

Magnetism in Azurite
Studied by Muon Spin Rotation
(a status report)

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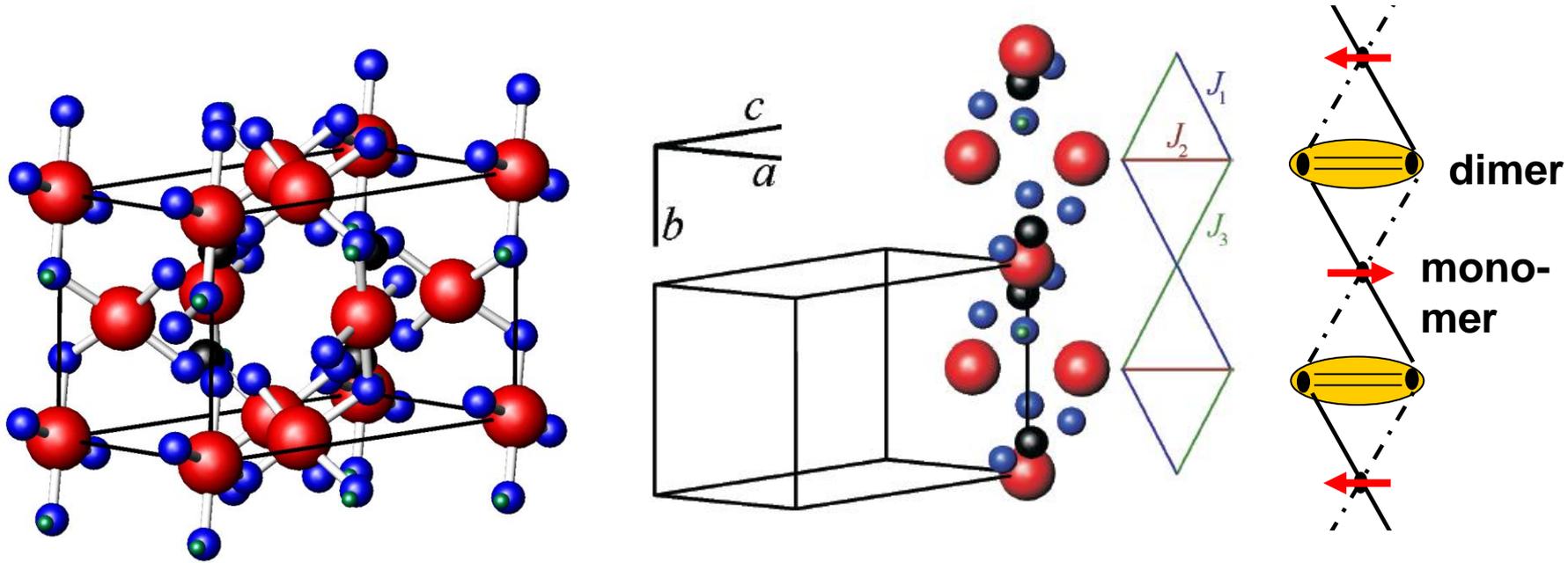
use as pigment
(typical during
Renaissance)



Albrecht Altdorfer ca. 1513
Emperor Maximilian's triumph

Azurite $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$

model for a Heisenberg $S=1/2$ chain



Belokoneva et al., PCM 2001

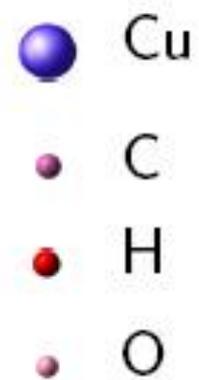
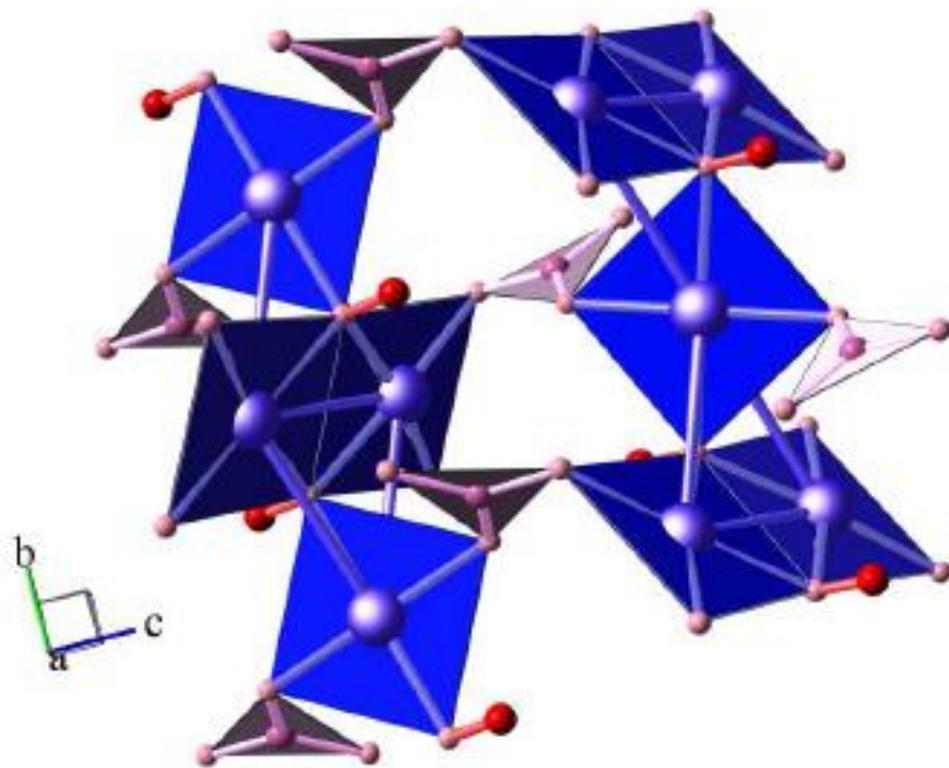
Various coupling scenarios

