HFBS : Under the Hood

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National Institute of Standards and Technology
U.S. Department of Commerce

Neutron Beam Guides.

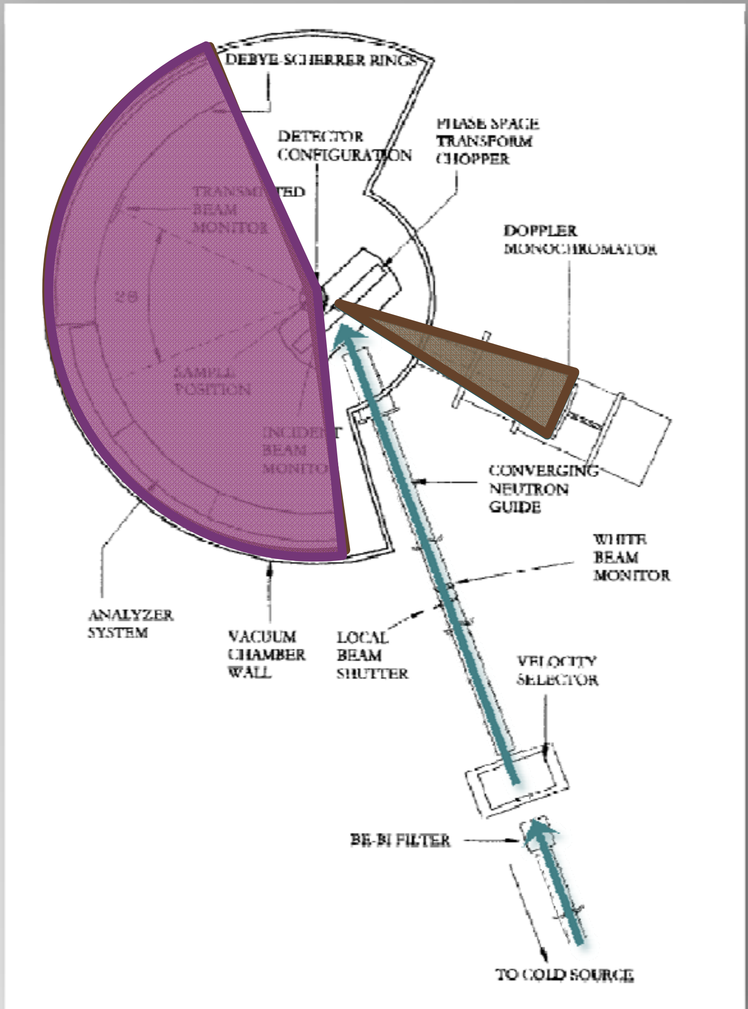
Neutron Velocity Selectors (NVS).

Phase Space Transform (PST) Chopper.

Monochromator/ Doppler.

Analyzers.

Detector Arrays.



Topics to be Addressed

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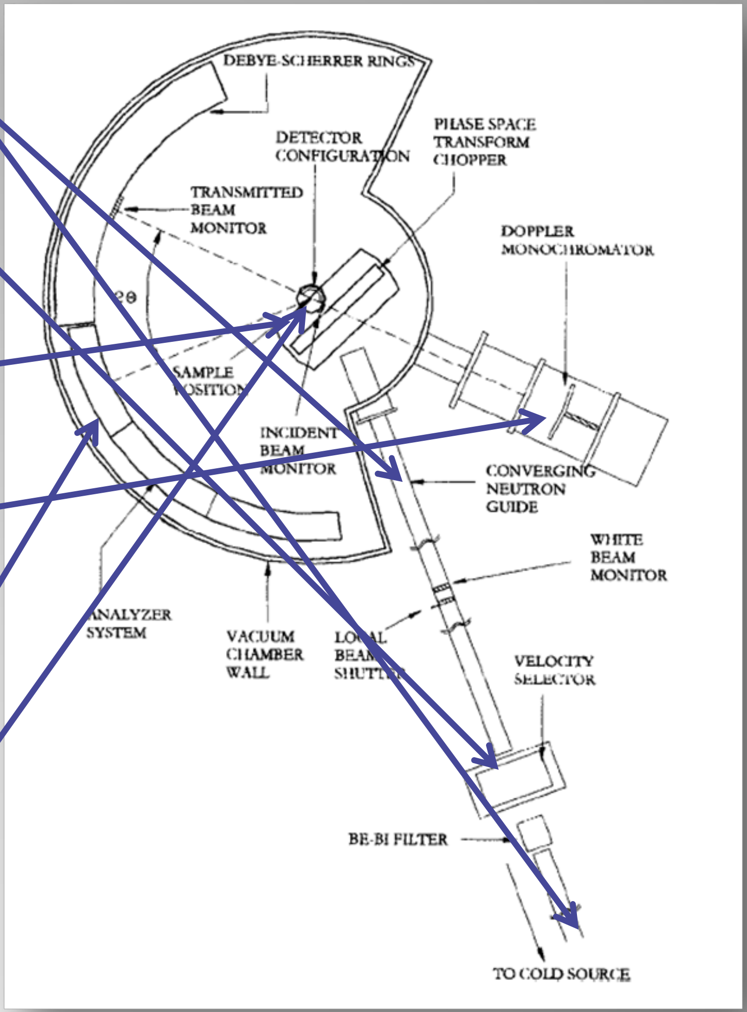

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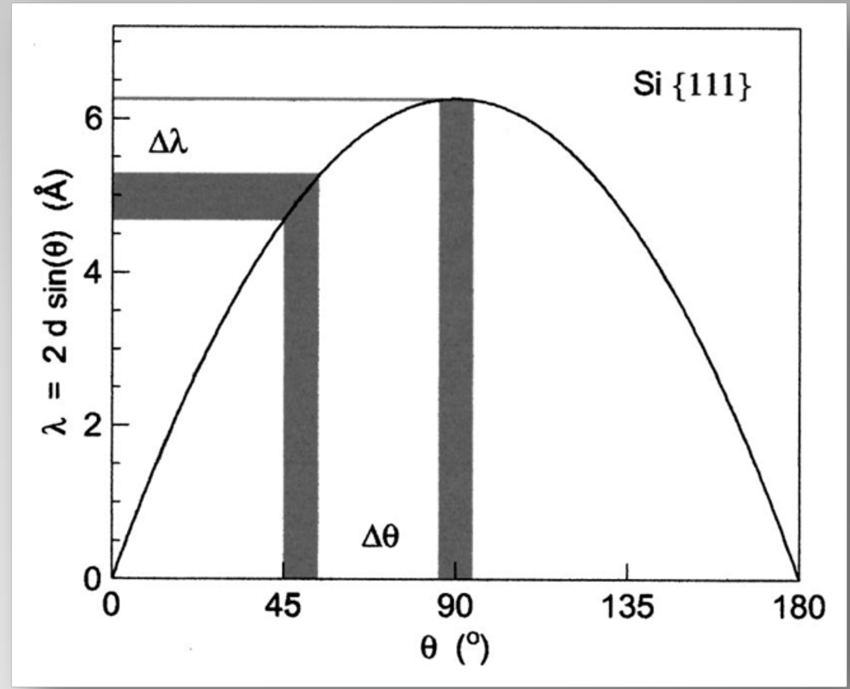
$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta d}{d} + \frac{\Delta\theta}{\tan\theta}$$

When 2Θ → 180° or Θ → 90°

d (the distance between the Bragg planes in the crystal) determines the wavelength spread.



