Axion Research at CAPP/KAIST: Plans and progress

Woohyun Chung

Center for Axion and Precision Physics (CAPP)/KAIST
at
Institute for Basic Science

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- Detecting Axions
- ADMX and CAPP
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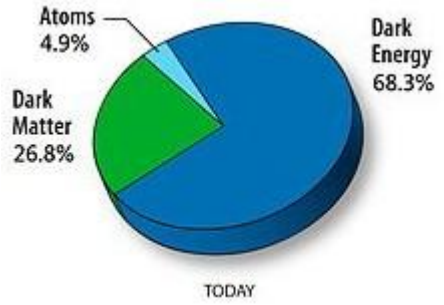
Center for Axion and Precision Physics (IBS/KAIST)

Axion & Dark Matter

- Strong CP Problem of QCD in Standard Model
- In 1977 Peccei and Quinn postulated an elegant solution by adding a new global symmetry
- Weinberg and Wilczek pointed out that the existence of a field implied a corresponding particle
- Hypothesized new particle called “Axion” (named after a popular brand of detergent)
- What is Axion?
  - Pseudo Goldstone Boson
  - No Electric Charge
  - Small Mass ($1\mu eV<m_a<100\mu eV$)
  - Very Weakly Interacting

- Dark Matter: A kind of matter to account for gravitational effects that appear to be the result of invisible mass
  - 84.5% of total matter in the universe
  - Doesn’t interact with light
  - Not the matter we know



Axion is an excellent Dark Matter Candidate!

Detecting Axions

- Wait 10^{50} seconds and an axion will naturally decay into two photons (not good!)

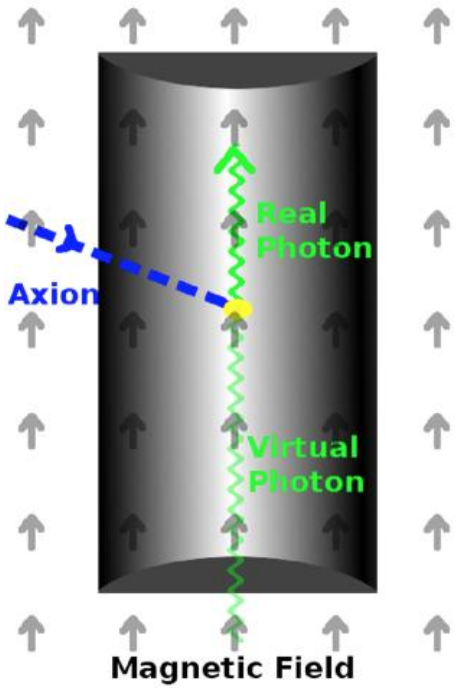
- Axion Haloscope (on earth): P. Sikivie's Scheme (Phys. Rev. Lett. 1983)

  - Axions will convert to photons in a strong magnetic field
  - Reverse Primakoff Effect
  - Enhanced (as much as Q of Cavity) signal if photon's frequency corresponds to the cavity's resonant frequency
  - Tunable, resonant cavity immersed in a strong B-field
  - Conversion Power: $P_a \propto VB_0^2Q$ (~ 10^{-22} Watt)
  - Signal power is so small: a great challenge to experimentalists
  - Sensitivity of the detector: Signal to Noise Ratio

$$\mathrm{SNR} = (P_a/P_N)\sqrt{bt} = (P_a/k_B T_S)\sqrt{t/b}.$$

  - Mass scan rate: 10 times cooler means 100 times more data!

$$dm_a/dt \propto (B_0^2 V)^2/T_S^2$$



Detecting Axions (cont'd)

