The Evaluated Nuclear Reaction Data for fusion at CNDC

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China Nuclear Data Center， CIAE

2025.05

Outlines

Introduction

Nuclear Reaction Study

Perspective

Nuclear Reaction Study

- Platform for Theoretical Models
- Nuclear Data Improvement
- Covariance Evaluations
- AI and Nuclear Data Evaluation

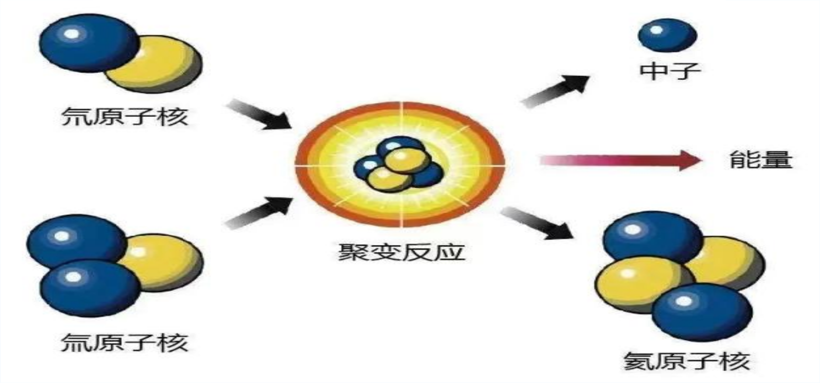
Fusion energy

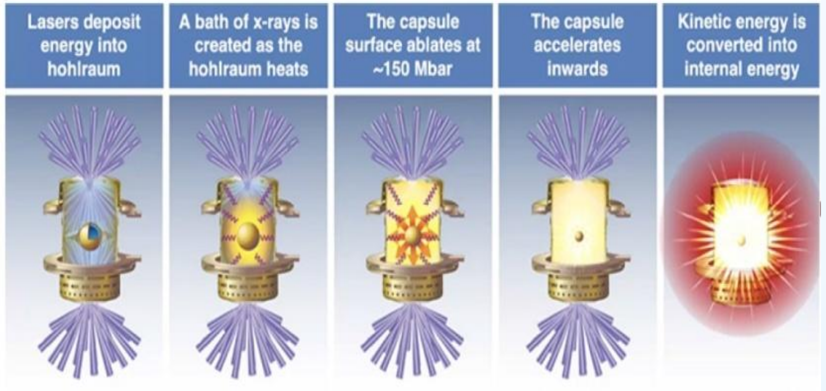
$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

Fusion energy follows the principle of nuclear fusion, where light atomic nuclei (e.g., deuterium and tritium) merge under extreme heat/pressure to form heavier nuclei (helium).

Neutron, and electrons emission as well as vast energy releasing via mass-to-energy conversion ($E=mc^2$), will provide huge energy source.

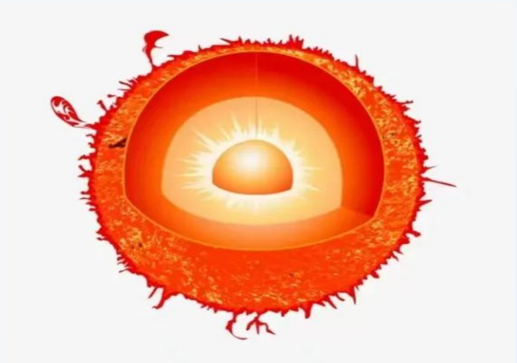
Ultra-high Temperature Plasma Environment





Alternative to fossil fuels, offering zero-carbon operation and virtually inexhaustible fuel supplies.

Earth' s oceans harbor 45 trillion tons of deuterium, enough to sustain global energy demand for tens of billions of years



Average energy released per nucleon in fusion 3.6MeV

Average energy released per nucleon in fission 0.85MeV

General Information of CNDC

Nuclear data study started in 60's last century by measurements with the first reactor and cyclotron in CIAE, China Nuclear Data Center (CNDC) was established in 1975 and joined the nuclear data activities of IAEA as the national nuclear data center of China since 1984. As a window, CNDC has been open to the world since 1978. and CNDC has established a good cooperative relationship with the IAEA, OECD/NEA, and major nuclear data centers and institutions in the world.

The main task of CNDC:

- ✓ The management of domestic nuclear data activities.
- ✓ The nuclear data evaluations, libraries and relevant methodology studies.
- ✓ Nuclear data measurements and methodology studies
- ✓ The exchange of nuclear data activities with IAEA, foreign nuclear data centers and agencies.
- ✓ The services for domestic and foreign nuclear data application users.

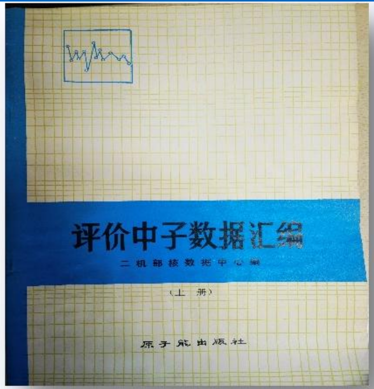
Mainly tasks of CNDC in 2025：

- ✓ New Five Years Plan (2021-2025) for nuclear data (CENDL Project).
- ✓ Data evaluation for next CENDL version and sub-libraries
- ✓ Methodological studies of nuclear data evaluation(incl. theoretical and experimental for fission process…).
- ✓ Nuclear data measurements and related methodological studies.(Mr.Ruan)
- ✓ The compilations for EXFOR.
- ✓ Nuclear data services.

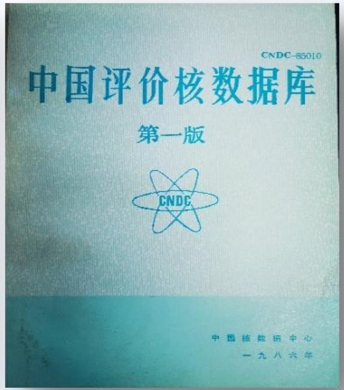
The 1st reactor and cyclotron in China

Introduction

Nuclei	Edited ~ 1979, 16	CENDL-1, 1986, 36	CENDL-2 1991, 66	CENDL-3.1 2010, 240	CENDL-3.2 2020, 272
Few body	^{1,2,3}H,^{3,4}He	^{1,2,3}H,^{3,4}He	^{1,2,3}H,^{3,4}He	^{1,2,3}H,^{3,4}He	nn-1, ^{1,2,3}H,^{3,4}He
Light	^{6}, ^{7}Li, ^{9}Be	^{6,7}Li,^{9}Be,^{10,11}B,^{14}N,^{16}O,^{19}F	^{6,7}Li,^{9}Be,^{10,11}B,^{14}N,^{16}O,^{19}F	^{6,7}Li,^{9}Be,^{10,11}B,^{12}C,^{14}N,^{16}O,^{19}F	Same
Medium heavy	^{0}Pb, ^{0}W, ^{0}Al, ^{0}Fe	19 nuclei ^{23}Na, ^{0}Mg, ^{27}Al, ^{0}Si, ^{0}V, ^{0}Cr, ^{0}Fe, ^{0}Ni, ^{0}Cu, ^{0}Zn, ^{0}Zr,^{93}Nb, ^{0}Mo,^{0}Sn, ^{0}Hf, ^{181}Ta, ^{0}W, ^{197}Au, ^{0}Pb	45 nuclei ^{23}Na, ^{0}Mg, ^{27}Al, ^{0}Si, ^{31}P, ^{0}S, ^{0}K, ^{0}Ca,^{0}Ti ^{0}V, ^{0,50,52,53,54,55}Cr, ^{55}Mn ^{0,54,56,57,58}Fe, ^{59}Co, ^{0}Ni, ^{0,63,65}Cu, ^{0}Zn, ^{0}Zr,^{93}Nb, ^{0}Mo,^{0,107,109}Ag, ^{0}Cd, ^{0}In, ^{0}Sn, ^{0}Sb, ^{0}Lu, ^{0}Hf, ^{181}Ta, ^{0}W, ^{197}Au, ^{0}Hg, ^{0}Tl, ^{0}Pb	192 nuclei ^{23}Na~^{208}Pb	223 nuclei ^{23}Na~^{208}Pb
Actinides	^{235,238}U,^{239,240}P	^{235}, ^{238}U, ^{239,240}Pu	8 nuclei ^{235}, ^{238}U, ^{237}Np, ^{239,240}Pu, ^{241}Am, ^{249}Bk, ^{249}Cf	34 nuclei ^{232}Th~^{249}Cf	34 nuclei ^{232}Th~^{249}C


评价中子数据汇编

原子能出版社


CNDC-85010

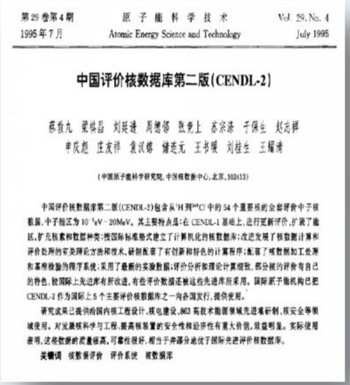
中国评价核数据库

第一版

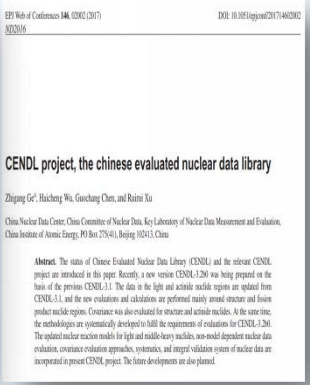
CNDC

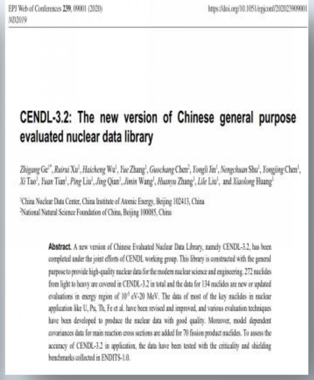
中国核数据中心

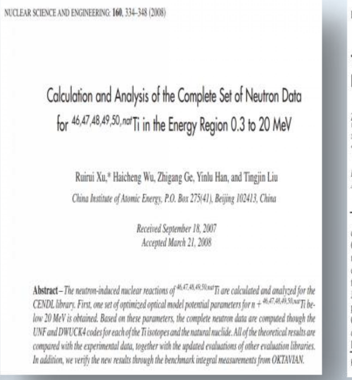
一九八六年


第29卷第4期 1995年7月 原子能科学技术 Atomic Energy Science and Technology Vol. 29, No. 4 July 1995

中国评价核数据库第二版(CENDL-2)

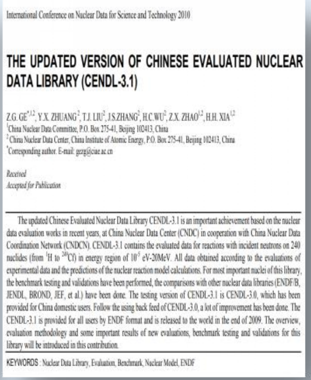

CENDL project, the chinese evaluated nuclear data library


CENDL-3.2: The new version of Chinese general purpose evaluated nuclear data library


NUCLEAR SCIENCE AND ENGINEERING: 160, 334–348 (2008)

Calculation and Analysis of the Complete Set of Neutron Data for ^{46,47,48,49,50,nat}Ti in the Energy Region 0.3 to 20 MeV

Ruirui Xu, Haicheng Wu, Zhigang Ge, Yinlu Han, and Tingjin Liu


International Conference on Nuclear Data for Science and Technology 2010

THE UPDATED VERSION OF CHINESE EVALUATED NUCLEAR DATA LIBRARY (CENDL-3.1)

The New Evaluation Project & Data in CENDL-4.0（2025. 12）

Nuclear	CENDL-4.0-v1 共 A=410, Z=86
Light Elements (A=17) (Z=10)	^{1}n, ^{1,2,3}H, ^{3,4}He, ^{6,7}Li, ^{9}Be, ^{10,11}B, ^{12,13}C, ^{14,15}N, ^{16}O, ^{19}F
Fission Products & Medium Elements (A=359) (Z=69)	^{22,23}Na, ^{24,25,26}Mg, ^{27}Al, ^{28,29,30}Si, ^{31}P, ^{32,33,34,36}S, ^{35,37}Cl, ^{39,40,41}K, ^{40,42,43,44,46,48}Ca, ^{46,47,48,49,50}Ti, ^{50,51}V, ^{50,52,53,54}Cr, ^{55}Mn, ^{54,56,57,58}Fe, ^{59}Co, ^{58,59,60,61,62,64}Ni, ^{63,65}Cu, ^{64,65,66,67,68,70}Zn, ^{69,71}Ga, ^{70,71,72,73,74,75,76,77,78}Ge, ^{74,75}As, ^{74,76,77,78,79,80,82}Se, ^{79,81}Br, ^{78,80,81,82,83,84,85,86,87,88}Kr, ^{85,86,87}Rb, ^{84,86,87,88,89,90}Sr, ^{89,90,91}Y, ^{90,91,92,93,94,95,96}Zr, ^{93,94,95,96}Nb, ^{92,93,94,95,96,97,98,99,100}Mo, ^{99,104}Tc, ^{96,98,99,100,101,102,103,104,105,106}Ru, ^{103,105}Rh, ^{102,104,105,106,107,108,110}Pd, ^{107,109,111}Ag, ^{106,108,109,110,111,112,113,114,115,116}Cd, ^{113,115}In, ^{112,113,114,115,116,117,118,119,120,122,123,124,125,126,128}Sn, ^{121,122,123,124,125,126,127}Sb, ^{120,122,123,124,125,126,127,128,130,132}Te, ^{127,129,130,131,133,135}I, ^{123,124,126,128,129,130,131,132,133,134,135,136}Xe, ^{133,134,135,136,137}Cs, ^{130,132,133,134,135,136,137,138,139,140}Ba, ^{138,139,140}La, ^{136,138,139,140,141,142,143,144}Ce, ^{141,142,143,145}Pr, ^{142,143,144,145,146,147,148,149,150}Nd, ^{147,148,148m,149,150,151}Pm, ^{144,145,146,147,148,149,150,151,152,153,154}Sm, ^{151,152,153,154,155,156,157}Eu, ^{152,153,154,155,156,157,158,159,160,161}Gd, ^{157,158,159,160,161}Tb, ^{156,157,158,159,160,161,162,163,164,165}Dy, ^{163,165,166}Ho, ^{162,164,166,167,168,169,170}Er, ^{168,169,170,171}Tm, ^{168,169,170,171,172,173,174,175,176}Yb, ^{175,176,177}Lu, ^{174,176,177,178,179,180,181}Hf, ^{180,181,182}Ta, ^{180,182,183,184,186,187,188}W, ^{185,187}Re, ^{191,193}Ir, ^{197}Au, ^{196,198,199,200,201,202,204}Hg, ^{203,205}Tl, ^{204,206,207,208}Pb, ^{209}Bi
Actinides (A=34) (Z=7)	^{232}Th, ^{232,233,234,235,236,237,238,239,240,241}U, ^{236,237,238,239}Np, ^{236,237,238,239,240,241,242,243,244,245,246}Pu, ^{240,241,242,242m,243,244}Am, ^{249}Bk, ^{249}Cf

~ neutron data of 30 nuclei are being improved based on the new experimental data

light elements: ^{6}Li, ^{9,10,11}B, ^{12,13,14,15}C, ^{14,15}N

Medium elements: ^{27}Al, ^{50,51}V, ^{52}Cr, $^{54,56-58}$Fe, ^{69,71}Ga, ^{95}Mo, $^{204,206-208}$Pb

Actinides: ^{235,238}U, ^{239,240,241}Pu

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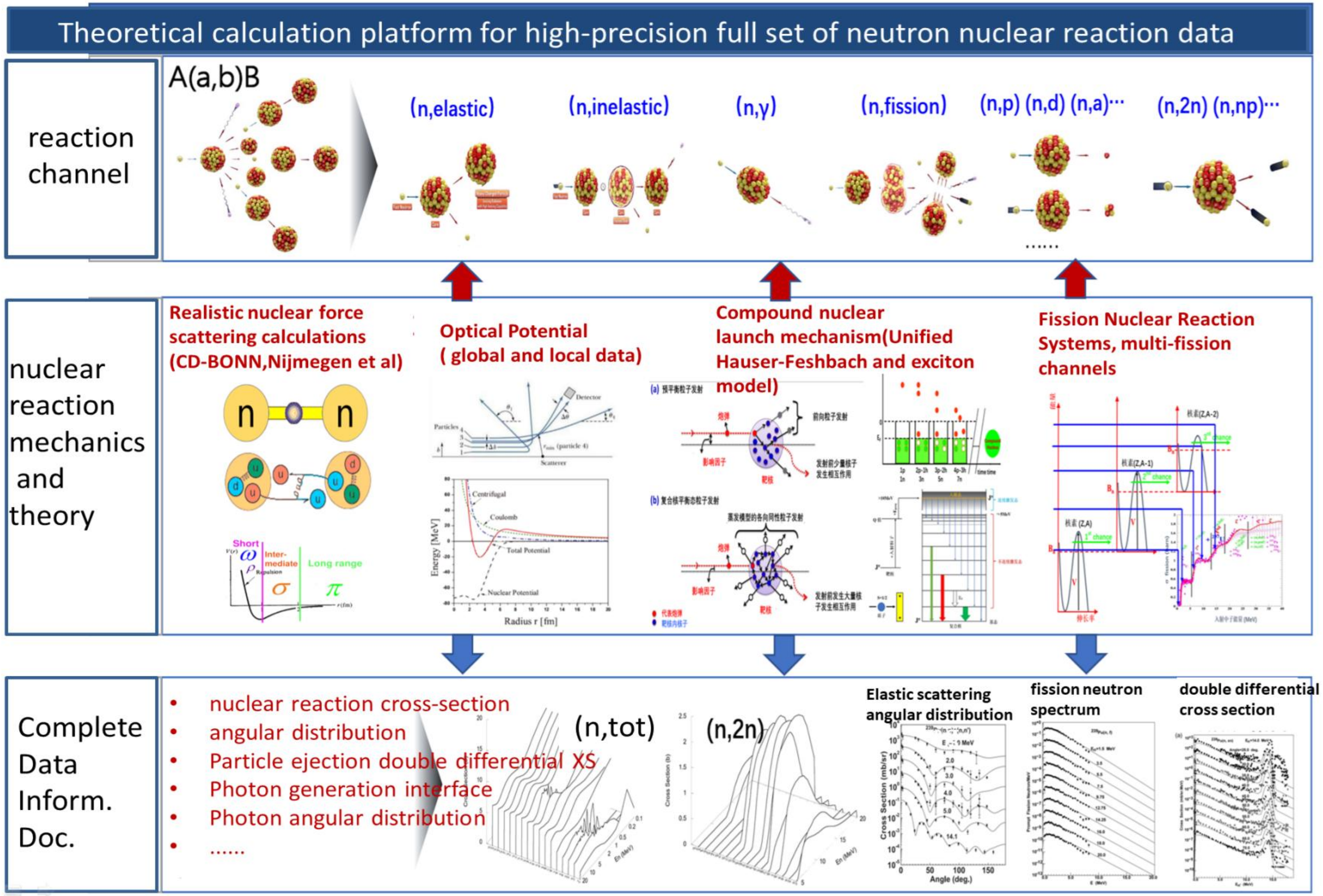
Platform of Chinese Theoretical Model for nuclear reaction