Basics of Backscattering

Meyer, A., et al. (2003). *Review of Scientific Instruments , 74* (5), 2759-2777.

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta d}{d} + \frac{\Delta\theta}{\tan\theta}$$

$$\frac{\Delta E}{E} = 2\frac{\Delta\lambda}{\lambda}$$

$$\lambda_0 = 2d = 6.2712\text{Å}$$
$$k_0 = 2\pi/\lambda_0 = 1.00\text{Å}^{-1}$$
$$\upsilon_0 = 630.8\, m/s$$
$$E_0 = 2.08 meV$$

Using this equation we can get an understanding of energy resolution.

0.16 μeV for the 0.70° beam divergence.

However, you pay a price in flux for resolution!!

Basics of Backscattering

1. The highest neutron flux on sample.
2. The largest dynamic range.
3. All while retaining the 1 μeV resolution.

- How do we do this?
  - Employ techniques to address these different issues.

Overall Goals for HFBS

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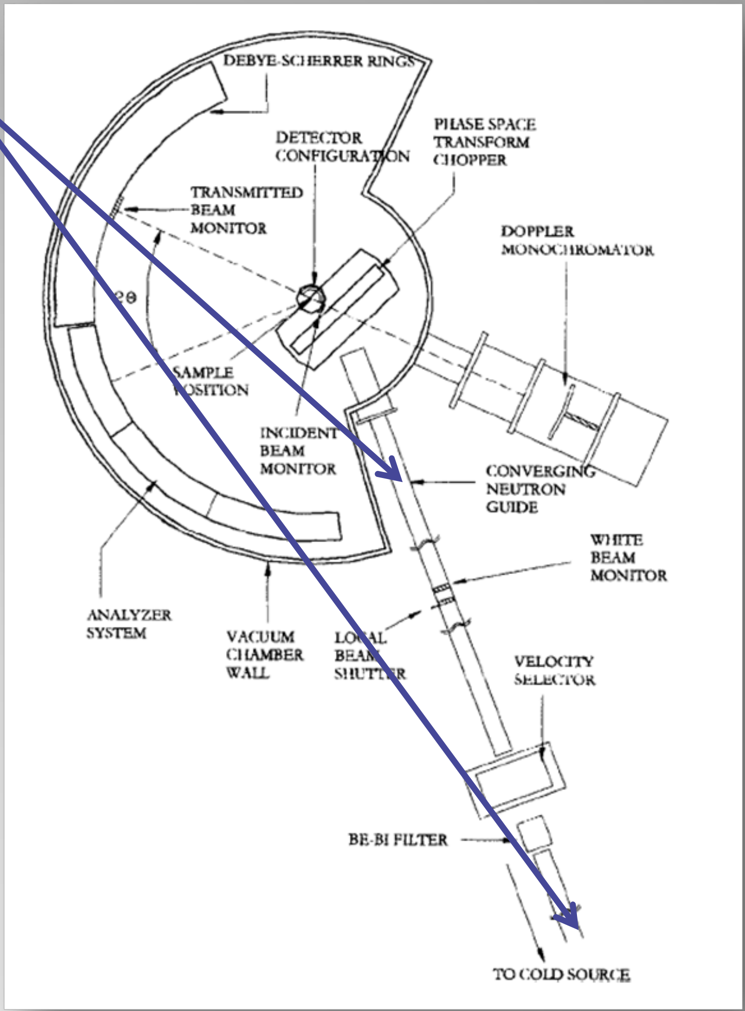

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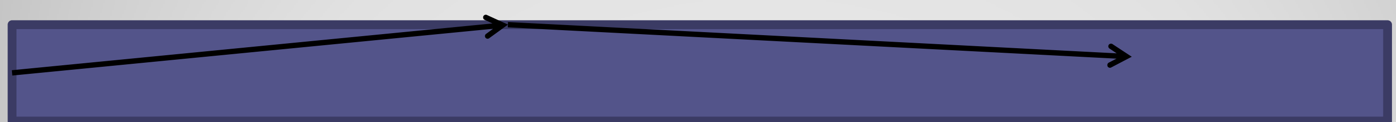
Neutron Beam Guides: Straight Guide

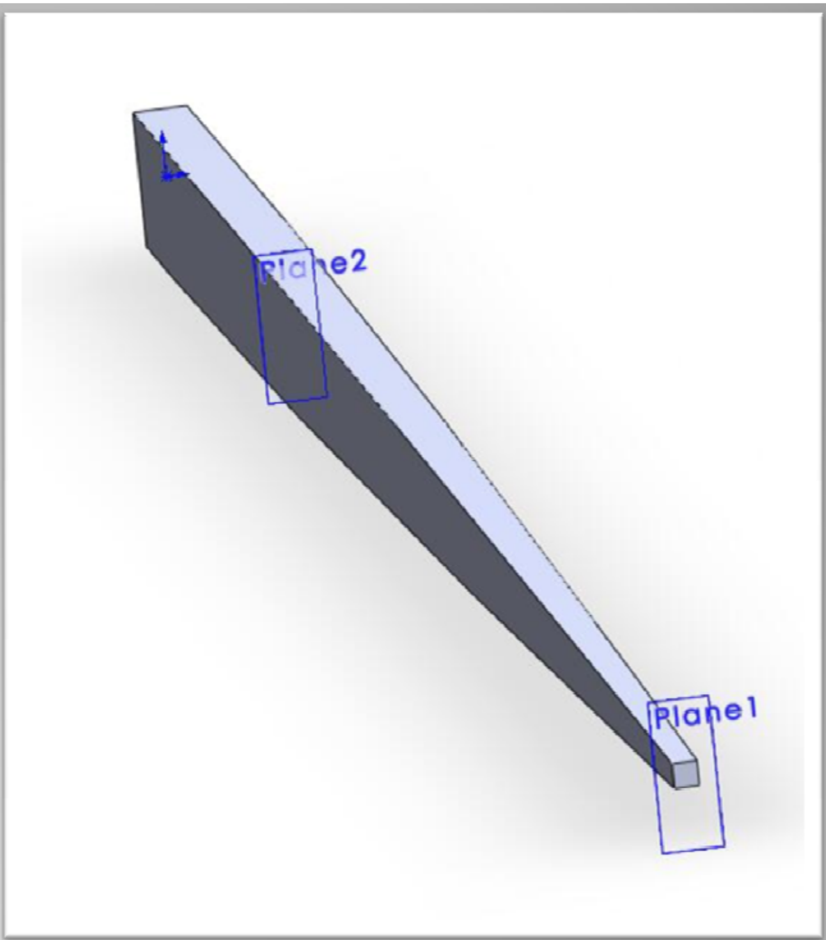
- Supermirror guides are the first step that the neutron takes after leaving the cold source.
  - Main function is to transport the neutrons to the instrument with minimal loss of flux.
- HFBS has *41.1 m* of *16 cm x 6 cm* guides.
- Guides have a coating to channel neutrons.
  - NiCTi (top and bottom) angle of reflection of $(0.044\ \text{Å}^{-1})\lambda$.
  - ^{58}Ni (sides) angle of reflection of $(0.026\ \text{Å}^{-1})\lambda$.
- HFBS has a guide cut at 26.3 m for filters and the neutron velocity selector.
  - The filters are polycrystalline beryllium and “pseudo” single crystal bismuth
  - The filters remove the fast neutrons and suppress the core gamma-ray (γ-ray) radiation.



