A Superconducting Axion Search Experiment

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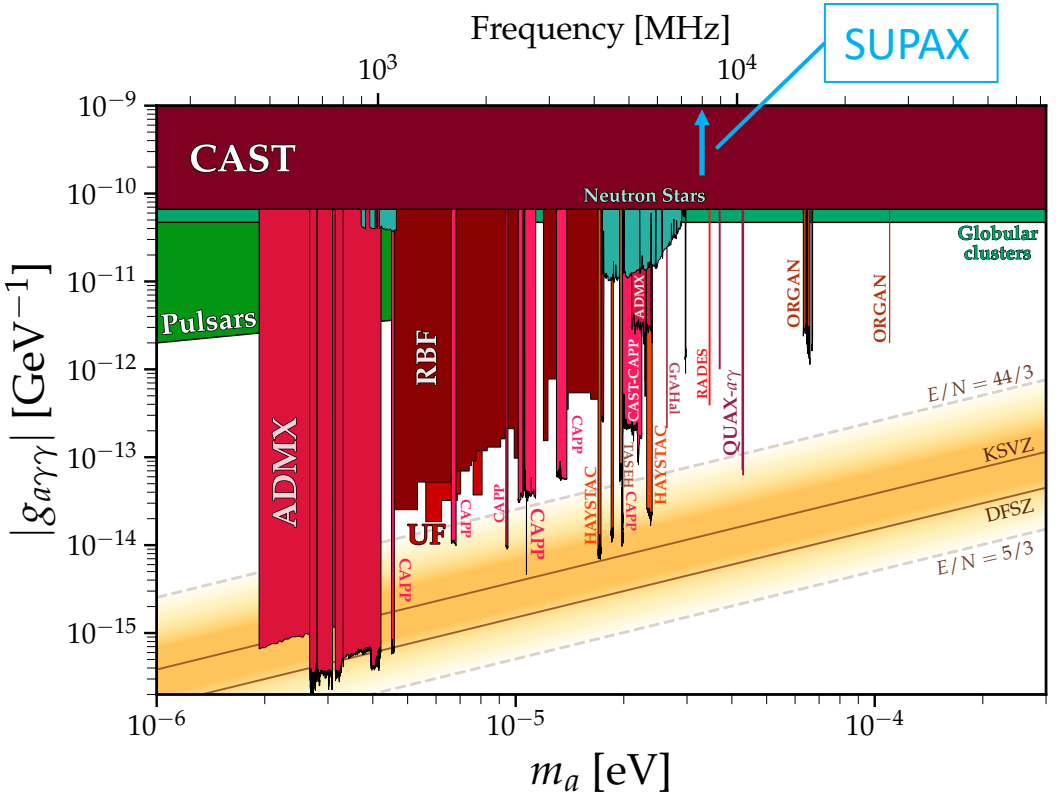
With great help of the RADES collaboration

SUPAX

- RF-Cavity haloscope in Mainz
- Started in 04/2022
- Search at 8 – 9 GHz (~ 35 µeV)
- Goal: axion search using 14T magnet, $Q_0 = 10^6$
- Until now:
  - Setup (✅)
  - DAQ ✅
  - first analysis of proof of concept data taking run ✅



Source: https://github.com/cajohare/AxionLimits

Axion detection in RF cavities

14T magnet in group of Prof. Budker

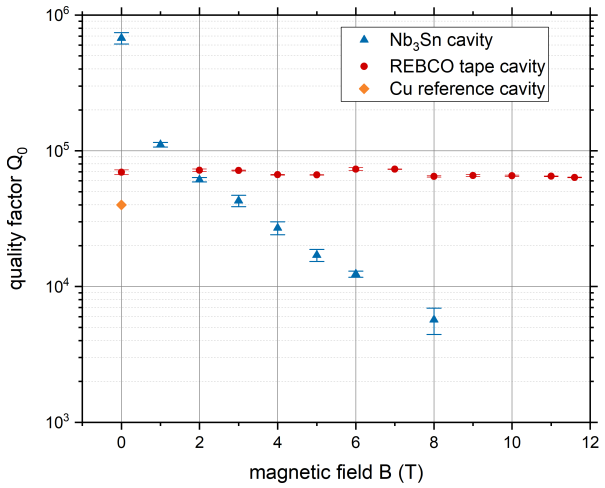
$$P_{sig} \propto B^2 Q_0 V g_\gamma^2$$

Volume limited by:

- Magnet size
- Resonance frequency
- Tuning elements

Depends on cavity material conductivity:

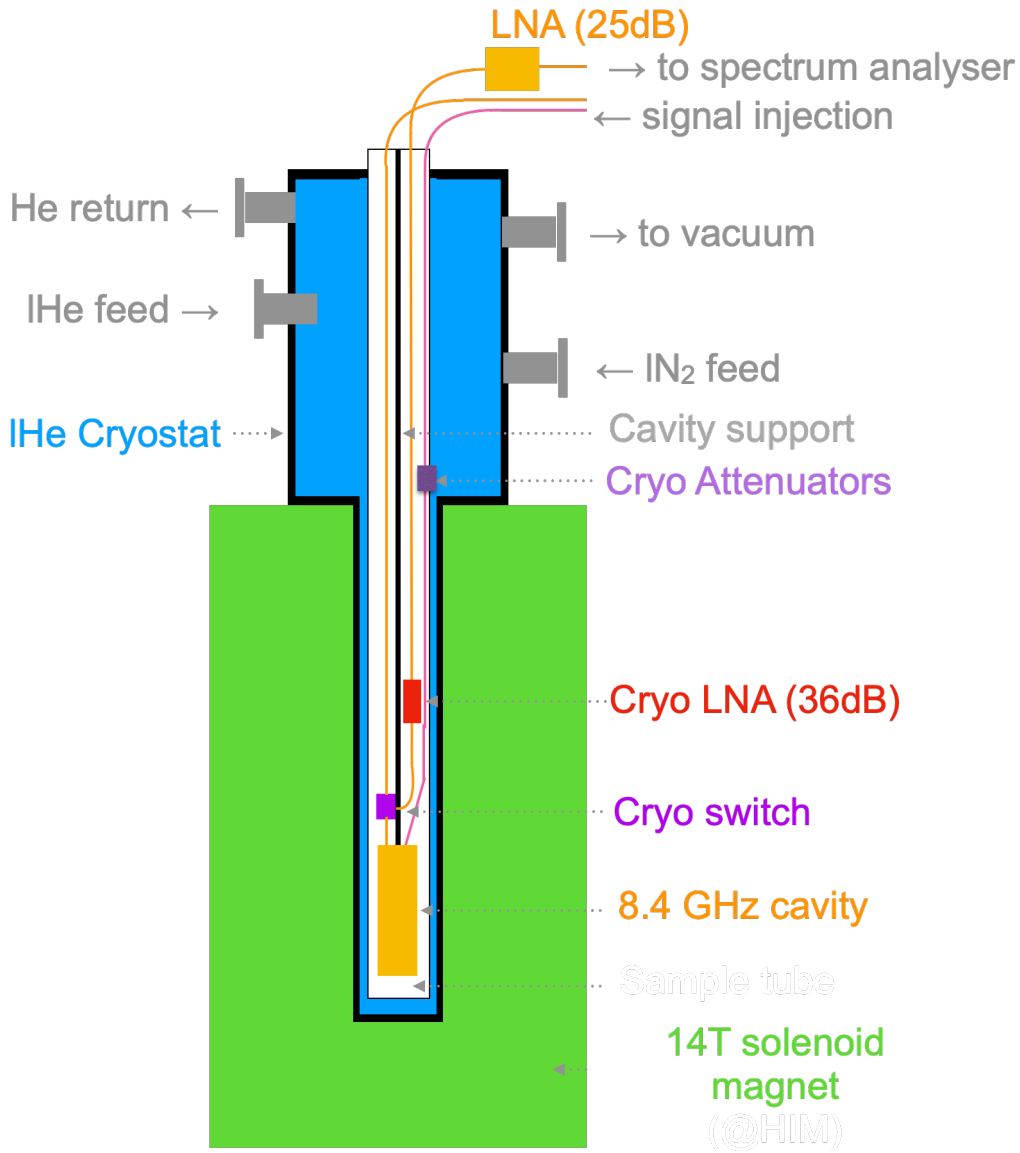
- High purity copper: $\sim 5 \cdot 10^4$
- Superconductor: difficult in high magnetic field
  - Target: 10^6
  - Demonstrated: $3 \cdot 10^5$ (CAPP)
  - Materials under study: Nb_3Sn, YBCO, REBCO
  - Planned for SUPAX: NbN, MgB_2



