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

Progress of Neutron Reaction Data Measurement at CIAE

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CHINA NUCLEAR DATA CENTER

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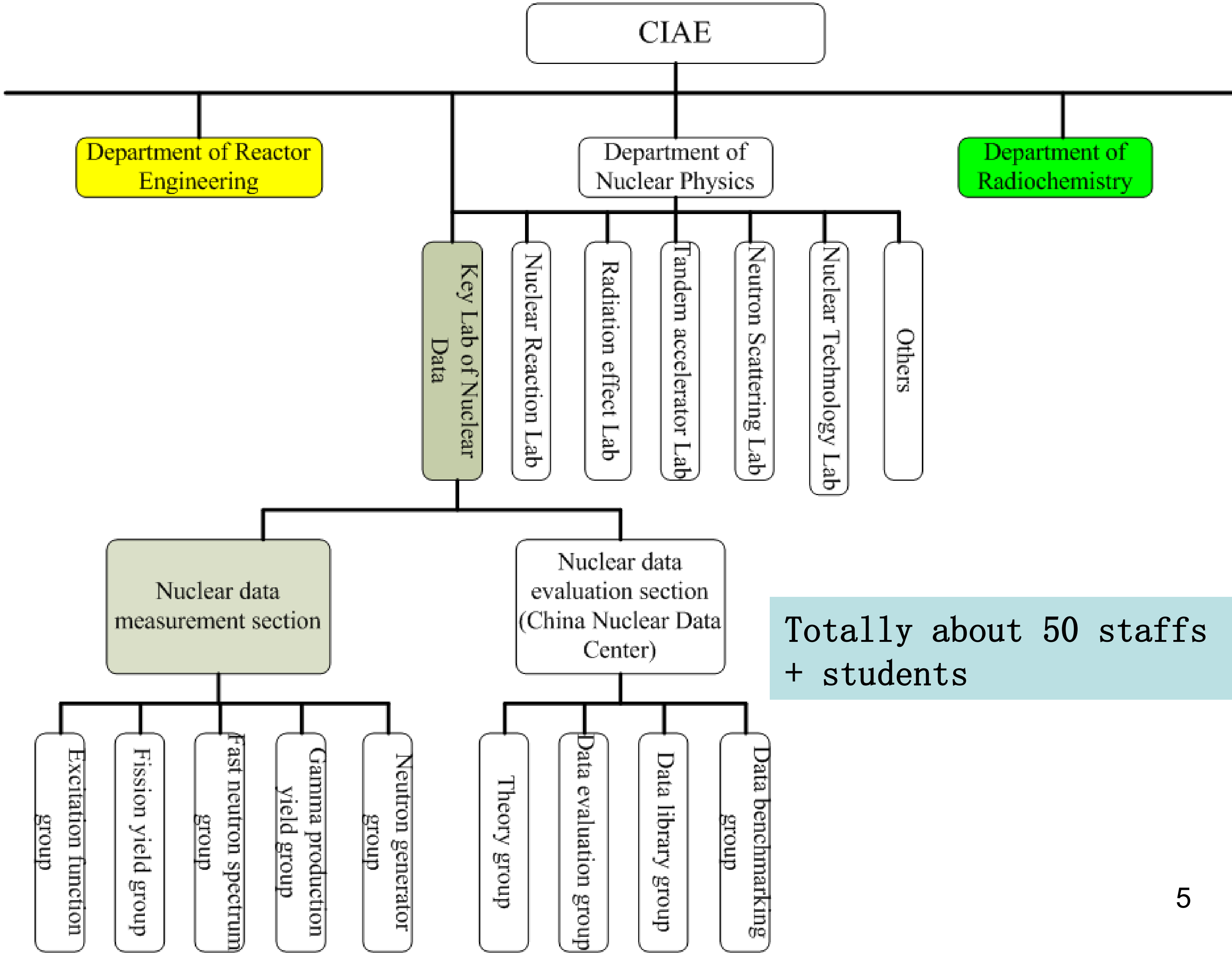
Introduction

Main purpose of ND production in China

- Nuclear energy system development
  - CIADS(Chinese Initiative Accelerator Driven System)
  - TMSR(Thorium Molten Salt Reactor)
  - Fusion reactor
  - Other new nuclear energy systems
- Nuclear science study
- Nuclear technology applications

Organization of ND lab at CIAE



Totally about 50 staffs + students

Neutron sources used for ND measurement at CIAE

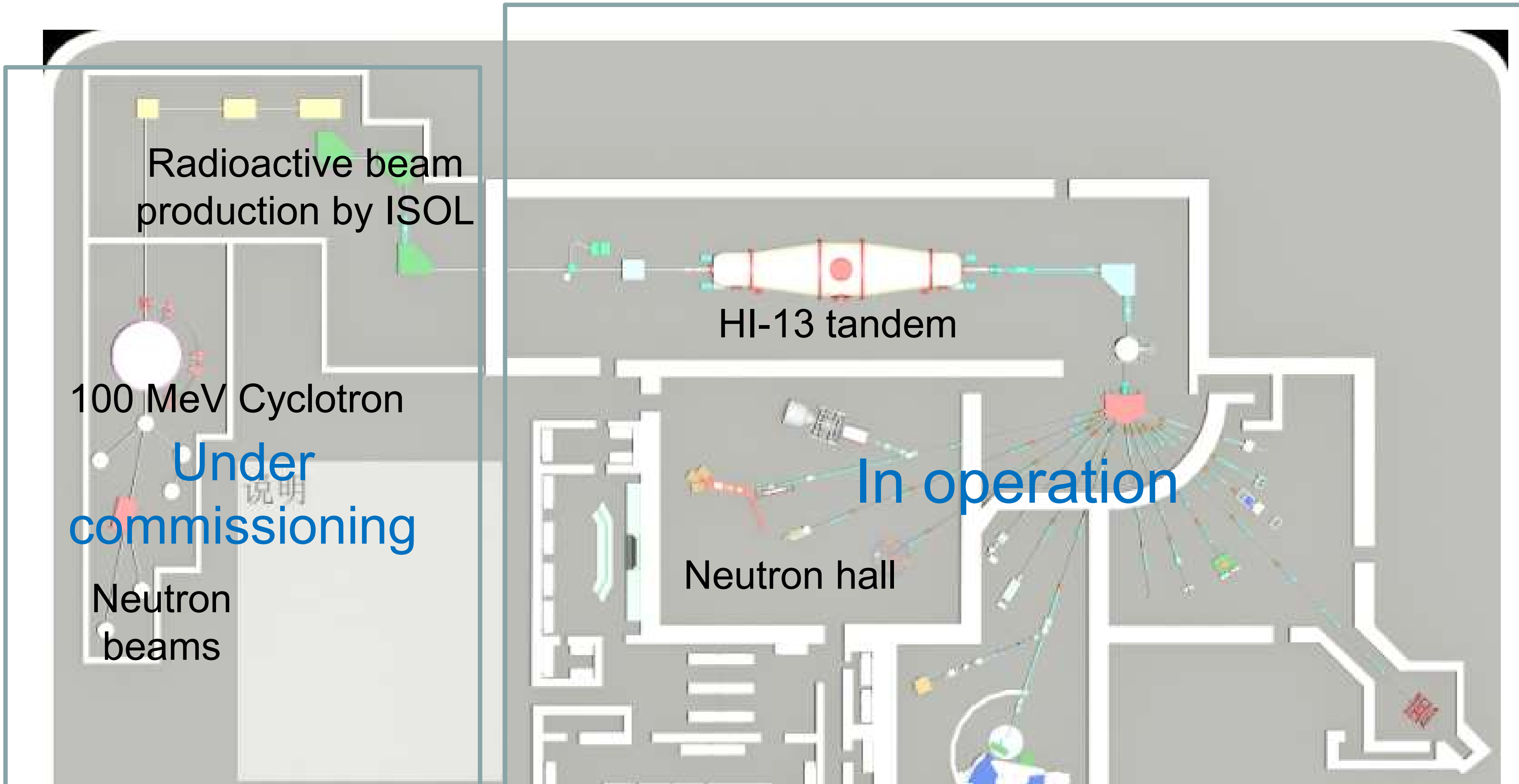
In operation:

1. **HI-13 2×13 MV tandem accelerator: 5-40 MeV (DC and pulsed)**
2. **Reactor: High flux thermal neutrons**
3. **Neutron generator: 14 MeV and 2.5 MeV (DC and pulsed)**
4. **2×1.7 MV tandem: 10 keV-5 MeV and 14-20 MeV (DC and pulsed)**
5. **China Spallation Neutron Source at IHEP (CSNS)**

Upcomming:

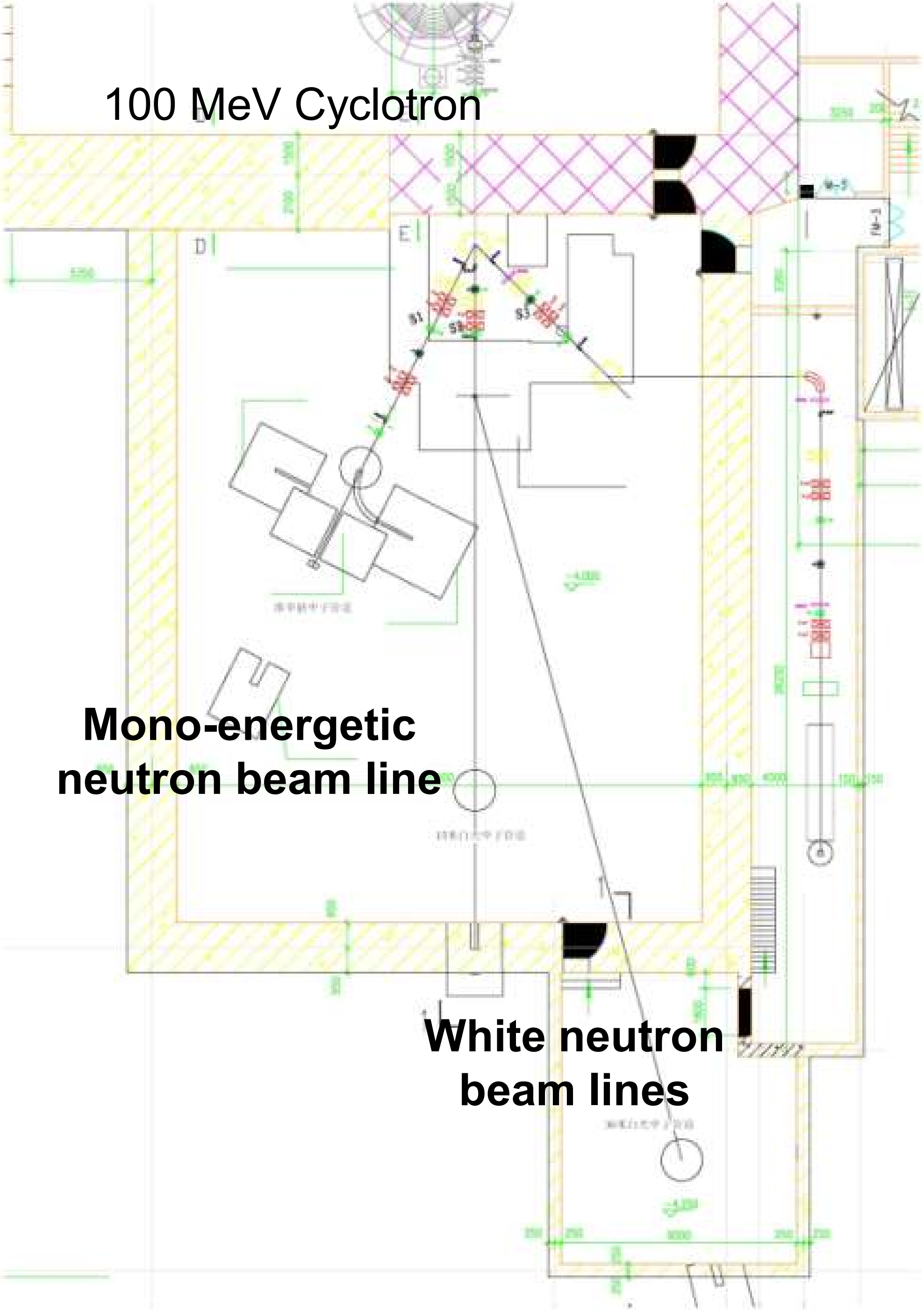
1. **100 MeV proton Cyclotron at CIAE**

HI-13 tandem accelerator



70-100 MeV (p+7Li)	10^{10} n/s/sr
WNS	10^{12} n/s/sr

8-26 MeV (d+D)	10^{8}
4-23 MeV (p+T)	10^{7} n/s/sr
22-42 MeV (d+T)	10^{6}



Three neutron beam lines designed:

1.Mono-energetic neutrons (70-100 MeV)

2.White neutrons with 15 and 30 meters FP.

