Physical design of PGAA and NDP at CSNS

Songlin Wang, Tiancheng Yi, Liubin Yuan, Tianjiao Liang

Institute of High Energy Physics of Chinese Academy of Sciences

ISINN31

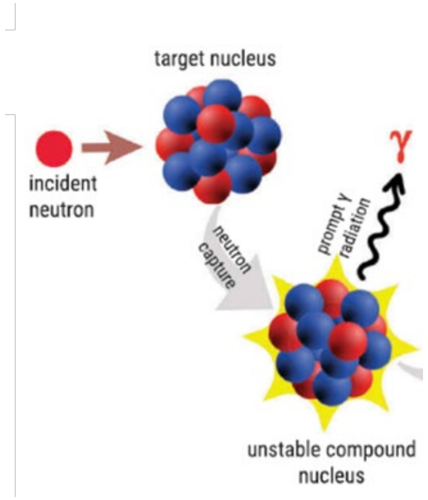
Outline

I. A brief introduction of the NPAI
II. Instrument design
III. PGAA physical design
IV. NDP physical design
V. Summary

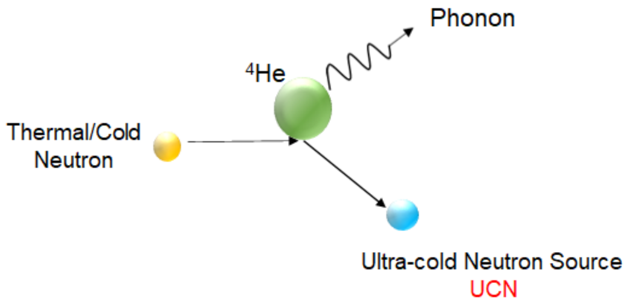
Outline

I. A brief introduction of the NPAI

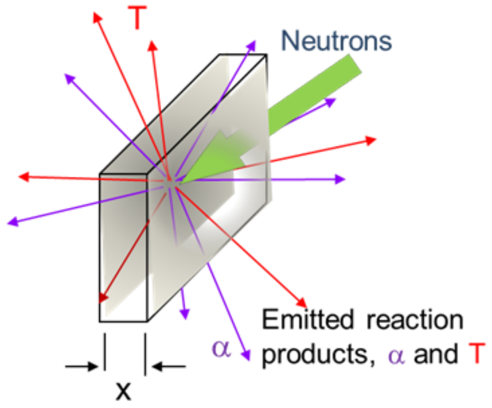
- **Neutron Physics and Application Instrument-NPAI have two beam lines expand the function.**
- **Application Beam line :**
  - Prompt Gamma Activation Analysis (PGAA)
  - Neutron Depth Profile (NDP)
- **Physics Beam line:**
  - Ultra Cold Neutrons (UCN)



PGAA



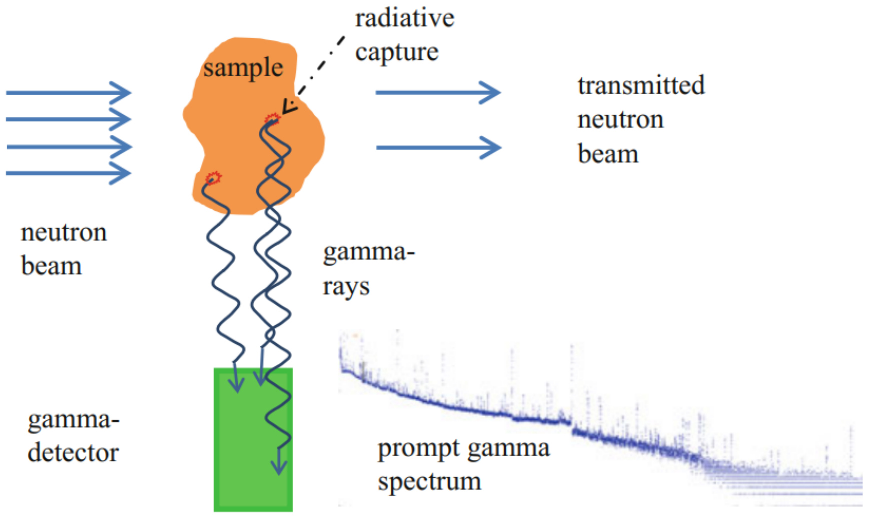
Ultra Cold Neutrons（UCN）



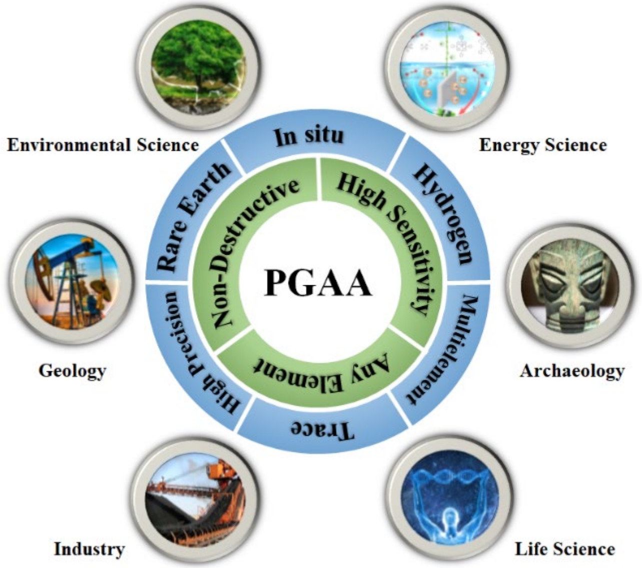
NDP

I. A brief introduction of the NPAI

- **Prompt Gamma Activation Analysis (PGAA)**
  - Capture thermal or cold neutrons, form a compound nuclei;
  - Release gamma rays upon de-excitation within a time frame of less than 10^{-14} seconds;
  - The characteristic gamma rays are detected using a high-resolution gamma spectrometer;
  - The energy of characteristic peaks is used to determine the elements (nuclei);
  - The elements (nuclei) concentration is performed by the normalized characteristic peak area.



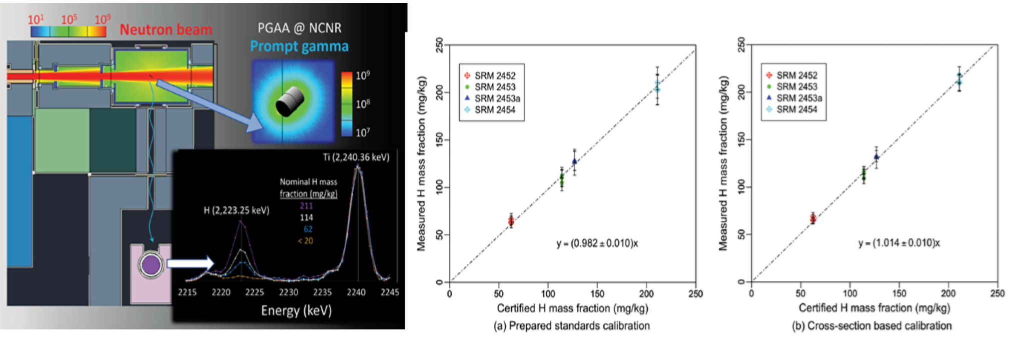
PGAA Schematic



PGAA advantages and applications

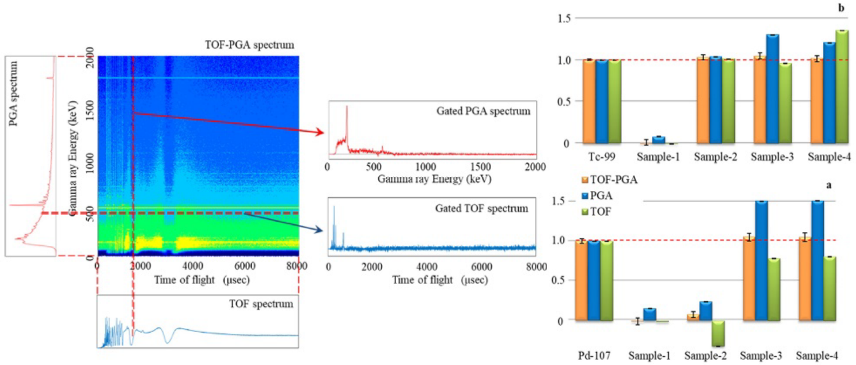
I. A brief introduction of the NPAI

- **Prompt Gamma Activation Analysis (PGAA) applicaitions**



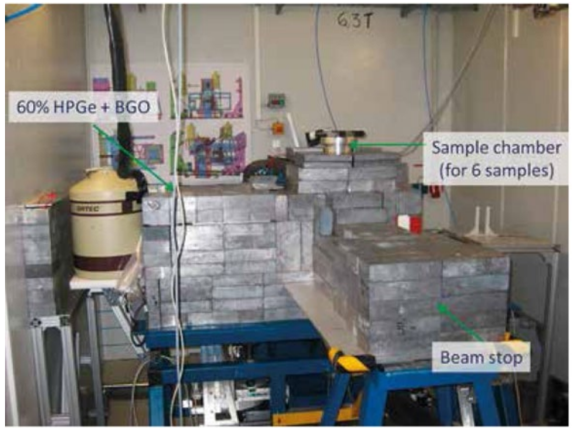
Assessment of PGAA capability for low-level measurements of H in Ti alloys

