Progress on Nuclear data Measurements in China

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China Nuclear Data Center
China Institute of Atomic Energy

WPEC-2019, June 24-28, 2019, Paris, France

Progress of ND measurements in the following institutes are collected

中国原子能科学研究院
CHINA INSTITUTE OF ATOMIC ENERGY

北京大学
PEKING UNIVERSITY

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

中国工程物理研究院
CHINA ACADEMY OF ENGINEERING PHYSICS

China Institute of Atomic Energy

Highlights in 2018

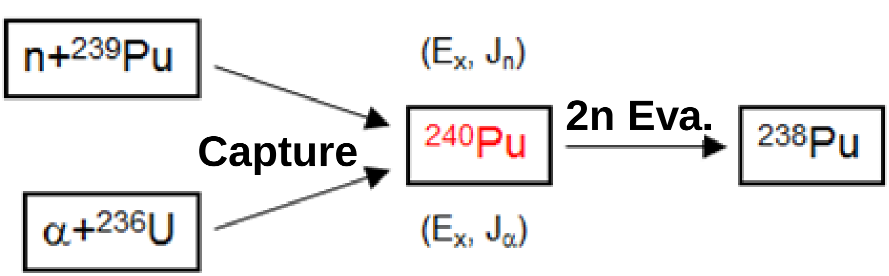
1. Measurement of (n,f) and (n,2n) Cross Sections of Actinides with the Surrogate Capture Reaction Method
2. Measurements at CSNS

Surrogate **Capture** Reaction Method

$$\sigma^{n,f}(E,J^{\pi}) = \sigma^{CN}(E_n,J^{\pi}) \times P_f(E,J^{\pi})$$

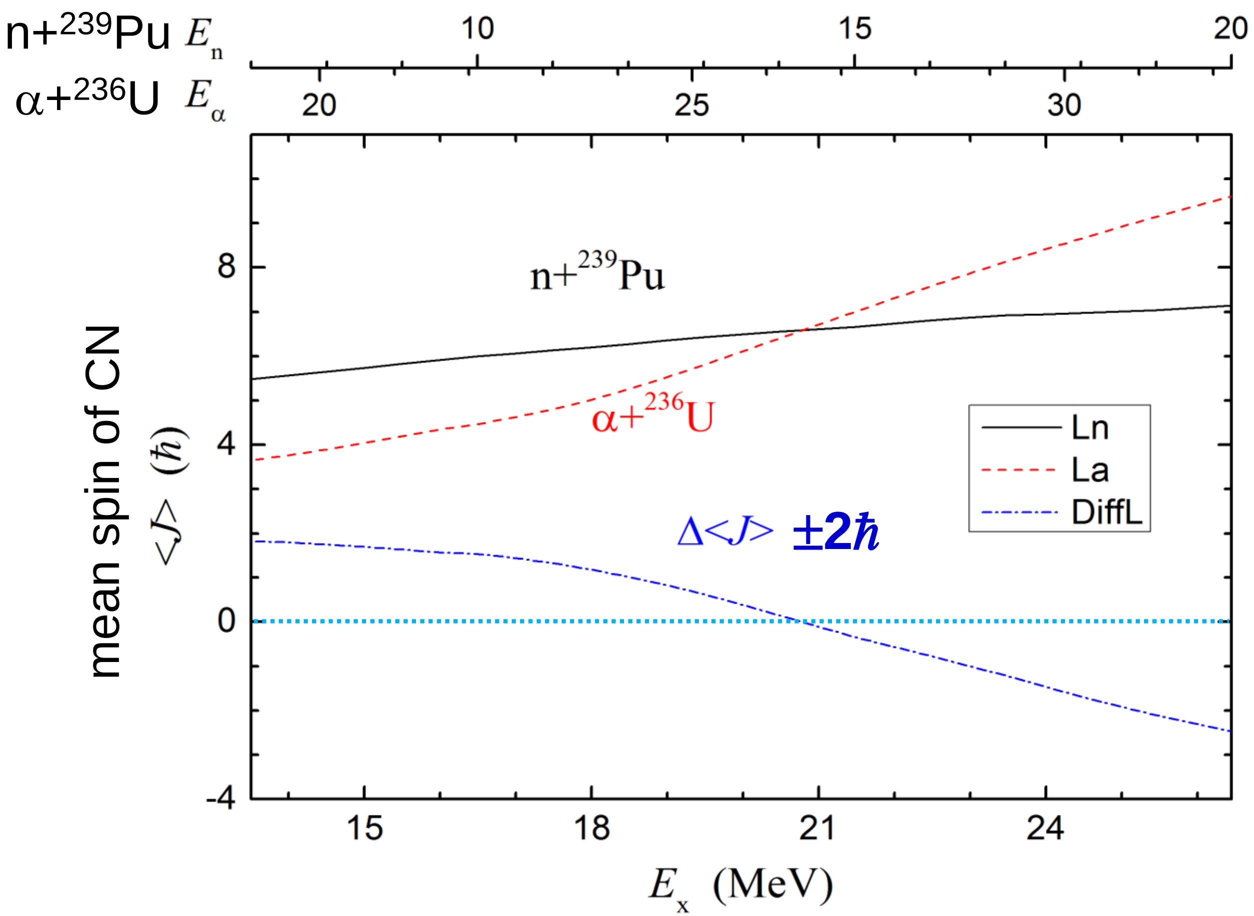
- ♠ Peripheral reactions, transfer or inelastic scattering like (t,pf), (d,pf), (α,α'f), (^{18}O,^{16}Of) …, are used as the surrogate reactions, where the angular momentum and parity (J^{π}) involved in CN are different to that of direct neutron reaction in general.
- ♠ In most cases, J^{π} plays a major role, which gives rise to the difficulty in theoretical correction.
- ♠ Considering this, we propose the capture of light charge-particle (p, d, t, ^{3}He, α …) as a surrogate reaction.

Example: ^{236}U(α,2n) $\rightarrow$ ^{239}Pu(n,2n)



$$\sigma_{(n,2n)} = \sigma_{(\alpha,2n)} \frac{\sigma_{cap}(E_n)}{\sigma_{cap}(E_{\alpha})}$$

J^π difference



- *J* differences in n and α reactions are less than 2*ħ* in 2n evaporation window
- π have little differences if *J* are similar for both capture reactions
- It reduces the difficulty in J^π correlation

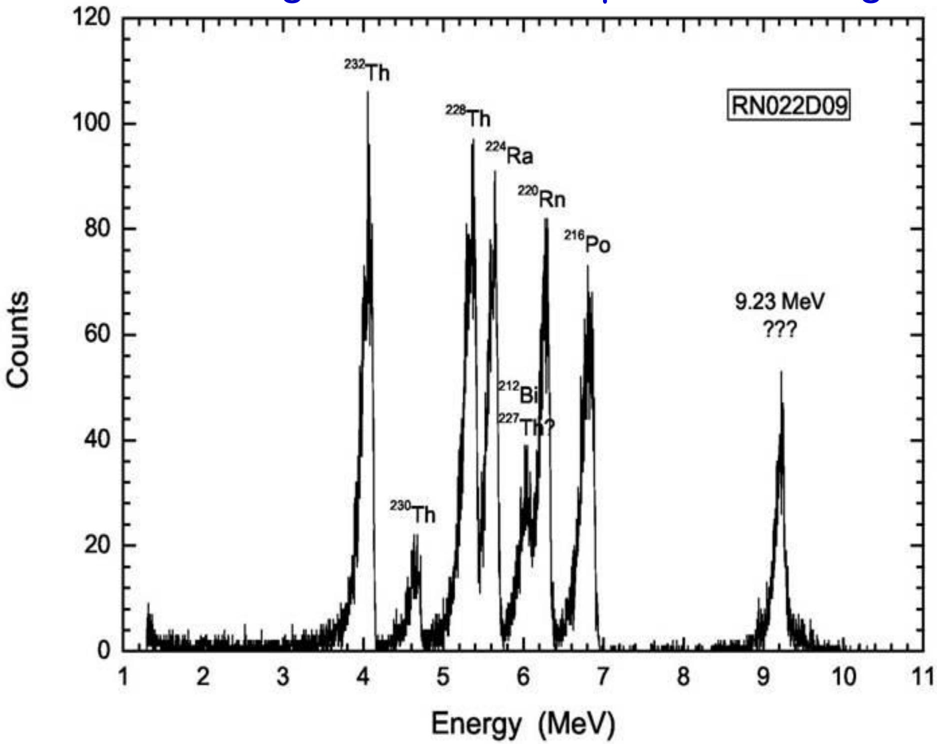
Test: $^{232}Th(\alpha,2n)\rightarrow^{235}U(n,2n)$

☞ Experiments were performed at HI-13 tandem accelerator at CIAE, Beijing.

☞ Angular distributions of elastic scattering and fission were measured by Si detectors.

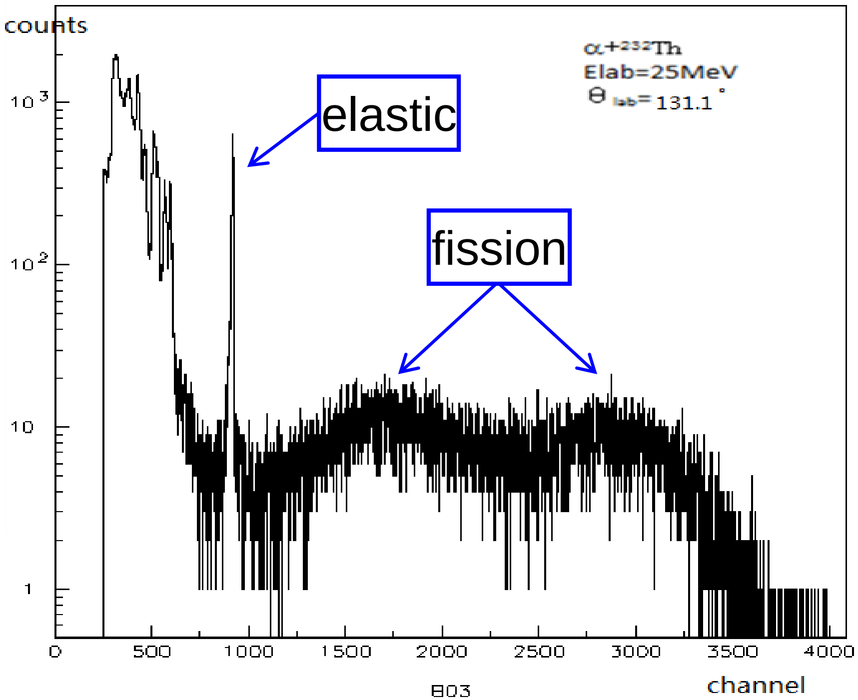
☞ Energy range: 15 – 36 MeV, total of 15 points.

0.1 mg/cm^2 ^{232}Th + 2 μm Al backing



α decays from ^{232}Th target

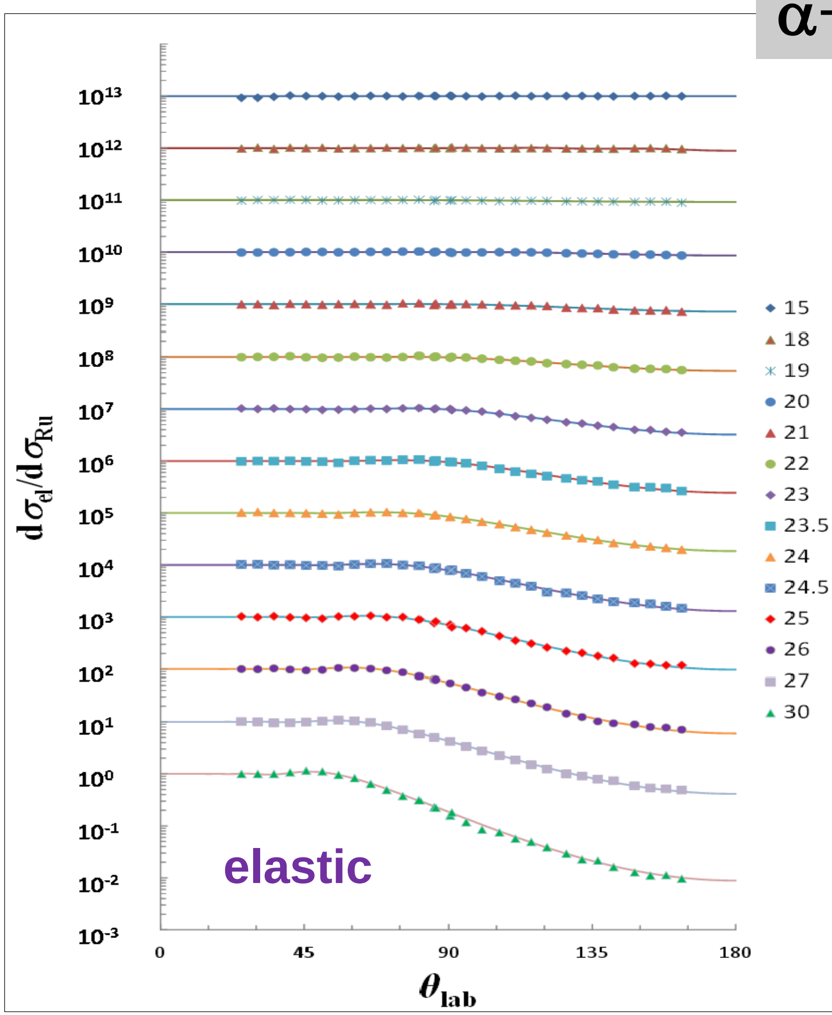
α+^{232}Th, E_{Lab} = 25 MeV, θ_{Lab} = 131.1°



