The Secondary Neutron Emission Double-differential Cross Section Measurements at CIAE

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Outline

- Introduction
- Experimental facilities and techniques developed at CIAE
- DDX measurements accomplished at CIAE
- Summary and outlook

1. Introduction

1. DDX data is important in

   Neutron shielding
   Data evaluation
   Model verification…

2. Few measured data available, especially at the energy region between 8 and 14 MeV and above 20 MeV

The aim of this work

1. Enrich the measured data, fill up the data blankness in 8---14 MeV region and above 20 MeV

2. Checking and improving model calculation and evaluation

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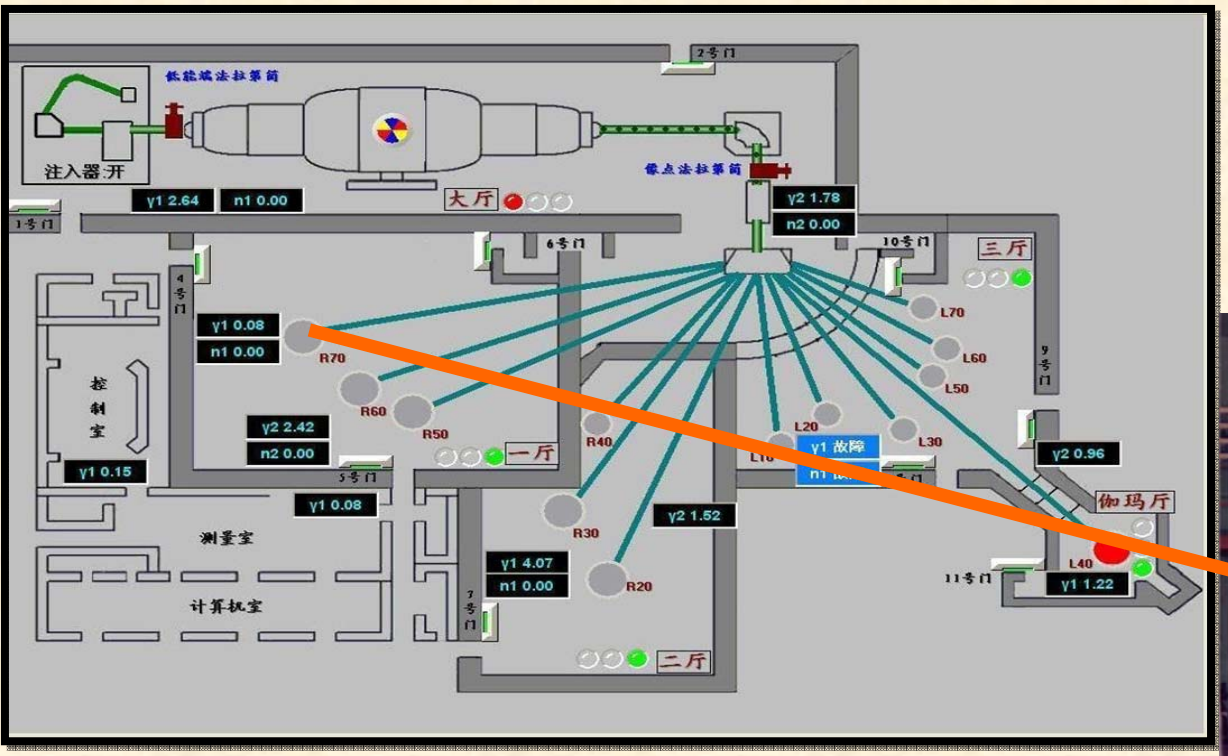
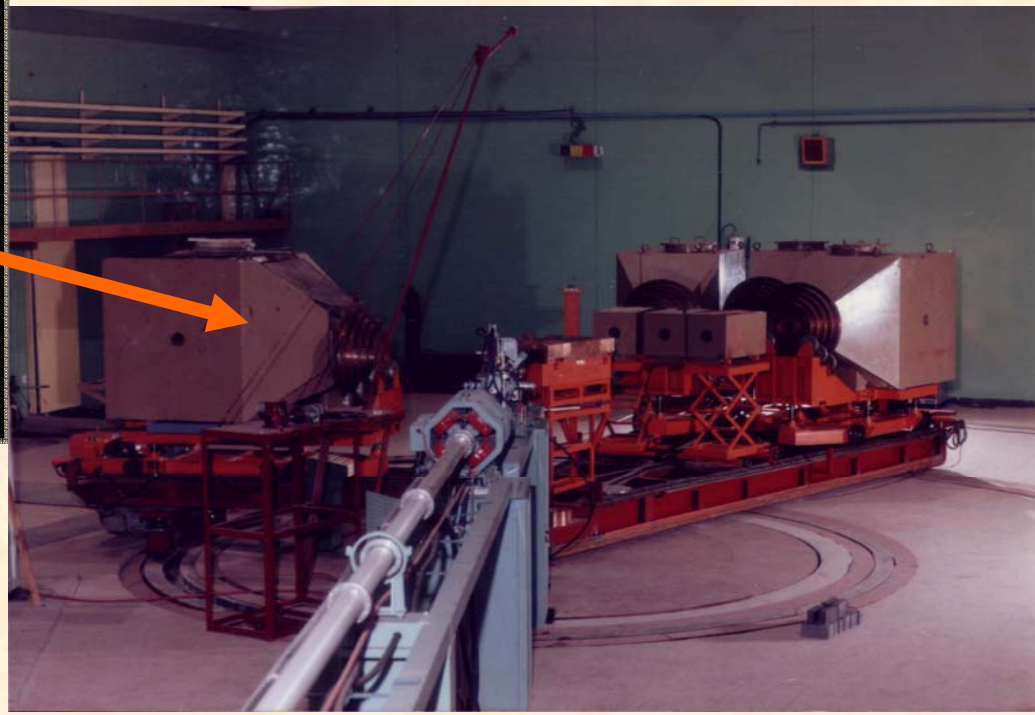
2. Experimental facilities at CIAE



HI-13 Tandem accelerator

TOF spectrometer



The neutron source

5—40 MeV neutrons by p-T, d-T and d-D reactions.
Pulsed and continuous available.

Deuterium and tritium gas target were employed.

