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17th Patras Workshop
on Axions, WIMPs and WISPs

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Le Hoang Nguyen for **BRASS** collaboration.
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Development, Calibration and Current Status of the BRASS-p Experiment

Contents:

1. Broadband dark matter search with dish antenna.
2. BRASS-p Setup
3. Hidden Photon Science Run and Preliminary Result.

Johannes Gutenberg in his workshop
Publisher: Encyclopædia Britannica

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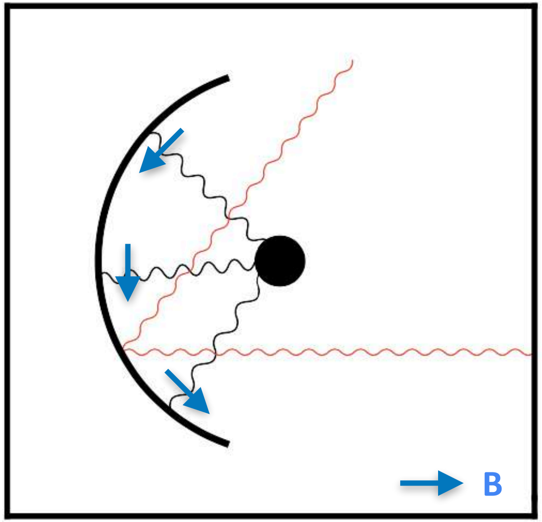
Broadband dark matter search with dish antenna.



"Searching for WISPy Cold Dark Matter with a Dish Antenna "

Horns et al. 2013

Hidden Photon

$$\chi_{\rm sens} = 4.5 \times 10^{-14} \left(\frac{P_{\rm det}}{10^{-23}\,{\rm W}}\right)^{\frac{1}{2}} \left(\frac{0.3\,{\rm GeV/cm^3}}{\rho_{\rm CDM,halo}}\right)^{\frac{1}{2}} \left(\frac{1\,{\rm m}^2}{A_{\rm dish}}\right)^{\frac{1}{2}} \left(\frac{\sqrt{2/3}}{\alpha}\right).$$

Axion/ALPs

$$g_{\phi\gamma\gamma,\,\rm sens} = \frac{3.6\times 10^{-8}}{\rm GeV} \left(\frac{5\,{\rm T}}{\sqrt{\langle|{\bf B}_{||}|^2\rangle}}\right) \left(\frac{P_{\rm det}}{10^{-23}\,{\rm W}}\right)^{\frac{1}{2}} \left(\frac{m_\phi}{\rm eV}\right) \left(\frac{0.3\,{\rm GeV/cm^3}}{\rho_{\rm DM,halo}}\right)^{\frac{1}{2}} \left(\frac{1\,{\rm m}^2}{A_{\rm dish}}\right)^{\frac{1}{2}}$$

Stefan (talk on Wed) and Osamu (talk on Thurs) 🙏

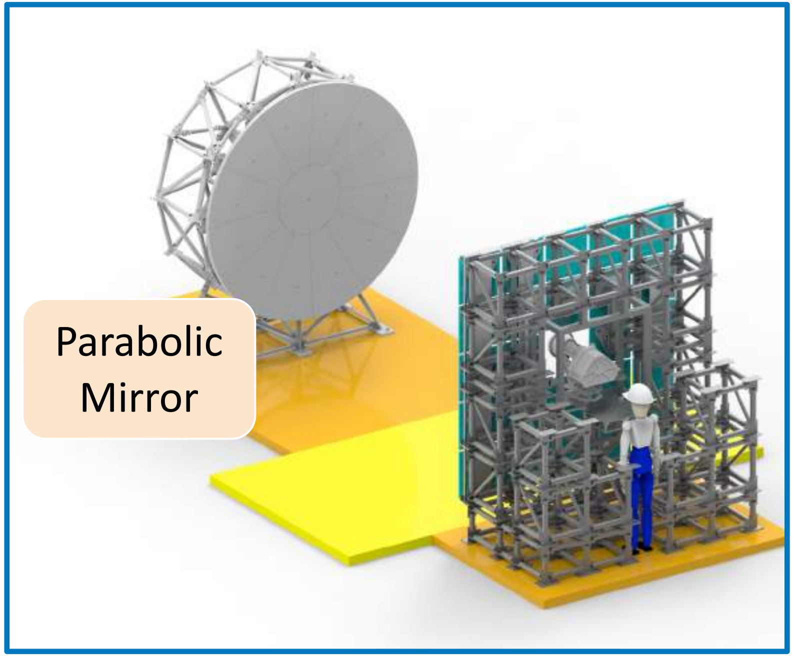
- **Broadband sensitivity to a large parameter space and resonant enhancement is compensated by the large surface area.**
- **Broadband Radiometric Axion SearcheS (BRASS)**
  - A parabolic mirror
  - Flat conversion panels (with permanent magnets)
  - Broadband antenna and digital backend to process the signal.

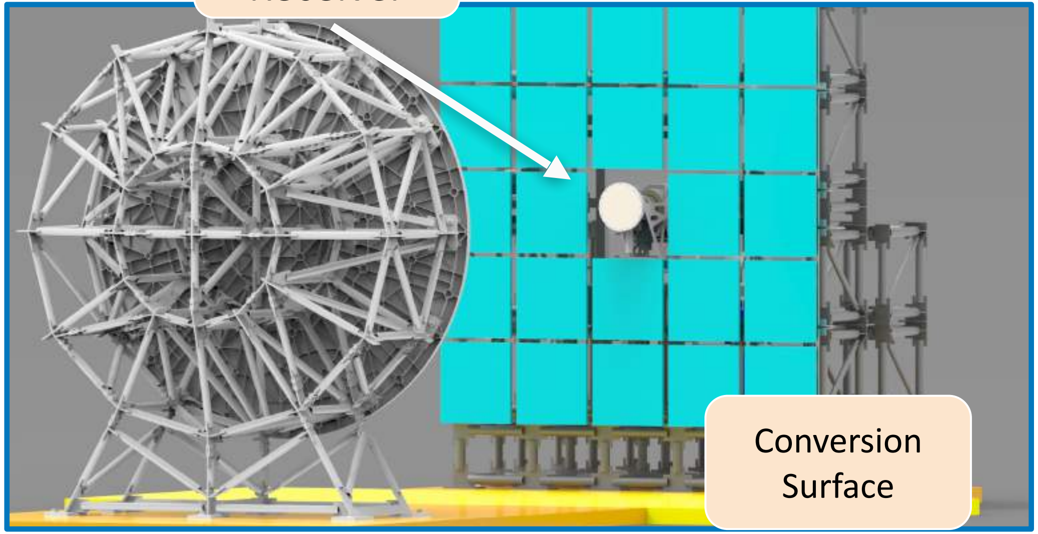
- **Broadband sensitivity to a large parameter space and resonant enhancement is compensated by the large surface area.**
- **Broadband Radiometric Axion SearcheS (BRASS)**
    - A parabolic mirror
    - Flat conversion panels (with permanent magnets)
    - Broadband antenna and digital backend to process the signal.

Prototype: BRASS-p

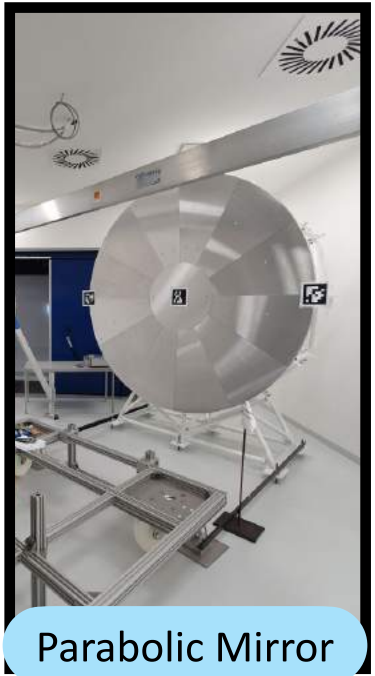
BRASS-p Setup

BRASS-p Setup

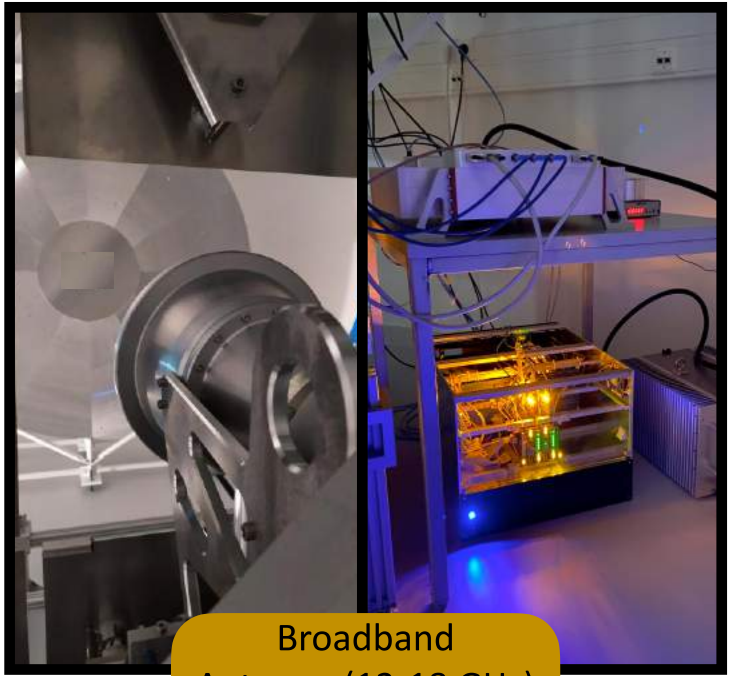




Conversion Panel
(24 x 0.25m²)

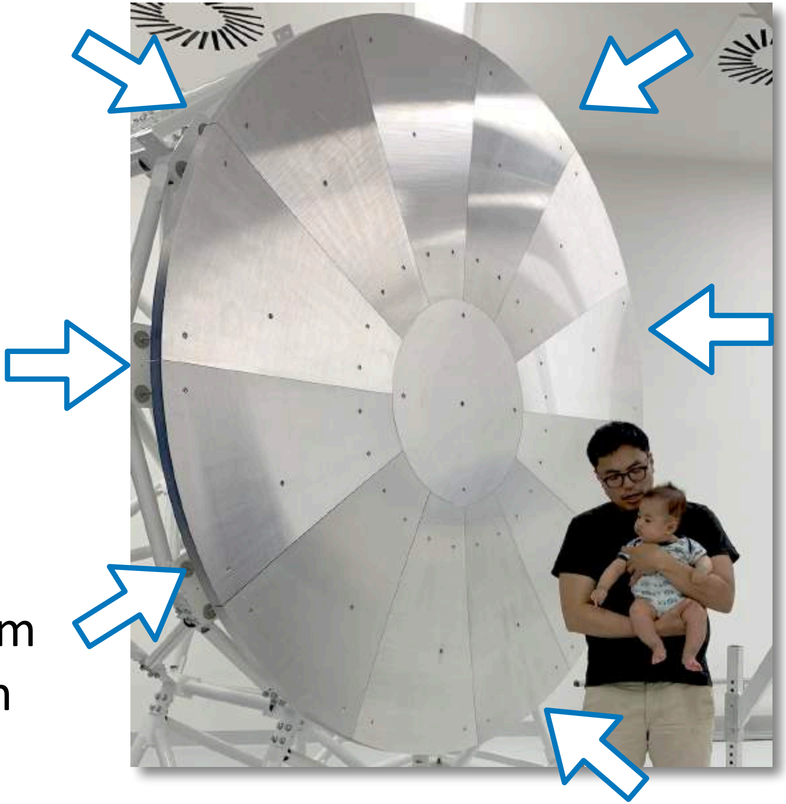


Parabolic Mirror



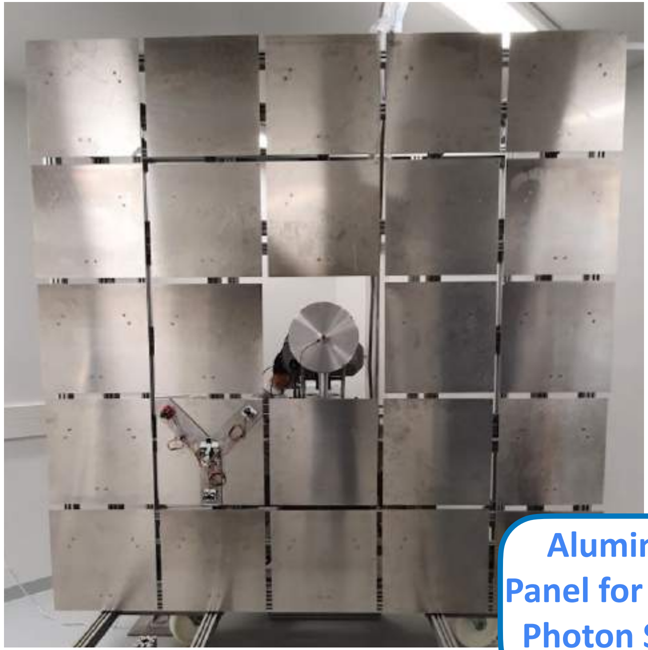
Broadband
Antenna (12-18 GHz)
and 8 GS/S Digitizer