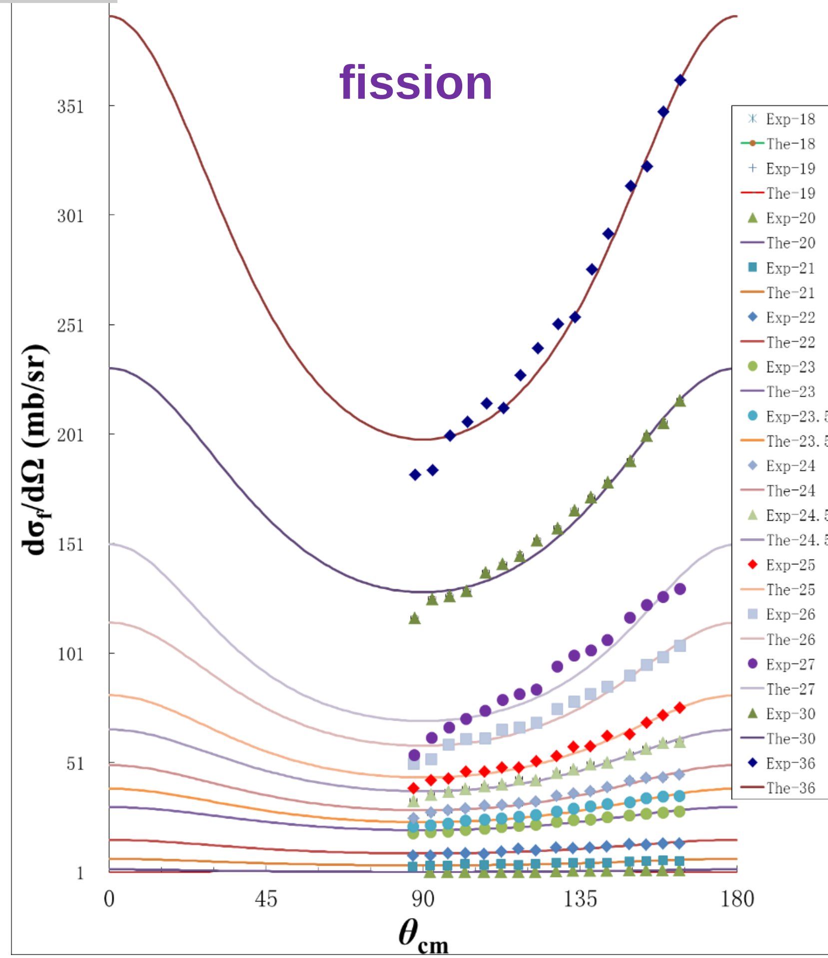
Online energy spectrum

Angular Distributions

$\alpha + ^{232}Th$



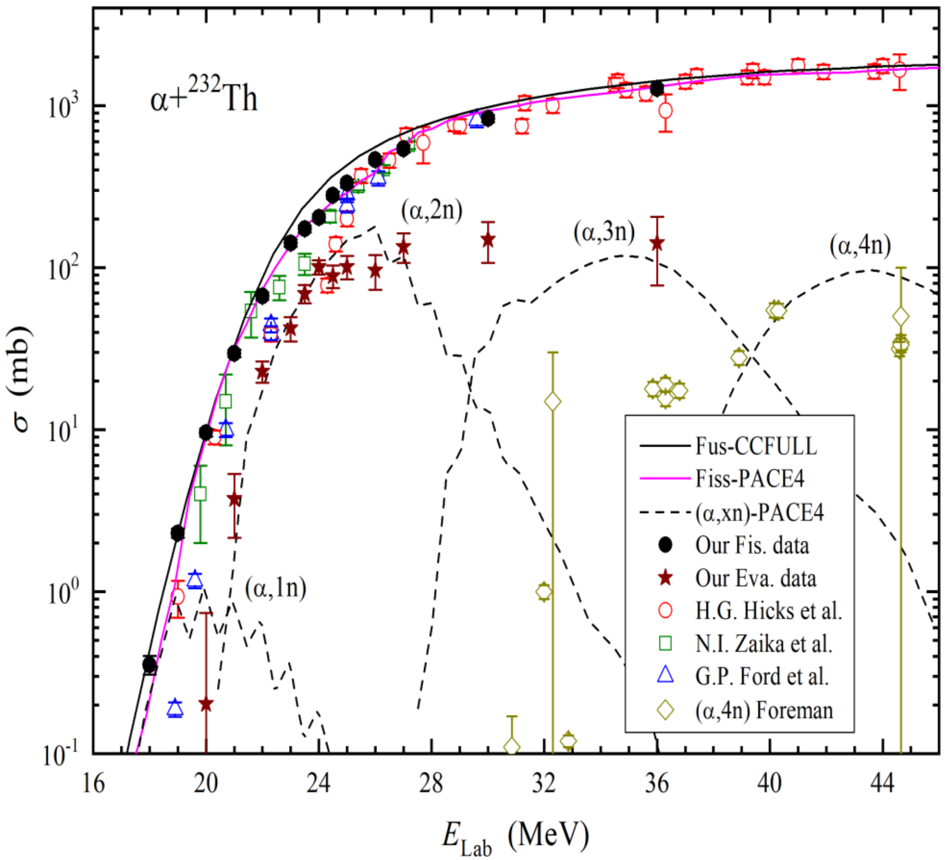
by the optical model

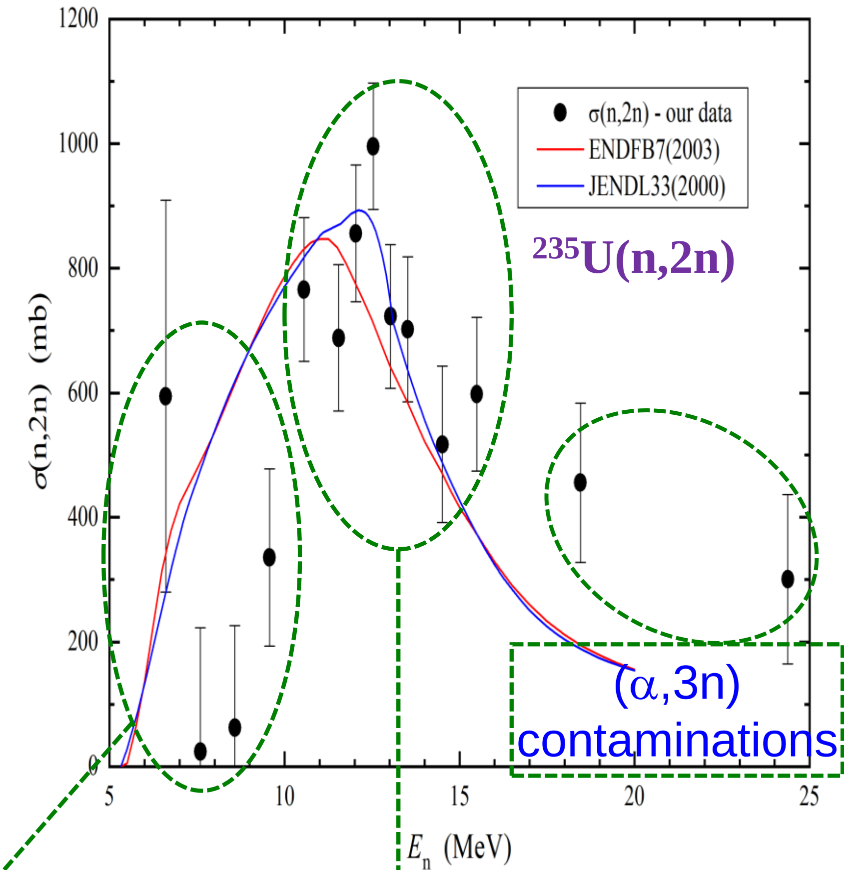


by the saddle-point transition-state model

Results of $^{235}U(n,2n)$

$^{232}Th(\alpha,f) \rightarrow {}^{232}Th(\alpha,2n) \rightarrow {}^{235}U(n,2n)$





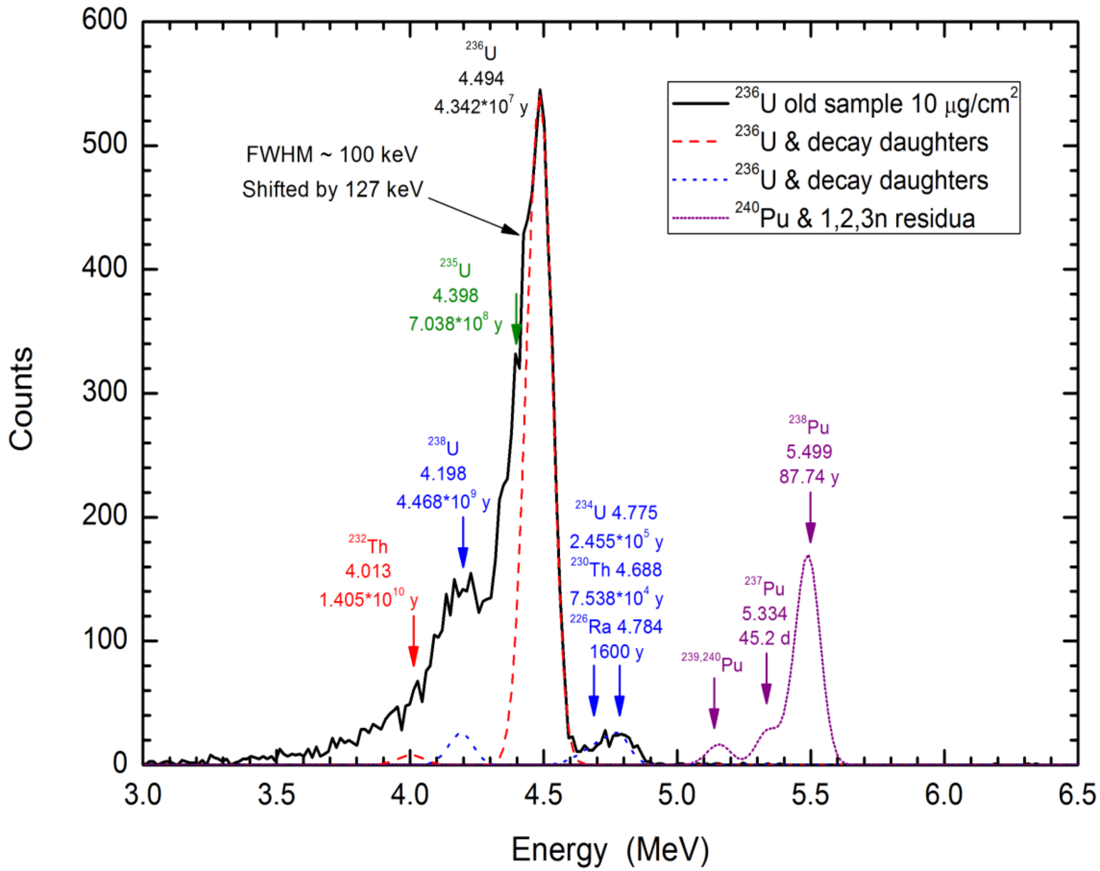
Eva. = Cap. - Fiss

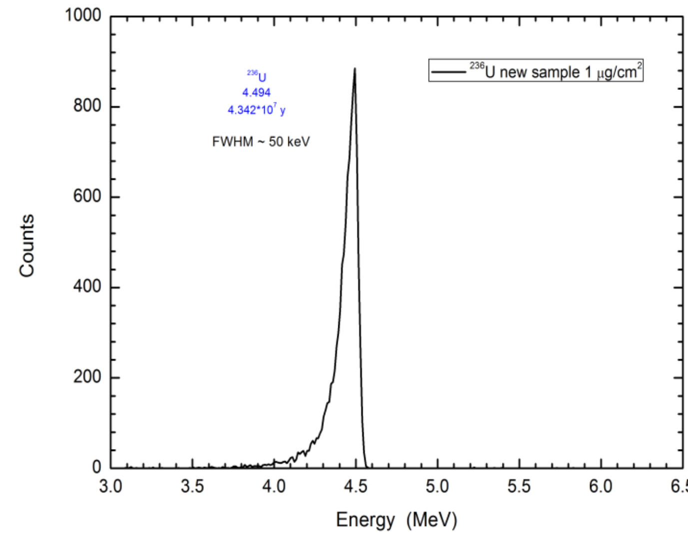
low statistics

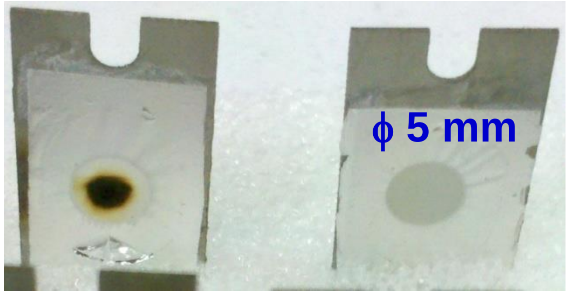
agree with evaluated data within error of 20%

^{236}U Targets

High purity ^{236}U (radionuclidic purity > 99.99%) was electrodeposited on Al backing.