Tritium gas target

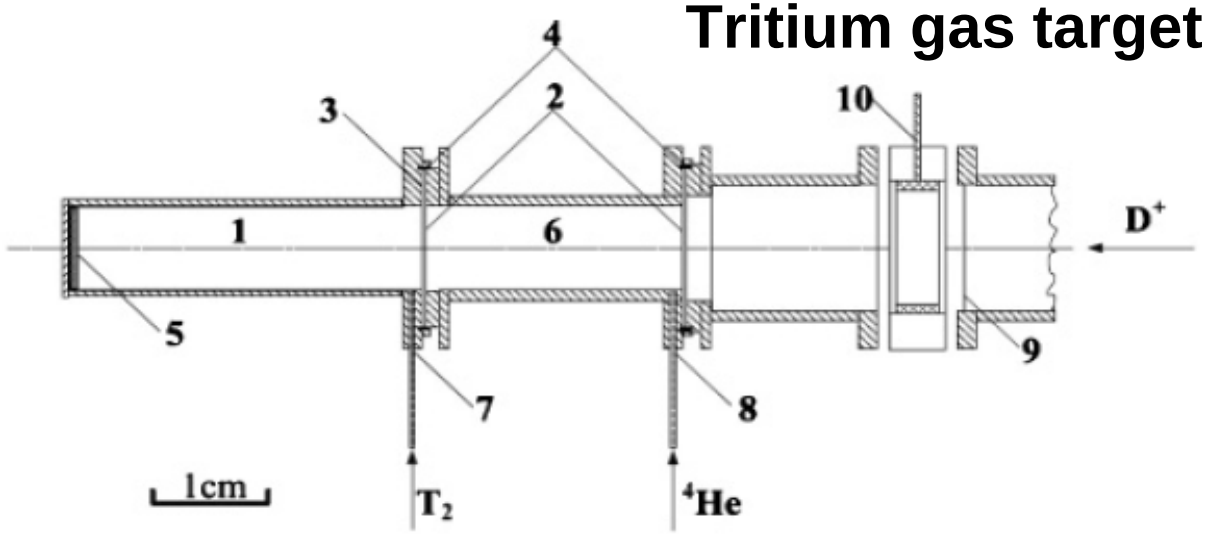
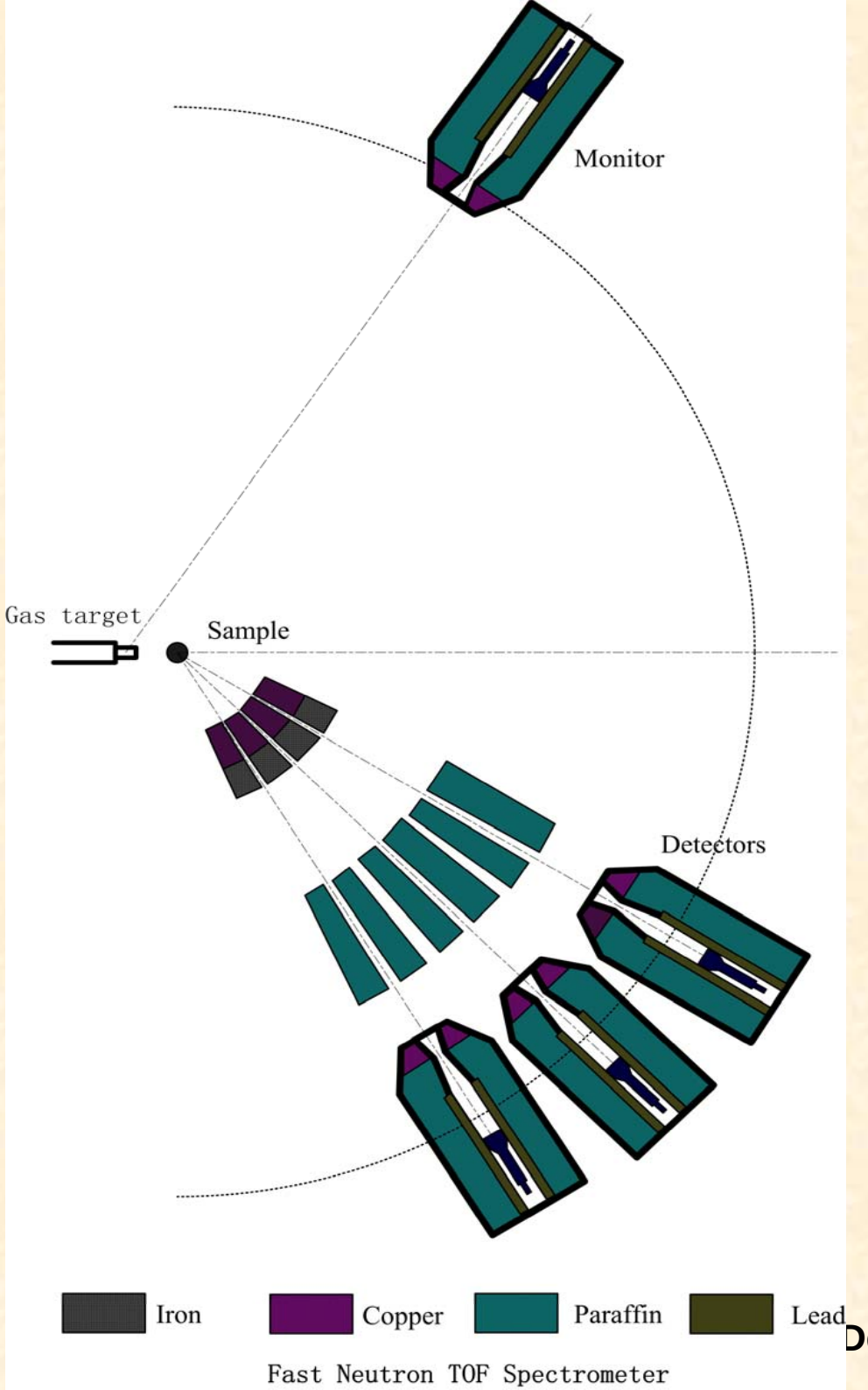


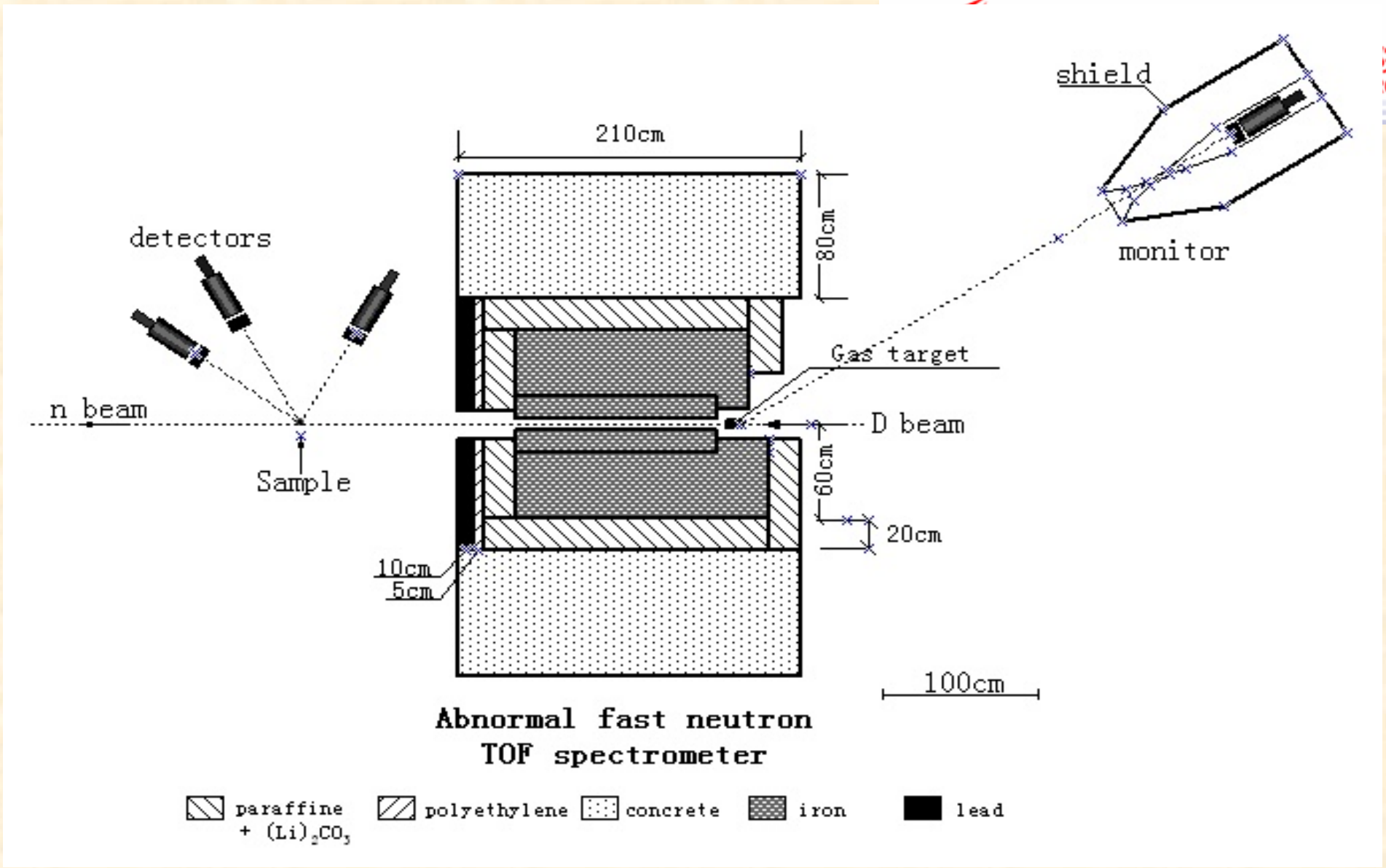
FIG. 2. Cross-section view of the tritium gas cell system. The labels indicate (1) tritium gas cell, (2) Mo foil, (3) indium O-ring, (4) rubber O-ring, (5) gold beam stop, (6) ^{4}He gas cell, (7) tritium gas tube, (8) ^{4}He gas tube, (9) Ta diaphram, and (10) electron suppressor.

Deuterium gas target is similar, but without helium gas cell.

Multi-detector Fast Neutron TOF spectrometer at CIAE



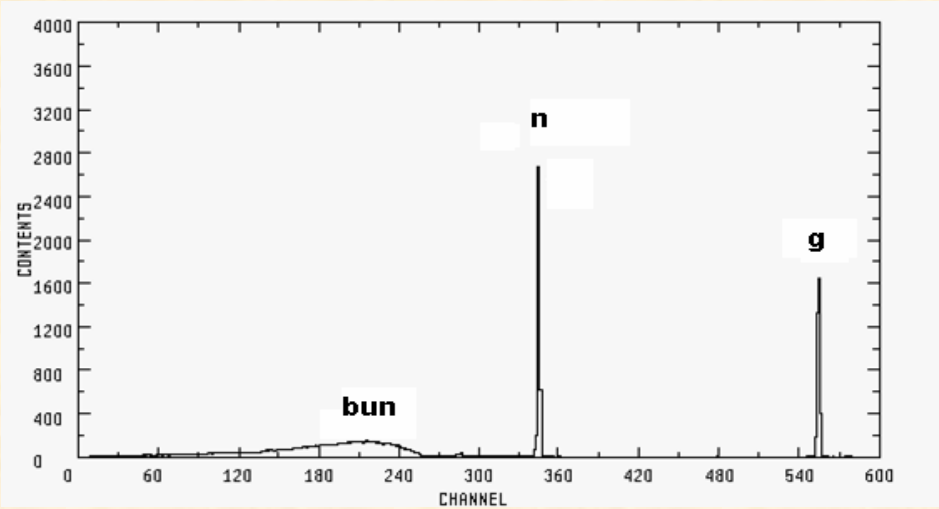
- 3 BC501A neutron detectors (Φ180 $\times$100 mm)
- One stilbene monitor (Φ30 $\times$30 mm)
- Flight path: about 6 m
- Detection angle: 15-155 deg.
- Threshold: about 1.5 MeV neutron
- Normalization: n-p scattering

