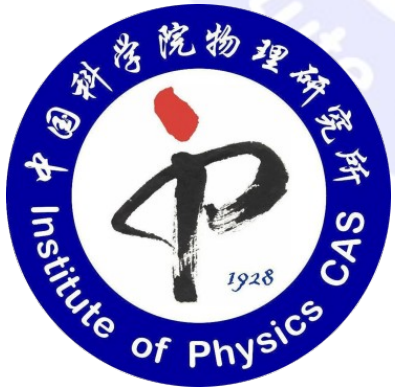
Gapped spinon in a new kagome quantum spin liquid $Cu_3Zn(OH)_6FBr$

Zi Yang Meng

(孟子杨)

http://ziyangmeng.iphy.ac.cn/



Strong Correlations require Strong Collaborations

Zili Feng
You-Guo Shi

Sample growth
Characterization

Zheng Li
Guo-qing Zheng

NMR

Yuan Wei
Shiliang Li

Neutron scattering

Shiyan Li
Lei Shu

Heat capacity
muSR

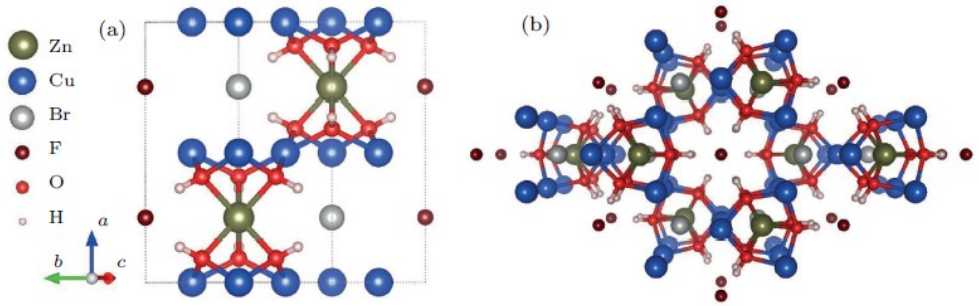
2am, early morning in December, 2016 @ IOP, Beijing

Jia-Wei Mei
Zheng Liu

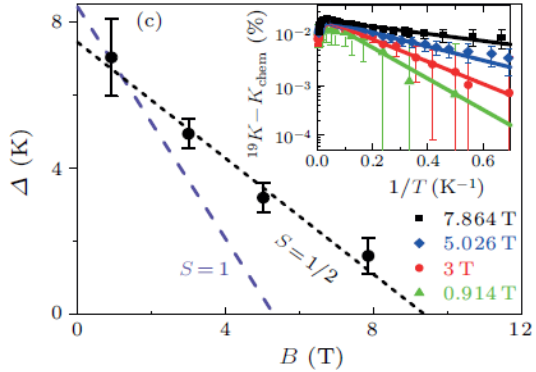
Theory

Content

- $Cu_3Zn(OH)_6FBr$: a new kagome quantum spin-liquid compound



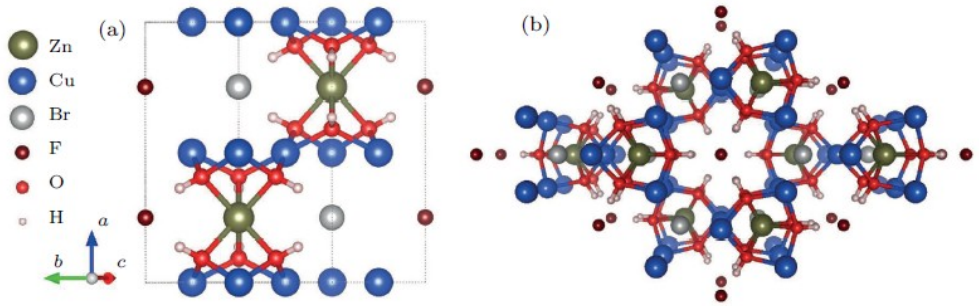
- Identify a gap in $Cu_3Zn(OH)_6FBr$: NMR
  - Zili Feng et al., Chin. Phys. Lett. 34, 077502 (2017)
  - Xiao-Gang Wen, Chin. Phys. Lett. 34, 090101 (2017)



- Identify a gap in $Cu_3Zn(OH)_6FBr$: Neutron Scattering
  - Yuan Wei, Zili Feng et al., in preparation

Content

- $Cu_3Zn(OH)_6FBr$: a new kagome quantum spin-liquid compound



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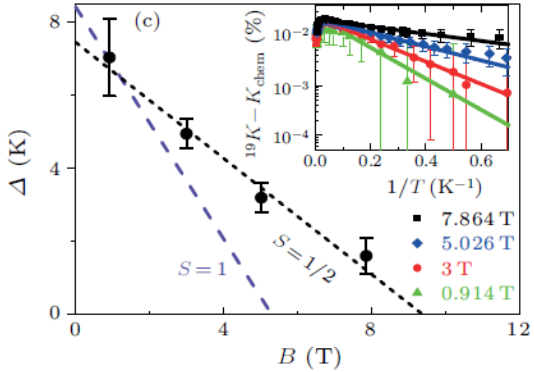
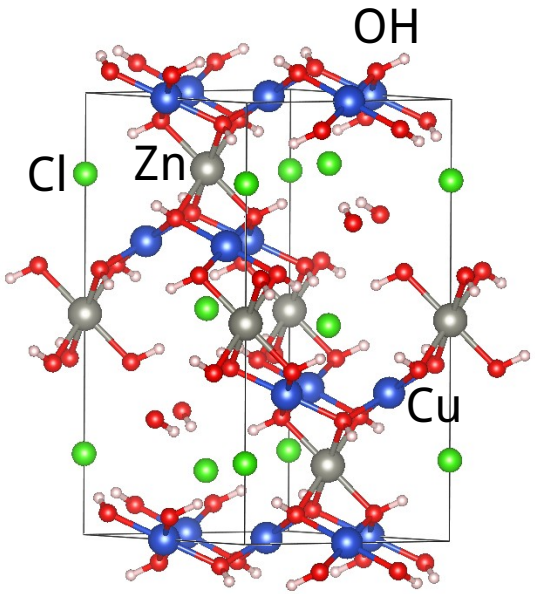
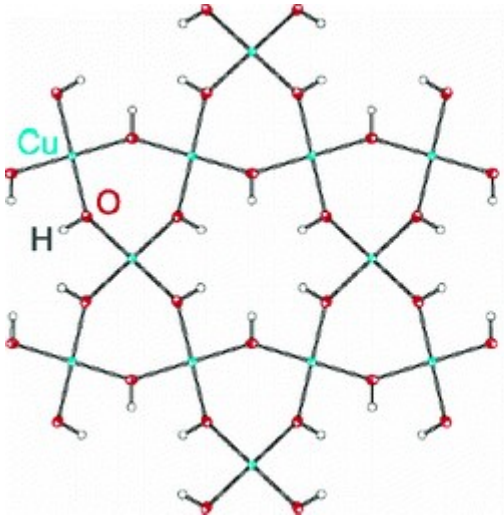


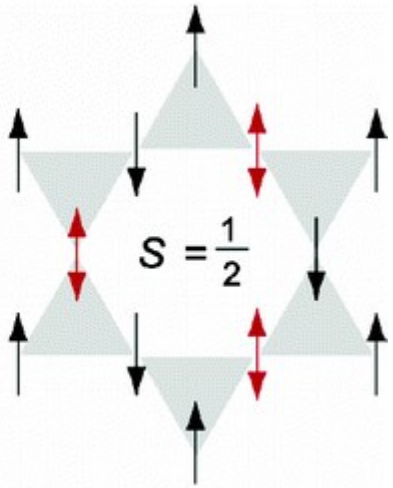
- Identify a gap in $Cu_3Zn(OH)_6FBr$: Neutron
  - Yuan Wei, Zili Feng et al., in preparation

