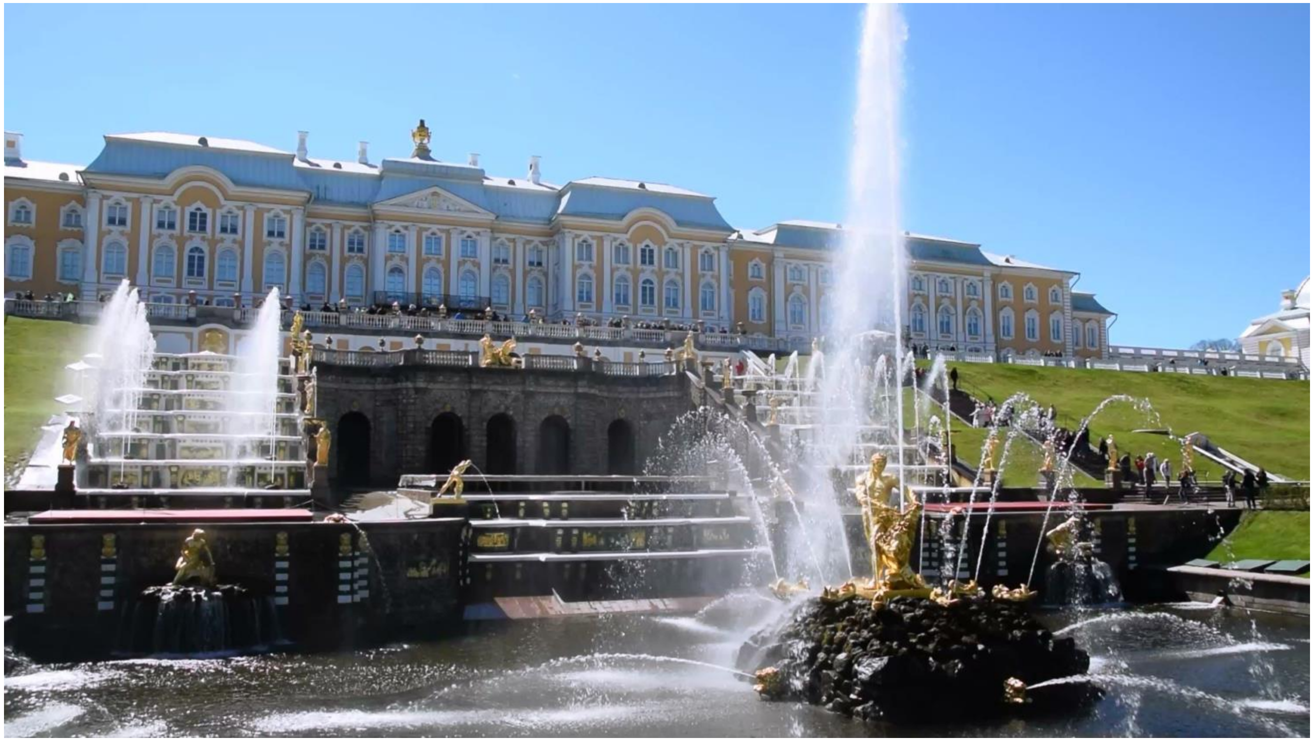
**PETERSBURG NUCLEAR PHYSICS INSTITUTE**
**NRC KI (GATCHINA, RUSSIA)**

**N.K. Pleshanov**


# *Polarizing neutron optics*



**CREMLIN workshop: Engineering for advanced neutron instrumentation and sample environment**
**13 - 15/05/2018 (Petergof, StPetersburg, RUSSIA)**

# Polarizing neutron techniques

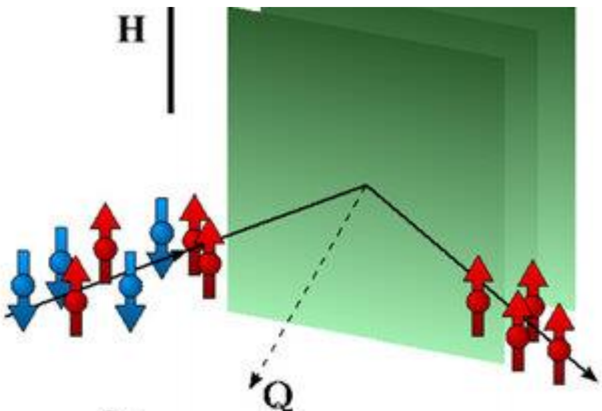
The basic techniques for neutron polarization:

1. polarizing crystal monochromators;
2. $^{3}He$ neutron spin filters;
3. polarizing neutron optics.

# Polarizing crystal monochromators

| | Polarizing crystal monochromators | | | | |
|---|---|---|---|---|---|
| **Compound** | $Co_{0.92}Fe_{0.08}$ | $Cu_2MnAl$ | $Fe_3Si$ | $^{57}Fe$: Fe | $HoFe_3$ |
| (*hkl*) with $\|F_n\| \sim \|F_m\|$ | (200) | (111) | (111) | (110) | (620) |
| $d_{hkl}$, Å | 1.76 | 3.43 | 3.27 | 2.03 | 1.16 |
| $2\theta_B$ for $\lambda$ = 1 Å | 33.1° | 16.7° | 17.6° | 28.6° | 50.9° |
| $\lambda_{max} = 2d_{hkl}$, Å | 3.5 | 6.9 | 6.5 | 4.1 | 2.3 |

**Heusler**

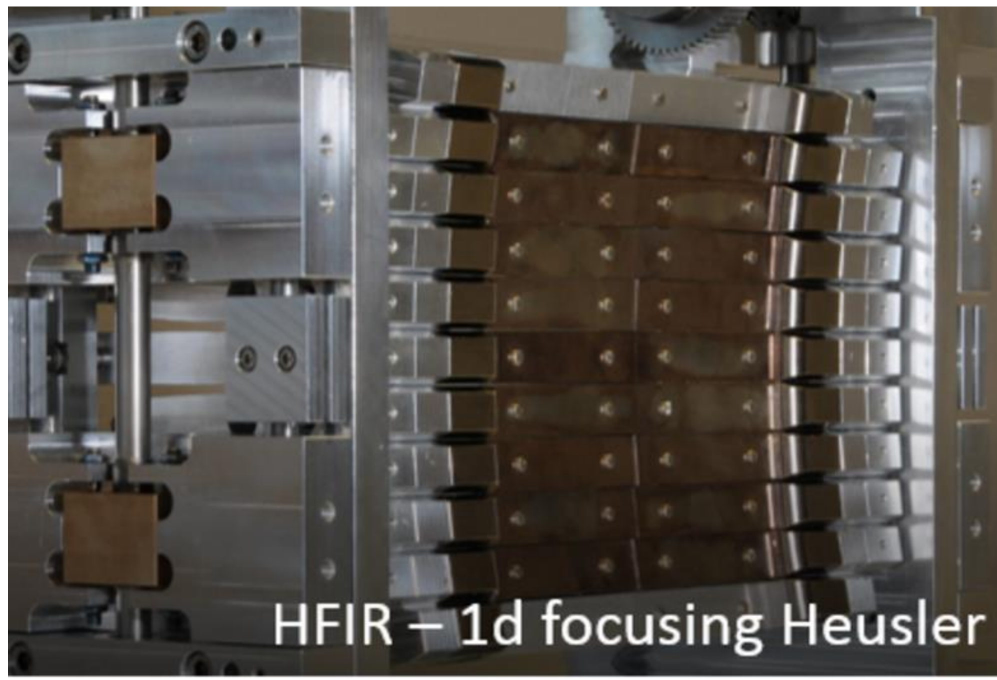



$$\frac{\delta\sigma}{\delta\Omega} = F_N^2 + 2F_N F_M + F_M^2$$

$$\uparrow \quad \frac{\delta\sigma}{\delta\Omega} = (F_N + F_M)^2$$

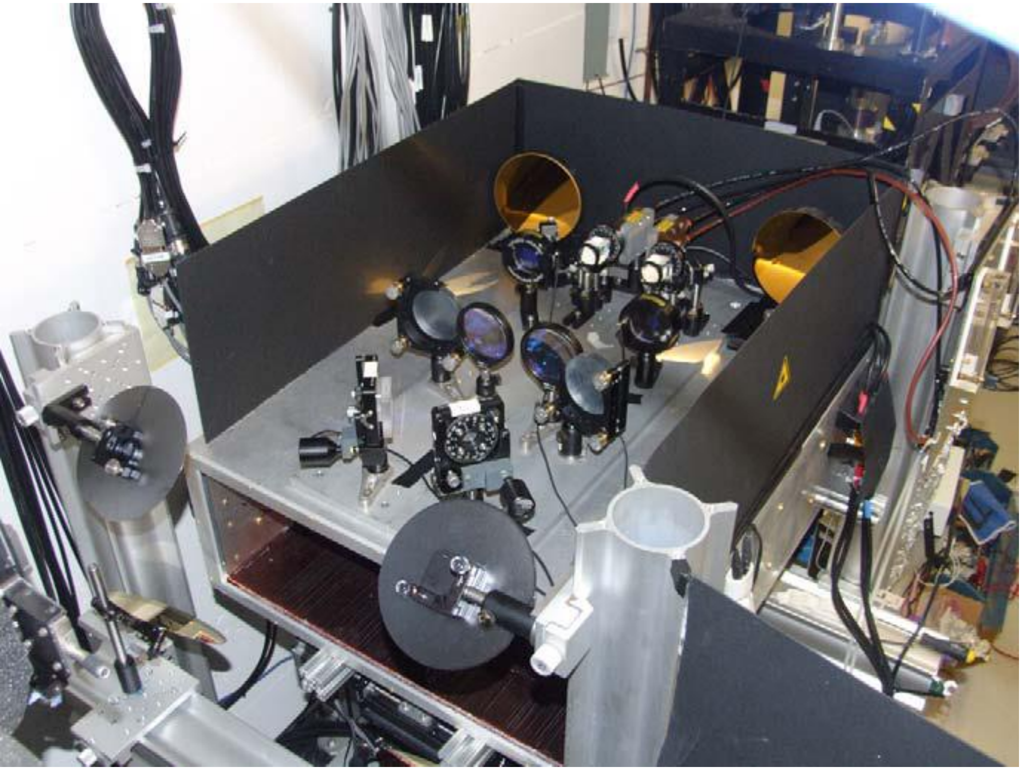
$$\downarrow \quad \frac{\delta\sigma}{\delta\Omega} = (F_N - F_M)^2$$

$$P = \frac{2F_n(\mathbf{q}_{hkl})F_m(\mathbf{q}_{hkl})}{F_n^2(\mathbf{q}_{hkl}) + F_m^2(\mathbf{q}_{hkl})}$$

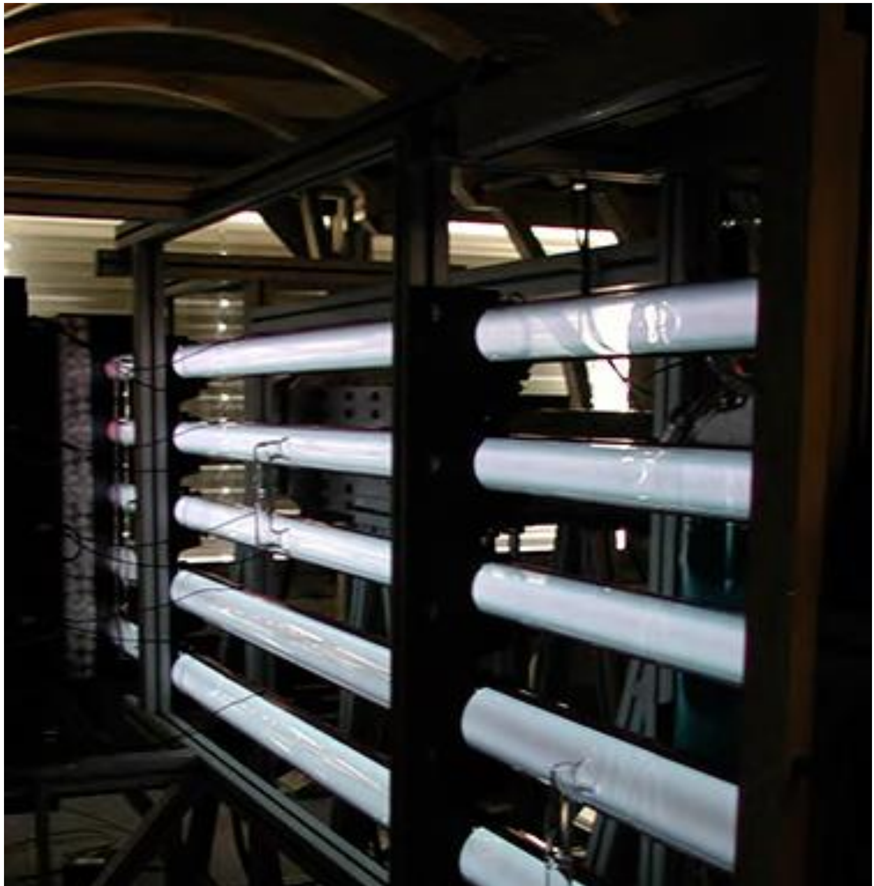



Polarizing crystal monochromators are well suited to the needs of polarized beam diffractometry and polarized beam triple-axis spectrometry, since they simultaneously polarize, monochromate and form beams of required divergence.

# $^3$He neutron spin filters



⇐ SEOP tests performed at ISIS on the reflectometer CRISP



MEOP station at ILL ⇒

$$T = \exp(-\mu_0 l)\cosh(\mu_0 l P_{\mathrm{He}})$$

$$P = \tanh(\mu_0 l P_{\mathrm{He}})$$

$$\mu_0\, l \cong 0.7282 \cdot \mathrm{p[bar]} \cdot l\mathrm{[cm]} \cdot \lambda\mathrm{[nm]}$$

Si-window spin-filter cell for local filling

# $^3$He neutron spin filters

| Advantages | Disadvantages |
|---|---|
| High efficiency for cold, thermal or hot neutrons | Increasing $T_+$, one increases $T_-$ |
| Good efficiency in a sufficiently wide working wavelength range ($\lambda_{max}/\lambda_{min} \sim 3$) | The working wavelength range not always sufficiently wide ($\lambda_{max}/\lambda_{min} \sim 3$) |
| Rectilinear trajectories of passing neutrons | Strong dependence of transmission on the wavelength |
| Practically unlimited angular acceptance | Deterioration of the gas polarization in time (MEOP) |
| Compactness and easy change of the cell size and shape | Technological complexity |
| Integration of the spin filter and a high-efficiency spin flipper | High cost of the equipment and its maintenance |
| Predictable and uniform transmission | High-tech infrastructure required |
| Low level of diffuse scattering | |
| No contribution into the $\gamma$-background | |

$$P = \tanh(\mu_0 l P_{He})$$

$$\mu_0\, l \cong 0.73 \cdot \mathrm{p[bar]} \cdot l\mathrm{[cm]} \cdot \lambda\mathrm{[nm]}$$

# Polarizing neutron optics

Although the $^3$He polarization level (near 80%) achieved by optical pumping with both metastability exchange (MEOP) and spin exchange (SEOP) techniques allows of efficient beam polarization with <u>neutron spin filters</u>,

<u>neutron optical polarizers</u> on the basis of neutron polarizing coatings can still be more relevant and efficient:

- for preparation of polarized neutron beams with relatively small divergence (as often required by the instrumental resolution);
- for analysis of the polarization of neutrons scattered by the sample, provided that a multichannel analyzer can be placed far enough from the sample (2-3 m, when the transverse sample size does not exceed 1 cm), a small angular aperture for each channel ensuring a high throughput.

In these cases, the advantages of neutron optical polarizers can outweigh:

- simplicity of production and exploitation,
- zero maintenance costs,
- autonomy (no sophisticated infrastructure is needed),
- the possibility to polarize neutrons in a broader wavelength band.

