中性子散乱実験装置についてもう一度考える
―積み木型の中性子散乱実験装置―

北大院工 古坂道弘、佐藤他加志、藤田文行、本間彰、
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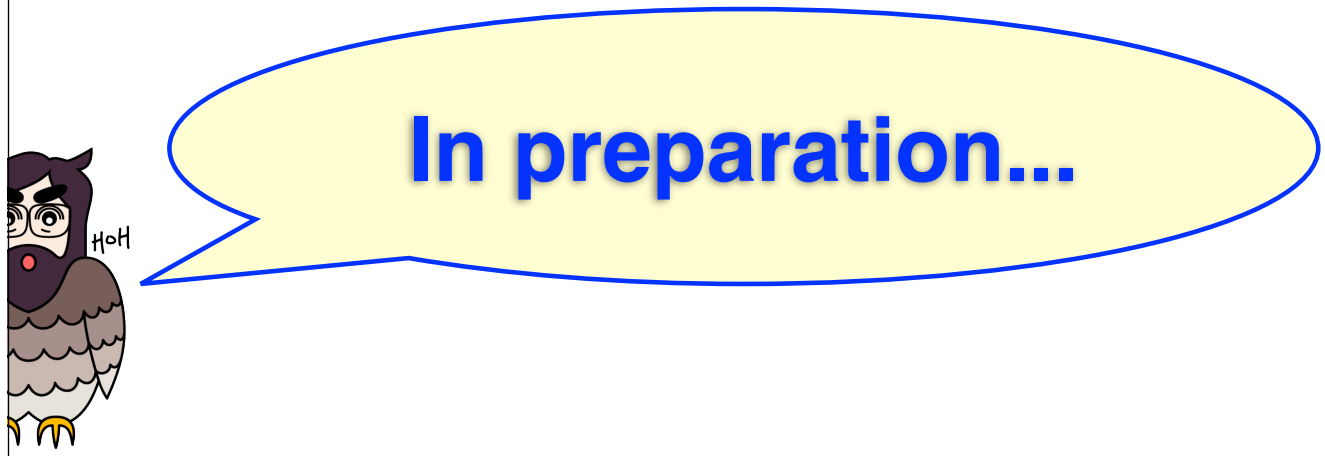
京大原子炉実験所　杉山正明、日野正裕



中性子散乱実験装置についてもう一度考える
ー積み木型の中性子散乱実験装置ー

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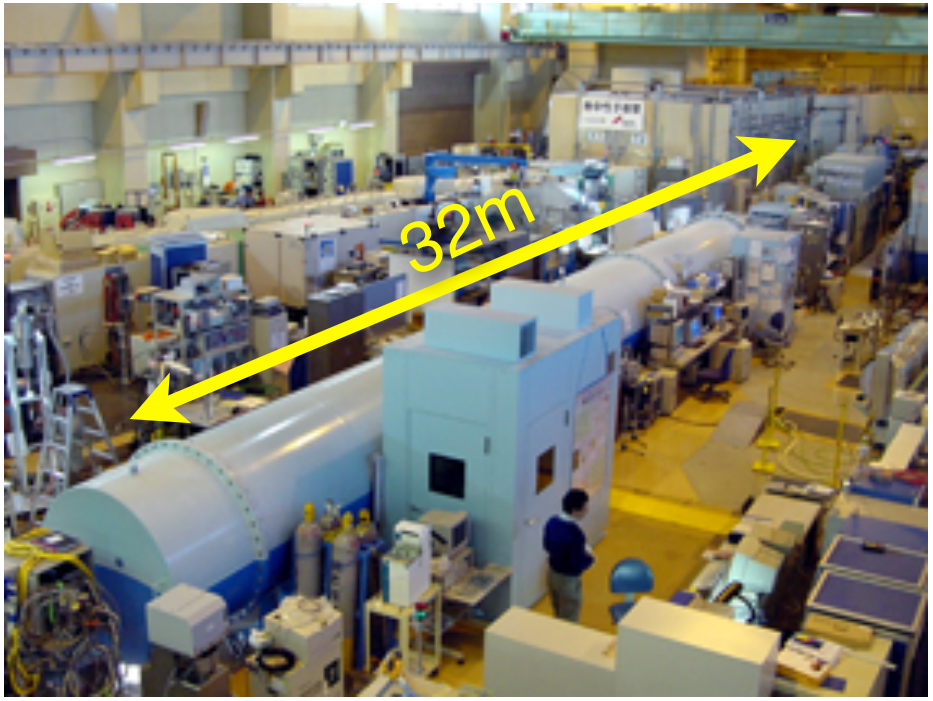
Conventional SANS instrument

Neutron SAS instruments

- Typical SANS instruments
- about 10 mmø sample size

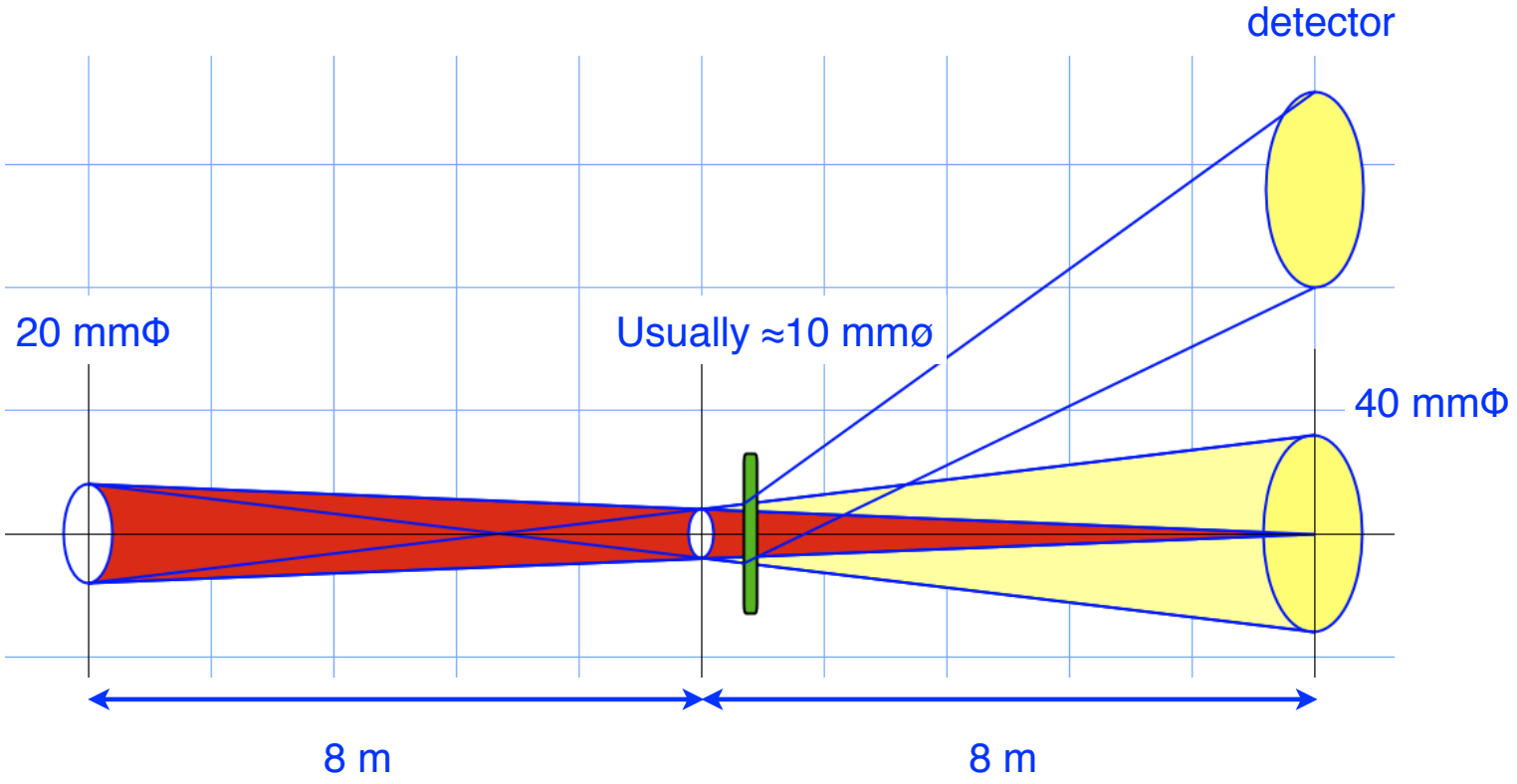


SANS-U@JRR-3

New D11 @ ILL
http://www.ill.eu/instruments-support/instruments-groups/instruments/d11/news-from-d11/

Small Pin-hole Time-of-flight SANS

- Usually, sample diameter ≈ 10 mm ø at SANS-U
- 16 m+16m at maximum
- $Q_{min} \approx 5 \times 10^{-3}$ A^{-1}



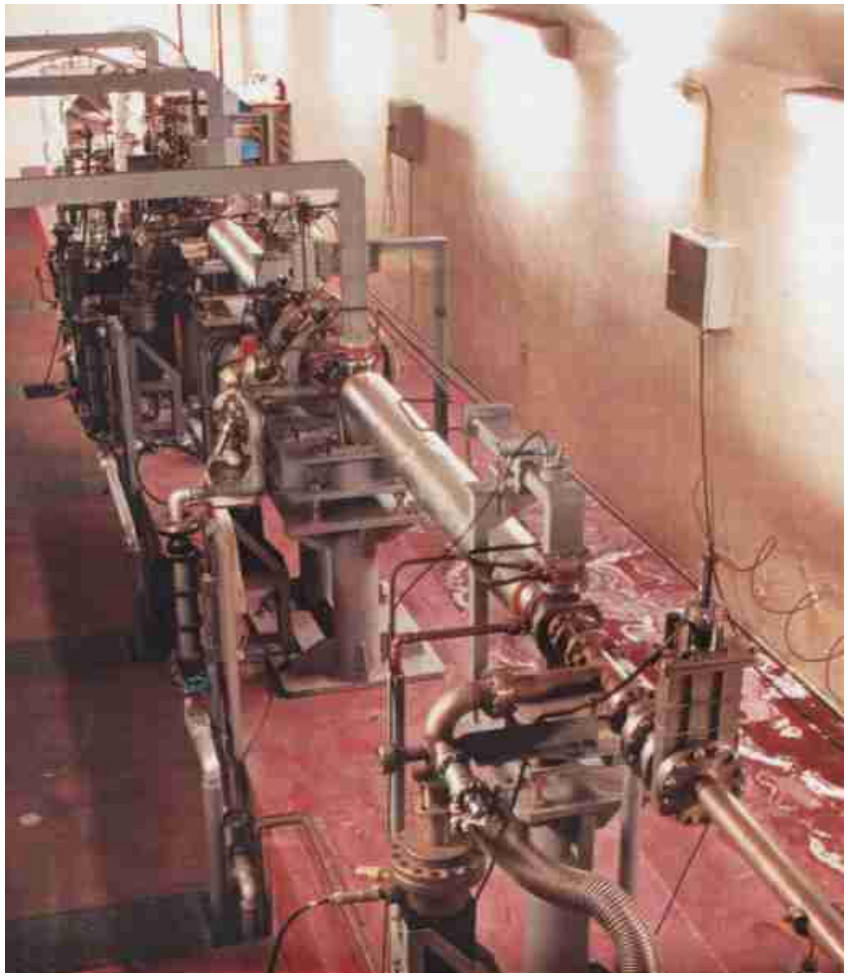
Electron linac based pulsed neutron source

at Hokkaido University

45MeV Electron Linac @Hokkaido University

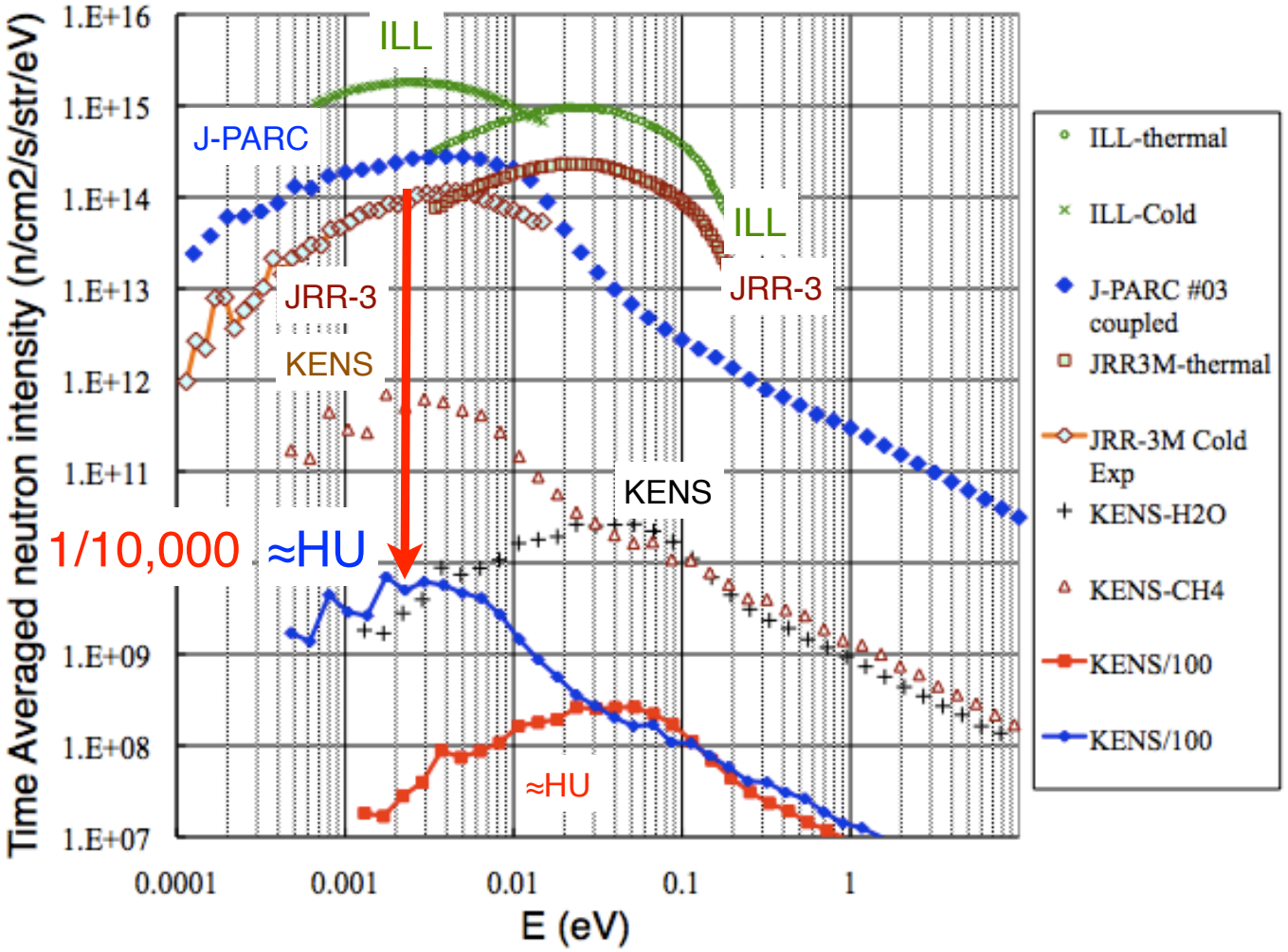
- The first generation compact pulsed neutron source
  - First beam ≈1975
  - still running...
- 35 MeV, 30 μA, 50 pps

Hokkaido University Electron Linac



Time averaged intensity

Factor 2-3 uncertainties

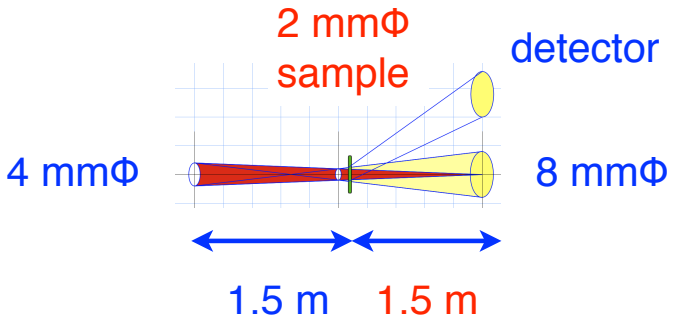


Tailor made experiment.
example 1.
Small Pin-hole Time-of-flight SANS

Small Pin-hole Time-of-flight SANS

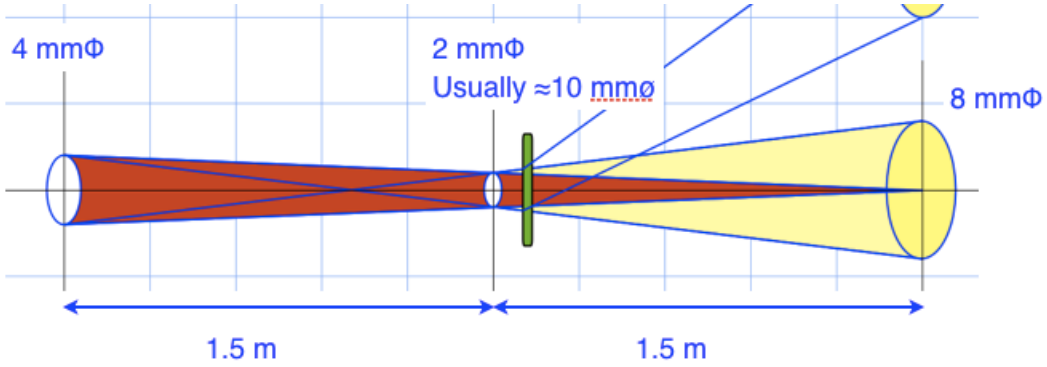
- What do you think of this
  SANS instrument at Hokkaido Univ.
  - Sample size ≈ 2 mm ø
  - flight path only 1.5m
  - no vacuum tube
- Poor intensity ≈ 1/25???

$$I(Q) \propto \phi \cdot d\Omega_i \cdot \frac{d\Sigma}{d\Omega} \cdot V_{\text{sample}} \cdot \eta \cdot d\Omega_f$$

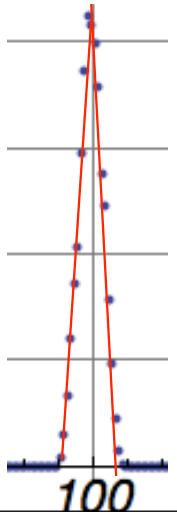


Very clean direct beam!

