Compact Neutron Instrumentations and Optical Devices at Compact Sources

Michihiro Furusaka

In preparation...

**Graduate School of Engineering,
Hokkaido University**

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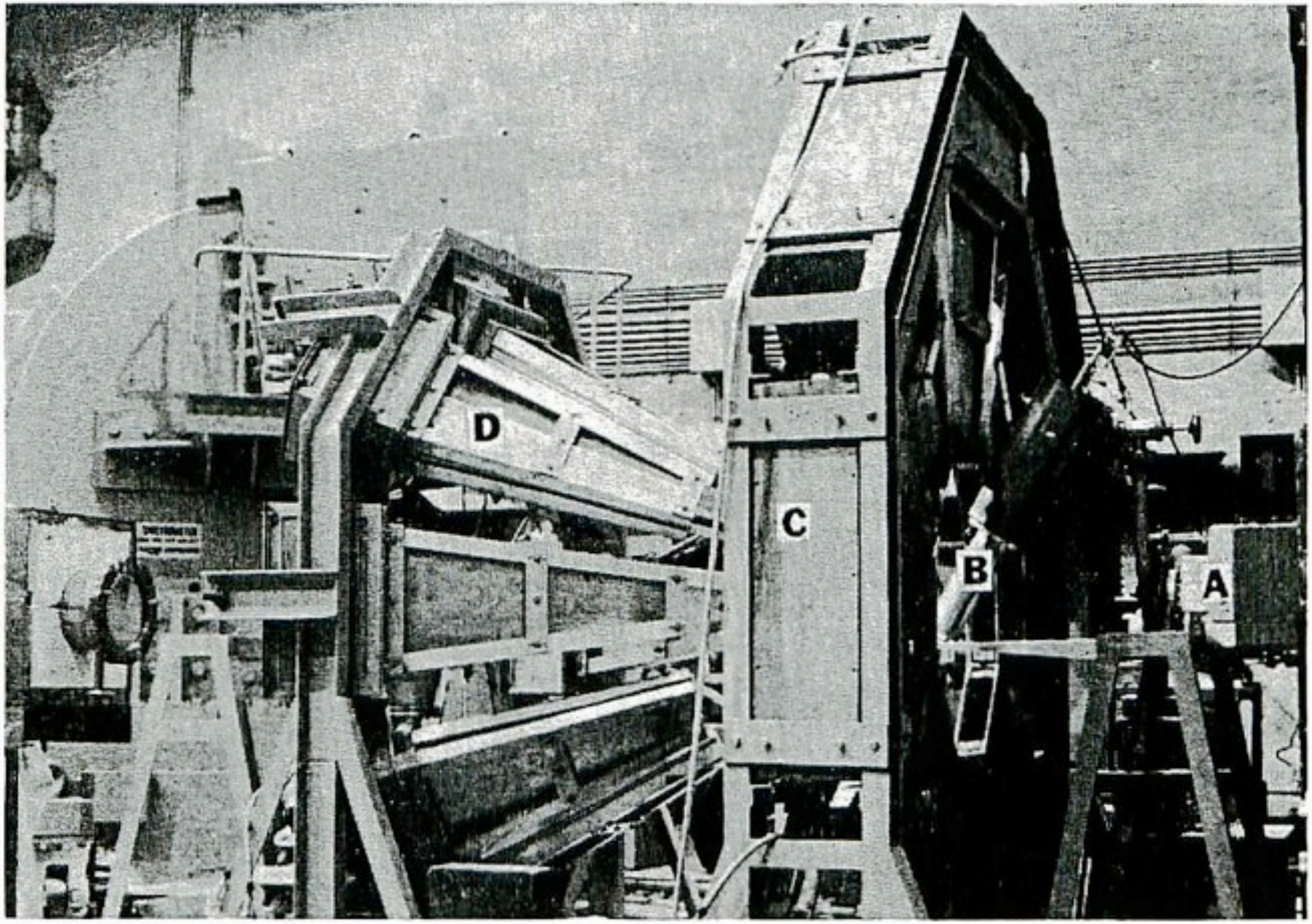
What is it?



Hokkaido University Electron linac based neutron source facility

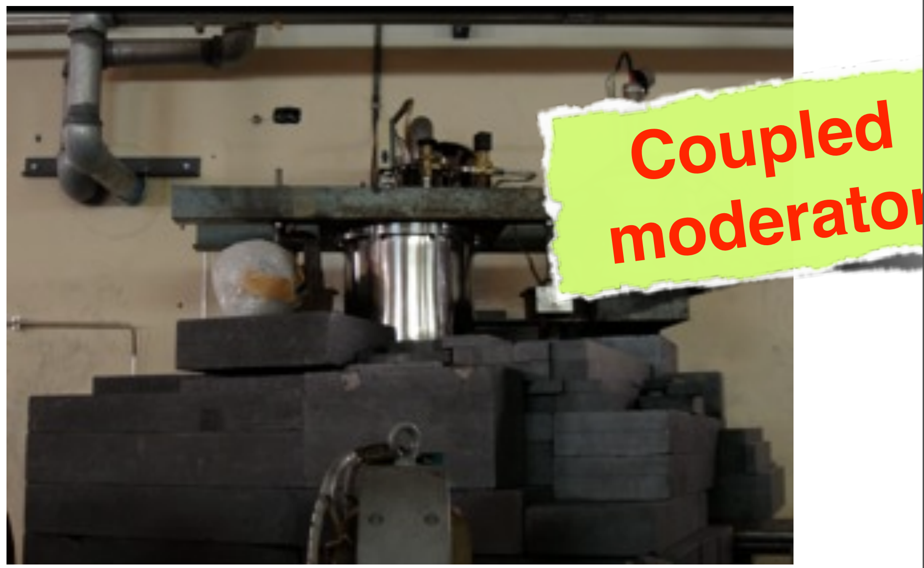
Typical example of
a compact accelerator driven
neutron source.

45MeV Electron Linac @Hokkaido University

- **The first generation compact pulsed neutron source**
  - **First beam ≈1973**
  - **still running...**
- **35 MeV, 30 μA, 50 pps**

Accelerator sections

Pb-Target,
solid methane
cold moderator
@17K



45MeV Electron Linac @Hokkaido University

- **The first generation compact pulsed neutron source**
  - First beam ≈1973
  - still running...
- **35 MeV, 30 μA, 50 pps**

We are playing with the neutrons from the linac

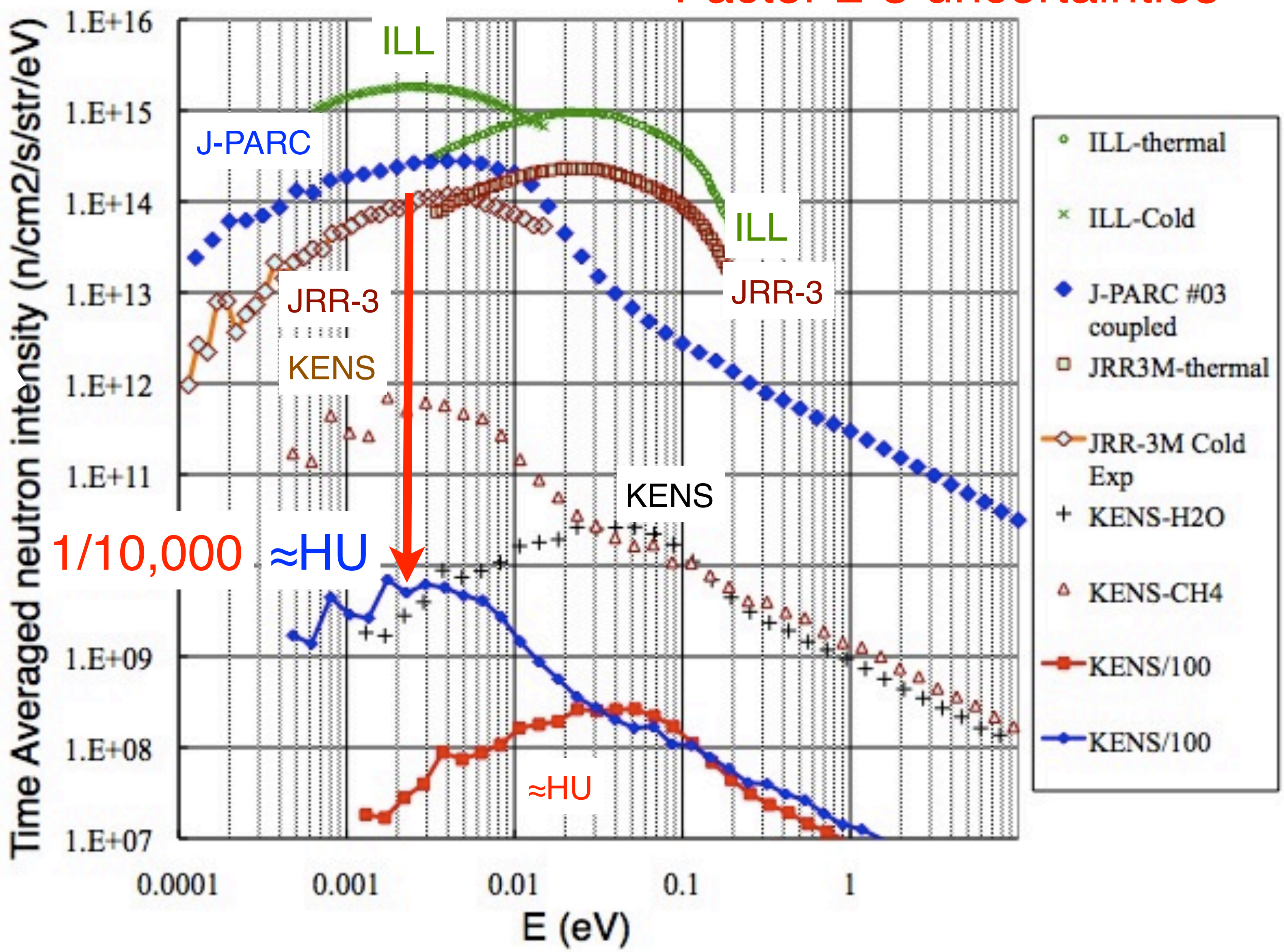
Accelerator sections

Pb-Target, solid methane cold moderator @17K

Coupled moderator

Time averaged intensity

Factor 2-3 uncertainties



Time averaged

Peak≈ xseveral ×100

Compact neutron source should NOT be a compact "large facility".

If you move instruments from a large facility, you end-up with poor performance.

Compact neutron source should NOT be a compact "large facility".

If you move instruments from a large facility, you end-up with poor performance.

What we need is
an extreme optimization;
beyond our imagination limits.

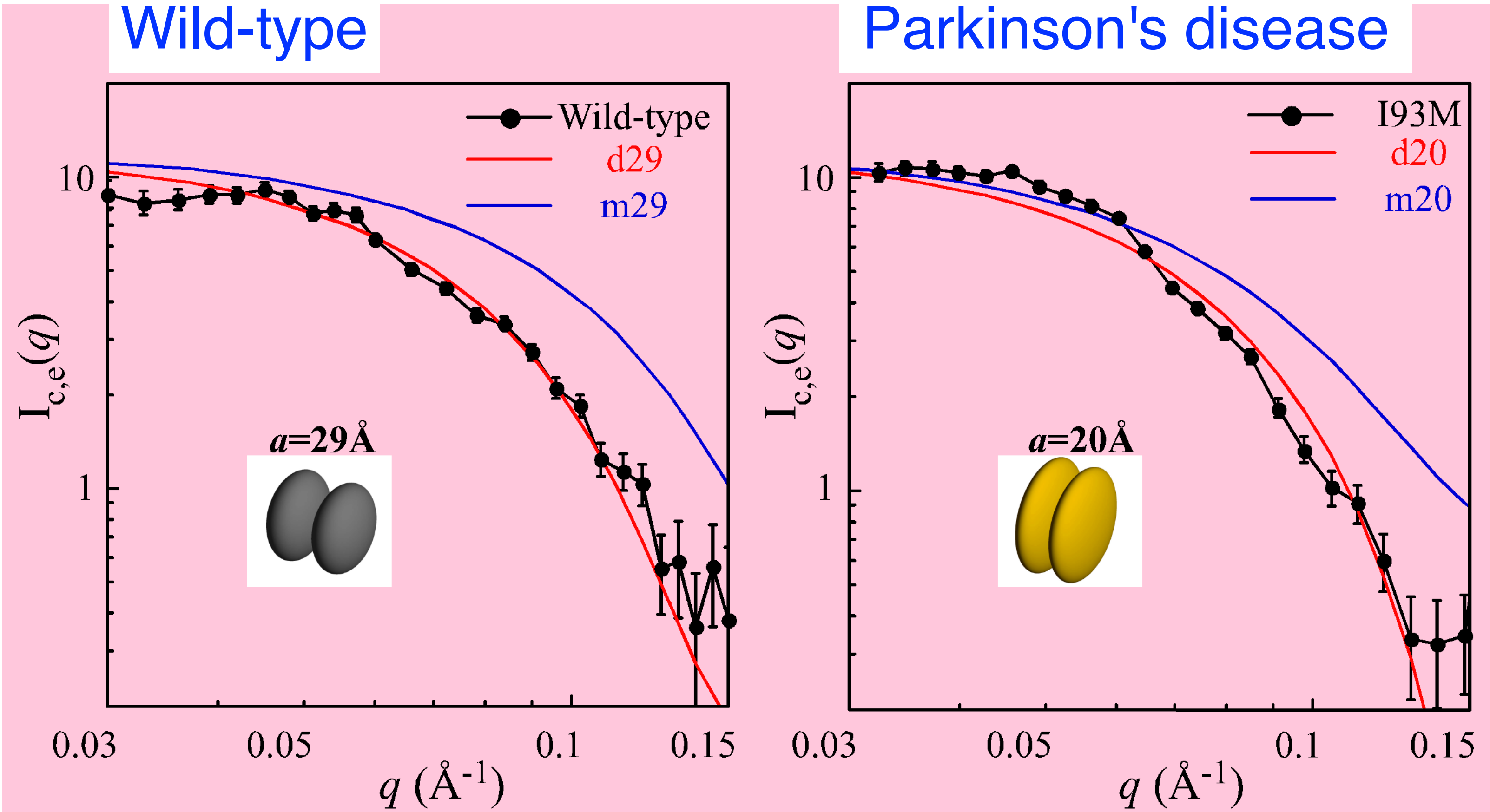
Today's menu

- Two of our goals:
  - protein solution SANS
  - Nanoscopic precipitations in steel
  - Requirements to the instrument.
- Various SANS instruments and others
  - Conventional SANS instrument
  - Small-pinhole SANS
  - Compact focusing SANS instruments
- Intermediate-angle neutron scattering instrument
  - Powder diffraction test.

Let me talk about Our goal first...

UCH-L1: Parkinson's disease related protein

- **Proteins deform and aggregate in solution**
  - **Related to functionality**
- **SANS solution study should be a powerful technique**
  - **Not fully exploited yet.**

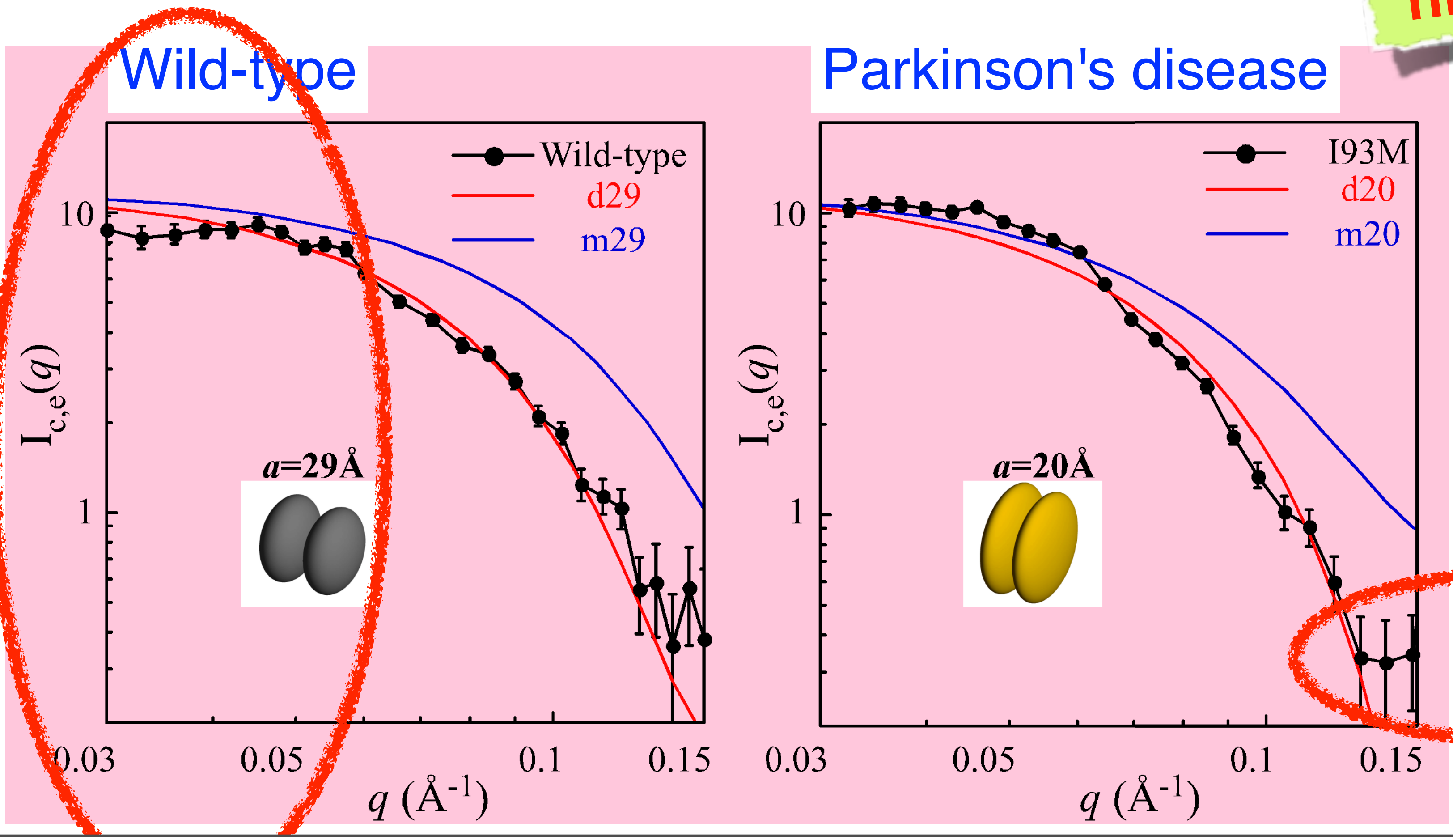


Measured at KENS

UCH-L1: Parkinson's disease related protein

- **Lowest-Q requirement**
  - **modest ≈0.02-0.03 A^{-1}**
  - **Relatively high intensity**

