Asian Forum for Accelerators and Detectors 2023

Development status of the neutron detectors for instruments at CSNS

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Outline

1 **Team introduction and development planning**

2 **Development of the neutron detectors**

- **^{3}He-based, Scintillator, GEM, imaging detector**

3 **Summary**

Introduction to detector and electronics group

Motivation: Develop advanced neutron detectors for CSNS and other neutron sources in China

Responsibility: Operation, maintenance, research and development of detectors at CSNS

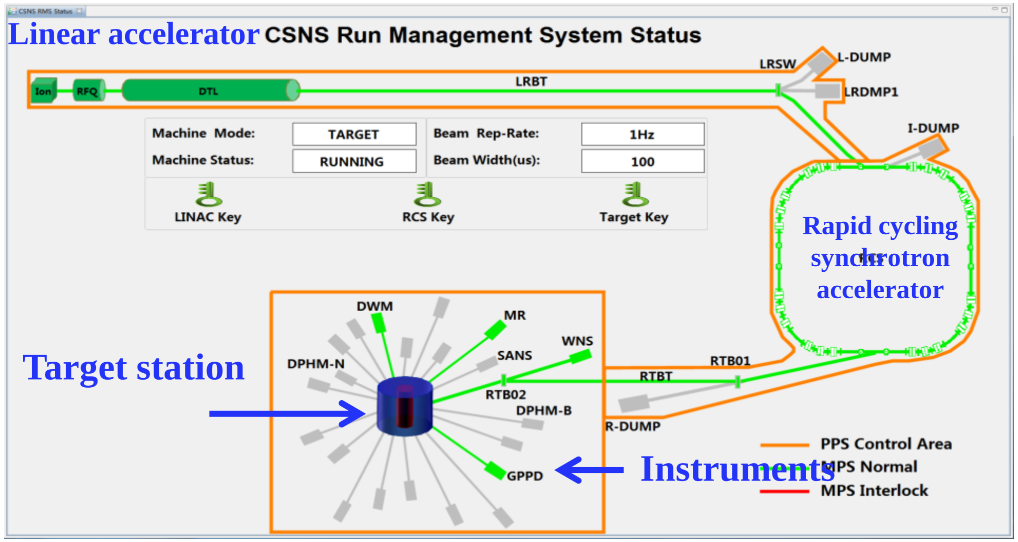
Team: Professors 3, associate professors 8, 40+ in total, including physics, electronics, software, mechanics

Three neutron sources and the demand for detectors

- Nearly 60 instruments of three neutron sources will be planned in China
- Each instument costs ¥ 100 million, in which detector takes up 30-50%
- The neutron detectors mainly depend on import, a massive, urgent and critical demand for multi-types of detectors

China Spallation Neutron Source(CSNS)

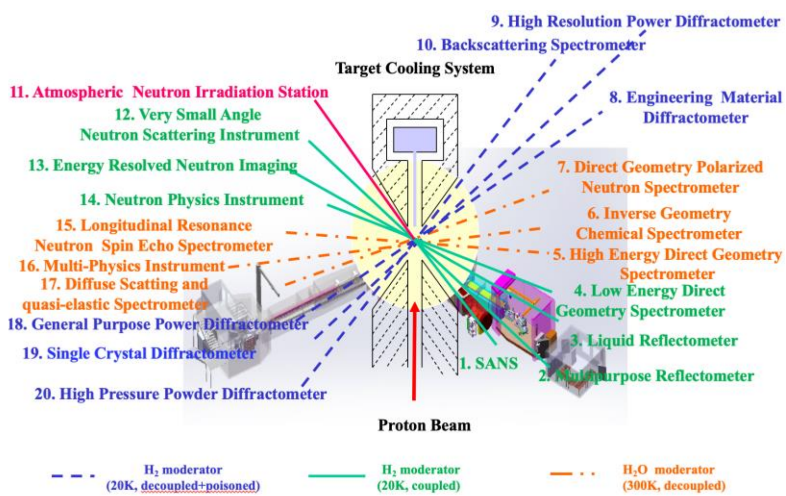
National major science and technology infrastructure during the 12th Five Year Plan



CSNS technical parameters

	Phase I	Phase II
Proton beam power(kW)	100	500
Pulsed repetition frequency (Hz)	25	25
Average beam current (μA)	62.5	312.5
Beam energy(GeV)	1.6	1.6
RCS injection energy (MeV)	80	300
Number of instruments	3	11

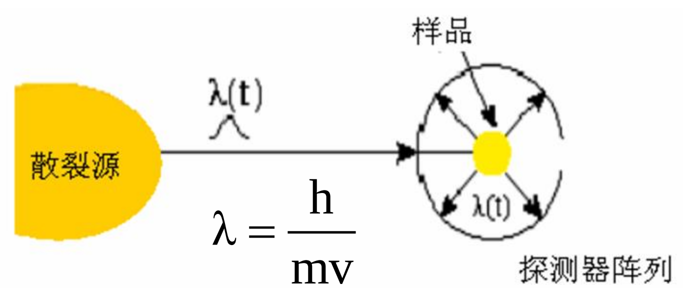
Neutron instrument suite



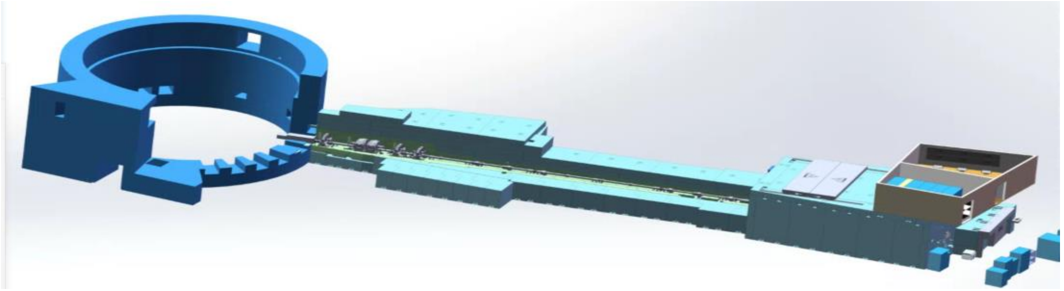
Large-scale scientific facility of Guangdong-Hong Kong-Macao Greater Bay Area

Neutron instrument and detector system

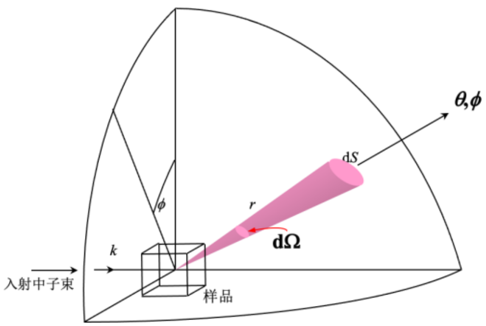
Neutron scattering principle:



Instrument architecture



The function and requirement of neutron detector for instrument

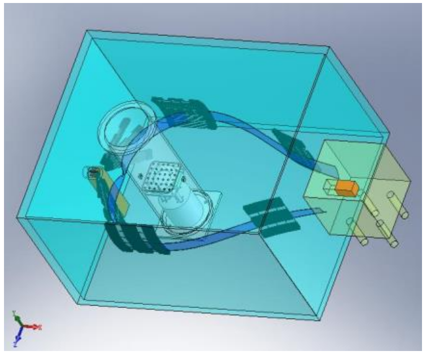


（λ， θ） ⟹（t， x， y）

Typical powder diffraction instrument resolution：

$$\left(\frac{\Delta d}{d}\right)^2 = \underline{\left(\frac{\Delta t}{t}\right)^2} + \left(\frac{\Delta L}{L_1}\right)^2 + \underline{(\Delta\theta\cot\theta)^2}$$

Time resolution: ~ μs,   Spatial resolution: ~ mm

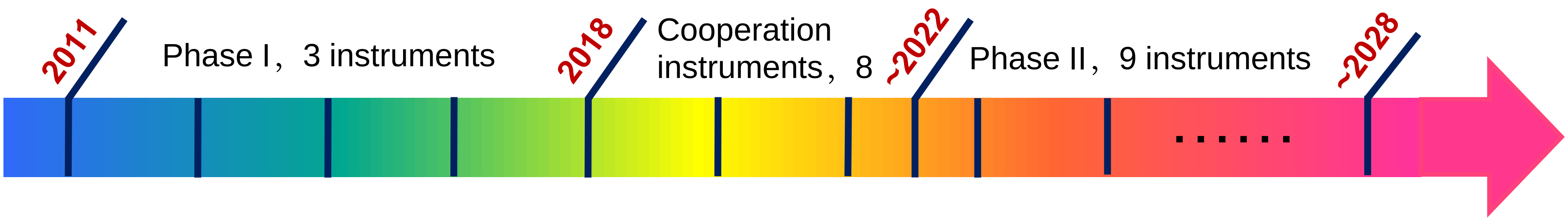


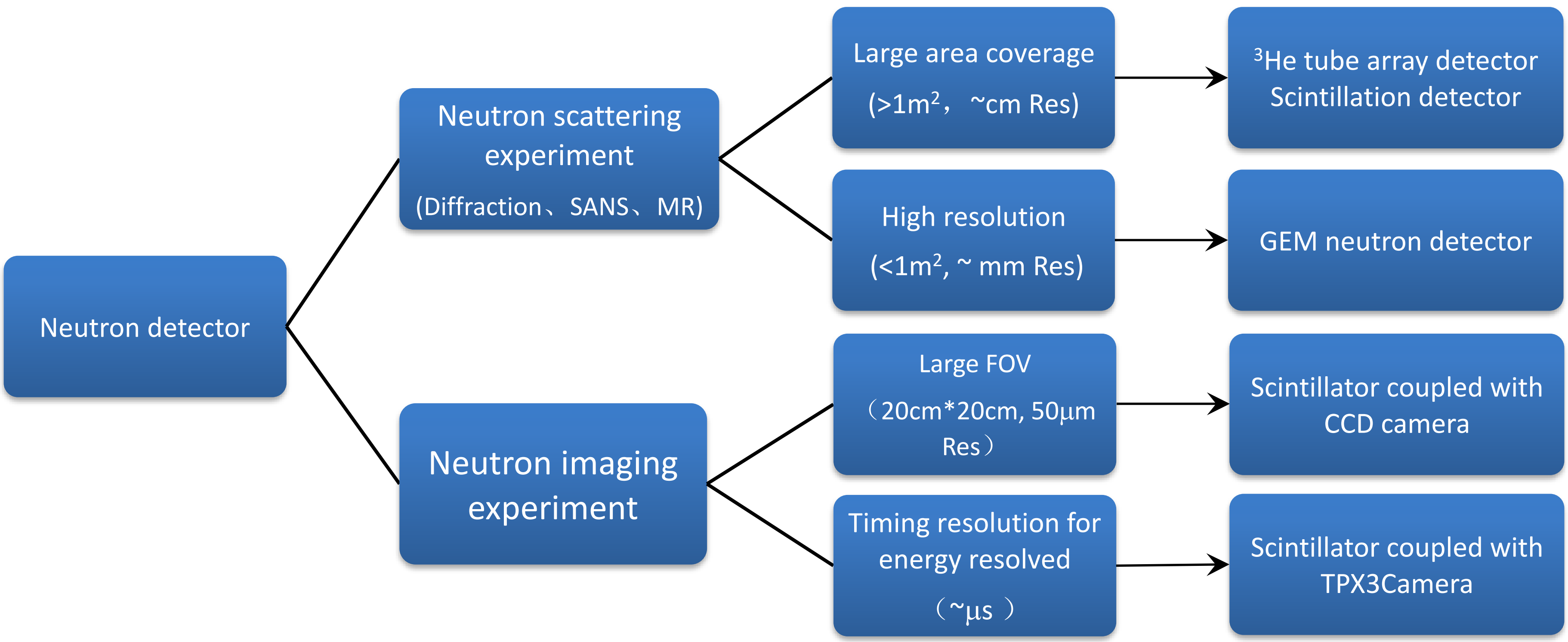
Detection area：～ m²
Detection efficiency：～ 80%

The framework of detector system at CSNS

Neutron convertor （^3He，^6Li，^{10}B） → Charged particle/ Photon detection （Sensor） → Frond-end electronics (ASIC) → Digital logic electronics (FPGA) → Data acquisition (DAQ) → Data-driven System for Neutron Instrumentation (Based on Kafka)

CSNS neutron detector development planning





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3 Summary

Large area ^{3}He tube array detector

Phase I

Achieved detector and electronics in vacuum and passed national acceptance

Started to develop ^{3}He tube array detector in vacuum for SANS

Cooperation instruments

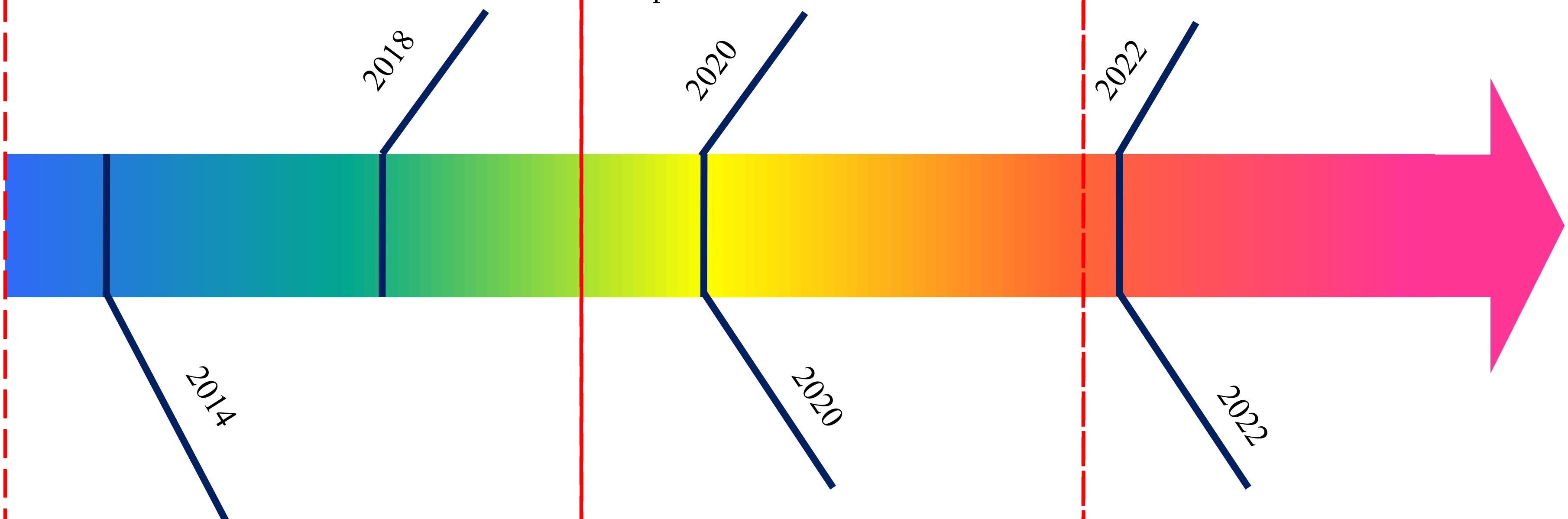
Developed ^{3}He tube array detector using standard module design, upgraded the electronics and improved the resolution for MPI

Started to develop ^{3}He tube and dedicated ASIC chip with low power consumption

Phase II

Realize ASIC-based electronics and self-developed ^{3}He tubes to serve the construction of CSNS phase II

Start the construction of CSNS phase II



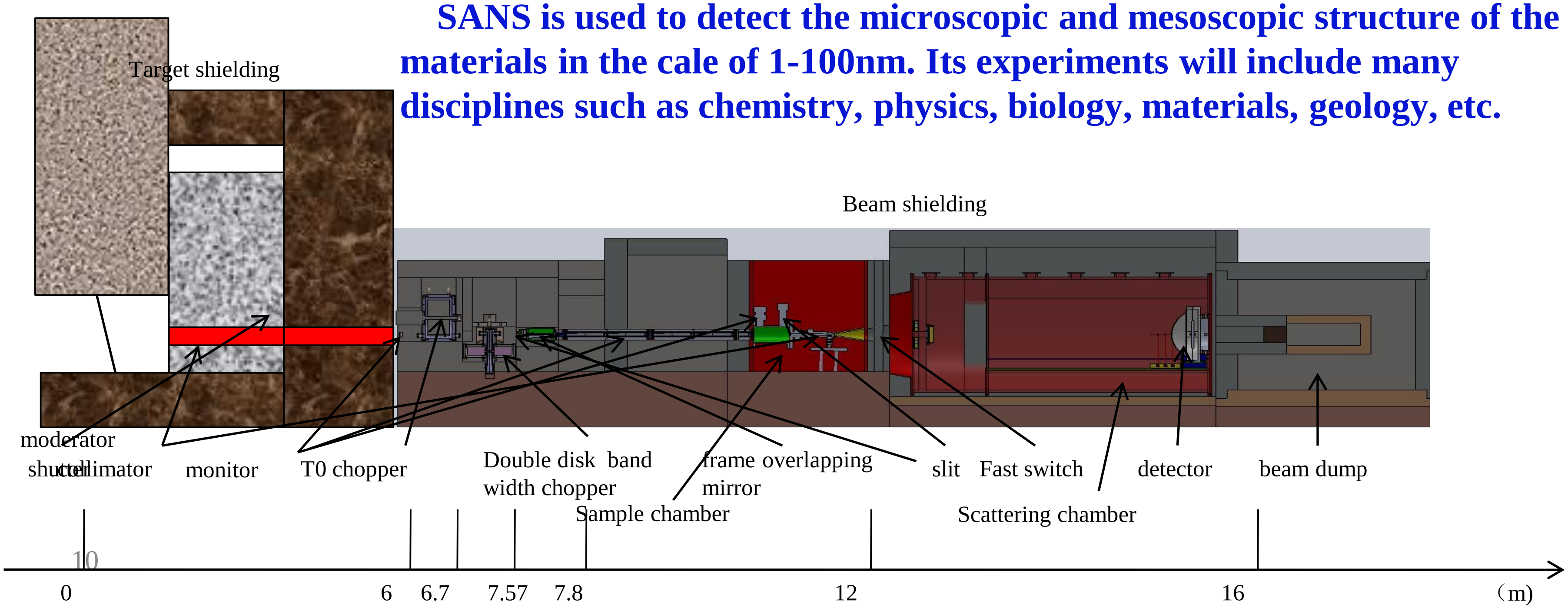
Small Angle Scattering instrument（SANS）

Scientific goals:

- **Data range of high confidence: 0.01~0.5 Å^{-1}**
- **Q_{min} resolution: ~30%**
- **Adjusted sample size**
- **Large sample loading space**

Moderator	CHM（20K）
MS distance	14 m
SD distance	1~5 m
Detector	**120 pcs ^{3}He 8mm PSD**
Effective area	100×100 cm^2
Resolution	1 cm (FWHM)
Δλ	0.4-8 Å
q range	0.004-3.4 Å^{-1}

SANS is used to detect the microscopic and mesoscopic structure of the materials in the cale of 1-100nm. Its experiments will include many disciplines such as chemistry, physics, biology, materials, geology, etc.



