Status and Early Results

ADMX-HF Extreme Axion Experiment

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Outline

I. Overview of experiment

II. Equipment and infrastructure

III. Operations

IV. First data run

V. Future plans

ADMX-HF/X3 Team

Yale University (experiment site)

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CU Boulder/JILA

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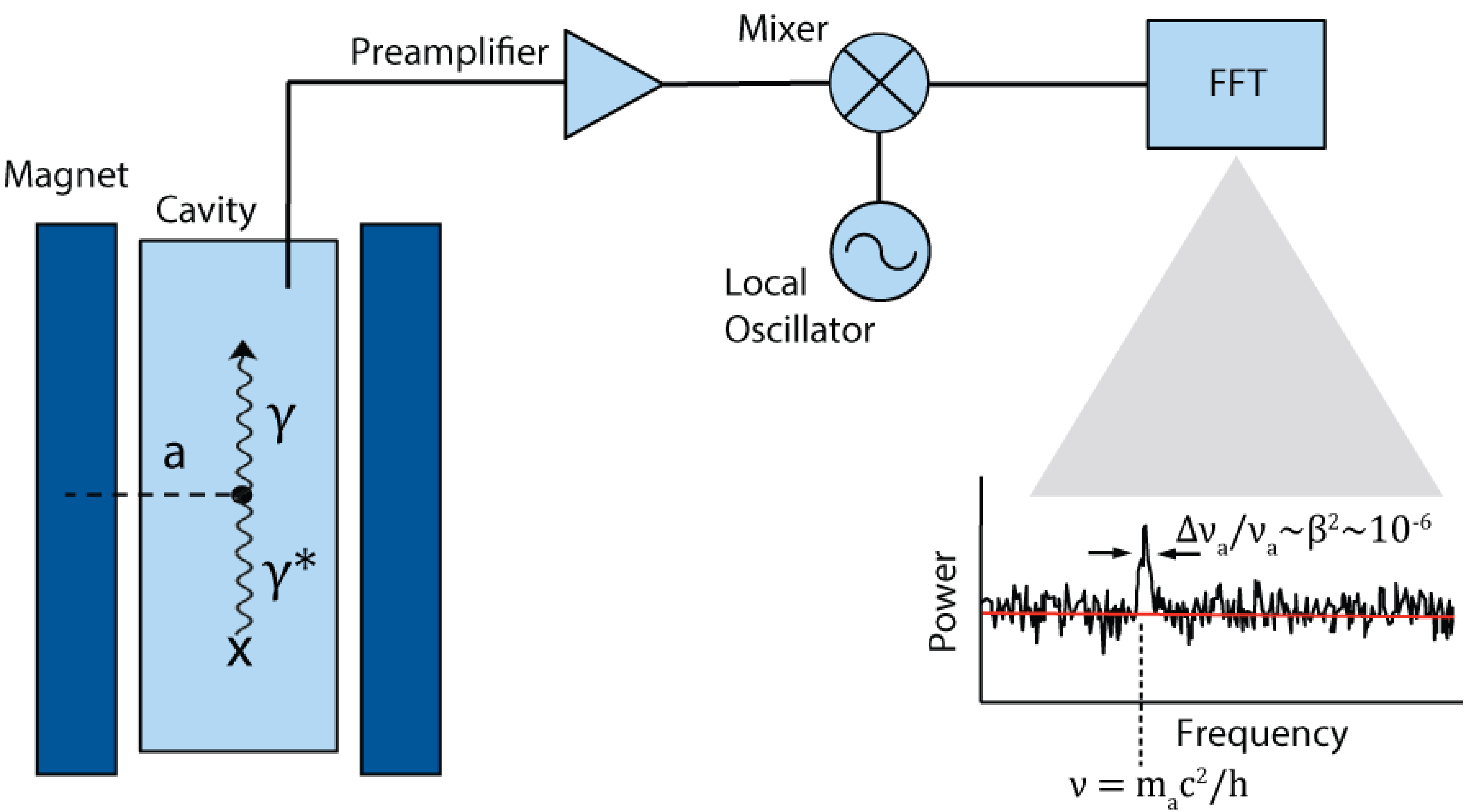
Lawrence Livermore National Lab

Gianpaolo Carosi, Tim Shokair

Motivation

- Searching for QCD axions around 10^{-5} eV
- Same detection technique as ADMX: haloscope
- Designed to be a small, adaptable experiment with quick turnaround times
  - Platform to test new amplifier and cavity technologies
  - First look at data in the 10 to 50 μeV range
- Now in operational phase: the Extreme Axion Experiment (X3)

Detection technique



Signal power and system noise

Signal to noise ratio:

$$\frac{s}{n} = \frac{P_{sig}}{kT_{sys}} \sqrt{\frac{t}{\Delta\nu}}$$

Signal power:

$$P_{sig} \propto (B^2 V Q_{cav} C_{nml}) \left(g_{a\gamma\gamma}{}^2 \frac{\rho_a}{m_a} \right)$$

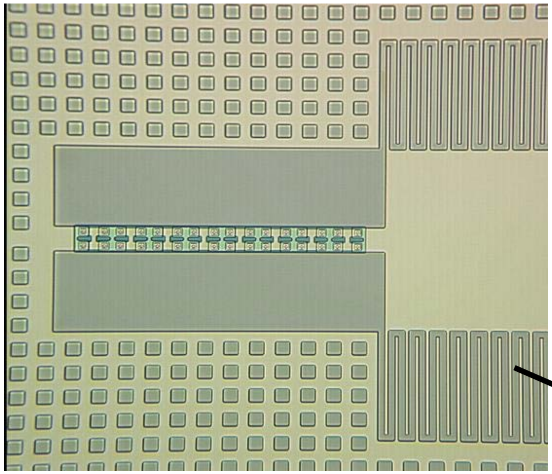
Noise temperature:

$$kT_{sys} = h\nu \left(\frac{1}{e^{h\nu/kT} - 1} + \frac{1}{2} \right) + kT_A$$

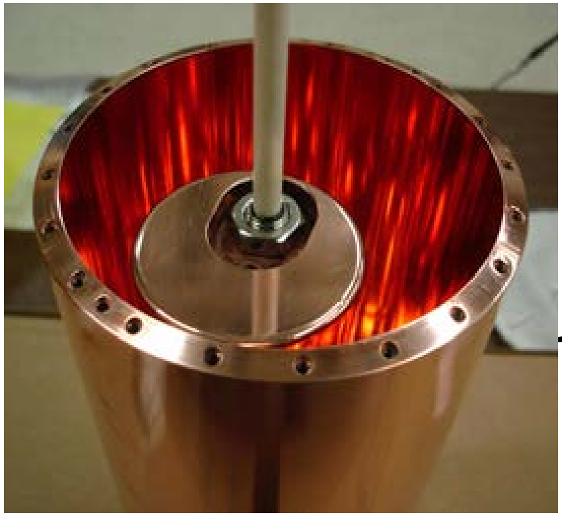
Equipment and infrastructure

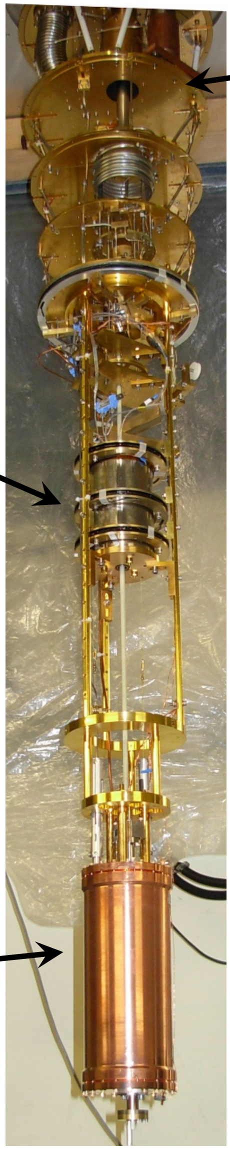
Full experiment

Josephson Parametric Amplifier



Microwave Cavity (copper)



