High intensity white beam specular reflectometers

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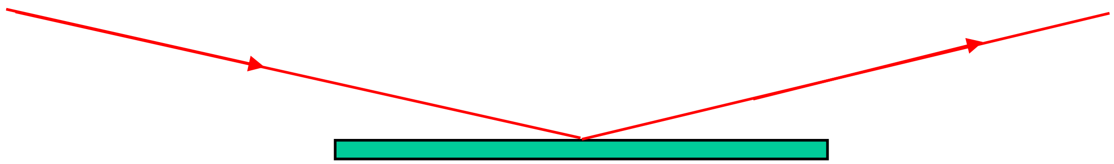
Aim

- Increase the luminosity of reflectometers
  - Gain in counting rates of 1-2 orders of magnitude in specular reflectivity
  - Reflectivity curves in minutes instead of hours

- What for?
  - Very fast measurements
  - Kinetic studies
  - Systematic studies versus external parameters
    - Temperature, pressure, magnetic field, partial vapor pressure
  - Measurements on very small samples
  - But NOT for measurements at very low R ($<10^{-6}$)

High flux specular reflectometry

- *Objective:* gain in flux (1-2 orders of magnitude)
- *How :* use the « whole » real space



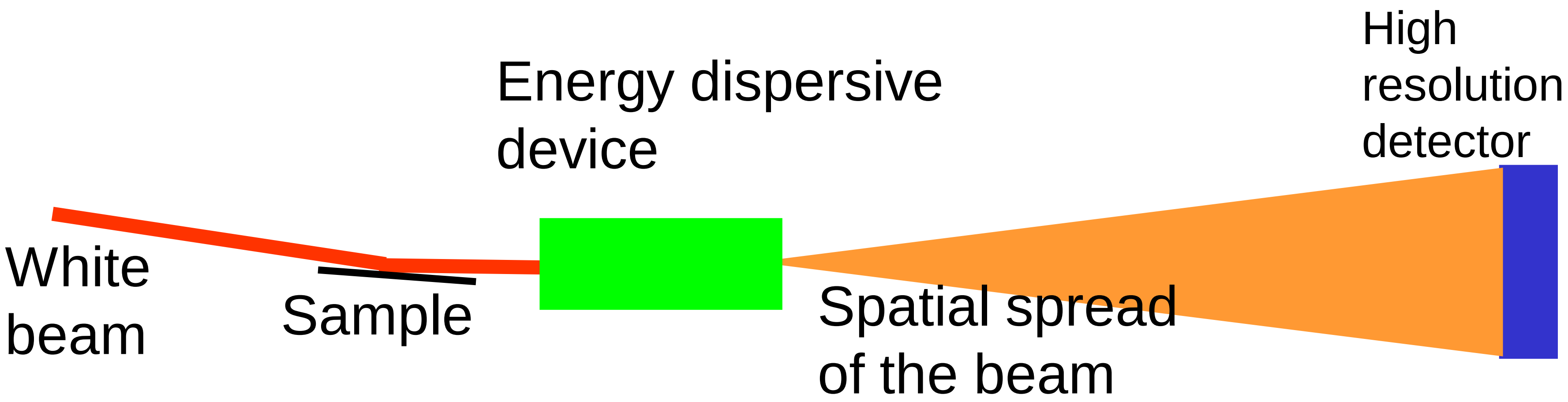
- *Possibilities:*
  - *Spin – space encoding (SERGIS)*
  - *Time – space encoding (TILTOF)*
  - *Energy – space encoding*
    (PRISMs, EASYREF, GRADTOF, REFOCUS)

Get rid of the chopper & the monok

ENERGY – SPACE encoding

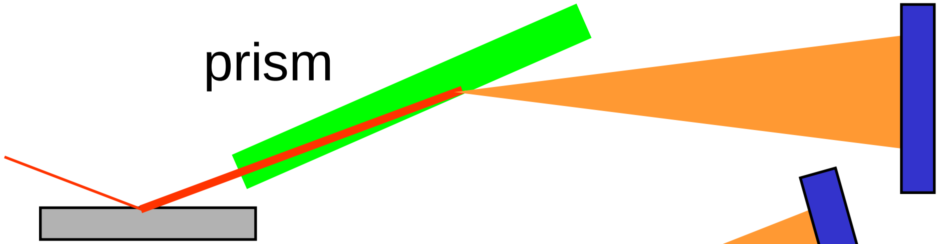
Energy – space encoding

- Energy analysis AFTER the sample

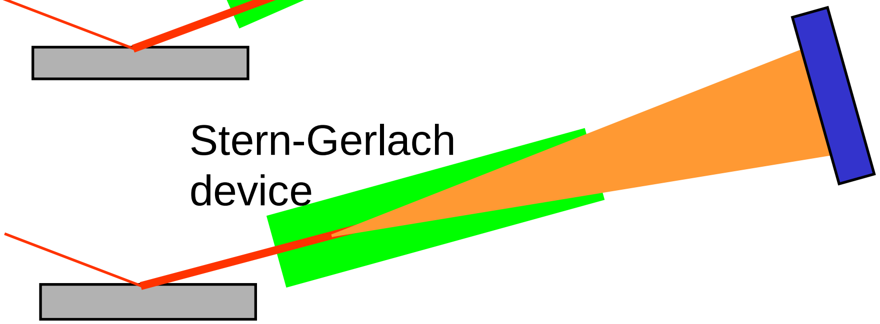


Energy analysis Implementation

REFRACTION

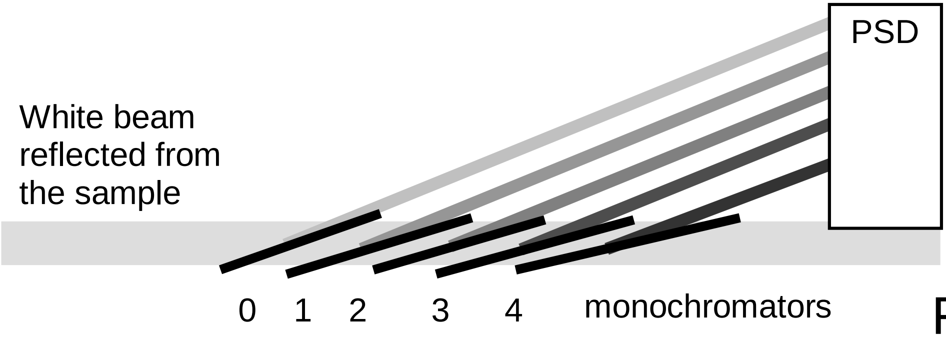


R. Cubitt et al, NIM A **558** (2006) 547-550.



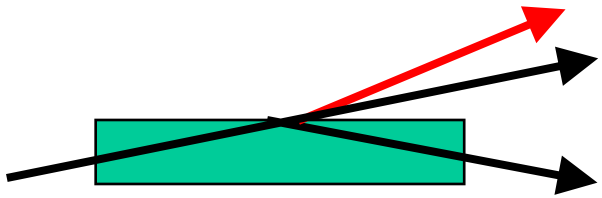
F. Ott et al, Physica B **397** (2007) 153-155.

EASYREF

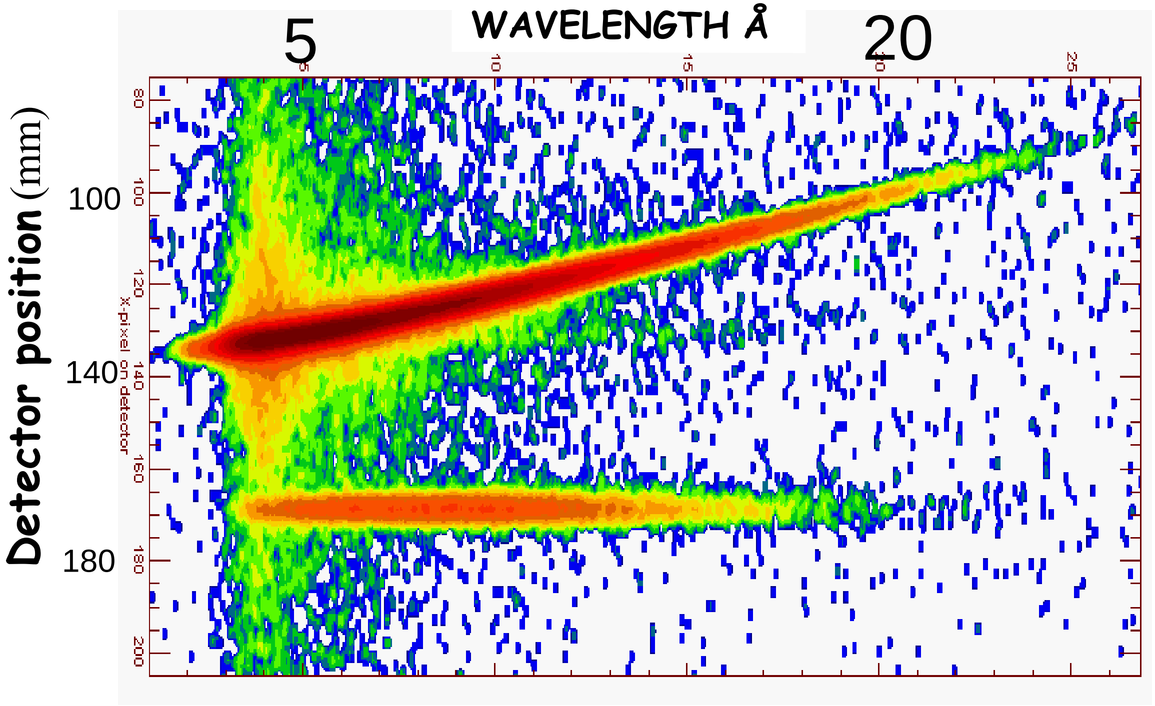


F. Ott et al, NIM A **584** (2008) 401-405

Energy analysis using refraction in a prism (R. Cubitt, ILL)



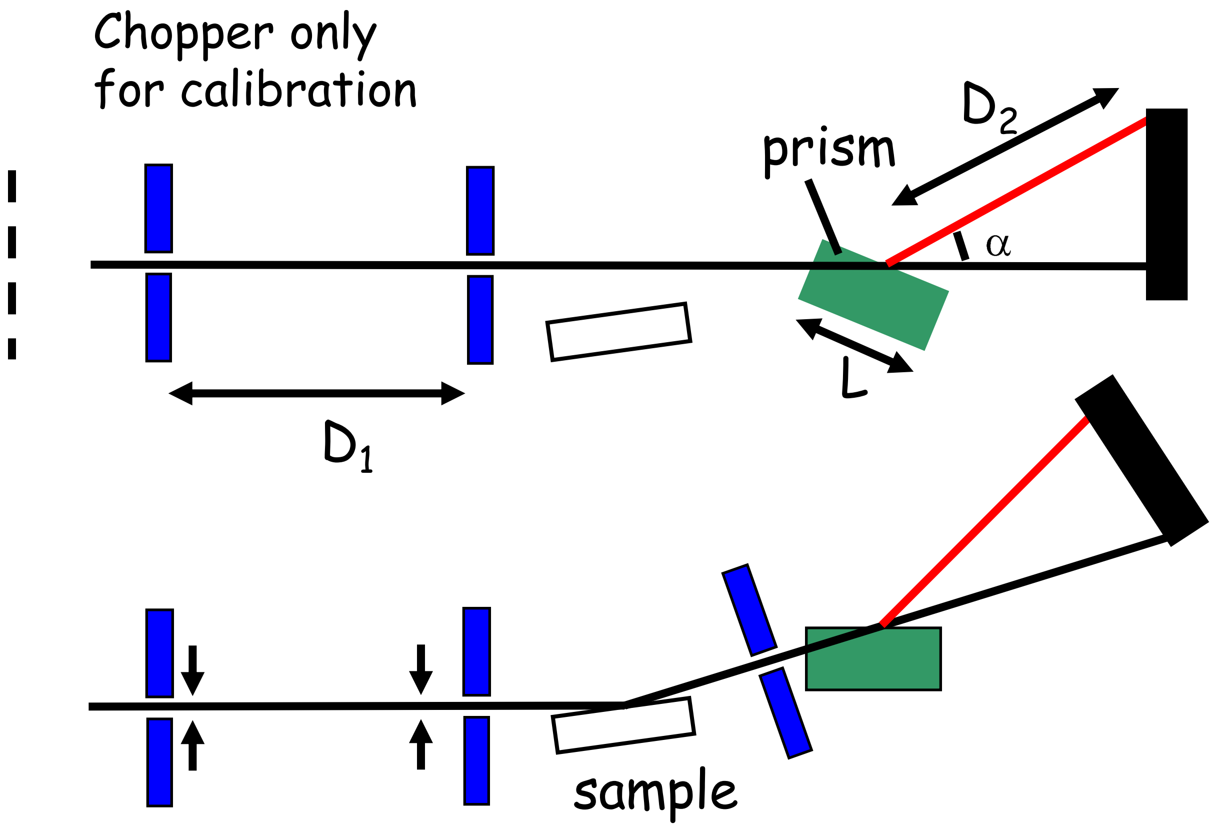
Best for wide wavelength range

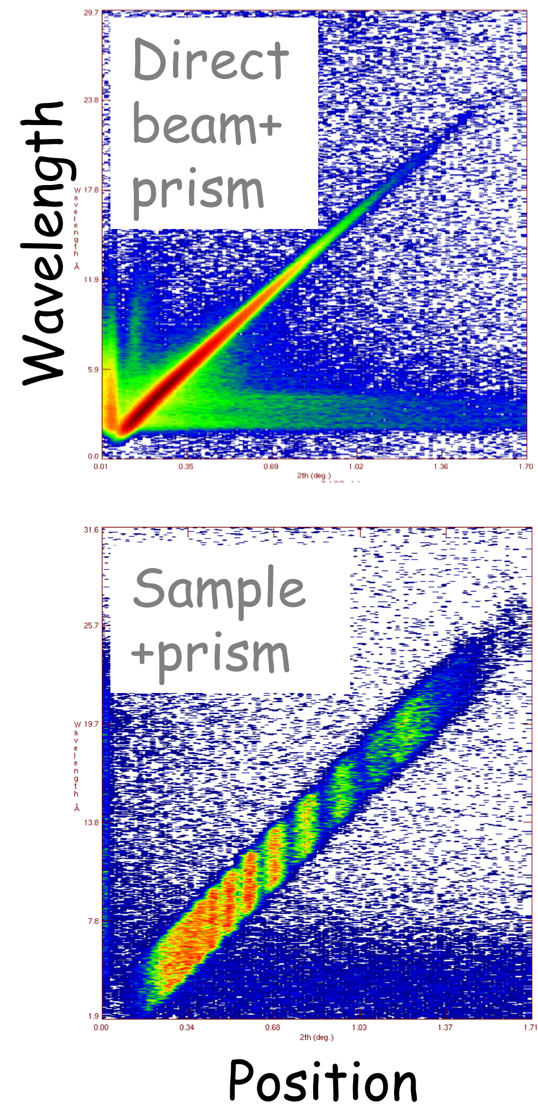


R. Gahler Phys Rev D 25 2887 (1982)

R. Cubitt NIM A 558 547- (2006)

Reflectometry experiment using a prism (R. Cubitt, ILL, D17)

