High-Pressure Technique
and
High-Pressure μSR at the RIKEN-RAL

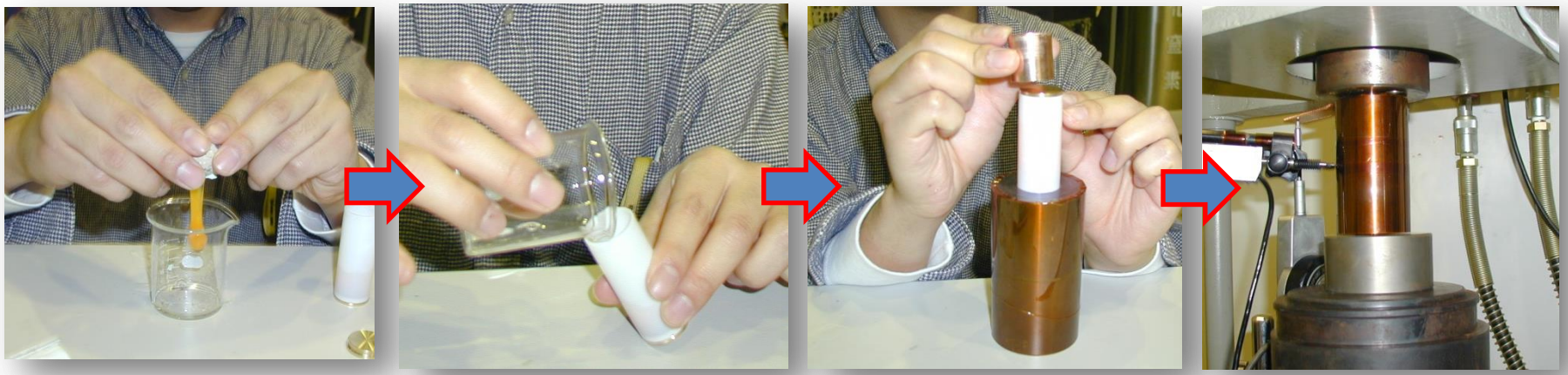
High-Pressure

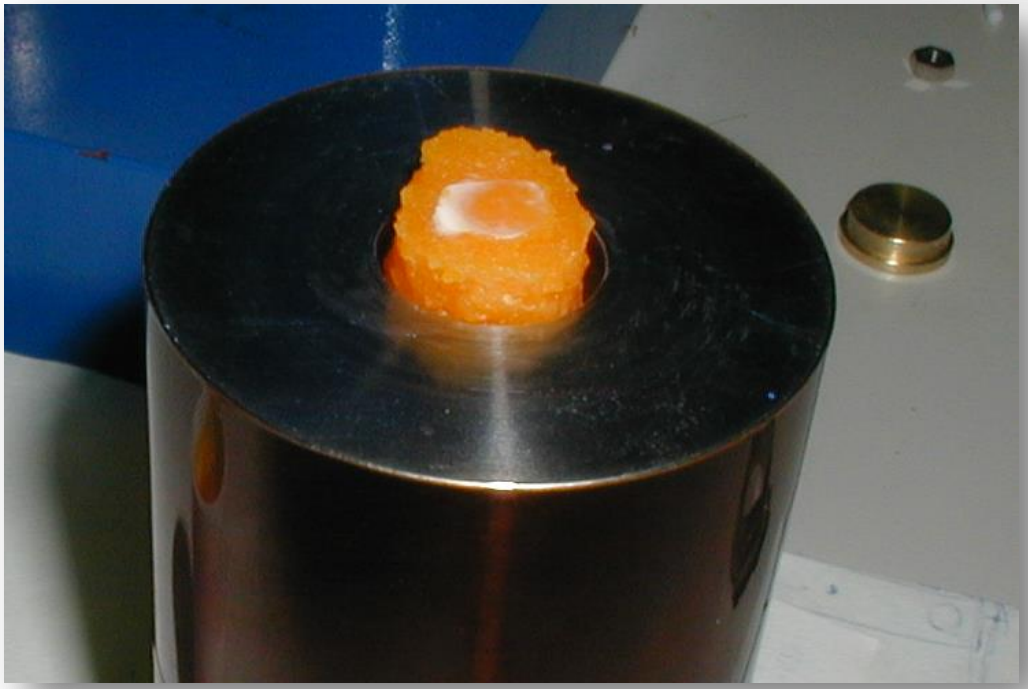
at 1,000 m sea depth

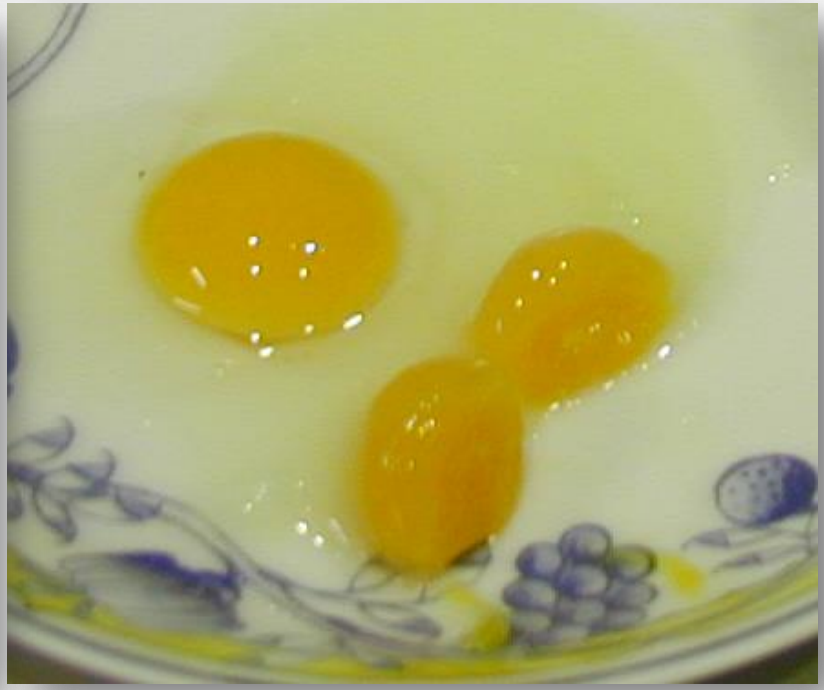
High-Pressure

property of egg protein was changed by heat

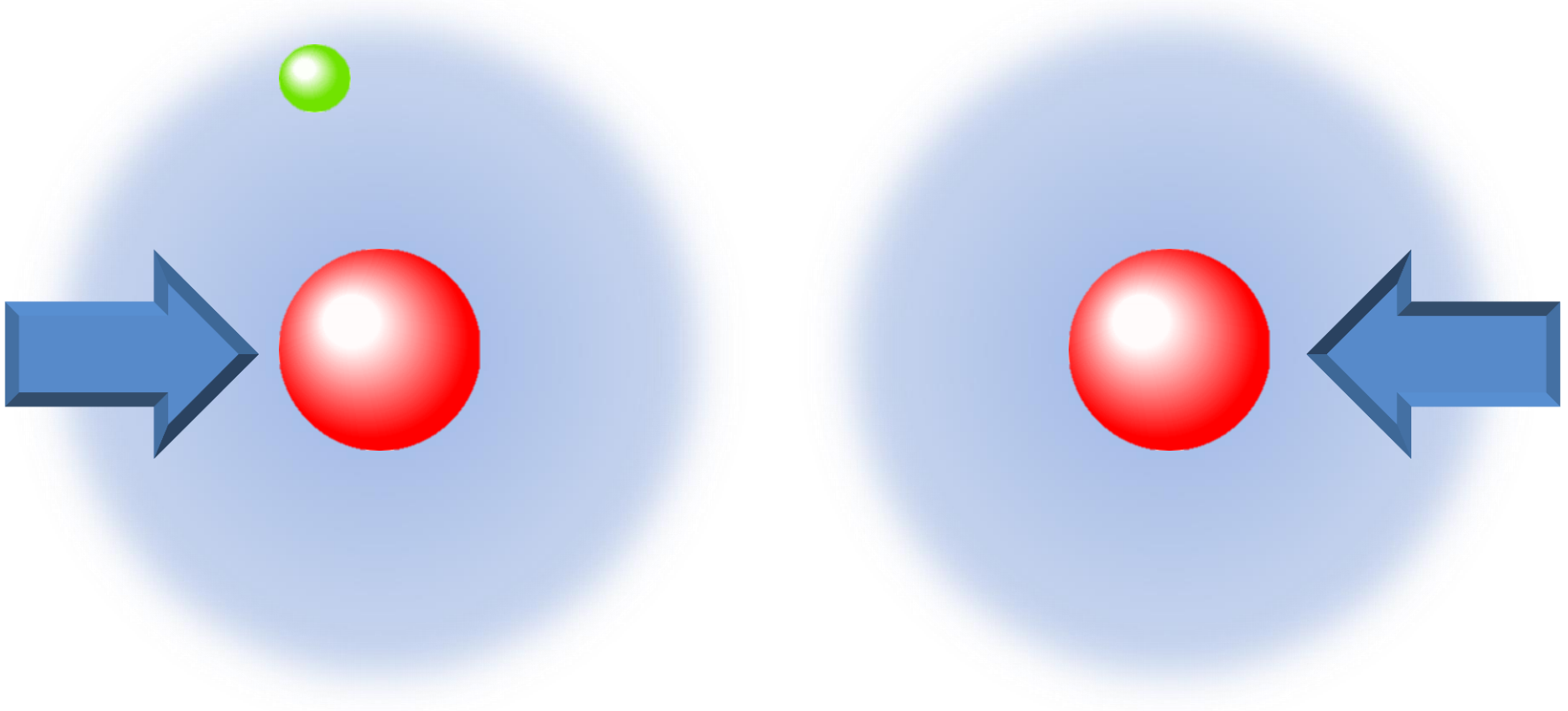
High-Pressure



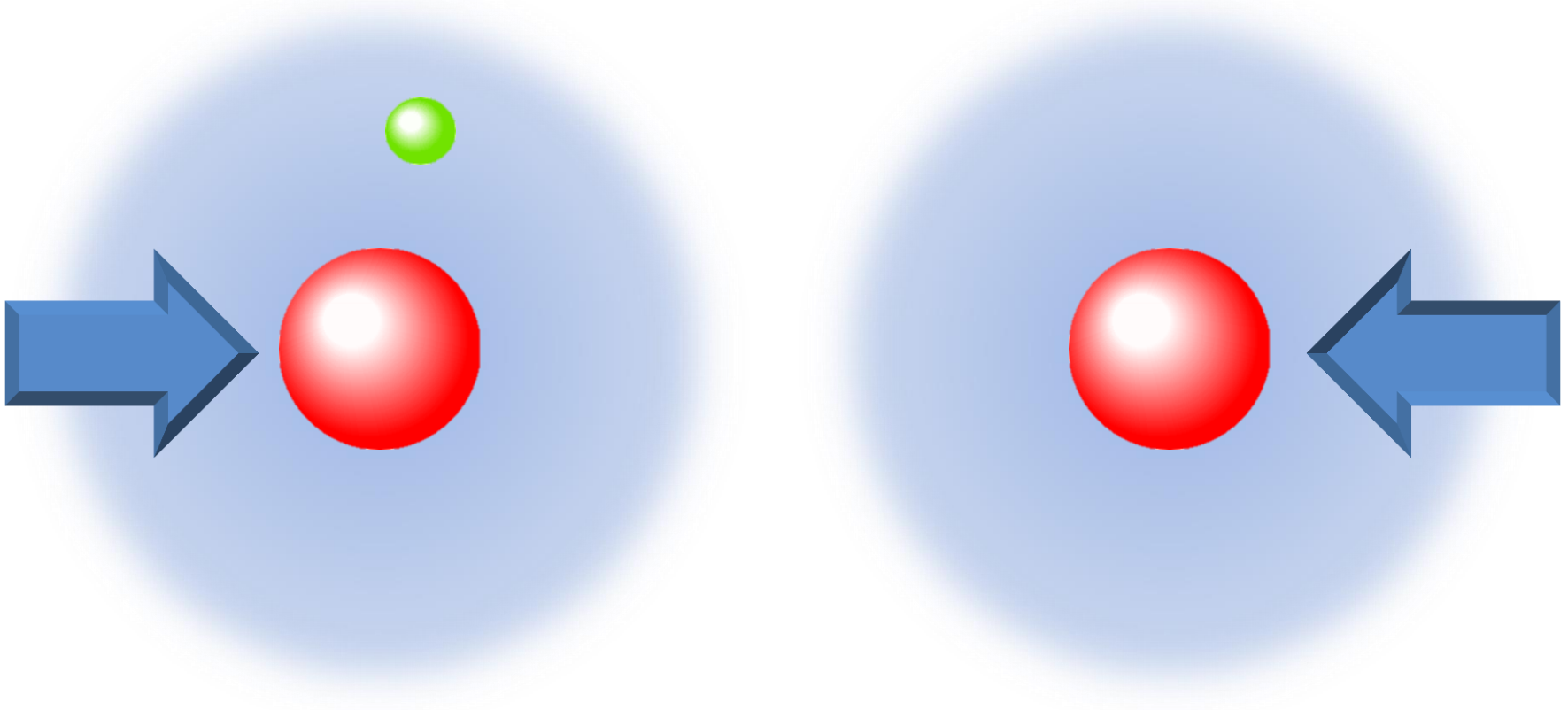




High-Pressure



High-Pressure



High-Pressure

Percy W. Bridgman

- **The Nobel Prize in Physics 1946**
