CAPP
Center for Axion and Precision Physics Research

CULTASK, Launching Axion Experiment in Korea

Woohyun Chung

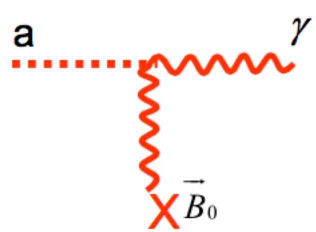
Center for Axion and Precision Physics Research (CAPP)
Institute for Basic Science (IBS)

OUTLINE

- OVERVIEW
  - Axion & Dark Matter
  - CAPP's Axion programs
  - R&D projects
- CULTASK (CAPP's Ultra Low Temperature Axion Search in Korea) 2016 with Two BlueFors DRs
  - Cavity Development & RF Testing
  - Engineering Run (complete RF chain) in 2016
- Plans beyond 2016
  - Low Vibration Pads (LVP) with Four more DRs in 2016
  - Major improvements by 2018
- Summary

Axion & Dark Matter

- Peccei and Quinn (1977) postulated an elegant solution by adding a new global symmetry to resolve the Strong CP Problem in Standard Model
- Axion is an excellent (and attractive) dark matter candidate
  - Pseudo Goldstone Boson
  - No Electric Charge
  - Small Mass ($1\mu eV < m_a < 10 meV$)
  - Extremely Weakly Interacting
  - Local Halo Density of 0.45 GeV/cm^3
  - $\beta \sim 10^{-3} \rightarrow Q_a \sim 10^{-6}$
- Detection scheme by P. Sikivie (PRL 51:1415 1983) : Haloscopy
  - Axions will convert to photons in a strong magnetic field



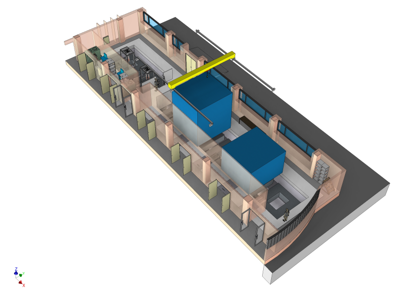
$$L_{a\gamma\gamma} = g_\gamma \frac{\alpha}{\pi} \frac{a}{f_a} \vec{E} \cdot \vec{B}$$

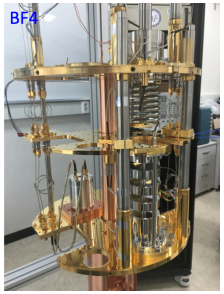
Overview

Axion Research at CAPP

CULTASK

Lead: Woohyun Chung
2 DRs installed and operational
Complete RF chain (w/ DAQ) soon
4 more frig. in Nov. at LVP



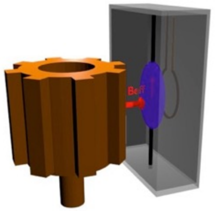


CAPP/CAST

Lead: Lino Miceli
First installation at CAST

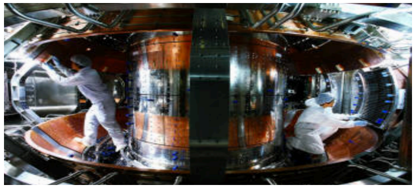
ARIADNE

Lead: Yunchang Shin
NMR based
R&D in progress



Large Toroid

Lead: Beongrok Ko
Requires big collaboration
R&D in progress



CULTASK

P. Sikivie's Haloscope:

Axion Conversion Power (~10^{-24}W): $P_{a\to\gamma\gamma} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B^2 V C_{mnp} \min(Q_L, Q_a)$

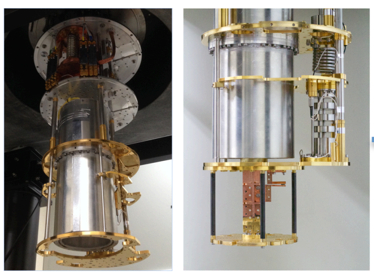
Signal to Noise Ratio: $SNR \equiv \frac{P_{signal}}{P_{noise}} = \frac{P_{a\to\gamma\gamma}}{k_B T_{syst}} \sqrt{\frac{t_{int}}{\Delta f_a}}$