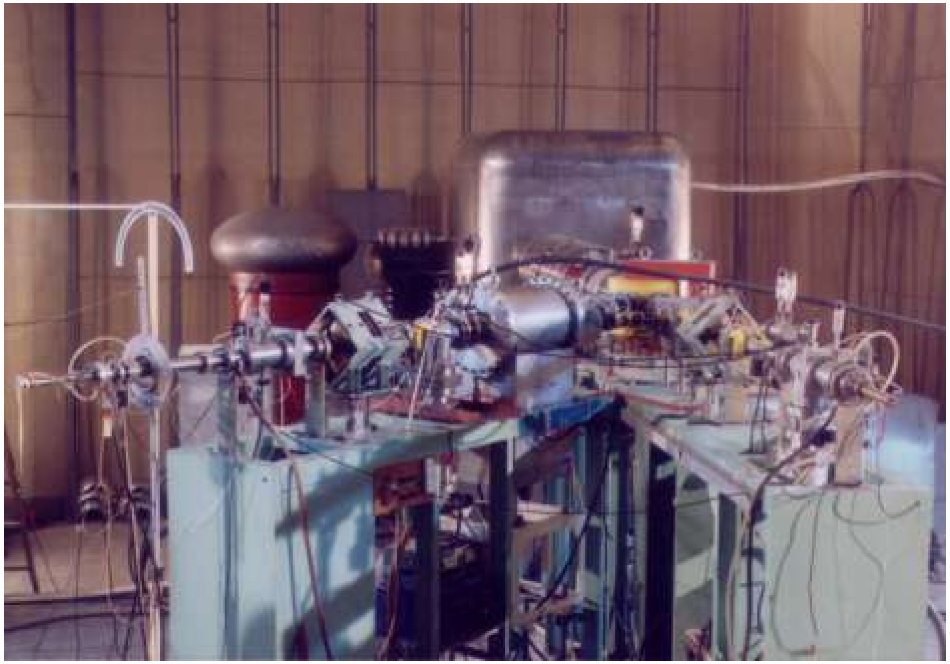
Various ND measurements are planed with these neutron beam lines

600 kV Cockcroft-Walton neutron generator

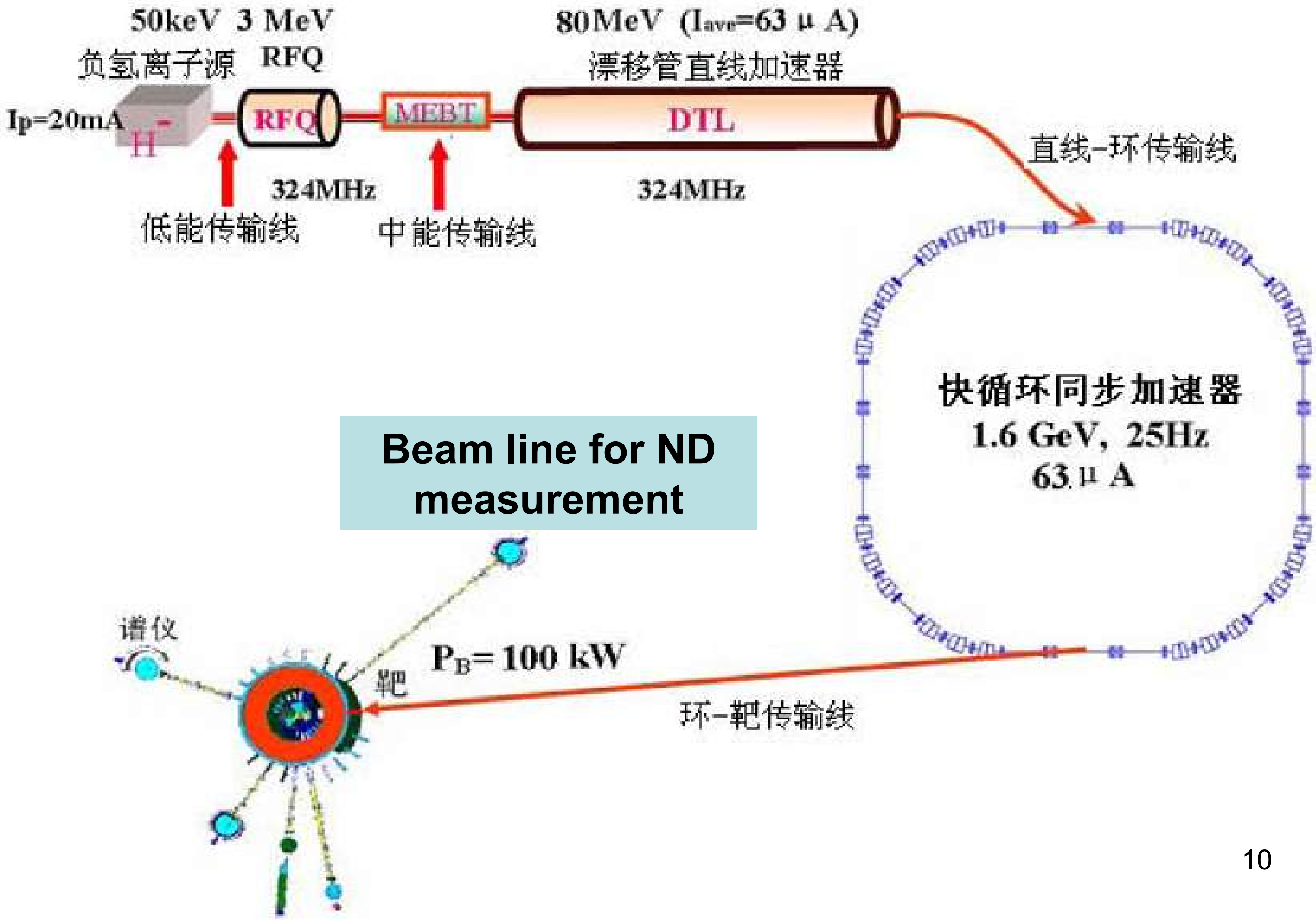
- Provide 14 and 2.5 MeV neutrons for ND measurement, detector calibration and other applications
- Provide 6.13 MeV gammas for detector calibration

- > 1000 hours beam time every year for different users

Ions	p and d	
Current	Maximum 1 mA (DC) ~30 μA (pulsed)	
Pulse width	~2 ns	
Neutron yield	10^{11} n/s for DC 10^{9} n/s for pulsed	14 MeV
	10^{9} n/s for DC 10^{8} n/s for pulsed	2.5 MeV



The back-streaming neutron beam of CSNS



Beam line for ND measurement

Summary of neutron sources for ND measurement

facility	energy	intensity (1/s/sr)
Reactors	thermal	10^{14} n/cm^2/s
HI-13	8-26 MeV (d+D) 4-23 MeV (p+T) 22-42 MeV (d+T)	10^8 [illegible]
2×1.7MV	3-6 MeV [illegible] [illegible] [illegible]) [illegible]eV (p+Li)	[illegible] 10^8 10^9 10^8
[illegible]	2.5, 14 MeV	10^8， 10^{10}
CSNS	0.5 eV-100 MeV	10^7 n/cm^2/s
Cyclotron	0.1-20 MeV	10^{12}

From thermal to hundred MeV, mono-energetic, quasi-monoenergetic, white neutron source

Spectrometers and recent progress of ND measurement

HPGe detector for gamma spectroscopy

- Well calibrated
- Excitation function measurement
- Fission yield measurement
- Decay data measurement

Excitation function (94 neutron reactions, 18 charged particle reactions)