Analyst. 2017, 142, 3822



Nondestructive Quantitative Analysis of Difficult-to-Measure Radionuclides 107Pd and 99Tc

Anal.Chem. 2021, 93, 9771



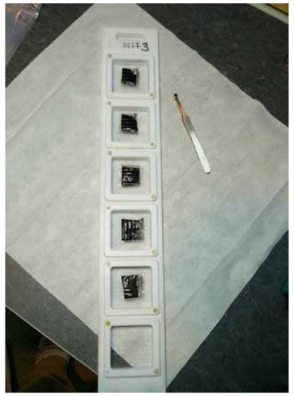
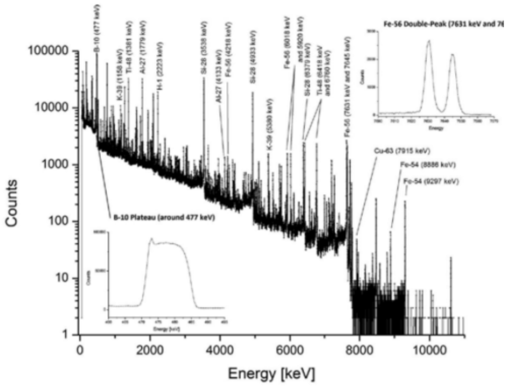


Fig. 4 PGAA sample ladder made of FTPE can accommodate up to six samples measured automatically in one batch in possibly evacuated sample chamber. Five homogenized clay crucible samples (see **fig. 7**) are sealed in FTPE foil here. – (© by the authors).

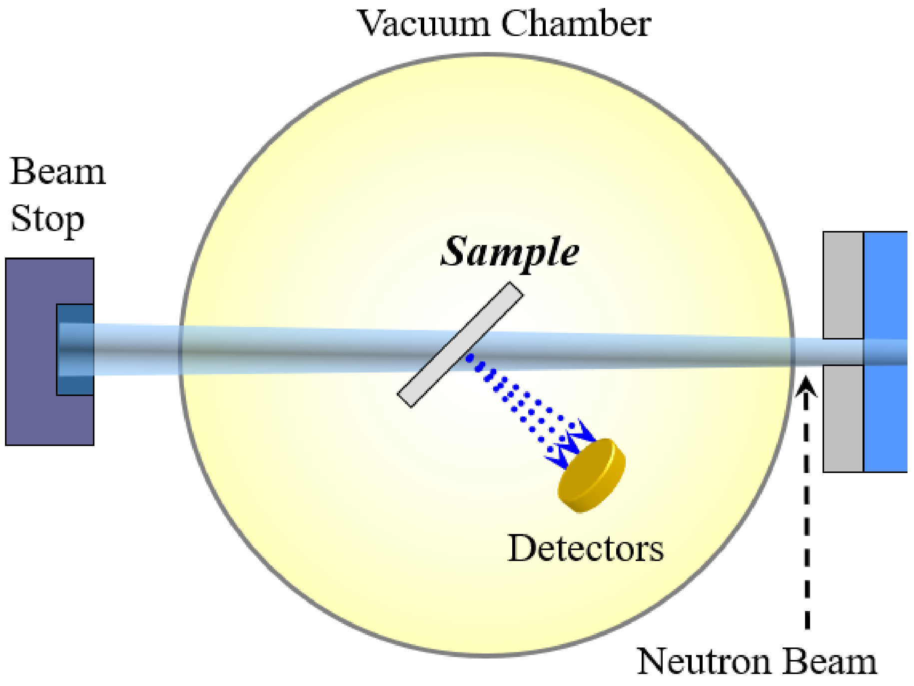


Restaurierung und Archäologie, 2015, 8: 115-124.

Measurement of clay crucible sample in FRMII

I. A brief introduction of the NPAI

- **Neutron Depth Profile (NDP)**
  - Neutrons react with elements, and produce charged ions with a well-defined energy;
  - The charged ions that escape the sample are collected by a surface barrier detector;
  - The energy of detected ions is used to determine the initial location of the nuclear reaction;
  - The normalized counts are proportional to the abundance of Li at the corresponding depth.



Advantages:

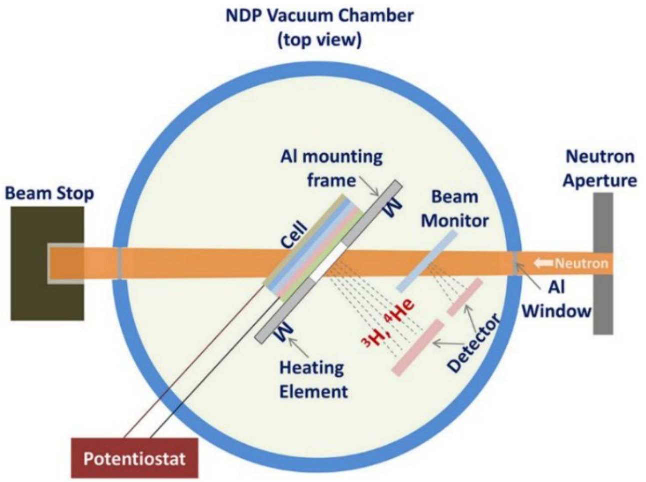
- High sensitivity for light elements;
- Quantitative and non-destructive;
- 10s nm resolution and 10s μm depth range.

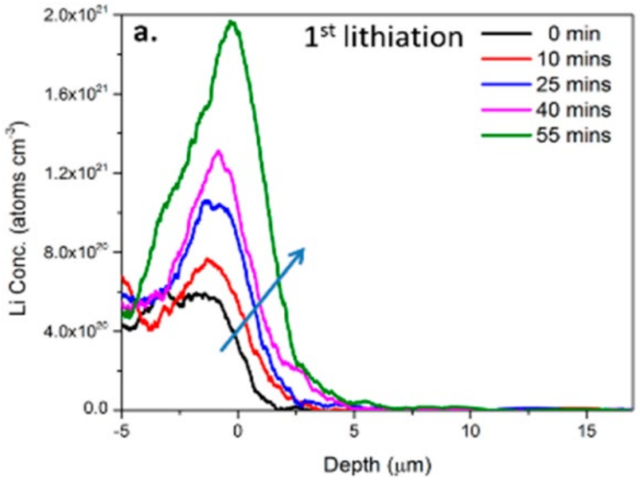
Applications:

- Battery failure analysis;
- Microstructural evolution;
- Electrode optimization.