J. HOSKINS *et al.* PHYSICAL REVIEW D **84,** 121302(R) (2011)

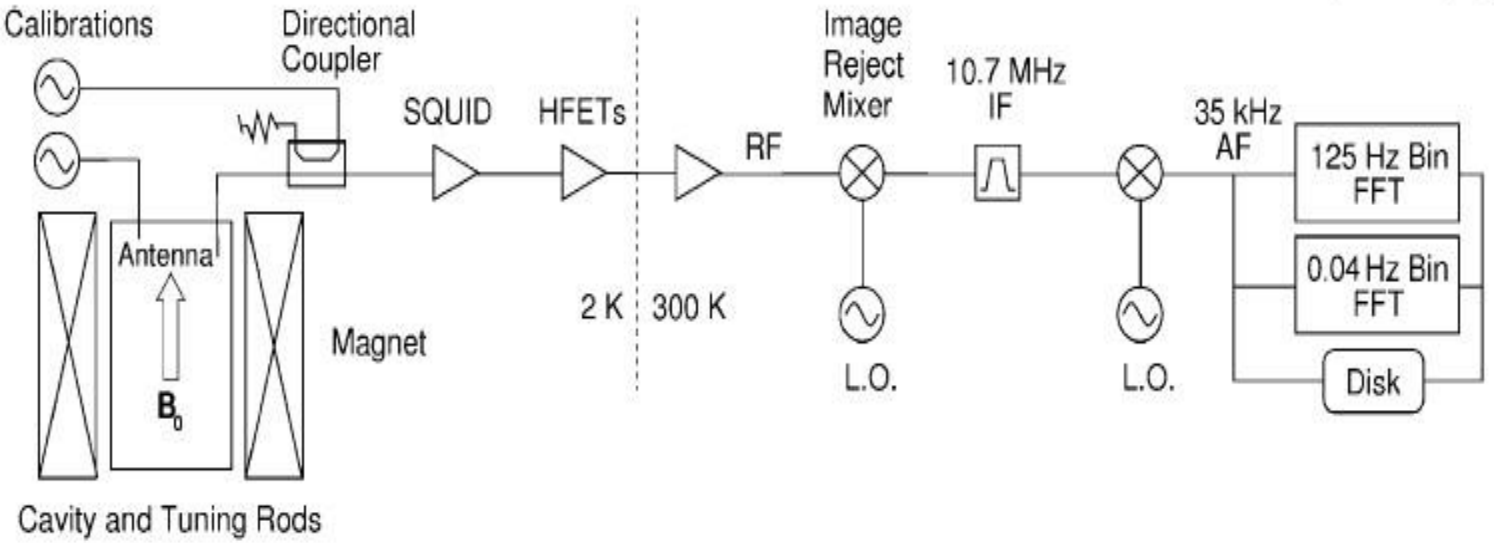
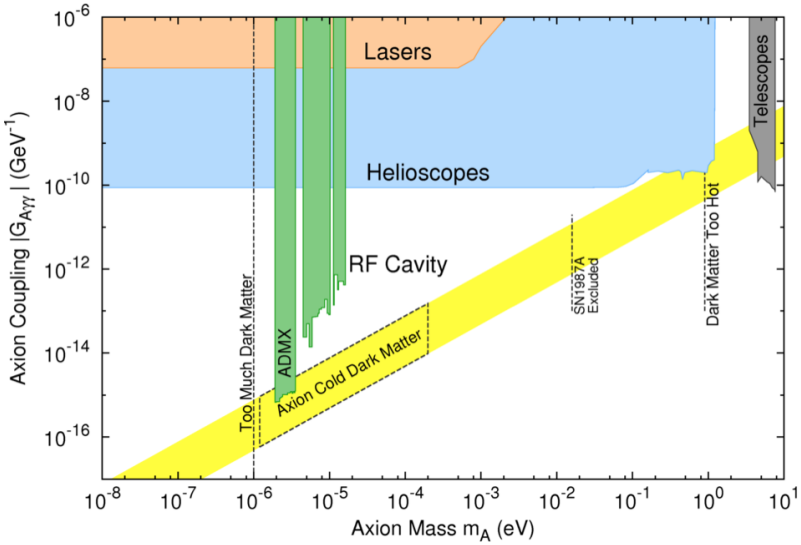


FIG. 1. Diagram of the ADMX cavity and receiver chain. The power read out from the cavity is sent through both cold and room temperature amplification stages, is mixed down from radio frequencies to audio frequencies via two local oscillators (L.O.), and is ultimately saved to disk.