SANS large area ^{3}He tube array detector

SANS scattering chamber

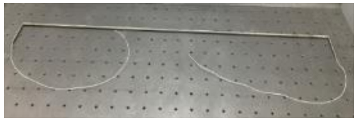
Front of the detector

Protective connector

Sealing welding

^{3}He tube

^{3}He tube with protective connectors

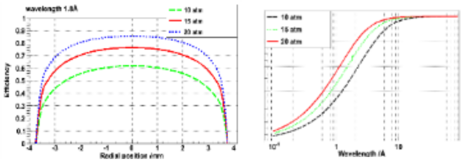


- The first domestically developed SANS detector
- The detector can work in a full range of vacuum enviroment.

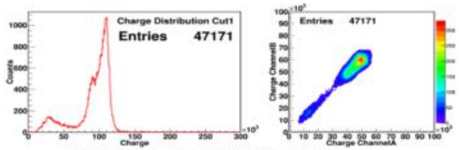
Neutron tests

Readout electronics

Neutron detection efficiency

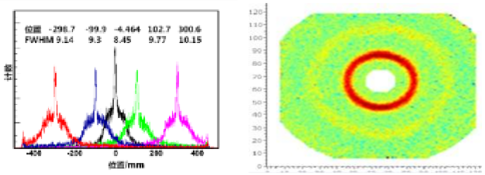


Detector output charge



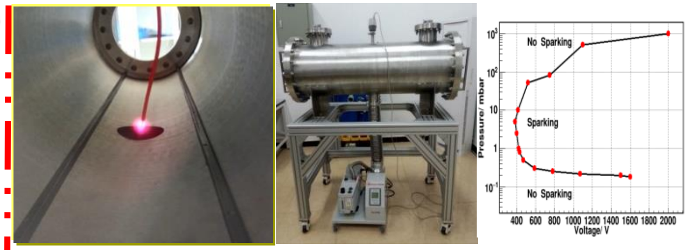
总电荷分布图（左）和两端电荷二维分布图（右）

Detector spatial resolution



- Spatial resolution: 9 mm，Detection efficiency: 81%@2Å
- Meet the requirement of large-area neutron detector in the vacuum for SANS

HV discharge experiment in vacuum

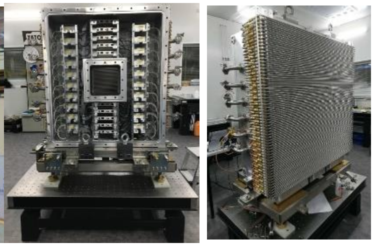


Massive sealing weld of ^{3}He tube

Straightness detection

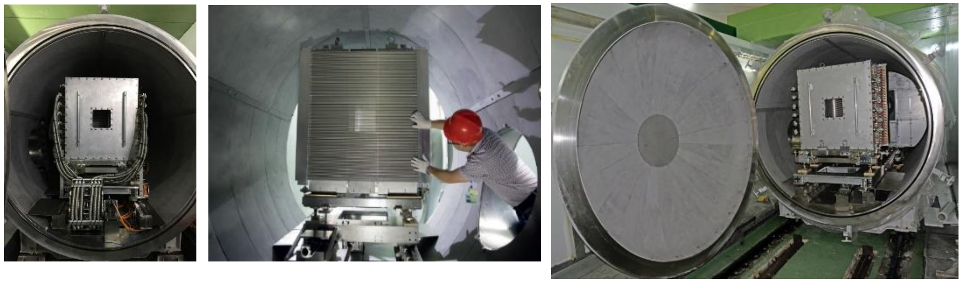
Mechanical manufacturing

Detector and electronics assembly



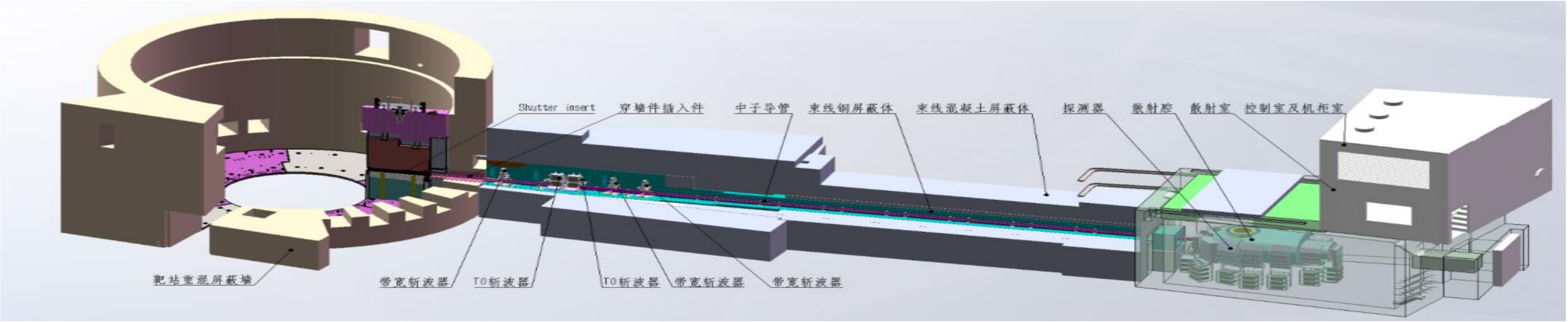
SANS detector installation @08, 2017

^{3}He tube array detector in SANS instrument

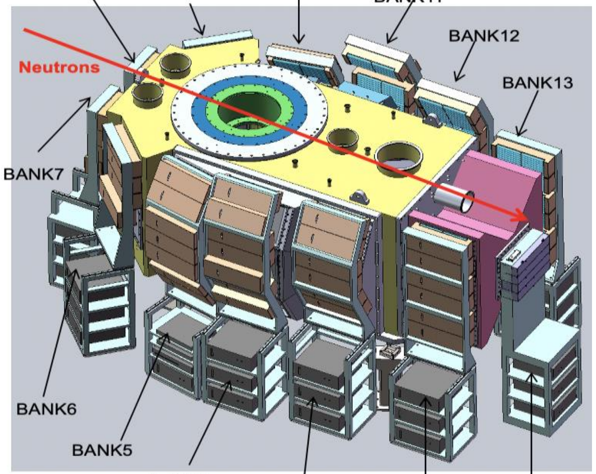


Multi physics instrument（MPI）

MPI can be used to conduct research on chemical engineering, crude oil and gas recovery, enviromental science,renewable energy,separation technology,food safety,biology and pharmacology, etc.

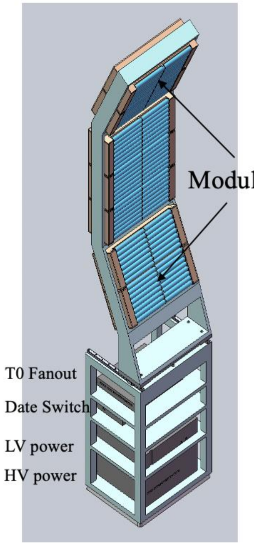


Mechanical design and detector module



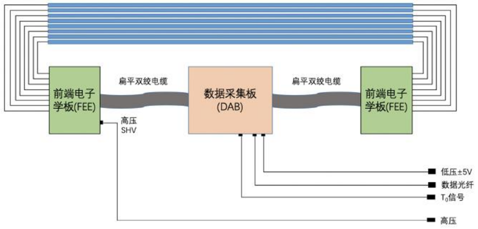
Detector system layout

Bank layout

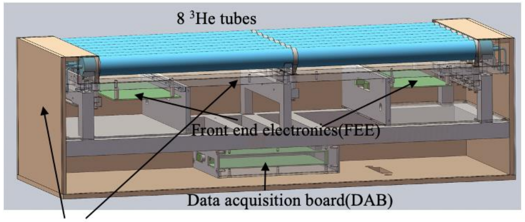


Self-developed readout electronics with high spatial resolution

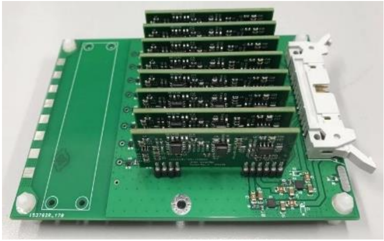
Schematic diagram of module



Structure of module



Front end electronics(FEE)



Data acquisition board(DAB)

Detector assembly, tests and installation

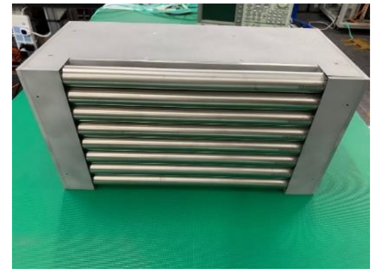
May 20-Nov. 15, 2020, Complete the batch assembly of modules and tests in Lab

Assembly and tests

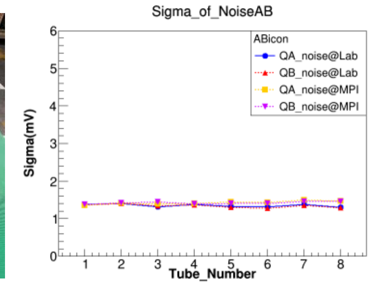
Assemble ^{3}He tube

Assemble elctronics

Module appearance



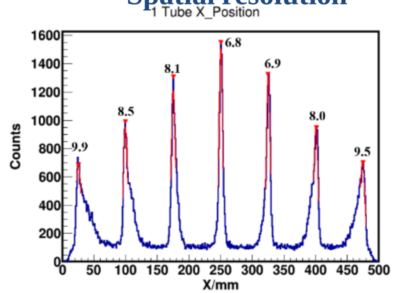
Noise level 2mV



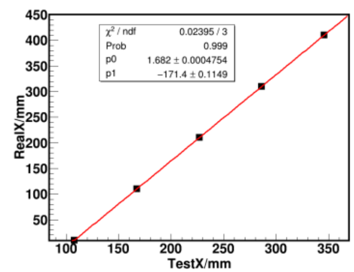
Oct. 26-Dec. 10, 2020, Complete the detector calibration and the system tests at BL20

System test at BL20

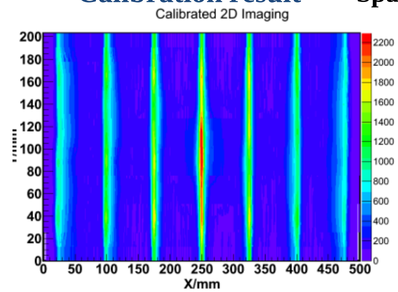
Spatial resolution



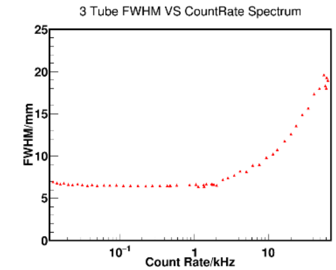
Calibration curve



Calibration result



Spatial resolution with counting rate



Dec. 6, 2020-Mar. 5, 2021，Complete the detector installation and commissioning with the instrument

Bank assembly site

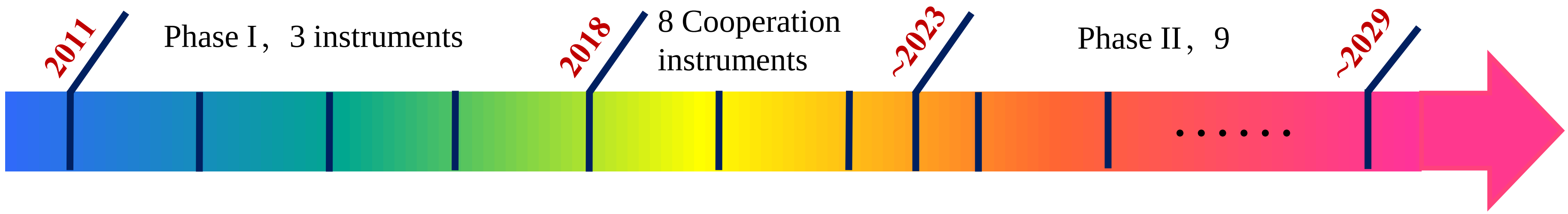
Bank assembly

Bank installation

Monitor installation

Detector installation

Demand analysis on ^{3}He tube detector for CSNS



~ 6000 ^{3}He tubes will be used, ¥100,000 each, about ¥ 600 million in total！

Periods	Technical specifications	Qty	Instrument
2011-2018 (Phase I)	Diameter 8mm， effective length 1000mm， 20 atm	120	SANS
	Diameter 8mm， effective length 300mm， 20 atm	4	MR
2019-2023 (Cooperative instrument)	Diameter 25.4mm， effective length 500/300mm， 20 atm	544	MPI
	Diameter 8mm， effective length 1000mm， 20 atm	512	VSANS
	Diameter 12.7mm， effective length 500mm， 20 atm	928	HP
	Diameter 25.4mm， effective length3000mm， 10 atm	264	HD
	Diameter 12.7mm， effective length 600mm， 20 atm	1376	High resolution
2023-2029 (Phase II)	Diameter 25.4/12.7/8mm， effective length300-3000mm， 10-20 atm	~2000	11 instruments

Self-development on ^{3}He tube detector

Since 2019, CSNS and China Nuclear Power Research Institute have concentrated on the collaboration and development of various types of ^{3}He tubes, aiming to provide mass-produced ^{3}He tubes for the large-scale scientific facilities in China.

- ^{3}He tube detector of three types：
  - –Diameter: 25.4mm, Length: 300-3000mm, 10-20atm
  - –Diameter:12.7/8mm, Length: 300-1000mm, 10-20 atm
  - –Anode wire resistance： 6-10kΩ/m，Diameter: ~15 μm
  - – Filling pressure accuracy： 0.01atm
  - – Batch deviation： ±5%
  - –Wall material： 304 stainless steel, Thickness: 0.2-0.5mm
  - – Connector： SHV/ wire leading

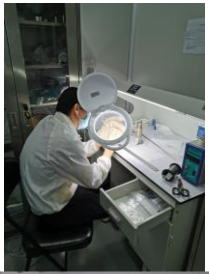
- Further interests：
  - –^{3}He tube detector with finer diameter， even 4mm/6mm
  - – High spatial resolution along the wire, ~2mm

Self-development on ^{3}He tube detector

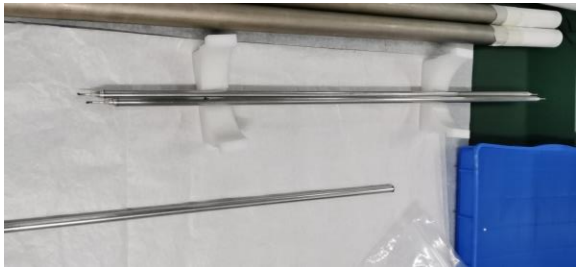
At present, **several types of ^{3}He tubes have been successfully developed. Beam test results at CSNS show that the critical performances have reached the level of commercial products,** and the feasibility of the technical scheme is initially verified.