I. A brief introduction of the NPAI

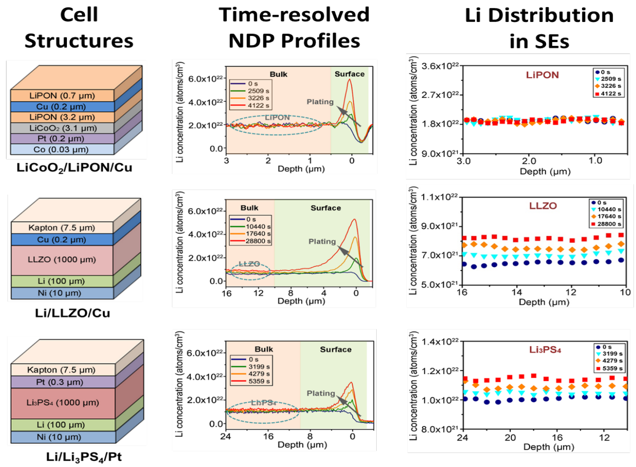
- **In-situ NDP applications**





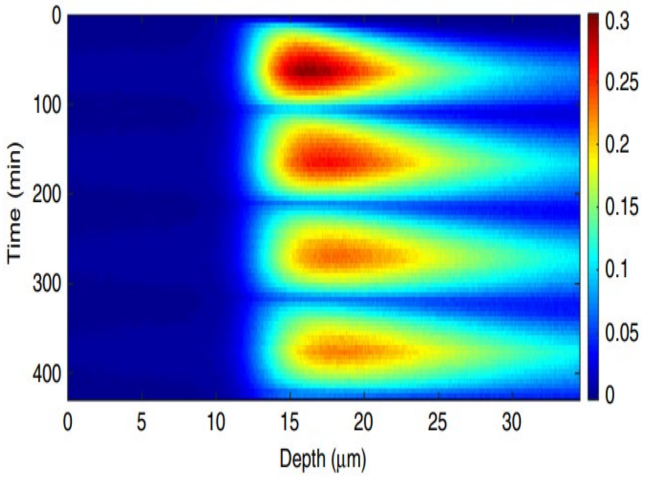
Revealing Chemical Processes

J. Am. Chem. Soc. 2016.



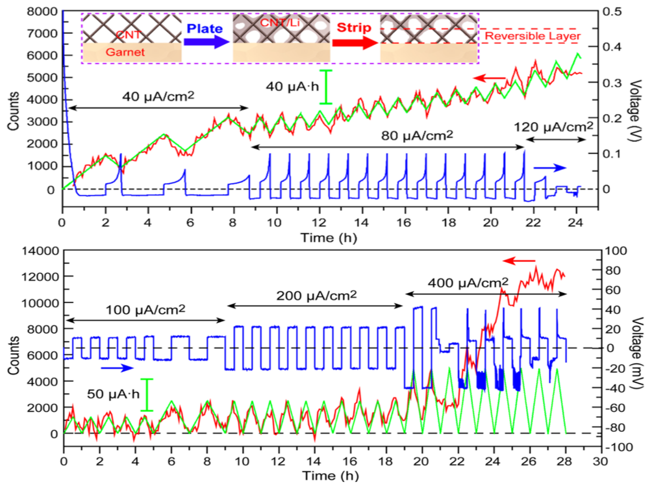
Depth Distribution in Electrolytes

Nature Energy, 2019.



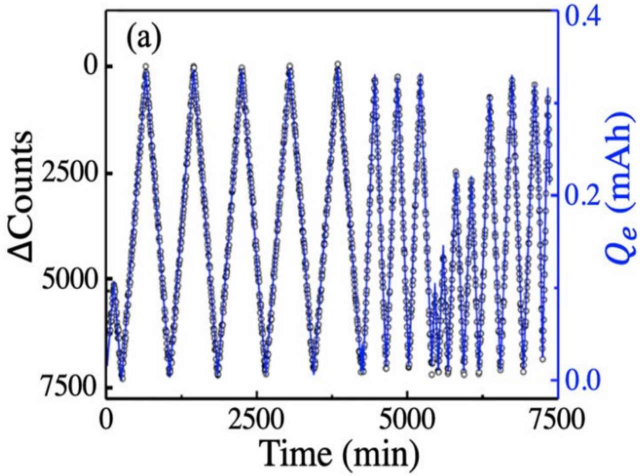
Failure mechanisms in Li metal anodes

Nature communication, 2018.



Failure Analysis of Li battery

J. Am. Chem. Soc. 2017.

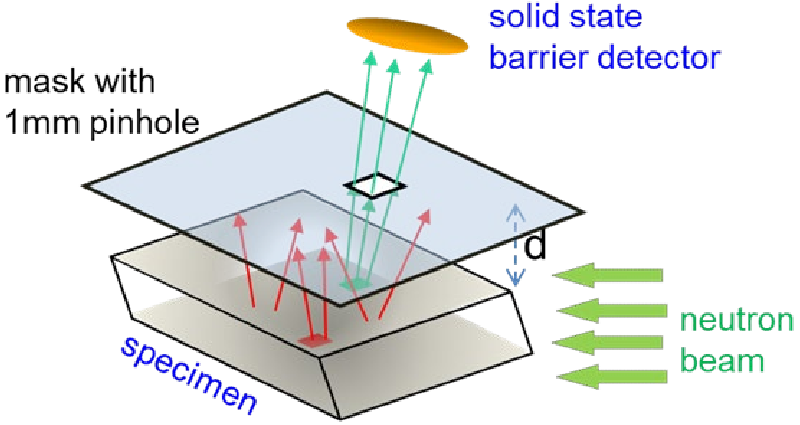


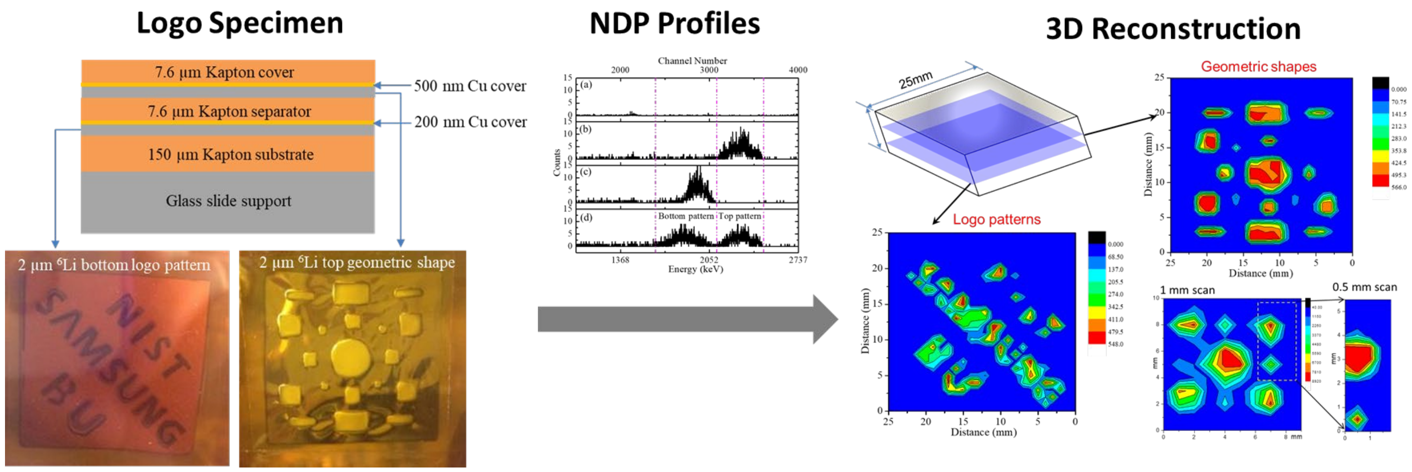
Expanding the metrology of CE

Radiation Effects & Defects in Solid, 2019.

I. A brief introduction of the NPAI

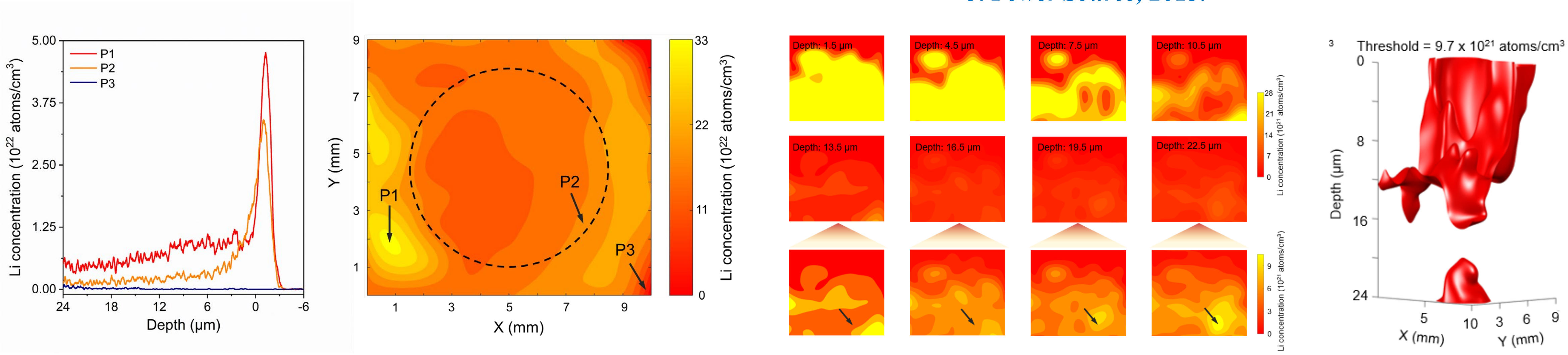
- **3D NDP applications**





Visualizing the buried logo and shapes

***J. Power Source*, 2015.**



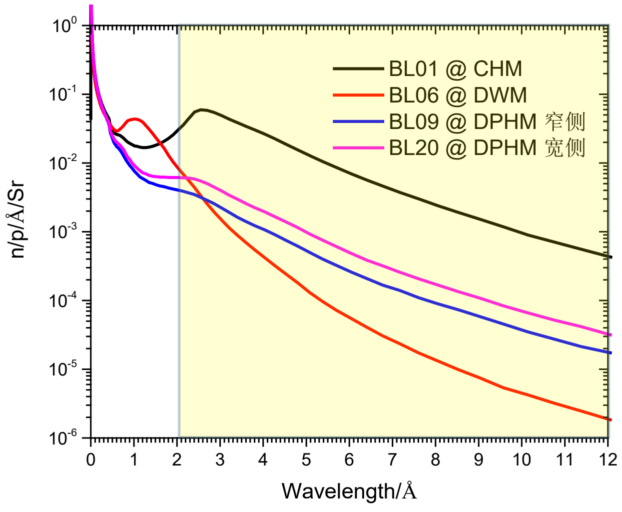
Structure of Li Dendrites in Polymer Electrolytes

