



# *The Chinese work on $^{56}\text{Fe}$*

**Jing QIAN, Zhigang GE, Tingjin LIU, Hanlin LU, Xichao RUAN  
Guochang CHEN, Huanyu ZHANG, Yangbo NIE**

**China Nuclear Data Center(CNDC)  
China Institute of Atomic Energy(CIAE)  
P.O.Box 275-41, Beijing 102413, P.R.China  
E-Mail:qianj@ciae.ac.cn**





- **Evaluation of all cross sections in fast range**
- **Integral Benchmarking**
- **Summary**



## ■ Evaluation of all cross sections in fast range

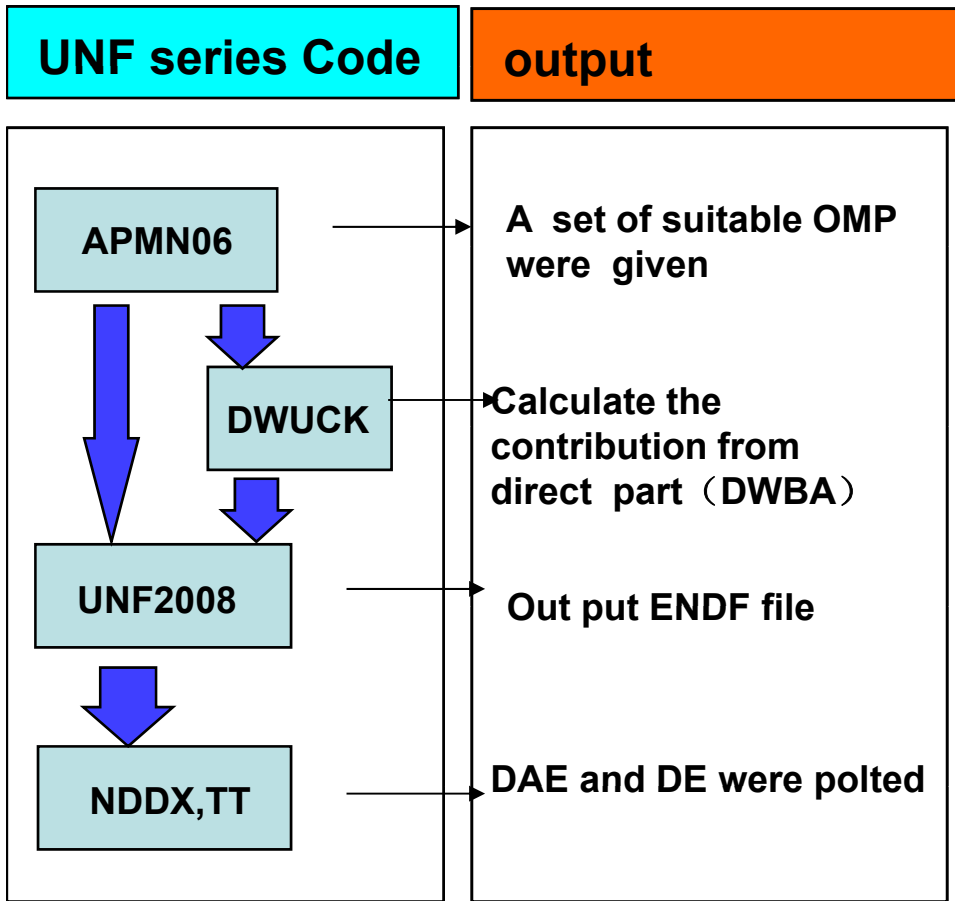
- ➡ Experimental data evaluation
- ➡ Theoretical calculation by UNF series code
- ➡ Compilation of evaluated data ( CHECKING, CRECTJ6)

New Resonance range evaluation (adopted from CIELO-Iron-beta1)  
were merged with the new fast-neutron evaluation

ACE file processed by NJOY2012.50 (by M.Herman and Ramon)

Comparison with other evaluated data  
(CIELO-Iron-beta1 B7.1 JEFF3.2 RSF JENDL4.0 CENDL-3.1)

# Theoretical calculation result by code UNF



OMP			
$V_0$	54.52155685	$U_2$	-0.00040197
$V_1$	-0.23792717	$r_r$	1.09132423
$V_2$	-0.00590990	$r_s$	1.27747381
$V_3$	-24.87143517	$r_v$	1.49487329
$V_4$	-0.00619497	$\alpha_r$	0.65029401
$W_0$	10.84276485	$\alpha_s$	0.50812095
$W_1$	-0.25981072	$\alpha_v$	0.44999999
$W_2$	-12.94733429	$U_{SO}$	6.23620844
$U_0$	-1.39829016	$r_{so}$	1.08222973
$U_1$	-0.19923522	$a_{so}$	0.62750721

level	Energy	$J\pi$	$\beta$
1	0.4868	2+	0.260
2	2.0851	4+	0.44
3	2.6576	2+	0.06
5	2.9599	2+	0.08
8	3.3698	2+	0.12
11	3.4453	3+	0.03
20	3.8564	3+	0.03
24	4.1199	3+	0.05
29	4.3948	3+	0.01
30	4.4014	2+	0.05
38	4.6583	3+	0.12

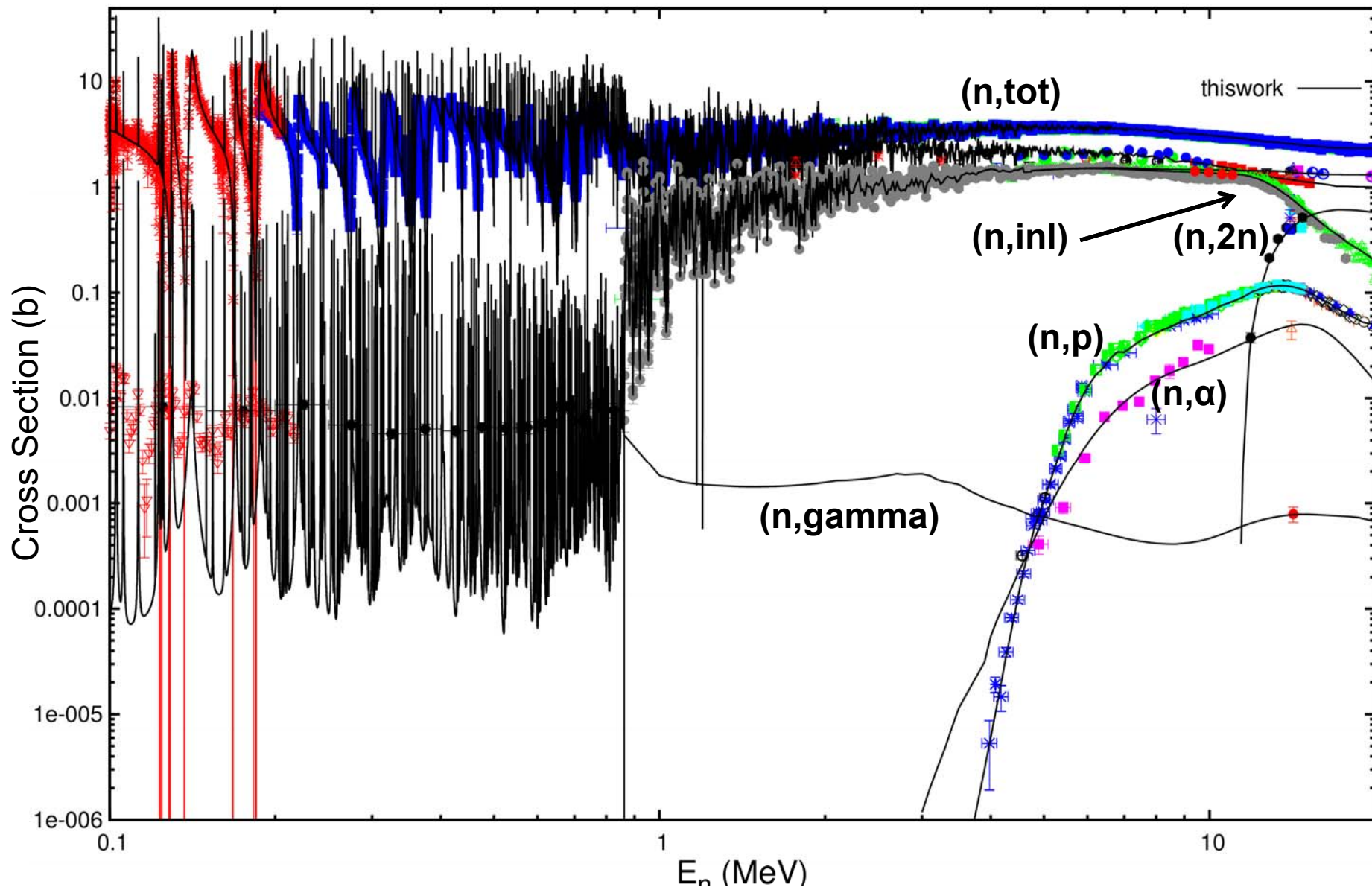
**$\beta$  parameters**

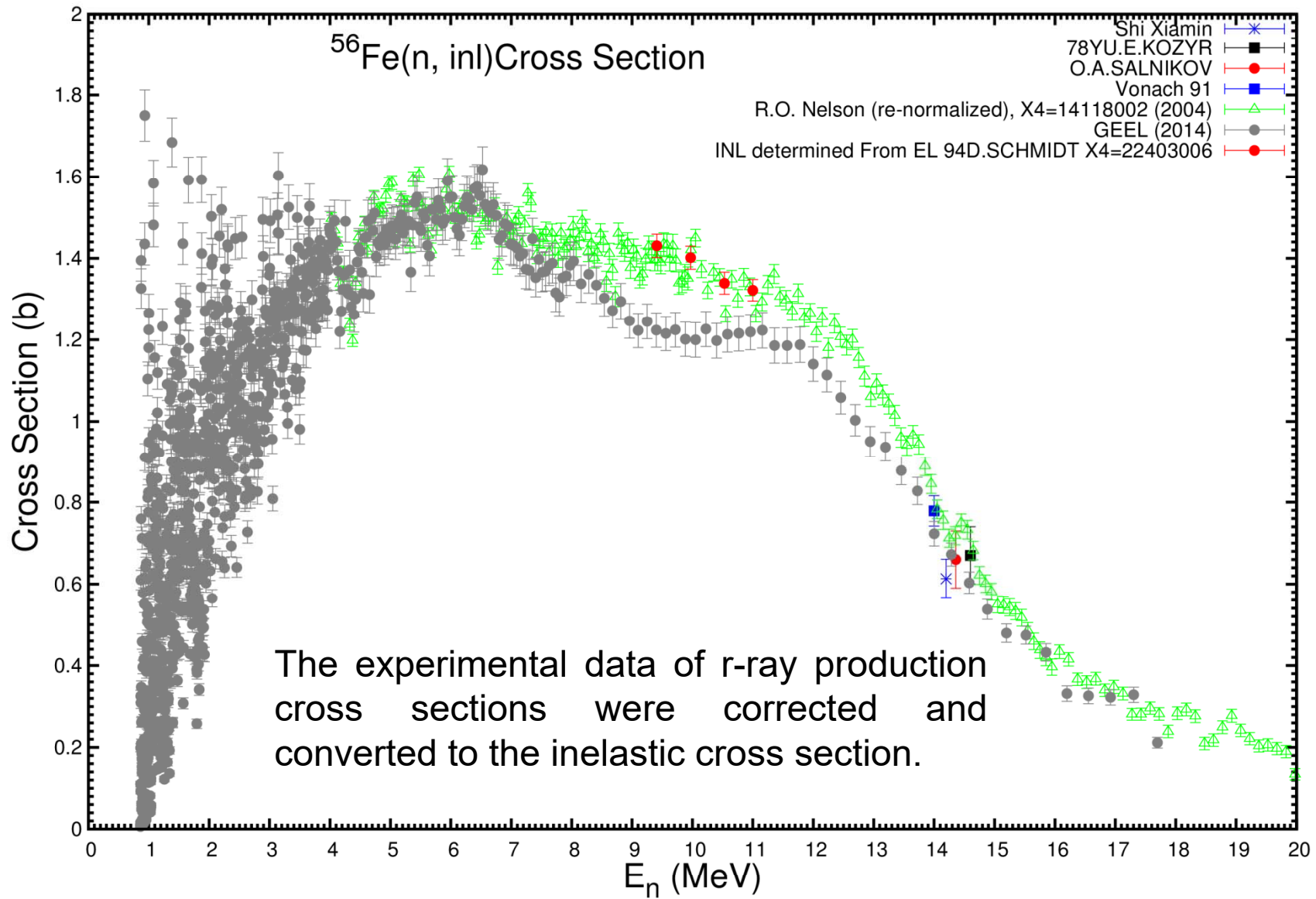
## Level density parameters and pair correction:

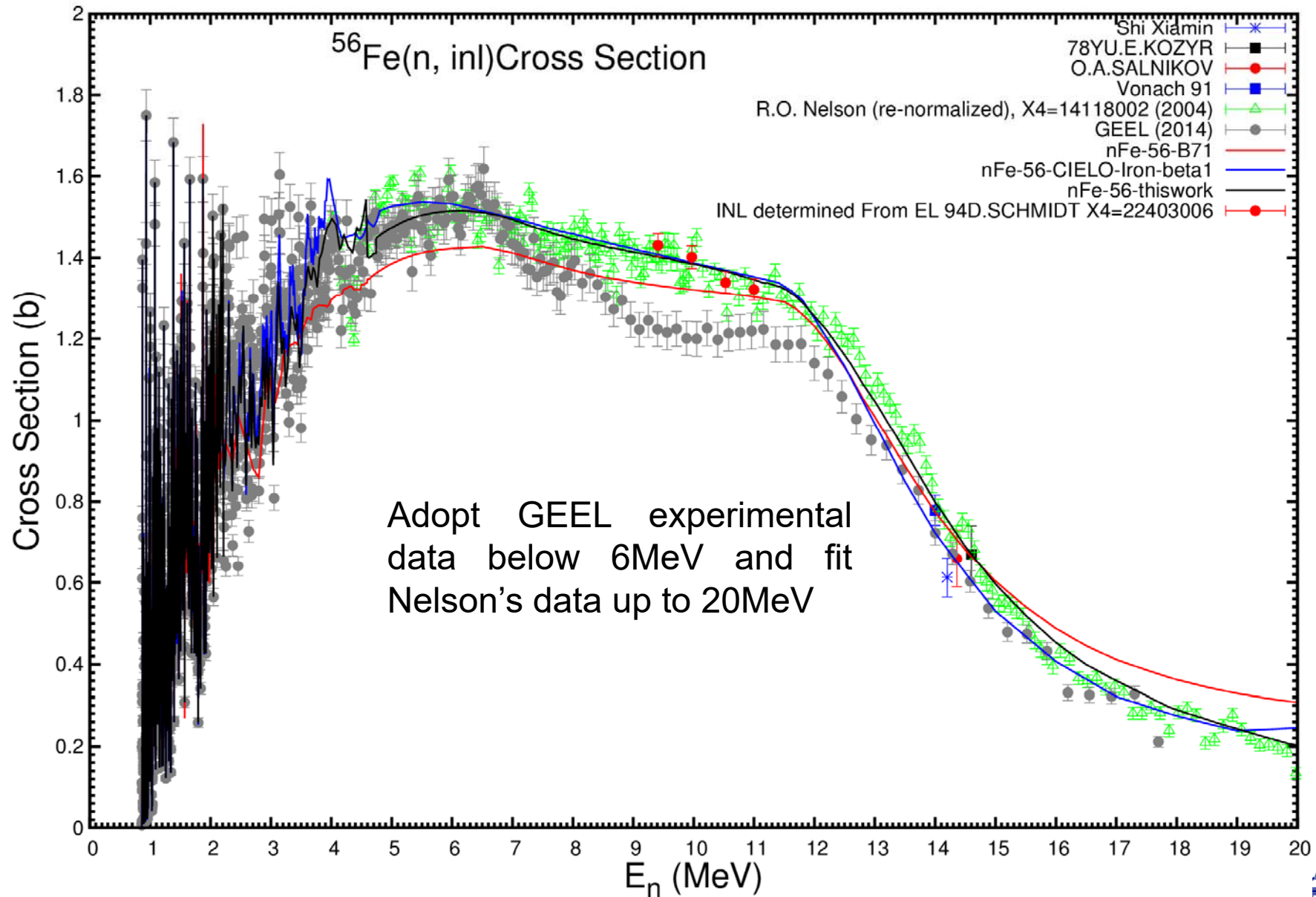
	(n, $\gamma$ )	(n,n')	(n,p)	(n, $\alpha$ )	(n, $^3\text{He}$ )	(n,d)	(n,t)	(n,2n)	(n,n $\alpha$ )	(n,np)	(n,3n)
Level density parameters	7.650	5.152	6.395	5.680	6.076	6.334	6.337	5.261	5.416	7.157	5.577
Pair correction	0.100	0.25	-0.75	0.40	0.35	0.15	0.00	0.50	0.40	0.20	0.50