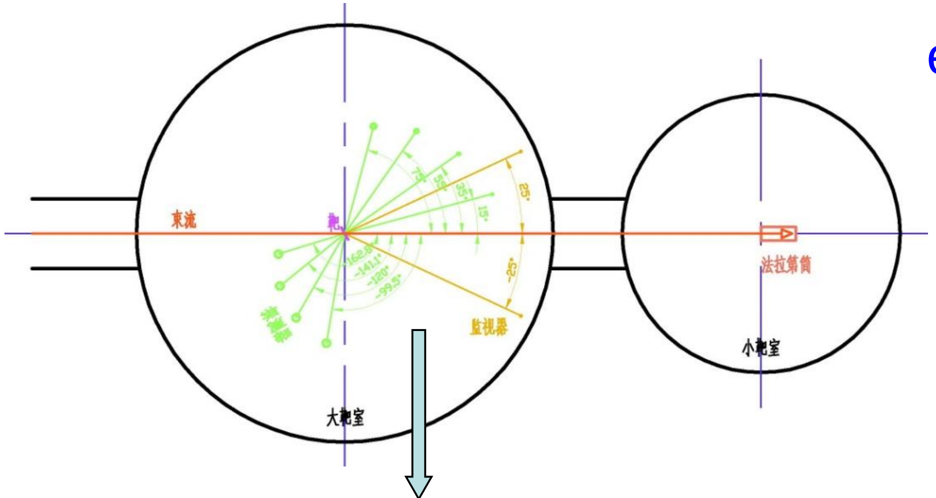
☞ 10 μg/cm^2 ^{236}U + 2 μm Al backing (2 pieces for online measurement)

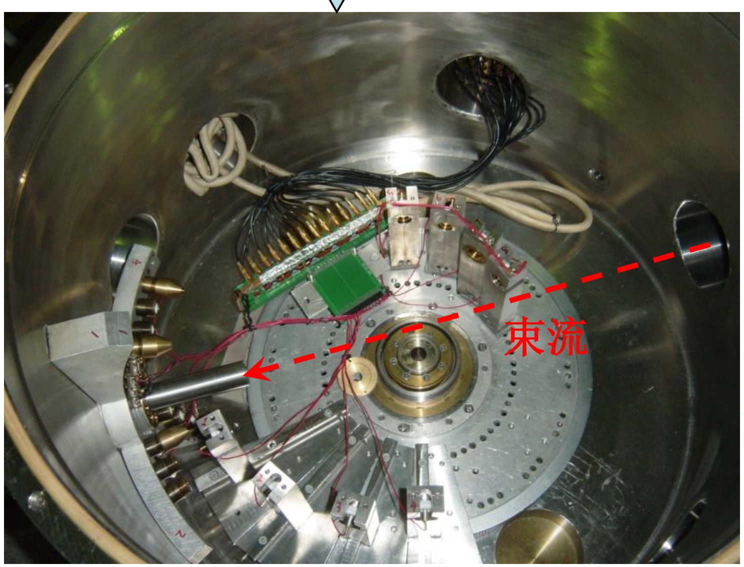
☞ 1-2 μg/cm^2 ^{236}U + 2 μm Al backing (18 pieces for irradiation & offline measurement)

Step 1: Online Measurements

Elastic & fission － HI-13 tandem accelerator, R60 scattering

er



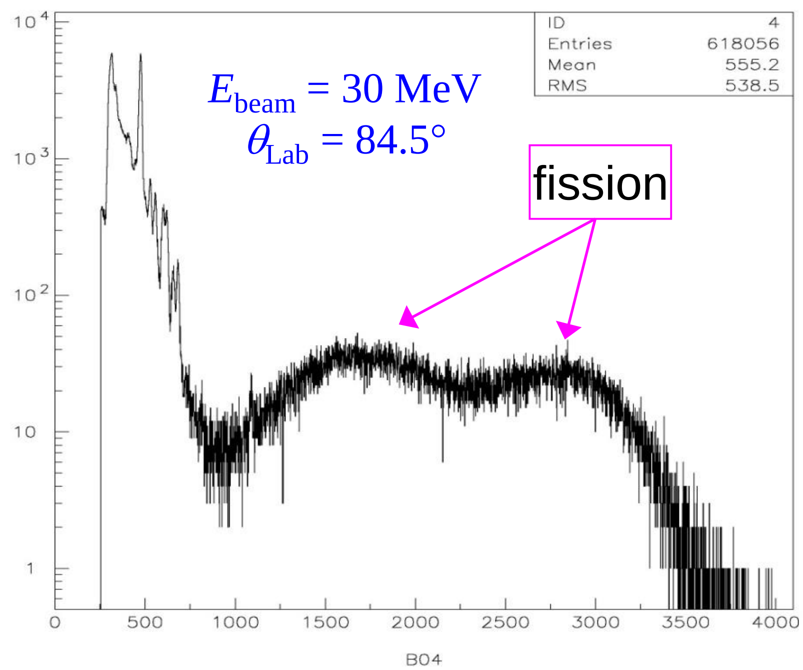


$E_{beam}(^4He)$= 14, 18 – 36 MeV

Total of 16 energy points

Energy at 14 MeV for

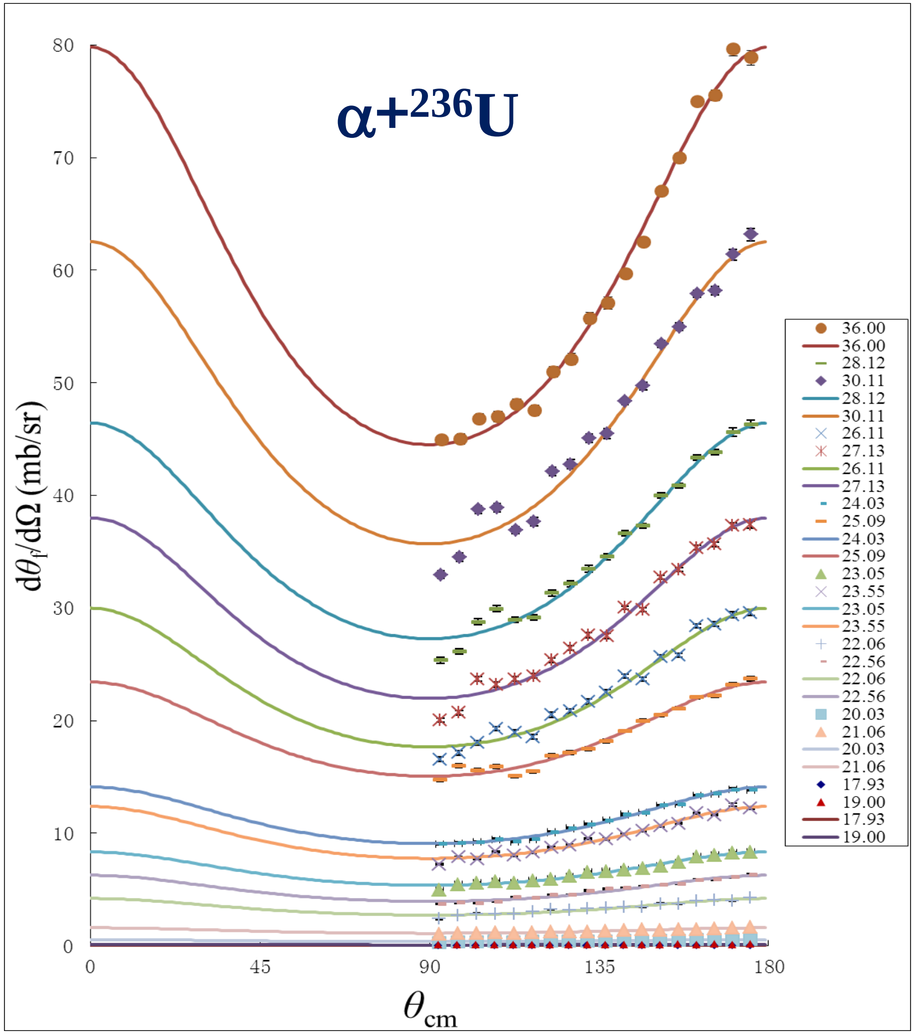
calibration



Fission Angular Distributions

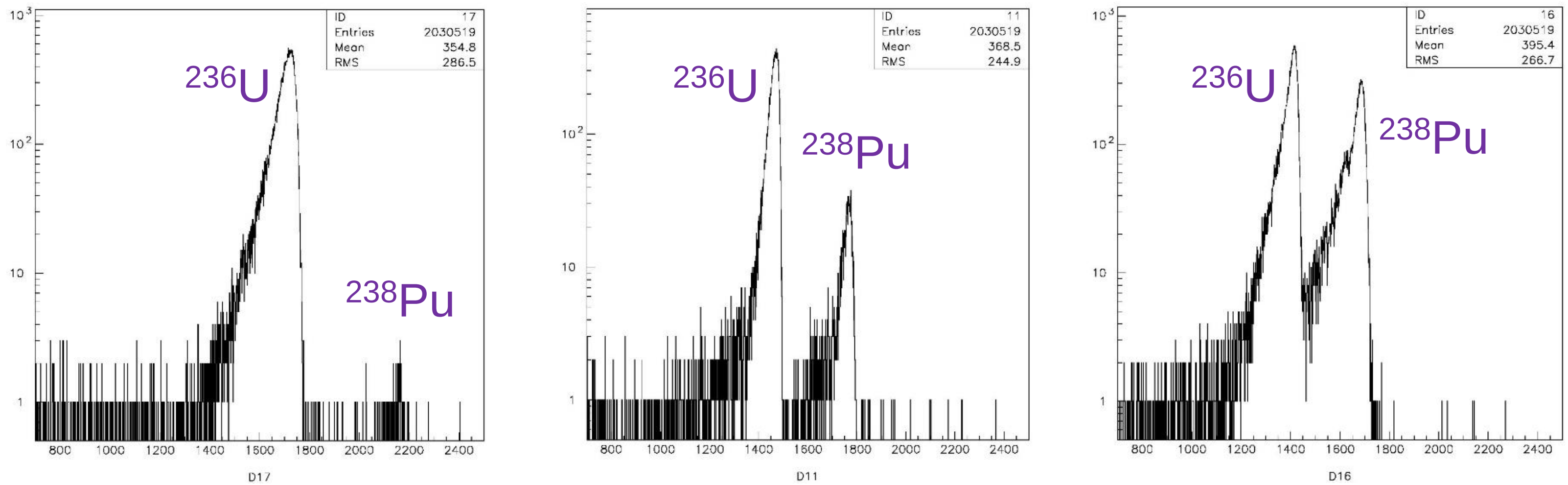
saddle-point transition-state model:

$$W(\theta) \propto \sum_{I=0}^{\infty} \frac{(2I+1)^2 T_I \exp\left[-\frac{(I+\frac{1}{2})^2 \sin^2\theta}{4K_0^2}\right] J_0\left[i\frac{(I+\frac{1}{2})^2 \sin^2\theta}{4K_0^2}\right]}{\mathrm{erf}\left[\frac{I+\frac{1}{2}}{\sqrt{2K_0^2}}\right]}$$



α Activities

α activities measurements (last 1-2 years)

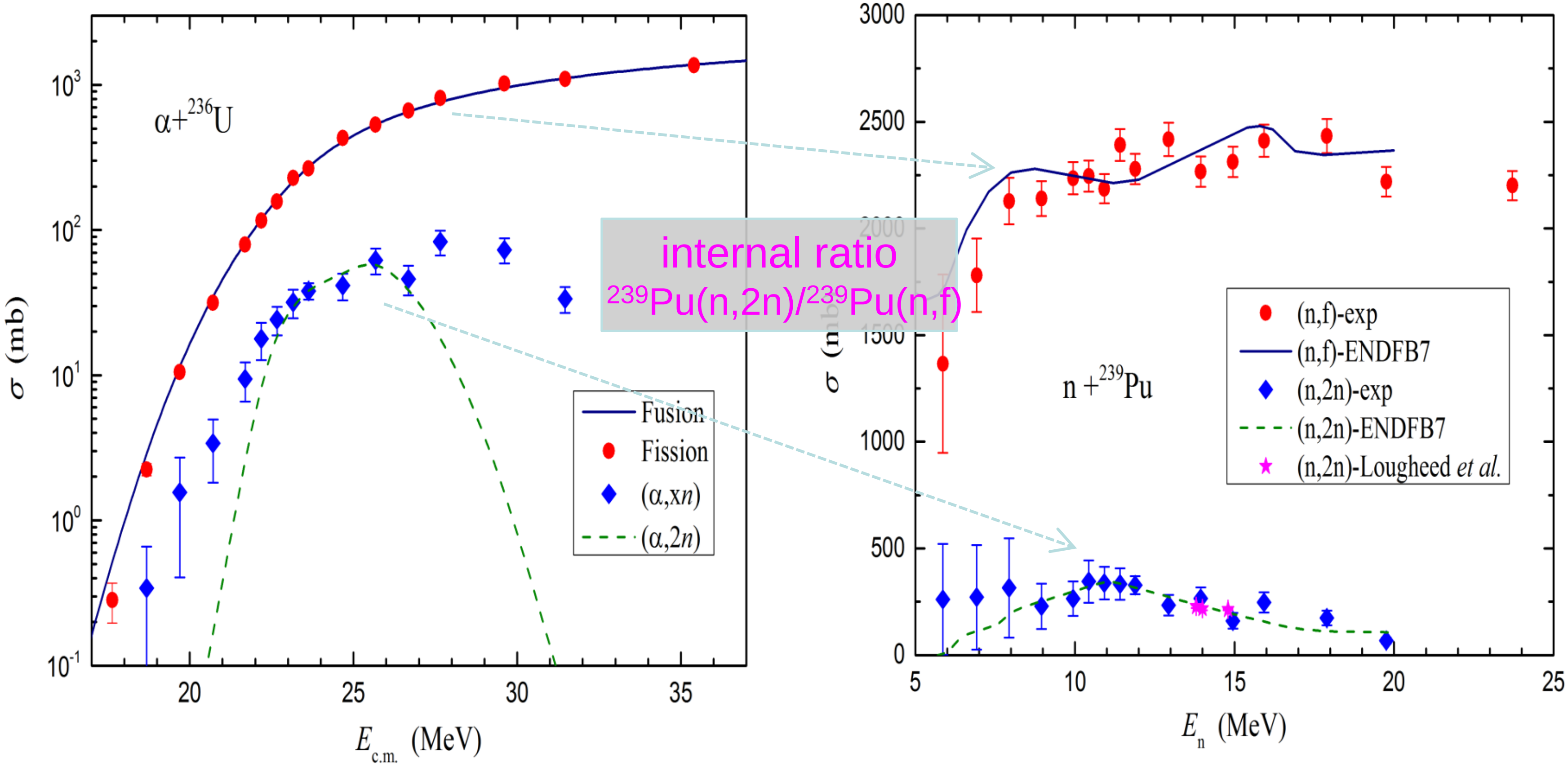


E_{lab} = 18.98 MeV 21.06 MeV 32.01
MeV

- The α decays from ^{238}Pu are clearly identified.
- The ^{238}Pu yield increases with energy increasing.

^{239}Pu(n,f) & (n,2n)

^{236}U(α,f) & (α,2n) → ^{239}Pu(n,f) & (n,2n)



★ Excitation functions of ^{239}Pu(n,f) &(n,2n) are successfully obtained by the SCRM.