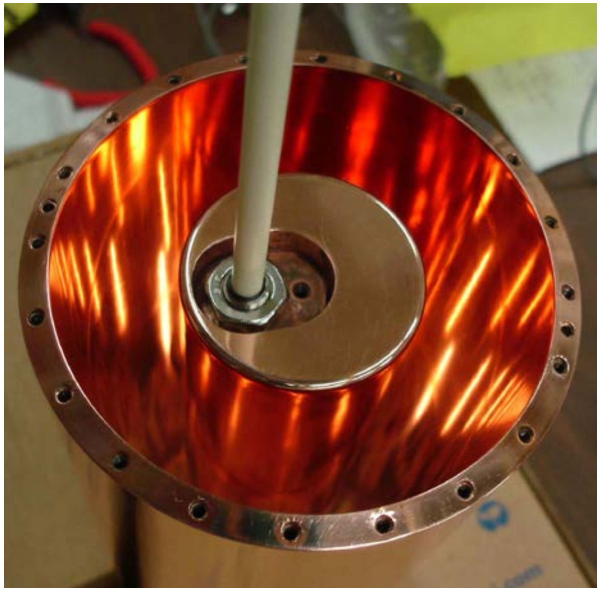


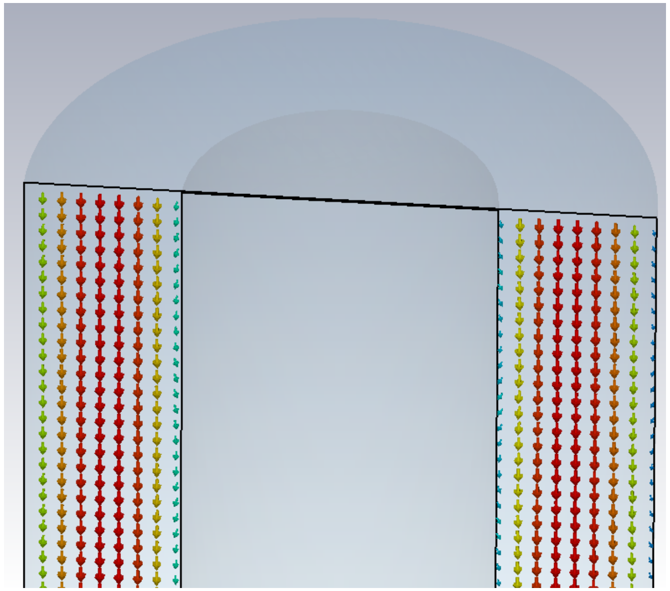
$^{3}He/^{4}He$ Dilution Refrigerator

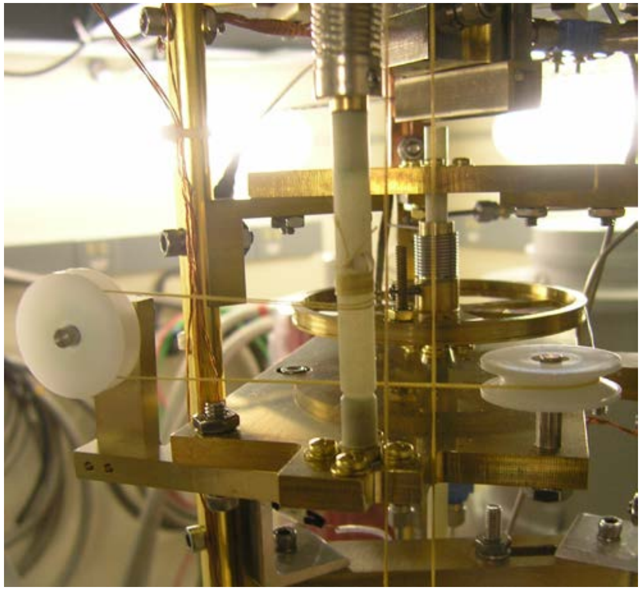
9.4 Tesla, 10 Liter Magnet

Microwave cavity (UC Berkeley/LLNL)

- Cu body with off-axis Cu tuning rod
- Tunable over roughly 3-6 GHz (TM_{010} mode)
- $Q_c \sim 20{,}000$
- Kevlar lines used for motion control at 100 mK