# Polarizing neutron optics

Although the $^3$He polarization level (near 80%) achieved by optical pumping with both metastability exchange (MEOP) and spin exchange (SEOP) techniques allows of efficient beam polarization with neutron spin filters,

neutron optical polarizers on the basis of neutron polarizing coatings can still be more relevant and efficient:

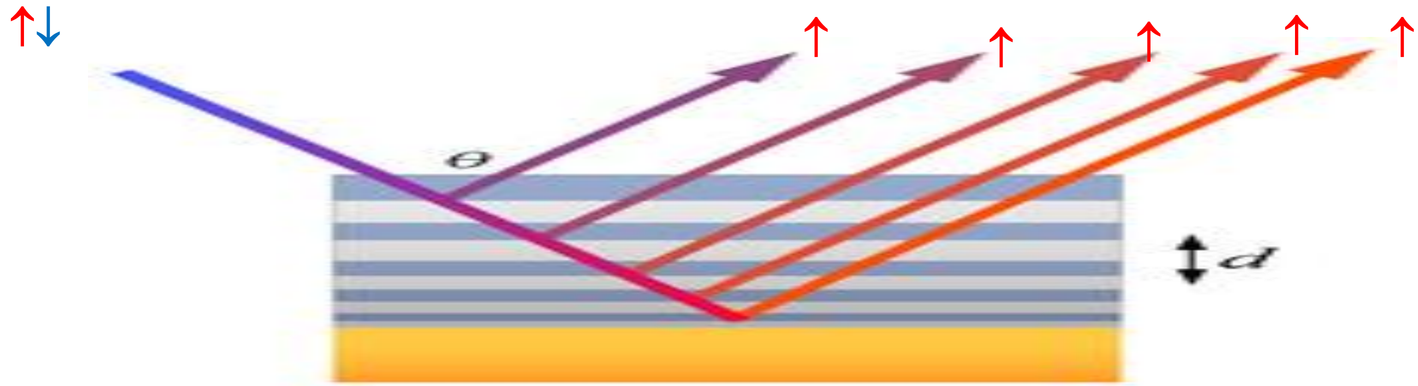
- for preparation of polarized neutron beams with relatively small divergence (as often required by the instrumental resolution);
- for analysis of the polarization of neutrons scattered by the sample, provided that a multichannel analyzer can be placed far enough from the sample (2-3 m, when the transverse sample size does not exceed 1 cm), a small angular aperture for each channel ensuring a high throughput.

In these cases, the advantages of neutron optical polarizers can outweigh:

- simplicity of production and exploitation,
- zero maintenance costs,
- autonomy (no sophisticated infrastructure is needed),
- the possibility to polarize neutrons in a broader wavelength band.

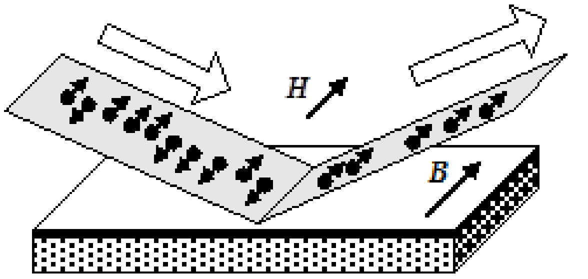
! The efficiency of neutron optical polarizers is largely determined by the efficiency of the polarizing supermirrors.

# Polarizing neutron supermirrors



# Polarizing neutron supermirrors

$$P = \frac{R_+ - R_-}{R_+ + R_-}\ ;\ 1 - 2\frac{R_-}{R_+}$$

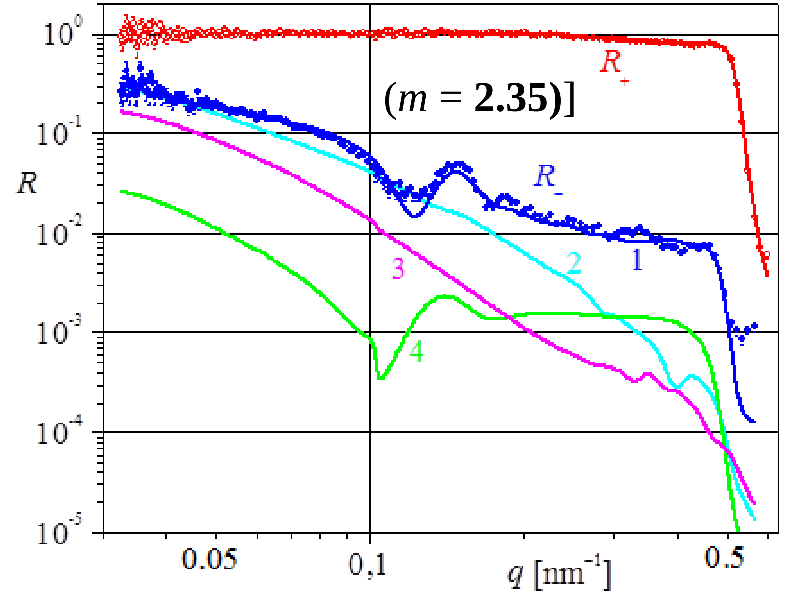



The polarizing supermirrors are designed so that the spin-up reflectivity $R_+$ ~ 1 in the working q-range. Therefore, the key task is to minimize the spin-down reflectivity $R_-$ by matching the potentials of the layers for spin-down neutrons.

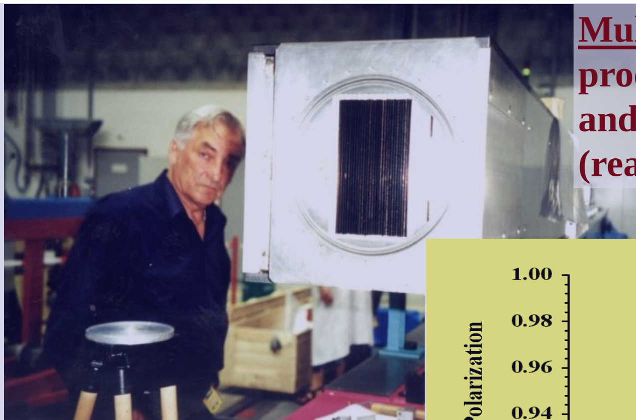
# Polarizing neutron supermirrors

**Enormous efforts to match the potentials of the layers in CoFe/TiZr supermirrors led to $R_{-} \sim 10^{-2}$ (experimental points in SM region $q$>0.2 $nm^{-1}$). Such supermirrors were successfully used in most polarizers and analyzer produced in PNPI (Gatchina).**

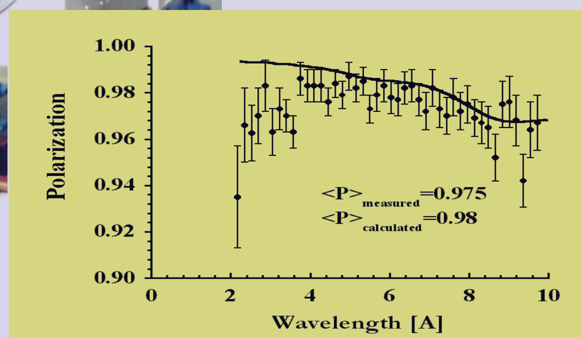
[N.K. Pleshanov, et al., Physica B 397 (2007) 62]



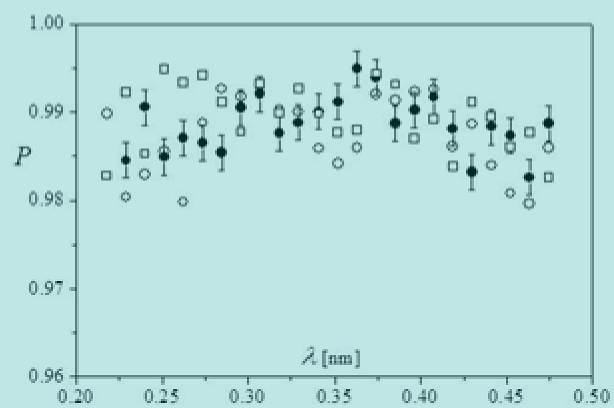

**Experimental (symbols) and calculated reflectivities as functions of *q*.**



**Multichannel polarizer produced (2000) in PNPI and mounted at beam 51 (reactor SINQ, PSI)**



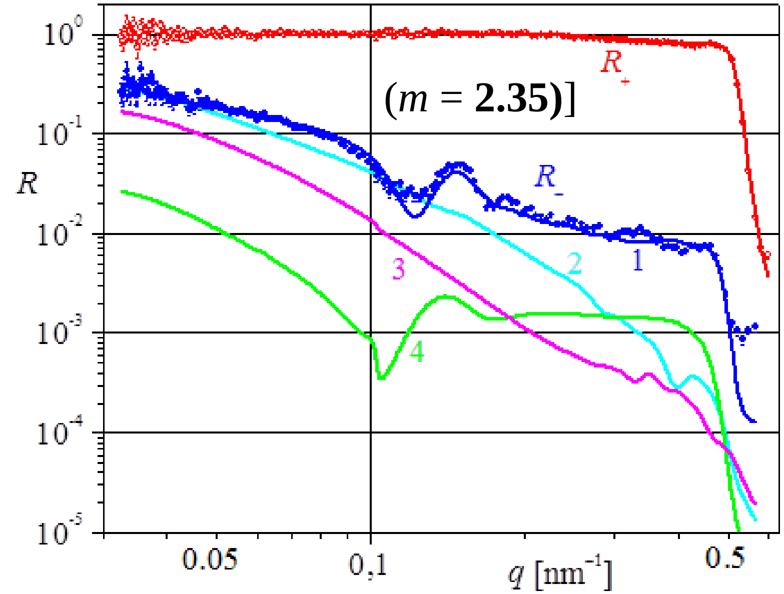

**Multichannel fan analyzer produced (2013) in PNPI and mounted at Magnetism Reflectometer (SNS, ORNL)**



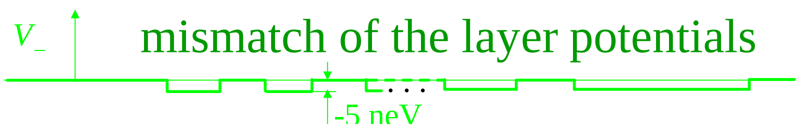
# Polarizing neutron supermirrors

**contributions into R_**

[N.K. Pleshanov, et al., Physica B 397 (2007) 62]




mismatch of the layer potentials

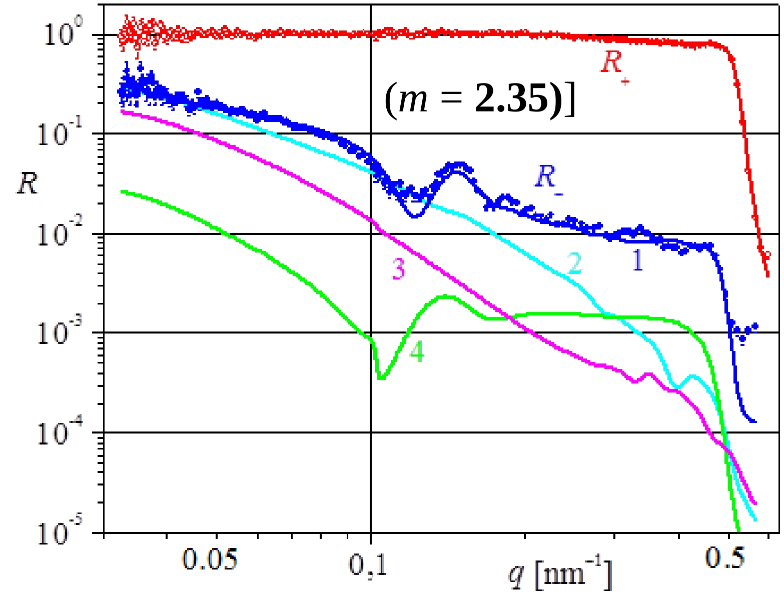



**Experimental (symbols) and calculated reflectivities as functions of *q*.**

# Polarizing neutron supermirrors

## contributions into R_

[N.K. Pleshanov, et al., Physica B 397 (2007) 62]

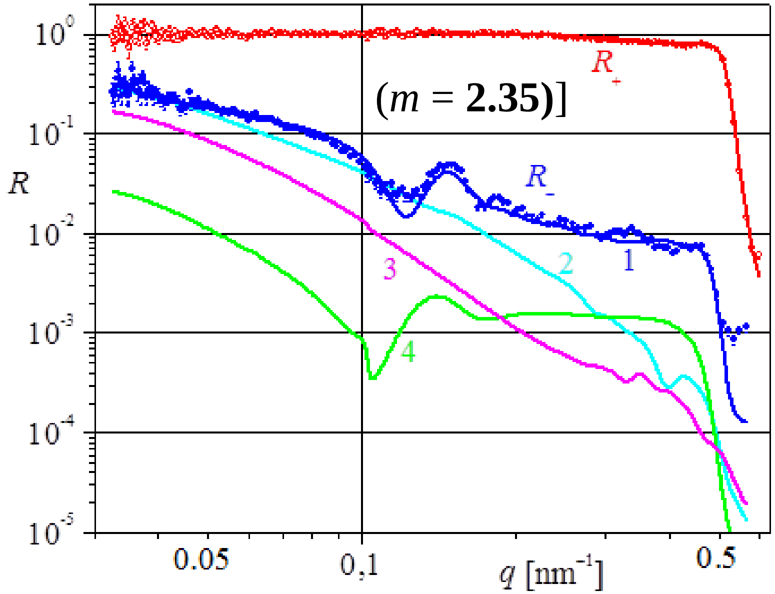




**Experimental (symbols) and calculated reflectivities as functions of *q*.**

# Polarizing neutron supermirrors

## contributions into R_

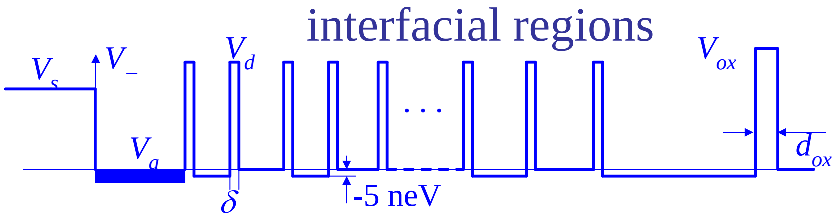

[N.K. Pleshanov, et al., Physica B 397 (2007) 62]



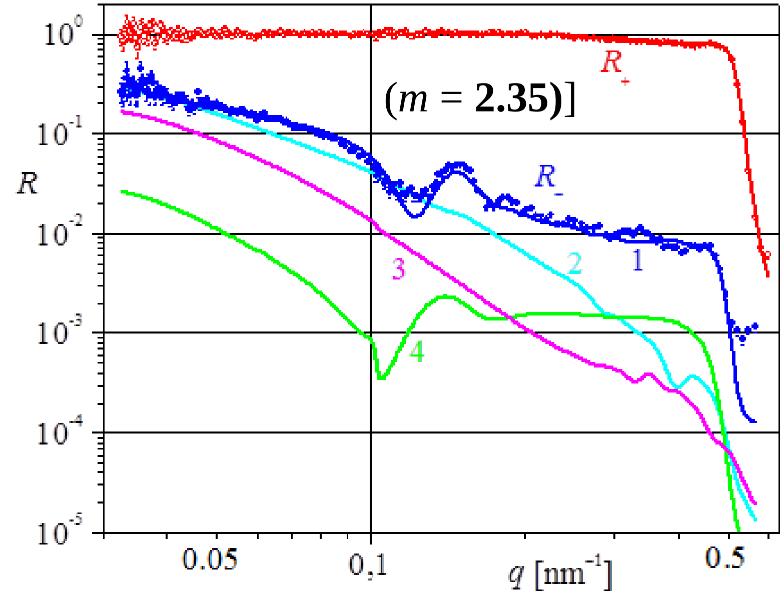

**Experimental (symbols) and calculated reflectivities as functions of *q*.**

# Polarizing neutron supermirrors

## contributions into R_




[N.K. Pleshanov, et al., Physica B 397 (2007) 62]

