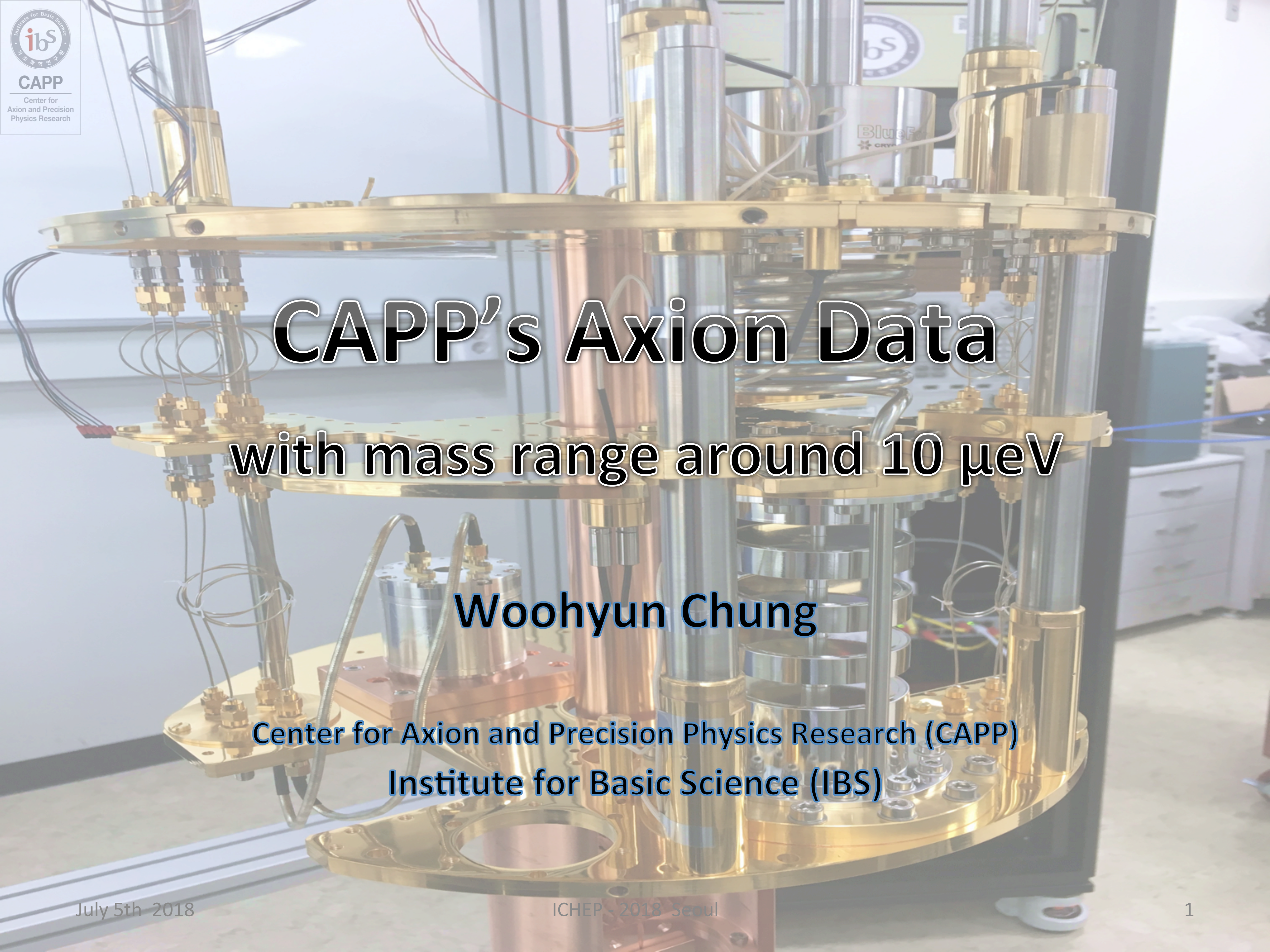
CAPP
Center for Axion and Precision Physics Research



CAPP's Axion Data

with mass range around 10 μeV

Woohyun Chung

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

IBS CAPP Center for Axion and Precision Physics Research

OUTLINE

- Introduction
  - IBS/CAPP
  - CAPP's effort (CULTASK)
- CAPP-PACE (Pilot Axion Cavity Exp.)
  - R&D machine
  - First complete LT axion experiment
  - 50 MHz data and more…
- Critical R&D
  - High Field Magnets
  - Quantum-limited Amplifiers
  - SC and dielectric cavity
- Future Plans
  - Improve B^2 and T_{sys}
- Summary

IBS/CAPP

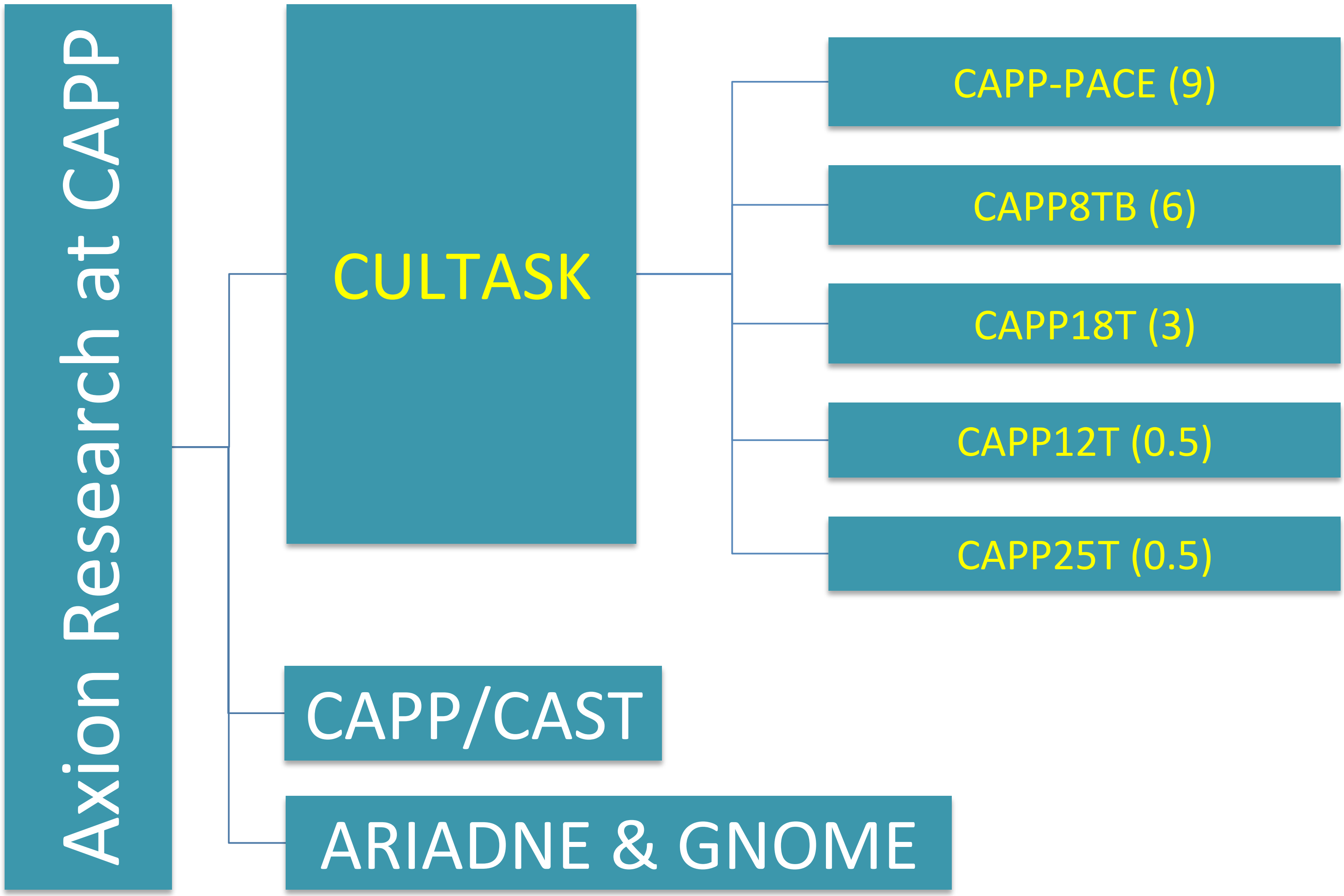
Center for Axion and Precision Physics Research (CAPP) Funded by the Institute for Basic Science (IBS)