Frustration?

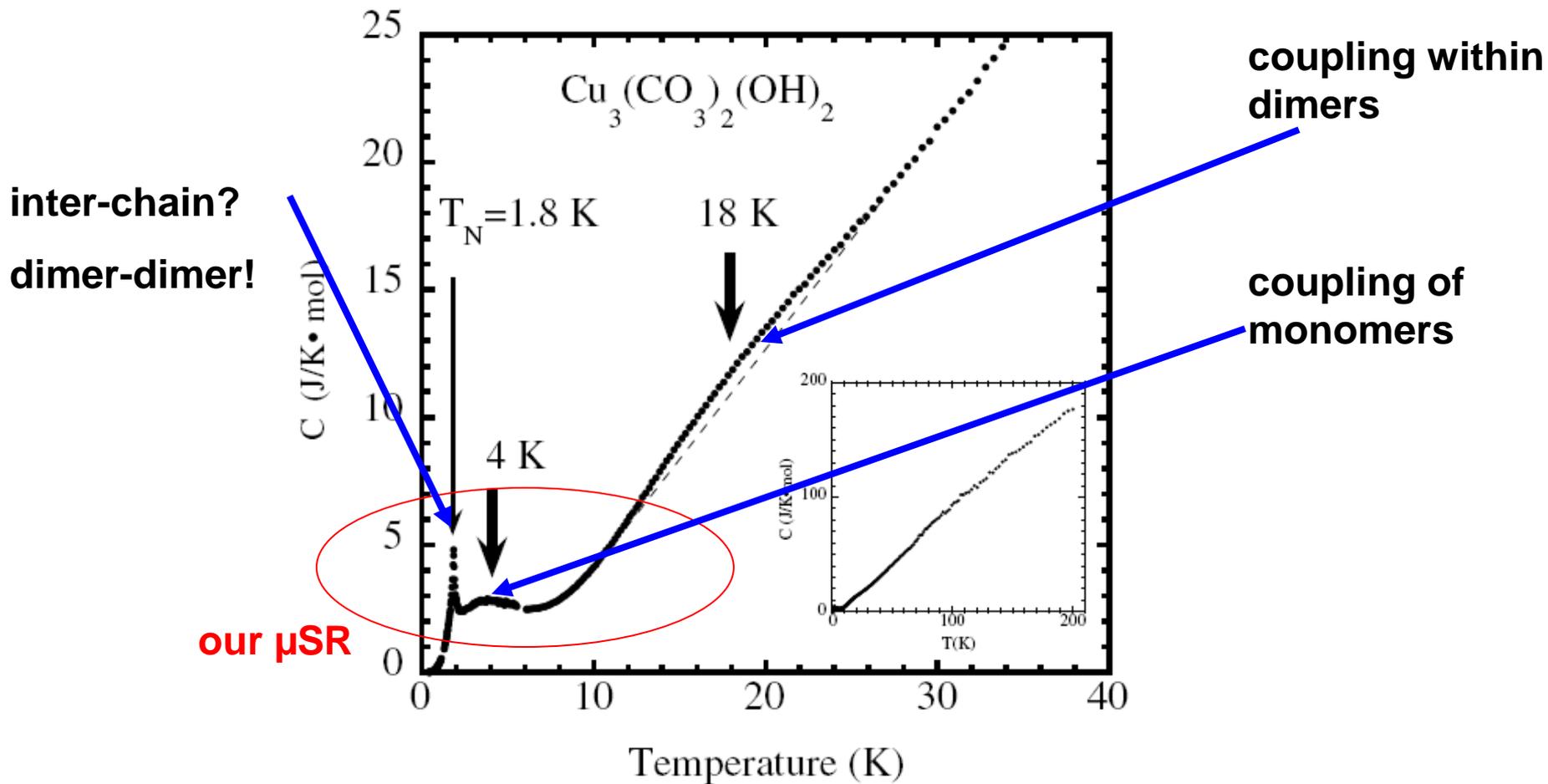
is there magnetic order?