Statistics at a higher-Q range



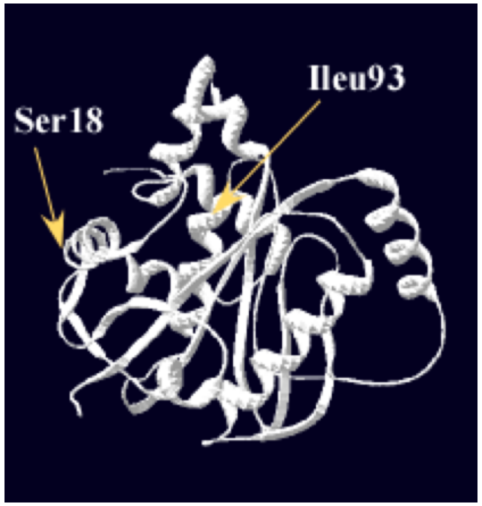
$q_{max} \leq 0.5$ (~2) A^{-1}

Access to a higher-q range

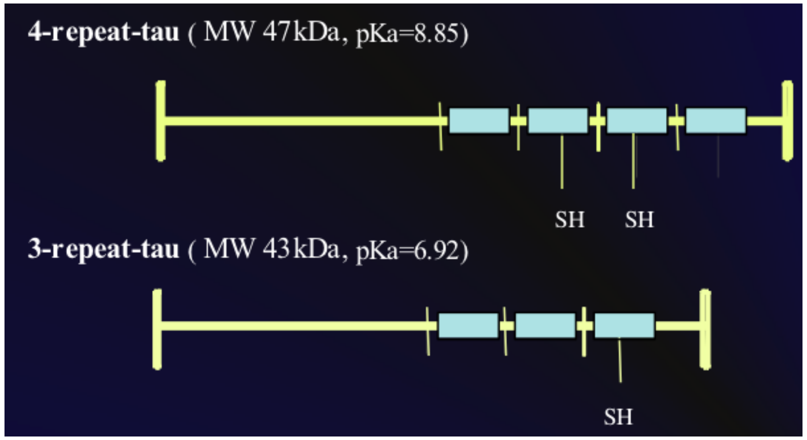
⇒ Shape information!

Protein systems related to brain disease

- UCH-L1(ubiquitine carboxy-terminal hydlorase L1)
  - Found in Lewy body
  - Related to proteasome system (removes garbage proteins)



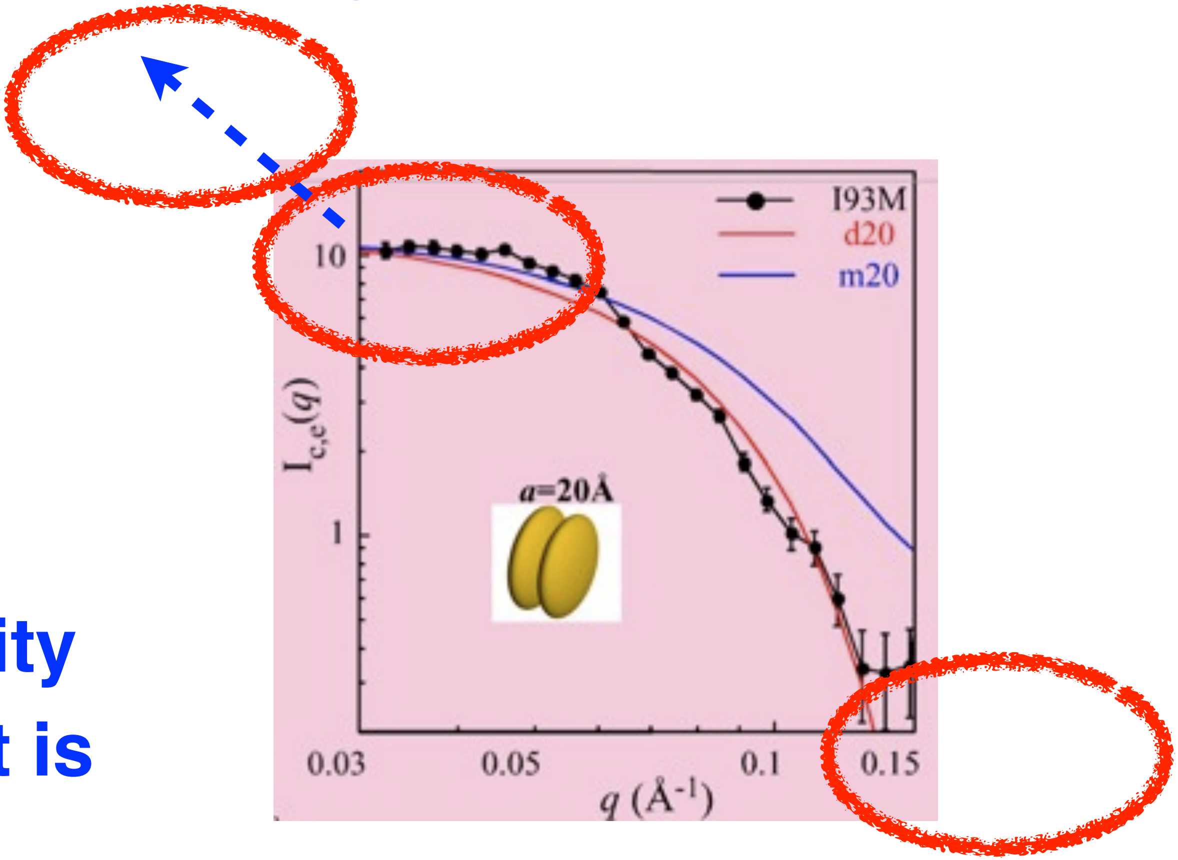
- Tau:
  - Microtubline bound protein
  - Abnormal aggregation (tauopacy)



- α-synuclein:
  - Parkinson's disease
  - Abnormal aggregation

S. Naito (KEK)

- **Access to an intermediate-q range is crucial**
  - **$q_{max} \leq 0.5$ (~2) A^{-1}**
  - **Very high-intensity**
  - **modest Q resolution**
- **Lowest-Q requirement**
  - **modest ≈0.02-0.03 A^{-1}**
  - **Relatively high intensity**
- **Lower-Q measurement is preferable**
  - **Lowest-Q ≈ several $\times 10^{-3}$ A^{-1}**
  - **or lower**



$q_{max} \leq 0.5$ (~2) A^{-1}

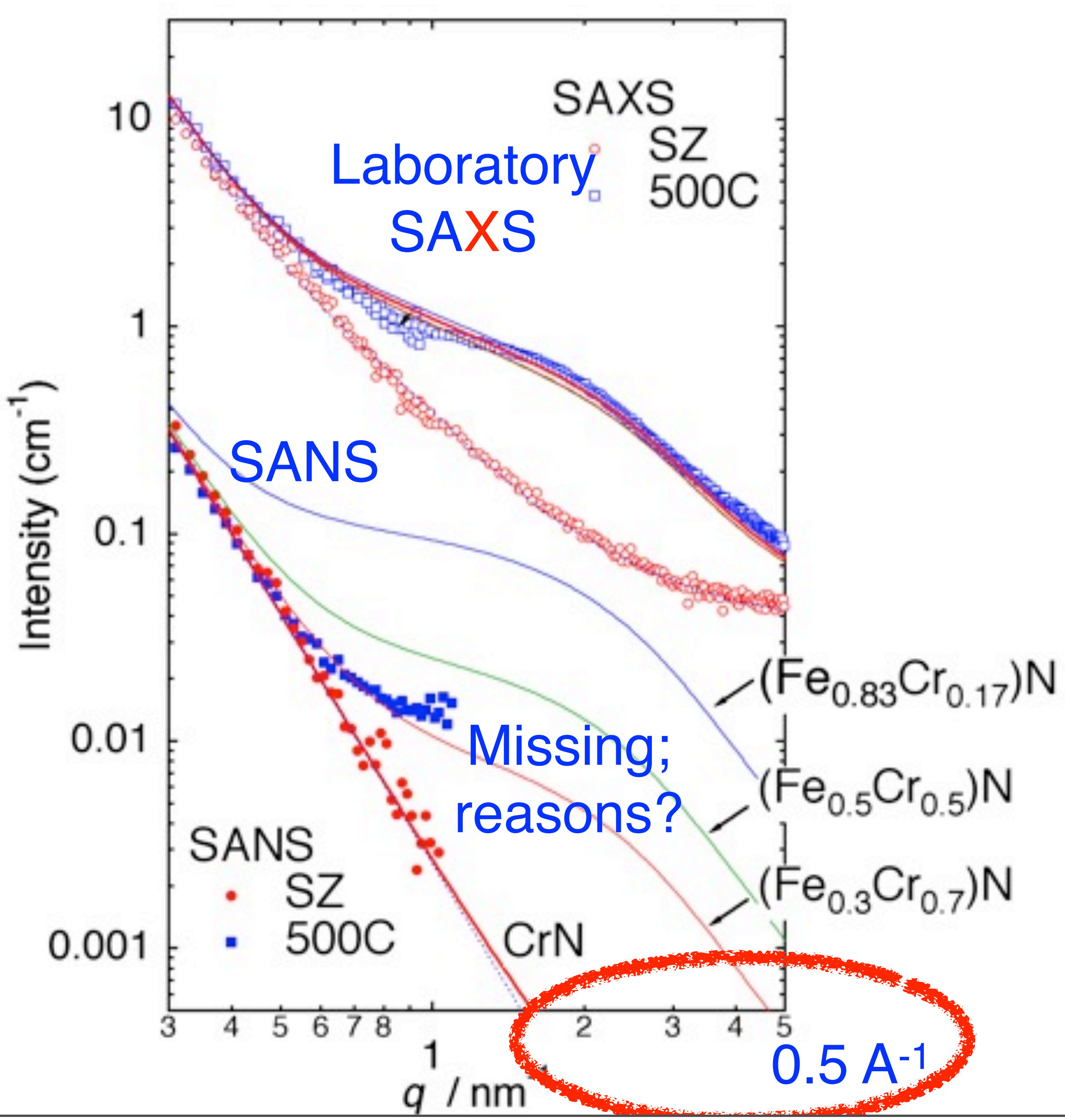
14

Masato Ohuma,

National Institute for Materials Science,

NIMS

Nanoscopic precipitates in Steel



Conventional SANS instruments are large

Neutron SAS instruments

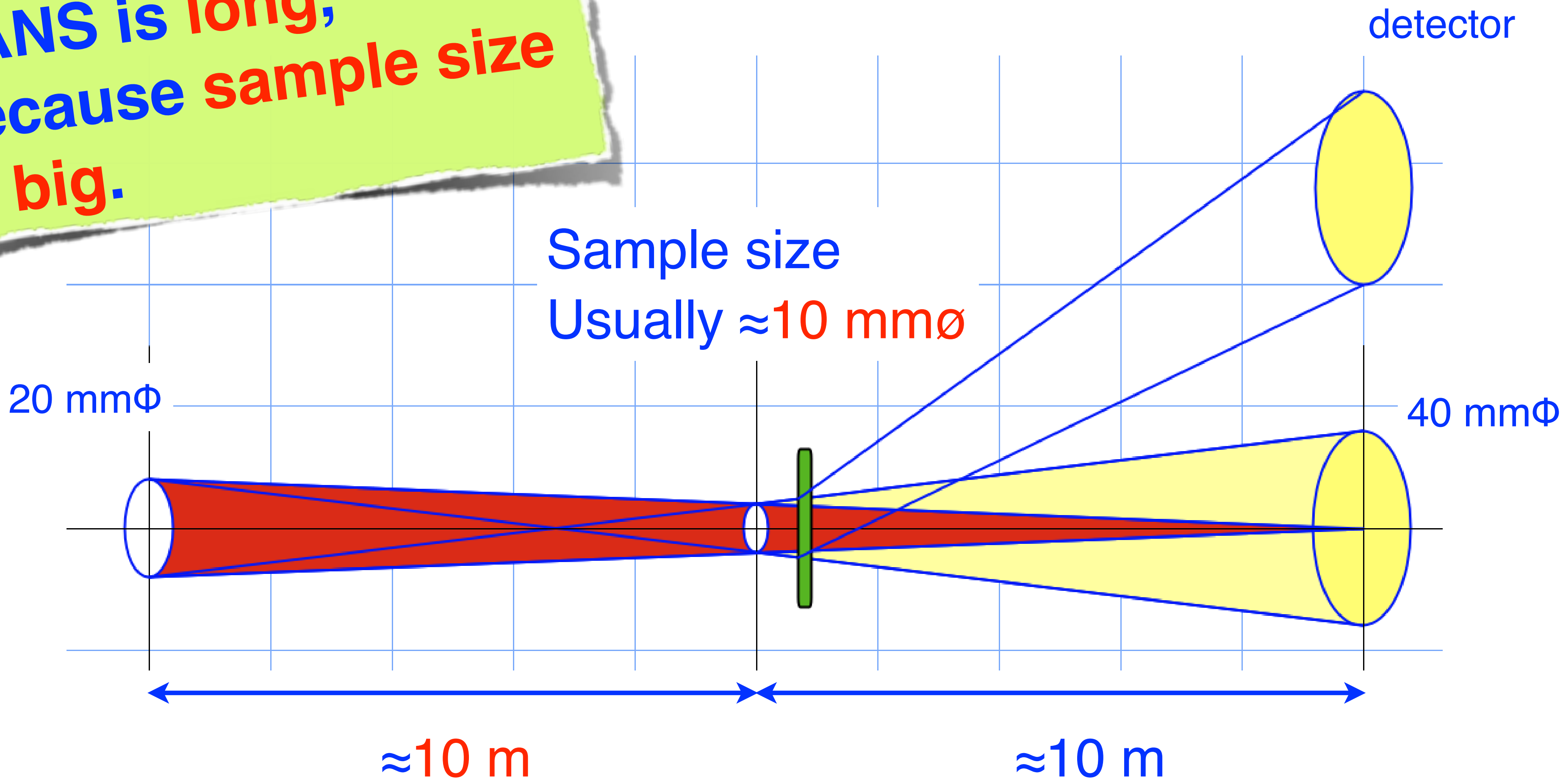
- **Lowest-Q measurement: OK.**
- **Intermediate-angle scattering: questionable.**

SANS-U@JRR-3

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

SANS instruments are large

SANS is long, because sample size is big.



Typically,

Δθ≈1 mrad ≈10 mm/10 m

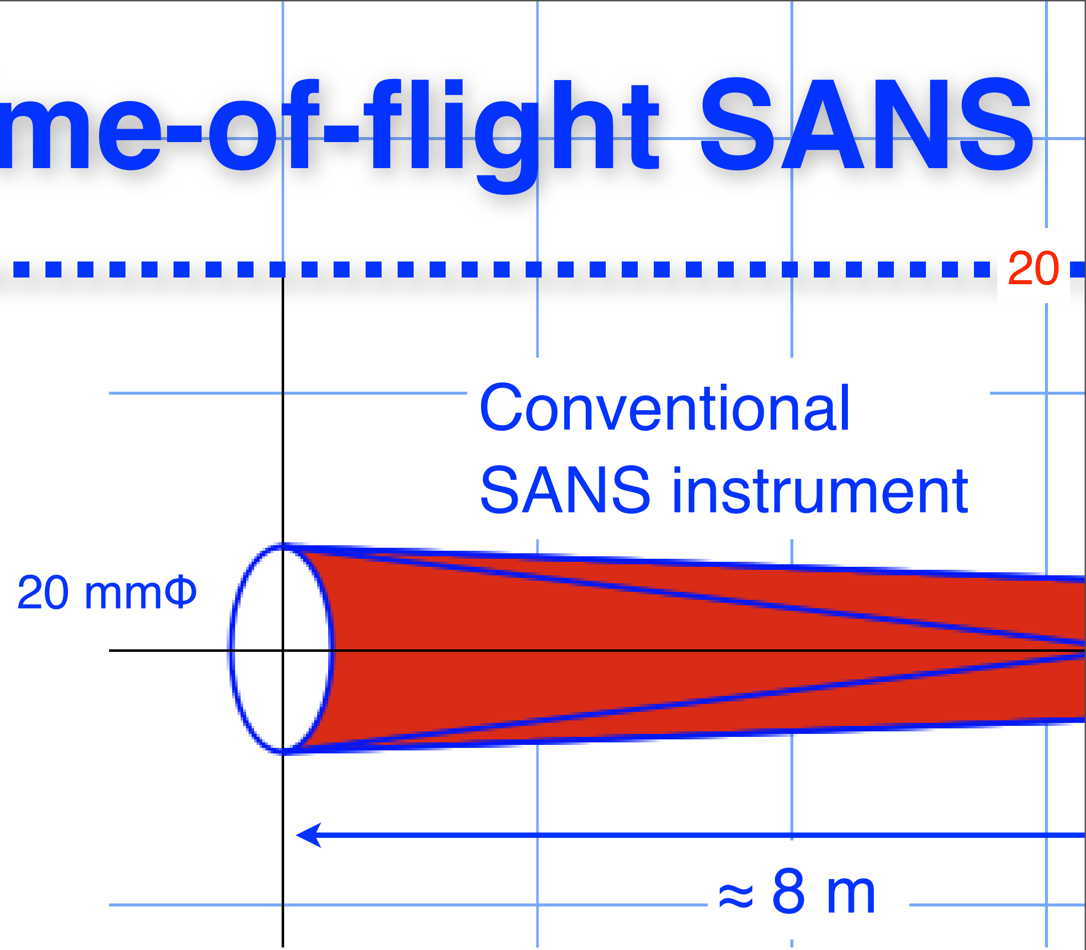
Low-Q end

Why not use a smaller pin-hole...