Technical seminar

Anode wire welding

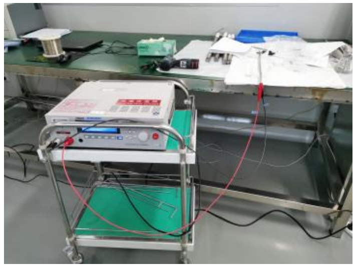


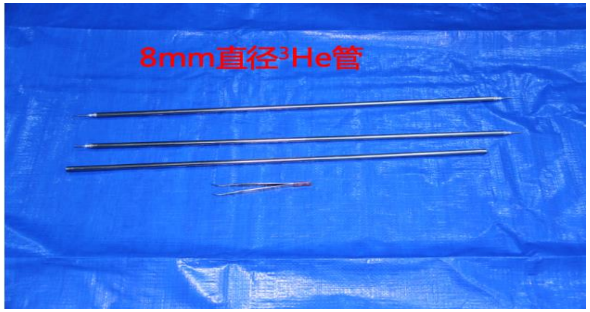
Assembly

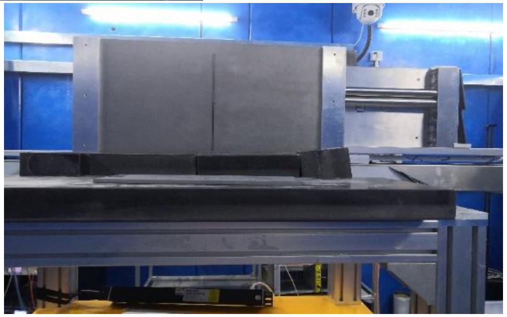


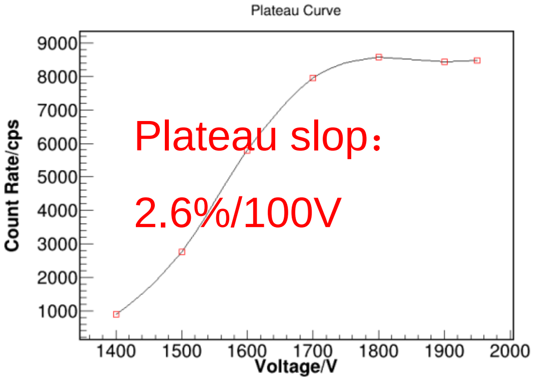
Laser sealing welding

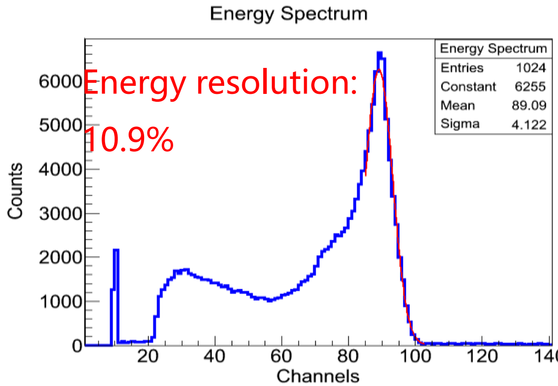
Leakage current test

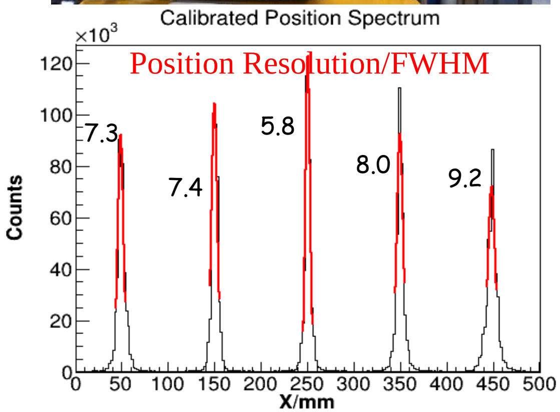






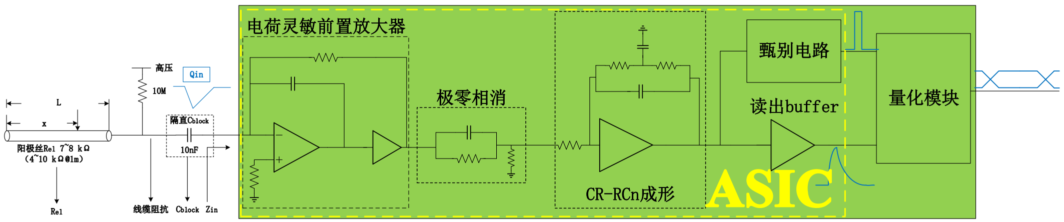






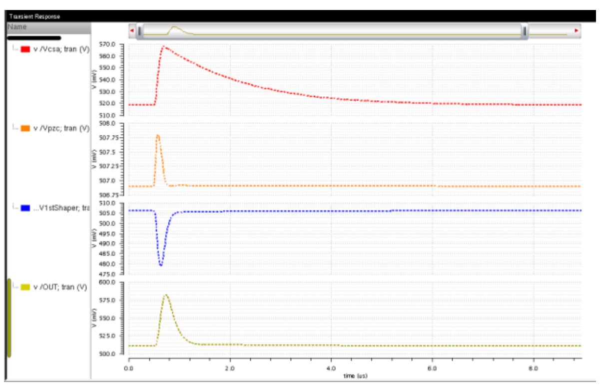
ASIC for front-end electronics

Schematic diagram of ASIC for low power readout of Helium-3 tube

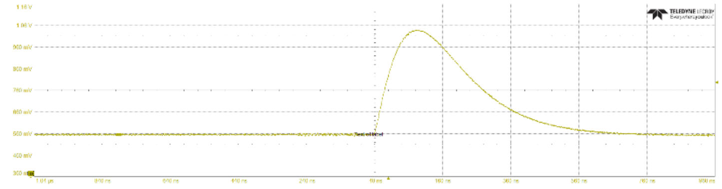


Parameters	Specification
Channels	8
Input charge range	10fC~1pC
Counting rate	500 kHz
ENC	1000 e-@15pF
Linearity	<5‰
Power Consumption	9 mW/Chn.

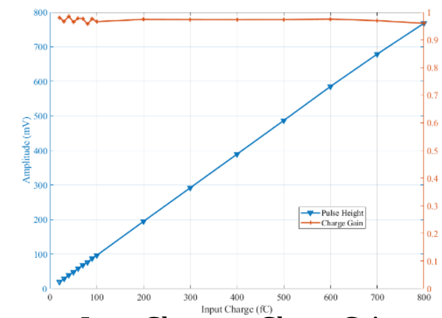
Simulation results when the input charge is 50 fC



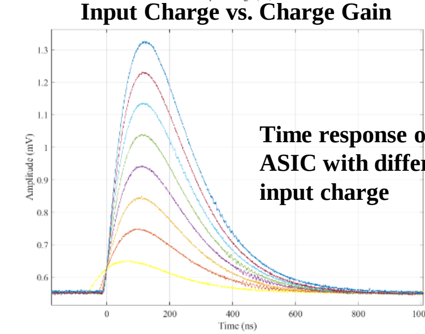
The chip die and test board



The measured waveform Qin = 500 fC



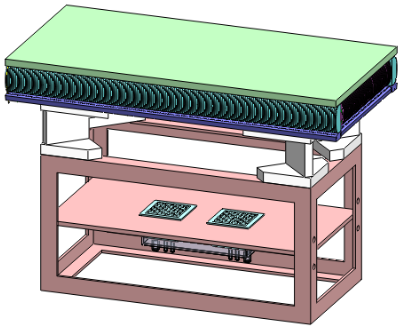
Input Charge vs. Charge Gain

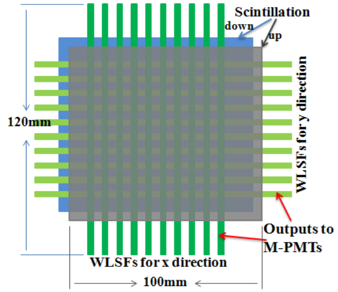


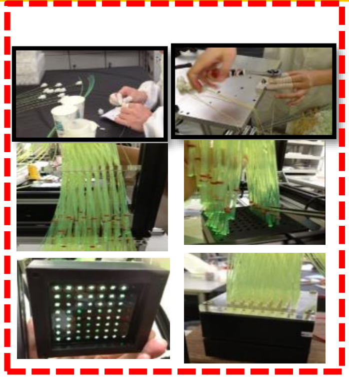
Time response of the ASIC with different input charge

We acknowledge Prof. Wei WEI in the IHEP for his strong guidance and advice on this ASIC chip.

Large-area scintillation detector (^{6}LiF/ZnS(Ag))





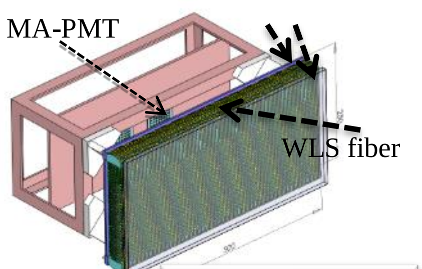


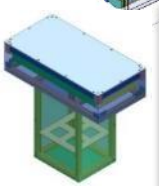
Time	2010~2018	2018~2021	2022~2028
Goals	**Scintillation detector V1** ➢ Breakthrough 0->1 ➢ PMT readout ➢low-cost and large solid angle coverage replacing ^{3}He tubes. ➢Dedicated ASIC readout electronics to realize the integration with detectors complted	**Scintillation detector V2** ➢SiPM readout, solve the probelm of non-uniformity of detection efficiency. ➢the optical fiber is bent at 90 degrees, reduce the dead zone of detection. ➢ Self-production on key components： • Transparent ceramics: LiF/ZnS(Ag) • Domestic LiF/ZnS(Ag) screen • SiPM readout	**Scintillation detector V3** **Ultra-thin new structure** **（There is no detector of the same type in the world）** ➢Thickness smaller than10cm without fibers， simplify the installation process and reduce the cost. ➢the scintillation screen inclined to improve the detection efficiency （50%@1Å）
Application	GPPD	GPPD-II(upgrade) ERNI, EMD and HP diffractometer	CSNS Phase II
Expand application	Fast neutron imaging detector（plastic scintillation screen+SiPM readout） Li glass optical fiber beam monitor（Li glass optical fibre+SiPM readout		

Large-area scintillation detector (^{6}LiF/ZnS(Ag))

GPPD-scintillation neutron detector

Double layer Scintillator
^{6}LiF/ZnS（Ag)



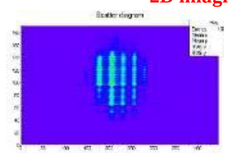


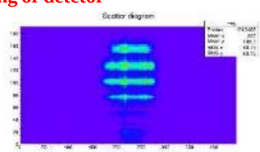
- The scintillator detector with this structure is realized in a large scale use for the first time in the world.
- Multi-anode photomultiplier tube and ASIC electronic digital readout are innovatively used.
- Large-scale scintillator detector arrays will become important candidate for large area coverage of neutron detection.

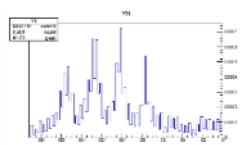
- Innovative detector manufacturing process for mass-production
- Obtained 5 invention patents

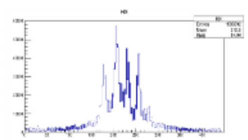
Data acquisition interface

2D imaging of detctor

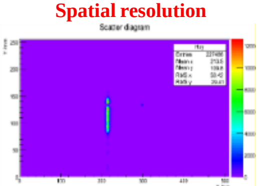




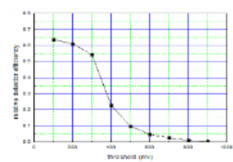




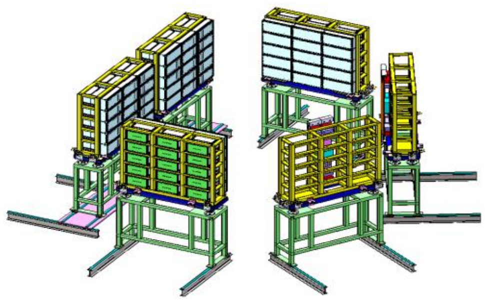
Spatial resolution



Detection efficiency



- Spatial resolution: 2mm, detection efficiency: >50%@2Å;
- The performances meet the requirements of GPPD for large area of neutron detector



The scintillation detector array

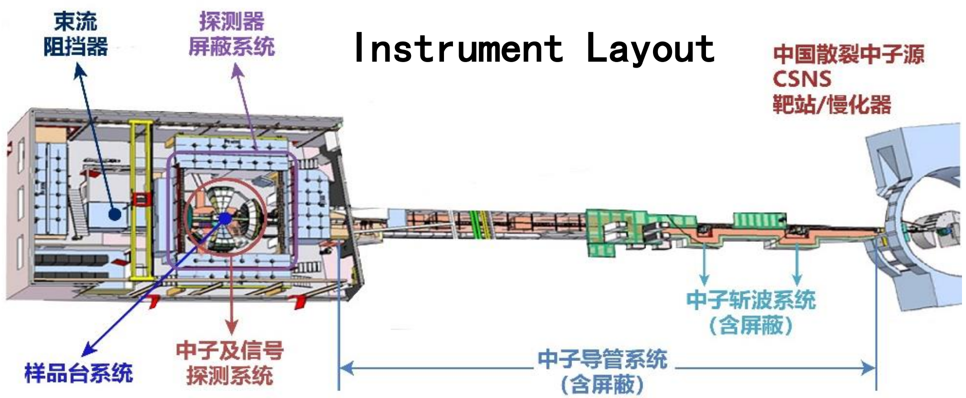
3*5 detector array

40 detector moduls

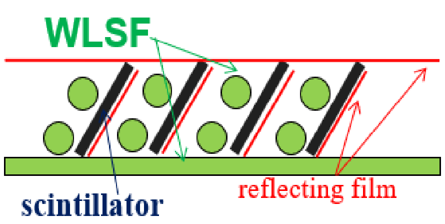
- Integrated detector module, front-end digital for fast readout, highly integration design, easy assembly and maintenance
- The detector can realize large area coverage, expected to be applied in neutron scattering and imaging experiment

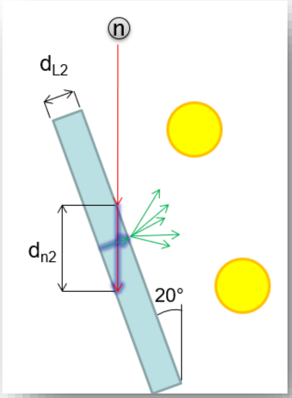
Engineering Materials Diffractometer(under construction)

Detector solution：^{6}LiF/ZnS(Ag)+WLSF+SiPM

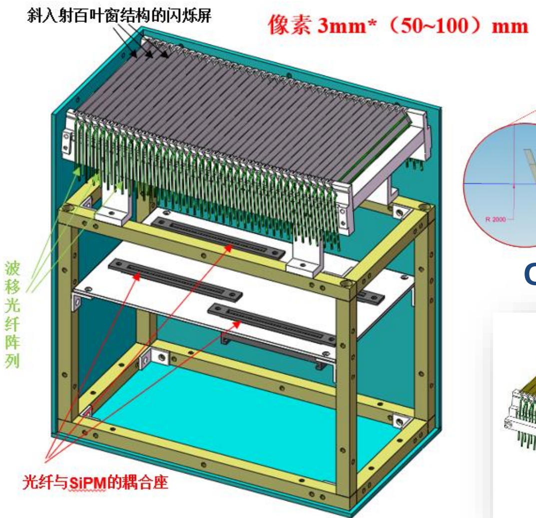


The oblique incidence detector

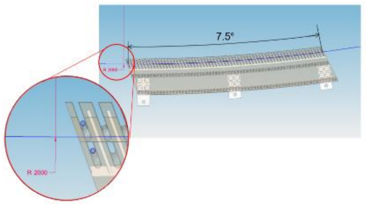




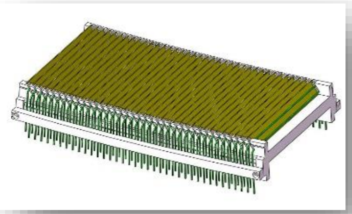
- Oblique screen can effectively improve the efficiency of neutron detection

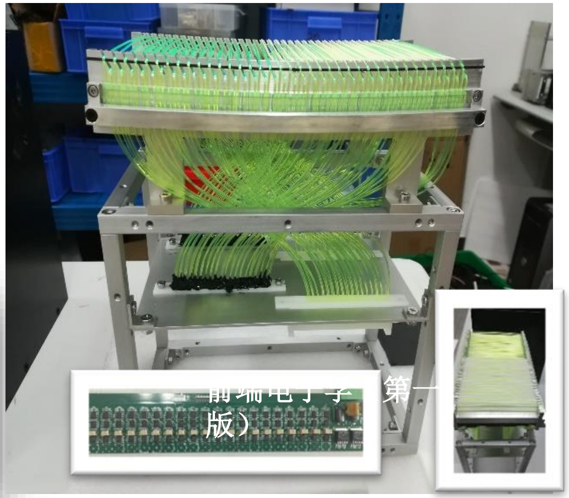


Schematic diagram of detector structure



Curved detector head



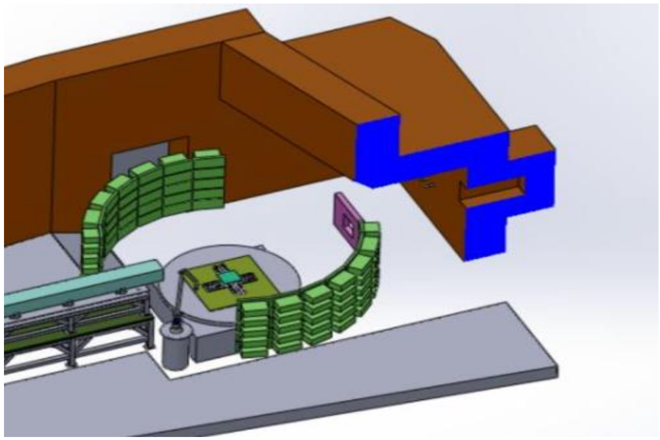


Technical parameters:

- Detection efficiency：
  40％ @ 1Å
- Position Resolution：
  3mm(H) × 50mm(V)
- Time Resolution ：
  1μs
- Count Rate：
  80 kHz
- Module size：
  200mm × (100~50) mm

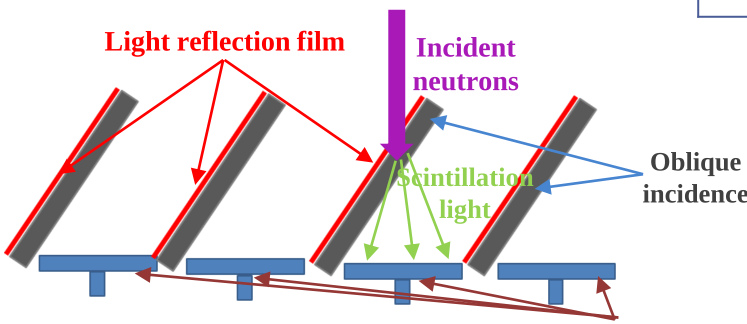
Energy-Resolved Neutron Imaging instrument (under construction)

Schematic diagram of diffraction detector



Detector requirements

Diffraction detector	**Distance from samples**	2 m
	Resolution Δd/d	< ~0.6% at 90 degree
	Specifications	Scintillation detector 90° Banks: **pixel size 3mm x 3mm, efficiency 40% @ 1 Å** other Banks: pixel size 3mm x 50 mm, efficiency 40% @ 1 Å
	Detector coverage	Horizontal coverage angle: 5 ~ 170 ° Vertical coverage angle: ±20°

