Rustem Khasanov :: Scientist :: Paul Scherrer Institut

Muon-spin rotation/relaxation under hydrostatic pressure: outlook and perspectives

Bridge2023, October 18th – October 20th , 2023

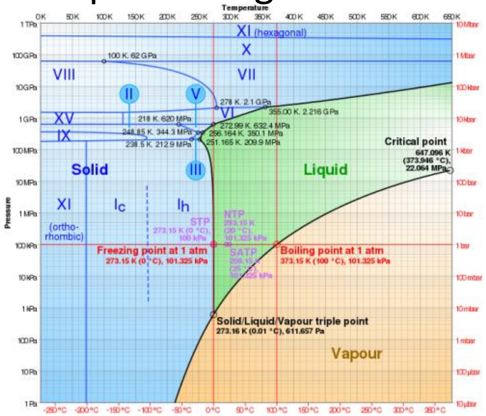
Common tuning parameters

T

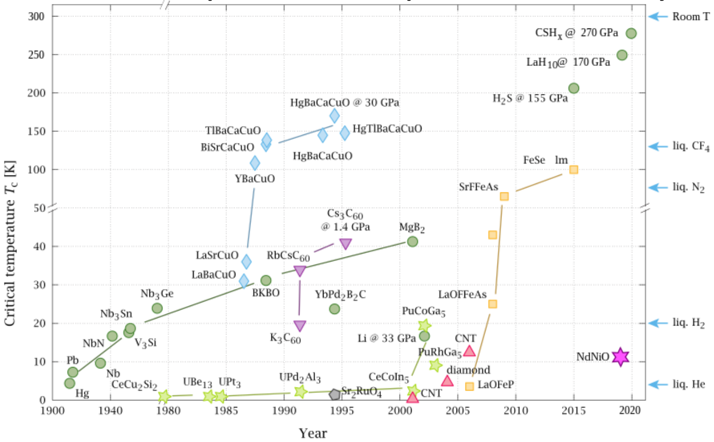
B

P

P-*T* phase diagram of water

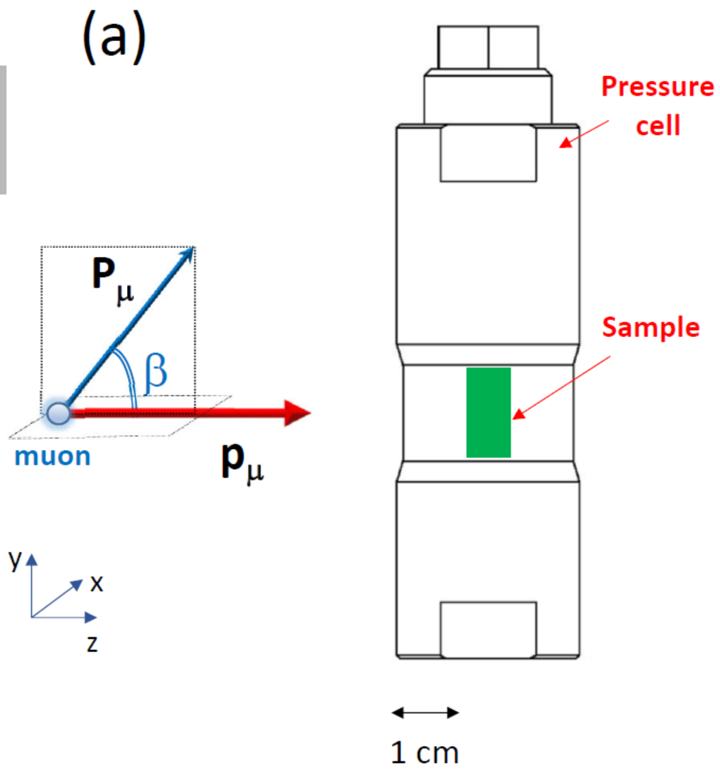


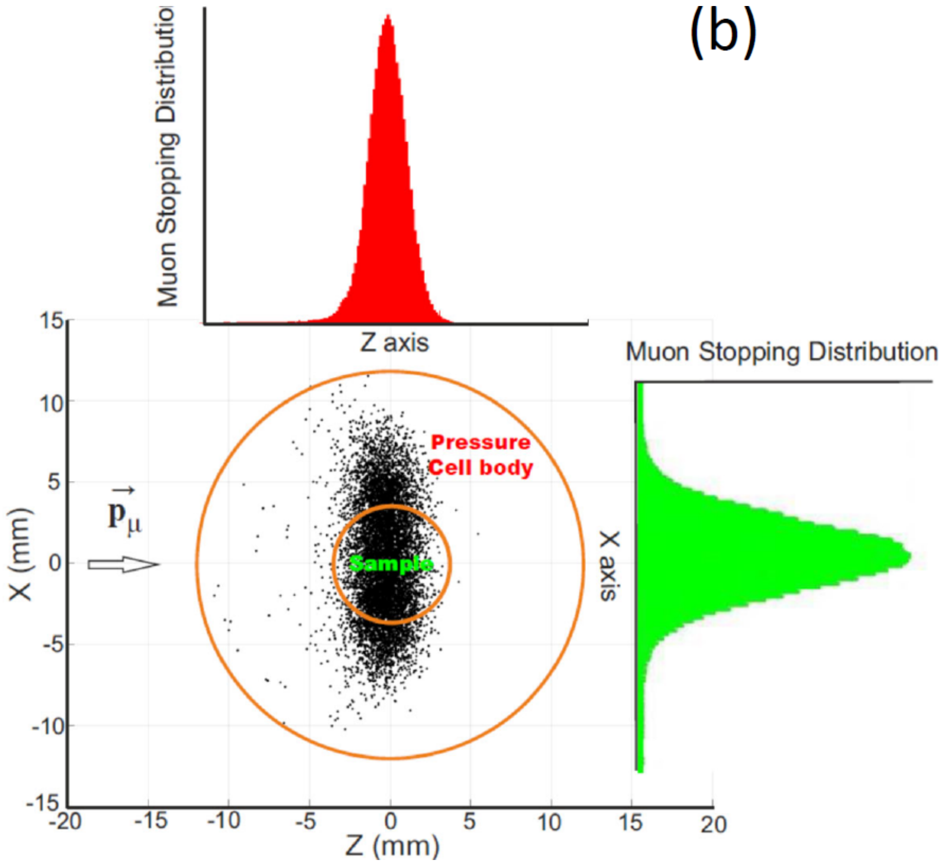
Room temperature superconductivity



Wikipedia

μSR under pressure: basic principles





Khasanov, Journal of Applied Phys. 2022

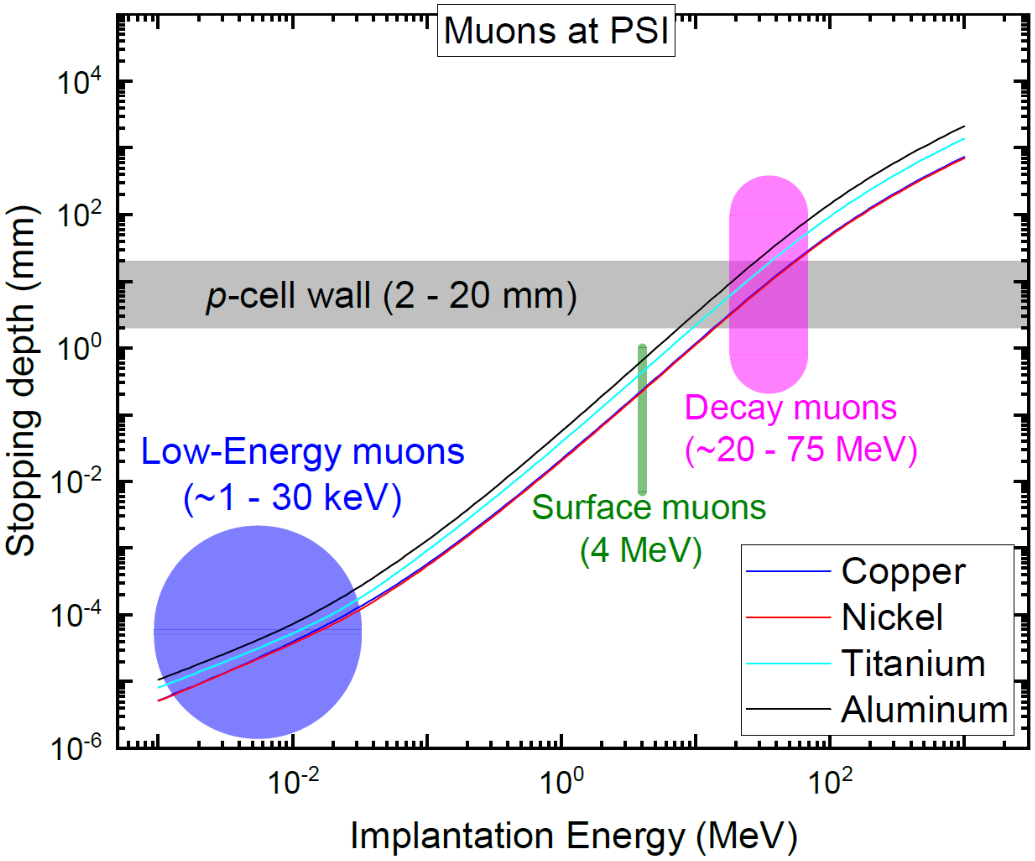
PAUL SCHERRER INSTITUT

μSR under pressure

