Compact Pulsed Hadron Source

Commissioning of 3-MeV proton & neutron beam lines at CPHS：

(Compact Pulsed Hadron Source)

Status report on accelerator and neutron activities at Tsinghua U.

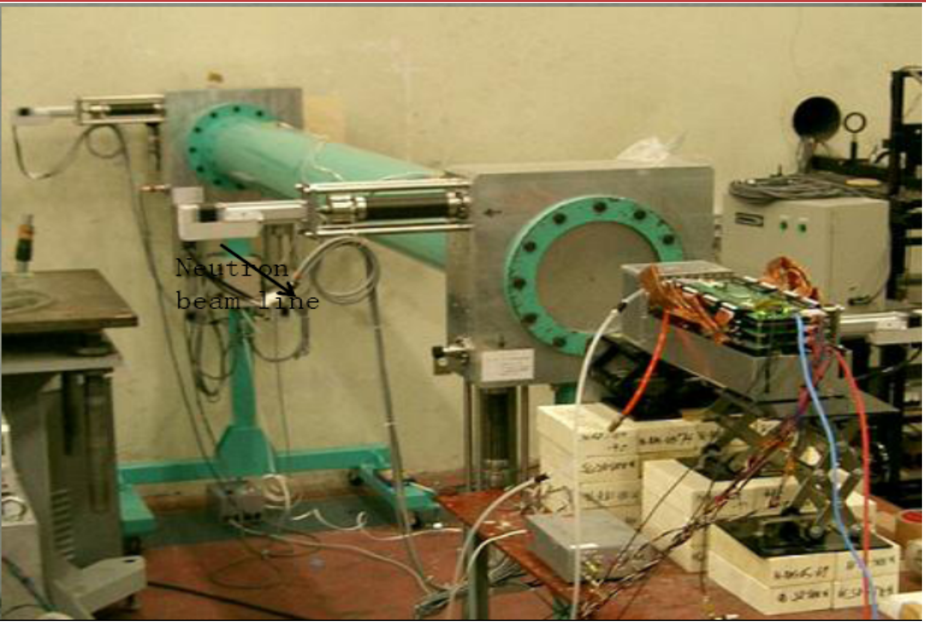
Xuewu WANG wangxuewu@tsinghua.edu.cn

CPHS team

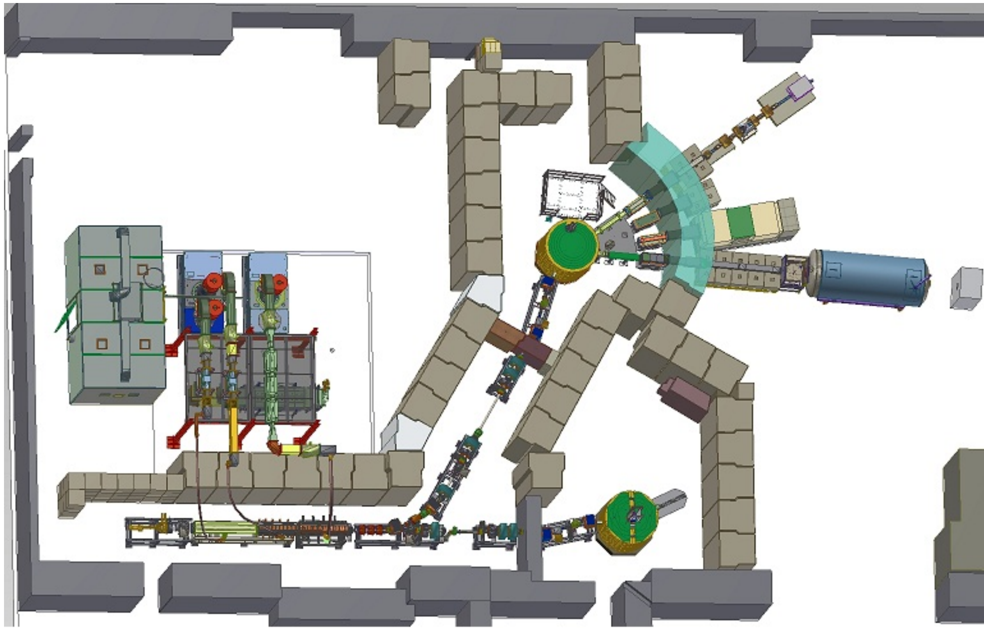
Dept of Engineering Physics, Tsinghua Univ., Beijing, China

UCANS−V, Laboratori Nazionali di Legnaro (Padova) , Italy, May 12-15, 2015

Thanks for example & help from CANS



Hokkaido Univ: 45 MeV Linac (γ,n)



Indiana Univ: 13 MeV LENS (p,n)

Thanks for people helping CPHS

Outline

- Overview of the CPHS project
- Status of CPHS facility in 2014
- Imaging station
- Development of neutron detectors
- Research on neutron optics for small neutron source
- Summary

Outline

- Overview of the CPHS project
- Status of CPHS facility in 2014
- Imaging station
- Development of neutron detectors
- Research on neutron optics for small neutron source
- Summary

The CPHS project was approved in 2009

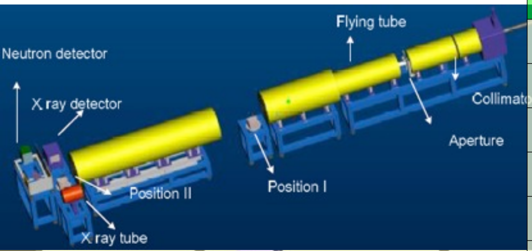
- The ***CPHS Project approved by the university*** around March 2009
- Received a ***starting budget of ~$3M*** in Jun 2009; ~***$1.5M*** in Apr 2011; ***~1M*** in Jan 2012; ***~2M*** in 2013-2014
- Another ***~$1M*** for reconstruction of laboratory in Mar 2010

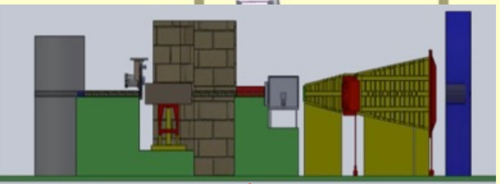
Roles of the CPHS: in-house source

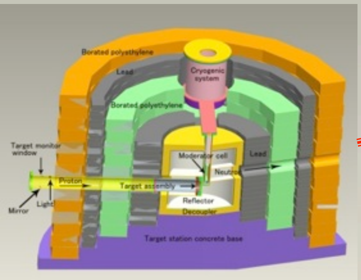
- ***Compact:*** State-of-the-art accelerator & source technology
- ***Mission:***
  - *Education: Training of students & staff*
  - *Research: In-time to support the development of major projects & application of neutron in China*
  - *Innovation: Grow of domestic technology*

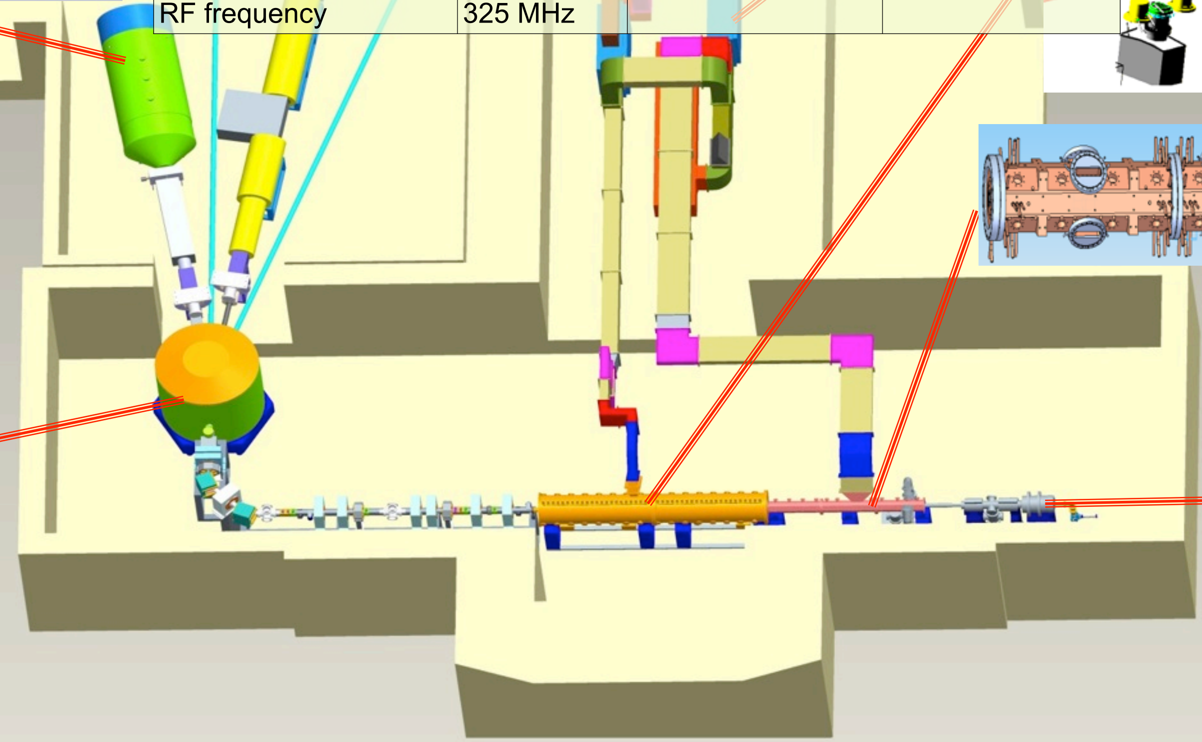
Layout of CPHS

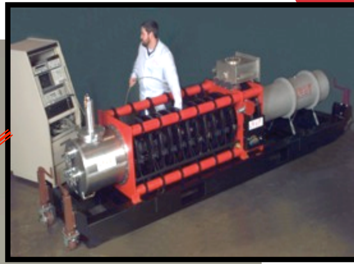
Key Design Parameters of CPHS			
Protons		Neutrons	
Beam power on target	16 kW	Target for ~6 cm x 6cm proton beam	
Output energy		Material	Be ~1.2 mm thick
DTL	13 MeV	Coolant	Chilled water
RFQ	3 MeV	Moderator	
Ion source	50 KeV	Material	Solid CH_4 ~20 K
Average beam current	1.25 mA	*n*-emitting surface	10 cm x 10 cm
Pulse repetition rate	50 Hz	Reflector	Water
Pulse length	0.5 ms	Pulse length	~1 ms
Peak beam current	50 mA	Neutron yield (est.)	~5 x 10^{13} /s
Protons per pulse	1.56 x 10^{14}		
RF frequency	325 MHz		