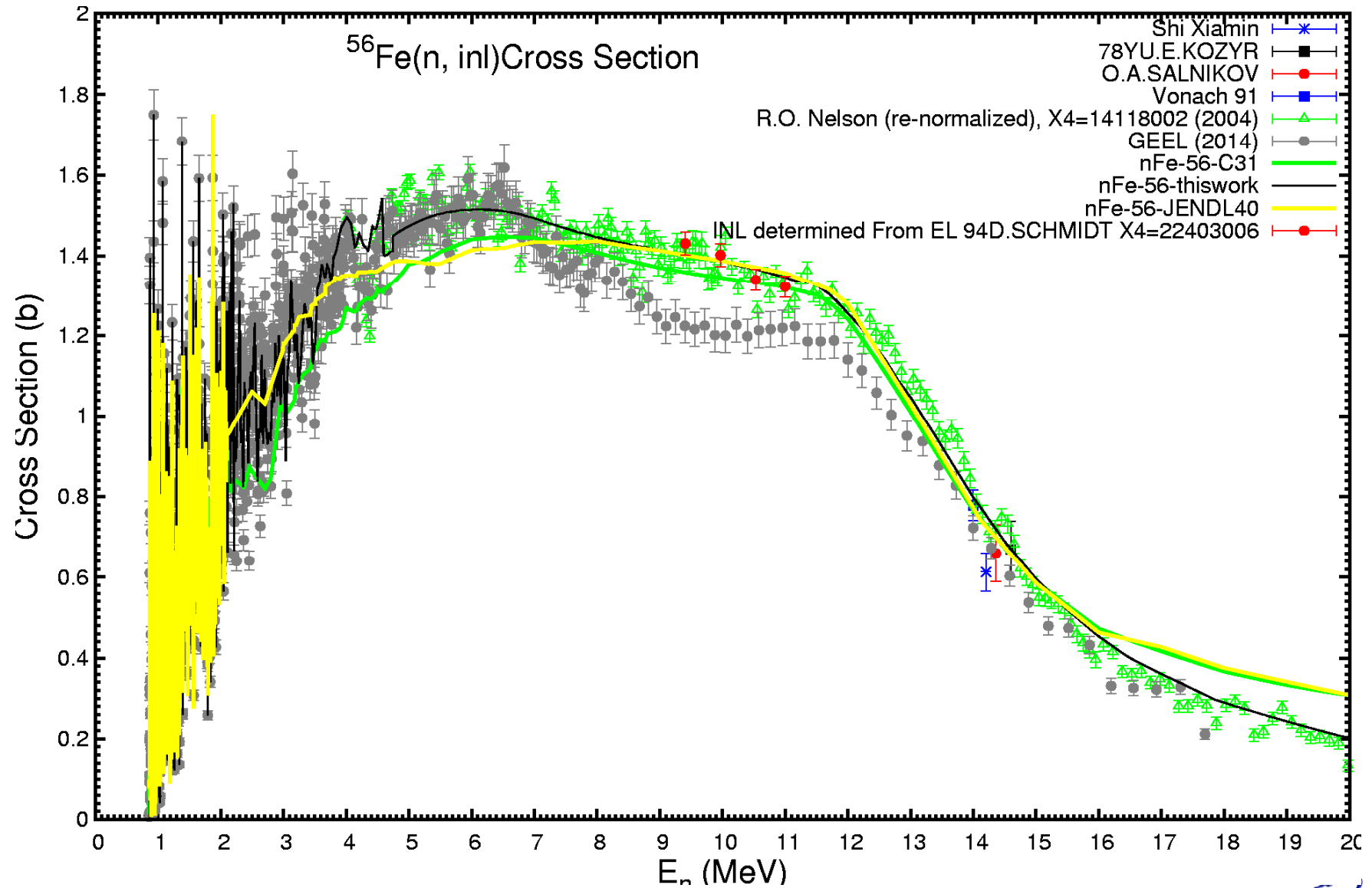


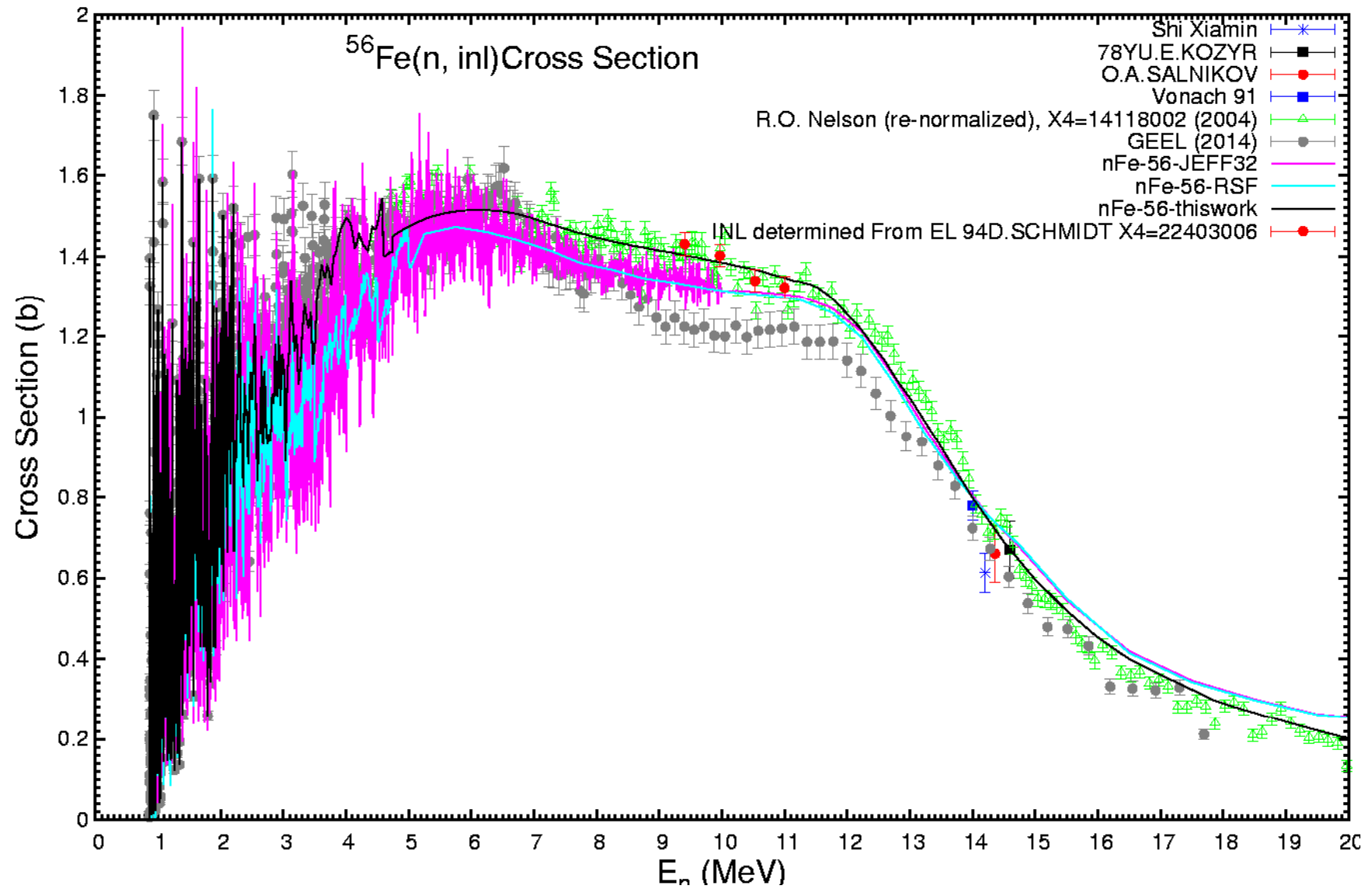
MF	MT	Data Source	
2	151	<b>Cielo –Iron-beta1</b> A resonance evaluation was performed at ORNL (Leal) from 1.0e-5 eV to 2 MeV using transmission data taken at the LINAC (Danon) and inelastic cross section measurements done GEEL (Plompen).	
3	1	ENDF/B-VII.1	
	4	Adopt GEEL2014 Exp Data(~6MeV)+Fit Nelson2004Exp Data(6~20MeV)	
		3,51	Adopt GEEL2014 Exp Data(~4.577MeV) + Theoretical calculated result(UNF) (4.577~20MeV)
		3,52~88	Theoretical calculated result(UNF)
		3,91	(3,4)-(3,51:88)
	16	Fit Exp Data and ENDF/B-VII.1	
	103	ENDF/B-VII.1	
	102, 104,105, 106,107	Theoretical calculated result(UNF)	
	3	(3,3)=(3,102)+(3,4)+(3,16)+(3,103)+(3,104)+(3,105)+(3,106)+(3,107)	
	2	(3,2)=(3,1)-(3,3)	
4	2	Theoretical calculated result(UNF)	
5, 6		Theoretical calculated result(UNF)	