1. Muon beam-line – fast muons with tunable energy
2. μSR Spectrometer
3. μSR pressure cells

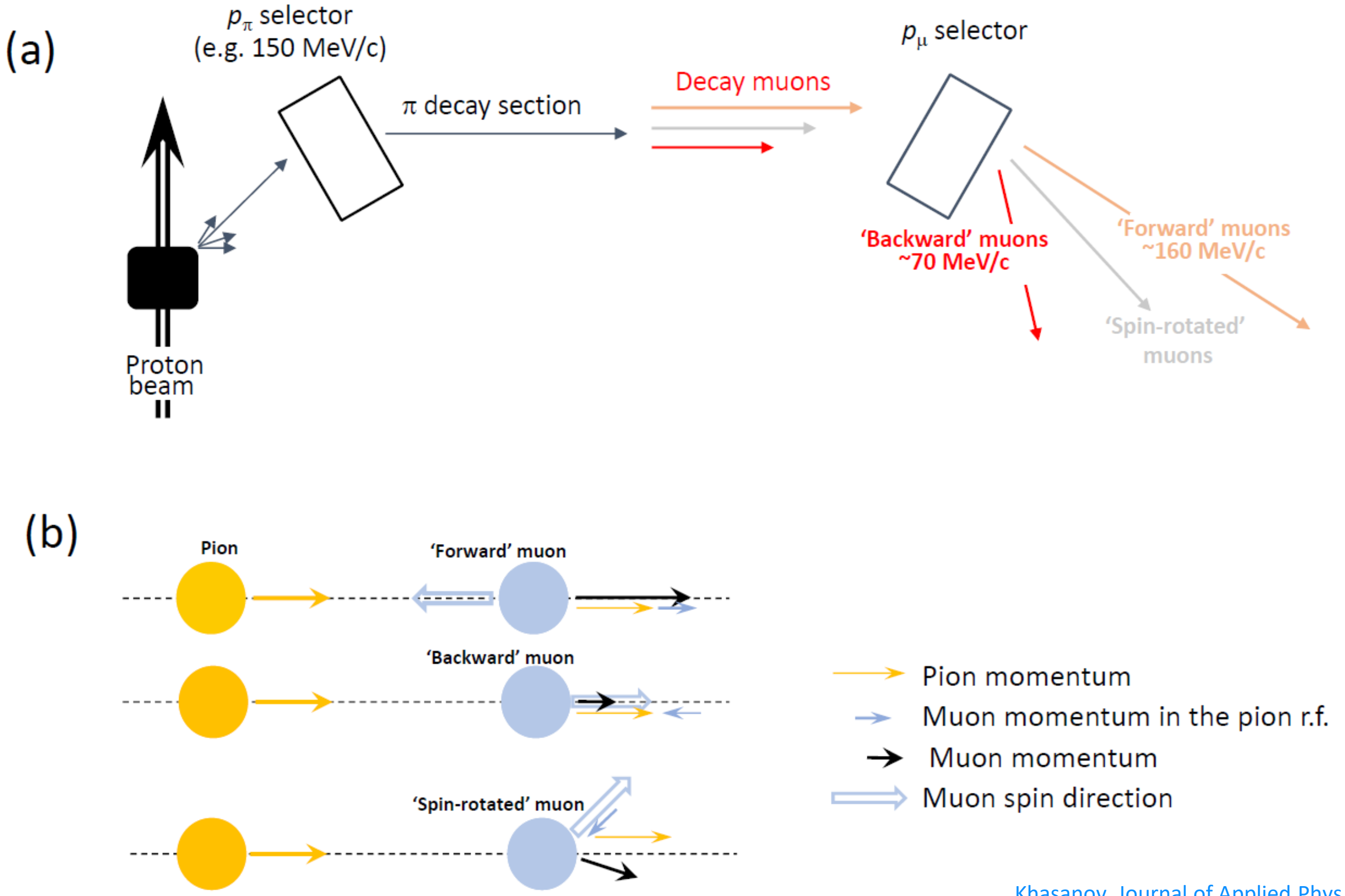
PAUL SCHERRER INSTITUT PSI

Muon beam



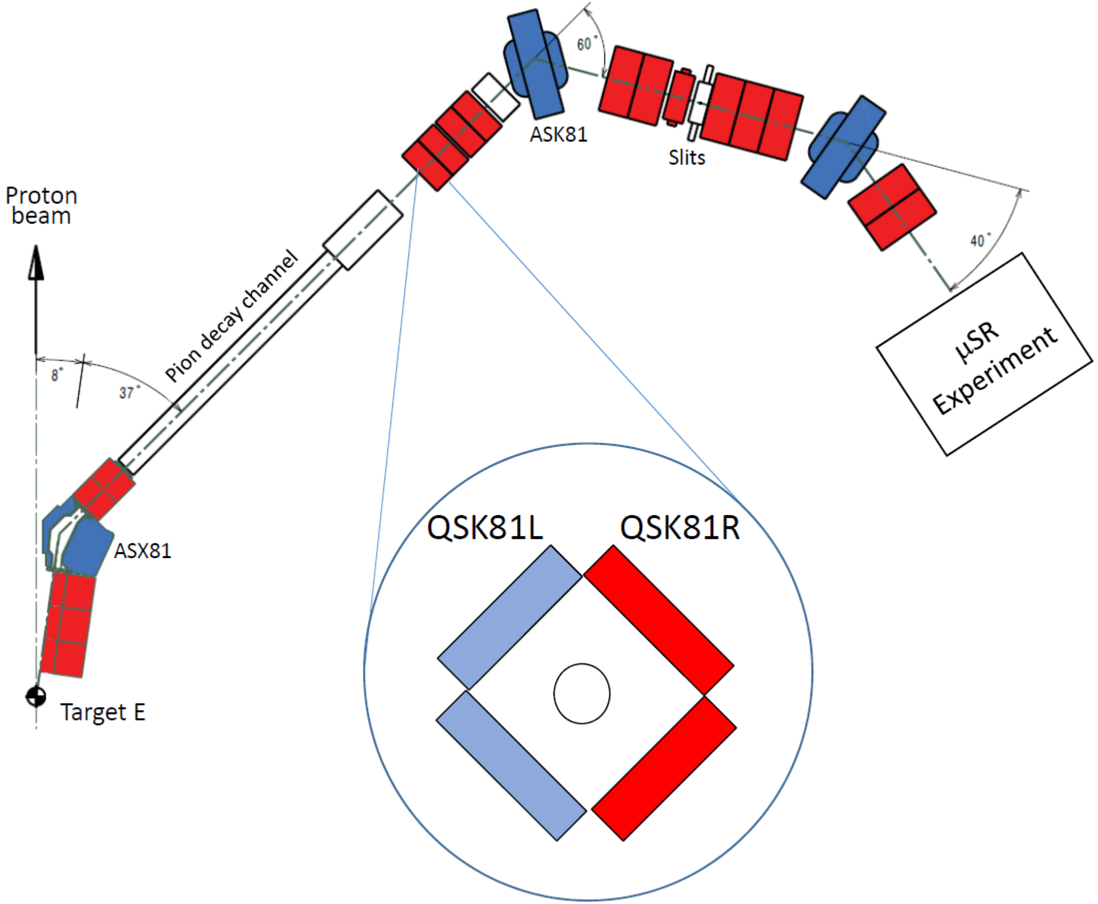
Khasanov, Journal of Applied Phys. 2022

Decay muon beam-line



Khasanov, Journal of Applied Phys. 2022

μE1 decay beam-line at PSI

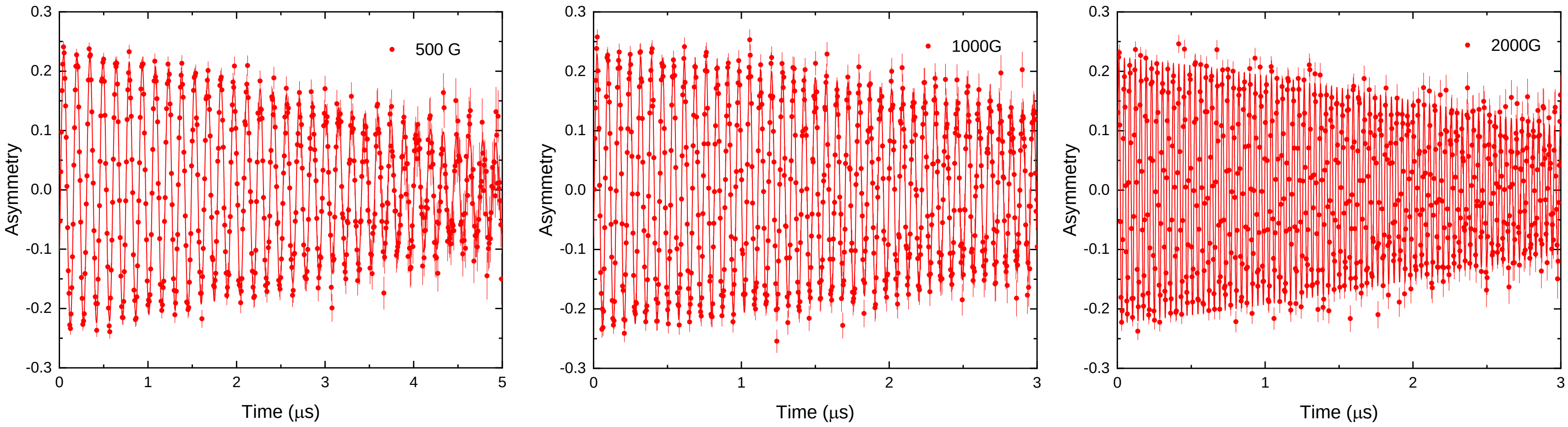


The use of the spllited Quadrupolar magnet (QSK81) allows to collect muons with turned spins. This a unique possibility which is accessible for decay muon beam-lines.

The first spin-rotation experiments were conducted in TRIMF at M9B beamline

Khasanov, Journal of Applied Phys. 2022