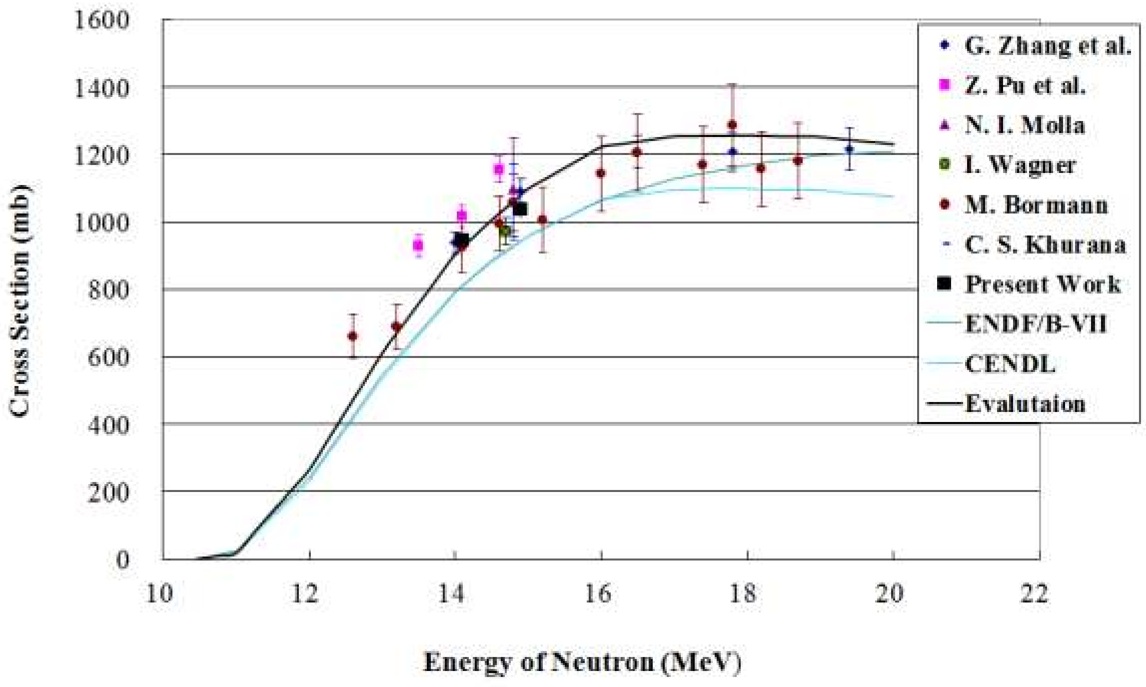
$^{23}Na(n,2n)^{22}Na$	$^{24}Mg(n,p)^{24}Na$	$^{27}Al(n, a)^{24}Na$	$^{45}Sc(n,2n)^{44g,}Sc$	$^{45}Sc(n,2n)^{44m}Sc$	$^{45}Sc(n,2n)^{44m+g}Sc$
$^{46}Ti(n,p)^{46}Sc$	$^{47}Ti(n,p)^{47}Sc$	$^{48}Ti(n,p)^{46}Sc$	$^{51}V(n,a)^{48}Sc$	$^{55}Mn(n,2n)^{54}Mn$	$^{54}Fe(n,p)^{54}Mn$
$^{54}Fe(n,a)^{51}Cr$	$^{56}Fe(n,p)^{55}Mn$	$^{59}Co(n,2n)^{58}Co$	$^{59}Co(n,p)^{59}Fe$	$^{59}Co(n,a)^{56}Mn$	$^{58}Ni(n,2n)^{57}Ni$
$^{58}Ni(n,p)^{58}Co$	$^{58}Ni(n,x)^{57}Co$	$^{60}Ni(n,p)^{60}Co$	$^{62}Ni(n,a)^{59}Co$	$^{62}Ni(n, a)^{59}Fe$	$^{63}Cu(n,a)^{60}Co$
$^{66}Zn(n,2n)^{65}Zn$	$^{67}Zn(n,p)^{67}Cu$	$^{70}Zn(n,2n)^{69m}Zn$	$^{71}Ga(n,r)^{72}Ga$	$^{85}Rb(n,2n)^{84m}Rb$	$^{85}Rb(n,2n)^{84m+g}Rb$
$^{85}Rb(n,p)^{85m}Kr$	$^{85}Rb(n, a)^{82}Br$	$^{87}Rb(n,2n)^{86}Rb$	$^{87}Rb(n,p)^{87}Kr$	$^{89}Y(n,2n)^{88}Y$	$^{90}Zr(n,2n)^{89}Zr$
$^{89}Zr(n,2n)^{88}Zr$	$^{96}Zr(n,2n)^{95}Zr$	$^{92}Mo(n,p)^{92}Nb$	$^{98}Mo(n,r)^{99}Mo$	$^{93}Nb(n,2n)^{92m}Nb$	$^{93}Nb(n,a)^{90m}$ Y
$^{109}Ag(n,2n)^{108m}Ag$	$^{113}In(n,2n)^{112m}In$	$^{113}In(n,n')^{113m}In$	$^{115}In(n,2n)^{114m}In$	$^{115}In(n,n')^{115m}In$	$^{115}In(n,r)^{116m}In$
$^{115}In(n,p)^{115}Cd$	$^{115}In(n,a)^{112}Ag$	$^{127}I(n,2n)^{126}I$	$^{124}Xe(n,2n)^{123}Xe$	$^{132}Ba(n,2n)^{131}Ba$	$^{134}Ba(n,2n)^{133m}Ba$
$^{134}Ba(n,2n)1^{33m+g}Ba$	$^{134}Ba(n,p)^{134m+g}Cs$	$^{134}Ba(n,a)^{131m}Xe$	$^{137}Ba(n,p)^{137}Cs$	$^{136}Ba(n,p)^{136}Cs$	$^{138}Ba(n,a)^{135}Xe$
$^{136}Ce(n,2n)^{135}Ce$	$^{138}Ce(n,2n)^{137m}Ce$	$^{140}Ce(n,2n)^{139}Ce$	$^{140}Ce(n,p)^{140}La$	$^{142}Ce(n,2n)^{141}Ce$	$^{151}Eu(n,2n)^{150m}Eu$
$^{151}Eu(n,r)^{152m}Eu$	$^{151}Eu(n,r)^{152g}Eu$	$^{153}Eu(n,2n)^{152g}Eu$	$^{153}Eu(n,r)^{154}Eu$	$^{159}Tb(n,2n)^{158}Tb$	$^{159}Tb(n,r)^{160}Tb$
$^{165}Ho(n,r)^{166m}Ho$	$^{169}Tm(n,2n)^{168m}Tm$	$^{169}Tm(n,3n)^{167}Tm$	$^{169}Tm(n,r)^{170}Tm$	$^{175}Lu(n,2n)^{174m+g}Lu$	$^{176}Hf(n,2n)^{175}Hf$
$^{180}Hf(n,r)^{181}Hf$	$^{179}Hf(n,2n)^{178m2}Hf$	$^{180}Hf(n,2n)^{179m2}Hf$	$^{181}Ta(n,2n)^{180m}Ta$	$^{181}Ta(n,p)^{181}Hf$	$^{182}W(n,n'a)^{178m2}Hf$
$^{185}Re(n,2n)^{184m}Re$	$^{185}Re(n,2n)^{184m+g}Re$	$^{187}Re(n,2n)^{186g}Re$	$^{187}Re(n,2n)^{186m}Re$	$^{193}Ir(n,2n)^{192m2}Ir$	$Pt(n,x)^{195m}Pt$
$^{198}Pt(n,2n)^{197}Pt$	$^{197}Au(n.2n)^{196}Au$	$^{197}Au(n,3n)^{195}Au$	$^{204}Pb(n,2n)^{203}Pb$		

$^{51}V(d,2n)^{51}Cr$	$^{89}Y(p,n)^{89}Zr$	$^{89}Y(p,2n)^{88}Zr$	$^{89}Y(p,pn)^{88}Y$	$^{51}V(p,n)^{51}Cr$	$Fe(p,x)^{57}Co$
$Fe(p,x)^{54}Mn$	$Fe(p,x)^{55}Co$	$Fe(p,x)^{56}Co$	$^{27}Al(d,pa)^{24}Na$	$Ti(p,x)^{48}V$	$Ti(d,x)^{48}V$
$Mo(p,x)^{95m,g}Tc$	$Mo(p,x)^{96g}Tc$	$Mo(p,x)^{99}Mo$	$Mo(d,x)^{95m,g}Tc$	$Mo(d,x)^{96g}Tc$	$Mo(d,x)^{99}Mo$

Excitation function measurement

1. 69Ga(n,2n)68Ga cross section measurement

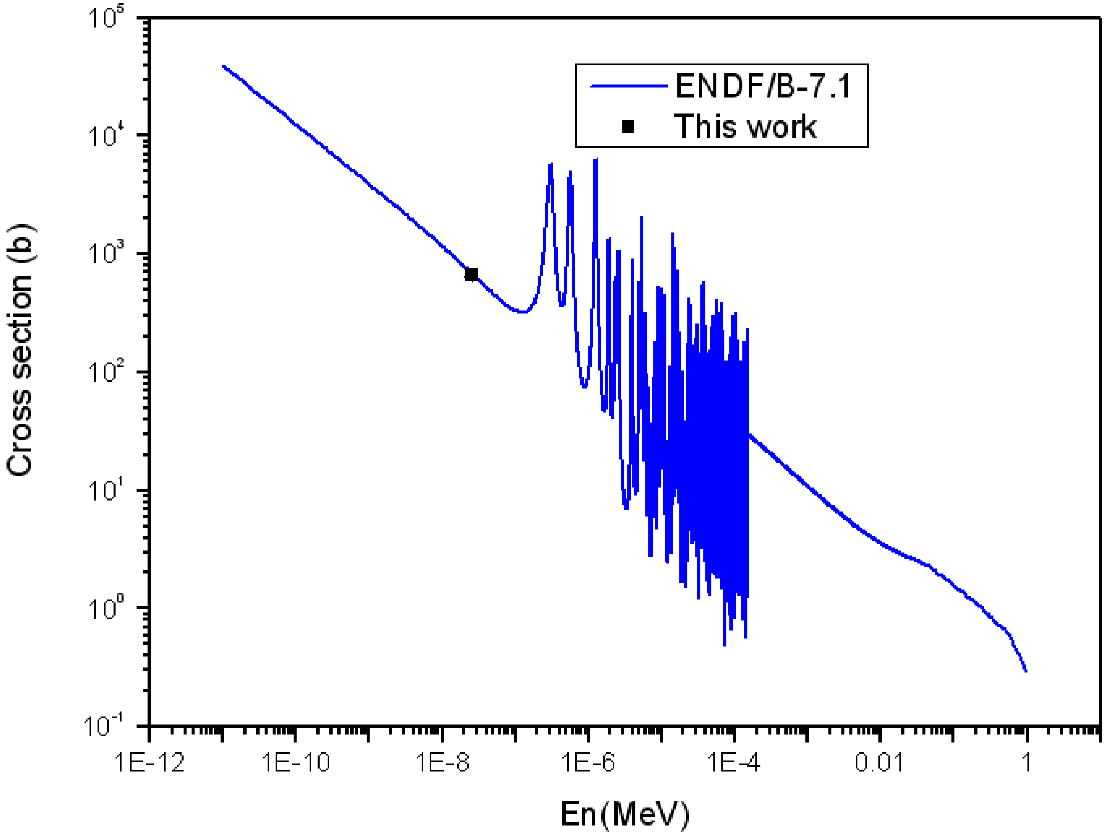
Method: activation
Neutron source: d-T reaction, 14.1 and 14.9 MeV
Measurement: HPGe detector
Findings: the 511 keV gammas can't be used, the branching ratio of 68Ga decay should be re-evaluated
Evaluation: New evaluation has been proposed



Excitation function measurement

2. ^{241}Am(n,g)^{242g}Am cross section measurement

Method: activation
Neutron source: 49-2 reactor at CIAE, 5×10^{10} n/cm^2/s
Measurement: Si-Au detector
Result: Preliminary result obtained



Fission yields

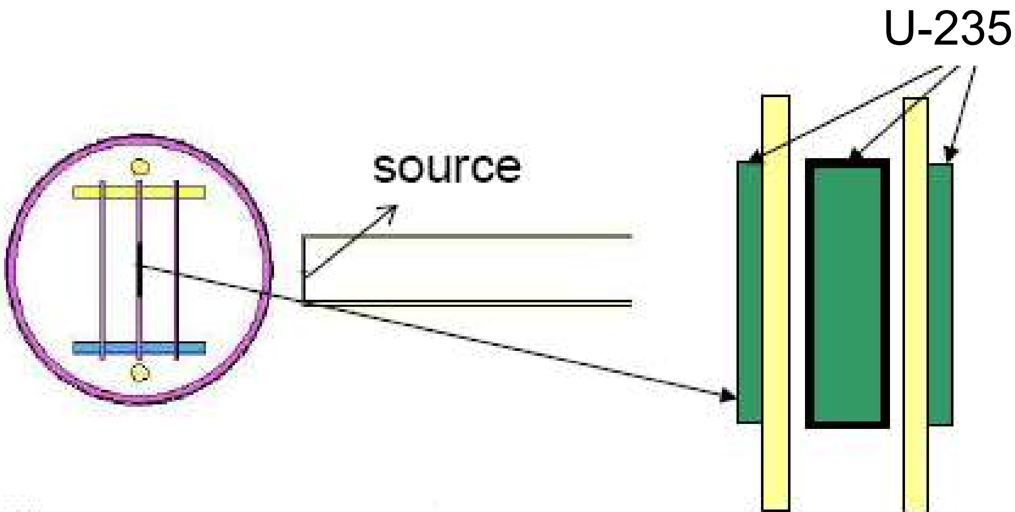
Nuclei	En	FY	Method
U-238	Fission spectrum, 3, 5, 8, 14MeV	^{95}Zr, ^{99}Mo, ^{140}Ba, ^{147}Nd etc.	RC, γ
U-235	Thermal, 0.5, 1, 1.5, 3, 5, 8, 14MeV	^{95}Zr, ^{99}Mo, ^{140}Ba, ^{147}Nd etc.	Γ
U-235、238	Thermal, 3, 14MeV	^{85m,87,88}Kr, ^{135,138}Xe etc. (gas yield)	γ
Th-232	14 MeV	^{95}Zr, ^{99}Mo, ^{140}Ba, ^{147}Nd etc.	γ
U-235,Pu-239	Thermal	^{95}Y, ^{138}Cs, ^{101}Mo, ^{142}La etc. (short life nuclei)	RC, γ

