BrightnESS

The Multi-Blade project

Boron-10-based detector for reflectometry instruments

Francesco Piscitelli

Detector Group

NSS seminar

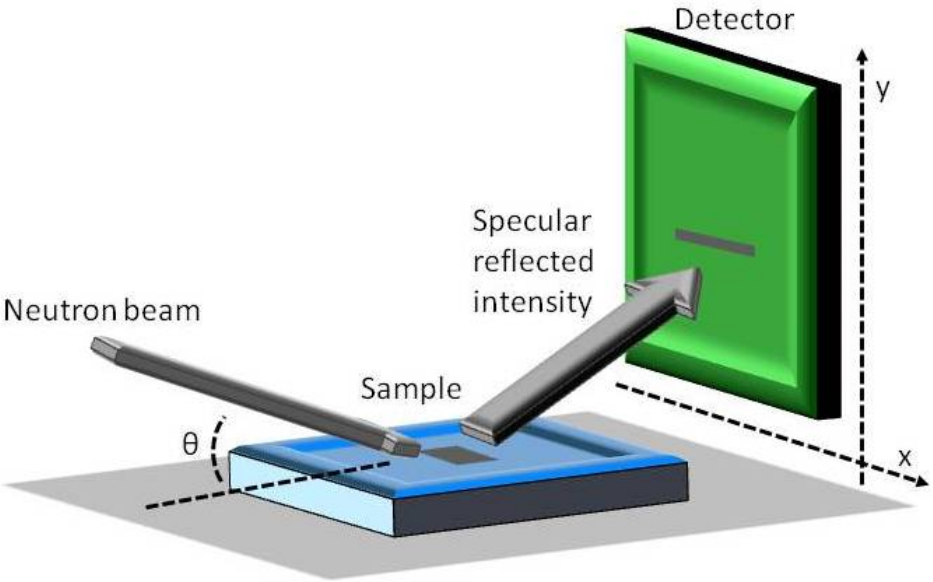
2016/01/19

EUROPEAN SPALLATION SOURCE

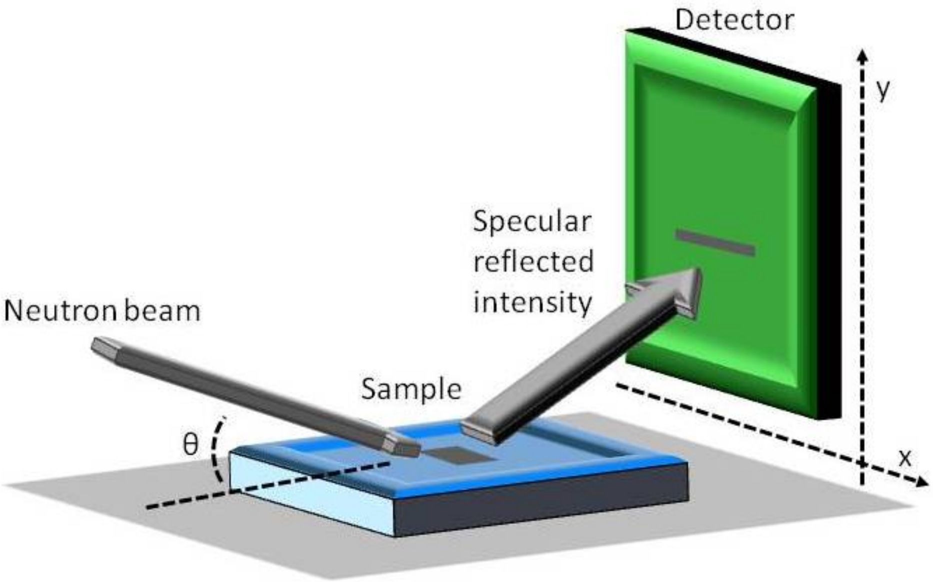
Outline

- Reflectometry
- Reflectometry at ESS: FREIA and ESTIA
- The Multi-Blade detector
- Forthcoming plans

Reflectometry: an introduction

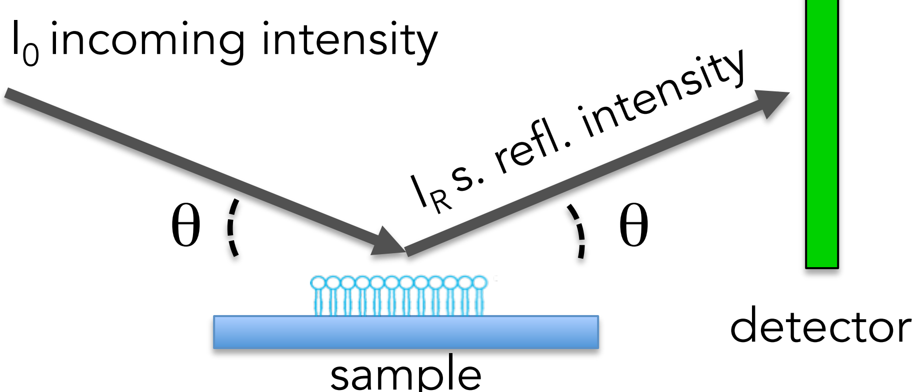


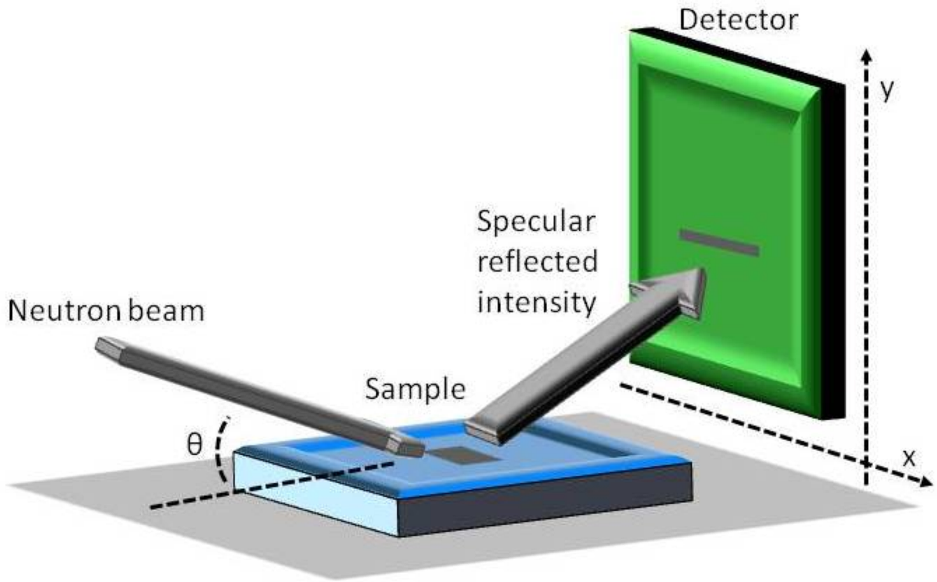
Reflectometry is a technique to study
SURFACES AND INTERFACES



Reflectometry is a technique to study
SURFACES AND INTERFACES

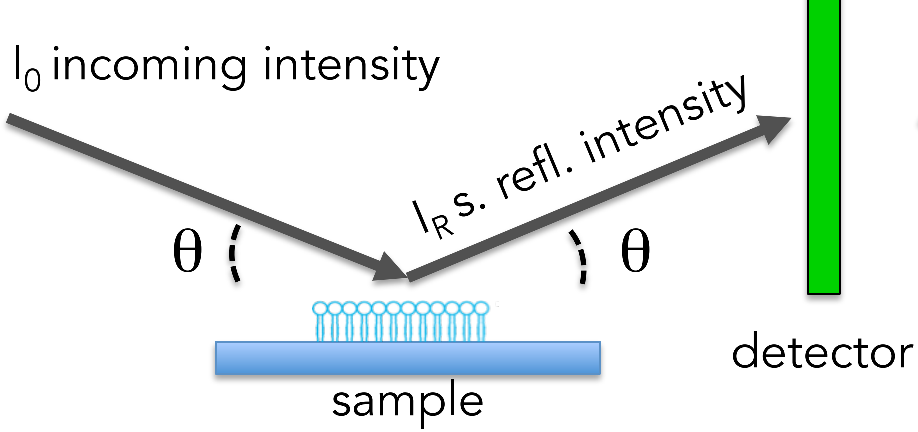
Specular reflection



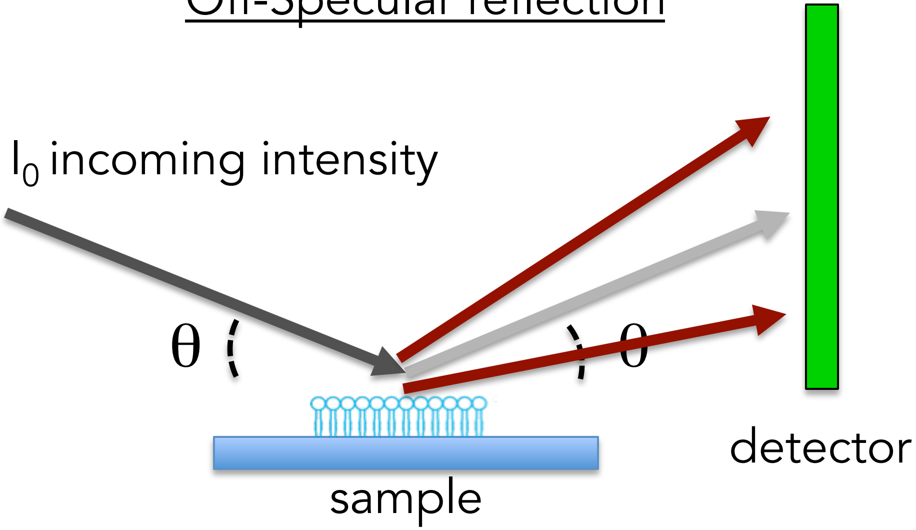


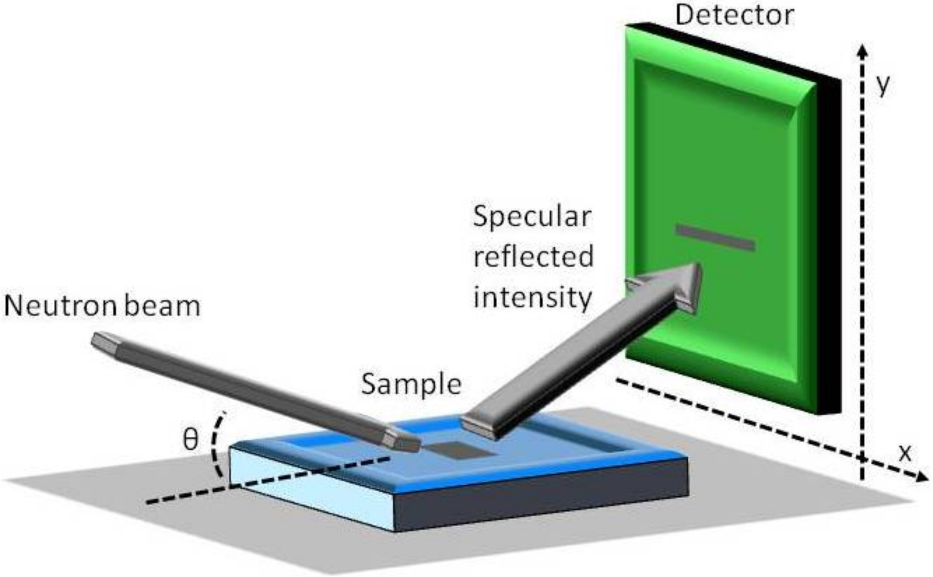
Reflectometry is a technique to study
SURFACES AND INTERFACES

Specular reflection



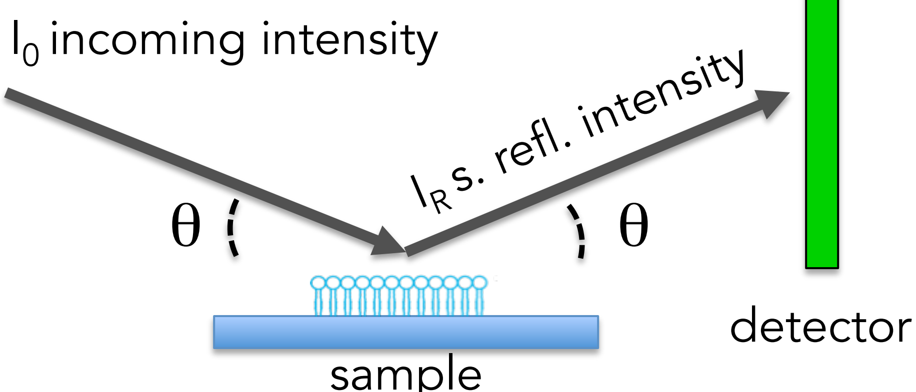
Off-Specular reflection

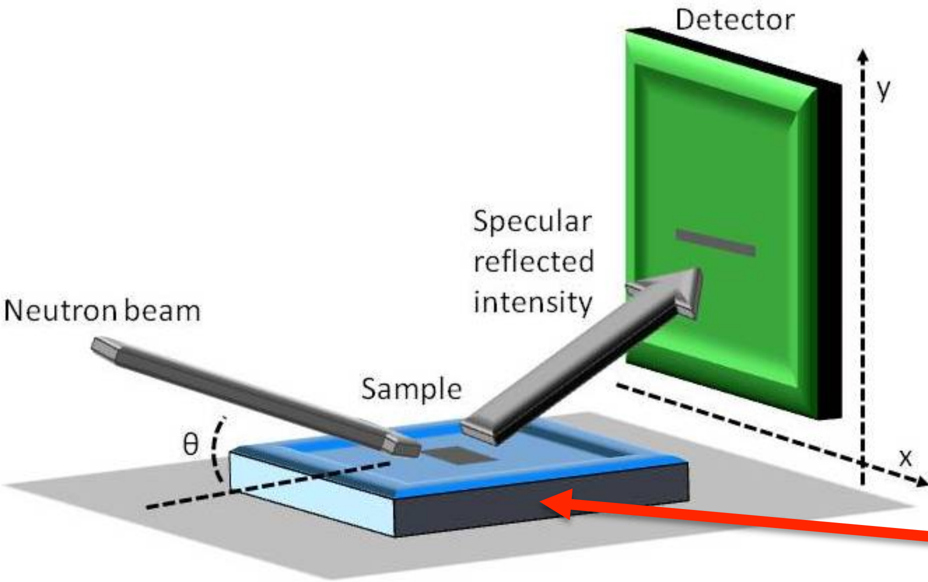


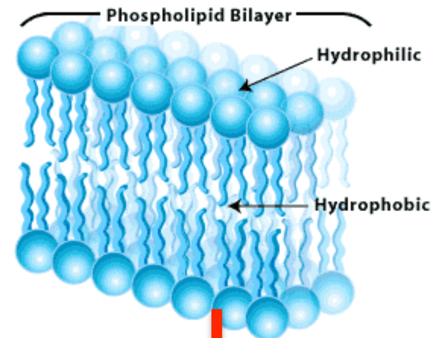


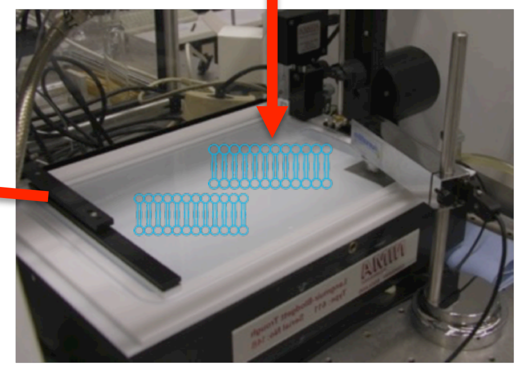
Reflectometry is a technique to study
SURFACES AND INTERFACES

Specular reflection



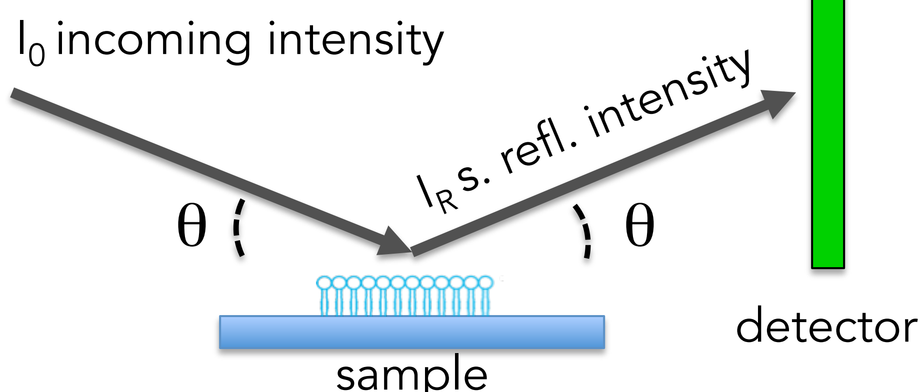


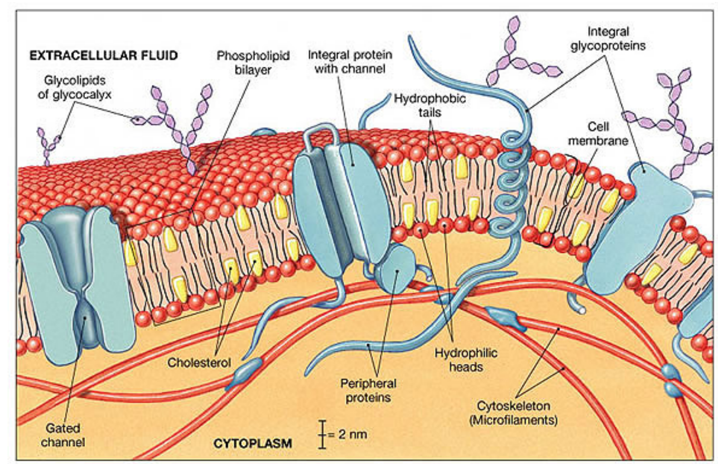


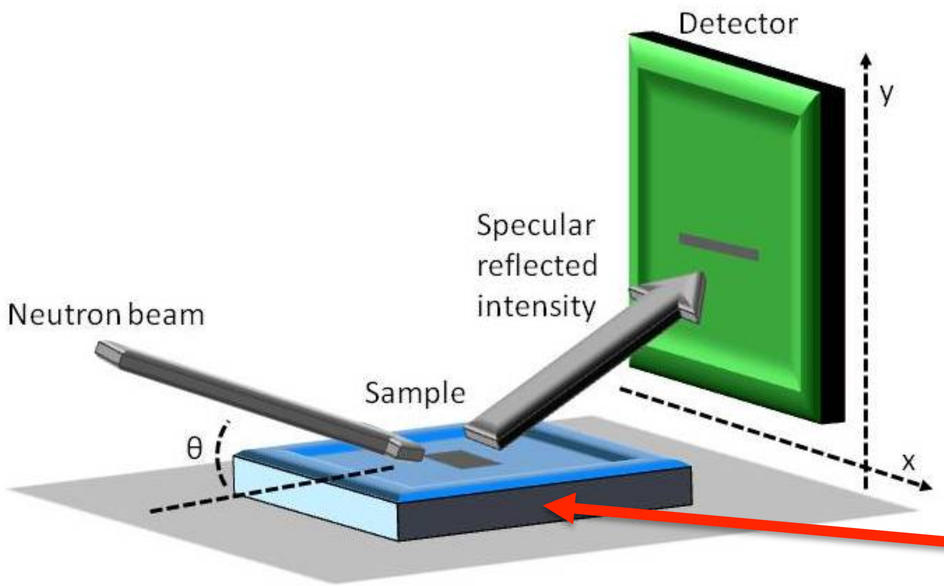


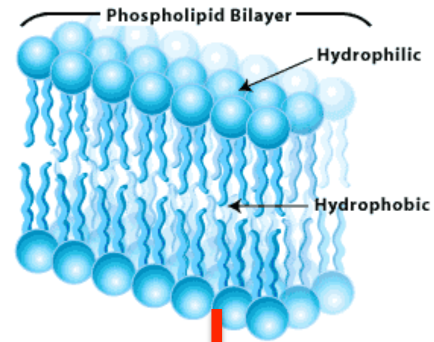
Langmuir–Blodgett trough

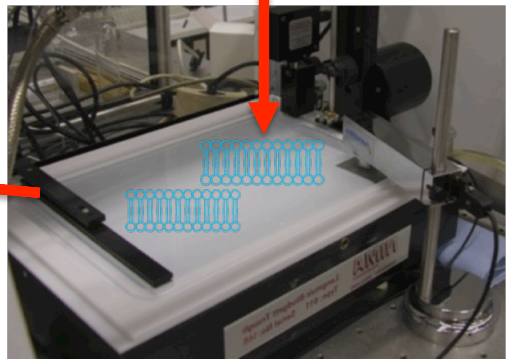
Specular reflection





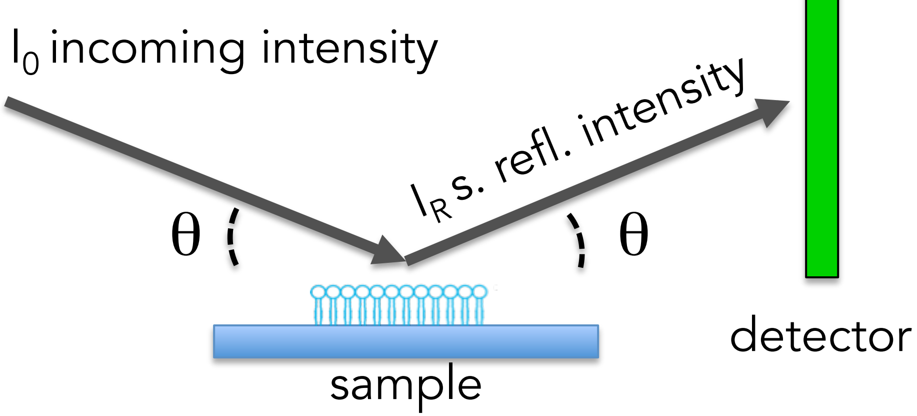


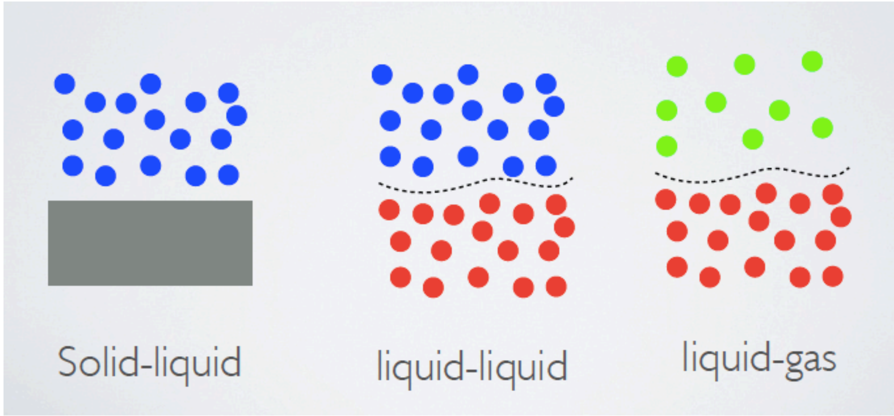


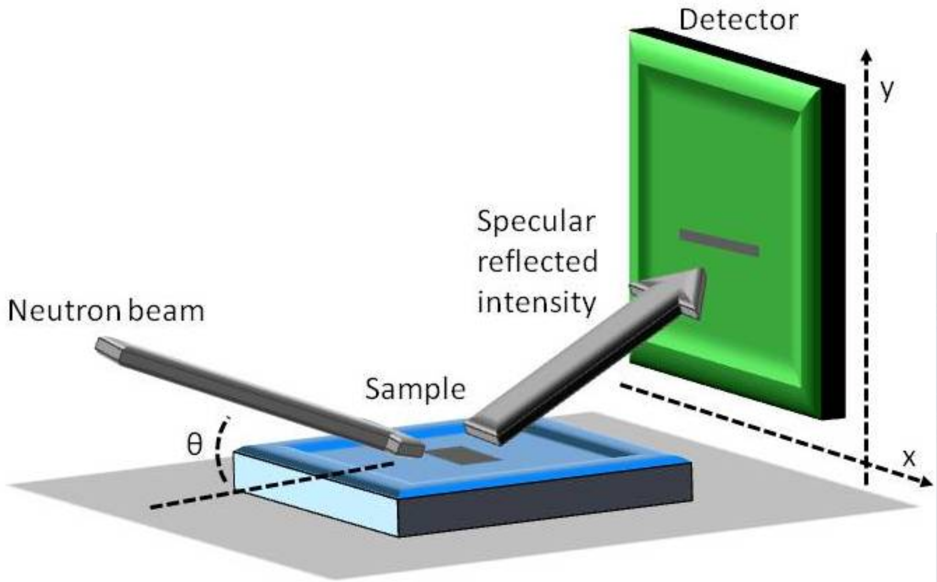


Langmuir–Blodgett trough

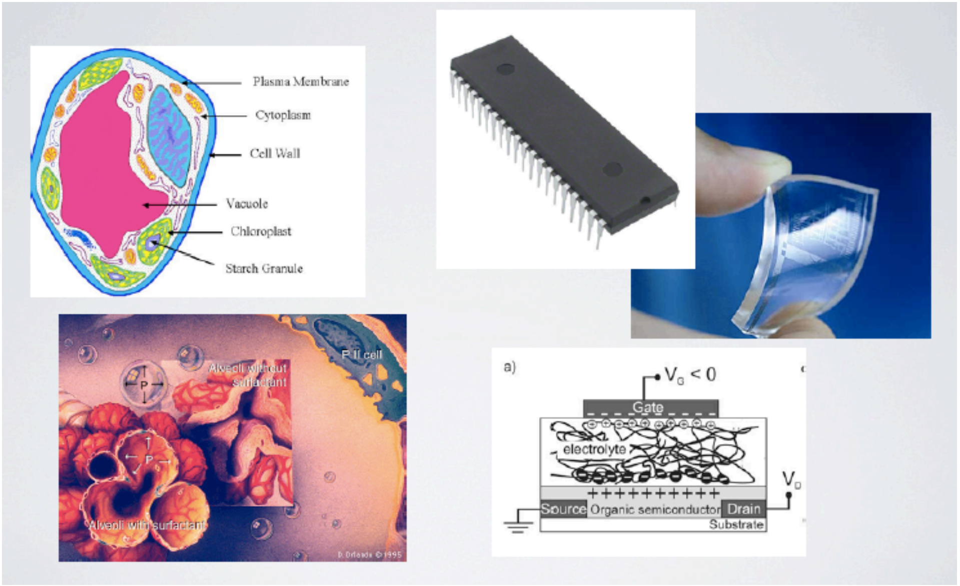
Specular reflection



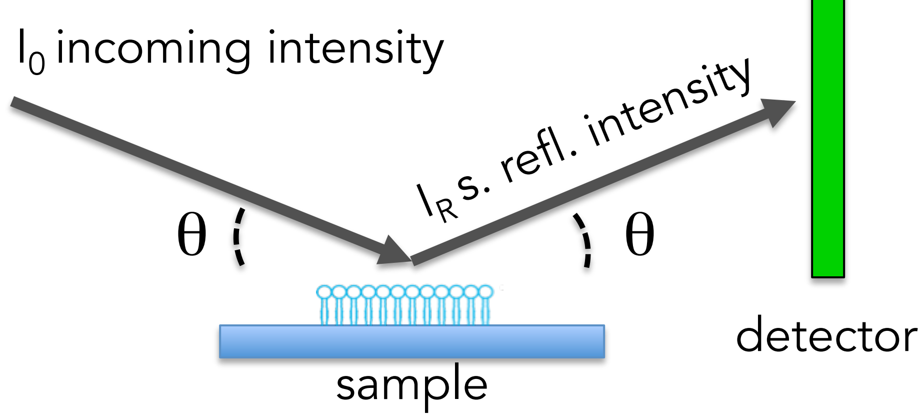


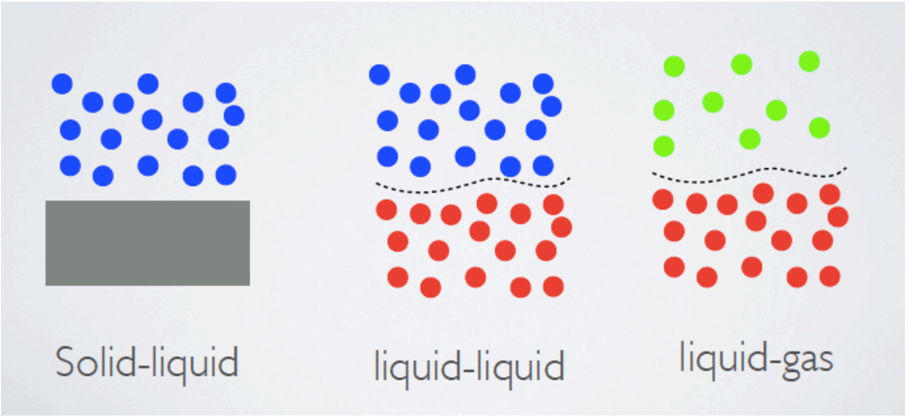


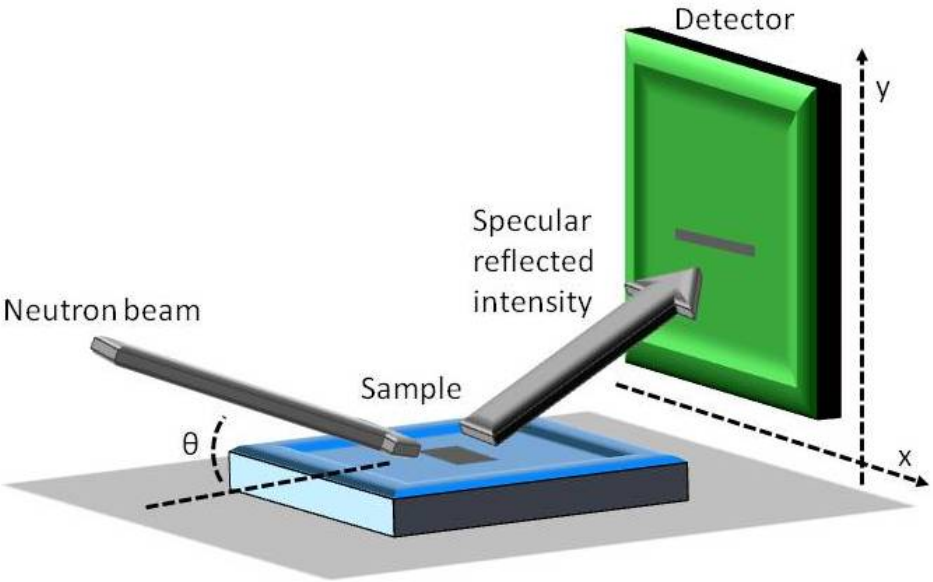
Reflectometry is a technique to study
SURFACES AND INTERFACES



