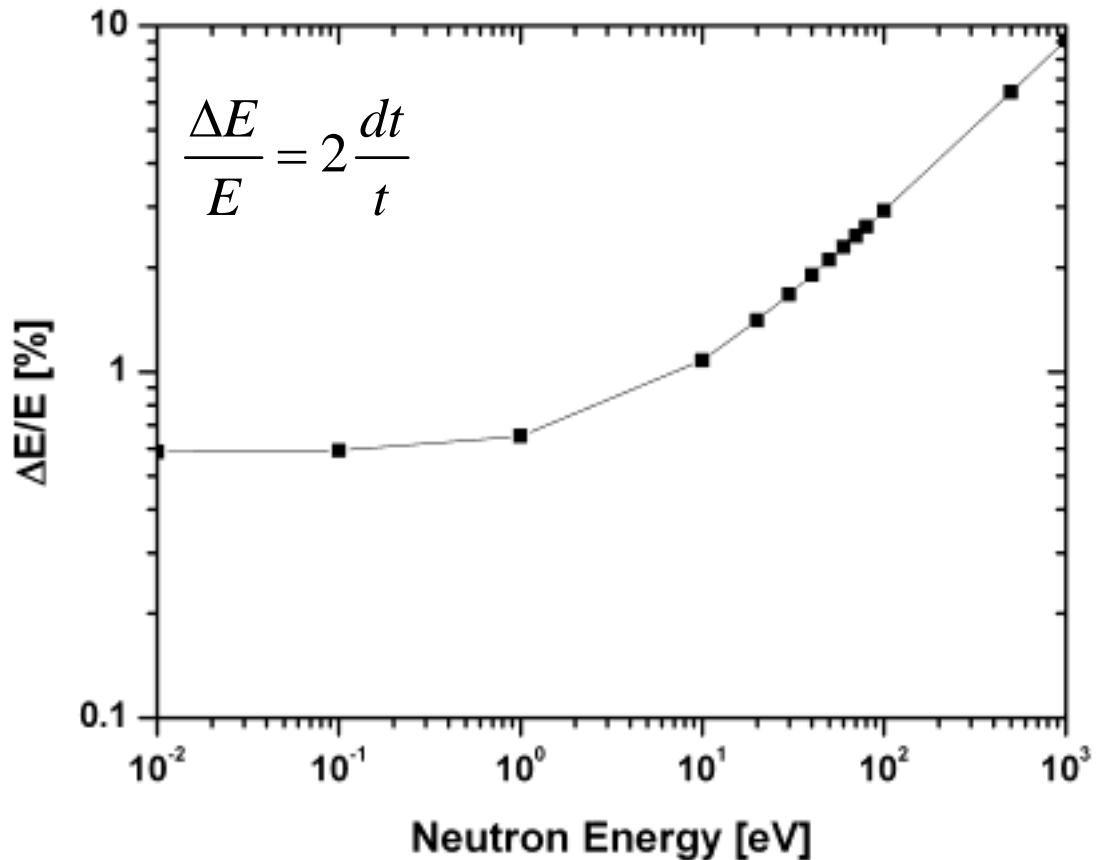
# Measured Neutron Flux Distribution





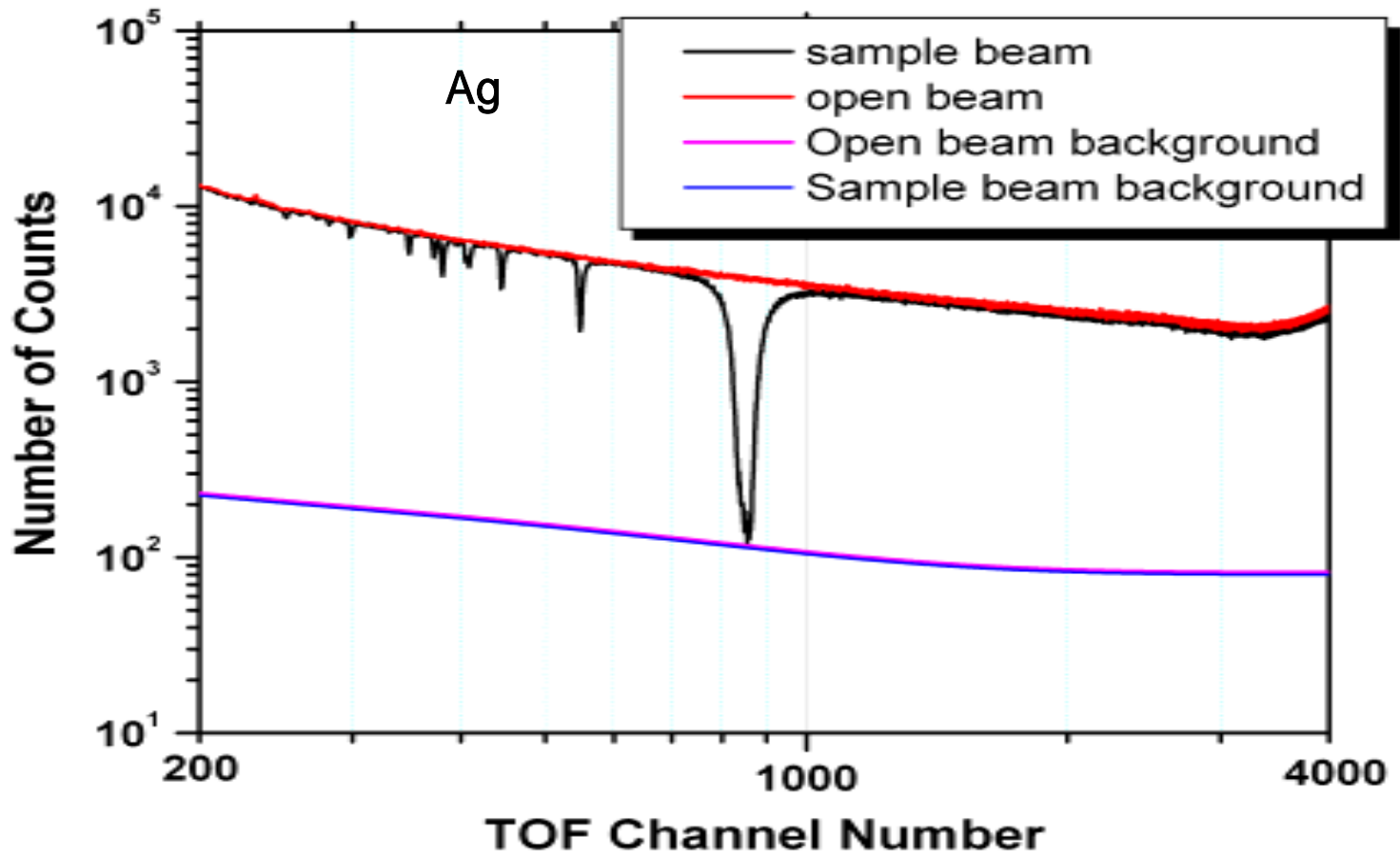
# Energy Resolution in TOF measurement using 10.8 m Flight Path

Neutron Energy [eV]	$10^{-2}$	$10^{-1}$	1	10	$10^2$	$10^3$
TOF of 10.8 m [ $\mu$ s]	7808	2469	780.8	246.9	78.08	24.69
Energy Resolution [%]	0.586	0.593	0.652	1.078	2.923	9.075