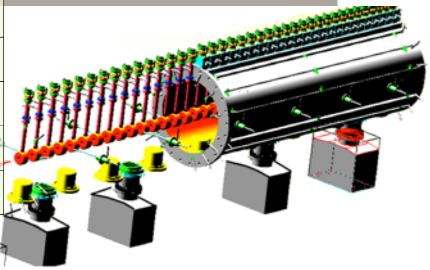


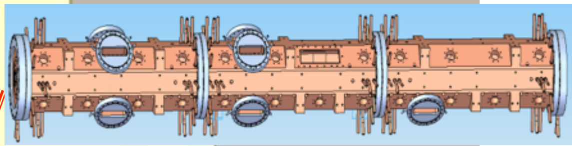


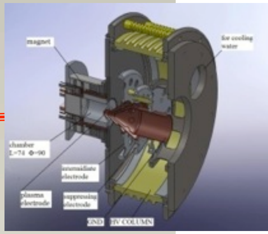




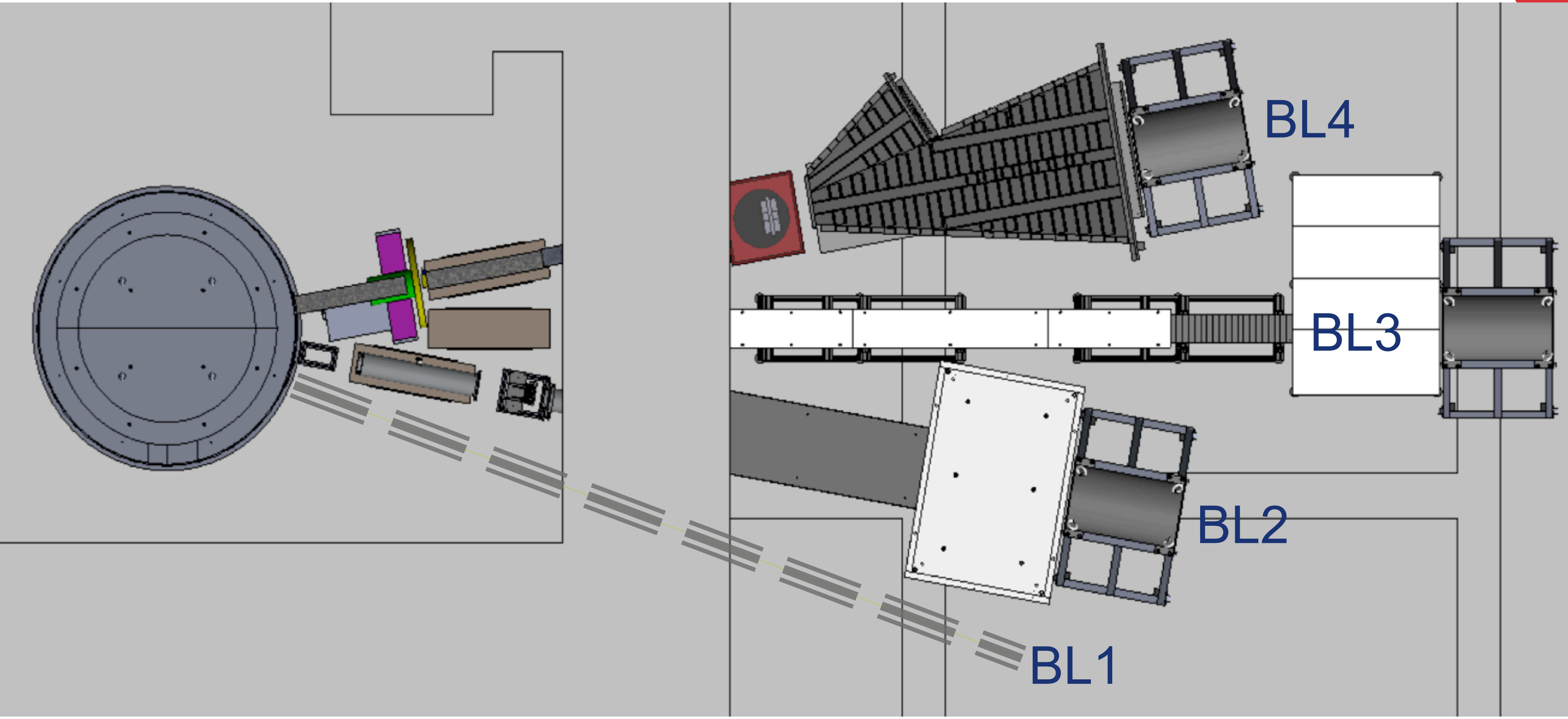








Layout of neutron beamlines



BL1. TBD (original test beamline)

BL2. Neutron imaging station

BL3. Test beamline (original TBD to 25~30m)

BL4. SANS

CPHS milestones

- First 3-MeV proton beam of RFQ on 25-Mar-2013
  - Transmission of RFQ (88%, input 50mA, output 44mA) on 27-Mar-2013
- First neutron beam on 18-Jul-2013 (**mid-term objective achieved**)
  - First neutron imaging on 26-Jul-2013
  - Transmission of HEBT (> 90%) on 13-Aug-2013
- RFQ conditioned to 442kW/50Hz/500μs on 2014/04

Parameter	Designed	Achieved
Beam Energy	13 MeV	**3 MeV**
Beam Current	50 mA	**23 mA**
Pulse Length	500 μs	**100 μs**
Repetition Rate	50 Hz	**20/50 Hz**

First neutron beam on 18-Jul-2013

Repetition rate: **50 Hz**
Pulse length: **80us**
Beam current after bending 90°: **22.4 mA**
Neutron flux (~10meV ~a few hundred meV): **1.9×10^{9}**
Total calculated neutron flux: **2.8×10^{10}**
(neutron efficiency of 5×10^{-5})

Tsinghua – Xi'an Proton Facility

✧A 200MeV proton sychrontron

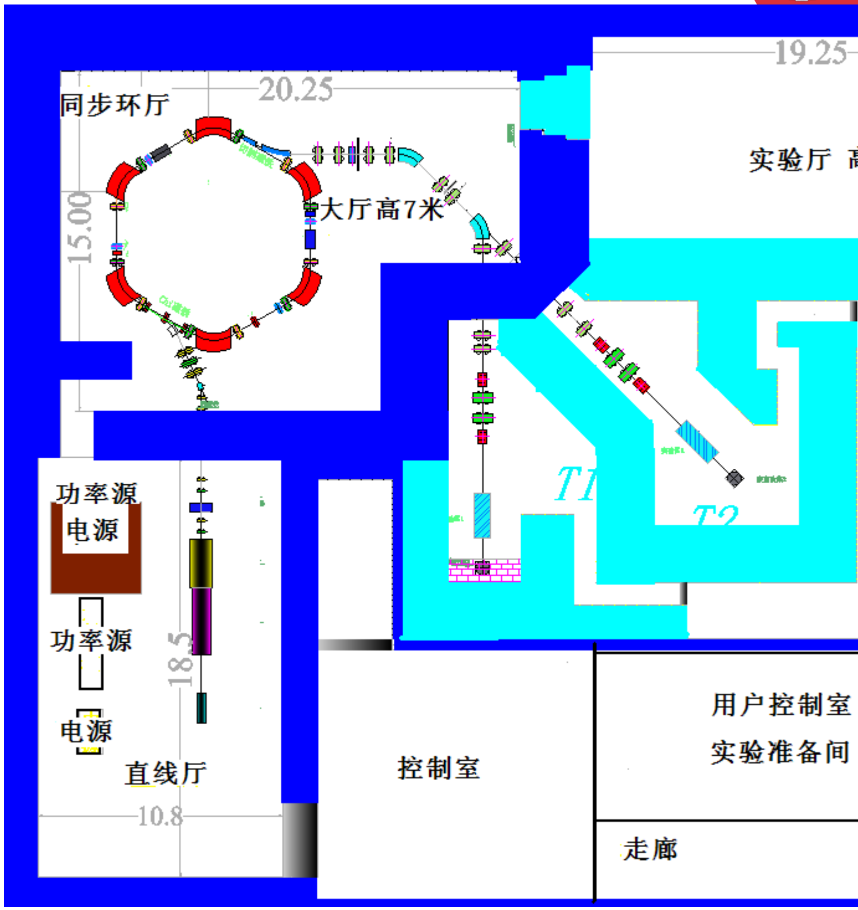
- 2014-2018, 5 years
- Mainly for irradiation effect research

✧Parameters

- Injector: 7MeV H^-
- Slow extraction， up to 0.5Hz
- Proton energy 60-200MeV
- Flux: 10^5-$10^8 p/cm^2/s$ @ 10×10cm^2

✧Characters

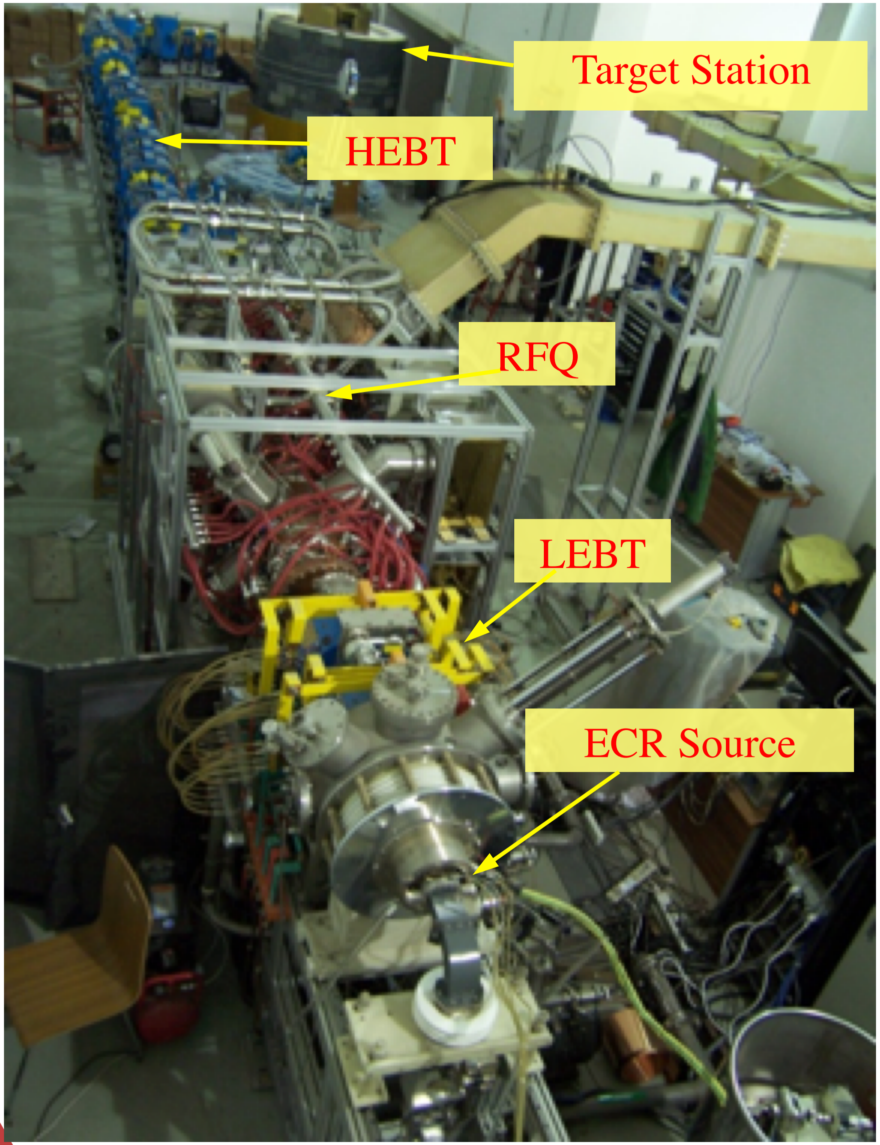
- Microwave ECR H- source without Cs
- Four-vane RFQ with ramped inter-vane voltage
- Alvarez DTL with permanent magnets
- Synchrotron with six-folded symmetrical topological structure
- Air-cooled magnetic alloy RF cavity
- Third-order resonant extraction



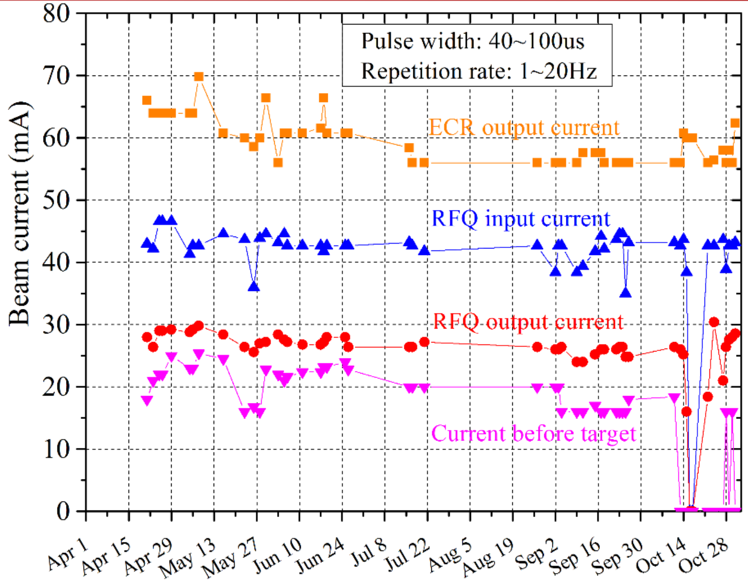
Outline

- Overview of the CPHS project
- Status of CPHS facility in 2014
- Imaging station
- Development of neutron detectors
- Research on neutron optics for small neutron source
- Summary