Axion Dark Matter eXperiment and CAPP

- ADMX: Only running experiment searching for microwave axion
  - Leading experts with many years of experience
  - In U. of Washington since 2010
  - Scanned 500 to 850 MHz mass range
  - 100 years to cover whole axion mass range
- CAPP: What's there to improve?
  - Higher B^2, Q and V: >100 times improvement
  - Running Colder (<100mk): scan faster!
  - R&D for higher frequencies (higher mass range)
- ADMX Gen2 (US DOE and NSF Dark Matter program)
  - Dilution Refrigerator (~100mk) will be installed
  - Agree to collaborate with CAPP
  - Stronger Magnet (22T) (CAPP/ADMX)
  - New JPA from UC Berkeley
  - Will explore higher mass range

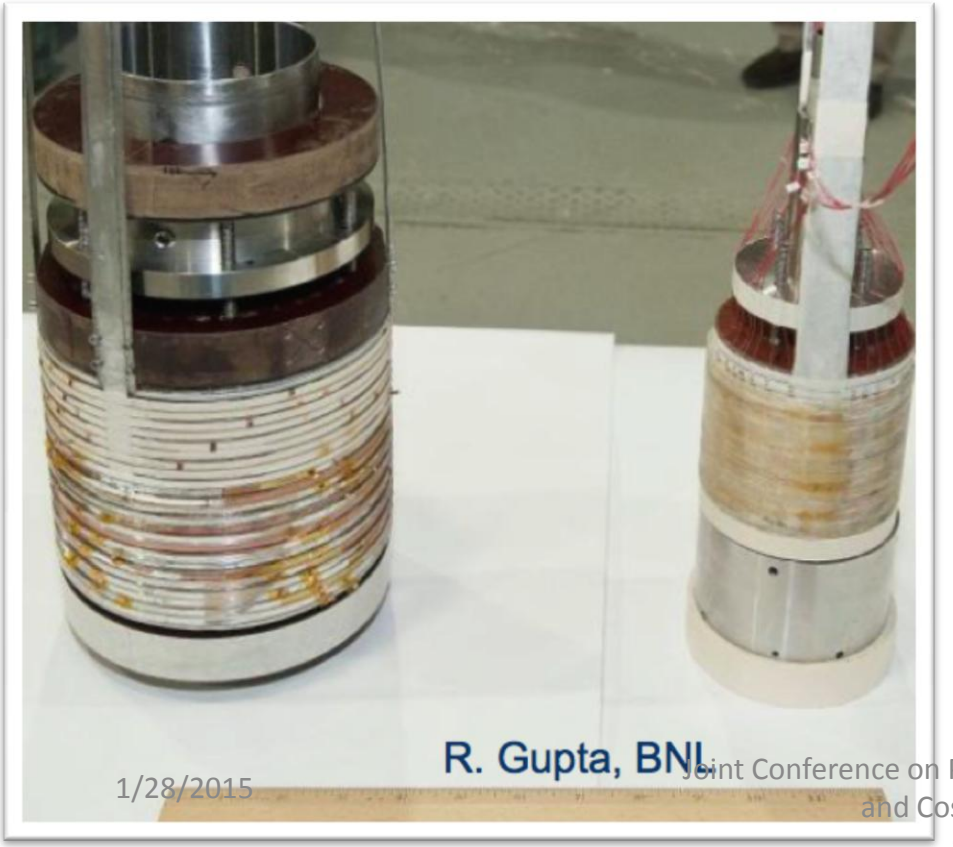


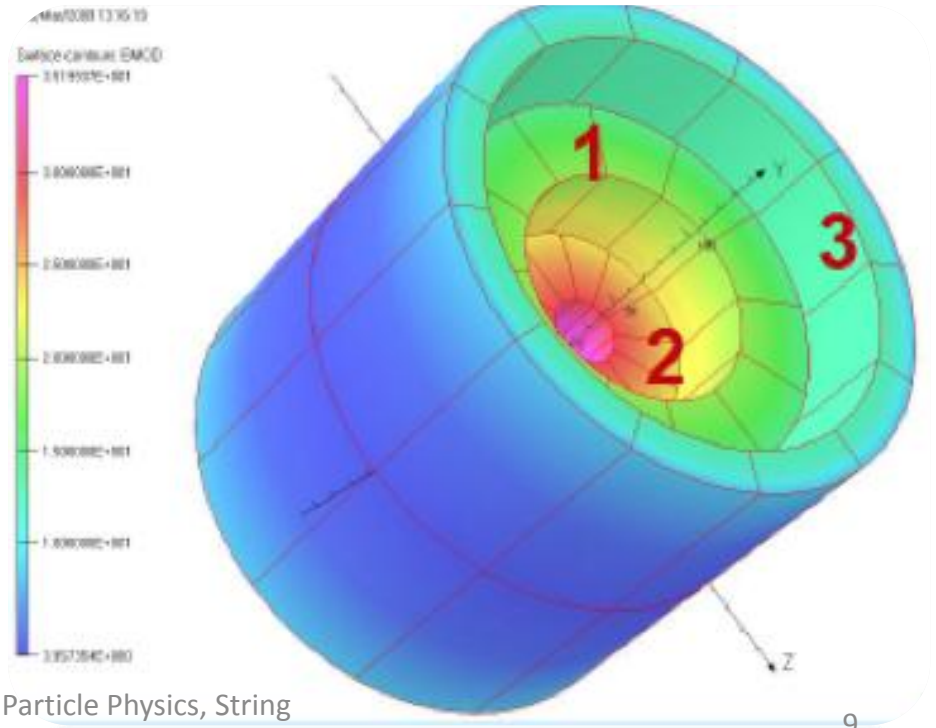
CAPP's Plan (Overview)

- Lab Space at the Creation Hall at KAIST Munji Campus: End of 2015
- R & D
  - 25T and then 35T Superconducting Magnet at BNL
  - Primary Cryo Amplifier
    - SQUID Amplifier at KRISS
    - Josephson Parametric Amplifier from UC Berkeley
  - Cavity R&D
    - Superconducting Coating w/ special top/bottom plates
    - Giant Toroidal Cavity
    - Multiple Cavities in-phase

CAPP's Plan (R&D: Magnet)

- Started an R&D Program with BNL's Magnet Group (Dr. R. Gupta)