Asymmetry spectra in spin-rotated TF mode



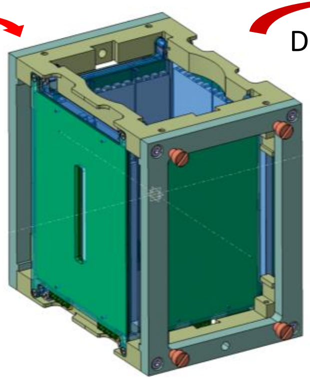
The intial asymmetry, A_{LR} = 0.25, corresponds to about 60^o spin rotation!

PAUL SCHERRER INSTITUT

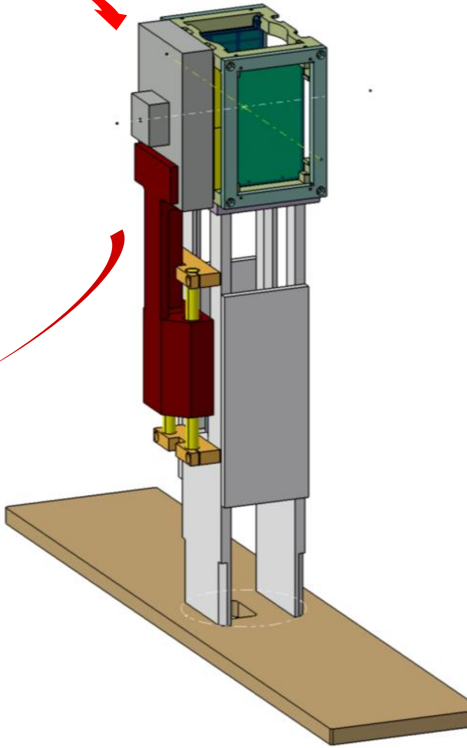
Detectors, GPD Spectrometer

Individual Detector

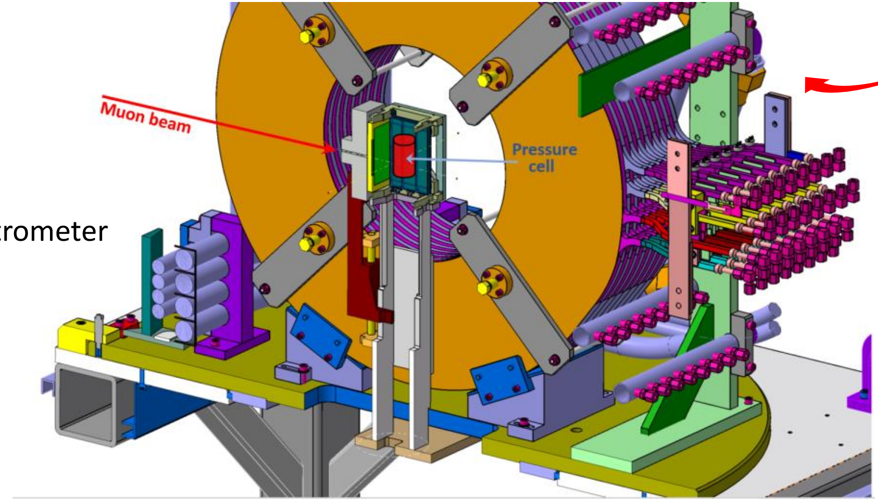
Detector head



Detector setup



GPD spectrometer



PAUL SCHERRER INSTITUT PSI

Construction material suitable for μSR

Nonmagnetic Alloys

	CuBe	$TiAl_6V_4$	NiCrAl	MP35N
Yield strength	1.1 Gpa (300 K)	1.05 Gpa (300 K)	2.06 Gpa (300 K)	2.15 GPa (300 K)
Young modulus	131 GPa (300 K)	97 Gpa (300 K)	190 Gpa (300 K)	215 Gpa (300 K)

