3rd Lecture
NSE

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NSF NSE Workshop October 28th, 2021

University of Delaware

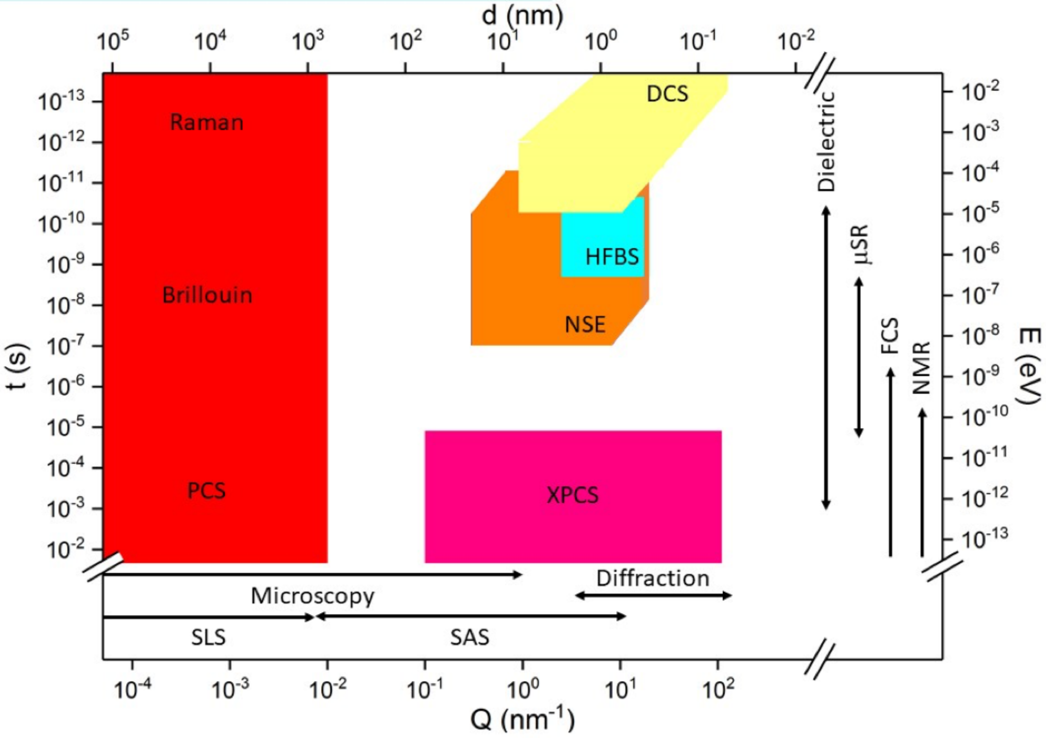
Learning Goal

- ✓ Understand the length/time range covered by NSE.
- ✓ Understand the principle of NSE operation.
- ✓ Understand the types of soft matter problems that can be solved by NSE.
- ✓ Understand the new opportunities for the upgraded NSE at NIST.
- ✓ Understand how to plan a successful NSE experiment.

Outline

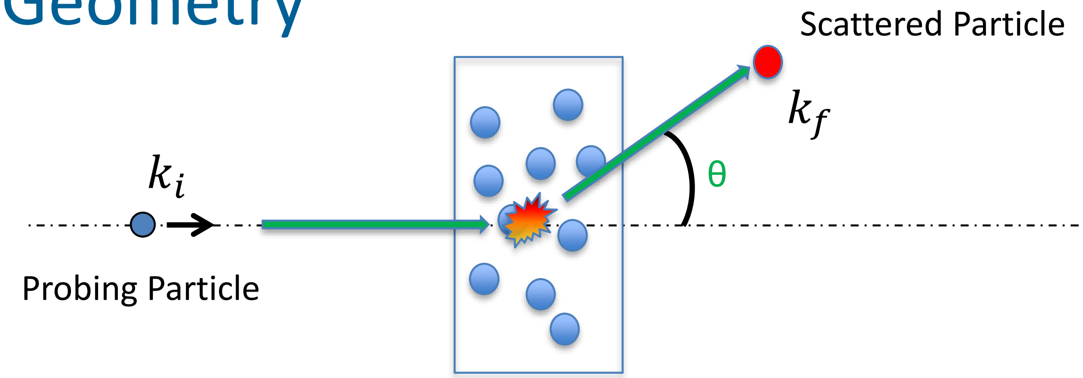
- Dynamic range
- Conventional QENS machine
- Principle of NSE
  - Neutron polarization
  - Larmor precession of neutron spins in a magnetic field
  - Fouier time
  - Measurement of S(Q,t) and S(Q,0)
- NSE data reduction
- Example science on NSE
- Upgrade of the CHRNS-NSE
- Planning a NSE experiment

Dynamic Range

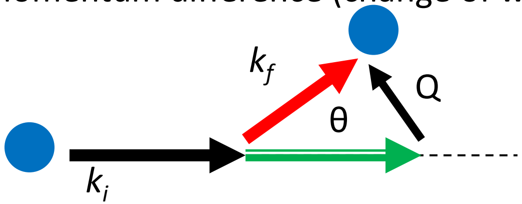


- NSE is one of QENS techniques
- NSE covers smallest Q (biggest size) and longest t (smallest energies or slowest motions) among them

Scattering Geometry



1. Momentum difference (change of wave vector)



2. Energy difference

$|k_i| \neq |k_f|$

$\Delta \mathrm{E} = E_f - E_i = \hbar\omega$

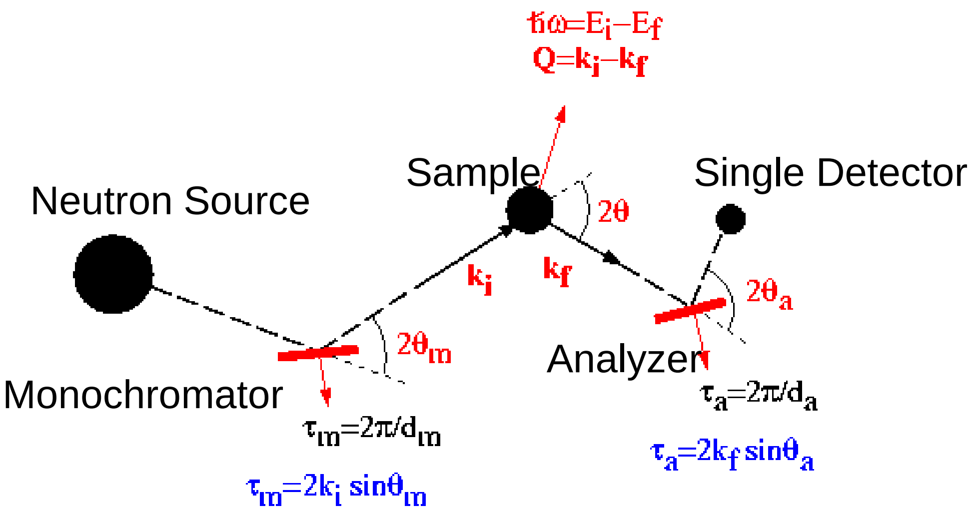
The scattering intensity, $I(\theta, E_i, E_f)$, can be rewritten as $I(Q, \Delta E), or\ I(Q, \omega)$.

Dynamic scattering: $\frac{d^2\sigma}{d\Omega d\Delta E} = S(Q, \Delta E)$

How to measure dynamic neutron scattering?

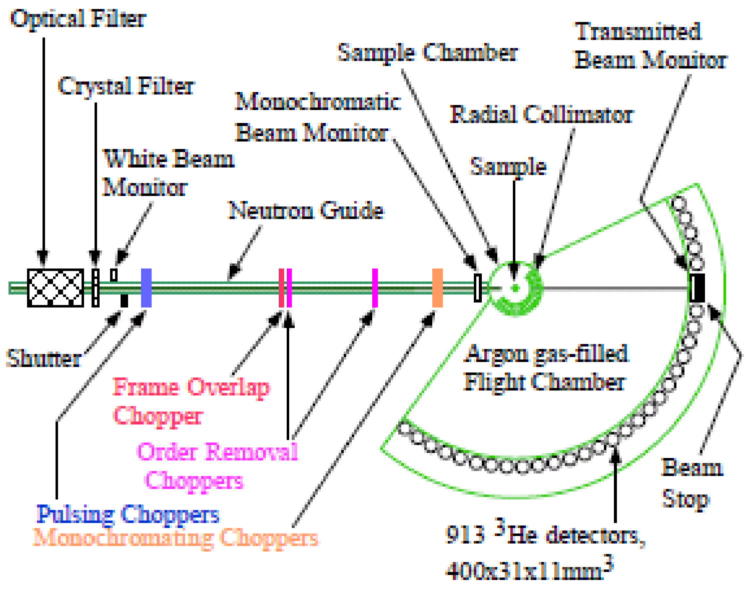
Triple axis spectrometer

Monochromatization by Bragg reflection of crystals



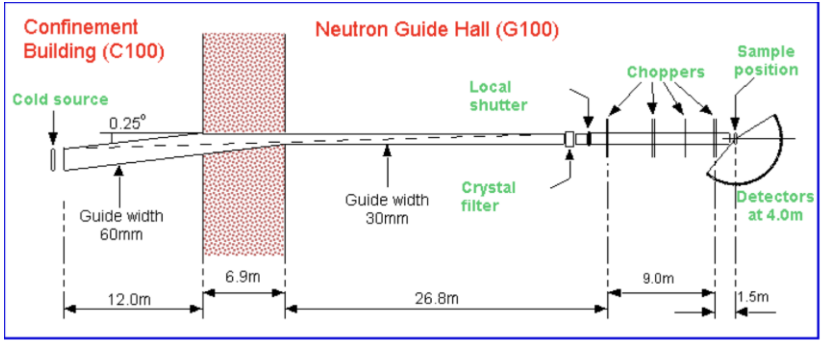
Time of Flight spectrometer

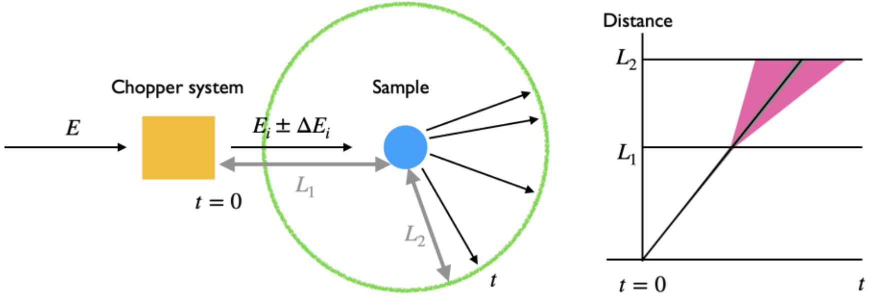
Monochromatization by choppers



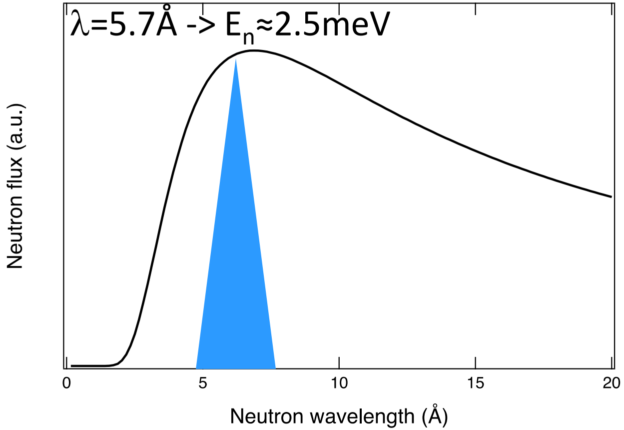
How to measure dynamic neutron scattering?

Time of flight instrument (DCS@NCNR)





Energy resolution 10 - 100 μeV



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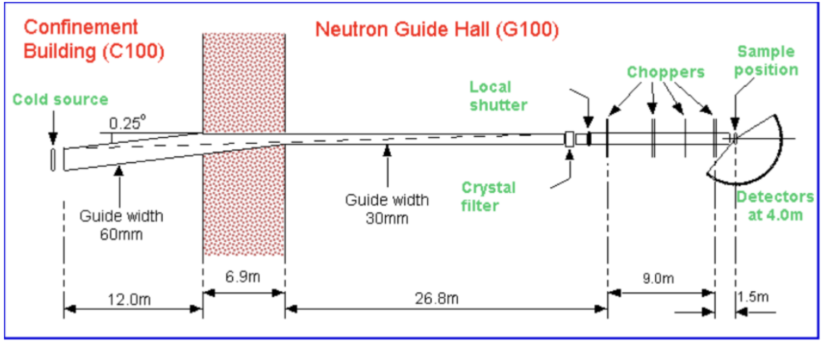

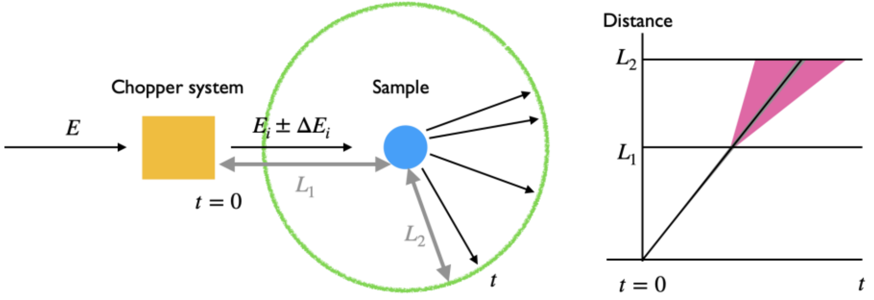

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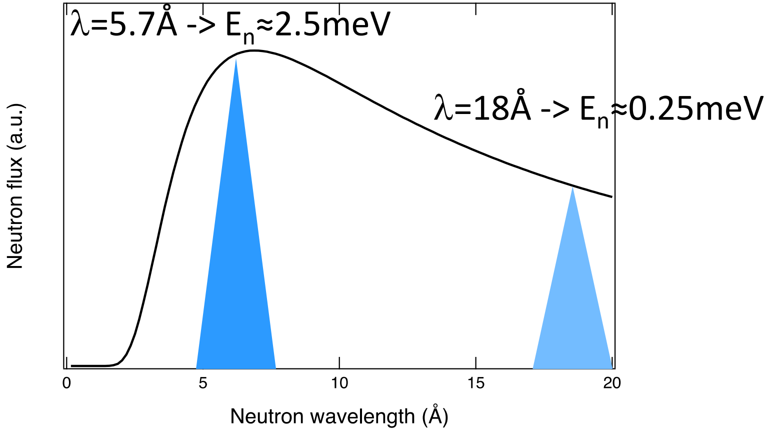

To have better energy resolution, i.e., to measure smaller energy exchanged, use smaller incident energy

How to measure dynamic neutron scattering?

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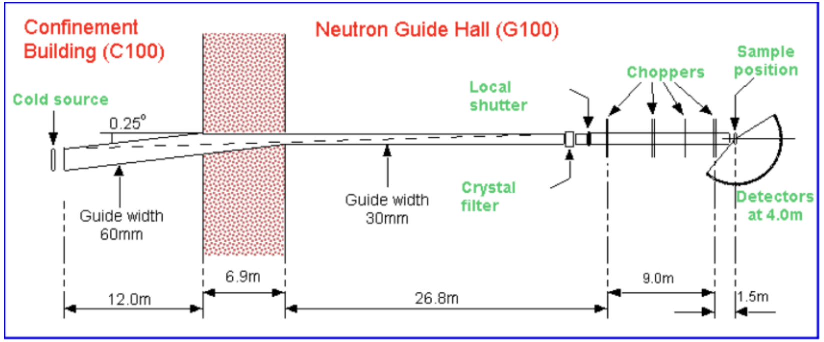

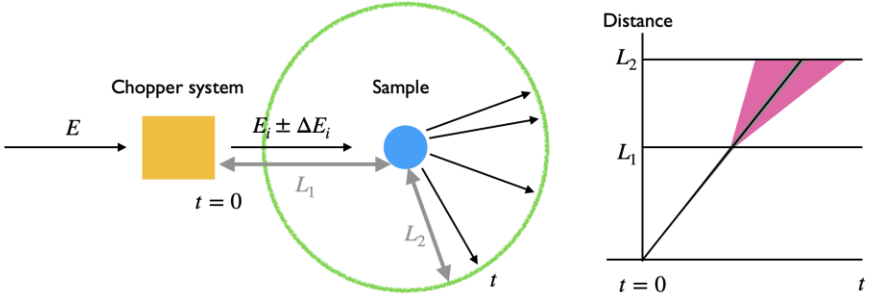

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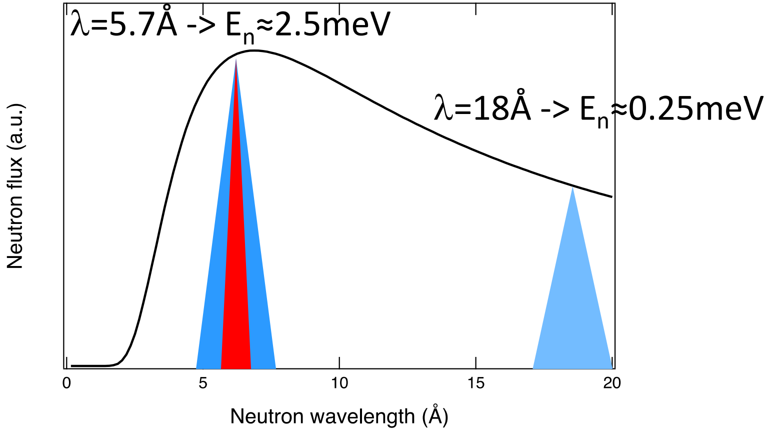

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smaller incident energy

narrower energy distribution

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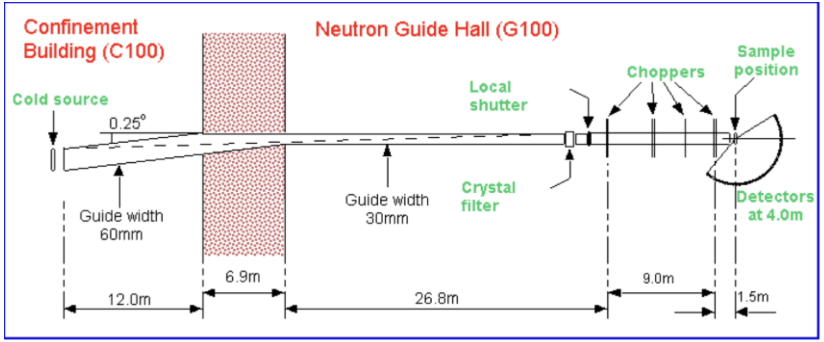