For Nuclear Data — Neutron and Photon beams



Chinese Nuclear Reaction Codes:

1. UNF: UNiFed function

- **Incident: Neutron, proton, photon**
- **Target: light, medium heavy, actinides**
- **Energy: ~ 20MeV**

J.S. Zhang, Nucl. Sci. Eng. 142, 207, 2002

J.S. Zhang, Nucl. Sci. Eng. 114, 55, 1993

2. MEND: Medium Energy Nuclear Data

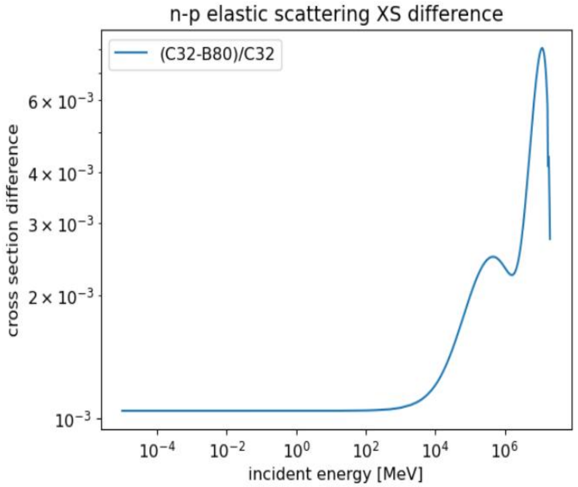
- **Incident: neutron, proton, deuteron, triton, alpha, photon**
- **Target: medium heavy, actinides**
- **Energy: ~ 200MeV**

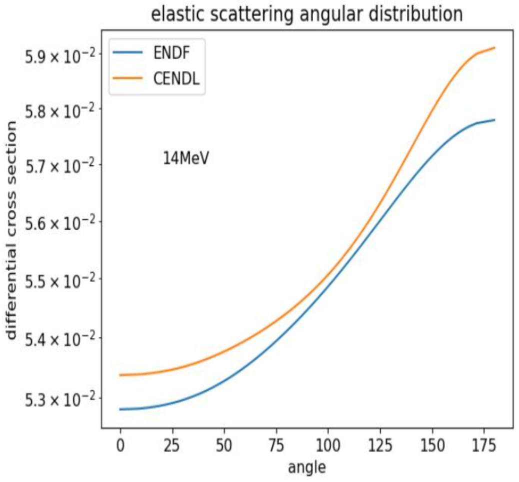
C.H. Cai, Nucl. Sci. Eng. 153, 93, 2006

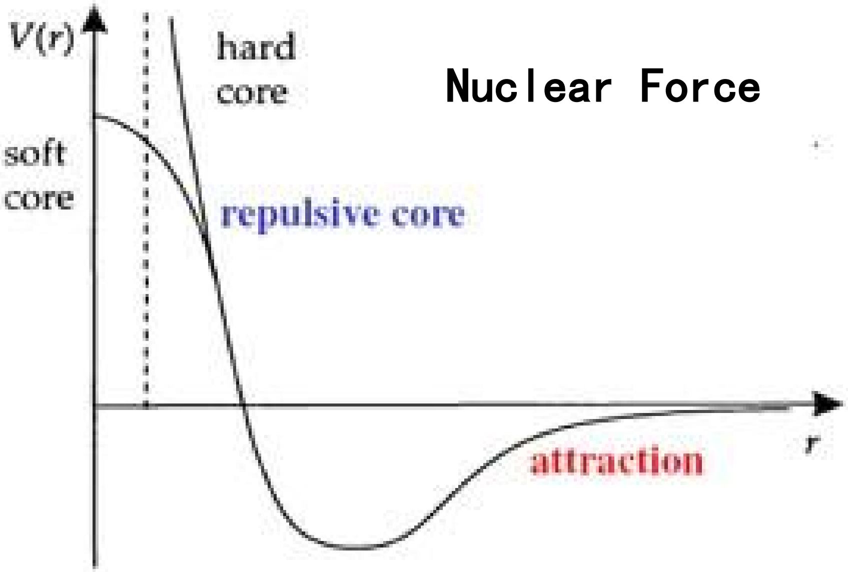
C.H. Cai, Chin. J. Comp. Phys. 20, 279, 2003

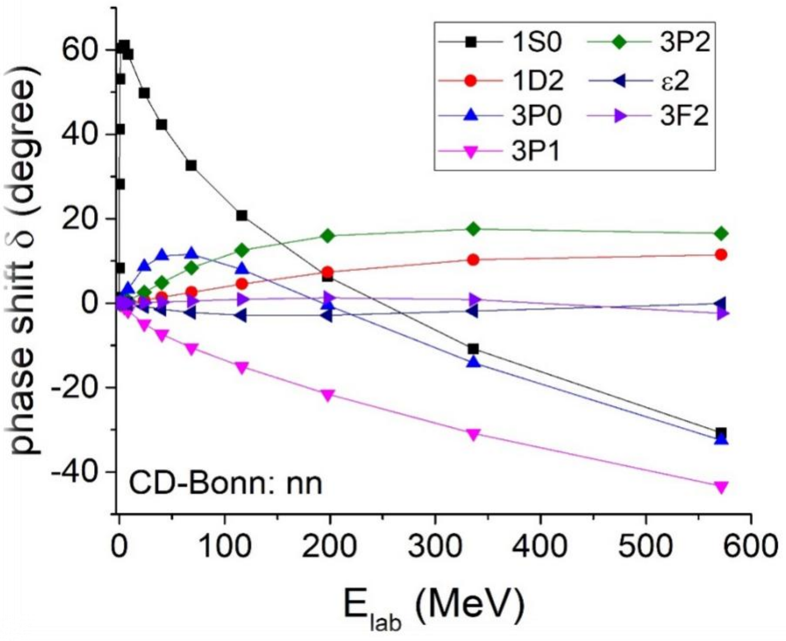
1. Neutron-proton scattering evaluation

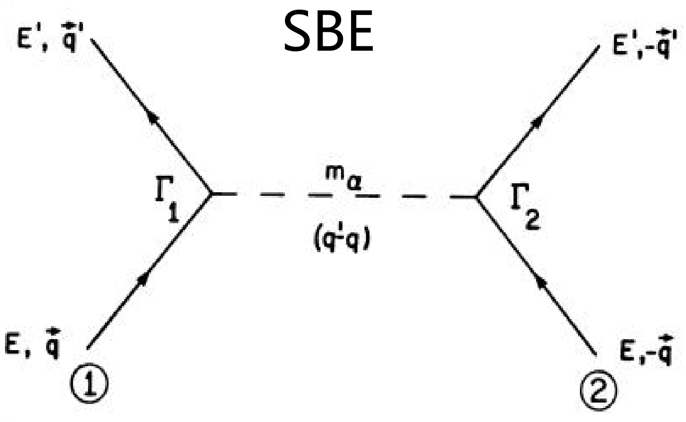
- Based on the knowledge of nuclear force and the partial wave analysis of phase shift, the nucleon-nucleon scattering data is well understood.
- The neutron-proton scattering cross section and its angular distribution are theoretically calculated using the CD-Bonn interaction for CENDL-3.2.
- The calculation is in good agreement with ENDF values, with a deviation of about 0.1% for low-energy and a deviation less than 0.6% when the energy increases.











$$\frac{\tilde{u}_1(\vec{q}')\Gamma_1 u_1(\vec{q}) P_\alpha \tilde{u}_2(-\vec{q}')\Gamma_2 u_2(-\vec{q})}{(q'-q)^2 - m_\alpha^2}$$

2. Improving nuclear data library of light nucleus

The n+d systems are calculated by solving the following Faddeev-AGS equation:
$U = Pv_1 + Pv_1G_1U$,
where U, P, v_1 and G_1 are the transition operator, the permutation operator, the channel interaction, and the channel resolvent, respectively. The Faddeev equation is solved with the wave-packet method described in *O.A. Rubtsova et al., Ann. Phys. 360, 613 (2015).*

NN interactions used: For elastic scattering and total reaction cross sections: Nijmegen potential: nijmI. For breakup double-differential cross sections: MT I-III s-wave separable potential

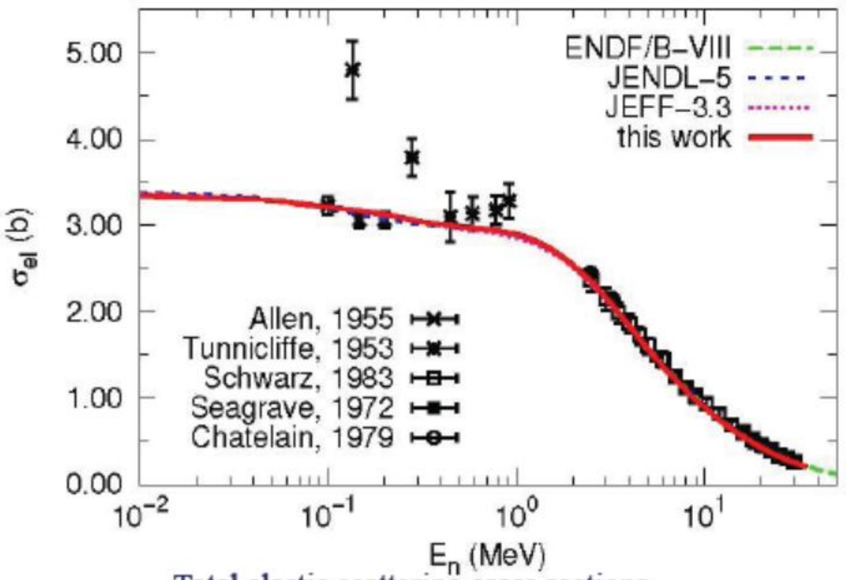
The elastic scattering amplitude:

$$A_{el}^{\Gamma\alpha\beta}(q_0) \approx \frac{2m}{3q_0}\frac{\langle Z_{1j0}^{\Gamma\alpha\beta}|\mathfrak{U}^{\Gamma}|Z_{1j0}^{\Gamma\alpha\beta}\rangle}{d_{j0}}$$

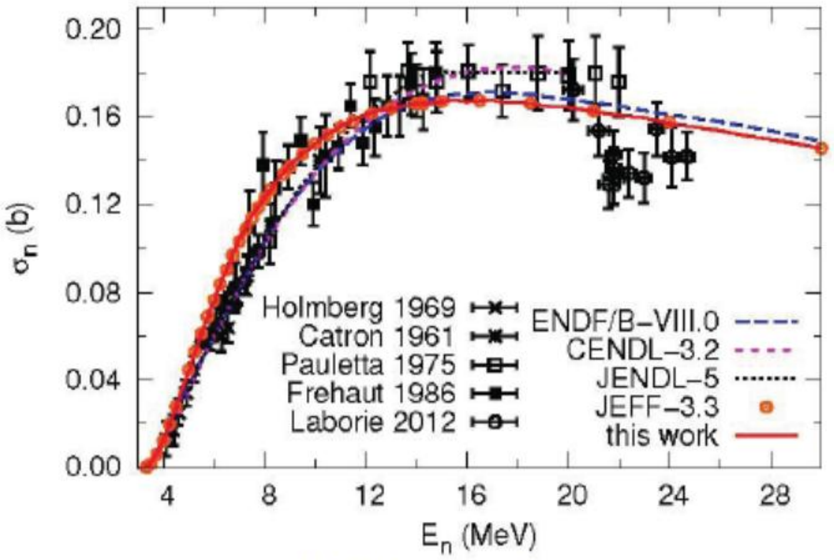
The breakup amplitude:

$$A_{bu}^{\Gamma\alpha\beta}(\theta) = \frac{4\pi m}{3\sqrt{3}} q_0 K^4 e^{\frac{i\pi}{4}} T^{\Gamma\alpha\beta}(p,q), \quad \theta = \tan^{-1}\left(\frac{\sqrt{3}q}{2p}\right)$$

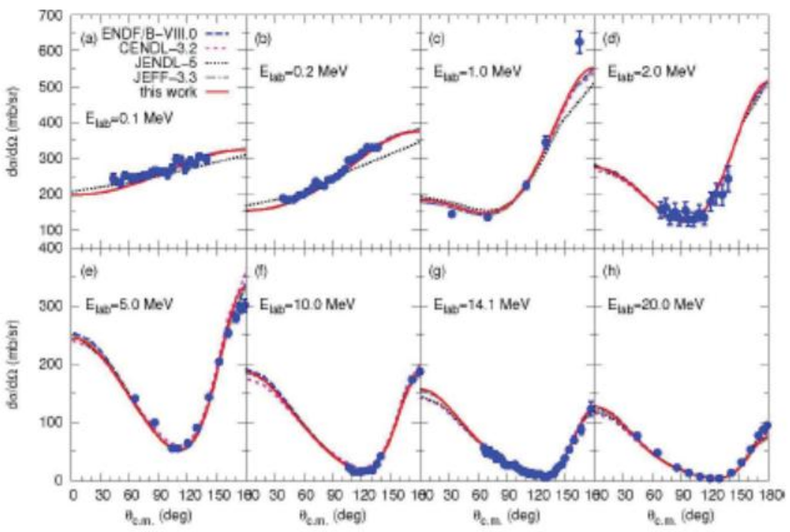
$$T^{\Gamma\alpha\beta}(p,q) \approx e^{i\delta(p_k)} \frac{\mathbb{T}^{\Gamma\alpha\beta}_{1j0,kj}}{p_k q_j q_0} \qquad \mathbb{T}^{\Gamma\alpha\beta}_{1j0,kj} \equiv \frac{\langle Z^{\Gamma\alpha\beta}_{1j0}|\mathfrak{U}^{\Gamma}|Z^{\Gamma\alpha\beta}_{kj}\rangle}{\sqrt{d_{j0}d_k d_j}}, \quad \begin{cases} q_0 \in \mathfrak{D}_{j_0} \\ q \in \mathfrak{D}_j \\ p \in \Delta_k^{s} \end{cases}$$



Total elastic scattering cross sections



d(n,2n)p cross sections

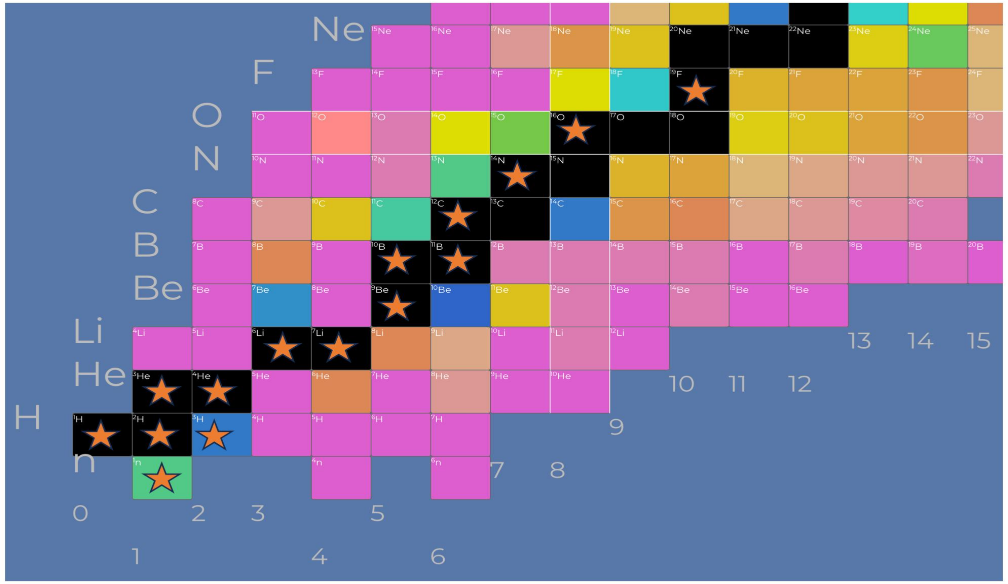


Elastic scattering angular distributions

Atomic Energy Science and Tech.. Vol.56,No5(2022).

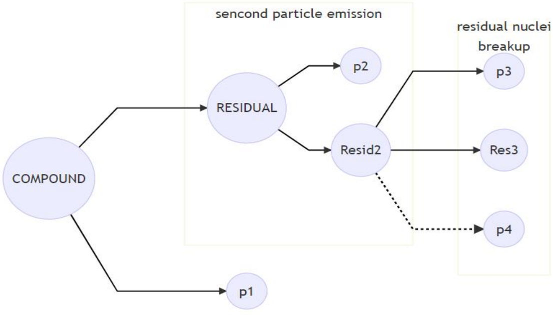
2 Improving nuclear data library of light nucleus

- **Neutron induced nuclear reaction dataset for light nucleus are incomplete, only including ^{3,4}He, ^{6,7}Li, ^{9}Be, ^{10,11}B, ^{12}C, ^{14}N, ^{16}O, ^{19}F in CENDL-3.2.**
- **Key steps and technologies:**
  - **Theoretical models beyond R matrix**
  - **Consistent evaluation both experimental and theoretical results for the fast neutron energy**
  - **Nuclear data processing research**



Applying **S**tatistical **T**heory of **L**ight **N**ucleus reactions to predict complete nuclear reaction data, key considerations:

- Must include special but not negligible channels, for example ^{6}Li(n, ddt) with tens of mb cross section
- The number of open levels increase significantly when induced neutron energy as large as 30 MeV
- Providing both cross-sections and energy-angular double differential spectra data
- Understanding reaction mechanism of pre-equilibrium emission and complex particle formation process



1. Dynamics of Compound nuclei

2. Kinematics of emission

$$\sigma_{m_1,k_1}(E_L)=\sum_{j\pi}\sigma_a^{j\pi}(E_L)\left\{\sum_{n=3}^{n_{max}}P^{j\pi}(n)\frac{W^{j\pi}_{m_1,k_1}(n,E^*,\varepsilon_{m_1})}{W_T^{j\pi}(n,E^*)}+Q^{j\pi}(n)\frac{W^{j\pi}_{m_1,k_1}(E^*,\varepsilon_{m_1})}{W_T^{j\pi}(E^*)}\right\}$$

