京大炉におけるビーム利用のための
次期中性子源検討2ワークショップ
140117@KUR

J-PARCにおける超高精度非球面スーパーミラーの開発

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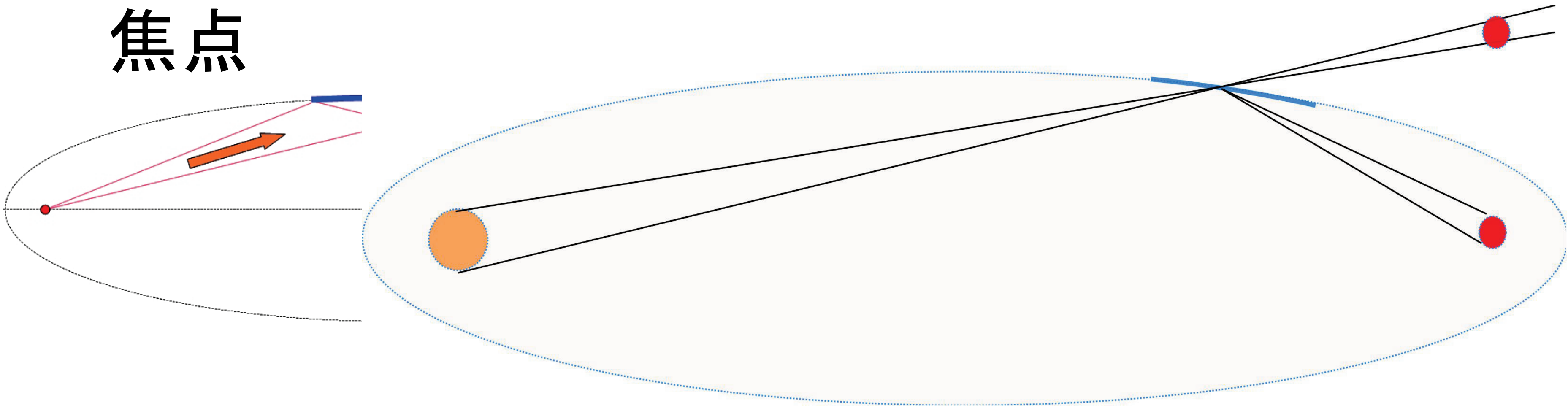
概要

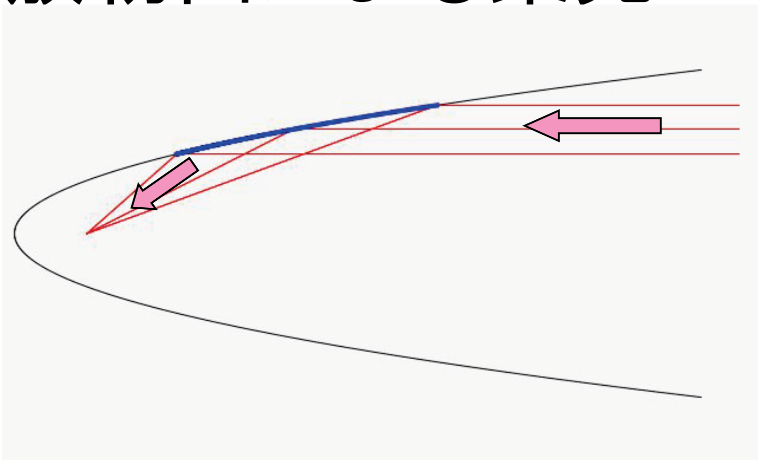
- 反射ミラー集光とその特徴
- 作成プロセス; Supermirror, NC- LWE
- １次元集光スーパーミラーの開発
- スタック用の薄い集光スーパーミラー
- Kirkpatrick-Baez 配置での２次元集光試験n
- 適用例

非球面ミラーによる中性子集光

- 楕円による集光：　焦点からの発散ビーム→焦点



- 放物面による集光：　平行ビーム→焦点

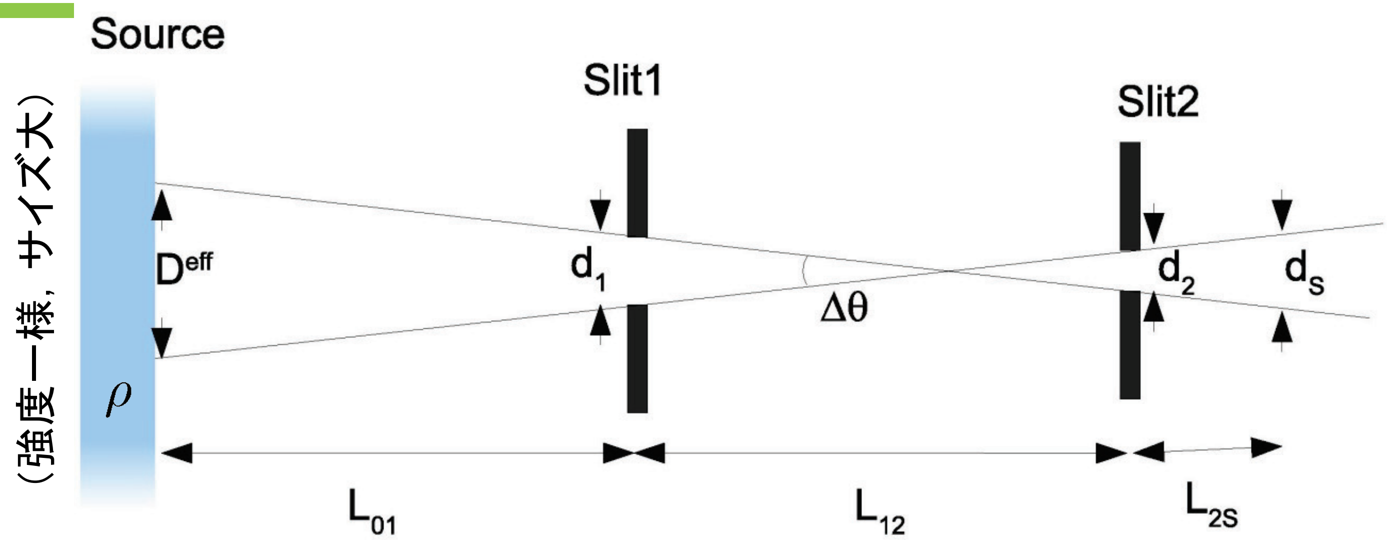


- 焦点＝検出器面
  - **小角散乱，斜入射小角散乱**
- 焦点＝試料位置
  - **微小試料，試料内微小領域の観測**

反射型微小ビーム集光の特徴

- 離れた位置から白色ビームを集光できる.
  - 集光位置手前に物を置けない系.
  - 試料環境がある場合．小角散乱など.
- スリット・コリメーションに比べて発散角を稼げる.
  - 強度増
- 集光サイズの外では強度が桁落ちする.
  - 照射したい所にだけ当てる．バックグラウンド低減. コマ収差.
- 集光位置直前にピンホールを置けるなら不要
  - 集光型ガイド管＋試料直前ピンホールがよい.
- 反射によりビーム方向が変わる
  - 建設済みのビームラインへの導入は簡単ではない.

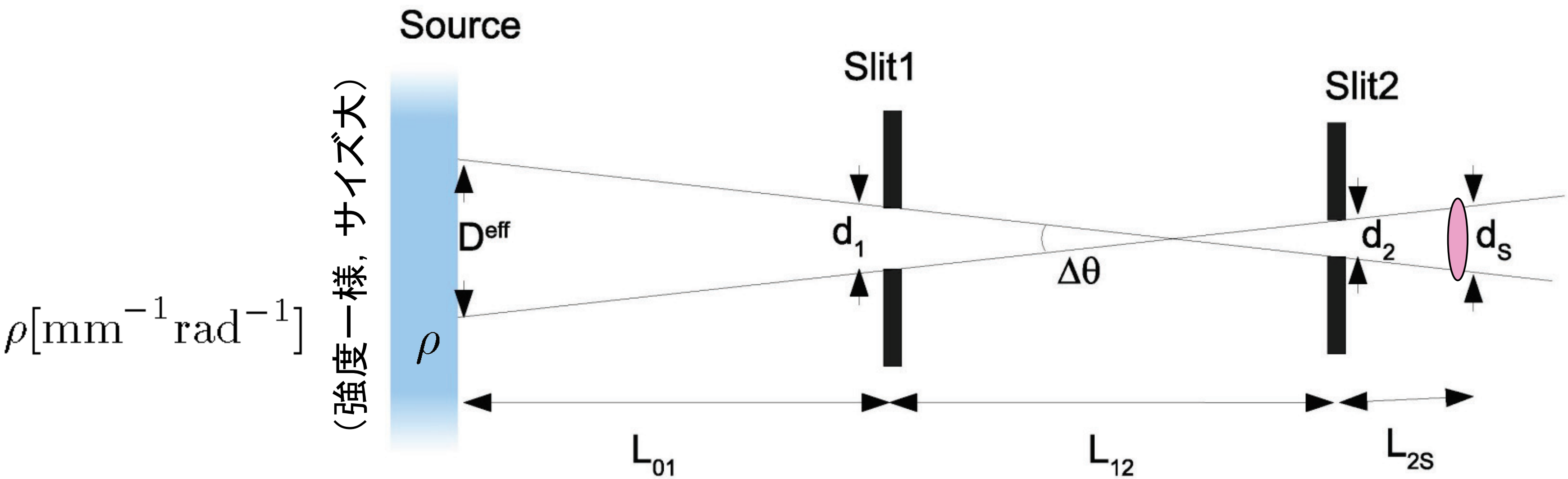
スリットによるコリメーション



$\rho[\mathrm{mm}^{-1}\mathrm{rad}^{-1}]$

- スリット設定とビーム強度，発散角．
  - ビーム強度はスリット幅の積で決まる $I = \dfrac{d_1 d_2}{L_{12}}\rho$ （1次元的強度）
  - 発散角は $\Delta\theta = \dfrac{d_1 + d_2}{L_{12}}$ $\quad I = -d_1(d_1 - L_{12}\Delta\theta)\rho/L_{12}$
  - 発散角を固定すると $d_1 = d_2 = L_{12}\Delta\theta/2$ で強度が極大．
  - 試料位置でのビームサイズ $d_s = \dfrac{L_{2S}}{L_{12}}d_1 + \dfrac{L_{12}+L_{2S}}{L_{12}}d_2$

スリットによるコリメーション



- 試料サイズ d_s に合わせてスリットを絞る.
  - ds によって最適な発散角，スリット設定が決まる.

$$\Delta\theta \equiv \frac{d_1 + d_2}{L_{12}} \rightarrow \frac{(L_{12} + 2L_{2S})d_S}{2L_{2S}(L_{12} + L_{2S})}$$