J. Golm et. al (RADES)
https://arxiv.org/abs/2110.01296

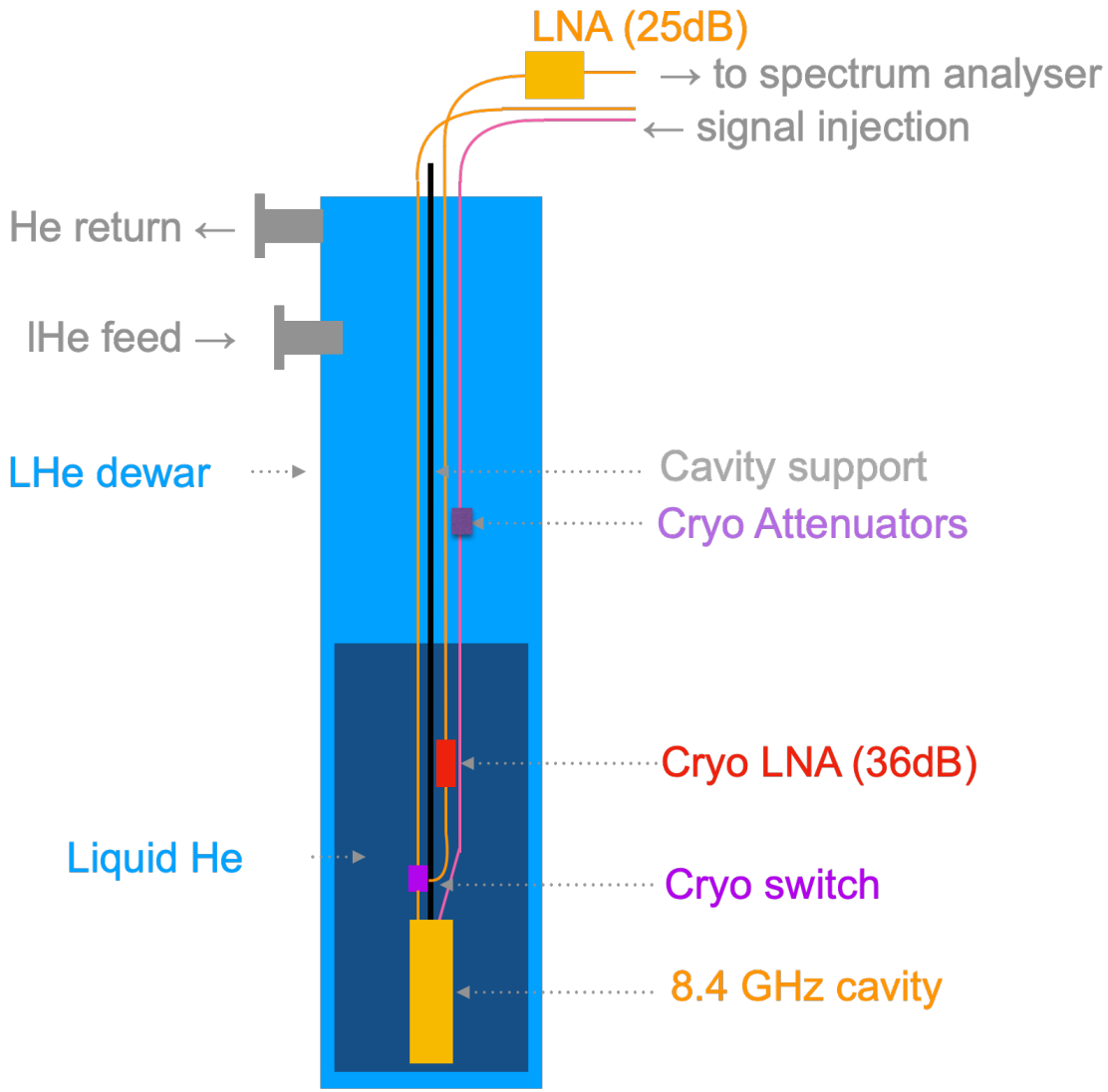
The Axion Setup

- 14T magnet
  - Ready for operation in Q3/Q4 2023
- LHe Cryostat
  - Setup in the next weeks
- Cavity & DAQ system complete and tested
- Cryo PreAmp @ 4K, 10GHz:
  - Gain: 36 dB
  - Noise: 3.6K (0.05 dB)
  - Main Noise source of the setup



