Neutron Scattering Study of a Triplet Superconductor

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Outline

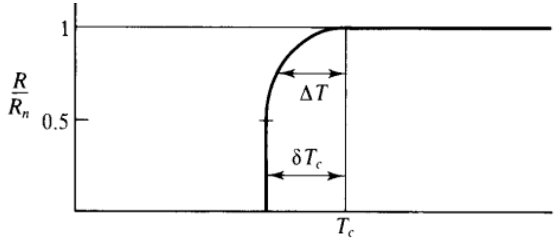
1. Introduction to superconductivity.
2. Superconductivity and magnetic fluctuations in UTe_2.
3. Introduction to small angle neutron scattering (SANS).
4. How we used SANS to examine spin fluctuations in UTe_2.

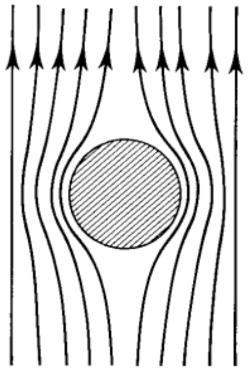
Superconductivity

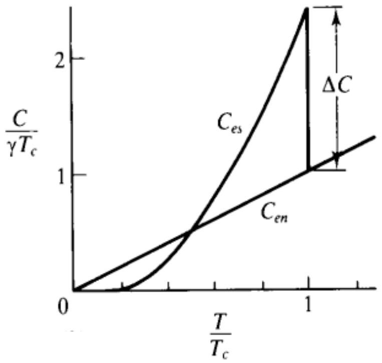
The typical hallmarks of superconductivity are:

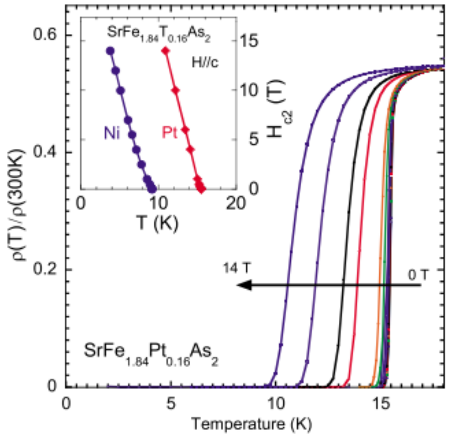
1. A transition to zero resistance.
2. Expulsion of a magnetic field.
3. An anomalous transition in heat capacity.

Too strong of a magnetic field can destroy the superconductivity and return the material to its normal state.



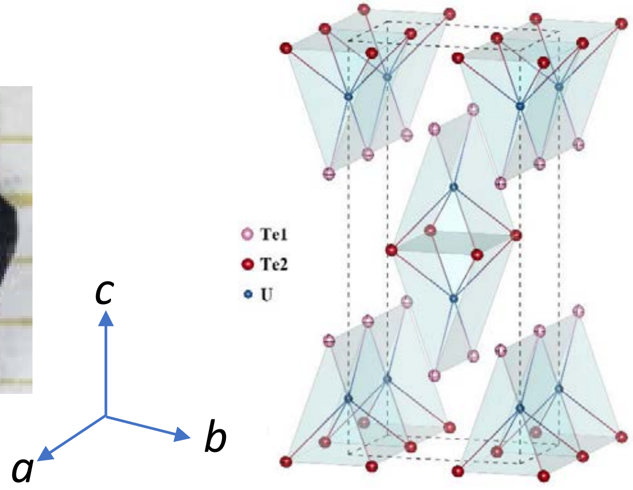


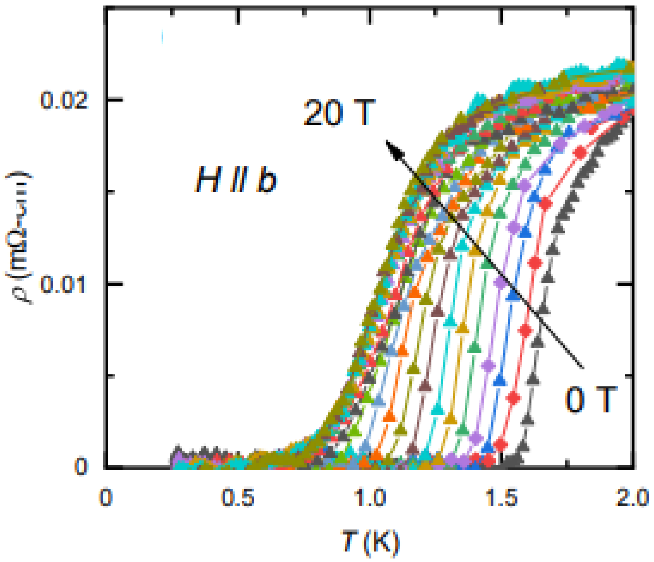




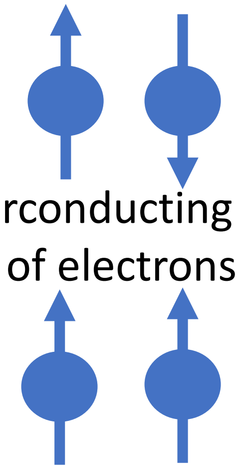
Exotic Superconductivity in UTe_2

- Samples are grown using chemical vapor transport in an orthorhombic structure.
- When applying magnetic fields up to 20 T, the detrimental effects of the magnetic field appear to halt.





