Phase correction by ellipsoidal focusing mirrors for a high-resolution neutron resonance spin echo spectrometer

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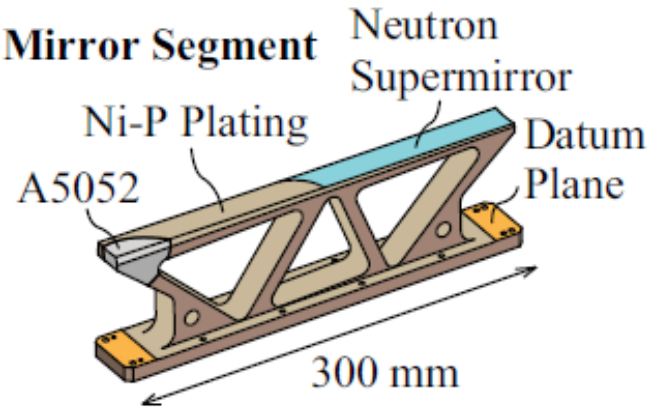
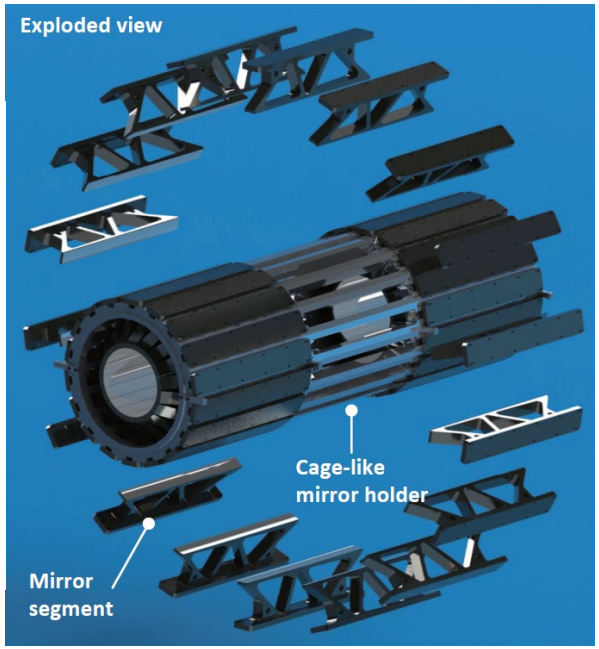
(RIKEN Center for Advanced Photonics)

Outline

1. Neutron resonance spin echo spectrometers at BL06 MLF, J-PARC
2. Phase correction by ellipsoidal focusing mirrors for neutron spin echo
3. Ellipsoidal neutron supermirror on metal substrate
4. Performance test
5. Summary





Collaborators

↑ M. Hino,
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↑ T. Hosobata, ↑ Y. Yamagata,
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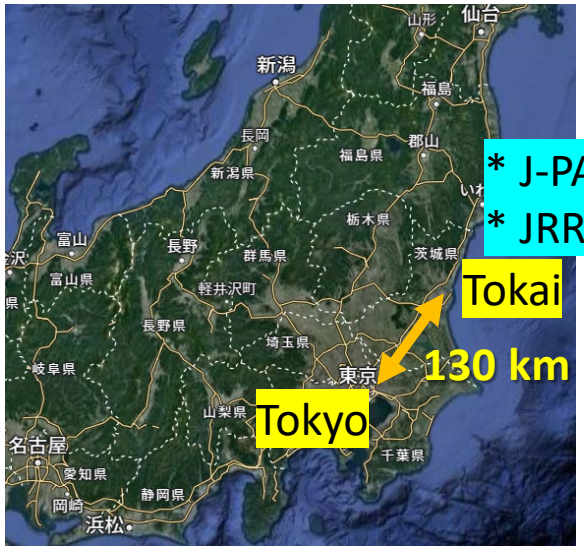
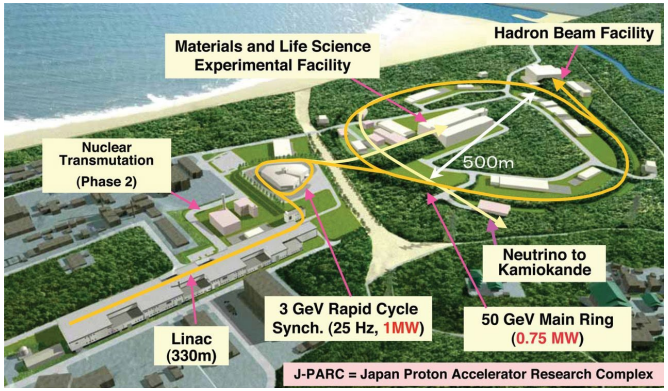
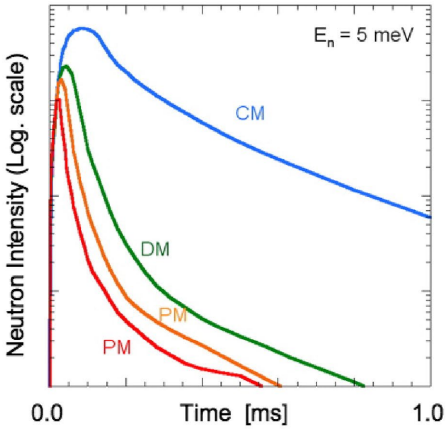
↑ F. Funama (PhD at Kyoto Univ, currently postdoc at ORNL)

Japan Spallation Neutron Source at MLF, J-PARC



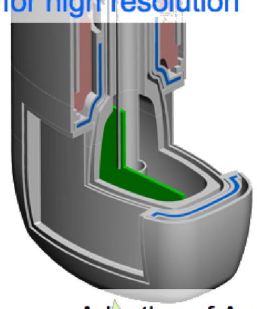


J-PARC at Tokai, Ibaraki, Japan



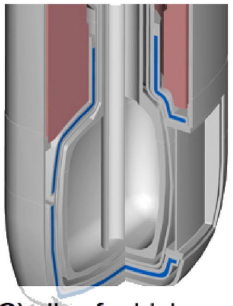
Poisoned Decoupled moderator (PM)

for high resolution



Decoupled moderator(DM)

for balanced performance

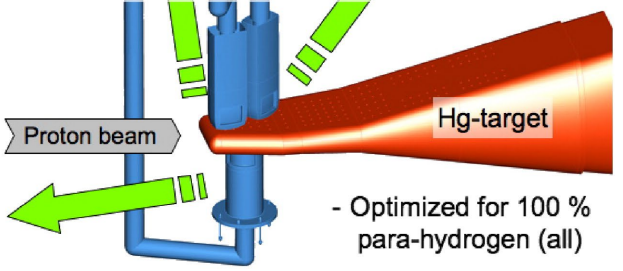


Coupled moderator (CM)

for high intensity

- large & cylindrical
- wide angle beam extraction

- Adoption of Ag-In-Cd (AIC) alloy for high decoupling energy at 1 eV
- optimized decouple coverage for lower pulse tail
- Adoption of Cd poison