- Led by Director Yannis Semertzidis
- Physics at CAPP:
  - Dark Matter Axion Search (Cosmic Frontier)
  - Storage Ring Proton EDM (Strong CP)
  - Muon g-2, J-PARC, COMET, CAST, ARIADNE
- Located at and working with KAIST

  (Korea Advanced Institute of Science and Technology)
- 50+ members and growing

IBS HQ Construction Overview

CAPP's Axion Research



Axion Detection Scheme (CULTASK)

P. Sikivie's Haloscope:

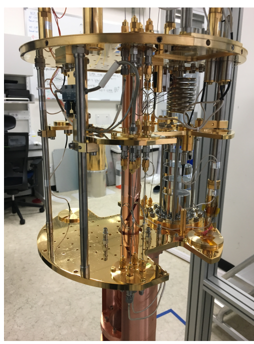
Axion Conversion Power (~10^{-24}W): $$P_{a\to\gamma\gamma} = g_{a\gamma\gamma}^2 \frac{\rho_a}{m_a} B^2 V C_{mnp} \min(Q_L, Q_a)$$

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

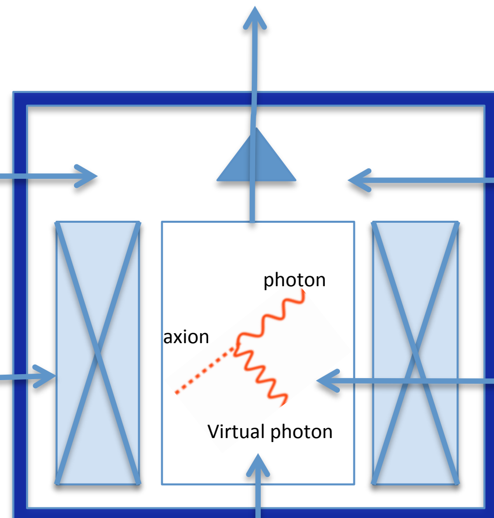
Scan rate: $$\frac{df}{dt} \sim B^4 V^2 C^2 Q_L T_{syst}^{-2}$$

Cryogenics

<50mK



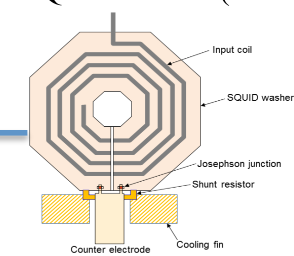
To RF Receiver



(Reverse) Primakoff Effect

SQUID Amplifier

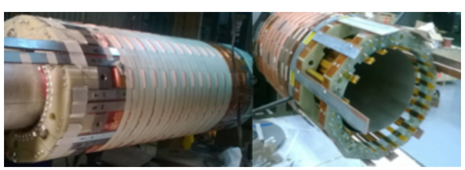
SQUID or JPA (commercial?)



High Field SC Magnet

25T and then 35T

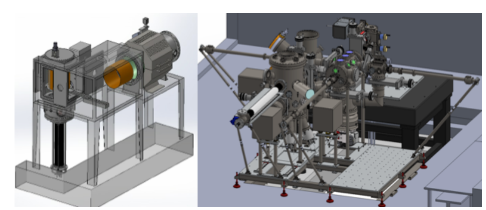
BNL (HTS Technology) Design



High Q Tunable Cavity

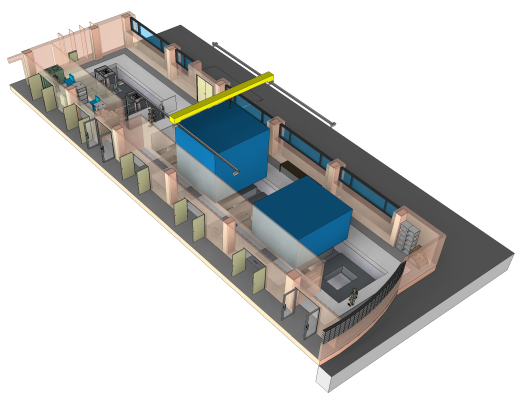
Superconducting Coating

Prof. Jhinhwan Lee of KAIST

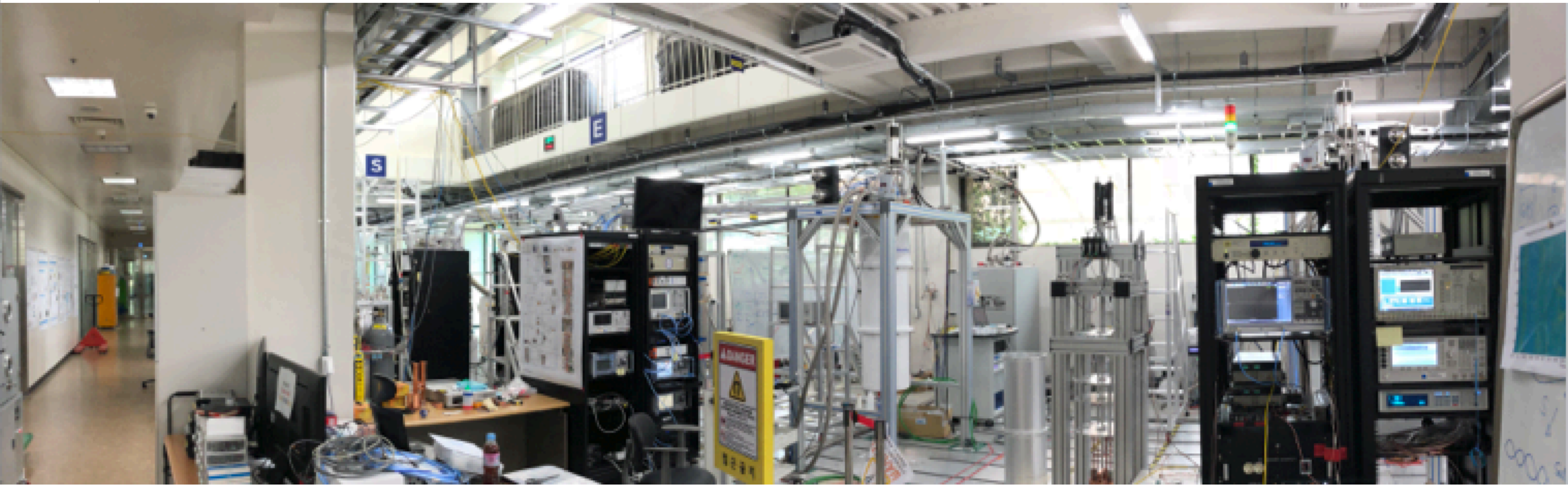


In 2017

Axion Lab with 7 Low Vibration Pads in KAIST Munji campus



CAPP Experimental Hall (LVP)



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CULTASK Refrigerators and Magnets

Refrigerators

Vendor	Model	T_B (mK)	Cooling power	Installation
BlueFors (BF3)	LD400	10	18μW@20mK 580μW@100mK	2016
BlueFors (BF4)	LD400	10	18μW@20 580μW@100	2016
Janis	HE3	300	25μW@300mK	2017
BlueFors (BF5)	**LD400**	**10**	18μW@20mK 580μW@100K	**2017**
BlueFors (BF6)	LD400	10	18μW@20mK 580μW@100K	2017
Leiden	DRS1000	100	1mW @100mK	2018
Oxford	Kelvinox	<30	400 @120mK	2017

Magnets

B field	Bore (cm)	Material	Vendor	Delivery
26T	3.5	HTS	SUNAM	2016
18T	7	HTS	SUNAM	2017
9T	12	NbTi	Cryo-Magnetics	2017
8T	**12**	**NbTi**	**AMI**	**2016**
8T	16.5	NbTi	AMI	2017
25T	**10**	HTS	BNL/CAPP	2020
12T	**32**	Nb_3Sn	Oxford	2020

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SQUID and Cavity R&D

Magnets

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8T	16.5	NbTi	AMI	2017
25T	**10**	HTS	BNL/CAPP	2020
12T	**32**	Nb_3Sn	Oxford	2020

CAPP-PACE

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CAPP-PACE

- R&D Machine preparing for CAPP25T
- First complete axion experiment in Korea
- Optimization study for
  - Cryogenics and cryo-RF
    (Heat vs Noise)
- First engineering run in Jan. 2018
  - 2.45 – 2.50 GHz scan for 22 days
  - Flawless operation of
    - Freq. tuning system w/ Piezo actuators and a sapphire rod
    - DAQ and Controls
  - Target sensitivity: 10*KSVZ
- Second run is about to start
  - 2.50 – 2.75 GHz

