

Benchmark experiment on iron with D-T neutrons at CIAE

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Experimental Arrangement



How is it done:

1. Use a D-T neutron beam with a TOF setup
2. Position sample to change different measured angles
3. Compare the measurements to detailed simulations

Measuring Angle : 60° and 120° ;

Flight Distance: about 8m

Pulse Width: $< 2\text{ns}$;

Neutron Detector: BC501A($\phi 2 \times 1$ inch)

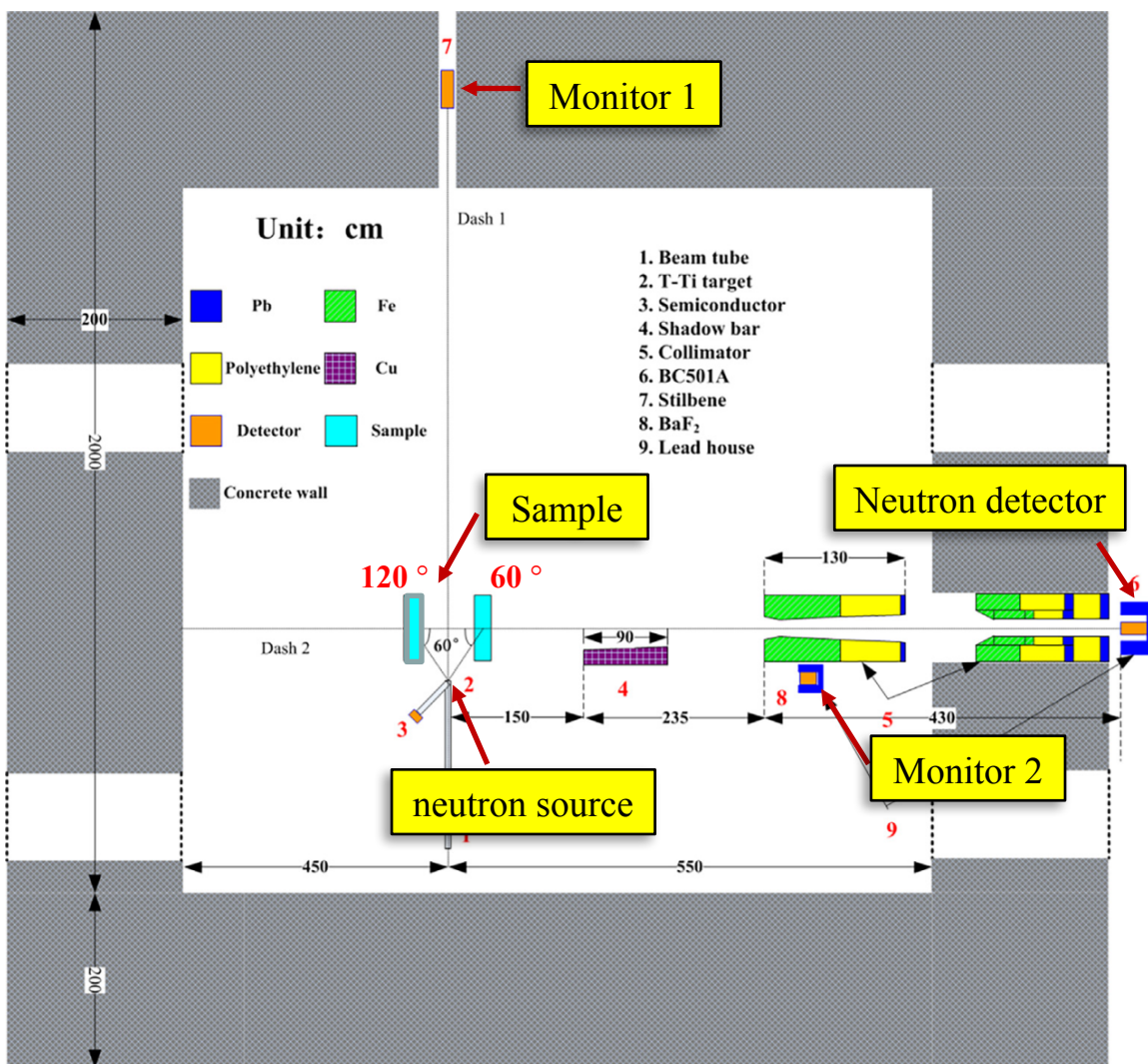


Fig. 1 Experimental arrangement for benchmark validation at CIAE

Description of the Neutron Source

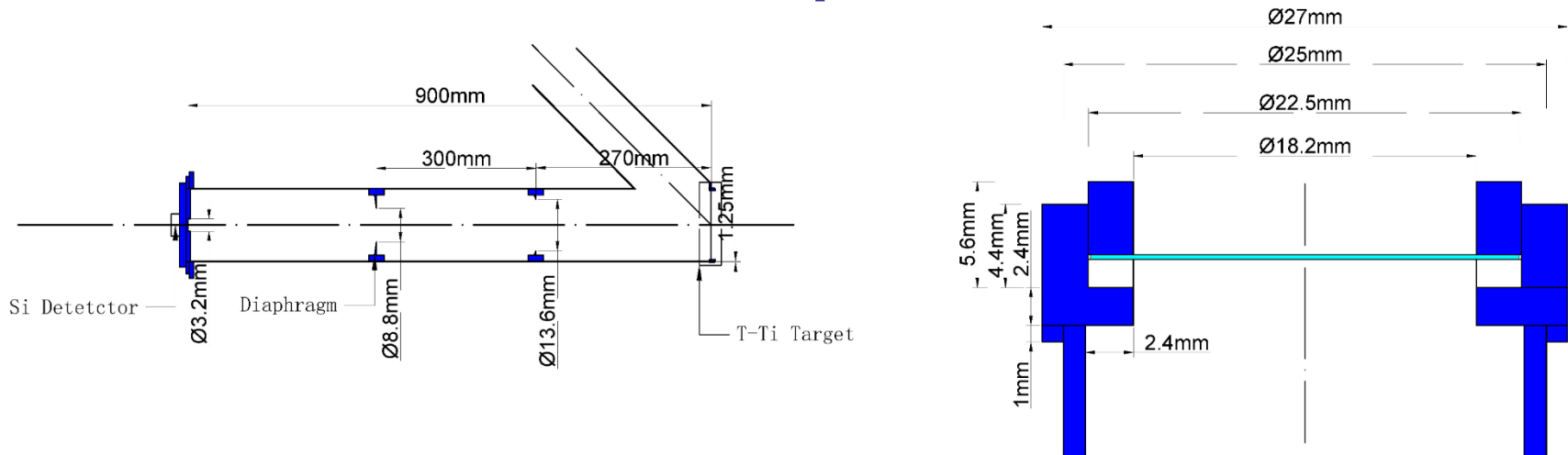


Fig. 2 The dimensions of associated particle target tube and the T-Ti target

- The source **neutron yield** is monitored by **Associated Particle System (Si detector)**
- **Estimated by the following equations:**