Parabolic Mirror

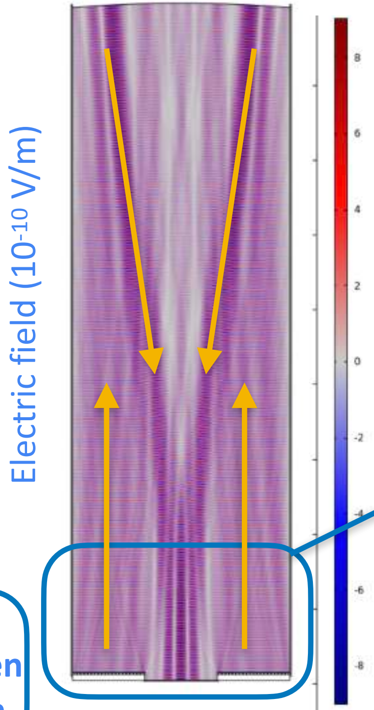


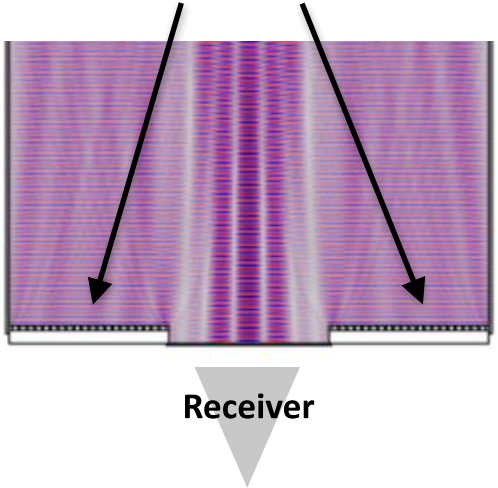
d = 2.5m
f= 4.8m

Conversion Panels



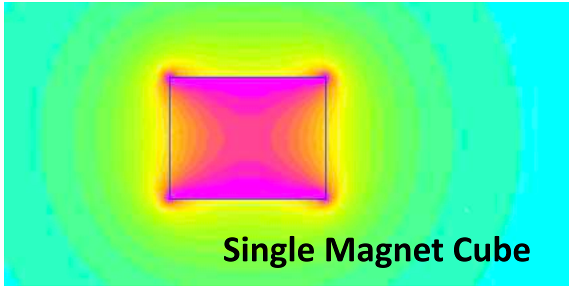
Aluminium Panel for Hidden Photon Search

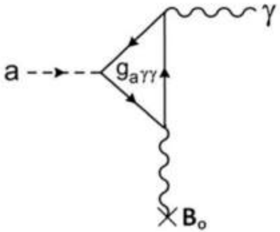


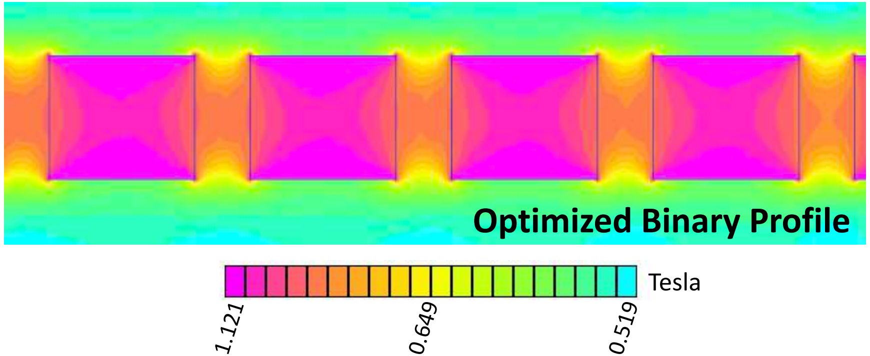


👉 Johannes Ulrichs blitz talk and poster on Monday

Permanent Magnet Panel for Axion/ALPs Search



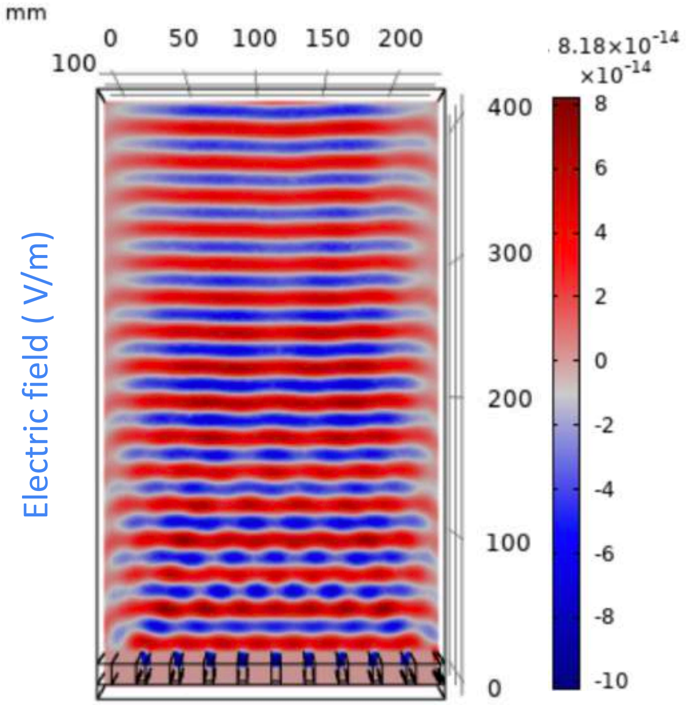




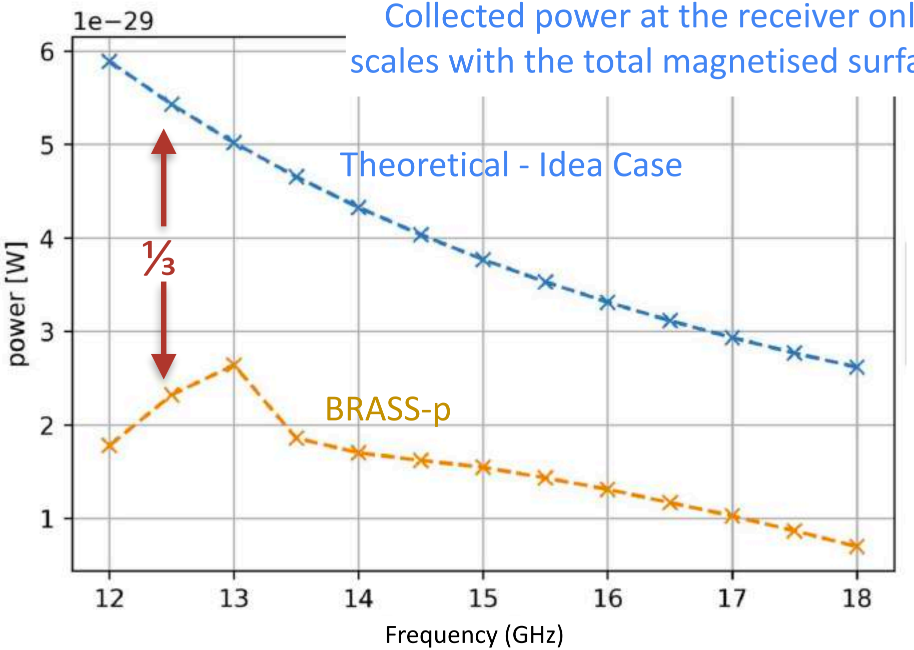
Averaged horizontal field strength is approx 0.9 Tesla

Converted Radiation Simulation

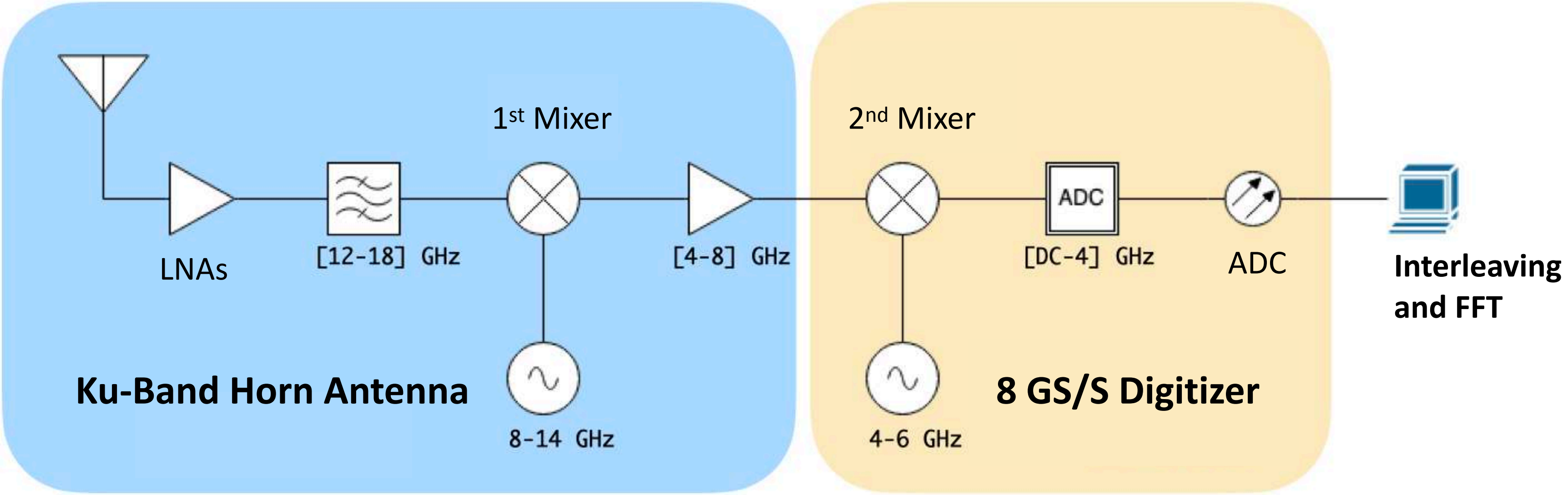
Electric field (V/m)



Collected power at the receiver only scales with the total magnetised surface.

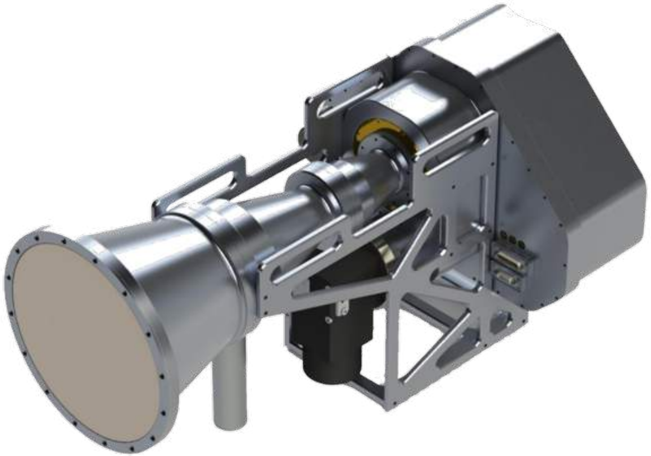


Analog Frontend and Digital Backend



Analog Frontend: Ku-Band Horn Antenna

- Broadband receiver and first mixing stage from 12 to 18 GH to IF 4-8 GHz.
- 3-LNA-chain with 1st stage operated at approx 10 K
- Two polarisation outputs for DM signal study/rejection.