- **"for the invention of an apparatus to produce extremely high pressures, and for the discoveries he made therewith in the field of high pressure physics"**

1905~

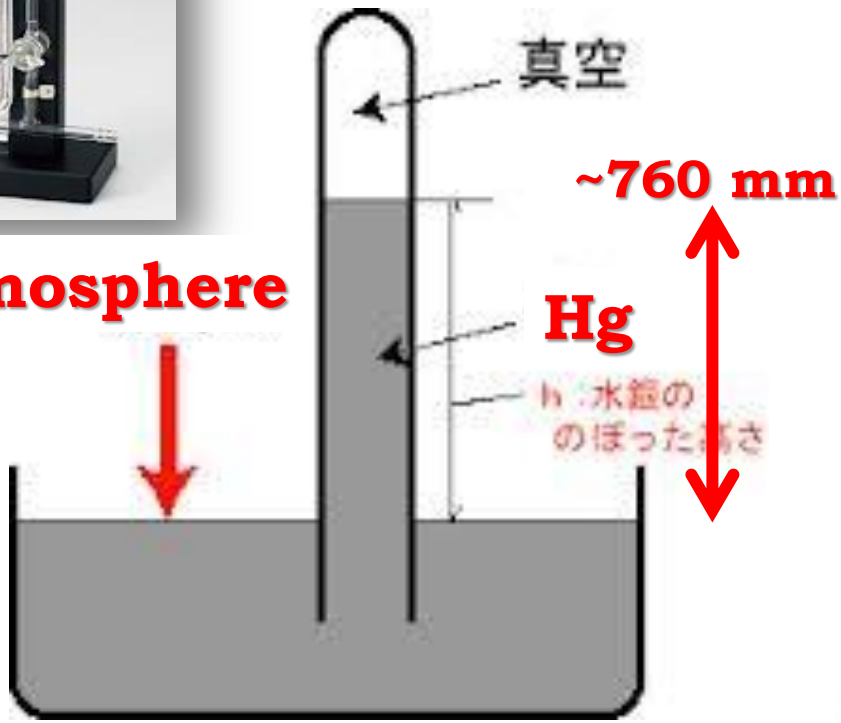
<u>Up to 10 GPa (100,000 atm)</u>

- Compressibility
- Resistivity
- Thermal conductivity
- Elastic properties

More than 100 different materials!!

High-Pressure for μSR

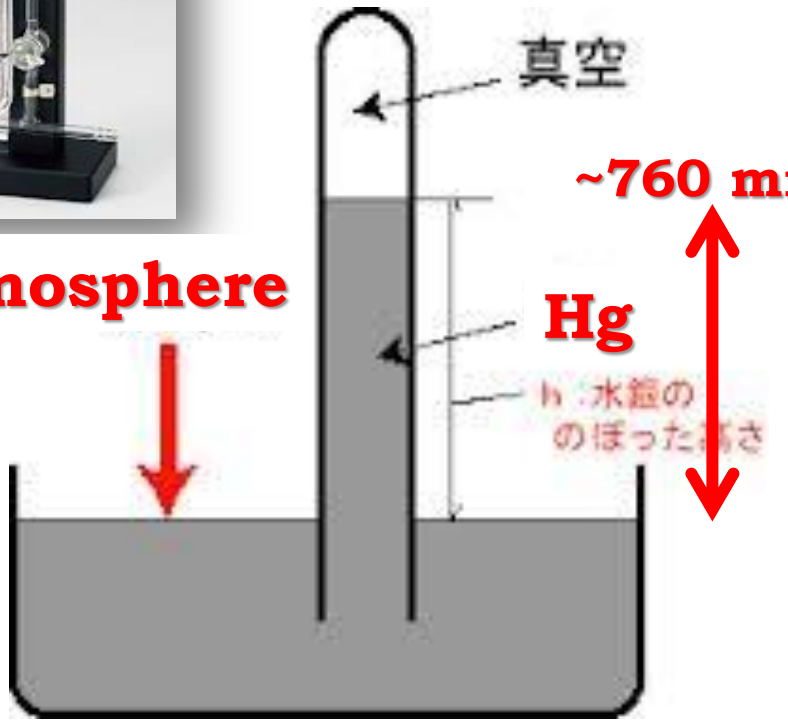
- 1 atm
- 1,013 mbar
- 1,013 HPa



Atmosphere

High-Pressure for μSR

- 1 atm
- 1,013 mbar
- 1,013 HPa



Atmosphere

~2 kg

High-Pressure for μSR

~6.4 kbar

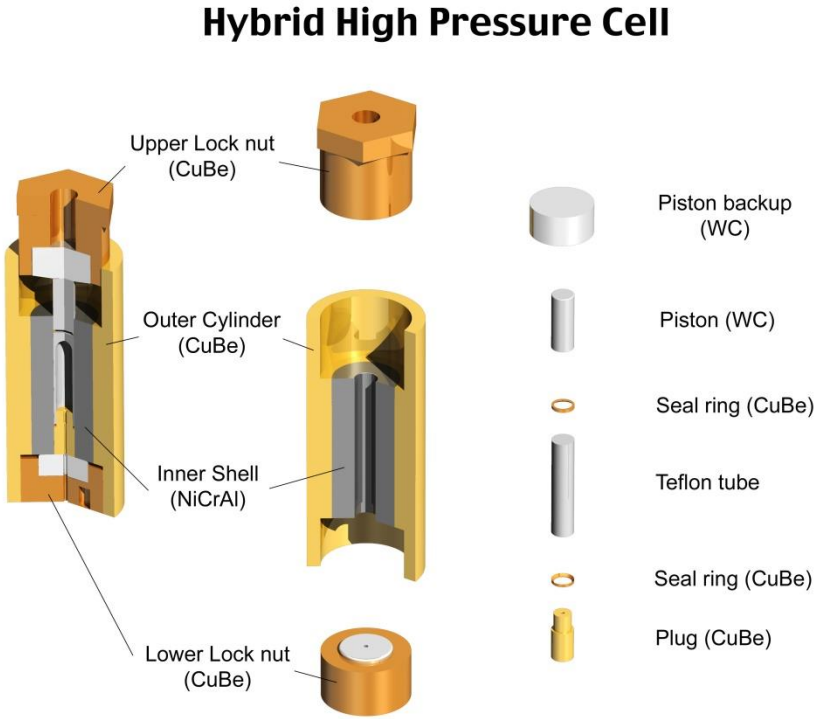
?