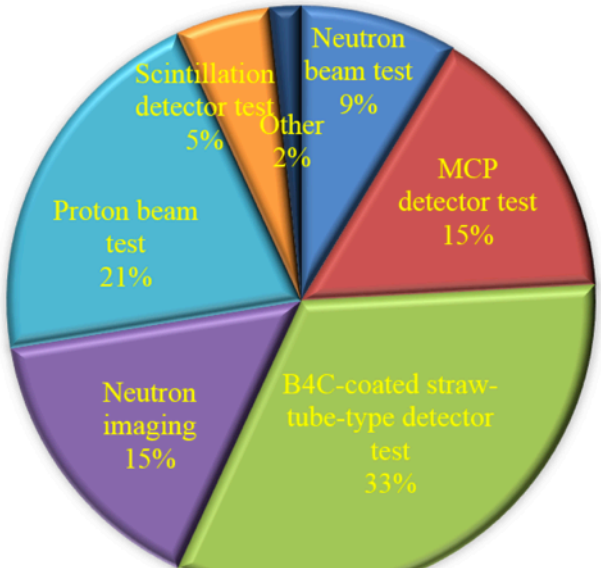
CPHS operation time ~500 hrs in 2014



3MeV-RFQ based CPHS



Operation history in 2014

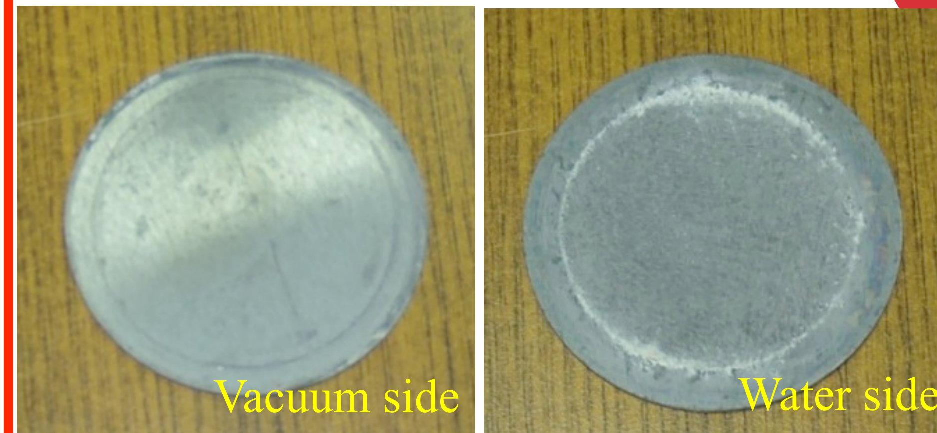


Time percentage of CPHS operation for different applications in 2014

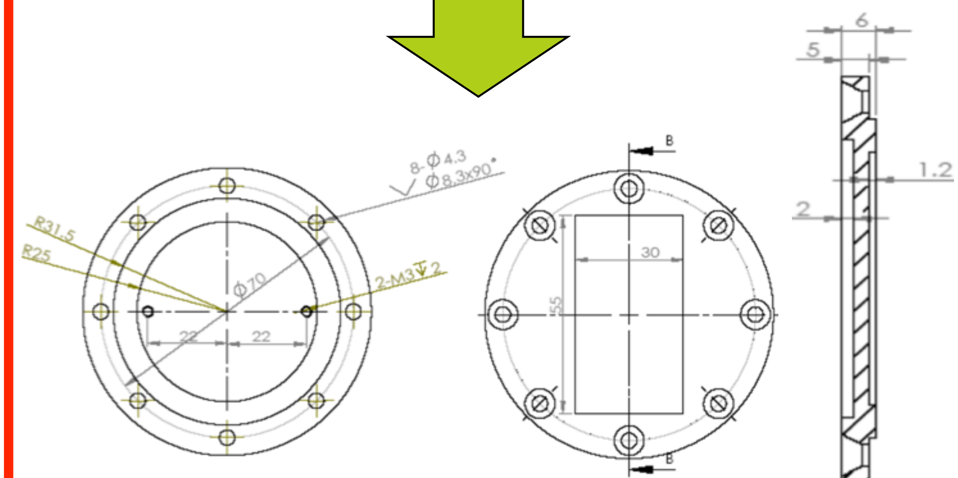
Target & Monitoring

- 1.2-mm Beryllium target
- Broken twice with the original design with the operation repetition rate of 50 Hz
- Target enhanced by mounting it on one Aluminum plate

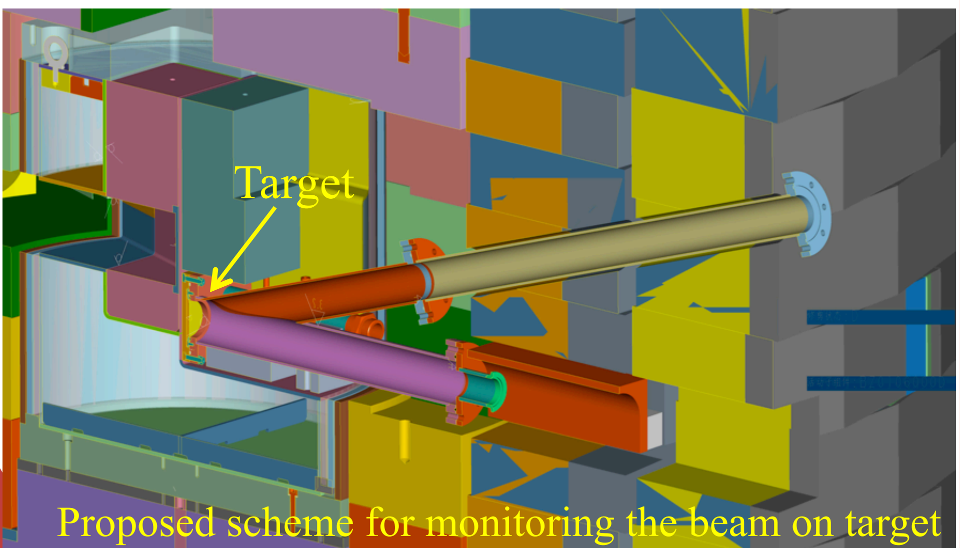
- Monitoring of the beam on the target will be performed



The broken Beryllium target



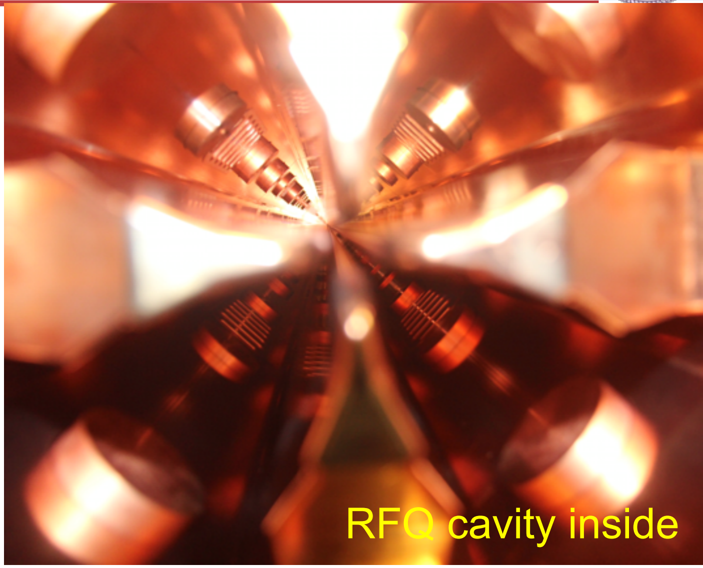
Beryllium target mounted on an Aluminium plate



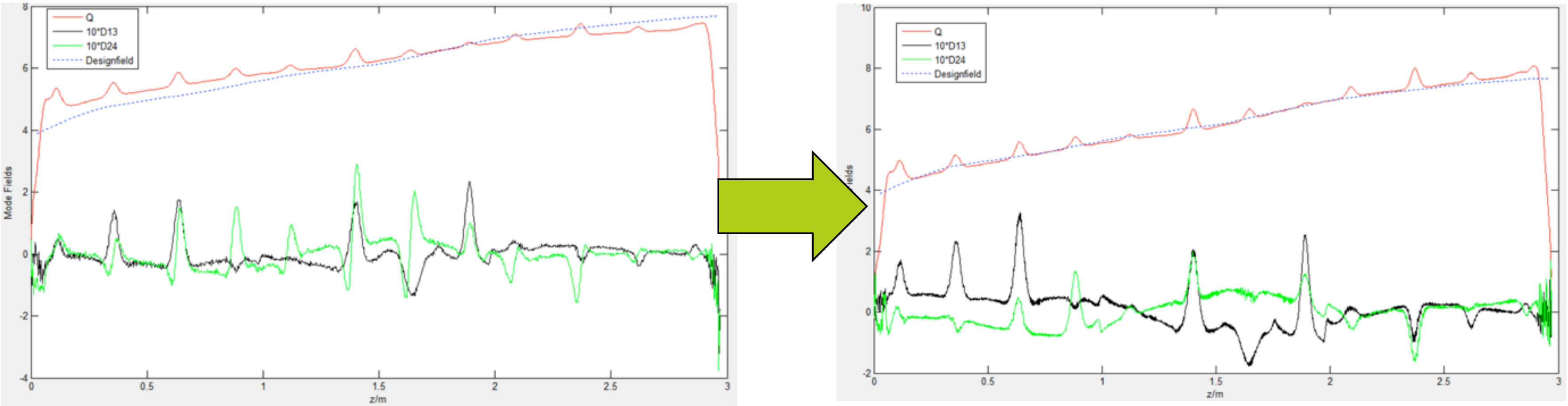
Proposed scheme for monitoring the beam on target

CPHS maintenance and upgrade in 2015

- Upgrade of the power distribution system of the ECR source/LEBT to polish the possible damage due to the sparking
- Recovery and upgrade of the control system of the ECR source/LEBT to facilitate the operation
- Adding one chopper unit in the LEBT
- Increase the output current of the RFQ accelerator



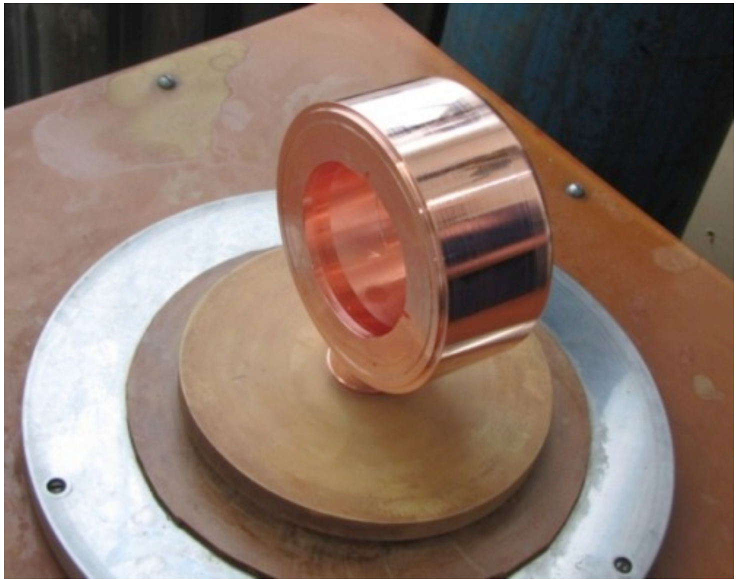
Courtesy Dr. Qingzi XING



Field distribution of the quadrupole (red line) and dipole (green and black lines) modes (left: before tuning; right: after tuning).