- Hokkaido Univ. small pin-hole SANS, 2 mmø
  - Cd plate drilled with Boric acid

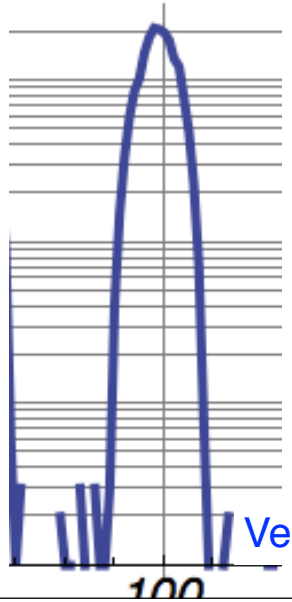


Exact triangular shape



4 mmø
FWHM

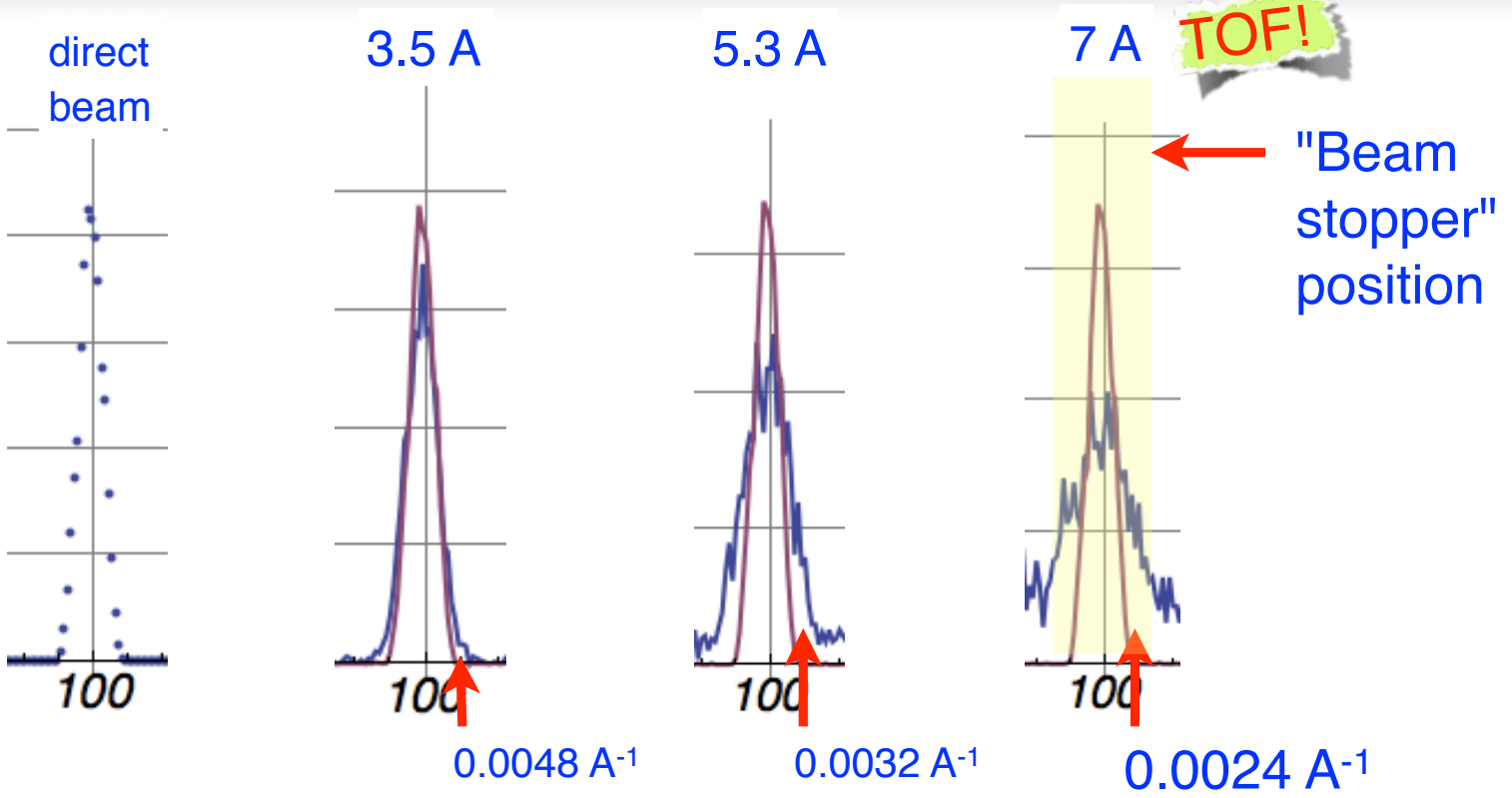
8 mmø
bottom



Very clean tail !

SANS near the direct beam

Preliminary



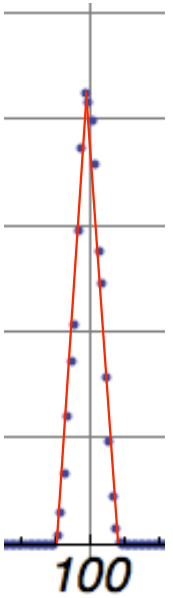
- Cf. Conventional SANS machine:
  - Direct beam stopper covers low angle part!
  - SANS B.G. due to collimation

Cf. ≈0.004 A^{-1} with 8 m

Data analysis

- 2mmø sample SANS is possible evan at Hokkaido University.
- TOF necessary
- Direct beam profile is precisely defined
  - Triangular shape direct beam
  - With fine resolution area detector
- How to de-convolute the result?
  - Fit with resolution function convoluted with S(Q)?

Exact triangular shape



4 mmø FWHM

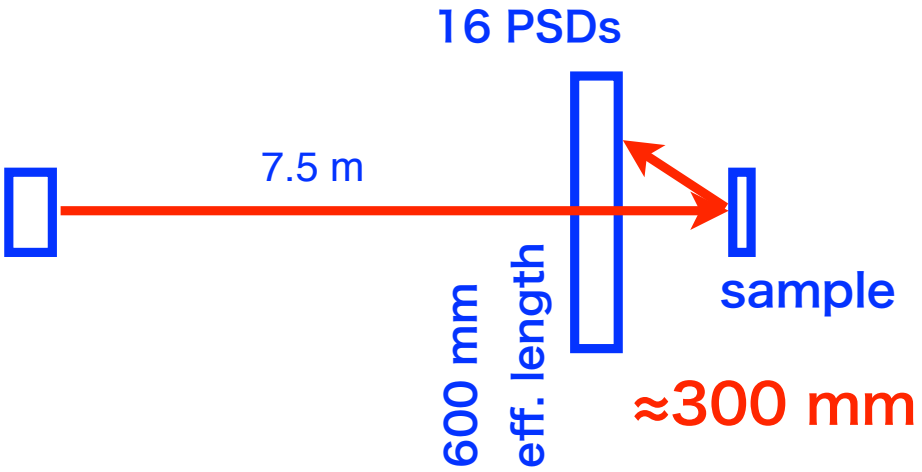
8 mmø bottom

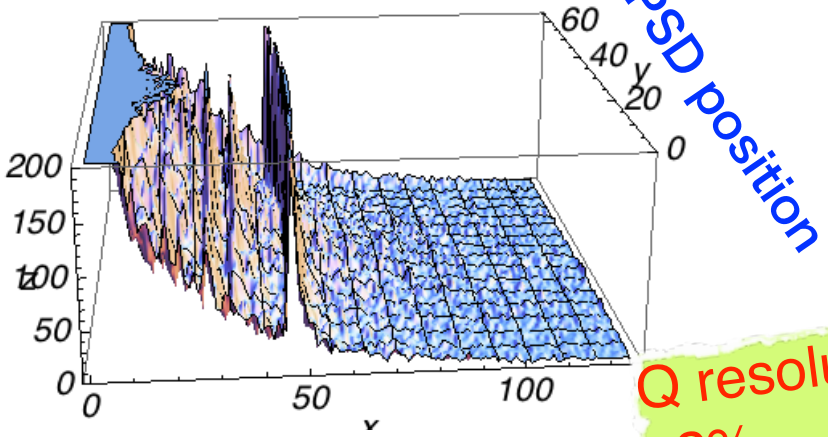
Ex. 2. Diffractometer

Very low resolution

Diffraction in a steel plate

Preliminary



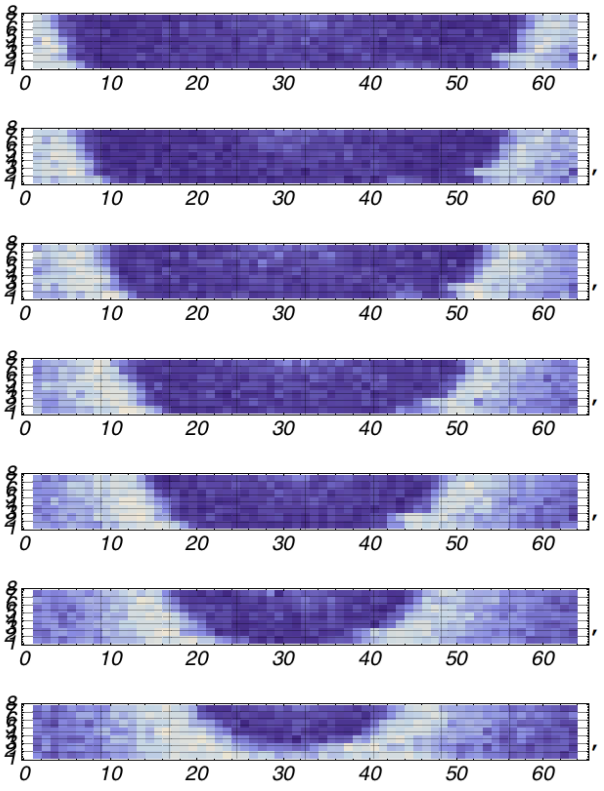


Q resolution ≈2%

PSD 1...8

PSD position

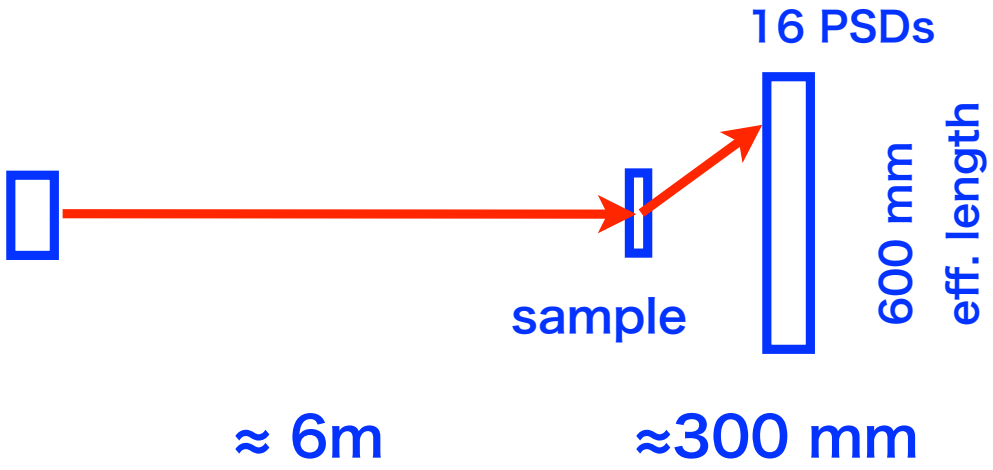
Time-of-flight



Ex. 3. Intermediate-angle scattering

In between small-angle and wide angle.

Intermediate-angle scattering



To be performed

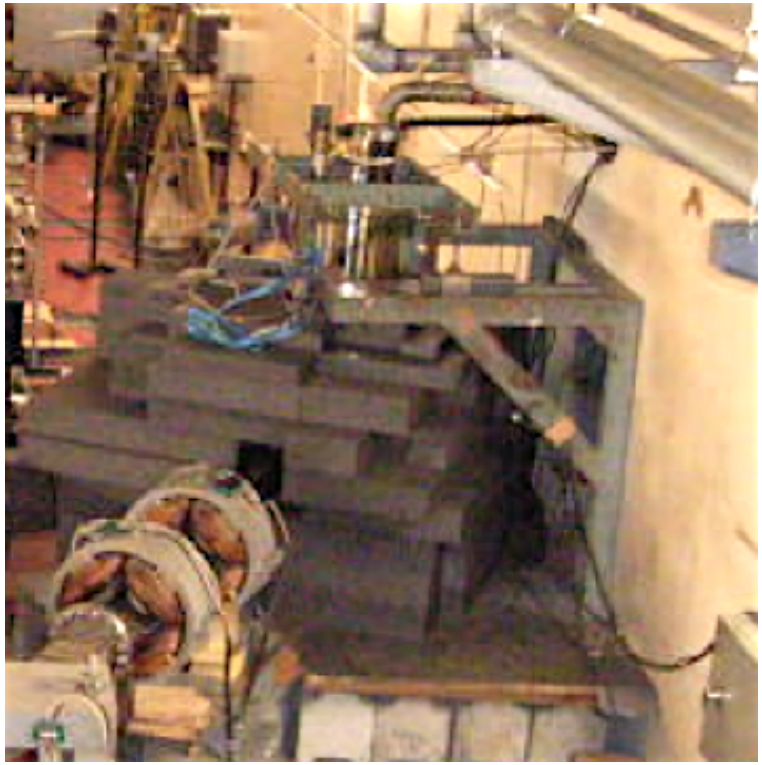
- $0.05\ A^{-1} < Q < 4\ A^{-1}$
  - with λ=1, 12 A
- Ex. Precipitations in steel

What is the tailor-made experiment (TME) beamline

Compact pulsed neutron source is a best place for TME beamline.