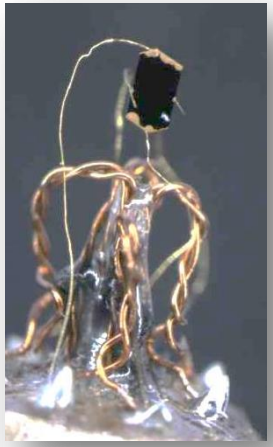
High-Pressure for μSR

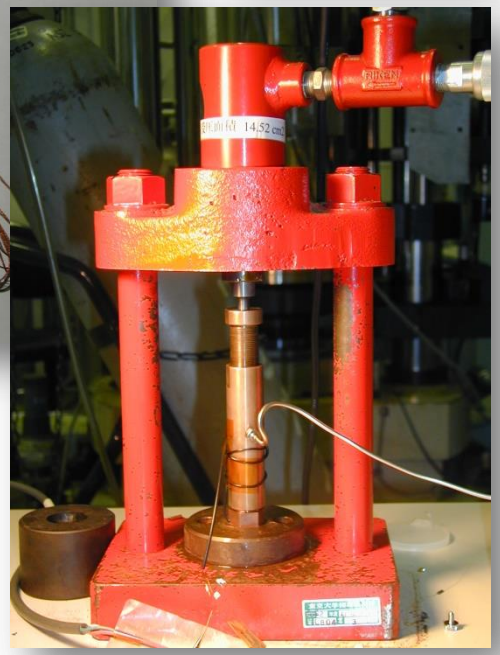
~6.4 kbar

High-Pressure Techniques

Hydrostatic Pressure Cells



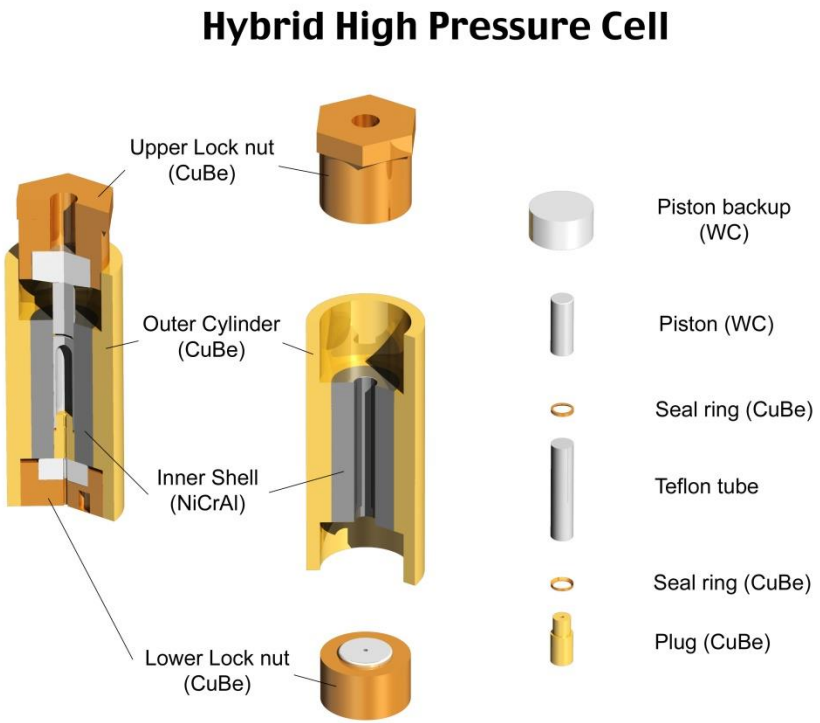




~30 kbar

High-Pressure Techniques

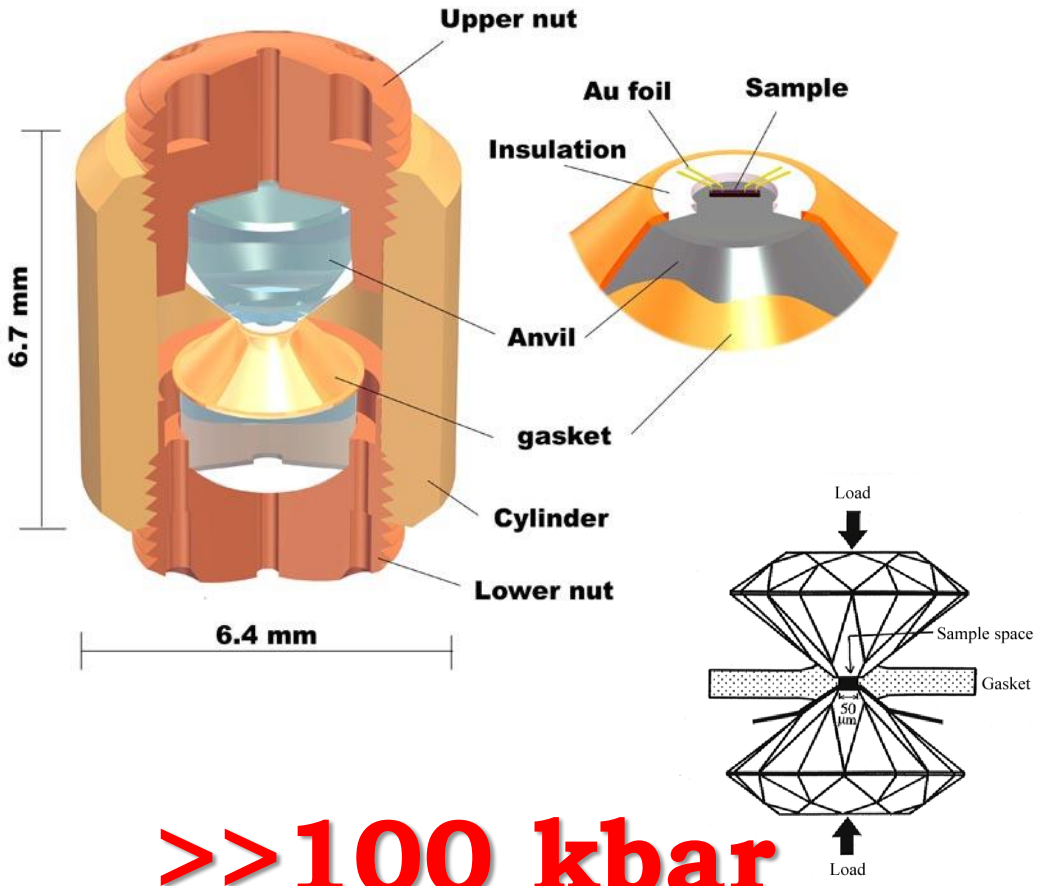
Hydrostatic Pressure Cells



>>30 kbar

High-Pressure Techniques

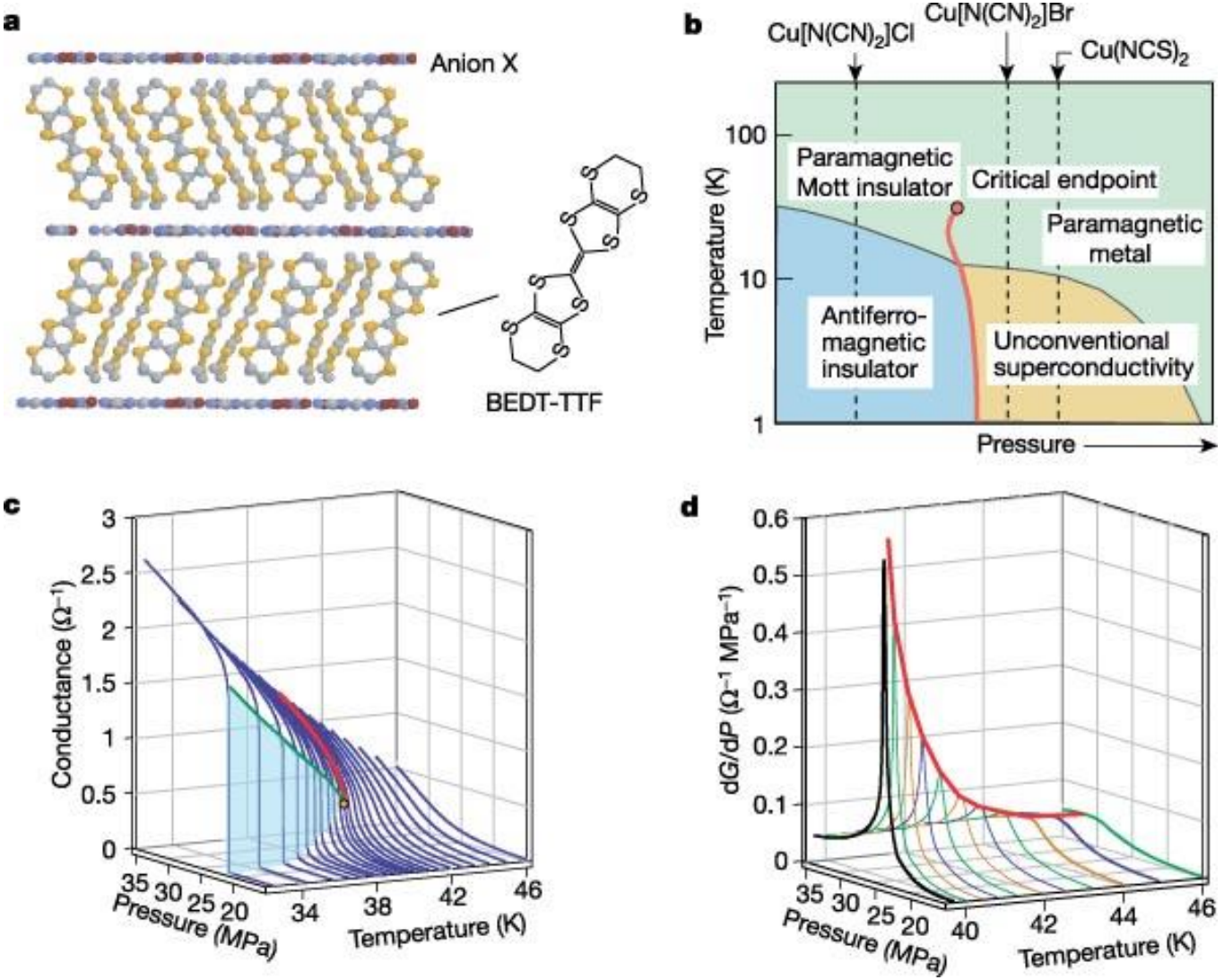
Hydrostatic Pressure Cells



>>100 kbar

High-Pressure Techniques

High-Pressure Techniques



F. Kagawa et al. Nature 436, 534 (2006)

High-Pressure for Pulsed Muon

The RIKEN-RAL Muon Facility

High-Pressure for Pulsed Muon

Restrictions for Pulsed Muons

☆ **Beam Diameter**

- ~ 40 mm
- background signals
- need to be collimated

☆ **Expensive Beam Cost**

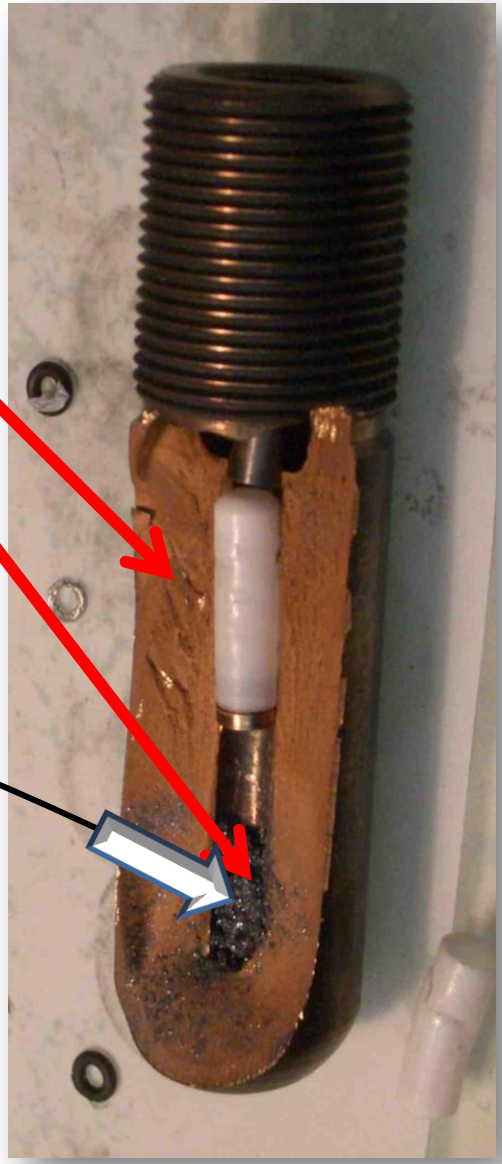
- cannot change samples and pressure so frequently

High-Pressure for Pulsed Muon

Why RIKEN-RAL ??

