SUPAX – A SUPERCONDUCTING AXION SEARCH EXPERIMENT

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JG|U
SUPAX
Graduate School Particle Detectors
DFG Deutsche Forschungsgemeinschaft

Motivation

- *Dark Photons* (DP) are hypothetical massive vector bosons with no direct coupling to Standard Model particles
- Similar to axions DPs are a *Dark Matter* (DM) candidate[1,2]
- Represented by adding a U(1) symmetry to the Lagrangian
- Interaction with photons via kinetic mixing[3], strength given by kinetic mixing parameter χ
- Assuming a DM halo consisting of DPs, axions or axion like particles (ALPs), a cavity resonator can be used as haloscope[4]

Cavity haloscopes

- Used to search for halo DM such as axions and DPs
- Mass peak of DM particle is enhanced by cavity resonance
- Axion
  - Need strong external B-field (14 T planned for SUPAX)
  - Convert via inverse Primakoff effect to photons
  - Signal power $P_S \sim B^2 Q_0 V_{eff}$
- Dark Photons
  - No magnetic field necessary
  - Oscillate into photons via kinetic mixing
  - Signal power $P_S \sim Q_0 V_{eff} \cos^2(\theta)$
- Previously reached quality factors $Q_0 \sim 1.2 \times 10^6$
  - For frequencies near 8 GHz (33 μeV) up to 8 T
  - Using superconducting tapes → not suitable for cavities with curvatures
  - SUPAX is testing superconducting NbN coating to improve Q_0 without tapes

$\cos^2(\theta) =$
- $^1/_3$ for random polarisation of DP field
- $[0, ^1/_3]$ for fixed polarisation of DP field, depending on location of experiment and data acquisition time

