Data Acquisition (DAQ) in DMRadio-50L: Progress & Roadmap

Pam Stark
Stanford University
DMRadio Collaboration Meeting, Oct 2025

Data acquisition (or, how do we get science data out of 50L?)

The data acquisition system refers to all **real-time data handling and processing**, including both hardware and software

Cooldown

Fixed hardware; may contain multiple phases

Phase

Period of time within the cooldown

"Commissioning"
"Engineering"
"Science"

Operations

Campaign

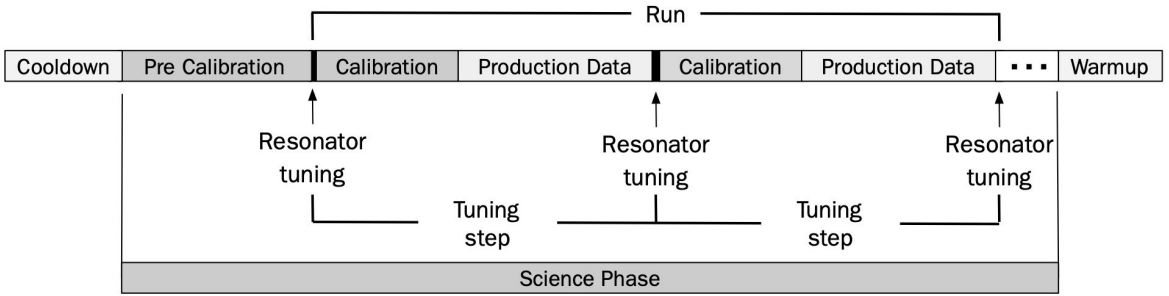
Frequency region of interest. Fixed hardware.

I.e. 100 kHz - 200 kHz

"Nibble"

How do we partition the campaign?

Axion Science Data



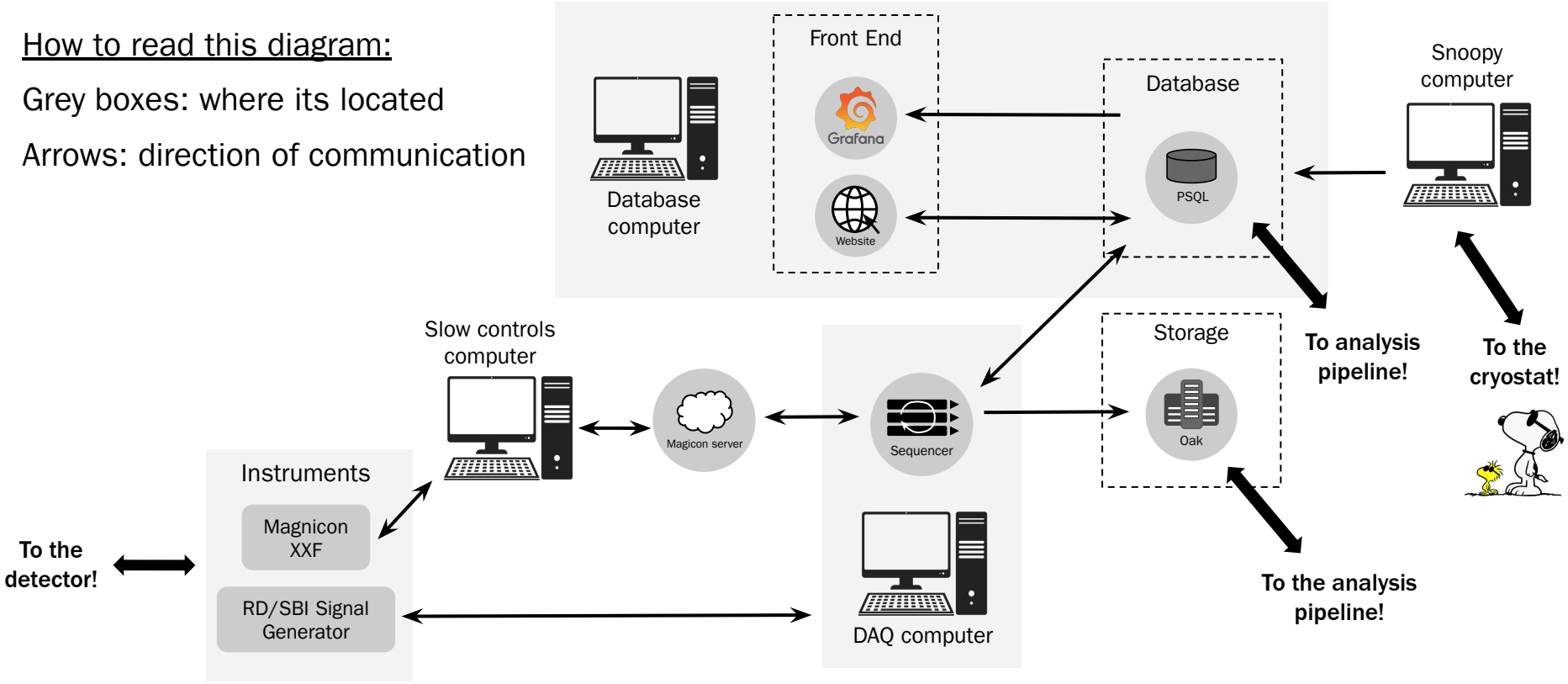
Note: a single cooldown might have several phases

DAQ architecture

<u>How to read this diagram:</u>

Grey boxes: where its located

Arrows: direction of communication



DAQ architecture

Grey boxes: where its located

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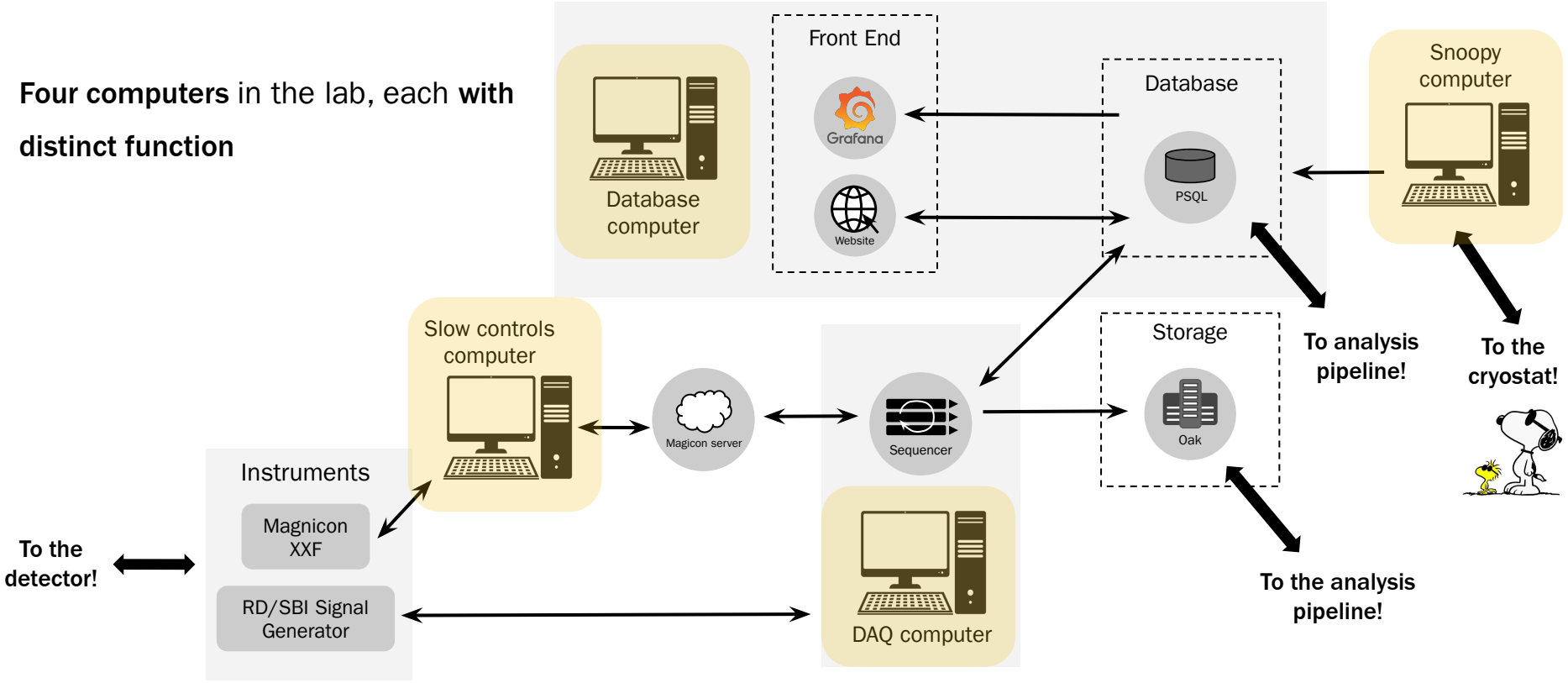
Four computers in the lab, each **with distinct function**