Moderator development

- Best place for developing high-performance moderator
  - Coupled moderator concept
  - Solid methane moderator
- Hands-on modification!
  - Low flux means low activation
- J-PARC moderators are developed here.
  - SNS composite moderator tested.

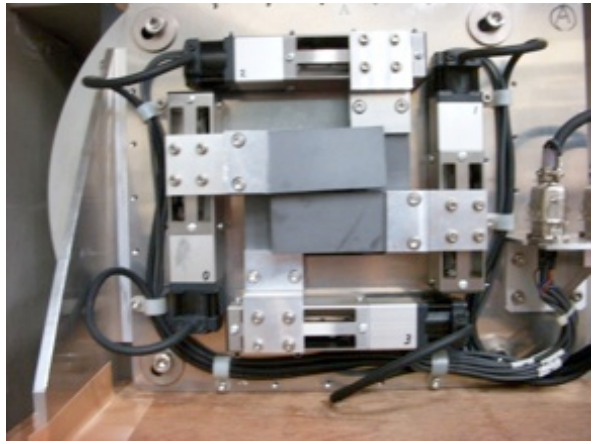


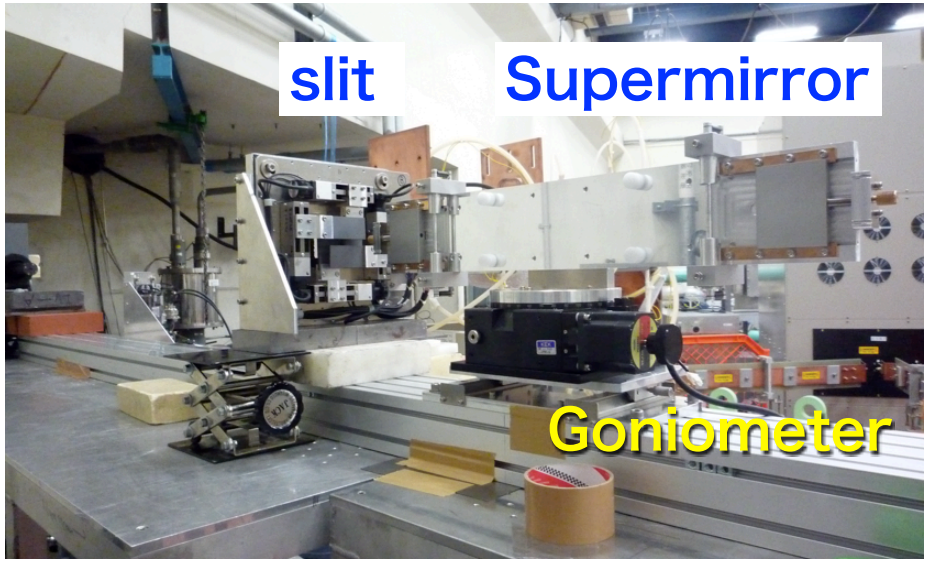
Just imagine some components

Pulsed cold neutron source
solid methane@≈20K

Neutron beam exit

Just imagine some components

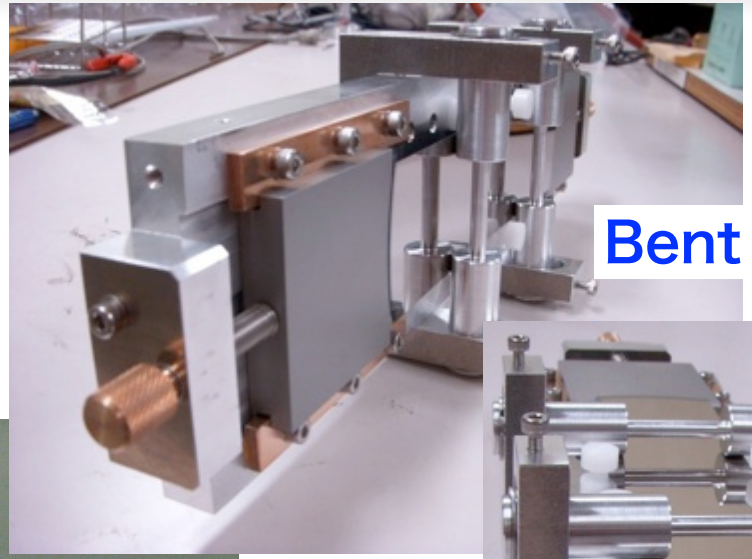




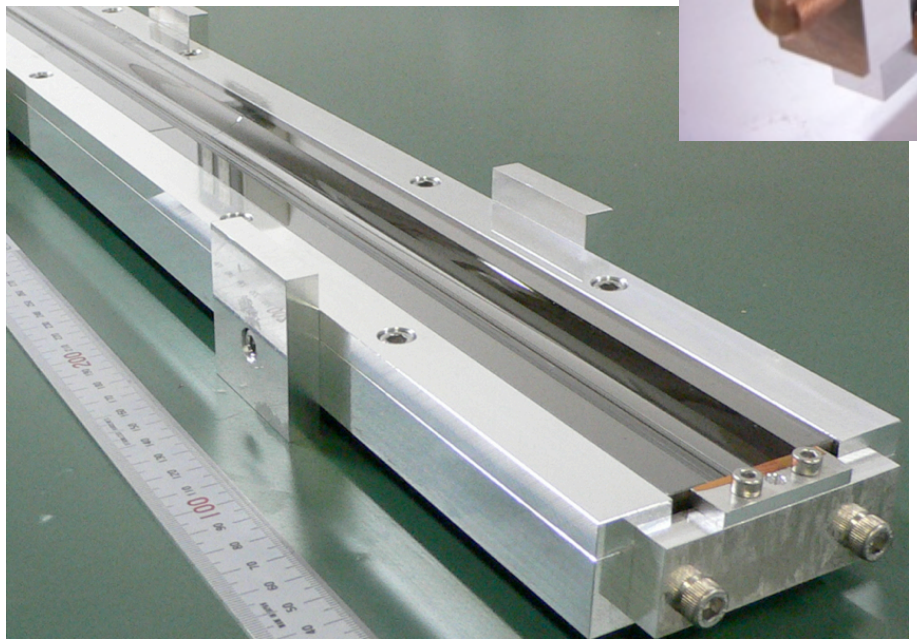
Tables "optical bench"

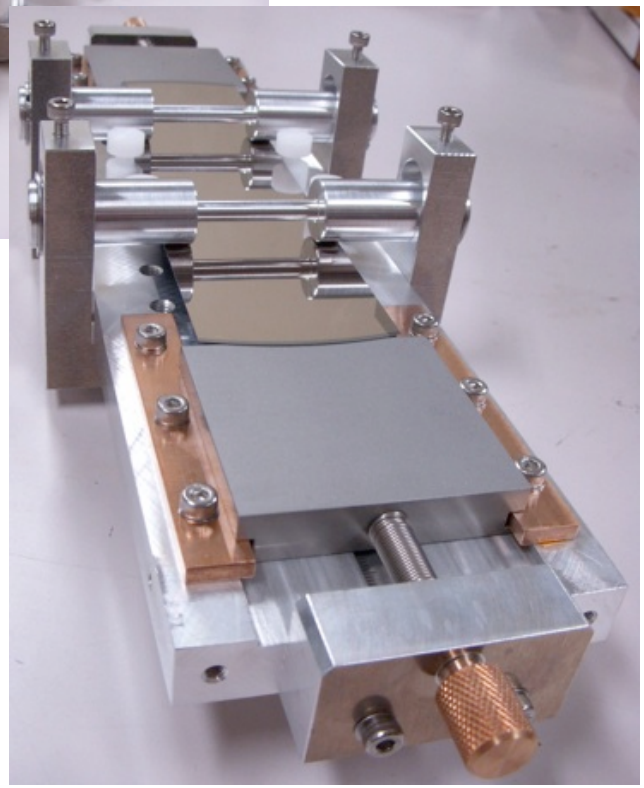
Supermirror components

Bent supermirror



ellipsoidal mirror





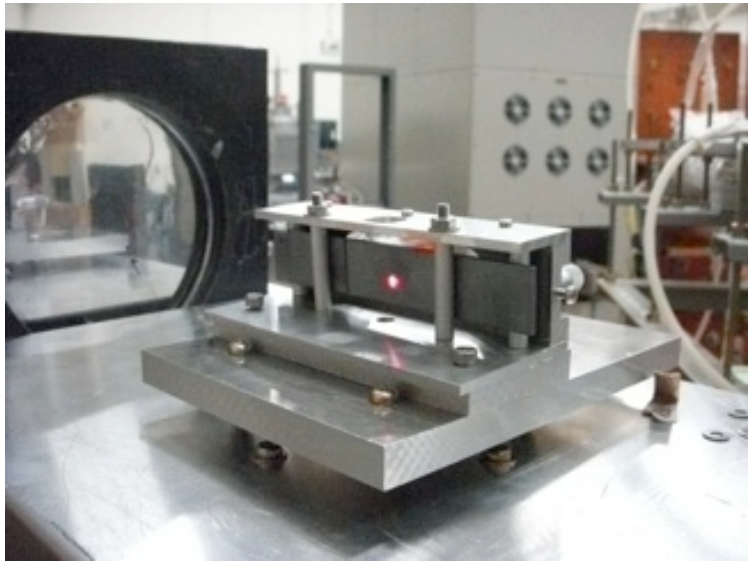
Si perfect crystal bender

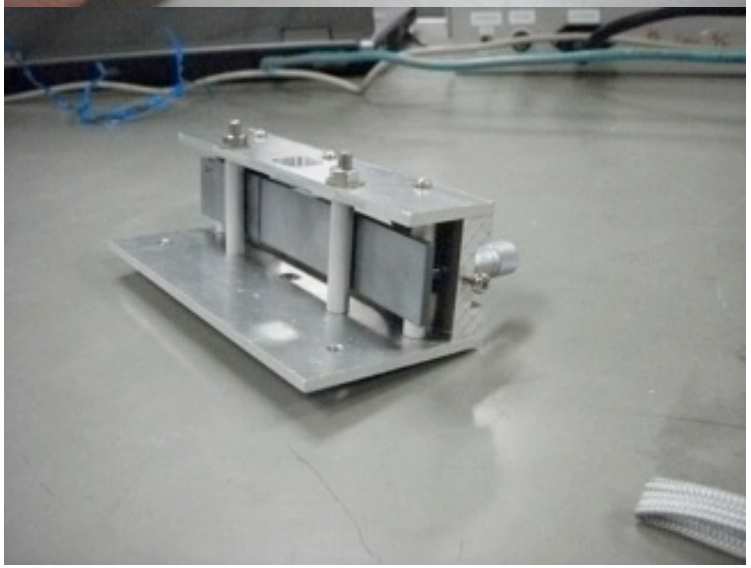
- High resolution area detector

(RPMT)

Resistive wire type

Photomultiplier

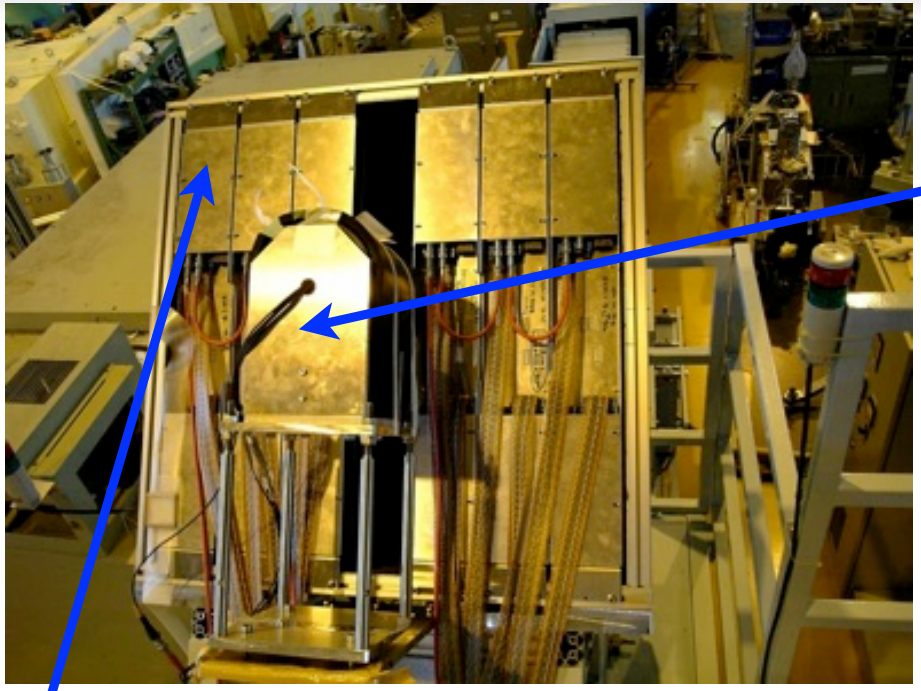




Shielding blocks!

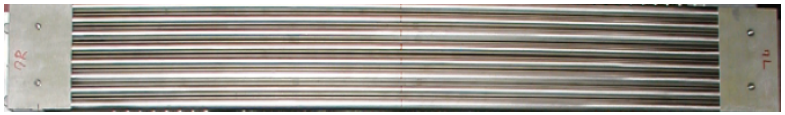
Tape-engineering!

Detector components



- High resolution area detector
(RPMT)
Resistive wire type
Photomultiplier

- Linear Position Sensitive Detectors
(LPSDs)
8 LPSDs/module×6 units

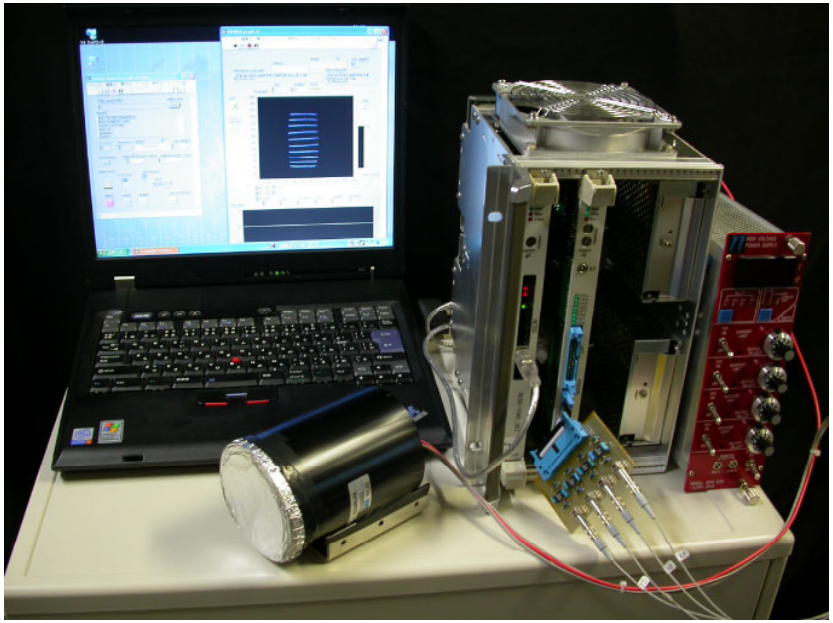


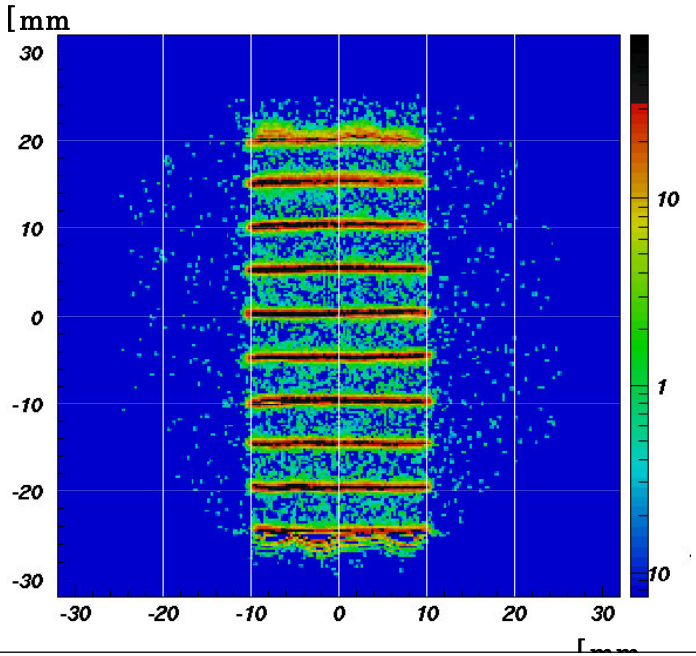
- He-gas:
difficult to purchase?