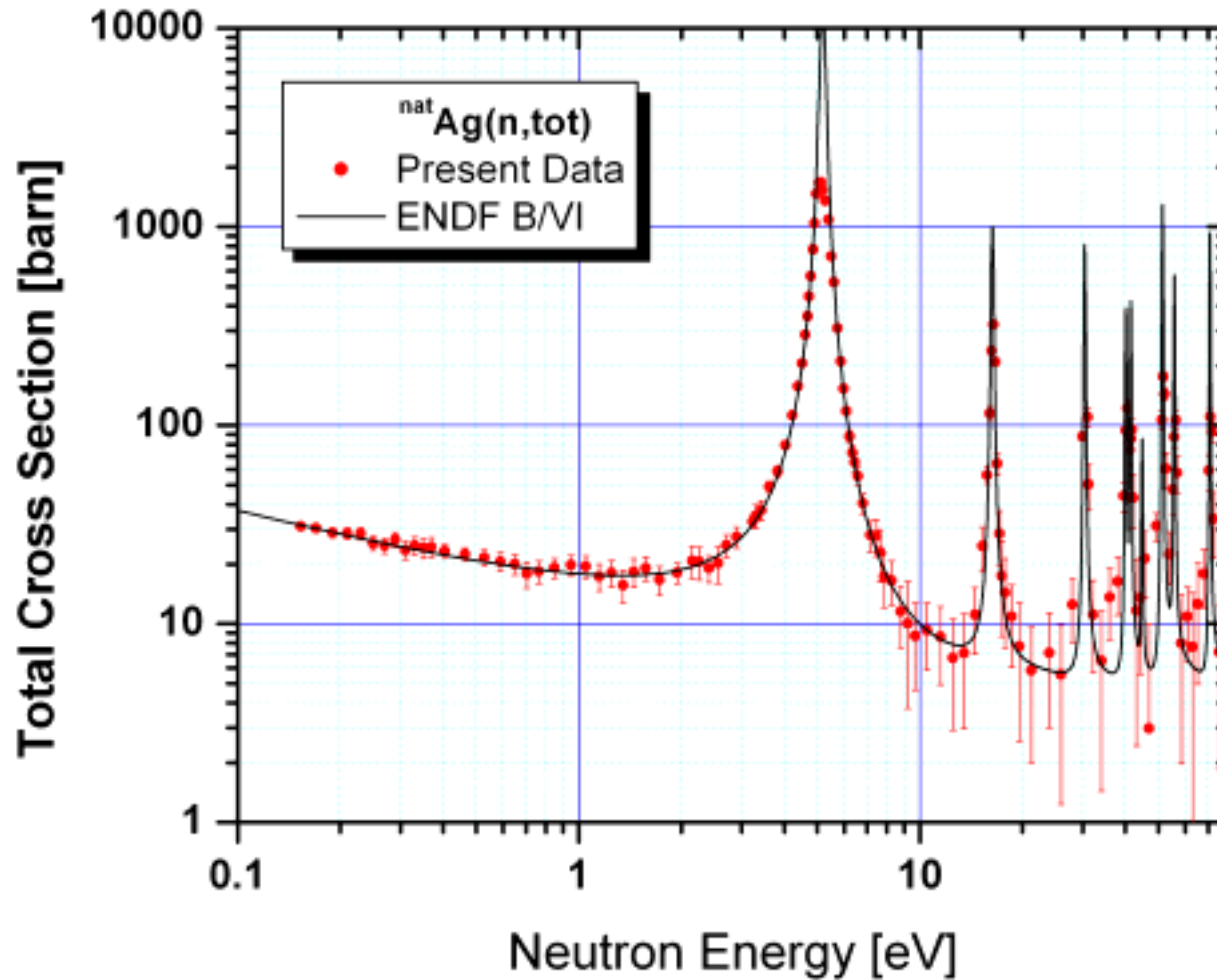




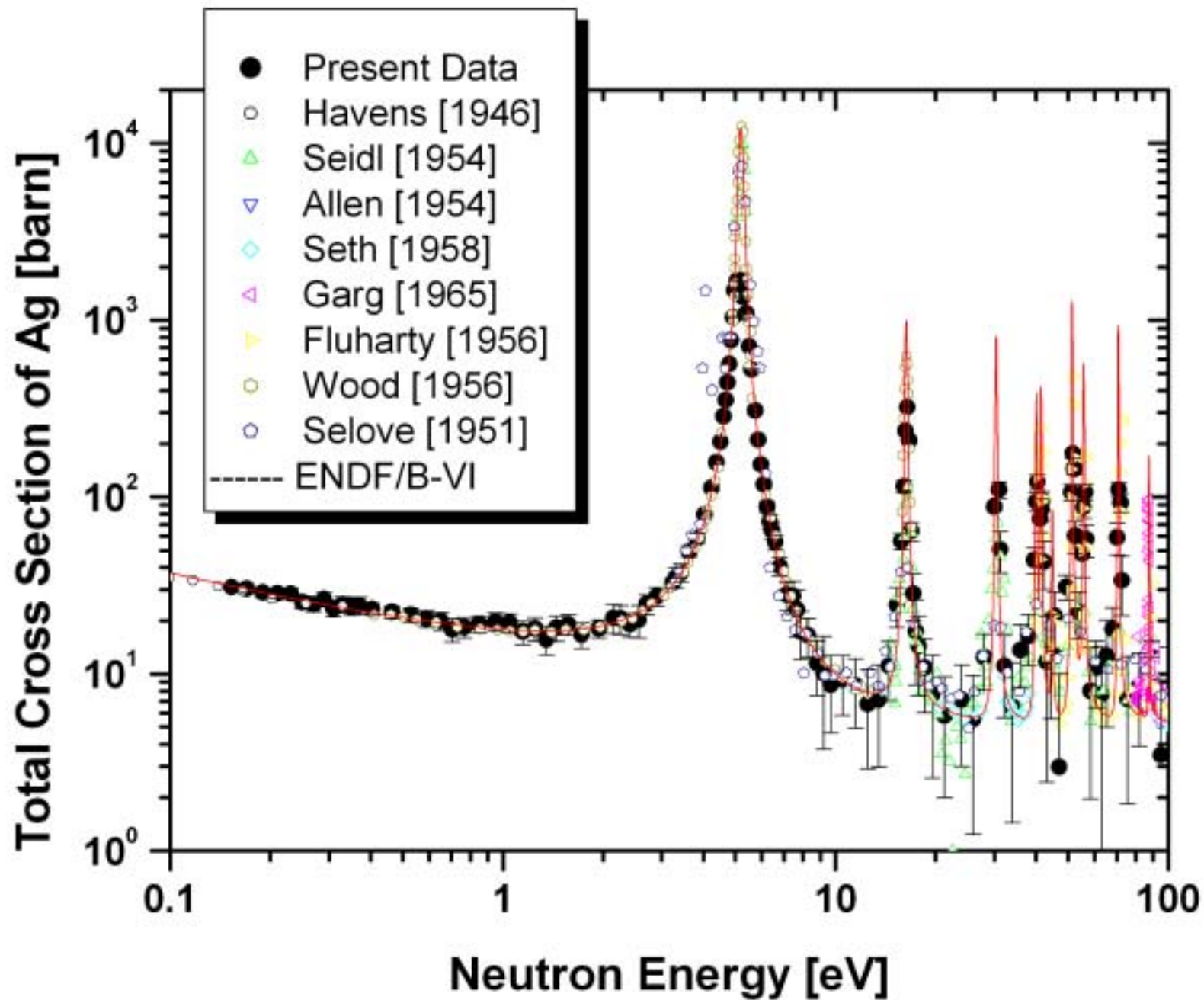
# Neutron TOF Spectra



# Measured Total Cross Sections of natural Ag







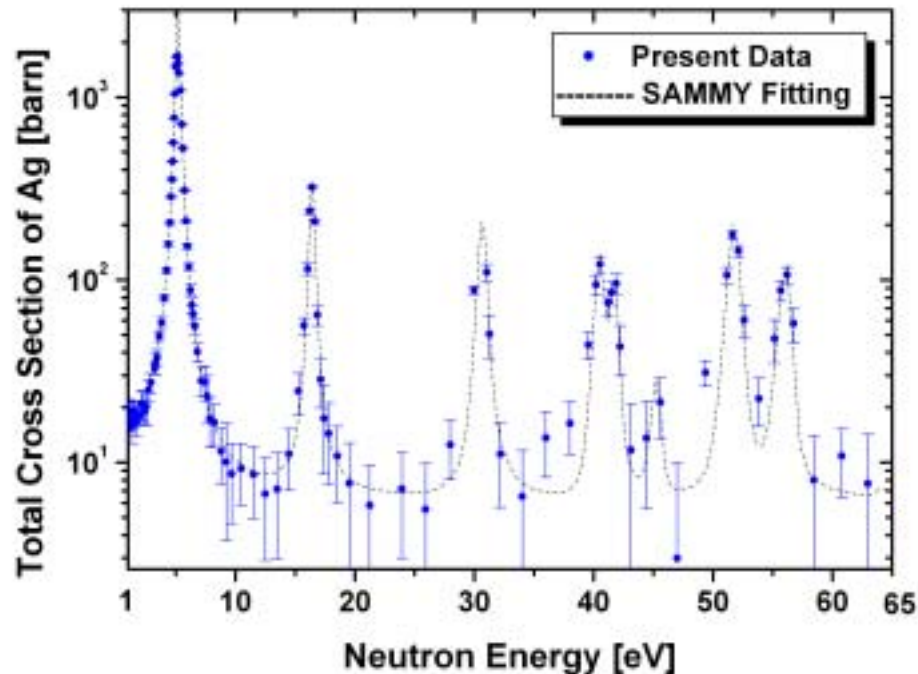


# Resonance Parameter Fitting

SAMMY fitting with the following Resolution Function which consists of the convolution of Gaussian and exponential function

$$R_{GE}(E, E') = \frac{1}{\Delta_E \Delta_G \sqrt{\pi}} \int_{E-\Delta E_S}^{\infty} dE^0 \exp\left\{-\frac{(E^0 - (E - \Delta E_S))}{\Delta_E}\right\} \exp\left\{-\frac{(E' - E^0)^2}{\Delta_G^2}\right\}$$
$$\Delta_G = E[aE + b]^{1/2} \quad \Delta_E = cE^{3/2}$$

$$a=1.364 \times 10^{-6} \text{ eV}^{-1}, \quad b=9.128 \times 10^{-6} \text{ eV}^{-1/2}, \quad c=6.3969 \times 10^{-4} \text{ eV}^{-1/2}$$



Comparison of the measured total cross sections of natural Ag with the predicted total cross section from the SAMMY fitting