***eScience*, 2024.**

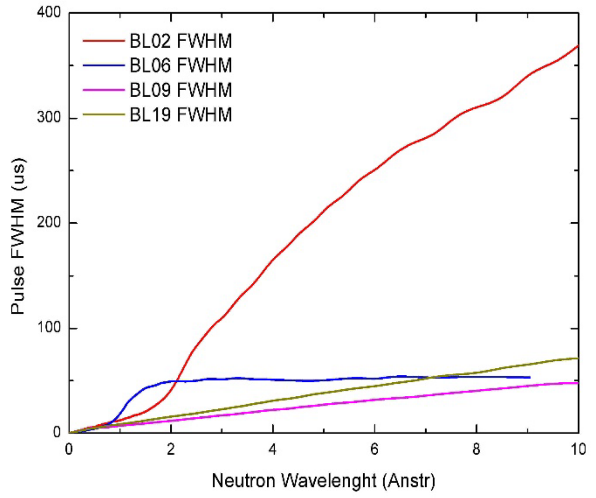
Outline

II. Moderator

- **Physics Beam line：** Cold neutron convert UCN, require high cold neutron flux, no requirement for pulse width；
- **Application Beam line：** Cold neutrons have capture reactions with the sample, and the released gamma rays or charged particles are measured. It is required to have a high cold neutron flux and low pulse width requirements.



Neutron wavelength spectrum



Neutron pulse width

We can see for the most used wavelength range CHM has the best flux and acceptable resolution, whose **BL-12** has also the most available space, therefore we chose it for this instrument.