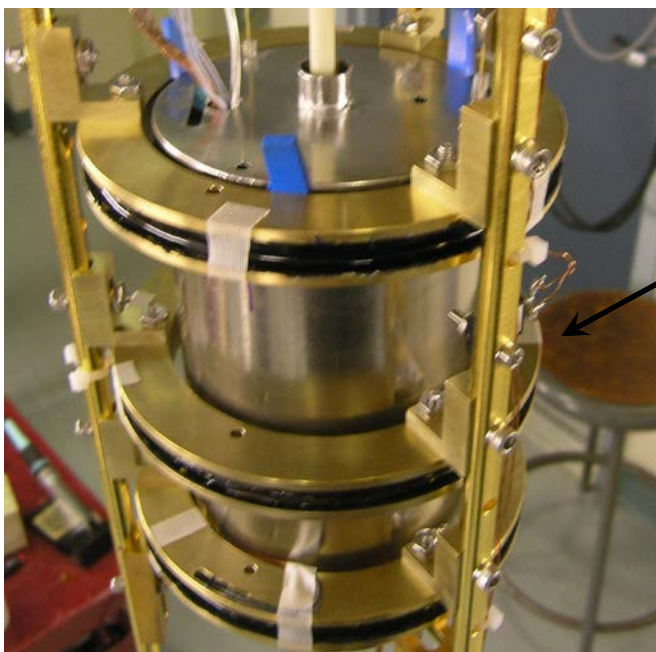




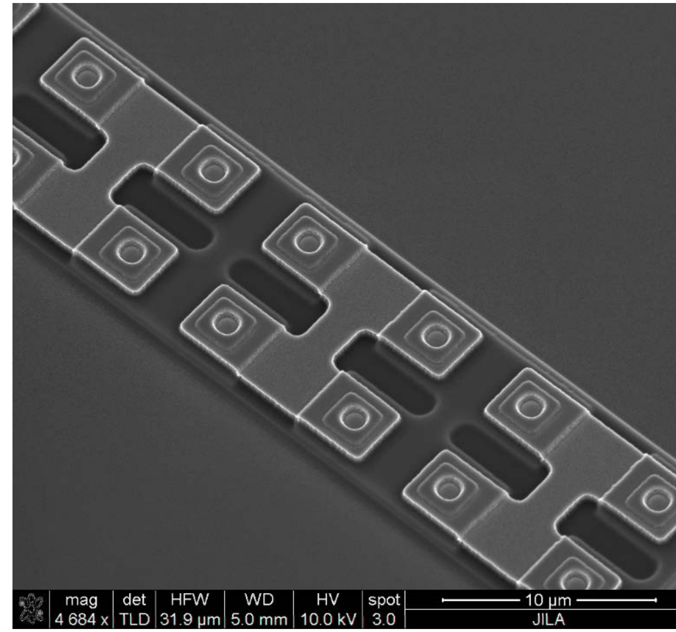


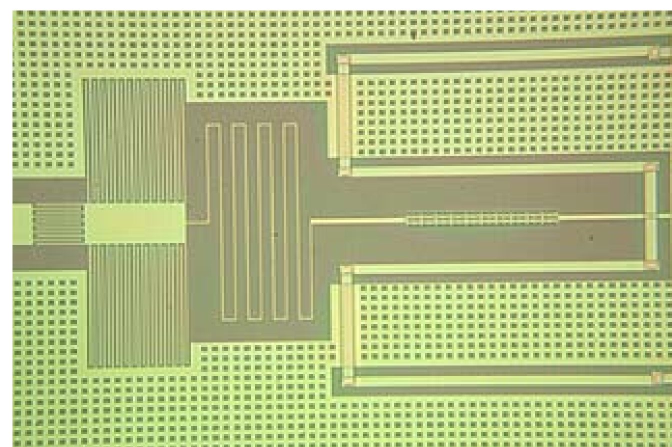
Amplifier (Colorado/JILA)

- Josephson Parametric Amplifier composed of SQUIDs
- Tunable from 4.4-6.5 GHz with 20 dB of gain



Persistent coils for field cancellation

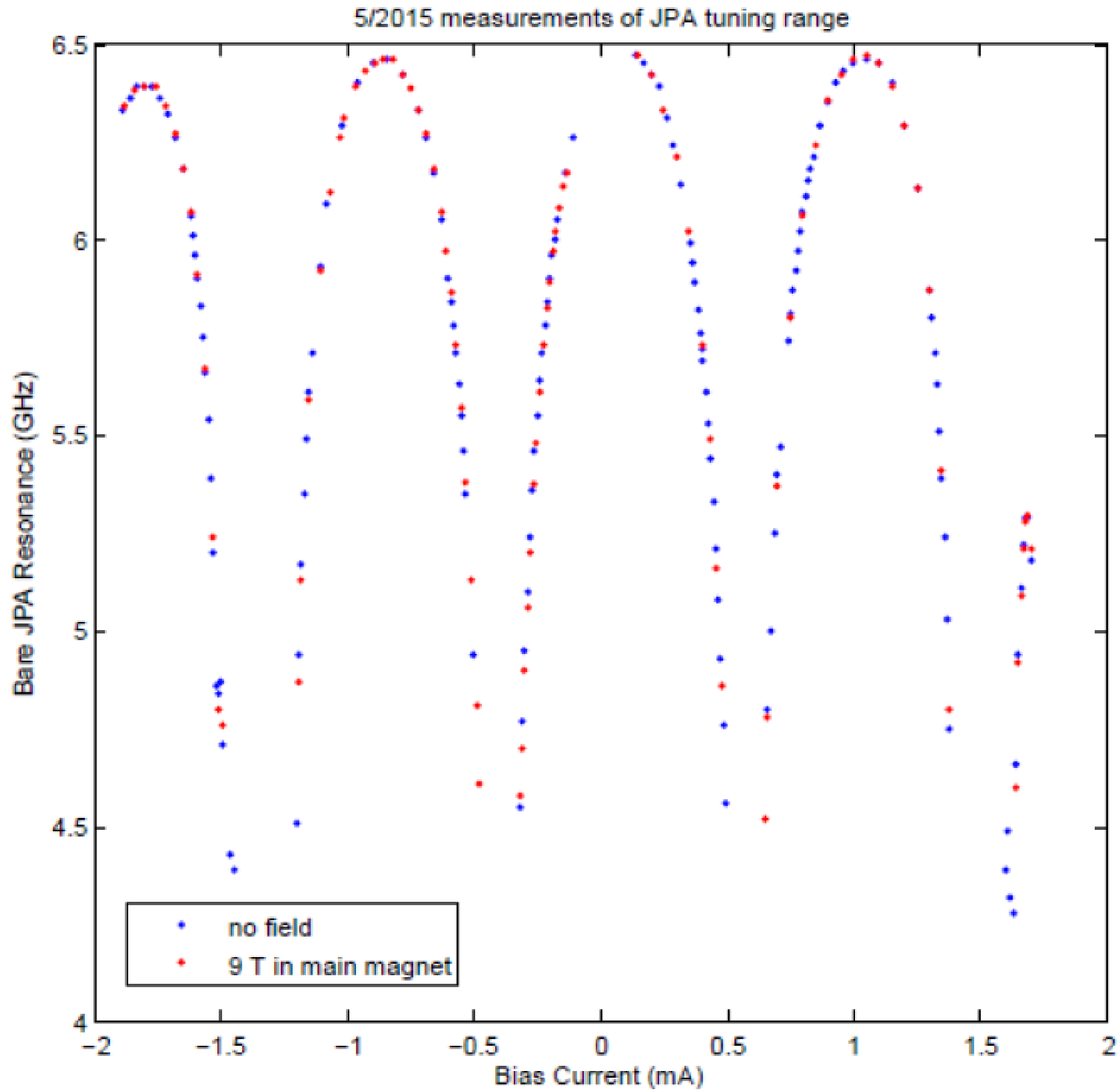




Amplifier (Colorado/JILA)

- Bucking coil, passive coils, mu metal, and a superconducting shield reduce presence of external field at JPA by a factor of 10^8