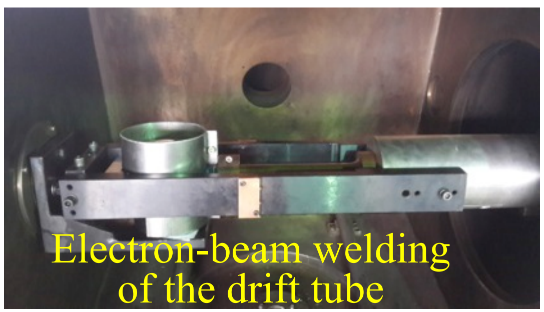
The relative error of the quadrupole field reduces from ±7.3% to ±2.6% after tuning.

CPHS DTL development



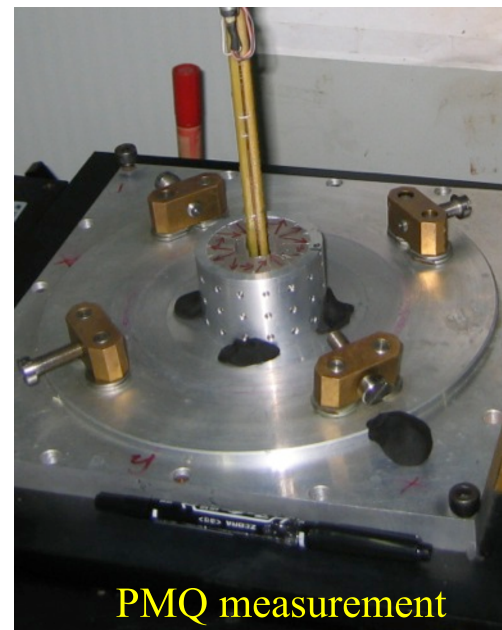
Drift tube

Input/output energy	3/13	MeV
Peak current	50	mA
Synchronous phase	-30→-24	Degree
Accelerating field	2.2→3.8	MV/m
Peak power	1.2	MW
Lens gradient	84.6	T/m
Lens effective length	4	cm
Cell number	40	
Total length	4.37	m

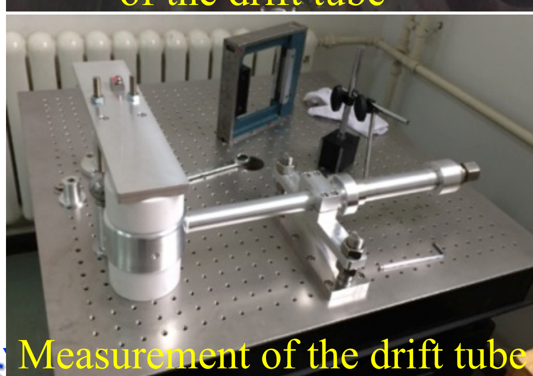


Electron-beam welding of the drift tube

PMQ



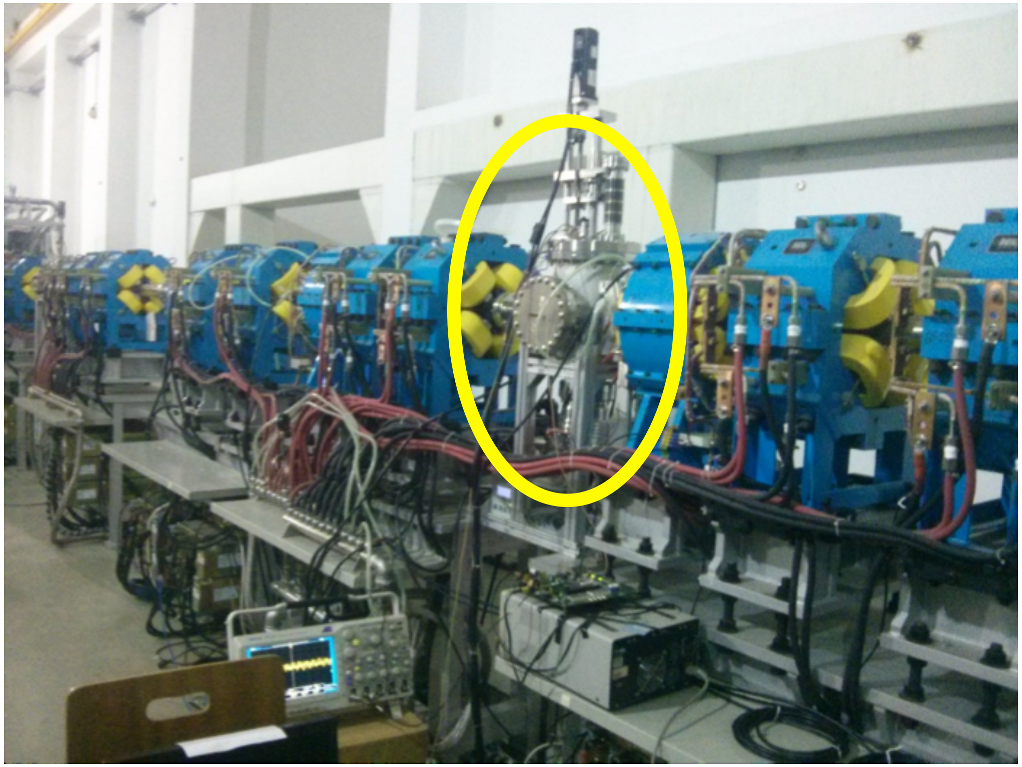
PMQ measurement

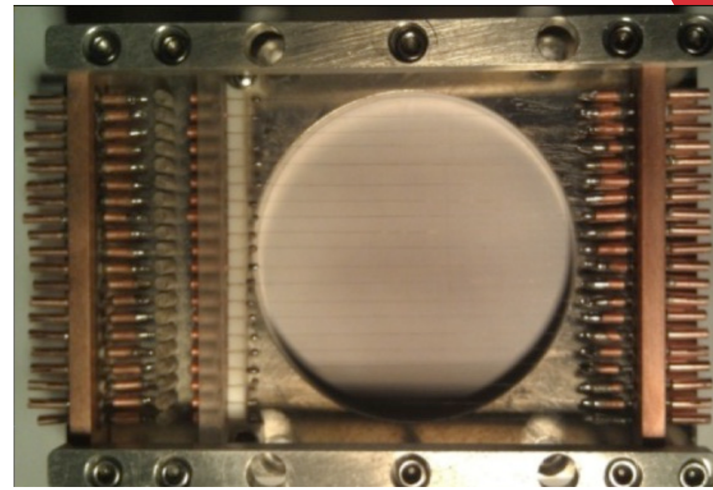


Measurement of the drift tube

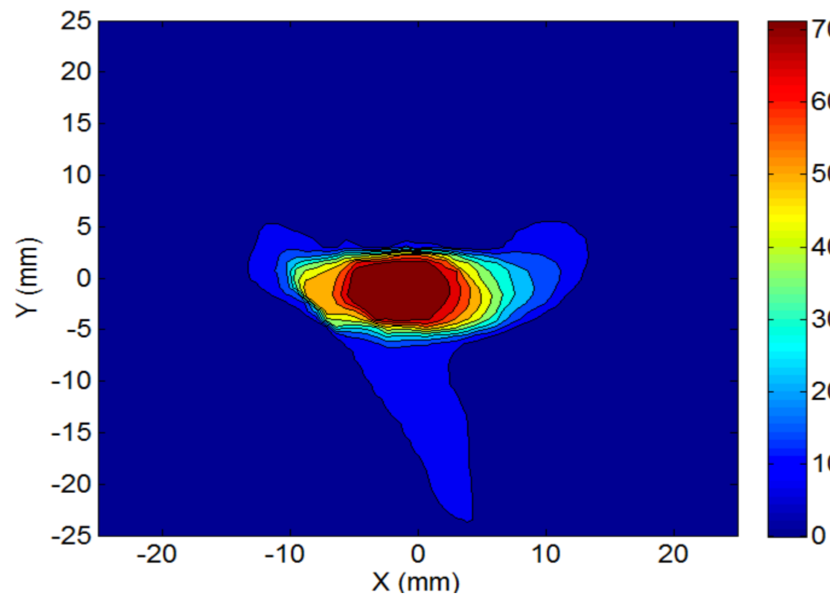
Alignment of the drift tubes on the base

2D profile measurement of the proton beam





Rotatable multi-wires



The 2D profile of the proton beam

- 2D profile measurement by the CT algorithm
- Twenty carbon wires rotatable with the diameter of 30 μm
- Primary experiment done with only one wire
- The electronics system for the measurement of the twenty wires simultaneously will be ready in this month

Outline

- Overview of the CPHS project
- Status of CPHS facility in 2014
- Imaging station
- Development of neutron detectors
- Research on neutron optics for small neutron source
- Summary

