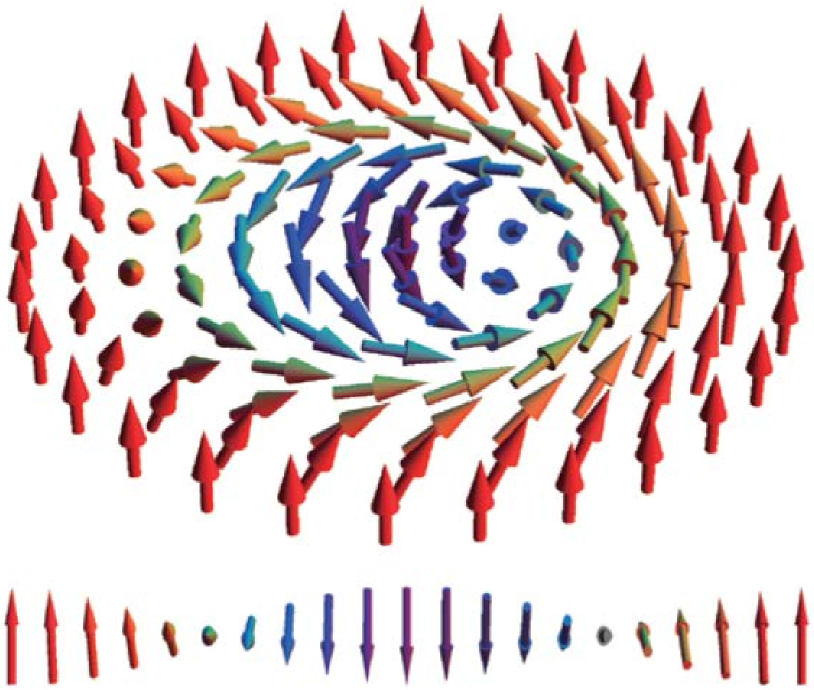
Depth Dependence of Skyrmions in Thin Films

Lizabeth Quigley

What are Skyrmions?

- Topologically protected magnetic whirlpools
- Difficult to destroy or deform
- Easy to move with electric currents
- Thin films are best for electronics
    - Fit within existing devices
    - Mostly surface interface

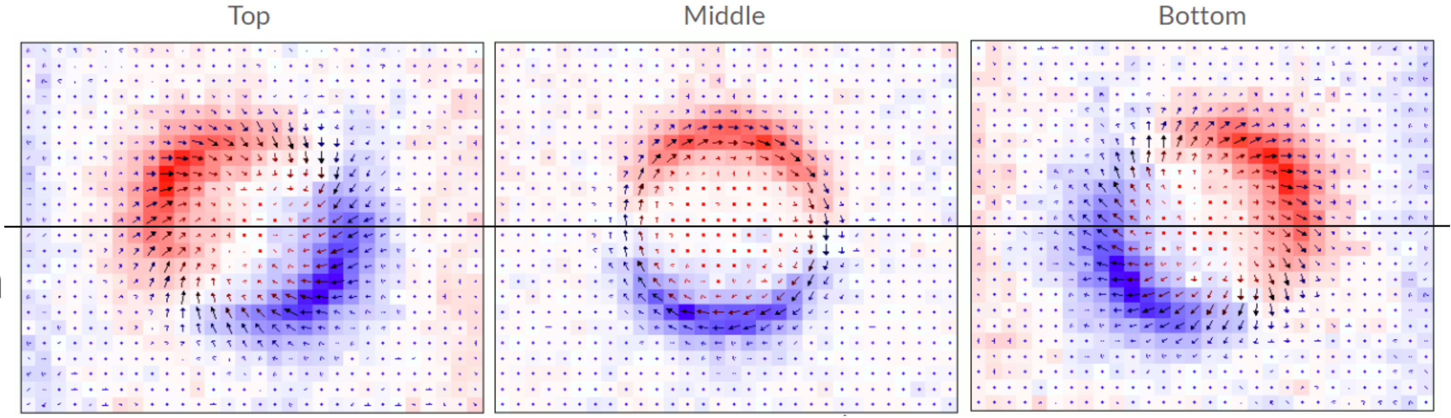
Need to discover difference between the surfaces and middle of thin film skyrmions



I. Kézsmárki, Nature Materials (2015)

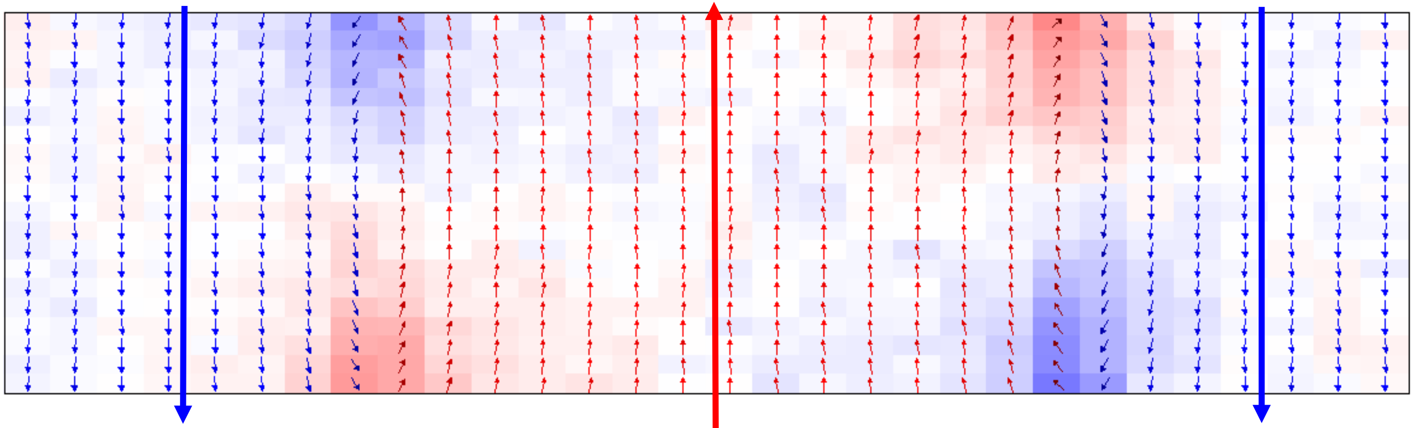
Skyrmion Differences

- Thin film depth profile is still unknown
- Top and bottom differ from middle



Top down view

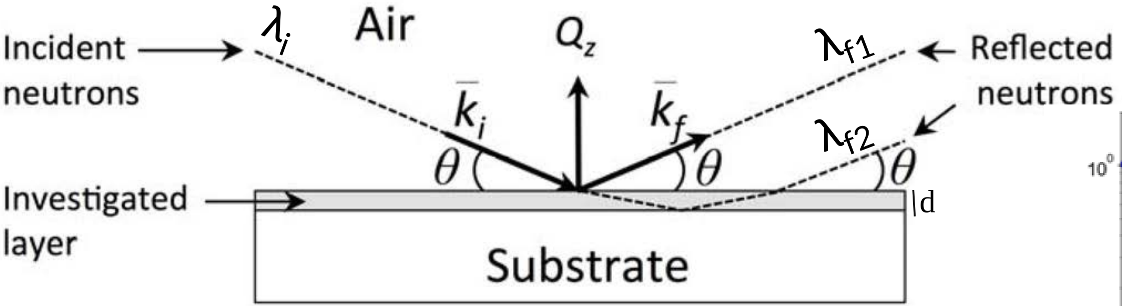
Blue → arrows pointing left
Red → arrows pointing right