**role of inter-chain
coupling?**

or anisotropy? (DM)



K. Rule et al



Kikuchi et al., PRL 2005

Earlier μ SR data: Kikuchi et al, Prog. Theor. Phys. Suppl. 2005
indications for static order below T_N

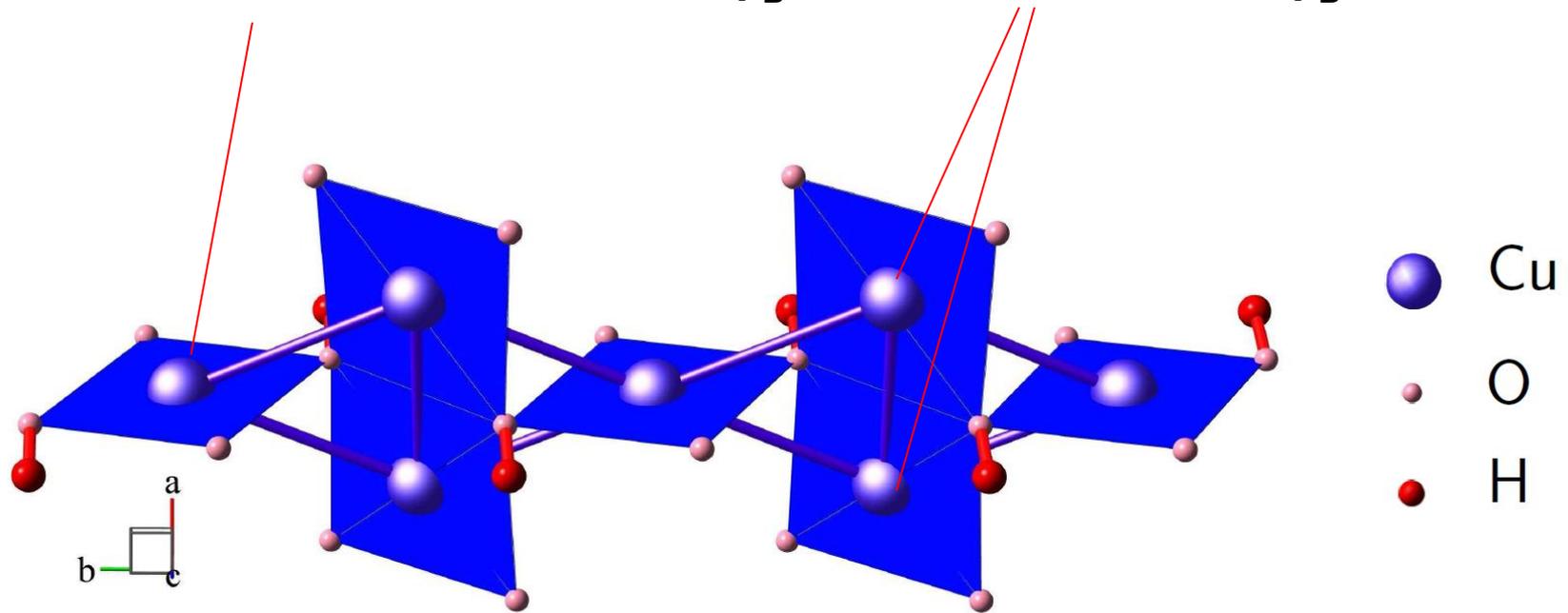
μ^+ SR:

- magnetically ordered fractions
- spontaneous muon spin rotation frequencies in ordered state
- inhomogeneous and homogeneous broadening
- critical slowing-down

Samples: single-crystal and powder (same as used for neutron experiments, C. Gibson et al, PRB 81, 2010)

From recent neutron scattering (C. Gibson et al):

