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Wide-angle polarization analysis using ^{3}He spin filters on the LET spectrometer

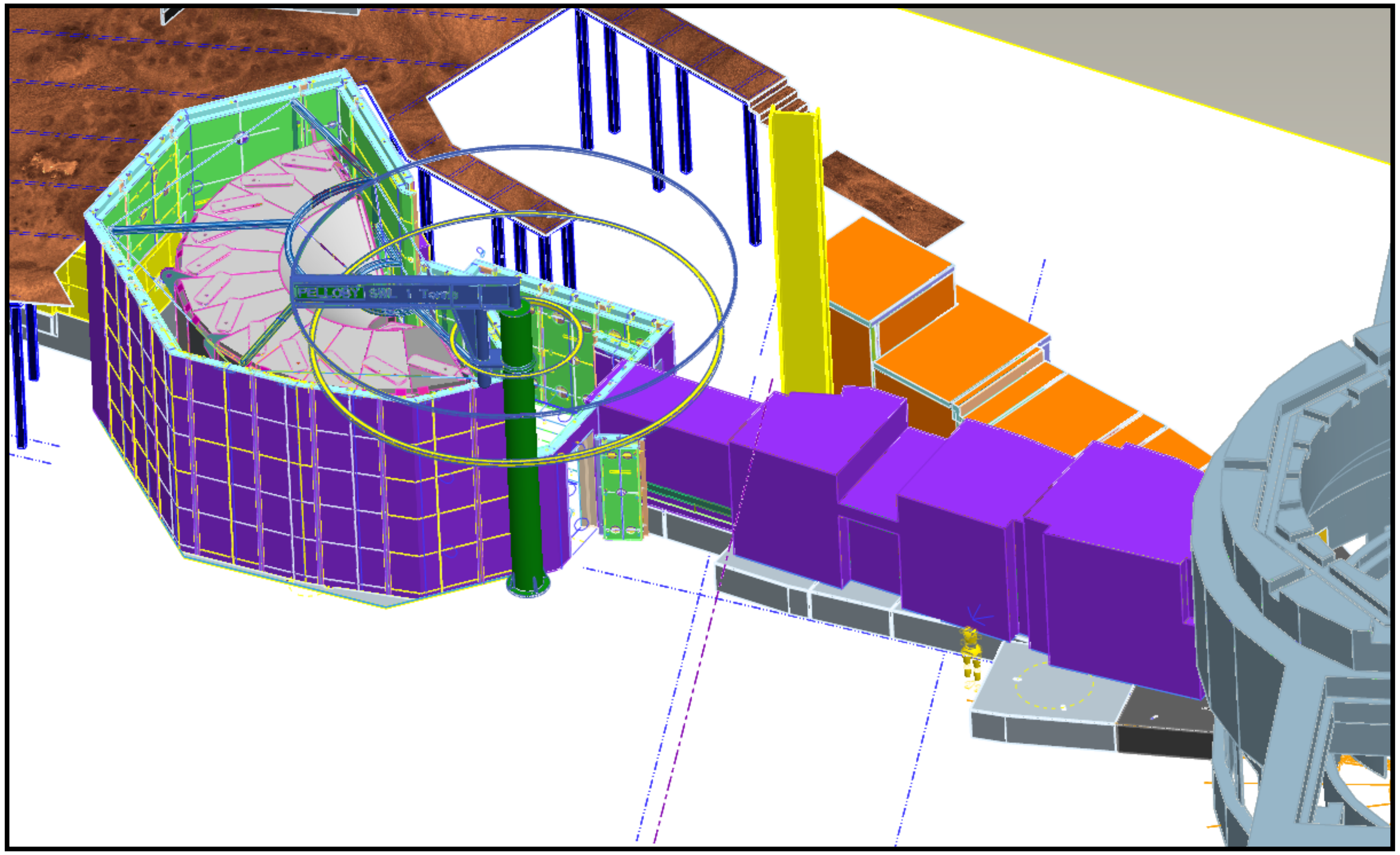
Gøran Nilsen
ISIS Neutron and Muon Facility
Rutherford Appleton Laboratory
ICANS 15/10/2019

Outline

- The LET time-of-flight spectrometer
- Quick introduction to polarized neutrons
- The case for polarized neutrons on LET
- Technical implementation
- Polarized QENS: D_2O
- Powder magnetic scattering: $Ho_2Ti_2O_7$

The LET time-of-flight spectrometer

Direct geometry TOF spectrometer on coupled H_2 Moderator



E_i	1 - 25 meV
Resolution	1 - 4 %
ϕ (3 Å)	3×10^5 $ncm^{-2}s^{-1}$
Beam size	2×4 cm^2
Detectors	^{3}He PSD
Coverage	π st.

Multi-chopper system: multiple E_i in each time frame

Russina et. al. NIMA **604** 624

LET: QENS

Hexadecane ($C_{16}H_{34}$)

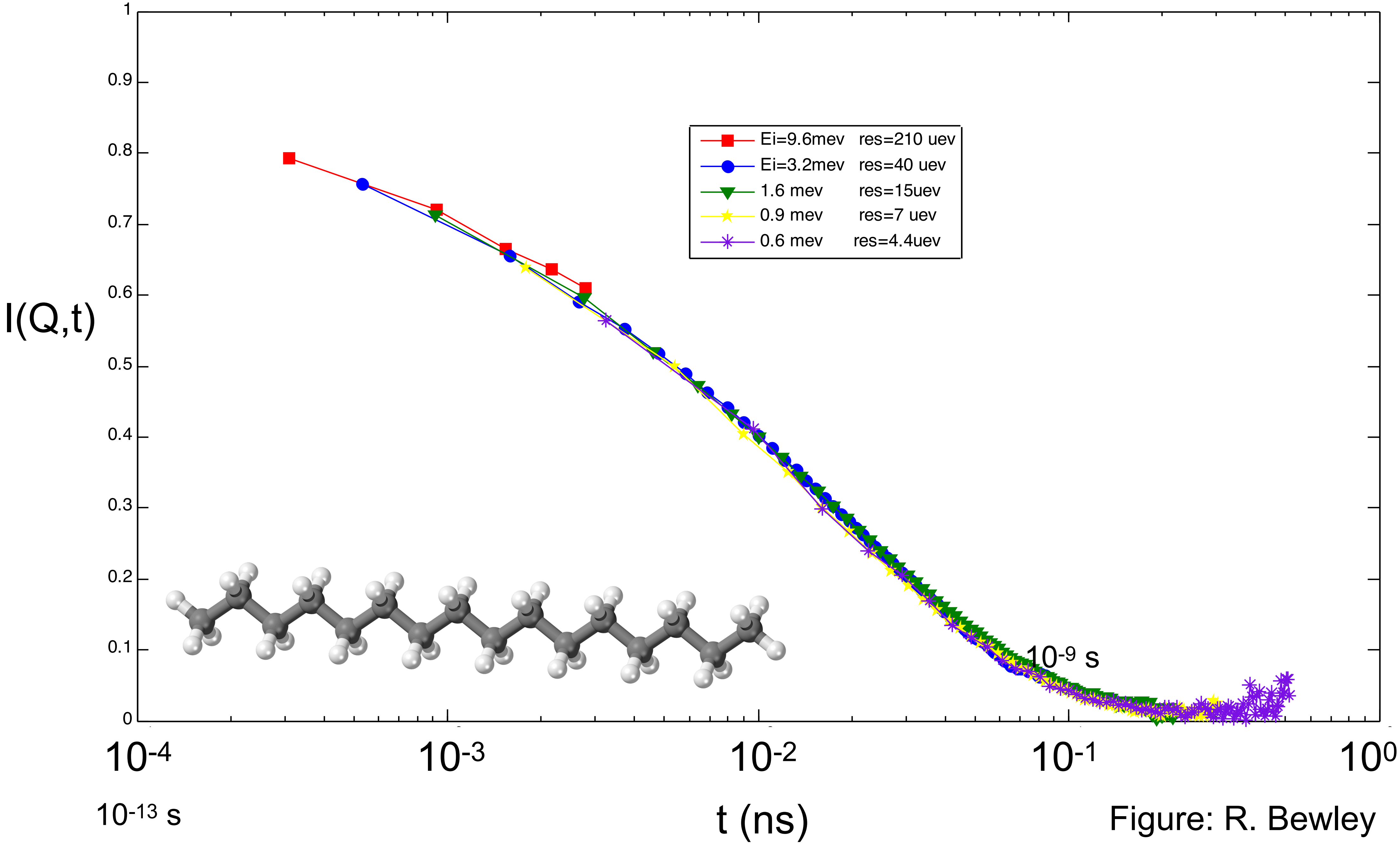


Figure: R. Bewley

LET: QENS

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Hexadecane ($C_{16}H_{34}$)

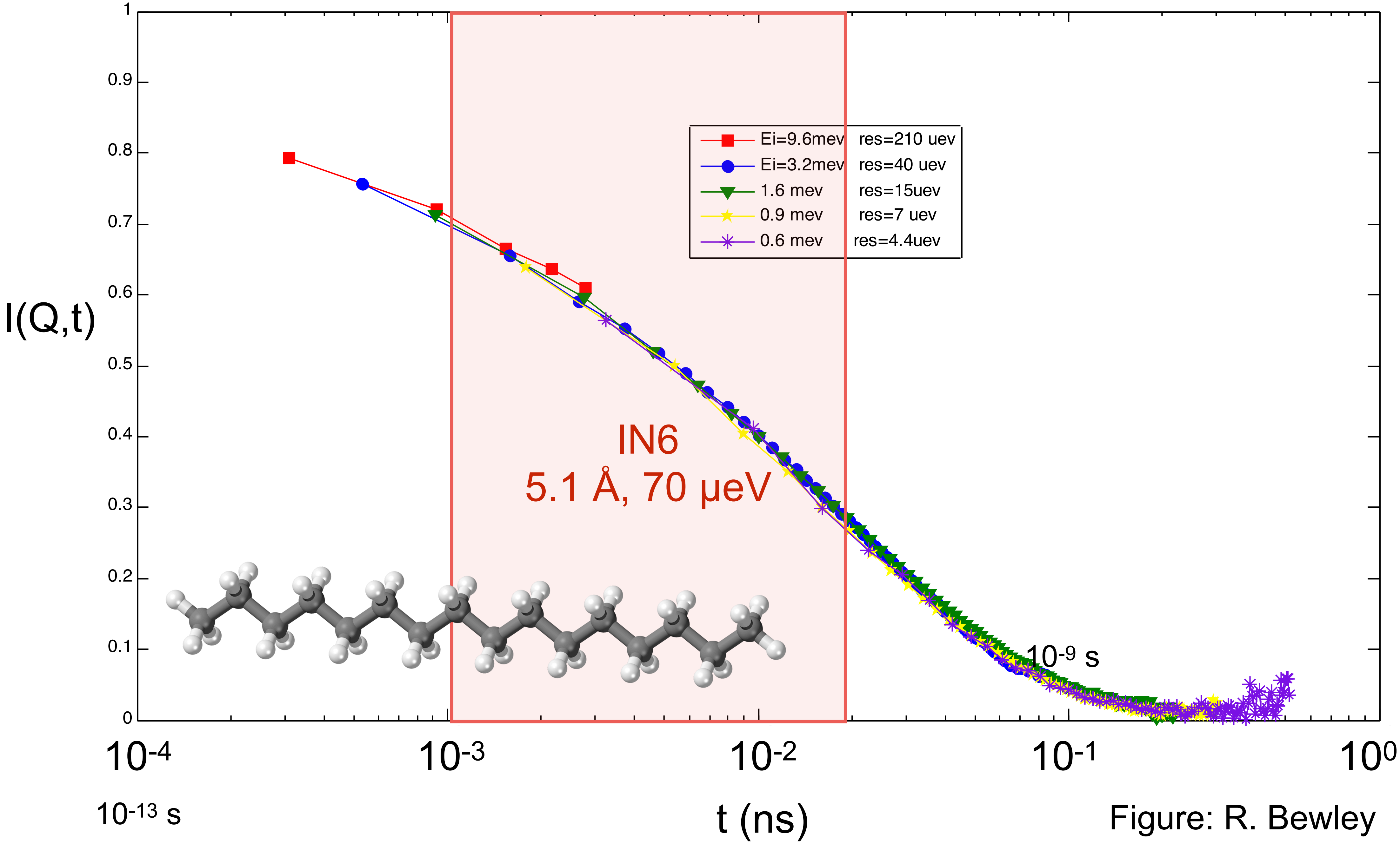


Figure: R. Bewley

LET: QENS

Hexadecane ($C_{16}H_{34}$)