- 5 year Program
- Goal is 25T and then 35T (Current Axion Ex. are using <10T)
- Based on High T_c SC cable (including SuNAM, Korean Company)





CAPP's Plan (R&D: Cavity R&D)

- Started an R&D Program to achieve high Q (>10^6) in high B-field
- Cavity with SC walls including special top/bottom plates (by Prof. Jhinhwan Lee of KAIST/IBS)
  - Two to Three year plan
  - Acquiring equipment to develop SC cavities
- Multiple Cavities in-phase
  - Dr. Sungwoo Youn of IBS Young Scientist Program will develop with CAPP
  - 5 year Program
- Giant Toroidal Cavity
  - 10 year Program
  - Large Volume for Low Frequencies
  - Expensive
  - Opportunity for large collaboration

CAPP's Plan (R&D: Primary Amplifier)

- SQUID Amplifier at KRISS (Dr. Yong-Ho Lee's Group)
  - Started a development program for Quantum Noise Limited SQUID Amplifiers in the 1-10 GHz range
  - Testing Prototypes begins in summer of 2015
  - Physical temperature aiming for 30 mK
  - Evaluate method for higher frequency
  - 5 year program
- Josephson Parametric Amplifier from UC Berkeley (Prof. Irfan Siddiqi)
  - Will deliver JPA to ADMX soon
  - Top notch amplifier with broad bandwidth and tunable frequency range (1-10 GHz)
  - Agreement on Collaboration with CAPP in progress