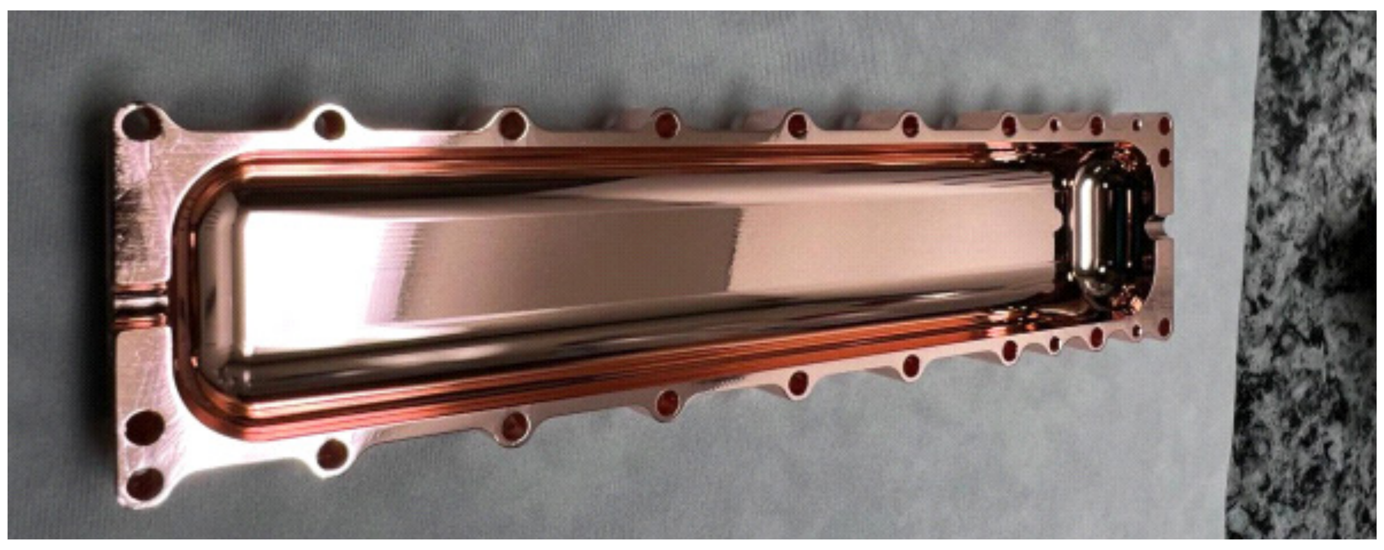
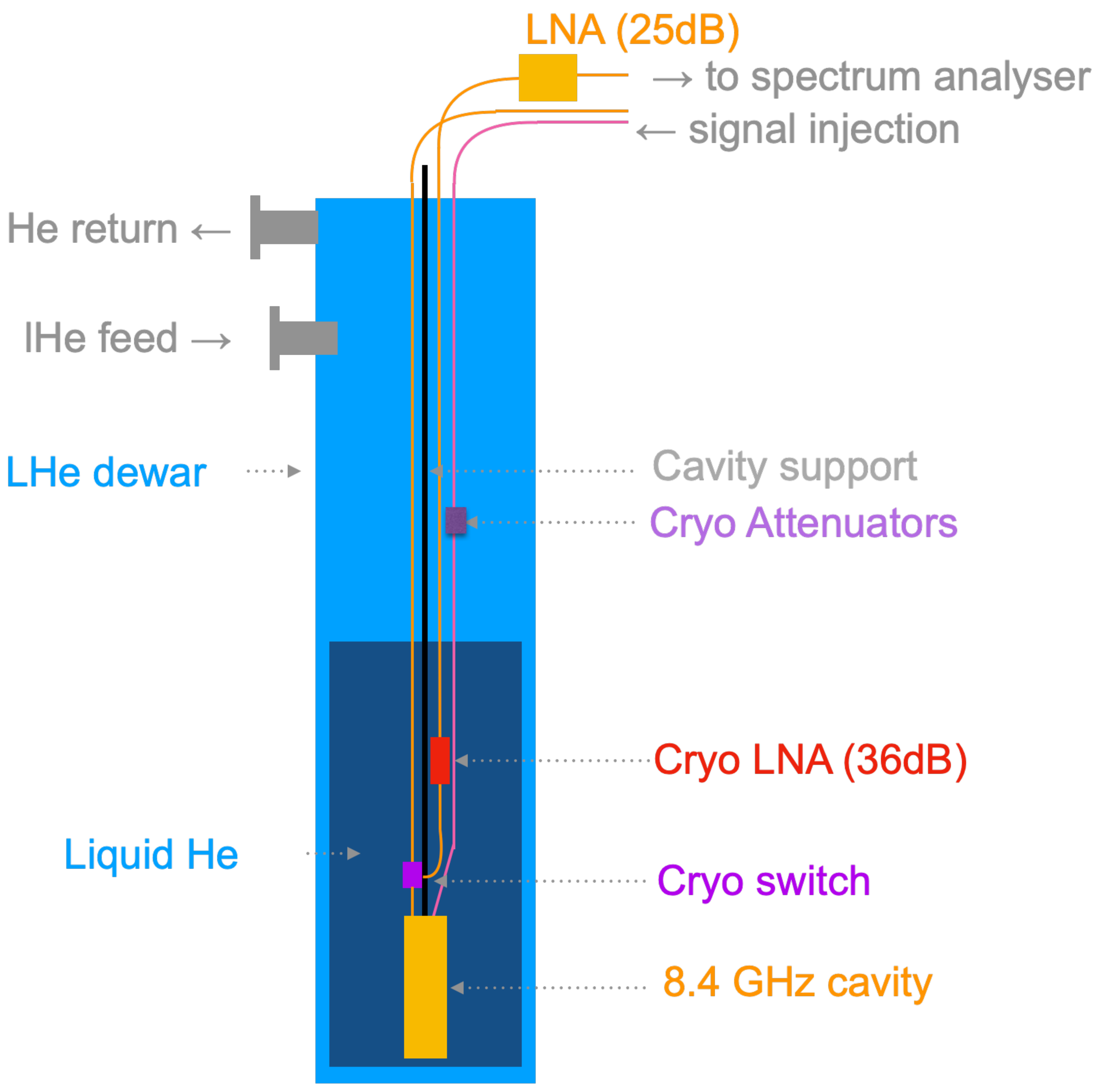


FIG. 1 Copper cavity with effective volume $V_{eff} = 18.8 \pm 0.2$ cm^3, $Q_0 = 39660 \pm 518$