Spin Singlet

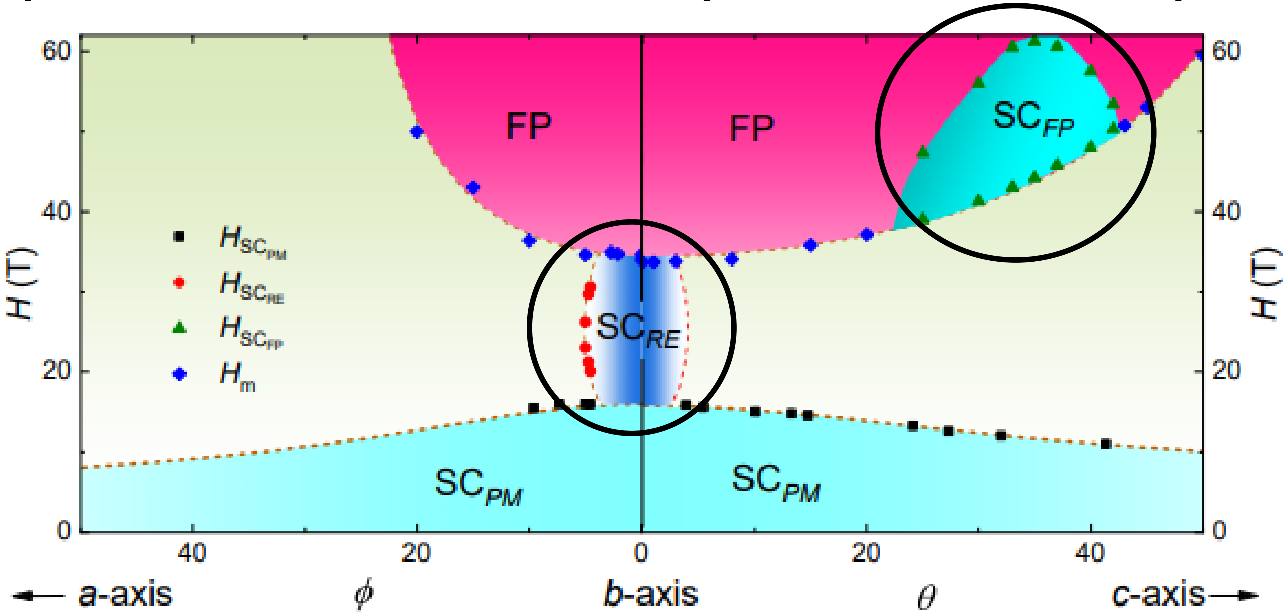


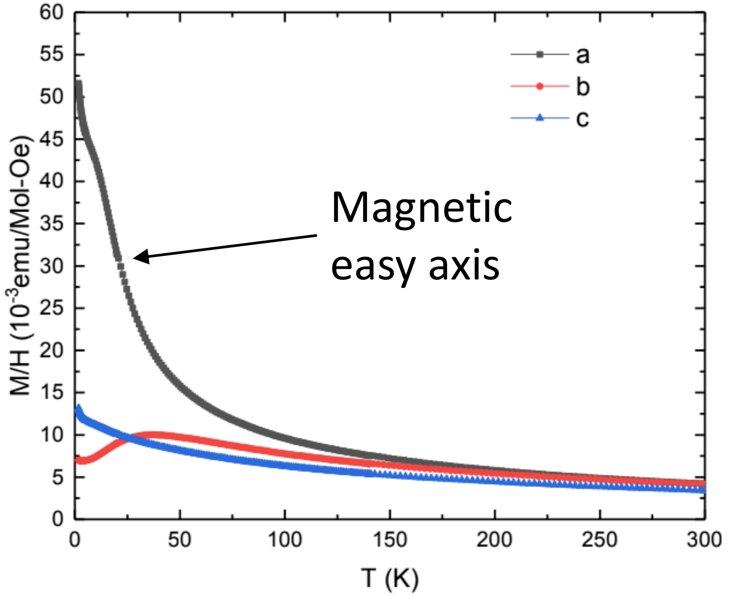
Superconducting pairs of electrons

Spin Triplet

Mediation of SC in UTe_2

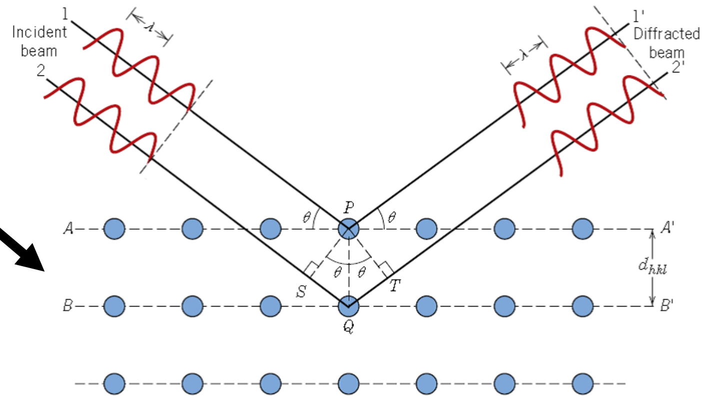
- Re-entrant superconductivity at magnetic fields up to 60 T.
- 15 T re-entrant superconductivity is not unusual for a ferromagnetic superconductor, but UTe_2 never undergoes a ferromagnetic transition!