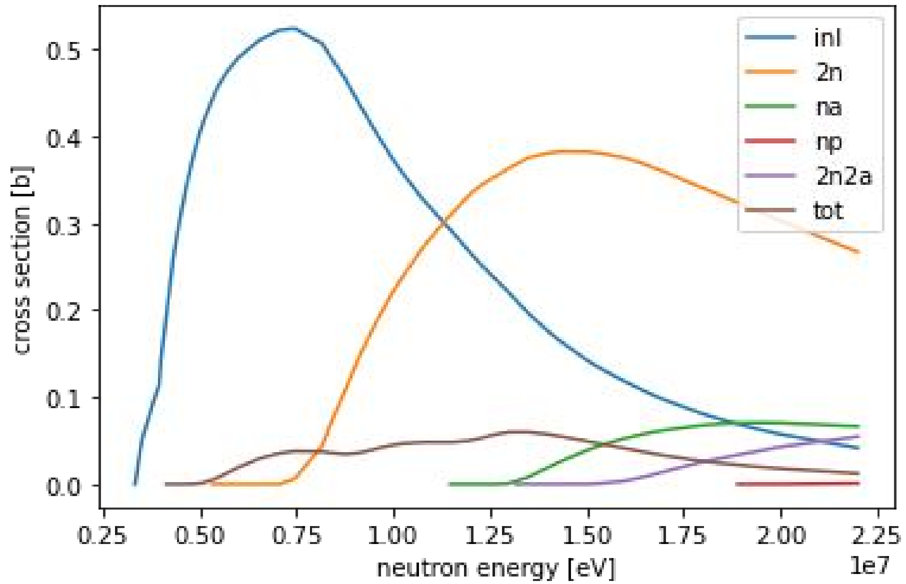
Absorb XS

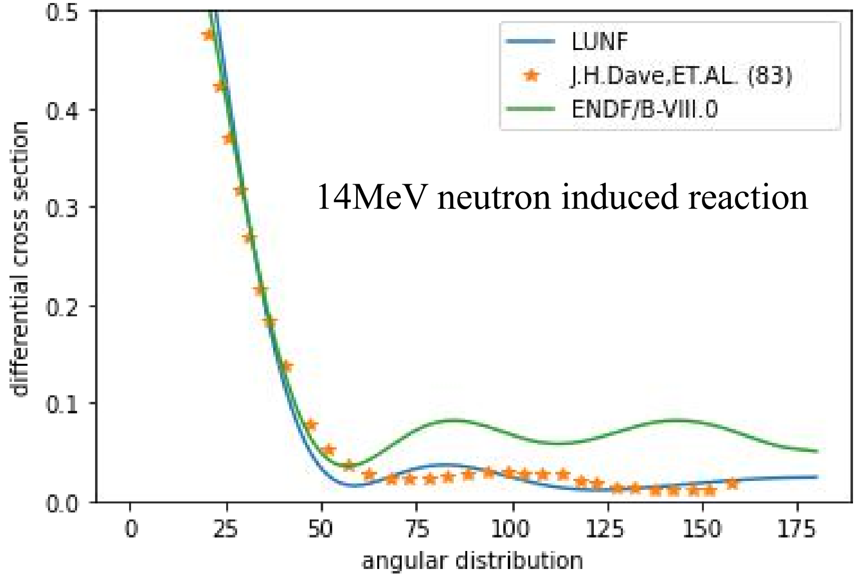
pre-equilibrium emission

equilibrium emission

3. n+^{13}C nuclear reaction data

$$
n+^{13}C \rightarrow ^{14}C^{*} \rightarrow \begin{cases}
\gamma+^{14}C, & E_{th}=0 \\
n+^{13}C & E_{th}=0 \\
p+^{13}B, & E_{th}=13.6MeV \\
d+^{12}B, & E_{th}=16.5MeV \\
t+^{11}B, & E_{th}=13.4MeV \\
\alpha+^{10}Be, & E_{th}=4.13MeV \\
^{9}Be+^{5}He \rightarrow \{n+\alpha, \quad k\geq 1 & E_{th}=12.3MeV \\
2n+^{12}C, & E_{th}=5.33MeV \\
n+p+^{12}B, & E_{th}=18.9MeV \\
n+\alpha+^{9}Be \rightarrow \{n+2\alpha, \quad k>1 & E_{th}=11.5MeV \\
2\alpha+^{6}He \rightarrow \{2n+\alpha, \quad k>1 & E_{th}=12.1MeV \\
n+^{5}He+^{8}Be \rightarrow \{n+3\alpha, \quad k\geq 1 & E_{th}=14.06MeV \\
\alpha+2\,^{5}He \rightarrow \{2n+2\alpha, \quad k\geq 1 & E_{th}=14.75MeV
\end{cases}
$$





- The cross section and its angular distribution are obtained simultaneously with neutron energy lower than 20 MeV
- The differential cross section well agree with measurements

$$
\sigma_{m_1,k_1}(E_L)=\sum_{j\pi}\sigma_a^{j\pi}(E_L)\{\sum_{n=3}^{n_{max}}P^{j\pi}(n)\frac{W^{j\pi}_{m_1,k_1}(n,E^*,\varepsilon_{m_1})}{W_T^{j\pi}(n,E^*)}+Q^{j\pi}(n)\frac{W^{j\pi}_{m_1,k_1}(E^*,\varepsilon_{m_1})}{W_T^{j\pi}(E^*)}\}
$$

Absorb XS

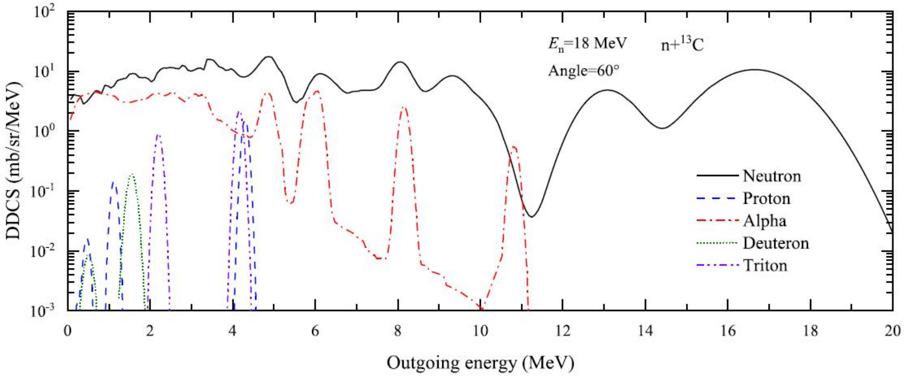
pre-equilibrium emission

equilibrium emission

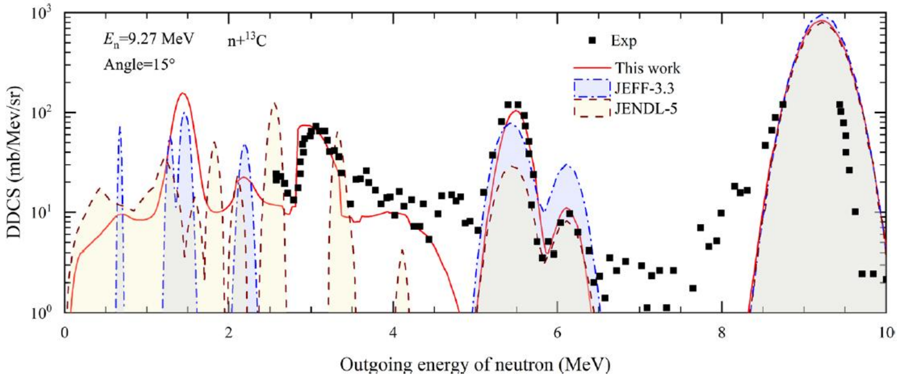
3. n+^{13}C nuclear reaction data

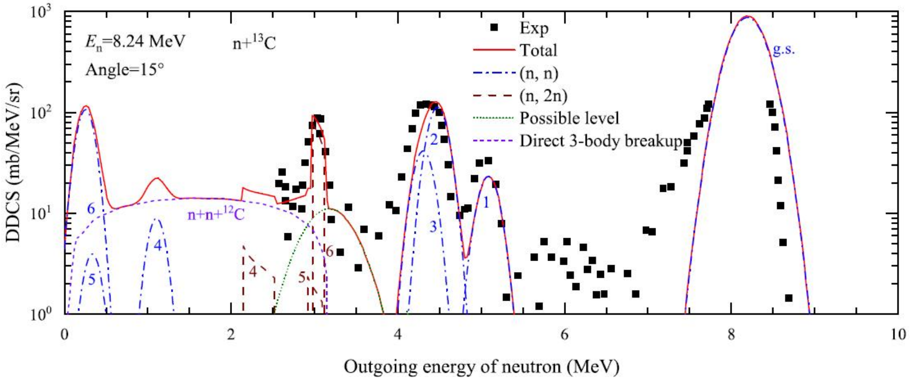
Effects of energy levels on the double-differential cross sections for n+^{13}C reaction below 20 MeV

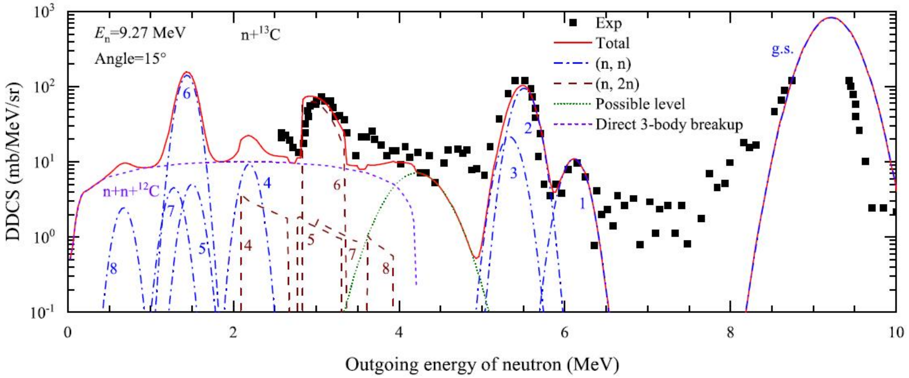
- Based on the unified Hauser Feshbach and exciton model STLN theory, the calculated results are in reasonable agreement with experimental measurements.
- Considering the three body breakup process is crucial for inelastic scattering data and can compensate for the shortcomings of the DWUCK.
- Theoretical self-consistency describes the emission cross sections of neutron and charged particles such as protons, deuterons, tritium nuclei, and alpha particles, which can be used to analyze the generation of gases in fusion devices.



Eur. Phys. J. A 61, 86 (2025)

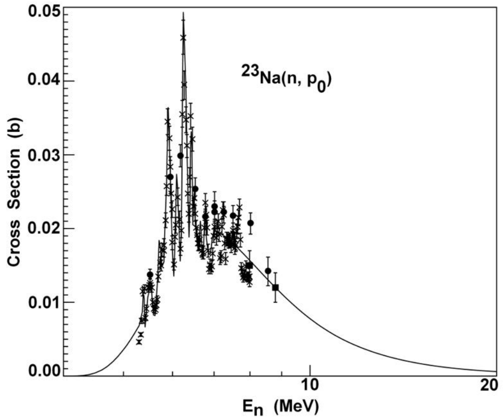


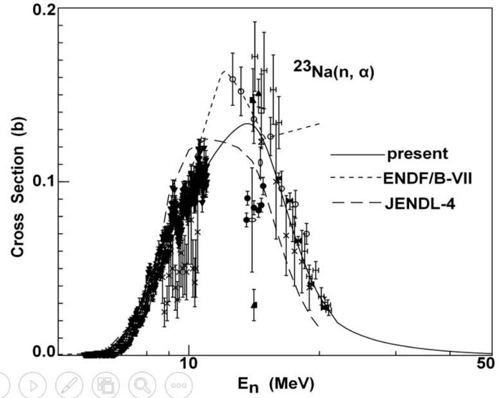




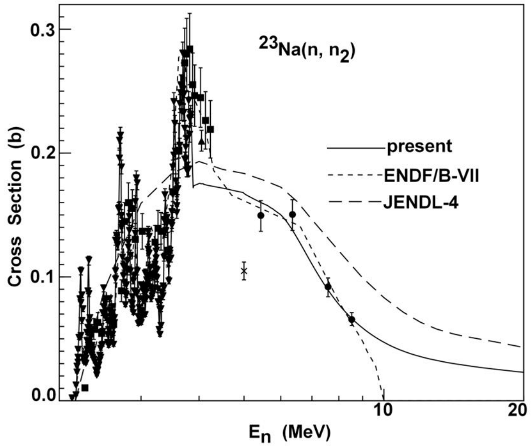
4. n+ ^{23}Na and ^{27}Al

^{23}Na

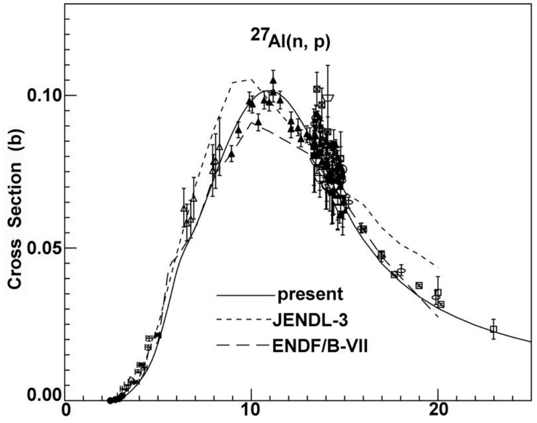


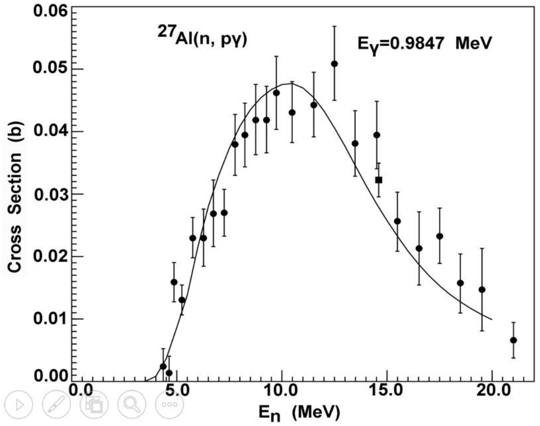


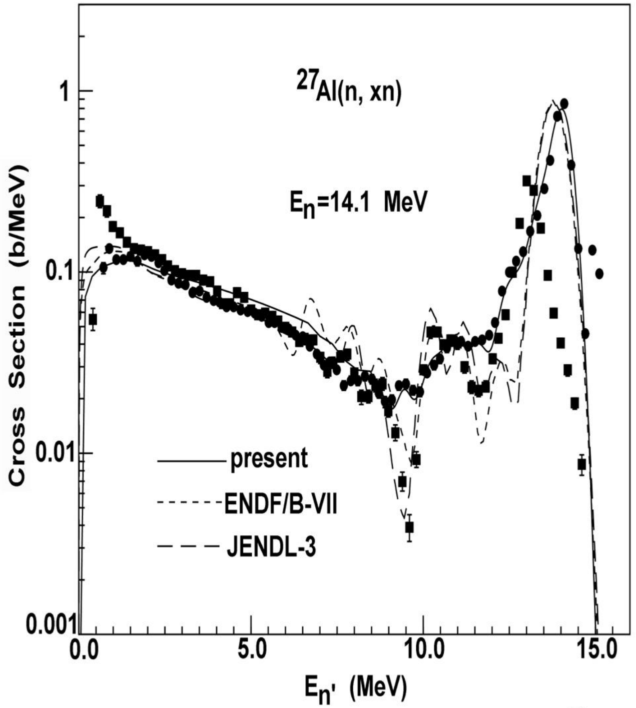
Nuclear Reactions



^{27}Al





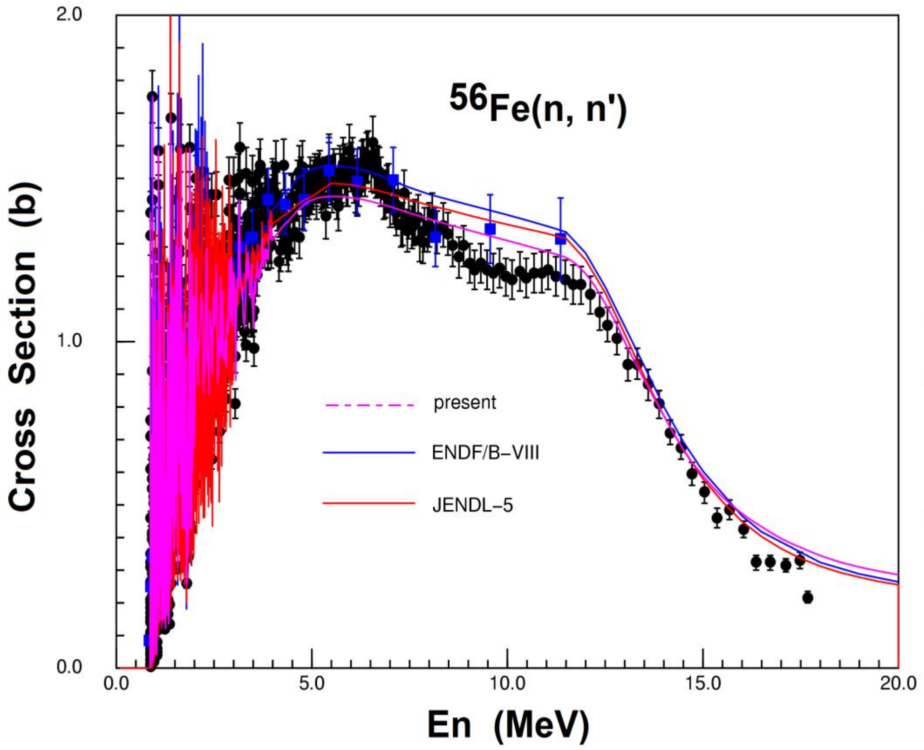


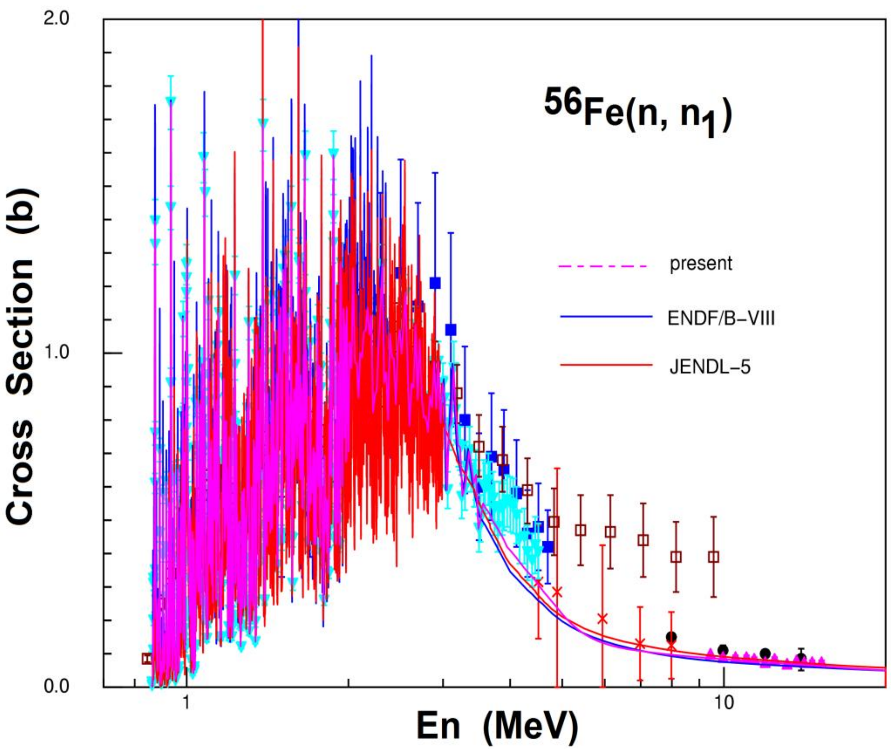
5. n+ Fe nuclear reaction data

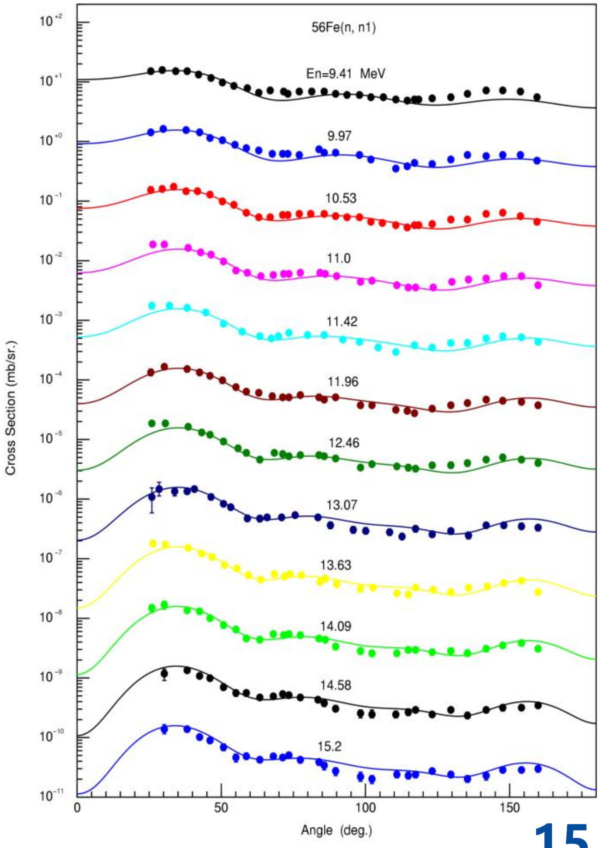
$^{54, 56-58}$Fe have been re-calcuated and evaluated in CNDC.