2. Measurements at CSNS

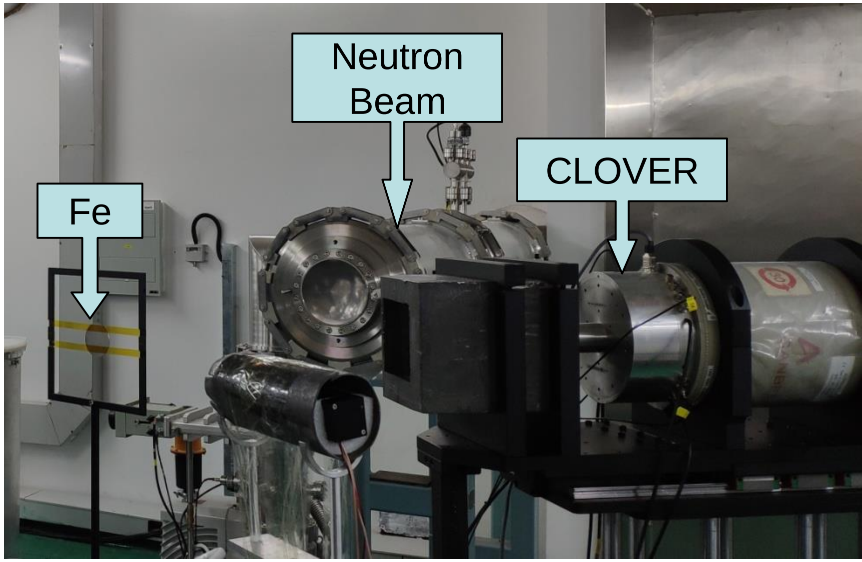
1. (n,γ) measurement with C6D6

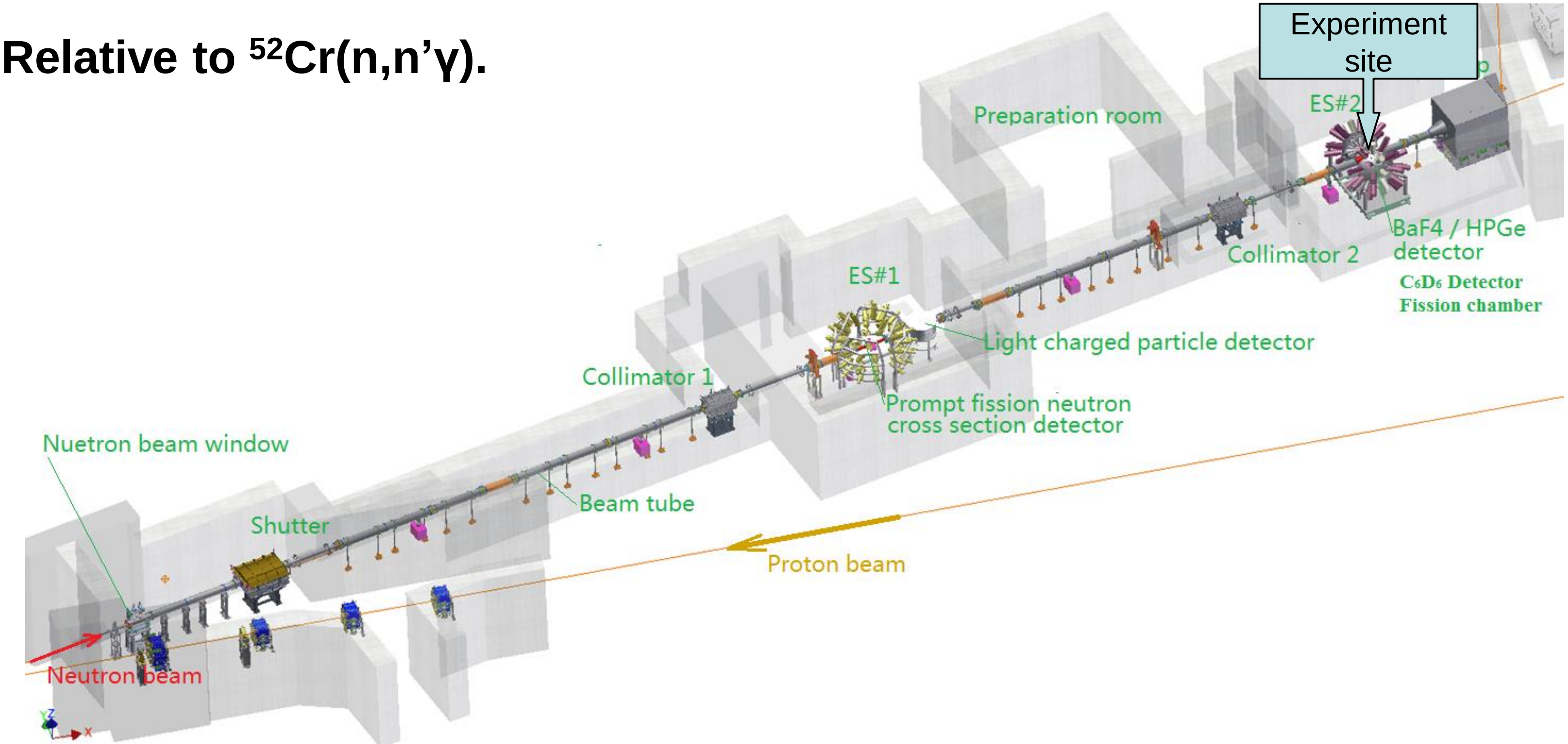
   ^{169}Tm, ^{93}Nb, ^{238}U data collected

   Data analysis undergoing.
2. Test measurement of $Fe(n,n'\gamma)$.

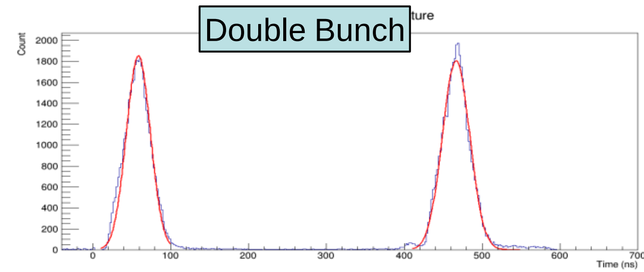
First HPGe experiment at CSNS

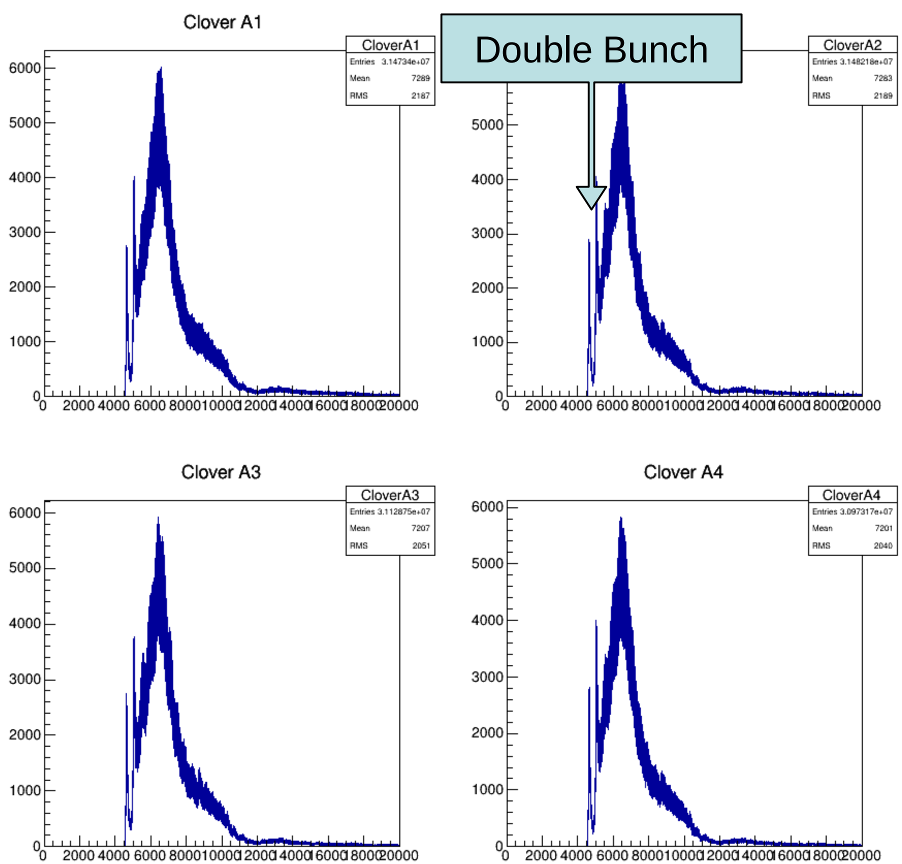
- ✓ ES#2, Double bunch , February,2019.
- ✓ TOF to determine the neutron energy.
- ✓ CLOVER and LaBr3. 125^o
- ✓ ^{nat}Fe target : Φ40×3mm.
- ✓ Relative to $^{52}Cr(n,n'\gamma)$.

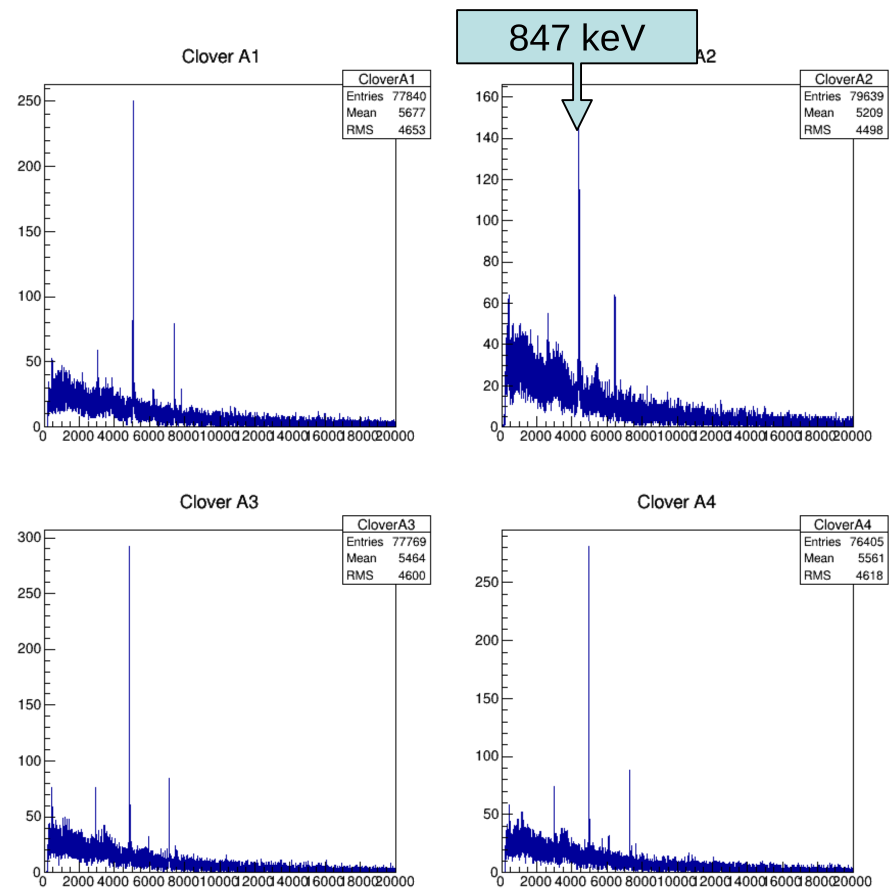




- ✓ **TOF spectrum.**
- ✓ **Gamma spectrum in [6400 ns , 6441 ns]**
- ✓ **For double bunch, need to unfold the TOF to obtain the neutron energy and corresponding cross section.**





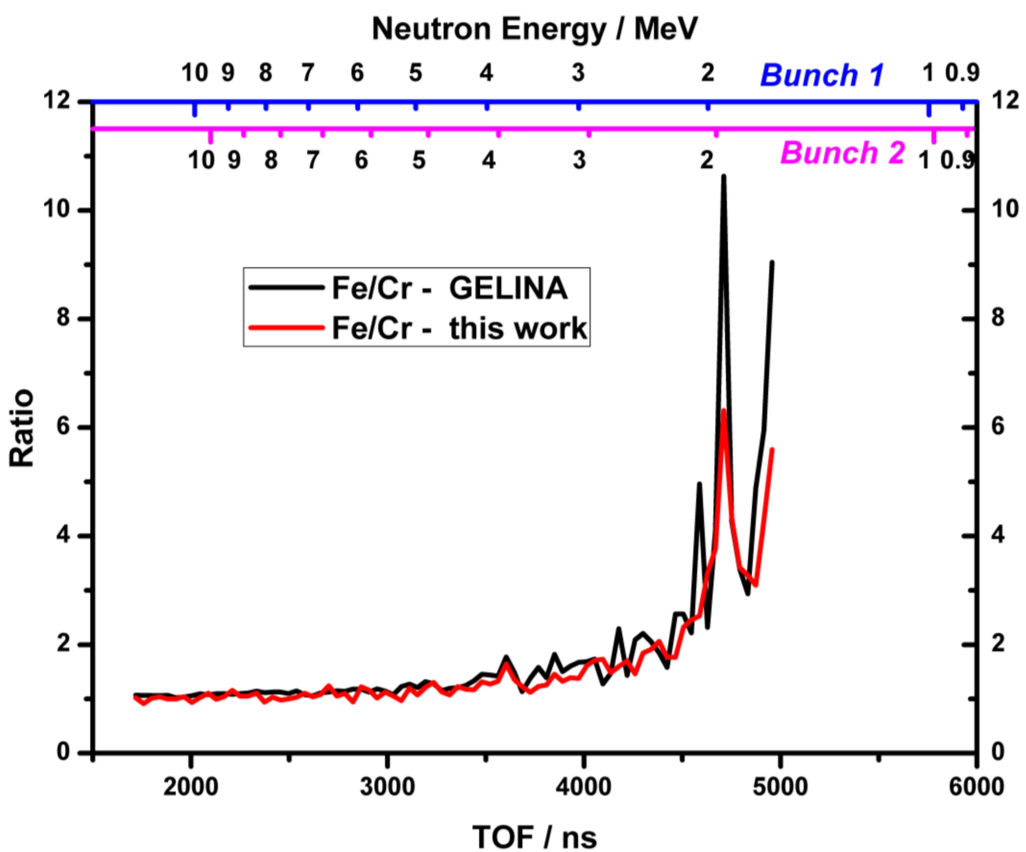


preliminary result !!!

- ✓ **Compare the yield ratio of Fe-847keV and Cr-1434keV with the result of GELINA.**

normalized yield ratio = cross section ratio

- ✓ **The agreement is acceptable.**
- ✓ **The ratio is consistent . The Shape is similar.** ⇨ ***Our system is reliable!***



Outlook:

Improve the measurement at CSNS.