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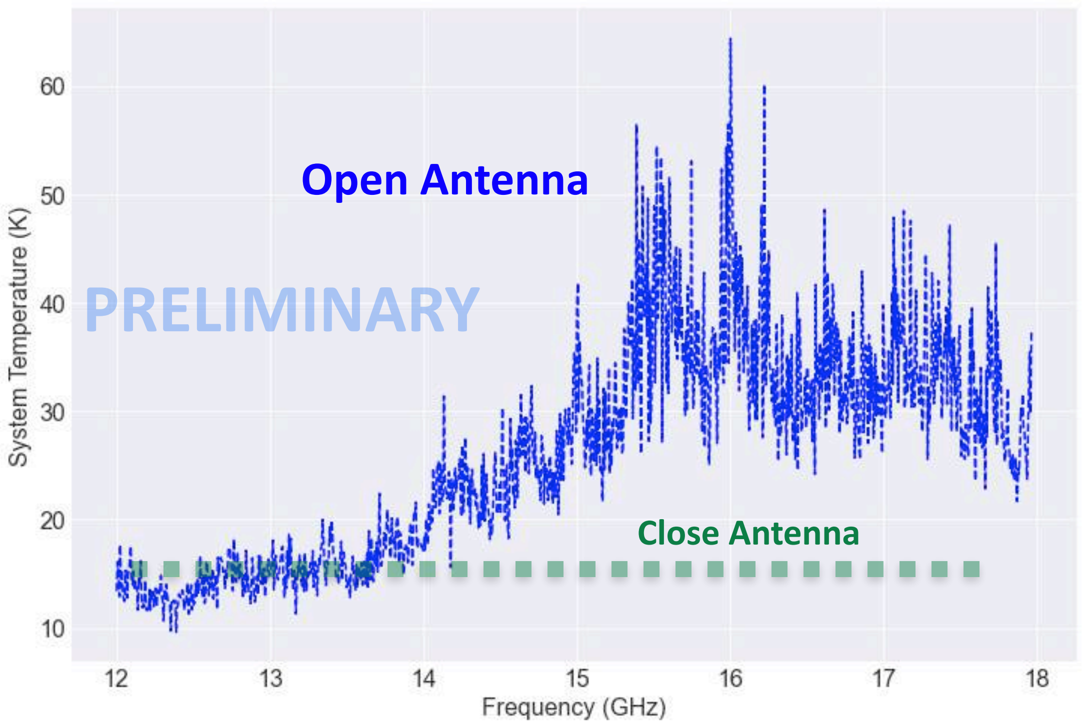
Receiver's System Temperature



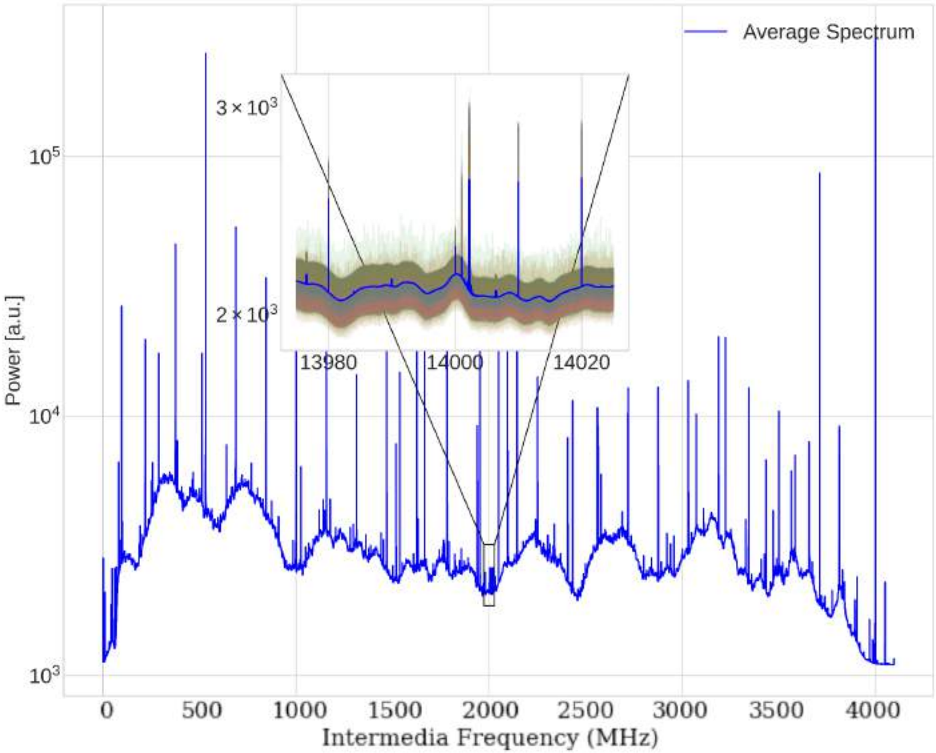
Digital Backend: 8 GS/S Processing

- Second mixing stage of the signal from the receiver output to a DC - 4 GHz IF range.
- 4 interleaved ADCs at 2 GSPS digitizing the IF signal.
- Data is transferred to the acquisition PC, followed by the interleaving and FFT (WISPDMX's processing structure)
- GPU powered FFT produces high resolution (up to 25 Hz) with ~~real-time~~ post processing.

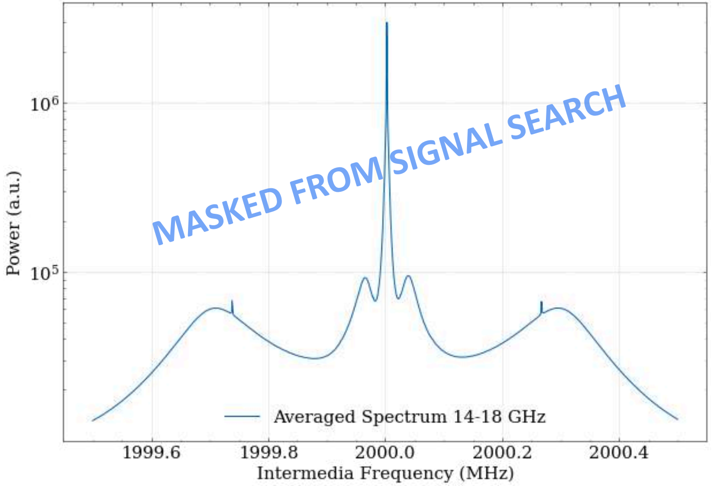
→ 40% of dead time 😔

First Science Run

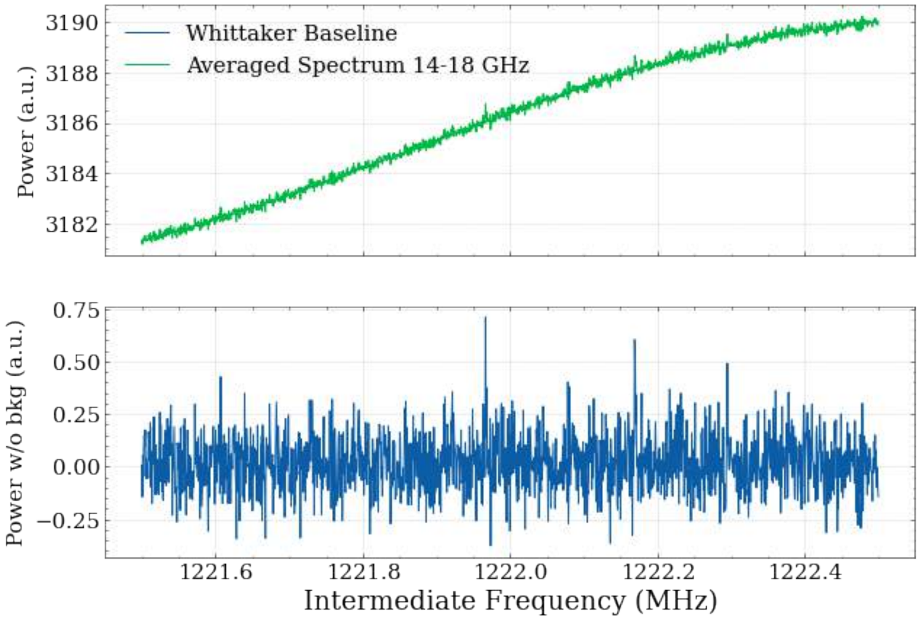
- First science run with conversion panel of **2 m²**
  - **Only sensitive to hidden photons since no magnets are installed yet**
  - Science run 1a in December: 53 hours, 12-16 GHz, resolution of 625 Hz
  - Science run 1b in March: 83 hours, 14-18 GHz, resolution of 625 Hz

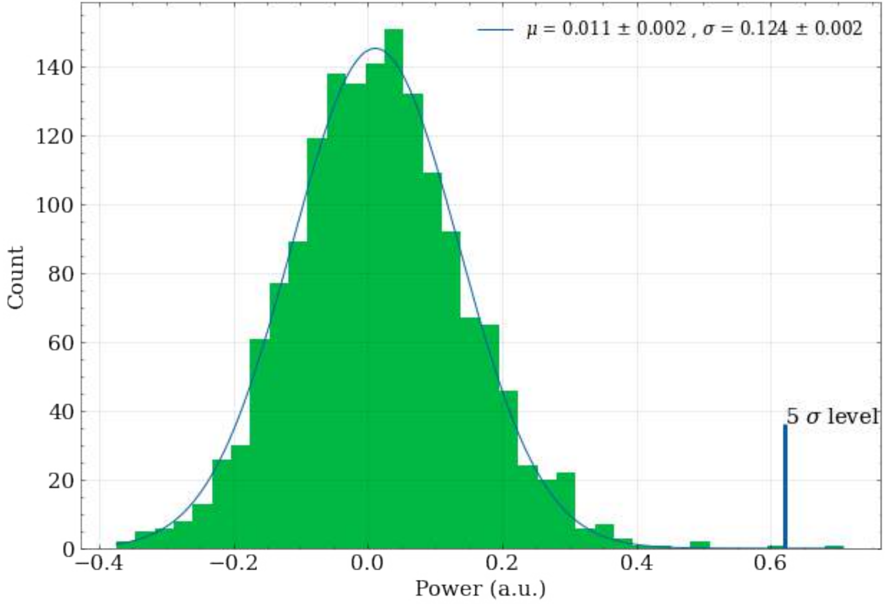


- Single spectrum is averaged from 20 second of data @ 625 Hz
- Science run 1a: 10000 single spectra
- Science run 1b: 15000 single spectra