- Consistency in tuning demonstrated with and without external field



Infrastructure

Superconducting magnet

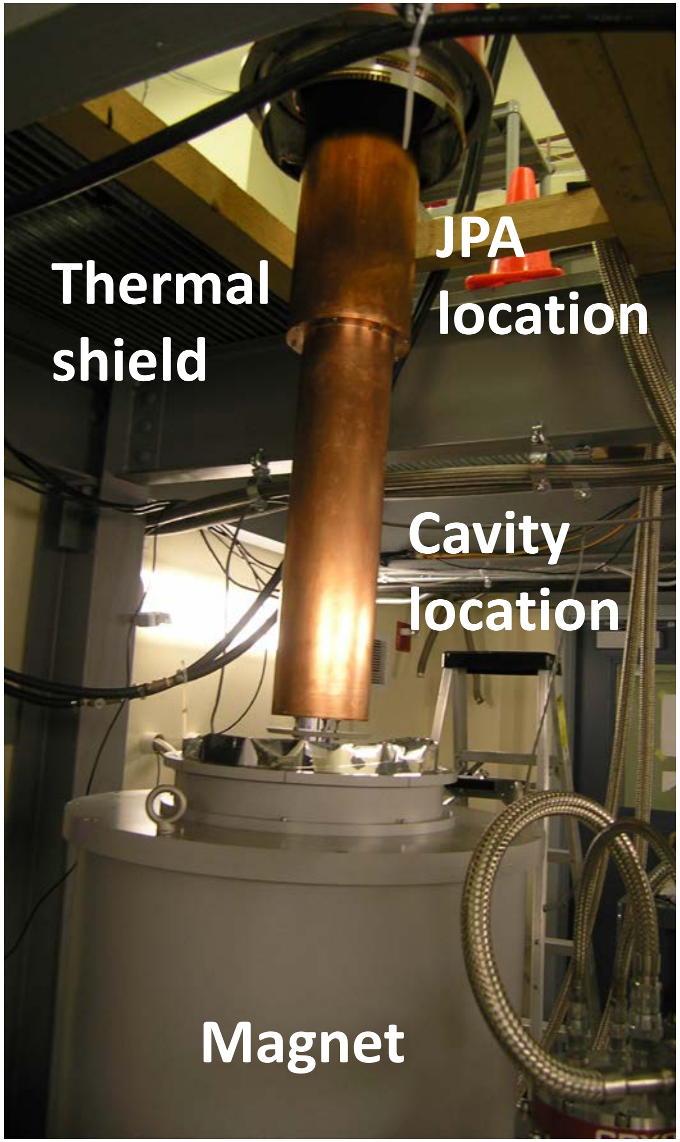
- Made by Cryomagnetics, Inc.
- Maximum field of 9.4 T
- Large bore/long straight field region
- Dry system

Dilution refrigerator

- 25 mK base temperature
- Experiment operates at 100 mK to stabilize the JPA
- Thermal shield contains gantry, JPA, and cavity