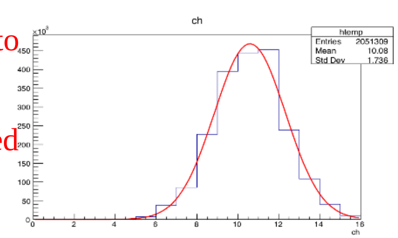


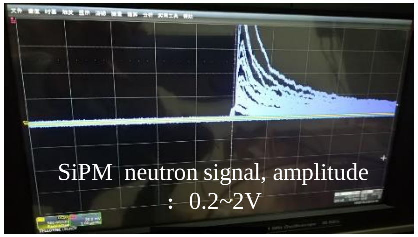
Schematic diagram

Detector prototype effective area: 5cm×5cm

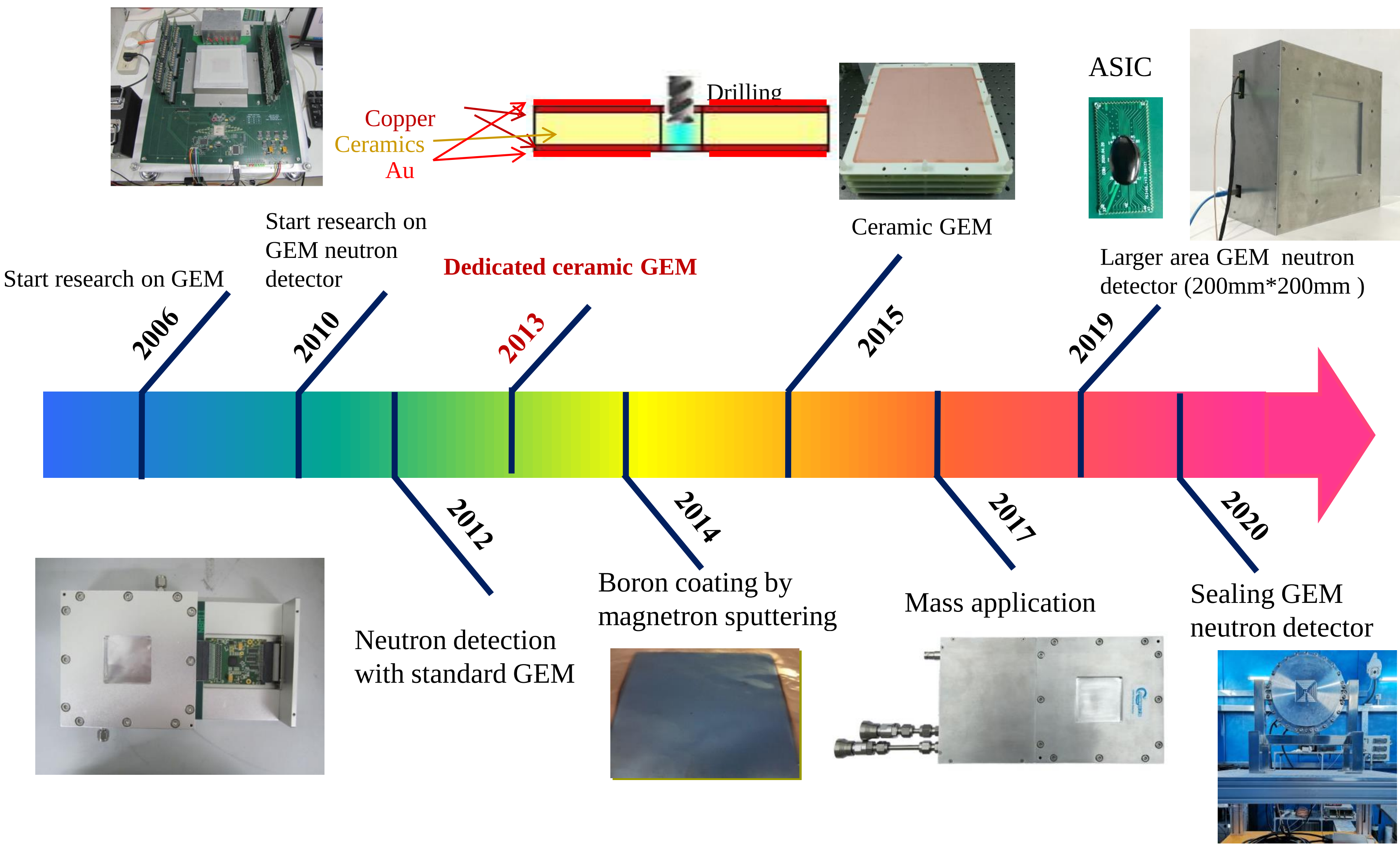
- The scintillation light induced with neutrons is collected by 3~5 SiPM units, and the position of the incident neutron is calculated by the centroiding method to improve the spatial resolution.
- Difficulties: Need for ADC-based ASIC electronics, SiPM and electronics need lots of channels and highly cost.

Scintillation light distribution in SiPM





High-resolution GEM neutron detector



High-resolution GEM neutron detector

Excellent performance

Independent and controllable

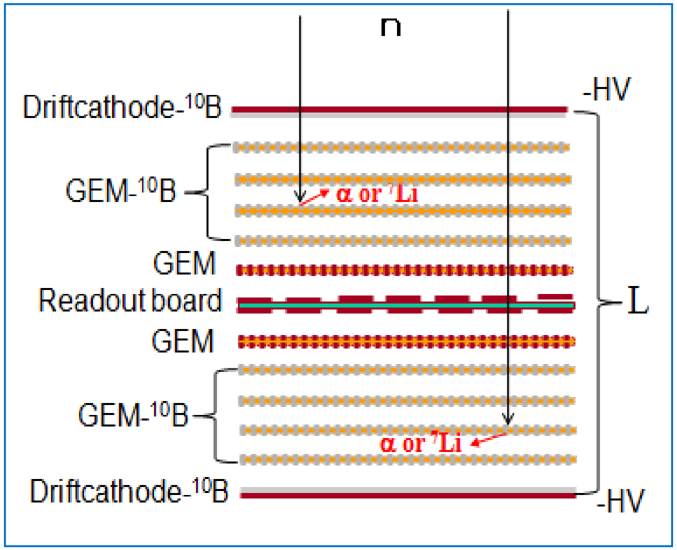
Production system

Aiming at the application of neutron instrument

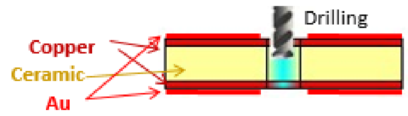
Solve the key technologies

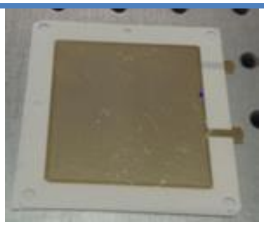
Goals： 1. Replace ^{3}He-based detectors
2. Localization, system construction
3. Advanced level

Physical design and M.C. simulation of detector

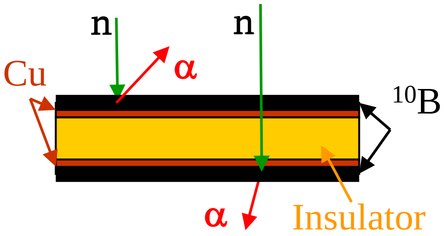


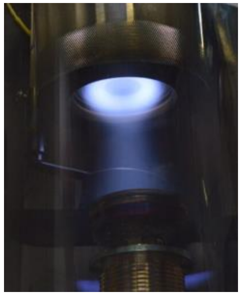
Three key technological breakthroughs



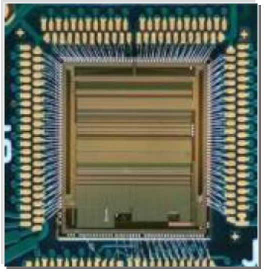


Mass production of ceramics GEM invented by CSNS





Large-area boron coating by magnetron sputtering



Dedicated ASIC chip and fast FPGA-based digital electronics

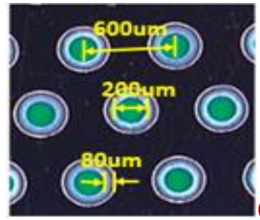
Detector And Applications

Dedicated ceramic GEM for neutron detection

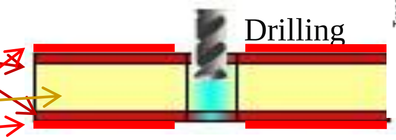
In 2013, the dedicated GEM was proposed： reduce hydrogen containing materials, easy to assemble, operate and maintain, self-developed in China

Specifications：

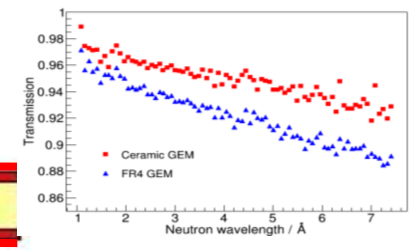
- **Substrate:** composite ceramics
- **Processing technology：** standard PCB mechanical drilling
- **Parameters：** thickness 0.2 mm, hole diameter 0.2mm, pitch 0.6mm, accuracy 50μm, Rim 80 μm
- **Mass production yield：** ~80%

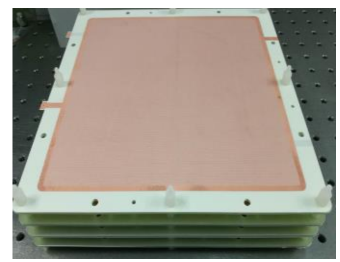


Production processing



Neutron transmittance





惠州金百泽——"厚型气体电子倍增器用电路板技术成果转化"科技成果鉴定会

Active area： 200mm×200mm							
Institute	**GEM type**	**Insulator substrate**	**Hole d(μm)**	**Pitch p(μm)**	**Copper thickness (μm)**	**Total thickness (μm)**	**Copper coverage rate η**
CERN	Standard GEM	Kapton	70	140	5	60	77%
	THGEM	FR4	200	500	10-20	200-500	85%
	nGEM	Kapton	70	210	5	60	90%
KEK	GEM	LCP	70	140	5	100	77%
CSNS	**Ceramic GEM**	**Ceramic**	**200**	**600**	**20**	**200**	**90%**

Dedicated ceramic GEM for neutron detection

Production process of Ceramic GEM

Mechanical drilling

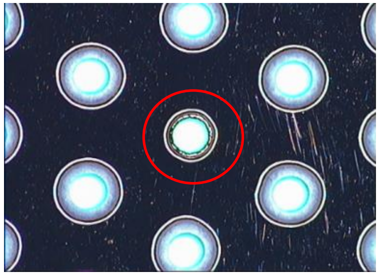
Corrosion

Chemical cleaning

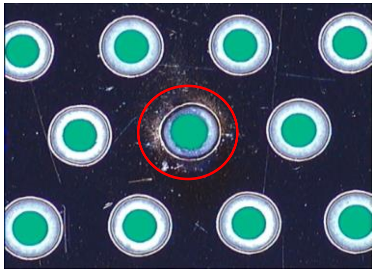
Plate making

ultrasonic cleaning

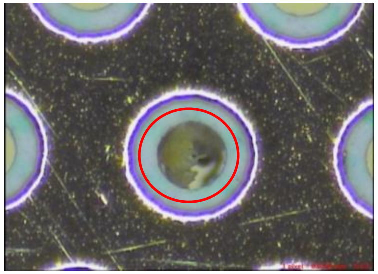
Common problems and improvement:



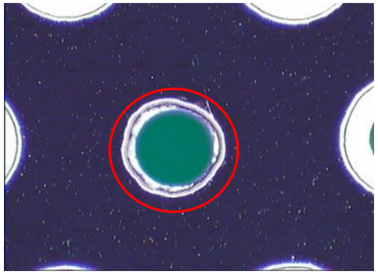
Inconsistent pore diameter



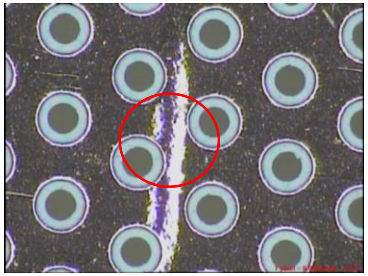
Irregular pores



Foreign matter in pore

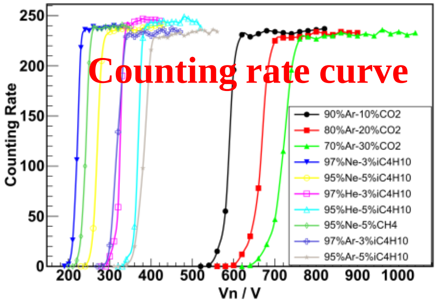


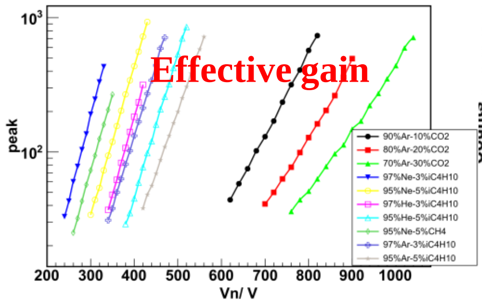
rim edge is not corroded



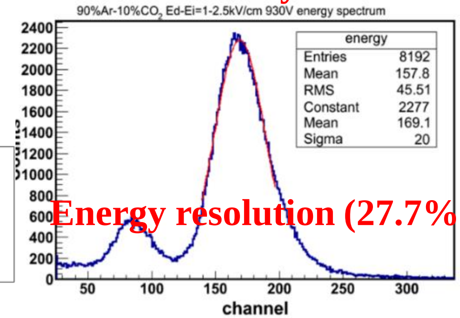
Scratches

Improvements：replace the drill bitmore frequently, ultrasonic cleaning, improve the printing ink baking time and packaging

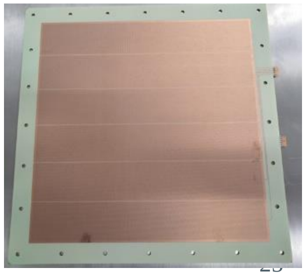




X-ray beam test



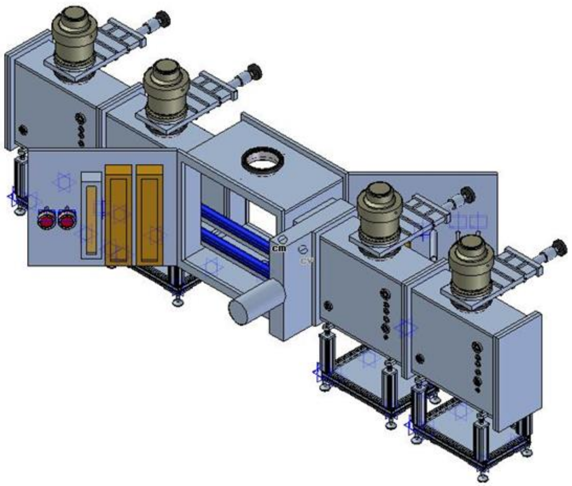
300mm*300mm@2020

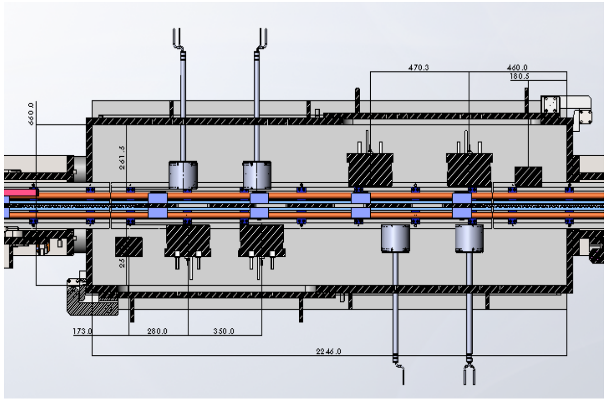


Large-area boron coating by magnetron sputtering

Research on Boron Coating Technology of Neutron Convertor (Jingtao Zhu)

According to the characteristics of the boron coating process, develop a special large-area coating facility with max coating area of 1500mm*500mm.



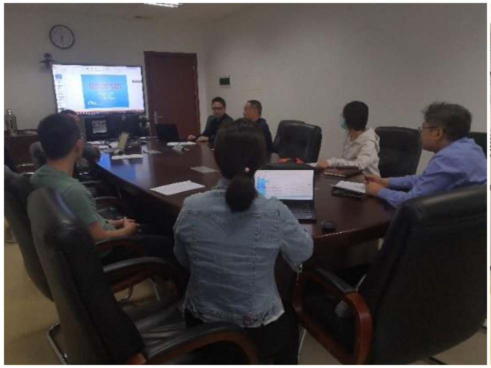


Main components:

- Sputtering chamber
- Magnetron target
- Sample frame and transmission system
- Intake system
- Vacuum pumping system
- Vacuum measurement system
- system
- Electronic and computer control system

Magnetron sputtering coating facility

Acceptance meeting

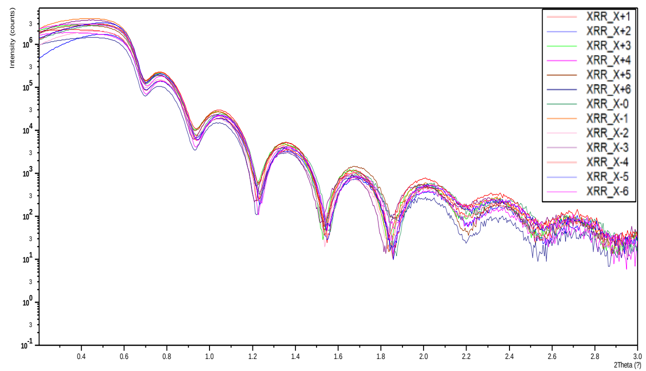


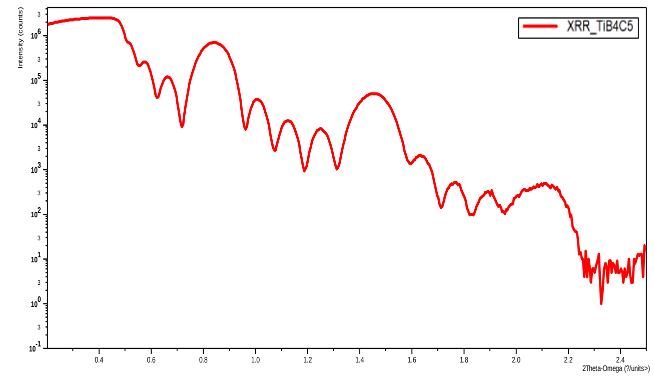
Acceptance experiments

Commissioning and acceptance were completed in October 2020, it has been put in use now.