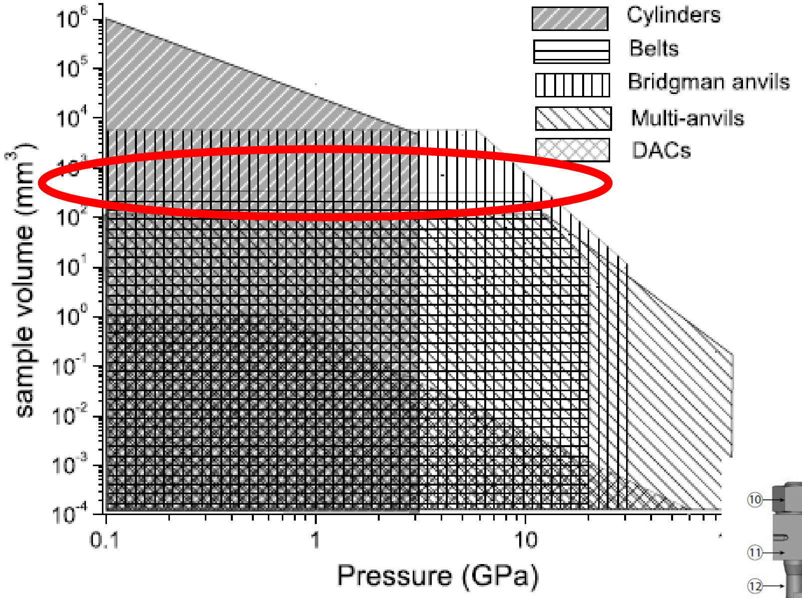
Sintered materials

	WC	cBN	SiC	ZrO_2-Y_2O_3	Al_2O_3-ZrO_2	Si_3N_4
Compressive strength	5.0-11.0 Gpa	2.9 GPa	7.6-8.3 GPa	2.20 GPa	4.7 GPa	5.1-5.5 GPa
Young modulus	600-670 Gpa		918 GPa	210 Gpa	357 GPa	241 GPa

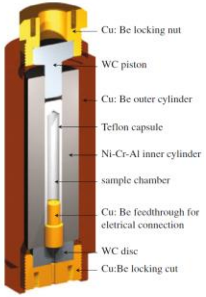
- Strong enough to hold the pressure
- Should not have "strong" μSR response
- Should have temperature independent response

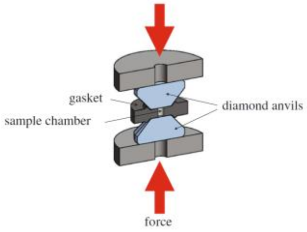
Khasanov *et al.*, High Pressure Research. 2016
Shermadini, Khasanov *et al.*, High Pressure Research. 2016
Khasanov *et al.*, High Pressure Research. 2022
Khasanov *et al.*, High Pressure Research. 2023

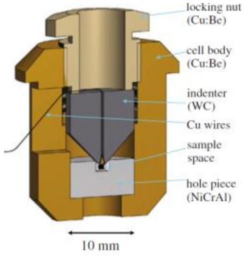
Pressure cells

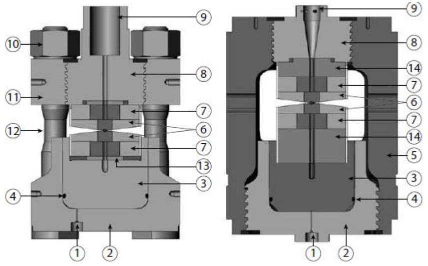


S. Klotz, "Techniques in High Pressure Neutron Scattering"



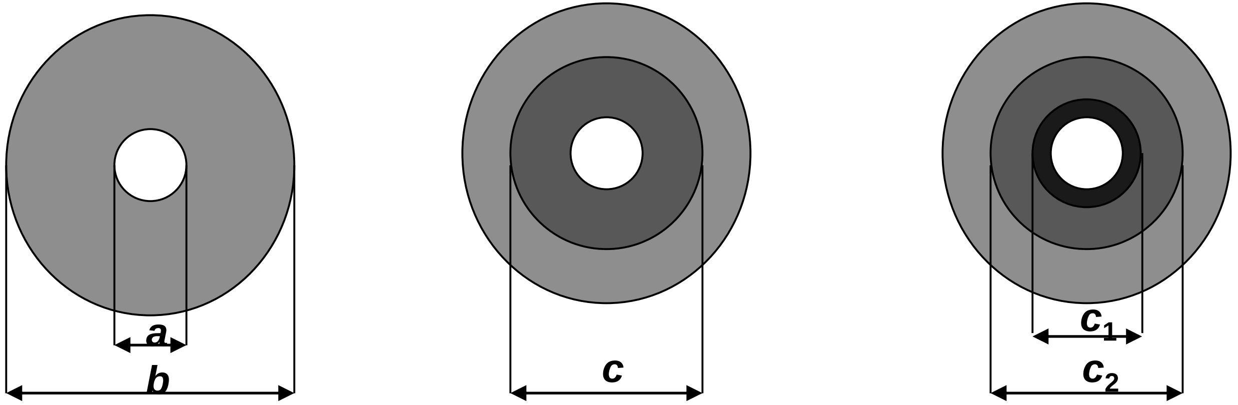






Pressure cell construction: compound cylinder

Single wall cell | Double wall cell | Three wall cell



$$p_{max} \propto \frac{1}{2} - \frac{a^2}{2\,b^2}$$

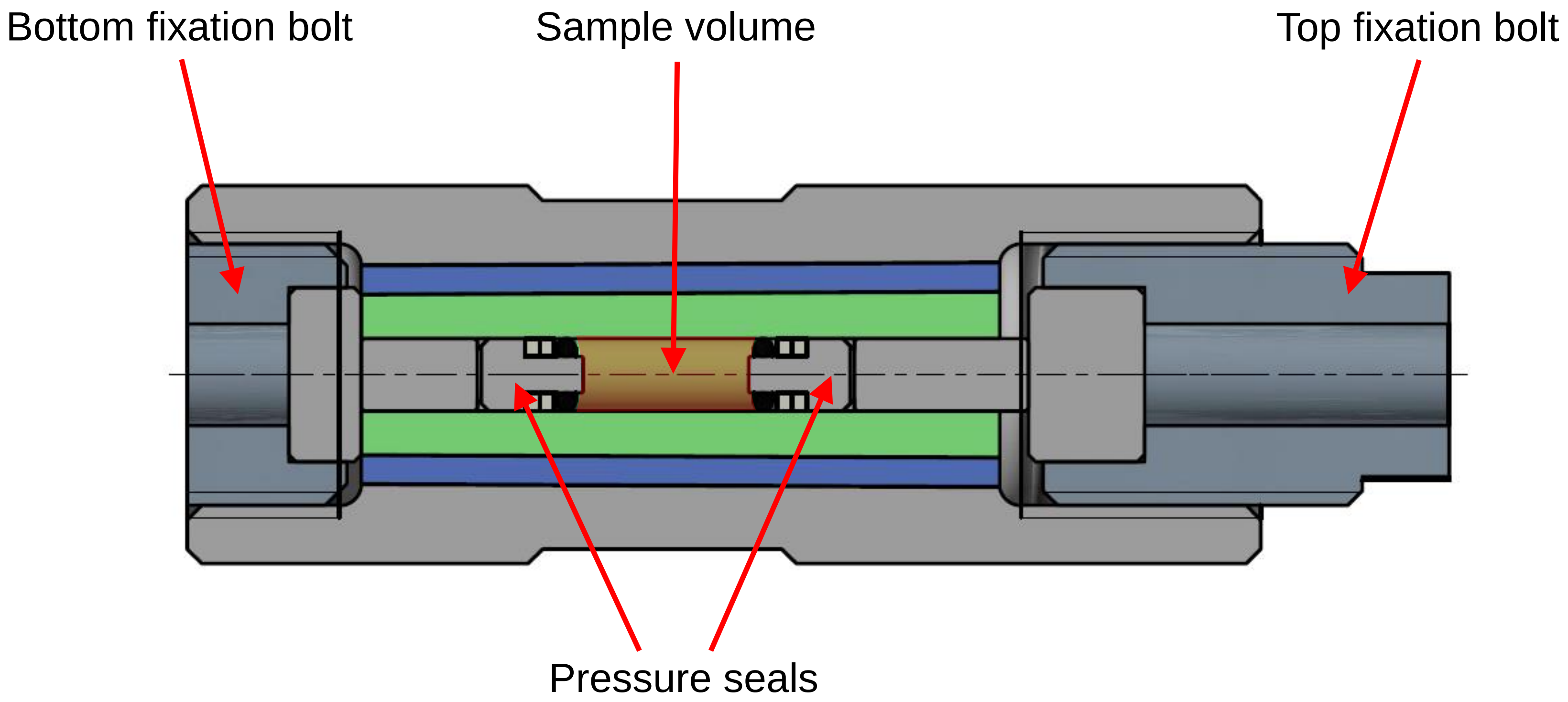
$$p_{max} \propto 1 - \frac{a^2}{2\,c^2} - \frac{c^2}{2\,b^2}$$

$$p_{max} \propto \frac{3}{2} - \frac{a^2}{2\,c_1^2} - \frac{c_1^2}{2\,c_2^2} - \frac{c_2^2}{2\,b^2}$$