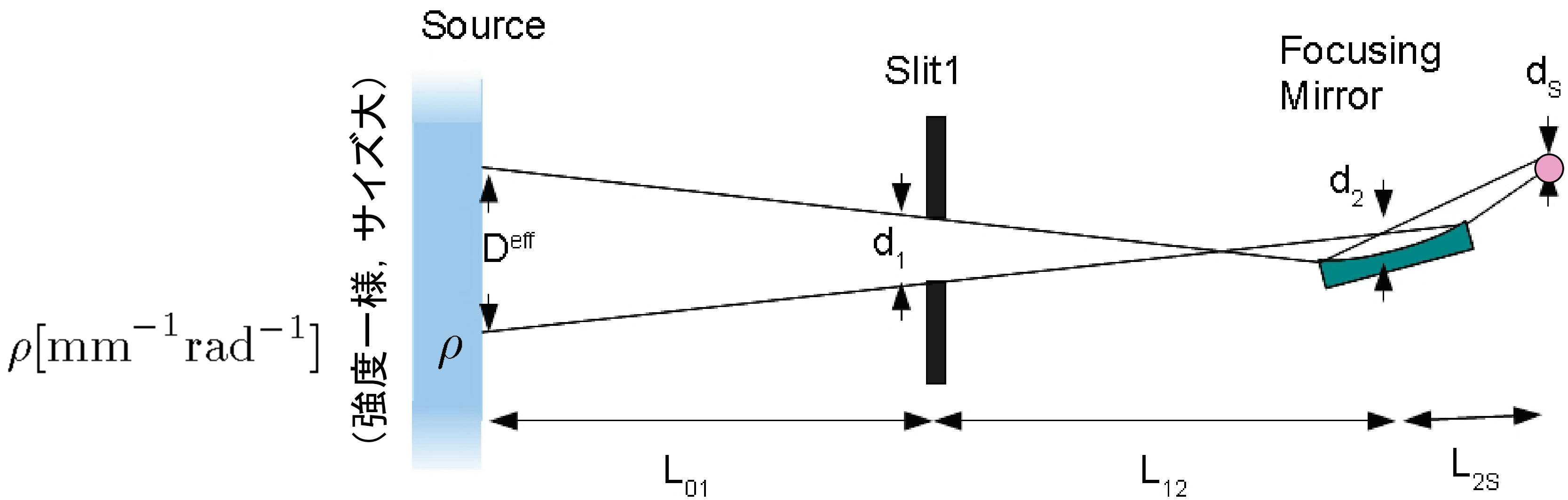
$$d_1 = \frac{L_{12}}{2L_{2S}} d_S$$

$$d_2 = \frac{L_{12}}{2(L_{12} + L_{2S})} d_S$$

  - 試料位置のビーム強度（1次元）

$$I = Ad_s^2 < \frac{d_S^2}{2L_{2S}}\rho \qquad A = \frac{L_{12}}{2L_{2S}(L_{12} + L_{2S})}\rho$$

ミラーによる集光の場合



集光ミラー系

– d1, d2はスリットコリメーションよりもずっと大きく取れる.

$$d_1 = \frac{L_{12}}{L_{2S}} d_S \qquad d_2 = L_{\mathrm{mirror}} \sin\theta \ (\gg d_1)$$

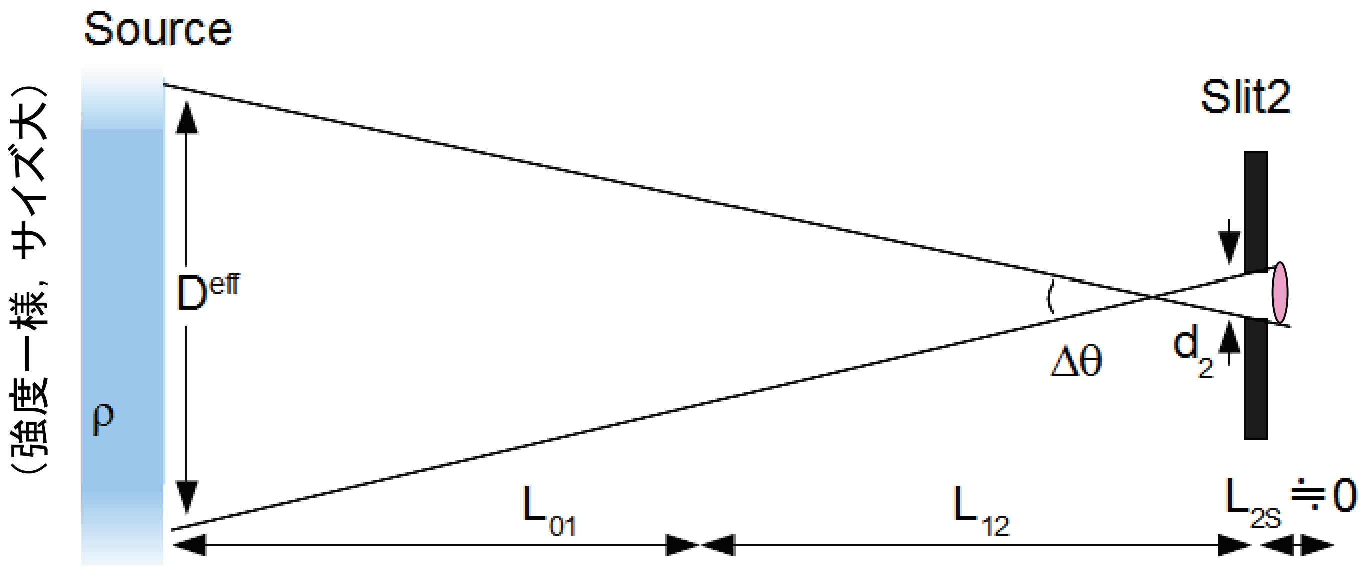
– 試料位置の強度(1次元)

$$I = \frac{d_1 d_2}{L_{12}} \rho \times R = \frac{d_s L_{\mathrm{mirror}} \sin\theta}{L_{2S}} \rho R$$

発散角

$$\Delta\theta = \frac{d_2 + d_S}{L_{2S}}$$

直前スリットによるコリメーション



集光ミラー系

- ソース全体を見込む発散角が取れる.

$$\Delta\theta = \frac{D^{\mathrm{eff}} + d_2}{L_{01} + L_{12}}$$

- Slitの後ろでは急激にビームサイズが広がる.

$$d_s = L_{2S}\Delta\theta + d_2$$

- Slit直後に集光するなら，集光ミラー不要．集光ガイド管の併用が吉.

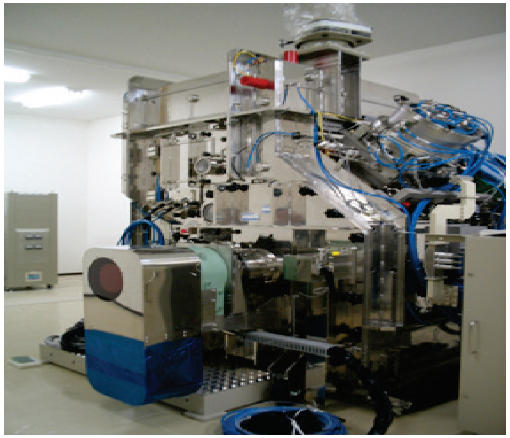
微小点集光ミラーが使えるとき

- 微小スポット以外にビームを当てたくないとき.
- 集光位置の直前にスリット等を置けないとき.
- ビームラインが変わってもよいとき.
- 白色ビームを集光したいとき