The evaluation is updated via the prompt gamma measurements.

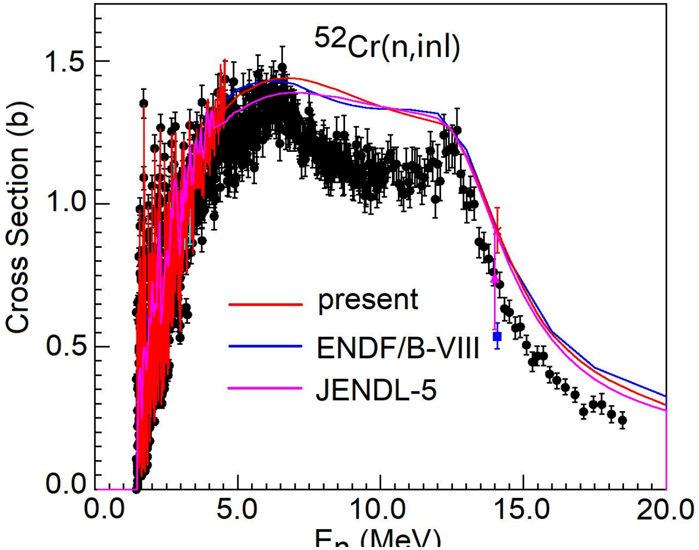
Other improvements by Haicheng are also performed via considering the Benchmark testing experiments(not included here)

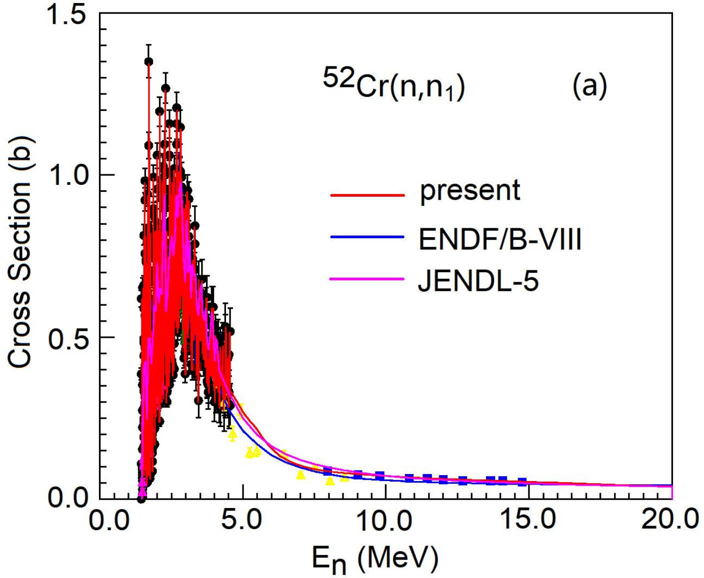


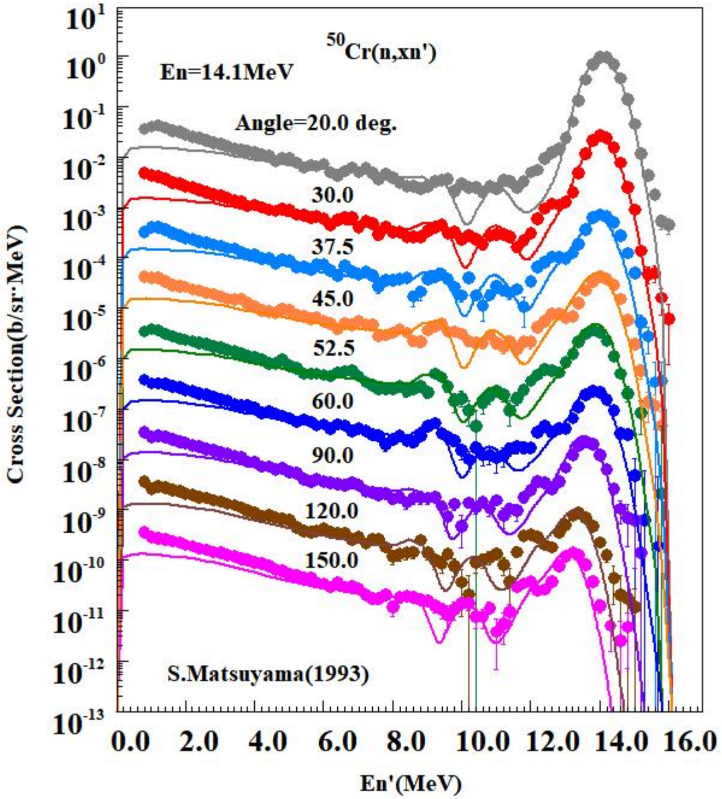


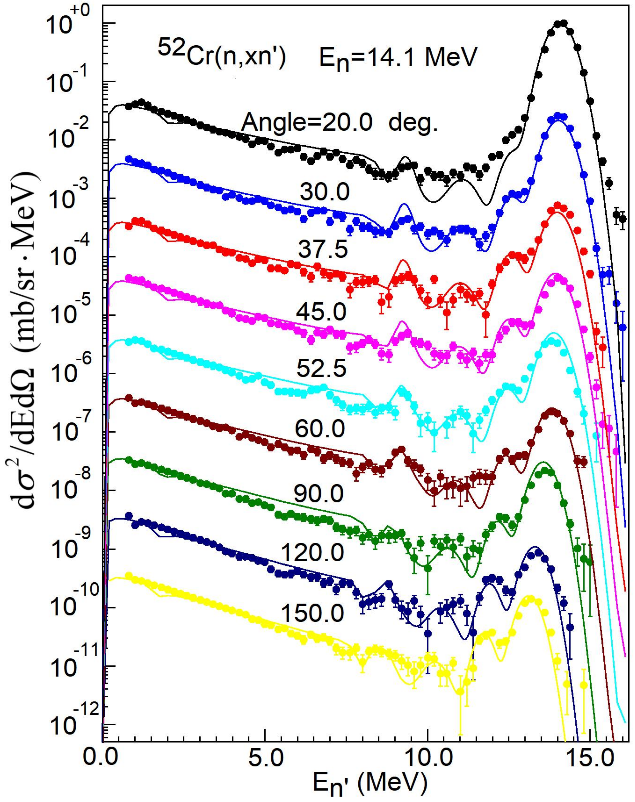


6. n+ Cr nuclear reaction data





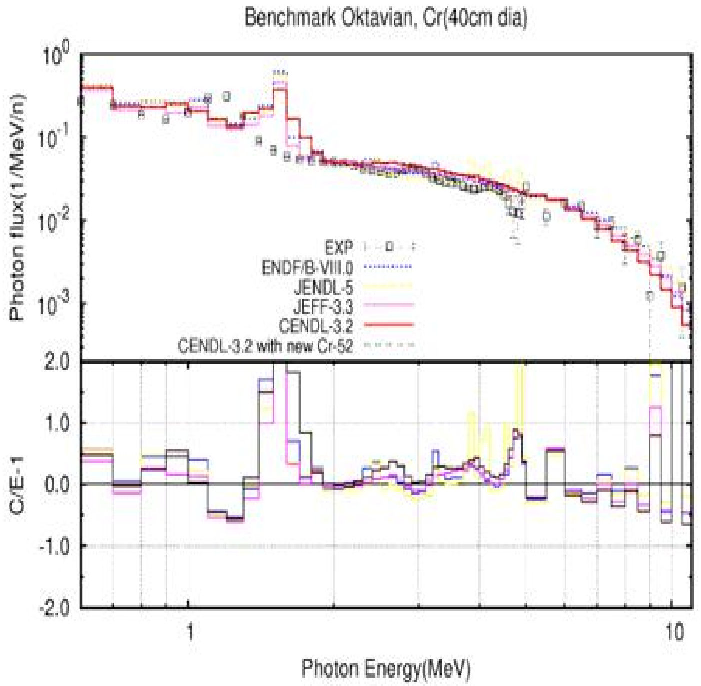


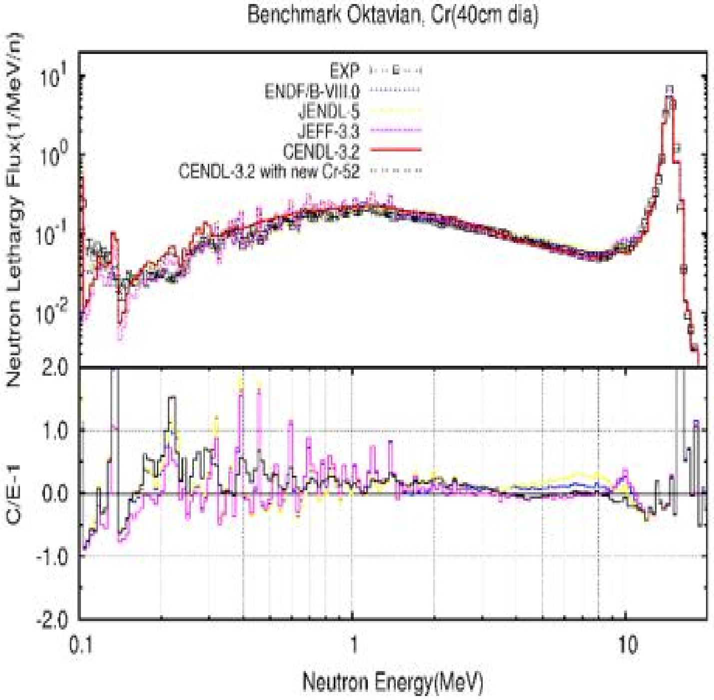


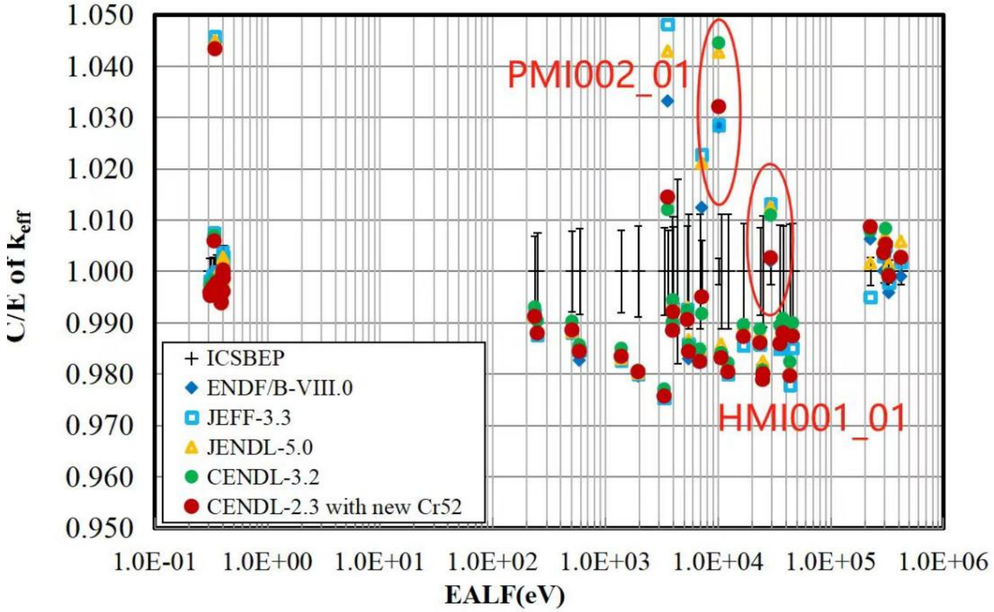
Wenye Wang, et.al., Nuclear Sci. and Eng., 2024.02.