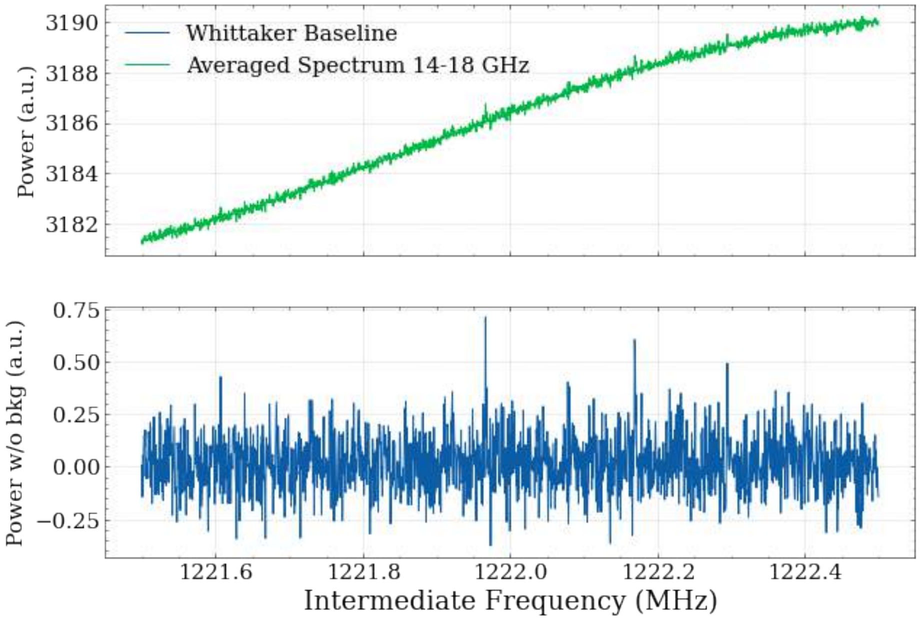


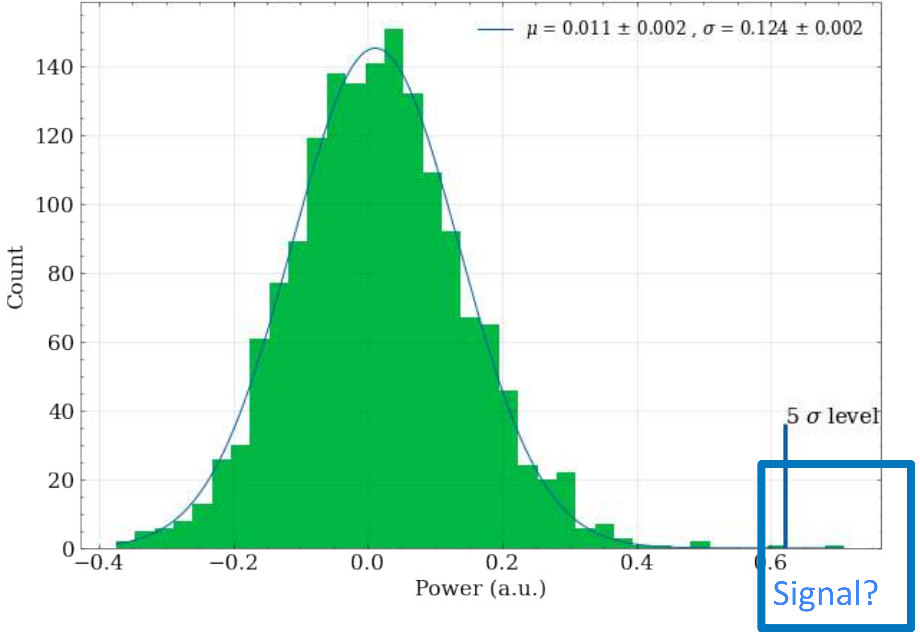
Scanning for signal - Moving 1 MHz ROI





Scanning for signal - Moving 1 MHz ROI





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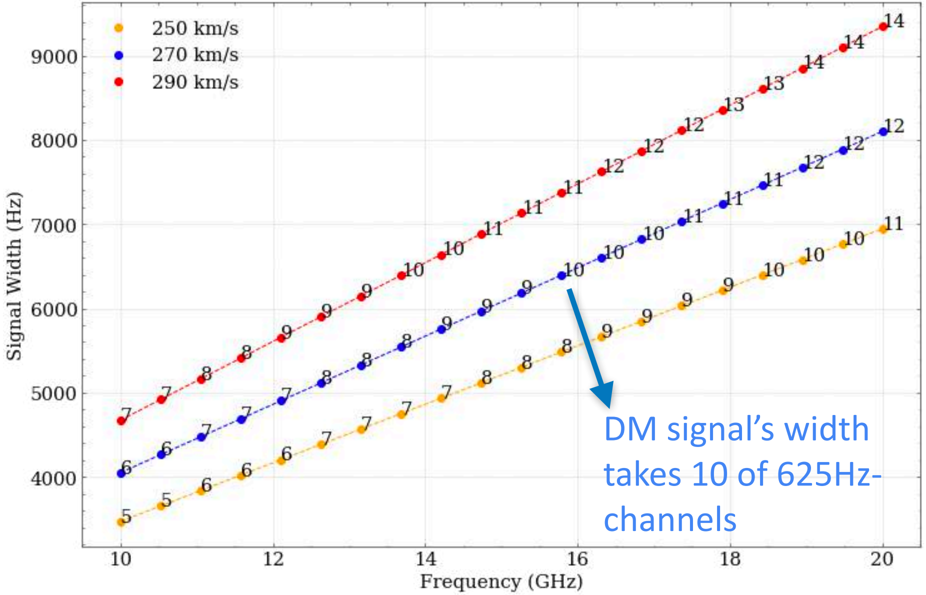
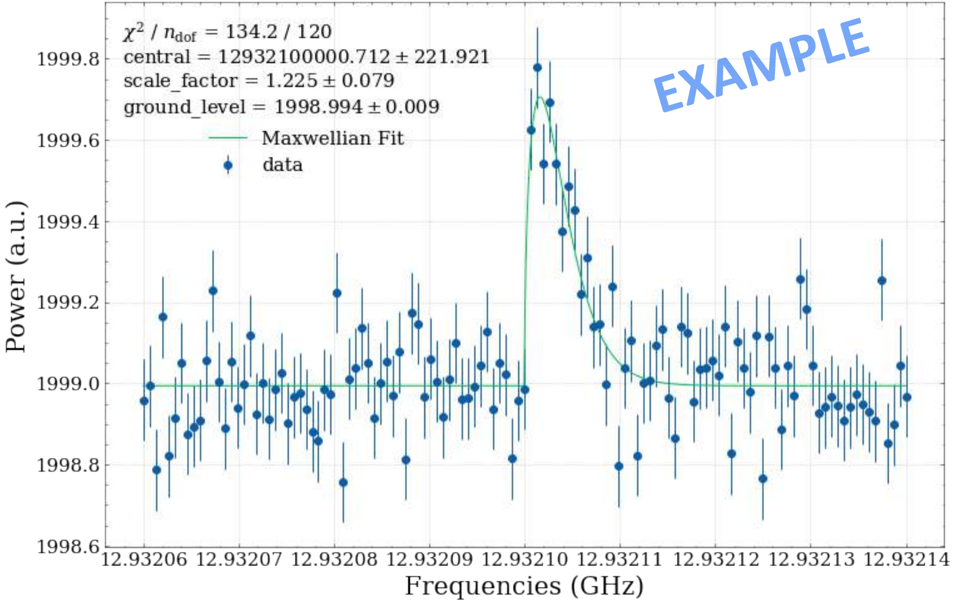
Signal Criteria

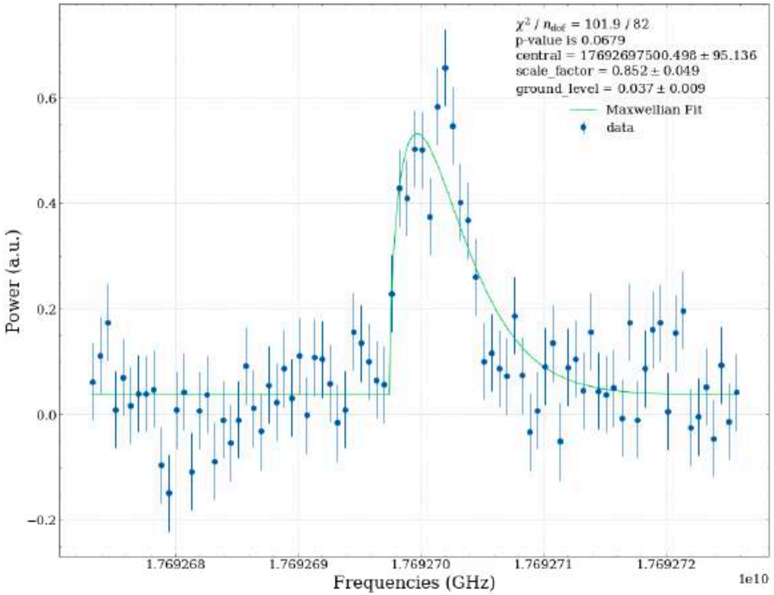


1. Matching signal width

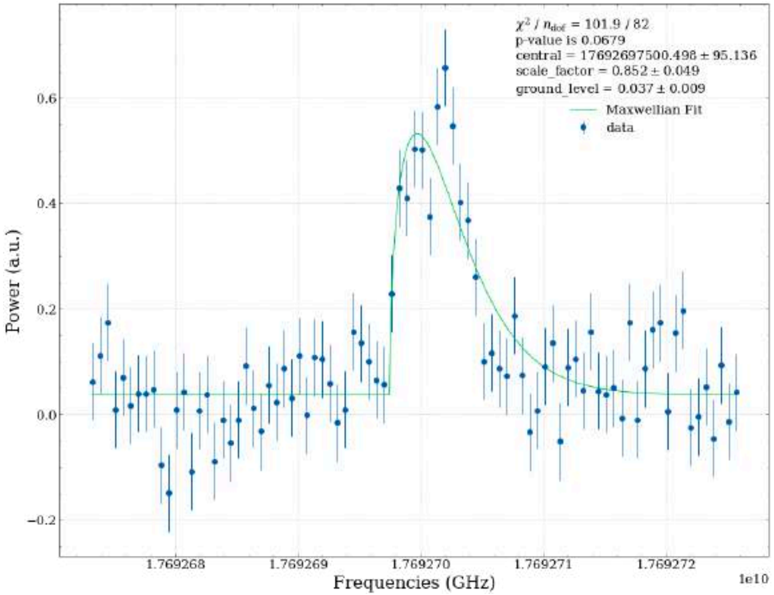


2. Matching Maxwellian profile

Result:


χ^2 / n_{dof} = 101.9 / 82
p-value is 0.0679
central = 17692697500.498 ± 95.136
scale_factor = 0.852 ± 0.049
ground_level = 0.037 ± 0.009
Maxwellian Fit
data
Power (a.u.)
Frequencies (GHz)
1e10
1.769268
1.769269
1.769270
1.769271
1.769272
0.6
0.4
0.2
0.0
−0.2