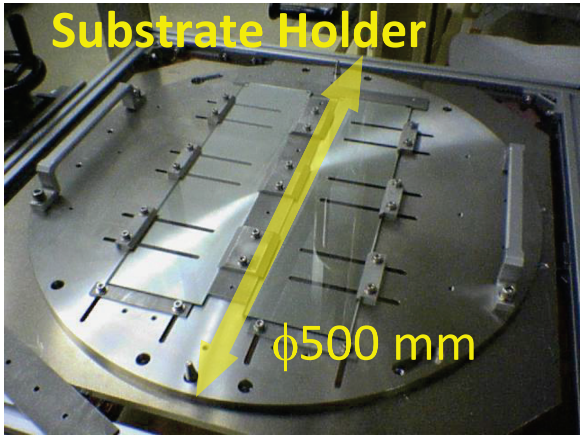
High-Performance Supermirror at J-PARC

J-PARC/MLF

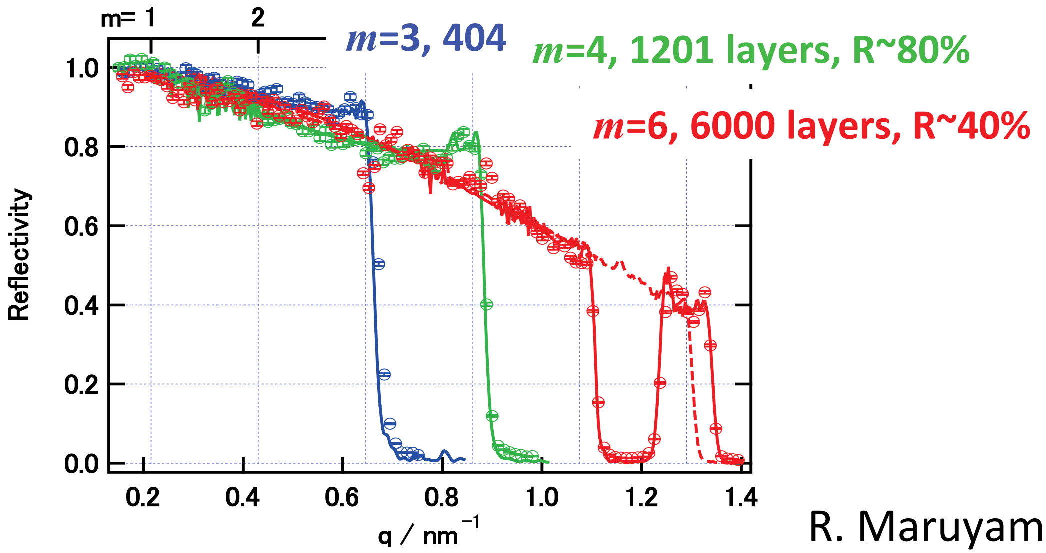
Ion Beam Sputtering Machine



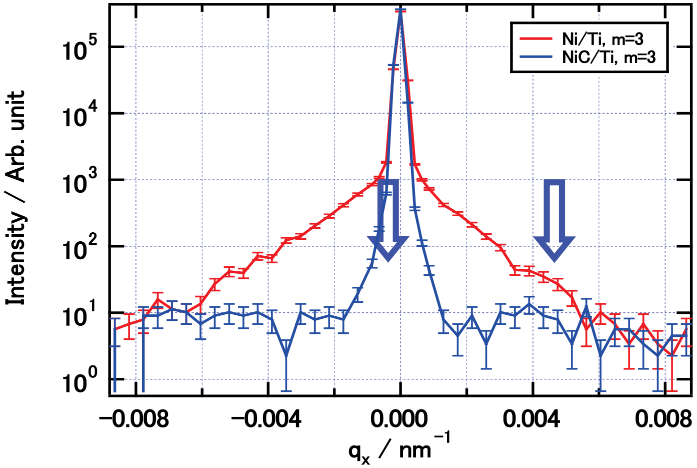
Large Sputering Area



High Qc and High Reflectivity



Reduction of diffuse scattering



R. Maruyama et al., Thin Solid Films 515 (2007) 5704.

Focusing supermirror development

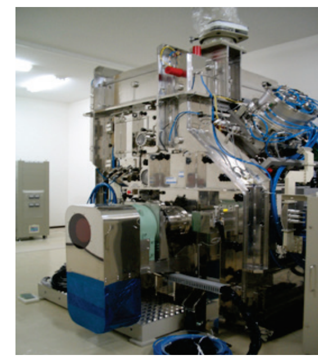
Osaka University

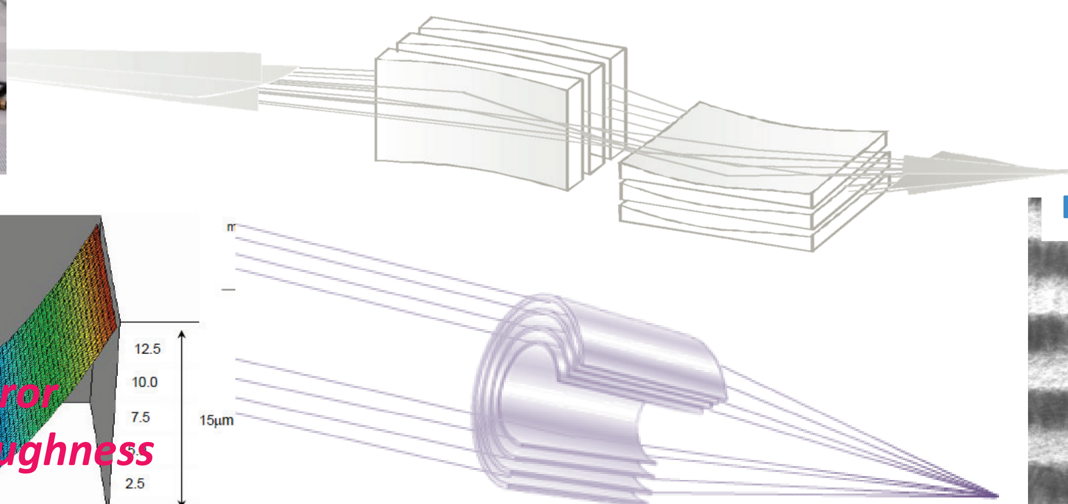
Ultraprecise Aspheric Surfaces by NC-Local Wet Etching

J-PARC/MLF

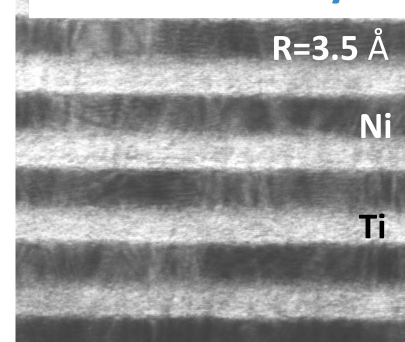
High Performance Supermirrors by ion beam sputtering

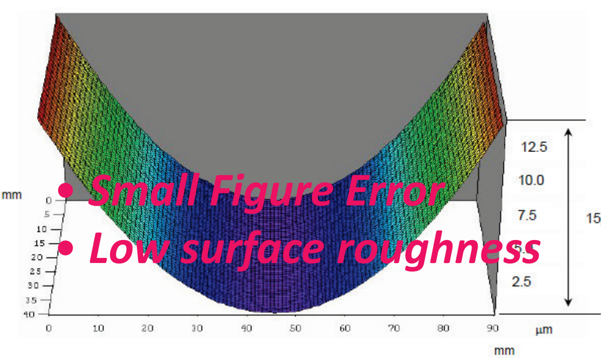
High performance Focusing supermirror





m=6.7 8000layers





- *Small Figure Error*
- *Low surface roughness*

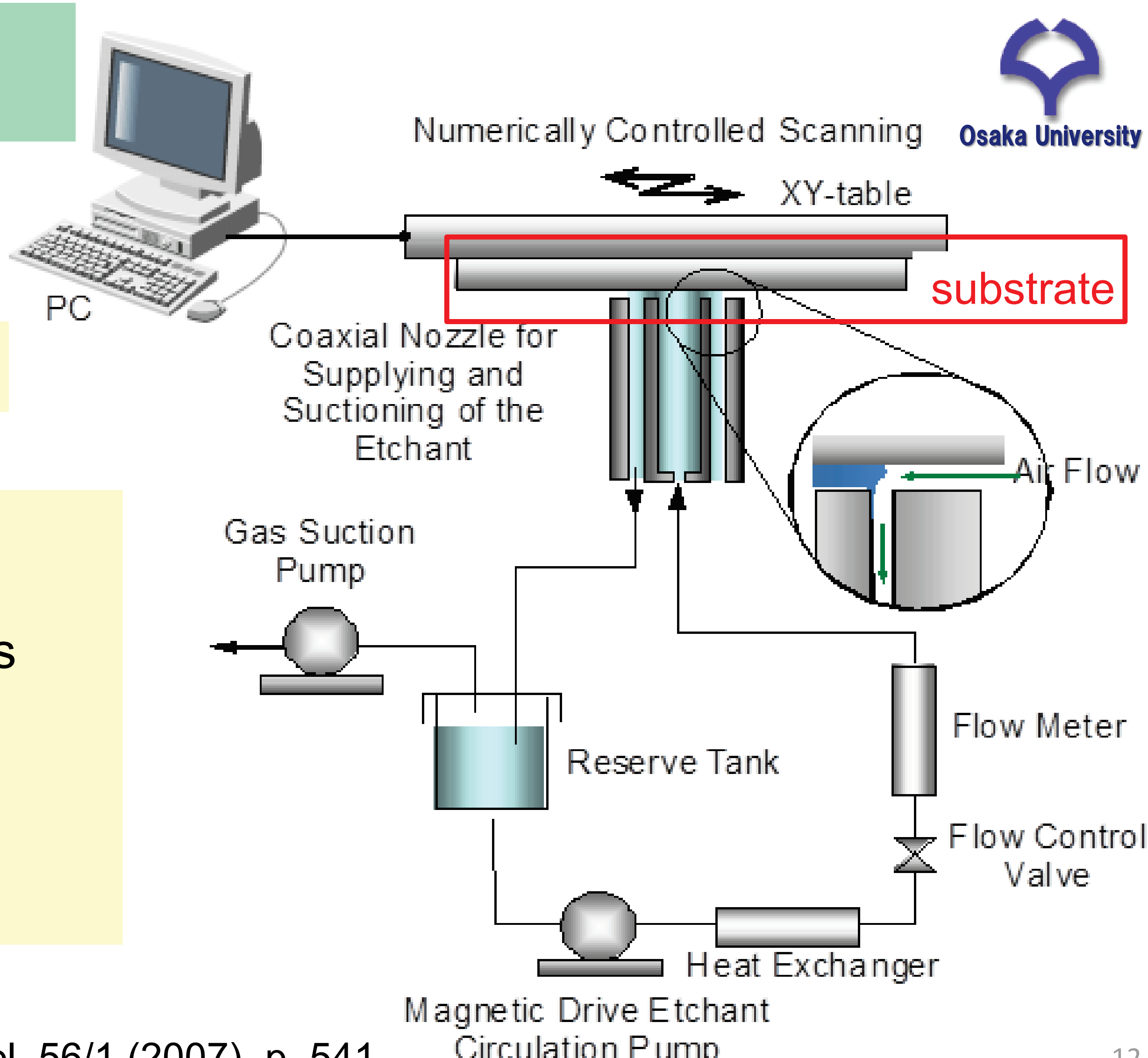
加工後形状 (評価領域90mm×40mm)

Numerically Controlled Local-Wet-Etching (NC-LWE)