Peking University

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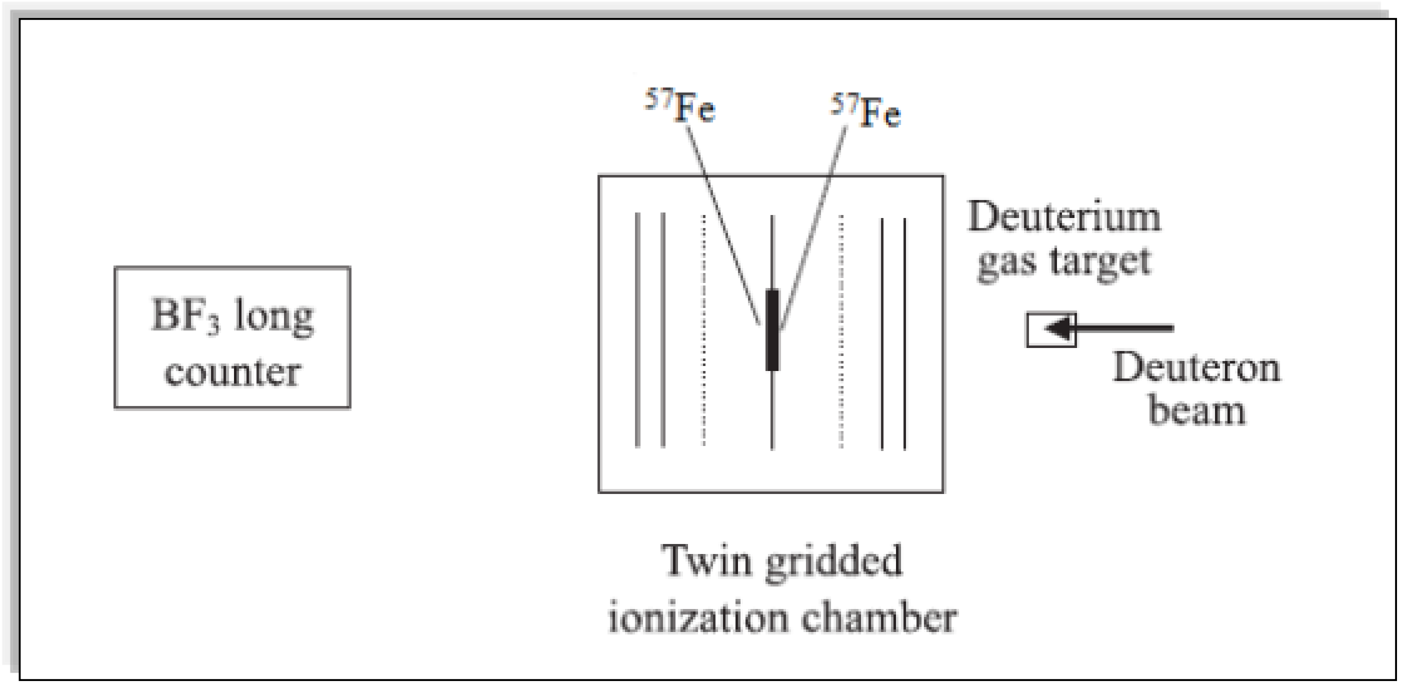
Reaction	E_n (MeV)	Publication
^{6}**Li**(n,t)^{4}He	1.05, 1.54, 1.85, 2.25, 2.67, 3.67, 4.42	**NSE** 134 (3) (2000) 312-316 **NSE** 143(1) (2003) 86-89 **NSE** 153(1) (2006) 41-45 **NIMA** 566 (2006) 615–621
^{10}**B**(n,α)^{7}Li	4.0, 5.0	**ARI** 66 (2008) 1427–1430
^{10}**B**(n, $t2a$) (n,α)	4.0, 4.5, 5.0	**PRC** 96, 044620 (2017) **PRC** 96, 044621 (2017)
^{25}**Mg**(n,α), (n,α_0)	4.0, 4.5, 5.0, 5.5, 6.0	**PRC** 98, 034605 (2018)
^{39}**K** / ^{40}**Ca** (n,α)	4.5, 5.5, 6.5 / 5.0, 6.0	**PRC**, 61, 054607(2000) **NSE** 134(1) (2000) 89-96
^{40}**Ca**(n,α_0)(n,a_{12})(n,α_{345})	4.0, 4.5, 5.0, 5.5, 6.0, 6.5	**EPJA** (2015) 51: 12
^{54}**Fe**/^{56}**Fe**/^{57}**Fe**(n,α) ^{54,56}**Fe**(n,α)	4.0, 4.5, 5.5, 6.5/5.5, 6.5/ 5.0, 5.5, 6.0, 6.5 5.5 7.7 8.5 9.5 10.5	**PRC** 92, 044601 (2015) **PRC** 89, 064607 (2014) PRC 99, 024619 (2019)
^{58}**Ni**(n,α)	4.0, 4.5, 5.0	**INDC**(CPR)-034/L, 1995, 13, 1-9
^{63}**Cu**(n,α)	5.0, 5.5, 6.0, 6.5	**PRC** 89, 064607 (2014)
^{64}**Zn**(n,α)^{61}Ni	2.54, 4.00, 5.50, 5.03, 5.95	**NSE** 156 (2007)115-119 **NSE** 160 (2008) 123-128
^{67}**Zn** (n,α) (n,α_0)	4.0, 5.0, 6.0	**PRC** 82, 054619 (2010)
^{95}**Mo**(n,α)	4.0, 5.0, 6.0	**ARI** 68 (2010) 180–183
^{143}**Nd**(n,α)	4.0, 5.0, 6.0	**PRC** 80, 044602 (2009)
^{147}**Sm**(n,α)	5.0, 6.0	**PRC** 80, 044602 (2009) **ARI** 67 (2009) 46–49
^{149}**Sm**(n,α)	4.5, 5.0, 5.5, 6.0, 6.5	**PRC** 82, 014601 (2010) **PRL** 107, 252502 (2011)

$^{56,54}Fe(n, \alpha)^{53,51}Cr$ Cross Sections in the MeV Region

- **(n,α) reaction cross section measurement in the 5.0-11.0 MeV region for 54Fe and 56Fe**



PHYSICAL REVIEW C **99**, 024619 (2019)

^{56,54}Fe(n, α)^{53,51}Cr cross sections in the MeV region

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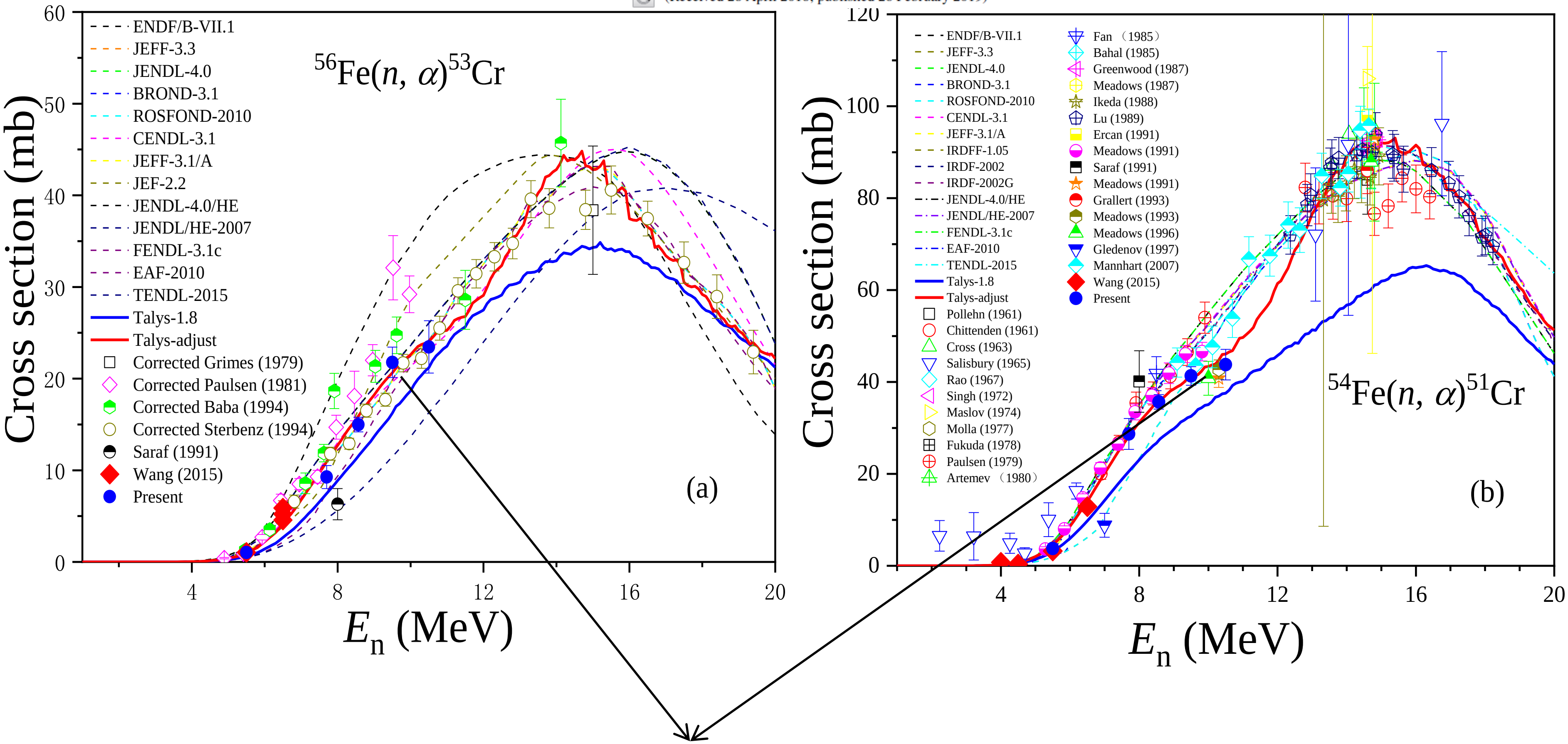
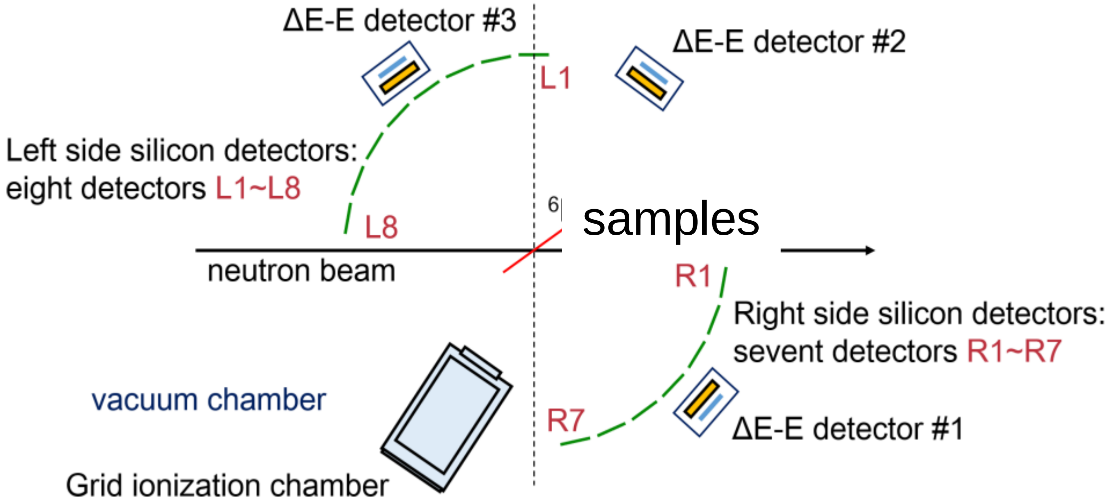


A shoulder was observed around 10 MeV, the reason is unknown

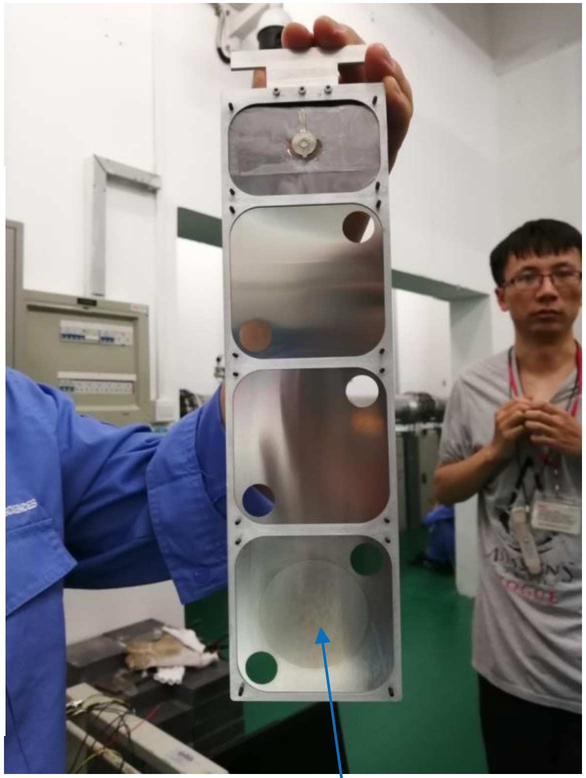
the 1st measurement at CSNS, Back-n: $^{6}Li(n, t)^{4}He$

Three kinds of detectors: **Silicon, ΔE-E, GIC**

8 + 7 = 15 silicon detectors (19.2° ~ 160.8°)