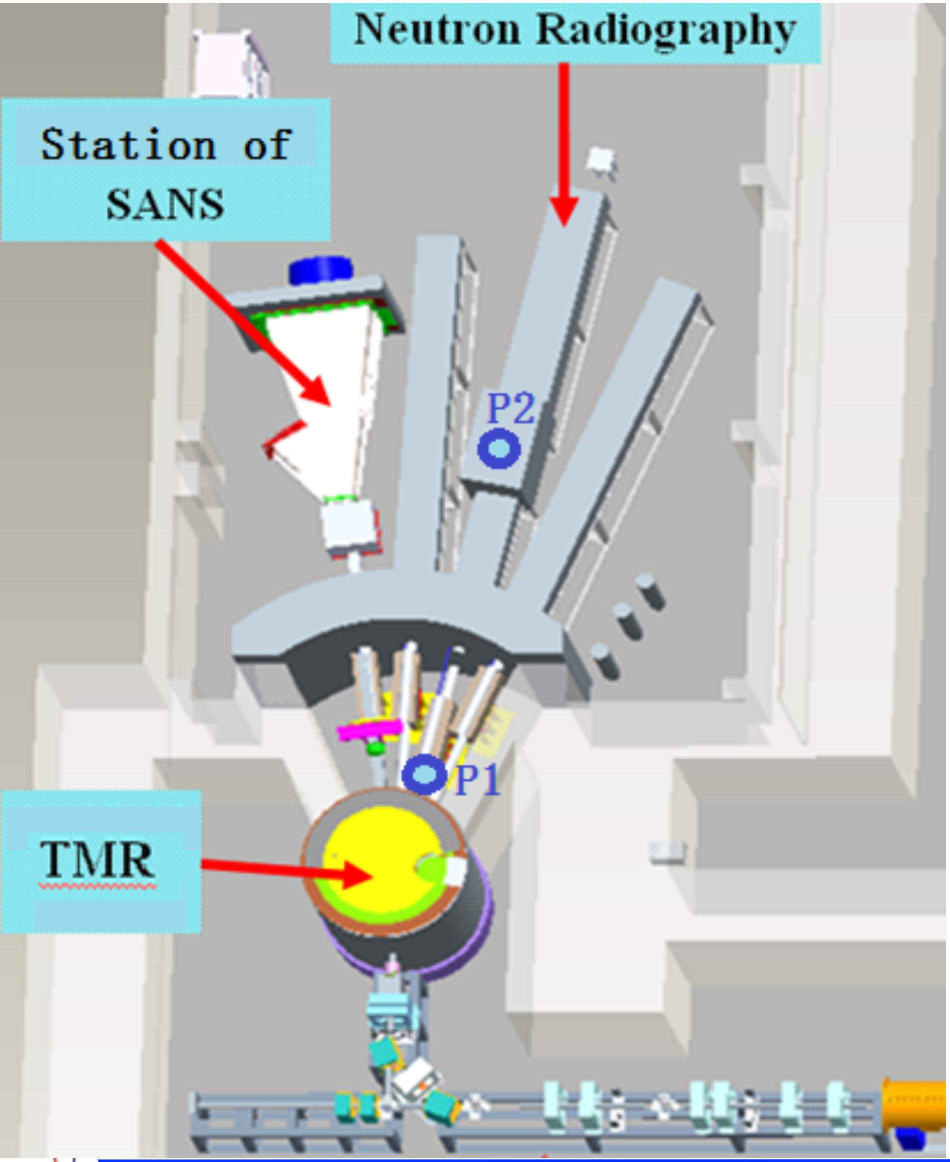
The neutron imaging station

The neutron imaging station at CPHS

The neutron imaging plate

Preliminary Neutron Imaging Experiments

Test position P1 and P2



Postion	Distance TMR-BPI	Expose time
P1	1 meter	30 minutes
P2	5 meters	10 hours

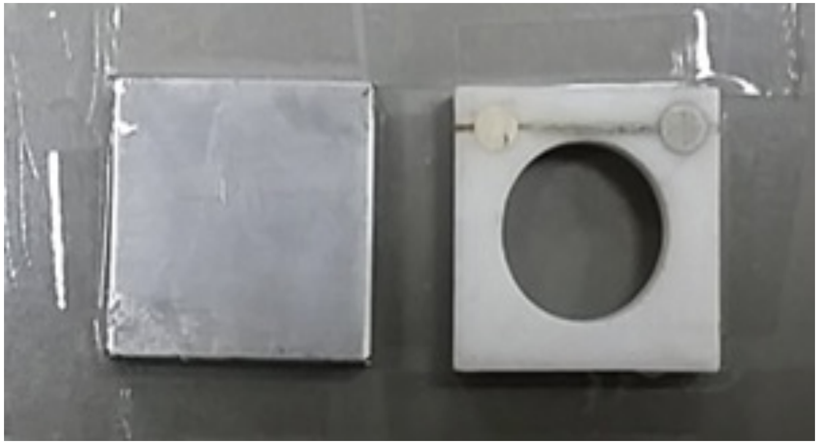
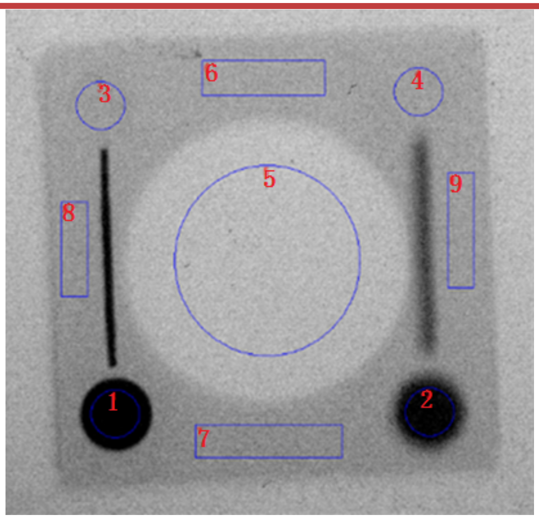
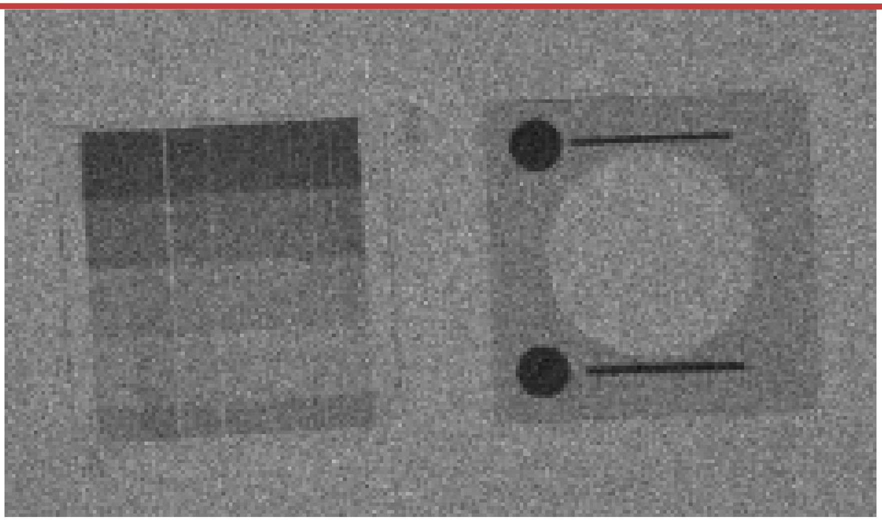


Image Quality Indicator (IQI)

Neutron image and data process



Neutron image in position P1



Neutron image in position P2

Courtesy Dr. Yongshun XIAO

Table 1. PSL of selected positions in BPI image @ P1 and P2

PSL/mm²	@P1	@P2
D_{B1}	473.03	67.43
D_{B2}	598.36	67.29
D_{L1}	1496.41	217.62
D_{L2}	1526.87	214.33
D_H	1778.51	272.65
D_T	1565.44	222.78

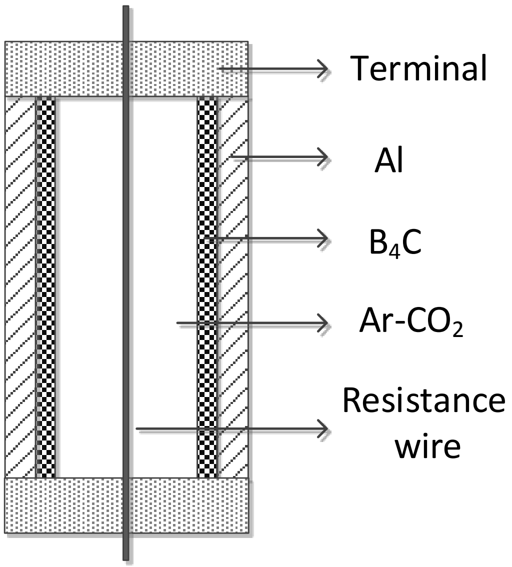
Table 2. Exposure Contributors @ P1 and P2

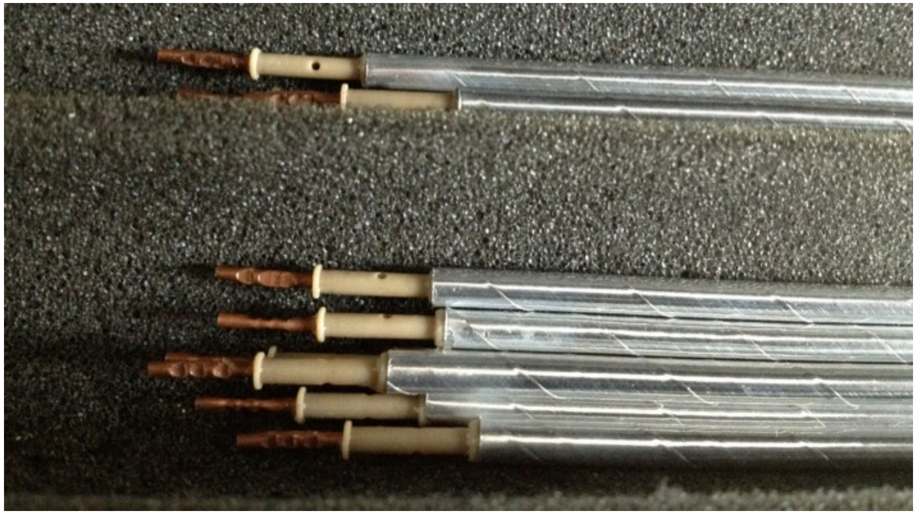
Image system parameters	@P1	@P2
NC	64.64	74.06
S	7.05	0.05
γ	3.88	3.10
P	1.71	1.21

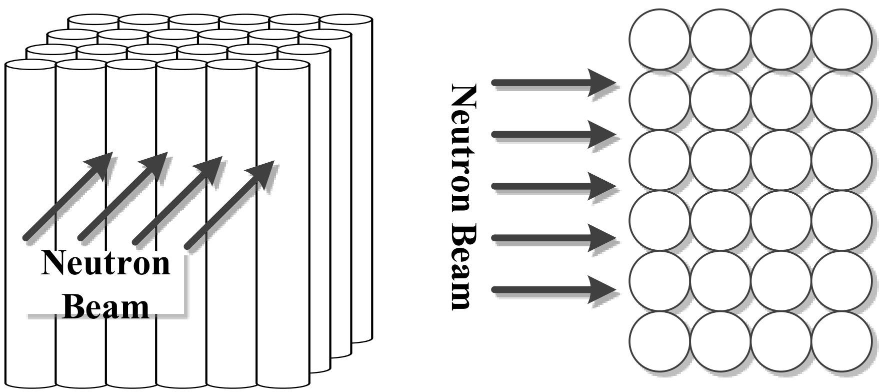
Outline

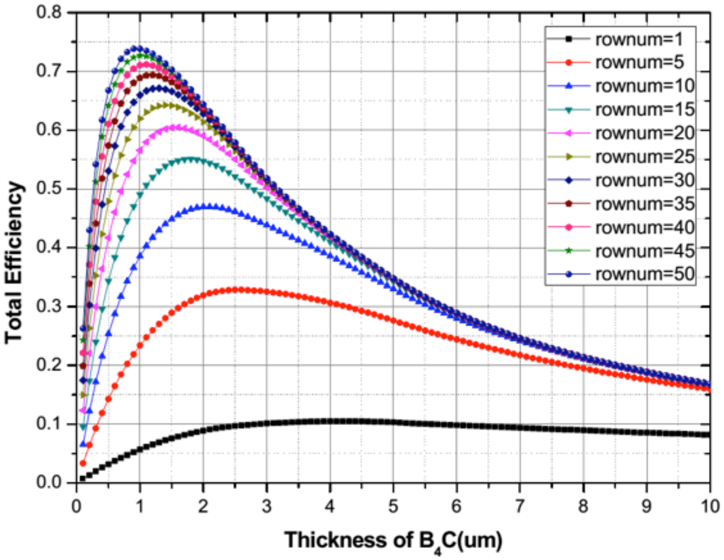
- Overview of the CPHS project
- Status of CPHS facility in 2014
- Imaging station
- Development of neutron detectors
- Research on neutron optics for small neutron source
- Summary