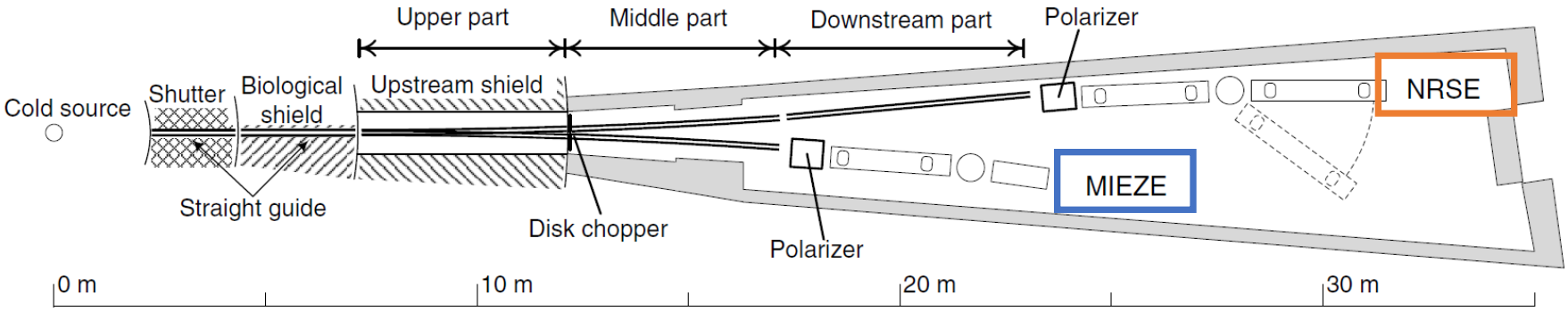


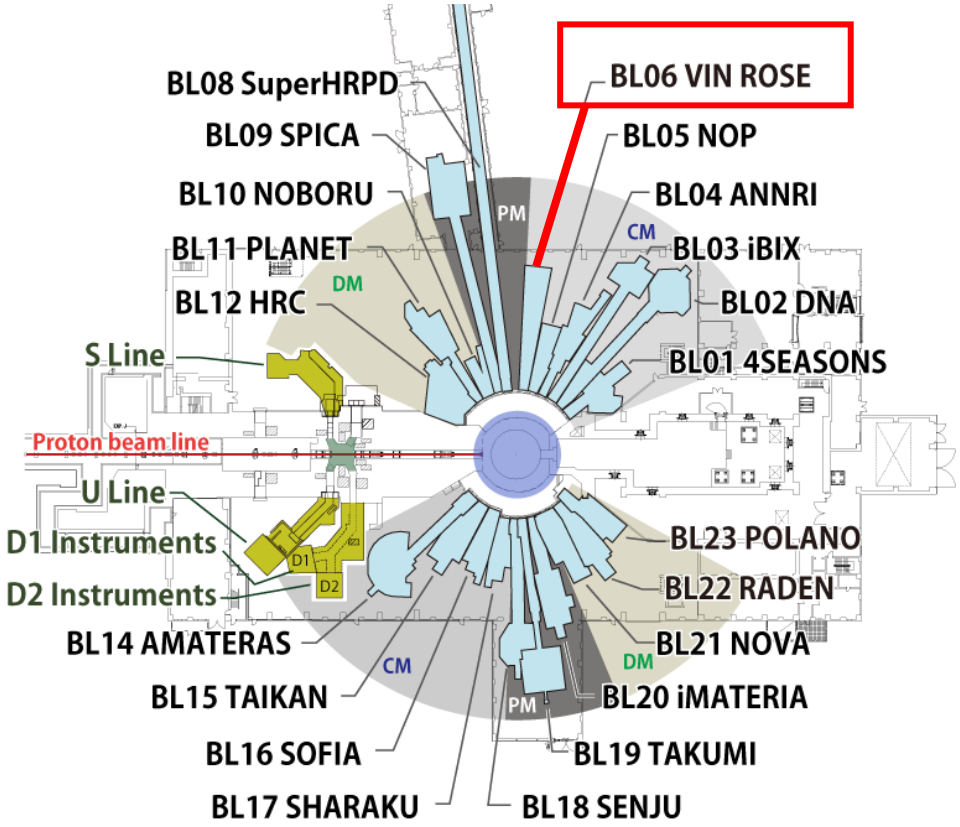
- Optimized for 100 % para-hydrogen (all)

Proton beam power: 1MW (currently 0.8 MW)
Frequency: 25 Hz (TOF frame 40 ms)
Hg Target, Three types of moderator

F. Maekawa et al., Nucl. Instrum. Methods A **620**, 159-165 (2010)

BL06 at MLF, J-PARC





Constructed by KEK and Kyoto Univ

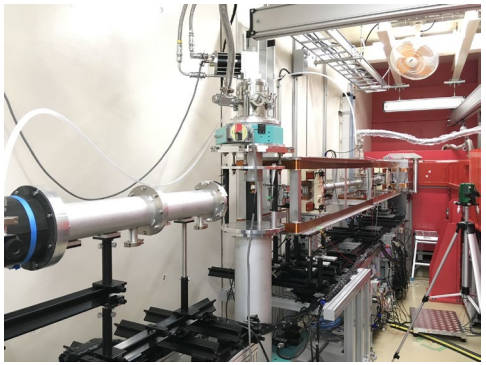
https://mlfinfo.jp/ja/blmap.html

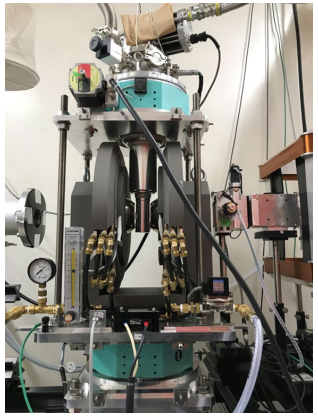
Village of neutron resonance spin echo spectrometers (VIN ROSE)

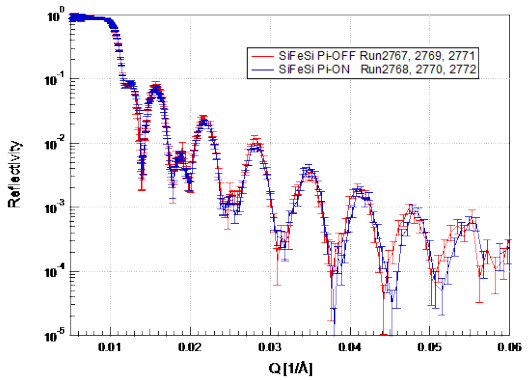
Two types of resonance-type spin echo at BL06:

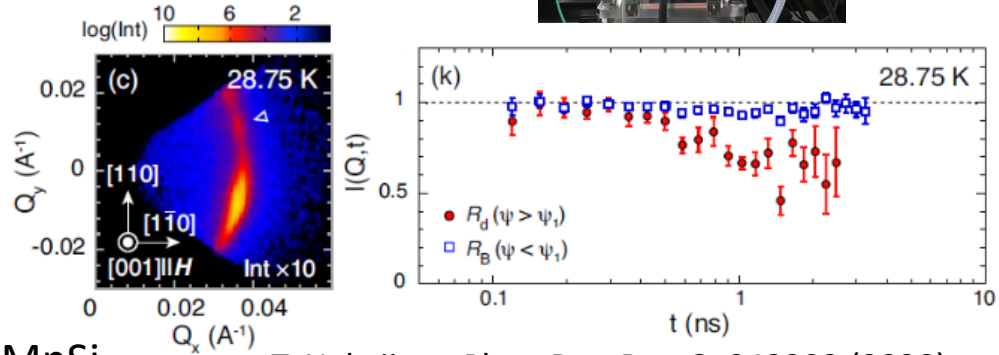
- NRSE (Neutron resonance spin echo) for high energy resolution ($\tau > 100$ ns)
- MIEZE (Modulation of intensity with zero effort) ⇒ Open for users

Study of spin dynamics under a high magnetic field and other extreme conditions



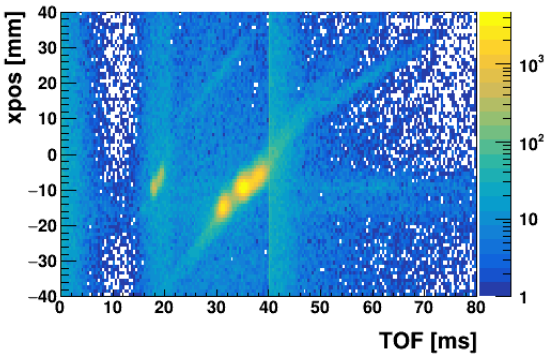






MnSi

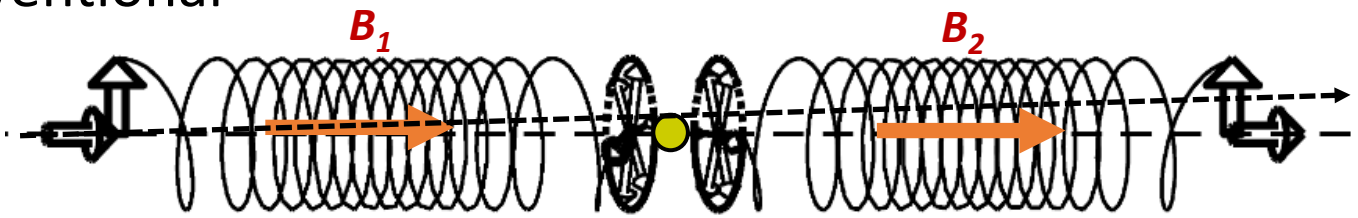
T. Nakajima, Phys. Rev. Res. **2**, 043393 (2020)



2. Phase correction approach using ellipsoidal focusing mirrors for neutron spin echo

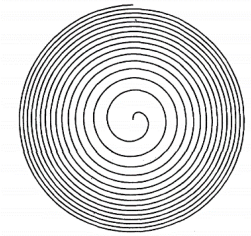
Larmor phase deviation in NRSE

Conventional NSE



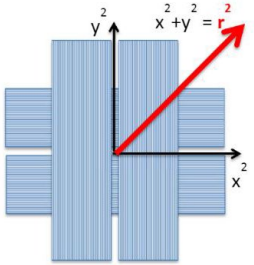
$$\phi = \frac{\gamma_n}{v} \int B_1 dl$$

M. Monkenbusch, et al., *C. R. Physique* 8 (2007)



Fresnel coil

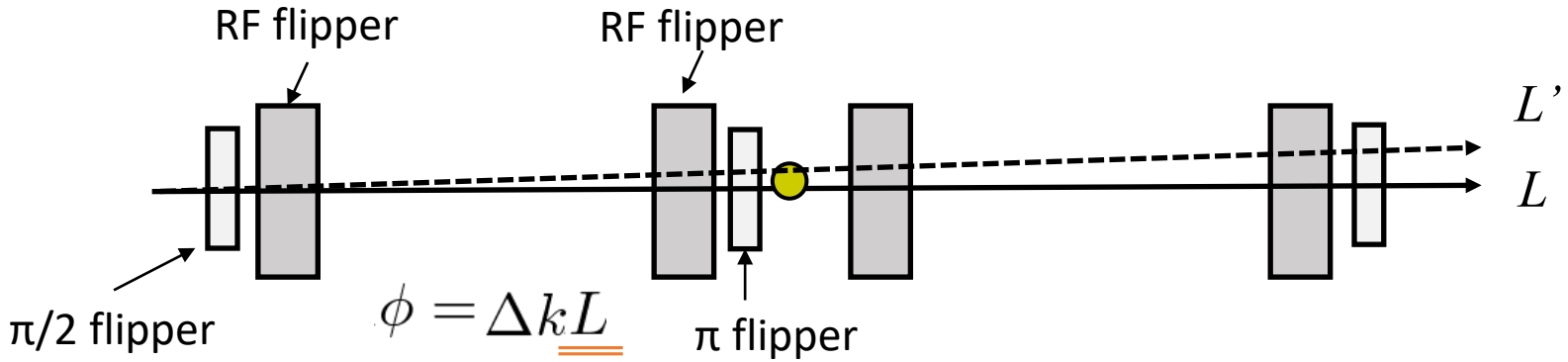
(Neutron Data Booklet, ILL)



