pEDM kick-off meeting, CERN, March 13-14, 2017

State-of-the-art SQUIDs

Andrei Matlashov
Center for Axion and Precision Physics, Institute for Basic Science,
Daejeon, Korea

CAPP
Center for
Axion and Precision
Physics Research

andrei@ibs.re.kr

Andrei Matlashov, Ph.D.

Institute of Radio Engineering and Electronics, Moscow 1982 – 1994
Conductus Inc., Sunnyvale, California, USA 1994 – 1997
Los Alamos National Laboratory, Los Alamos, NM, USA 1997 – 2016

Center for Axion and Precision Physics, Institute for Basic Science, Daejeon, Korea since January 16, 2017

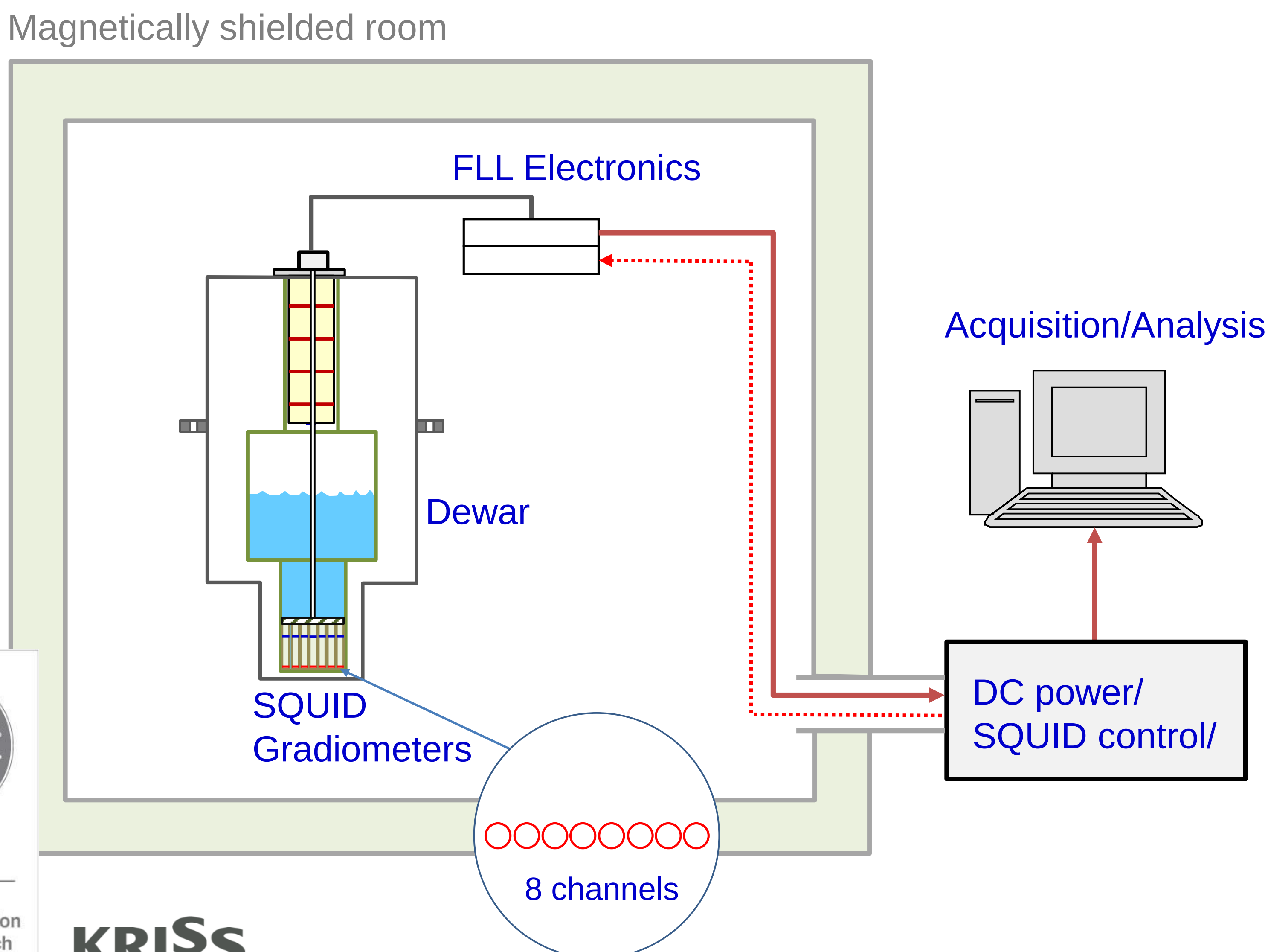
35 years in SQUID Instrumentation:

Magneto-Encephalography (MEG) Systems
Magneto-Cardiography (MCG) Systems
Ultra Low Field Nuclear Magnetic Resonance (ULF NMR)
Ultra Low Field Magnetic Resonance Imaging (ULF MRI)
Superparamagnetic Relaxation with Nanoparticles (SPMR)
Neutron EDM experiments at LANL

