Neutron reflectometry at DNS-IV

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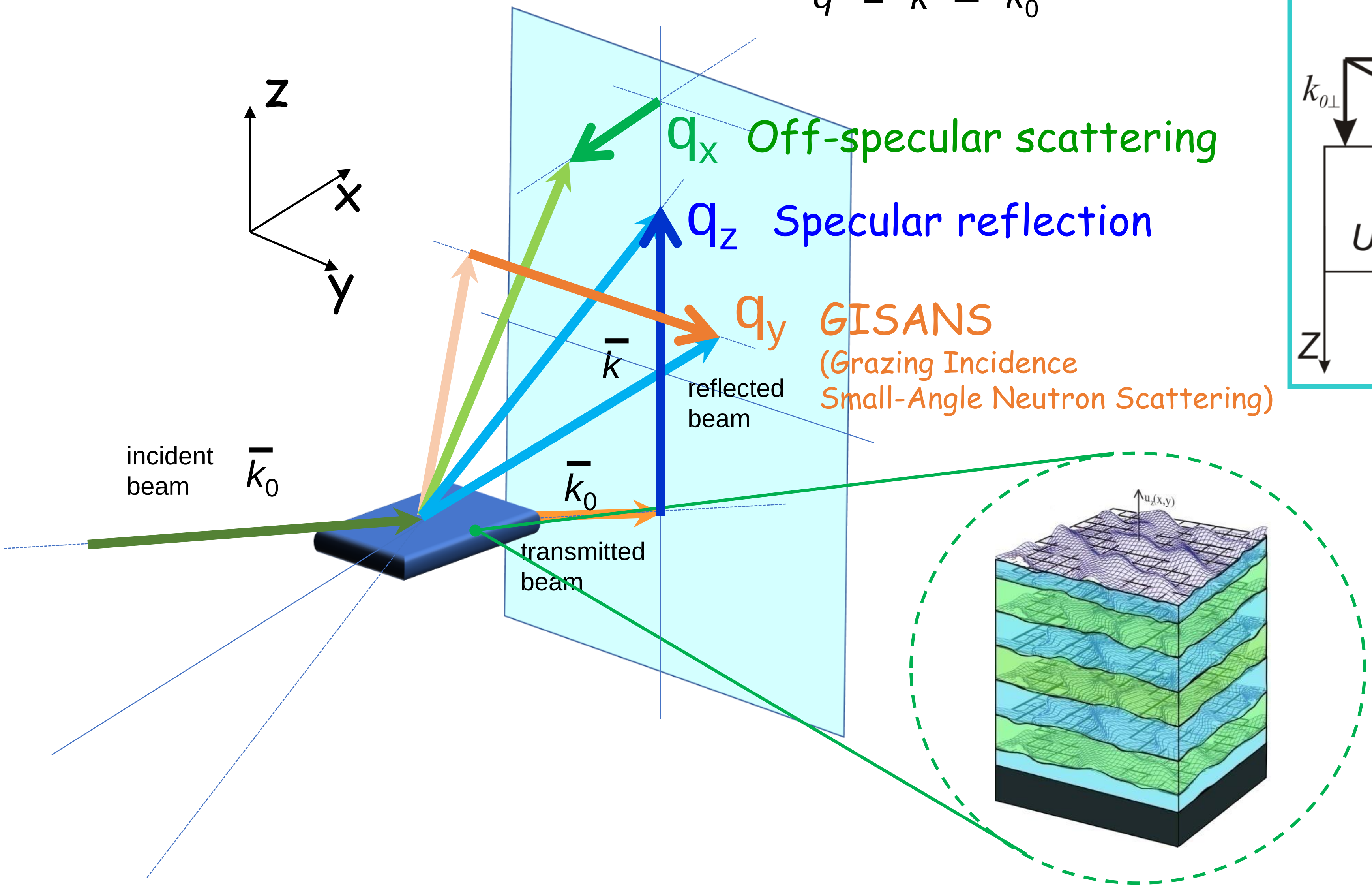
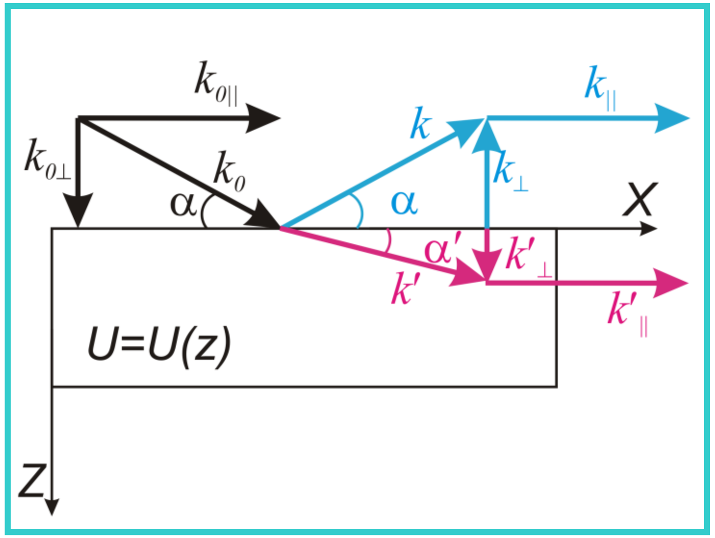
Outline

- Neutron reflectometers (NR). Basic aspects
- NR at the IBR-2 reactor
- Trends in NR development for pulsed neutron sources
- Requirements for the sample environment
- NR at the future source DNS-IV
- Conclusions

Complete reflectometrey scheme

$$\bar{q} = \bar{k} - \bar{k}_0$$





Complete reflectometry

$q_x\, q_y\, q_z$

$u_z(x,y)$ – vertical surface displacement

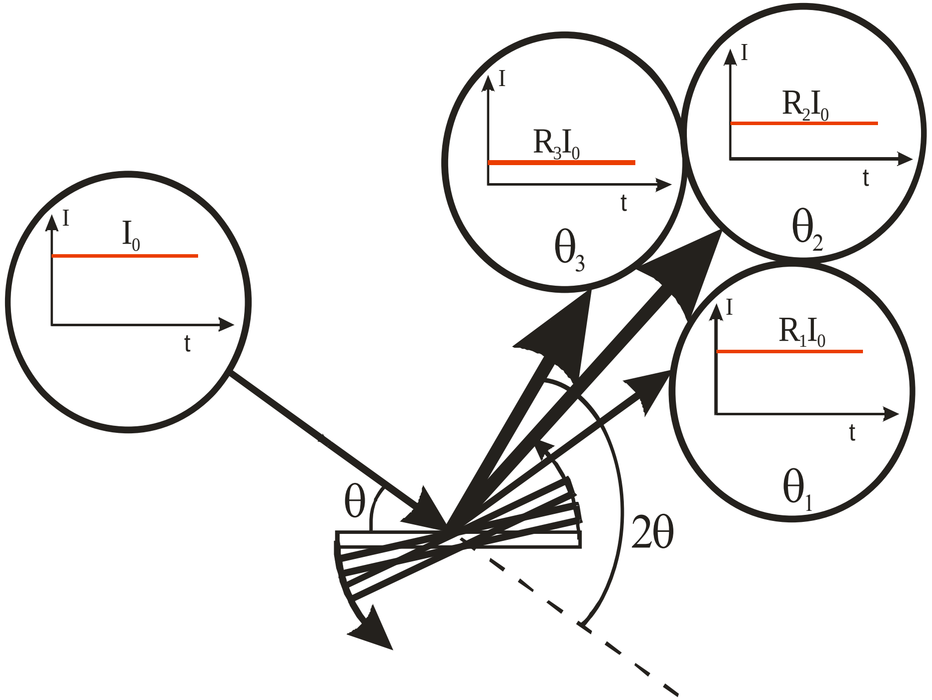
$\xi_x,\ \xi_y$ – correlation lengths

Fields of NR applications

- Layered nanostructures
- Interlayer magnetic coupling
- Depth magnetization behaviour
- Proximity effects
- Magnetic field penetration into the superconductive thin films. Magnetic vortex structures
- Time-resolved domain structures
- Interfaces roughness
- Biological layers
- Magnetic liquids and electrolites
- Langmuir-Blodgett films