Specular reflection

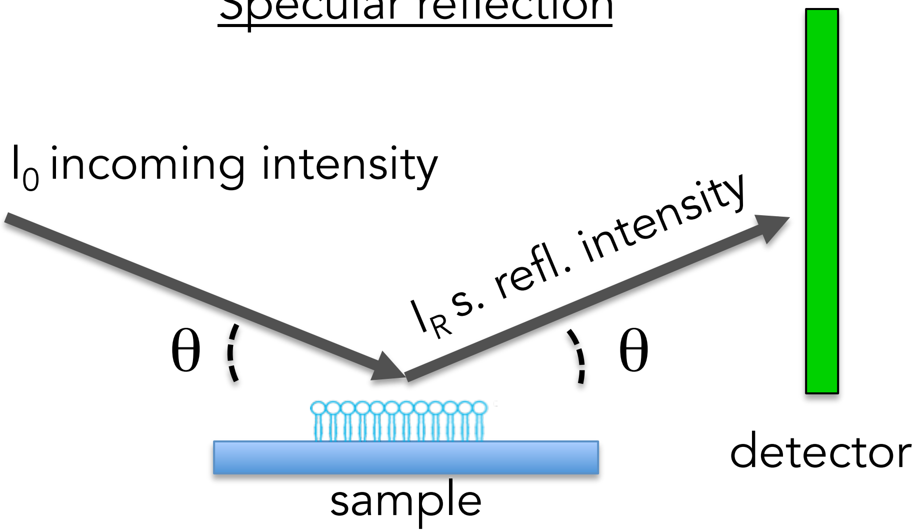






To measure the reflected neutrons as a function of q

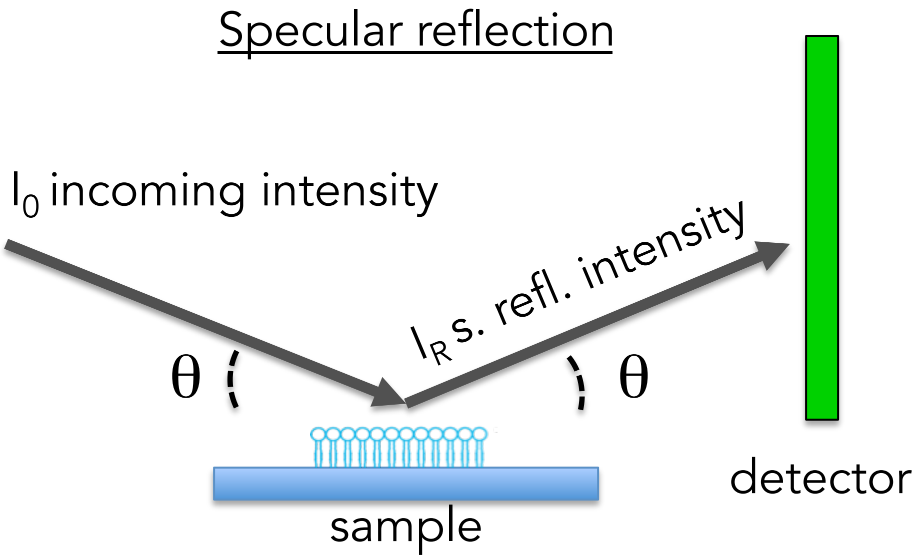
Specular reflection



Neutron wavelength

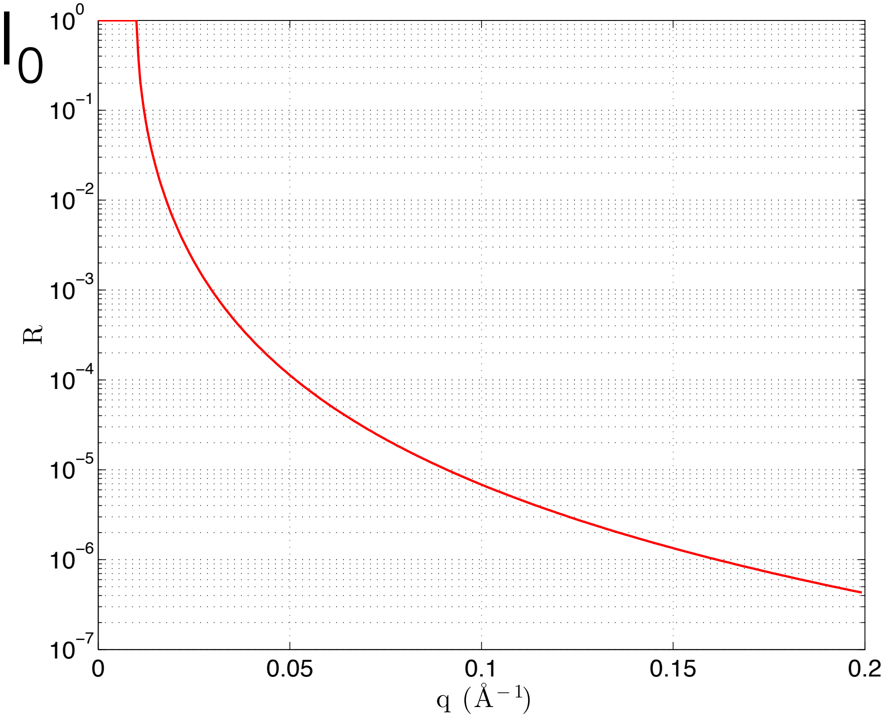
$$q = (4\pi/\lambda)\sin(\theta)$$

Incidence angle

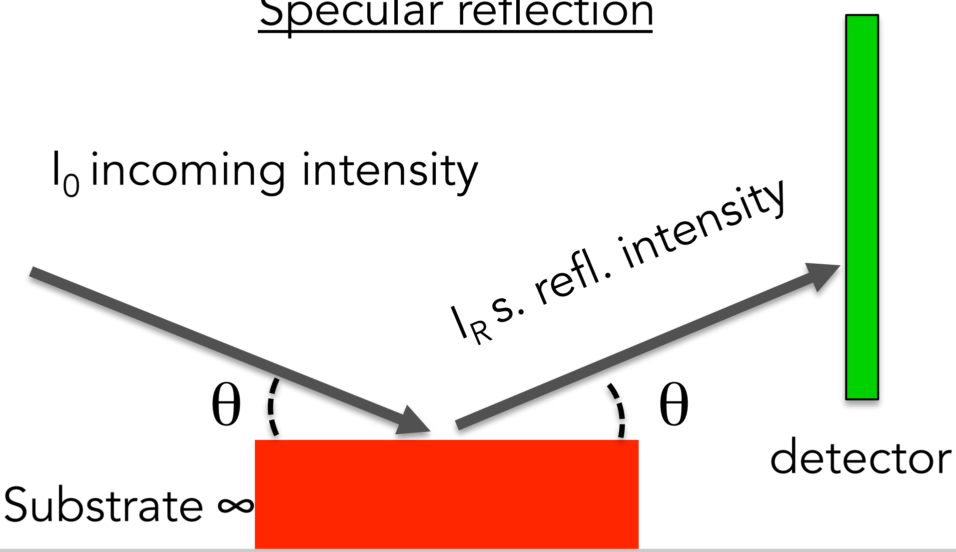


$$q = (4\pi/\lambda)\ \sin(\theta)$$

$$R = I_R/I_0$$

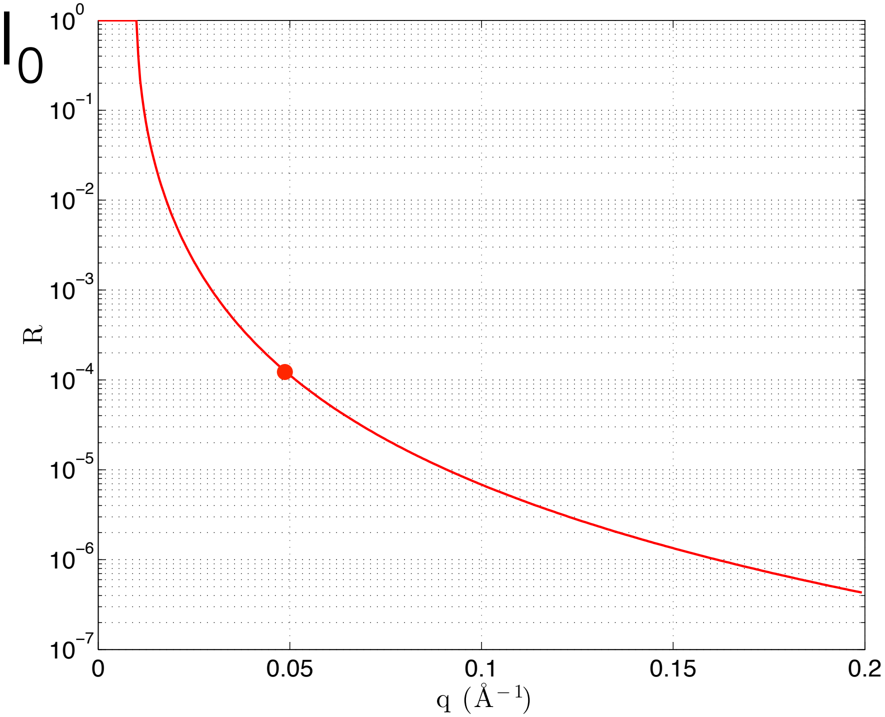


<u>Specular reflection</u>

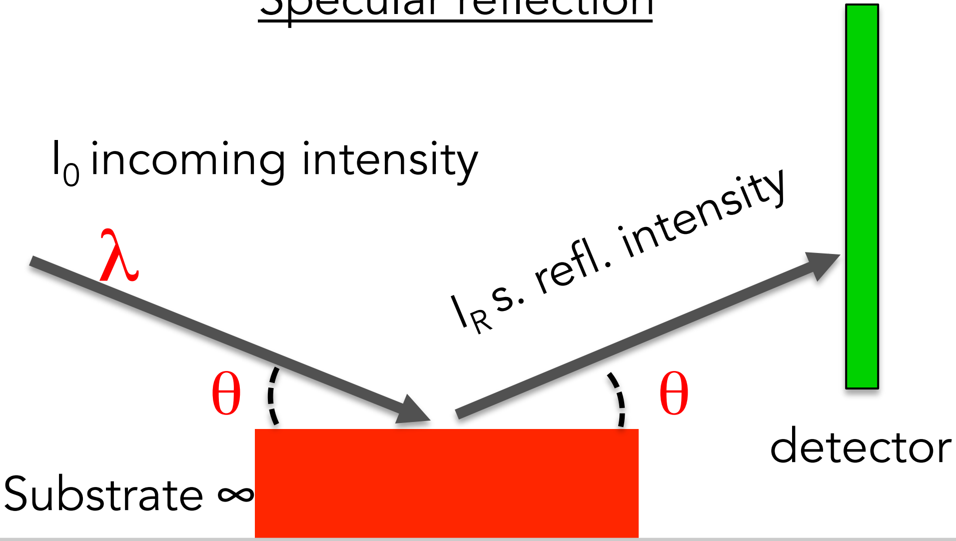


$$q = (4\pi/\lambda)\sin(\theta)$$

$R = I_R/I_0$

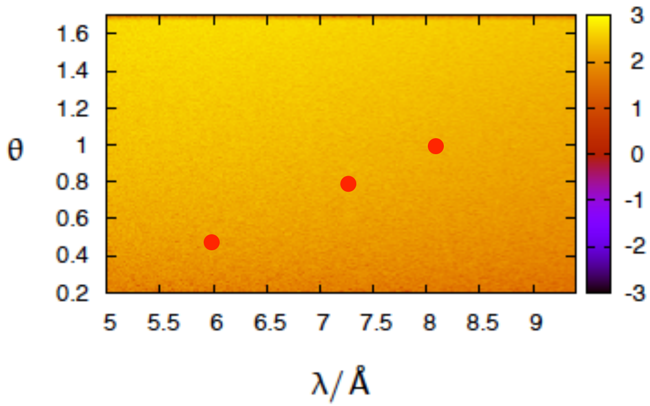


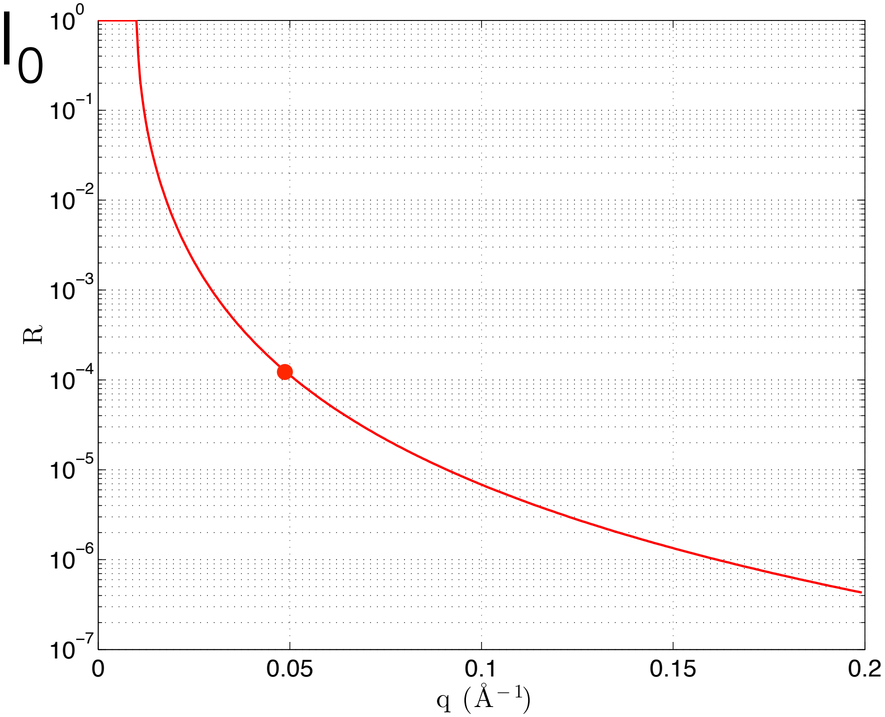
Specular reflection



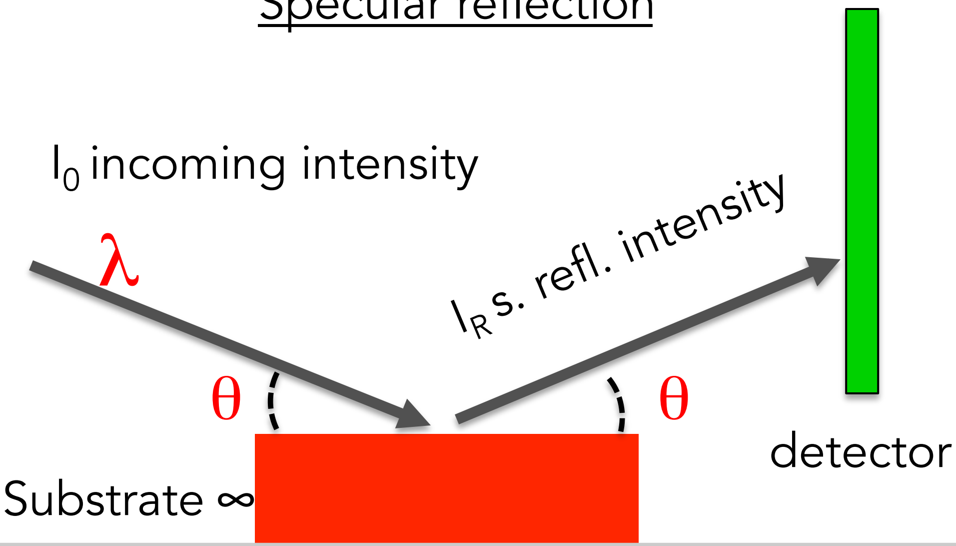
$$q = (4\pi/\lambda)\sin(\theta)$$

$$R = I_R / I_0$$



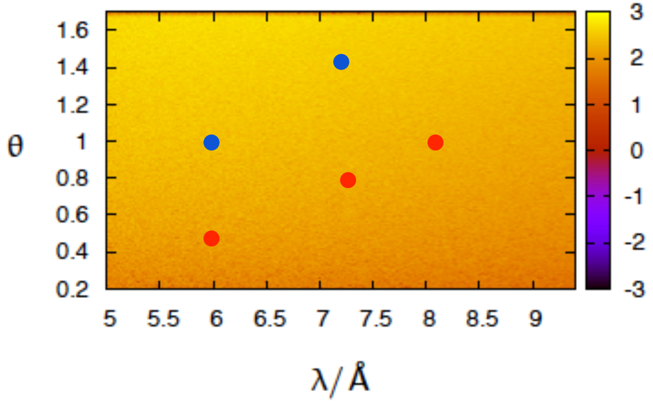


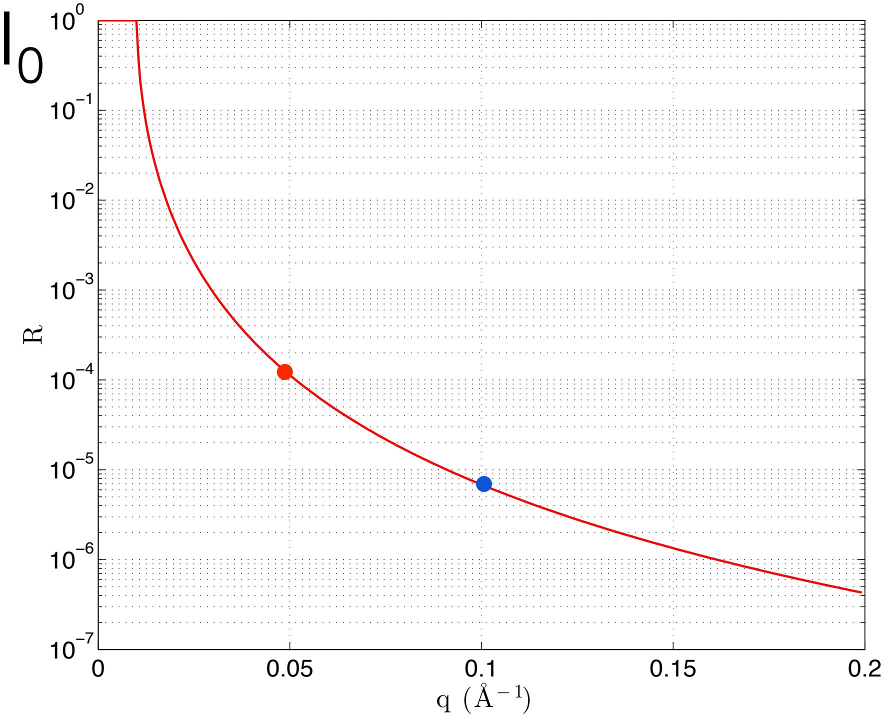
Specular reflection



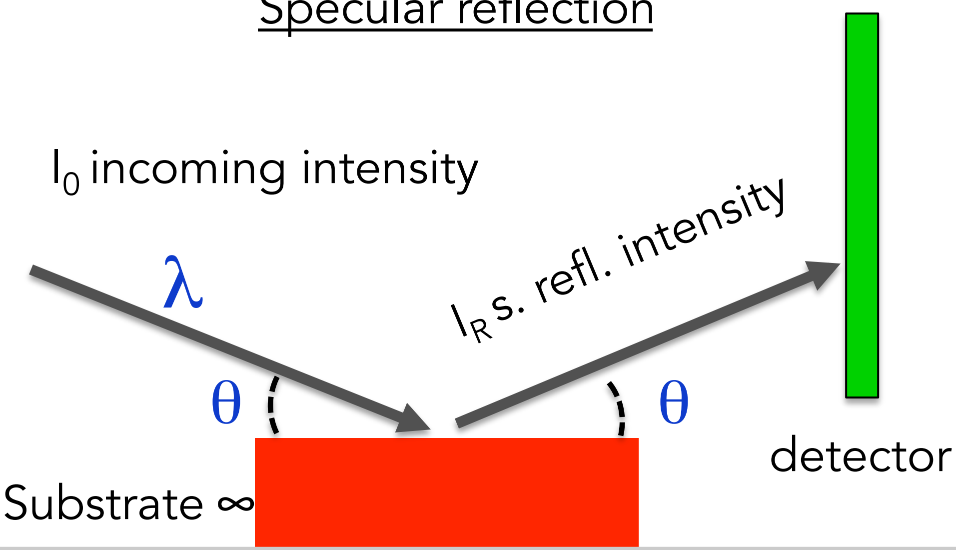
$$q = (4\pi/\lambda)\sin(\theta)$$

$R = I_R/I_0$



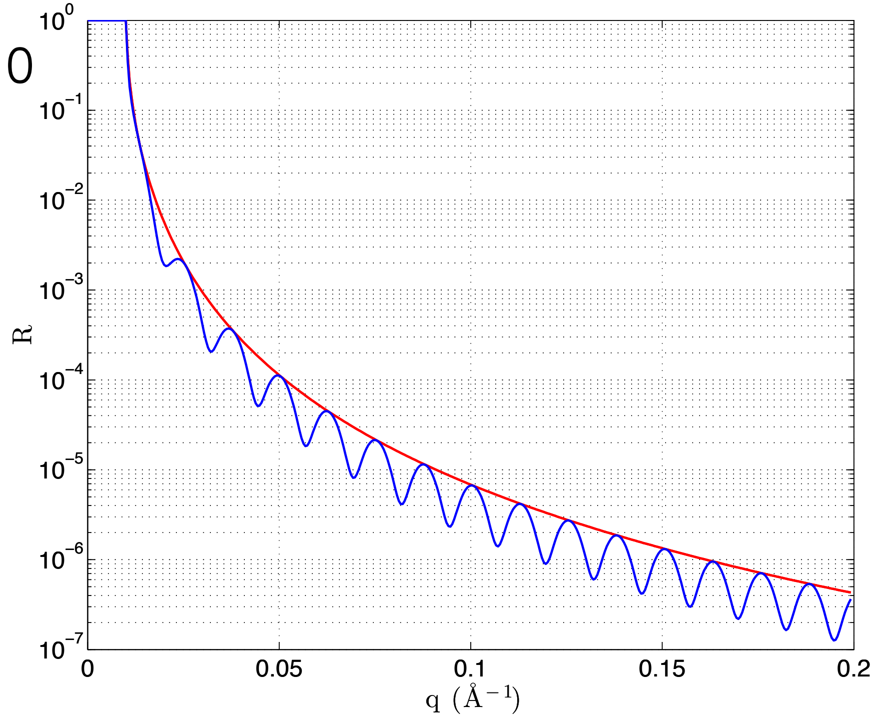


Specular reflection

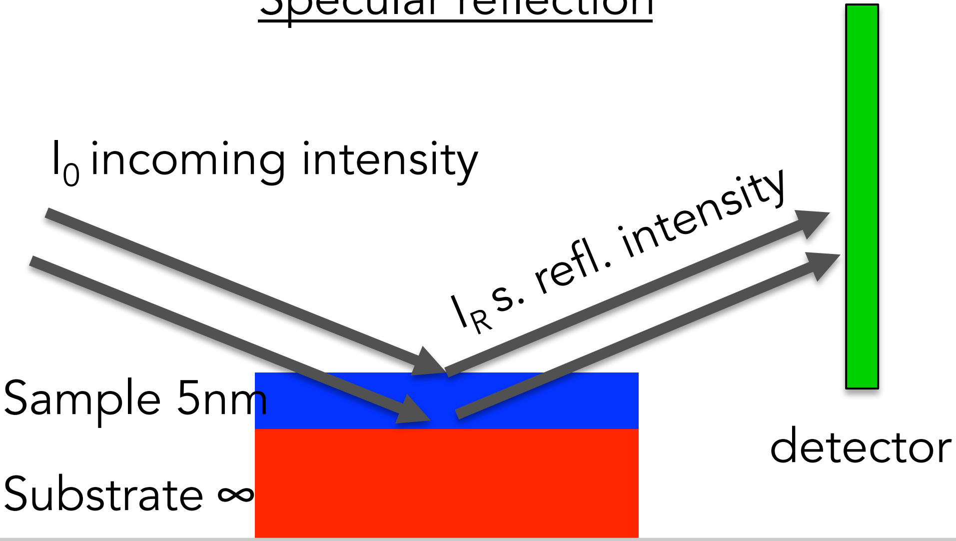


$$q = (4\pi/\lambda)\sin(\theta)$$

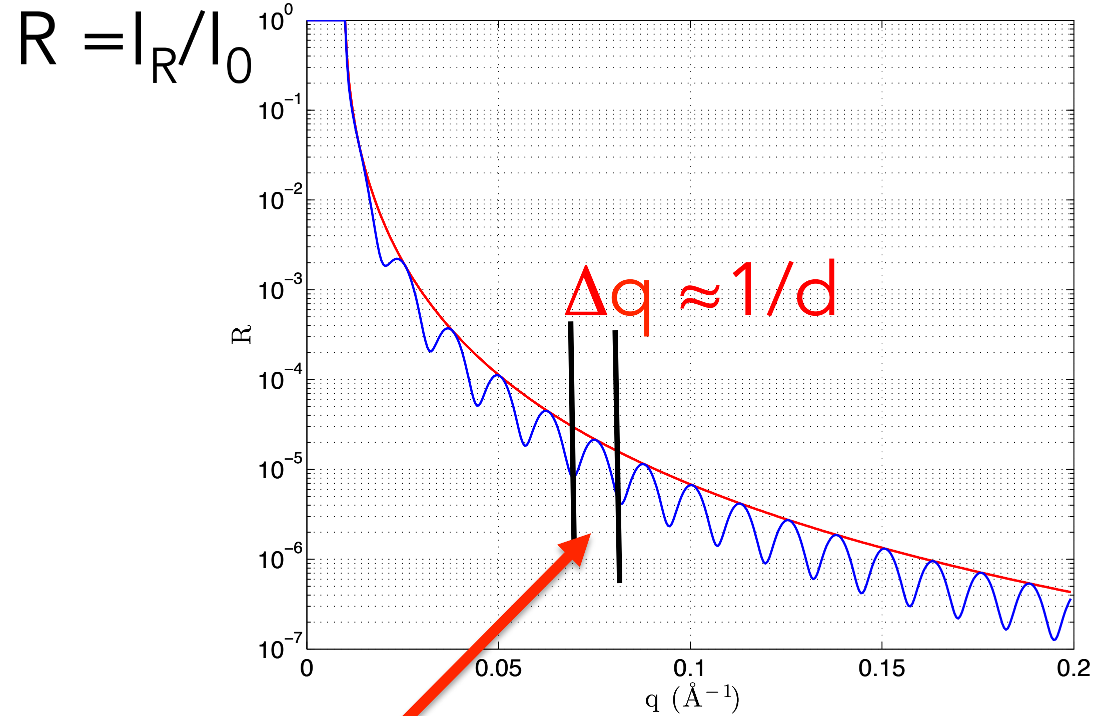
$R = I_R/I_0$



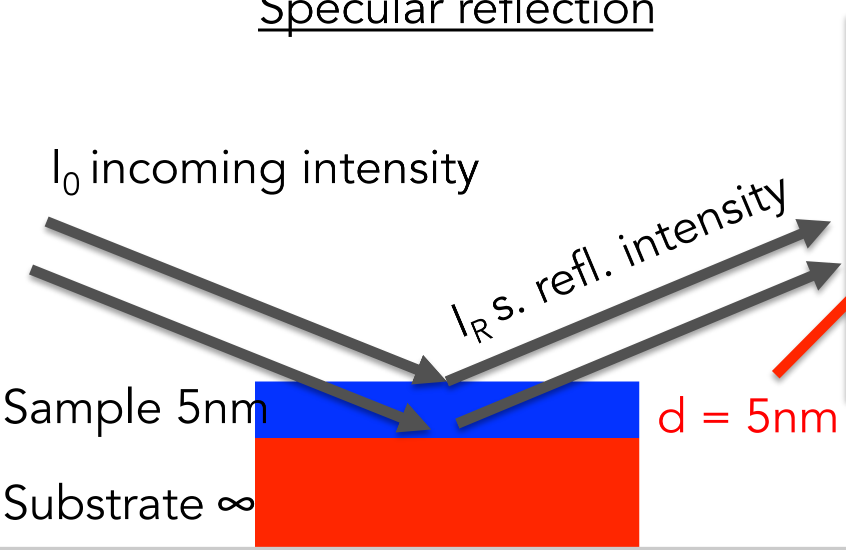
Specular reflection



$$q = (4\pi/\lambda)\sin(\theta)$$

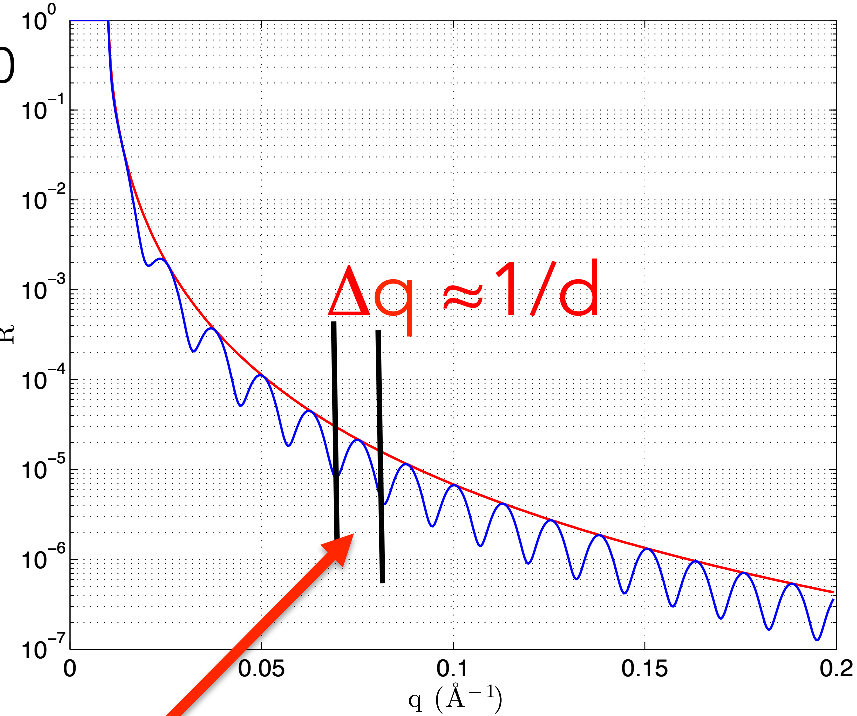


Specular reflection



$$q = (4\pi/\lambda)\sin(\theta)$$

$R = I_R/I_0$



FITTING & INVERSION

R PROFILE

SAMPLE (SLD profile)

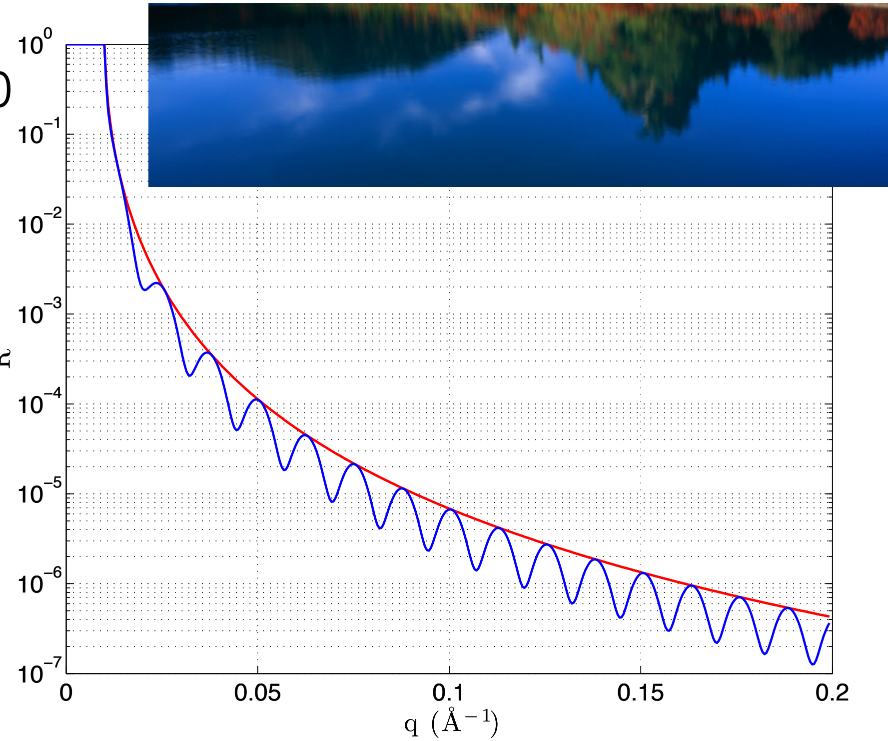
$q = (4\pi/\lambda)\sin(\theta)$

Sample 5nm

Substrate ∞

d = 5nm

$R = I_R/I_0$



FITTING & INVERSION

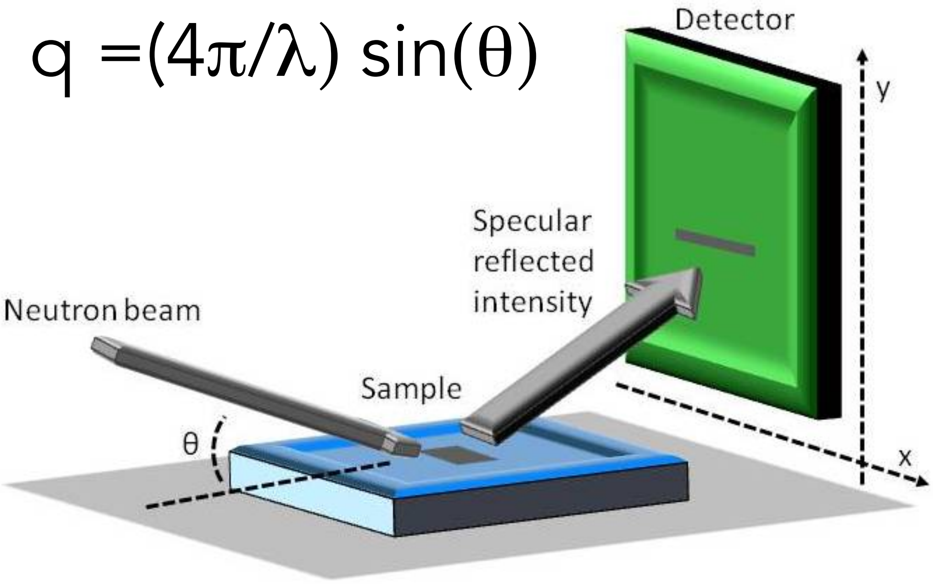
R PROFILE

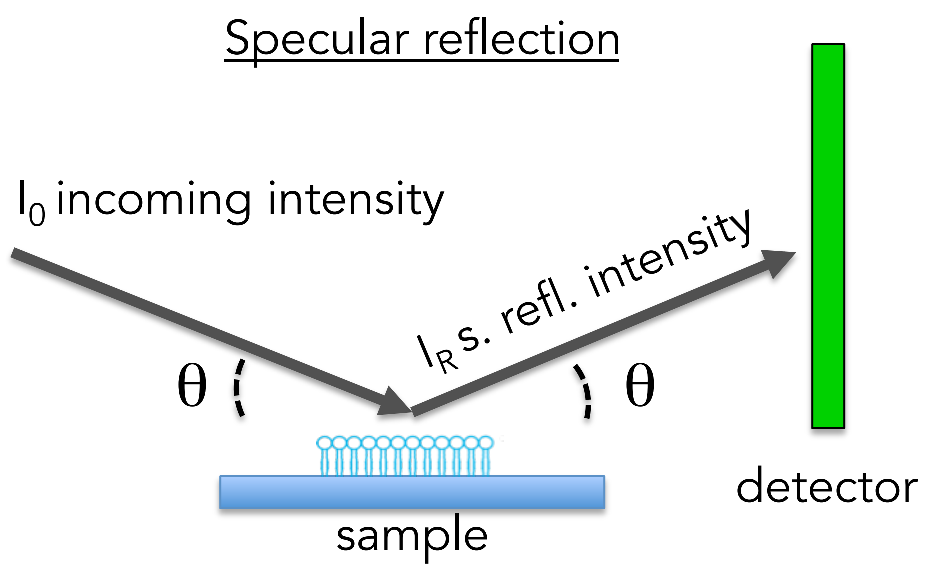
SAMPLE
(SLD profile)

