Neutron Instrumentation Part 4: Advanced components

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What we will cover in Part 4

- An introduction to polarization devices
- Phase space transformers

Polarizing devices
An introduction

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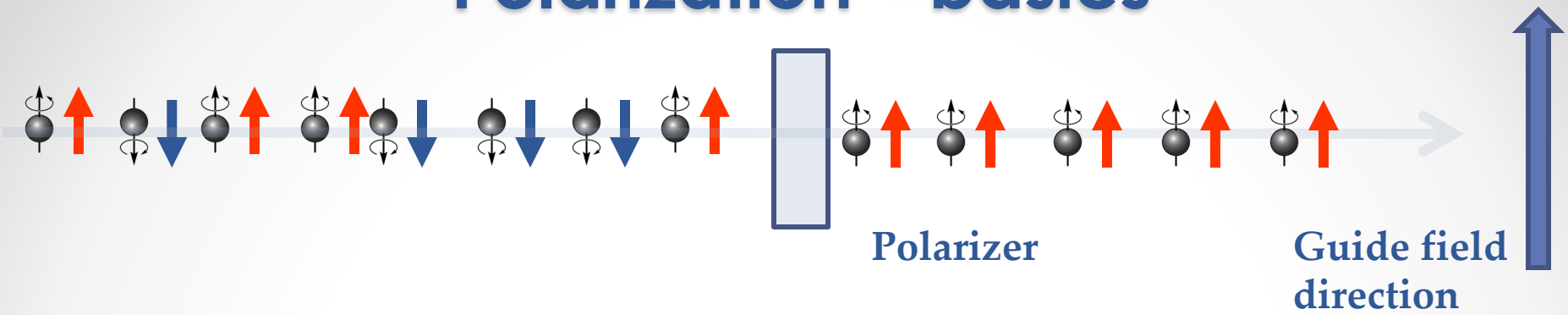
Polarization – basics



The main parameter to be considered when describing the effectiveness of a polarizer is the polarizing efficiency, P, defined as:

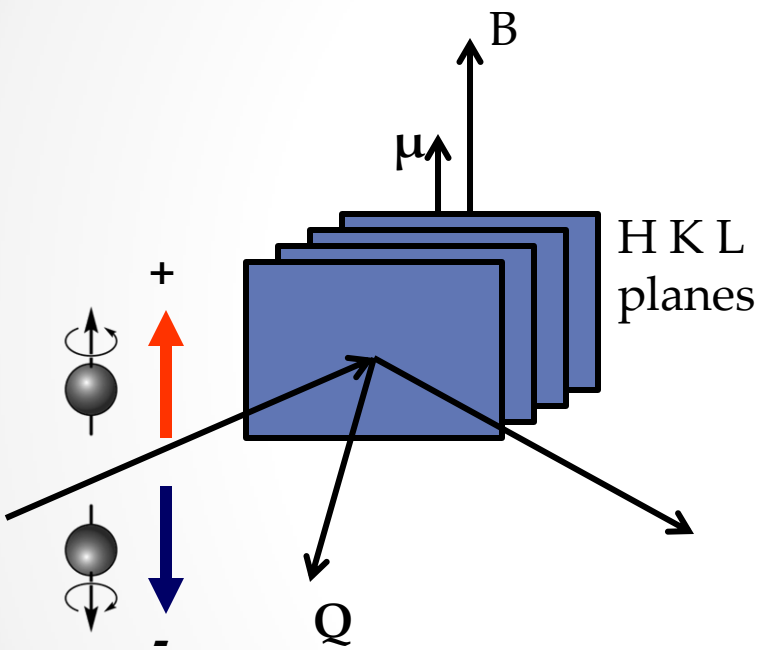
$$P = (N_+ - N_-)/ (N_+ + N_-)$$

$N_{+/-}$ number of neutrons with spin parallel (+), or antiparallel (-), to the **guide field** in the outgoing beam

The other parameter is the transmission of the wanted spin state. That depends on various factors such as acceptance angles, absorption, and reflection

Polarizing monochromators

Reflected intensity $I \sim d\sigma/d\Omega = F_N(\mathbf{Q})^2 + F_M(\mathbf{Q})^2 + 2F_N(\mathbf{Q}).\ F_M(\mathbf{Q}).(\mathbf{P}.\boldsymbol{\mu})$



$(\mathbf{P}.\boldsymbol{\mu}) = 1$

Intensity $\sim (F_N + F_M)^2$

$(\mathbf{P}.\boldsymbol{\mu}) = -1$

Intensity $\sim (F_N - F_M)^2$

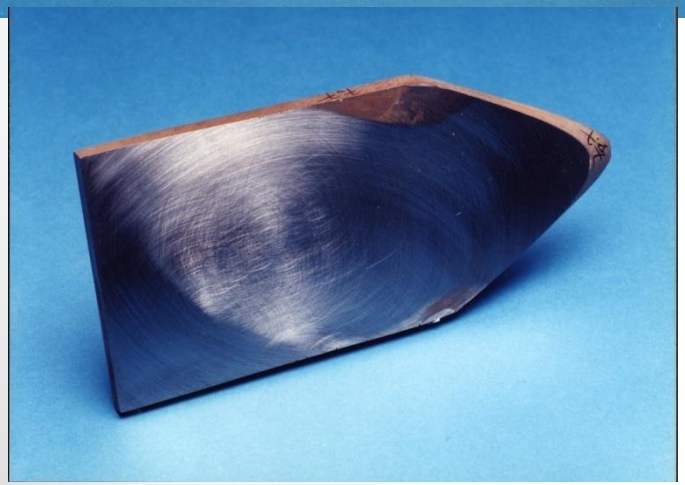
Polarization $= (I_+ - I_-)/(I_+ + I_-) = \pm\, 2F_N(\mathbf{Q}).\ F_M(\mathbf{Q})/[F_N(\mathbf{Q}) - F_M(\mathbf{Q})]^2$

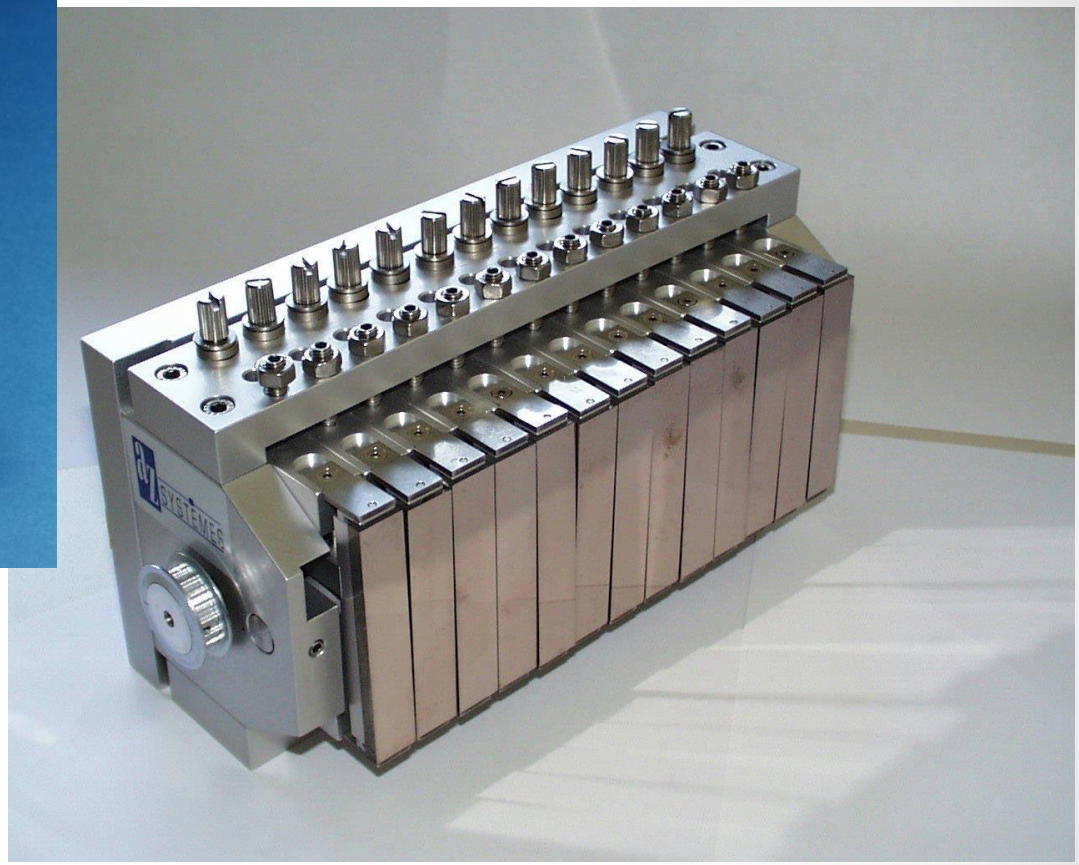
Properties of polarizing crystal monochromators

Heusler alloy

	$Co_{0.92}Fe_{0.08}$	Cu_2MnAl	Fe_3Si	^{57}Fe:Fe	$HoFe_2$
Matched reflection $\lvert F_N \rvert \sim \lvert F_M \rvert$	(200)	(111)	(111)	(110)	(620)
d-spacing (Å)	1.76	3.43	3.27	2.03	1.16
Take-off angle $2\theta_B$ at 1 Å (deg)	33.1	16.7	17.6	28.6	50.9
Cut-off wavelength, λ_{max} (Å)	3.5	6.9	6.5	4.1	2.3

Heusler production at ILL (Pierre Courtois)