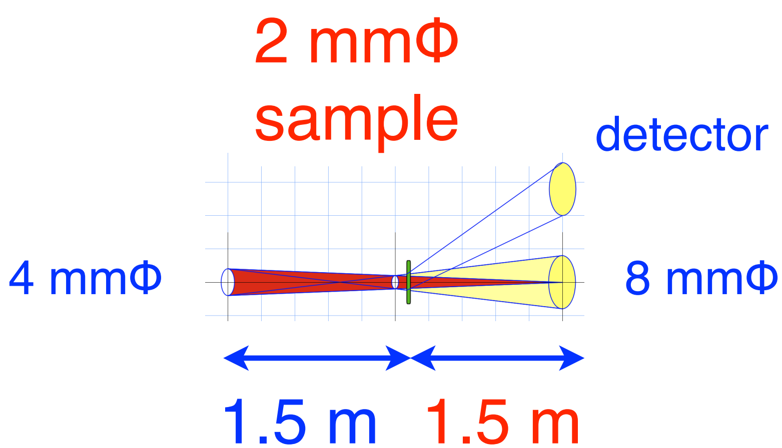
Low-q scattering is usually very intense.

Small Pin-hole Time-of-flight SANS

- **Sample size ≈ 2 mm ø**
  - **flight paths only 1.5m**
  - **no vacuum tube**
- **Poor intensity ≈ 1/25???**



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



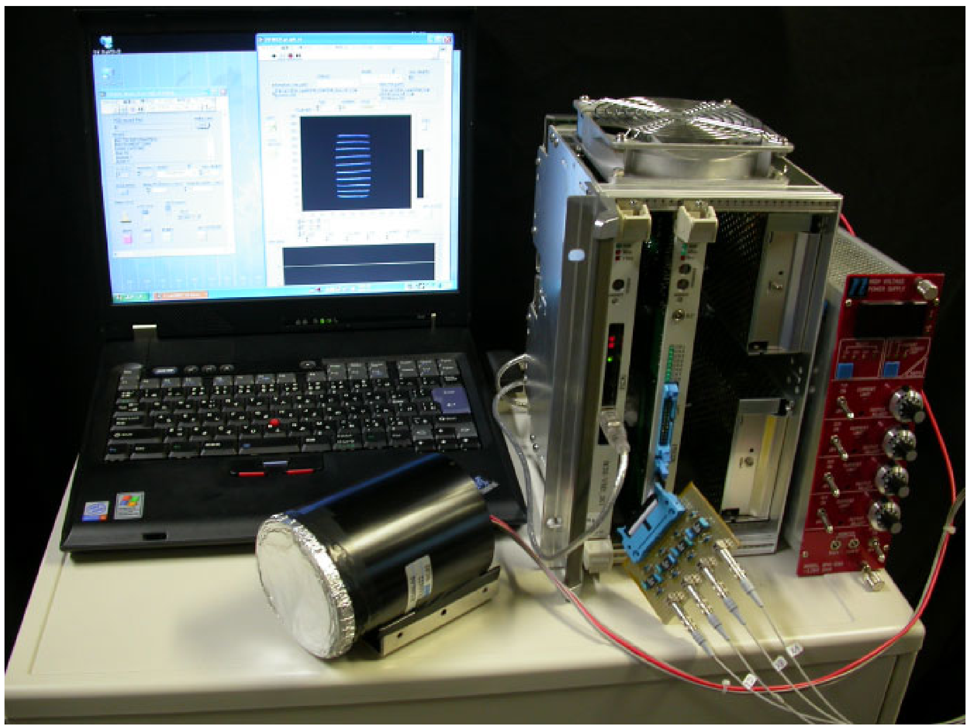
**Same Q-resolution;
Very low intensity**

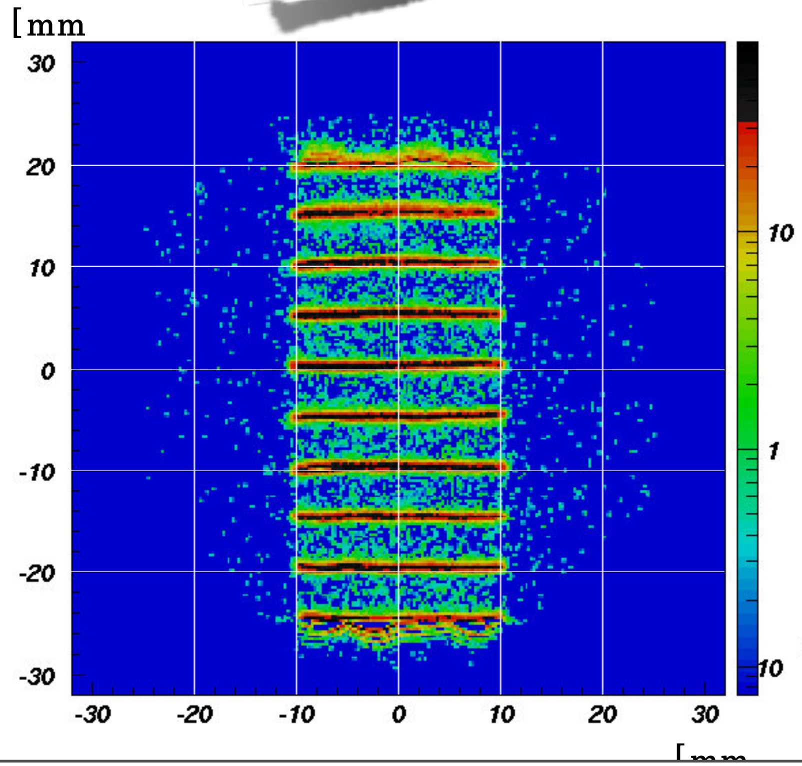
Resistive wire type PMT +ZnS scintillator

- Li (n, α); ZnS(Ag) scintillation
- 3inch, 5inch PMT
  - R2486-04
- Good resolution
  - <1mm

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

Other detectors almost online: GEM, MSGC, MPGC

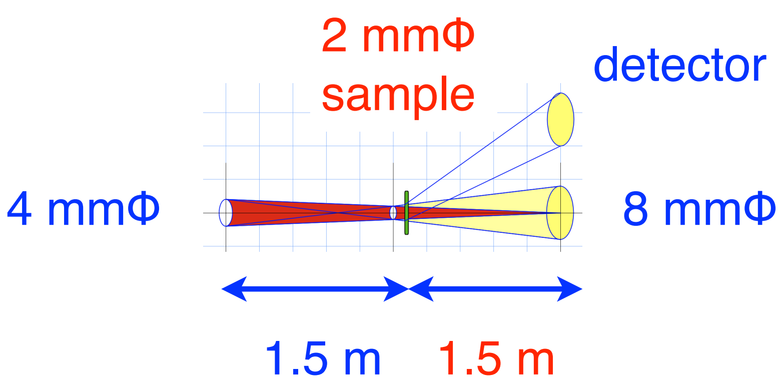




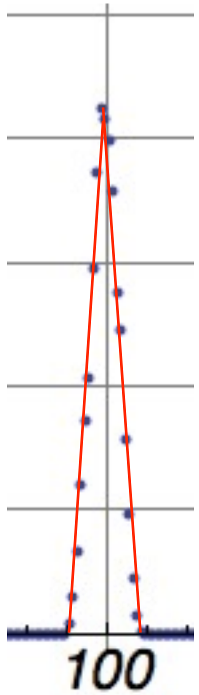
2 mmø sample compact SANS instrument at Hokkaido University

Very clean direct beam!

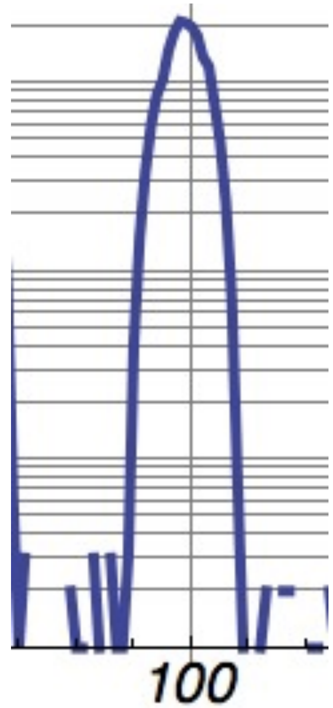
- Hokkaido Univ. small pin-hole SANS, 2 mmø
  - Cd plate drilled with Boric acid



Exact triangular shape

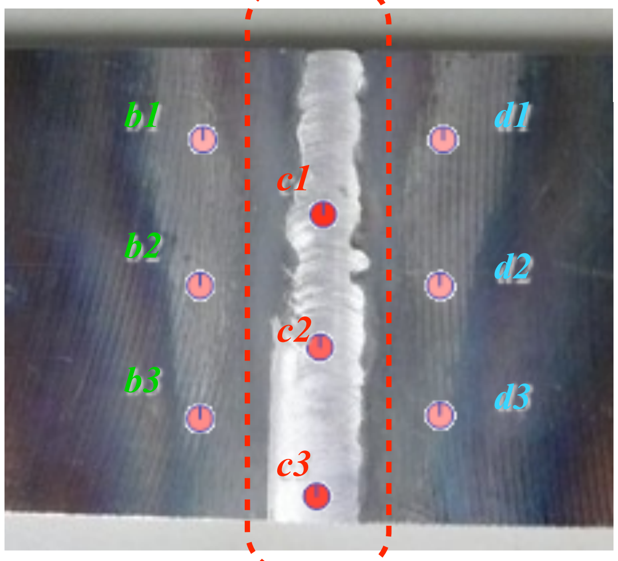


Very clean tail !

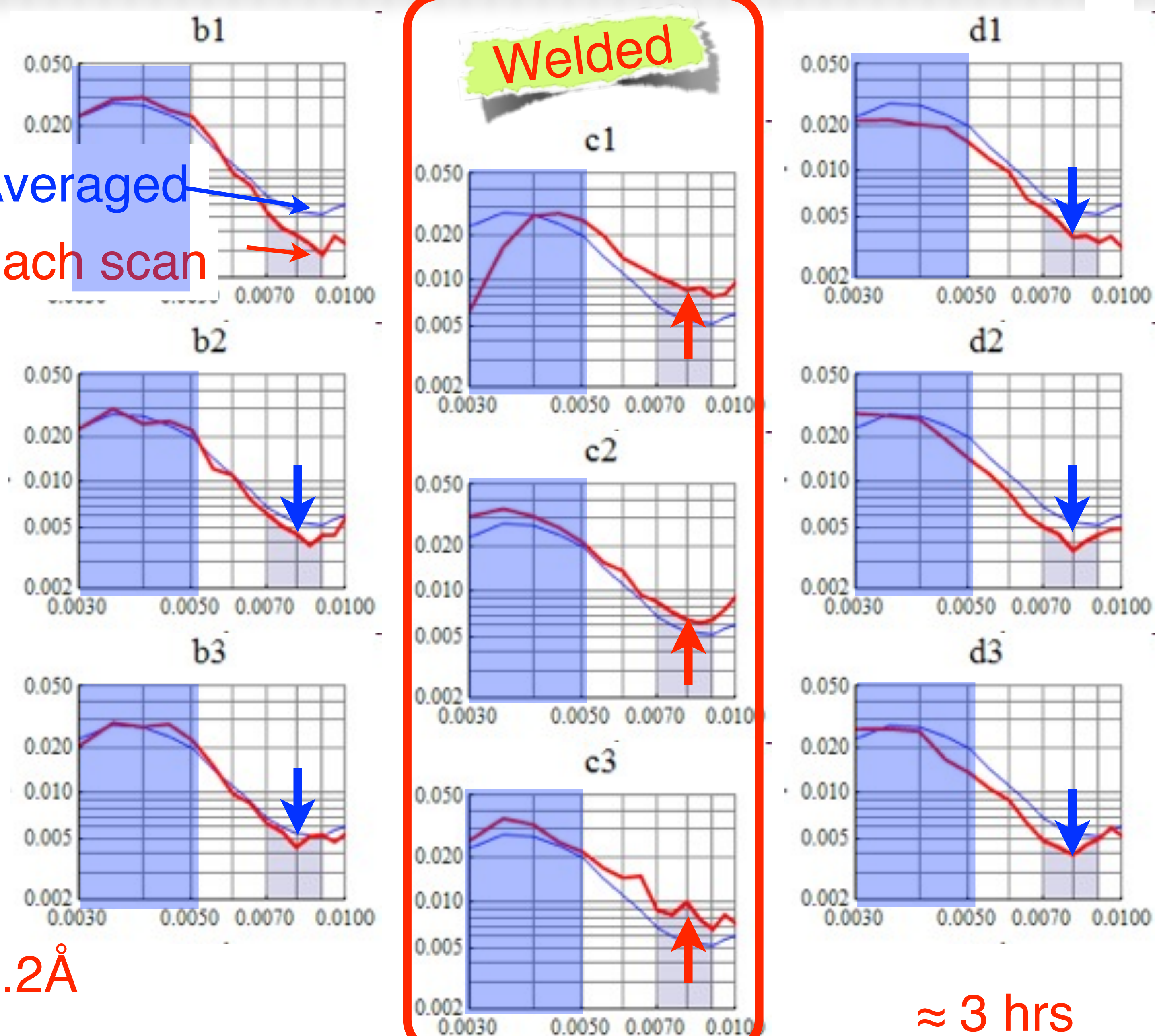


Scanning TOF SANS; 2mmø at Hokkaido University

Preliminary



Welded part



4.4〜6.2Å

≈ 3 hrs

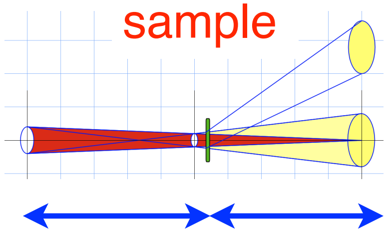
0.2 mmø pin-hole SANS???

- **Can you imagine 0.2 mmø pin-hole SANS instrument?**

2 mmΦ
sample

detector

4 mmΦ



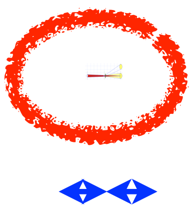
8 mmΦ

1.5 m 1.5 m

or maybe
0.5 mmø one

0.2 mmΦ
sample

0.4 mmΦ

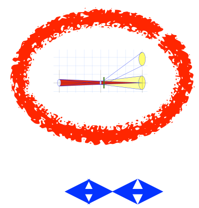


detector
0.8 mmΦ

15 cm 15 cm

0.5 mmΦ
sample

1 mmΦ



detector
2 mmΦ

38 cm 38 cm

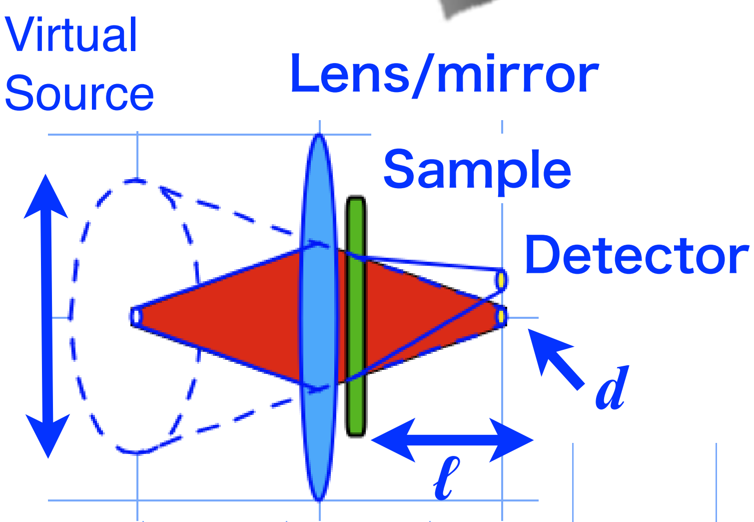
200μm resolution
detector required.

Using a focusing device

Same Q-range, Q-resolution;
Very short flight-path.

Focusing SANS instrument is Compact!