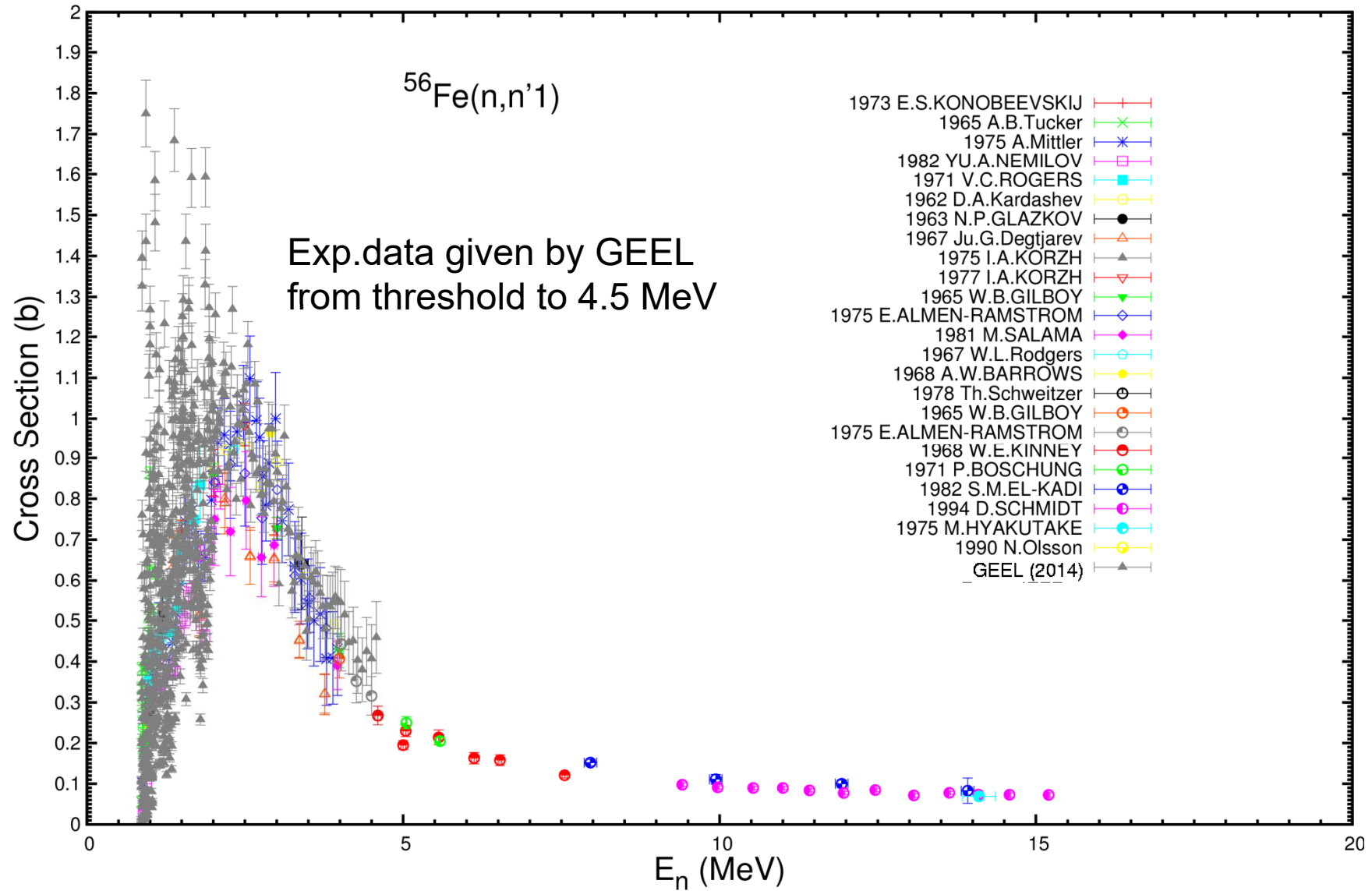


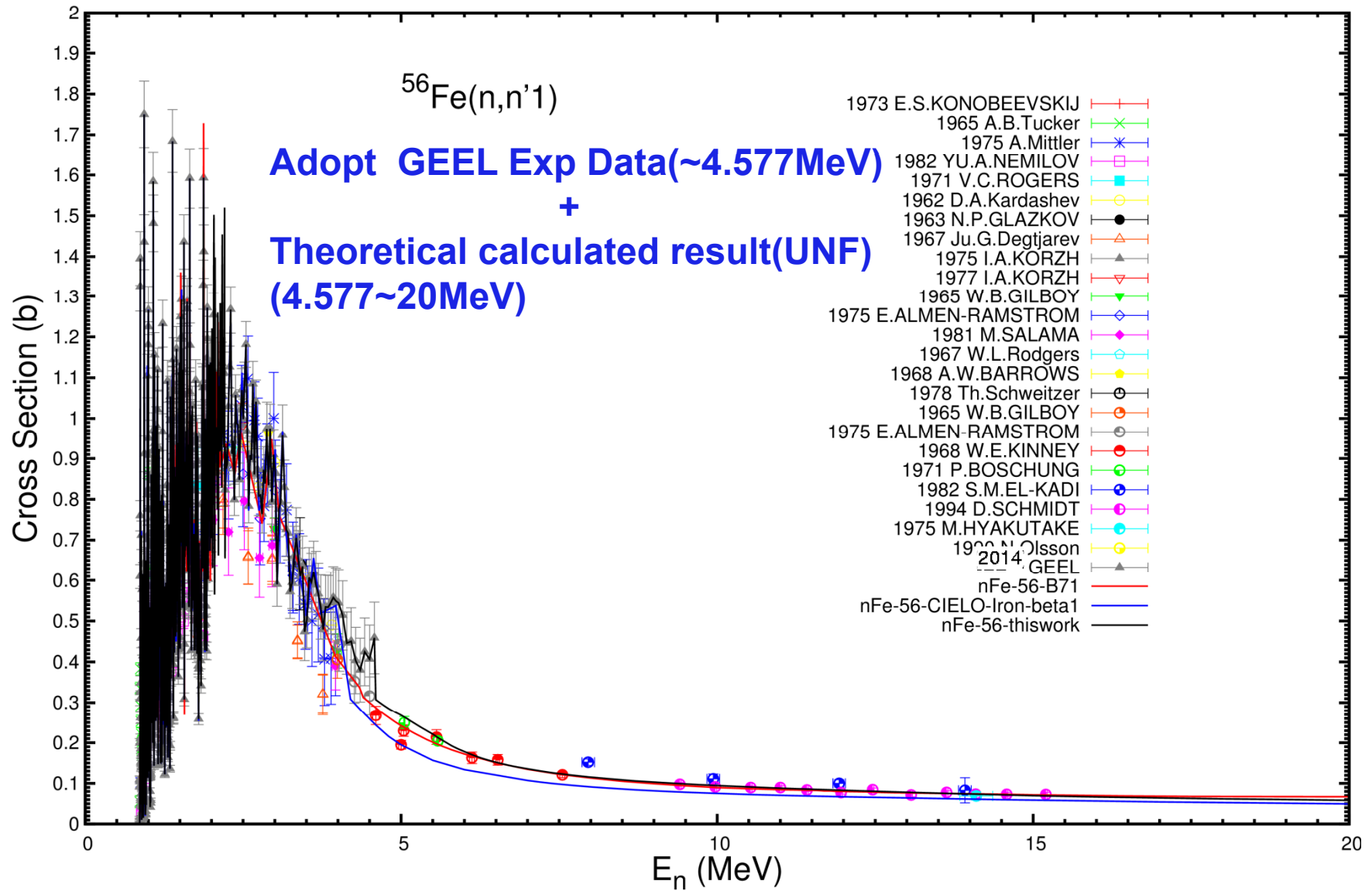




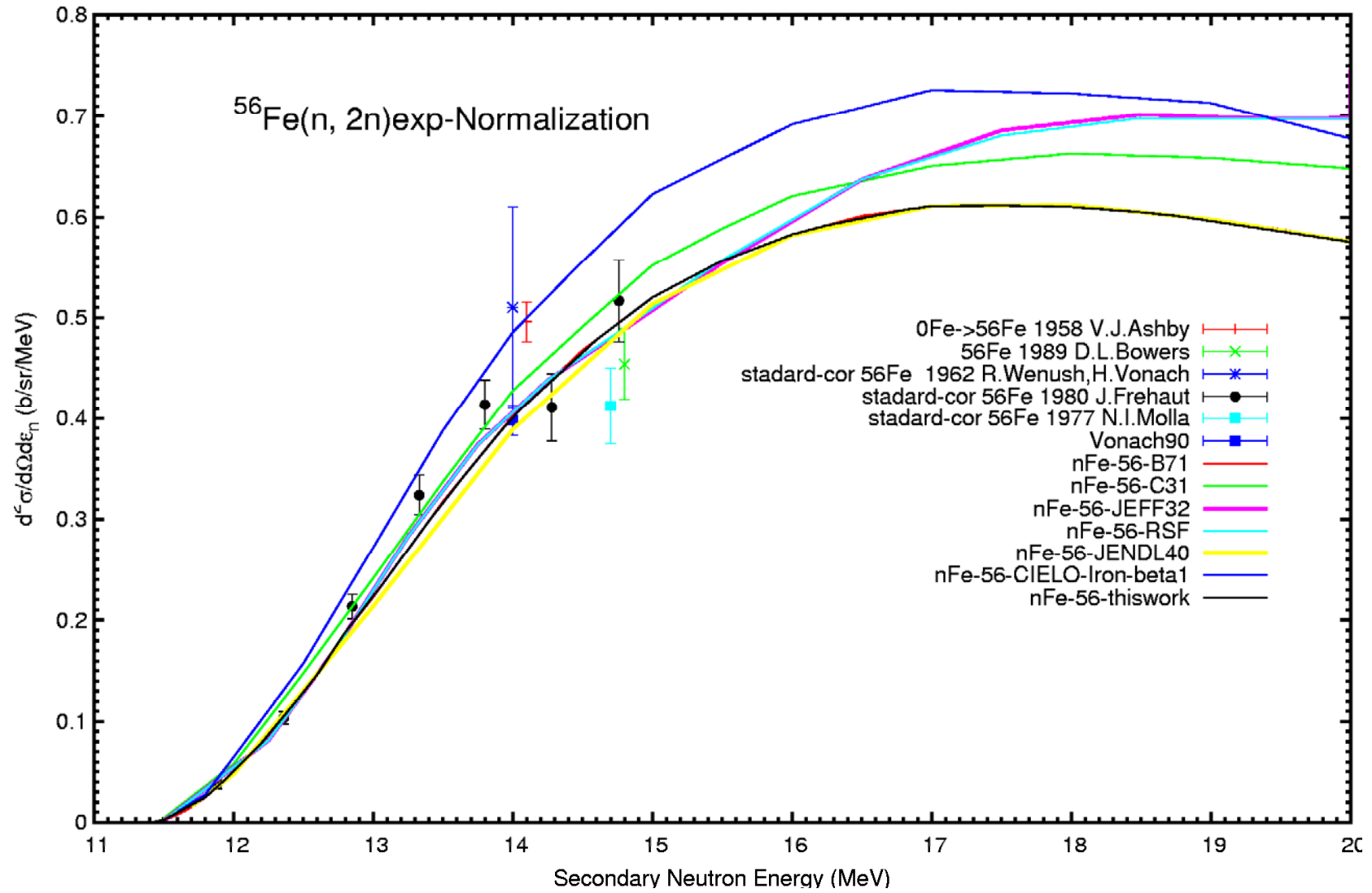


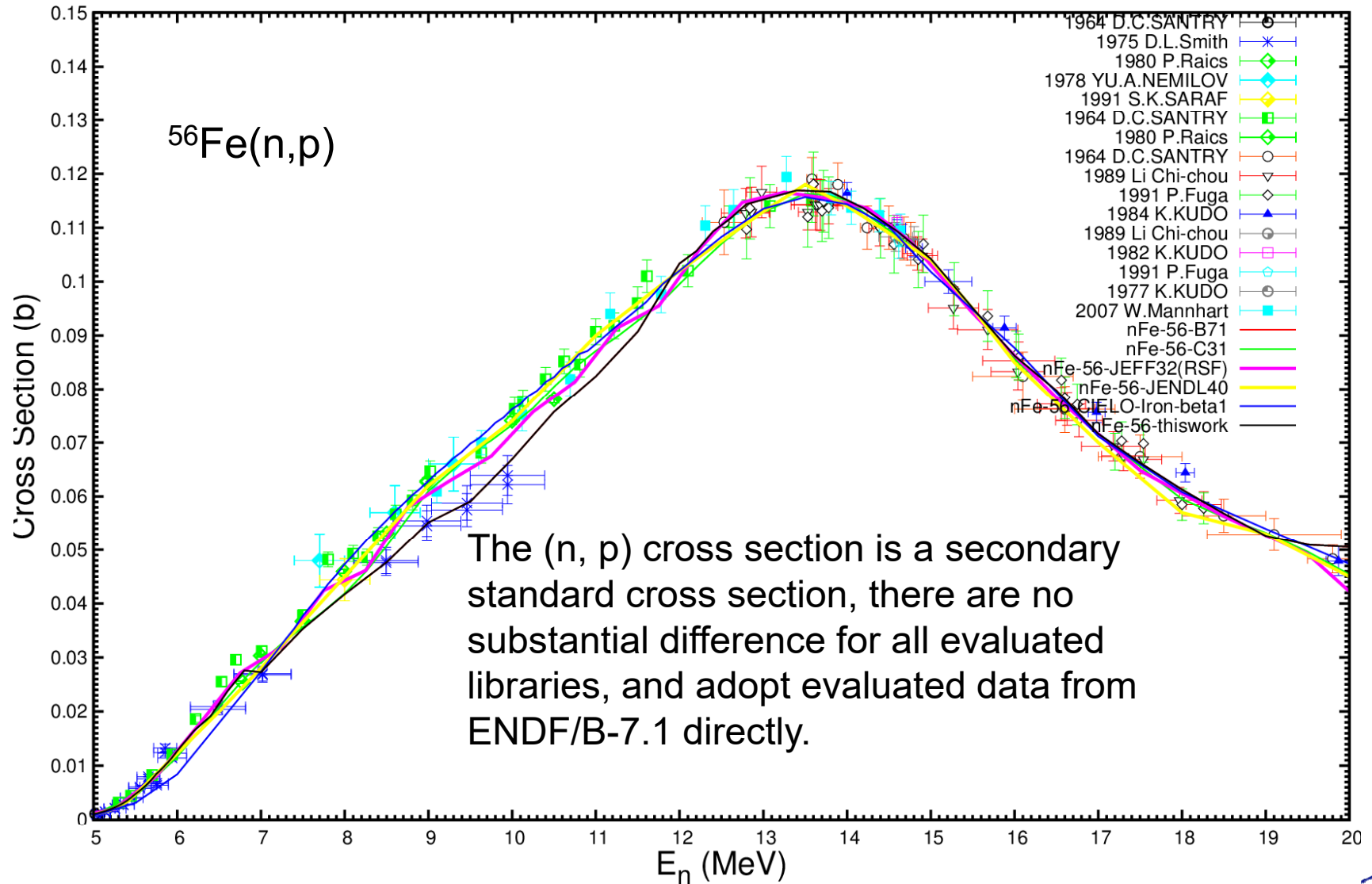


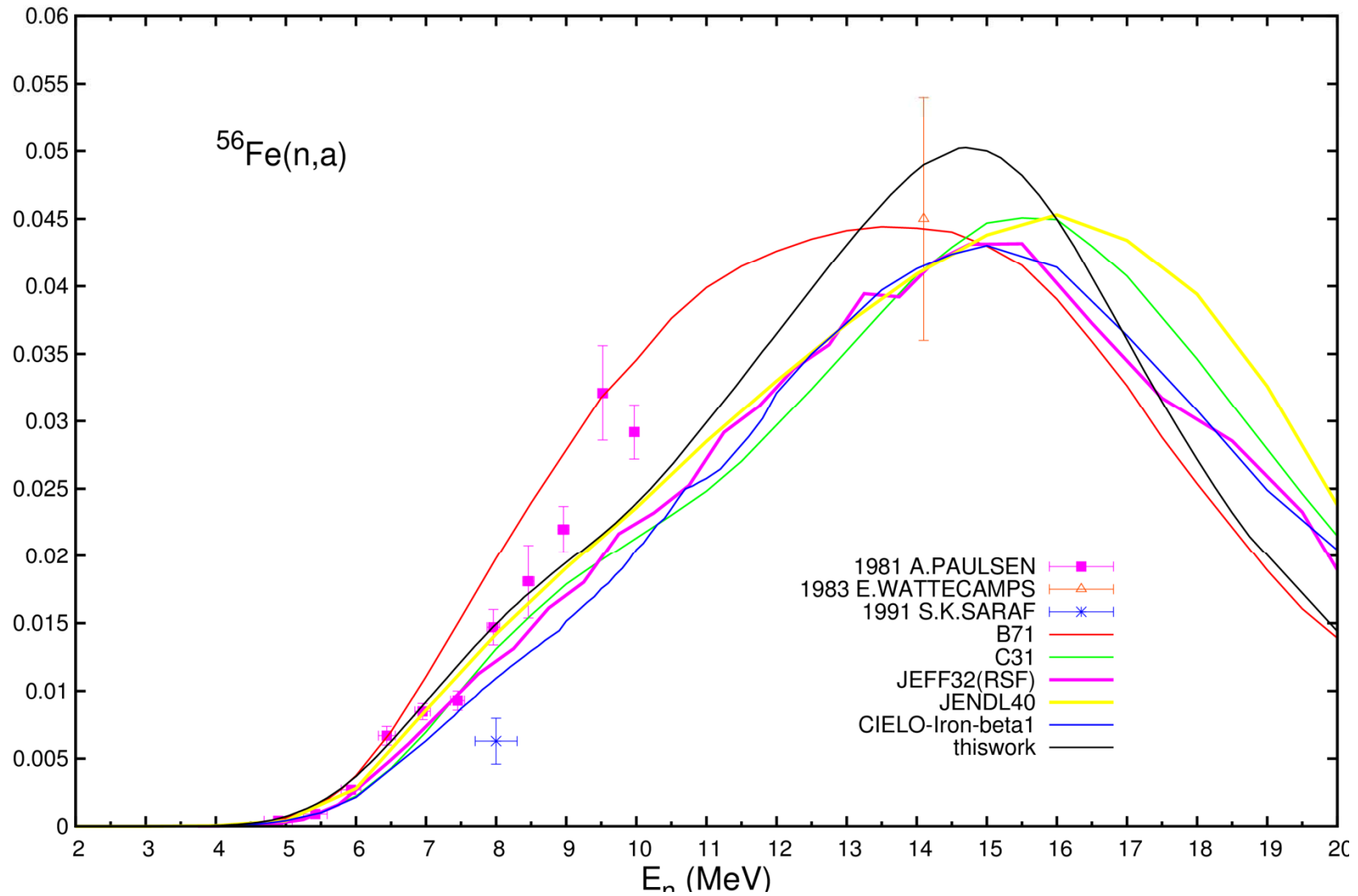


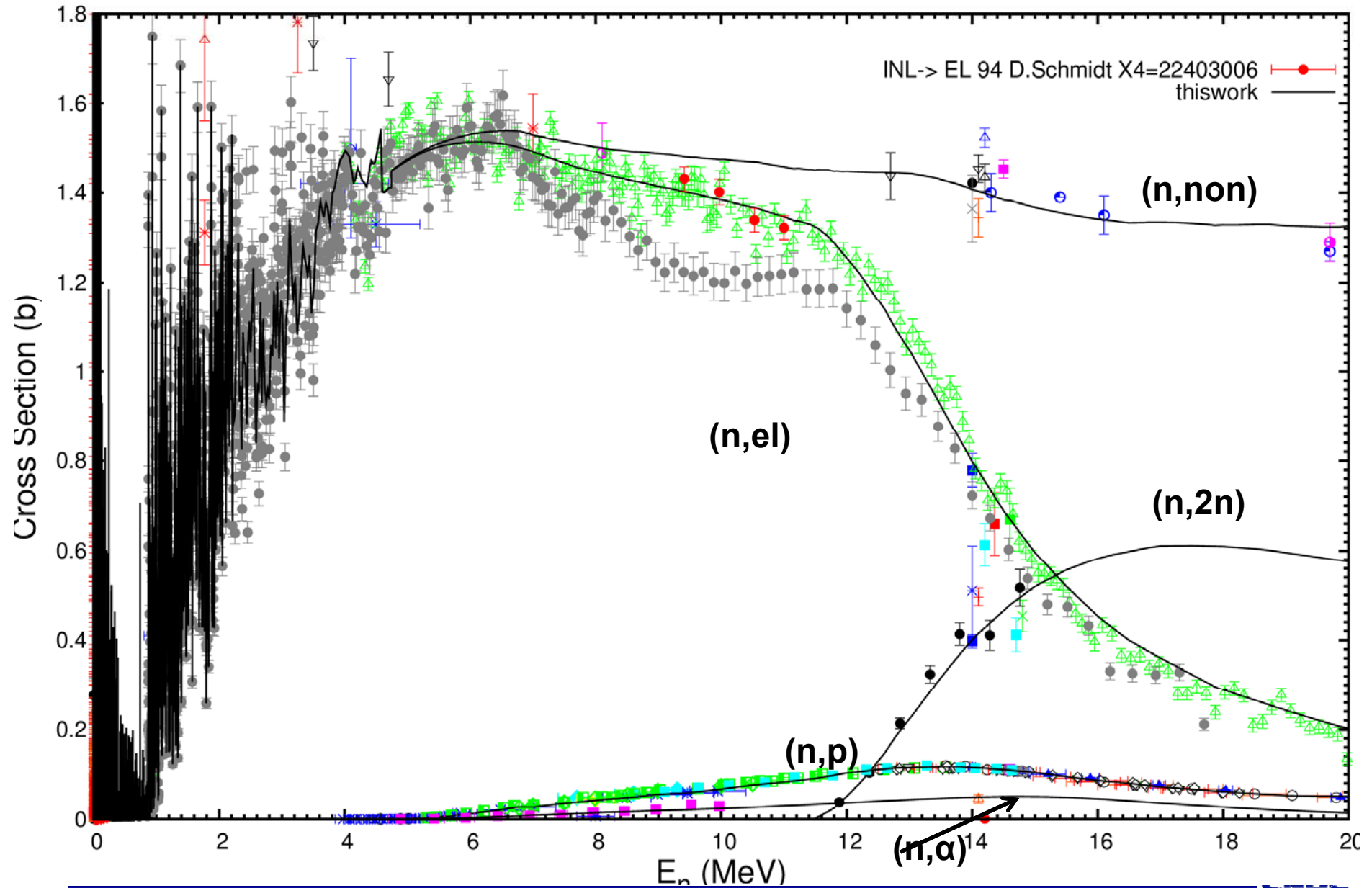


MF	MT	Data Source	
2	151	Cielo –Iron-beta1 A resonance evaluation was performed at ORNL (Leal) from 1.0e-5 eV to 2 MeV using transmission data taken at the LINAC (Danon) and inelastic cross section measurements done GEEL (Plompen).	
3	1	ENDF/B-VII.1	
	4	Adopt GEEL2014 Exp Data(~6MeV)+Fit Nelson2004Exp Data(6~20MeV)	
		3,51	Fit GEEL2014 Exp Data(~4.577MeV) + Theoretical calculated result(UNF) (4.577~20MeV)
		3,52~88	Theoretical calculated result(UNF)
		3,91	(3,4)-(3,51:88) The continuous inelastic cross section was given by subtracting the all discrete levels from total inelastic cross section
	16	Fit Exp Data and ENDF/B-VII.1	
	103	ENDF/B-VII.1	
	102, 104,105, 106,107	Theoretical calculated result(UNF)	
3	(3,3)=(3,102)+(3,4)+(3,16)+(3,103)+(3,104)+(3,105)+(3,106)+(3,107)		
	2	(3,2)=(3,1)-(3,3)	
4	2	Theoretical calculated result(UNF)	
5, 6		Theoretical calculated result(UNF)	