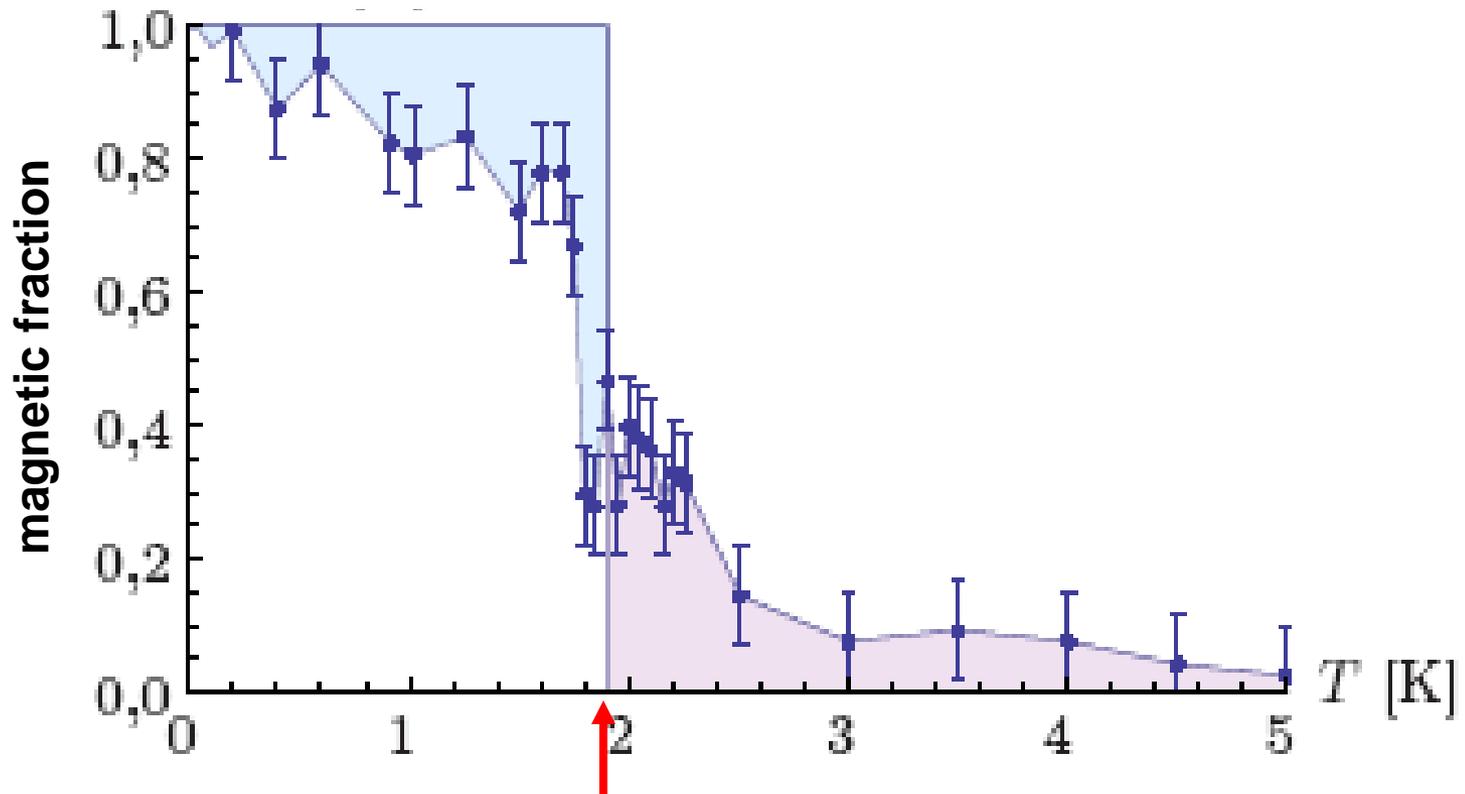
Cu^{2+} monomer moment $\sim 0.68 \mu_B$ Cu^{2+} in dimer $\sim 0.25 \mu_B$