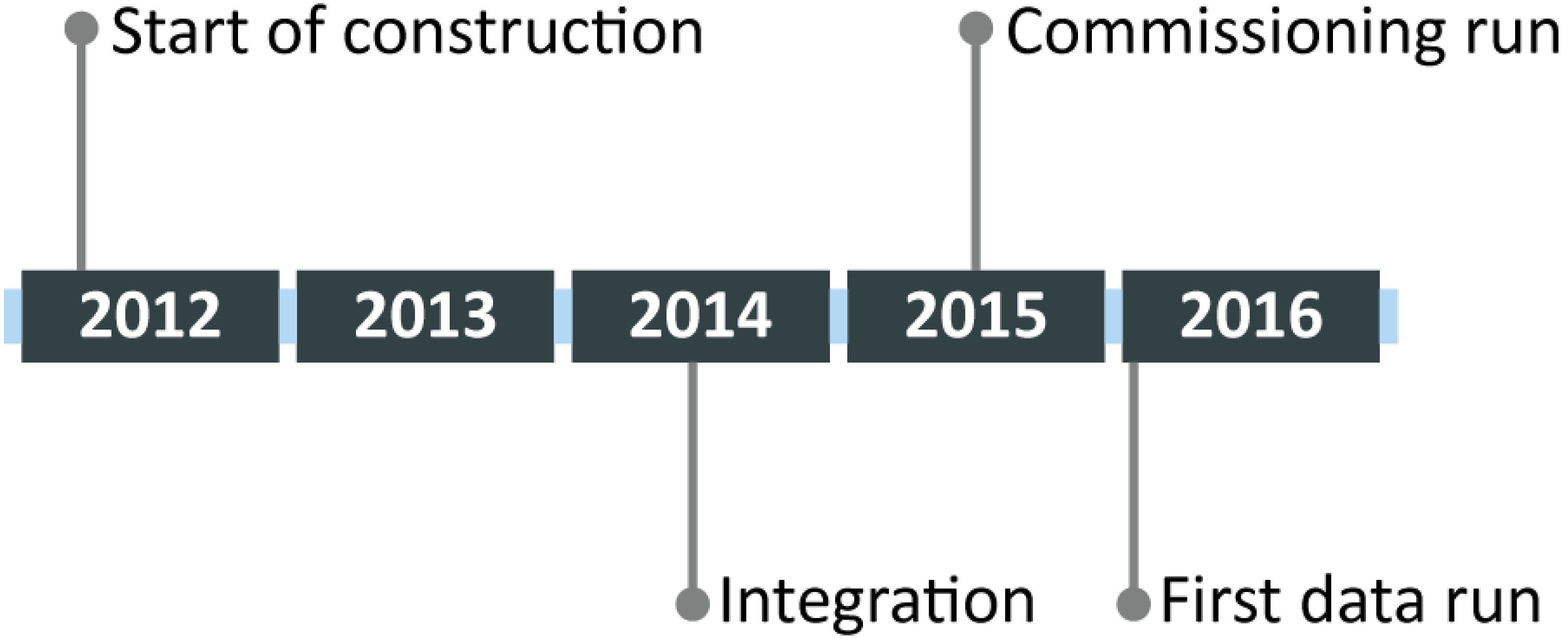
Data analysis

- Two analysis sites: Yale and Berkeley



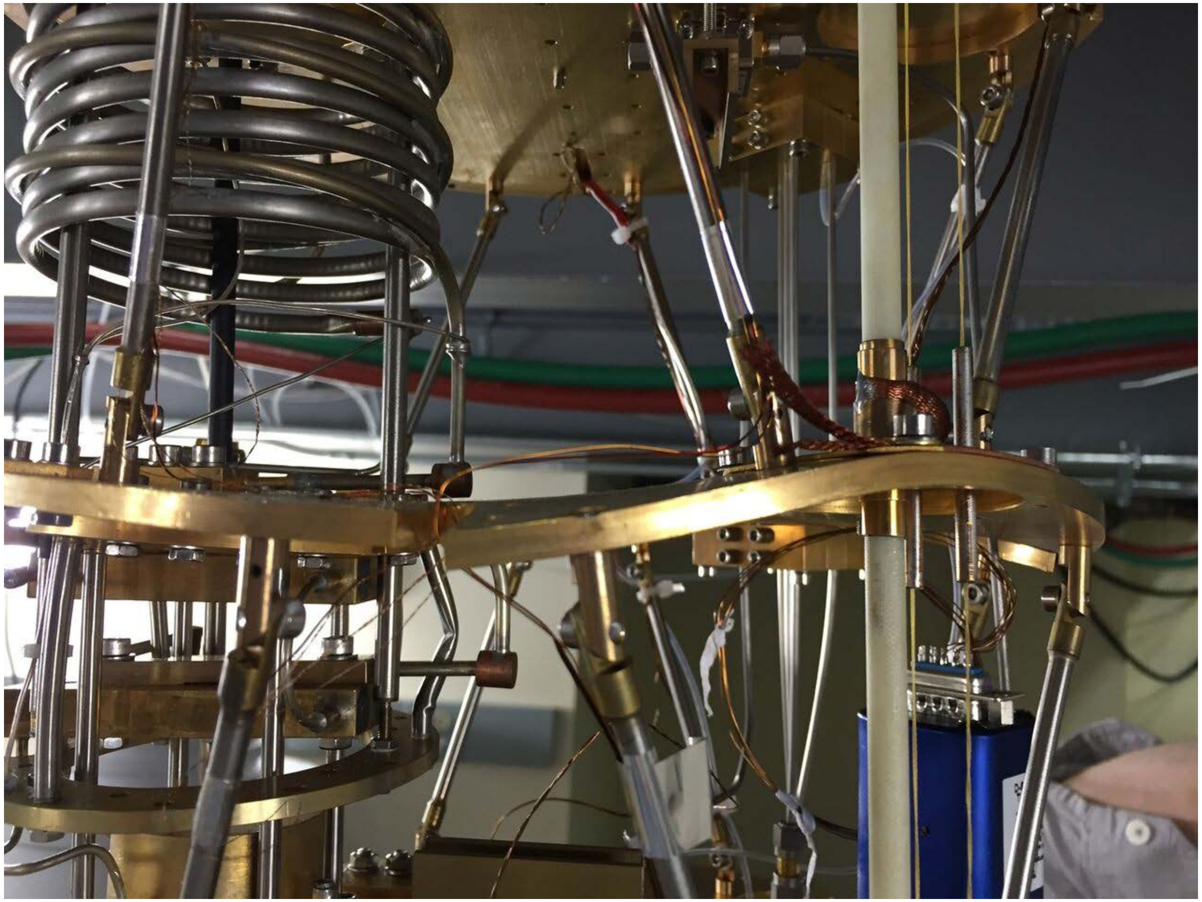
Operations

Timeline


Start of construction
Commissioning run
2012
2013
2014
2015
2016
Integration
First data run

Magnet quench

- Experienced a magnet quench in early March
- Surprisingly little damage
- Repairs completed and data run resumed



First data run (01/16-07/16)

Run characteristics

Frequency: $f \sim$ 6 GHz ($m_a \sim$ 25 μeV/c^2)

- Scanning 100 MHz

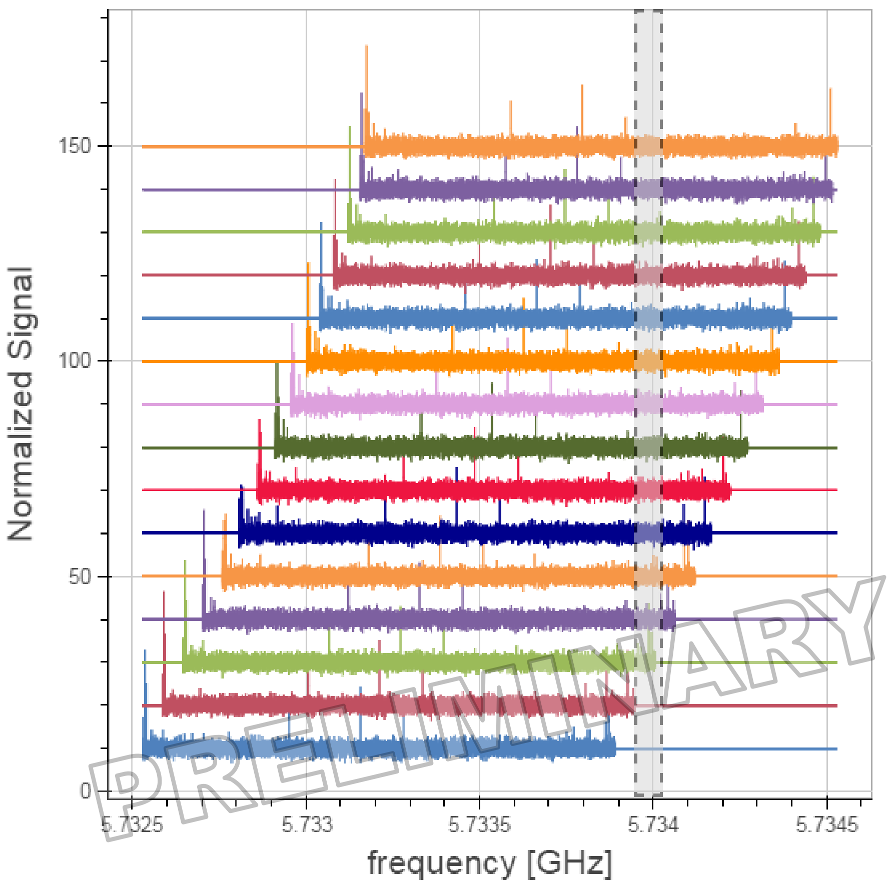
Noise: $T_{SYS} \sim$ 1100 mK or 3.5 x SQL

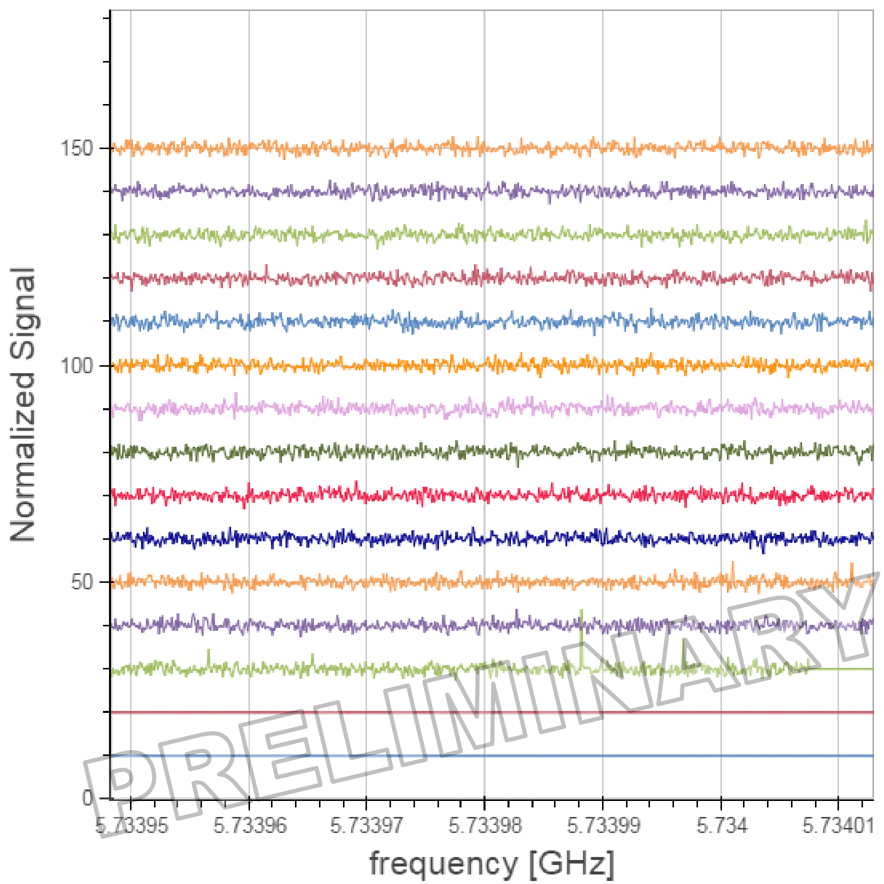
- Added noise from "hot rod": tuning rod not cooling properly
- Thermal shunt for tuning rod being tested at Berkeley