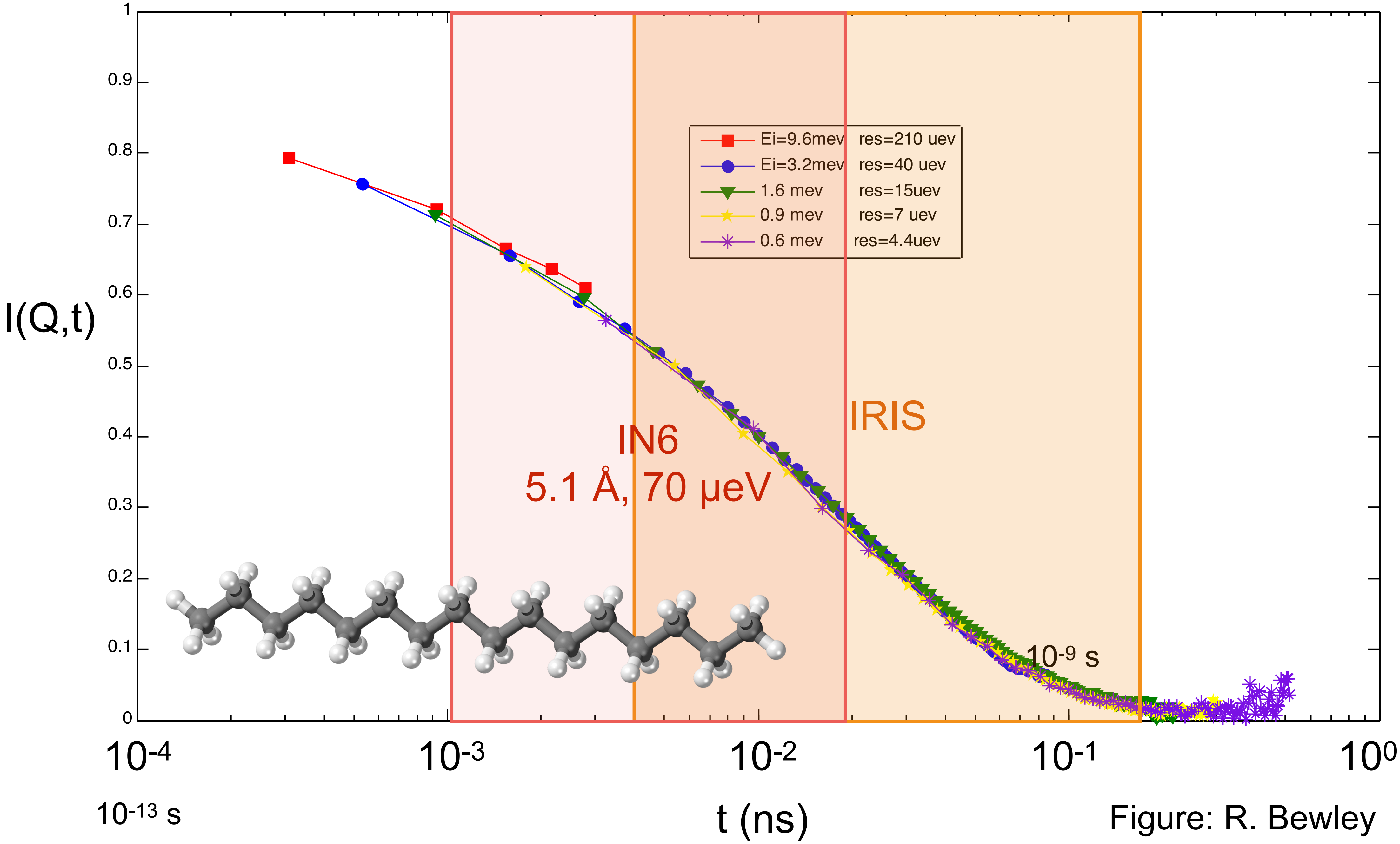


Figure: R. Bewley

LET: QENS

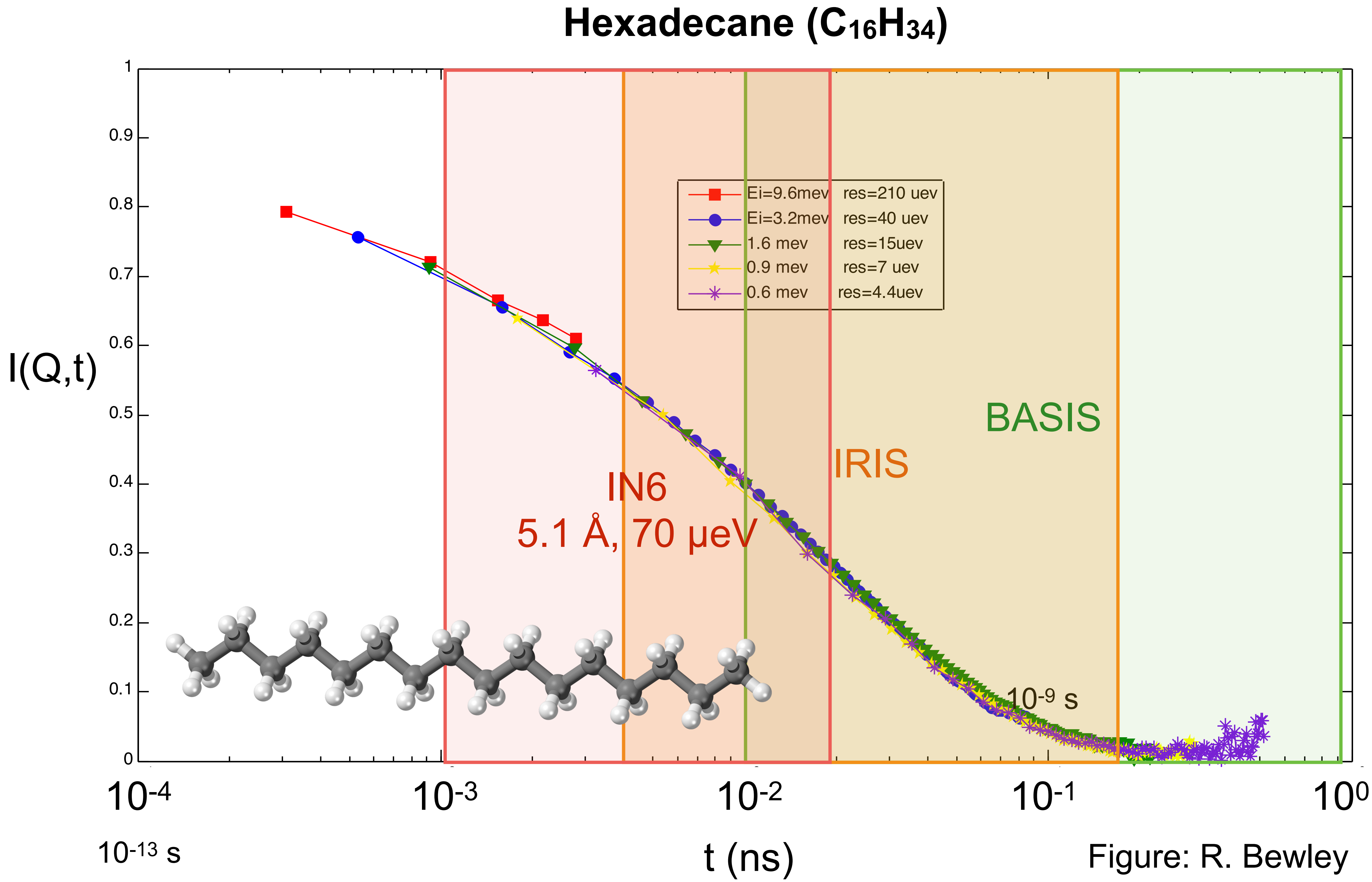


Figure: R. Bewley

LET: QENS

Hexadecane ($C_{16}H_{34}$)

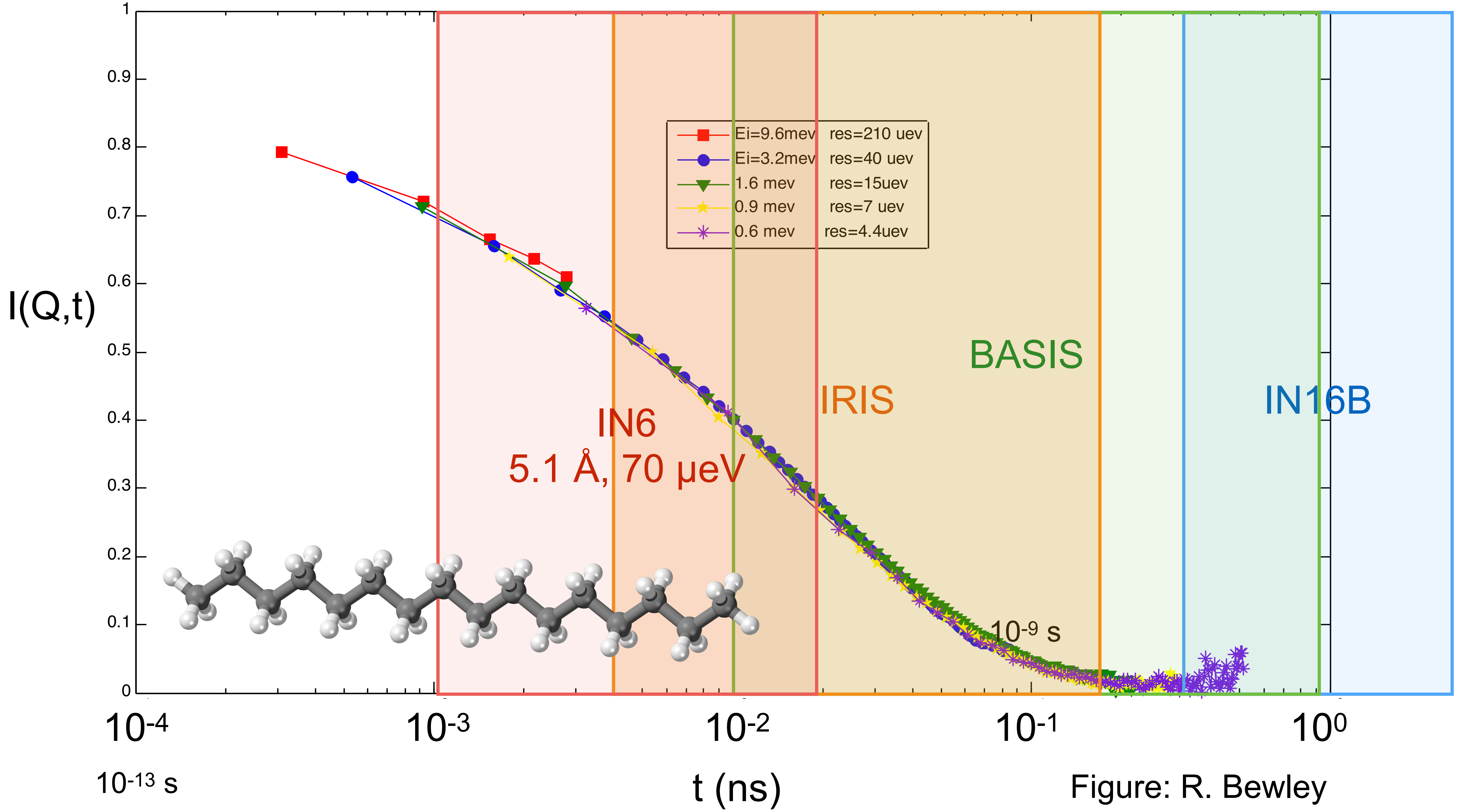
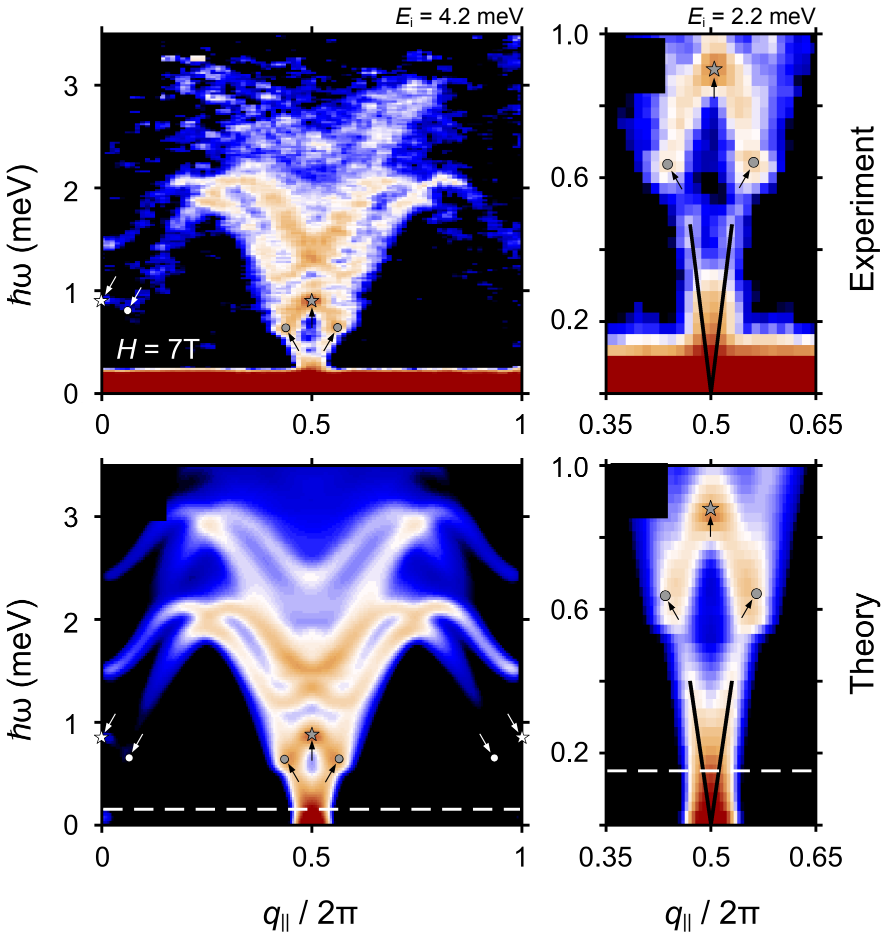