Scan rate: $\frac{df}{dt} \sim B^4 V^2 C^2 Q_L T_{syst}^{-2}$

Cryogenics

<100mK

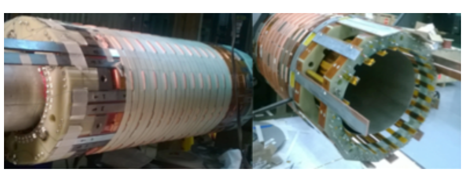
Prof. Hyoungsoon Choi of KAIST



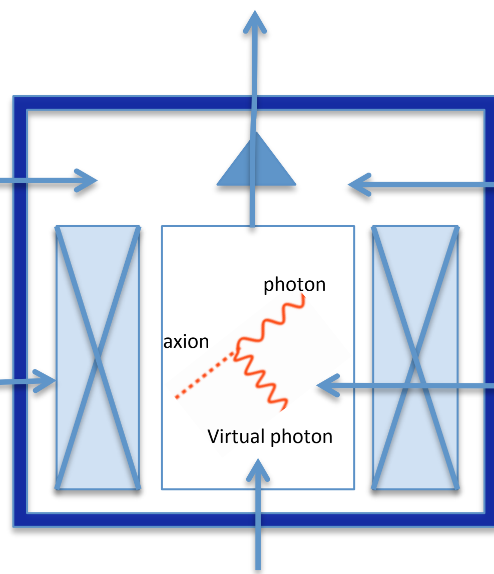
High Field SC Magnet

25T and then 35T or 40T

BNL (HTS Technology) Design



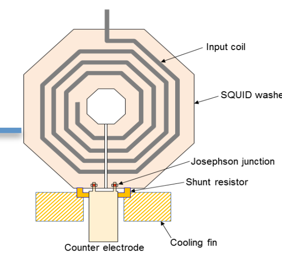
To RF Receiver



(Reverse) Primakoff Effect

SQUID Amplifier

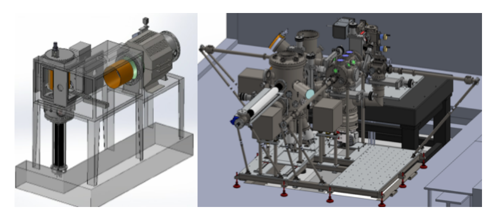
Outsourced Research from KRISS



High Q Tunable Cavity

Superconducting Coating

Prof. Jhinhwan Lee of KAIST



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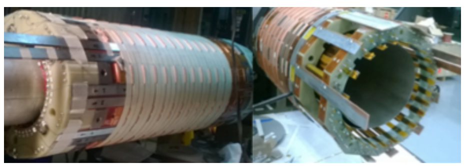
R & D

R&D for Axion Research

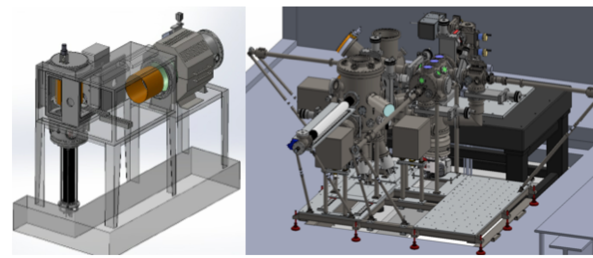
SC Magnets

HTS 25T-10cm (->35T or 40T) by BNL
HTS 21T-5cm (SuNAM)
HTS 26T-3.5cm (SuNAM:WR)
LTS 12T-35 cm (Oxford)
Small Toroid 12T, V=80 L
Giant Toroid 5T, V=9900 L

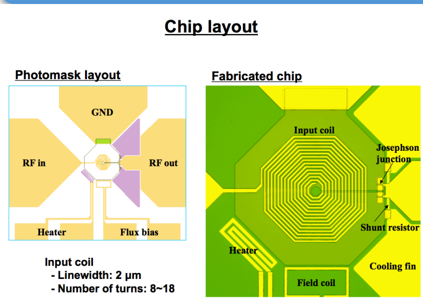


SC High Q Cavity

Jhinhwan Lee and Wonjun Jang
Equipment setup in progress
First Sputtering Sc coating

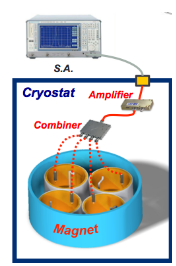


SQUID Amp



Yong-ho Lee of KRISS
Delivery in 3 years
In parallel : JPA / SLUG
commercial:ez-SQUID

Multiple Cavities



SungWoo Youn
Higher Freq.
Phase locking
R&D in progress

Refrigerators & SC Magnets

BF3:RF and Cavity test

BF4:Complete RF readout with DAQ
+ HEMT
+ 10cm Cu cavity
+ FTS

NbTi
8T-10cm

RF Room

BF5

BF6

DRS-1000

JANIS-He3

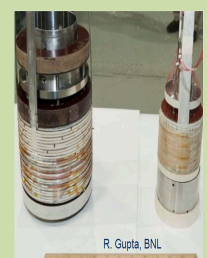
NbTi
8T-15cm

NbTi
8T-10cm

HTS
25T-10cm
From BNL

HTS
21T-5cm
SuNAM

LTS
12T-35cm
Oxford



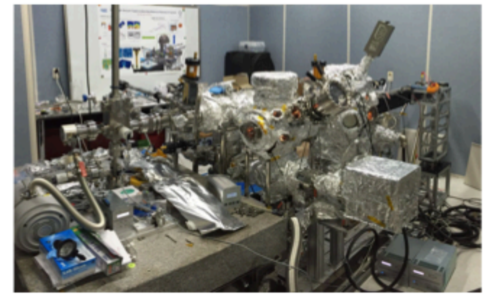
HTS
26.4T-3.5cm
SuNAM - WR

LVP

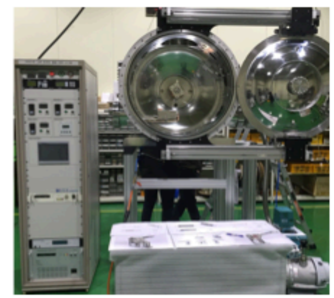
Superconducting Cavity

Process for manufacturing of superconducting cavity

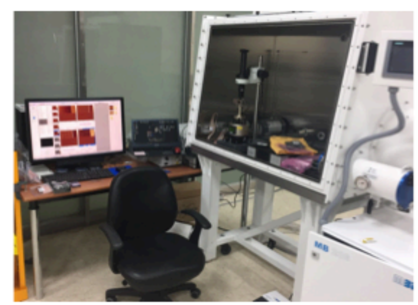
R&D of recipe for Nb_3Sn or FeSe film on small substrate
1. Molecular beam epitaxy system (Growth of Nb_3Sn film)
2. LEED & RHEED (Characterization of Nb_3Sn film)
3. Low temperature UHV-STM (Superconductivity)



