CAPP-8TB: Search for Axion Dark Matter in a Mass Range of 6.62 to 7.04 μeV

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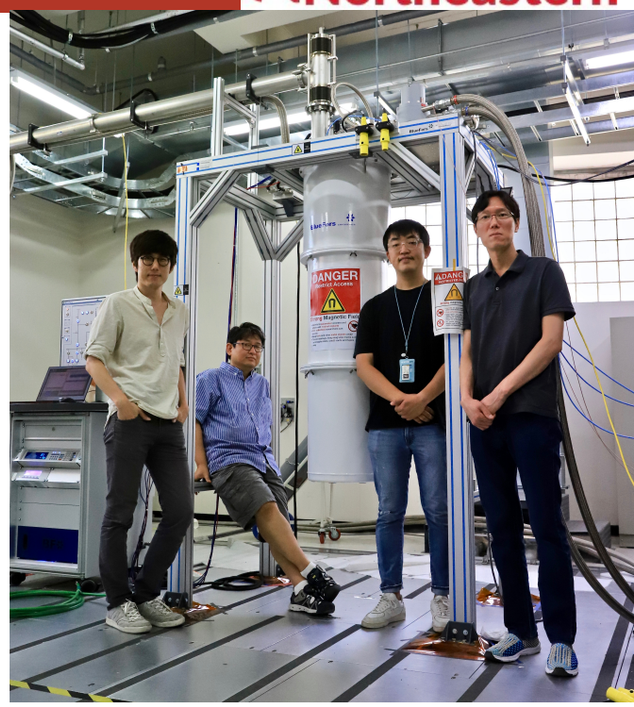
Introduction to CAPP-8TB



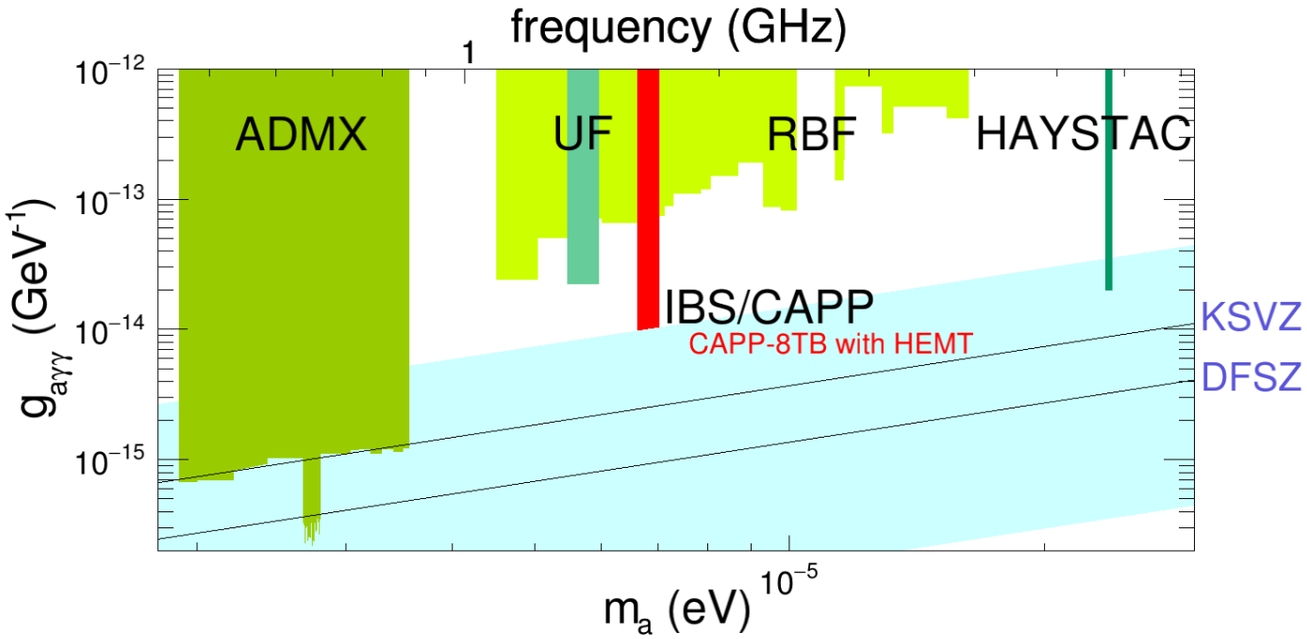
- CAPP-8TB is an axion haloscope to search for axion dark matter in 6.62 - 7.04 μeV mass range
  - Corresponds to 1.6 - 1.7 GHz in frequency domain
  - Detects microwave photons produced via inverse Primakoff effect under an external magnetic field