6. n+ Cr nuclear reaction data

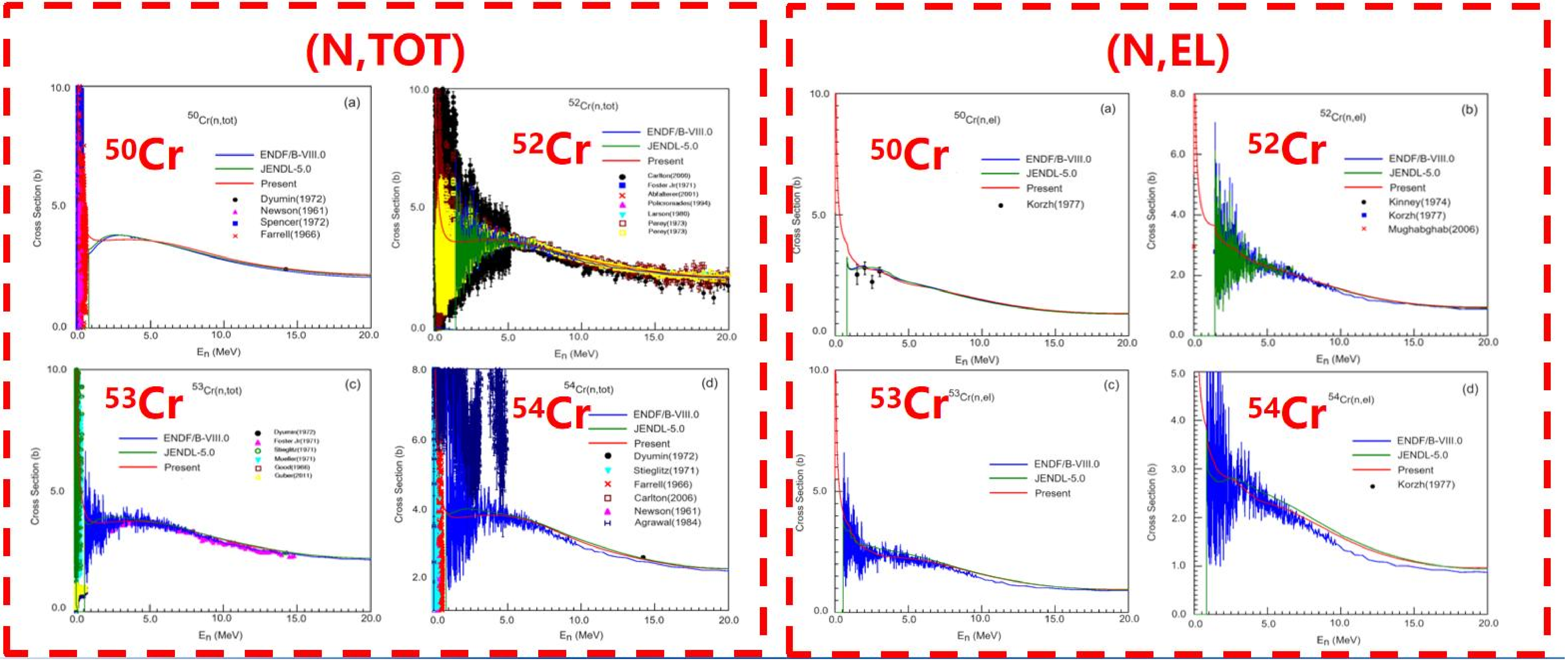
Benchmark testing results for Cr-52



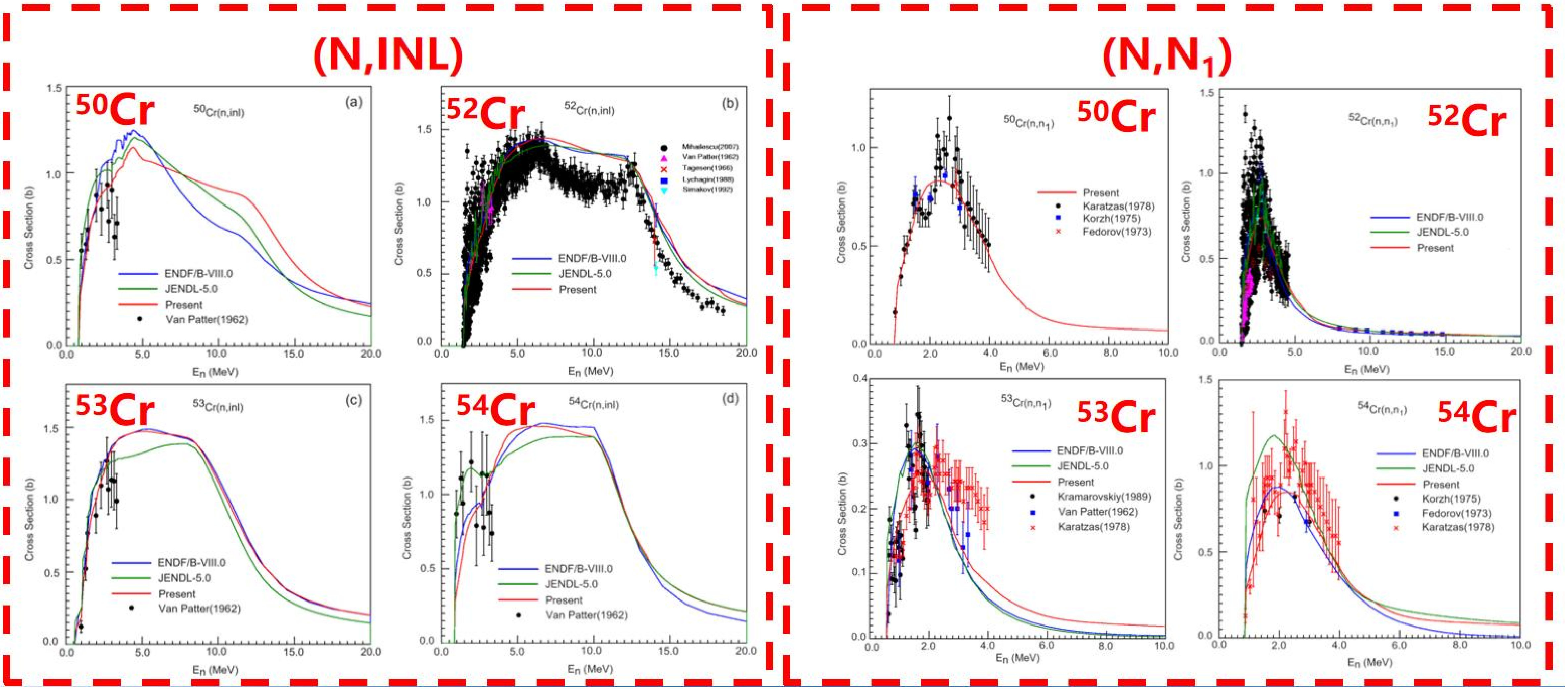




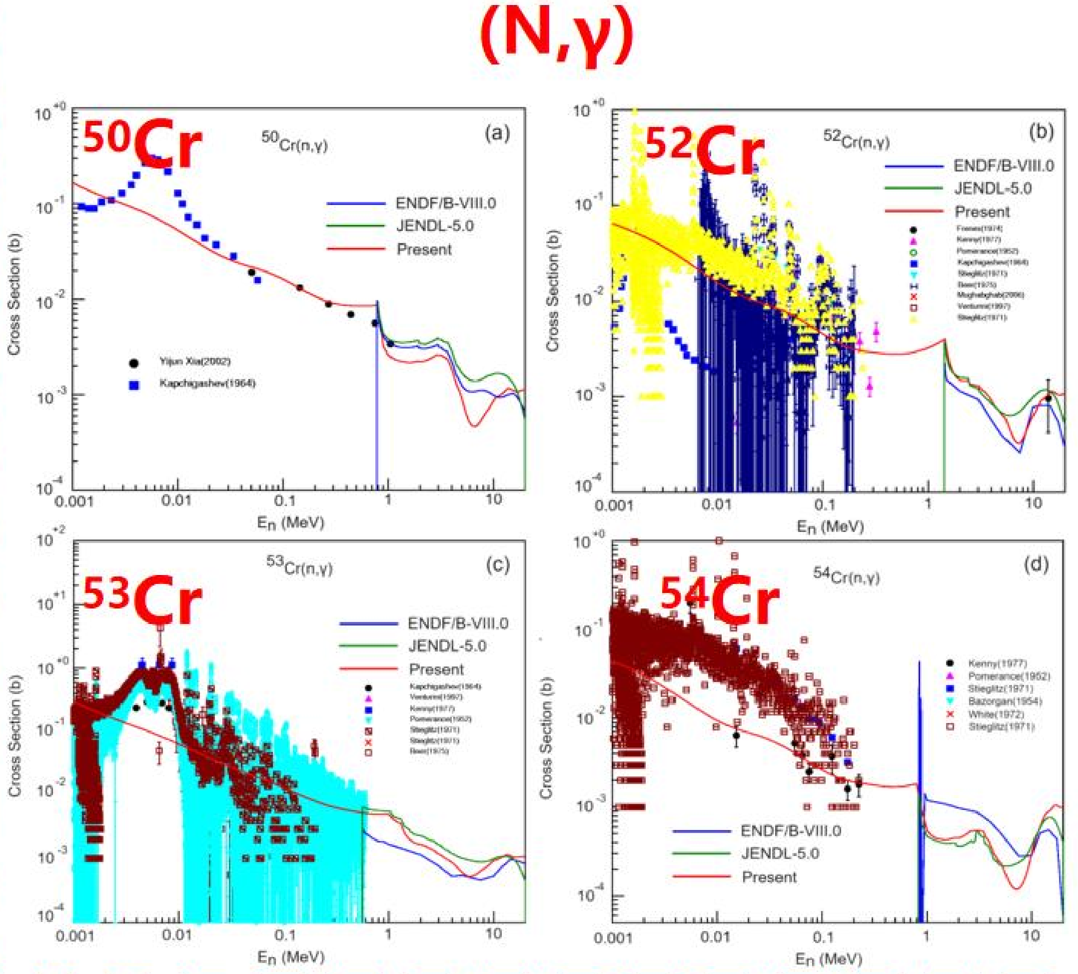
6. n+ Cr nuclear reaction data

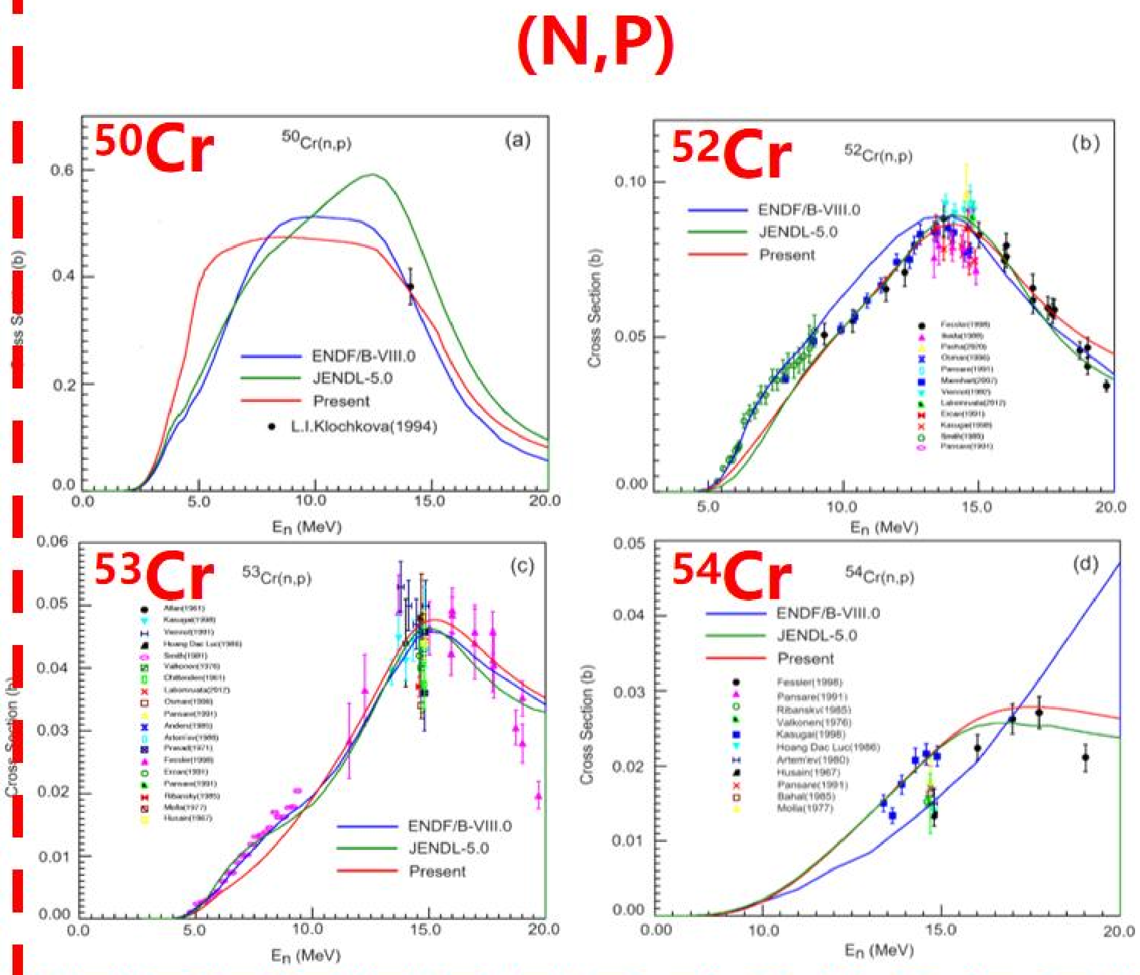


6. n+ Cr nuclear reaction data

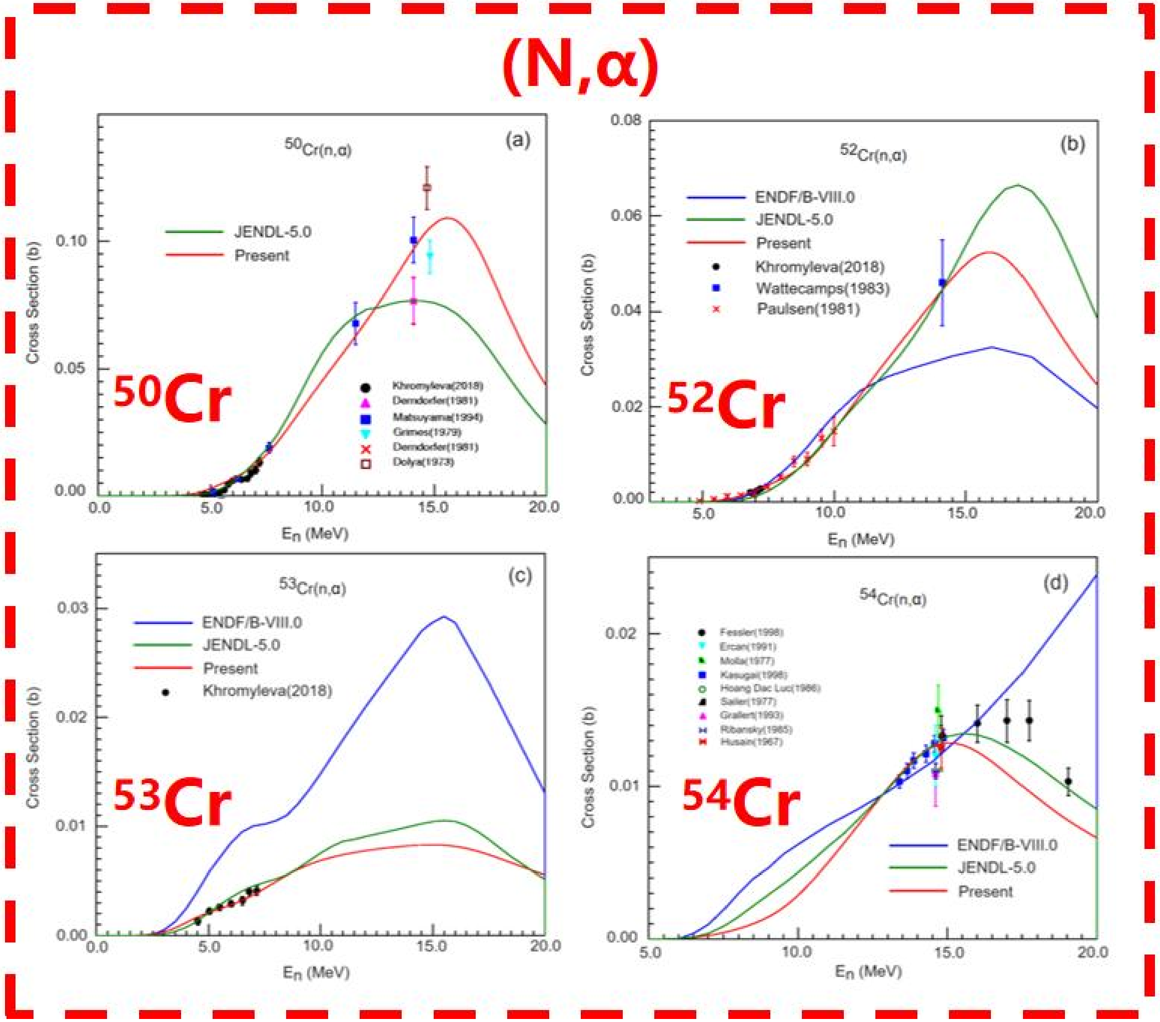


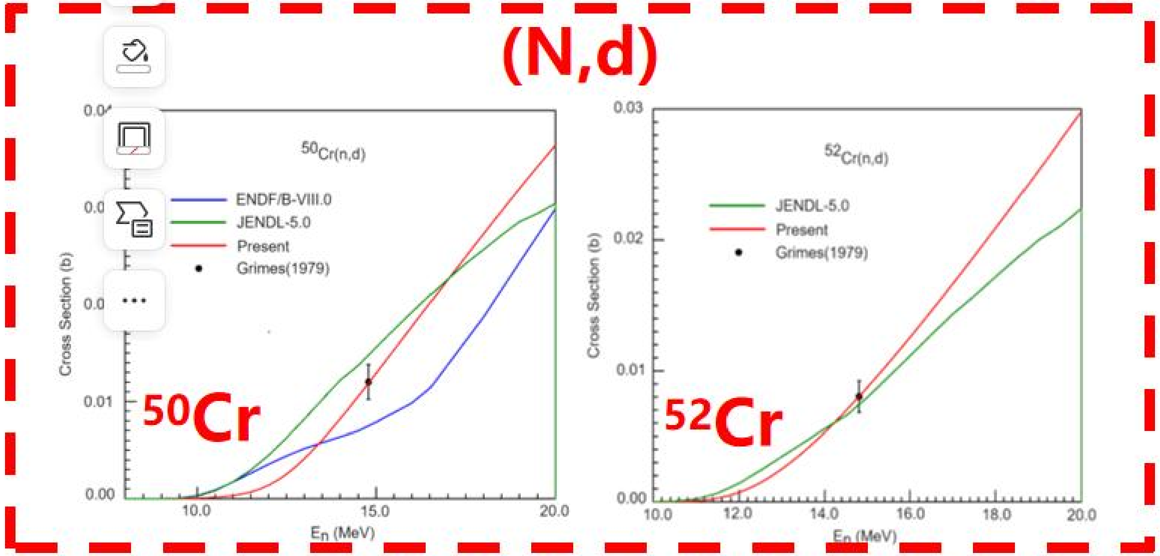
6. n+ Cr nuclear reaction data

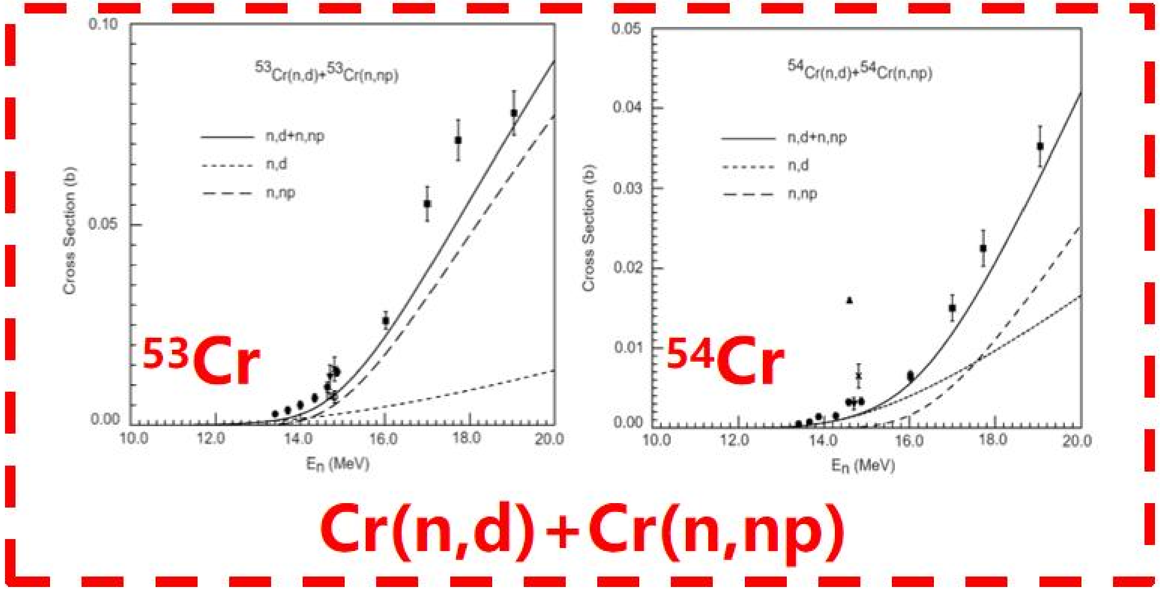




6. n+ Cr nuclear reaction data

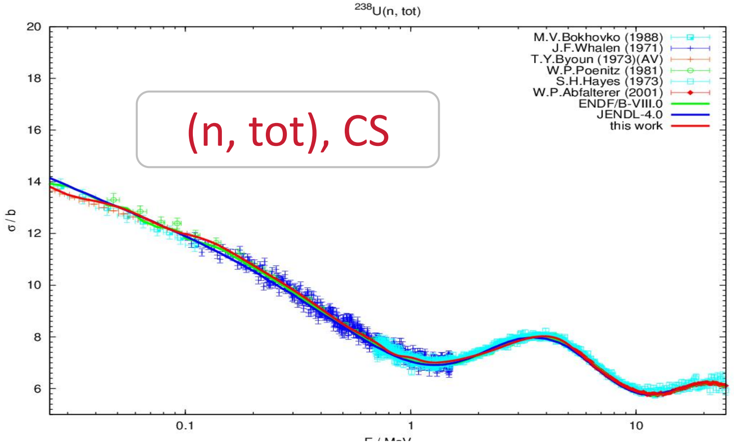


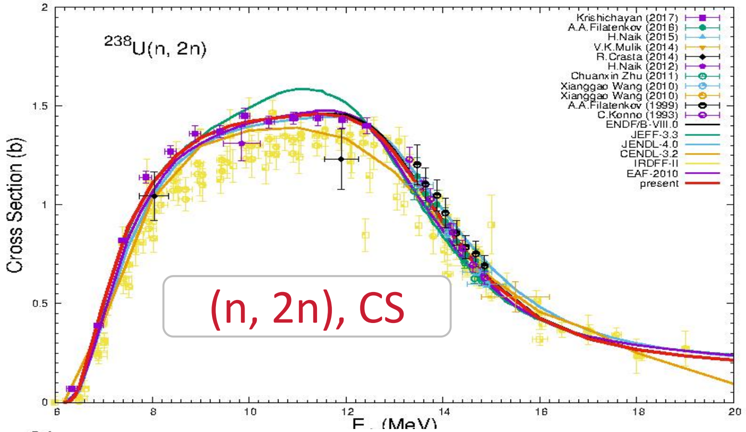


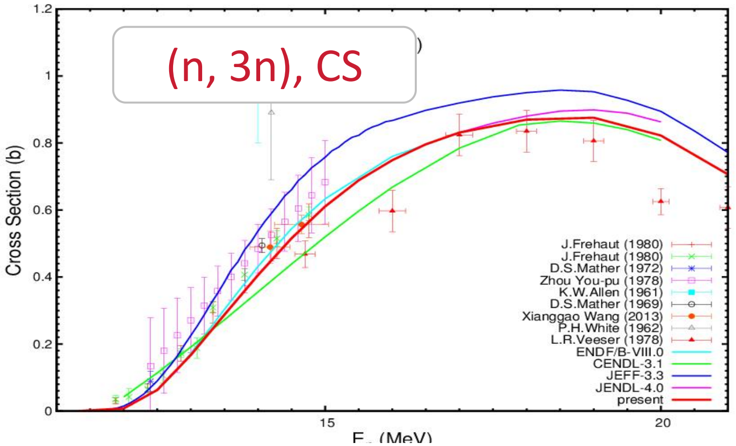


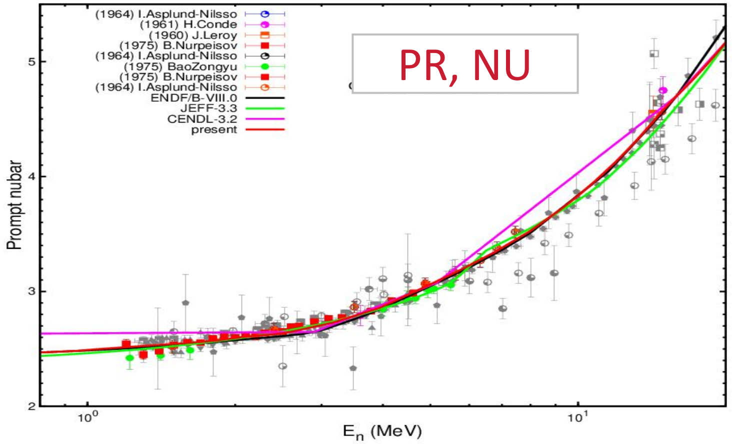
7. n+ ^{238}U

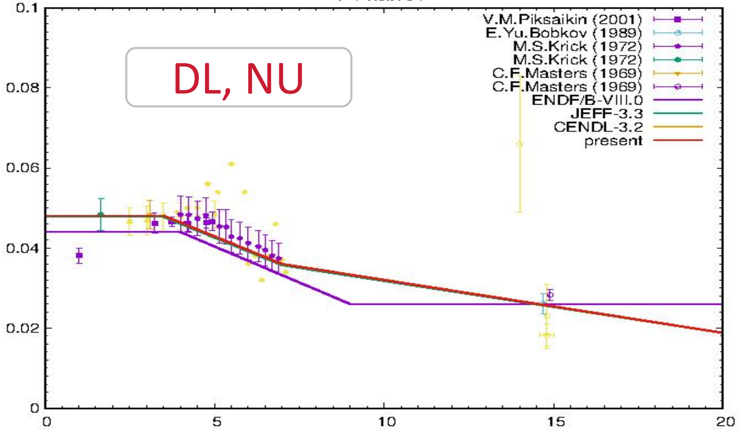
- Based on experimental data analysis, Nu-bar, (n,tot), (n,γ), (n,f), (n,2n) and (n,3n) cross sections evaluated.
- Experimental data evaluation based on factors such as experimental methods, experimental objectives, neutron monochromaticity, detector resolution capability, sample quantification, monitor cross-section selection, data correction, and uncertainty analysis.