Application of growth of Nb_3Sn film on cavity
1. Molecular beam epitaxy system (Growth of Nb_3Sn film)
2. Radiative thermal heater (Superconductivity)
3. 4 probe measurement (Superconductivity)



Anodized Al oxide for vortex pinning
1. Chemical etching system (Growth of AAO surface)
2. Atomic force microscope (Characterization of AAO surface)

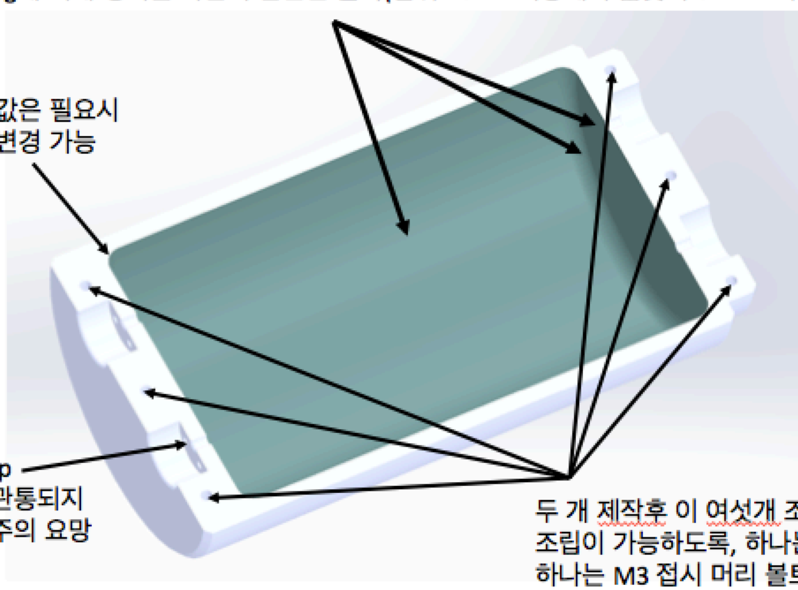


By Won-Jun Jang

Superconducting Cavity

청자색 내부면을 거울 수준 (요철 1um 미만) polishing 처리.
눈에 보이는 수준의 가공 요철, 단차, 주름 등은 일체 없어야 함.
Polishing에 의해 생기는 약간의 완만한 굴곡(범위 10mm이상에서 높낮이 0.1mm미만)은 허용.