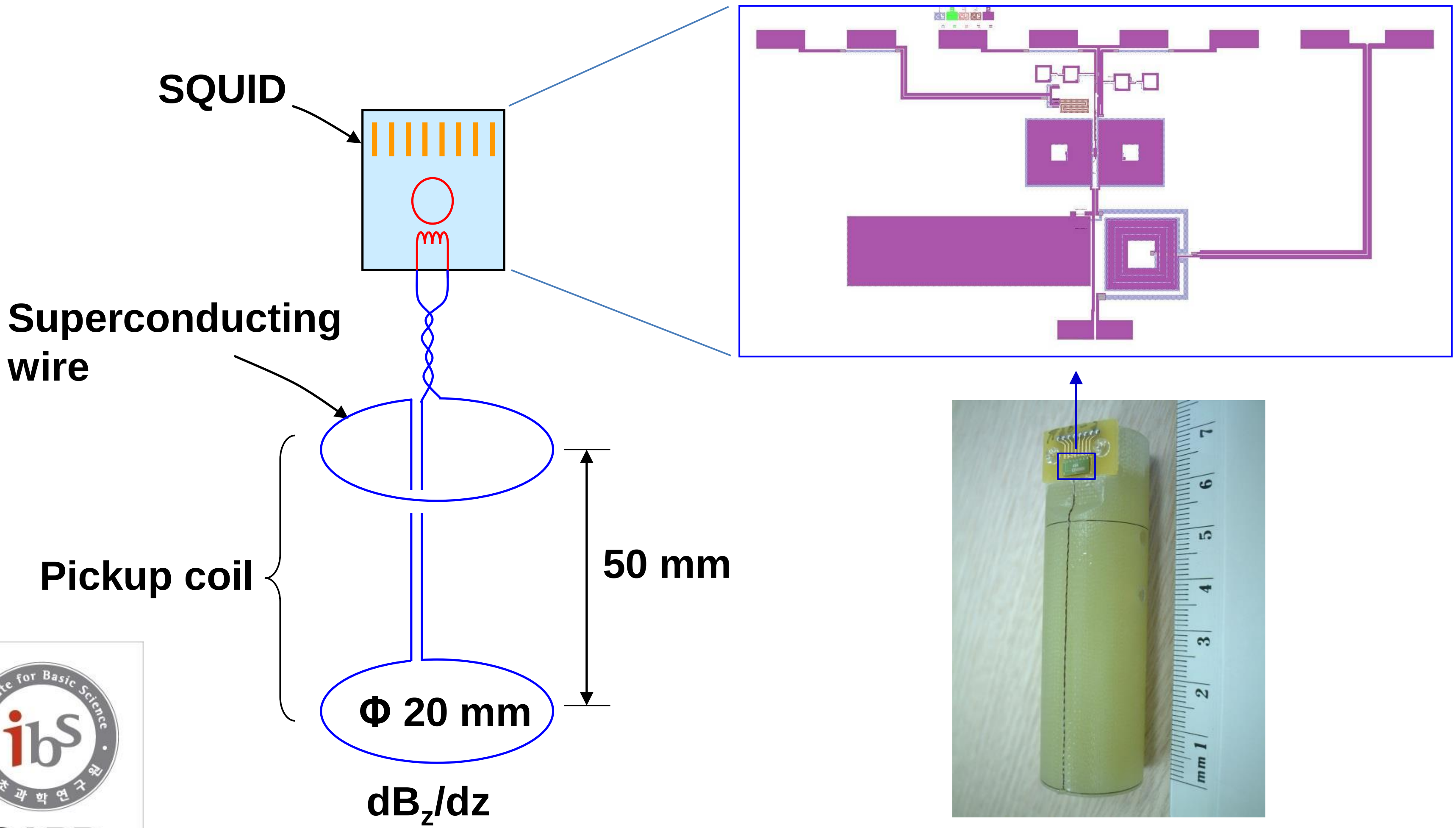
All SQUID-involved projects and experiments at CAPP