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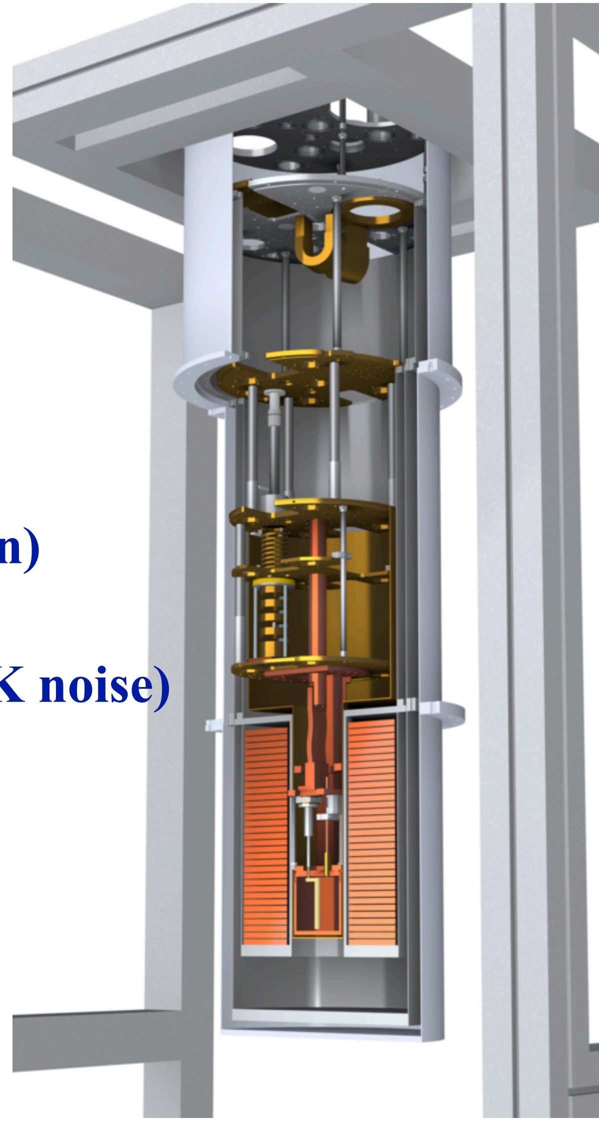
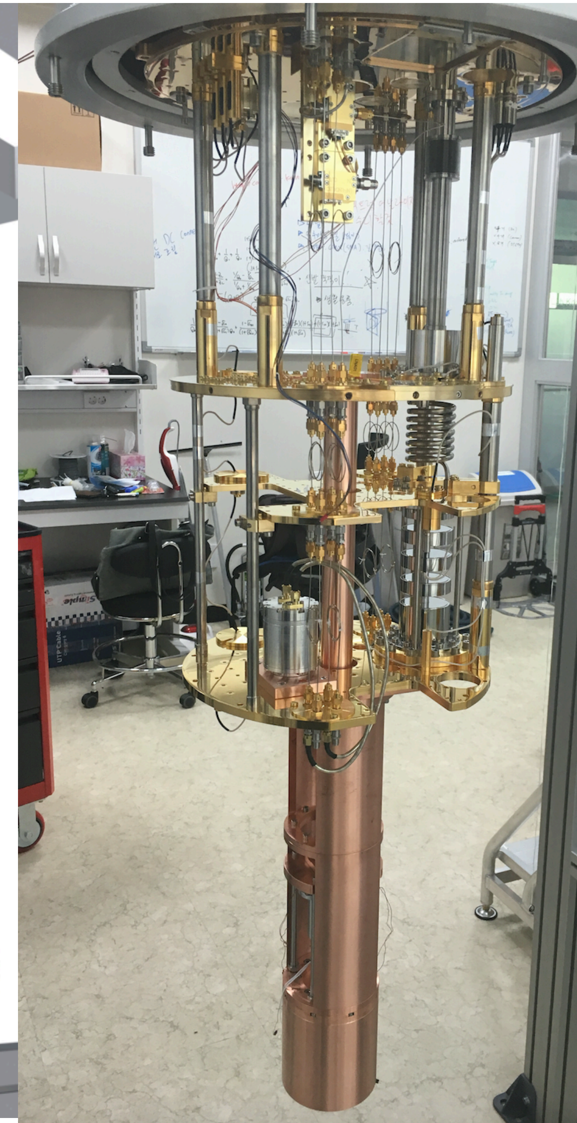
CAPP-PACE

- T_{cavity} : **<40mK (WR)**
- Magnetic field: **8T**
- Bore size: 11.8cm
- Cavity volume: 0.59L
- Frequency: **2.45~2.75GHz**
  (2.45~2.50 at 1st run)
- Q unloaded: **>80,000**
- Low noise amplifier: **HEMT (1K noise)**
- C (geometrical factor) >0.55
- DAQ Efficiency:0.45
- Target sensitivity: **10*KSVZ**