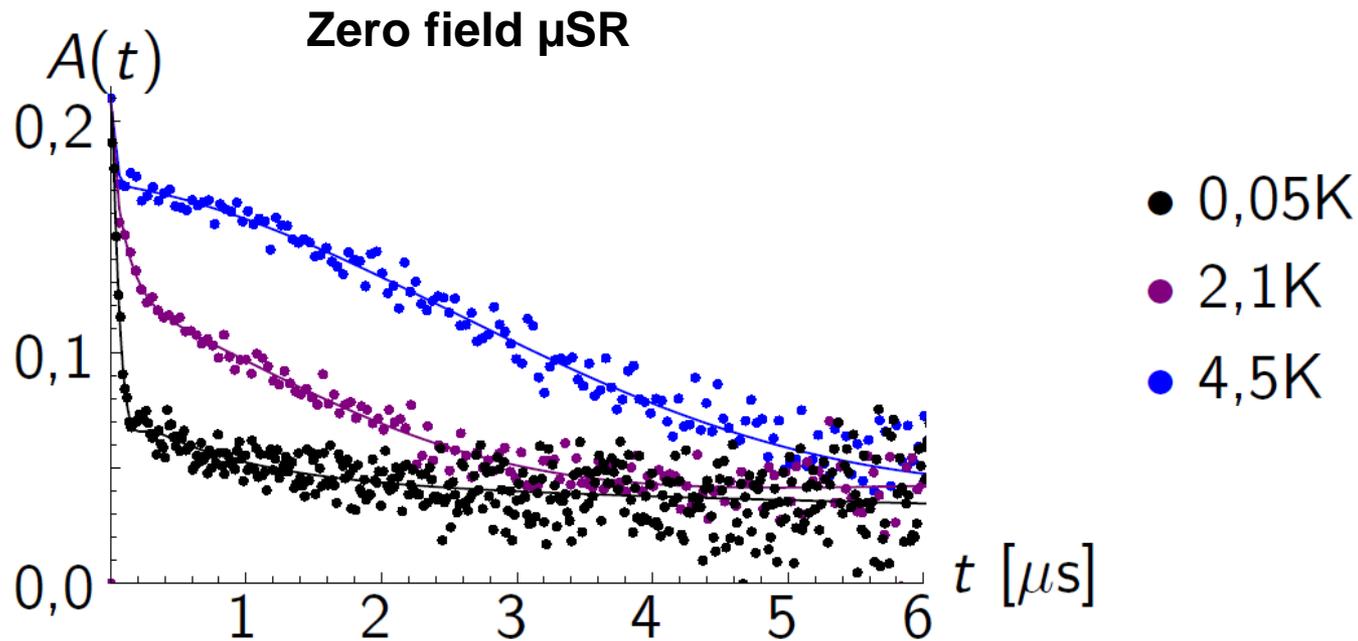
location of μ^+ ?

probably close to O, not yet clarified

from μ SR in transverse magnetic field,
polycrystalline sample



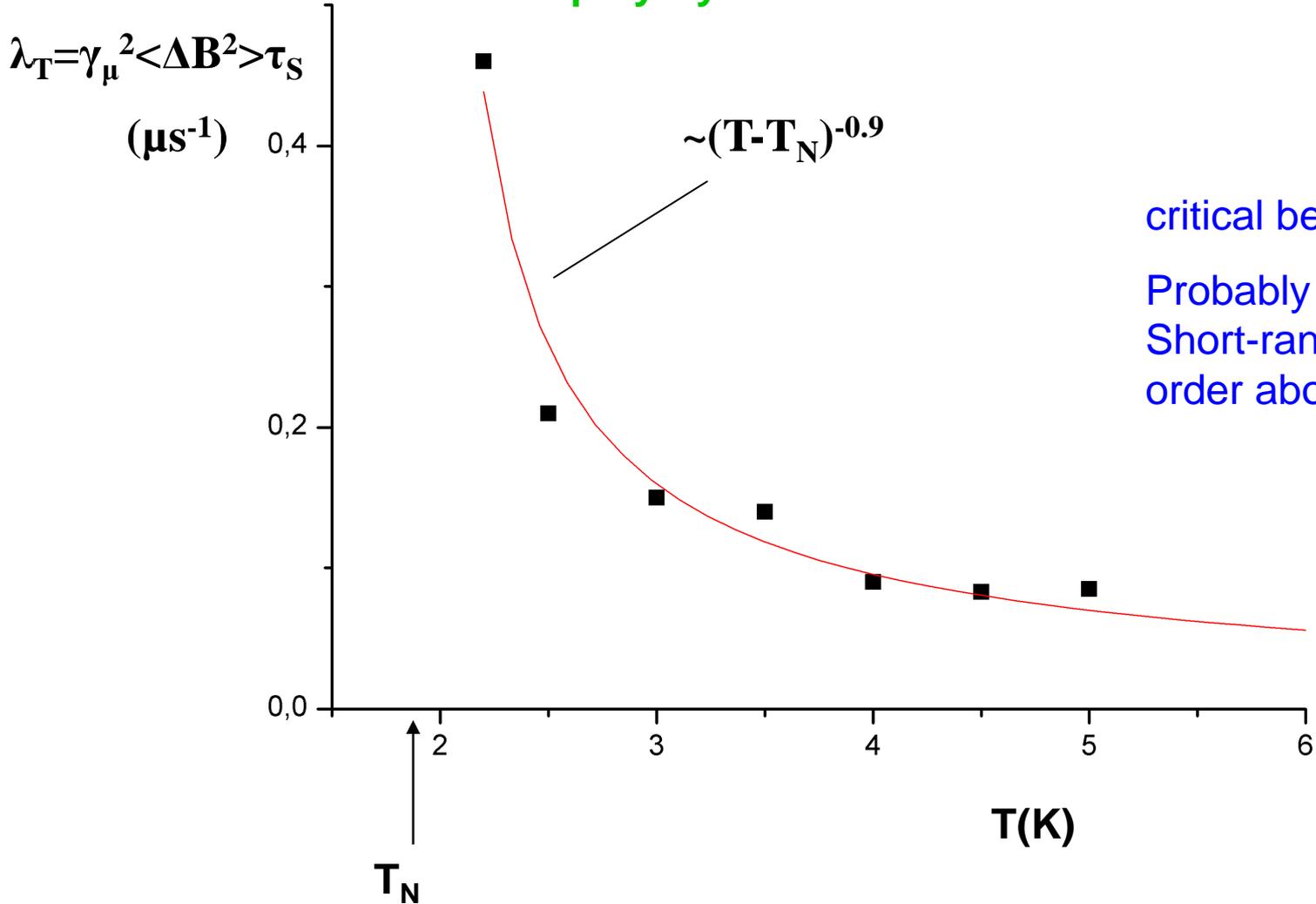
T_N strongly broadened
short range order above T_N