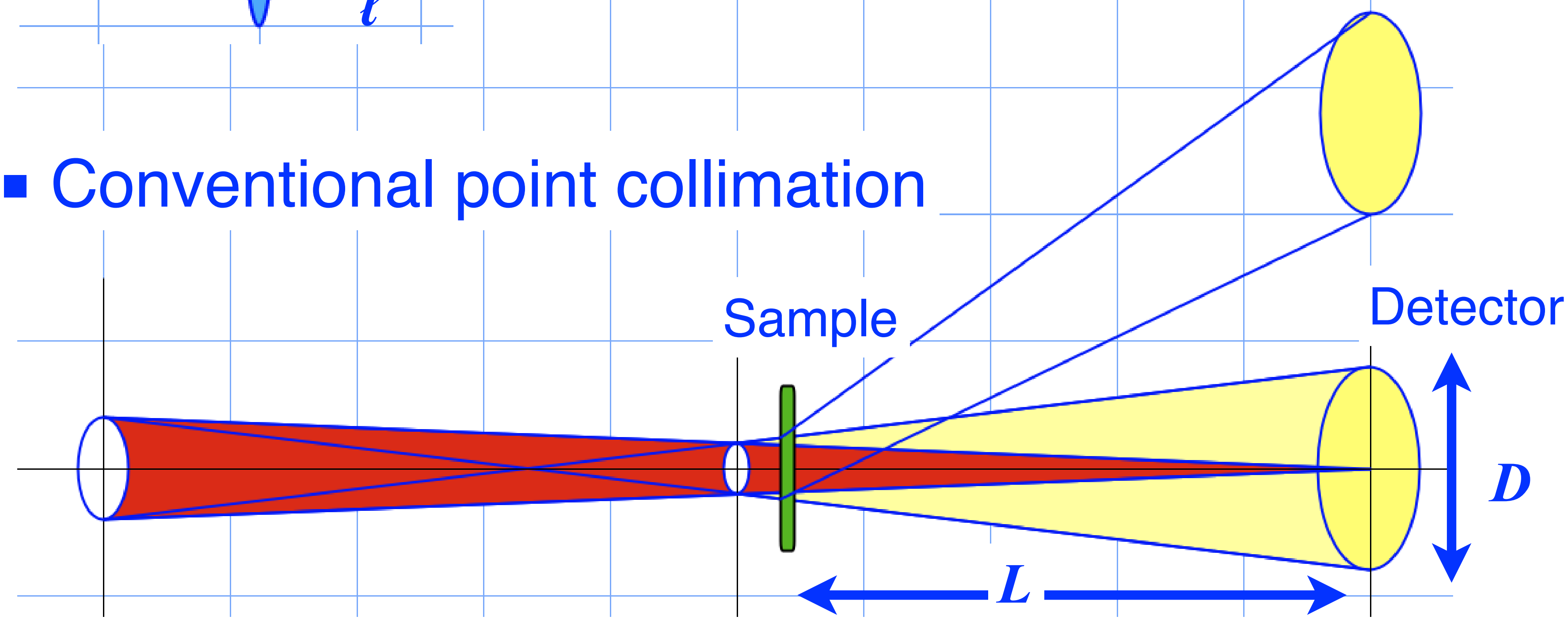
- Focusing ≈ compact



- 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



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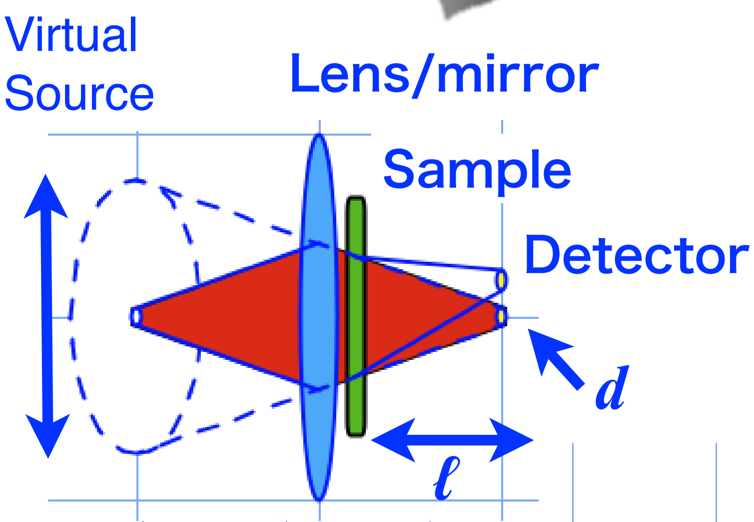
- Focusing

≈ compact

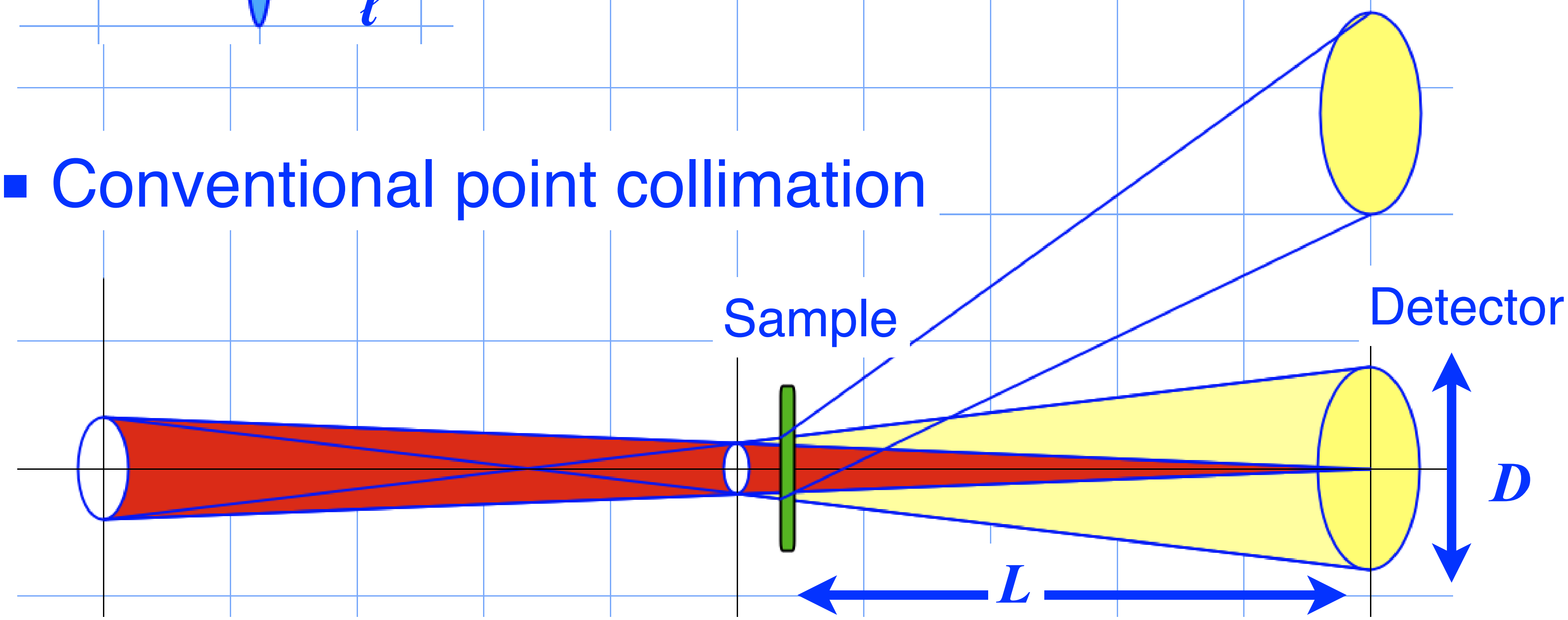


Sample size is independent of the q-resolution.

- 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



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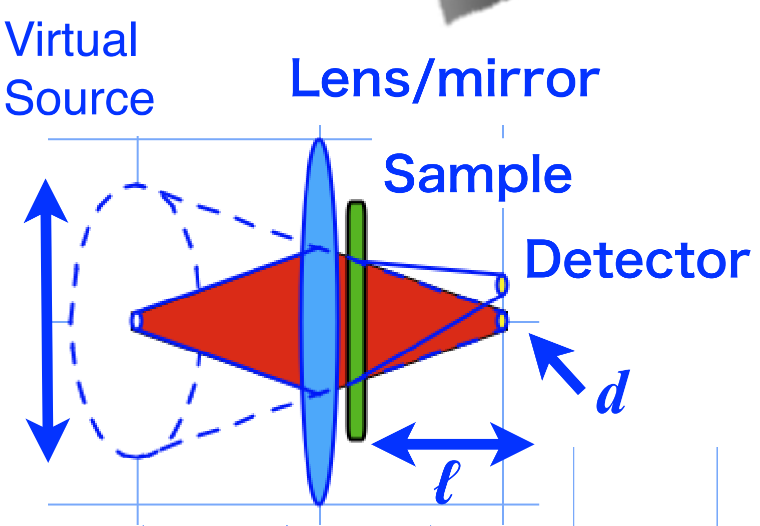
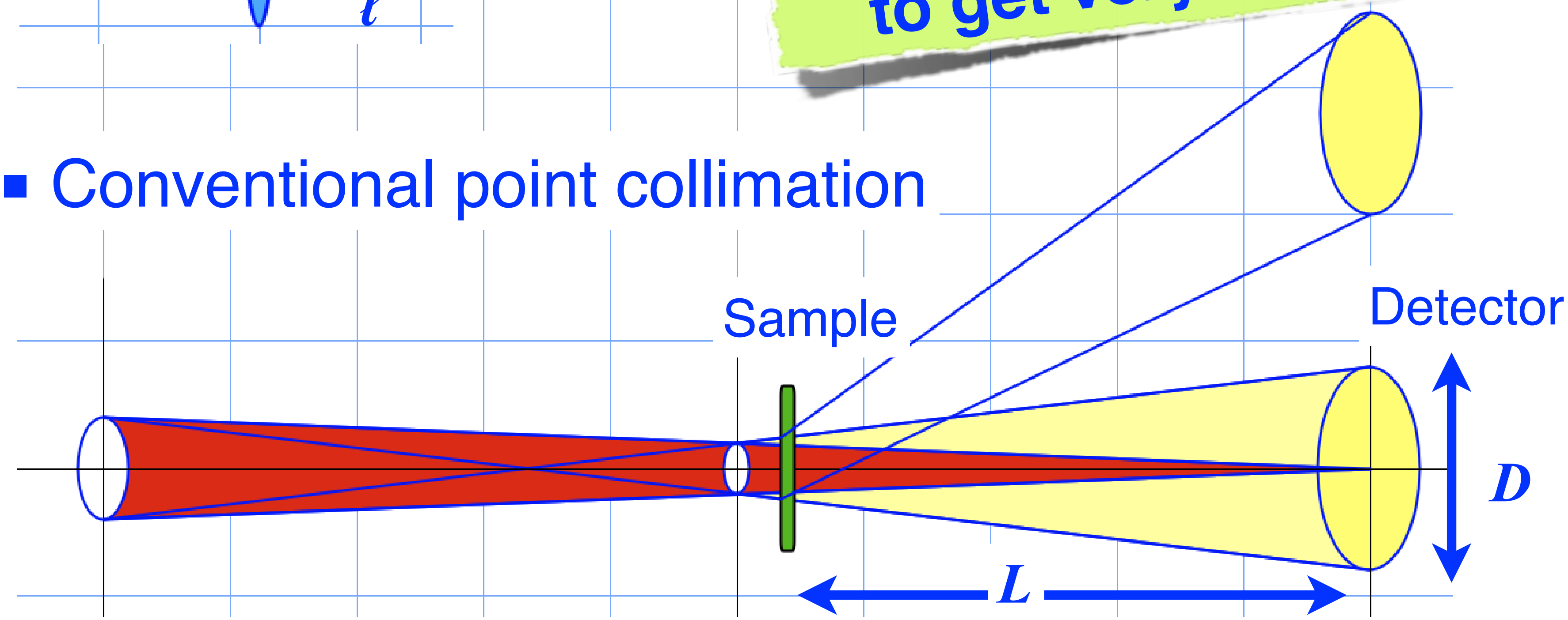


Sample size is independent of the q-resolution.

- Intensity:

Reduce the pin-hole size to get very low q-resolution.

- Conventional point collimation



Focusing SANS

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

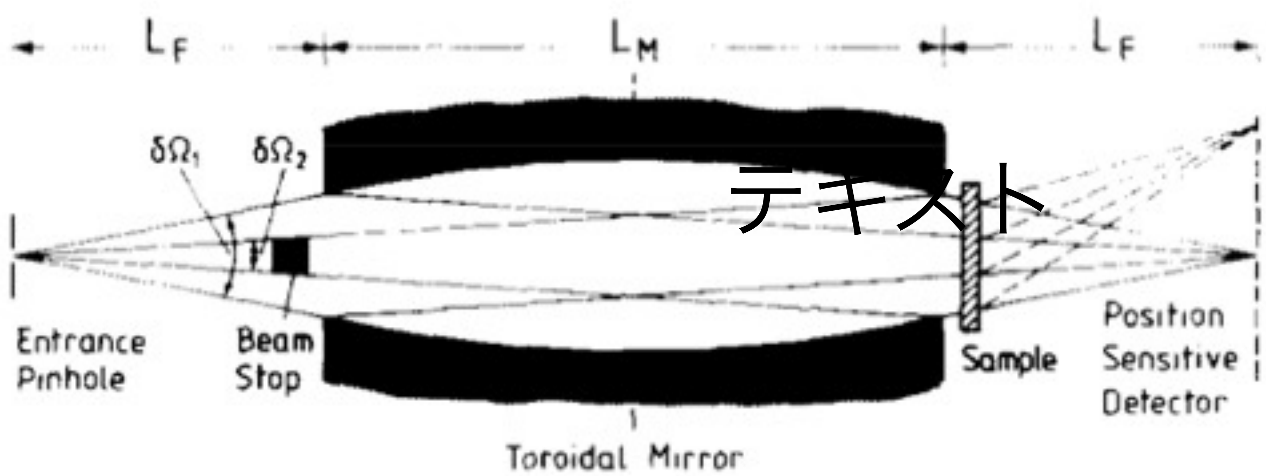
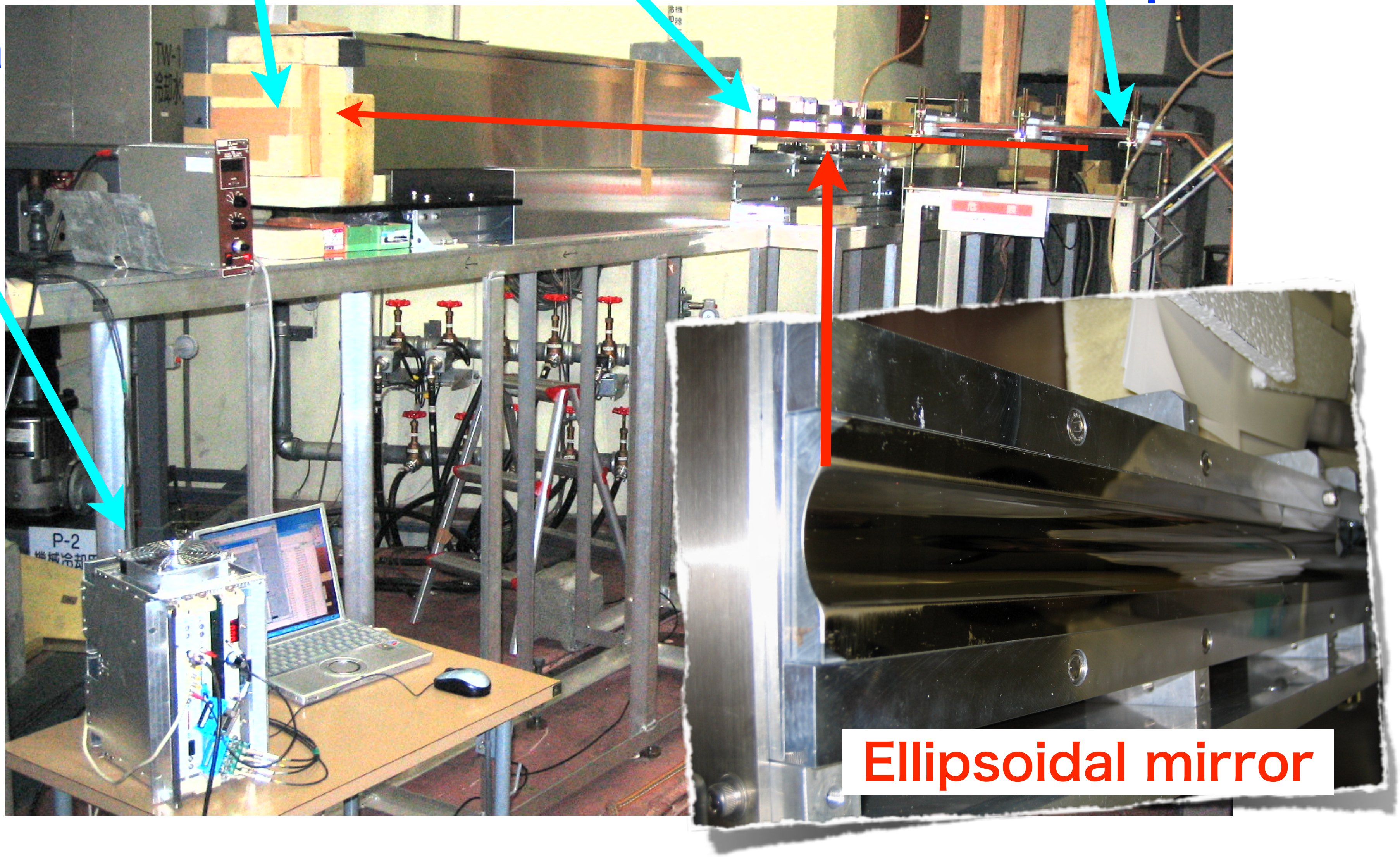


Fig. 1. Toroidal mirror with the image in the detector plane.