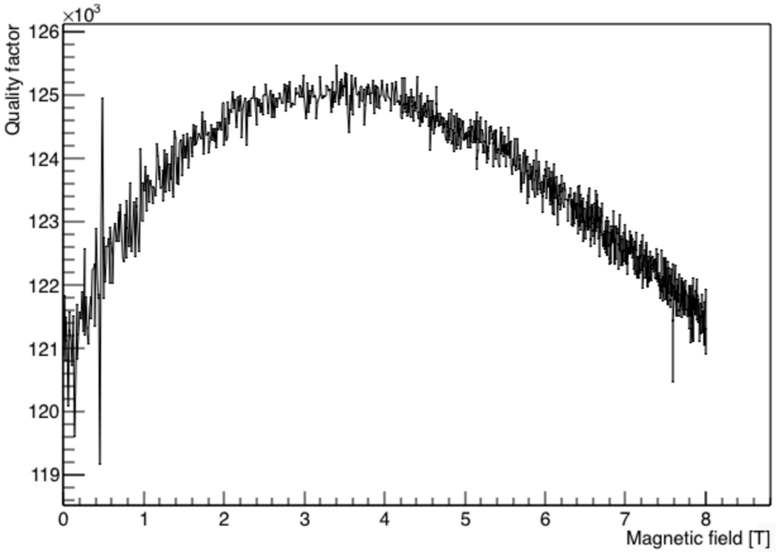


CAPP-PACE

Cavity: OFHC Cu split type

Unloaded Q-factor of ~120,000 w/ Sapphire rod

Pure (6N) Cu and Al (annealed) will be fabricated

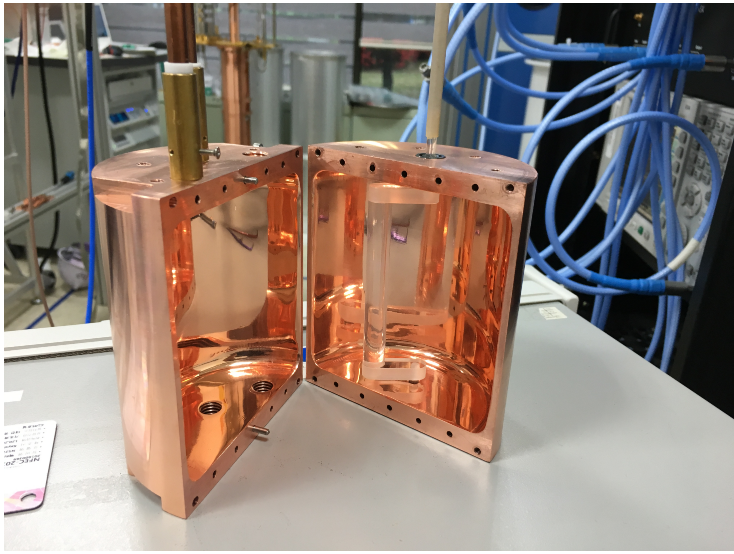


FTS: Attocube piezoelectric actuators

Thermal link to 1K plate

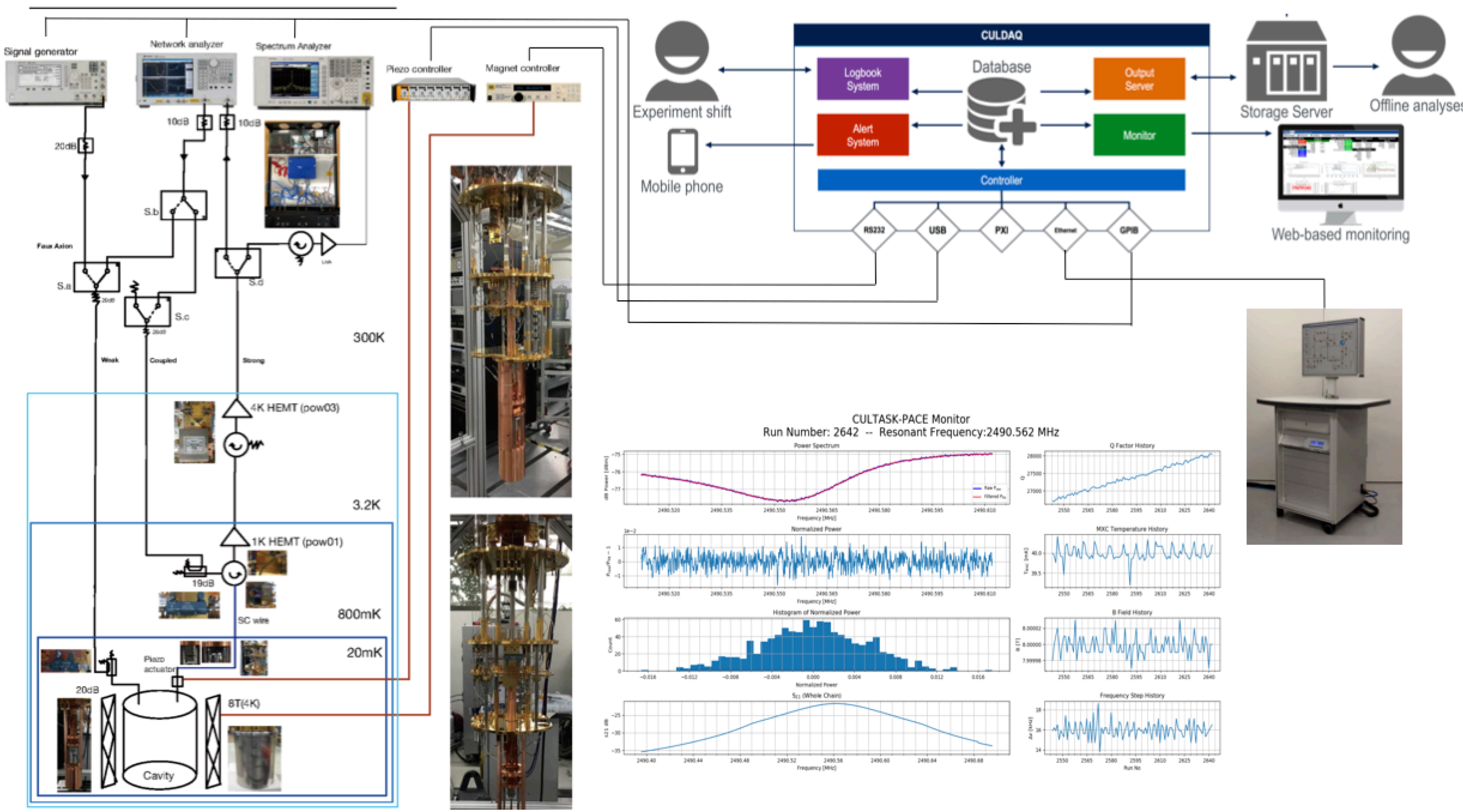
→ Sapphire rod to cavity by cryo bearing