Result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Maxwellian Fit
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−0.2
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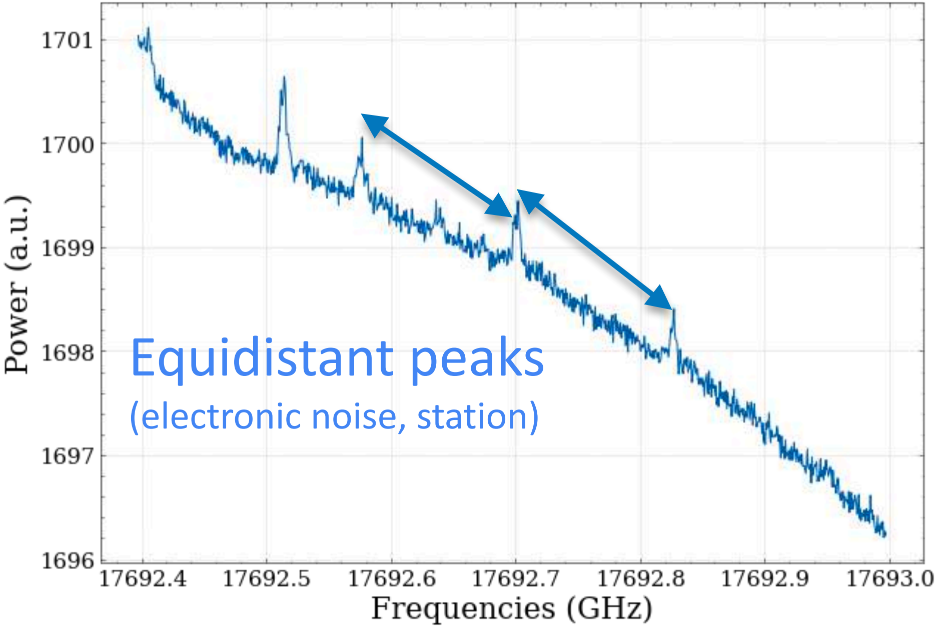
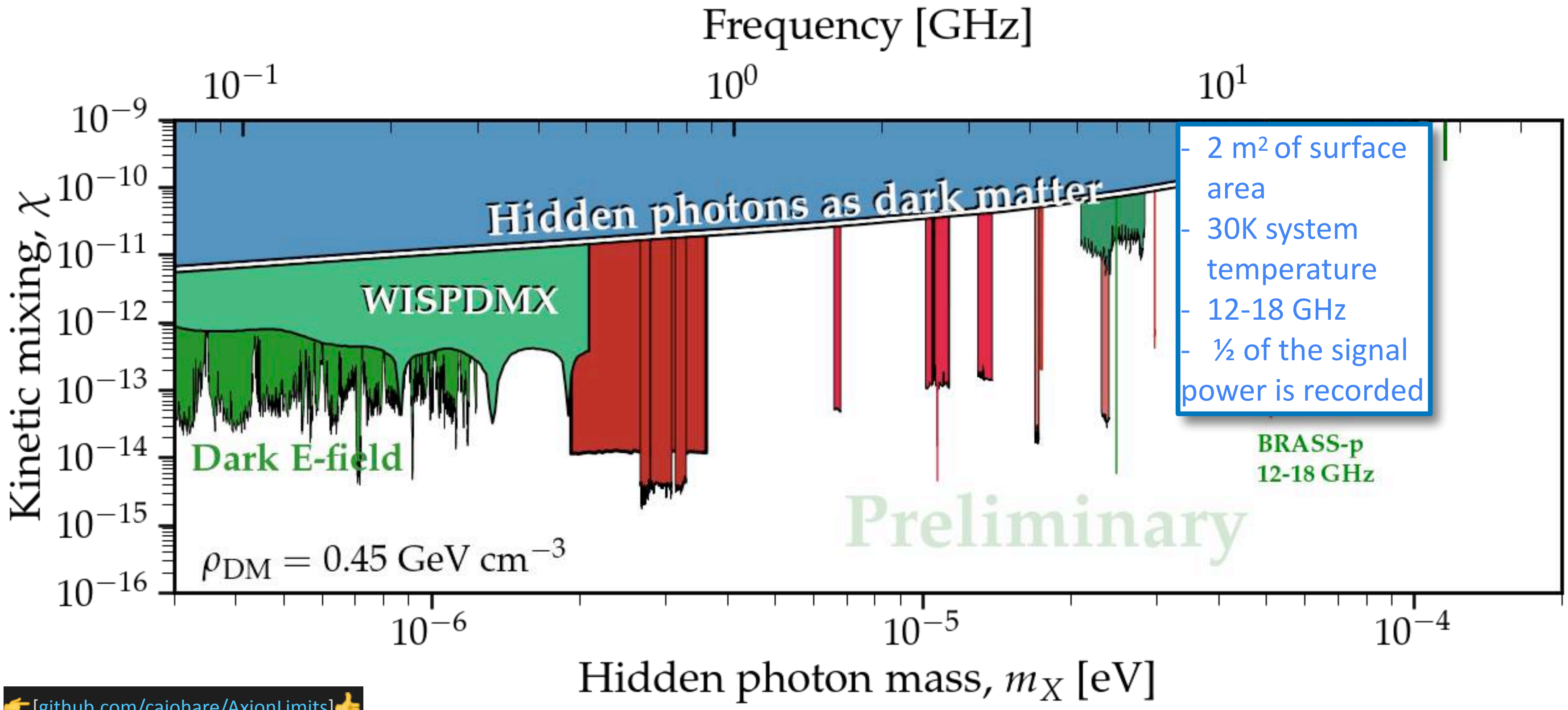
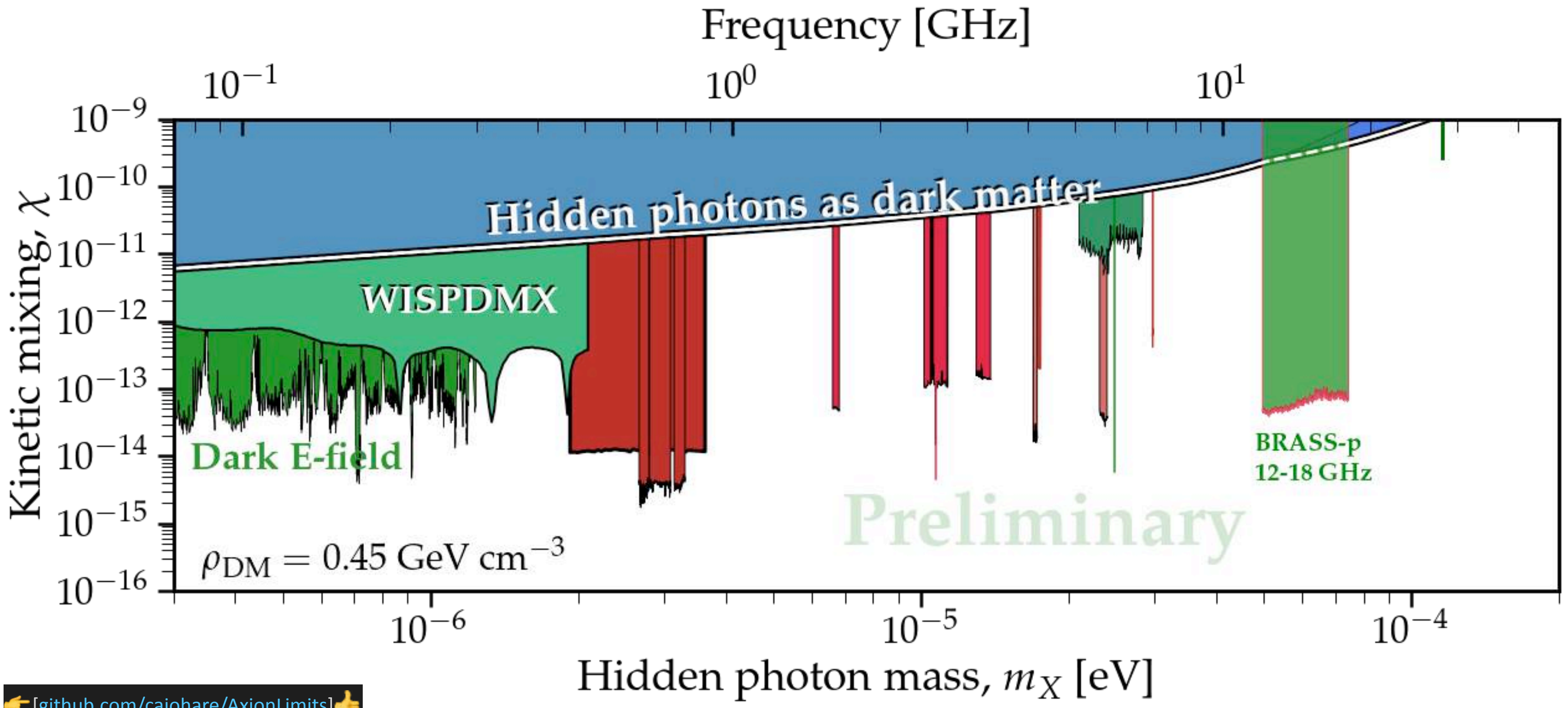
1.769270
1.769271
1.769272
1e10
Frequencies (GHz)


Power (a.u.)
1701
1700
1699
1698
1697
1696
17692.4
17692.5
17692.6
17692.7
17692.8
17692.9
17693.0
Frequencies (GHz)
Equidistant peaks
(electronic noise, station)



- 2 m² of surface area
- 30K system temperature
- 12-18 GHz
- ½ of the signal power is recorded

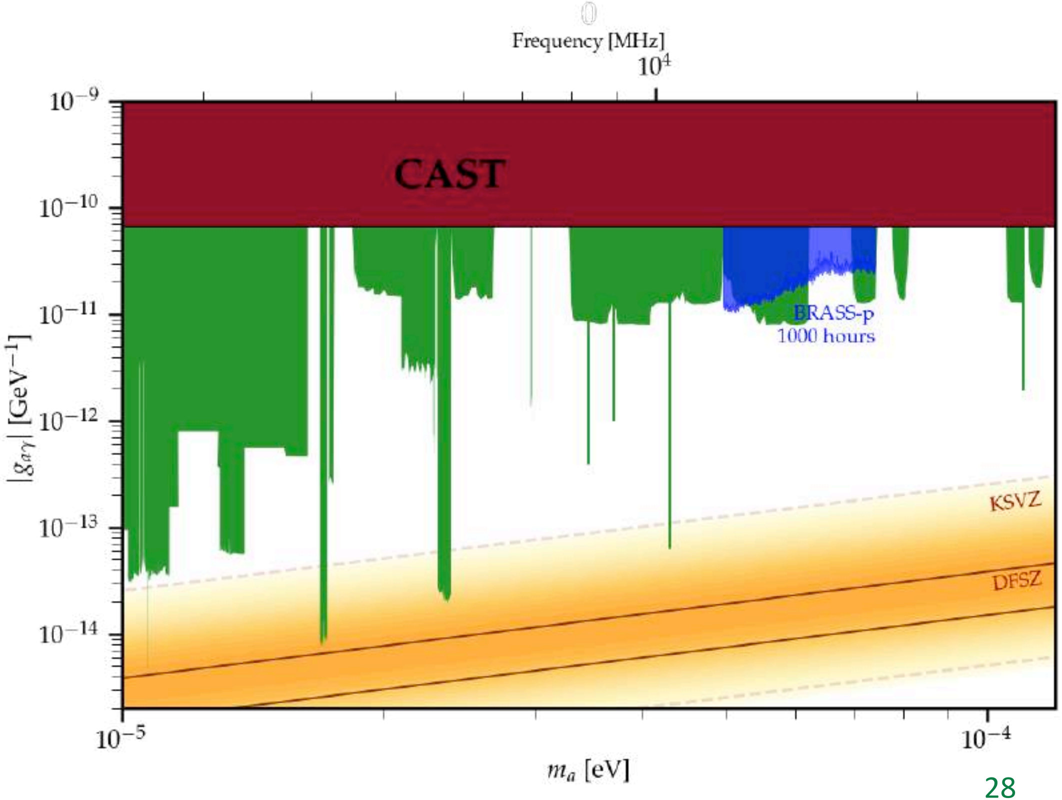
[github.com/cajohare/AxionLimits]



👉[github.com/cajohare/AxionLimits]👍

Future plans:

- Publication with technology roadmap and first result.
- Guided hidden photon search.
- Improved insulation.
- Axion with magnet panels.
- Seasonal modulation signal searches.
- BRASS-p is easily scalable (frequency, IF bandwidth, conversion surface, mirror).

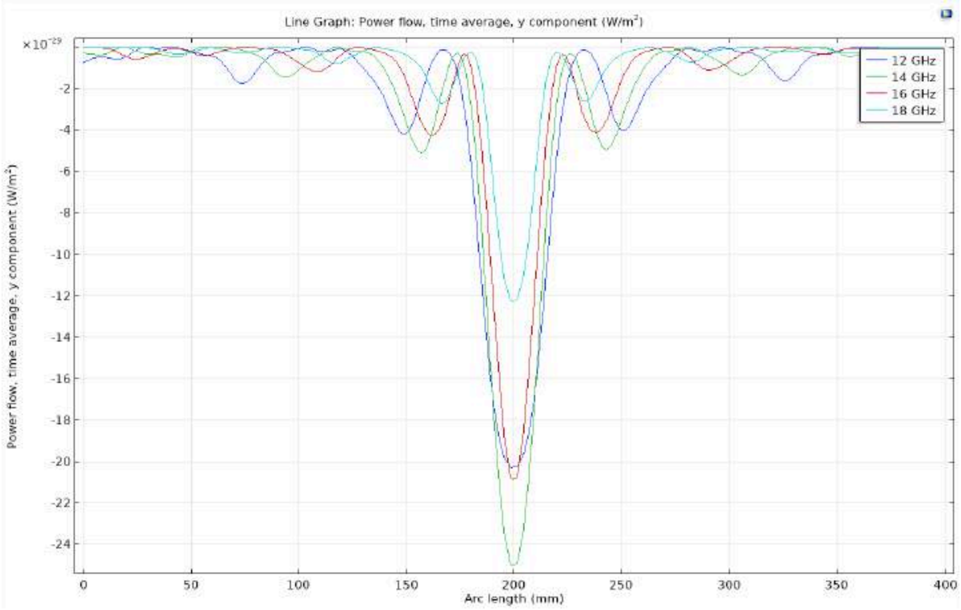


[github.com/cajohare/AxionLimits]

- BRASS-p is the implementation of the mature radio astronomy technology.
- The most powerful hidden photon dark matter telescope with leading sensitivity in the mass range.
- Unique design of the magnet panels for axion/alps search (with future upgrade) that drives down the cost of the experiment.
- A green experiment 🌱🌱🌱