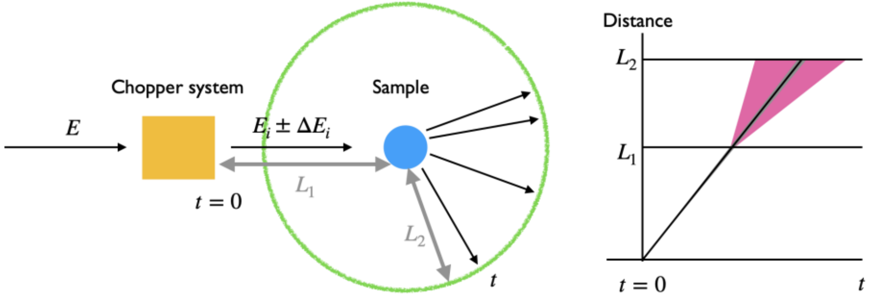

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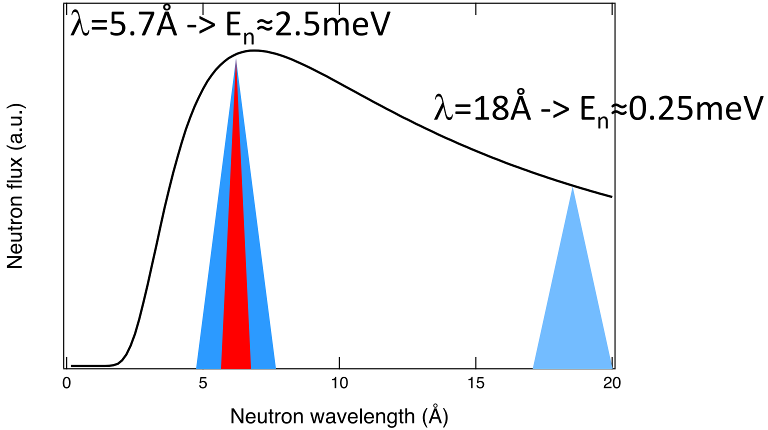

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The better the resolution, the smaller the resolution volume and the lower the count rate

The Idea of NSE

- Traditional – define both incident & scattered wavevectors in order to define E and Q accurately
- Traditional – use collimators, monochromators, choppers etc to define both k_i and k_f
- NSE – measure as a function of the difference between appropriate components of k_i and k_f (original use: measure k_i-k_f i.e. energy change)
- NSE – use the neutron's spin polarization to encode the difference between components of k_i and k_f
- NSE – can use poor monochromatization to increase signal intensity, while maintaining very good resolution

Neutron Precession in a magnetic field

Neutron Properties

charge: $q = 0$

mass: $m_n = 1.675\text{x}10^{-27}$ kg

life time: $t_l = 886.7$s

spin: $S = 1/2$ [in unit of $h/(2\pi)$]

Magnetic moment: $\mu_n = -9.66\text{x}10^{-27}$ J/T

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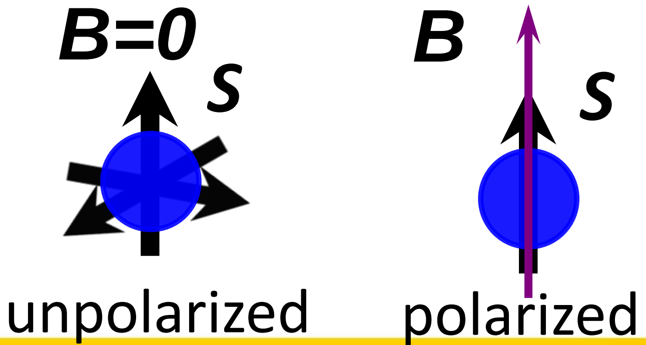
In a Magnetic Field



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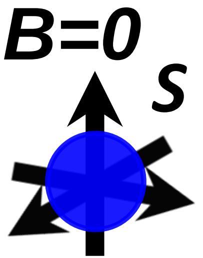
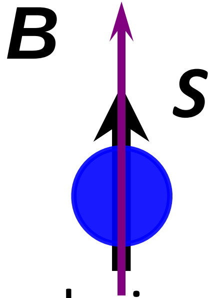


unpolarized



polarized

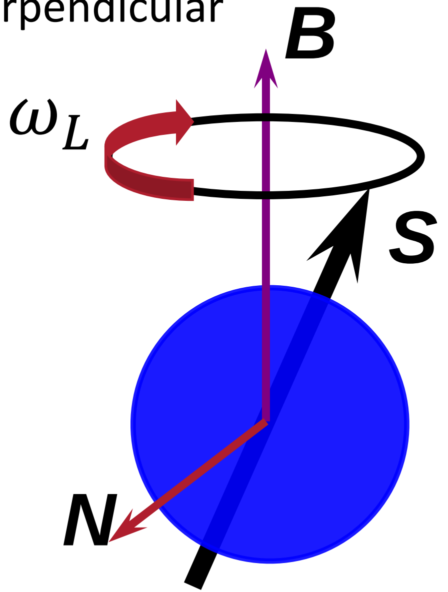
The neutron experiences a torque, ***N***, from a magnetic field ***B*** perpendicular to its spin direction

$$\frac{d\boldsymbol{S}}{dt} = \boldsymbol{N} = \boldsymbol{S} \times \boldsymbol{B}$$

Precession with Larmor frequency

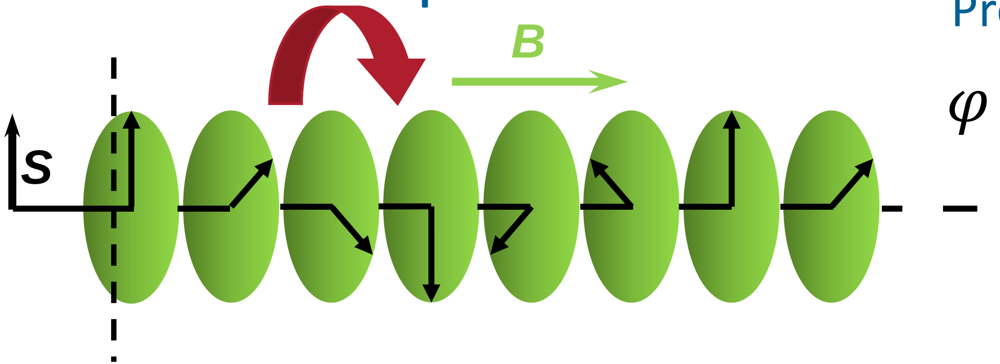
$$\omega_L = \gamma B$$

Gyromagnetic ratio:
$\gamma = 1.832 \times 10^8$ /s/T



Larmor precession

Number of precession

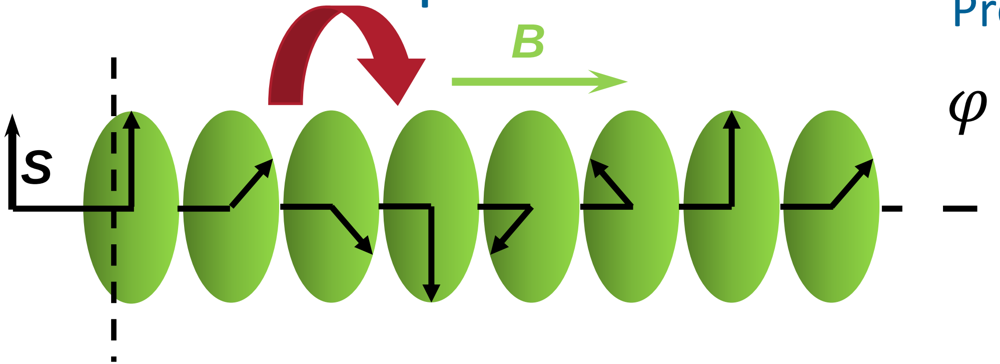


Precession angle

$$\varphi = \omega_L t = \gamma B \frac{l}{v} = \gamma \frac{\int B dl}{v} = \gamma \frac{J}{v}$$

$$J = \int B dl$$ Field integral

Number of precession



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$$J = \int B dl$$ Field integral

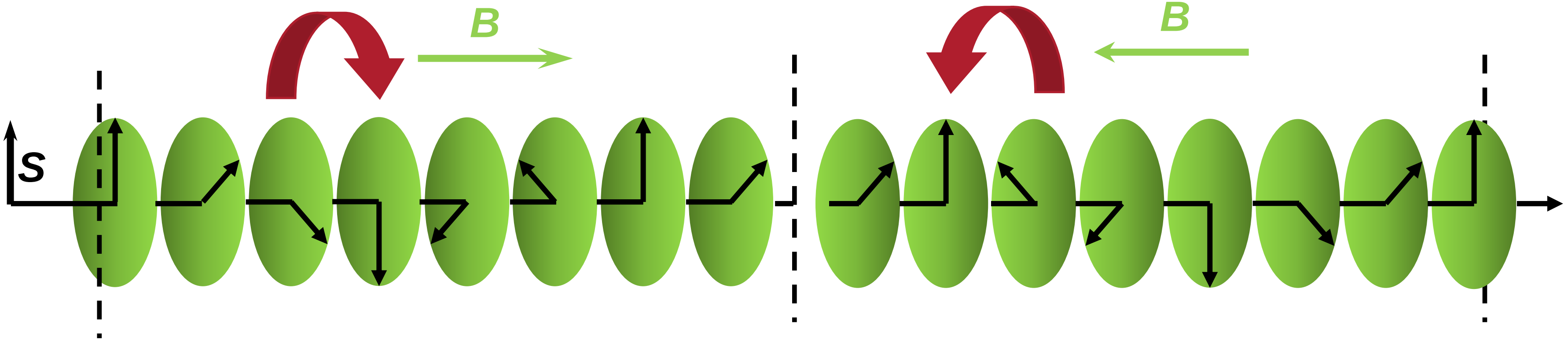
At NCNR, 0.0001 < J < 0.5 T m, how many turns do you expect when λ=8Å

de Broglie relation: $\lambda = \frac{h}{mv}$

$$\sim 6 < N(\lambda) = \frac{\varphi}{2\pi} = \frac{\gamma m \lambda}{2\pi h} J = 7370 \times J\,[T \cdot m] \times \lambda\,[\text{Å}]$$

$$< \sim 3 \times 10^4$$

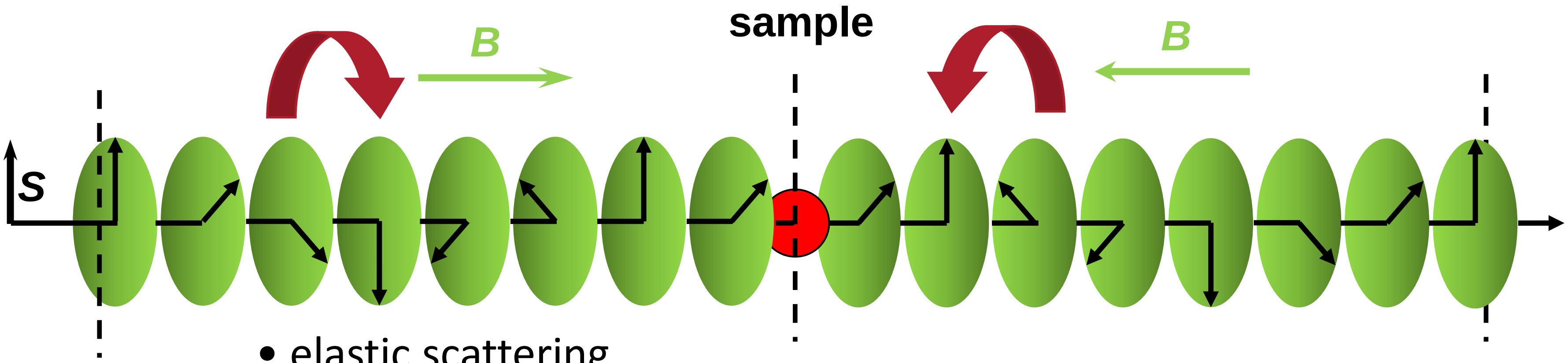
A combination of magnetic fields



$$\varphi = \gamma \frac{\int B dl}{v} = \gamma \frac{J}{v}$$

$$\Delta\varphi = \gamma \left(\frac{J}{v} - \frac{J}{v} \right) = 0$$

Scattering event: single neutron



- elastic scattering

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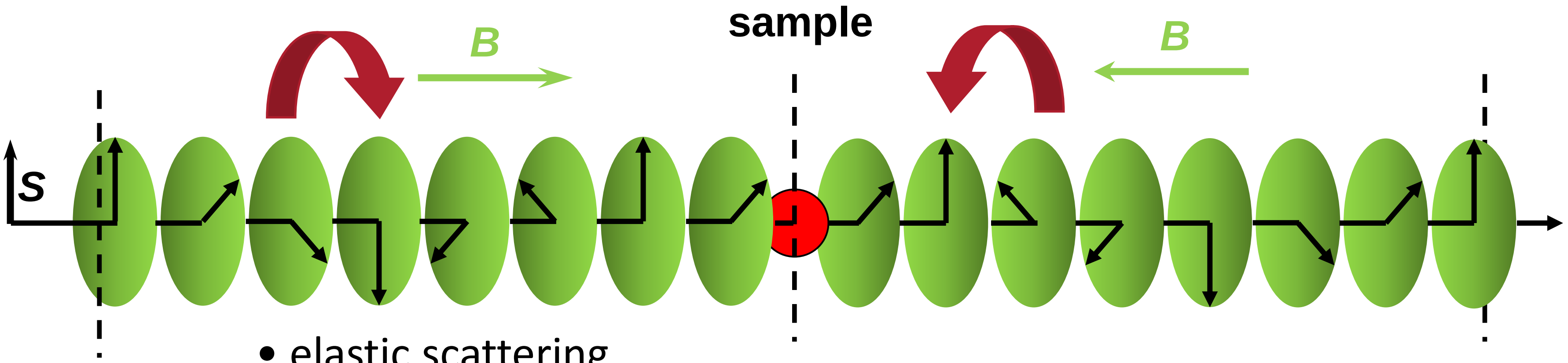

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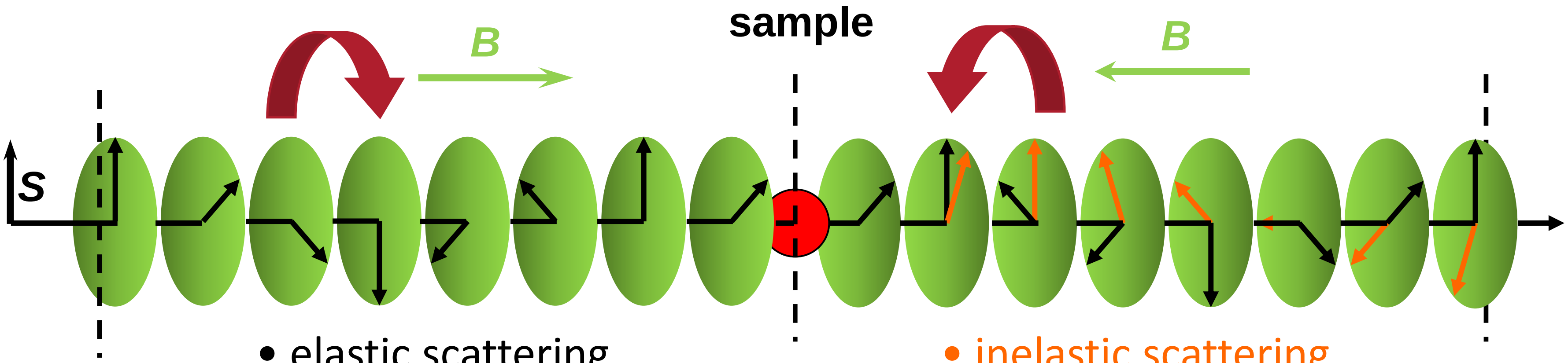
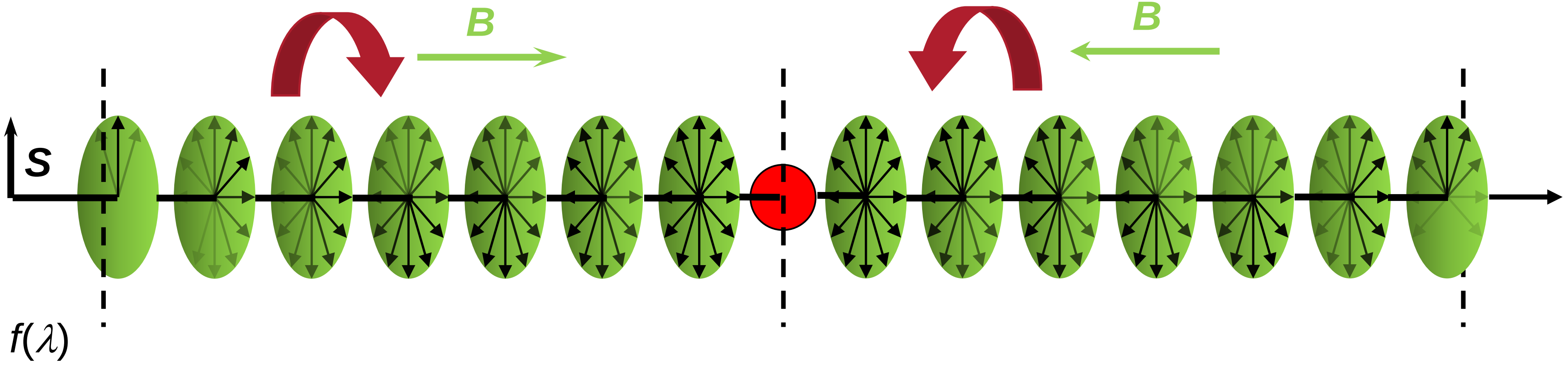


- elastic scattering
- inelastic scattering

$$\varphi = \gamma \frac{\int B dl}{v} = \gamma \frac{J}{v}$$

$$\Delta\varphi = \gamma\left(\frac{J}{v} - \frac{J}{v+\delta v}\right) \approx \frac{\gamma J}{v^2}\delta v = \gamma J \frac{m\lambda}{h}\frac{\delta v}{v} = \frac{\gamma m}{h} J \delta\lambda$$