Projected sensitivity: $g_{a\gamma\gamma} \sim$ 2.5 x KSVZ

- After fix of hot rod problem, $g_{a\gamma\gamma} \leq$ 2 x KSVZ

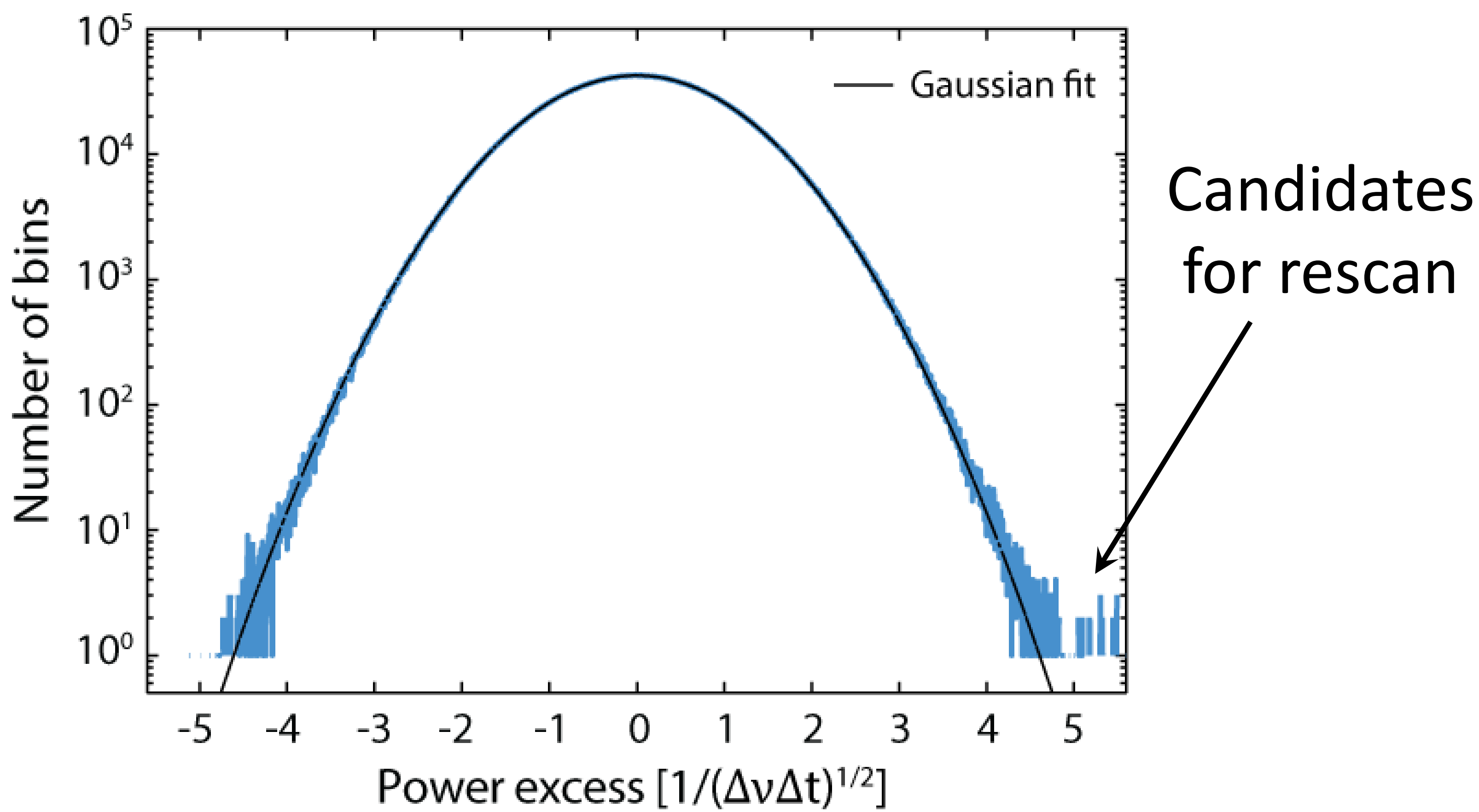
Preliminary data





Data quality and analysis

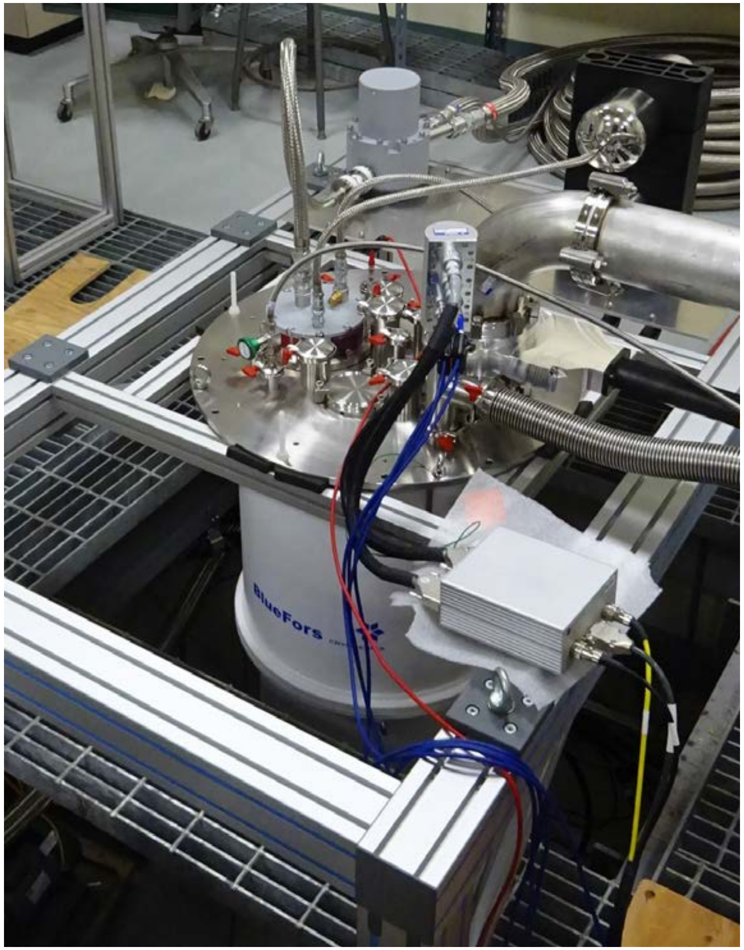
- Data quality appears high after first pass
- Tests of analysis software are underway



