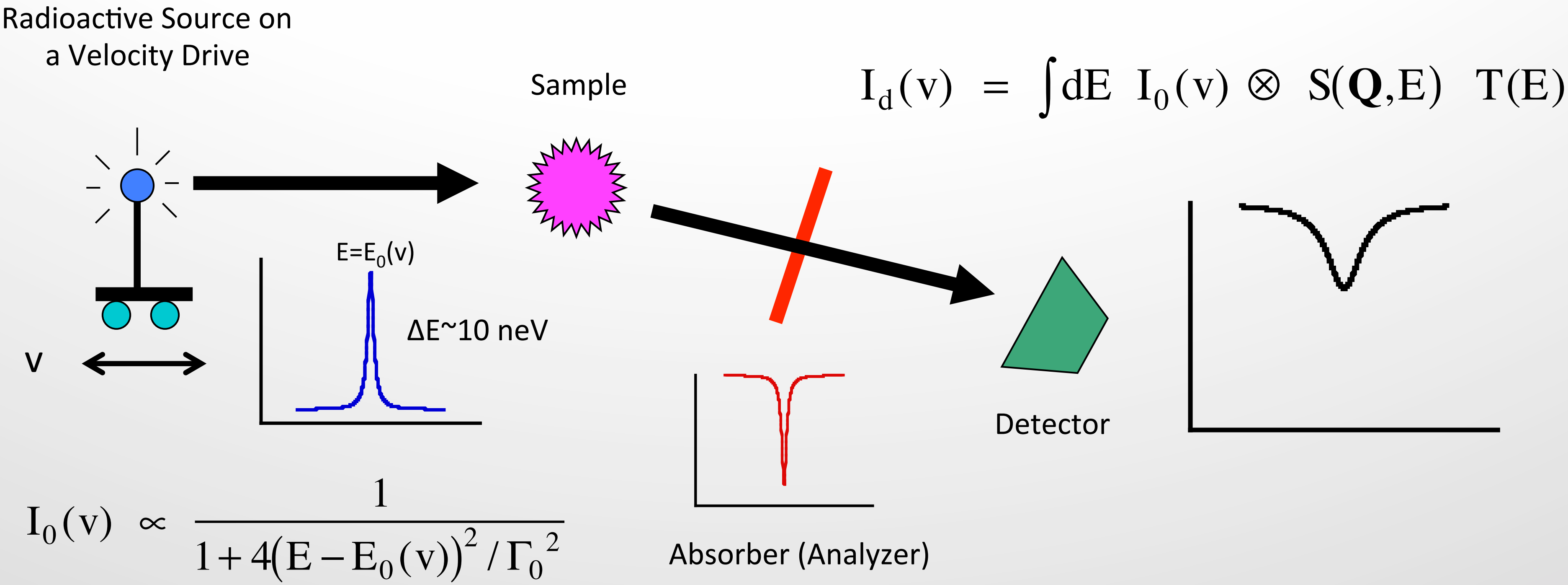
Dynamics on ns to μs time scales using Nuclear Resonant Scattering

	Radioactive Source	SR Source (Time)	SR Source (Frequency)
Resonant Sample	Classical MB Relaxation	Nuclear Forward Scattering	Synchrotron MB Source
Non-resonant Sample	Rayleigh Scattering Of MB Radiation (RSMR)	Time Domain Interferometry (TDI)	SR Based RSMR using Sync. MB Source

RSMR



$$I_d(v) = \int dE \; I_0(v) \otimes S(\mathbf{Q},E) \; T(E)$$

$$I_0(v) \propto \frac{1}{1+4(E-E_0(v))^2/\Gamma_0^{\,2}}$$

In Principle: useful for probing dynamics on scale of source/absorber linewidths

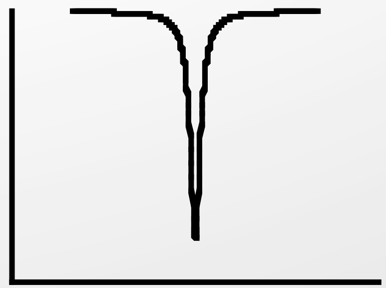
In Practice: a very hard experiment, not done very often

Fourier Transform Relationship

Fourier transform relationship

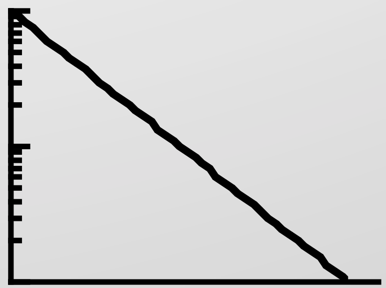
Impulse Response $$G(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} R(\omega)\ e^{-i\omega t}\ d\omega$$