# Resonance Parameters for Ag isotopes

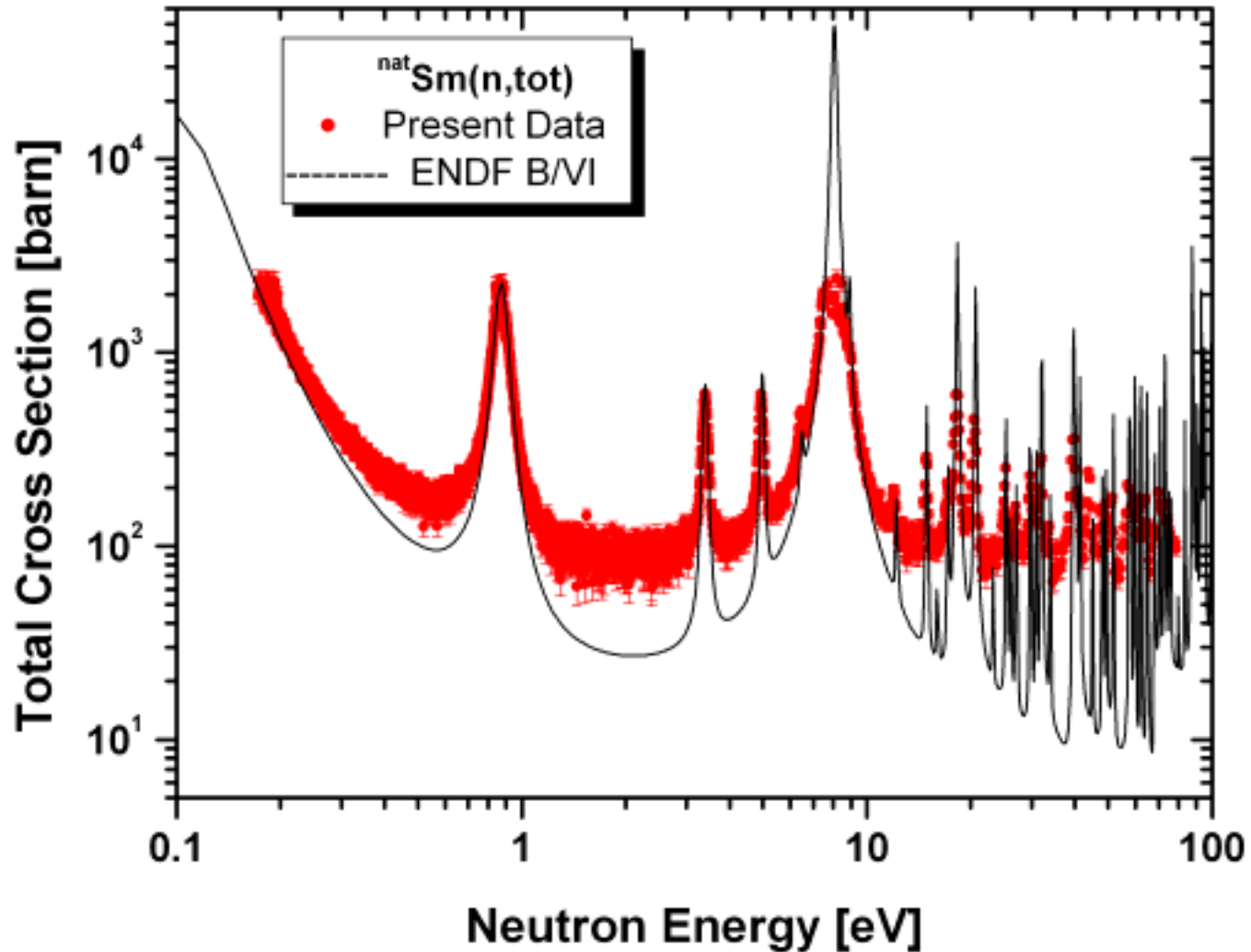
<sup>107</sup>Ag

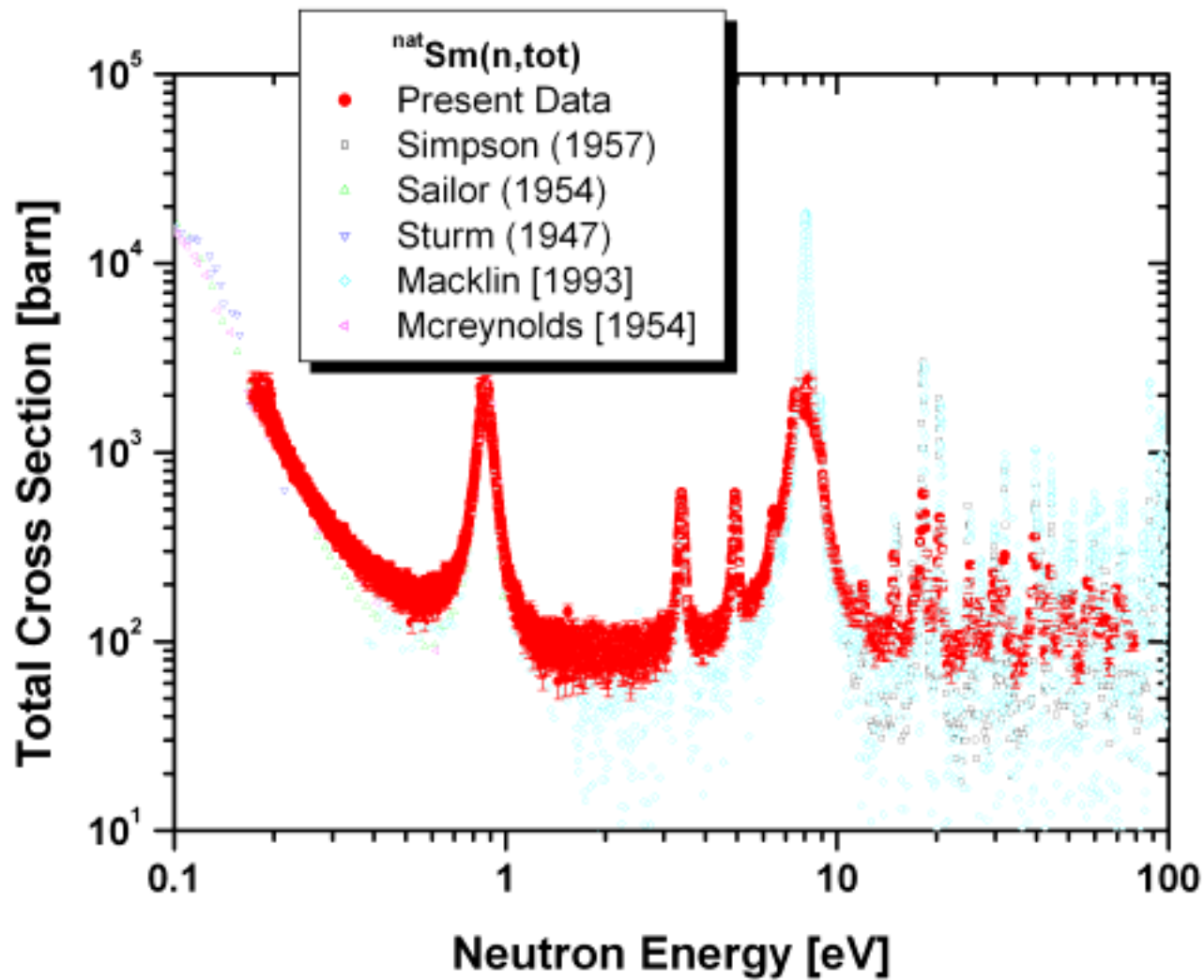
J/l	E[eV]	$\Gamma_n$ [meV]	$\Gamma_{\text{total}}$ [meV]
<b>0/0</b>	16.423±0.004	7.545±0.112	363.54±10.64
<b>1/1</b>	18.899±0.140	0.0001±0.00001	100.00±10.00
<b>1/1</b>	20.323±0.147	0.0002±0.00002	99.99±10.00
<b>1/1</b>	35.826±0.233	0.0004±0.00004	100.00±10.00
<b>1/0</b>	41.726±0.026	2.5219±0.1273	163.78±15.68
<b>1/1</b>	42.751±0.276	0.0047±0.0005	100.00±10.00
<b>1/0</b>	45.264±0.118	1.8478±0.1701	150.12±14.94
<b>1/0</b>	51.756±0.018	9.7141±0.2916	314.97±24.32
<b>1/1</b>	64.197±0.428	0.0260±0.0026	99.97±10.00
<b>2/1</b>	64.565±0.431	0.0105±0.0011	100.00±10.00