II. Position

CSNS II Neutron Instruments

12

BL20: Polarized chopper spectrometer

BL19: Single crystal diffractometer

BL17: Quasi-elastic spectrometer

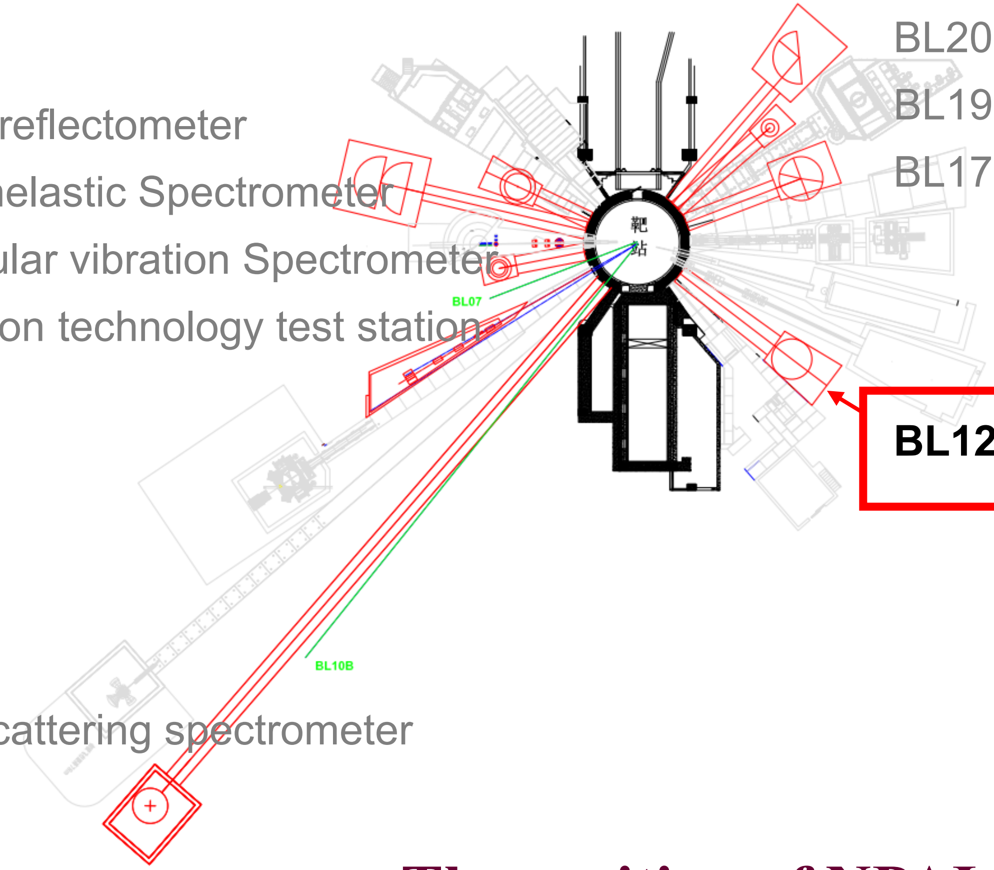
BL03: Liquid reflectometer

BL04: Cold inelastic Spectrometer

BL06: molecular vibration Spectrometer

BL08A: neutron technology test station

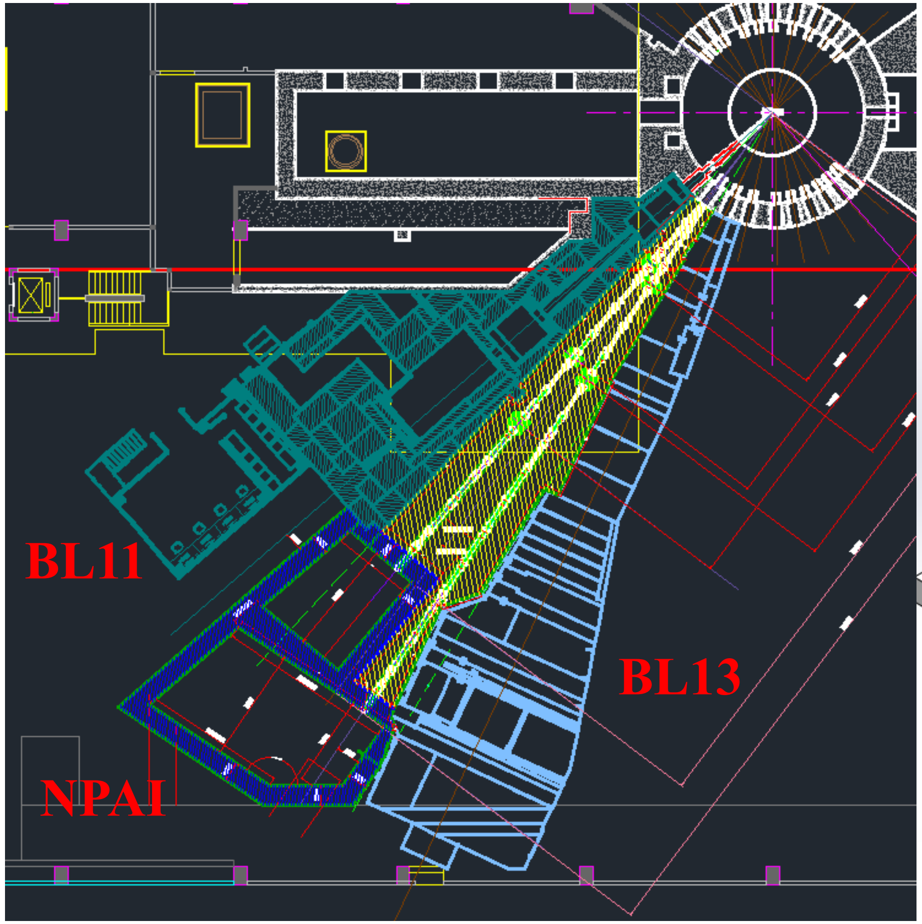
BL10: Backscattering spectrometer



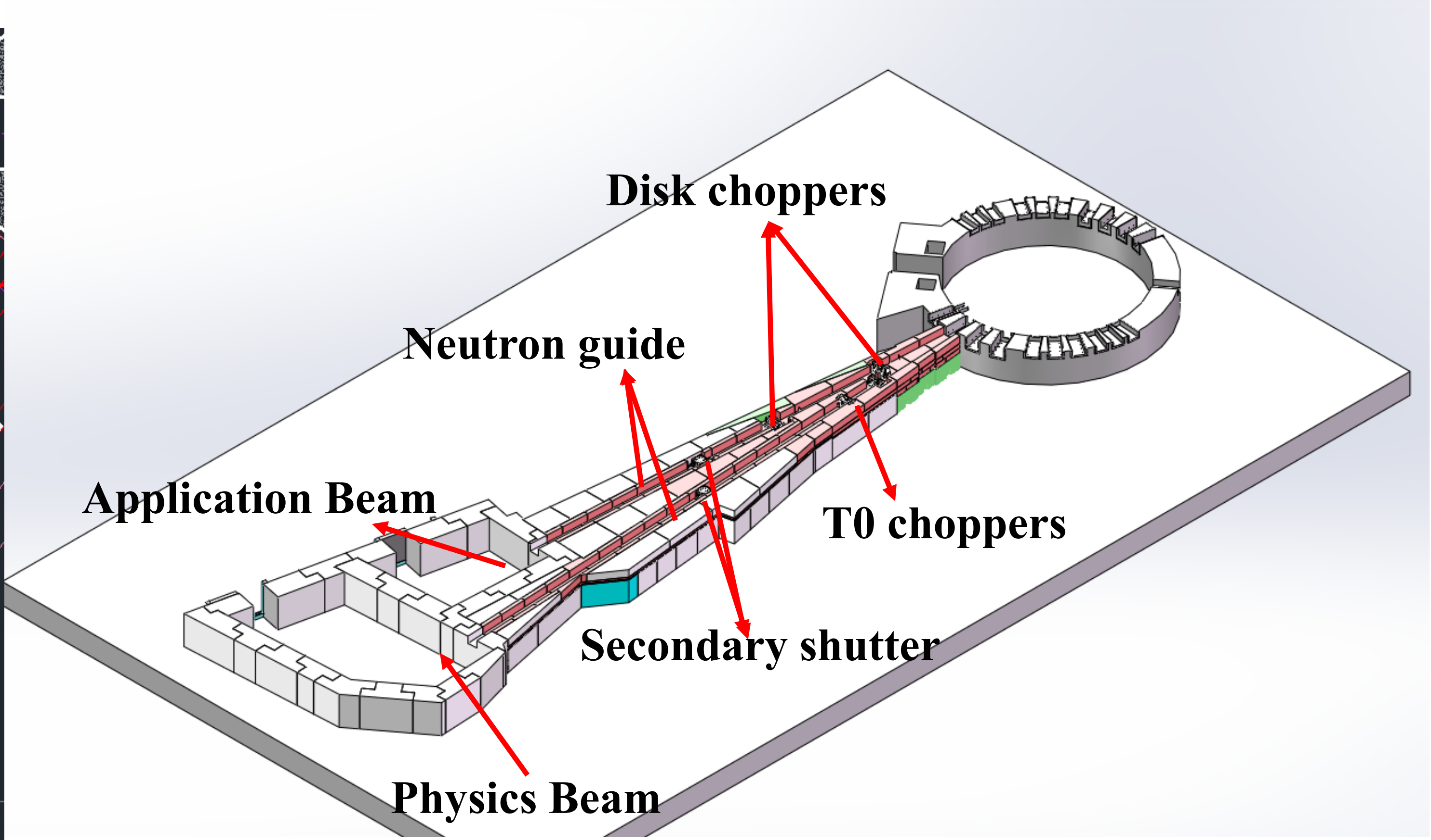
BL12: Neutron Physics and Application Instrument

The position of NPAI

II. Available space



The location of NPAI



The plan view of NPAI

Outline

I. A brief introduction of the NPAI

II. Instrument design

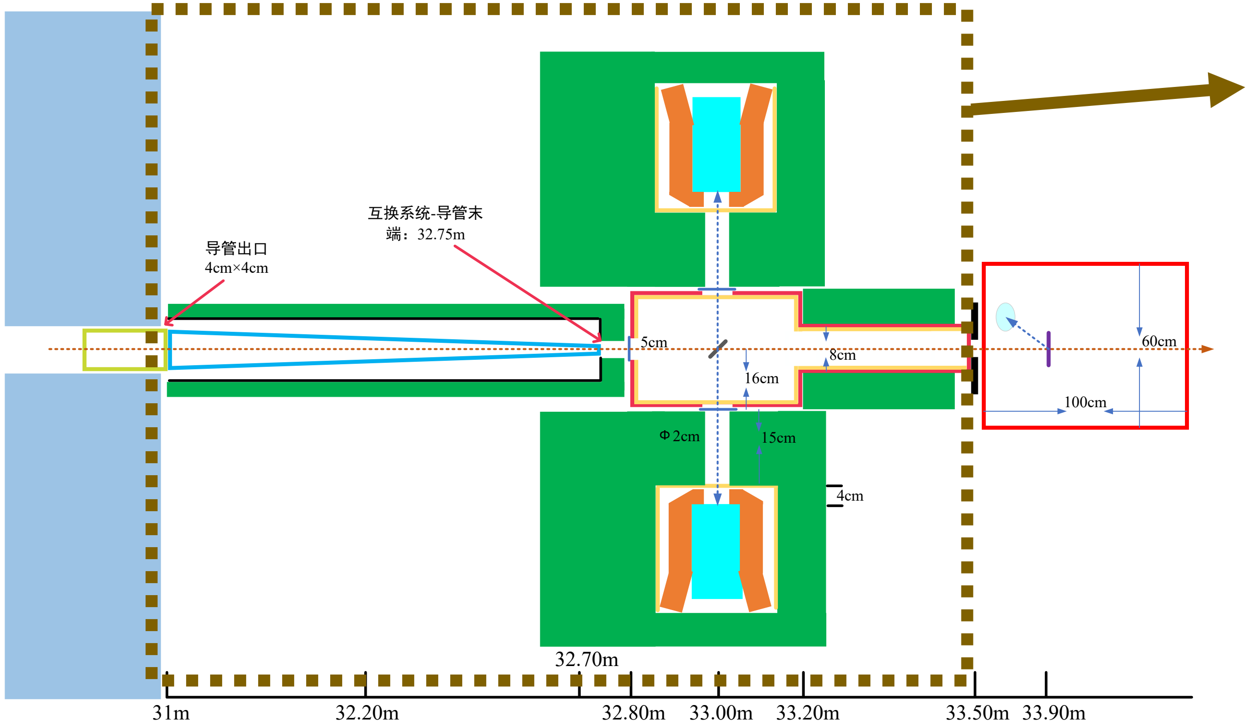
III. PGAA physical design

IV. NDP physical design

V. Summary

III. PGAA physical design

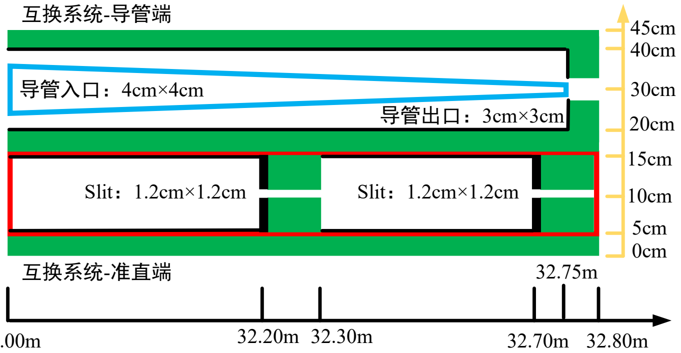
❑ Prompt Gamma Activation Analysis Layout



Guide end exit	3cm×3cm
Guide end	31m
Switchable part	Guide / Collimator
Switchable part position	31m~32.8m
Sample position	33m
Sample angle	45°
Sample chamber	38cm*32cm*50cm
Gamma collimation aperture Length	Φ2cm 15cm
Length (De-Sa)	35cm (16cm+15cm+4cm)
Bandwidth	2Å~6.7Å
Gamma detector	N-type HPGe
Sample size	3cm*3cm / 1.2cm*1.2cm

Guide

Collimator



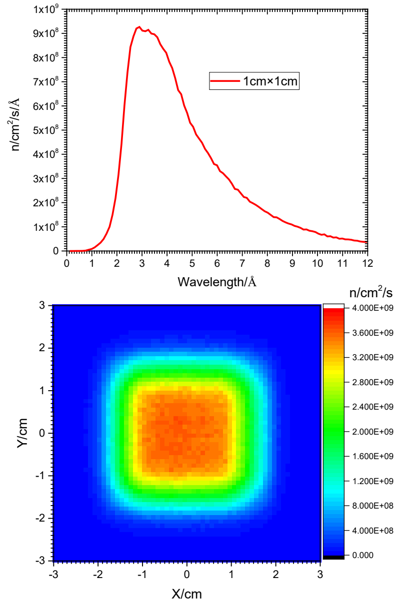
Switchable part

III. PGAA physical design

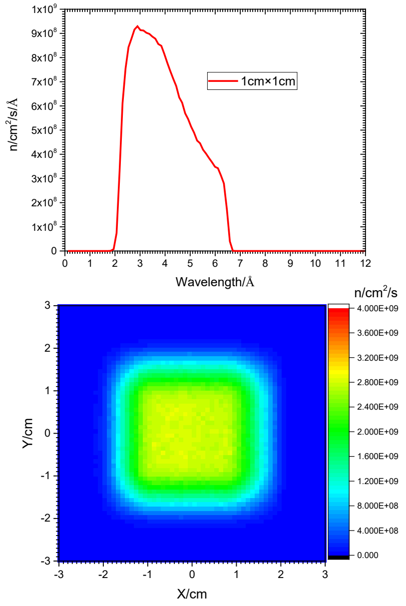
❑ Neutron Performance at PGAA Sample Position