Resistive wire type PMT +ZnS scintillator

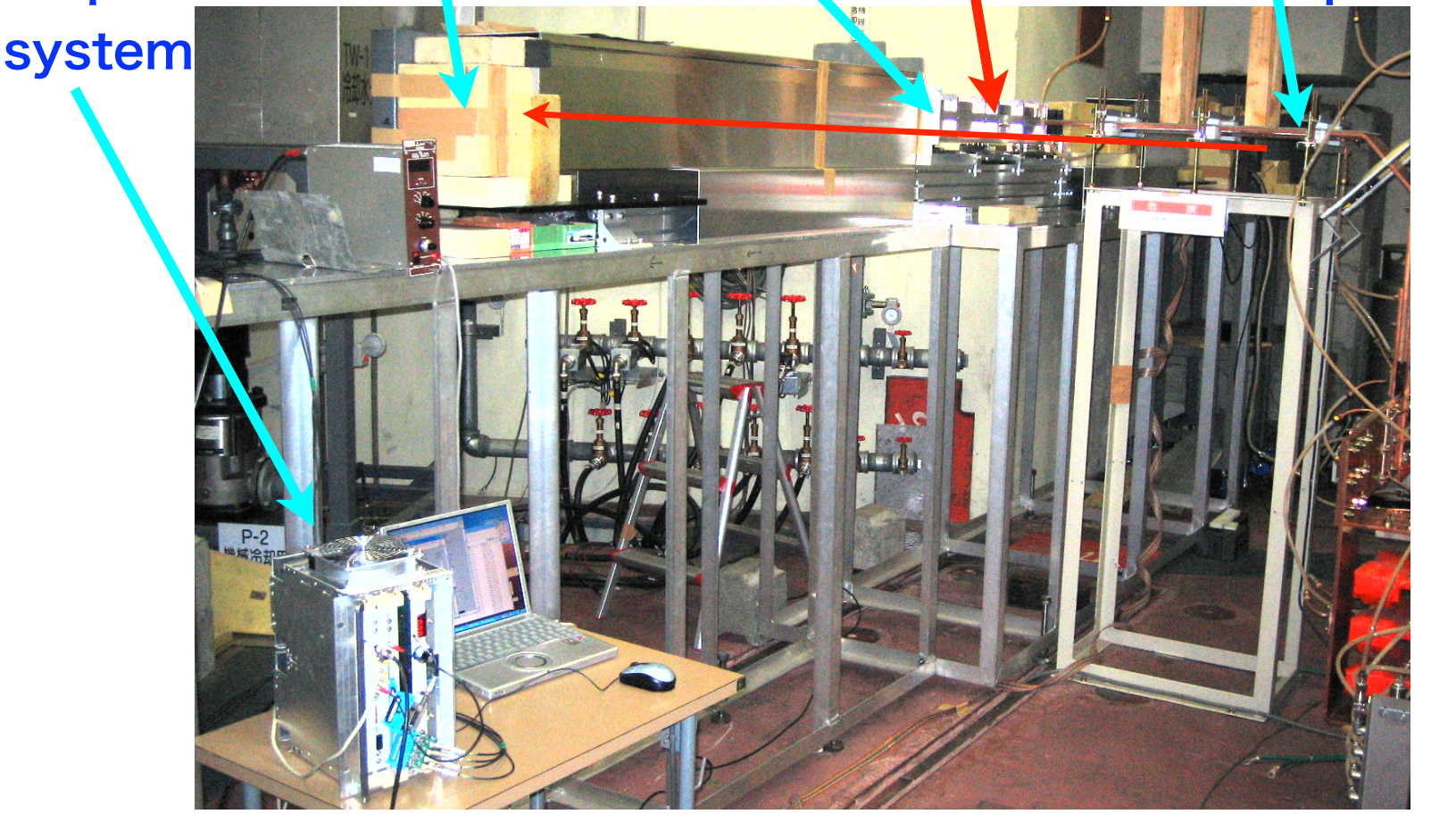
- Li (n, α); ZnS(Ag) scintillation
- 3inch, 5inch PMT
  - R2486-04
- Good resolution
  - <1mm
- convenient system for optical device test.

Hirota, Satoh et al.
(RIKEN, KEK, NOP)





mfSANS at Hokkaido Univ.



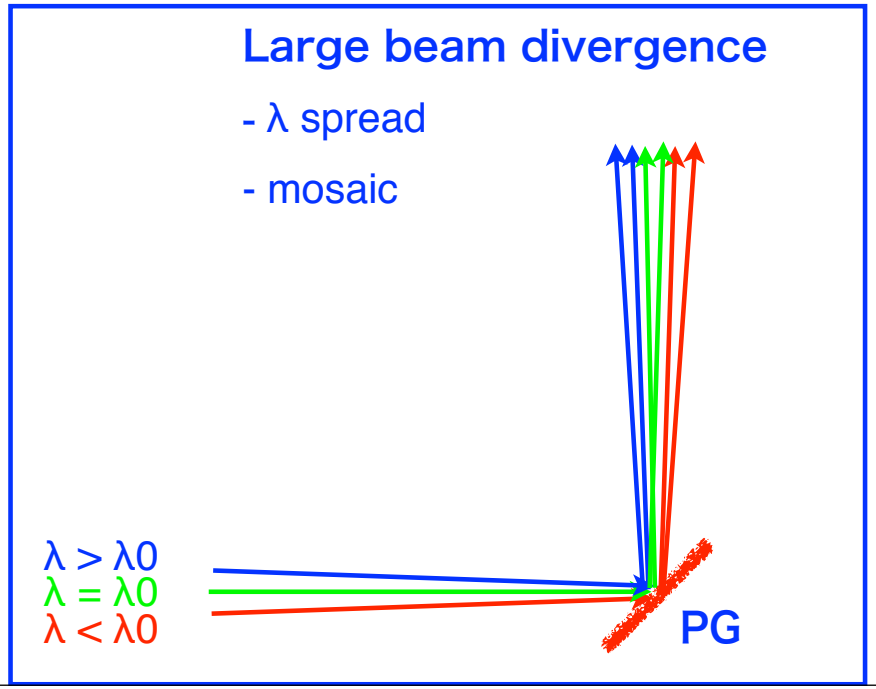
Ex. 4. High intensity monochromator

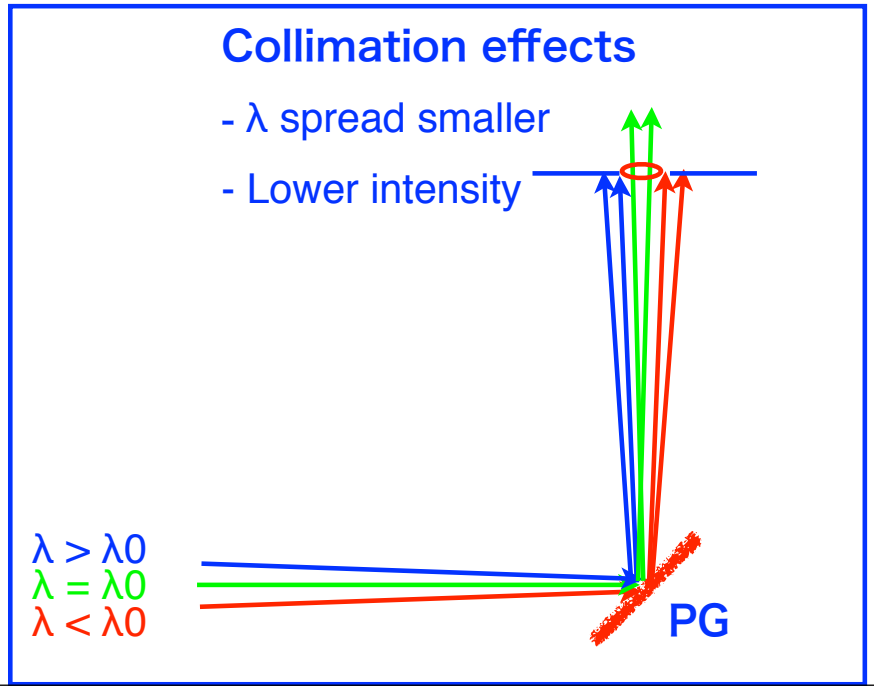
for mfSANS@JRR-3

Commonly used monochromator

- Pyrolitic Graphite
  - Mosaic crystal
  - Reflectivity≈80%
  - Δλ/λ ≤ 1%
    - depending on beam divergence

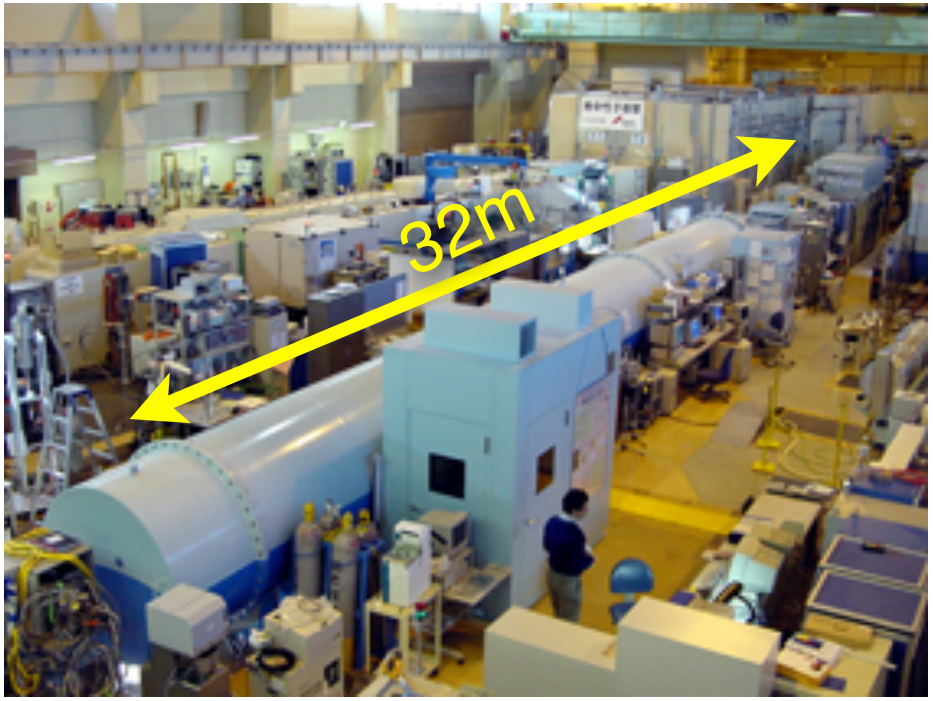
Not suitable to SANS, Reflectometer





Neutron SAS instruments

- 1 instrument at the end of beamline.



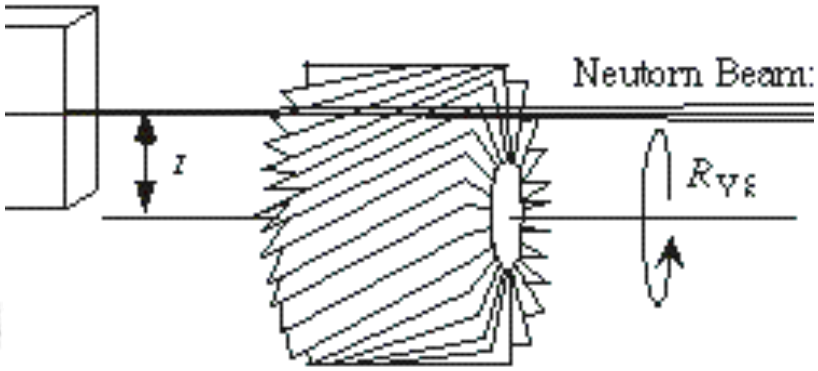
SANS-U@JRR-3

New D11 @ ILL
http://www.ill.eu/instruments-support/instruments-groups/instruments/d11/news-from-d11/

SANS monochromator

- Velocity selector is the choice
  - High intensity quasi-monochromator
  - $\Delta\lambda/\lambda \approx 5 \sim 20\ \%$