CAPP
Center for Axion and Precision Physics Research

G1 Beam Position Monitoring SQUID system



Axial Wire-Wound First-Order Gradiometers



Pickup coil: Diameter 20 mm, baseline 50 mm

CAPP
Center for Axion and Precision Physics Research

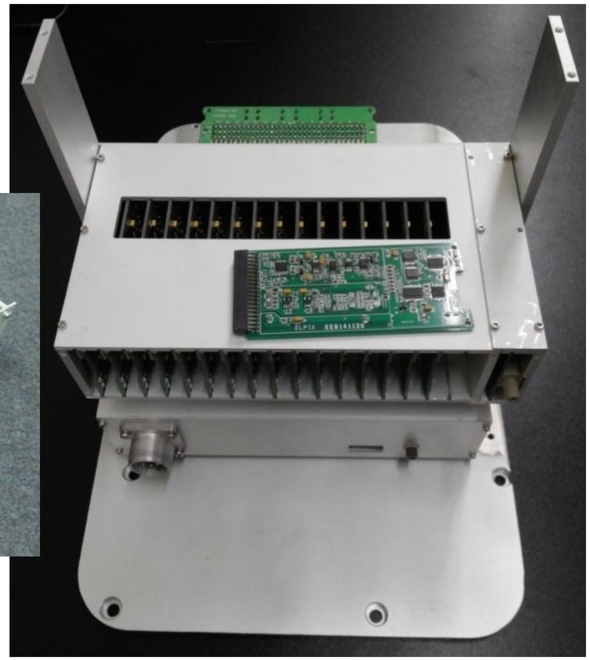
KRISS

3-Layer Magnetically Shielded Room at CAPP

CAPP
Center for
Axion and Precision
Physics Research

SQUID Electronics

Flux-lock loop circuits



DC-power and acquisition

High-pass filter: 200 Hz
Low-pass filter: 2 kHz
Sensitivity: 1.0 nT/V and 0.01 nT/V with Gain = 100
LSB: 15 × 10^{-15} T and 0.15 × 10^{-15} T with Gain = 100

Institute for Basic Science
ibs
CAPP
Center for Axion and Precision Physics Research

G2 Beam Position Monitoring SQUID system

Number of SQUIDs: 2 × 8

Pickup coil: 2-turn wire-wound magnetometer, Ø 20 mm

SQUIDs-in-Vacuum

Superconductive Shielding

Superconducting Imaging Surface → the First-Order Gradiometers

Cylindrical Dewar

System Field Resolution: 0.5 fT/√Hz @1 kHz

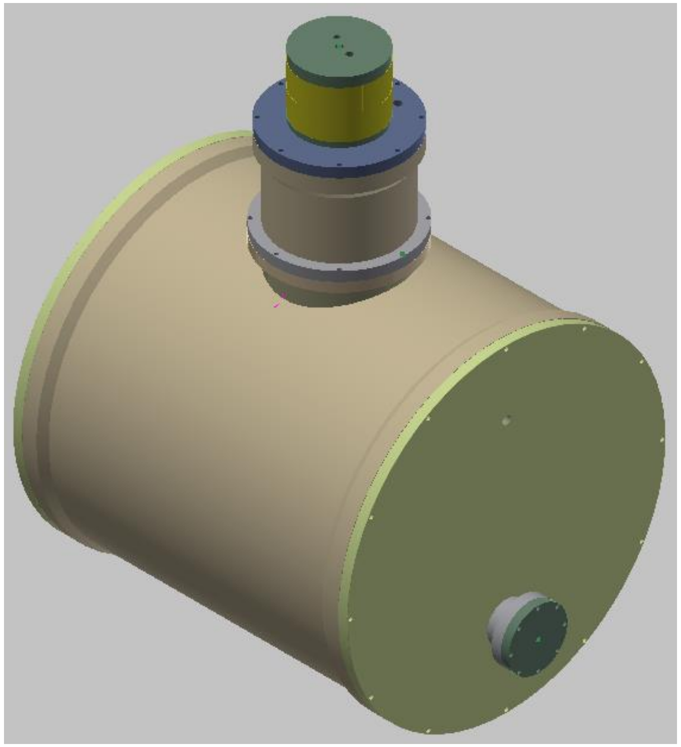
CAPP
Center for Axion and Precision Physics Research

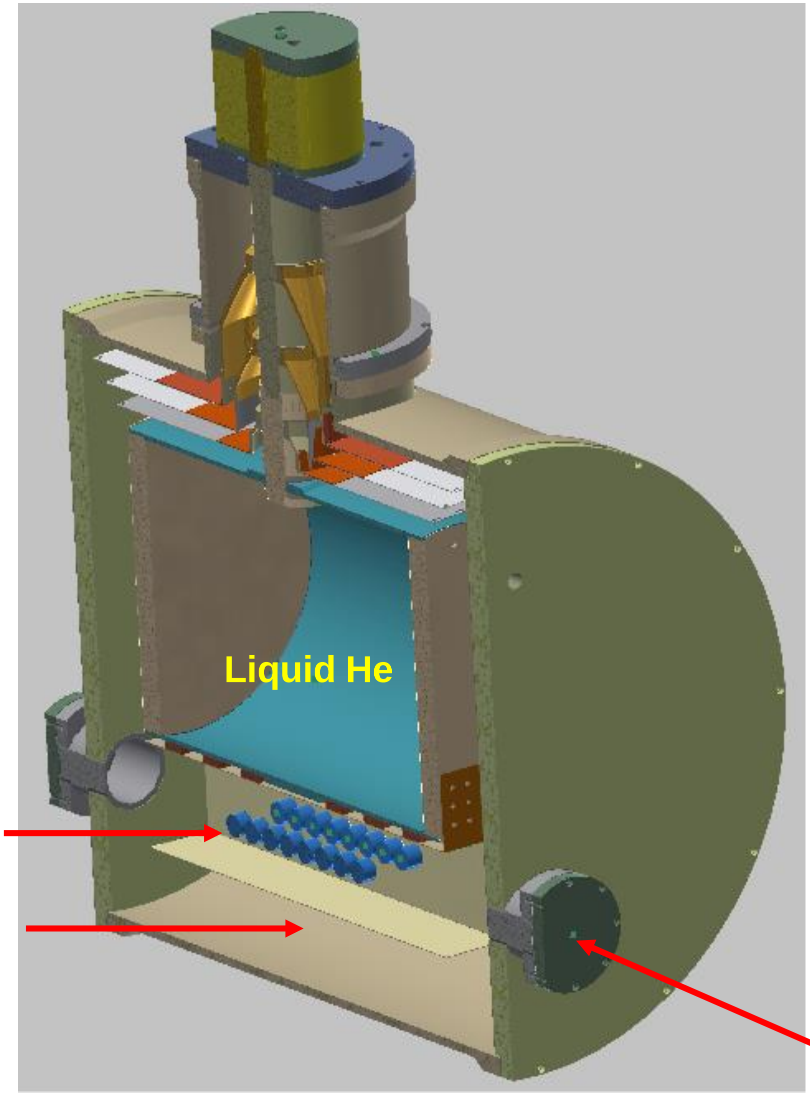
Superconductor imaging surface magnetometry