Decay data

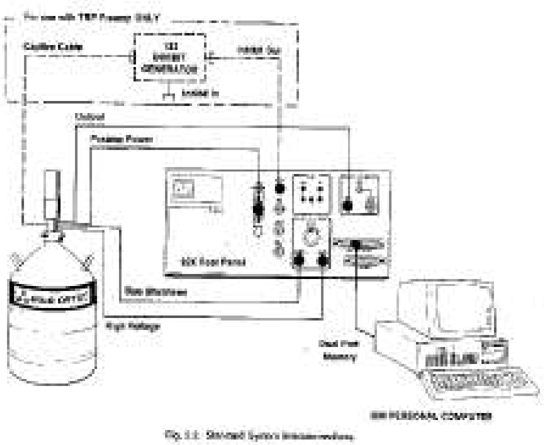
Measurement and evaluation of branching ratio of ^{56}Co, ^{66}Ga. The uncertainty was reduced from 2％(^{56}Co) and 3％ (^{66}Ga) to 1％ and 1.3％.

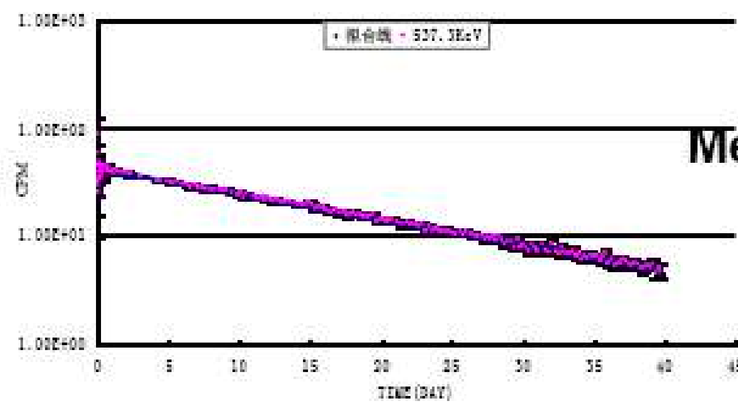
Fission yields measurement

The fission yields of ^{235}U at 3 MeV, 14 MeV and ^{252}Cf spontaneous fission neutrons, ^{232}Th at 14 MeV neutrons were measured.



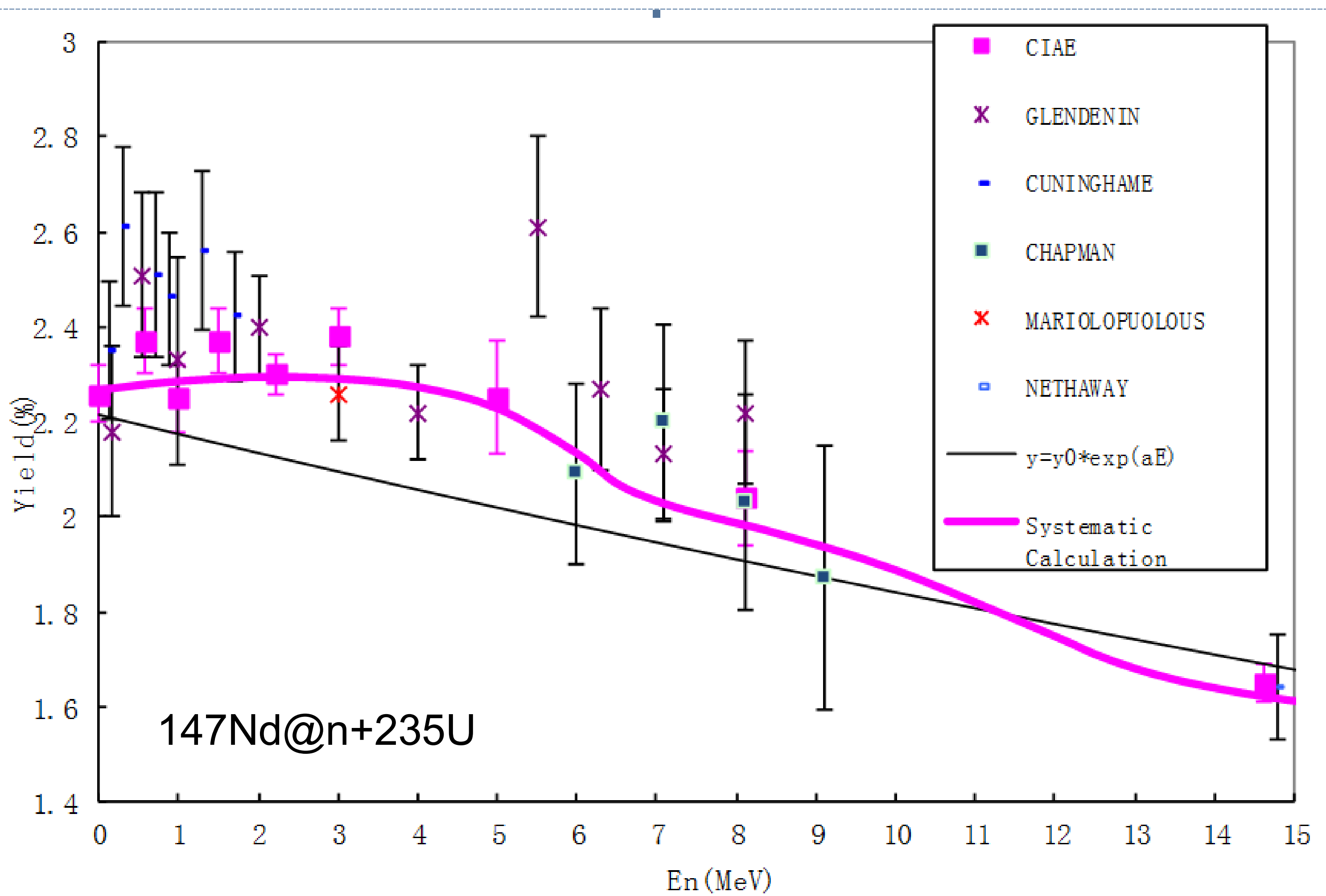
Sample irradiation



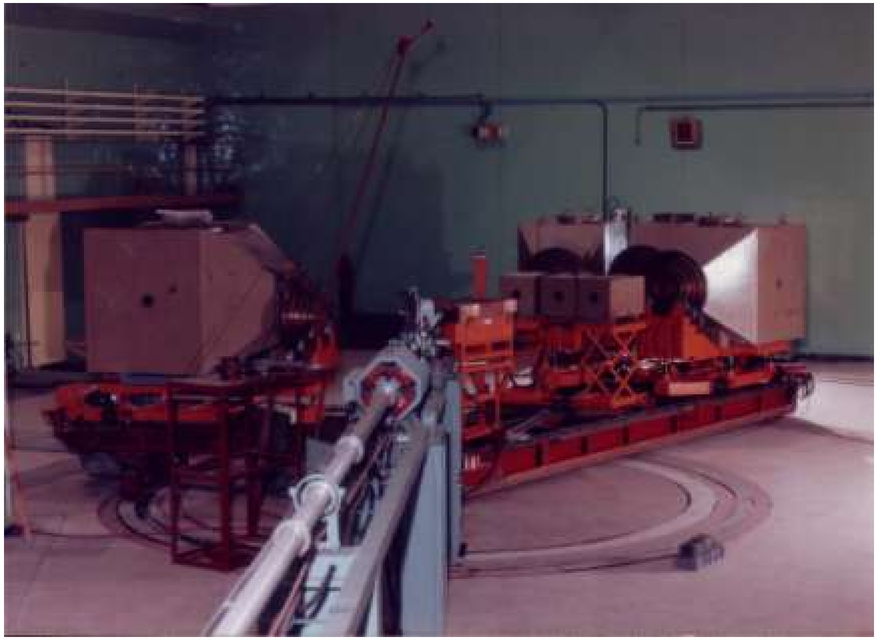


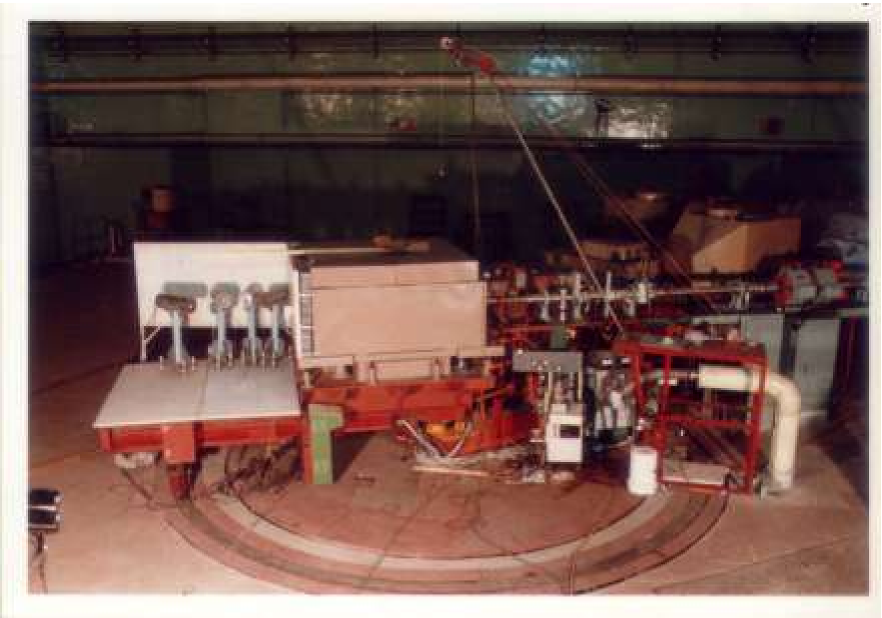
Measurement

Combined with our previous measurements, the energy dependent fission yields were studied with a systematic method.
The fission yields for some products deviate from a linear function more than 10%.