- A **coefficient B** is defined as:

$$B = \frac{A_{\alpha} \times \sigma_{tot}}{\Delta\Omega \times \sigma(\theta)} \quad (3)$$

$$N_n = \frac{N_{\alpha} \times A_{\alpha} \times \sigma_{tot}}{\Delta\Omega \times \sigma(\theta)} \quad (1)$$

Solid Angle
of Si detector

$$\Delta\Omega = \frac{\pi \times r^2}{L^2} \quad (2)$$

- Incident deuteron : 300KeV
 - Associated α detection angle : 135°
 - Neutron emission angle: 0°
- We obtain **$B=1.508 \times 10^6$**

System Verification with Standard Sample

— Polyethylene

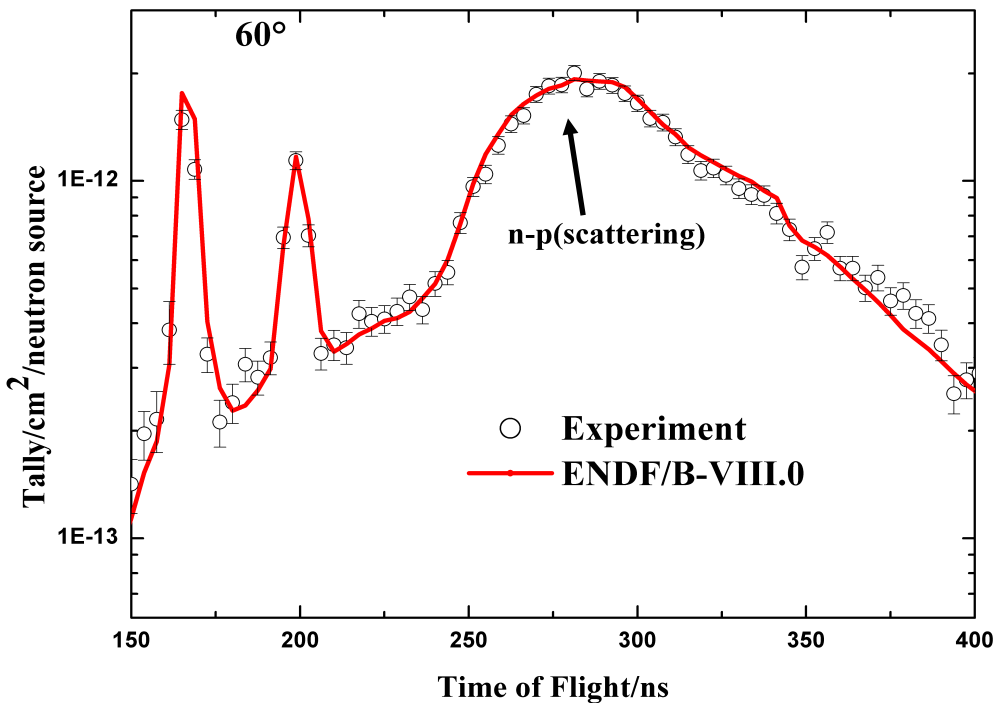


Fig.3 Leakage neutron spectra from polyethylene sample of $\Phi 13\text{cm} \times 6\text{cm}$ at 60°

- A coefficient $B^1 = 1.481 \times 10^6$ can be obtained with Eq.(4),

$$N_n = \frac{N_p^e}{N_p^c} = B^1 \times N_\alpha^p \quad (4)$$

Neutron(Exp.)
Neutron(Cal.)