- Scan rate with a microwave resonant cavity

$$\frac{df}{dt} \propto \frac{B^4 V^2 C_{010}^2 Q_L}{T^2}$$

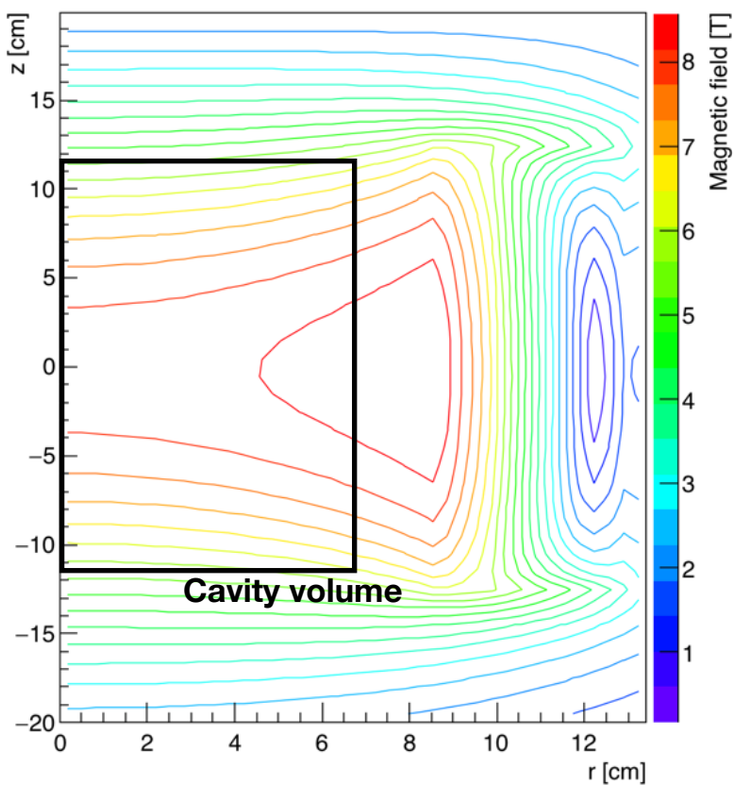
B: External magnetic field
V: Cavity volume
C_{010}: Cavity form factor associated with TM_{010} mode
Q_L: Loaded quality factor of cavity
T: System noise temperature

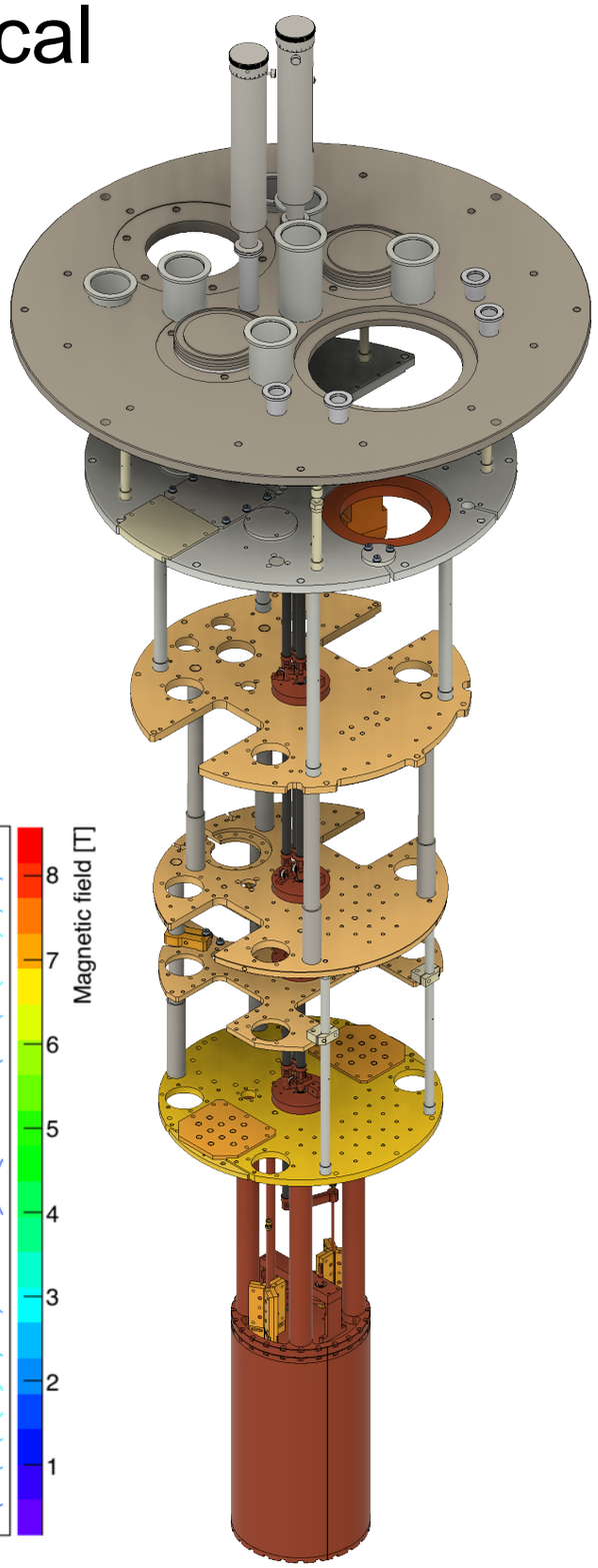
- In the 1st stage of CAPP-8TB, we will touch QCD axion band with commercial HEMT (high electron mobility transistor) based amplifiers



System Overview

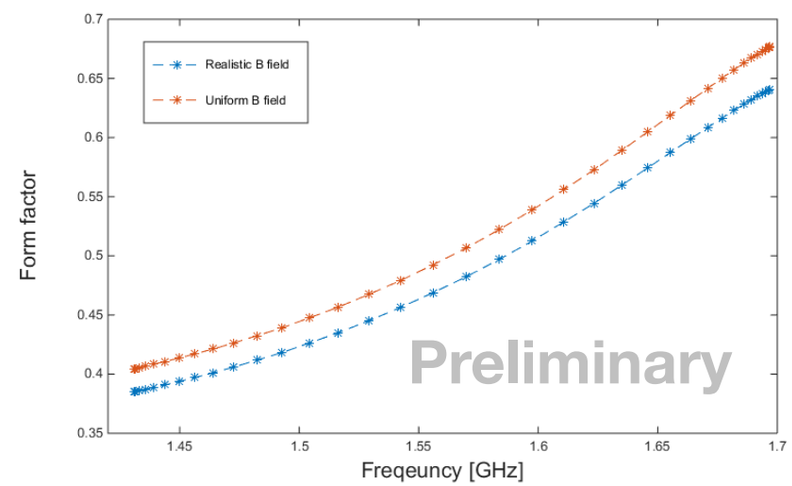
- Microwave resonant cavity is maintained at a physical temperature of 50 mK
  - BlueFors dilution refrigerator
  - Cooling power of 16 μW at 20 mK
- External magnetic field is provided by a superconducting solenoid magnet
  - Average magnetic field in the cavity volume: 7.3 T
- Receiver chain components are located at various temperature stages
- Frequency and coupling tuning is driven from stepping motors sitting at room temperature