Fast neutron Time-of-Flight spectrometers (HI-13 Tandem)



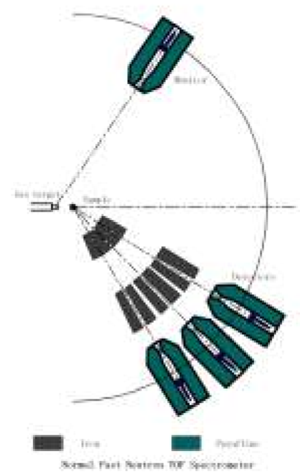


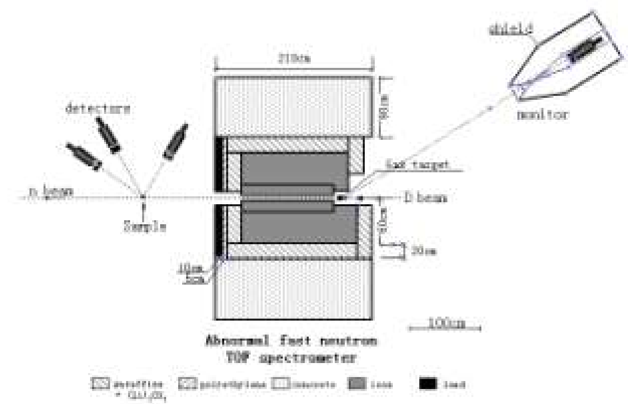
- Composed of Normal and Abnormal fast neutron TOF spectrometers
- Mainly for fast neutron spectrum measurement, ND measurement(DX and DDX), basic science research, detector calibration and other applications
- Combined with the 5-40 MeV neutrons produced by the HI-13 Tandem accelerator.

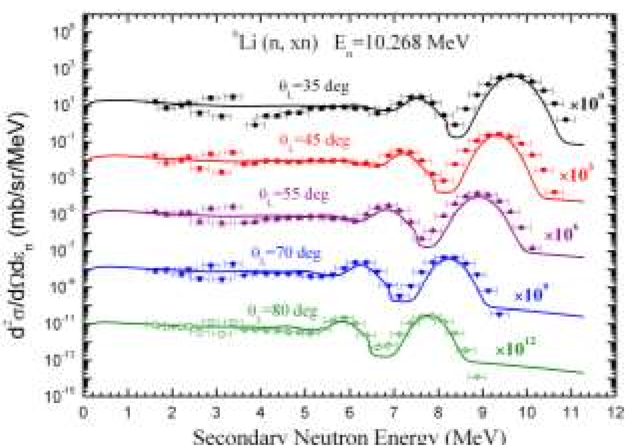
Secondary neutron DX and DDX measurement

With the Normal and Abnormal fast neutron TOF spectrometer and the deuterium and tritium gas target. Many of the secondary neutron DX and DDX data were measured.

En	Samples
14 MeV	C、^{238}U、D、^{209}Bi、^{6,7}Li、Zr、Al
6 MeV	Be
8 MeV	^{6,7}Li、Fe、Be、D
10 MeV	^{6,7}Li、Be、V、^{238}U、^{209}Bi、Fe、C
20-40	Be、C、^{209}Bi



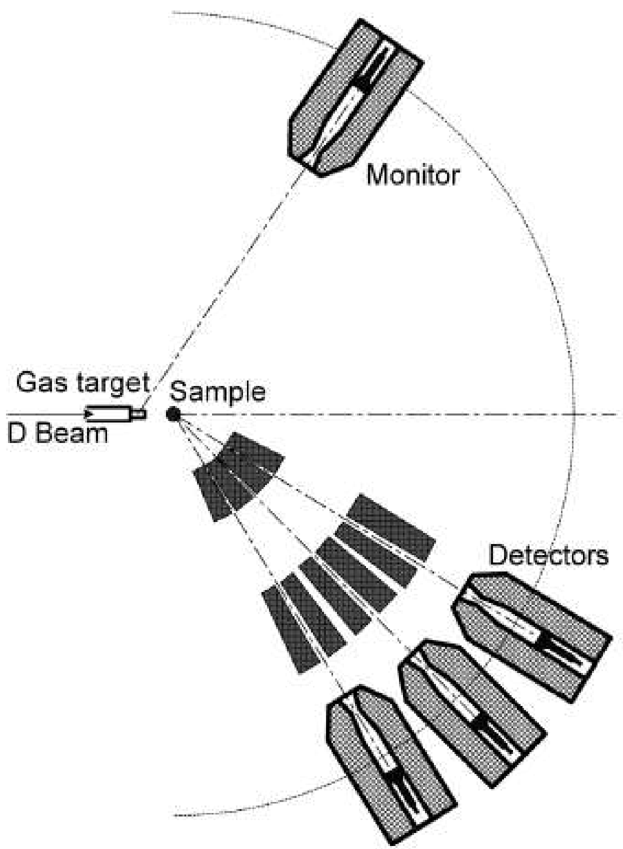




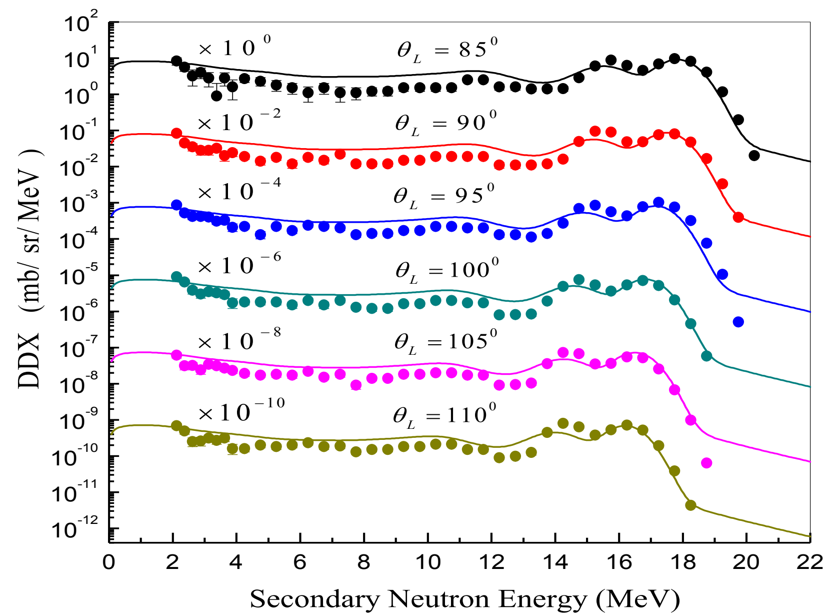
The abnormal TOF spectrometer was used to eliminate the influence from the breakup source neutrons between 8 and 14 MeV

Secondary neutron DX and DDX measurement

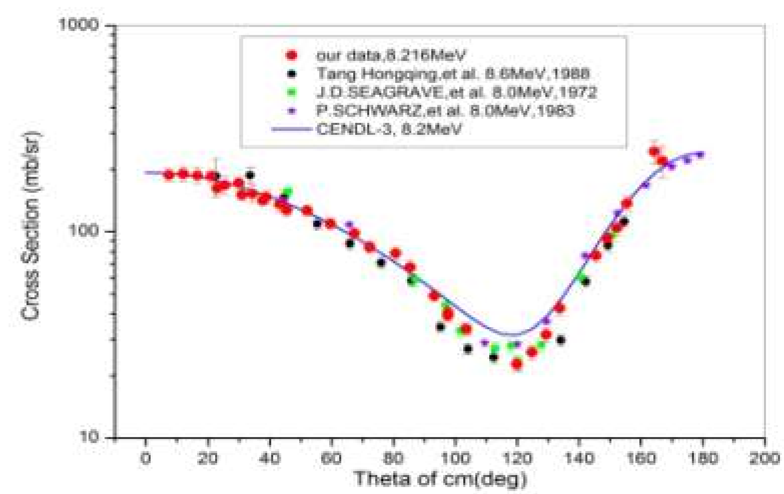
^{9}Be at 22 and 25 MeV
D at 8.2 MeV have been finished