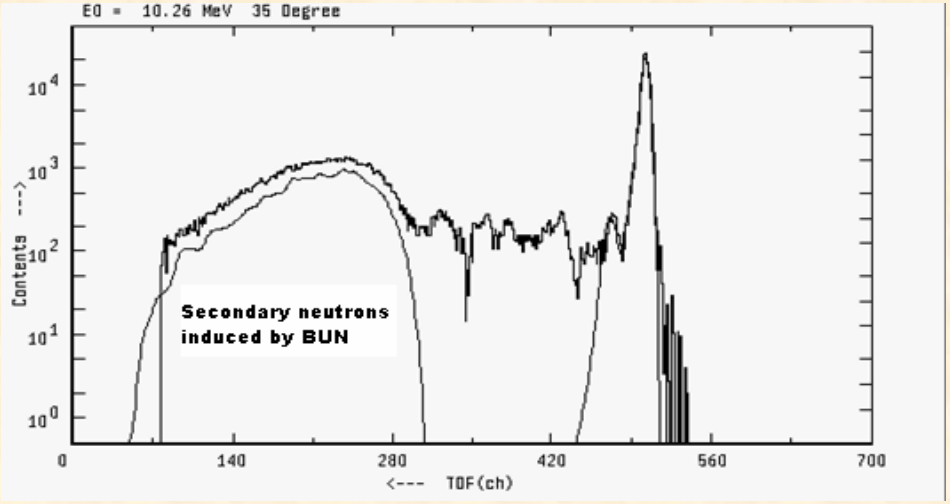


An abnormal TOF spectrometer was developed to eliminate the influence from breakup source neutrons at 8-14 MeV region

Difficulties for DDX measurement at 8 --- 14 MeV

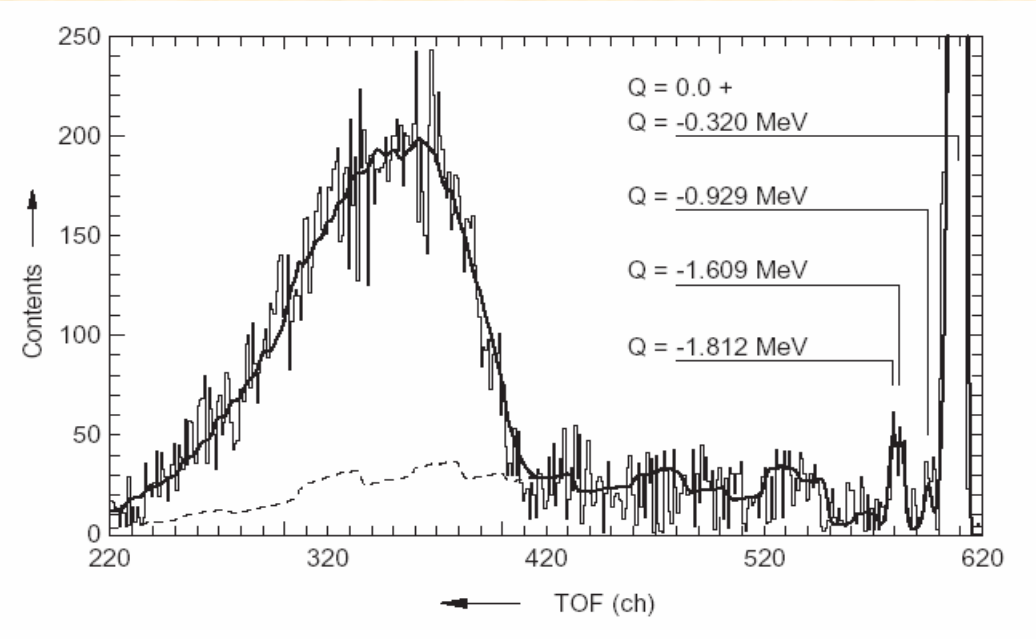
- The commonly used sources in this energy region (d-D, p-T) are not mono-energetic.
- The low energy part of the measured DDX will be contaminated by the neutrons induced by breakup neutrons.





Methods used to solve this problem

1. Use H(t,n) source, LANL
   (D.M.Drake et al., Nucl. Sci. and Engineering, 63 (1977) 401)
2. Monte-Carlo method to correct the data, PTB (Nucl. Instr. and Meth. in Phys. Research A 545 (2005) 658–682)
3. Abnormal TOF spectrometer, CIAE



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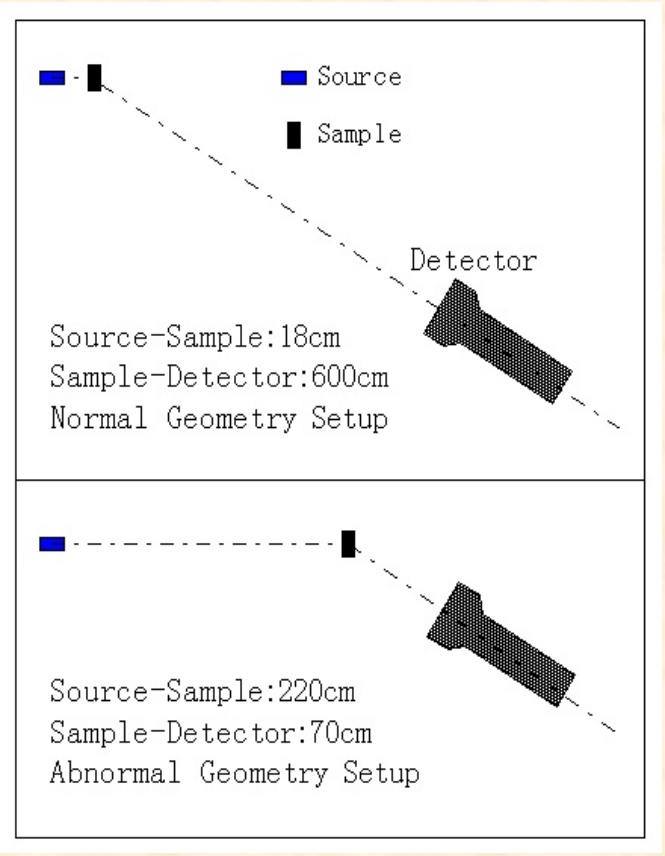
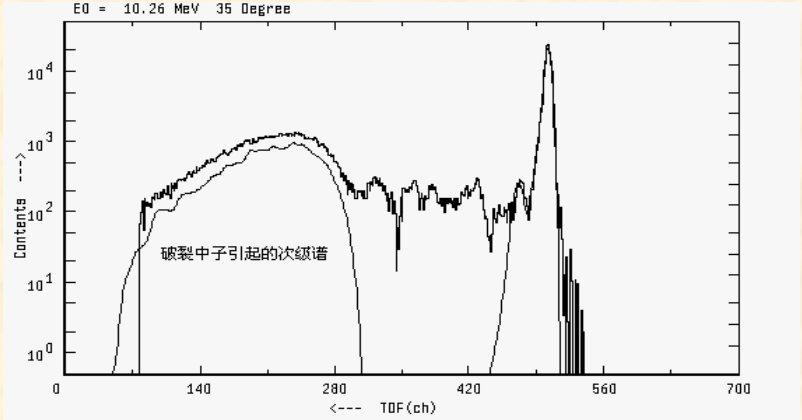
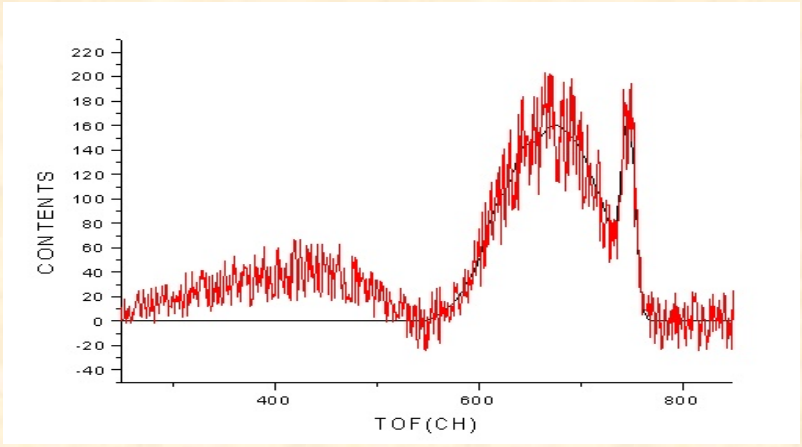
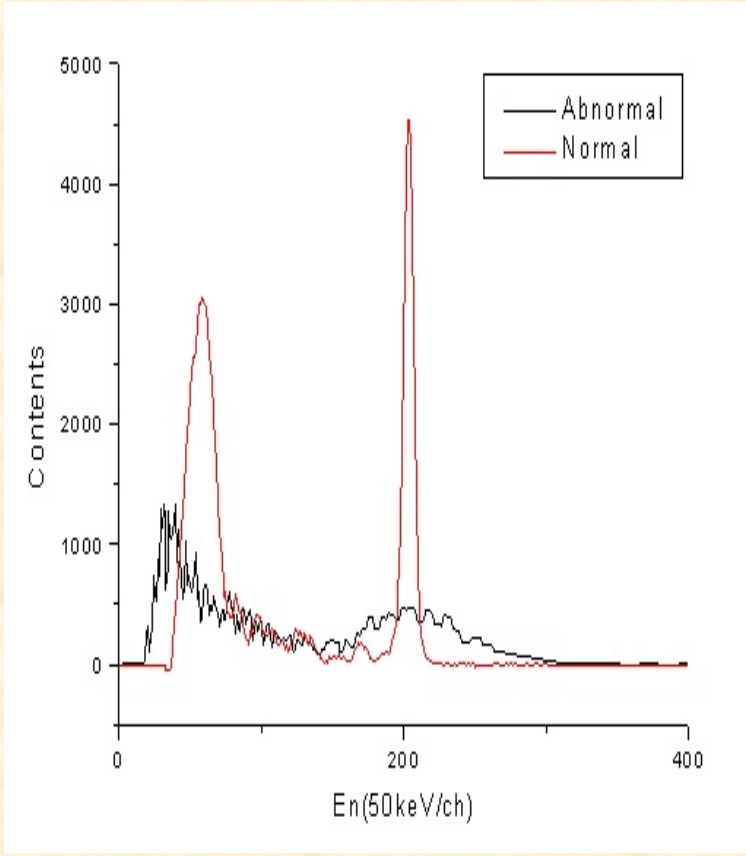