Thank you for listening

Power distribution at the focal point/phase center



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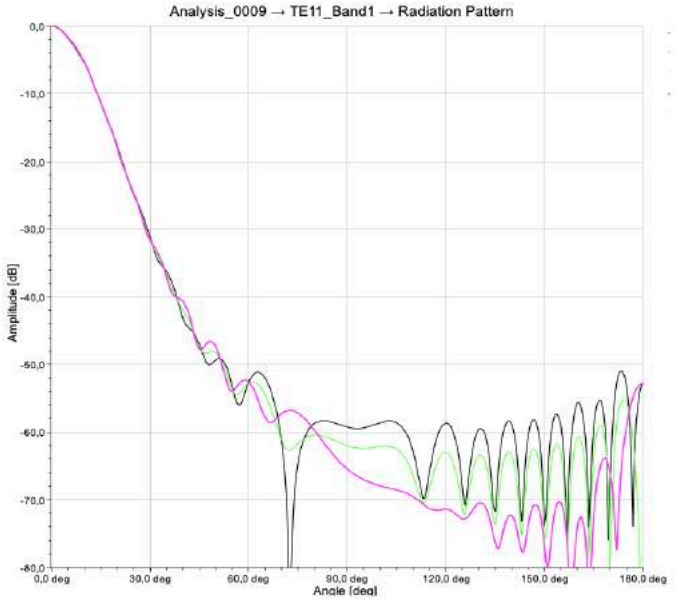
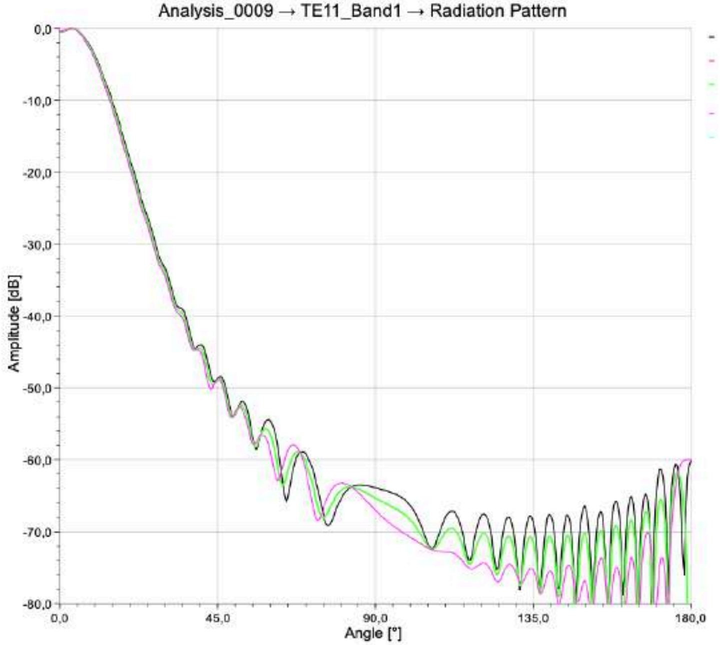
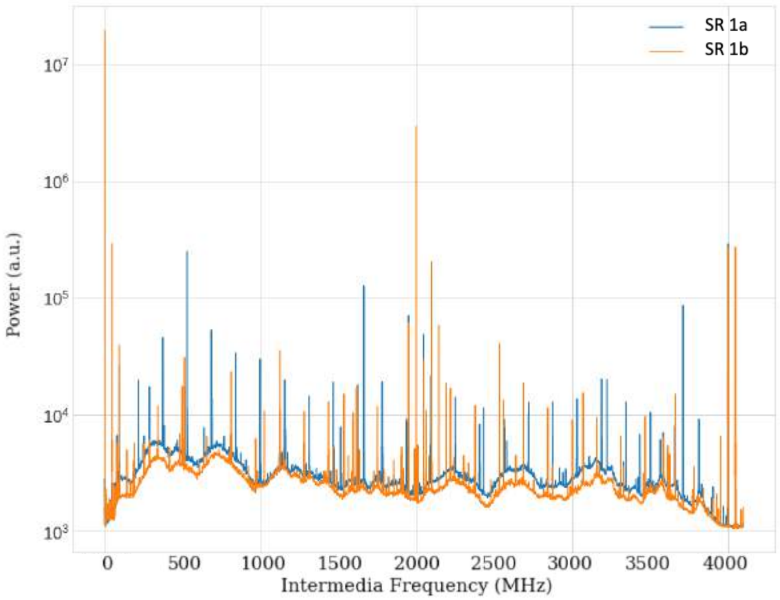
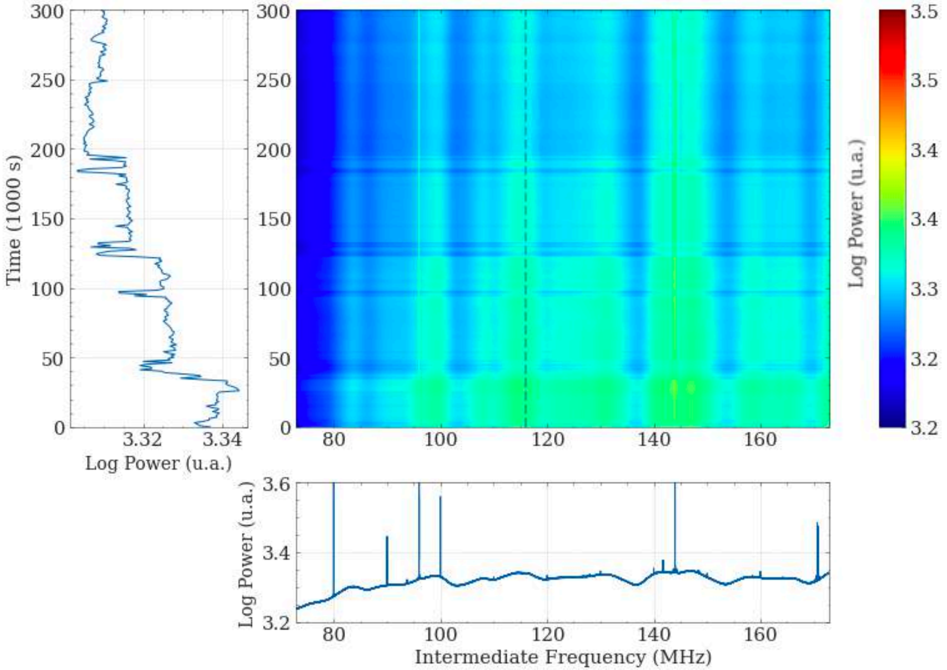




Radiation Pattern at 12 GHz and 15 GHz

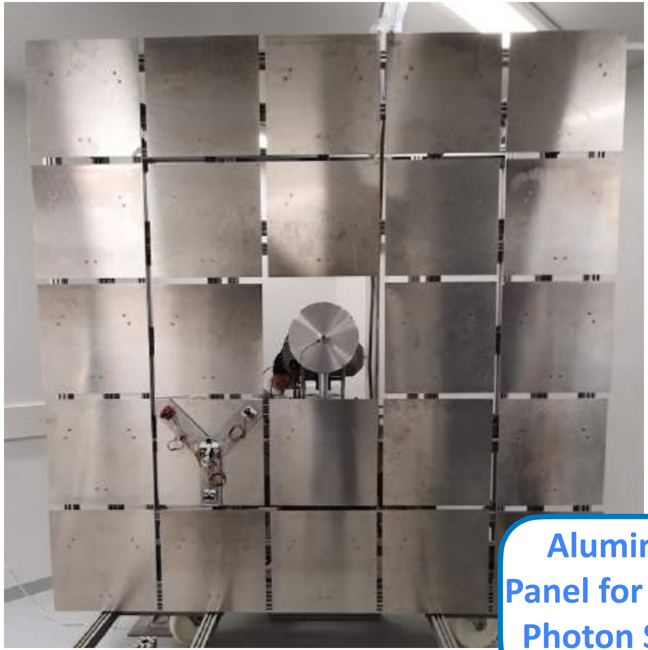


Broadband IF Spectrum

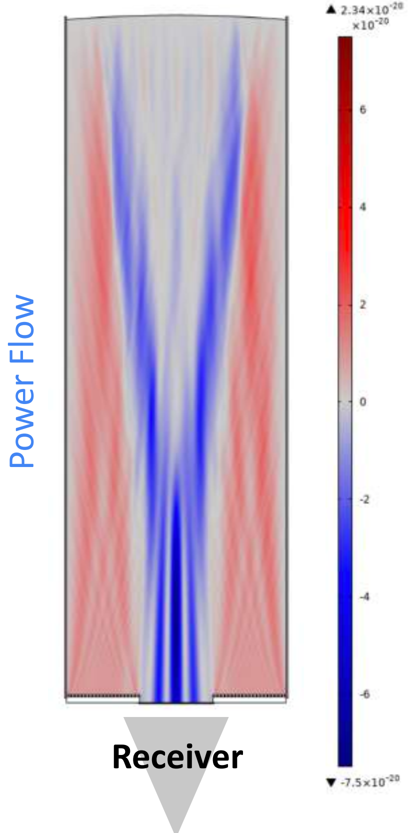


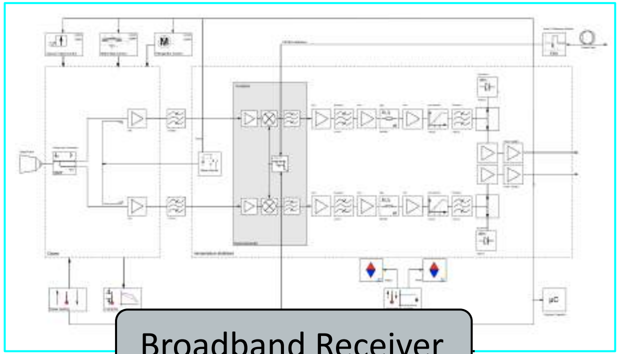
Waterfall Plot of SR 1b (70-190 MHz)

Conversion Panels



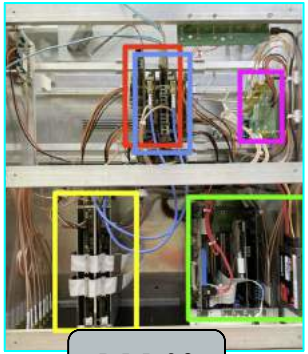
Aluminium Panel for Hidden Photon Search





Broadband Receiver

IF 4-8GHz



DBBC3

8 GS/S

SSD Storage

CUDA based FFT

Spectra Storage

Acquisition PC

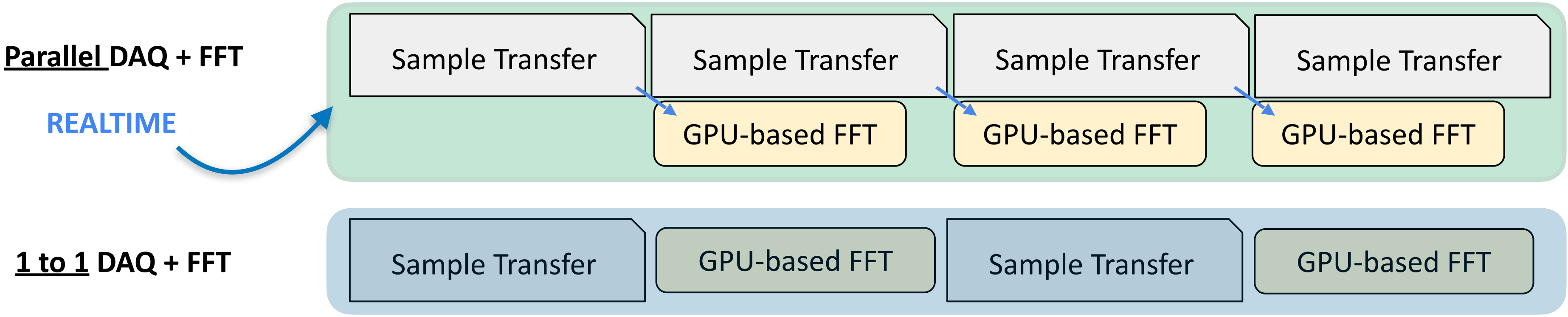
GUI

UHH Network

Monitoring and complete remote controlled.

A fully turnkey system for science run.