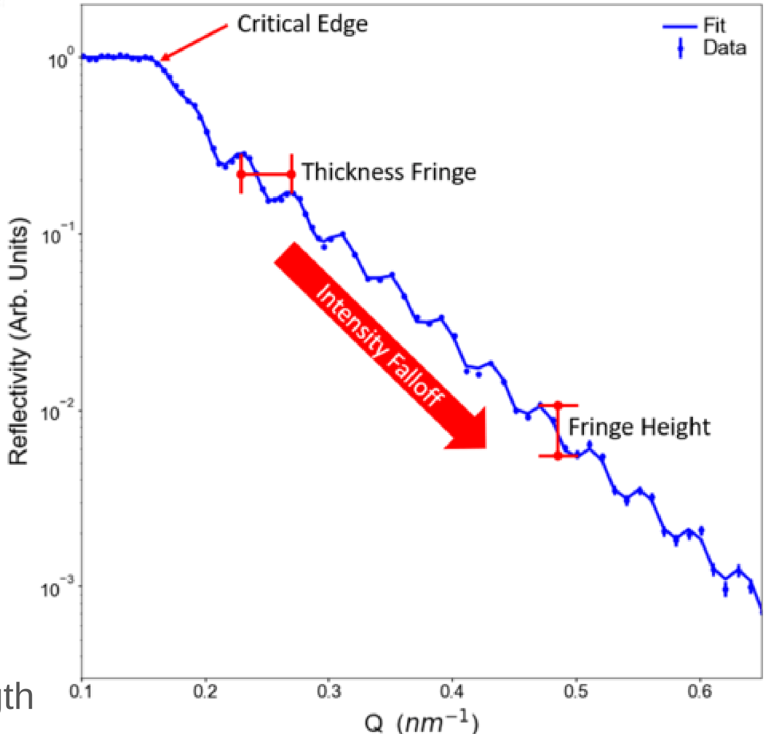
Side view

Reflectometry

$n\lambda=2d*\sin(\Theta)$
Peak → constructive λ_{f1} and λ_{f2}
Valley → destructive λ_{f1} and λ_{f2}



Michael Demkowicz and Jaroslaw Majewski, Metals (2016)

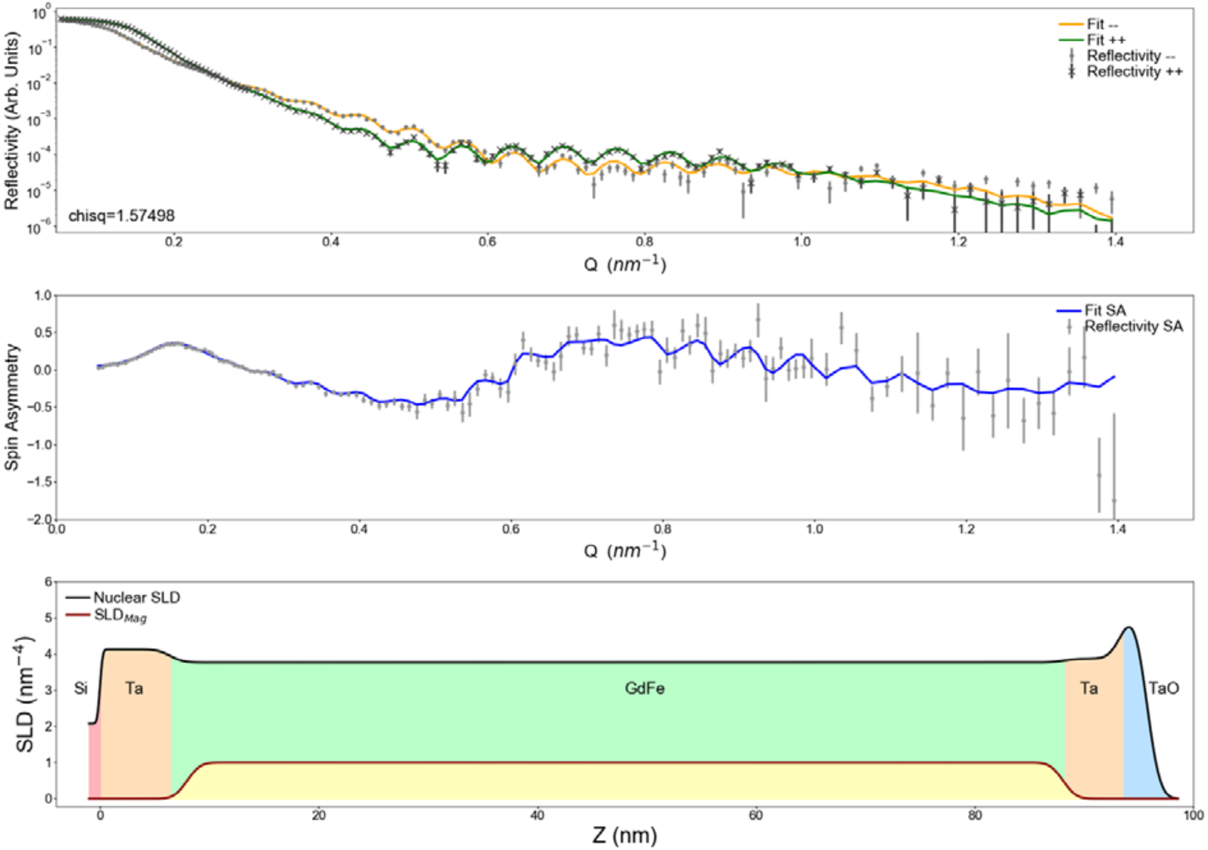


https://w3auth.nist.gov/ncnr/understanding-nr-data-features

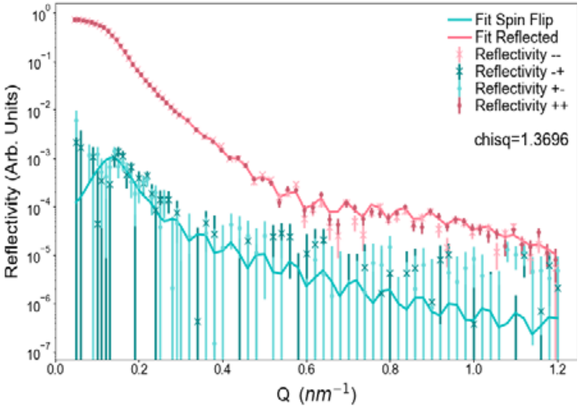
- ❑ Intensity Falloff → Roughness
- ❑ Critical Edge → Where neutrons go through the sample
- ❑ Thickness Fringe → Thicknesses
- ❑ Fringe Height → Layer contrast
- ❑ ↑↑ ↓↓Splitting → Magnetization along field
- ❑ ↑↓ ↓↑ Spin Flip → Magnetization perpendicular to field
- ❑ Scattering Length Density (SLD) → scattering power of material based off of density and nuclear scattering length