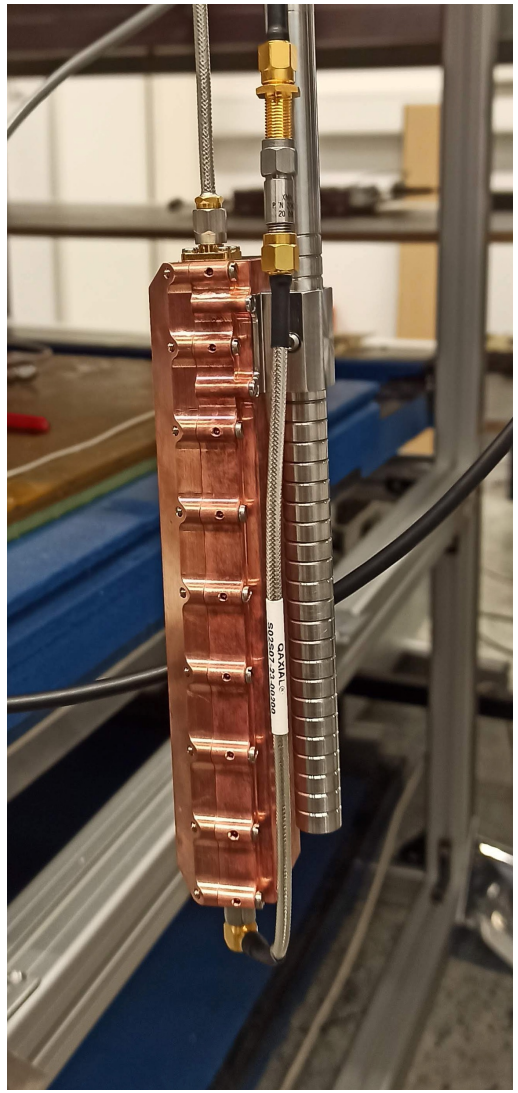
The Dark Photon Setup

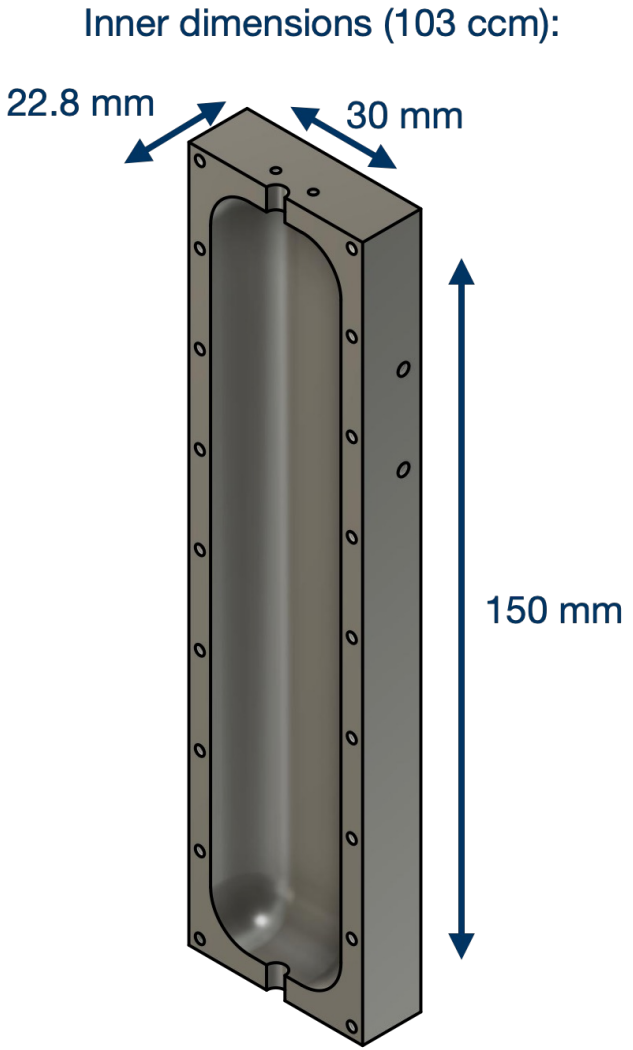
- While waiting for Magnet installation
  - Setup without magnet usable for Search for Dark Photons (Another DM candidate)
- Delay of Cryostat
  - Setup put into liquid helium (LHe) dewar
- Following results acquired this way



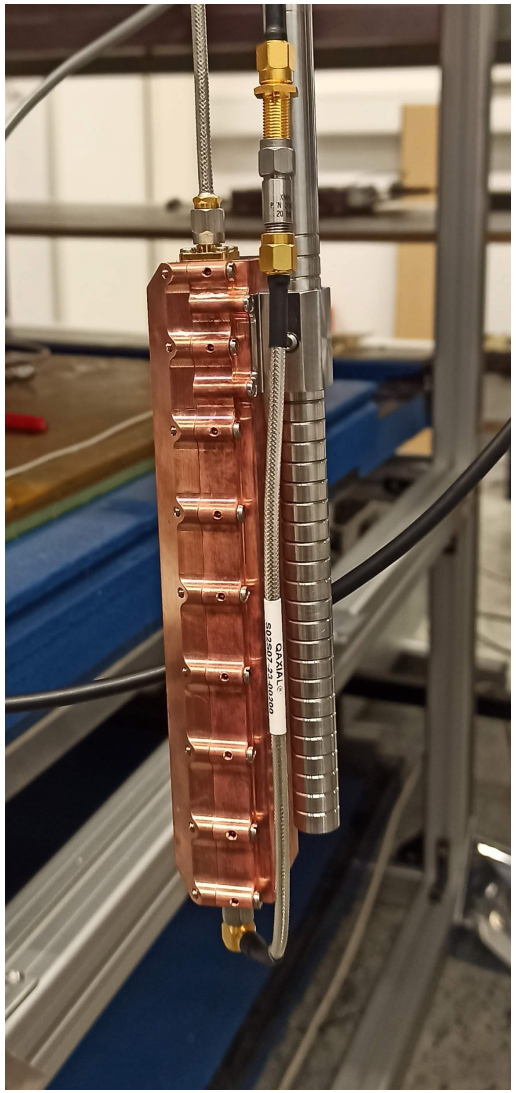
Cavity Design

- Custom built cavity to fit into cryostat, including holding structure
- Made of high purity copper