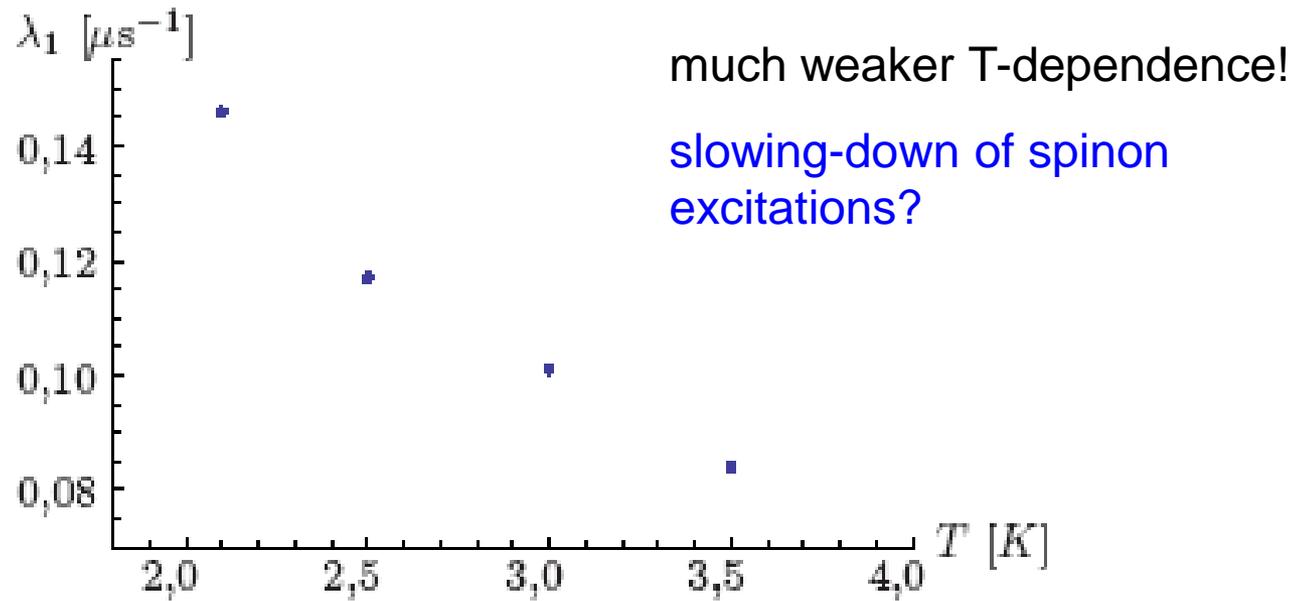
Above about 6 K: mainly Gaussian damping due to static nuclear moments

Below about 6 K: one fast + one slowly damped signal: electronic spin fluctuations