- Spin-fluctuations may influence superconductivity in UTe_2.

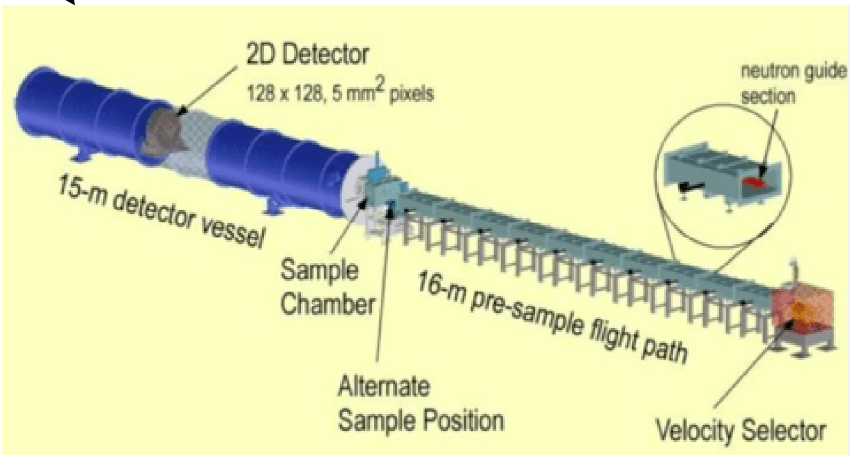




Introduction to SANS

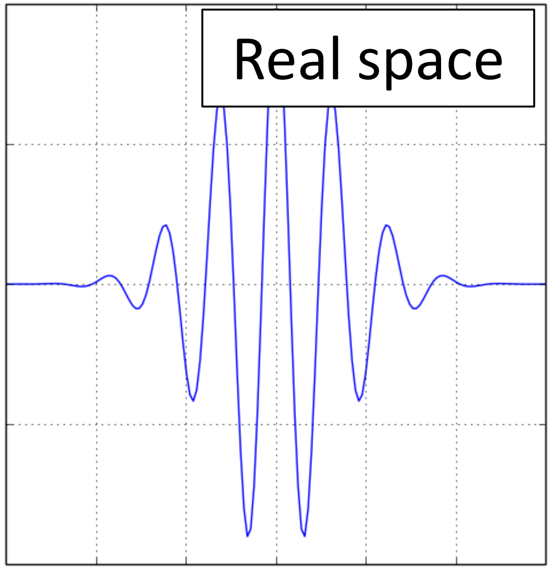
- Charge density periodicity → X-Ray scattering
  Nuclear periodicity
  Magnetic periodicity } → Neutron scattering





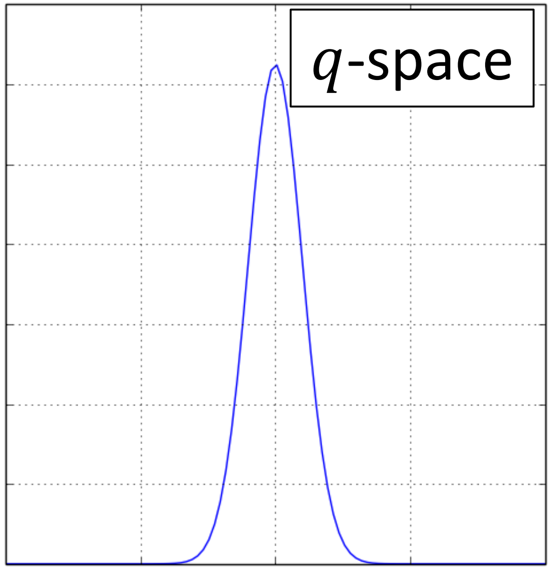
- Scattering takes the Fourier Transform of real space.