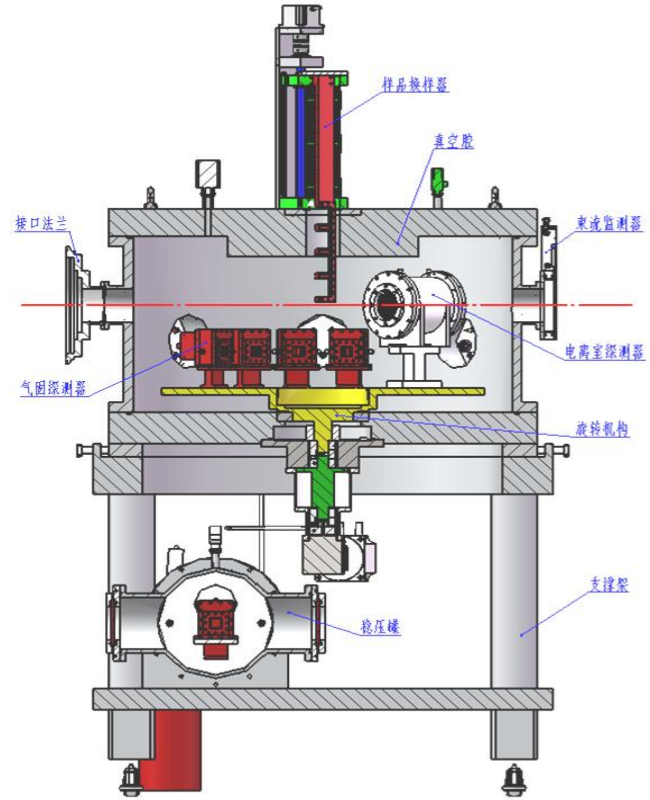


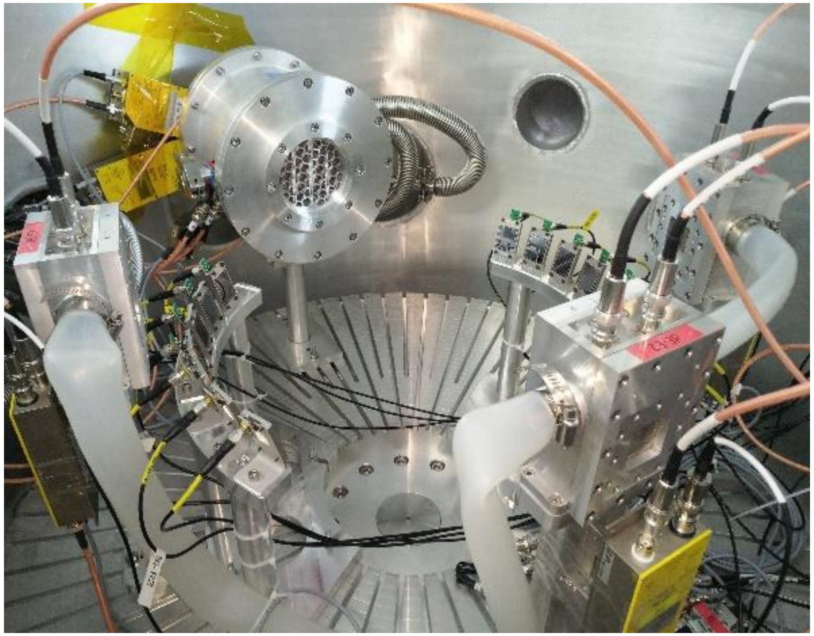
The detector setup



The ^{6}LiF sample

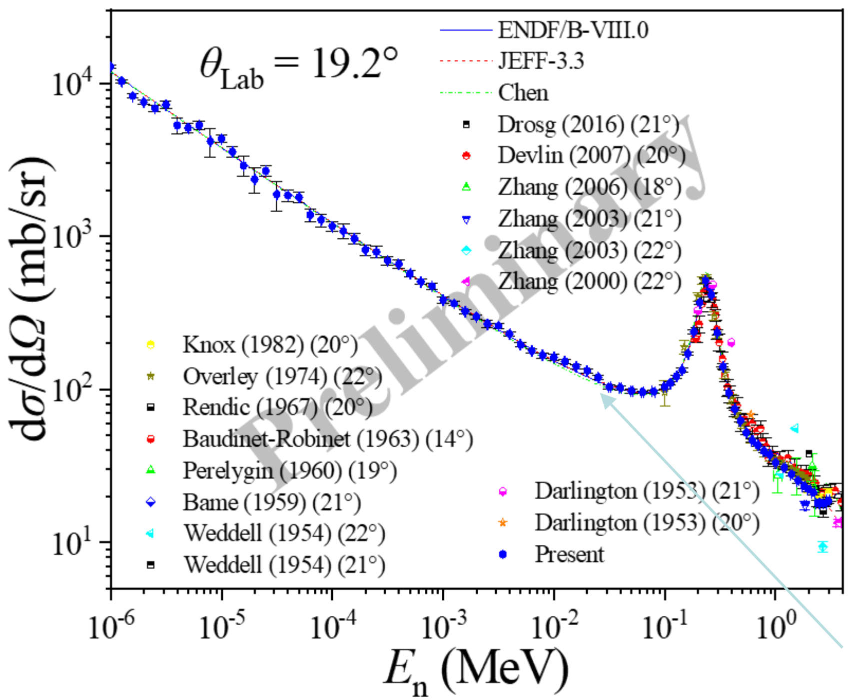
LPDA (Light-charged Particle Detector Array)



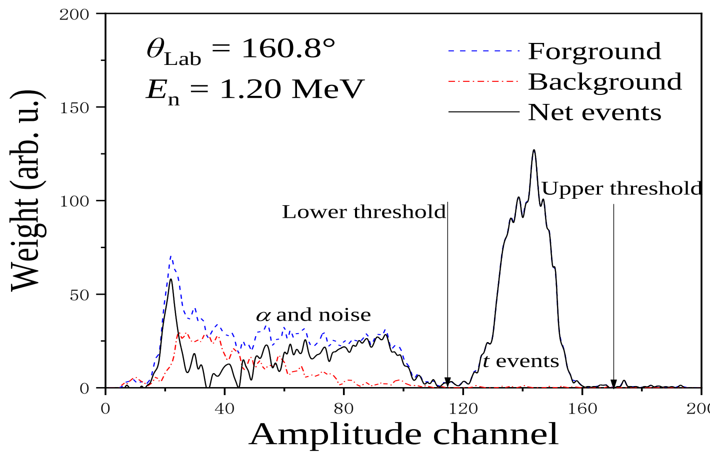


$^{6}Li(n, \underline{t})^{4}He$

Systematic <u>results</u> (from 1 eV to 3 MeV)



Differential cross sections for tritons at 19.2º in the lab. system



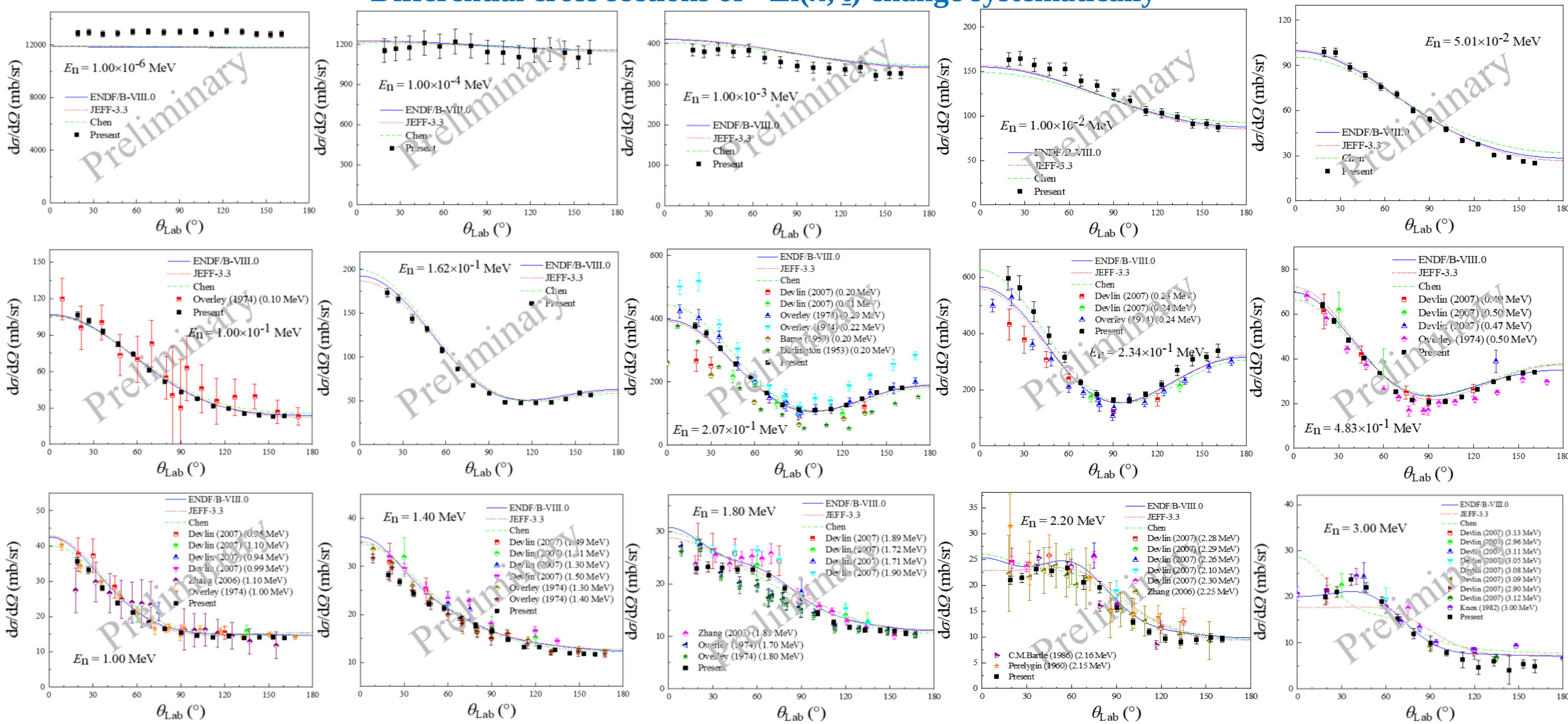
<u>80</u> energies (E_n) * <u>15</u> angles (θ_{Lab}) = 1200

- **At each angle position, 80 differential cross sections are obtained**
- **At each neutron energy, 15 angular differential cross sections are obtained**
- **<u>R-matrix analysis are performed</u>("Chen")**

No previous DA measurement below E_n = 0.1 MeV

Selected angular differential cross sections (15/80)

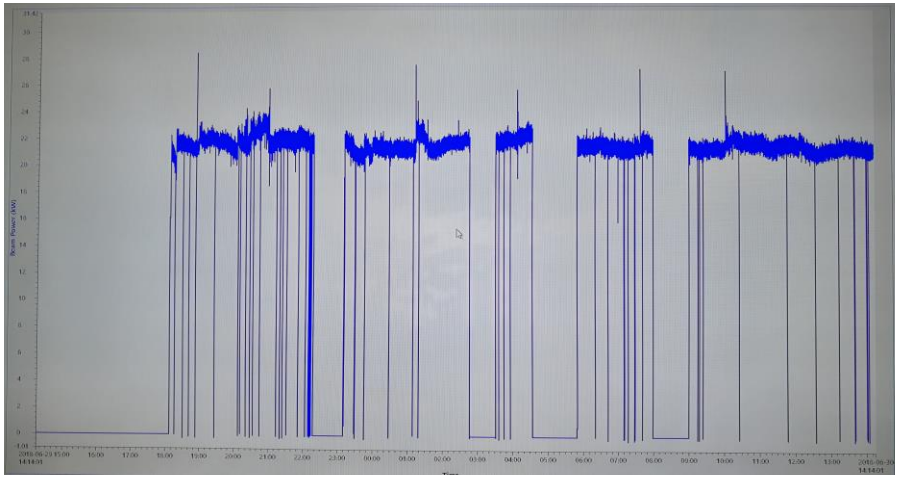
Differential cross sections of ^{6}Li(n, t) change systematically



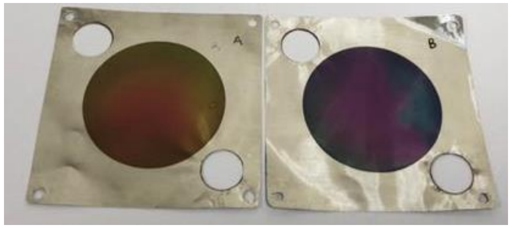
^{10}B(n, $\underline{\alpha}$)^{7}Li reaction

the 2nd measurement at CSNS, Back-n

- **2018 06-07**
- Double ^{10}B sample
  ^{10}B 90%, ~85 μg/cm^2 each, ϕ50 mm
- Beam 357 h (ϕ60mm)
  foreground : background ~ 2:1
- 20 kW   Recorded Data 8TB

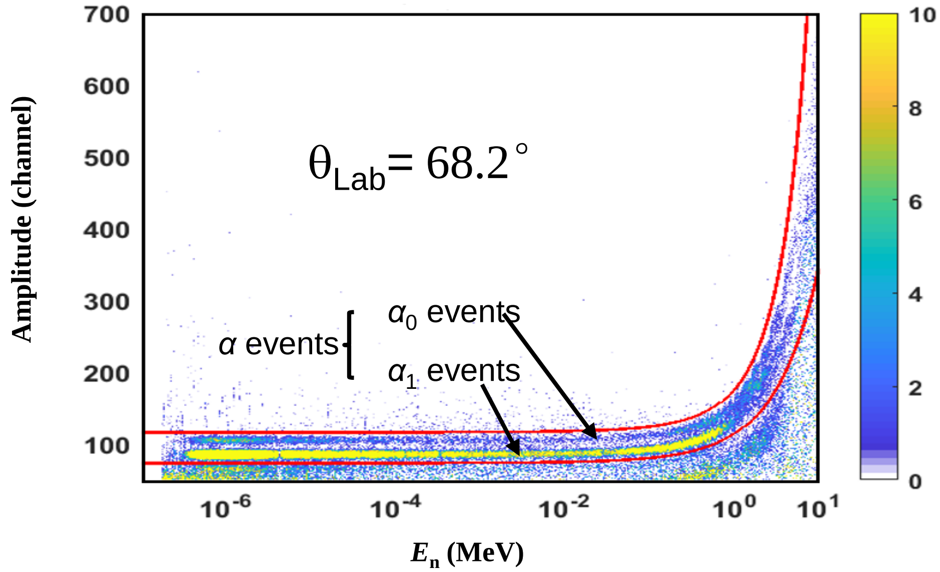


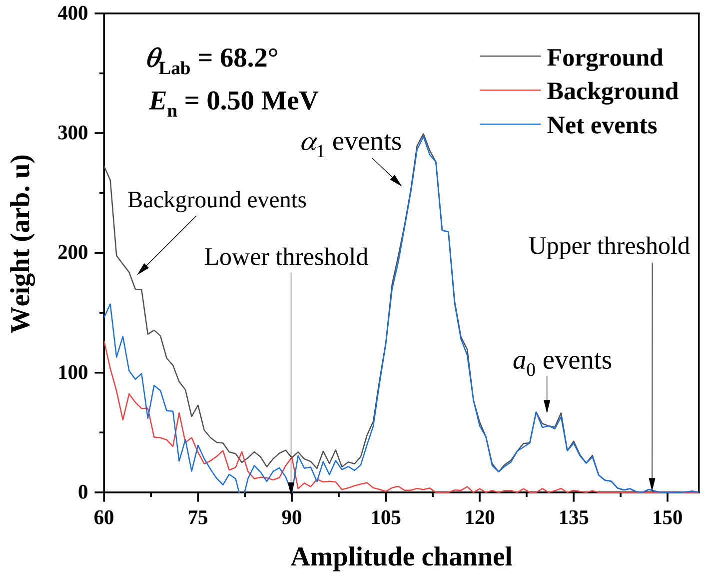
Details are shown in
<u>Haoyu Jiang</u>'s
Presentation (R233)
"Measurements of differential and angle-integrated cross sections for the ^{10}B(n,α)^{7}Li eaction in the neutron energy ange of 1 eV < E_n < 2.5 MeV"