➢ **Switchable part is Guide port, for high neutron flux;**

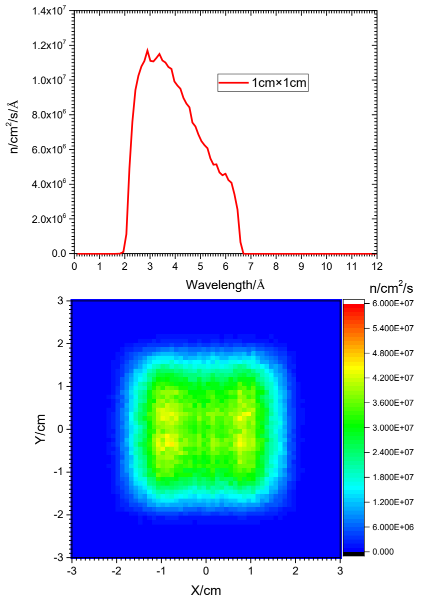
Mode	Attenuator	Chopper	Flux
White Beam	Off	0.1 Å ~ 12 Å	3.57E+09 n/cm^2/s @ 500kW
Normal Beam	Off	2 Å ~ 6.7 Å	2.80E+09 n/cm^2/s @ 500kW
Low flux	On	2 Å ~ 6.7 Å	3.52E+07 n/cm^2/s @ 500kW



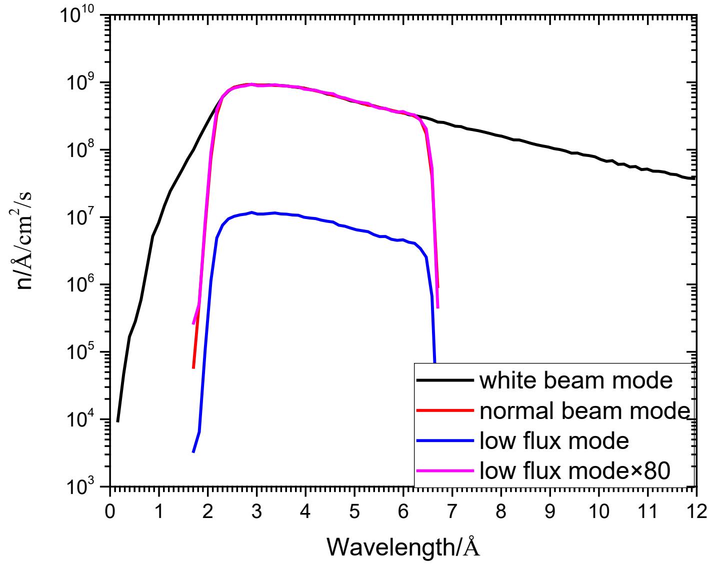
White beam mode



Normal beam mode



Low flux mode



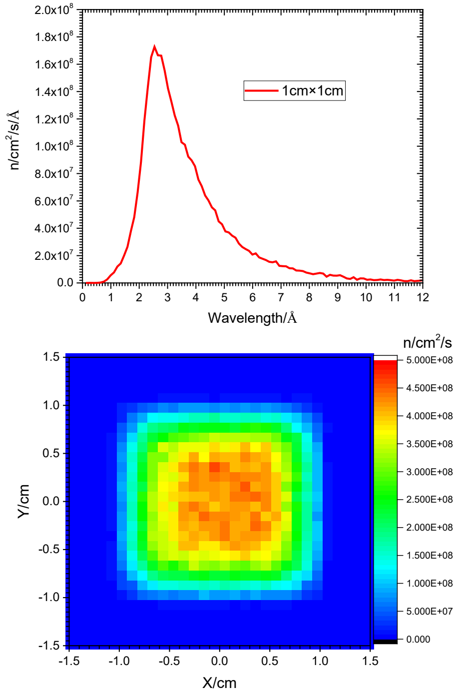
Neutron Wavelength Spectrum Compare

III. PGAA physical design

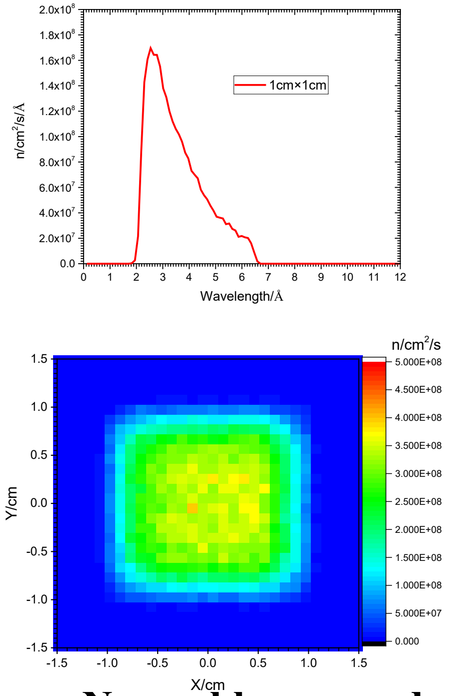
❑ Neutron Performance at PGAA Sample Position

➢ **Switchable part is Collimator port, for low background;**

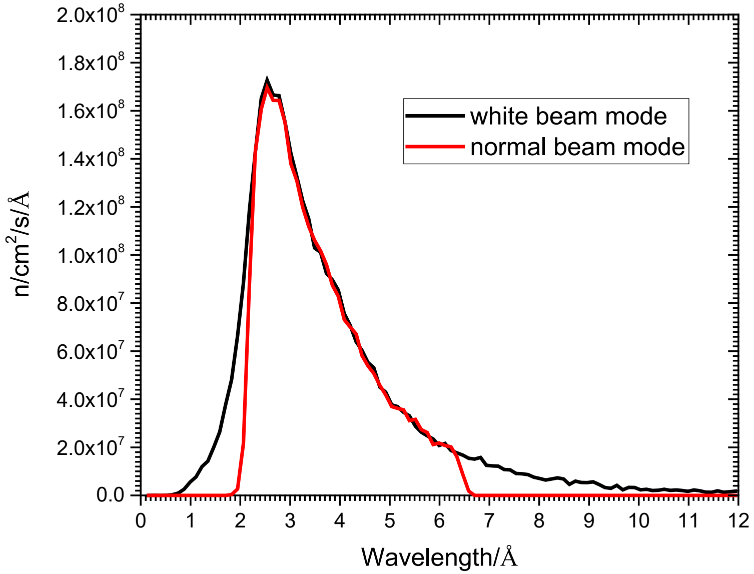
Mode	Attenuator	Chopper	Flux
White Beam	Off	0.1 Å ~ 12 Å	4.13E+08 n/cm^2/s @ 500kW
Normal Beam	Off	2 Å ~ 6.7 Å	3.38E+08 n/cm^2/s @ 500kW



White beam mode



Normal beam mode



Neutron Wavelength Spectrum Compare

III. c

☐ Detection limit:

Summary of Prompt Gamma Activation Analysis example detection sensitivities
for the Neutron Physcis and Application Insturment at China Spallation Neuton Source