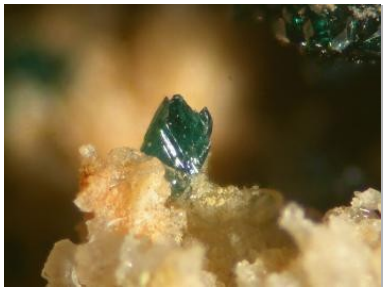
Kagome quantum spin liquid

Herbertsmithite $ZnCu_3(OH)_6Cl_2$







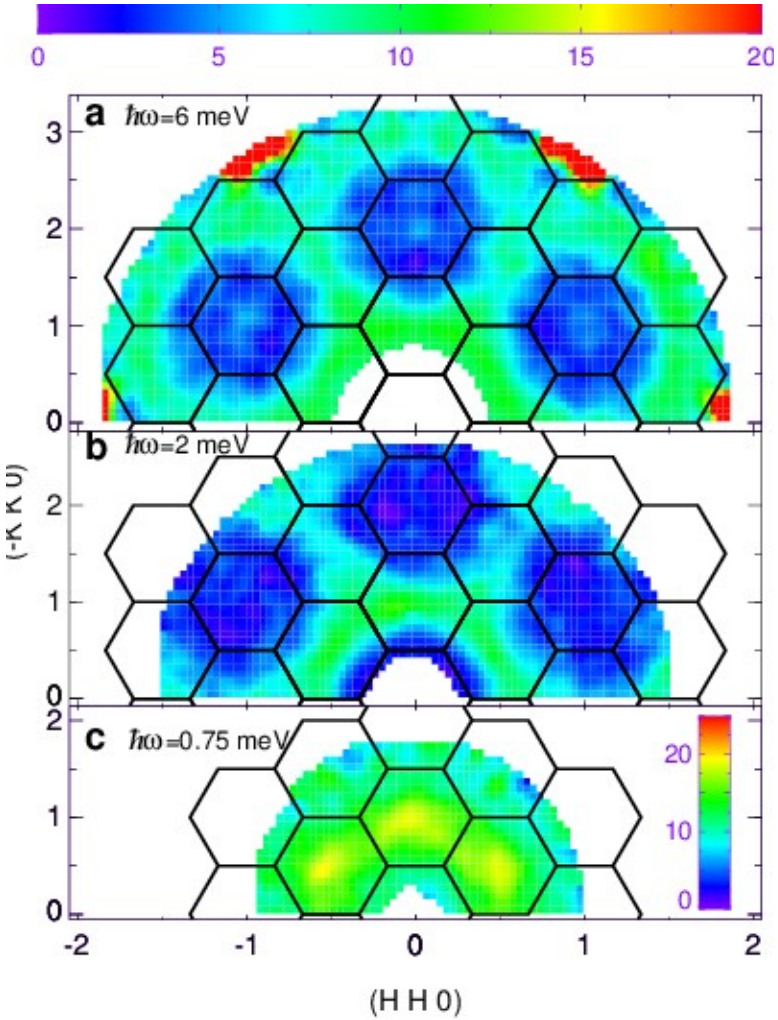


Quantum spin liquid:

- quantum many-body entanglement -- topological order
- fractional quantum Hall
- fault-tolerant quantum computation
- the understanding of cuprate high temperature superconductors
- ……

➢ Shores et al, JACS, 127, 13462 (2005)

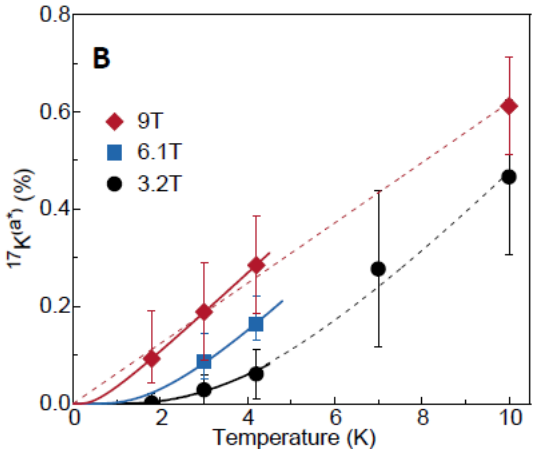
Herbertsmithite $ZnCu_3(OH)_6Cl_2$: confusing reality

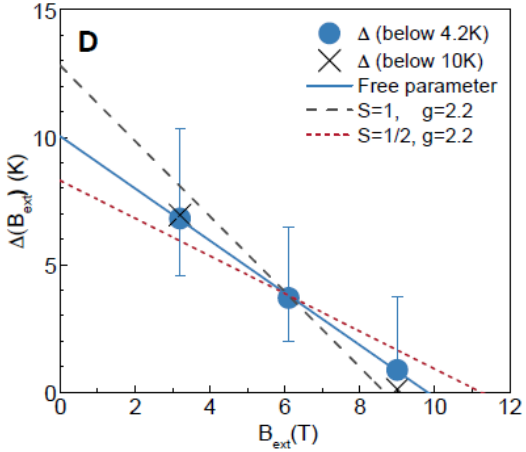


$J \sim 17$ meV Gapless

➢ Tian-Heng Han et al., Nature 492, 406 (2012)

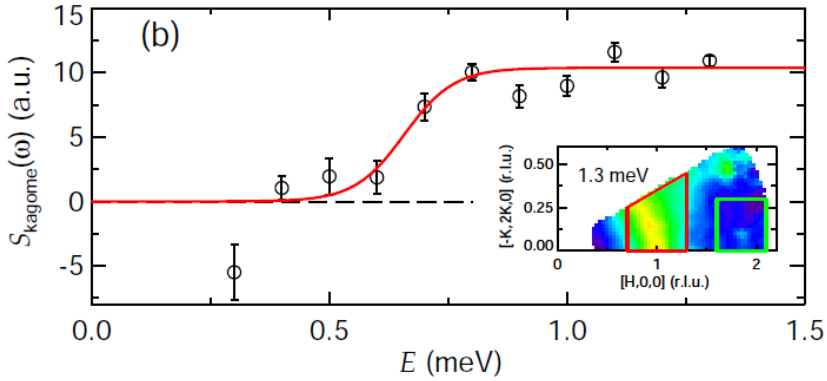
Oxygen-17 NMR (I=5/2)





$\Delta \sim 0.9$ meV Gapped S=1/2 or S=1 ?

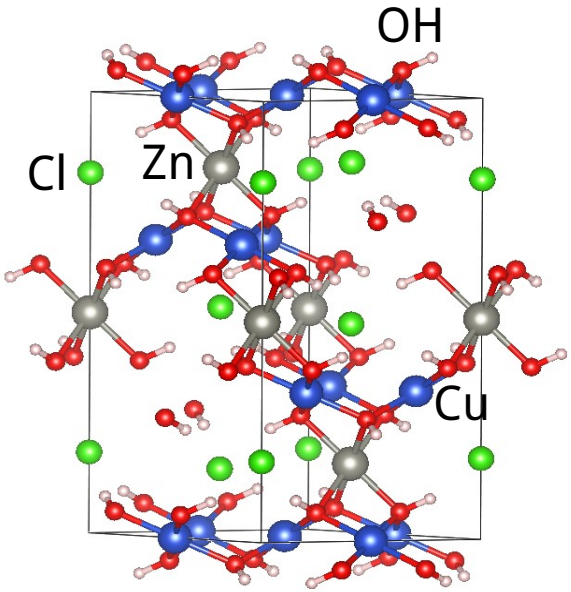
➢ Mingxuan Fu et al., Science 350, 655 (2015)

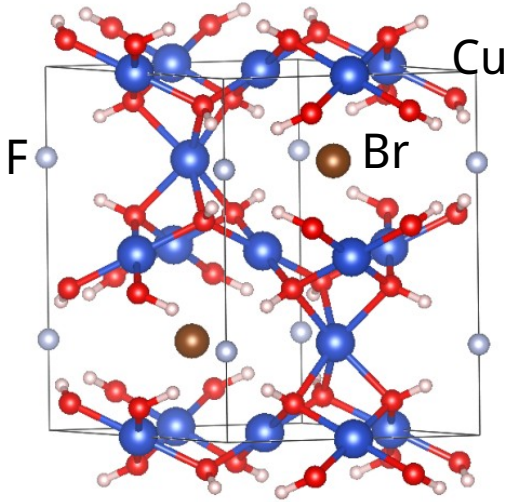


$\Delta \sim 0.7$ meV smaller gap?