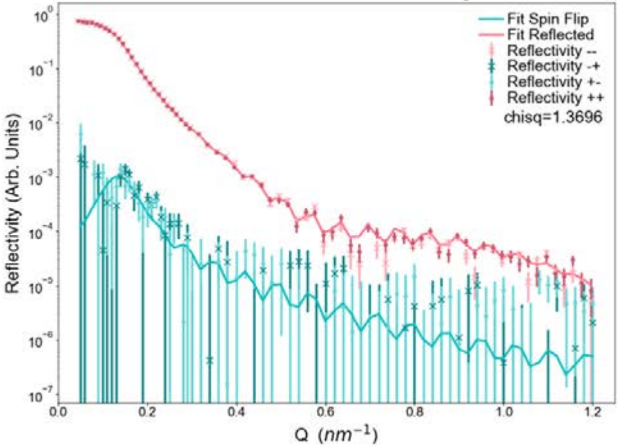
Polarized Neutron Reflectometry (PNR)

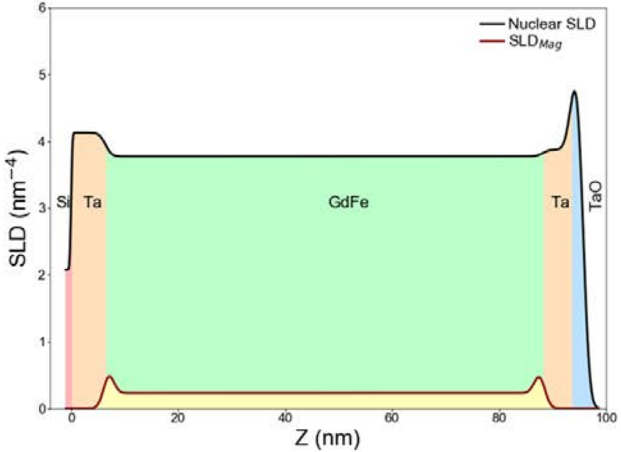
- Saturated magnetization
- Fit with Refl1D
  - Fit scattering length densities (SLDs), thicknesses, interfaces, and percentage iron
- Developed parameters to be used in later fits and models
- Final fit goes with what we know about skyrmions
- Gives depth profile

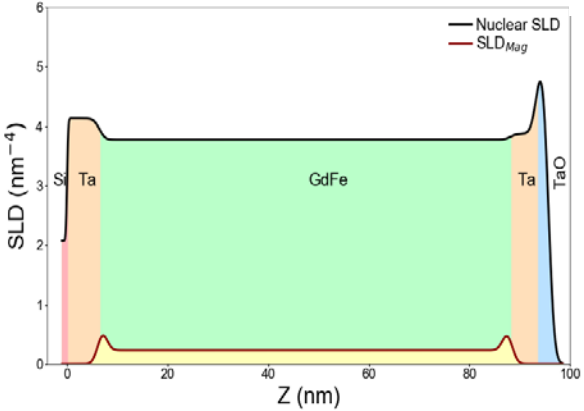


Skyrmion State Reflectometry



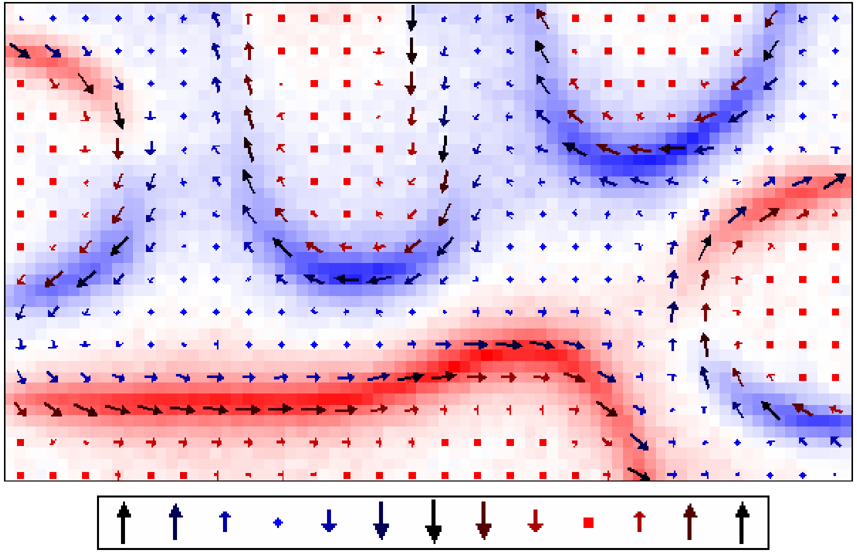


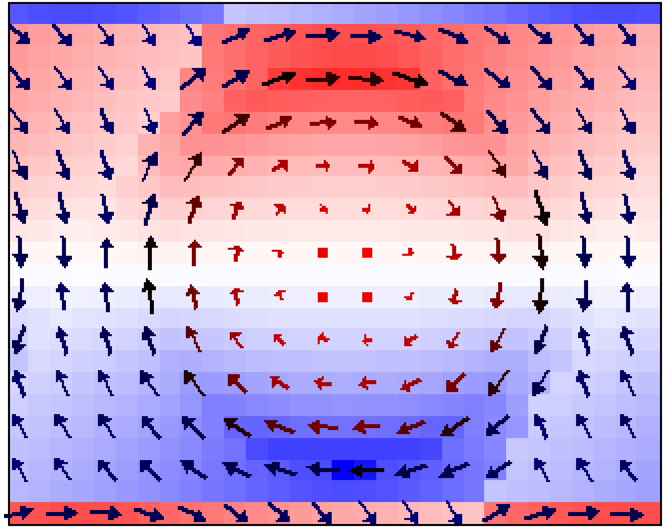




- Magnetization was out of plane
  - Neutrons hit in plane magnetization of skyrmions
- Only magnetic SLD was fit
  - GdFe was split into three sections to allow for differing magnetization
- Many possible solutions

Object Oriented MicroMagnetic Framework (OOMMF)





Goals:

How different parameters affect the model

Build model of thin film

Varying Exchange Energy

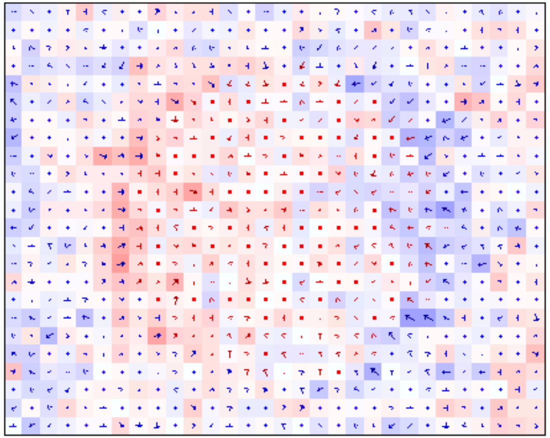
Anisotropy = 200e3 J/n

Magnetization = 3.52 A

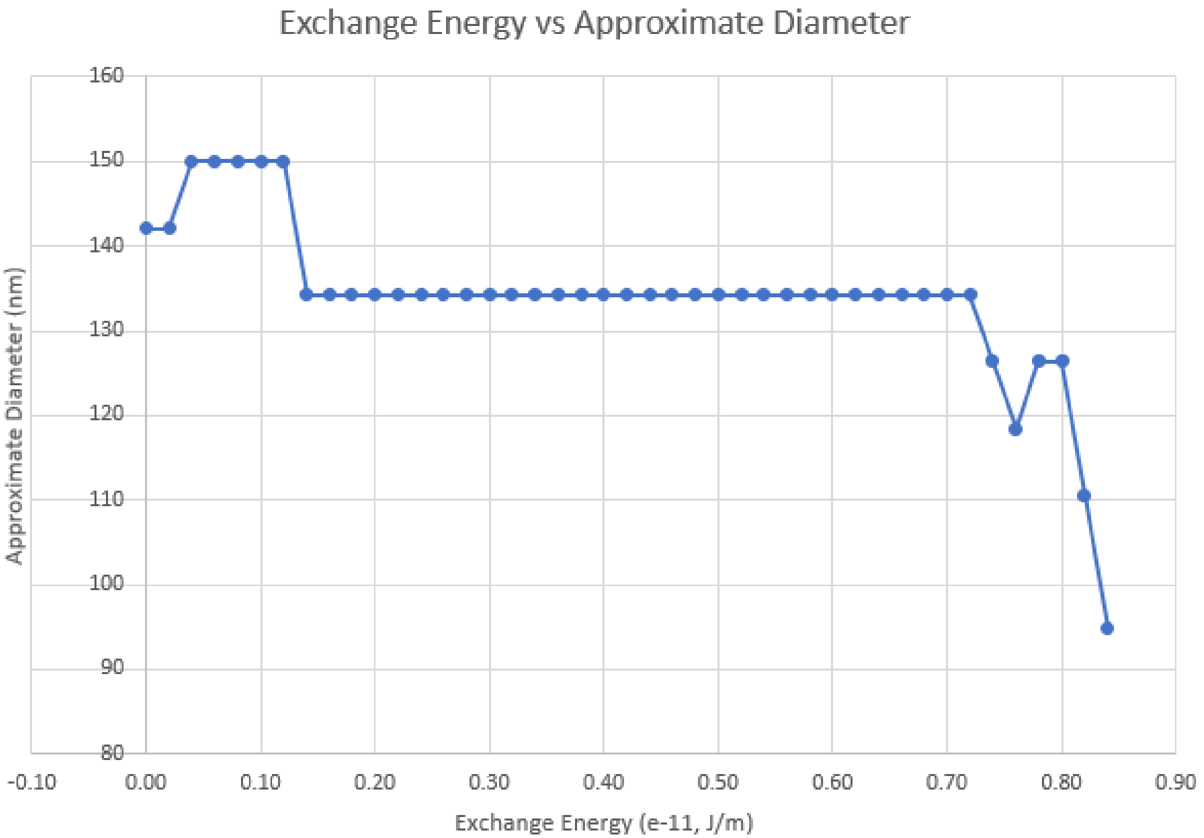
How much the magneti

the same direction

Top



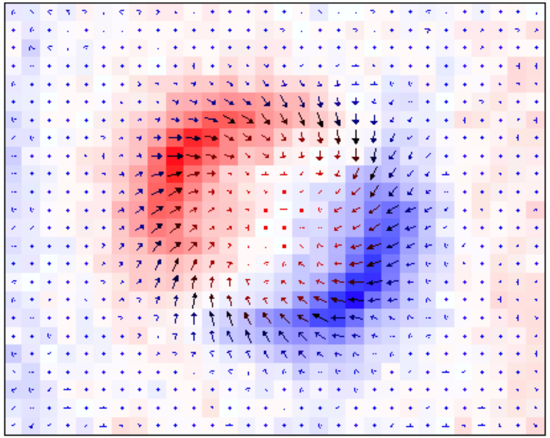
Exchange=0.00 J/m e-11



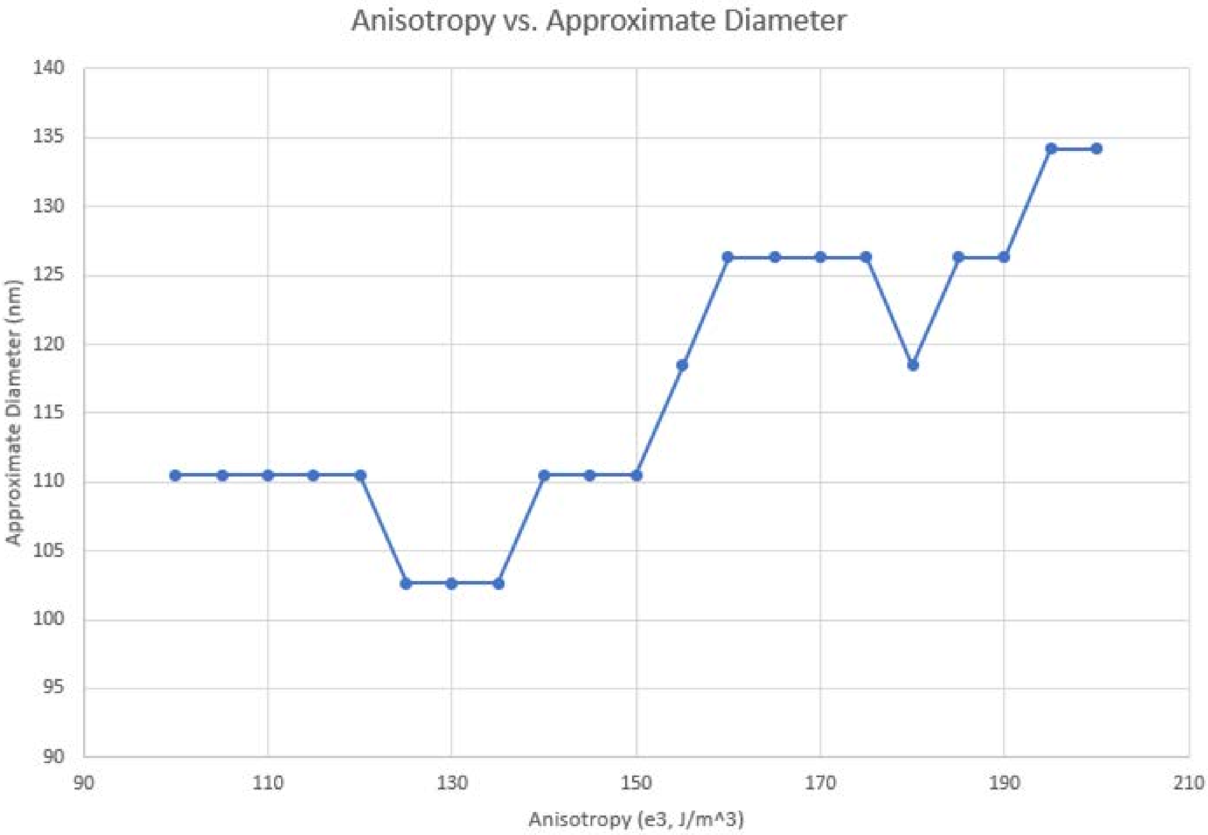
Varying Anisotropy

Exchange Energy = (
Magnetization = 3.52
How much one magr
a direction, not deper