DAQ architecture

Grey boxes: where its located

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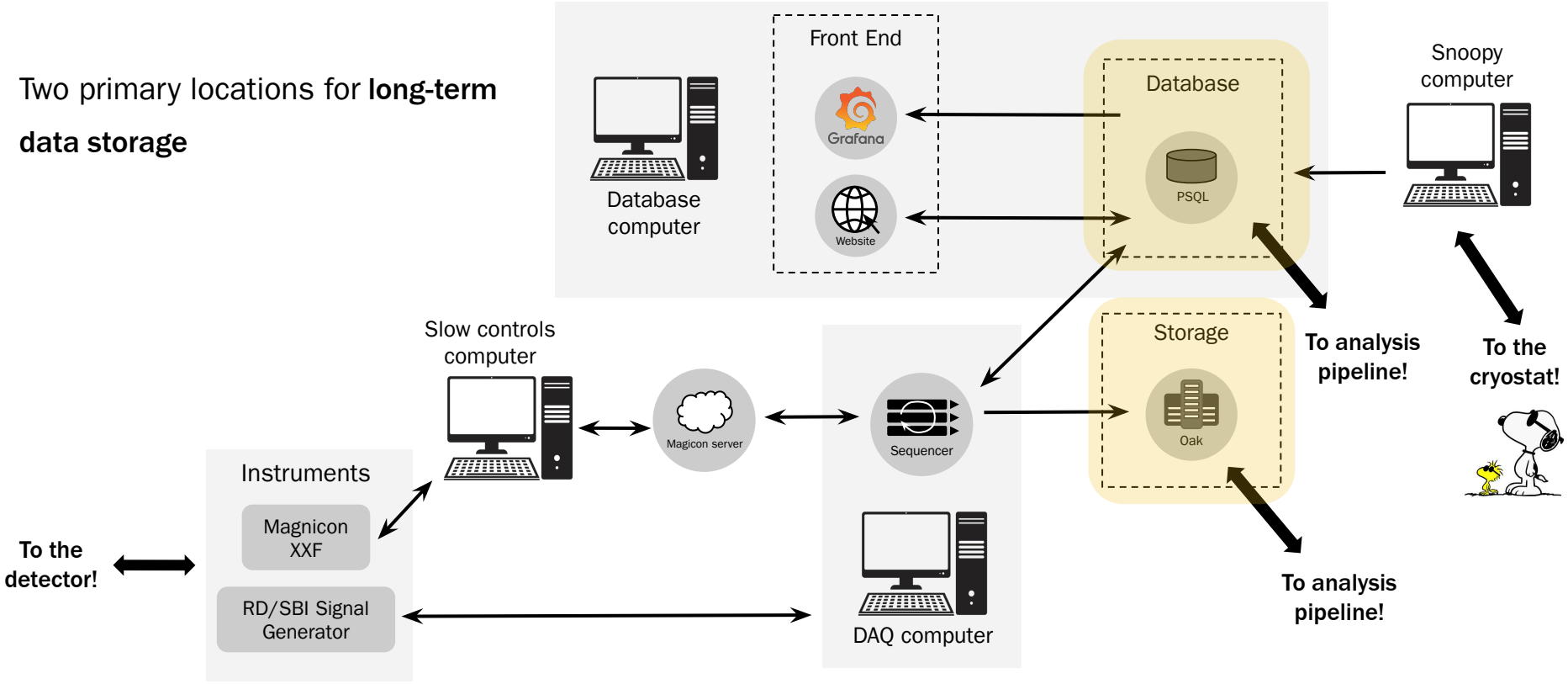
Two primary locations for **long-term data storage**



DAQ architecture

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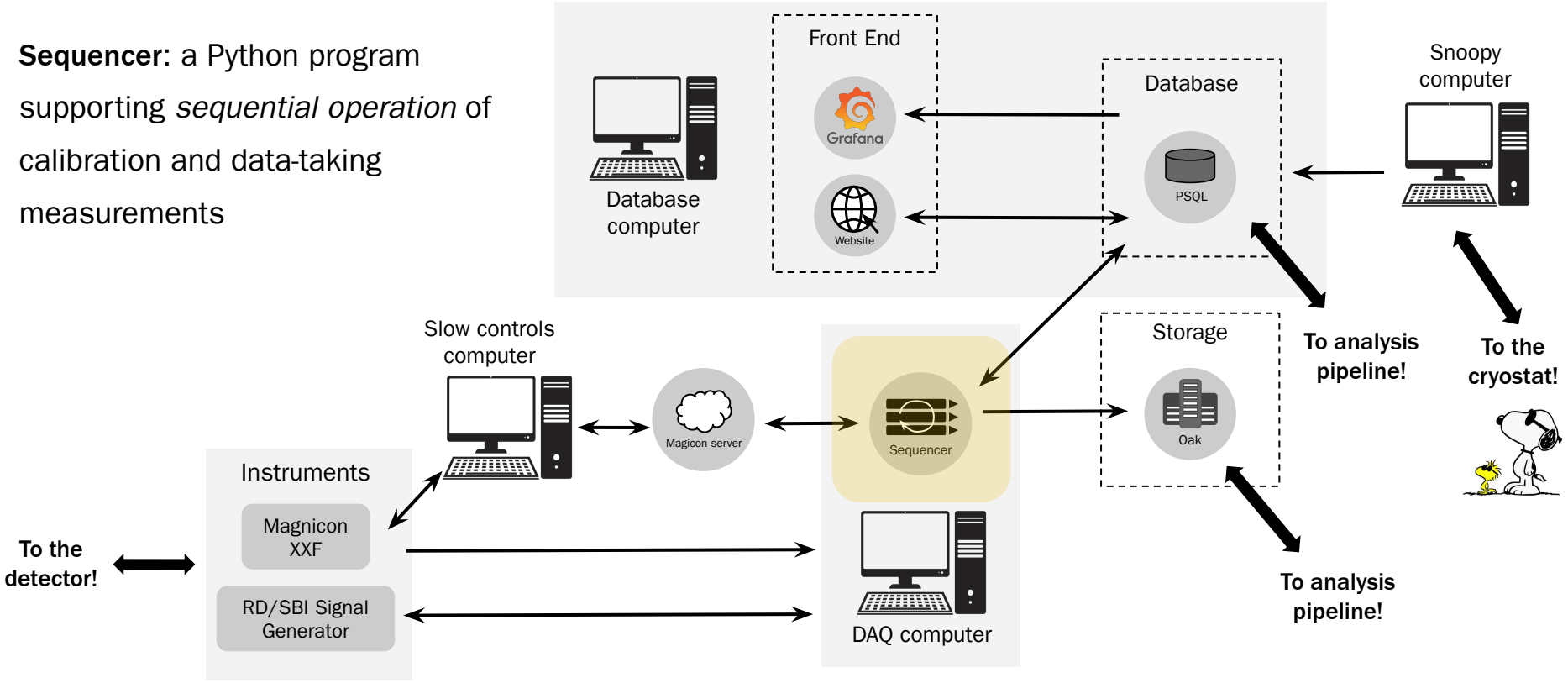
Sequencer: a Python program supporting *sequential operation* of calibration and data-taking measurements



DAQ architecture

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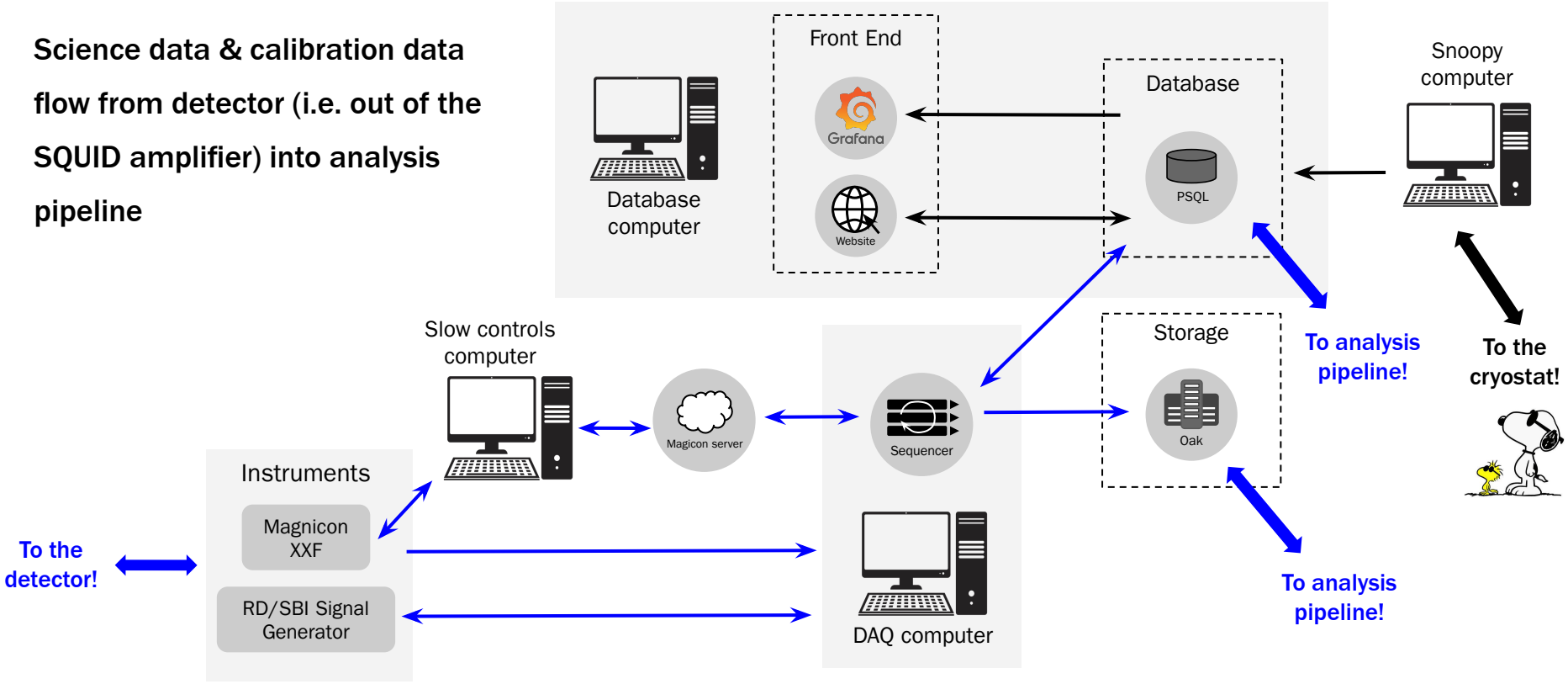
Science data & calibration data flow from detector (i.e. out of the SQUID amplifier) into analysis pipeline