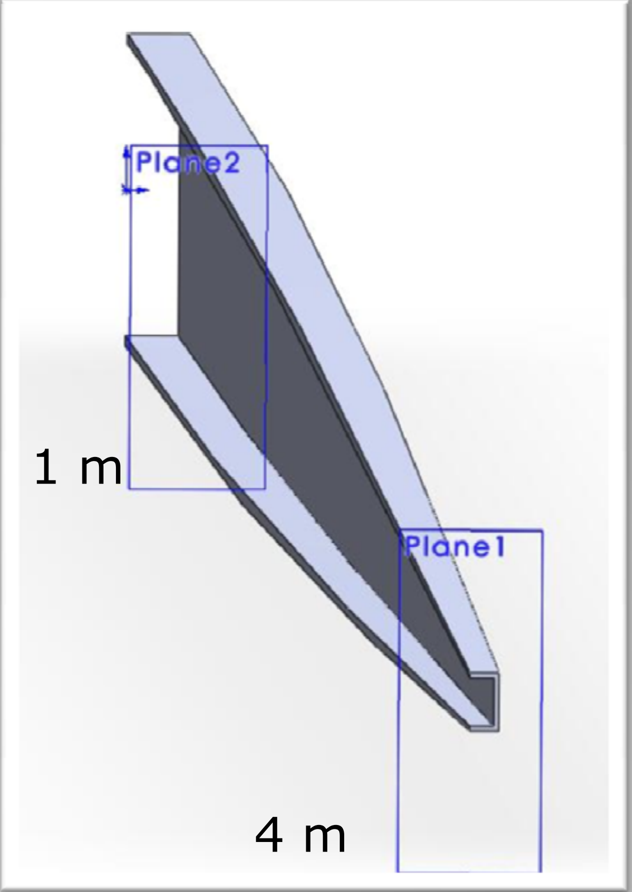
Neutron Beam Guides: Converging Guide

- 4 m after the local shutter.
- Goal is to focus the beam to an usable size (2.8 x 2.8 cm^2).
- Minimizing gaps in the neutron beam while maximizing the flux on sample.

Flux Gain is a factor of ***3.4***



- Acceptance diagrams were used to determine the optimal lengths for vertical and horizontal focusing.
  - Ray-tracing technique to determine how scattered neutrons are focused.
- Horizontal – 3 m
- Vertical – 4 m



Neutron Beam Guides: Converging Guide

Copley, J. (1993). The Joy of Acceptance Diagrams. *Journal of Neutron Research , 1* (2), 21-36.

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Monochromator/ Doppler.

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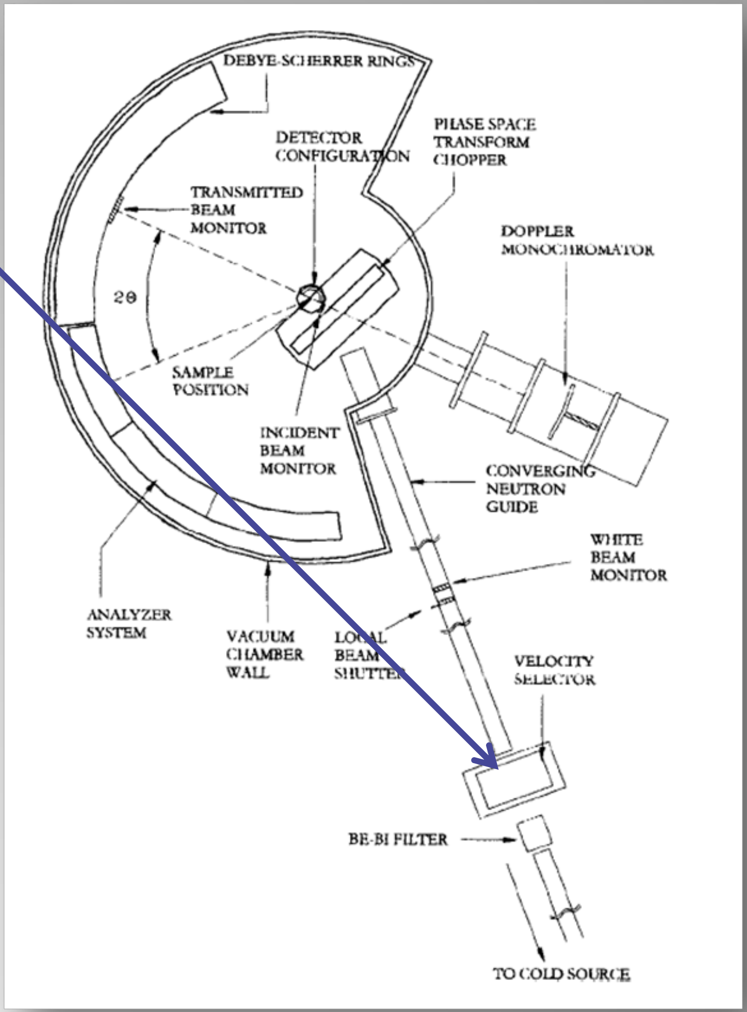
Detector Arrays.