- B^1 agrees with the calculated B within **2%**

➤ The result indicates that the experimental system **works well.**

sample	n-p scattering		C/E
	Experiment	Calculation	
$\Phi 13\text{cm} \times 6\text{cm}$	4.269E-11	4.349E-11	1.019

Uncertainties of Experimental Data

- The measured spectra for iron are normalized by the **n-p scattering (standard sample)** with equation.(5),

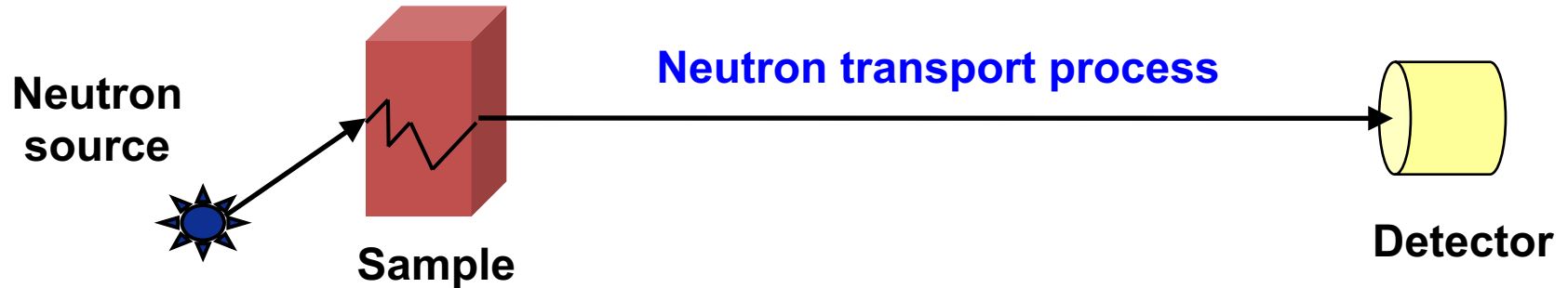
$$\text{num. of neutron/} \leftarrow \frac{N_B^e}{N_n} = \frac{N_B^e}{B^1 \times N_\alpha^B} = \frac{N_B^e \times N_P^C \times N_\alpha^P}{N_P^e \times N_\alpha^B} \quad (5)$$

time bin (Fe)

- most of the systematic uncertainties can be suppressed
 - the absolute detection efficiency
 - the solid angle for associated α and neutron detection

Statistical Uncertainty		Systematic Uncertainty	
N_B^e neutrons per time bin from exp. (Fe)	<8%	relative neutron detection efficiency	<3%
N_P^C n-p scattering neutrons from cal. (PE)	<0.5%		
N_P^e n-p scattering neutrons from exp. (PE)	<0.5%	scattering angle ambiguity	<1%
N_α^P associated α particles (PE)	<0.5%		
N_α^B associated α particles (Fe)	<0.5%		

The Details of Monte Carlo Simulation



● Parameters considered in simulation :

- Energy spectrum and angular distribution of source neutrons ;

- Time structure of pulsed beam ;