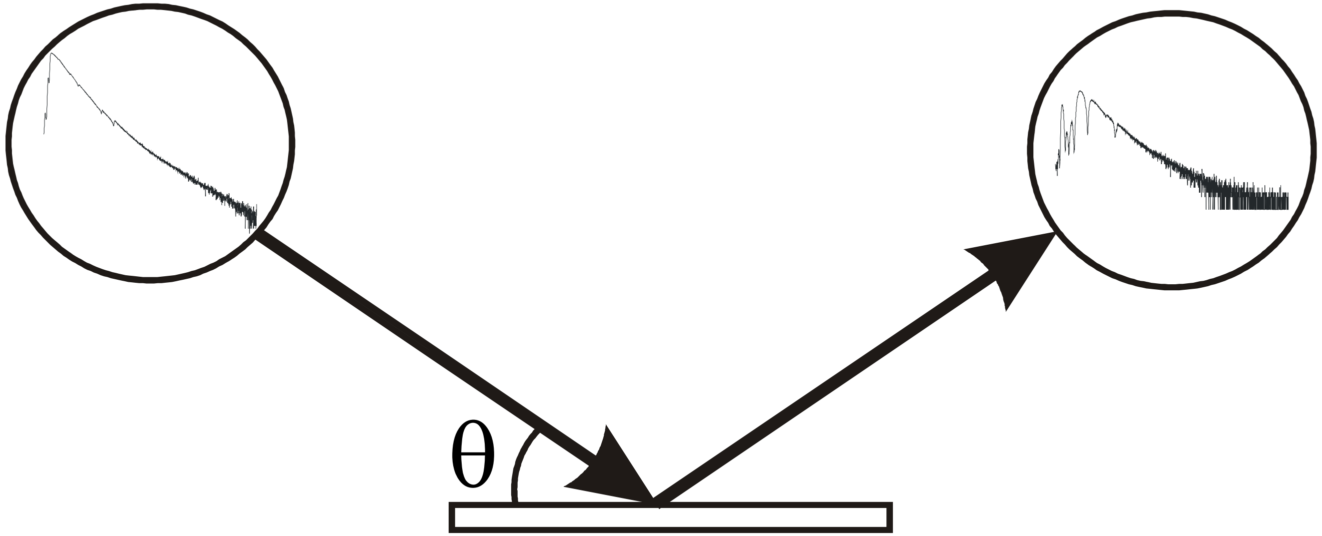
Two types of measurements

λ=const



$$q = \frac{4\pi}{\lambda}\sin\frac{\theta}{2}$$

TOF
θ=const



$$q = \frac{4\pi}{\lambda}\sin\frac{\theta}{2}$$

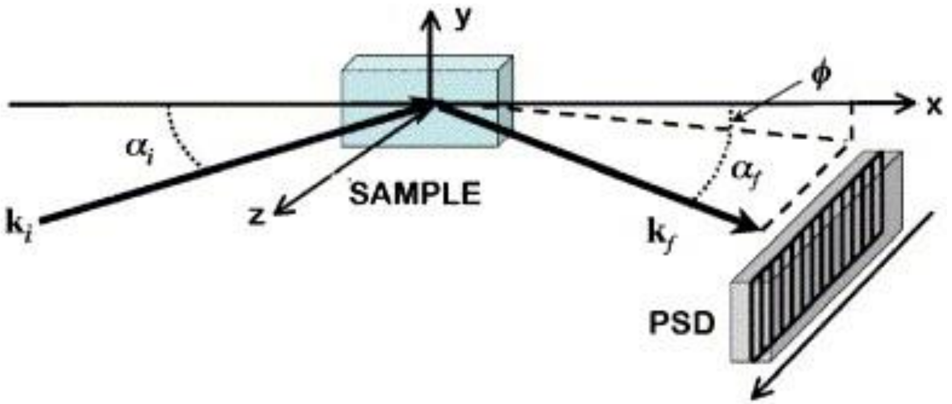
$$\lambda = \frac{h\ TOF}{mL}$$

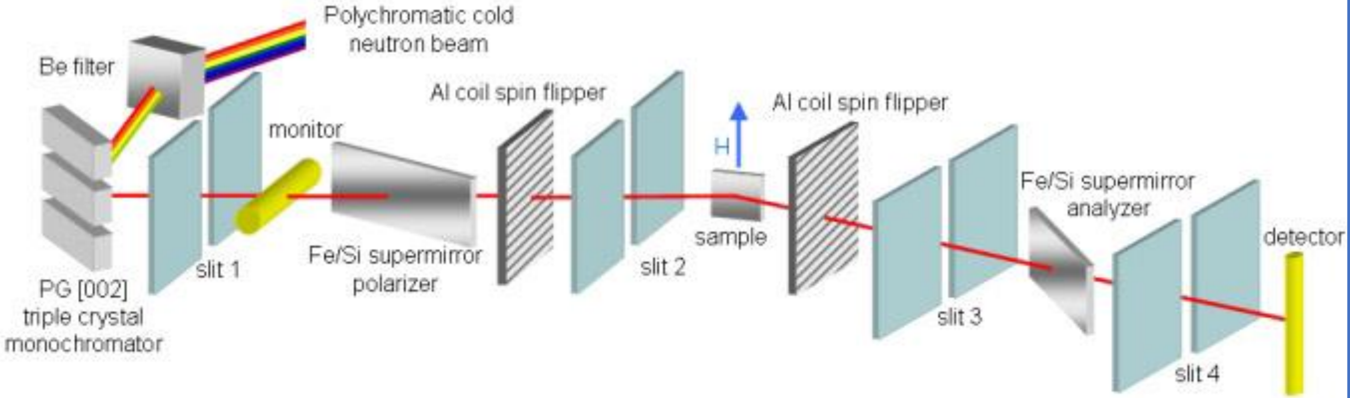
time-of-flight

flight path

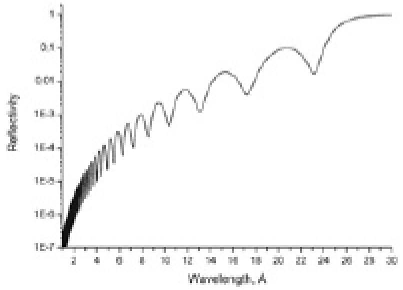
Vertical and horizontal NR

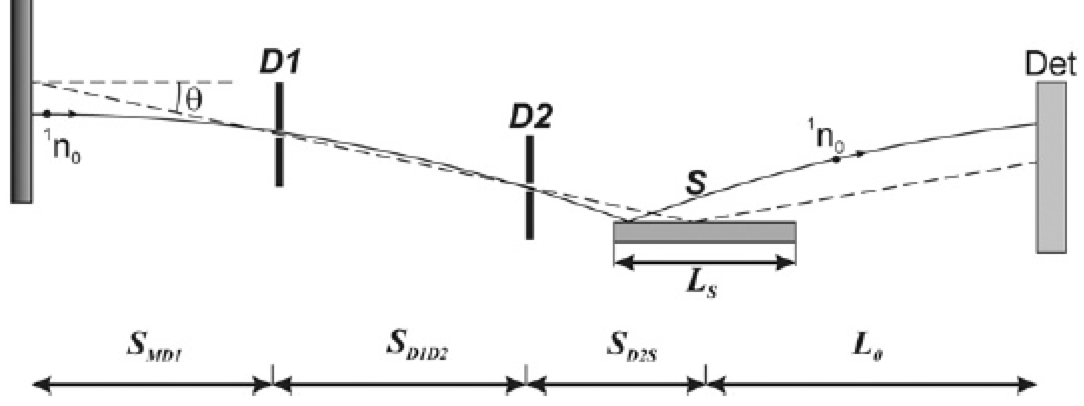
Vertical sample geometry





Horizontal sample geometry

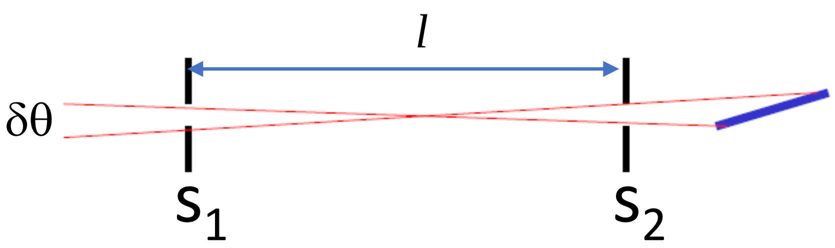


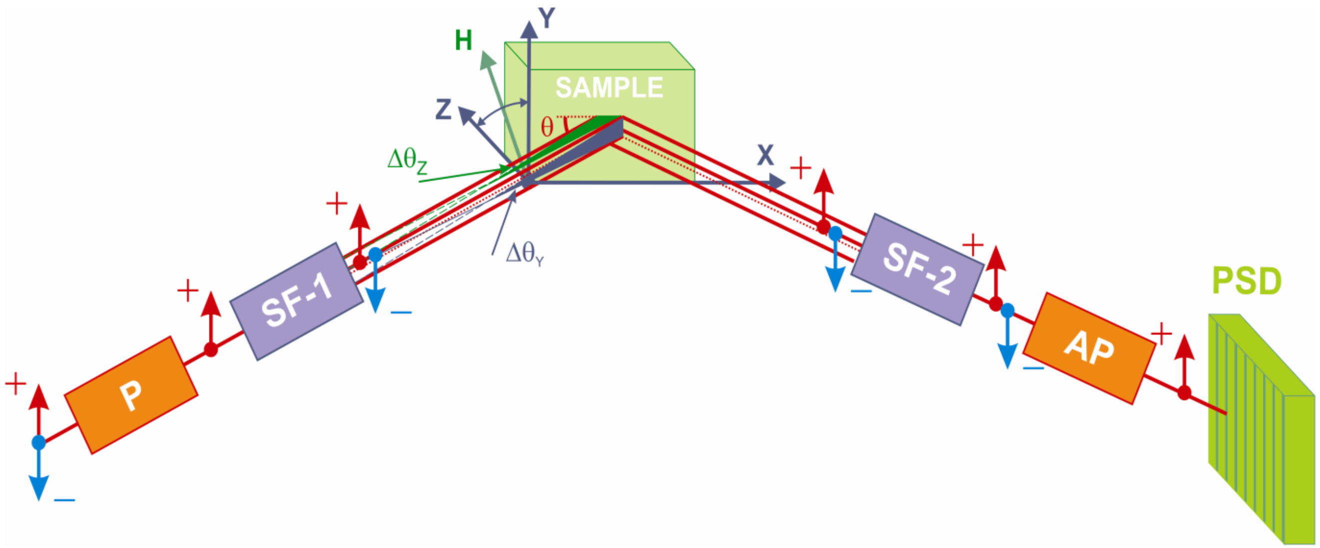


NR with horizontal sample positioning

Title	Source	Country	Source type	Set-up type	Polarized neutrons	Flux at sample	q-interval	Minimal reflectivity
REFSANS	FRM II	Germany	SS	TOF	POL	~10^6 $cm^{-2}s^{-1}$	0.05 - 10 nm^{-1}	$5x10^{-7}$
N-REX	FRM II	Germany	SS	SS	POL	$3x10^6$ $cm^{-2}s^{-1}$	0.01 - 1.5 nm^{-1}	$1x10^{-7}$
FIGARO	ILL	France	SS	TOF	POL	~10^8 $cm^{-2}s^{-1}$	0.05 - 4 nm^{-1}	1×10^{-6}
AMOR	SINQ	Switzerland	SS	TOF	non-POL	$1x10^8$ $cm^{-2}s^{-1}$	0.01 - 5 nm^{-1}	$1x10^{-5}$
Platypus	OPAL	Australia	SS	TOF	POL	$1x10^9$ $cm^{-2}s^{-1}$	0.05 - 5 nm^{-1}	$1x10^{-7}$
LR	SNS	USA	Pulsed	TOF	non-POL	$1x10^7$ $cm^{-2}s^{-1}$	0.01 - 2 nm^{-1}	$1x10^{-6}$
GRAINS	IBR-2	Russia	Pulsed	TOF	POL	$2x10^6$ $cm^{-2}s^{-1}$	0.05 - 1 nm^{-1}	$1x10^{-5}$
Inter	ISIS	UK	Pulsed	TOF	non-POL	$1x10^7$ $cm^{-2}s^{-1}$	0.01 - 5 nm^{-1}	$1x10^{-5}$
PolRef	ISIS	UK	Pulsed	TOF	POL	$1x10^7$ $cm^{-2}s^{-1}$	0.01 - 5 nm^{-1}	$1x10^{-6}$
OffSpec	ISIS	UK	Pulsed	TOF	POL	$1x10^7$ $cm^{-2}s^{-1}$	0.01 - 5 nm^{-1}	First experim.
B16	J-PARC	Japan	Pulsed	TOF	POL	$1x10^7$ $cm^{-2}s^{-1}$	0.01 - 5 nm^{-1}	First experim.
REF	CARR	China	SS	SS	non-POL	~10^7 $cm^{-2}s^{-1}$	0.03 - 0.5 nm^{-1}	Under constr.