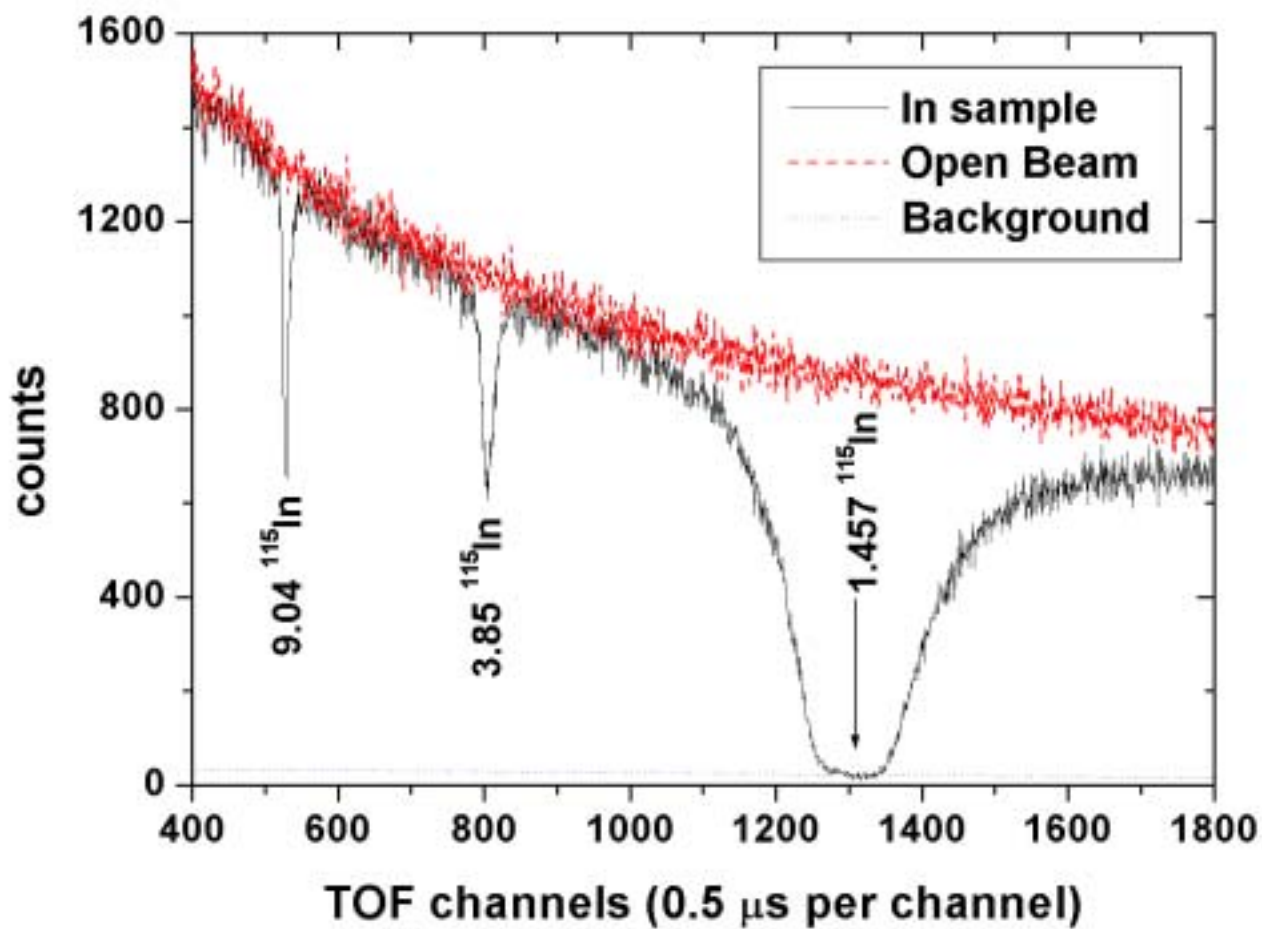
<sup>109</sup>Ag

J/l	E[eV]	$\Gamma_n$ [meV]	$\Gamma_{\text{total}}$ [meV]
<b>1/0</b>	5.186±0.001	5.9511 ±0.0004	345.27±3.61
<b>1/0</b>	30.674±0.011	4.4958±0.1135	432.99±24.17
<b>1/1</b>	32.694±0.214	0.0092±0.0009	100.09±10.01
<b>1/0</b>	40.492±0.020	3.7147±0.1484	231.62±19.89
<b>0/0</b>	56.048±0.032	19.559±0.898	171.55±16.32

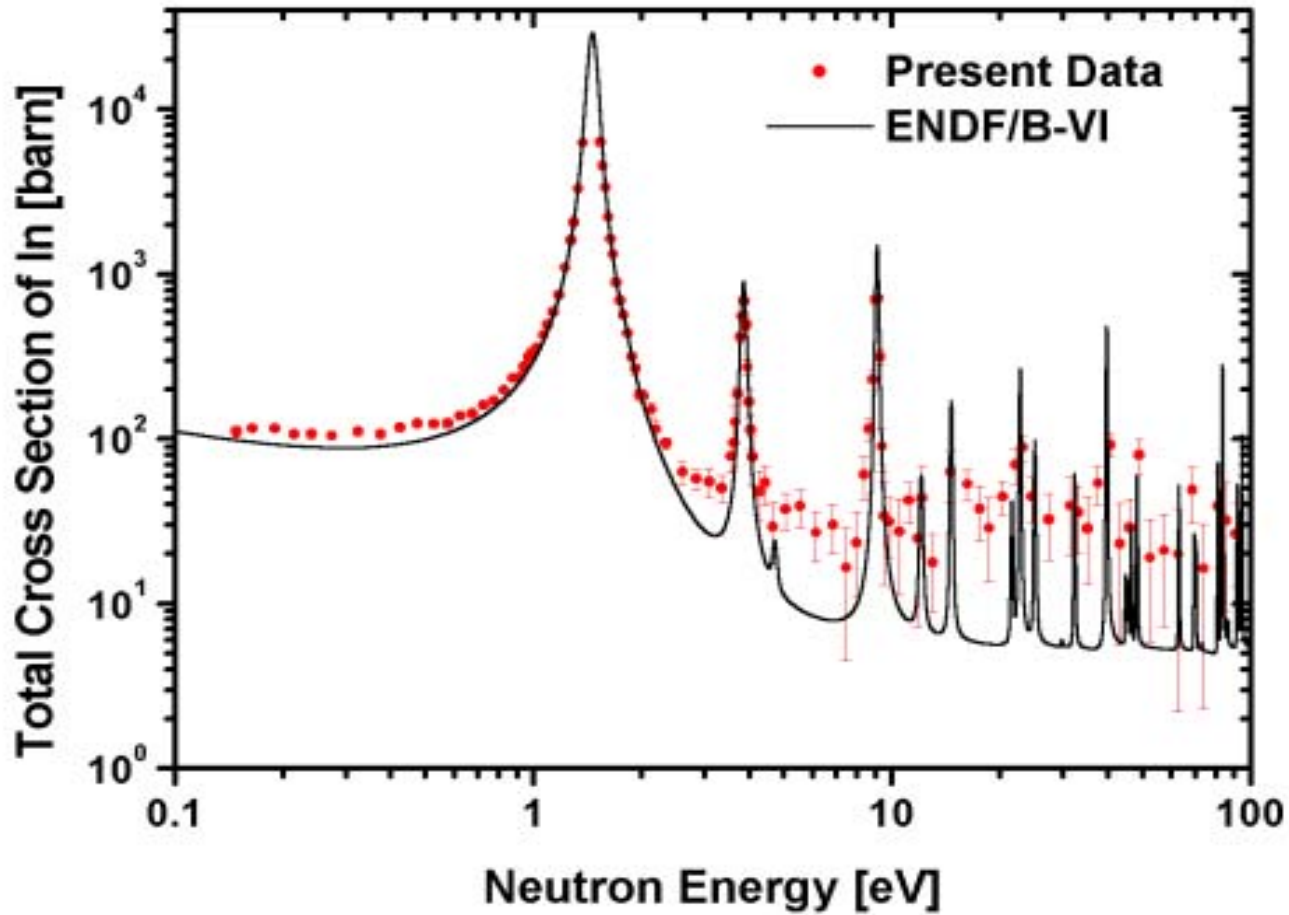
# Measured Total Cross Sections of natural Sm