ρ



x

I



q

SANS in UGe_2

Ultra-High Resolution Neutron Spectroscopy of Low-Energy Spin Dynamics in UGe_2

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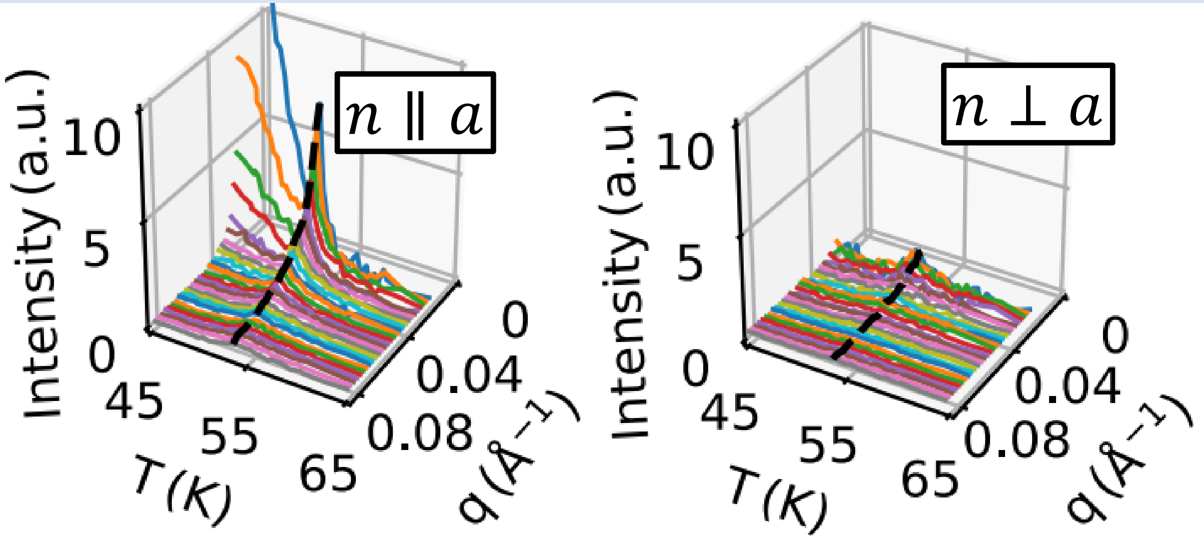
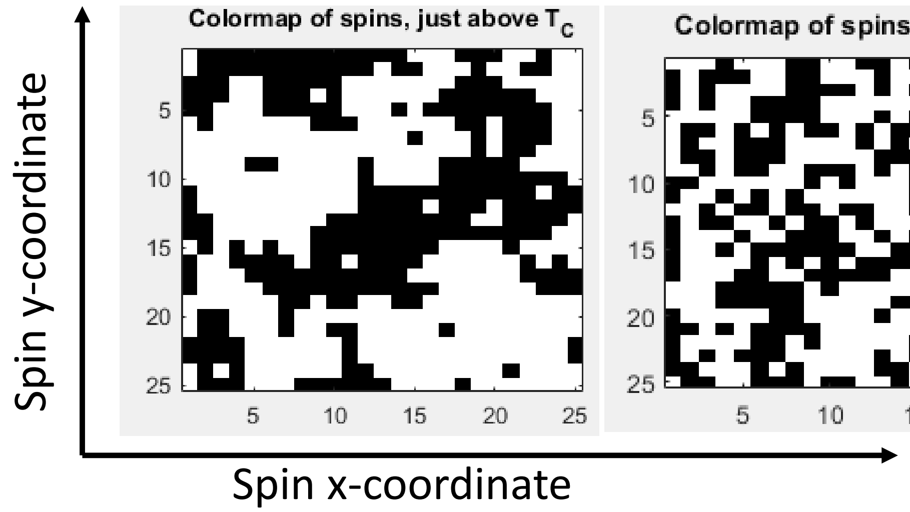
- SANS on triplet superconductor UGe_2 showed that magnetic fluctuations exist above the Curie temperature.
- Strong scattering only present along the magnetic easy axis.
- Fluctuations are present in I vs. q as a Lorentzian:

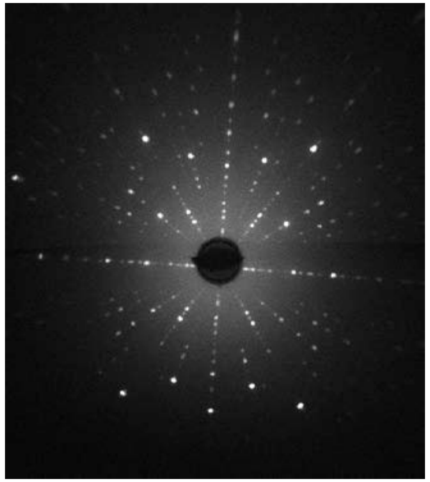
$$\frac{a_1}{a_2^2+1}$$ where a_2 is the correlation length.