Scattering event: neutron beam

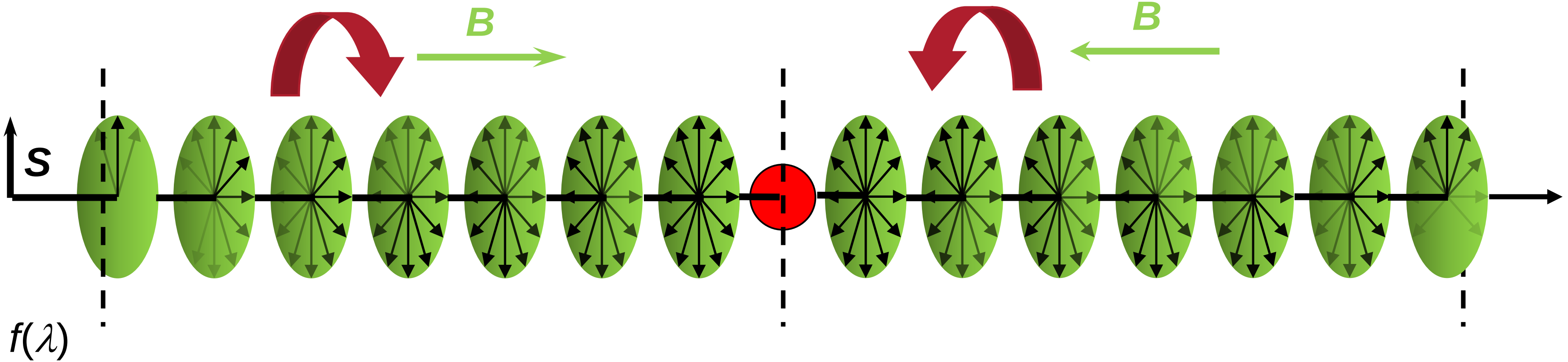


- elastic scattering

$$\bar{\varphi} = \left\langle \gamma\left(\frac{J}{v} - \frac{J}{v}\right)\right\rangle_{f(\lambda)} = 0$$

$$P_x \approx 1$$

Scattering event: neutron beam



- quasielastic scattering

$$\bar{\varphi} = \left\langle \gamma \frac{J}{v} - \gamma \frac{J}{v + \delta v} \right\rangle_{f(\lambda)} \neq 0$$

$$P_x \neq 1$$

Relation of $\langle\varphi\rangle = \omega t = \frac{\Delta E}{\hbar} t$

$$\langle\varphi\rangle = \langle -\frac{\gamma J}{v} + \frac{\gamma(J+\delta J)}{v+\delta v}\rangle = \frac{\gamma m}{h}\langle -\lambda J + (\lambda+\delta\lambda)(J+\delta J)\rangle \approx \frac{\gamma m}{h}(J\delta\lambda + \lambda\delta J)$$

On the other hand, we know energy exchange can be written

$$\Delta E = \hbar\omega = \frac{h^2}{2m}\left[\frac{1}{\lambda^2} - \frac{1}{(\lambda+\delta\lambda)^2}\right] \approx \frac{h^2}{m}\frac{\delta\lambda}{\lambda^3} \longrightarrow \delta\lambda = \frac{m\lambda^3}{2\pi h}\omega = \frac{m\lambda^3}{h^2}\Delta E$$

Then,

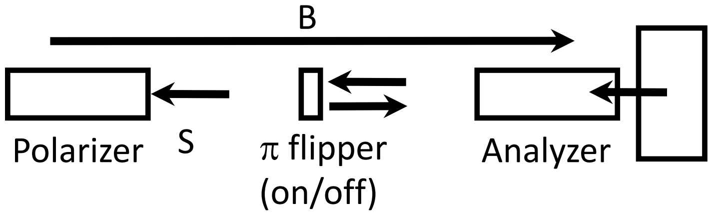
$$\langle\varphi\rangle \approx \left[\frac{\gamma m^2 J\lambda^3}{2\pi h^3}\Delta E + \frac{\gamma m\lambda}{h}\delta J\right]$$

When $\delta J = 0$
(symmetric condition)

$$\langle\varphi\rangle \approx \frac{\gamma m^2 J\lambda^3}{2\pi h^3}\Delta E = \frac{\gamma m^2 J\lambda^3}{2\pi h^2}\omega \longrightarrow t = \frac{\gamma m^2 J\lambda^3}{2\pi h^2} = \frac{m\lambda^2}{h}N(\lambda)$$

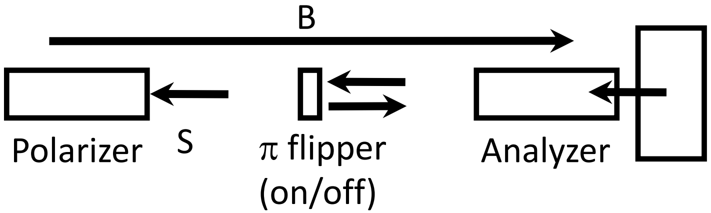
Fourier time

Function of (spin) analyzer



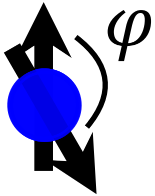
Select one state
of neutron spin

Function of (spin) analyzer



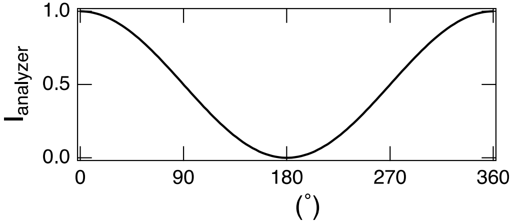
Select one state of neutron spin

Multiple neutrons with various polarization



Analyzer will transmit neutrons with the probability

$$I_{analyzer} = \frac{1 + \cos\langle\varphi\rangle}{2}$$



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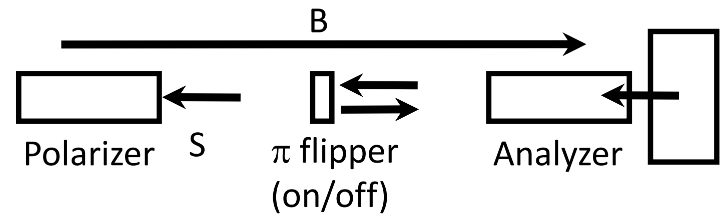

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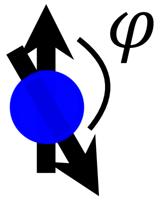

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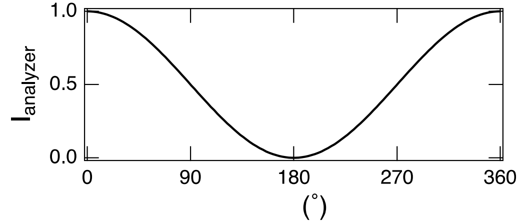
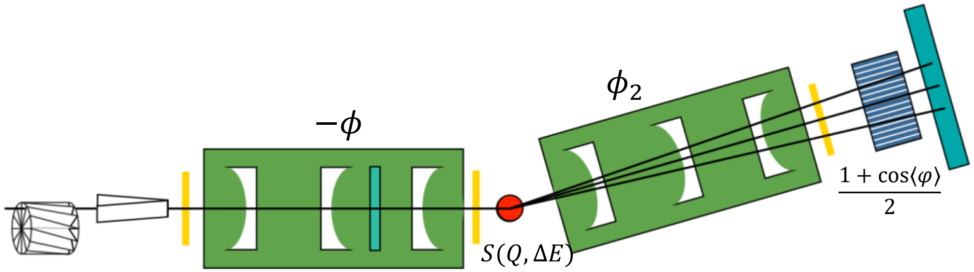




$$\varphi = -\phi + \phi_2 = -\frac{\gamma J}{v} + \frac{\gamma J}{v+\delta v}$$

$$I_{NSE} \propto \int_{-\infty}^{\infty} S(Q,\Delta E)\frac{1+\cos\langle\varphi\rangle}{2}d\omega = \frac{1}{2\hbar}\left[\int_{-\infty}^{\infty} S(Q,\Delta E)\Delta E + \int_{-\infty}^{\infty} S(Q,\Delta E)\cos\left(\frac{\Delta E}{\hbar}t\right)d\Delta E\right]$$

$$\langle\varphi\rangle = \frac{\Delta E}{\hbar}t$$

$$FT\{S(Q,\Delta E)\} = S(Q,t)$$

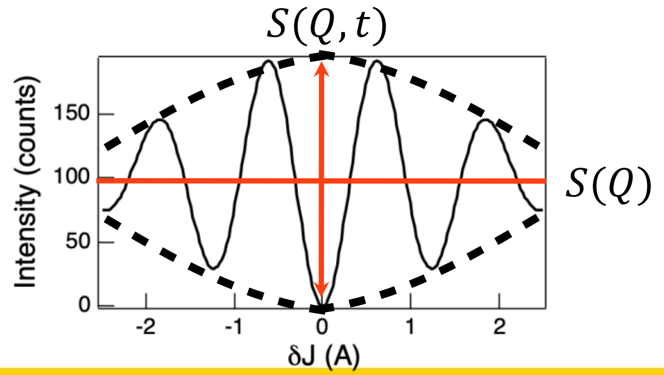
In reality, wavelength distribution $f(\lambda)$

$$I_{NSE} \propto \int\int_{-\infty}^{\infty} f(\lambda) S(Q, \frac{\Delta E}{\hbar}) \frac{1+\cos\langle\varphi\rangle}{2} d\frac{\Delta E}{\hbar} d\lambda = \frac{1}{2\hbar}\left[\int\int_{-\infty}^{\infty} f(\lambda) S(Q, \frac{\Delta E}{\hbar}) d\Delta E d\lambda + \int\int_{-\infty}^{\infty} f(\lambda) S(Q, \frac{\Delta E}{\hbar}) \cos\langle\varphi\rangle d\Delta E d\lambda\right]$$

Wavelength resolution smeared $S(Q)$

$$\int d\lambda \int_{-\infty}^{\infty} d\Delta E f(\lambda) S(Q, \frac{\Delta E}{\hbar}) \cos\left[\frac{\gamma m^2 J \lambda^3}{2\pi h^3}\Delta E + \frac{\gamma m \lambda}{h}\delta J\right] = \int d\lambda \int_{-\infty}^{\infty} d\Delta E f(\lambda) S(Q, \frac{\Delta E}{\hbar}) \cos(\frac{\Delta E}{\hbar} t) \cos\left(\frac{\gamma m \lambda}{h}\delta J\right)$$

$$= \int f(\lambda) \cos\left(\frac{\gamma m \lambda}{h}\delta J\right) d\lambda \times \int_{-\infty}^{\infty} S(Q, \frac{\Delta E}{\hbar}) \cos(\frac{\Delta E}{\hbar} t) d\Delta E$$



$$I_{NSE} \propto S(Q) + S(Q,t) \exp\left(-\Lambda^2 \gamma^2 \frac{m^2}{h^2} \delta J^2\right) \cos\left(\gamma \frac{m}{h} \lambda \delta J\right)$$

Λ: relating to the wavelength spread $\Delta\lambda$

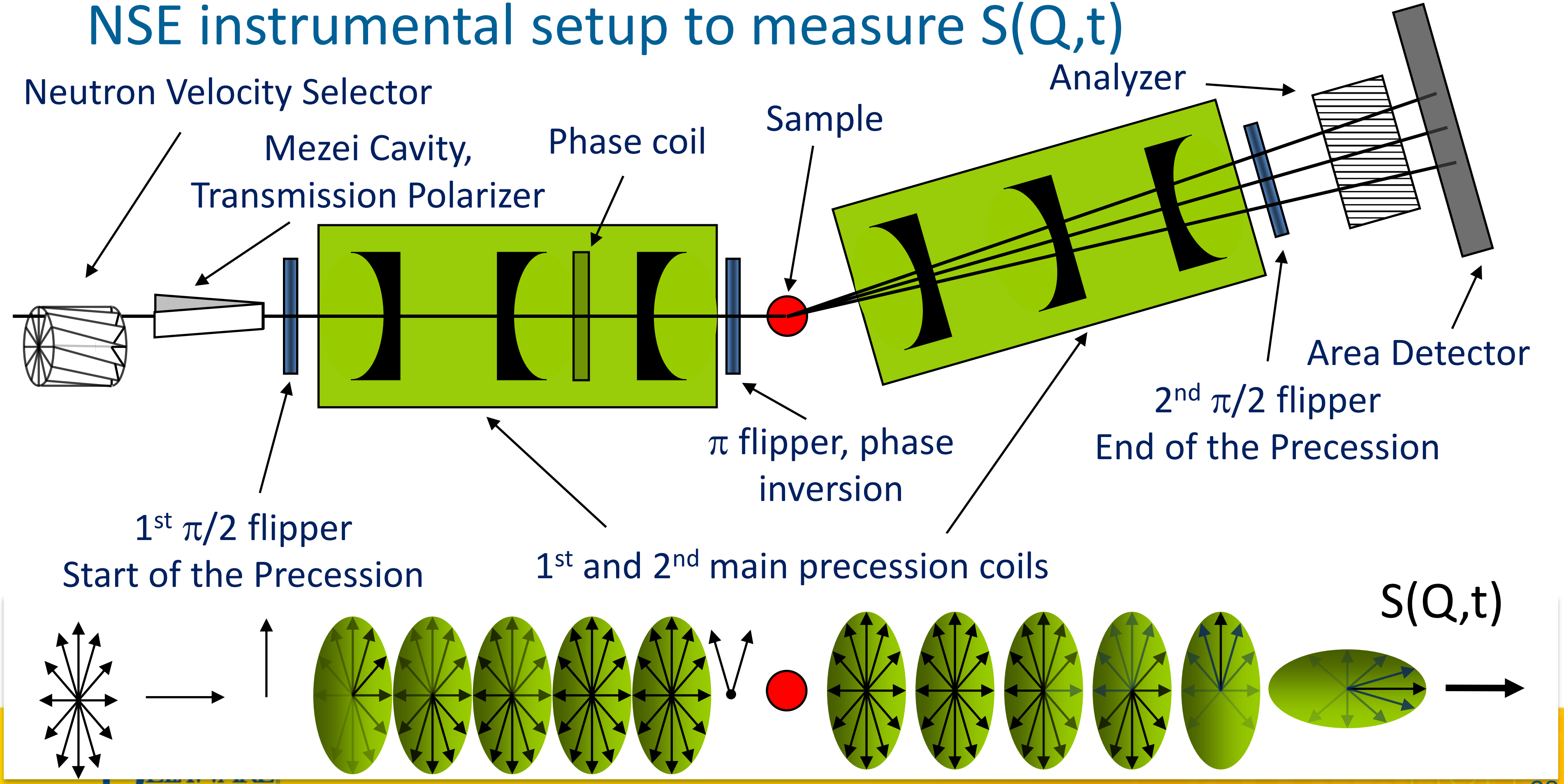
Period of oscillation $\propto \lambda$

Decay of oscillation relates to the wavelength distribution

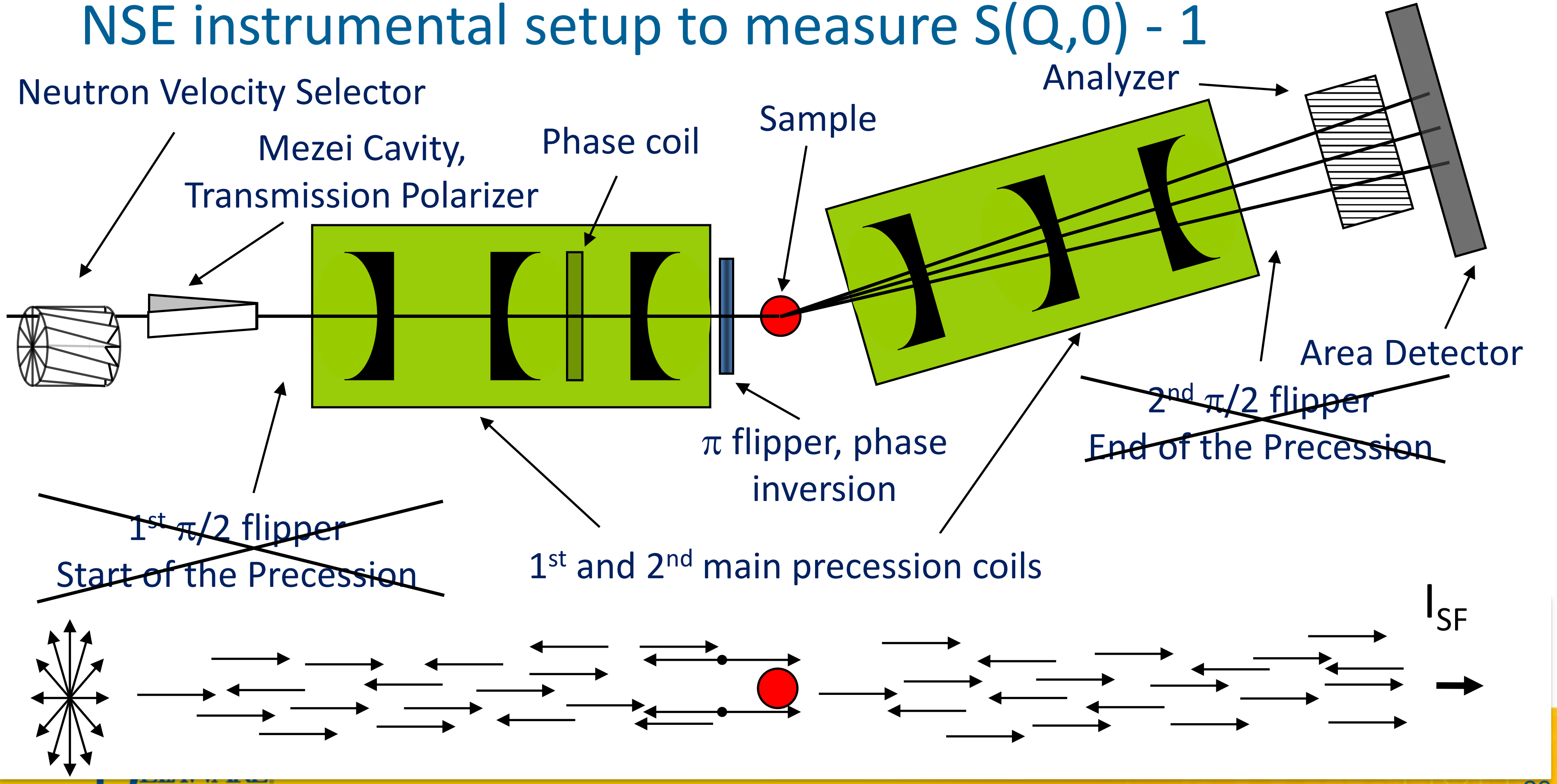
NSE principles - summary

- If a spin rotates anticlockwise & then clockwise by the same amount it comes back to the same orientation
  - Need to reverse the direction of the applied field
  - Independent of neutron speed provided
- The same effect can be obtained by reversing the precession angle at the mid-point and continuing the precession in the same sense
  - Use a π rotation (π flipper)
- If the neutron's velocity is changed by the sample, its spin will not come back to the same orientation
  - The difference will be a measure of the change in the neutron's speed or energy.