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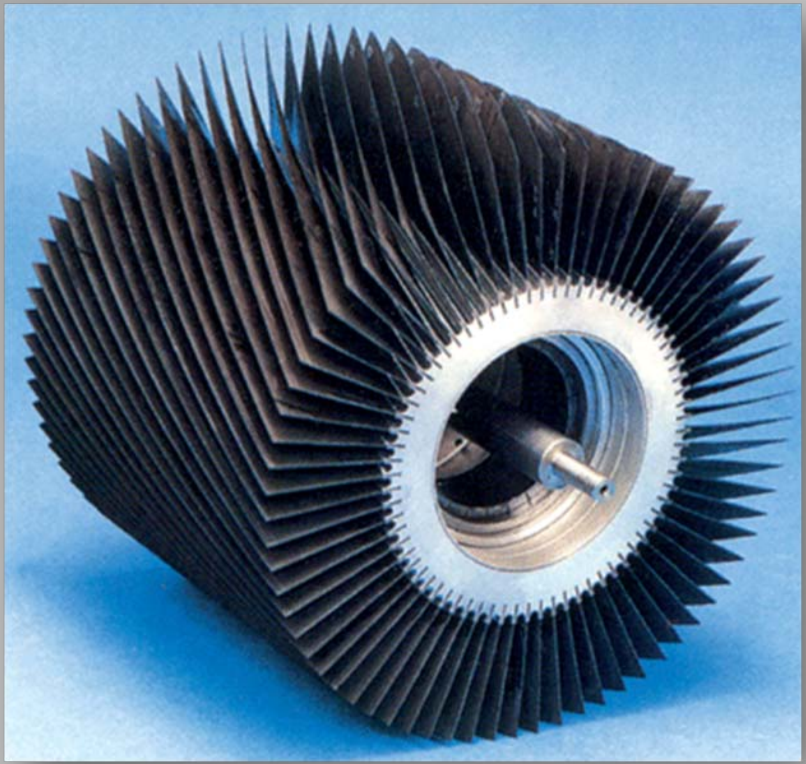
Neutron Velocity Selector (NVS)

Invented by Enrico Fermi, 1945

- Used to limit the wavelength of neutrons passed to the PST.
  - $\Delta\lambda/\lambda$ is 18% this is the range of neutrons passed about the 6.27 Å incident wavelength.
    - This is a limit of the design.
  - This acts as a background reduction feature.
- Sets the incident wavelength at 6.27 Å.
- ^{10}B coated blades.
- 83% transmittance at wavelength.
  - Rotation speed of 16,200 rpm.
  - Tangential speed of 410 m/s.

Fermi, E., Marshall, J., & Marshall, L. (1947). A Thermal Neutron Velocity Selector and Its Application to the Measurement of the Cross Section of Boron. *Physical Review , 72* (3), 193-196.



- Used in SANS instruments commonly.
- Helical fins allow the selection of wavelength based on rotation speed.
- HFBS has a large beam at the NVS requiring longer fins to cover the entire beam.

Neutron Velocity Selector (NVS)

http://www.gkss.de/templates/images_d/werkstoff/selector.gif

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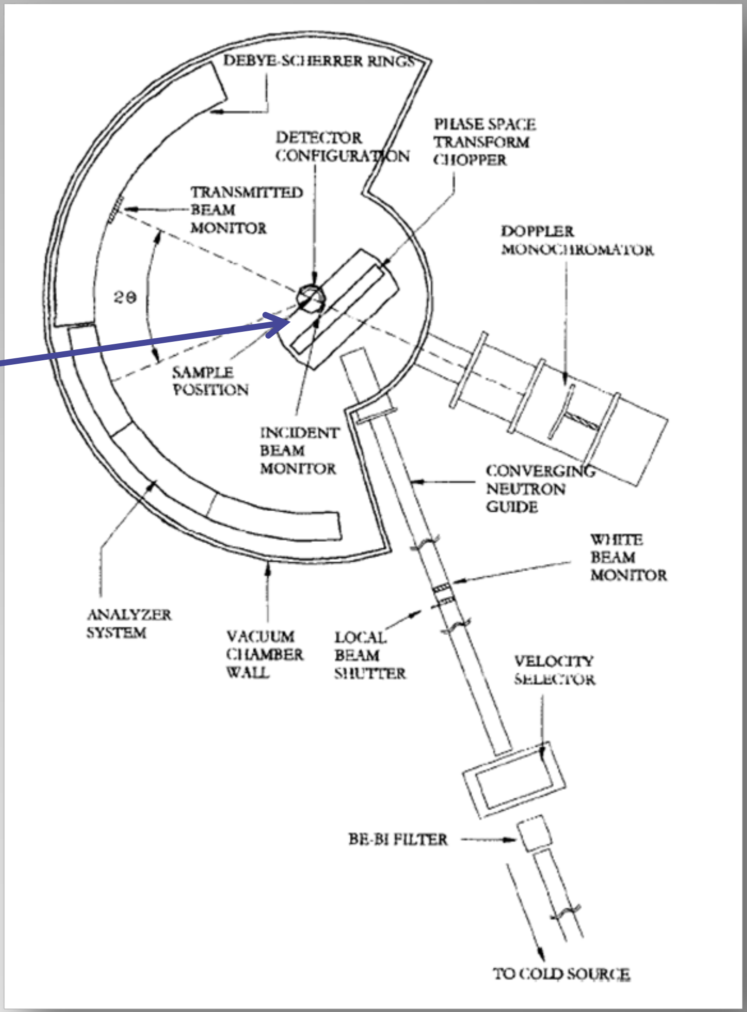

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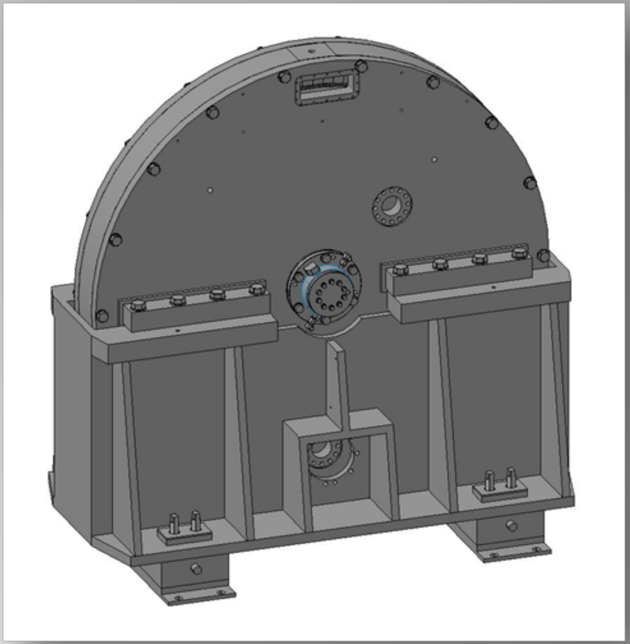
- Used to create a divergent beam from the convergent guide focused beam.
- Moving disk of orientated crystals.
- Enhances the flux at the corresponding backscattering energy E_0, 2.08 meV.