DAQ architecture

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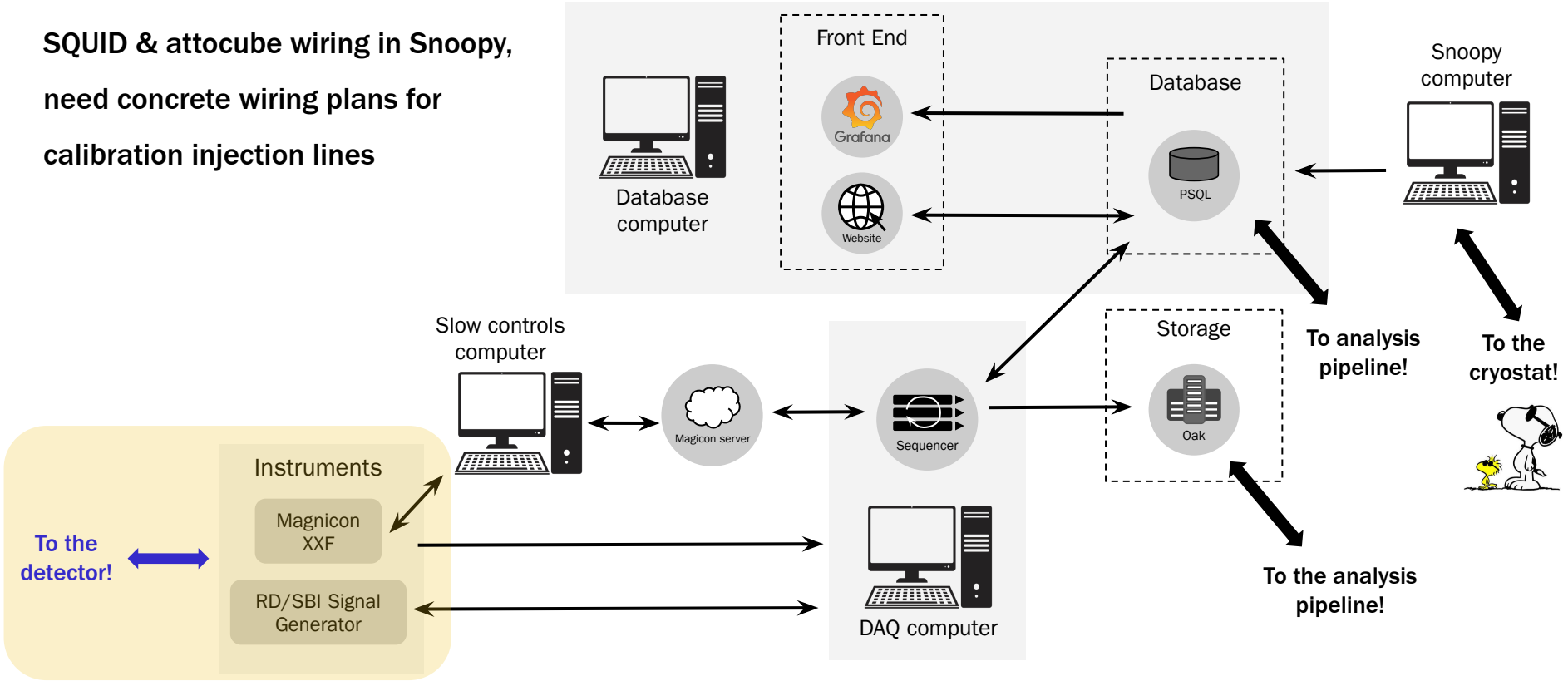
SQUID & attocube wiring in Snoopy, need concrete wiring plans for calibration injection lines



DAQ architecture

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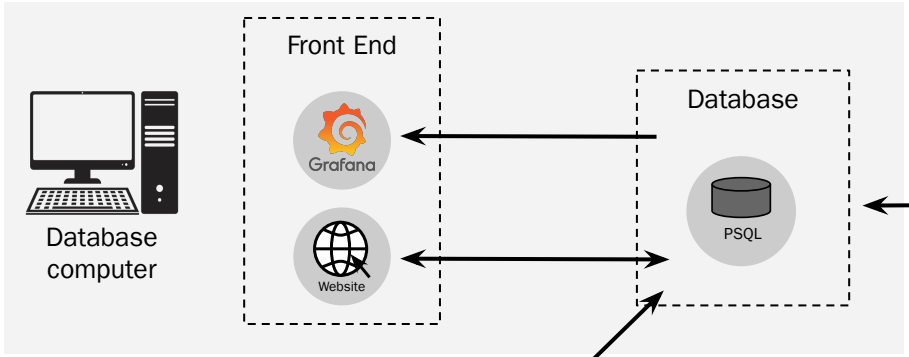
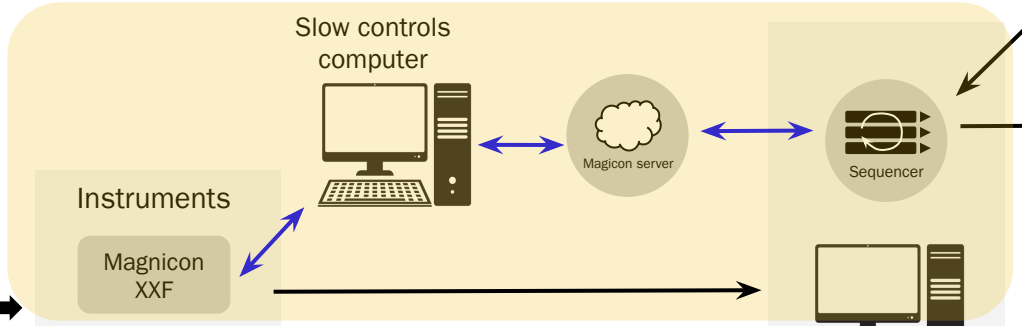
(High priority) Test Magnicon controls:

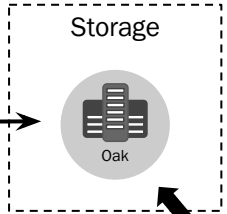
1) local control of Magnicon with Python

2) remote control of Magnicon with server

3) remote control of Magnicon with Sequencer







To the detector!

To the cryostat!

To the analysis pipeline!

DAQ architecture

Grey boxes: where its located

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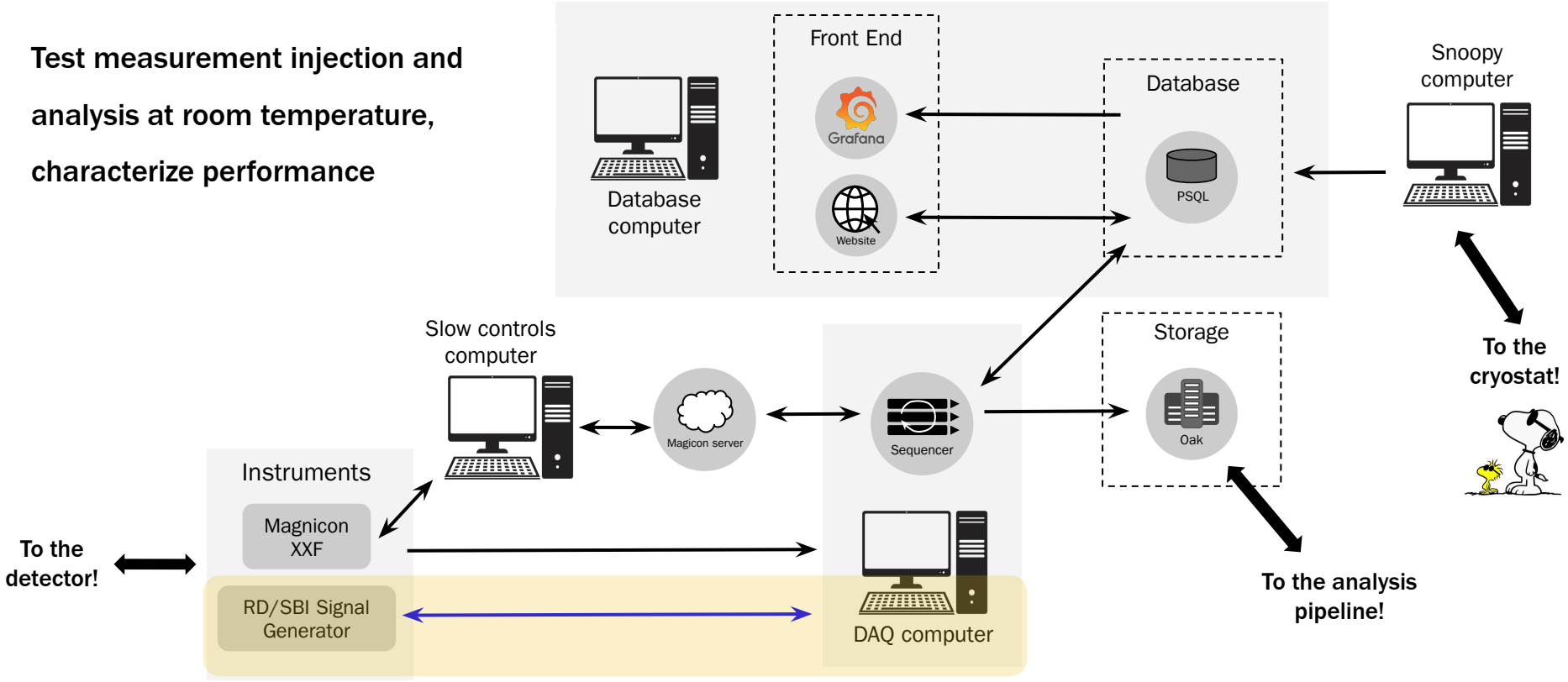
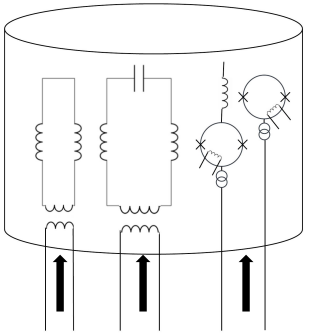
Test measurement injection and analysis at room temperature, characterize performance



Extensive room temperature testing has already been conducted

- Full integration includes integrating measurements into software to enable remote/sequenced operation



Measurement = Acquisition + Online Analysis

	Description	Purpose	DAQ Integration	Status
Ringdown	On-resonance burst injection into resonator	Measuring Q, f0	Done	Tested on simulation and at room temperature, cold tests forthcoming
Sideband Injection	Off-resonance injection into mimetic loop, resonator, or SQUID amplifier	Measuring system gain	Done	Tested on simulation, room temperature testing forthcoming
SAG	Axion lineshape injected into resonator	Blinding, end-to-end gain	In progress	Preliminary design tested at room temperature
SQUID biasing	Adjusting bias current and feedback to select bias point	Bias point selection	In progress	Control scripts written, awaiting testing

