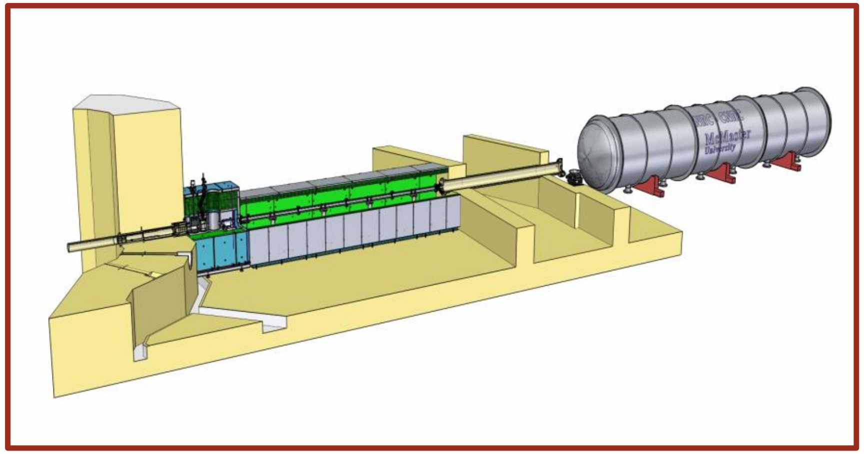
MacSANS: Small Angle Neutron Scattering for Nanostructured Materials at McMaster University



Pat Clancy[1], Zin Tun[2], Maikel Rheinstadter[1], Chris Heysel[3], Bruce Gaulin[1]

[1]McMaster University, [2]Canadian Neutron Beam Centre, [3]McMaster Nuclear Reactor

Brockhouse Institute for Materials Research

McMaster University

Take-Home Message:

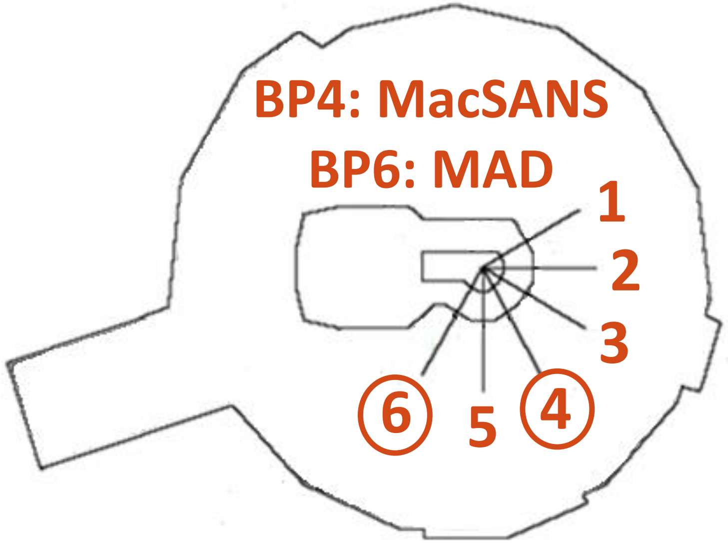
- As of April 1st, the **McMaster Nuclear Reactor** is Canada's only source of neutron beams for materials research
- MNR currently has 2 beamlines devoted to neutron scattering:
- **McMaster Alignment Diffractometer (MAD)** - general purpose triple-axis spectrometer, open for proposals
- **McMaster Small Angle Neutron Scattering beamline (MacSANS)** - under construction, commissioning experiments to begin in Spring 2019
- We are looking for new users and new experiments

•Contact us: clancyp@mcmaster.ca or macneutrons@gmail.com

The McMaster Nuclear Reactor

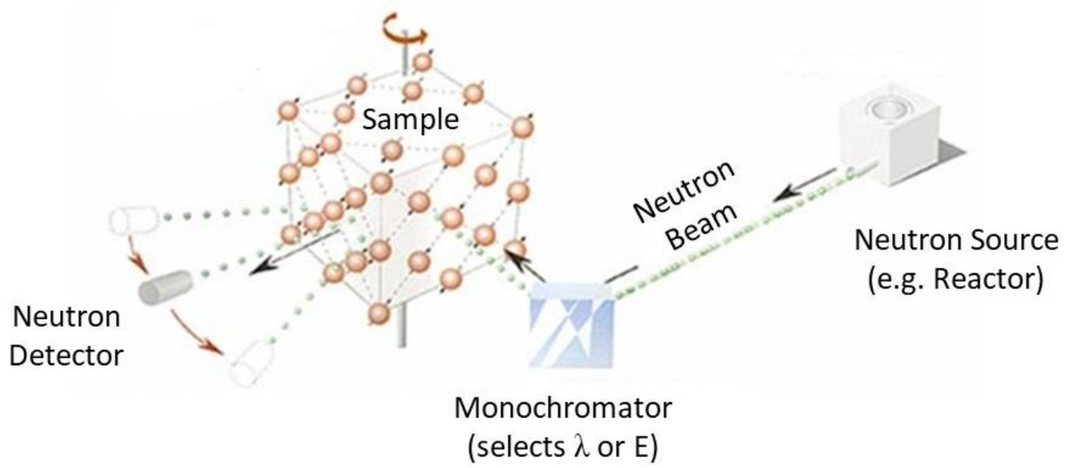
- 5 MW open-pool reactor (operates 3 MW, ~ 80 hours/week)
- Core flux ~ 1 × 10^{14} neutrons/cm^2/s
- In operation since 1959
- Multi-purpose research reactor:
  - **Neutron scattering**
  - Production of medical isotopes
  - Neutron irradiation/activation analysis
  - Neutron radiography
  - Intense positron beam facility