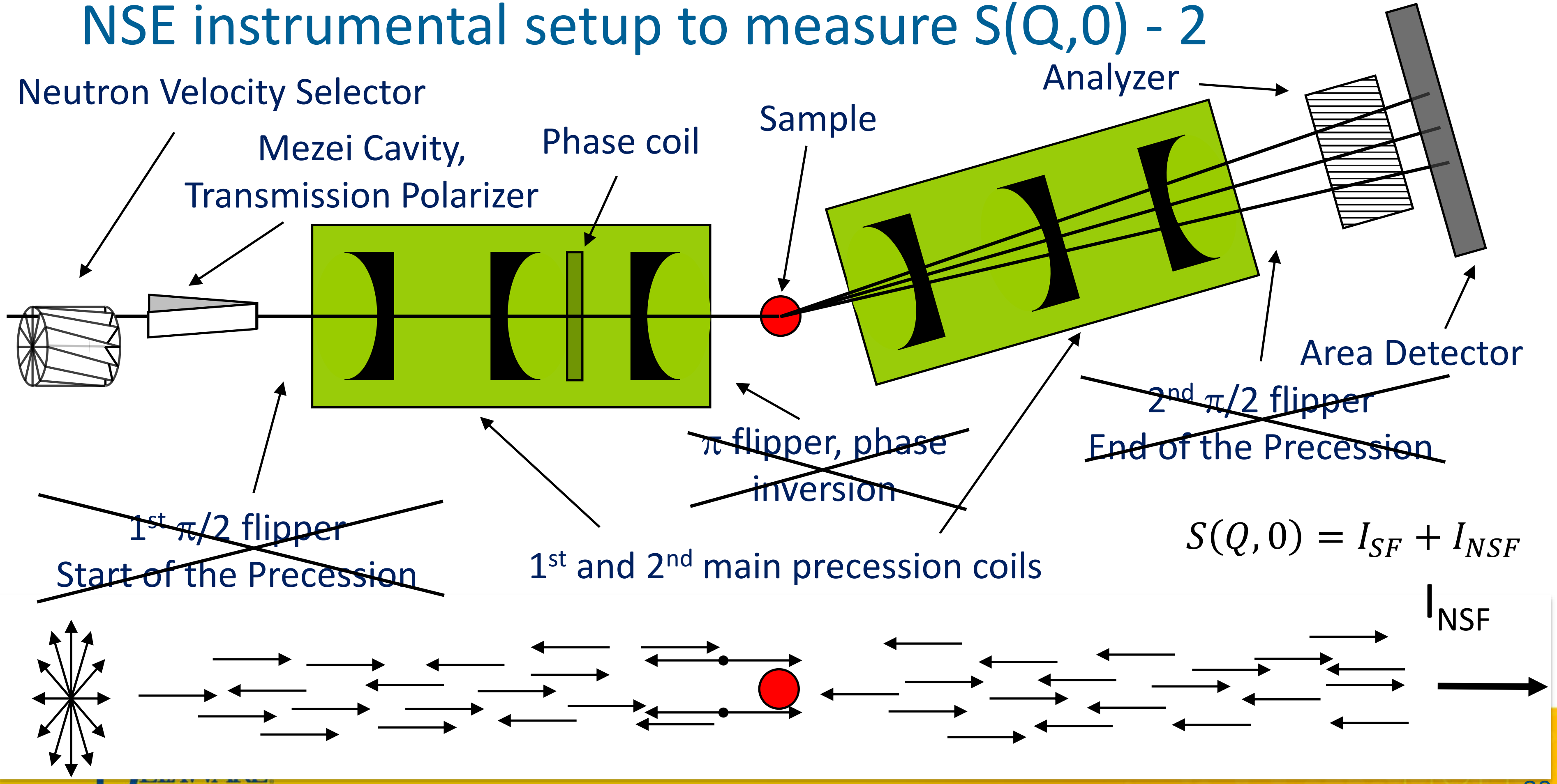
NSE instrumental setup to measure S(Q,t)



NSE instrumental setup to measure S(Q,0) - 1



NSE instrumental setup to measure S(Q,0) - 2

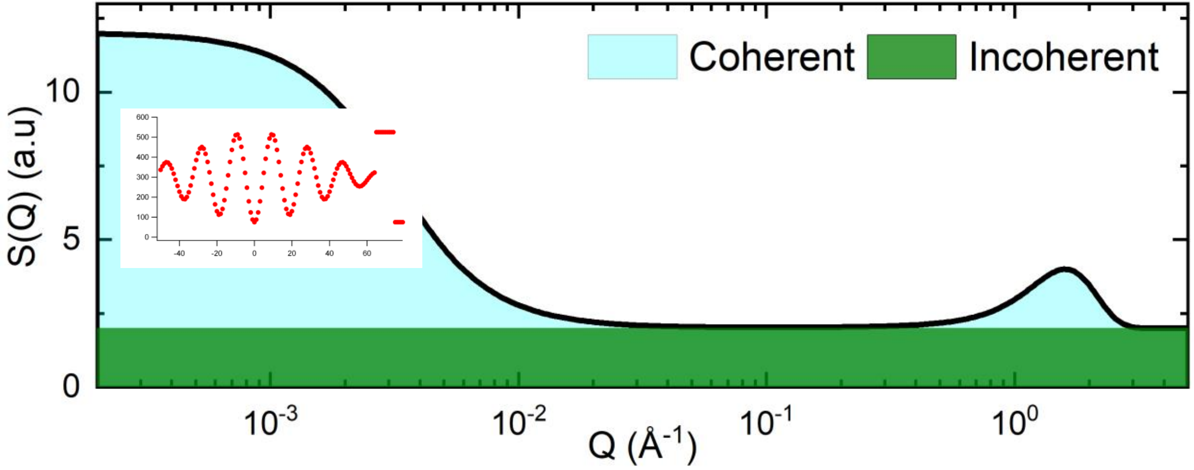


NSE: coherent vs incoherent

$$\frac{S(Q,t)}{S(Q,0)} = \frac{S_{coh}(Q,t) - \frac{1}{3}S_{inc}(Q,t)}{S_{coh}(Q,0) - \frac{1}{3}S_{inc}(Q,0)}$$

NSE is known for the investigation of the coherent dynamics.

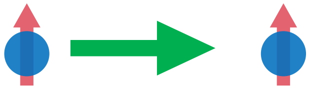
Incoherent scattering intensity is reduced to -1/3 in NSE. The best achievable flipping ratio is 0.5.



Spin-flip/Non-spin-flip Scattering

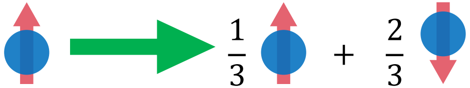
Sample scattering events sometimes involve with spin-flip scattering

Coherent scattering: Non-Spin-Flip Scattering



Isotope incoherent scattering: Non-Spin-Flip Scattering

Spin incoherent scattering: Spin-Flip Scattering -- 2/3 Spin-Flip probability



$$I_{NSF} = I_{coh} + I_{i-inc} + \frac{1}{3} I_{s-inc}$$

$$I_{SF} = \frac{2}{3} I_{s-inc}$$

$$I_{total} = I_{coh} + I_{i-inc} + I_{s-inc} = I_{NSF} + I_{SF}$$

Separation of coherent + isotope-incoherent from spin-incoherent scattering

$$I_{coh} + I_{i-inc} = I_{NSF} - \frac{1}{2} I_{SF}$$

$$I_{s-inc} = \frac{3}{2} I_{SF}$$

NSE: coherent vs incoherent

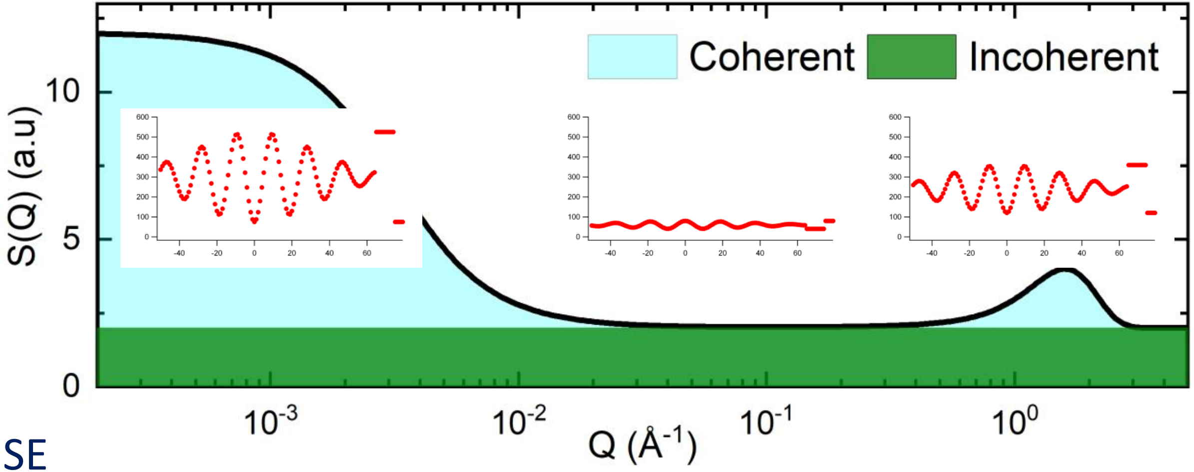
$$\frac{S(Q,t)}{S(Q,0)} = \frac{S_{coh}(Q,t) - \frac{1}{3}S_{inc}(Q,t)}{S_{coh}(Q,0) - \frac{1}{3}S_{inc}(Q,0)}$$

NSE is known for the investigation of the coherent dynamics.

Incoherent scattering intensity is reduced to -1/3 in NSE. The best achievable flipping ratio is 0.5.

However, the main limitation to the study of incoherent scattering by NSE is the *Q* coverage of instrument.

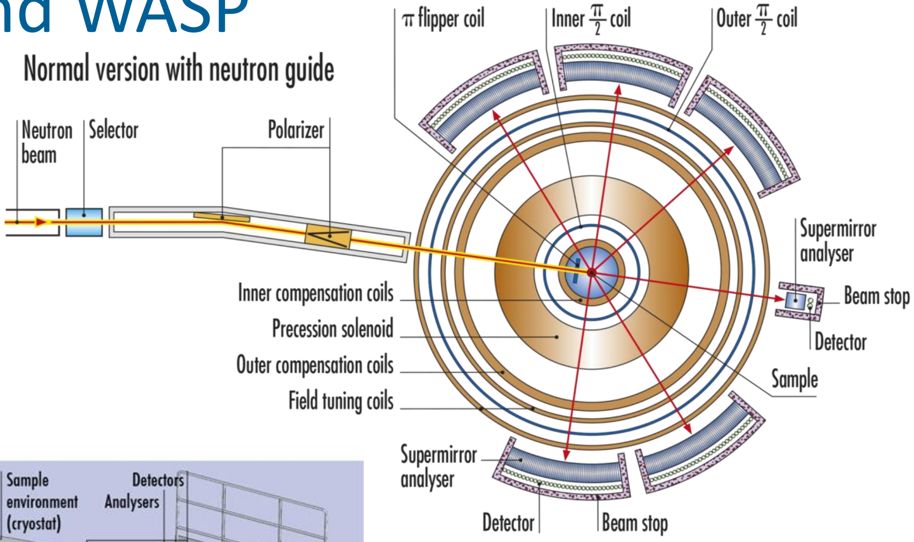
Recent advancements in NSE instrumentation aim to overcome this limitation (WASP at ILL).

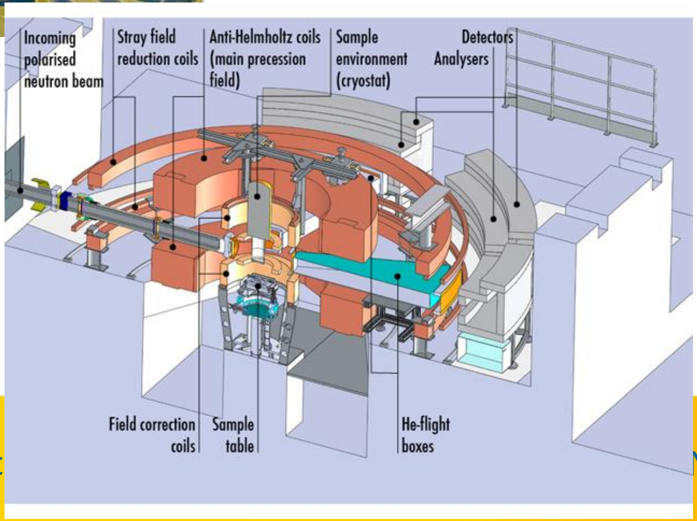


Most important is to avoid *Q* areas where coherent and incoherent intensity cancel each other.

