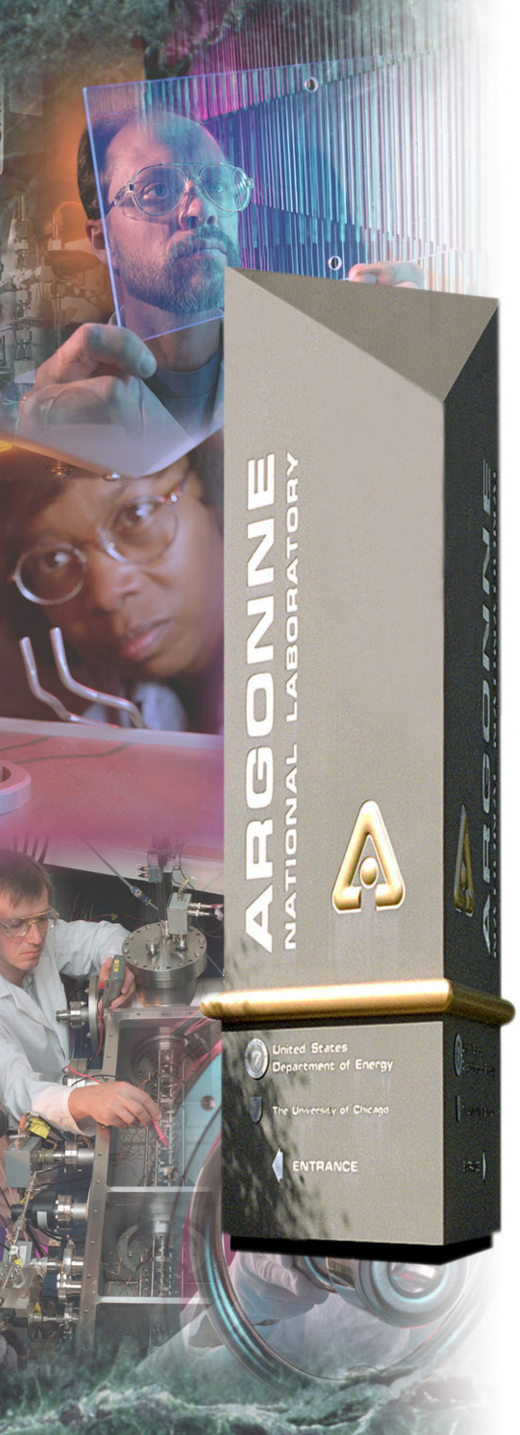


Science Opportunities with High-field magnets and Synchrotron Radiation

***Jonathan Lang**, Zahir Islam, George Srajer - APS*
Young Lee-MIT
Valery Kiryukhin-Rutgers

APS-Renewal Meeting
August 10, 2006

Motivation: Why in-field scattering studies?

Magnetic field is a unique variable that can be used to tune in novel phases of matter that are otherwise impossible to observe.

New material's properties are often discovered in extreme sample environments.

Appling magnetic field has profound effects on the not just the magnetic properties, but also the orbital, charge and structural degrees of freedom. X-rays are uniquely situated to study all these effects simultaneously.

Why synchrotron x-rays?

In-field Scattering ≠ Magnetic Scattering

Many (Most?) in-field measurements involve structural effects such as phase transitions, lattice modulations, short range order etc. Understanding them is key to understanding the properties of the material.

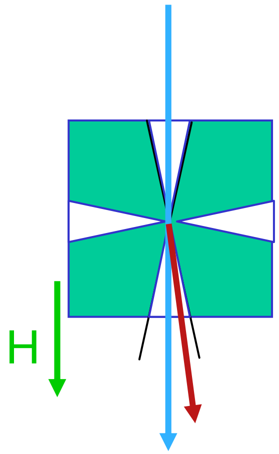
- **High momentum resolution → subtle changes**
- **High brilliance → small and dilute samples (doping)**
- **Element specificity → heterogeneous systems**
- **Small beam → spatial resolution**

