第6次用户研讨会

中子标准截面与实验测量

北京大学
张国辉

2022-08-20

中子与中子核反应

- **中子是世界上最特殊的粒子**
- **中子不带电**
- **中子不能被加速**
- **中子在原子核内**
- **裂变和聚变核能的释放都与中子有关**
- **中子既无处不在 又难以获得：**同位素/反应堆/加速器 中子源
- **中子能区极其广泛：**超冷中子~极端相对论中子 近20个数量级
- **中子可诱发各种核反应：**中子与物质的相互作用是概率性的
- **中子的探测是间接性的：**中子核反应产生带电粒子 (或γ射线)，探测器探测带电粒子(或γ射线)

提纲

1. **引言** (从NDS到NDS)
2. **标准截面现状及其发展**
3. **标准截面的实验测量**
4. **展望**

1. 引言 (从NDS到NDS)

- **IAEA Nuclear Data Services** (NDS1)
  https://www.iaea.org/
  - **EXFOR** Experimental Nuclear reaction data 实验核数据
  - **ENDF** Evaluated Nuclear Reaction Libraries 评价核数据
  - **ENSDF** Evaluated Nuclear Structure and Decay Data 核结构数据
  - **Doc & Codes** 文件与程序 - **Index (Qcalc)** Q值计算 ...
- **IAEA Neutron Data Standards** (NDS2) 中子标准数据
- [”Provided by the Nuclear Data Section (NDS3)”]

https://www-nds.iaea.org/

International Atomic Energy Agency

Nuclear Data Services

Provided by the Nuclear Data Section

IAEA.org | NDS Mission | Mirrors: India | China | Russia

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Hot Topics » IAEA-CIELO • TENDL-2019 • JENDL-5 • ENDF/B-VIII.0 **News** » Pointwise2020//TENDL-2019

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Download data, codes, packages

Quick Links

- Photon Strength Function database
- Photonuclear
- RIPL
- RNAL
- SIGACE
- SPECOMP
- SPECTER
- STAYSL PNNL
- Safeguards Data
- SigmaCalc
- Spallation models
- Specialized Evaluated Libraries
- Standards
- Stopping Power Data
- TALYS
- Tendl2019
- Th-U
- Thermal Scattering Law Library

NEW

JENDL-5 Japanese evaluated nuclear data library, 2021: [page] [download] [list] [retrieve]
GRUCON-2021 ENDF data processing code package (includes source code): [page] [download]
Empire-3.2.2/2021.11 - nuclear reaction model code system for data evaluation [page]
β-delayed neutrons reference database for beta-delayed neutron emission [page]
TALYS nuclear reaction model code; TALYS-related software and databases [page]

Main | All | Reaction Data | Structure & Decay | by Applications | Doc & Codes | Index | Events | Links | News

EXFOR Experimental nuclear reaction data	**LiveChart of Nuclides** Interactive Chart of Nuclides	**CINDA** Nuclear reaction bibliography
ENDF Evaluated nuclear reaction libraries	**ENSDF** evaluated nuclear structure and decay data (+XUNDL) **	**NSR** Nuclear Science References *

NuDat-2 selected evaluated nuclear structure data **	**RIPL** reference parameters for nuclear model calculations	**IBANDL** Ion Beam Analysis Nuclear Data Library	**Charged particle reference cross section** Beam monitor reactions
PGAA Prompt gamma rays from neutron capture	**FENDL** Fusion Evaluated Nuclear Data Library	**Photonuclear** - IAEA Photonuclear Data Library, 2019 - EPICS Electron & Photon Interaction Data, 2017	**IRDFF-II** International Reactor Dosimetry and Fusion File
NAA Neutron Activation Analysis Portal	**Safeguards Data** Last updated: May 2021	**Medical Portal** Medical Portal	**Standards** - Neutron cross-sections, 2017 - Decay data, 2005

*Database at the IAEA, Vienna **Database at the US NNDC

IAEA Nuclear Data Section

IAEA-NDS Mission | A+M Atomic and Molecular Data | Meetings Workshops | Newsletters | Coordinated Research Projects | NRDC Nuclear Reaction Data Center Network | NSDD Nuclear Structure & Decay Data Network | INDEN International Network of Nuclear Data Evaluators | Technical Documents INDC Reports Publications | Computer Codes | IAEA-NA Department of Nuclear Sciences and Applications

Mirrors

Partners

Events «1:2»

European Commission

School on models in support of nuclear data in the frame of the SANDA project
May 9-13, 2022
EC-JRC Geel, Belgium

LXXIIth International Conference `Nucleus-2022: Fundamental problems and applications`
July 11-16, 2022
Moscow, Russian Federation

https://www-nds.iaea.org/exfor/

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Help » Manual PDF | Lexfor | Output | Plot+ | R33 Databases » ENDF | CINDA | IBANDL CD-ROM » EXFOR-CINDA | X4Lite | CD-Catalog

NNDC NRDC

Experimental Nuclear Reaction Data (EXFOR)

Database Version of 2022-08-03

Software Version of 2022-08-04

The EXFOR library contains an extensive compilation of experimental nuclear reaction data. Neutron reactions have been compiled systematically since the discovery of the neutron, while charged particle and photon reactions have been covered less extensively. EXFOR Reference Paper: Nucl. Data Sheets 120(2014)272, [arxiv].

EXFOR Web database retrieval system provides: data search, output to various formats (incl.XML), plotting and comparison to ENDF, re-normalization old data to new standards, calculating data for inverse reactions and kinematics, constructing correlation matrices from partial uncertainties, etc. EXFOR Web Database & Tools Paper: NIM A 888 (2018) 31, [arxiv].

The EXFOR database contains data from 24292 experiments (see statistics and recent database updates). Mirror-sites

Search: Go ?

Examples of requests: 1 2 3 4 5 6 7...

1 Cross section σ(E) /updates/ MF3 More examples...

Request Submit Reset Help

Target ?
Reaction ?
Quantity ?
Product ?
Energy from to eV ?
Author(s) ☑ Guohui Zhang ?
Publication year ?
Last modified ?
Accession # ?

Extended
Keywords
Expert
Evaluator

Submit Reset
Submit in new Window

Go to: [upload your data]

Options

- Exclude superseded data
- No reaction combinations (ratios,..)
- Exclude evaluated/calculated data
- Enhanced search of Products
- Show evaluators flags //2021
- Retrieve listing only
- Disable Prompt-help

Sort by: ◉ reaction ○ publication
View: ○ basic ◉ extended

Ranges (Z,A)
Reaction Sub-Fields
Feedback and User's Input
Clone Request: CINDA ENDF

More Web Tools

Plotting. See also: [video-guide]

建议：发表文章时用全名

Note:
- all criteria are optional (selected by checking ☑)
- selected criteria are combined for search with logical AND
- criteria separated in a field by ";" are combined with logical OR
- criteria starting with "^" will be used as logical NOT
- wildcards (*) and intervals (..) are available

Statistics of usage: visits: 220, requests: 961, since 04-Aug-2022 https://www-nds.iaea.org/exfor/

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NNDC NRDC

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Search: Go ?

Examples of requests: 1 2 3 4 5 6 7...
1 Cross section σ(E) /updates/ MF3 More examples...

Request Submit Reset Help

Target	☑	6Li
Reaction	☑	n,t
Quantity	☑	CS
Product	☐	
Energy from	☐	to ☐ eV
Author(s)	☐	
Publication year	☐	
Last modified	☐	
Accession #	☐	

Extended
Keywords
Expert
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Submit in new Window

Go to: [upload your data]

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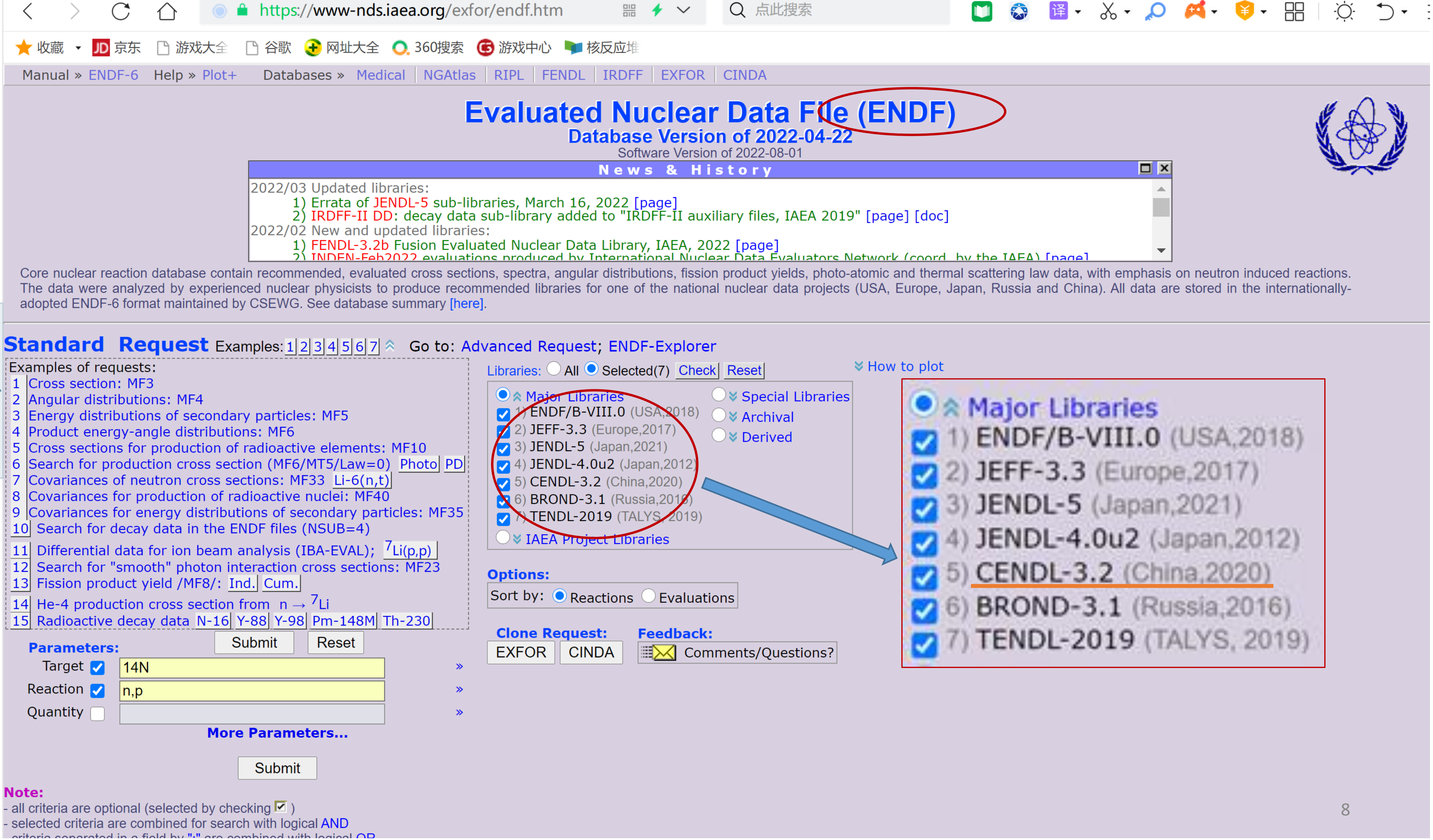
Statistics of usage: visits: 221, requests: 964, since 04-Aug-2022


https://www-nds.iaea.org/exfor/endf.htm
Manual » ENDF-6 Help » Plot+ Databases » Medical | NGAtlas | RIPL | FENDL | IRDFF | EXFOR | CINDA
Evaluated Nuclear Data File (ENDF)
Database Version of 2022-04-22
Software Version of 2022-08-01
News & History
2022/03 Updated libraries:
1) Errata of JENDL-5 sub-libraries, March 16, 2022 [page]
2) IRDFF-II DD: decay data sub-library added to "IRDFF-II auxiliary files, IAEA 2019" [page] [doc]
2022/02 New and updated libraries:
1) FENDL-3.2b Fusion Evaluated Nuclear Data Library, IAEA, 2022 [page]
Core nuclear reaction database contain recommended, evaluated cross sections, spectra, angular distributions, fission product yields, photo-atomic and thermal scattering law data, with emphasis on neutron induced reactions. The data were analyzed by experienced nuclear physicists to produce recommended libraries for one of the national nuclear data projects (USA, Europe, Japan, Russia and China). All data are stored in the internationally-adopted ENDF-6 format maintained by CSEWG. See database summary [here].
Standard Request Examples: 1 2 3 4 5 6 7 Go to: Advanced Request; ENDF-Explorer
Examples of requests:
1 Cross section: MF3
2 Angular distributions: MF4
3 Energy distributions of secondary particles: MF5
4 Product energy-angle distributions: MF6
5 Cross sections for production of radioactive elements: MF10
6 Search for production cross section (MF6/MT5/Law=0) Photo PD
7 Covariances of neutron cross sections: MF33 Li-6(n,t)
8 Covariances for production of radioactive nuclei: MF40
9 Covariances for energy distributions of secondary particles: MF35
10 Search for decay data in the ENDF files (NSUB=4)
11 Differential data for ion beam analysis (IBA-EVAL); 7Li(p,p)
12 Search for "smooth" photon interaction cross sections: MF23
13 Fission product yield /MF8/: Ind. Cum.
14 He-4 production cross section from n → 7Li
15 Radioactive decay data N-16 Y-88 Y-98 Pm-148M Th-230
Submit Reset
Parameters:
Target 14N
Reaction n,p
Quantity
More Parameters...
Submit
Libraries: All Selected(7) Check Reset
How to plot
Major Libraries
1) ENDF/B-VIII.0 (USA,2018)
2) JEFF-3.3 (Europe,2017)
3) JENDL-5 (Japan,2021)
4) JENDL-4.0u2 (Japan,2012)
5) CENDL-3.2 (China,2020)
6) BROND-3.1 (Russia,2016)
7) TENDL-2019 (TALYS, 2019)
IAEA Project Libraries
Special Libraries
Archival
Derived
Options:
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Clone Request: EXFOR CINDA
Feedback: Comments/Questions?
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Charged particle reference cross section Beam monitor reactions

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FENDL Fusion Evaluated Nuclear Data Library

Photonuclear
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- EPICS Electron & Photon Interaction Data, 2017

IRDFF-II International Reactor Dosimetry and Fusion File

NAA Neutron Activation Analysis Portal

Safeguards Data Last updated: May 2021

Medical Portal Medical Portal

Standards
- Neutron cross-sections, 2017
- Decay data, 2005

*Database at the IAEA, Vienna **Database at the US NNDC

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IAEA.org International Atomic Energy Agency

Nuclear Data
IAEA Nuclear Data Services Home Page

STANDARDS 2017
HOME
Nuclear Data Sheets 148 (2018) 143-188
Neutron Standards Data in the ENDF-6 Formatted Files, presentation by V.G. Pronyaev, December 2019

STANDARDS 2006
STD 2006
Technical Report

Downloads
Codes and Programs
Test cases
Most recent calculations

Documents
Documents and Reports

IAEA NEUTRON DATA STANDARDS (2017)

A.D. Carlson, et al., Nuclear Data Sheets 148 (2018) 143-188

#	Reaction	Energy Range	ENDF-6 formatted data	Free text format
1	H(n,n)	Standard range: 1 keV to 20 MeV	std17-001_H_001.endf	std17-001_H_001.txt
2	^{6}Li(n,t)	1e-5 eV to 4 MeV (Standard range: Thermal - 1 MeV)	std17-003_Li_006.endf	std17-003_Li_006.txt
3	^{10}B(n,α);(n,α$_1$γ)	1e-5 eV to 1 MeV (Standard range: Thermal - 1 MeV)	std17-005_B_010.endf	std17-005_B_010.txt
4	^{nat}C(n,n)	up to 6.45 MeV (Standard range: 1keV - 1.8 MeV)	std17-006_C_000.endf	std17-006_C_000.txt
5	^{197}Au(n,γ)	2.5 keV to 2.8 MeV (Standard range: Thermal, 200keV - 2.5MeV)	std17-079_Au_197.endf	std17-079_Au_197.txt
6	^{235}U(n,f)	150 eV to 200 MeV (Standard range: Thermal, 150keV - 200MeV)	std17-092_U_235.endf	std17-092_U_235.txt
7	^{238}U(n,f)	0.5 to 200 MeV (Standard range: 2 - 200MeV)	std17-092_U_238.endf	std17-092_U_238.txt
8	Thermal Neutron Constants: nubar, (n_{th},f), (n_{th},el), (n_{th},g) cross sections for fissile targets ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu. Total nubar ^{252}Cf(sf).	0.0253 eV (2200 m/s)		Standards2017_TNC.txt
9	^{197}Au(n,γ)	MACS (30 keV)= 620(11) mb		
10	^{235}U(n,f)	Integral from 7.8 eV to 11 eV = 247.5(3.3) b*eV		

Neutron Cross-section Standards

Reaction	Neutron Energy Range			
	1987	2002-2005/06		
			ENDF-6 Format	Free text Format
H(n,n)	1 keV to 20 MeV	1 keV to 20 MeV	std-001_H_001.endf	not available
^{3}He(n,p)	0.0253 eV to 50 keV	0.0253 eV to 50 keV (1987 adopted)	std-002_He_003.endf	not available
^{6}Li(n,t)	0.0253 eV to 1 MeV	0.0253 eV to 1 MeV	std-003_Li_006.endf	standards-6Li_xs-data.txt
^{10}B(n,α)	0.0253 eV to 250 keV	0.0253 eV to 1 MeV	std-005_B_010.endf	standards-10B_na-xs-data.txt
^{10}B(n,$α_1$γ)	0.0253 eV to 250 keV	0.0253 eV to 1 MeV	std-005_B_010.endf	standards-10B_na1-xs-data.txt
C(n,n)	up to 1.8 MeV	up to 1.8 MeV (1987 adopted)	std-006_C_000.endf	not available
Au(n,γ)	0.0253 eV, and 0.2 to 2.5 MeV	0.0253 eV, and 0.2 to 2.5 MeV	std-079_Au_197.endf	standards-197Au_xs-data.txt
^{235}U(n,f)	0.0253 eV, and 0.15 to 20 MeV	0.0253 eV, and 0.15 to 200 MeV	std-092_U_235.endf	standards-235U_xs-data.txt
^{238}U(n,f)	threshold to 20 MeV	2 to 200 MeV	std-092_U_238.endf	standards-238U_xs-data.txt