Large-area boron coating by magnetron sputtering

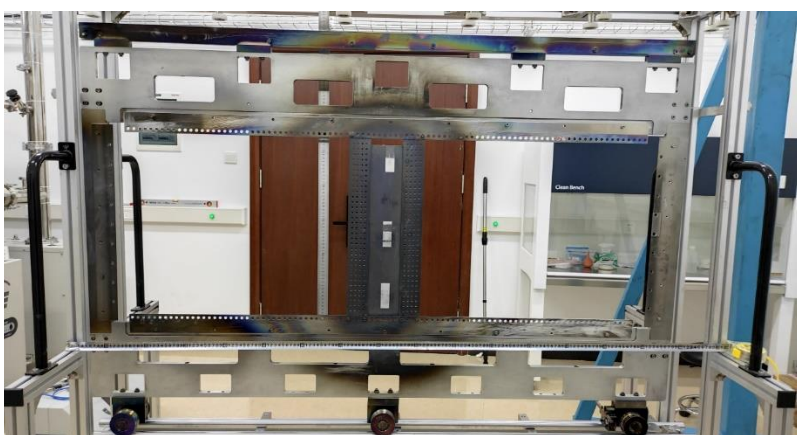
Research on Boron Coating Technology of Neutron Convertor

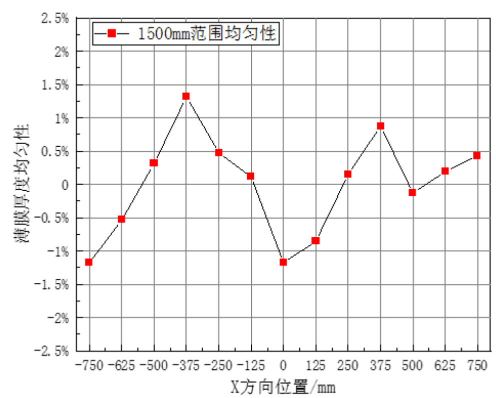


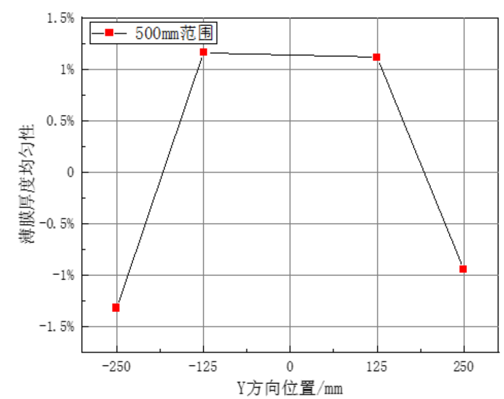


The thickness control precision **1nm**, deposition rate **0.075nm/s,** Target sweeping speed 3.25mm/s. It takes about 4 hours and 27 times of sweeping the target to coat 1 μm thick film.

Double-sided Ti/B_4C film sample



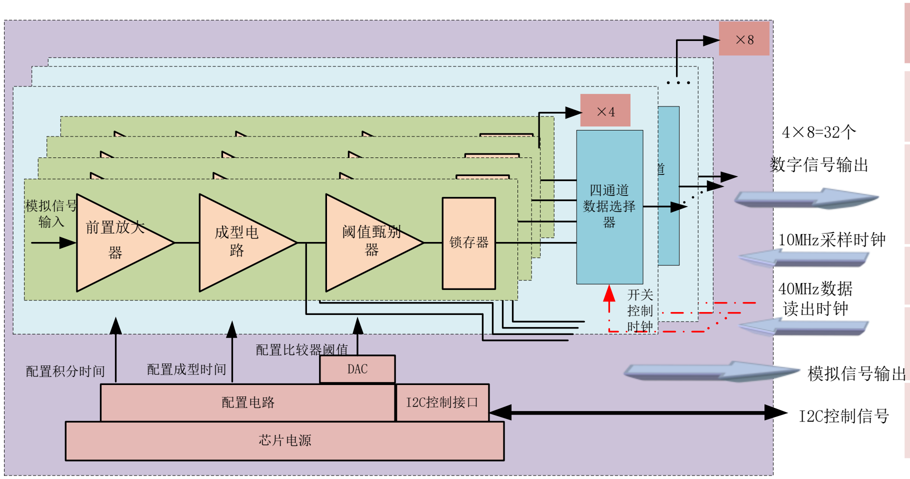




Test results： thickness non-uniformity is ≤±1.32% and ≤±1.32% along 1500mm and 500mm

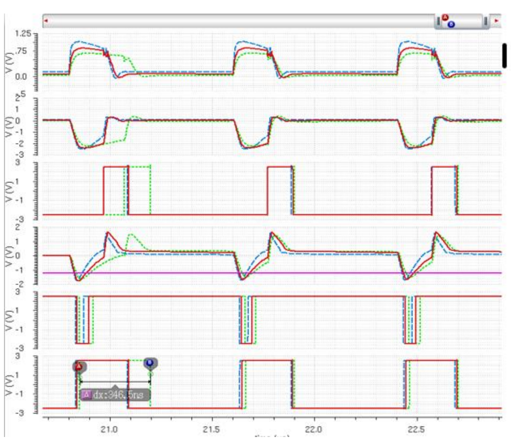
ASIC chip development

Principle diagram of ASIC for fast readout of GEM (Yichao Ma)

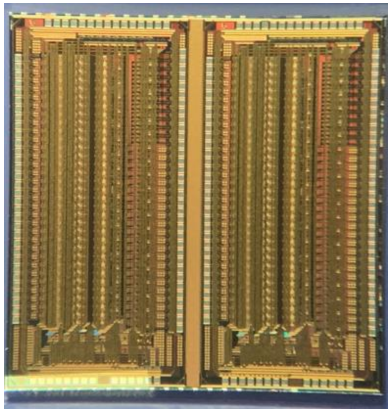


Parameters	Specification
Input charge	±10fC ~ ±400fC
Counting rate of single channel	> 1MHz
Channels	32
Output characteristics	Digital signal: 2.5V TTL
Threshold	External DAC is adjustable

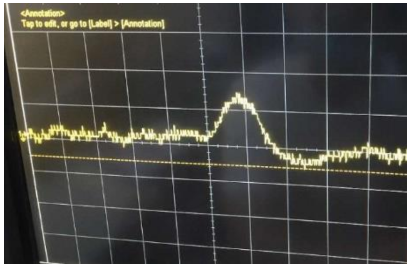
Simulation results when the input is -400fc/1.25Mhz

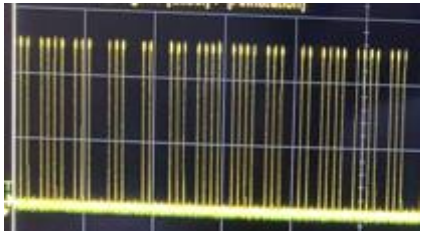


Chip photo under microscope 2.5mmx5mm



COB package module 2cmx1cm



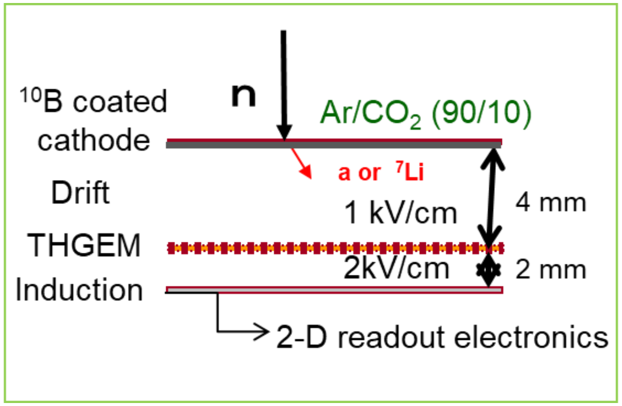


160 chips available, COB packaging and the performance were completed in May 2020

(1) 2D position sensitive neutron beam monitor

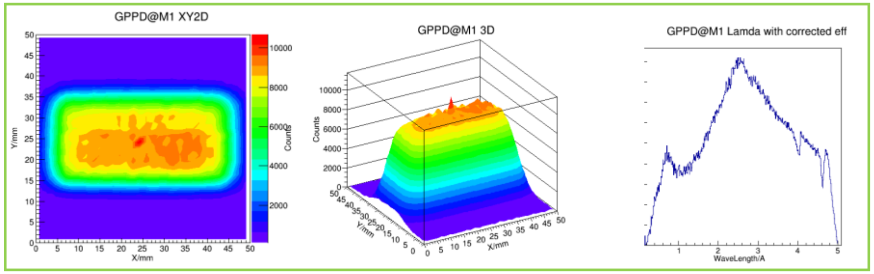
Seven GEM beam monitors were used during phase I of CSNS. They operated successfully for 5 years. It has been considered as standard solution of monitor at CSNS.

Configuration:



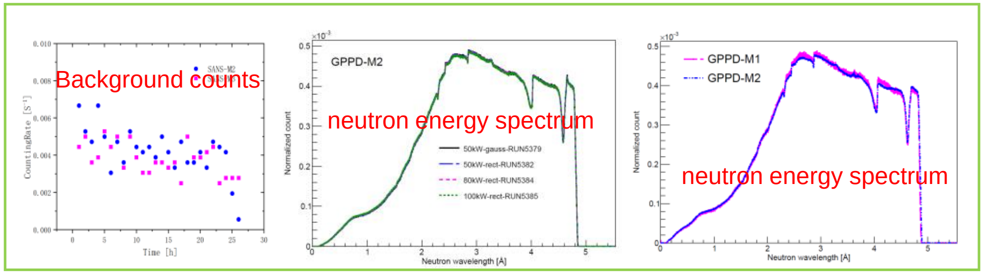
Parameter	Specification
Active Area	50mm*50mm
Max. Neutron Flux	10^8 n/cm^2.s
Pixel size	1.56 mm
Efficiency@1.8Å	0.1 %
Max Counting Rate	1.7 MHz
Working mode	Real-time

Beam Profile at Guide Exit of GPPD @2017



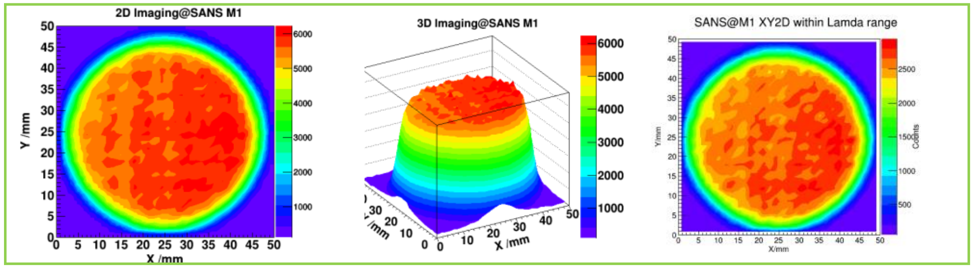
First neutron beam profile measured on November 1, 2017

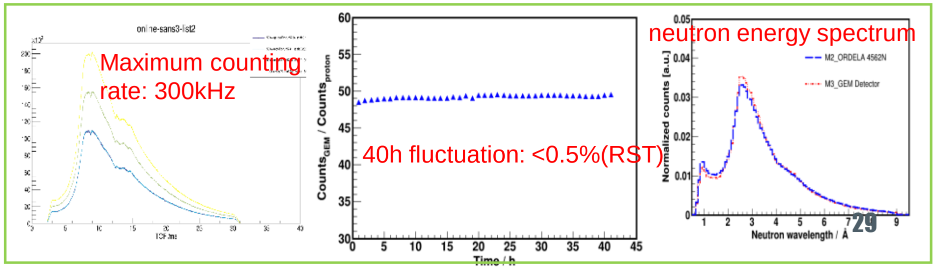
Beam Test at GPPD@2020



2-3Å

Beam Test at SANS@2019

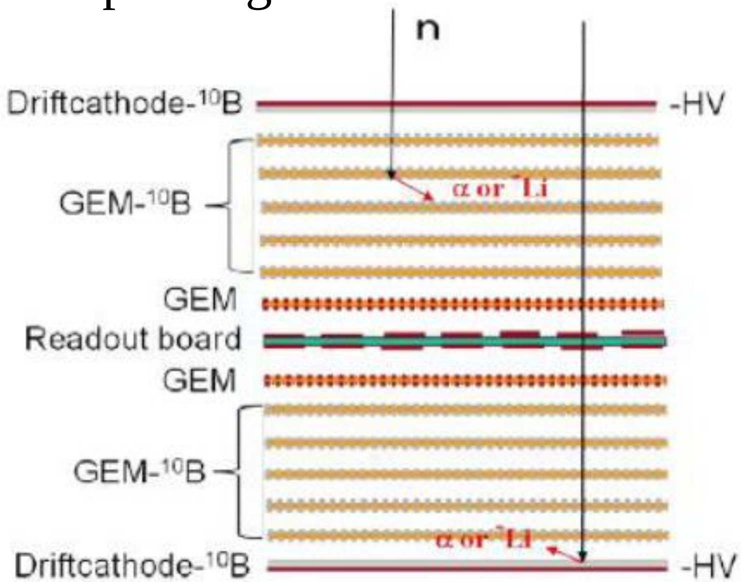




（2） High-efficiency and large-area GEM neutron detector

A high-efficiency and large-area GEM neutron detector was developed to meet the requirements of ENRI and VSANS.

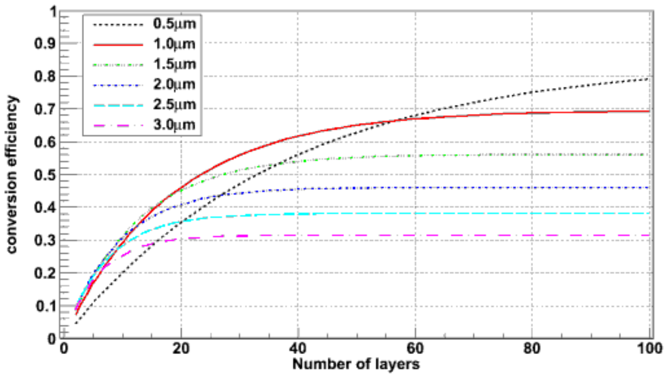
Principle diagram

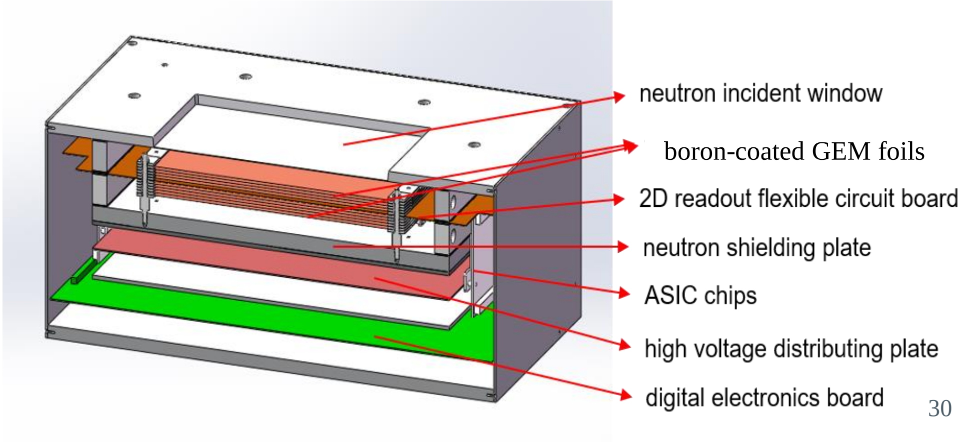


Design specifications

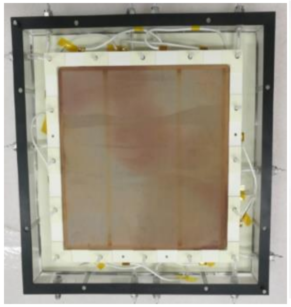
Parameter	Specification
Active Area	200 mm* 200mm
Efficiency	~40%@2Å
Spatial Resolution	≤ 3mm (FWHM)
Ceramic GEM	Pitch：600μm, hole：200μm, thickness:200μm
Boron Convertor	^{10}B:>96%, thickness：1.2 μm
Pixel size	0.78mm
Electronics	64 Ch/ASIC × 8+FPGA+Ethernet
Channel No.	256Ch(X)+256Ch(Y)=512Ch