Current in-field scattering capabilities

4 Tesla Horizontal Field

11-ID (7-Tesla) for high energy

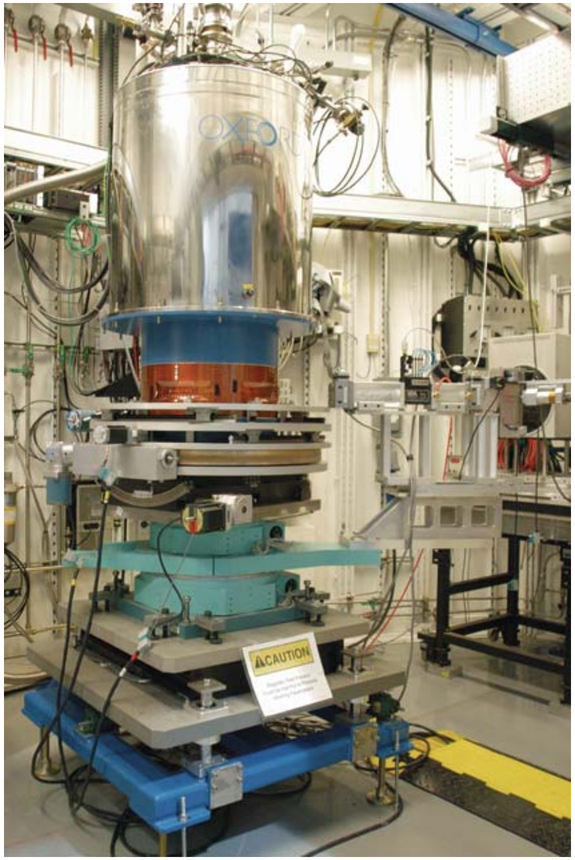
Split Coil

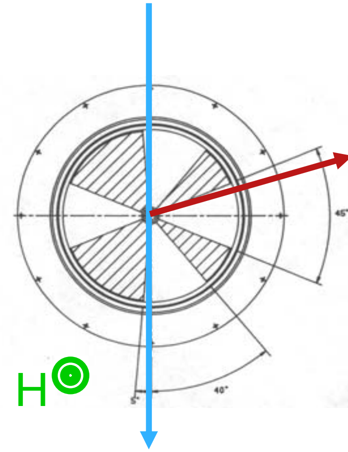


X: $2\theta \sim 30^\circ$

Y: $2\theta \sim 5^\circ$

13 Tesla Vertical Field



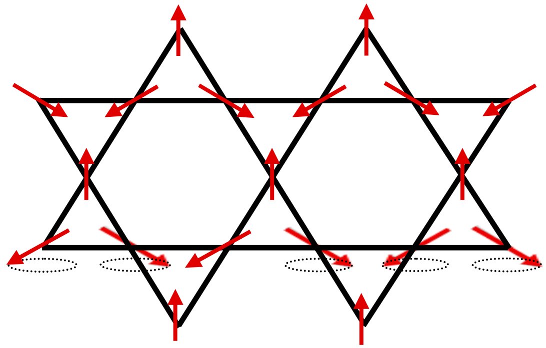


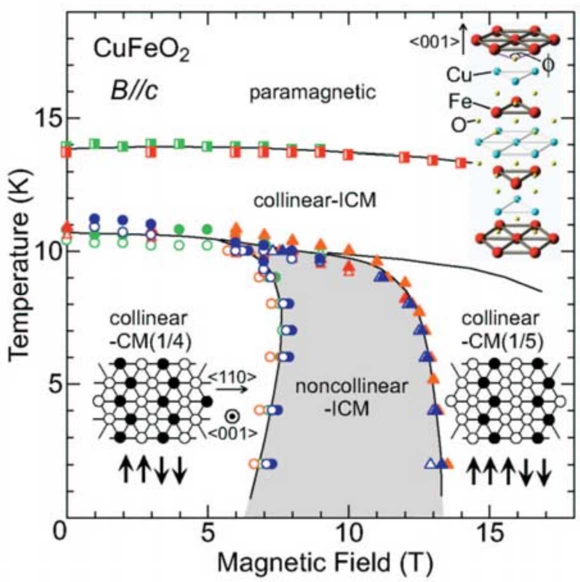
$2\theta \sim 180^\circ$

T=2→300K

- **Beam along split better for diffraction (more access)**
- **ESRF (10T), Spring-8 (15T), NSLS (13T)**

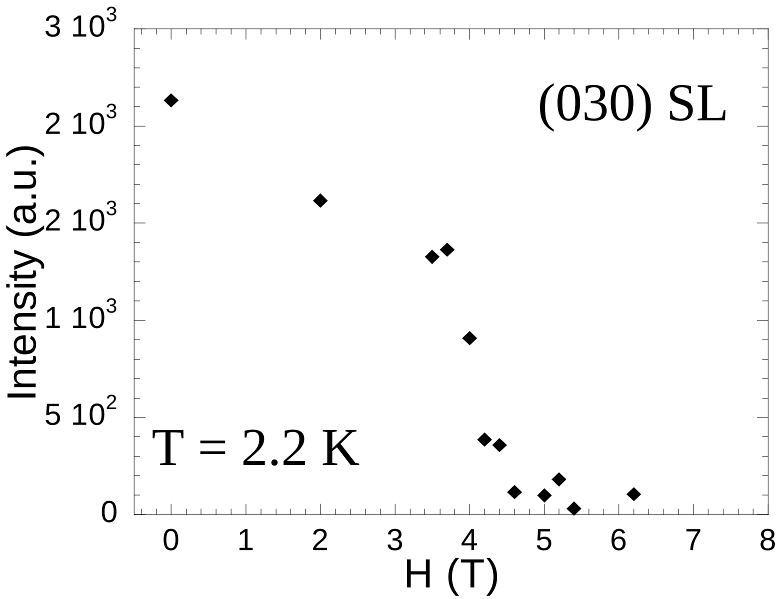
Spin Frustration in $CuFeO_2$





T. Kimura et al., (2005)

- *Triangular lattice → spin frustration*
- *Magnetoelastic coupling*
  - *→ Structural distortions*
  - *→Forbidden superlattice peaks*