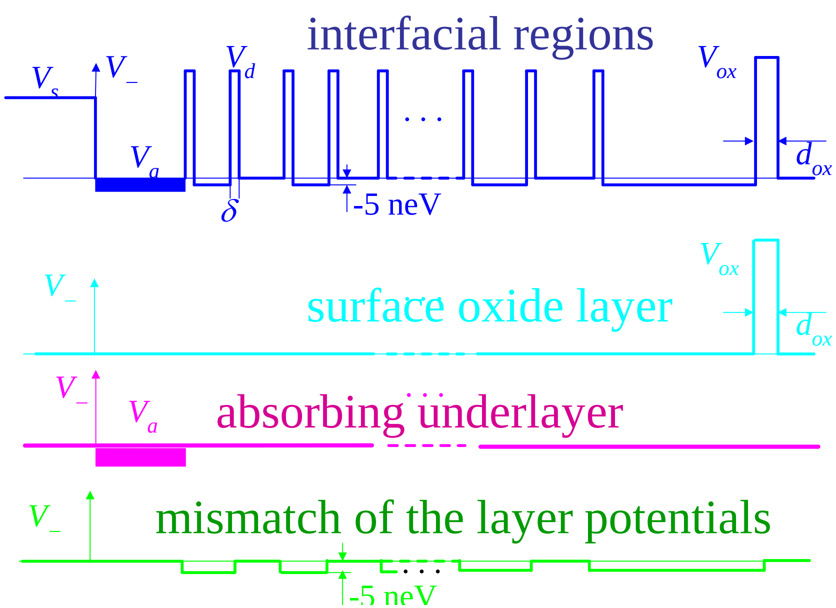



**Experimental (symbols) and calculated reflectivities as functions of *q*.**

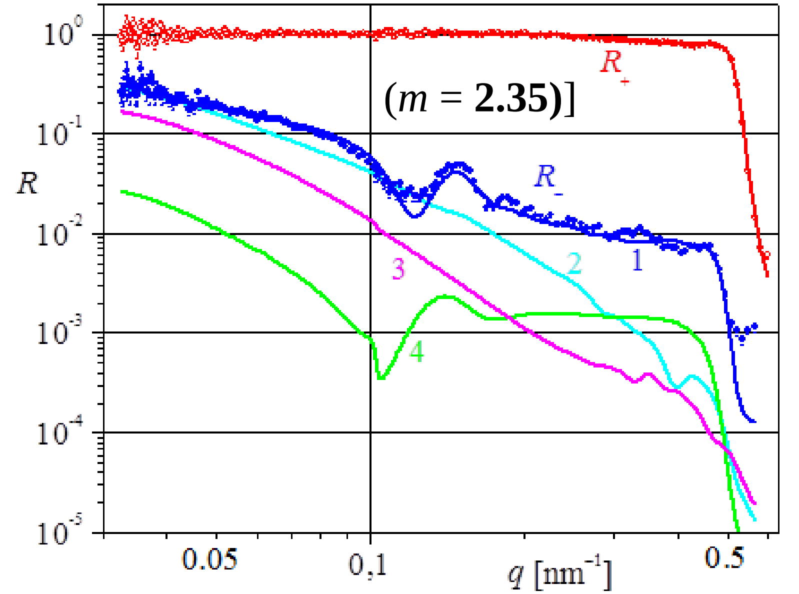
**The main contribution is reflection of spin-down neutrons from magnetically dead regions formed at each interface (i.e. from numerous barriers).**

# Polarizing neutron supermirrors

## contributions into R_




[N.K. Pleshanov, et al., Physica B 397 (2007) 62]

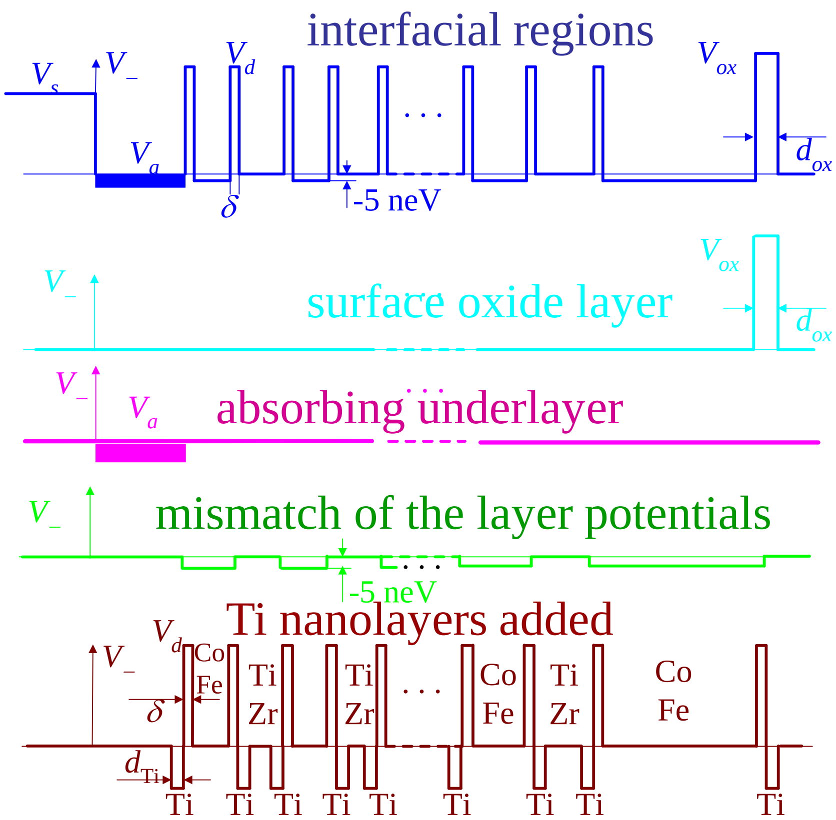



**Experimental (symbols) and calculated reflectivities as functions of *q*.**

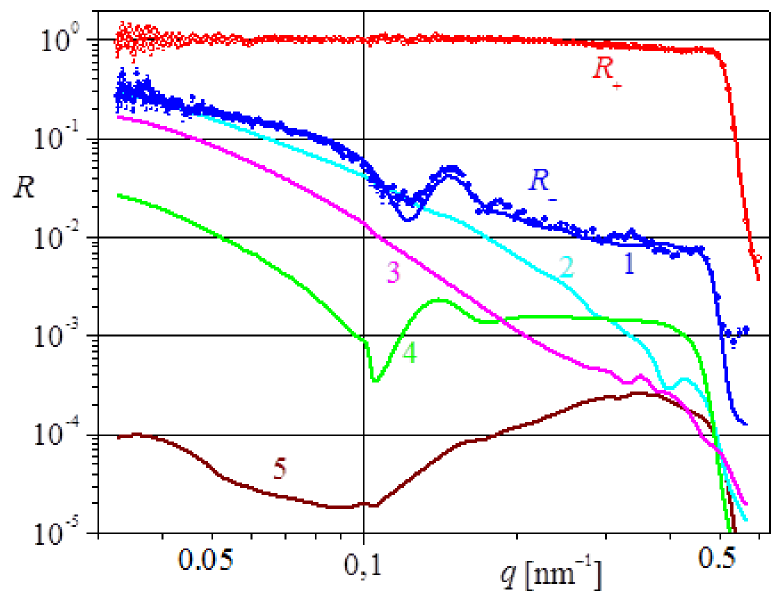
For the first time, both $R_+$ and $R_-$ for a polarizing supermirror were consistently fitted in a wide q-range, the difference in magnetic and structural roughness playing an important role. The magnetic roughness was found to be less by 0.22 nm.

# Polarizing neutron supermirrors

## suppression of R_




[N.K. Pleshanov, NIM A 613 (2010) 15]



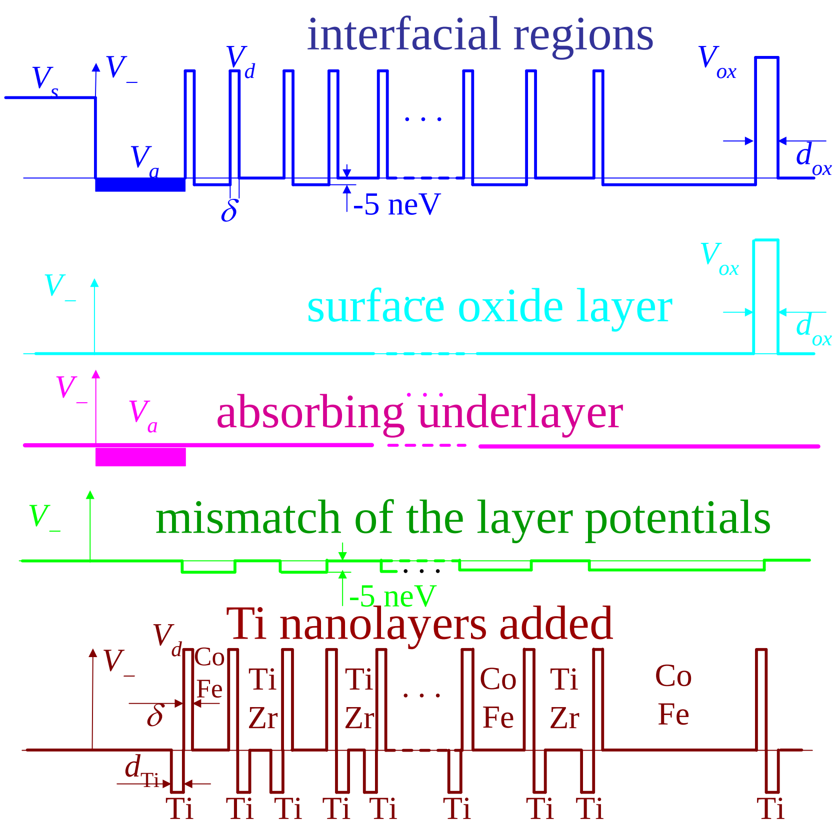

**Experimental (symbols) and calculated reflectivities as functions of *q*.**

**Suppression of reflection of the spin-down neutrons from the interfacial barriers by means of Ti interlayers ($d_{Ti}$=1.2 nm).**

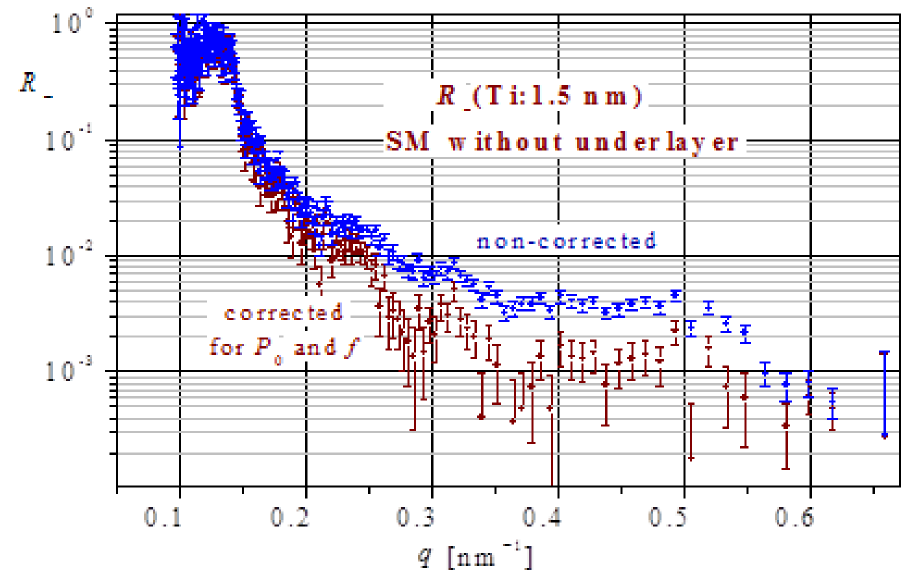
**The model developed was used to substantiate the method of suppression of reflection of spin-down neutrons from numerous barriers by using layers with a negative potential at each interface: cf. reflectivities 1 (no interlayers) and 5 (Ti interlayers with a thickness 1.2 nm).**

# Superpolarizing neutron supermirrors

**suppression of R_**




[N.K. Pleshanov, NIM A 613 (2010) 15]

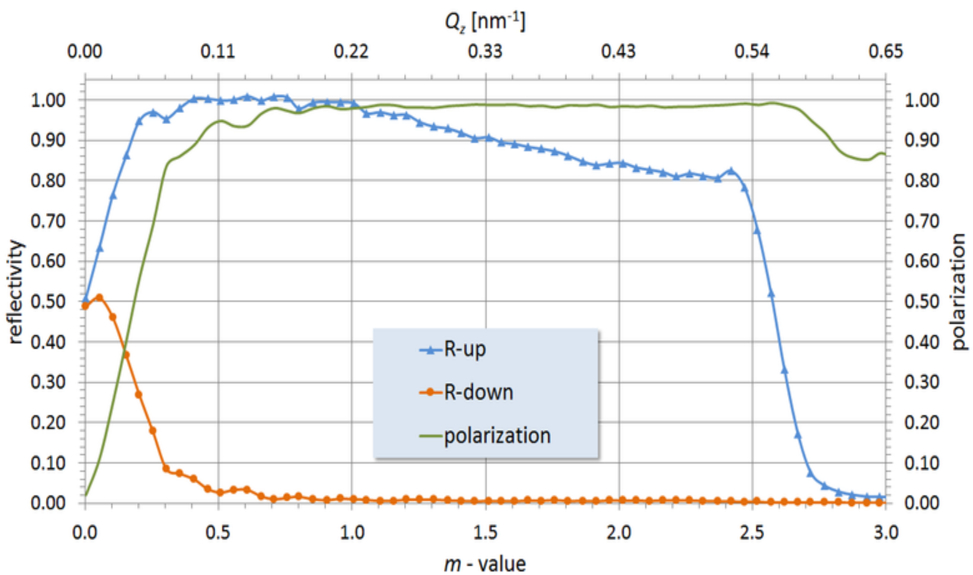



**Experimental reflectivities *R_(q)* for CoFe/T/TiZr/Ti supermirrors (with Ti 1.5 nm interlayers), not corrected and corrected for the direct beam polarization $P_0 \neq 1$ and the flipper efficiency $f \neq 1$.**

Using Ti interlayers, the spin-down neutron reflectivity R_ was reduced by an order of magnitude ('superpolarizing supermirrors'). Theoretically, suppression of R_ by two orders of magnitude is possible.

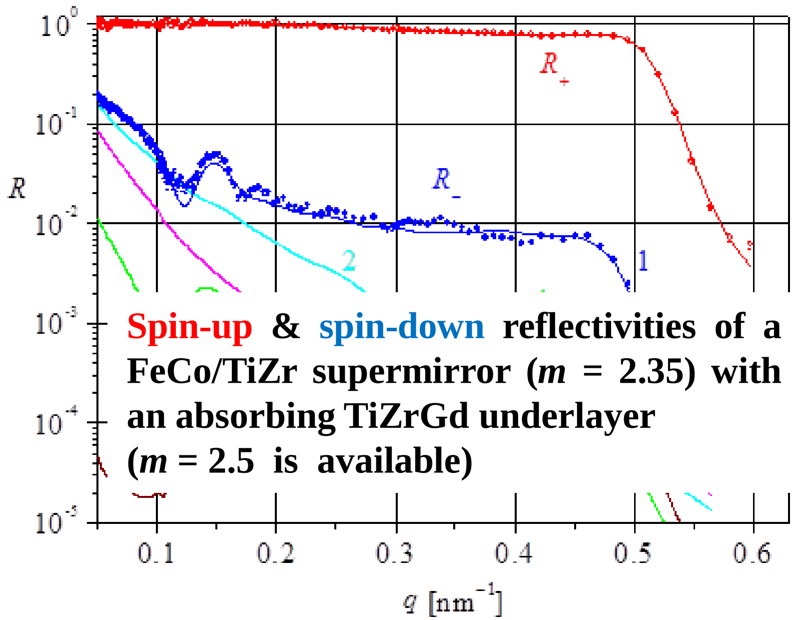
# Polarizing neutron supermirrors

## Swissneutronics




**Spin-up & spin-down reflectivities and polarization of a FeCoV/TiN supermirror (*m* = 2.5) with an absorbing TiGd underlayer (*m* = 3 is available)**

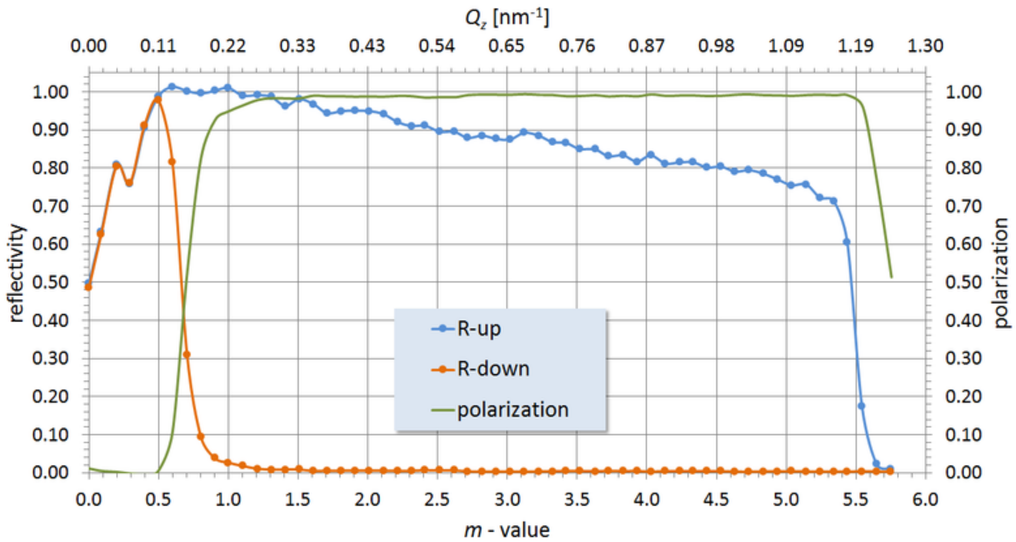
## PNPI




**Spin-up & spin-down reflectivities of a FeCo/TiZr supermirror (*m* = 2.35) with an absorbing TiZrGd underlayer (*m* = 2.5 is available)**