Detection efficiency vs convertor



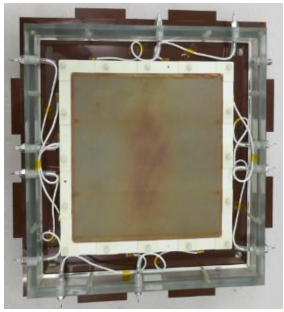


（2） High-efficiency and large-area GEM neutron detector



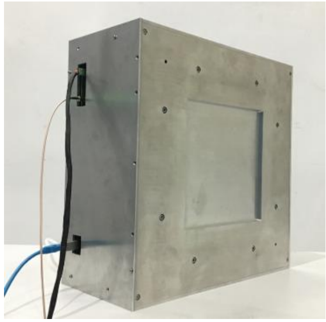
Detector inside

Readout board

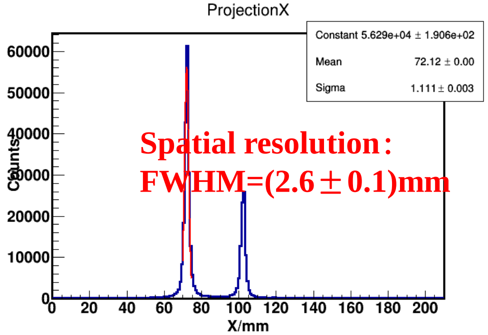


Detector inside

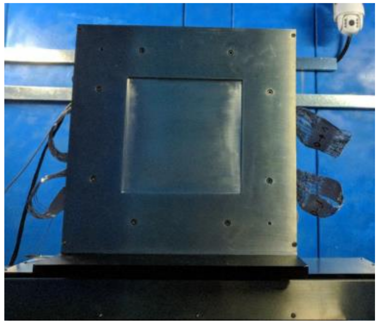
Detector side



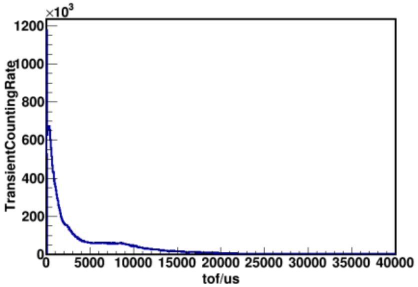
Detector appearance

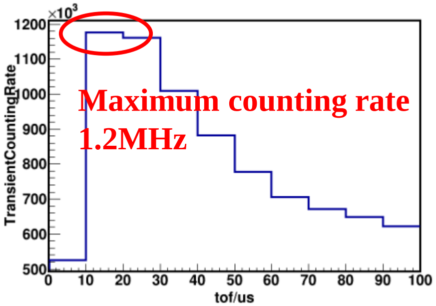


Spatial resolution

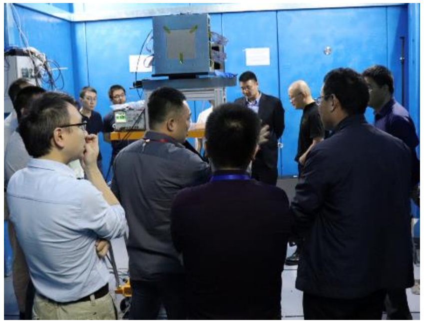


Experimental setup

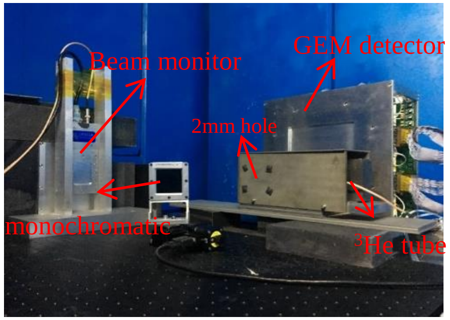




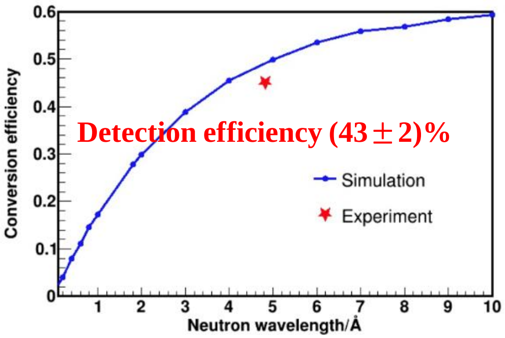
Instaneous counting rate spectrum



Technical test and acceptance @2019.04.19



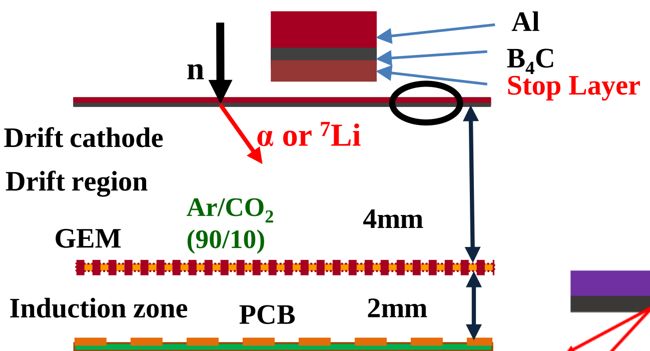
Detection efficiency measurement



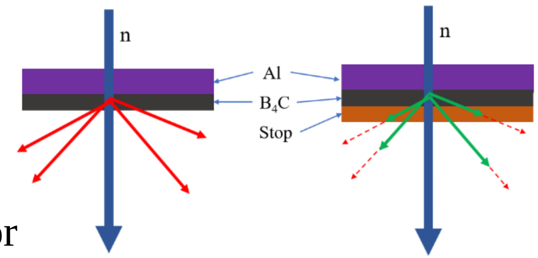
Detection efficiency result

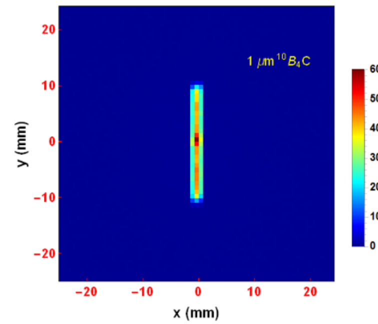
(3) High-resolution GEM neutron detector

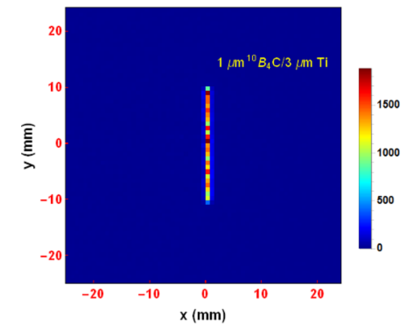
A sub-mm high resolution GEM neutron detector is developed to meet the requirements of ERNI



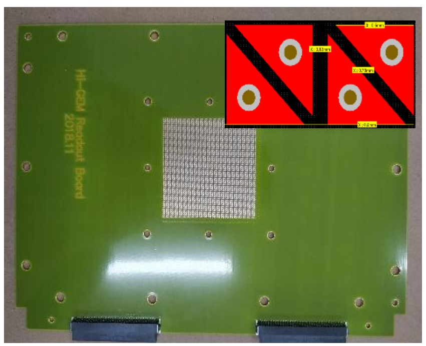
3.0μm thick Ti stoping layer is coated on B_4C, pitch period is 0.78mm, drift region gap is 4 mm, spatial resolution can reach sub-mm scale.

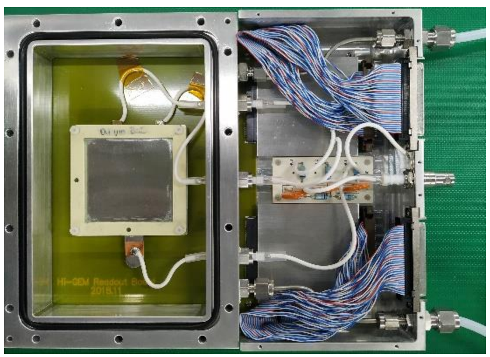


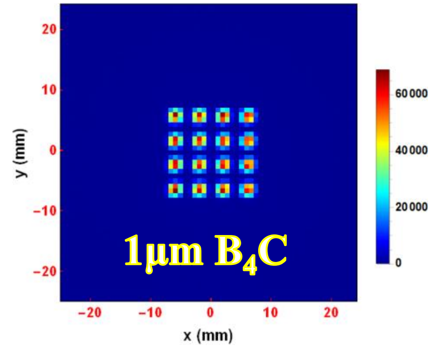


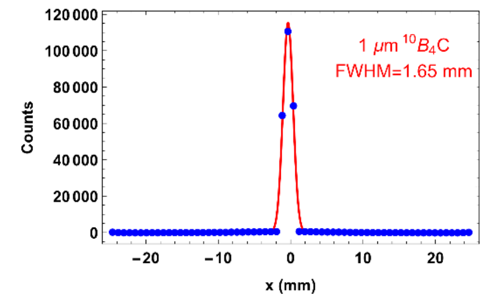


High-resolution detector

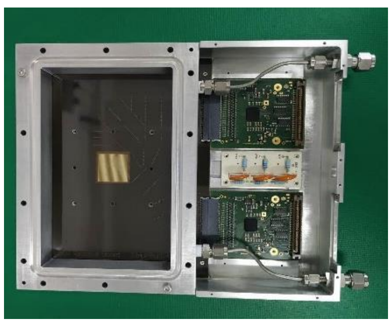


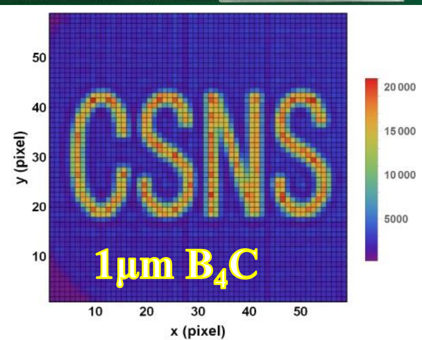


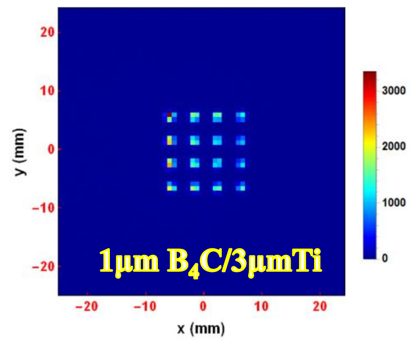


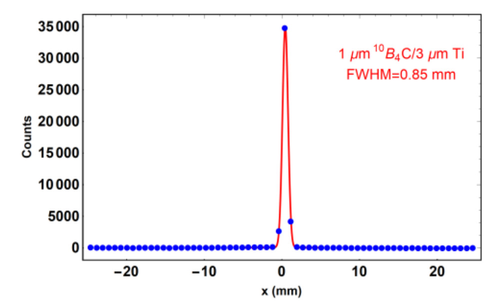


Spatial resolution





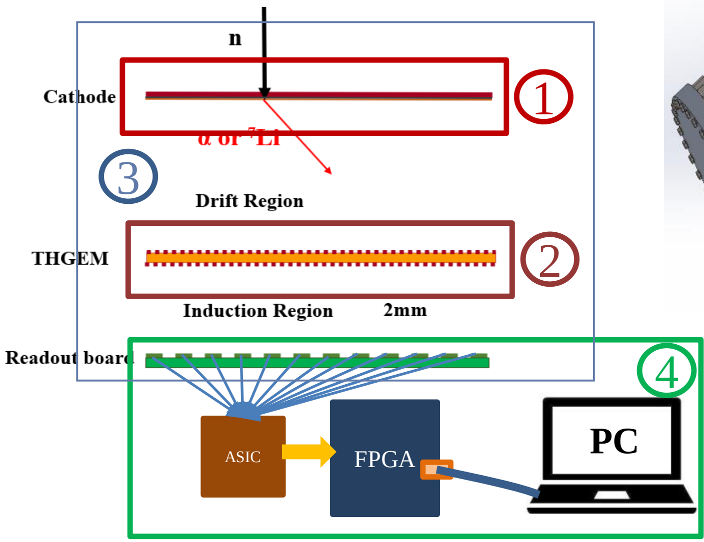




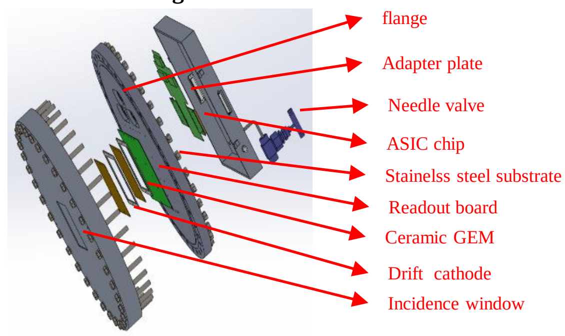
(4) Sealed GEM neutron detector

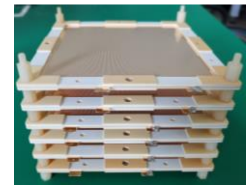
A sealed GEM neutron detector is developed to be used in vacuum of instruments

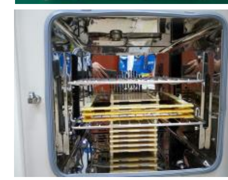
Detector structure

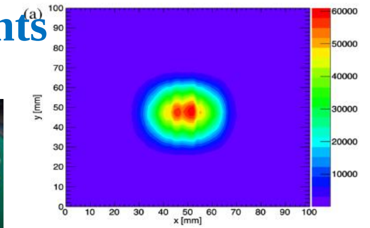


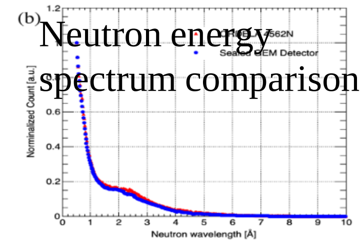
Mechanical design of detector

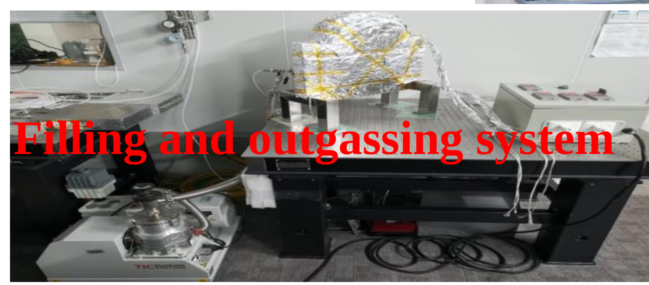


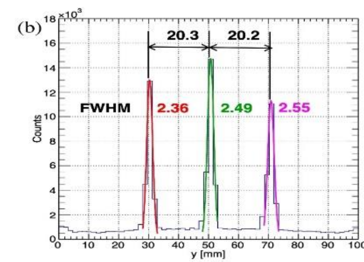




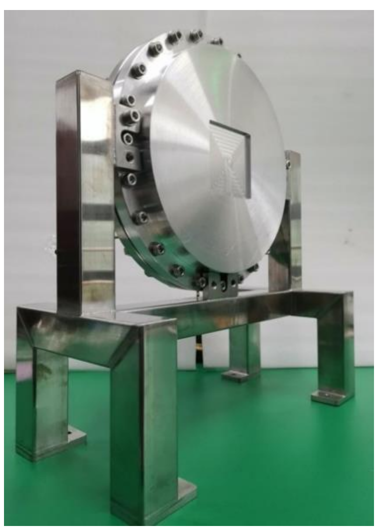


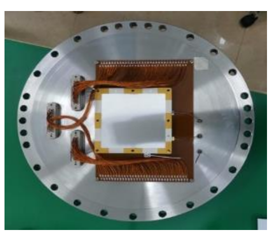


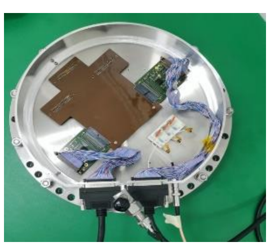


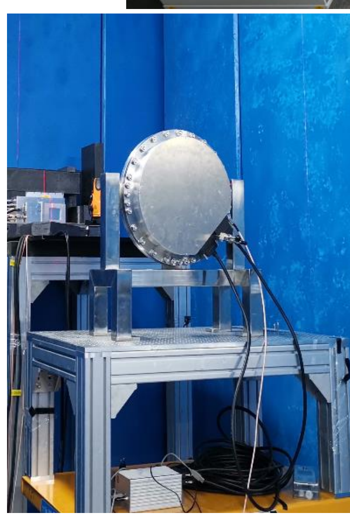


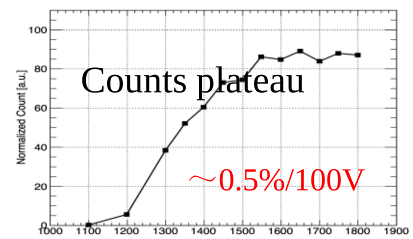
Sealed GEM neutron detector

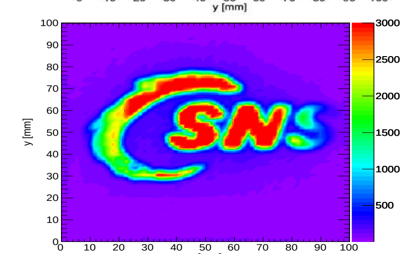


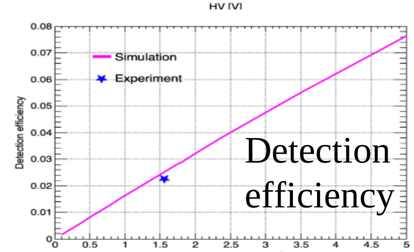


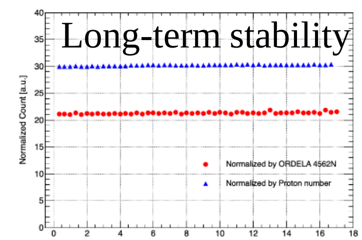












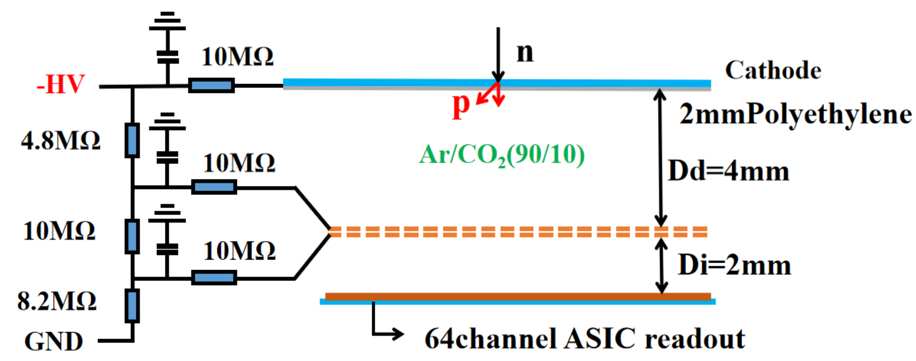
(5) Fast neutron GEM detector

Application: fast neutron flux measurement for Atmosphere Neutron Irradiation Spectrometer

Requirements:

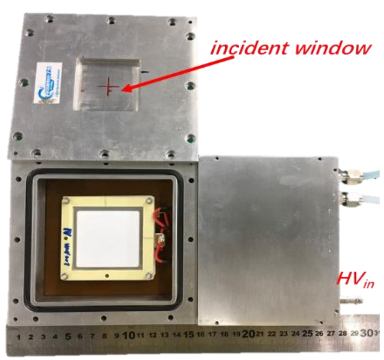
1. Spatial resolution ≤ 3mm
2. Detection area ≥ 10cm*10cm
3. Counting rate ≥ 1 MHz