Pythagoras coil

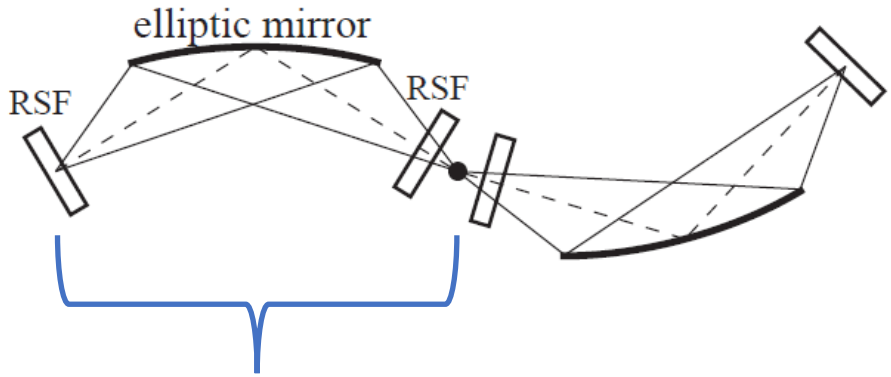
O. Ivanova, J. Physics: Conf. Series **862** 012009 (2017)

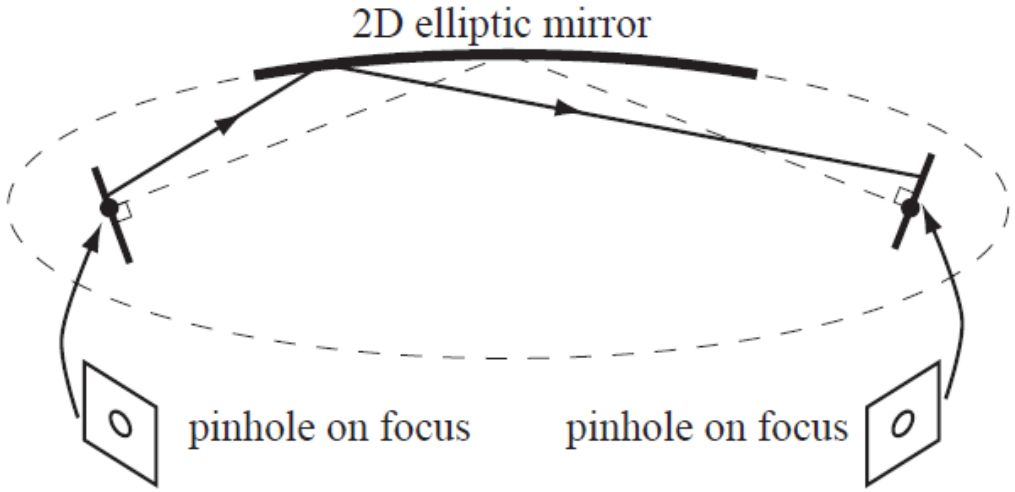
NRSE (transverse)

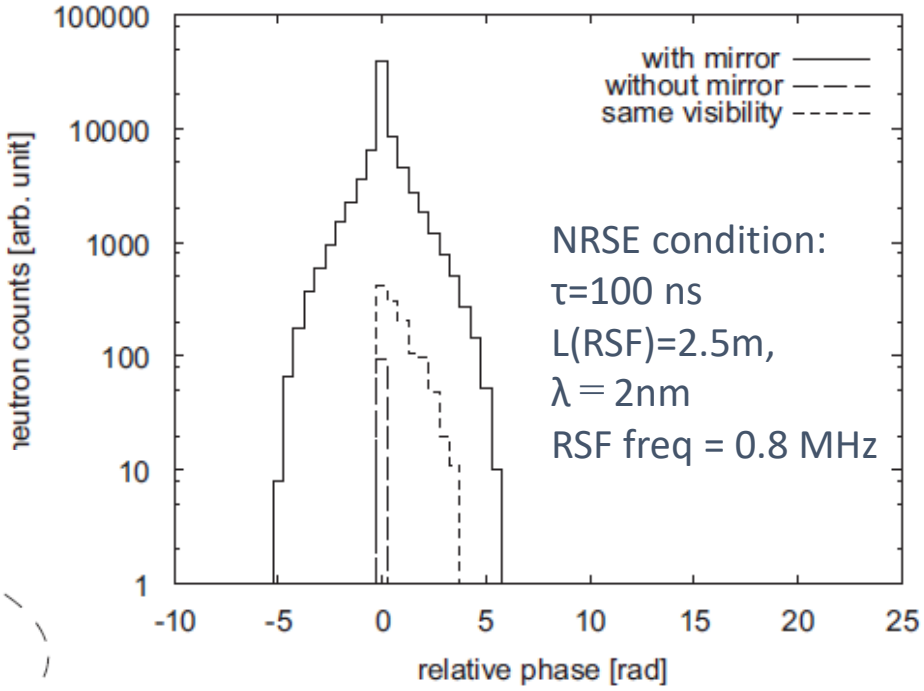


Divergent beam makes path deviation (phase deviation)

Phase correction (path length correction) approach by elliptic focusing mirror



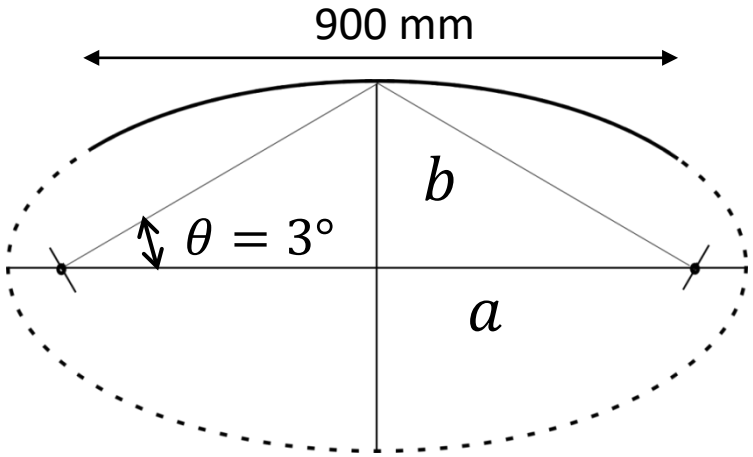




On an elliptic the sum of distances from two focal points is constant

M. Kitaguchi, et al., Physica B **406** (2011) 2470

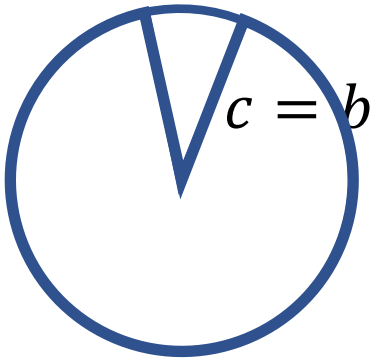
Ellipsoidal supermirror

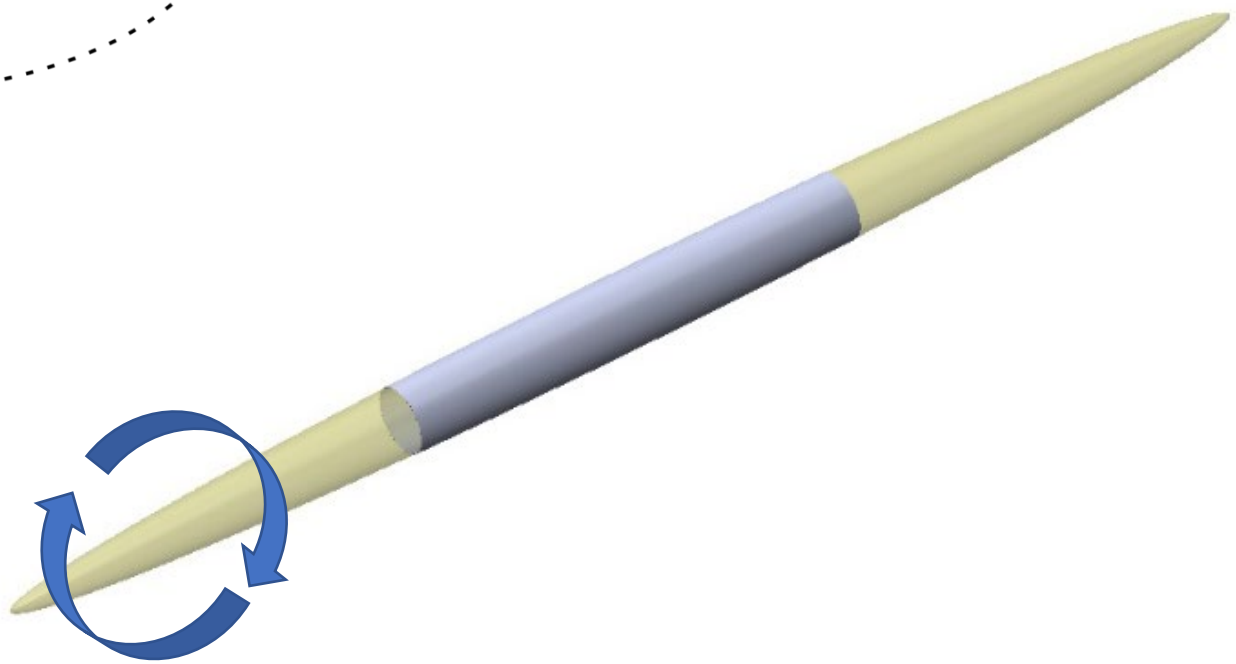


a = 1250 mm

b = c = 65.4 mm

Focal length = 2a = 2500m



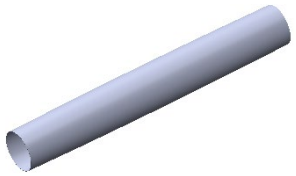


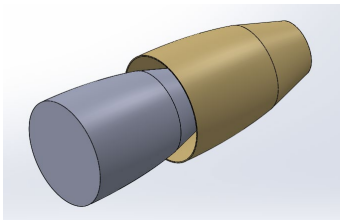
Full revolution!