The TOF spectrometer



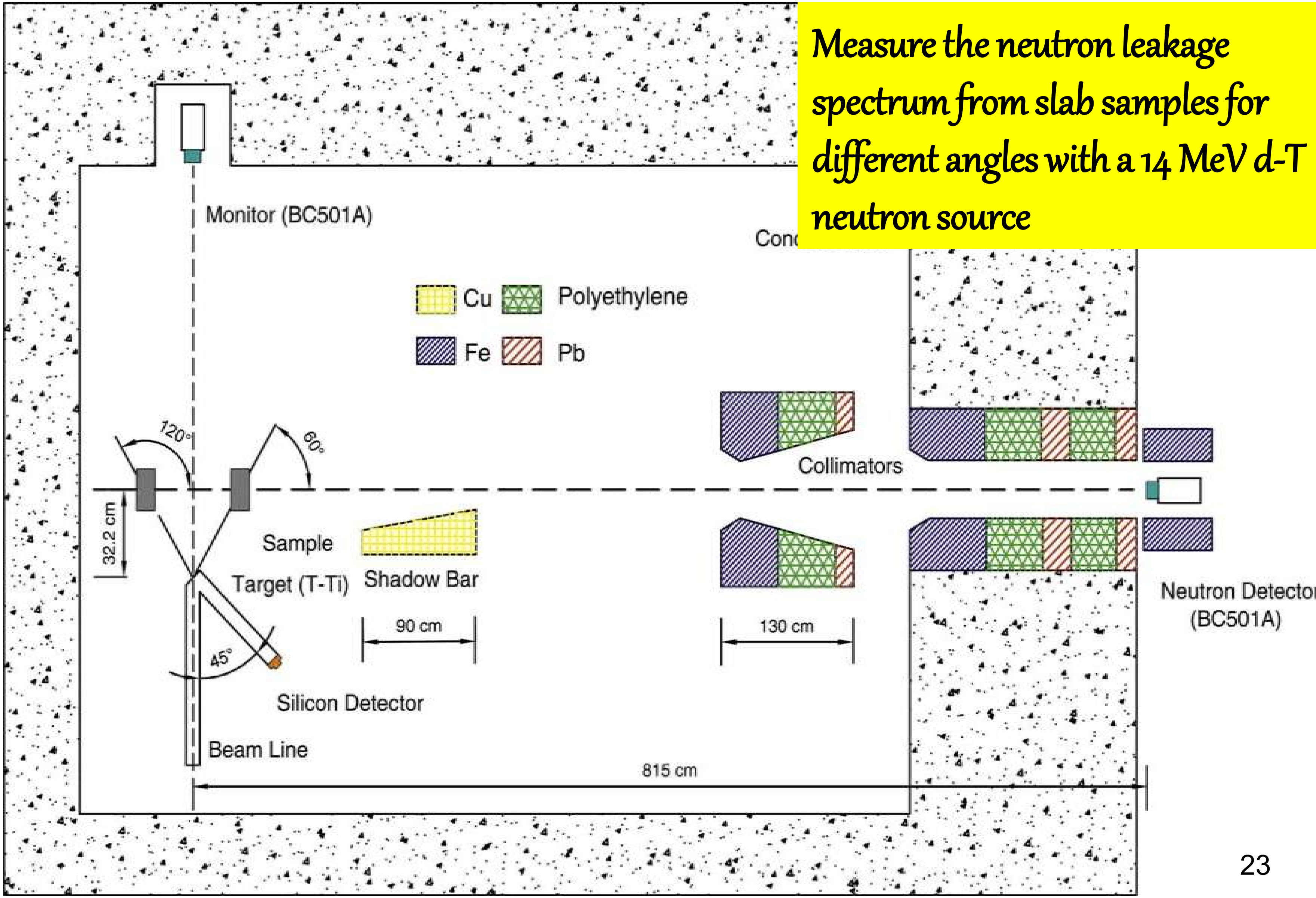
DDX for Be at 22 MeV

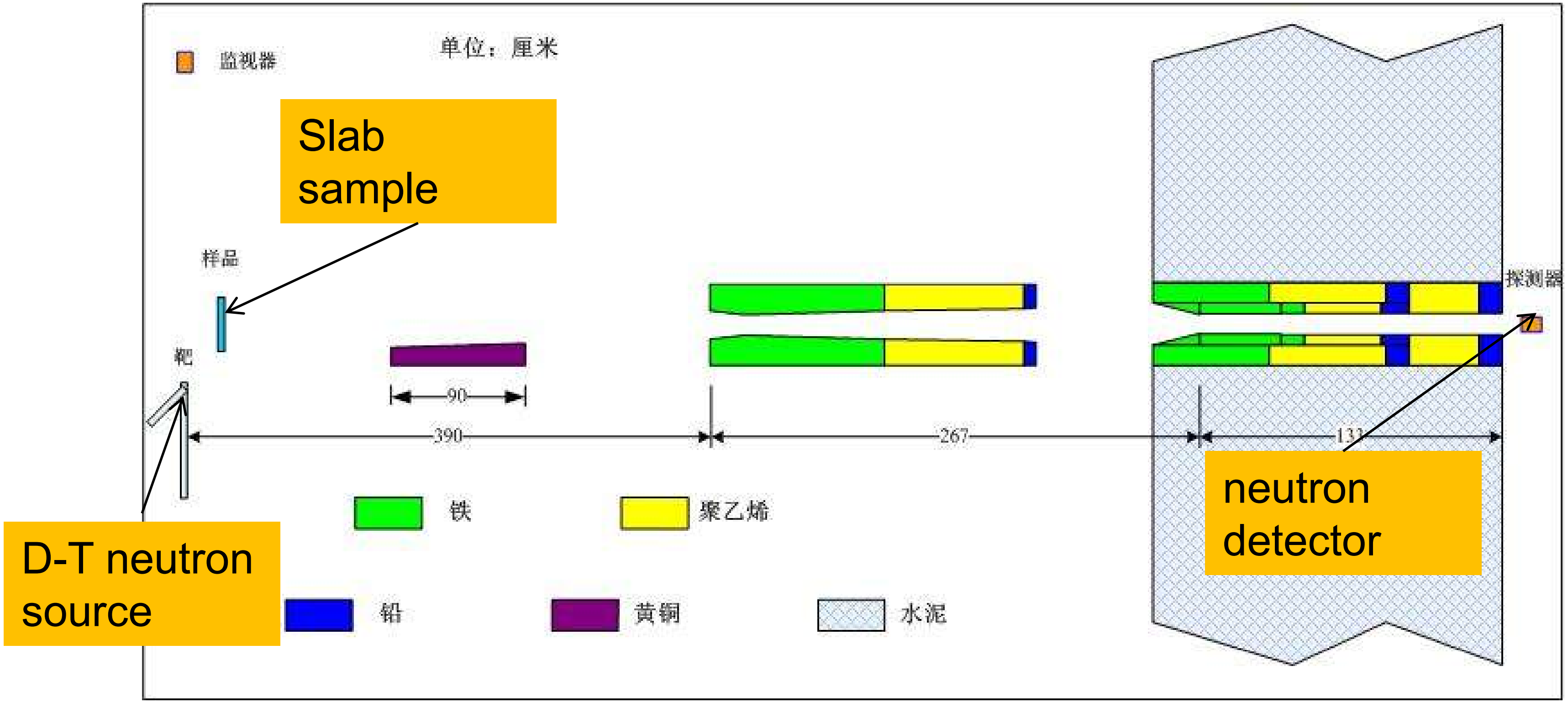


DX for D at 8.2 MeV

Nuclear data benchmark experimental setup at CIAE

Measure the neutron leakage spectrum from slab samples for different angles with a 14 MeV d-T neutron source





The collimator system

List of measured samples

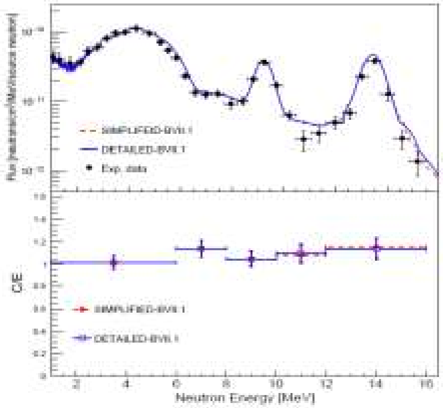
Sample	Sample size/cm	Sample thickness/cm	Angle/°	Institute
^{238}U	10×10	5	45、135	CIAE
Be	10×10	5、11	60、120	
^{nat}Fe	10×10	5、10	60、120	
Nb	10×10	5、10	60、120	
H_2O	Φ13	5.2	60	
PE	Φ13 10×10	6 5	60 45	
Pb	Φ13	5	60	CIAE-INEST
Pb-Bi	Φ13	5	60	
ThO_2	Φ13	5.4、10.8	60、120	CIAE-SINAP

Collaboration between CIAE-IMP for ADS purpose

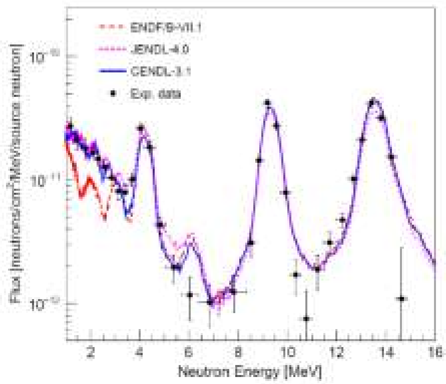
sample	dimension	Angle
Polyethylene	10cm*10cm*5cm	60
Gallium	10cm*10cm*5cm, 10cm*10cm*10cm, Ø13cm*3.2cm, Ø13cm*6.4cm	60,120
Tungsten(block)	10cm×10cm×3.6cm, 10cm×10cm×7.2cm	60,120
Tungsten(Granular)	9.8*9.9*7.2cm，（granular diameter:1mm）	60
Graphite	Φ13*2cm, Φ13*20cm	60,120
SiC	Φ13*2cm, Φ13*20cm	60,120
238U	10cm*10cm*2cm,	60
238U	10cm*10cm*5cm, 10cm*10cm*11cm	60, 120
W+U	W:10cm*10cm*3.5cm , U: 10cm*10cm*2cm	60
W+U+C	W:10cm*10cm*3.5cm, U: 10cm*10cm*2cm C: 10cm*10cm*2cm	60
W+U+C+CH2	W:10cm*10cm*3.5cm , U: 10cm*10cm*2cm C: 10cm*10cm*2cm, CH2: 10cm*10cm*2cm	60
U+C	U: 10cm*10cm*5cm , C: 10cm*10cm*10cm	60
U+C+CH2	U: 10cm*10cm*5cm , C: 10cm*10cm*10cm CH2: 10cm*10cm*10 cm	60