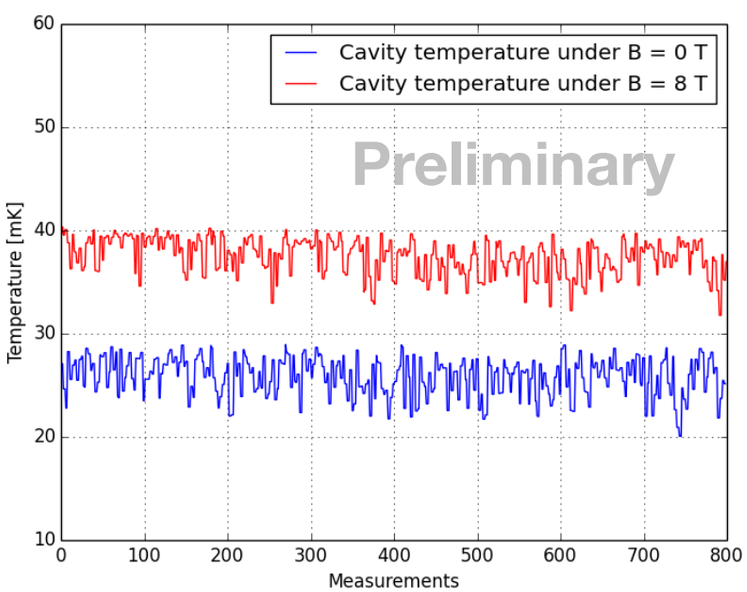


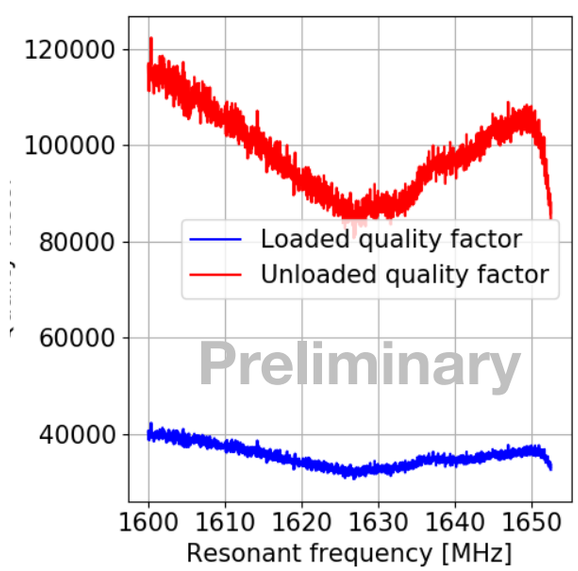


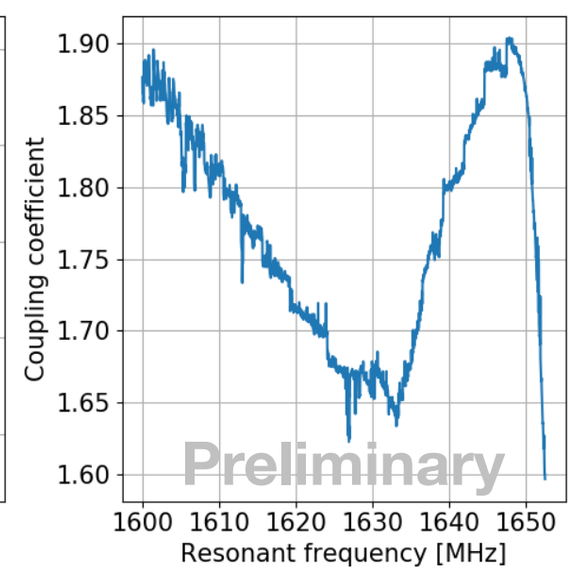
Microwave Resonant Cavity

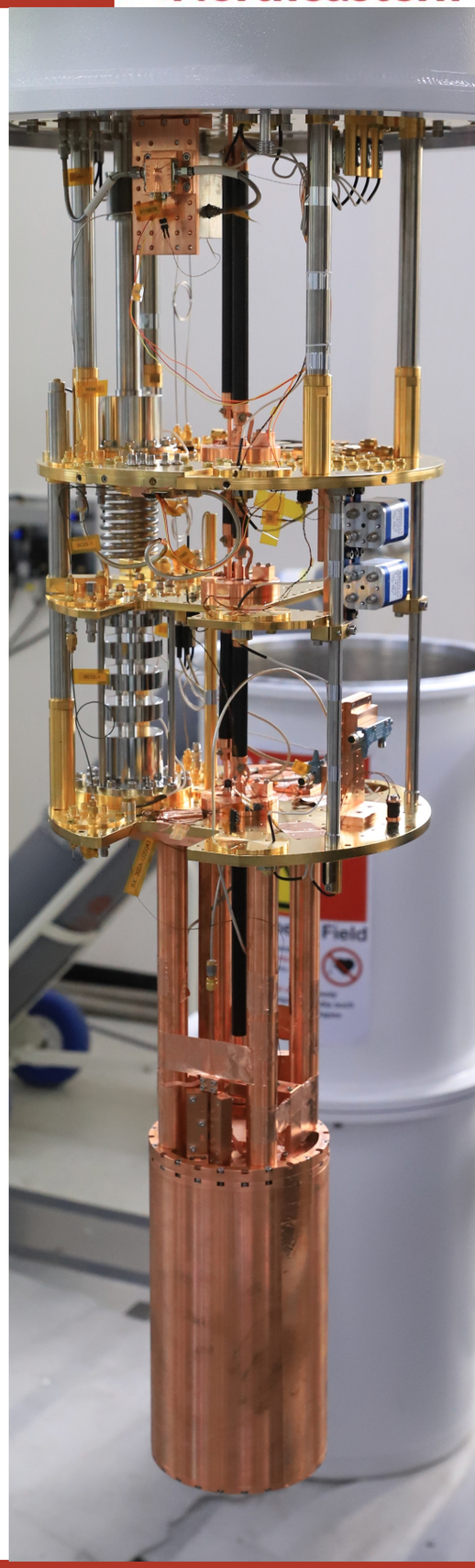
- Microwave resonant cavity as a detector is made of pure copper
  - Inner diameter: 134 mm, inner height: 236 mm
  - Inner volume: 3.5 L
- Capable to search 1.4 - 1.7 GHz frequency range with a dielectric tuning rod
  - Form factor of TM_{010} > 0.5
  - Unloaded quality factor ~ 100,000