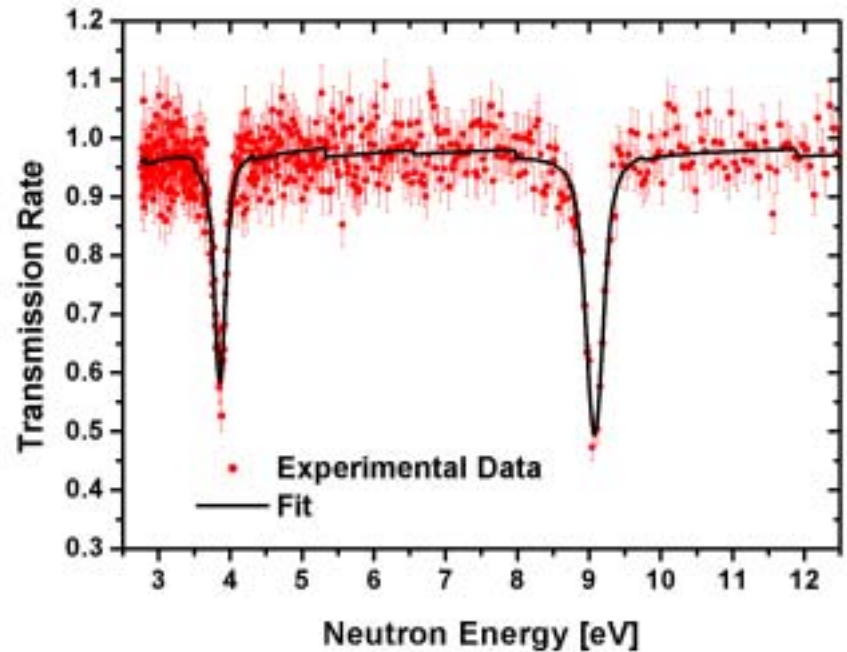
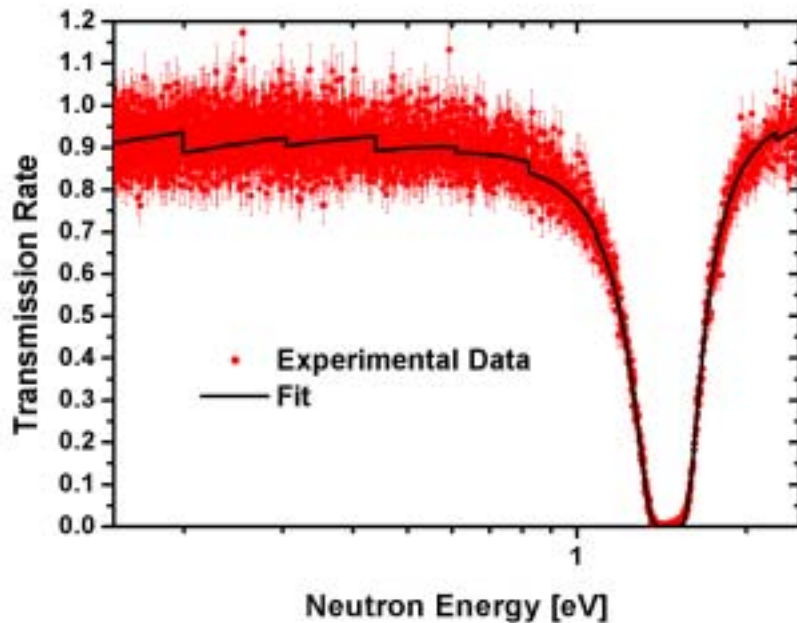








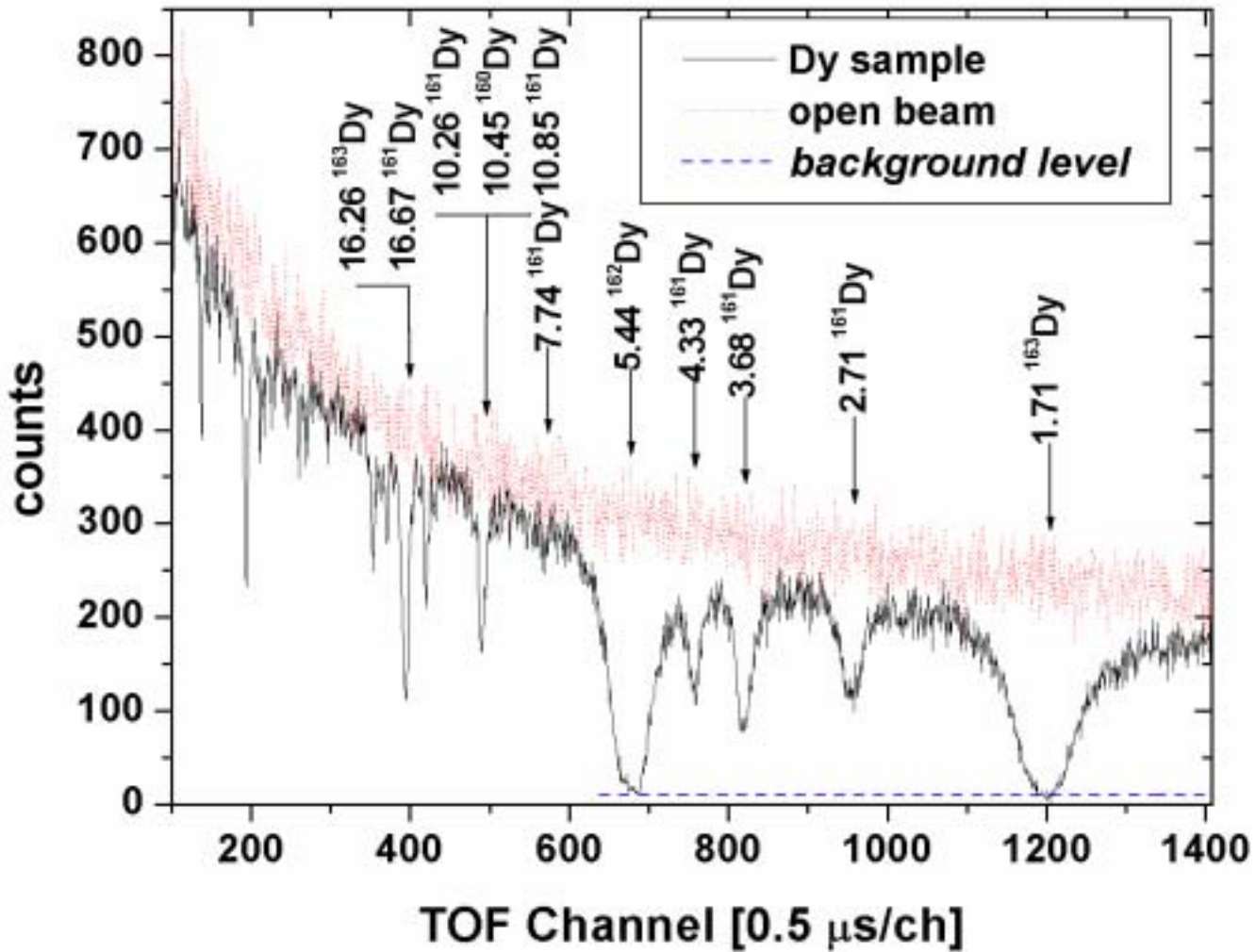




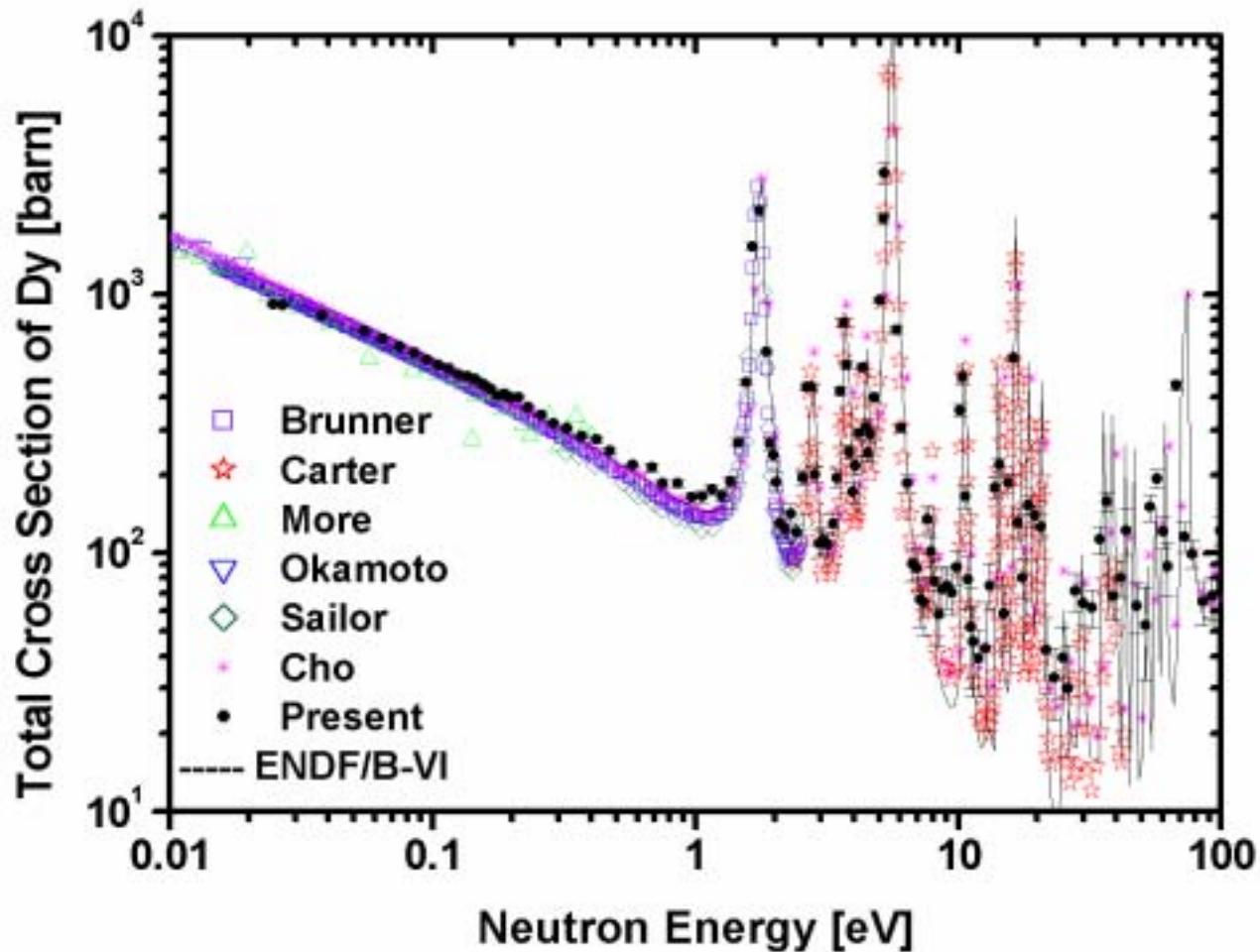
Isotope	J	E [eV]	$g\Gamma_n$ [meV]	$\Gamma_\gamma$ [meV]
$^{115}\text{In}$	5	$1.458 \pm 0.004$	$1.33 \pm 0.03$	$93.8 \pm 2.7$
		$1.457 \pm 0.002$	$1.67 \pm 0.03$	$72 \pm 2$
$^{115}\text{In}$	4	$3.849 \pm 0.003$	$0.153 \pm 0.005$	$112 \pm 8$
		$3.85 \pm 0.01$	$0.170 \pm 0.007$	$81 \pm 4$
$^{115}\text{In}$	5	$9.05 \pm 0.005$	$0.711 \pm 0.023$	$143.7 \pm 11.1$
		$9.04 \pm 0.03$	$0.81 \pm 0.04$	$80 \pm 40$