Geometry of the NIST-NSE and WASP

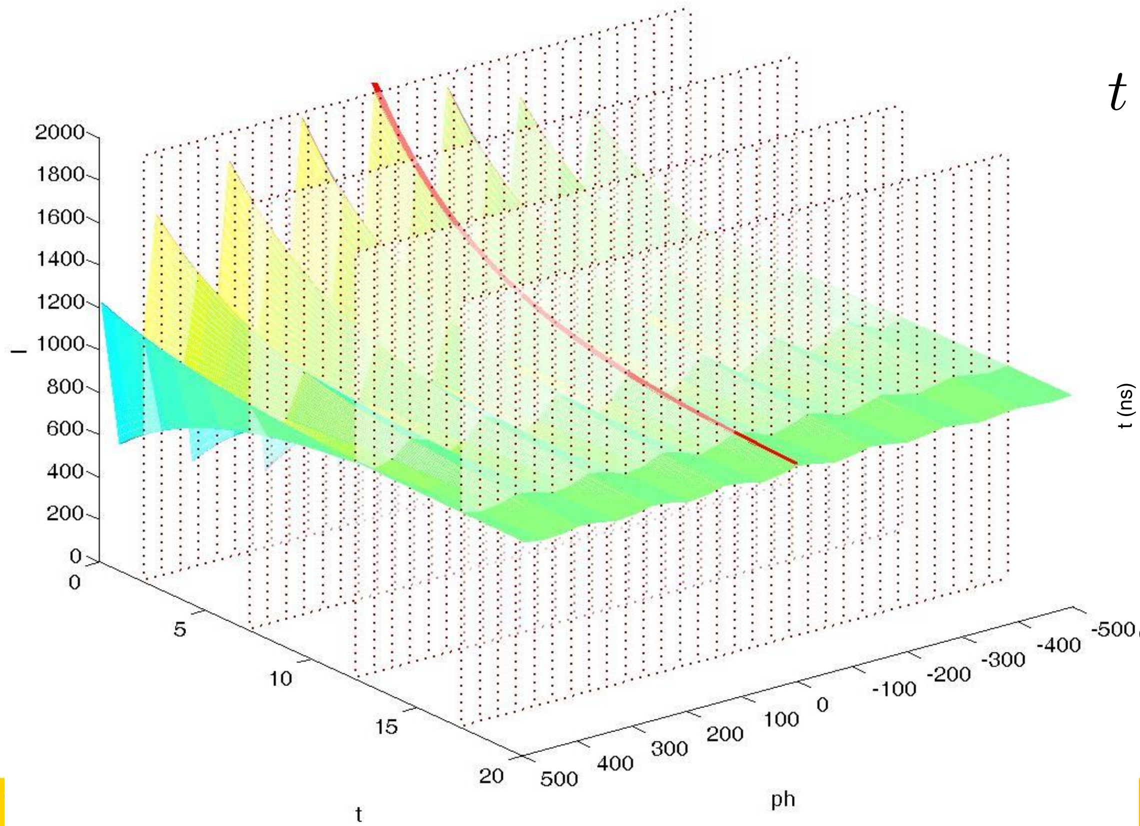
NIST-CHRNS-NSE



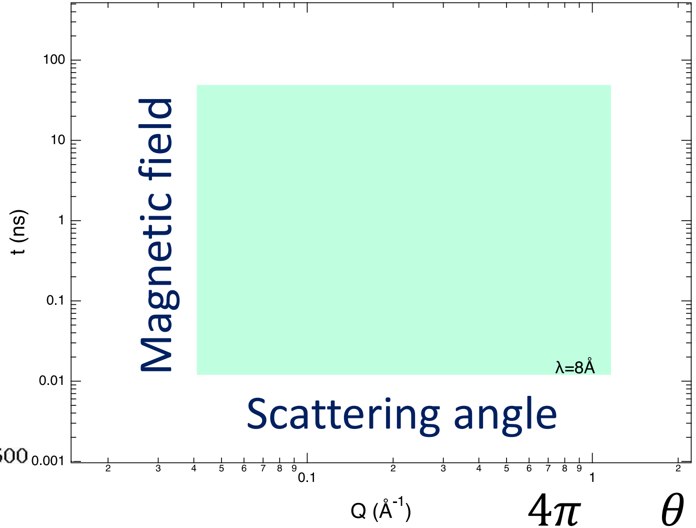


WASP @ ILL

Data reduction: intensity vs phase (echo signal) and t

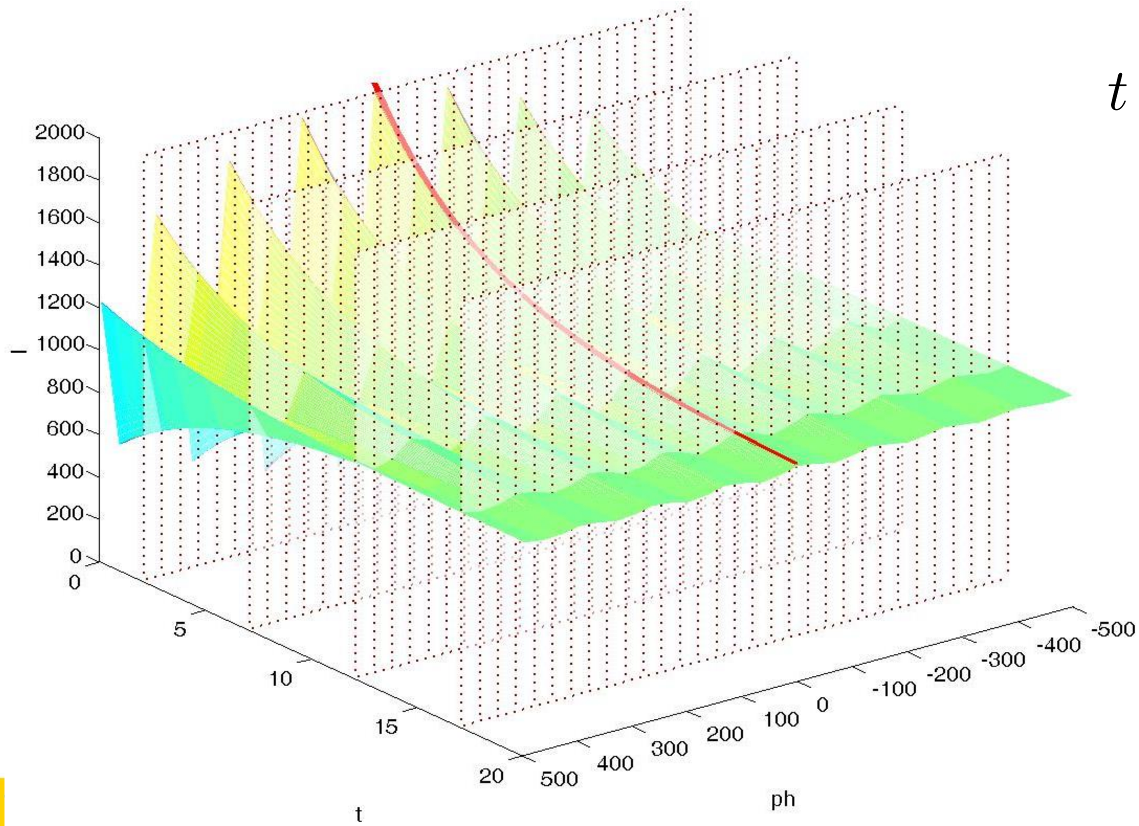


$$t = \gamma \frac{m^2}{2\pi h^2} J_0 \lambda^3$$

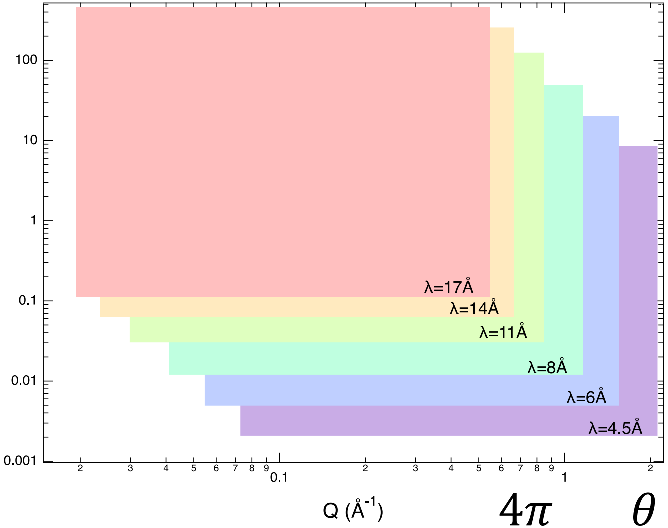


$$Q = \frac{4\pi}{\lambda} \sin\frac{\theta}{2}$$

Data reduction: intensity vs phase (echo signal) and t

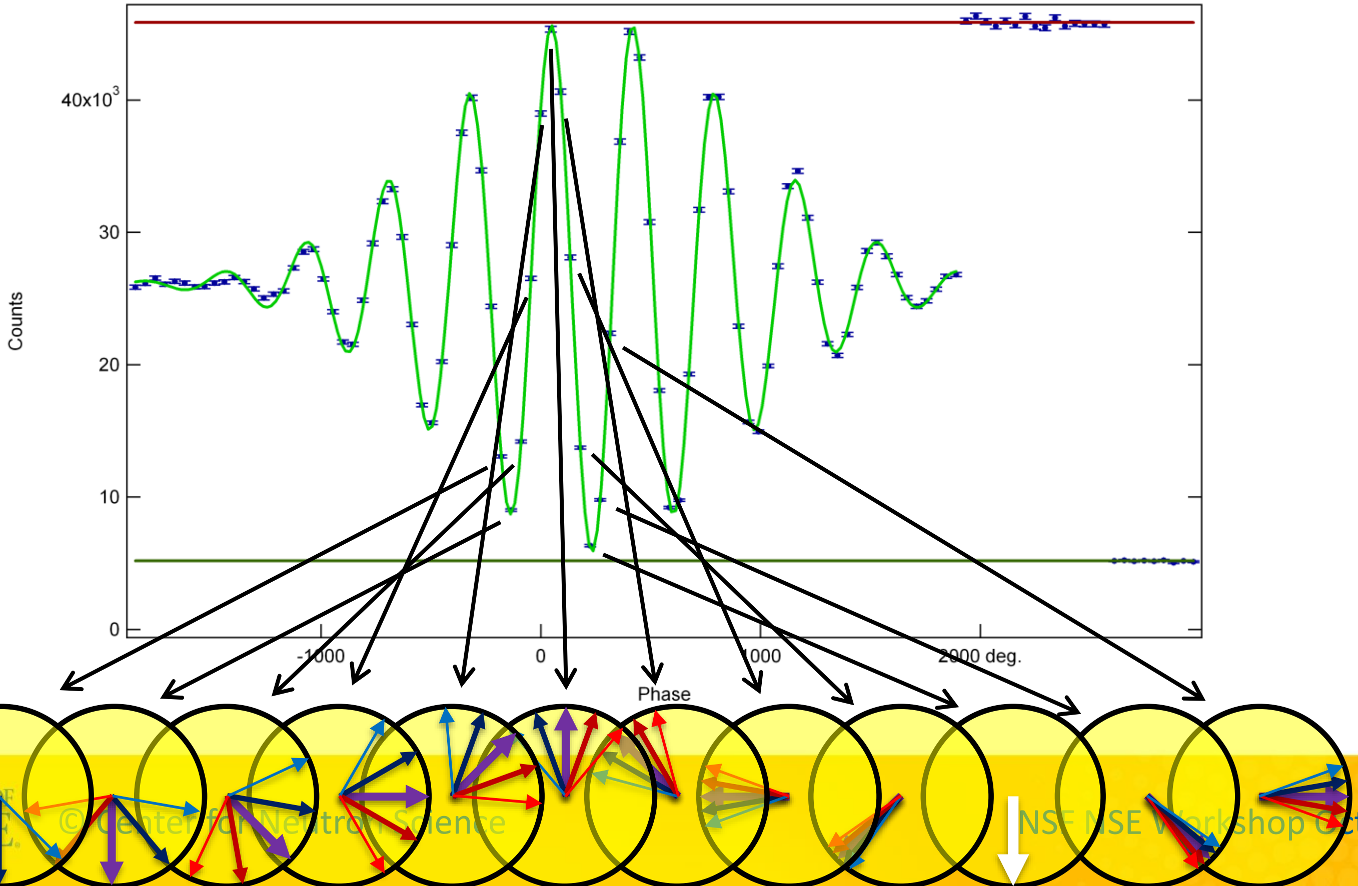


$$t = \gamma \frac{m^2}{2\pi h^2} J_0 \lambda^3$$



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

Polarized intensity vs phase (echo signal)



Fitting the echo

$$I_{NSE} \propto S(Q) + S(Q,t)\exp\left(-\Lambda^2\gamma^2\frac{m^2}{h^2}\delta J^2\right)\cos\left(\gamma\frac{m}{h}\lambda\delta J\right)$$

I_0 Average Intensity

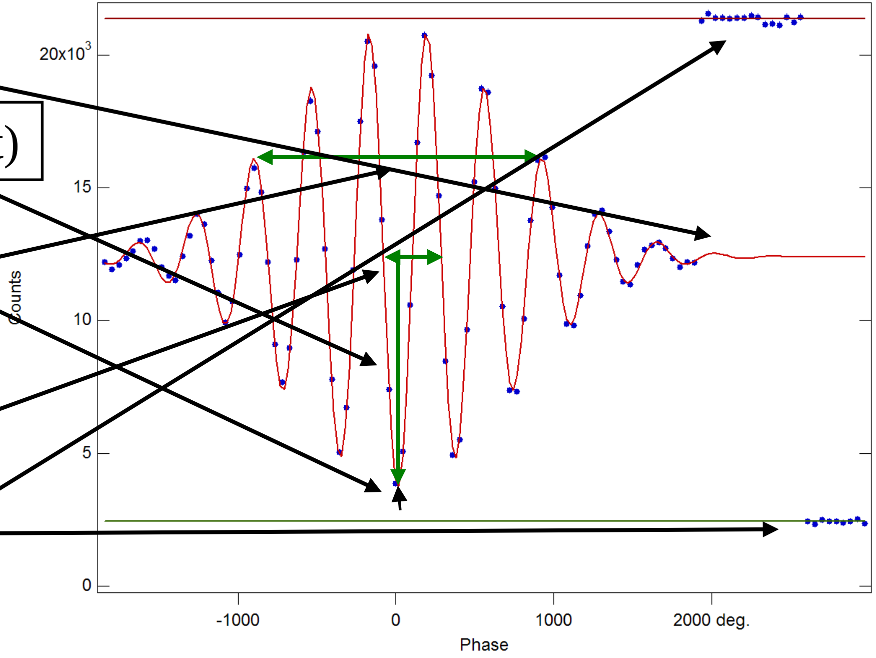
A Amplitude, related to I(Q,t)

ph_0 Echo point

σ Echo width, function of f(λ) width distribution

T Period, function of ⟨λ⟩

Static measurements
(Up and Down)
t=0 (J=0): ∫S(Q,ω)dω



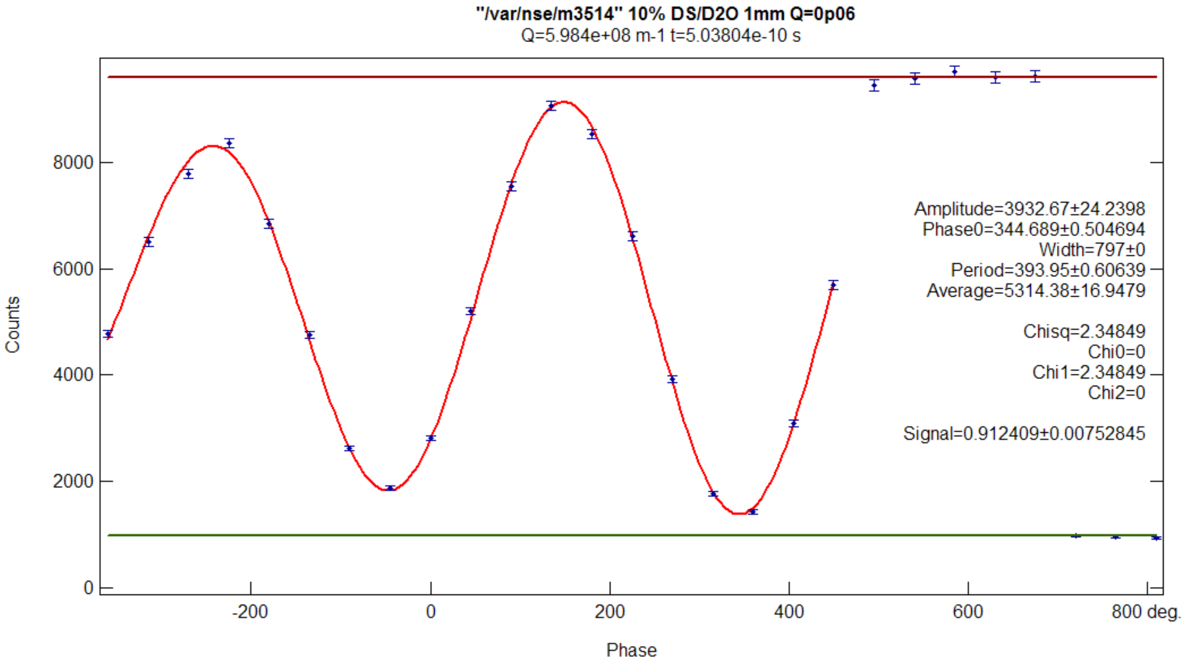
$$I^p = I_0 + A\exp\left[\frac{(ph - ph_0)^2}{2\sigma^2}\right]\cos\left[\frac{360}{T}(ph - ph_0)\right]$$

The physical information is all in the amplitude

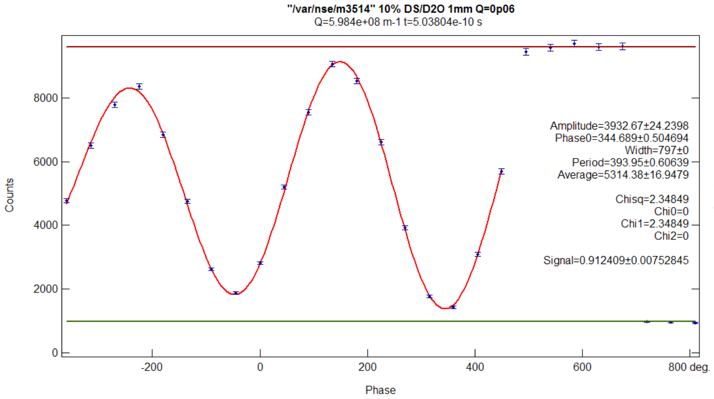
$$\frac{I(Q,t)}{I(Q)} \propto \frac{2A}{Up - Dwn}$$

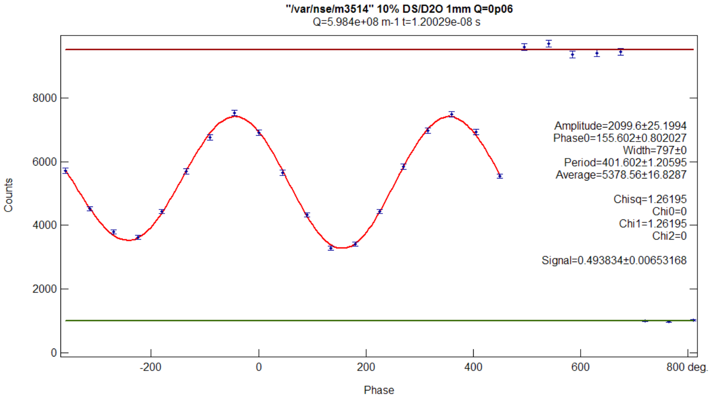
Incidentally, in this way, both polarization and detector efficiency effects are taken care off.

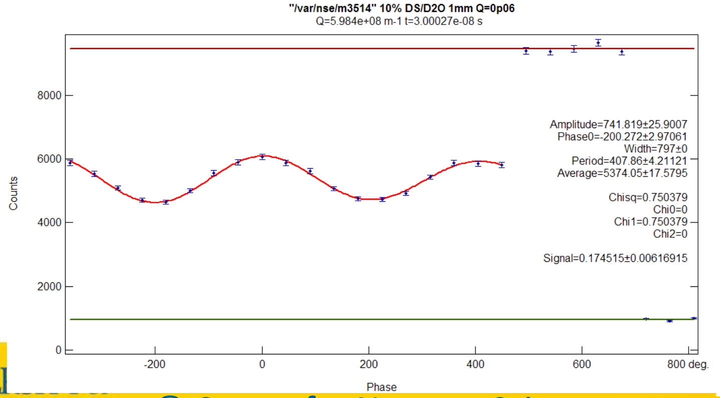
A small portion of the echo will do

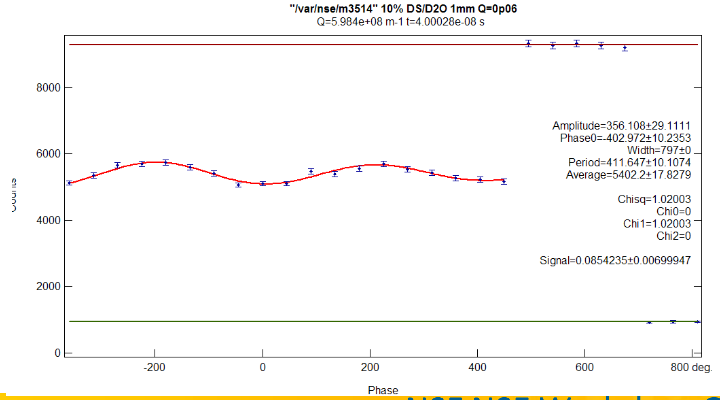


Polarized intensity vs t

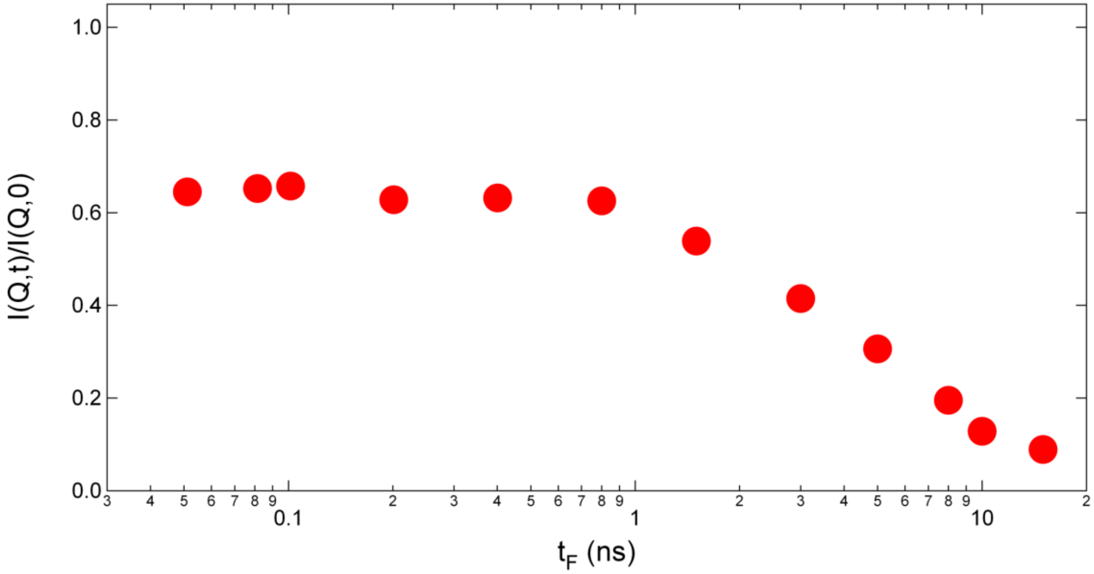








Resolution normalization



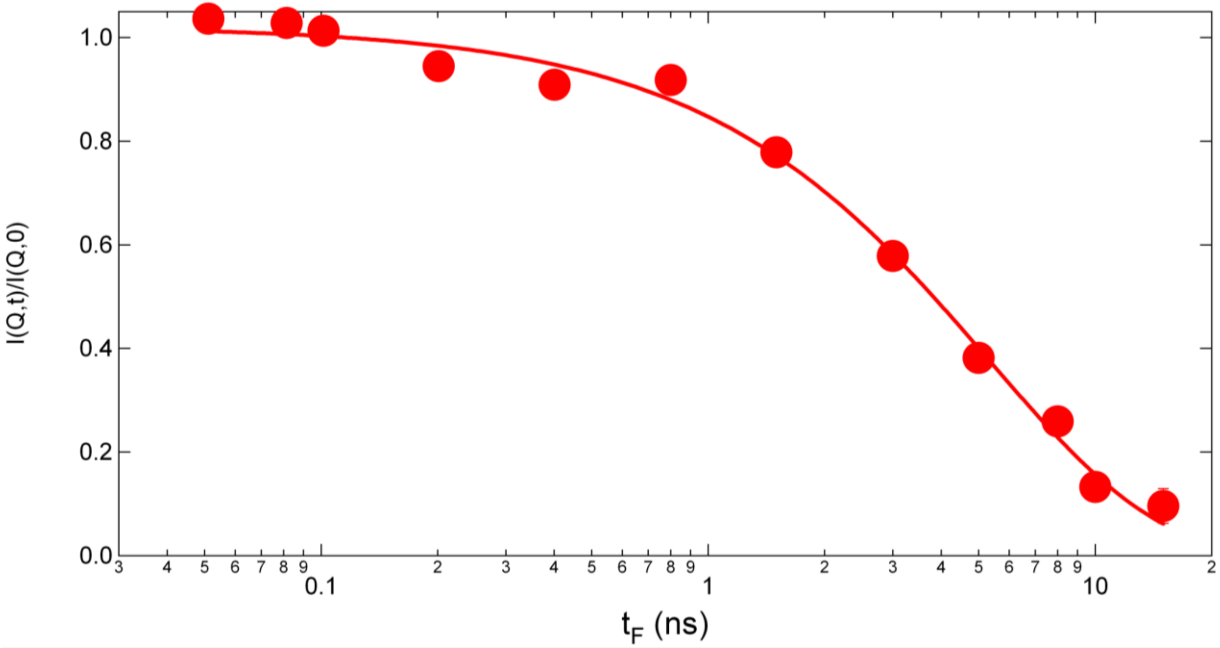
$$\frac{I(Q,t)}{I(Q,0)} = \frac{2A/(Up - Dwn)}{2A^R/(Up^R - Dwn^R)}$$

Even for an elastic scatterer the echo signal will decrease with the increase of the Fourier time.