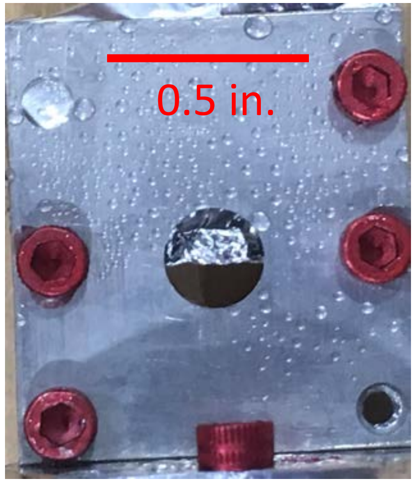


SANS in UTe_2

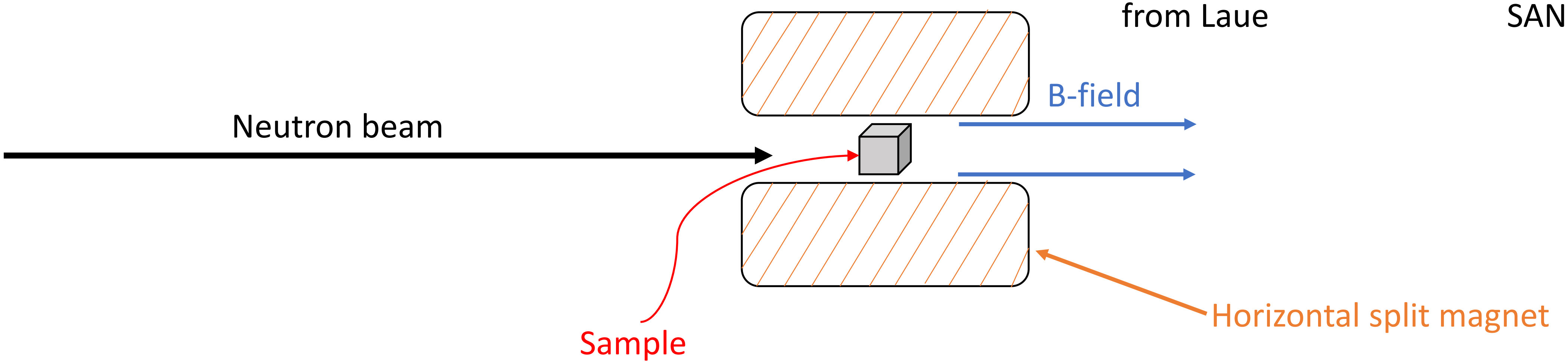
- 90-milligram UTe_2 sample aligned along the *a*-axis (easy axis) using the NIST Laue.
- Sample wrapped in Al foil with Cd mask and Al stand.
- We used a horizontal split magnet to have the magnetic field along the beam.