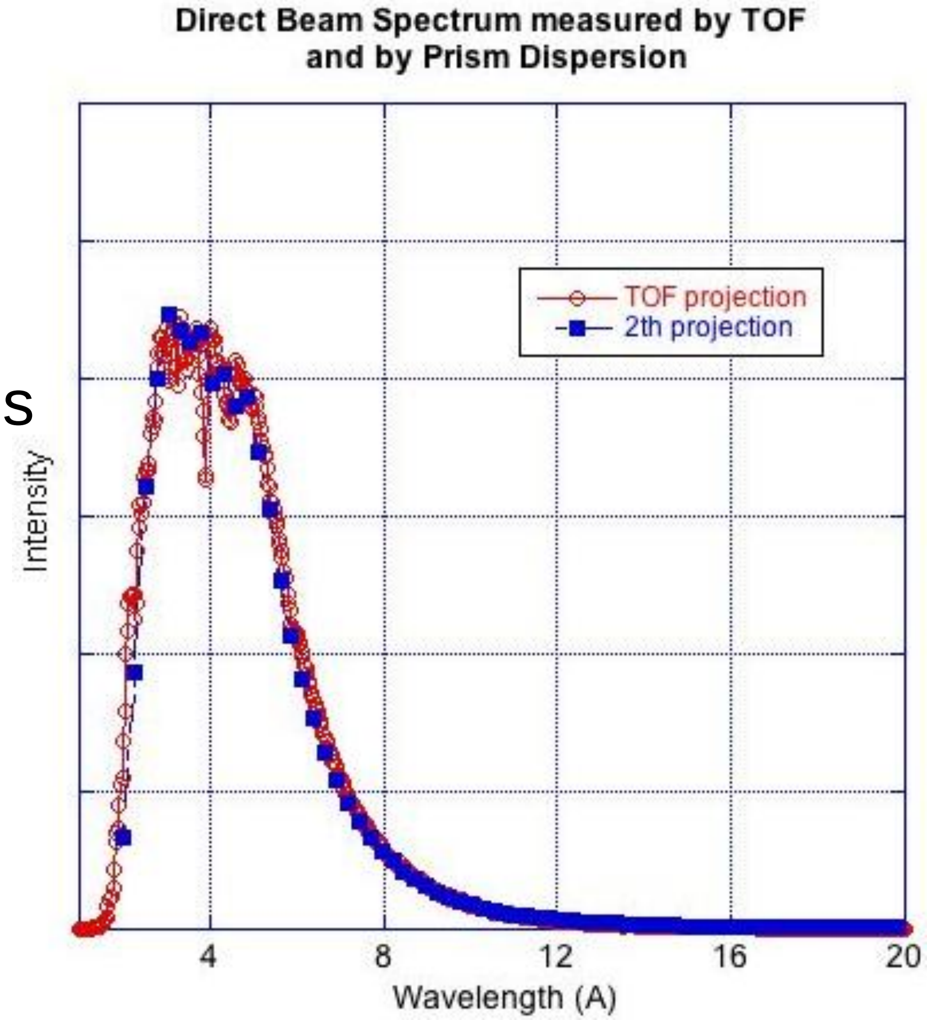




2th 0-1.7 deg.

Refraction using prisms (R. Cubitt, ILL)

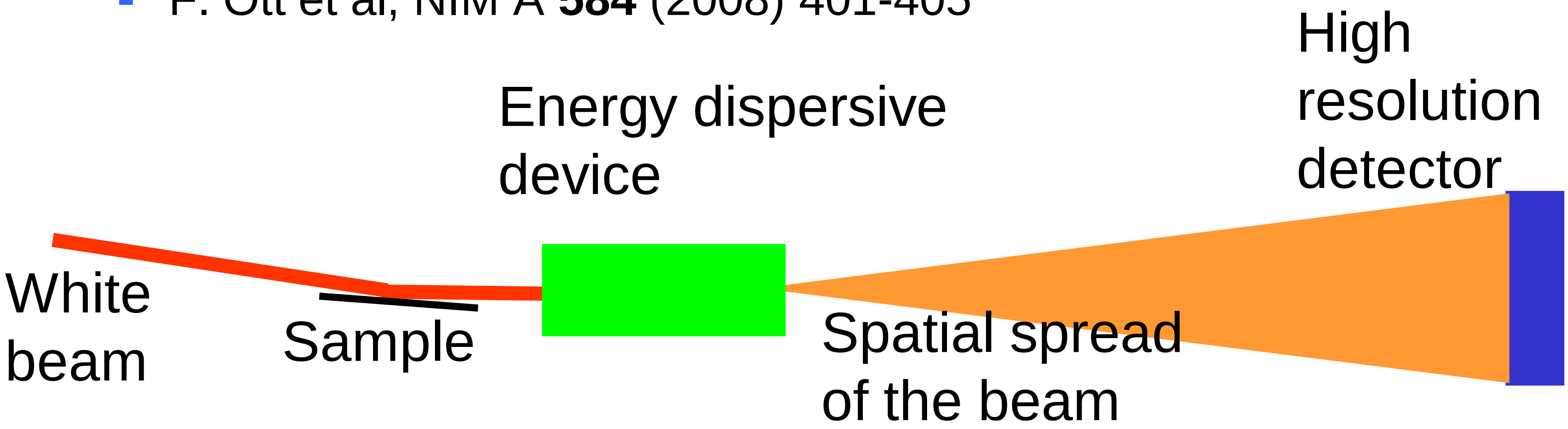
- Cost:
  - k€3 MgF_2 flat prism
- Limitation
  - Rather weak refraction effects for short wavelengths
  - MgF_2 is already the best possible crystal (single crystal; low absorption)
  - High resolution detector or long flight path (10m)

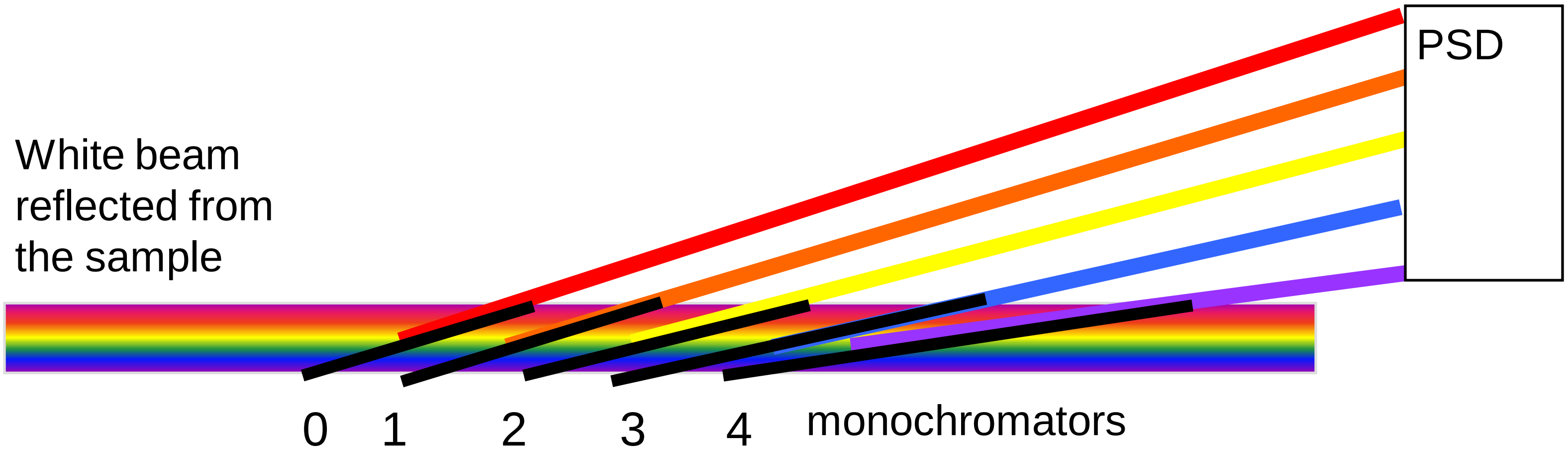


Energy analysis using diffractive optics EASYREF

EASYREF

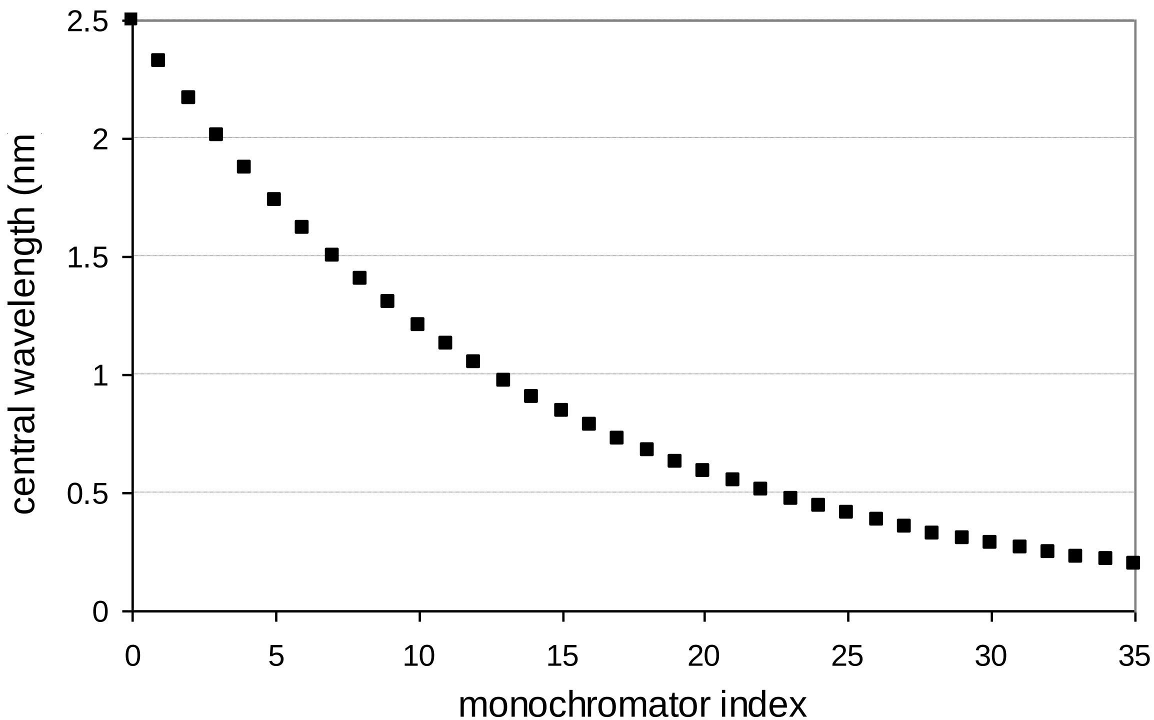
- Energy Analysis System for Reflectometry
  - F. Ott et al, NIM A **584** (2008) 401-405





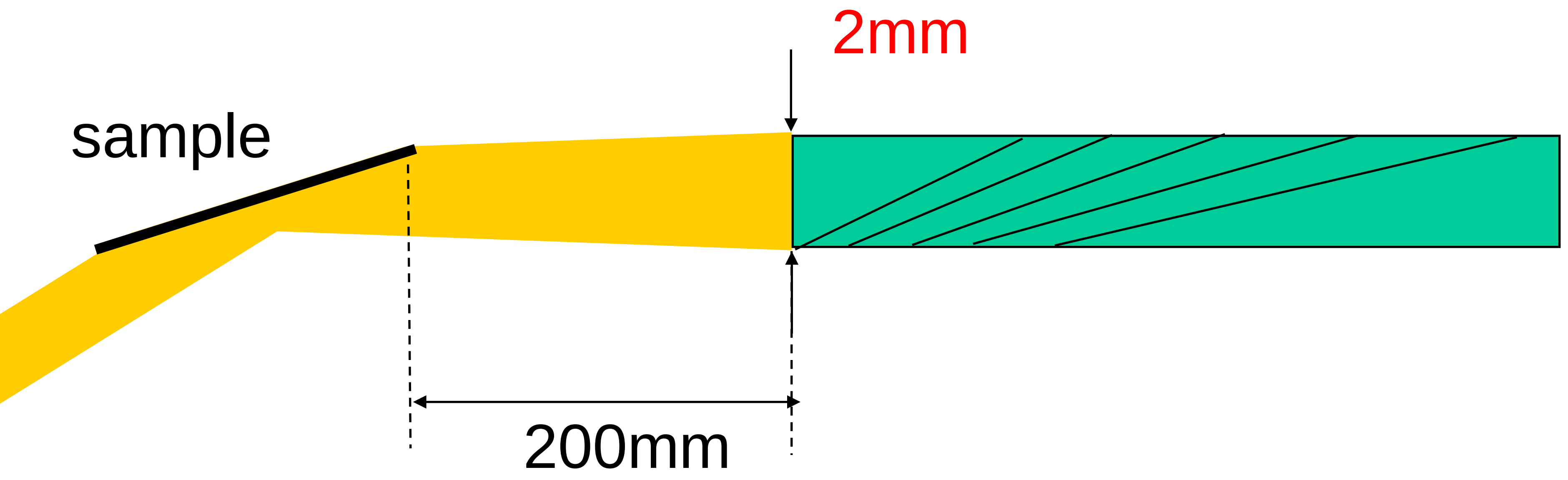
Requirements for a realistic device

- TOF wavelength bandwidth: 0.2 - 2.5 nm
- Wavelength resolution: BW = 7%
- $\lambda_n = (1\text{-BW})^n \, \lambda_{max}$
- 35 points measured at once



Typical reflectivity setup

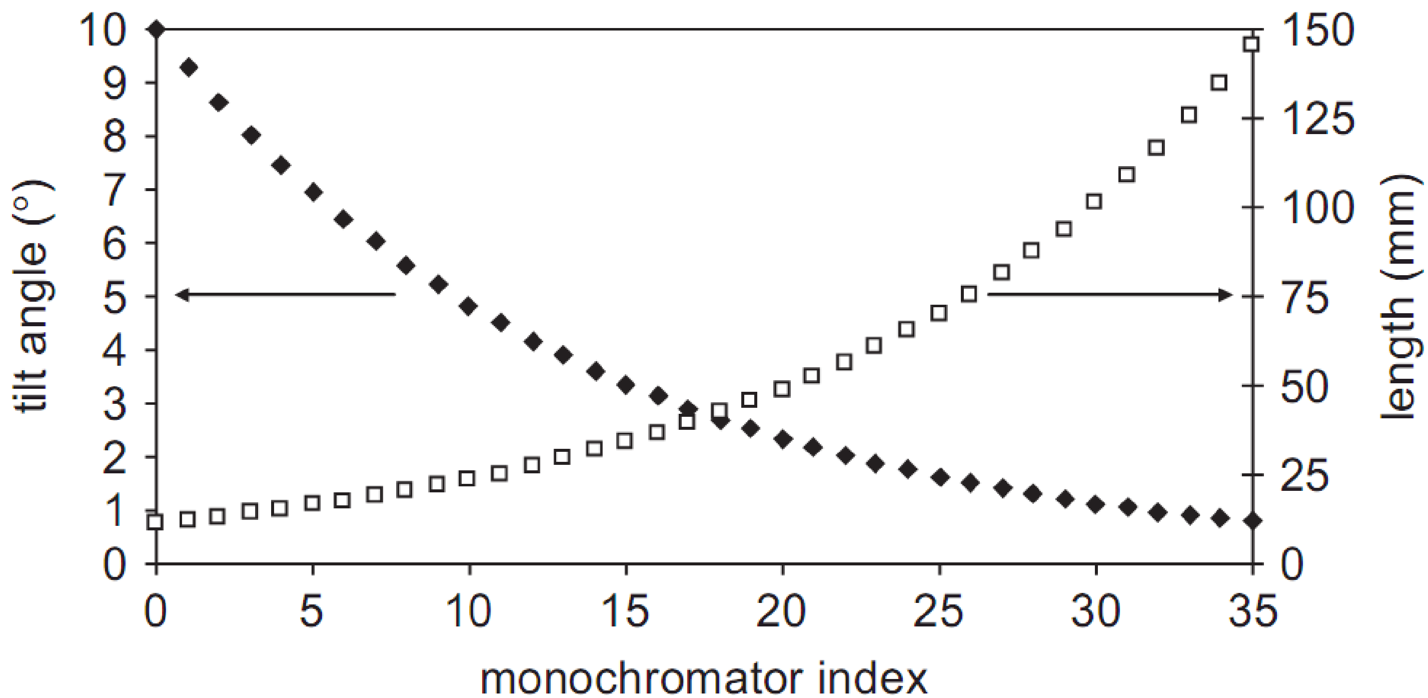
- Sample of 40mm
- Incidence angle 2.5°
- Divergence 0.06°