➢ Tian-Heng Han et al., PRB 94, 060409(R) (2016)

Search for new kagome spin liquid compounds



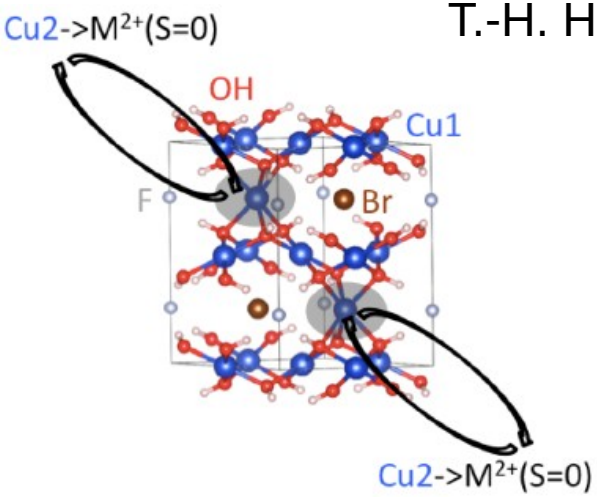


	Herbertsmithite	Barlowite
Formula	$Cu_3Zn(OH)_6Cl_2$	$Cu_4(OH)_6FBr$
Ground state	QSL	Ordered
Θ_{cw} (K)	180	140
T_N (K)	<2e-2	15
Ref.	JACS, 127, 13462 (2005)	PRL 113, 227203 (2014)
Notes	• Identical inplane kagome structure • Interkagome Zn is now replaced by Cu • Hint: Interkagome spin and coupling may play an important role	

Search for new kagome spin liquid compounds

- "Barlowite: A spin-1/2 Antiferromagnet with a Geometrically Perfect Kagome Motif",

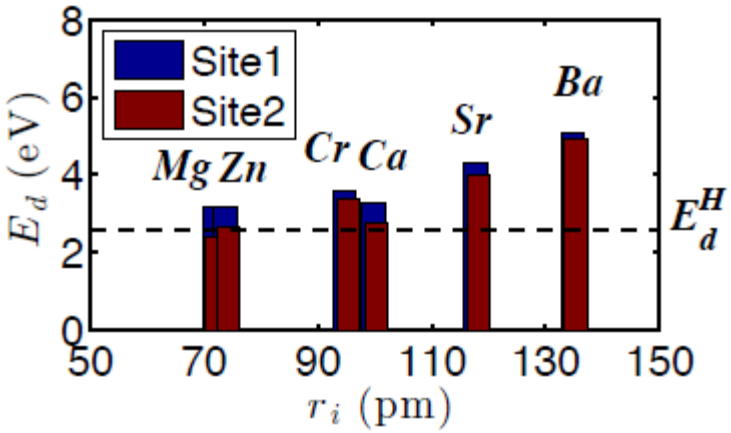
  T.-H. Han et al, Phys. Rev. Lett. 113, 227203 (2014)



M^{2+}: 4d transition non-magnetic ions, such as Sn^{2+} or Cd^{2+} ions

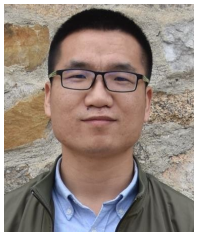
- "Selectively Doping Barlowite for Quantum Spin Liquid",