Fast neutron detector by using recoil protons

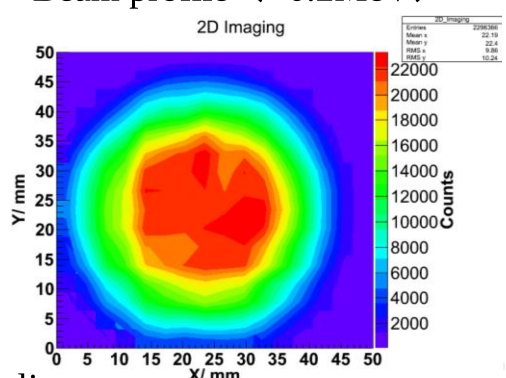


Beam tests at Back-n Beamline of CSNS

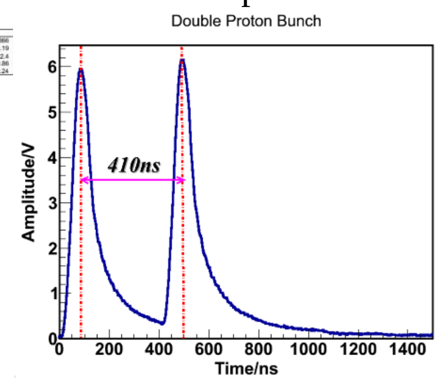
Fast neutron GEM detector



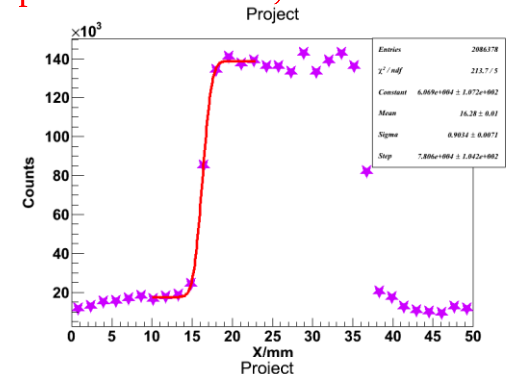
Beam profile（>0.2MeV）



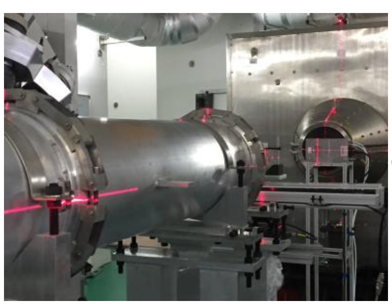
TOF spectrum

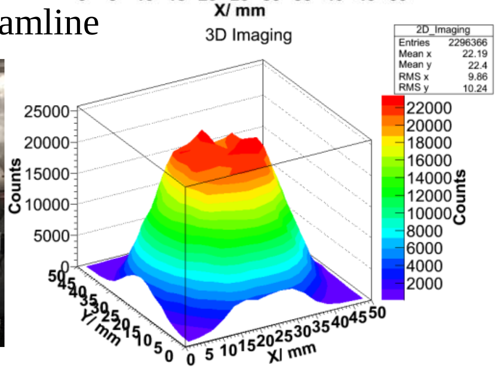


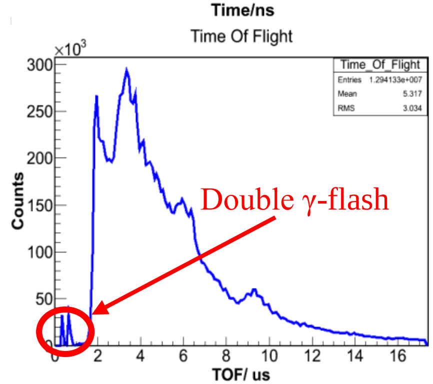
Spatial Resolution, FWHM~2.1mm

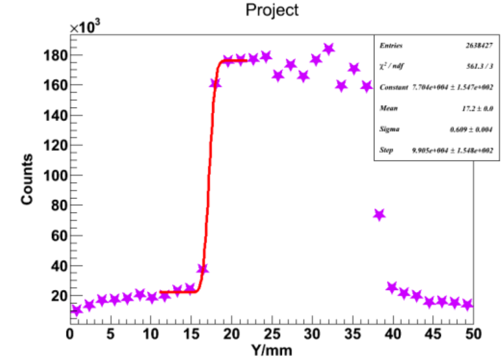


Experiment at Back-n Beamline



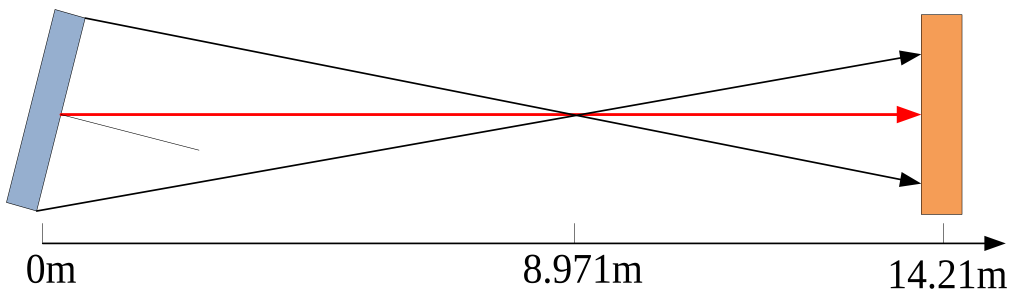




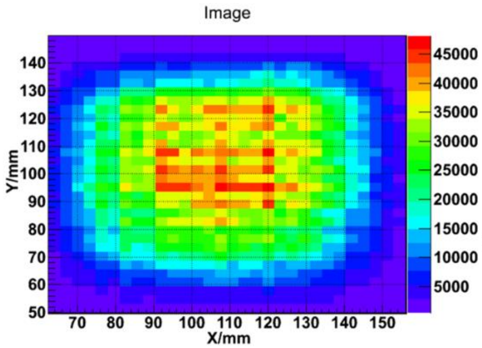


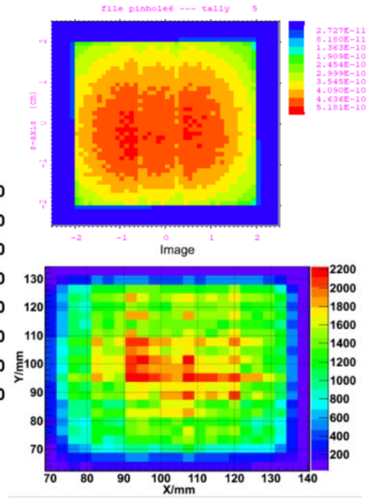
Neutron imaging experiments using GEM detector

Pinhole neutron imaging on the moderator of CSNS (Songlin Wang)



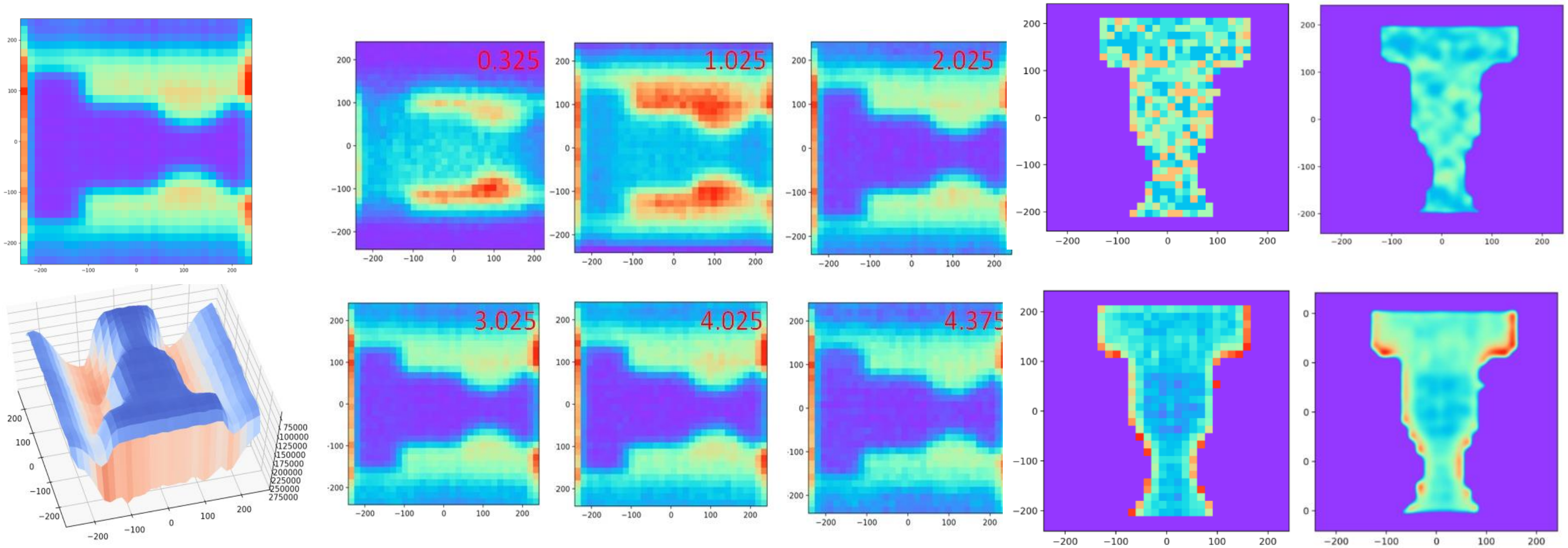
Neutron distribution





Neutron wavelength：>2.86Å

Bragg edge imaging experiment of 304L steel at GPPD(Jie Chen)

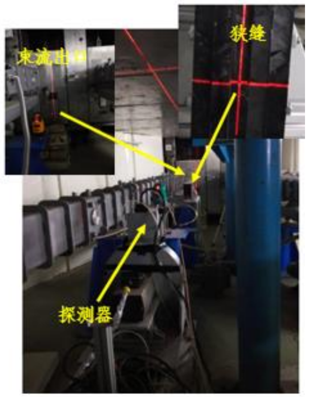


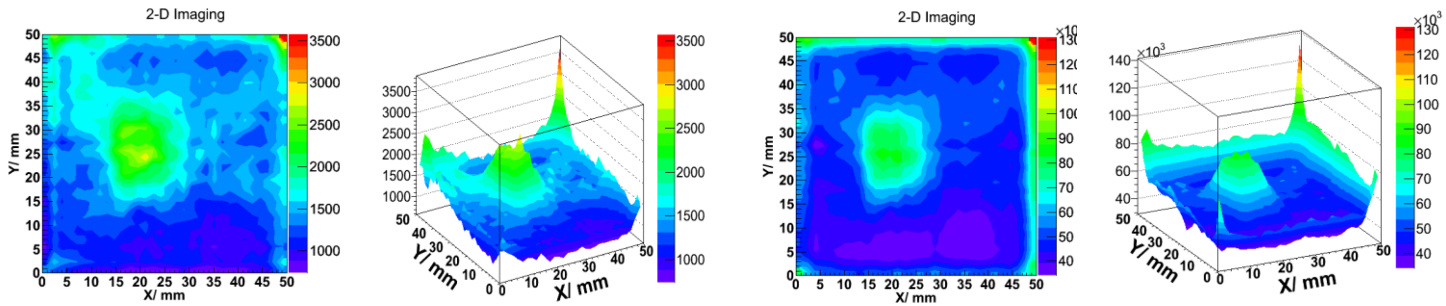
Stress distribution

Texture distribution

Typical applications on other scientific facilities

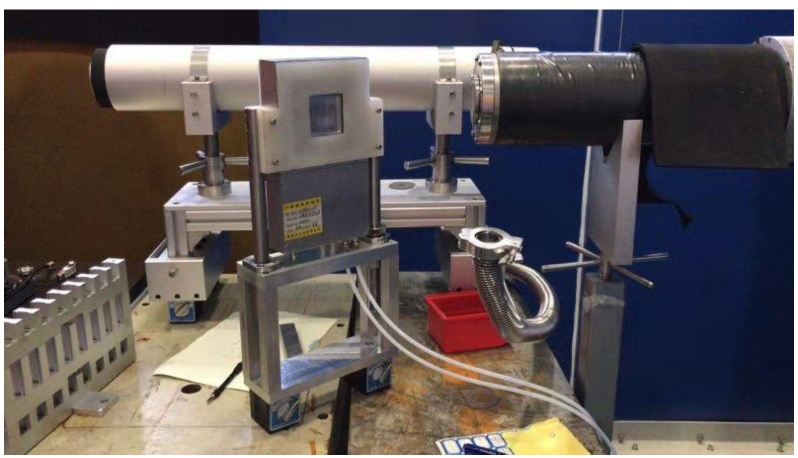
Neutron beam diagnosing detector @CARR





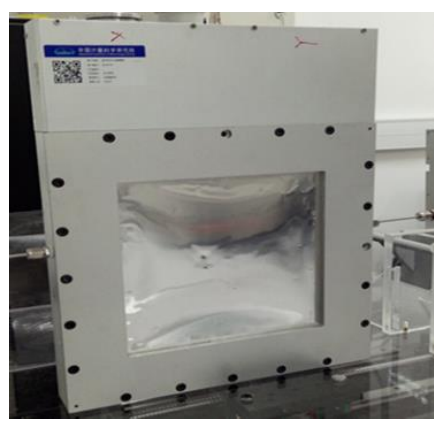
Neutron beam measurement under different power at CARR reactor

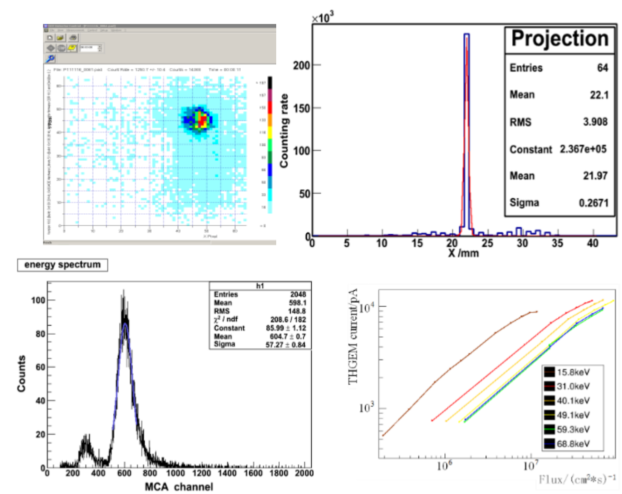
Neutron beam monitor @CMRR



SANS monitor at CMRR

X-ray tracing detector@ National Institute of Metrology





X ray tracking and dose measurement

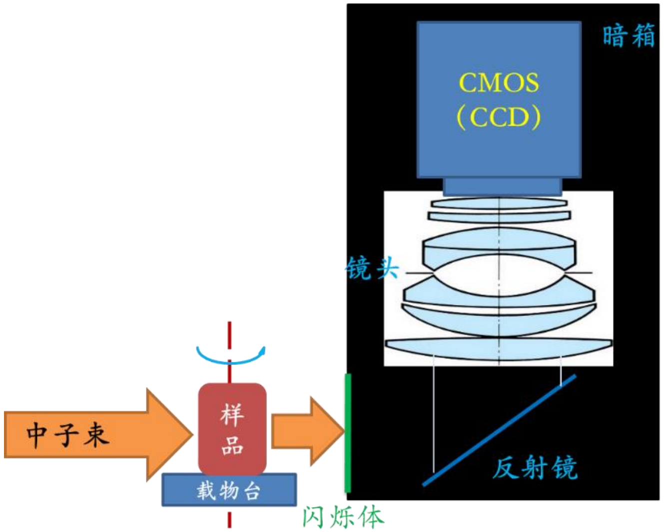
Neutron imaging detector

Goal: Develop multi-types of neutron imaging detector for CSNS, aiming for ultra-high spatial , timing resolution and large FOV .

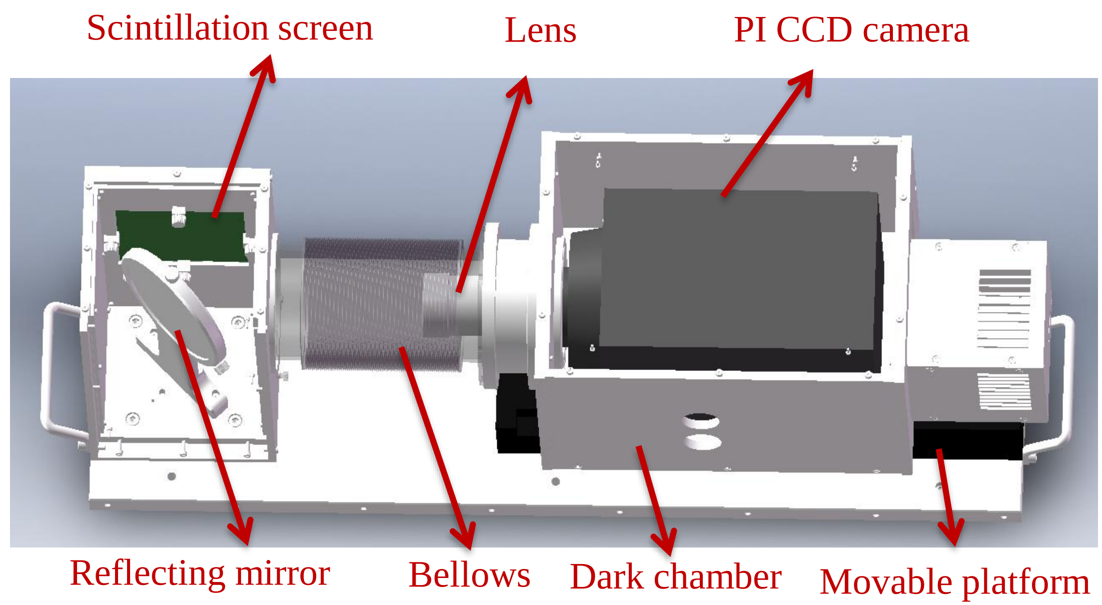
	High resolution	General purpose	Large area	Time resolution
Detector types	Gd_2O_2S:(Tb) +CMOS	^{6}LiF/ZnS+CCD	GEM	1) ^{6}LiF/ZnS + TPX3Cam 2) nMCP + Pixel ASIC
Imaging area	<5*5cm^2	<20*20 cm^2	>20*20 cm^2	<5*5cm^2
Detection efficiency	~ 40%	~ 20%	~ 40%	~ 20%
Spatial resolution	< 30 μm	30~200 μm	~1000 μm	~ 100μm
Time resolution	None	None	1μs	1μs
Neutron flux	10^6 ~ 10^8 n/cm^2. s			
Pixels	512×512～2048×2048			