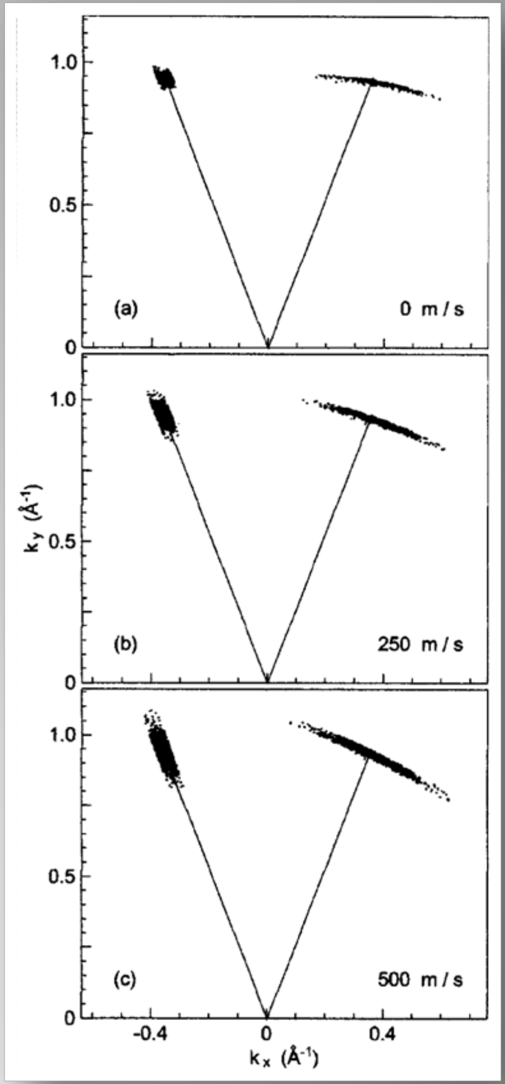


Phase Space Transform Chopper (PST)

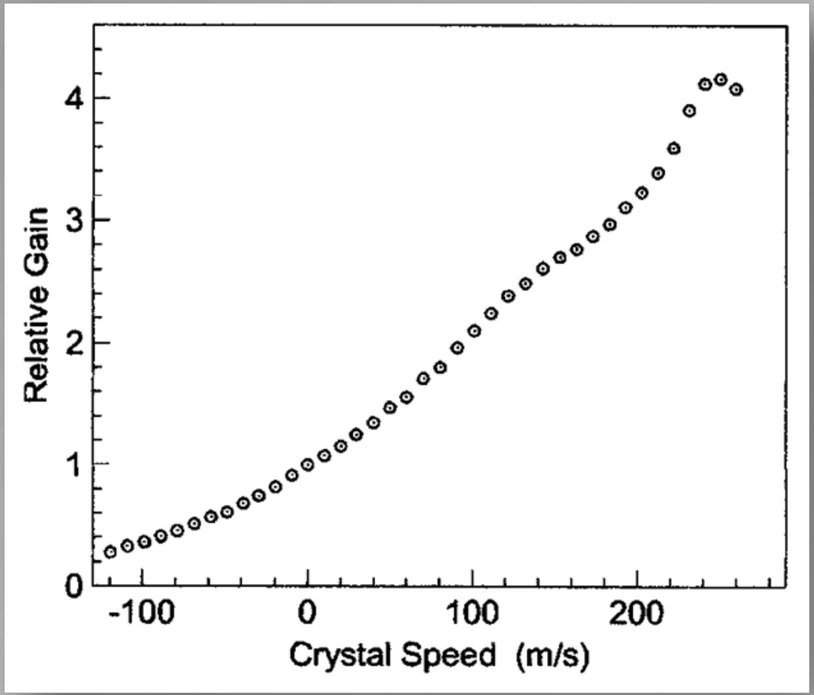
What is the PST?

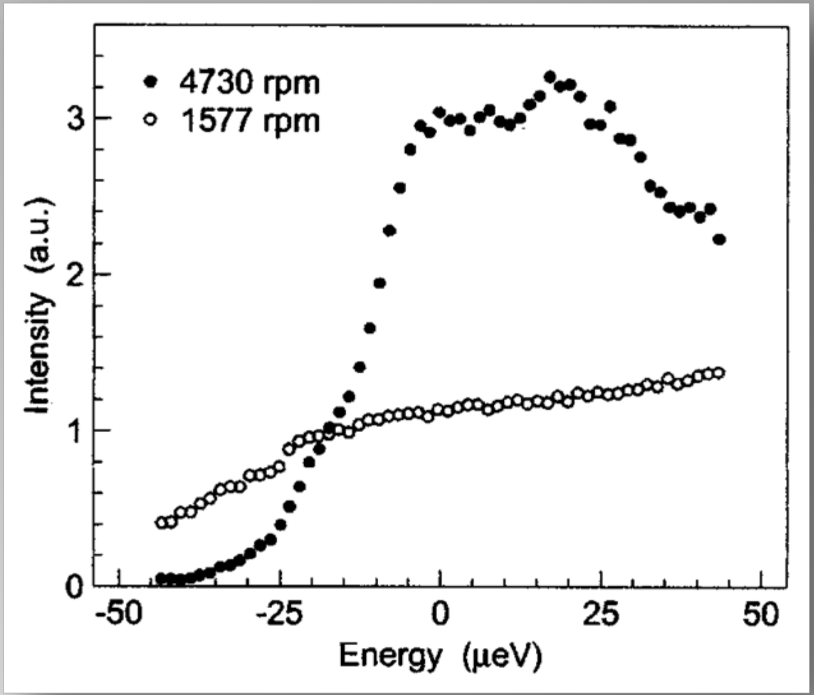
- PST disk
  - Divided into 6 sections of alternating cassettes of oriented pyrolytic graphite and openings.
  - Axis of rotation is parallel to the average scattering vector for graphite.
  - d spacing of the {002} plane is close to the Si spacing of the monochromator, {111}.
- The disk introduces a pulse nature into the beam.

- The Importance of Divergence.
  - The overall effect is to address a spread in wavevector of the incident beam.
  - The PST takes the incident beam and focuses it in the backscattering energy of 2.08 meV.
  - Converts a spread in wave vector to an angular spread at the required energy.



PST





- As the disk is spun faster there is an increase in flux (maximum of about **4.2** at 250 m/s).
- The flux for energy distribution is shown on the right at full speed (4730 rpm) and 1/3 speed (1577 rpm).