5mm R값은 필요시
의논후 변경 가능

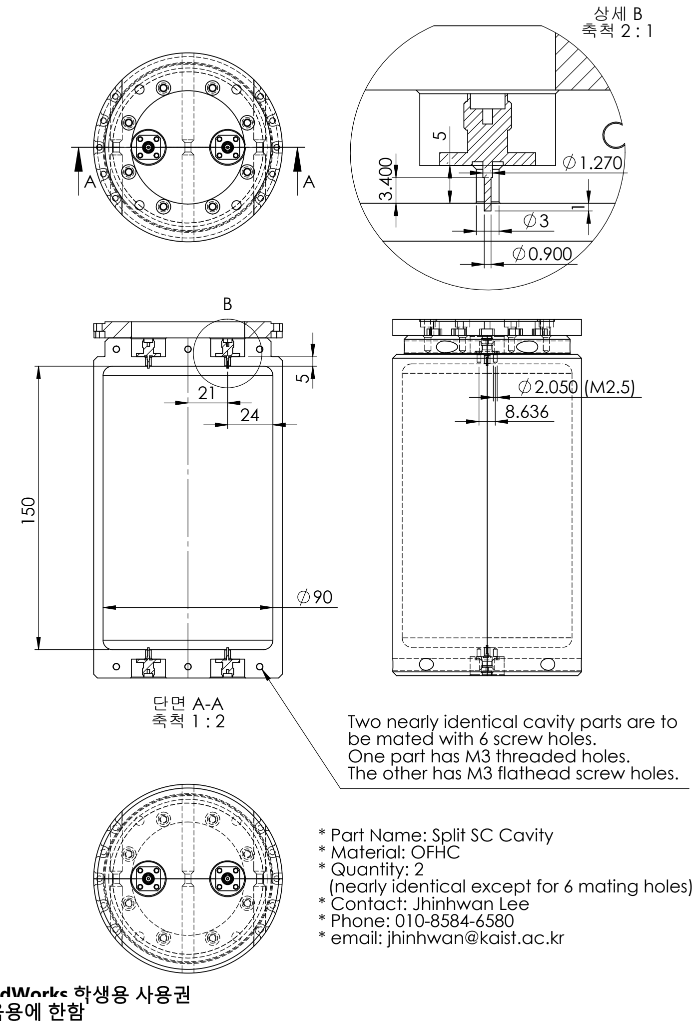


M2.5 tap
내부로 관통되지
않도록 주의 요망

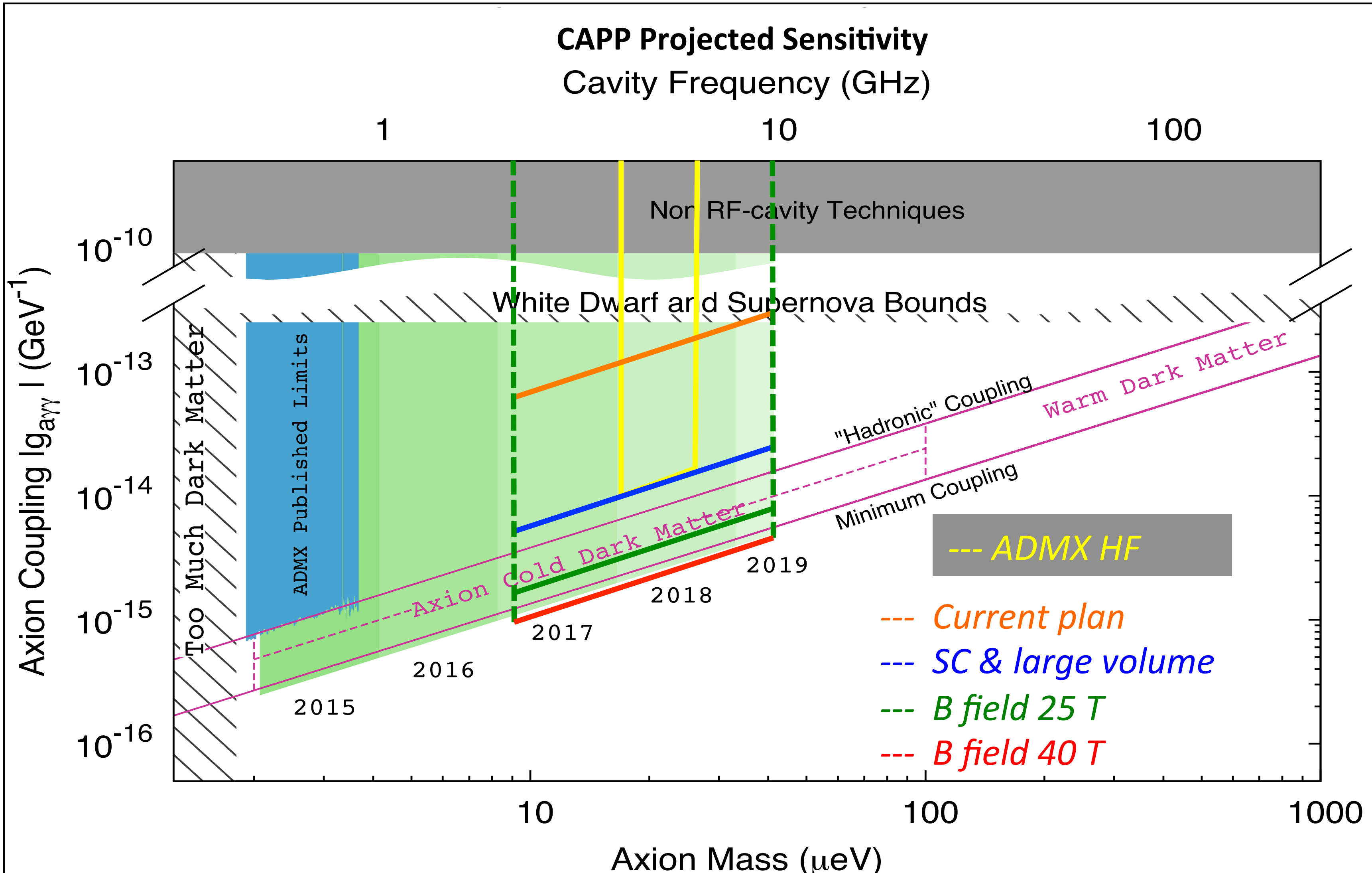
두 개 제작후 이 여섯개 조립 구멍을 이용한
조립이 가능하도록, 하나는 M3 tap,
하나는 M3 접시 머리 볼트 구멍 으로 제작.

수량: 2
재질: OFHC Copper

연락처:KAIST 이진환
(010-8584-6580, Jhinhwan@kaist.ac.kr)



Overview



CAPP Projected Sensitivity
Cavity Frequency (GHz)
1
10
100
Non RF-cavity Techniques
White Dwarf and Supernova Bounds
Too Much Dark Matter
ADMX Published Limits
Axion Cold Dark Matter
Warm Dark Matter
"Hadronic" Coupling
Minimum Coupling
2015
2016
2017
2018
2019
--- ADMX HF
--- Current plan
--- SC & large volume
--- B field 25 T
--- B field 40 T
Axion Coupling |gaγγ| (GeV-1)
10-10
10-13
10-14
10-15
10-16
10
100
1000
Axion Mass (μeV)

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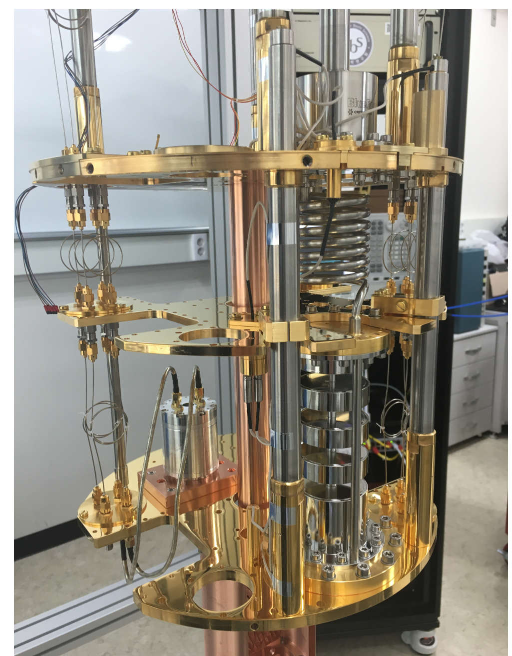
CULTASK 2016 w/ Two DRs

Two BlueFors Dilution Refrigerators were delivered, installed and are operational now!