Figure: R. Bewley

LET: current science

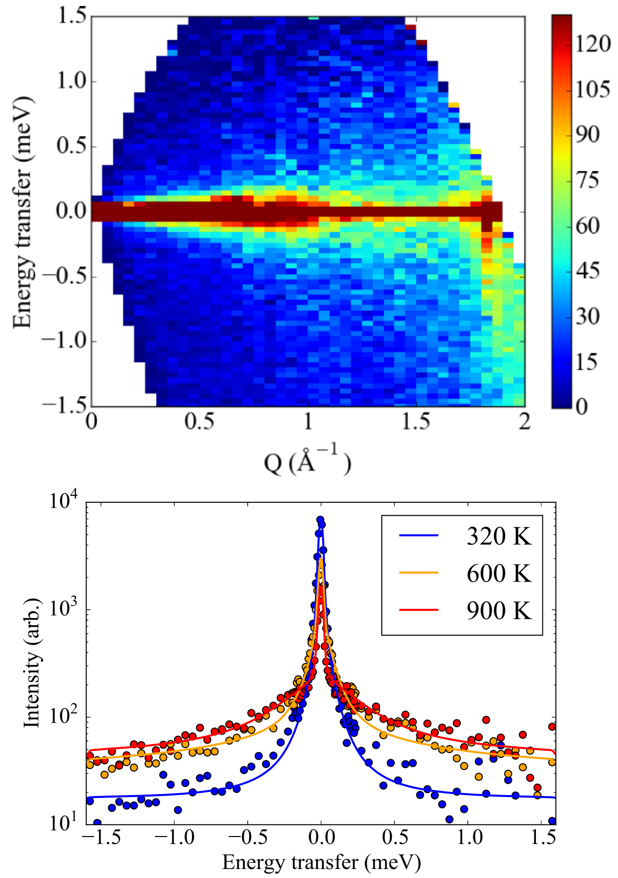
Magnetism 85%



e.g. exotic phases in quantum magnets

Schmidiger et. al. PRL **115** 147201

QENS 15%



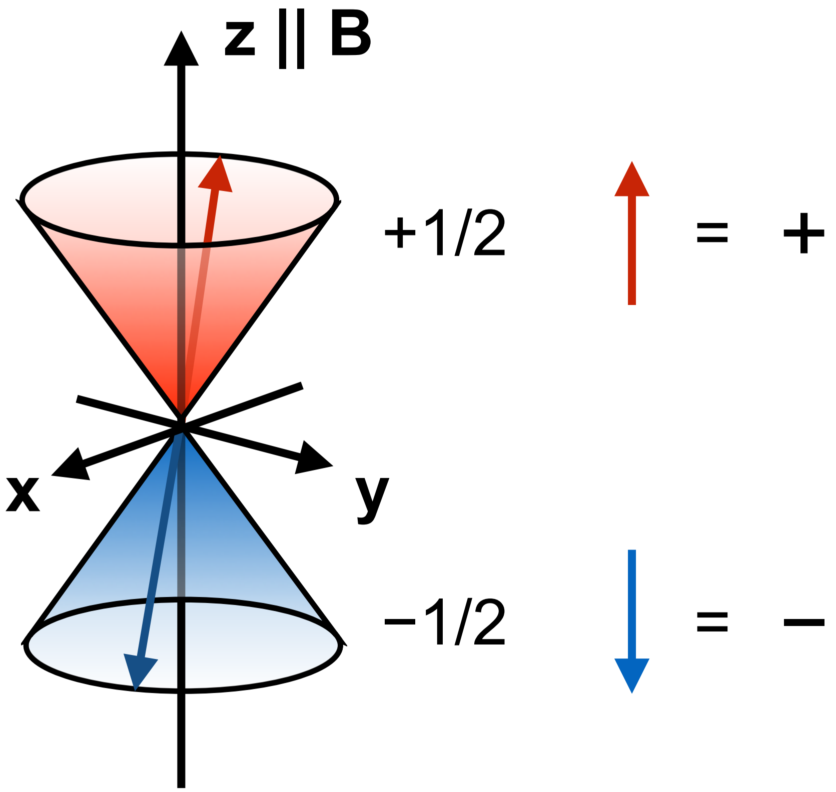
e.g. diffusion in ionic conductors

Voneshen et. al. PRL **118** 145901

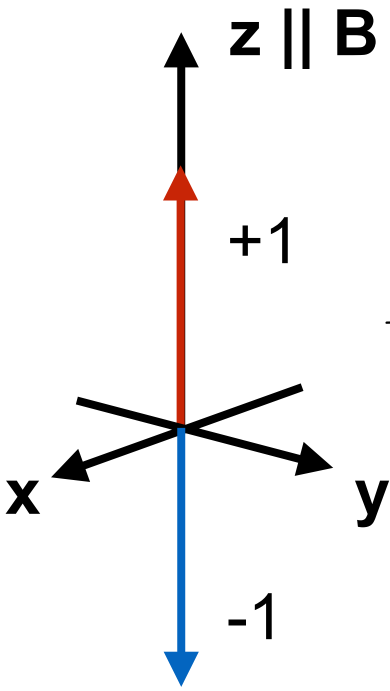
Polarized neutron beams

Neutrons possess an inherent spin-angular momentum S = 1/2:

Single neutron



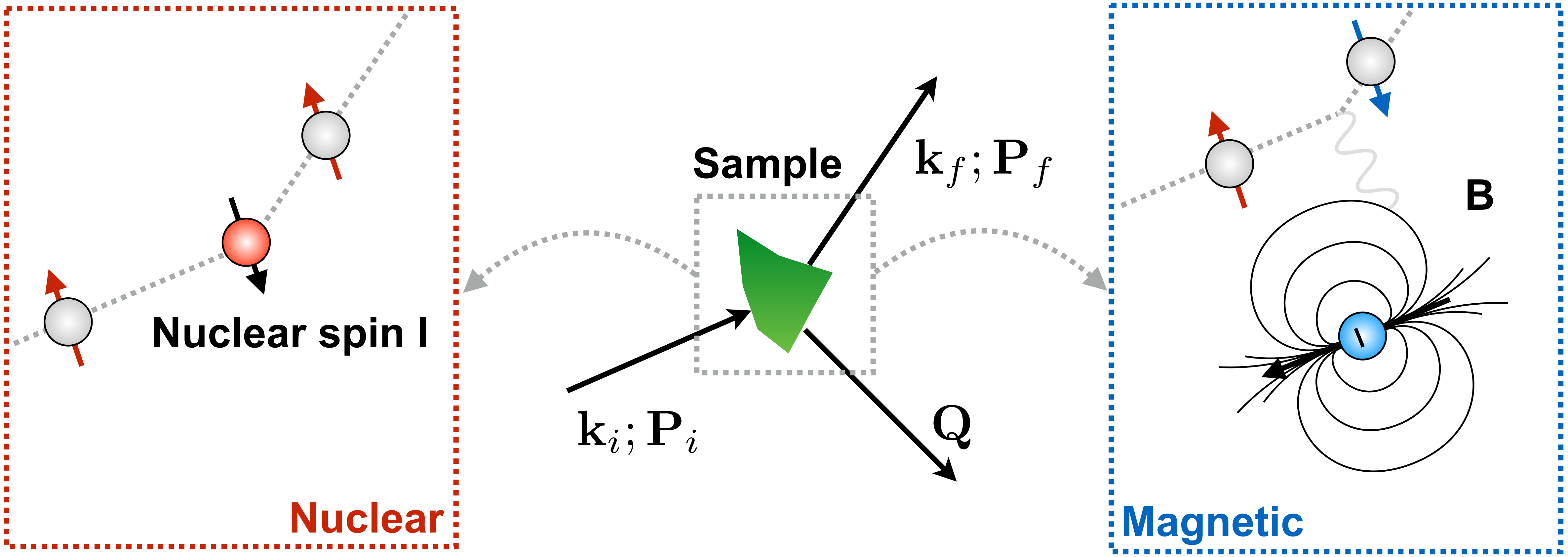
Beam of neutrons



$$P = \frac{N_+ - N_-}{N_+ + N_-}$$

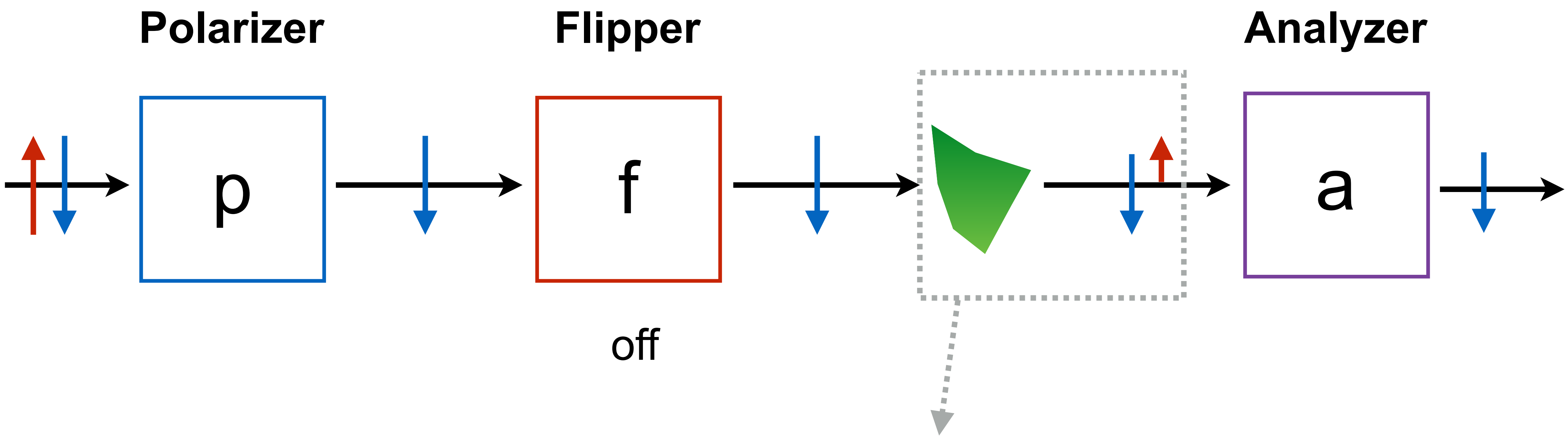
Neutron polarization analysis

Samples also contain magnetic moments, either from nuclei or electrons (*i.e.* magnetism):



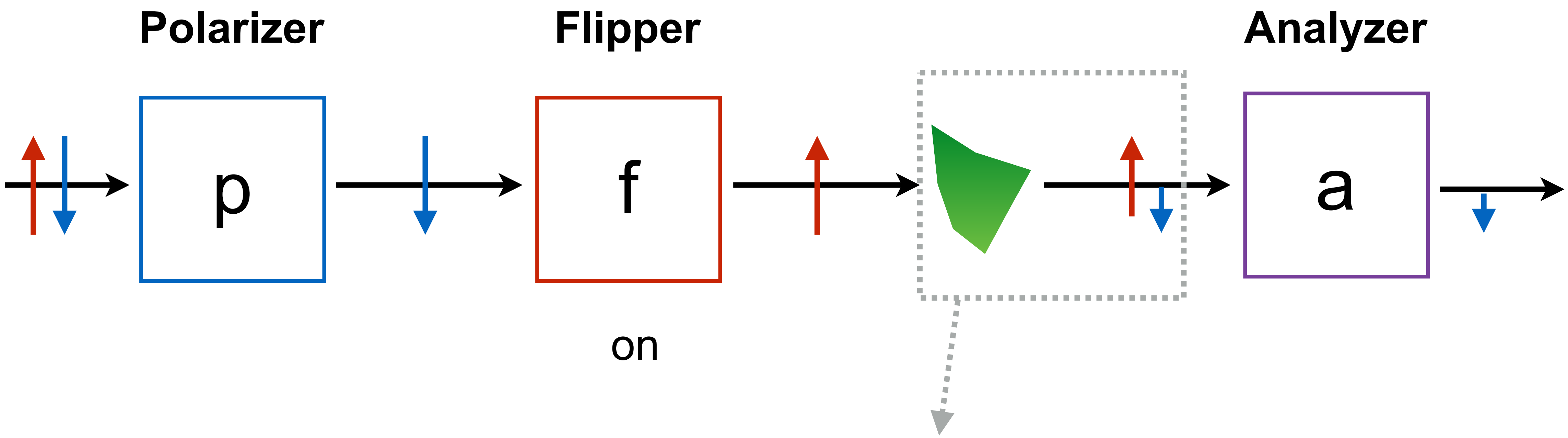
Some processes flip the neutron spin, others don't - also depends on the relative orientations of the neutron moment and the moments in the sample

Uniaxial polarization analysis



	Coherent	Spin incoherent	Paramagnetic powder	Magnetic crystal
Non spin flip	1	1/3	$\frac{1}{2}\left[1-(\hat{\mathbf{P}}\cdot\hat{\mathbf{Q}})^2\right]$	$\hat{\mathbf{P}}\cdot\left[\mathbf{Q}\times(\mathbf{M}(\hat{\mathbf{Q}})\times\hat{\mathbf{Q}})\right]$
Spin flip	0	2/3	$\frac{1}{2}\left[1+(\hat{\mathbf{P}}\cdot\hat{\mathbf{Q}})^2\right]$	…

Uniaxial polarization analysis



	Coherent	Spin incoherent	Paramagnetic powder	Magnetic crystal
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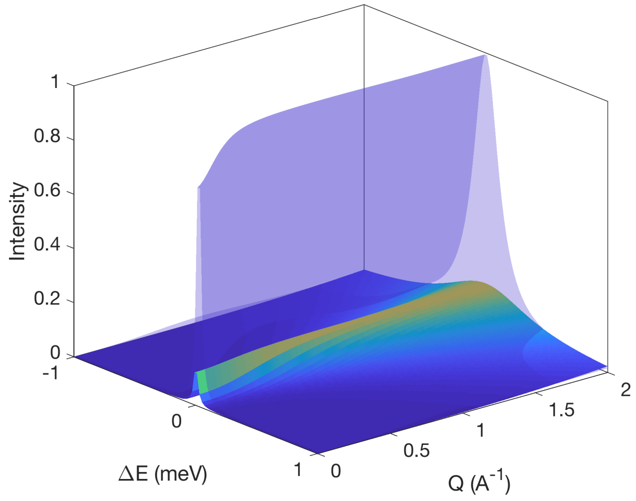
Spin flip	0	2/3	$\frac{1}{2}\left[1+(\hat{\mathbf{P}}\cdot\hat{\mathbf{Q}})^2\right]$	…

LET with polarization analysis

Components of $S(Q,\omega)$: *e.g.* battery



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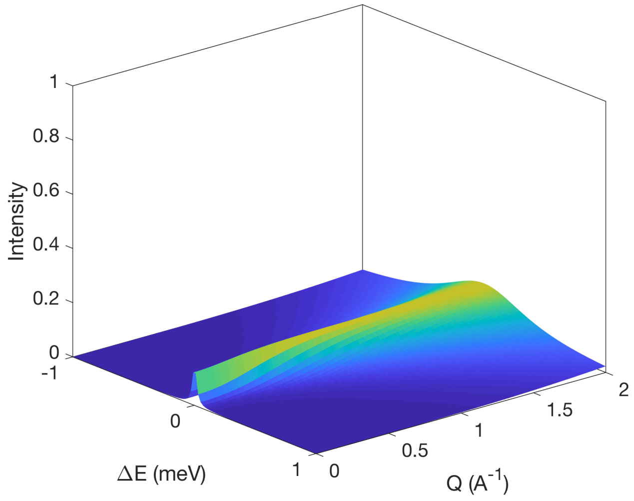
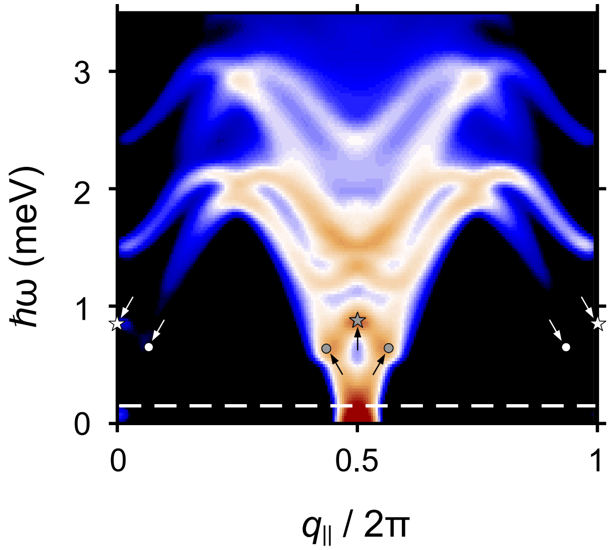