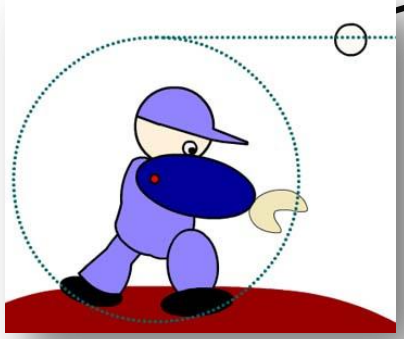
CuBe Wall ~8 mm

Sample Space



MUON

Accelerator

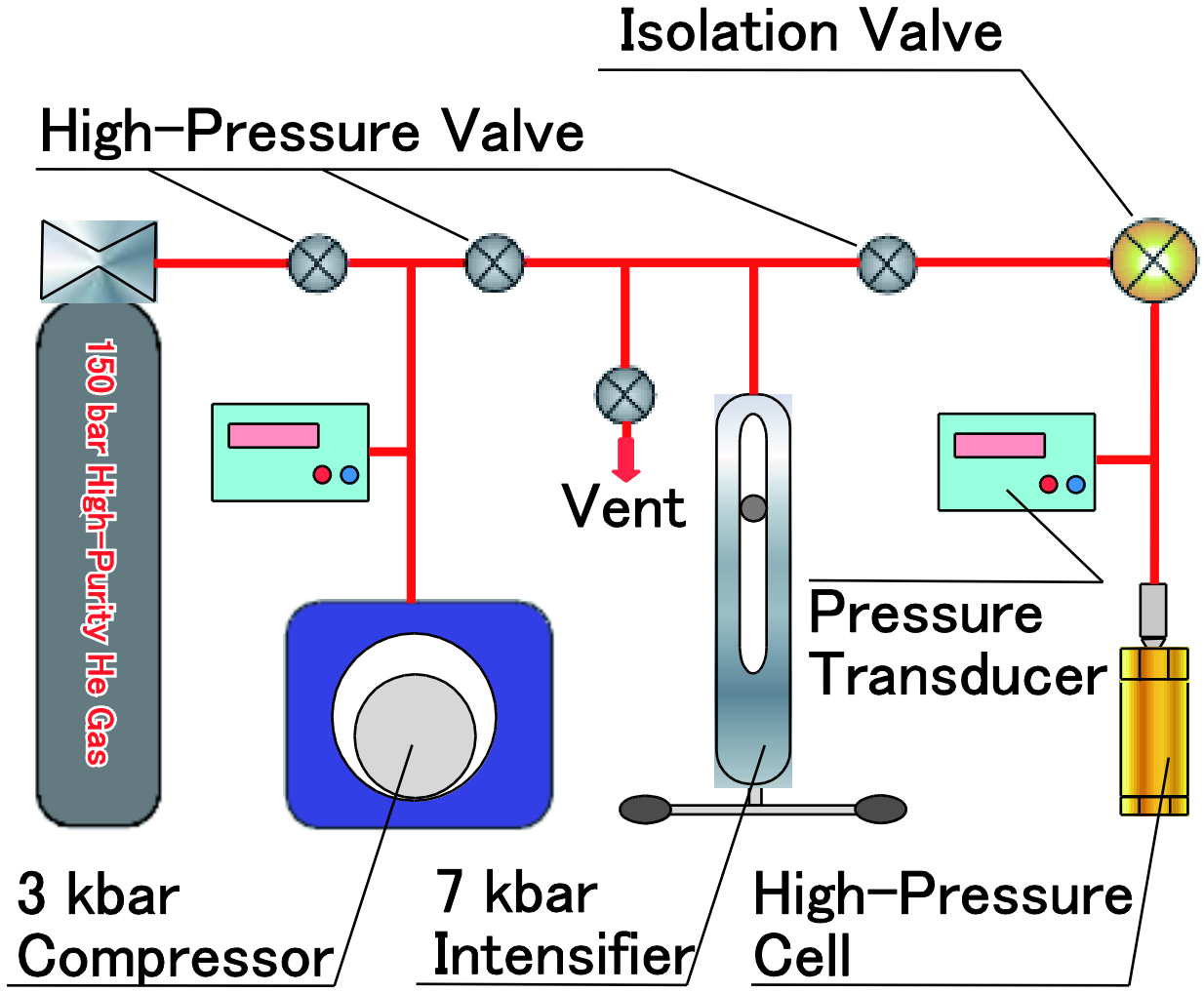


High-Momentum Muons

ISIS : ~ 200 μm depth

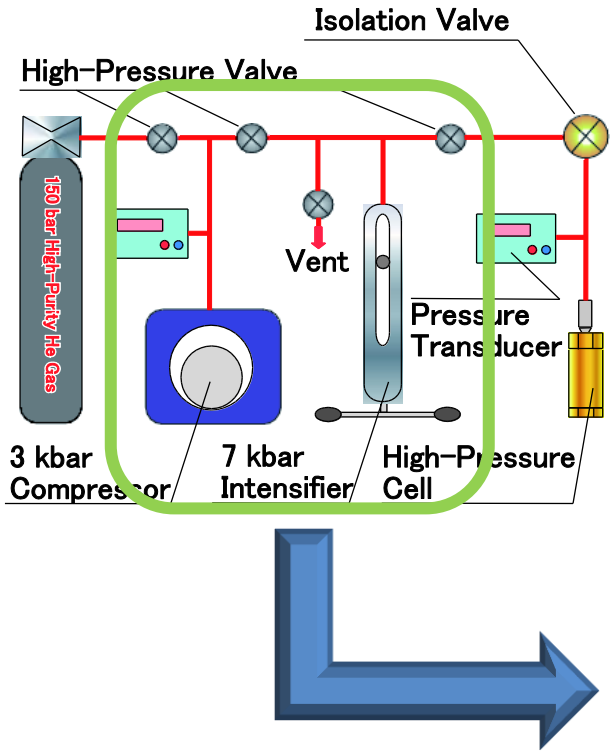
High-Pressure for Pulsed Muon

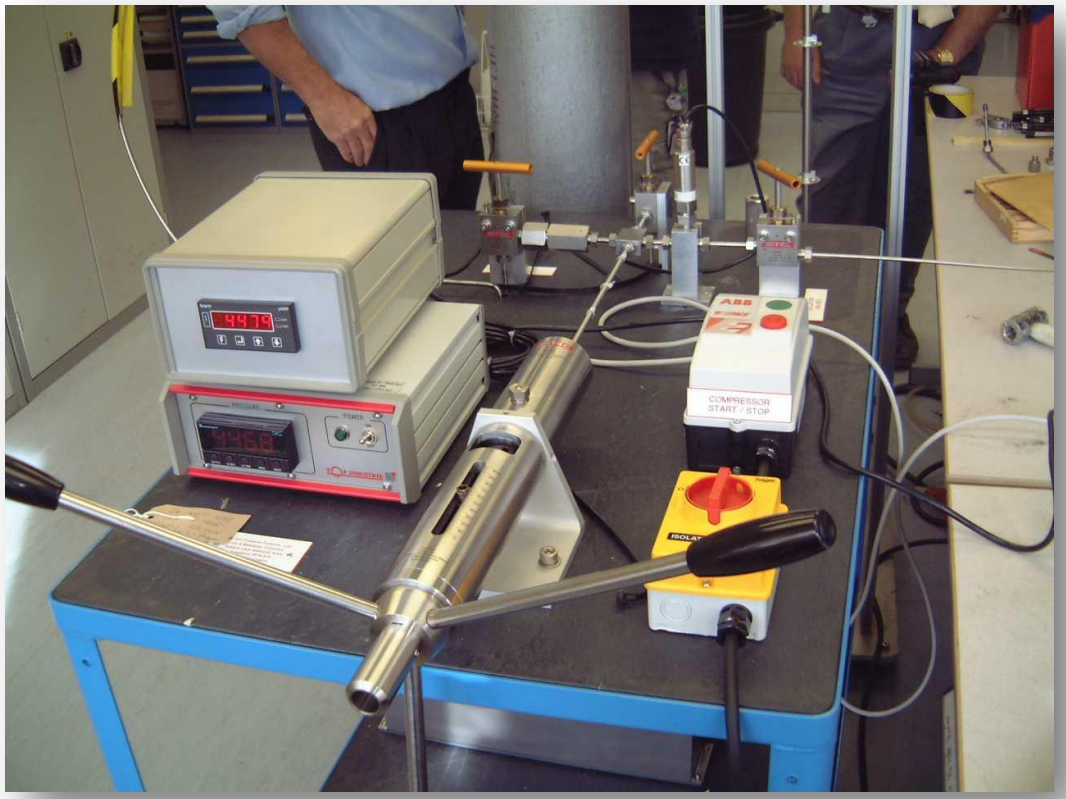