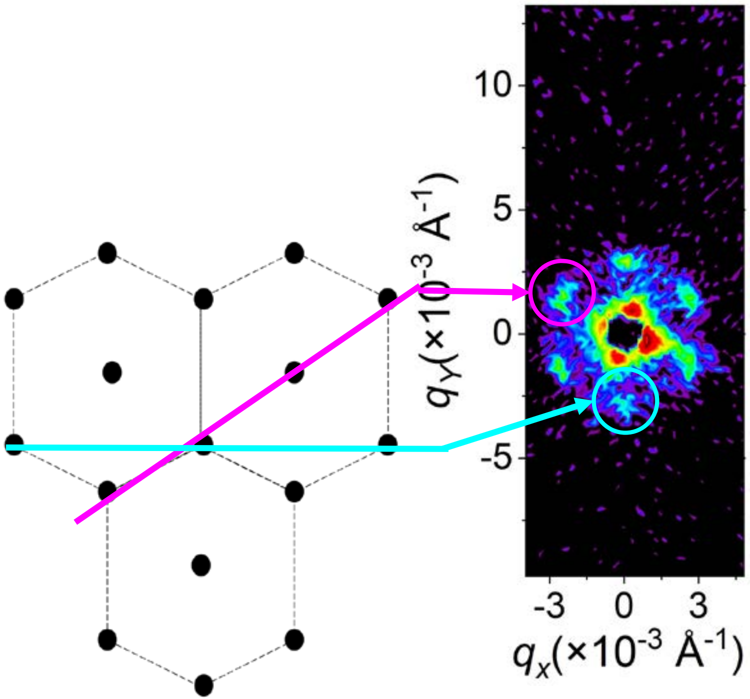
Top

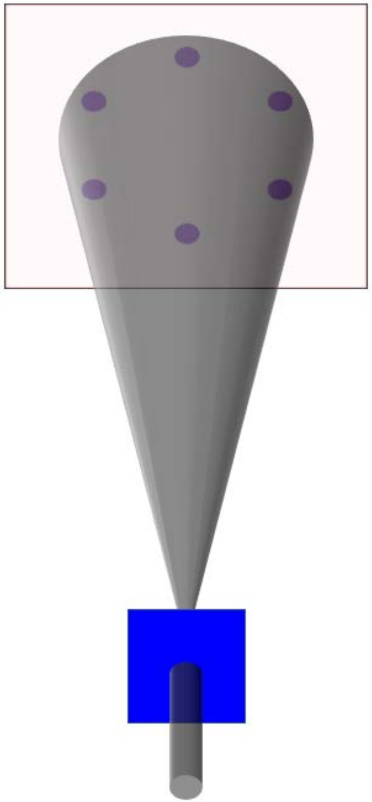


Anisotropy= 100e3 J/m^3

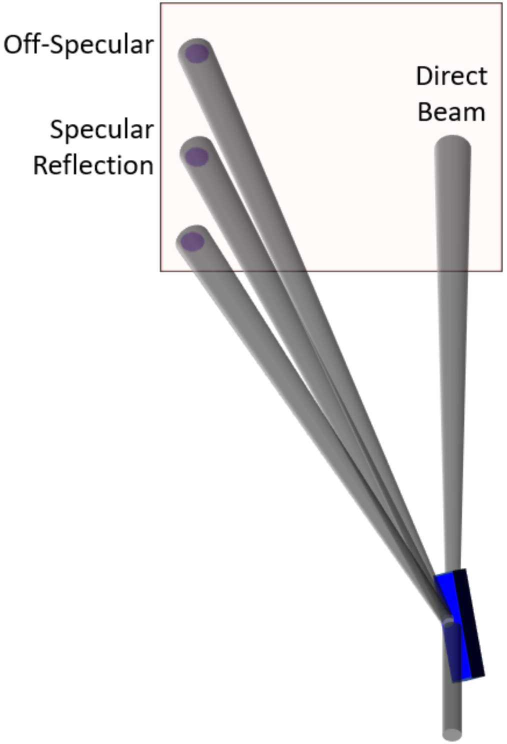


Small Angle Neutron Scattering (SANS)



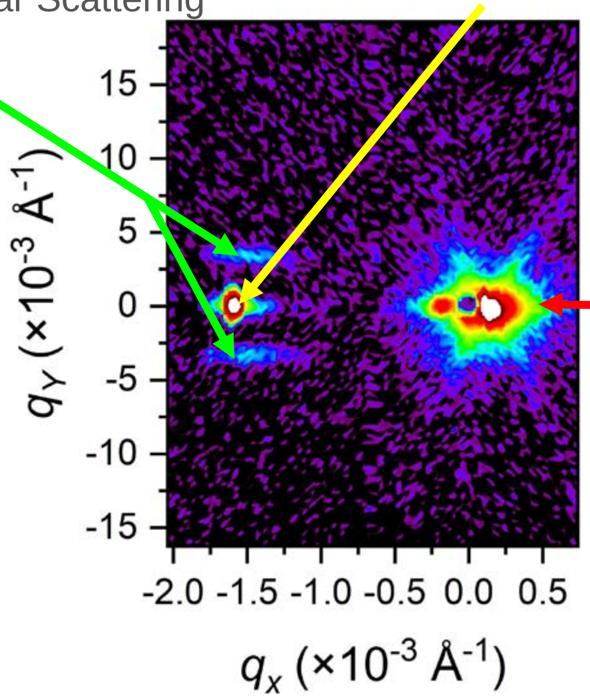


Grazing Incidence Small Angle Neutron Scattering (GISANS)