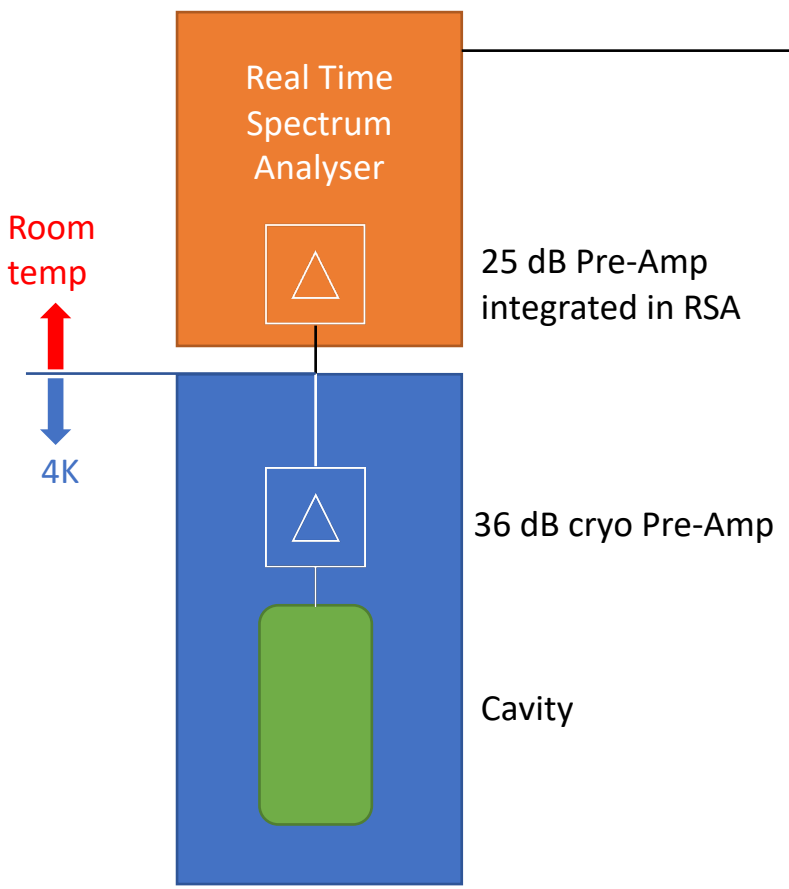




The Dark Photon Setup



Real Time Data Acquisition



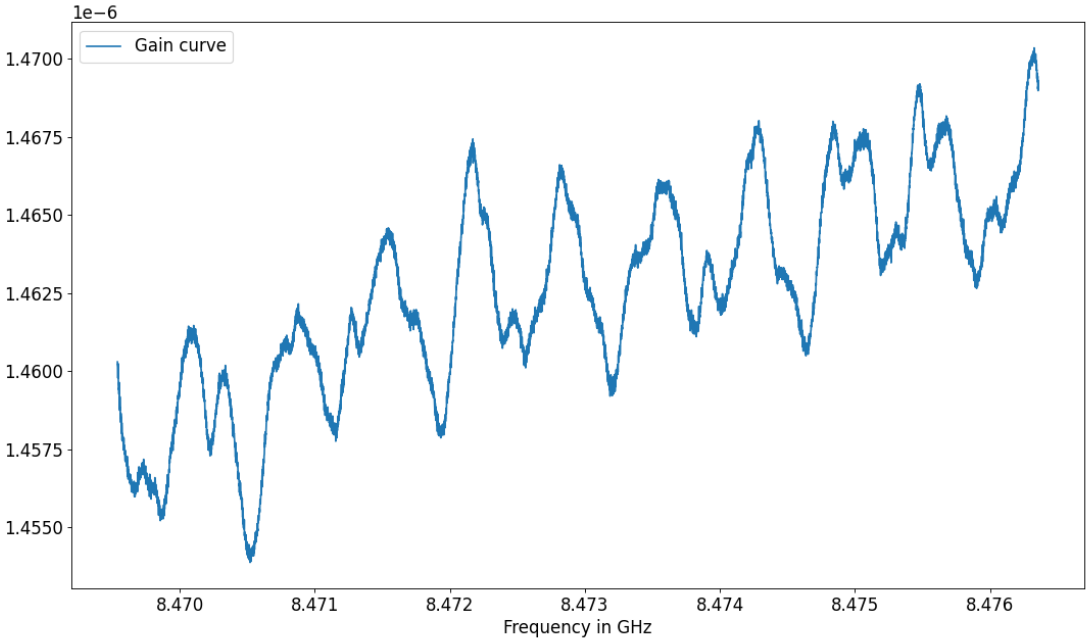
RSA:
- 40 MHz realtime bandwidth
  - (10 MHz used)
- IQ data streamed to PC
  - Continuous readout

DAQ Software (C++):
- Realtime conversion to frequency
  - 1 kHz readout bandwidth
- Stacking of 2 second blocks
- Storage of spectra in ROOT files

Analysis (Python):
- Alignment & integration of spectra
- RSA Gain curve elimination
- Cavity resonance curve removed by SG filter
- Analysis of residual

Gain curve of DAQ

- Noise structure of RSA with cryo Pre-Amp
- Measured with input terminated with 50Ω
- Clear Gain curve, not Noise dominated