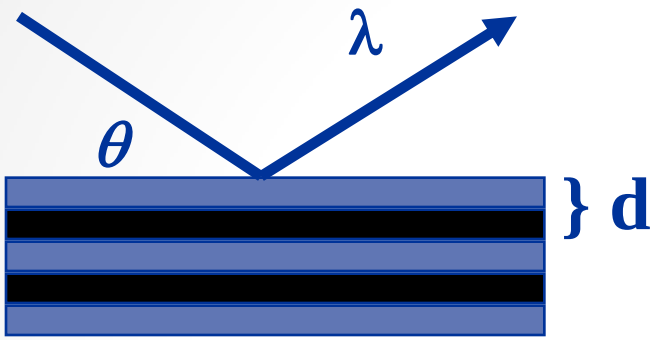


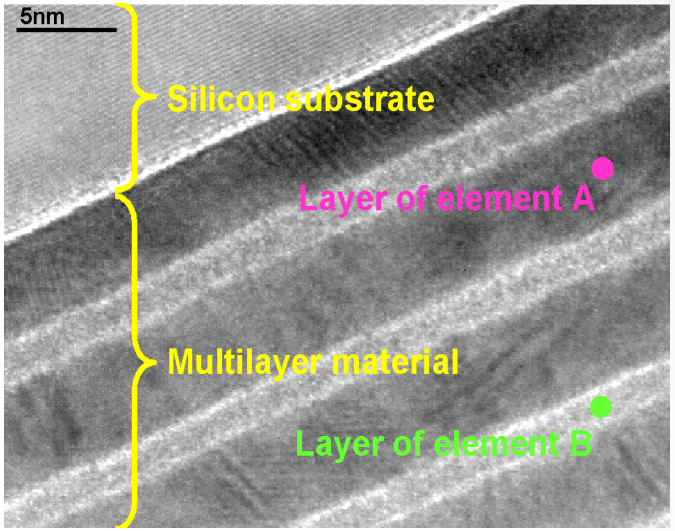
IN20 Analyser (ILL)

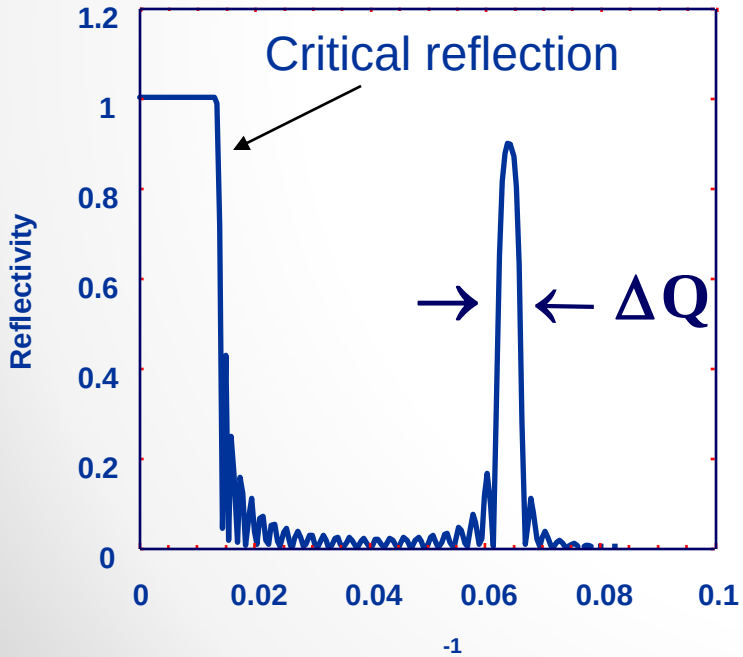
Typical neutron properties of Heusler Crystals produced at I.L.L.

Dimensions (max)	100 x 20 x 5 mm^3
Neutron mosaic	$0.2^0 < FWHM < 0.6^0$
Peak Reflectivity (unmagnetized state)	$R = 90 – 100\% \ R_{theoretical}$ (Bacon and Lowde) ($R \approx 30\%$ at $\lambda = 1.8$ Å; $FWHM = 0.35^0$)
Polarization	$P > 90\%$ (20 < Flipping Ratio < 46)

Reflection from multilayers





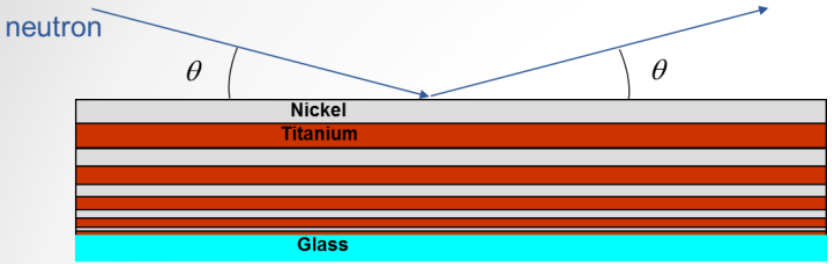


$$\theta \sim \lambda/2d$$

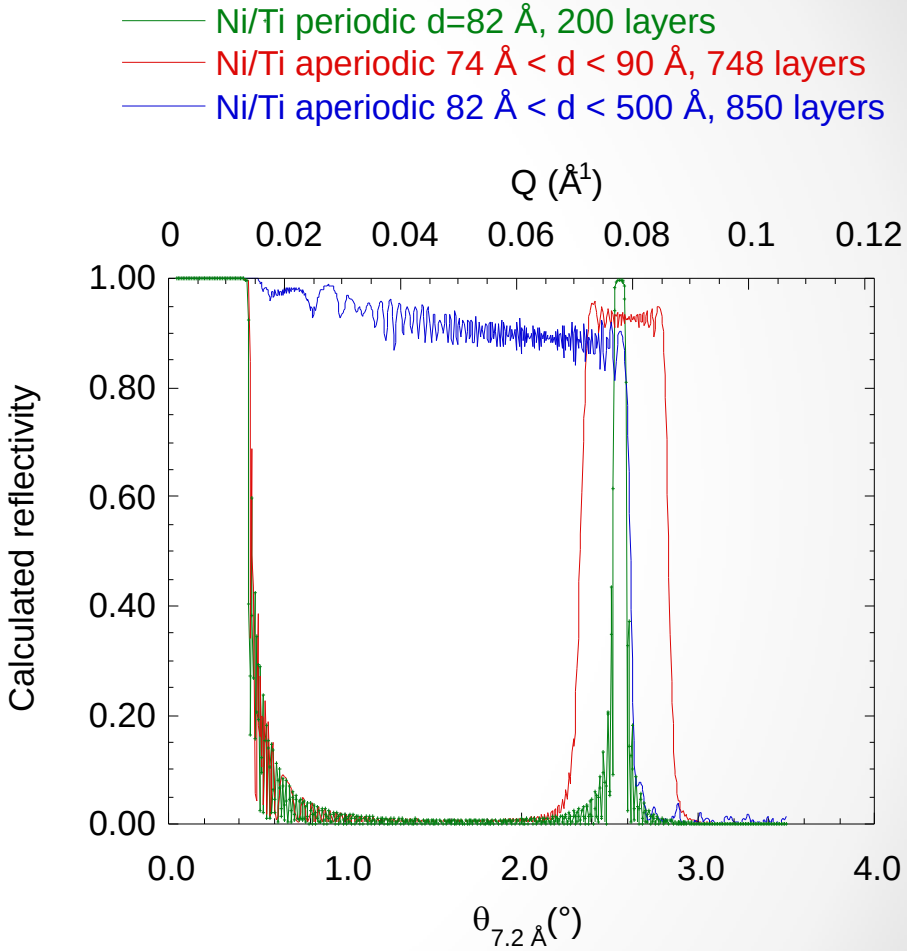
$$R = \frac{4N^2d^4(Nb_1 - Nb_2)^2}{\pi^2 n^4}$$

$$\frac{\Delta\lambda}{\lambda} = \frac{2d^2\,(Nb_1 - Nb_2)}{\pi}$$

An introduction to supermirrors



Material	Nb ($x10^{-38}$ m^{-2})
^{58}Ni	13.31
Diamond	11.71
Ni	9.41
Quartz	3.64
Germanium	3.64
Silver	3.50
Aluminium	2.08
Silicon	2.08
Vanadium	-0.27
Titanium	-1.95
Manganese	-2.95