Sample 5nm

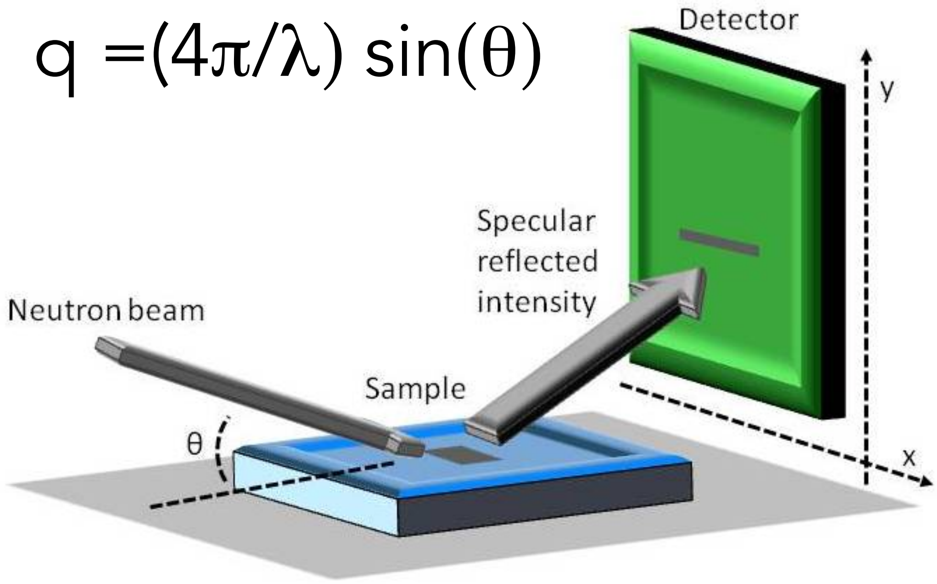
Substrate ∞

$$q = (4\pi/\lambda)\sin(\theta)$$

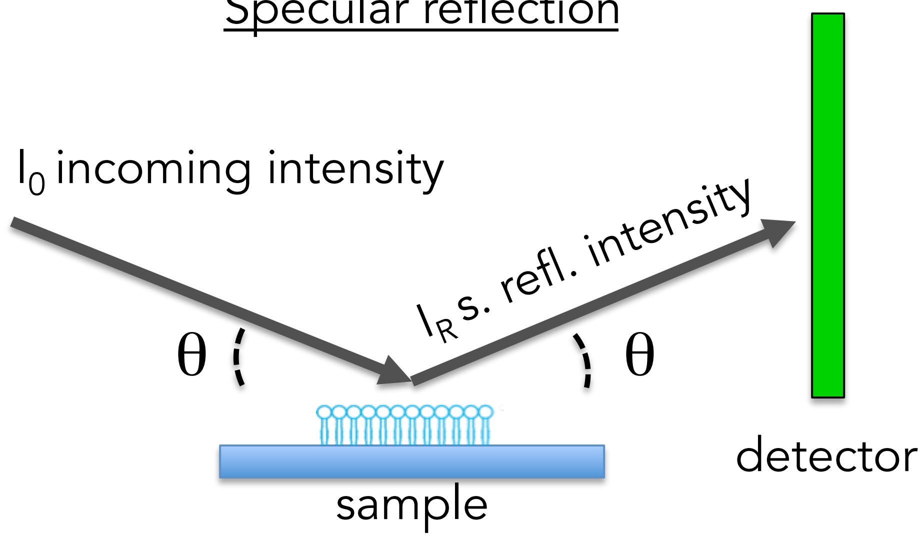


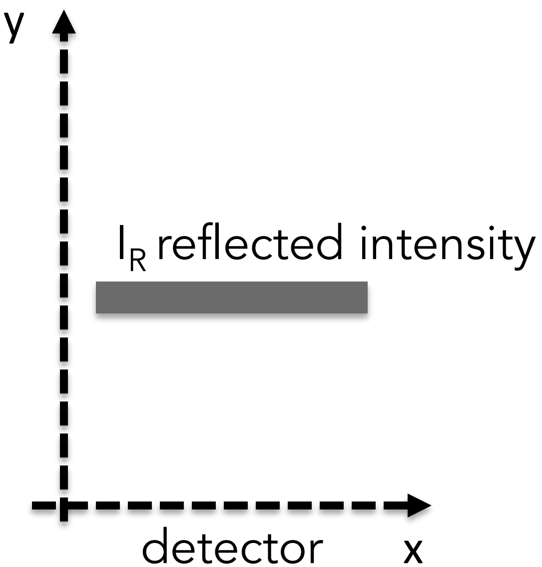


$q = (4\pi/\lambda)\sin(\theta)$

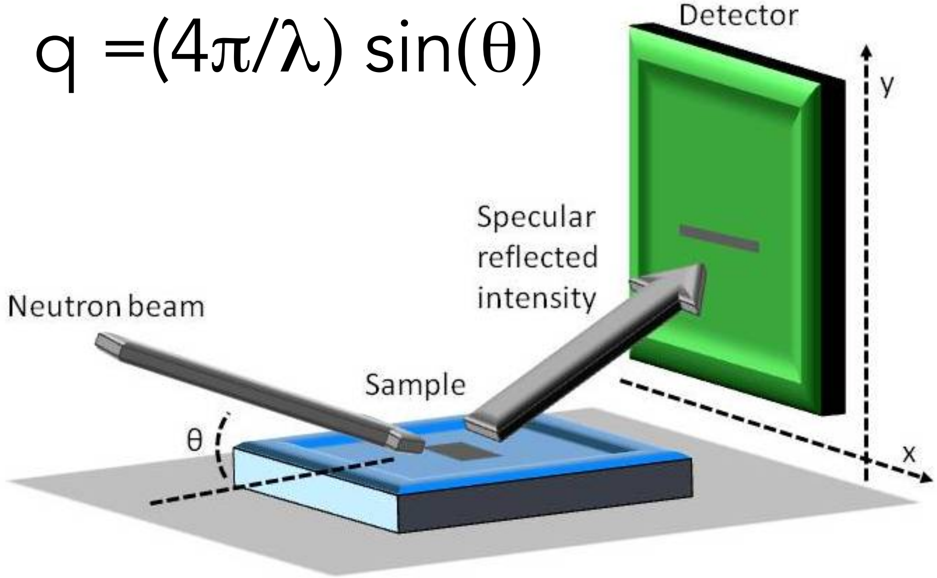


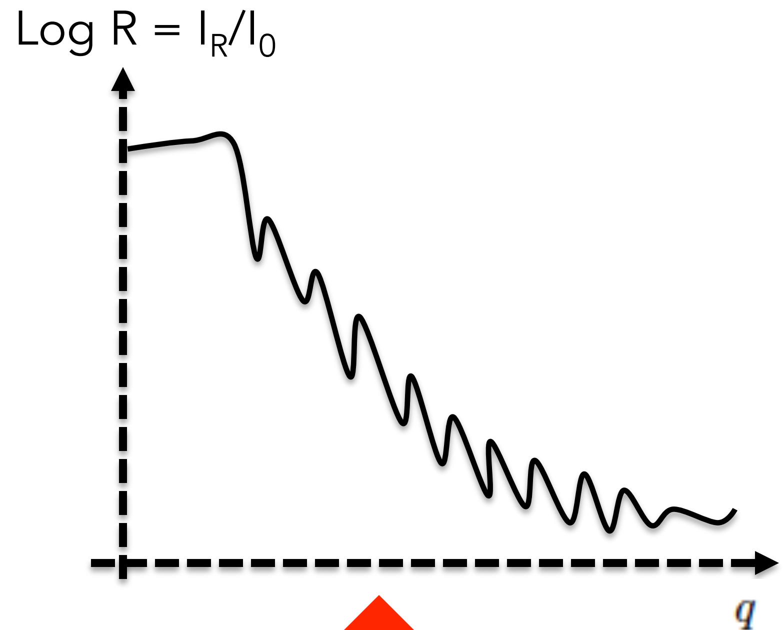
Specular reflection



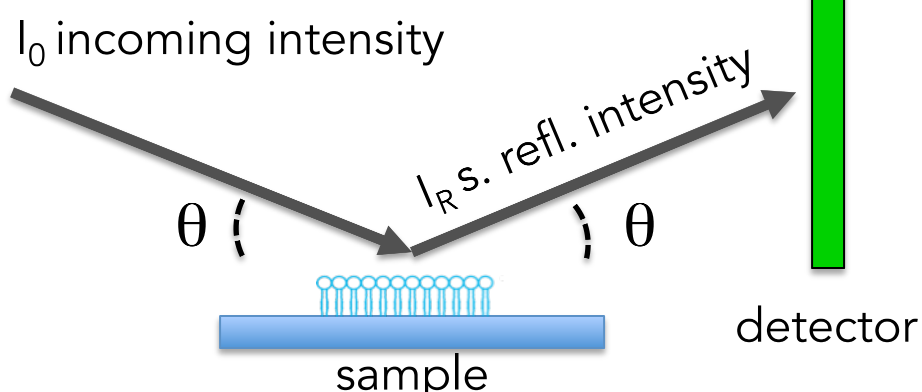


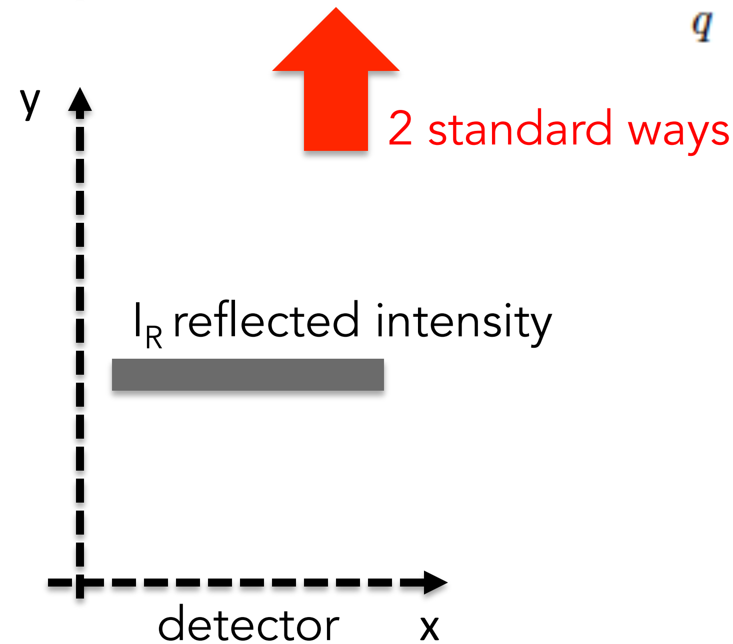
$q = (4\pi/\lambda)\sin(\theta)$





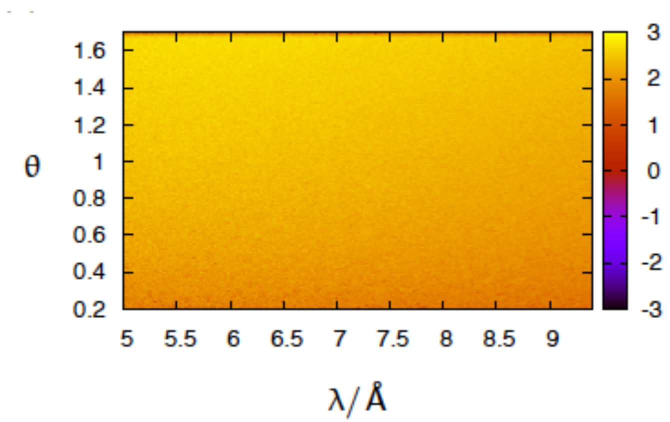
Specular reflection

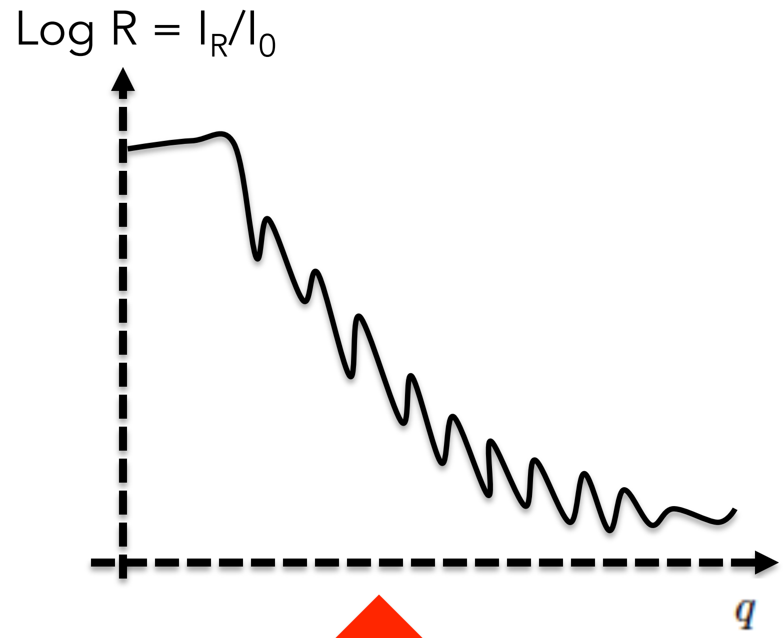




$$q = (4\pi/\lambda)\sin(\theta)$$

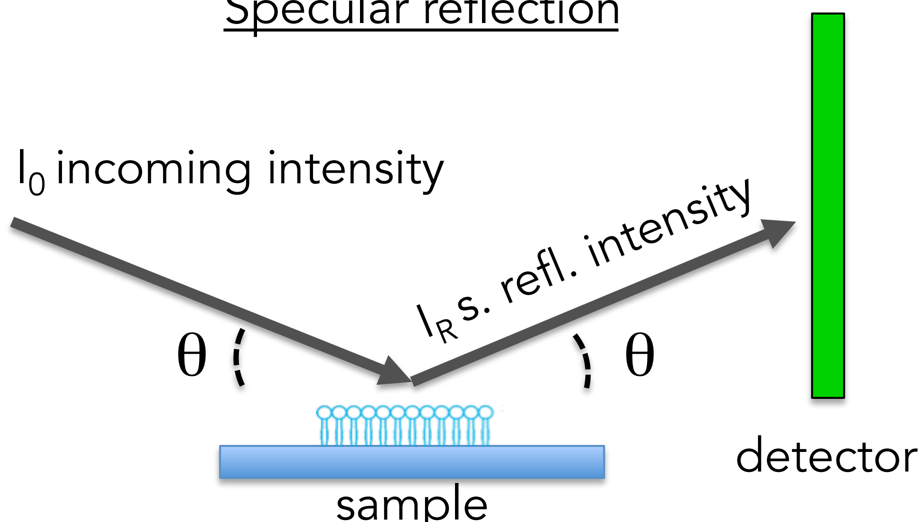
1. ToF (λ scan, θ fixed)
2. Monochromatic (λ fixed, θ scan)

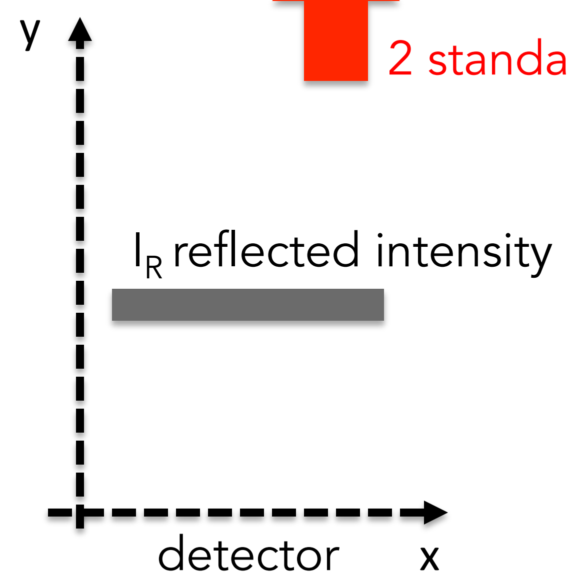




2 standard ways

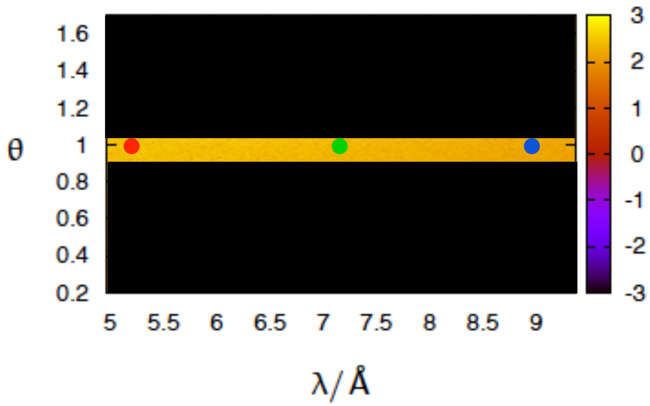
Specular reflection



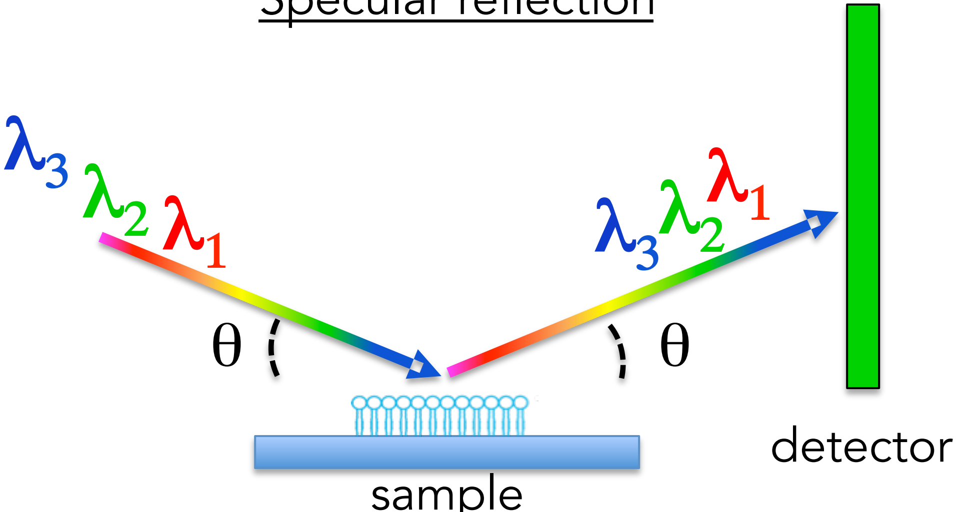


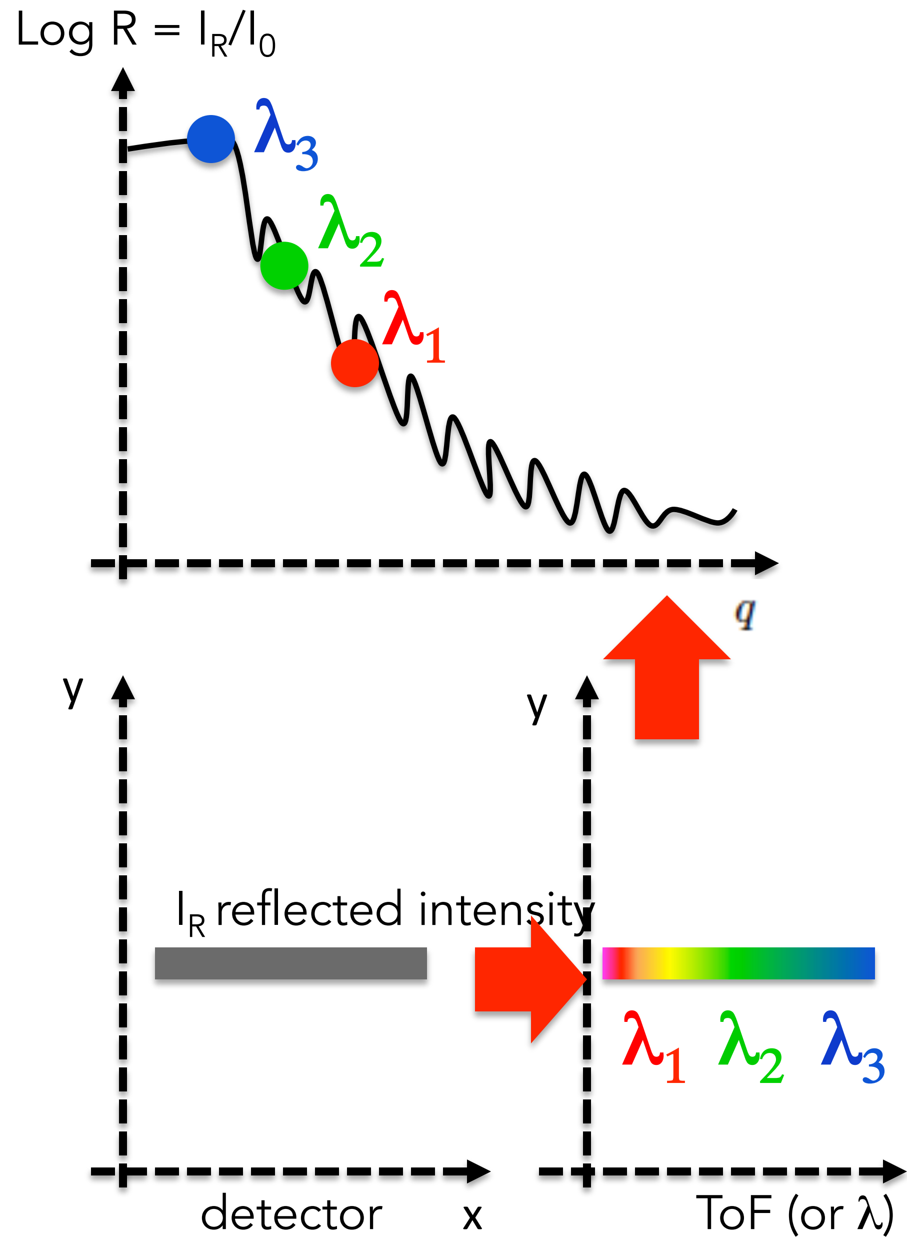
$q = (4\pi/\lambda)\sin(\theta)$

1. ToF (λ scan, θ fixed)
2. Monochromatic (λ fixed, θ scan)



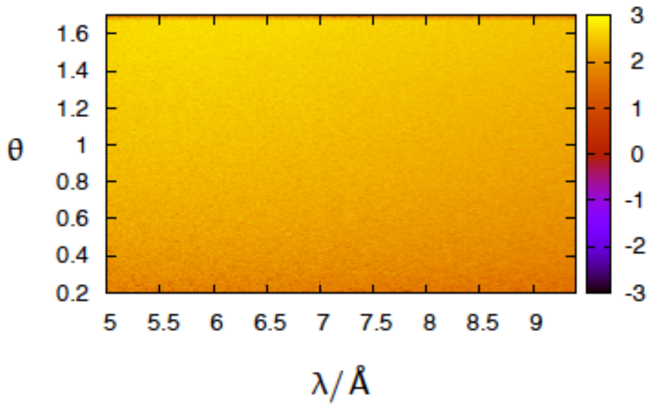
Specular reflection

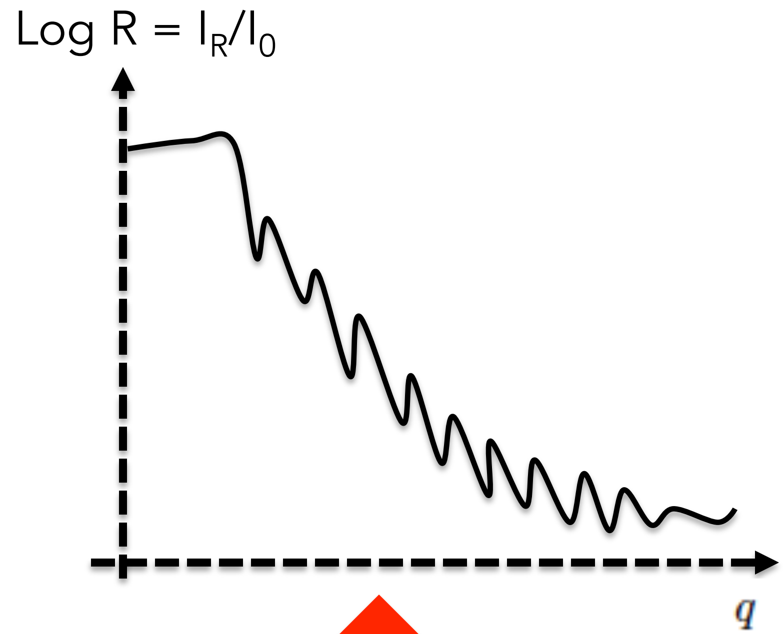




$q = (4\pi/\lambda)\sin(\theta)$

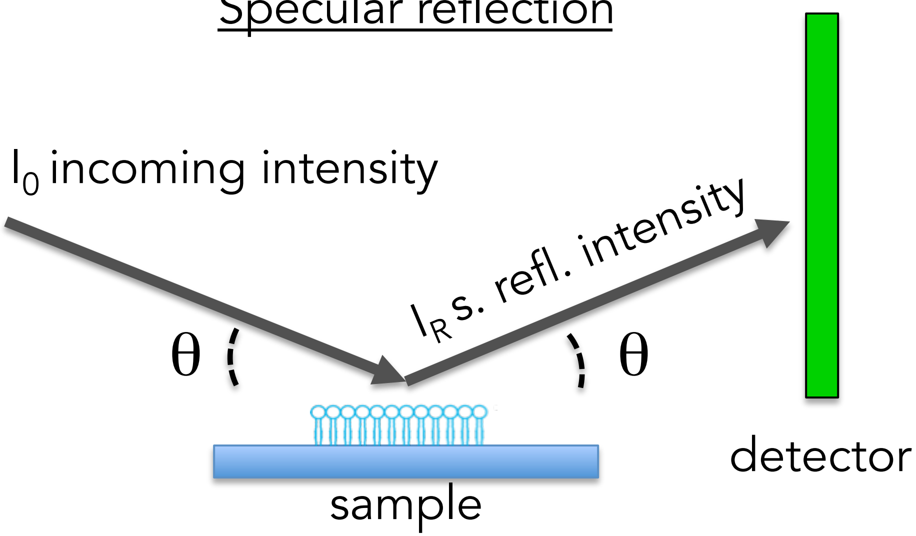
1. ToF (λ scan, θ fixed)
2. Monochromatic (λ fixed, θ scan)

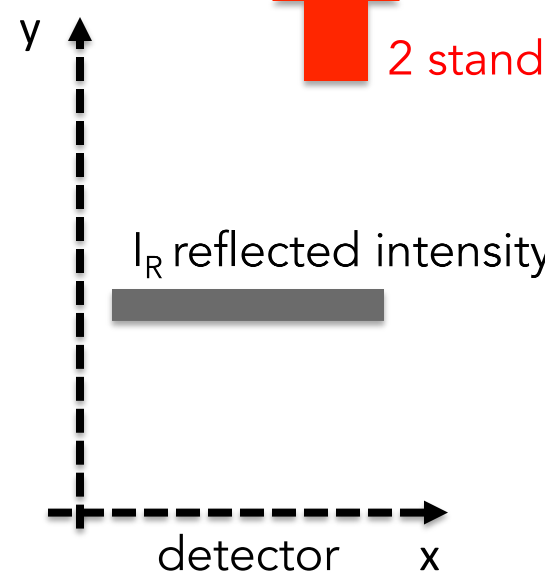




2 standard ways

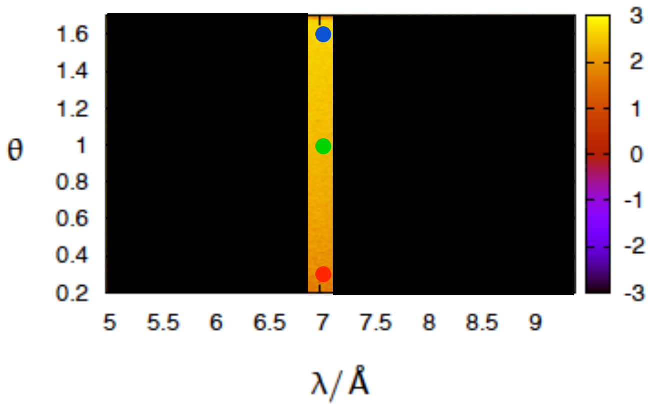
Specular reflection

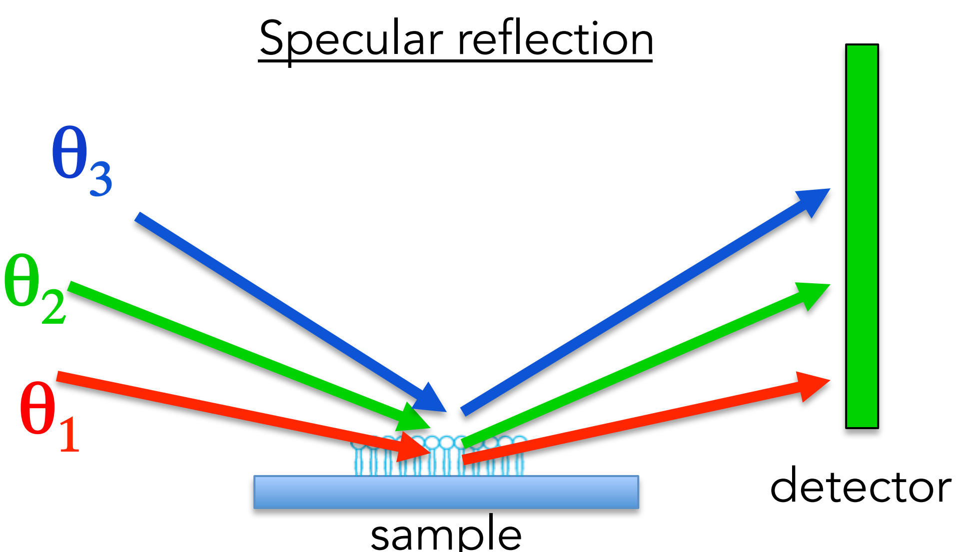


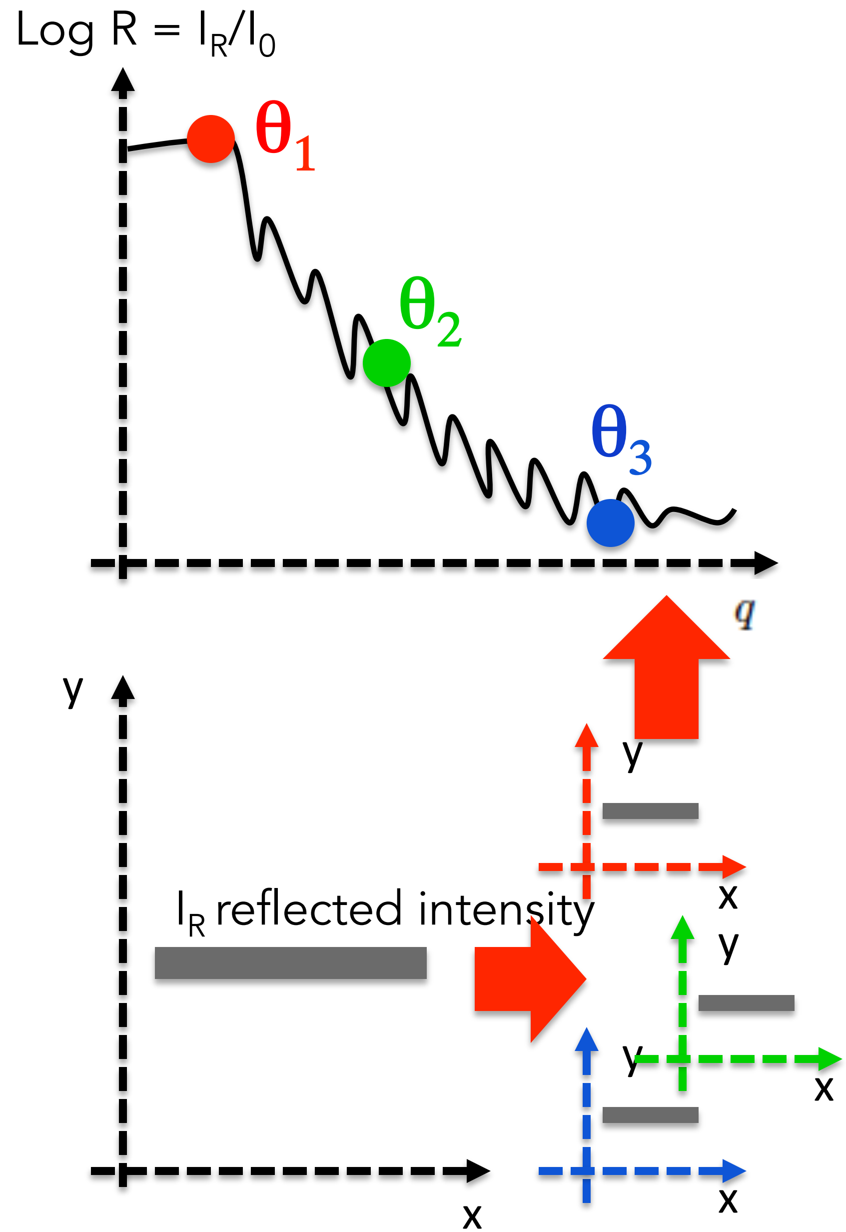


$q = (4\pi/\lambda)\sin(\theta)$

1. ToF (λ scan, θ fixed)
2. Monochromatic (λ fixed, θ scan)



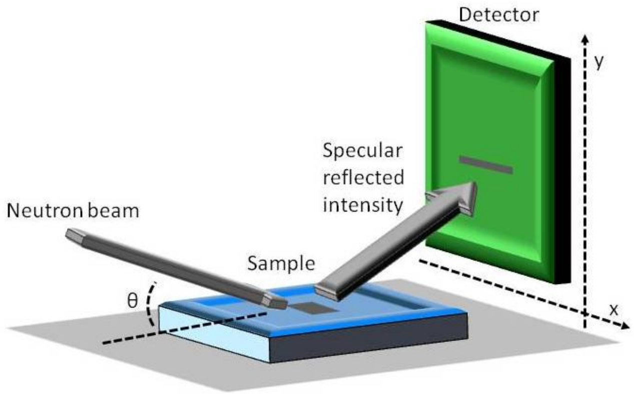




Reflectometry at ESS: FREIA and ESTIA

Reflectometry at ESS: FREIA and ESTIA

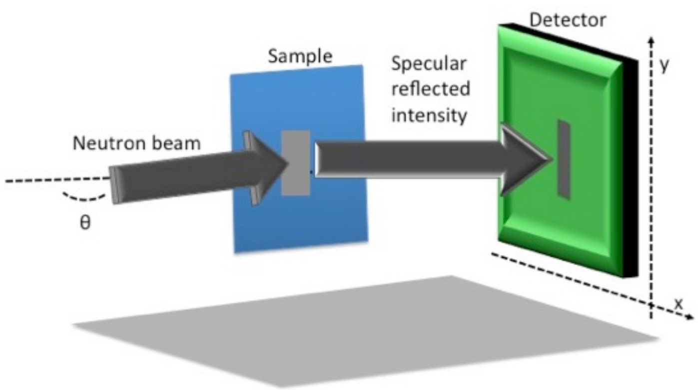
FREIA



<u>Horizontal Reflectometer</u>
(FREIA)

Suitable for liquids
(limited angular range)

Estia



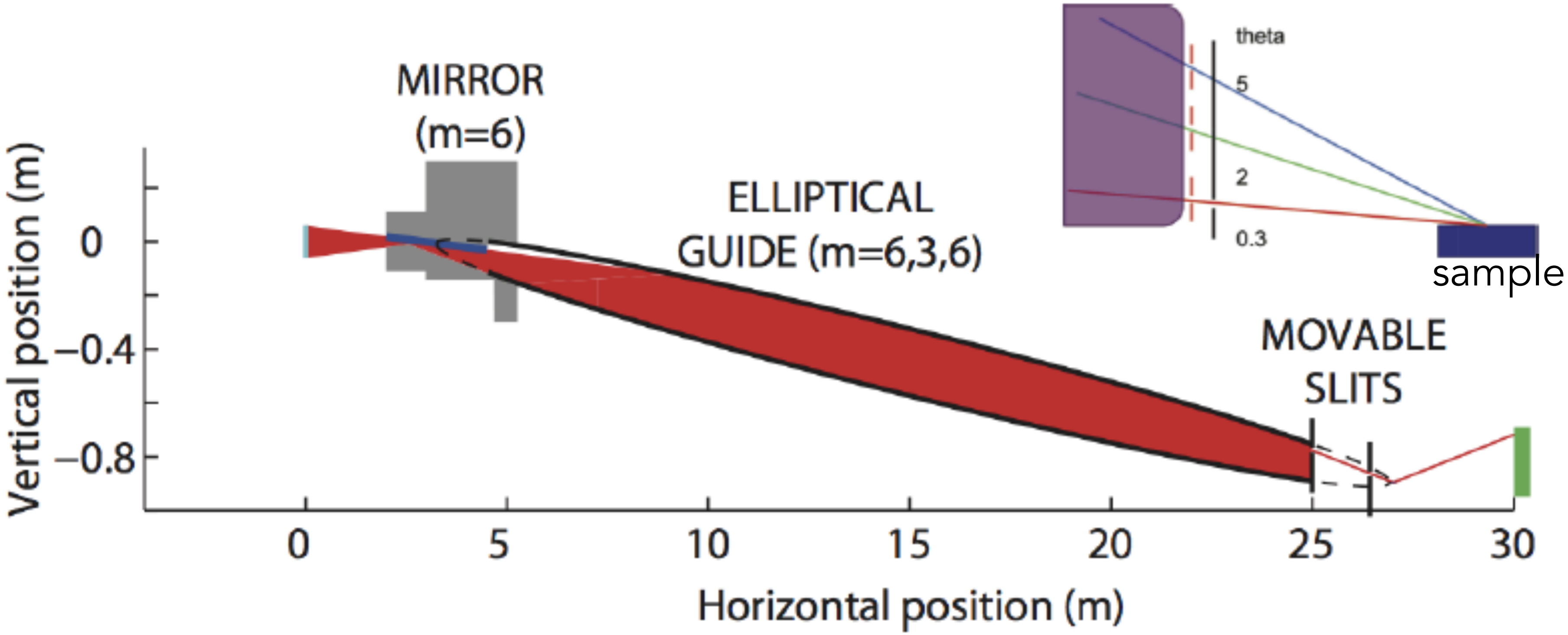
<u>Vertical Reflectometer</u>
(ESTIA)

Not suitable for liquids
More versatile
(wide angle range)

Freia, (Frejya, Freyia, Frøya, Frøjya, and Freja) in Old Norse the "Lady", one of the Vanir gods, rules over the heavenly afterlife field Fólkvangr and there receives half of those that die in battle.

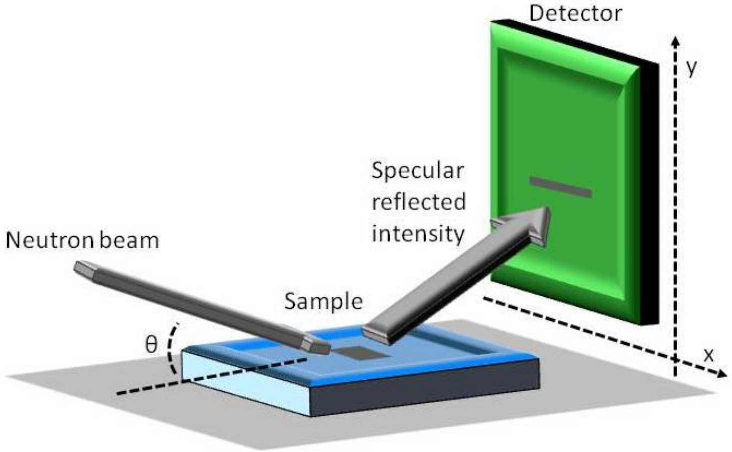
FREIA – a reflectometer for kinetics and liquid surfaces

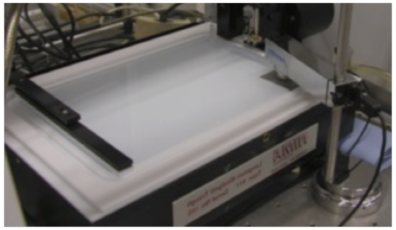
FREIA


MIRROR
(m=6)
ELLIPTICAL
GUIDE (m=6,3,6)
theta
5
2
0.3
sample
MOVABLE
SLITS
Vertical position (m)
0
−0.4
−0.8
0
5
10
15
20
25
30
Horizontal position (m)

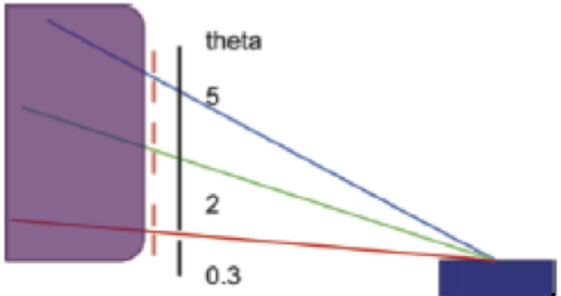
FREIA

$$q = (4\pi/\lambda)\sin(\theta)$$



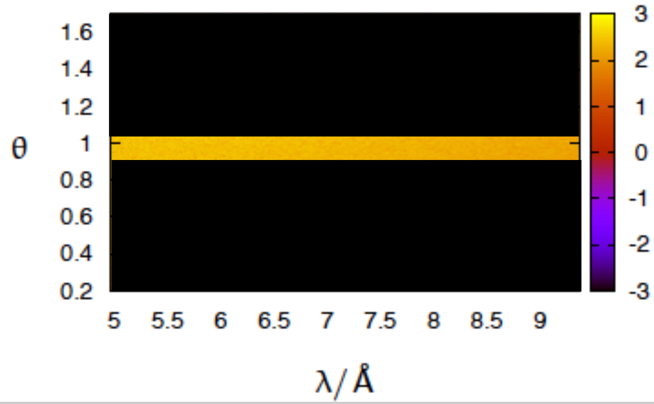


Langmuir–Blodgett trough

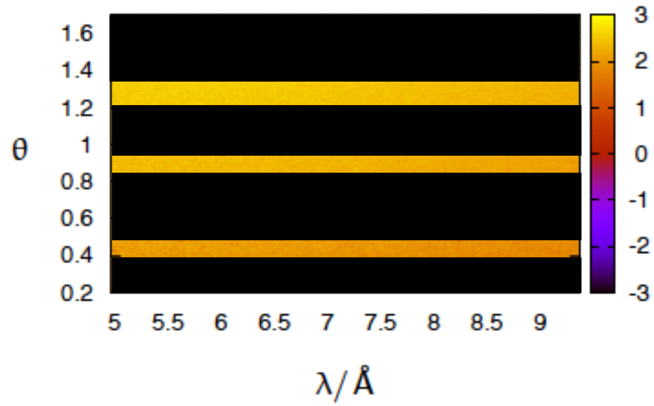


sample

Conventional ToF refl.