- Detector efficiency

**Neutron
Production**

**Neutron
Detection**

Time Structure of Pulsed Beam

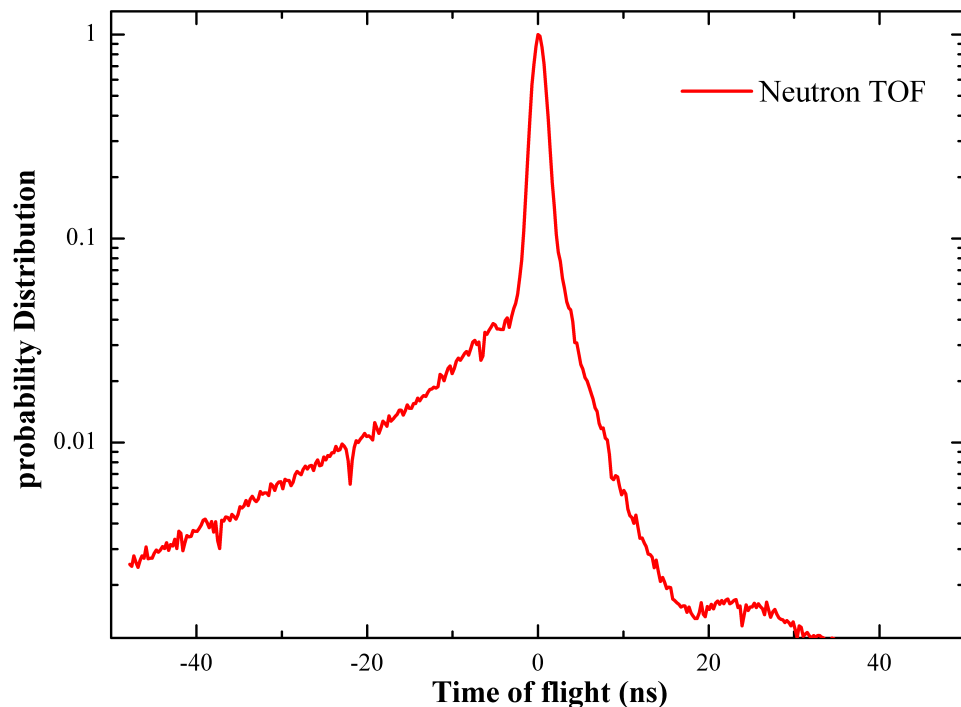


Fig. 4 The time structure of pulsed neutron source

Energy Spectrum and Angular Distribution of Source Neutrons

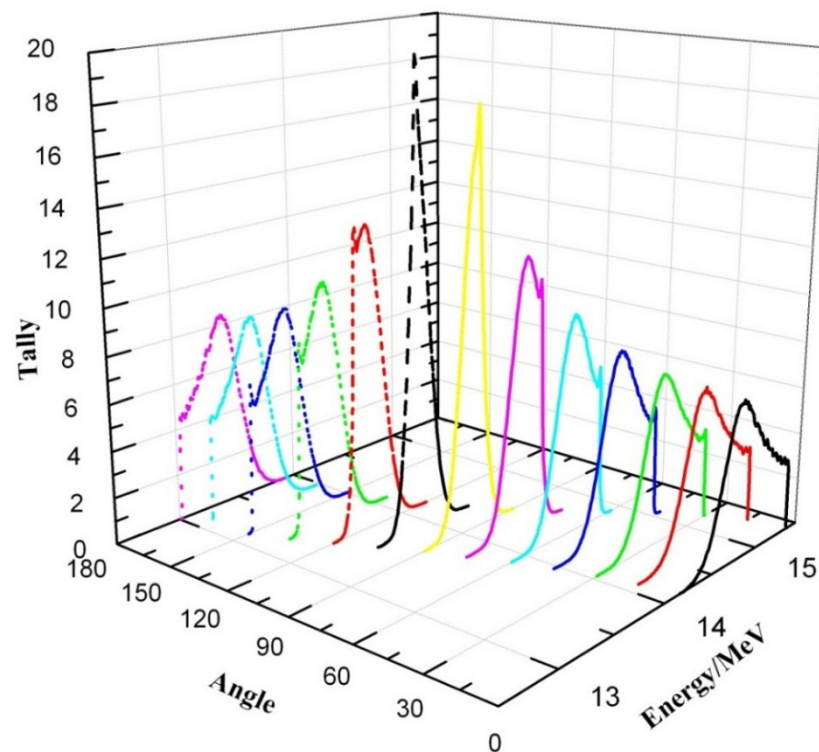


Fig. 5 The angle dependent energy distribution of the source neutrons

Detector Efficiency

How is it do:

- Calibration of **relative efficiency curve**
 - TOF method ;
 - ^{252}Cf neutron source.
- Calibration of **absolute efficiency curve**
 - TOF method;
 - the d-D reaction neutron source.
- compare with **calculated result**