2016

FEB	MAR	APR	MAY	JUN	JUL

- Delivered (FEB)
- Installed (end of FEB)
- Test and Training (APR)
- MAY–JUL: Cavity Development w/ pure Cu and Al; Noise Figure Measurement w/ HEMT amp



CULTASK 2016 w/ Two DRs

	BF3	BF4
Model	BlueFors LD400	BlueFors LD400
Magnet	None	8T (AMI), 12cm ID
RF lines	24	8
DC lines	72	72
Cool down to <10 mK	20 ~ 24 hours	40 ~ 48 hours
Base temp at MXC	9 mK	7 mK w/ SC magnet
MXC temp w/ Load	11 mk w/ Al cavity (4cm id) and HEMT amp	30 mk w/ 10 kg OFHC copper support structure and cavity + HEMT amp + Network Analyzer + Piezo Controller

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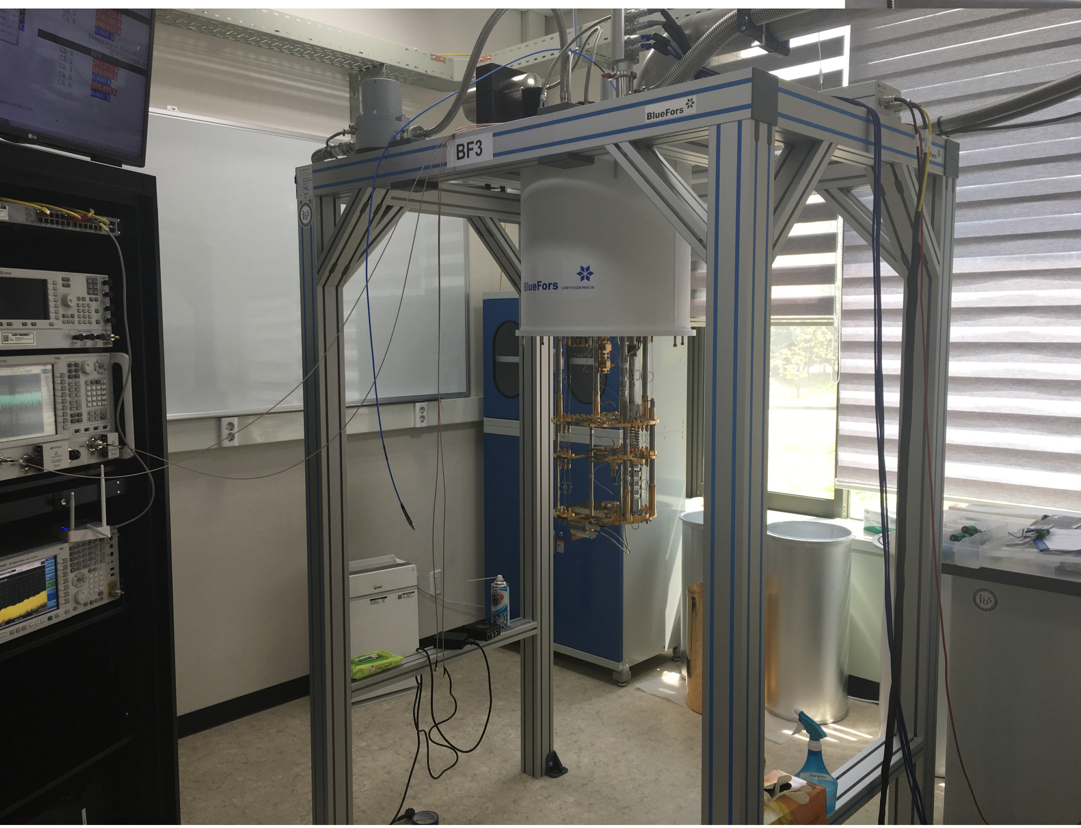
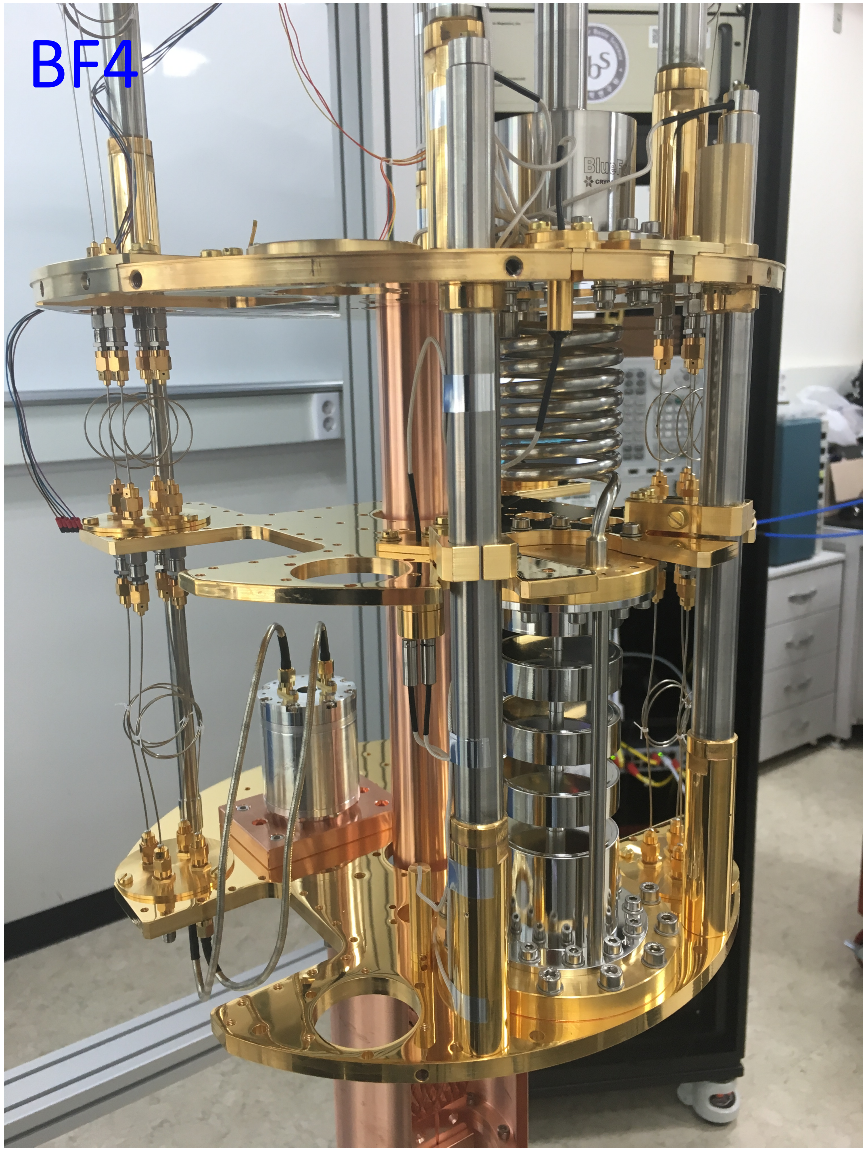
CULTASK 2016 w/ Two DRs