Ultraprecise figuring of a surface of quartz substrate

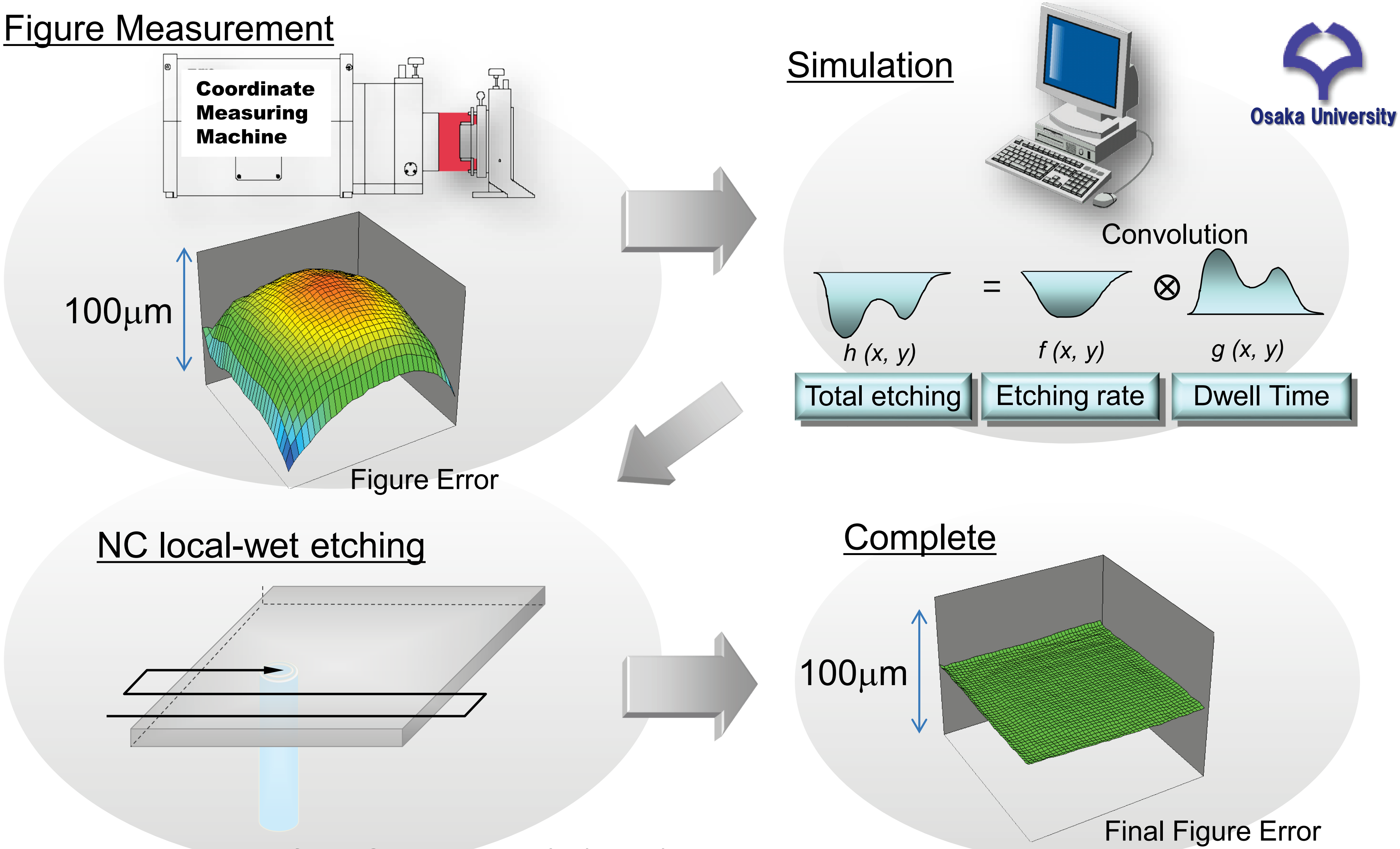
Etchant = HF acid

- Non-Contact process
- Purely chemical process
  ↓
- Stable process
- No mechanical damage



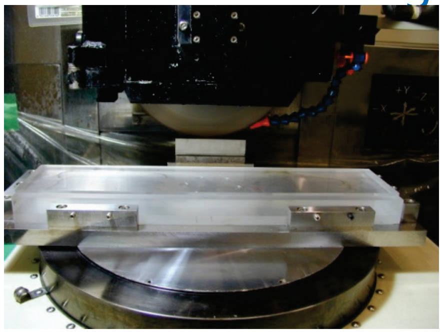
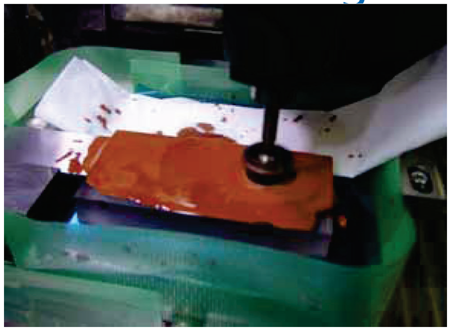
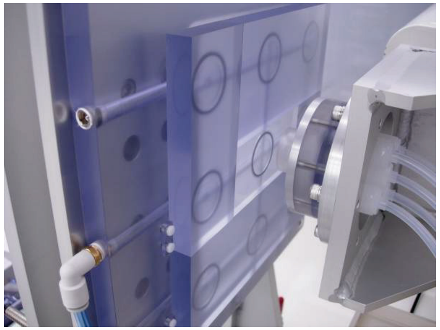
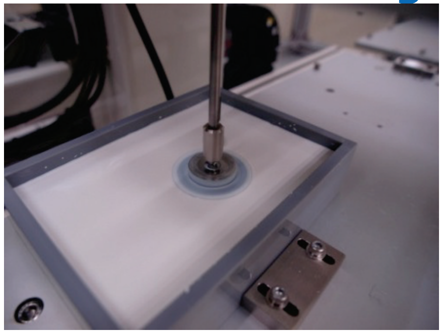
K. Yamamura: Ann. of the CIRP Vol. 56/1 (2007), p. 541

Process of NC Local-Wet-Etching



K. Yamamura: Ann. of the CIRP Vol. 56/1 (2007), p. 541

High-Precision Aspheric Supermirror

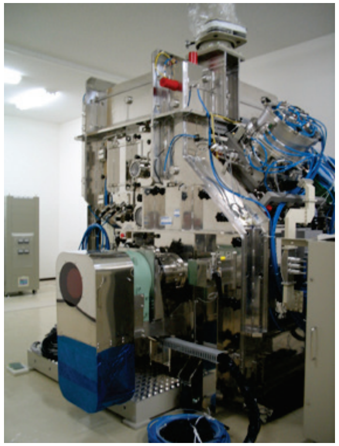
Precision Grinding	1st Polishing	NC-LWE	2nd&3rd Polishing
			

[The Purpose of Each Process]

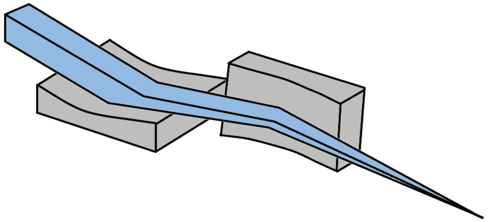
Micrometric level figuring in short time	Removal of subsurface damage	Sub-micrometric level deterministic figuring	Removal of tool-mark & MSFR

Ion Beam Sputtering

Deposition of NiC/Ti multilayer



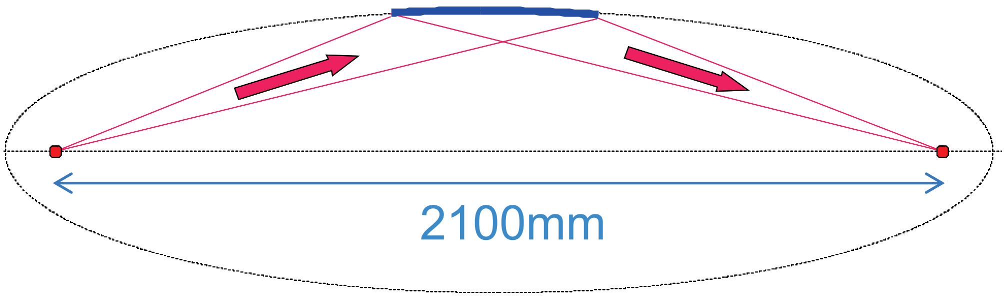
Aspherical Supermirror

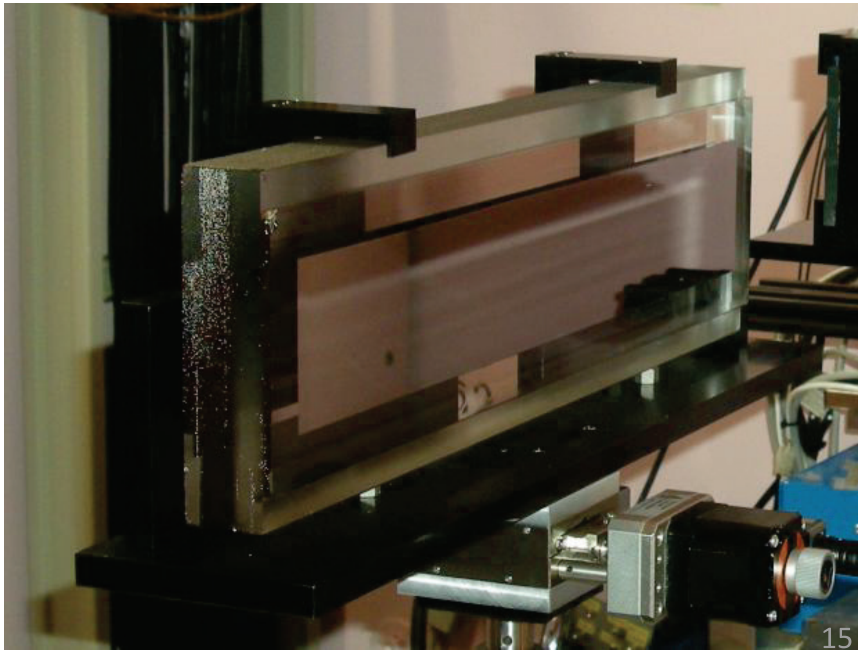


high precision & high efficiency

1-dimensional focusing supermirror

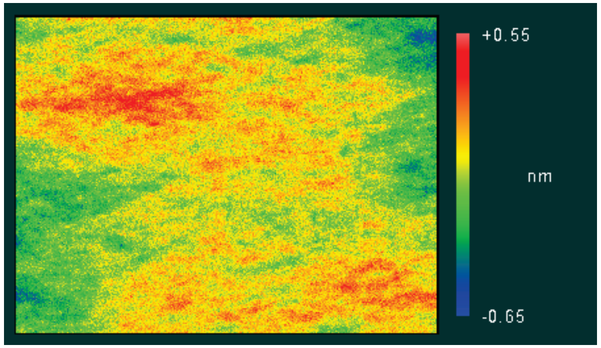
- 400mm L (elliptical) x 100mm H x 35mm T
- NiC/Ti Supermirror m=4
  - Focal Lengths : 2100 mm = 1050mm + 1050mm
  - Incident angle 1.40 deg
  - $\lambda > 3.5$ Å
  - Beam acceptance ~10mm
  - Beam divergence ~0.53deg



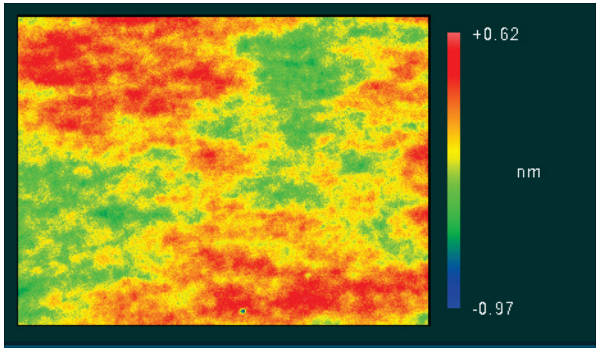


Surface Roughness and Figure Errors

Surface Roughness



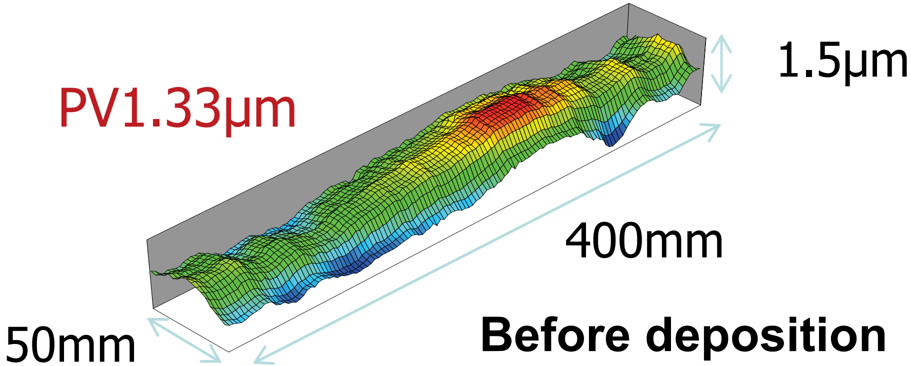
Before Deposition 0.151nm rms

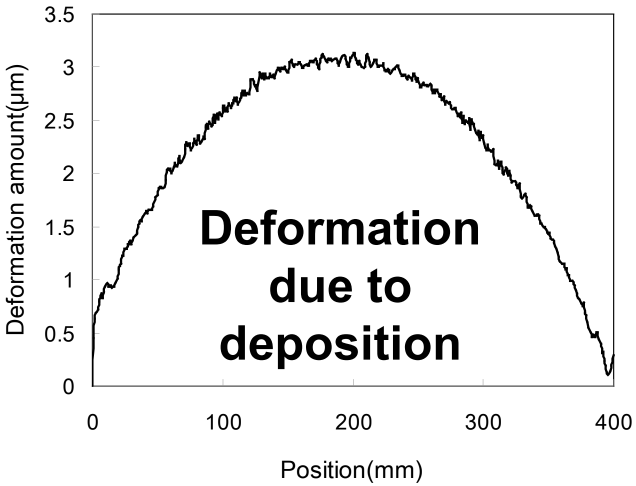


After Deposition 0.202nm rms

(64 × 48μm^2)