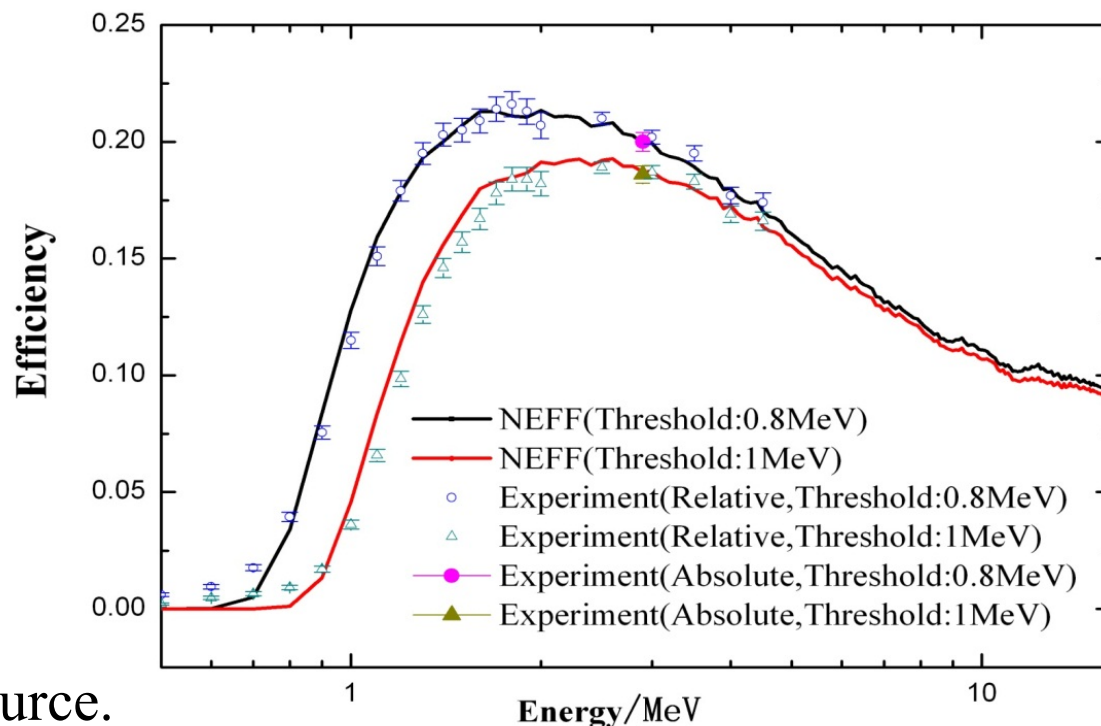


Fig.6 The detection efficiency with different thresholds.

➤ the calculated result was in good agreement with the experimental one.

Calculated Mode

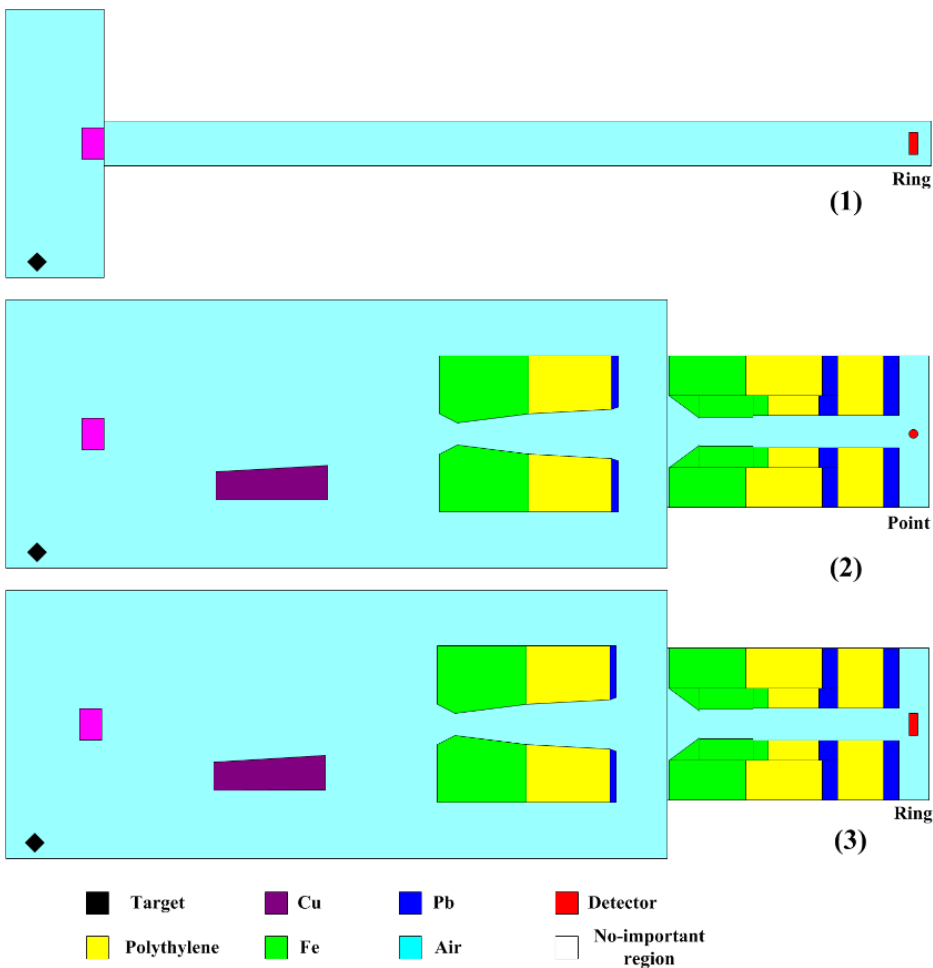


Fig.7 The models were used in MCNP simulation.

- (1) Simple model with ring detector
- (2) Complex model with point detector
- (3) Complex model with ring detector