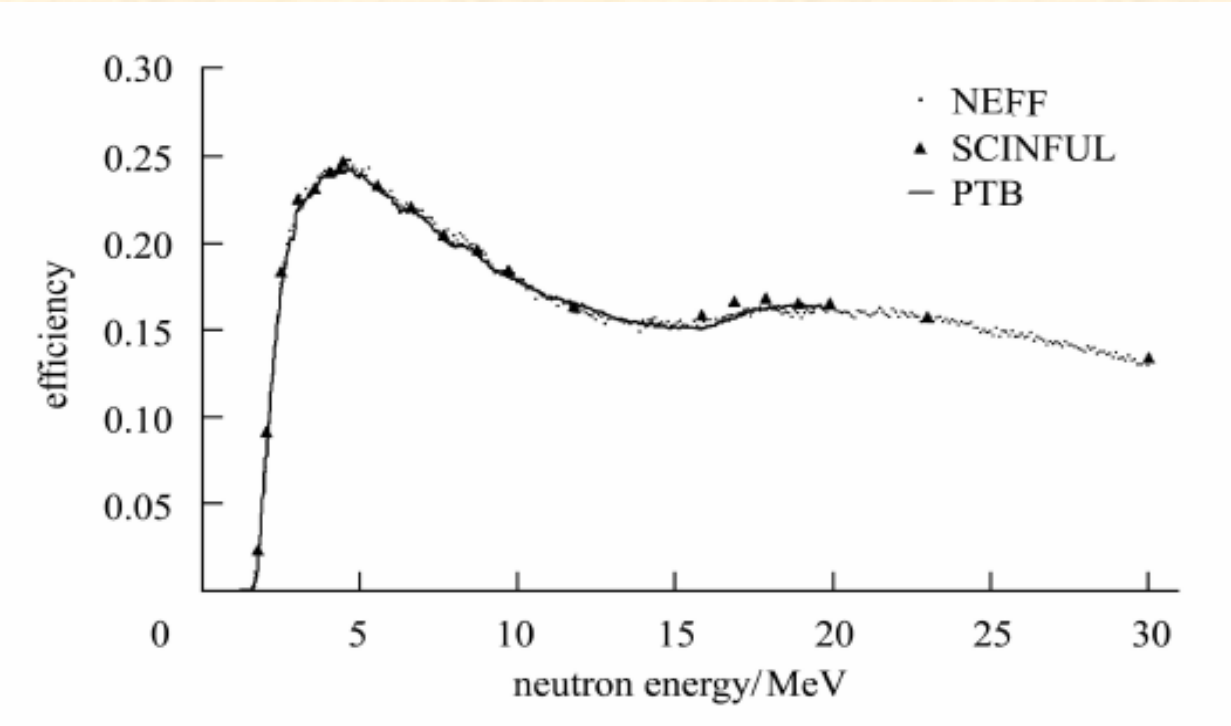


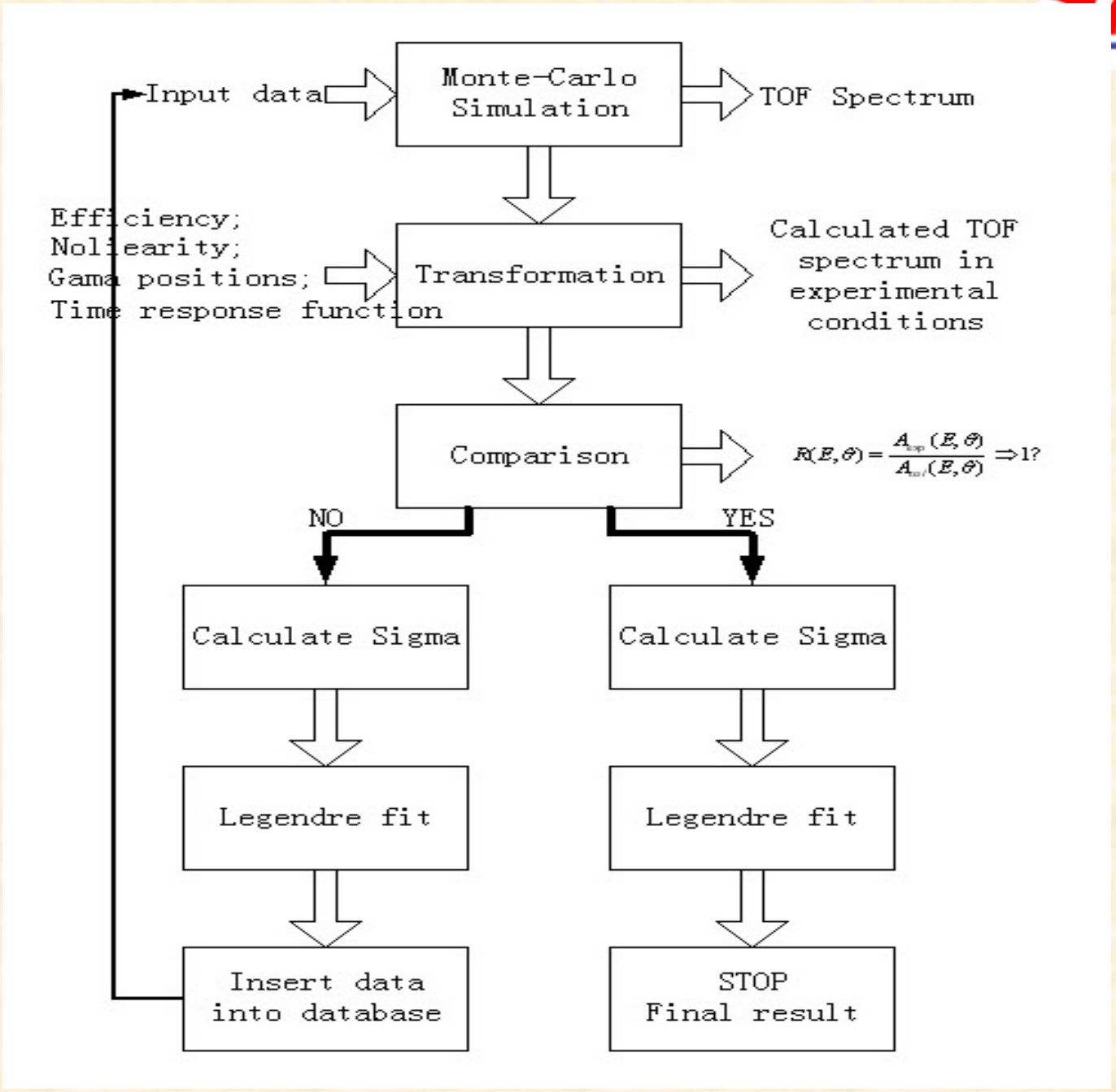


Principle of normal and abnormal TOF method in CIAE

The detection efficiency

1. Light output function has been calibrated in the neutron energy range 1 – 30 MeV.
2. The neutron response and detection efficiency were simulated by the NRESP50 and Scinful codes.
3. Corrections of the efficiency have been made via comparing the measured and calculated response spectra.
4. The uncertainty of the efficiency: about 3% (2 – 30 MeV)