Digitizer and Postprocessing Calibration



- Only one polarization is digitized by the DBBC3.
- Bottle neck: computational power, CPU cores, PCIe.
- For every 1000 DAQ, there is 2 DAQ with sample loss > 0.5 %

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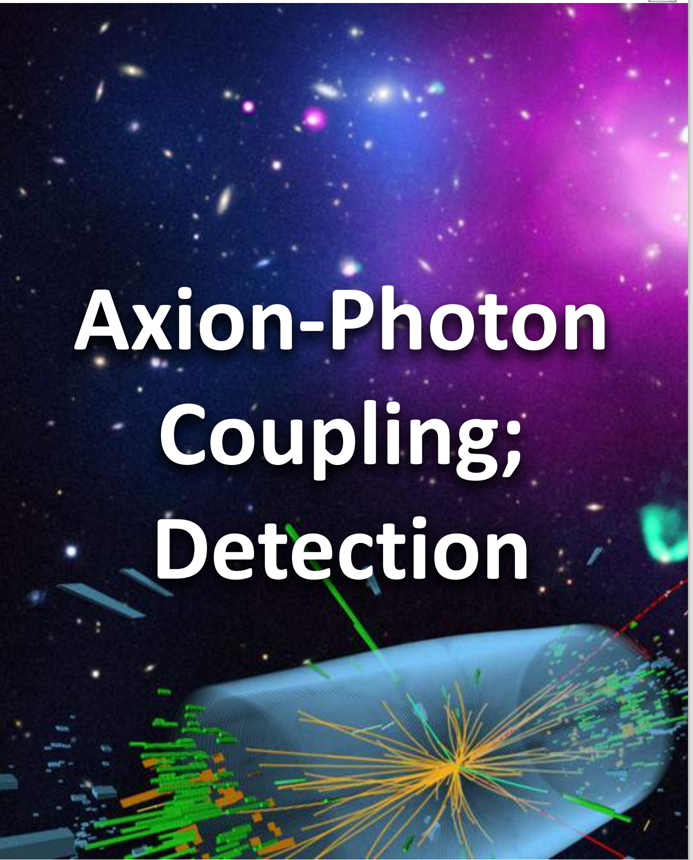
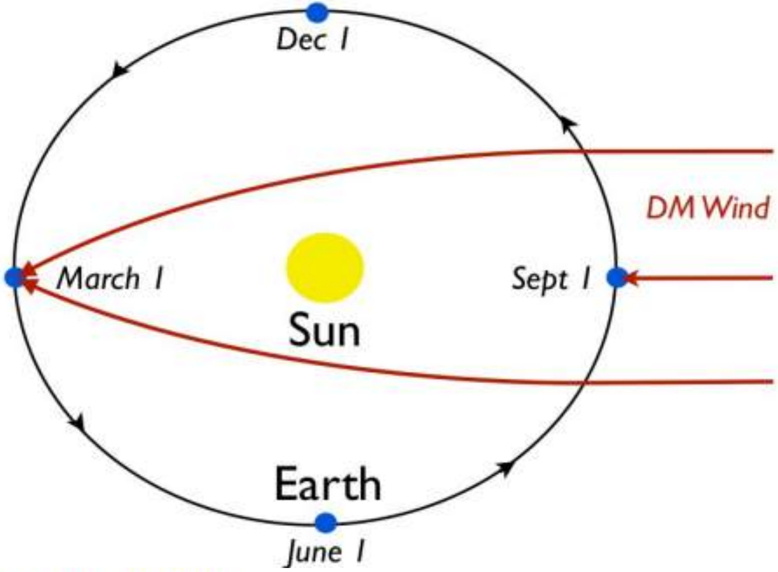
Axion-Photon Coupling; Detection



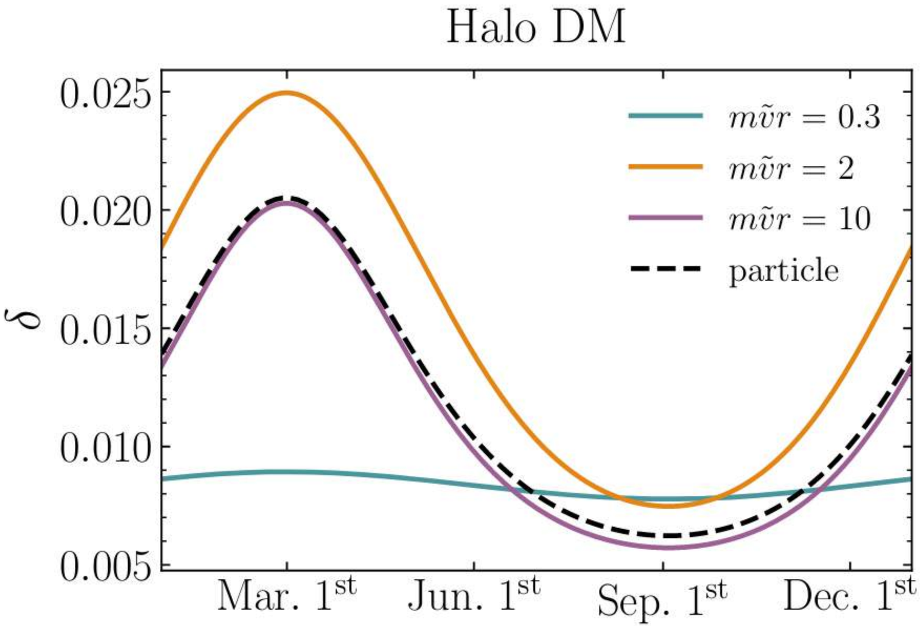
$$P_{\mathrm{SIG}} = \eta g_{a\gamma\gamma}^2 \left(\frac{\rho_a}{m_a}\right) B_0^2 V C Q_L$$

Where:

- $g_{a\gamma\gamma}$: axion coupling constant
- m_a: axion mass
- ρ_a: local density of axions in the halo
- B_0: magnetic field strength
- V: volume of the cavity
- C: mode dependent form factor
- Q: cavity quality factor



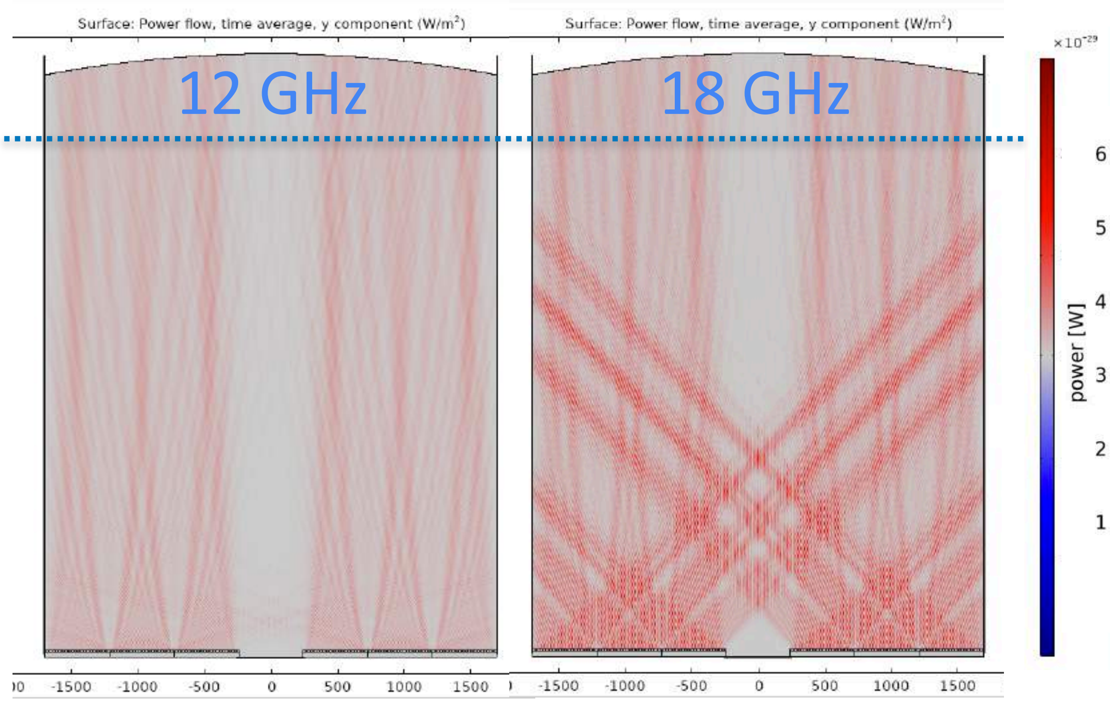
Lee et al. PRL 112 (2014)

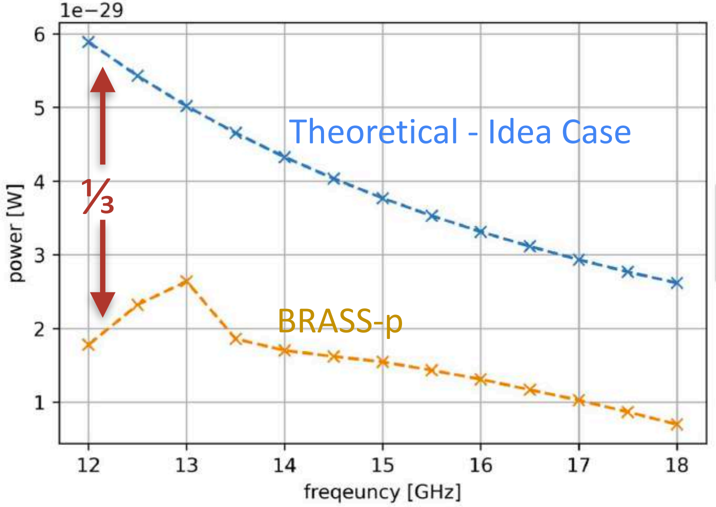


Kim and Lenoci 2021

Results/Radiation simulation 2D

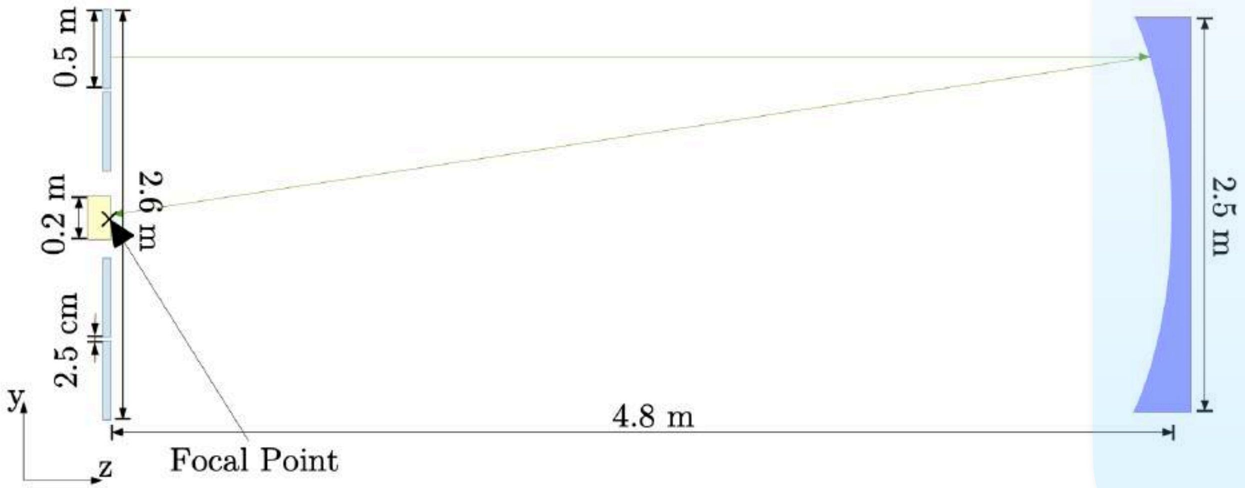
$$g_{a\gamma\gamma} = 10^{-14}\ \text{GeV}^{-1}$$





Position Calibration

FIXED!