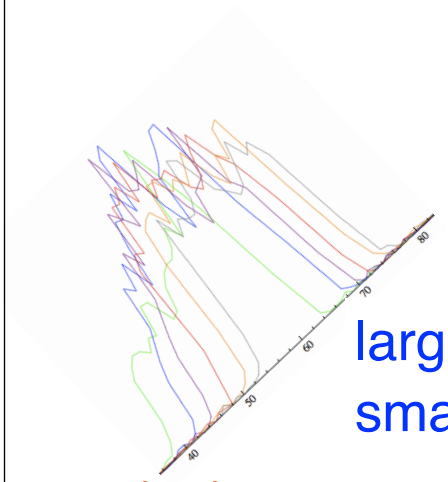
Extremely good performance



- 1 selector/Guide-end

- Supermirror/monochromator would be other possibility
  - NOP beamline

Test experiment at H.U. pulsed neutron source

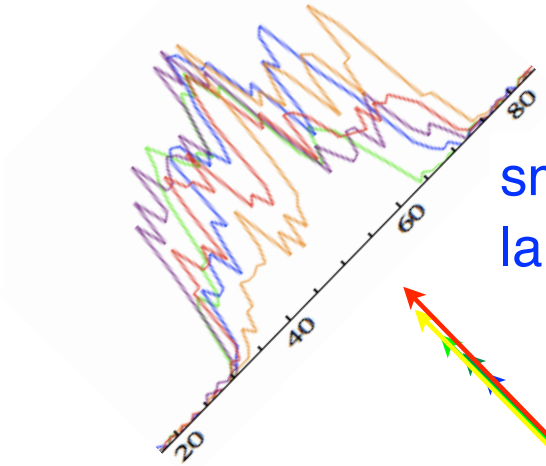


large divergence
small Δλ/λ

λ < λ0 λ > λ0

Bent Si

λ < λ0
λ = λ0
λ > λ0



small divergence
large Δλ/λ≈4%

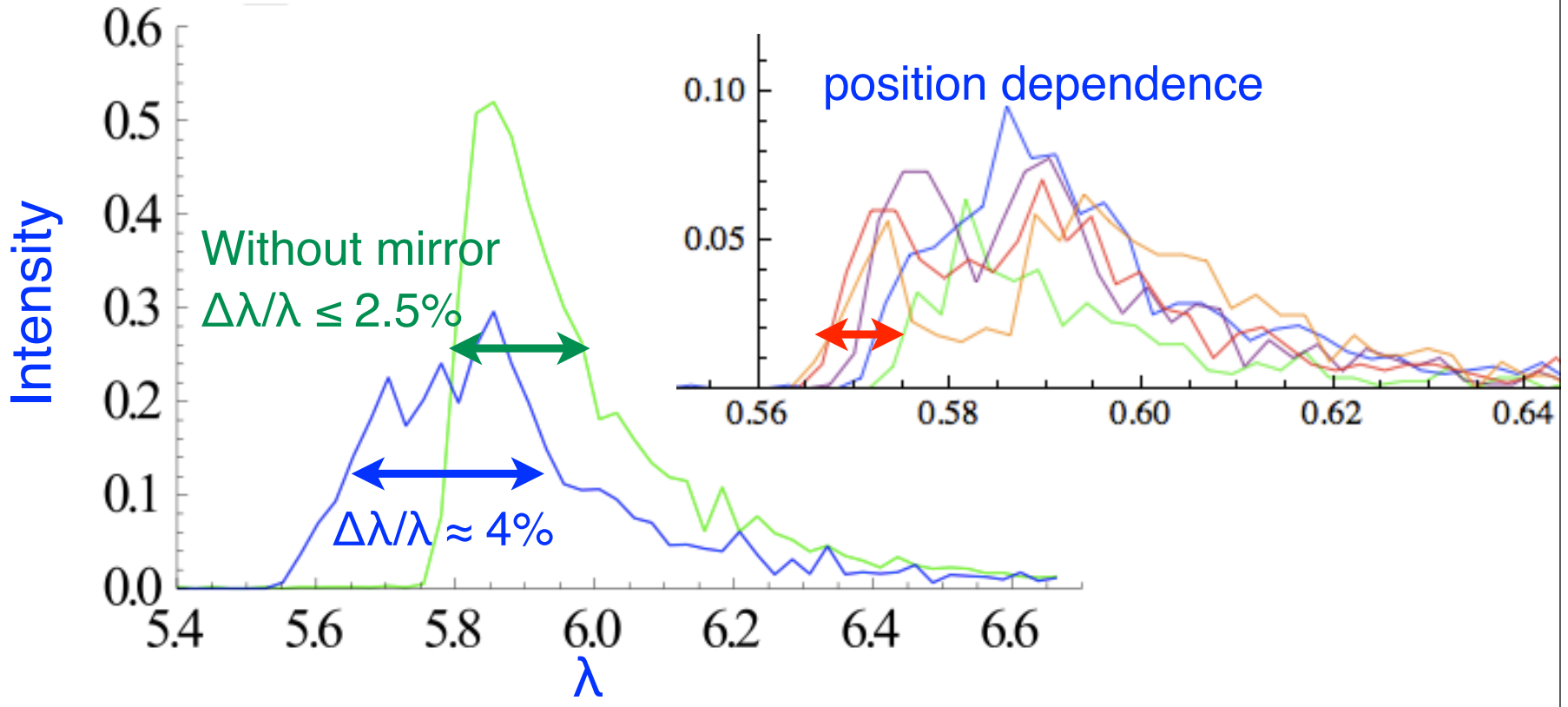
Large divergence

Bent Si

λ < λ0
λ = λ0
λ > λ0

Wide λ band realized

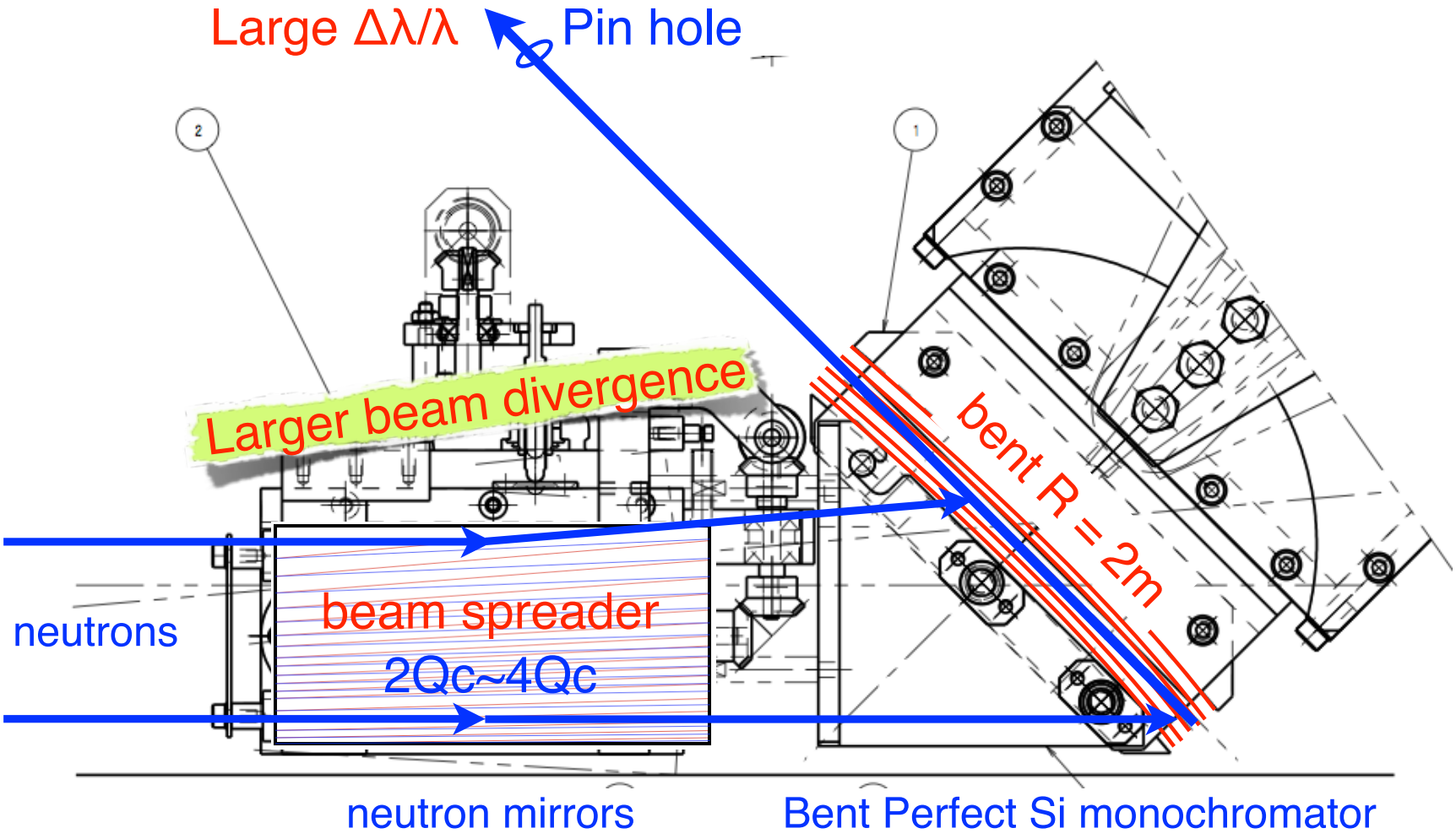
- λ dependence by time-of-flight measurement
  - Not easy at a reactor.



High intensity monochromator with a beam deflector

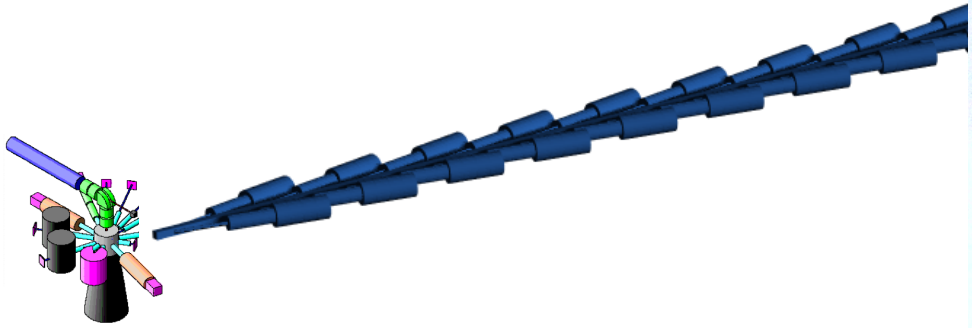
New concept!

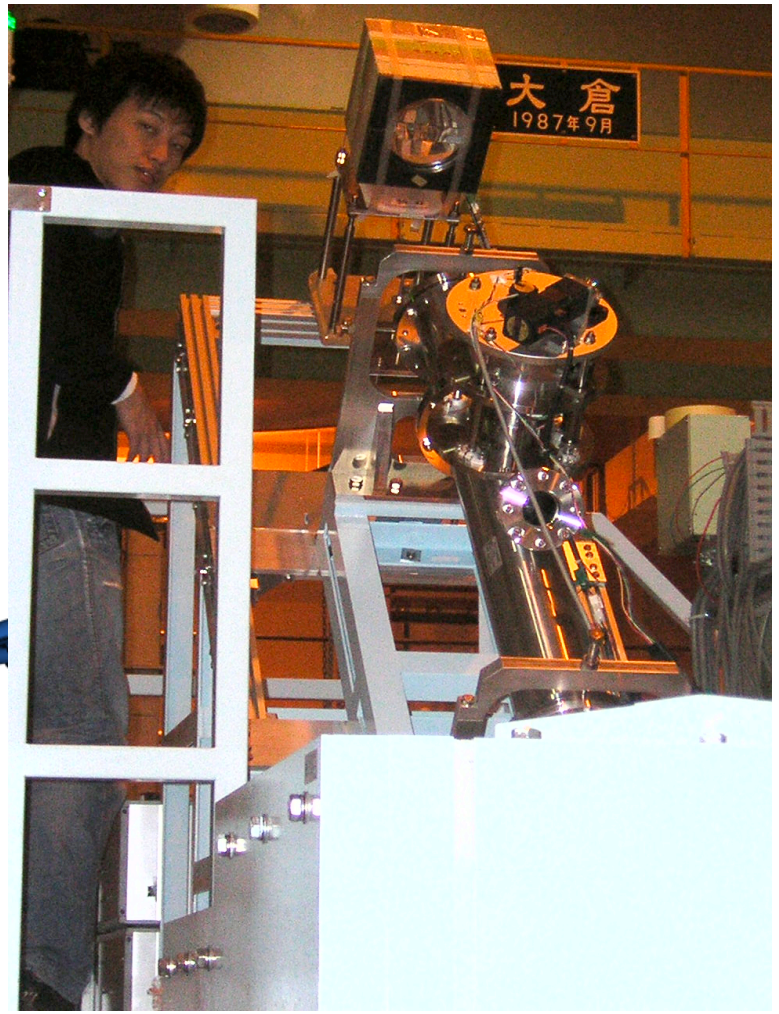
- Improved monochromator being tested



Idea of compact SANS instruments

- Many SANS modules
  - along a beamline
- To have long enough machine time anytime,
  - Ex. For protein solution research
- Educate young scientists
- Check your new ideas
- Your own SANS instrument





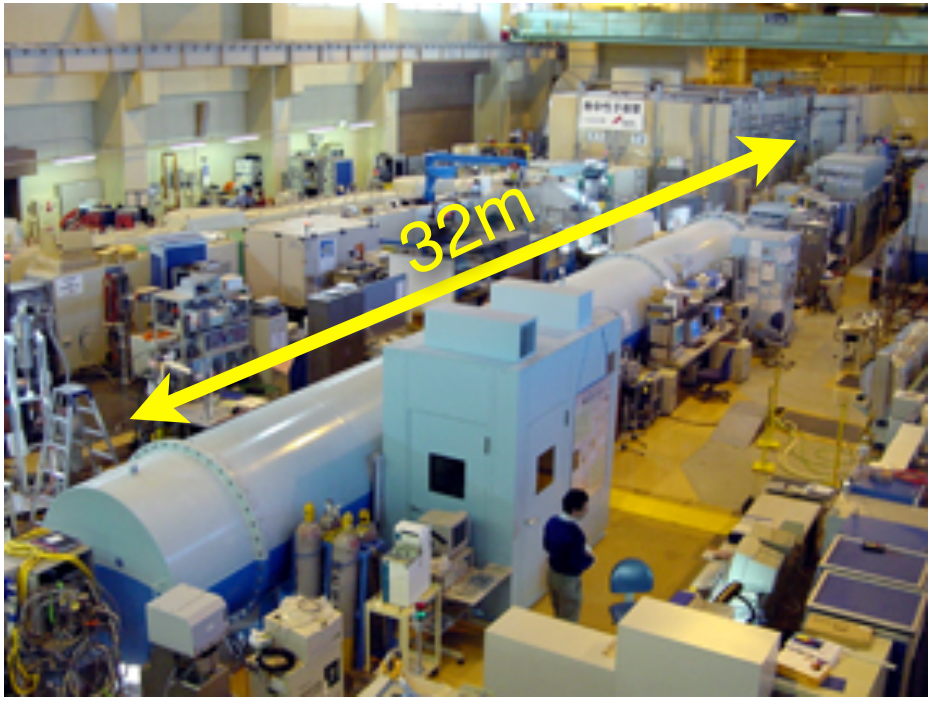
Tailor made experiment beamline

- Test new ideas
  - Very easy to tailor an instrument.
- Best way of learning neutron scattering and instrumentation.
  - To educate young people
  - Teach yourself
- Low cost
- Relaxed resolution to gain intensity
- Tailor made experiment:
  - Ex. just to look at...
  - Intermediate Q ≈ 0.1~2 A^{-1} region
  - a magnetic diffraction peak

Just to review focusing SANS instrument

Neutron SAS instruments

- Need a cold neutron source.
- Only 1 instrument at a guide-end.



SANS-U@JRR-3

New D11 @ ILL
http://www.ill.eu/instruments-support/instruments-groups/instruments/d11/news-from-d11/

X-ray SAS instruments are Small…

X-ray SAS instrument

- Laboratory sources are available anywhere
- Proper training methods are established
  - Variety of books available
  - You can ask experienced people around.
- If laboratory source is not appropriate, you can always use synchrotron radiation

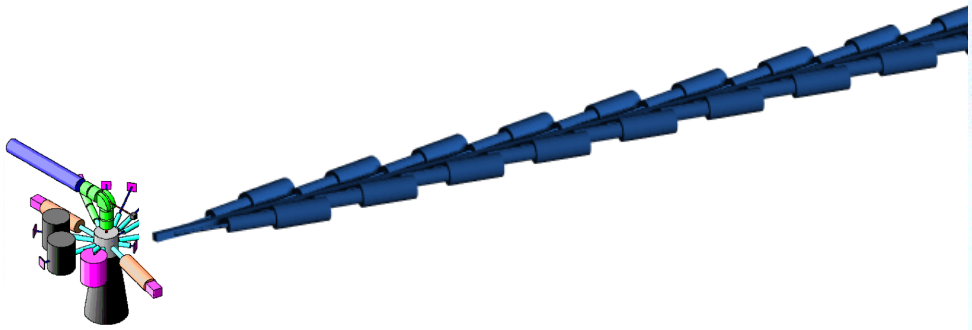
SAXS
http://matrix-dev.ansto.gov.au/research/bragg_institute/facilities/instruments/saxs/mimi_saxs

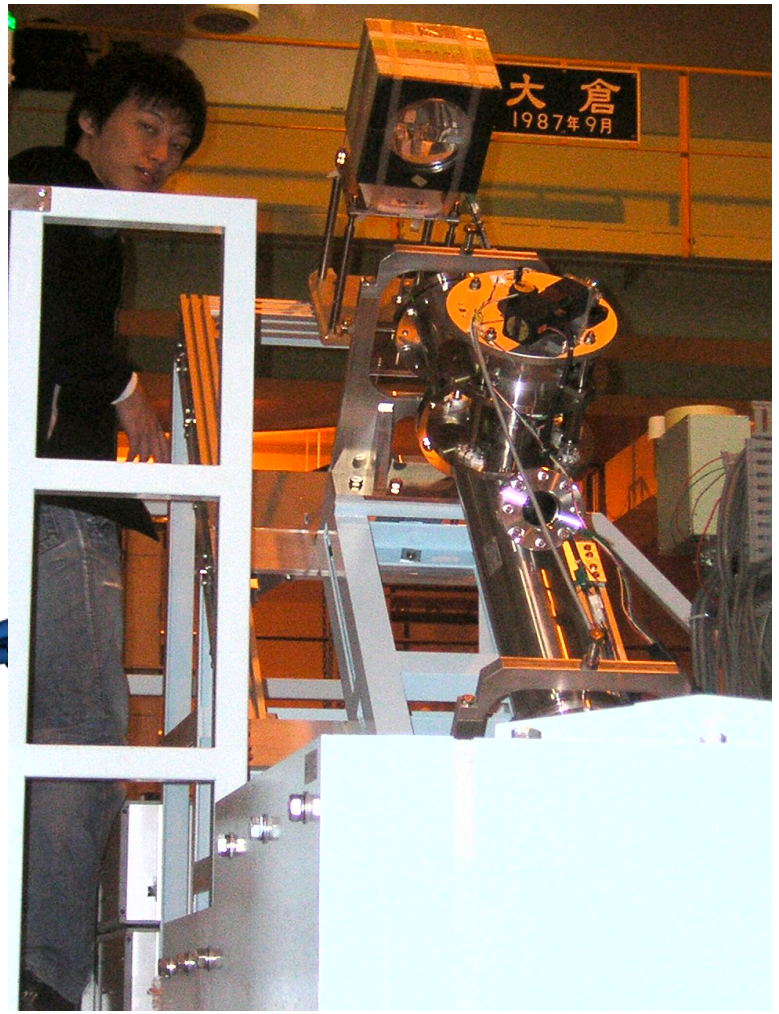
ESRF
http://www.lightsources.org/cms/?pid=1000103

Why not have compact neutron SAS instrument

Idea of compact SANS instruments

- To have long enough machine time anytime,
  - Ex. For protein solution research
- Educate young scientists
- Check your new ideas
- Many SANS modules
- Your own SANS instrument





to match with large neutron facilities

- Big facilities like
  - ILL, Oak Ridge, Munich, NIST, JRR-3, KAERI, ANSTO, ...
  - ISIS, Luhan center, PSI, SNS, J-PARC

J-PARC
http://j-parc.jp/ja/layout-j.html

How to make compact instruments: Focusing is the key.