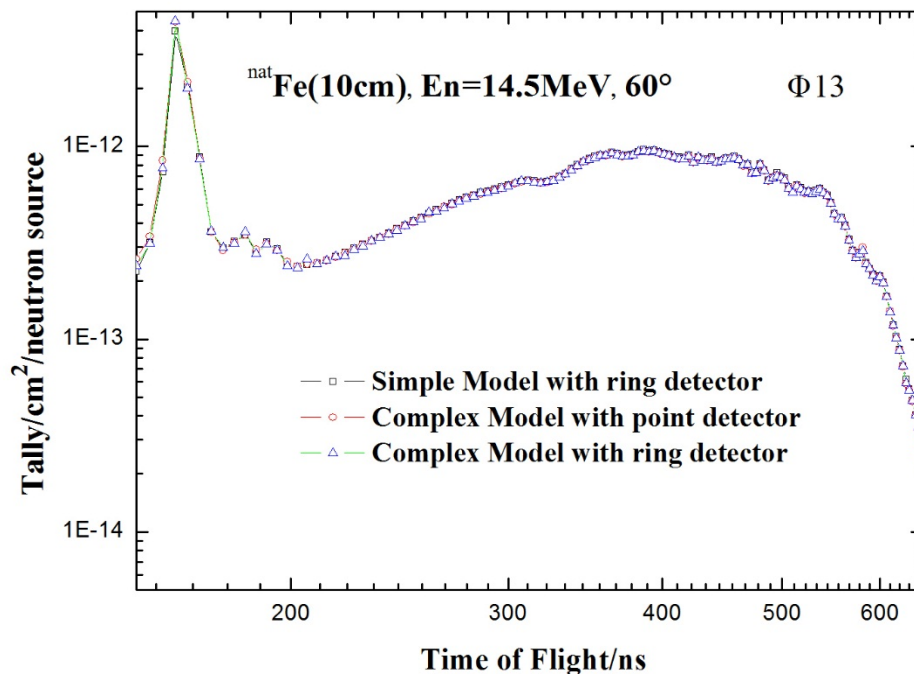


Fig.8 The simulated results from different models.

● The deviation of the calculated results of different models is less than 1%.

➤ Simple model with ring detector model is **reliable and efficient** for simulation in this work



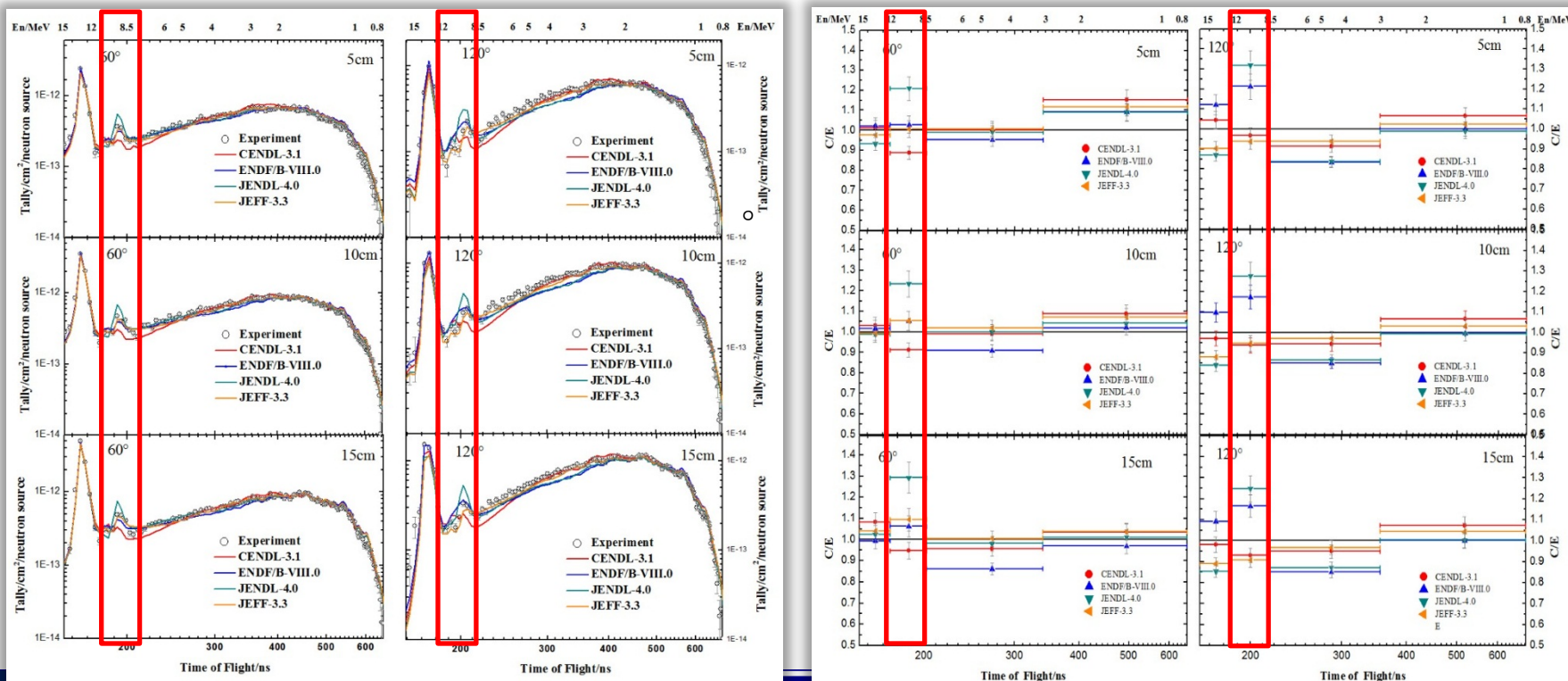
Benchmarking of evaluated nuclear data for iron by a TOF experiment with slab samples