Boron coated straw tube

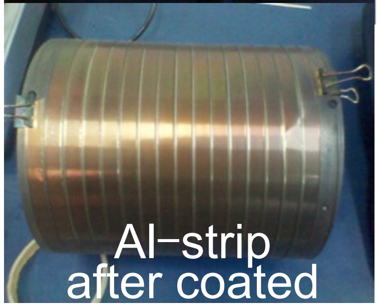


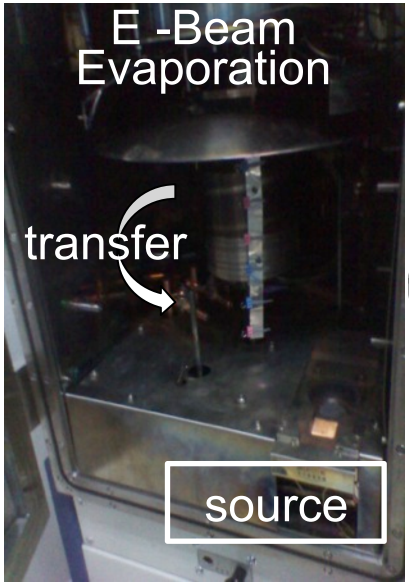


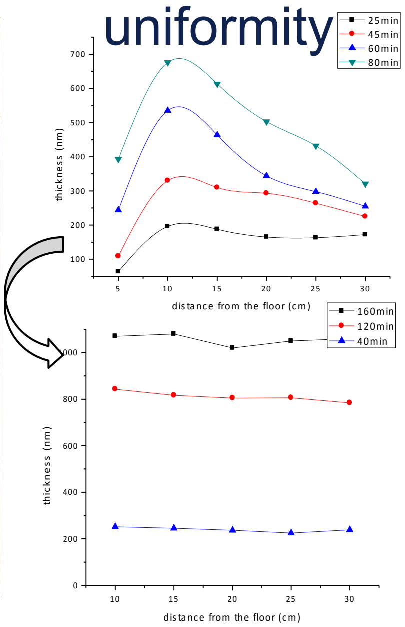


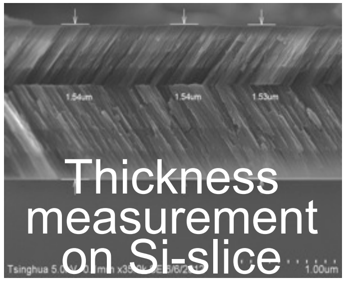


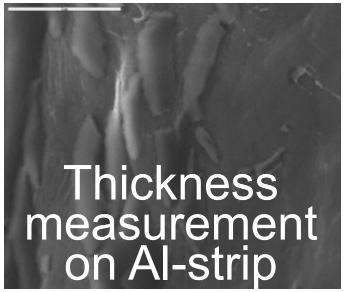
Boron coated straw tube

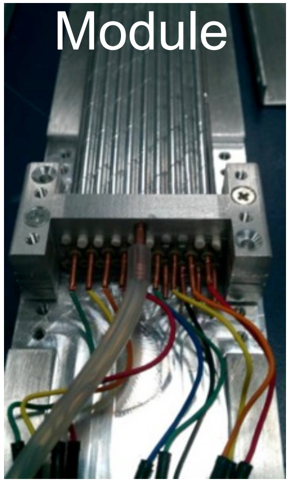




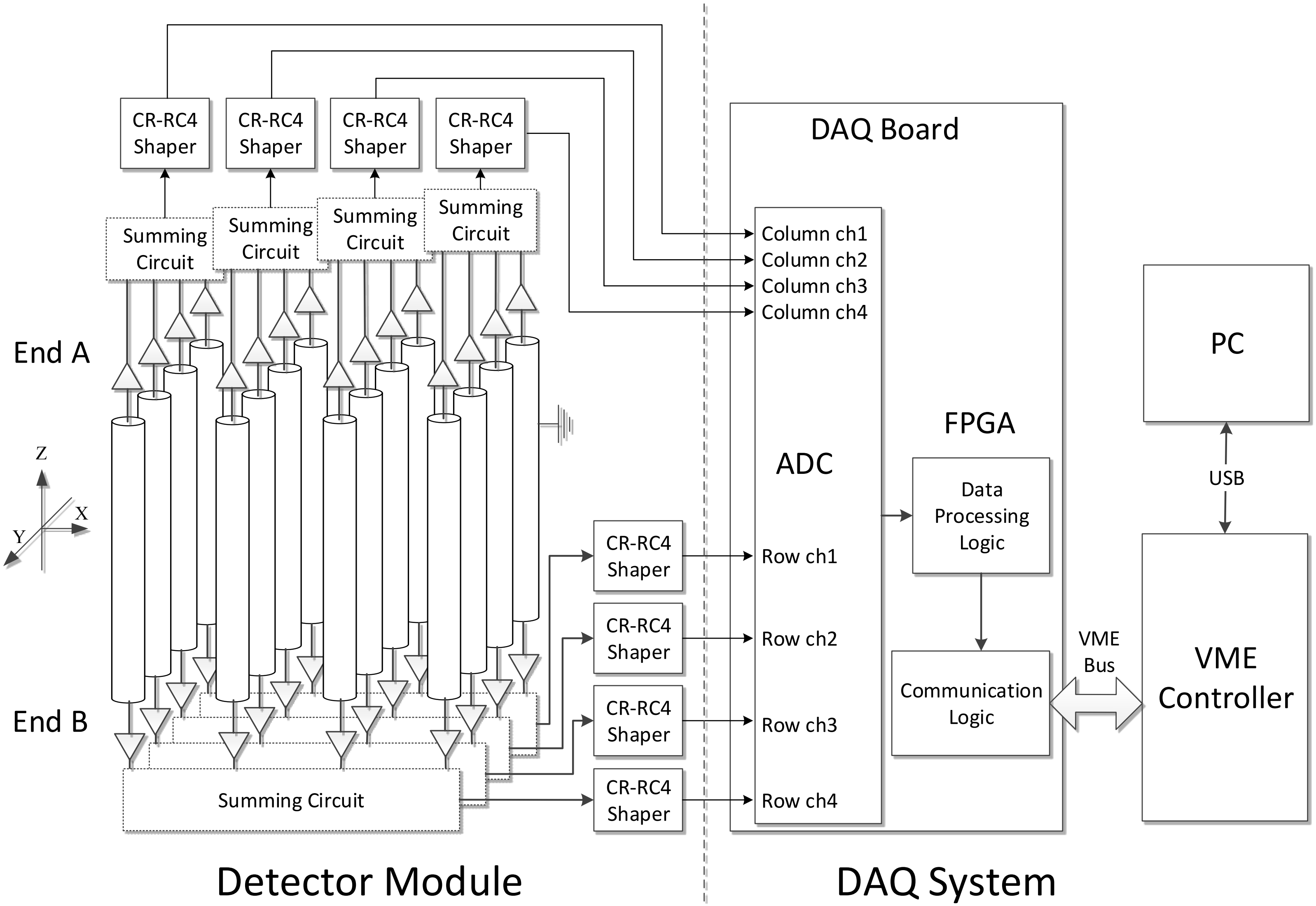






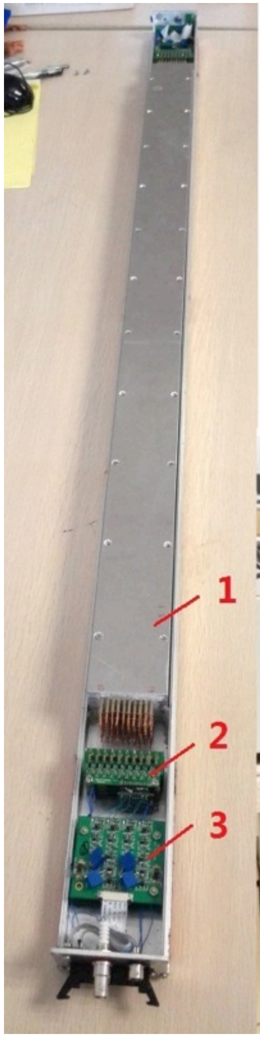


Boron coated straw tube



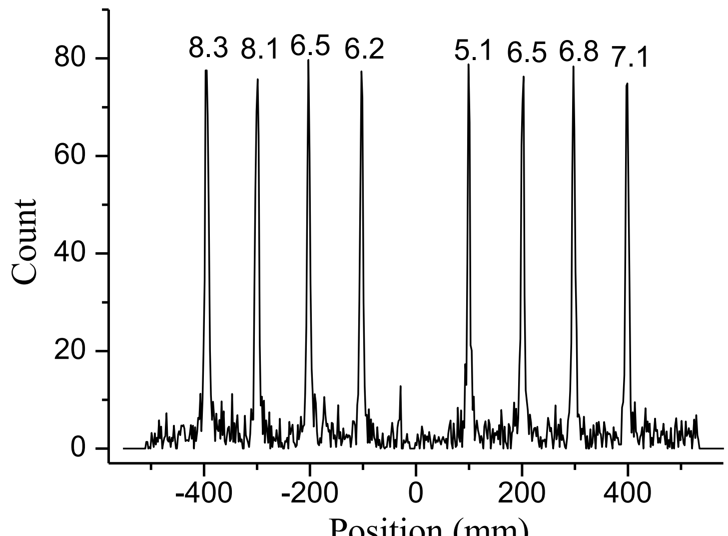
Boron coated straw tube

Courtesy Dr. Hui GONG



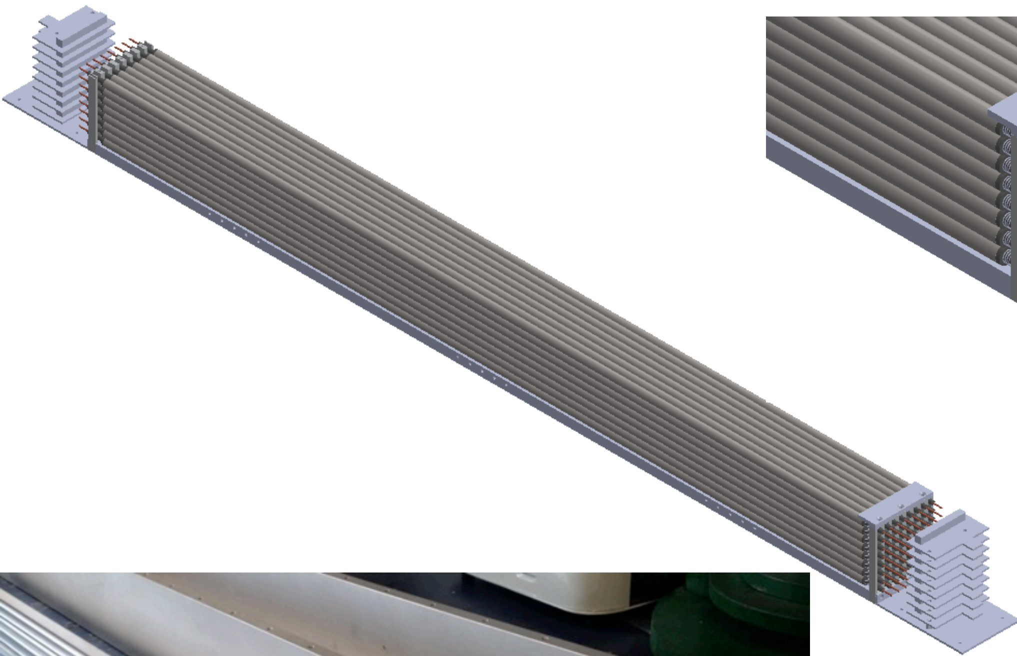
1 Straw tube array
2 Preamplifiers
3 Adders and shapers
4 VME controller
5 ADC board
6 DAQ board

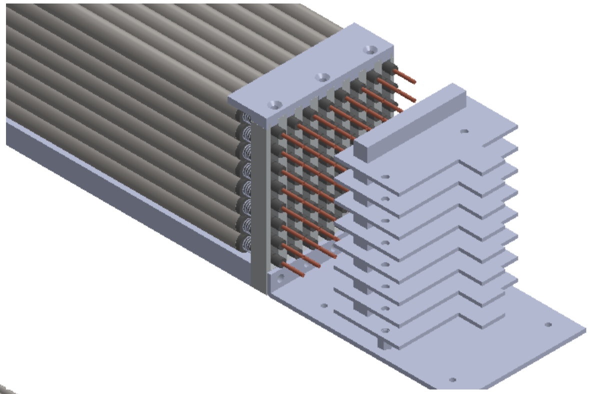
Average spatial resolution - 6.8×4×4 mm^3

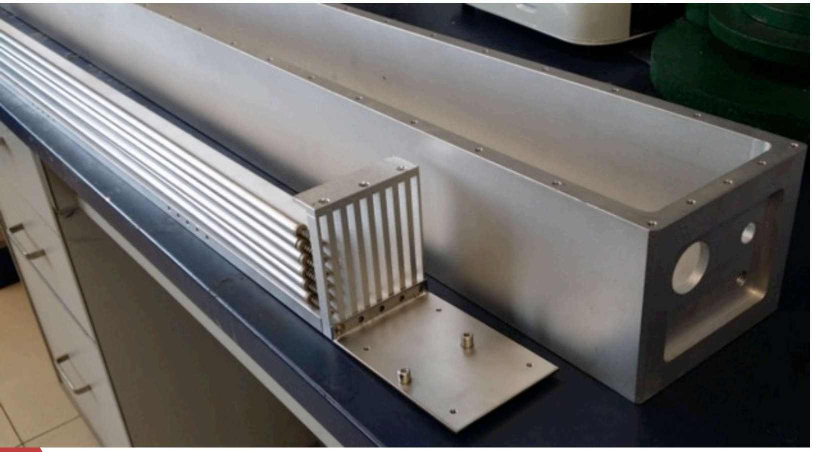


Boron coated tube detector

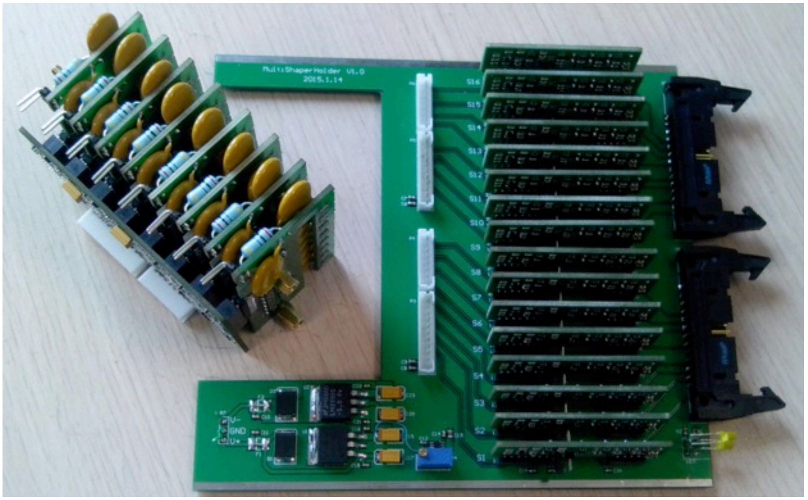
- Another prototype of boron coated tube array detector with an area of 800mm×800mm and a tube diameter of 8mm is under development.