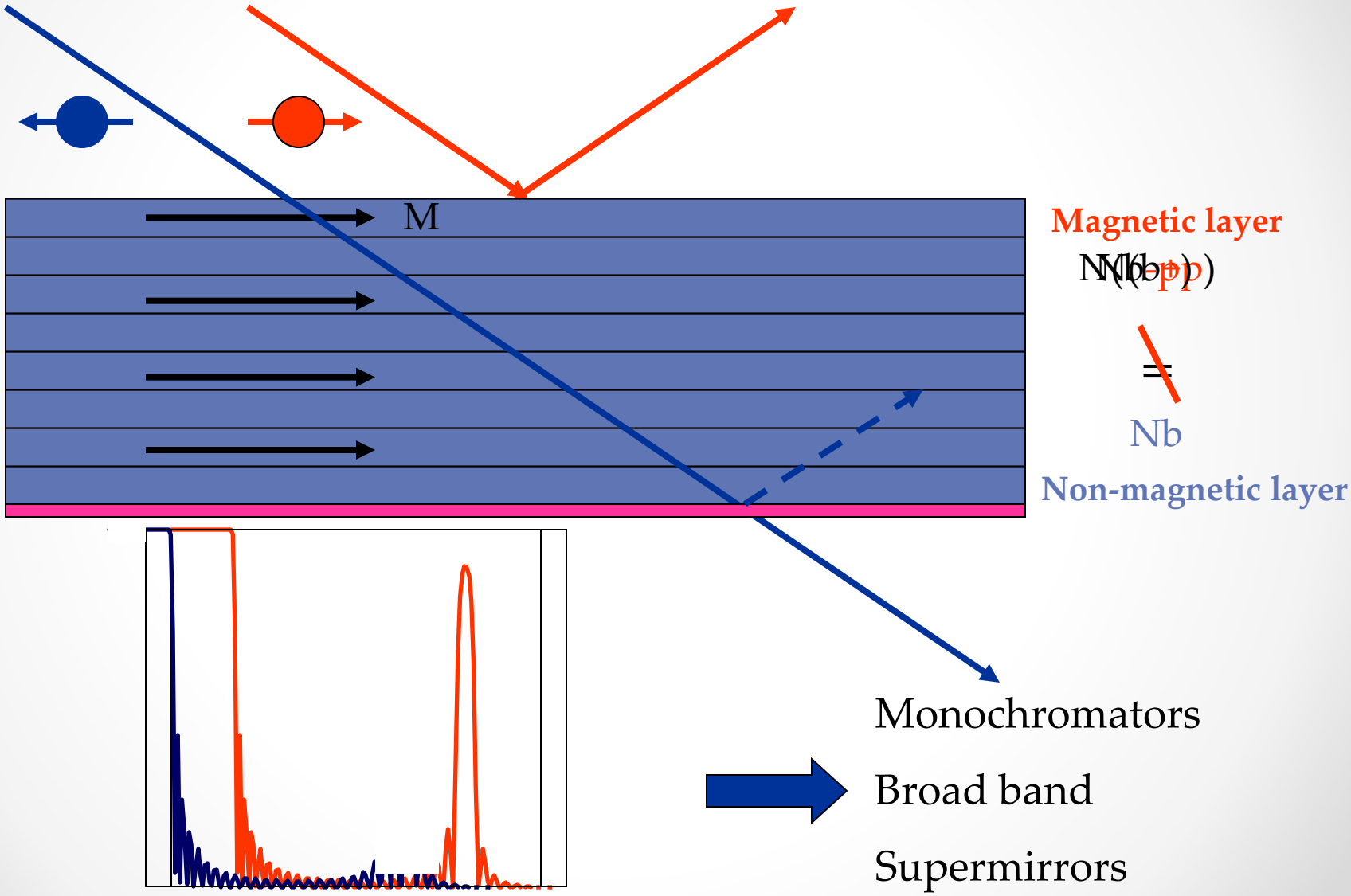
Polarizing mirrors

$$R = \frac{4N^2 d^4 (Nb_1 - Nb_2)^2}{\pi^2 n^4}$$

$$b_{total} = b \pm p = b \pm \frac{\mu_n}{h^2 N}(B - H)_s 2m_n \pi$$

$$n_{\pm}^2 = 1 - \lambda^2 N(b_{coh} \pm p)/\pi,$$

How does a polarizing mirror work?



Monochromators

Broad band

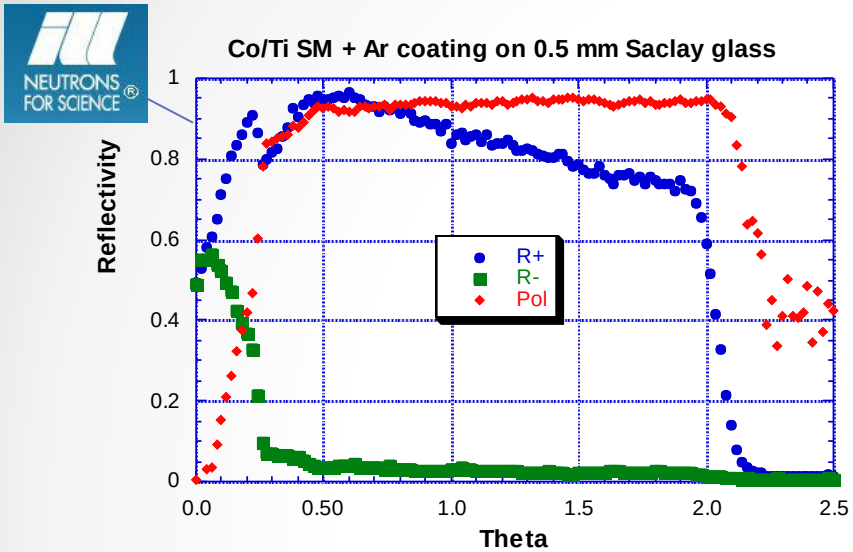
Supermirrors

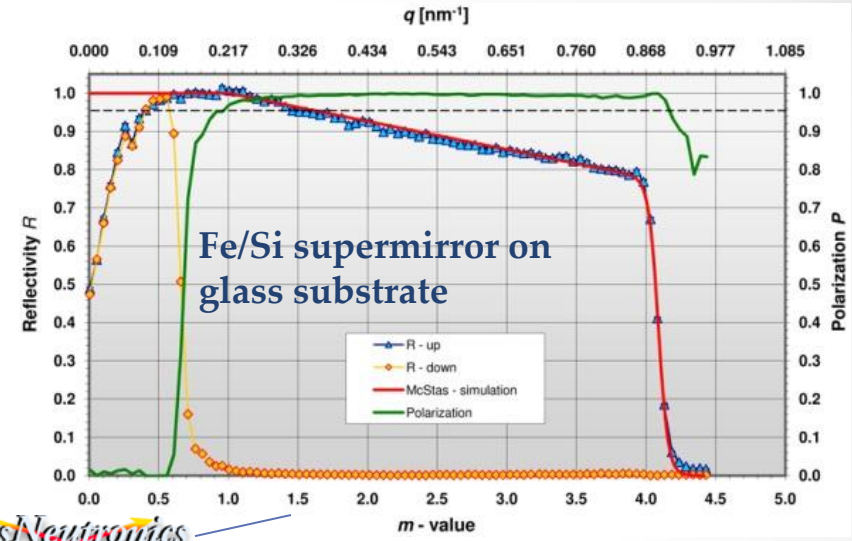
Scattering length densities for some typical materials used

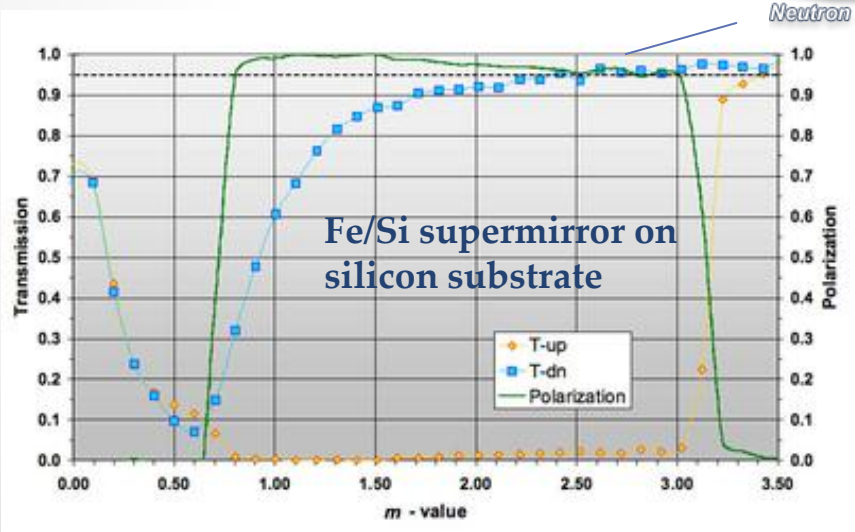
Magnetic layer	N(b+p) (10^{-6} Å^{-2})	N(b-p) (10^{-6} Å^{-2})	Non-magnetic layer	Nb (10^{-6} Å^{-2})
			Ge	3.64
			Ag	3.50
Fe	13.04	3.08	W	3.02
			Si	2.08
			Al	2.08
Fe:Co (50:50)	10.98	-0.52	V	-0.27
			Ti	-1.95
Ni	10.86	7.94		
Fe:Co:V (49:49:2)	10.75	-0.63	V	-0.27
			Ti	-1.95
Fe:Co:V (50:48:2)	10.66	-0.64	V	-0.27
			Ti	-1.95
Fe:Ni (50:50)	10.53	6.65		
Co	6.55	-2.00	Ti	-1.95
Fe:Co:V (52:38:10)	6.27	2.12	Si	2.08
			Al	2.08

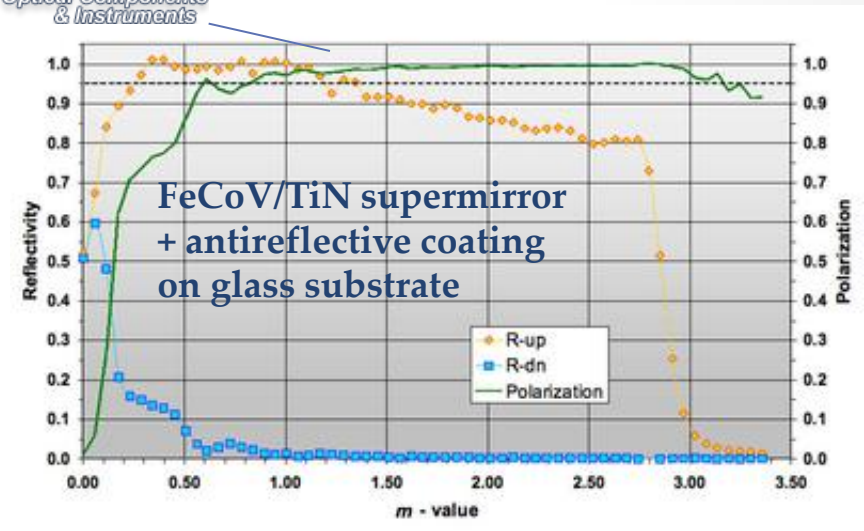
But:
Don't forget the substrate!