^{10}B samples

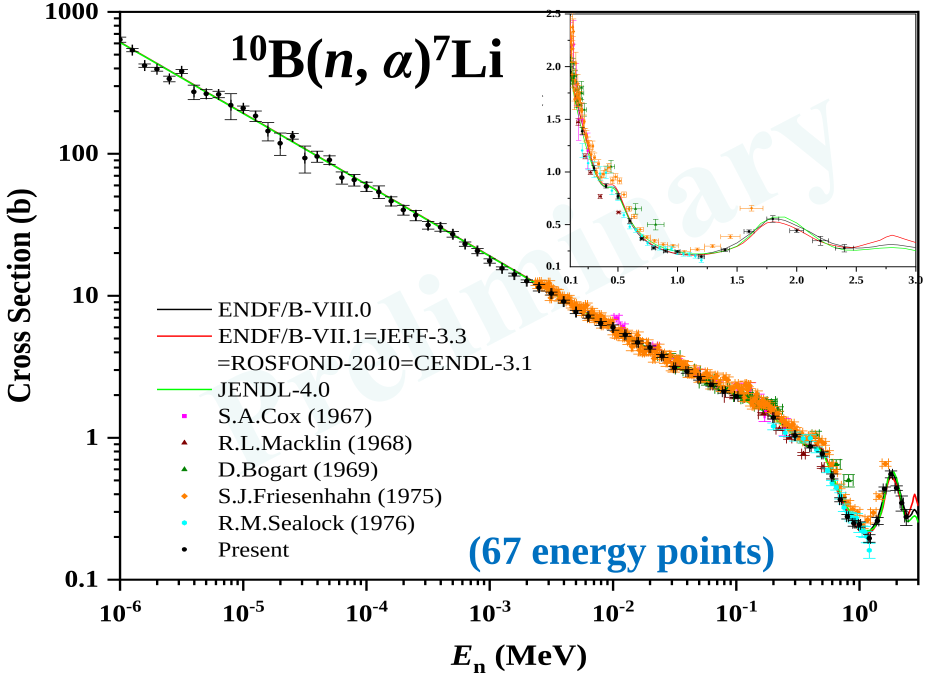
LPDA (15 silicon detectors 19.2° ~ 160.8°)

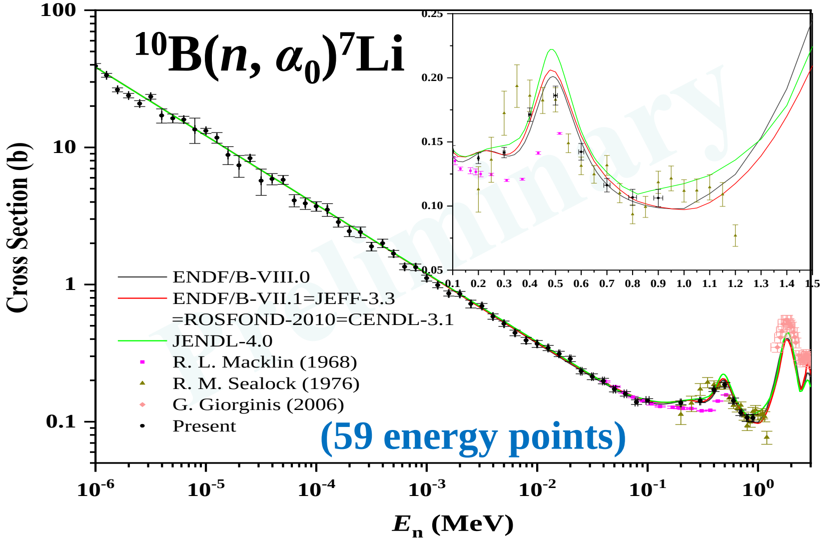


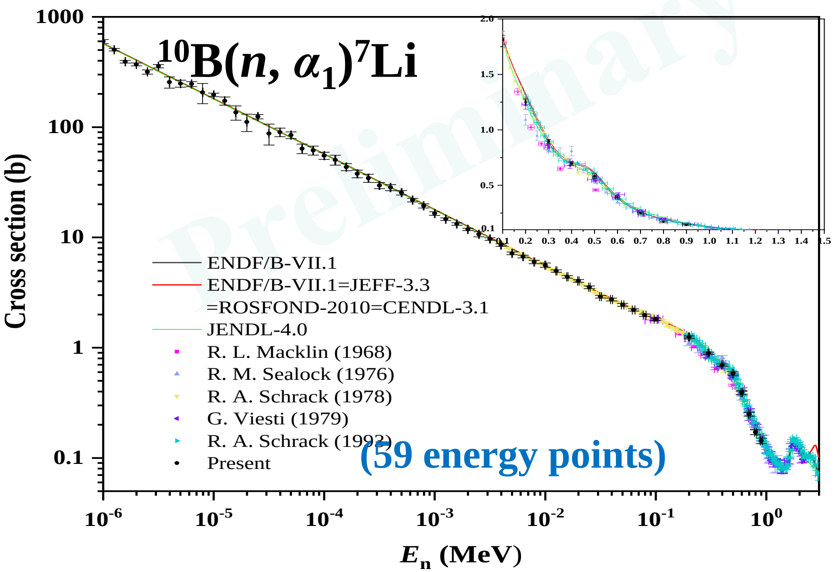


$^{10}B(n, \underline{a})^{7}Li$

Cross sections







ADS related nuclear data measurements at IMP,CAS (2018)

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Institute of Modern Physics,
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2018:

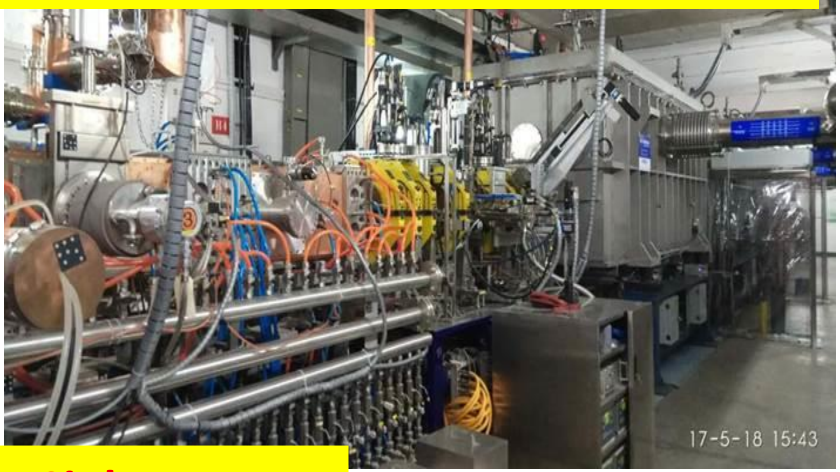
- "26.7 MeV/u ^{4}He + Be, C, W, Pb" experiments for the neutron energy spectrum measurements and angular distribution. (The primary ions were stopped in the targets. (November 2018)

2019:

- " 25-30 MeV ^{4}He + Bi" experiments for isotope production. (January 2019)
- "80.5 MeV/u ^{12}C + Be, C, W, Pb" for the neutron energy spectrum measurements and angular distribution experiments. (The primary ions were stopped in the targets) (March 2019)
- "80.5 MeV/u ^{12}C + C, Cu, Pb, Au" (thin target) for the light charged particles measurements. (March 2019)

$^{4}He+^{209}Bi \rightarrow$ ^{211}At experiments

- ^{211}At can be used in alpha particle emitting targeted radiotherapy.
- ^{211}At production experiments have been done based on ADS superconducting LINAC at IMP.



ADS superconducting LINAC

Target system

^{209}Bi targets

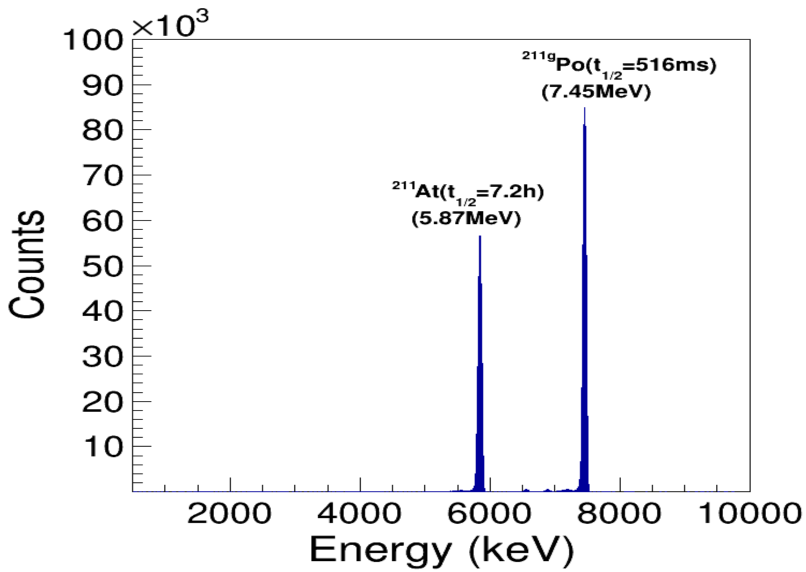
Si detectors

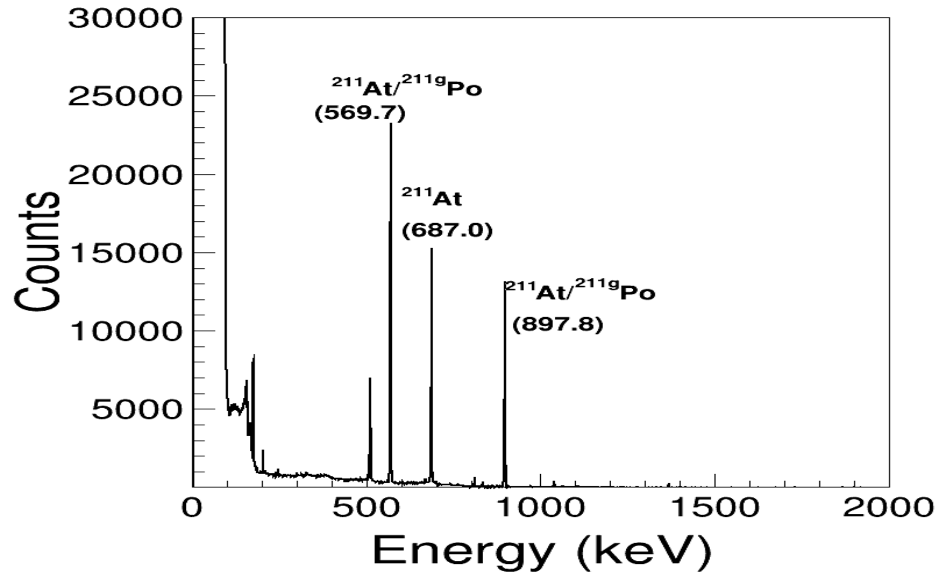
HpGe detector

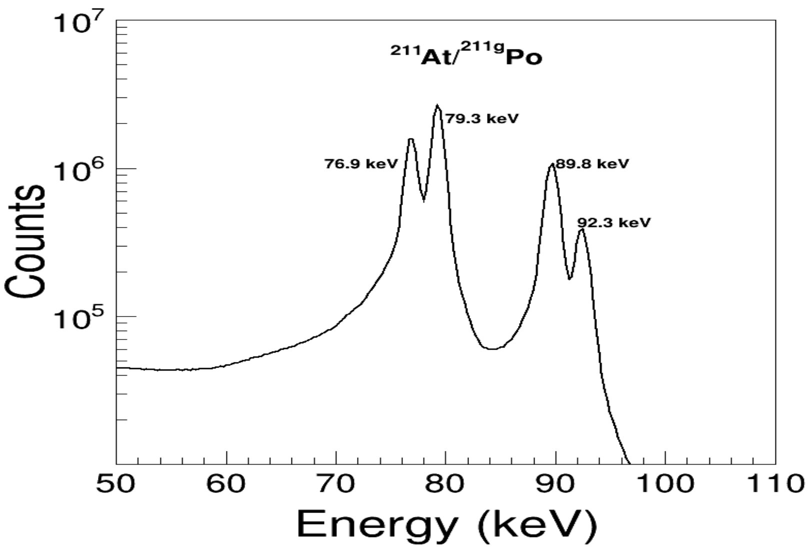
Target frames

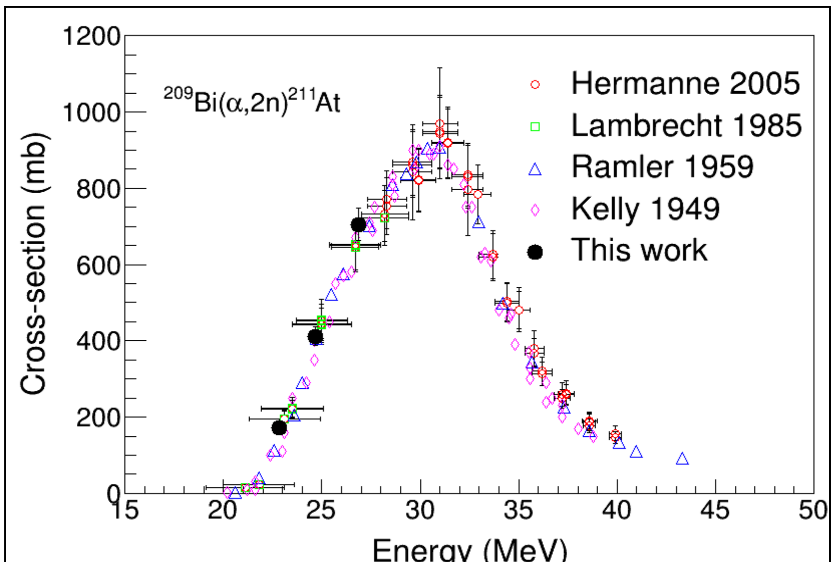
$^{4}He+^{209}Bi \rightarrow\ ^{211}At$ cross section measuremens