Rotator resolution of 1/1000 deg → 16 kHz per step

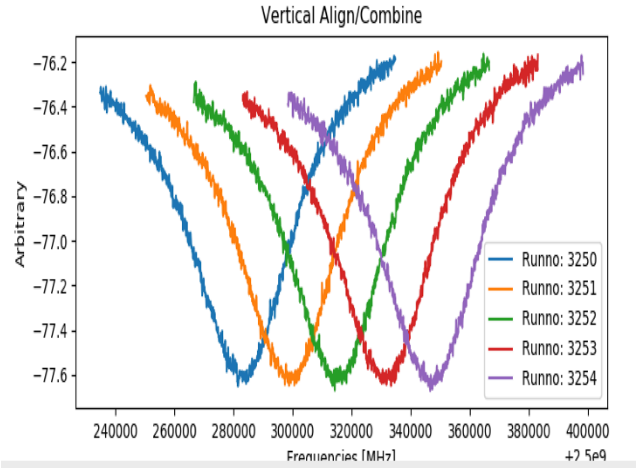


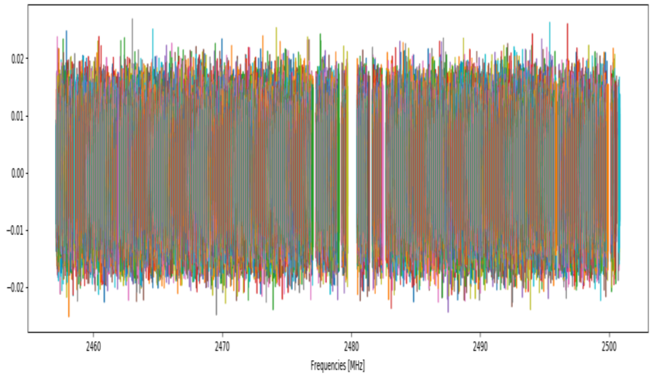
CAPP-PACE

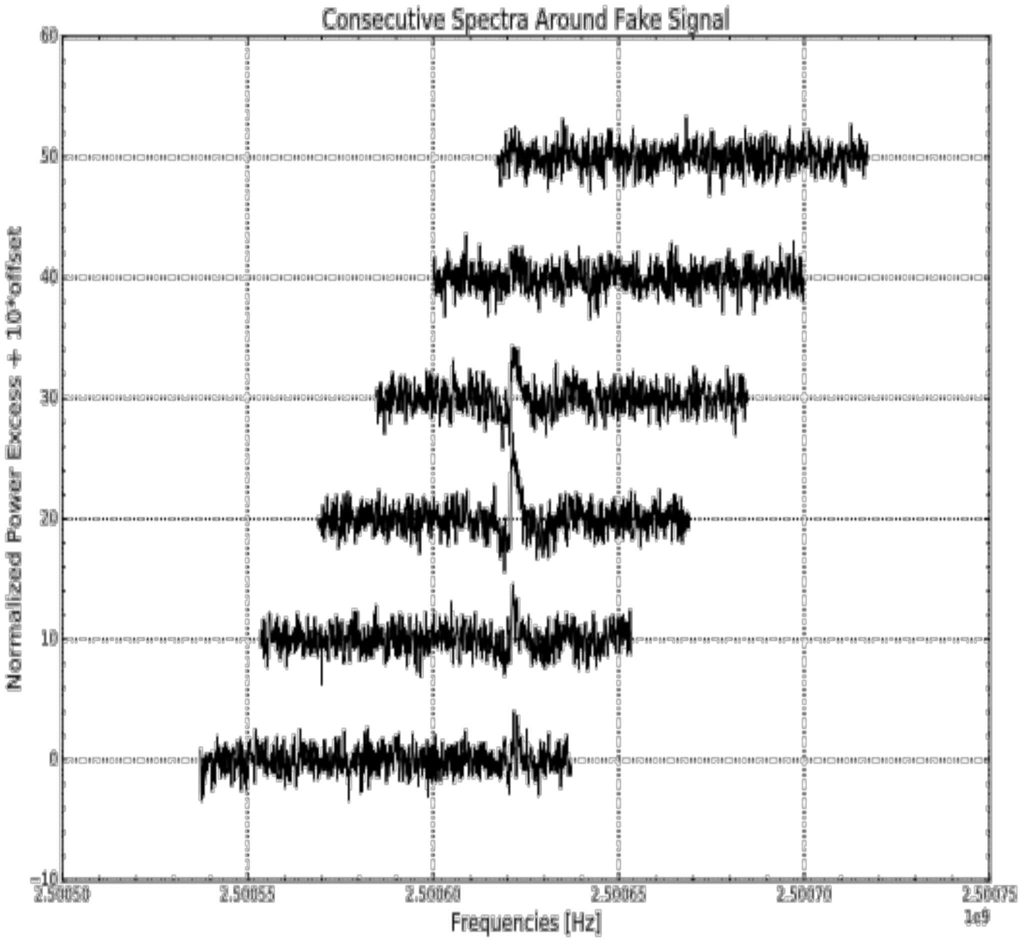
RF read-out chain & Controls



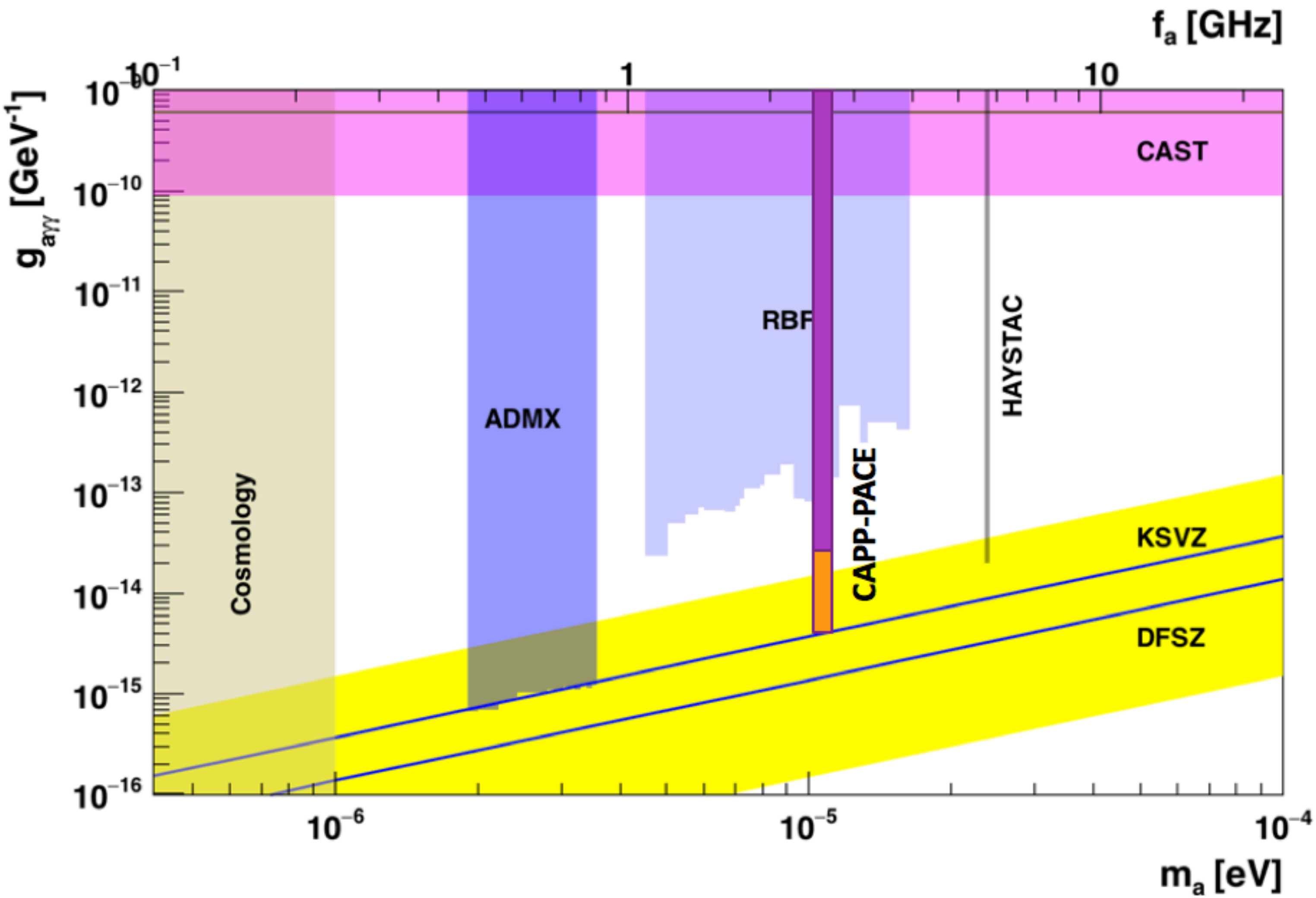
CAPP-PACE 1st data (2.24- 2.50 GHz)







CAPP-PACE Sensitivity (planned)



CAPP-PACE R&D

How to improve?

- Maximize B^2V
  - 25T 10cm bore HTS magnet by BNL (2020)
  - 12T 32cm bore LTS magnet by Oxford (2020)
  - Way to increase frequency with volume fixed
    - Dielectric rings (TM_{030} and TM_{050})
    - Photonic cells

- Scan faster (minimize T_{amp} ← dominating factor)
  - Quantum Amplifier - SQUID or JPA
  - Optimize cryo-RF receiver chain

- Others
  - Improve Q-factor of cavity – pure metal or SC cavity
  - Dead-time-less DAQ

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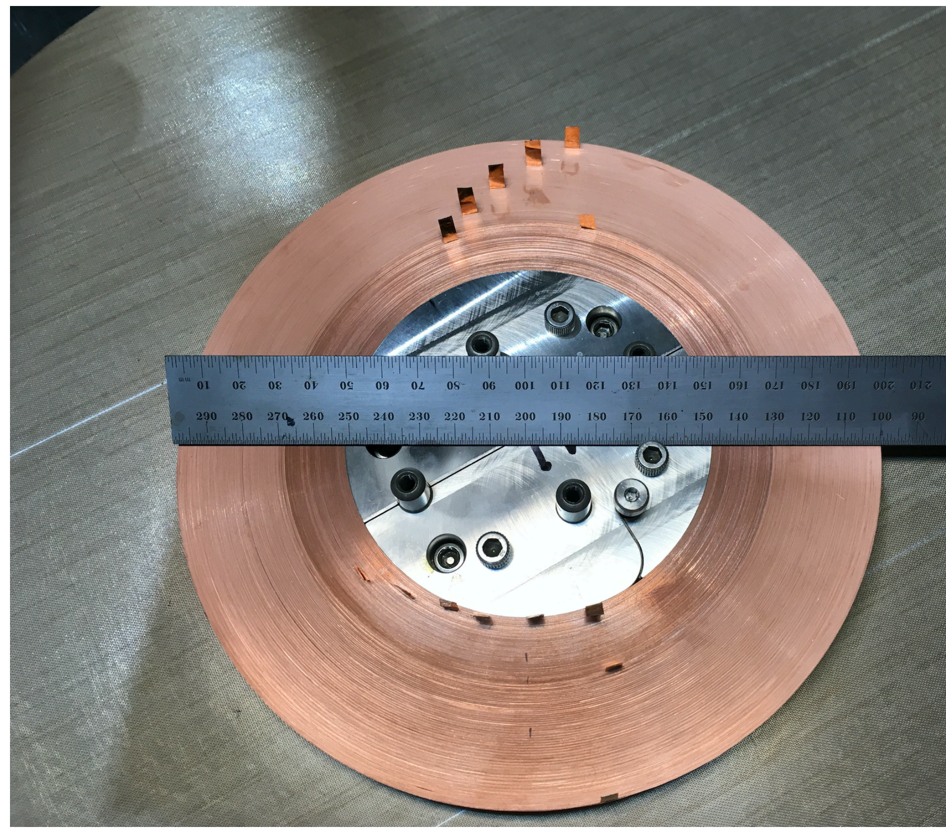
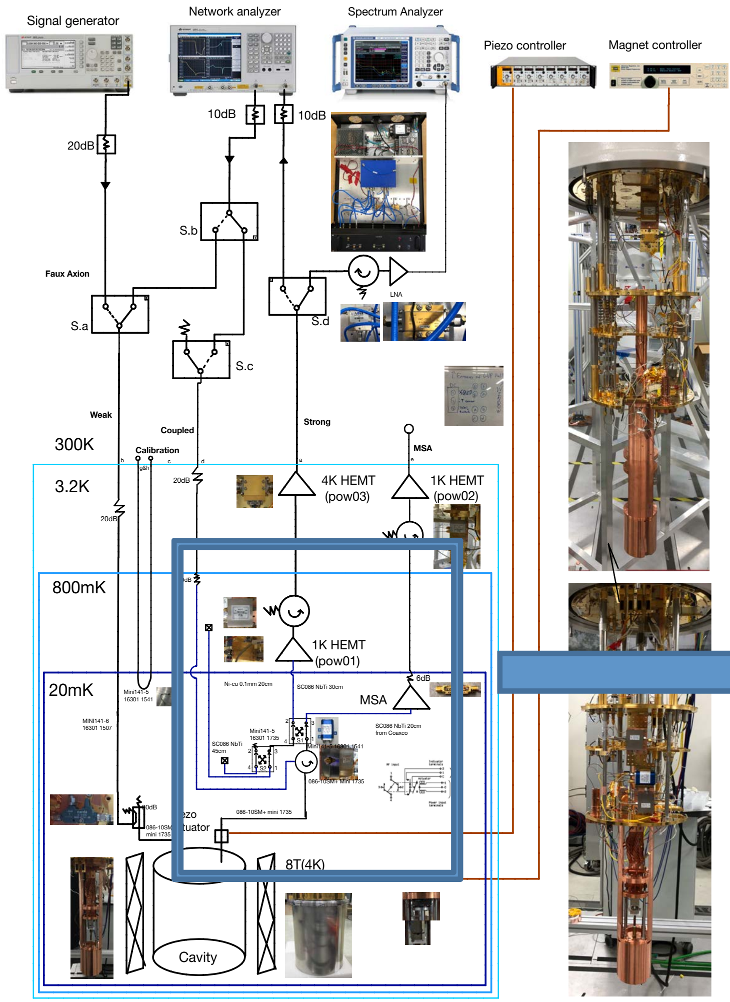
CAPP-PACE R&D