H$^+$, D$^+$, Li$^+$, Na$^+$…

Components of $S^{\alpha\beta}(Q,\omega)$: *e.g.* ladder



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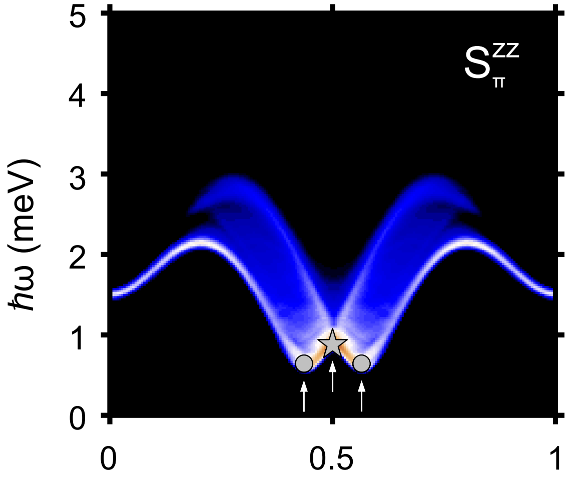
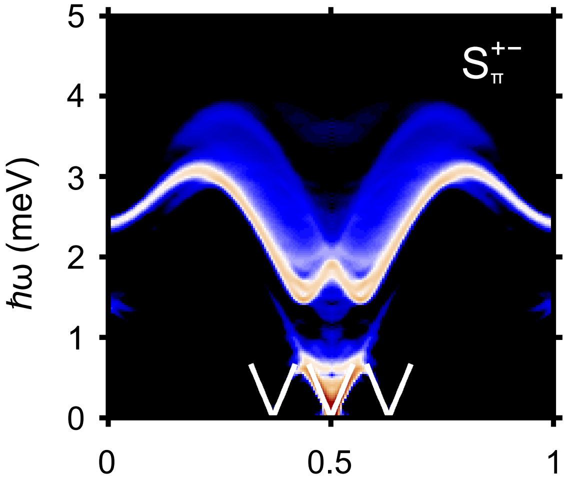
Longitudinal



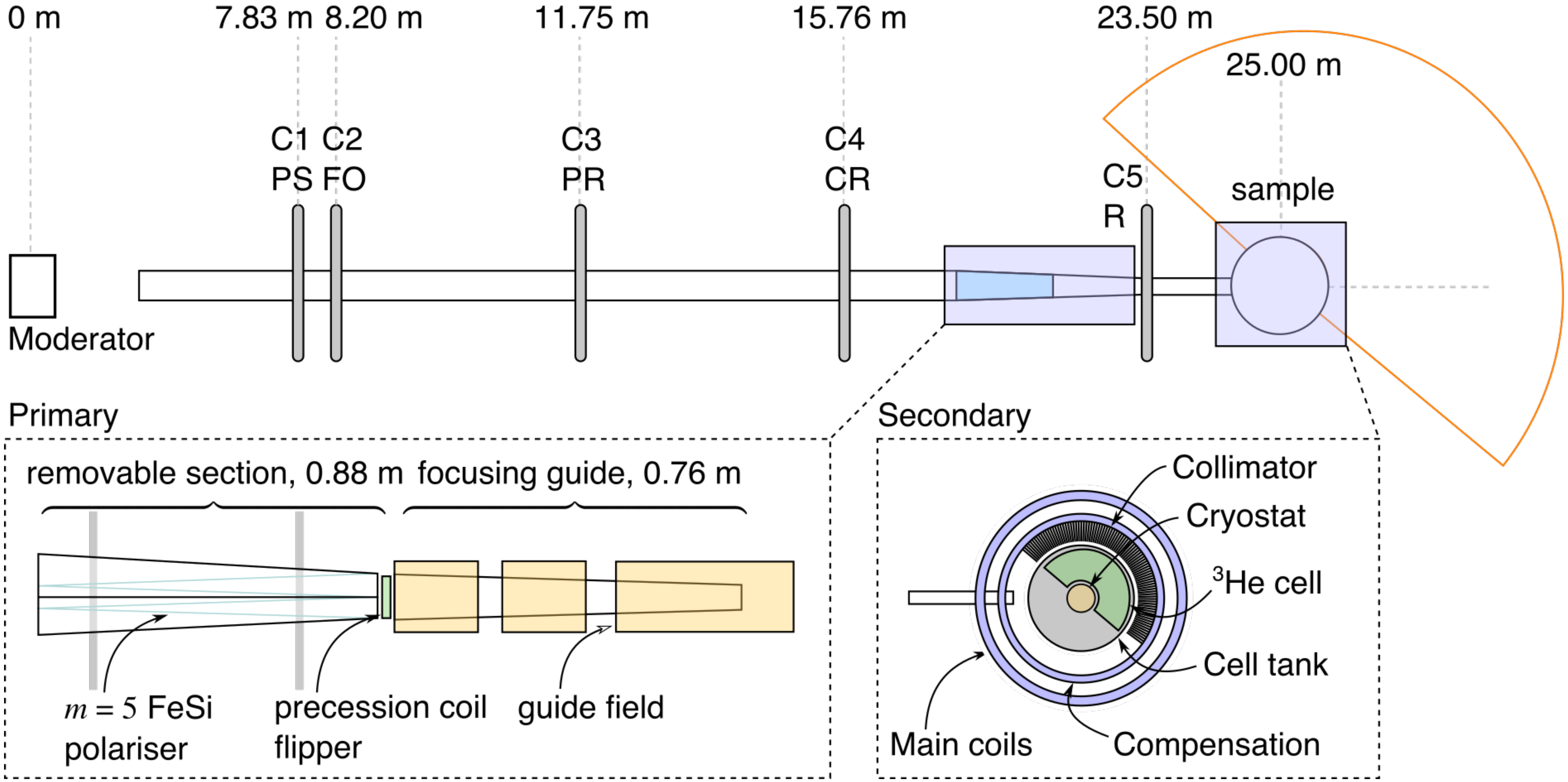
+

Transverse



Polarized LET: Concept

Supermirror polarizer, current-ramped Mezei (precession coil) flipper, ^{3}He analyzer



Nilsen et. al. J. Phys.: Conf. Series **115** 012019

Polarizer and flipper: implementation

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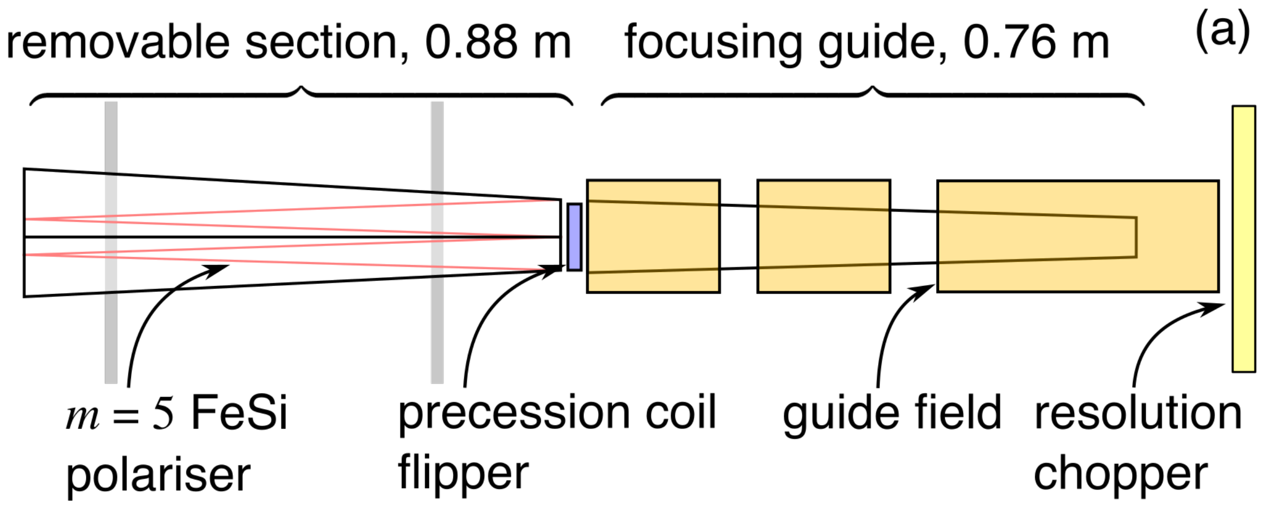
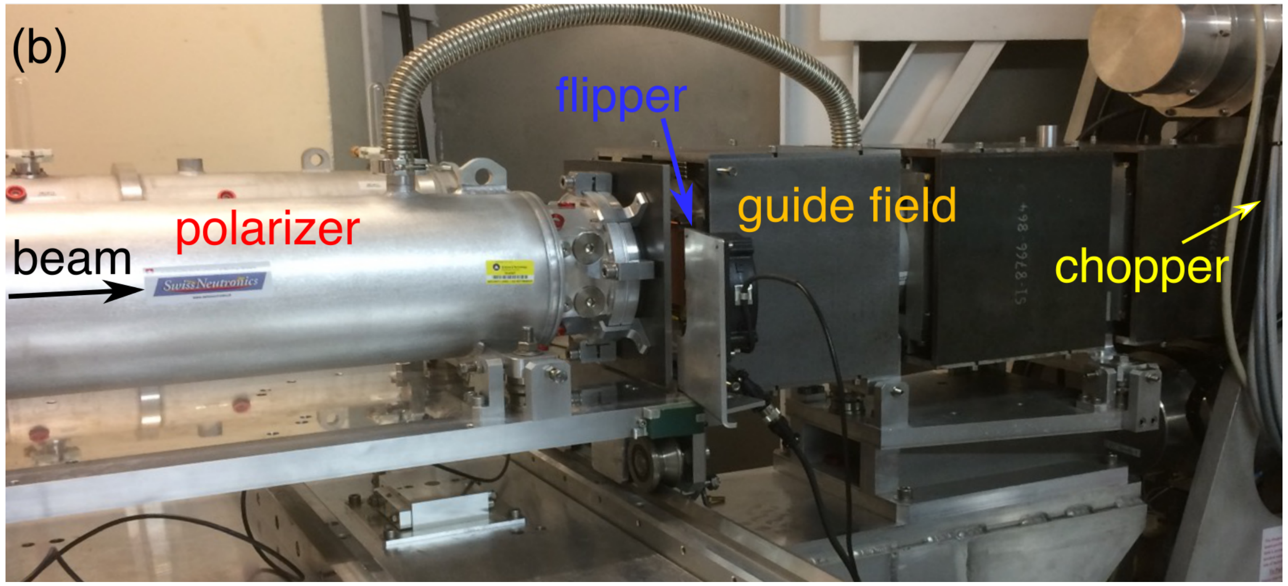
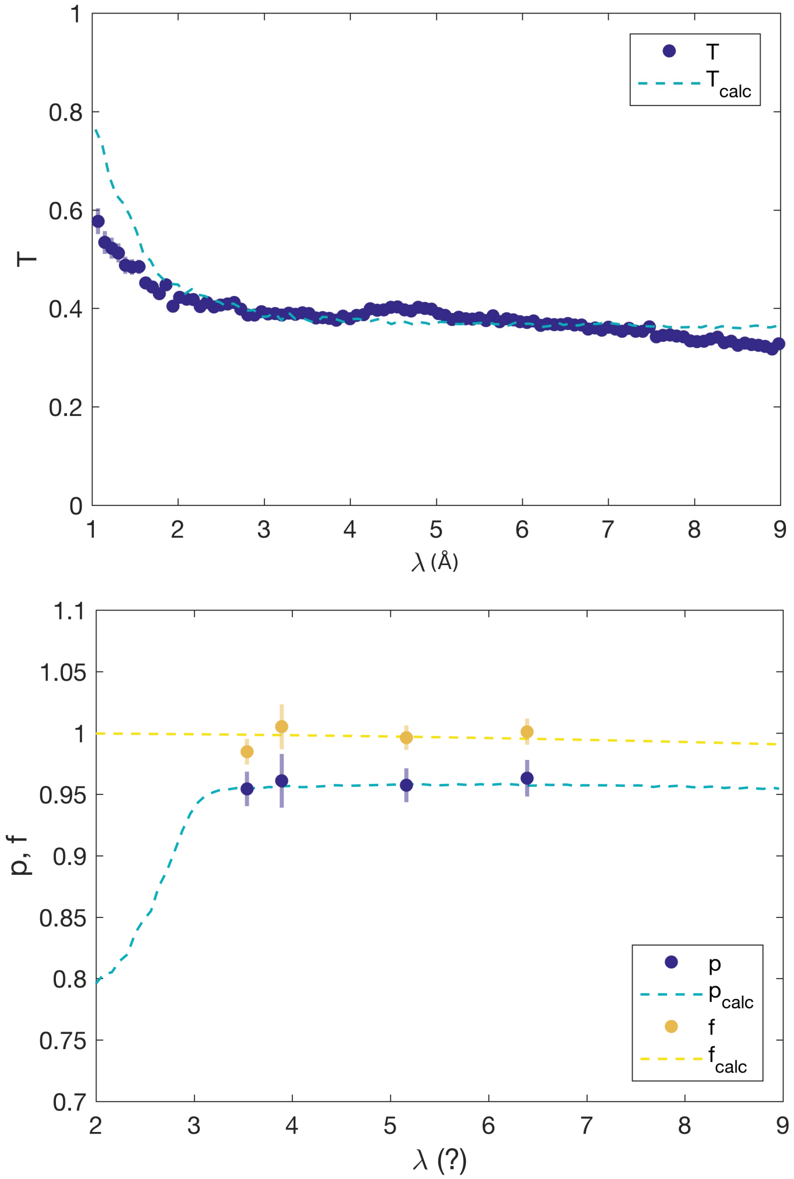
Polarizer, flipper, and guide field give P ~ 0.94 at λ > 3 Å (E_i < 9 meV) with T ~ 0.4:

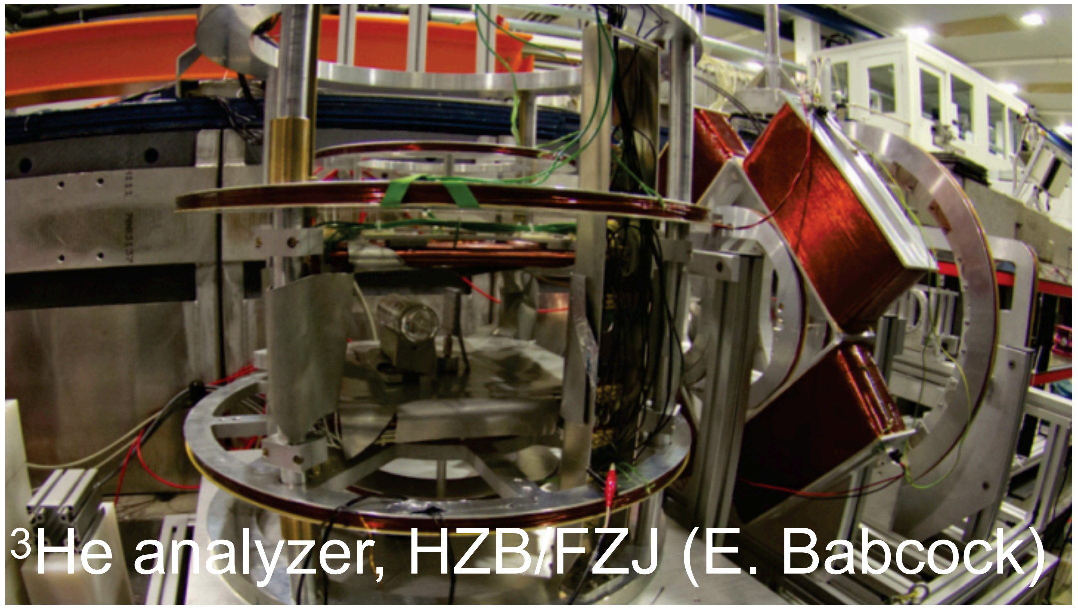




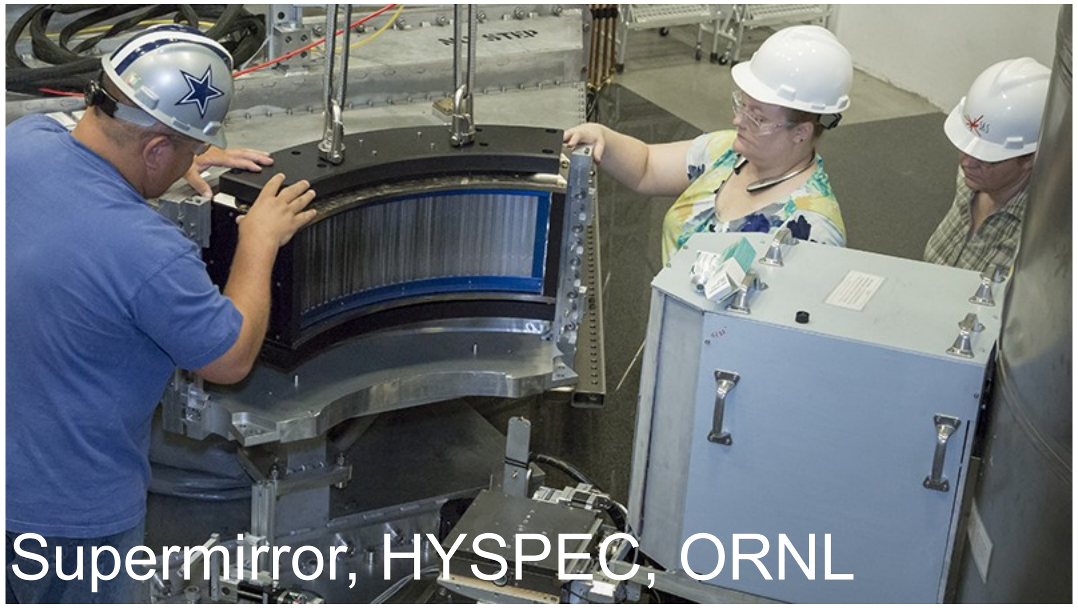


Kosata et. al. Physica B **551** 476

Analyzer: ^{3}He versus supermirrors



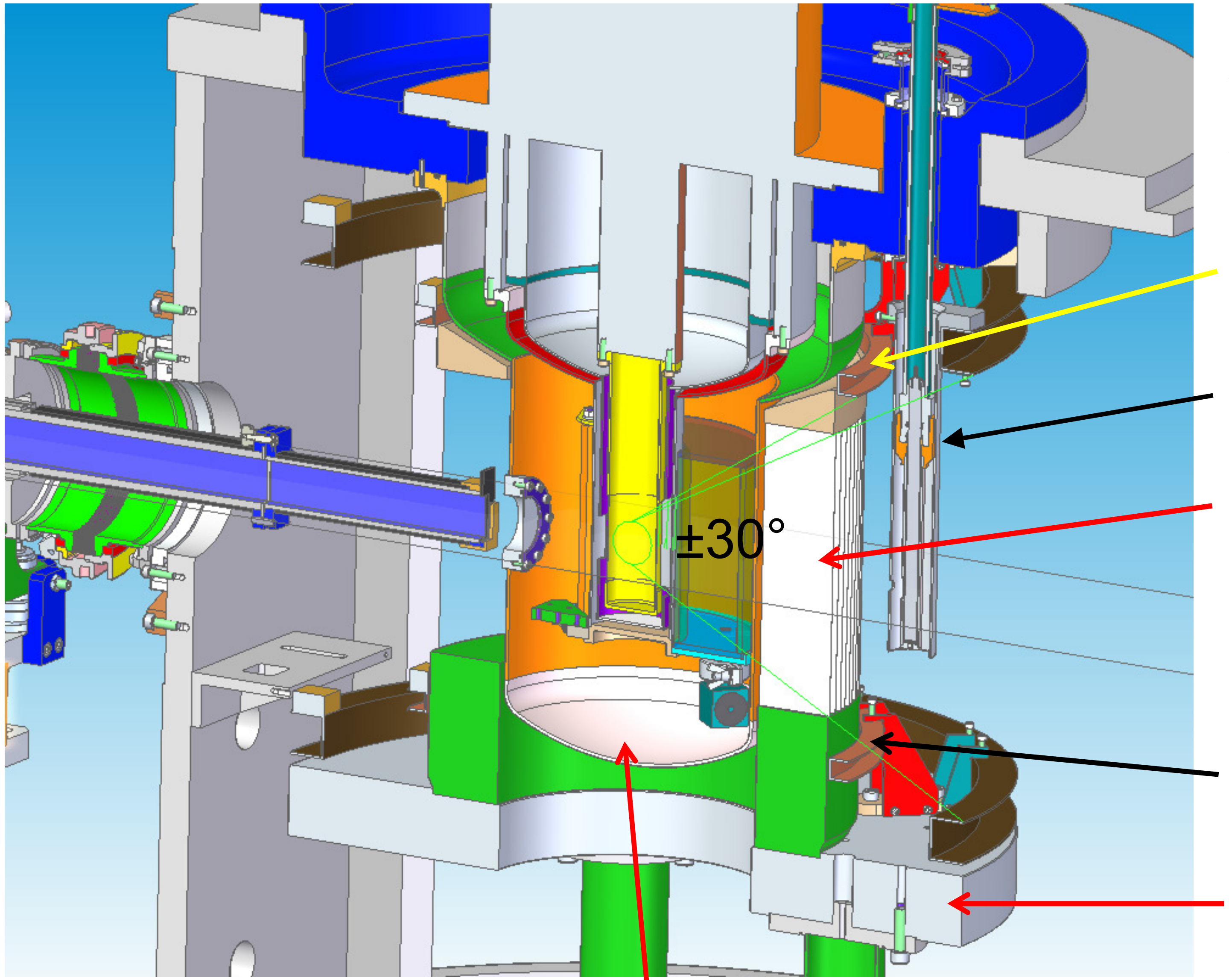
^{3}He analyzer, HZB/FZJ (E. Babcock)



Supermirror, HYSPEC, ORNL

Hyperpolarized ^{3}He	Supermirrors
Cheap(er) hardware	Expensive
Time-dependent, requires monitoring	Static
Large solid angle	Smaller solid angle
Sensitive to field gradients	No strict requirements
Easy corrections	Difficult corrections, systematic errors

Analyzer: concept



Sectional View of Sample Vessel and Analyser Assembly

Field Coils (Upper)

^{3}He monitor

Radial oscillating collimator

Field Coils (Lower)

Collimator Mounting Plate

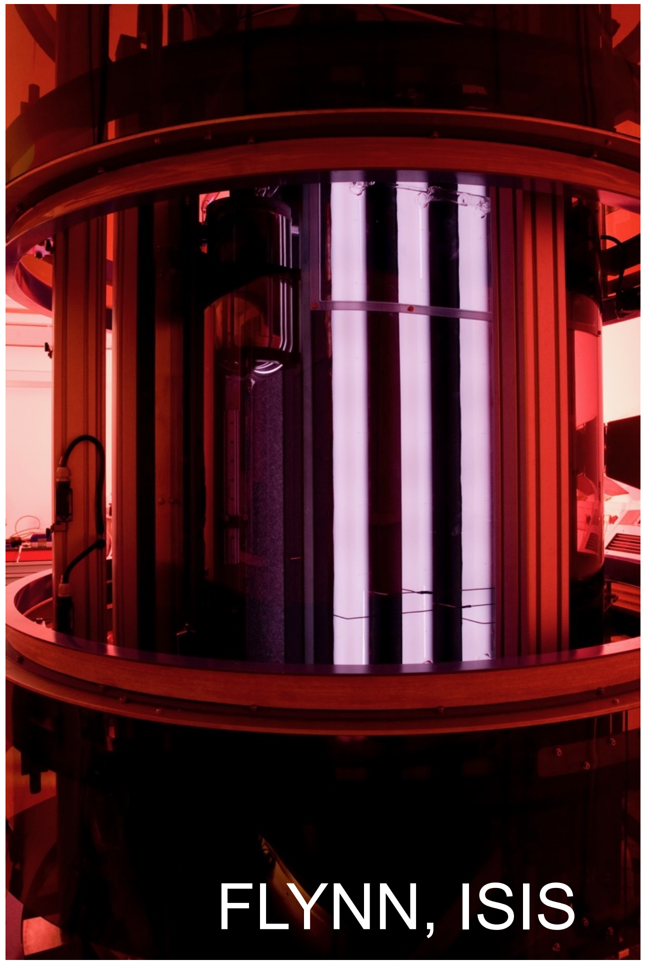
Gas Vessel

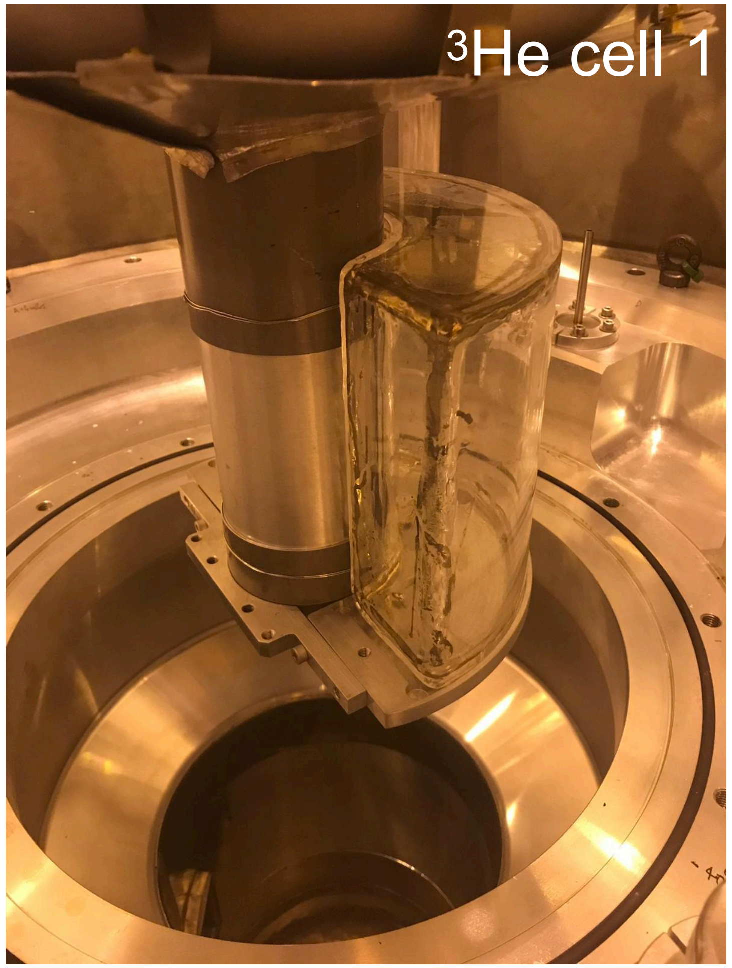
Figure: P. Galsworthy

Cassella et. al. J. Phys.: Conf. Series, *in press*

Analyzer: implementation

Two cells constructed (T_1^{cell1} = 55 hours T_1^{cell2} = 18 hours), initial ^{3}He polarization P_0~60%, rapid (20 s) changeover:

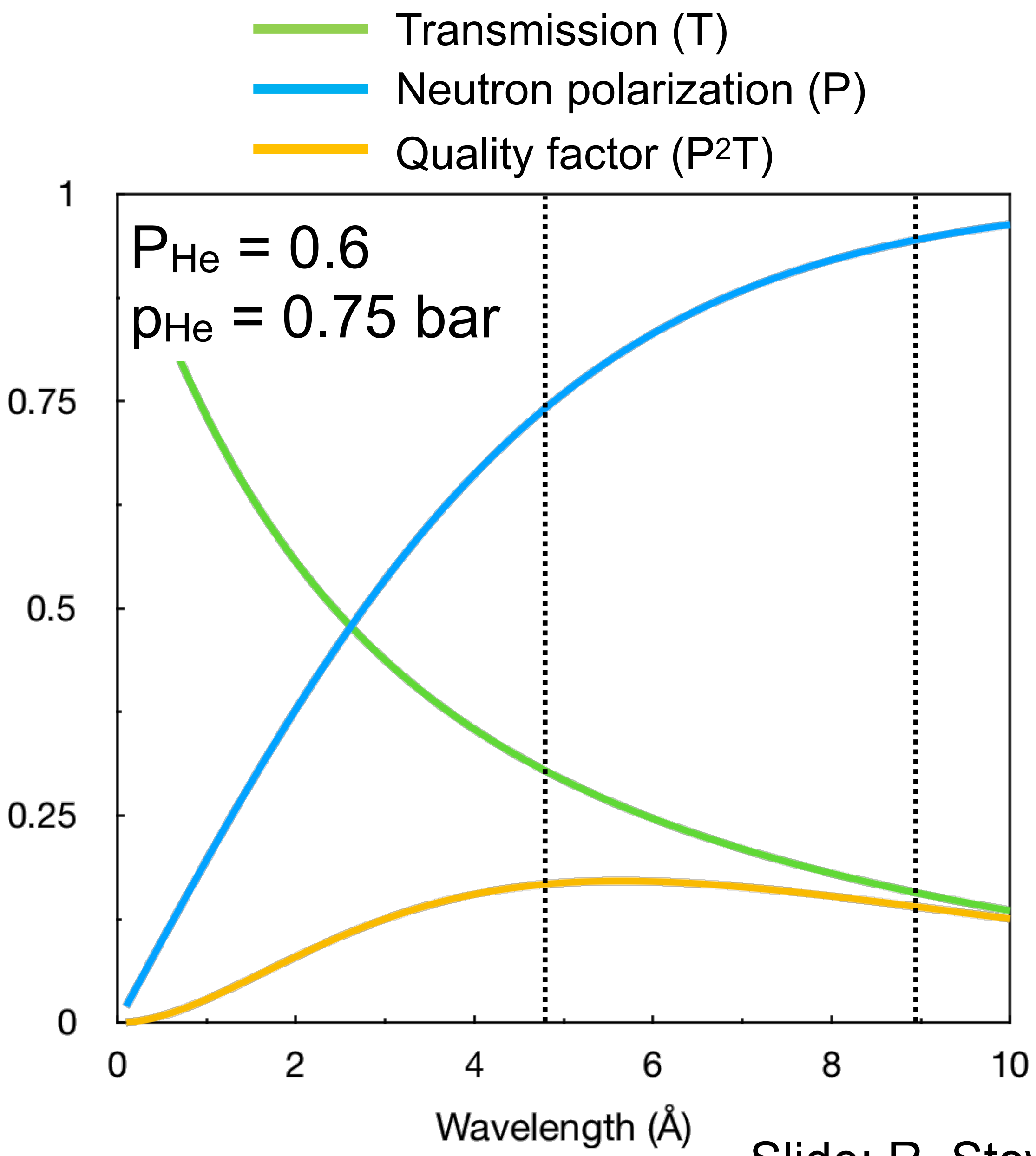




Cassella et. al. J. Phys.: Conf. Series, *in press*

Polarized LET: Overall performance

	3.84 meV	1.05 meV
T_p	0.4	0.35
fp	0.94	0.94
T_a	0.32	0.16
a	0.72	0.94
FR	5.2	15.7