Neutron Cross-section References (2015)

Reaction	Energy Range	ENDF-6 Format	NJOY plot	Free text format
235U(n,f)	0.0253 eV - 1 GeV	235U-Ref-HighErg.endf	file.pdf	235U_nf_Reference_xs_data.txt
238U(n,f)	0.0253 eV - 1 GeV	238U-Ref-HighErg.endf	file.pdf	238U_nf_Reference_xs_data.txt
239Pu(n,f)	0.0253 eV - 300 MeV	239Pu-Ref-HighErg.endf	file.pdf	239Pu_nf_Reference_xs_data.txt
209Bi(n,f)	34 MeV - 1 GeV	209Bi-Ref-HighErg.endf	file.pdf	209Bi_nf_Reference_xs_data.txt
natPb(n,f)	34 MeV - 1 GeV	natPB-Ref-HighErg.endf	file.pdf	natPb_nf_Reference_xs_data.txt

2. 标准截面现状及其发展

- 2.1 中子标准截面现状
- 2.2 标准截面的发展

2.1 标准截面现状 Neutron Cross Section Standards

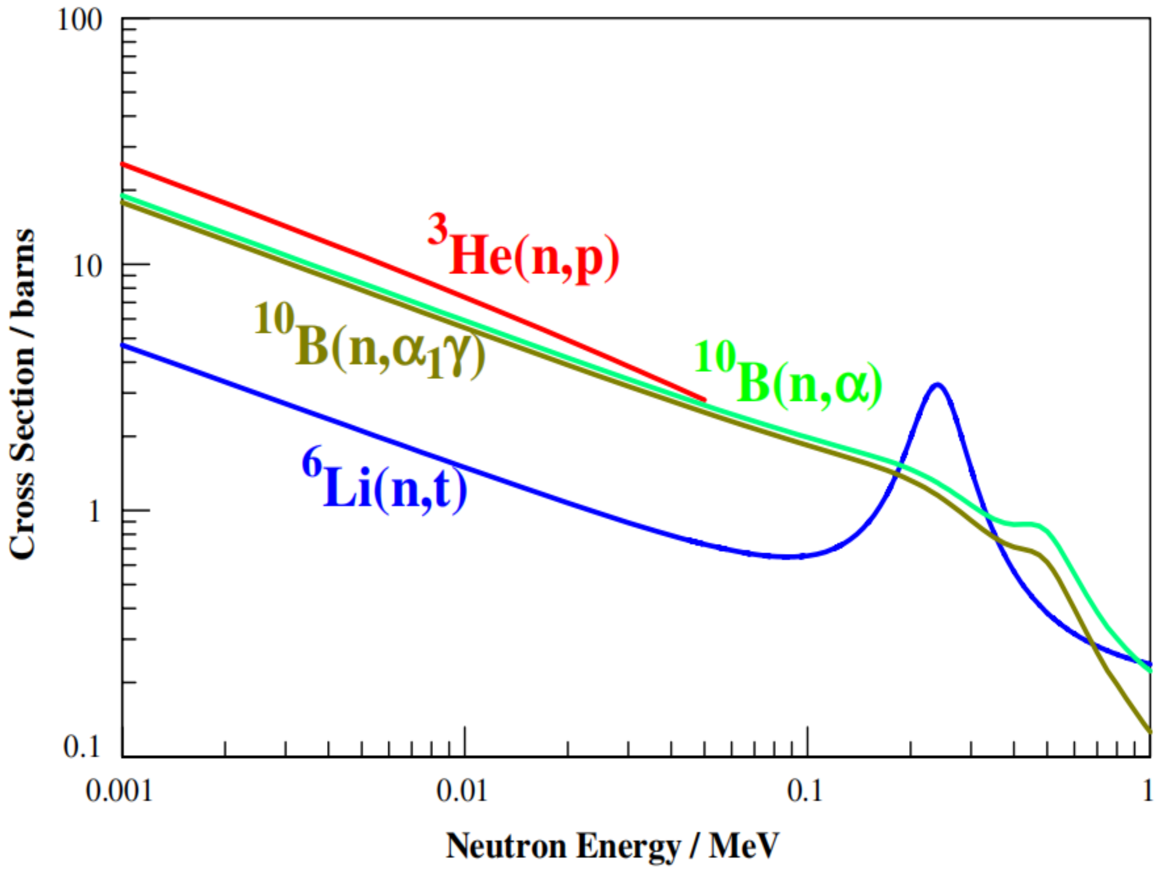
4类核反应：
- 弹性散射(2)
- 轻带电粒子出射(4)
- 辐射俘获(1)
- 裂变反应(2)

其他分类：
- 出射带电粒子，出射伽马射线
- 高能标准，低能标准
- 轻核反应，重核反应

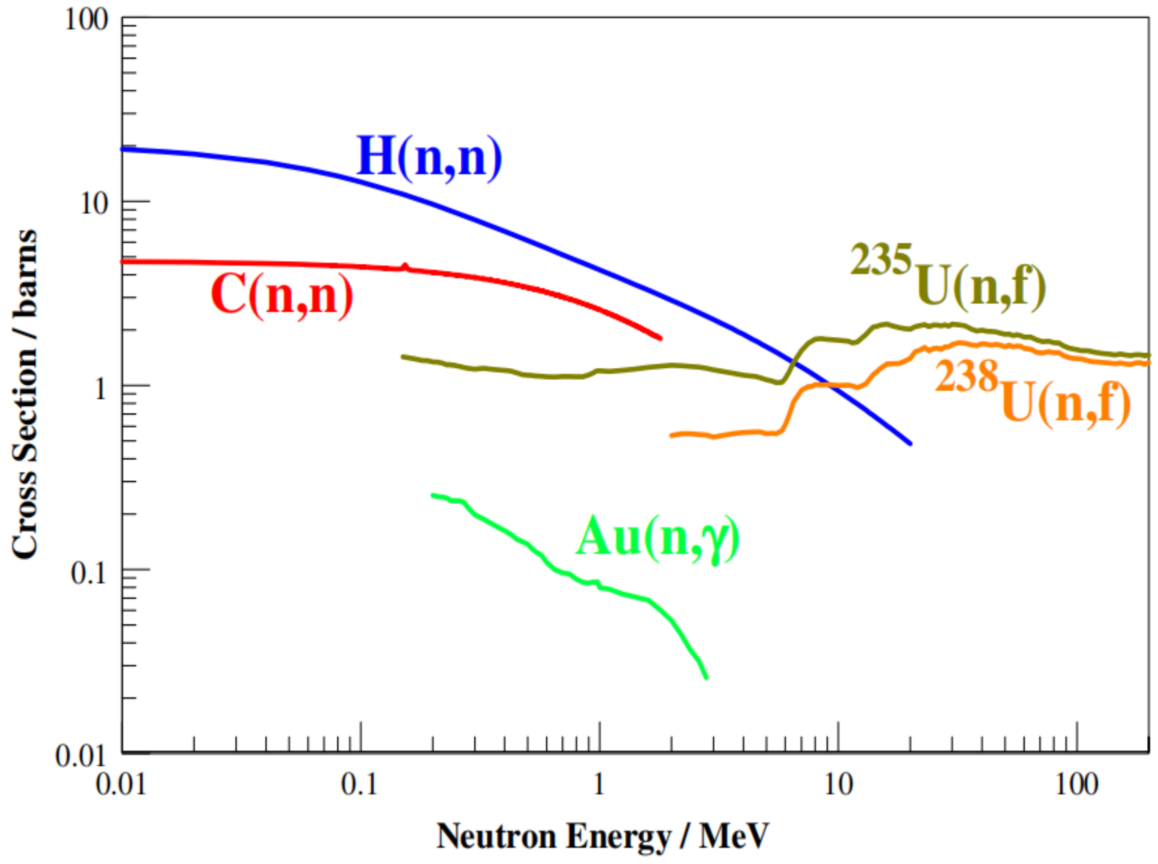
A. D. Carlson ND2022报告

	Reaction	Energy Range
1.	H(n,n)	1 keV to 20 MeV
2.	^{3}He(n,p)	0.0253 eV to 50 keV
3.	^{6}Li(n,t)	0.0253 eV to 1 MeV
4.	^{10}B(n,α)	0.0253 eV to 1 MeV
5.	^{10}B(n,$\alpha_1\gamma$)	0.0253 eV to 1 MeV
6.	^{Nat}C(n,n)	10 eV to 1.8 MeV
7.	^{197}Au(n,γ)	0.0253 eV, 0.2 to 2.5 MeV, 30 keV MACS
8.	^{235}U(n,f)	0.0253 eV, 7.8--11 eV, 0.15 MeV to 200 MeV
9.	^{238}U(n,f)	2 MeV to 200 MeV

中子标准截面(9条激发函数曲线)



The low neutron energy cross section standards.
Data below 1 keV are not shown.



The high-energy neutron cross section standards.
Data below 10 keV are not shown.

对中子标准核反应的要求

能作为中子标准截面的核反应要满足下列要求：

- 能区宽　截面尽量大 Q值大
- 激发函数曲线光滑 结构简单
- 干扰反应尽量少
- 靶核同位素成分简单
- 材料易加工获得(不至于过分昂贵)

中子标准截面的特点

- **国际统一性**
- **基础性、标准性**

  中子标准截面是核数据库中所有核反应截面的基准
  (i.e. 核数据大厦的基础和四梁八柱)

- **处于不断完善过程中**

  基于新的实验测量和评价手段
  - 标准截面精度不断提高
  - 能区不断拓展

- **中子标准截面精度的提高 能使相对测量结果以及核数据库中所有核数据的精度都得到提高**

2.2 标准截面的发展

- 标准截面的评价和更新主要由 Cross Section Evaluation Working Group (CSEWG小组)完成，该小组定期召开会议对标准截面结果进行讨论，加入最新的实验结果，发现已有标准截面中可能存在的问题。

- 在ENDF/B-IV库之前，评价方法主要是通过对测量数据点取平均，然后绘制平滑曲线来进行的，这种方法难以进行细致的误差分析和协方差分析。ENDF/B-IV评价库改进了评价方法，对较轻核引入了R矩阵分析。

- H(n,n)截面是最早的标准截面，其次是^{6}Li(n,t)截面，第三是^{10}B(n,α)截面；^{3}He(n,p)截面是标准截面中测量较少的，目前IAEA网站最新的标准截面库(2017版)里没有纳入，而在更早的版本里面包括了^{3}He(n,p)截面。

标准截面的三个正式版本 (NDS网站)

1984版本 对应ENDF/B-V库

2006版本 对应ENDF/B-VII库

2017版本 对应ENDF/B-VIII库

其他时间，IAEA的标准截面库没有更新，但是各个评价库会更新几个相关核反应的评价数据。

Progress in Nuclear Energy, Vol. 13, No. 2/3, pp. 79-127, 1984.
Printed in Great Britain.

1984年版本介绍

0149-1970/84 $0.00 + .50

STANDARD CROSS-SECTION DATA

A. D. CARLSON

National Bureau of Standards, Washington, DC 20234, U.S.A.

(*Received* 1 *August* 1983)

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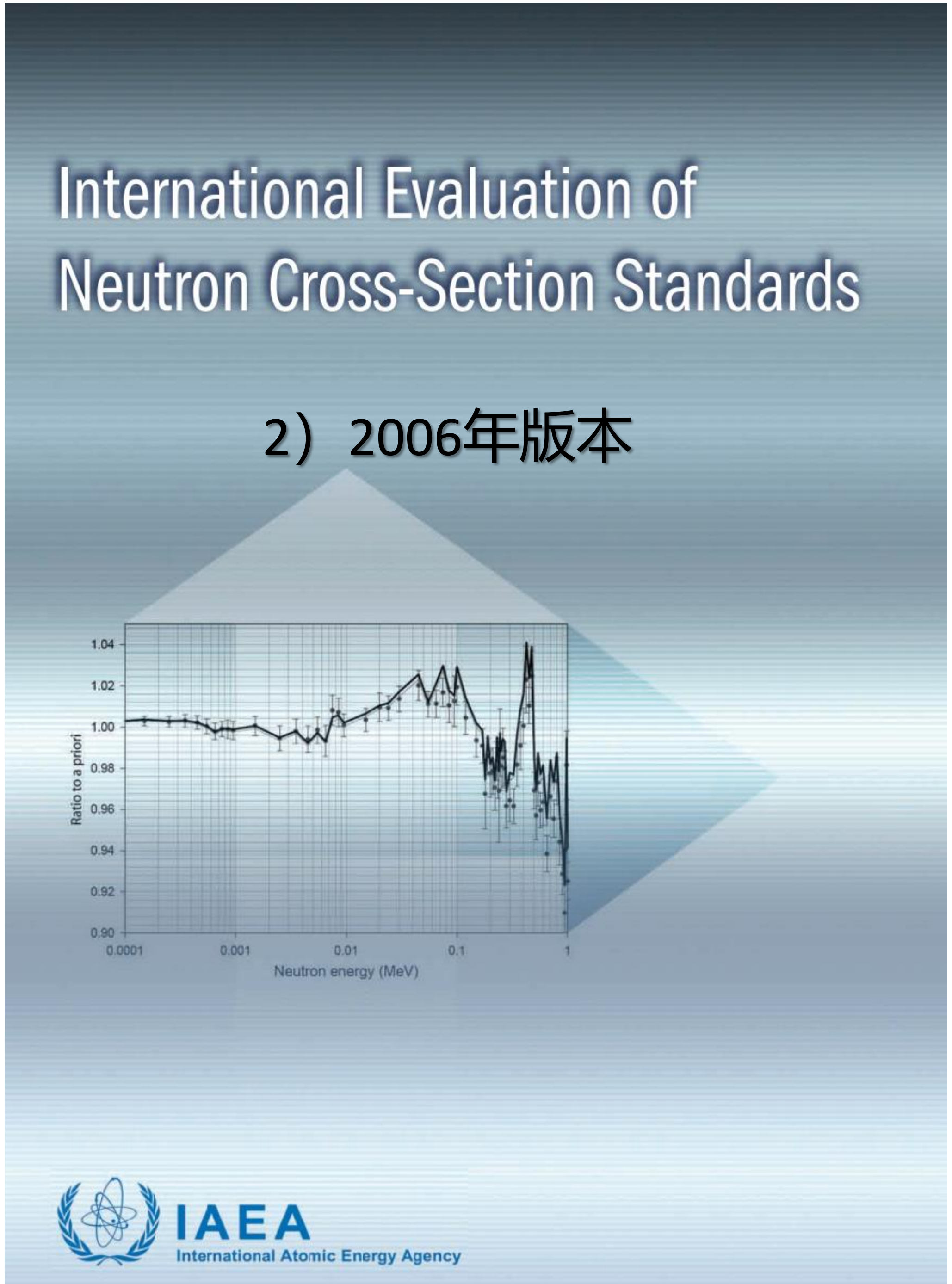

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ScienceDirect

3）2017版本介绍

Nuclear Data Sheets 148 (2018) 143–188

Nuclear Data Sheets

www.elsevier.com/locate/nds

Evaluation of the Neutron Data Standards

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(Received 3 September 2017; revised received 30 October and 12 November 2017; accepted 20 November 2017)

中子标准截面数据的再版

- 以新的实验测量结果为基础
- 采用新的数据评价技术
- 发现并解决以往标准以及评价方法中存在的问题
- 提高数据精度
- 扩展能区

中子标准截面的实验测量及评价永无止境...

我们有责任不断提高中子标准截面的实验测量精度

3. 标准截面的实验测量

- 3.1 Back-n建成以前基于北大中子源完成的标准截面测量
- 3.2 基于Back-n完成的标准截面测量

- **高精度的实验测量是标准截面发展完善的基础和前提**

3.1 Back-n建成前基于北大中子源完成的标准截面测量

与杜布纳联合核子所合作

- **完成了3项有关的自然科学基金项目**

6Li(n,t)4He反应微分截面实验研究
2003. 01—2005. 12 (25万元)
项目批准号 10275001

快中子10B(n,a)7Li反应截面与微分截面实验方法研究
2009. 01—2011. 12 (42万元)
项目批准号 10875006

快中子硼-10三体造氚核反应实验方法研究
2015.01 – 2018.12 (86万元)
项目批准号：11475007

基于
PKU-VDG加速器
Dubna-GIC探测器

两次实验法
分别测量前向t
与前向α粒子

不对称双电离室
证实存在Leaking Effect
首次测量了Leaking截面

薄衬薄10B样品+前后符合
DAQ全数字化
在测量10B(n,t+2a)三体反应同时
得到了更准确的10B(n,t)7Li截面

NUCLEAR SCIENCE AND ENGINEERING: **134**, 312–316 (2000)

Technical Note

第一篇SCI论文...