BF3



BF4

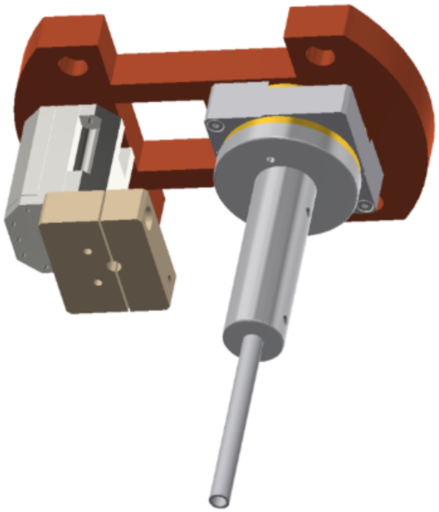
CULTASK 2016 w/ Two DRs

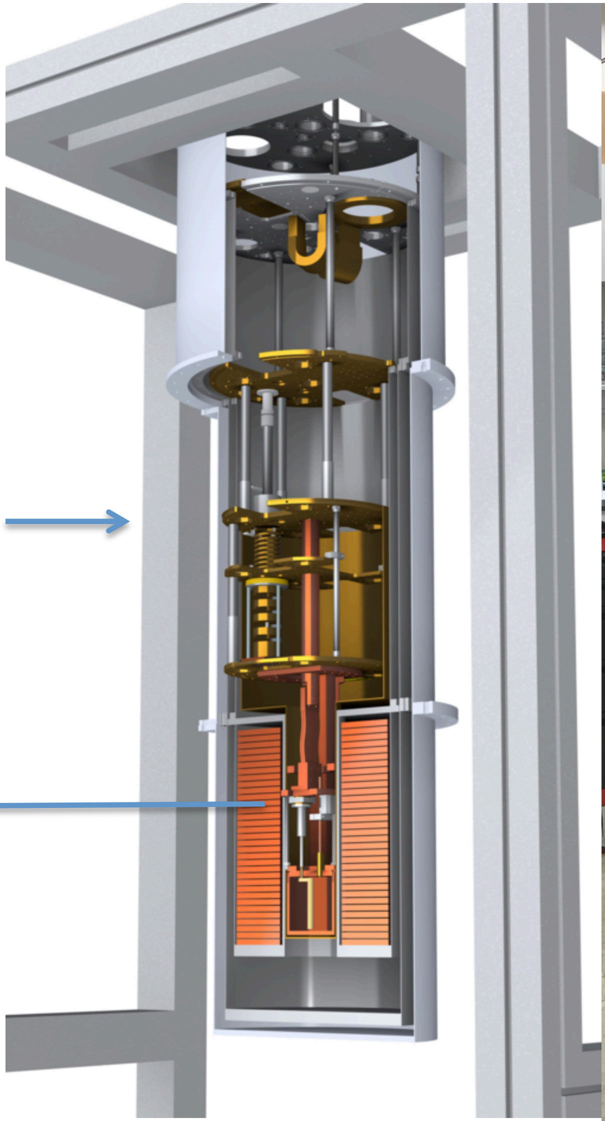


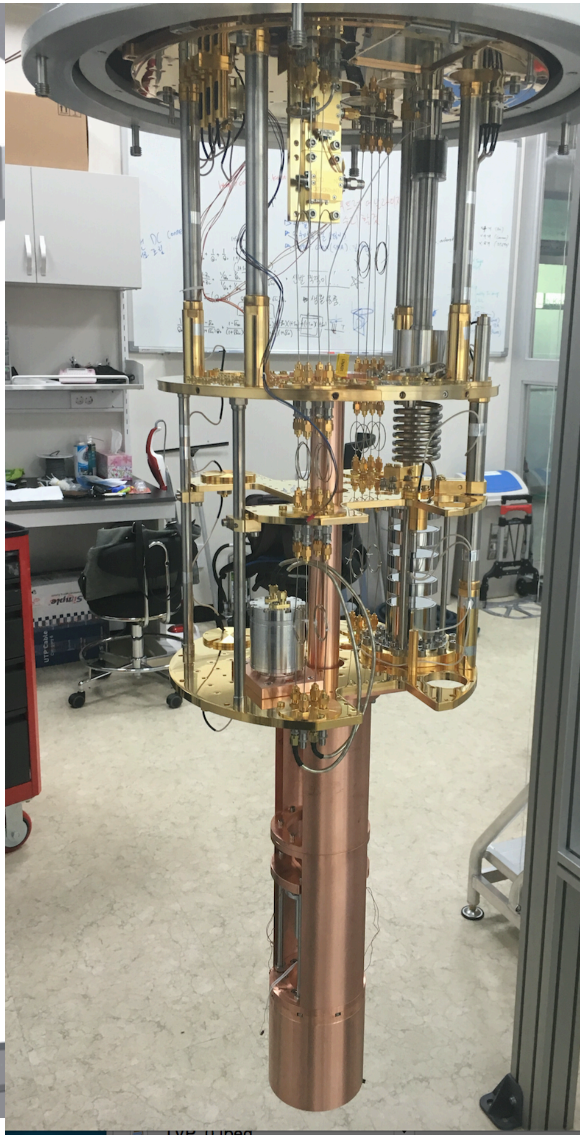
CULTASK 2016 w/ Two DRs

OFHC Support Structure and Frequency Tuning System

- Cu Cavity of 10cm OD
- Modular design
- Sapphire tuning rod, 1cm OD
- Rotational piezo for tuning
- Linear piezo for antenna
- Piezo holder thermally linked to 1K plate



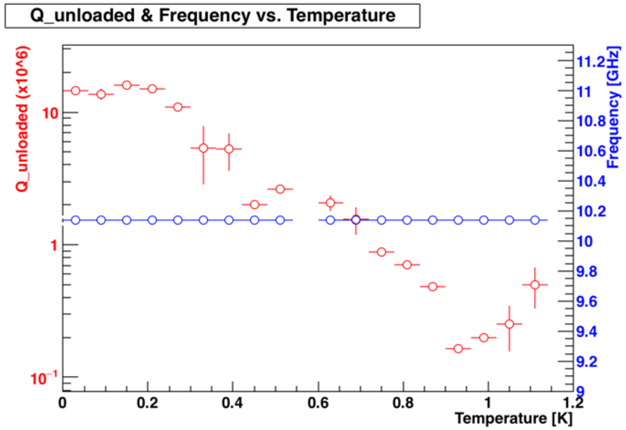


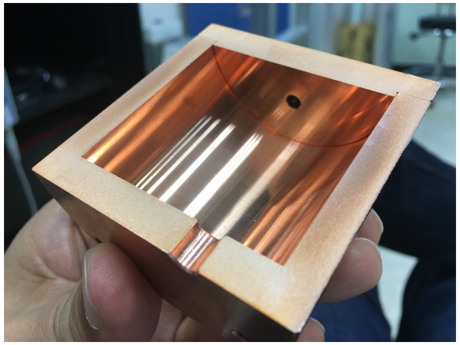


CULTASK 2016 w/ Two DRs

High Q-Factor Cavity Development:

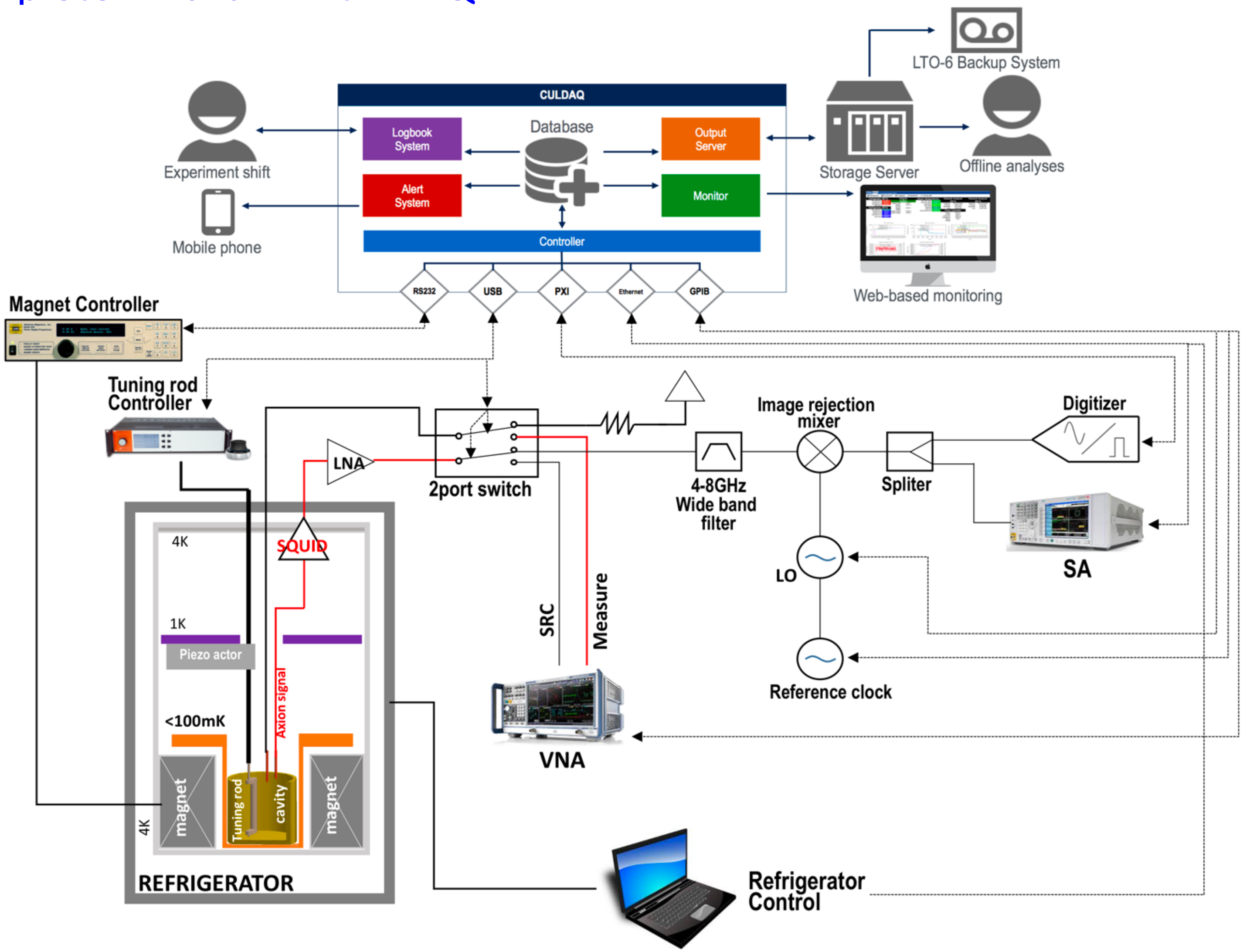
- Variety of samples (OFHC Cu, 5N Al, 6N Al with sizes and different types of lids were tested
- Beginning to use Annealing Furnace to investigate annealing temp. and duration
- Superconducting Al:
    - Al becomes superconducting below 1.2K
    - Q-factor grows to >200,000 for TM010
    - TE011 mode (no contact problem: Fritz's suggestion)
      Q-factor : ~2M at ~800 mK and ~20M at 11 mK
- Split cavity < --- > diffusion bonding
    - Q-factor of cavity cut in half stays the same – verified
    - It could eliminate contact problem between lids and wall
    - Will be useful for superconductor coating