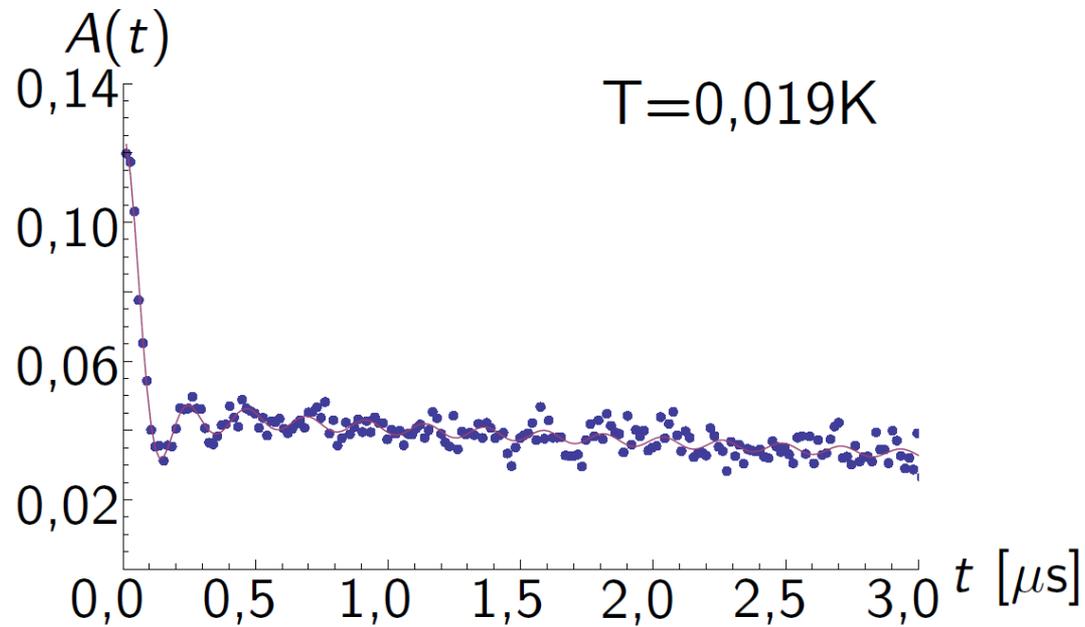
damping of slowly damped
signal above T_N for
polycrystal



critical behavior?
Probably not!
Short-range
order above T_N !