  Z. Liu et al, Phys. Rev. B, 92 220102(R) (2015)



Mg/Zn as the most ideal substitutes

Synthesizing $Cu_3Zn(OH)_6FBr$

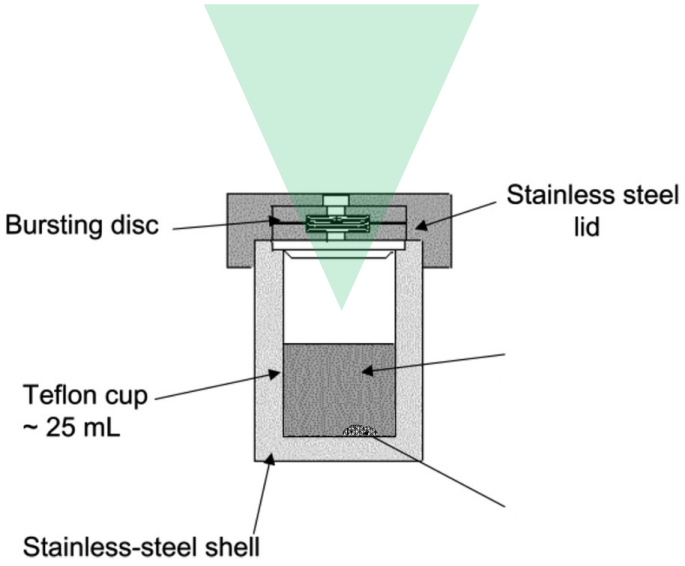


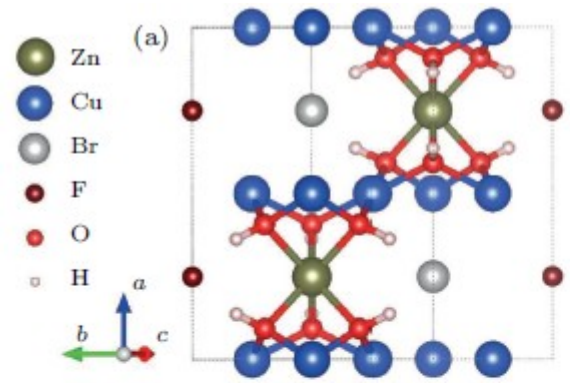
Zili Feng

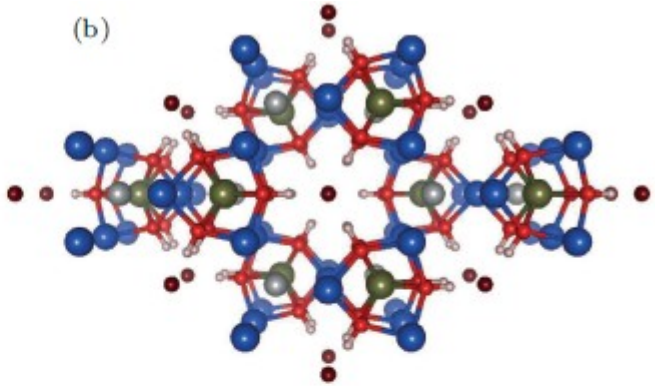
Youguo Shi

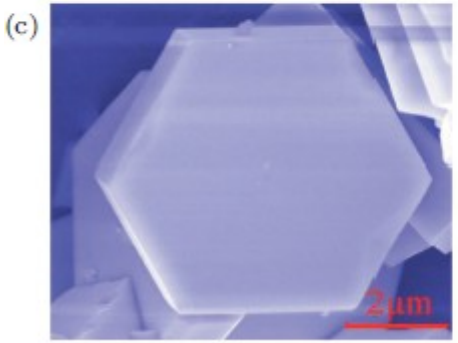
Hydrothermal synthesis

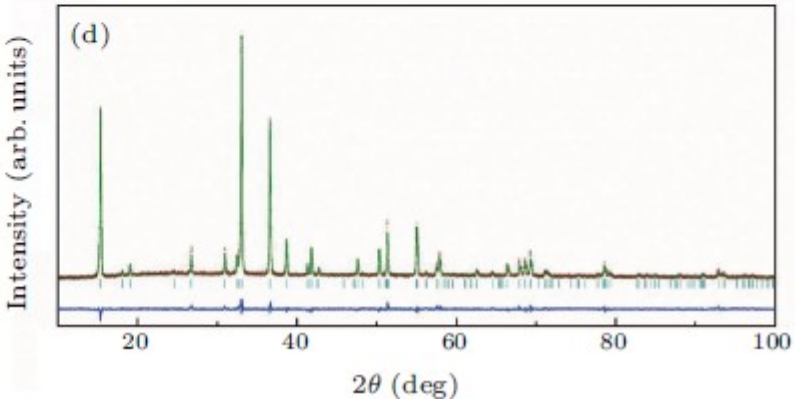
Cu^{2+}, Zn^{2+}, F^-, Br^-









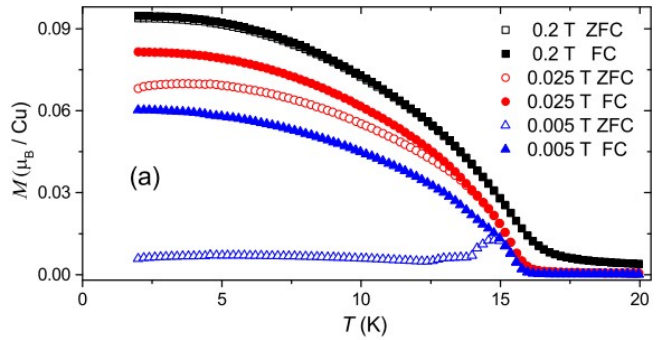


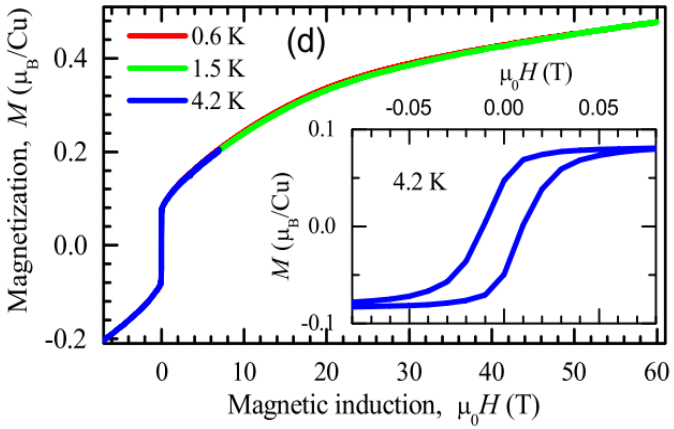
- $Cu_3Zn(OH)_6FBr$ with Cu^{2+} forming the kagome planes
- *AA* stacked along *c*-axis
- Kagome planes are separated by non-magnetic Zn^{2+}
- No structure distortion

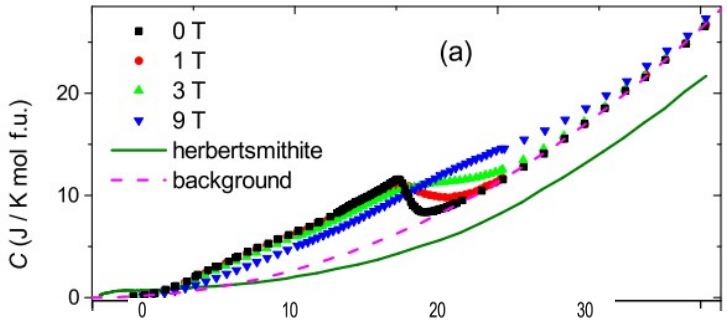
- Zili Feng et al., Chin. Phys. Lett. 34, 077502 (2017)

Thermodynamics

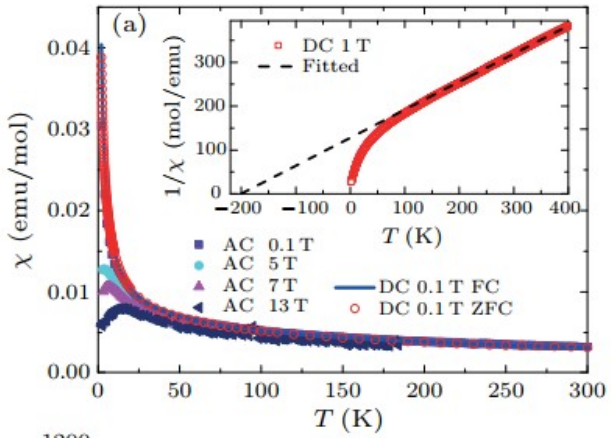
$Cu_4(OH)_6FBr$

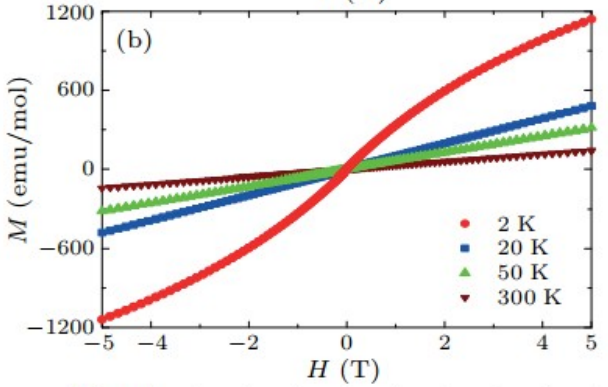


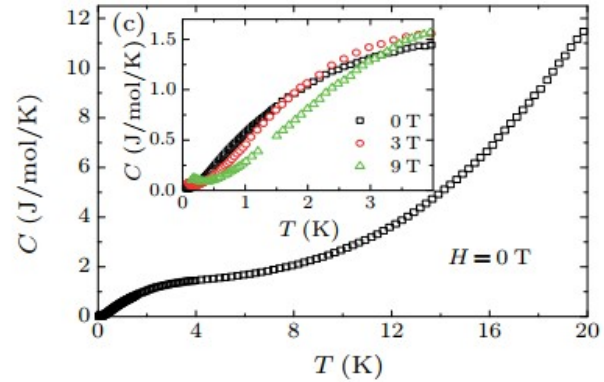




$Cu_3Zn(OH)_6FBr$







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Content

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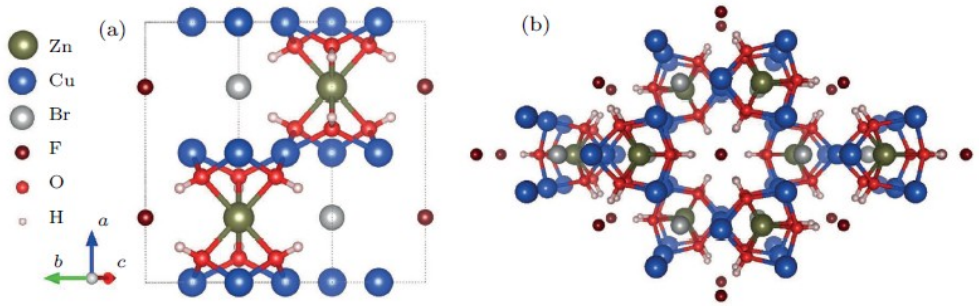

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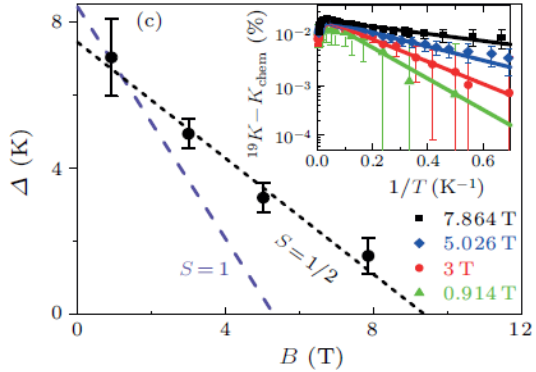