Experimental Setup



Calibration of the readout electronics

- Gain curve of RSA shows clear structure
- SG filter[10] used to remove structure
- Remaining noise behaves Gaussian
- Gain curve generally stable but varies slightly over time (Fig. 2)
  - → Therefore not: Integrate all data, apply SG filter, analyse residual
  - → Instead: Integration of 1 min of data, apply SG filter, integrate residuals, analyse

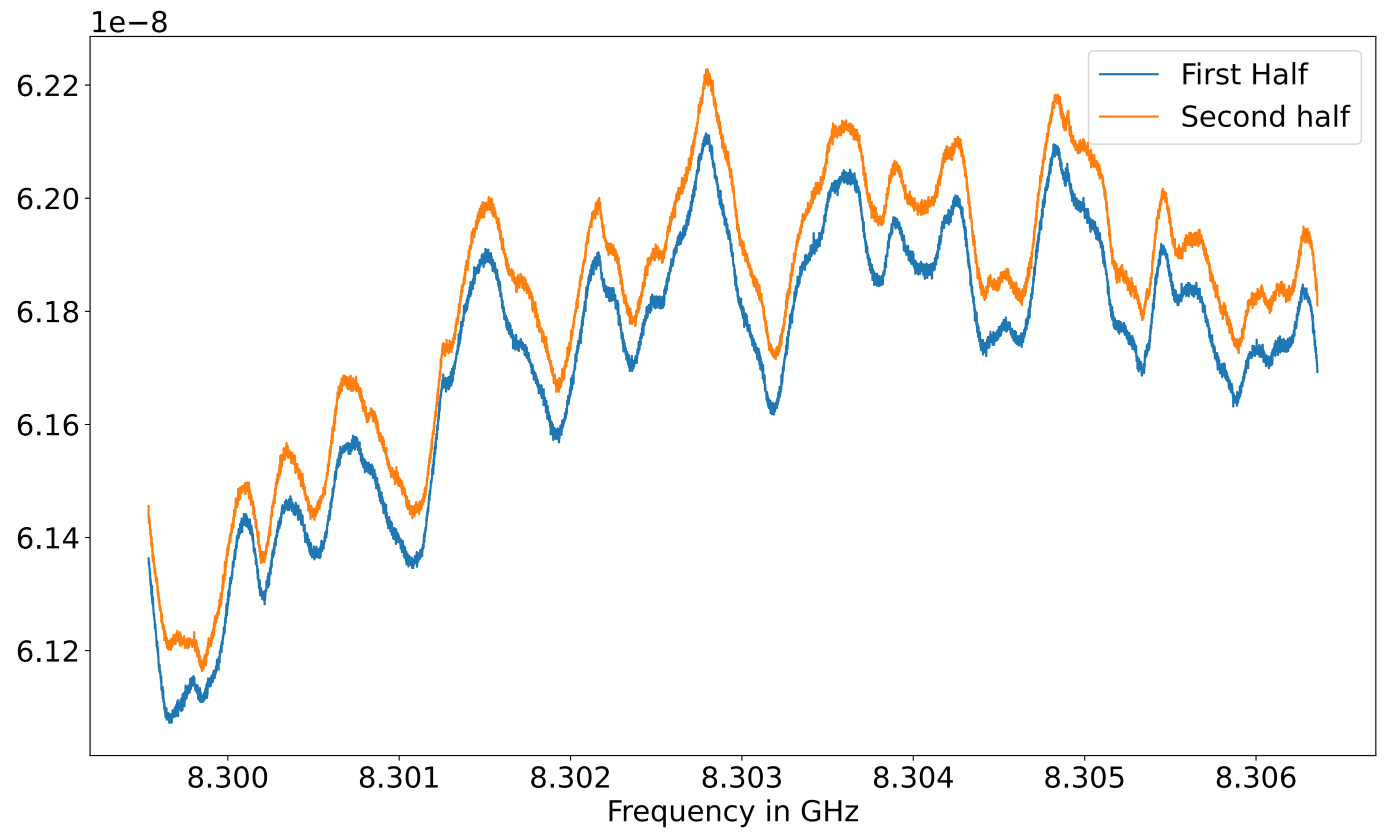


FIG. 2 Hours 1-6 and 7-12 of a 12 h consecutive gain curve acquisition.