Field melts low-T superstructure

Y. Lee (MIT) et al. APS-4-ID

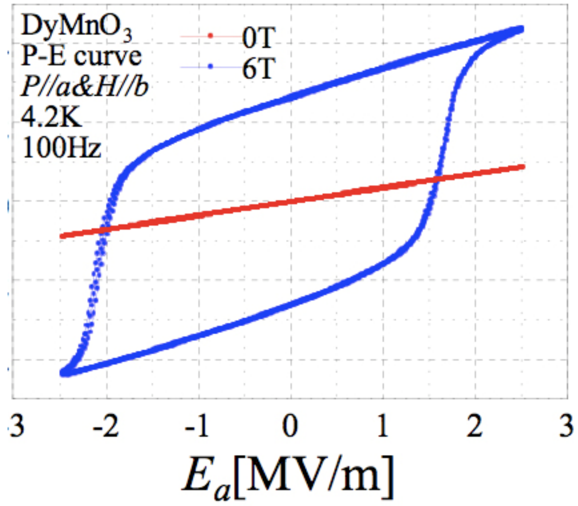
Multi-ferroic $RMnO_3$

Materials which exhibit both (ferro-)magnetic, ferro-electric, properties

Magnetization ⟺ Electric polarization

coupling

$DyMnO_3$



T. Kimura *et al*. *Nature* **426**, 55 (2003).

T. Goto *et al*. *Phys.Rev. Lett.* **92**, 257201 (2004).

Multi-ferroic $RMnO_3$

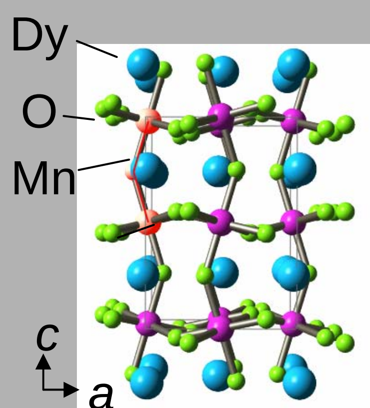
Materials which exhibit both (ferro-)magnetic, ferro-electric, properties

Magnetization ⟷ Electric polarization

coupling

Perovskite structure

Frustrated Antiferromagnet



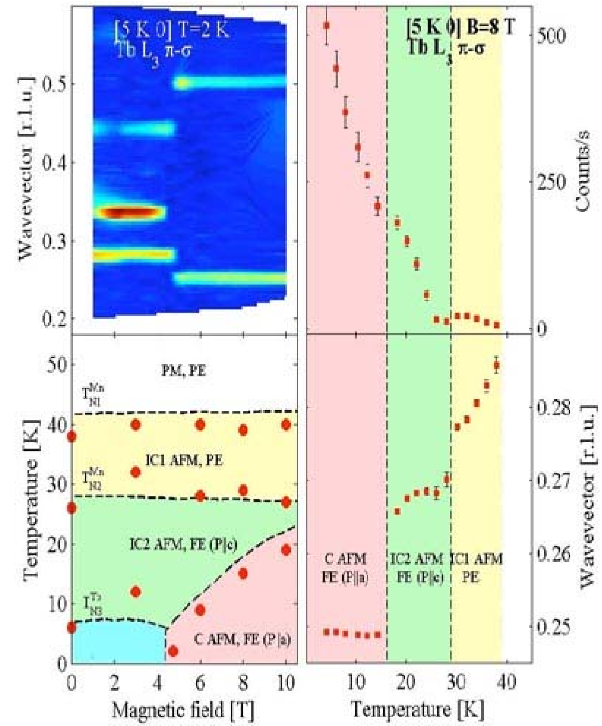
Magnetic field
→Atomic Displacements
→Ferroelectric Behavior