David B. van Hulsteyn, Albert G. Petschek, Edward R. Flynn, and William C. Overton, Jr.
Los Alamos National Laboratory, Physics Division, Los Alamos, New Mexico 87544

(Received 14 November 1994; accepted for publication 24 March 1995)

G2 Beam Position Monitoring: Concept

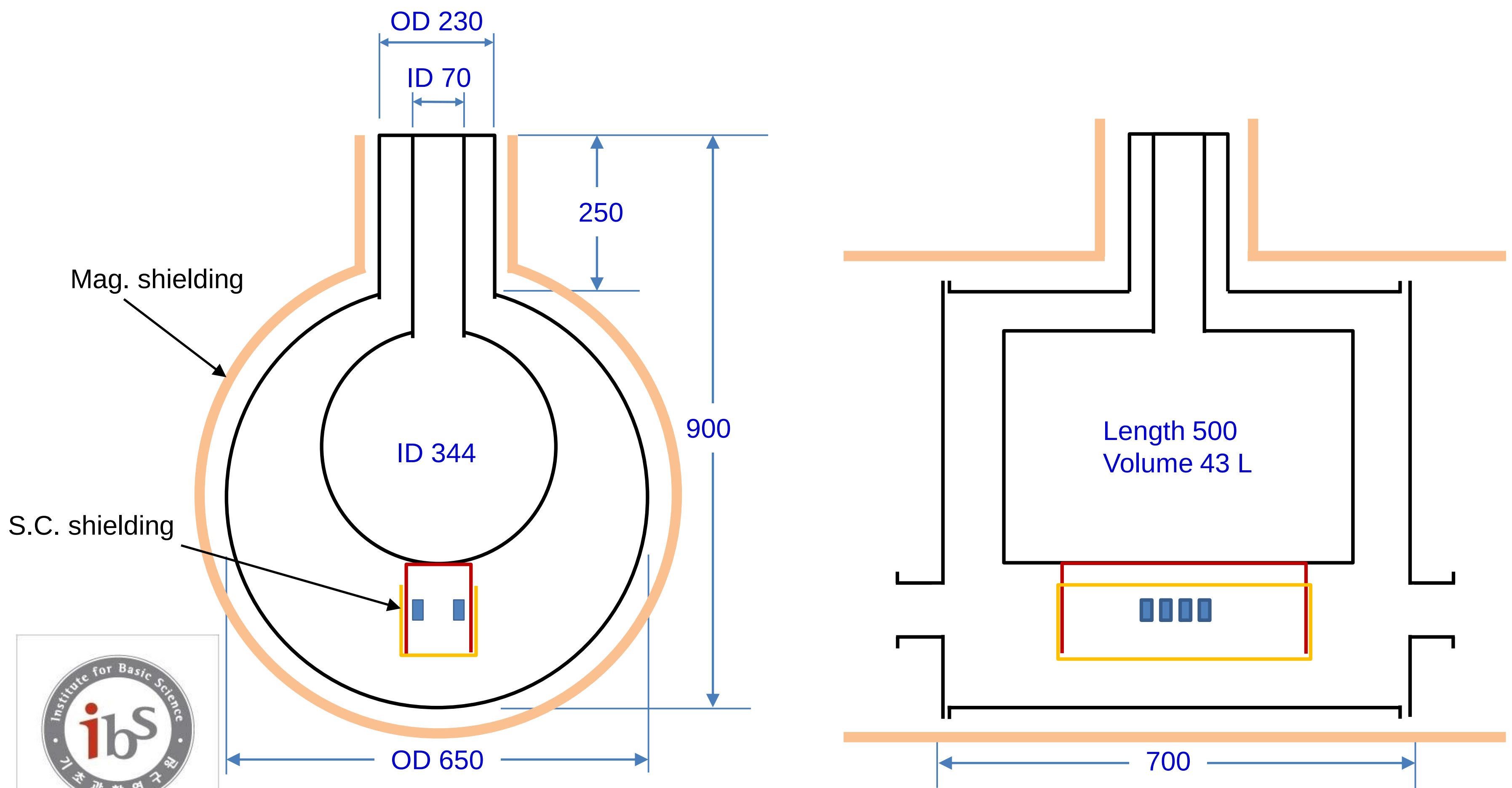




Institute for Basic Science
CAPP