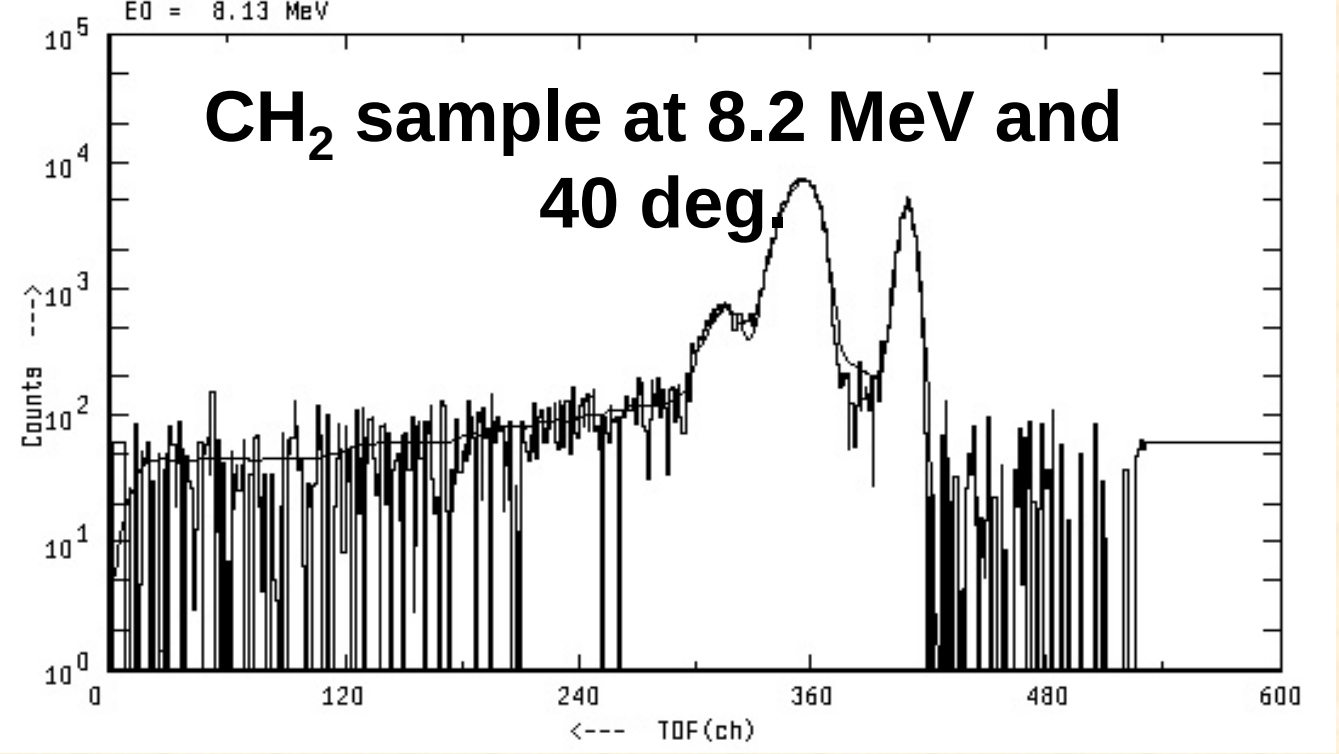




Data analysis

A realistic MC simulation procedure was used to correct the measured data.

The simulated TOF spectra can be directly compared with the measured ones.



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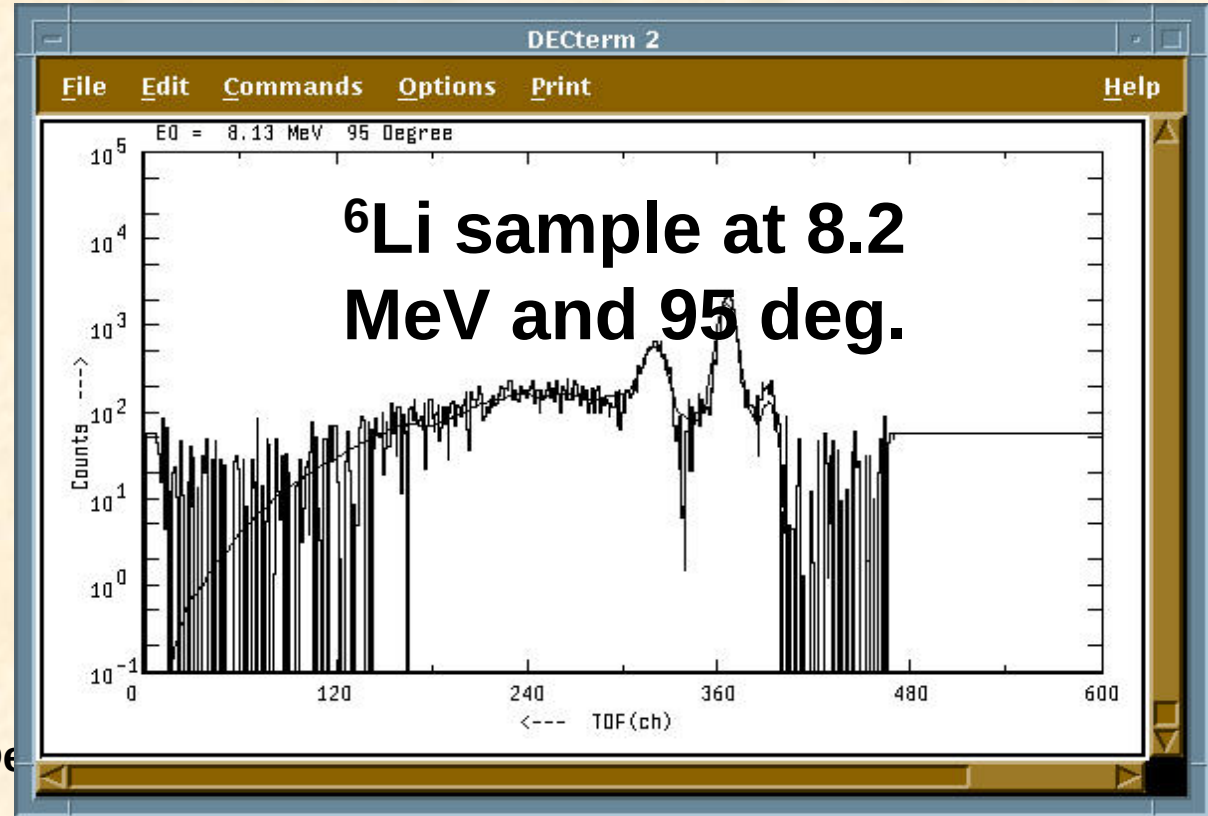
Comparison of simulated and measured TOF spectra



3. DDX measurements accomplished at CIAE

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Energy	Sample
8 MeV	^{6,7}Li、Fe、Be
10 MeV	^{6,7}Li、Be、V、^{238}U、^{209}Bi、Fe
20-30 MeV	Be(22 and 25 MeV)

The following shows some examples:

^{51}V at 10 MeV

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The neutron emission spectrum