Resonant X-ray Scattering

- **•Magnetic Structure**
  - o**Field**
  - o**Tempererature**

Diffuse scattering

- **•Atomic Displacements**

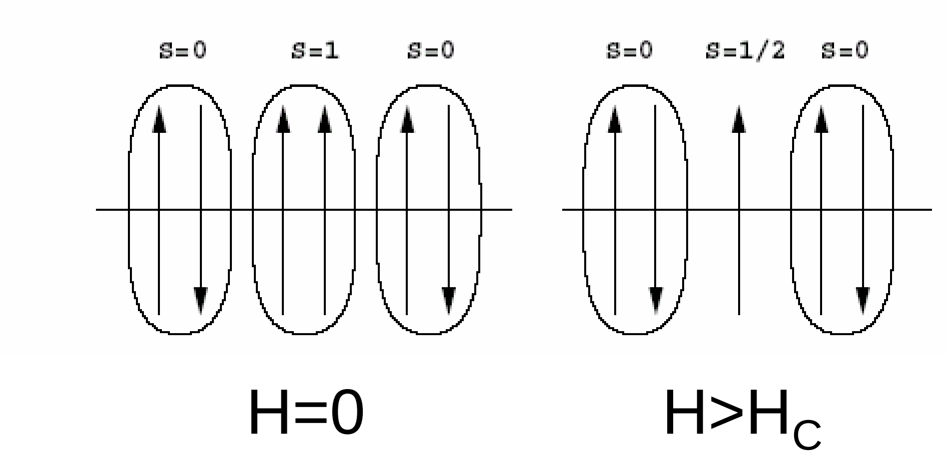


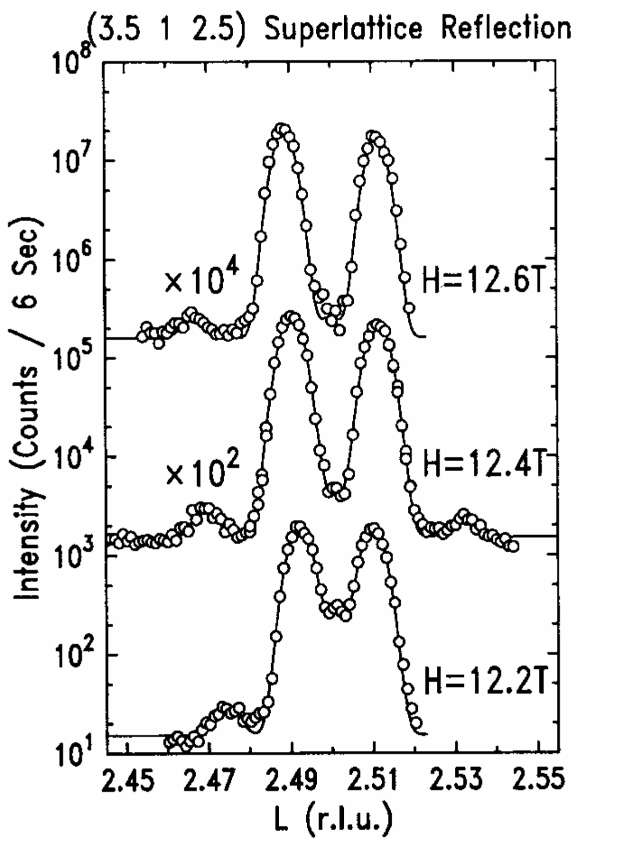
D.F. McMorrow et al.
ESRF ID-20

Structures >10T?

Spin-Peierls (1D Quantum Magnet) $CuGeO_3$

1D chains of spin 1/2 on a deformable 3D lattice





Incommensurate lattice of unpaired spins form in high magnetic fields.

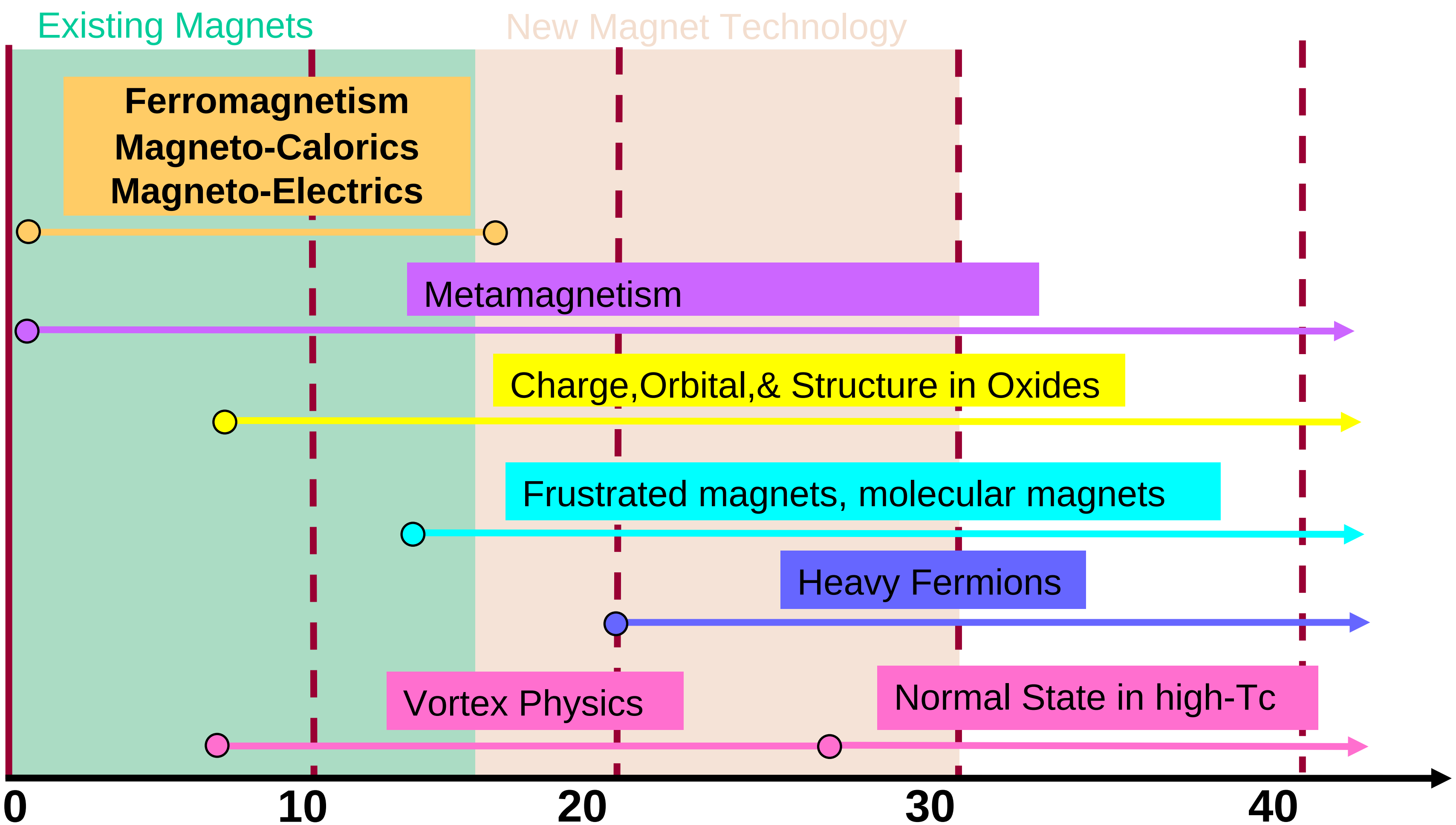
Predicted splitting does not match theory