Slide: R. Stewart

QENS: D_2O

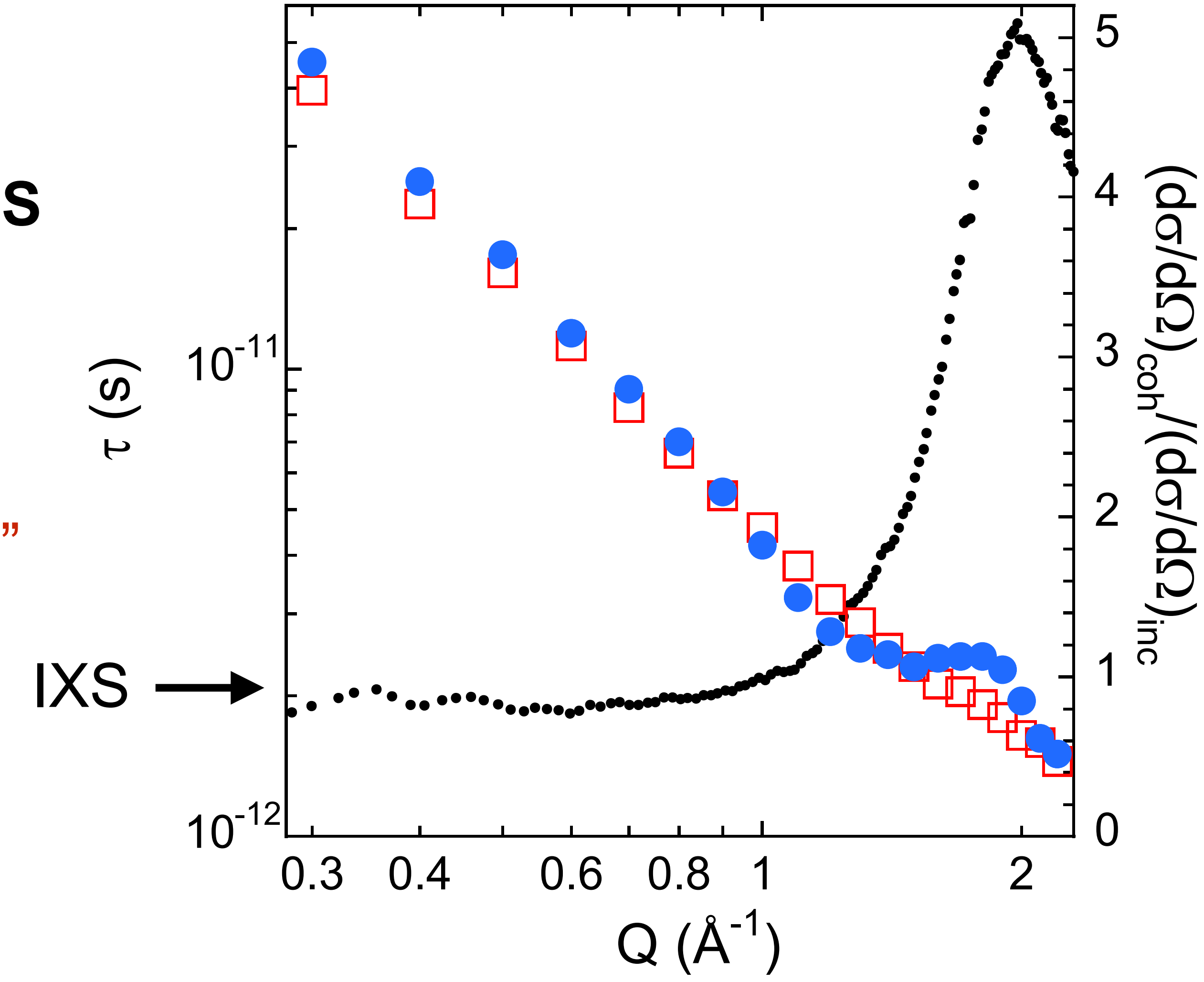
Arantxa Arbe, Juan Colmenero, Fernando Alvarez
University of the Basque Country
Victoria Garcia-Sakai, Ross Stewart
ISIS

First experiment: context

Intermediate-length scale diffusion in water and glass formers almost unexplored

Unpolarized QENS
(IN5, ILL)

- ● D_2O “coherent”
- ☐ H_2O “incoherent”



Polarized diffraction
(D7, ILL)

- Ratio coherent to incoherent, energy integr.

Arbe et. al. Phys. Rev. Lett. **117** 185501

First experiment: context

Intermediate-length scale diffusion in water and glass formers almost unexplored

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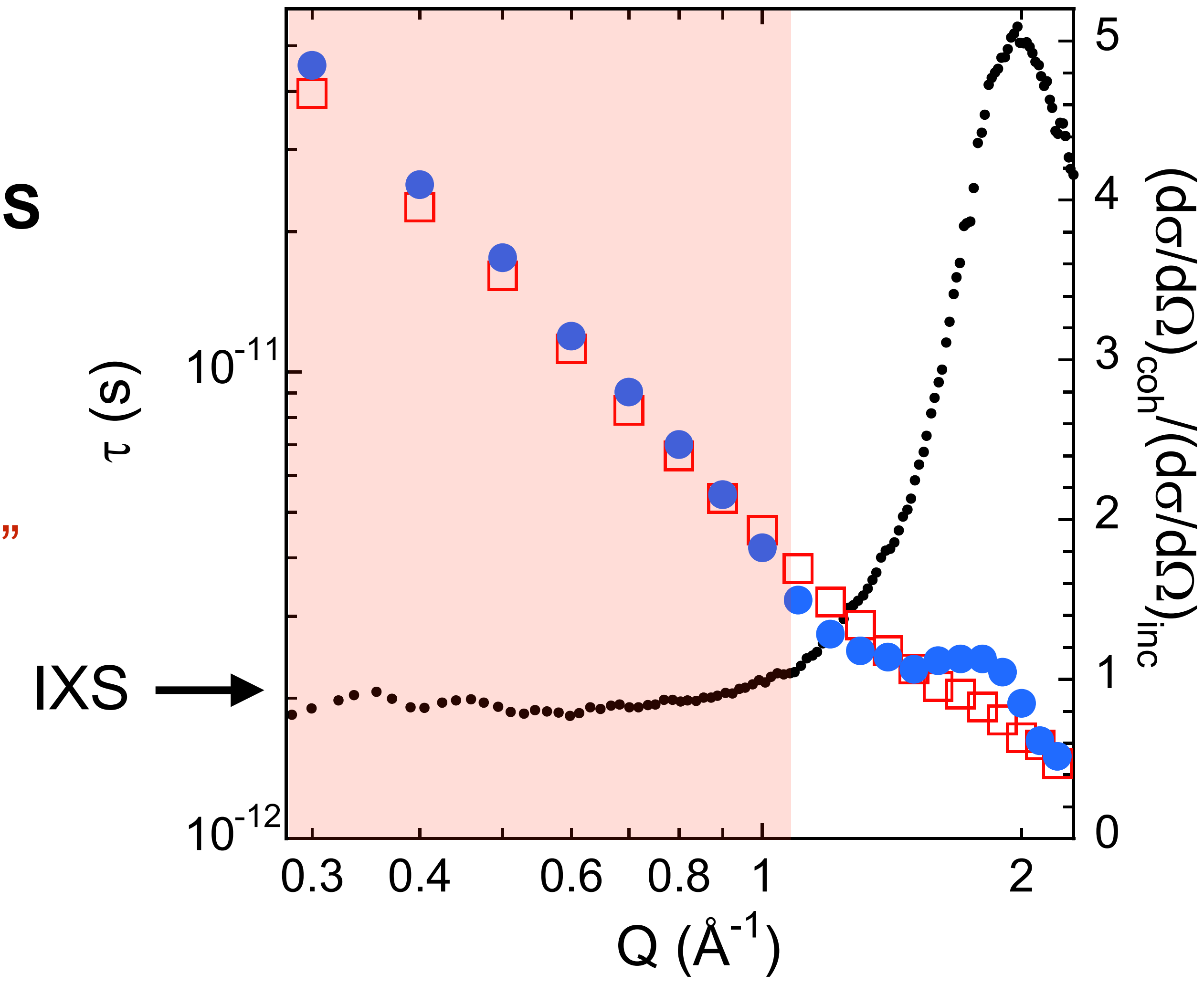

Polarized diffraction
(D7, ILL)

- Ratio coherent to incoherent, energy integr.

Arbe et. al. Phys. Rev. Lett. **117** 185501

D_2O: incoherent-coherent separation

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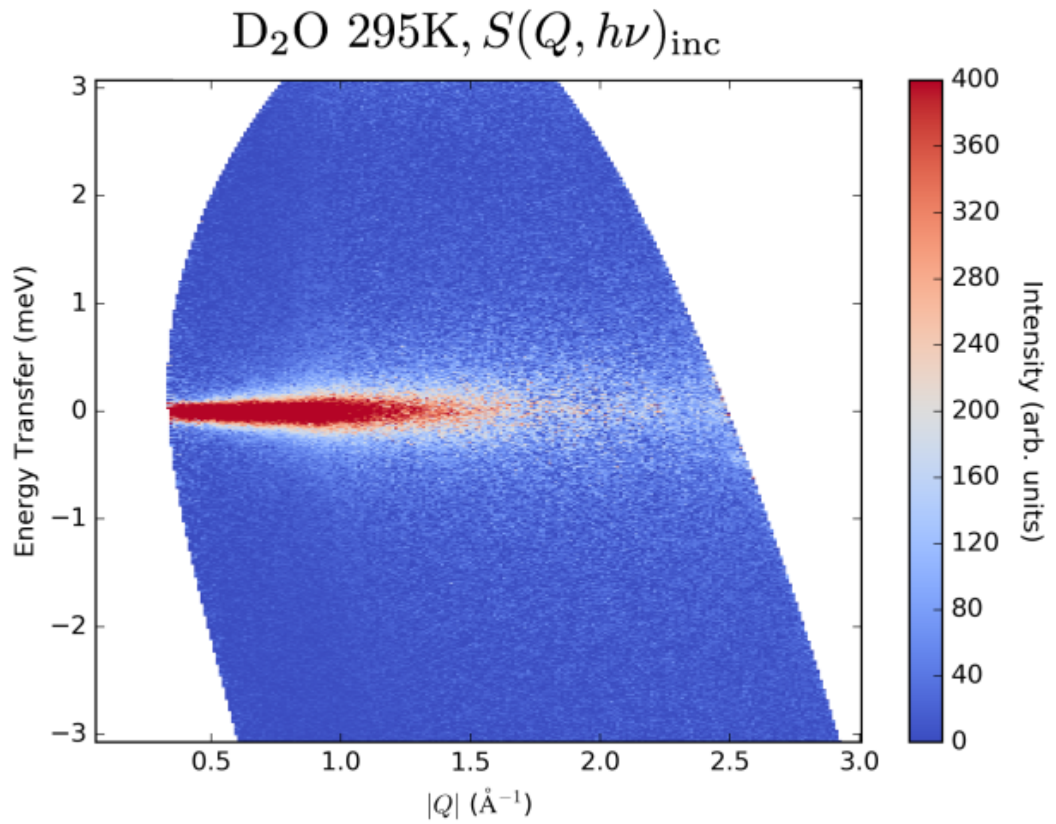
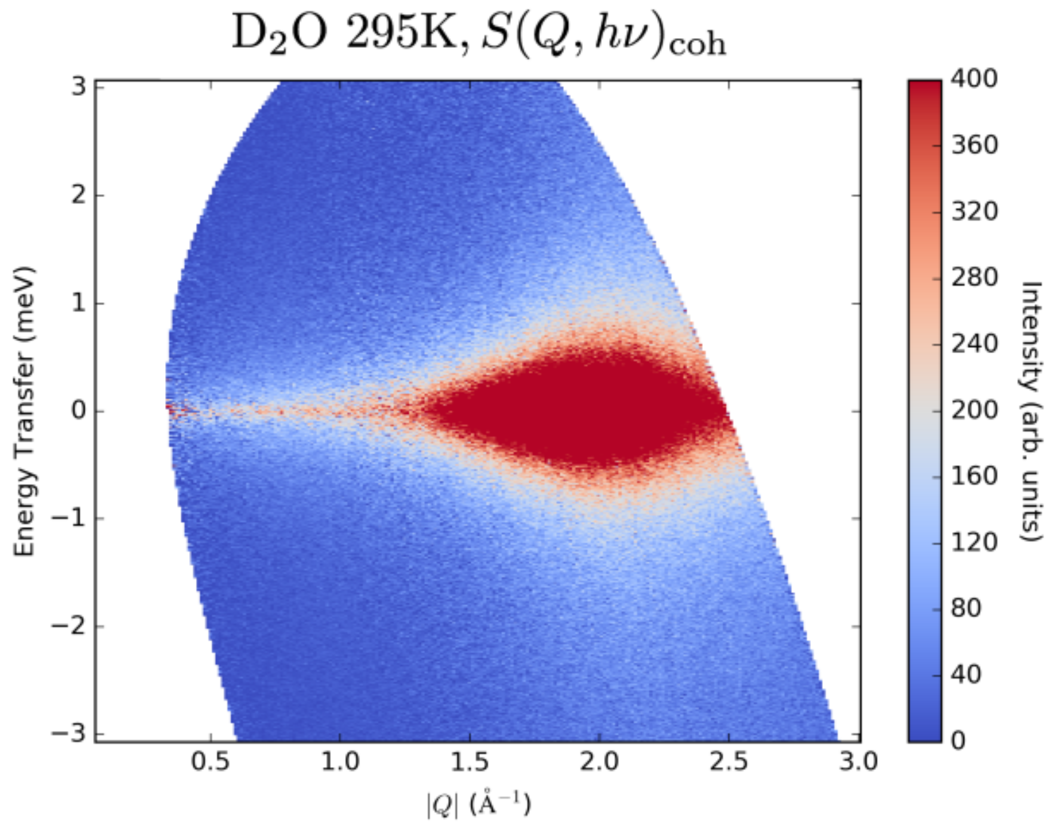