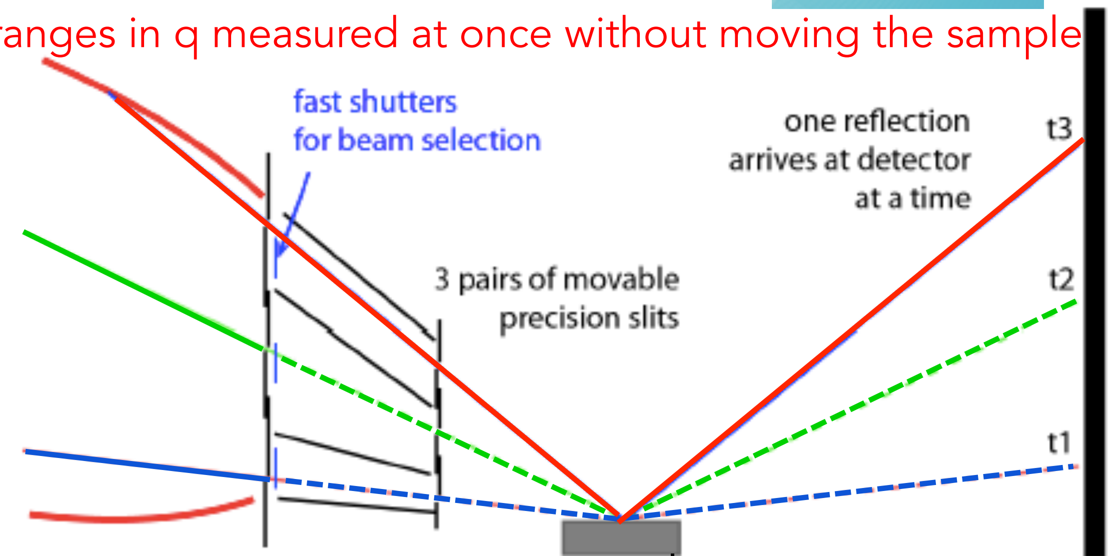
FREIA

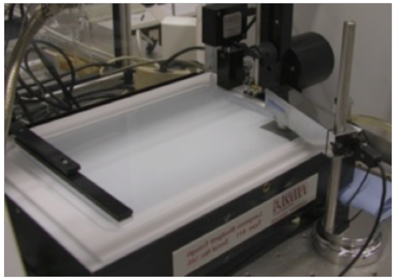


FREIA

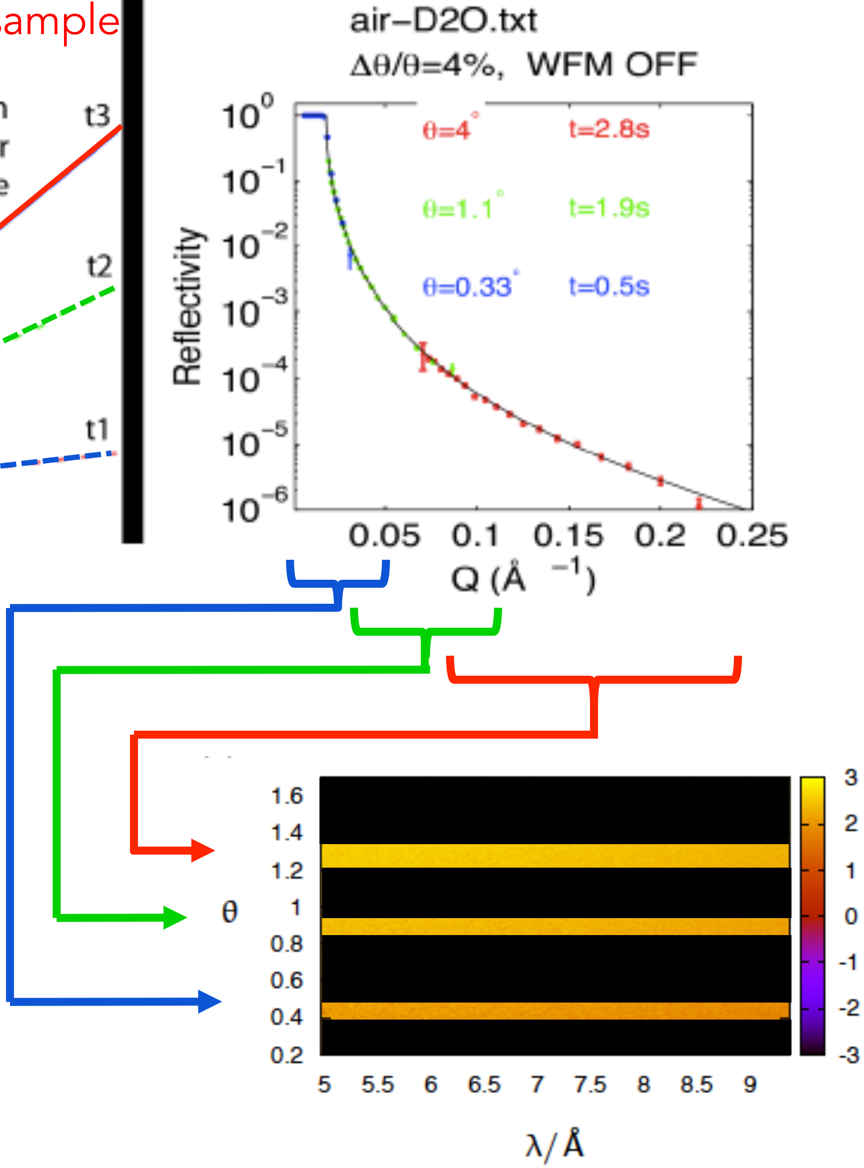
$$q = (4\pi/\lambda)\sin(\theta)$$

3 ranges in q measured at once without moving the sample





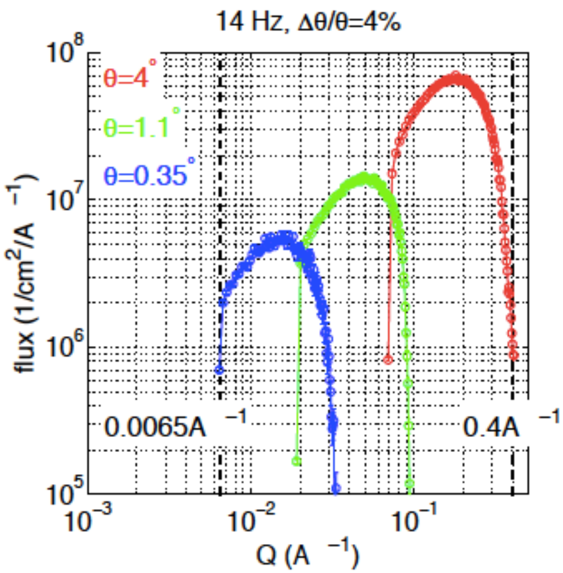
Langmuir–Blodgett trough

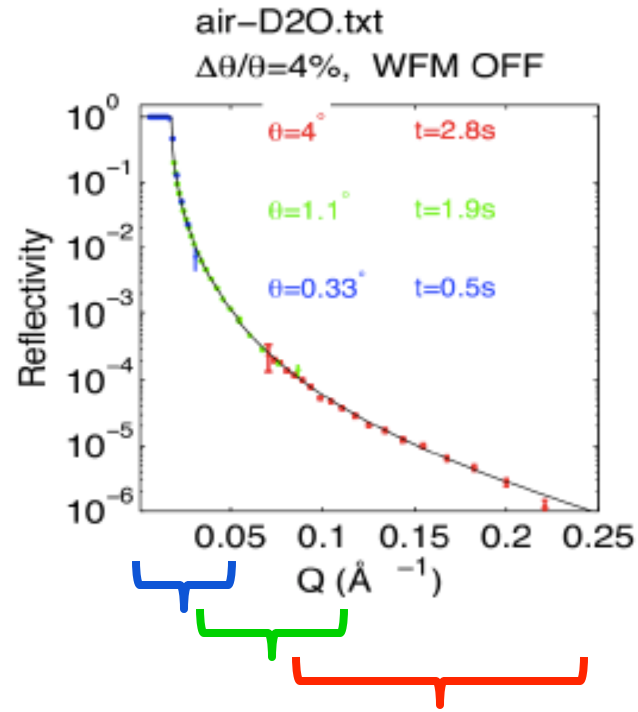


FREIA

$$q = (4\pi/\lambda)\sin(\theta)$$

Flux at sample





$5 \bullet 10^6$

10^7

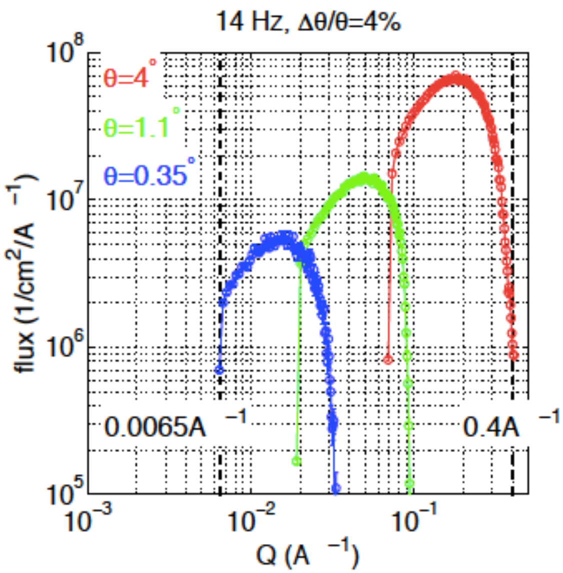
$5 \bullet 10^8$ n/s/Å/cm^2

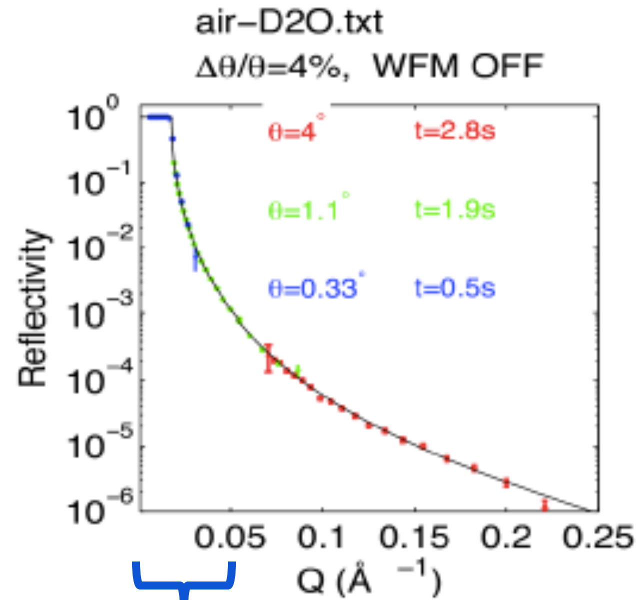
(at λ peak)

FREIA

$$q = (4\pi/\lambda)\sin(\theta)$$

Flux at sample





$5 \bullet 10^6$

10^7

$5 \bullet 10^8$ n/s/Å/cm^2

(at λ peak)

$R = 10^0$

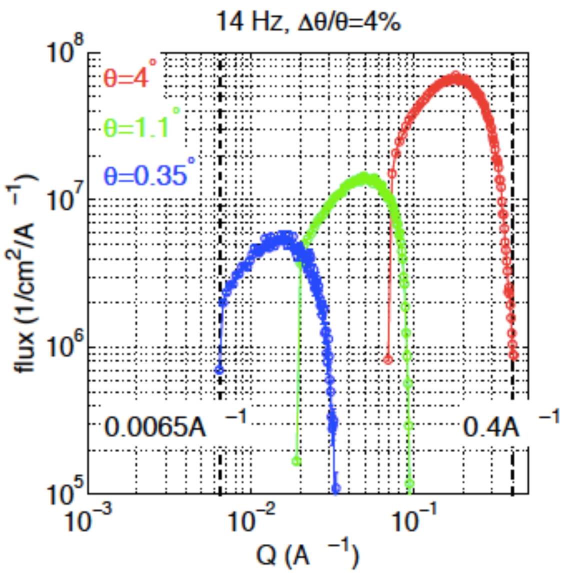
$R < 10^{-1}$

$R < 10^{-4}$

FREIA

$q = (4\pi/\lambda)\sin(\theta)$

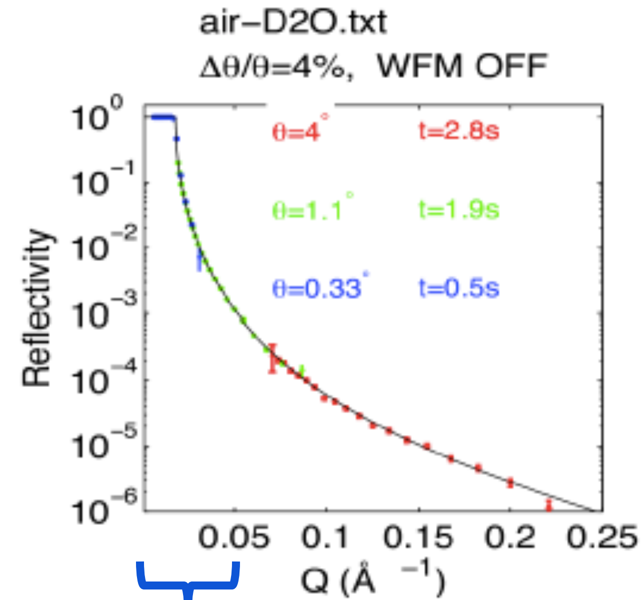
Flux at sample



$5 \cdot 10^6$

10^7

$5 \cdot 10^8$ n/s/Å/cm²
(at λ peak)



$R = 10^0$

$R < 10^{-1}$

$R < 10^{-4}$

$<10^2$ n/s/Å/mm²

$<10^4$ n/s/Å/mm²

Flux at detector

$10^0 \cdot 5 \cdot 10^6 =$
$5 \cdot 10^6$ n/s/Å/cm² =
$= 5 \cdot 10^4$ n/s/Å/mm²

The state of the art

Instrument	Facility	techn.	area ($mm \times mm$)	spatial res. ($mm \times mm$)	efficiency	global rate (s^{-1})	local rate ($s^{-1}mm^{-2}$)
FIGARO [9]	ILL	^{3}He	512×256	$\sim 2 \times 7.5$	$\sim 63\%$ @ 2.5Å $\sim 90\%$ @ 10Å $\sim 80\%$ @ 30Å	$3 \cdot 10^7$	230
SuperADAM [11]	ILL	^{3}He	300×300	2.8×2.8	76% @ 4.4Å	$2 \cdot 10^5$	-
REFSANS [12]	FRM2	^{3}He	500×500	$\sim 2 \times 2$	58% @ 10Å $\geq 50\% \in [5, 18]$Å	$2.2 \cdot 10^5$	300
INTER [13]	ISIS	^{3}He,^{6}Li	200×200	$\sim 1 \times 1$	-	-	-
POLREF [14, 15]	ISIS	^{3}He	200×200	$\leq 1 \times 1$	-	-	-
BIOREF [16]	HZB	^{3}He	300×300	2×3	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
LR	SNS	^{3}He	200×200	1.3×1.3	-	-	-
MR	SNS	^{3}He	210×180	1.5×1.5	-	-	-
Platypus [17]	OPAL	^{3}He	500×250	1.2×1.2	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
SOFIA [18, 19]	J-PARC	^{3}He ^{6}Li	128×128 256×256	2×2 4×4	- -	- -	300 300

The state of the art

Instrument	Facility	techn.	area $(mm \times mm)$	spatial res. $(mm \times mm)$	efficiency	global rate (s^{-1})	local rate $(s^{-1}mm^{-2})$
FIGARO [9]	ILL	^{3}He	512×256	$\sim 2 \times 7.5$	$\sim 63\%$ @ 2.5Å $\sim 90\%$ @ 10Å $\sim 80\%$ @ 30Å	$3 \cdot 10^7$	230
SuperADAM [11]	ILL	^{3}He	300×300	2.8×2.8	76% @ 4.4Å	$2 \cdot 10^5$	-
REFSANS [12]	FRM2	^{3}He	500×500	$\sim 2 \times 2$	58% @ 10Å $\geq 50\% \in [5, 18]$Å	$2.2 \cdot 10^5$	300
INTER [13]	ISIS	^{3}He,^{6}Li	200×200	$\sim 1 \times 1$	-	-	-
POLREF [14, 15]	ISIS	^{3}He	200×200	$\leq 1 \times 1$	-	-	-
BIOREF [16]	HZB	^{3}He	300×300	2×3	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
LR	SNS	^{3}He	200×200	1.3×1.3	-	-	-
MR	SNS	^{3}He	210×180	1.5×1.5	-	-	-
Platypus [17]	OPAL	^{3}He	500×250	1.2×1.2	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
SOFIA [18, 19]	J-PARC	^{3}He ^{6}Li	128×128 256×256	2×2 4×4	- -	- -	300 300

FREIA

Max rate on detector (at peak)	10^5 n/s/Å/mm^2
Max global rate	12 MHz (1.2x100mm^2 footprint*) 12 MHz (detector area*)
Wavelength range	2.5 – 12 Å (optional up to 25Å)
Efficiency	>60% (above 4Å)
Max detector size	500x500mm^2
Spatial resolution	4mm x 1mm
Sample-Detector distance	Not fixed (mostly 3m)
Window scattering	$<10^{-4}$

x300

Flux at detector

The state of the art

Instrument	Facility	techn.	area ($mm \times mm$)	spatial res. ($mm \times mm$)	efficiency	global rate (s^{-1})	local rate ($s^{-1}mm^{-2}$)
FIGARO [9]	ILL	^{3}He	512×256	$\sim 2 \times 7.5$	$\sim$ 63% @ 2.5Å $\sim$ 90% @ 10Å $\sim$ 80% @ 30Å	$3 \cdot 10^7$	230
SuperADAM [11]	ILL	^{3}He	300×300	2.8×2.8	76% @ 4.4Å	$2 \cdot 10^5$	-
REFSANS [12]	FRM2	^{3}He	500×500	$\sim 2 \times 2$	58% @ 10Å $\geq 50\% \in [5, 18]$Å	$2.2 \cdot 10^5$	300
INTER [13]	ISIS	^{3}He,^{6}Li	200×200	$\sim 1 \times 1$	-	-	-
POLREF [14, 15]	ISIS	^{3}He	200×200	$\leq 1 \times 1$	-	-	-
BIOREF [16]	HZB	^{3}He	300×300	2×3	$\sim$ 60% @ 10Å	$2 \cdot 10^5$	300
LR	SNS	^{3}He	200×200	1.3×1.3	-	-	-
MR	SNS	^{3}He	210×180	1.5×1.5	-	-	-
Platypus [17]	OPAL	^{3}He	500×250	1.2×1.2	$\sim$ 60% @ 10Å	$2 \cdot 10^5$	300
SOFIA [18, 19]	J-PARC	^{3}He ^{6}Li	128×128 256×256	2×2 4×4	- -	- -	300 300

FREIA

Max rate on detector (at peak)	10^5 n/s/Å/mm^2
Max global rate	12 MHz (1.2x100mm^2 footprint*) 12 MHz (detector area*)
Wavelength range	2.5 – 12 Å (optional up to 25Å)
Efficiency	>60% (above 4Å)
Max detector size	500x500mm^2
Spatial resolution	4mm x 1mm
Sample-Detector distance	Not fixed (mostly 3m)
Window scattering	<10^{-4}

x300

Flux at detector

Swiss-Danish ESS
instrumentation consortium

Jochen Stahn
Marité Cardenas
Ursula B. Hansen

ESS SAC Meeting
21. 05. 2014, Lund

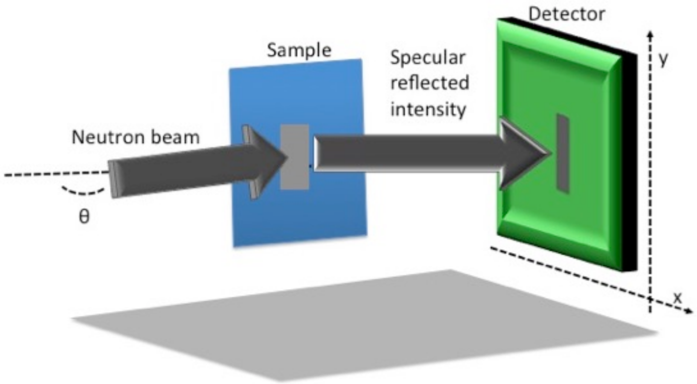
Estia

a

focusing reflectometer for small samples

based on the

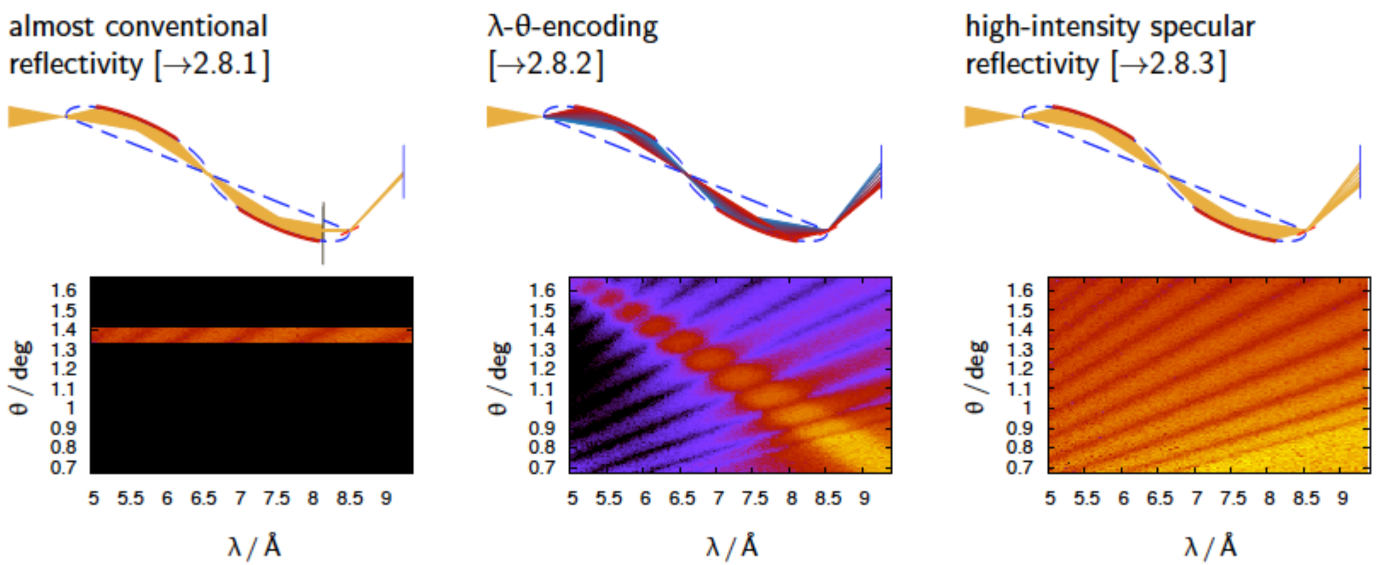
Selene guide concept



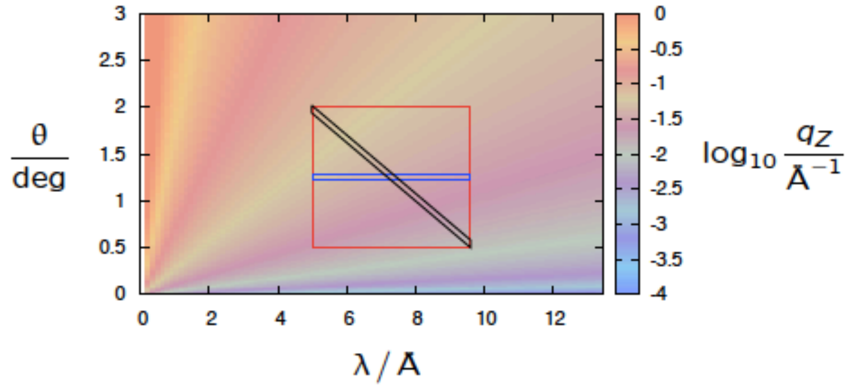
Vertical ToF Reflectometer

$$q = (4\pi/\lambda)\sin(\theta)$$

It can work in 3 different modes:



operation modes



almost conventional reflectivity

= TOF

- defined foot-print
- off-specular reflectivity

λ-θ-encoding

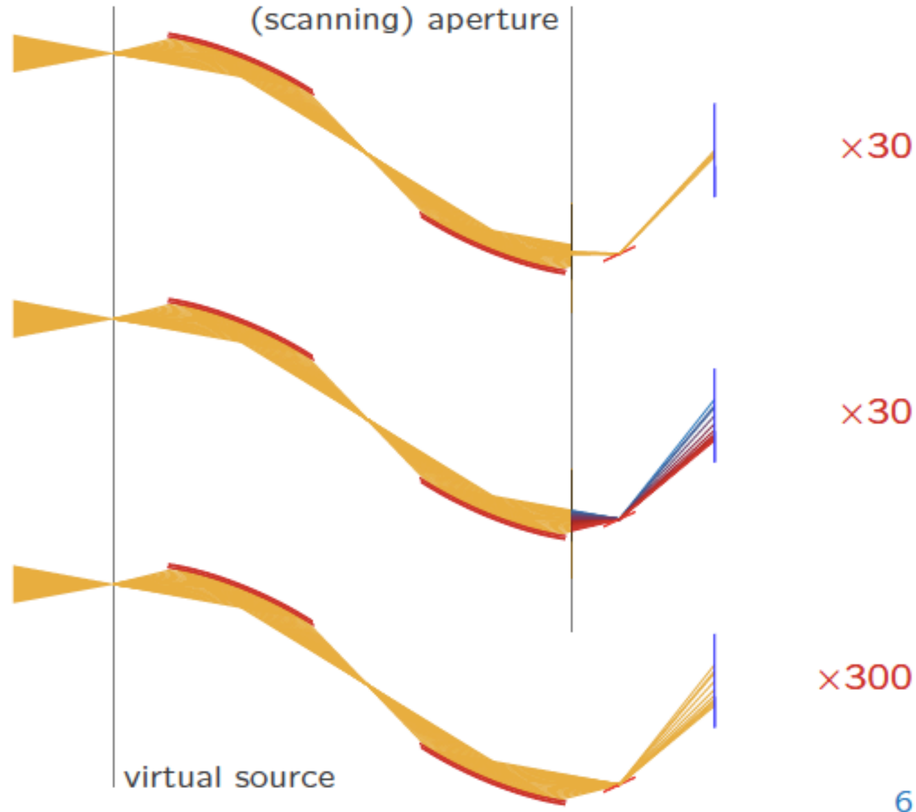
= TOF(θ)

- wider q_z-range
- constant $\Delta q/q$

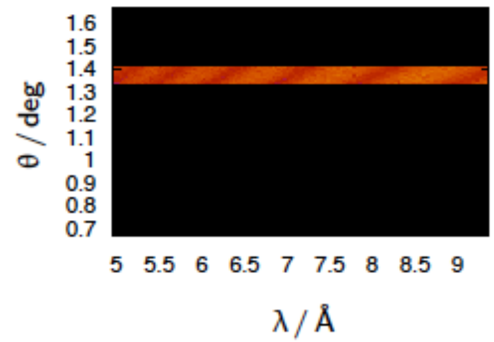
high-intensity specular reflectivity

= TOF × θ-dispersive

- split-second t-resolution
- screening of parameter space



Conventional Reflectivity mode



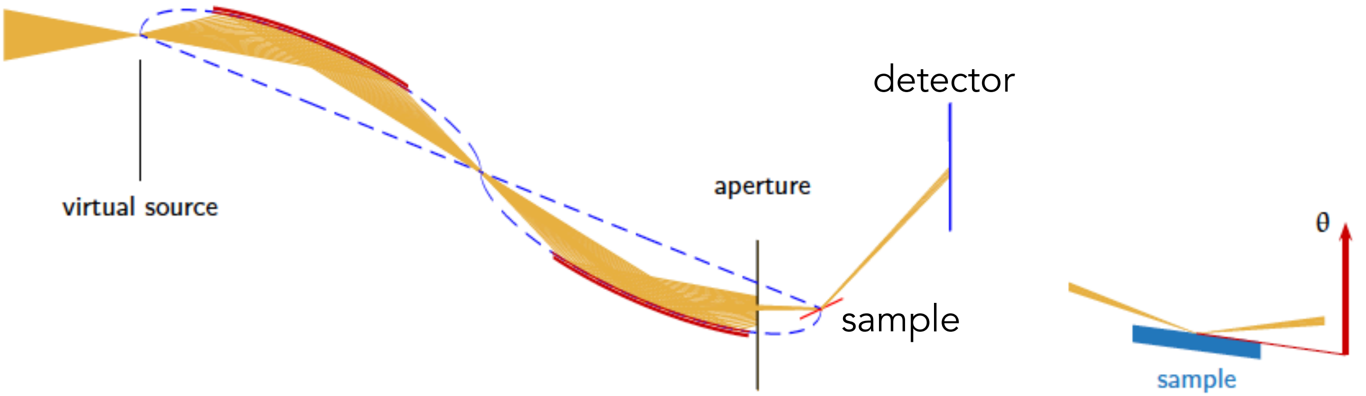
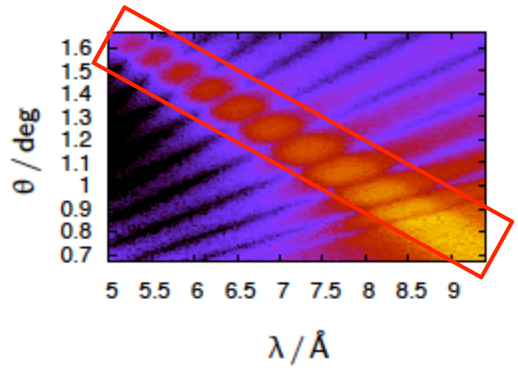


Figure 10.1: Sketch to illustrate the operation scheme: the beam (gold) is transported with the full divergence and without chopping to the end of the guide system. There an aperture (black) defines $\Delta\theta$, and its position together with the sample orientation ω also the angle of incidence θ. The beam footprint on the sample is defined by size and orientation of the virtual source.

The flux at sample is spread on about 5x1cm^2 area maximum. On detector, due to divergence, will be same flux (below critical edge R=1) on 2mm x 6cm area; then about 10^5 n/s/Å/mm^2 (at peak).

λ−θ encoding



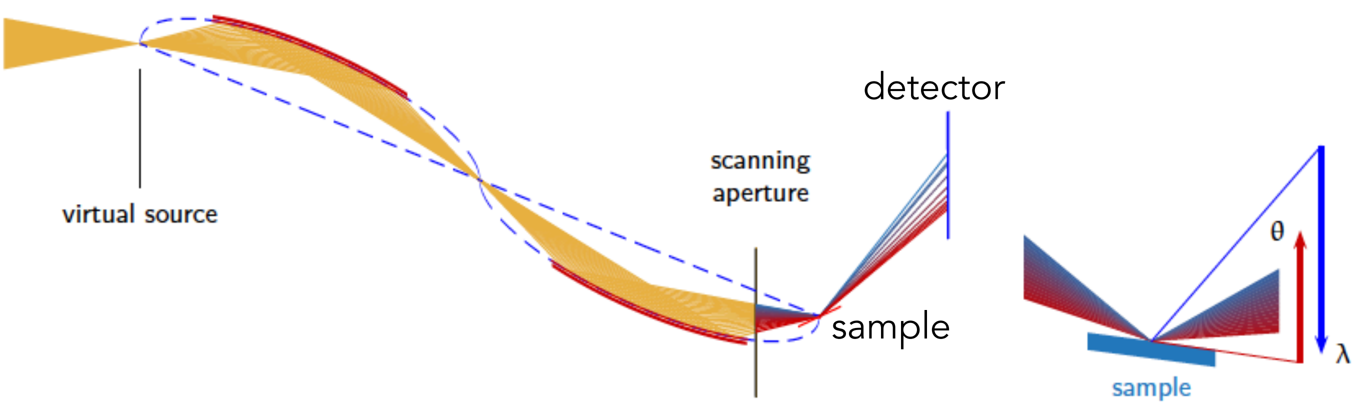
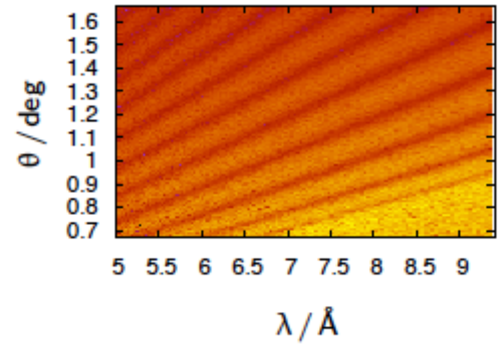


Figure 10.2: Sketch to illustrate the operation scheme: the beam (gold) is transported with the full divergence and without chopping to the end of the guide system. As in the conventional mode [→10.2], a slit (black) defines Δθ and together with the sample orientation ω also the angle of incidence θ. But the opening and position change during the passing of each pulse. This way high θ can be related to low λ and vice versa.

The flux is spread on a wider detector surface with respect to the conventional reflectometry mode. Spatial resolution (0.5mm) is needed to resolve the different theta.



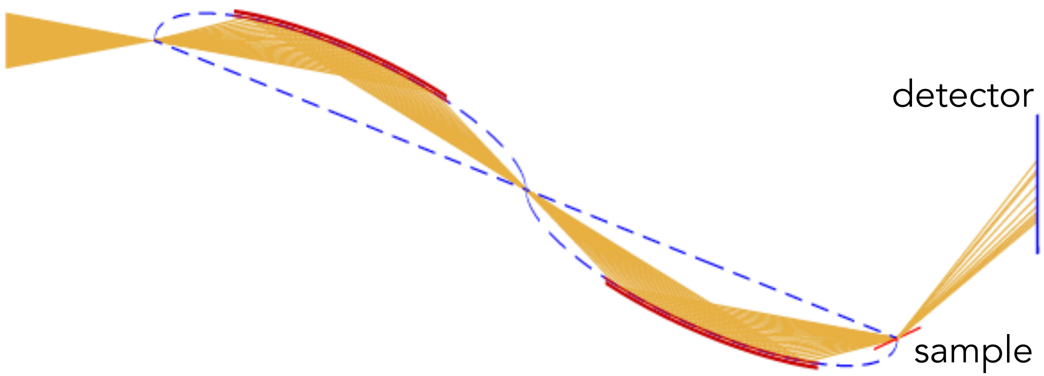


Figure 10.7: Sketch to illustrate the high-intensity specular reflectivity operation mode.

The flux is spread on a wider detector surface with respect to the conventional reflectometry mode. Spatial resolution (0.5mm) is needed to resolve the different theta.

In the high-intensity mode about 105x105mm^2 area of the detector is illuminated with 10^8 n/s, i.e. 10^4 n/s/mm^2 (at peak).
The final optimal detector size is 40x25cm^2.