3. Development and production of ellipsoidal neutron supermirror on metal substrate

Difficulties in realizing ellipsoidal mirror

- Surface flatness
- Supermirror deposition
- Accuracy of ellipsoidal form





Surface flatness

By courtesy of Dr. Hosobata

substrate material

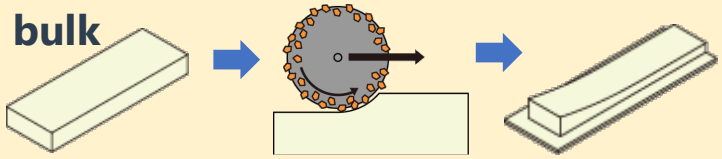
- ✓ Amorphous → glass
- ✓ Single crystal → silicon
- ✗ Polycrystalline → metal

Roughness due to crystal grains

Bending
(Float glass, Silicon wafer)

Limitation on deformed shape

Grinding of bulk materials



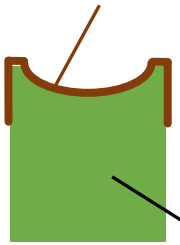
Time-consuming & high cost

Our solution: Electroless Nickel-Phosphorus plating

Phosphorus content	Structure
1 – 4 %	Polycrystalline
5 – 8 %	(Intermediate)
9 – 12 %	**Amorphous**

Coatings for optical element molds

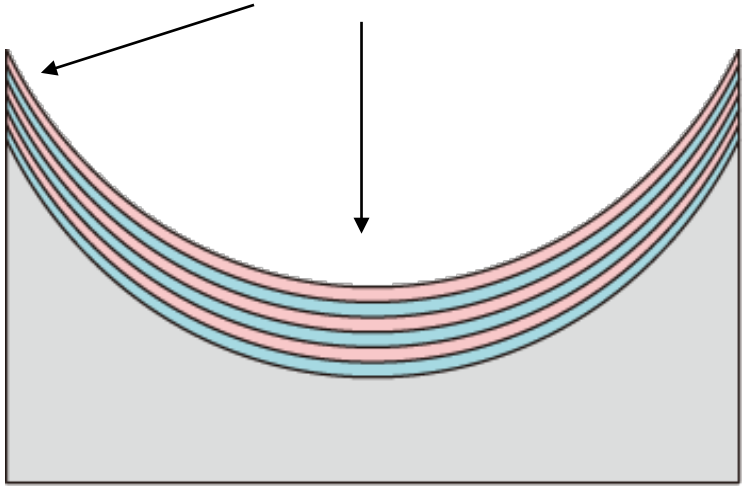
from https://www.nittohkogaku.co.jp/

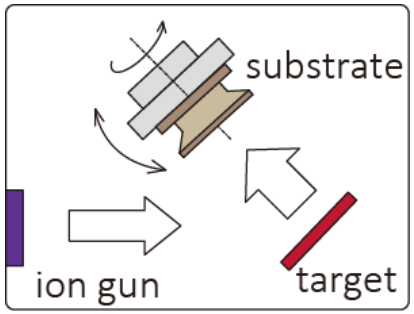


Supermirror deposition

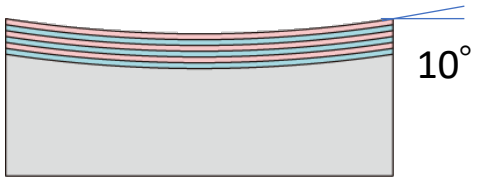
By courtesy of Dr. Hosobata

😢 Steep curve makes non-uniformity of deposition

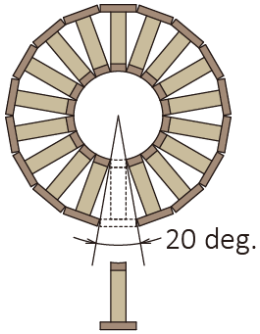




Rotating & tilting workpiece ⇒ uniform deposition on ±10° inclined surface

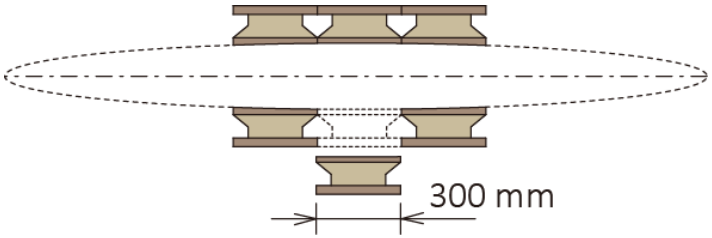


18 sectors



×

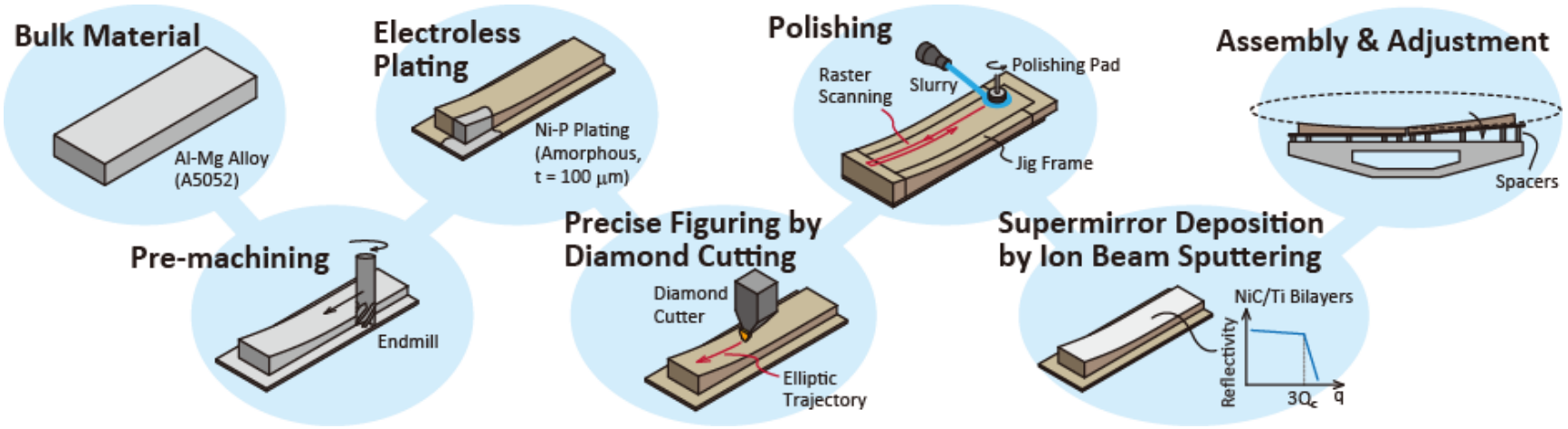
3 longitudinal divisions



= **54 segments**

Overview of mirror production

By courtesy of Dr. Hosobata



Left to right:

*Al-Mg pre-machining
(easily machinable metal)

*Ni-P plating
(Amorphous)

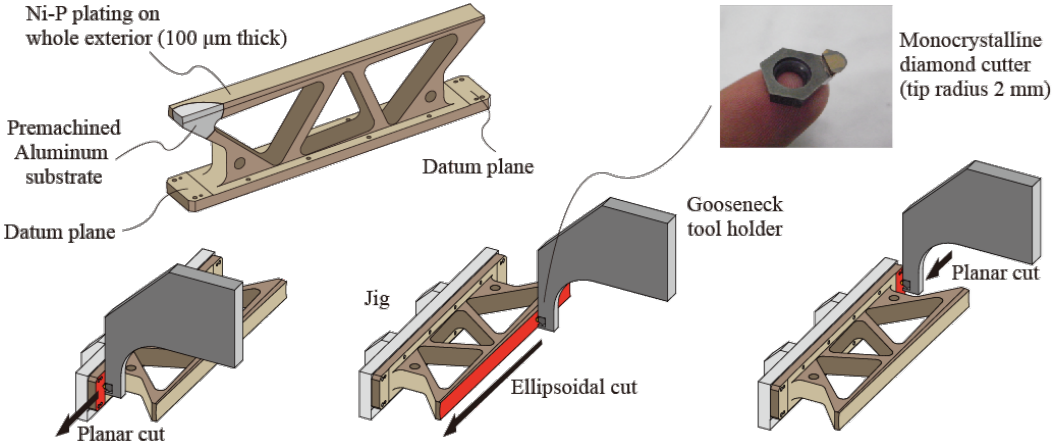
*Diamond cut
(high-precision figuring)

*Polishing
(remove roughness)

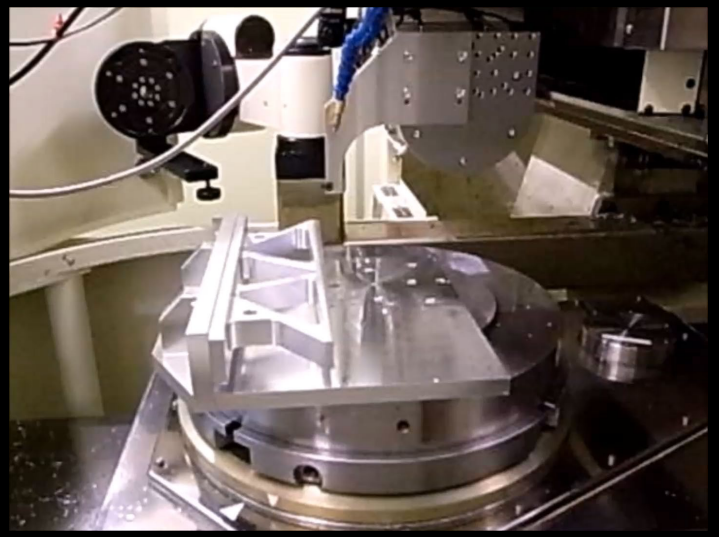
Precise figuring process

By courtesy of Dr. Hosobata

One chuck processing for the curved surface and datum plate



Demonstration of cutting (x 8)