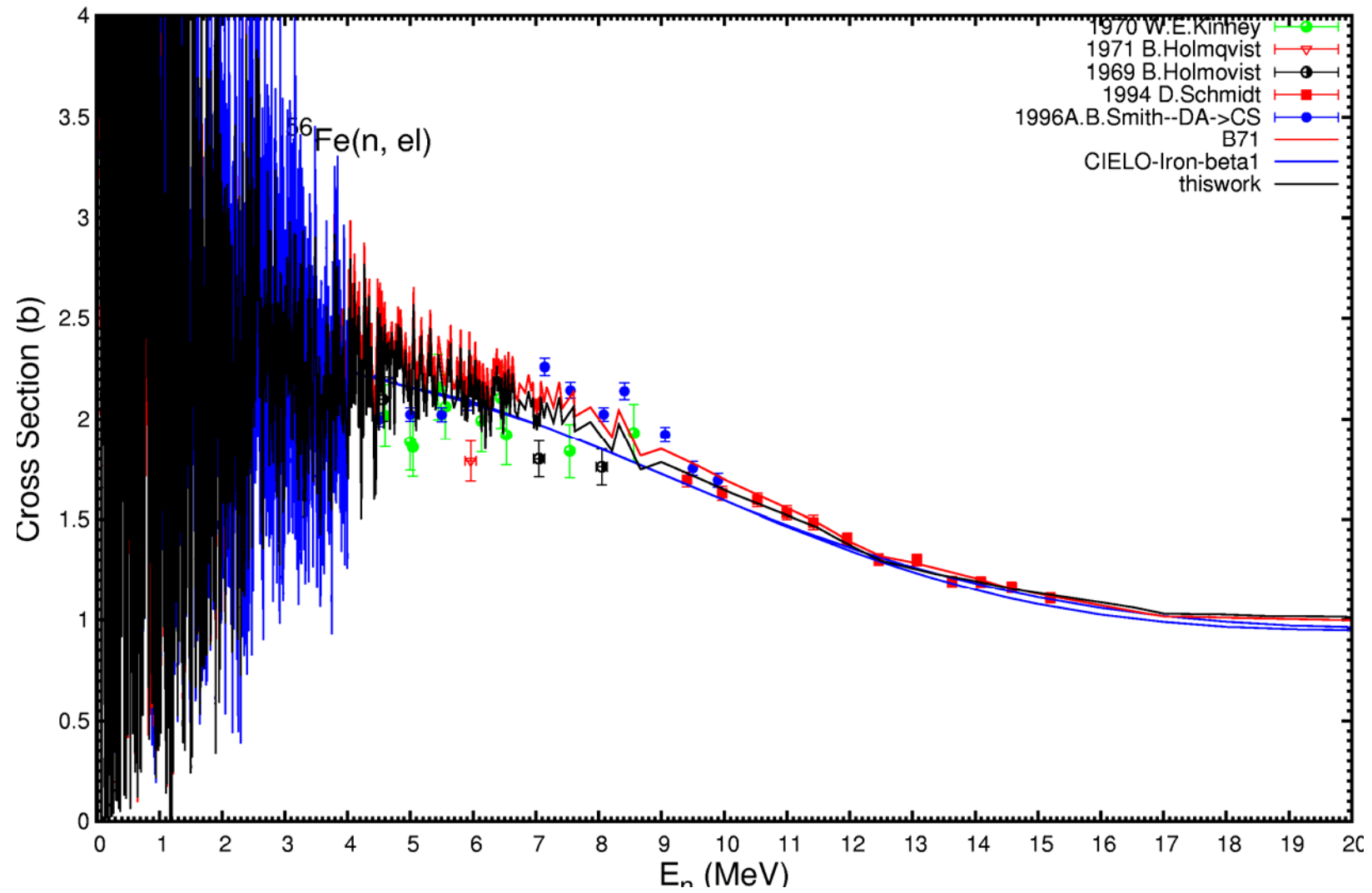


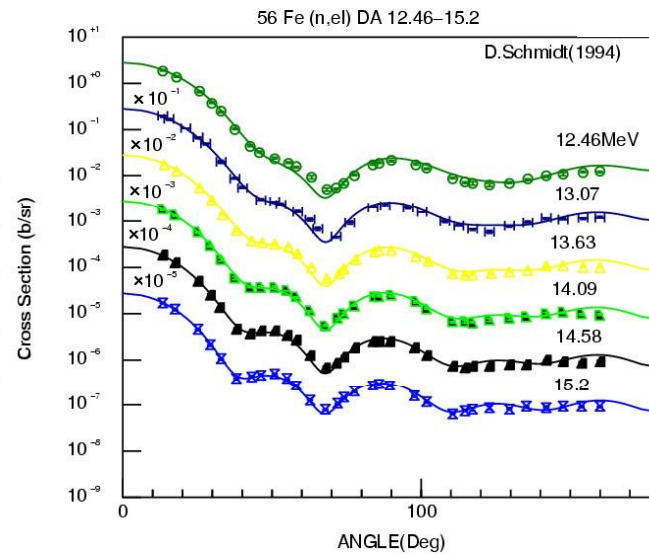
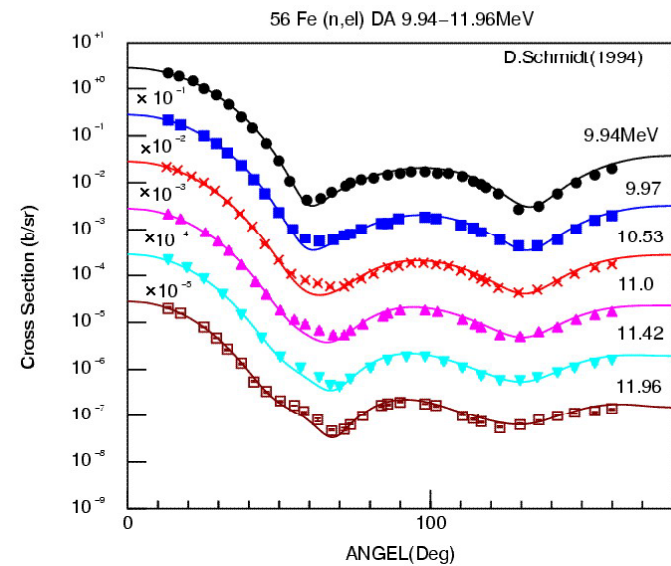
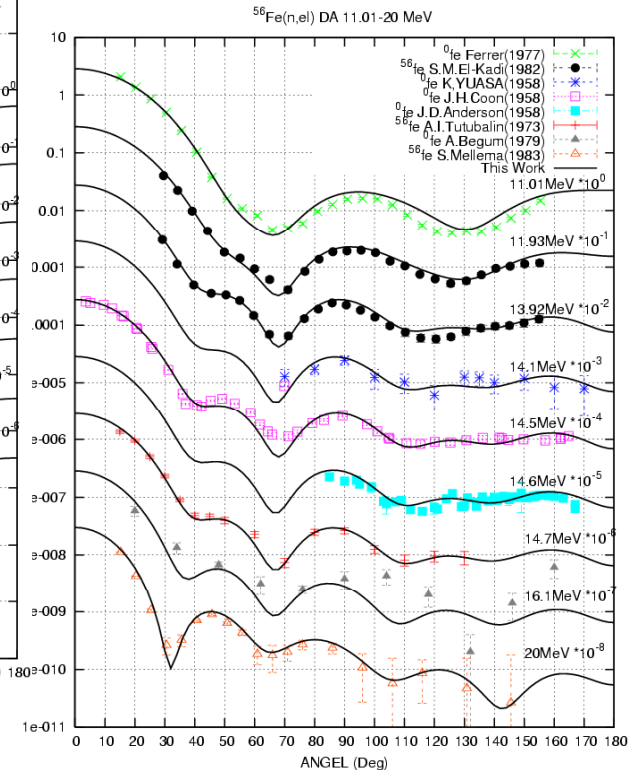
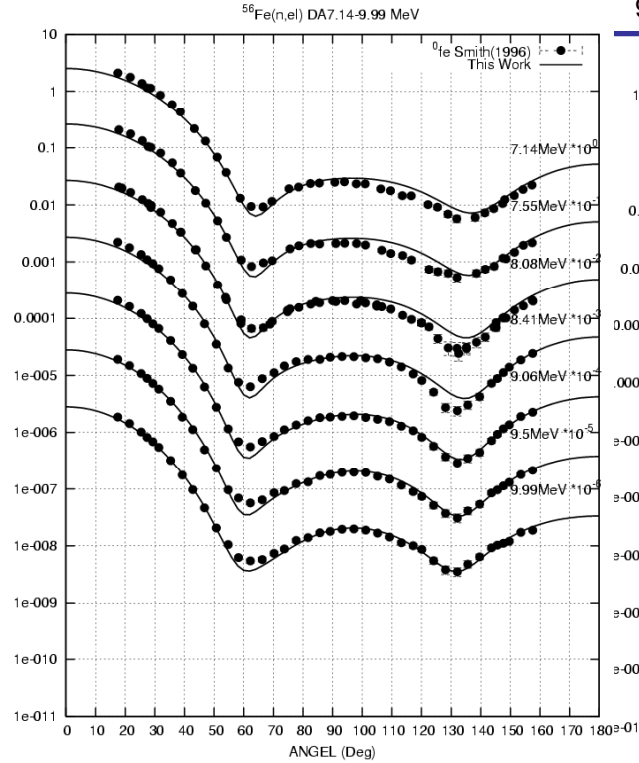
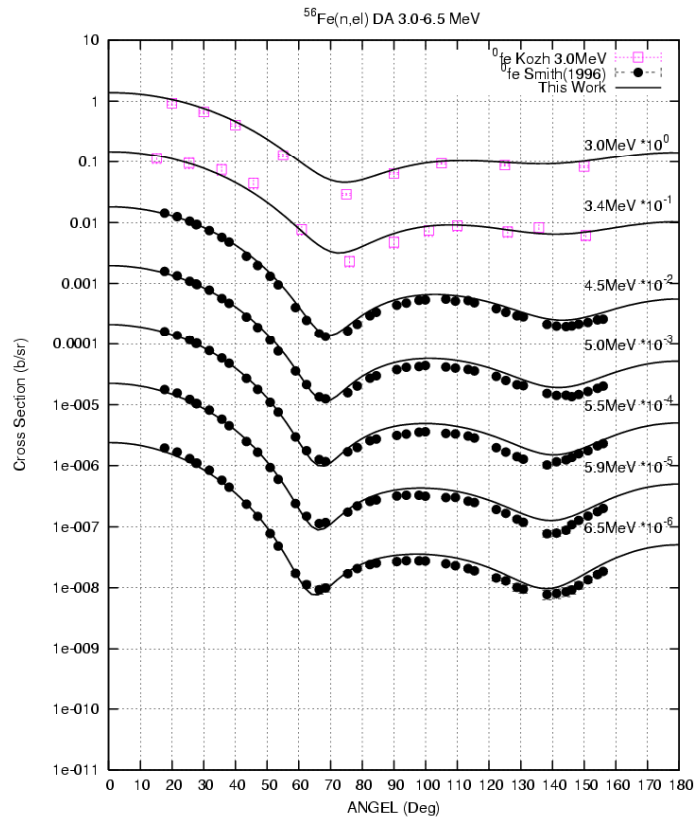






MF	MT	Data Source	
2	151	<b>Cielo –Iron-beta1</b> A resonance evaluation was performed at ORNL (Leal) from 1.0e-5 eV to 2 MeV using transmission data taken at the LINAC (Danon) and inelastic cross section measurements done GEEL (Plompen).	
3	1	ENDF/B-VII.1	
	4	Fit GEEL2014 Exp Data(~6MeV)+Nelson2004Exp Data(6~20MeV)	
		3,51	Fit GEEL2014 Exp Data(~4.577MeV) + Theoretical calculated result(UNF) (4.577~20MeV)
		3,52~88	Theoretical calculated result(UNF)
		3,91	(3,4)-(3,51:88)
	16	Fit Exp Data and ENDF/B-VII.1	
	103	ENDF/B-VII.1	
	102, 104,105, 106,107	Theoretical calculated result(UNF)	
	3	$(3,3)=(3,102)+(3,4)+(3,16)+(3,103)+(3,104)+(3,105)+(3,106)+(3,107)$	
	2	$(3,2)=(3,1)-(3,3)$	
4	2	Theoretical calculated result(UNF)	
5, 6		Theoretical calculated result(UNF)	

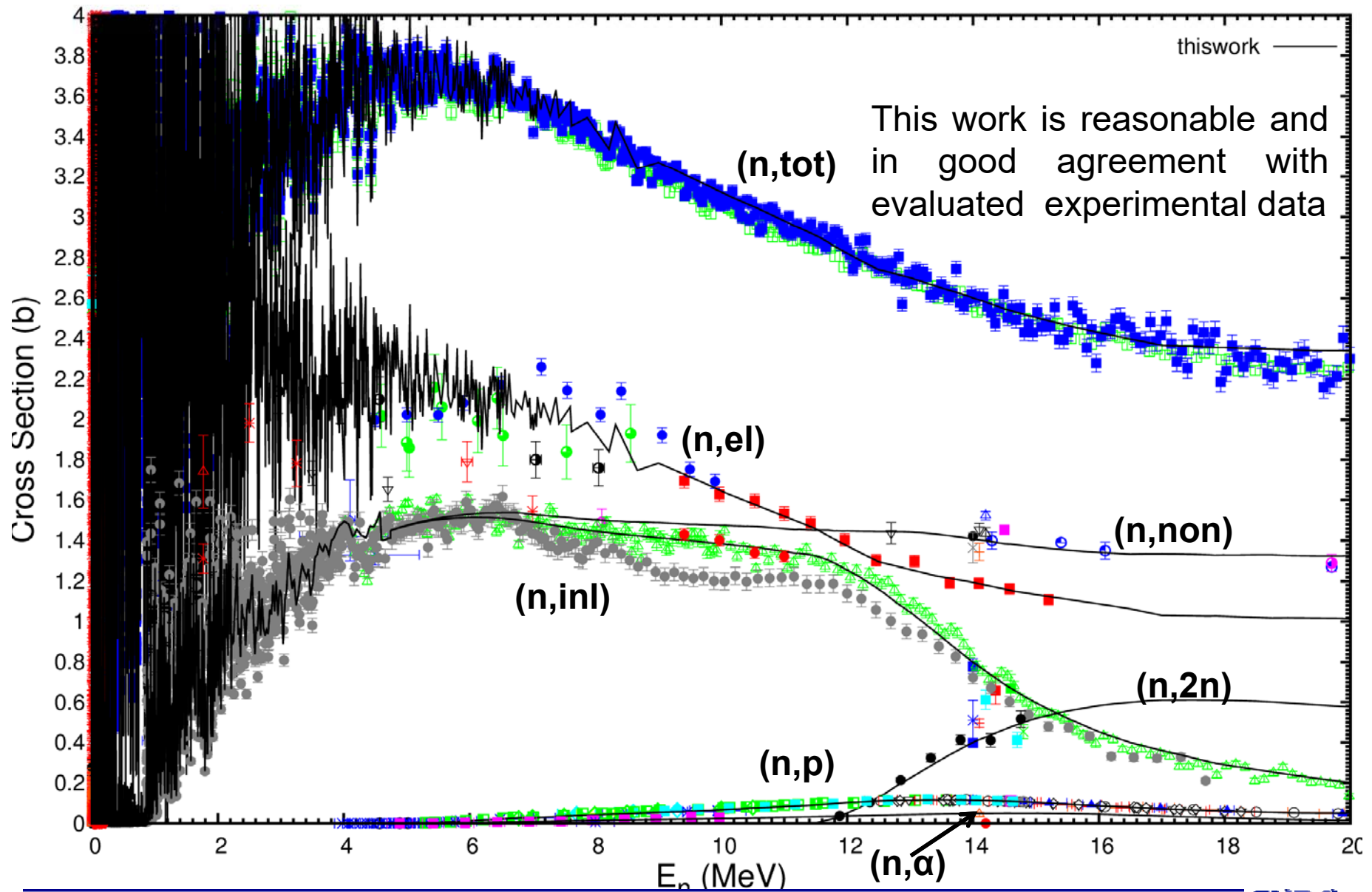




Elastic scattering  
angular distribution

# The relationship between each reactions

Presentation for the CIELO Meeting of the NEA  
9-11 May 2016 Paris, France

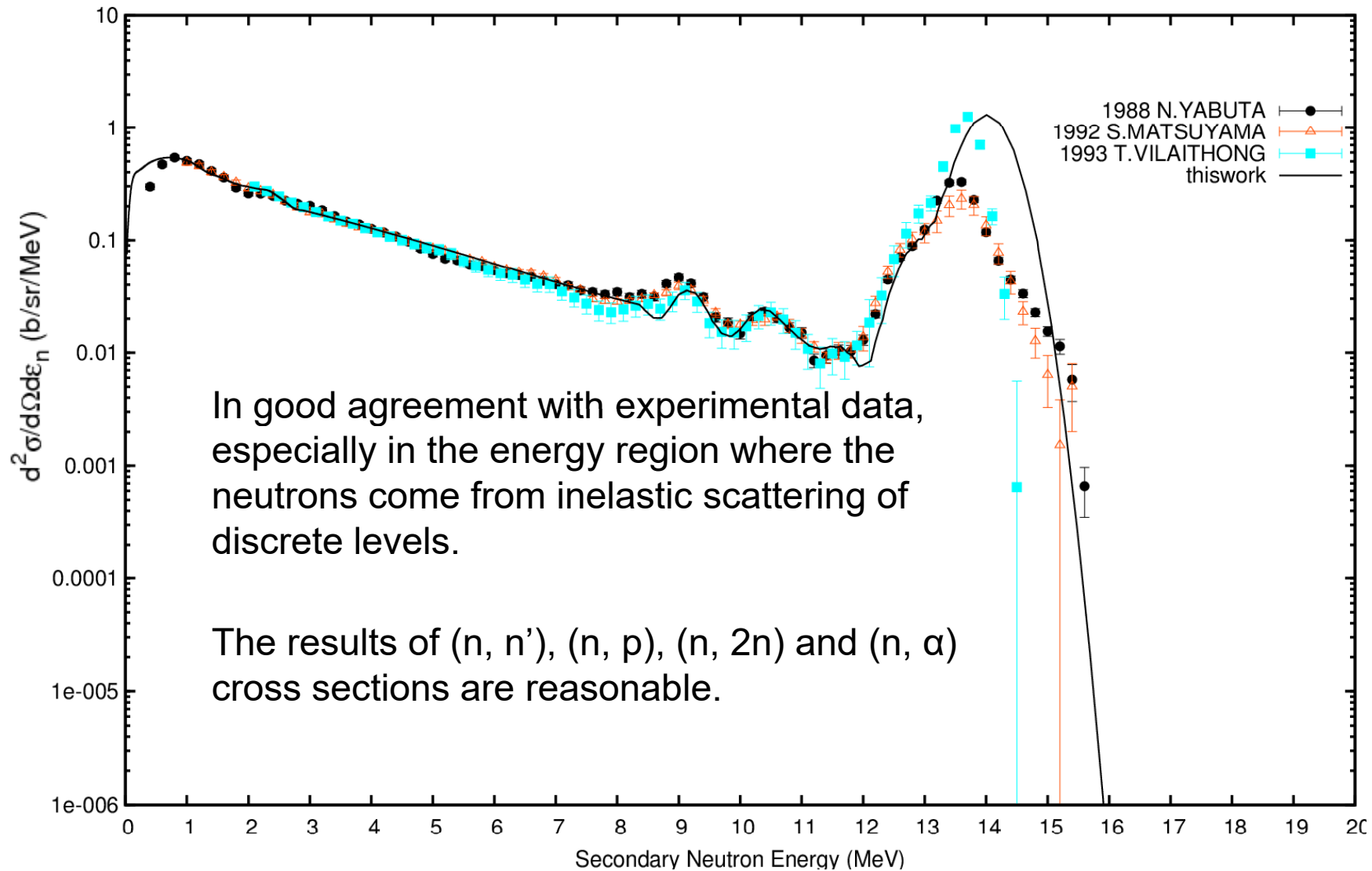




MF	MT	Data Source	
2	151	<p><b>Cielo –Iron-beta1</b></p> <p>A resonance evaluation was performed at ORNL (Leal) from 1.0e-5 eV to 2 MeV using transmission data taken at the LINAC (Danon) and inelastic cross section measurements done GEEL (Plompen).</p>	
3	1	ENDF/B-VII.1	
	4	Adopt GEEL2014 Exp Data(~6MeV)+ Fit Nelson2004Exp Data(6~20MeV)	
		3,51	Fit GEEL2014 Exp Data(~4.577MeV) + Theoretical calculated result(UNF) (4.577~20MeV)
		3,52~88	Theoretical calculated result(UNF)
		3,91	(3,4)-(3,51:88)
	16	Fit Exp Data and ENDF/B-VII.1	
	103	ENDF/B-VII.1	
	102, 104,105, 106,107	Theoretical calculated result(UNF)	
	3	(3,3)=(3,102)+(3,4)+(3,16)+(3,103)+(3,104)+(3,105)+(3,106)+(3,107)	
	2	(3,2)=(3,1)-(3,3)	
4	2	Theoretical calculated result(UNF)	
5, 6		<b>Theoretical calculated result(UNF)</b>	