- Inhomogeneities in the magnetic field will depolarize the beam.

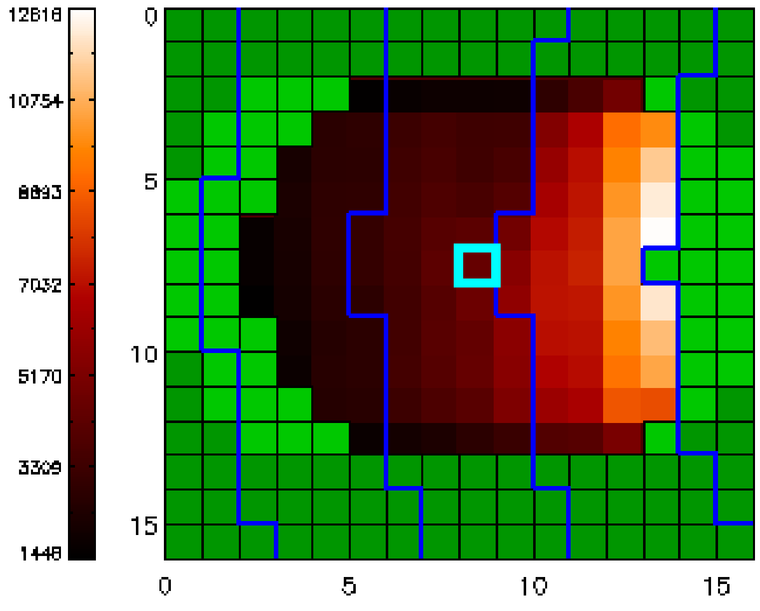
In Neutron Spin-Echo the resolution can be simply divided out from the data.

Blank correction

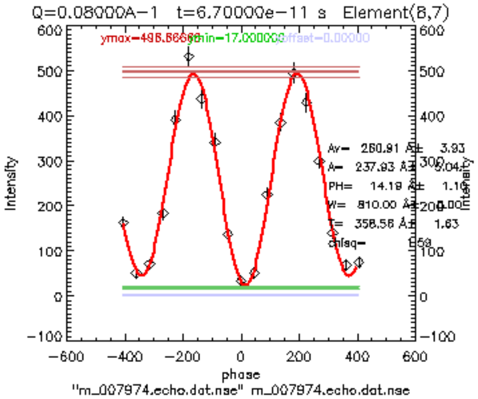


$$\frac{I(Q,t)}{I(Q)} = \frac{2\left[A-(1-\phi)\dfrac{T}{T^{BKG}}A^{BKG}\right] \Big/ \left[(Up-Dwn)-(1-\phi)\dfrac{T}{T^{BKG}}\left(Up^{BKG}-Dwn^{BKG}\right)\right]}{2A^{R} \Big/ \left(Up^{R}-Dwn^{R}\right)}$$

In reality, 2D detector



2D detector: 32 x 32 pixels with 1 cm^2 resolution



Each pixel has an echo

at multiple Fourier time points

+ multiple scattering angles

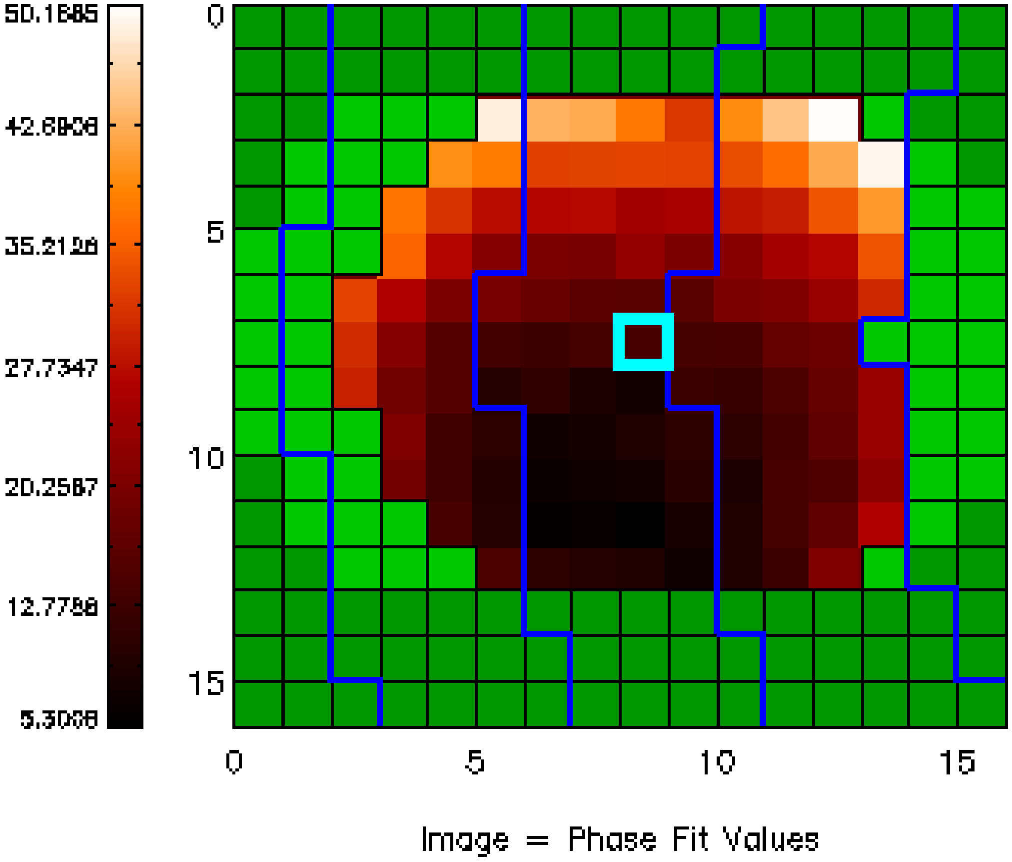
Data reduction software is available

Data Analysis and Visualization Environment

DAVE @ NCNR

Question: What do the blue lines define?

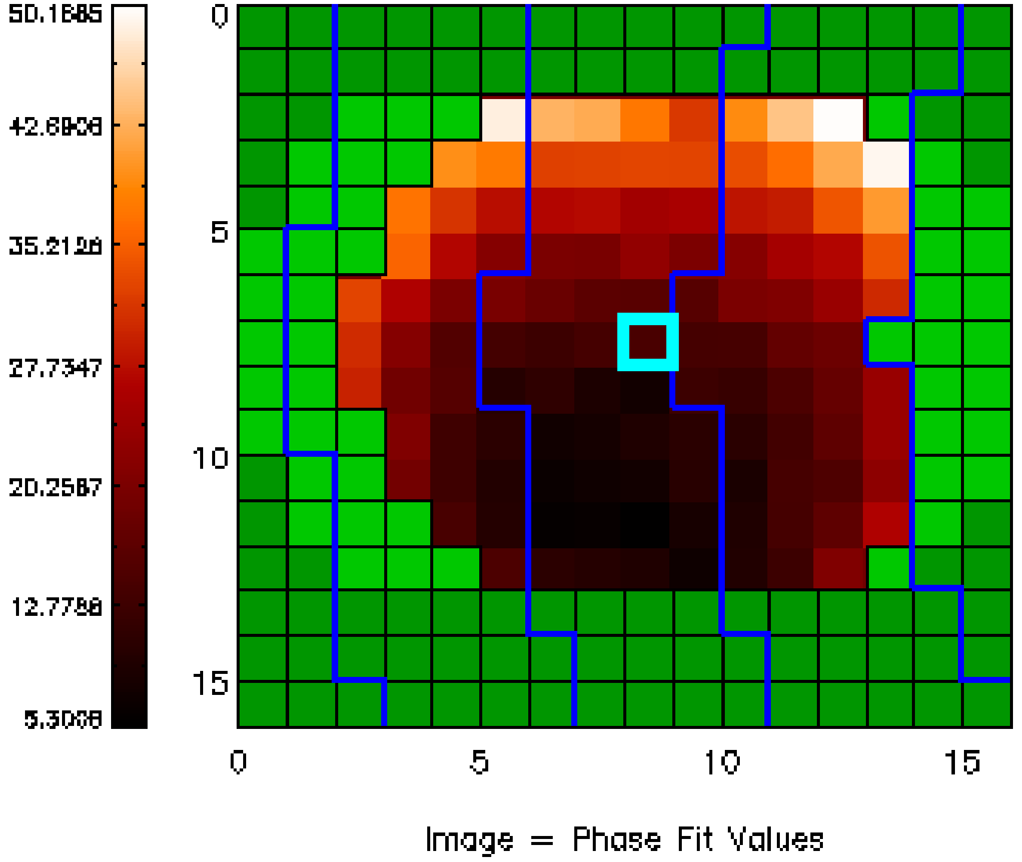
Phase map



Phase (=echo point) varies with detector pixel.

Why?

Phase map



Phase (=echo point) varies with detector pixel.

Why?

Neutron trajectories are different. Each neutron trajectory, the magnetic field integral J may be different.

Difference in J (δJ) changes the precession angle: potential reason to reduce the instrument resolution

$$\langle\varphi\rangle \approx \left[\frac{\gamma m^2 J \lambda^3}{2\pi h^3}\Delta E + \frac{\gamma m \lambda}{h}\delta J\right]$$

Science on NSE

Coherent dynamics

Density fluctuations corresponding to some SANS pattern

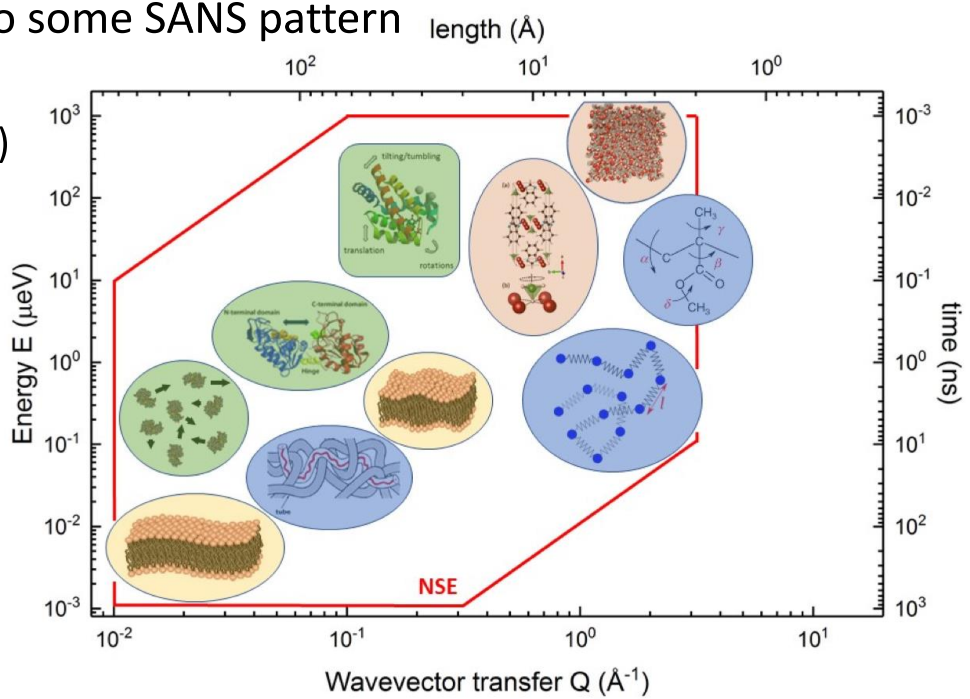
- Diffusion
- Shape fluctuations (Internal dynamics)
- Polymer dynamics
- Liquids and Glass systems

Incoherent dynamics

Self-dynamics (hydrogen atoms)

Magnetic dynamics

Spin glasses

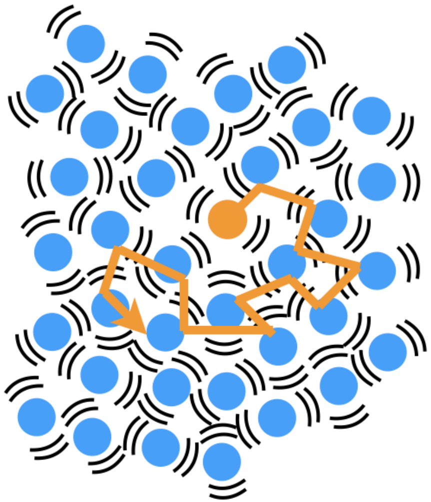


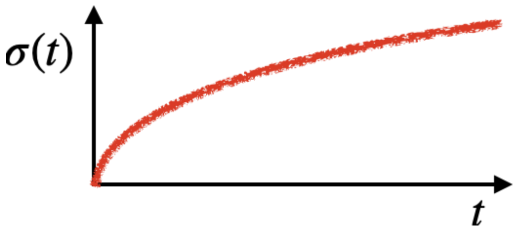
Gardner, Ehlers, Faraone, and Garcia-Sakai, *Nature Reviews Physics* **2**, 103 (2020).

Self-diffusion of a particle - diffusion

Here, we assume self-part of the van Hove correlation function that follows Gaussian shape

$$G_s(r,t) = \frac{1}{(2\pi)^{\frac{3}{2}}\sigma^3(t)} e^{-\frac{r^2}{2\sigma^2(t)}}$$





Experiment and theory suggest the Gaussian width follows $\sigma(t) = \sqrt{2Dt}$

The second moment of $G_s(r,t)$ corresponds to the mean square displacement (MSD), $\langle r^2 \rangle$

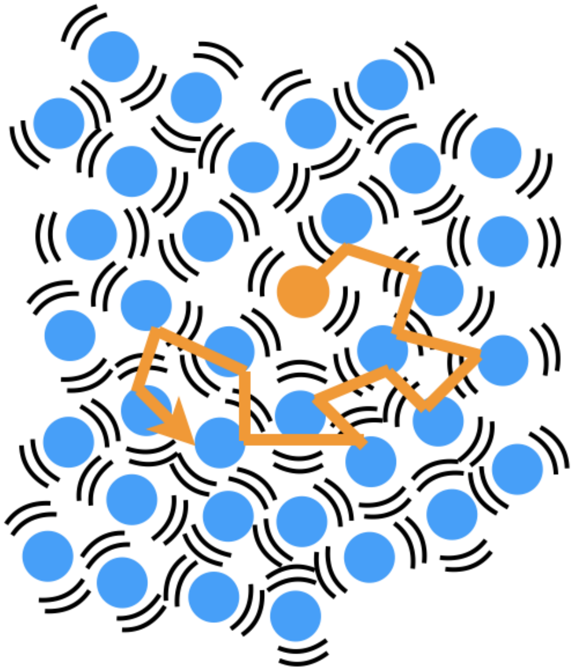
$$\langle r^2 \rangle = \int_{-\infty}^{\infty} r^2 G_s(r,t) dr = 6Dt$$

A property of Gaussian functions $\left\langle e^{iQ[r_i(t)-r_j(0)]} \right\rangle = e^{-\frac{Q^2}{6}\left\langle \left| r_i(t)-r_j(0) \right|^2 \right\rangle}$

$$S(Q,t) = e^{-DQ^2 t}$$

Self-diffusion of a particle - diffusion

A particle in interest undergoes many collisions with neighboring particles



Trajectory is a random walk

Probability distribution $G_s(r,t)$ is the solution of the diffusion equation

$$\frac{\partial G_s(r,t)}{\partial t} = D\nabla^2 G_s(r,t)$$

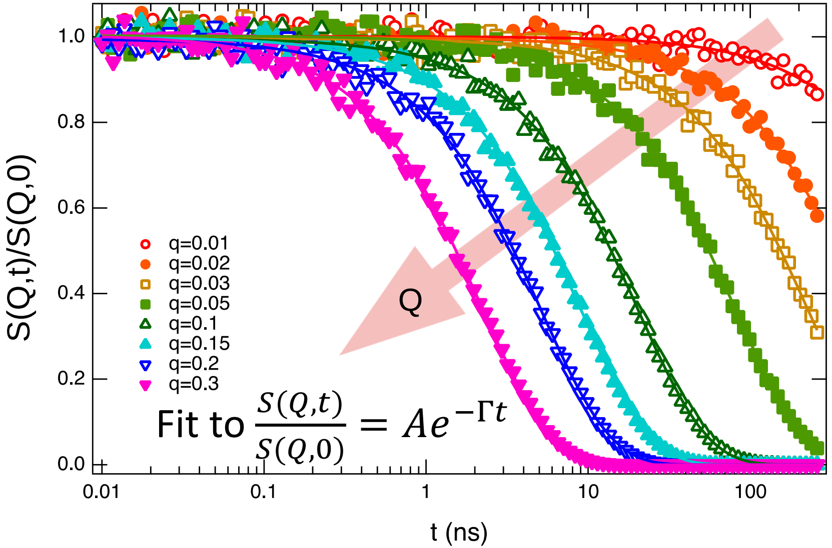
D is the diffusion constant

$$G_s(r,t) = (4\pi Dt)^{-3/2} e^{-\frac{r^2}{4Dt}}$$

Space Fourier Transform

$$S(Q,t) = e^{-DQ^2 t}$$

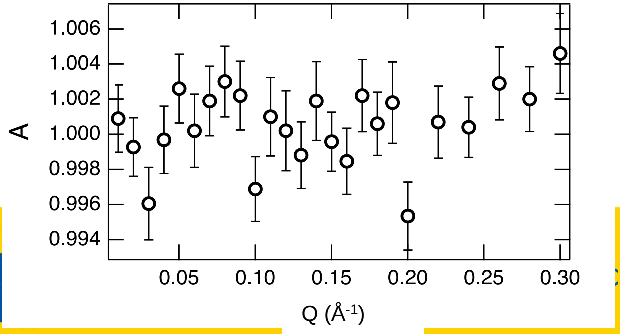
Diffusing colloidal particles

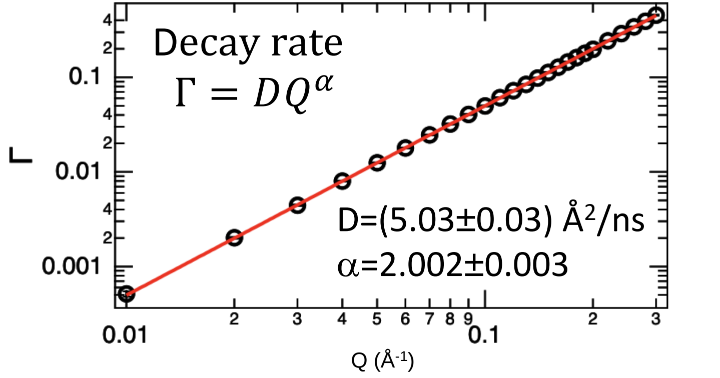


In general…

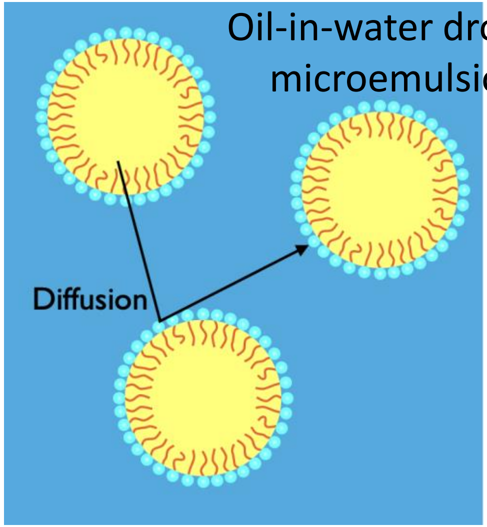
Decay gets faster as Q increases

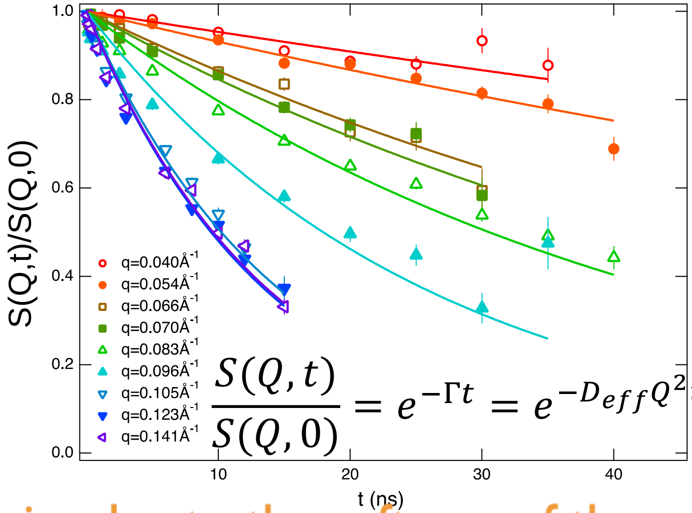
- Smaller Q -> larger length scale
  - Larger objects move slower
- Larger Q -> smaller length scale
  - Smaller objects move faster