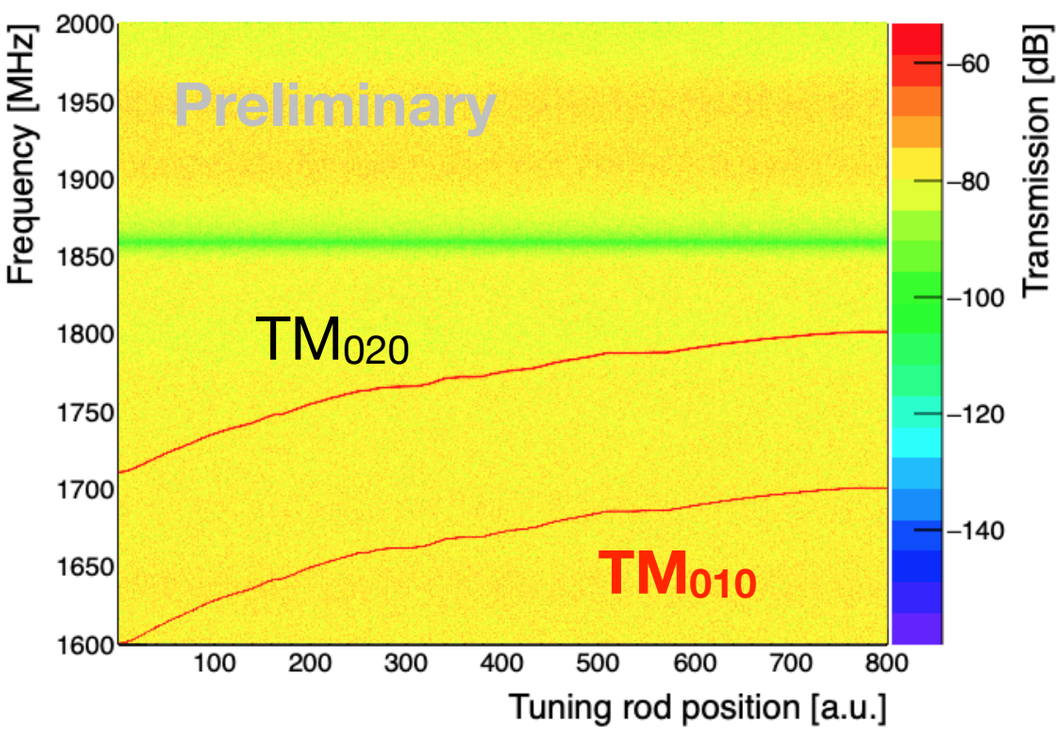


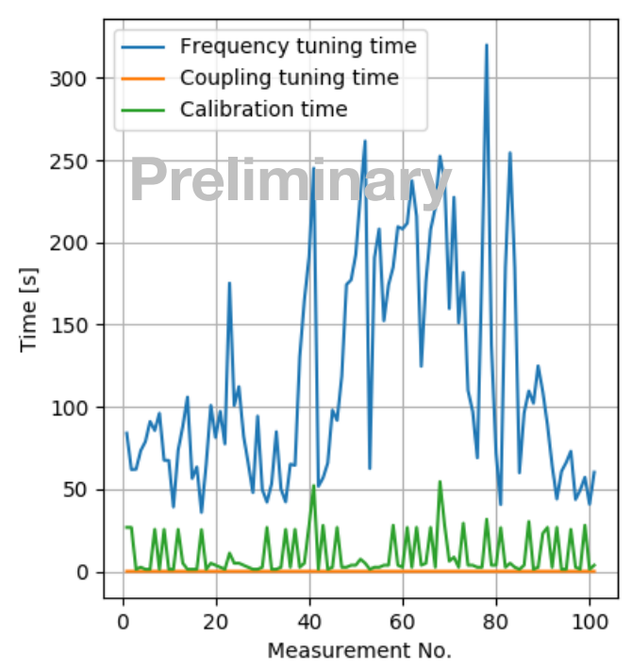




Tuning Mechanism

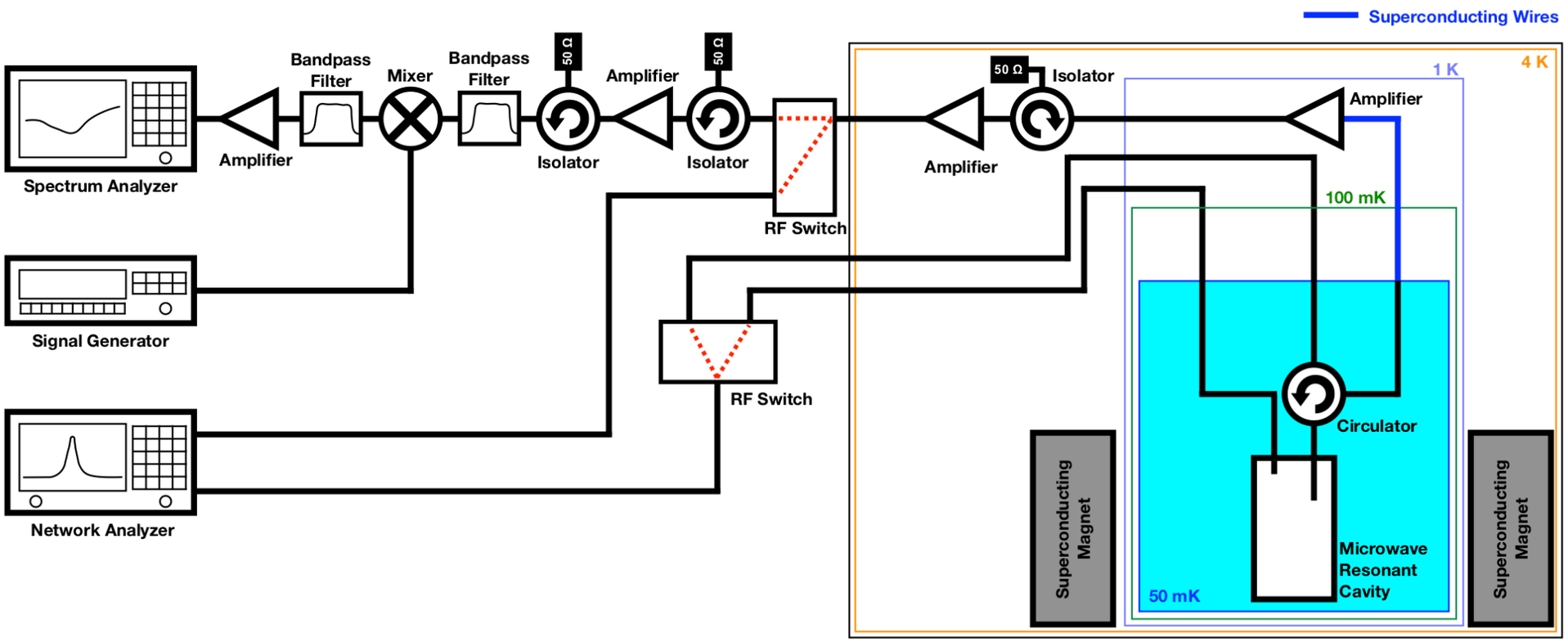
- Resonant frequency and antenna coupling are tuned by stepping motors located at room temperature
  - Driving forces are transmitted through shafts down to cavity
  - Dielectric tuning rod (Al_2O_3) is employed for frequency tuning
    - Since the axle of tuning rod is slightly off from the axle of driving shaft, a locomotive tuning mechanism is employed
  - No mode-crossing for TM_{010} is found