Future plans

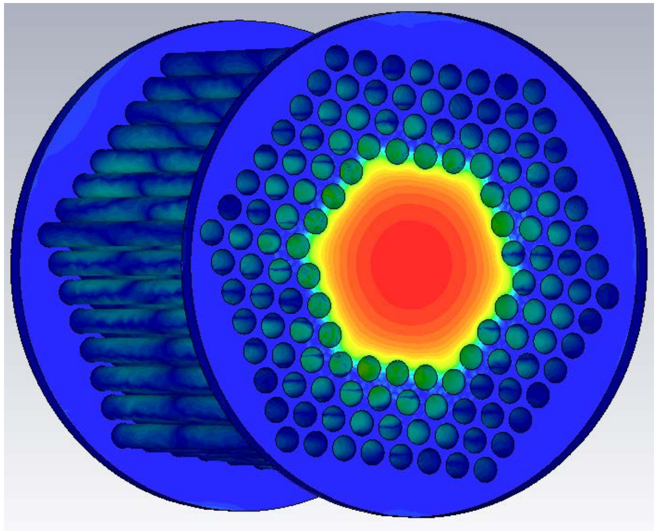
Planned upgrades for 2016

- Fix for hot rod problem (fall)
  - Achieve sensitivities below 2 x KSVZ
- Upgrade to BlueFors dilution refrigerator (fall)
  - Reduced vibrations
- Implementation of a squeezed state receiver (winter)
  - Could greatly increase the scan rate



Microwave cavity R&D

- Superconducting thin film multilayers and Dielectric Bragg Reflectors: substantially raise Q
- Photonic Band Gap structures: eliminate unwanted modes and move to higher frequencies
- First designs will be implemented in early 2017
- More details in my poster later today!