Mirrors arrangement

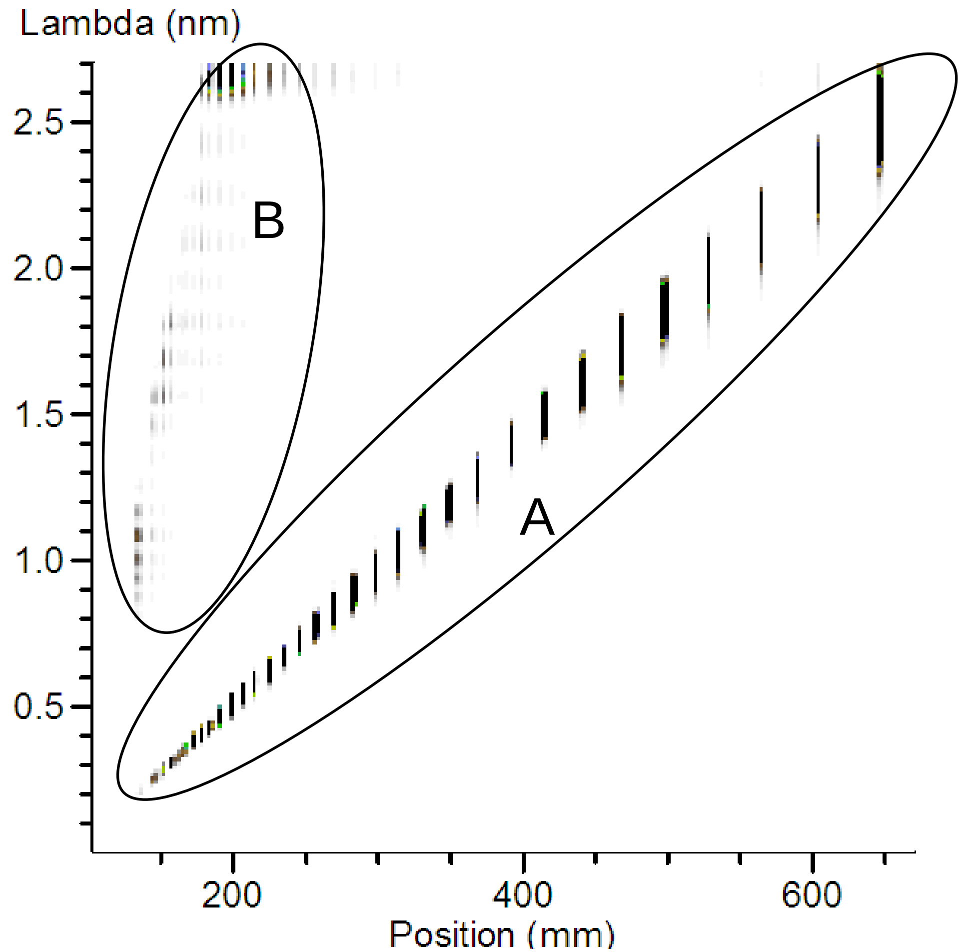
2mm

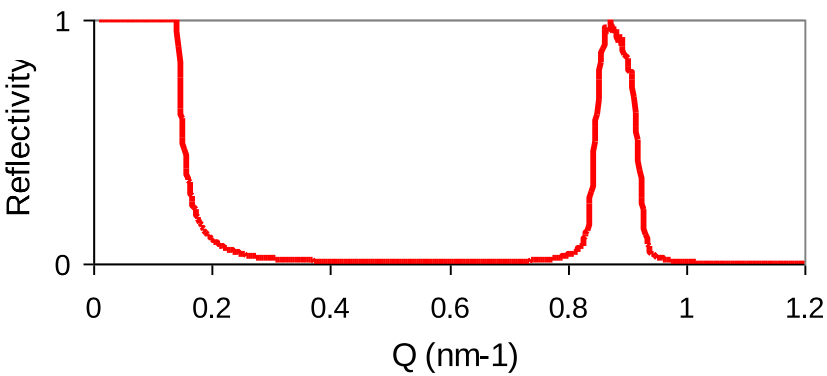
$4\theta_c$ monoks mirrors

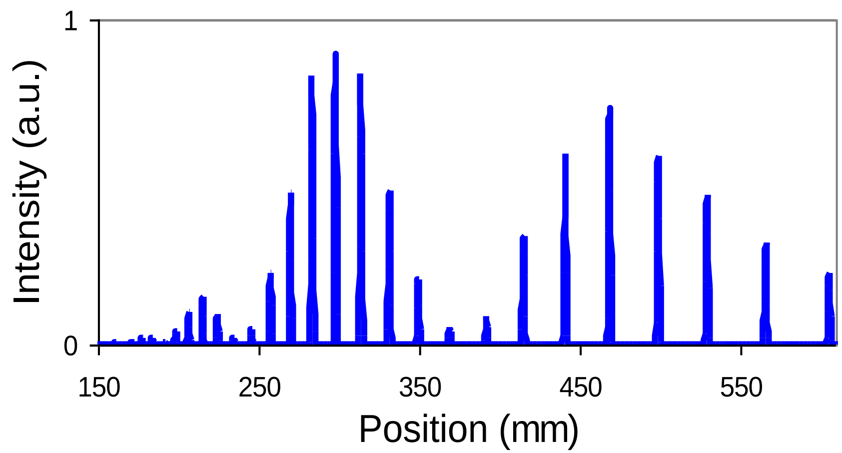


Monte-Carlo modelling

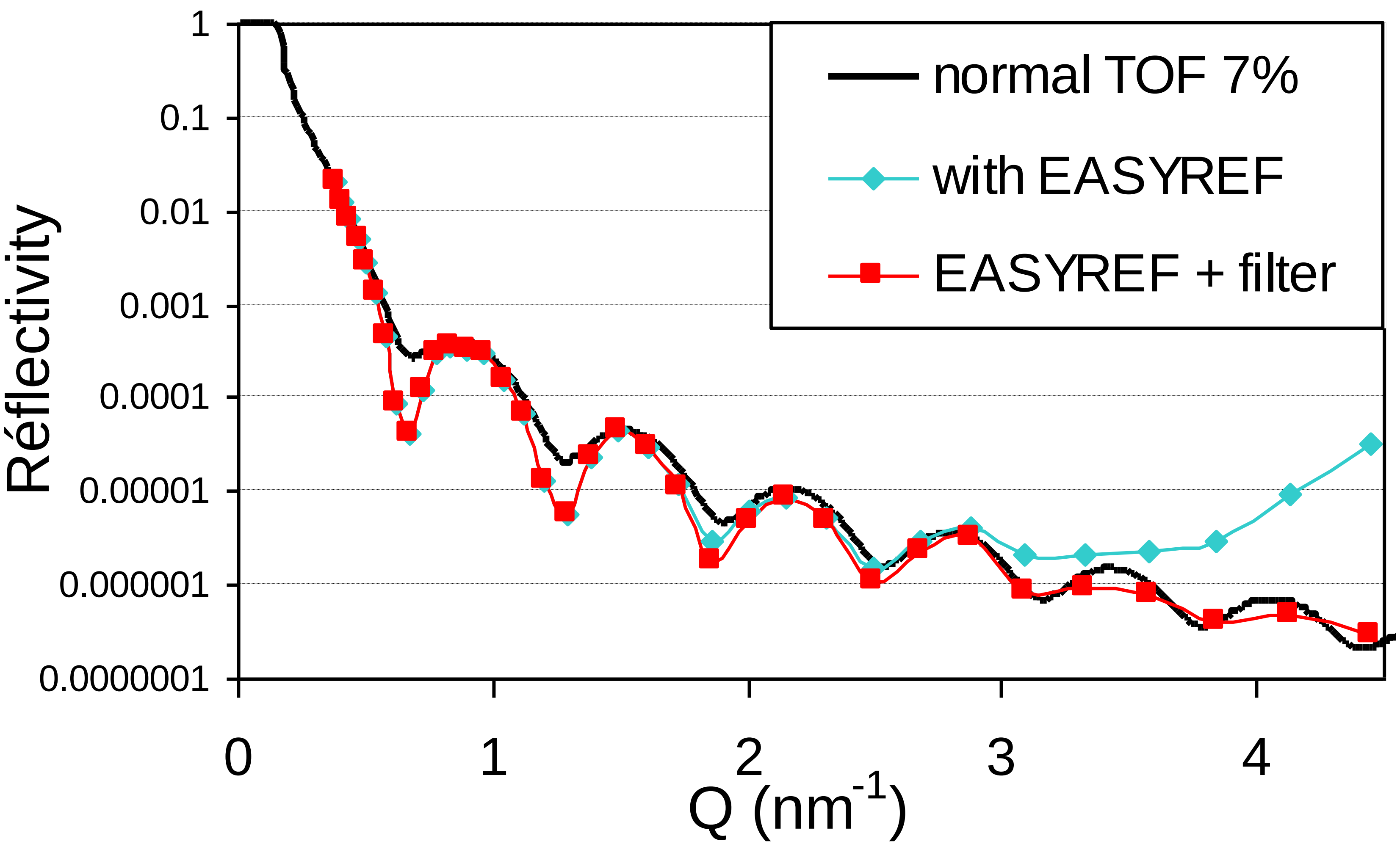
- $4\theta_c$ monoks
- Detector set at 1500mm after the device







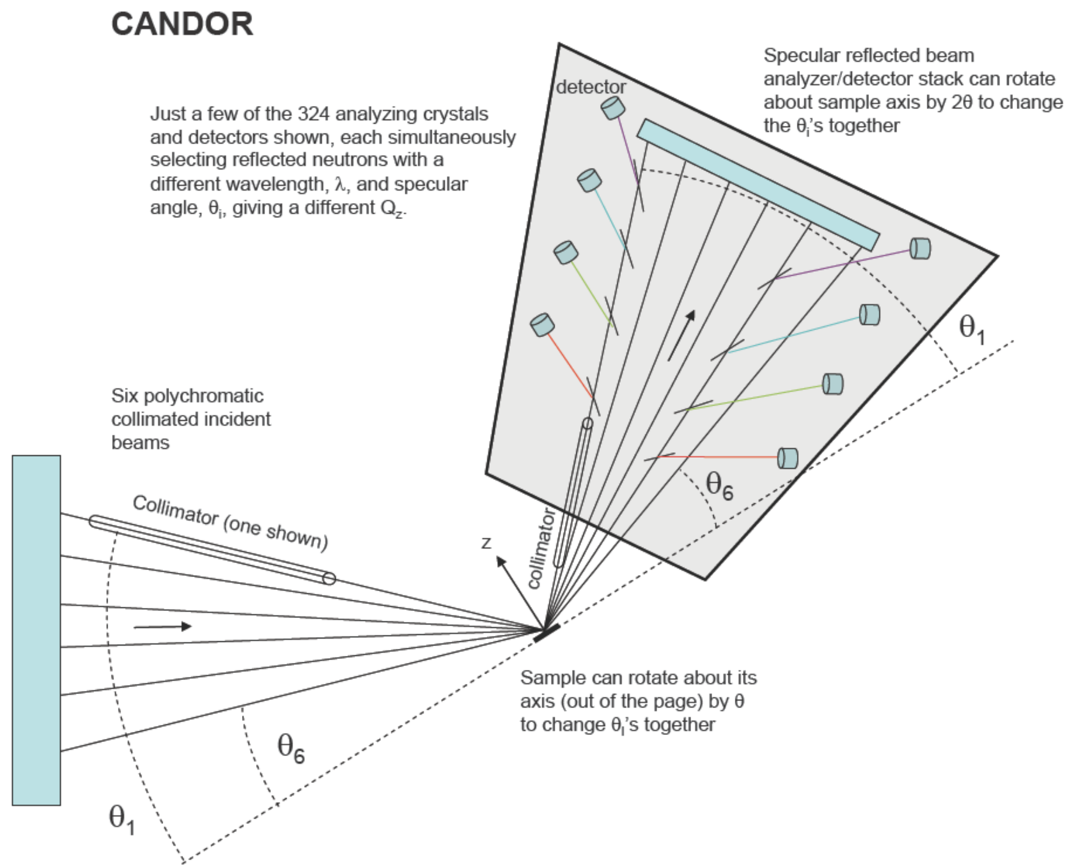
Reflectivity on Ni(10nm)//Si



Similar proposals using diffractive optics

- C.F. Majkrzak, Physica B **173** (1991) 75-88.
- Graphite – Si crystals (K. Andersen – H. Ronnov ILL – EPFL)
- CANDOR @ NIST

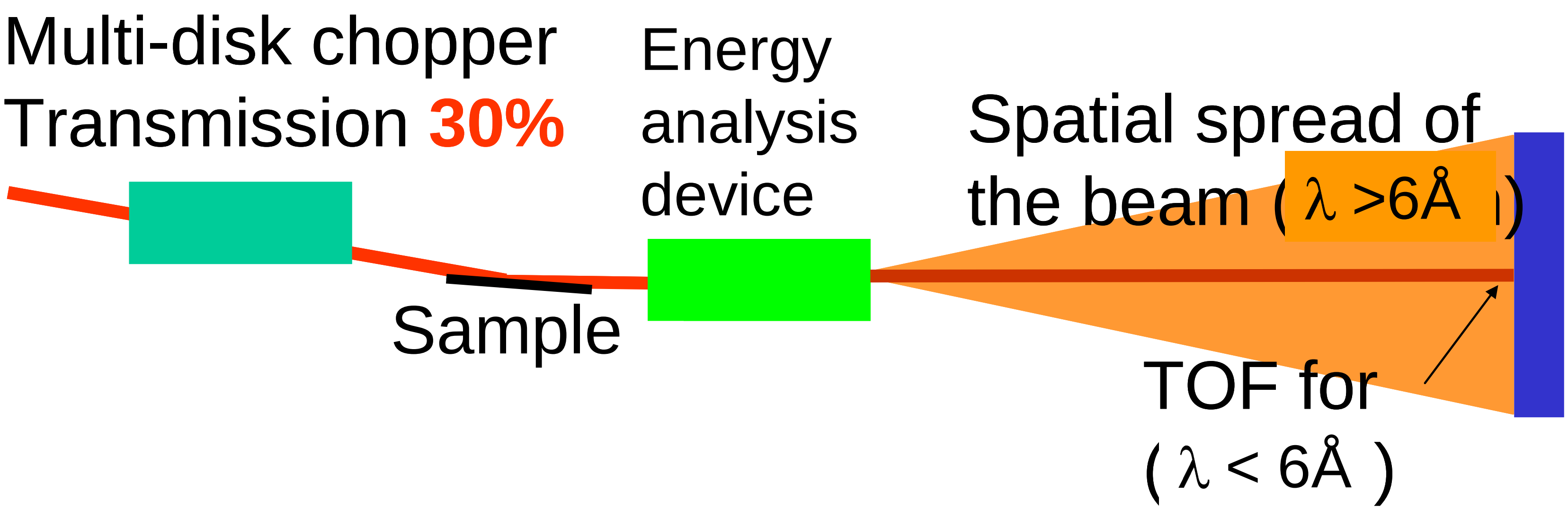
Chromatic Analysis Neutron Diffractometer Or Reflectometer