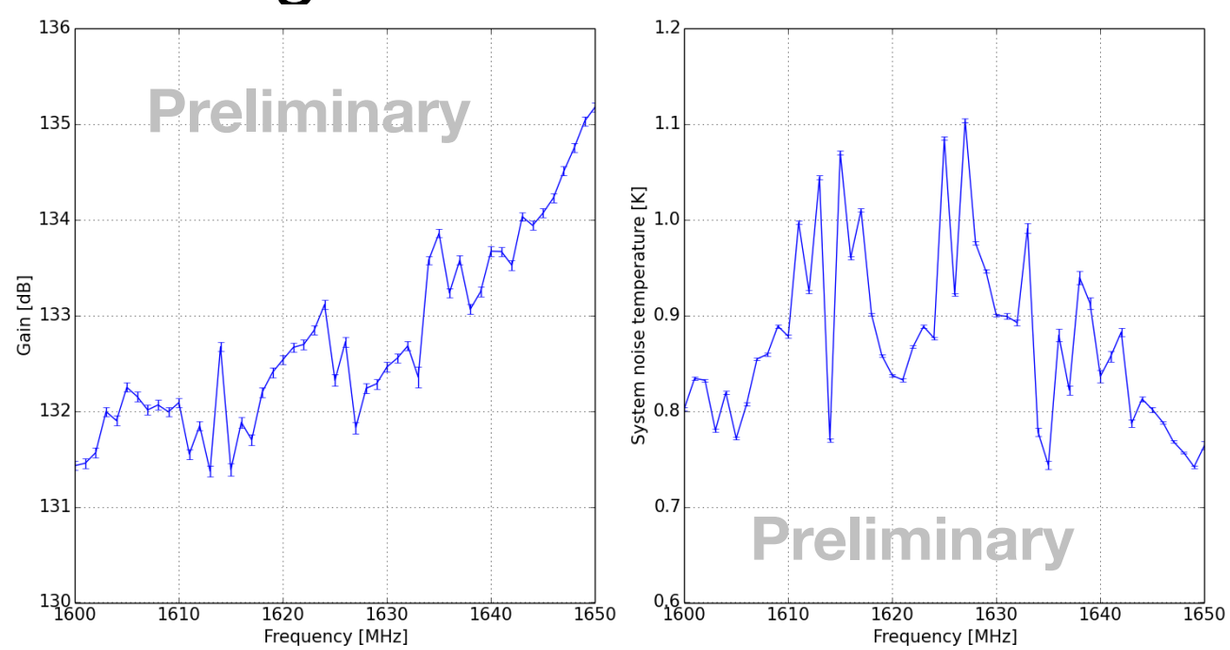


with 1 MHz step tuning

Microwave Receiver Chain

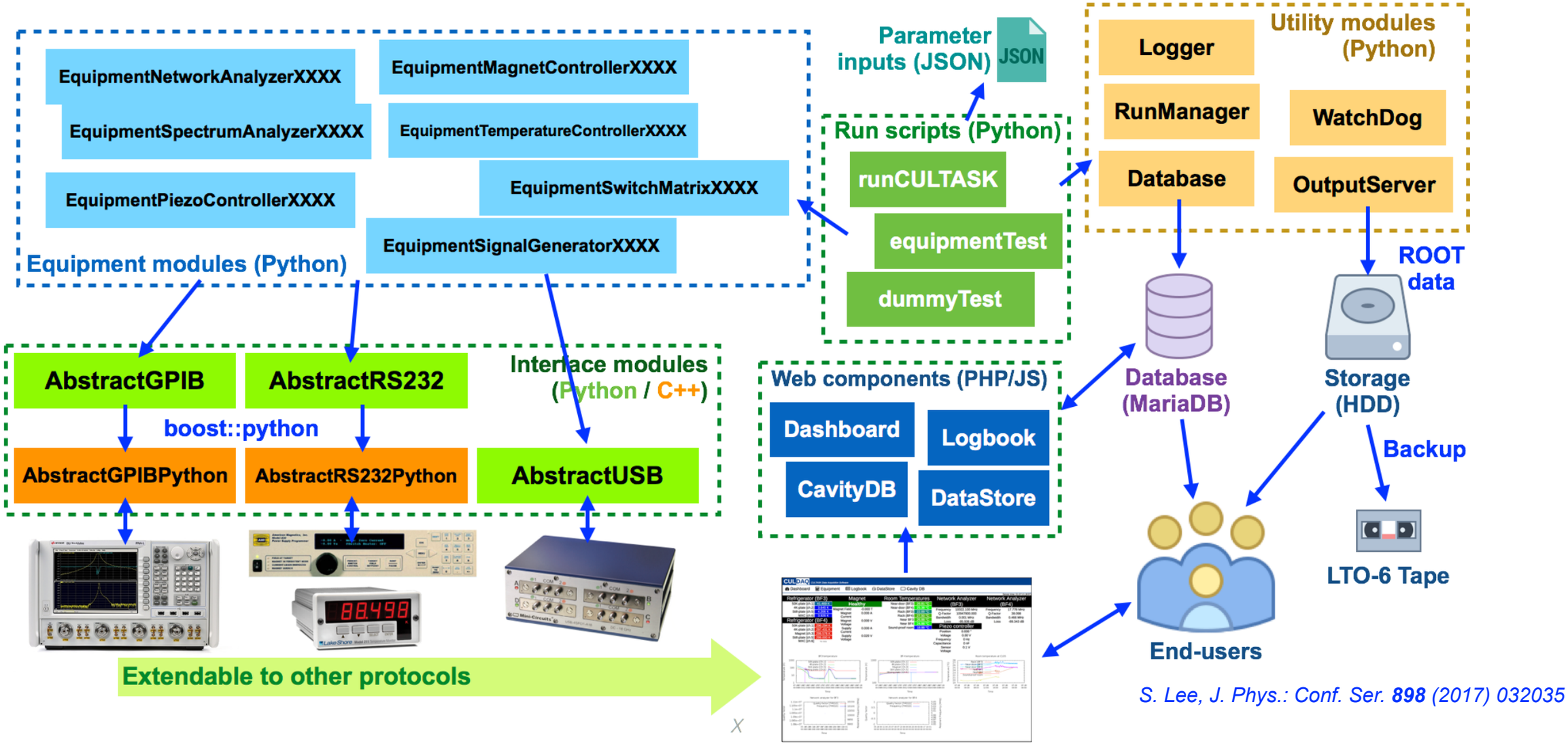


- Microwave signals are transmitted through the receiver chain
  - 2 amplifiers in cryogenic environment and 2 more at room temperature (total system gain: ~133 dB)
  - Signals are down-converted to frequency centered at 70 MHz
  - System noise temperature: ~1 K



Data Acquisitions and Controls

- Data acquisitions and controls are governed by a home-grown software, CULDAQ
  - Various interfaces are supported (GPIB, RS232, USB, Ethernet, …)
  - Experiment is monitored via web interface (Grafana, …)