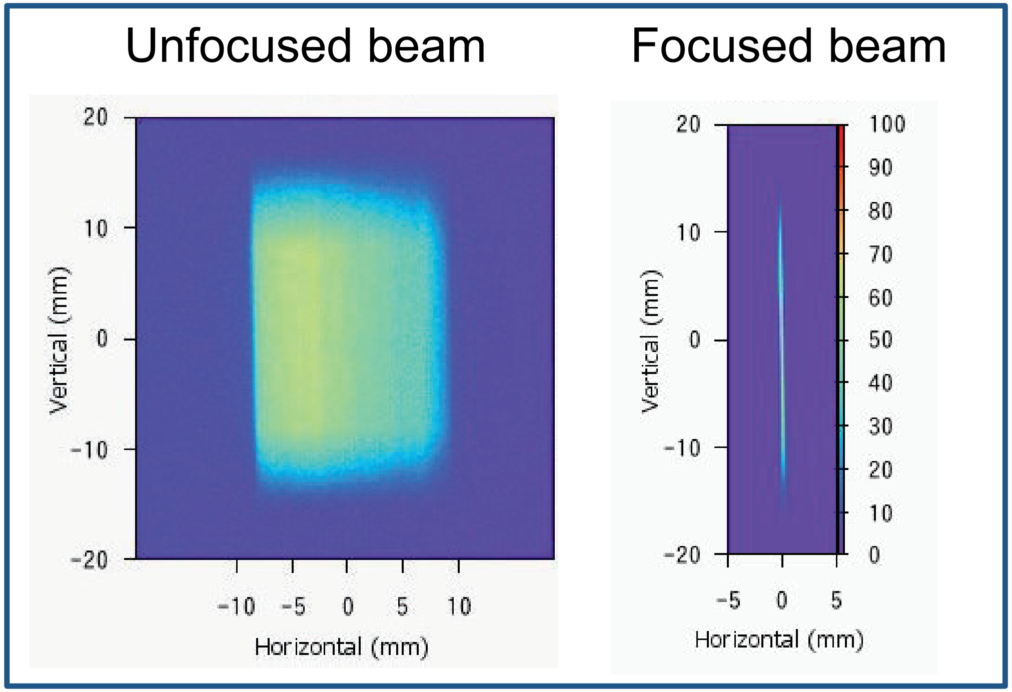
Figure-Error

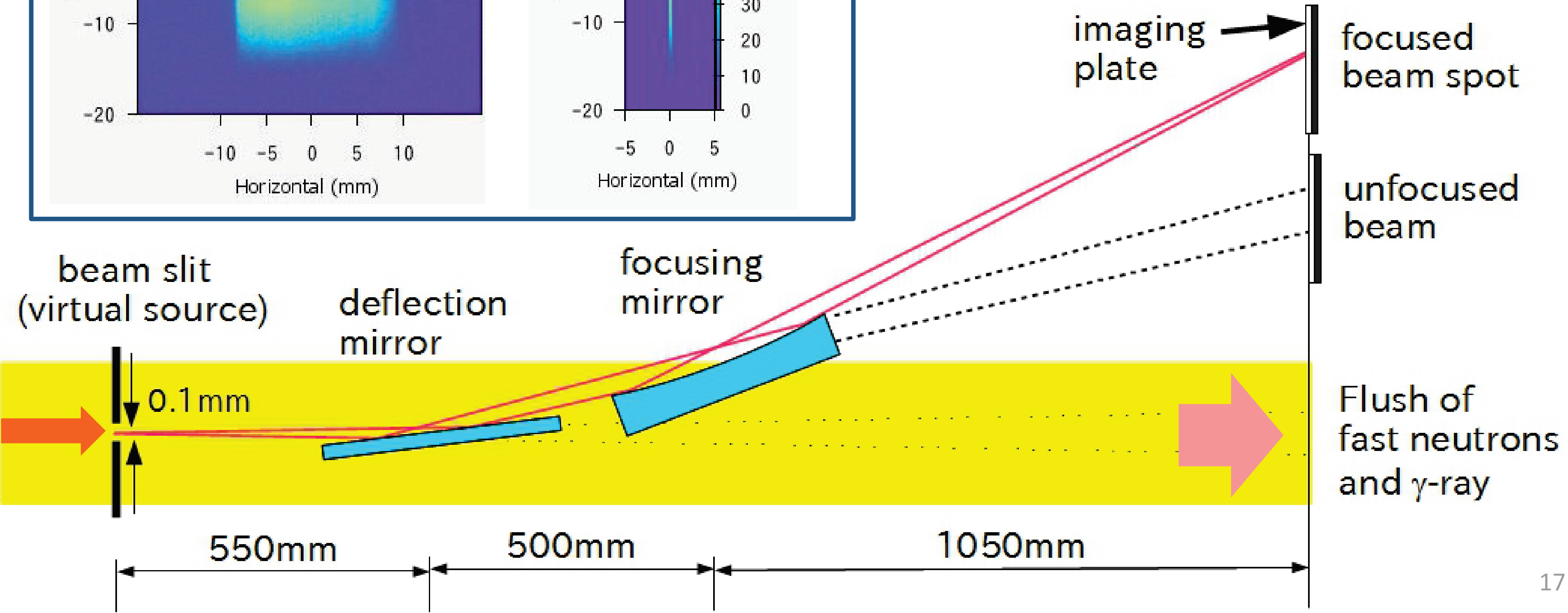




M. Nagano et al., J. Phys.: Conf. Ser. 340 (2012) 012034.

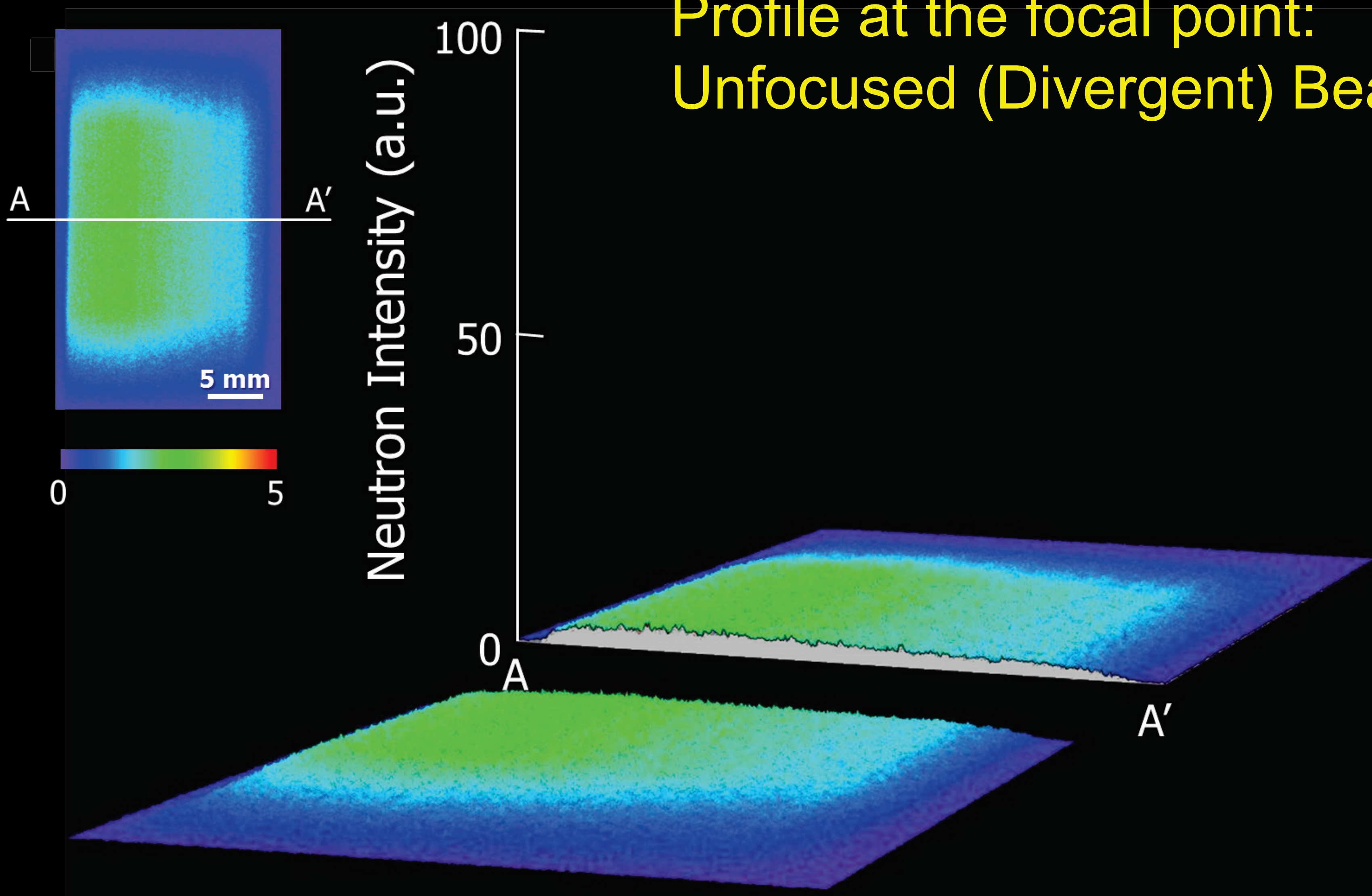
Focusing Experiment with Pulsed Neutrons