Resolution factor

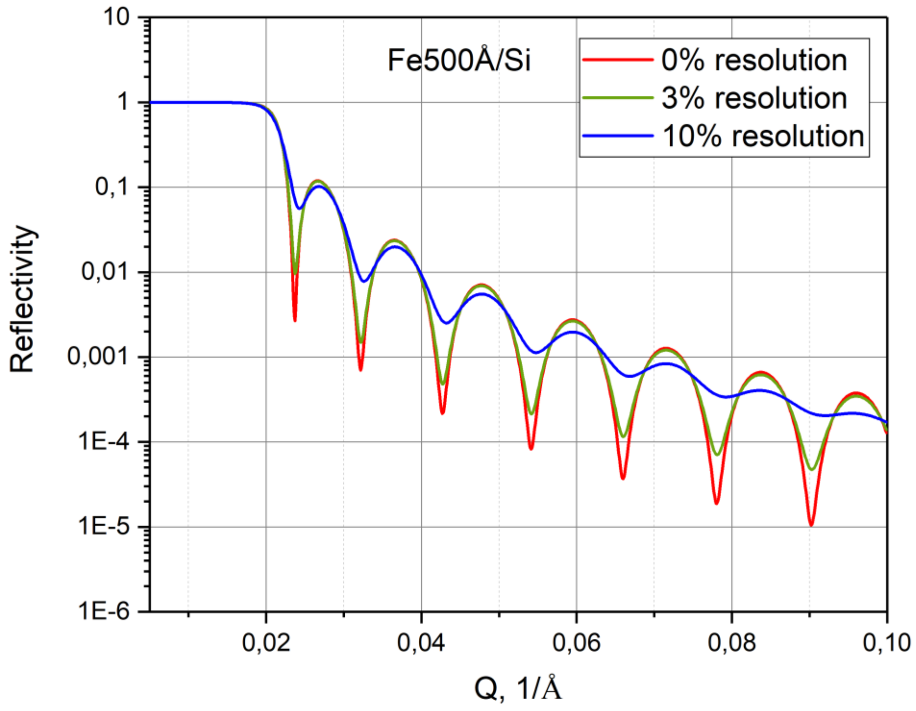


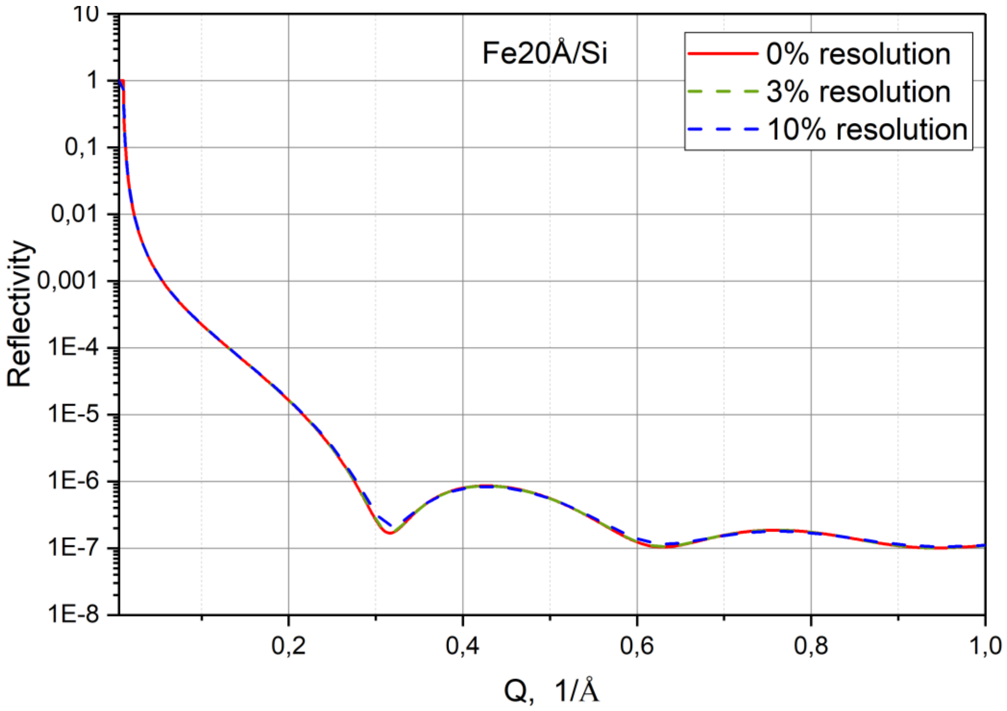


$\delta\theta=(s_1+s_2)/l$

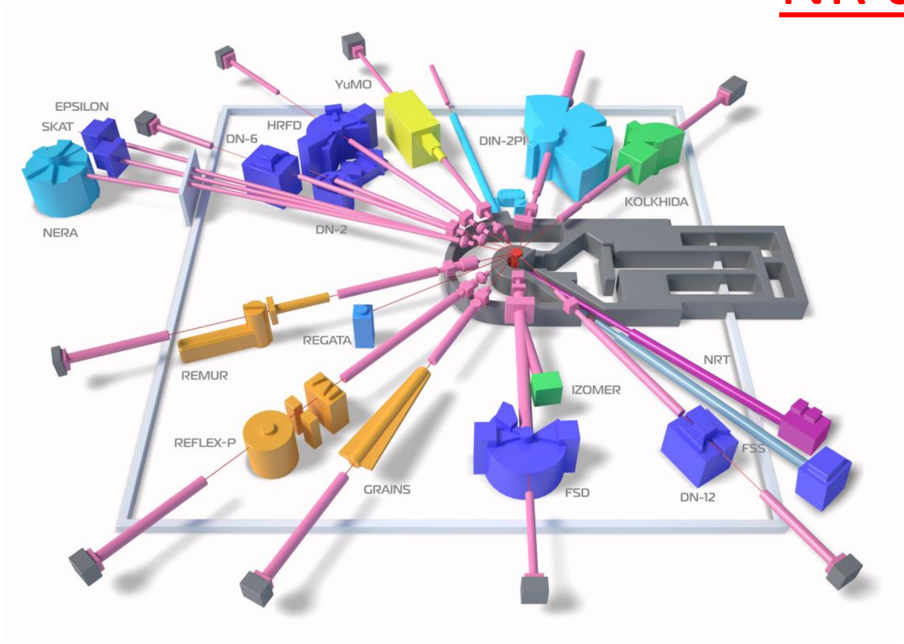
$\delta\lambda/\lambda \sim \tau/L$,

τ- pulse width, L- flight path mod-det

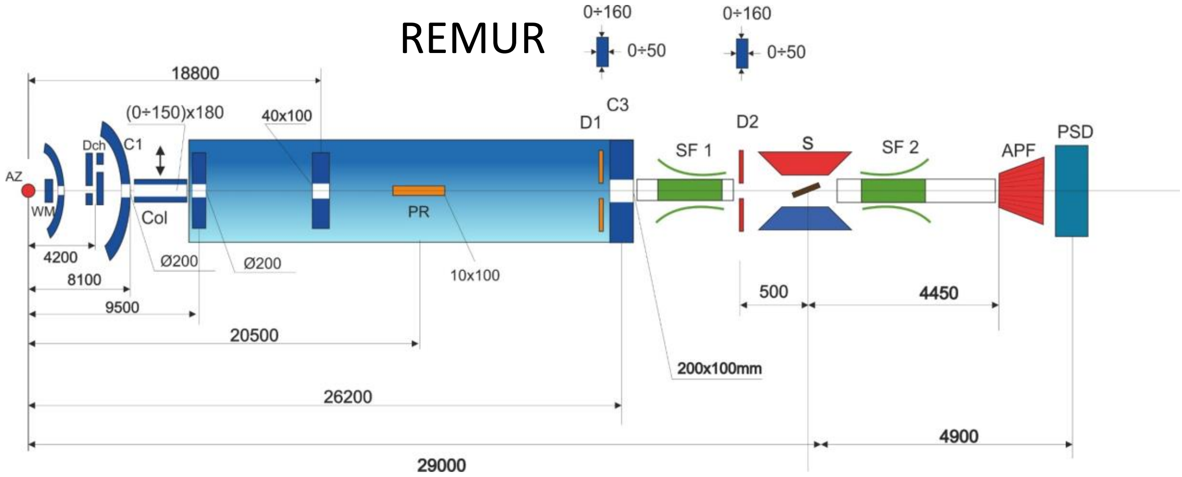




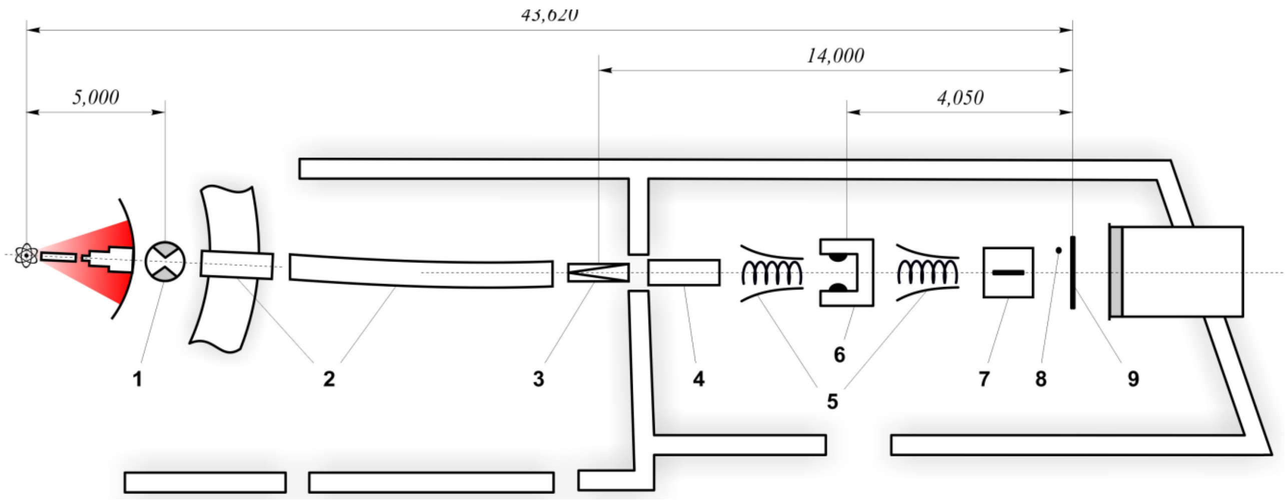
NR at the IBR-2 reactor.