CAPP's Plan (R&D: Cryo)

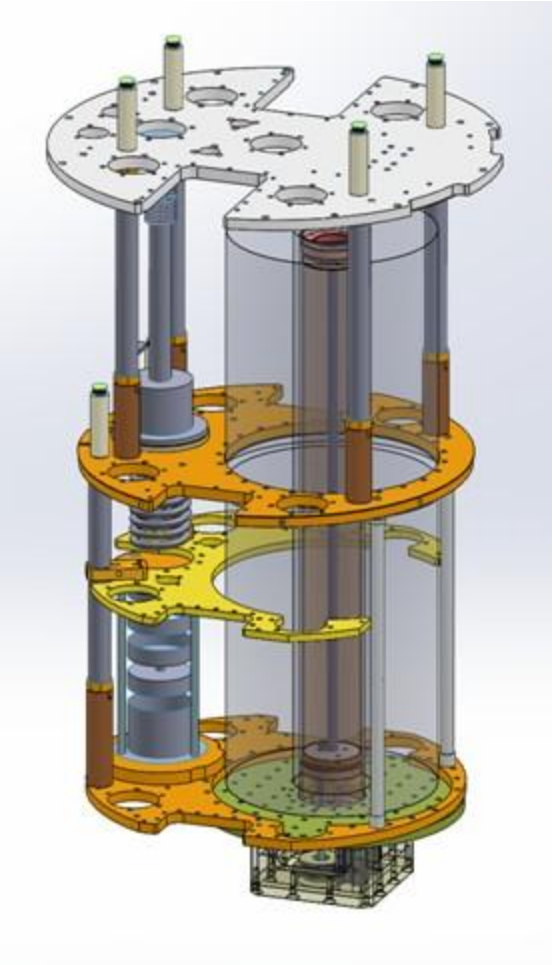
From Dr. Yonuk Chong (KRISS)

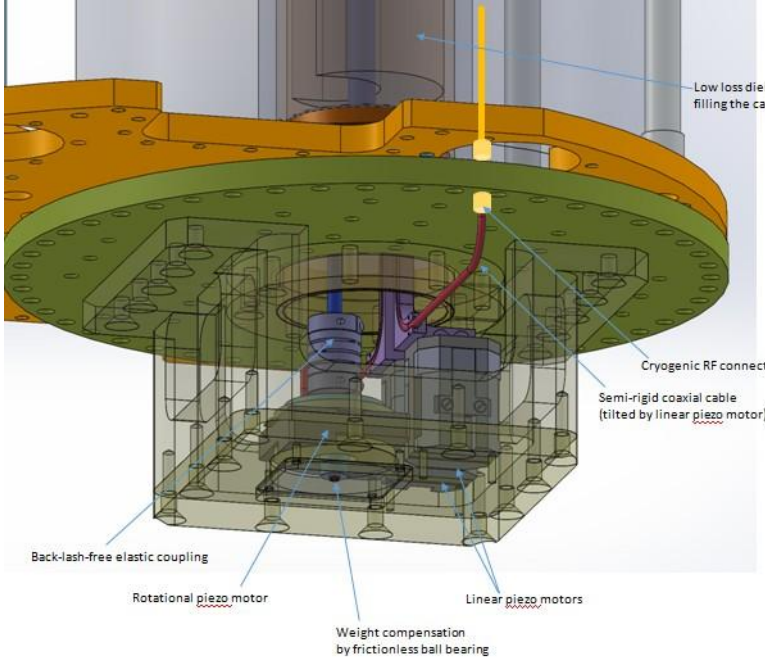
	2014	2015	2016	2017	2018	.....
Essential Equipments	CF-DR(RF1) CF-DR(magnet) Wet-He3(large bore)					
Quantum Amplifier Research		CF-DR(RF2)				
Small-sclae Integration			CF-DR(testbed)			
Low-noise Experiments				Wet-DR1(precision) Wet-DR2(precision)		
AxionDetector main					Main DR (Axion Detector)	