Need higher Fields

VK, et al., PRL 76, 4608 (1996)

Physics at higher fields ?

More powerful magnets would enable new types of experiments
Normal SC magnets limited to ~15T → Hybrid magnets

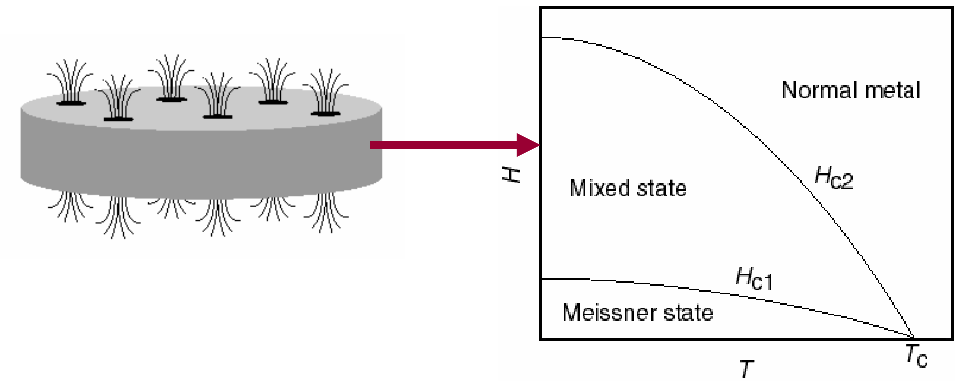


Normal state - High Tc

High magnetic field (~30T) can suppress superconductivity in high-Tc materials.

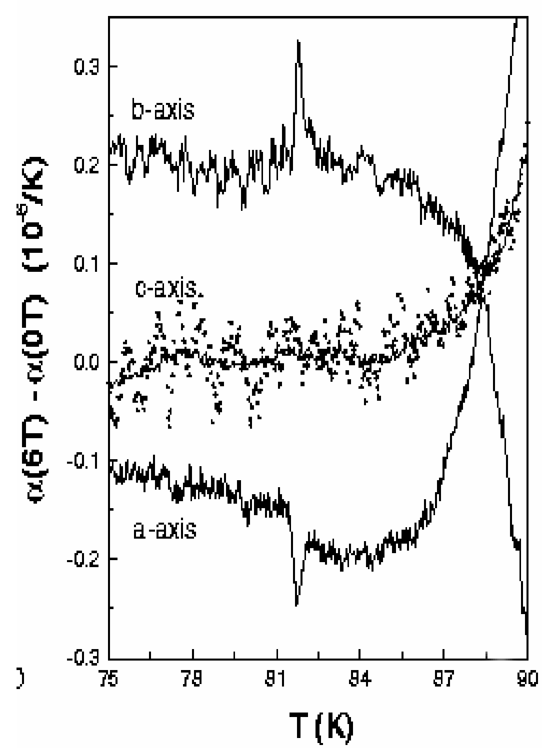
Look for competing phases (charge,spin stripe phases)

Intermediate fields have the vortex state



Coupling between the vortex lattice and crystal lattice.