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Sample Size (cm): $\Phi 13 \times 5$, $\Phi 13 \times 10$, $\Phi 13 \times 15$
Library: CENDL-3.1, ENDF/B-VIII.0, JENDL-4.0, JEFF-3.3



8.5-12MeV

Size (cm)	C/E			
	CENDL-3.1	ENDF/B-VIII.0	JENDL-4.0	JEFF-3.3
60°				
5cm	0.833	0.997	1.185	0.963
10cm	0.824	0.980	1.156	0.978
15cm	0.843	0.982	1.155	1.005
120°				
5cm	0.912	1.215	1.358	0.977
10cm	0.867	1.140	1.230	0.924
15cm	0.891	1.166	1.250	0.925

- The results with **JENDL-4.0** library are overestimated around 20% at both 60° and 120° .
- At 60° , the results with CENDL-3.1 library are underestimated around 15%.
- At 120° , the results with ENDF/B-VIII.0 are overestimated by more than 15%.

Analysis and Discussion

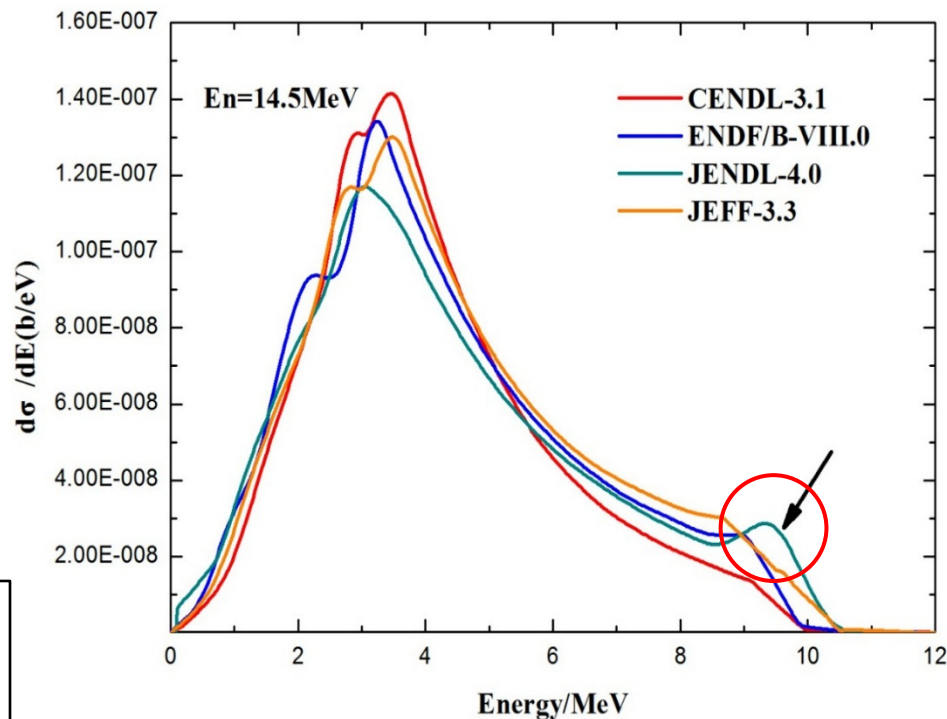


Fig.9 The contributions from the continuum inelastic scattering for iron at the incident neutron.

➤ **The JENDL-4.0 library is overestimated near 10MeV.**

12-15MeV

Size (cm)	C/E			
	CENDL-3.1	ENDF/B-VIII.0	JENDL-4.0	JEFF-3.3
60°				
5cm	0.955	1.003	0.896	0.915
10cm	0.951	0.966	0.897	0.924
15cm	0.927	0.917	0.871	0.904
120°				
5cm	0.940	1.072	0.814	0.822
10cm	0.853	0.983	0.752	0.757
15cm	0.837	0.970	0.744	0.752

- Calculated scattering peaks with the **ENDF/B-VIII.0** library well reproduce the experimental ones.
- Results with CENDL-3.1, JENDL-4.0 and JEFF-3.3 are underestimated at 120° about 10%-25%.