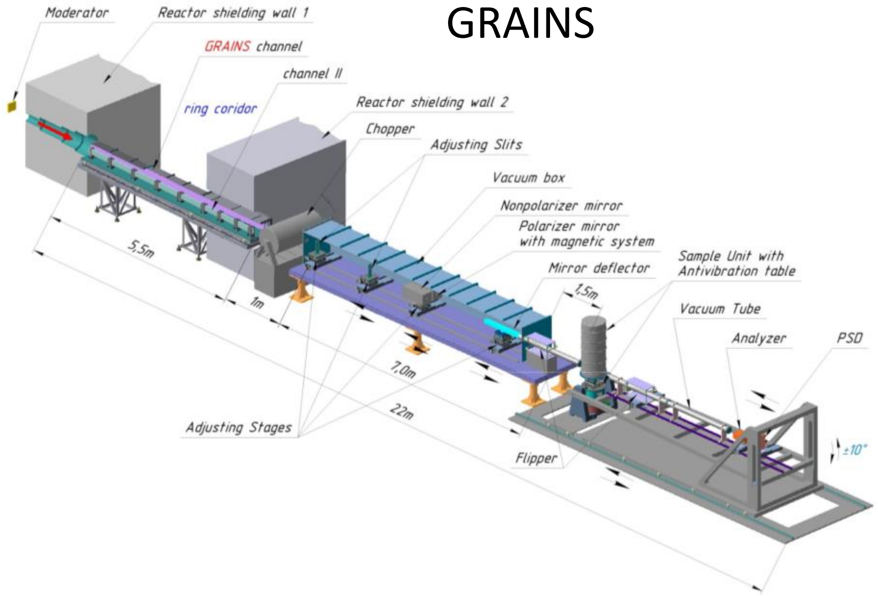
REMUR



REFLEX



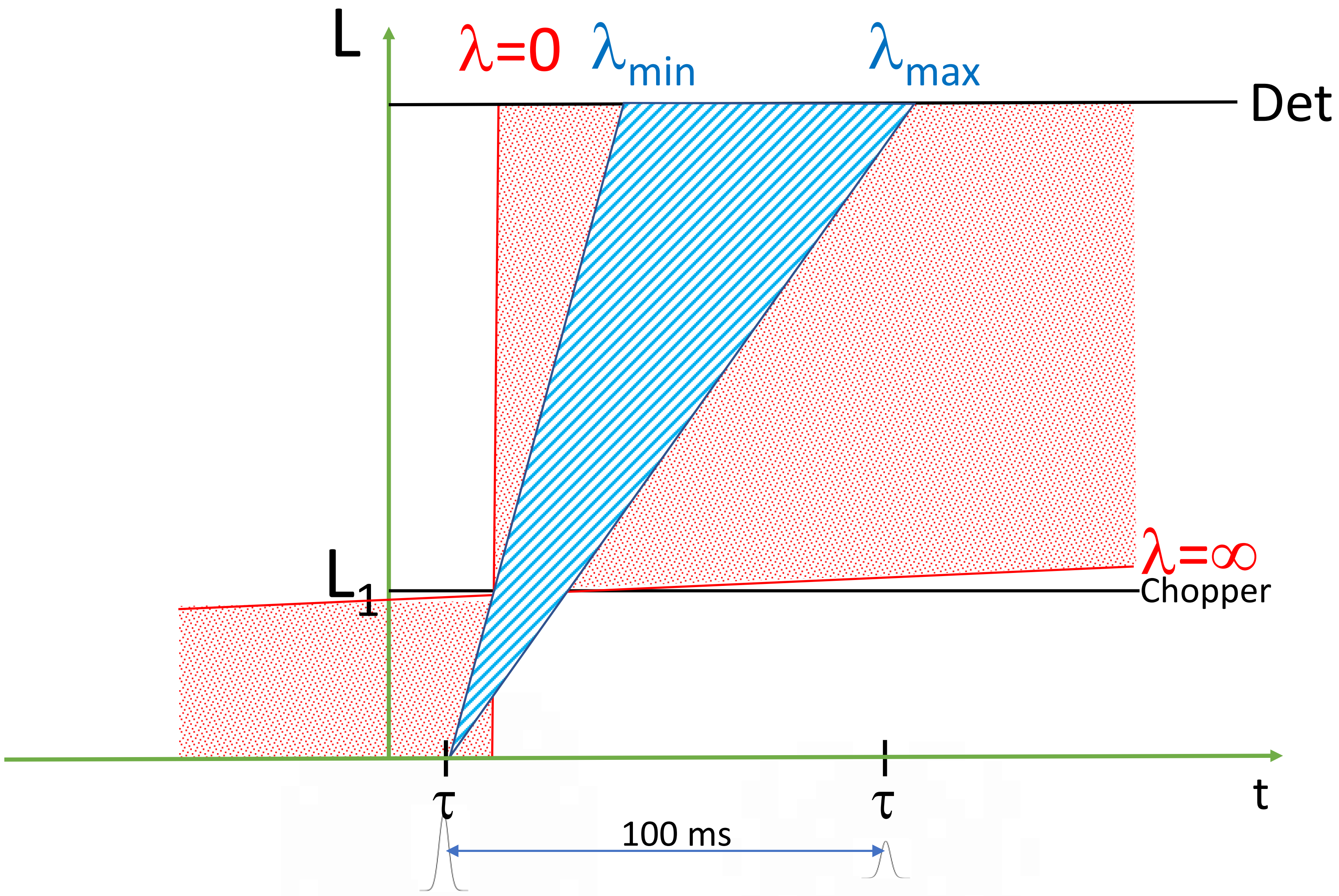
GRAINS



NR at the IBR-2 reactor

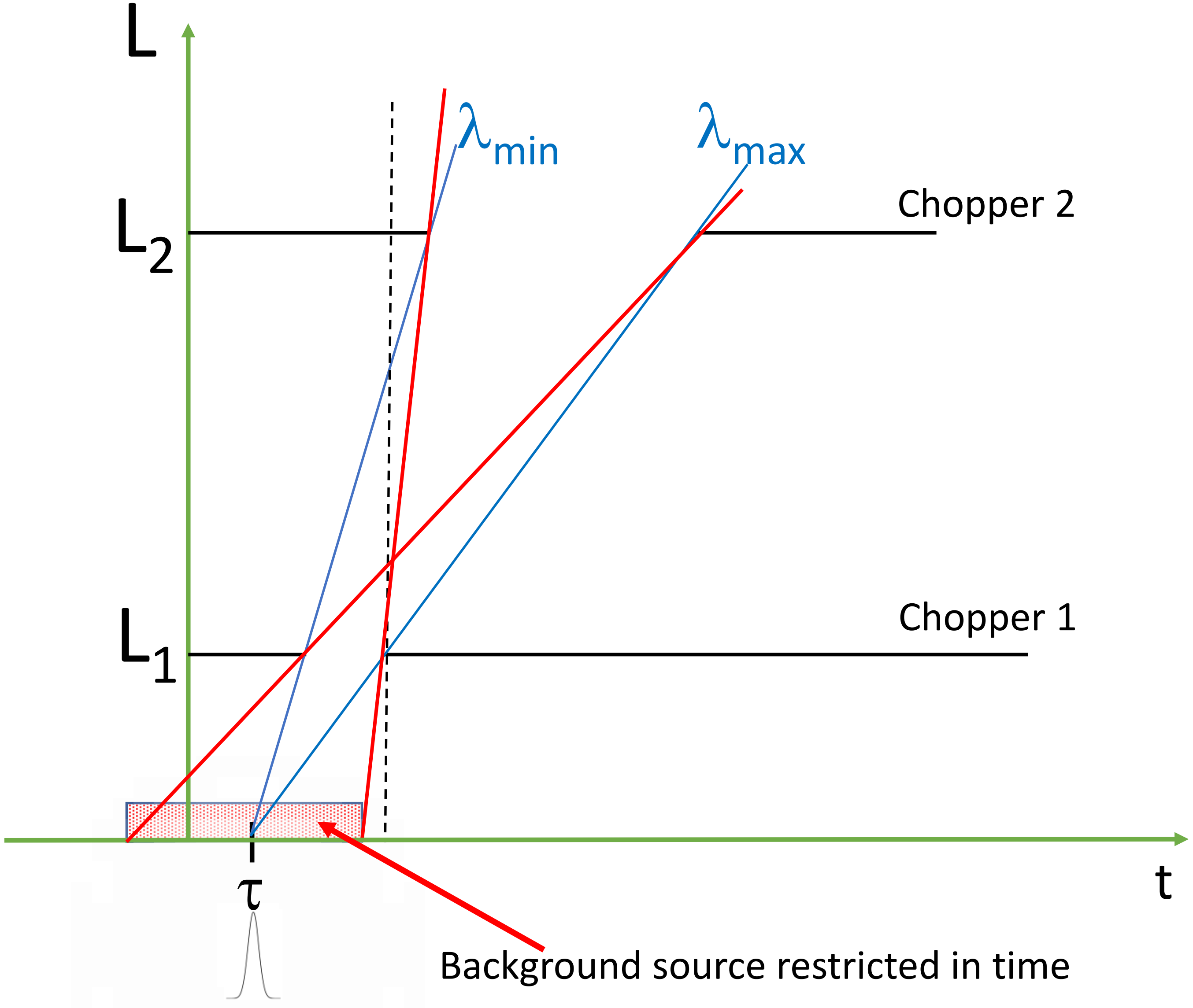
Instrument	Plane of scattering	Polarization	Flux at the sample position	Q-range	λ - range, Å
REMUR	H	+	3 x10^5 с$^{-1}$ см$^{-2}$	0.05 – 7 нм$^{-1}$	0.9 ÷ 15
REFLEX	H	+	10^5 с$^{-1}$ см$^{-2}$	0.01 – 1.3 нм$^{-1}$	1.4 ÷ 10
GRAINS	V	(+)	2 x10^6 с$^{-1}$ см$^{-2}$	0.05 – 3 нм$^{-1}$	0.5 ÷ 10