S.F. Mughabhab "Neutron Cross Sections", Academic Press, N.Y., 1984

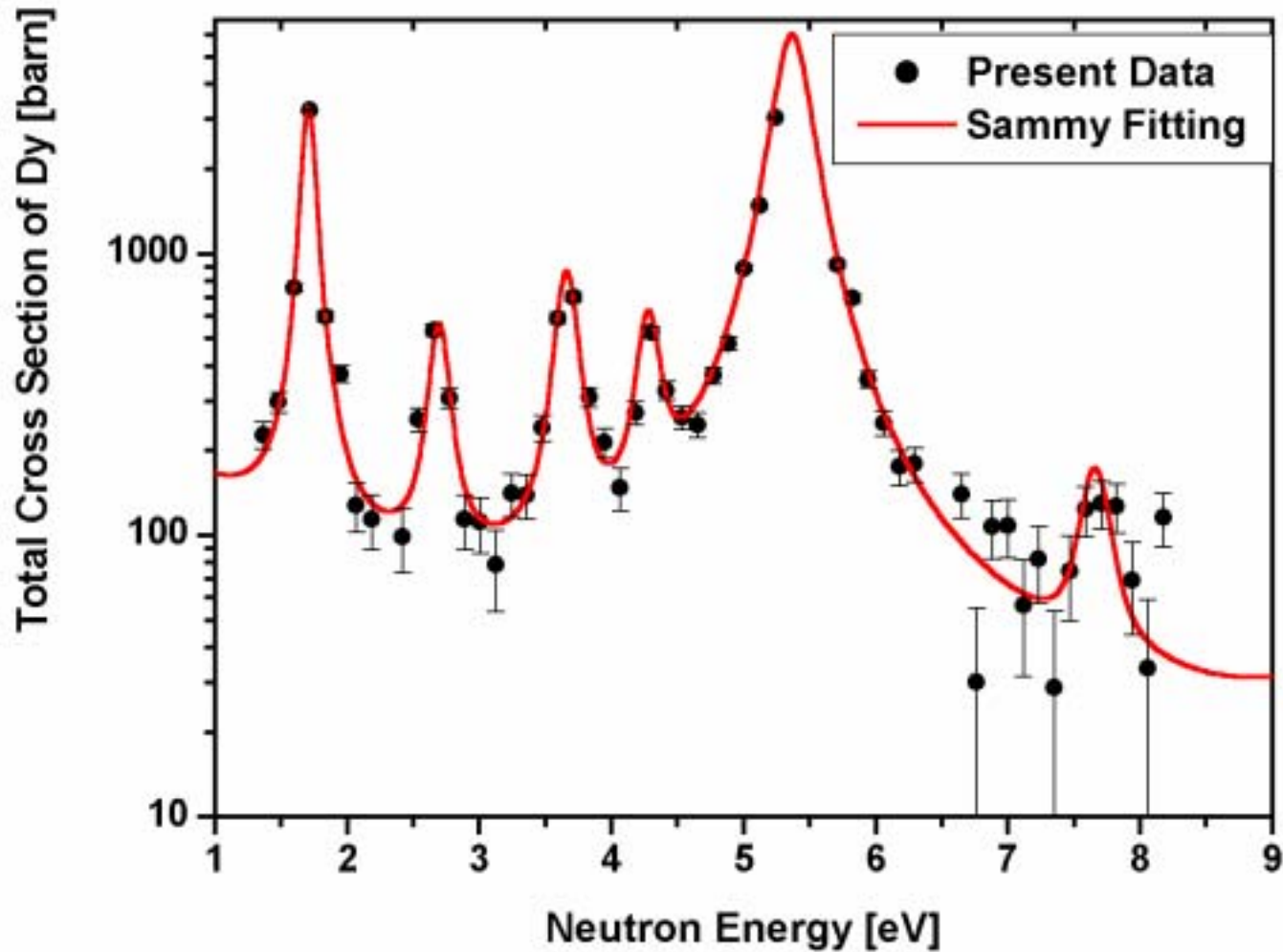
# Neutron TOF Spectra



# Measured Total Cross Sections of natural Dy



# Resonance Parameter Fitting



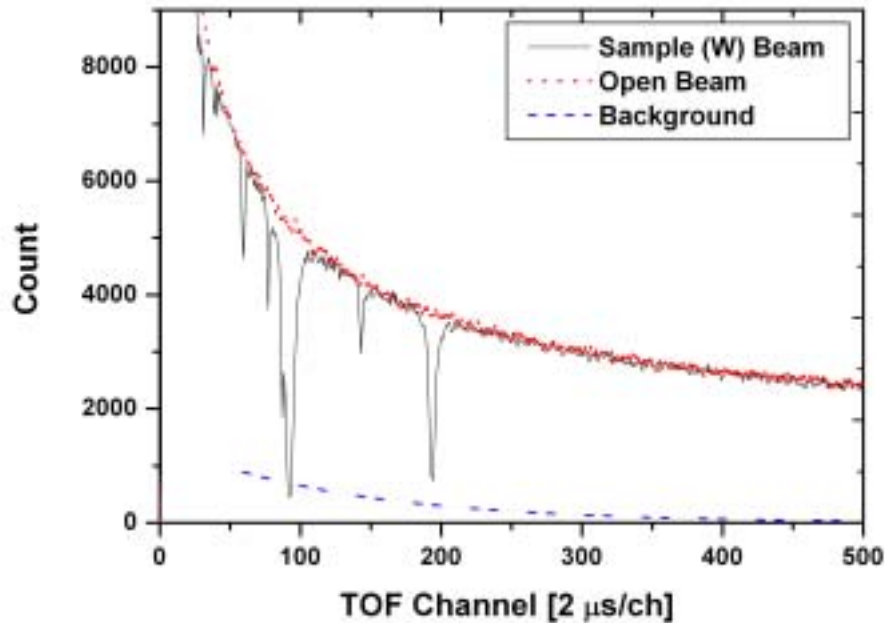


# Resonance Parameters for Dy isotopes

Isotope	J	E[eV]	$g_n$ [meV]	$\gamma$ [meV]
$^{163}\text{Dy}$	2	$1.7093 \pm 0.0007$ (1.713 ± 0.004)	$0.9344 \pm 0.0105$ (0.85 ± 0.05)	$91.574 \pm 0.827$ (102.6 ± 0.8)
$^{160}\text{Dy}$	1/2	$1.8871 \pm 0.0321$ (1.88)	$0.1394 \pm 0.0135$ (0.20)	$124.97 \pm 12.32$ (105.80)
$^{161}\text{Dy}$	3	$2.6979 \pm 0.0028$ (2.71 ± 0.02)	$0.3929 \pm 0.0122$ (0.328 ± 0.015)	$130.12 \pm 6.632$ (119 ± 10)
$^{161}\text{Dy}$	2	$3.6618 \pm 0.0025$ (3.68 ± 0.03)	$0.9524 \pm 0.0243$ (0.89 ± 0.04)	$139.14 \pm 6.087$ (124 ± 15)
$^{161}\text{Dy}$	2	$4.2810 \pm 0.0041$ (4.33 ± 0.02)	$0.6677 \pm 0.0273$ (0.575 ± 0.065)	$130.25 \pm 8.702$ (80 ± 3)
$^{162}\text{Dy}$	1/2	$5.3697 \pm 0.0022$ (5.44 ± 0.02)	$14.492 \pm 0.4007$ (21 ± 1.5)	$262.08 \pm 11.08$ (148 ± 15)
$^{163}\text{Dy}$	2	$5.8377 \pm 0.0775$ (5.81)	$0.0198 \pm 0.0017$ (0.0135)	$108.07 \pm 10.81$ (108.60)
$^{161}\text{Dy}$	3	$7.6632 \pm 0.0195$ (7.74)	$0.4284 \pm 0.0340$ (0.30)	$158.01 \pm 14.46$ (107.00)