Analysis and Discussion

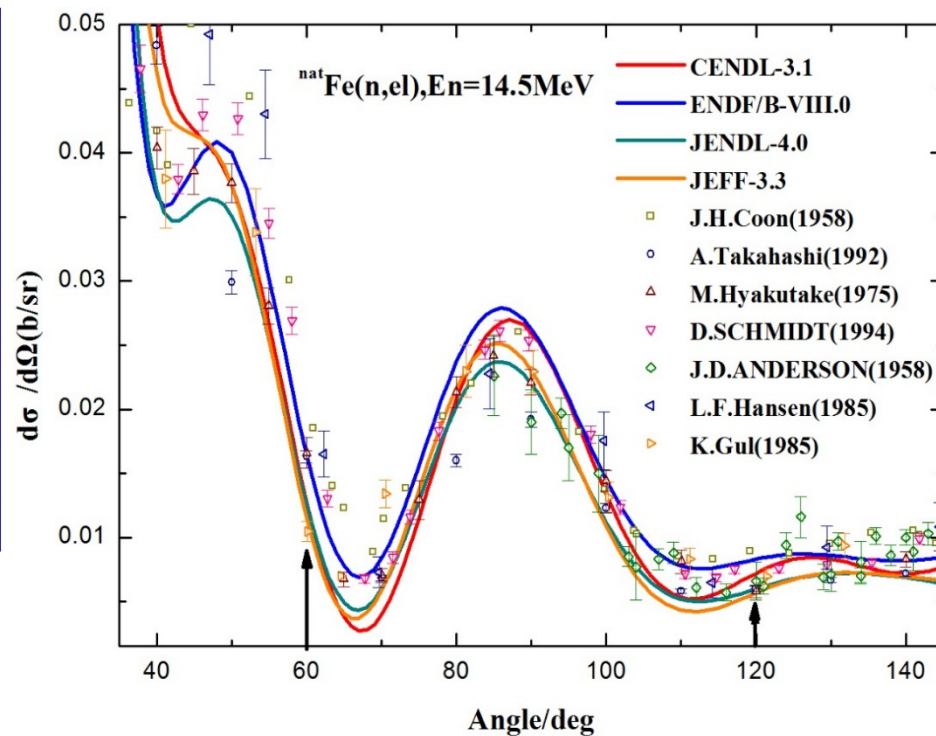


Fig.10 The energy distributions of emission neutrons for iron

➤ **ENDF/B-VIII.0** library is much closer to most known experimental data

CENDL-3.1 and CENDL-3.2

— Fe

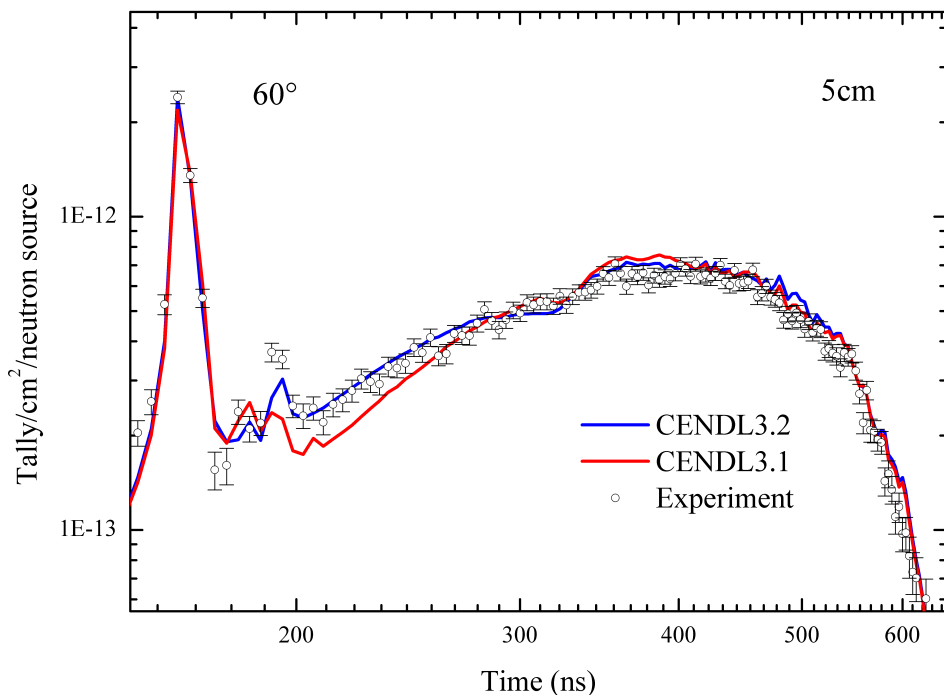


Fig.11 Comparison of measured and calculated spectra of CENDL-3.1 and CENDL-3.2 for Fe sample.

Energy (MeV)	C/E	
	CENDL3.2	CENDL3.1
12-15	0.972	0.955
8.5-12	0.901	0.833
3-8.5	1.017	0.969
0.8-3	1.089	1.088
Total	1.049	1.030

➤ This work provides guidance for the improvement of evaluated data for **Fe** in CENDL-3.1 to CENDL-3.2



Summary of benchmark experiment at CIAE

Sample	Size (cm)	Thickness (cm)	Degree (°)
^{238}U	10*10	5	45、135
Be	10*10	5, 11	60、120
Fe	$\phi 13$	5, 10, 15	60、120
$^{\text{nat}}\text{Ga}$	$\phi 13$	3, 2, 6, 4	60、120
$^{\text{nat}}\text{W}$	10*10	3, 5, 7	60、120
C	$\phi 13$	20	60、120
^{238}U	10*10	2, 5, 11	60、120
SiC	$\phi 13$	20	60、120
Pb	$\phi 13$	5	60
Pb-Bi	$\phi 13$	5	60
ThO_2	$\phi 13$	10.8	60、120
Fe	30*30	5, 10, 15	60、120
Bi	30*30	5, 10, 15	60、120
Nb	$\phi 13$	5, 10, 15	60、120
Pb	30*30	5, 10, 15	60、120



Thank you for your attention !