UTe_2 pattern from Laue

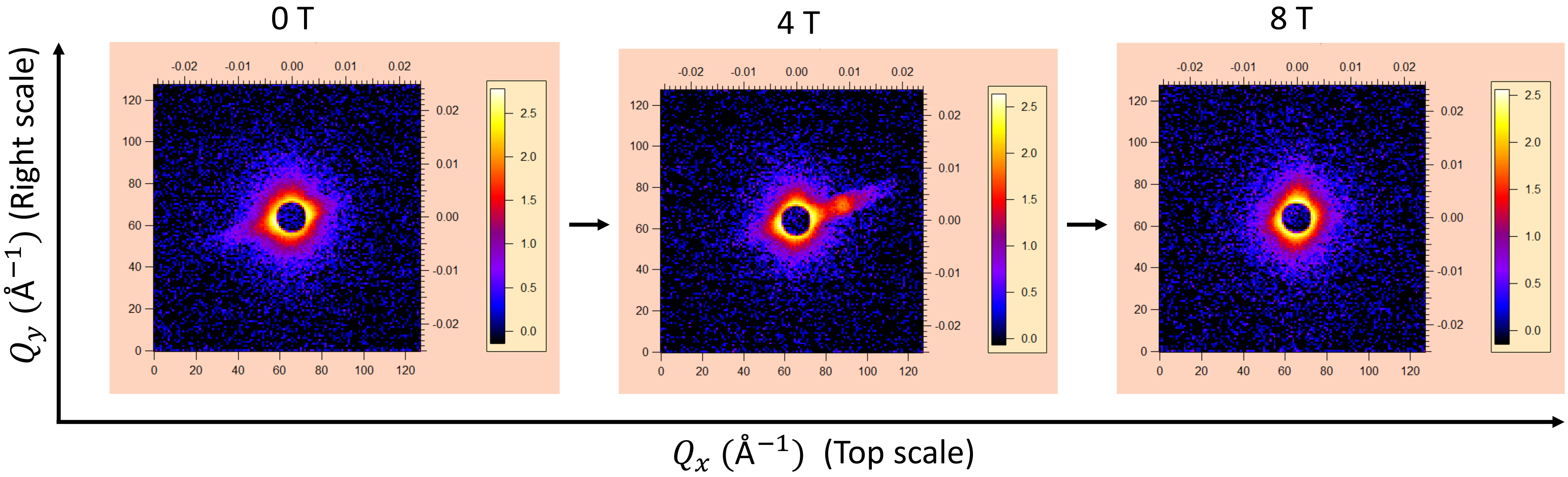


Mounted UTe_2 SANS sample



SANS in UTe_2

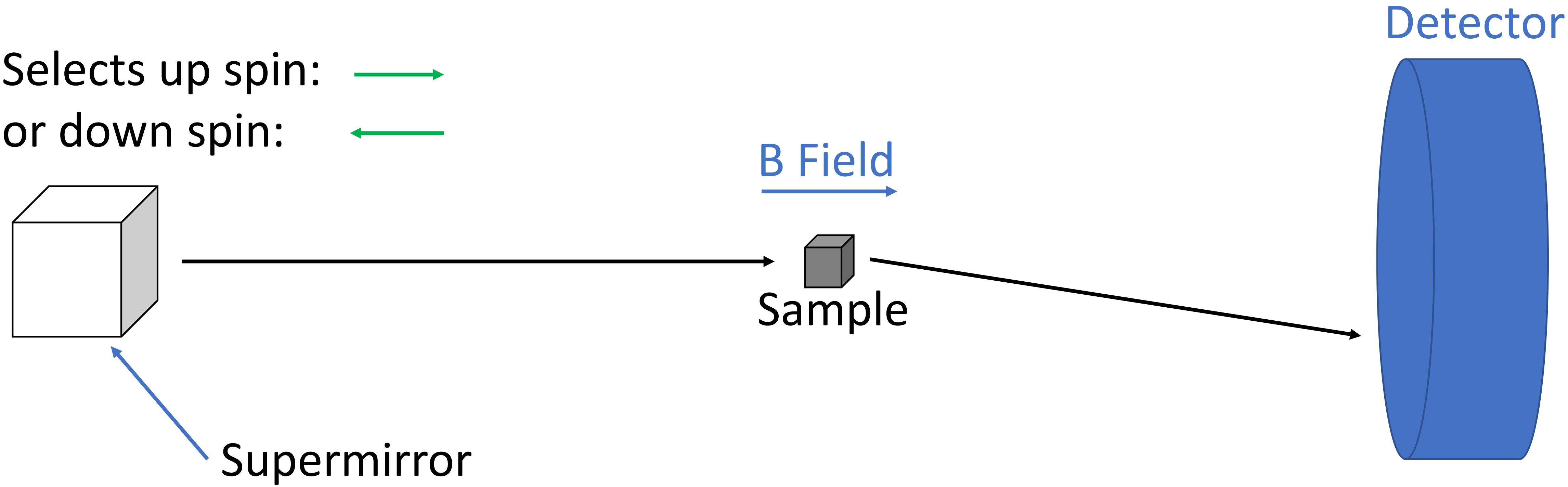
- Observed a weak signal and a flare from crystal facets:



- Solution: extract the magnetic component by using a polarized beam.