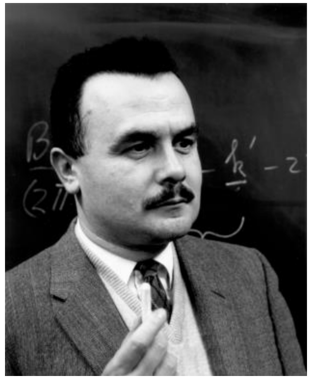
6 neutron beamports at MNR



MAD: McMaster Alignment Diffractometer

- Triple-axis neutron spectrometer located on Beamport 6
- Built on site of Brockhouse's original McMaster triple-axis
- Primarily used for elastic scattering (alignment, crystal quality)
- Operating since 2010, upgraded in 2017

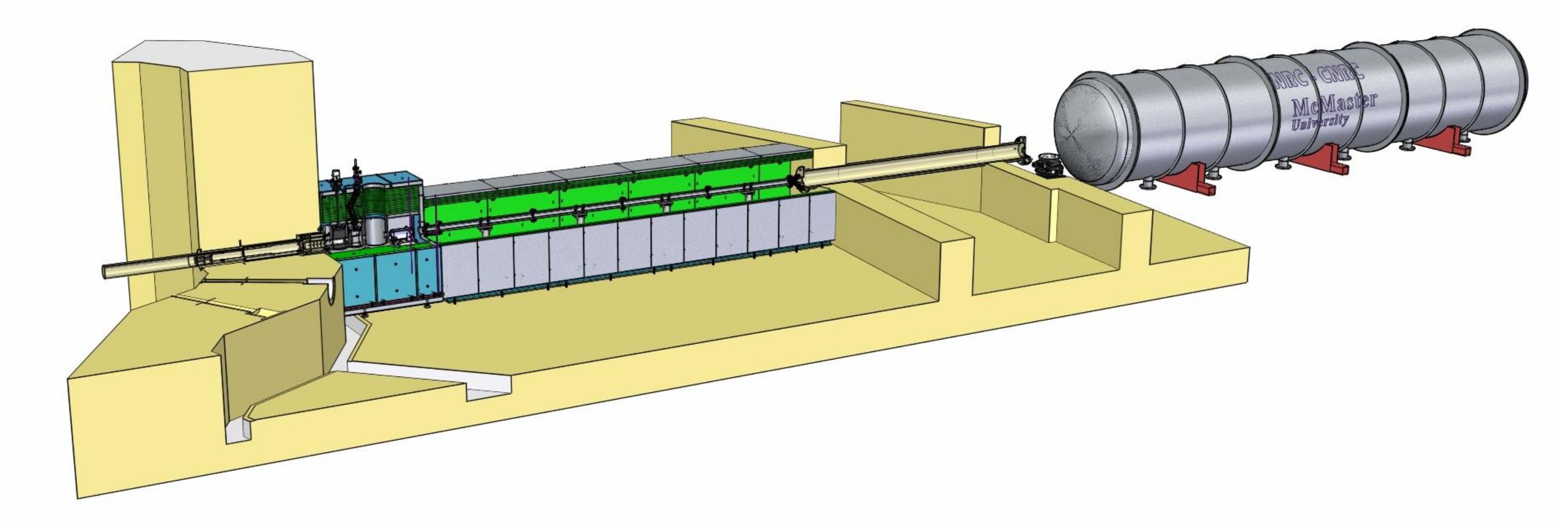




Bertram Brockhouse (1918-2003)
1994 Nobel Prize in Physics
McMaster Professor 1962-1984

MacSANS: Small Angle Neutron Scattering

- State-of-the-art small angle neutron scattering (SANS) beamline for study of nanostructured materials (biological membranes, polymers, high temperature superconductors, novel magnets, metals and alloys)
- Currently under construction on Beamport 4
- Scheduled to begin commissioning experiments in **Spring 2019**



MacSANS Neutron Beam Hall
(Completed Oct. 2017)

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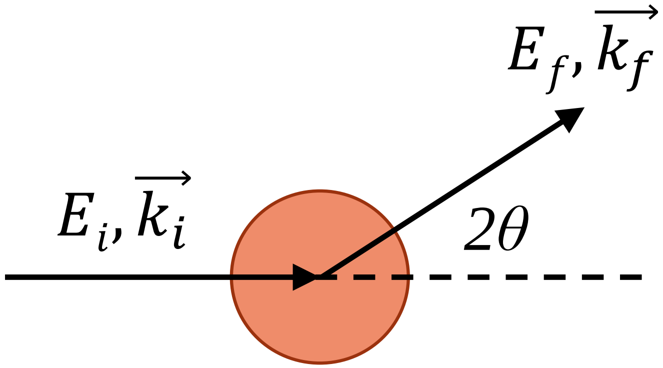
Why Small Angle Neutron Scattering?