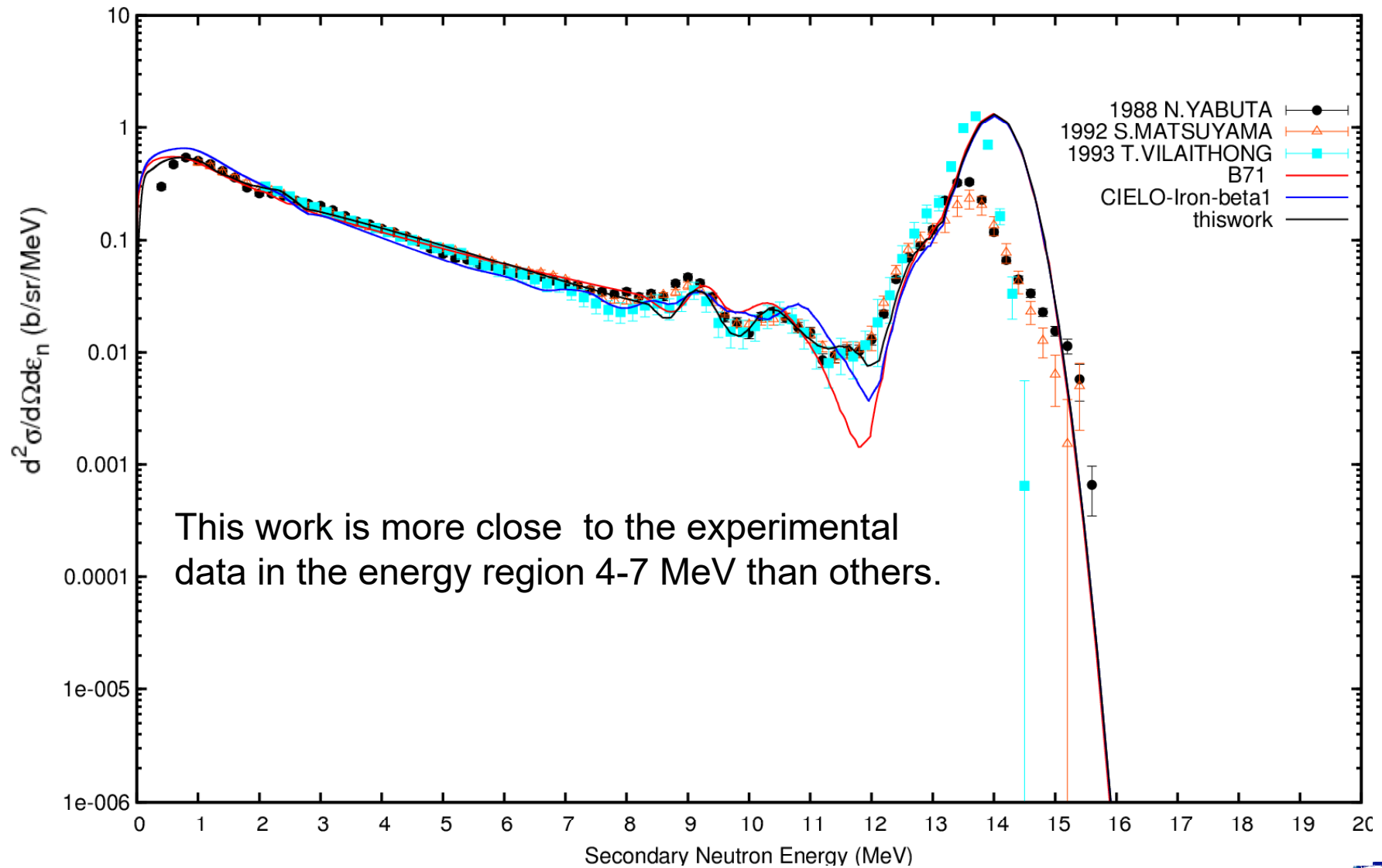


### $^{56}\text{Fe}(n,xn)$ DE 14.1MeV



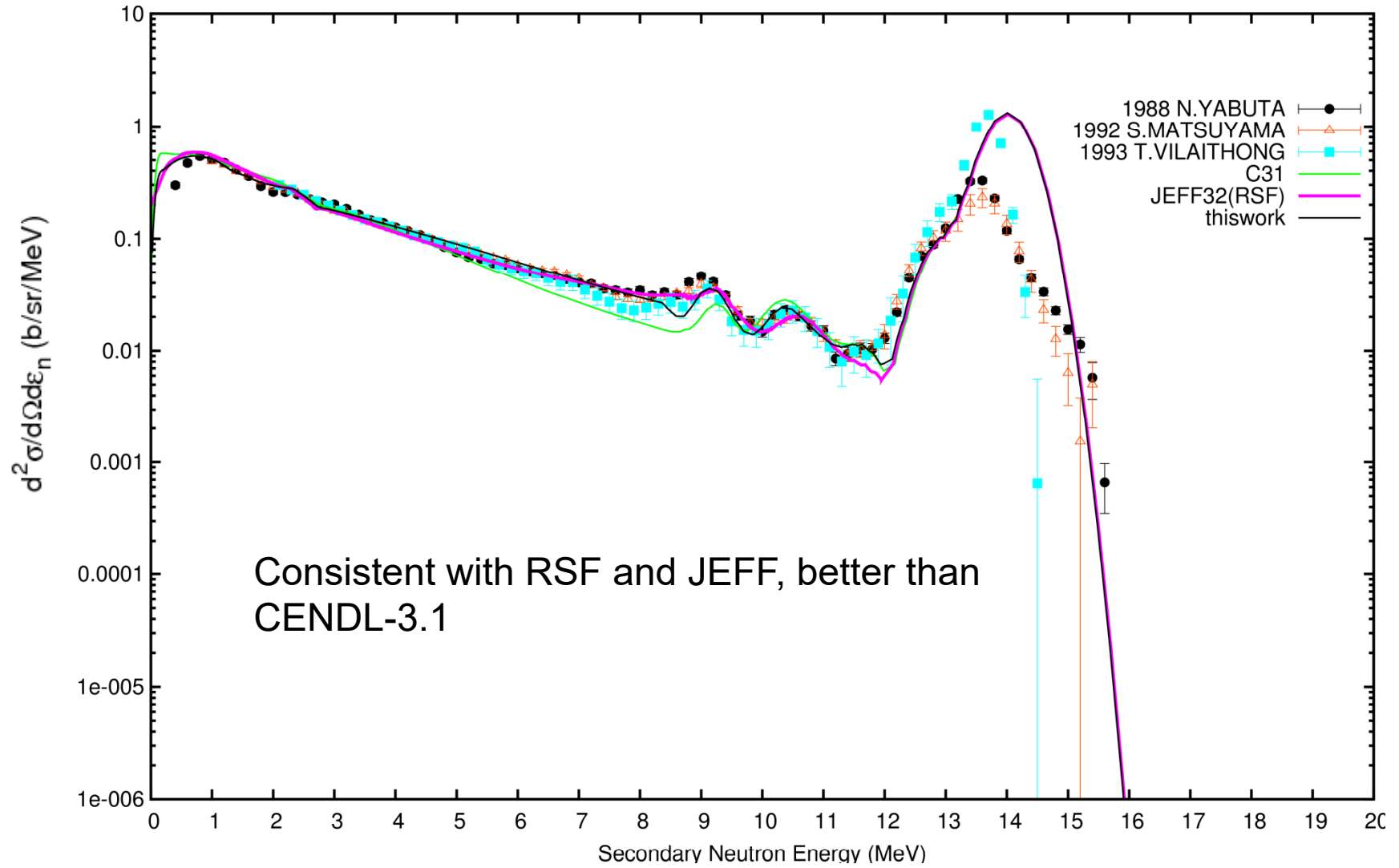


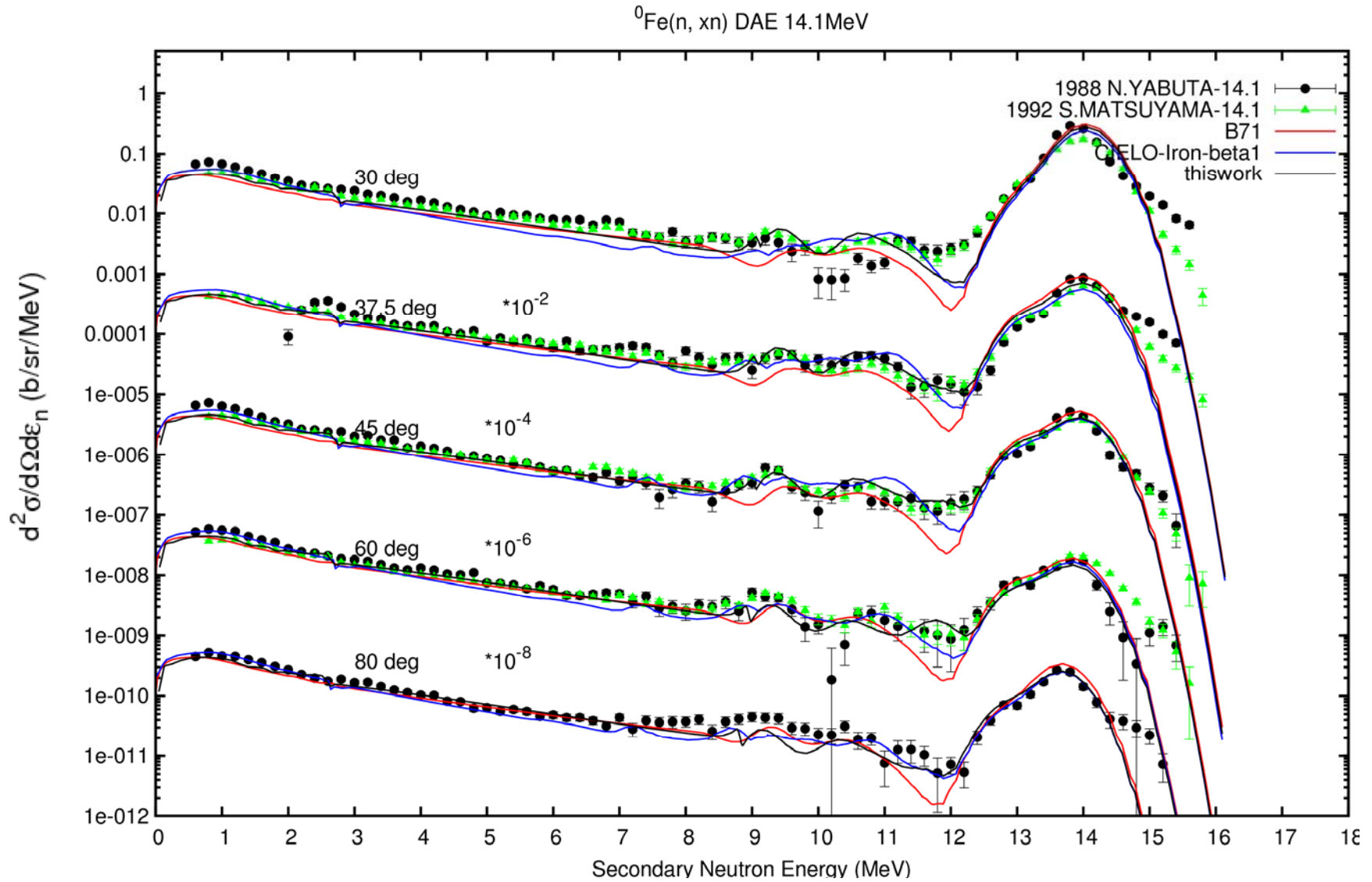
### $^{56}\text{Fe}(n,xn)$ DE 14.1MeV

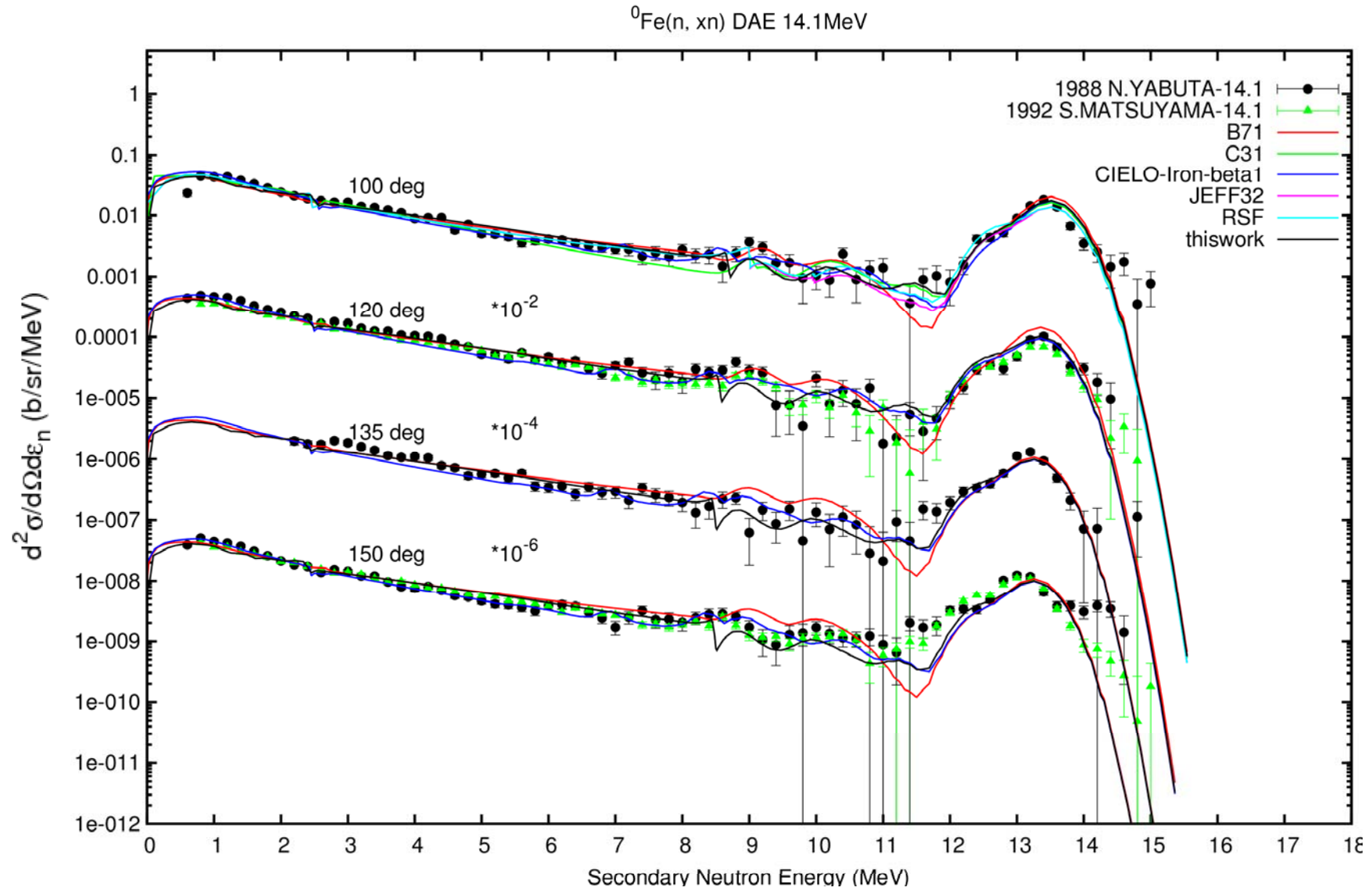




### $^{56}\text{Fe}(n,xn)$ DE 14.1MeV









- **Evaluation of all cross sections in fast range**
- **Integral Benchmarking**
- **Summary**



## ■ Integral Benchmarking

( By Huanyu Zhang, CNDC, China)

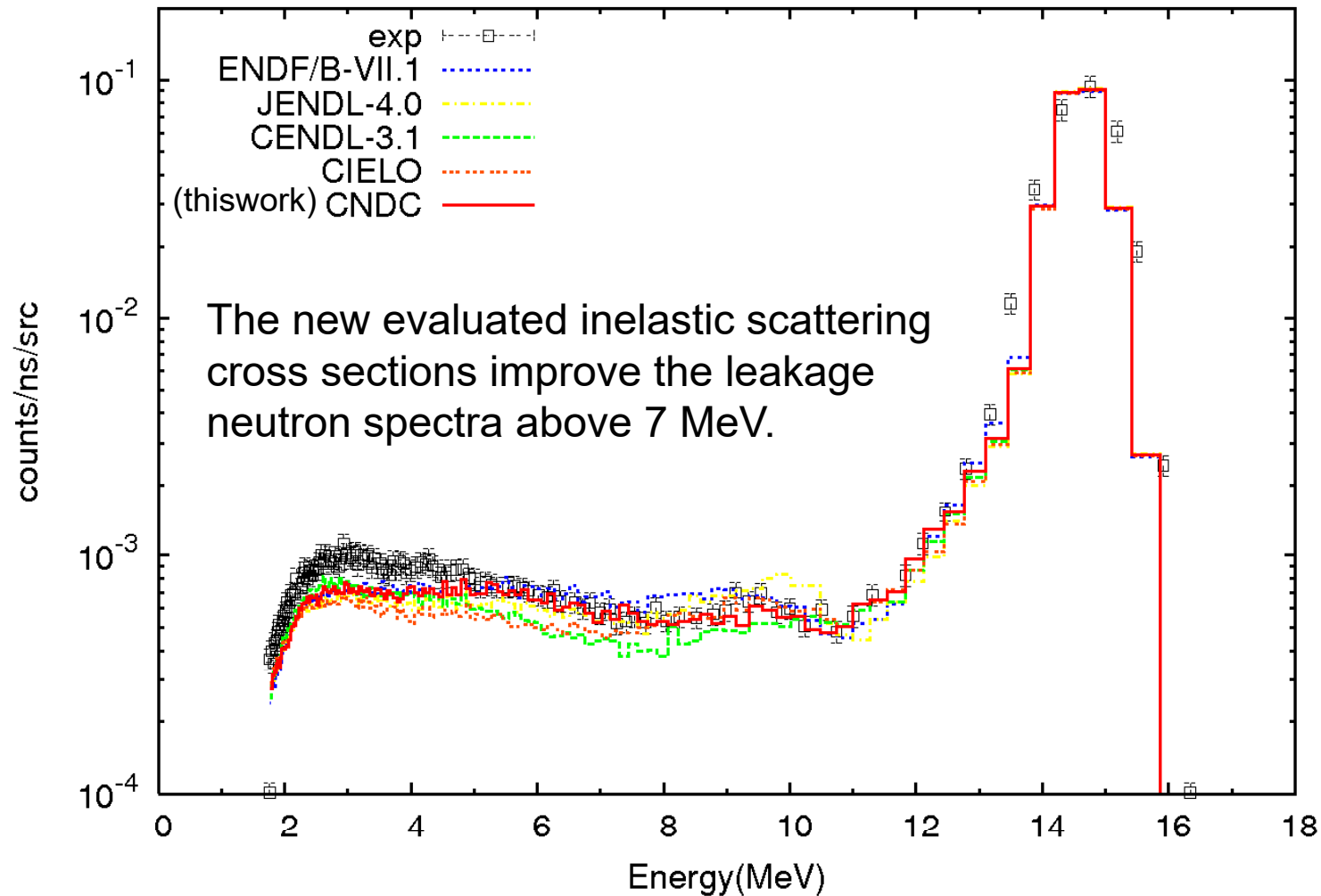
The new evaluated Fe-56 of this work were tested with shielding and criticality benchmarks by using MCNP5.