For ***a***=6 mm and ***b***=24 mm, $p_{max}^{s} \div p_{max}^{d} \div p_{max}^{t}$ = 1 / 1.6/ 1.96

Khasanov *et al.*, High Pressure Research. 2022

Three-wall pressure cell construction

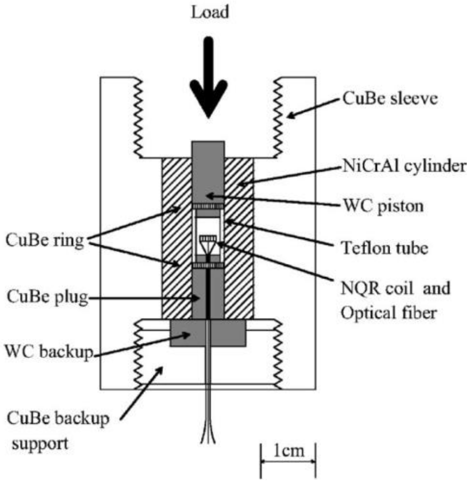


$p_{max}(RT)$ ~3.3 Gpa, p_{max} (LT) ~ 3.0 GPa

Khasanov *et al.*, High Pressure Research. 2022

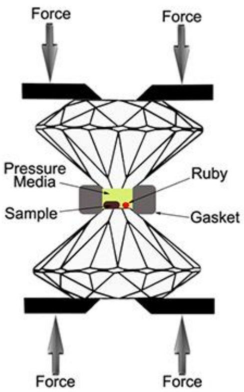
Pressure determination, pressure probes

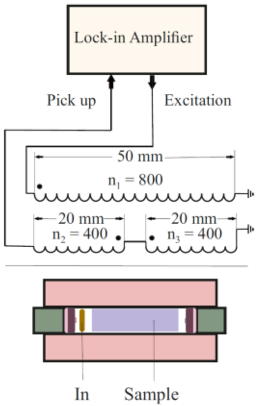
Contact (feedthroughs)