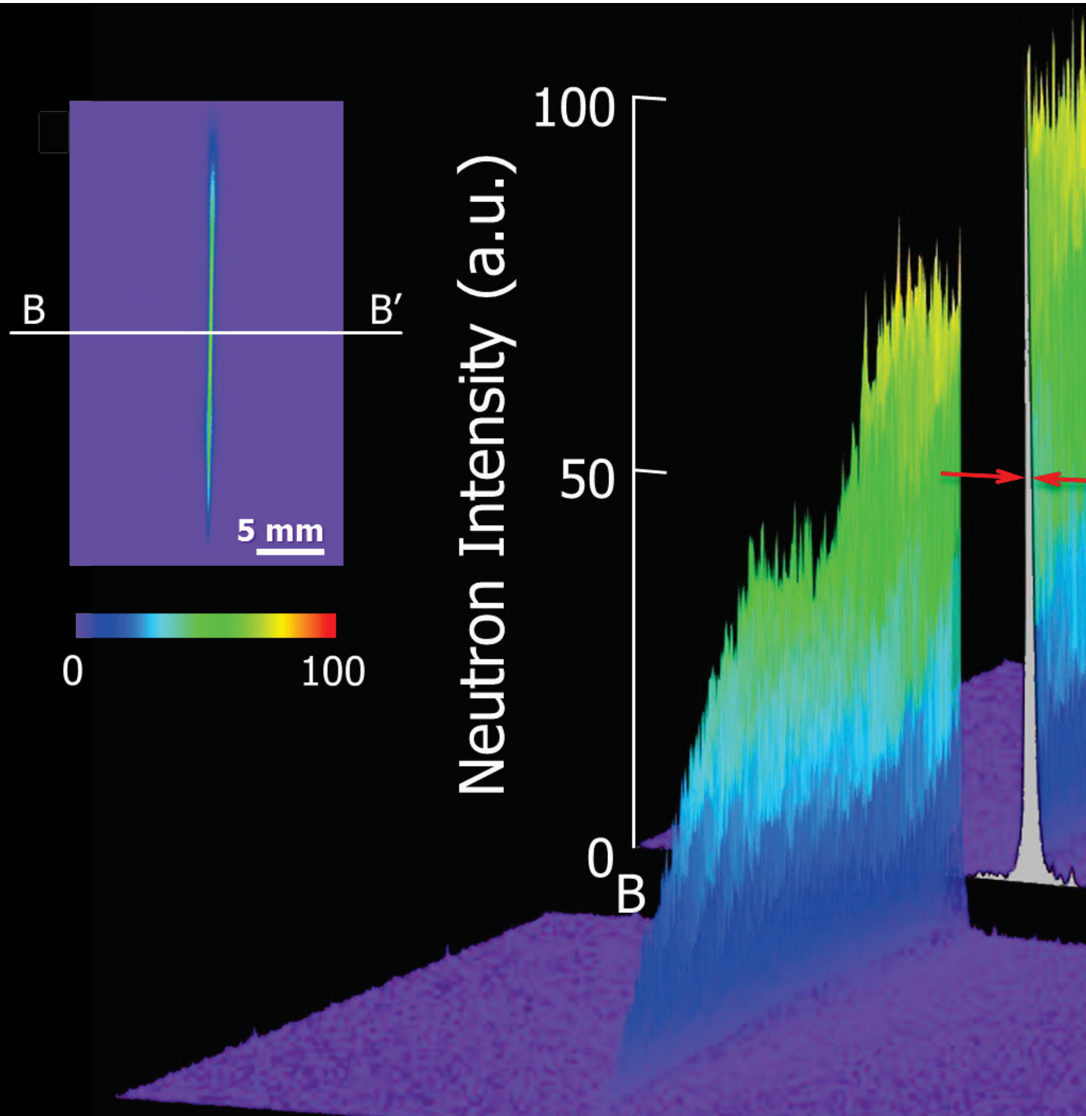


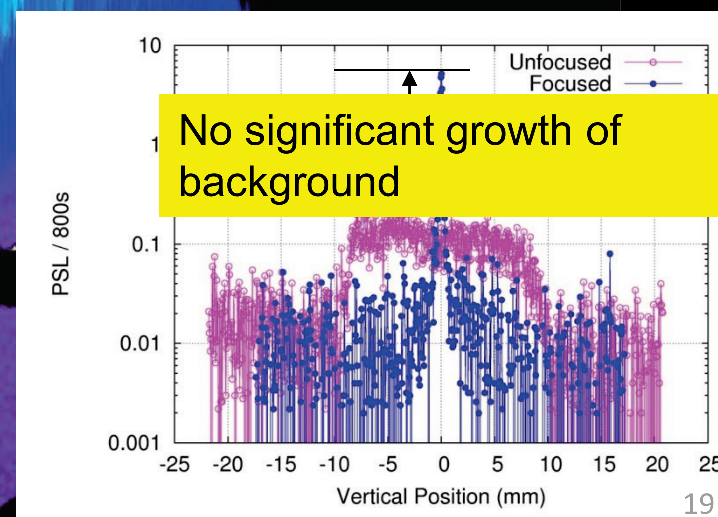
Focusing Experiment with Pulsed Neutrons
- Spatial beam profile

Profile at the focal point:
Unfocused (Divergent) Beam



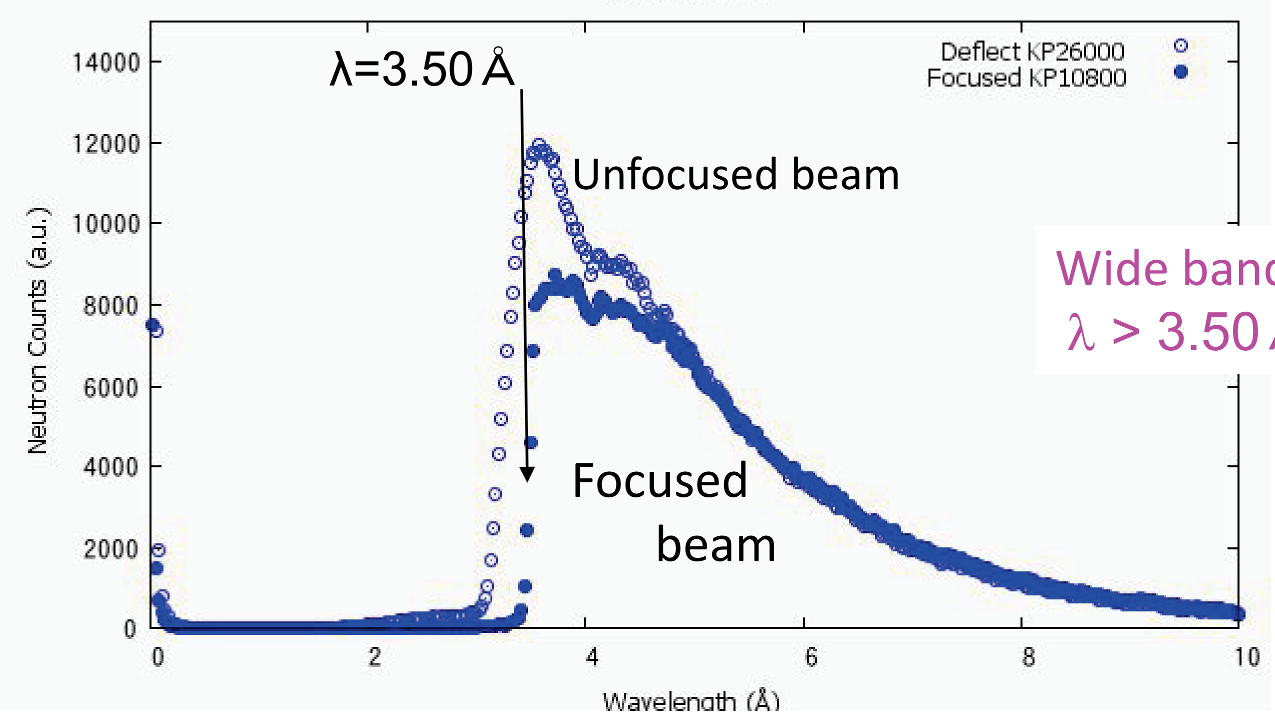
Focusing Experiment with Pulsed Neutrons
- Spatial beam profile





M. Nagano et al., J. Phys.: Conf. Ser. 340 (2012) 012034.

Focusing Experiment with Pulsed Neutrons
- Wavelength distribution

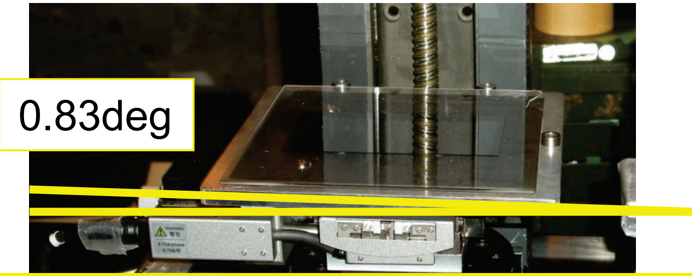


Wide band neutrons
λ > 3.50 Å were focused.

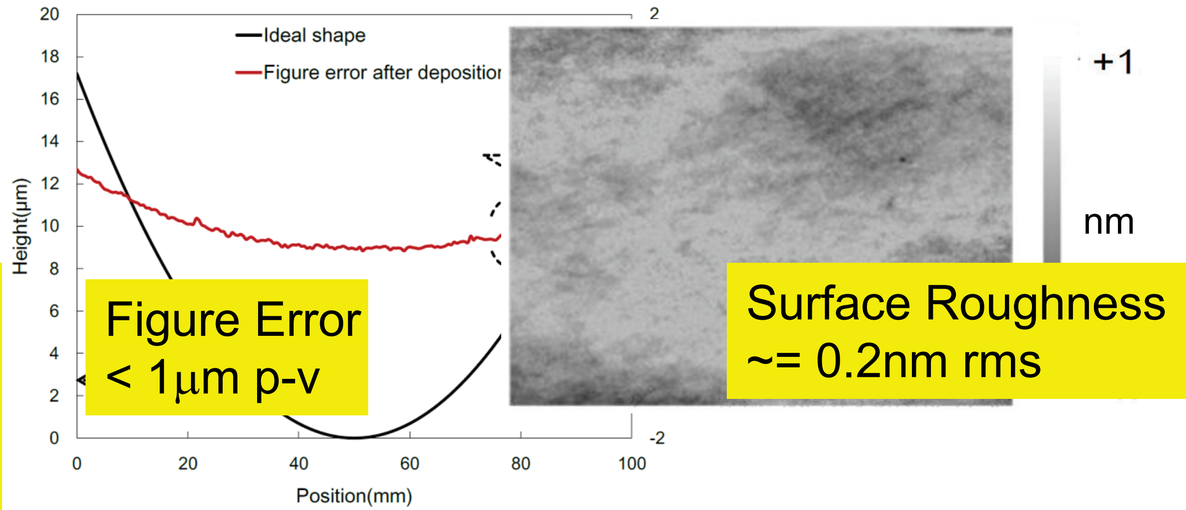
Summary on focusing experiment:

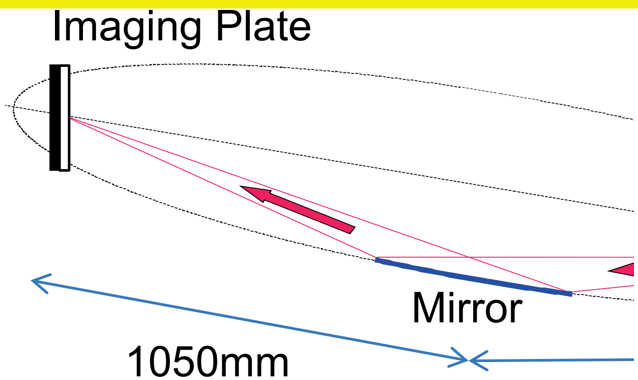
- 1 dimensional beam focusing into < 0.15mm
- intensity gain 52 at focused peak
- wideband focusing λ>3.5 Å
- No significant growth of background due to the mirror

Thin focusing mirrors for stacking

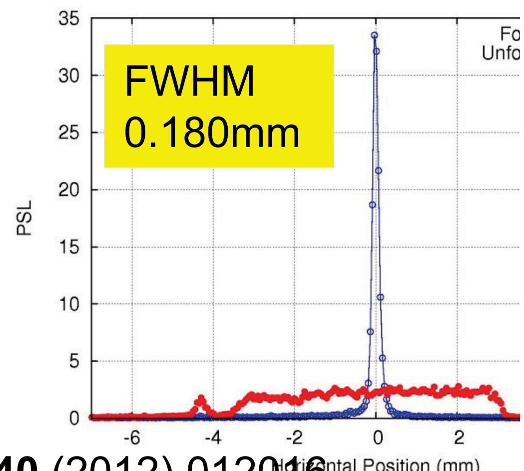


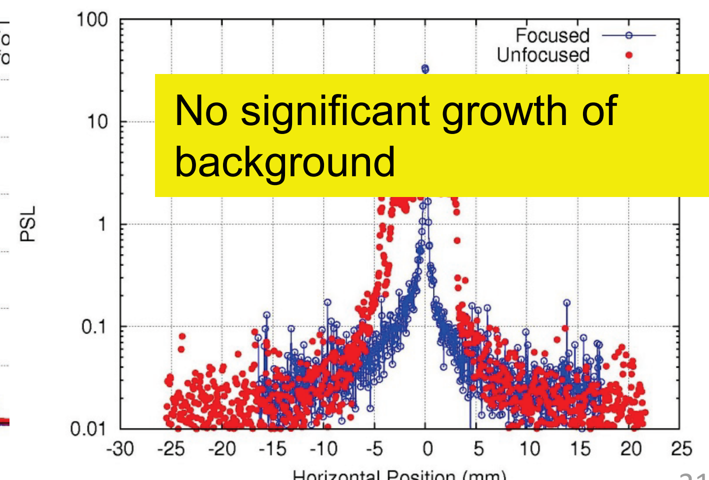
- Quartz substrate: 150x150x1.5mm
- 1-dimensionally elliptical shape
- NiC/Ti supermirror (m=3) deposited over 110 x 60 mm^2
- Vertical focuisng





1 dimensional profiles obtained with an Imaging Plate



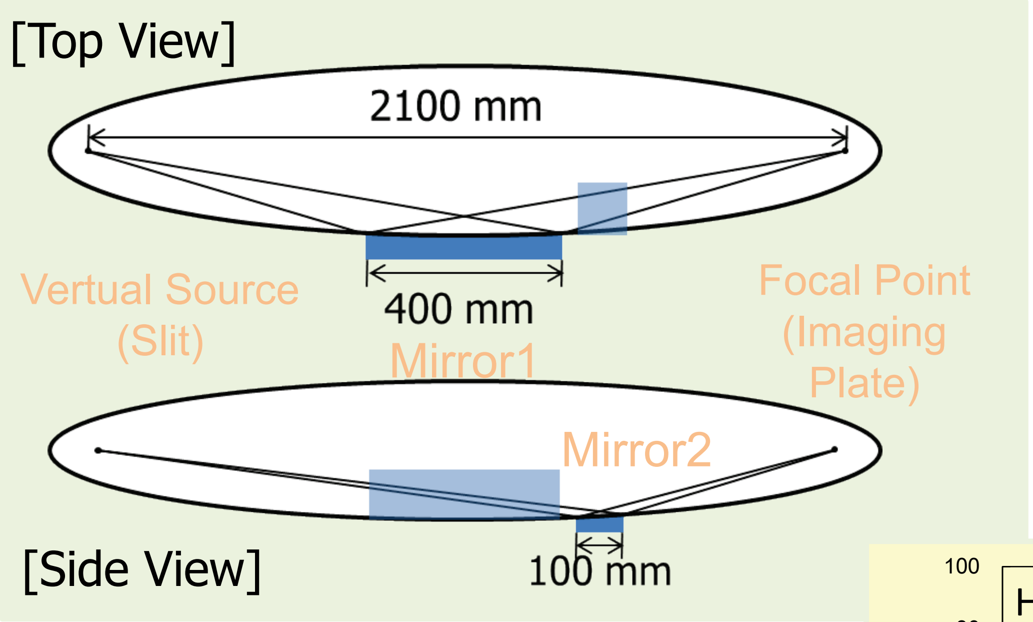


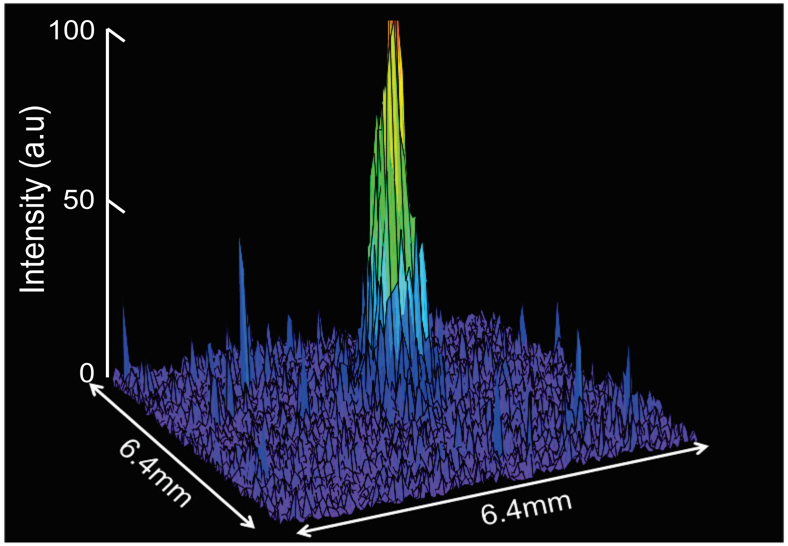
Nagano et al, J. Phys. Conf. Ser **340** (2012) 012016