$$S(Q,\nu)_{\mathrm{inc}} = \frac{3}{2} S(Q,\nu)_{\mathrm{sf}}$$

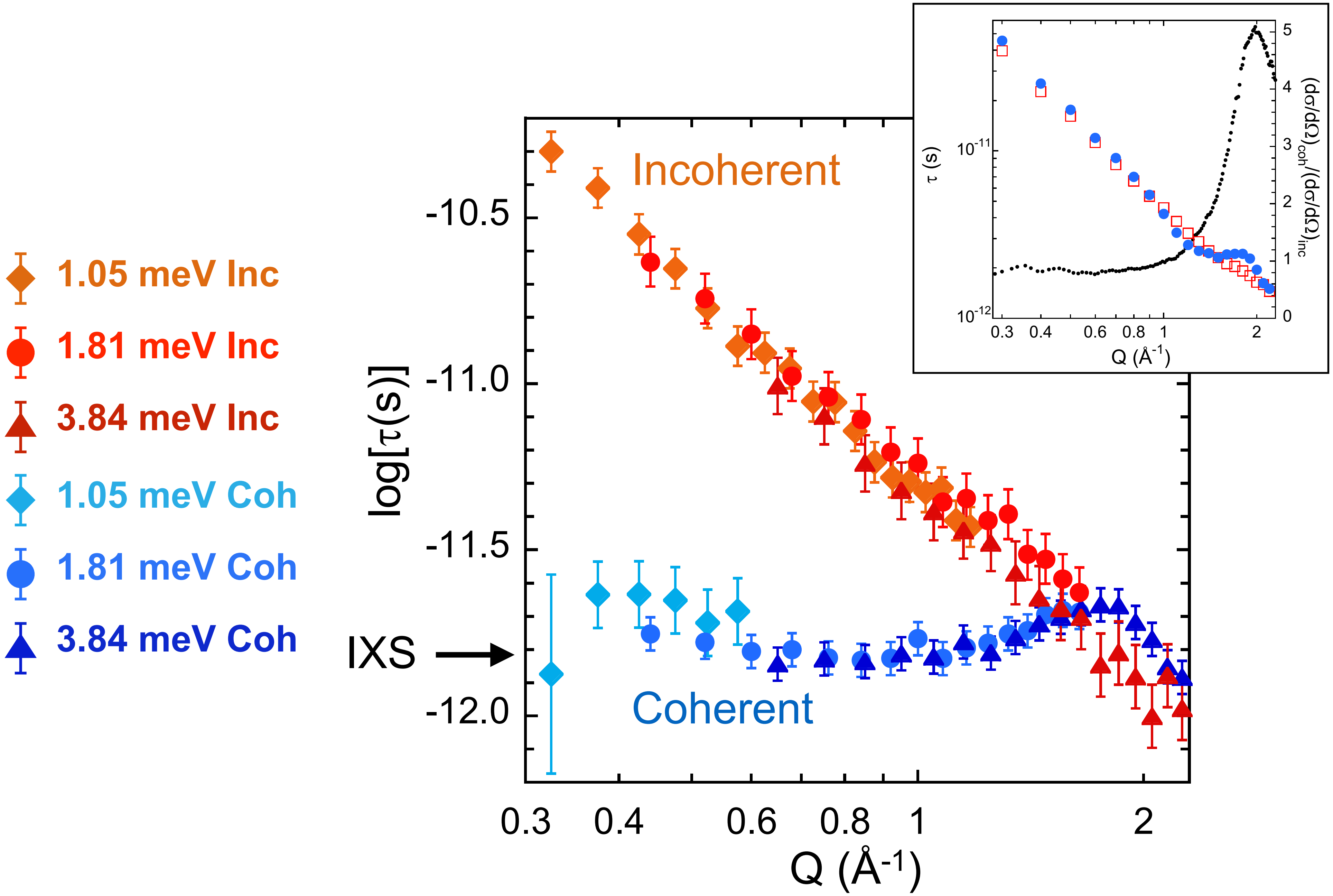
$$S(Q,\nu)_{\mathrm{coh}} = S(Q,\nu)_{\mathrm{nsf}} - \frac{1}{2} S(Q,\nu)_{\mathrm{sf}}$$

self motions

collective and self motions

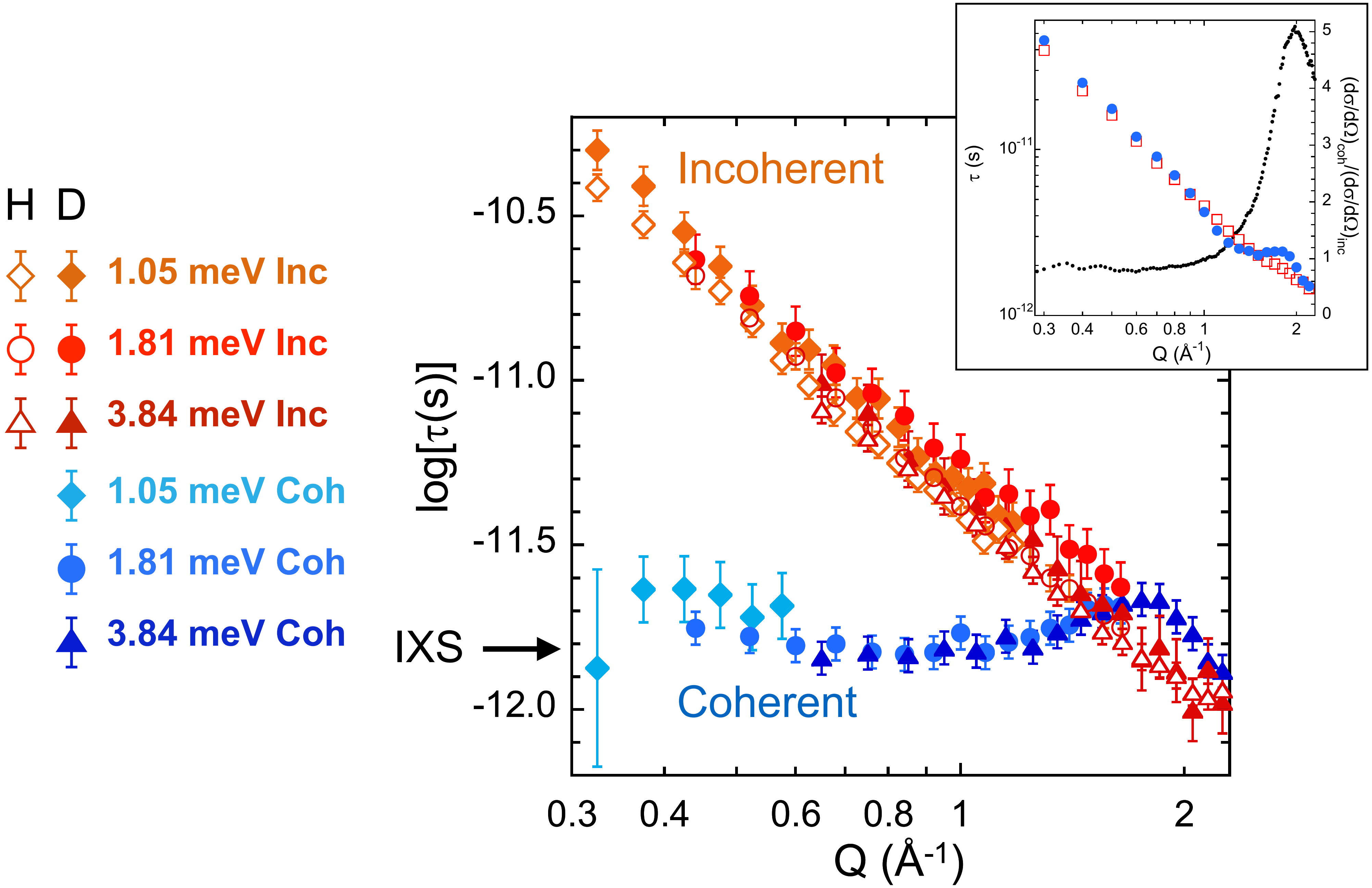
Arbe et. al., submitted to Phys. Rev. Lett.

D$_2$O: separation of timescales at low Q



Arbe et. al., submitted to Phys. Rev. Lett.

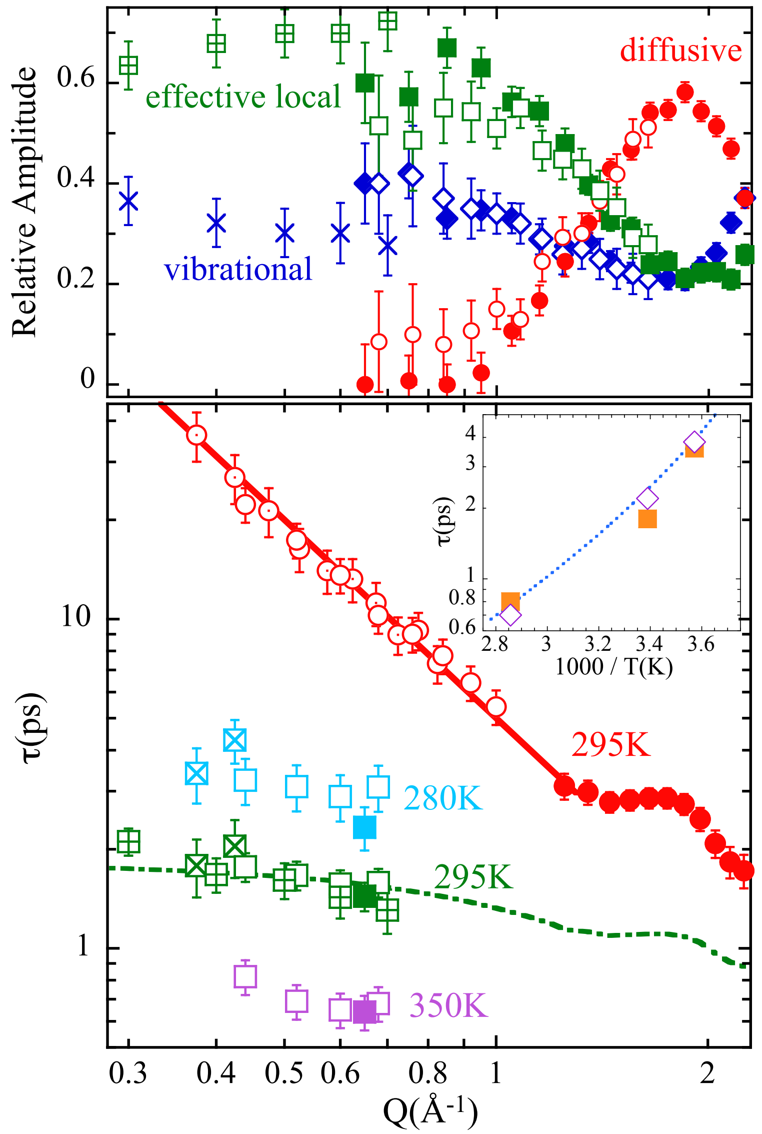
D_2O: separation of timescales at low Q



Arbe et. al., submitted to Phys. Rev. Lett.

D_2O: reconciling results with model

Three contributions to coherent dynamics, consistent with state-of-the art model:



- ✕ ⊞ 3-component model from MD simulation
- □ ■ effective local (1.81 meV and 3.84 meV)
- ◇ ◆ vibrational (1.81 meV and 3.84 meV)
- ○ ● diffusive (1.81 meV and 3.84 meV)

- ○ ○ ● diffusive (1.05 meV, 1.81, and 3.84 meV)
- ⊠ □ ■ overall coherent 295 K (1.05 meV, 1.81, and 3.84 meV)
- ⊠ □ ■ overall coherent 280 K (1.05 meV, 1.81, and 3.84 meV)
- ⊠ □ ■ overall coherent 350 K (1.05 meV, 1.81, and 3.84 meV)
- ⊞ effective coherent relaxation time from MD simulation
- ■ T-dependence of neutron coherent relaxation time
- ◇ T-dependence of IXScoherent relaxation time

Arbe et. al., submitted to Phys. Rev. Lett.