The state of the art

Instrument	Facility	techn.	area $(mm \times mm)$	spatial res. $(mm \times mm)$	efficiency	global rate (s^{-1})	local rate $(s^{-1}mm^{-2})$
FIGARO [9]	ILL	^{3}He	512×256	$\sim 2 \times 7.5$	$\sim 63\%$ @ 2.5Å $\sim 90\%$ @ 10Å $\sim 80\%$ @ 30Å	$3 \cdot 10^7$	230
SuperADAM [11]	ILL	^{3}He	300×300	2.8×2.8	76% @ 4.4Å	$2 \cdot 10^5$	-
REFSANS [12]	FRM2	^{3}He	500×500	$\sim 2 \times 2$	58% @ 10Å $\geq 50\% \in [5, 18]$Å	$2.2 \cdot 10^5$	300
INTER [13]	ISIS	^{3}He, ^{6}Li	200×200	$\sim 1 \times 1$	-	-	-
POLREF [14, 15]	ISIS	^{3}He	200×200	$\leq 1 \times 1$	-	-	-
BIOREF [16]	HZB	^{3}He	300×300	2×3	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
LR	SNS	^{3}He	200×200	1.3×1.3	-	-	-
MR	SNS	^{3}He	210×180	1.5×1.5	-	-	-
Platypus [17]	OPAL	^{3}He	500×250	1.2×1.2	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
SOFIA [18, 19]	J-PARC	^{3}He ^{6}Li	128×128 256×256	2×2 4×4	- -	- -	300 300

The state of the art

Instrument	Facility	techn.	area ($mm \times mm$)	spatial res. ($mm \times mm$)	efficiency	global rate (s^{-1})	local rate ($s^{-1}mm^{-2}$)
FIGARO [9]	ILL	^{3}He	512×256	$\sim 2 \times 7.5$	$\sim$ 63% @ 2.5Å $\sim$ 90% @ 10Å $\sim$ 80% @ 30Å	$3 \cdot 10^7$	230
SuperADAM [11]	ILL	^{3}He	300×300	2.8×2.8	76% @ 4.4Å	$2 \cdot 10^5$	-
REFSANS [12]	FRM2	^{3}He	500×500	$\sim 2 \times 2$	58% @ 10Å $\geq$ 50% $\in$ [5, 18]Å	$2.2 \cdot 10^5$	300
INTER [13]	ISIS	^{3}He,^{6}Li	200×200	$\sim 1 \times 1$	-	-	-
POLREF [14, 15]	ISIS	^{3}He	200×200	$\leq 1 \times 1$	-	-	-
BIOREF [16]	HZB	^{3}He	300×300	2×3	$\sim$ 60% @ 10Å	$2 \cdot 10^5$	300
LR	SNS	^{3}He	200×200	1.3×1.3	-	-	-
MR	SNS	^{3}He	210×180	1.5×1.5	-	-	-
Platypus [17]	OPAL	^{3}He	500×250	1.2×1.2	$\sim$ 60% @ 10Å	$2 \cdot 10^5$	300
SOFIA [18, 19]	J-PARC	^{3}He ^{6}Li	128×128 256×256	2×2 4×4	- -	- -	300 300

Estia

Max rate on detector (at peak)	• Conventional refl. 10^5 n/s/Å/mm^2 • High intensity mode 10^4 n/s/Å/mm^2
Max global rate	• Conventional refl. 12MHz (2x60mm^2 footprint or on whole detect. area) • High intensity mode 100MHz ** (105x105mm^2 footprint or on whole detect. area)
Wavelength range	4 – 12 Å
Efficiency	>60% (above 4Å)
Max detector size	300x500mm^2
Spatial resolution	4mm x 0.5mm
Sample-Detector distance	Fixed ~4m

x300

Flux at detector

The state of the art

Instrument	Facility	techn.	area $(mm \times mm)$	spatial res. $(mm \times mm)$	efficiency	global rate (s^{-1})	local rate $(s^{-1}mm^{-2})$
FIGARO [9]	ILL	^{3}He	512×256	$\sim 2 \times 7.5$	$\sim 63\%$ @ 2.5Å $\sim 90\%$ @ 10Å $\sim 80\%$ @ 30Å	$3 \cdot 10^7$	230
SuperADAM [11]	ILL	^{3}He	300×300	2.8×2.8	76% @ 4.4Å	$2 \cdot 10^5$	-
REFSANS [12]	FRM2	^{3}He	500×500	$\sim 2 \times 2$	58% @ 10Å $\geq 50\% \in [5, 18]$Å	$2.2 \cdot 10^5$	300
INTER [13]	ISIS	^{3}He,^{6}Li	200×200	$\sim 1 \times 1$	-	-	-
POLREF [14, 15]	ISIS	^{3}He	200×200	$\leq 1 \times 1$	-	-	-
BIOREF [16]	HZB	^{3}He	300×300	2×3	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
LR	SNS	^{3}He	200×200	1.3×1.3	-	-	-
MR	SNS	^{3}He	210×180	1.5×1.5	-	-	-
Platypus [17]	OPAL	^{3}He	500×250	1.2×1.2	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
SOFIA [18, 19]	J-PARC	^{3}He ^{6}Li	128×128 256×256	2×2 4×4	- -	- -	300 300

Estia

Max rate on detector (at peak)	• Conventional refl. 10^5 n/s/Å/mm^2 • High intensity mode 10^4 n/s/Å/mm^2
Max global rate	• Conventional refl. 12MHz (2x60mm^2 footprint or on whole detect. area) • High intensity mode 100MHz ** (105x105mm^2 footprint or on whole detect. area)
Wavelength range	4 – 12 Å
Efficiency	>60% (above 4Å)
Max detector size	300x500mm^2
Spatial resolution	4mm x 0.5mm
Sample-Detector distance	Fixed ~4m

x300

Flux at detector

The state of the art

Instrument	Facility	techn.	area ($mm \times mm$)	spatial res. ($mm \times mm$)	efficiency	global rate (s^{-1})	local rate ($s^{-1}mm^{-2}$)
FIGARO [9]	ILL	^{3}He	512×256	$\sim 2 \times 7.5$	$\sim 63\%$ @ 2.5Å $\sim 90\%$ @ 10Å $\sim 80\%$ @ 30Å	$3 \cdot 10^7$	230
SuperADAM [11]	ILL	^{3}He	300×300	2.8×2.8	76% @ 4.4Å	$2 \cdot 10^5$	-
REFSANS [12]	FRM2	^{3}He	500×500	$\sim 2 \times 2$	58% @ 10Å $\geq 50\% \in [5, 18]$Å	$2.2 \cdot 10^5$	300
INTER [13]	ISIS	^{3}He,^{6}Li	200×200	$\sim 1 \times 1$	-	-	-
POLREF [14, 15]	ISIS	^{3}He	200×200	$\leq 1 \times 1$	-	-	-
BIOREF [16]	HZB	^{3}He	300×300	2×3	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
LR	SNS	^{3}He	200×200	1.3×1.3	-	-	-
MR	SNS	^{3}He	210×180	1.5×1.5	-	-	-
Platypus [17]	OPAL	^{3}He	500×250	1.2×1.2	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
SOFIA [18, 19]	J-PARC	^{3}He ^{6}Li	128×128 256×256	2×2 4×4	- -	- -	300 300

The ESS requirements

	FREIA	Estia
Max local rate	10^5 n/s/Å/mm^2	• Conventional refl. 10^5 n/s/Å/mm^2 • High intensity mode 10^4 n/s/Å/mm^2
Spatial resolution	4mm x 1mm	4mm x 0.5mm

The Multi-Blade project

BrightnESS

EUROPEAN SPALLATION SOURCE

LUND UNIVERSITY

Wigner Research Institute

BNC Budapest Neutron Centre

Budapest Neutron Centre

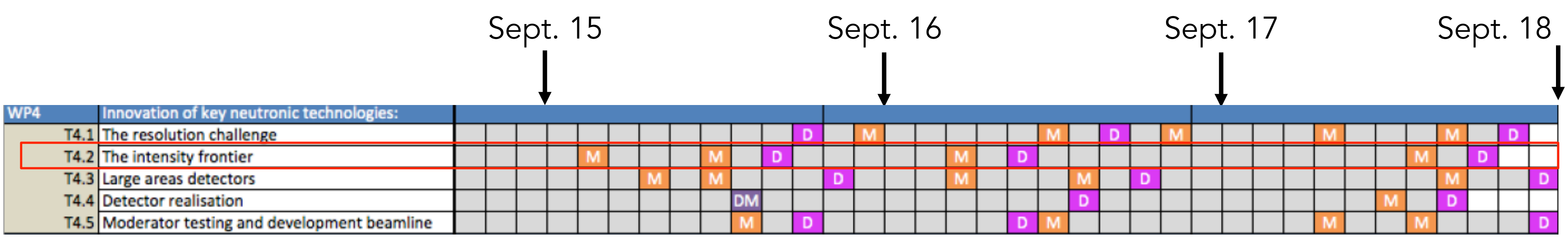
Task 4.2 Neutron Detectors – The Intensity Frontier

The key objective of WP4 is the technological evolution of neutron detectors in terms of resolution, intensity and dimensions.

Wigner Research Institute

Budapest Neutron Centre

3 years



Deliverable

Milestone

Partners Involved

ESS Detector Group
(Francesco Piscitelli)

Wigner Research Institute
(Dezsõ Varga and Eszter Dian)

BNC-Wigner is the largest organization in Hungary comprising 45 research group of various profile.
BNC-Wigner has a long tradition in working with industrial companies; in 10y over 25 companies of various size and profile were involved in technology transfer related to neutron developments.
BNC-Wigner will support with the detector development required in the intensity frontier task in WP4.

LUND UNIVERSITY
Division of Nuclear Physics
(Kevin Fissum)

LU has a long story of developing novel particle detectors for hostile particle accelerator.
LU has completed the construction of the Source-Testing Facility for prototype commissioning.
Their experience with developing and testing detectors will be crucial for the task in WP4.

The Multi-Blade project

concept introduced in 2005

NEUTRONS FOR SCIENCE

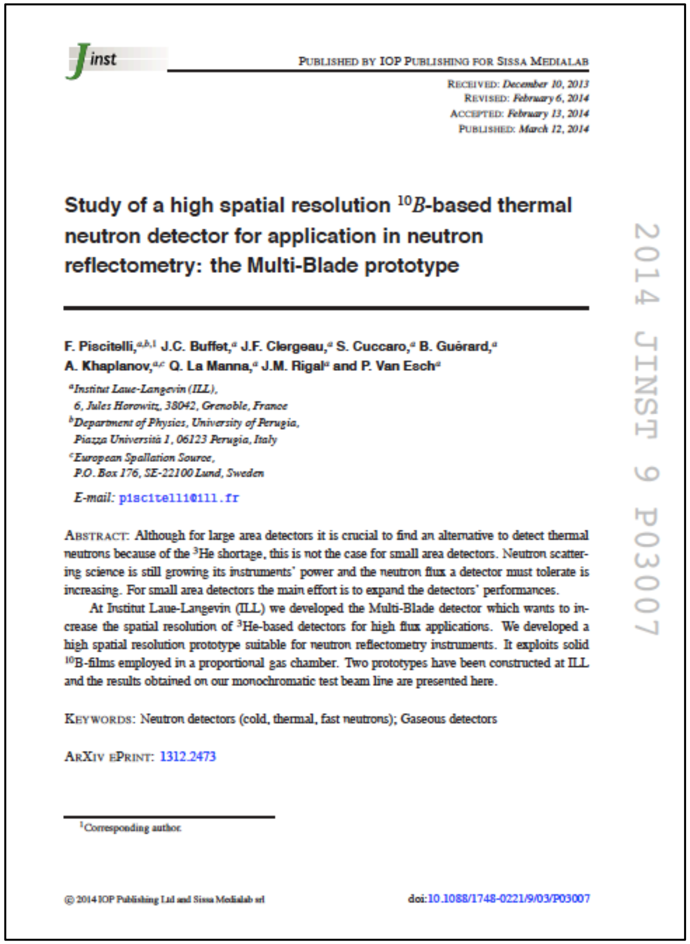
Institut Laue-Langevin

proof of concept in 2012

NEUTRONS FOR SCIENCE

Institut Laue-Langevin

University of Perugia



JINST

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *December 10, 2013*
REVISED: *February 6, 2014*
ACCEPTED: *February 13, 2014*
PUBLISHED: *March 12, 2014*

Study of a high spatial resolution ^{10}B-based thermal neutron detector for application in neutron reflectometry: the Multi-Blade prototype

F. Piscitelli,[a,b,1] J.C. Buffet,[a] J.F. Clergeau,[a] S. Cuccaro,[a] B. Guérard,[a] A. Khaplanov,[a,c] Q. La Manna,[a] J.M. Rigal[a] and P. Van Esch[a]

[a] *Institut Laue-Langevin (ILL), 6, Jules Horowitz, 38042, Grenoble, France*
[b] *Department of Physics, University of Perugia, Piazza Università 1, 06123 Perugia, Italy*
[c] *European Spallation Source, P.O. Box 176, SE-22100 Lund, Sweden*

E-mail: piscitelli@ill.fr

ABSTRACT: Although for large area detectors it is crucial to find an alternative to detect thermal neutrons because of the ^{3}He shortage, this is not the case for small area detectors. Neutron scattering science is still growing its instruments' power and the neutron flux a detector must tolerate is increasing. For small area detectors the main effort is to expand the detectors' performances.

At Institut Laue-Langevin (ILL) we developed the Multi-Blade detector which wants to increase the spatial resolution of ^{3}He-based detectors for high flux applications. We developed a high spatial resolution prototype suitable for neutron reflectometry instruments. It exploits solid ^{10}B-films employed in a proportional gas chamber. Two prototypes have been constructed at ILL and the results obtained on our monochromatic test beam line are presented here.

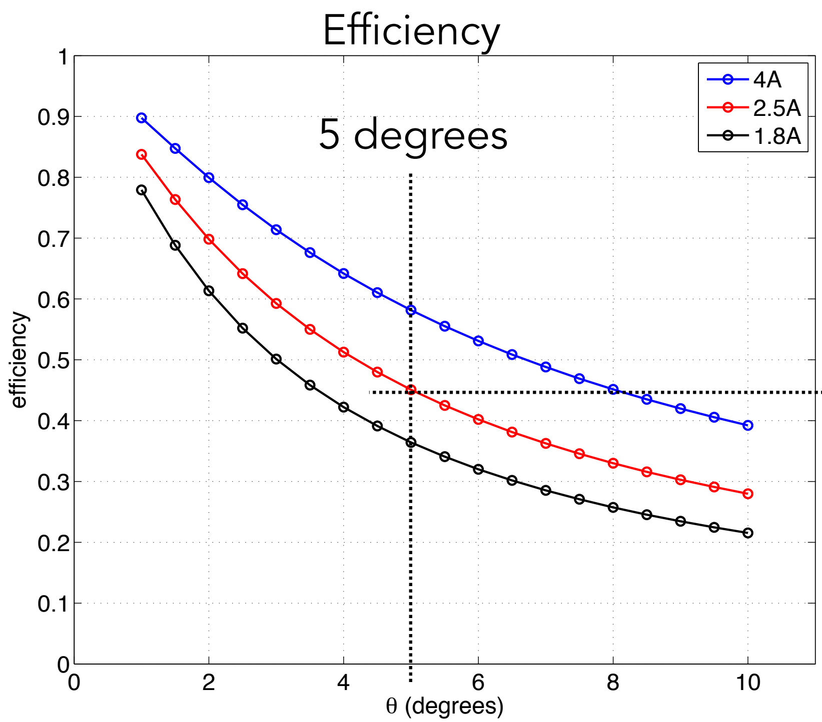
KEYWORDS: Neutron detectors (cold, thermal, fast neutrons); Gaseous detectors

ARXIV EPRINT: 1312.2473

[1] Corresponding author.

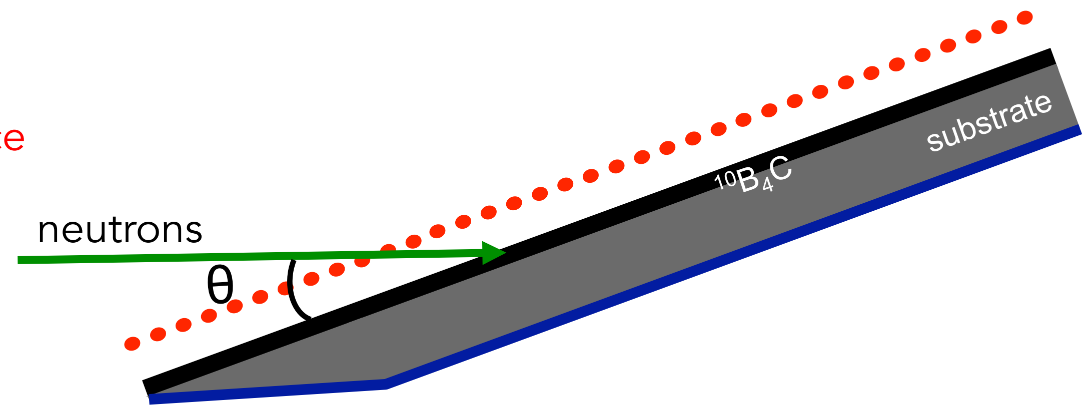
 doi:10.1088/1748-0221/9/03/P03007

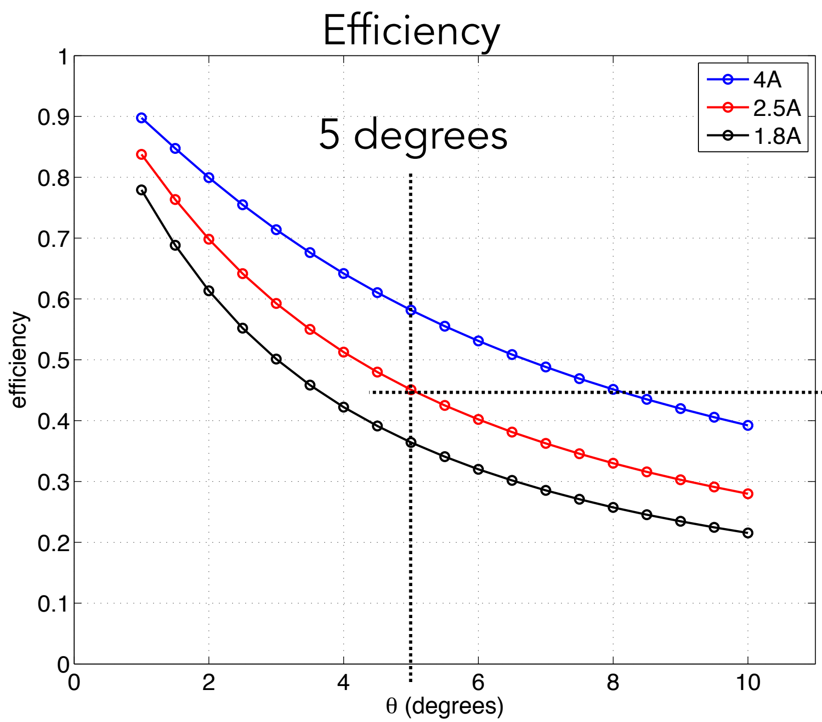
2014 JINST 9 P03007



Efficiency 45% at 2.5Å
A single Boron layer inclined at 5 degrees

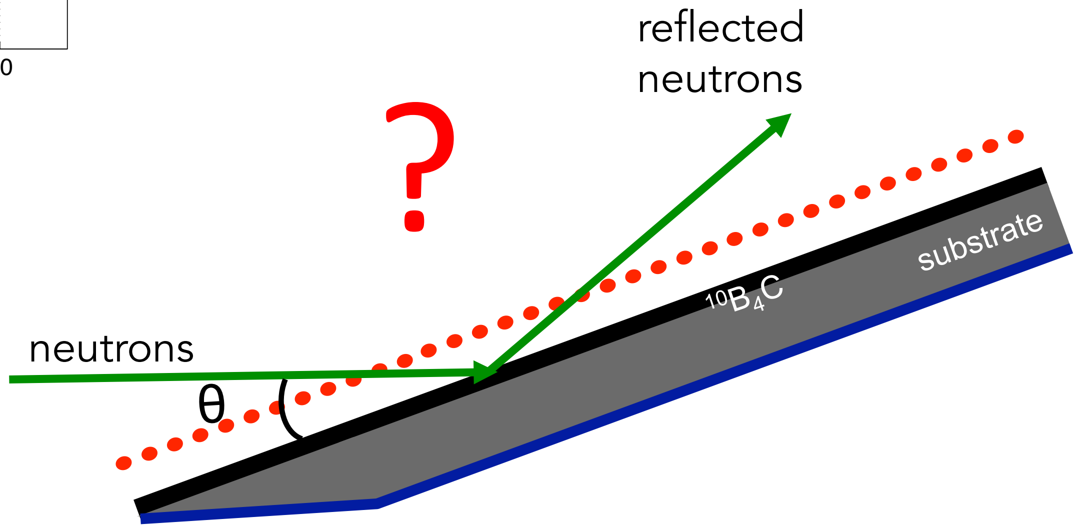
The intensity is spread over a wider surface
(5 degrees = factor x10)



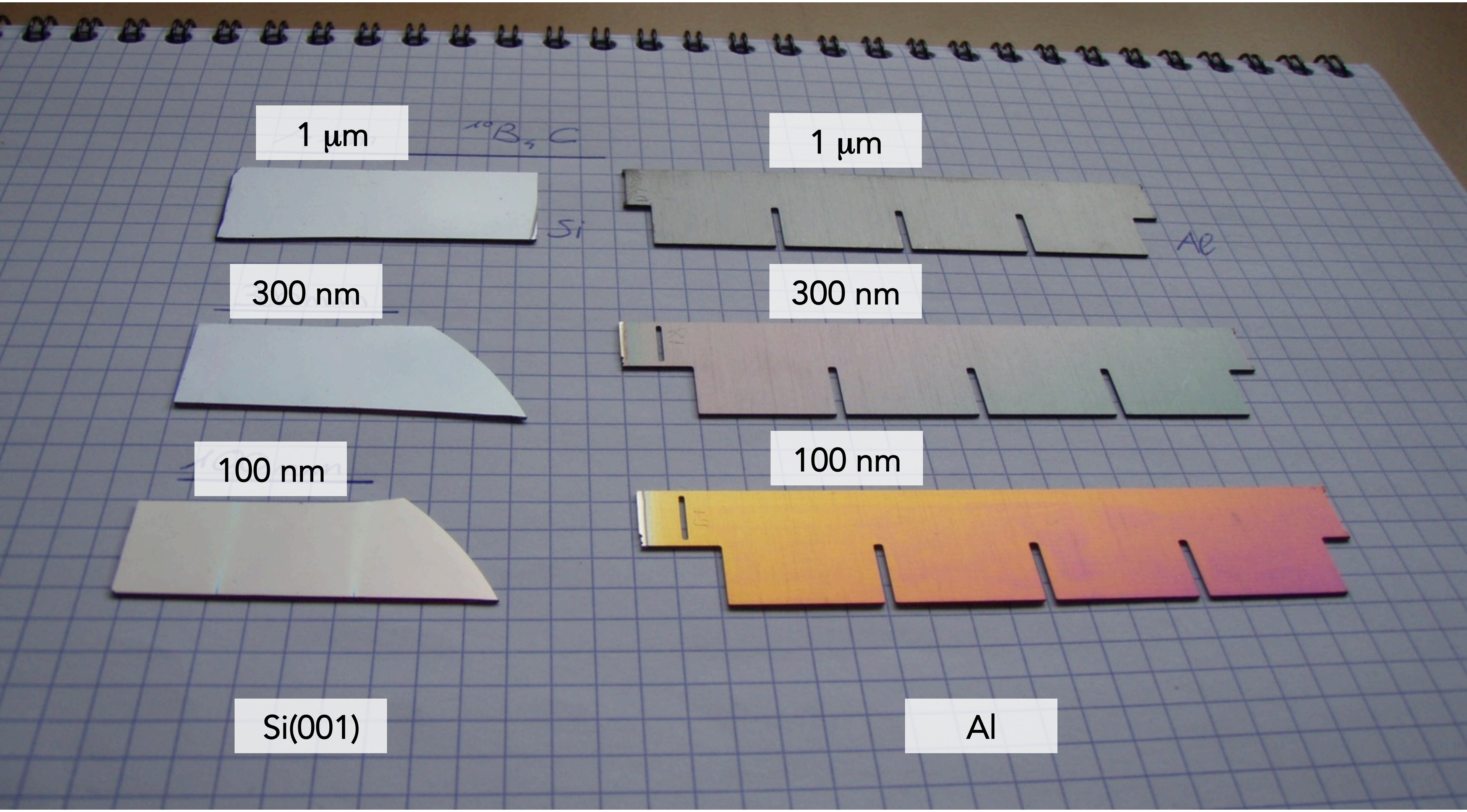


Reflection can reduce the efficiency

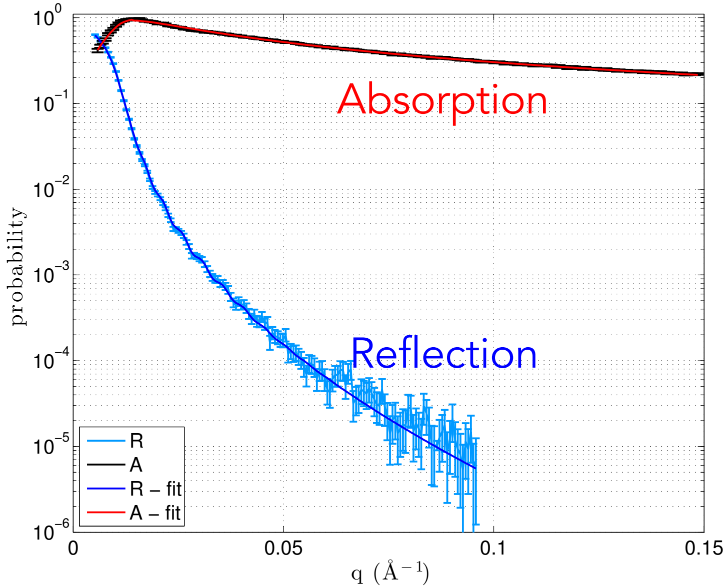
Efficiency 45% at 2.5Å
A single Boron layer inclined at 5 degrees

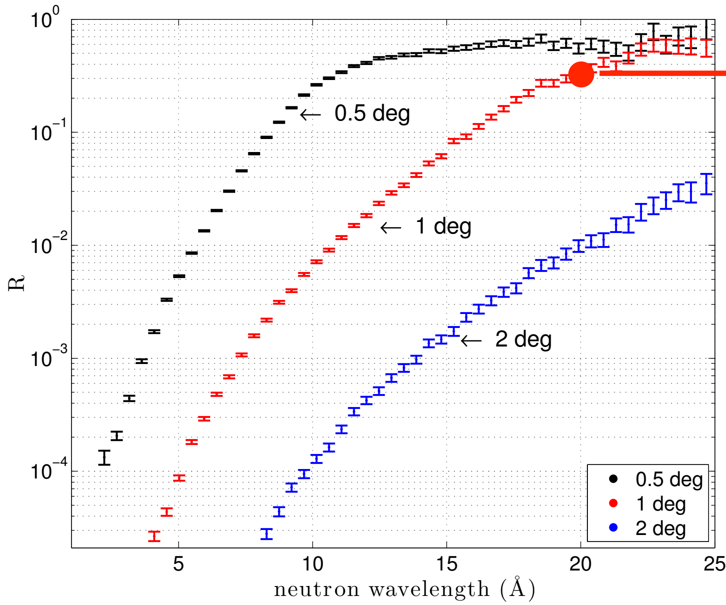


$^{10}B_4C$ Samples



EUROPEAN SPALLATION SOURCE





R = 30% @ 20Å, 1°

ARTICLE IN PRESS

PROCEEDINGS A

rspa.royalsocietypublishing.org

Research

CrossMark

Neutron reflectometry on highly absorbing films and its application to $^{10}B_4C$-based neutron detectors

F. Piscitelli[1,2,3], A. Khaplanov[1,2], A. Devishvili[4], S. Schmidt[1,5], C. Höglund[1,5], J. Birch[5], A. J. C. Dennison[2,6], P. Gutfreund[2], R. Hall-Wilton[1,7] and P. Van Esch[2]

[1]European Spallation Source ERIC, PO Box 176, Lund 22100, Sweden
[2]Institut Laue-Langevin (ILL), 71, Avenue des Martyrs, Grenoble 38042, France
[3]Department of Physics, University of Perugia, Piazza Università 1, Perugia 06123, Italy
[4]Ruhr-Universität Bochum, Bochum 44780, Germany
[5]Thin Film Physics Division, Linköping University, Linköping 58183, Sweden
[6]Department of Physics and Astronomy, Uppsala University, BP 516, Uppsala 75120, Sweden
[7]Mid-Sweden University, Sundsvall 85170, Sweden

Cite this article: Piscitelli F *et al.* 2016 Neutron reflectometry on highly absorbing films and its application to $^{10}B_4C$-based neutron detectors. *Proc. R. Soc. A* 20150711. http://dx.doi.org/10.1098/rspa.2015.0711

Received: 15 October 2015

Accepted: 22 December 2015

Subject Areas:
materials science

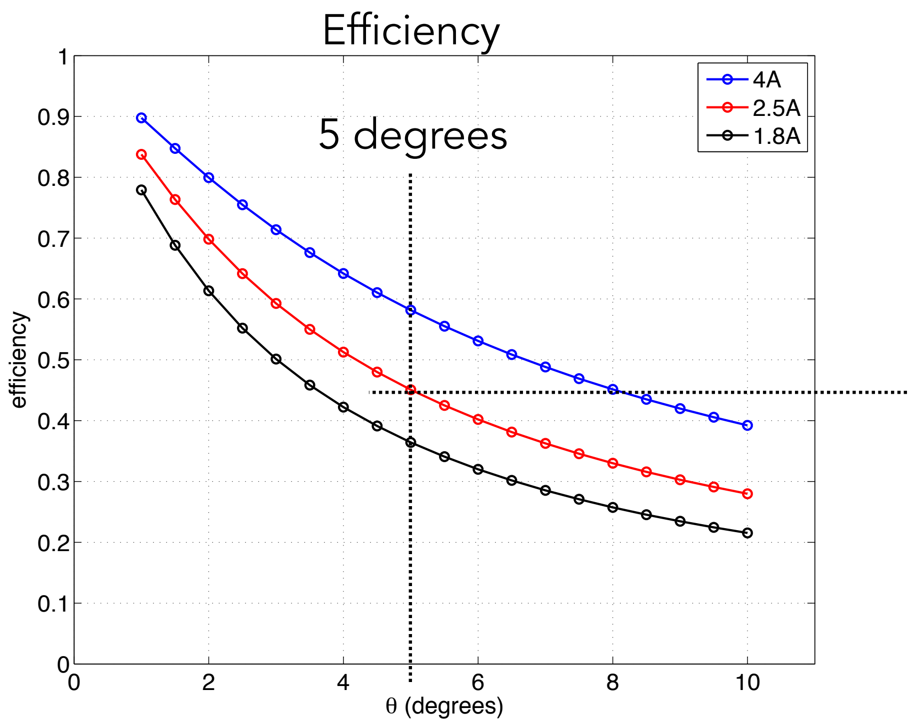
Keywords:
neutron-induced fluorescence, neutron reflectometry, Boron-10, neutron detection

Author for correspondence:
F. Piscitelli
e-mail: francesco.piscitelli@esss.se

Neutron reflectometry is a powerful tool used for studies of surfaces and interfaces. The absorption in the typical studied materials is neglected and this technique is limited only to the reflectivity measurement. For strongly absorbing nuclei, the absorption can be directly measured by using the neutron-induced fluorescence technique which exploits the prompt particle emission of absorbing isotopes. This technique is emerging from soft matter and biology where highly absorbing nuclei, in very small quantities, are used as a label for buried layers. Nowadays, the importance of absorbing layers is rapidly increasing, partially because of their application in neutron detection; a field that has become more active also due to the ^{3}He-shortage. We extend the neutron-induced fluorescence technique to the study of layers of highly absorbing materials; in

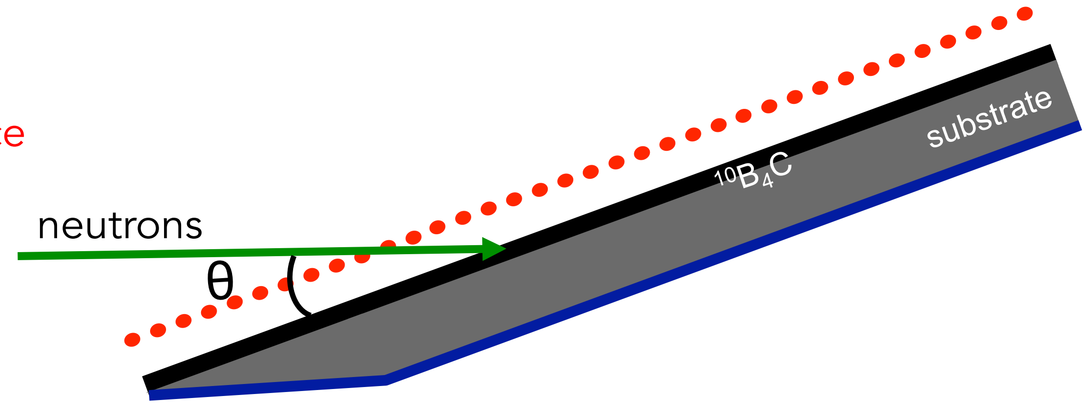
Electronic supplementary material is available at http://dx.doi.org/10.1098/rspa.2015.0711 or via http://rspa.royalsocietypublishing.org.