PST

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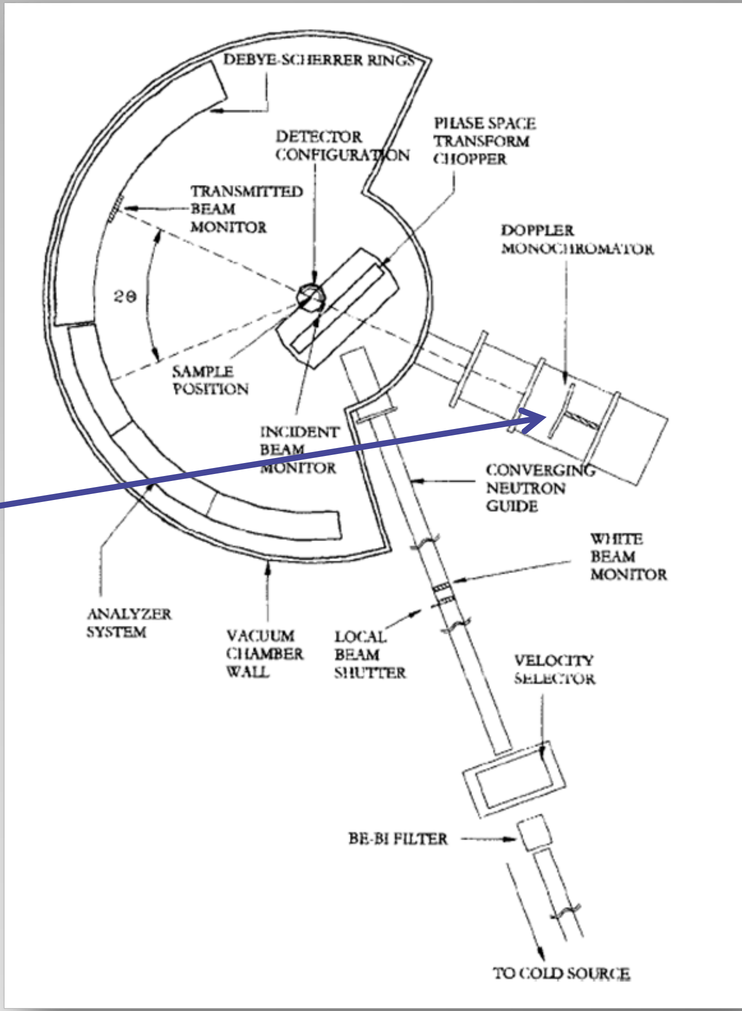

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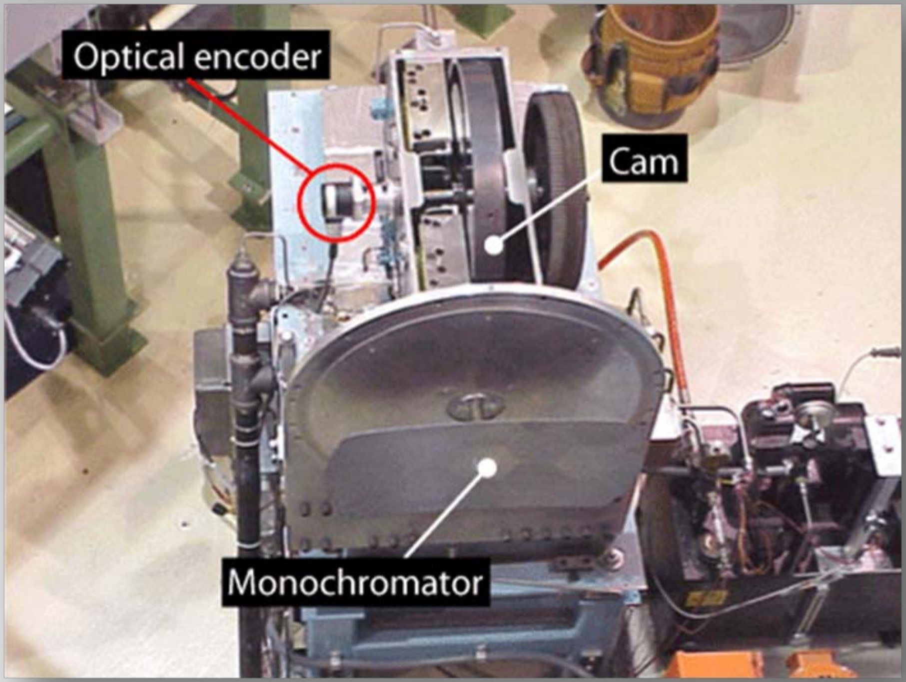
- 52 cm wide by 28 cm tall curved about a radius of 2.12 m. To focus the neutrons from the PST on to the sample.
- In the stationary position, HFBS runs in elastic mode (fixed window scan).



Monochromator/Doppler

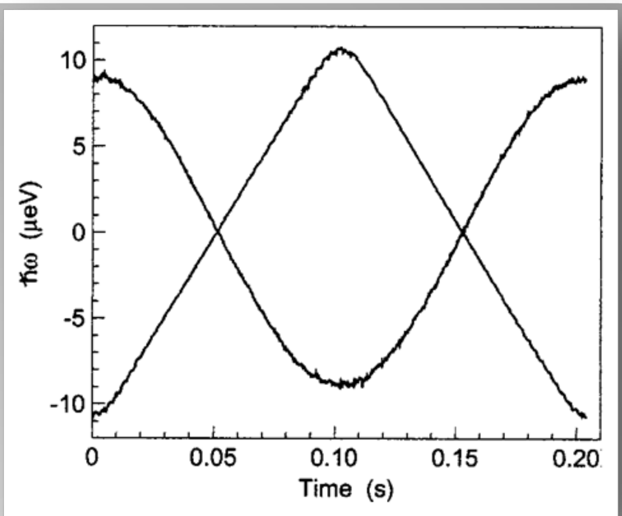
- The Doppler uses a circular cam to introduce a shift in the neutrons.
  - Parallel to the silicon {111} plane.
  - Bragg diffraction from a moving lattice.
  - The velocity of the monochromator relates to the final energy of the neutrons through

$$\Delta E = E_m - E_0 = 2E_0\left(\frac{\upsilon_m}{\upsilon_0}\right) + E_0\left(\frac{\upsilon_m}{\upsilon_0}\right)^2$$

Monochromator/Doppler

Monochromator/Doppler

- By rotating the Doppler at a set frequency you can specific the dynamic range for quasielastic experiments.
  - 15 Hz = ± 11μeV
  - 24 Hz = ± 17μeV
  - 50 Hz = ± 36μeV
- As the frequency increases the scattering decreases.