Dark Photon Analysis

1. Removal of the coarse structure imprinted by the electronics on the measured spectrum (Fig. 3 blue → orange)
2. Removal of the variable gain curve and the cavity's resonance structure via an SG filter & normalisation of resulting spectrum (Fig. 4)
3. Limit setting
   - SNR (Fig.4) tested for significant values (> 5σ at 95% CL ≙ 3.455σ) in signal region[11] (at resonance freq. $f_{res} = 8.303$ GHz)
   - Comparison with theoretical SNR[5-8] $^{P_S}/_{P_N}$

$$P_N = k_B T_{sys} \nu$$
$$P_S = P_0 \frac{\beta}{\beta+1} L(f, f_0, Q_L)$$
$$P_0 = \eta \chi^2 m_{A'} \rho_{A'} V_{eff} Q$$
$$L(f, f_0, Q_L) = \left(1 + \left(Q_L \frac{f - f_0}{f_0}\right)^2\right)^{-1}$$

   - → Limit on kinetic mixing set to

$$\chi < (6.20 \pm 3.15^{(exp.)} \pm 9.65^{(SG)}) \cdot 10^{-14}$$
$$\text{at } f_0 = 8303.06\,\text{MHz} \equiv 34.34\,\mu\text{eV}$$

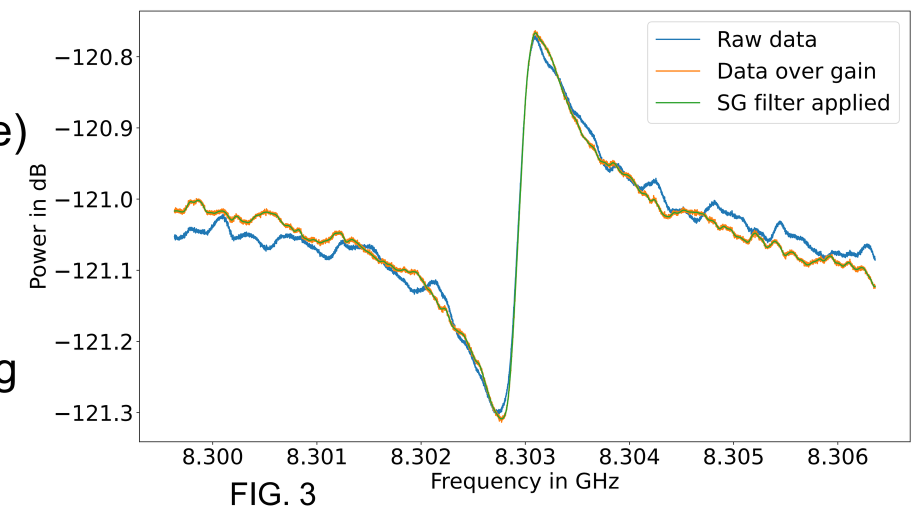


FIG. 3
Raw acquired data, data over electronics gain curve and SG filter on 126 min data run.

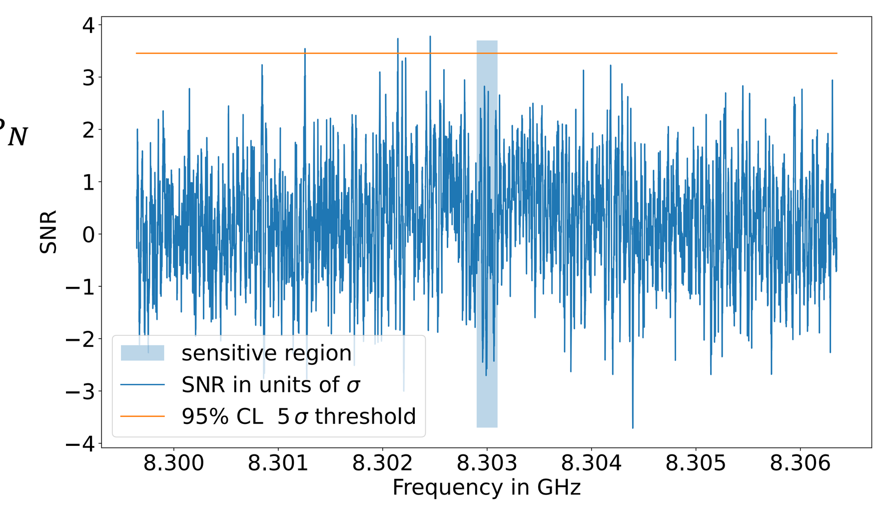


FIG. 4
SNR (data over SG filtered data) of FIG. 3 run.