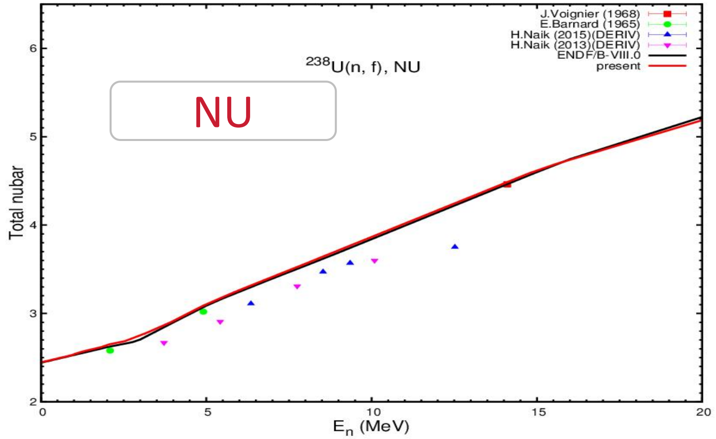








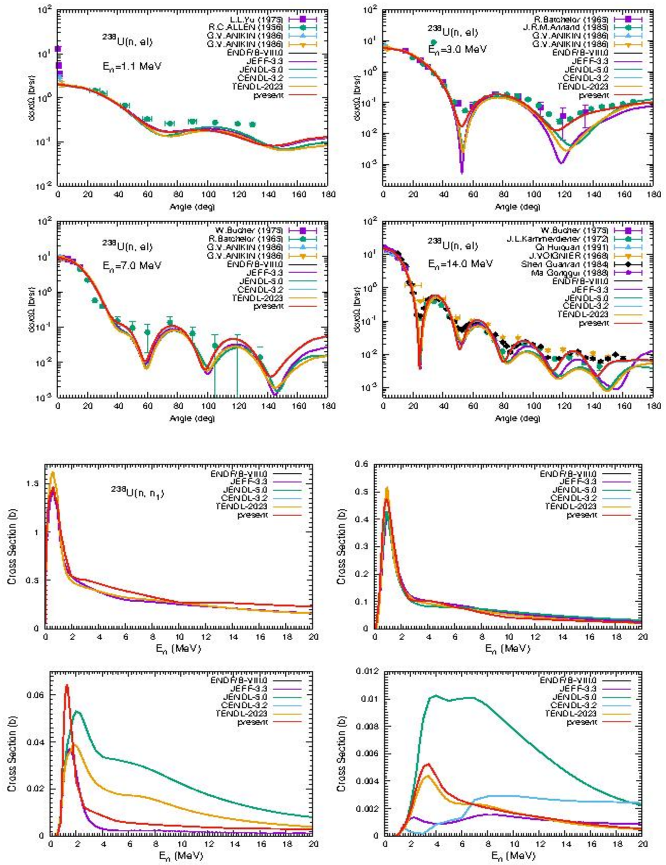


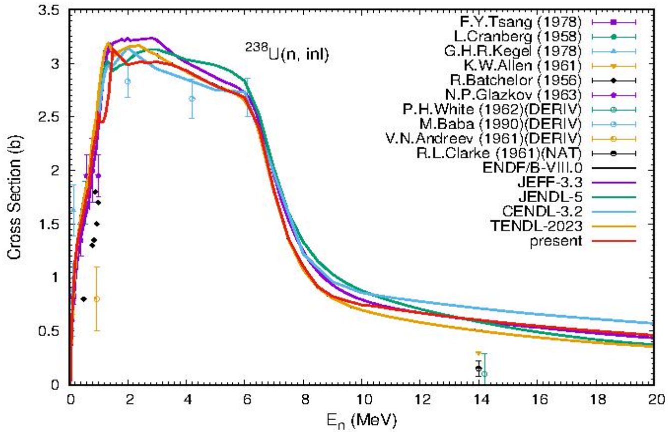


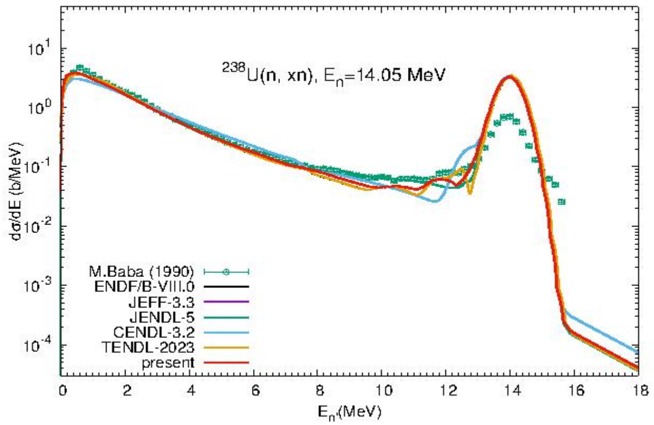
Zhang Yue, Xu Ruirui, Tian Yuan, et.al., Nuclear Engineering and Technology, 2024.08.

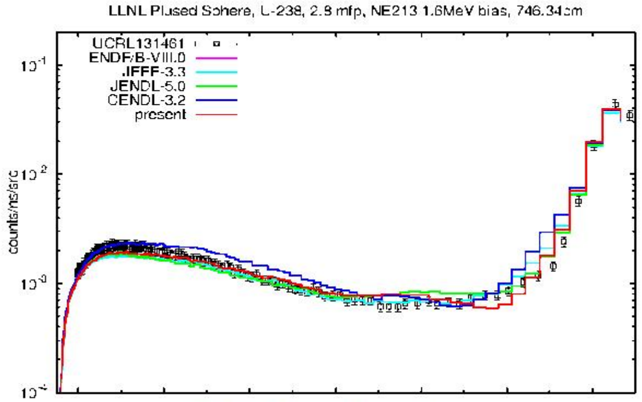
7. n+ ^{238}U

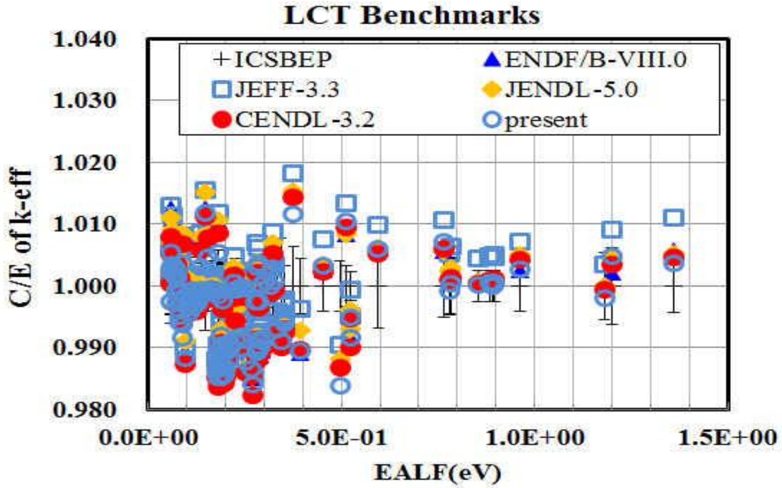
- New theoretical calculations based on Hauser-Feshbach and pre-equilibrium carried out.
- ENDF-6 file obtained with resonance parameters and prompt fission neutron spectrum taken from ENDF/B-VIII.0.
- Guided by integral benchmark, (n,inl), (n,γ) and (n,f) cross sections underwent multiple adjustments.
- The final benchmark results indicates a significant improvement in the final data quality.











Outlines

Introduction

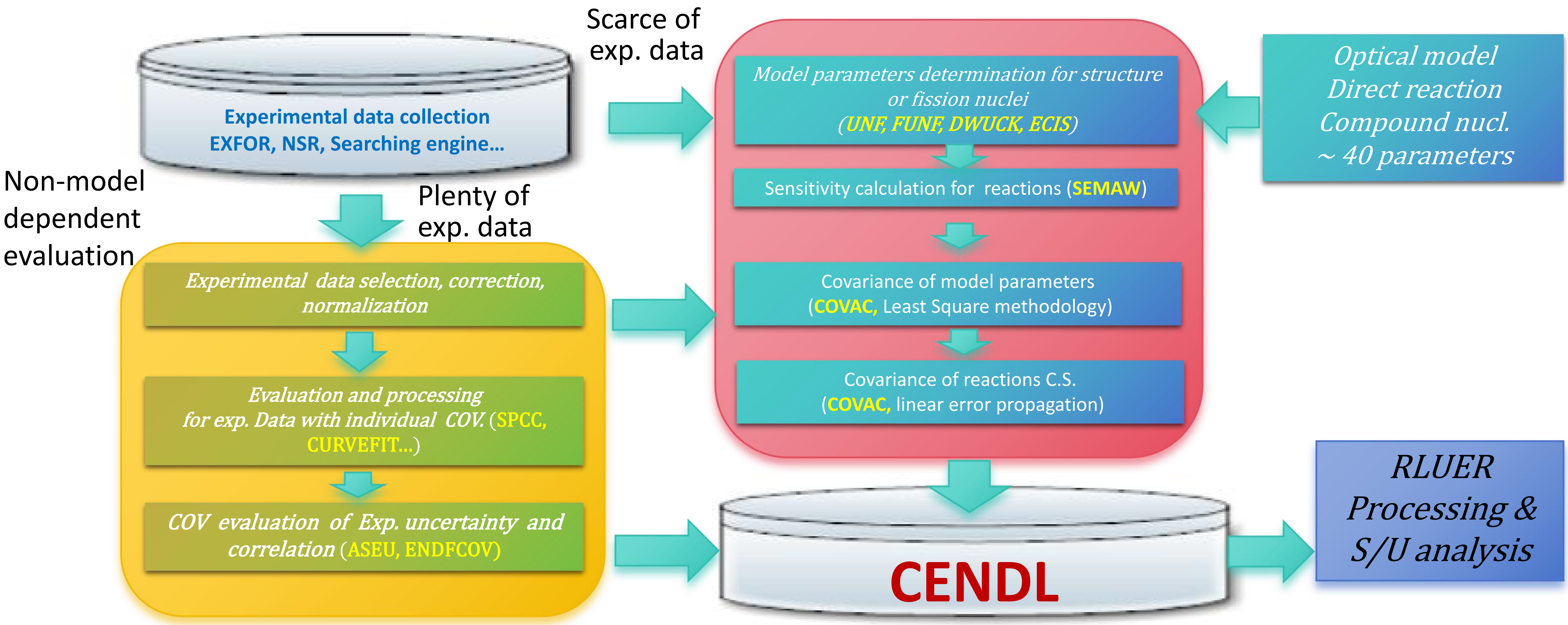
Nuclear Reaction Study

Perspective

Nuclear Reaction Study

- Platform for Theoretical Models
- Nuclear Data Improvement
- Covariance Evaluations
- AI and Nuclear Data Evaluation

1. Application of Bayes determinstic to broad mass range



Correlations among single (or multiple) set(s) of experimental data are vital elements to get an ‘honest’ covariance.

1. Application of LS to broad mass range

Descriptions to the current COV scheme at CNDC:

① Tech. for non-model & model dependent

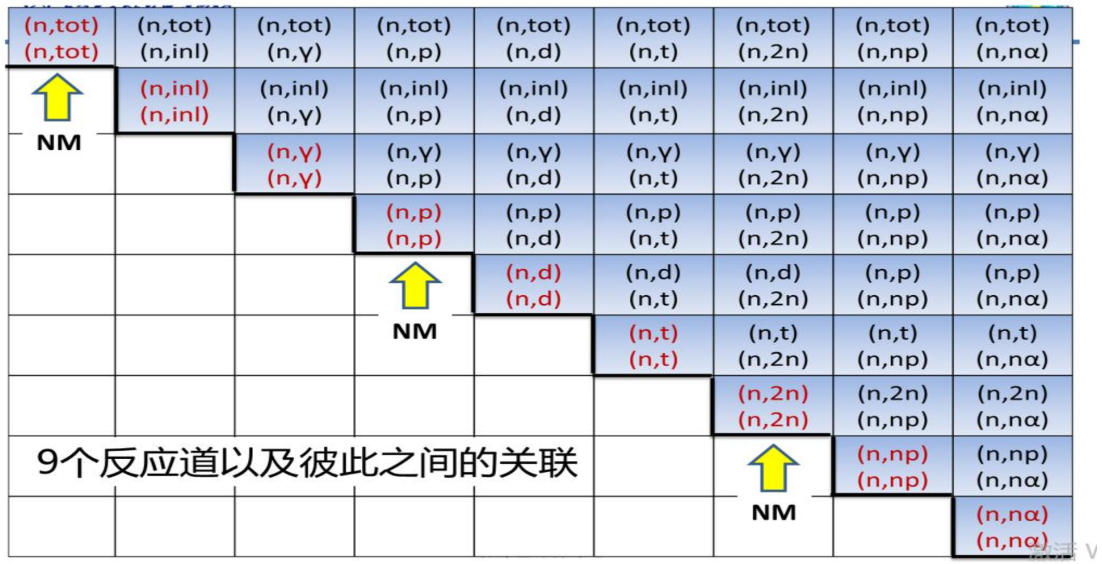
② Energies for structure & smooth regions

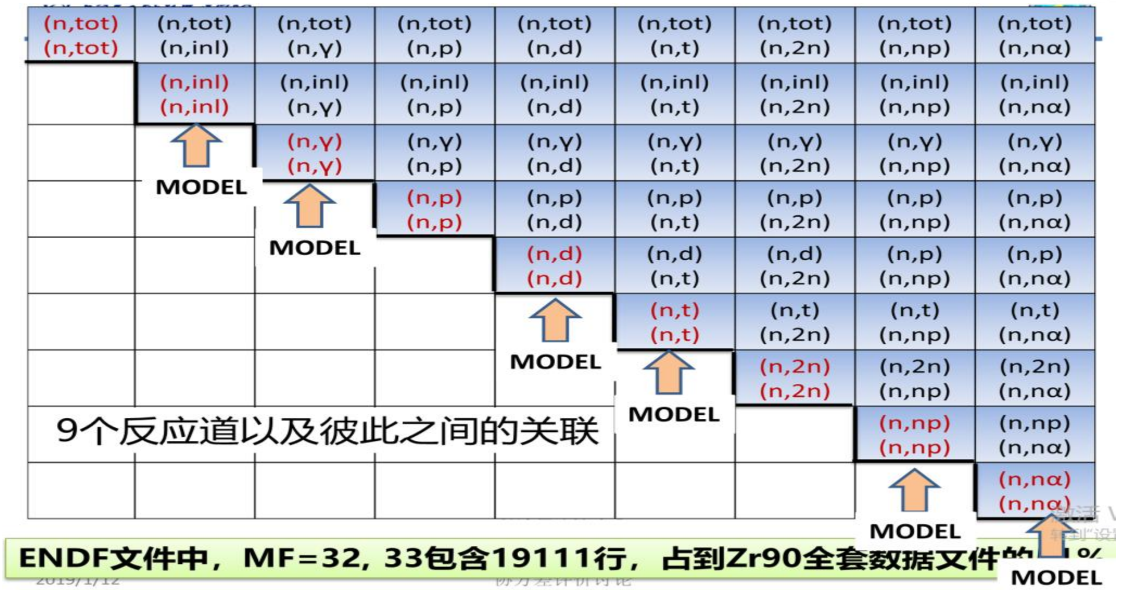
③ COV data types for NI & NC

④ Tech. deal with single & multiple measurements

⑤ Tech. for parameter sensitivity selection

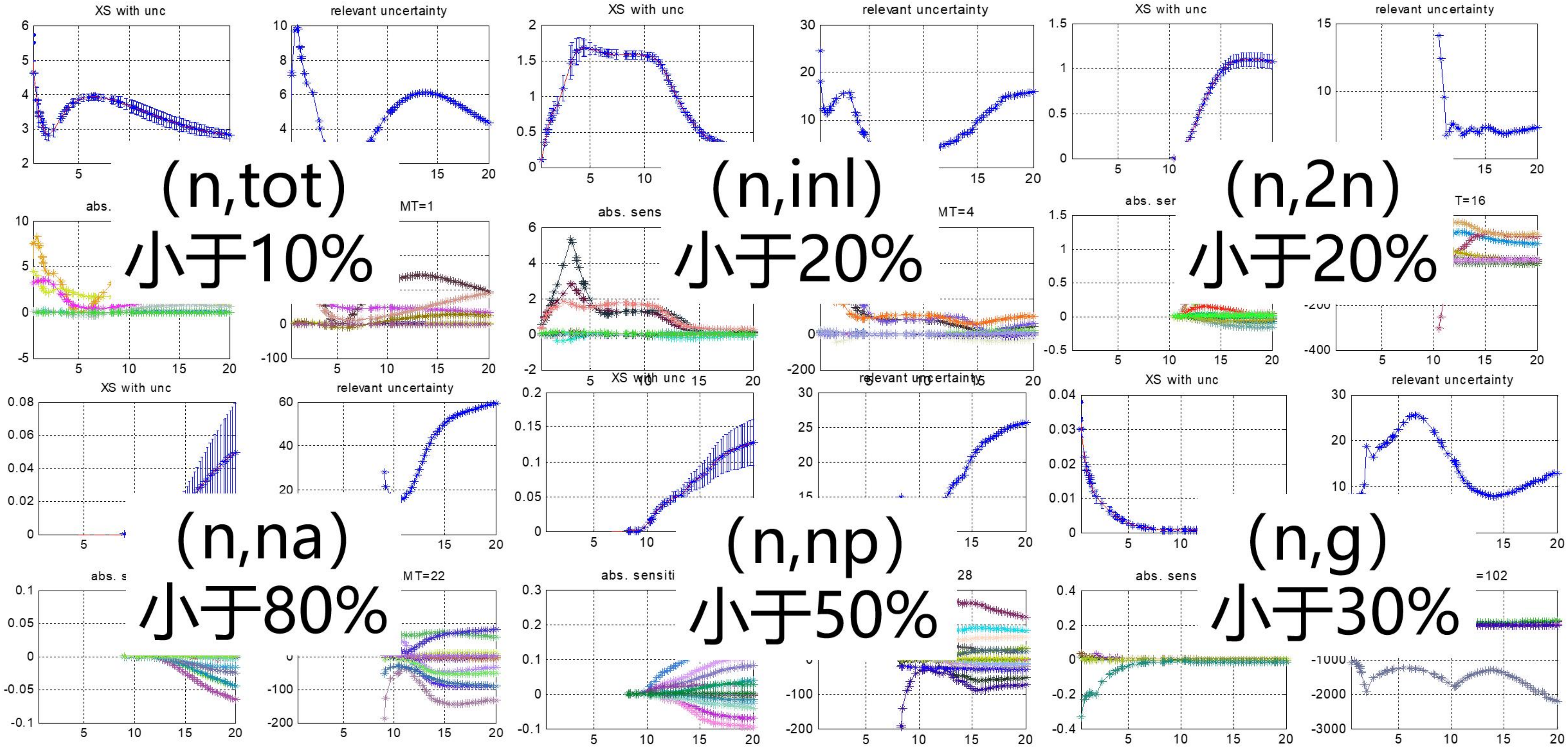
⑥ COV matrix positive definition treatment