Paramagnetic scattering: $Ho_2Ti_2O_7$

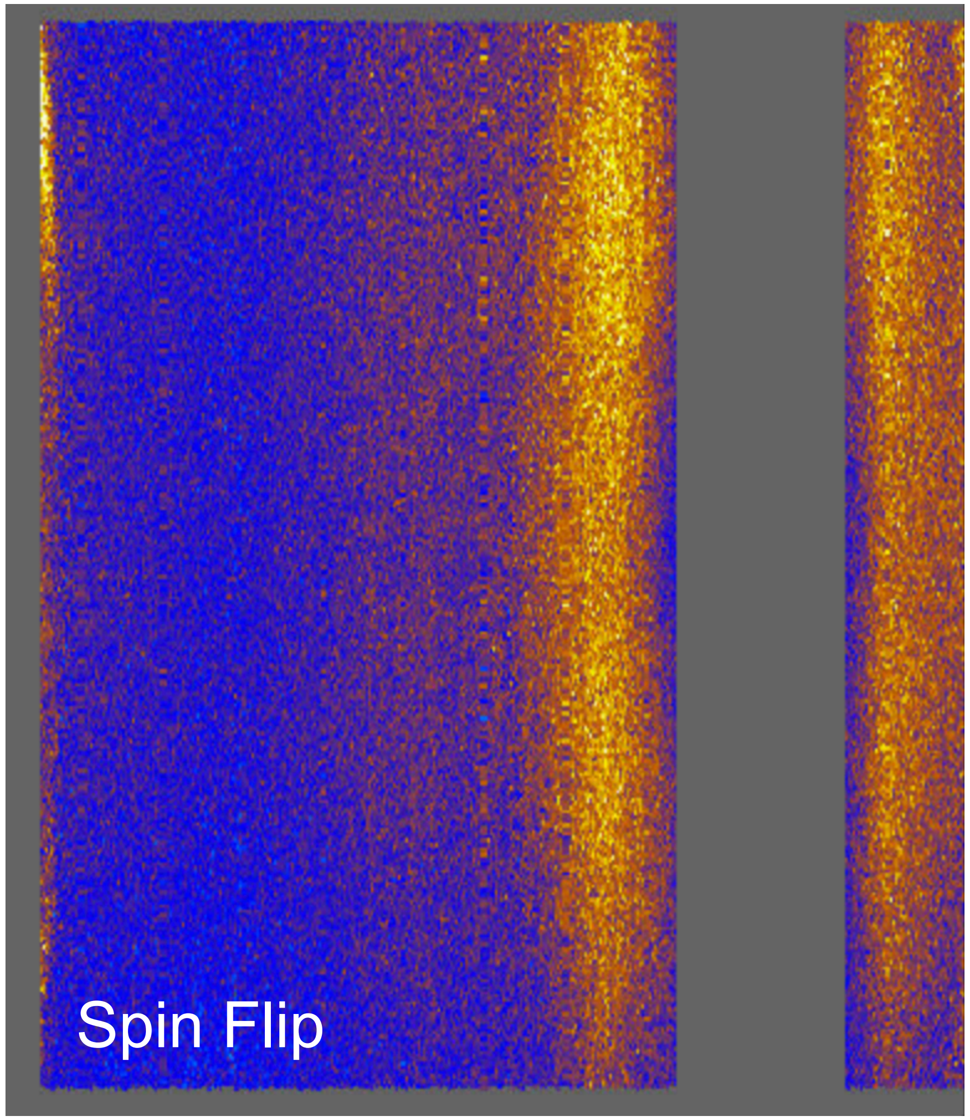
Polarization analysis on a 2D detector

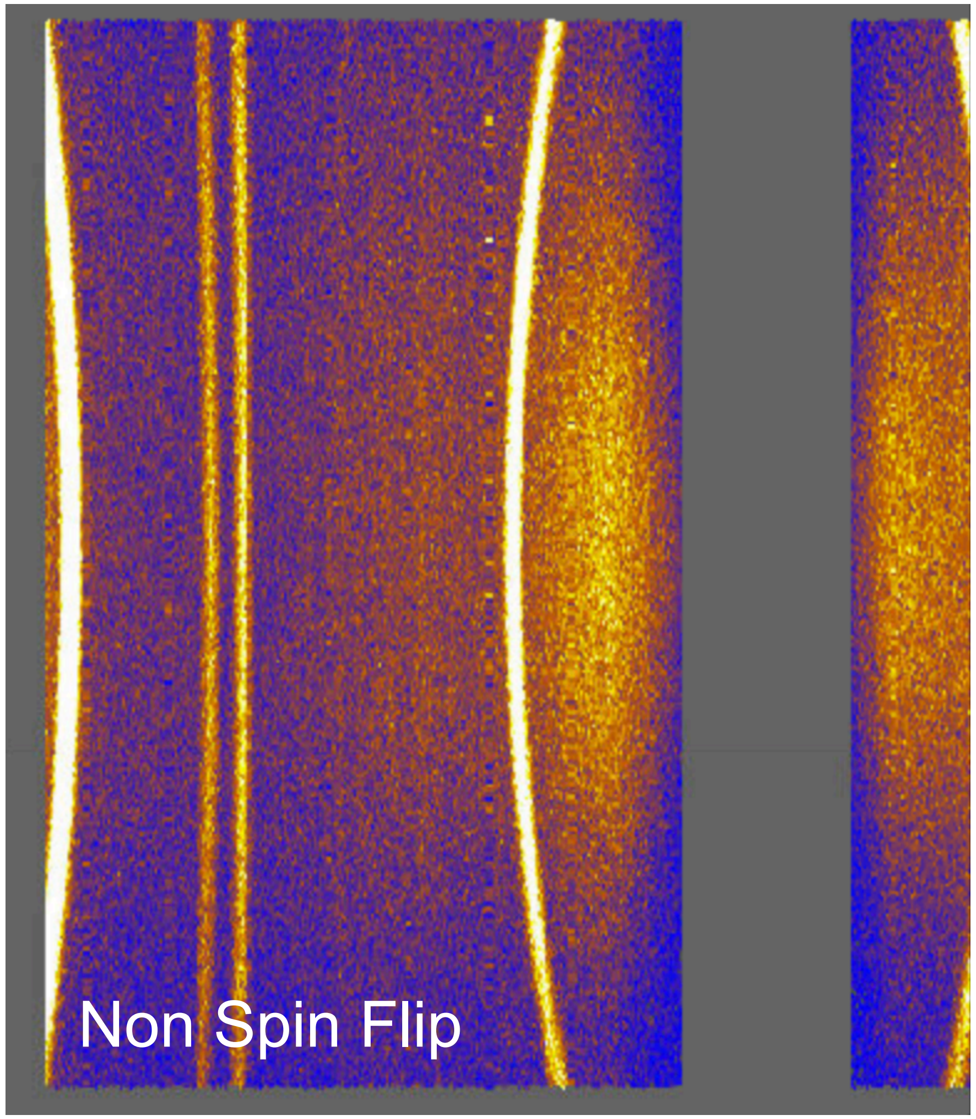

LET detector, ~100000 pixels

	Coherent	Spin incoherent	Paramagnetic powder	Magnetic crystal
Non spin flip	1	1/3	$\frac{1}{2}\left[1-(\hat{\mathbf{P}}\cdot\hat{\mathbf{Q}})^2\right]$	$\hat{\mathbf{P}}\cdot\left[\mathbf{Q}\times(\mathbf{M}(\hat{\mathbf{Q}})\times\hat{\mathbf{Q}})\right]$
Spin flip	0	2/3	$\frac{1}{2}\left[1+(\hat{\mathbf{P}}\cdot\hat{\mathbf{Q}})^2\right]$	$\ldots$

Paramagnetic powder: $Ho_2Ti_2O_7$

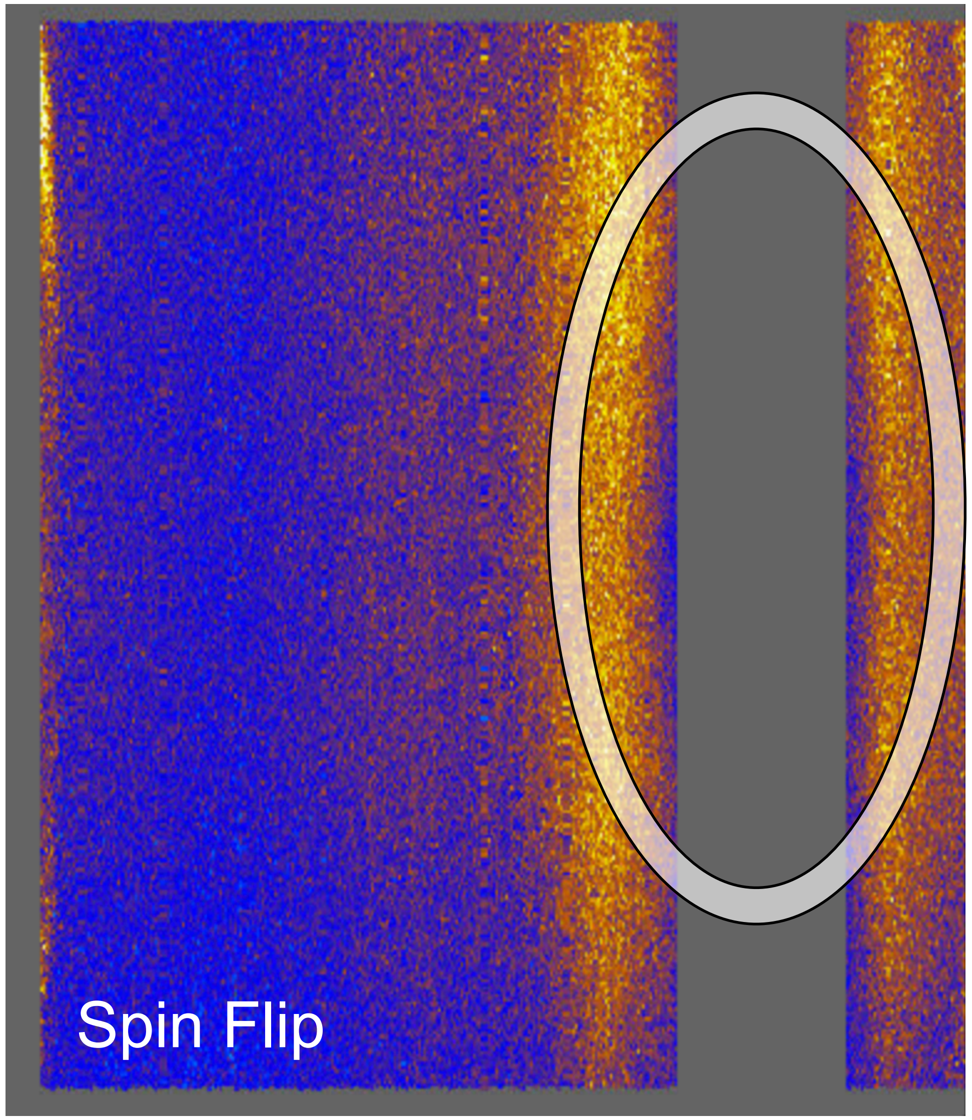
$Ho_2Ti_2O_7$, 2 K, E_i = 4.0 meV, energy integrated:

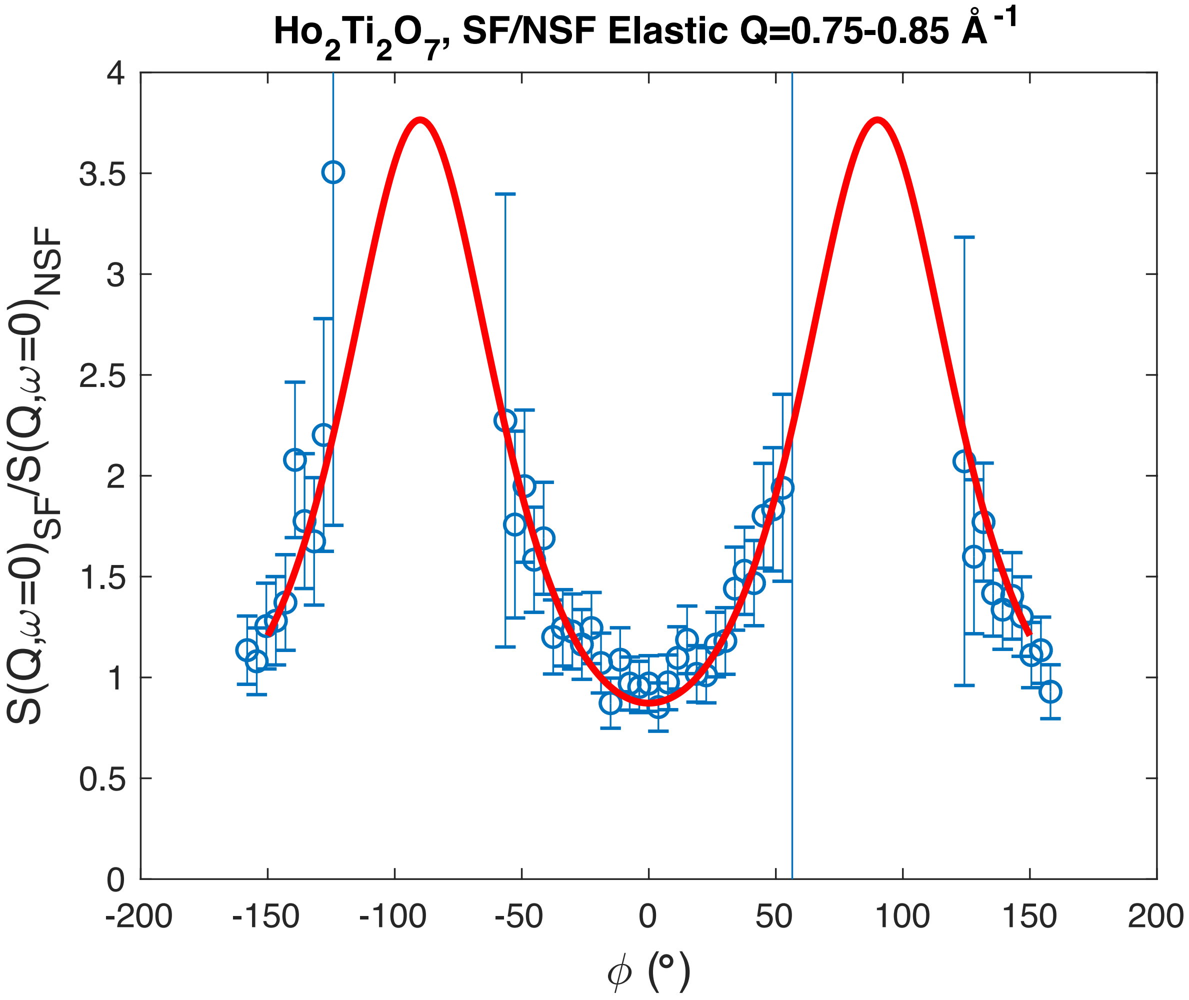




Z^+: using PSD for separation

$Ho_2Ti_2O_7$, 2 K, E_i = 4.0 meV, energy integrated:





Conclusion

- A uniaxial polarisation mode has been constructed for the LET spectrometer
- Overall performance is excellent, although some improvements remain to be made for the ^{3}He analyser
- The potential of the polarised mode for QENS is demonstrated by the first user experiment on D_2O
- Magnetic scattering on a spectrometer with large out-of-plane coverage is new territory - new approaches required

Acknowledgements

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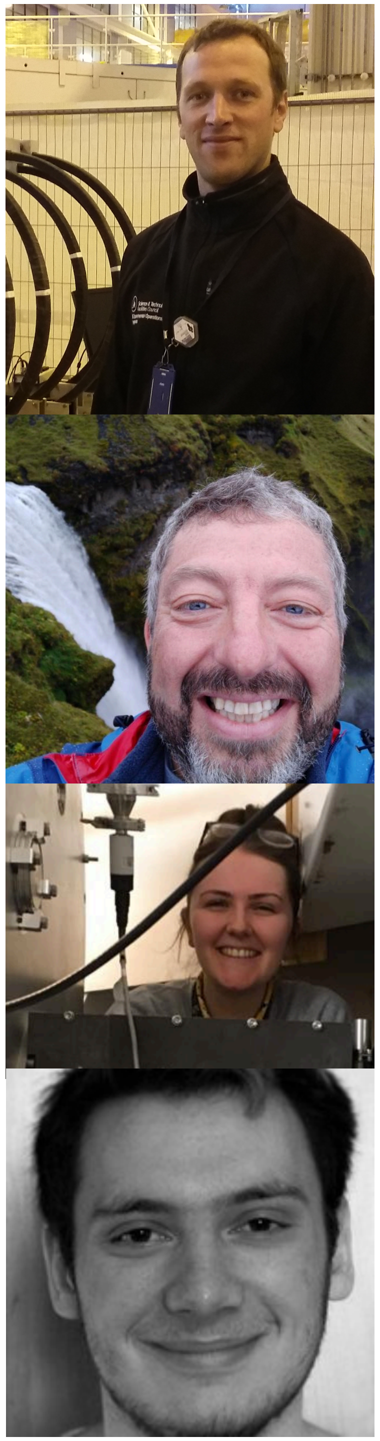
Dan Pooley
Jason Chandler
Maksim Schastny
Jon Bones, Josef Lewis…



D_2O
U of the Basque Country
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ISIS
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$Ho_2Ti_2O_7$
ISIS/UCL
Robin Perry