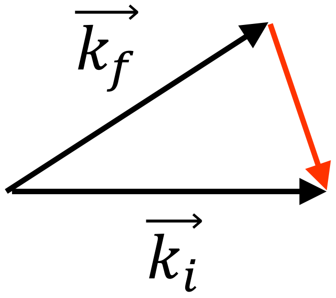
- Neutrons are an ideal tool for investigating the structural and magnetic properties of materials

- Electrically neutral: non-destructive and very penetrating

- Magnetic dipole moment: sensitivity to magnetism

- Scattering length depends on properties of nucleus: elemental/isotopic contrast and sensitivity to light atoms (e.g. H and Li)





$$\vec{Q} = \vec{k_i} - \vec{k_f}$$

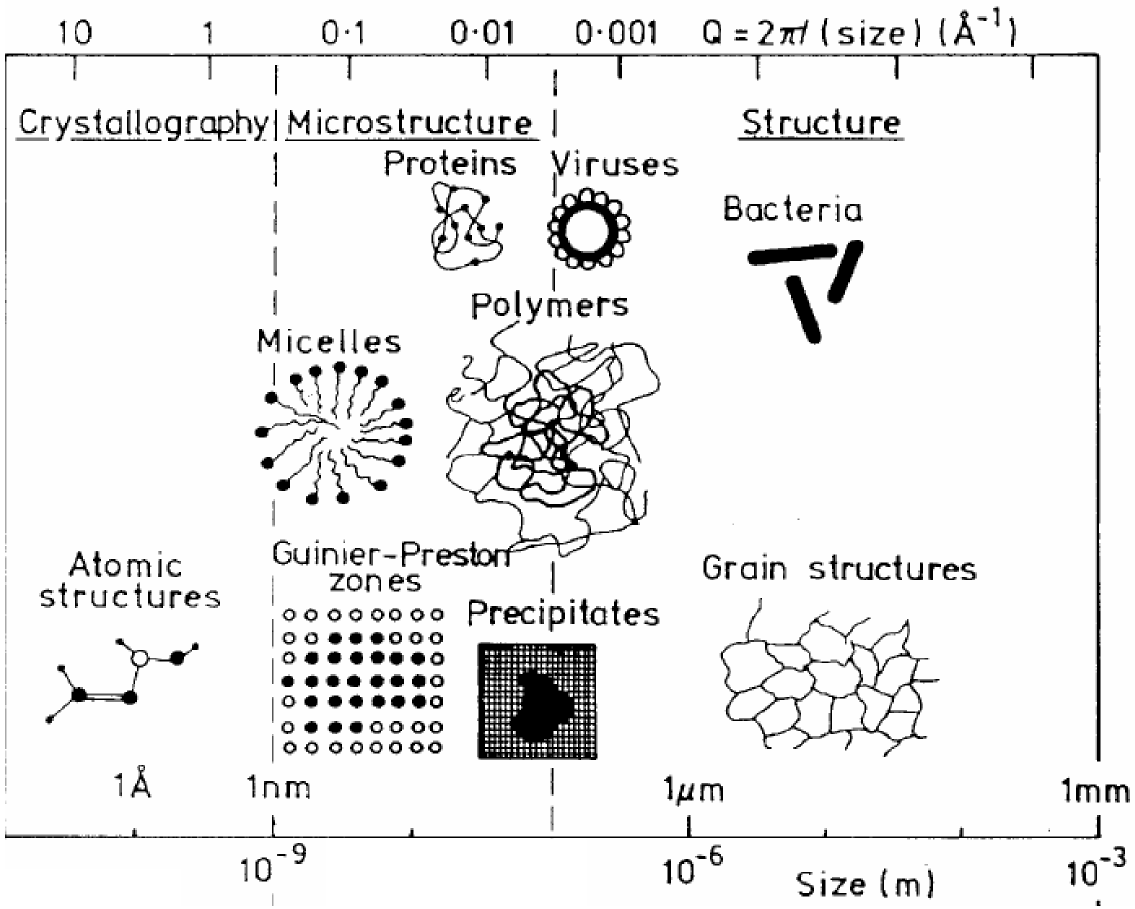
(elastic scattering)

$$n\lambda = 2d\sin\theta$$

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

- SANS is a diffraction (i.e. elastic scattering) technique: probes structure and static properties

For larger length scales, need smaller angles…



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Adapted from C. Glinka, NCNR