14MeV n + Polyethylene, Graphite, SiC

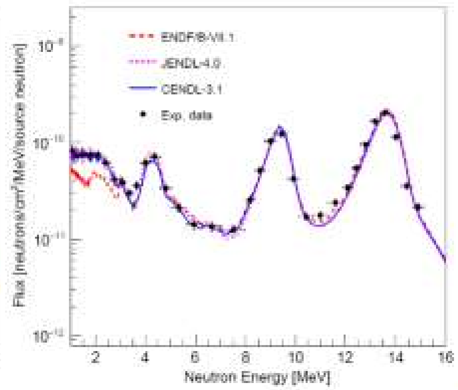
Polyethylene: 60°



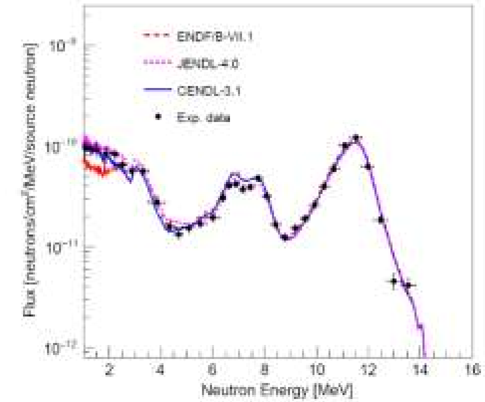
Graphite: 2cm, 60°



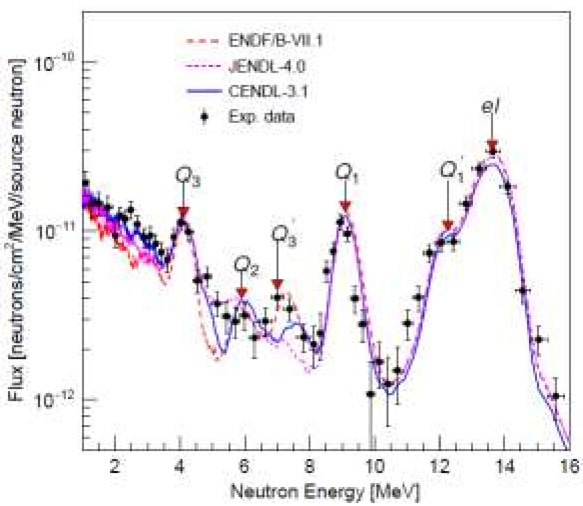
Graphite:20cm, 60°



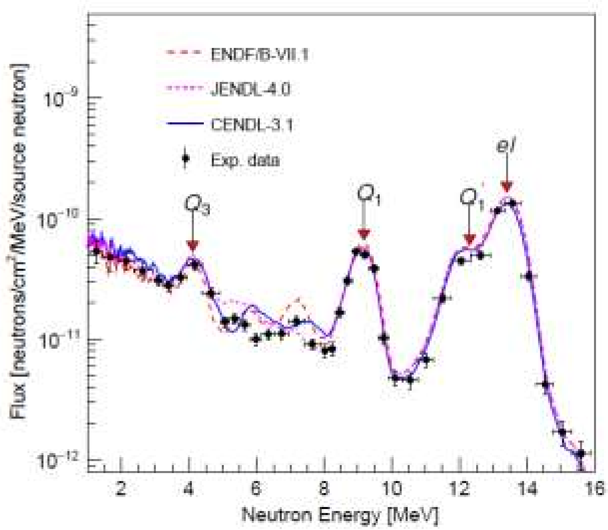
Graphite: 20cm,120°



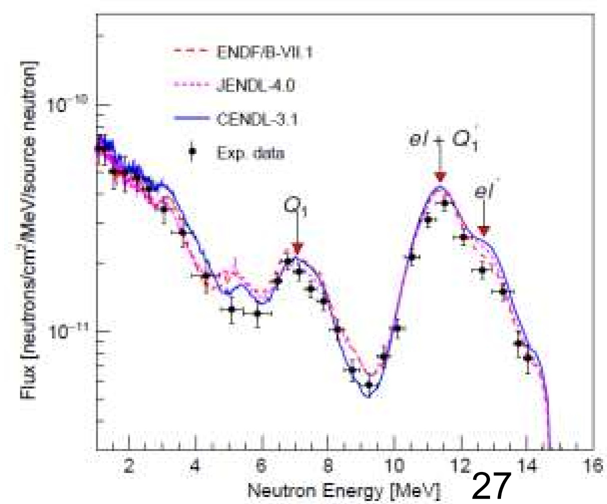
SiC: 2cm, 60°



SiC: 20cm, 60°



SiC: 20cm, 120°

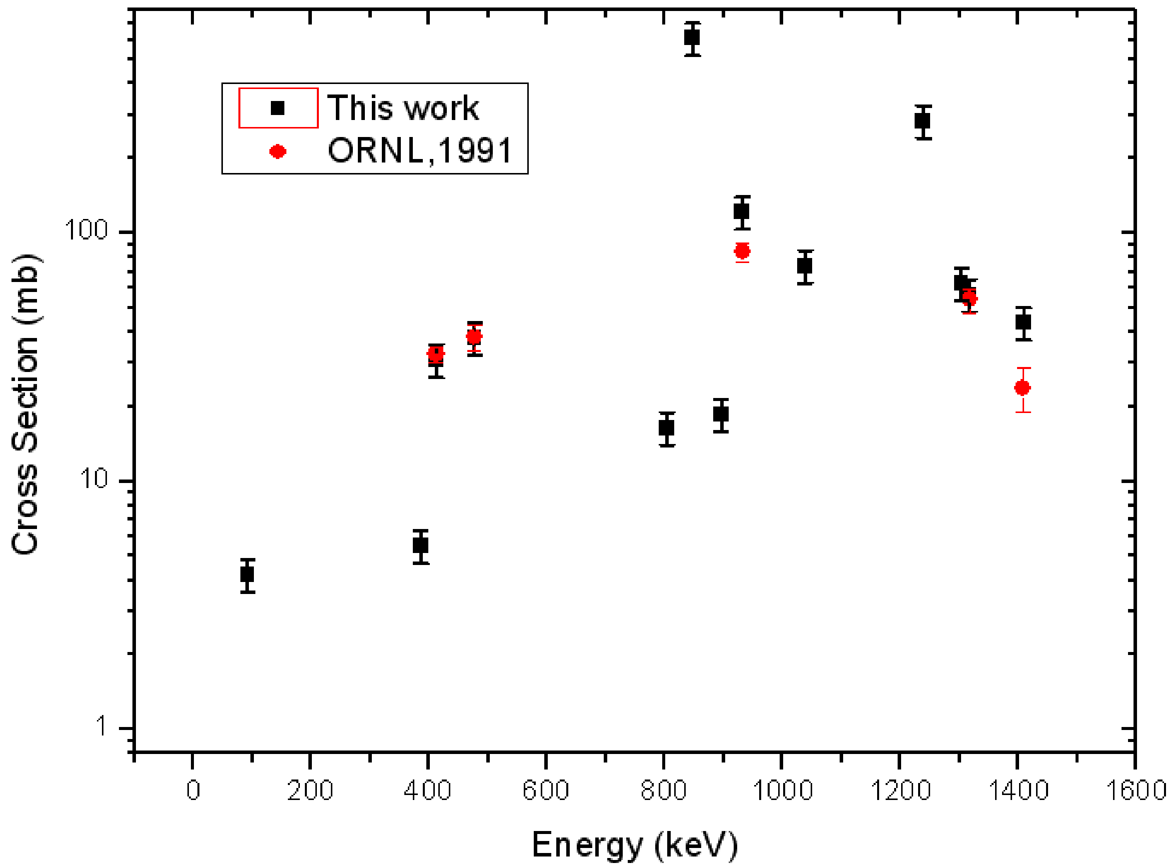


HPGe detector array for high resolution gamma spectroscopy

- 6 Clover and 6 HPGe detectors
- Mainly used for (n, 2nγ) and (n, n'γ) measurement

Gamma production CS measurement

$^{nat}Fe(n,n'\gamma)$ and $^{235,238}U(n,2n\gamma)$ have been carried out

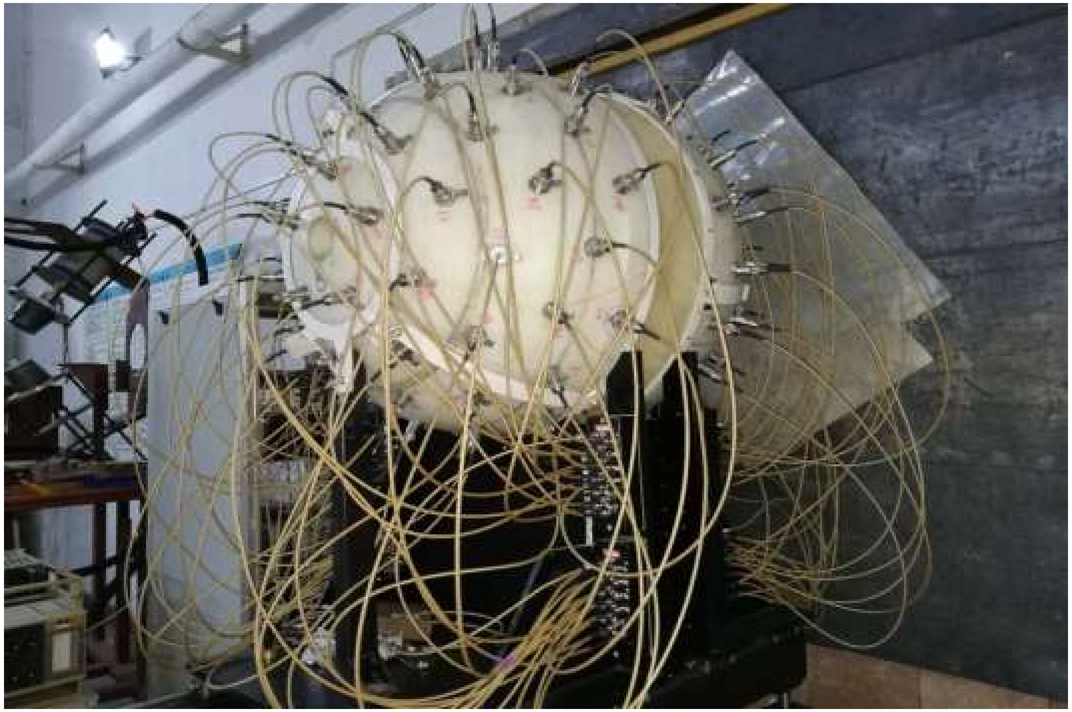


The measured results for $^{56}Fe(n,n'\gamma)$

(n,2n) measurement with HeSAN

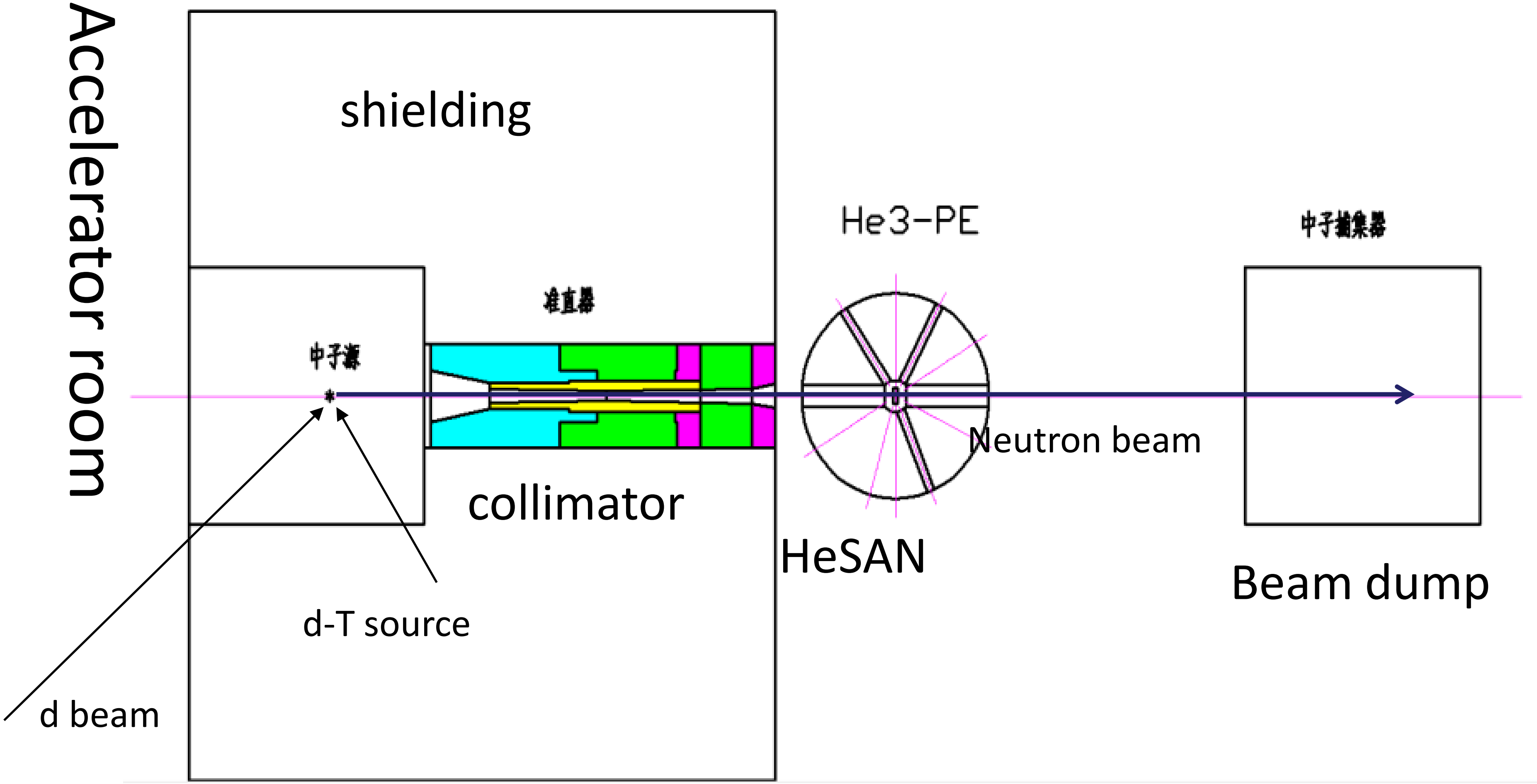
HeSAN (氦-3): He-3 SphericAl Neutron Detector Array