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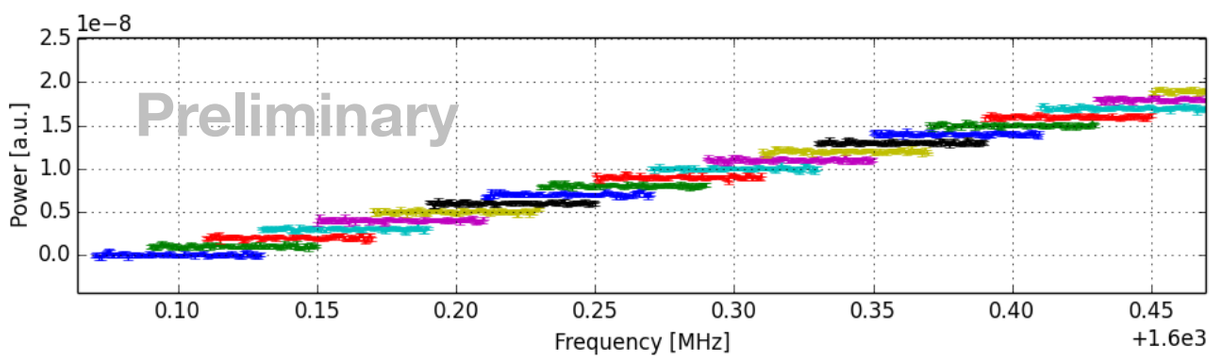
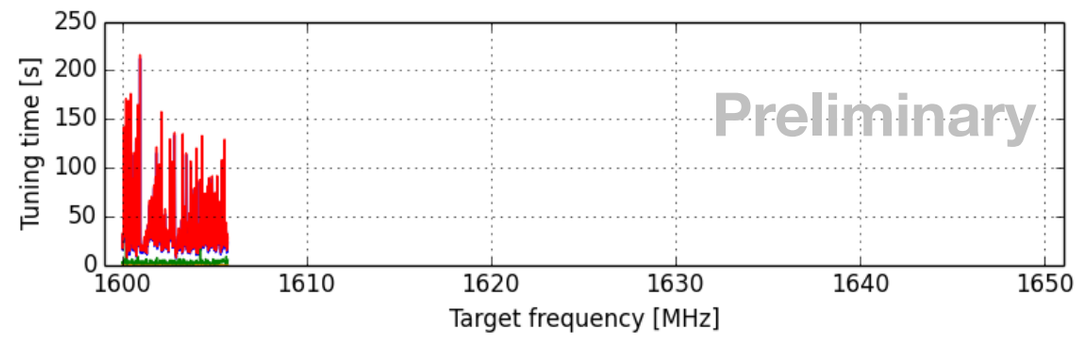
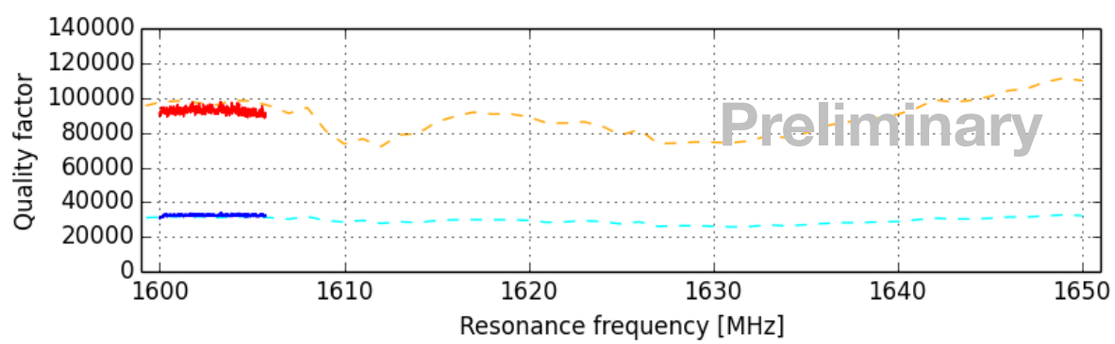
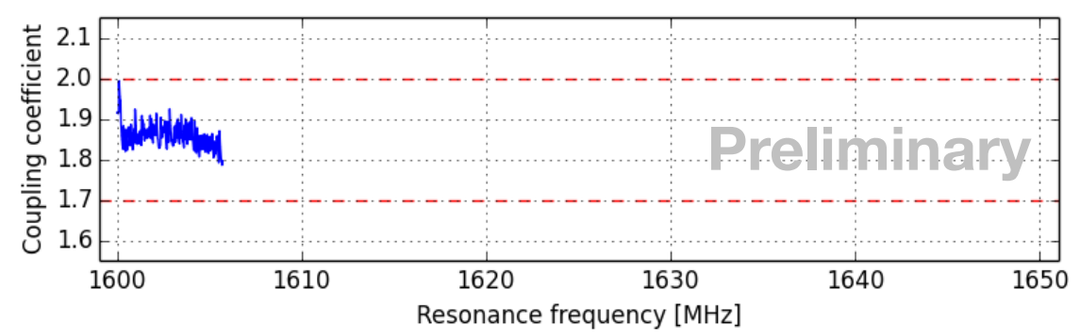
Commissioning and Physics Runs

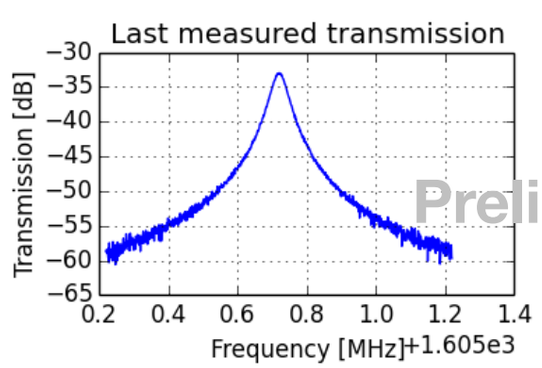
- From commissioning runs, we confirmed that the experiment is ready to go
  - Frequency range of 1.60 - 1.65 GHz will be scanned first
  - We may choose either 1.65 - 1.70 GHz or 1.55 - 1.60 GHz to scan depending on the cavity characteristics