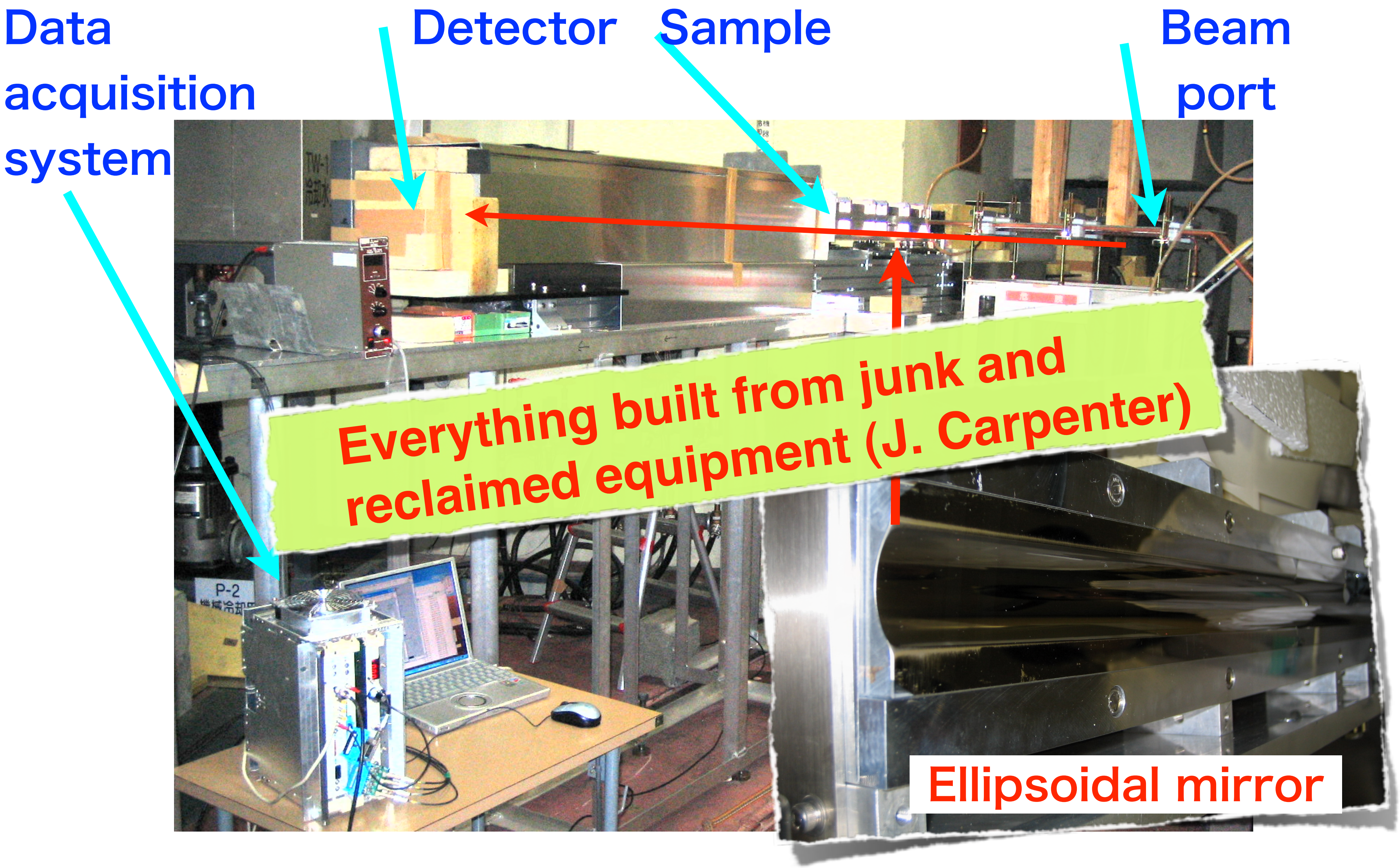
B. Alefeld et al./ Physica B 234-236 (1997) 1052-1054

- MgO_2 lens, sextupole lens are available.

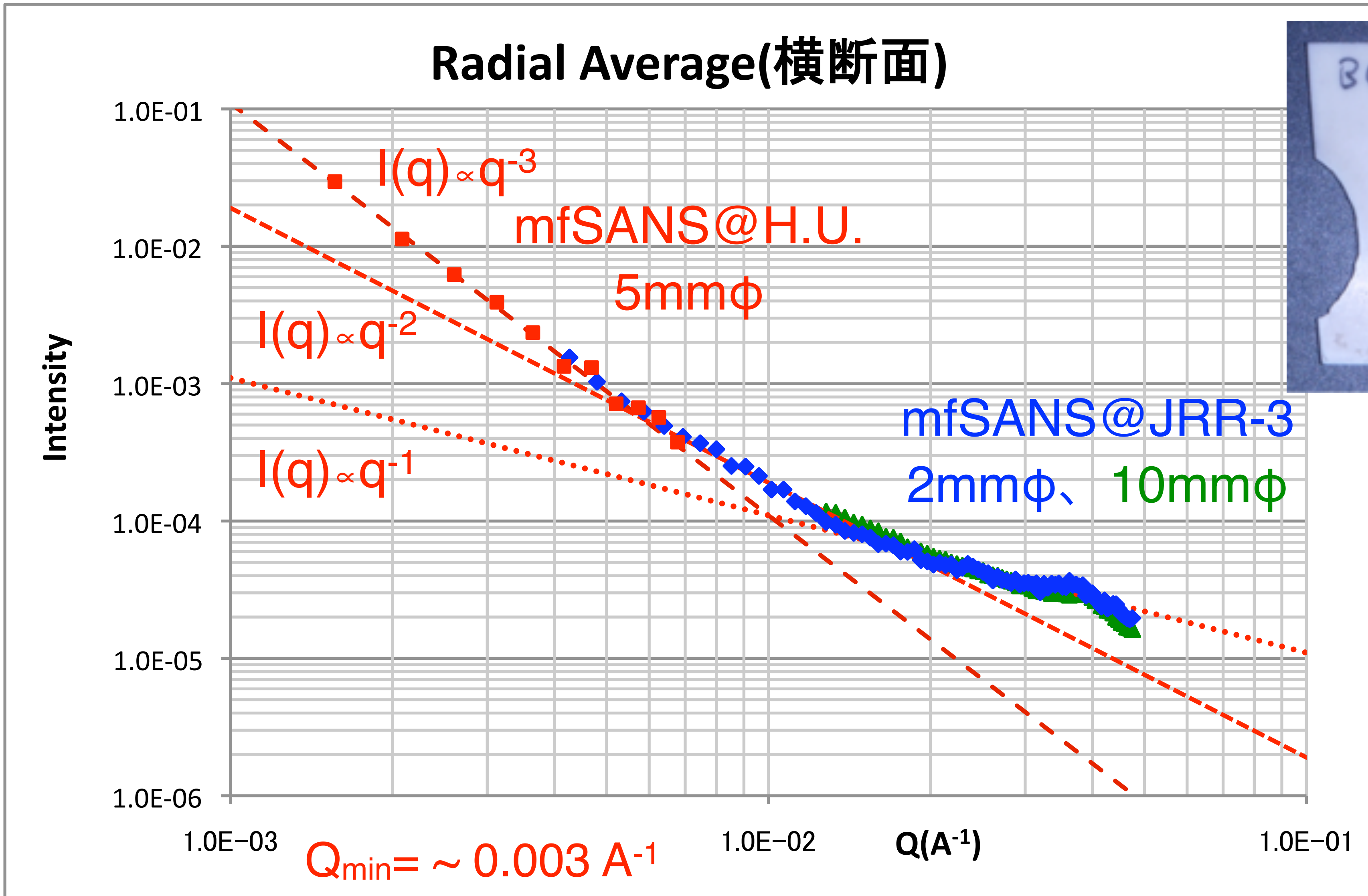
A compact focusing SANS at Hokkaido Univ.



A compact focusing SANS at Hokkaido Univ.



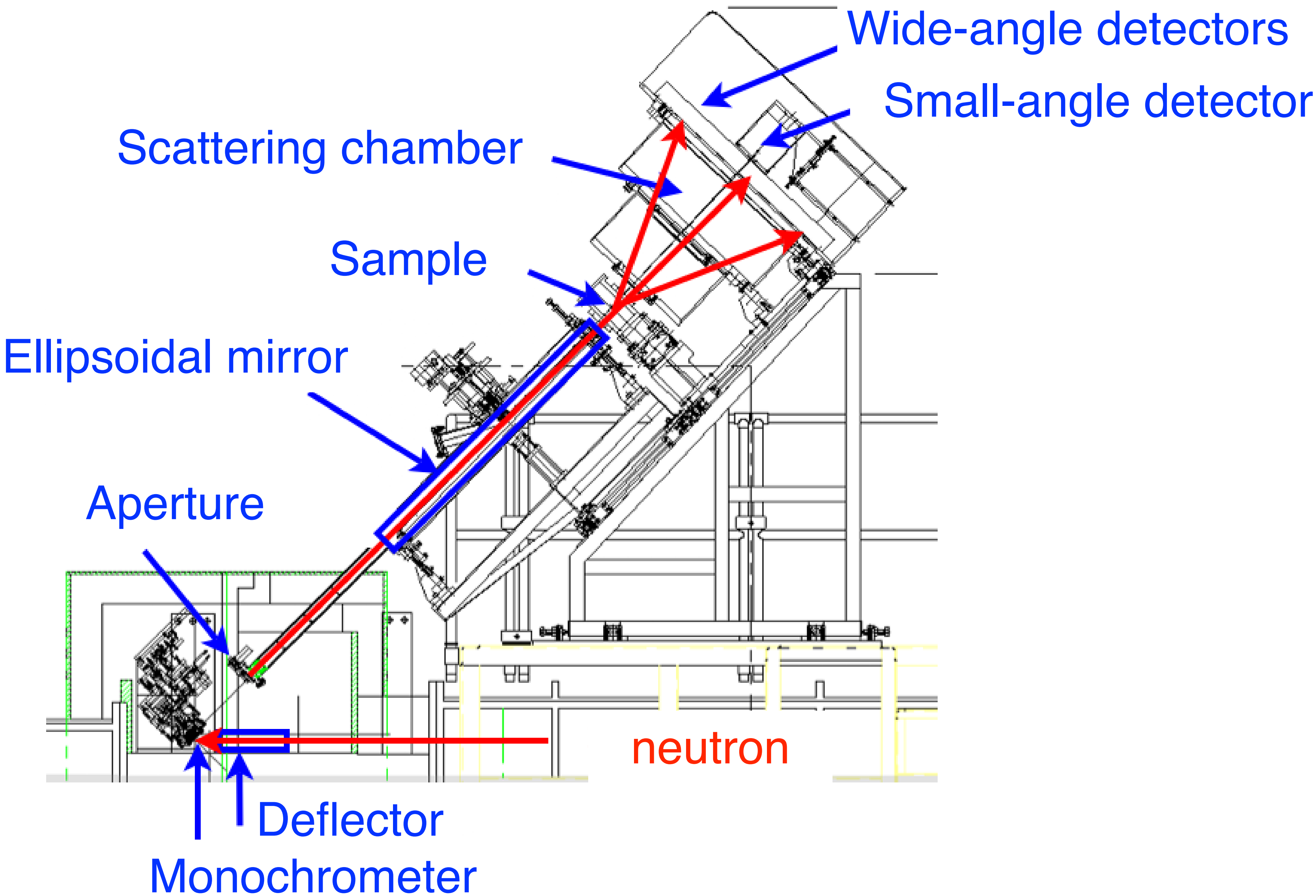
Bovine thighbone, cross section SANS preliminary analysis



Okusawa et al

Mini-focusing SANS instrument @JRR-3

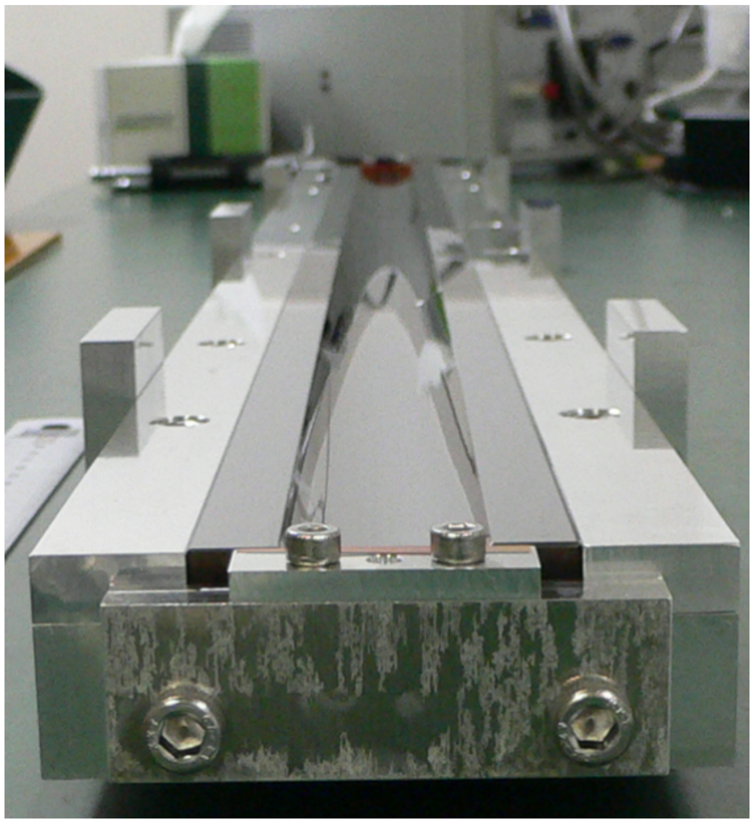
mfSANS@JRR-3



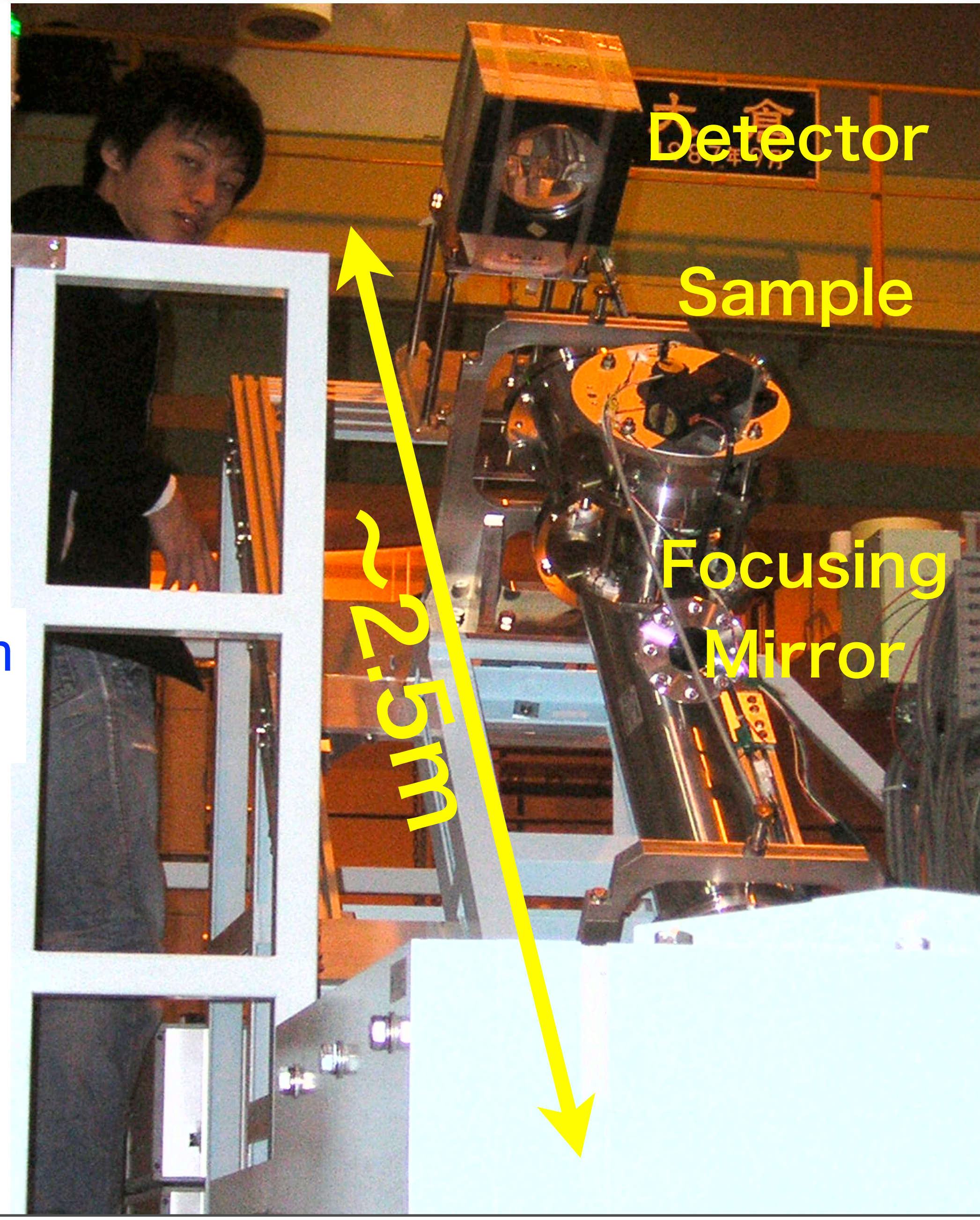
Wide-angle detectors
Small-angle detector
Scattering chamber
Sample
Ellipsoidal mirror
Aperture
neutron
Deflector
Monochrometer