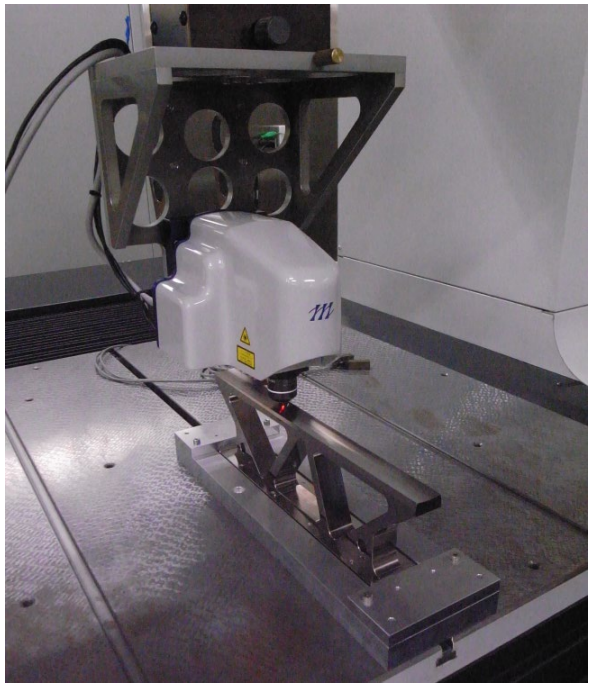


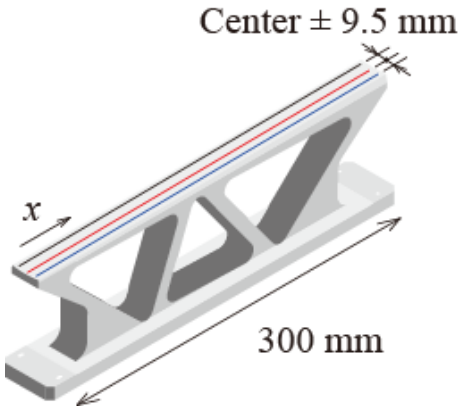
NAGASE i NPIC-M200
(Positioning resolution : 10 nm)

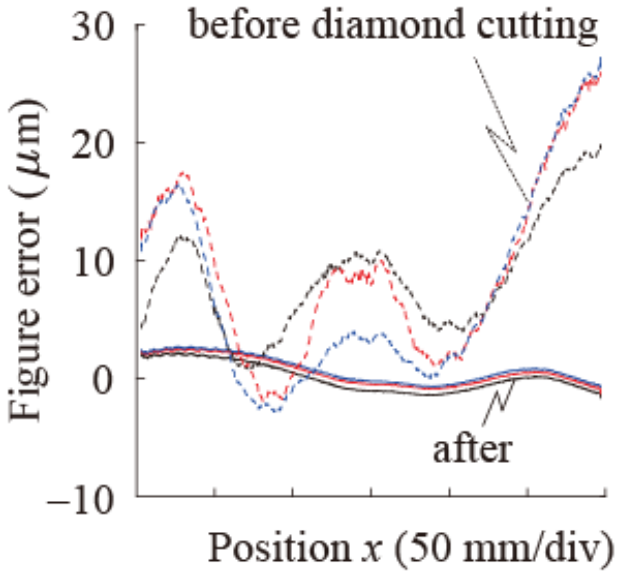
Relative position accuracy between the datum plane and curved surface
≒ Precision of ultra-precision machining center

Figure error

By courtesy of Dr. Hosobata





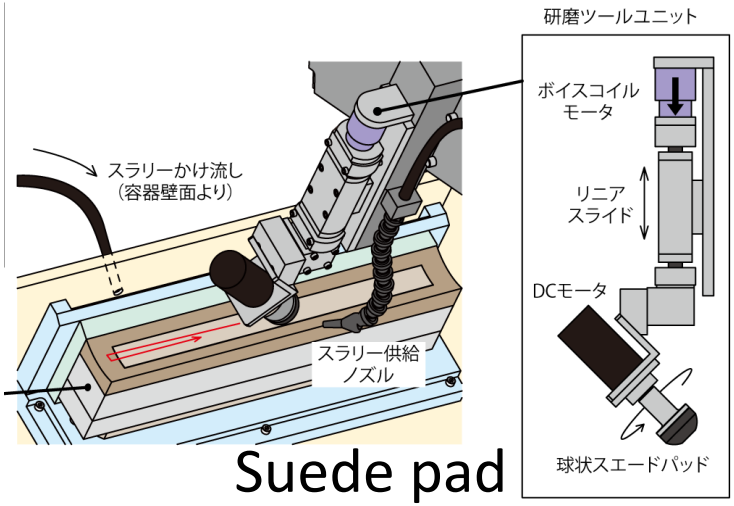


Laser AF probe (Mitaka Khoki PFU-3)
on 3D measuring instrument (Mitsutoyo Legex)

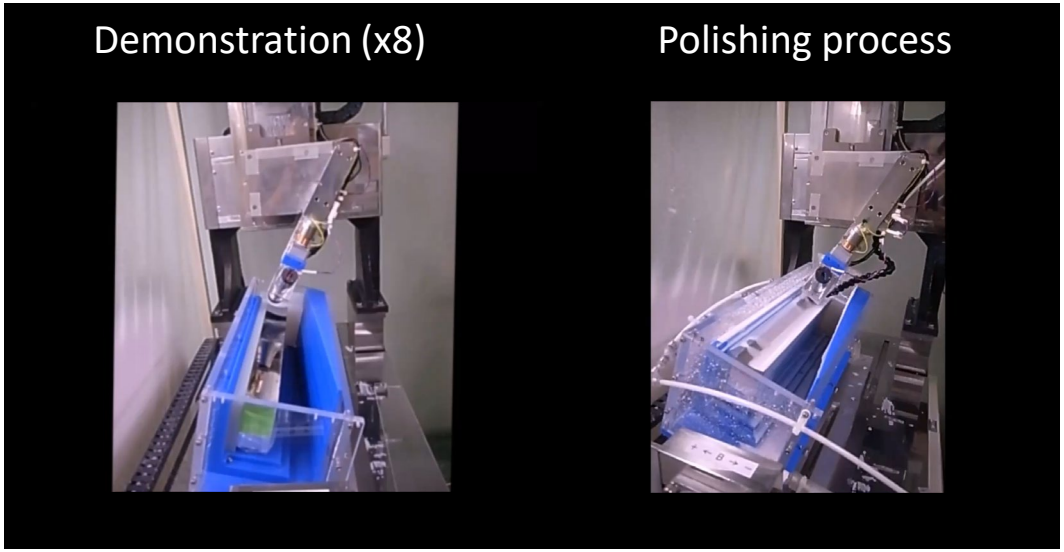
Polishing process

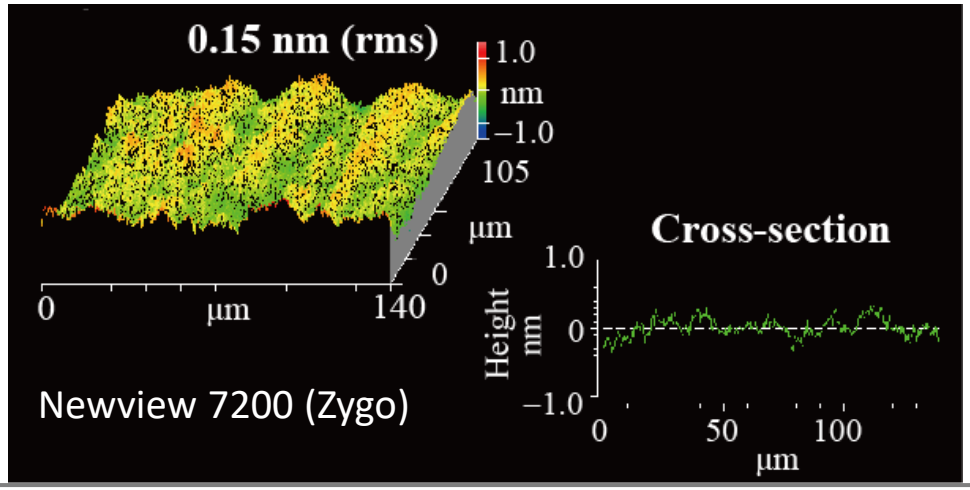
By courtesy of Dr. Hosobata

Slurry (alumina 300 nm → colloidal silica 80 nm)



Suede pad

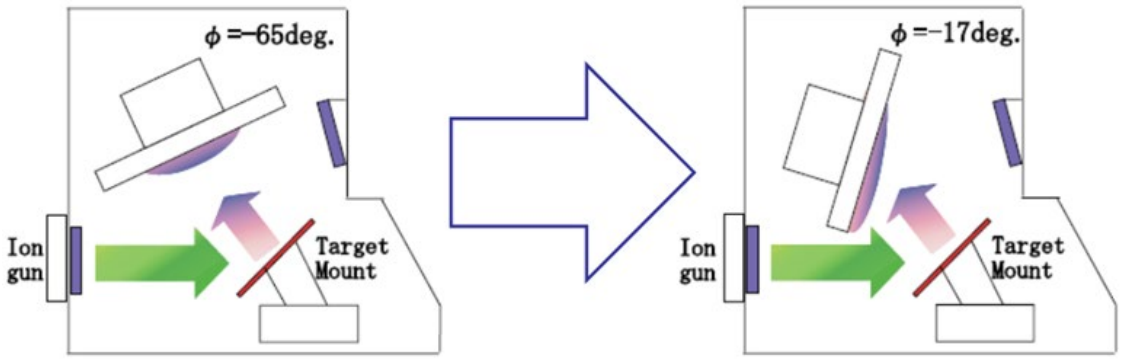


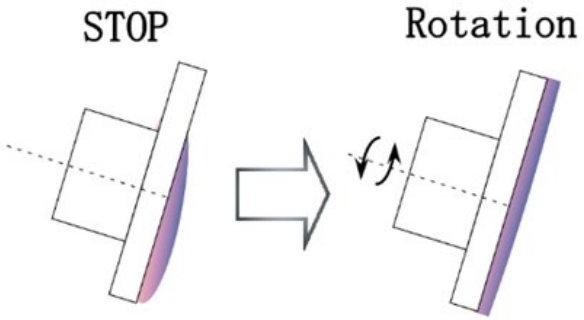


Cutter mark removal with alumina + Finishing with colloidal silica ⇒
Roughness < 0.2 nm (rms) in 24 hours