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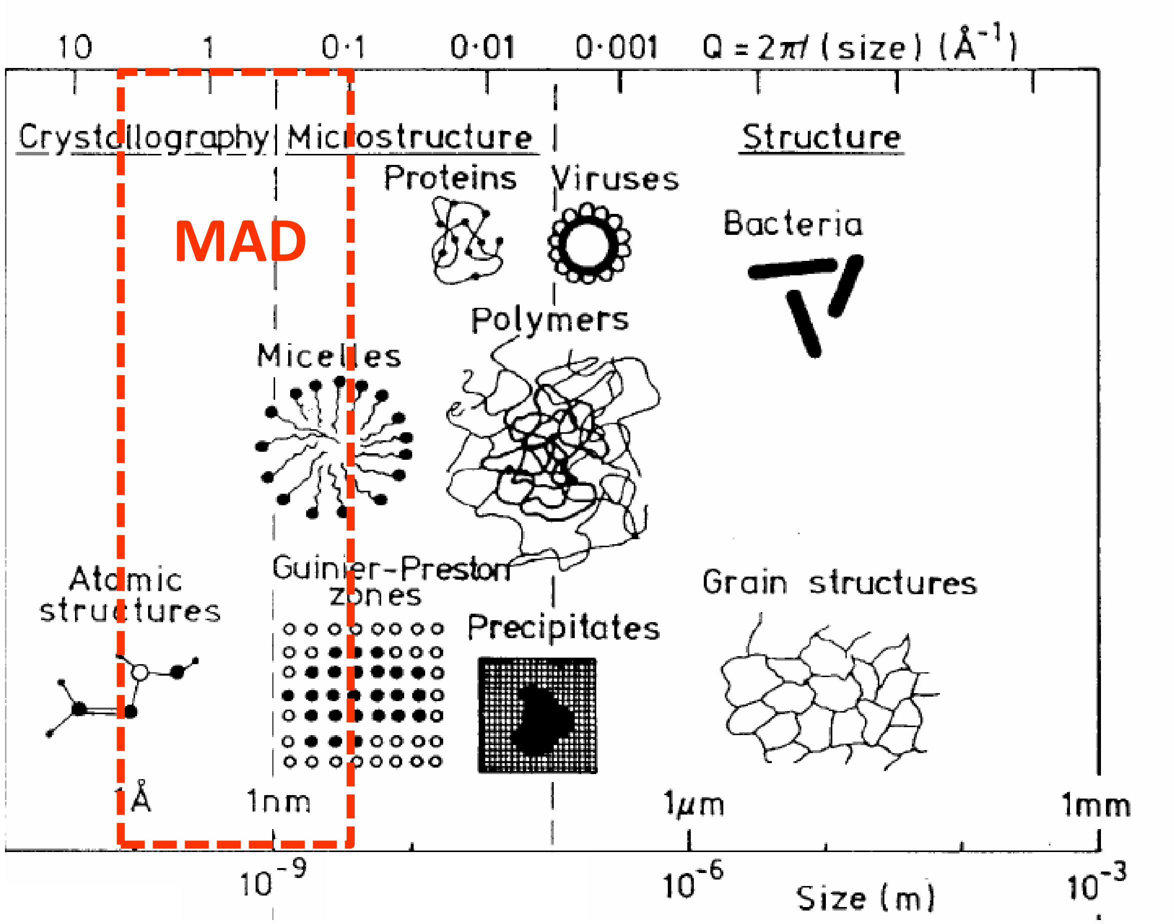

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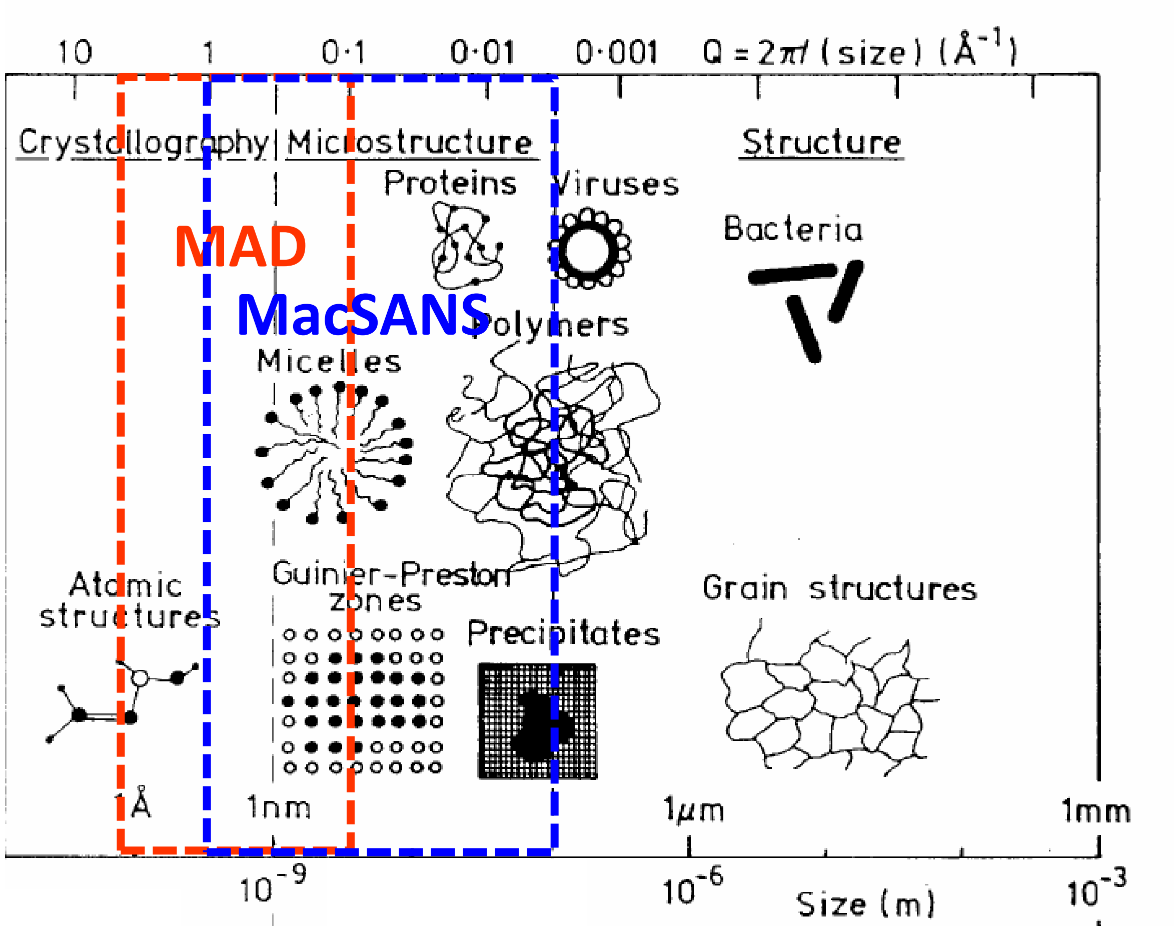
- MAD: wide angle neutron scattering (Q_{min} ~ 0.1 Å^{-1}, length scales < 70 Å)