Background at the IBR-2 reactor



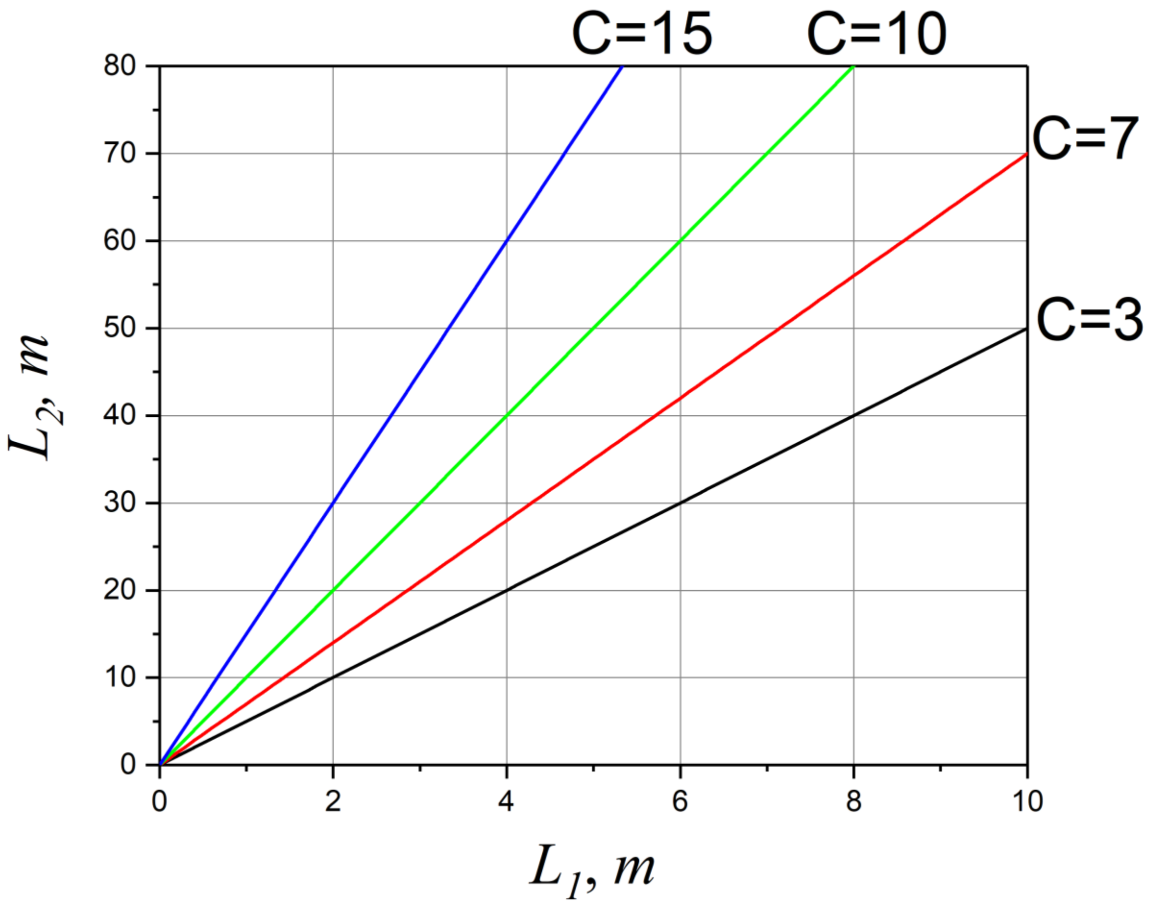
Background at the IBR-2 reactor

Background suppression with 2 choppers



$$L_{2min} = \frac{\lambda_{max}}{\lambda_{min}} L_1$$

C

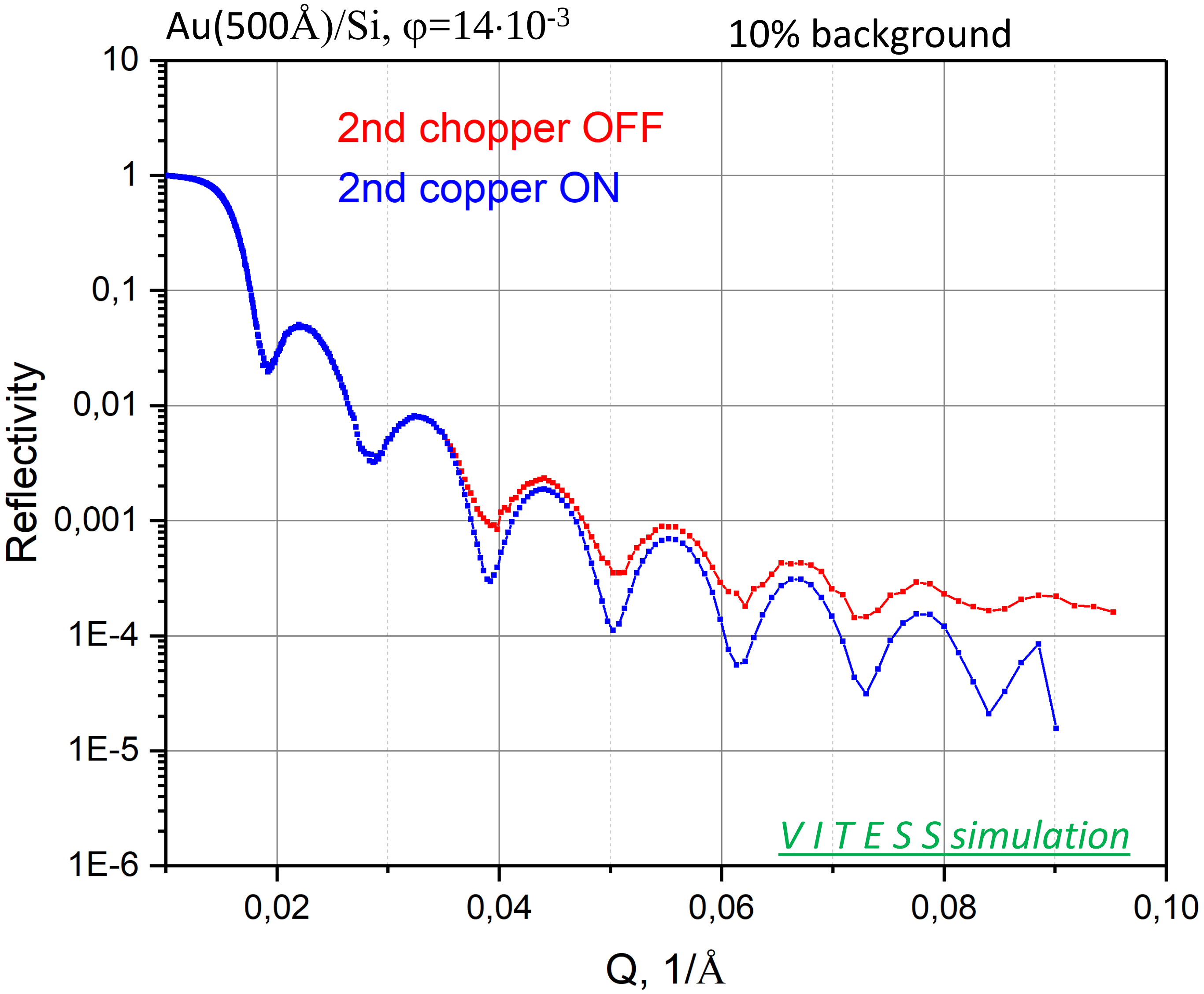


Background at the IBR-2 reactor

1st chopper base - 5m

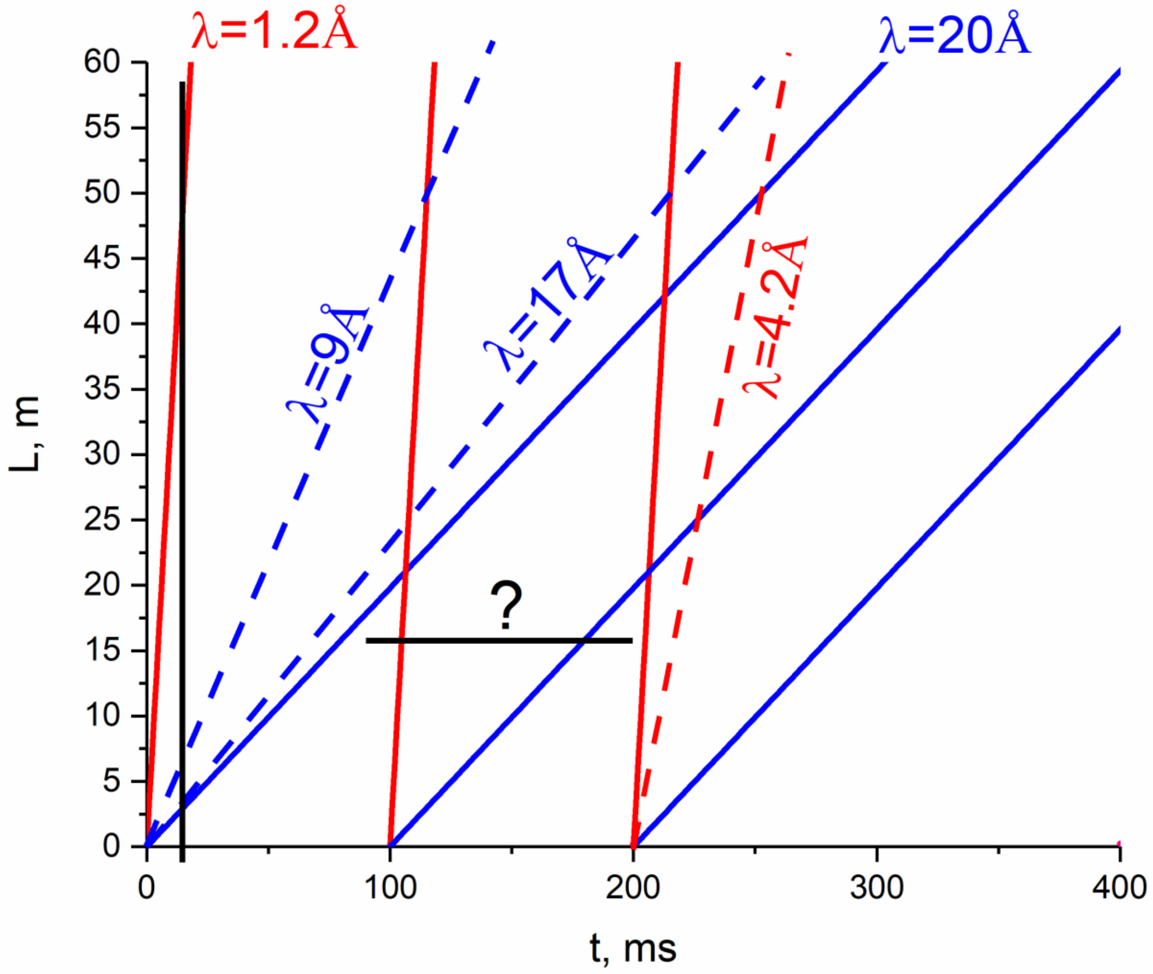
2nd chopper base 40m

Wavelength band
