# Searching for potential signals in the noise for ADMX G2-Run1C APS April Meeting 2021



### Chelsea Bartram 04/18/2021



## Matter, matter everywhere, but not enough, we think...





Perhaps it is wave-like dark matter, specifically the QCD axion.

## How do we find it then?







## warm electronics (DAQ rack) this way







## Analysis requires understanding 2 components...

### **Expected Axion Signal Power:**

 $P = (8.05 \times 10^{-23}) \left(\frac{V}{136\,\ell}\right) \left(\frac{B}{7.6\,\mathrm{T}}\right)^2 \left(\frac{C_{010}}{0.4}\right) \left(\frac{Q}{80,000}\right) \left(\frac{g_{\gamma}}{0.97}\right)^2 \left(\frac{\rho_a}{0.45\,\mathrm{GeV/cc}}\right) \left(\frac{f_a}{1020\,\mathrm{MHz}}\right)$ 

V: cavity volume B: static magnetic field C<sub>010</sub>: form factor Q: quality factor

### **Expected Noise Power:**

 $T_{\rm sys} = T_{\rm phys} + T_{\rm amp}$ 

 $g_{\gamma}$ : axion photon coupling ρ<sub>a</sub>: dark matter density f<sub>a</sub>: Axion frequency

 $P_n = k_B T_{\rm sys} b$ 

System noise is a result of amplifier noise and physical temperature





## **Medium Resolution Analysis**

- 10,000 of the 10ms subspectra were coadded together at the level of the digitizer code
- Results in 100 seconds worth of data (integration time)
- Raw spectra undergo processing before axion signals can be identified









# Filtering



- Spectrum after warm electronics background and cold electronics shape is removed
- Gray band shows  $1\sigma$  error bar.





# Lorentzian cavity shape

- A real axion signal would follow this Lorentzian shape
- Can be used to identify radio frequency interference (RFI) vs axion. Noise entering downstream of the cavity will not follow the Lorentzian shape of the cavity.







# Axion velocity distribution ("line shape")



### Detectable with High Resolution Search (10 mHz)



# Individual spectra are combined

## **Co-adding procedure:**

Divide power by the system noise

$$P_{i,lor}^{j} = (P_{i}^{j}/T_{sys}) * \text{Lorentzian}$$

• Divide by  $Q, V, C_{010}, B^2$  to obtain the unit axion power

$$P_{i_{\text{scaled}}}^{j} = P_{i,\text{lor}}^{j} \left(\frac{1}{C_{010}}\right) \left(\frac{1 \text{ m}^{3}}{V}\right) \left(\frac{1}{Q}\right) \left(\frac{1}{Q}\right)$$

*i* is the bin index, *j* is the scan index



### Compute grand spectrum power







# Grand Power Spectrum (Simulated Data)

- Combination of the individual processed raw spectra
- Axion candidates are identified at this stage



### SIMULATED DATA!



## Software injections

### **SIMULATED DATA!**



- Used to determine our detection efficiency and verify our analysis
- $\bullet$ removal.



### **SOFTWARE INJECTIONS**

### Generated at the start of the analysis and include axion line shape

Developed new techniques to mitigate sensitivity reduction due to baseline



## ADMX Rescans

When do you decide to rescan?

3 conditions:

- Not enough data (low SNR): min SNR of 3
- 3.4σ excess
- Excess at DFSZ threshold or above

 $P_{\rm measured} + 0.85\sigma > P_{\rm DFSZ}$ 

There will always be some of these remaining just due to statistics!





## **Persistence Checks**

- Synthetic axion signals should go away when turned off
- RFI that comes and goes is clearly not an axion
- Virialized axion signal would persist in every scan
- Time between scans typically 2 weeks or less. Important details for high-res search.

 $\sim$ Scan

4

can

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## **Persistence Checks**

# Secondary SAG

- A real axion or a secondary SAG would persist in all scans, requiring the operators to advance to the next step in the data-taking decision tree.
- Move to the TM011 mode....



## Synthetic Signal

### Clearly a synthetic because it appeared to be even stronger on the TM011 mode



## **Clear Maxwell-Boltzmann line shape generated by SAG.**





## **ADMX Exclusion Limit**







Bartram, Chelsea, et al. "Axion dark matter experiment: Run 1B analysis details." *Physical Review D* 103.3 (2021): 032002.

# Conclusion

- Run 1C data-taking progressing from 800 MHz— 1020 MHz
- First pass at somewhat lower sensitivity (roughly 2x DFSZ) due to COVID limitations (assuming 100% axion dark matter density)
- Will resume at DFSZ sensitivity after post-Covid improvements
- Improvements already made to SAG, analysis, etc





This work was supported by the U.S. Department of Energy through Grants No DE-SC0009800, No. DE-SC0009723, No. DE-SC0010296, No. DE-SC0010280, No. DE-SC0011665, No. DEFG02-97ER41029, No. DE-FG02-96ER40956, No. DEAC52-07NA27344, No. DE-C03-76SF00098 and No. DE-SC0017987. Fermilab is a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359. Additional support was provided by the Heising-Simons Foundation and by the Lawrence Livermore National Laboratory and Pacific Northwest National Laboratory LDRD offices.



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## **Axion Search Decision Tree**







## Axion Search Decision Tree