Focusing makes instrument compact!
compact ≈ low cost

Cf. Focusing gives us no-gain in intensity!

Focusing SANS

- Toroidal mirror focusing to extend low-Q limit.
  - Moved from Jülich to München
  - $Q=4\times10^{-4}A^{-1}$

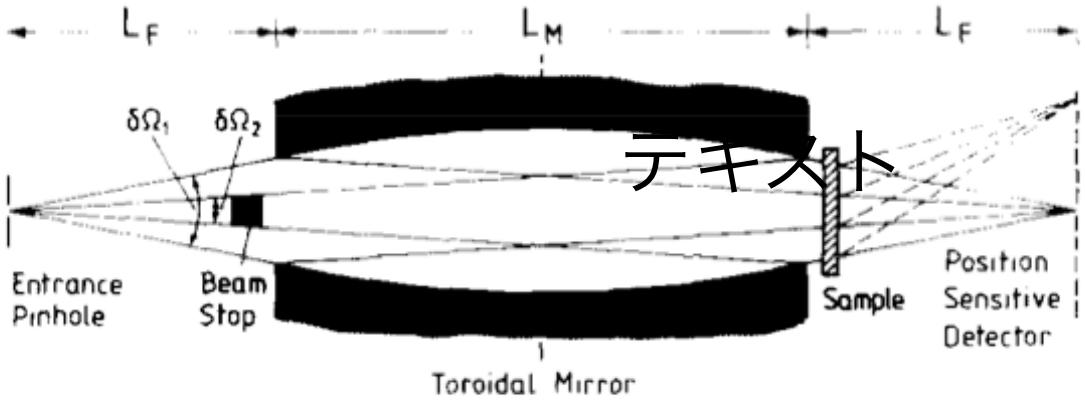


Fig. 1. Toroidal mirror with the image in the detector plane.

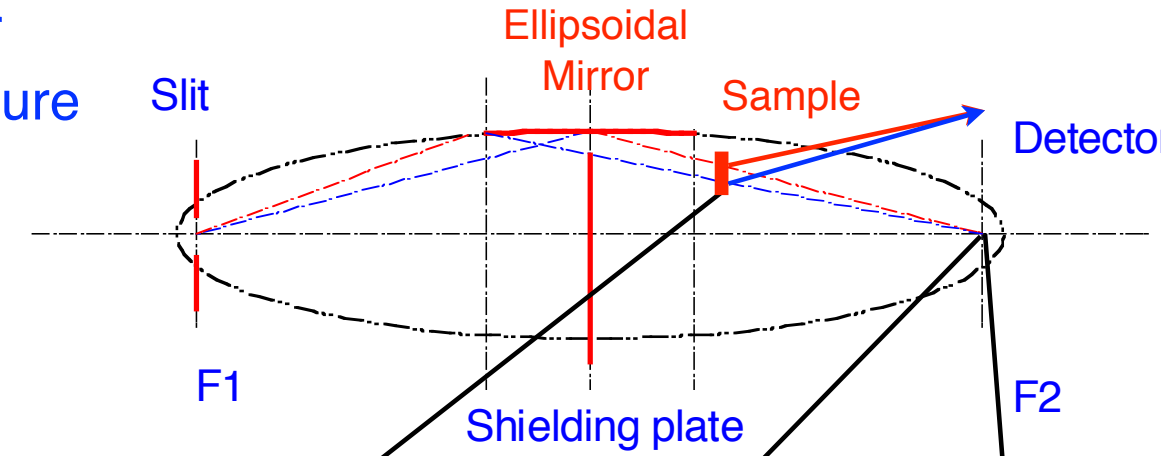
B. Alefeld et al./ Physica B 234-236 (1997) 1052-1054

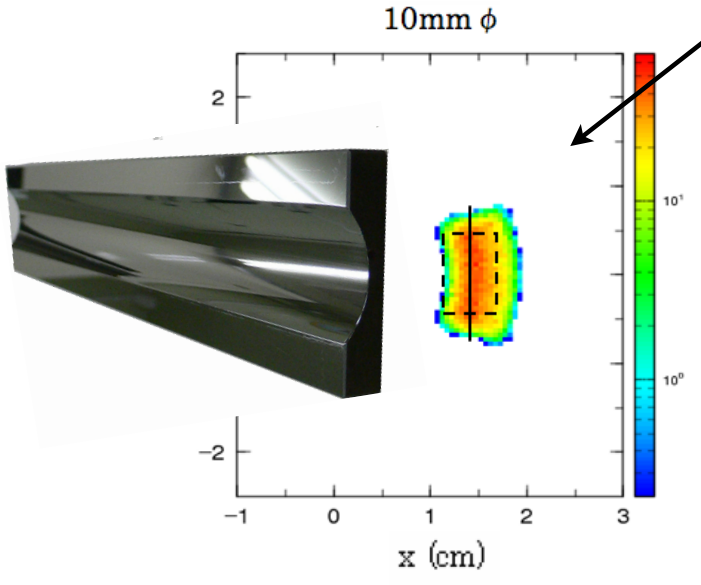
- MgO_2 lens, sextupole lens are available.

Ellipsoidal mirror focusing SANS

Kamada et al. (Hokkaido Univ.)

- Ellipsoidal mirror
- 1~10 mmø aperture





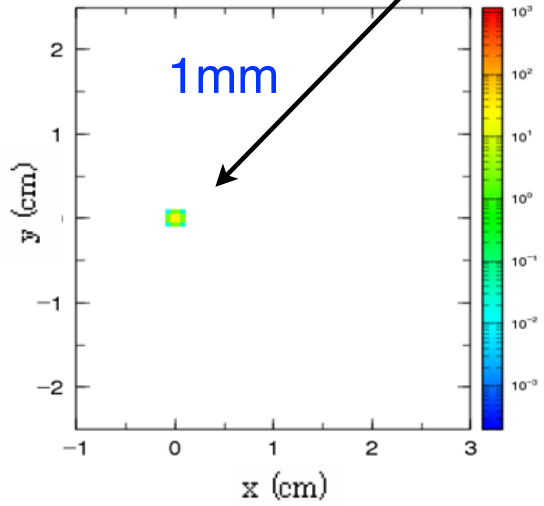


図 4.12 Aperture : 1mm ϕ

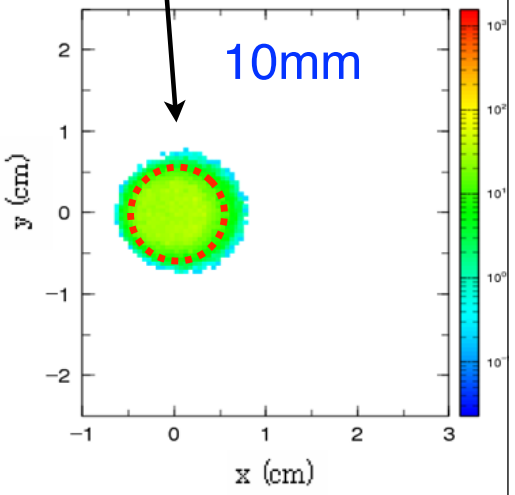
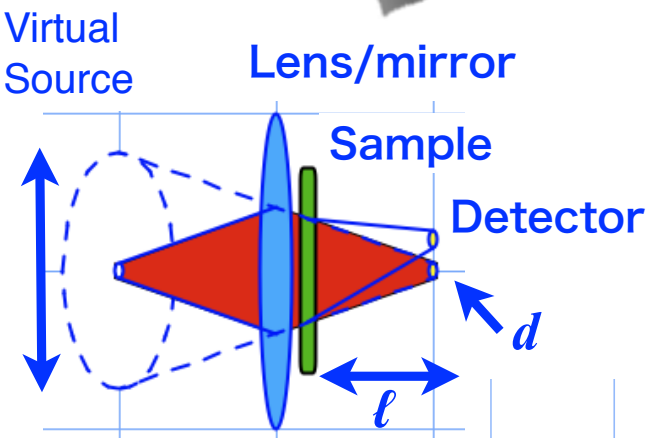


図 4.17 Aperture : 10mm ϕ

Focusing SANS instrument is Compact!

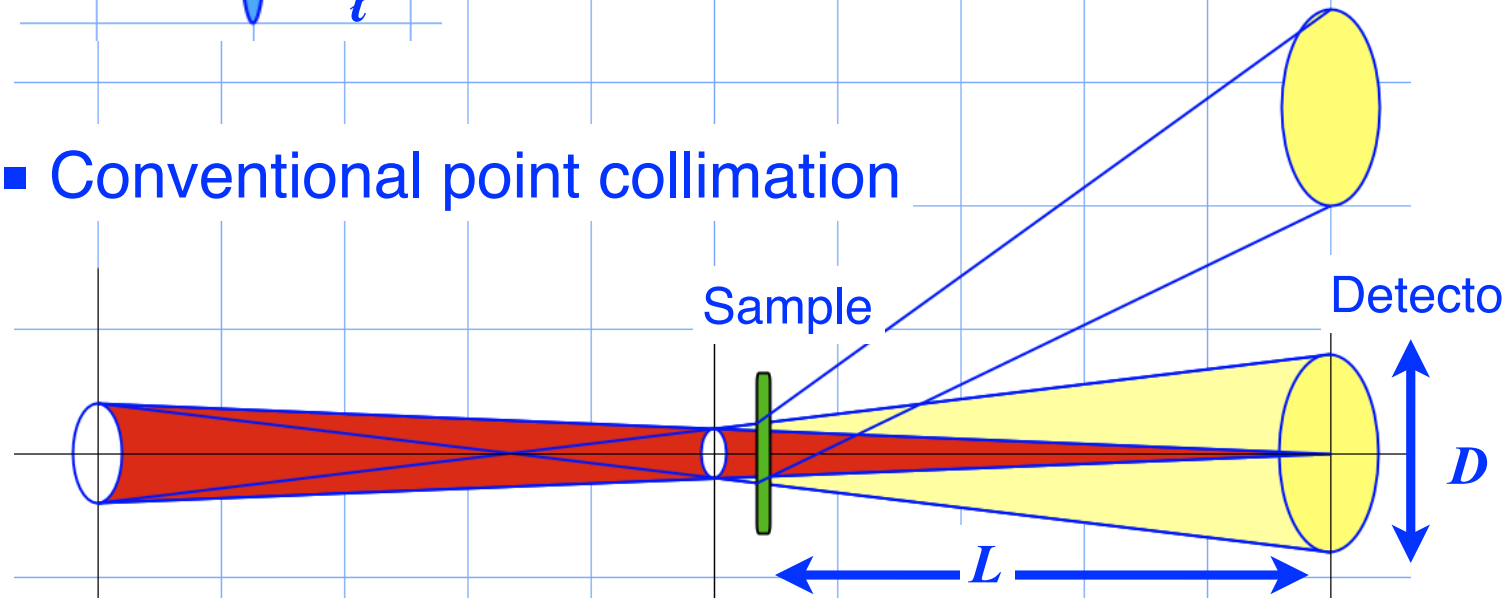
- Focusing ≈ compact



- Same resolution/intensity
  - Angular resolution
    ≈D/L≈ d/ ℓ
  - Intensity:

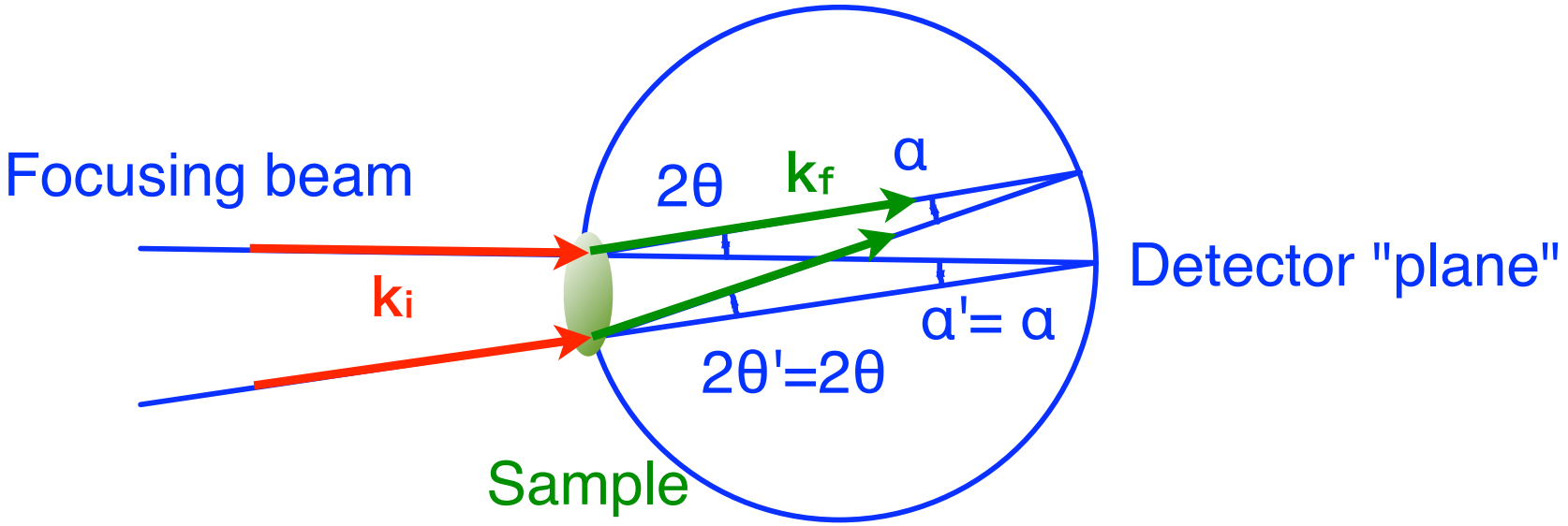
$$I \propto \phi \cdot d\Omega_i \cdot \frac{d\Sigma}{d\Omega} \cdot V_{sample} \cdot \eta \cdot d\Omega_f$$