Resistivity, AC susceptibility, NMR, NQR, specific heat, optical …

Contactless

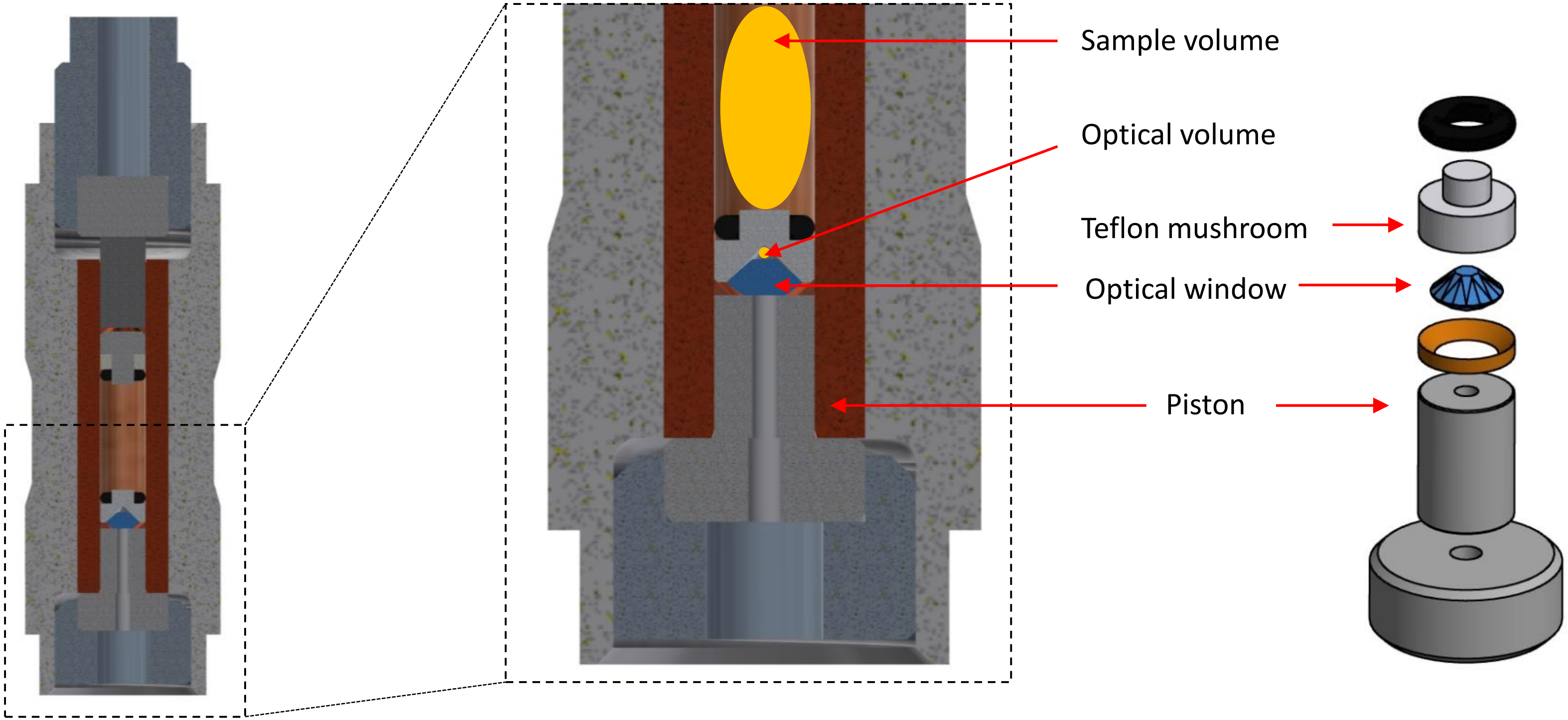




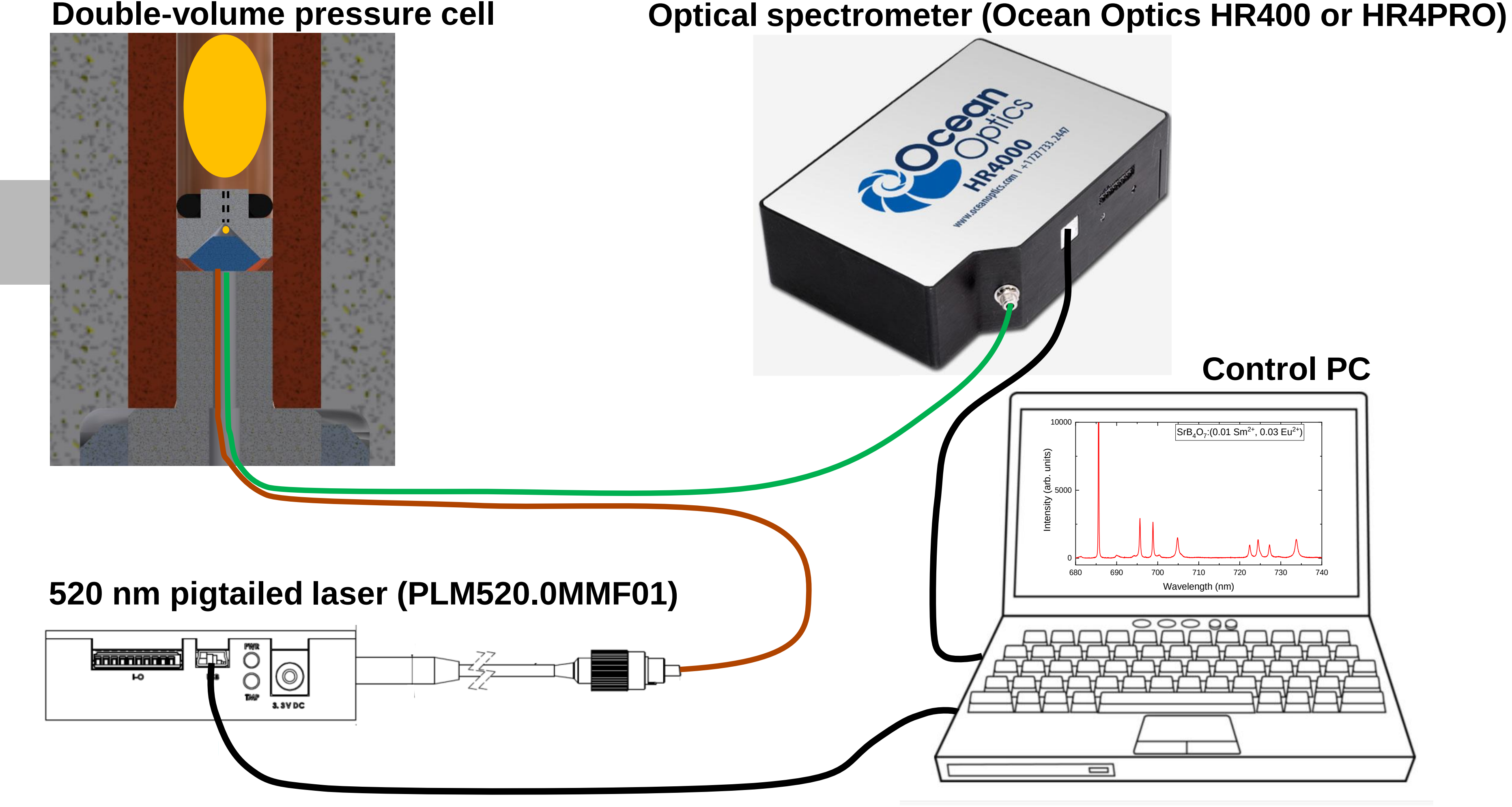
Optical, AC susceptibility, NMR, NQR, specific heat, Neutron scattering (equation of state)…

Substantial part of the pressure cell volume is occupied by the pressure indicator

Double volume piston-cylinder cell



Naumov…Khasanov, Phys. Rev. Applied, 2022

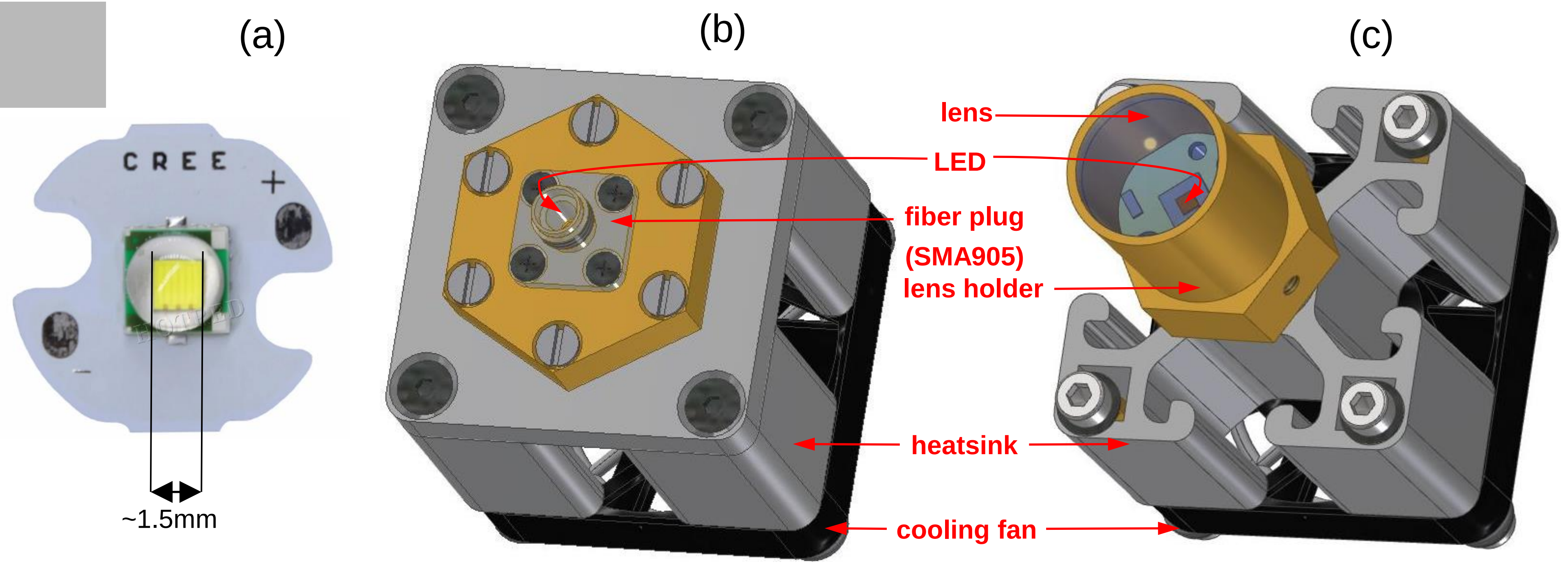


Naumov…Khasanov, Phys. Rev. Applied, 2022

Risk potential of laser classes

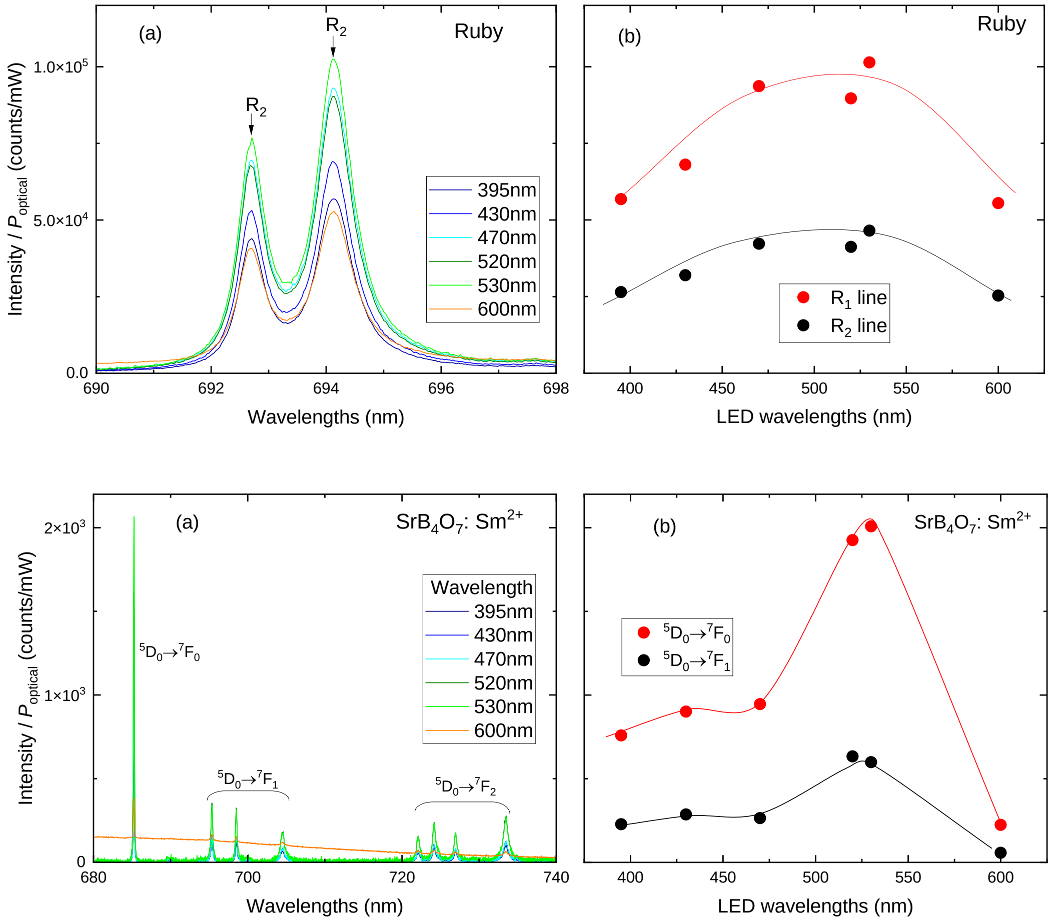
Laser class		Measures
Class 1	Safe under all conditions of normal use	No measures neccessary
Class 1M	Safe if not viewed through optical instruments	Warn persons with optical instruments
Class 2	Harmless for a moment	Do not stare into beam, do not aim at faces
Class 2M	Safe if not viewed through optical instruments	Warn persons with optical instruments
Class **3R**	Considered safe if handled carefully, with restricted beam viewing	To be used by trained personal only
Class **3B**	Hazardous if the eye is exposed directly to the beam, scattered radiation considered harmless	Separate area constructional, restricted access Signal laser at the entrance To be used by trained personal only Wear laser goggles
Class **4**	Can cause permanent eye damage and burn the skin as a result of direct or diffuse beam viewing; fire hazard	Measures as given for class 3 Where required use additional protection for body parts