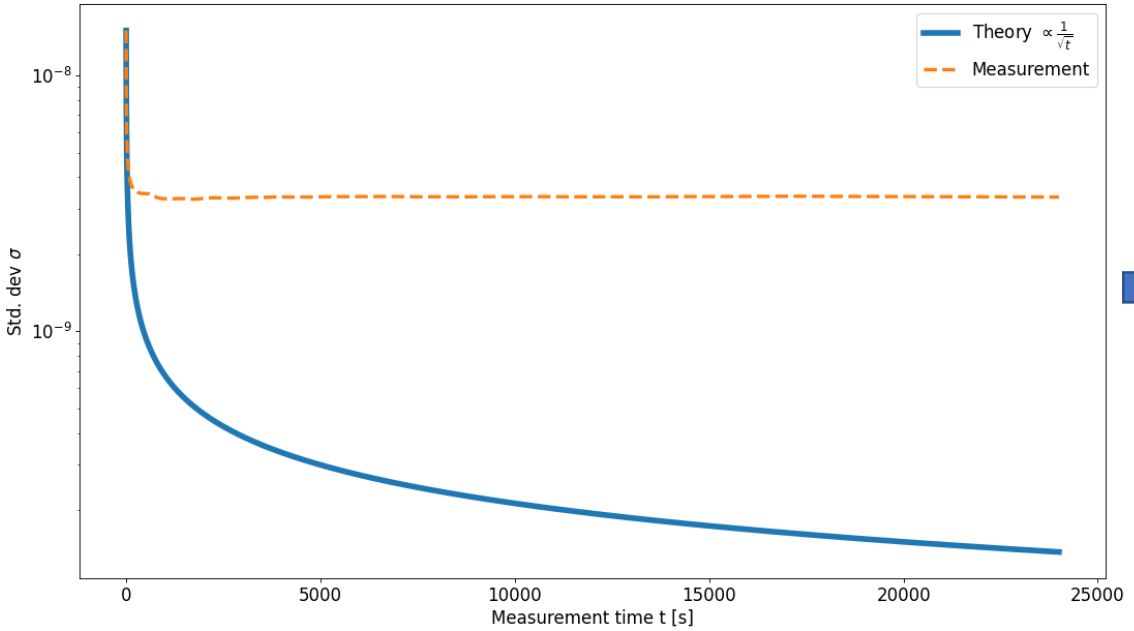
- 10 MHz readout window around resonance frequency
  - Measurement at room temperature
  - 6:40h integration time

- General structure stable but drifts slightly
- Cryo Pre-Amp does not add additional fine structure

- Gain curve consistent over various frequency windows

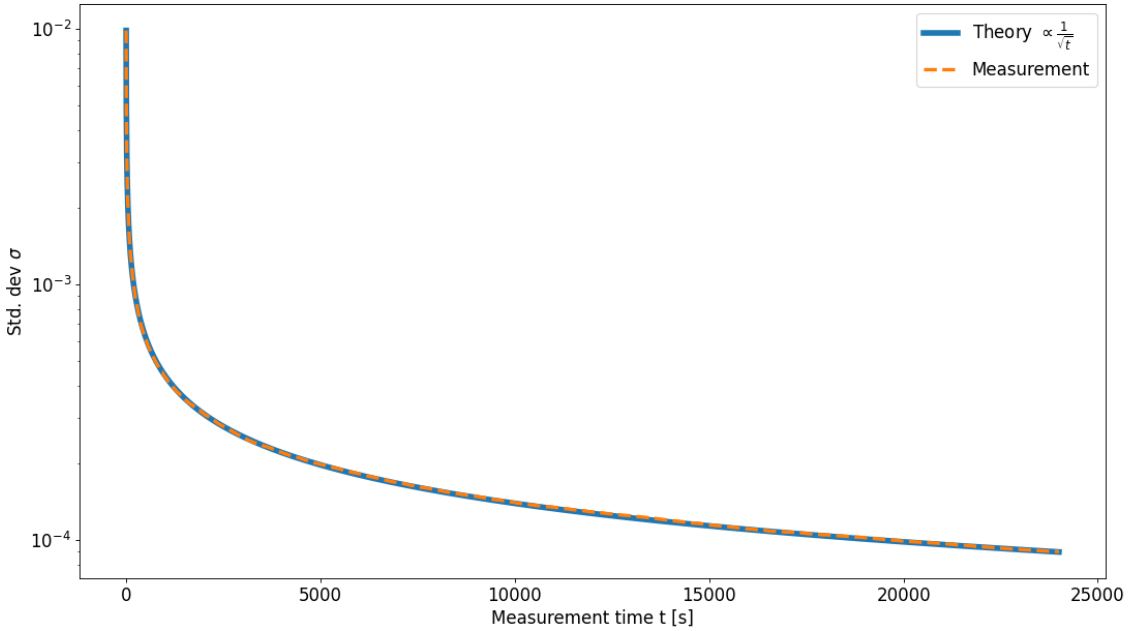
Gaussian distribution of Noise

- If Gain curve Noise dominated → standard deviation $\sigma \propto \frac{1}{\sqrt{t}}$
- Gain curve clearly not noise dominated