2-dimensional beam focusing

J-PARC/MLF

Kirkpatrick-Baez (KB) Configuration

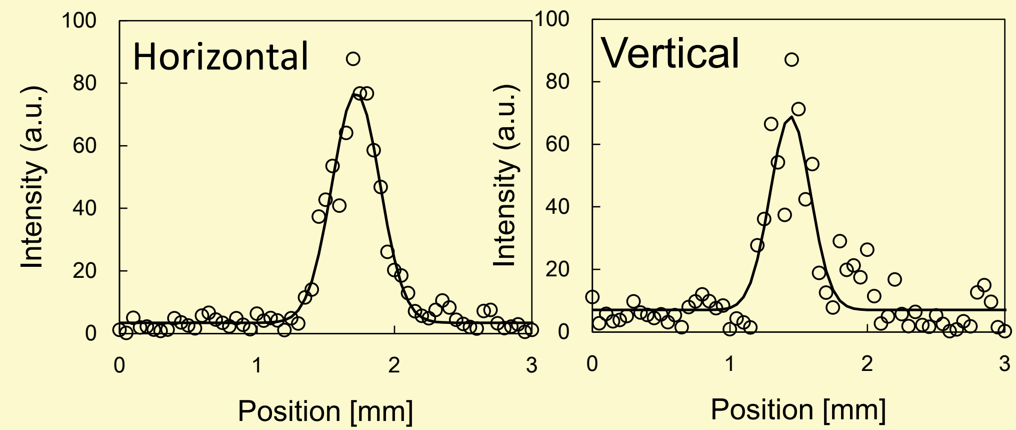




Profile of Focused Beam

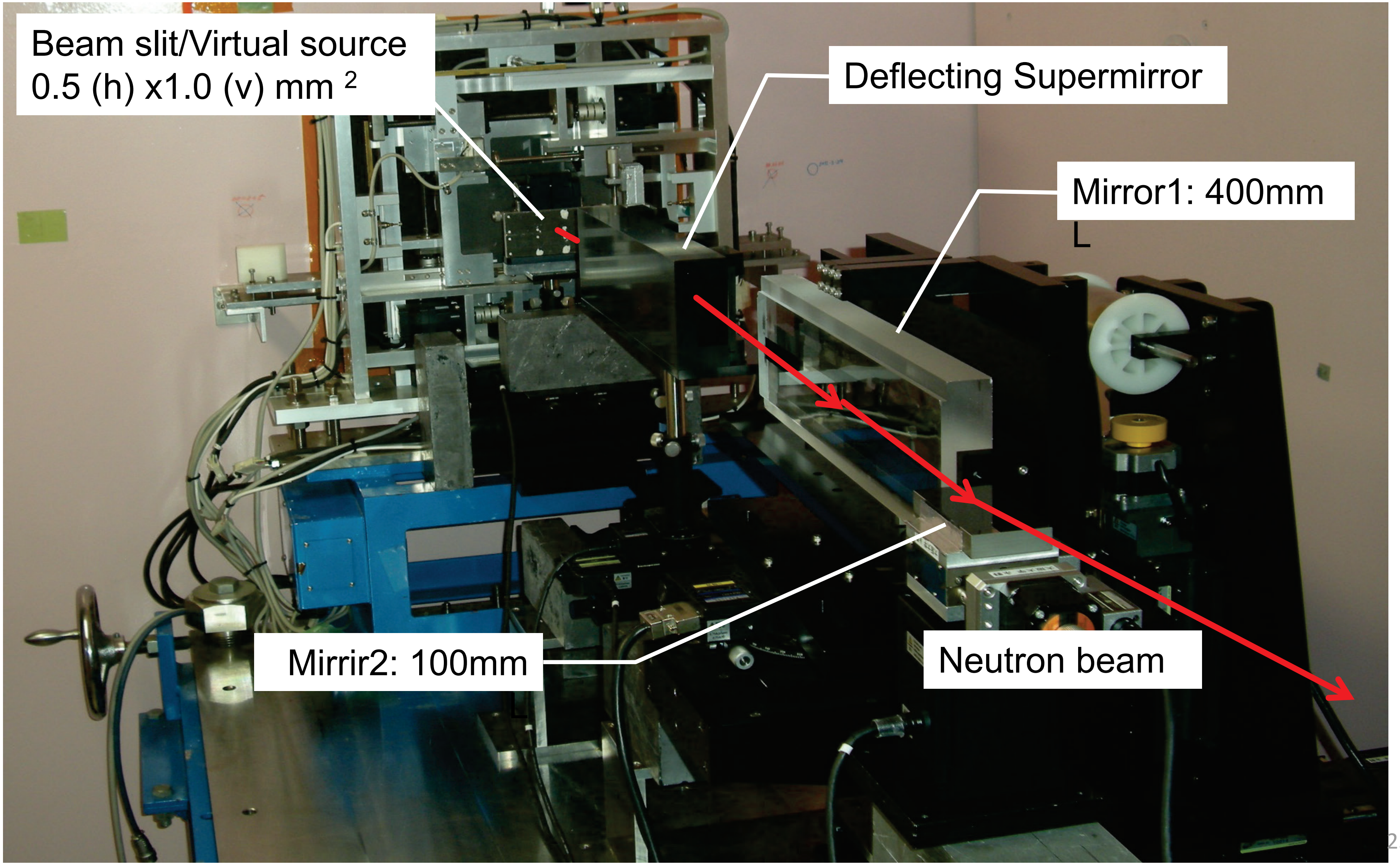
Parameters for focusing

Beam Line	BL10(NOBORU)
Focal Length(mm)	2100
Length of Mirror1(mm)	400
Length of Mirror2(mm)	100
Size of virtual source (mm)	0.5(H) x 1.0(V)
Contraction Rates	x1 (H), x0.45 (V)



Focused Beam Size 0.5x0.5mm^2 (FWHM)

2-dimensional beam focusing



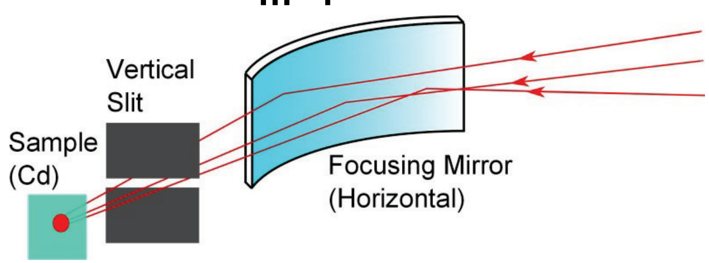
Prompt γ-Ray Activation Analysis at a small spot of a sample

J-PARC/MLF

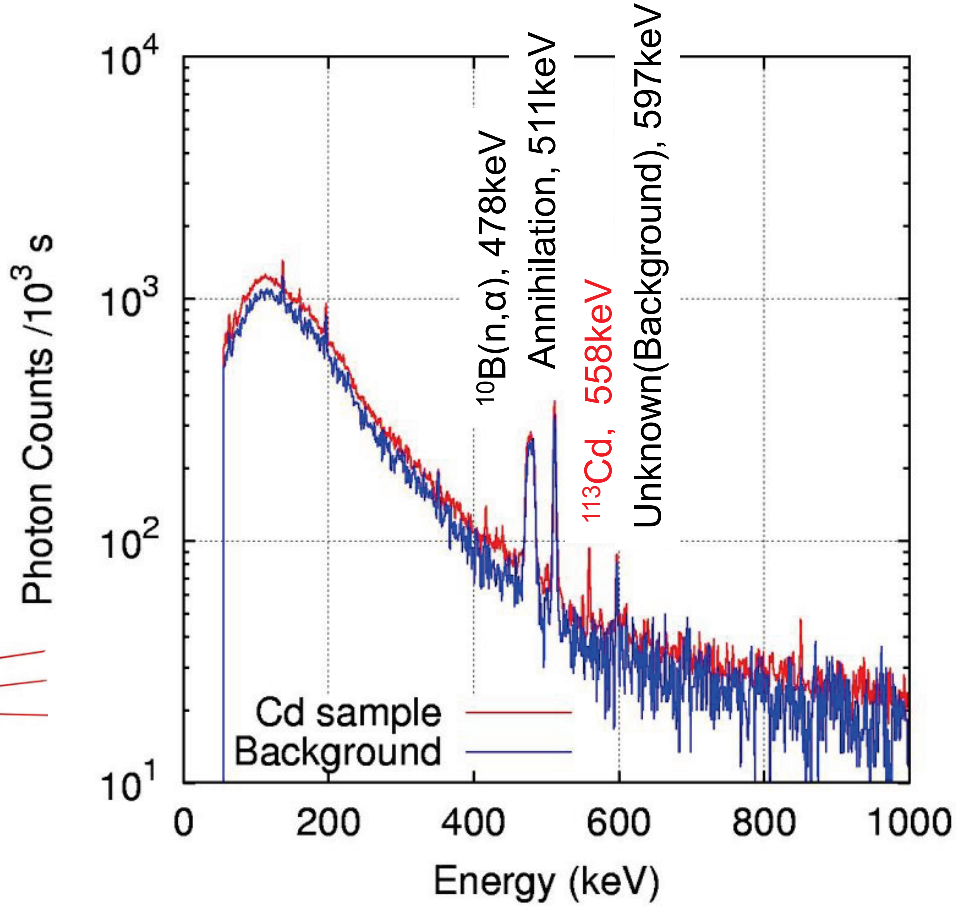
★Horizontally Focused 1x1mm²
★Vertically Collimated
★neutron intensity 10^{+3} cps / 1mm²
★Measuring time 2000sec(Cd), 600s(B.G.)
★N-type Germanium Detector
efficiency: 15% (at 1.33 MeV)
resolution: 1.9 keV (at 1.33)

Ge detector with no shielding

Horizontal supermirror m=4



Cd (1mm in thickness)



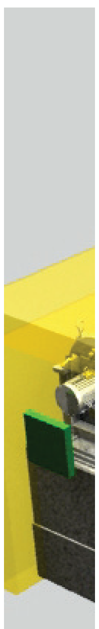
A significant peak of Cd was successfully observed with no shield covering the detector

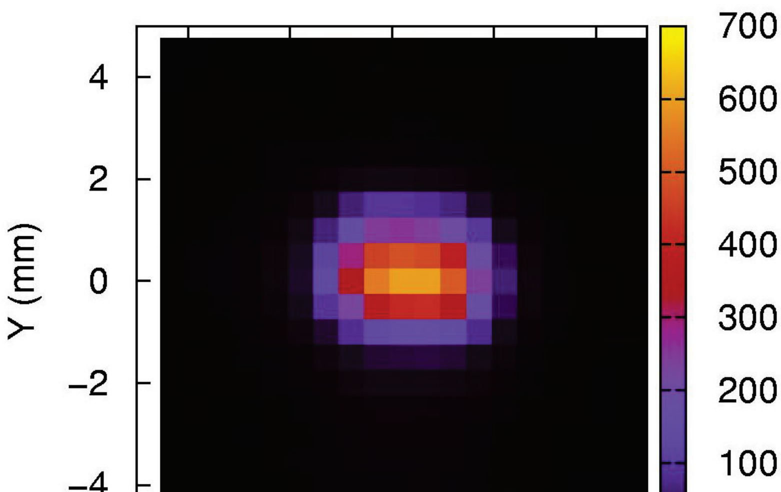
⇒Useful for activation analyses of small regions of a sample

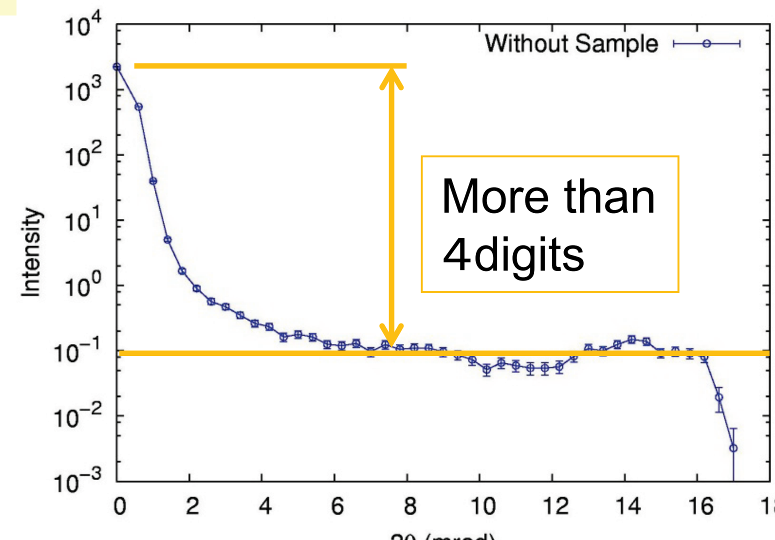
Focusing for Compact small angle scattering

★J-PARC BL17 (PNR with coupled moderator)
★Vertically Focused
★Horizontally Collimated
★1.0x1.5mm^2 @ Detector Position
★Focal Length : 7430 + 3620 mm
★Sample-Detector: 2500mm
★RPMT scintillation detector

PRELIMINARY







The Signal-to-Noise ratio can be improved by 2-D focusing and noise reductions on the RPMT detector.

Summary

- Focusing mirror devices combining ultra-precise surface figuring and high-performance supermirror deposition with IBS.
- No figure-adjustment needed after fabrication.
- High focusing performance without growth of background.
- 2-dimensional focusing with the Kirkpatrick-Baez configuration.

Summary

- Applications
  - PGAA at small regions of materials
  - Compact small angle scattering
- Under development
  - Grazing Incidence Small Angle Neutron Scattering
  - Angular Divergent Neutron Reflection
- Also applicable to
  - Samples in a high-pressure cell

Collaborators

- J-PARC Center
  - R. Maruyama, H. Hayashida, K. Soyama (design and supermiror deposition)
- Osaka University
  - M. Nagano, F. Yamaga, N. Mitsushima, K. Yamamura (elliptic surfaces of quartz substrate)
- Support in beam experiments
  - Y. Kasugai, M. Katagiri, T. Shinohara, M. Harada, K. Oikawa, K. Aizawa, N. Miyata*, Y. Sakaguchi*, M. Mizusawa* , K. Akutsu*

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End