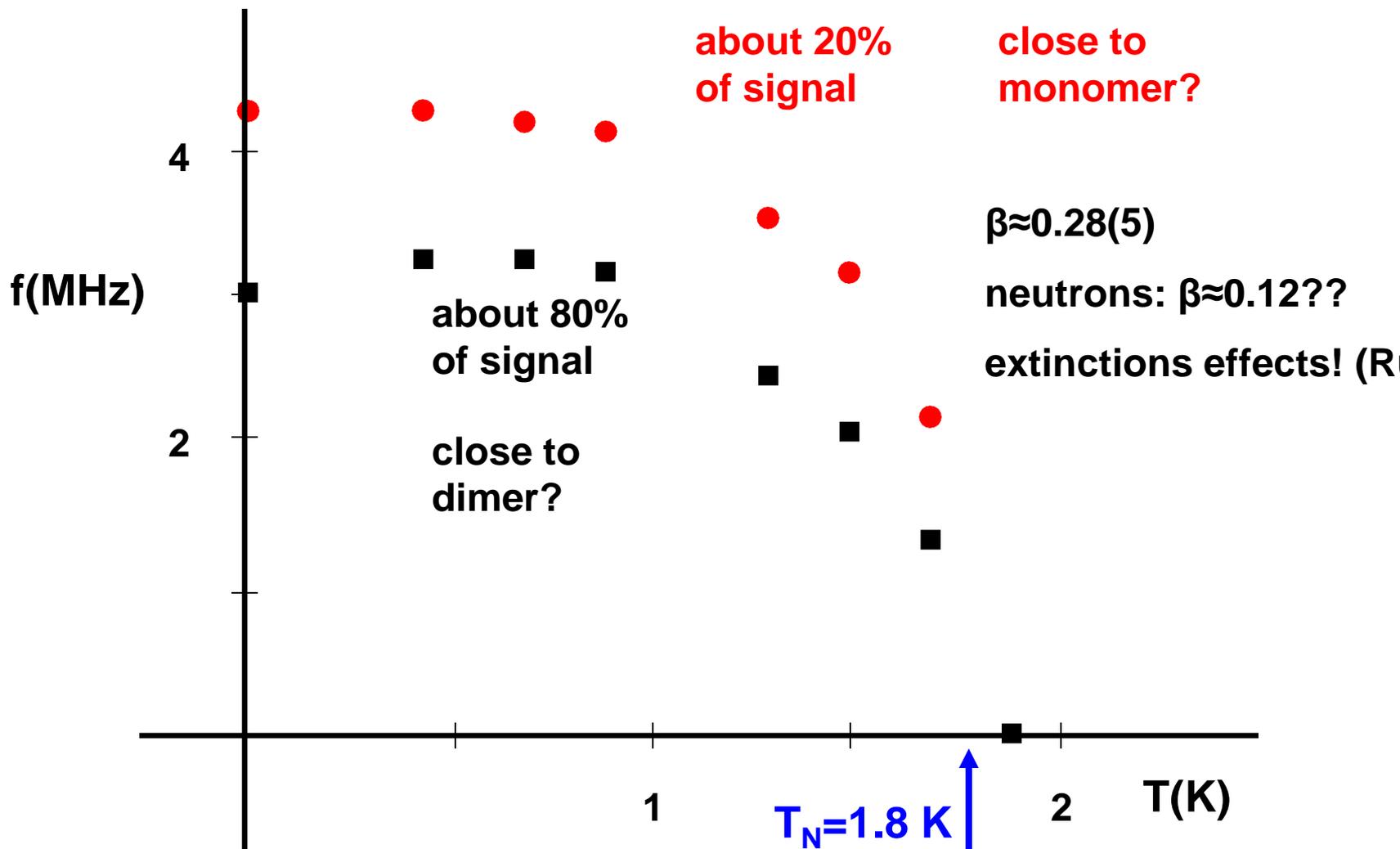


**T dependence of weakly damped signal above T_N
for **single crystal****



**(at least) 2 “spontaneously“ rotating signals
below T_N**

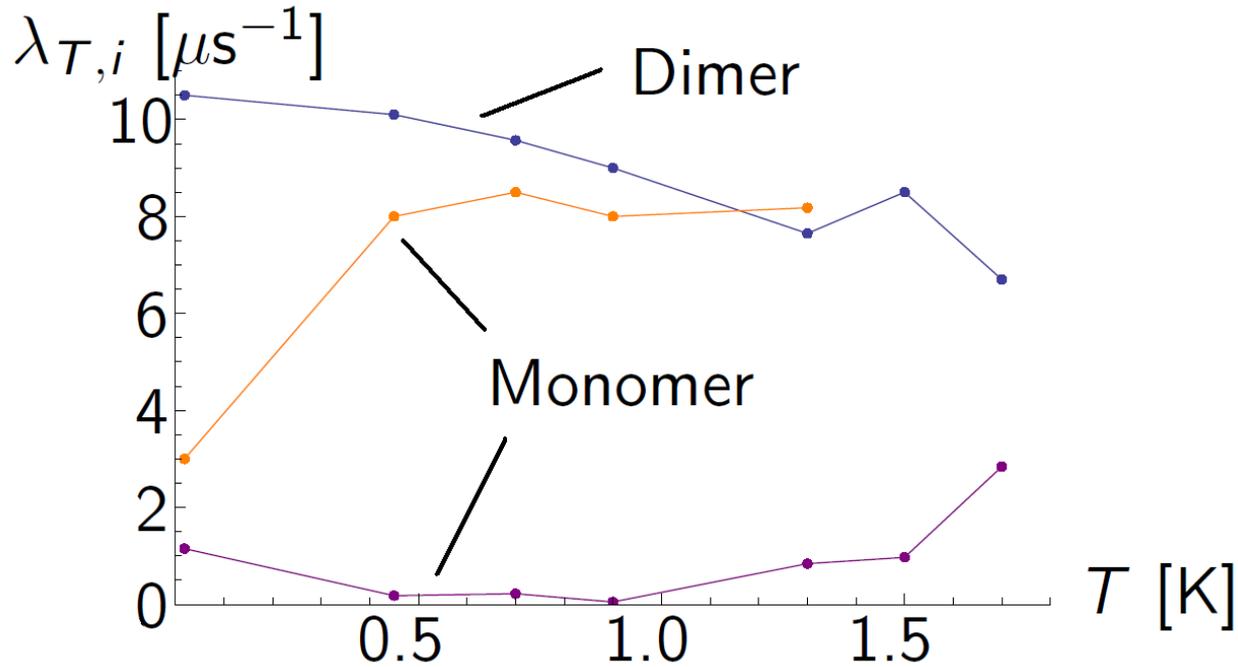
For single crystal, not observed in polycrystal



spontaneous muon
 spin rotation
 frequencies

→ static order!

Transverse damping of μ^+ close to



still another transition, see also neutron (Rule et al) and elastic data (Cong et al 2009)

Summary:

- polycrystal: short range order above $T_N=1.8\text{K}$
- damping above T_N : $\langle \Delta B^2 \rangle \tau_S \sim (T-T_N)^{-0.9}$, critical? Probably not!
- τ_S are on the order of tens to hundreds of ns
(from “LF decoupling experiments“): dynamic sro
- static magnetic order below $T_N \approx 1.9\text{K}$, strongly broadened
- single crystal: well defined $T_N=1.8\text{ K}$
- damping above T_N : much weaker T dependence than for polycrystal, spinons?
- at least 2 spontaneous muon spin rotation frequencies
(different sites), magnetization curve
- despite muon sites are not yet identified: ordered Cu moments can only be on the order of tenths of μ_B (see neutron data)
- indications for a further magnetic change below 0.5K
- reason for 3D order still not clarified

No “simple“ model system!