Off-specular Scattering

Specular Scattering

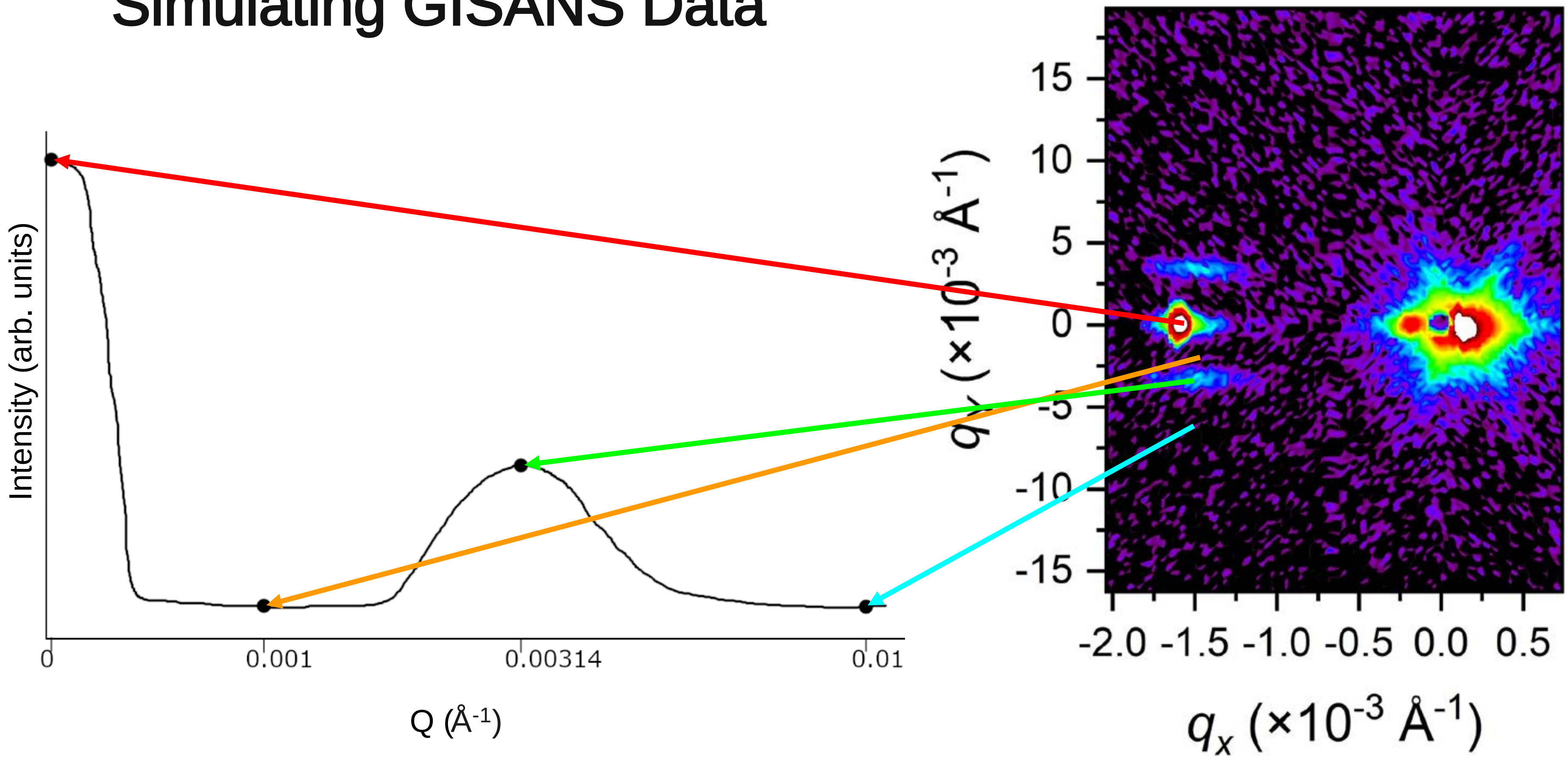


Beam passing through sample

Specular- reflecting off sample at the same angle that it came in with

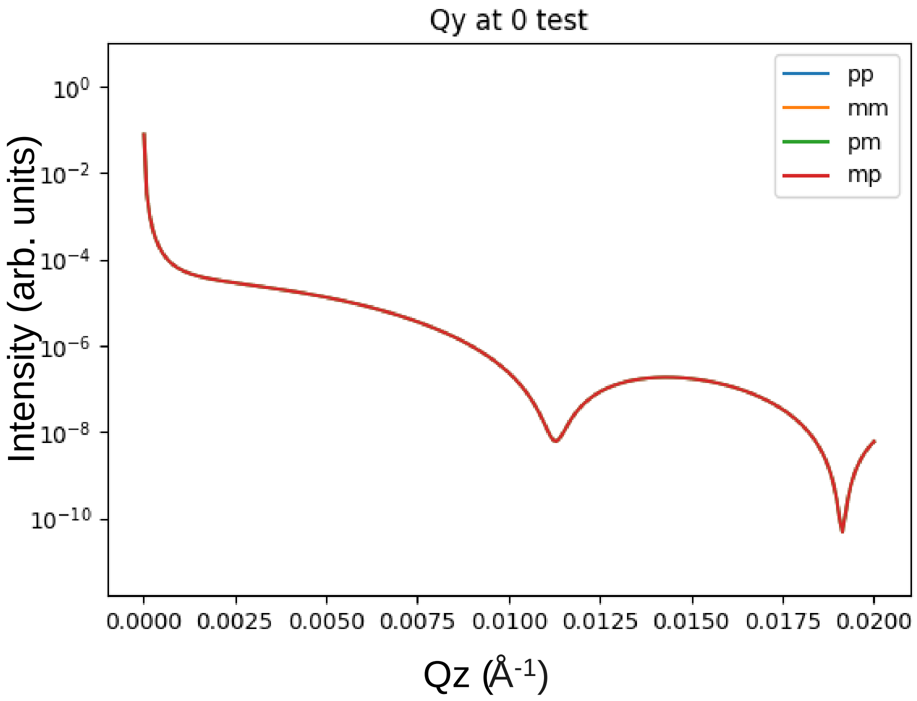
Off Specular- reflecting at a different angle then what it came in with