- Integral experiments
  - Lawrence Livermore National laboratory pulse sphere experiment
  - Neutron leakage spectra measurement in CIAE
  - 168 critical benchmarks was selected from ICSBEP (Fe-56 collision weight simulated by MCNP > 0.1).
- The evaluated Fe-56
  - CNDC (this work)
  - CIELO (Cielo-beta1)
- Comparison of benchmarking results
  - Other nuclides except Fe-56 in the benchmarks are from ENDF/B-VII.1.



# Comparison of Shielding Benchmarks Result

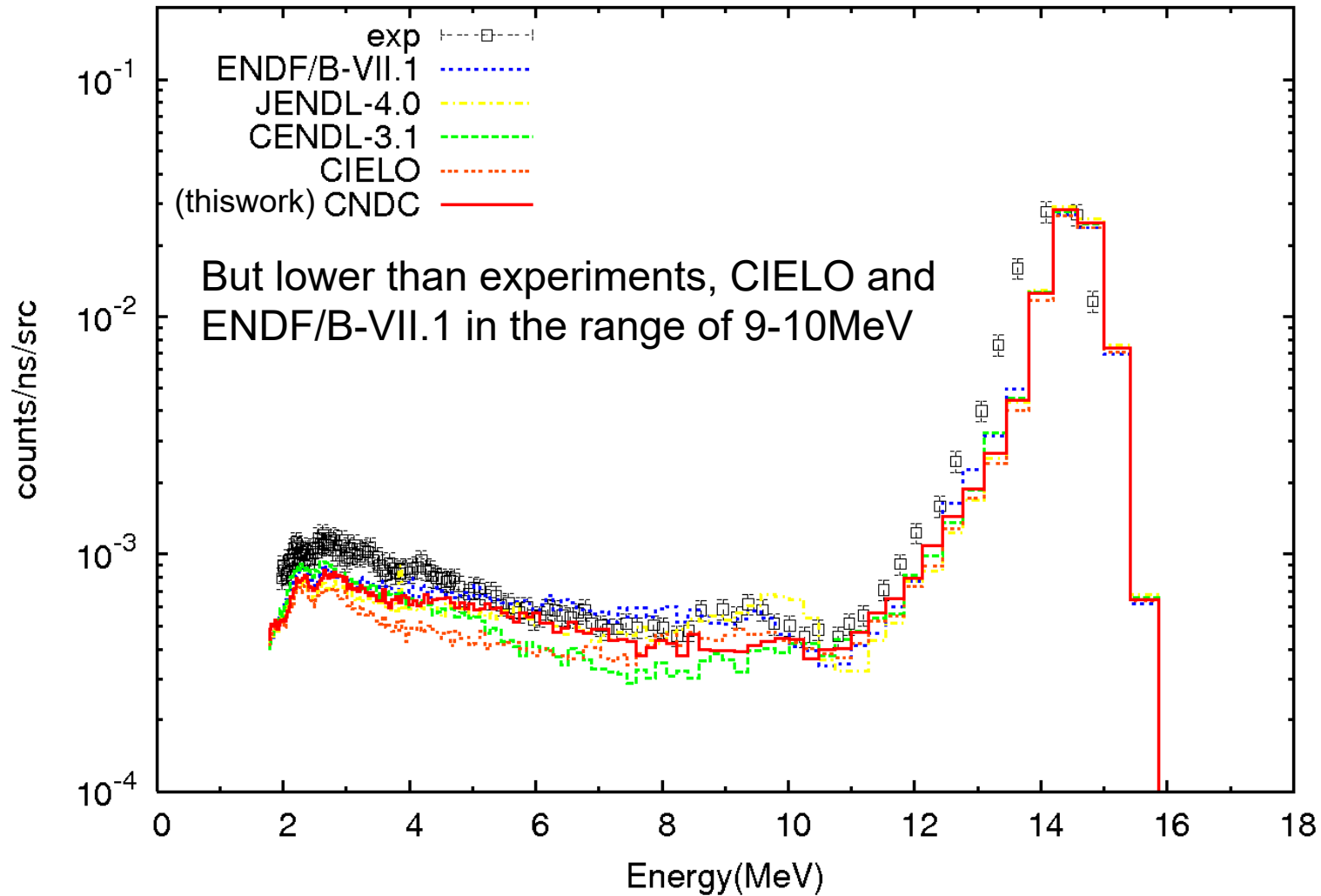
LLNL Plused Sphere, Fe, 0.9 mfp, NE213 1.6MeV bias, 766 cm 14.1MeV





## Comparison of Shielding Benchmarks Result (2)

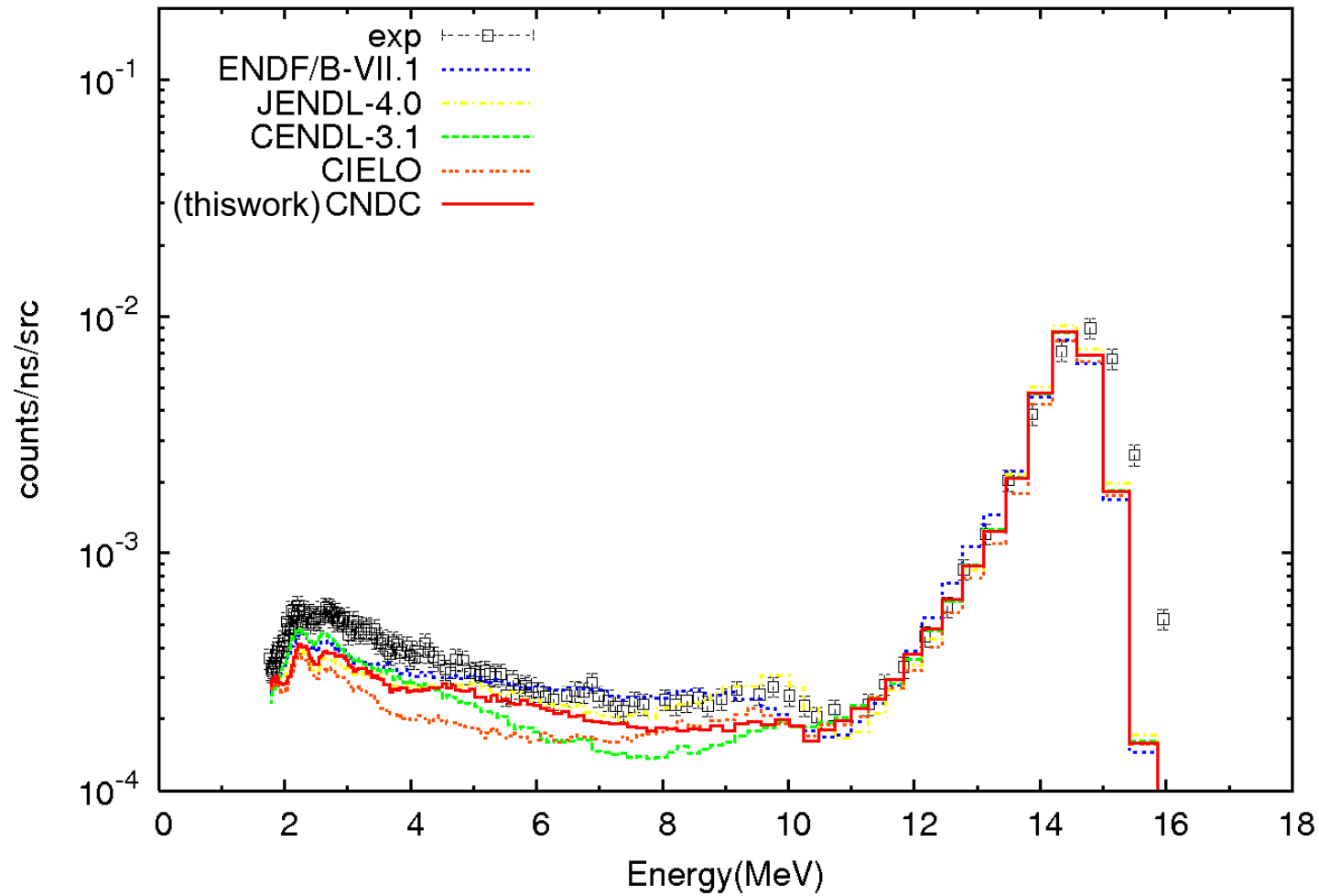
LLNL Plused Sphere, Fe, 3.0 mfp, NE213 1.6MeV bias, 766 cm 14.1MeV





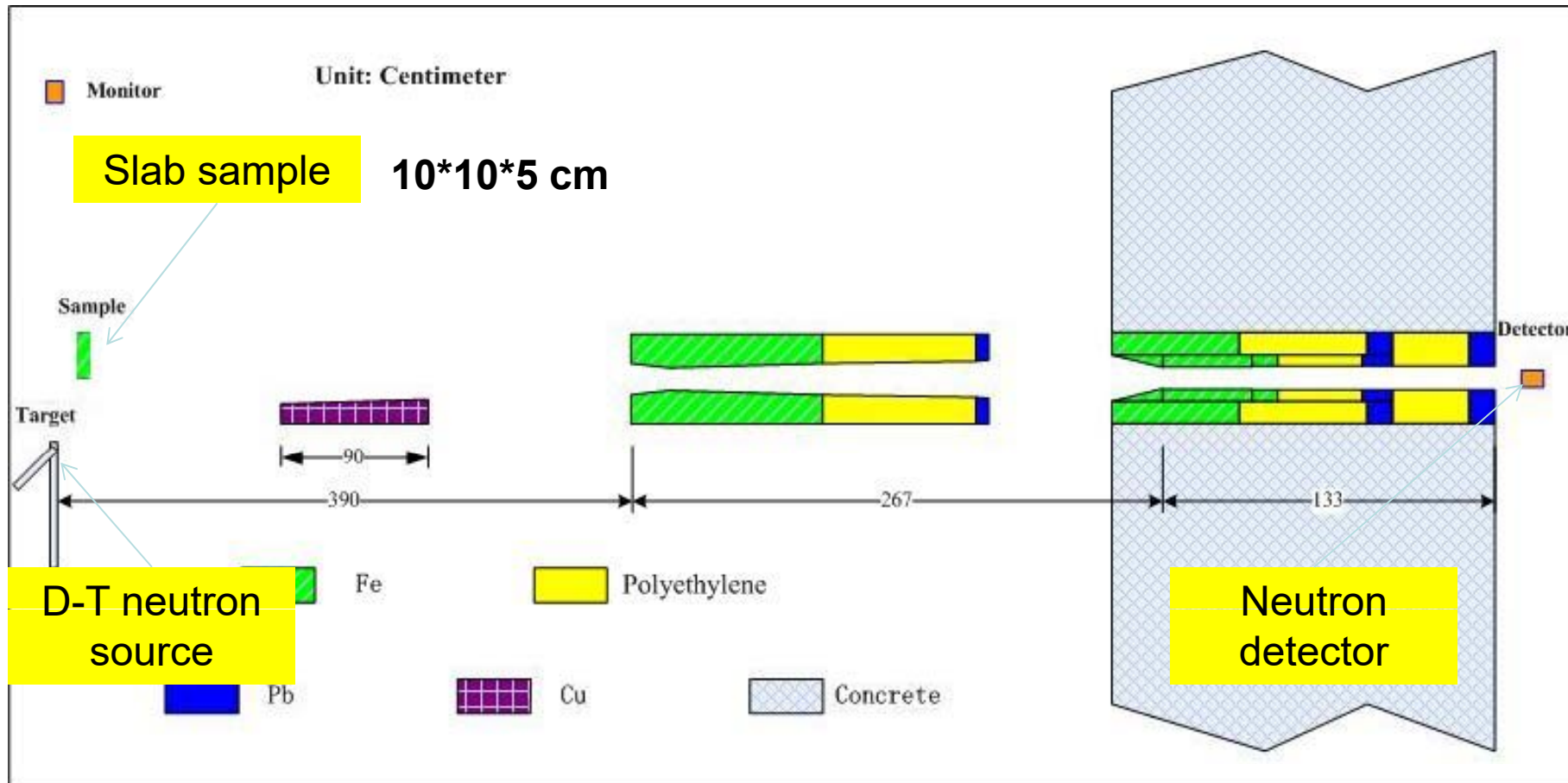
## Comparison of Shielding Benchmarks Result (3)

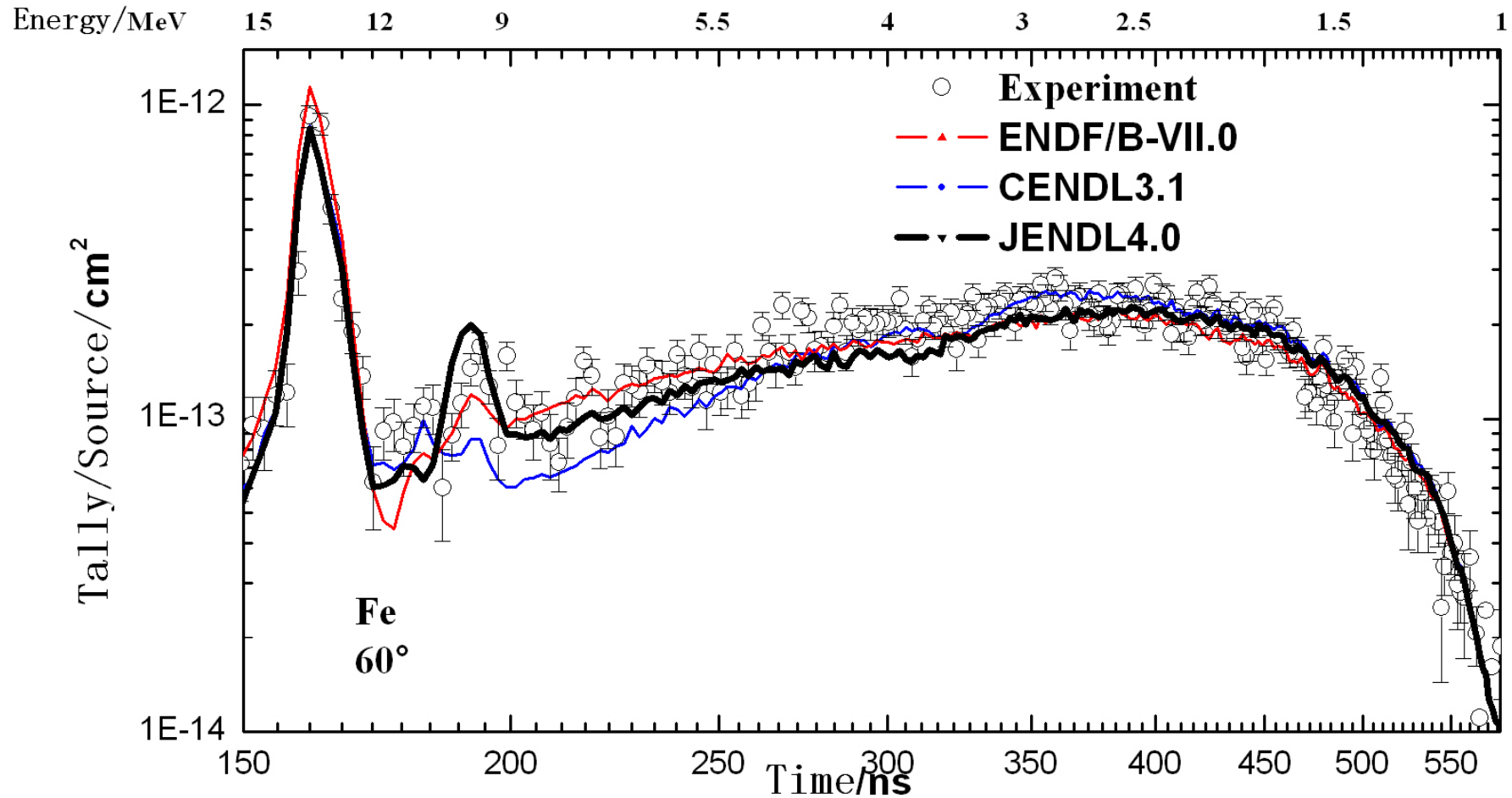
LLNL Plused Sphere, Fe, 4.8 mfp, NE213 1.6MeV bias, 766 cm 14.1MeV





# Neutron leakage spectra measurement induced by 14 MeV neutrons ( By Yangbo Nie, CIAE, China)





The experimental data is a preliminary result which is consistent with evaluated data. Our new evaluation will be compared with data later.