Hybrid setups

Hybrid setup: GradTOF

- Combine ***Energy Analysis*** with a high speed chopper (200Hz)

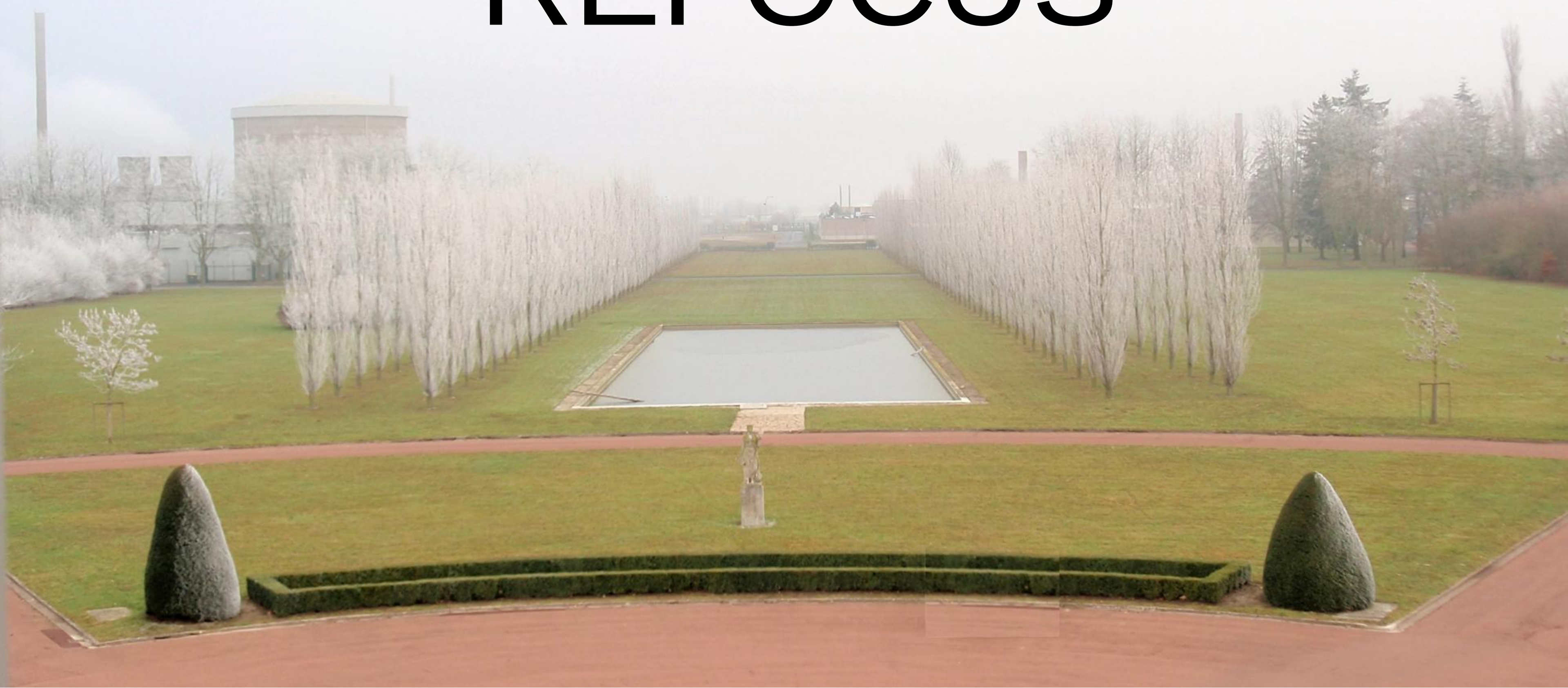


- Typical TOF reflectometer (EROS – D17): λ from 0.2 to 3 nm,
  - New disk chopper for a band between 0.2 to 0.5nm
  - = gain of a factor 6 in flux for the short λ
  - Long λ (0.6 - 3nm) are analyzed using one of the energy analysis device.

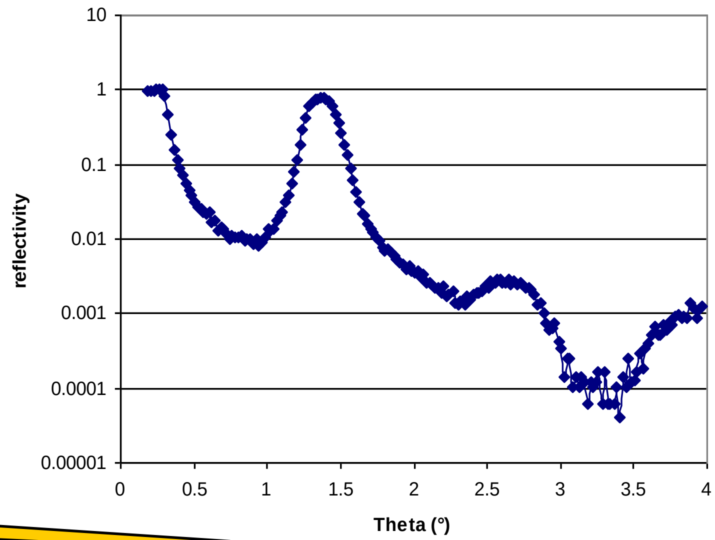
- **No compromise in resolution**

Energy – Space encoding <u>before</u> the sample

REFOCUS

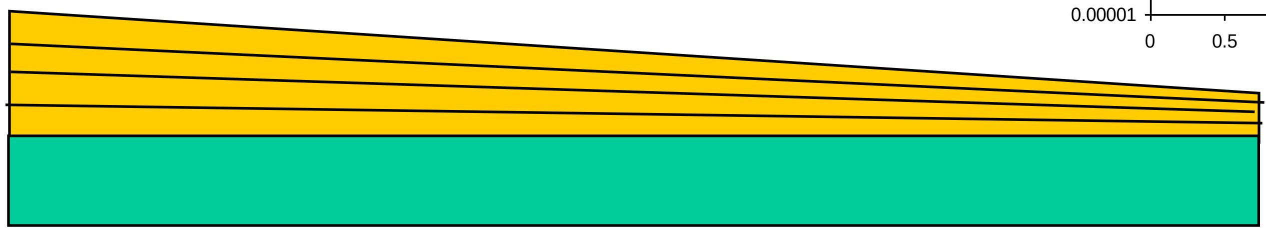


Use of advanced reflective optical components



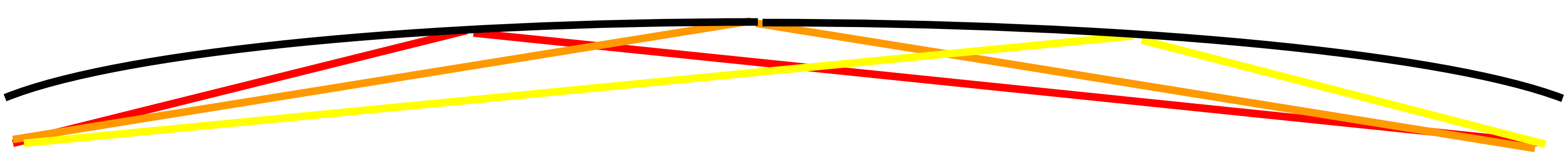
- High *m* monochromators
  (without harmonics, m>3)
  J. Padiyath et al, APL **89** (2006)

- Graded mirrors



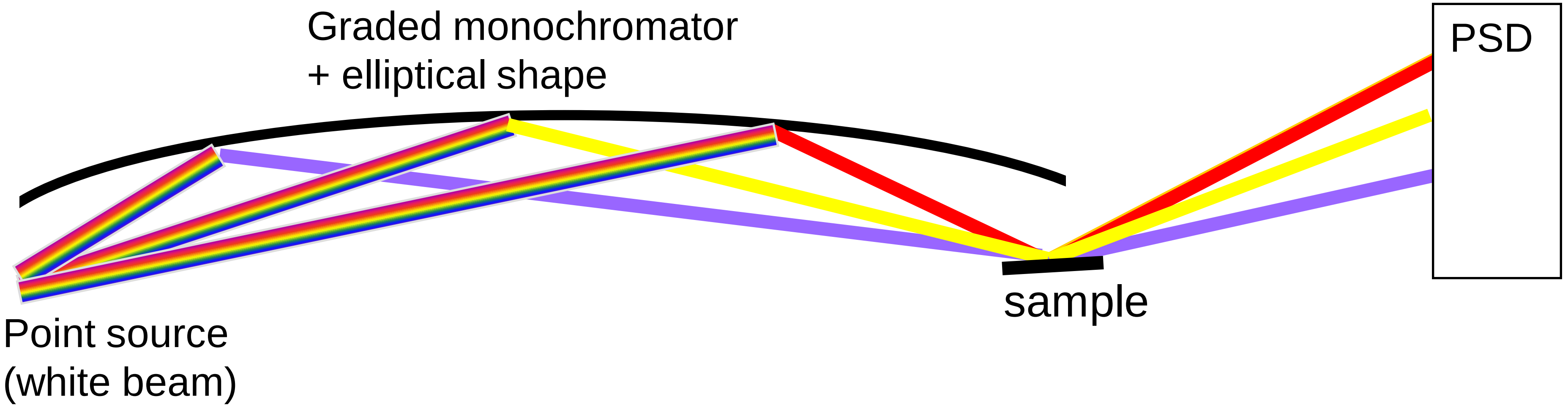
(M. Schneider, J. Stahn, P. Böni, to be published)

- Elliptical mirrors, C. Schanzer et al, NIMA 529 (2004)



REFocus : General principle

- *Energy – space encoding* *(<u>before</u> the sample)*
  - Correlate the wavelength with the incidence angle on the sample.

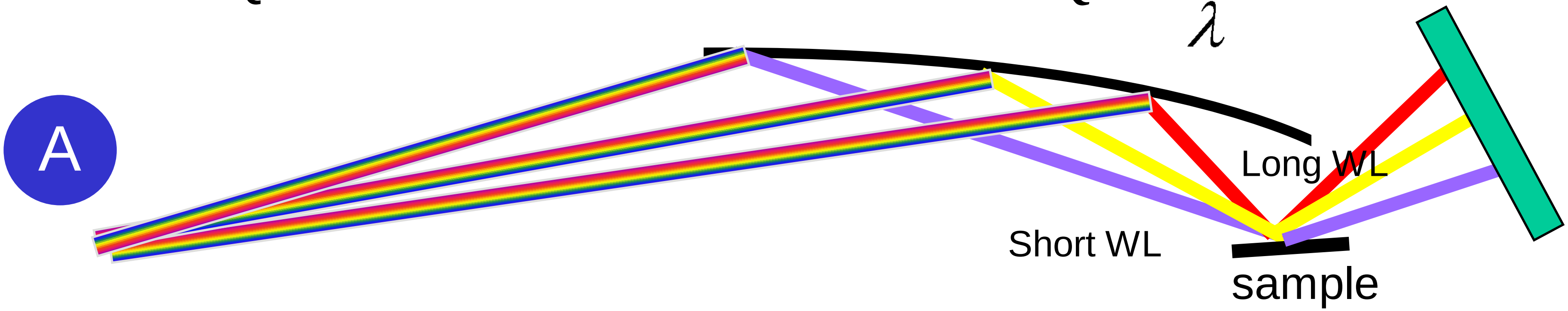


- F. Ott and A. Menelle, NIM A **586** (2008) 23–30.
- Key technologies
  - High m, without harmonics ML monochromators (m>3)
  - Graded mirrors
  - Elliptical curved mirror

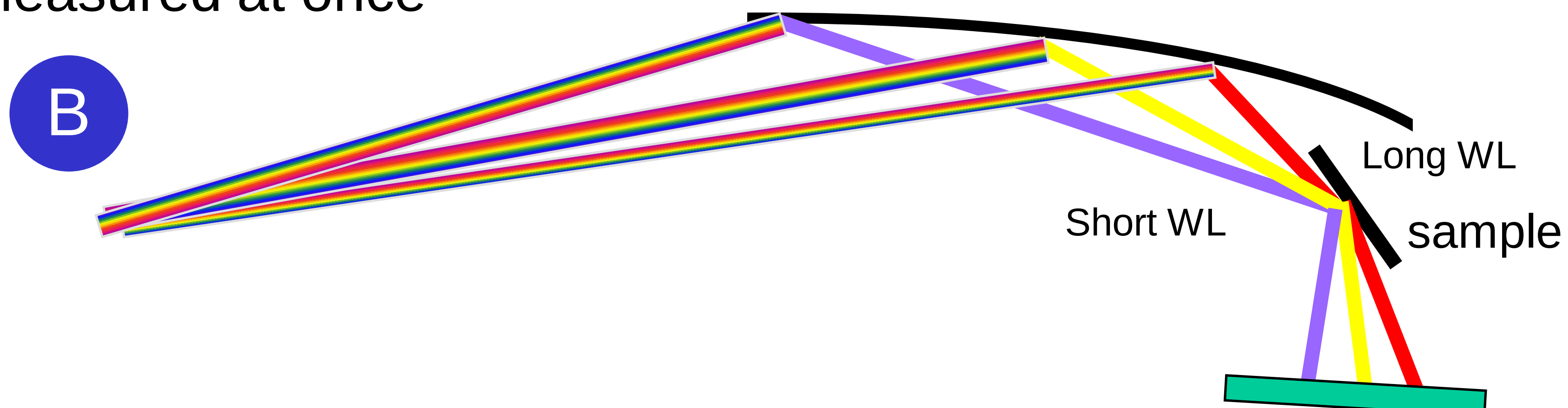
Operation modes

« Constant Q mode »