Differential Cross-Section Measurement for the $^{6}Li(n,t)^{4}He$ Reaction at 3.67 and 4.42 MeV

国内期刊投稿被拒

申请基金2次被拒

Guohui Zhang,* Guoyou Tang, Jinxiang Chen, Zhaomin Shi, and Guangzhi Liu

Peking University, Institute of Heavy Ion Physics, Beijing, China 100871

Xuemei Zhang and Zemin Chen

Tsinghua University, Department of Physics, Beijing, China 100084

and

Yu. M. Gledenov, M. Sedysheva, and G. Khuukhenkhuu

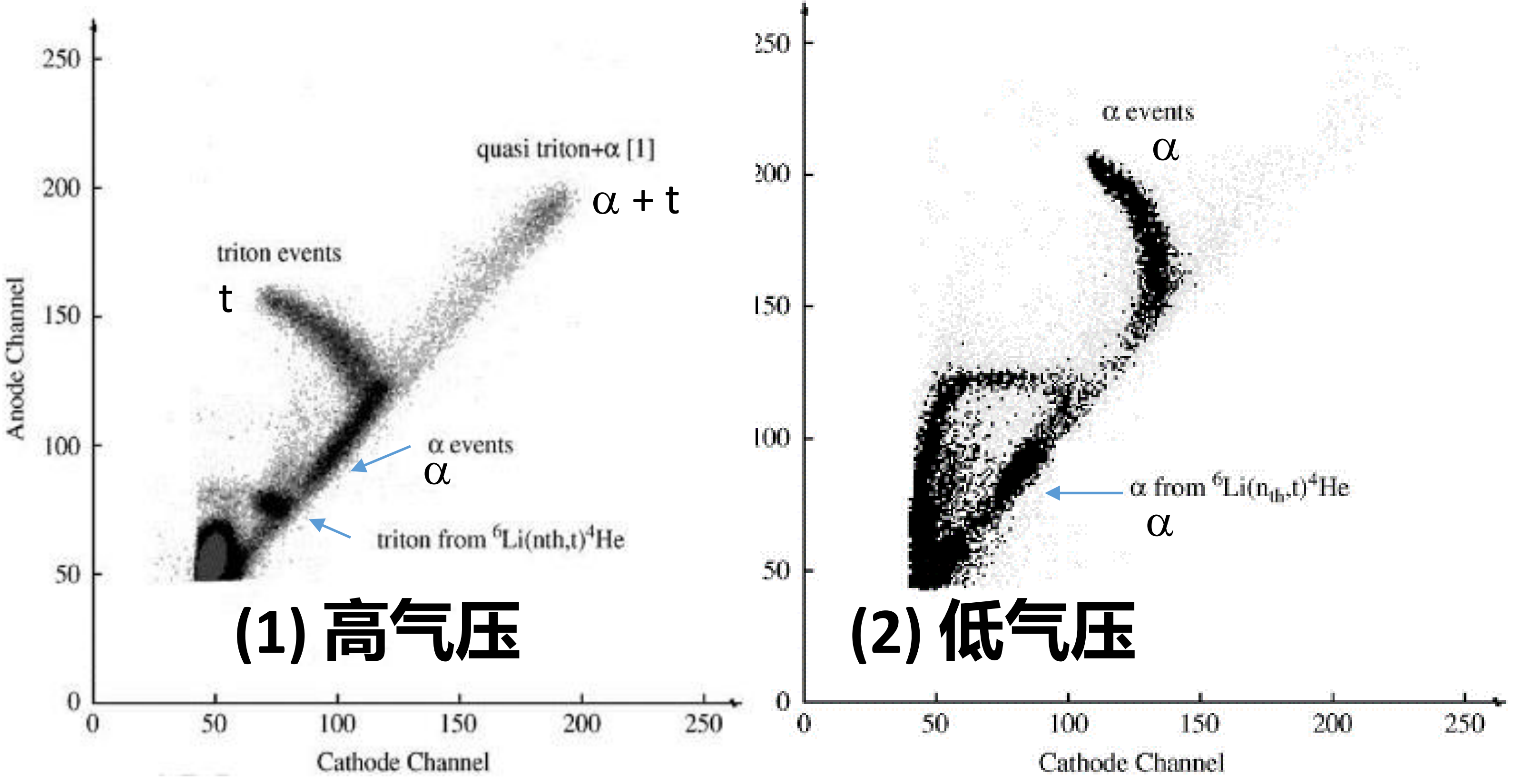
Joint Institute for Nuclear Research, Frank Laboratory of Neutron Physics, Dubna, Russia 141980

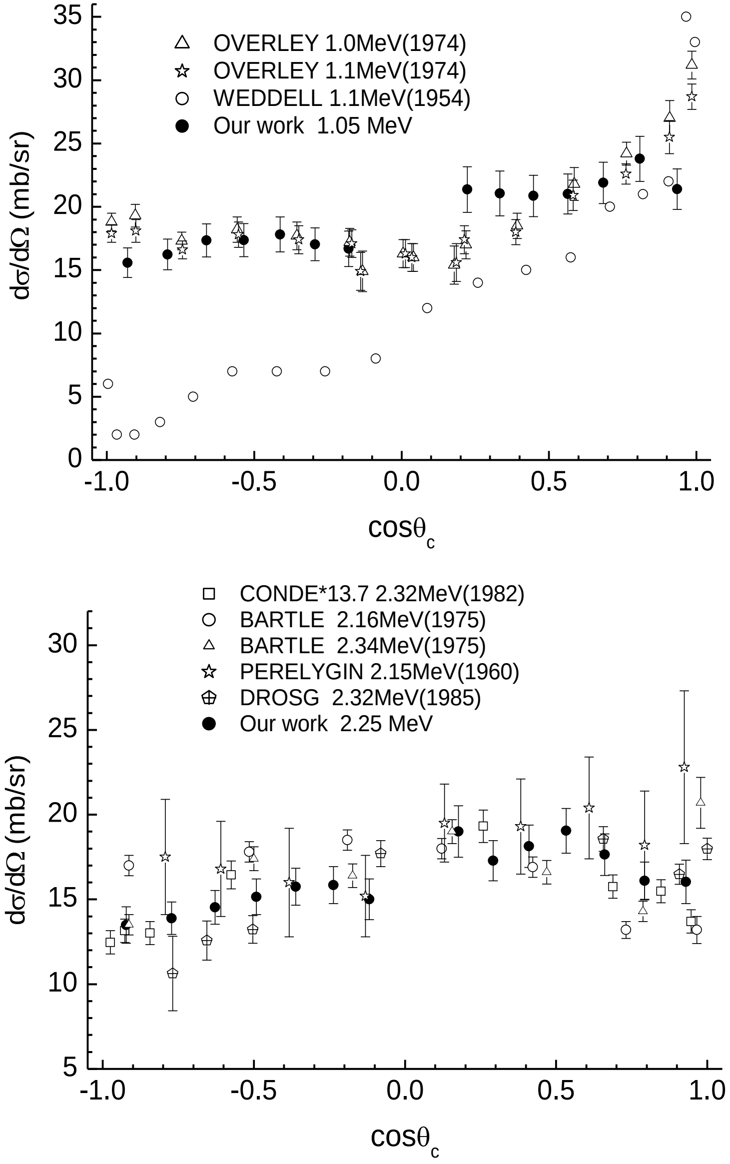
3个合作单位
10位作者
(2个能点)

Received June 3, 1999
Accepted September 23, 1999

$^{6}Li(n, t)^{4}He$

NIM A 566(2006)615
NSE 143 (2005) 86





实验方案： 前向氚 + 前向α (→得后向氚)

- **完成了第一个自然科学基金项目(2003-05)**

(得到了 7个能点的微分截面与截面)

$^{10}B(n, \alpha)^7Li$

ARI 66 (2008) 1427   CPL 28 (2011) 082801

- 采用前后不对称GIC +前向测量
- 在国际上首次得到Leaking截面
  (G. Giorginis "effect of particle leaking" NIM A 538 (2005) 550)
- 首先发现硼样品随时间减少

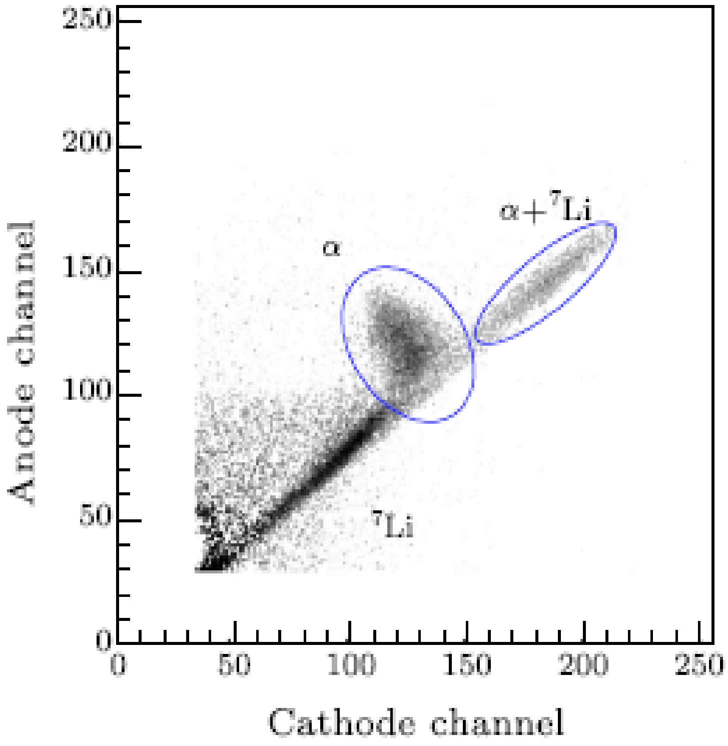


Fig. 3. Cathode-anode two dimensional spectrum for forward event measurements at $E_n = 4.0$ MeV after background subtraction.

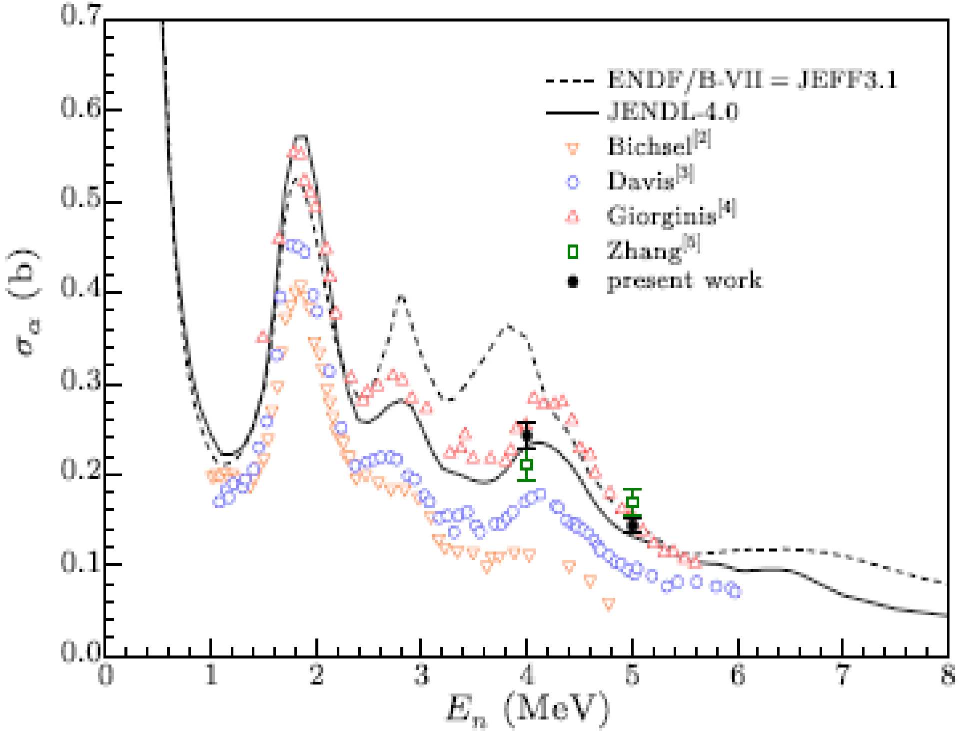


Fig. 6. Present cross sections of the $^{10}B(n,\alpha)^7Li$ reaction compared with previous measurements and evaluations.

- Dr. Zhang,
- I would like to get more information on **the 10B thickness loss problem** you are having. Members of our group have also seen this problem.
- Allan Carlson
- ________________________________
- Date: Fri, 23 Sep 2011 11:47:18 -0700 (PDT)
- From: Allan carlson <allandcarlson@yahoo.com>
- Subject: Re: 10B data   To: guohuizhang@pku.edu.cn

从2011
到2022

On Sat, Jul 16, 2022 at 5:26 AM 张国辉 <guohuizhang@pku.edu.cn> wrote:
"Allan Carlson" <carlson.std@gmail.com>

Allan,

The results of the 10B(n,a)/6Li(n,t) ratios are illustrated in the attached file.

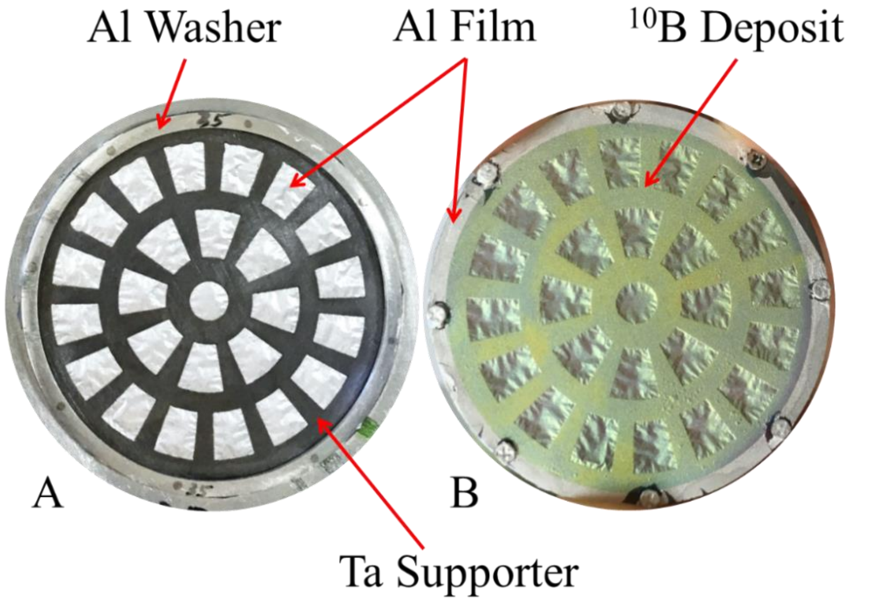
The complete results are so many that it is hard for us to plot all the figures, so only typical ones are included.

Please send me your comments and suggestions. Thank you!