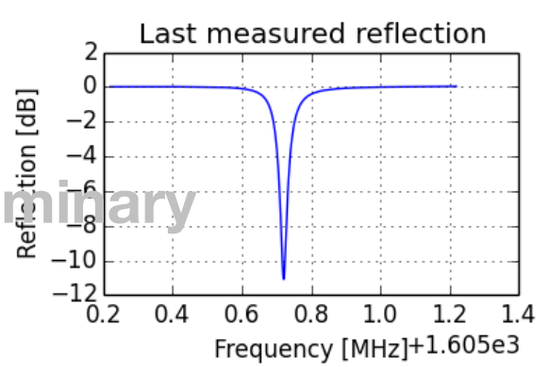


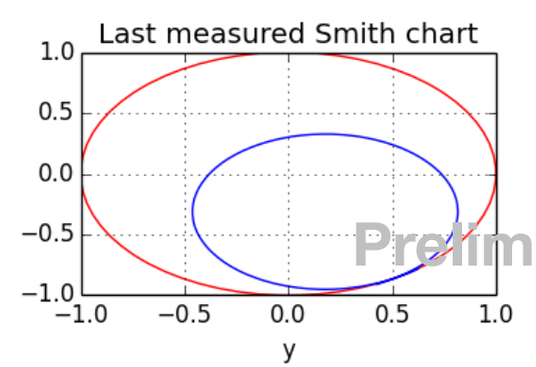


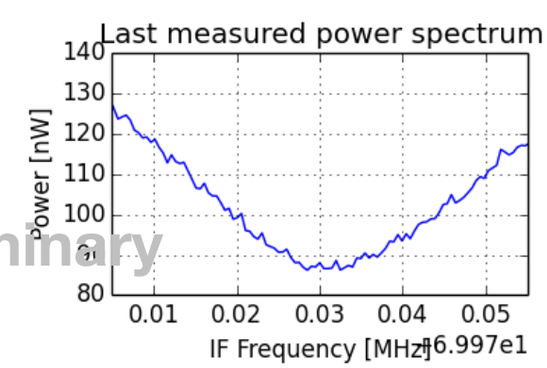








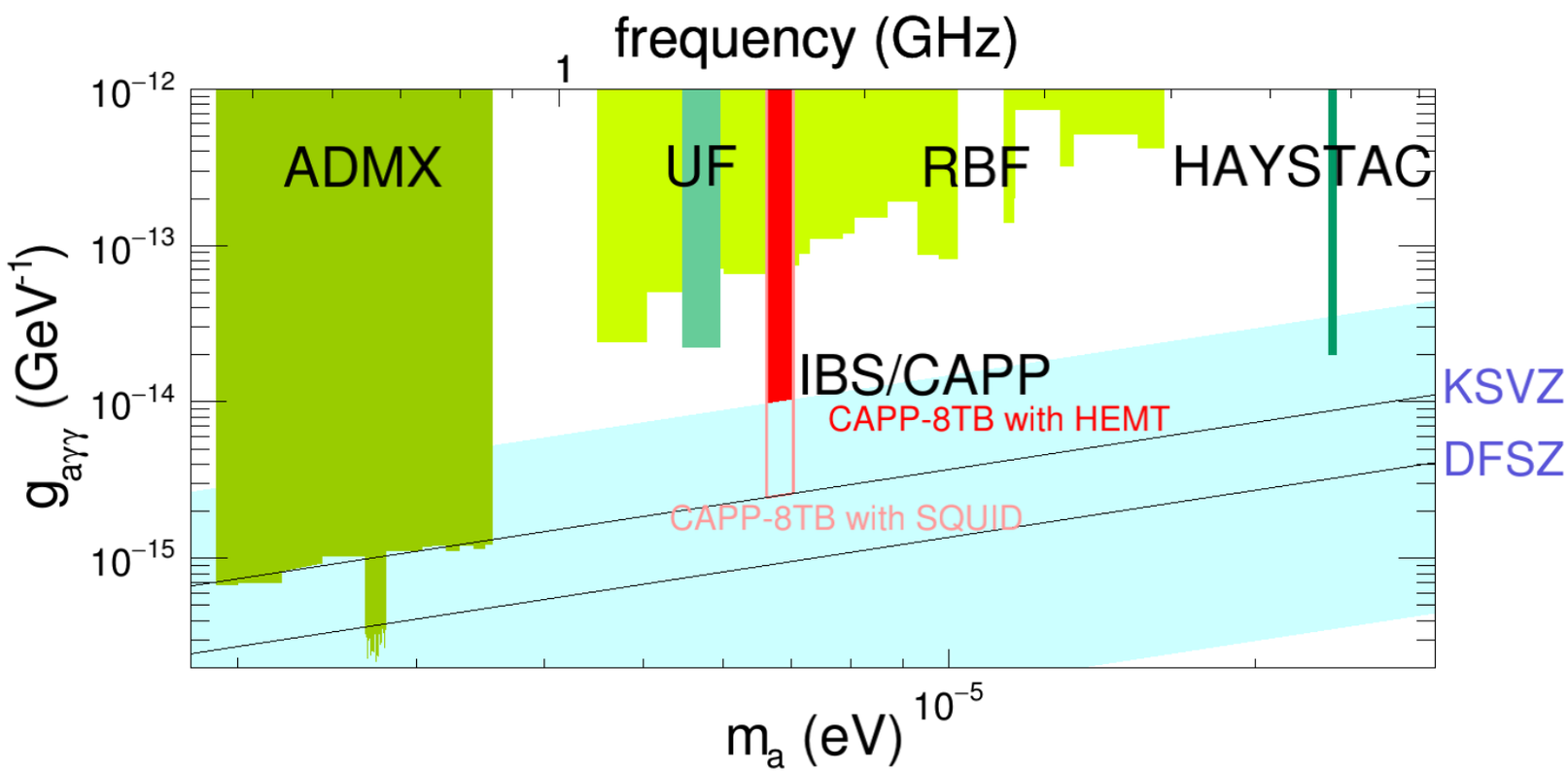




Status and Plans

- Physics run has just started 5 days ago
  - As of today, we have scanned from 1600 to 1606 MHz
  - Expecting ~90 days of operation to reach QCD axion band within the frequency range of 1.60 - 1.70 GHz (or 1.55 - 1.65 GHz)

- In the 2nd stage of the experiment, quantum-limited noise amplifiers will be employed to reduce the system noise temperature → we will challenge KSVZ sensitivity



Summary

- CAPP-8TB is an axion haloscope to search mass range of 6.62 - 7.04 μeV
  - At a physical temperature of 50 mK under 7.3 T magnetic field
  - Pure copper resonant cavity with a dielectric tuning rod
  - Locomotive frequency tuning mechanism is managed by a home-grown DAQ software

- In the 1st stage, it will touch QCD axion band with commercial HEMT amplifiers
  - Successful commissioning runs
  - Physics run has just started, ~90 days operation expected

- In the 2nd stage, it will try KSVZ sensitivity with quantum-limited noise amplifiers