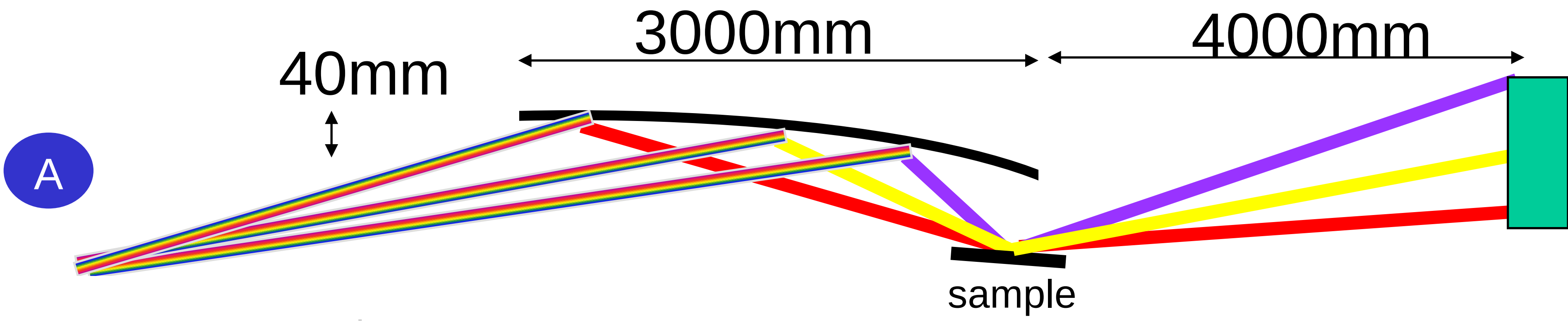
$$Q = \frac{4\pi}{\lambda}\sin\theta$$

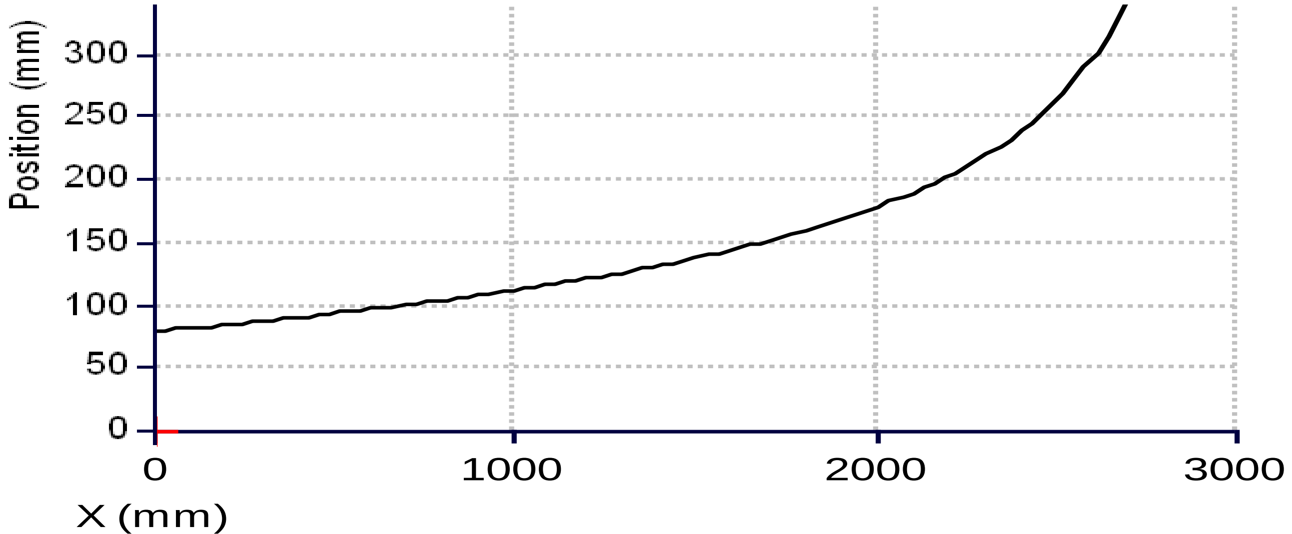


A large Q span is measured at once



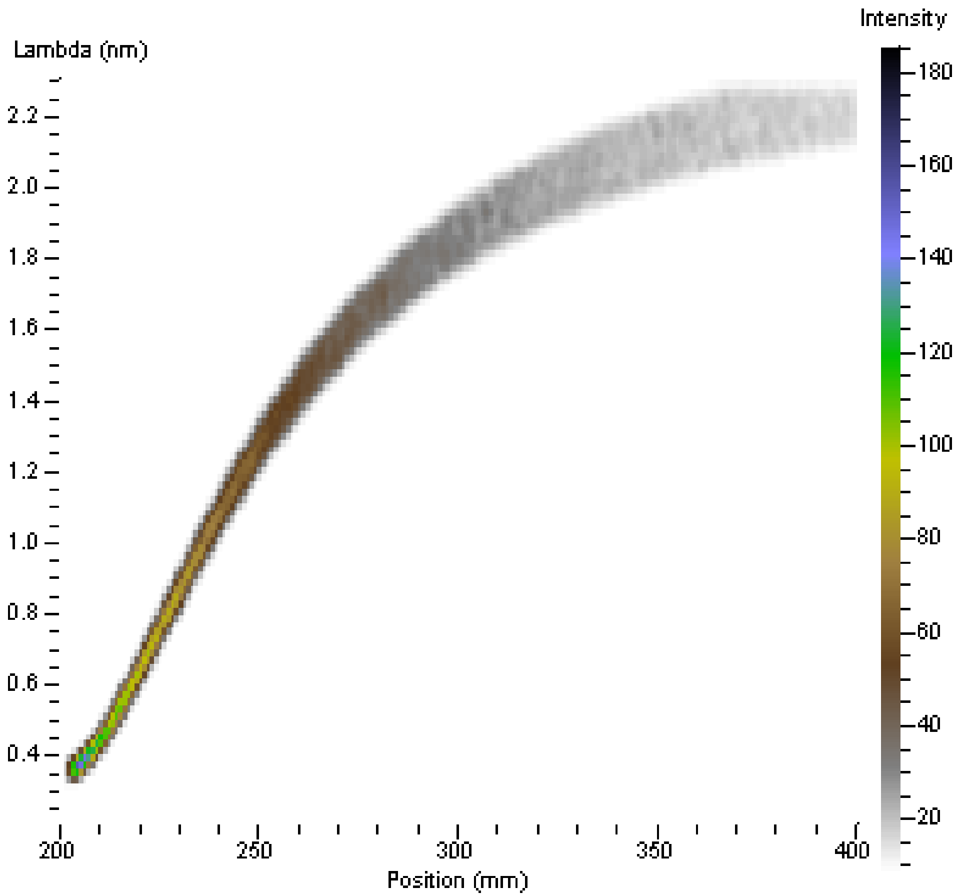
Detection


3000mm
4000mm
40mm
A
sample


Position (mm)
300
250
200
150
100
50
0
0
1000
2000
3000
X (mm)

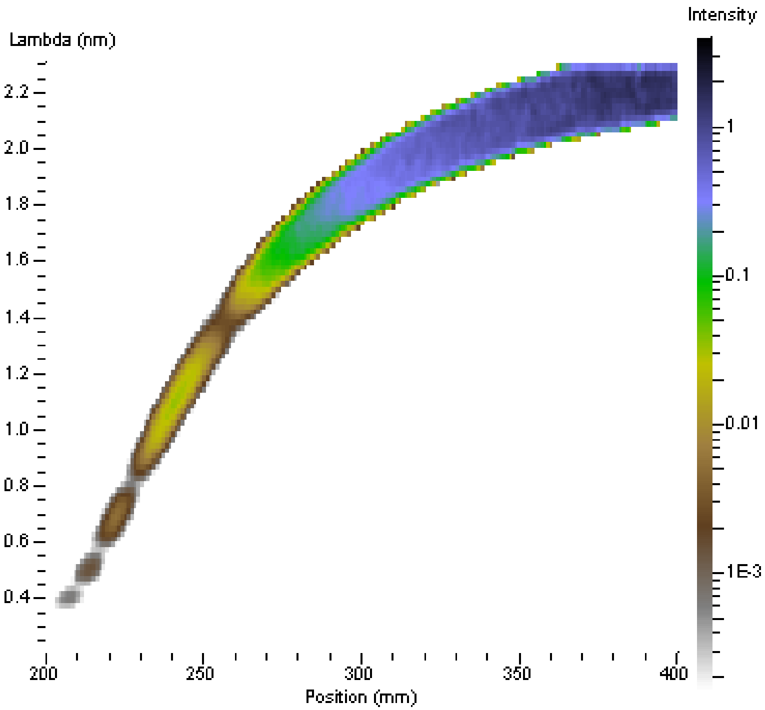
Monte Carlo modelling

- λ vs Position on detector

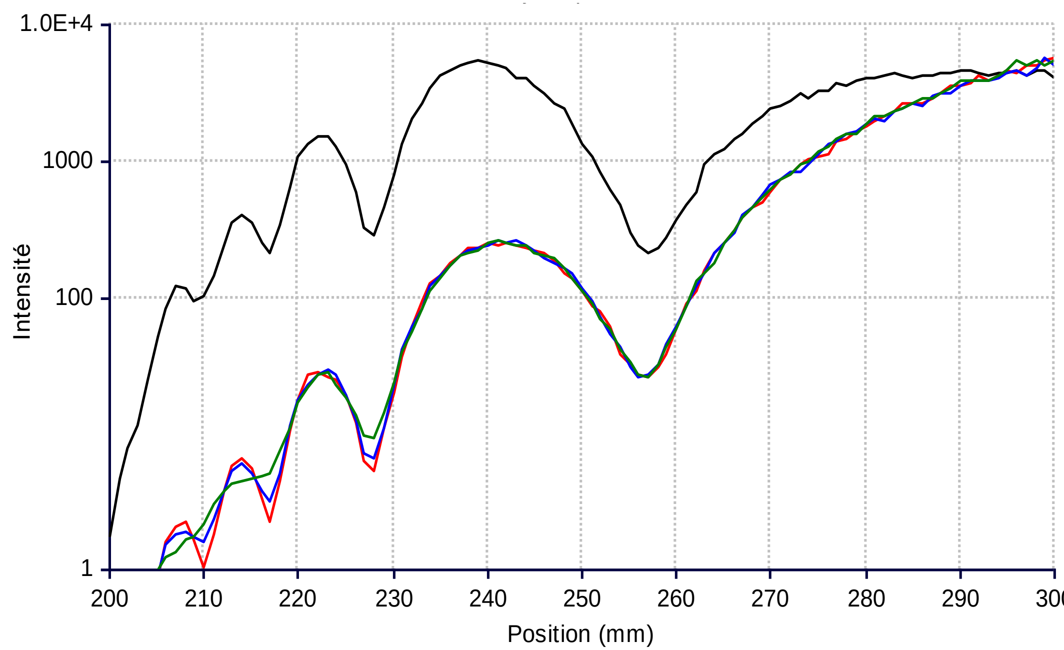


Slit 1: 1-4 mm
Sample: 100mm
θ_i = 6°

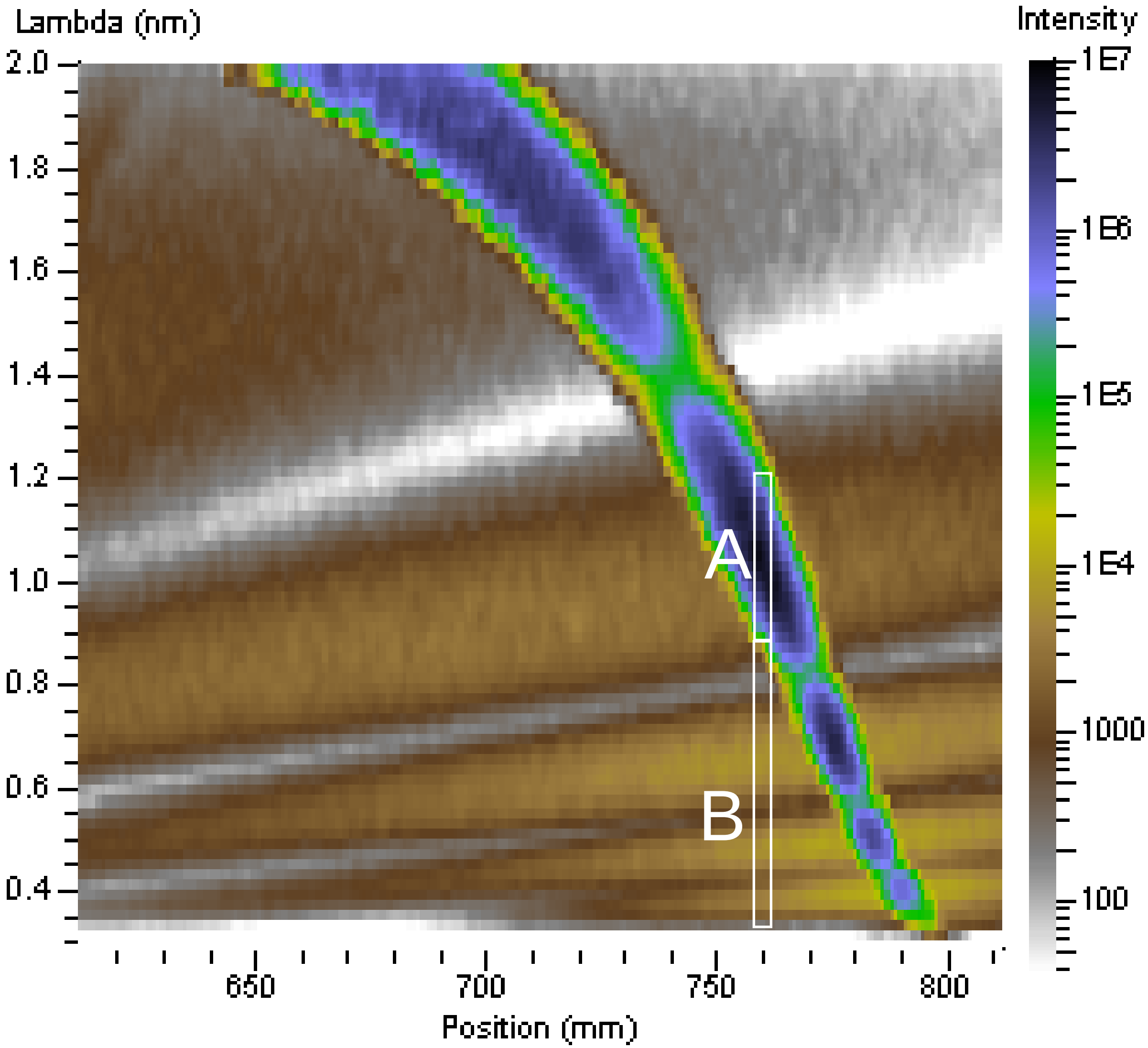
Real reflectivity in Mode B



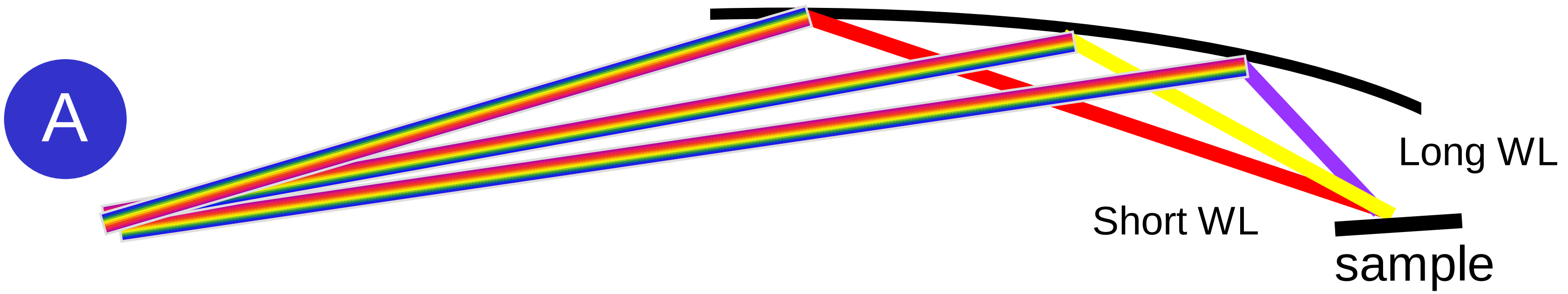
- Reflectivity (as measured)
- Reflectivity (normalized)
  - Input slit 1mm
  - Input slit 2mm
  - Input slit 4mm