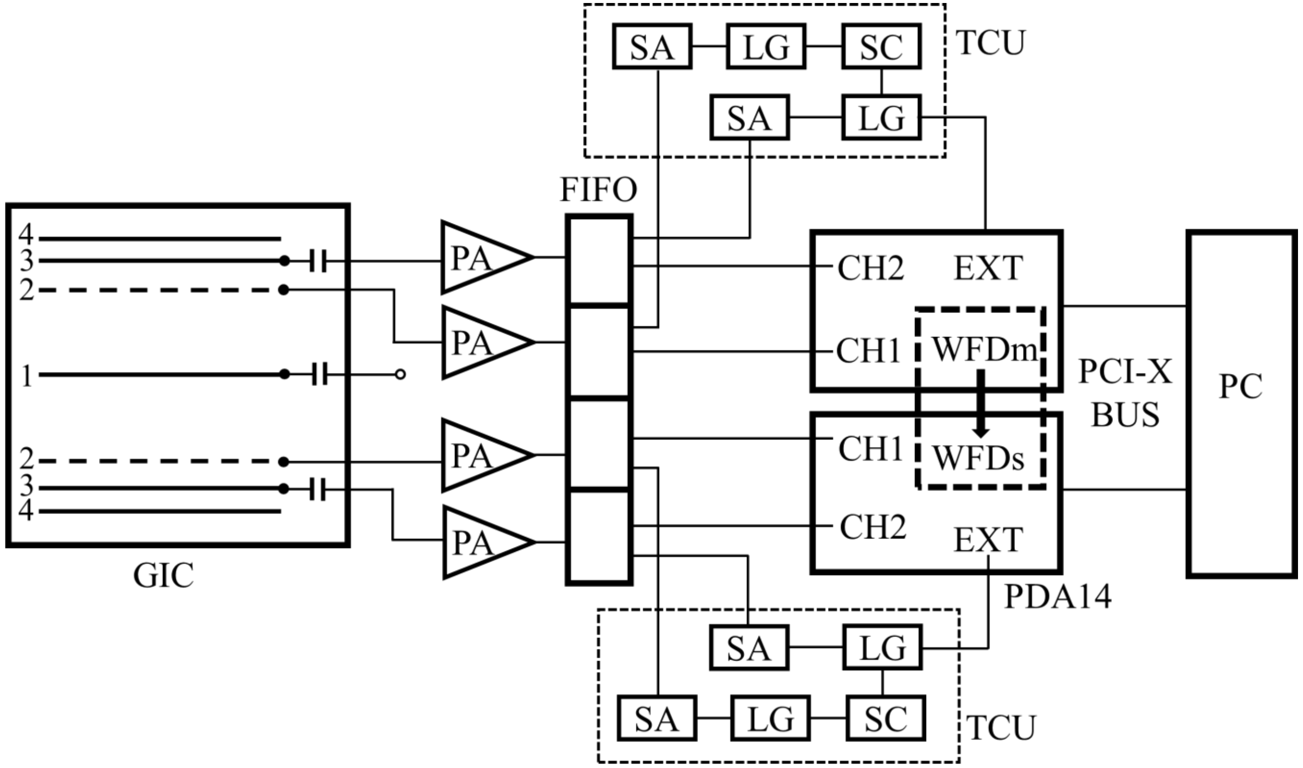
With my best wishes!
Guohui

$^{10}B(n, t+2\alpha)$

薄衬^{10}B样品
设计、制备与核数测量



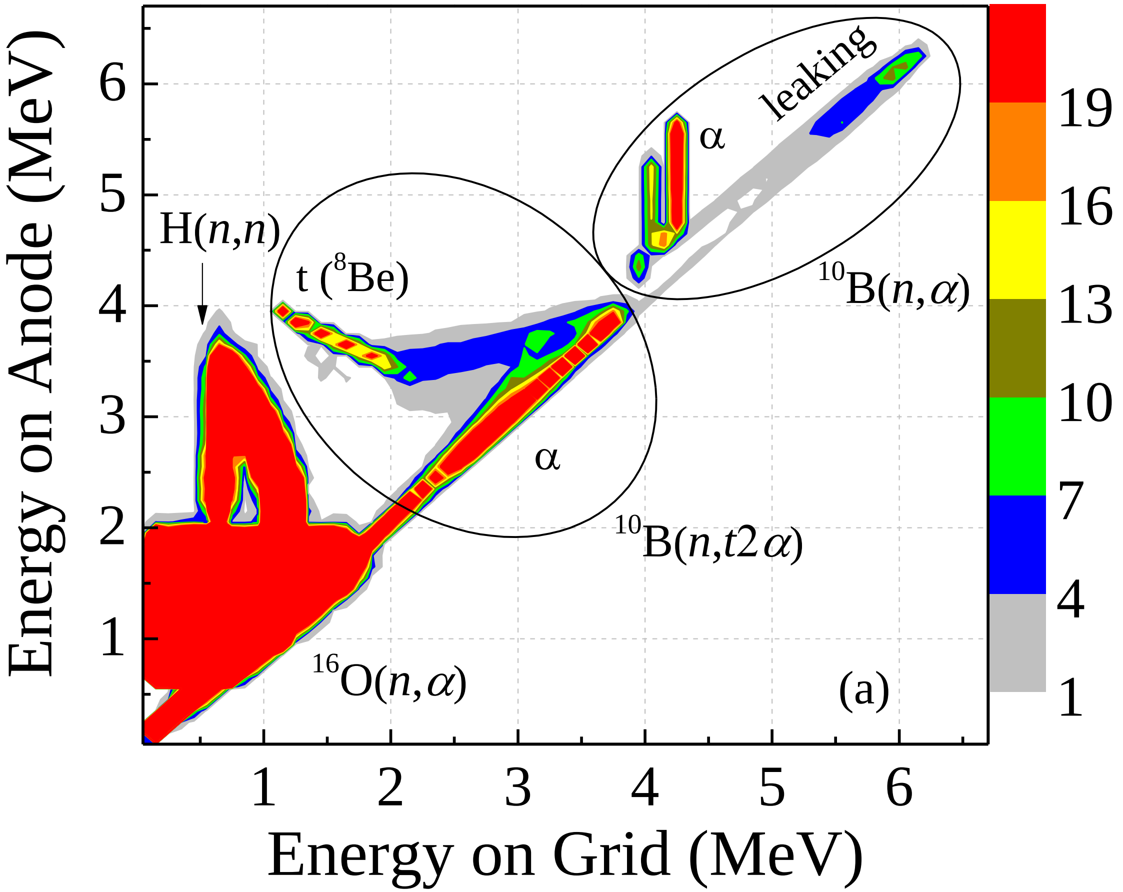
基于LabVIEW的**数据获取系统**
阳极-栅极 前向-后向 双重符合



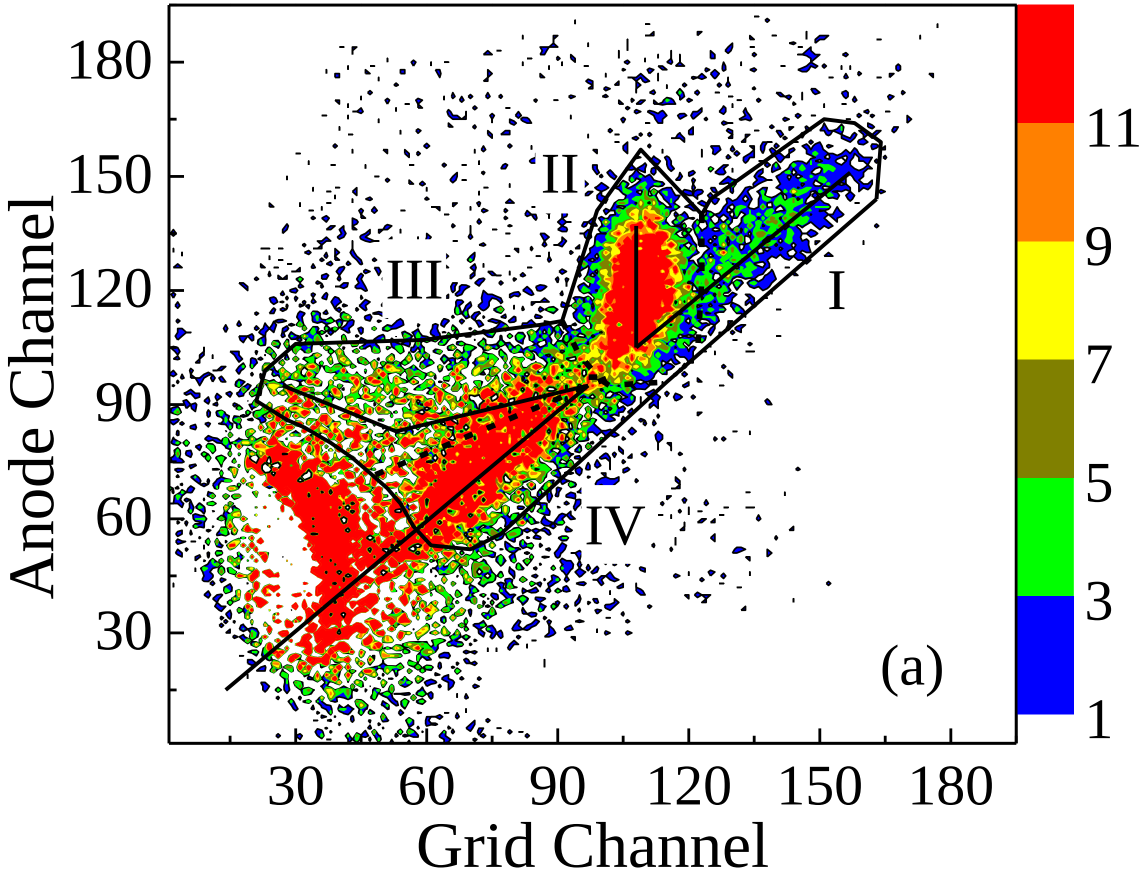
1-cathode, 2-grid, 3-anode, 4-shield

理论分析与模拟预测谱

实验测量谱

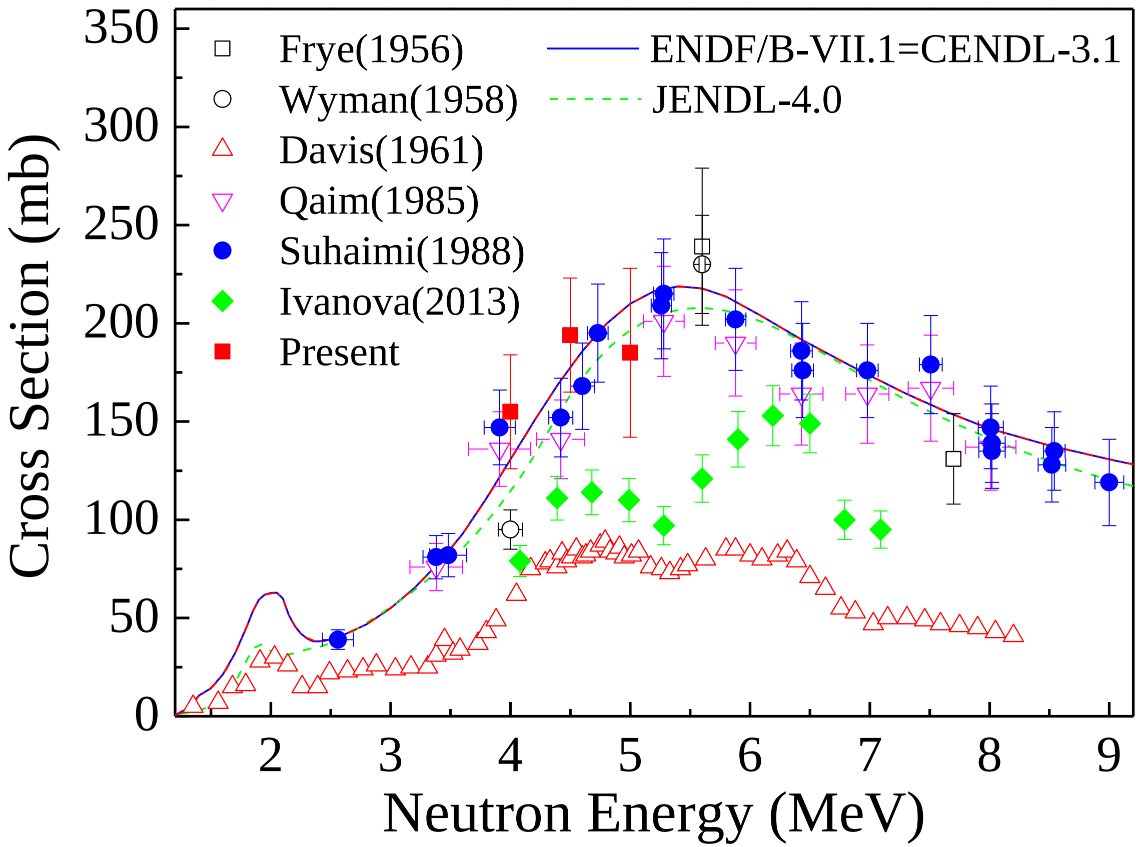


理论预测谱
(E_n =4.0 MeV)

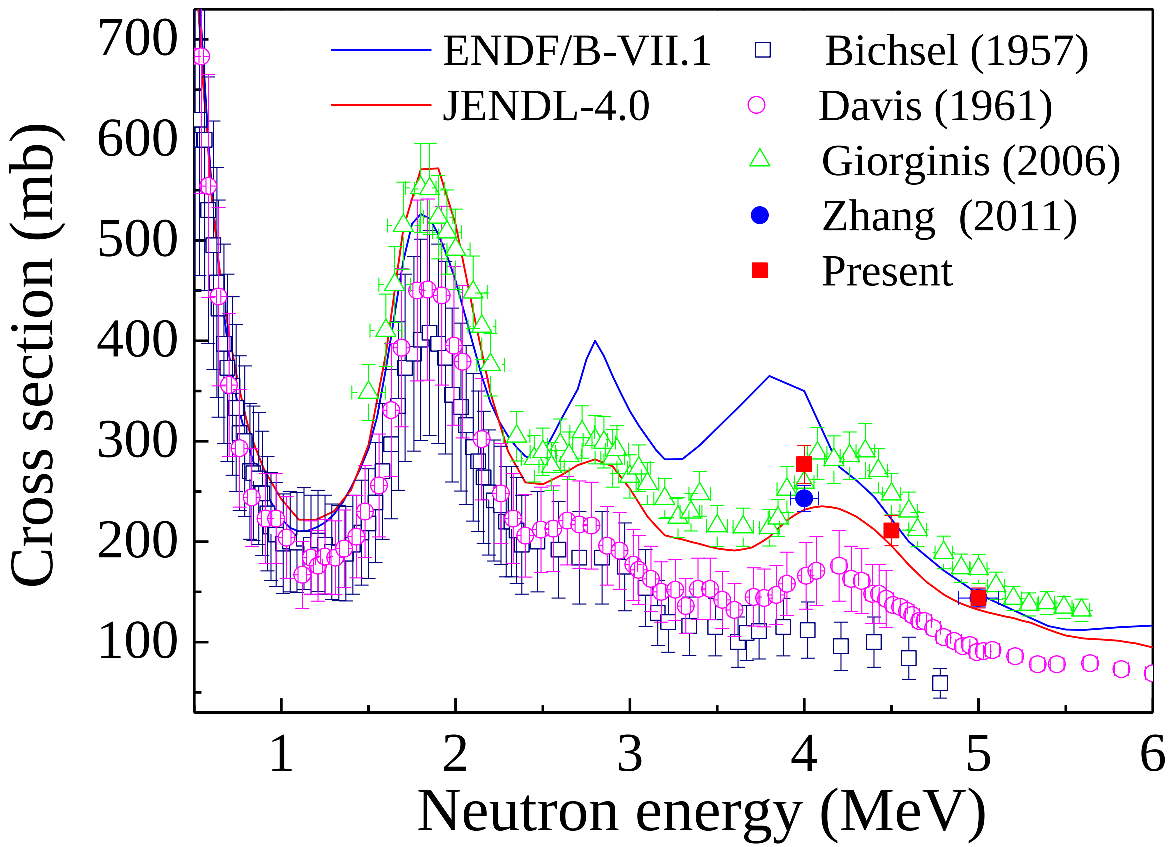


前向阳极-栅极符合谱
(E_n =4.0 MeV)

数据分析与实验结果



$^{10}B(n,t+2\alpha)$ 三体反应截面



$^{10}B(n,\alpha)^{7}Li$ 两体反应截面

PHYSICAL REVIEW C 96, 044620 (2017)

Cross section measurement for the $^{10}B(n,t2\alpha)$ three-body reaction at 4.0, 4.5, and 5.0 MeV. I. Prediction of the experimental spectrum

Zhimin Wang,[1,2] Huaiyong Bai,[1] Luyu Zhang,[1] Haoyu Jiang,[1] Yi Lu,[1] Jinxiang Chen,[1] Guohui Zhang,[1,*]
Yu. M. Gledenov,[3] M. V. Sedysheva,[3] and G. Khuukhenkhuu[4]

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[3] *Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, Dubna 141980, Russia*
[4] *Nuclear Research Centre, National University of Mongolia, Ulaanbaatar 17032, Mongolia*

理论预言

采用了27个公式

(Received 29 June 2017; published 24 October 2017)

PHYSICAL REVIEW C 96, 044621 (2017)

实验测量结果

Cross section measurement for the $^{10}B(n,t2\alpha)$ three-body reaction at 4.0, 4.5, and 5.0 MeV. II. Experimental setup and results

Zhimin Wang,[1,2] Huaiyong Bai,[1] Luyu Zhang,[1] Haoyu Jiang,[1] Yi Lu,[1] Jinxiang Chen,[1] Guohui Zhang,[1,*] Yu. M. Gledenov,[3]
M. V. Sedysheva,[3] and G. Khuukhenkhuu[4]

[1] *State Key Laboratory of Nuclear Physics and Technology, Institute of Heavy Ion Physics, Peking University, Beijing 100871, China*
[2] *Department of Physics, School of Information Science and Engineering, Ocean University of China, Qingdao 266100, China*
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[4] *Nuclear Research Centre, National University of Mongolia, Ulaanbaatar 17032, Mongolia*

(Received 29 June 2017; published 24 October 2017)

3.2 基于Back-n完成的标准截面测量

A. D. Carlson 在ND2022 报告中提到了我们的5项工作

- **^{6}Li(n,t)^{4}He** 微分截面与截面 **基于LPDA**
  Huaiyong Bai, Ruirui Fan, et al. **Chinese Phys. C** 44, (2020) 014003
- **^{10}B(n,α)^{7}Li** 微分截面与截面 **基于LPDA**
  Haoyu Jiang, Wei Jiang, *et al.* **Chinese Phys. C** 43, (2019) 124002
- **^{1}H(n,n)** 微分截面 **基于LPDA**
  Haoyu Jiang, Wei Jiang, et al., **Eur. Phys. J. A** (2021) 57:6
- **^{238}U/^{235}U** 裂变截面比 **基于FIXM**
  Jie Wen, Yiwei Yang, et al., **Annals of Nuclear Energy** 140 (2020) 107301
- **^{235}U(n,f), ^{238}U(n,f)** 截面 相对于^{1}H(n,n) 的测量 **基于FIXM**
  Yonghao Chen, et al., ND2022 裂变分会报告

Database work for the new Neutron Cross Section Standards Evaluation

Speaker
A. D. Carlson[1],

Primary authors
A. D. Carlson[1], R. Capote[2], D. Neudecker[3], V. G. Pronyaev[4], G. Schnabel[2]

[1]NIST, BNL
[2]IAEA
[3]LANL
[4]Atomstandart

Presented at

The ND2022 Meeting, August 22-26, 2022

在Back-n上还完成了 ^{12}C(n,tot)和^{197}Au(n,γ)反应截面测量：

- Xing-Yan Liu, Yi-Wei Yang, Rong Liu, et al., Measurement of the neutron total cross section of carbon at the Back-n white neutron beam of CSNS, **Nucl. Sci. Tech** (2019) 30:139 **基于NTOX** (10 eV – 1.8 MeV 全截面就等于弹散截面)
- 李鑫祥，刘龙祥，蒋伟等，脉冲高度权重技术测量^{197}Au中子俘获截面，**核技术**，第43卷 第8期 **基于C6D6**

Chinese Physics C Vol. 44, No. 1 (2020) 014003

Measurement of the differential cross sections and angle-integrated cross sections of the ^{6}Li(*n*, *t*)^{4}He reaction from 1.0 eV to 3.0 MeV at the CSNS Back-n white neutron source*