# Polarizing neutron supermirrors

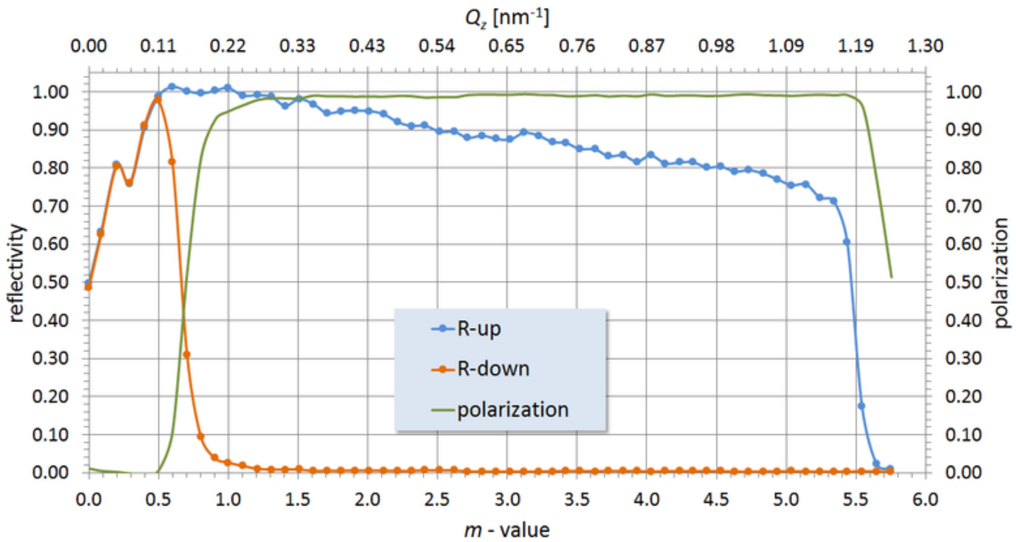
## Swissneutronics



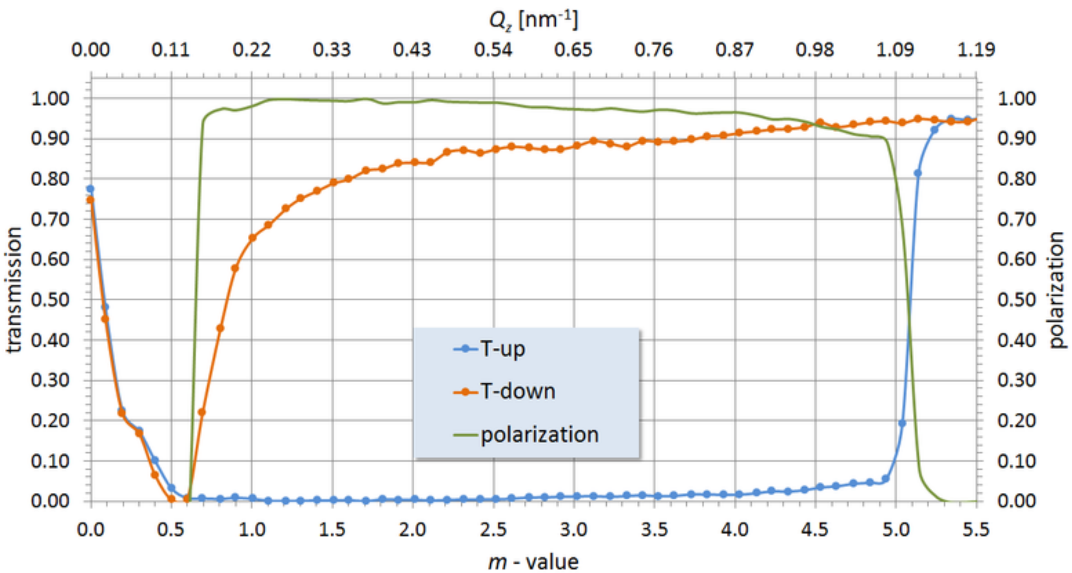

Spin-up & spin-down reflectivities and polarization of a Fe/Si supermirror (*m* = 5.5) (no absorbing underlayer).

# Polarizing neutron supermirrors

## Swissneutronics

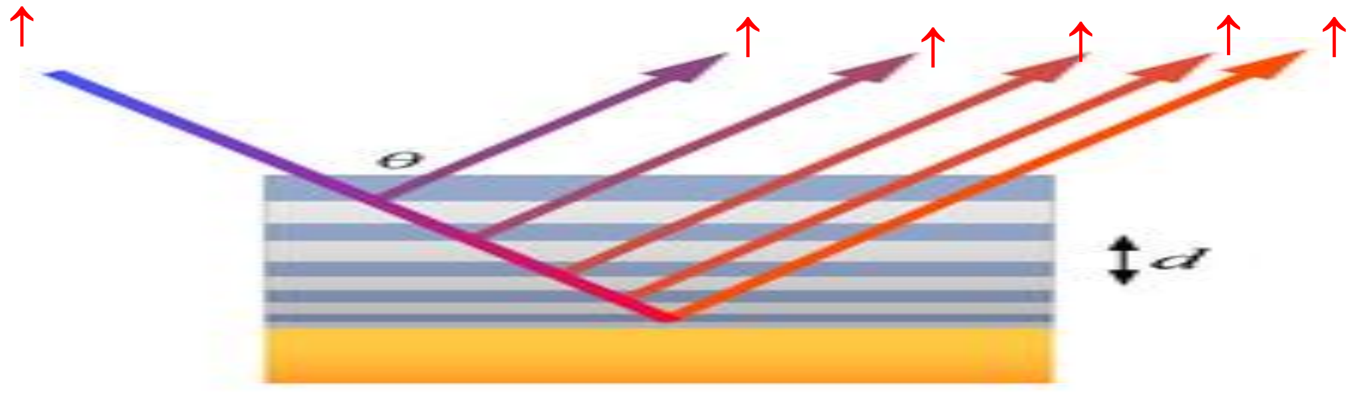



**Spin-up & spin-down reflectivities and polarization of a Fe/Si supermirror (*m* = 5.5) (no absorbing underlayer).**

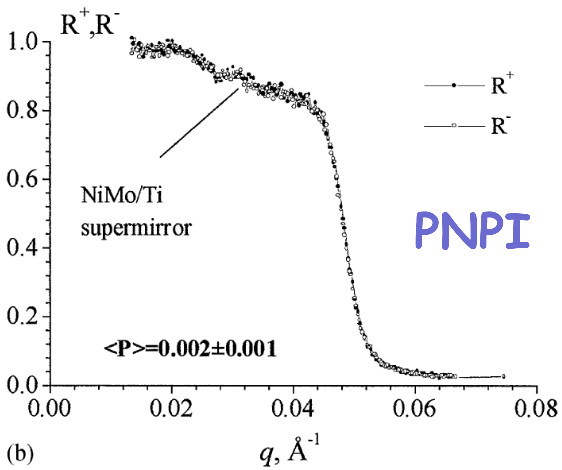



**Spin-up & spin-down transmission and polarization of a Si-wafer coated on both sides with a Fe/Si supermirror (*m* = 5).**

# Non-depolarizing neutron supermirrors



# Non-depolarizing neutron supermirrors

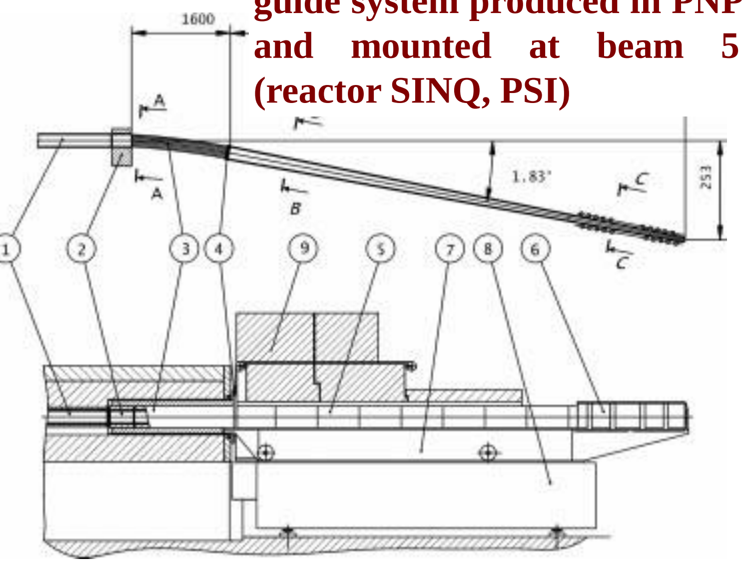


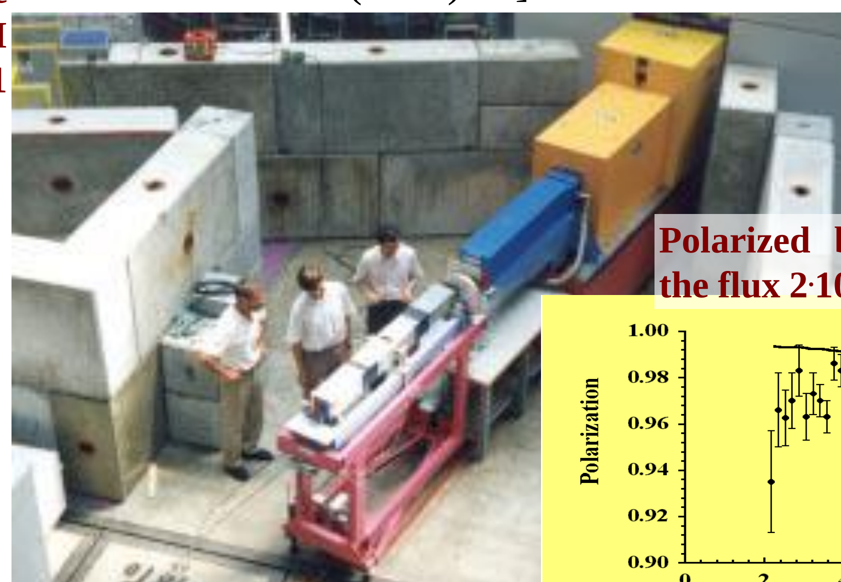

[A. Schebetov, A. Kovalev, B. Peskov, N. Pleshanov, V. Pusenkov, P. Schubert-Bischoff, G. Shmelev, Z. Soroko, V. Syromyatnikov, V. Ul'yanov, A. Zaitsev, Nucl. Instr. and Meth. A 432 (1999) 214]

**Spin-up & spin-down reflectivities of a non-depolarizing NiMo/Ti supermirror (*m* = 2)**

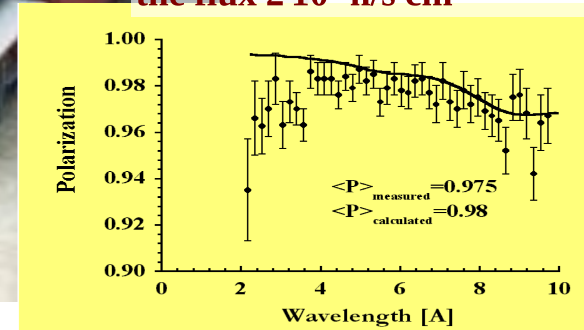
[K. Bodek, P.Böni, C. Hilbes, J.Lang, M.Lasakov, M.Luthy, S. Kistryn, M. Markiewicz, E. Medvedev, V.Pusenkov, A.Schebetov, A. Serebrov, J. Sromicki, A. Vassiljev, Neutron News 3 (2000) 29]

**Transportation of polarized neutrons from the polarizing bender (3) to the exit of the guide system produced in PNPI and mounted at beam 51 (reactor SINQ, PSI)**

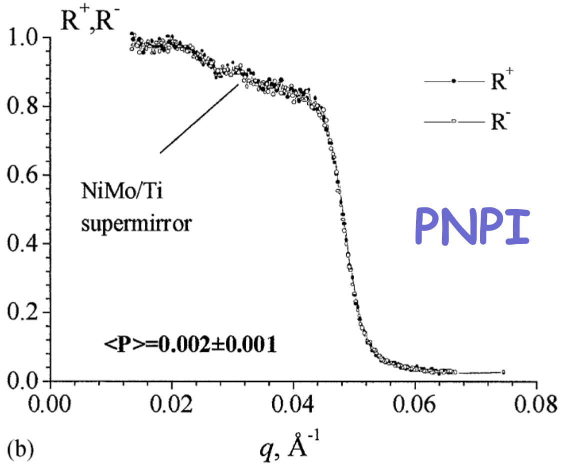


**Polarized beam 40x150 mm$^2$, the flux 2·10$^8$ n/s cm$^2$**



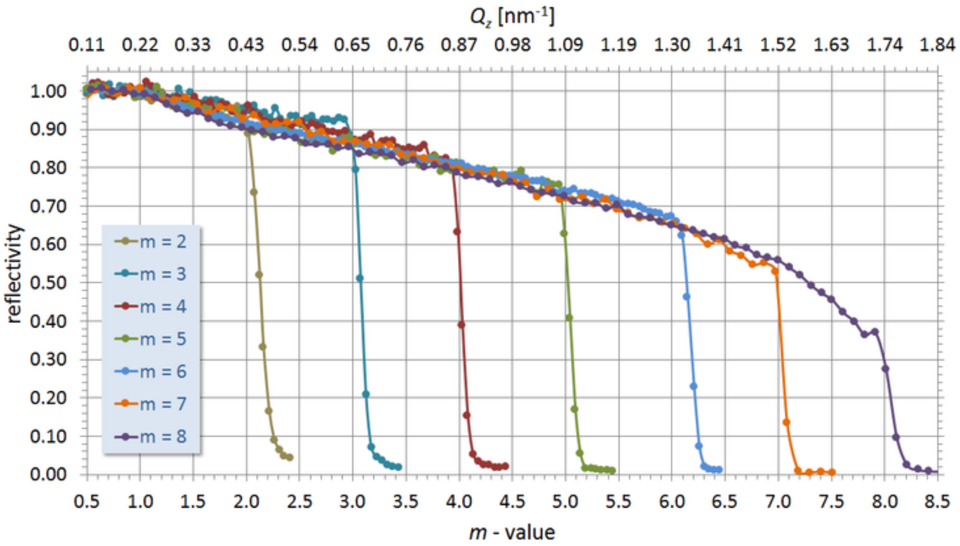
# Non-depolarizing neutron supermirrors




PNPI

[A. Schebetov, A. Kovalev, B. Peskov, N. Pleshanov, V. Pusenkov, P. Schubert-Bischoff, G. Shmelev, Z. Soroko, V. Syromyatnikov, V. Ul'yanov, A. Zaitsev, Nucl. Instr. and Meth. A 432 (1999) 214]

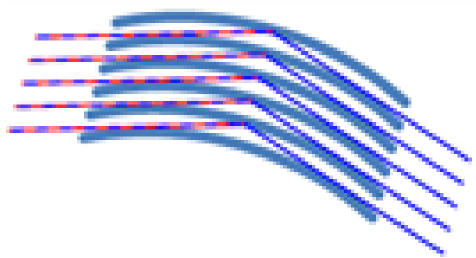
**Spin-up & spin-down reflectivities of a non-depolarizing NiMo/Ti supermirror (*m* = 2)**