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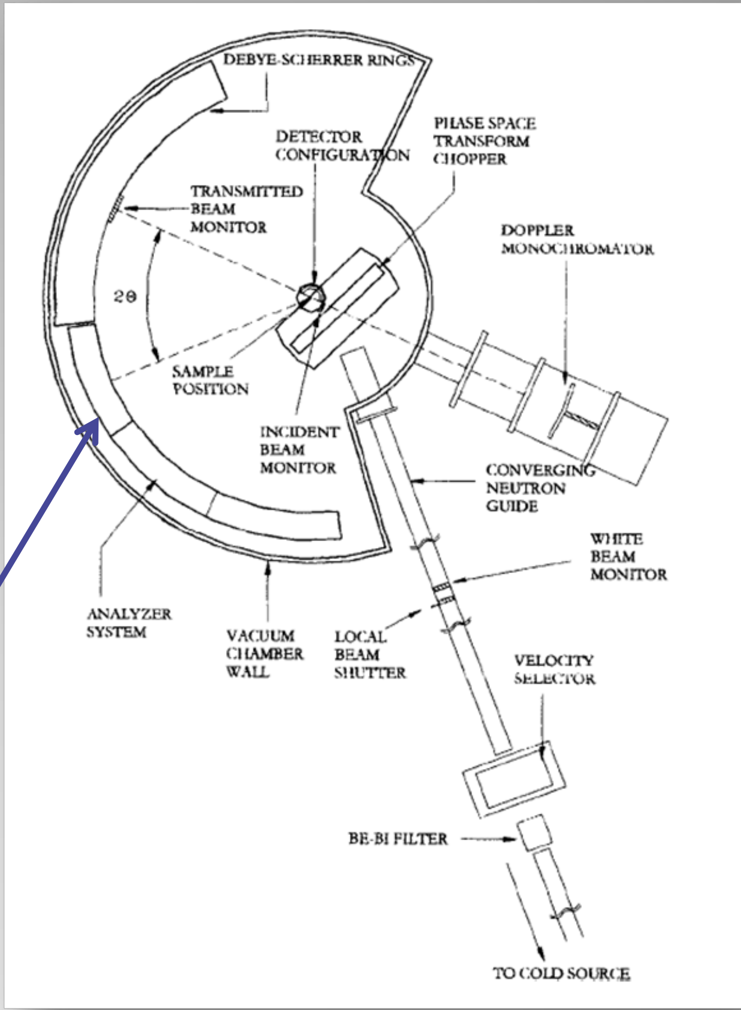

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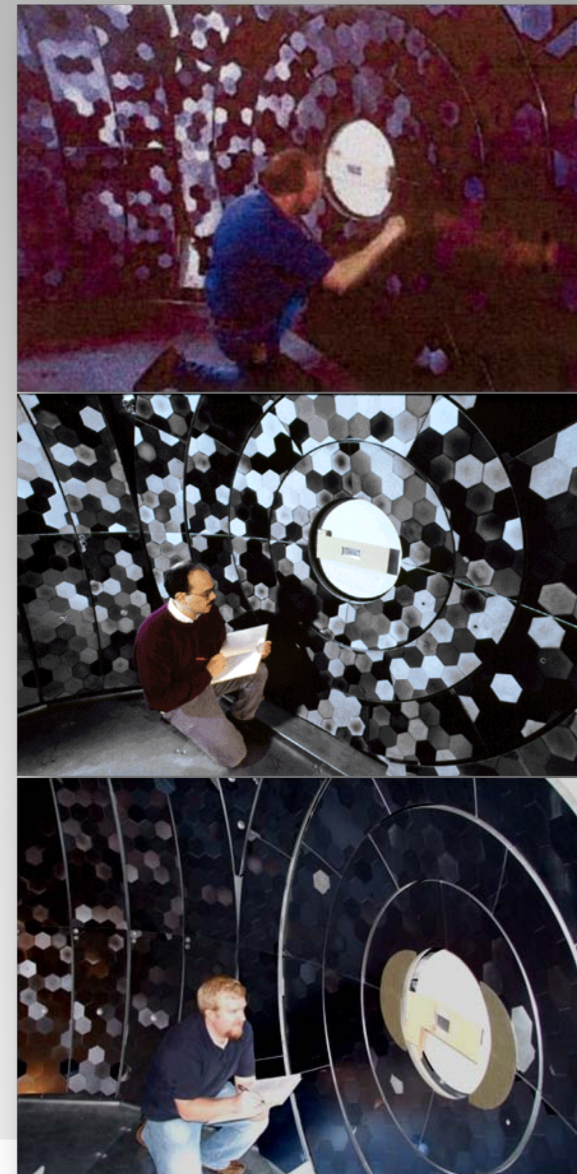
Analyzer

- Cover 2Θ angles from 39.3° to 124.3° with Debye-Scherrer rings (7.8°≤|2Θ|≤39°). About 12 m^2 of silicon.
- Radius of 2.05 m focusing the neutrons on the detectors.
- The silicon crystals are bent to increase the lattice gradient. Three fold increase in count rate.



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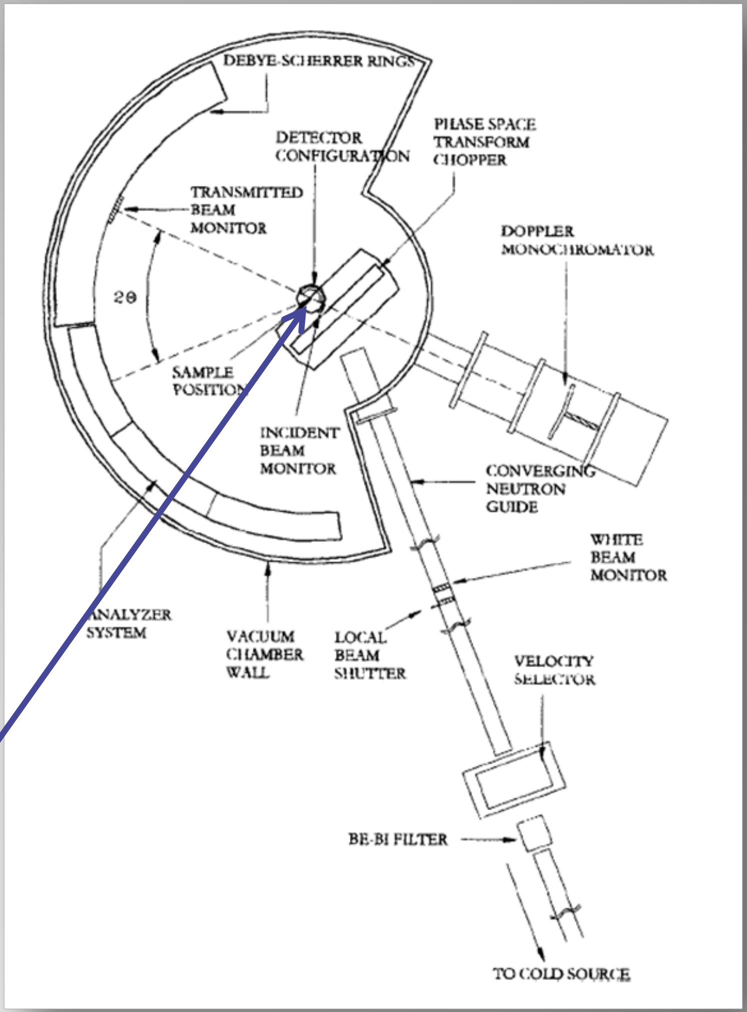