25T 10cm bore HTS magnet by BNL

- The first (of 24) pancake wound! - test will follow
- 5 km of SC tape will be delivered next 5 months

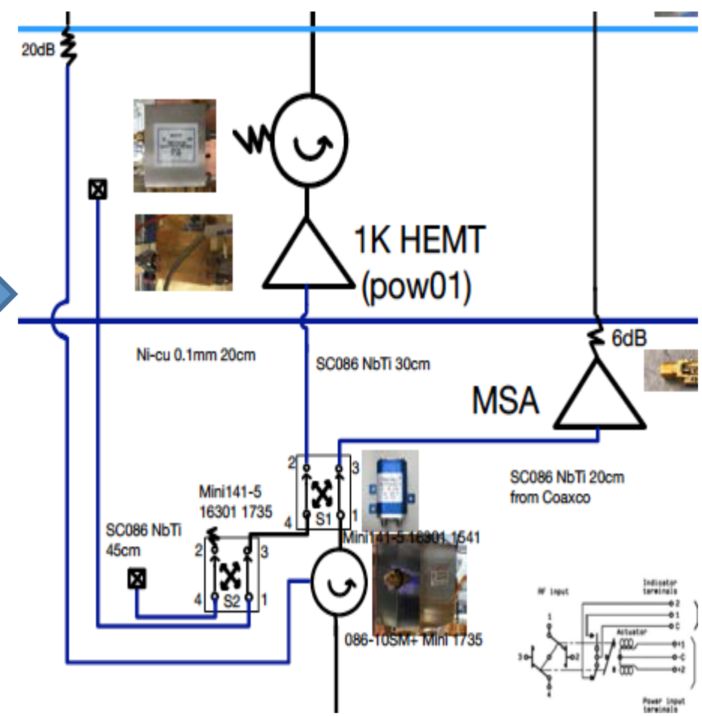


CAPP-PACE NT Measurements



05/14/2018 modified. Port 1&4 of Switch2 is interchanged. Readout line from S1 to HEMT is directly connected. Coupled line configuration is modified.

- "Cold Terminator method" with cryo-switch
- "On-Off Resonance method" ADMX style
- Custom-made Y-factor method
- LHe dewar tests



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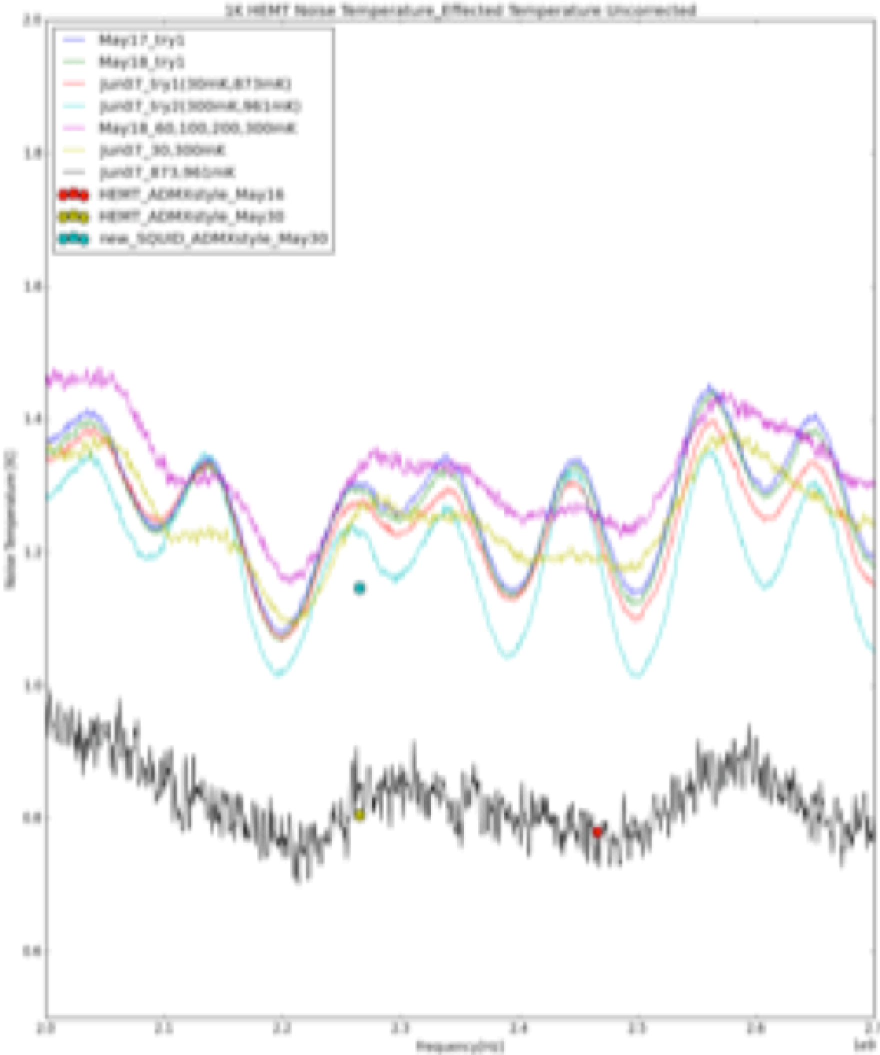
CAPP-PACE NT Measurements