## ■ Integral Benchmarking

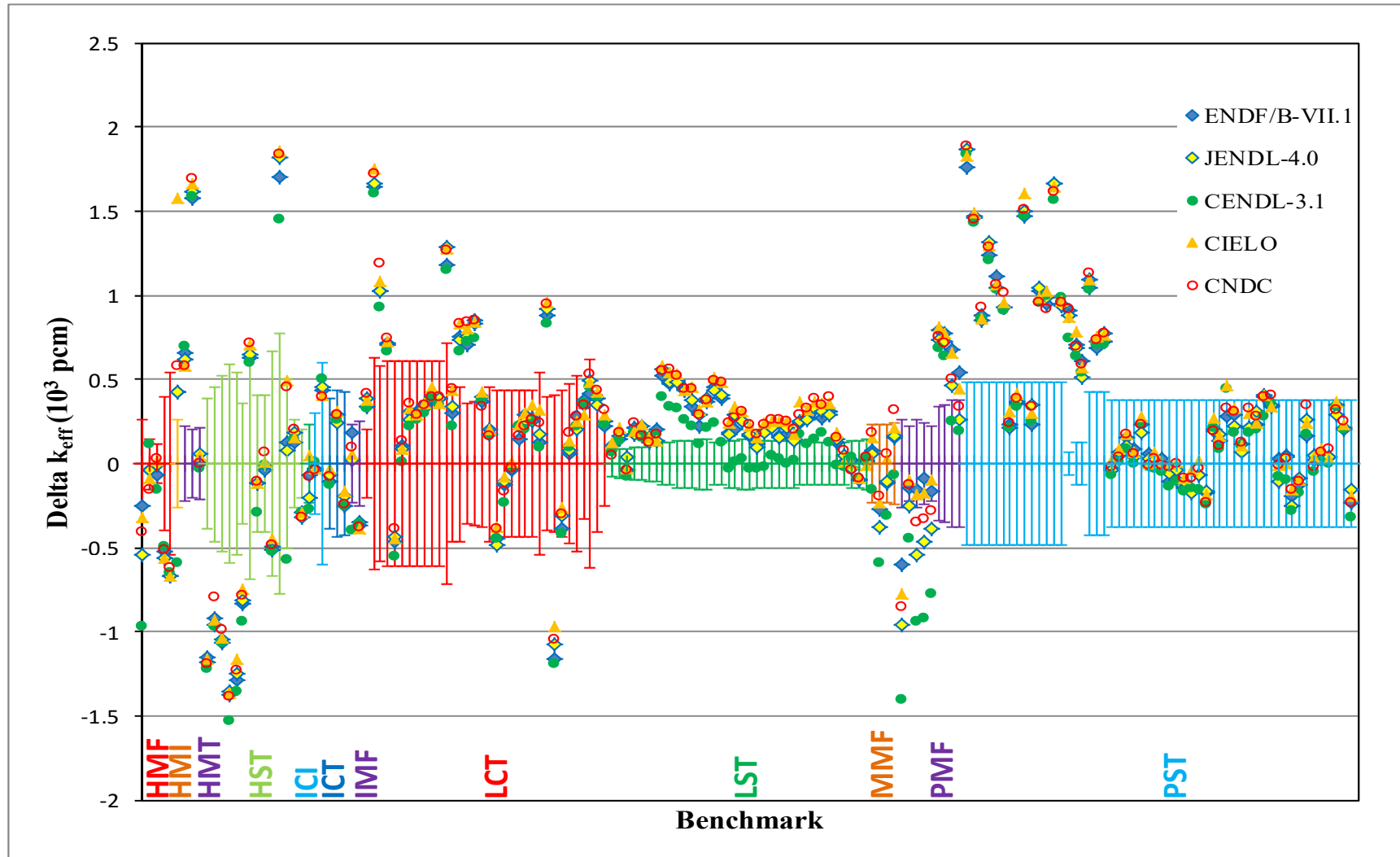
( By Huanyu Zhang, CNDC, China)

The new evaluated Fe-56 of this work were tested with shielding and criticality benchmarks by using MCNP5.

- Integral experiments
  - Lawrence Livermore National laboratory pulse sphere experiment
  - Neutron leakage spectra measurement in CIAE
  - **168 critical benchmarks was selected from ICSBEP (Fe-56 collision weight simulated by MCNP > 0.1).**
- The evaluated Fe-56
  - CNDC (this work)
  - CIELO (Cielo-beta1)
- Comparison of benchmarking results
  - Other nuclides except Fe-56 in the benchmarks are from ENDF/B-VII.1.

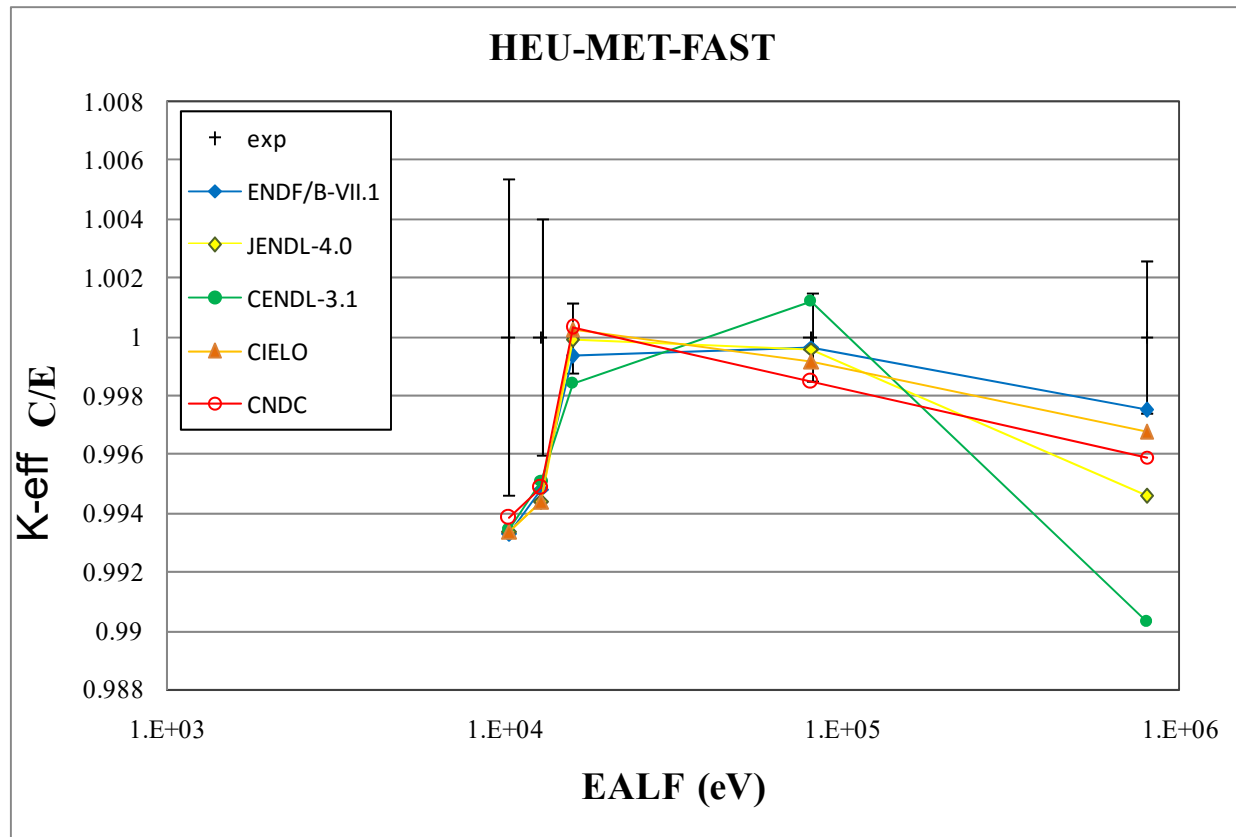


# Comparison of Critical Benchmarks Result

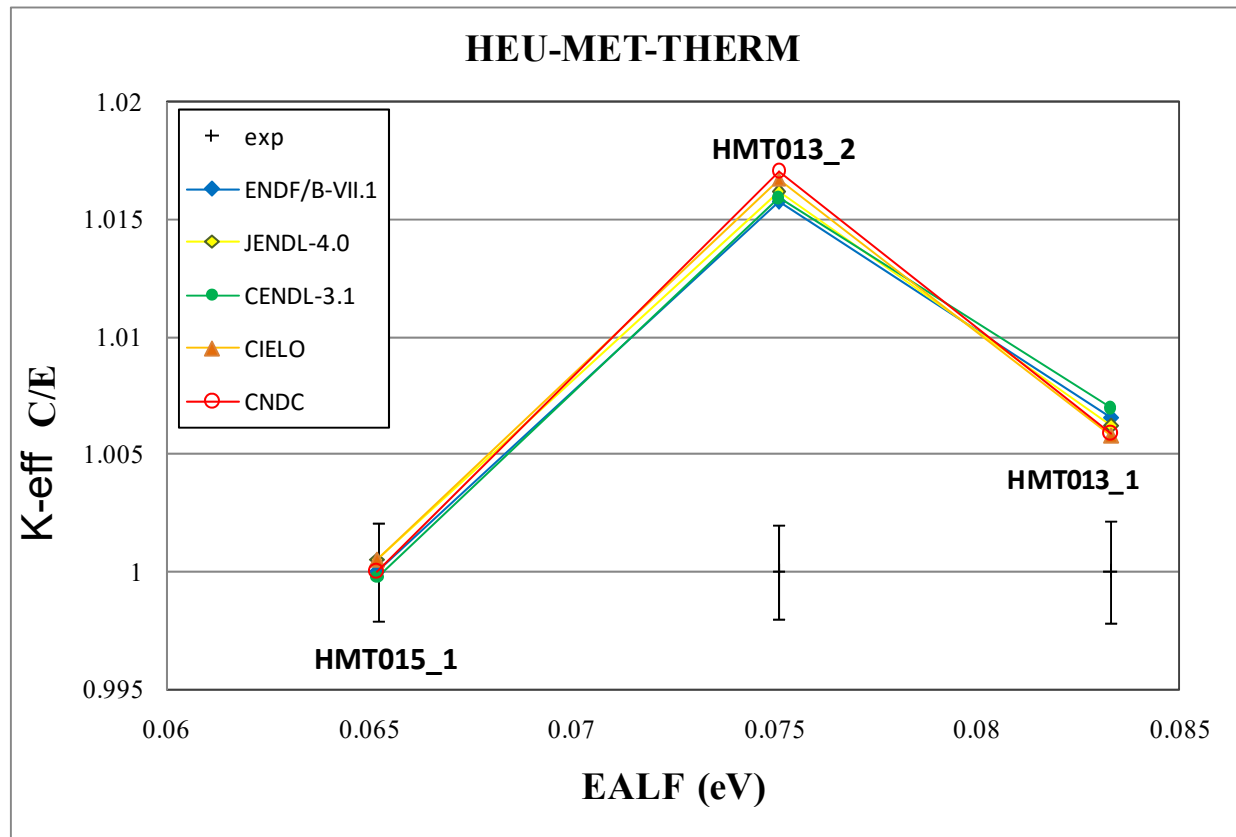




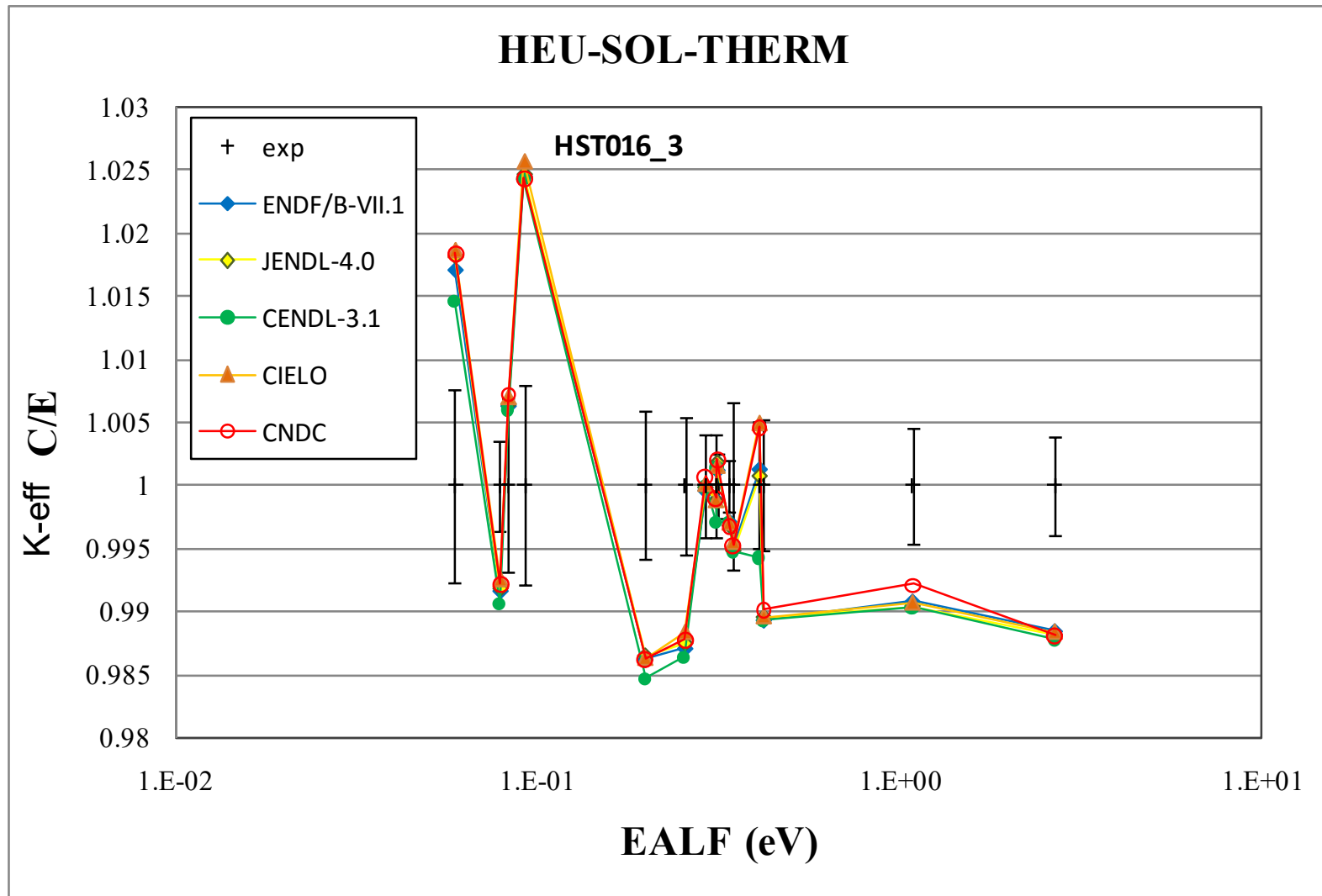
# Highly Enriched Uranium System



HMF021\_01, HMF024\_01, HMF034\_03, HMF048\_16, HMF048\_17



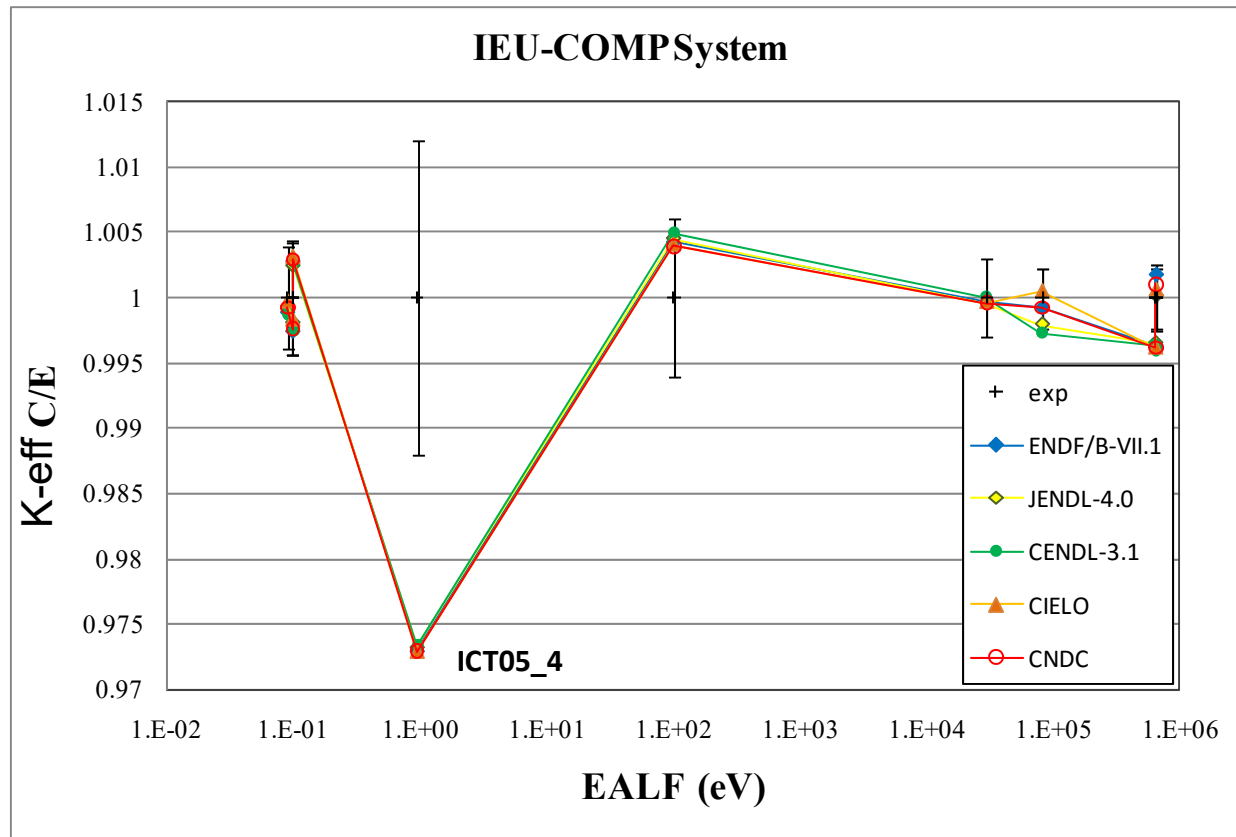
HMT013\_01, HMT013\_02, HMT015\_01



HST004\_03~06, HST006\_09, HST016\_01, HST016\_02, HST019\_01, HST019\_02,  
HST019\_03, HST020\_05, HST038\_15, HST049\_01, HST049\_09