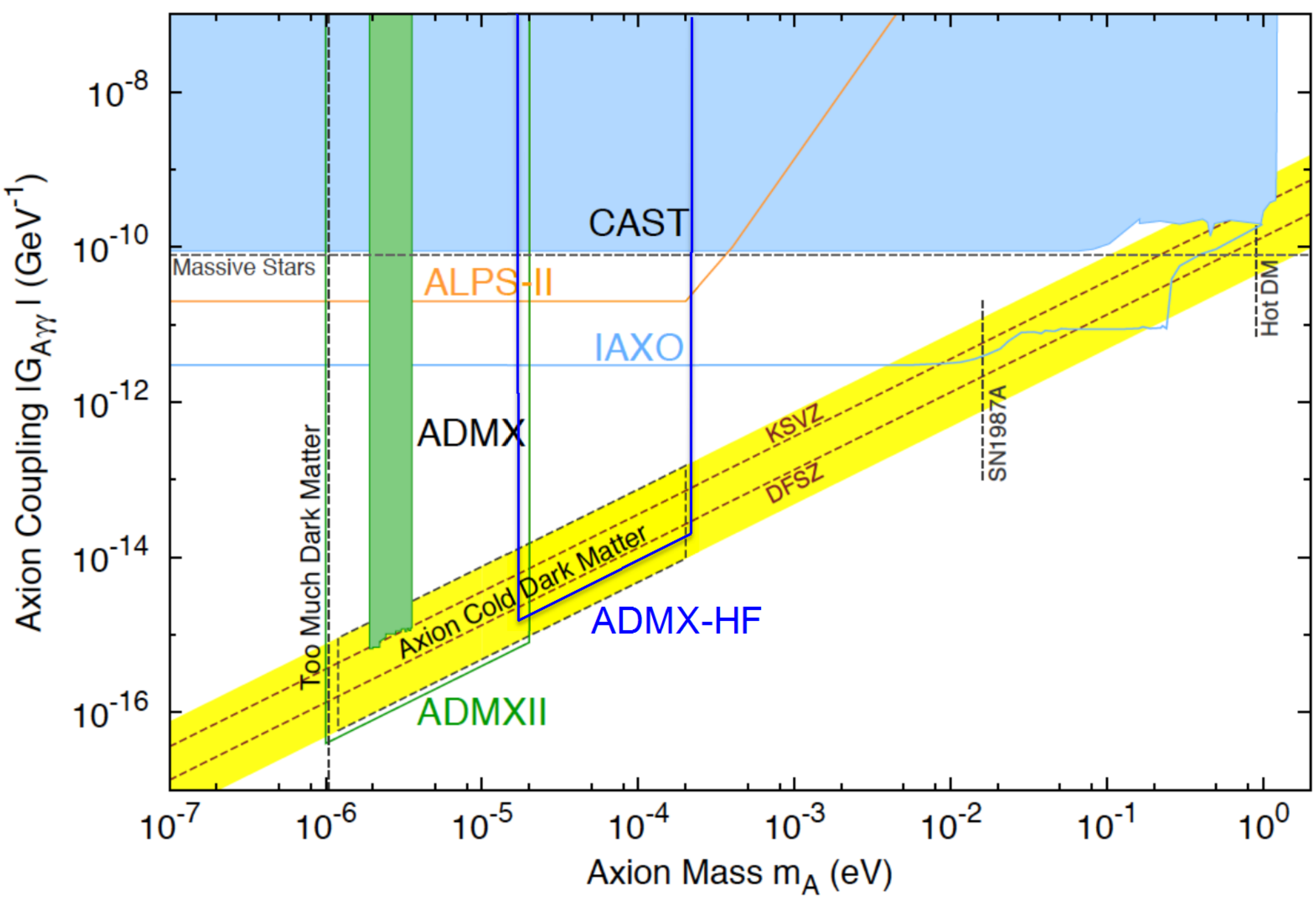


Summary

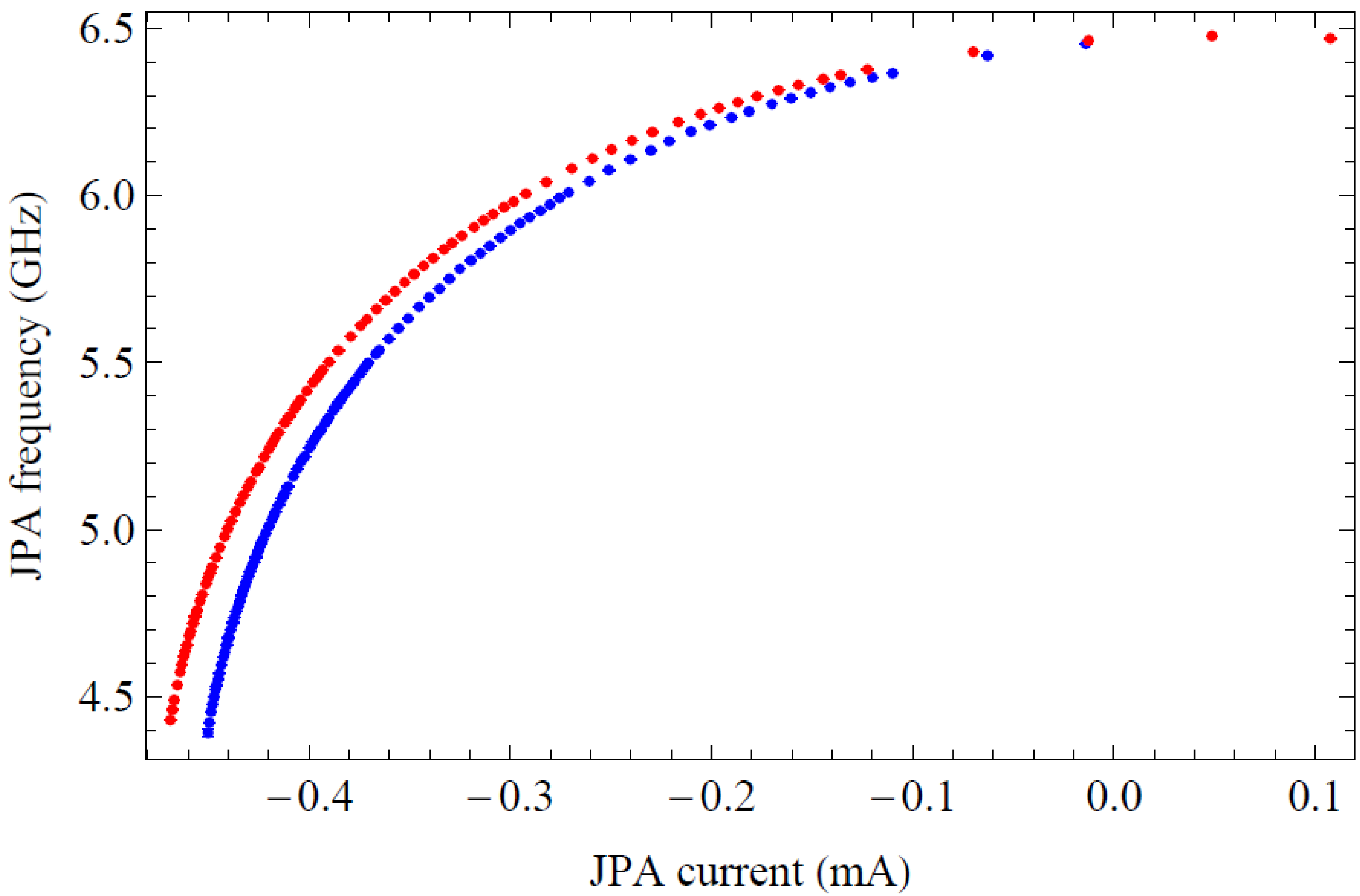
- ADMX-HF/X3 has entered its operational phase
- First data run is ongoing (January 2016 – July 2016)
- Expected to achieve 2.5 x KSVZ at 6 GHz in current run
- Upgrades planned that will lower noise, improve sensitivity
- R&D is ongoing to develop amplifiers and microwave cavities for 10 GHz and up

Backup slides

Axion Experiments

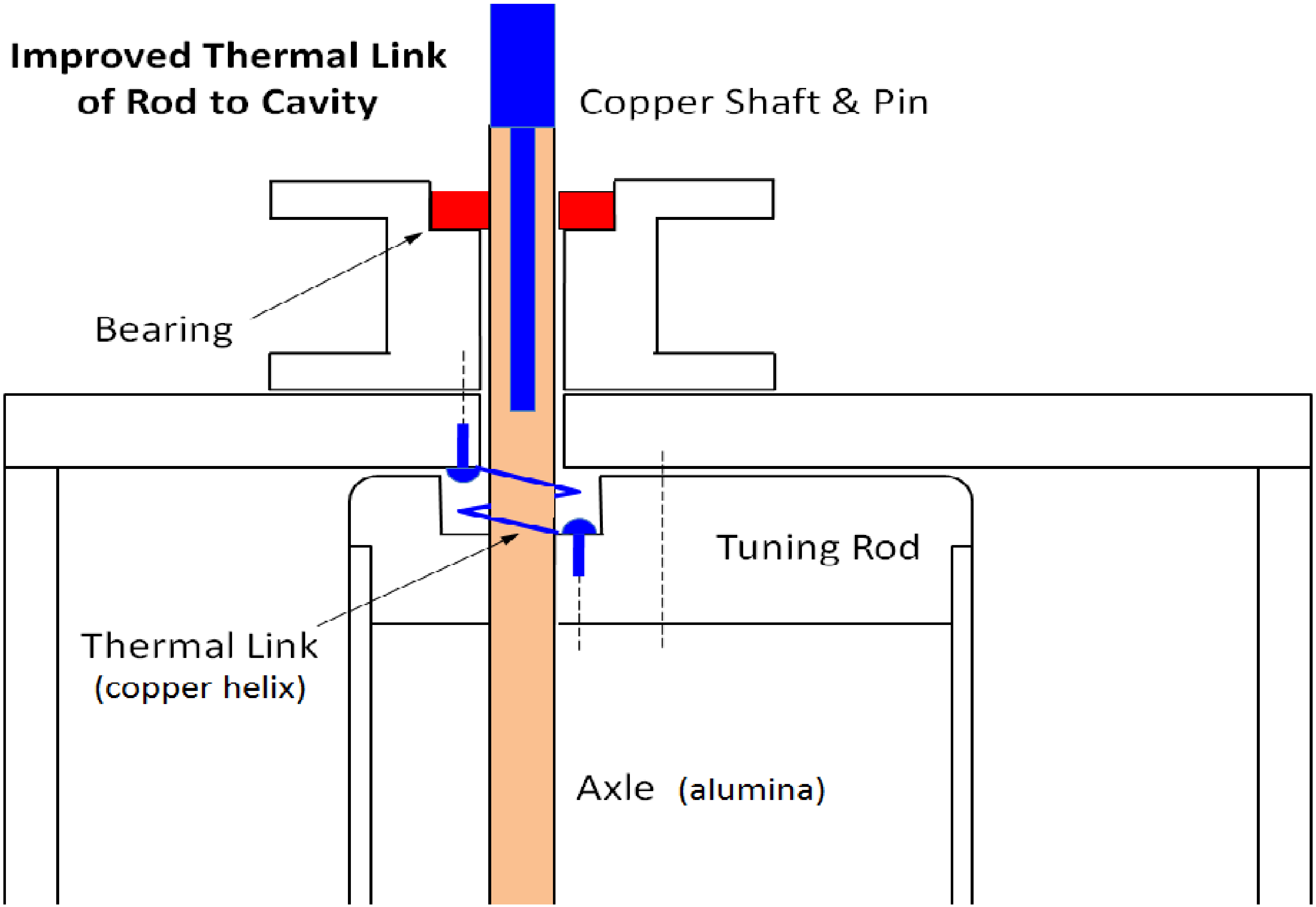


JPA Tuning



In 5 T field (blue) and no field (red)

Hot rod solution



Cavity tuning