Center for Axion and Precision Physics Research

KRISS

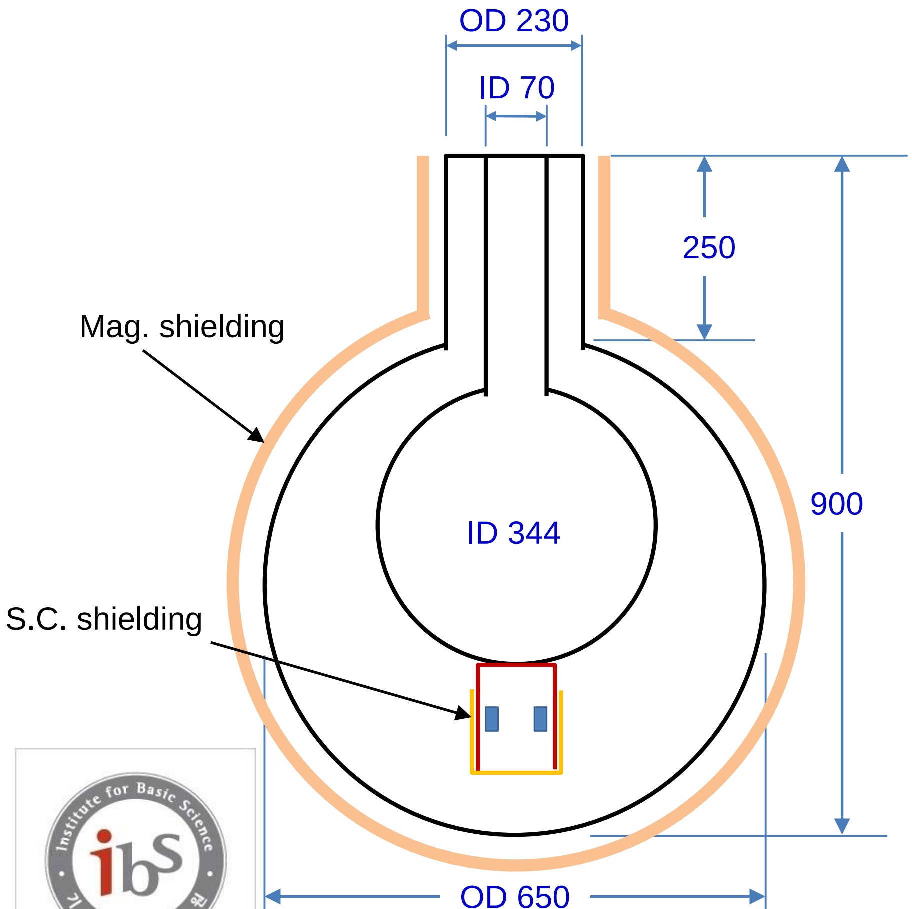
Cylindrical Cryostat: Dimensions

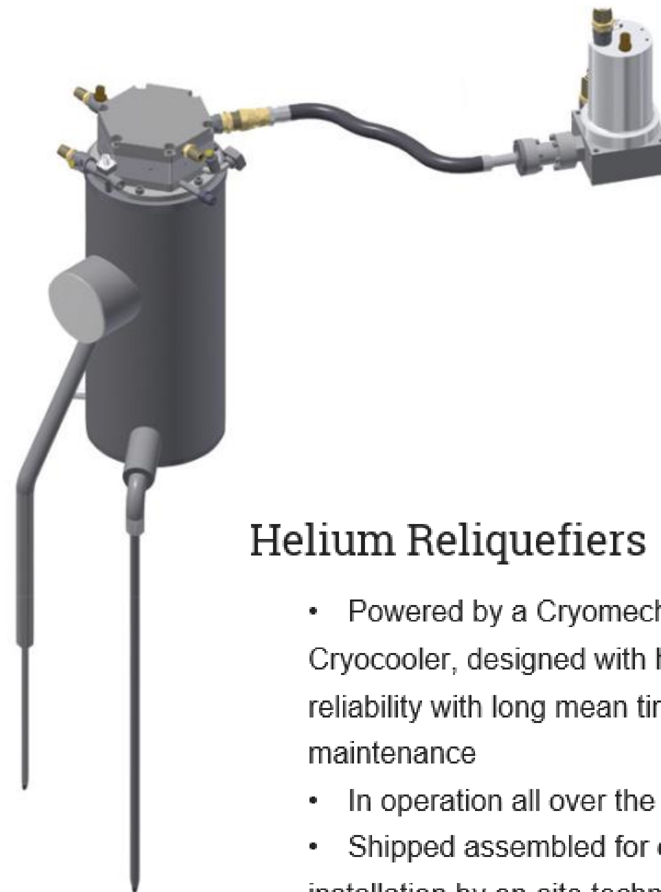


CAPP
Center for Axion and Precision Physics Research

KRISS

Cylindrical Cryostat: Re-Liquefier





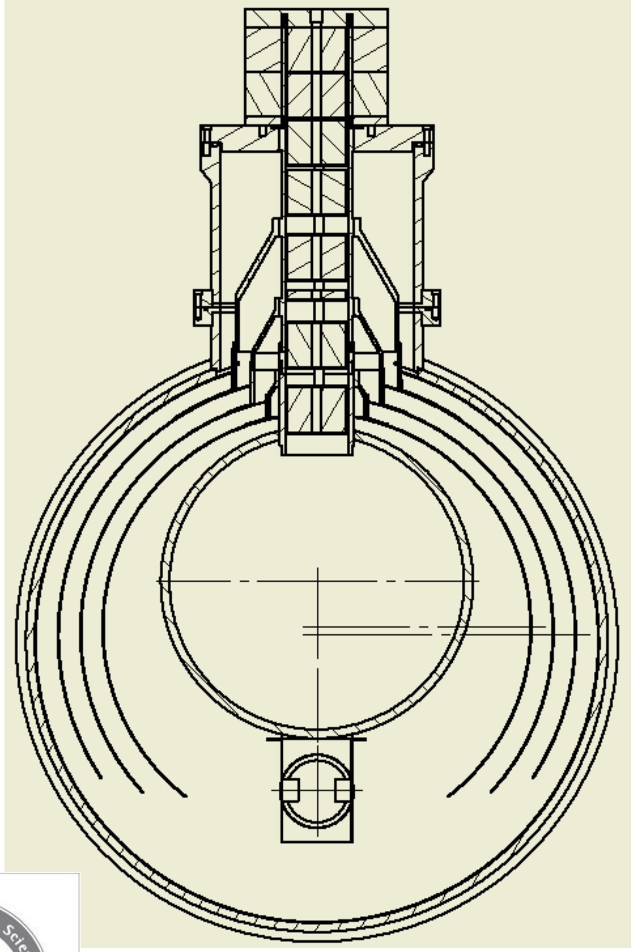
Helium Reliquefiers

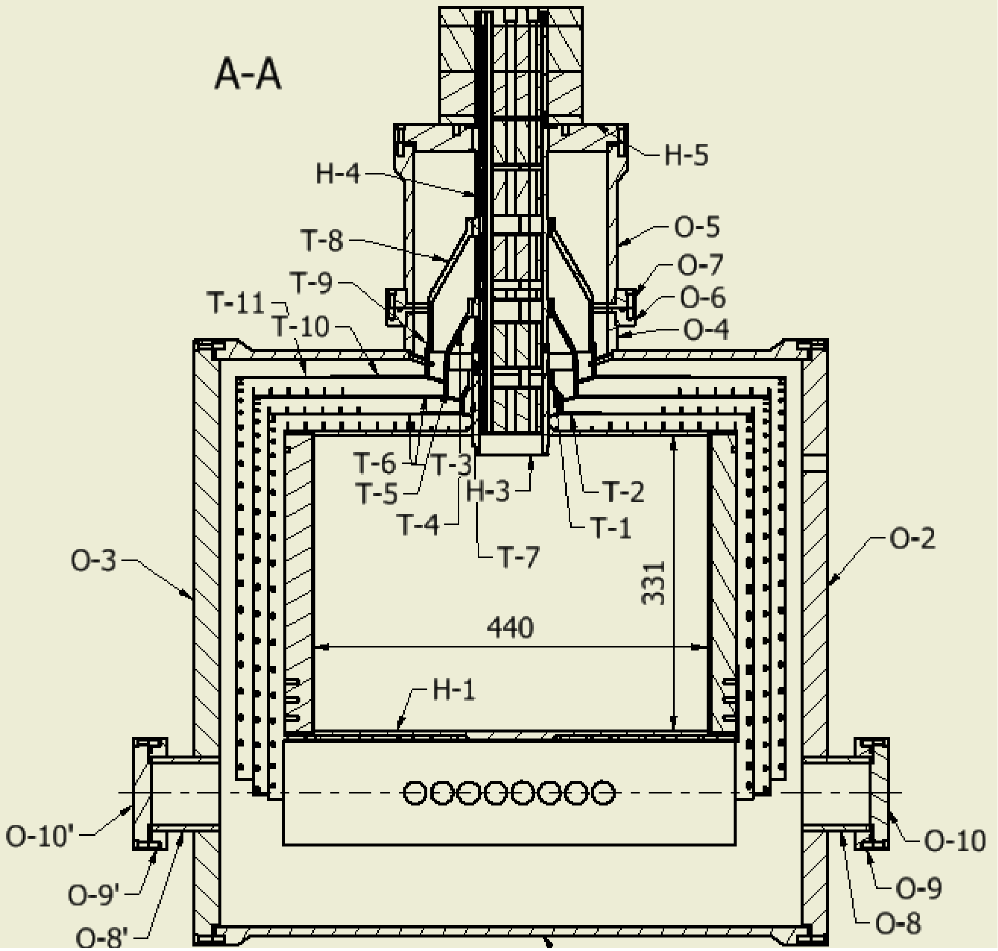
- Powered by a Cryomech Pulse Tube Cryocooler, designed with high reliability with long mean times between maintenance
- In operation all over the world
- Shipped assembled for ease of installation by on-site technician
- Operate 24 hours a day, 7 days a week reliably, automatically and safely
- Customized design for each application