Safety concern: Laser *vs.* LED light



Khasanov *et al.*, High Pressure Research. 2023

Ruby and Sr tetraborite



Khasanov *et al.*, High Pressure Research. 2023

Uniaxial pressure (Strain cell)

PAUL SCHERRER INSTITUT

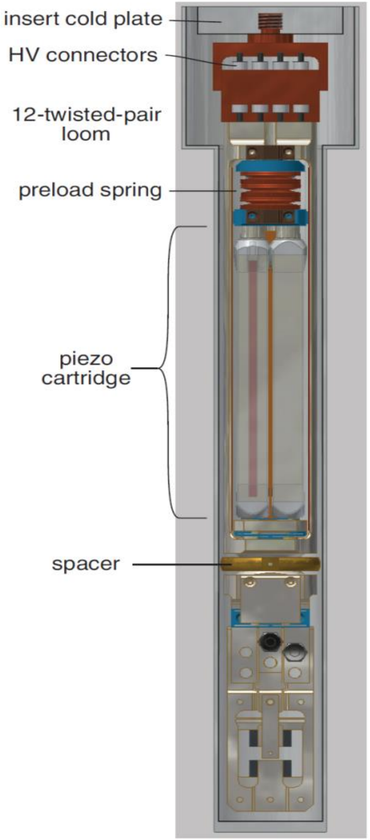
Hubertus Luetkens

Zurab Guguchia

Matthias Elender

MAX-PLANCK-INSTITUT
FÜR CHEMISCHE PHYSIK FESTER STOFFE

Clifford Hicks



TECHNISCHE UNIVERSITÄT DRESDEN

Hans-Henning Klauss
Rajib Sarkar

Vadim Grinenko

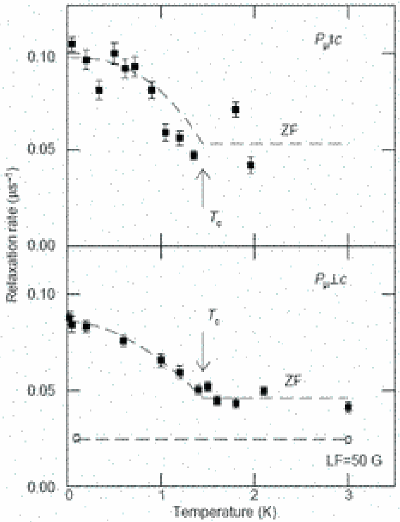
Shreenanda Ghosh

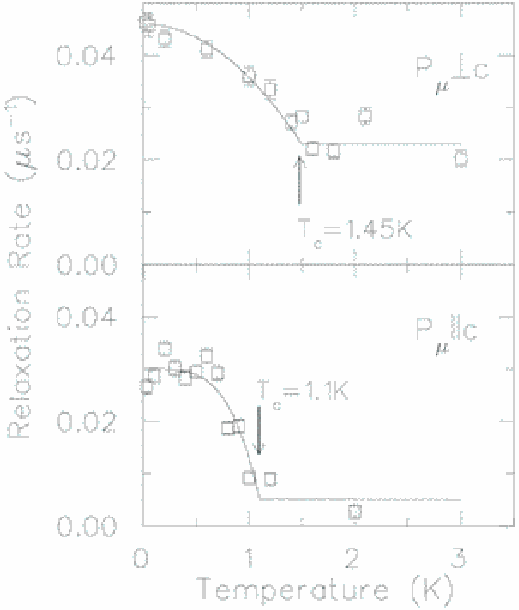
Scientific example

1. The uniaxial and hydrostatic pressure effects on TRSB in Sr_2RuO_4

Time-reversal symmetry breaking in Sr_2RuO_4

Broken Time Reversal Symmetry

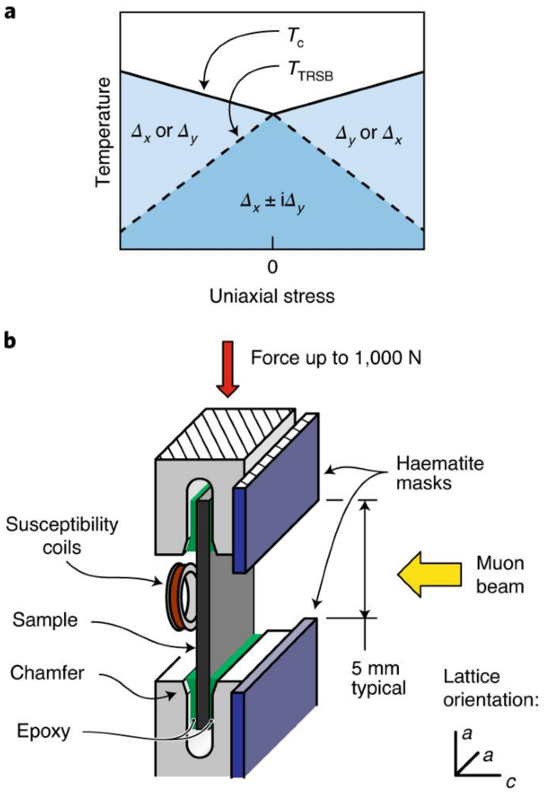


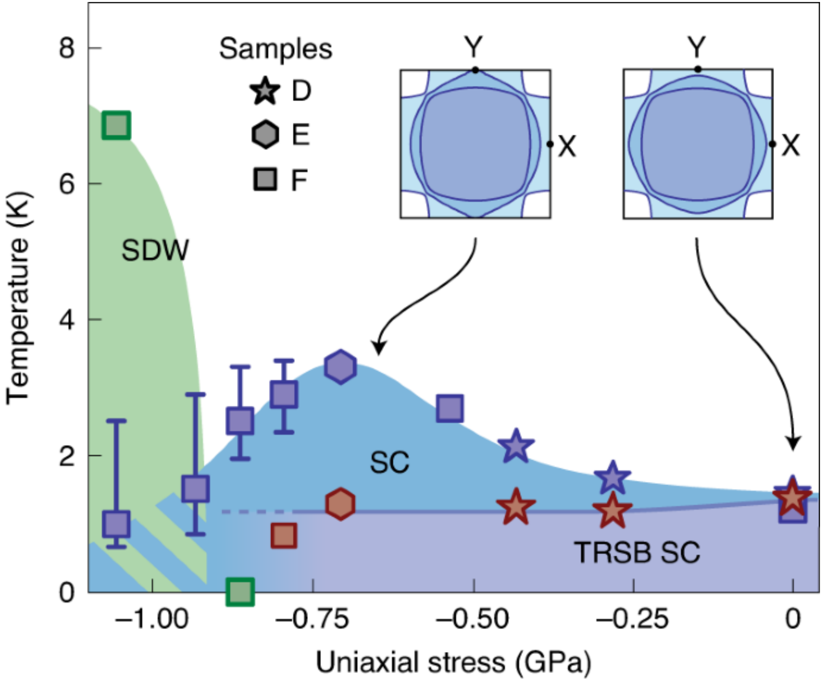


- Spontaneous field seen below T_c, for P_m//c, //a.
- B_{loc}~1G.