CULTASK 2016 w/ Two DRs

Complete RF chain with DAQ

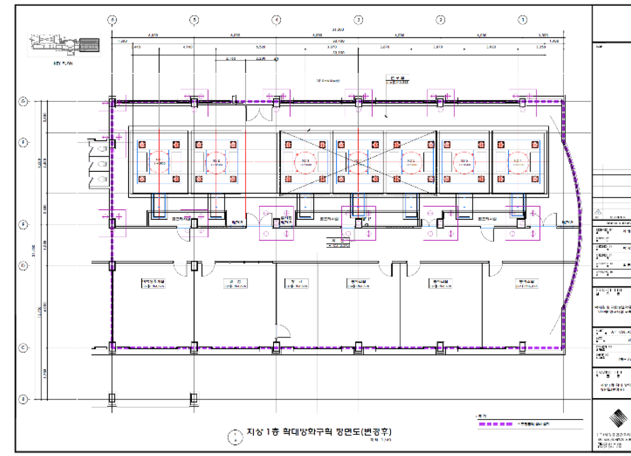


CULTASK 2016 w/ Two DRs

- New Lab space in
  - KAIST Munji Campus Creation Hall (RF room) completed
- Two BlueFors DRs (one w/ 8T SC magnet)
  - RF Room infrastructure done (esp. electricity and chiller)
  - Delivered and installed: end of Feb.
  - Design 10 cm cavity (~2.5 GHz) and support structure with frequency tuning system
  - Cryo RF noise figure measurement
  - Complete RF chain set-up with DAQ
  - Fake axion signal injection (blind test?)
  - Take reasonable sensitivity DATA in 2016
- 4 More DRs and 2 magnets in Oct. (LVP)

Plans beyond 2016

Axion Lab with 7 Low Vibration Pads in KAIST Munji campus



	2014	2015	2016	2017	2018	......
Essential Equipments	CF-DR(RF1) CF-DR(magnet) Wet-He3(large bore)					
Quantum Amplifier Research		CF-DR(RF2)				
Small-sclae Integration		CF-DR(testbed)				
Low-noise Experiments			Wet-DR1(precision) Wet-DR2(precision)			
AxionDetector main				Main DR (Axion Detector)		
Helium Liquefier			Helium Liquefier			

Plans beyond 2016

	2015	2016	2017	2018	2019
Lab Space	Munji Campus Design & Renovation	LVP	Occupation		
High Field Magnet	Prototype, testing of SuperC cables	25T-10cm design 21T-5cm delivery 15T-35 cm production		Magnet Delivery	
SC Cavity Development	Procure Equip. Study res. and geom.	Development of high Q SC resonator	Production of high Q resonator		
SQUID Amplifier	Design and production of prototype SQUID for 1-10 GHz Acquire JPA and test		SQUID delivery from KRISS Develop higher freq. amplifier		
Axion Cavity Experiment	Building infrastructure. Engineering Run at KAIST	Experimental Setup at Munji Test Runs		High Field Magnet + SQUID + SC Cavity	
Cryogenics	Setup plan, acquisition	4 Dry DRs + Wet He3 DR + Wet DR		Main DR and He liquefier	

Summary

- State of the Art Axion Research at CAPP/IBS in Korea
- Major R&D Efforts
  - Higher B Field: HTS (21T, 25T…) + LTS (12T-35cm)
  - Higher Q Factor with B Field: Factor of >10 Improvement
  - Larger Volume: Toroidal Cavity
  - R&D for Higher Frequencies (>10 GHz)
- CULTASK 2016 ready to build a complete experiment
  - Cavity R&D and Cryo-RF testing
  - Could reach close to QCD Axion Sensitivity soon!
- Major improvement in Axion Experiment

  as early as in 5 years

Thank You For Your Attention!