# Neutron TOF Spectra for W and Ti



Physical parameter for W

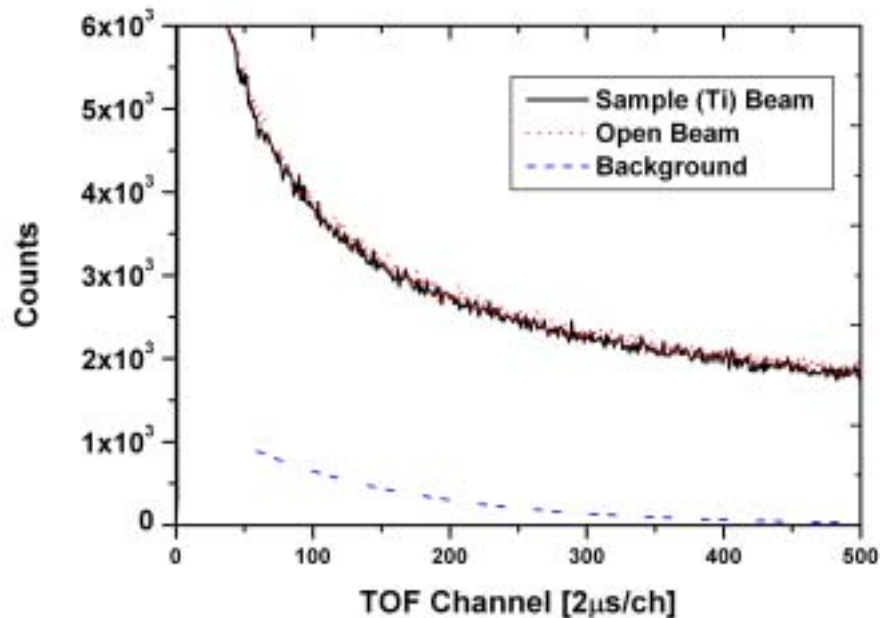
Purity : 99.98 %

Size: 10cm×10cm×0.2mm

Density : 19.3 g/cm<sup>3</sup>

Data Taking Time

Sample in/out : 48 hr



Physical parameter for Ti

Purity : 99.99 %

Size: 10cm×10cm×0.5mm

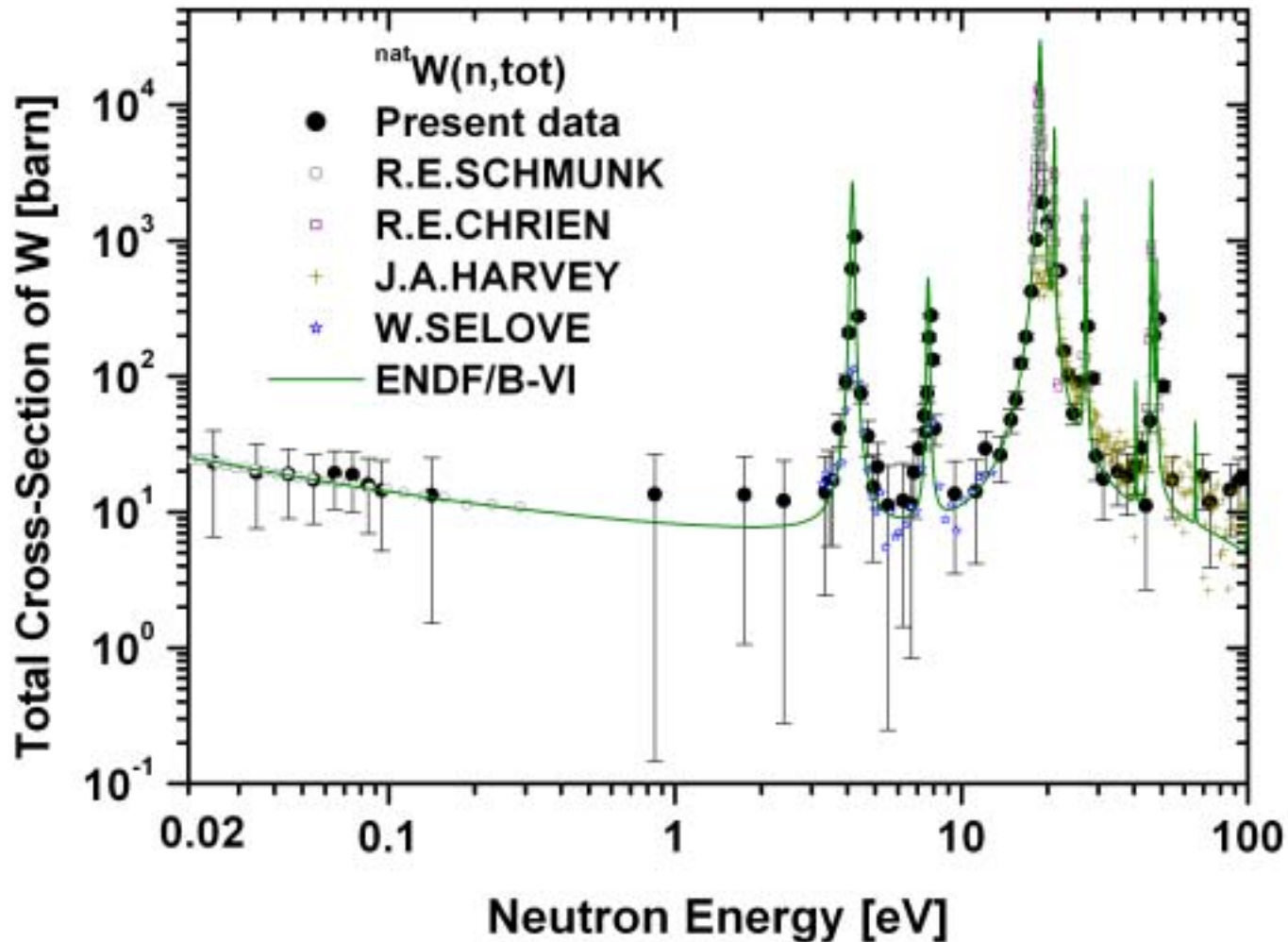
Density : 4.5 g/cm<sup>3</sup>

Data Taking Time

Sample in/out : 43 hr



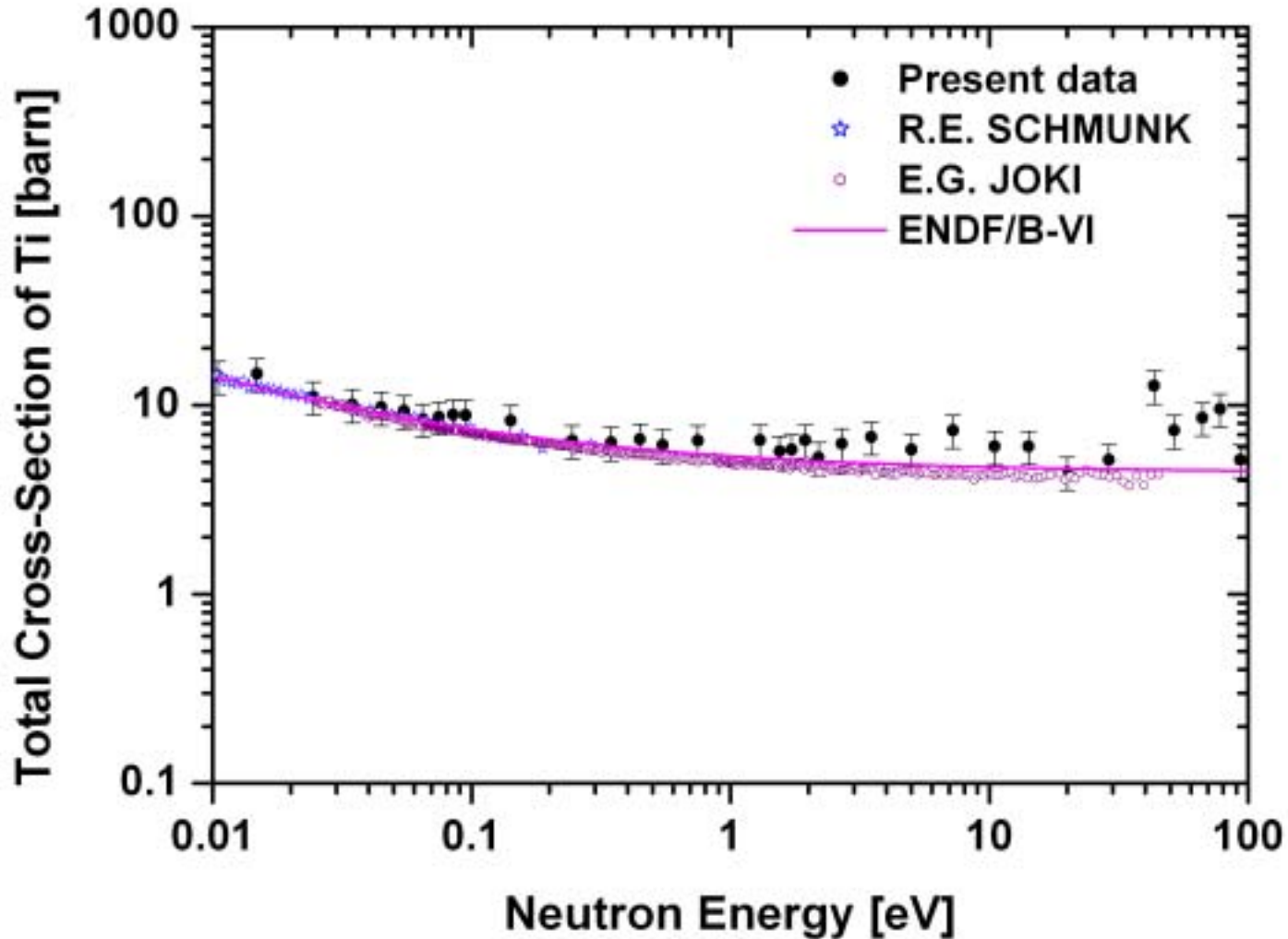
# Measured Total Cross Sections of natural W