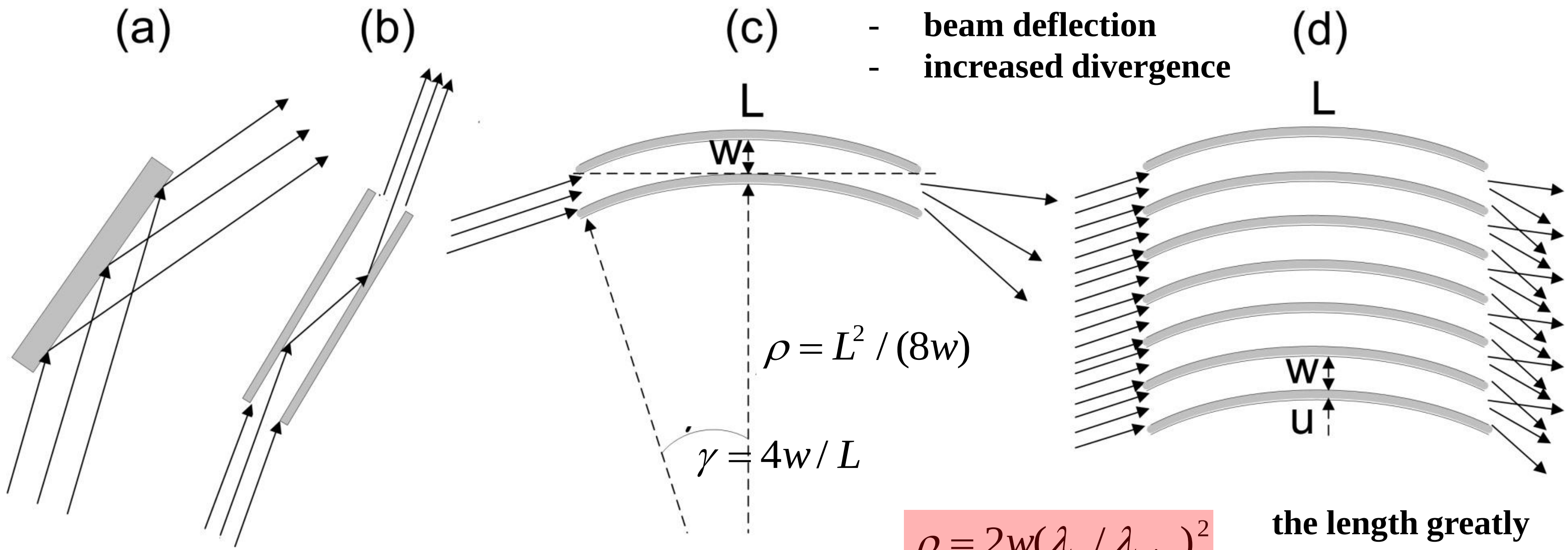

Swissneutronics

**Neutron reflectivities of non-depolarizing NiMo/Ti supermirrors (*m* = 2÷8)**

# Neutron supermirror polarizers



# Neutron polarizers: classical designs




$$\rho = 2w(\lambda_c / \lambda_{\min})^2$$

$$L = 4w\lambda_c / \lambda_{\min}$$

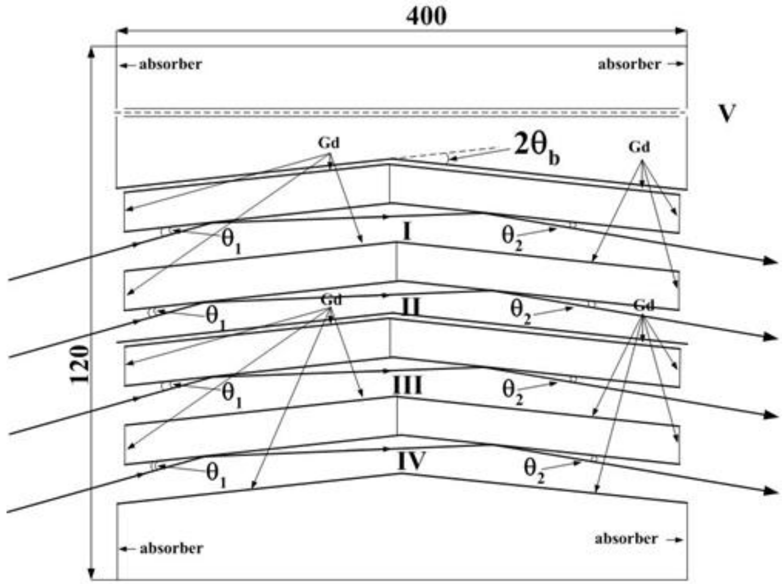
$$\lambda_c = \frac{4\pi}{mq_{\mathrm{Ni}}}$$

**the length greatly reduced**

Classical designs of reflection polarizers:

(a) Flat mirror
(b) Straight guide
(c) Bent guide
(d) Bender (bent multichannel guide)

# Double reflection polarizers



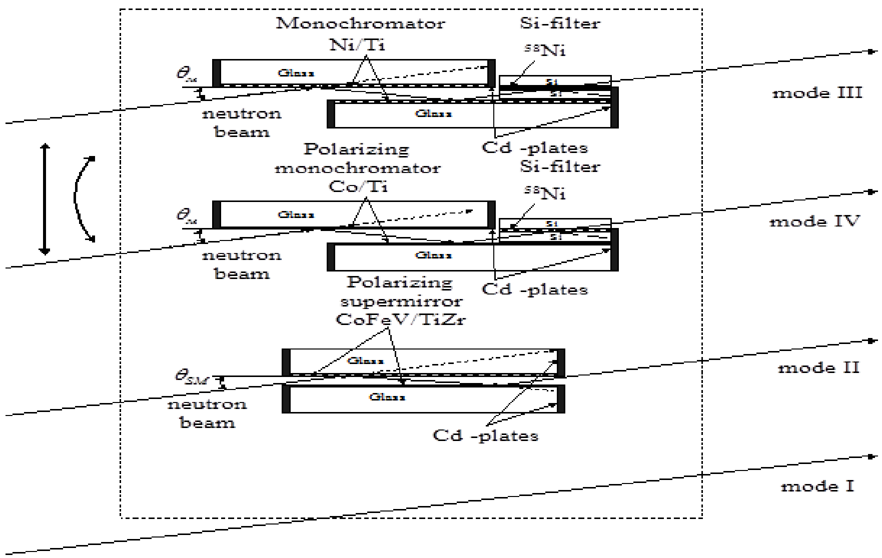

- divergence, the same or reduced
- beam deflection

Double reflection polarizers form well-collimated monochromatic/white highly polarized beams. Moving the respective couple of (non-polarizing/polarizing) multilayers/ supermirrors into the initial beam, the user selects the beam incident onto the sample. Beam deflection prevents the direct view of the crystal monochromator by the sample.

Photo: A neutron beam former (blue) including double reflection polarizers at the reflectometer SuperAdam (ILL, Grenoble)

# Double reflection polarizers

[V.G. Syromyatnikov, N.K. Pleshanov, V.M. Pusenkov, A.F. Schebetov, V.A. Ul'yanov, Ya.A. Kasman, S.I. Khakhalin, M.R. Kolkhidashvili, V.N. Slyusar, A.A. Sumbatyan, Preprint PNPI-2619 Gatchina (2005)47p]




The task: to polarize the beam without changing it direction.
Face-to-face design of double reflection polarizers solves the task.

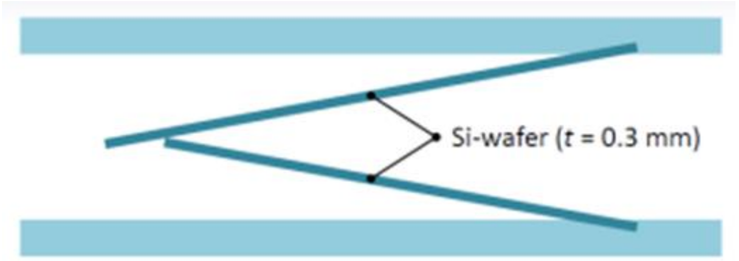
- **divergence, the same or reduced**
- **no beam deflection**

Double reflection polarizers form well-collimated monochromatic/white highly polarized beams. Moving the respective couple of (non-polarizing/polarizing) multilayers/ supermirrors into the initial beam, the user selects the beam incident onto the sample.

**Photo: A neutron beam former including double reflection polarizers at the reflectometer NR-4M (PNPI, Gatchina)**

# Neutron supermirror polarizers

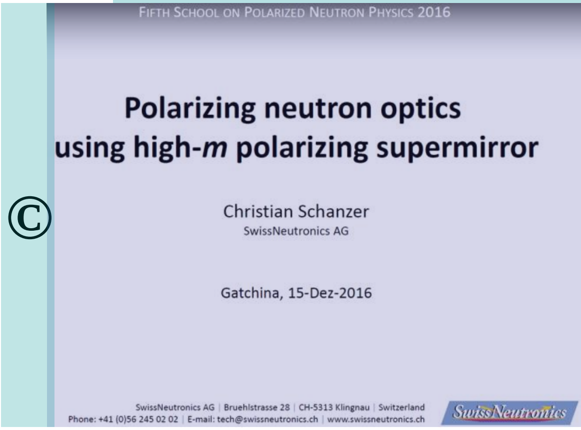
[N. Keller, Th. Krist, A. Danzig, U. Keiderling, F. Mezei, A. Wiedenmann, Nucl. Instr. Meth. A 451 (2000 ) 474]

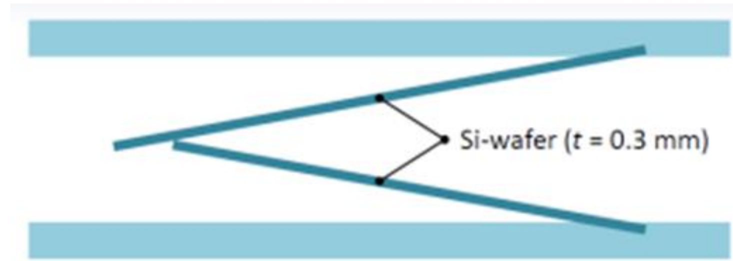


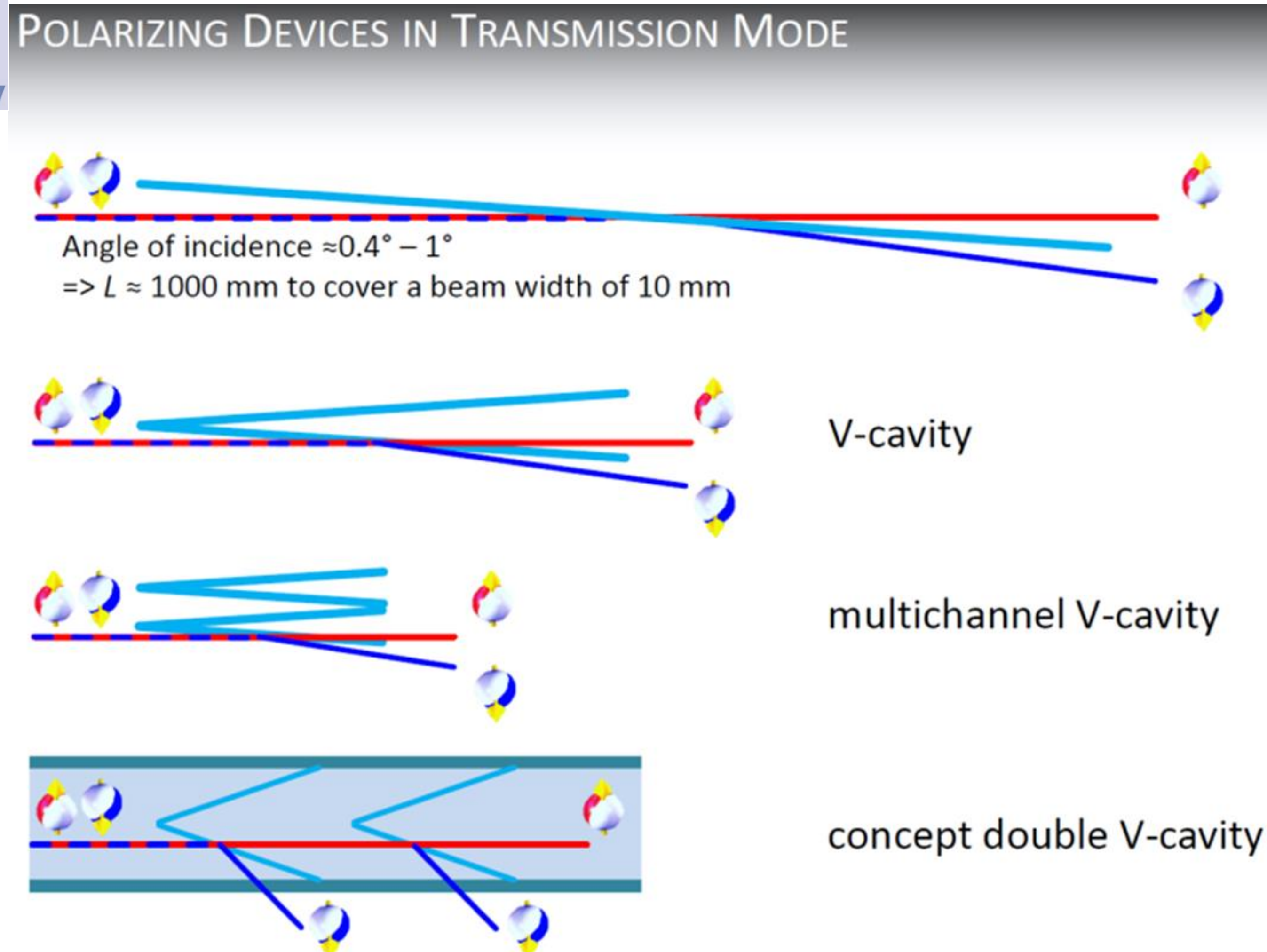

Polarizing V-cavity: Si wafers coated by polarizing SM on both sides are crossed so that only transmitted (mostly spin-down) neutrons reach the guide exit. The transmitted polarized beam is not deflected.

The task: to polarize the beam without changing it direction

# Neutron supermirror polarizers



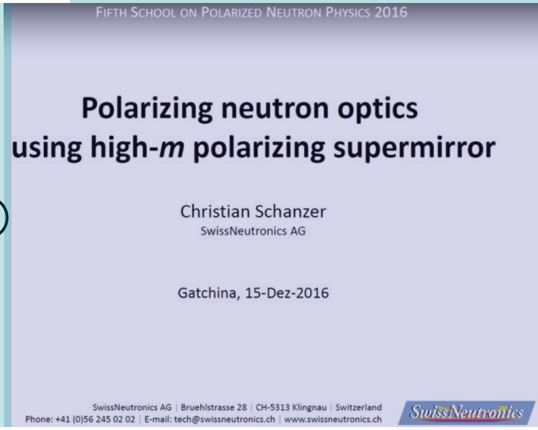




**The task: to polarize the beam without changing it direction**

**developments of the concept:**

# Neutron supermirror polarizers


Fifth School on Polarized Neutron Physics 2016

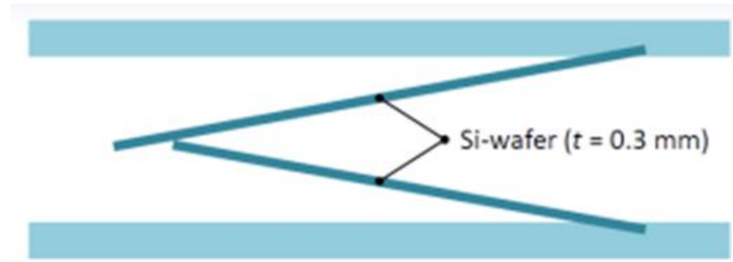
Polarizing neutron optics using high-*m* polarizing supermirror

Christian Schanzer
SwissNeutronics AG

Gatchina, 15-Dez-2016

SwissNeutronics AG | Bruehlstrasse 28 | CH-5313 Klingnau | Switzerland
Phone: +41 (0)56 245 02 02 | E-mail: tech@swissneutronics.ch | www.swissneutronics.ch
SwissNeutronics

©




**The task: to polarize the beam without changing its direction**

**developments of the concept:**

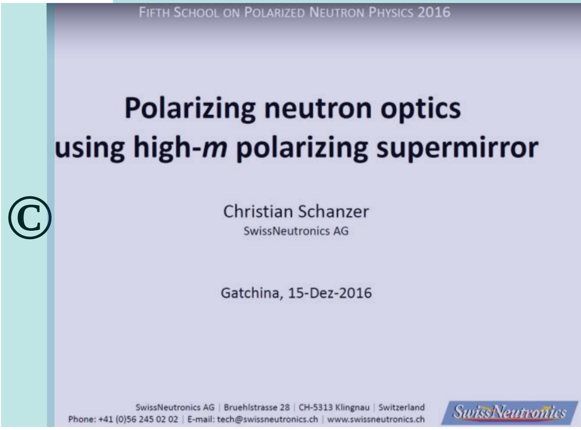
## Multi-Channel V-Cavities – Experimental Setup

<u>Features of multi-channel cavity (PONTA @ JRR-3m)</u>

- 11-channel double V-cavity
- width of channels: $w_{ch}$ = 6.45 mm
- thickness of separators: $t_{blade}$ = 0.3 mm
- thickness of Si-wafer: $t_{Si}$ = 0.3 mm
- polarizing Fe/Si supermirror: $m$ = 5.0
- taper angle of Vs: $\theta_V$ = ±0.6°
- length: $L$ = 500 mm