Off-specular scattering

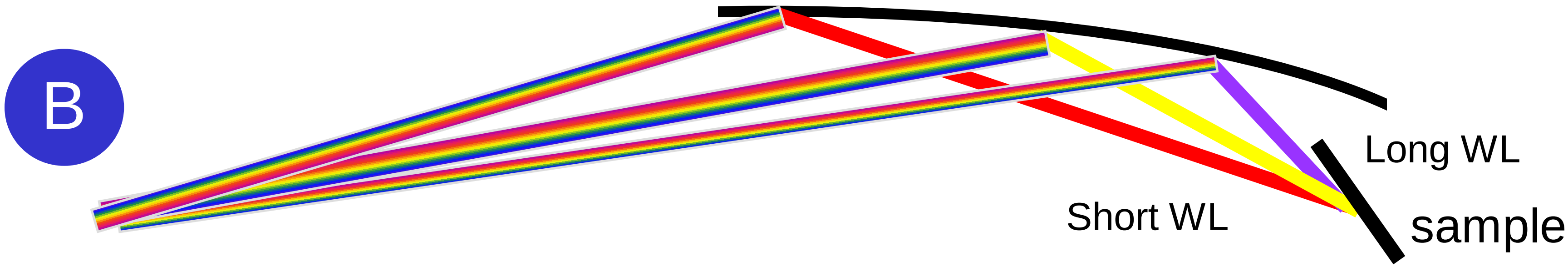


Mode A



- Equivalent to $\theta/2\theta$ operation mode
- ☺ Constant Q operation (almost)
  - ☺ Low resolution detector is sufficient
  - ☺ Low sensitivity to off-specular scattering
  - ☺ Limited spectral purity is sufficient
- ☹ Sample scan is required

Mode B

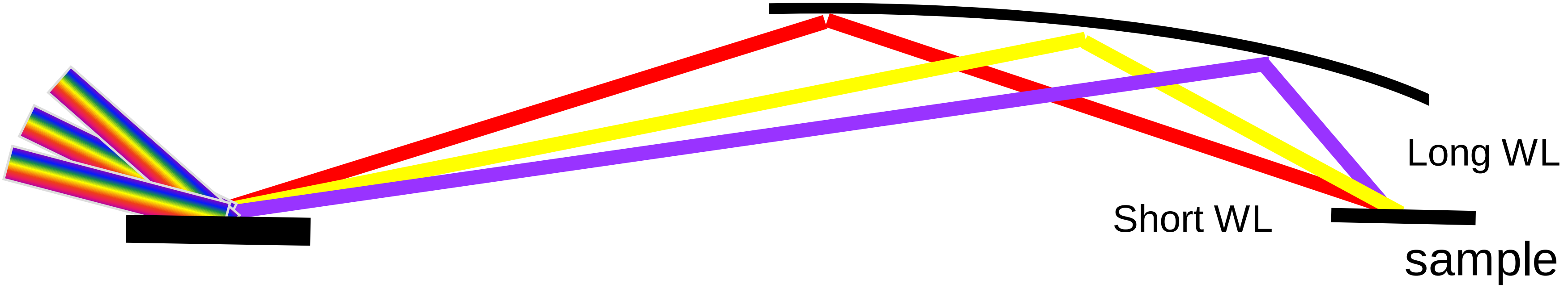


- Equivalent to TOF operation mode
- ☺ The whole reflectivity is measured at once
  - ☺ Ultra fast measurements
  - ☺ Stroboscopic measurements
- ☹ Large, high resolution (2mm), fast detector is required
- ☹ Higher sensitivity to spectral purity and to off-specular scattering

Issues

- Problems with graded mirrors
  - The resolution is not constant along the length of a graded mirror monochromator
  - Not a problem for low resolution measurements
- Diffuse scattering from mirrors
  - Not a problem,
  - can be filtered out at the sample position with a slit
- Incoherent scattering from sample
  - Integrated on the detector (no collimation after the sample)
  - Problem because of white beam illumination

SELENE (J. Stahn)



- <u>SPLIT </u>the functions to avoid graded mirror:
  - monochromatization
  - Focussing
- Technologically less demanding

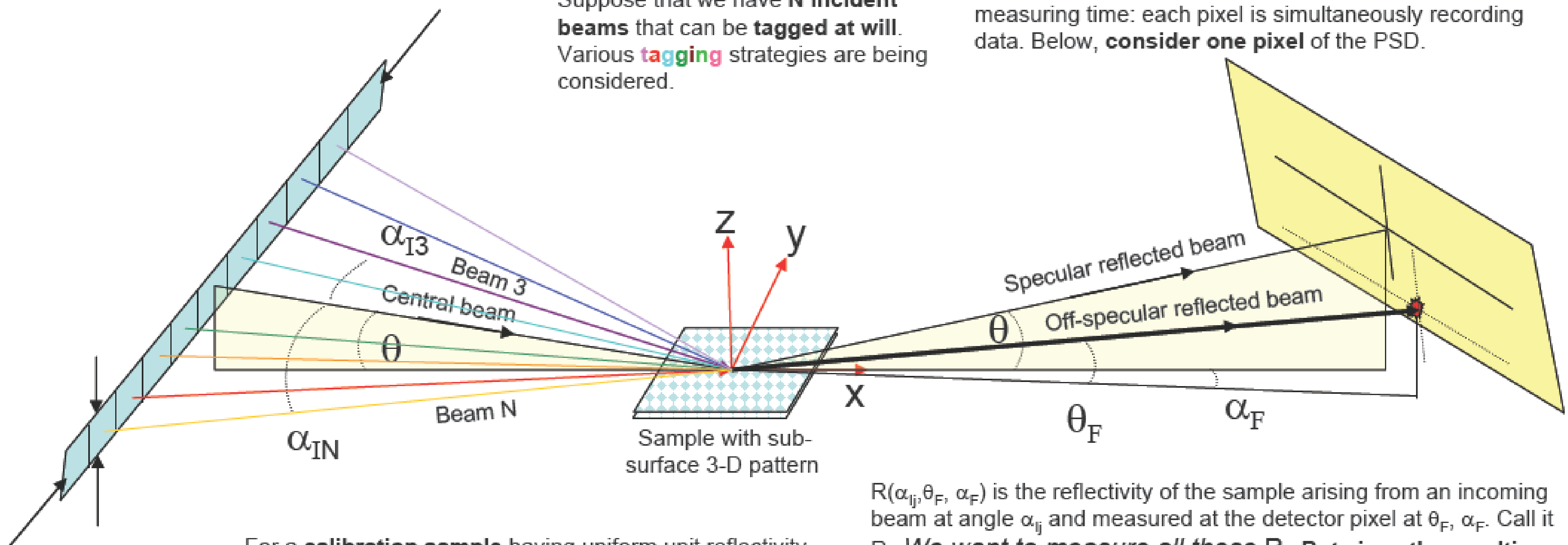
Similar proposal at NIST

Multiple Angle Grazing Incidence K (MAGIK) reflectometer

We can **increase intensity** by using **multiple** beams to reduce measuring time.

Suppose that we have **N incident beams** that can be **tagged at will**. Various **tagging** strategies are being considered.

A second way to gain: a **Position Sensitive Detector** (PSD) permits **parallel processing** to reduce the measuring time: each pixel is simultaneously recording data. Below, **consider one pixel** of the PSD.



Sample with sub-surface 3-D pattern

The slit is narrow along z to fix θ, but **broad along y** to gain Intensity.

For a **calibration sample** having uniform unit reflectivity, R = 1, the contribution, M, of each beam to the signal at the detector pixel for each tagging condition must be measured separately.

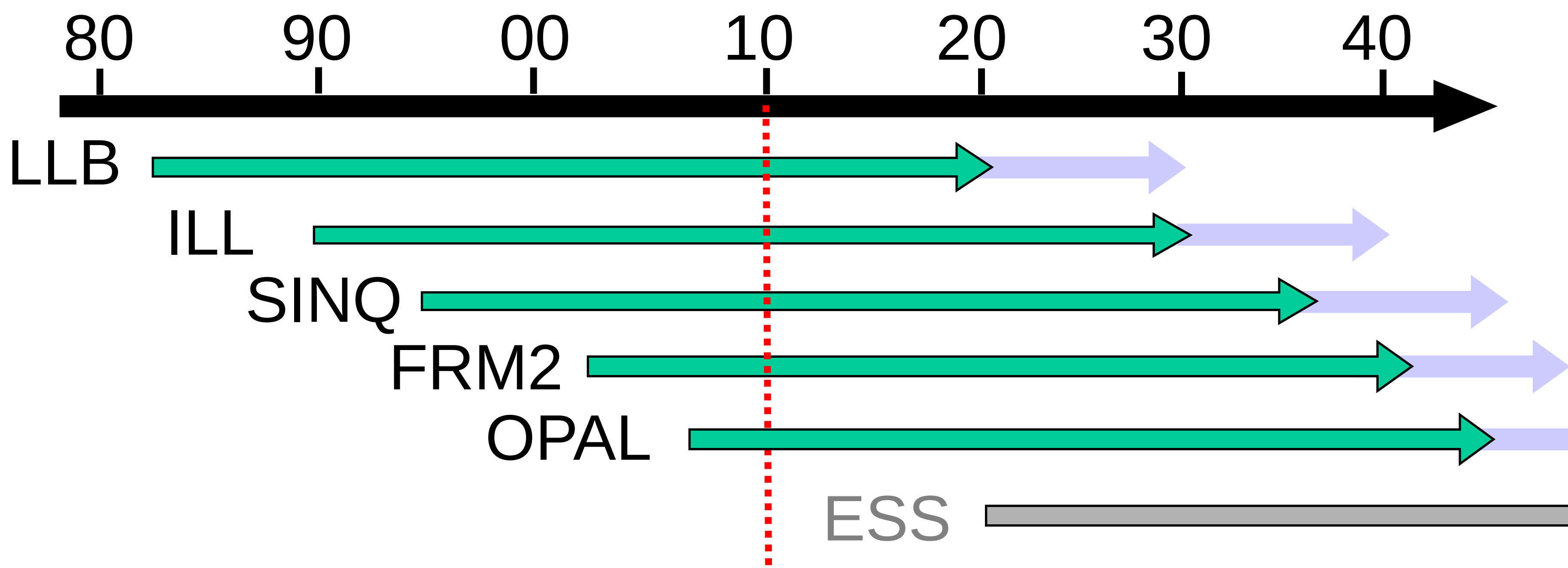
$R(\alpha_{Ij},\theta_F, \alpha_F)$ is the reflectivity of the sample arising from an incoming beam at angle α_{Ij} and measured at the detector pixel at θ_F, α_F. Call it R_j. *We want to measure all these* R_j. **But since the resulting signal contains the SUM of terms arising from each incident beam, the terms need to be separated.** By using a number of tagging conditions and measuring once for each condition, this separation can be accomplished.

Comparisons

Methods	Refraction	EASYREF	GRADTOF	SELENE	REFOCUS
Complexity	simple	simple	average	average	average
Data acquisition	simple	simple	average	average	average
Data processing	simple	simple	simple	average	average
Efficiency	high	high	Medium (x6)	high	high
Cost	€10000	€40000	€100000	€50000	€50000

Future

- Note that these techniques are efficient only on <u>continuous sources</u>
- Presently, building of spallation sources :
  - SNS, JPARC, ISIS II, ESS (?)
- Continuous sources still have a long time life



Conclusion

- Lots of new design proposals for high flux reflectometers
  - More efficient use of the available neutrons
  - Gains in flux ~ 50-100

- Open questions (to be tested experimentally)
  - Off-specular scattering (OK)
  - Incoherent scattering (?)
  - Background noise

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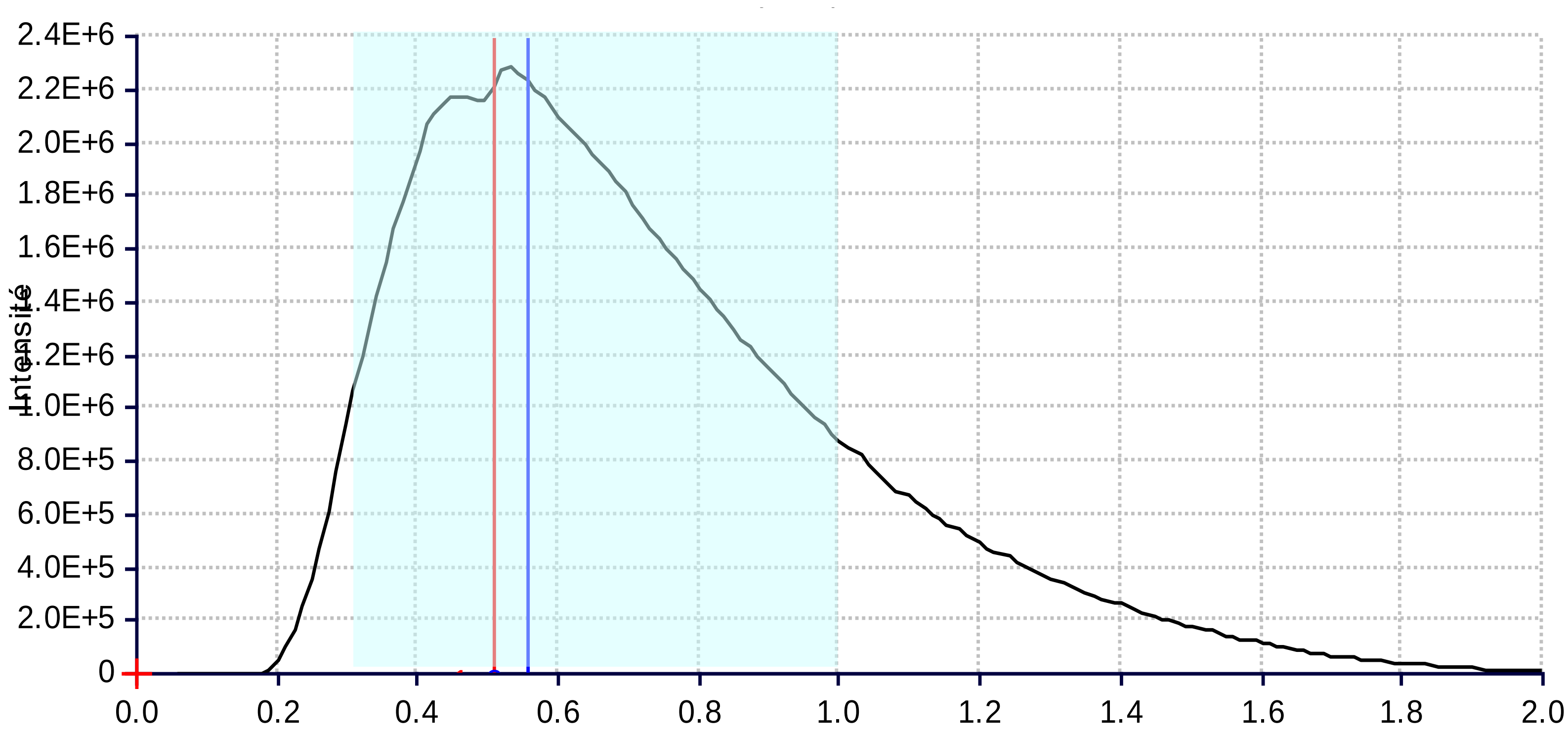
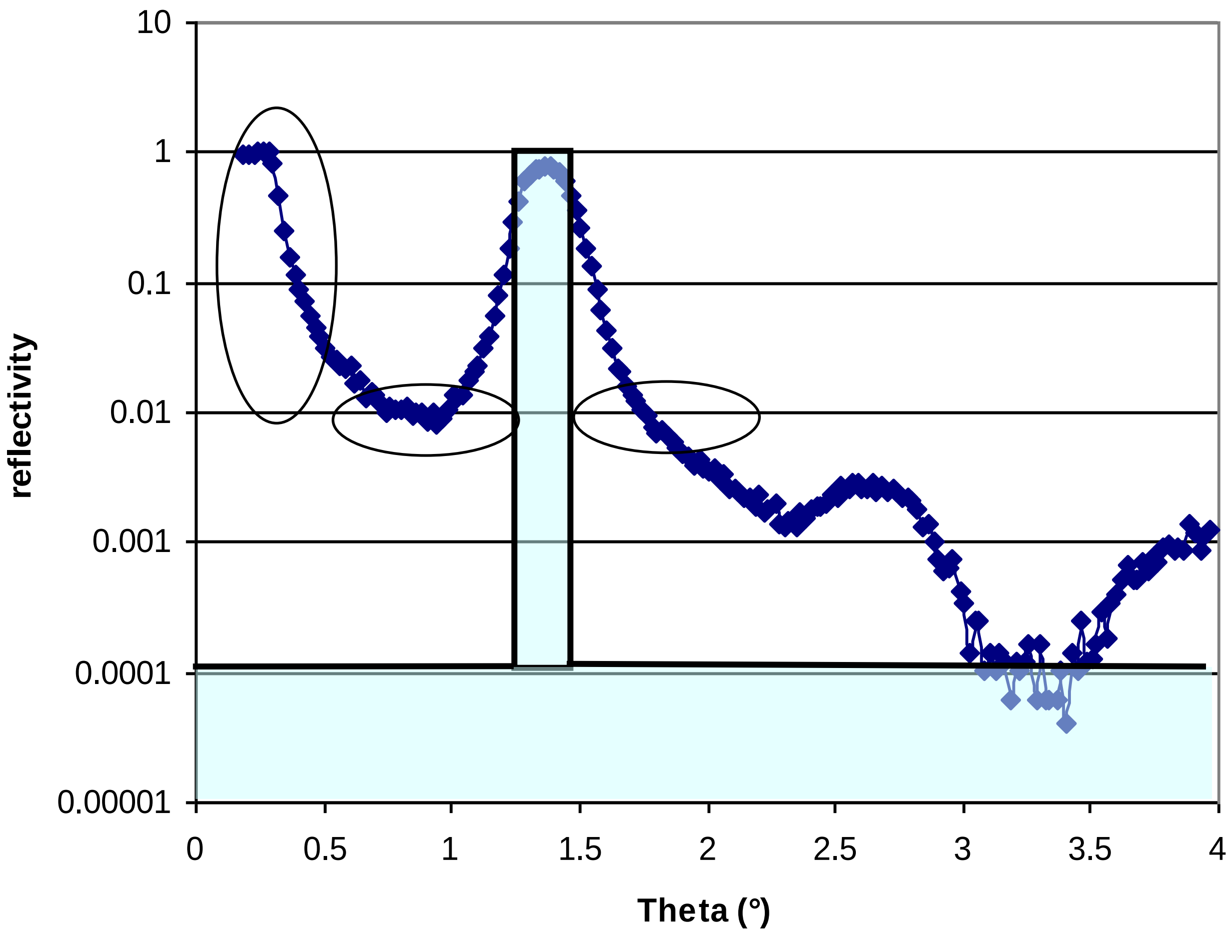
Efficiency in Mode A