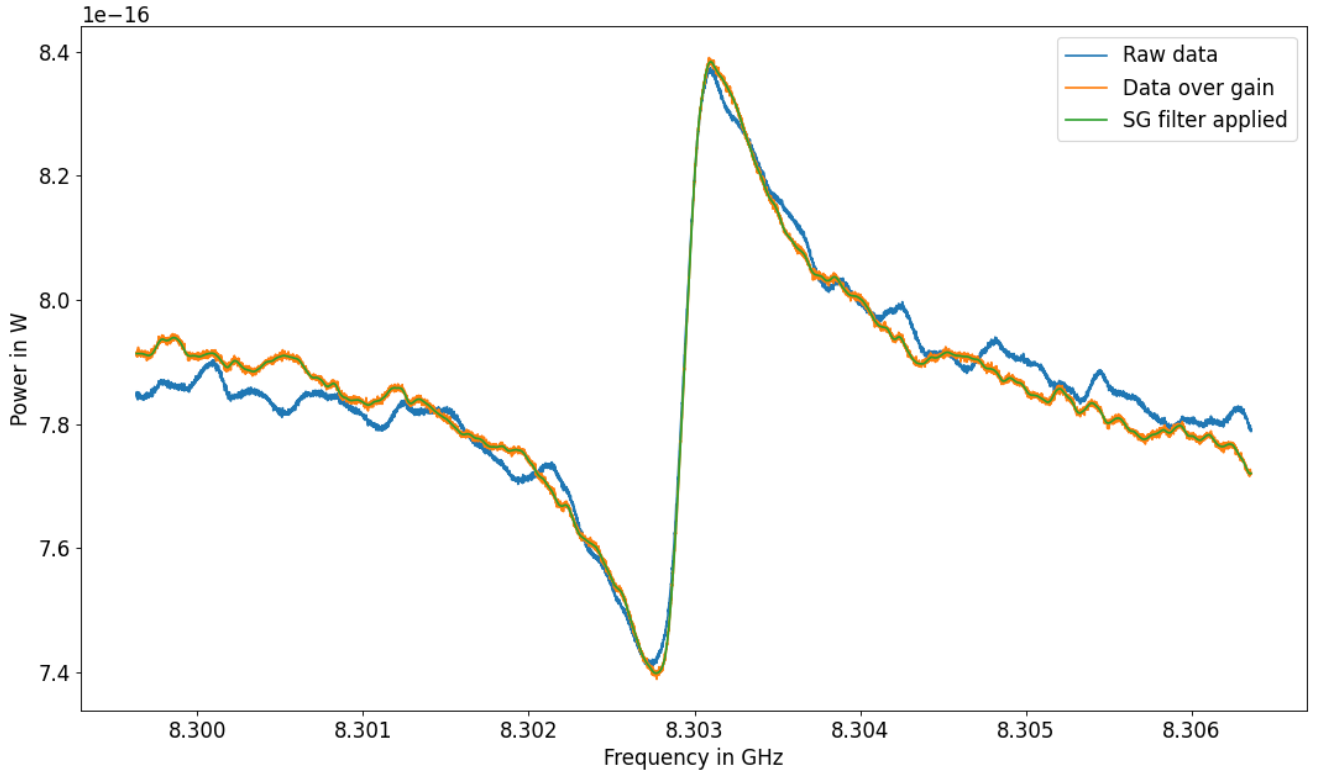
SG filter

On Gain curve

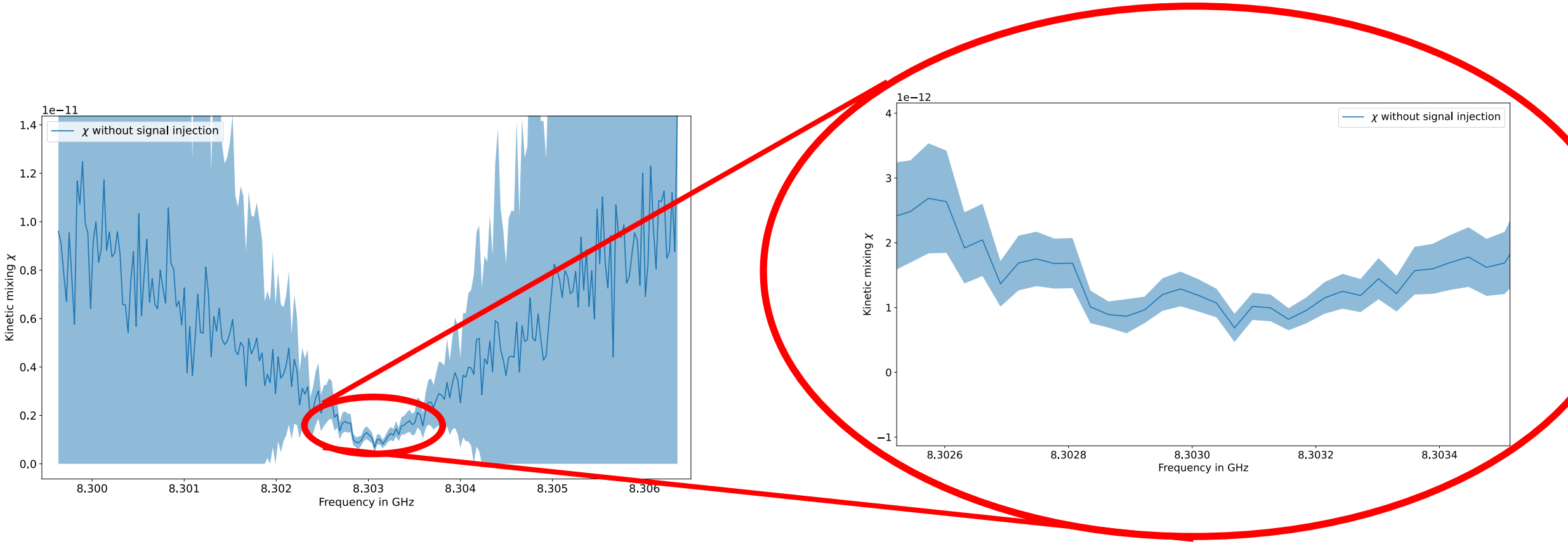


First preliminary physics results

- Search for Dark Photons, experimental setup in LHe dewar



First limit on DP kinetic mixing χ^2



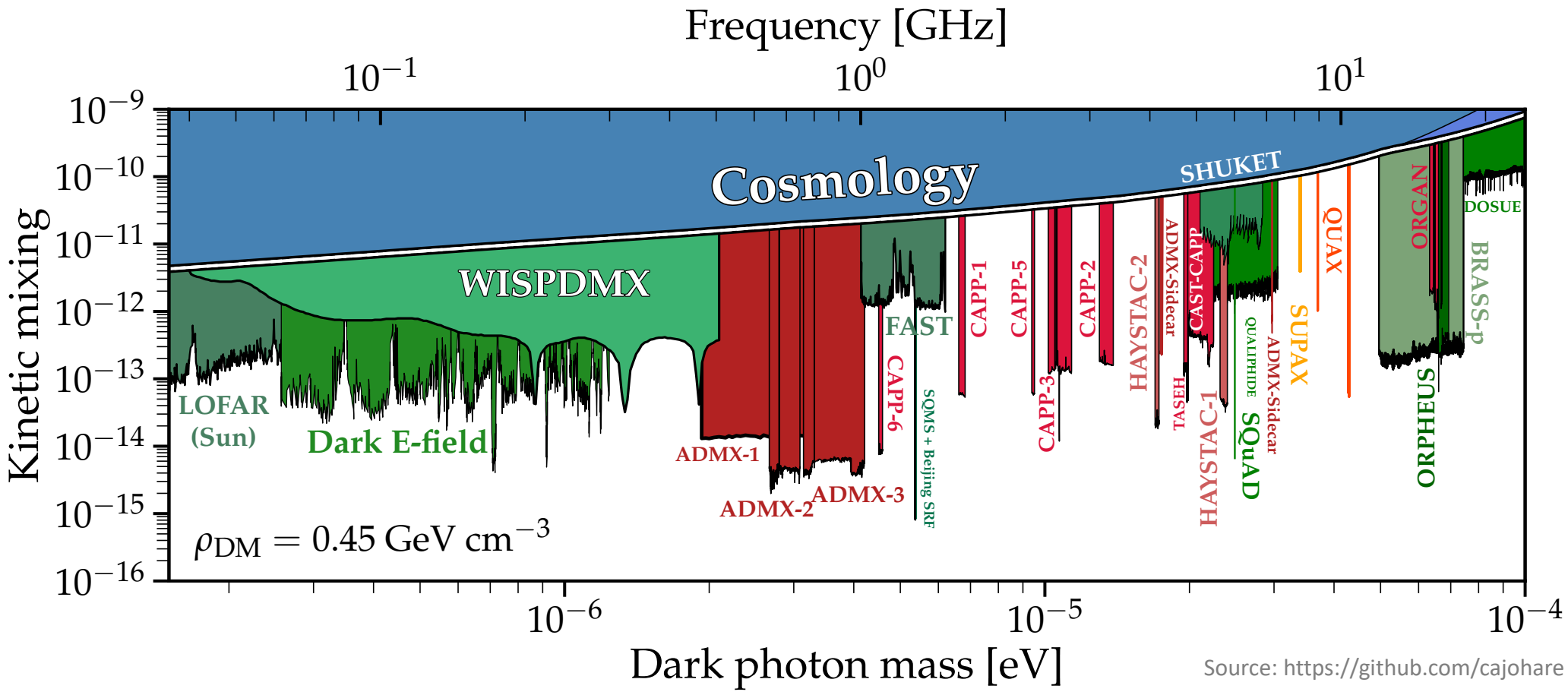
Only sensitive near resonance frequency of cavity f = 8303.06 MHz

First limit on DP kinetic mixing χ^2

First limit on Dark Photons with a mass of 34.34 µeV in randomised polarisation scenario:

$$\chi < (6.86 \pm 2.17^{(\mathrm{exp.})} \pm 1.75^{(\mathrm{SG})}) \cdot 10^{-13}$$

Existing limits



Source: https://github.com/cajohare

Conclusion & Outlook

- Many thanks to RADES for their help in hardware and analysis questions
- Experiment works in principle, but much work is ahead
  - Add circulator
  - Test operation in B-field
- Tunable cavities
  - Without need of tuning rods?
- Test cryostat operation @ T = 1.5 K
- Test performance of superconductor on Q_0 with and without magnetic field
- Data run and axion limit until next PATRAS conference ☺

Thank you for your attention!

Backup: Signal injection test

- Simulations with injecting a signal in shape of a dark photon
- Width according to $Q_{DM} = 10^6$
- Signal strength as expected with kinetic mixing from previous slide
- Signal can be seen very clearly