Huaiyong Bai(白怀勇)[1,#] Ruirui Fan(樊瑞睿)[2,3,4,#] Haoyu Jiang(江浩雨)[1] Zengqi Cui(崔增琪)[1] Yiwei Hu(胡益伟)[1]
Guohui Zhang(张国辉)[1;1)] Zhenpeng Chen(陈振鹏)[5] Wei Jiang(蒋伟)[3,4] Han Yi(易晗)[3,4] Jingyu Tang(唐靖宇)[3,4]
Liang Zhou(周良)[3,4] Qi An(安琪)[2,6] Jie Bao(鲍杰)[7] Ping Cao(曹平)[2,6] Qiping Chen(陈琪萍)[8]
Yonghao Chen(陈永浩)[3,4] Pinjing Cheng(程品晶)[9] Changqing Feng(封常青)[2,6] Minhao Gu(顾旻皓)[2,3]
Fengqin Guo(郭凤琴)[3,4] Changcai Han(韩长材)[10] Zijie Han(韩子杰)[8] Guozhu He(贺国珠)[7]
Yongcheng He(何泳成)[3,4] Yuefeng He(何越峰)[9] Hanxiong Huang(黄翰雄)[7] Weiling Huang(黄蔚玲)[3,4]
Xiru Huang(黄锡汝)[2,6] Xiaolu Ji(季筱璐)[2,3] Xuyang Ji(吉旭阳)[2,11] Hantao Jing(敬罕涛)[3,4] Ling Kang(康玲)[3,4]
Mingtao Kang(康明涛)[3,4] Bo Li(李波)[3,4] Lun Li(李论)[3,4] Qiang Li(李强)[3,4] Xiao Li(李晓)[3,4]
Yang Li(李洋)[2,3] Yang Li(李样)[3,4] Rong Liu(刘荣)[8] Shubin Liu(刘树彬)[2,6] Xingyan Liu(刘星言)[8]
Guangyuan Luan(栾广源)[4] Yinglin Ma(马应林)[3,4] Changjun Ning(宁常军)[3,4] Binbin Qi(齐斌斌)[6] Jie Ren(任杰)[7]
Xichao Ruan(阮锡超)[7] Zhaohui Song(宋朝晖)[10] Hong Sun(孙虹)[3,4] Xiaoyang Sun(孙晓阳)[3,4]
Zhijia Sun(孙志嘉)[2,3,4] Zhixin Tan(谭志新)[3,4] Hongqing Tang(唐洪庆)[7] Pengcheng Wang(王鹏程)[3,4]
Qi Wang(王琦)[7] Taofeng Wang(王涛峰)[12] Yanfeng Wang(王艳凤)[3,4] Zhaohui Wang(王朝晖)[7]
Zheng Wang(王征)[3,4] Jie Wen(文杰)[8] Zhongwei Wen(温中伟)[8] Qingbiao Wu(吴青彪)[3,4] Xiaoguang Wu(吴晓光)[7]
Xuan Wu(吴煊)[3,4] Likun Xie(解立坤)[2,11] Yiwei Yang(羊奕伟)[8] Li Yu(于莉)[2,6] Tao Yu(余滔)[2,6]
Yongji Yu(于永积)[3,4] Jing Zhang(张旌)[3,4] Linhao Zhang(张林浩)[3,4] Liying Zhang(张利英)[2,3,4]
Qingmin Zhang(张清民)[13] Qiwei Zhang(张奇玮)[7] Xianpeng Zhang(张显鹏)[10] Yuliang Zhang(张玉亮)[3,4]
Zhiyong Zhang(张志永)[2,6] Yingtan Zhao(赵映潭)[13] Zuying Zhou(周祖英)[7] Danyang Zhu(朱丹阳)[6]
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[10]Northwest Institute of Nuclear Technology, Xi'an 710024, China
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[12]Beihang University, Beijing 100083, China
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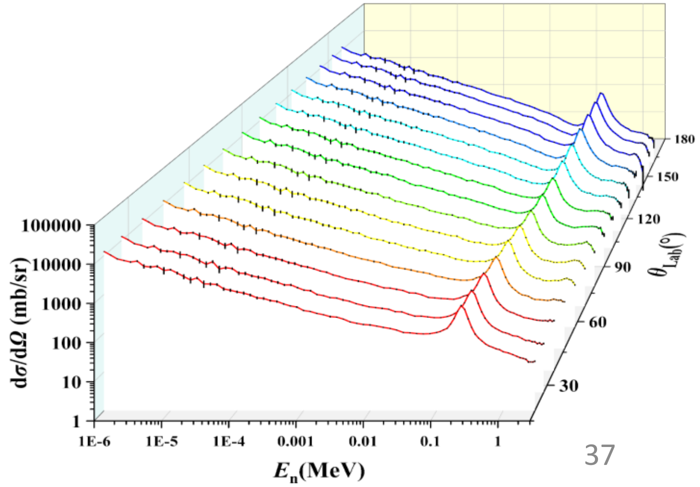
Back-n首批实验
^{6}Li(n,t)反应
20年后再次测量
(1→100)

感谢清华大学陈振鹏教授多年的支持与帮助！

13个合作单位
83位作者！
(80个能点：
80*15=1200数据点)

LPDA-v1



^{6}Li(n,t) Measurements at the CSNS by Bai et al.白怀勇

Huaiyong Bai(白怀勇), et al. **Chinese Physics C** 44 (1) (2020) 014003

Recent Work on Neutron Standards

Allan D. Carlson

Presented at

The IAEA Consultancy (Virtual) Meeting on Neutron Data Standards

Oct 12-16, 2020

The agreement with the standard in many regions is relatively good. More work is planned.

This work could provide the data necessary for a smooth transition from the H(n,n) standard to the ^{6}Li(n,t) standard with sufficient overlap.

Recent LANL Work on Reactions in the ^{7}Li System

LA-UR-20-28120

^{6}Li(n,t) Measurements at the CSNS by Bai et al.白怀勇

Huaiyong Bai(白怀勇), et al.
Chinese Physics C 44 (1) (2020) 014003

Los Alamos NATIONAL LABORATORY EST.1943

Gerry Hale and Mark Paris
12 October 2020

NNSA

- A large data set added was the recent measurement by Bai et al. of the differential cross section for the ^{6}Li(n,t)^{4}He reaction at energies up to 3 MeV.

- The data for most reactions are fit well, including the extensive new CSNS data set of Bai et al., which may be overall the most complete, and best-quality, set of relative differential cross sections for the ^{6}Li(n,t)^{4}He reaction that presently exists at energies below 3 MeV.

Chinese Physics C Vol. 43, No. 12 (2019) 124002

Measurements of differential and angle-integrated cross sections for the $^{10}B(n, \alpha)^{7}Li$ reaction in the neutron energy range from 1.0 eV to 2.5 MeV*

Haoyu Jiang(江浩雨)[1,#] Wei Jiang(蒋伟)[2,3,#] Huaiyong Bai(白怀勇)[1] Zengqi Cui(崔增琪)[1]
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Jingyu Tang(唐靖宇)[2,3] Qi An(安琪)[4,5] Jie Bao(鲍杰)[6] Yu Bao(鲍煜)[2,3] Ping Cao(曹平)[4,5]
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Hanxiong Huang(黄翰雄)[6] Weiling Huang(黄蔚玲)[2,3] Xiru Huang(黄锡汝)[4,5] Xiaolu Ji(季筱路)[2,4]
Xuyang Ji(吉旭阳)[4,10] Zhijie Jiang(姜智杰)[4,5] Hantao Jing(敬罕涛)[2,3] Ling Kang(康玲)[2,3]
Mingtao Kang(康明涛)[2,3] Bo Li(李波)[2,3] Chao Li(李超)[4,5] Jiawen Li(李嘉雯)[4,10] Lun Li(李论)[2,3]
Qiang Li(李强)[2,3] Xiao Li(李晓)[2,3] Yang Li(李样)[2,3] Rong Liu(刘荣)[7] Shubin Liu(刘树彬)[4,5]
Xingyan Liu(刘星言)[7] Guangyuan Luan(栾广源)[6] Qili Mu(穆奇丽)[2,3] Binbin Qi(齐斌斌)[4,5] Jie Ren(任杰)[6]
Zhizhou Ren(任智洲)[7] Xichao Ruan(阮锡超)[6] Zhaohui Song(宋朝晖)[8] Yingpeng Song(宋英鹏)[2,3]
Hong Sun(孙虹)[2,3] Kang Sun(孙康)[2,3,9] Xiaoyang Sun(孙晓阳)[2,3,9] Zhijia Sun(孙志嘉)[2,3,4] Zhixin Tan(谭志新)[2,3]
Hongqing Tang(唐洪庆)[6] Xinyi Tang(唐新懿)[4,5] Binbin Tian(田斌斌)[2,3] Lijiao Wang(王丽娇)[2,3,9]
Pengcheng Wang(王鹏程)[2,3] Qi Wang(王琦)[6] Taofeng Wang(王涛峰)[11] Zhaohui Wang(王朝辉)[6] Jie Wen(文杰)[7]
Zhongwei Wen(温中伟)[7] Qingbiao Wu(吴青彪)[2,3] Xiaoguang Wu(吴晓光)[6] Xuan Wu(吴煊)[2,3]
Likun Xie(解立坤)[4,10] Yiwei Yang(羊奕伟)[7] Li Yu(于莉)[2,3] Tao Yu(余滔)[4,5] Yongji Yu(于永积)[2,3]
Linhao Zhang(张林浩)[2,3,9] Qiwei Zhang(张奇玮)[6] Xianpeng Zhang(张显鹏)[8] Yuliang Zhang(张玉亮)[2,3]
Zhiyong Zhang(张志永)[4,5] Yubin Zhao(赵豫斌)[2,3] Luping Zhou(周路平)[2,3,9] Zuying Zhou(周祖英)[6]
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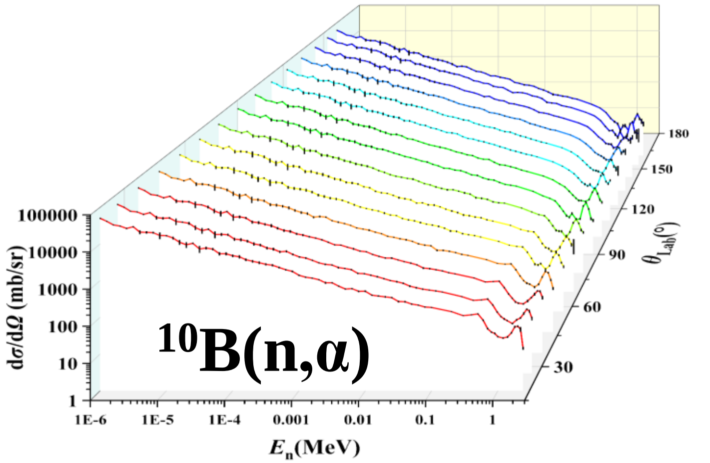

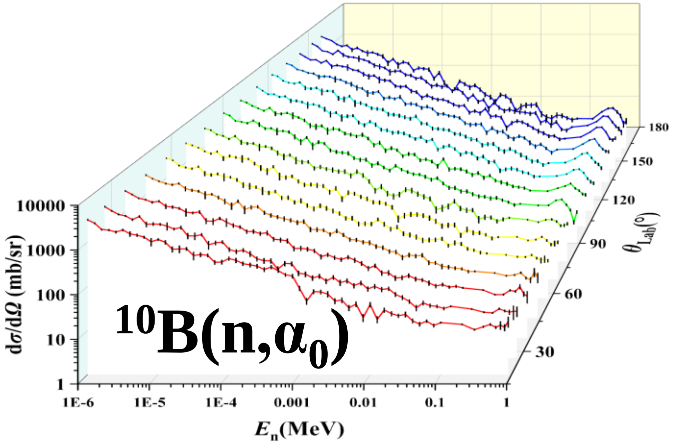

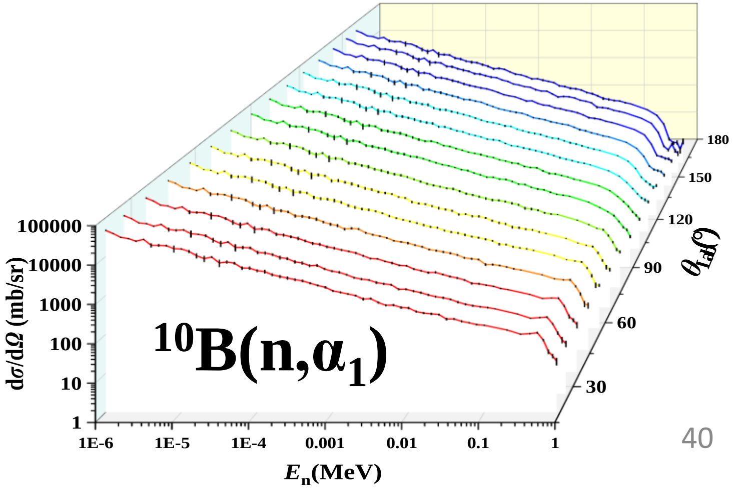

$^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1)$ Measurements at CSNS by Jiang et al. 江浩雨

Haoyu Jiang(江浩雨), et al. **Chinese Physics C** 43(12) (2019) 124002

Recent Work on Neutron Standards

Allan D. Carlson

Presented at

The IAEA Consultancy (Virtual) Meeting on Neutron Data Standards

Oct 12-16, 2020

- There are a number of cases where both the $^{10}B(n,\alpha_1)$ and $^{10}B(n,\alpha)$ differential cross section data are somewhat low compared with the standard. The integrated $^{10}B(n,\alpha_1)$ cross section data are in good agreement with the standard values. The integrated $^{10}B(n,\alpha)$ cross section data are in largely in good agreement but somewhat low in the several hundred keV energy region compared with the standard.

- This work could provide the data necessary for a smooth transition from the H(n,n) standard to the $^{10}B(n,\alpha)$ standards with sufficient overlap.

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THE EUROPEAN PHYSICAL JOURNAL A

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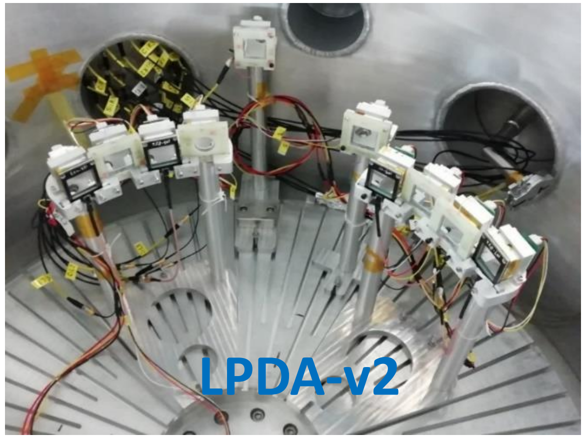
Regular Article - Experimental Physics

Measurement of the relative differential cross sections of the $^{1}H(n, el)$ reaction in the neutron energy range from 6 MeV to 52 MeV



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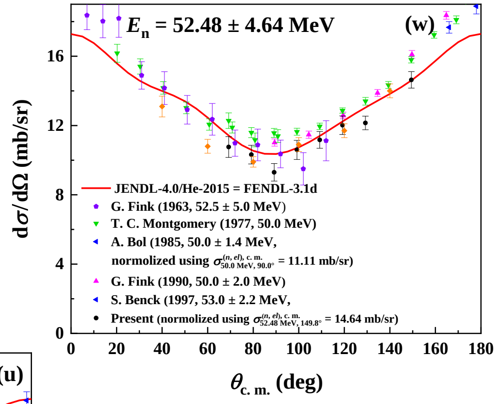

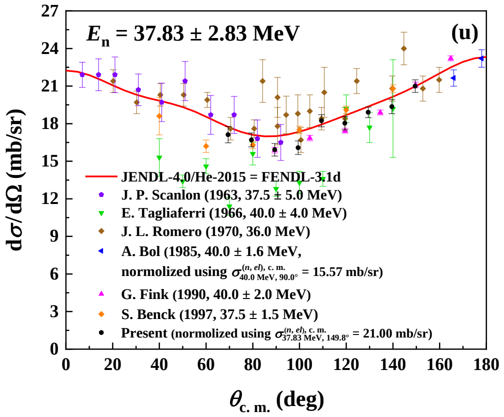

测量了23个能点的n-p散射微分截面

Received: 29 July 2020 / Accepted: 22 November 2020

国际专家的评价

国际中子标准截面工作组

A.D.Carlson NIST USA

Haoyu Jiang, et al. **Eur. Phys. J. A** (2021) 57: 6

Recent Work on Neutron Standards

Allan D. Carlson

Presented at

The IAEA Consultancy (Virtual) Meeting
on
Neutron Data Standards

Oct 12-16, 2020

H(n,n)H Angular Distribution Work at the China Spallation Neutron Source (CSNS) by Jiang et al.江浩雨

- Measurements were made from 10 to 55 degrees (10 angles) in the laboratory system. All angles were measured simultaneously. Uncertainties vary from 1 to 8%.

文章尚未发表，结果已被引用

- The measurements extend from 6 MeV to 52 MeV with 23 energy points. Plans have been made to use multi-wire proportional counters in the E-DE telescopes so it should be possible to obtain data to considerably lower energies (possibly as low as 0.5 MeV). They are also considering measurements at higher energies.