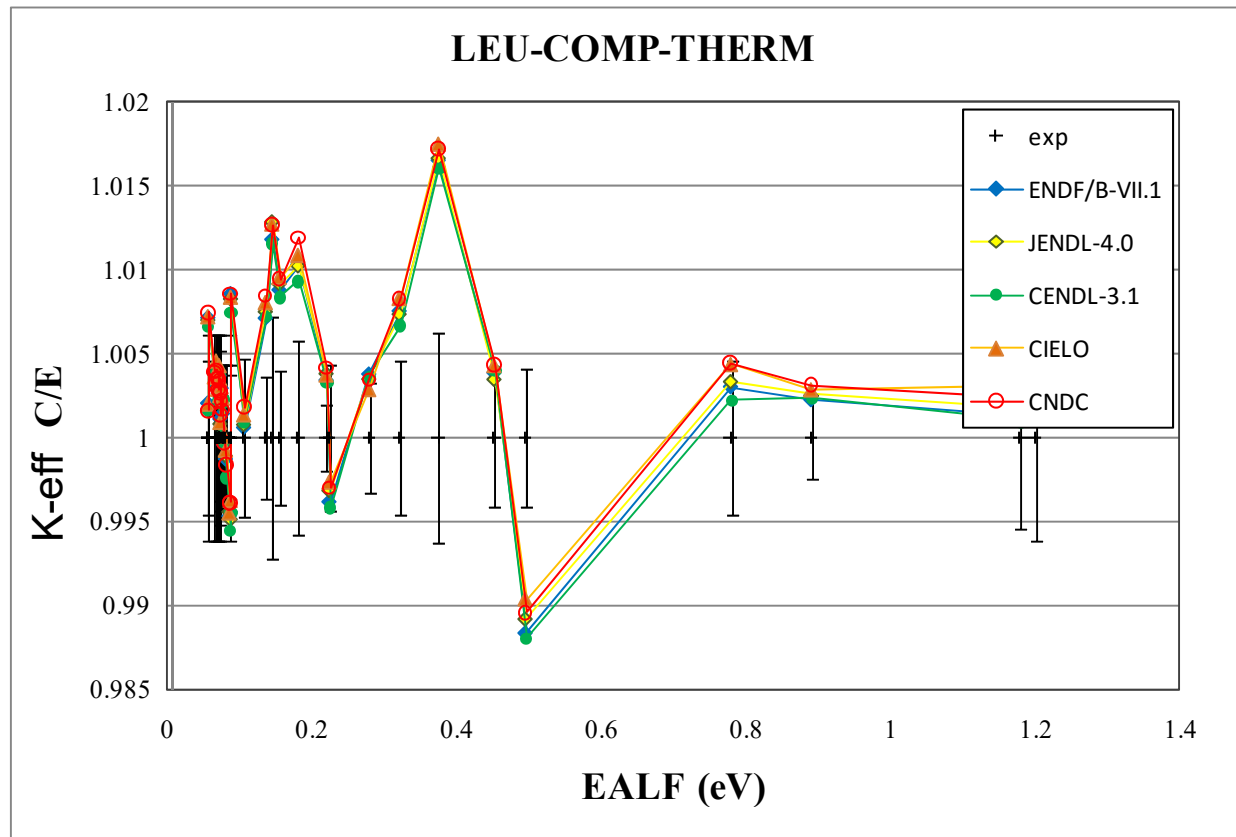
# Intermediate Enriched Uranium System



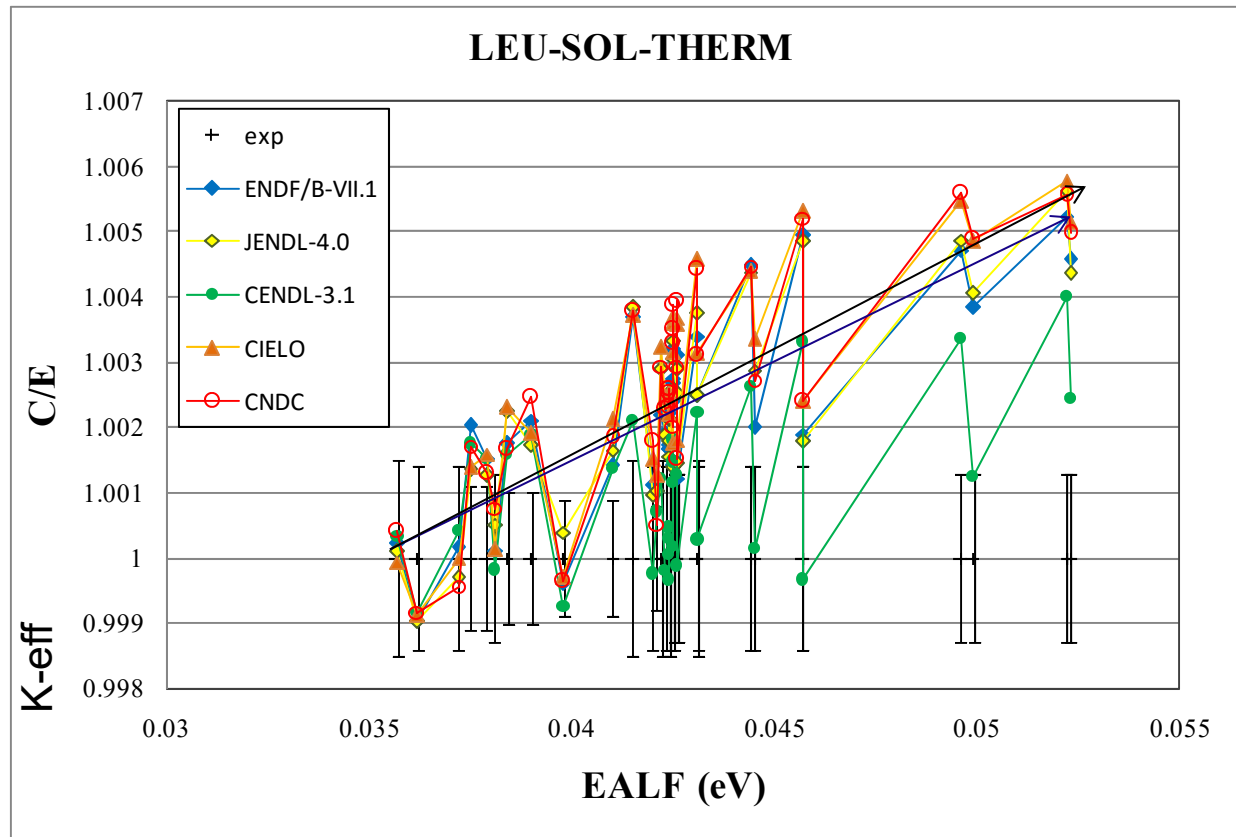
ICF001\_01, ICI001\_02, ICI001\_03, ICT002\_01, ICT002\_03, ICT002\_05



# Low Enriched Uranium System



LCT018\_01, LCT019\_01~03, LCT020\_01~07, LCT021\_01, LCT022\_01~06,  
LCT023\_01~06, LCT024\_01~02, LCT025\_01~04, LCT026\_01, LCT026\_03,  
LCT026\_05, LCT048\_01

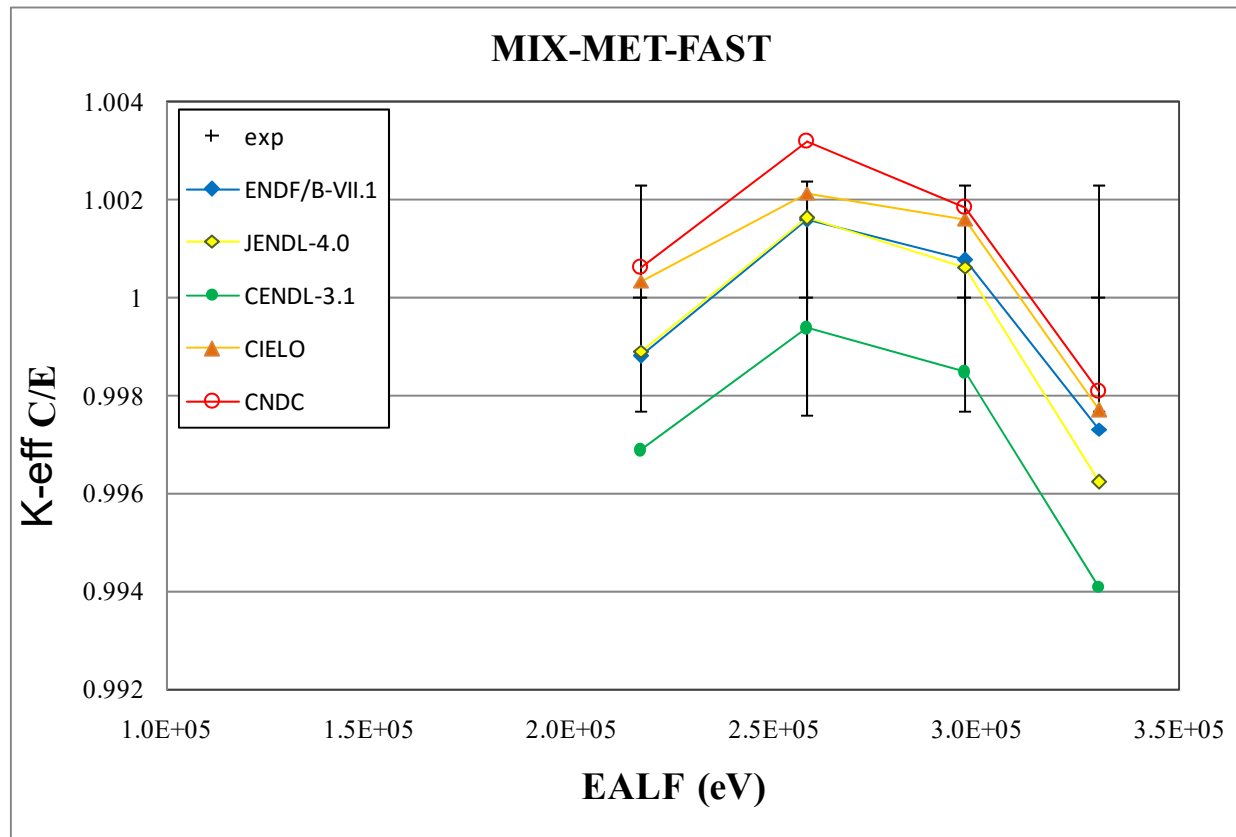


LST004\_01~07, LST016\_01~07, LST017\_01~06, LST018\_01~06,  
LST019\_01~05, LST020\_01~04

For LST system, the  $k_{\text{eff}}$  bias against  $EALF$  is related to Fe-56. The new evaluated RRP's cause the slope of the bias get a little large.



# ZPPR-21 Assemblies

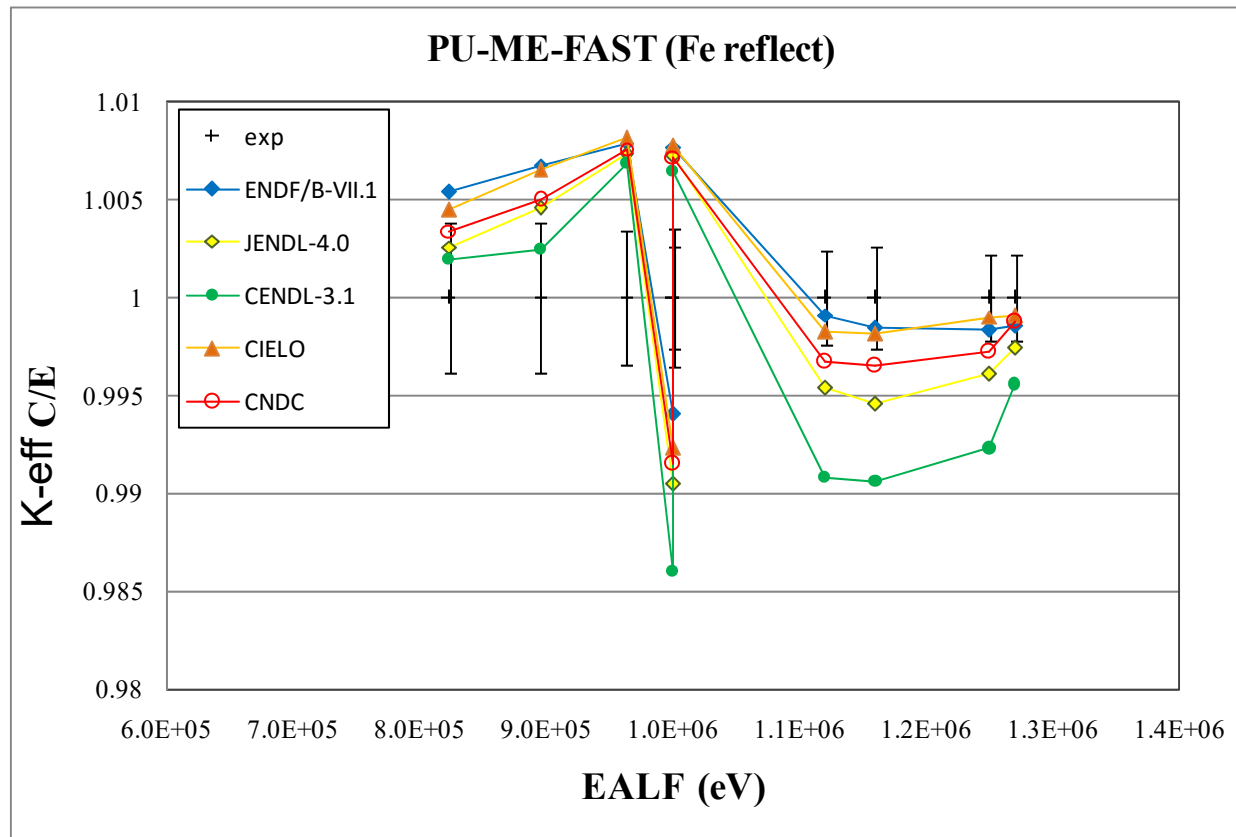


MMF011\_01 ~04

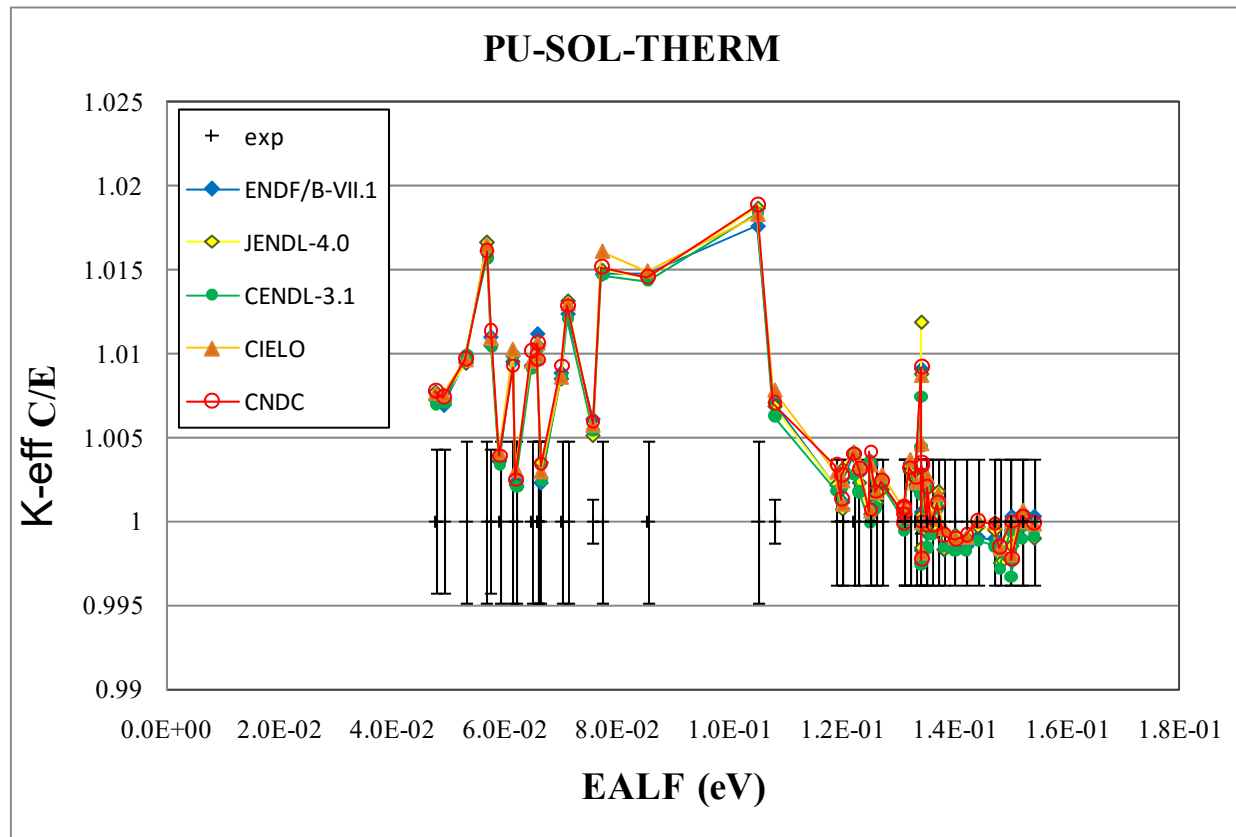
It is sensitive to  $^{56}\text{Fe}(n,\text{inl})$  and  $(n,\text{el})$  cross sections. The calculated results get worse or better than B71



# Plutonium system



PMF045\_07, PMF045\_06, PMF045\_02, PMF015, PMF045\_03, PMF028  
, PMF026, PMF032, PMF025



PST010\_01~14, PST012\_06~12, PST023\_01~34



- **Evaluation of all cross sections in fast range**
- **Integral Benchmarking**
- **Summary**



## ■ **summary**

- **Evaluation of all cross sections from CNDC in fast range was finished. The result is in good agreement with evaluated experimental data. Energy spectra and double differential cross sections for neutron emission show the cross sections are reasonable.**
- **Integral Benchmarking shows the new evaluated inelastic scattering cross sections improve the leakage neutron spectra above 7 MeV.**
- **The results of CNDC show good agreements with those results from CIELO. But no significant improvement was found in criticality benchmarks.**