1. Application of LS to broad mass range

^{55}Mn ~ ^{160}Gd



2. Application of Unified Monte Carlo (UMC-B) for n+48Ti

$$p(\sigma) = C\, L(y_E, V_E|\sigma)\, p_0(\sigma|\sigma_C, V_C)$$

$$\langle \sigma_i \rangle = \int_S \sigma_i\, p(\sigma)\, d\sigma$$

$$(V)_{ij} = \langle \sigma_i \sigma_j \rangle - \langle \sigma_i \rangle \langle \sigma_j \rangle$$

$$L(y_E, V_E|\sigma) \sim \exp\left\{ -\frac{1}{2}\left[(y - y_E)^T \bullet V_E^{-1} \bullet (y - y_E) \right] \right\}$$

$$p_0(\sigma|\sigma_C, V_C) \sim \exp\left\{ -\frac{1}{2}\left[(\sigma - \sigma_C)^T \bullet V_C^{-1} \bullet (\sigma - \sigma_C) \right] \right\}$$

y_e, v_e : measured quantities with “n” elements
σ_C, v_C : calculated using nuclear models with “m” elements

UMC-B：

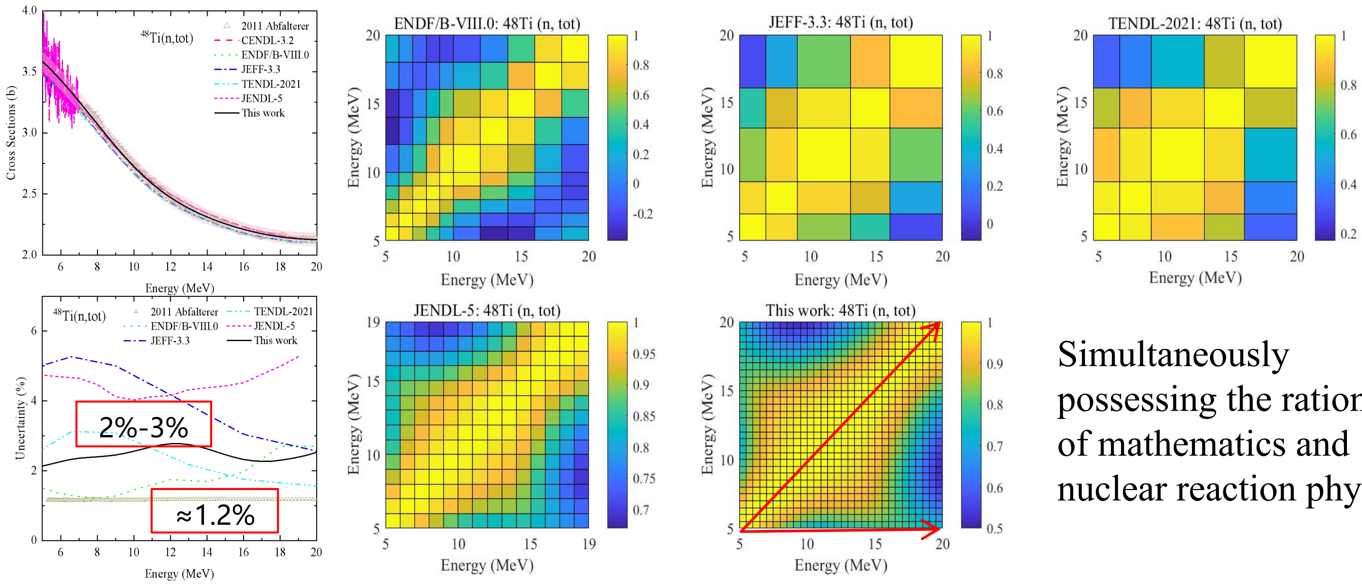
For each random set $\{\sigma_i\}$ we calculate

$$\omega_k = \exp\left\{ -\frac{1}{2}\left[(y_k - y_E)^T \bullet V_E^{-1} \bullet (y_k - y_E) \right] \right\}$$

$$\sigma_i = \left[\sum_{k=1,K} \omega_k \sigma_{Cik} \right] / \left[\sum_{k=1,K} \omega_k \right]$$

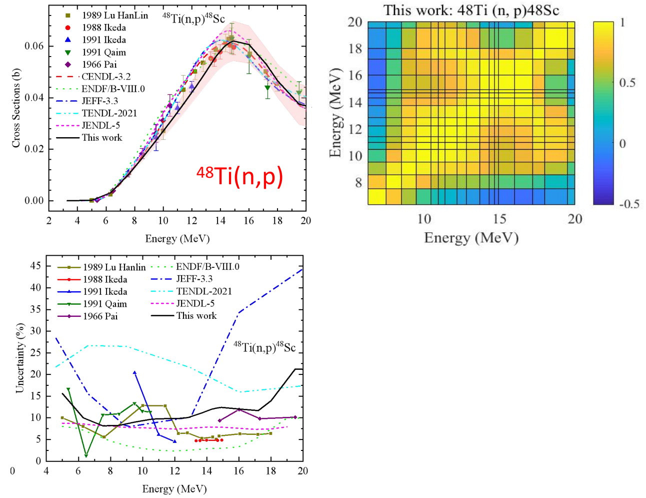
$$(V_\sigma)_{ij} = \left[\sum_{k=1,K} \omega_k \sigma_{Cik} \sigma_{Cjk} \right] \Big/ \left[\sum_{k=1,K} \omega_k \right] - \sigma_i \sigma_j$$

total cross section:

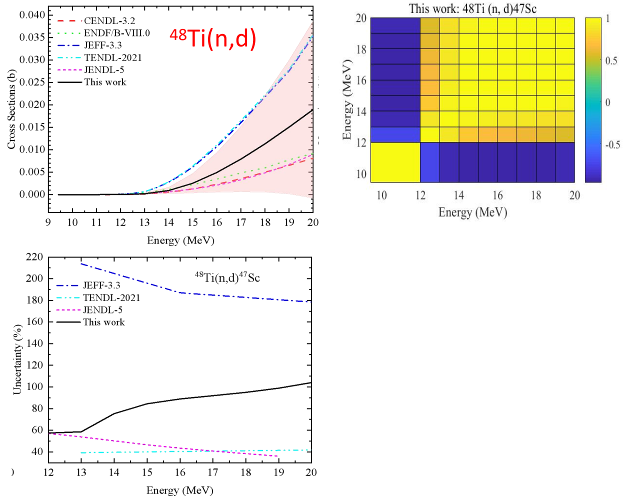


Simultaneously possessing the rationality of mathematics and nuclear reaction physics

rich experimental data:



lack of experimental data:



This work was in collaboration with R. Capote(IAEA),
Chinese Physics C Vol. 48, No. 7 (2024) 074101; doi: 10.1088/1674-1137/ad432c

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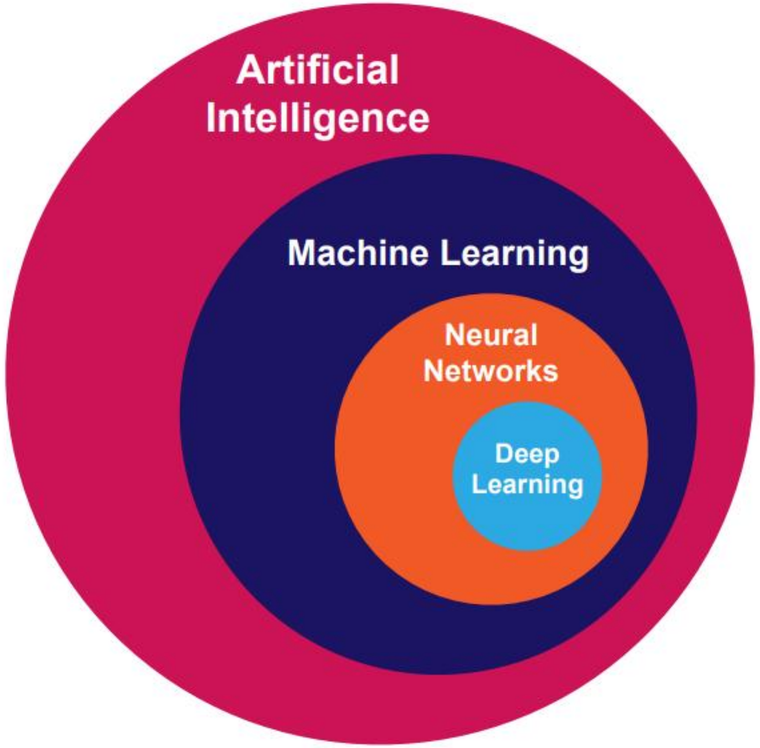
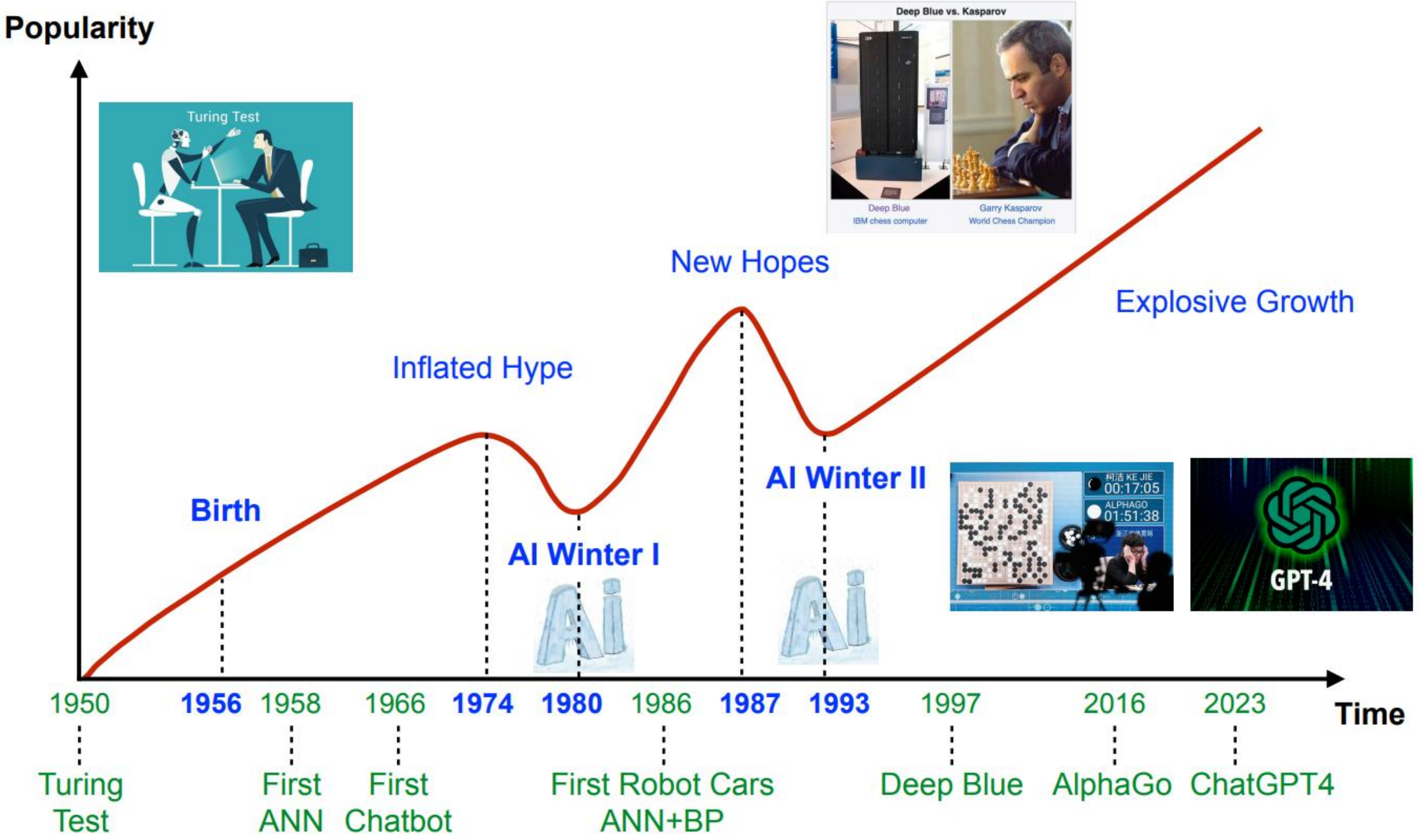

Artificial Intelligence
Machine Learning
Neural Networks
Deep Learning

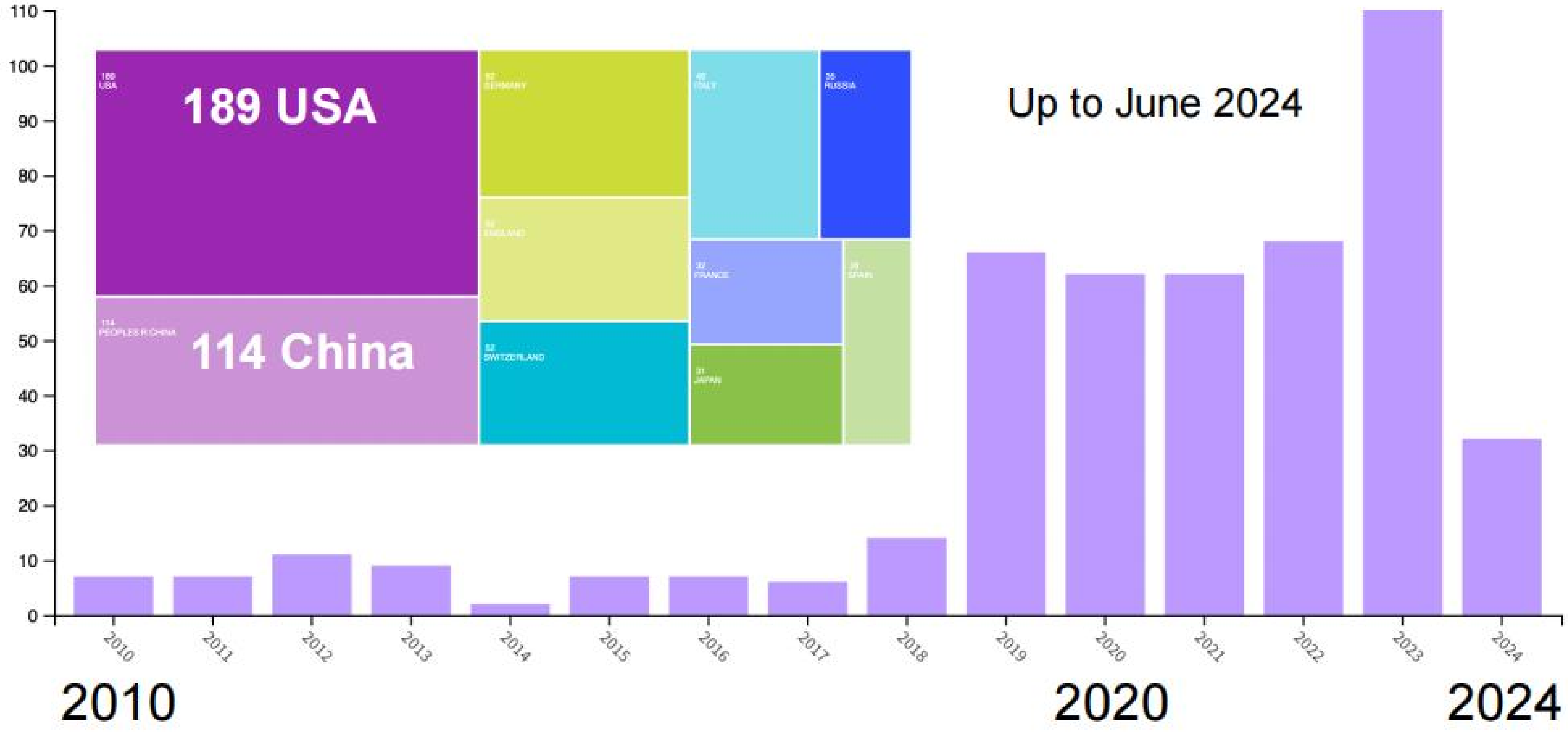

Popularity
Time
Turing Test
Deep Blue vs. Kasparov
Deep Blue
IBM chess computer
Garry Kasparov
World Chess Champion
Birth
Inflated Hype
AI Winter I
New Hopes
AI Winter II
Explosive Growth
KE JIE
00:17:05
ALPHAGO
01:51:38
GPT-4
1950
1956
1958
1966
1974
1980
1986
1987
1993
1997
2016
2023
Turing Test
First ANN
First Chatbot
First Robot Cars ANN+BP
Deep Blue
AlphaGo
ChatGPT4