- Identify a gap in $Cu_3Zn(OH)_6FBr$: Neutron

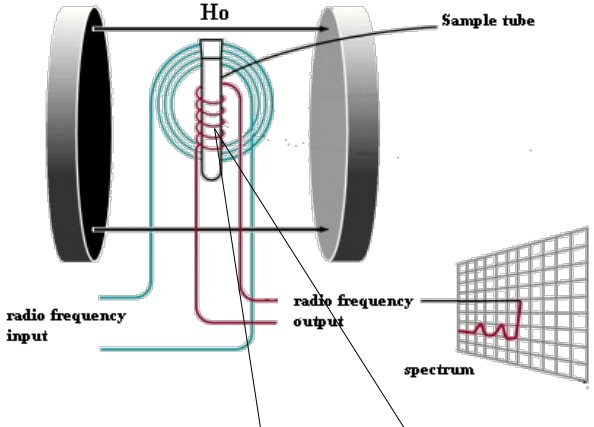
  - Yuan Wei, Zili Feng et al., in preparation

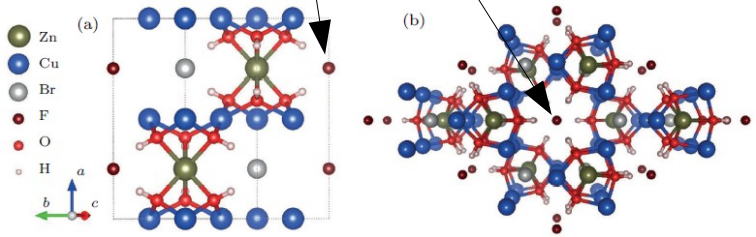
Probe the gap in $Cu_3Zn(OH)_6FBr$ from ^{19}F NMR

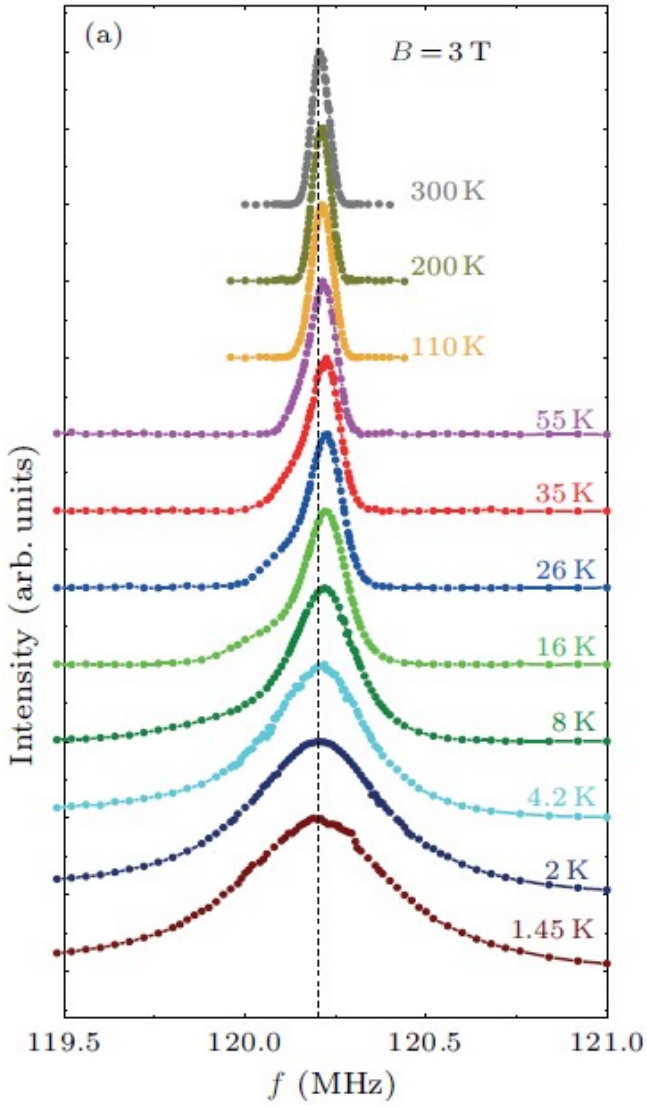
Zheng Li

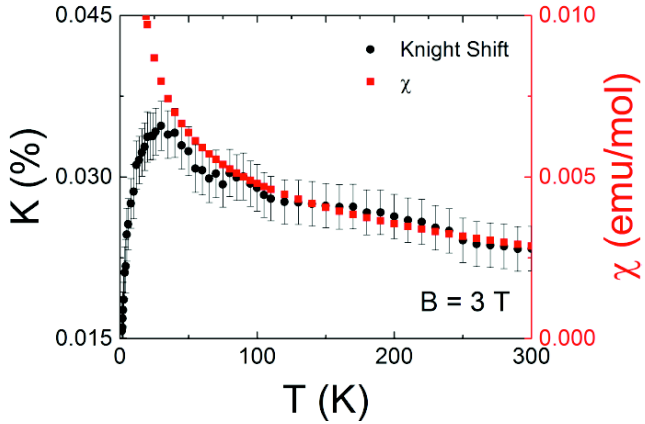
Guo-qing Zheng

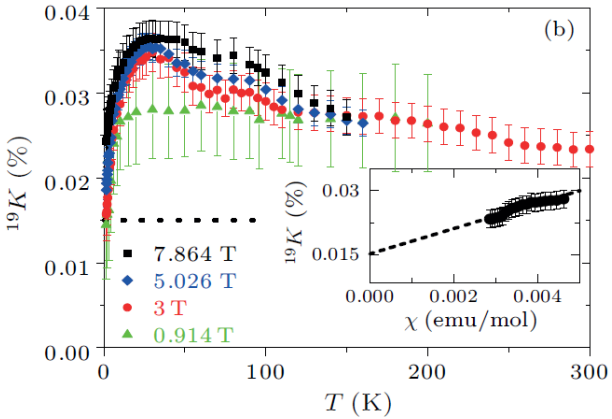
Fluorine-19 NMR (I=1/2)