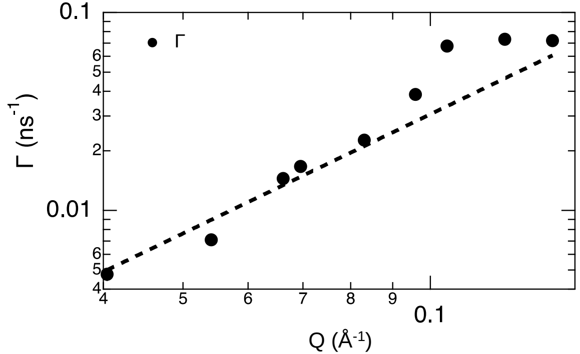


Diffusion of microemulsion droplets



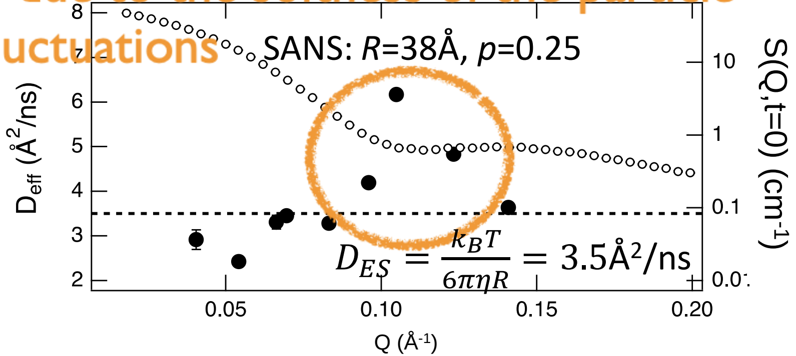


$$\frac{S(Q,t)}{S(Q,0)} = e^{-\Gamma t} = e^{-D_{eff}Q^2 t}$$



$$D_{eff} = \frac{\Gamma}{Q^2}$$

Dynamics due to the softness of the particle = shape fluctuations

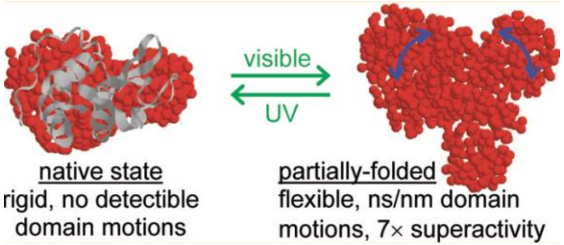


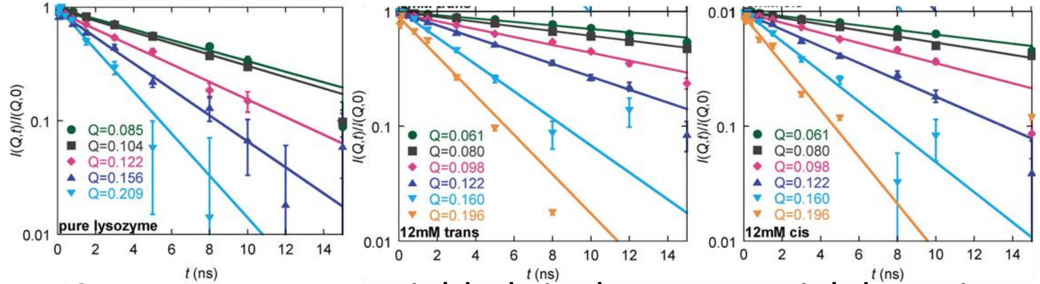
$$D_{ES} = \frac{k_B T}{6\pi\eta R} = 3.5Å^2/ns$$

S.-C. Wang, P. Mirarefi, A. Faraone, and C. Ted Lee, Jr., *Biochemistry* **50**, 8150 (2011).

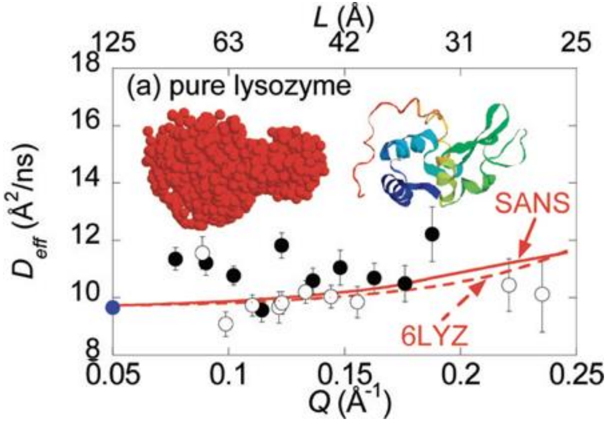
Diffusion and internal dynamics of proteins

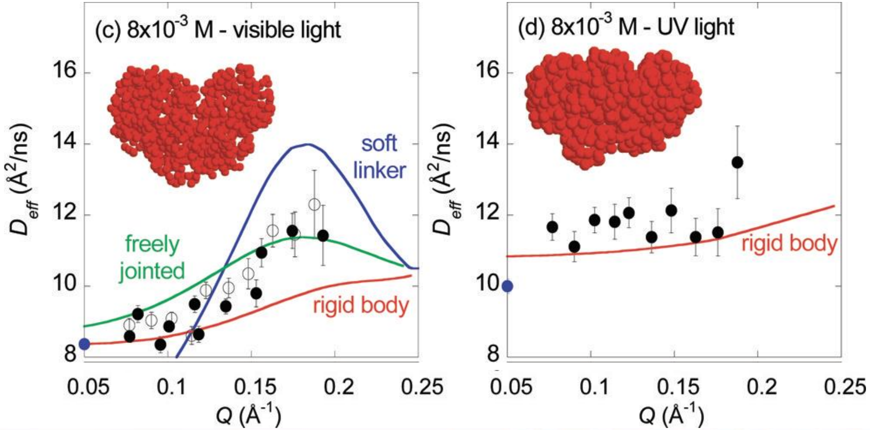
Lysozyme solution + azoTAB surfactant



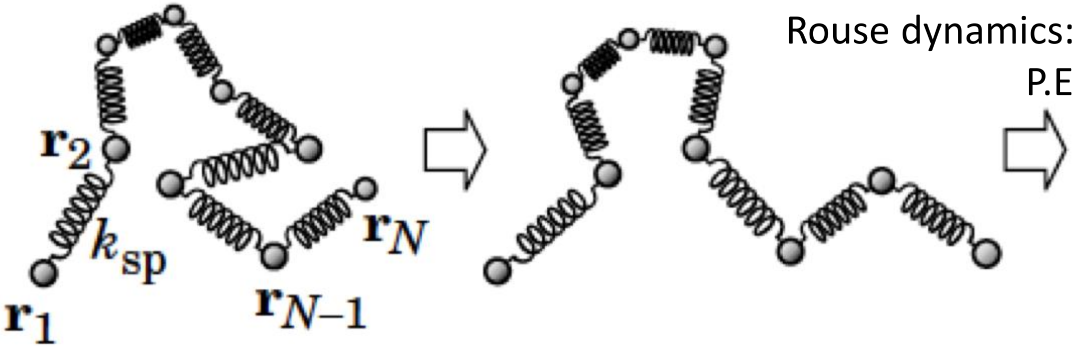


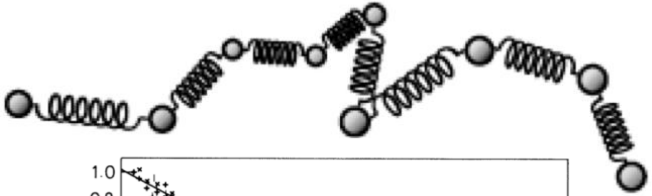
NSE measurements yielded single exponential decay in ns





When beads are connected – polymer dynamics



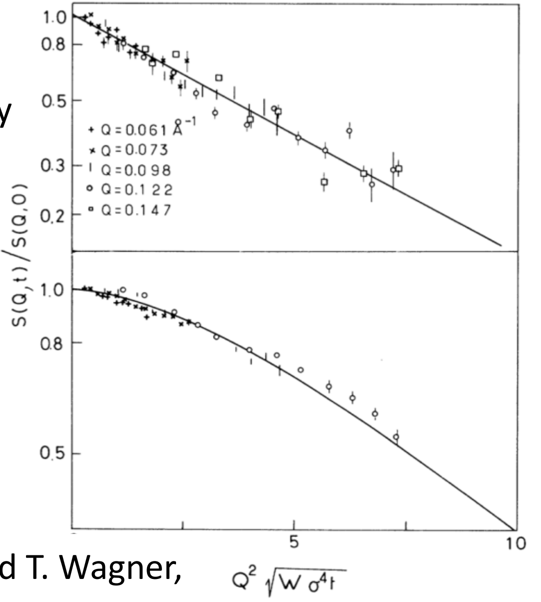


Rouse dynamics: polymer single chain dynamics in melt
P.E. Rouse, J. Chem. Phys. 21, 1272 (1953).

I. Teraoka, Polymer Solutions: An Introduction to Physical Properties, John Wiley & Sons., Inc. (2002).

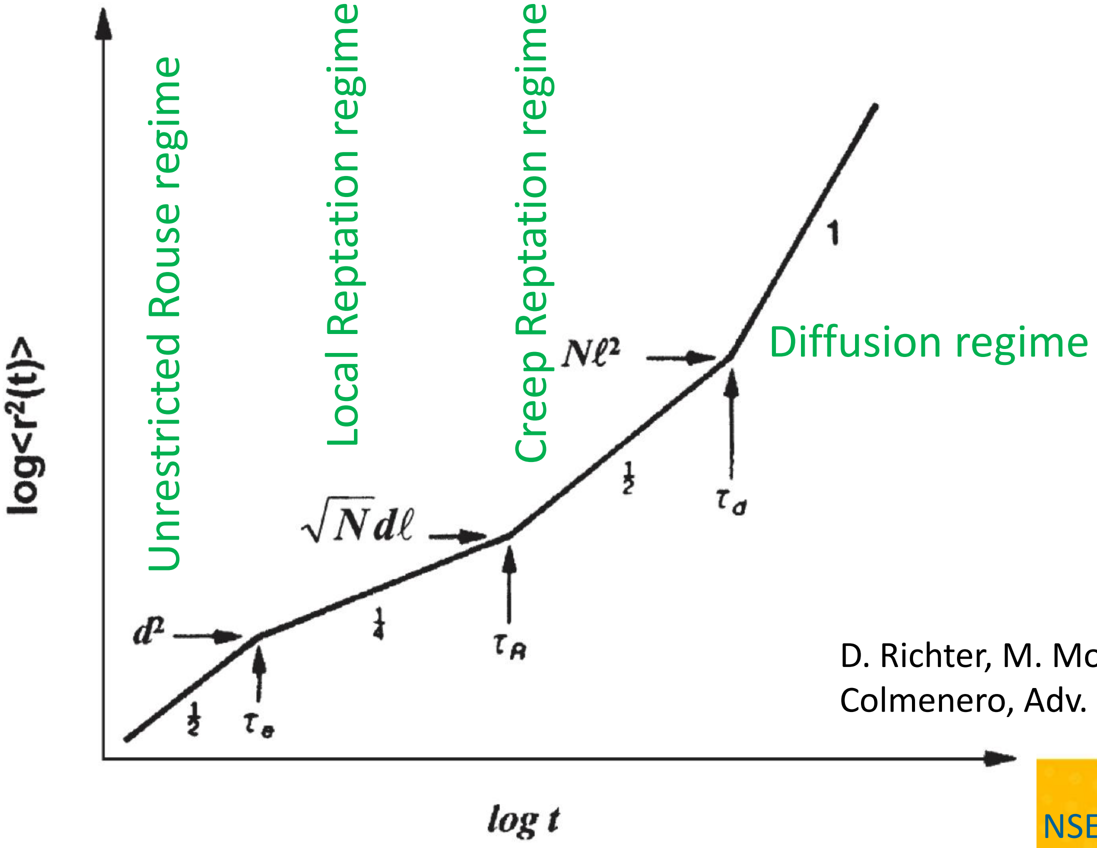
Polymer chain: bead and spring
bead: central of viscous force (Gaussian chain in a bead)
spring: elastic force

- Both coherent and incoherent dynamic structure factors are solved



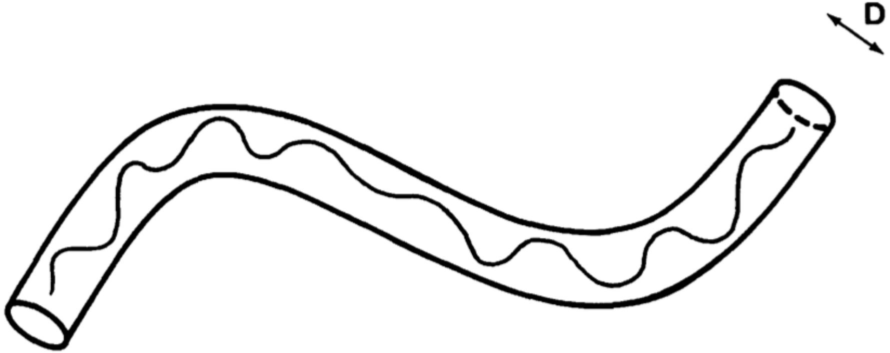
D. Richter, B. Ewen, B. Farago and T. Wagner, Phys. Rev. Lett. 62, 2140 (1989).

MSD for a chain segment

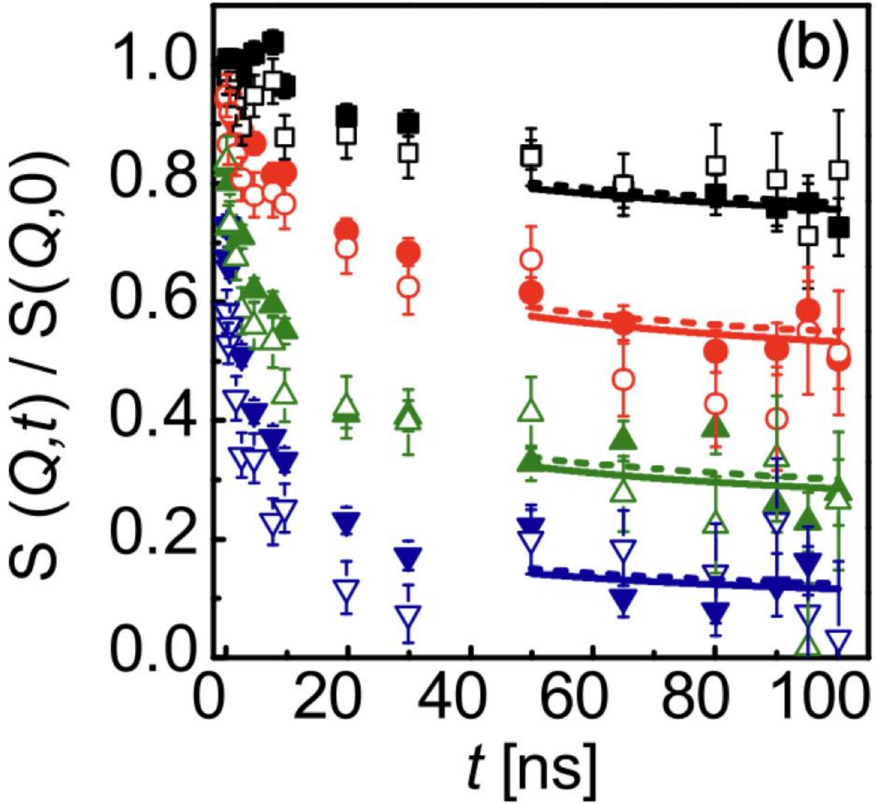


D. Richter, M. Monkenbusch, A. Arbe, and J. Colmenero, Adv. Polym. Sci. 174, 1 (2005).

Rouse to local reptation

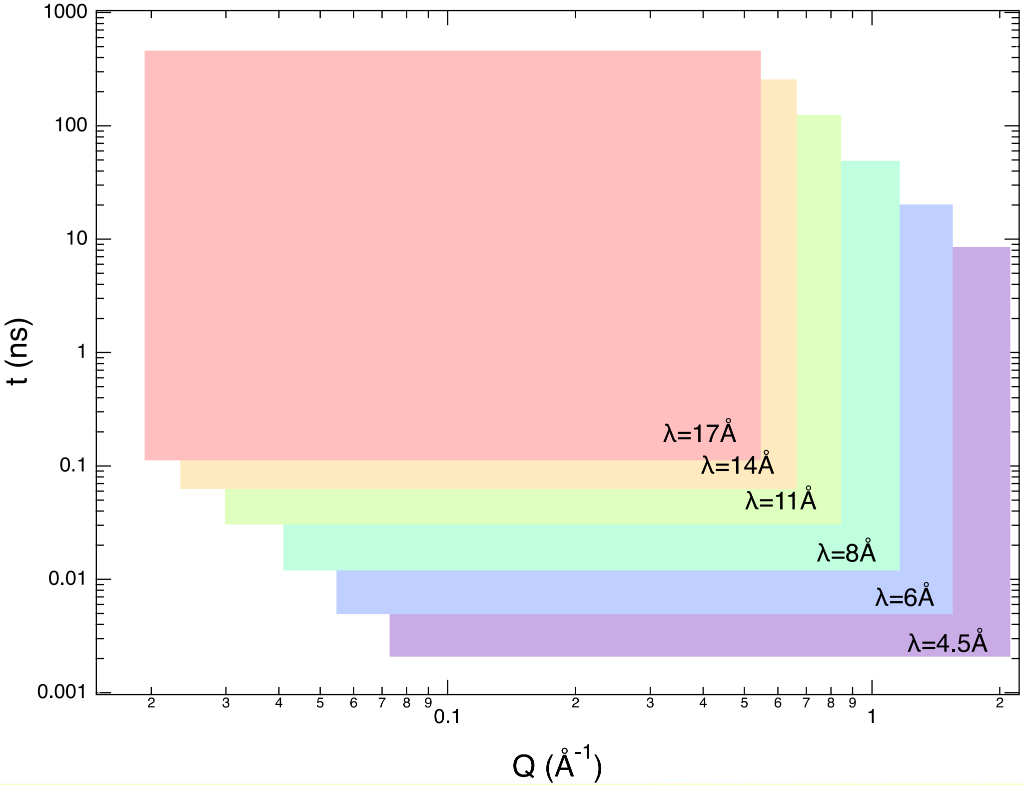


P.G. de Gennes, J. Phys. Paris 42, 735 (1981).