- Conventional point collimation

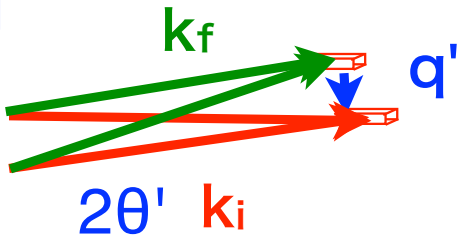


Focusing in k space

Real space



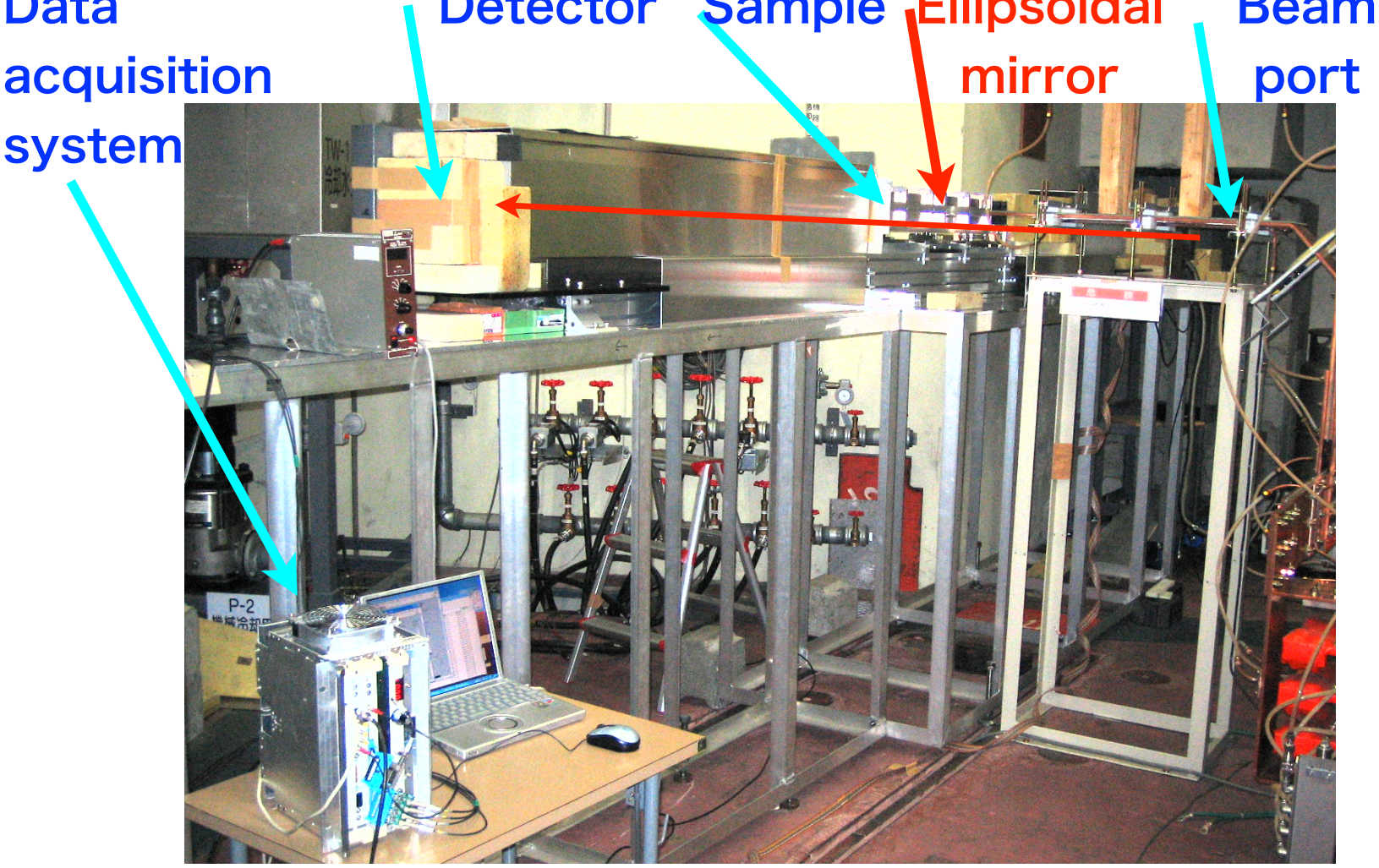
Reciprocal space



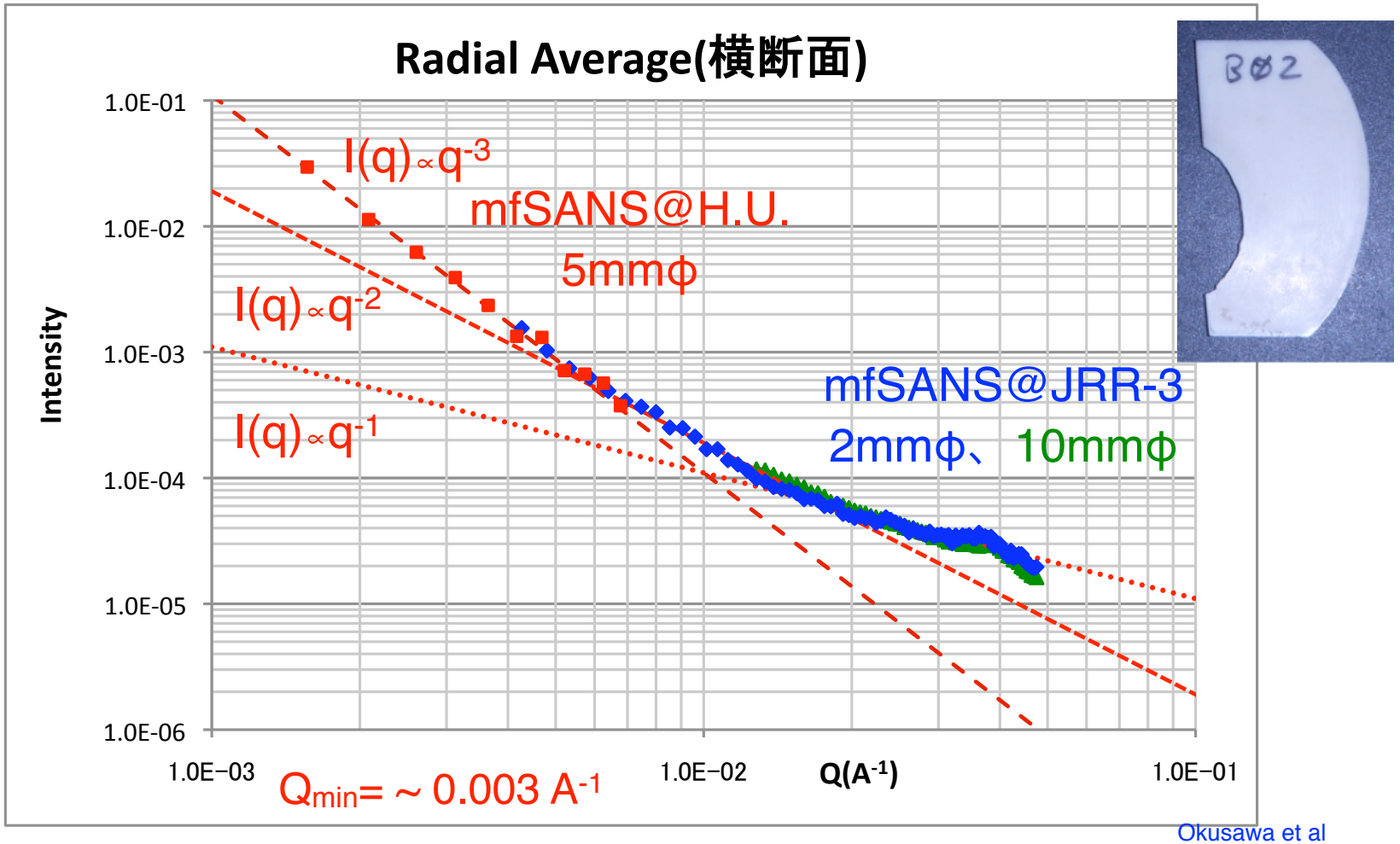
Mini-Focusing Small-Angle Neutron Scattering Instrument (mfSANS) @Hokkaido University

Time-of-flight focusing SANS

mfSANS at Hokkaido Univ.



Bovine thighbone, cross section SANS preliminary analysis



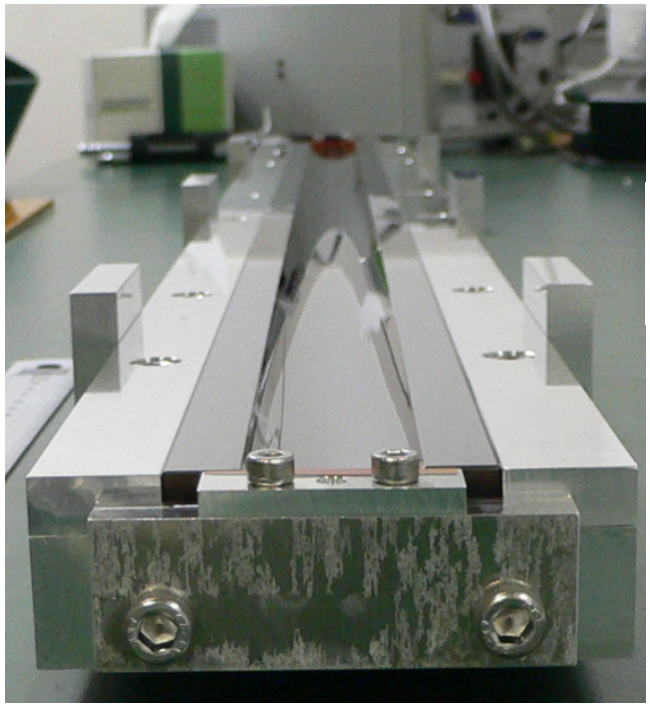
Okusawa et al

mfSANS@JRR-3/JAEA

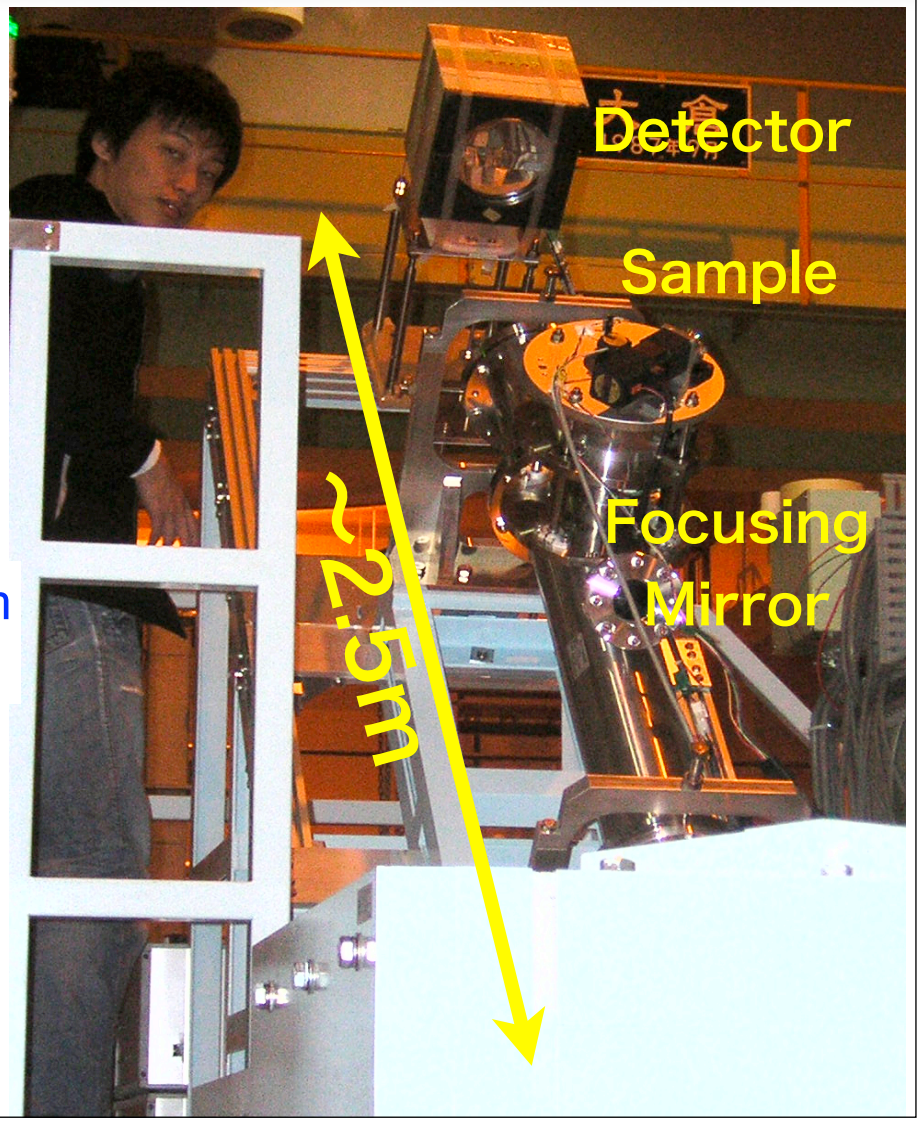
Monochromatic neutron
focusing SANS

Prototype focusing SANS@JRR-3

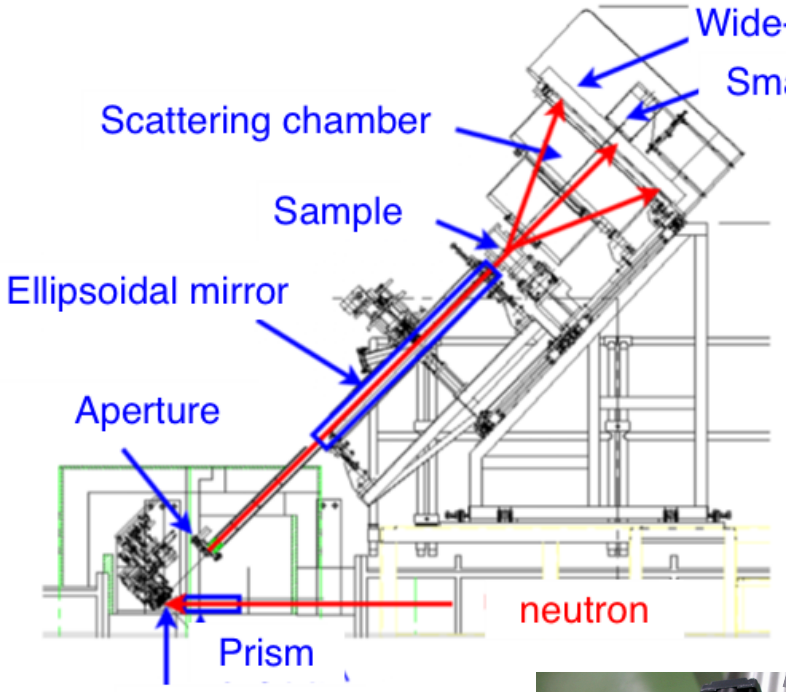
- Ellipsoidal mirror
  - 2.5 Q_c supermirror
  - 2.5 m between focal points
  - short radius 20 mm