Polarized Neutron Scattering

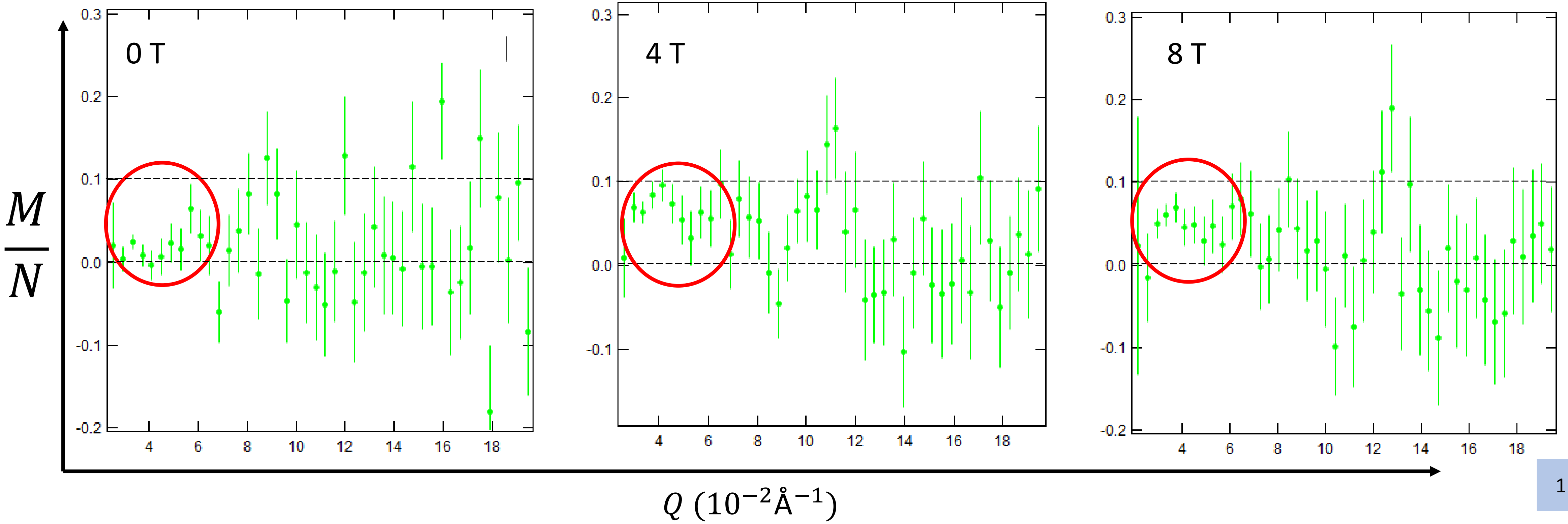
Selects up spin:
or down spin:



SANS in UTe_2

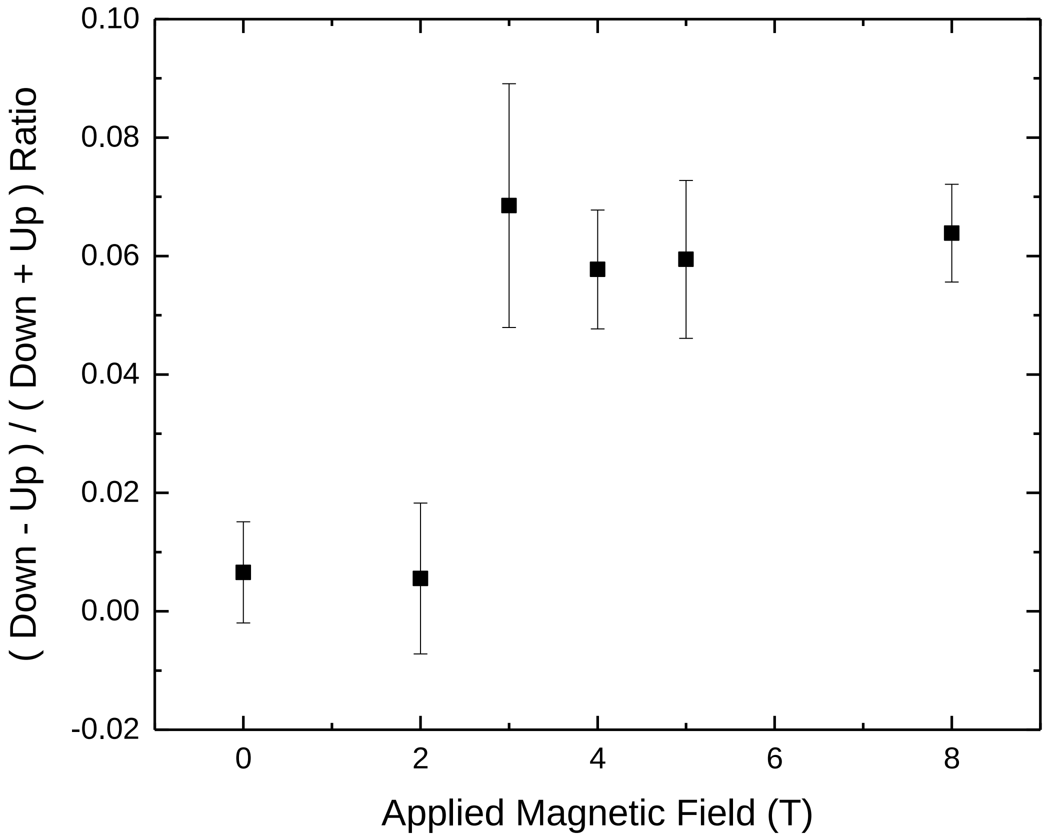
- Extract magnetic component with: $\frac{NM}{N^2} \propto \frac{down-up}{down+up} \propto \frac{M}{N}$.
- Signal does not increase with field as we expect!