E. Senses, S.M. Ansar, C.L. Kitchen, Y. Mao, S. Narayanan, B. Natarajan, and A. Faraone, Phys. Rev. Lett. 118, 147801 (2017).

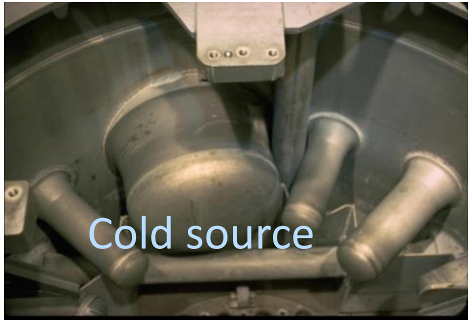
Future direction of the NIST-CHRNS-NSE

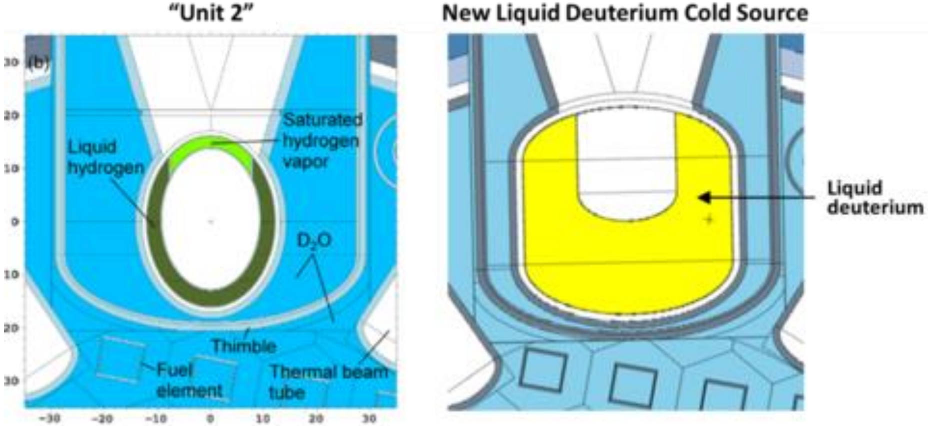


- More neutrons!
  - Cold source upgrade at the NCNR (planned in 2023)
- Smaller Q to access larger length scales!
  - Use longer wavelength neutrons
- Larger t to access longer time scales!
  - Use longer wavelength neutrons and increase magnetic field integral

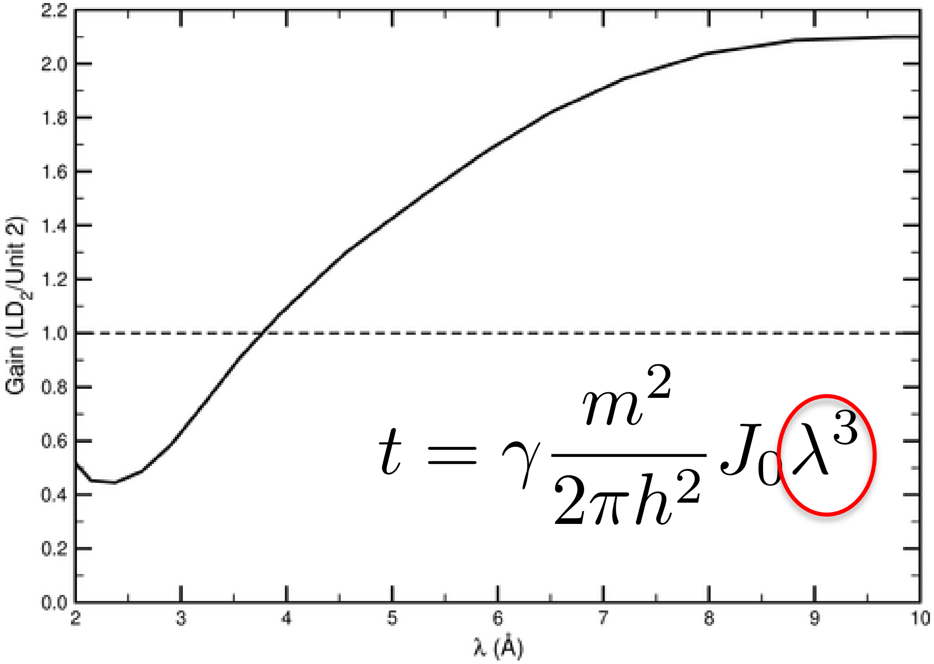
$$t = \gamma \frac{m^2}{2\pi h^2} J_0 \lambda^3$$

NCNR cold source upgrade

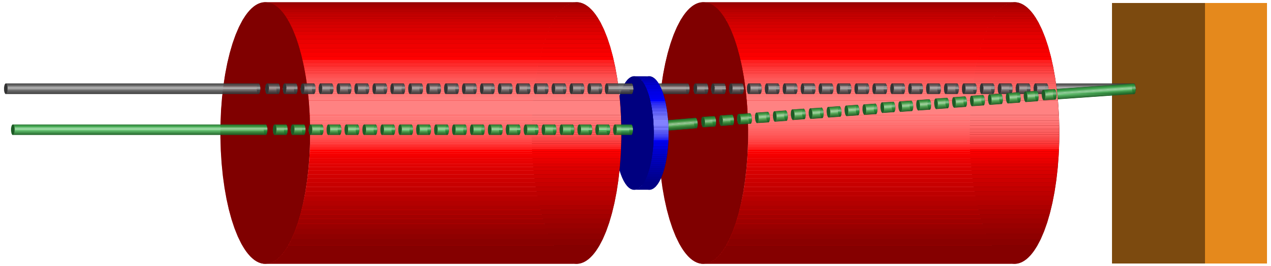




2x gain at long wavelengths

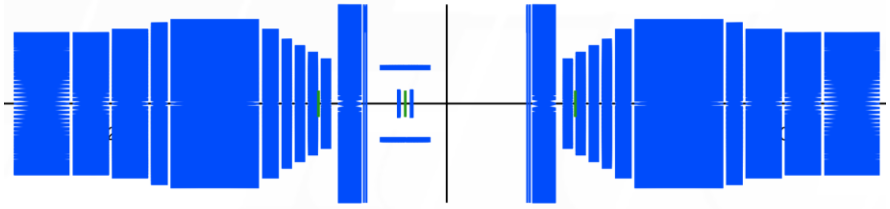


Improve magnetic field strength

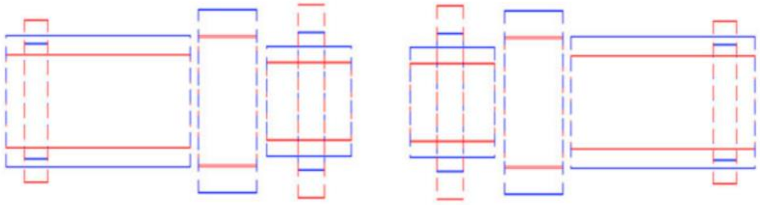


- Coil shape determines J_{max}
- Neutrons at different trajectories feel different J, which limits ability of NSE spectroscopy

Asymmetric Coil Shape = Optimized for NSE

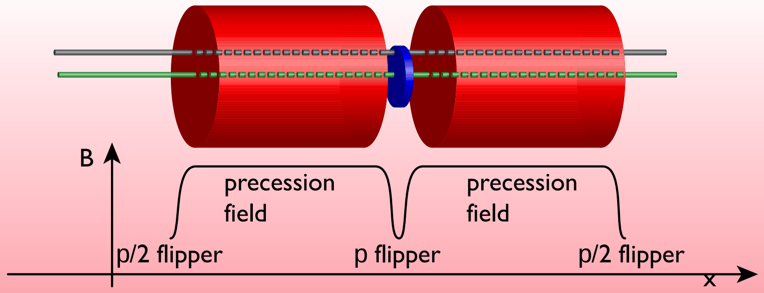


Design on IN15 at ILL by Bela Farago



Design on J-NSE-Phoenix at JCNS by Michael Monkenbusch

Improve magnetic field inhomogeneity

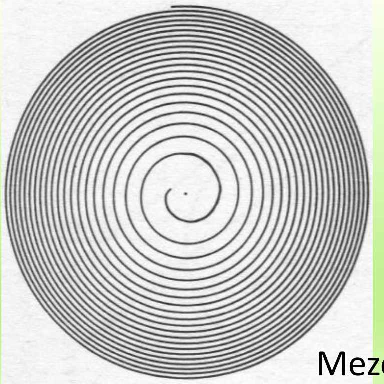


$$J = \int B(x)dx + \frac{r^2}{8}\int \frac{1}{B(x)}\left(\frac{dB(x)}{dx}\right)^2 dx + \cdots$$

Needs for higher order terms corrections

$$r^2 = x^2 + y^2$$

Fresnel coil: technology from the 1970s



Spiral cut to realize an array of concentric loops with

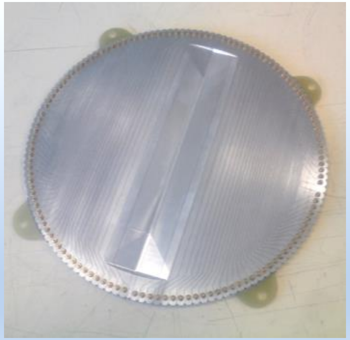
$$r \propto \sqrt{n}$$

will compensate r^2 inhomogeneity

Mezei, *Lect. Notes Phys.* **128**, 178 (1979).

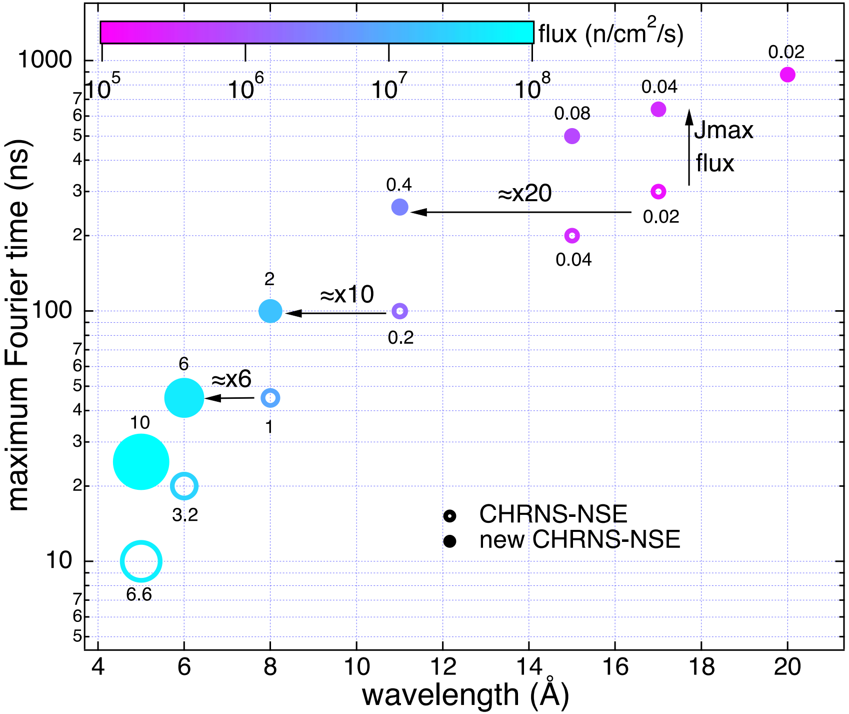
Pythagoras coil

Version at Juelich



Version at ILL

Gains

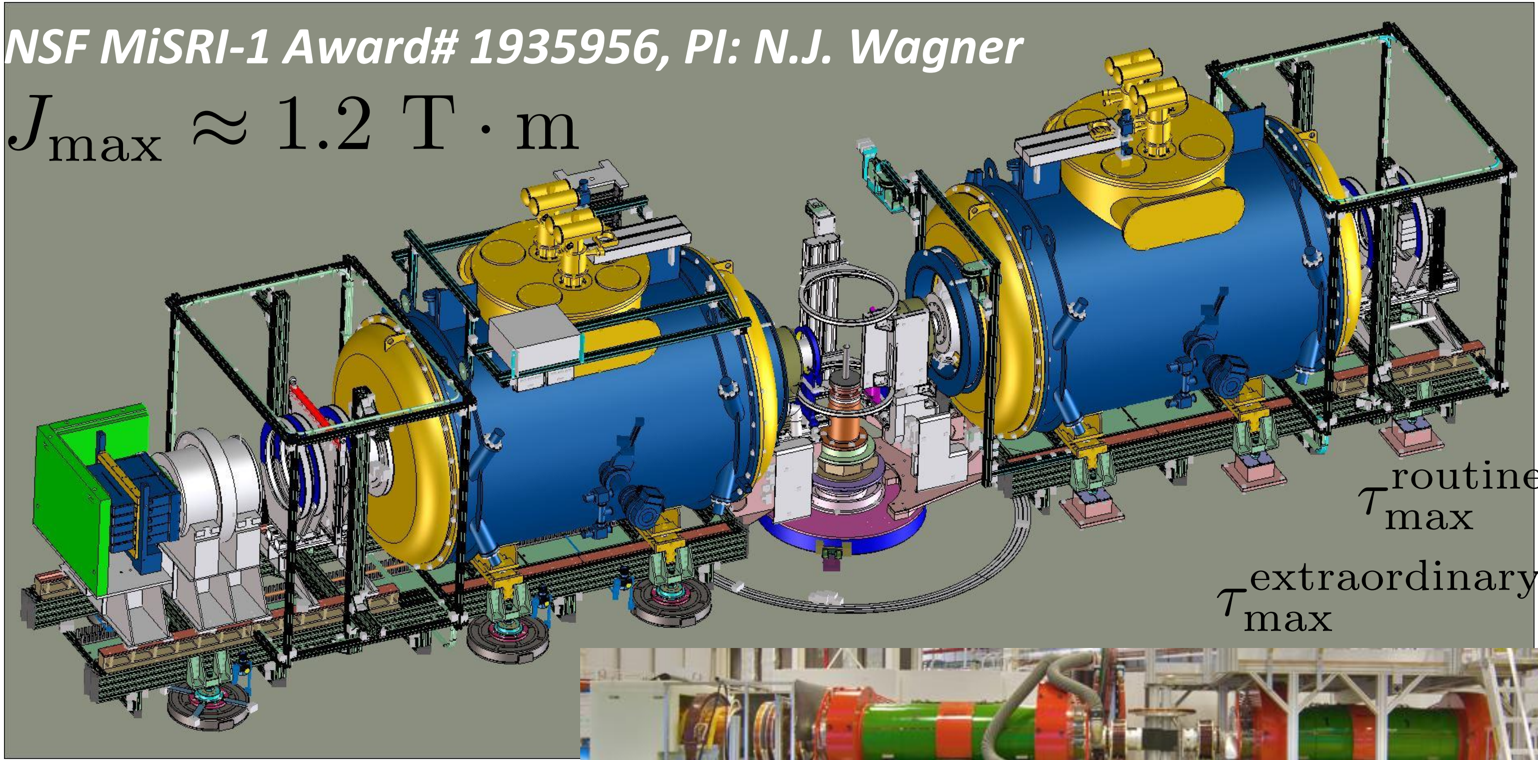


- Improving data rate a factor 10 to access 100 ns (currently by 11 Å, in future by 8 Å)
  - More gain at longer wavelengths
- Routine operation up to 300 ns
  - Currently 100 ns
- Maximum achievable time to 700 ns
  - Current record 300 ns
- Out reach & education
  - This workshop!

Future NIST-CHRNS-NSE

NSF MiSRI-1 Award# 1935956, PI: N.J. Wagner

$$J_{\max} \approx 1.2\ \mathrm{T \cdot m}$$



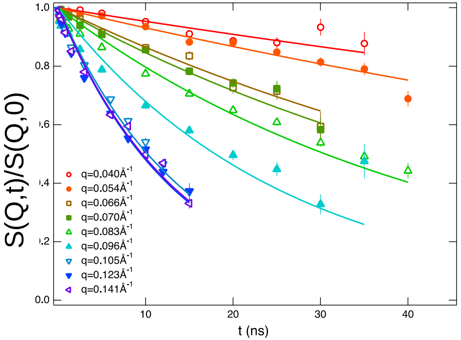
$$\tau_{\max}^{\text{routine}} \approx 300\ \text{ns}$$

$$\tau_{\max}^{\text{extraordinary}} \approx 700\ \text{ns}$$

Current CHRNS-NSE

Planning a NSE experiment

- Which dynamics do you want to identify?
  – Prepare a few clear targets why you measure dynamics of which system
- Most probably you would like to know the structure before even thinking to study dynamics
  – Dynamics are measured simultaneously with static structures
  – Intensity distributions including coherent/incoherent
- Guestimate timescale of the motion
  – NMR?, dielectric spectroscopy?, DLS?, NBS?, simulation?...
- Gather enough amount of materials
  – Typical sample size 30 mm x 30 mm x 1 - 4 mm
- Discuss with an expert



Learning Goal

- Understand the length/time range covered by NSE
  - Nanometer and nanosecond scales
- Understand the principle of NSE operation
  - Larmor precession to decouple instrument and probe energy resolution
- Understand the types of soft matter problems that can be solved by NSE
  - Various coherent soft matter dynamics
- Understand the new opportunities for the upgraded NSE at NIST
  - Extended Fourier time range with increased data rate
- Understand how to plan a successful NSE experiment
  - Better to (almost must) know static structures, before dynamics studies

Presentation 10/29 10:10 am

- Use what you learned from this workshop to present your research that can be benefit from NSE (the one in your application or something else). Send it to Kuo-Chih by 11:59 pm kuo-chih.shih@nist.gov

Proposal Review (Optional)

- If you like, you can submit a proposal through our IMS proposal system (we will tell you how to do this, of course) and reviewers will review your proposal and give you feedback.

Polymer: Main Conference Room

Membrane: Key Room

Protein: Tubman Room