Frequency Response $$R(\omega) = \int_{-\infty}^{+\infty} G(t)\ e^{+i\omega t}\ dt$$



$$R(\omega) = \frac{-1}{2\hbar(\omega-\omega_0)/\Gamma_0 + i} \Leftrightarrow G(t) = \frac{i}{2\tau_0}\ e^{-i\omega_0 t}\ e^{-t/2\tau_0}\ \Theta(t)$$

Lorentzian $$\Gamma_0\ \tau_0 = \hbar$$ Exponential Decay



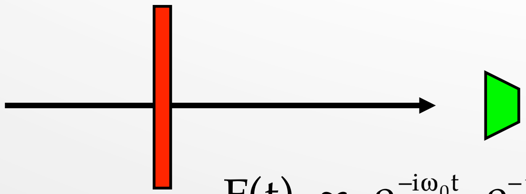
Transmission through an ***ideal thin*** *foil*

NFS Setup

Quantum Beats

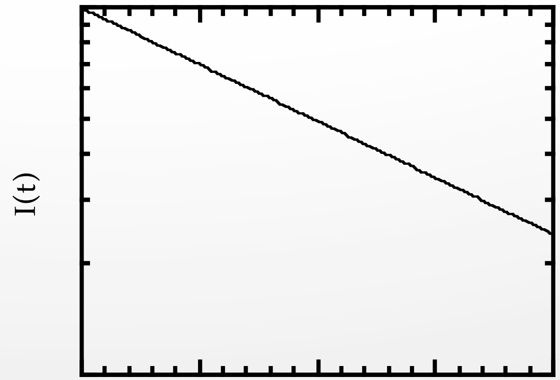
(Thin Foils)

Single (thin) foil
Any *Constant* velocity



$$E(t) \propto e^{-i\omega_0 t} \; e^{-t/2\tau}$$

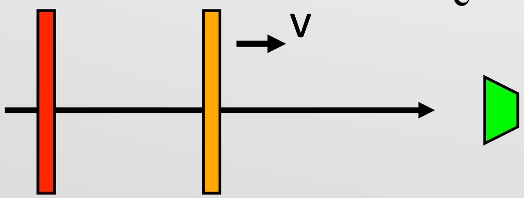
$$I(t) \propto e^{-t/\tau}$$



Stationary Foil

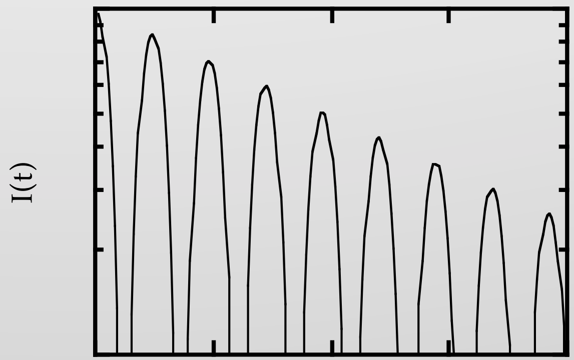
Moving Const. v

$$\Omega = \frac{v}{c}\omega_0$$



$$E(t) \propto e^{-t/2\tau}\left[e^{-i(\omega_0+\Omega)t} + e^{-i\omega_0 t}\right]$$

$$I(t) \propto e^{-t/\tau}[1 + \cos(\Omega t)]$$



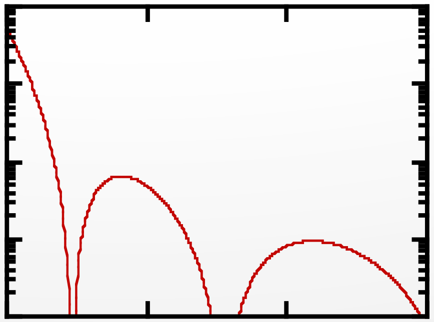
Quantum Beats

(Thick foils)

Single foil

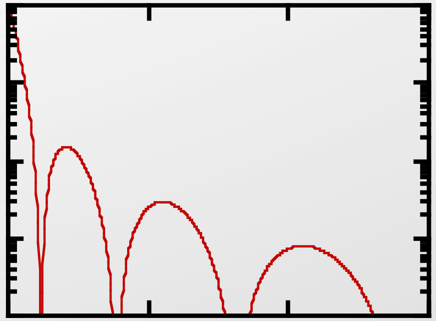
$$I(t) \propto \left|G_\beta(t)\right|^2$$

$$= e^{-t/\tau_0}\left[\frac{\beta}{4\tau_0}\right]^2\left[\frac{J_1\left(2\sqrt{\beta t/4\tau_0}\right)}{\sqrt{\beta t/4\tau_0}}\right]^2$$



Time After Excittion

Two Foils, Ω=0.