Adapted from C. Glinka, NCNR

For larger length scales, need smaller angles…

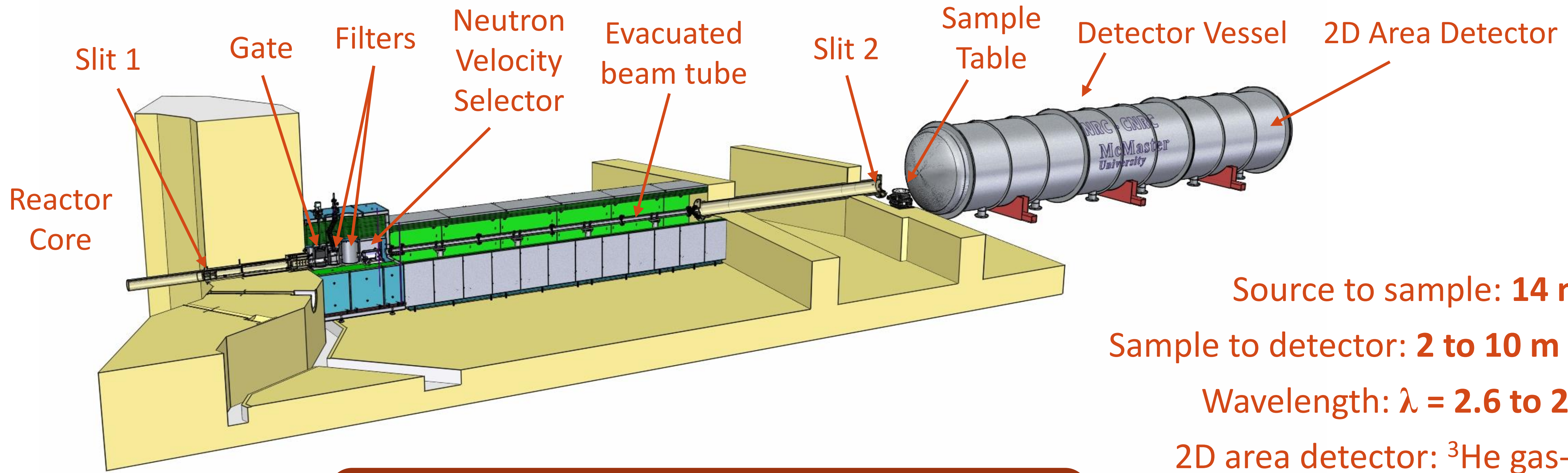


$$Q = \frac{4\pi}{\lambda}\sin\theta = \frac{2\pi}{d}$$

- MAD: wide angle neutron scattering (Q_{min} ~ 0.1 $Å^{-1}$, length scales < 70 Å)
- MacSANS: small angle neutron scattering (Q_{min} ~ 0.005 $Å^{-1}$, length scales < 1300 Å)
- Opens up many new opportunities for condensed matter science (hard and soft)

Adapted from C. Glinka, NCNR

MacSANS Instrument Design



Source to sample: **14 m**

Sample to detector: **2 to 10 m** (variable)

Wavelength: **λ = 2.6 to 23 Å**

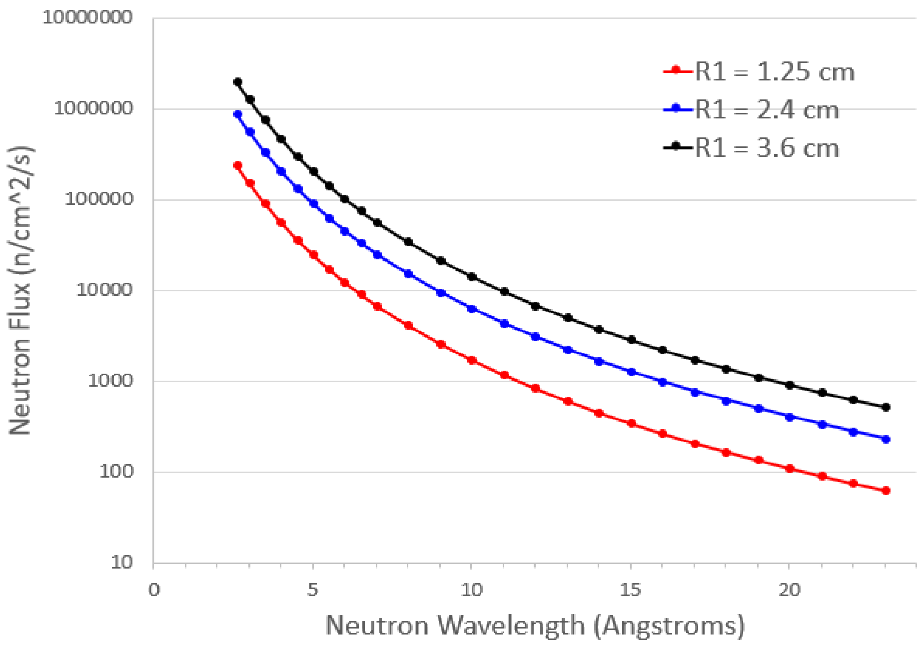
2D area detector: ^{3}He gas-filled **1m × 1m** area, **7 mm** resolution