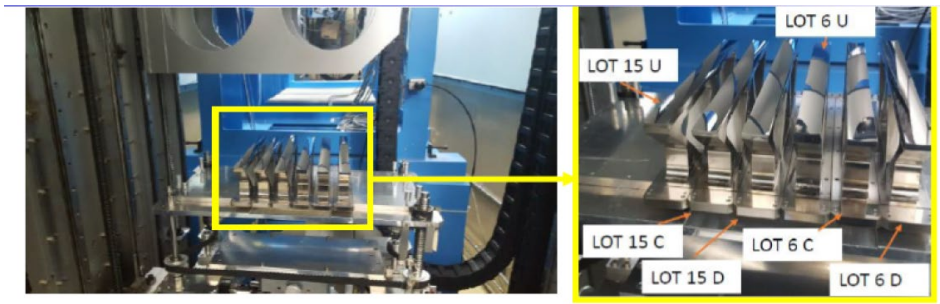
Supermirror ion beam sputtering deposition

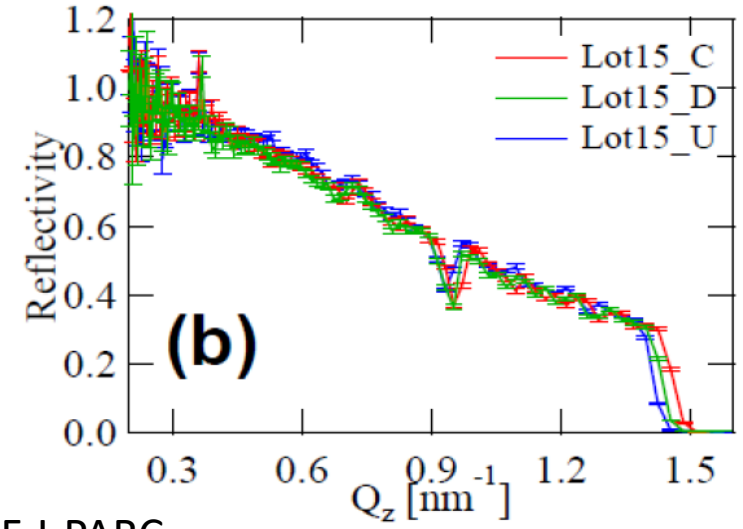
By courtesy of prof. Hino





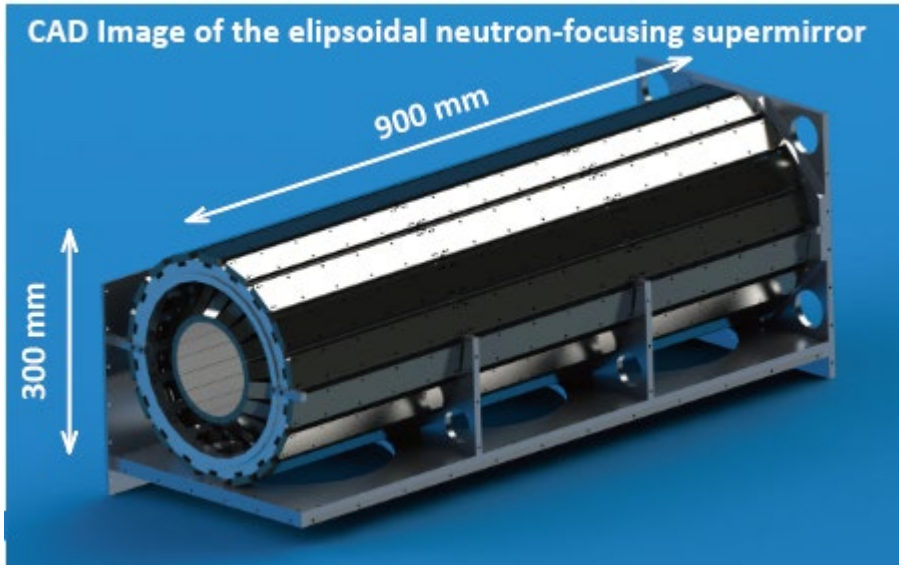
Rotating & tilting substrate ⇒
Uniform deposition in wide area

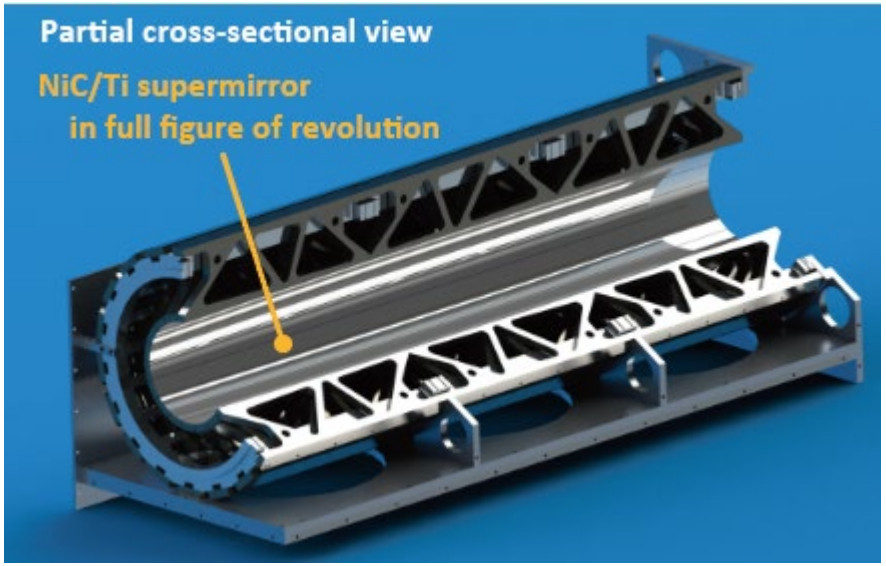




Reflectivity measurement of m=6.5 mirror at BL16 MLF J-PARC

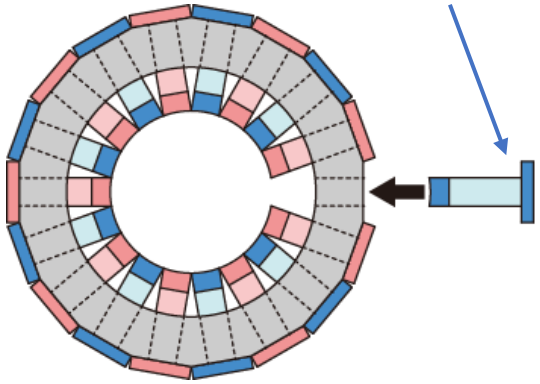
Cage-like assemble holder



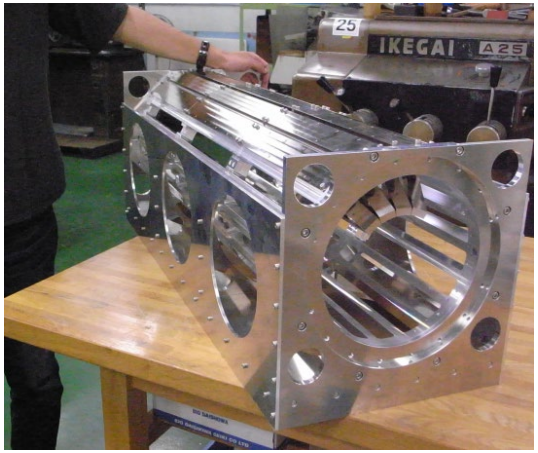


T. Hosobata et al., JPS Conf. Proc. (2018)

Datum plate in outer circumference



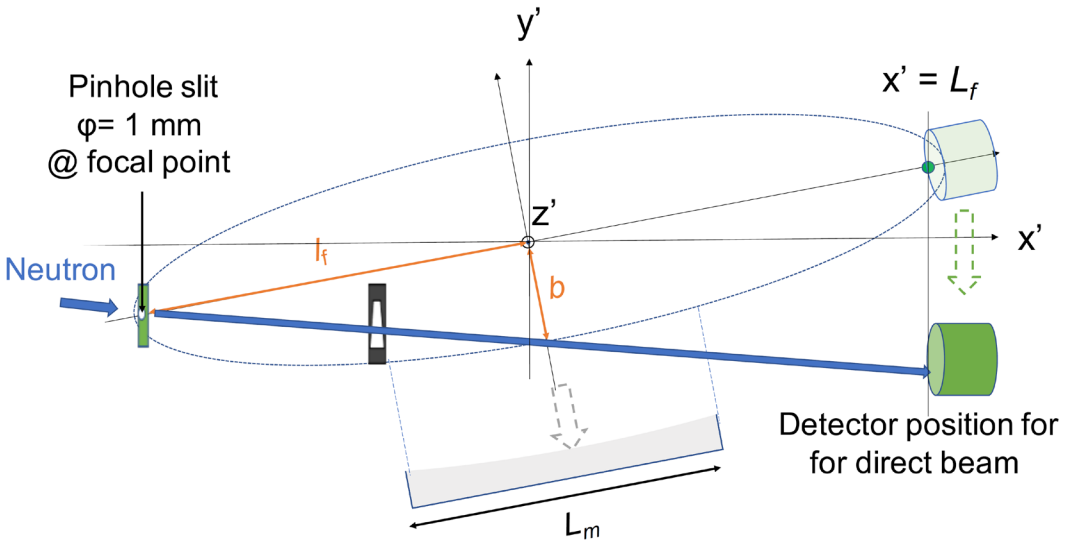
😊 Easy measurement
Mirror and datum plane are oriented in the same direction