Measurement Characterization: Ringdown

- Developed room temperature resonator boxes to test injection and analysis

			f0 (MHz)				Q-value
Board 1	4700 uH	50 pF	0.328	3.28 x 10^5	0.316	-3.67%	4.21
Board 2	220 uH	50 pF	1.517	1.517 x 10^6	1.418	-6.53%	2.53
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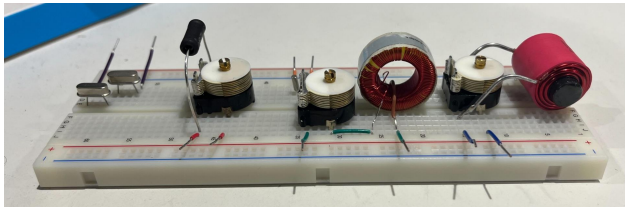
Low-Q RLC Resonator (developed by David Zhou)



High-Q quartz crystal resonator (developed by Noah Haile)

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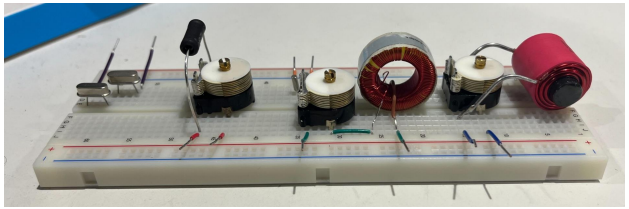

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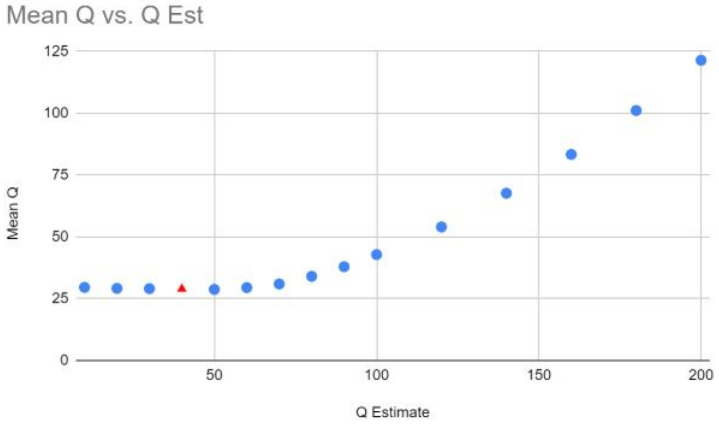

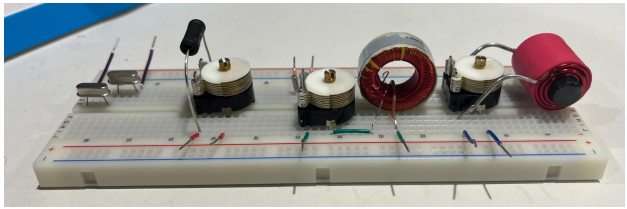

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- Info
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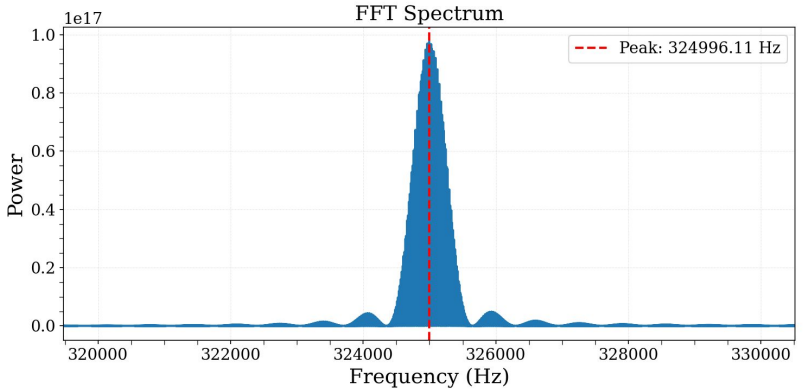

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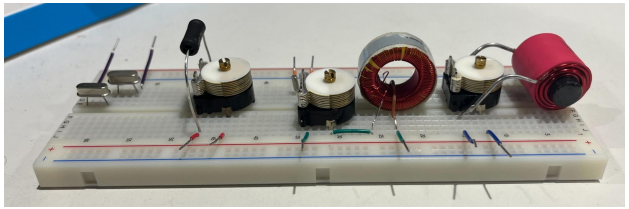

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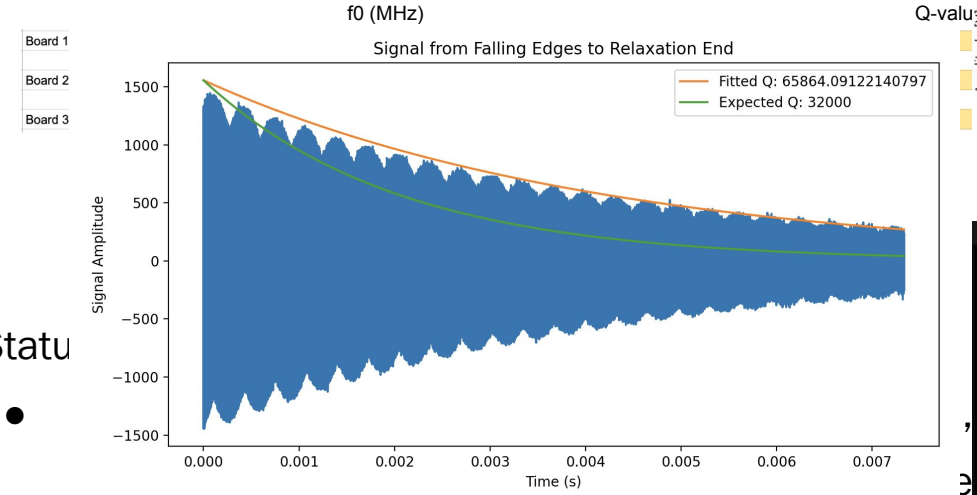
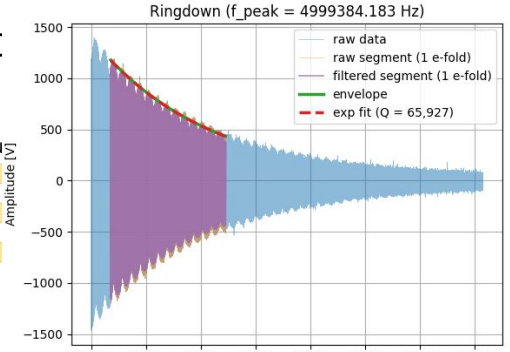
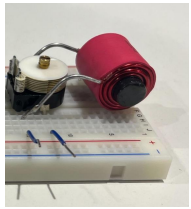
- Observed mode coupling behavior being further studied with SPICE simulations (Pam)

Measurement Characterization: Ringdown

- Developed room temperature resonator boxes tc







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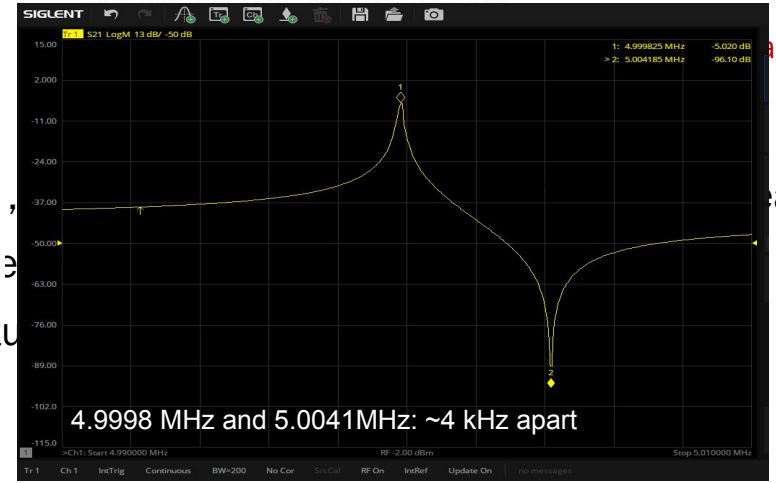

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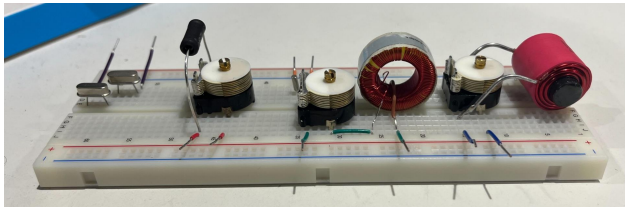

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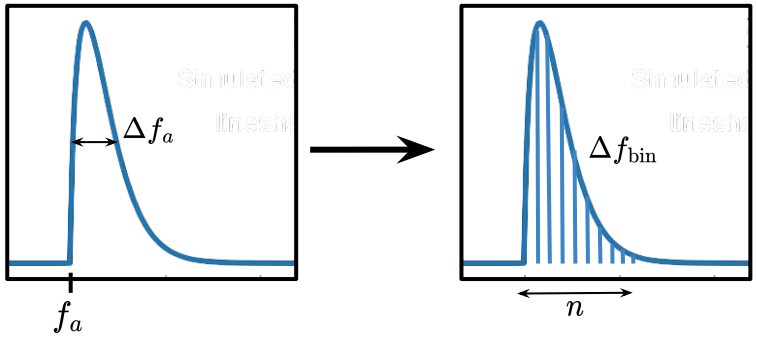
- Cold resonator prototype under development by Alex Droster & Noah Haile

Measurement Characterization: SAG

- **Synthetic axion generator** (SAG) designed and implemented by Barkotel Zemenu



Can we inject fake “axion” signal to (a) test readout chain end-to-end with axion-like signal and (b) develop blinding scheme for the analysis?