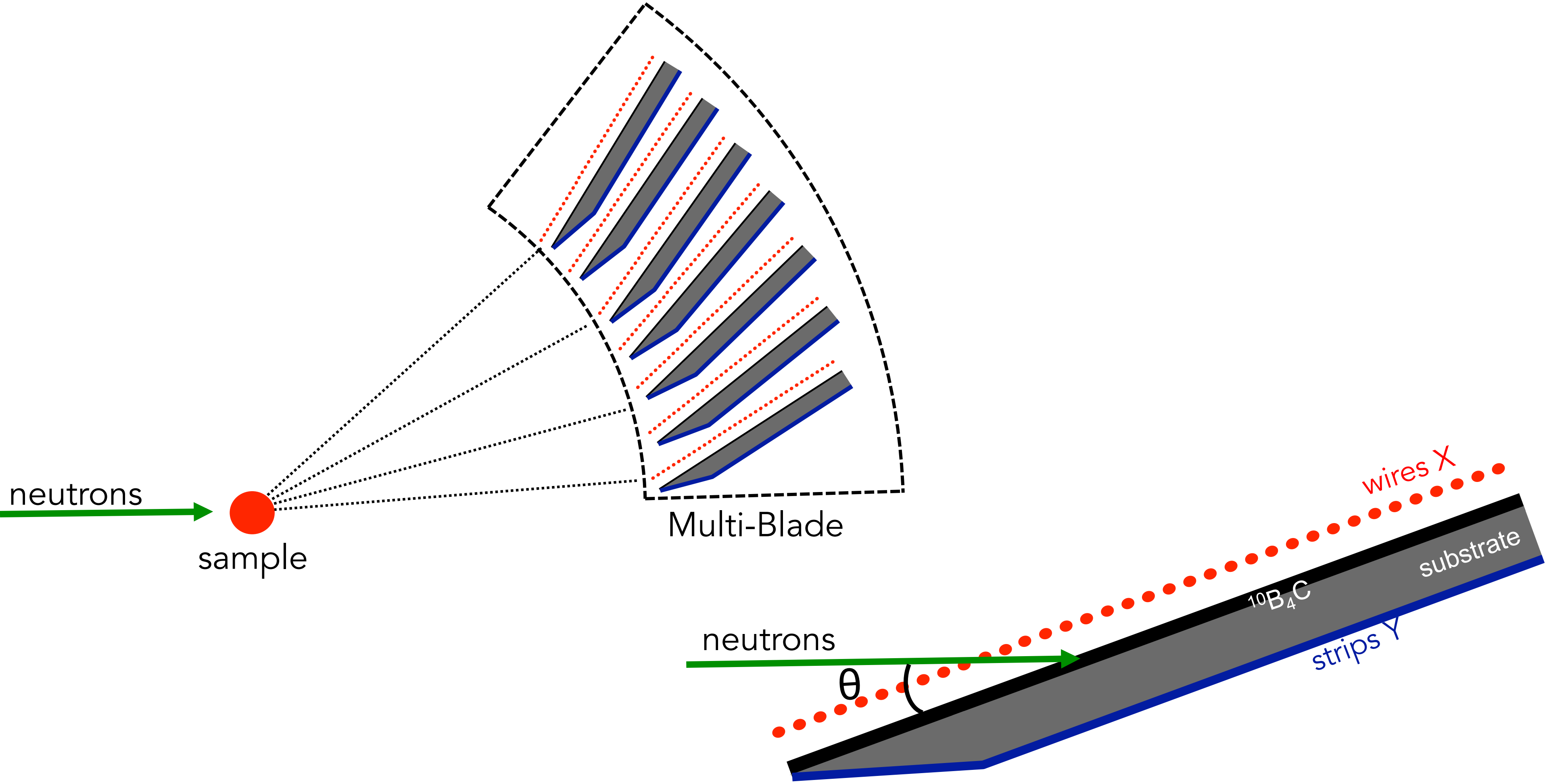
THE ROYAL SOCIETY
PUBLISHING

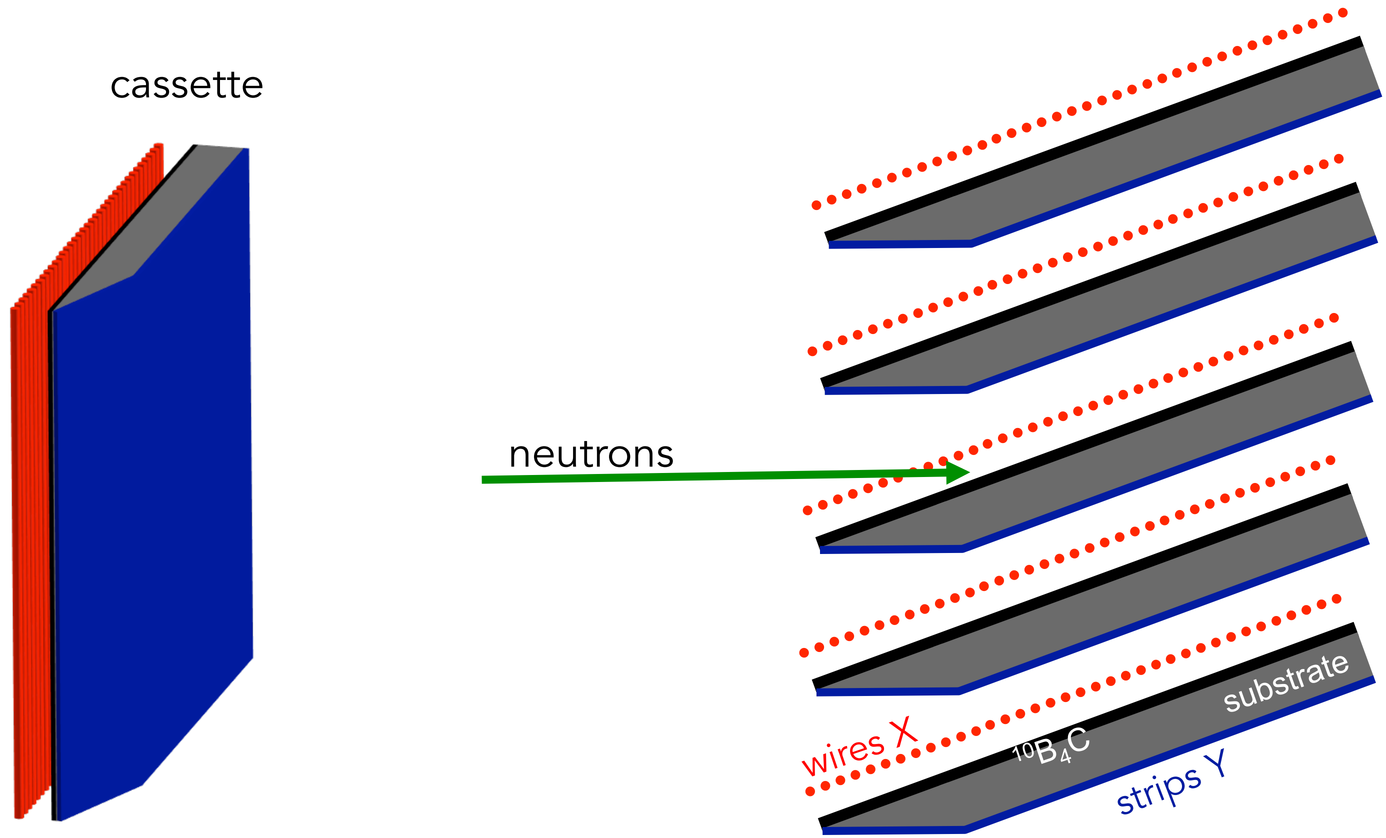


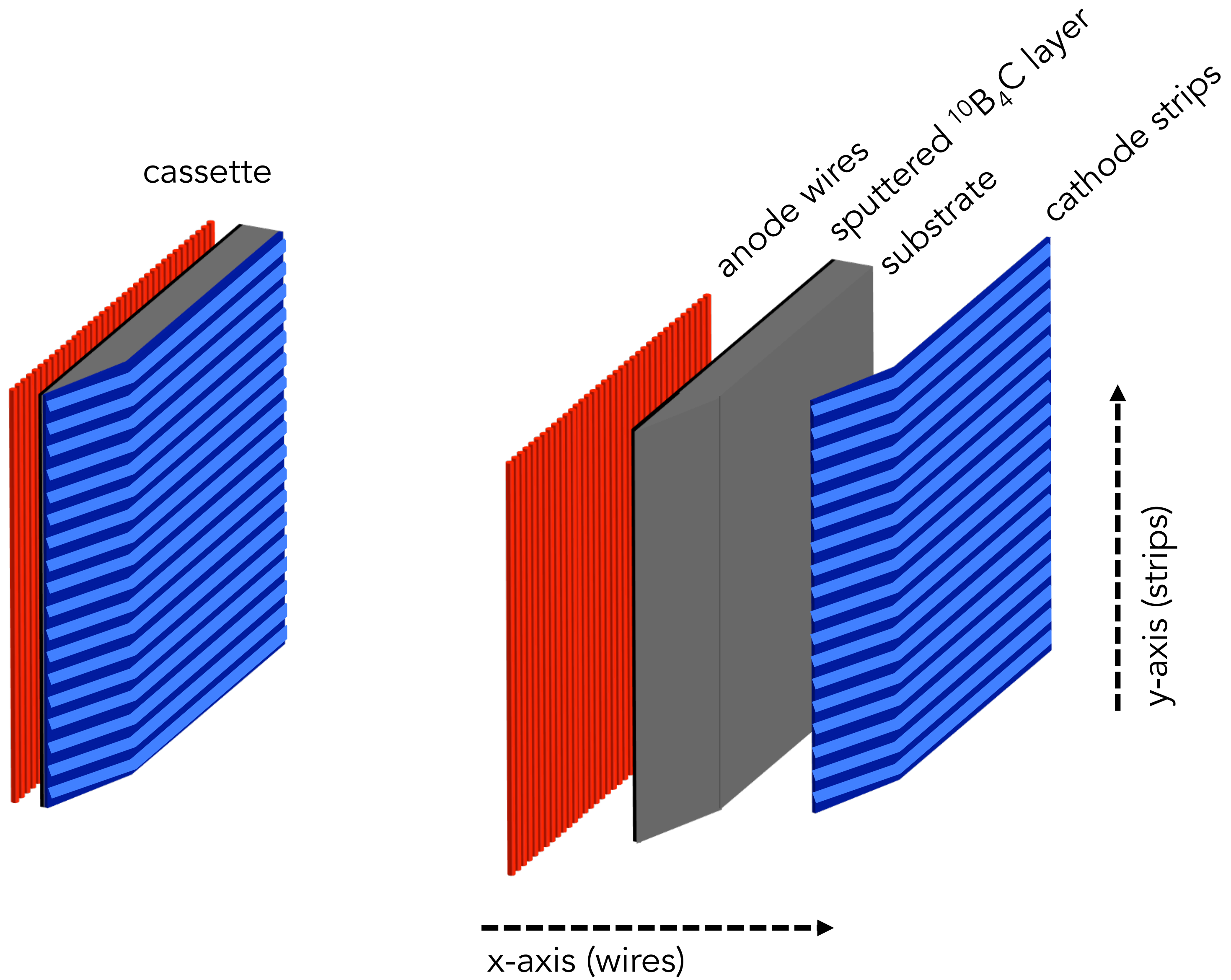
Efficiency 45% at 2.5Å
A single Boron layer inclined at 5 degrees

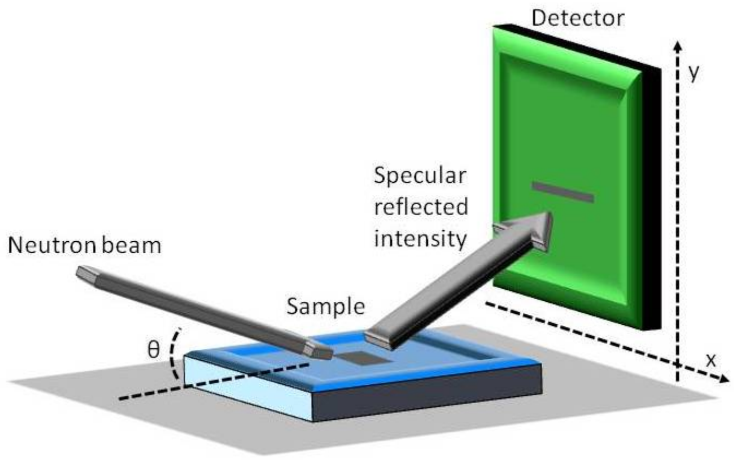
The intensity is spread over a wider surface
(5 degrees = factor x10)



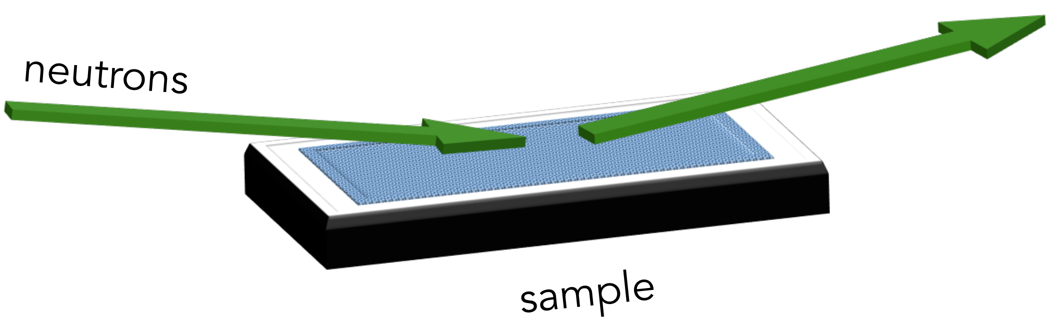

neutrons
sample
Multi-Blade
wires X
substrate
$^{10}B_4C$
strips Y
neutrons
θ


cassette
neutrons
wires X
$^{10}B_4C$
substrate
strips Y

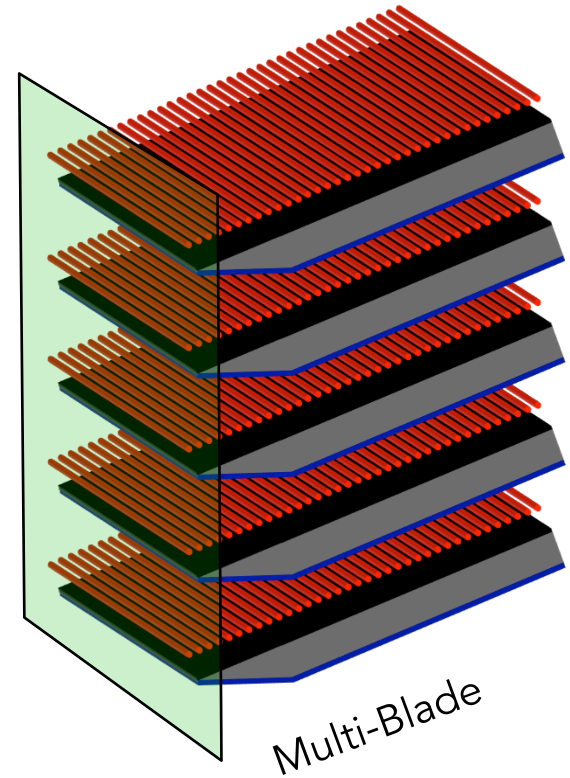

cassette
anode wires
sputtered $^{10}B_4C$ layer
substrate
cathode strips
y-axis (strips)
x-axis (wires)



Detector
y
Specular
reflected
intensity
Neutron beam
Sample
θ
x

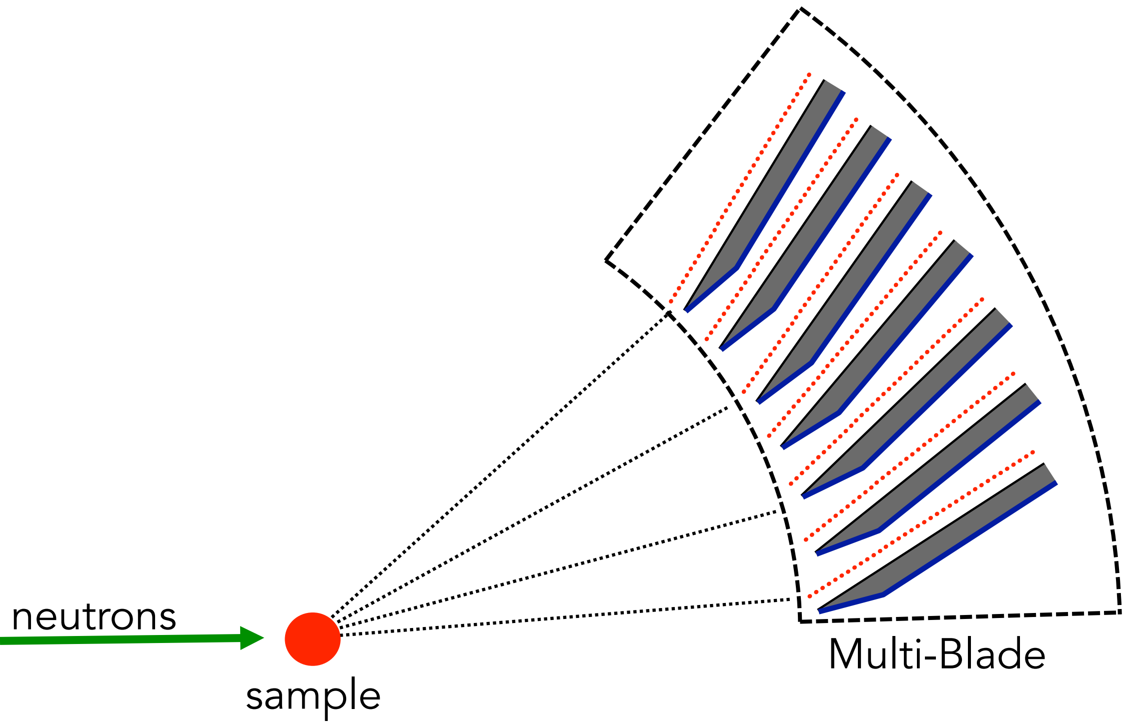


neutrons
sample



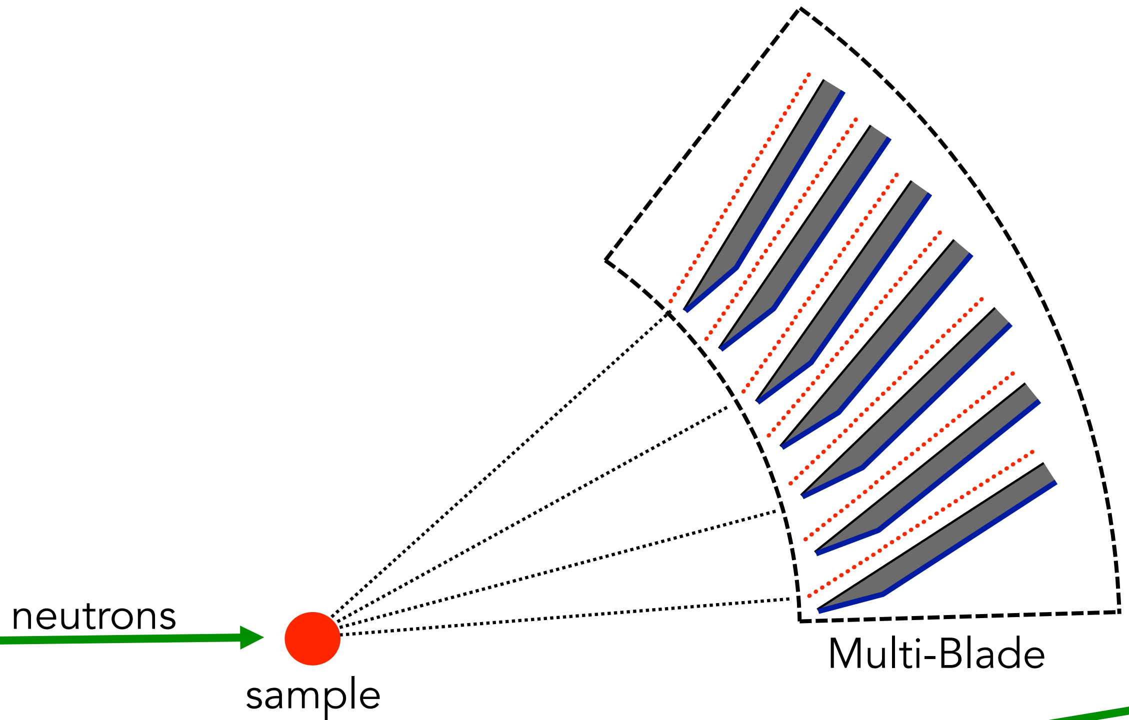
Multi-Blade

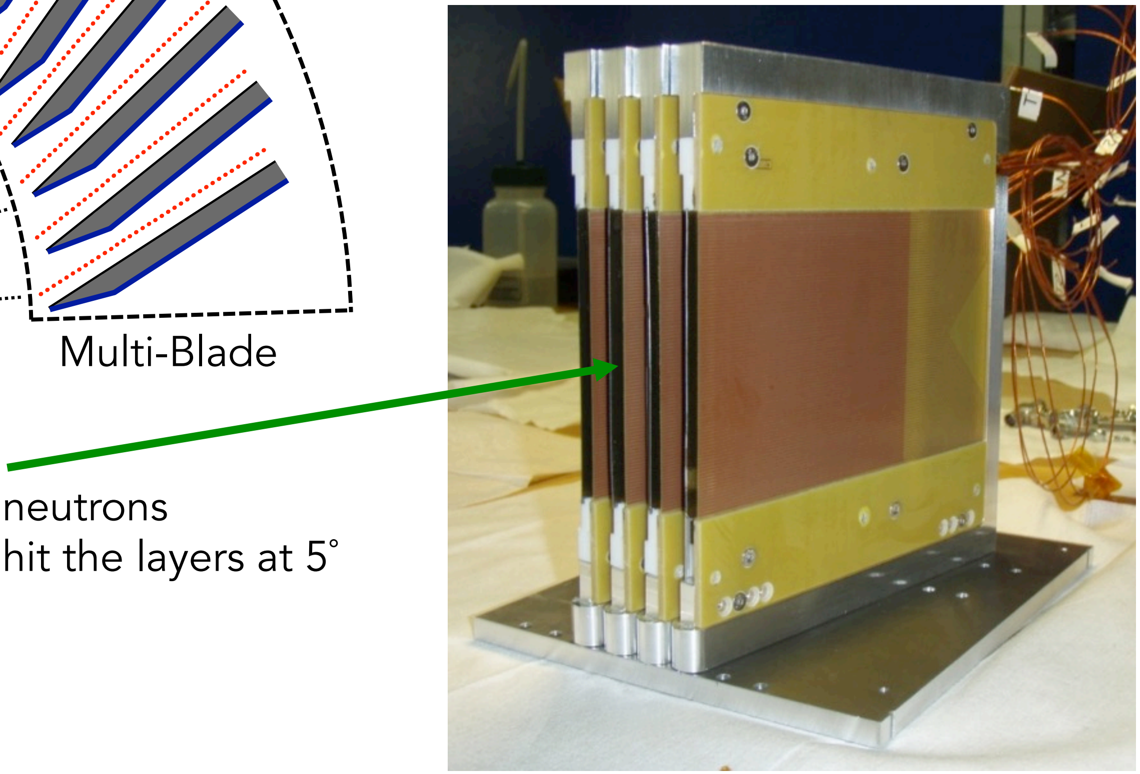
(Not in scale)


neutrons
sample
Multi-Blade

4 cassette demonstrator:

proof of concept in 2012

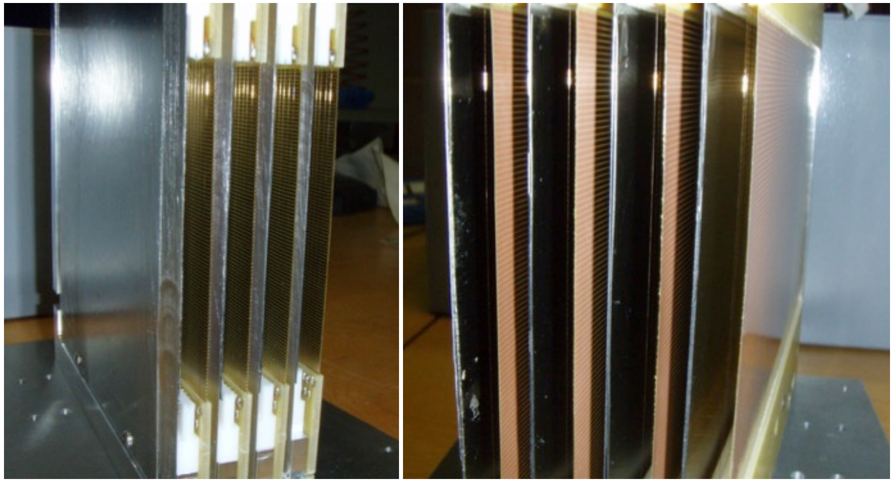


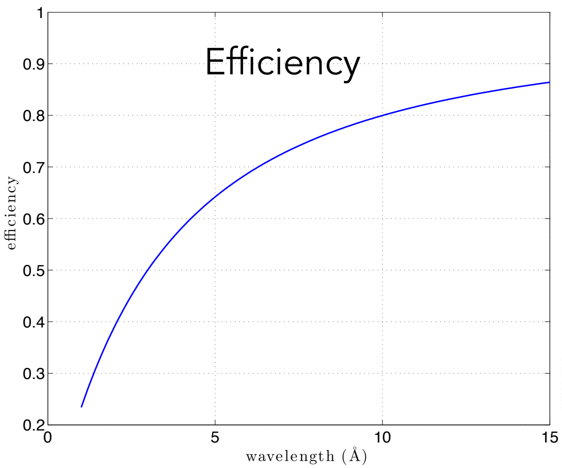


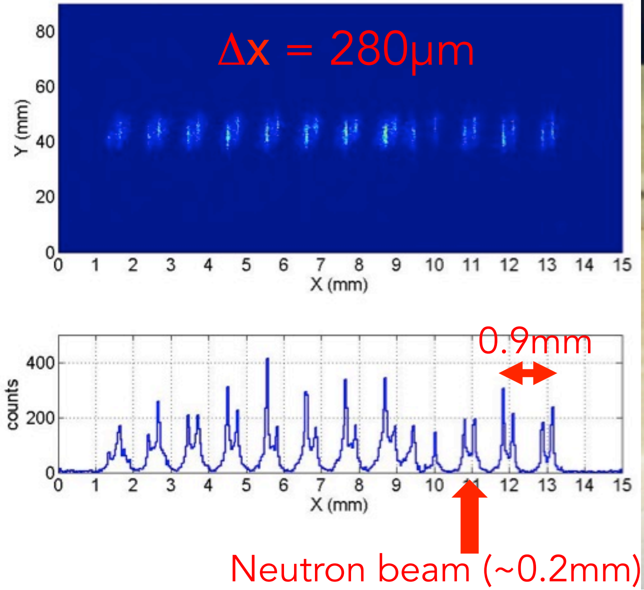
4 cassette demonstrator:

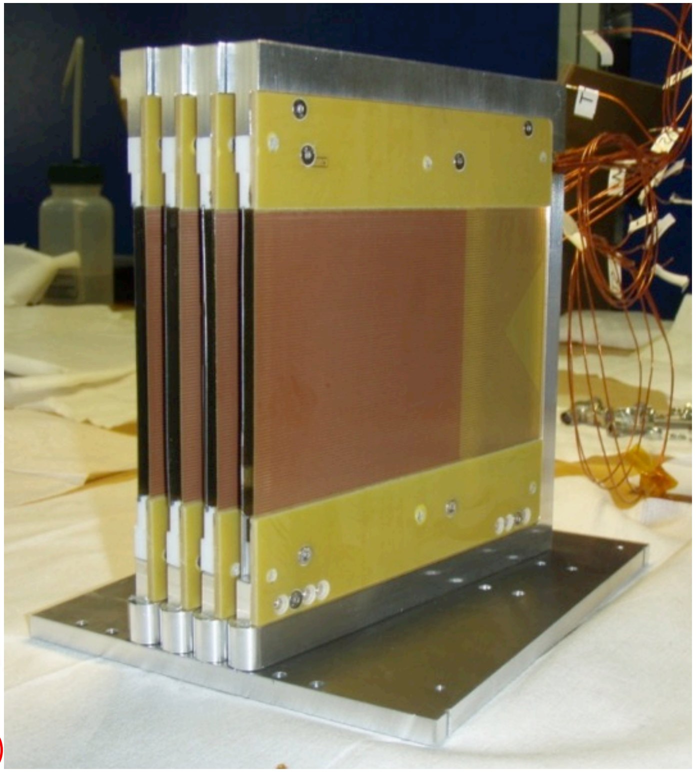
Results:

- Measured Efficiency 45% at 2.5Å
- Spatial Resolution 4mm x 280μm
- Counting rate capability ~5000 n/s/mm^2 at 2.5Å (limited by the electronics)
- Atmospheric pressure operation
  (thin vessel window, low scattering)
  (cost effective materials)





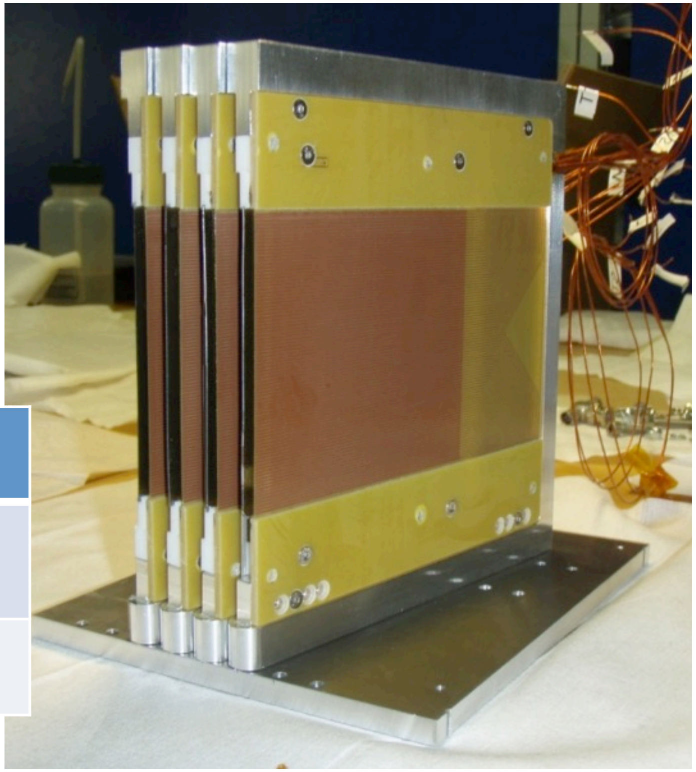




4 cassette demonstrator:

Results:

- Measured Efficiency 45% at 2.5Å
- Spatial Resolution 4mm x 280µm
- Counting rate capability ~5000 n/s/mm^2 at 2.5Å (limited by the electronics)
- Atmospheric pressure operation
  (thin vessel window, low scattering)
  (cost effective materials)



The ESS requirements

	FREIA	Estia
Max local rate	10^5 n/s/Å/mm^2	• Conventional refl. 10^5 n/s/Å/mm^2 • High intensity mode 10^4 n/s/Å/mm^2
Spatial resolution	4mm x 1mm	4mm x 0.5mm

4 cassette demonstrator:

Results:

- Measured Efficiency 45% at 2.5Å
- Spatial Resolution 4mm x 280μm
- Counting rate capability ~5000 n/s/mm^2 at 2.5Å (limited by the electronics)
- Atmospheric pressure operation
  (thin vessel window, low scattering)
  (cost effective materials)

x10

x20

x300

The state of the art

Instrument	Facility	techn.	area $(mm \times mm)$	spatial res. $(mm \times mm)$	efficiency	global rate (s^{-1})	local rate $(s^{-1}mm^{-2})$
FIGARO [9]	ILL	^{3}He	512×256	$\sim 2 \times 7.5$	$\sim$ 63% @ 2.5Å $\sim$ 90% @ 10Å $\sim$ 80% @ 30Å	$3 \cdot 10^7$	230
SuperADAM [11]	ILL	^{3}He	300×300	2.8×2.8	76% @ 4.4Å	$2 \cdot 10^5$	-
REFSANS [12]	FRM2	^{3}He	500×500	$\sim 2 \times 2$	58% @ 10Å $\geq$ 50% $\in$ [5, 18]Å	$2.2 \cdot 10^5$	300
INTER [13]	ISIS	^{3}He, ^{6}Li	200×200	$\sim 1 \times 1$	-	-	-
POLREF [14, 15]	ISIS	^{3}He	200×200	$\leq 1 \times 1$	-	-	-
BIOREF [16]	HZB	^{3}He	300×300	2×3	$\sim$ 60% @ 10Å	$2 \cdot 10^5$	300
LR	SNS	^{3}He	200×200	1.3×1.3	-	-	-
MR	SNS	^{3}He	210×180	1.5×1.5	-	-	-
Platypus [17]	OPAL	^{3}He	500×250	1.2×1.2	$\sim$ 60% @ 10Å	$2 \cdot 10^5$	300
SOFIA [18, 19]	J-PARC	^{3}He ^{6}Li	128×128 256×256	2×2 4×4	- -	- -	300 300

The ESS requirements

	FREIA	Estia
Max local rate	10^5 n/s/Å/mm^2	• Conventional refl. 10^5 n/s/Å/mm^2 • High intensity mode 10^4 n/s/Å/mm^2
Spatial resolution	4mm x 1mm	4mm x 0.5mm

4 cassette demonstrator:

Results:

- Measured Efficiency 45% at 2.5Å
- Spatial Resolution 4mm x 280μm
- Counting rate capability ~5000 n/s/mm^2 at 2.5Å (limited by the electronics)
- Atmospheric pressure operation
  (thin vessel window, low scattering)
  (cost effective materials)

x10

x20

x300

The state of the art

Instrument	Facility	techn.	area ($mm \times mm$)	spatial res. ($mm \times mm$)	efficiency	global rate (s^{-1})	local rate ($s^{-1}mm^{-2}$)
FIGARO [9]	ILL	^{3}He	512×256	$\sim 2 \times 7.5$	$\sim$ 63% @ 2.5Å $\sim$ 90% @ 10Å $\sim$ 80% @ 30Å	$3 \cdot 10^7$	230
SuperADAM [11]	ILL	^{3}He	300×300	2.8×2.8	76% @ 4.4Å	$2 \cdot 10^5$	-
REFSANS [12]	FRM2	^{3}He	500×500	$\sim 2 \times 2$	58% @ 10Å $\geq$ 50% $\in$ [5, 18]Å	$2.2 \cdot 10^5$	300
INTER [13]	ISIS	^{3}He, ^{6}Li	200×200	$\sim 1 \times 1$	-	-	-
POLREF [14, 15]	ISIS	^{3}He	200×200	$\leq 1 \times 1$	-	-	-
BIOREF [16]	HZB	^{3}He	300×300	2×3	$\sim$ 60% @ 10Å	$2 \cdot 10^5$	300
LR	SNS	^{3}He	200×200	1.3×1.3	-	-	-
MR	SNS	^{3}He	210×180	1.5×1.5	-	-	-
Platypus [17]	OPAL	^{3}He	500×250	1.2×1.2	$\sim$ 60% @ 10Å	$2 \cdot 10^5$	300
SOFIA [18, 19]	J-PARC	^{3}He ^{6}Li	128×128 256×256	2×2 4×4	- -	- -	300 300

The ESS requirements

	FREIA	Estia
Max local rate	10^5 n/s/Å/mm^2	• Conventional refl. 10^5 n/s/Å/mm^2 • High intensity mode 10^4 n/s/Å/mm^2
Spatial resolution	4mm x 1mm	4mm x 0.5mm

4 cassette demonstrator:

Results:

- Measured Efficiency 45% at 2.5Å
- Spatial Resolution 4mm x 280μm
- Counting rate capability ~5000 n/s/mm^2 at 2.5Å (limited by the electronics)
- Atmospheric pressure operation
  (thin vessel window, low scattering)
  (cost effective materials)

Next demonstrator:

- Counting rate capability
- Overlap and uniformity

The ESS requirements

	FREIA	Estia
Max local rate	10^5 n/s/Å/mm^2	• Conventional refl. 10^5 n/s/Å/mm^2 • High intensity mode 10^4 n/s/Å/mm^2
Spatial resolution	4mm x 1mm	4mm x 0.5mm

Next demonstrator (9 cassettes):

- Counting rate capability
- Overlap and uniformity

EUROPEAN SPALLATION SOURCE

- Build technology prototype
- Tests at both beam line and Reflectometry beam line

LUND UNIVERSITY

- Electric filed modeling
- Testing and availability of beam line
- Build technology prototype
- Data analysis

wigner

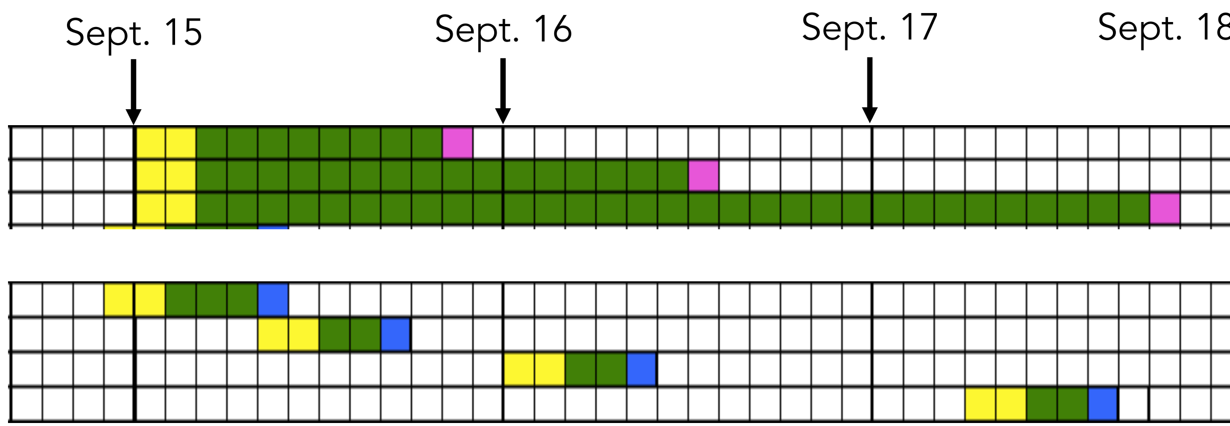
- Detailed GEANT4 on detector performance

All three partners will work together on the final detector for the ESS Reflectometers

Task 4.2 Neutron Detectors – The Intensity Frontier

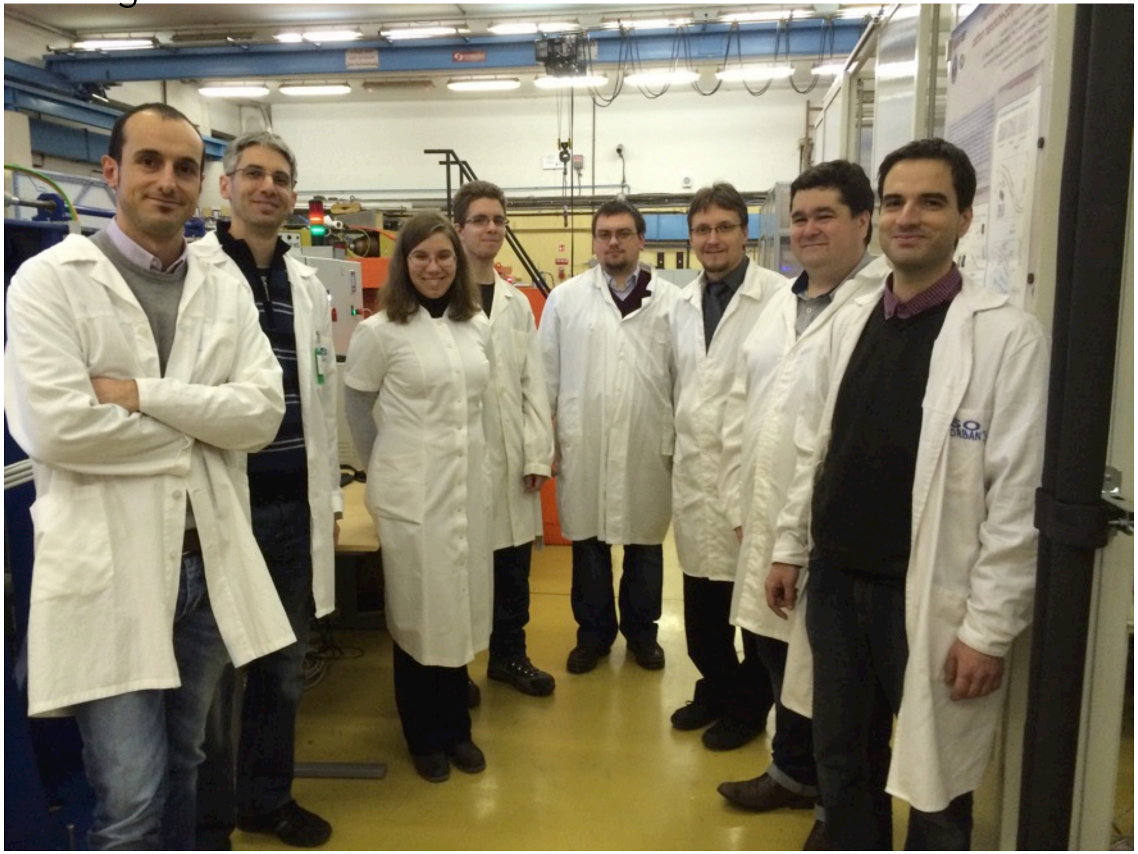
D4.2 Counting rate capability
D4.6 Detector Characterization
D4.12 Reflectometry detector