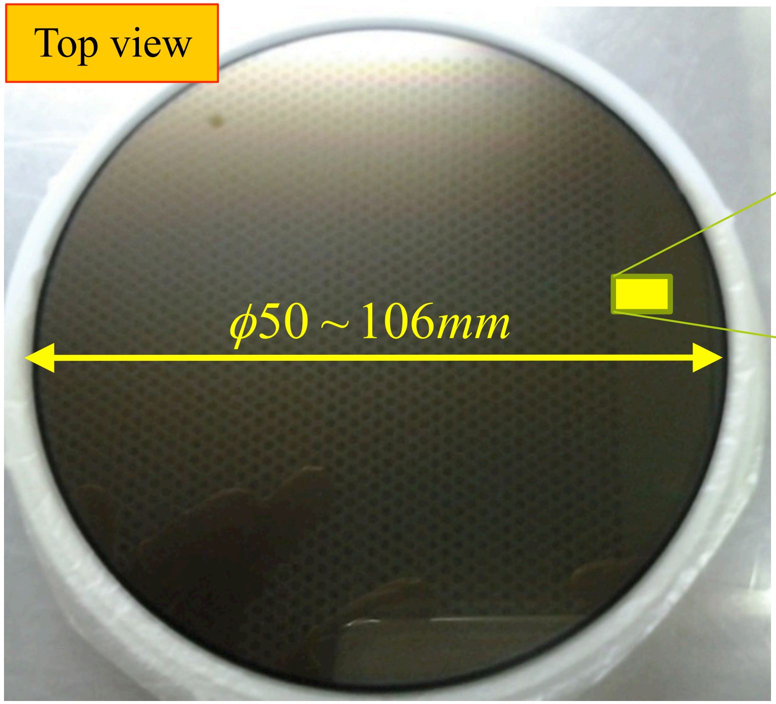


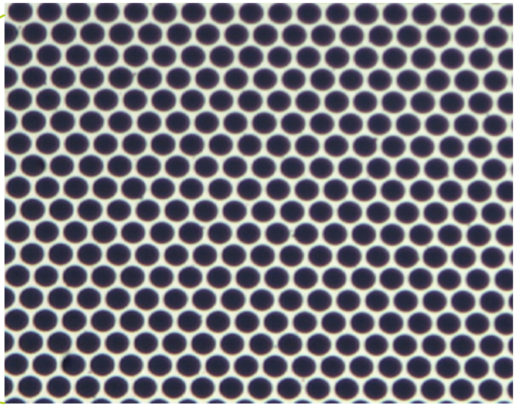
Structure of a 10×10 detector module



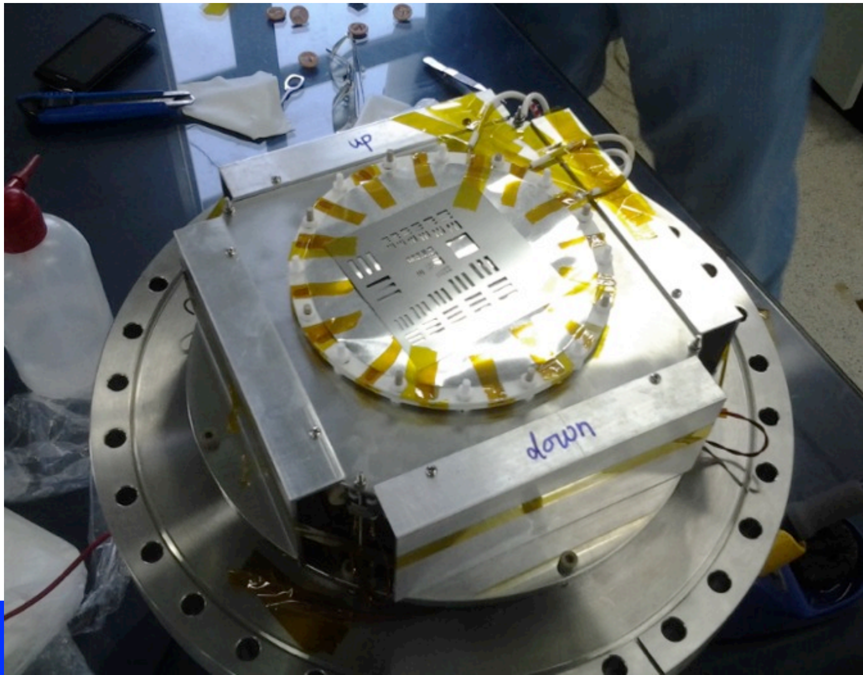
Multi-channel front end electronics for a detector module