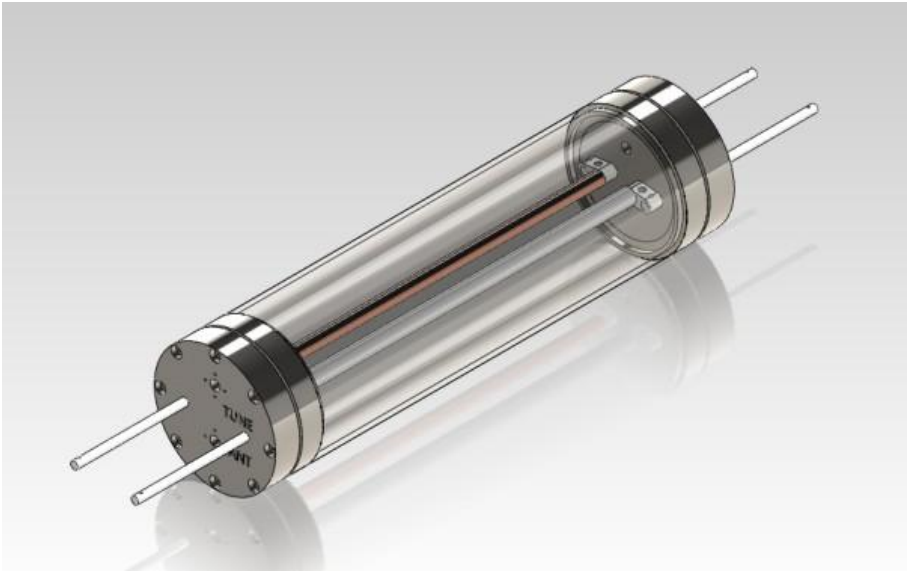
Example of a 7T-190mm cryogen free AMI magnet integrated with a BF-LD system (Protective aluminum magnet cover shield not shown in picture)