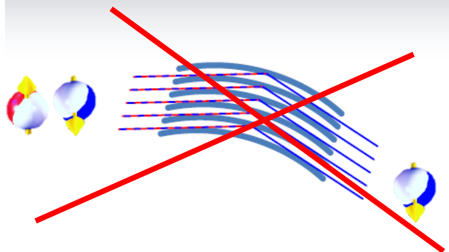

<u>NARZISS setup for neutron tests</u>

# Neutron supermirror polarizers




©

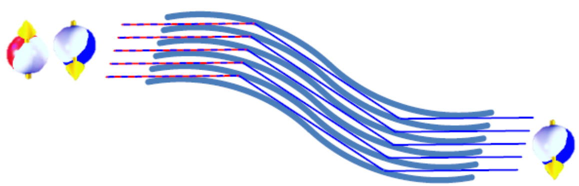
## POLARIZING BENDER (REFLECTION & TRANSMISSION)



Reflection bender

- neutrons of one spin state absorbed in substrate or dedicated absorbing coating
- increased divergence -> dilution of phase space
- deflection of beam

**The task: to polarize the initial beam without changing it direction**

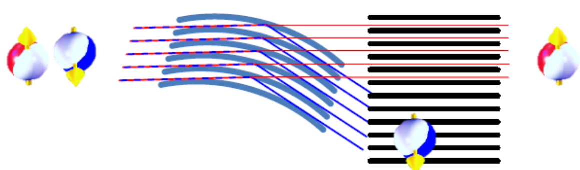


S-shaped bender

- neutrons of one spin state absorbed in substrate or dedicated absorbing coating
- increased divergence -> dilution of phase space
- no deflection of beam
- clear cut-off of wavelength

**Other solutions:**

[P. Böni, W. Münzer, A. Ostermann, Physica B 404 (2009 ) 2620]

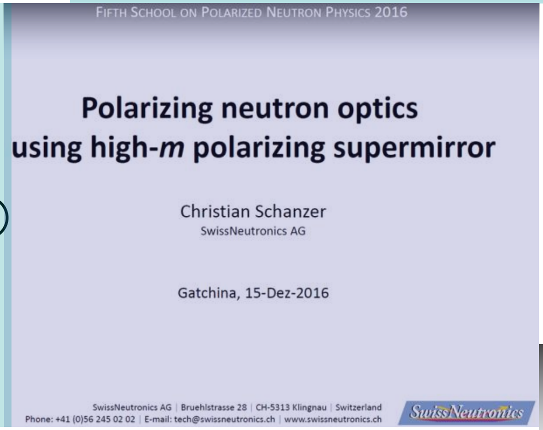


Transmission bender + collimator

- neutrons of one spin state absorbed in collimator
- uniform phase space
- no deflection of beam

# Neutron supermirror polarizers

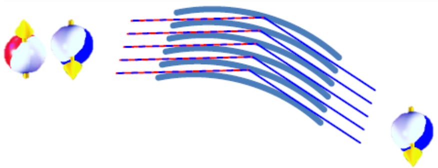
©




[V.G.Syromyatnikov,A.F.Schebetov,Z.N.Soroko, NIM A 324 (1993) 401.
Th. Krist, NIM A 529 (2004) 50.]

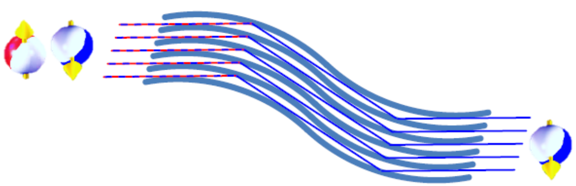
**Solid state benders: stacked Si wafers coated with polarizing SM serve as bent channels (compact polarizers)**

## Polarizing Bender (Reflection & Transmission)



Reflection bender

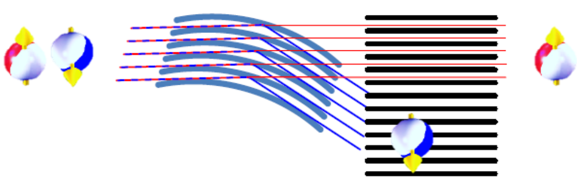
- neutrons of one spin state absorbed in substrate or dedicated absorbing coating
- increased divergence -> dilution of phase space
- deflection of beam



S-shaped bender

- neutrons of one spin state absorbed in substrate or dedicated absorbing coating
- increased divergence -> dilution of phase space
- no deflection of beam
- clear cut-off of wavelength

**Other solutions:** [P. Böni, W. Münzer, A. Ostermann, Physica B 404 (2009 ) 2620]



Transmission bender + collimator

- neutrons of one spin state absorbed in collimator
- uniform phase space
- no deflection of beam

# Neutron supermirror polarizers

[N.K. Pleshanov, Preprint PNPI-1883 (1993) 23 pp.]

**Solid state polarizing V-bender: two stacks of flat Si wafers, tilted to avoid the direct view**

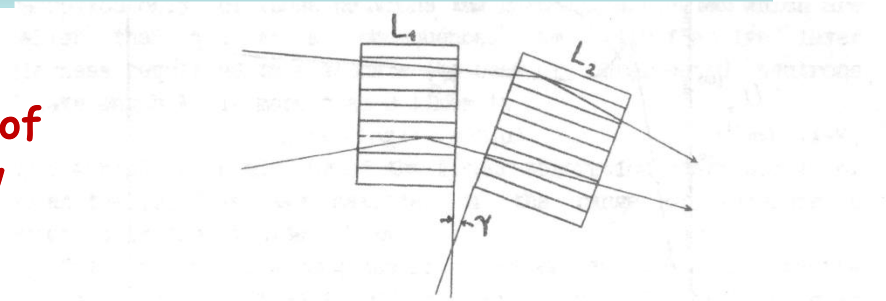
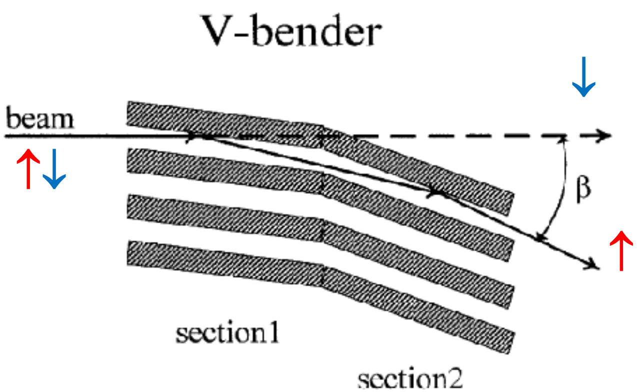
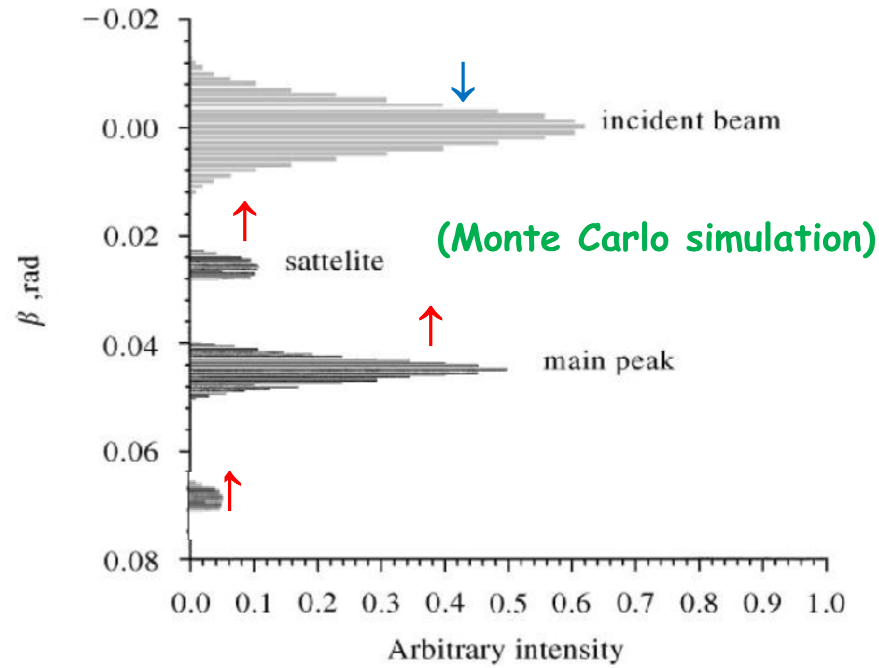



Fig.B-1. A V-bender built with two uncurved stacks of $Si$ wafers, tilted by an angle $\gamma$ to each other.

[A. Schebetov, A. Kovalev, B. Peskov, N. Pleshanov, V. Pusenkov, P. Schubert-Bischoff, G. Shmelev, Z.Soroko, V. Syromyatnikov, V. Ul'yanov, A.Zaitsev, Nucl. Instr. and Meth. A 432 (1999) 214]




**V-bender built as two stacks of flat supermirrors on glass substrates, tilted to avoid the direct view**




The beam is split into sub-beams: transmitted without deflection (↓), deflected by reflections (↑). Each beam spatially separates at a long distance or can be singled-out by a collimator.

# Neutron supermirror polarizers

[N.K. Pleshanov, Preprint PNPI-1883 (1993) 23 pp.]

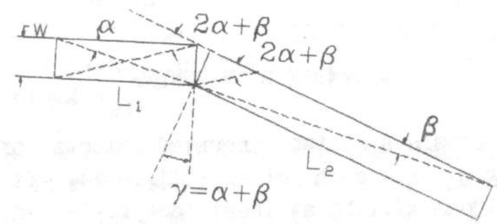



Fig.B-2. The geometry of a V-bender.

**solid state polarizing V-bender in reflection mode**

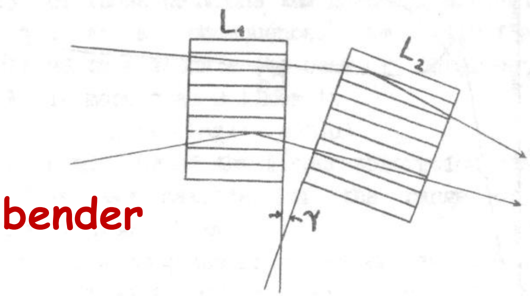
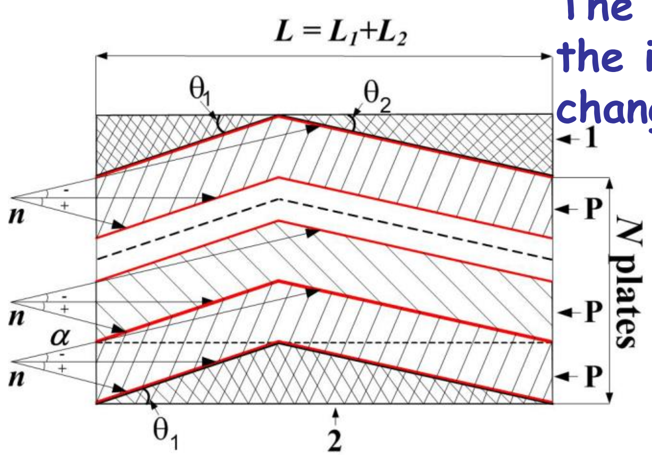


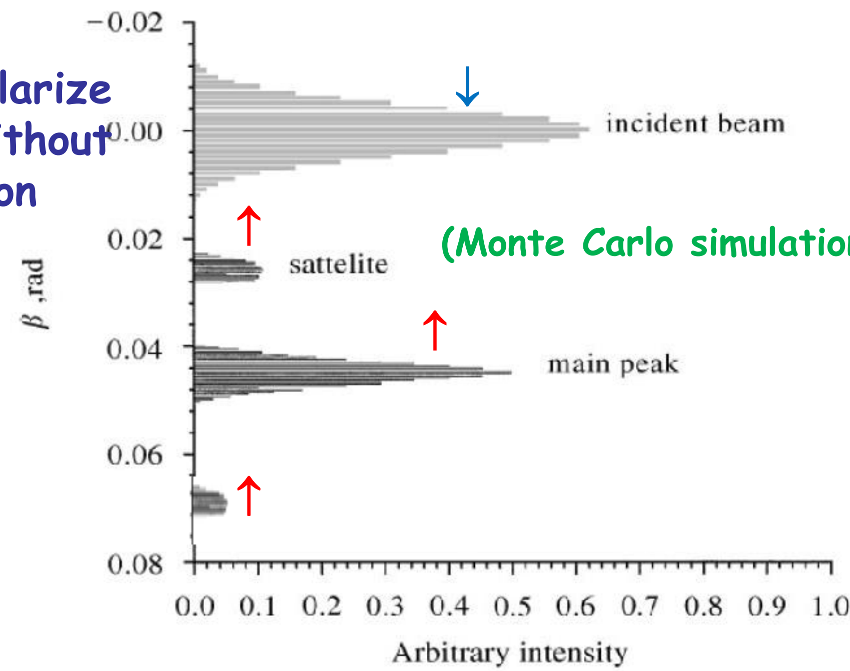

Fig.B-1. A V-bender built with two uncurved stacks of Si wafers, tilted by an angle γ to each other.

[V.G. Syromyatnikov, V.M. Pusenkov, J. Phys.: Conf. Ser. 862 (2017) 012028]

**The task: to polarize the initial beam without changing it direction**




**transmission *kink polarizer*: a stack of fractured Si wafers sandwiched between knee-shaped plates**




(Monte Carlo simulation)

! A long V-cavity can be replaced with a compact kink polarizer (now under experimental study).

# Neutron supermirror polarizers

[N.K. Pleshanov, Preprint PNPI-1883 (1993) 23 pp.]

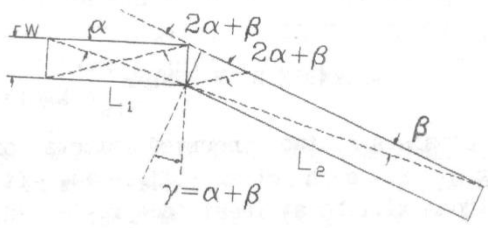



Fig.B-2. The geometry of a V-bender.

solid state polarizing V-bender
in reflection mode

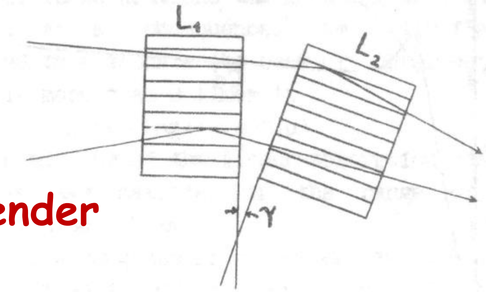
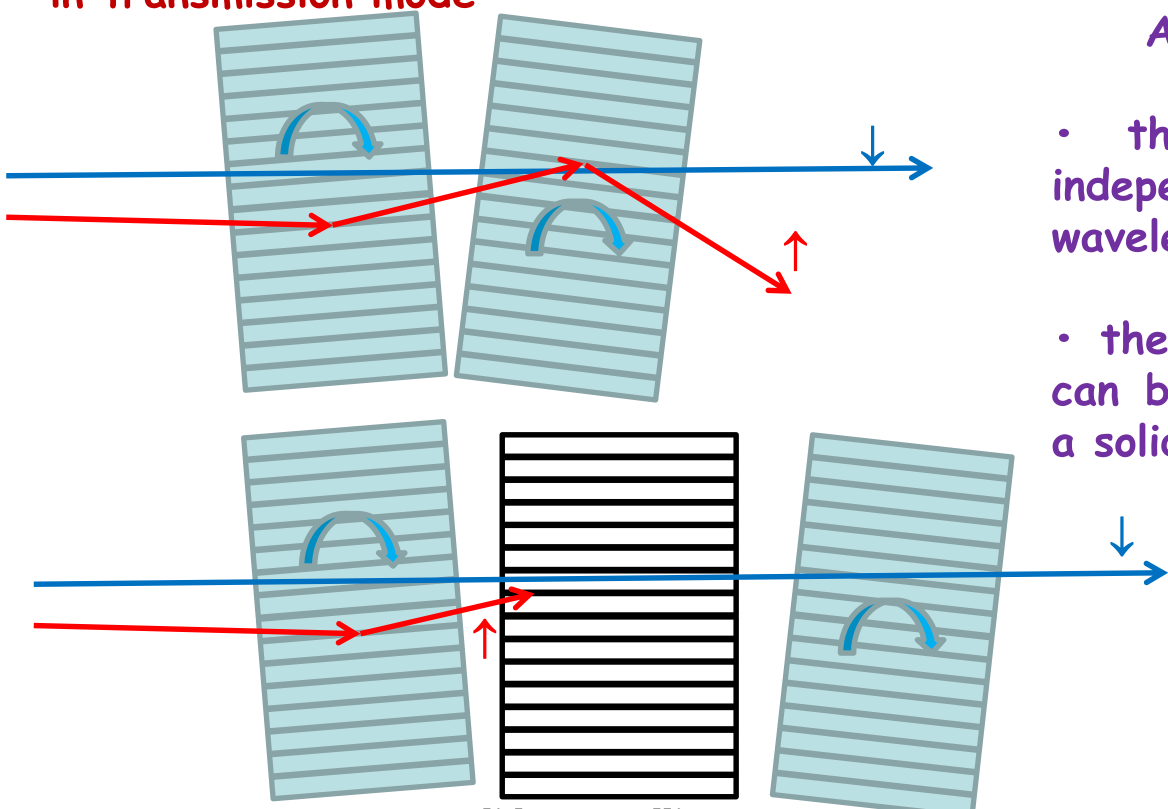