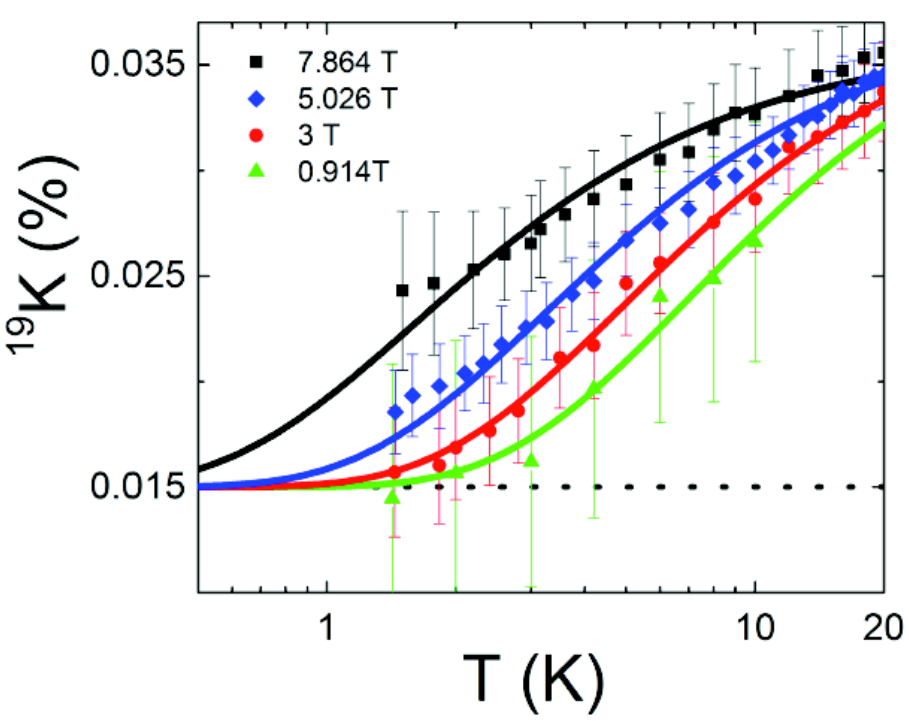




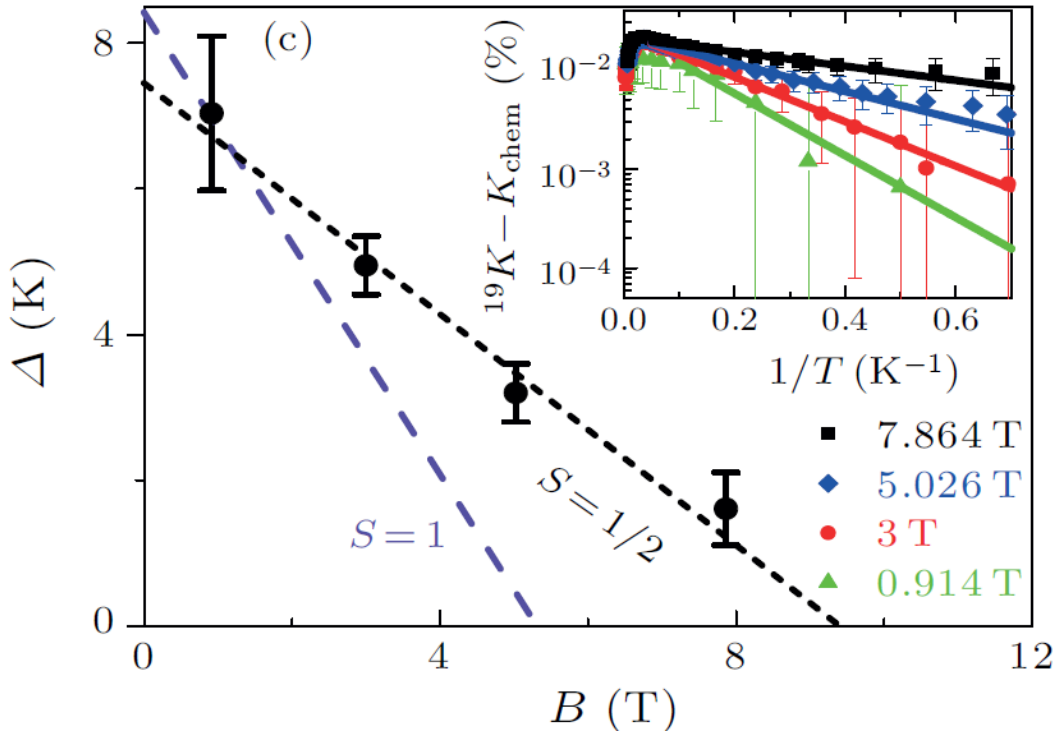
➢ Zili Feng et al., Chin. Phys. Lett. 34, 077502 (2017)

Probe the gap in $Cu_3Zn(OH)_6FBr$ from ^{19}F NMR

$K_{chem} + A \exp(-\Delta/T)$



$$\Delta(B) = \Delta(0) - g\mu_B SB$$



Gapped spinon with S=1/2

$$\Delta \sim 0.65 \text{ meV}$$

- Zili Feng et al., Chin. Phys. Lett. 34, 077502 (2017)
- "Discovery of Fractionalized Neutral Spin-1/2 Excitation of Topological Order", Xiao-Gang Wen, Chin. Phys. Lett. 34, 090101 (2017)

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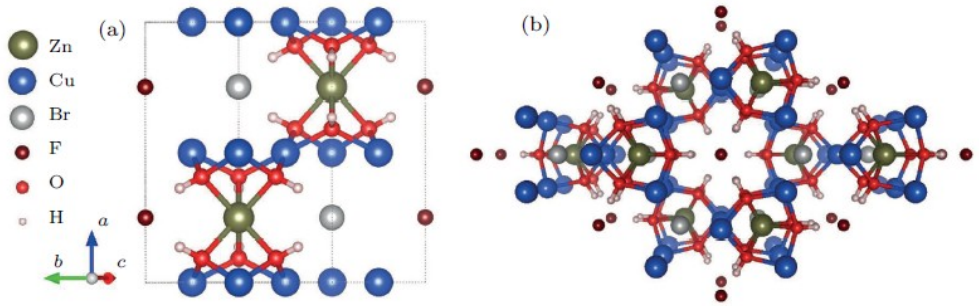

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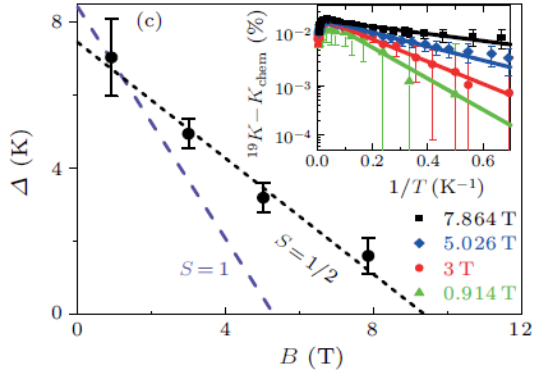

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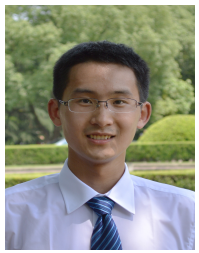
Inelastic Neutron scattering