- White beam in the G3bis bender (EROS)

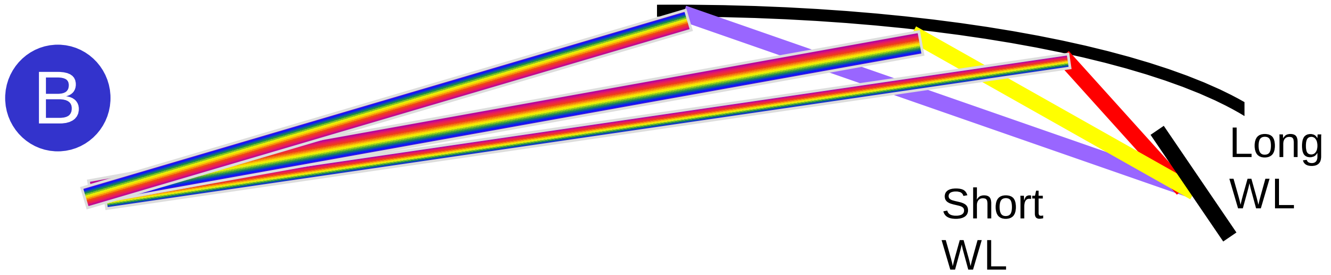


Monochromator

- Present ML monochromators are not perfect

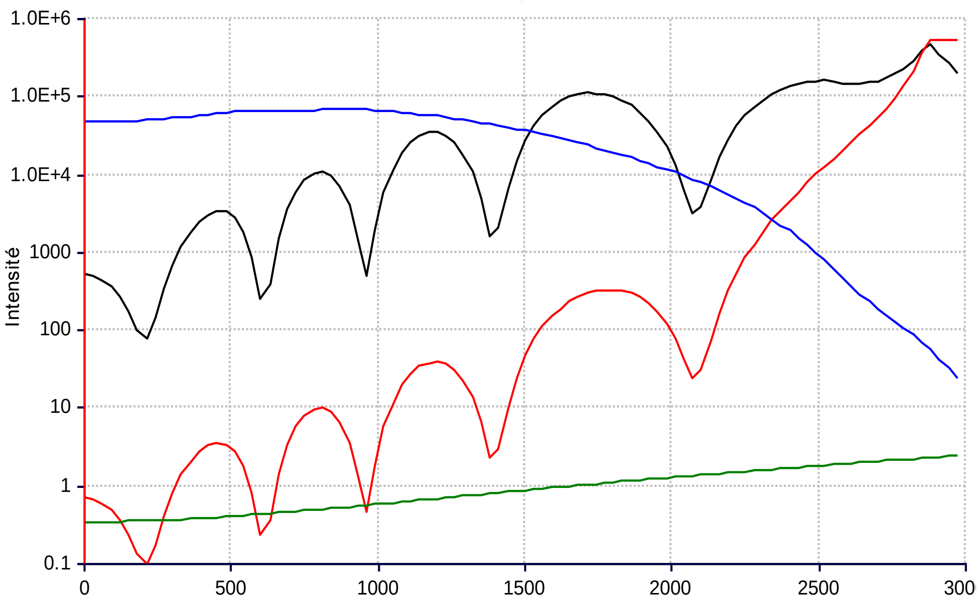


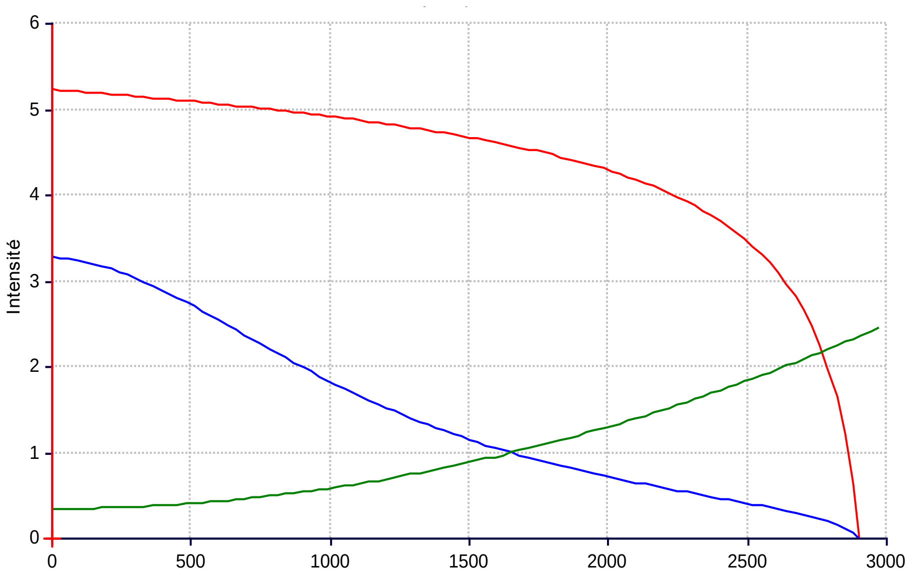
Reflectivity in Mode B



- Reflectivity (as measured)
- Reflectivity (normalized)
- Incident flux

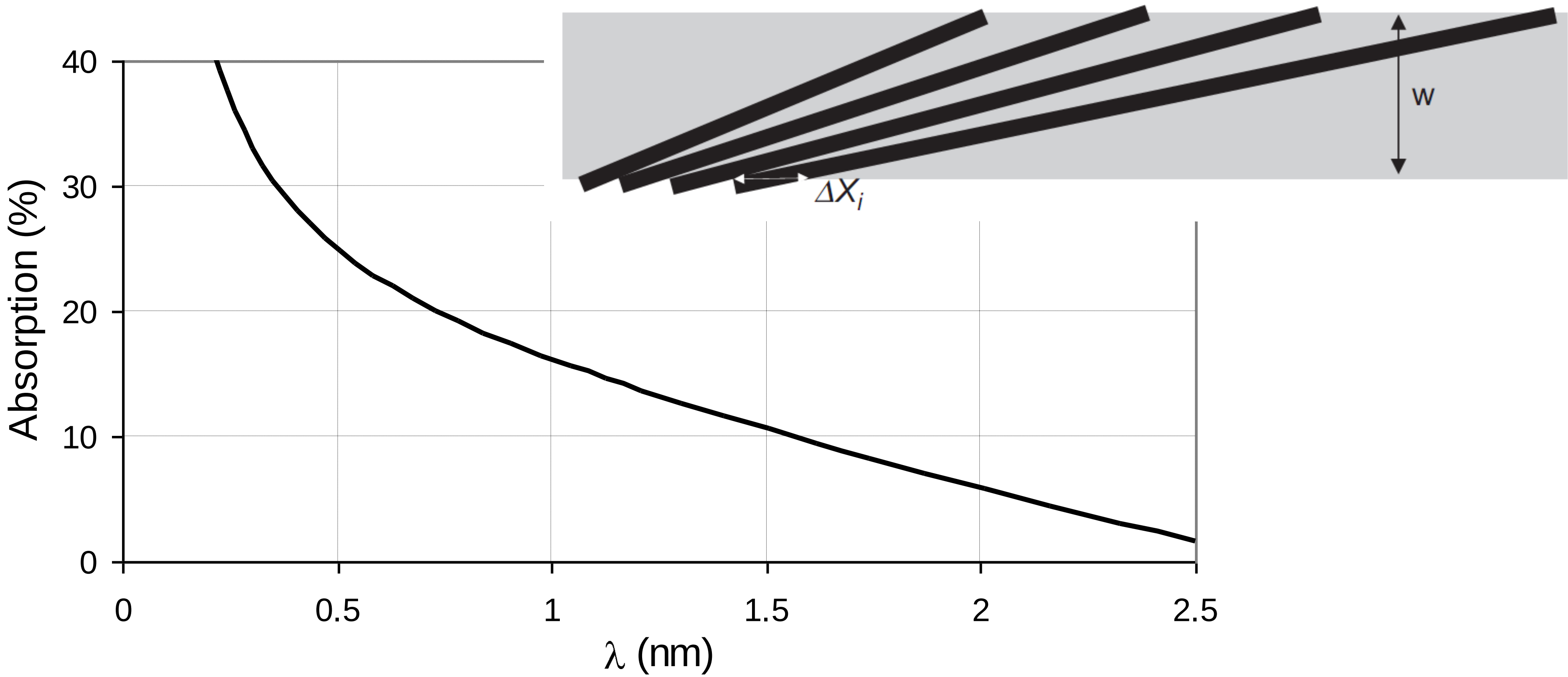
- Theta in (°)
- Lambda (A°)
- Q (nm-1)



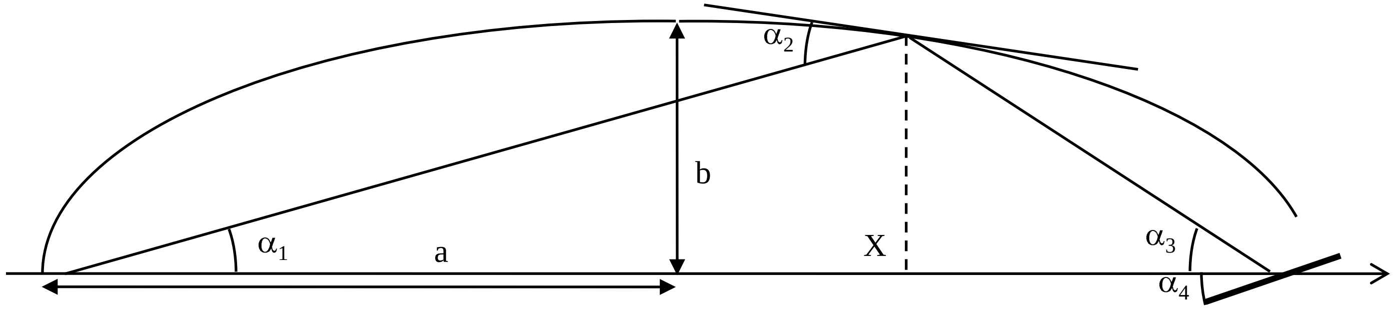


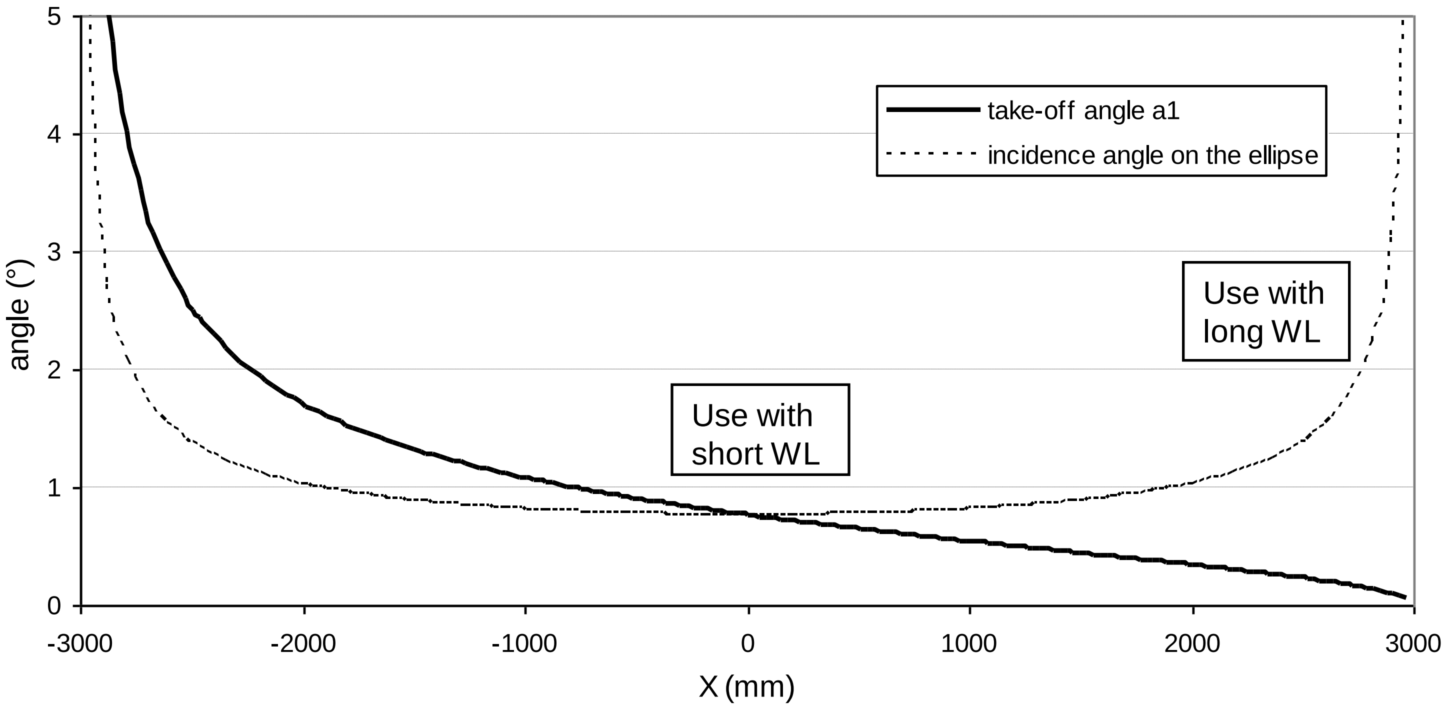
Absorption in the device

- Si absorption: (experimental measurement)
  - $A(\lambda)\ (\%/mm) = 0.1 + 0.4\ \lambda\ (nm)$