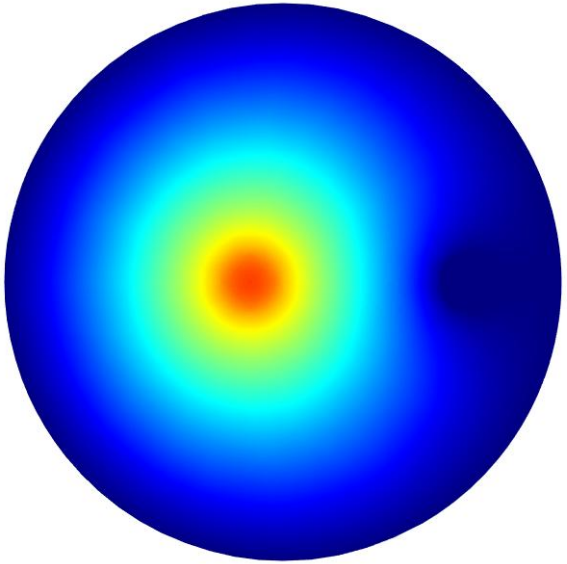
Shooting for the Summer 2015

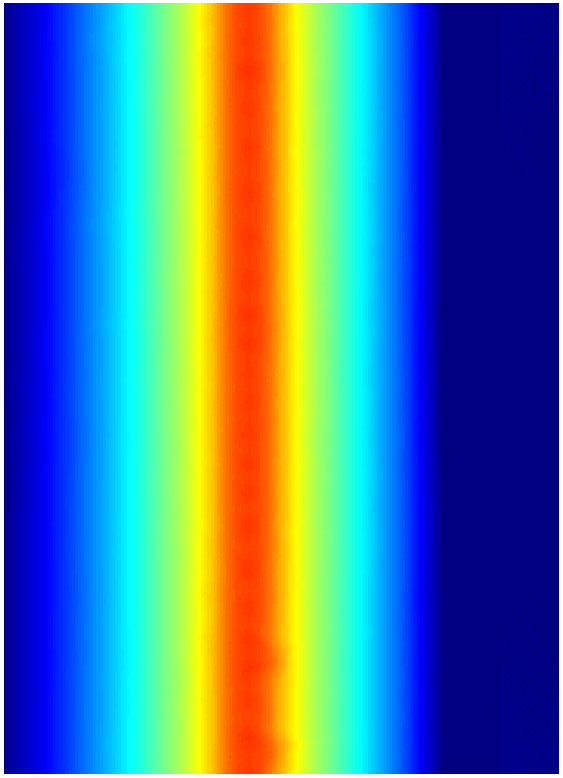
- Dilution Refrigerator (from Prof. Hyoungsoon Choi of KAIST/IBS) will be available for CAPP in 2015 summer(~ 4 months)
- The coldest axion experiment (base temp. ~10 mK)
- 8T Superconducting Magnets (6cm bore size: ~5 GHz)
- Started designing cavities with frequency tuning systems
- Electronics/DAQ will be ready by April
- SQUID amplifiers will not be ready for this run
- Great opportunity to prepare ourselves before Munji Campus