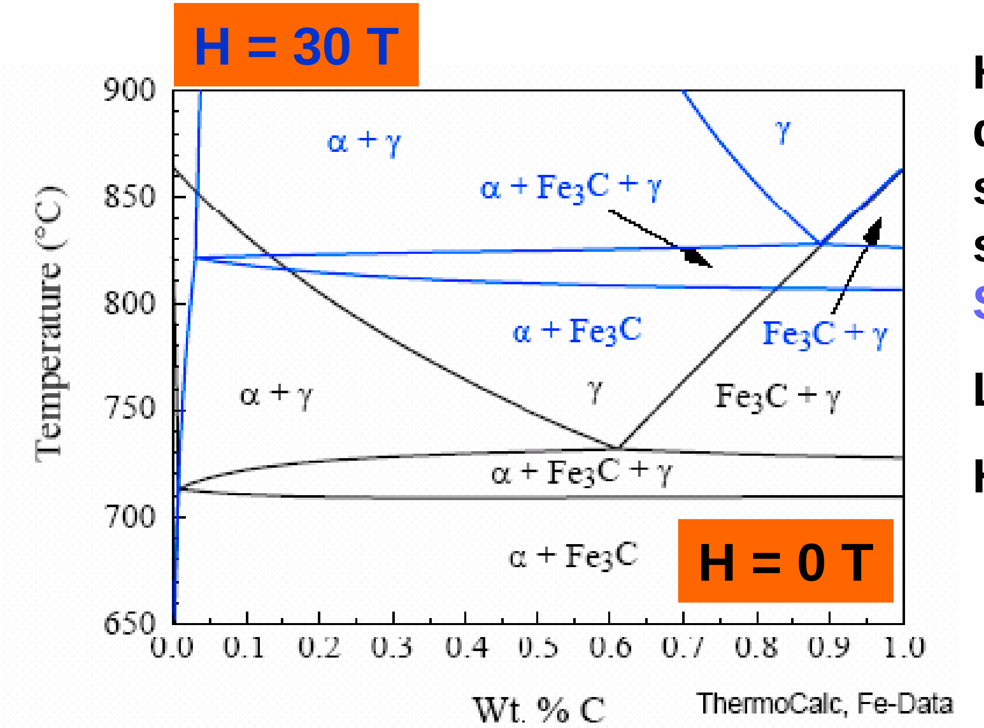
Small effect need very high resolution



R. Lortz et al. Phys. Rev. Lett. 90, 237002 (2003)

Isothermal solidification of Steel

Pseudo-binary phase diagram for SAE 1045 steel



High magnetic fields can have dramatic influence on the solidification temperatures and solubility limits of some steels. **Shifts of 100˚C!!!**

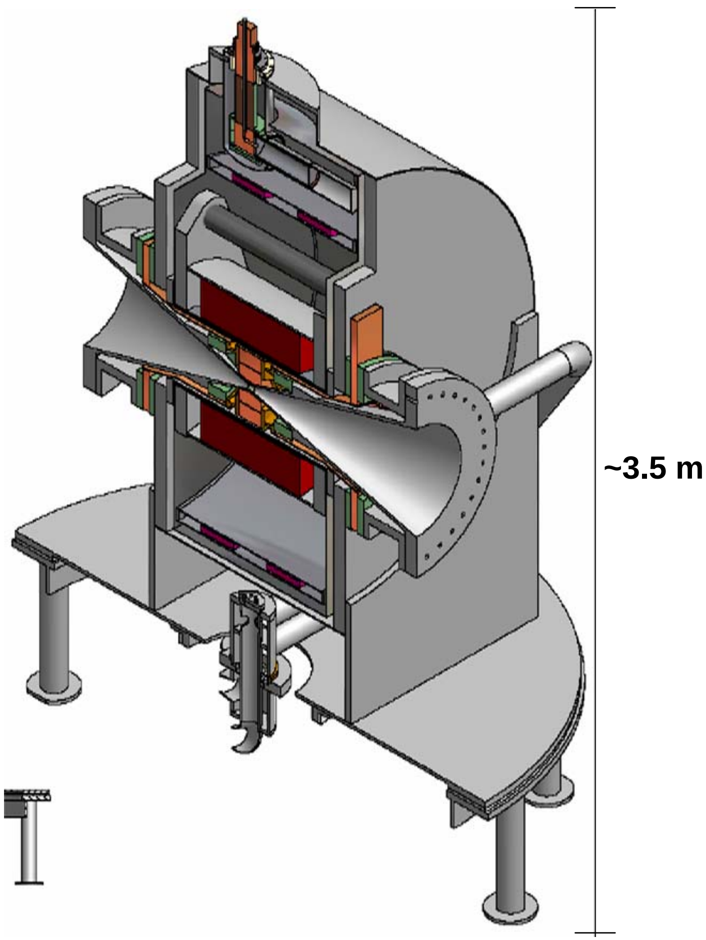
Lower Field to solidify sample.

High energy x-ray scattering!