Cold Terminator Method

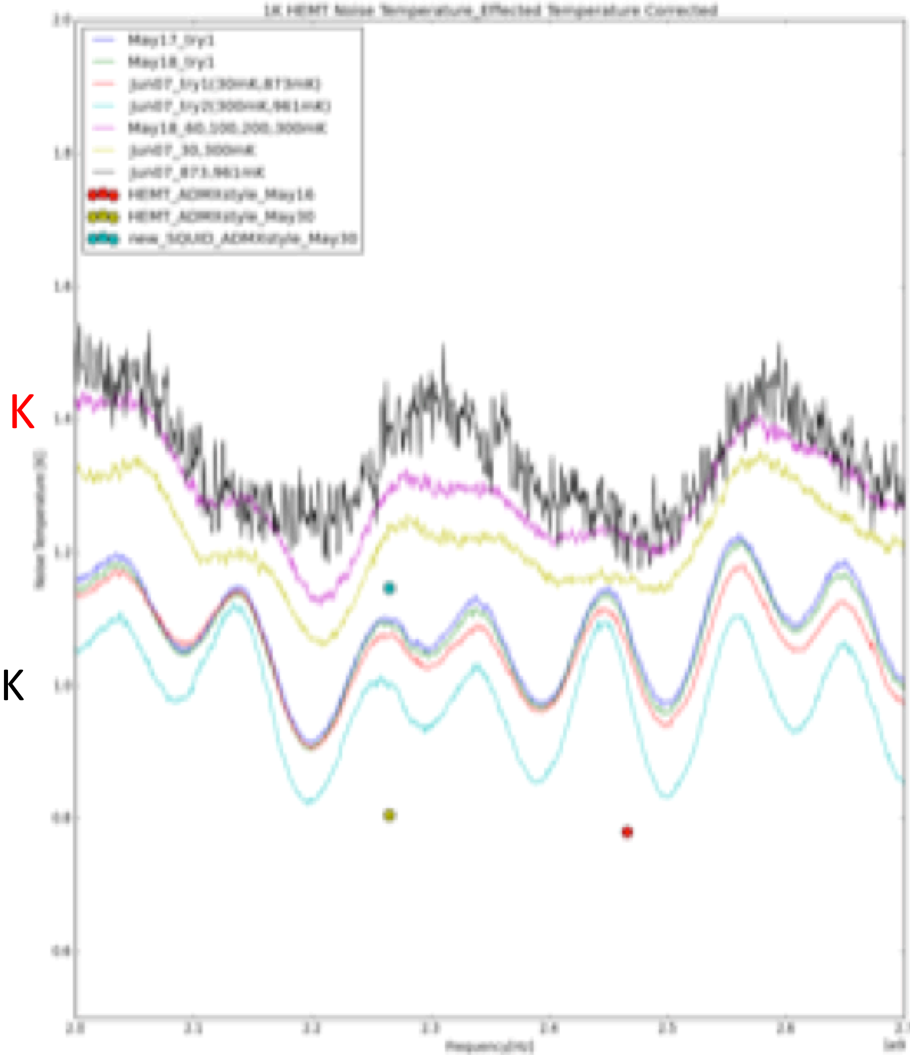
Before Corrections



1.4 K

1.0 K

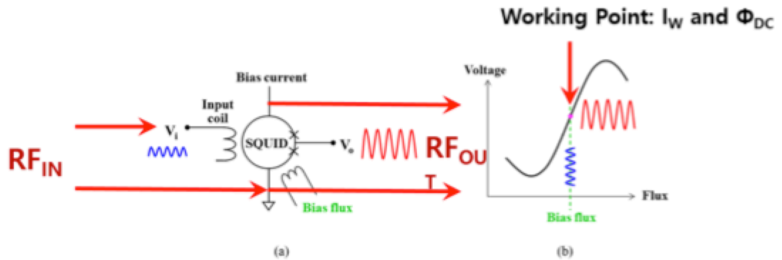
After Corrections



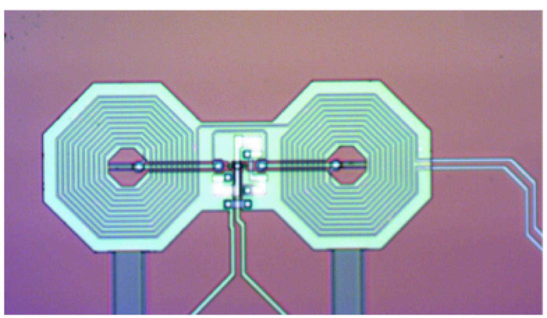
CAPP-PACE R&D (Quantum Amplifiers)

- Andrei Matlashov is leading an effort to optimize SQUID for axion experiment
- New type of microwave SQUID amplifier from IPHT (Jena, Germany)