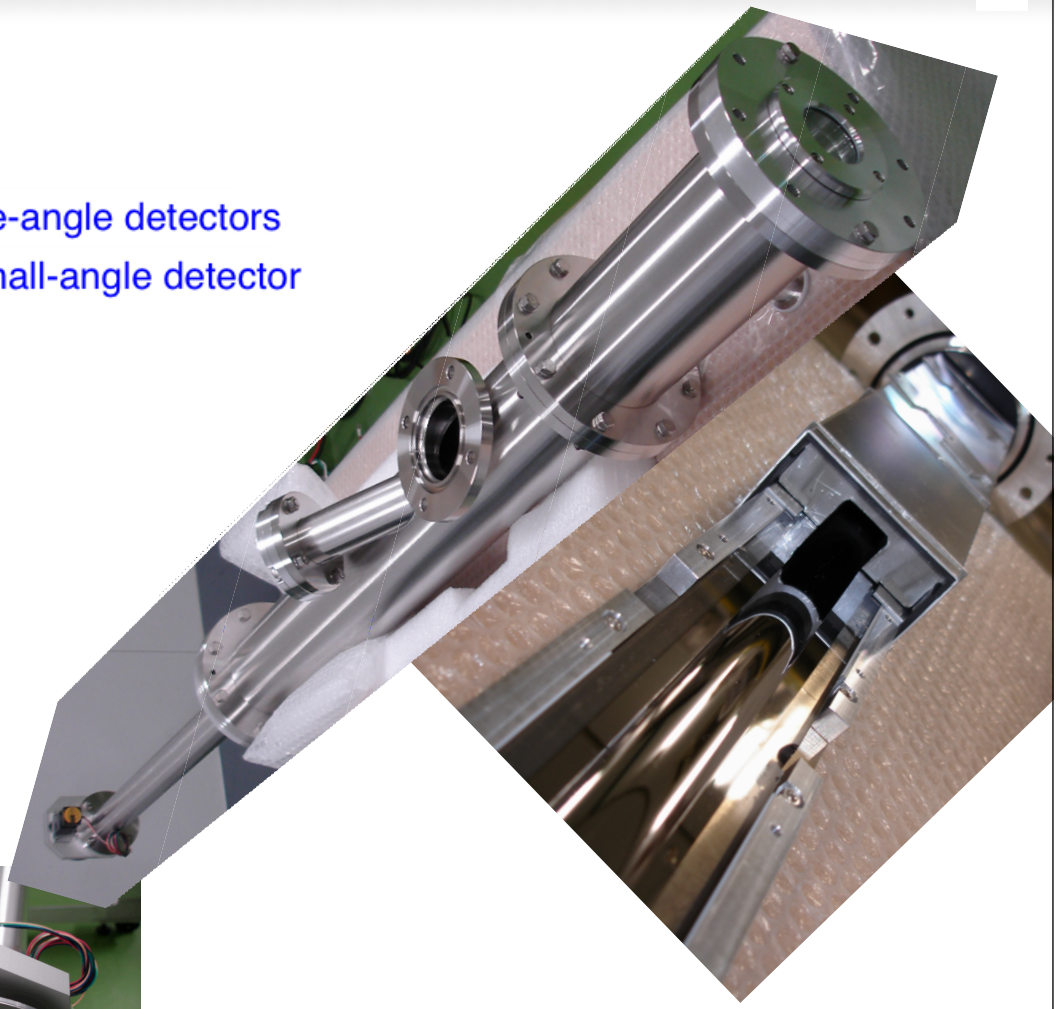


L: 900mm
W: 20mm



mfSANS@JRR-3

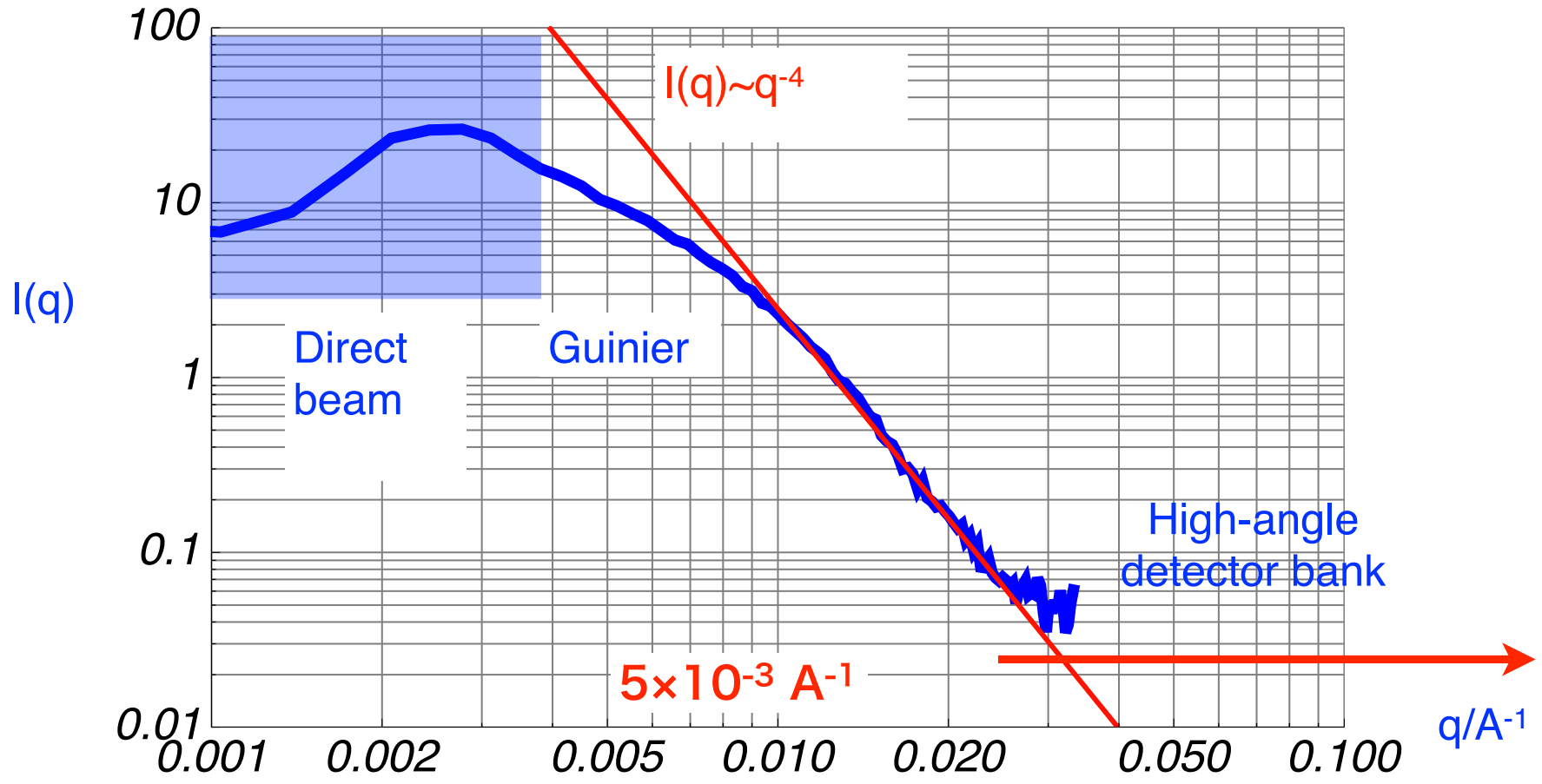

Wide-angle detectors
Small-angle detector
Scattering chamber
Sample
Ellipsoidal mirror
Aperture
neutron
Prism
Monochrometer



Ni powder 20nm

Preliminary data

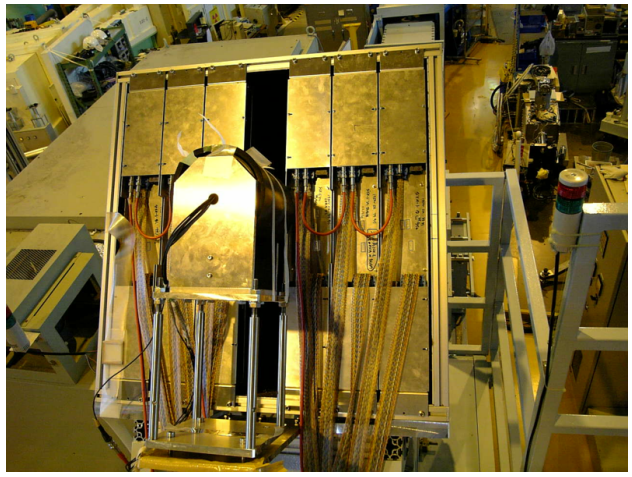
- Q_{min} = 5×10^{-3} A^{-1} using 2mmø aperture.



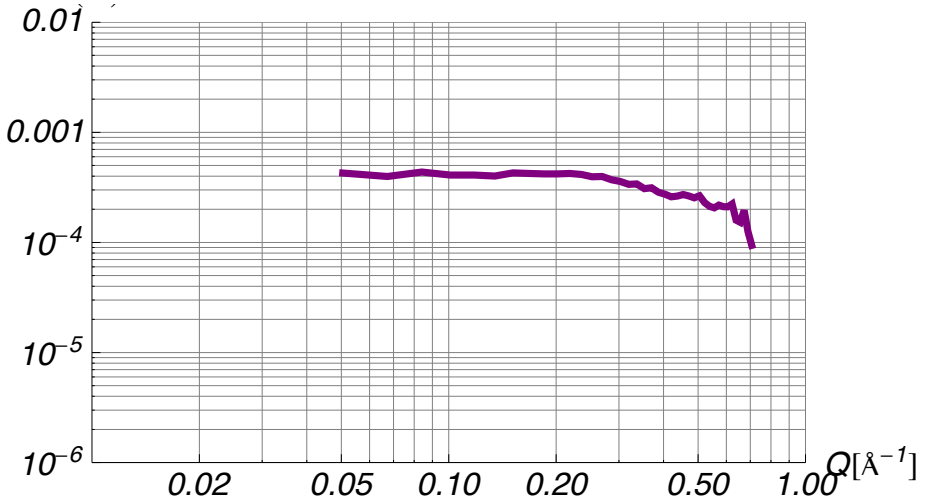
wider-angle scattering

Preliminary data

- 48 Linear position sensitive detectors at higher angle
  - 1/2 inch dia, 600 mm in length
  - GE made



I(q) Water

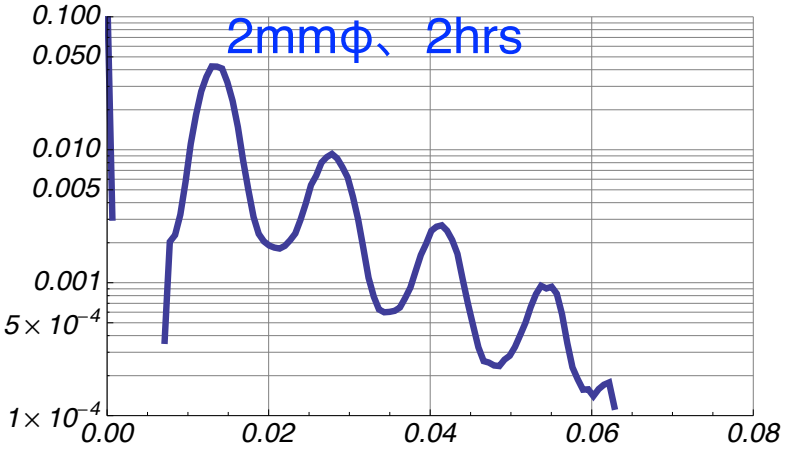


0.05 0.6 q/A^{-1}

Micro-phase separated block copolymer

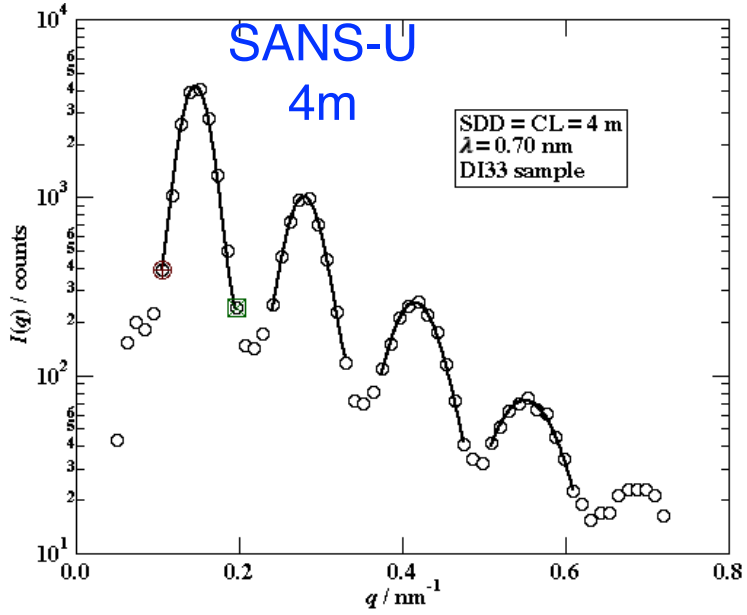
mfSANS

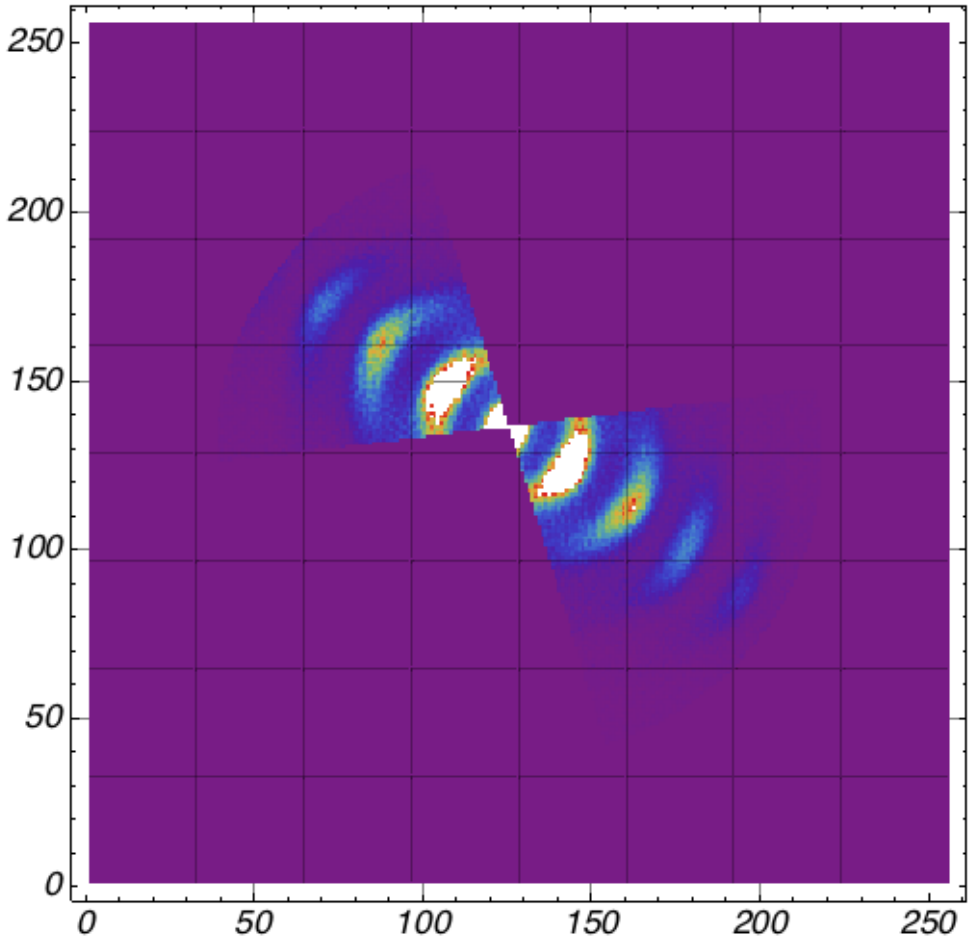
2mmϕ、2hrs



SANS-U

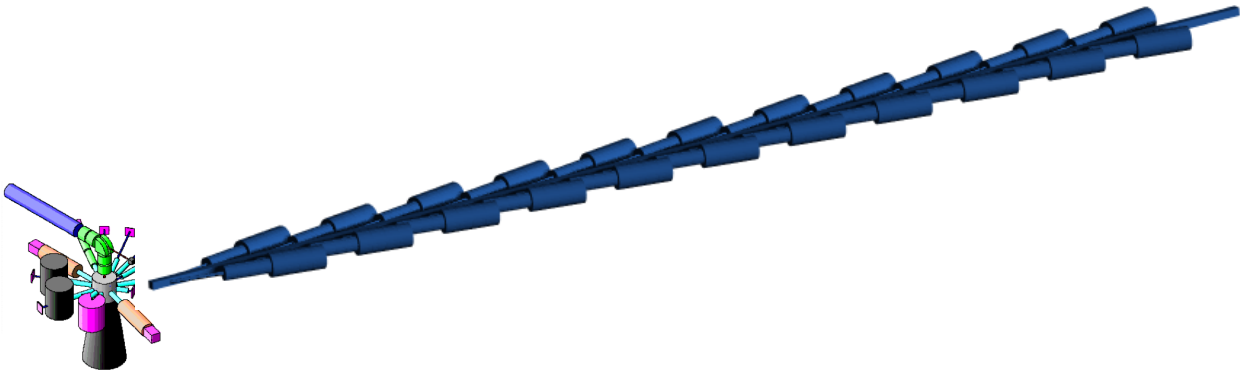
4m





Accelerator-driven Laboratory-size neutron-source

- RFQ accelerator + DTL ≈3-11MeV
  - Li or Be target
- Combined with:
  - many mfSANS modules,
  - mini-reflectometers,
  - mini-powder machines??



Summary

- Tailor-made neutron scattering instruments beamline
  - To check new ideas
  - Good for self-education
- Small-pinhole SANS demonstrated
- Various new devices under development
  - High performance monochromator
- Very compact SANS instruments under development
  - at Hokkaido university (pulsed neutron source)
  - at JRR-3 reactor of JAEA
  - High-performance SANS modules of your own at large facilities
- With focusing technique
  we can build very compact SANS instrument