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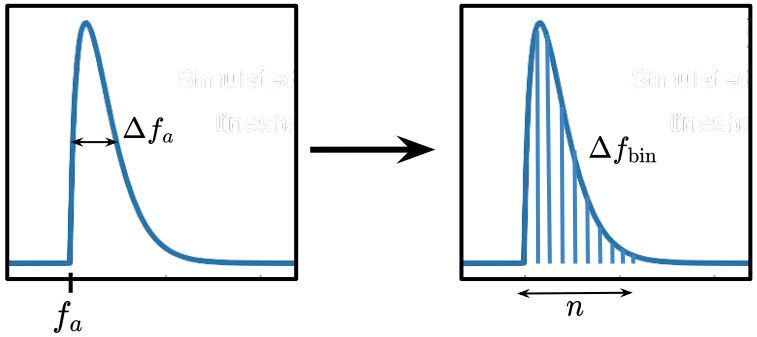

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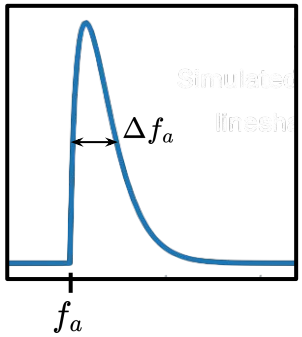

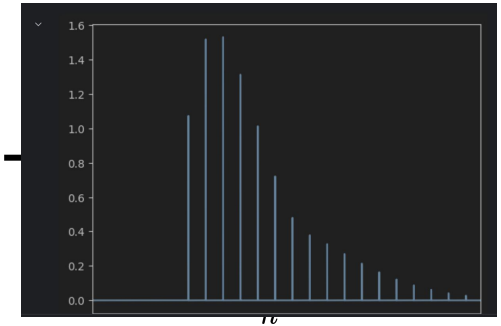

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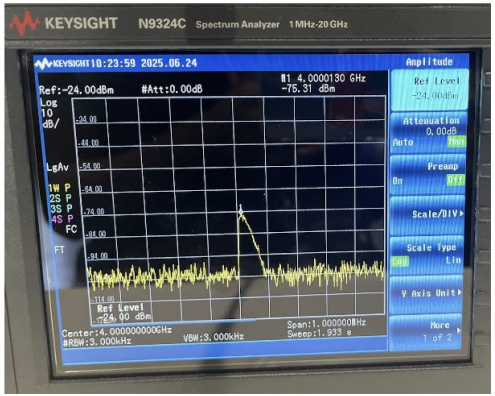

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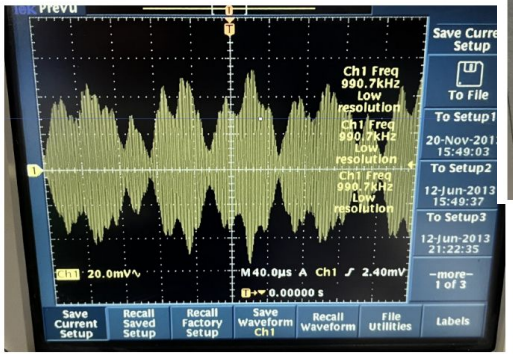

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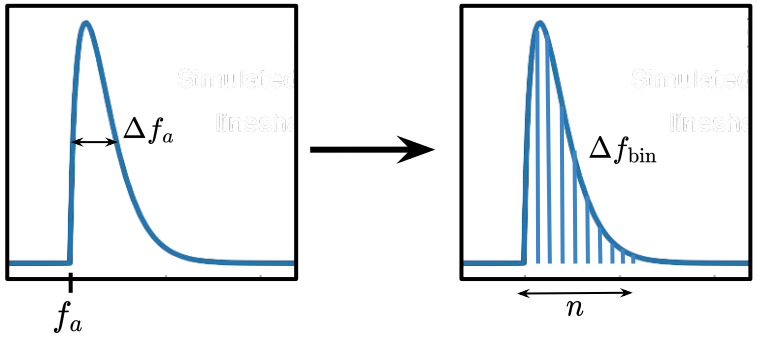

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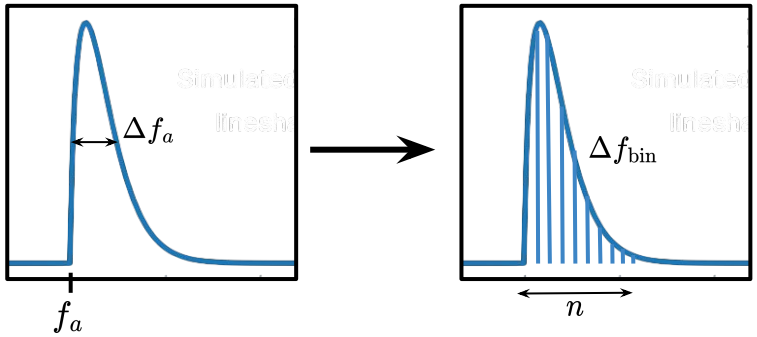

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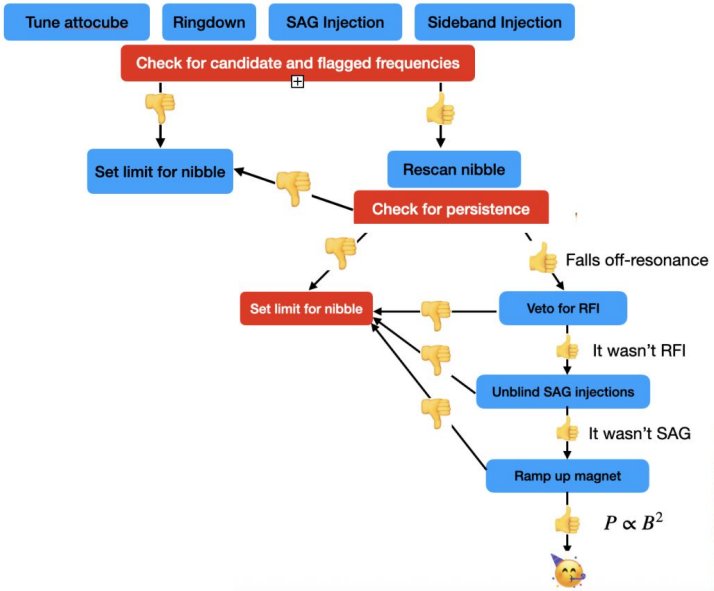

Towards a Synthetic Axion Generator for DMRadio

Barkotel Zemenu[1]

[1]*Department of Physics, Stanford University, Stanford, CA 94305, USA*

(Dated: October 6, 2025)

Direct searches for axion dark matter rely on detecting extremely narrowband electromagnetic signals whose Maxwellian spectral shape reflects the local axion velocity distribution. To validate experimental sensitivity, it is essential to inject realistic axion-like signals into the detection chain. High-frequency cavity haloscopes such as ADMX and HAYSTAC have developed a Synthetic Axion Generator (SAG) for this purpose. In this paper, we introduce the first SAG developed for low-frequency, lumped-element haloscopes such as DMRadio. We provide a derivation of the Maxwellian shape of the signal, detail the waveform injection protocol, and present results obtained from injecting the DMRadio SAG into a low-Q resonator.

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analysis?

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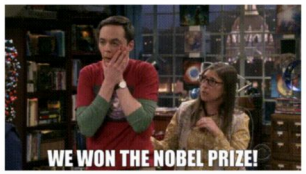

- hopping? (Ba
- l limitations (
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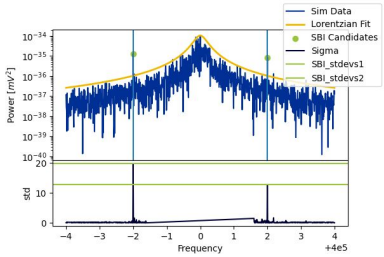
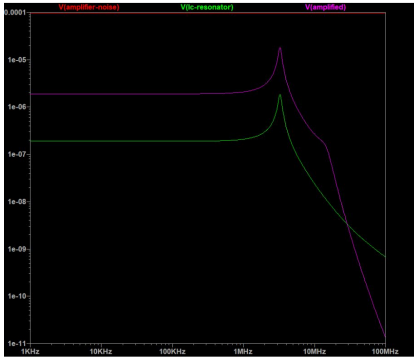
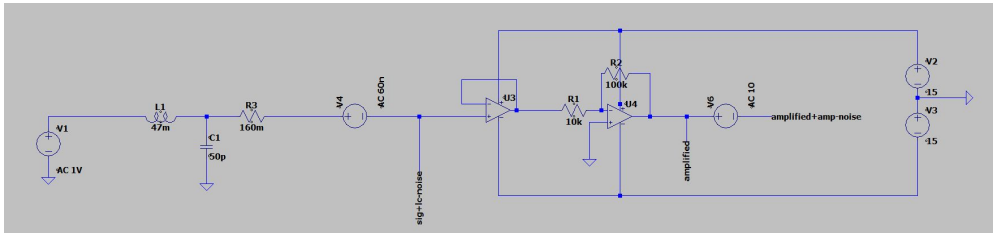
SCAN ME

Measurement Characterization: Sideband Injection

- **Sideband injection** is an off-resonance injection into the mimetic loop/resonator/amplifier to measure system gain







All plots courtesy of Shreya Puranam

Status:

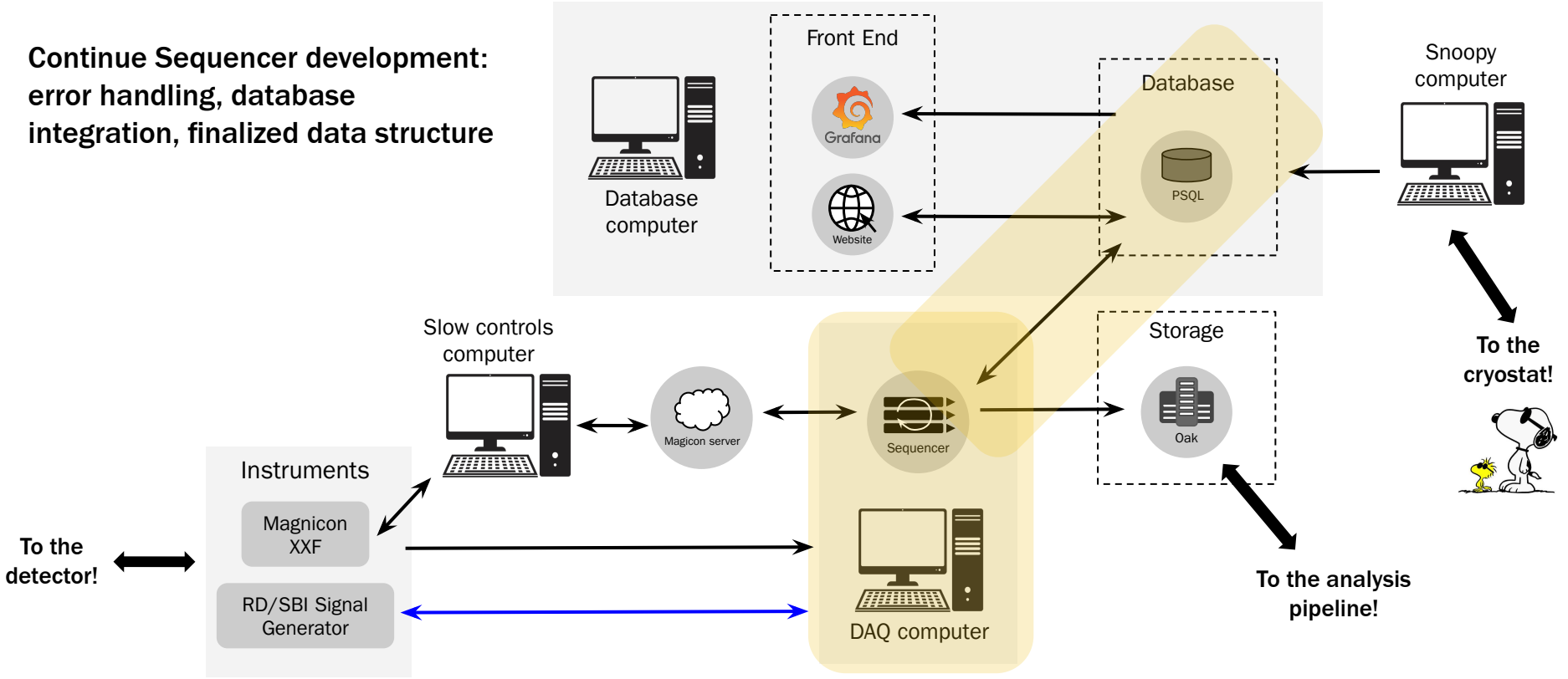
- Sideband analysis code tested on simulation from run-dmr (Kenny Vetter, Shreya)
- Feasibility of room-temperature testing explored in LTSpice simulation (Shreya)
- Acquired broadband room-temperature noise source to inject noise into system, testing underway (Pam, Shreya)

DAQ architecture

Grey boxes: where its located

Arrows: direction of communication

Continue Sequencer development: error handling, database integration, finalized data structure

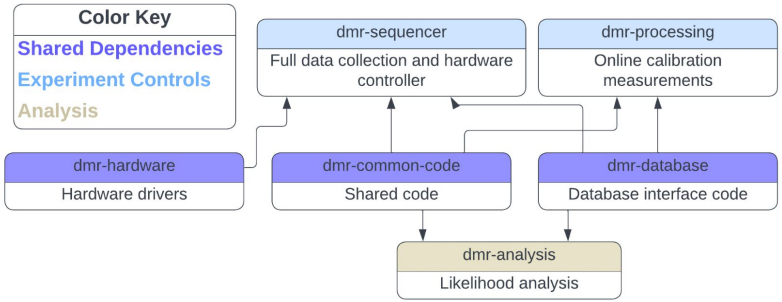


Data acquisition software (“dmr-software”) structure

```
dmr-software/
├─ dmr-sequencer/
├─ dmr-hardware/
├─ dmr-analysis/
├─ dmr-common-code/
├─ dmr-database/
│  ├─ requirements.txt
│  ├─ README.md
├─ dmr-website/
├─ README.md
├─ setup.sh
├─ venv/
├─ requirements-all.txt
```

Root directory where all DMRadio packages are installed

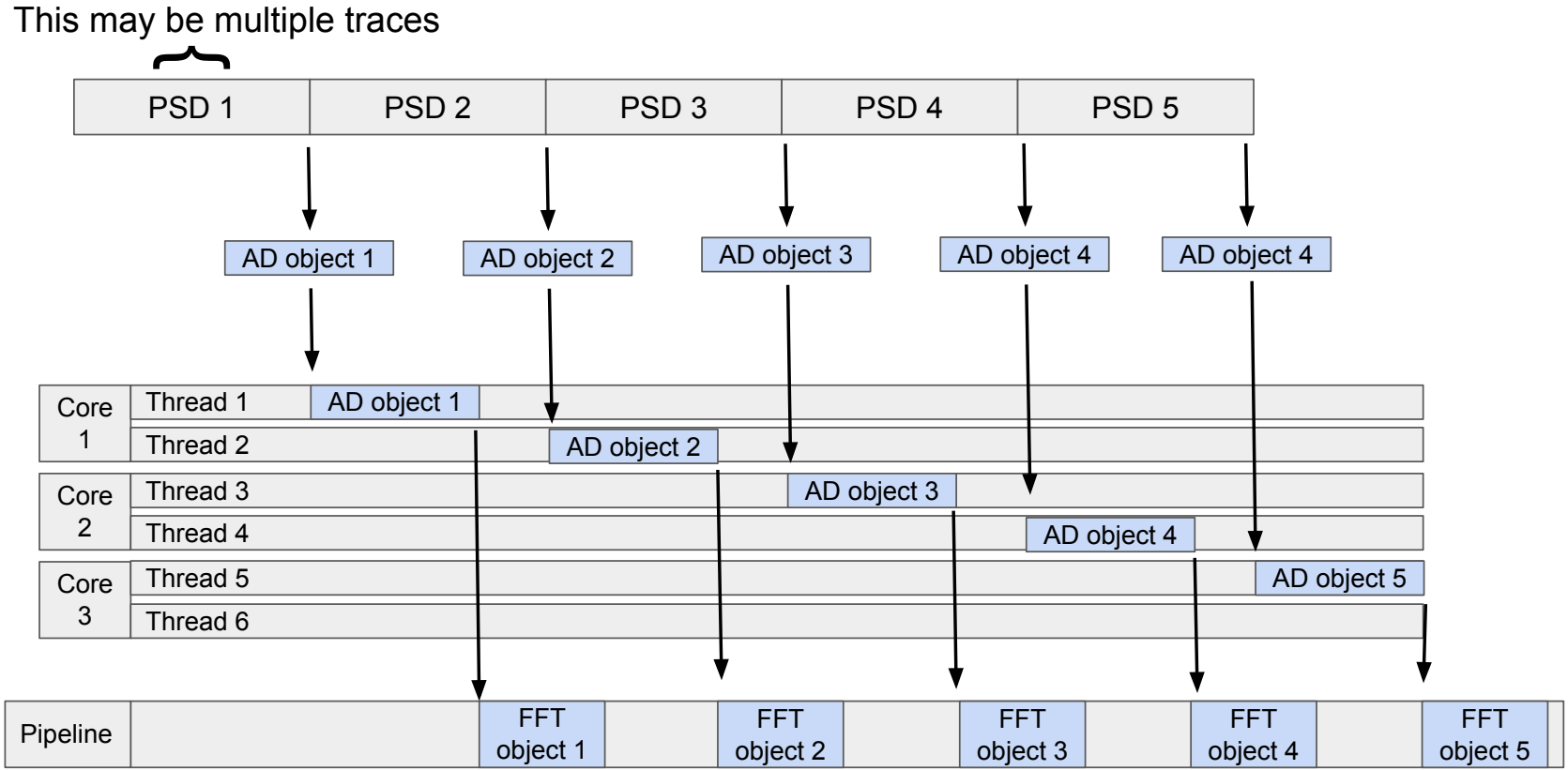
Cloned repos as necessary



Virtual environment, instructions and setup files

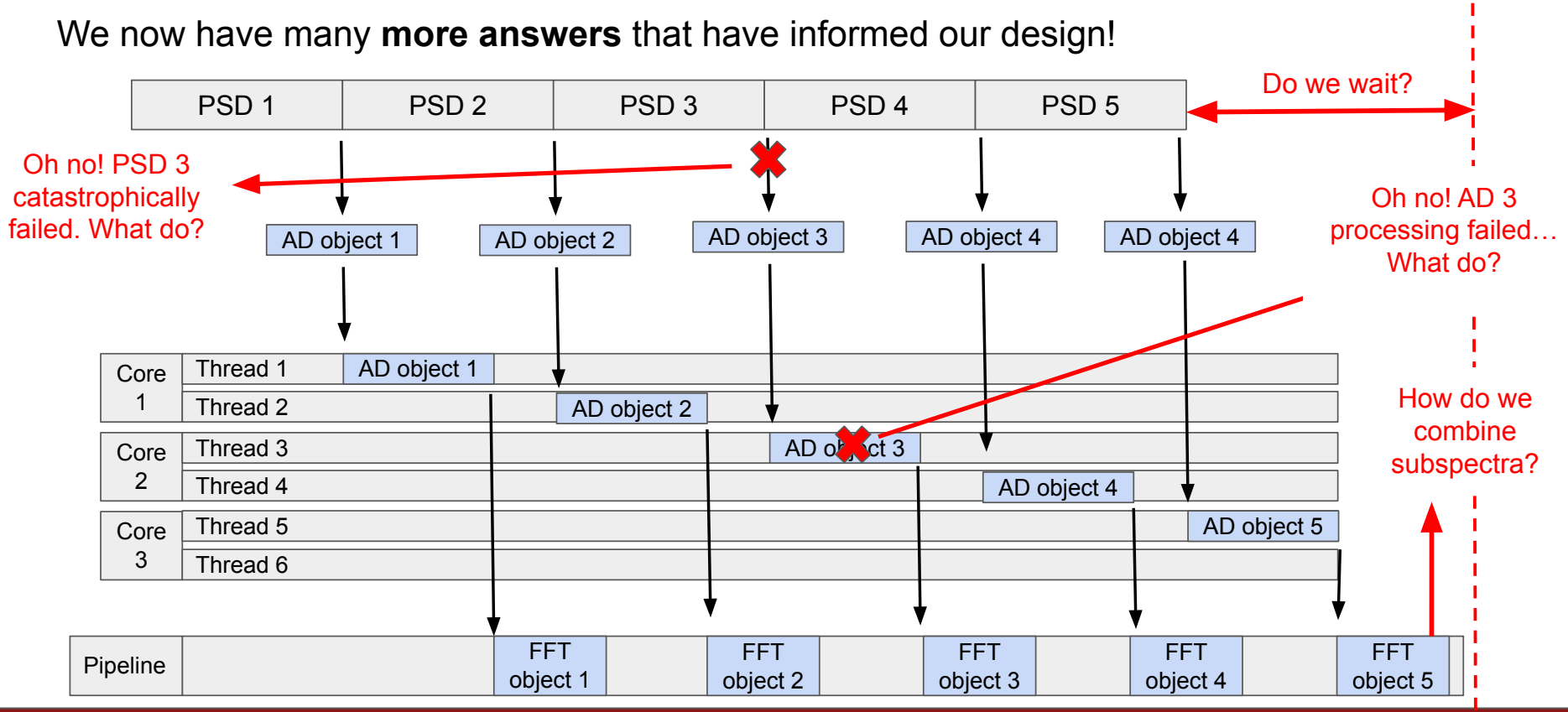
Comprehensive list of dependencies

Multi-threaded operation minimizes downtime and increases scan speed



Multi-threaded operation minimizes downtime and increases scan speed

We now have many **more answers** that have informed our design!