期待向更低能区、更高能区拓展

Annals of Nuclear Energy 140 (2020) 107301

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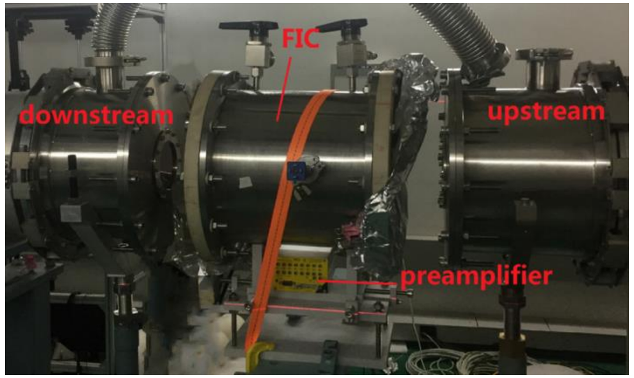
journal homepage: www.elsevier.com/locate/anucene

Back-n首批实验 基于FIXM



Measurement of the U-238/U-235 fission cross section ratio at CSNS – Back-n WNS

20MeV以下238U/235U裂变截面比

Jie Wen[a], Yiwei Yang[a], Zhongwei Wen[a], Rong Liu[a,*], Xingyan Liu[a], Zijie Han[a], Qiping Chen[a], Zhizhou Ren[a], Qi An[b,c], Huaiyong Bai[d], Jie Bao[e], Ping Cao[b,c], Yonghao Chen[f,g], Pinjing Cheng[h], Zengqi Cui[d], Ruirui Fan[b,f,g], Changqing Feng[b,c], Minhao Gu[b,f], Fengqin Guo[f,g], Changcai Han[i], Guozhu He[e], Yongcheng He[f,g], Yuefeng He[h], Hanxiong Huang[e], Weiling Huang[f,g], Xiru Huang[b,c], Xiaolu Ji[b,f], Xuyang Ji[b,j], Haoyu Jiang[d], Wei Jiang[e,f], Hantao Jing[e,f], Ling Kang[e,f], Mingtao Kang[e,f], Bo Li[e,f], Lun Li[e,f], Qiang Li[e,f], Xiao Li[e,f], Yang Li[b,f], Yang Li[e,f], Shubin Liu[b,c], Guangyuan Luan[e], Yinglin Ma[f,g], Changjun Ning[f,g], Binbin Qi[b,c], Jie Ren[e], Xichao Ruan[e], Zhaohui Song[i], Hong Sun[f,g], Xiaoyang Sun[f,g], Zhijia Sun[b,f,g], Zhixin Tan[f,g], Hongqing Tang[e], Jingyu Tang[f,g], Pengcheng Wang[f,g], Qi Wang[e], Taofeng Wang[l], Yanfeng Wang[f,g], Zhaohui Wang[e], Zheng Wang[e,f], Qingbiao Wu[e,f], Xiaoguang Wu[e], Xuan Wu[e,f], Likun Xie[b,j], Han Yi[f,g], Li Yu[f,g], Tao Yu[b,c], Yongji Yu[f,g], Guohui Zhang[d], Jing Zhang[f,g], Linhao Zhang[f,g], Liying Zhang[b,f,g], Qingmin Zhang[k], Qiwei Zhang[e], Xianpeng Zhang[i], Yuliang Zhang[f,g], Zhiyong Zhang[b,c], Yingtan Zhao[k], Liang Zhou[f,g], Zuying Zhou[e], Danyang Zhu[b,c], Kejun Zhu[b,f], Peng Zhu[f,g]

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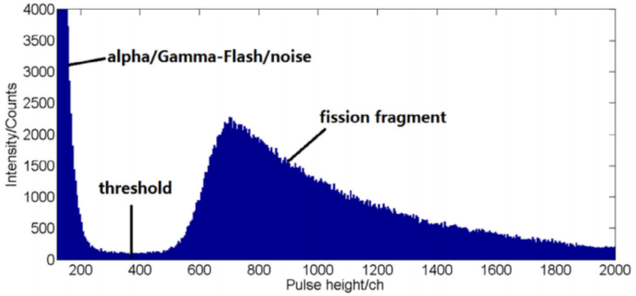
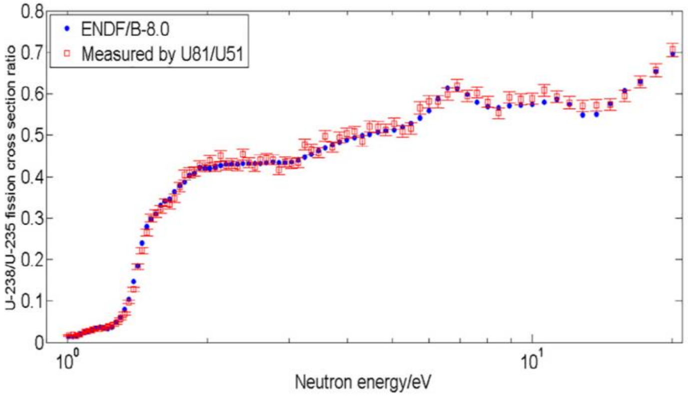




2019 05 24

ND2019

with A.D. Carlson

Database work for the new Neutron Cross Section Standards Evaluation

Speaker

A. D. Carlson[1],

Primary authors

A. D. Carlson[1], R. Capote[2], D. Neudecker[3], V. G. Pronyaev[4], G. Schnabel[2]

[1]NIST, BNL
[2]IAEA
[3]LANL
[4]Atomstandart

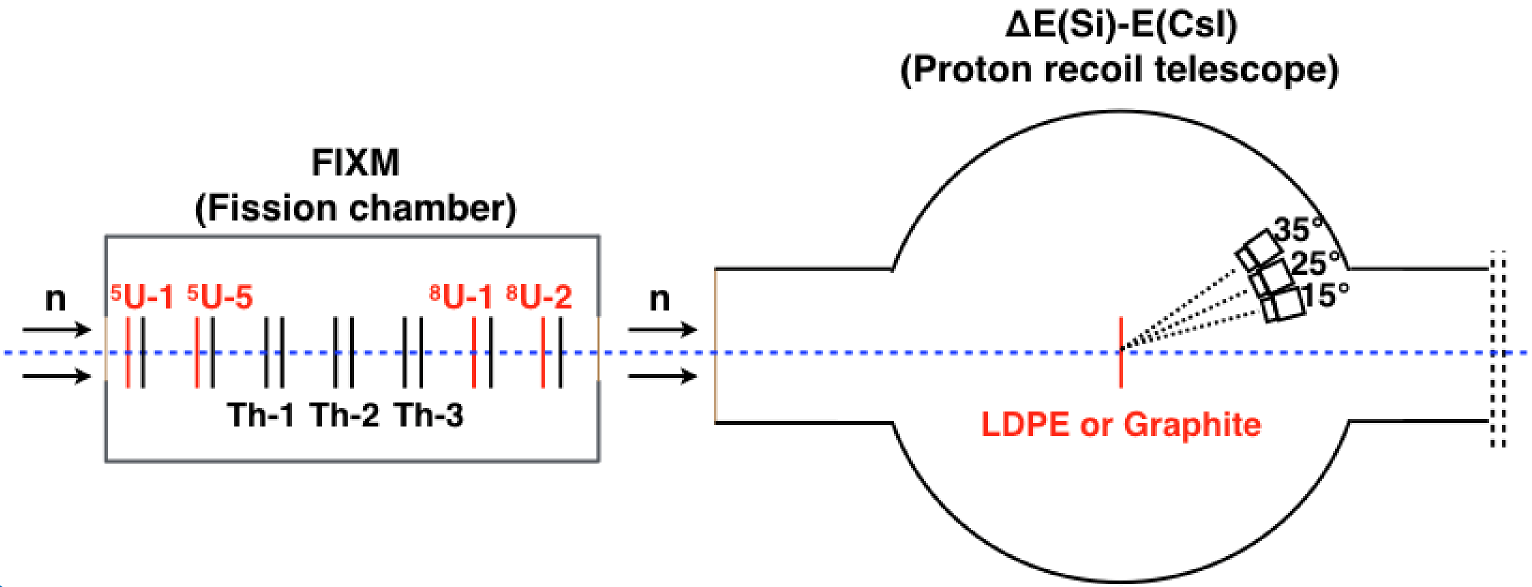
Presented at

The ND2022 Meeting, August 22-26, 2022

- "Absolute measurements of the ^{238}U(n,f)/ ^{235}U(n,f) cross section ratio were made by Wen *et al*. at the CSNS up to 20 MeV. They agree with the standards results within their uncertainties of 2.3% to 3.6%."

相对于n-p散射的^{235}U、^{238}U裂变截面测量

实验装置与方案



FIXM与LPDA有机结合

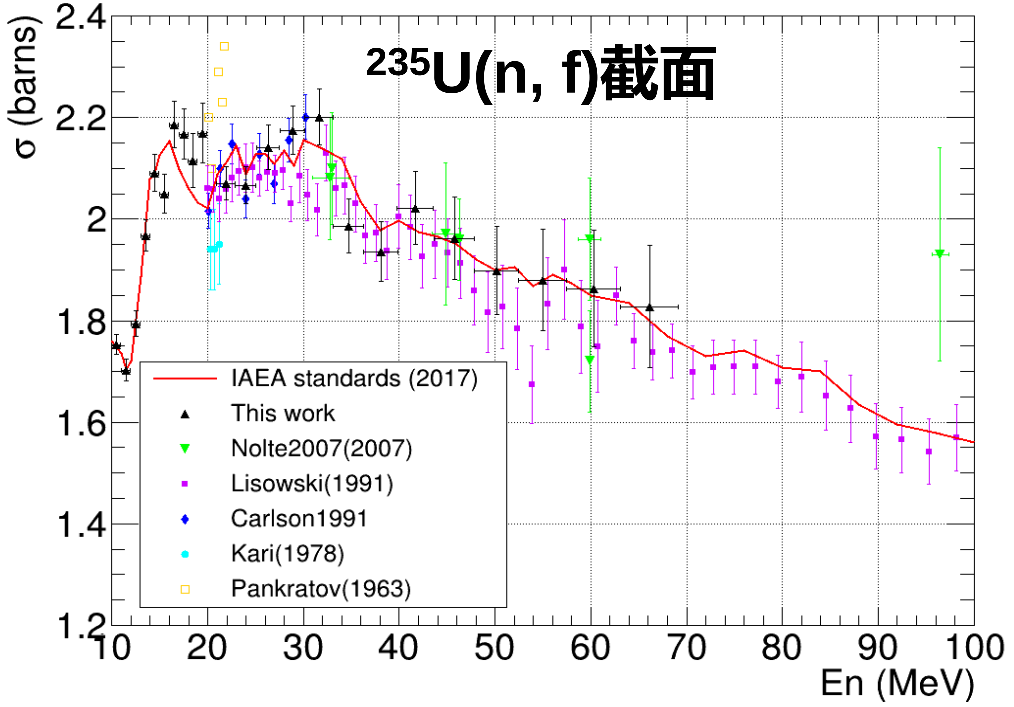
在两类标准截面之间建立起联系

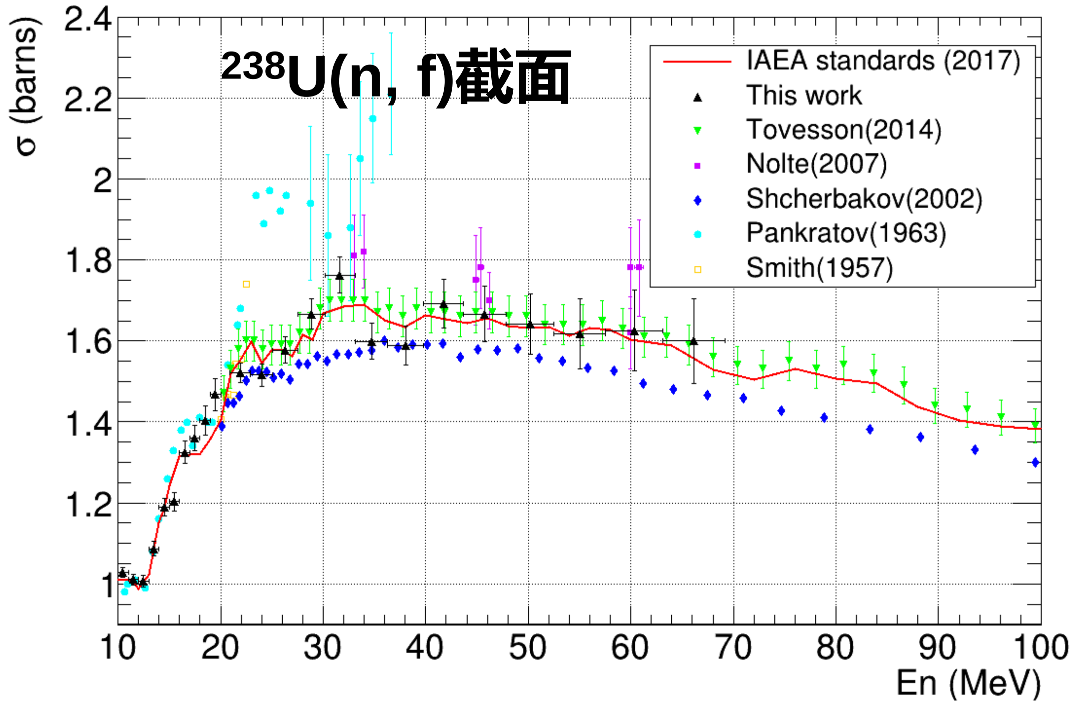
多层裂变室(FIXM)测量裂变

反冲质子望远镜(PRT)通过n-p散射测量中子能谱

(详见陈永浩裂变分会报告)

初步测量结果





1. 测量得到了10-66 MeV能区^{235}U和^{238}U的裂变截面
2. 高能区(20MeV以上)实验数据很少且分歧较大，本数据将为标准截面评价提供新的参考
3. 测量结果整体与标准截面符合较好，但在特定能区存在偏差(有待进一步研究)
4. 本方法可应用到其他标准截面的测量(如^{239}Pu(n, f)截面)

NUCL SCI TECH (2019)30:139
https://doi.org/10.1007/s41365-019-0660-9

天然碳的全截面

Measurement of the neutron total cross section of carbon at the Back-n white neutron beam of CSNS

Xing-Yan Liu[1] · Yi-Wei Yang[1] · Rong Liu[1] · Jie Wen[1] · Zhong-Wei Wen[1] · Zi-Jie Han[1] · Zhi-Zhou Ren[1] · Qi An[2,3] · Huai-Yong Bai[4] · Jie Bao[5] · Ping Cao[2,3] · Qi-Ping Chen[1] · Yong-Hao Chen[6,7] · Pin-Jing Cheng[8] · Zeng-Qi Cui[4] · Rui-Rui Fan[2,6,7] · Chang-Qing Feng[2,3] · Min-Hao Gu[2,6] · Feng-Qin Guo[6,7] · Chang-Cai Han[9] · Guo-Zhu He[5] · Yong-Cheng He[6,7] · Yue-Feng He[8] · Han-Xiong Huang[5] · Wei-Ling Huang[6,7] · Xi-Ru Huang[2,3] · Xiao-Lu Ji[2,6] · Xu-Yang Ji[2,10] · Hao-Yu Jiang[4] · Wei Jiang[6,7] · Han-Tao Jing[6,7] · Ling Kang[6,7] · Ming-Tao Kang[6,7] · Bo Li[6,7] · Lun Li[6,7] · Qiang Li[6,7] · Xiao Li[6,7] · Yang Li[2,6] · Yang Li[6,7] · Shu-Bin Liu[2,3] · Guang-Yuan Luan[4] · Ying-Lin Ma[6,7] · Chang-Jun Ning[6,7] · Bin-Bin Qi[3] · Jie Ren[5] · Xi-Chao Ruan[5] · Zhao-Hui Song[9] · Hong Sun[6,7] · Xiao-Yang Sun[6,7] · Zhi-Jia Sun[2,6,7] · Zhi-Xin Tan[6,7] · Hong-Qing Tang[5] · Jing-Yu Tang[6,7] · Peng-Cheng Wang[6,7] · Qi Wang[5] · Tao-Feng Wang[12] · Yan-Feng Wang[6,7] · Zhao-Hui Wang[5] · Zheng Wang[6,7] · Qing-Biao Wu[6,7] · Xiao-Guang Wu[5] · Xuan Wu[6,7] · Li-Kun Xie[2,10] · Han Yi[6,7] · Li Yu[2,3] · Tao Yu[2,3] · Yong-Ji Yu[6,7] · Guo-Hui Zhang[4] · Jing Zhang[6,7] · Lin-Hao Zhang[6,7] · Li-Ying Zhang[2,6,7] · Qing-Min Zhang[11] · Qi-Wei Zhang[5] · Xian-Peng Zhang[9] · Yu-Liang Zhang[6,7] · Zhi-Yong Zhang[2,3] · Ying-Tan Zhao[11] · Liang Zhou[6,7] · Zu-Ying Zhou[5] · Dan-Yang Zhu[3] · Ke-Jun Zhu[2,6] · Peng Zhu[6,7]

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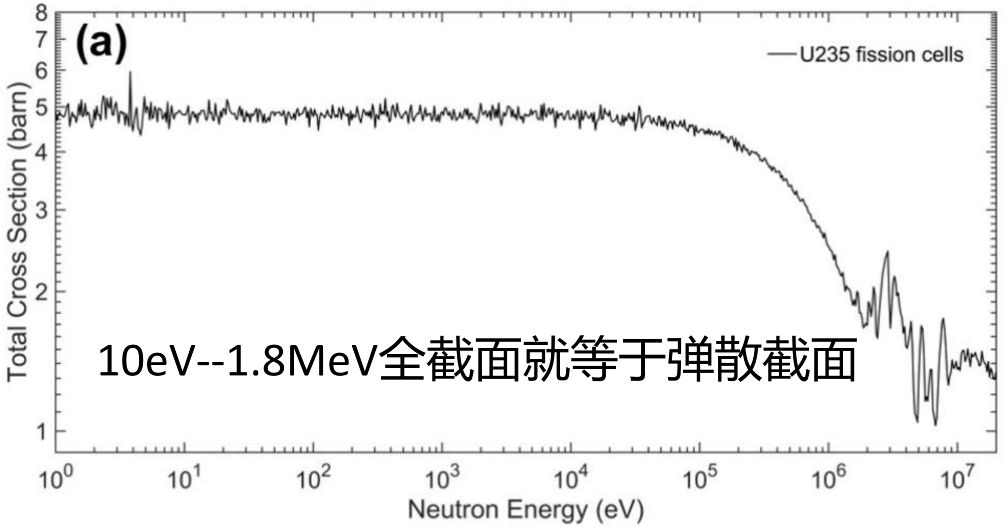
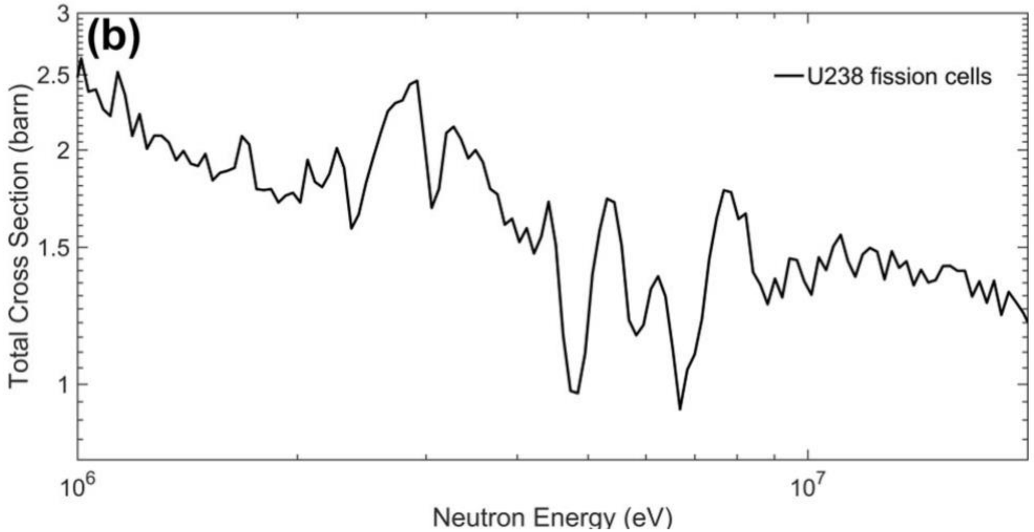
基于NTOX