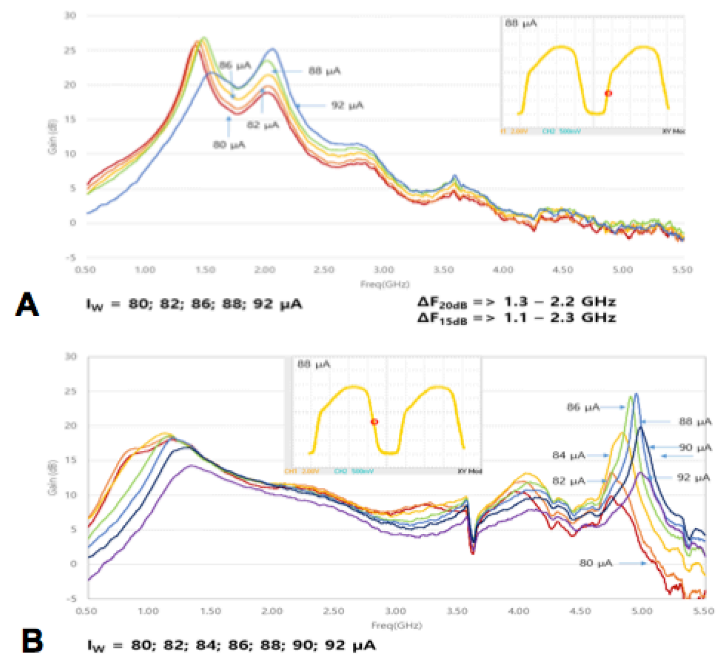
Microwave SQUID Amplifiers



SQUID Gradiometer Configuration

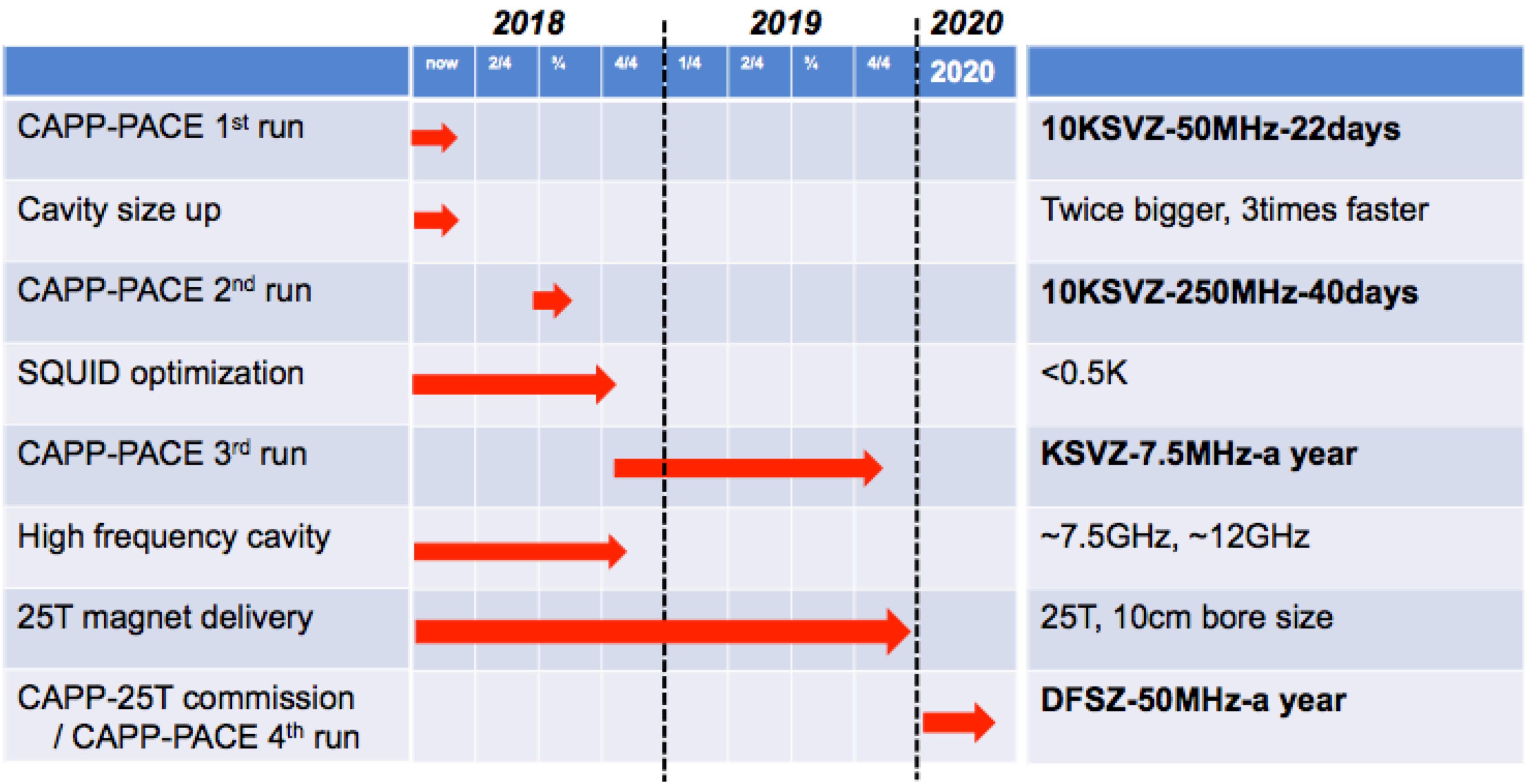


Gain vs. Frequency

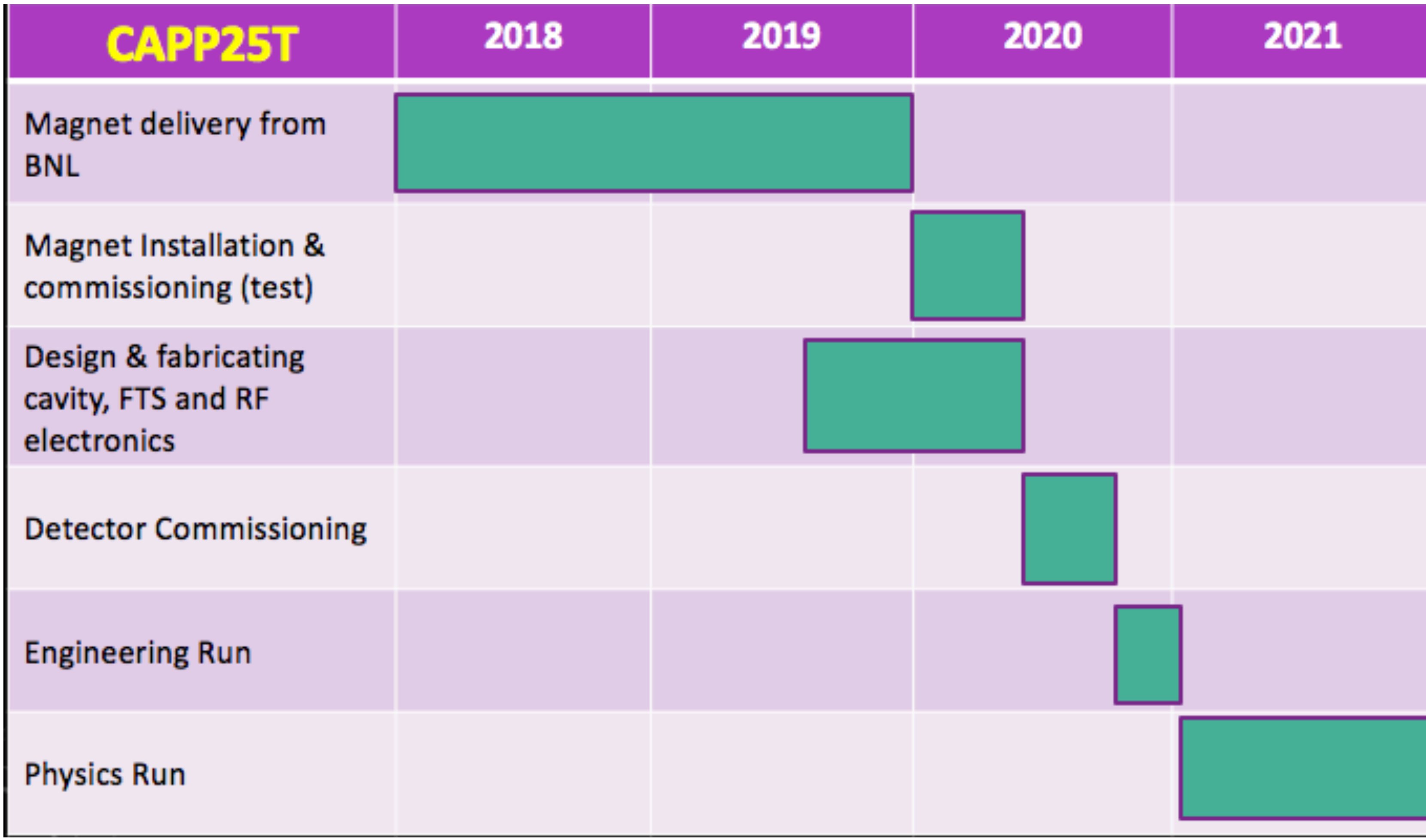


- Sergey Uchaikin (from D-Wave) will join the group in July to lead JPA effort

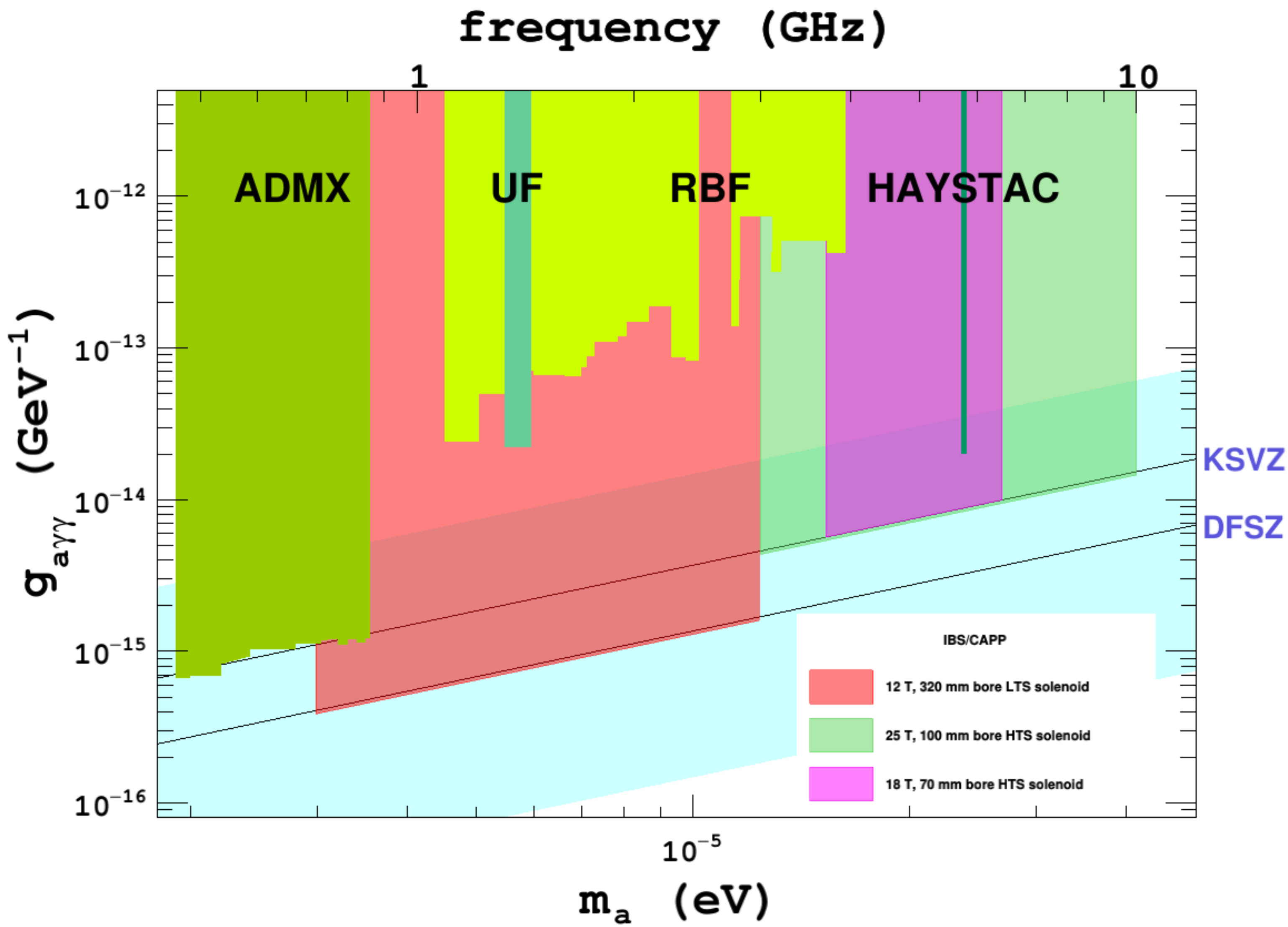
Timeline (CAPP-PACE)



Timeline (CAPP25T)



CULTASK Sensitivity



Summary

- **Axion Research at CAPP/IBS in Korea is getting mature**
- **CAPP-PACE is becoming a complete axion experiment and leading R&D efforts of CAPP**
- **Major R&D Efforts**
  - **Higher B Field: HTS (18T, 25T…)**
  - **Larger Volume: (12T 32cm LTS magnet)**
  - **Adding SQUID or JPA**
  - **R&D for Higher Frequencies (>10 GHz)**
- **Stay tuned for optimized Quantum Amplifiers!**

Thank You For Your Attention!