- **25- 27 MeV $^{4}He+^{209}Bi$ experiments have been done.**









Fission cross section measurement at CSNS by China Academy of Engineering Physics

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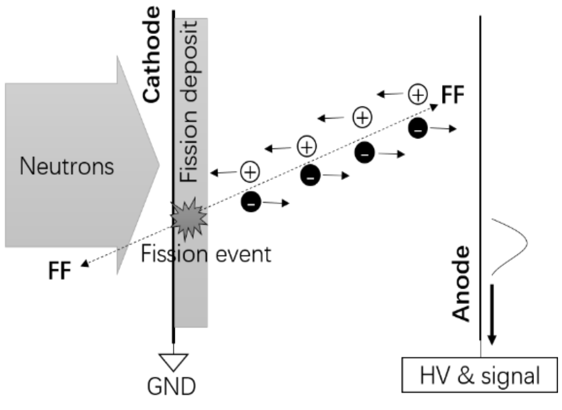
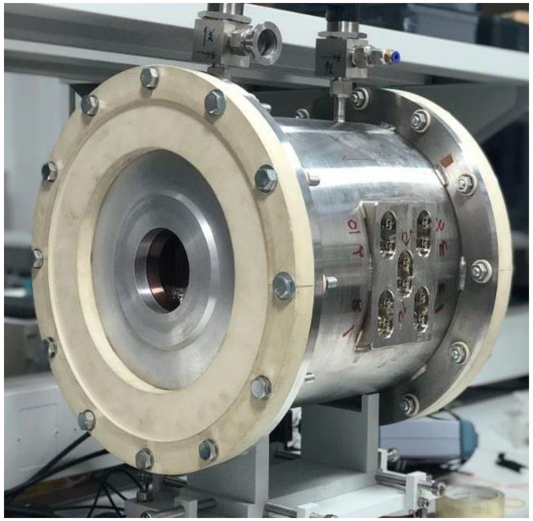
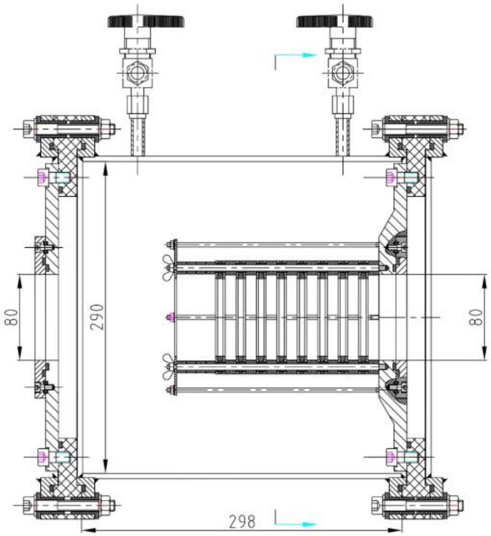
Fast Ionization Chamber for Fission Cross Section Measurement (FIXM)

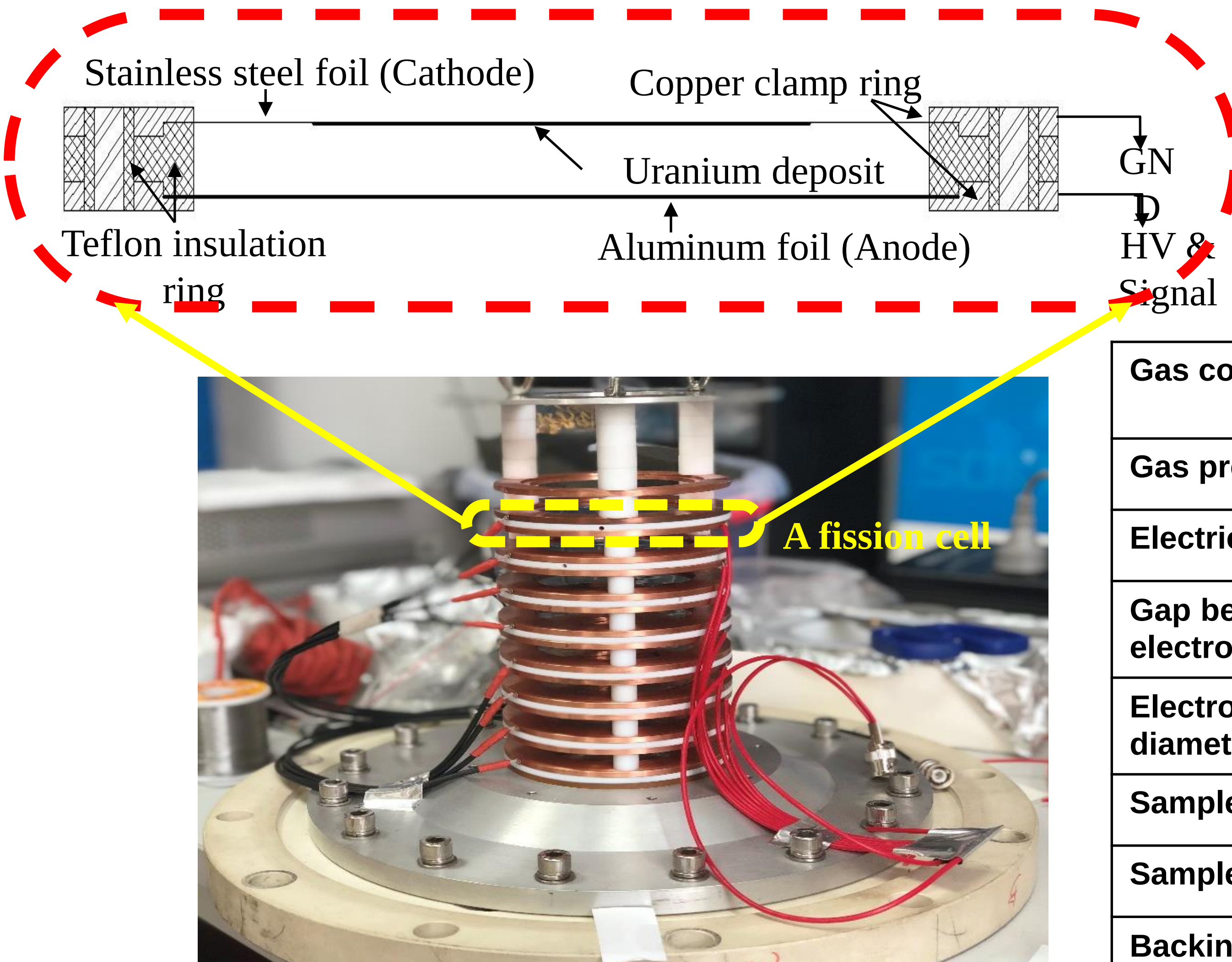
- Ionization chamber**: simple**, **stable**, **mature** and **fast enough** for current operation mode of CSNS.
- Electrons drift velocity (~60 mm/μs), cross the 5-mm-gap between the electrodes in ~80 ns.



Basic principle diagram



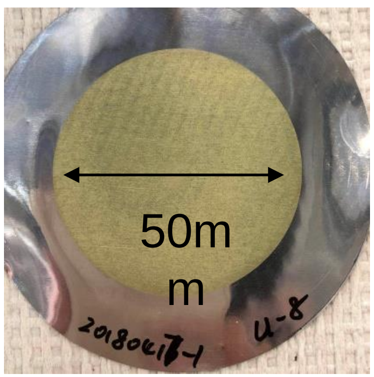


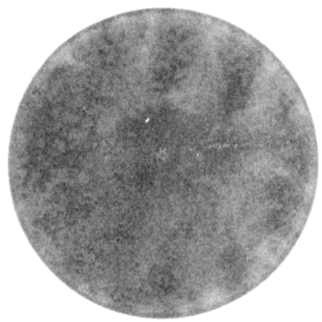


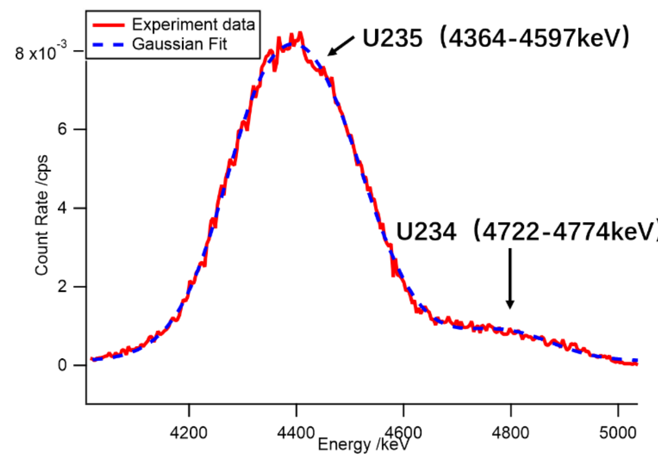
Gas composition	**Ar (90%)+CF_4(10%)**
Gas pressure	**800 mbar**
Electric field	**400 V/cm**
Gap between electrodes	**5 mm**
Electrode diameter	**100 mm**
Sample diameter	**50 mm**
Sample thickness	**150-300 μg/cm^2**
Backing thickness	**100 μm(Al) or 20 μm(Fe)**
Sample uniformity	**~5%**

Fission Samples

- Fissile material was electroplated on metal backing (Al or Stainless steel)
- Abundance: ^{235}U >99.98%), ^{238}U (>99.99%), ^{236}U (>99.9%), ^{232}Th (>99.9%)

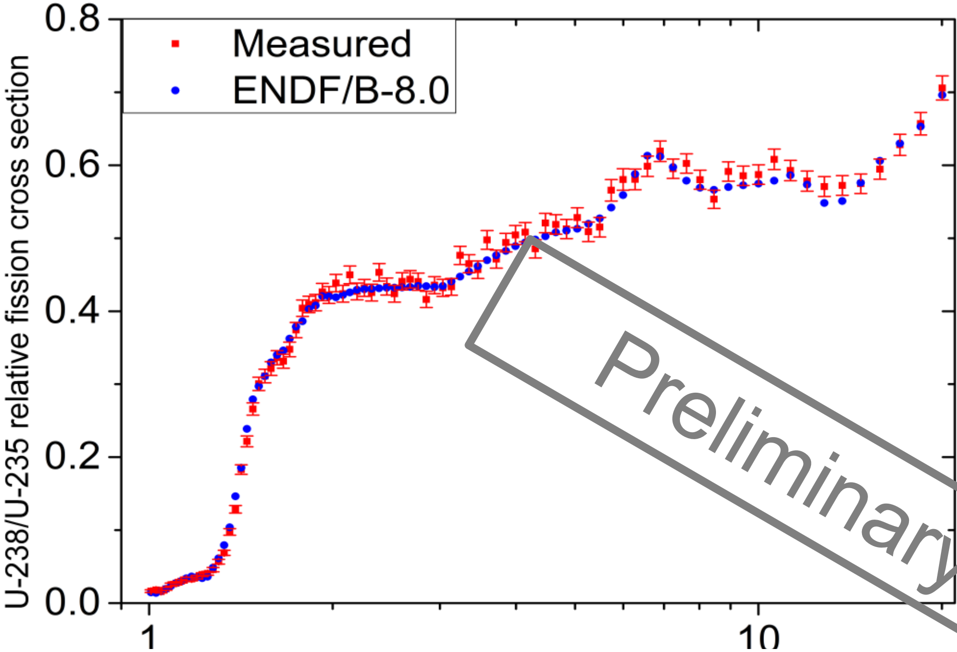


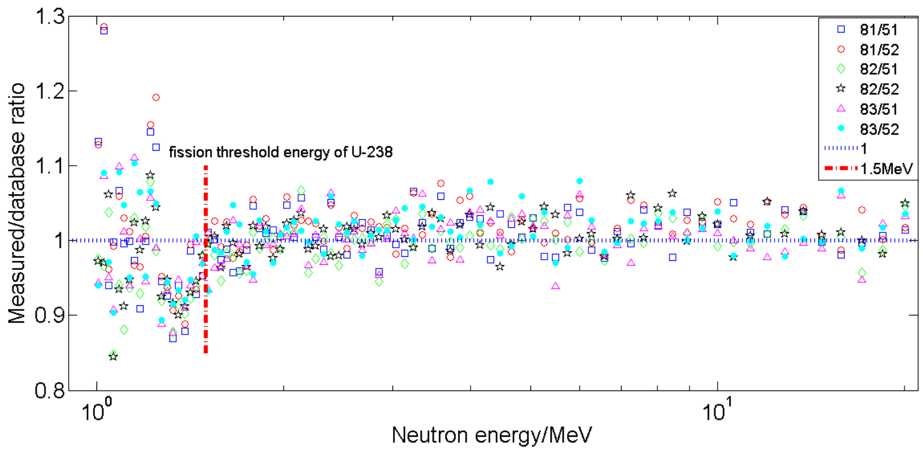




- Characterization:
  - Mass: small solid angle α-particle counting;
  - Uniformity: α-particle imaging plate;
  - Diameter: edge recognition of the α-particle image;

Cross-section ratio between U-238/235





- Cross-section ratio given by ENDF/B-VIII.0 is ~1.5% (in average) different from measurement
- The difference is less than 5% in effective energy range (1-20 MeV)
- The measurement uncertainty of the ratio is around 3%.
- **The FIXM did a good job!**
- The steep cross section and poor energy resolution in MeVs energy range led a worse result.

Thank you for your attention !