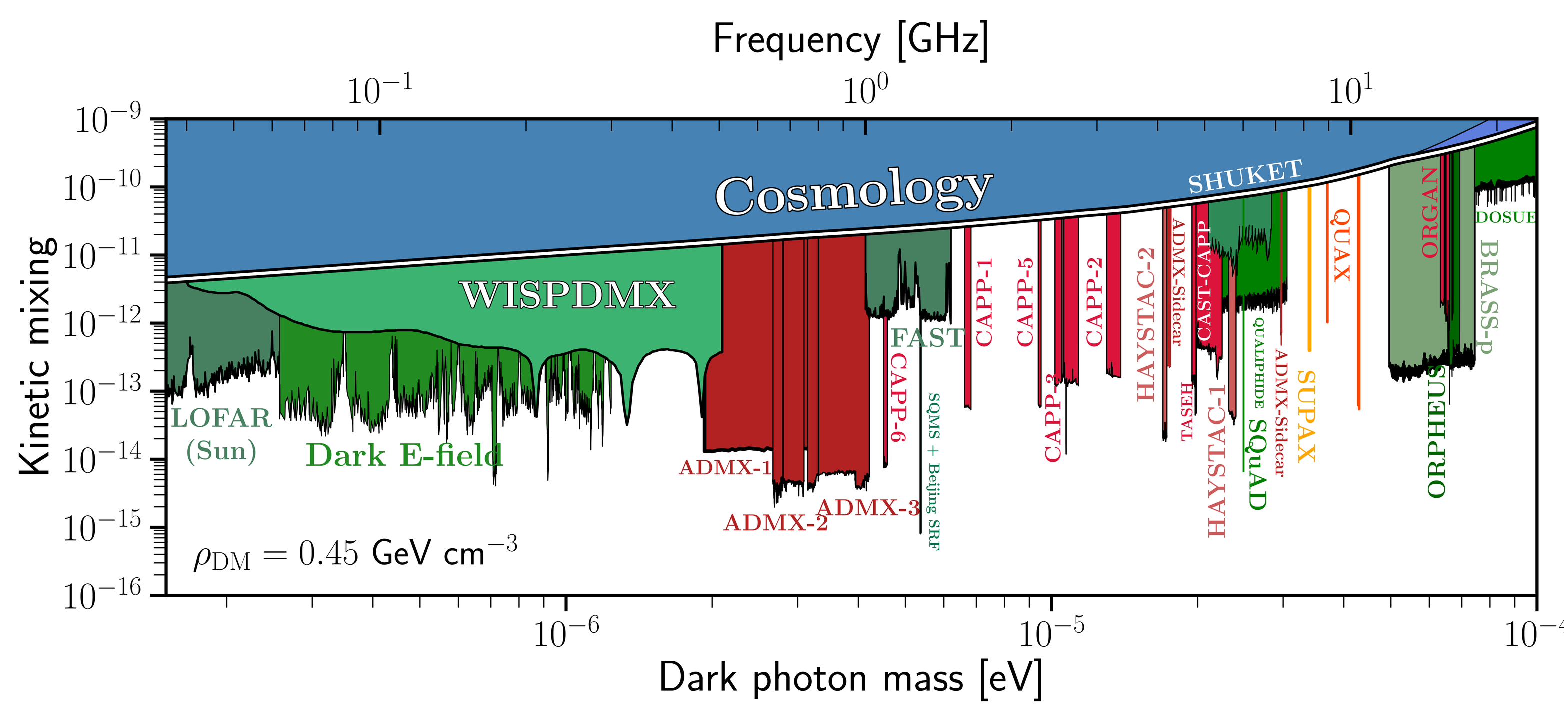


FIG. 5 Limit plot for dark photon kinetic mixing χ.[12] Green limits are helioscopes, halocopes are coloured red. SUPAX is highlighted in yellow.

Outlook

- Improvement of Q_0 by using superconductor coating with high critical B-field
- First measurement with cryostat at and below 4.2K
- First axion measurements with 14T magnet
- Construction & testing of a new tuneable cavity design without tuning rods

Sources

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