MS12 Improvement of the Multi-Blade design
MS16 Improvement of the counting rate cap.
MS20 Characterization of the demonstrator
MS29 1st Detector construction



- Planning
- Implementation
- Deliverable
- Milestone

Meeting at BNC - December 2015



Francesco Piscitelli
Tibor Zsíros
Eszter Dian
Péter Pázmándi
Gábor Kiss
Dezső Varga
Richard Hall-Wilton
János Orbán

BrightnESS

EUROPEAN SPALLATION SOURCE

LUND UNIVERSITY

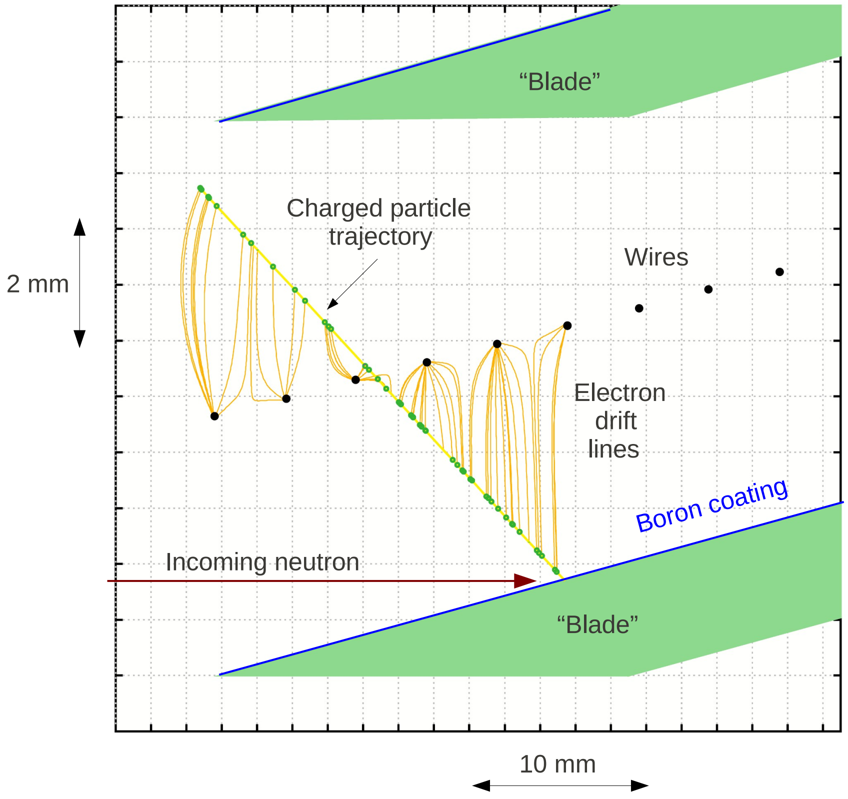
Wigner Research Institute

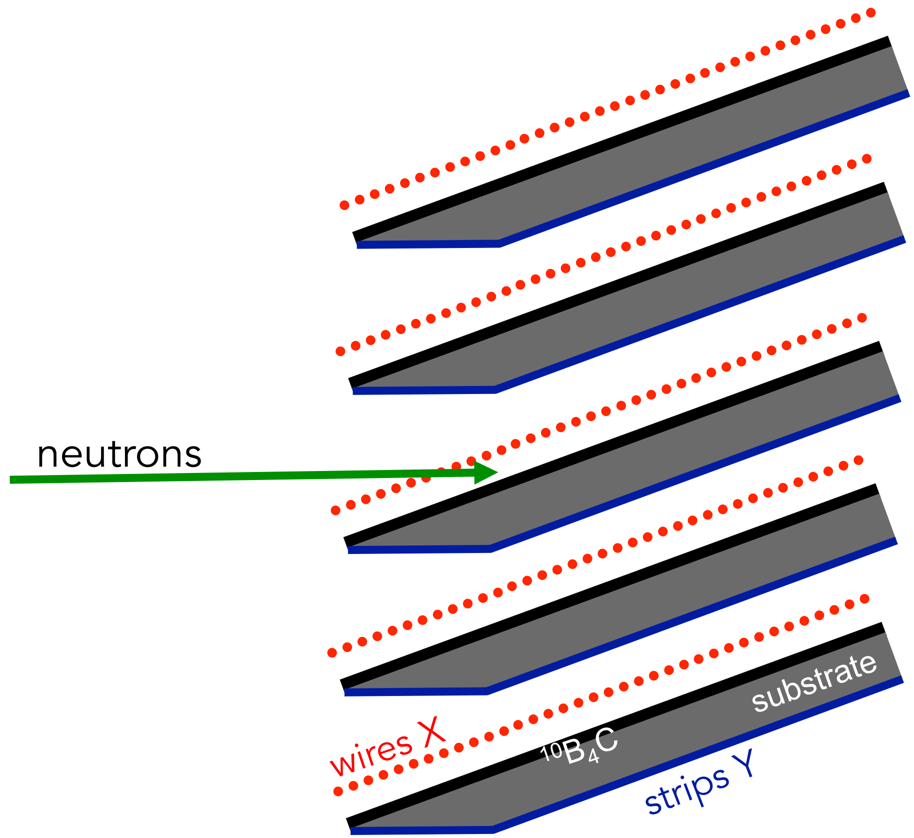
BNC Budapest Neutron Centre

Budapest Neutron Centre

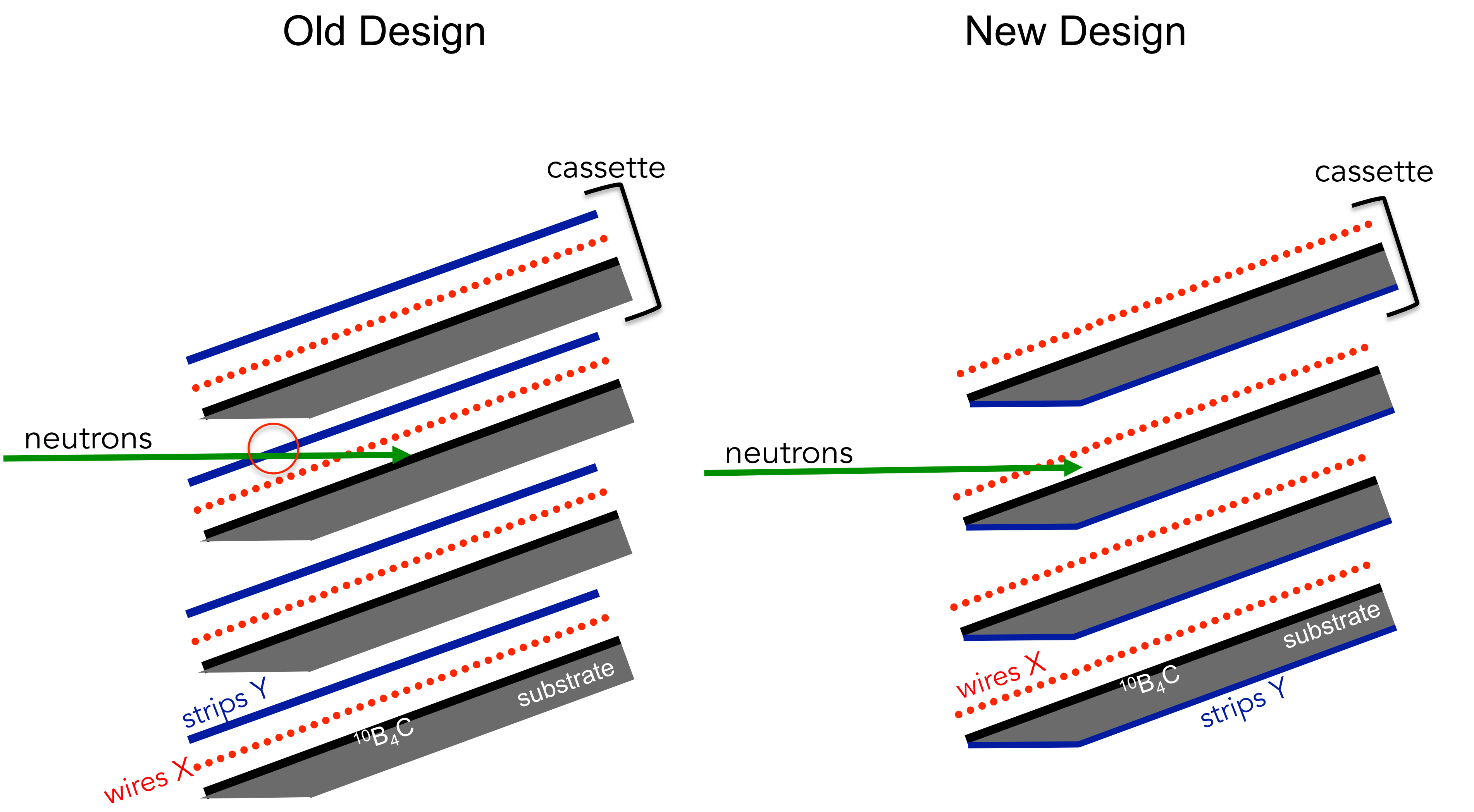
Electric field modeling

BrightnESS



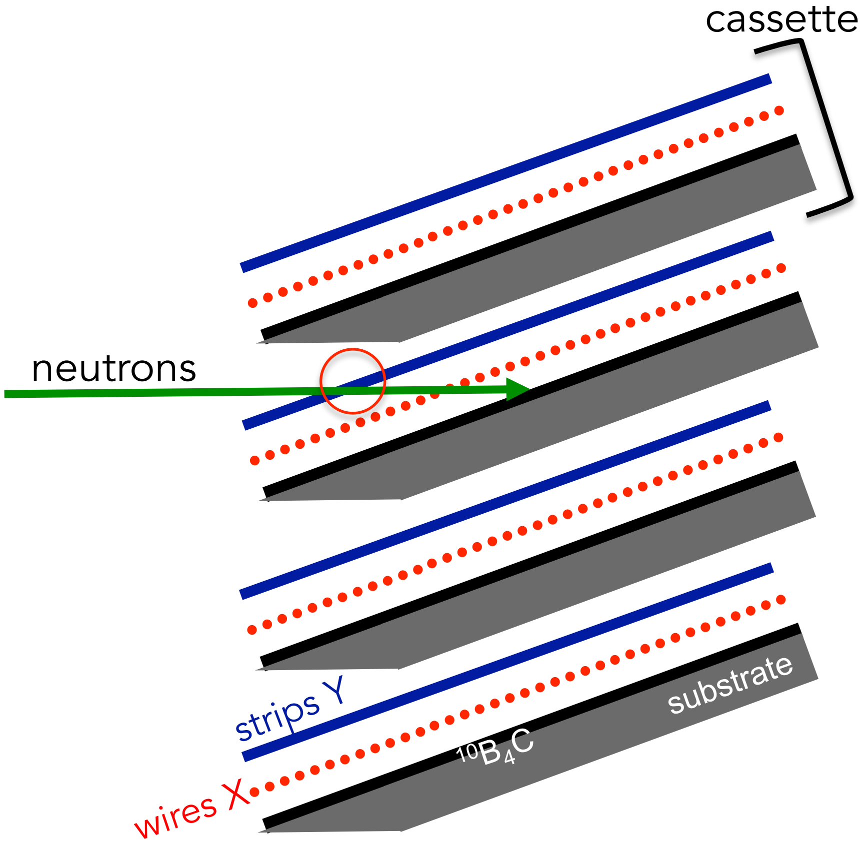


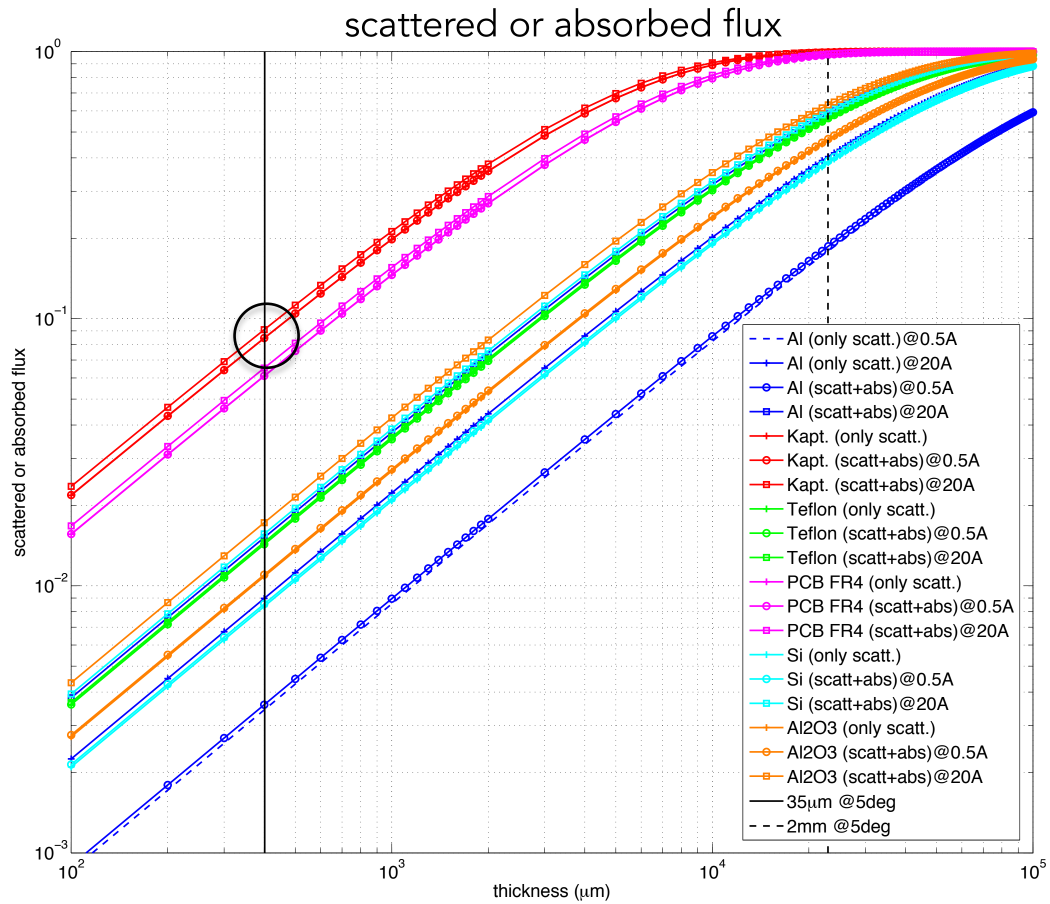
Materials evaluation



Materials evaluation

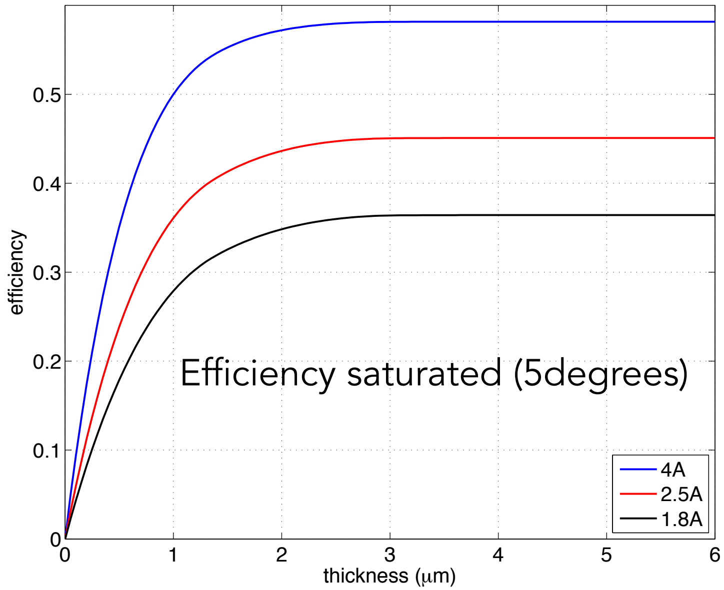
Old Design



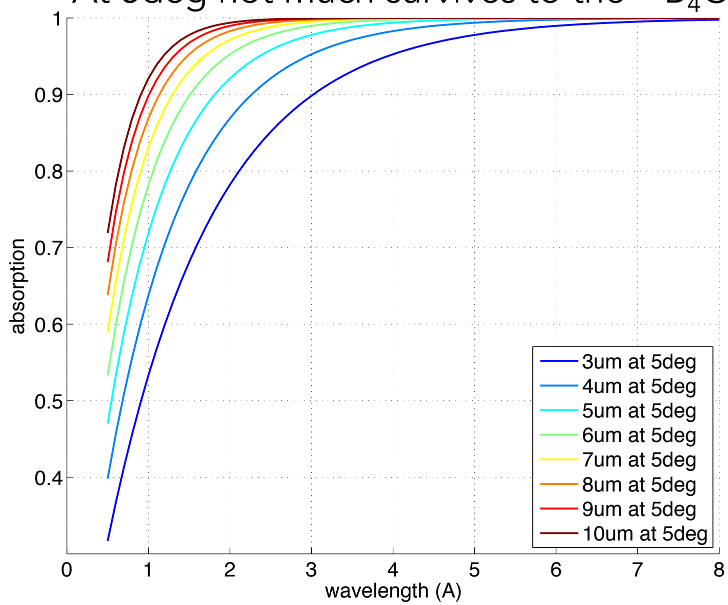


Any material holding the strips at 5deg scatters too much!

Materials evaluation

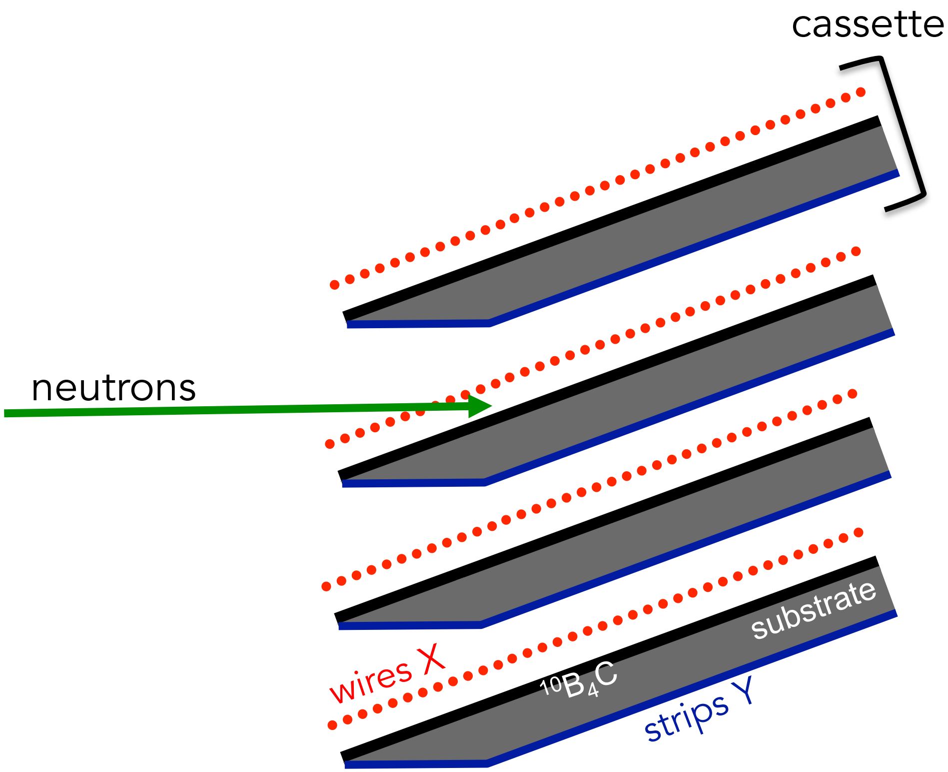


At 5deg not much survives to the $^{10}B_4C$

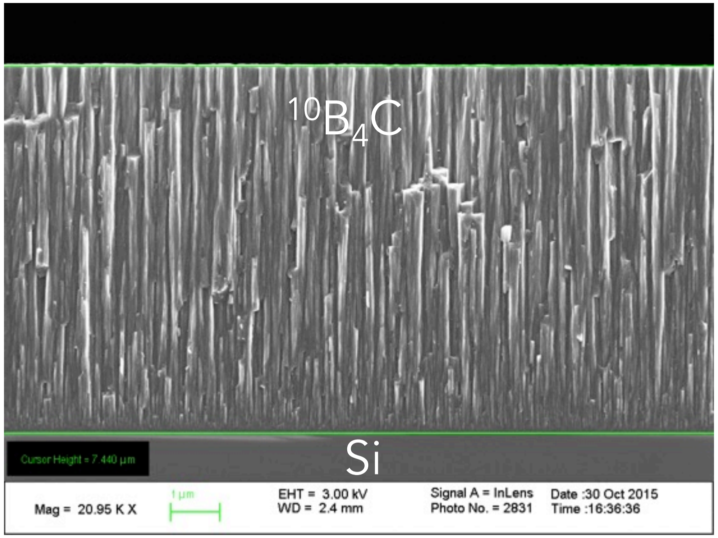


New Design

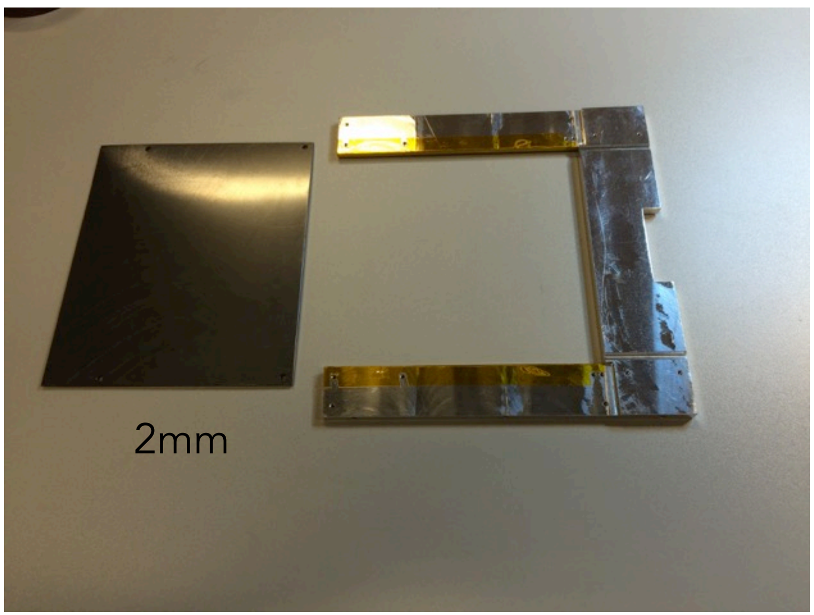
- Substrate as thick as necessary
- Kapton (strips) shielded by $^{10}B_4C$



Materials evaluation

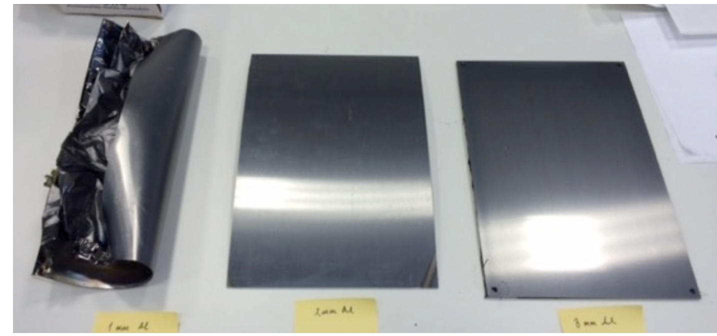


~7 µm single-side



Planarity is an issue on large surfaces

$200x300mm^2$ Al-plates single-side coated

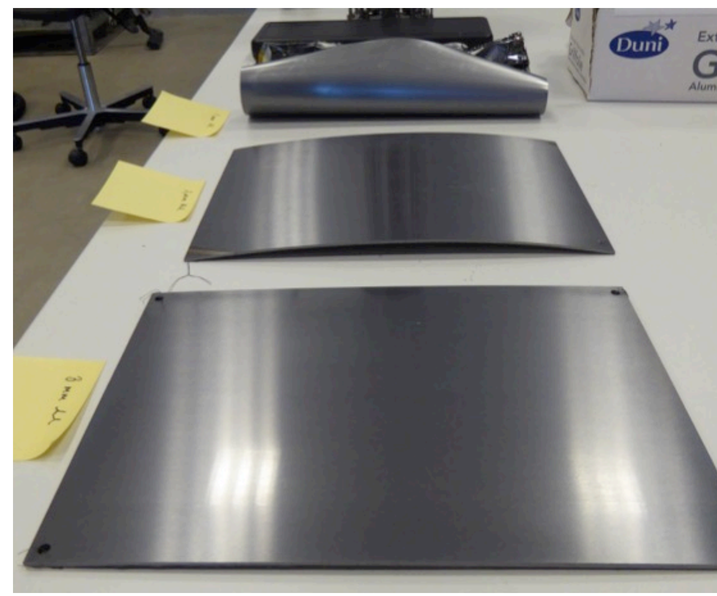


1mm 2mm 3mm

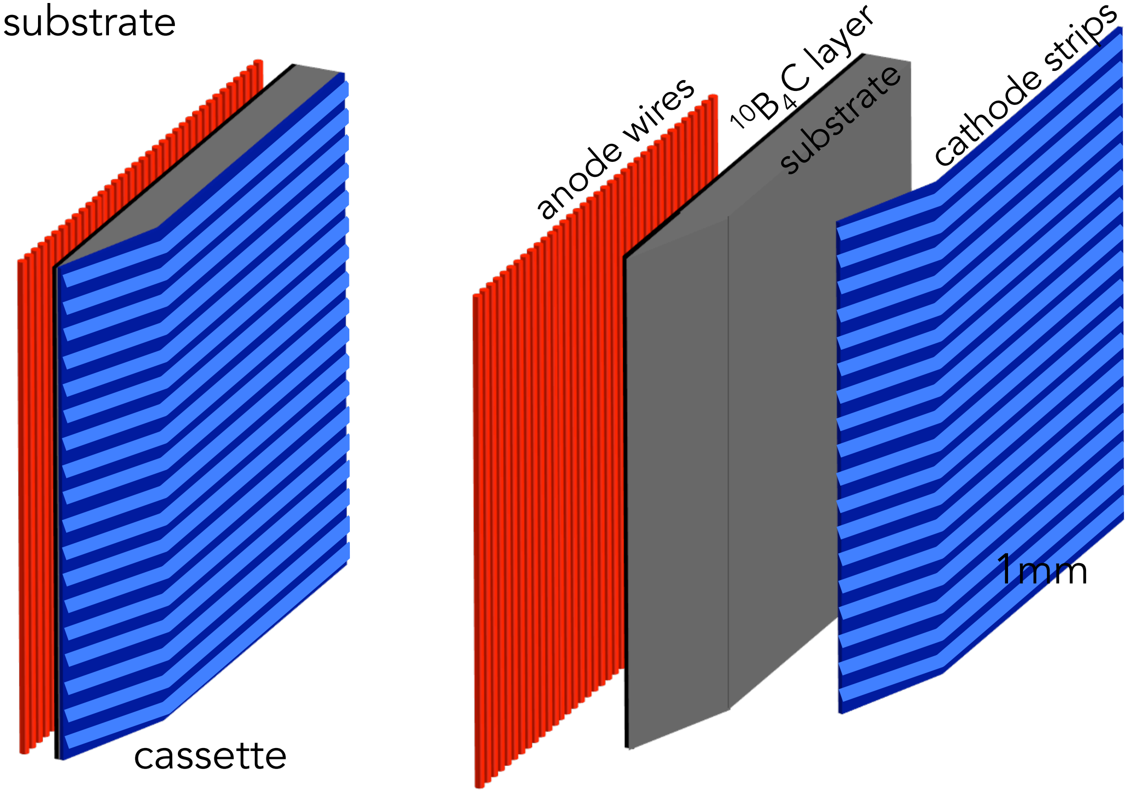
1mm

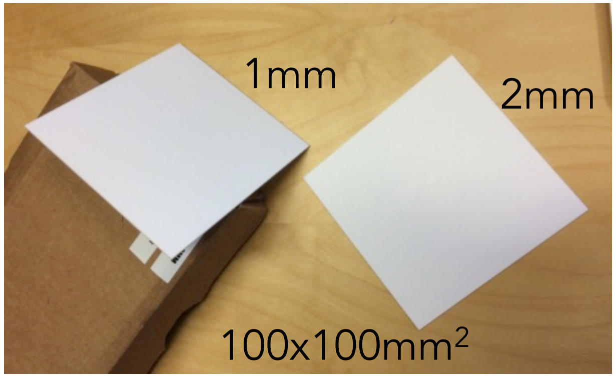
2mm

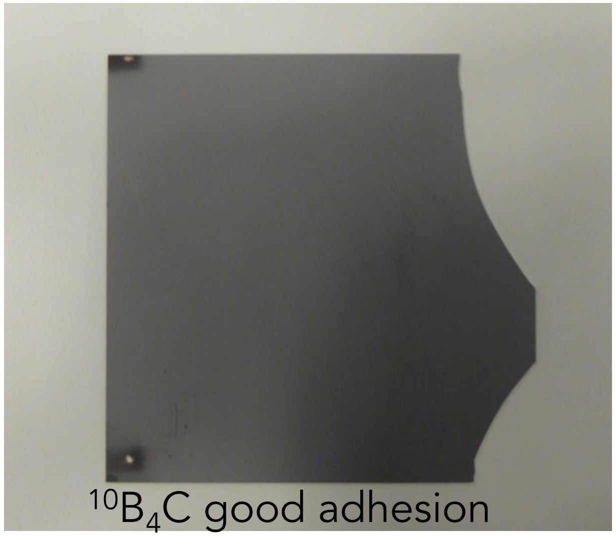
3mm

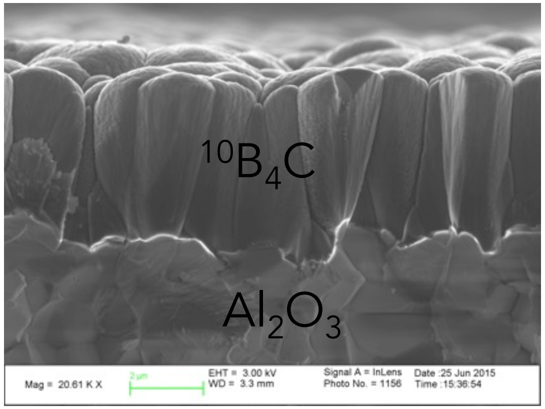


Al_2O_3 substrate





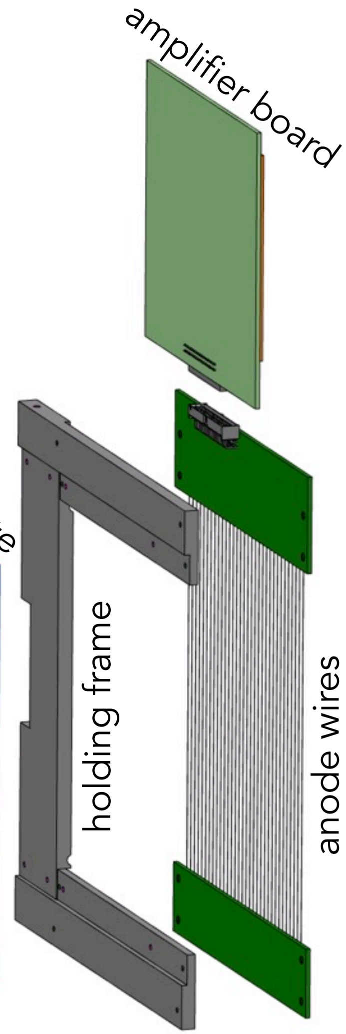


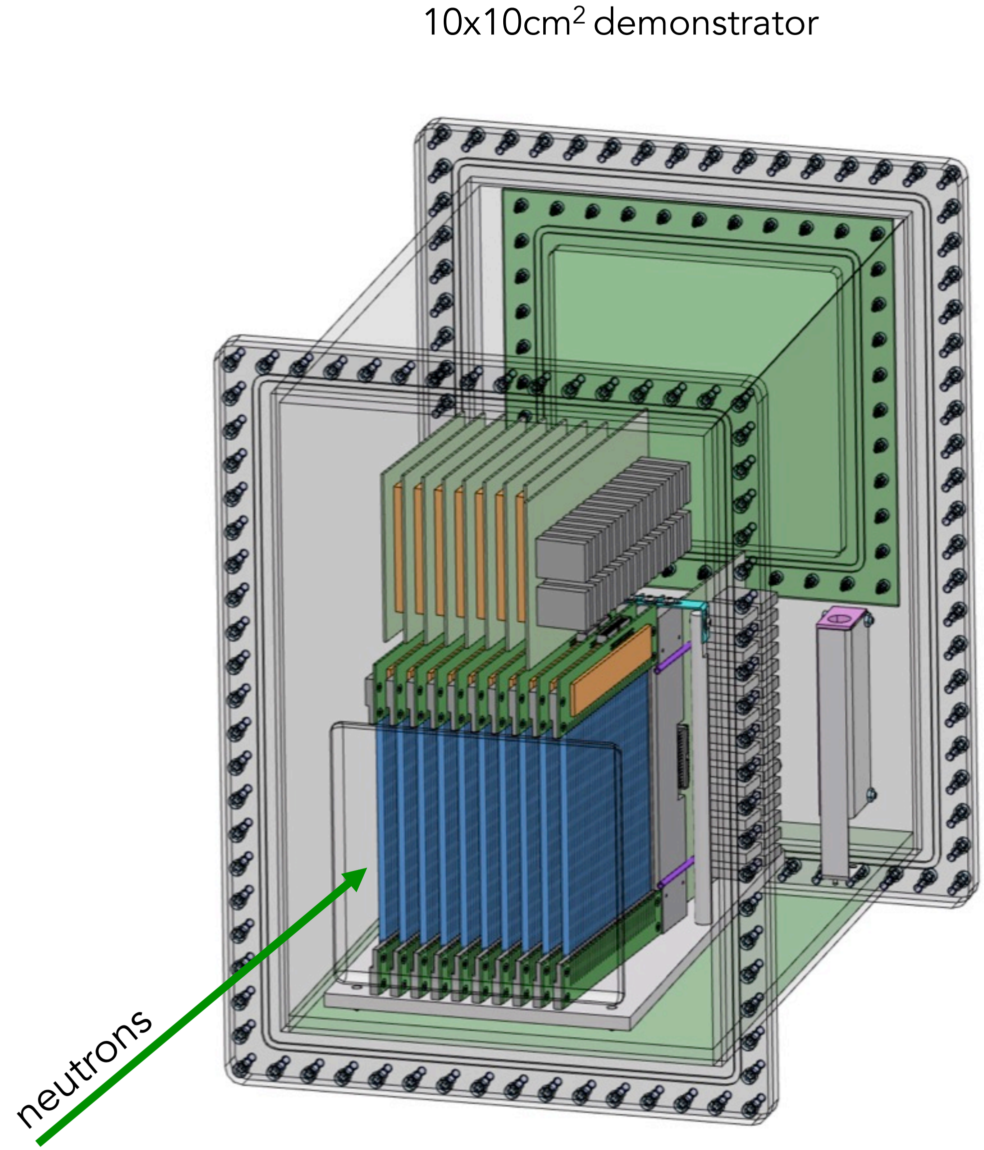


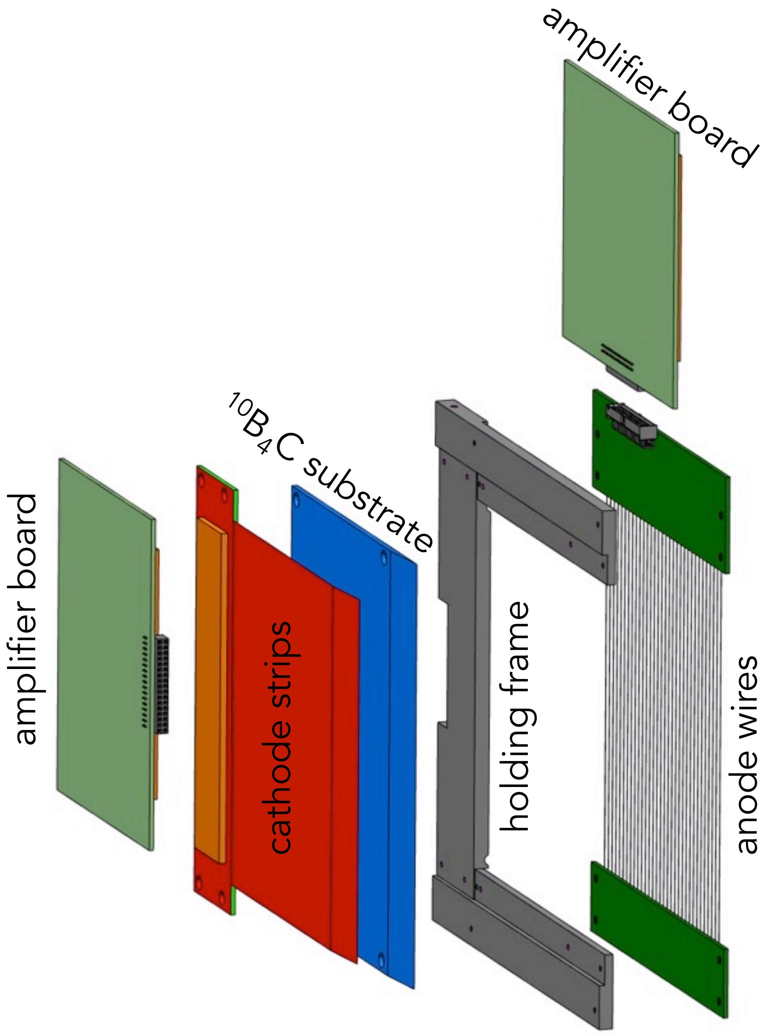
Advantages:
planarity, electrical insulation (strips can be deposited?)