Luke et al., Nature **394**, 558 (1998).

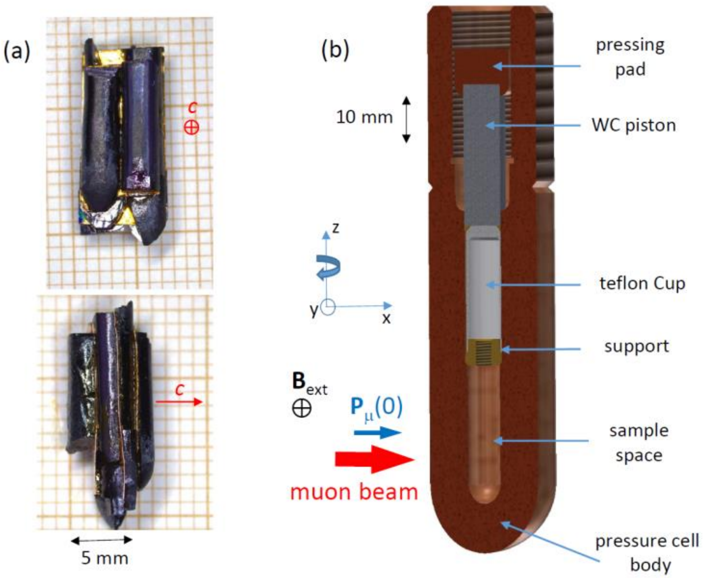
Uniaxial strain

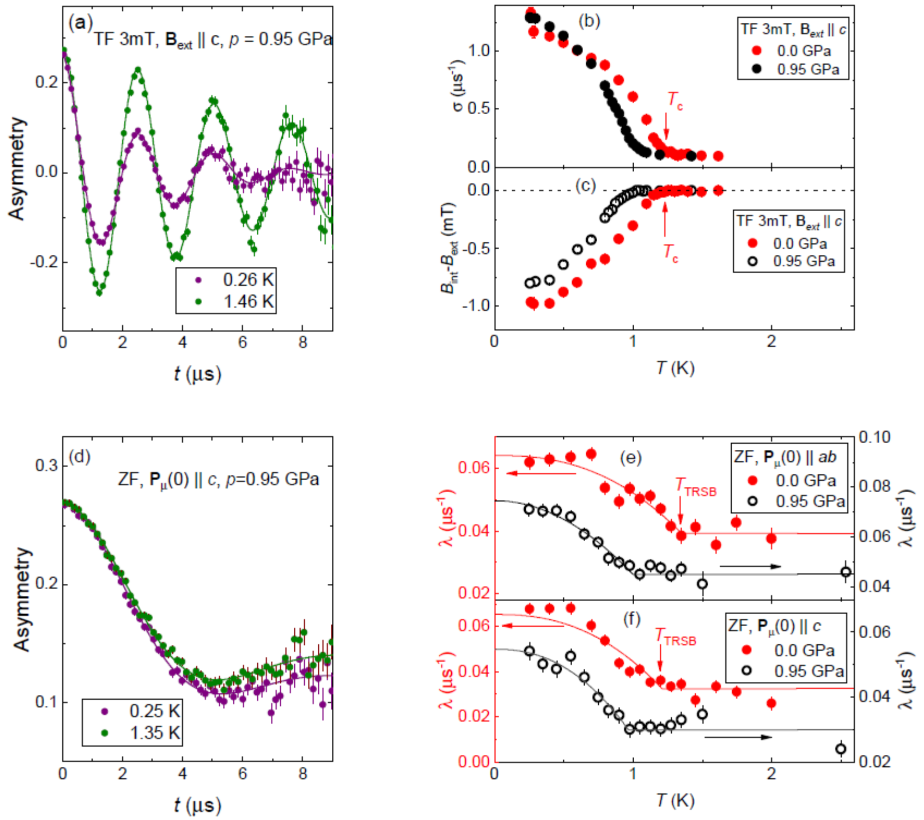




Grinenko *et al.*, Nature Phys. 2021

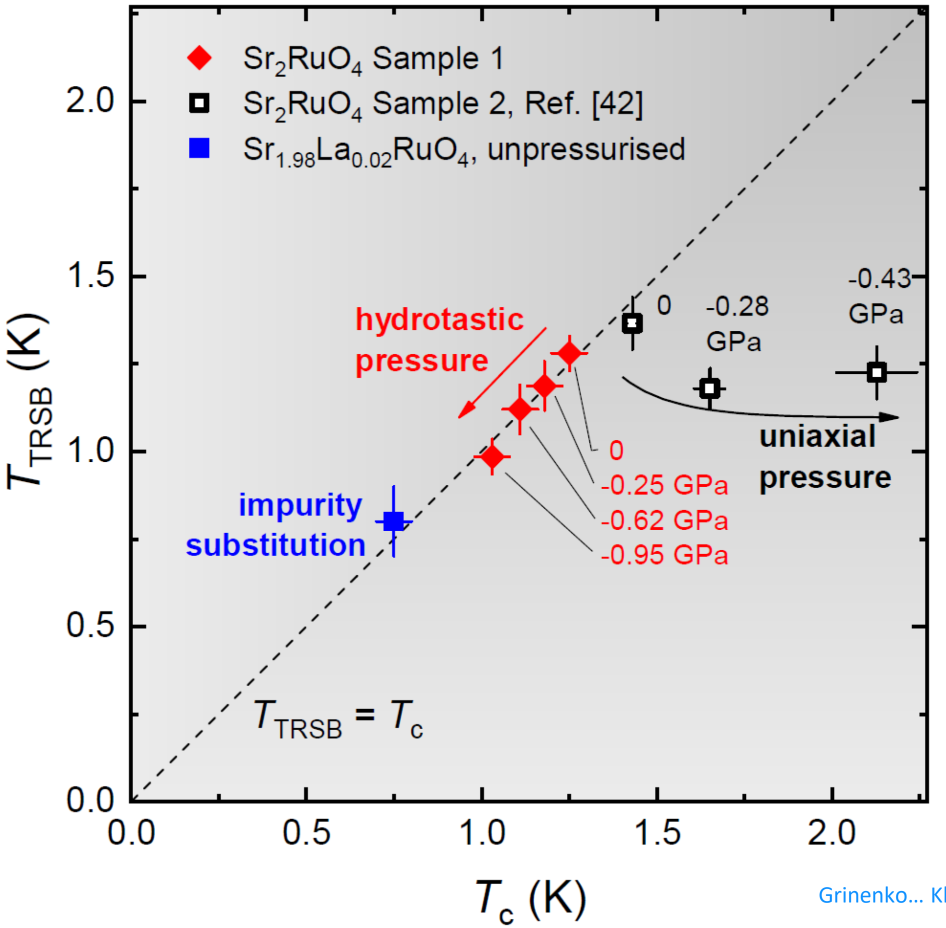
Hydrostatic pressure experiments





Grinenko... Khasanov, Nature Comm. 2022

Combined graph data



Grinenko… Khasanov, Nature Comm. 2022

Wir schaffen Wissen – heute für morgen

My thanks go to

- Matthias Elender
- Alexander Maisuradze
- Zurab Shermadini
- Zurab Guguchia
- Debarchan Das
- Ritu Gupta
- Gediminas Simutis
- Stefan Klotz
- Mark Janoschek
- Alex Amato
- Hubertus Luetkens