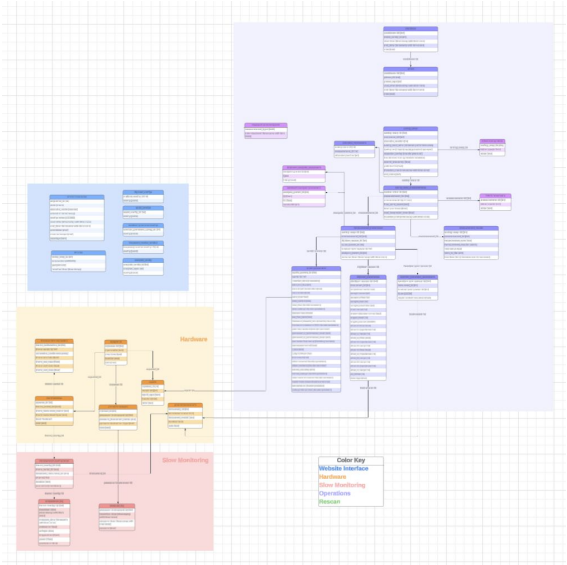
Seamless database/sequencer integration needed to record metadata

Completed:

- Finalized database design and data flow
- First integration merge into Sequencer
- Production schema deployment plan
- Initial measurements testing with database

In progress:

- Robust error handling and session management
- Fully database-integrated hardware tests

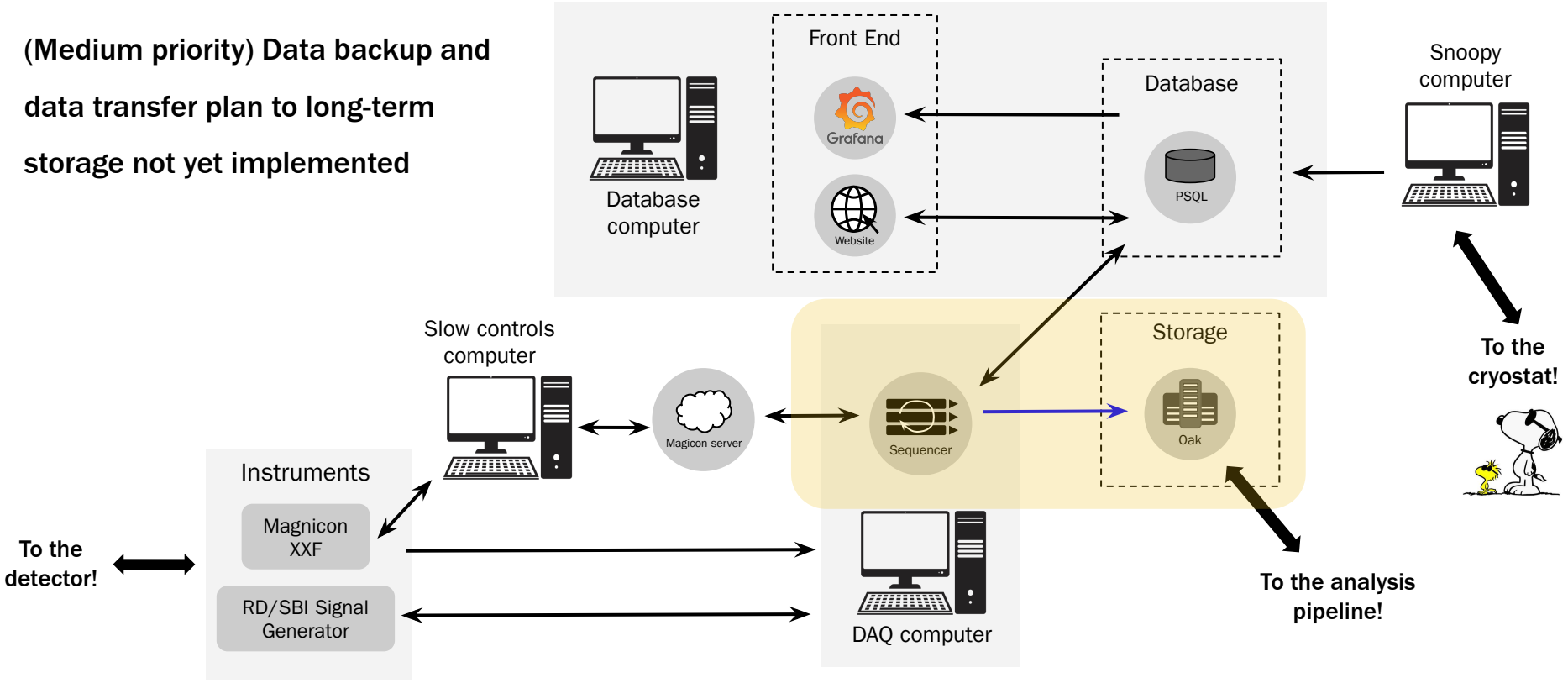


DAQ architecture

Grey boxes: where its located

Arrows: direction of communication

(Medium priority) Data backup and data transfer plan to long-term storage not yet implemented

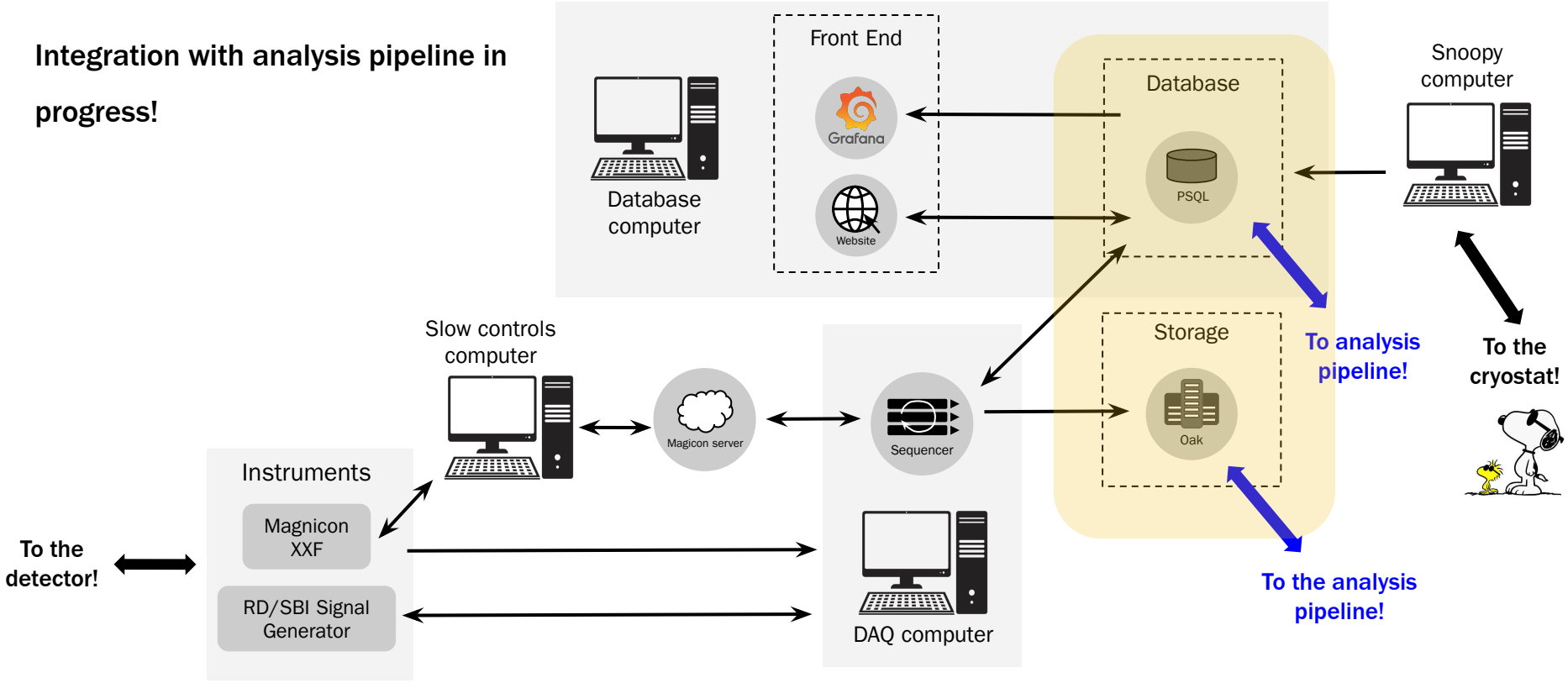


DAQ architecture

Grey boxes: where its located

Arrows: direction of communication

Integration with analysis pipeline in progress!