Some examples



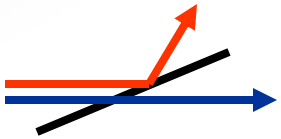




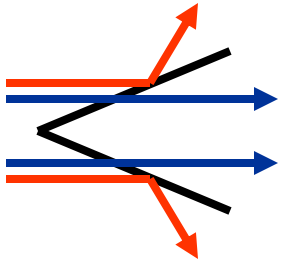


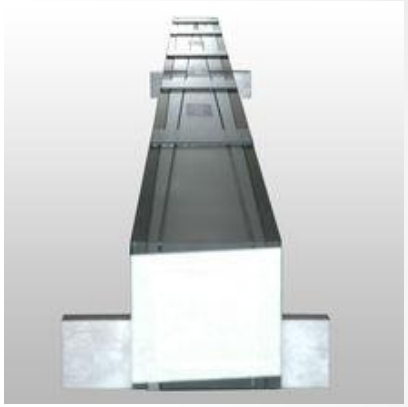
Polarizing Mirror Devices

- Simple mirror

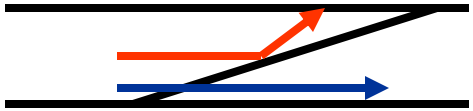


- V-shaped transmission polarizer

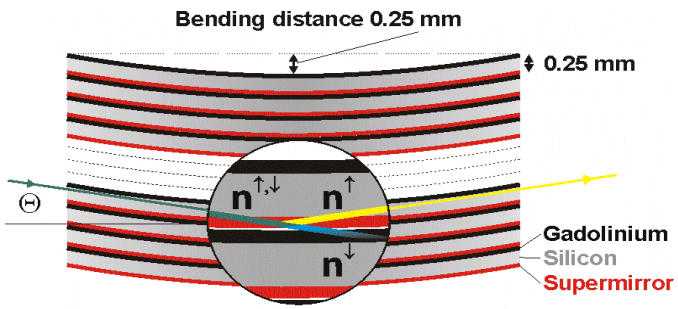


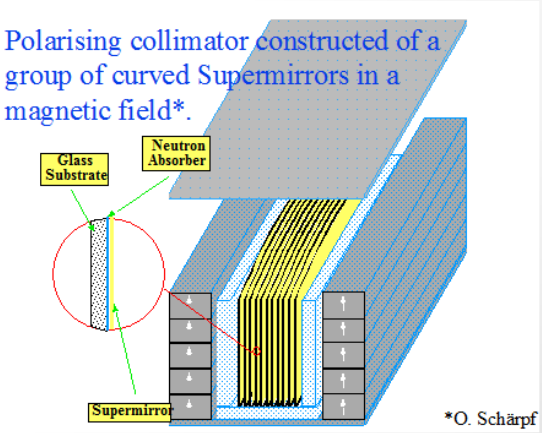


- Cavity (simple or v-shaped)



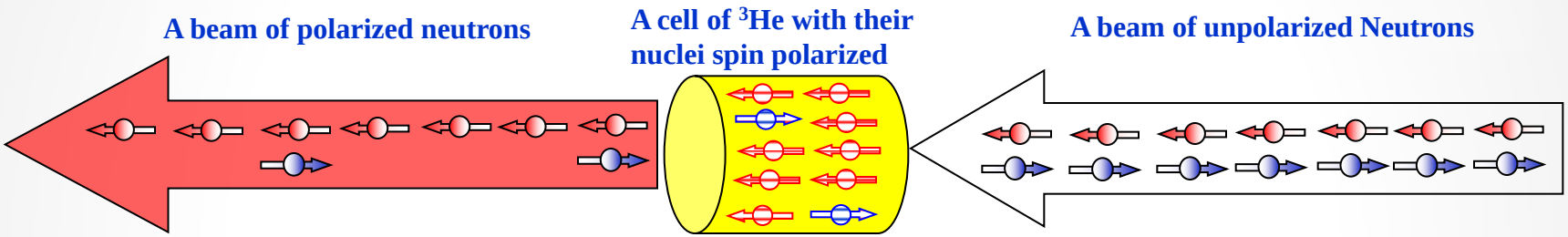
- Bender
  - Open channel
  - Solid state

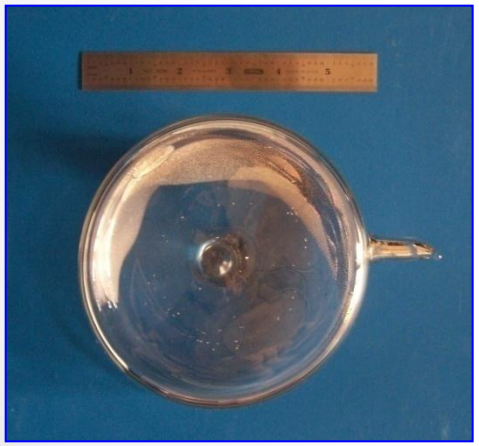




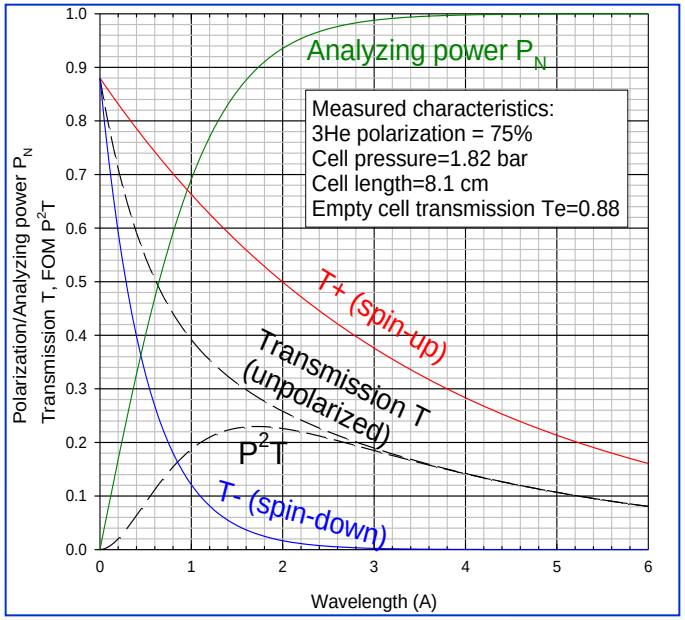
Polarized ^{3}He based neutron spin filter

Polarized ^{3}He neutron spin filter is based on the spin-dependence of the neutron absorption of ^{3}He. If the ^{3}He nuclear spin and the neutron spin are anti-parallel, the absorption is very strong: $\sigma_a(\uparrow\downarrow) = 5931$ b for λ=1 Å neutrons. If the spins are parallel, there is virtually no absorption. $\sigma_a(\uparrow\uparrow) \sim 0$. The absorption cross-section is proportional to the neutron wavelength λ.