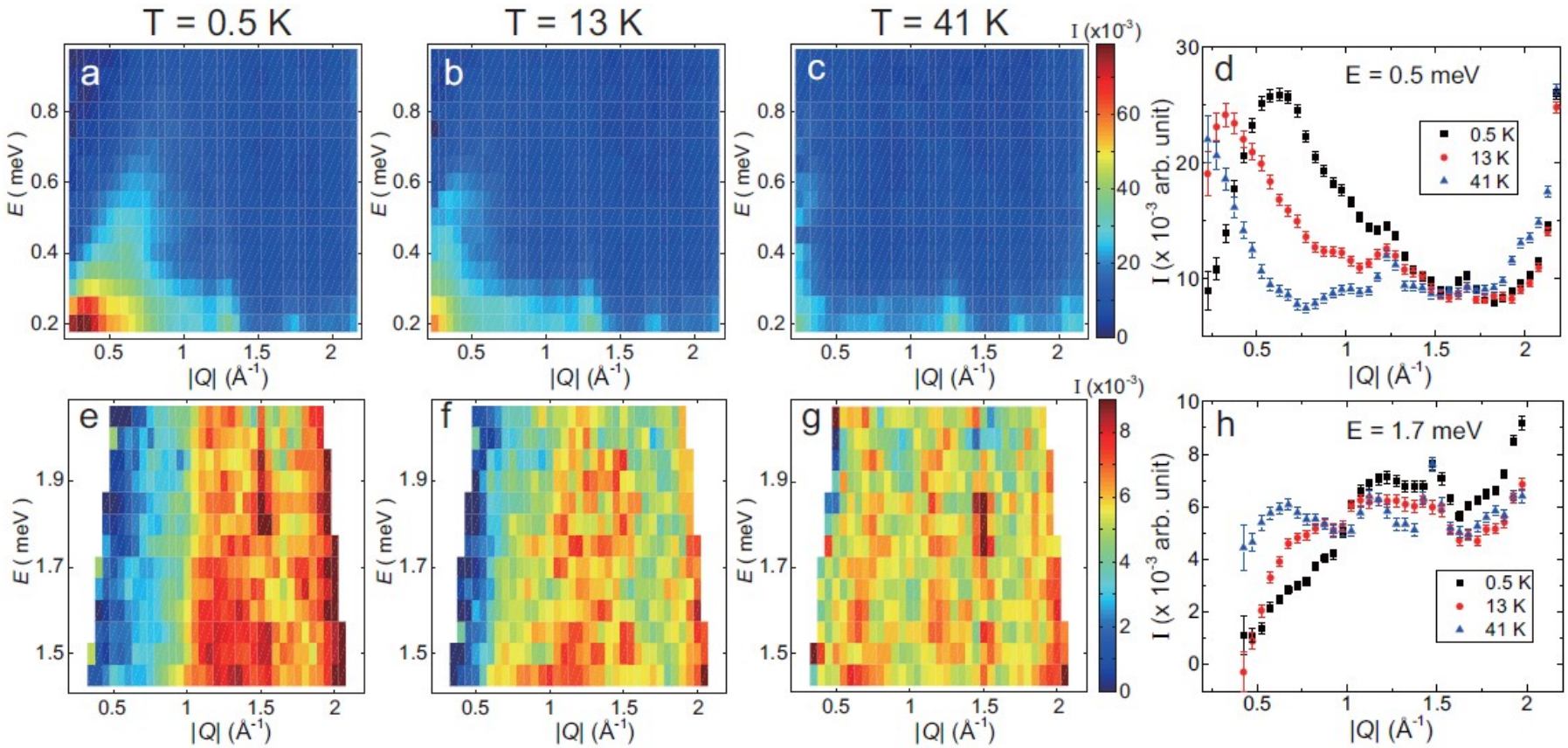
Yuan Wei

Shiliang Li

Wiebke Lohstroh
TOFTOF, FRM II

Anatoliy Senyshyn
SPODI, FRM II

Clarina dela Cruz
HB-2A, HFIR, Oak Ridge



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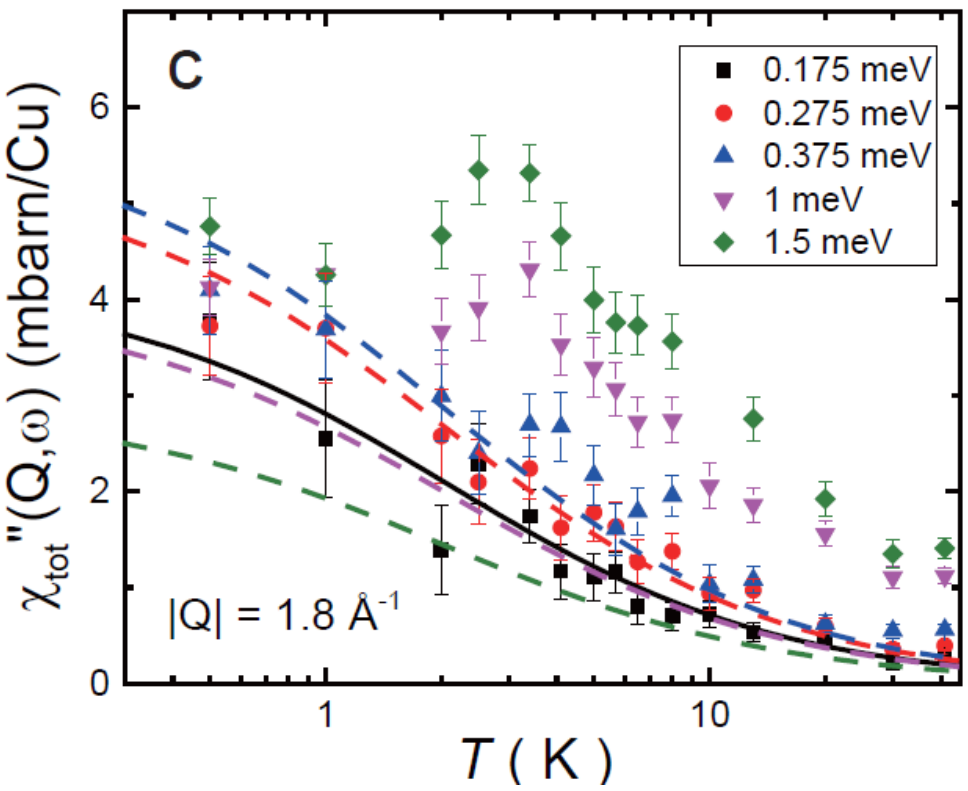
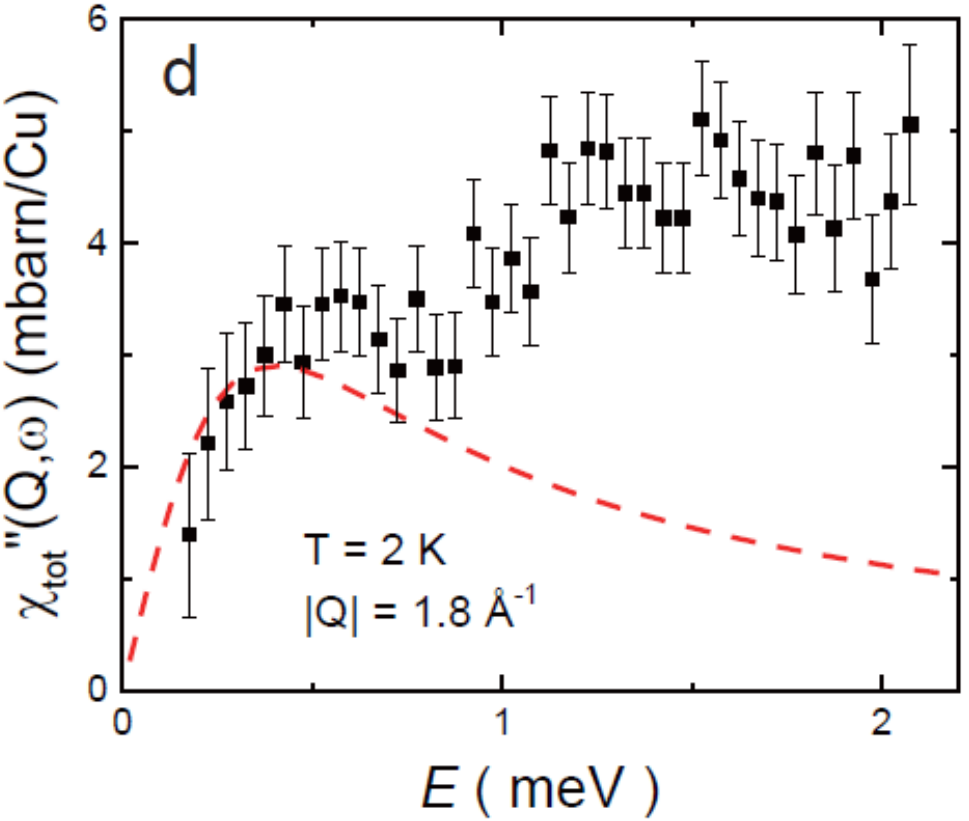




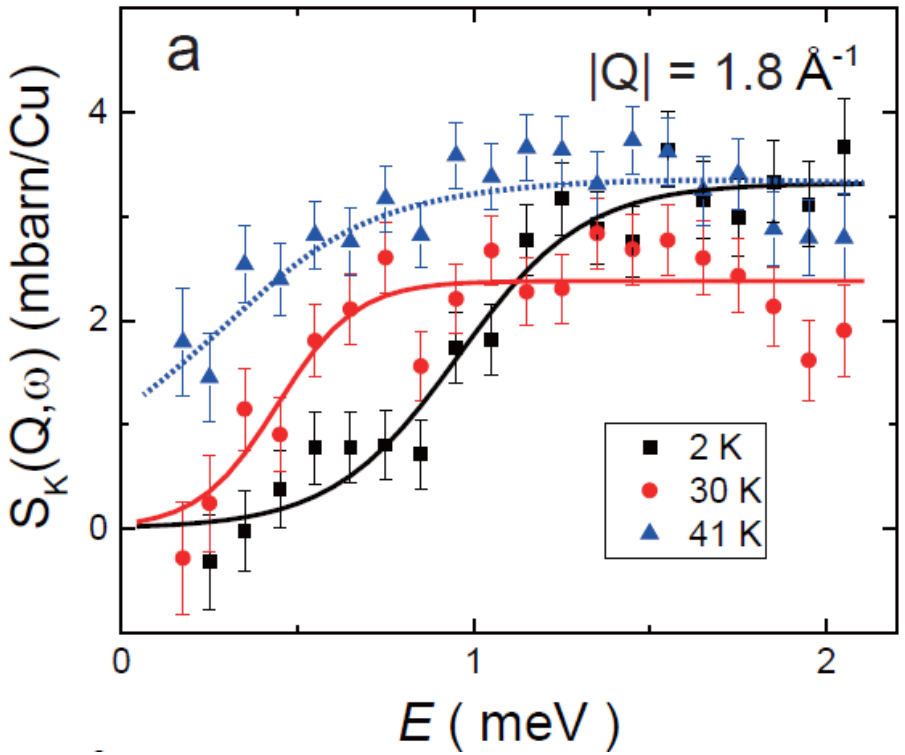
$$\chi''_{imp}(Q,\omega) = \frac{2(\gamma r_0)^2}{\pi \mu_0 \mu_B^2} |f(Q)|^2 \chi_{st}(T) \frac{\hbar\omega W}{(\hbar\omega)^2 + W^2}$$