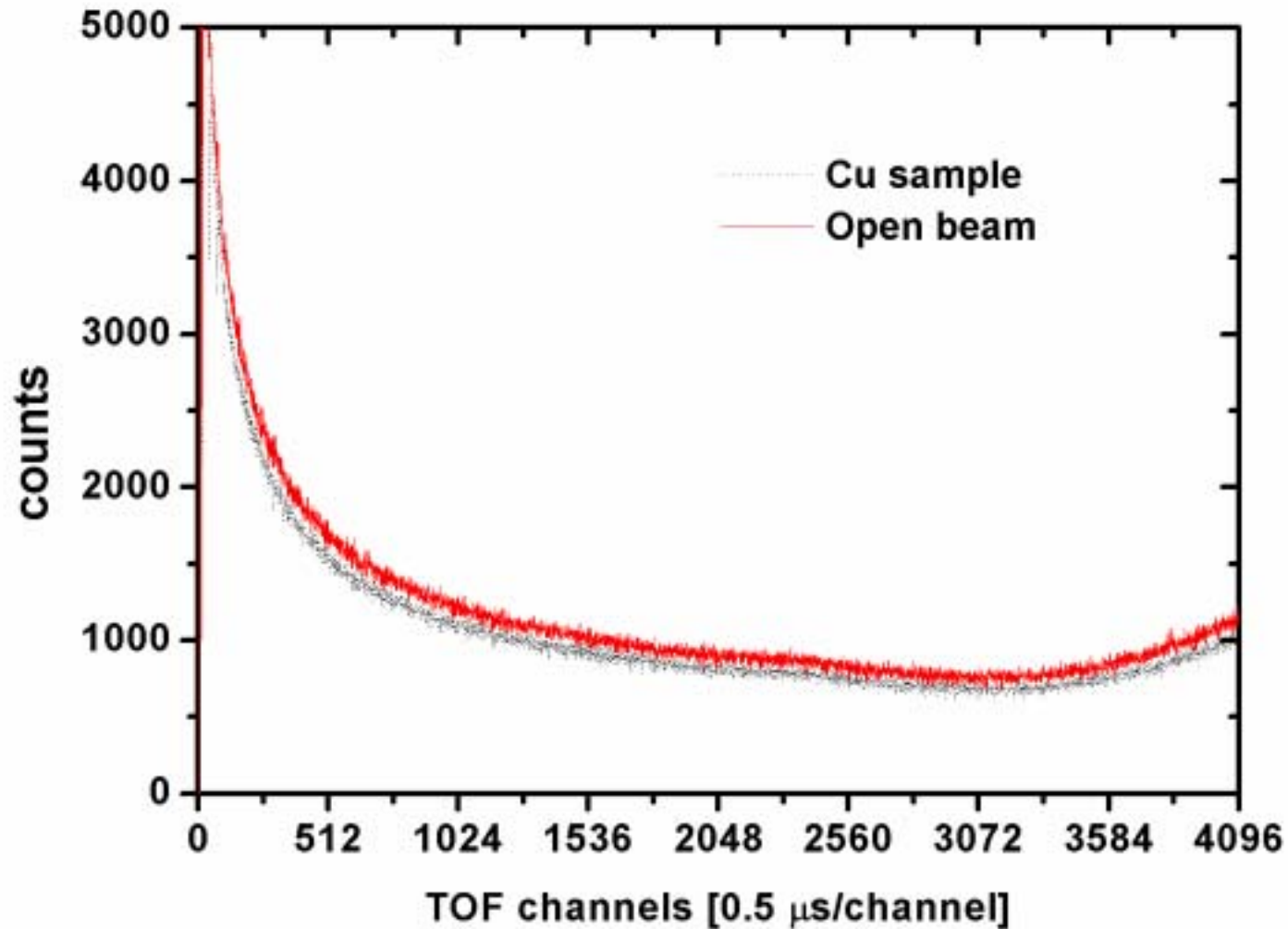




# Measured Total Cross Sections of natural Ti

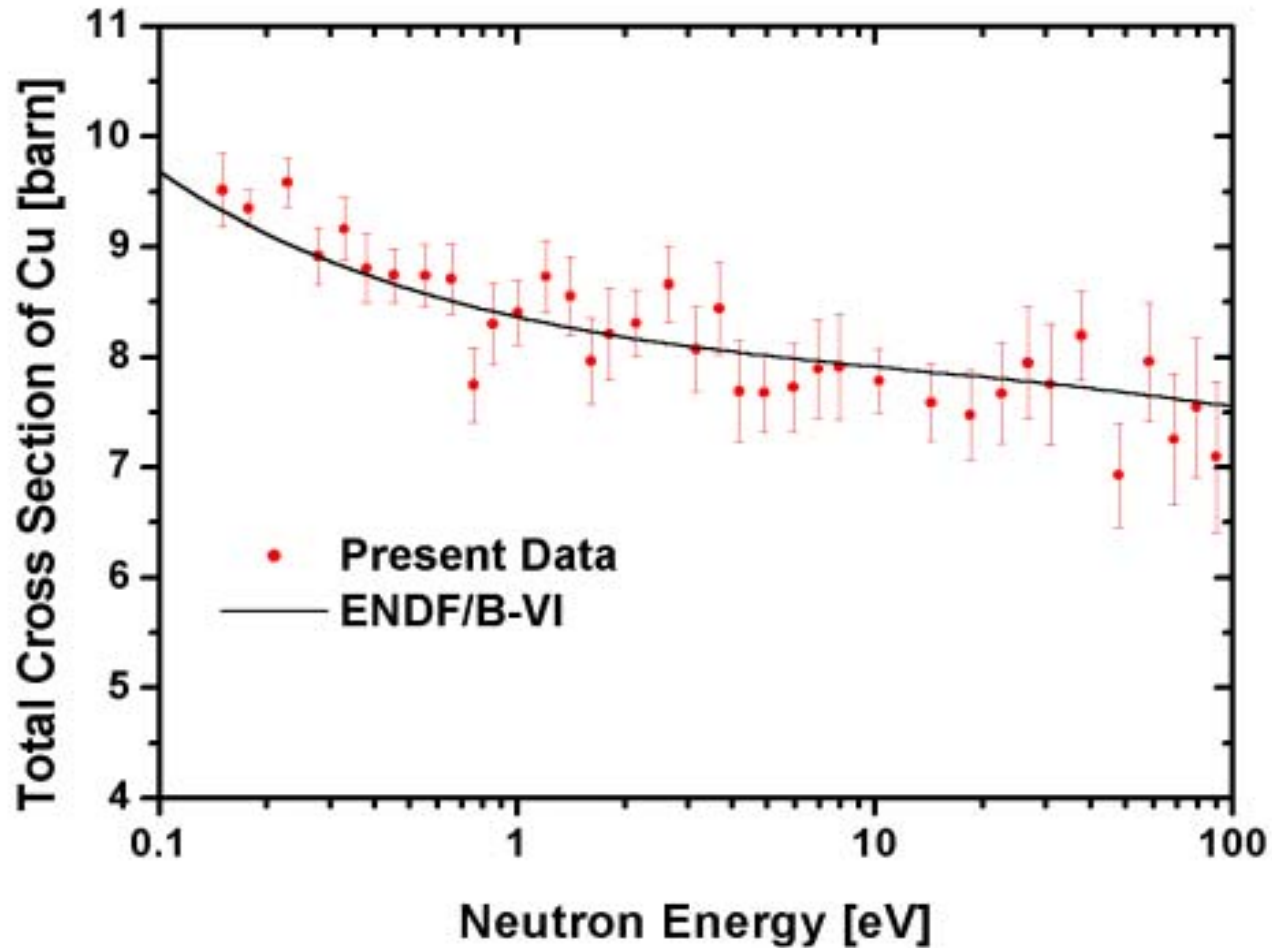


# Measured TOF Spectra of natural Cu





# Measured Total Cross Sections of natural Cu





# Summary and Discussion

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- **Pohang Neutron Facility is a pulsed neutron facility :**
  - **Operating for Total Cross Section Measurement**
    - 12 m TOF path length
    - Automatic Sample Changer
    - Neutron-Gamma Separation Electronics
    - CAMAC based Data Acquisition System
  - **Resonance Parameter Fitting is going on**
  - **Open for users in Domestic and Foreign Country**
    - Vietnam, China, India, Poland, Russia
    - KAERI
- **6<sup>th</sup> Workshop on Nuclear Data Production and Evaluation was held on Aug. 28-29 at Pohang Accelerator Laboratory, Pohang**  
(see <http://charm.postech.ac.kr/> )