Prototype focusing SANS@JRR-3

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

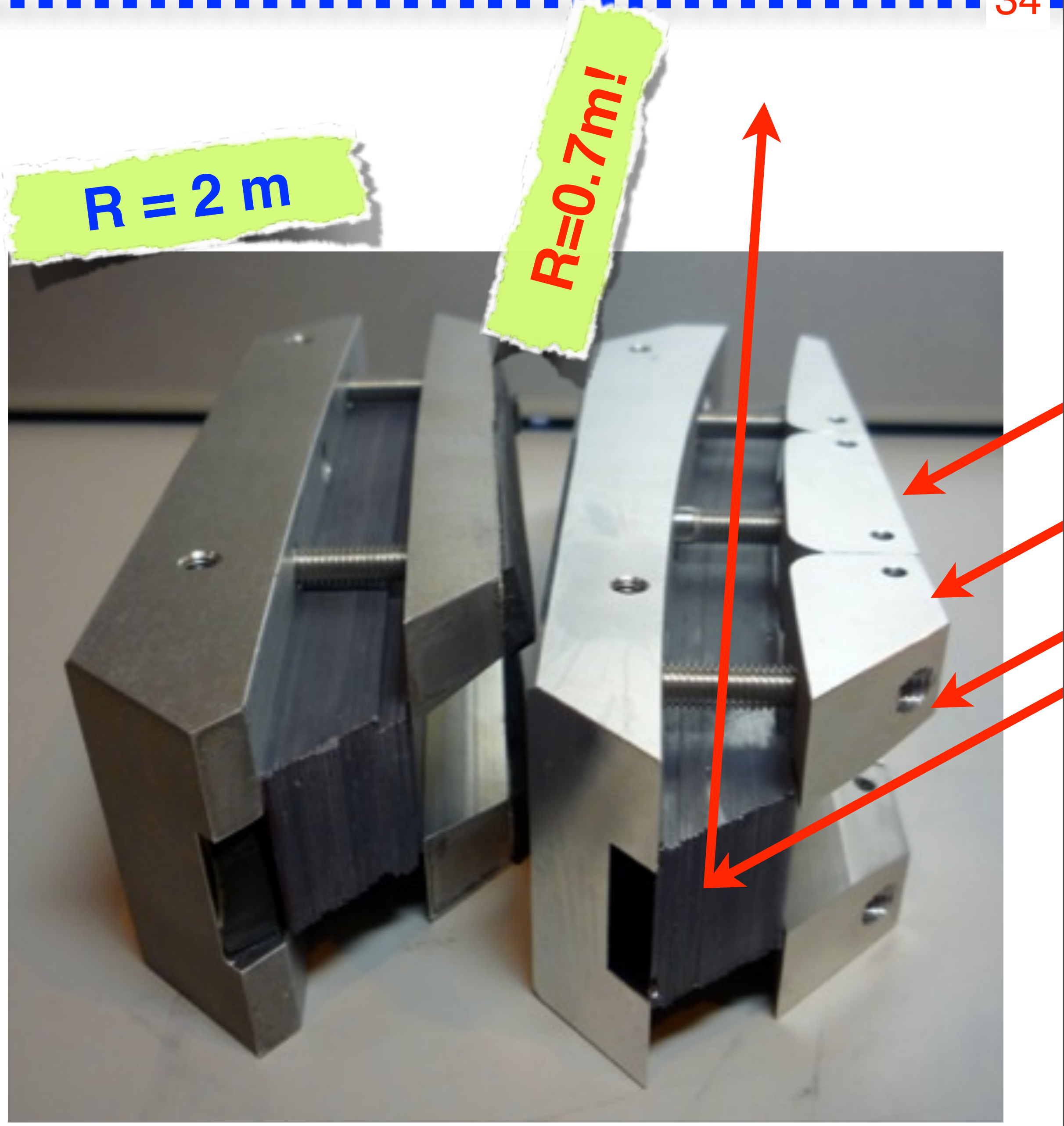


L: 900mm
W: 20mm



Si perfect crystal monochromator

- **Fully asymmetric geometry**
  - 5.8 A
  - 0.5 mm thick Si plates×30 plates
  - Brighter than a PG monochromator

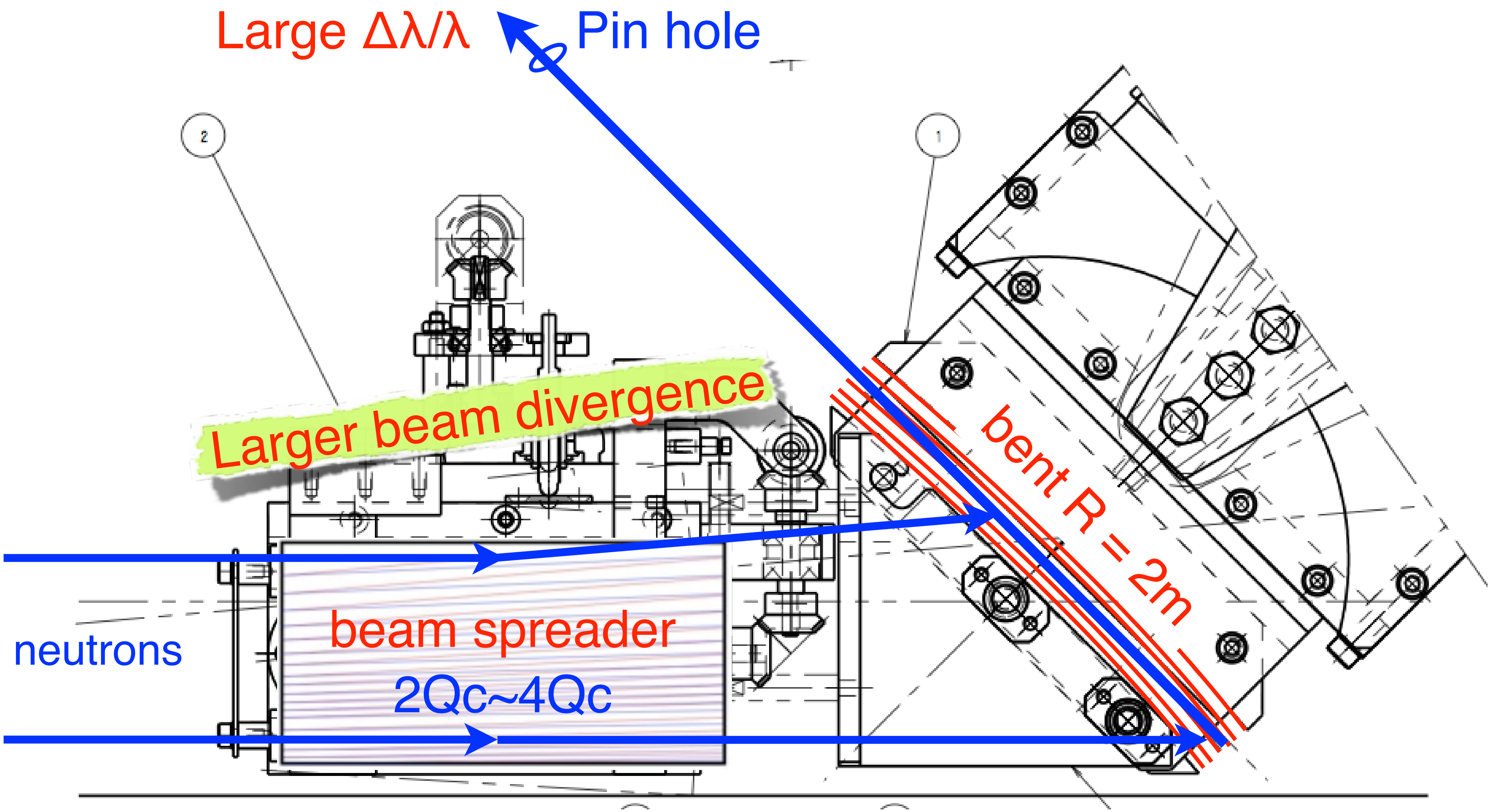


0.5 mm thick Si plates ×30 plates

High intensity monochromator with a beam deflector

New concept!

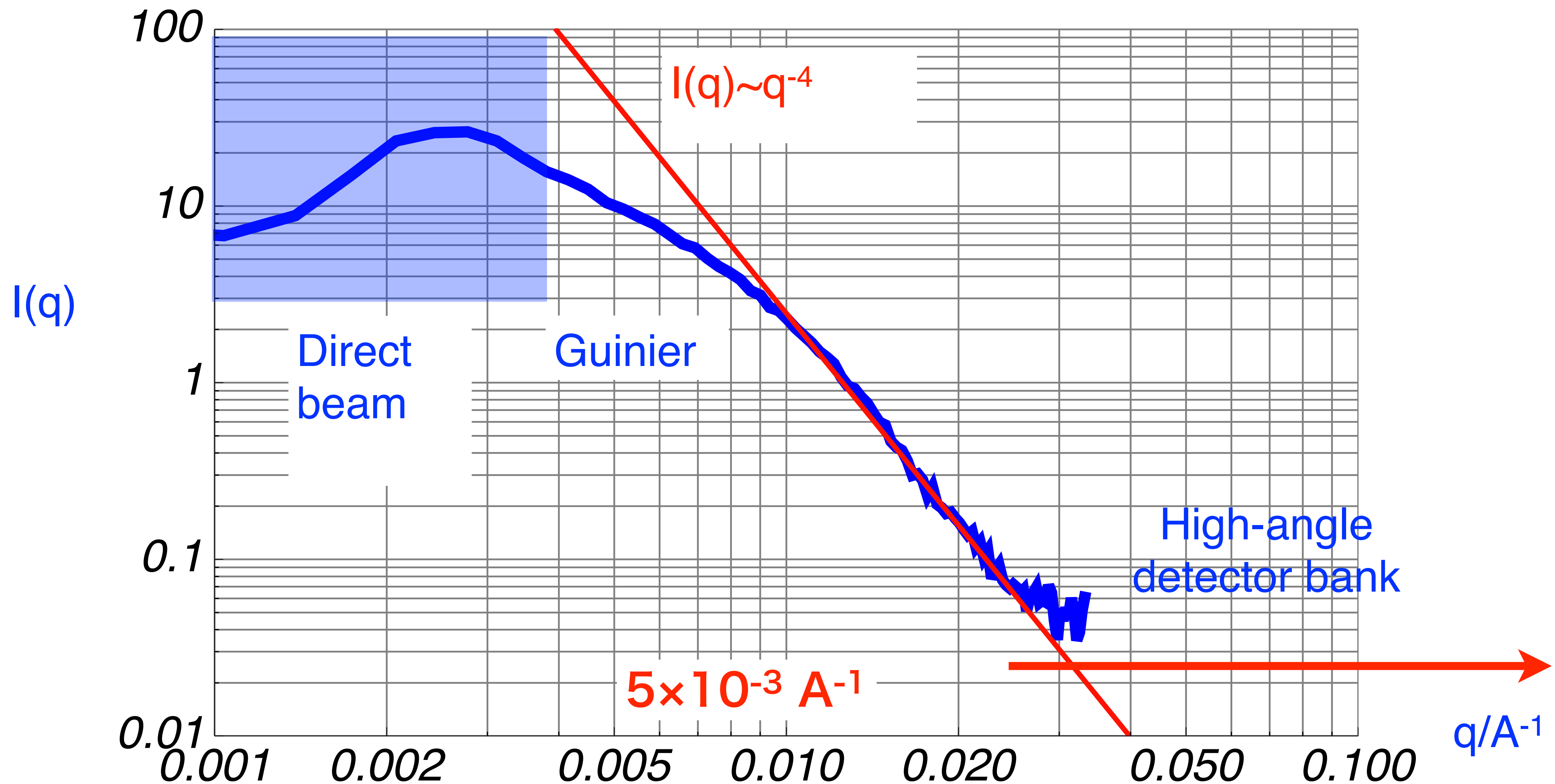
- Improved monochromator being tested



Ni powder 20nm

Preliminary data

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

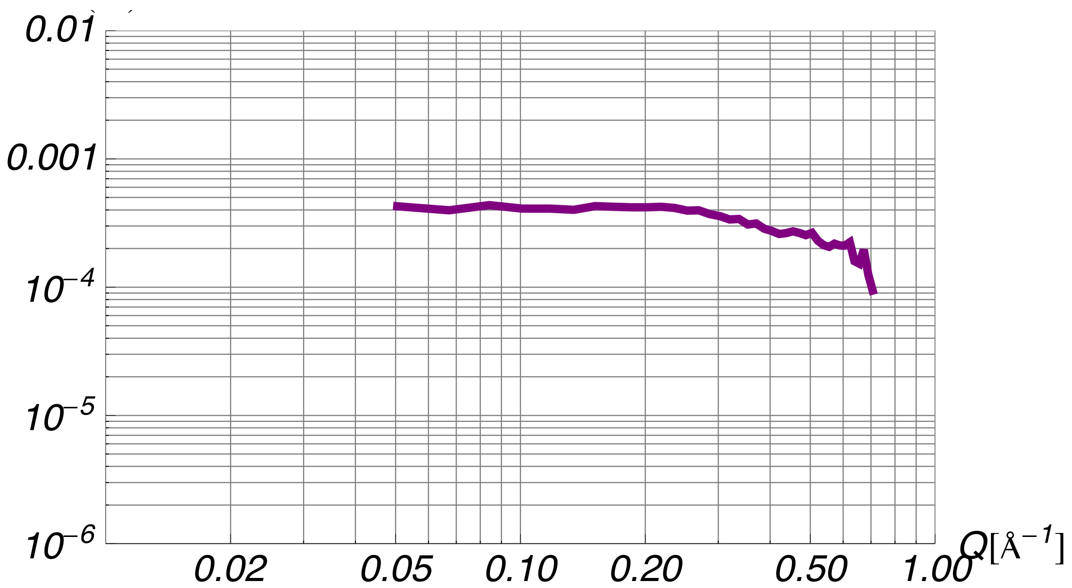


wider-angle scattering

Preliminary data

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

I(q) Water

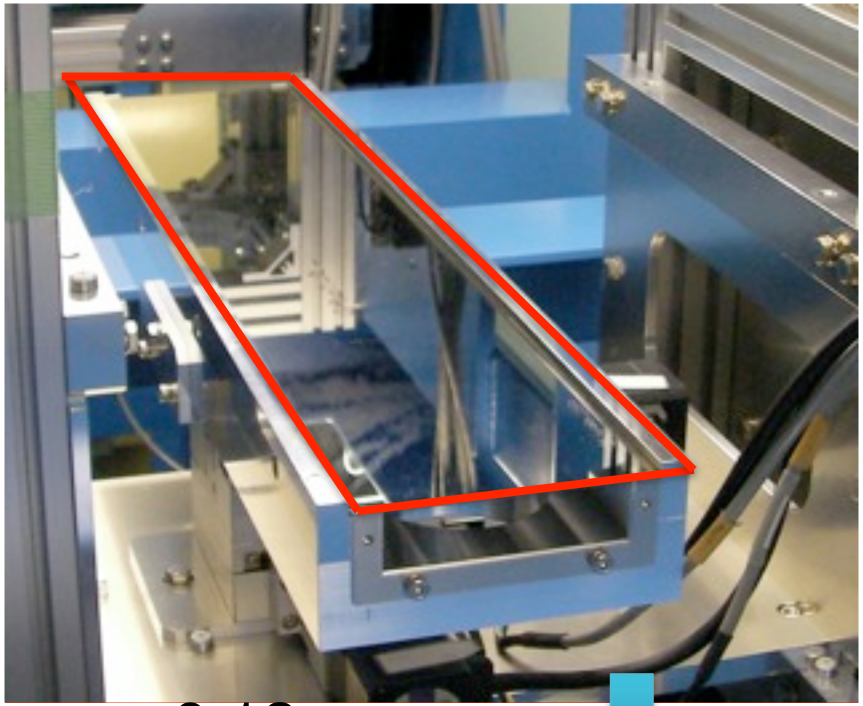


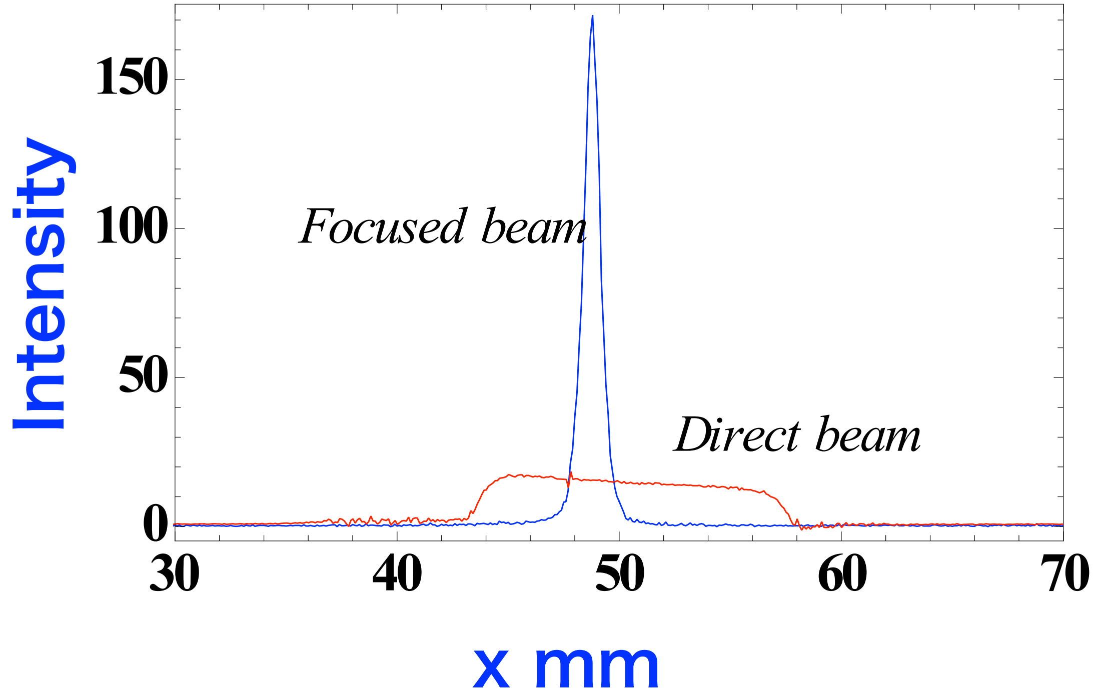
Other method of focusing: bent supermirror

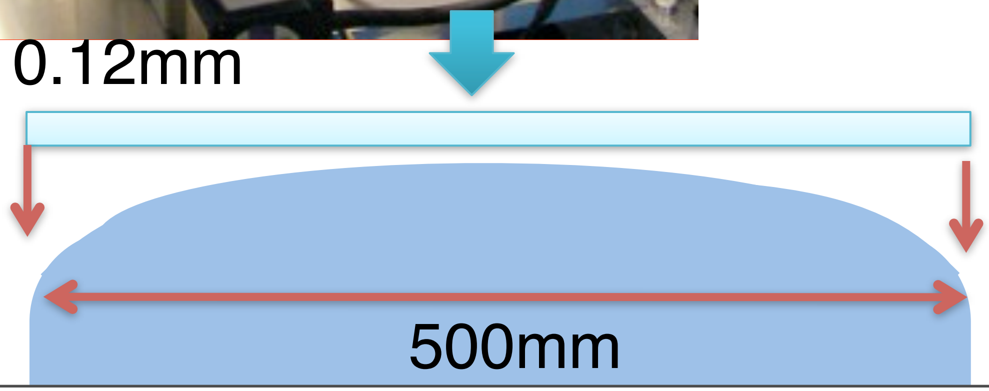
Should be easy and cost effective.