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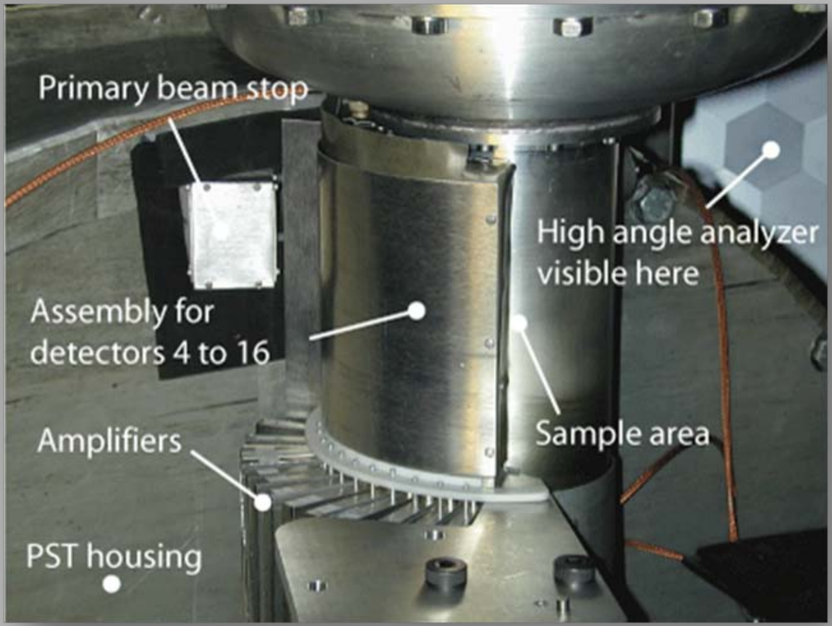
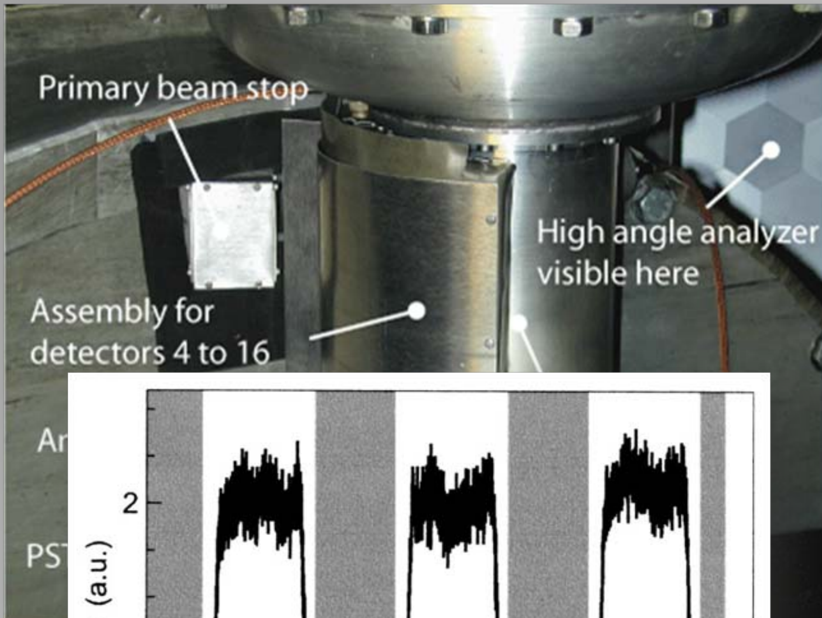
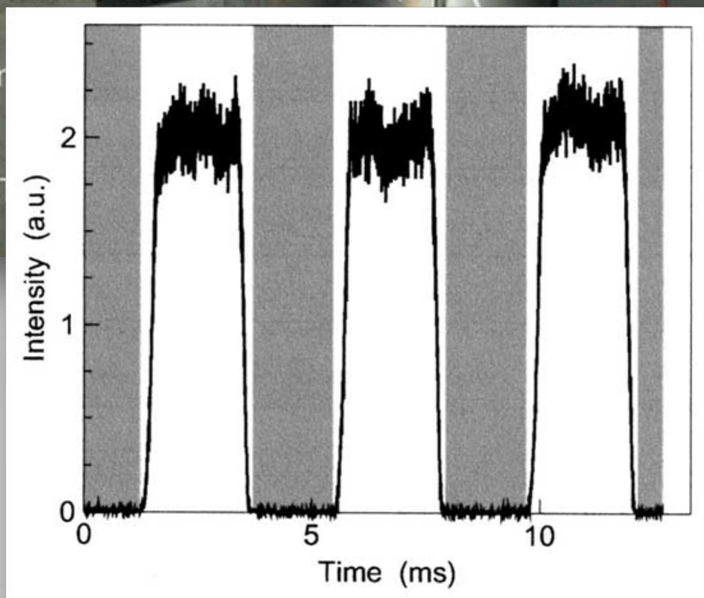


- The detectors are located close to the sample location.
  - They cover a range of Q from 0.56 $Å^{-1} \leq Q \leq 1.75$ $Å^{-1}$ (backscattering)
- There are four detectors that are slightly out of backscattering.
  - 0.25 $Å^{-1} \leq Q \leq 0.47$ $Å^{-1}$.

Detectors

Detectors





- The detectors are binned with the cycles of the PST.
- The large scattering effects are the prompt scattering from the sample.
- These are masked out leaving just the grayed sections recorded.

- **Flux Increases:**
  - PST = 4.2 increase in flux.
  - Converging guide = 3.2 increase in flux
  - The curved analyzer system and large coverage also contribute to the flux.
- **Dynamic range:**
  - Set by the Doppler speed.
- **Resolution:**
  - By matching the energy to the silicon d-spacing we get about 1 μeV.

Monochromator/Doppler Frequency (Hz)	Dynamic range (ueV)	Energy resolution (ueV)	Average Time (hrs)
15	11	0.80	4
24	17	0.87	8
50	36	1.01	12

Putting it all together

- SNS Backscattering (BASIS)
  - 84 meter guide for timing resolution
  - 3 μeV resolution over 258 μeV dynamic range.
- ISIS Backscattering (OSIRIS and IRIS)
  - OSIRIS
    - Combination diffratometer/spectrometer
    - 25 μeV resolution from 0.3 $Å^{-1}<Q<1.8$ $Å^{-1}$.
  - IRIS
    - Depending on crystal plane used between 1.0 – 54.5 μeV over a Q range of 0.1 – 3.7 $Å^{-1}$, *but not all at once*.

Comparisons to other backscattering instruments