CAPP
Center for Axion and Precision Physics Research

KRISS

Cylindrical Cryostat: Engineering Drawings





CAPP
Center for Axion and Precision Physics Research

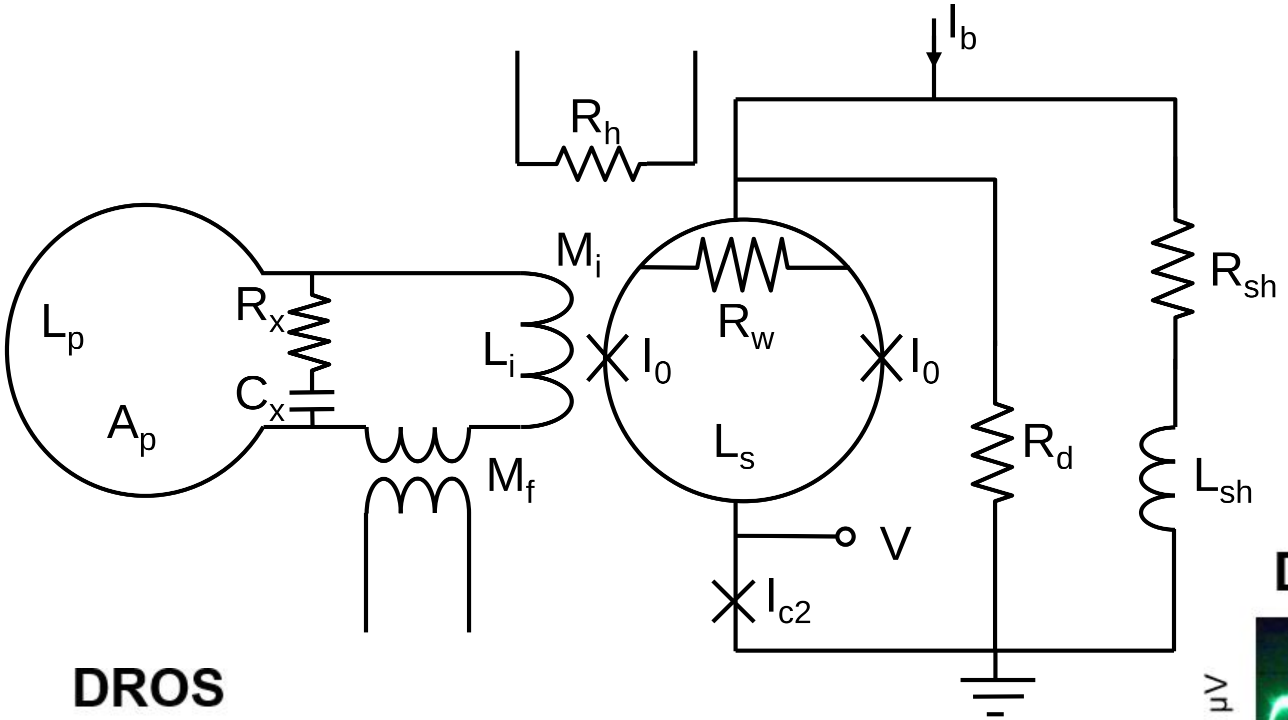
KRISS

Cylindrical Cryostat: Parts

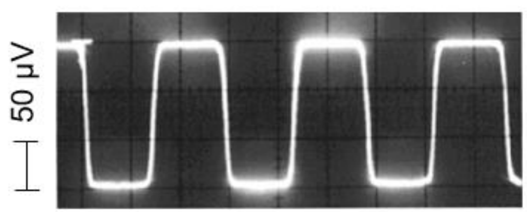
CAPP
Center for
Axion and Precision
Physics Research