A ^{3}He spin filter cell



$$T_+ = T_{glass} e^{-(1-P_{He})n\sigma\lambda l}$$

$$T_- = T_{glass} e^{-(1+P_{He})n\sigma\lambda l}$$

$$P_n = \tanh(P_{He} n\sigma\lambda l)$$

T = transmission

P_n = neutron polarization

P_{He} = ^{3}He polarization

n = number density of ^{3}He

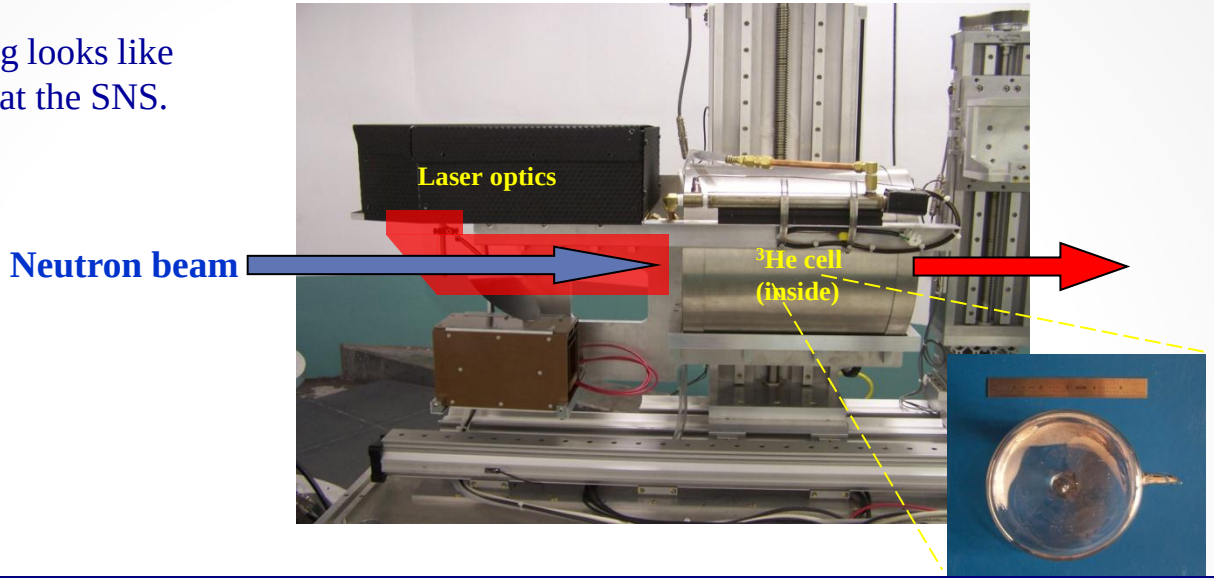
l = cell length

σ = absorption cross-section at 1 Å

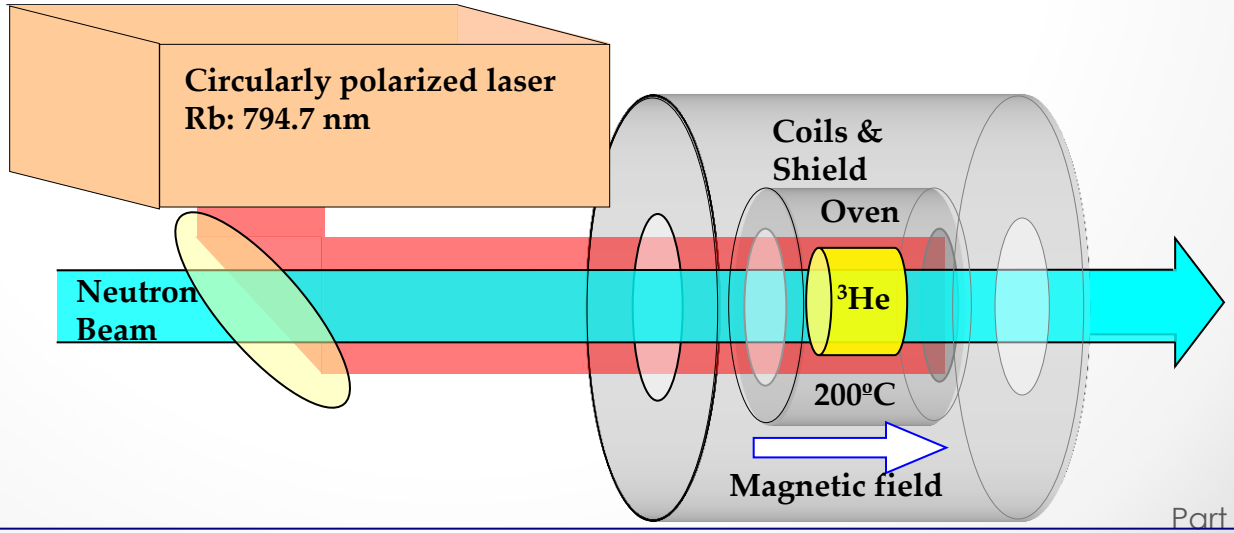
λ = neutron wavelength

Spin Exchange Optical Pumping to polarize ^{3}He

How the real thing looks like
on an instrument at the SNS.



Schematic diagram of a setup



Phase space transformers

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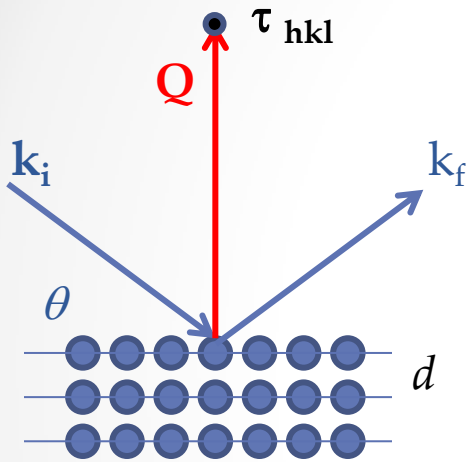
Reflection from crystals - revisited

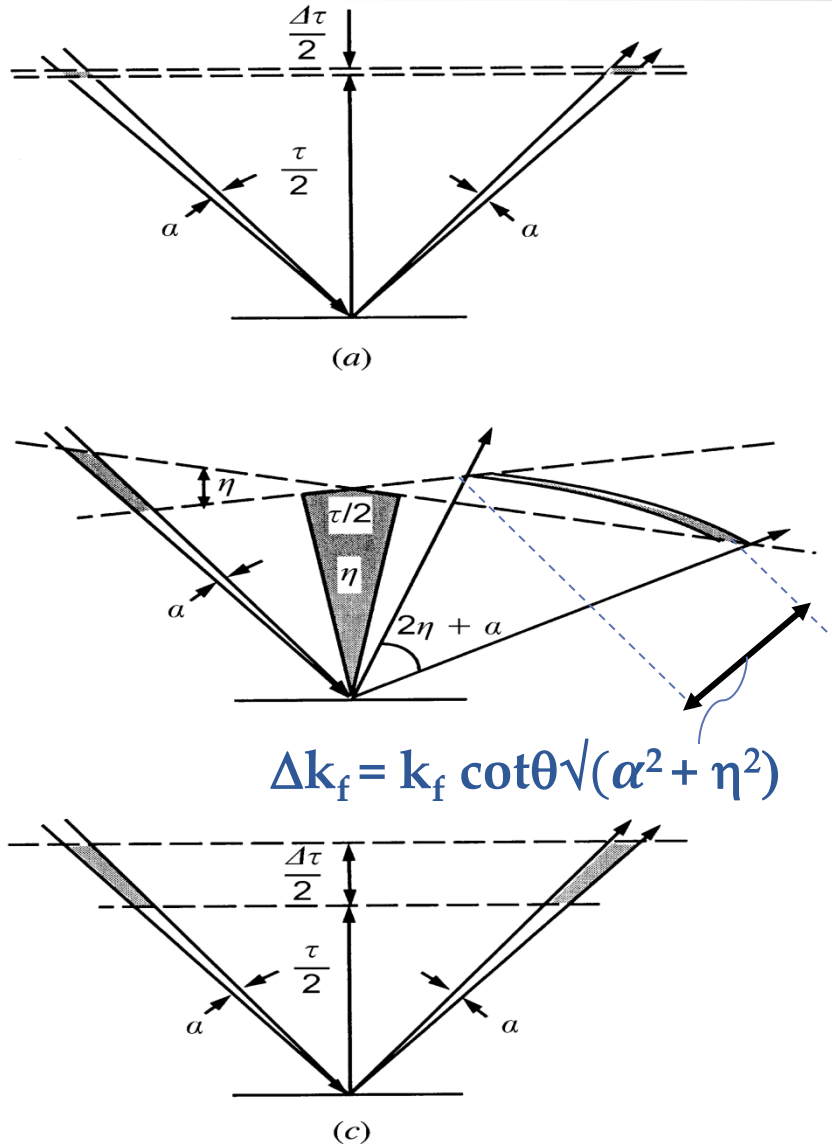
$\underline{Q} = \underline{k}_f - \underline{k}_i$ (from part 1)