1 H 0.062																	2 He
3 Li 3.774	4 Be 28.257											5 B 0.0003	6 C 87.139	7 N 21.006	8 O 2096.208	9 F 41.115	10 Ne 16.978
11 Na 0.756	12 Mg 16.885											13 Al 2.387	14 Si 5.104	15 P 21.101	16 S 1.983	17 Cl 0.500	18 Ar 1.564
19 K 0.884	20 Ca 2.356	21 Sc 0.154	22 Ti 0.182	23 V 0.220	24 Cr 0.801	25 Mn 0.088	26 Fe 1.768	27 Co 0.170	28 Ni 0.859	29 Cu 1.479	30 Zn 4.961	31 Ga 0.842	32 Ge 1.347	33 As 0.731	34 Se 0.745	35 Br 3.539	36 Kr 0.084
37 Rb 2072.704	38 Sr 1.877	39 Y 2.430	40 Zr 15.525	41 Nb 9.900	42 Mo 0.975	43 Tc	44 Ru 1.307	45 Rh 0.099	46 Pd 0.547	47 Ag 0.280	48 Cd 0.0016	49 In 0.015	50 Sn 18.268	51 Sb 0.955	52 Te 1.054	53 I 1.871	54 Xe 0.383
55 Cs 1.168	56 Ba 9.644		72 Hf 0.129	73 Ta 1.408	74 W 4.047	75 Re 0.868	76 Os 1.889	77 Ir 0.116	78 Pt 0.678	79 Au 0.044	80 Hg 0.016	81 Tl 11.649	82 Pb 27.273	83 Bi 181.346	84 Po	85 At	86 Rn
87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
		57 La 0.493	58 Ce 12.091	59 Pr 2.752	60 Nd 0.088	61 Pm	62 Sm 0.0010	63 Eu 0.0010	64 Gd 0.0006	65 Tb 7.487	66 Dy 0.0089	67 Ho 0.223	68 Er 0.067	69 Tm 0.355	70 Yb 0.400	71 Lu 0.054	
		89 Ac	90 Th 28.911	91 Pa	92 U 9.593	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

- ≤ 1 ng
- 1 - 10 ng
- 10 - 100 ng
- 0.1 - 1 µg
- 1 - 10 µg
- ≥ 10 µg

* Detection limit based on 0.001 cps, 0.001% geometric efficiency, and a neutron intensity of 3.57 × 10^9 $n/cm^2/s$.

Outline

I. A brief introduction of the NPAI

II. Instrument design

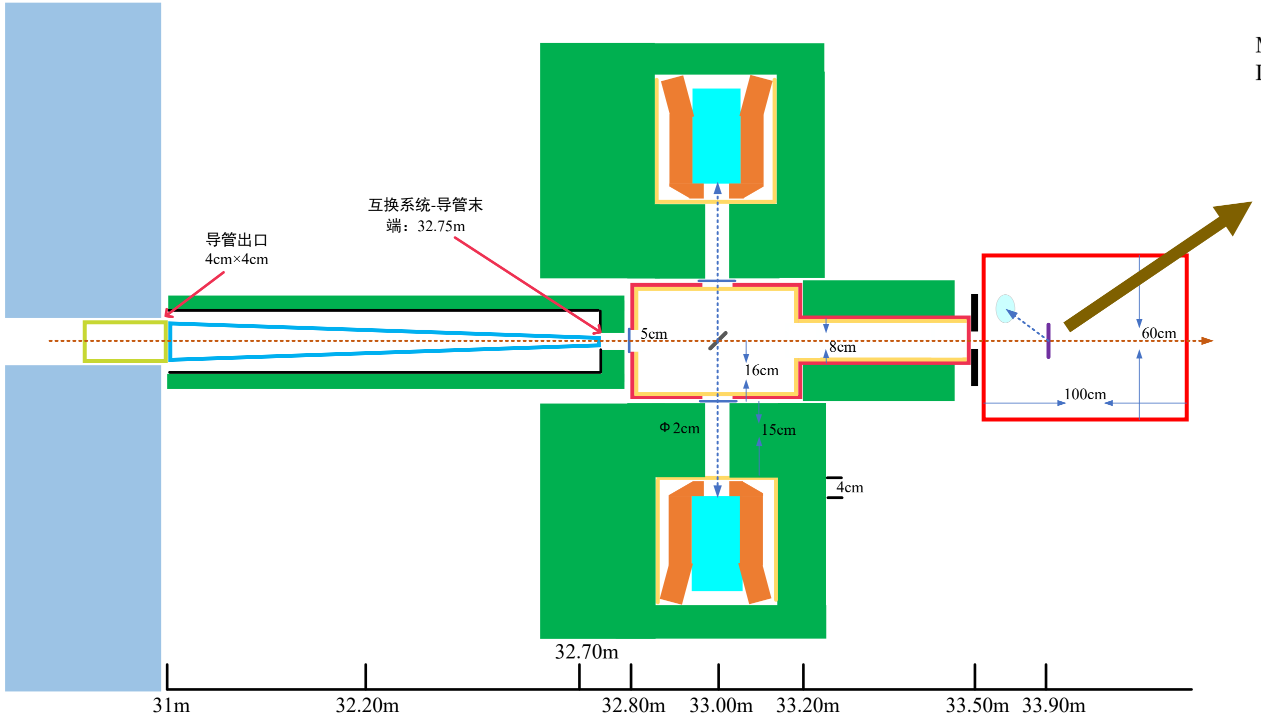
III. PGAA physical design

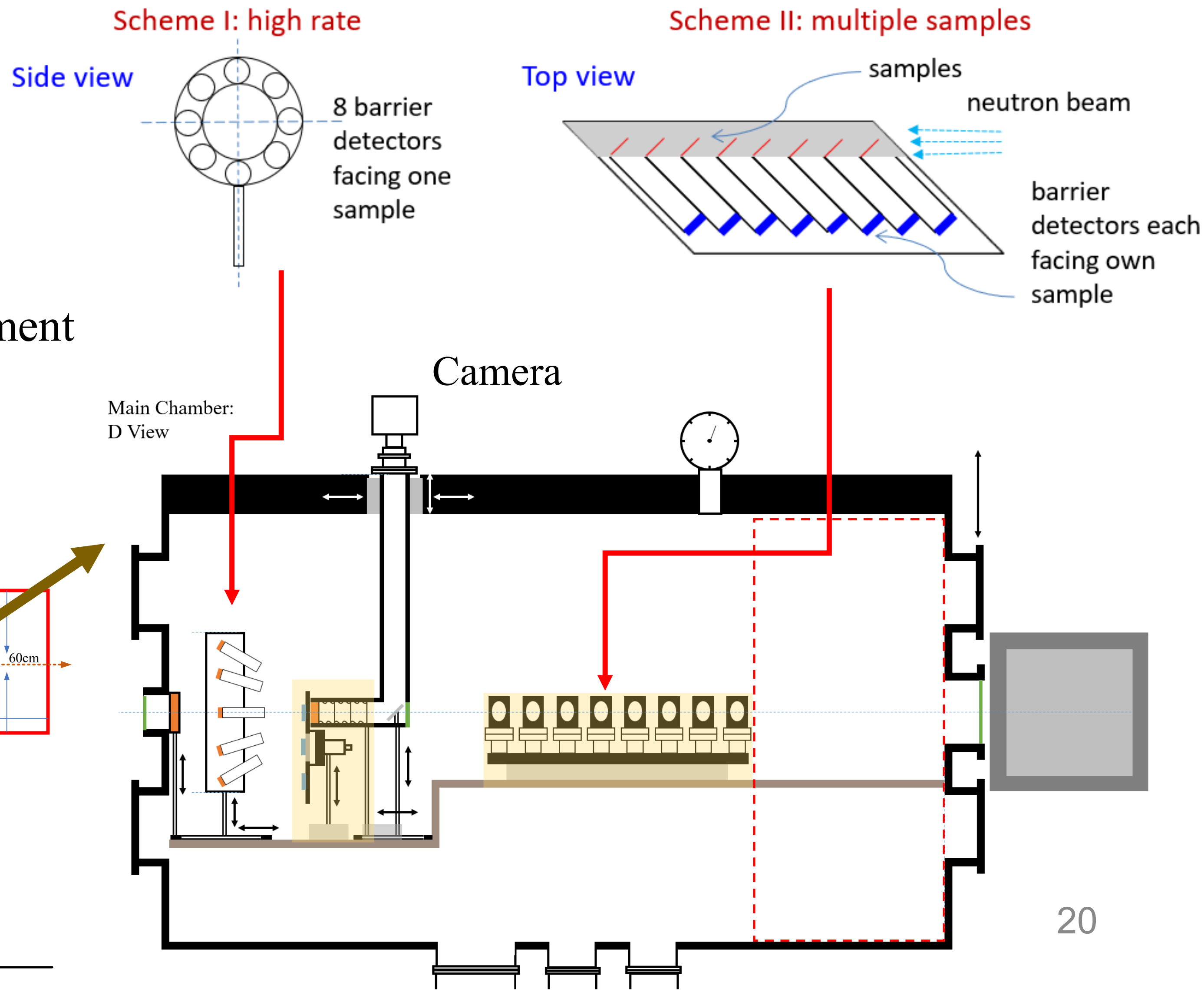
IV. **NDP physical design**

V. Summary

IV. NDP physical design

- ❑ **Neutron Depth Profiling Layout**
  - ❑ NDP sample at 33.9m, behind PGAA
  - ❑ More detectors offer higher count rates
  - ❑ NI provides a horizontal 2D distribution
  - ❑ Multiple samples simultaneous measurement