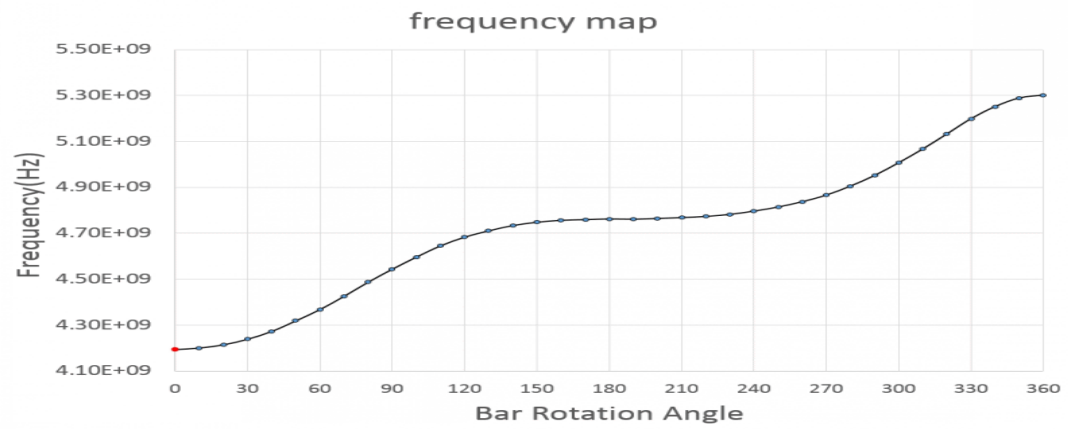


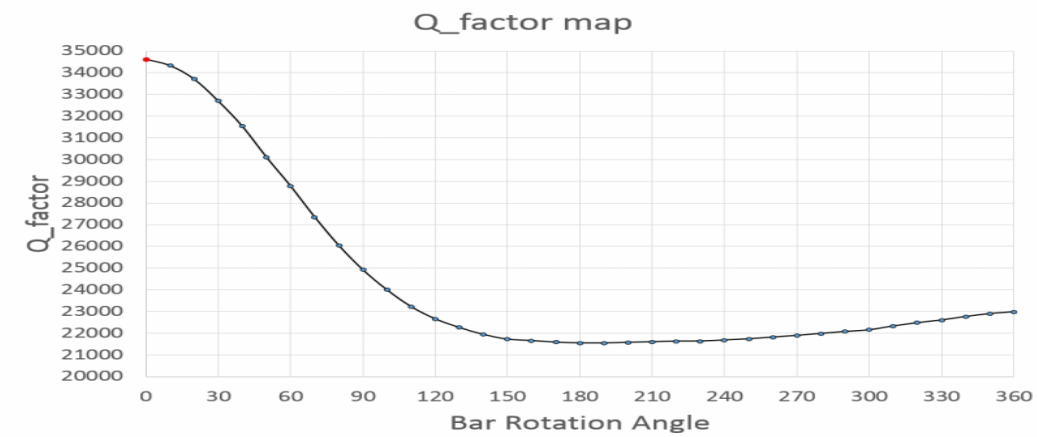

Low loss dielectric
filling the cavity volume
Cryogenic RF connector
Semi-rigid coaxial cable
(tilted by linear piezo motor)
Back-lash-free elastic coupling
Rotational piezo motor
Linear piezo motors
Weight compensation
by frictionless ball bearing

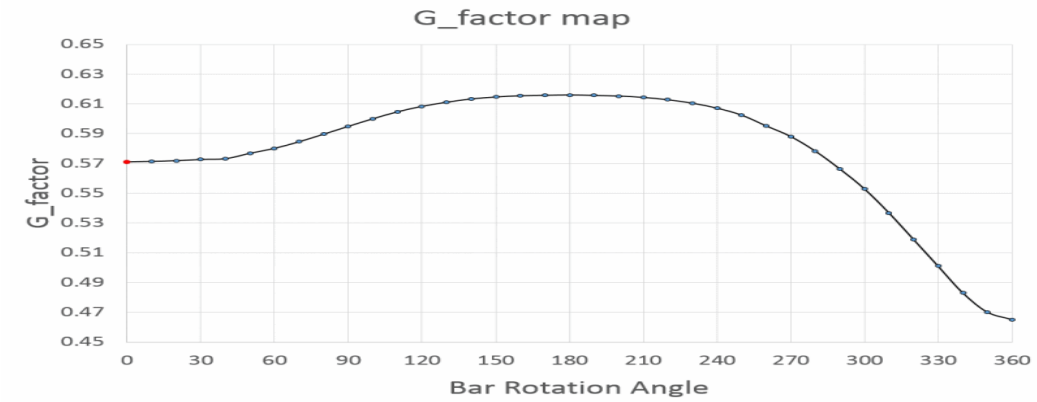







frequency map
Frequency(Hz)
5.50E+09
5.30E+09
5.10E+09
4.90E+09
4.70E+09
4.50E+09
4.30E+09
4.10E+09
0 30 60 90 120 150 180 210 240 270 300 330 360
Bar Rotation Angle


Q_factor map
Q_factor
35000
34000
33000
32000
31000
30000
29000
28000
27000
26000
25000
24000
23000
22000
21000
20000
0 30 60 90 120 150 180 210 240 270 300 330 360
Bar Rotation Angle


G_factor map
G_factor
0.65
0.63
0.61
0.59
0.57
0.55
0.53
0.51
0.49
0.47
0.45
0 30 60 90 120 150 180 210 240 270 300 330 360
Bar Rotation Angle

CAPP's Plan (Summary)

	2015	2016	2017	2018
Lab Space	Munji Campus Design & Renovation	Creation Hall completion Design & Construction of New IBS bldg at KAIST		Delivery of new IBS building
Magnet	Prototype, testing of SC cables	25T SuperC Magnet design	Work on 35T magnet	Magnet Delivery
Cavity Development	Procure Equip. Study res. and geom.	Development of high Q SC resonator	Production of high Q resonator	
Amplifier	Design and production of prototype SQUID for 1-10 GHz Acquire JPA, test		SQUID delivery from KRISS Develop higher freq. amplifier	

Summary

- State of the Art Axion Research at CAPP/IBS
- Major R&D Effort on improving Axion Dark Matter eXperiment
  - Higher B Field: 25T and then 35T
  - Higher Q Factor with B Field: Factor of >10 Improvement
  - Larger Volume: Toroidal Cavity (>50)
- World's most sensitive Axion Experiment as early as in 5 years
- Let's detect Axions in 1-100 μeV range by 2018-2020