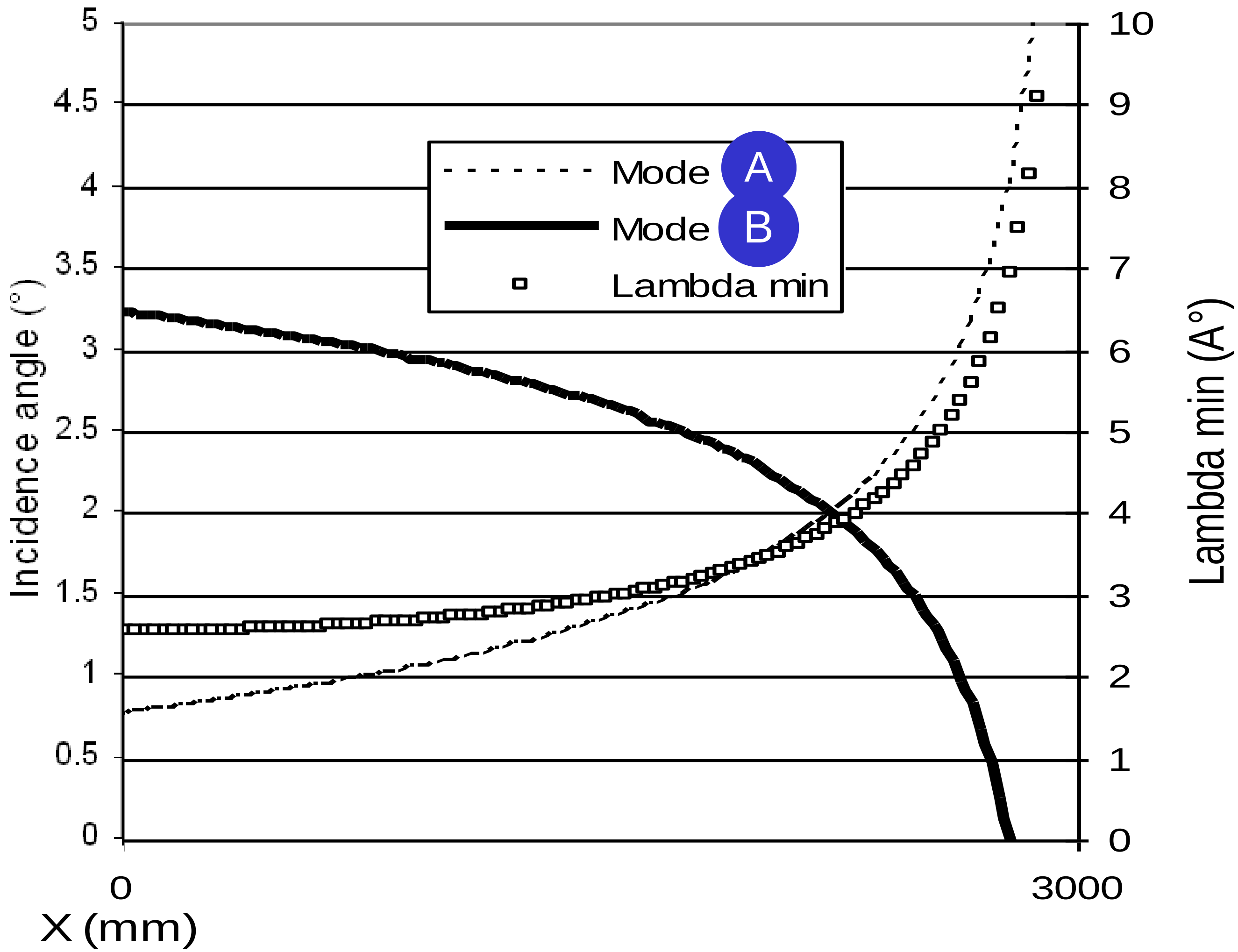


Focussing ellipse design

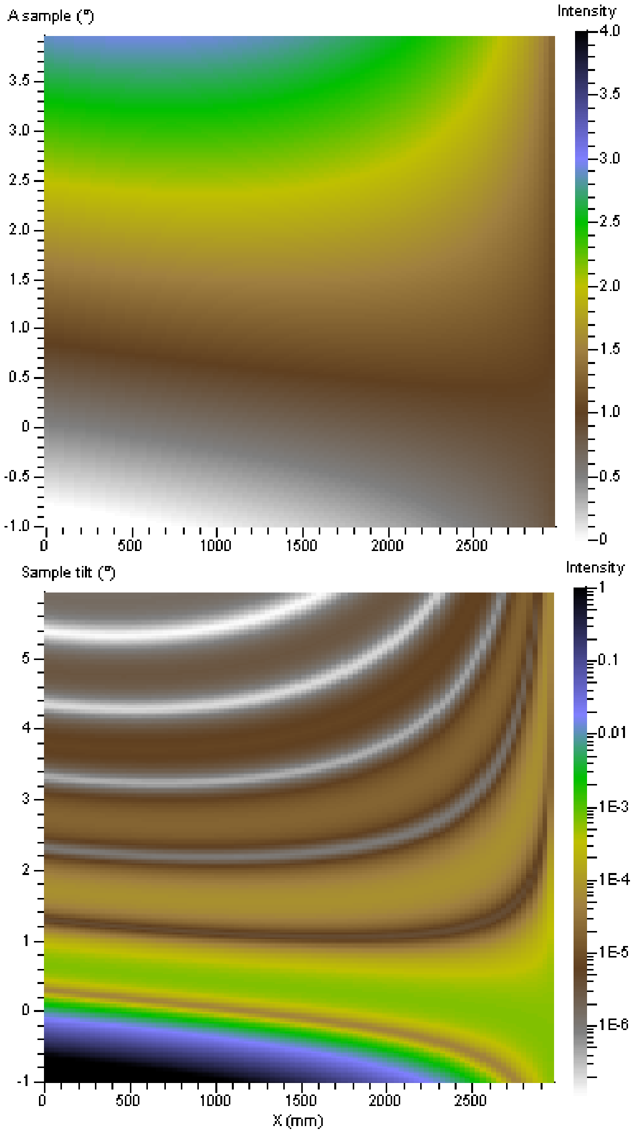


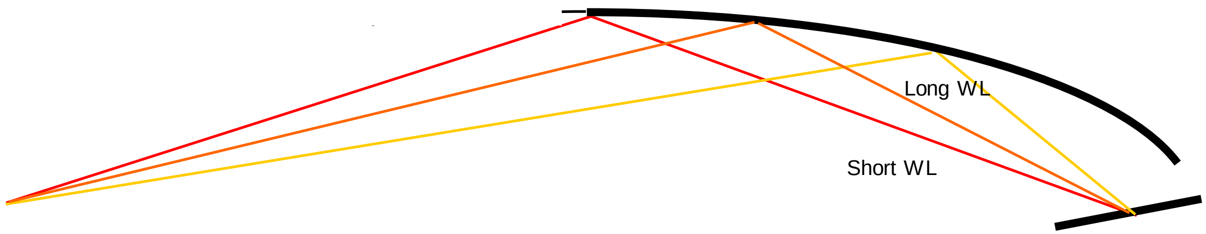


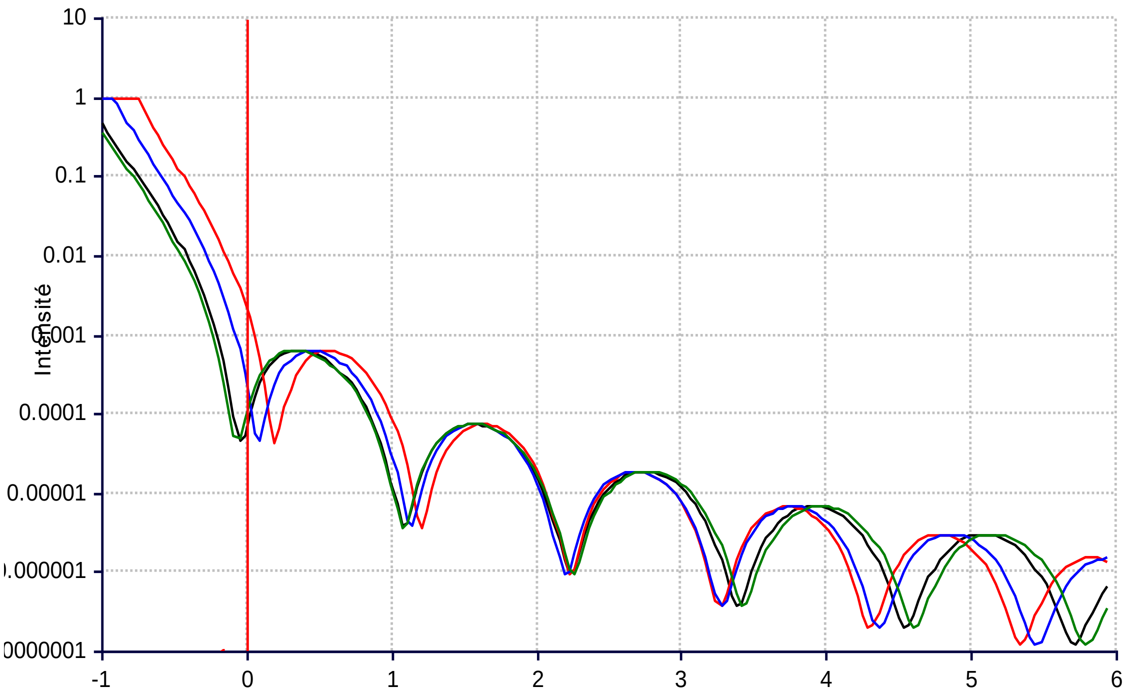
Operation parameters



Reflectivity in Mode A







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REFocus set-up : conclusion

- Gain in flux of 20 – 50 wrt existing reflectometers on continuous sources

- General purpose set-up
  - Small / large / magnetic samples
  - No compromise on resolution
  - Operation very close to existing reflectometers
  - Possibility to study liquid surfaces

- Set-up is simple (no complex mechanics)
- Technology is already available
- Cheap
- Possible to implement on existing reflectometers

Implementation

- <u>Detector</u>.
  - size of 300mm
  - resolution 2-3 mm
  - very high counting rate
  - such detectors do exist,

- <u>Focussing ellipse.</u>
  - 1D, 3000mm long.
  - Such optical elements have already been built at a reduced scale of 1/3.

- <u>Fabrication of graded monochromator.</u>
  - The technology exists and has been demonstrated.

- <u>Multilayer monochromators.</u>
  - 2 issues
    - total reflection region.
    - intensity ratio between the diffraction peak and the bottom of the peak is only of the order of 10^{-2}.

Improvements

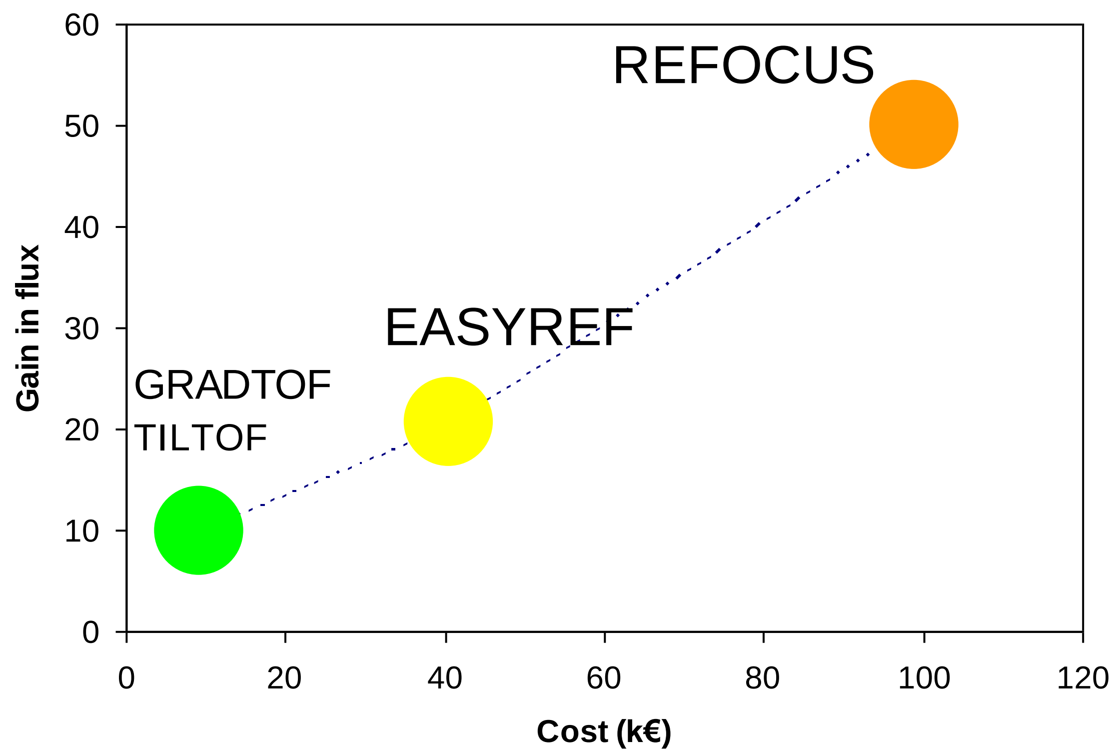
- Present design :
  - $3\theta_c$ monochromators ; length 3m
- Doubling the size of the device
  - Doubling of the solid angle
  - Flux multiplied by 2
- Use $4\theta_c$ or $5\theta_c$ monochromators
  - Solid angle can be increased for short wavelengths

Conclusion

- New reflective optics technology + High speed detectors

⇨ new designs of <u>specular</u> neutron reflectometers using all the neutrons in the guides

- Prototypes under construction within NMI3
- PSI (J. Stahn et al)
- HZB (T. Krist et al)
- TUM (P Böni et al)



Citer

- Se focaliser sur EASYREF
- Problème avec REFOCUS:
  - Graded SM pose un problème de résolution
  - Problème du hors spéculaire dans EASYREF
    - Faire le calcul! (à partir d'une mesure)
- Problème de l'incohérent et du diffus
- Prendre les tables de la diffusion incohérente
- Récupérer les fichier de diffusion hors spéculaire