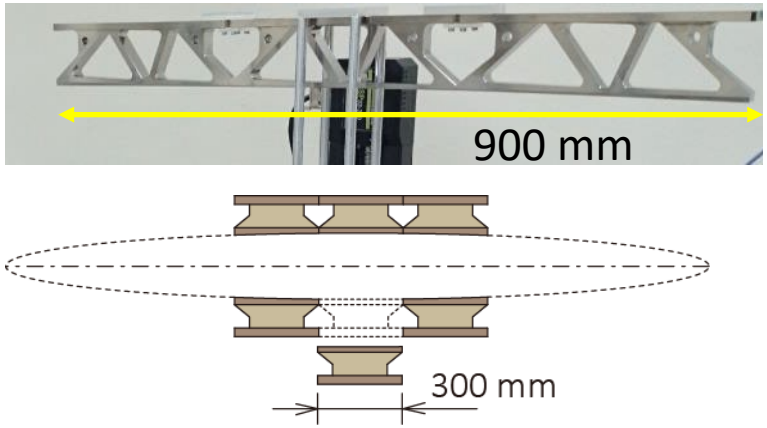


Metal substrate allows a flexible design

4. Performance test

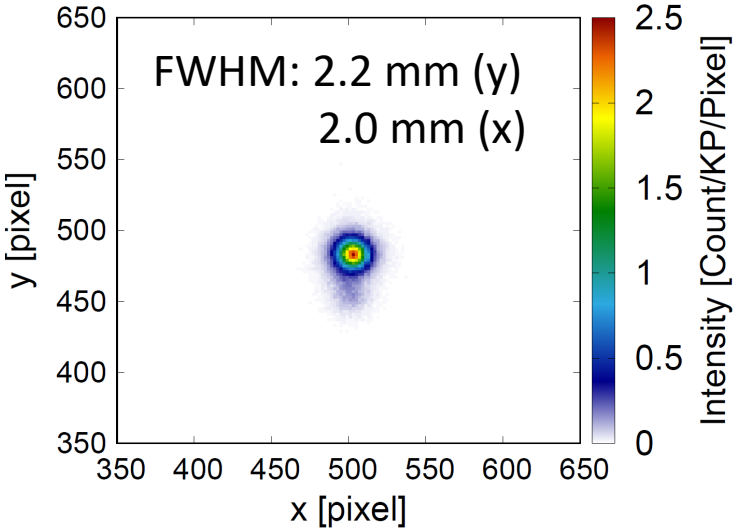
Performance test of single sector

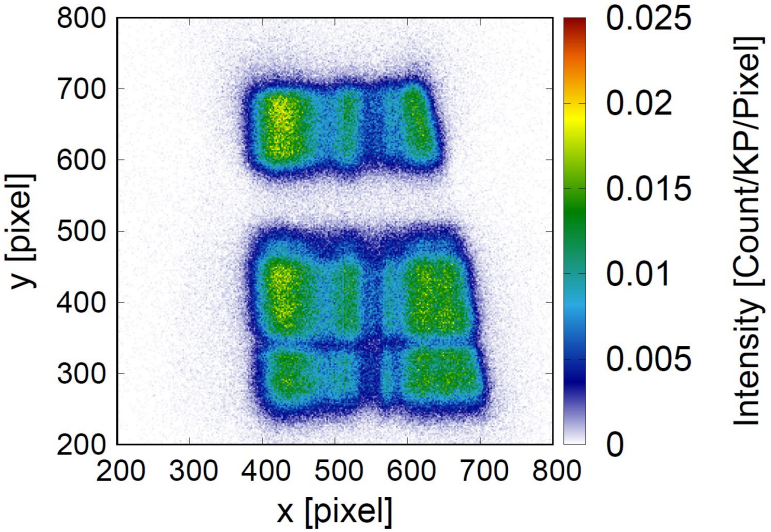




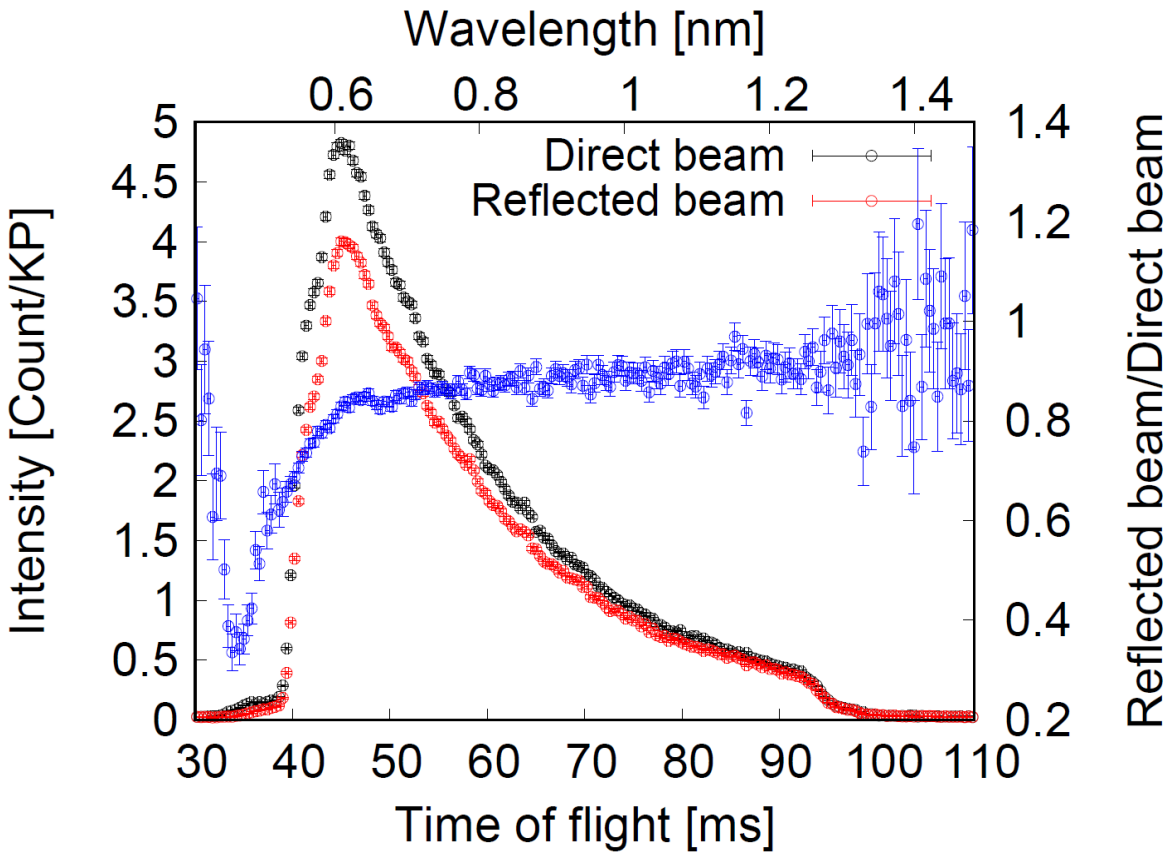
F. Funama, Doctor thesis, Kyoto University (2022)