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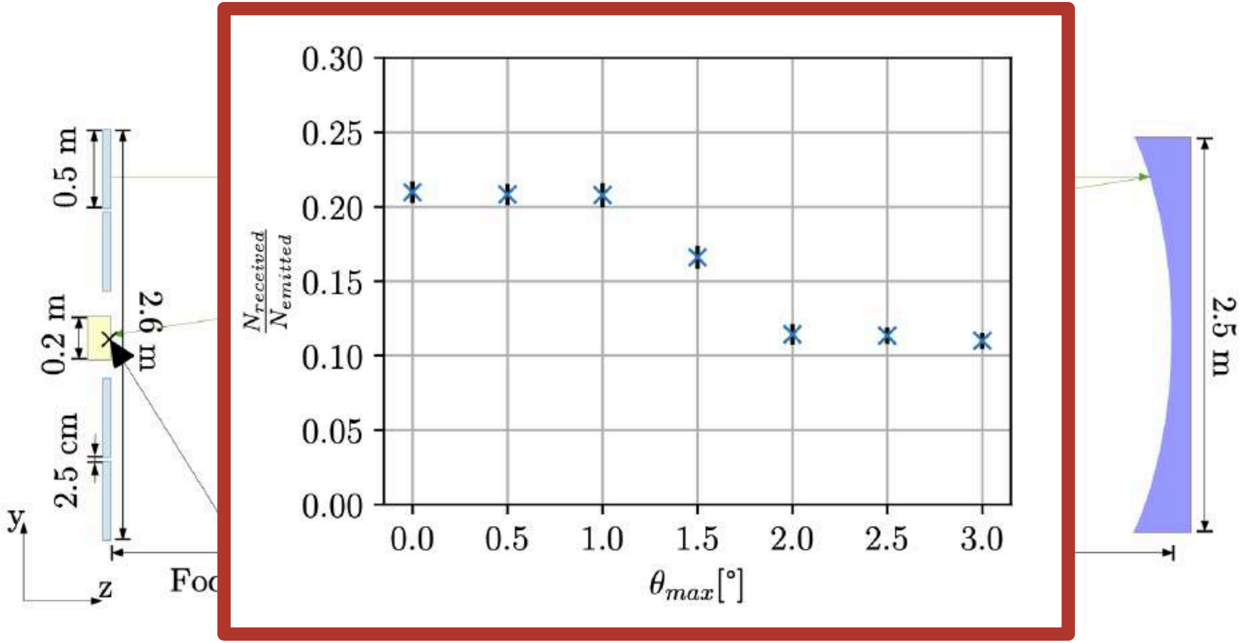
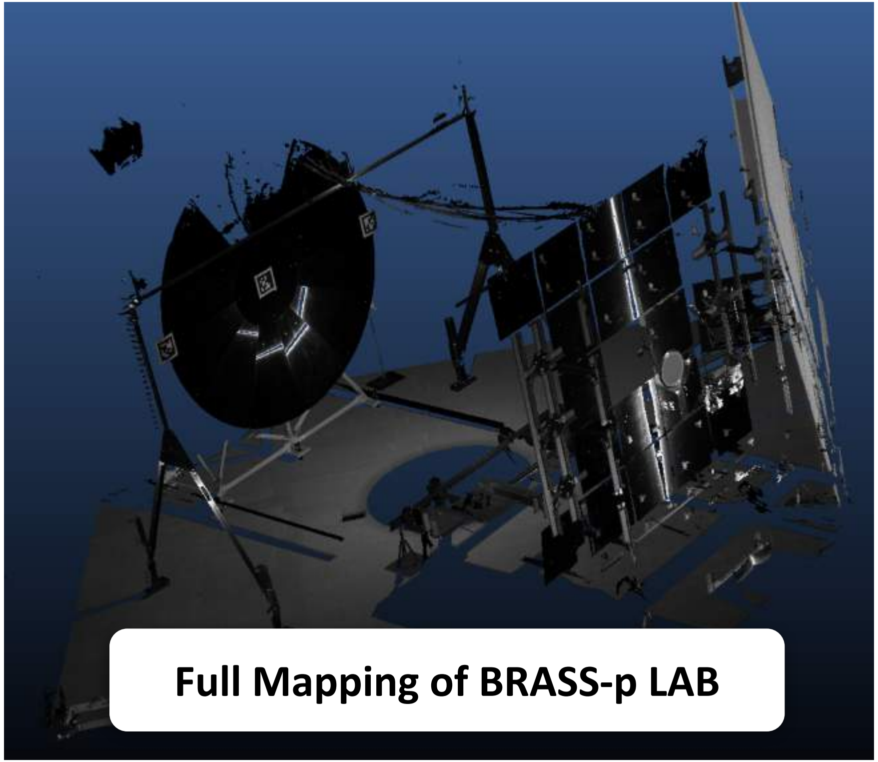
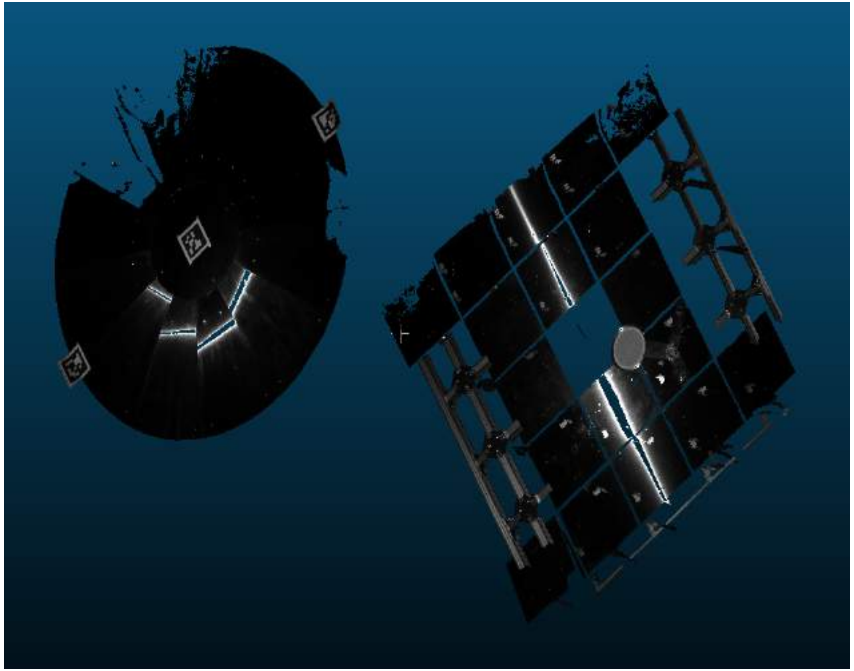
Position Calibration

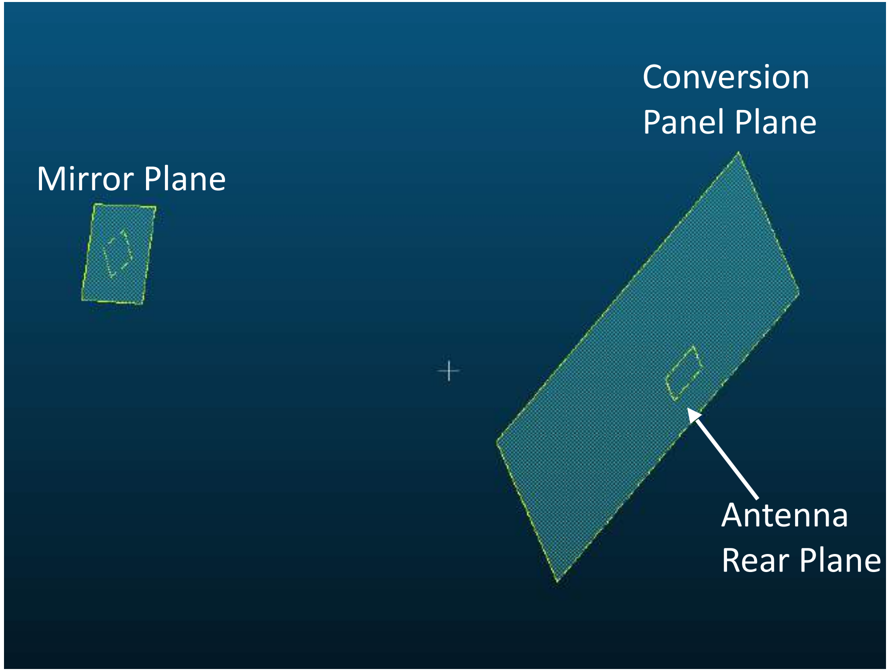


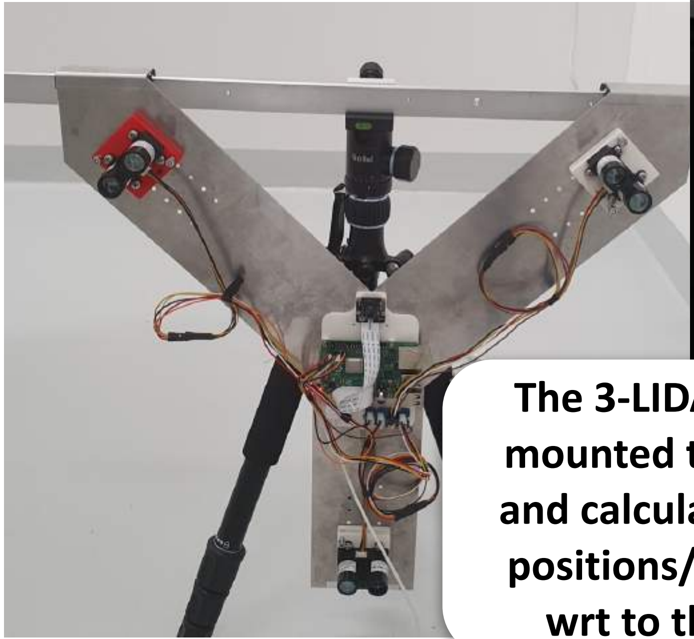
Laser LIDAR with approx 1 billion points at sub mm precision

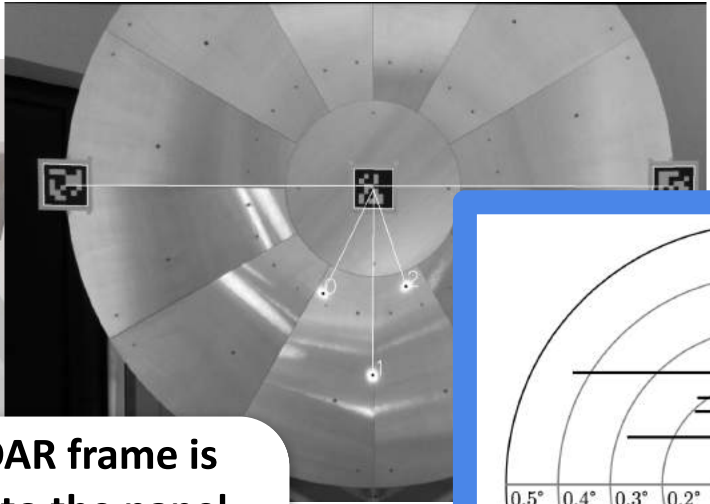


Full Mapping of BRASS-p LAB

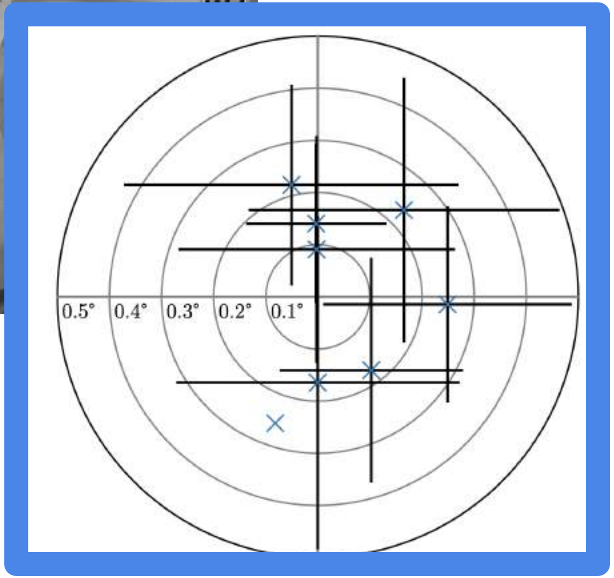



Conversion
Panel Plane
Mirror Plane
Antenna
Rear Plane





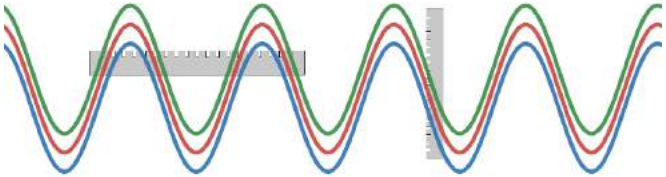
The 3-LIDAR frame is mounted to the panel and calculated the abs positions/tilted angle wrt to the mirror.



Setup 1: De-Broglie Wavelength Coherence

- De-Broglie wavelength: $\lambda = \frac{h}{mv}$
- Wave vector perpendicular to panel → always coherent.
- Wave vector parallel to panel. → highly depending on wavelength
- Short wavelength limit: phase varies completely over the experiment size.
- Example: 12 GHz, $\lambda_{DB} = 25m$

$$\phi_{max} = 0.38$$



short wavelength limit

long wavelength limit

Coherence Study

- J_a is modified with an additional phase factor: $J_a \exp(i\phi)$
- Phase ϕ can vary between (0,2π) and depends on the frequency and the dimension of the panels
- Negligible effect to the BRASS-p