Gas-Pressurized High-Pressure μSR System



High-Pressure for Pulsed Muon

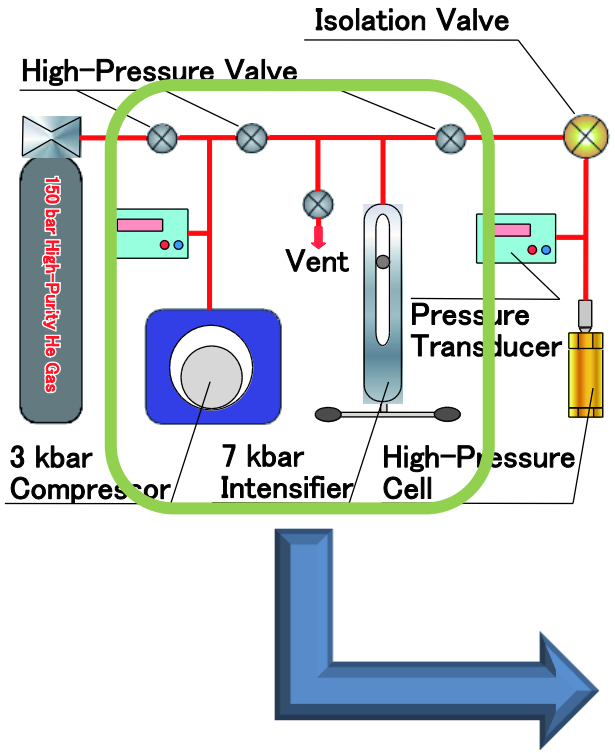
Gas-Pressurized High-Pressure μSR System

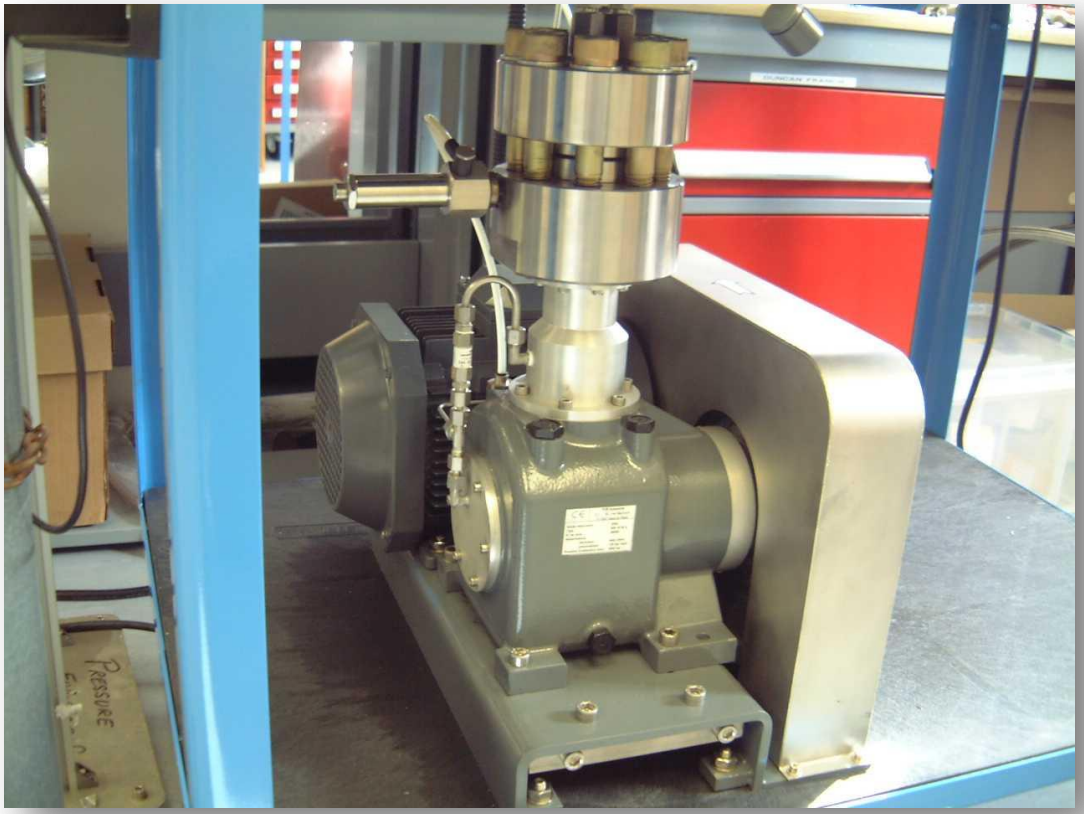




High-Pressure for Pulsed Muon

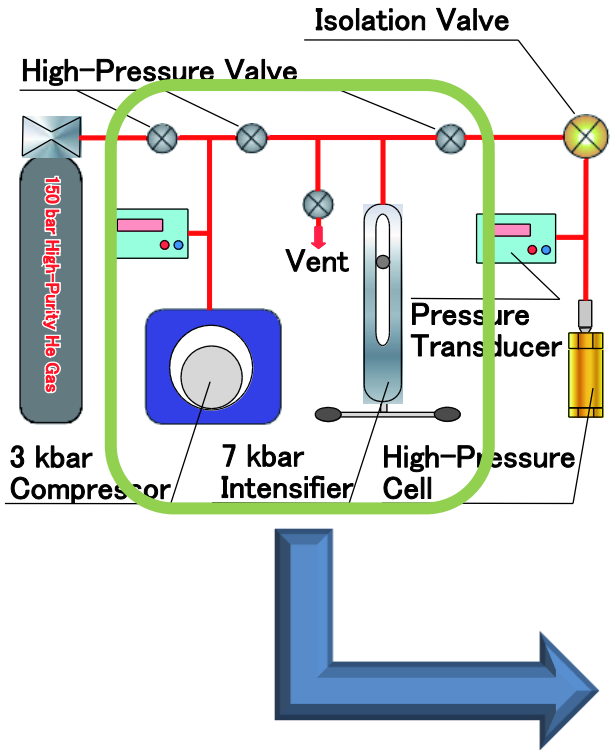
Gas-Pressurized High-Pressure μSR System