1Å< λ <10Å



Frame overlap problem

The repetition rate (10 Hz for DNS-IV) and the choice of instrument length defines the wavelength band of the instrument



Real-time reflectometry

↓

Wide Q range

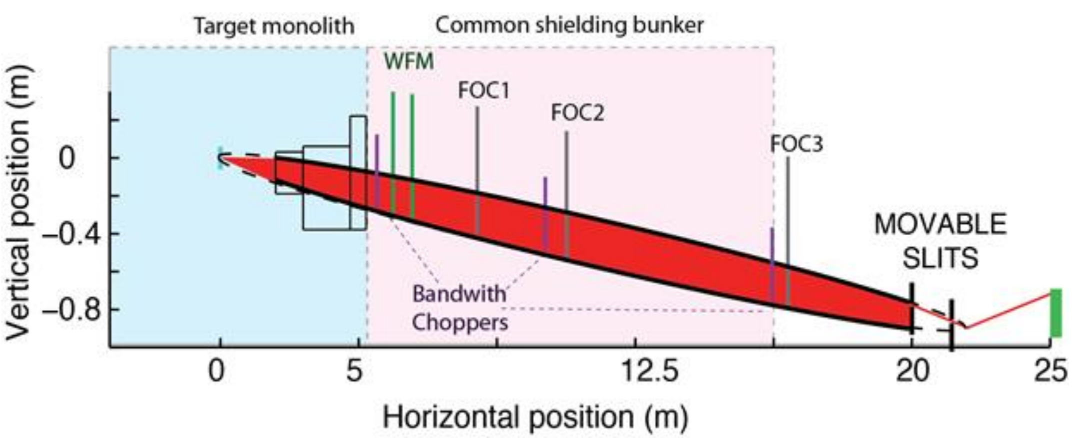
↓

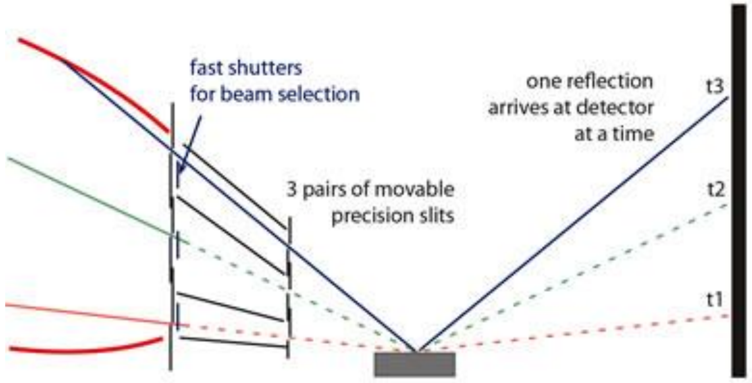
Additional choppers are needed

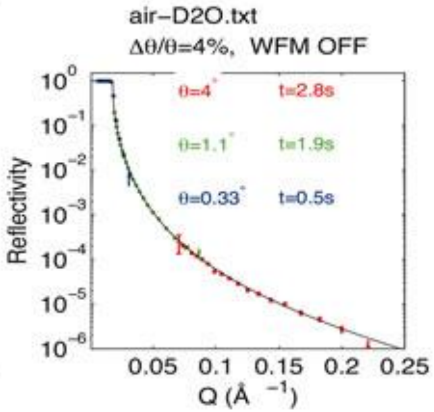
Trends in NR development.