Machine learning in nuclear physics

483 publications selected from Web of Science Core Collection

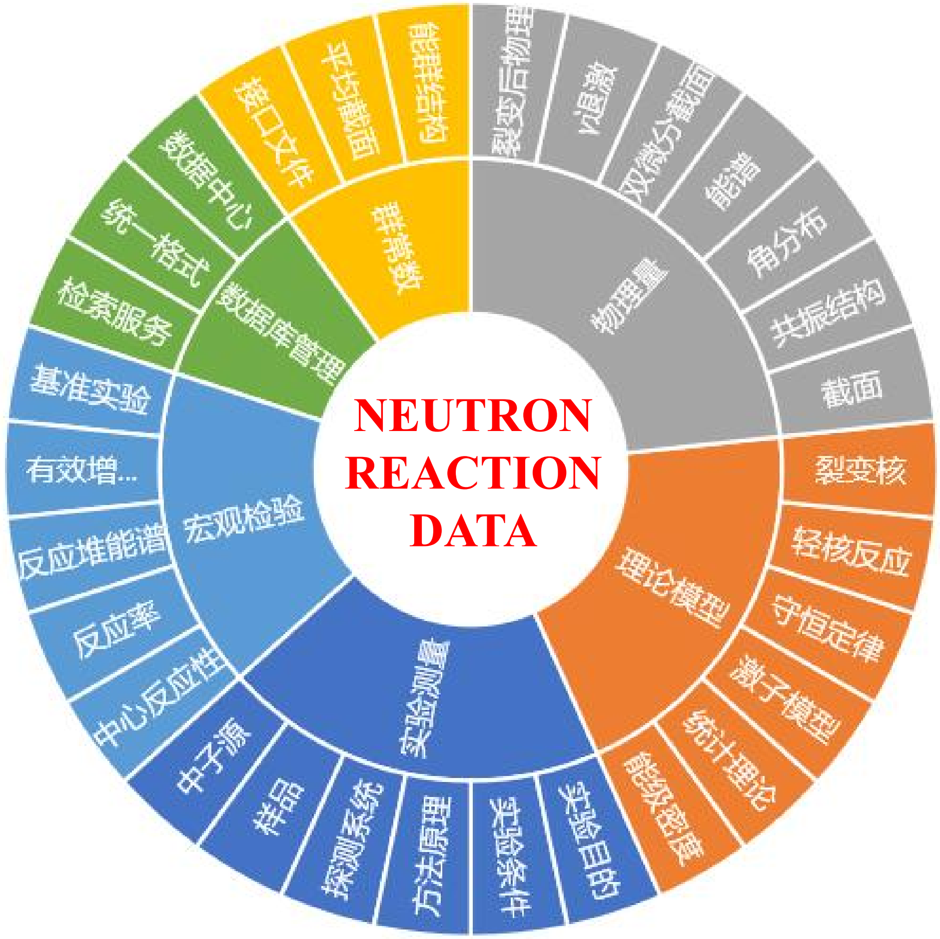
(TI=(machine learning) OR AB=(machine learning)) AND WC=(Physics, Nuclear)

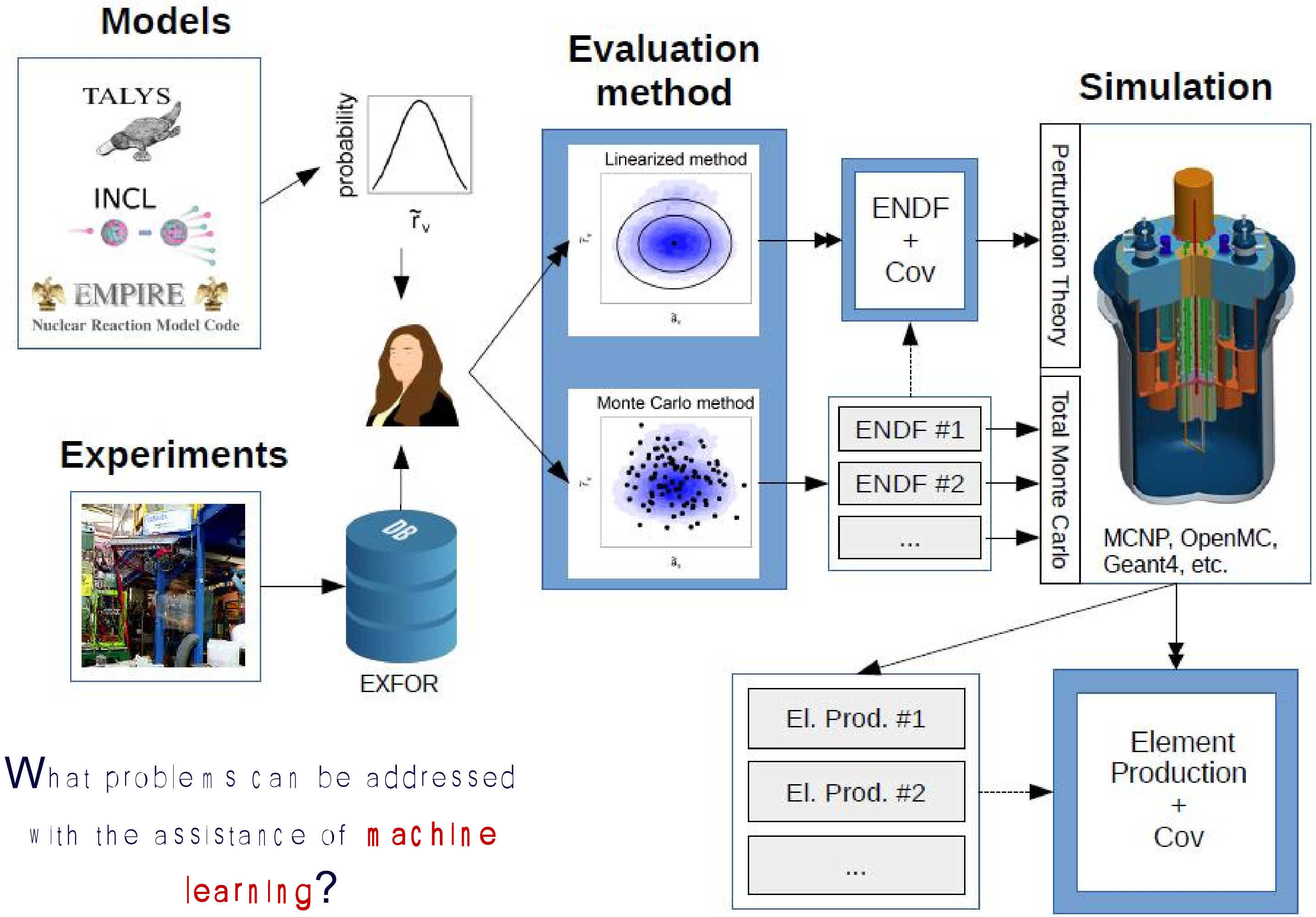
114/483 ~ **23.6%**



Nuclear data, which encompasses experimental measurements, theoretical models, evaluation, processing, validation, as well as database management and dissemination, necessitates highly specialized expertise.

Theory + Experiment + Statistics = evaluation

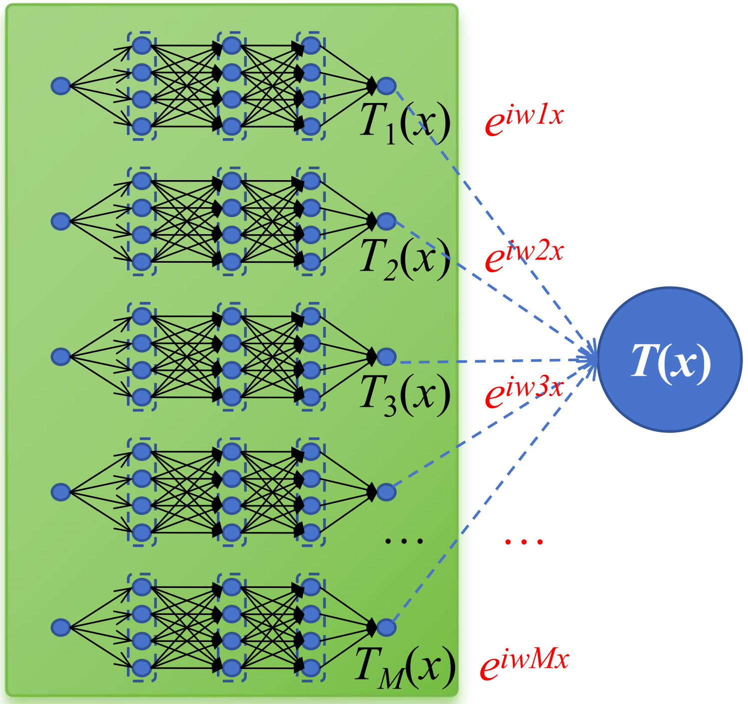




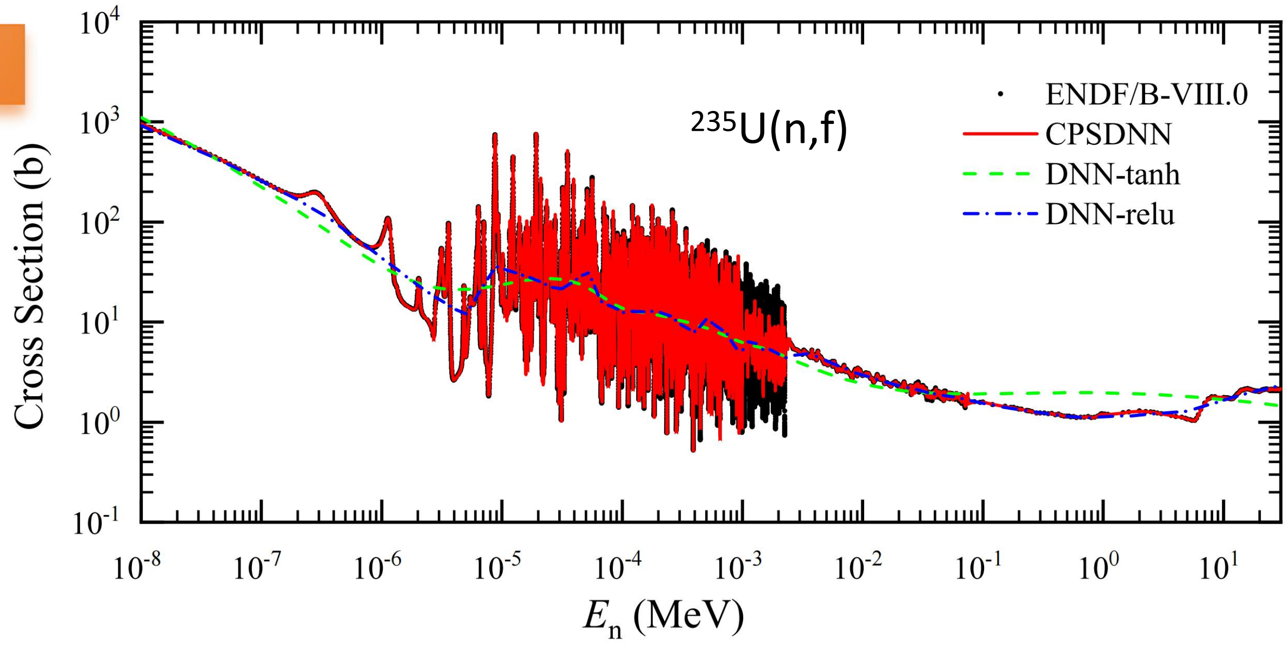
What problems can be addressed with the assistance of machine learning?

- Coupled Phase Shift Deep Neural Network(CPSDNN) Approach for Studying Resonance Cross Sections of ^{235}U(n,f) Reaction

CPSDNN to deal with high-frequency oscillating data



The neural network structure diagram of CPSDNN. Each $F_m(x)$ (m = 0, 1, ..., M) represents a neural network. The T(x) represents the training process of neural network.



The comparison of the raw cross sections, the predicted results of DNNs and CPSDNN for ^{235}U(n,f) reaction.

The black points are the evaluated data derived from ENDF/B-VIII.0. The green and the blue lines are the predicted results of DNNs with the tanh and relu activation functions, respectively.

The red line is the predicted results of CPSDNN.

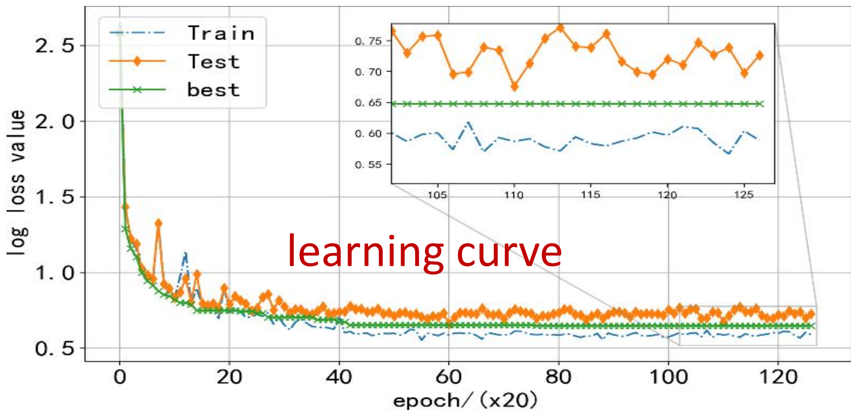
K. Xing（邢康）, X.J. Sun*, R.R. Xu*, et al. Phys. Lett. B 855 (2024) 138825

Systematic study of (n,2n) cross section adopting ANN and DT

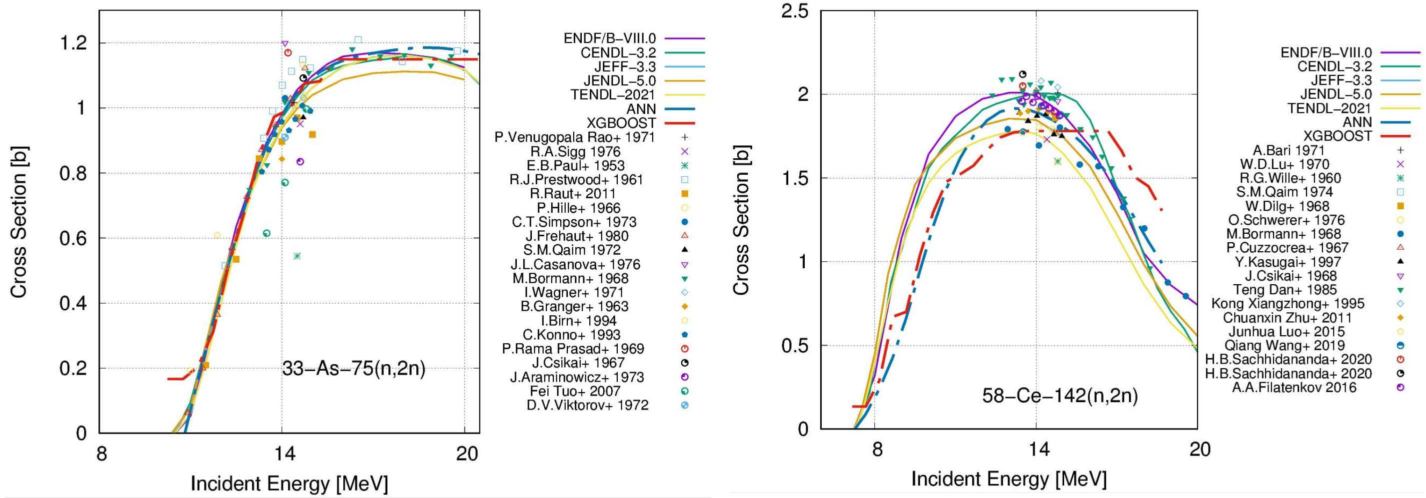
CHINA NUCLEAR DATA CENTER

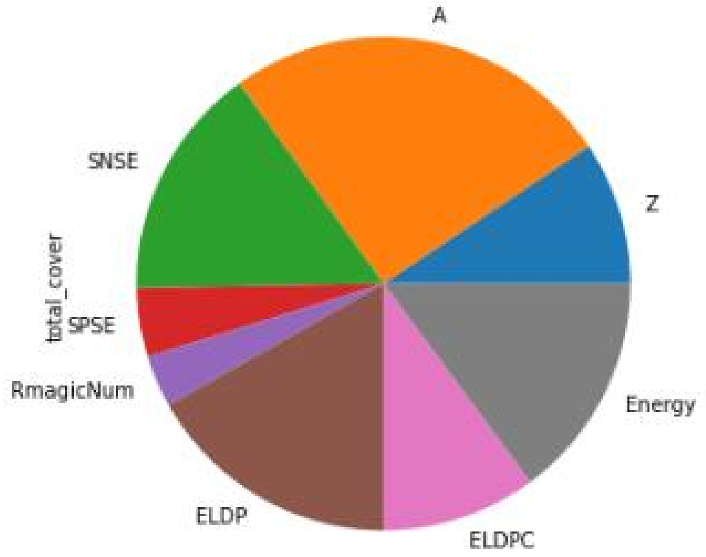
China nuclear industry college

The proportion of data exhibiting a prediction deviation of less than 10% surpasses 85%, enabling the successful calculation of covariance for cross-sectional data predictions across various energy levels.



Comparison of ML results, evaluation and experimental data





EPJ Conferences, 294, 04008 (2024)

Machine learning techniques uncover systematic patterns within nuclear reaction cross sections.

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New Evaluation Project and Data in CENDL-4.0

Motivation: Precision, Total number, Types

the coming end of 2025

ID	Reaction	JENDL-5 2021	ENDF/B-VIII.0 2018	JEFF-3.3 2017	CENDL-3.2 2020	CENDL-4.0 2025	BROND-3.1 2016	TENDL 2021
1	Photo-Nuclear Data (G)	2684	163	0	0	266	0	2804
2	Photo-Atomic Interaction Data (PHOTO)	100	100	0	0	0	0	0
3	Radioactive Decay Data (DECAY)	4071	3821	3852	0	2354 (A=66~172)	0	0
4	Spontaneous Fission Product Yields (S/FPY)	10	9	3	0	9	0	0
5	Atomic Relaxation Data (ARD)	100	100	0	0	0	0	0
6	Incident-Neutron Data (N)	795	557	562	272	410	372	2813
7	Neutron-Induced Fission Product Yields (N/FPY)	31	31	19	0	31	0	0
8	Thermal Neutron Scattering Data (TSL)	62	34	20	0	0	0	0
9	Electro-Atomic Interaction Data (E)	100	100	0	0	0	0	0
10	Incident-Proton Data (P)	239	49	0	0	78	0	2812
11	Incident-Deuteron Data (D)	9	5	0	0	0	0	2903
12	Incident-Triton Data (T)	0	5	0	0	0	0	2810
13	Incident-He3 Data (He3)	0	3	0	0	0	0	2809
14	Incident-Alpha Data (He4)	18	1	0	0	0	0	2808
15	Activation Data	Special purposed lib			0	818		

Many thanks to the collaborators and CENDL project:

All the great contributions from CNDC and CNDCN(China Nuclear Data Coordination Network**)**

IAEA: Roberto, Arjan, Vivian, Otsuka et al. from IAEA, and CRP 20466

Thank you for your attention!