Fig.B-1. A V-bender built with two uncurved stacks of Si wafers, tilted by an angle γ to each other.

solid state polarizing V-bender
in transmission mode

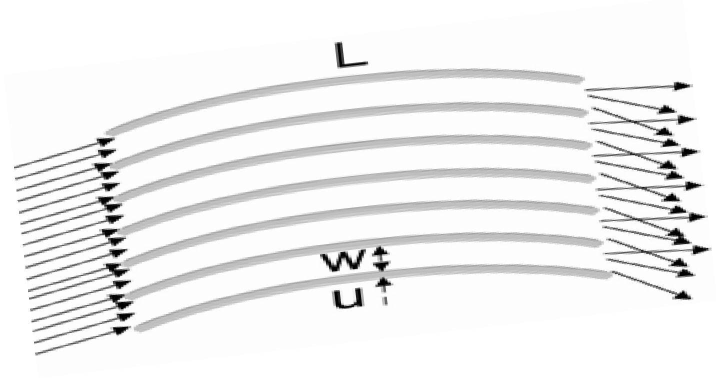


solid state collimator

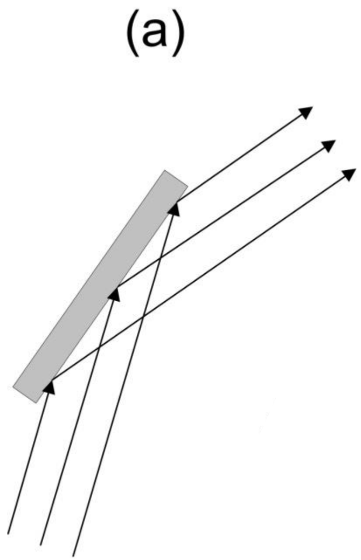
Advantages:

- the stacks can be rotated independently (optimal alignment, wavelength band selection, etc.)
- the distance between the stacks can be changed, e.g. to introduce a solid state collimator, etc.

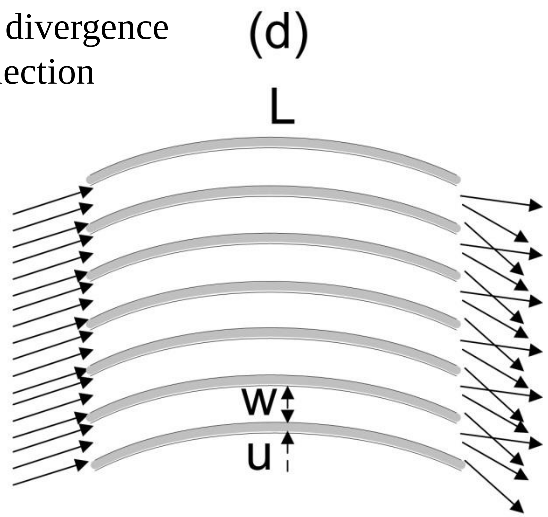
# Neutron supermirror analyzers



# Neutron supermirror analyzers




- increased divergence
- beam deflection




Classical designs of analyzers:
(a) Flat mirror
(b)
(c)
(d) Bender (bent multichannel guide)

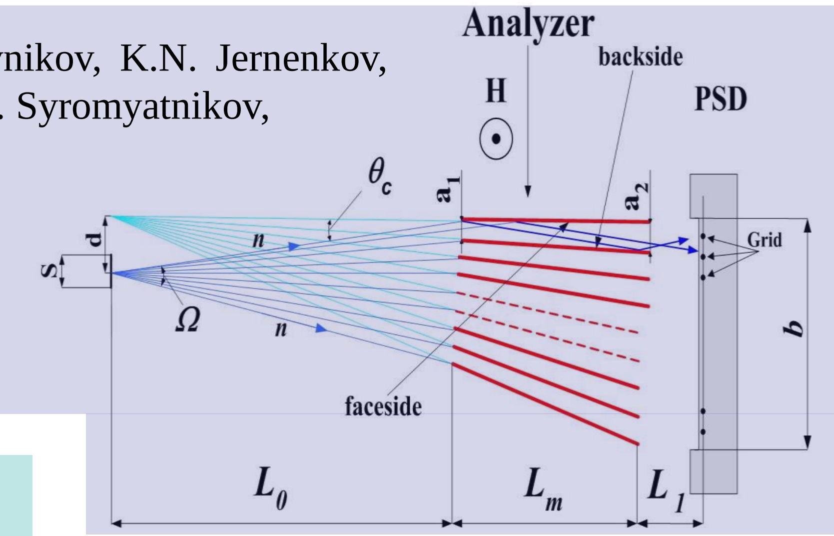
In principle, any polarizer can be used as an analyzer.

Now, with the advent of PSD with large area windows the designs of polarizers and analyzers became quite different.

# Fan analyzers

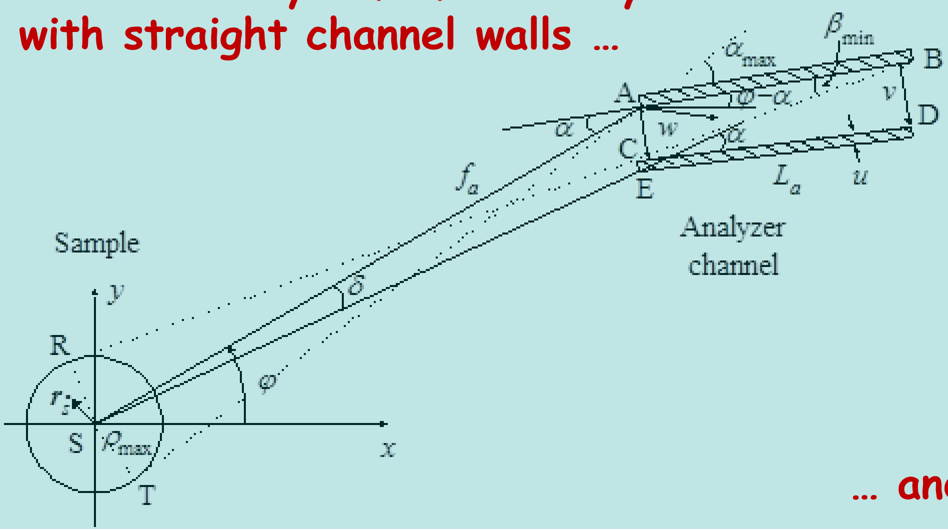
[Yu.V. Nikitenko, V.A. Ul'yanov, V.M. Pusenkov, S.V. Kozhevnikov, K.N. Jernenkov, N.K. Pleshanov, B.G. Peskov, A.V. Petrenko, V.V. Proglyado, V.G. Syromyatnikov, A.F. Schebetov, NIM A 564 (2006) 395]

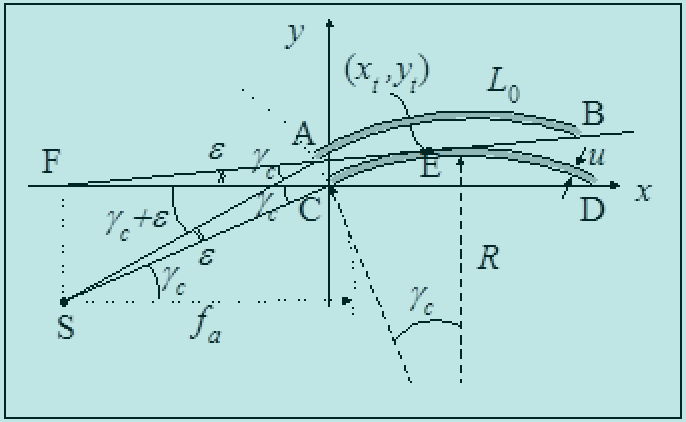
**The 1st fan analyzer with straight channels, designed&built in PNPI (Gatchina) and tested in JINR (Dubna) To avoid the direct view, the focus is shifted from the sample.**




[N.K. Pleshanov, A.F. Schebetov, NIM A 634 (2011) S126]

**exact theory of fan analyzers with straight channel walls …**



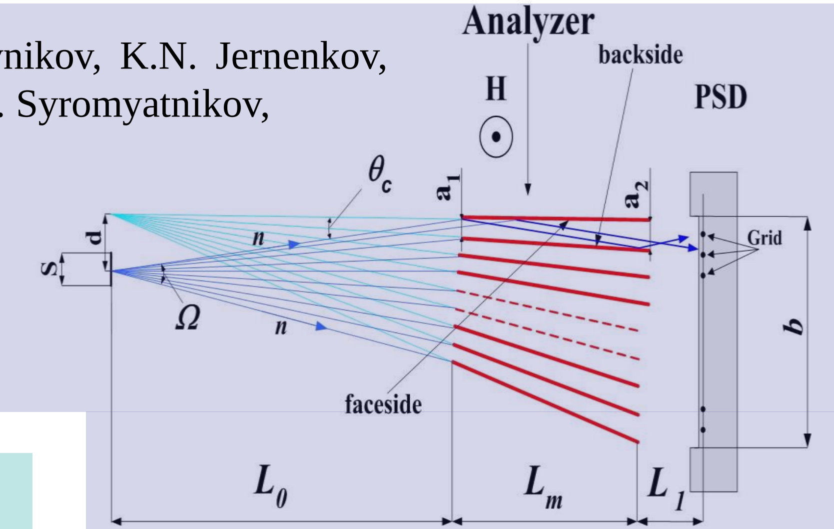

**… and curved channel walls**

***Fan analyzer*: a set of polarizing supermirrors aligned radially to form tapered channels with equivalent transmission for neutrons scattered by the sample in a wide range of angles, its geometry forbidding transmission of neutrons without being reflected at least once from a channel wall.**

# Fan analyzers

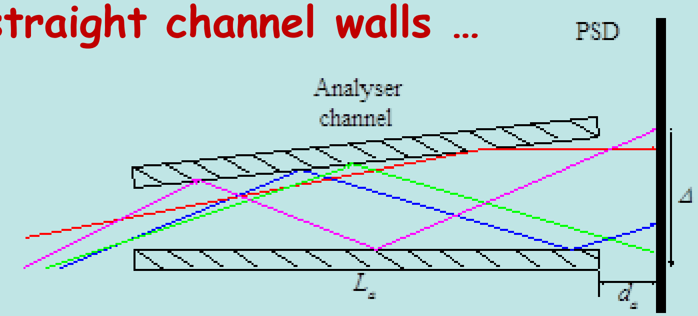
[Yu.V. Nikitenko, V.A. Ul'yanov, V.M. Pusenkov, S.V. Kozhevnikov, K.N. Jernenkov, N.K. Pleshanov, B.G. Peskov, A.V. Petrenko, V.V. Proglyado, V.G. Syromyatnikov, A.F. Schebetov, NIM A 564 (2006) 395]

1st fan analyzer with straight channels, designed&built in PNPI (Gatchina) and tested in JINR (Dubna) To avoid the direct view, the focus is shifted from the sample.




[N.K. Pleshanov, A.F. Schebetov, NIM A 634 (2011) S126]

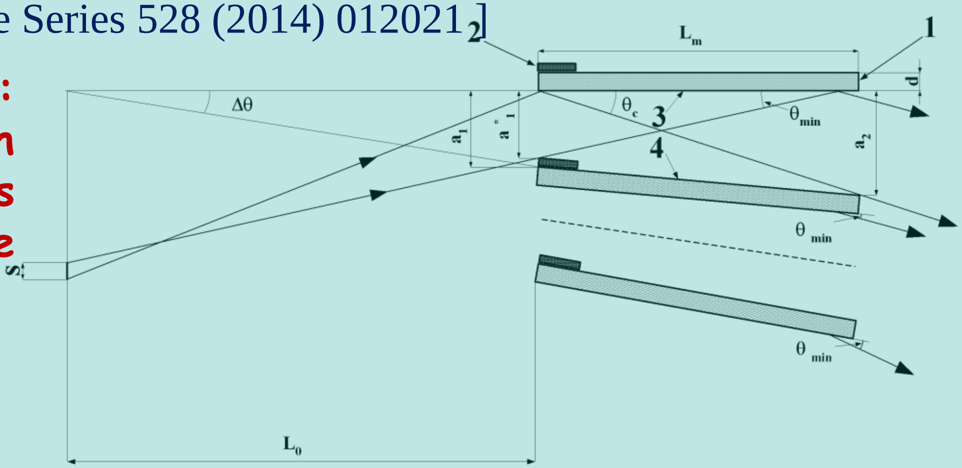
exact theory of fan analyzers with straight channel walls …



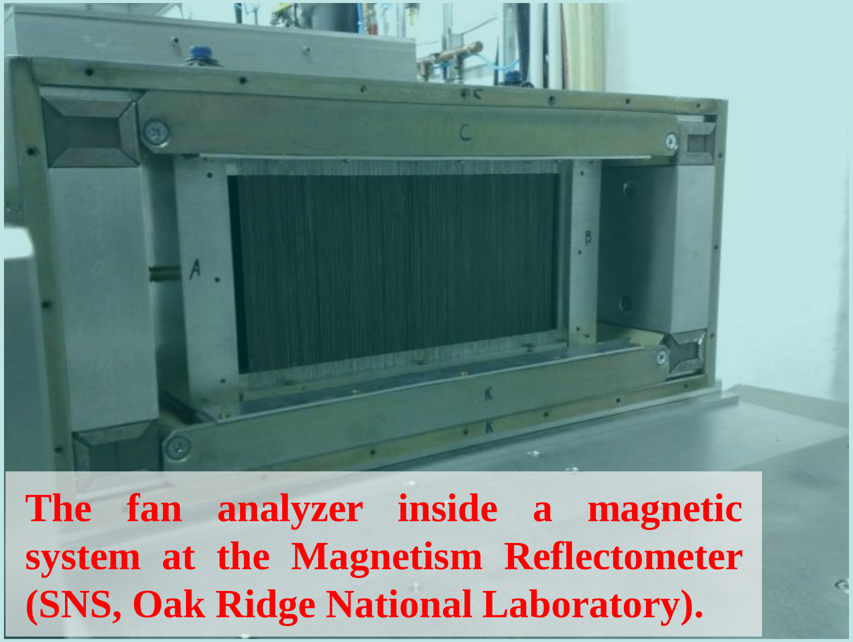

It was pointed out that reflection from the opposite walls may impair the intrinsic angular resolution defined by the spatial resolution of PSD.