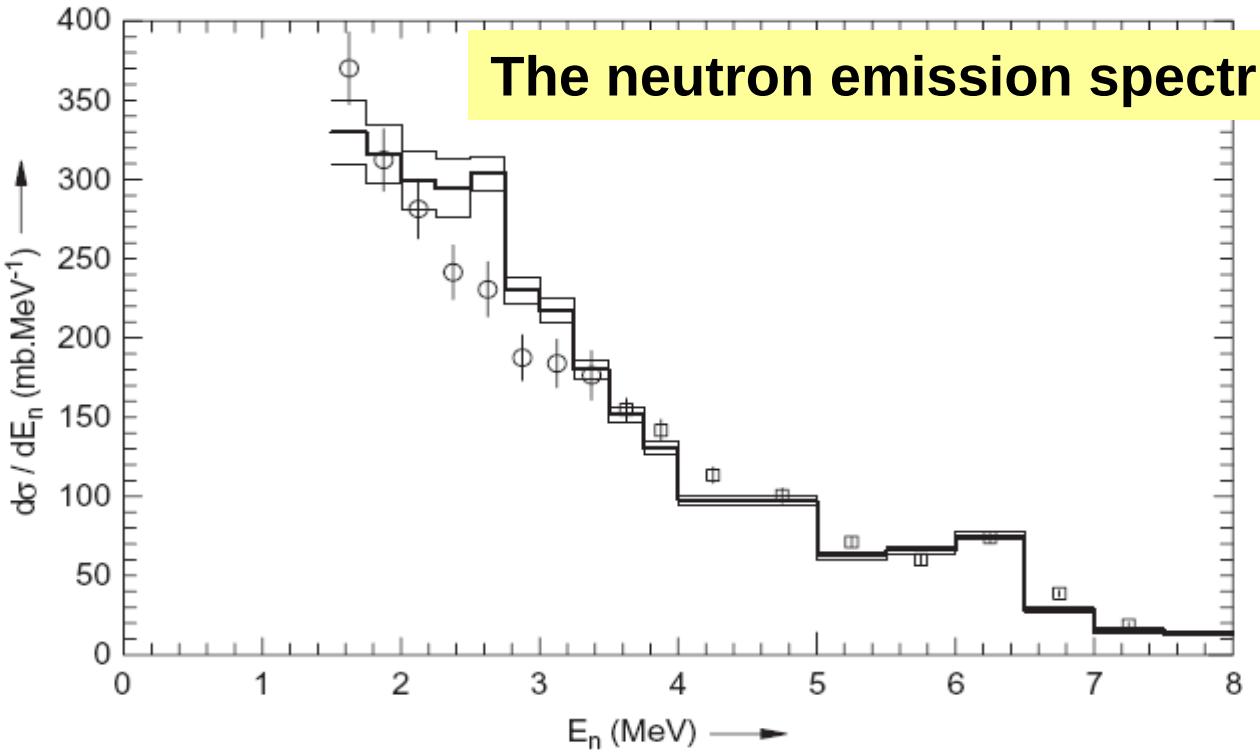


Fig. 22. Comparison of angle-integrated DDX (emission spectra) of vanadium measured at PTB (histogram, $E_0 = 10.21$ MeV; thick lines: DDX, thin lines: uncertainty band) and at CIAE (squares: normal geometry, circles: abnormal geometry, $E_0 = 10.26$ MeV; group data plotted as point-like data for better visibility).

Detailed comparison of Vanadium data at 10 MeV obtained with this method with the data measured at PTB

The determined DDX data

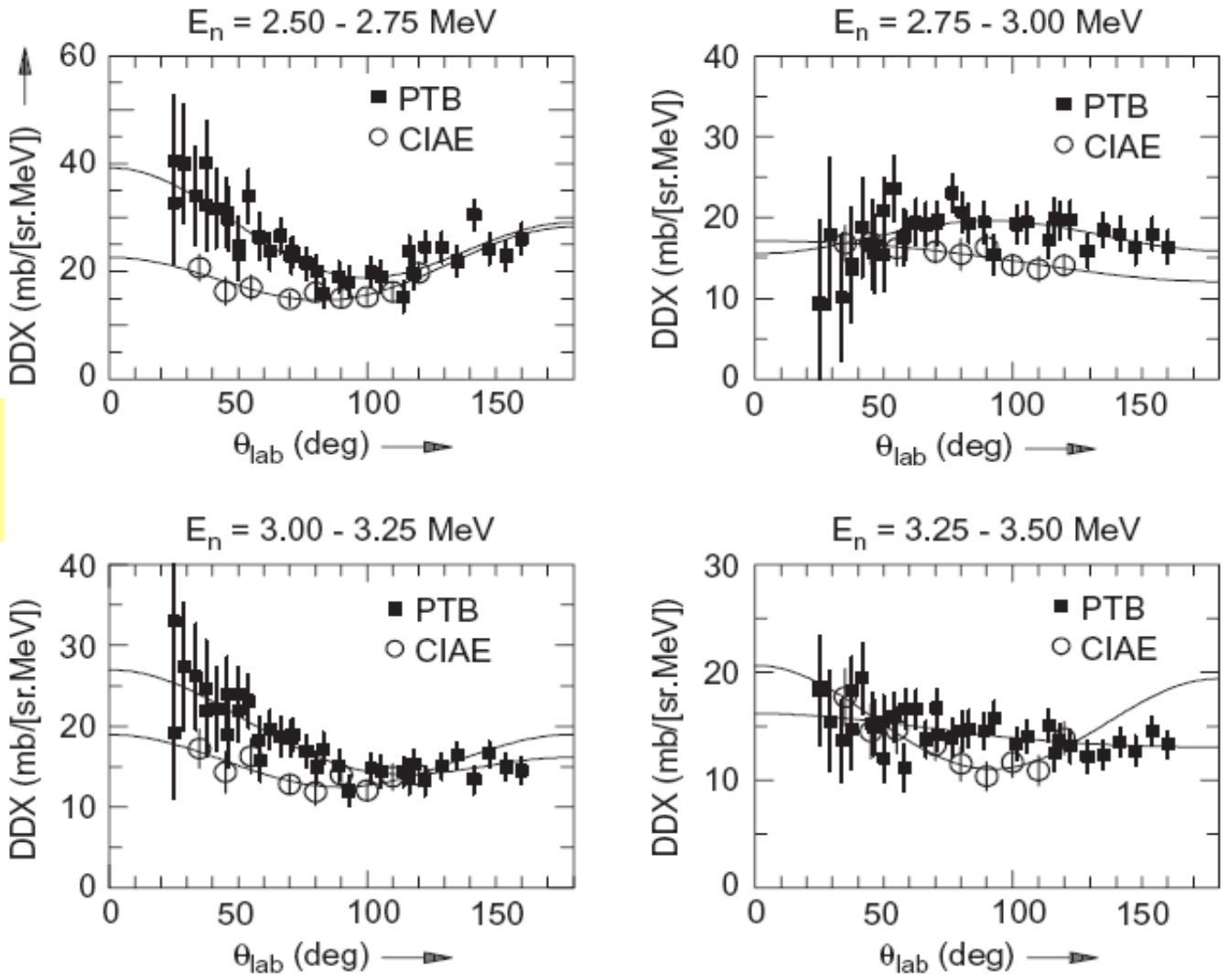


Fig. 23. DDX of vanadium measured at PTB (full squares, $E_0 = 10.21$ MeV) and at CIAE (open circles, $E_0 = 10.26$ MeV) for different intervals of emission energy E_n; the curves are fitted Legendre polynomial expansions.

Detailed comparison of Vanadium data at 10 MeV obtained with this method with the data measured at PTB

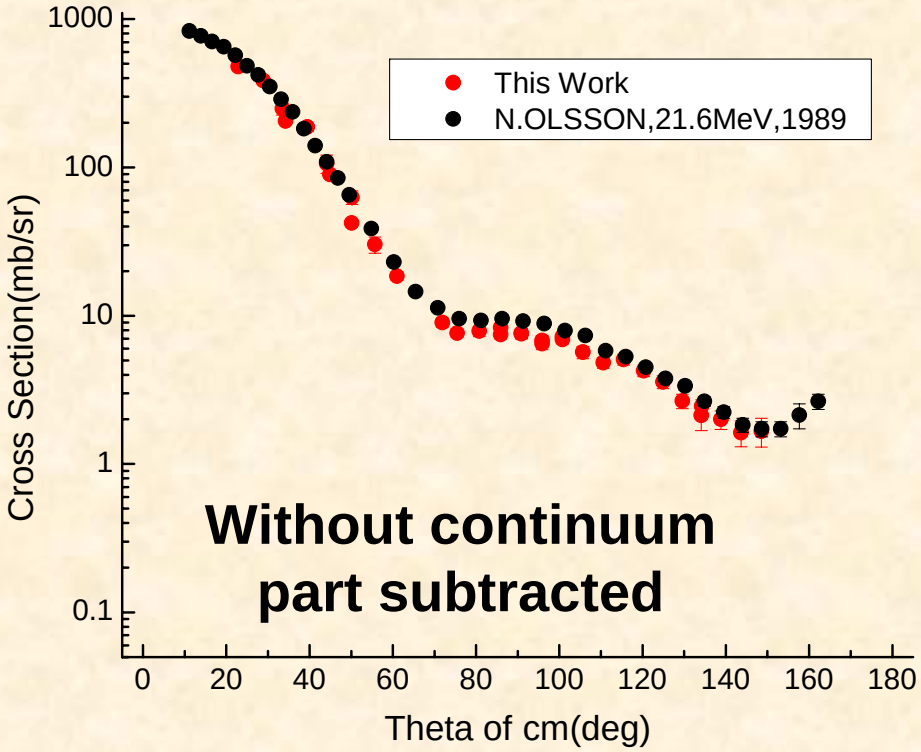
Detailed description and comparison of the CIAE method and PTB method are summarised in:

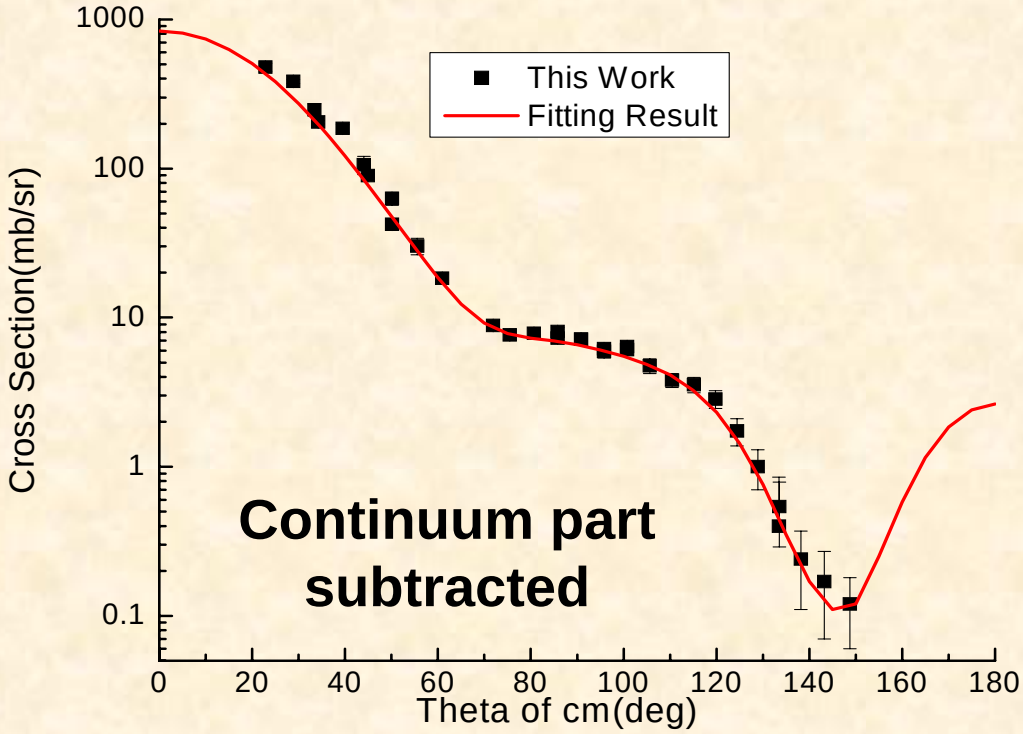
Nuclear Instruments and Methods in Physics Research A 545 (2005) 658–682

Such comparison is useful to tell us what is advantage and disadvantage for the two complete different methods and to give hints of how to improve the methods.