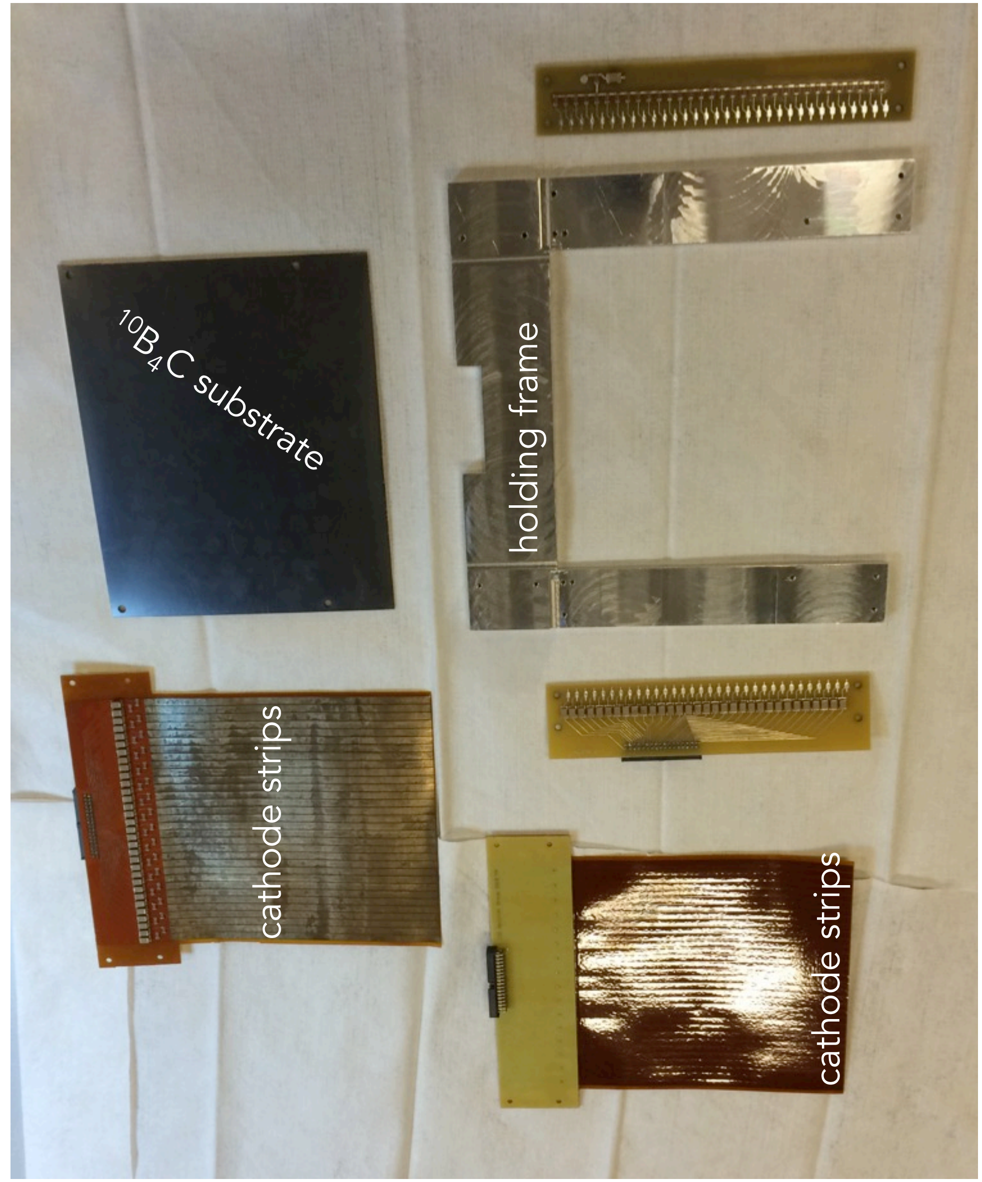
Disadvantages:
Availability in large surfaces?
Brittle!

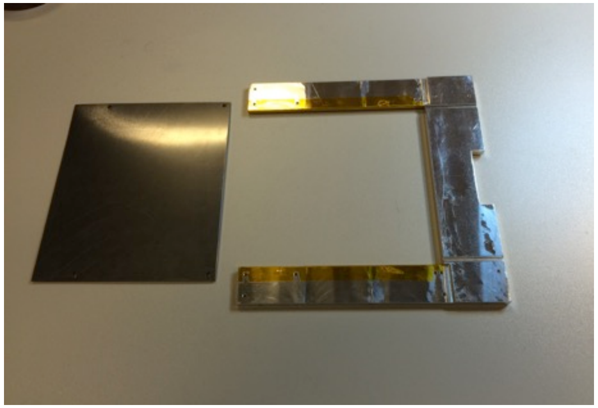
Multi-Blade mechanical design

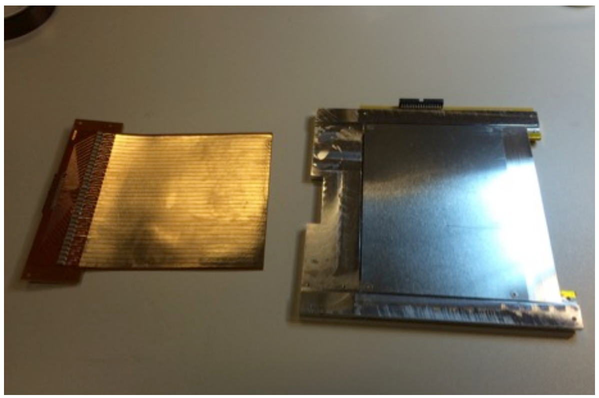


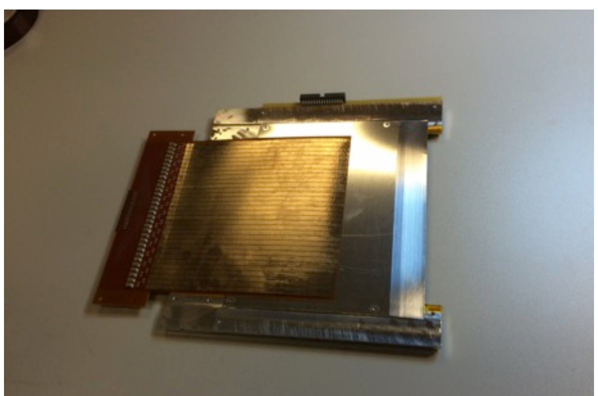


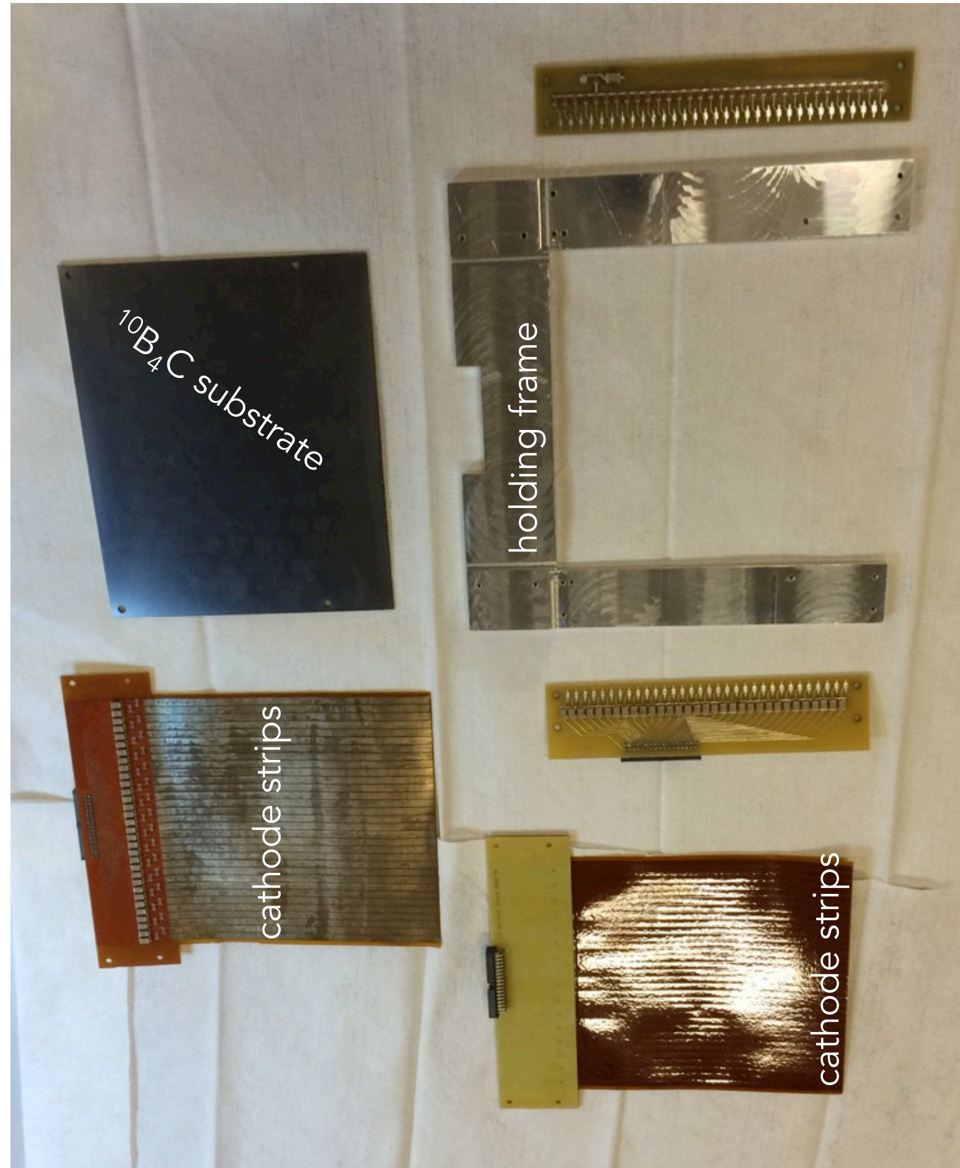

amplifier board
$^{10}B_4C$ substrate
amplifier board
cathode strips
holding frame
anode wires

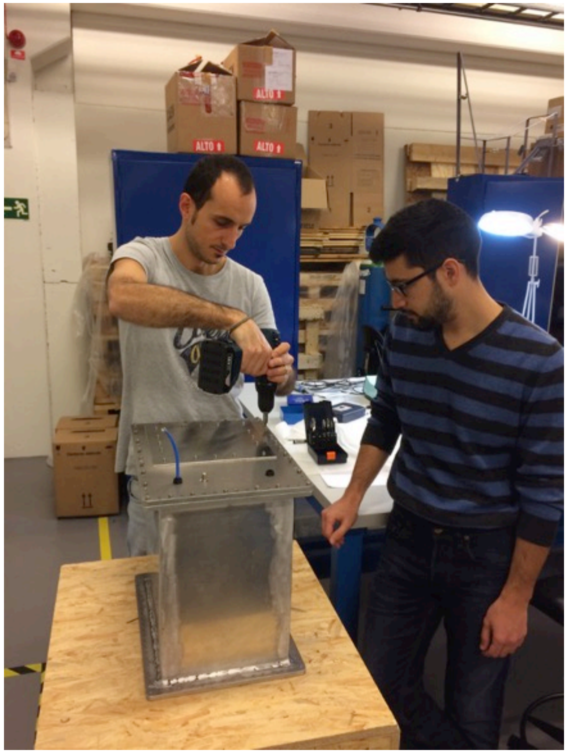

$^{10}B_4C$ substrate
holding frame
cathode strips
cathode strips

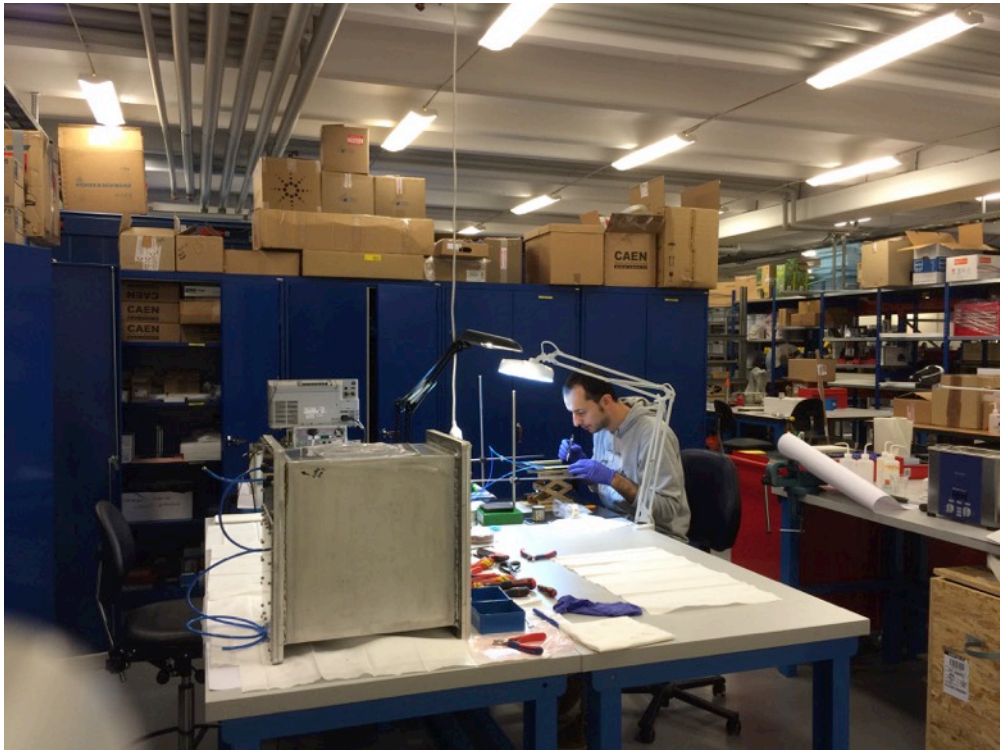




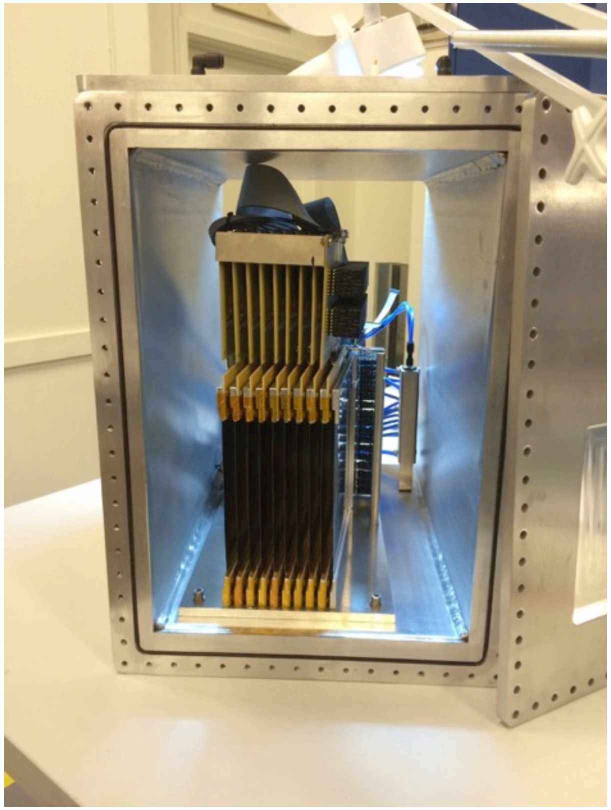
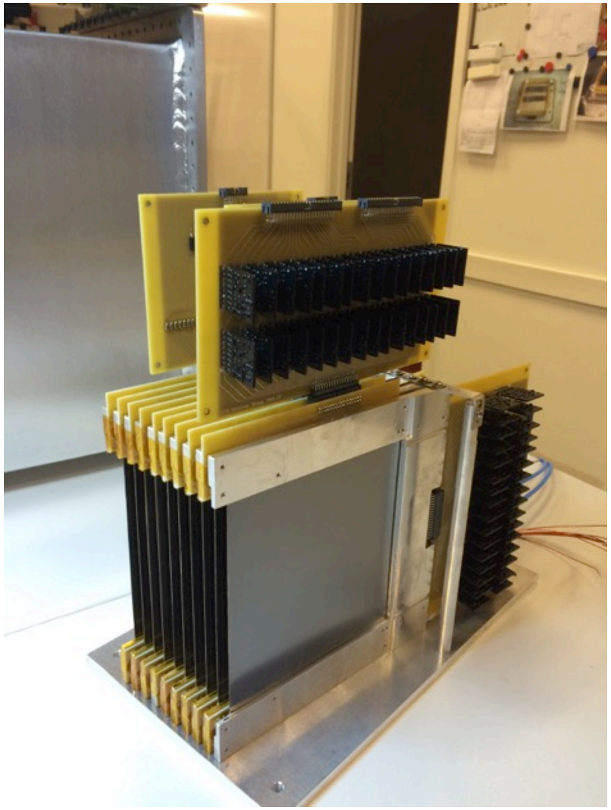
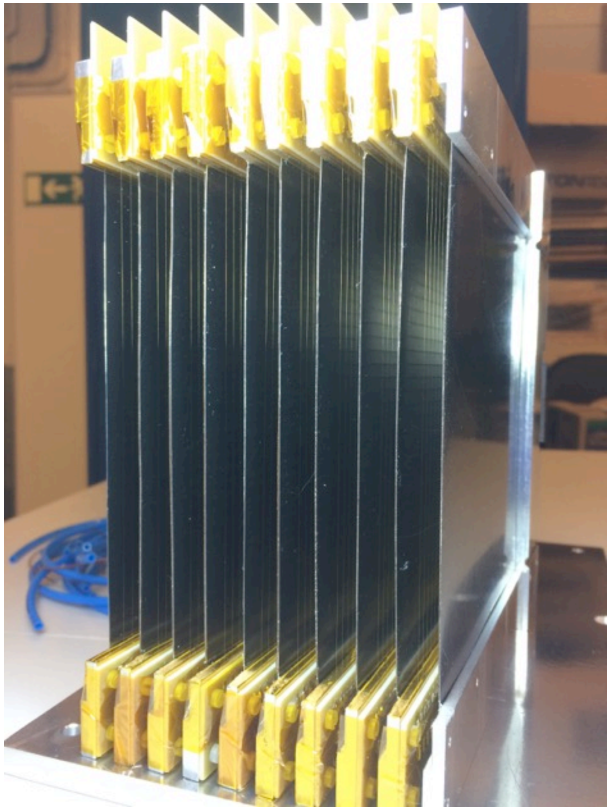
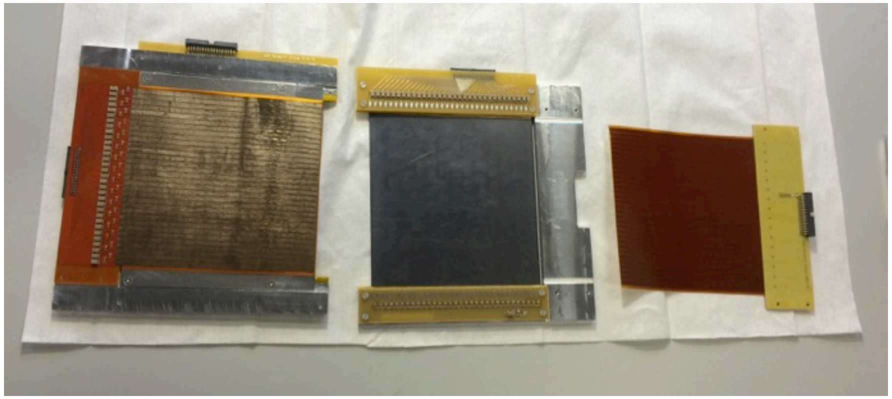



$^{10}B_4C$ substrate
holding frame
cathode strips
cathode strips

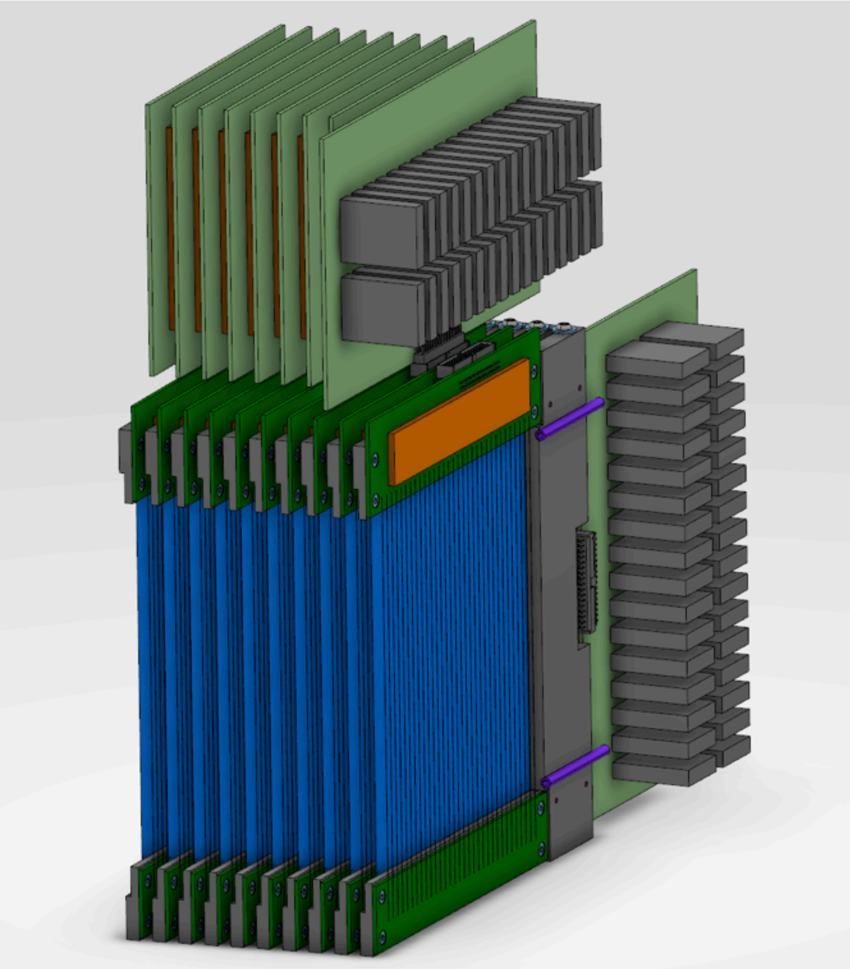


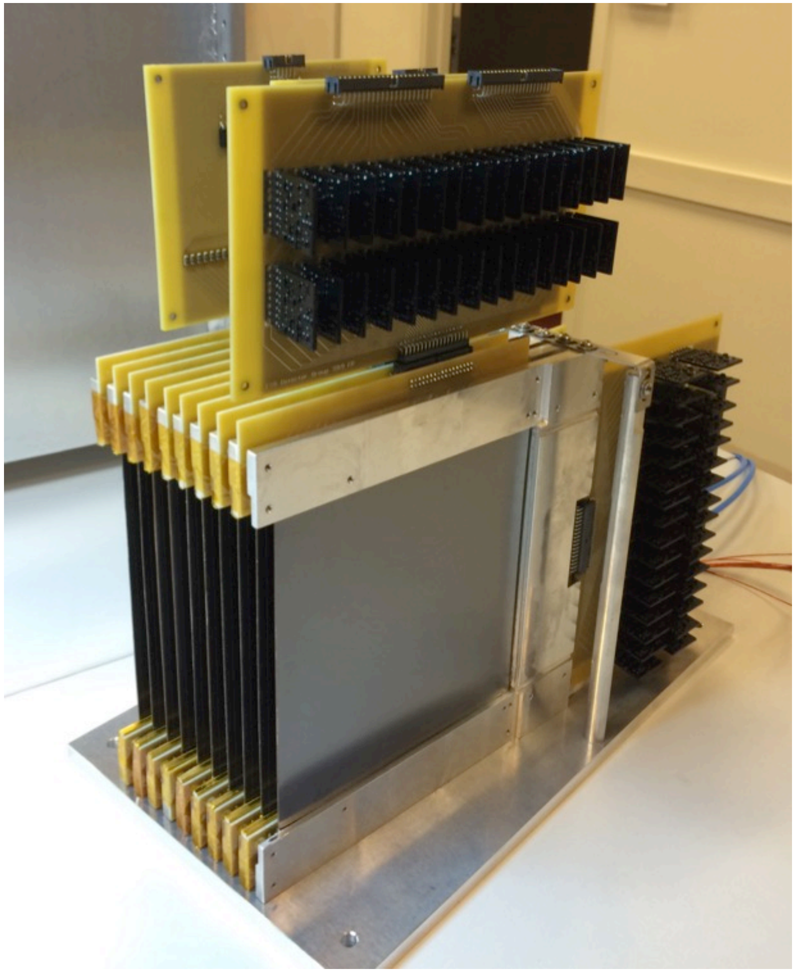


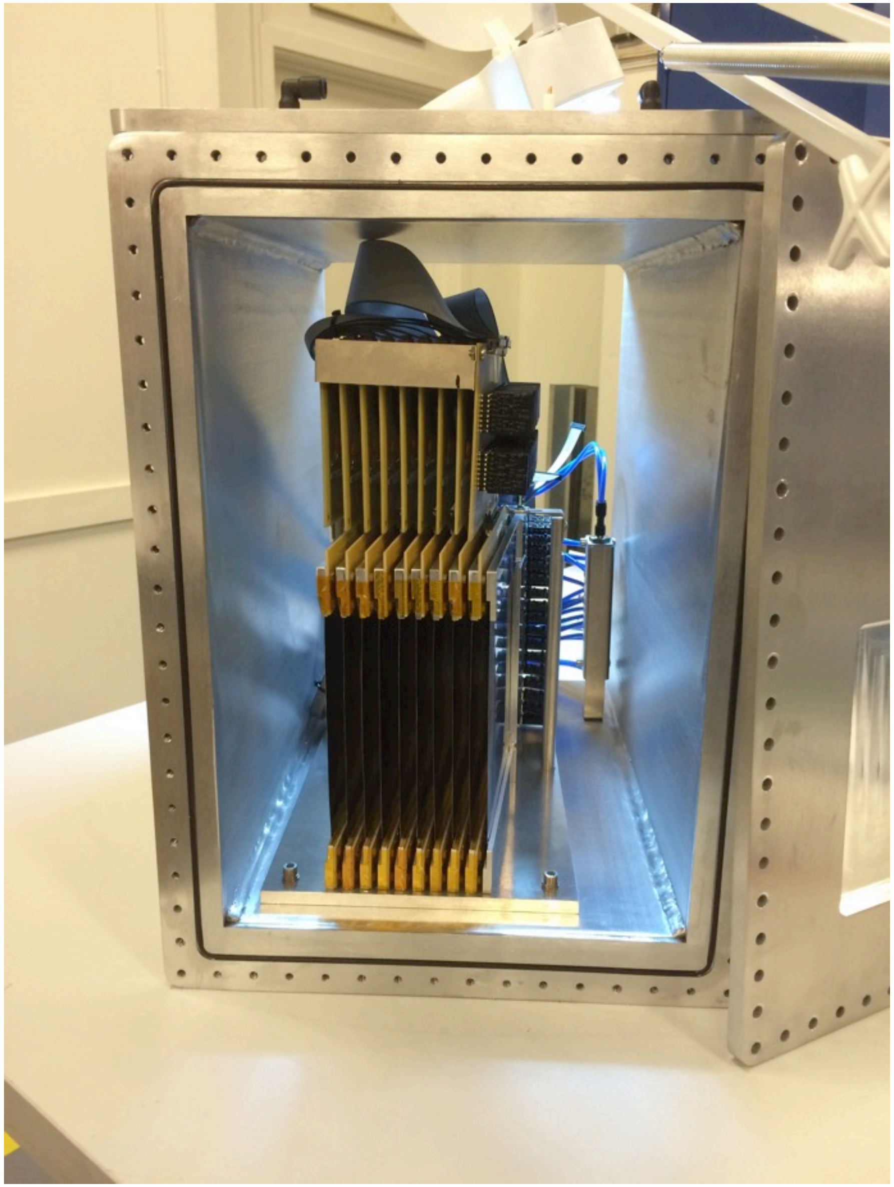
Assembly completed in December 2015

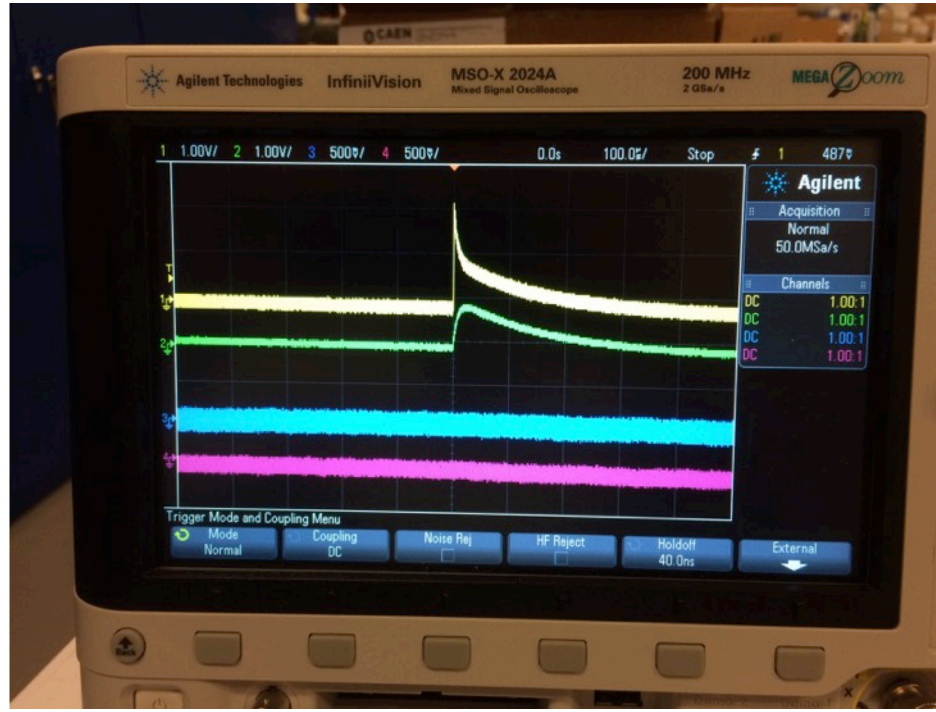
1 blade area: ~120x120 mm^2
9 cassettes (10 blades)
Coating area: ~ 10x120x120 mm^2 (single side)
Detector active area: ~10x9x120mm^2=90x120mm^2

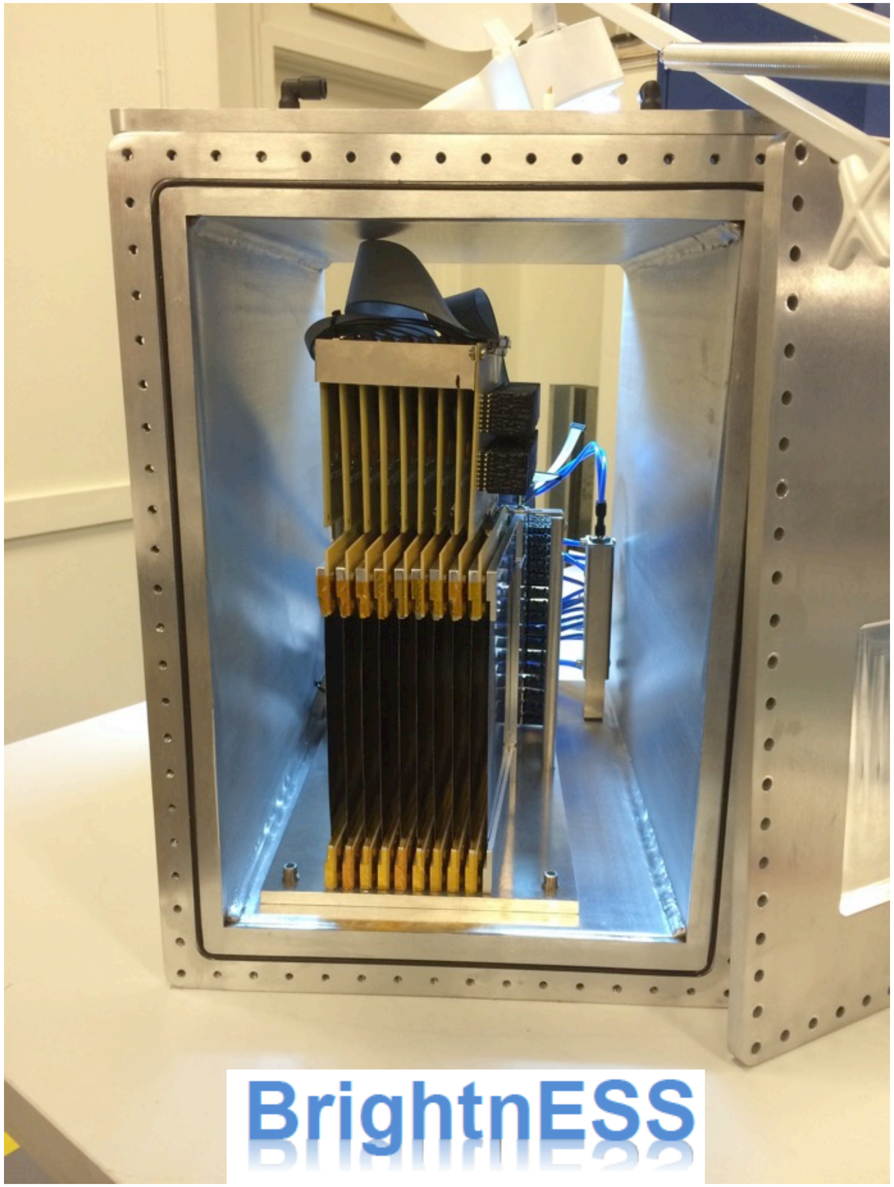






HV on! (at EMBLA)

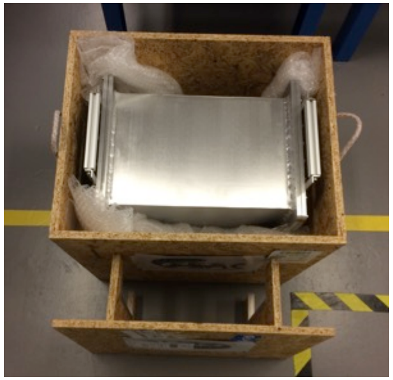


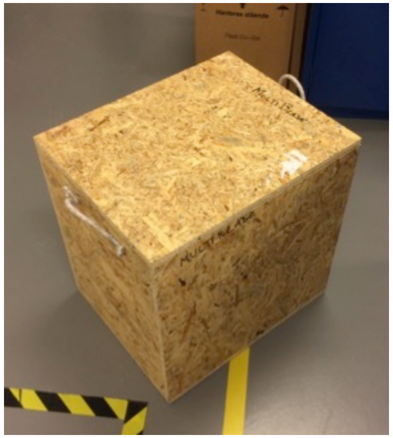


Demonstrator ready!

Tests to come:

- SF (Lund University) - Now
- BNC (Budapest) - February
- Real instrument - …





EUROPEAN SPALLATION SOURCE

LUND UNIVERSITY

wigner

Thank you.