$^{Nat}C(n,n)$ 标准截面：10 eV to 1.8 MeV

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NUCLEAR TECHNIQUES

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基于C6D6

脉冲高度权重技术测量 ^{197}Au 中子俘获截面

李鑫祥[1,2] 刘龙祥[1,3] 蒋 伟[4,5] 任 杰[6] 王宏伟[1,2,3] 范功涛[1,3] 曹喜光[1,2,3]
胡新荣[1,2] 张 岳[1,2] 王俊文[1,7] 郝子锐[1,2] 姜 炳[1,2] 王小鹤[1] 胡继峰[1]
王金成[8] 王德鑫[8] 张苏雅拉吐[8] 刘应都[9] 麻 旭[9] 马春旺[10] 王玉廷[10]
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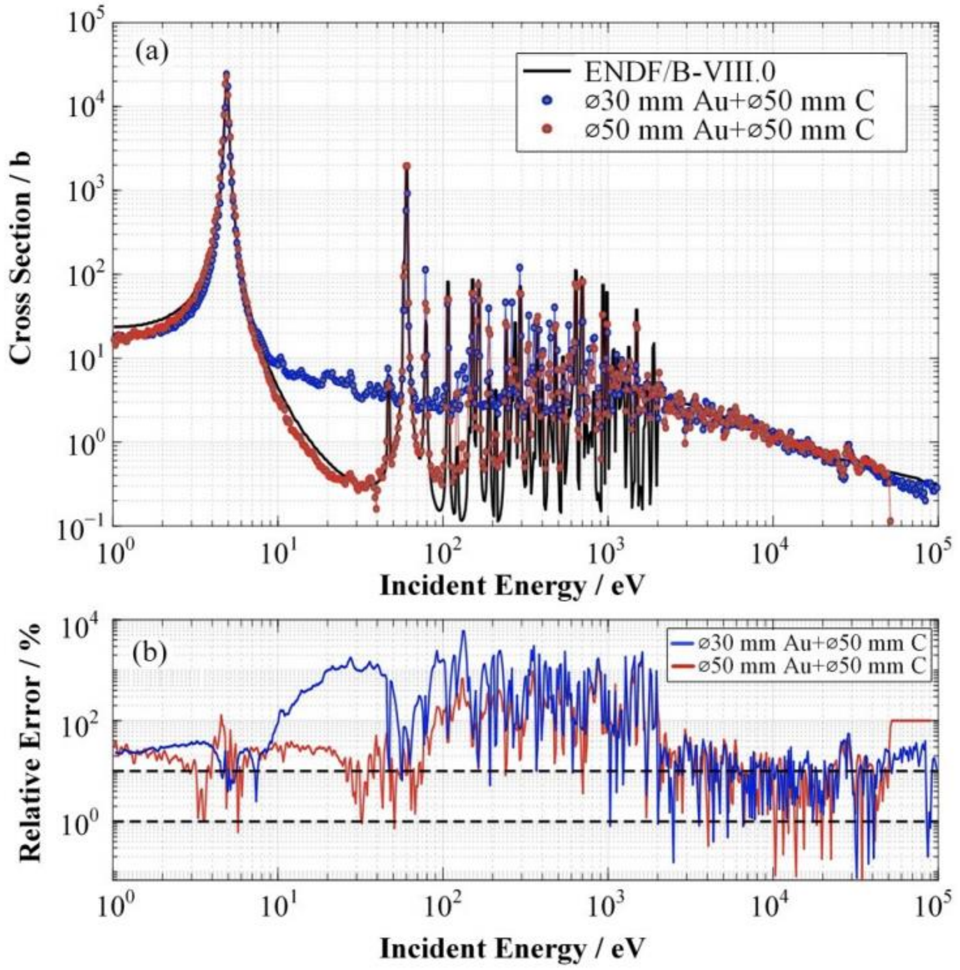

图8 金靶中子俘获截面测量值与评价值的比较(a)和测量值与评价值的相对误差(b)

^{197}Au(n,γ) 标准截面 0.0253 eV, 0.2 to 2.5 MeV, 30 keV MACS

1eV—10^{5}eV

Back-n上最近完成的相关工作

基于FIXM

Measurement of the $^{236,238}U$ (n, f) cross sections from the threshold to 200 MeV at CSNS Back-n

236U、238U 相对于235U的裂变截面

Zhizhou Ren[1,2], Yiwei Yang[2], Rong Liu[2*], Bangjiao Ye[1], Zhongwei Wen[2], Jie Wen[2],Hairui Guo[3],Yonghao Chen[4,5], Han Yi[4,5], Weili Sun[3], Jie Yan[2*], Zijie Han[2], Xingyan Liu[2], Qiping Chen[2], Tao Ye[3], Jiangbo Bai[2], Qi An[1,6], Huaiyong Bai[7], Jie Bao[8], Ping Cao[1,6], Pinjing Cheng[9], Zengqi Cui[7], Ruirui Fan[4,5,6], Changqing Feng[1,6], Minhao Gu[4,6], Fengqin Guo[4,5], Changcai Han[10], Guozhu He[8], Yongcheng He[4,5], Yuefeng He[9], Hanxiong Huang[8], Weiling Huang[4,5], Xiru Huang[3,6], Xiaolu Ji[4,6], Xuyang Ji[6,11], Haoyu Jiang[7], Wei Jiang[4,5], Hantao Jing[4,5], Ling Kang[4,5], Mingtao Kang[4,5], Bo Li[4,5], Lun Li[4,5], Qiang Li[4,5], Xiao Li[4,5], Yang Li(a)[4,6], Yang Li(b)[4,5], Shubin Liu[1,6], Guangyuan Luan[8], Yinglin Ma[4,5], Changjun Ning[4,5], Binbin Qi[1,6], Jie Ren[8], Xichao Ruan[8], Zhaohui Song[10], Hong Sun[4,5], Xiaoyang Sun[4,5], Zhijia Sun[4,5,6], Zhixin Tan[4,5], Hongqing Tang[8], Jingyu Tang[4,5], Pengcheng Wang[4,5], Qi Wang[8], Taofeng Wang[12], Yanfeng Wang[4,5], Zhaohui Wang[8], Zheng Wang[4,5], Qingbiao Wu[4,5], Xiaoguang Wu[8], Xuan Wu[4,5], Likun Xie[6,11], Li Yu[4,5], Tao Yu[1,6], Yongji Yu[4,5], Guohui Zhang[7], Jing Zhang[4,5], Linhao Zhang[4,5], Liying Zhang[4,5,6], Qingmin Zhang[13], Qiwei Zhang[8], Xianpeng Zhang[10], Yuliang Zhang[4,5], Zhiyong Zhang[1,6], Yingtan Zhao[13], Liang Zhou[4,5], Zuying Zhou[8], Danyang Zhu[1,6], Kejun Zhu[4,6], Peng Zhu[4,5]

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[2]Institute of Nuclear Physics and Chemistry, China Academy of Engineering Physics, Mianyang 621900, China
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[5]Spallation Neutron Source Science Center, Dongguan 523803, China
[6]Sate Key Laboratory of Particle Detection and Electronics, China
[7]State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China
[8]Key Laboratory of Nuclear Data, China Institute of Atomic Energy, Beijing 102413, China
[9]University of South China, Hengyang 421001, China
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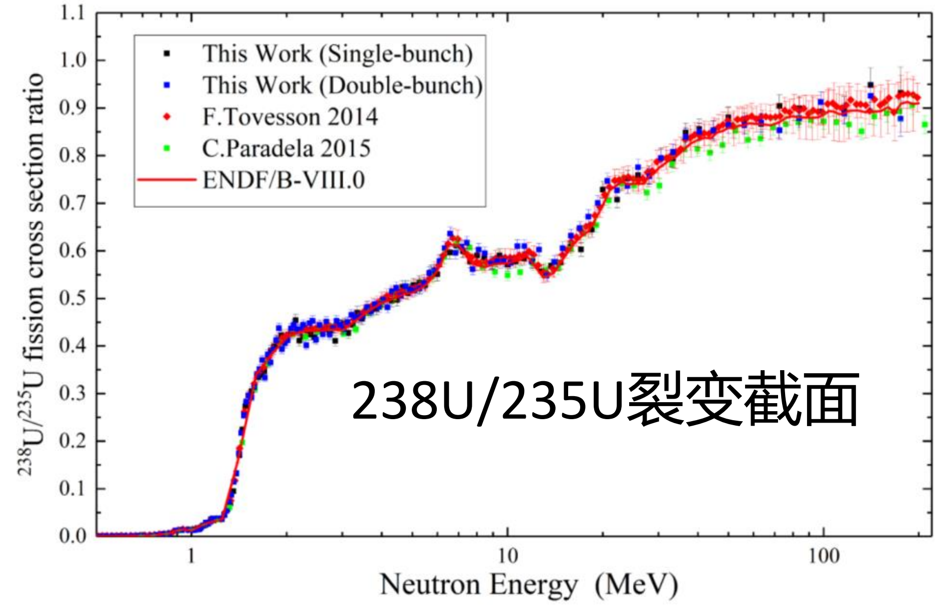
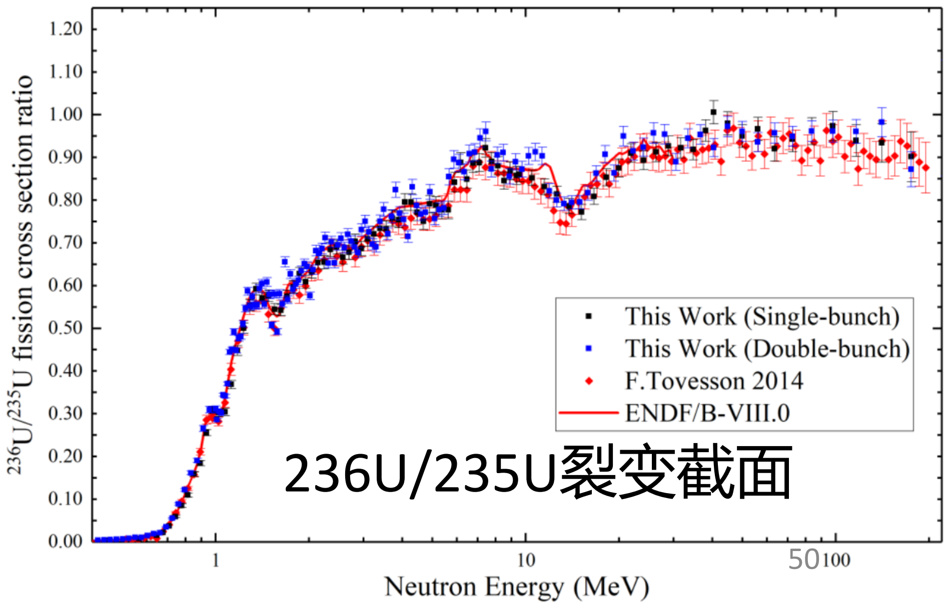
[11]Department of Engineering and Applied Physics, University of Science and Technology of China, Hefei 230026, China
[12]School of Physics, Beihang University, Beijing 100083, China
[13]Xi'an Jiaotong University, Xi'an 710049, China

*Corresponding author: liurongzy@163.com,yanjie@caep.cn

正在审稿中





基于FIXM 测量了^{239}Pu相对于^{235}U的裂变截面

Measurement of the $^{239}\mathrm{Pu}(n,f)$ cross section from 4 keV to 100 MeV using the Back-n white neutron beam at CSNS

Yijia Qiu,[1] Changlin Lan,[1,*] Yonghao Chen,[2,3] Liyang Jiang,[4] Jie Bao,[4] Yiwei Yang,[5] Zhongwei Wen,[5] Rong Liu,[5] Xichao Ruan,[4] Jingyu Tang,[2,3] Jie Ren,[4] Hantao Jing,[2,3] Guangyuan Luan,[4] Ruirui Fan,[2,3] Yangbo Nie,[4] Xianlin Yang,[1] Xiaojun Li,[1] Han Yi,[2,3] Wei Jiang,[2,3] Yi Yang,[4] Shilong Liu,[4] and Jincheng Wang[4]

[1] *School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China*
[2] *Institute of High Energy Physics, Chinese Academy of Sciences (CAS), Beijing 100049, China*
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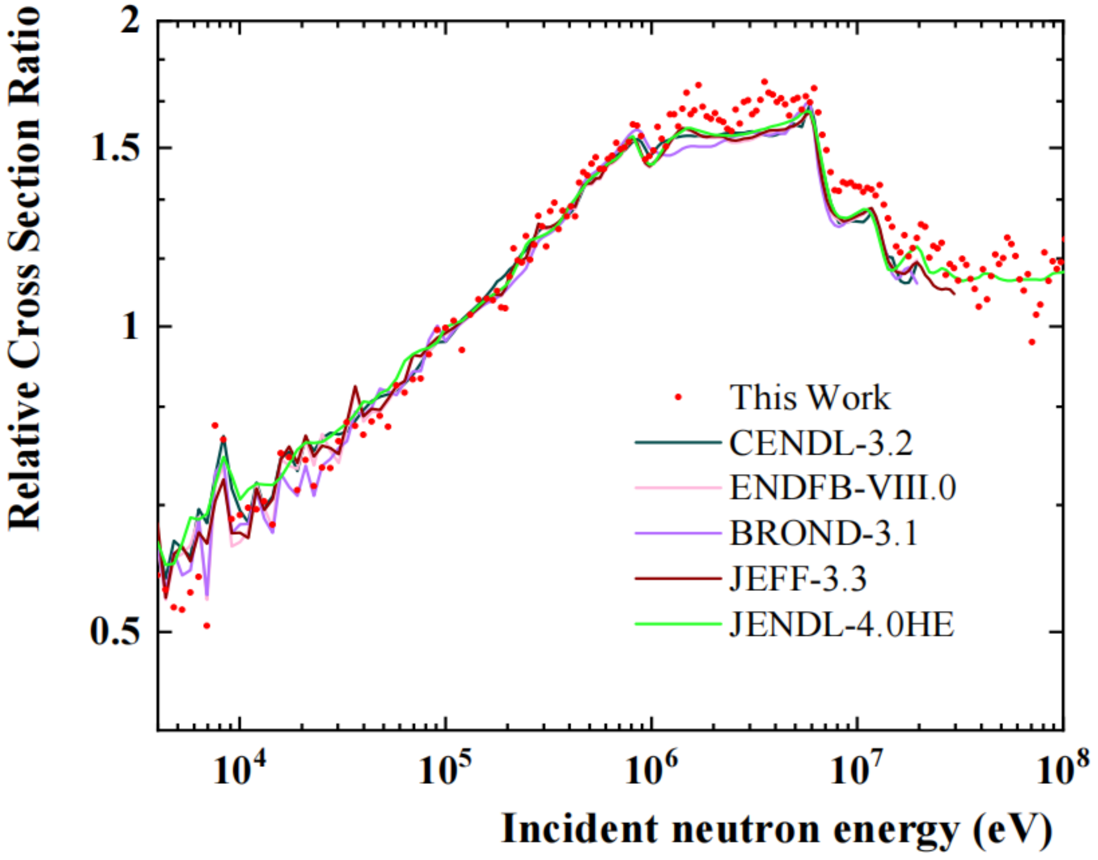
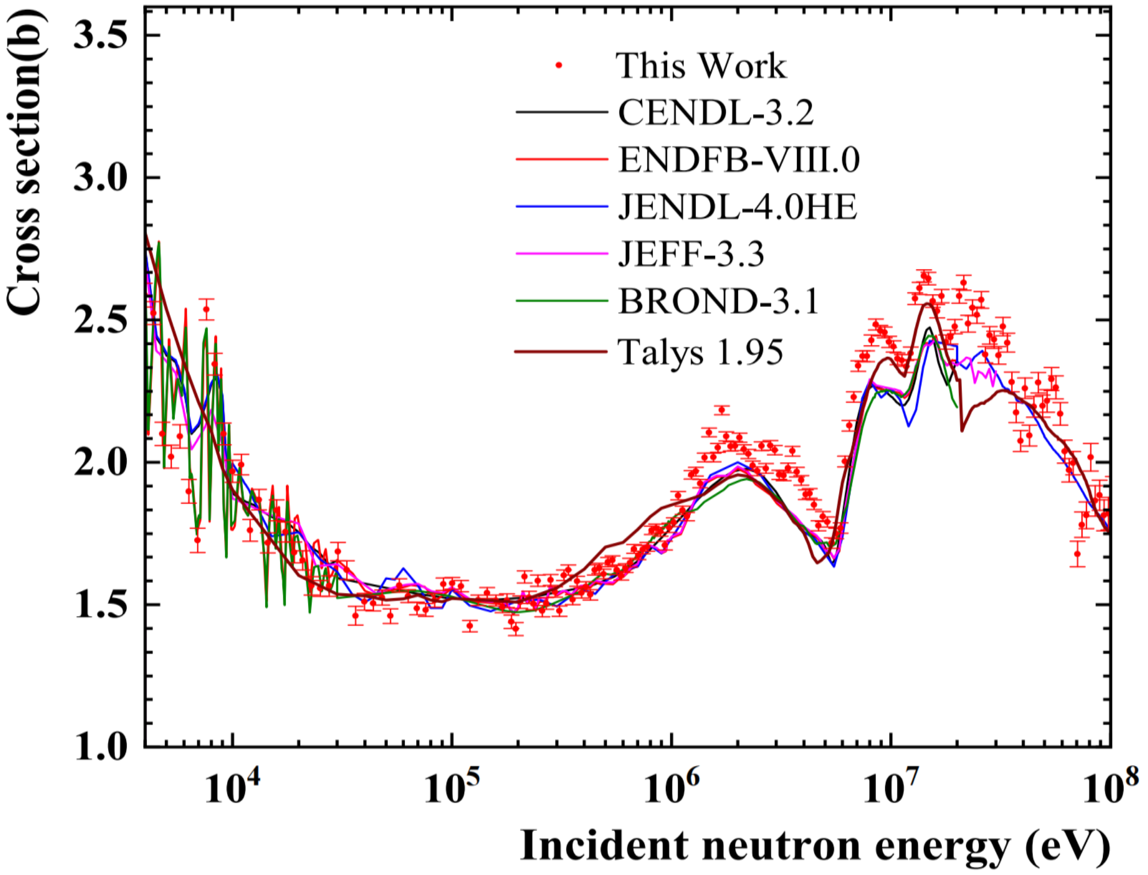
[5] *Institute of Nuclear Physics and Chemistry, China Academy of Engineering Physics, Mianyang 621900, China*

A new measurement of the neutron-induced fission cross section of ^{239}Pu relative to the ^{235}U cross section from 4 keV to 100 MeV was carried out by the time-of-flight method with a multicell fast fission ionization chamber at the back streaming white neutron beam line of the China Spallation Neutron Source. The reliability of the experimental setup was verified by the high consistency between measured resonance peak positions and the fission energy spectrum from the $^{235}\mathrm{U}(n,f)$ reaction. After correcting the influence of double-bunch, fission fragment detection efficiency and neutron flux attenuation, the ^{239}Pu fission cross sections were finally obtained with an uncertainty of 1-6% in the energy range from 4 keV to 100 MeV.