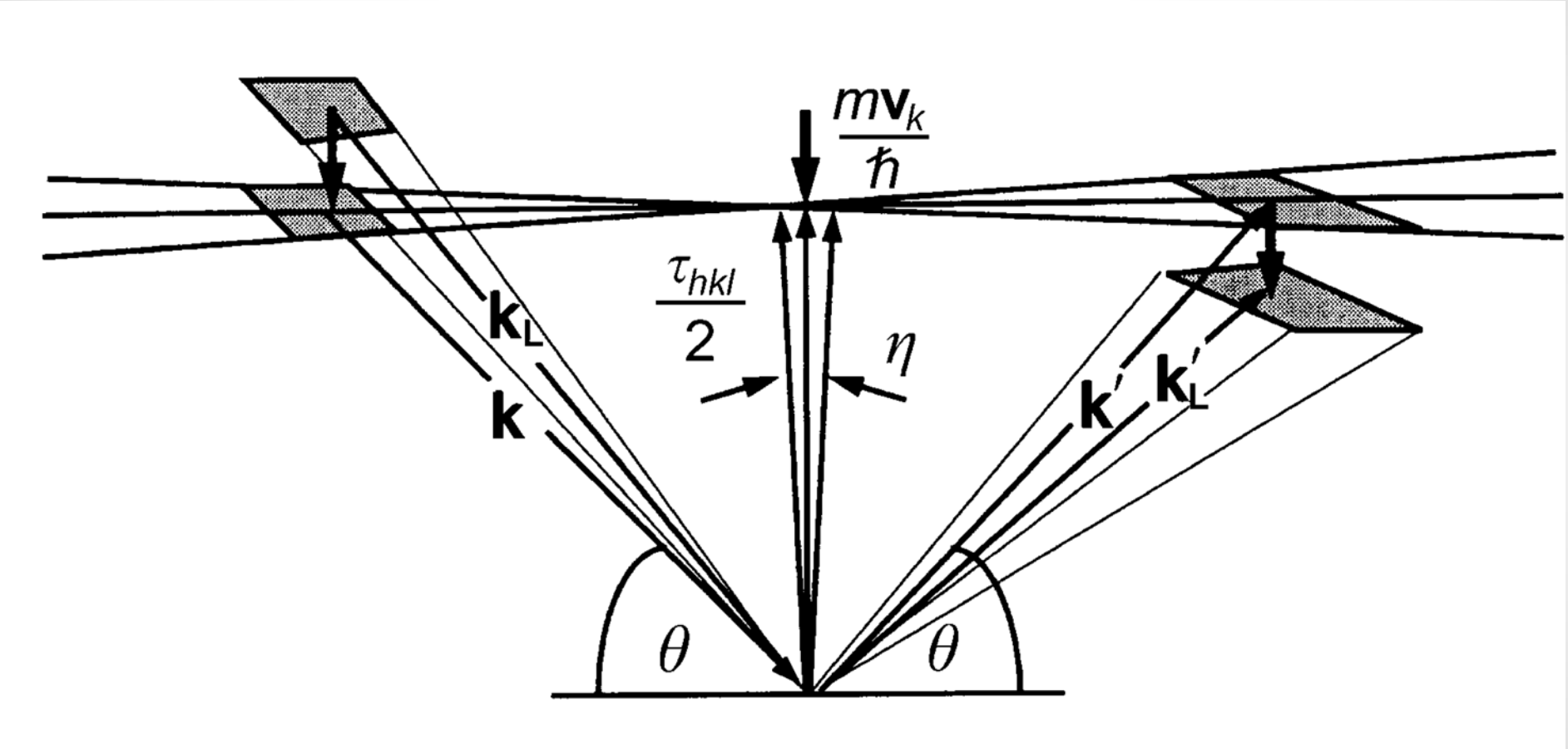
$k_i = k_f$

Bragg's law $\lambda = 2d\sin\theta$

In reciprocal space $\tau = 2k\sin\theta$

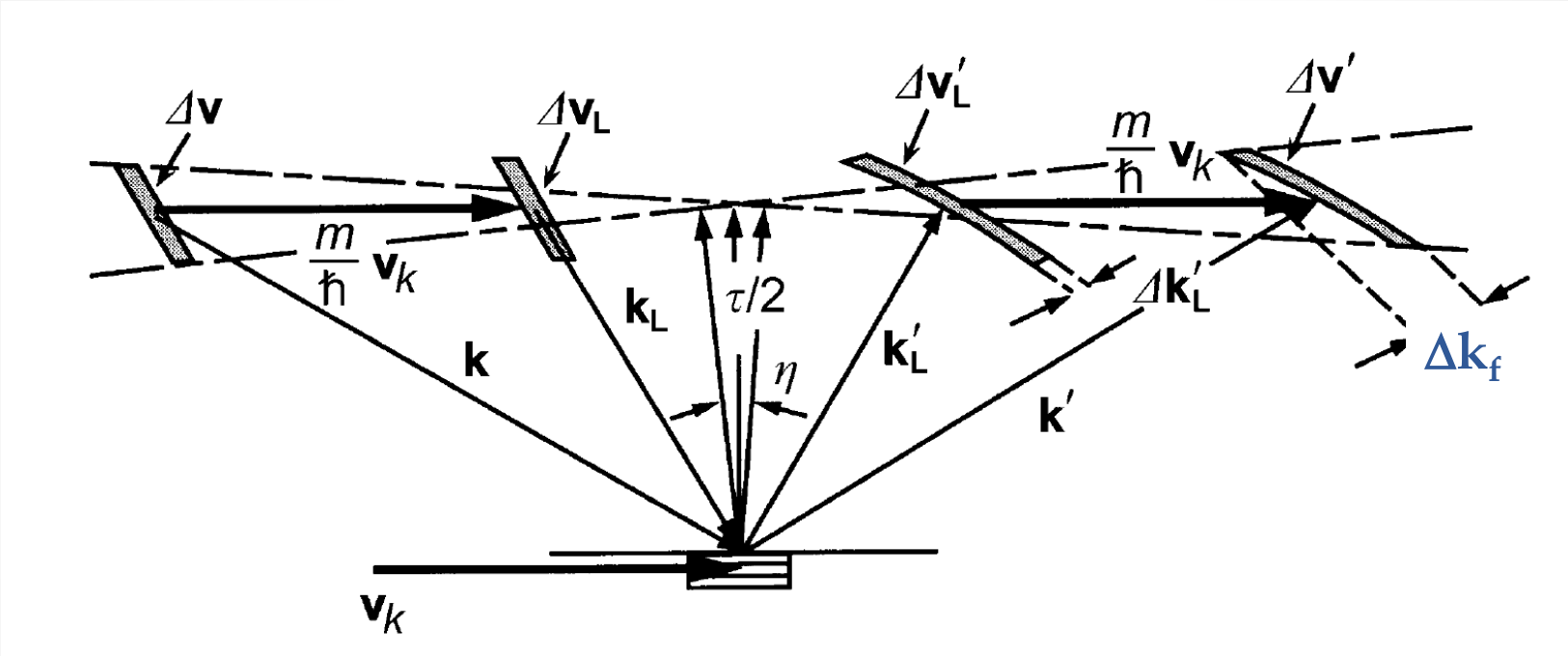


Reflection from moving crystals- movement perpendicular to crystal planes



the "doppler shift" changes the reflected energy

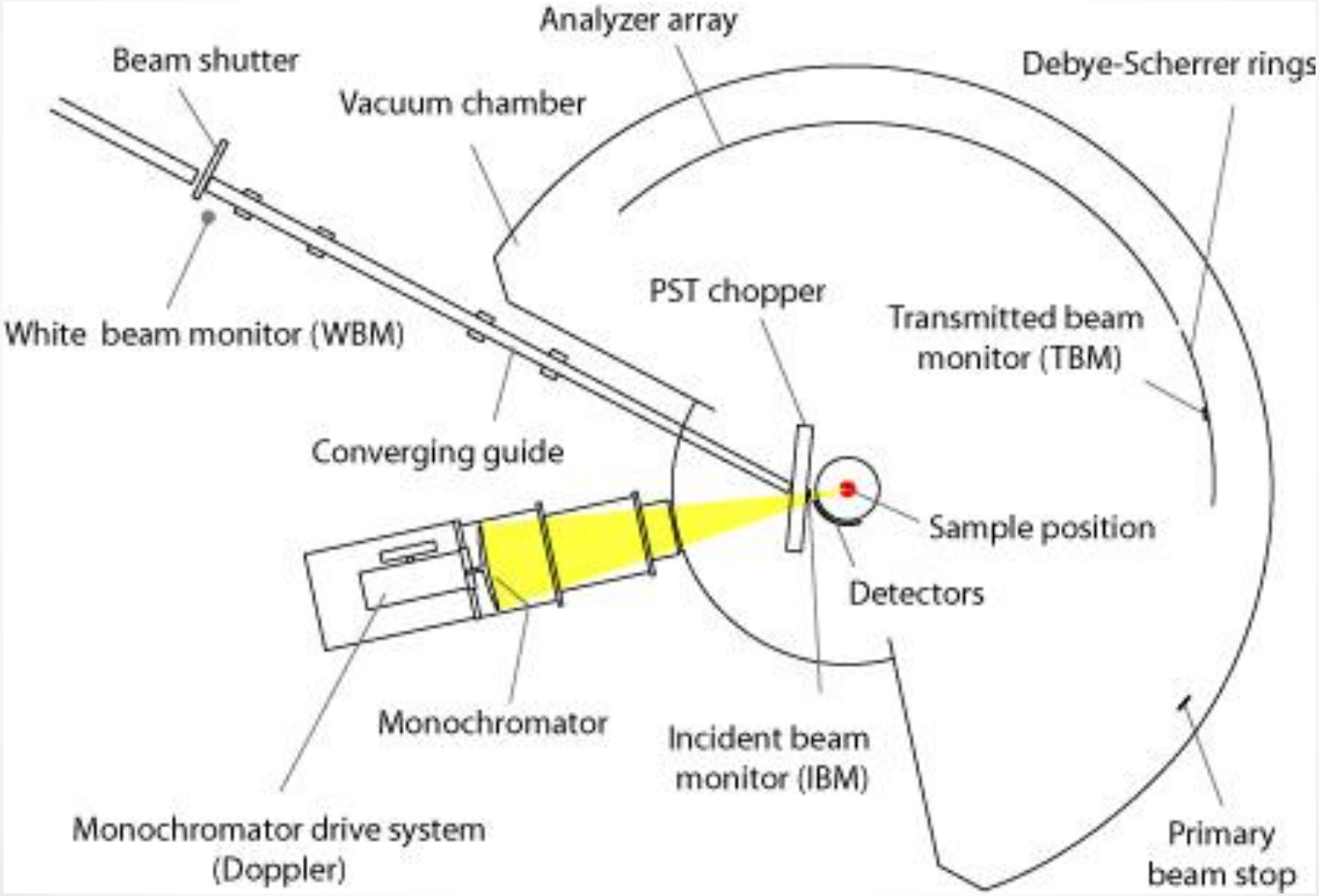
Reflection from moving crystals- movement parallel to crystal planes



"from white to wide"