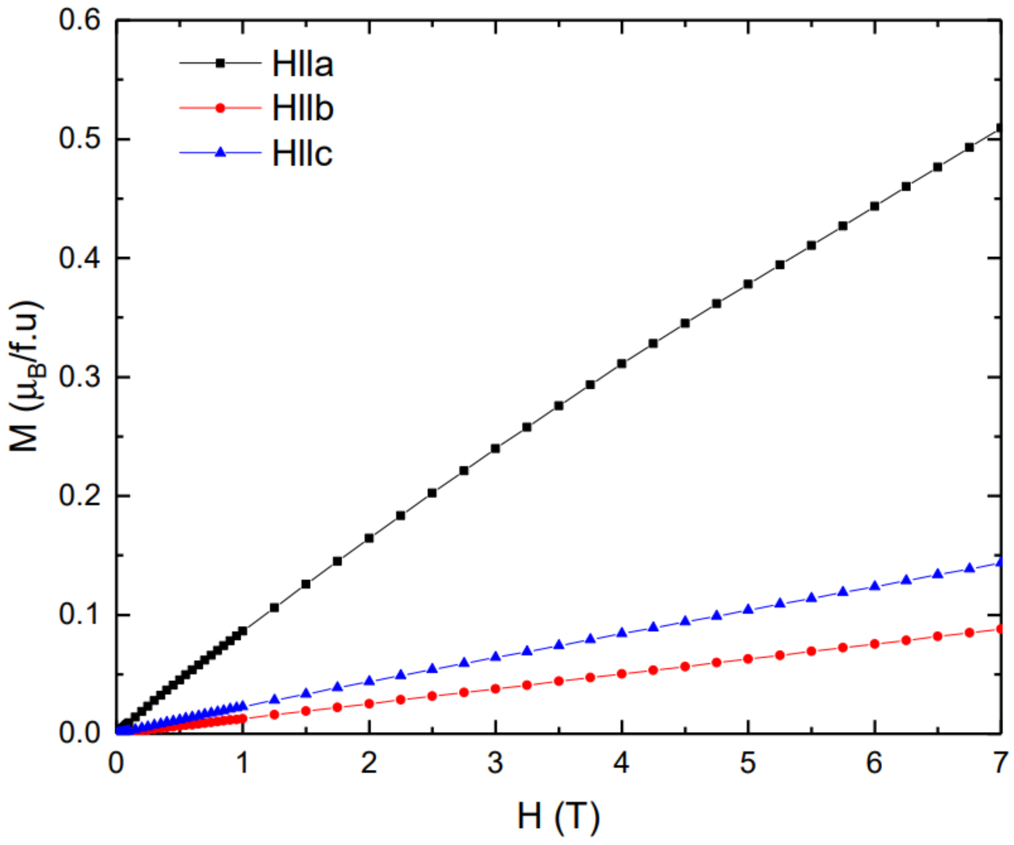
$M \equiv$ magnetic
$N \equiv$ nuclear



SANS in UTe_2

- Taking a closer look at all fields we see that intensity “turns on” at about 3 T.

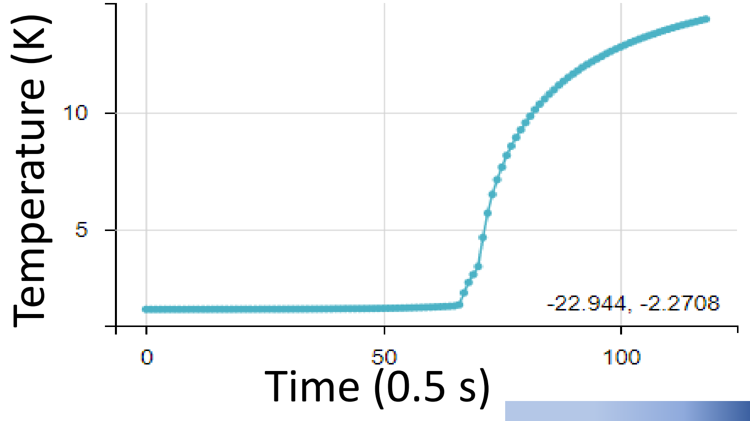




Future Steps

We would like to do more SANS measurements so we should:

- Grow larger samples/use an array of aligned samples.
  (if possible, shape the sample to reduce flares)
- Have better temperature control; use a different cryostat.
- Use a cryostat able to go to lower temperatures.
- Use a more powerful magnet (> 8 T).
- Test for reproducibility.



Summary

- We introduced SANS as a useful technique for studying magnetic fluctuations.
- We proposed our understanding of the fundamental physics inside UTe_2.
- We observed some result of spin fluctuations in UTe_2, but its temperature and field dependence are unclear.
- We need more measurements!

THANK YOU CHRNS & NIST Center for Neutron Research

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