Effect due to the differing magnetic susceptibilities of ferrous alloys

High Field Magnets at other Facilities

30 Tesla Horizontal Field magnet for HMI and planned for SNS

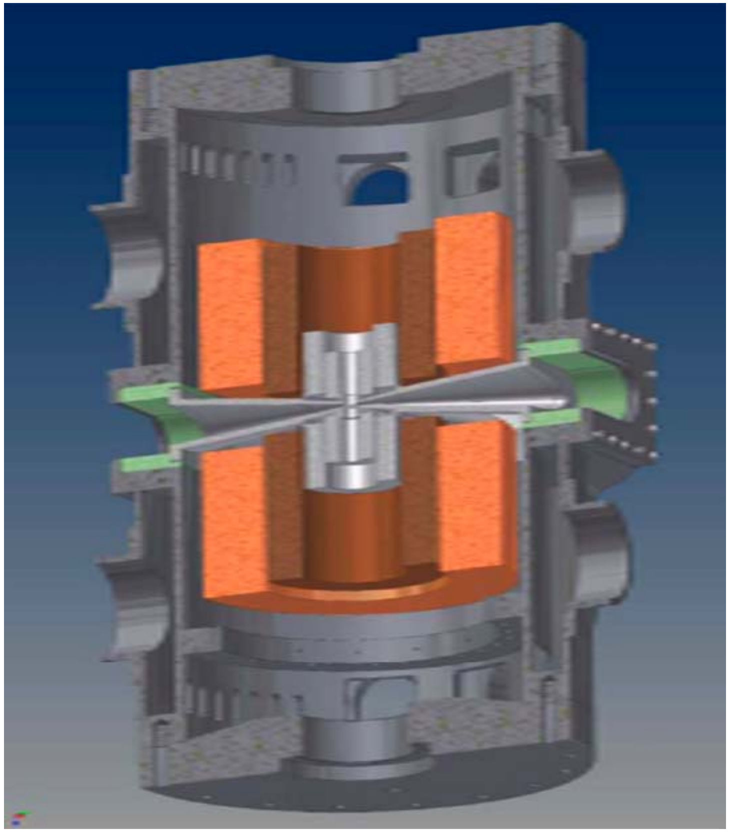


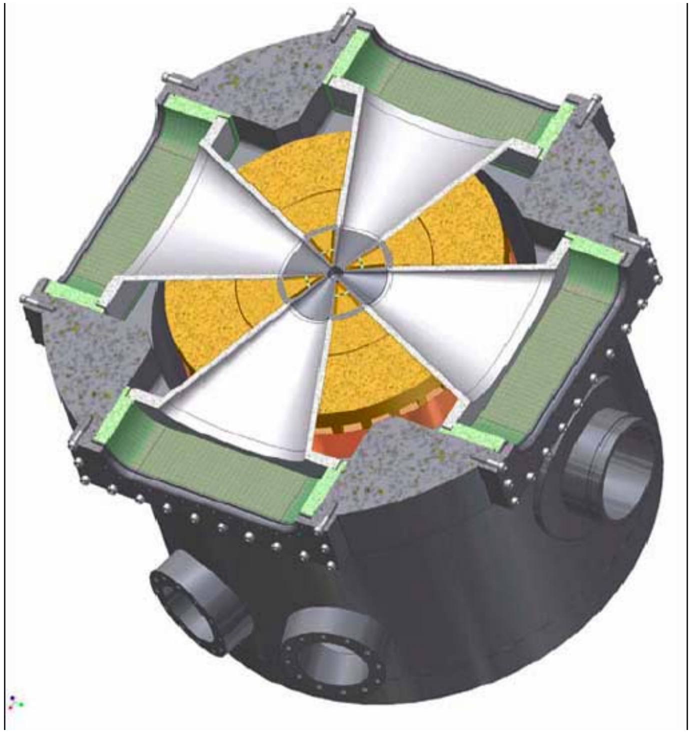
- Superconducting Hybrid Technology
  - SC outside with resistive insert
  - NHMFL proven technology
- Horizontal Bore (not Split coil!)
- Limited scattering angle
  - 30˚ max 2Θ
- Cryostat/sample comes in on same side as beam
- Not suitable for single crystal studies

High-Field Split -Gap Magnet

Split-Gap absolutely required for single crystal work

This is where most ground breaking science will be.





NHMFL confident they can build

NSF proposal to complete design work V. Karyukhin, Y. Lee, et al.

X-ray beamline for high-field scattering

A high-field magnet would be a unique facility maximize beamline flexibility to enable the most experiments (More like HP-CAT).

Maximize intensity on sample (flux limited)