Simulating GISANS Data

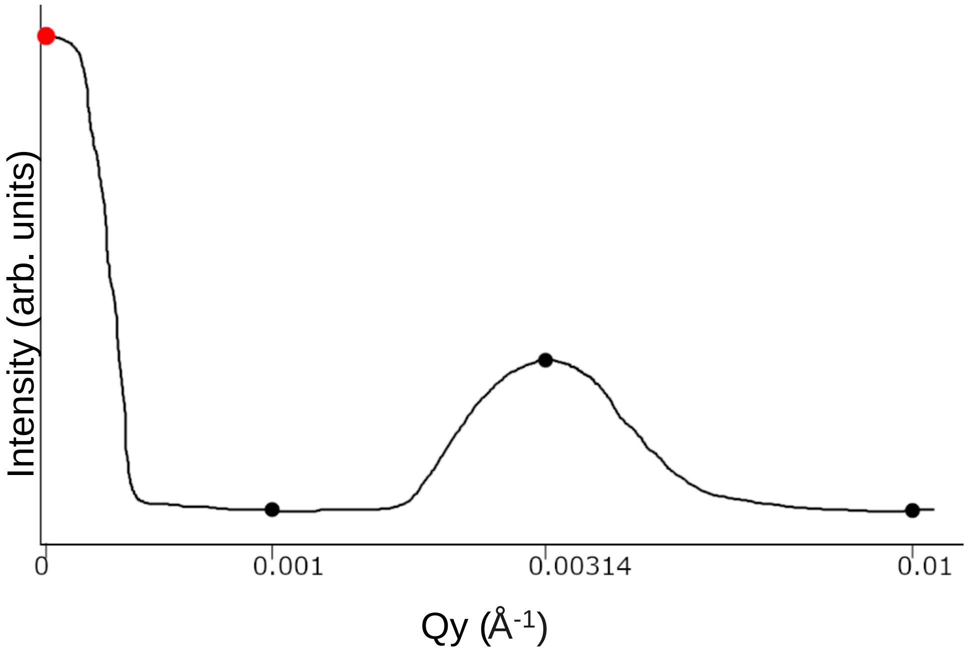


Simulating GISANS data

Simulated GISANS



Location



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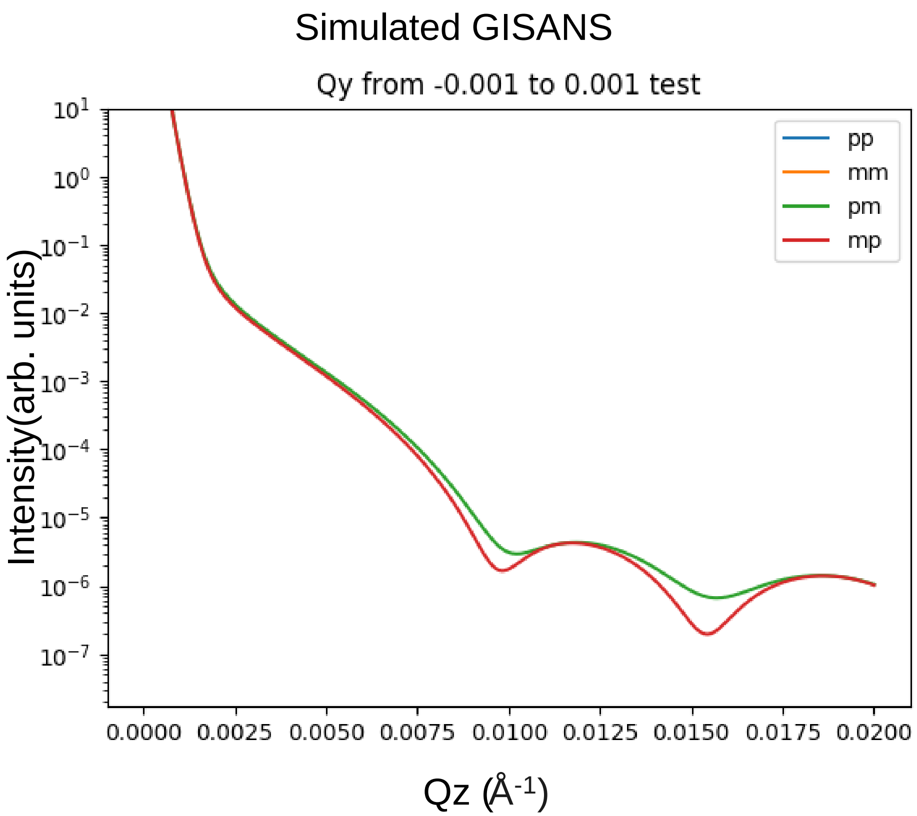

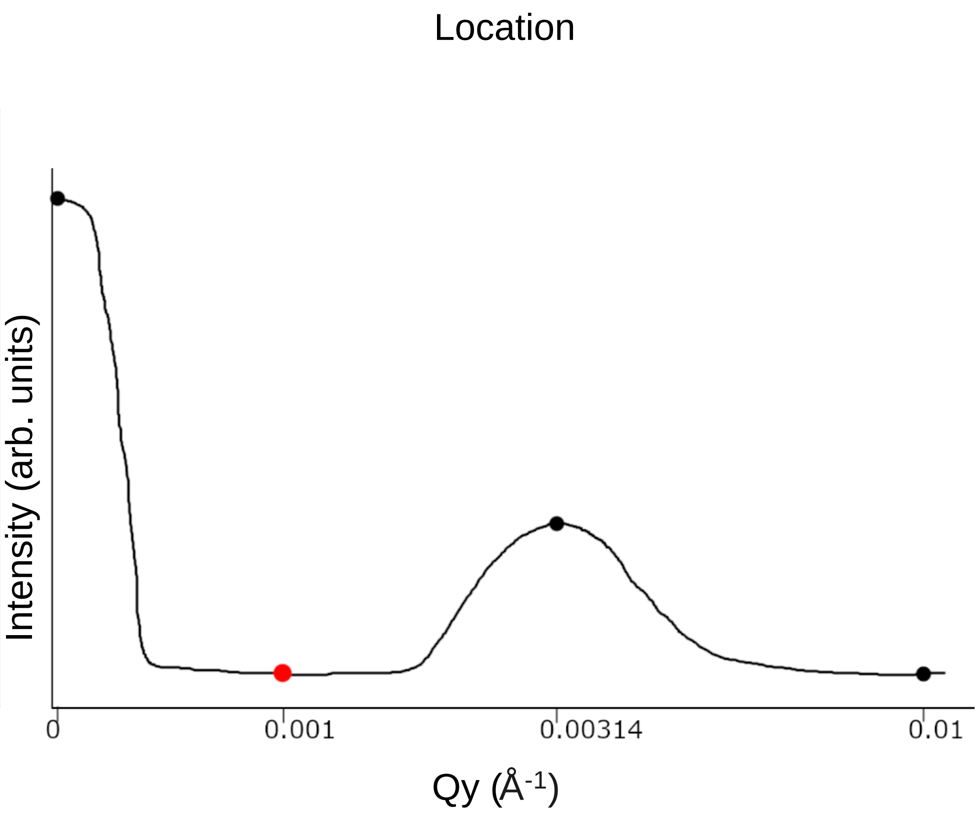

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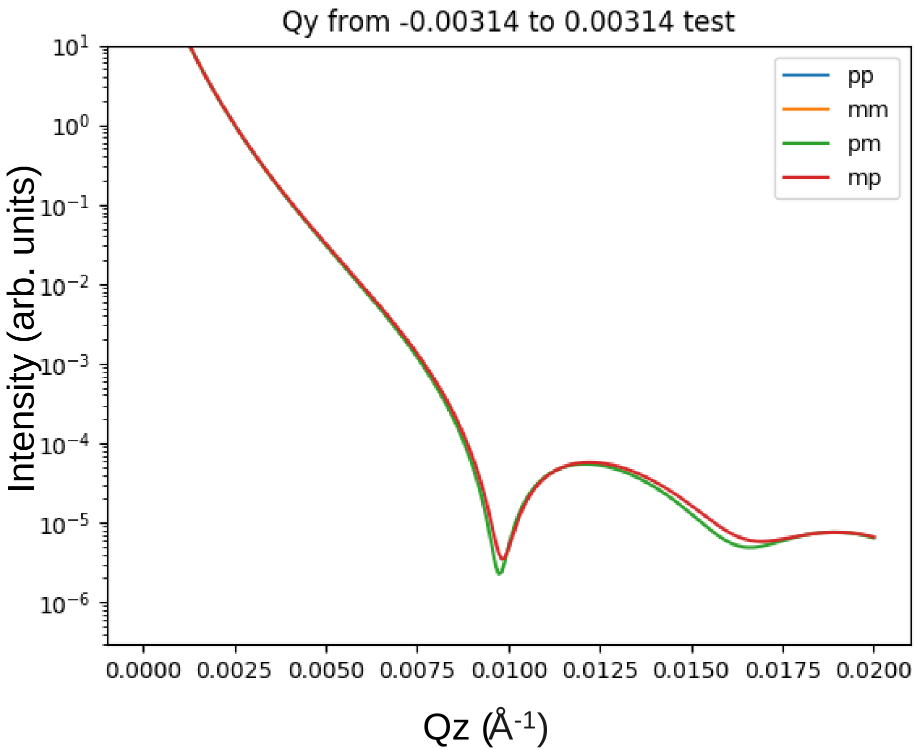