KRISS

Double Relaxation Oscillation SQUIDs at KRISS



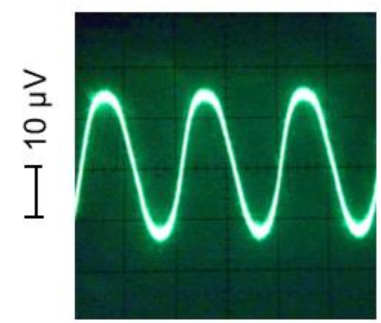
DROS



V_m= >100 µV_{pp}

V_Φ=~1000 µV/Φ_0

DC-SQUID



V_m=~30 µV

V_Φ=~100 µV/Φ_0

KRISS

New Generation State-of-the-art SQUIDs

Device name	ML2A	ML2B	ML4.5	ML7	ML12
Number of loops	8	4	8	10	12
Chip size (mm^2)	2.5 × 2.5	2.5 × 2.5	5.0 × 5.0	7.5 × 7.5	12.5 × 12.5
Outer pickup coil dimension (mm)	2.0	2.0	4.5	7.0	12.2
Transfer function, $1/A_{eff}$, (nT/Φ_0):					
Measured	5.55	3.03	1.09	0.57	0.25
Calculated	5.54	2.48	1.10	0.56	0.26
Junction size (μm × μm)	0.8 × 0.8	0.8 × 0.8	0.8 × 0.8	0.8 × 0.8	0.6 × 0.6
Junction critical current, I_c, (μA)	9.3	11.9	8.0	7.5	2.3
Damping resistance, R_n, (Ω)	19.8	16.0	19.8	18.6	47.8
Calculated SQUID inductance L (pH)	130	375	270	325	300
β_L	1.19	4.30	2.10	2.34	0.67
β_C	0.44	0.37	0.38	0.31	0.36
Voltage swing (μV_{pp}):					
Measured	170	145	135	110	100
Calculated	175	150	135	115	110
SQUID noise					
Intrinsic flux noise ($\mu\Phi_0$ $Hz^{-1/2}$) :					
Measured	0.63	1.50	1.10	1.23	1.34
Calculated	0.42	1.21	0.82	1.00	0.75
Measured intrinsic field noise (fT $Hz^{-1/2}$)	3.5	4.5	1.2	0.7	0.33
Energy resolution:					
Measured (h)	9.7	19.5	14.5	15.1	19.3
Calculated (h)	4.4	12.7	8.0	10.0	5.8

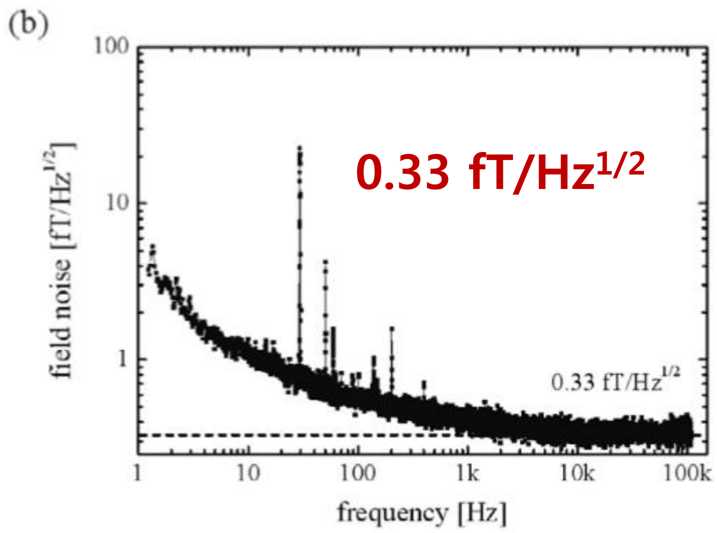


Figure 2. Typical noise spectra of two multi-loop SQUID magnetometers; (a) magnetometer of type ML7 with 0.8 μm × 0.8 μm Josephson junctions and (b) of type ML12 with 0.6 μm × 0.6 μm Josephson junctions.

Pick-up Loop: 12 × 12 mm^2
Noise = 0.33 fT/$Hz^{1/2}$

→

Pick-up Loop: 24 × 48 mm^2
Noise = 0.11 fT/$Hz^{1/2}$

CAPP
Center for Axion and Precision Physics Research

IPHT, Jena, Germany (2011)
Supercond. Sci. Technol. 24 (2011) 065009(5pp)
doi:10.1088/0953-2048/24/6/065009

SUMMARY

- ❖ The First generation (G1) of BMP system: tested at KRISS and moved to CAPP for further tests and research.
- ❖ The Second generation (G2) of BMP system: simulated, designed, key components manufactured; it will be assembled and tested in 2017.
- ❖ Field Resolution: current G1 system → 1.5 $fT/\sqrt{Hz}$ @1 kHz
- ❖ Field Resolution: under construction G2 system → 0.5 $fT/\sqrt{Hz}$ @1 kHz
- ❖ Field Resolution: new generation SQUIDs → 0.15 $fT/\sqrt{Hz}$ @1 kHz

CAPP
Center for Axion and Precision Physics Research

TANKS FOR YOUR ATTENTION !

CAPP
Center for
Axion and Precision
Physics Research