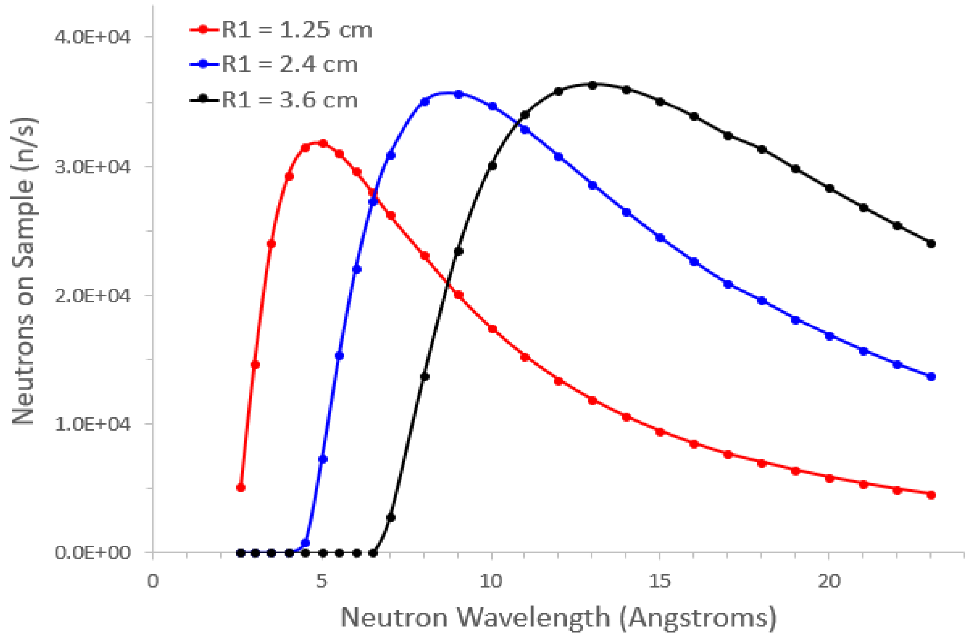
Q-range: **0.005 to 1.25 $Å^{-1}$**

MacSANS probes structure and magnetism on length scales ranging from **0.5 nm to 125 nm**

MacSANS Instrument Performance

- Predicted instrument performance for high resolution setting:

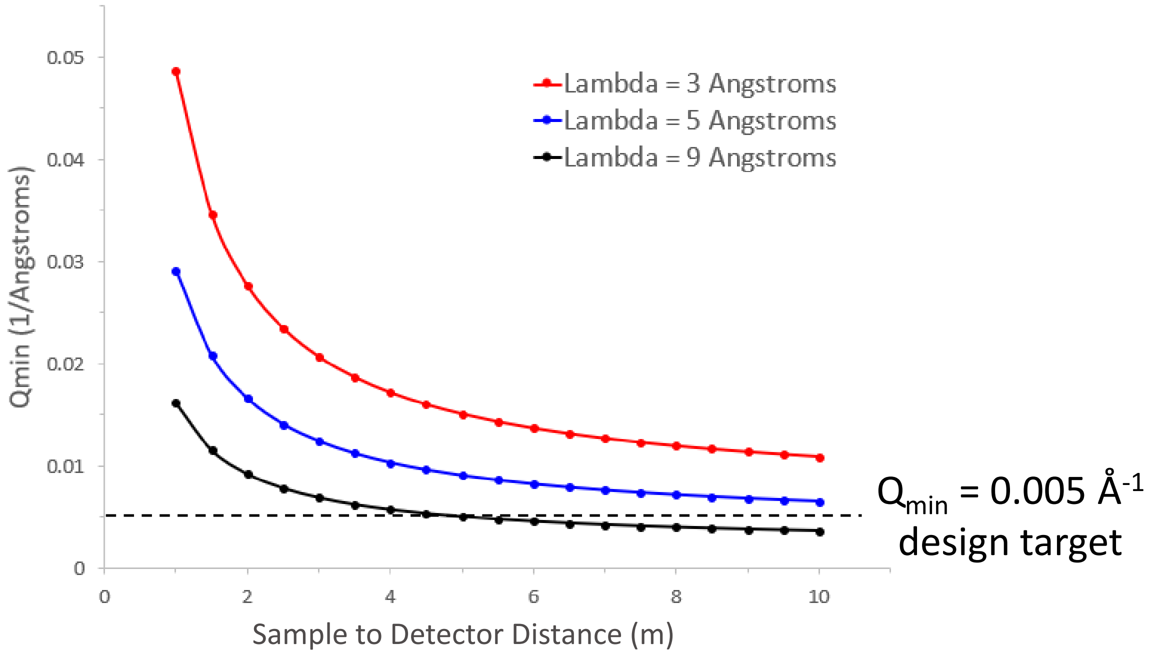


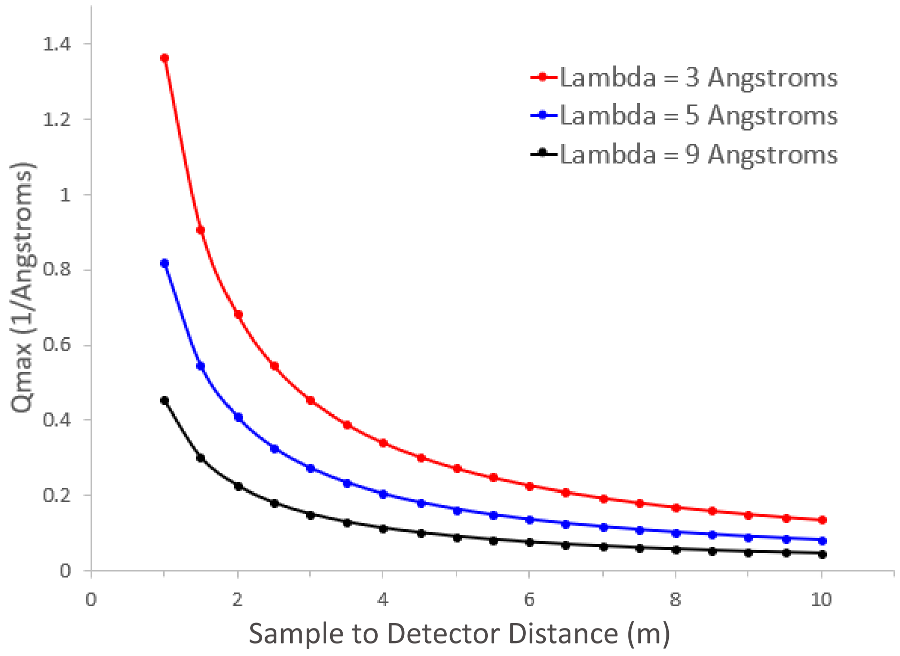


- Fix Q_{min} = 0.005 Å^{-1}, 10 m sample to detector distance, 3 possible choices for source aperture size (R1)
- **~3.5 × 10^4 neutrons/sec** at the sample position

MacSANS Instrument Performance

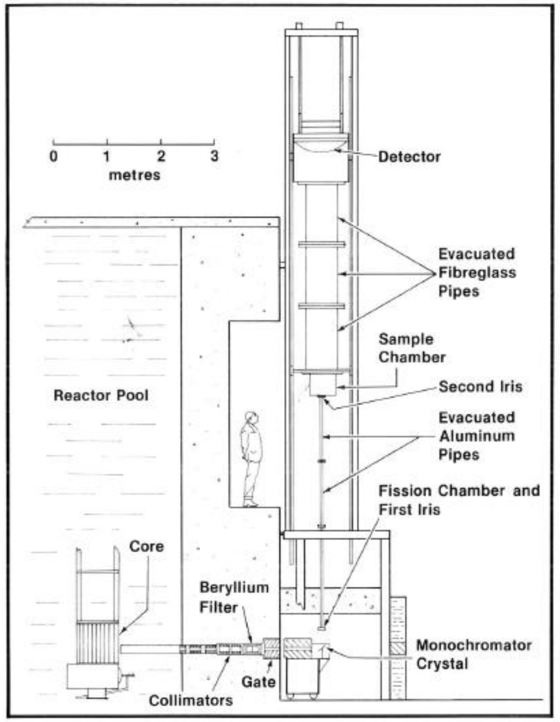
- Predicted instrument performance as a function of detector position:

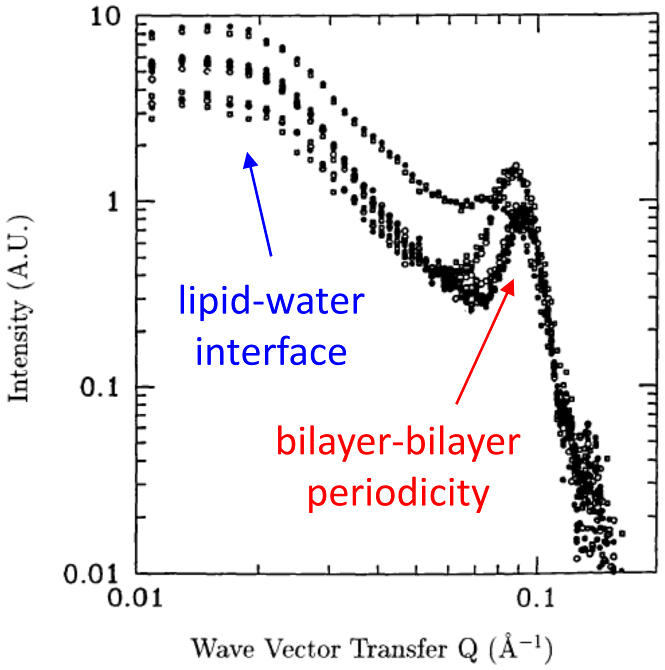




- Fix radii of source and sample apertures (R1 = 1.25 cm, R2 = 1.0 cm), 14 m source to sample distance (neglect horizontal detector translation)