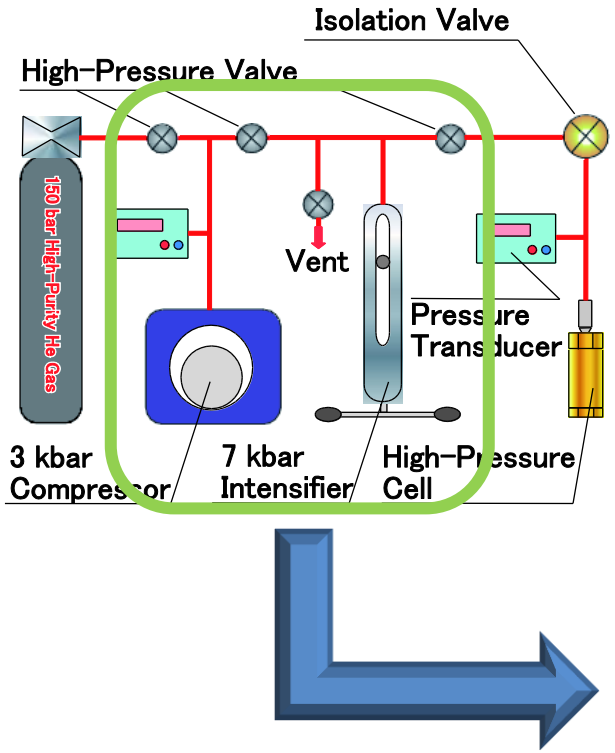
High-Pressure for Pulsed Muon

Gas-Pressurized High-Pressure μSR System



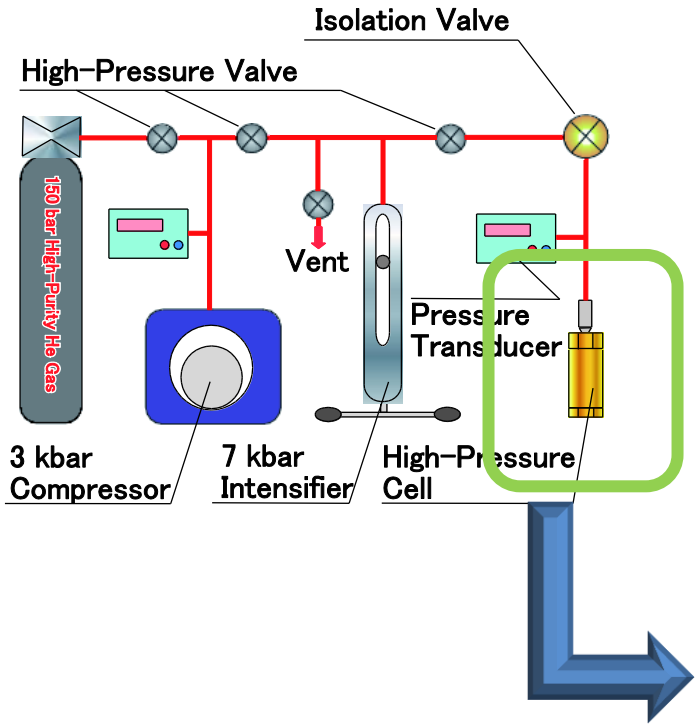
High-Pressure for Pulsed Muon

Gas-Pressurized High-Pressure μSR System



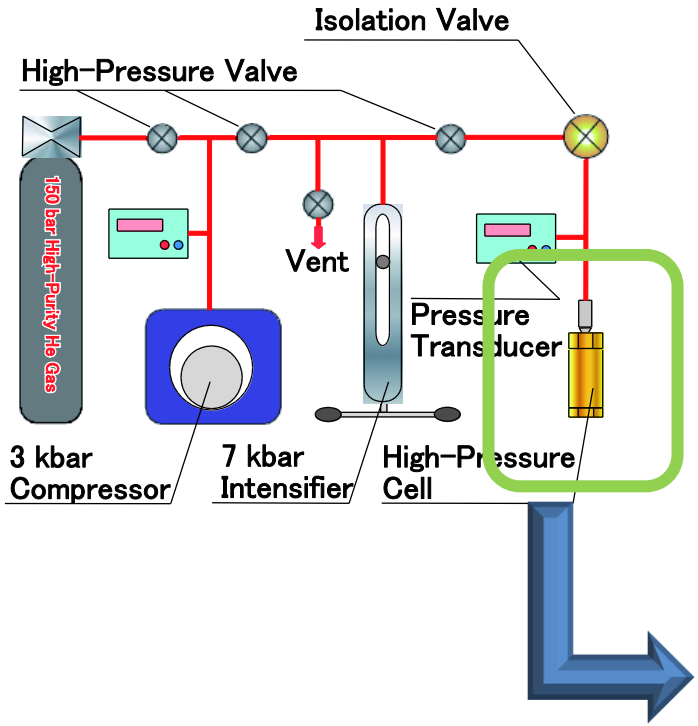
High-Pressure for Pulsed Muon

Gas-Pressurized High-Pressure μSR System



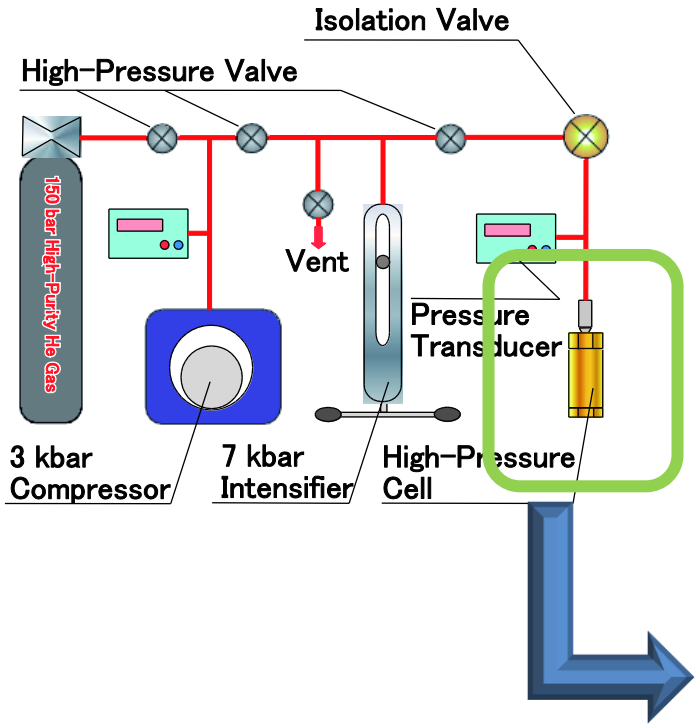
High-Pressure for Pulsed Muon

Gas-Pressurized High-Pressure μSR System



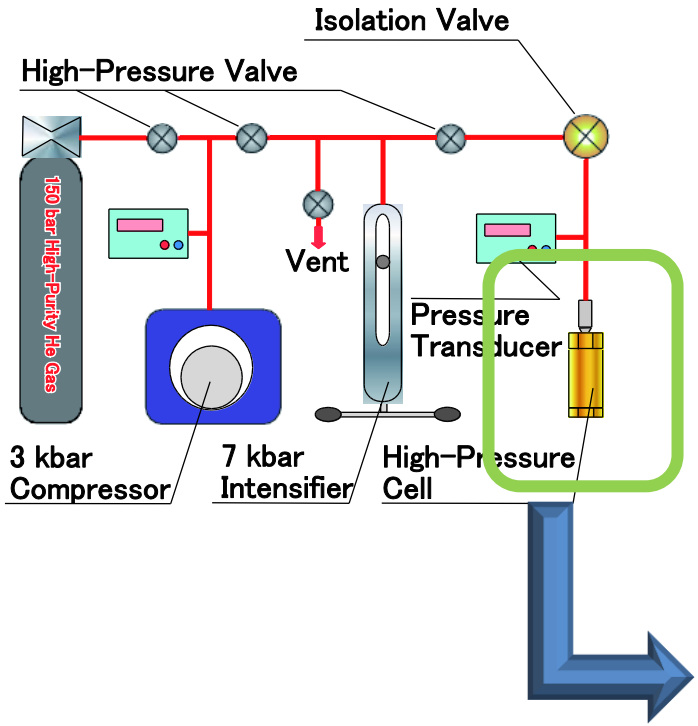
High-Pressure for Pulsed Muon

Gas-Pressurized High-Pressure μSR System

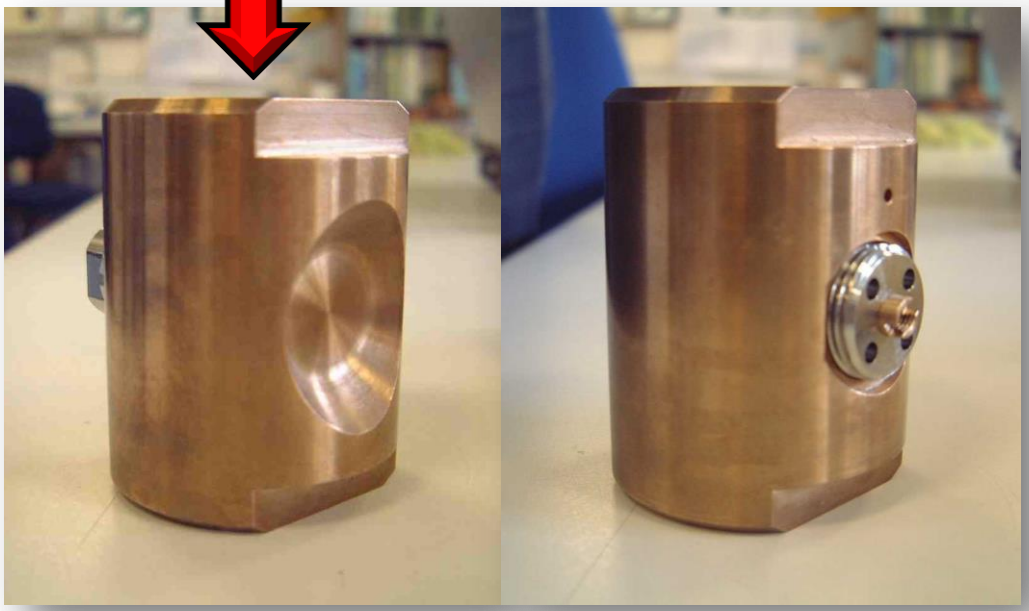


High-Pressure for Pulsed Muon

Gas-Pressurized High-Pressure μSR System

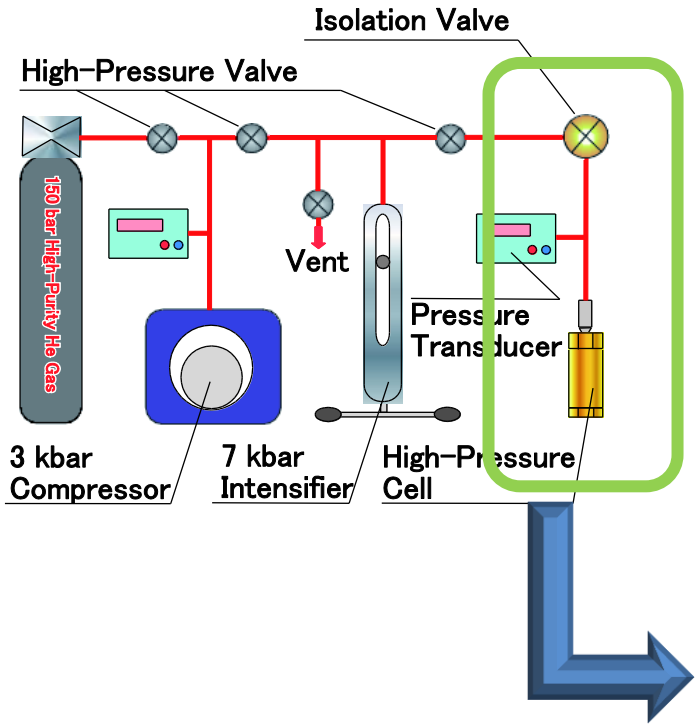


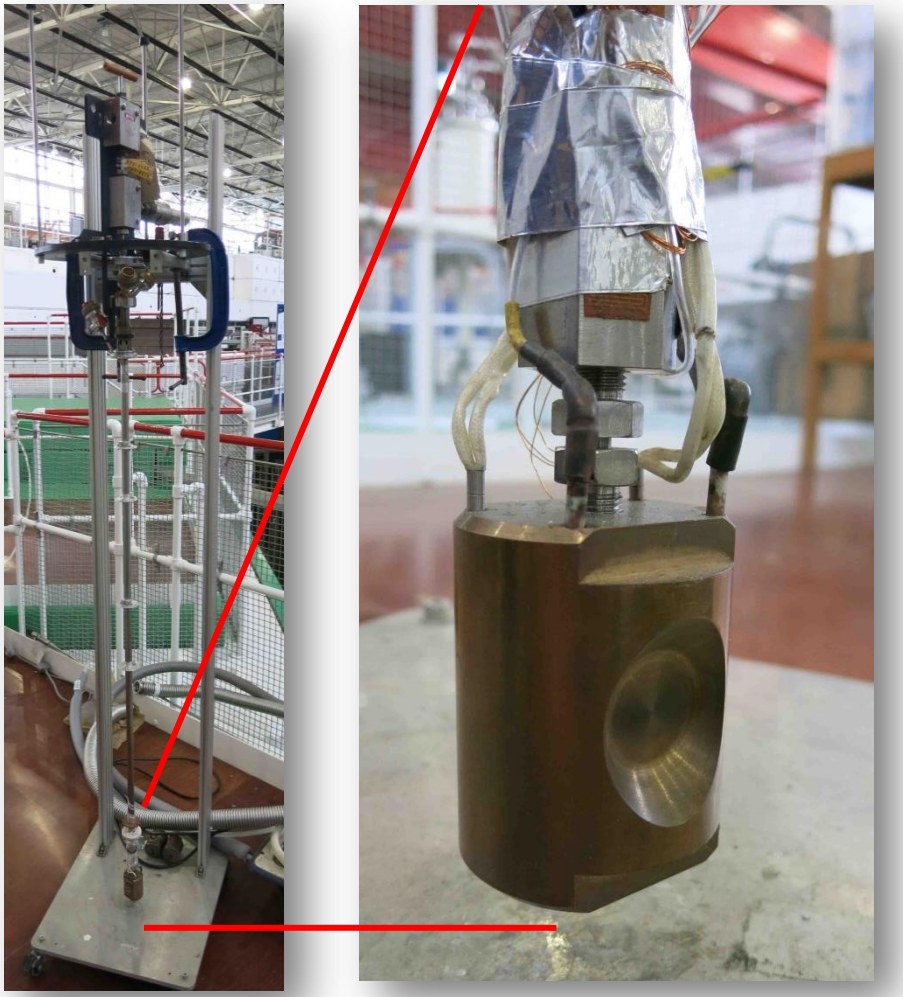
Pressure



High-Pressure for Pulsed Muon

Gas-Pressurized High-Pressure μSR System





Examples of High-Pressure μSR

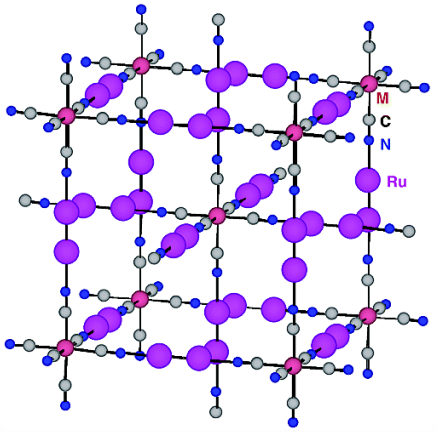