ESS. FREIA. Fast Reflectometer for Extended Interfacial Analysis. Fast Kinetic Studies to Reflectometry

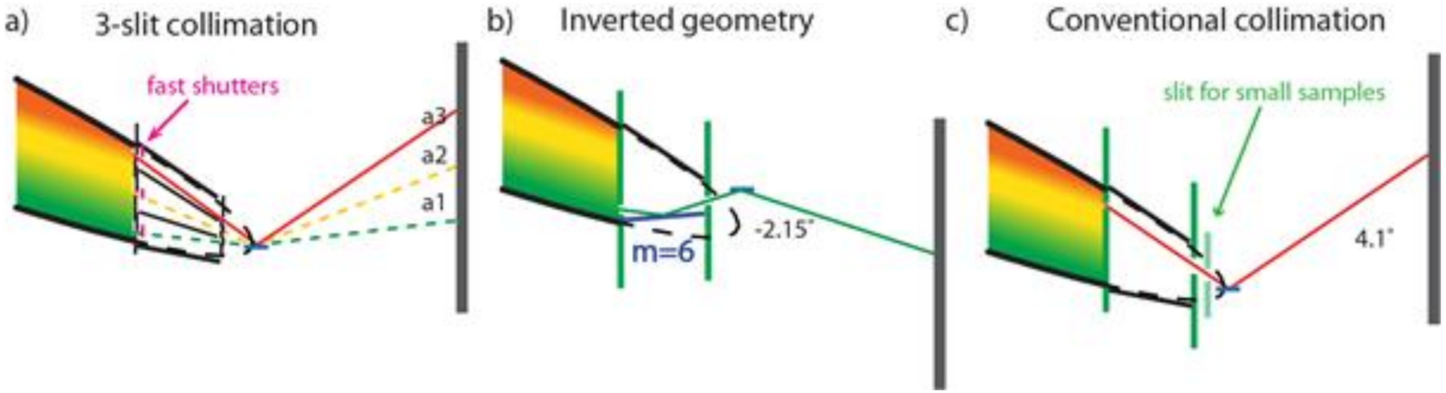
Hanna Wacklin, Anette Vickery, Hanna Wacklin, ESS Instrument Construction Proposal, 2013





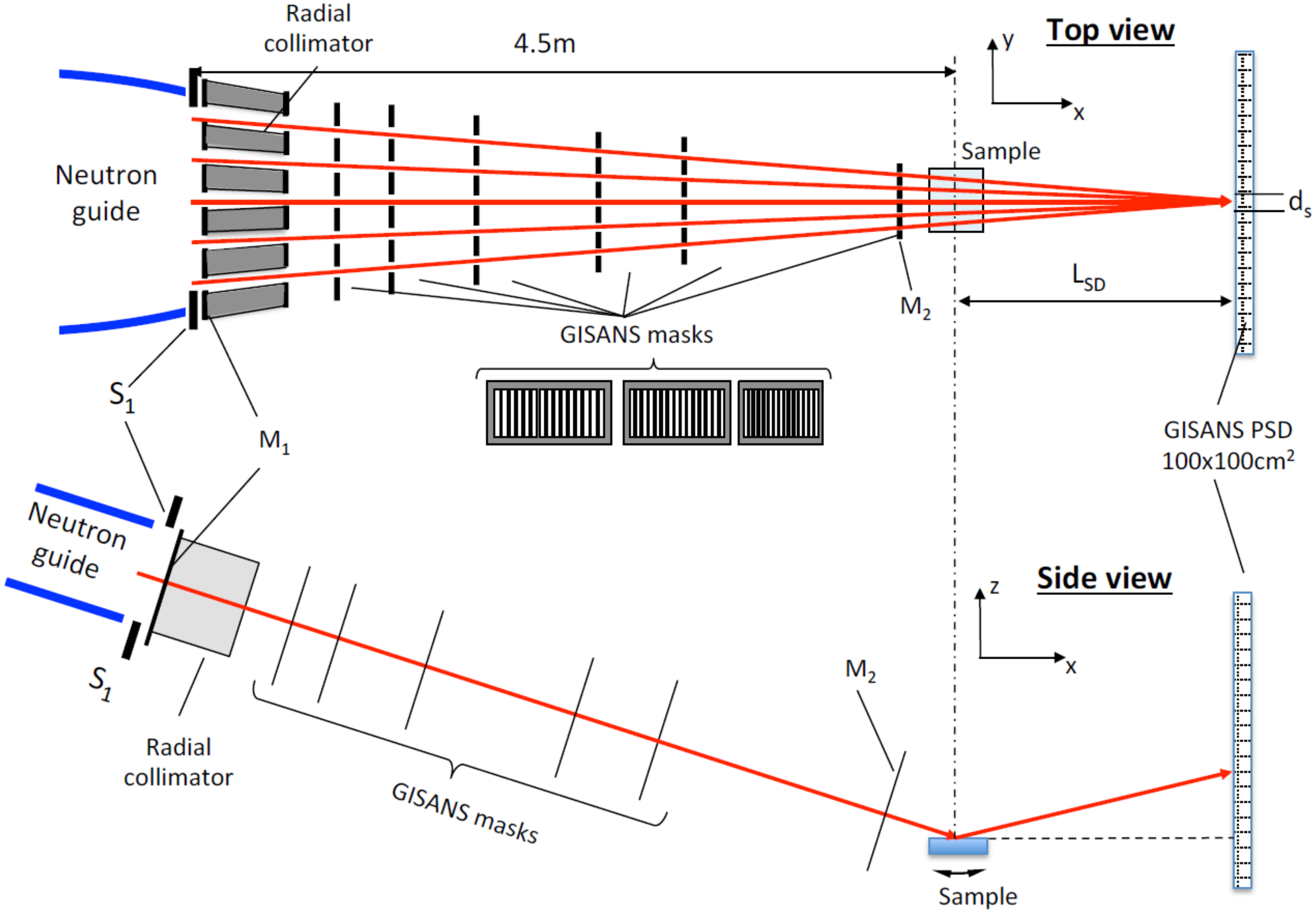


2.5Å <Δλ <11.3 (22.6)Å



Trends in NR development.

HERITAGE project for ESS. Focusing neutron guide and GISANS

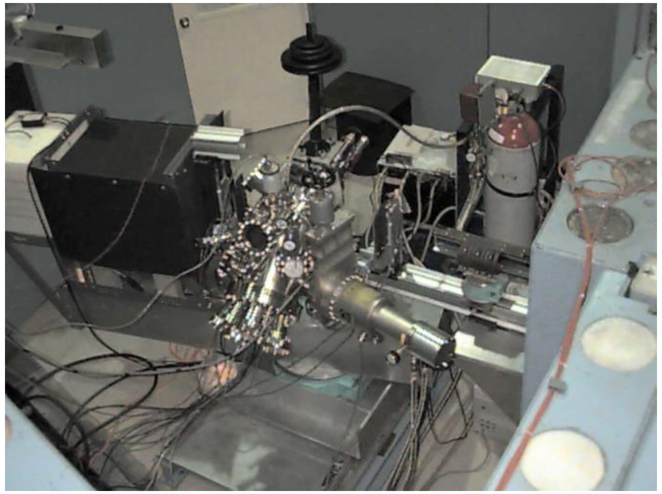


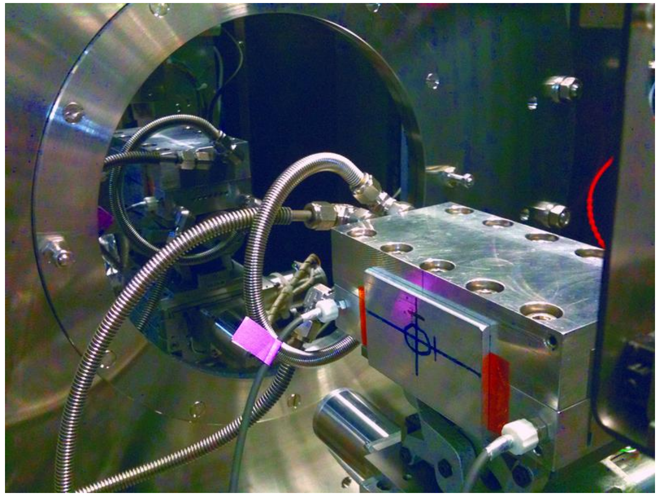
S. Mattauch et al. Nuclear Instruments and Methods in Physics Research A 841 (2017) 34–46.