110 He-3 counters uniformly distributed in a spherical PE moderator

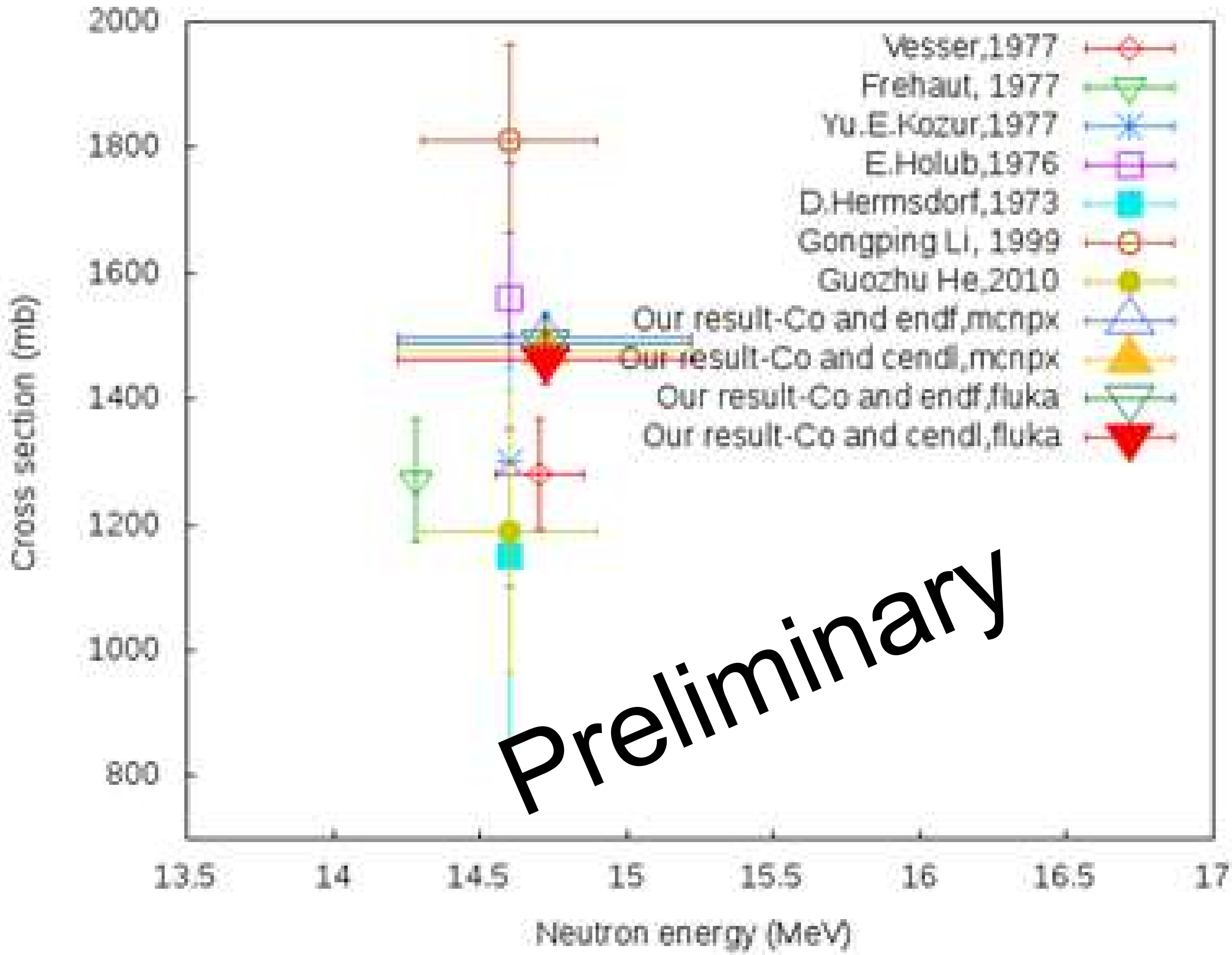


- Insensitive to gamma rays
- Detection efficiency acceptable (~33% for 252Cf source)
- Spherical design makes the efficiency more independent on energy

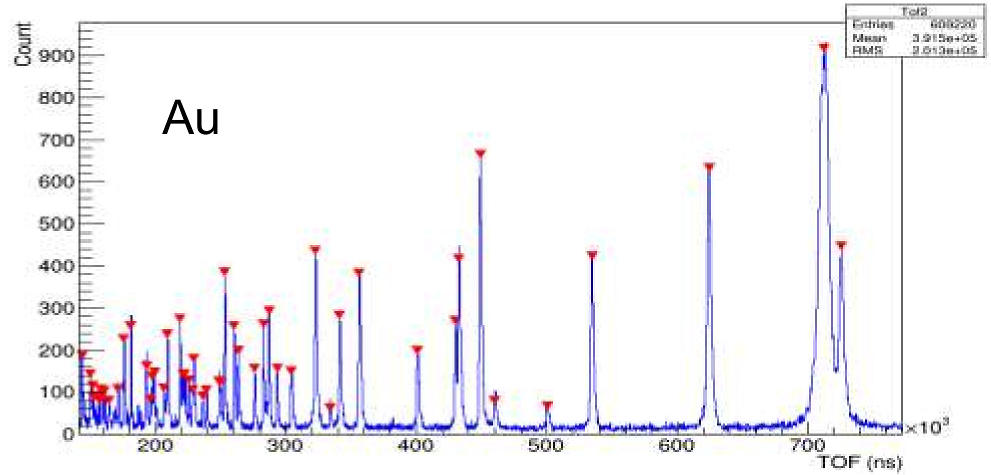
Experimental setup:

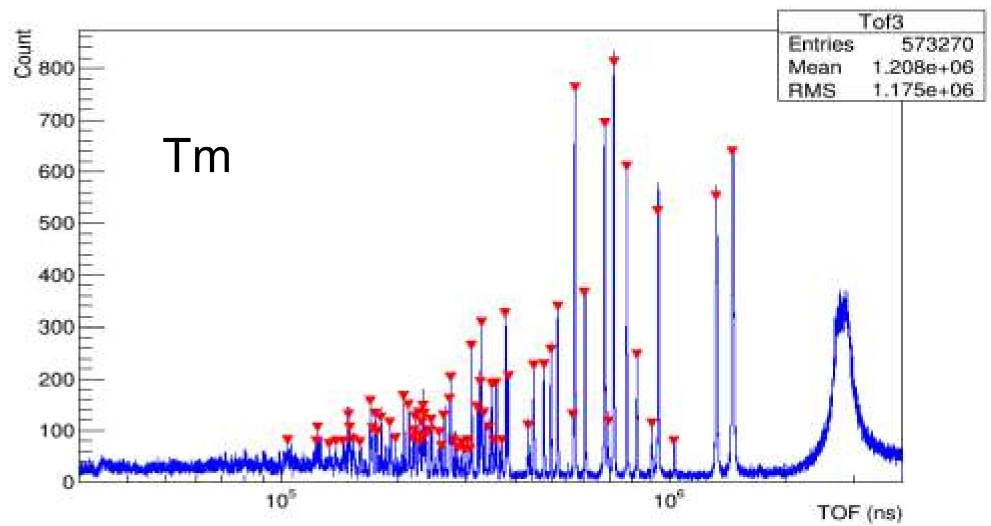


First measurement on 93Nb(n,2n) shows HeSAN work well



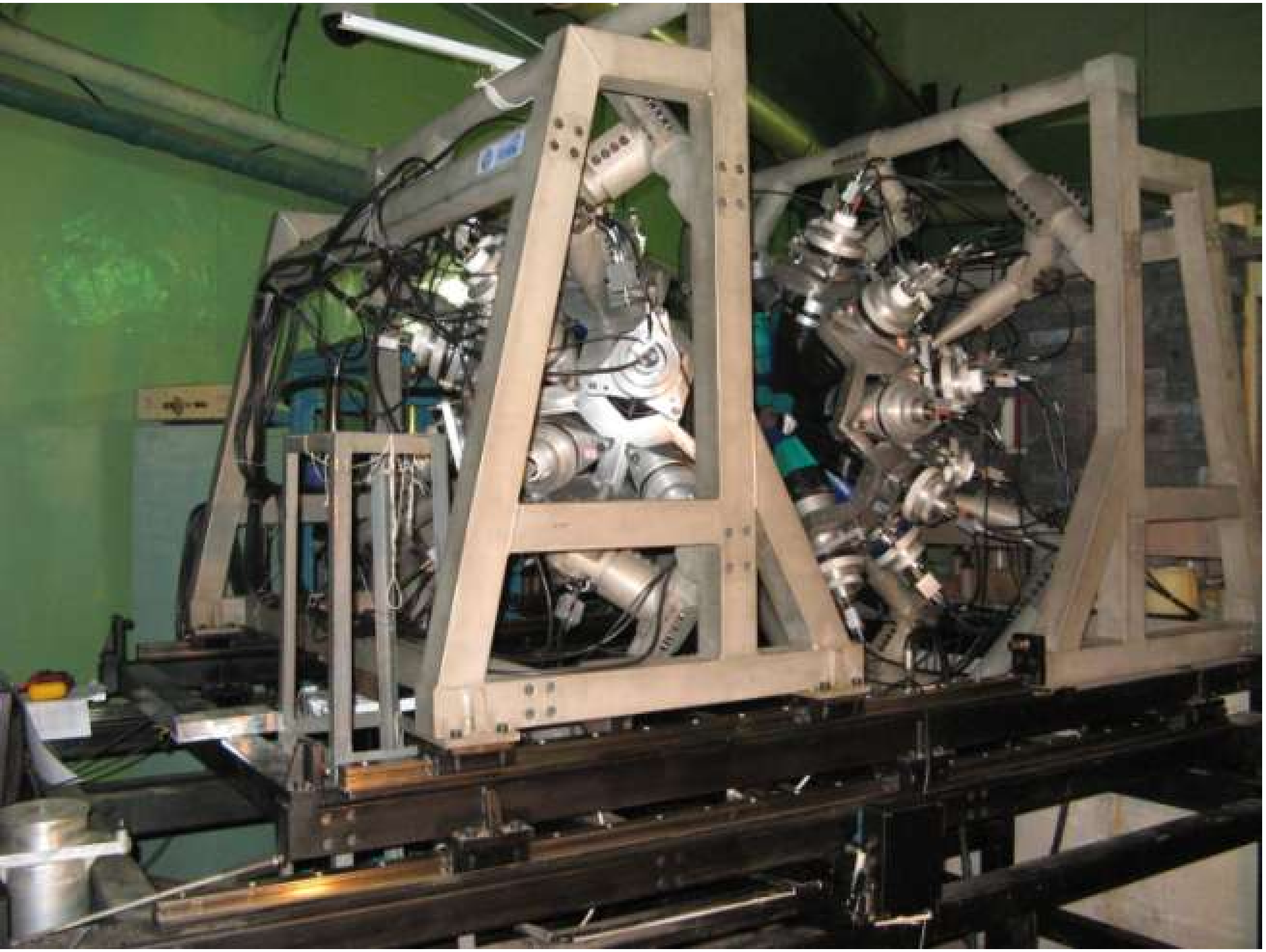
(n,g) reaction cross section measurement with C6D6 system at CSNS Back-n





First experiment on 169Tm(n,g) reaction finished in April,2018

Gamma Total Absorption Facility(GTAF) for neutron capture cross section measurement



- Composed of 42 BaF_2 detectors
- Readout by FADC
- Will be installed at CSNS for (n, g) measurement

CARR ISOL for decay data measurement

- Mass resolution > 400
- For short life decay data measurement

Summary

- Nuclear data needs increase in China in recent years, particularly driven by some large new nuclear energy system projects.
- Substantial progress on nuclear data measurement has been made in recent years.
- Some new facilities such as CSNS are finished, these facilities will greatly improve the capability of the nuclear data measurement in China in the near future

http://www.nd2019.org

When and Where?

核数据2019
International Conference on Nuclear Data for Science and Technology May 19-24, 2019

Important dates

- **Registration Open:** **May 01, 2018**
- **Abstract Sub. Deadline:** **Nov. 01, 2018**
- **Author Notification:** **Dec. 31, 2018**
- **On-line Reg. Deadline:** **Apr. 19, 2019**
- **On-site Reg:** **May. 19, 2019**
- **ND2019: May. 20~24, 2019**

Venue

China National Convention Center

核数据2019

International Conference on Nuclear Data for Science and Technology May 19-24, 2019

Thank you for your attention