PHYSICAL REVIEW B **84**, 092405 (2011)

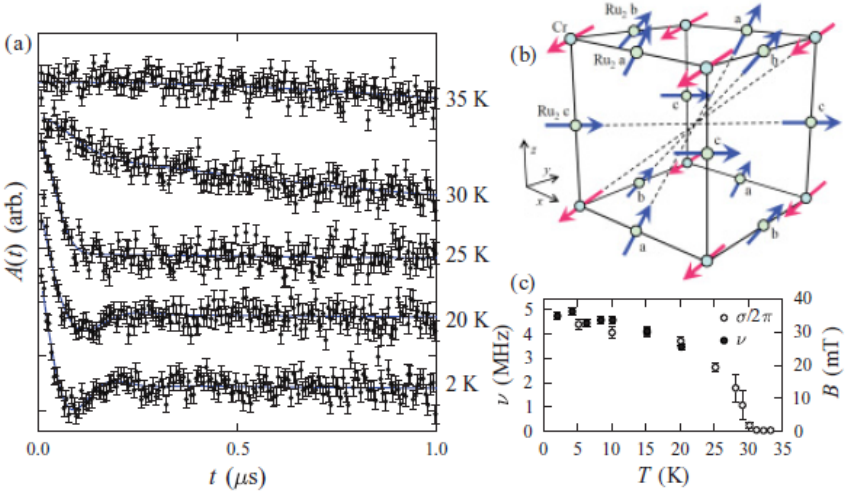
Local magnetism in the molecule-based metamagnet $[Ru_2(O_2CMe)_4]_3[Cr(CN)_6]$ probed with implanted muons

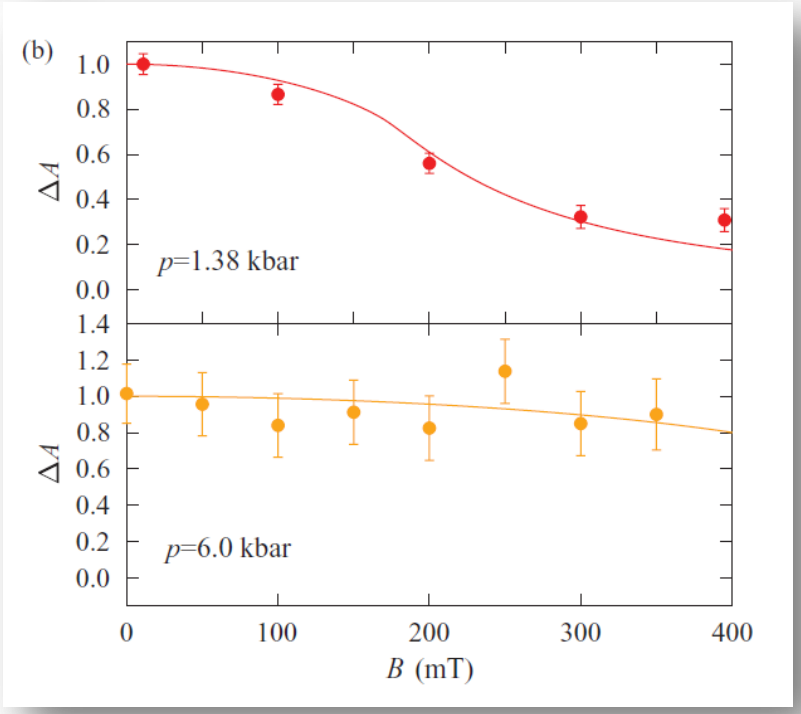
Tom Lancaster,[1,*] Francis L. Pratt,[2] Stephen J. Blundell,[1] Andrew J. Steele,[1] Peter J. Baker,[2] Jack D. Wright,[1] Isao Watanabe,[3] Randy S. Fishman,[4] and Joel S. Miller[5]

[1]*Oxford University Department of Physics, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, United Kingdom*
[2]*ISIS Facility, STFC Rutherford Appleton Laboratory, Chilton, Oxfordshire OX11 0QX, United Kingdom*
[3]*Muon Science Laboratory, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
[4]*Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6453, USA*
[5]*Department of Chemistry, University of Utah, Salt Lake City, Utah 84112-0850, USA*

(Received 16 August 2011; published 30 September 2011)