# Fan analyzers

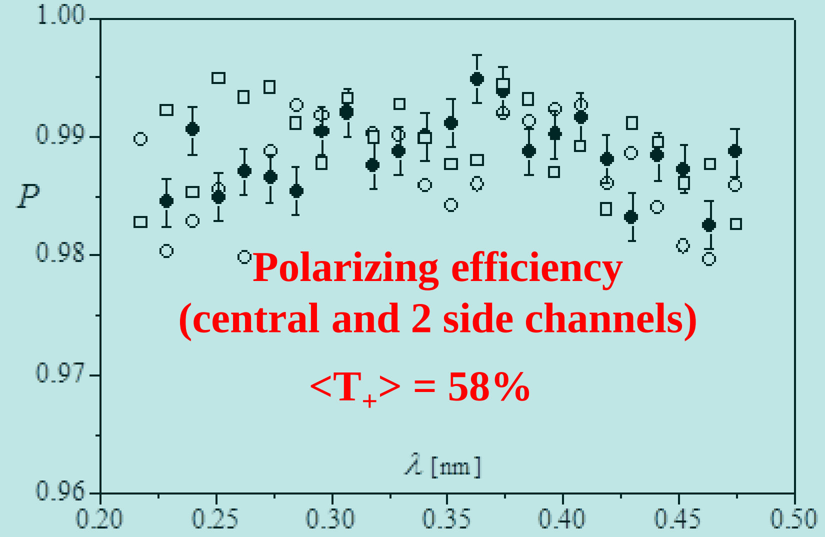
[V.G. Syromyatnikov, et al, J. Physics: Conference Series 528 (2014) 012021]




**An improved design of the fan analyzer: absorbing stripes on the edge of each channel preclude reflection of neutrons from one of the channel walls and the angular resolution is not impaired.**



**The fan analyzer inside a magnetic system at the Magnetism Reflectometer (SNS, Oak Ridge National Laboratory).**




**Polarizing efficiency (central and 2 side channels)**

**$\langle T_+ \rangle = 58\%$**

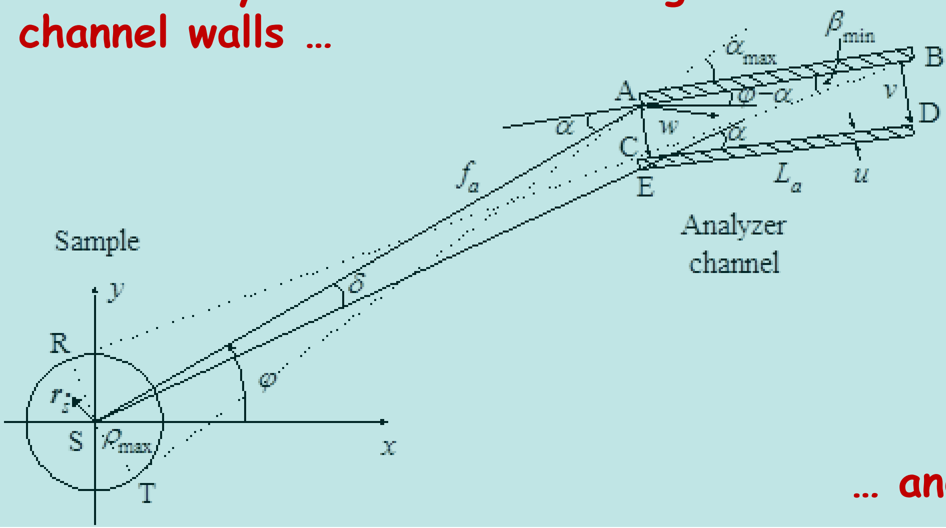
**High polarizing efficiency of the wide aperture analyzer achieved with**

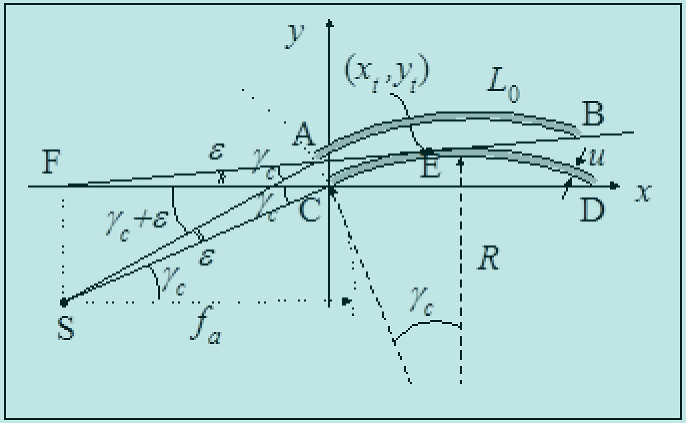
**- magnetic system of new design, the field verticality no worse than 5° (B=63 mT)**

[A.G. Gilev, N.K. Pleshanov, B.A. Bazarov, A.P. Bulkin, A.F. Schebetov, V.G. Syromyatnikov, V.V. Tarnavich, V.A. Ulyanov, NIM A 833 (2016) 233]

# Fan analyzers

fan analyzers with straight channel walls …




… and curved channel walls

When the critical angle of the polarizing SM noticeably exceeds the divergence of the sub-beam entering a channel, fan analyzers with straight channel walls are preferable.

Radial analyzers (fan analyzers with curved channels) always exclude the direct view and can be used, even when the distance to the sample is short and/or the sample is large.

# Radial analyzers

FIFTH SCHOOL ON POLARIZED NEUTRON PHYSICS 2016

## Polarizing neutron optics using high-*m* polarizing supermirror

Christian Schanzer
SwissNeutronics AG

Gatchina, 15-Dez-2016

SwissNeutronics AG | Bruehlstrasse 28 | CH-5313 Klingnau | Switzerland
Phone: +41 (0)56 245 02 02 | E-mail: tech@swissneutronics.ch | www.swissneutronics.ch

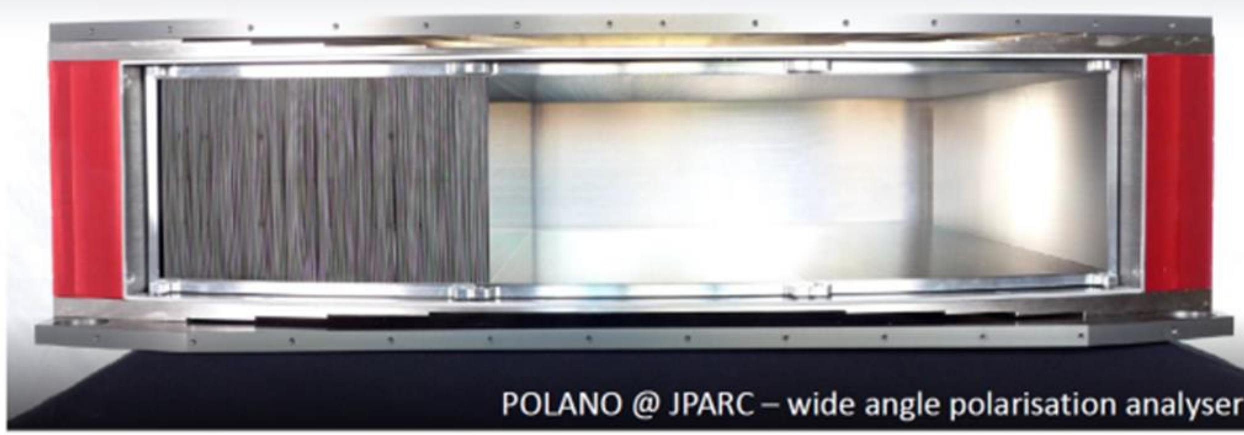


### Radial bender design

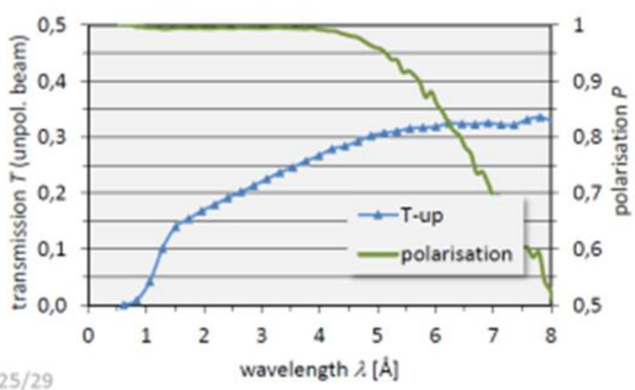
| | |
|---|---|
| Distance sample to entrance $R_{entr}$: | 850 mm |
| Distance sample to exit $R_{exit}$: | 1108 mm |
| Radius to curvature $R_{blade}$: | 8927 mm |
| Thickness of blade $t_{blade}$: | 0.3 mm |
| Channel width @ entrance $w_{entr}$: | 0.600 mm |
| Channel width @ exit $w_{exit}$: | 0.886 mm |
| Channel height @ entrance $h_{entr}$: | 120 mm |
| Channel height @ exit $h_{exit}$: | 163 mm |
| Length $L$: | 270 mm |
| Coating @ concave side: | Fe/Si, $m$ = 5.5 |
| Measured reflectivity @ $m$ = 5.5: | $R_{ave}$ = 0.70 |
| Coating @ convex side: | Fe/Si, $m$ = 1.5 |
| Measured reflectivity @ $m$ = 1.5: | $R_{ave}$ = 0.98 |
| Number of channels: | 660 |
| Angular coverage: | 40° |
| Critical wavelength $\lambda$*: | 1.8 Å (25 meV) |

### WIDE ANGLE POLARIZATION ANALYZER (WAPA)

SwissNeutronics

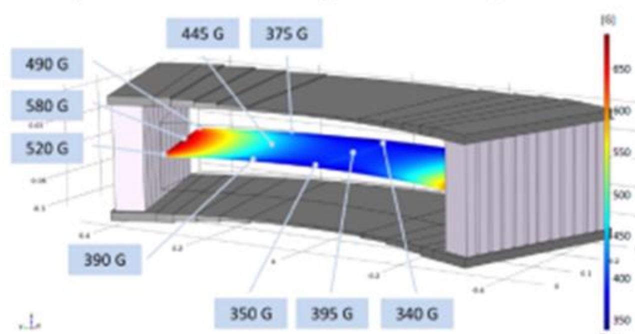



**McStas simulations**

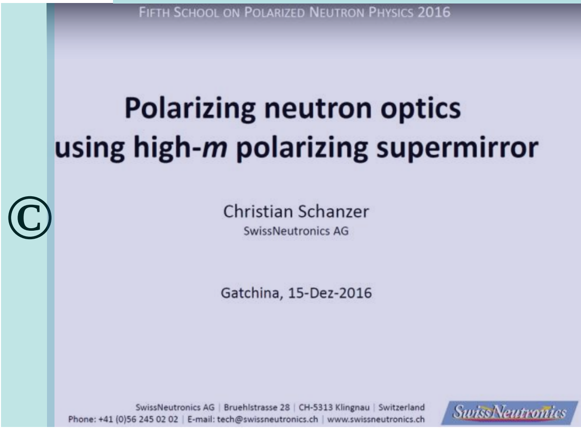



**Magnetic field calculation:**

- optimization of magnetic casing



# Radial analyzers



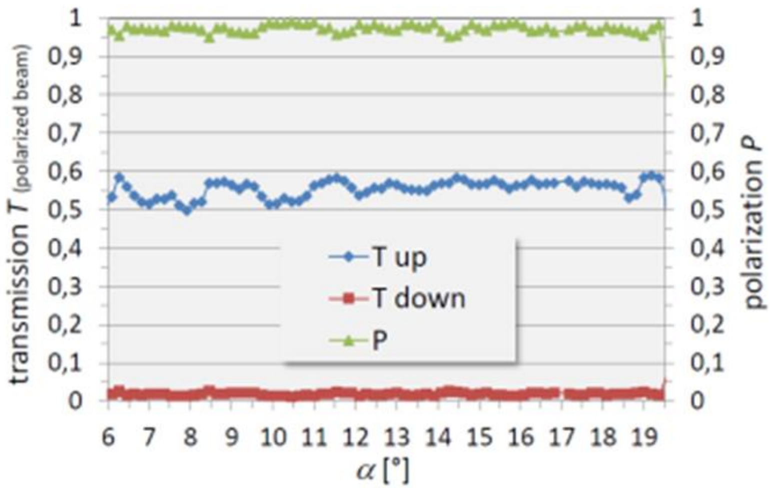

©

## Wide Angle Polarization Analyzer (WAPA)

SwissNeutronics


Neutron tests

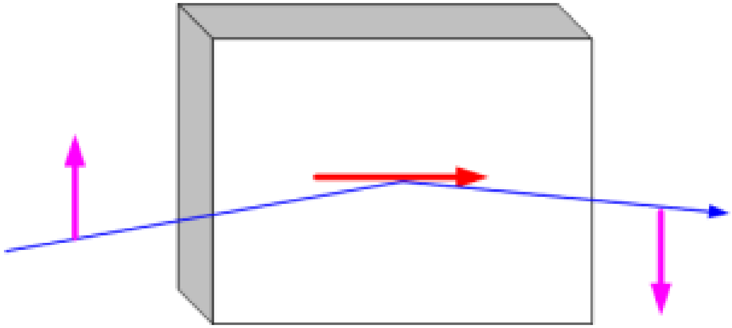
- instrument BOA @ PSI
- @ wavelength $\lambda$ = 3 Å




Performance

- Average transmission (polarized beam): $\langle T_{up} \rangle = 0.55$
- Average polarization: $\langle P \rangle = 97.5\%$

# Neutron spin optics



# Neutron spin optics

**Neutron spin optics (NSO) based on quantum aspects of the neutron interaction with magnetically anisotropic layers signifies expansion from 1D (spin selection) to 3D (spin manipulation) in polarized neutron optics.**

**Solutions that provide a high reflectivity (R ~ 1) and a weak dependence of the spin rotation angles on the neutron wavelength and on the glancing angle were suggested. They open new possibilities for spin manipulations. Neutron spin-turning reflectors (particularly, $\pi$/2-turners and $\pi$-turners) may be either directly used or combined to build compact devices: 3D-polarizers, 3D-analyzers, 3D-rotators (spin manipulators), hyperpolarizers, (Larmor and quantum) spin precessors and antiprecessors.**

N.K. Pleshanov, J. Phys.: Conf. Ser. 528 (2014) 012023.
– Neutron spin manipulation optics: basic principles and possible applications.

N.K. Pleshanov, Nucl. Instrum. Methods A 853, 61 (2017).
– Neutron spin optics: Fundamentals and verification.

# Neutron spin optics: verification

$$\sigma_0 = \frac{I_{\text{off,off}} - I_{\text{off,on}}}{I_{\text{off,off}} + I_{\text{off,on}}}$$

$$\sigma_F = \frac{I_{\text{on,on}} - I_{\text{on,off}}}{I_{\text{on,on}} + I_{\text{on,off}}}$$

**Modified method of measuring the flipper efficiencies**

$$f_1 = \frac{1}{2}\left[1 + \frac{|\sigma_{\text{F}}|/\sigma_0}{1+(P_0P_A/\sigma_0 - 1)(|\sigma_{\text{F}}| + \sigma_0)/(1+\sigma_0)}\right]$$

$$f_2 = \frac{1+(P_0P_A)^{-1}}{1+\sigma_0^{-1}}$$

$$\sigma = \frac{J_{\text{off}} - J_{\text{on}}}{J_{\text{off}} + J_{\text{on}}}$$

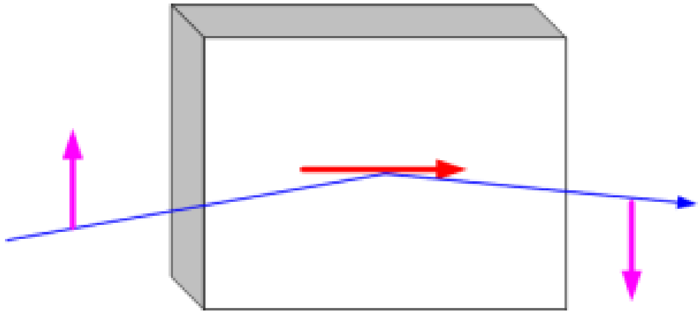
$$P_0P_A = [(1+\sigma^{-1})f_2 - 1]^{-1}$$

| H (mT) | Θ (mrad) | λ (nm) | $f_1$ | $f_2$ |
|---|---|---|---|---|
| 3 | 7.27 | 0.189 | 0.975 ± 0.005 | 0.995 ± 0.005 |

**the efficiency of the 1st mirror spin flipper** $f_1 = 0.975 \pm 0.005$

**Verification of NSO**

- ✓ The 1st element of NSO, a neutron mirror spin flipper, was tested.
- ✓ A method for measuring the efficiency of neutron mirror spin flippers was developed; the efficiency of the 1st mirror flipper was found to be 97.5±0.5%; it can be noticeably improved.



# Neutron spin optics: advantages

## Advantages of NSO

- ✓ **compactness** (miniaturization unlimited)**,**
- ✓ **zero-field option** (no external fields are required, guide fields are optional)**,**
- ✓ **multi-functionality** (handling beam spectrum, beam divergence and spin manipulations at the same time),
- ✓ **new possibilities**, one of which is the beam hyperpolarization, when the separation of neutrons with the opposite spins is followed by the flipping of the ‘wrong’ spins with mirror flippers (the polarized neutron flux gain up to 2 times/at the expense of increased divergence or beam width)**.**

## Conclusions

- ✓ polarizing neutron optics is envisaged as the basic technique for neutron polarization at the reactor PIK,
- ✓ influences of the transport neutron guide and other optical devices on polarizing neutron optics should be taken into account,
- ✓ developments in polarizing neutron optics should be studied by numerical simulations and in neutron experiments.

This contribution was supported by the Federal target program of Ministry of Education and Science of Russian Federation (project No. RFMEFI60717X0194).


Thanks for your attention!