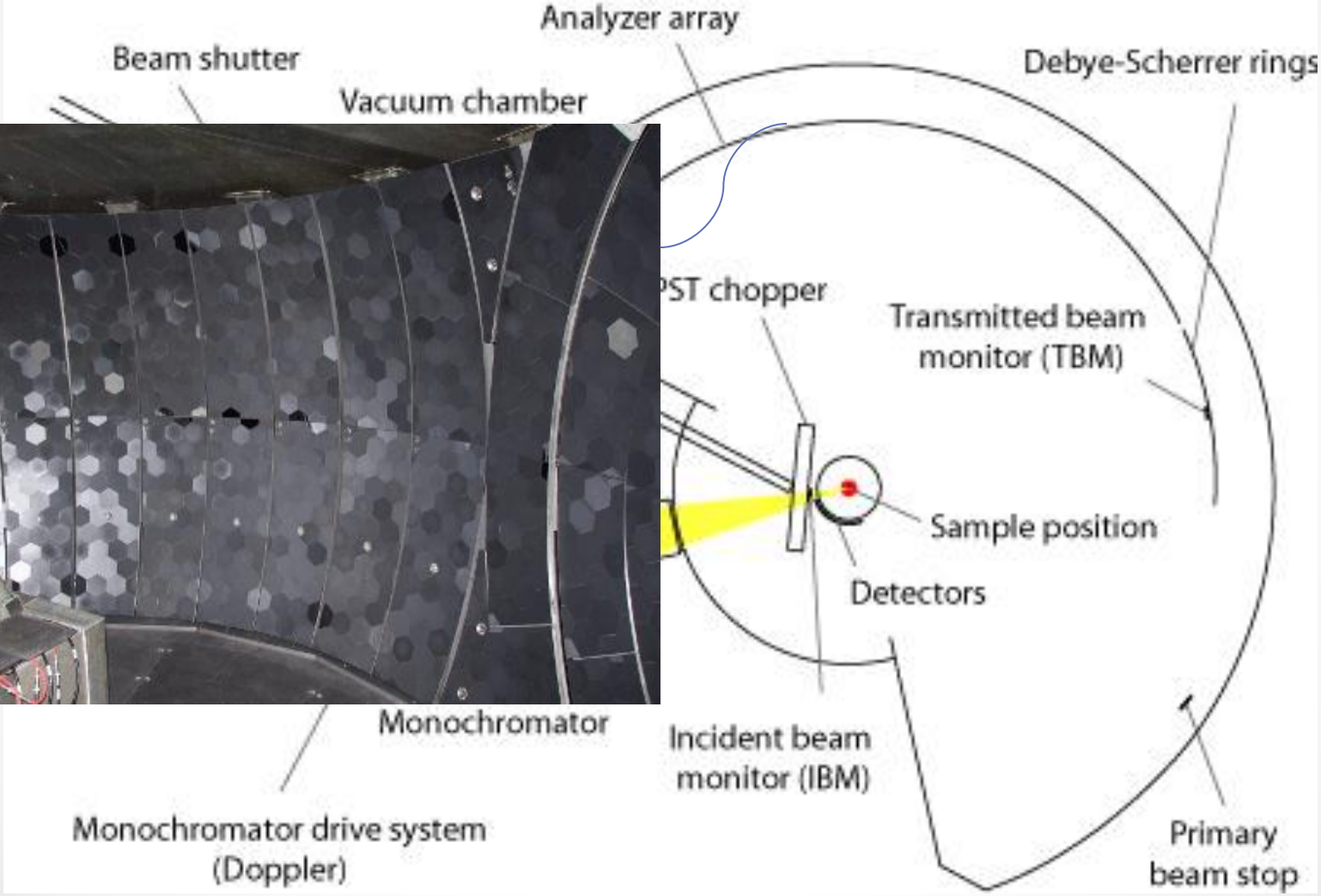
Example: HFBS at NCNR

uses at least 3 of the principles we have just talked about



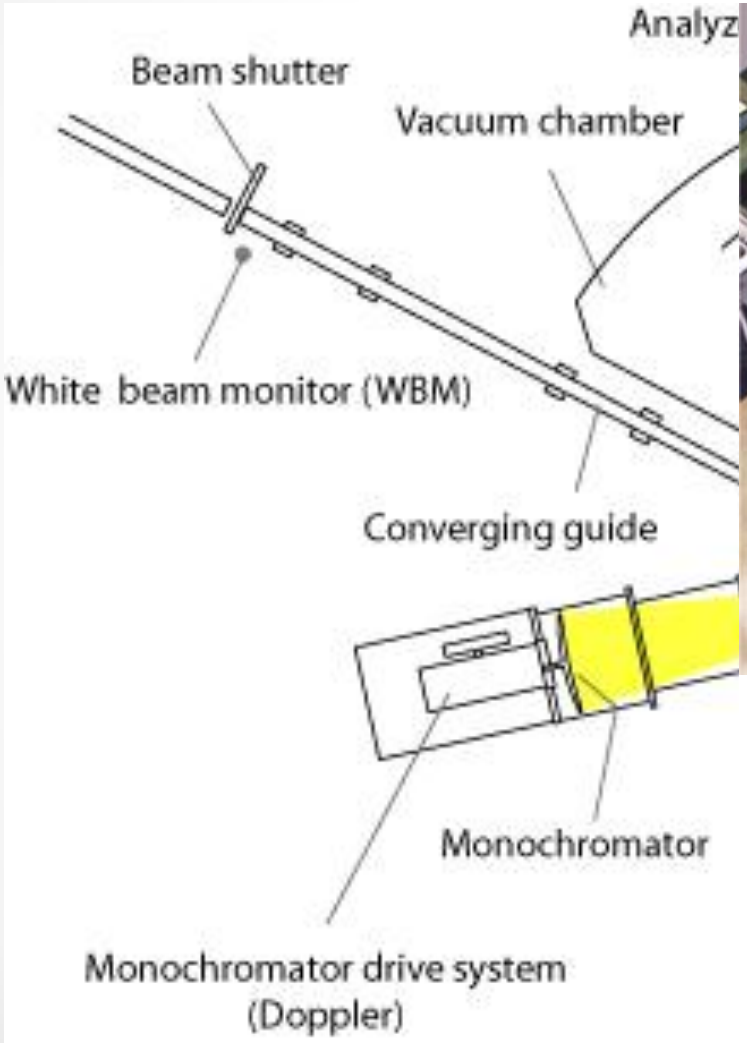
Example: HFBS at NCNR

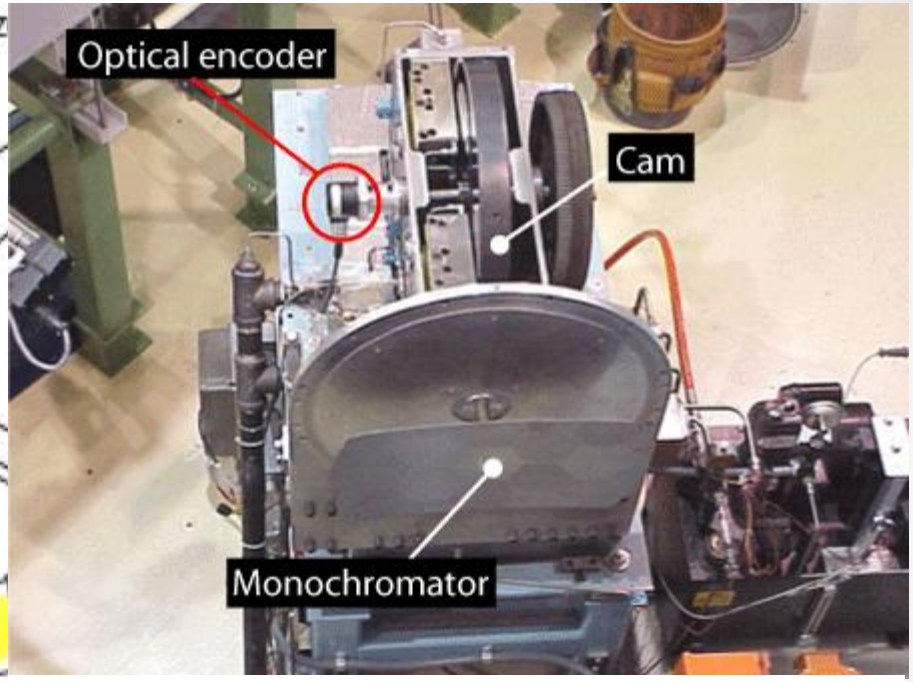
Si (111) analyzers in backscattering



Example: HFBS at NCNR

A Si (111) perfect crystal monochromator on a doppler drive

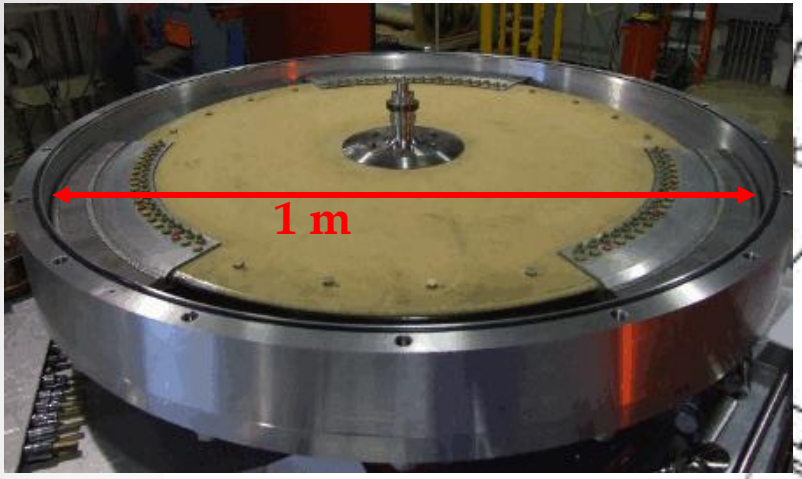


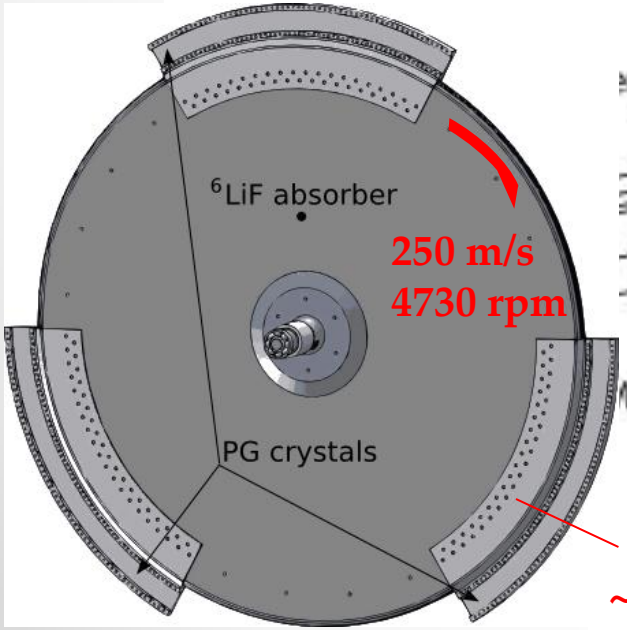


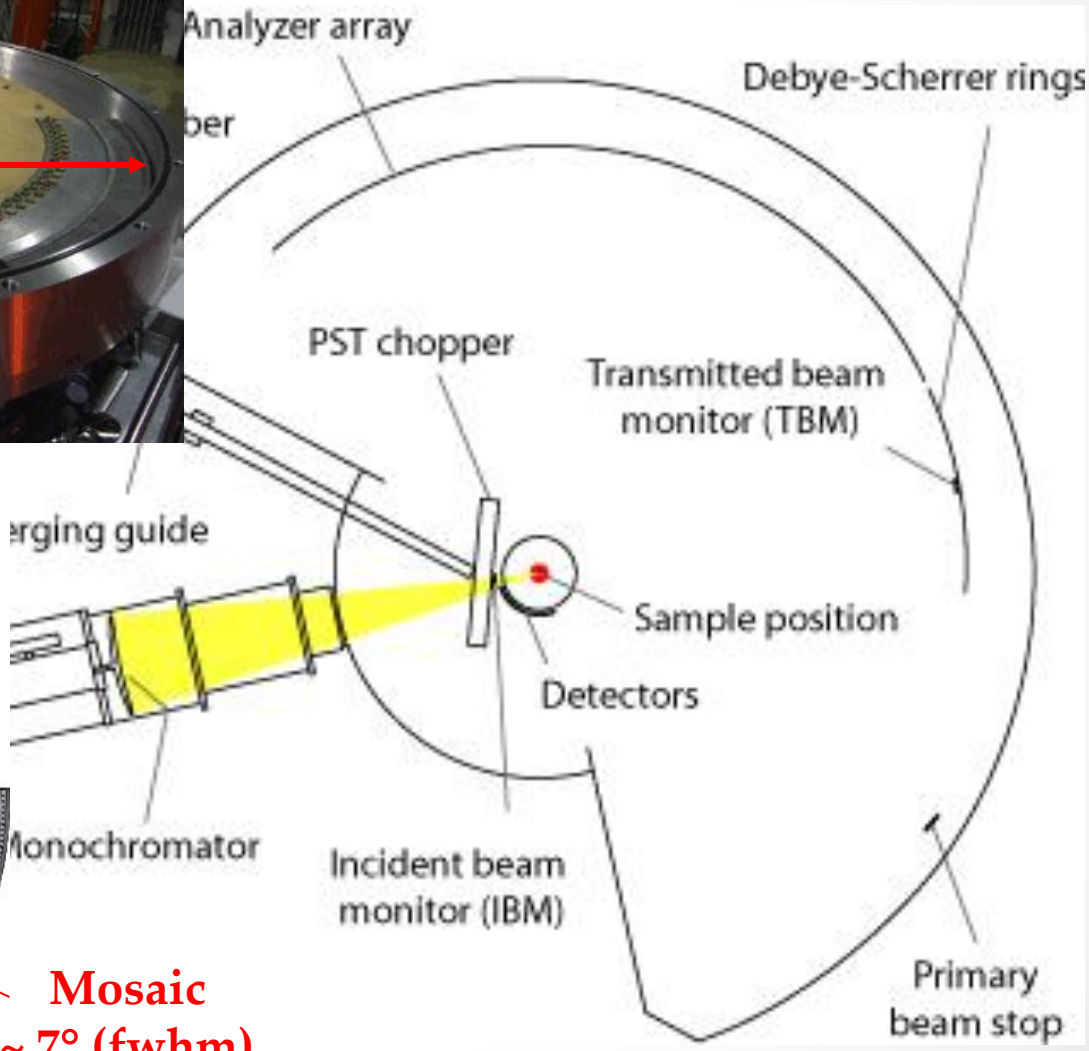
Doppler drive operates up to 16.2 Hz
Maximum dynamic range: ± 36 μeV

Example: HFBS at NCNR

a PG phase space transformer/deflector



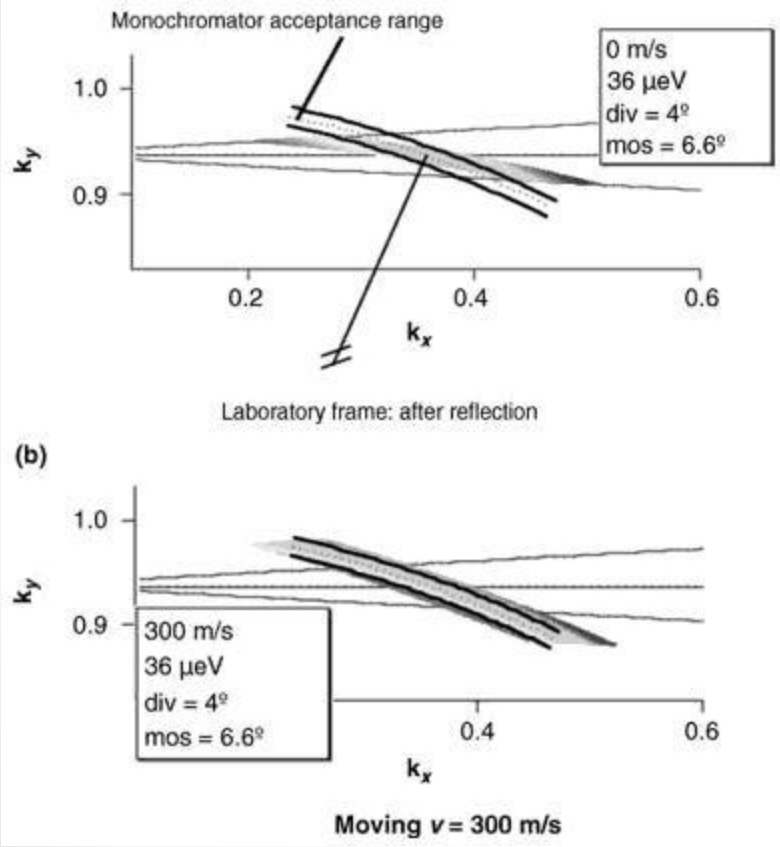


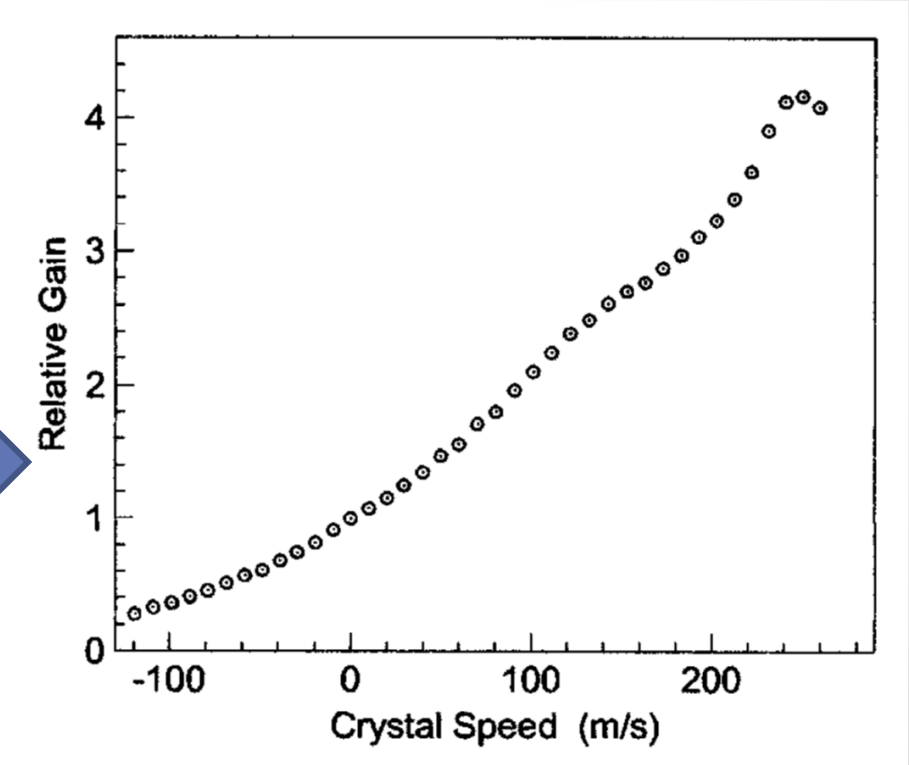


Mosaic ~ 7° (fwhm)

Example: HFBS at NCNR

The PST matches the resolution of the monochromator "white to wide"





Some things we didn't talk about:

- Rotating Crystals
- UCN/VCN production using PST's
- Transformation of UCN energies to thermal energies
  - In principle increases the phase space density
  - Requires Doppler velocities of 10^3 m s^{-1} in order to achieve neutron energies ~ 5 meV.
- And much more…….

Summary

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Reading material

- ILL Neutron Data Booklet (2002):
  - http://neutrons.ornl.gov/why/NeutronDataBooklet.pdf
- Neutron Scattering: A Primer by Roger Pynn (1990):
  - http://library.lanl.gov/cgi-bin/getfile?19-01.pdf
  - http://la-science.lanl.gov/cat_materials.shtml#neutron
- International Tables of Crystallography Vol. C (2004)
  - http://www.springerlink.com/content/q81j2r10u517qxq3/

Thank you!