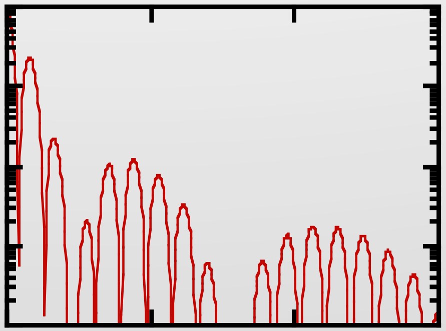


Time After Excittion

$$I(t) \sim \left|G_{2\beta}(t)\right|^2$$

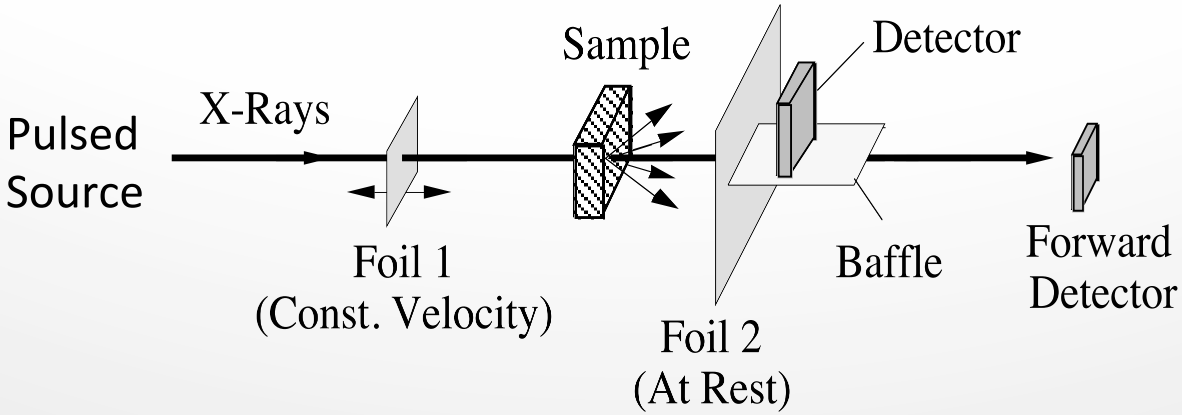
Two Foils, Large Ω.