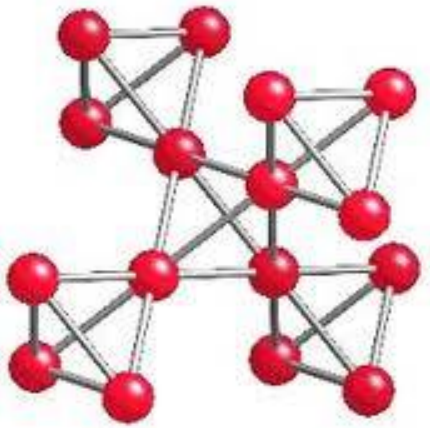


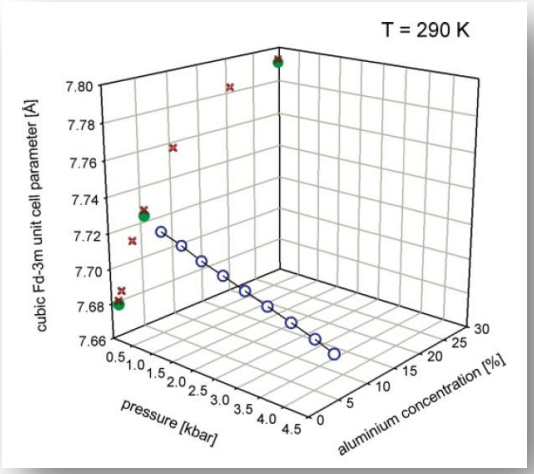
Examples of High-Pressure μSR

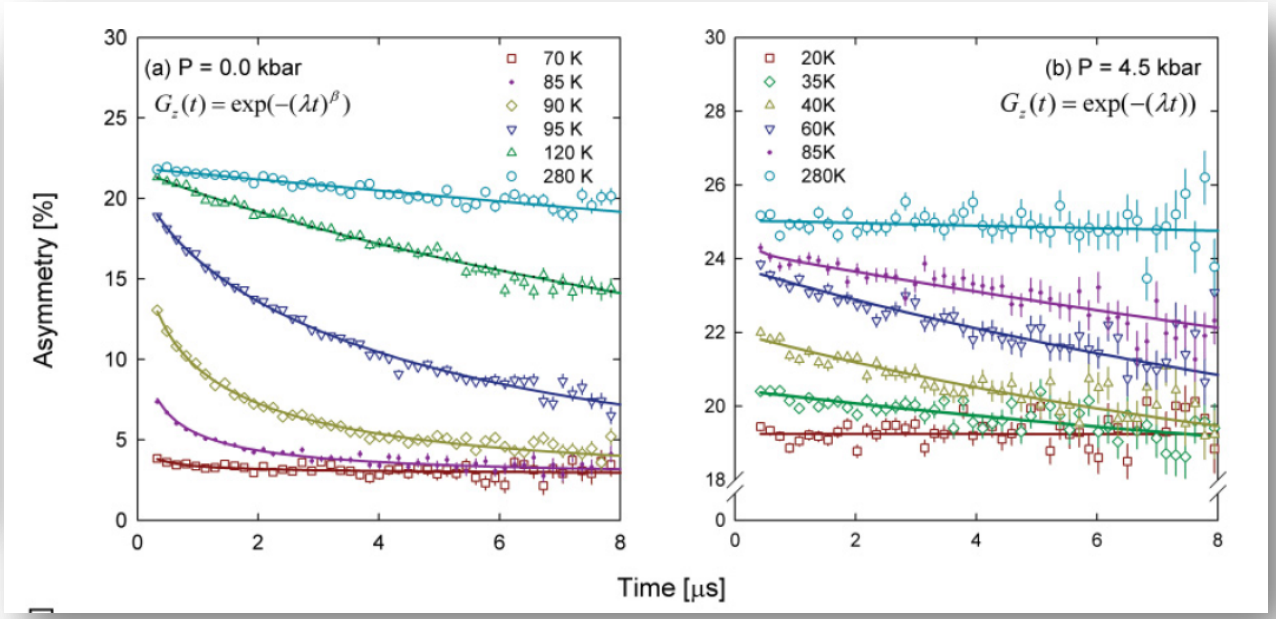
PHYSICAL REVIEW B **85**, 184416 (2012)

Pressure-dependent spin fluctuations and magnetic structure in the topologically frustrated spin glass alloy $Y(Mn_{0.95}Al_{0.05})_2$

M. T. F. Telling,[1,2,*] K. S. Knight,[1] F. L. Pratt,[1] A. J. Church,[1] P. P. Deen,[3,4] K. J. Ellis,[5] I. Watanabe,[6] and R. Cywinski[5]
[1]*ISIS Facility, Rutherford Appleton Laboratory, Chilton, OX11 0QX, United Kingdom*
[2]*Department of Materials, University of Oxford, Parks Road, Oxford, OX1 3PH, United Kingdom*
[3]*Institut Laue-Langevin, BP 156, 6, rue Jules Horowitz, 38042 Grenoble Cedex 9, France*
[4]*European Spallation Source (ESS AB), St Algatan 4, Lund, Sweden*
[5]*School of Applied Science, University of Huddersfield, Huddersfield, HD1 3DH, United Kingdom*
[6]*RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
(Received 19 January 2012; revised manuscript received 29 March 2012; published 17 May 2012)





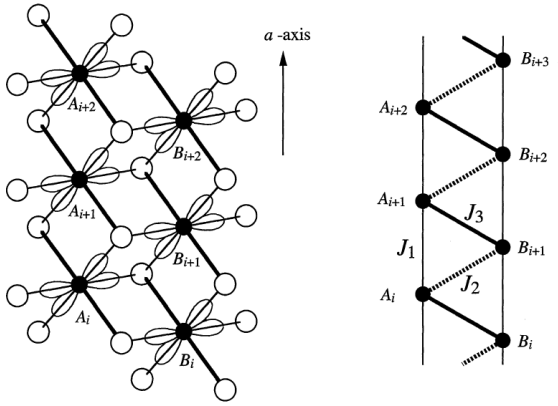


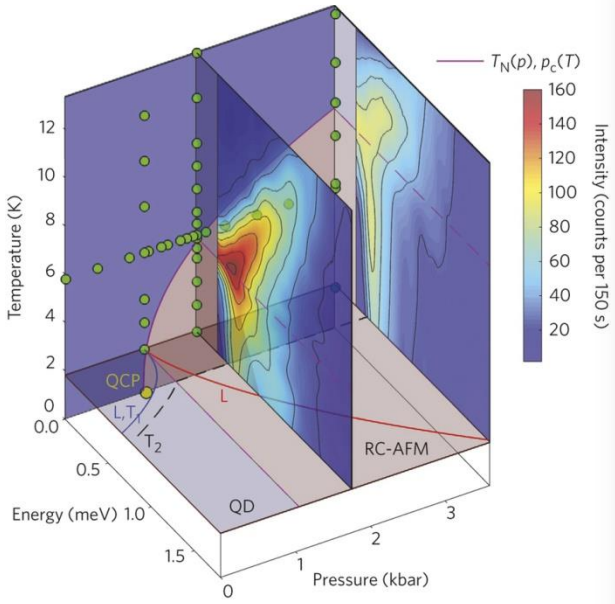
Examples of High-Pressure μSR

PHYSICAL REVIEW B **80**, 064407 (2009)

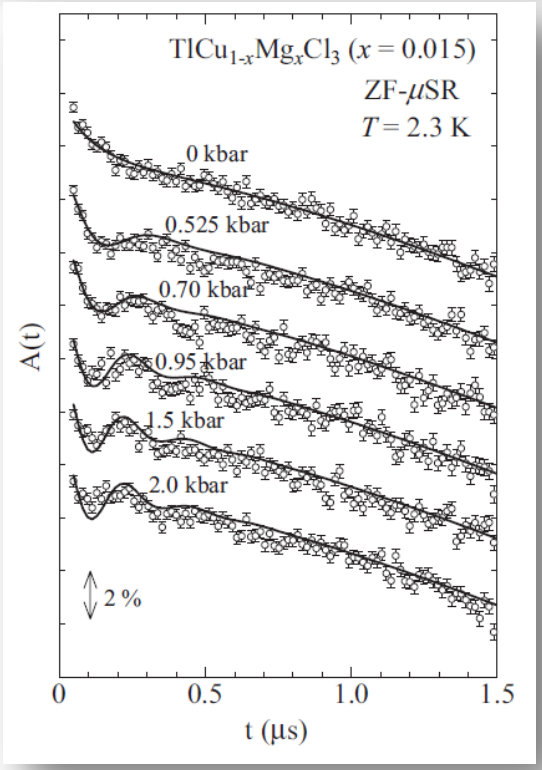
Evidence for continuous change of spin states between impurity-induced order and pressure-induced order in $TlCu_{0.985}Mg_{0.015}Cl_3$ probed via muon spin rotation

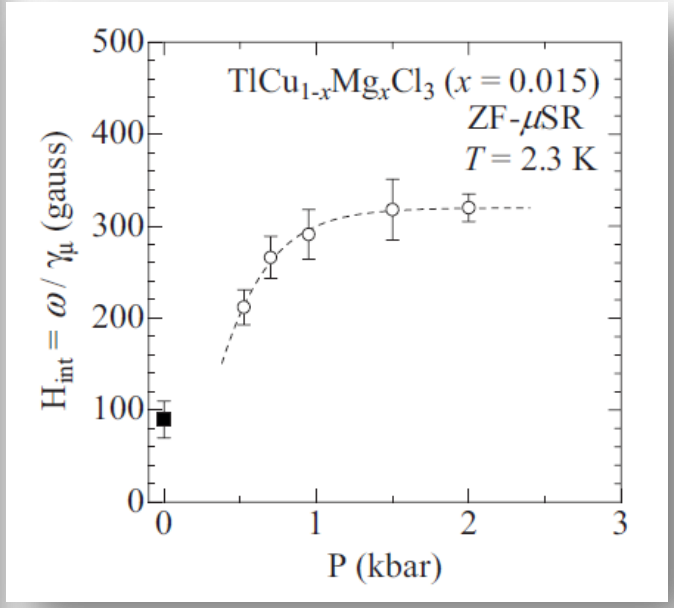
Takao Suzuki,[1,*] Isao Watanabe,[1] Fumiko Yamada,[2] Yasuyuki Ishii,[1] Kazuki Ohishi,[1] Risdiana,[1]
Takayuki Goto,[3] and Hidekazu Tanaka[2]
[1]*Advanced Meson Science Laboratory, RIKEN Nishina Center for Accelerator-Based Science, Hirosawa, Wako, Saitama 351-0198, Japan*
[2]*Department of Physics, Tokyo Institute of Technology, O-okayama, Meguro-ku, Tokyo 152-8551, Japan*
[3]*Faculty of Science and Technology, Sophia University, 7-1 Kioi-cho, Chiyoda-ku, Tokyo 102-8554, Japan*
(Received 7 April 2009; revised manuscript received 11 June 2009; published 13 August 2009)





P. Merchant et al., Nature Physics 10 373-379





High-Pressure