(1) Neutron imaging detector based on CCD camera

Schematic diagram

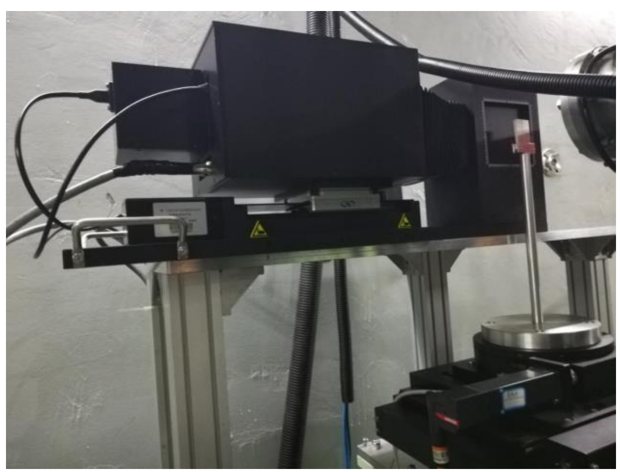


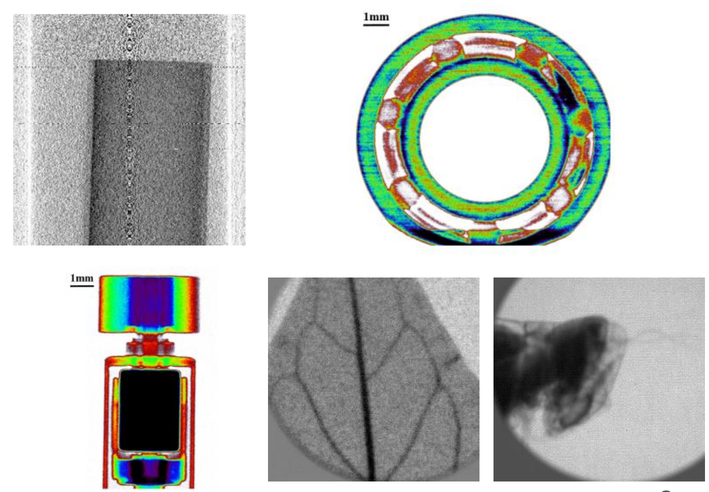
Detector structure and components



Key specifications:

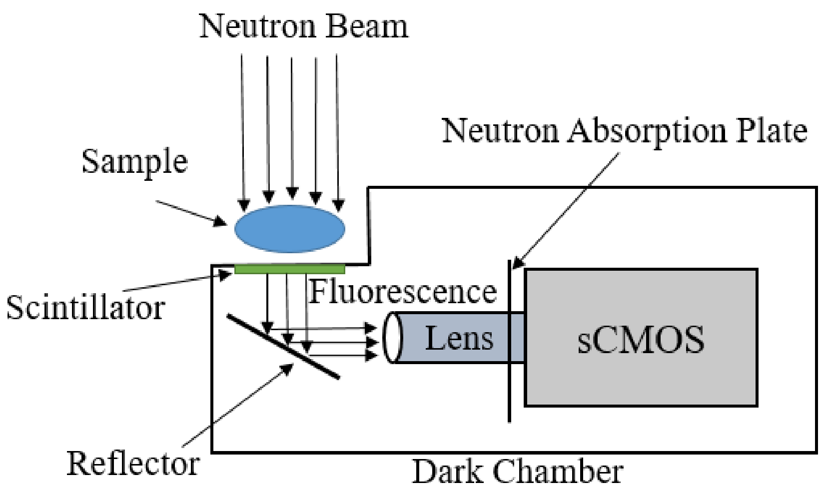
- Magnification: 0.15-1.0
- Working distance：90-438mm
- Field of view (FOV)：
  30mm*30mm->200mm*200mm
- Spatial resolution:
  30μm->200μm



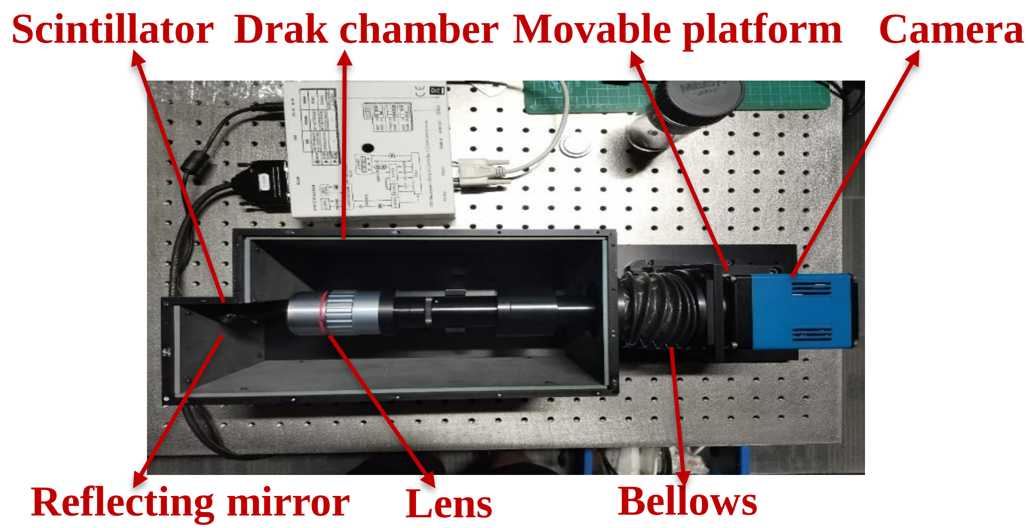


(2) Ultra-high resolution neutron imaging detector (~μm) using GOS

Principle diagram



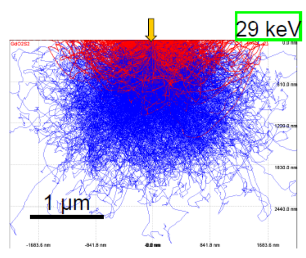
Detector structure and components



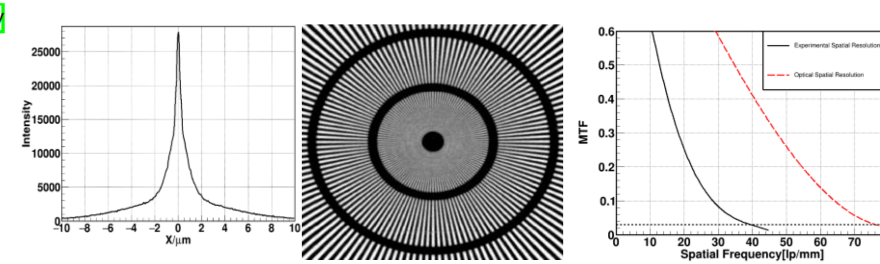
Main specifications：

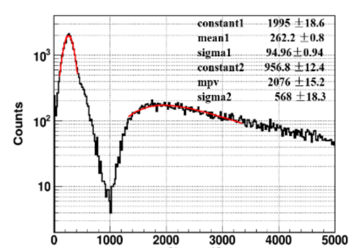
- Magnification：4X, 5X , 7.5X
- Working distance：34mm，44mm
- FOV：1.7mm*1.7mm-> 3.3mm*3.3mm
- Optical resolution：<4.4μm

M.C. simulation on scintillator



Neutron spatial resolution 13 μm

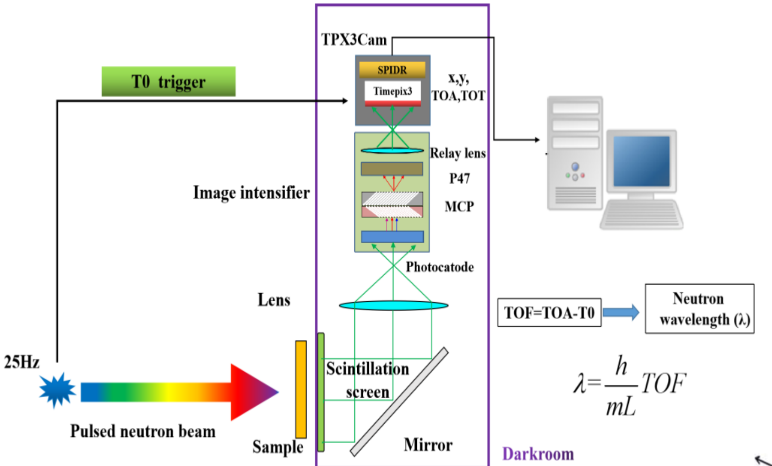




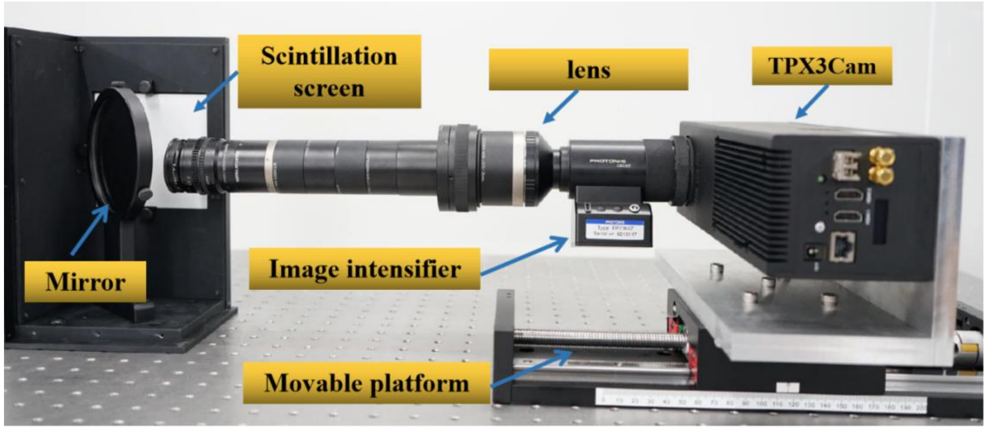
GOS transparent ceramic scintillator

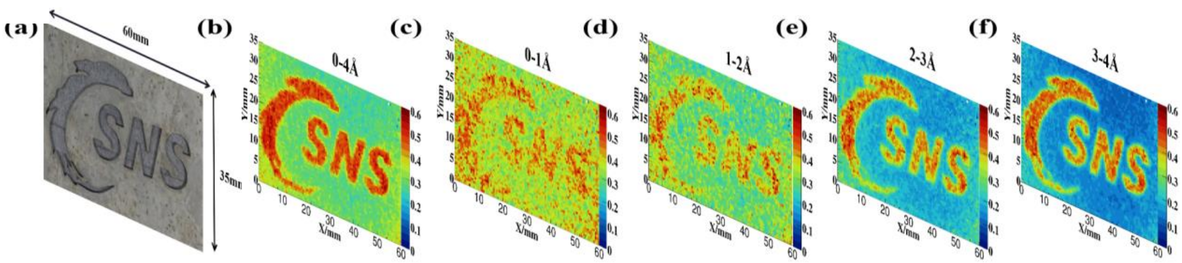
(3) A novel energy resolved neutron imaging detector based on TPX3Cam

Principle diagram



TPX3Cam is a time stamping optical camera





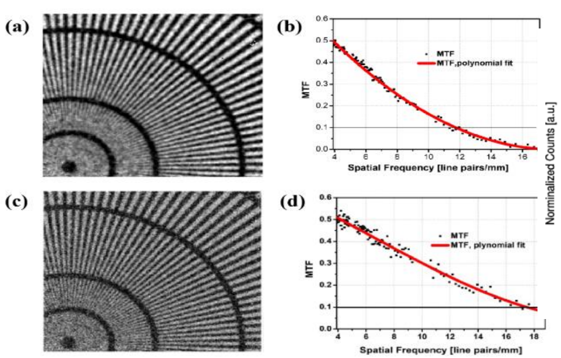
Main specifications:

- Chip size: 14.1mm*14.1mm
- Magnification: 0.5-2.7
- Working distance: 60-345mm
- FOV:

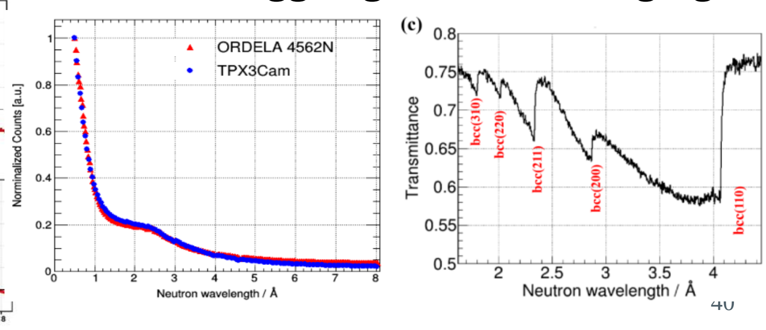
  5.2mm*5.2mm-28mm*28mm
- Spatial resolution:

  40μm->220μm

Neutron spatial resolution 40 μm



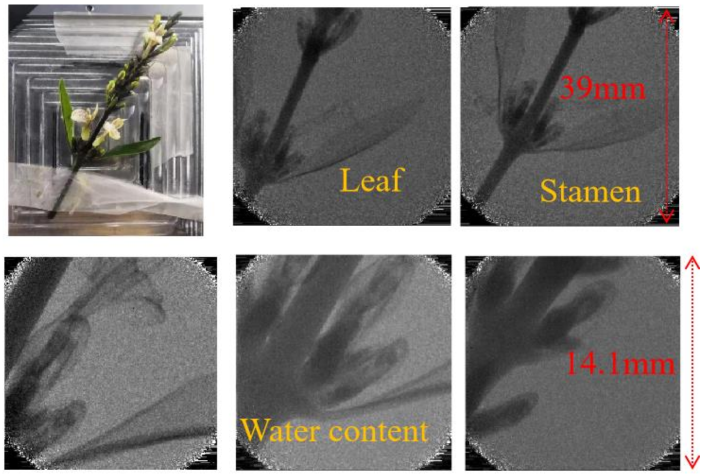
Bragg edge neutron imaging



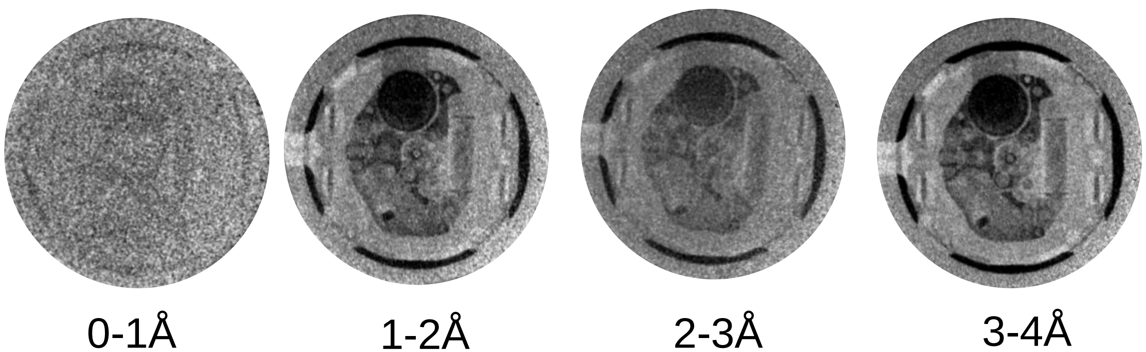
(3) A novel energy resolved neutron imaging detector based on TPX3Cam

Neutron imaging of different samples

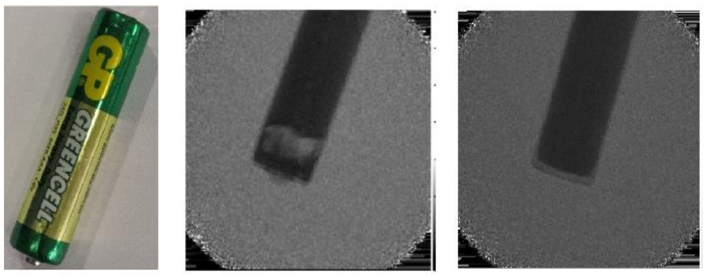
A quartz wrist watch and x-ray imaging



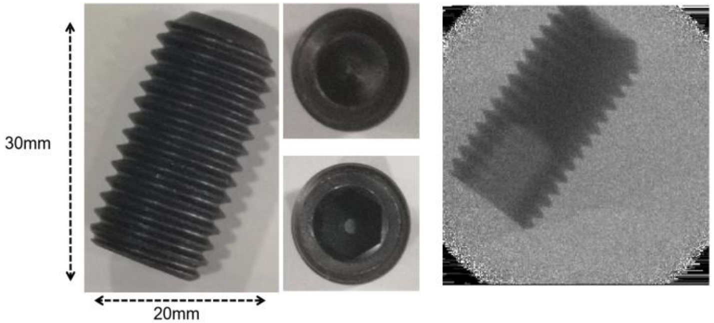
Flower imaging under different FOV



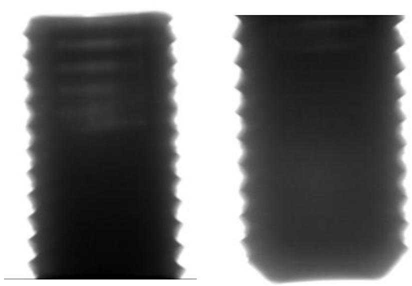
Neutron imaging of different wavelengths



No.7 battery and neutron imaging



Neutron imaging of Bolt



X-ray imaging of Bolt

X-ray imaging of No.7 battery

Outline

1 Team introduction and development planning

2 Development of the neutron detectors

- ^{3}He-based, Scintillator, GEM, imaging detector

3 Summary

Summary

- **4 instruments detectors passed the acceptances. This lays a good foundation for the detectors development in Phase II.**

- **Massive ^{3}He tubes will be used for instruments. CSNS intends to produce various types of ^{3}He tubes in China to satisfy the demand of Phase II.**

- **Scintillation detector with ^{6}LiF/ZnS(Ag) is an economical alternative to ^{3}He. The next is to improve neutron–gamma discrimination and the neutron detection efficiency.**

- **Ceramic GEM neutron detector shows good performances with high spatial resolution and high counting rate. However, the neutron detection efficiency still needs to be improved.**

- **For imaging detectors, the key is the ASIC chip with timing resolution.**

Acknowledgments

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Youth Innovation Promotion Association CAS

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1953
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中山大学
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SUN YAT-SEN UNIVERSITY

陕西科技大学
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