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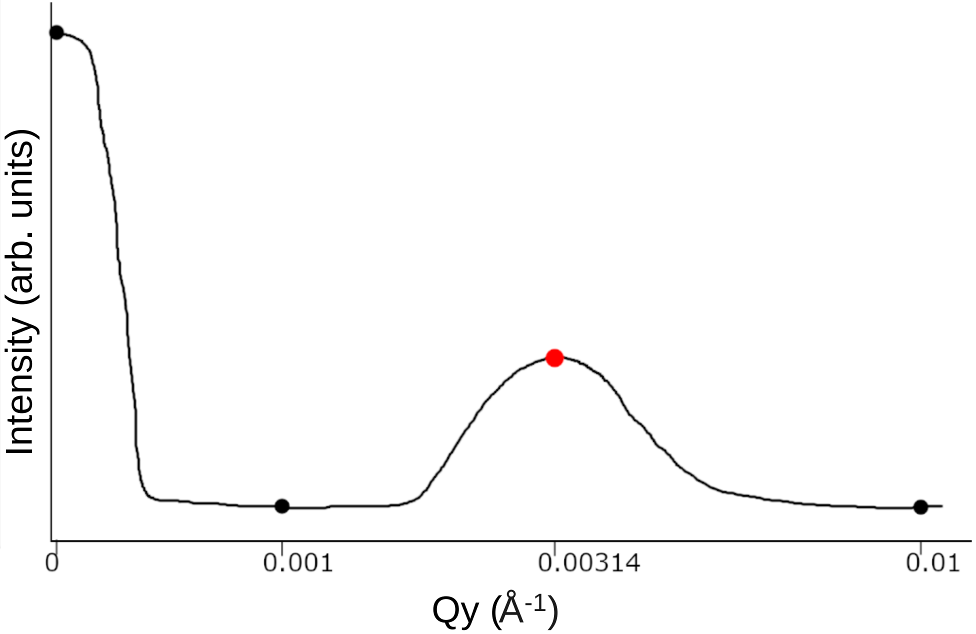

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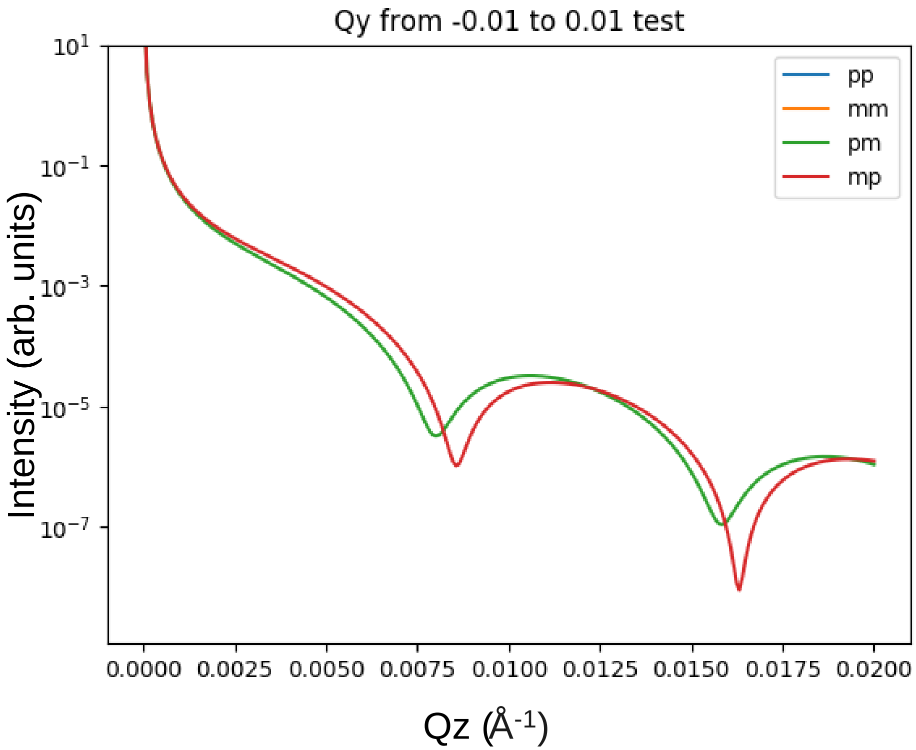

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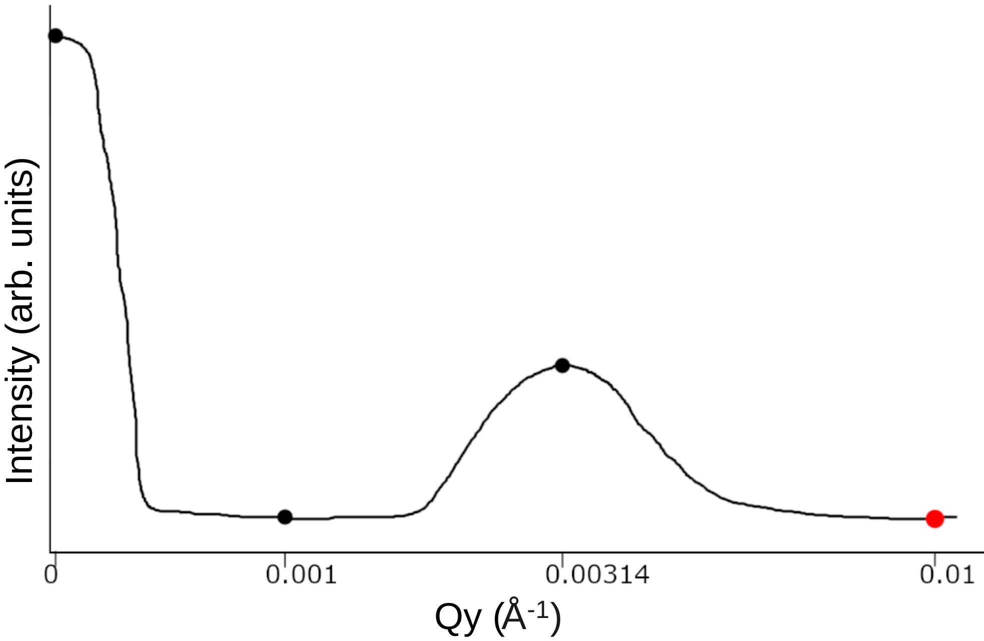

Future Work:

- ❑ Compare simulate GISANS data with actual data
- ❑ Make the two data sets equal
- ❑ Add neutron absorption by Gd to the code

Thanks to:

- ❑ NIST
- ❑ NCNR
- ❑ CHRNS
- ❑ Dr. Alex Grutter
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- ❑ Dr. Brian Maranville