$$I(t) \sim \left|G_\beta(t)\right|^2[1 + \cos(\Omega t)]$$



Time After Excittion

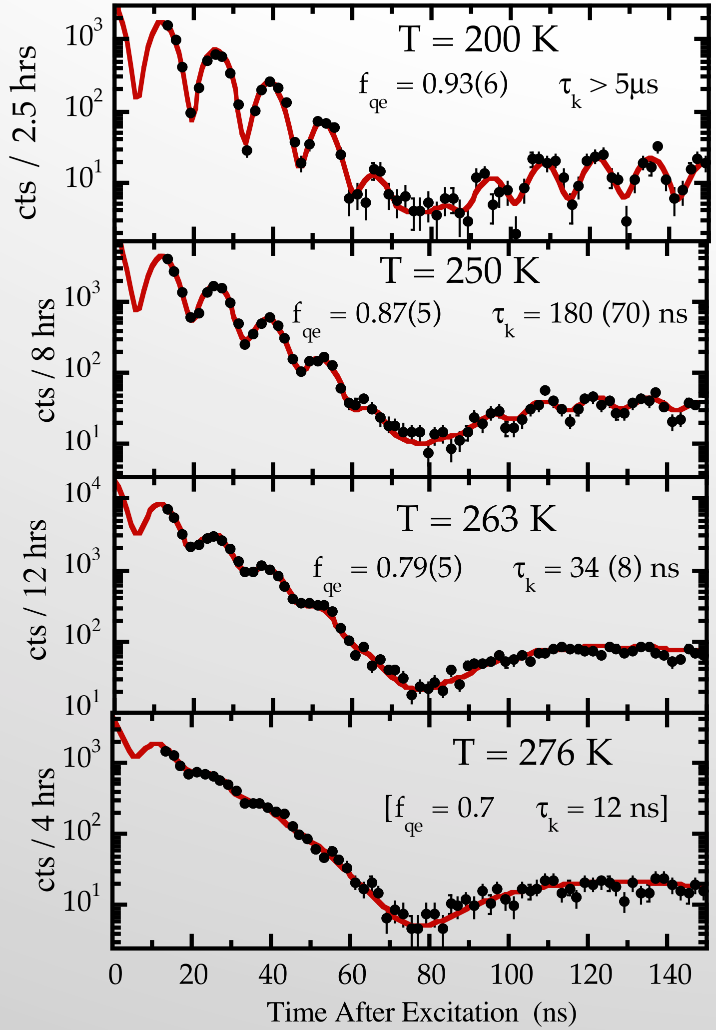
Time Domain Interferometry



$$I(\mathbf{Q},t) \approx |G(t)|^2 \left[1 + f_{qe}(\mathbf{Q})\cos(\Omega t) F(\mathbf{Q},t)\right]$$

Within some approximations, a direct measure of the intermediate scattering function

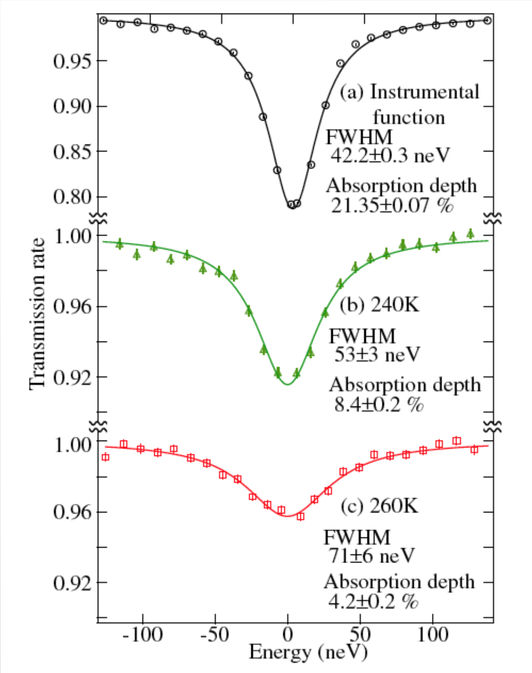
Test Measurement (Gycerol)