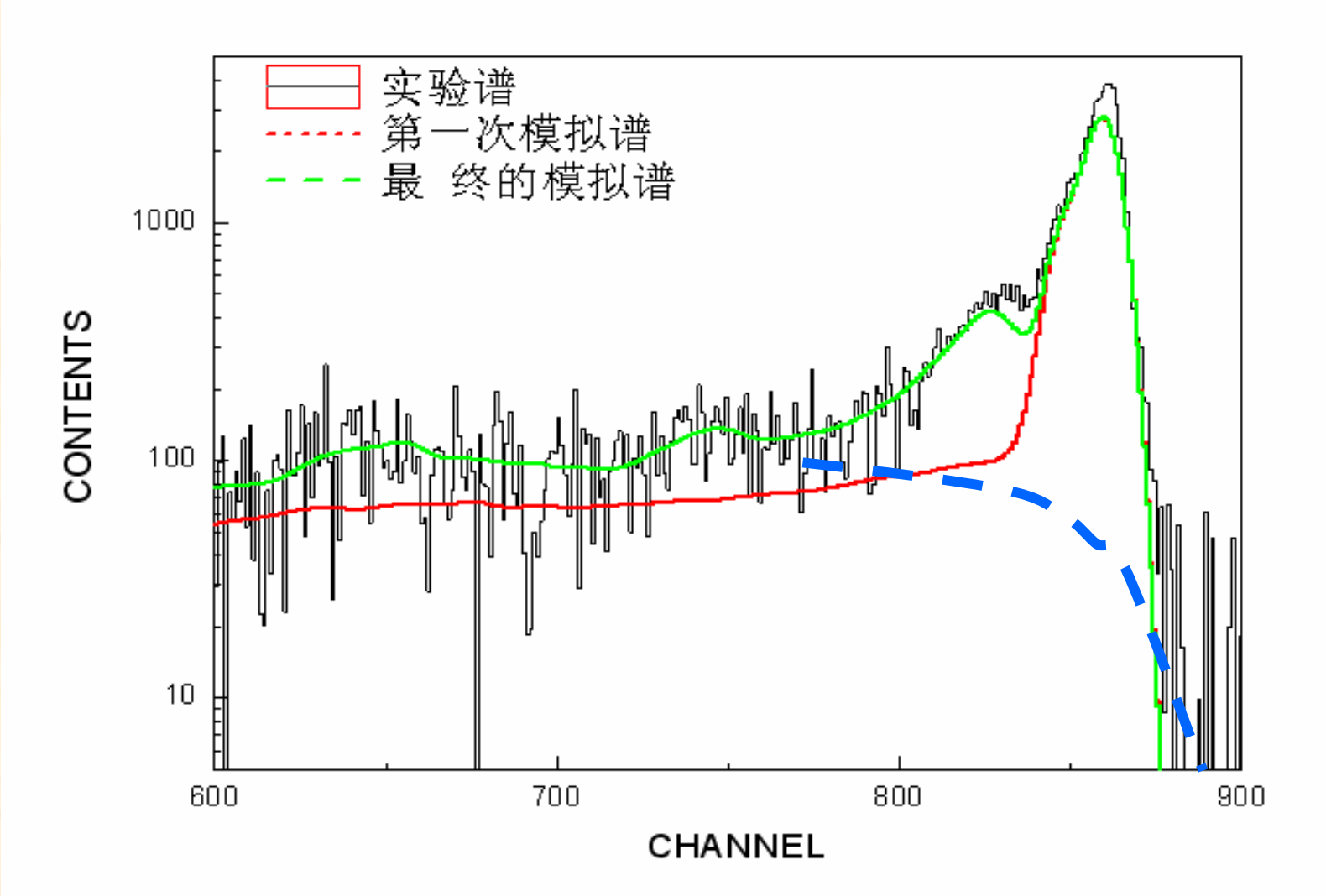
Be at 22 MeV

Elastic DX data at 21.94MeV



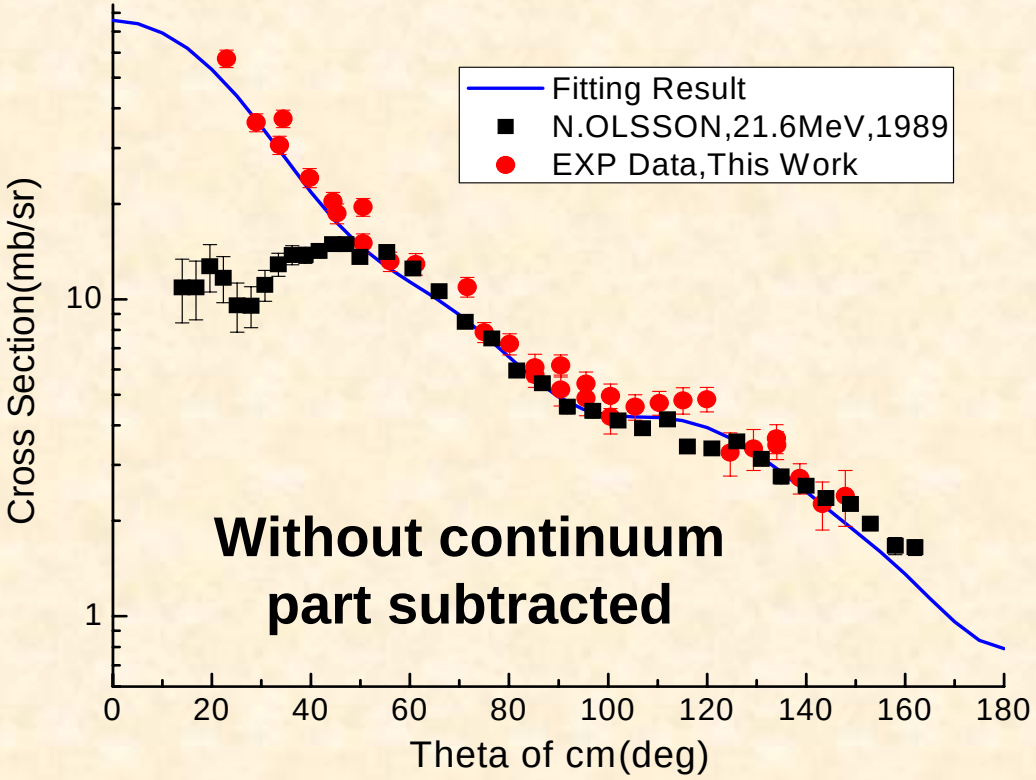


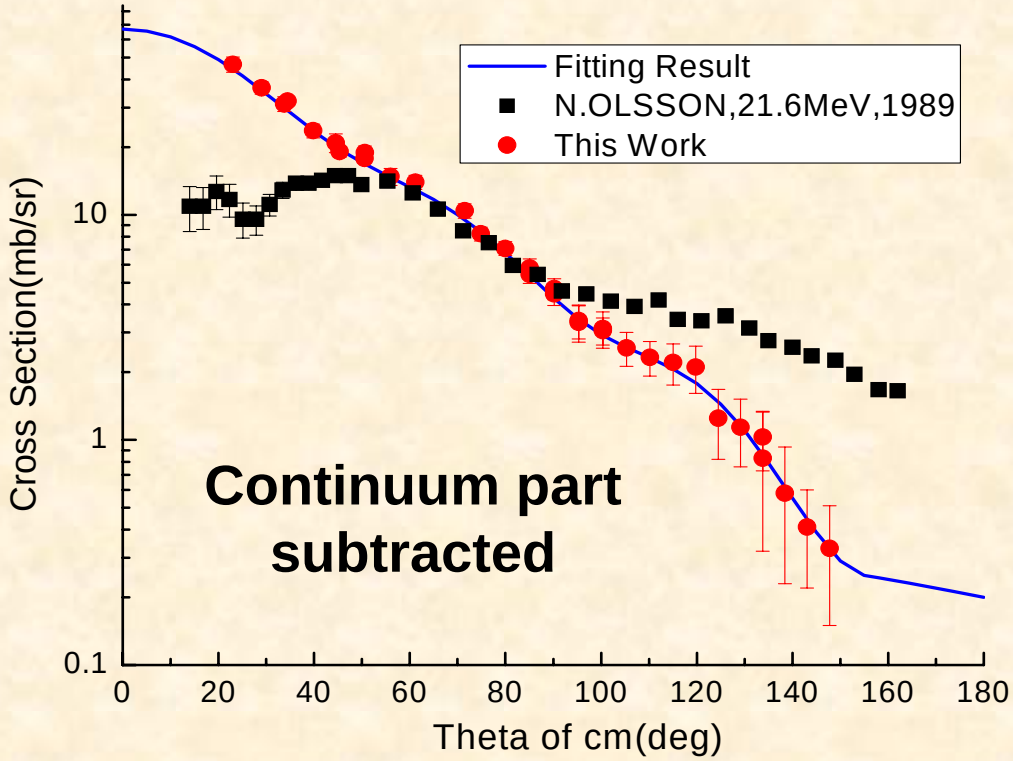
1. **In general good agreement with N.OLSSON's data, indicate that their data are also contaminated with continuum part.**
2. **Subtract the continuum part correctly is difficult, in this work the theoretical calculation was used. The DX data at large angle will be influenced greatly.**



The elastic peak is overlap with the continuum spectrum

The 1st inelastic DX data at 21.94MeV

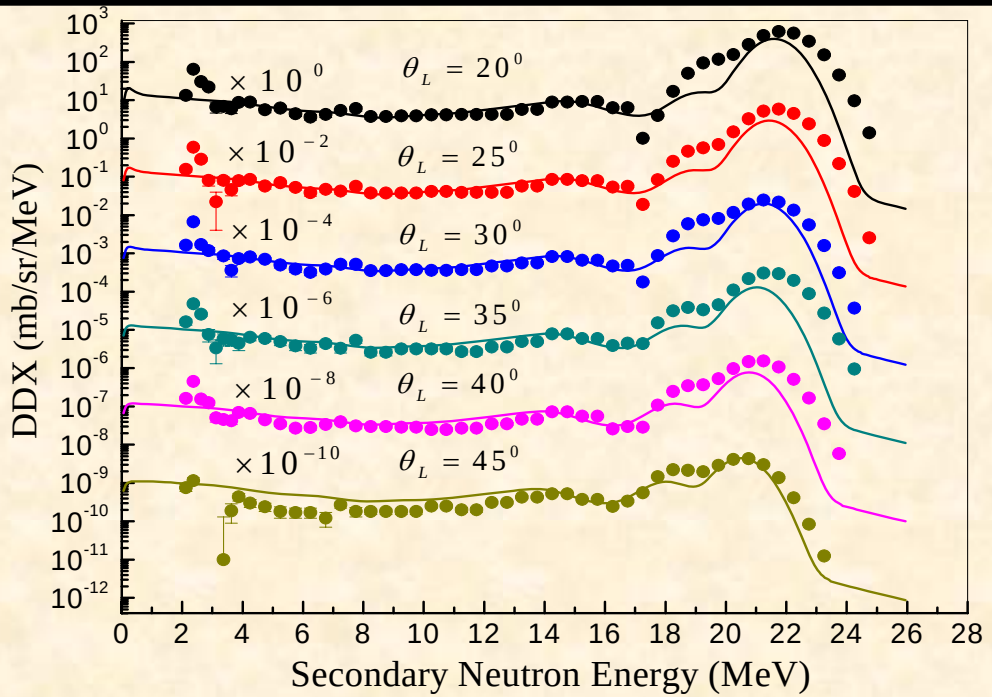


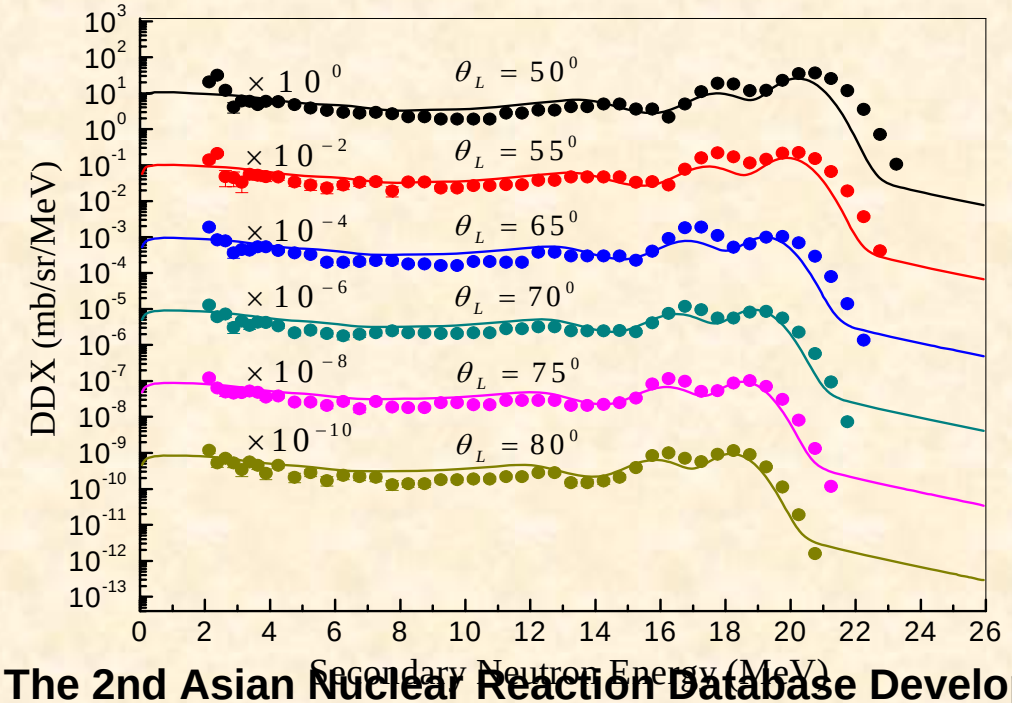


Again, the continuum data will influence the shape and the value of the determined data.

Lower cross section at small angles of N.OLSSON's data seems not reasonable, may be caused by the handling procedure due to bad energy resolution at small angles.

DDX data at 21.94MeV, compared with the LUNF calculation





In general, the agreement is fine.

The measured data at continuum part are more forward angled

The main publications and references list

- Application of Non-monoenergetic Sources in Fast Neutron Scattering Measurements. Dankwart Schmidt, Zhou Zuying, Ruan Xichao, Tang Hongqing, Qi Bujia, Xia Haihong, Deng Jianrong. NIM A545(2005)658-682
- Measurements of Neutron Emission Spectra for Neutron Induced Reactions on 9Be and 6,7Li. RUAN Xi-chao, ZHOU Zu-ying, CHEN Guo-chang et al. High Energy Phys. and Nucl. Phys. V31-5(2007)442
- Double-Differential Neutron Emission Cross-Section Measurements of 6Li and 7Li at Incident Neutron Energies of 8.17 and 10.27 MeV. Guochang Chen, Xichao Ruan, Zuying Zhou et al. NUCLEAR SCIENCE AND ENGINEERING: 163, 272–284 (2009)
- Measurement of the Secondary Neutron Emission Differential and Double-Differential Cross Sections Between 20 and 30 MeV, X.C.Ruan, G.C.Chen, C.L.Lan et al. Journal of Korean Physical Society, Volume: 59, Number: 23, Page: 1729 - 1732.

4. Summary and outlook

1. In the past 15 years, large amount of DDX data at 8-14 MeV and 20-30 MeV were measured at CIAE. Using the neutron source developed, combined with the Normal and Abnormal TOF spectrometers.
2. The usage of the Abnormal TOF spectrometer eliminate the influence from breakup source neutrons on DDX data successfully.
3. These data Enrich the experimental data set.
4. The measurements will be continued, especially on light nuclei.

thanks