Sample environment for NR

- Low temperatures — 1.5 ÷ 300 K
- High temperatures — 300 ÷ 900/1900 K
- Magnetic field — 10 ÷ 15 T
- Thermostat (temperature, humidity, pressure)
- X-Ray option
- MBE in-situ chamber
- …



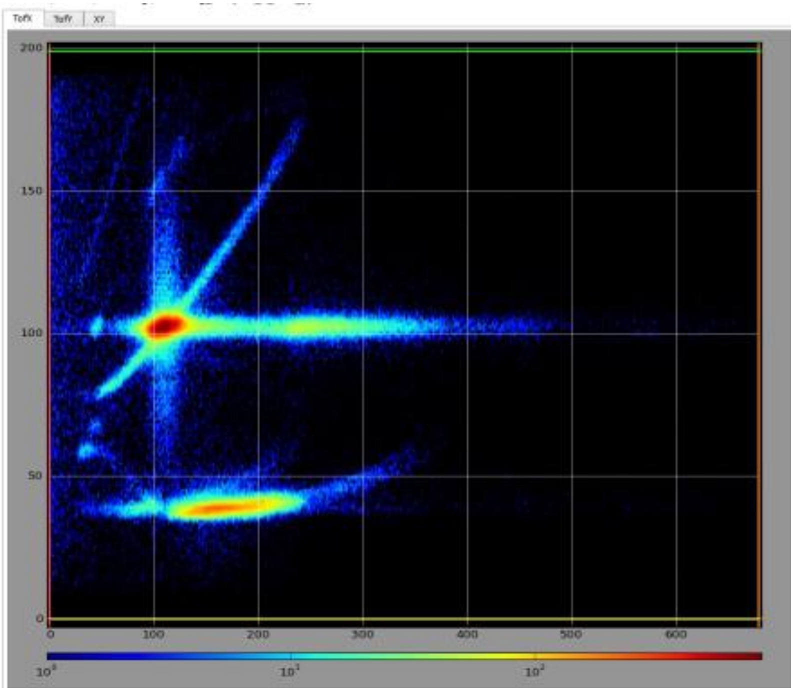




Detectors and DAQ

PSD area ~ 500 x 500 mm^2

Resolution ~ 2mm x 2 mm

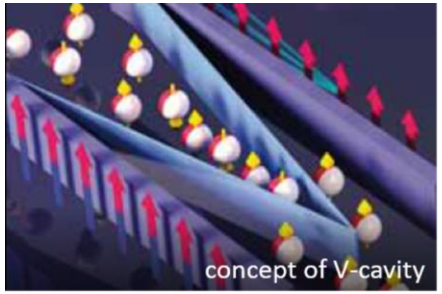


Expected count rate ~ $10^7 \div 10^8$ n/s

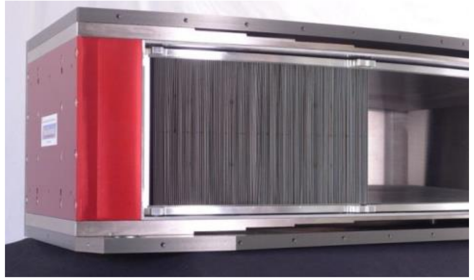
Corresponding fast electronics is needed

Polarization

Magnetic mirrors



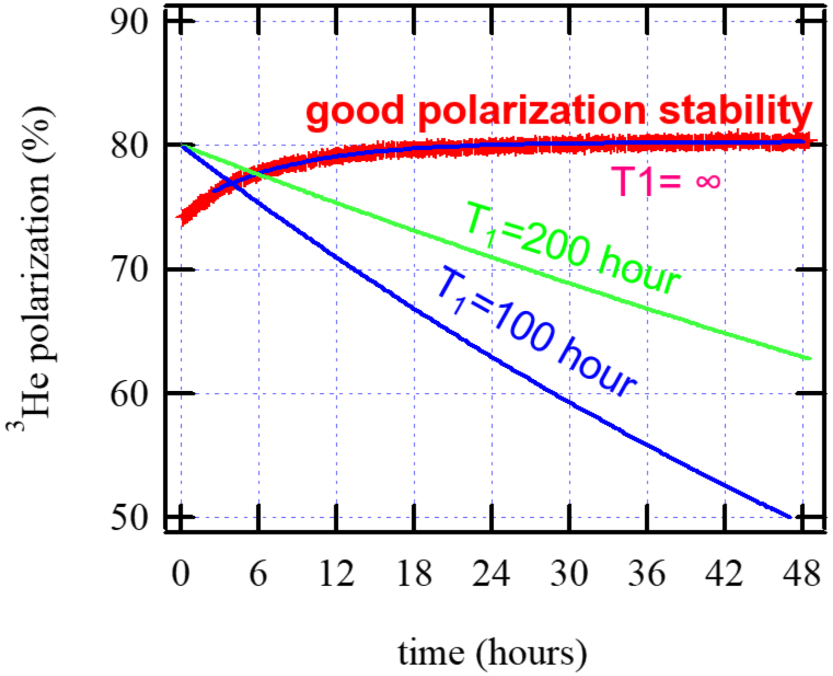
multi-channel V-cavity



wide angle polarisation analyser

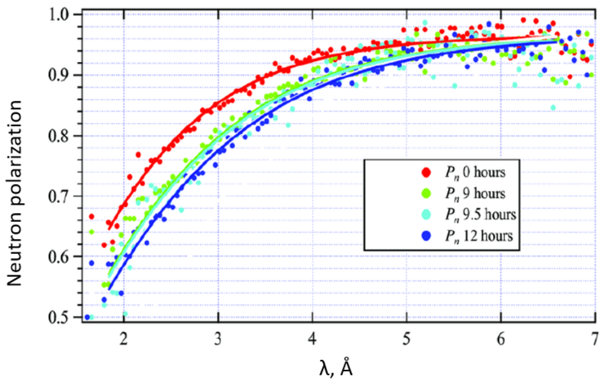
Pol He3 filter

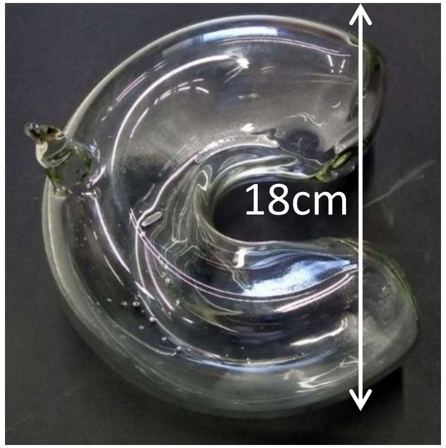
In situ pumping



J1 cell with
∅ = 6 cm!
$T1_{lab}$=660h

He-3 polarization decay in time





Polarization vs. time of J1 polarized in-situ on the JCNS reflectometer

- Very high ^{3}He polarization: 80.2% and T1= ∞

E. Babcock, S. Mattauch, A. Ioffe, *Nucl. Instrum. Methods A* **625**, 43 (2011).

NEPTUN: requirements

1. Time-average flux density:	$(0.5 \div 12)\cdot 10^{14}$	→	$\Phi_0 = 5\cdot 10^{14}$ n/cm²/s
2. Half-width of fast neutrons:	$(20 \div 200)$ μs	→	$\Delta t_0 = 200$ μs
3. Pulse repetition rate:	$(10 \div 30)$ Hz	→	ν = 10 Hz
4. Moderators (at least three):	VC, C, Th	→	very cold (~30 K)
5. Background power:	3.2 %		
6. Number of beam ports	20 - 32		

	SNS	ESS
1. Time-average flux density:	$0.1\cdot 10^{14}$	$3\cdot 10^{14}$
2. Half-width of fast neutrons:	$(20 \div 50)$ μs	2860 μs
3. Pulse repetition rate:	60 Hz	14 Hz
4. Time-average power:	1 MW	5 MW
5. Background power:	<1%	<1%
6. Number of beam ports:	22	42

Required minimum set of NR at the future DNS-IV neutron source

No.	Instrument	Main issue	Moderator
1	General purpose Horizontal scattering plane	Various resolution, $\Delta q/q$ - 1÷10% polarized neutrons, wide angle analyzer, focusing elements and multi-beam collimation, multi-chopper background suppression Off-specular, GISANS, PSD 0.5 x 0.5 m^2, extended sample environment (combinations with other techniques, in-situ studies) Real-Time	30 K
2	Liquid reflectometer Vertical scattering plane	Various resolution, $\Delta q/q$ - 1÷10% polarized neutrons, wide angle analyzer, focusing elements and multi-beam collimation, multi-chopper background suppression Off-specular, GISANS, PSD 0.5 x 0.5 m^2, extended sample environment for hard/liquid samples (combinations with other techniques, in-situ studies) Real-Time	30 K
3	Reflectometer for methodical studies	Testing of new elements and methodical ideas	

Conclusions

Basing on the trends in the science development in the world and our own experience one have to make a conclusions:

- **Two type of NR are demanded: horizontal and vertical planes scattering**
- **Multi-beam measurement to avoid excess intensity losses**
- **Instrument flexibility: wide range of measurement modes and parameters (polarized/unpolarized; focusing/collimation ets.)**
- **In-situ sample characterization and control**
- **Real-time measurements**
- **Wide spectrum of sample environment equipment**
- **Background suppression at the pulsed reactor demands a special approach**
- **There are competitive reflectometers can be realized at the future source DNS-IV by the set of basic parameters: intensity, resolution, Q-range.**

Thank you for your attention

Special thanks:

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