Flashback: Canada's First SANS Beamline



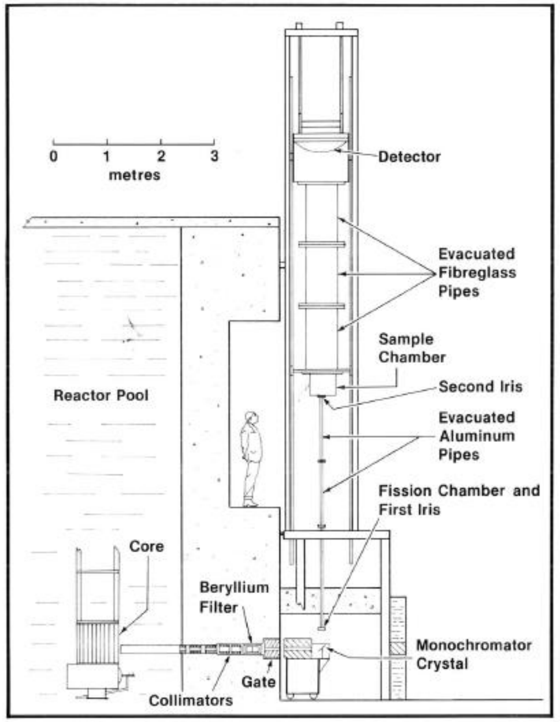


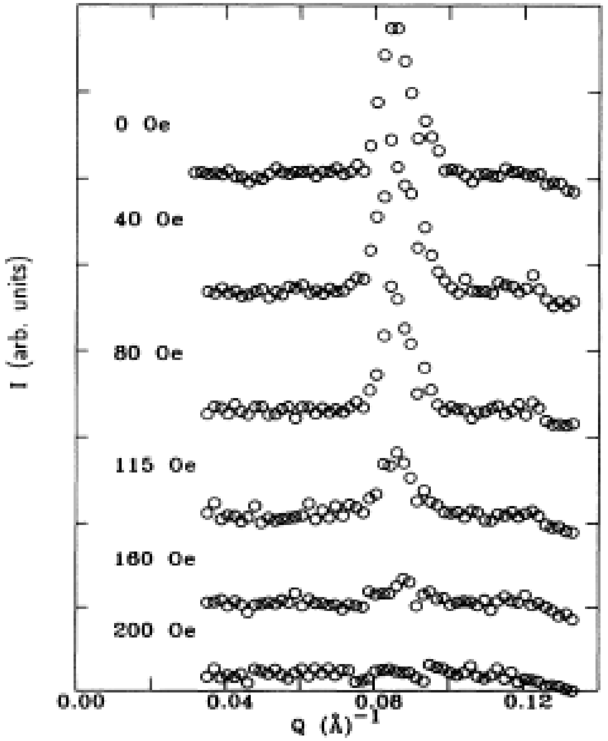
J. Avelar et al, Mat. Res. Soc. Symp. Proc. (1995)

- DPPC lipid membrane suspension in D_2O
- 3 phases: gel, ripple, and liquid crystal
- Track temperature evolution with SANS

- Beamport #3 at MNR: Vertical SANS (operational 1987 to 2003)
- Q-range: 0.012 to 0.085 Å^{-1} (detector at 4.5 m), 0.04 to 0.3 Å^{-1} (detector at 1.05 m)

Flashback: Canada's First SANS Beamline





X. Bian et al, Phys. Rev. B (1994)

- Magnetic ordering of $Ni_{80}Co_{20}$/Cu multilayers
- Measure bilayers 50Å-20Å-15Å thick
- Coalign 30 bilayers in sample
- Track field dependence of (0,0,0.5) magnetic Bragg peak with SANS

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MacSANS Timeline

April 2012:
CFI proposal submitted

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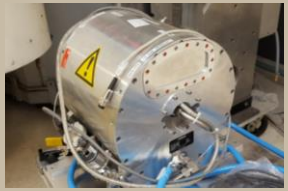
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

November 2012:
CFI funding awarded

October 2016:
Construction of SANS Experiment Hall begins

May 2017:
Velocity selector arrives



October 2017:
SANS Experiment Hall complete

June 12^{th}, 2018:
2018 CAP Congress

(YOU ARE HERE)

Summer 2018:
Fabrication of primary components

Fall 2018:
Installation of primary components

March 2019:
Area detector arrives

Spring 2019:
COMMISSIONING BEGINS

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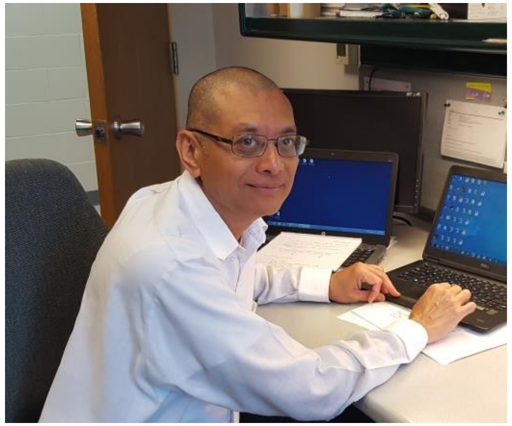
Acknowledgments

Bruce Gaulin & Chris Heysel



Zin Tun

Derrick West

Mark Vigder

Marek Kiela

- The neutron scattering program at MNR is grateful for incredible support from the staff of the McMaster Nuclear Reactor and the Canadian Neutron Beam Centre at Chalk River
- Funding for MacSANS is provided by the Canadian Foundation for Innovation and the Ontario Innovation Trust

CANADIAN NEUTRON BEAM CENTRE
Probing Materials for Science and Industry

McMaster Nuclear Reactor

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Ontario Innovation Trust

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