正在审稿中



Measured $^{239}Pu/^{235}U$ fission cross section ratios.



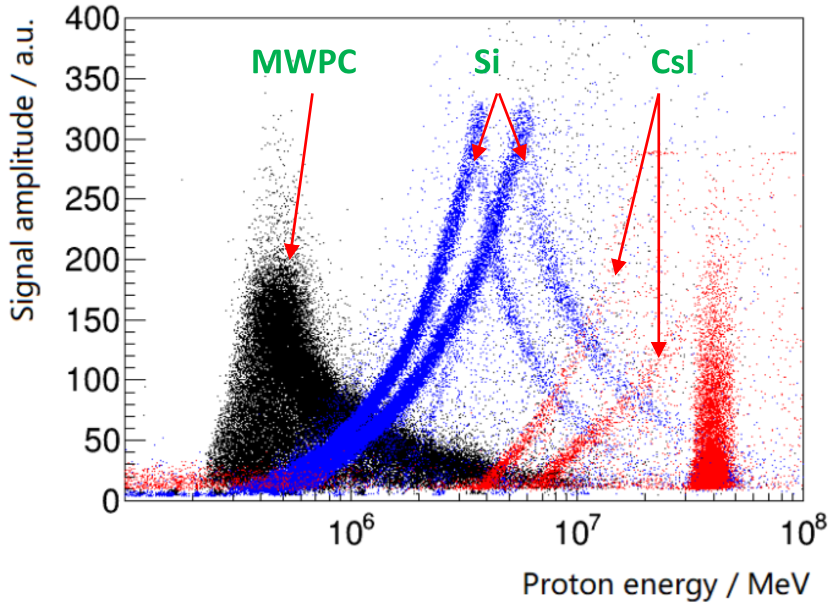
Measured $^{239}Pu(n,f)$ cross sections.

低能区n-p散射微分截面实验测量

樊瑞睿 易晗 孙艳坤 孙康 白浩帆等

基于LPDA望远镜探测器，在2021年10月开展了1.5~15 MeV能区**n-p散射微分截面实验测量**

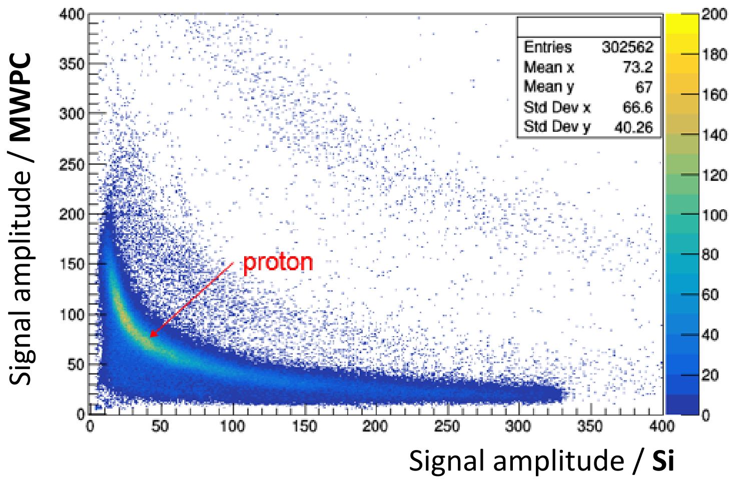
以24.5°处的望远镜为例，其ΔE-ΔE-E 3个探测器中脉冲幅度-质子能量二维谱结果，如右图所示

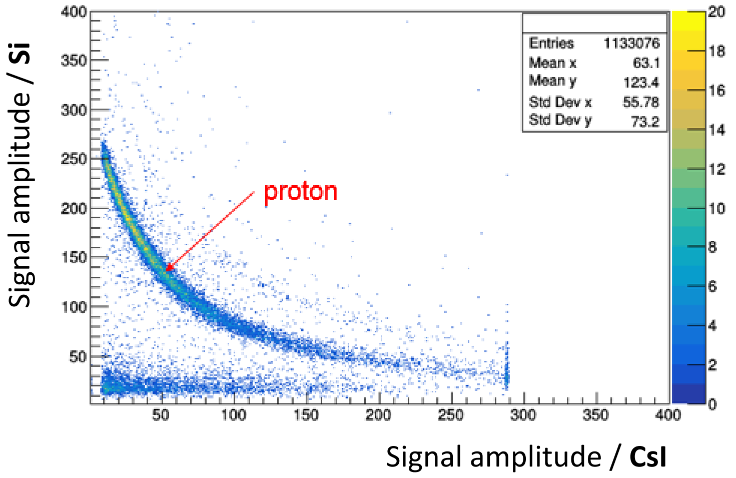


右图分别为MWPC+Si、Si+CsI两组ΔE-E二维谱

可以看到清晰的质子事件带

数据分析、实验改进之中





2000年以来标准截面实验测量统计(EXFOR)

- **标准截面的更新主要依赖新的实验数据，高精度实验测量十分重要**
  - $^{6}Li(n,t)$截面：2000年以来共有9家测量数据，其中有4家为中国的结果(G.Zhang等在北大能区3次测量、2020年白怀勇等在Back-n上的测量)
  - $^{10}B(n,\alpha)$截面： 2000年以来有9家测量数据，其中有5家为中国的结果(G.Zhang等在北大能区3次测量、2017年王志敏在MeV能区的测量，以及2019年江浩雨等在Back-n上的测量)
  - H(n,n)：2000年以来截面和微分截面共有15家测量数据，包括江浩雨等2021年在Back-n上的测量
  - $^{3}He(n,p)$截面： 2000年以来仅有3家测量，且所有年份的数据也明显比另外两个核反应少，没有微分截面实验数据

- $^{235}U(n,f)$截面： 2000年以来有~30家实验测量，包括文杰等2020年在Back-n上的测量

- $^{238}U(n,f)$截面： 2000年以来有~20家实验测量，包括2019年Niu Deqing等用活化法在K400上的测量(RPC,158,175,2019)、2020年Qiang Wang等在K400上的测量(NIM/B,469,28,2020)，以及2020年文杰等在Back-n上的测量

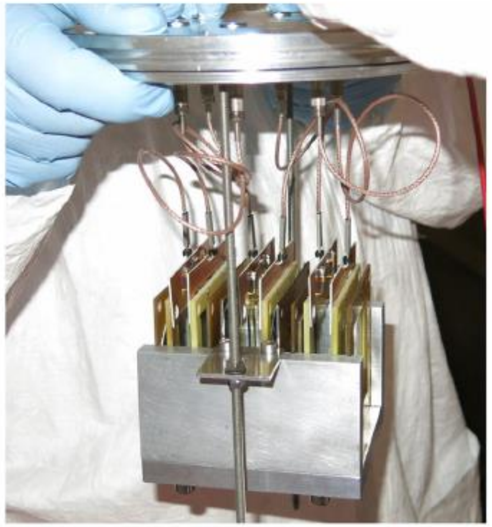
今后我们中国人的实验结果一定会越来越多！

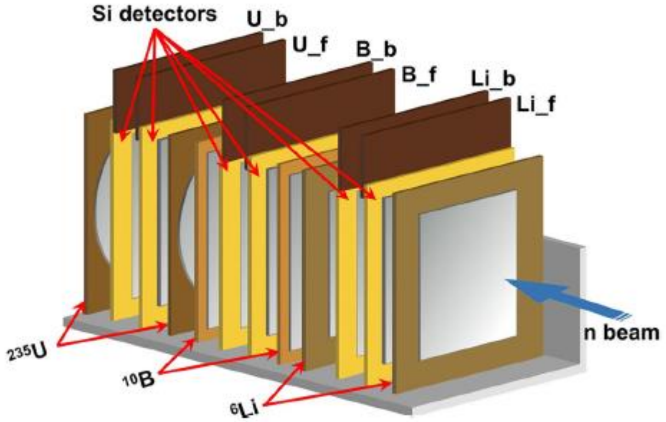
标准截面的测量建议：测量两个标准截面(或微分截面)**的比值，尽可能提高实验精度、降低实验结果的不确定度**

国际上的相关实验测量

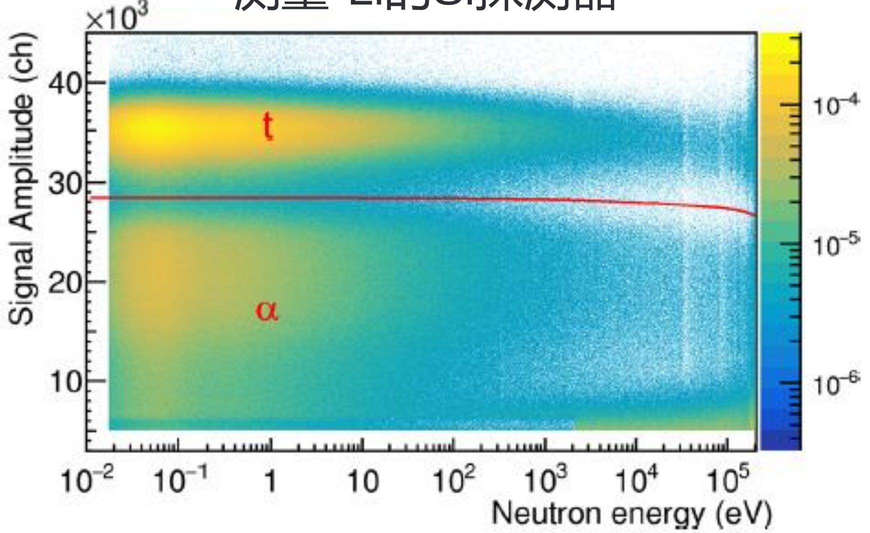
Eur. Phys. J. A (2019) **55**: 120

- 2019年n_TOF的测量

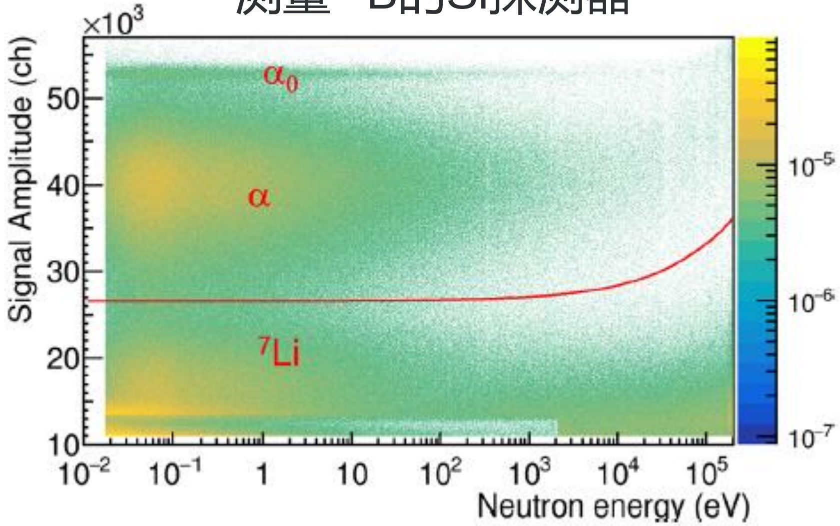




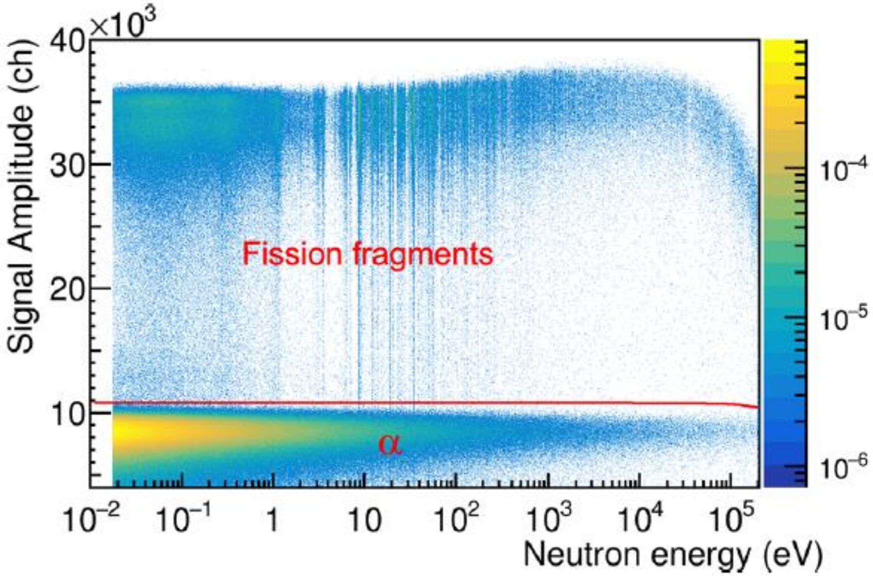
测量^{6}Li的Si探测器



测量^{10}B的Si探测器



测量^{235}U的Si探测器



测量了从热能区到170keV中子能区内，235U(n,f)截面与6Li(n,t)和10B(n,α)截面的比值。

直接将Si探测器与样品同时放在束线上，探测立体角大，其结果的误差小，就可以发现评价库的细微偏差。

4. 展望

基于Back-n全面开展四类标准截面测量

- 提高测量精度
- 扩展能区
- 测量$^{3}He(n,p)^{3}H$
- 相对测量
- 反复测量
- 用不同的探测器和探测方法进行测量
- 团队练兵的重要手段
- 提高基础实验水平

精益求精 追球卓越

4类标准反应的全面测量

4类标准反应：

- 轻带电粒子(4)
- 裂变反应(2)
- 弹性散射(2)
- 辐射俘获(1)

LPDA TPC SiC

FIXM

NTOX

C_6D_6 GTAF

全面测量(四类)

- 同一类内不同反应之间的相对测量
- 不同类之间的相对测量(探测器的联合应用)

探测器分类

带电粒子探测器

轻带电粒子

裂变碎片

伽马探测器

中 子 探 测 器

核反冲法，核反应法，核裂变法，活化法 ...

4类中子标准截面高精度测量

- **1.基于LPDA、TPC、SiC开展** 6Li(n,t) /10B(n,a)(n,a1) /1H(n,n) 相对测量 单束团 (详见下午带电粒子方向进展报告中的"展望"部分)
- **2.基于FIXM进一步开展裂变截面测量** 宽能区235U/238U(n,f)相对测量
  235U(n,f) **7.8—11eV 积分：** 247.5(3.3) b*eV
  更高能量的裂变截面测量： 235U, 238U, 239Pu, 209Bi, NatPb(n,f)

  [将轻带电粒子测量与裂变测量相结合: LPDDA+FIXM, 用LPDA测裂变角分布...]
- **3.基于NTOX的全截面**测量（低能区主要是**弹性散射**）12C(n,n) 13C(n,n)
  NatC(n,n) + CH2(n,n)→H(n,n) (?)
  基于TPC的 NatC(n,n) H(n,n)实验测量(测带电粒子)
- **4.基于C6D6的辐射俘获截面的测量** 197Au(n,γ) 自归一测量
  0.0253 eV, 0.2 – 2.5 MeV, 30 keV MACS (麦克斯韦谱平均截面)

4类之间的
相对测量!?
建立联系

Neutron Cross Section Standards

Detector		Reaction	Energy Range
LPDA, TPC, NTOX?	1.	H(n,n)	1 keV to 20 MeV
TPC	2.	^{3}He(n,p)	0.0253 eV to 50 keV
LPDA, TPC	3.	^{6}Li(n,t)	0.0253 eV to 1 MeV
LPDA, TPC	4.	^{10}B(n,α)	0.0253 eV to 1 MeV
LPDA, TPC, HPGE?	5.	^{10}B(n,$\alpha_1\gamma$)	0.0253 eV to 1 MeV
TPC, NTOX	6.	^{Nat}C(n,n)	10 eV to 1.8 MeV
C6D6?, GTAF?	7.	Au(n,γ)	0.0253 eV, 0.2 to 2.5 MeV, 30 keV MACS
FIXM, LPDA? TPC	8.	^{235}U(n,f)	0.0253 eV, 7.8-11 eV, 0.15 MeV to 200 MeV
FIXM, LPDA? TPC	9.	^{238}U(n,f)	2 MeV to 200 MeV

相关的实验测量

- **实验测量离不开理论指导**
- **理论分析与数据评价需要所有反应道的实验信息**
- **除了上述几个标准核反应的截面之外，微分截面** (角分布) **等实验信息也是非常重要的**
- **有关的其他各个反应道的实验信息**(如全截面、弹散截面、弹散角分布、(n, α)截面与微分截面…)**都是非常重要的**

不同的核反应之间具有普遍联系

总结

- 中子标准截面实验测量与评价意义重大
- 基于Back-n 和 LPDA, FIXM, NTOX, C_6D_6
  我们已经对标准截面开展了全面的实验测量
- 下一步要努力提高数据精度 扩展能区

- 高水平的实验测量需要理论家的合作与指导！

- 准备报告过程中得到了许多老师同学的帮助 特此致谢！

谢谢大家！