Neutron sensitive Micro Channel Plate



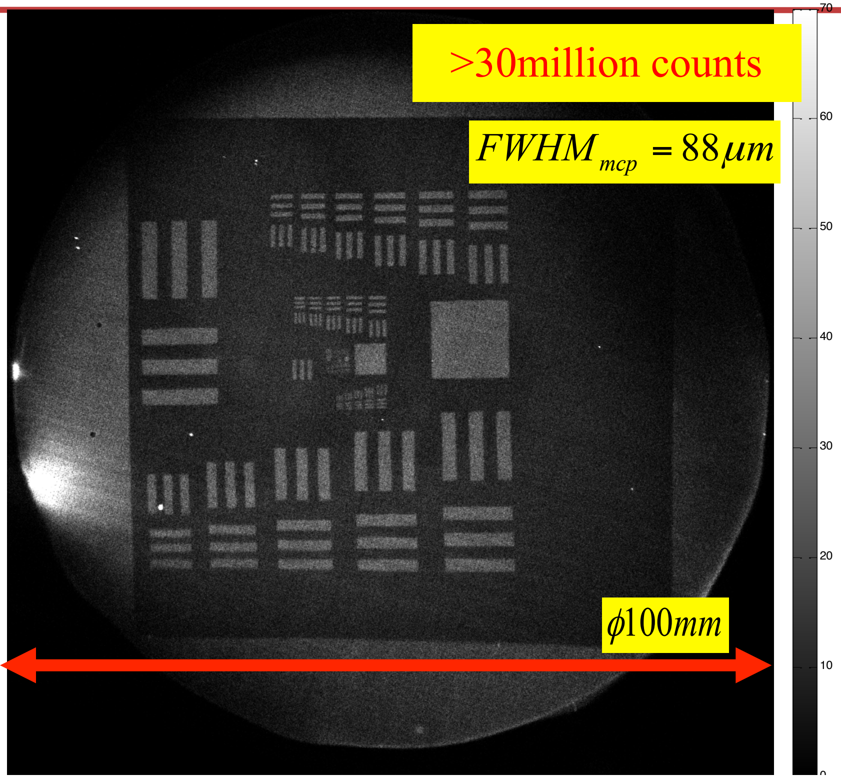


Readout

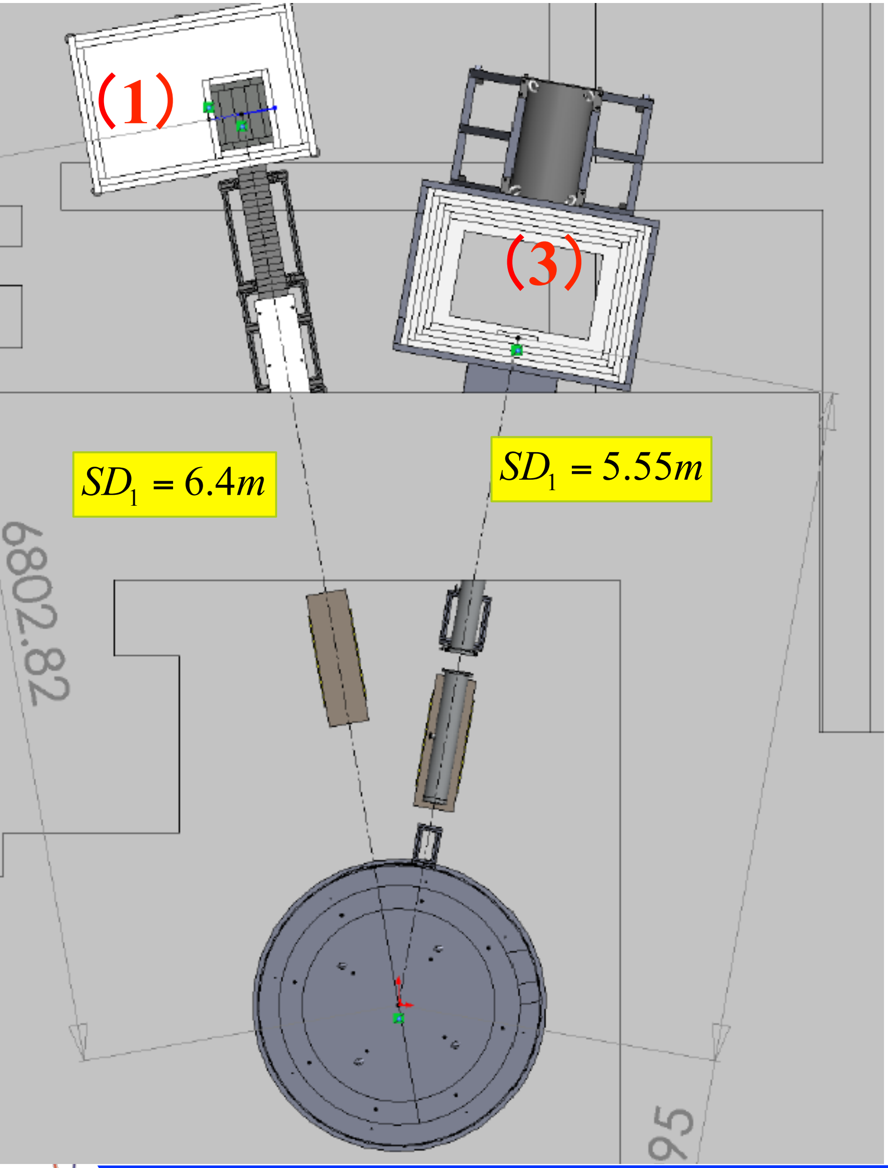


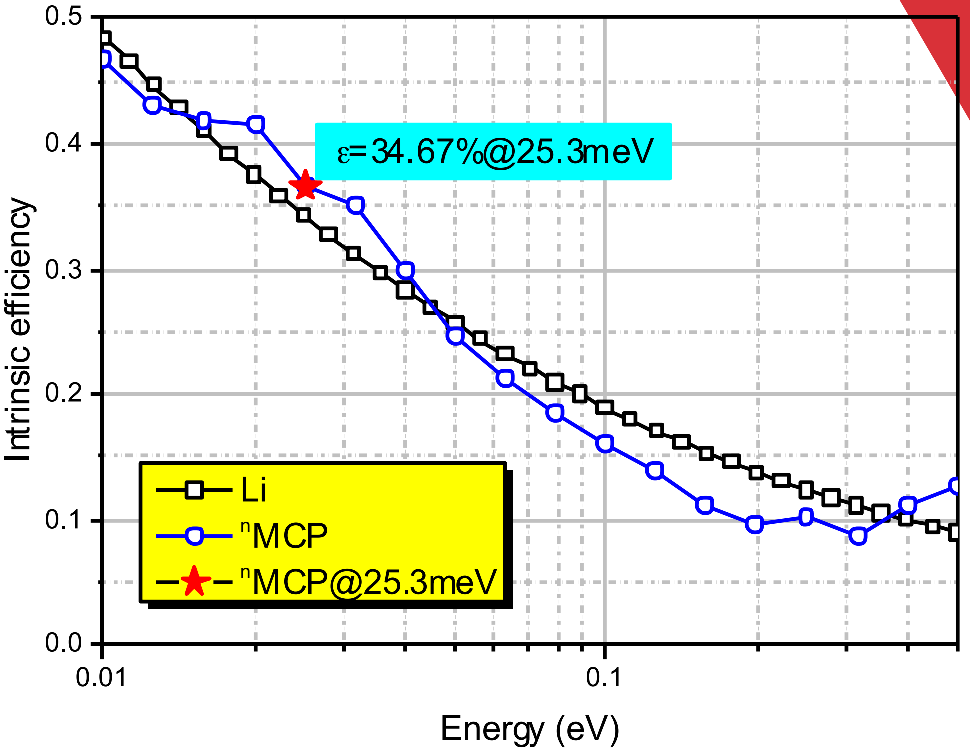
Dr. Yigang Yang:
The research of large area nMCP detector
@ Tsinghua University

MCP imaging @ CPHS



Evaluation of the detection efficiency @ CPHS





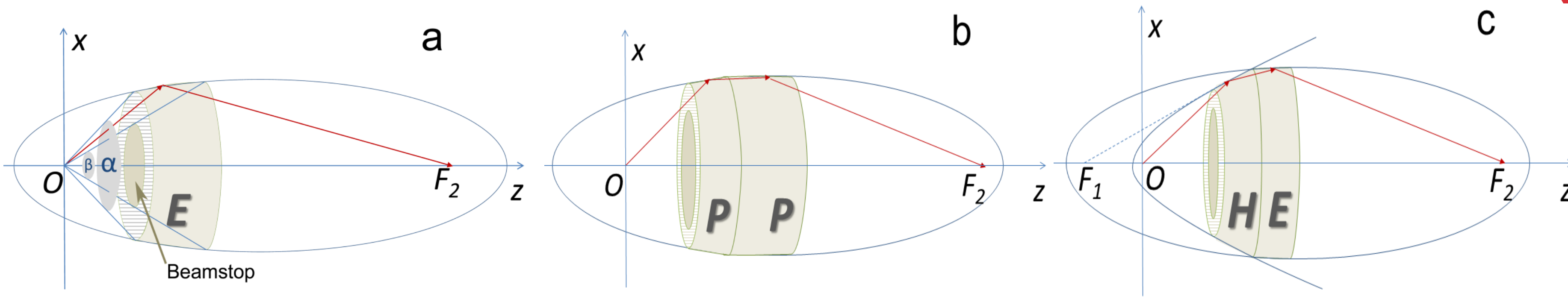
$$\frac{n_3}{n_1} = \frac{\varepsilon_3}{\varepsilon_1} \cdot \left(\frac{SD_1}{SD_3}\right)^2 \cdot \frac{S_3}{S_1} \cdot \frac{f_{\tau 3}}{f_{\tau 1}}$$

$$\varepsilon_3 = \varepsilon_1 \cdot \frac{n_3}{n_1} \cdot \left(\frac{SD_3}{SD_1}\right)^2 \cdot \frac{S_1}{S_3}$$

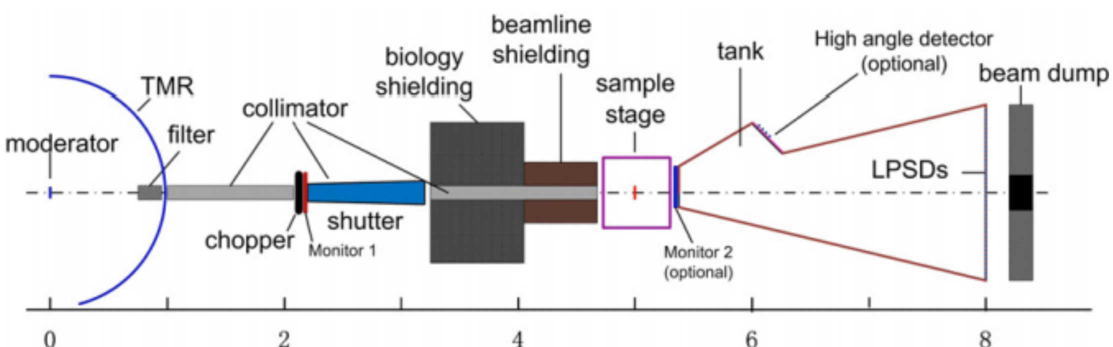
Outline

- Overview of the CPHS project
- Status of CPHS facility in 2014
- Imaging station
- Development of neutron detectors
- Research on neutron optics for small neutron source
- Summary

Neutron Focusing Mirrors for SANS



Geometries of focusing mirrors by MIT Boris group :
Ellipsoid, Paraboloid-Paraboloid, Hyperboloid-Ellipsoid

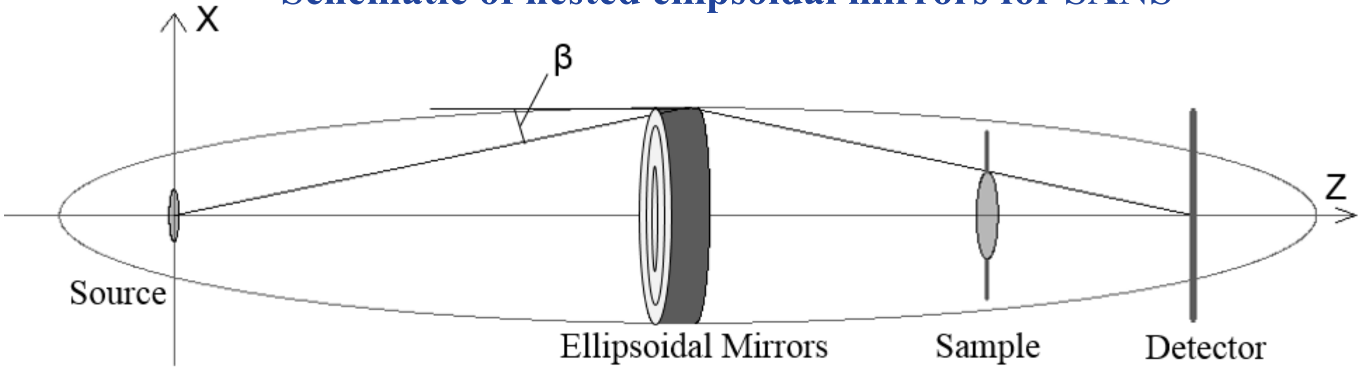


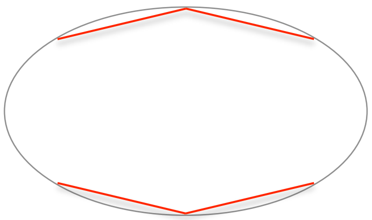
The conventional pinhole design of SANS instrument at CPHS

	Design with Pinhole System	Design with Focusing Mirrors
Source Radius(cm)	1.4	1.4
Sample Radius(cm)	0.5	3.75 ~ 7.5
Sample Position(m)	5	5
Detector Position(m)	8	8
Qmin(λ=10Å)(Å-1)	3.4×10^{-3}	2.9×10^{-3}
Neutron Flux on Sample (n/cm^2/s)	8×10^{3}	2.4×10^{6}
Mirrors' Radius(cm)	N/A	5.0 ~ 10.0
Mirrors' Position(m)	N/A	4

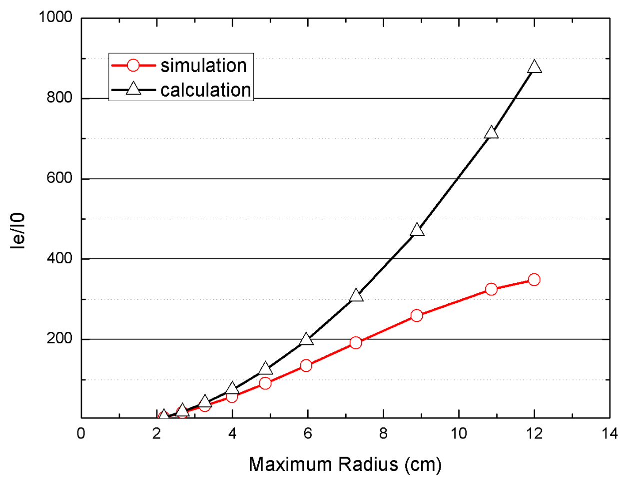
Nested Ellipsoidal and Conical Mirrors

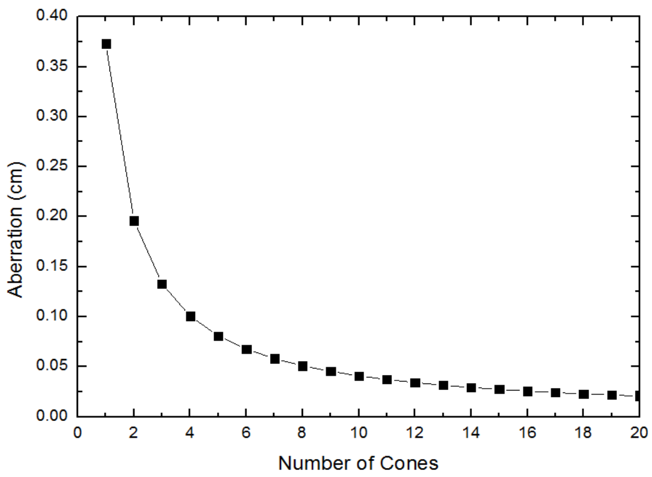
Schematic of nested ellipsoidal mirrors for SANS





Ellipsoid-shaped conical mirrors





The ratio of intensity gain between SANS with and without nested ellipsoidal mirrors when maximum radius of mirrors changes.

The aberration of ellipsoid-shaped conical mirrors when a 0.4m long ellipsoidal mirrors is divided into different number of cones

Outline

- Overview of the CPHS project
- Status of CPHS facility in 2014
- Imaging station
- Development of neutron detectors
- Research on neutron optics for small neutron source
- Summary

Summary

- Mission
  - To support national large-scale neutron sources
  - To train students and young scholar
- Main tasks
  - 3MeV operation & ➔13MeV : DTL linac & Solid methane moderator
  - New methods and technologies on CANS sources (Acc & TMR)
  - New methods and technologies on neutron instrumentation
  - Test beam line for components development
- Neutron imaging station
  - Imaging Plate & MCP detector
- Plan on SANS beam line
  - Boron-coated Straw Tube
  - Focusing Mirror
- Other neutron applications & China-CANS?
  - NAA & BNCT & ……

Thank you!

CPHS in Spring on 07-May-2015

CPHS after snow on 20-Mar-2013