Baron et al, PRL 1996

Frequency Domain SR work

SR MB Source: Smirnov et al, PRB 1996



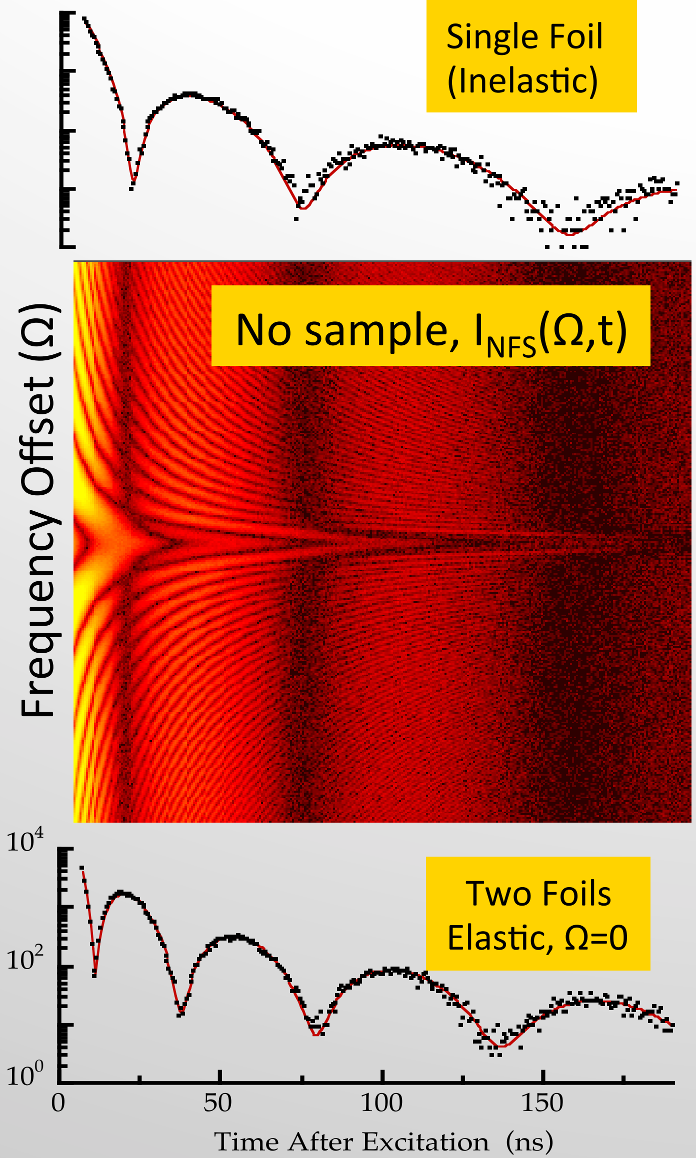
Masuda, et al, JJAP 2009

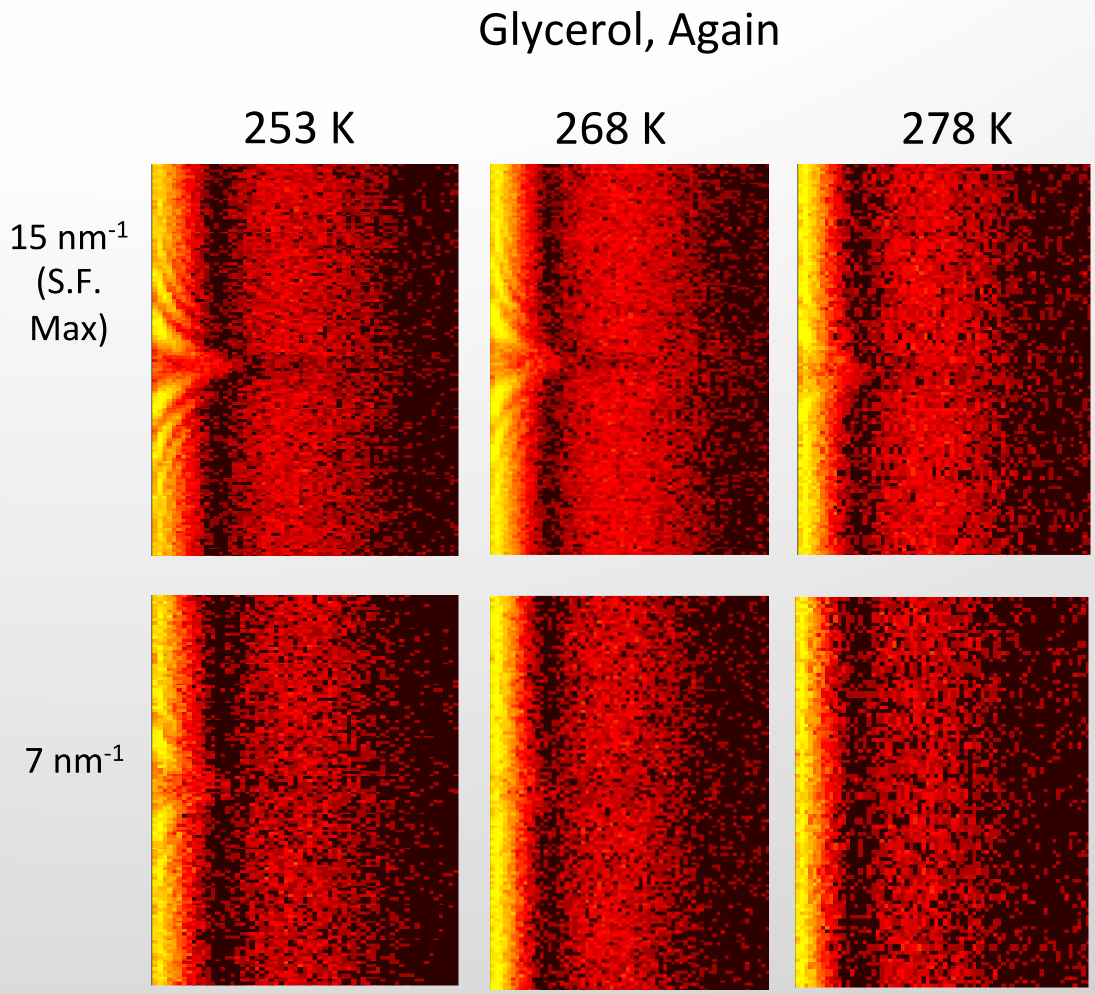
Possible Applications

Diffusion in Liquids & Confined Liquids
Polymers
Proteins in Solution
Diffusion in Solids
Central peak phenomena?

Time Domain: Possibly more sensitive to longer times (simulation)
Frequency Domain: certainly better for larger splitings

Scan the Velocity





Data Collection: ~90 minutes @ ~20 mA
for each temperature