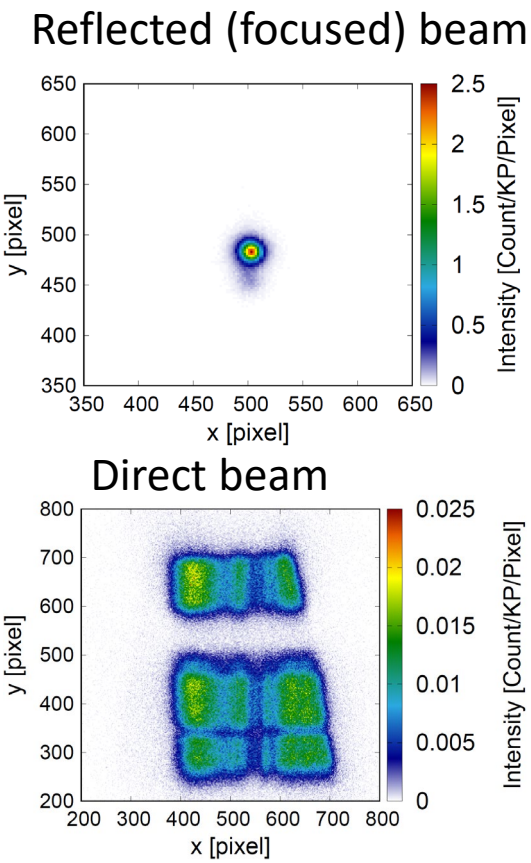
Reflected (focused) beam





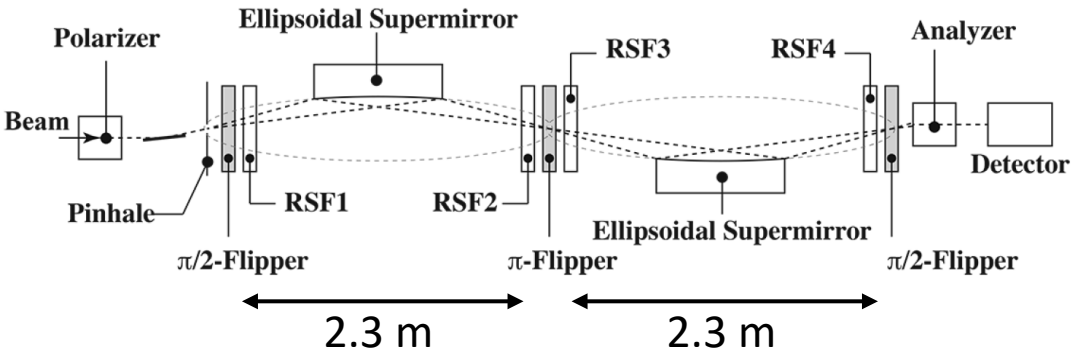
Performance test of single sector

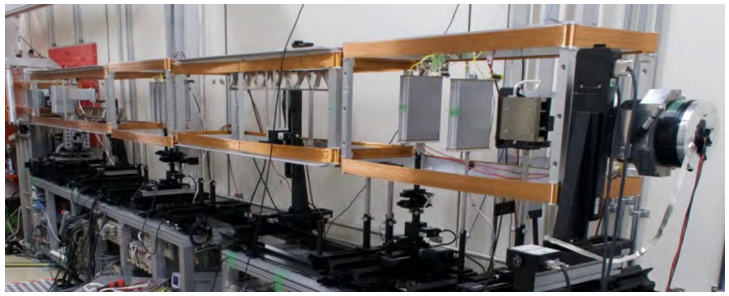




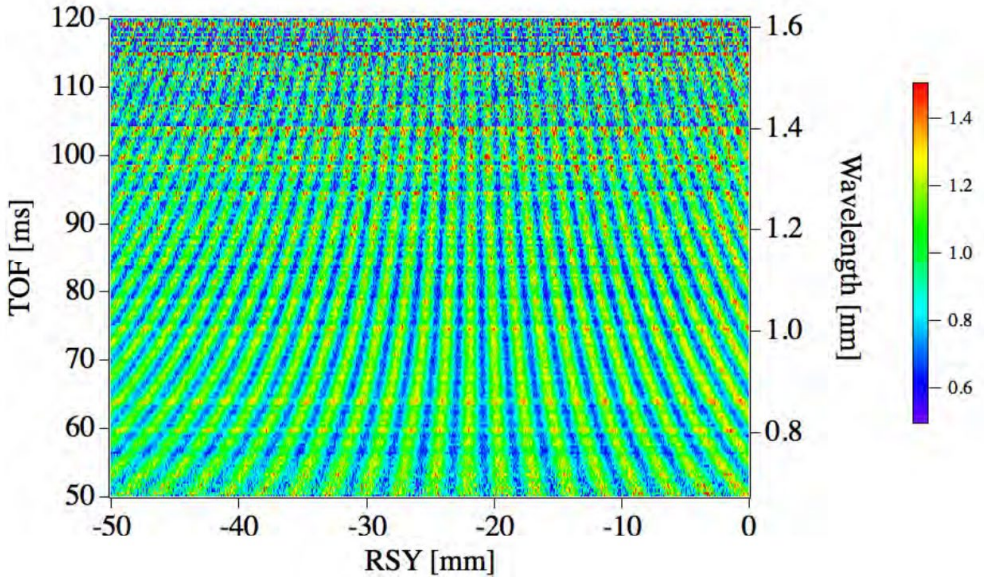
F. Funama, Doctor thesis, Kyoto University (2022)

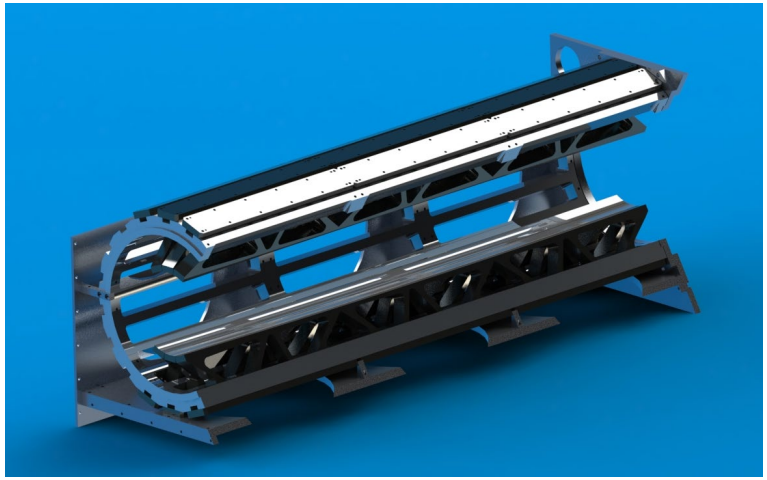
NRSE signal using sector mirrors





RSF1, 2, 3, 4 were operated at f = 100 kHz
The supermirrors m-value were m =5.

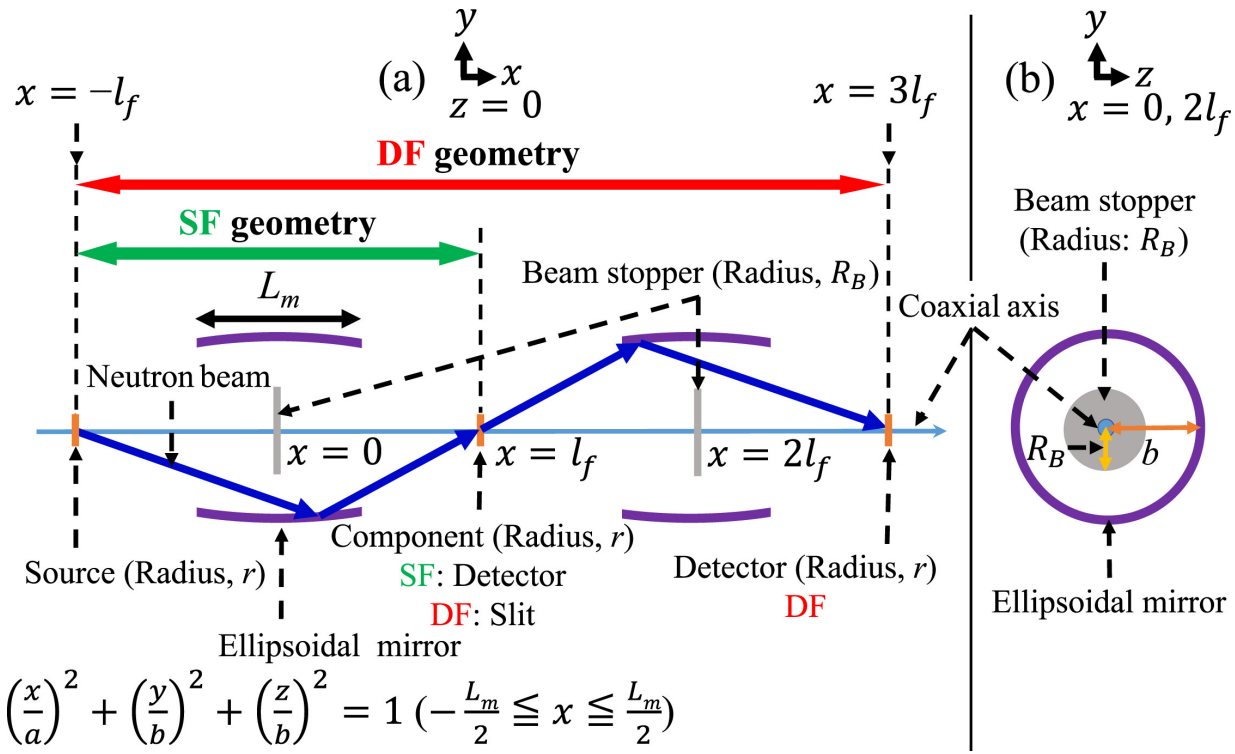


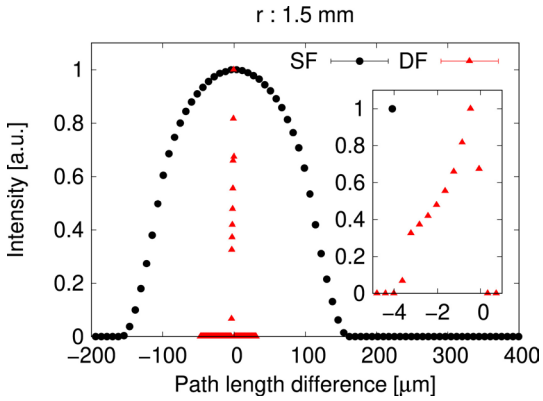


36 segments to be tested

H. Endo, et al., Physica B **564**, 91-93 (2019)

Simulation of double focusing for coma aberration correction



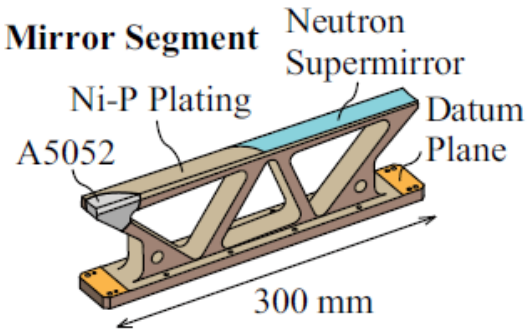


F. Funama, T. Tasaki M. Hino, T. Oda, H. Endo, Nucl. Instrum. Methods A, 1010 165480 (2021).

Two reflections with elliptical mirrors to eliminate coma aberration

Summary

- Ellipsoidal mirrors with *m*=6.5 supermirror on Ni-P plated metal substrate
- Segmental divided design for the deposition uniformity and machining space
- Design and basic performance test have been completed and mass production has begun



Most of the materials on the mirror fabrication are by courtesy of Dr. Hosobata at RIKEN.

Thank you for your attention