Focusing by a bent supermirror

- **Very gentle bending**
  - **Elliptical bending, ≈120μm at the ends**



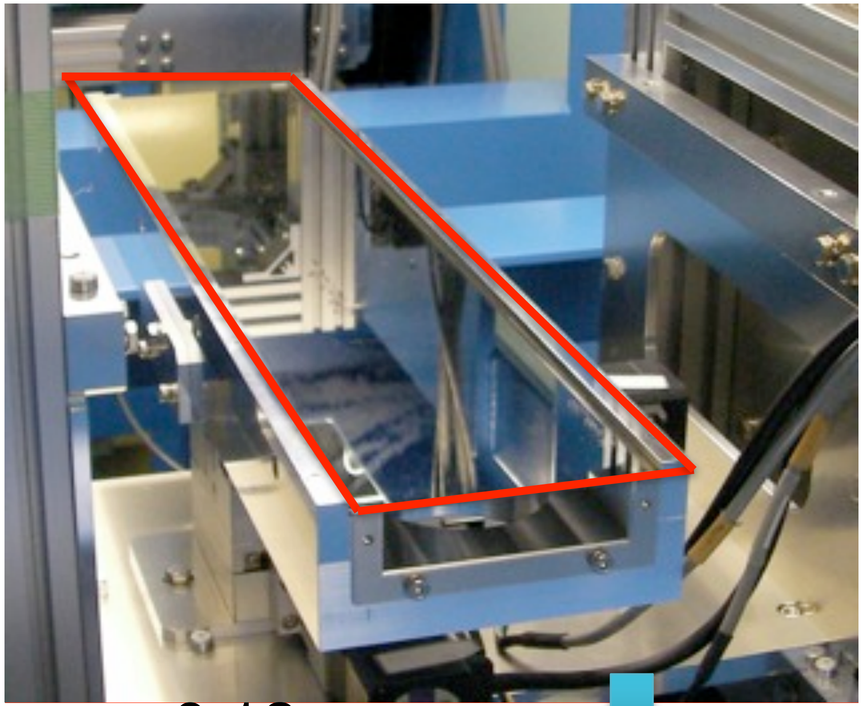


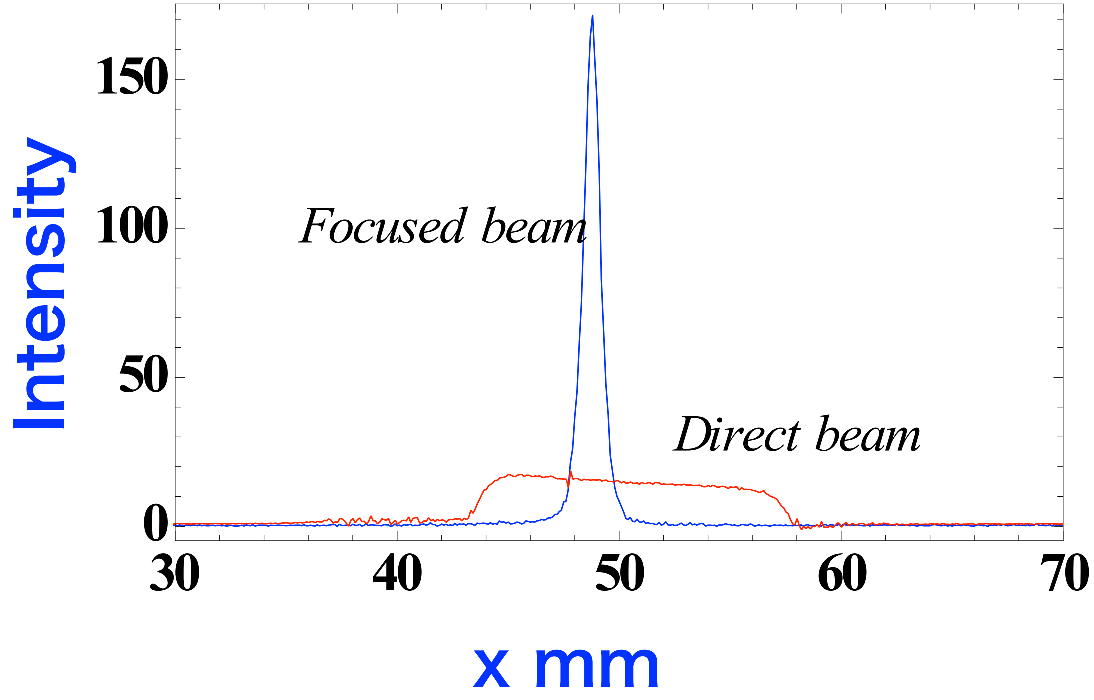


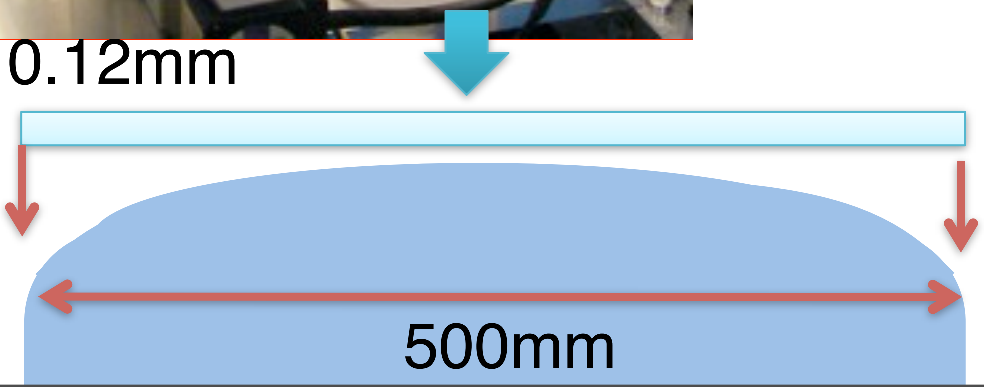
Focusing by a bent supermirror

For reflectometer
& K-B mirror type SANS

- **Very gentle bending**
  - Elliptical bending, ≈120μm at the ends





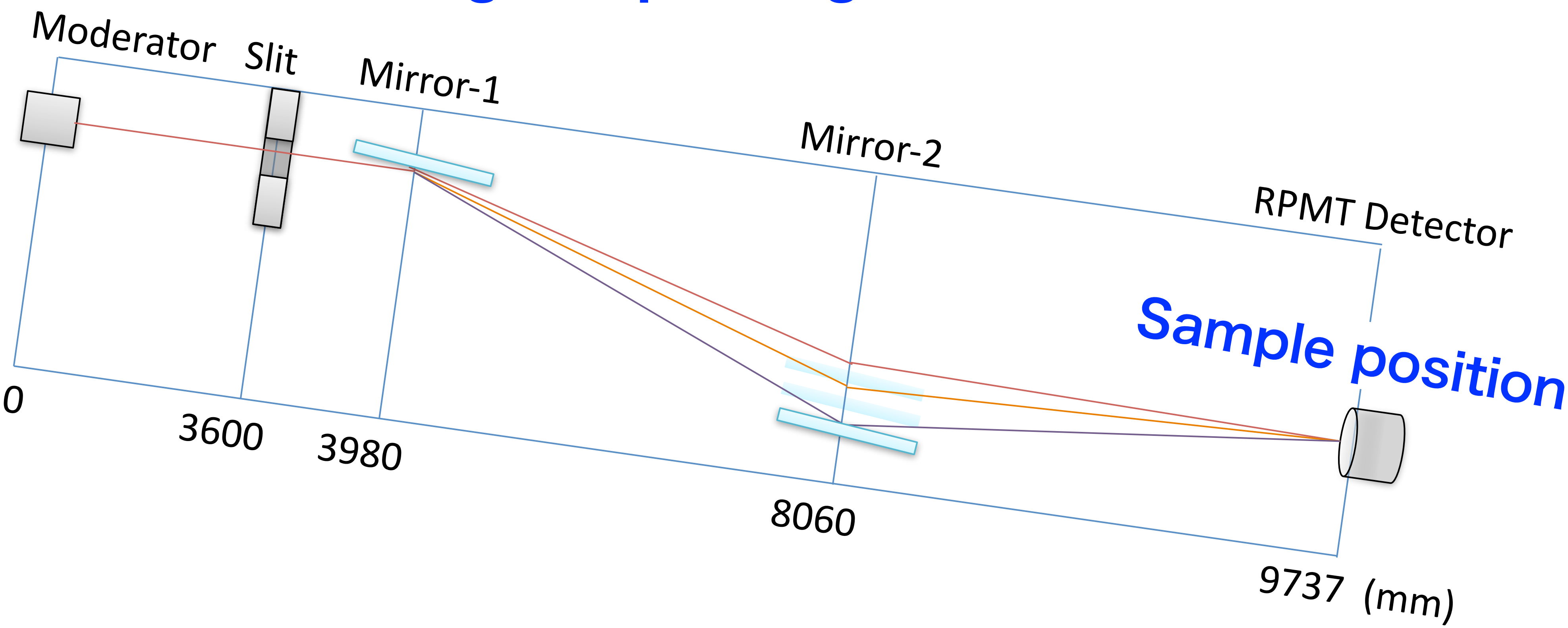


Two pieces of supermirrors replacing a guide

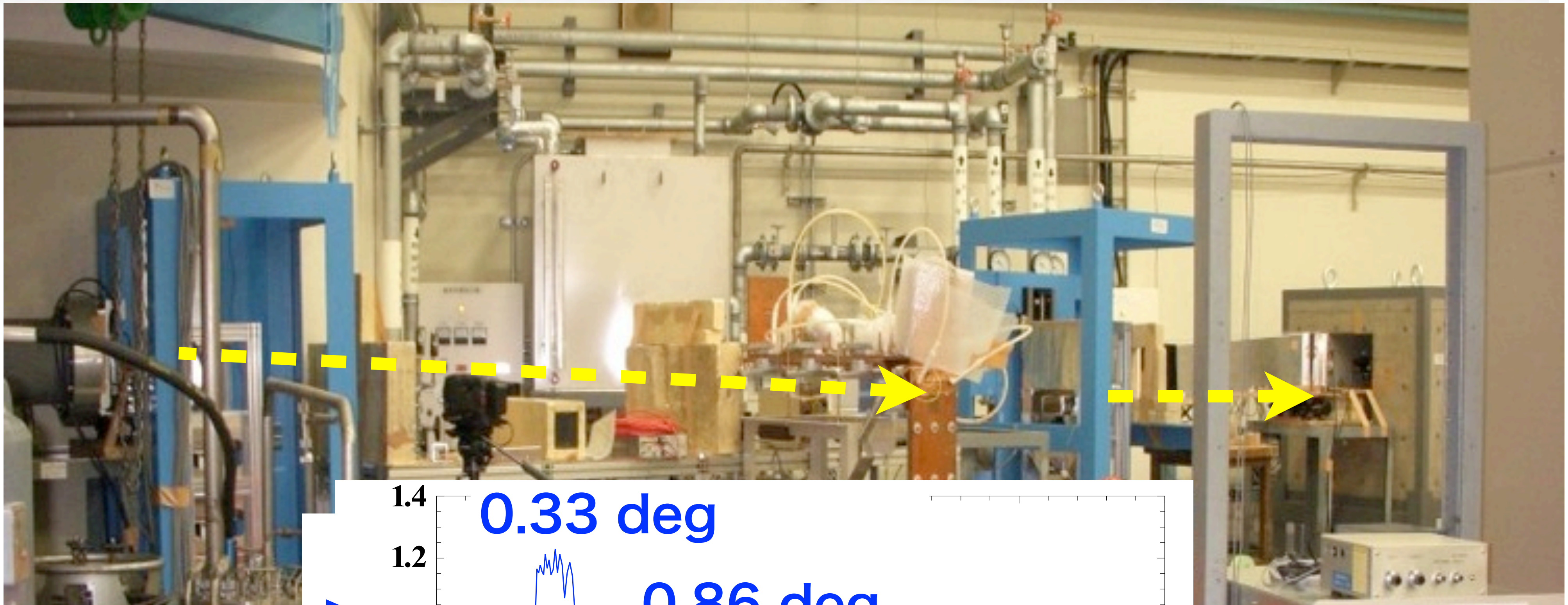
For neutron reflection measurement
for horizontal sample geometry.

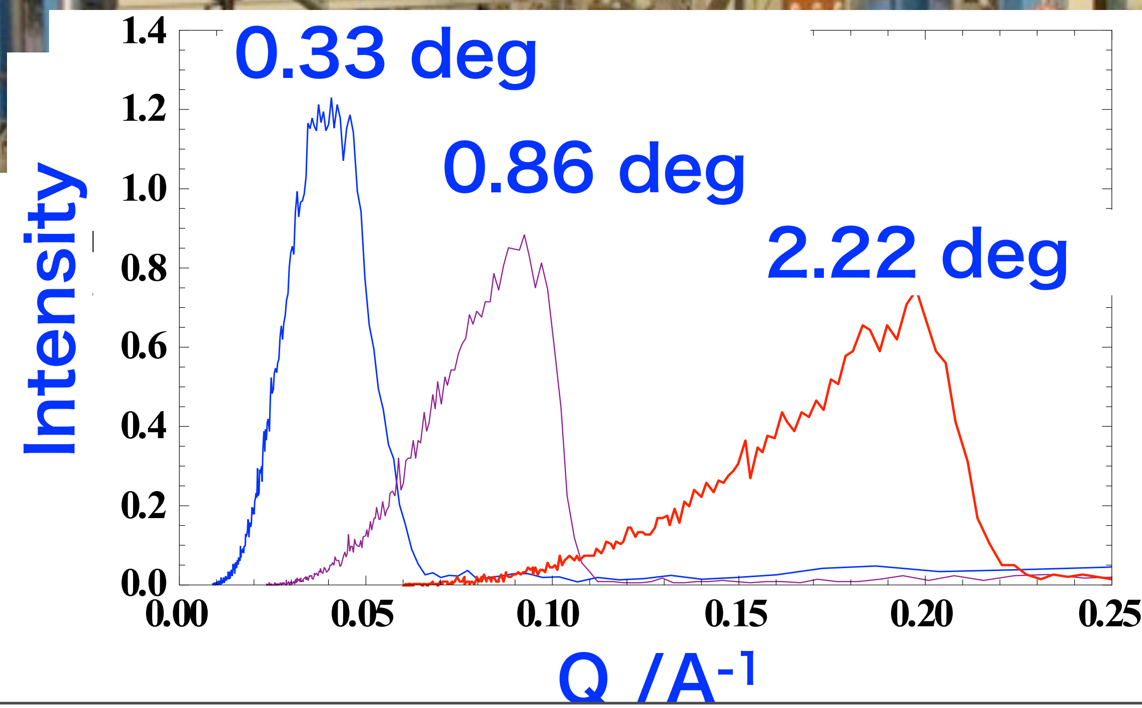
beamline for the reflectometer @J-PARC

- **Horizontal sample geometry**
  - **Inclined beamline+TOF**
- **No need of moving sample height**