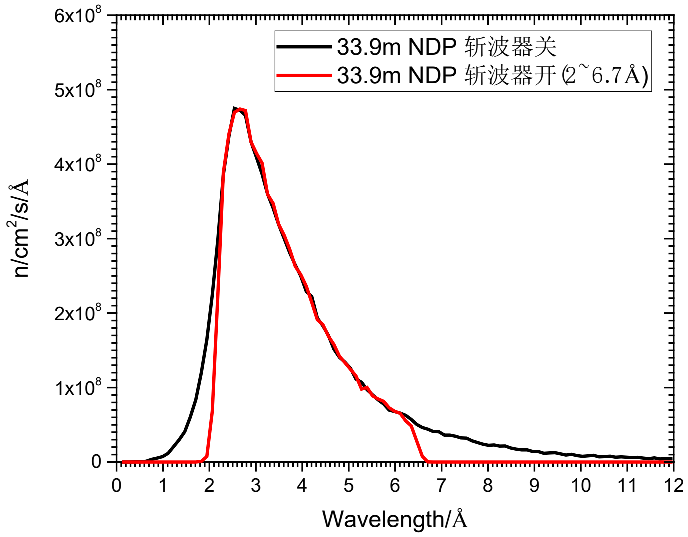




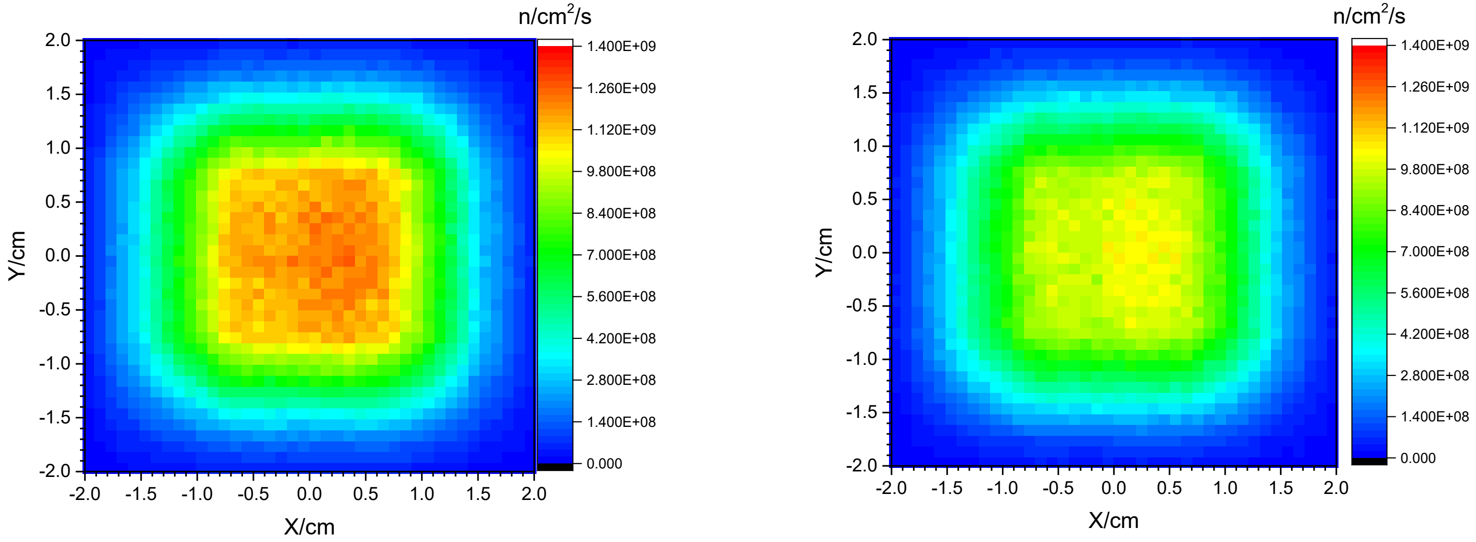
IV. NDP physical design

❑ Neutron Performance at NDP Sample Position

Mode	Chopper	Collimator	Flux
White Beam	0.1 Å ~ 12 Å	2 cm × 2 cm	1.18E+09 n/cm²/s @ 500kW
Normal Beam	2.0 Å ~ 6.7 Å	2 cm × 2 cm	9.99E+08 n/cm²/s @ 500kW



Neutron Wavelength Spectrum
Red line: white beam mode
Black line: normal beam mode



Neutron Spatial Distribution
Left: white beam mode
Right: normal beam mode

IV. NDP physical design

❑ NDP Design Parameters

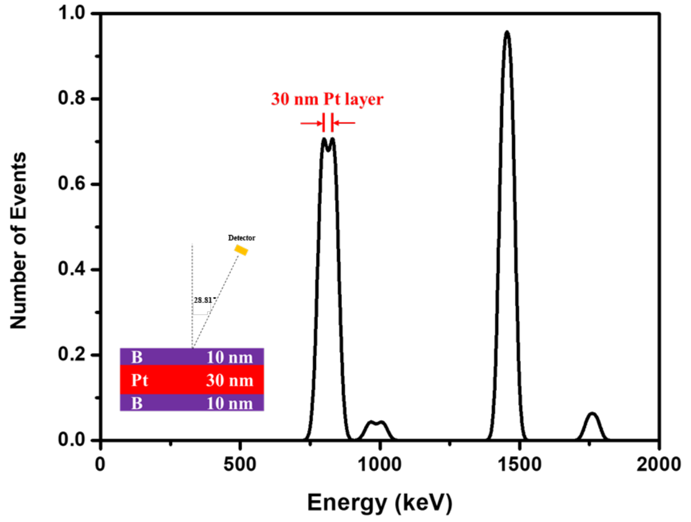
Det. Energy Resolution	Det. Solid Angle	Beam Spot Size	Boron Sensitivity
14 keV @ 5.5 MeV	0.0064 Sr	2 cm × 2 cm	$\leq 1 \times 10^{13}$ atoms/cm^2
Det. - Sam. Angle	**Det. - Sam. Distance**	**Chamber Vacuum**	**Depth Resolution**
28.81°	10 cm	1×10^{-4} Pa	$\leq$ 40 nm

Summary of Neutron Depth Profiling reaction characteristies and example detection sensitivities for the Neutron Physcis and Application Instrument at China Spallation Neuton Source

No.	Elem.	Reaction	% Abundance or (atoms/mCi)[a]	Particles Energy (keV)		Cross Section (barns)	Detection Limit (atoms/cm^2)[b]
1	He	^{3}He(n,p)^{3}H	0.00014	572	191	5333	2.27E+17
2	Li	^{6}Li(n,α)^{3}H	7.5	2055	2727	940	2.40E+13
3	Be[a]	^{7}Be(n,p)^{7}Li	(2.5×10^{14})	1438	207	48000	3.14E+10
4	B	^{10}B(n,α)^{7}Li	19.9	1472	840	3837	2.35E+12
5	N	^{14}N(n,p)^{14}C	99.6	584	42	1.83	9.30E+14
6	O	^{17}O(n,α)^{14}C	0.038	1413	404	0.24	1.90E+19
7	Na[a]	^{22}Na(n,p)^{22}Ne	(4.4×10^{15})	2247	103	31000	6.20E+10
8	S	^{33}S(n,α)^{30}Si	0.75	3081	411	0.19	2.62E+18
9	Cl	^{35}Cl(n,p)^{35}S	75.8	598	17	0.49	4.66E+15
10	K	^{40}K(n,p)^{40}Ar	0.012	2231	56	4.4	2.89E+18
11	Ni[a]	^{59}Ni(n,α)^{56}Fe	(1.3×10^{20})	4757	340	12.3	1.44E+14

[a] Radioactive specics.

[b] Detection limit based on 0.1 cps, 0.0064 Sr detector solid angle, and a neutron intensity of 1.18×10^{9} n/cm^2/s.



Depth resolution better than 40 nm

Outline

V. Summary

➢ Time Table

Time	Content
2025.03	Physical Design Review
2025.10	PGAA/NDP Equipment Design Review
2026.07	Front Neutron Beam Line Installation
2027.01	PGAA/NDP Equipment Installation
2028.11	Neutron Beam Performance Test
2029.07	NPAI Acceptance and Operation

➢ Team Member

Name	Work	Email
Songlin Wang	PGAA	wangsl@ihep.ac.cn
Tiancheng Yi	NDP	yitch@ihep.ac.cn
Liubin Yuan	Engineer	yuanlb@ihep.ac.cn

V. Summary

- Neutron Physics and Application Instrument have two split beamline, the Application port have PGAA and NDP;
- PGAA have Switchable part, Guide port for high neutron flux, Collimator port for low background;
- Simultaneous measurements with multiple detectors increase the NDP count rate by nearly an order of magnitude, thereby improving the time resolution of in situ NDP experiments.

Thank you for your attention!