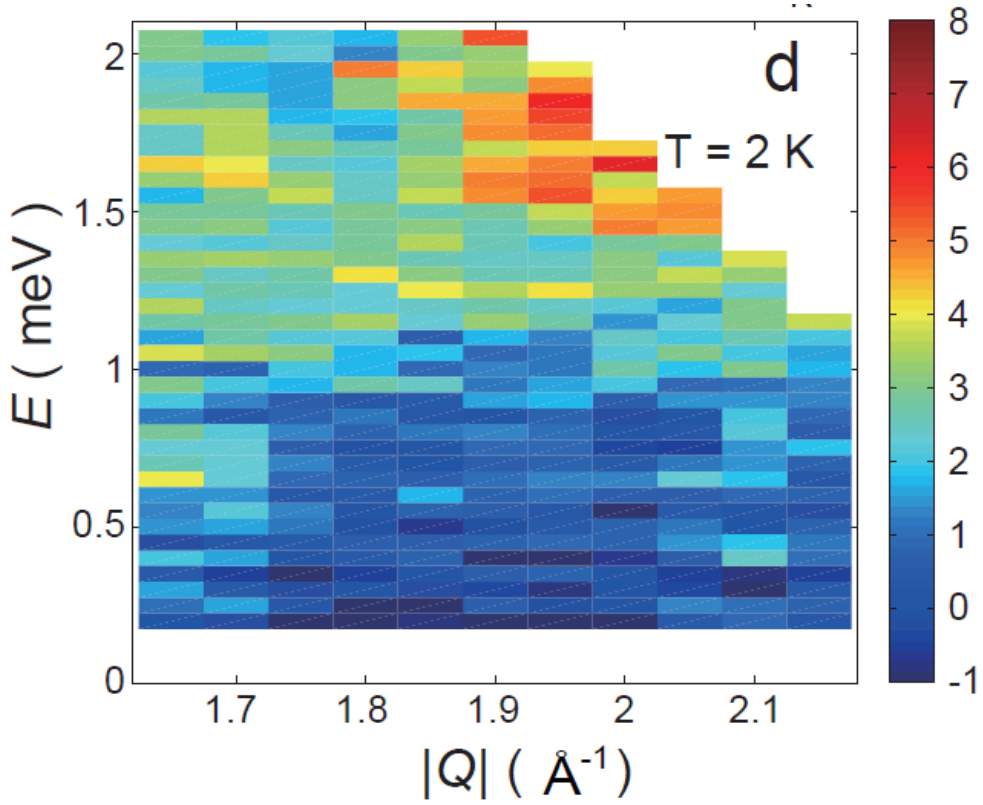
$W = 0.4$ meV only fitting parameter

Inelastic Neutron scattering

$$\chi''(Q,\omega)_{\mathrm{K}} = \chi''(Q,\omega)_{\mathrm{tot}} - \chi''(Q,\omega)_{\mathrm{imp}}$$

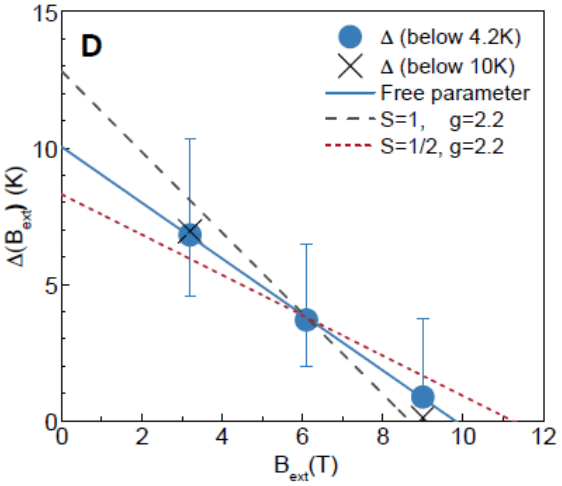
$$S(Q,\omega)_{\mathrm{K}} = \chi''(Q,\omega)_{\mathrm{K}}/(1-e^{-\hbar\omega/k_{\mathrm{B}}T}) \sim 1+\tanh(\frac{\omega-\Delta}{\Gamma})$$



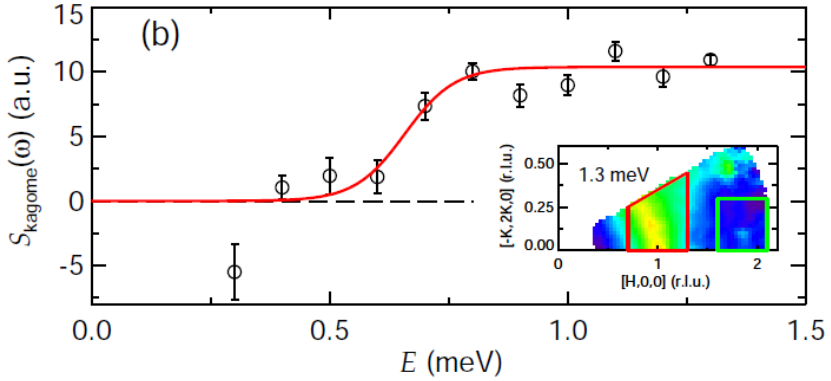


Comparison

$ZnCu_3(OH)_6Cl_2$

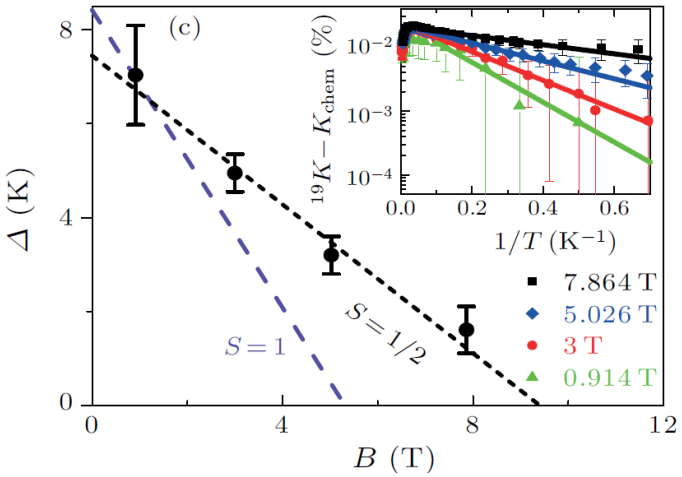


$\Delta \sim 0.9$ meV

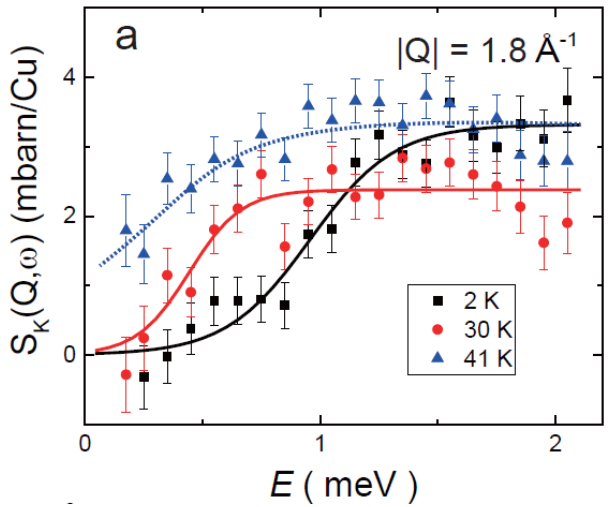


$\Delta \sim 0.7$ meV

$Cu_3Zn(OH)_6FBr$



$\Delta \sim 0.65$ meV



$\Delta = 1.132 \pm 0.13$meV