First test at HU Linac



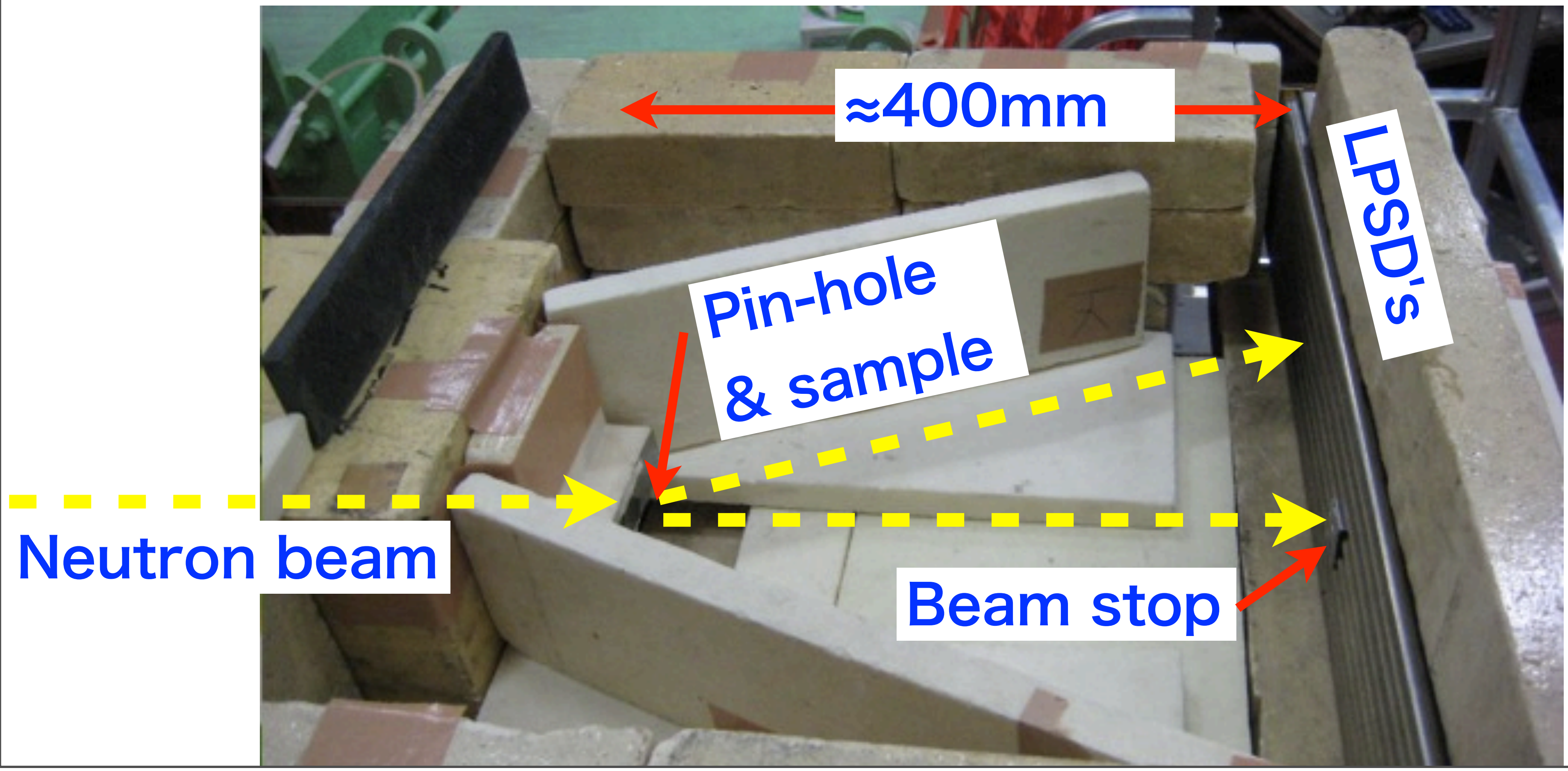


Higher-Q end

Intermediate-angle scattering instrument; using a very short flight-path

Intermediate-angle scattering instrument

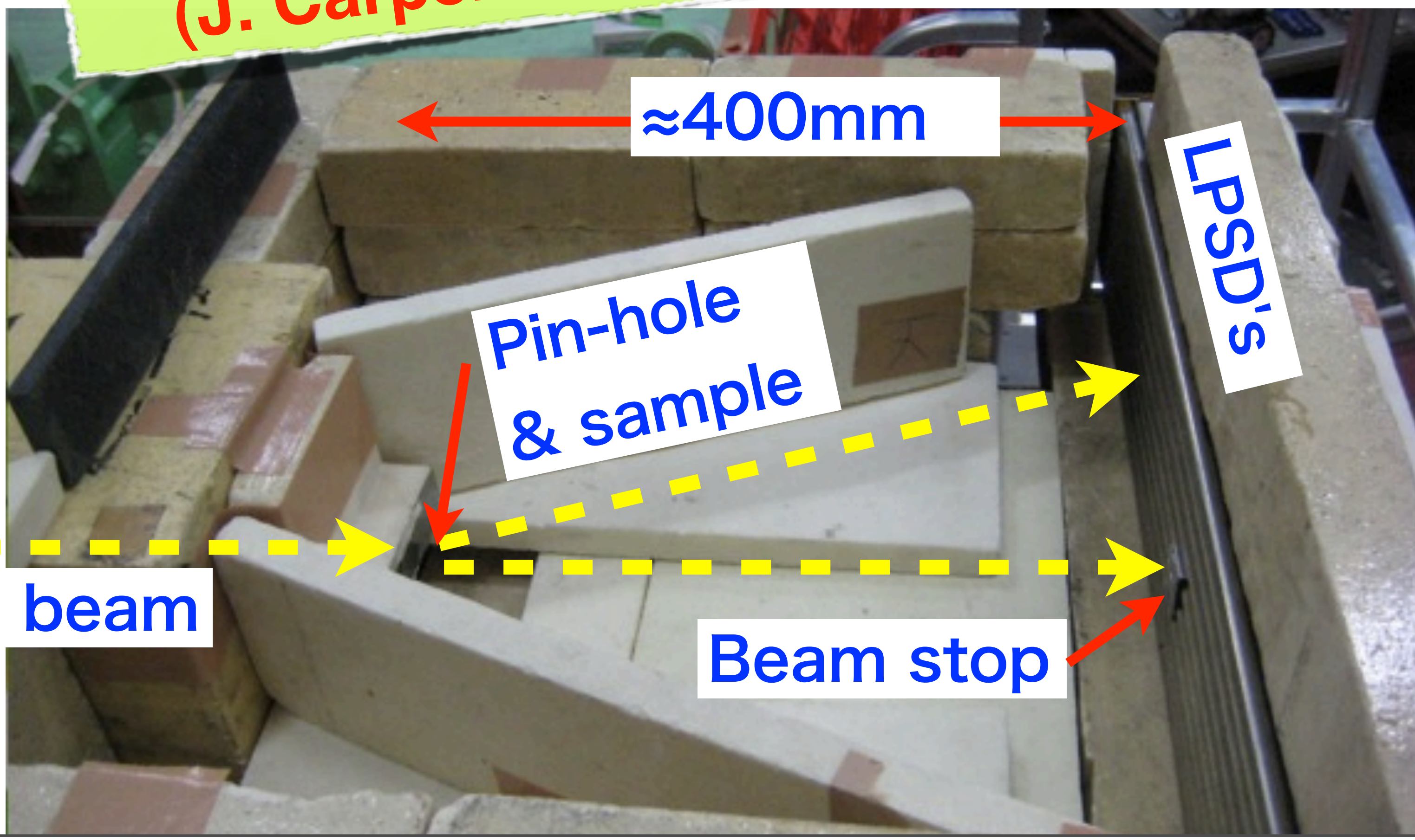
- Very low angular resolution
  =highly efficient at an intermediate-q range
- Large sample size; up to 20 mm
- Reasonable Q-range; $0.05 \leq Q \leq 2$ A^{-1}



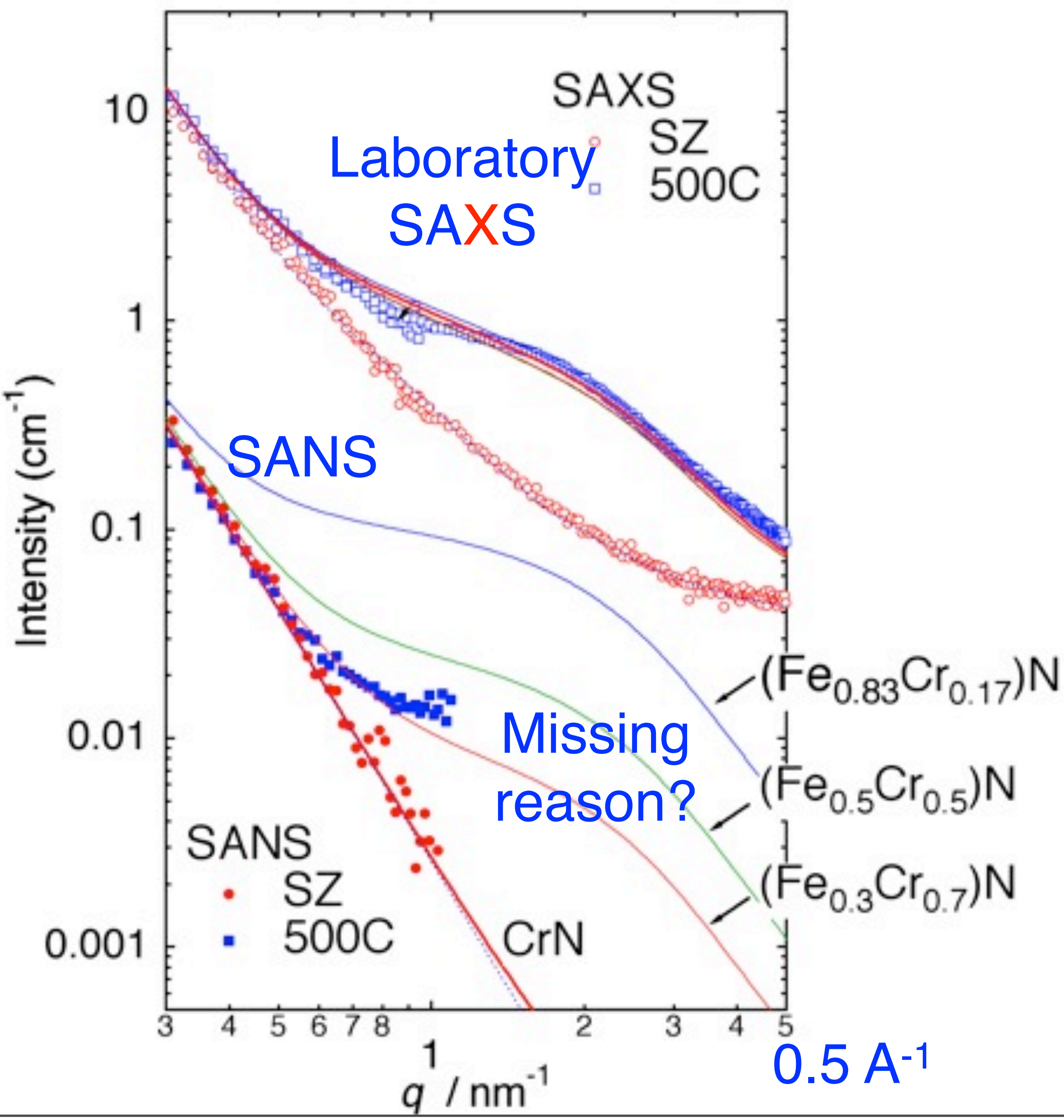
Intermediate-angle scattering instrument

- Very low angular resolution
  =highly effici
- Large s
- Reason

Everything built from junk and reclaimed equipment #2. (J. Carpenter)

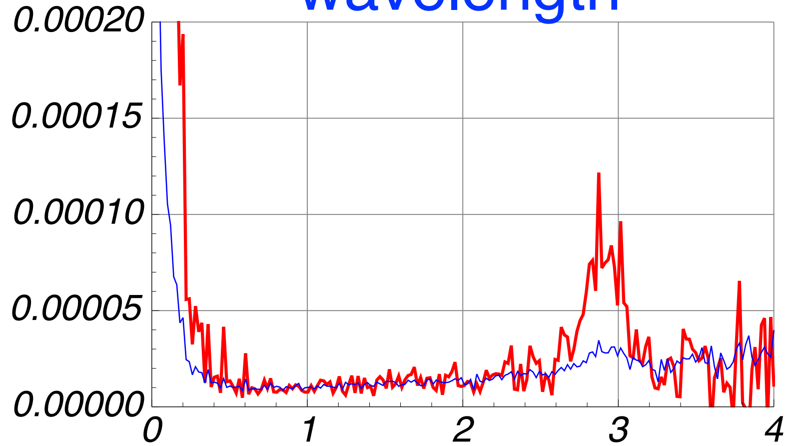


Nanoscopic precipitates in Steel



0.5 A^{-1}

Very preliminary.
A slice of
wavelength

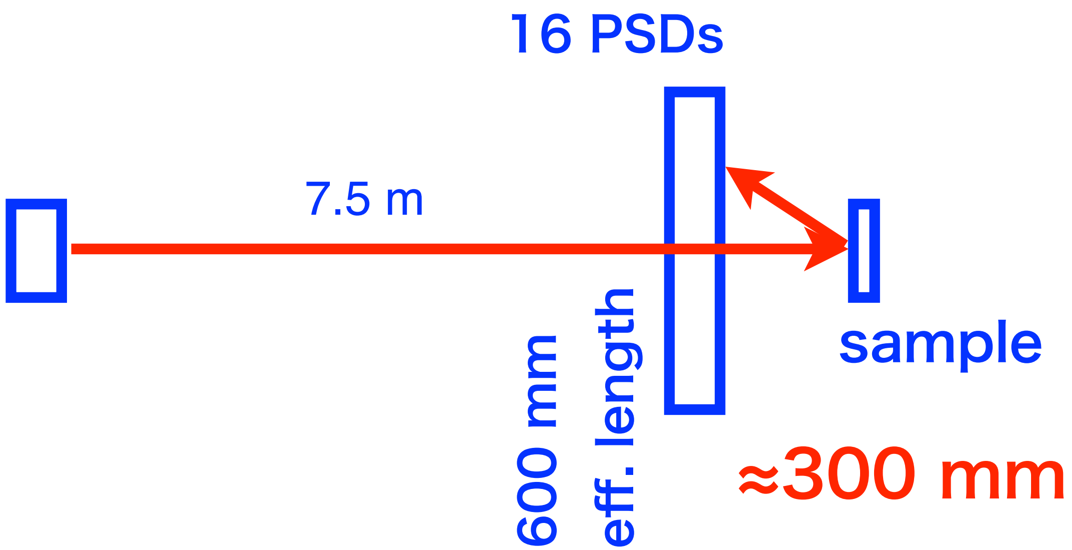


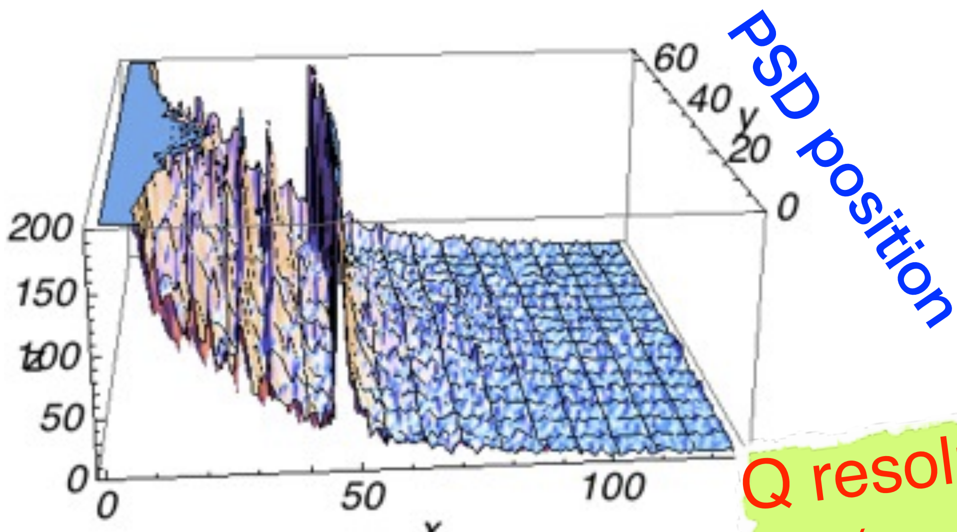
Diffractometer

Very low resolution

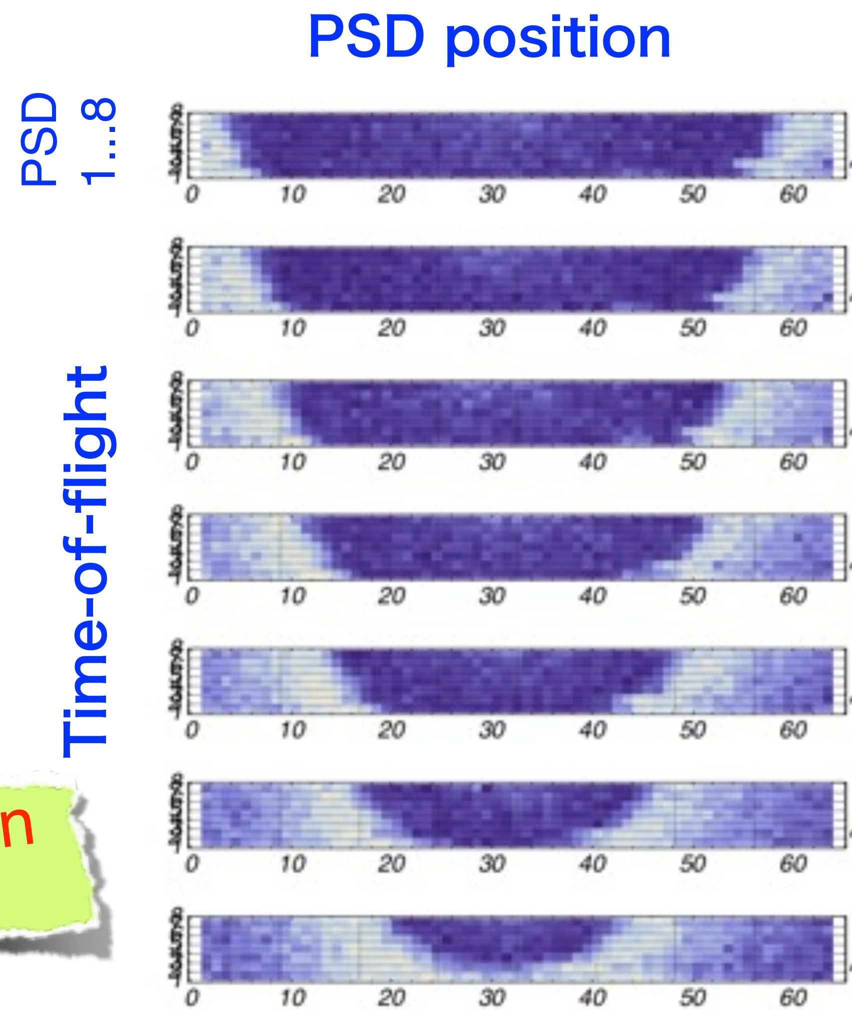
Diffraction in a steel plate

Preliminary





Q resolution ≈2%



Summary

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- HU Linac is a good example of cADNS in a university environment.
- Various SANS instruments and others
  - Conventional SANS instrument
  - Small-pinhole SANS
  - Compact focusing SANS instruments
- Intermediate-angle neutron scattering instrument
  - Powder diffraction test.
- Various optical device development
  - focusing devices
  - monochromators