Large energy range

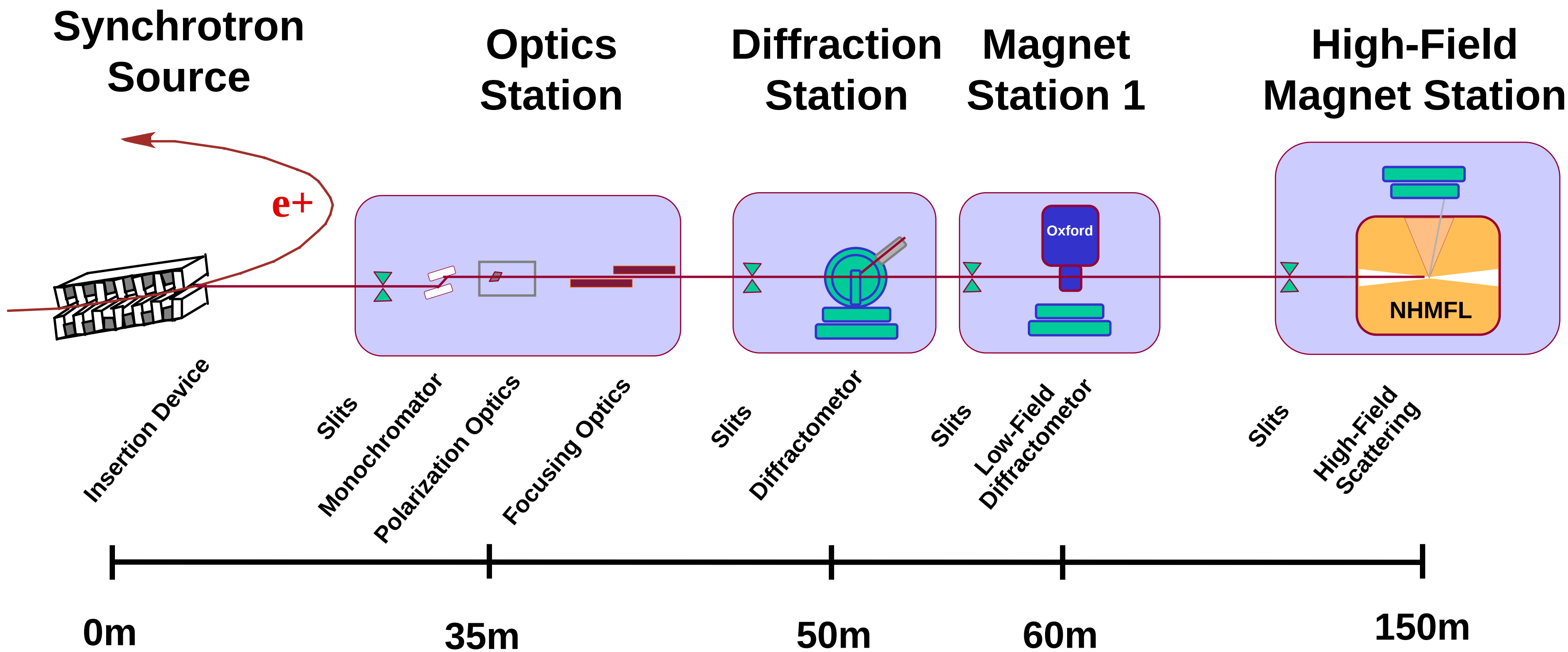
- Resonant 3.5<E<12 keV; *Magnetic, orbital scattering*
- Non-resonant E>30 keV; Structural work; Less sample heating
- Multiple IDs (long straight section)

Adjustable focusing

Polarization Control

- Rotate linear polarization; Circular?

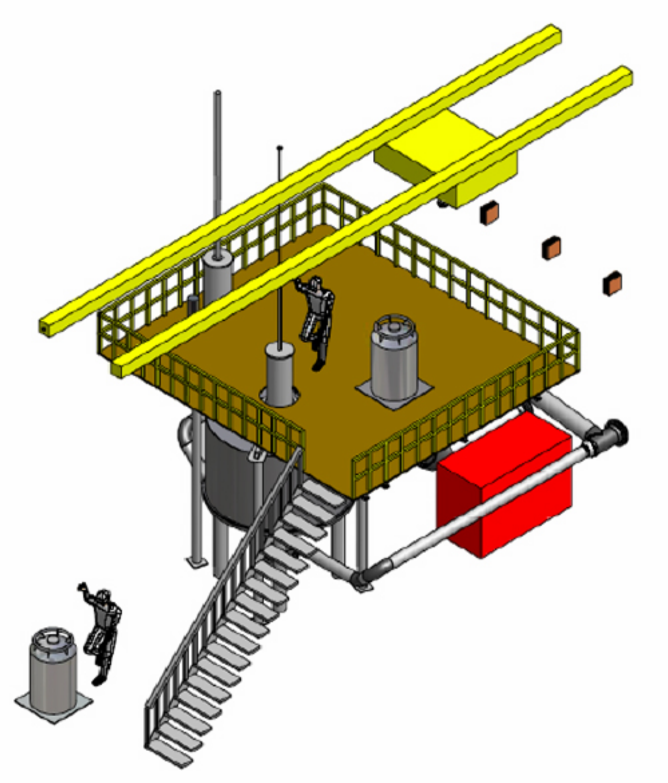
Dedicated in-field scattering beamline



Couple in-field diffraction station with high-resolution single crystal diffraction station

Pass through operation

Why build it outside the ring?



Size:

Difficult to get optical access with only 1.4m clearance

Utilities:

Electricity: ~8MW (600V, 20KA)

Water: 75 liters / s

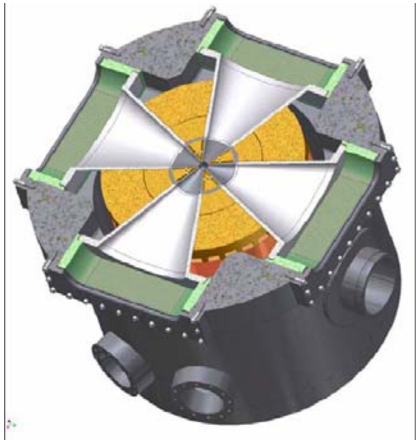
Liquid He: 1 liter / s

(Dedicated cryo-cooler)

Summary

High Field magnets enables novel new science

⇒Competing Phases in High-Tc cuprates
⇒Interplay of orbital, spin and charge ordering
⇒Frustrated magnetism
⇒Metamagnetic phase transitions
⇒Field mediated crystallization



APS renewal offers unique opportunity to build a best in world high-field scattering facility