DAQ architecture

Grey boxes: where its located

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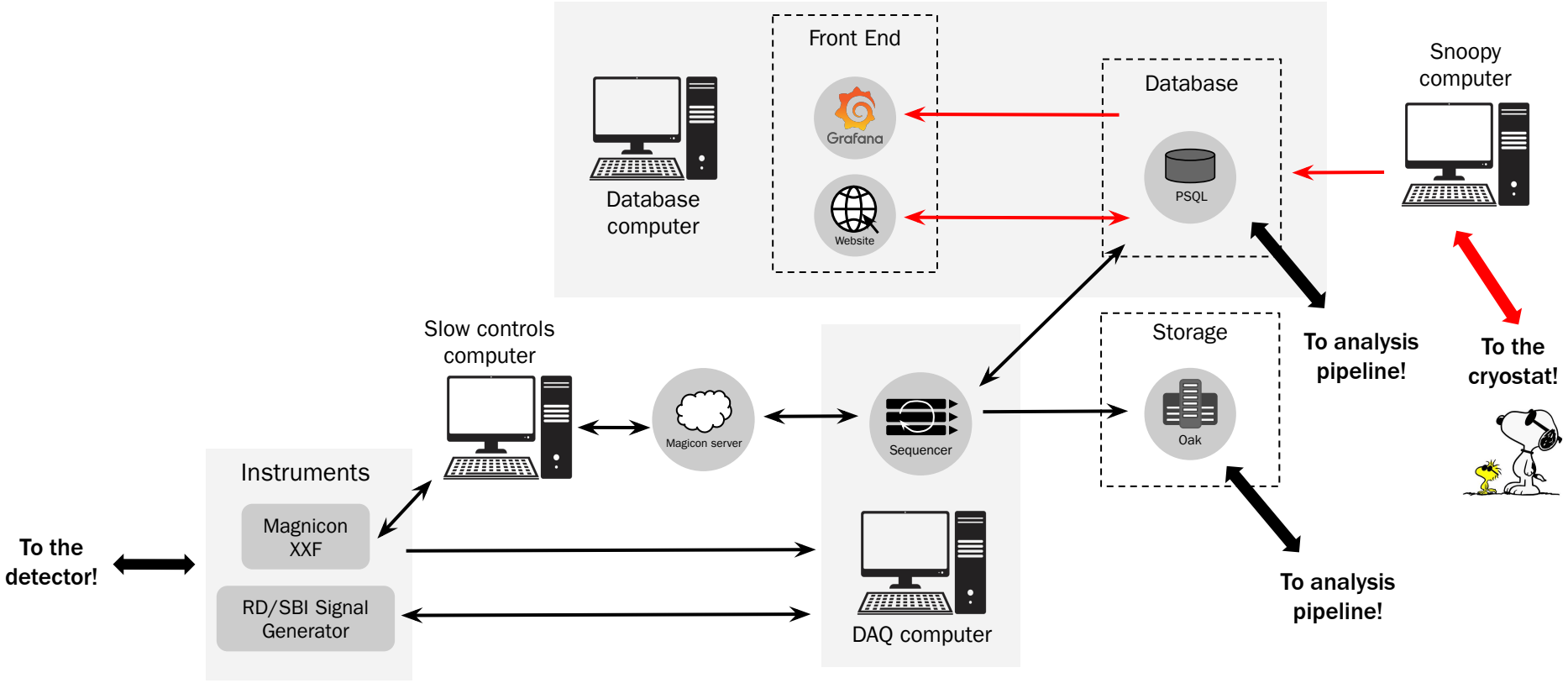


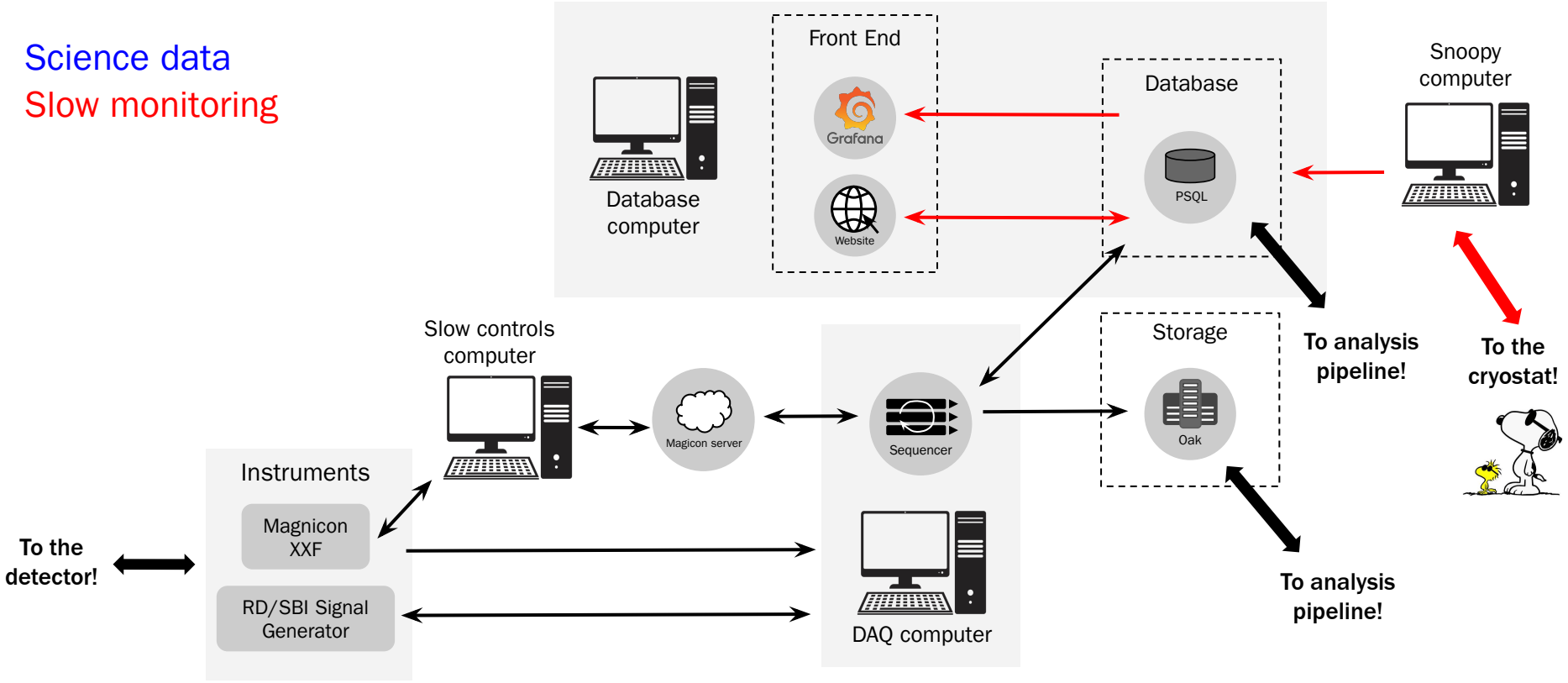
DAQ architecture

Grey boxes: where its located

Arrows: direction of communication

Science data

Slow monitoring

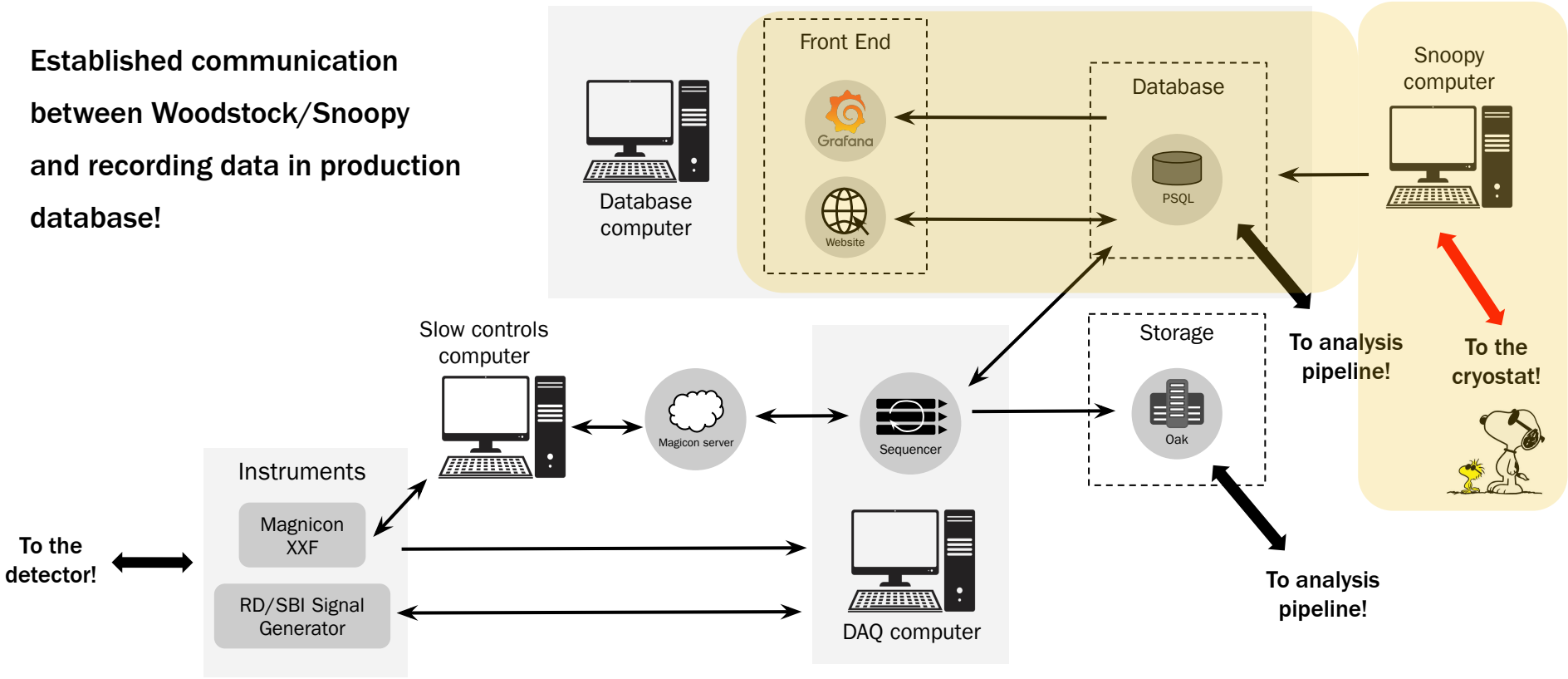


DAQ architecture

Grey boxes: where its located

Arrows: direction of communication

Established communication between Woodstock/Snoopy and recording data in production database!



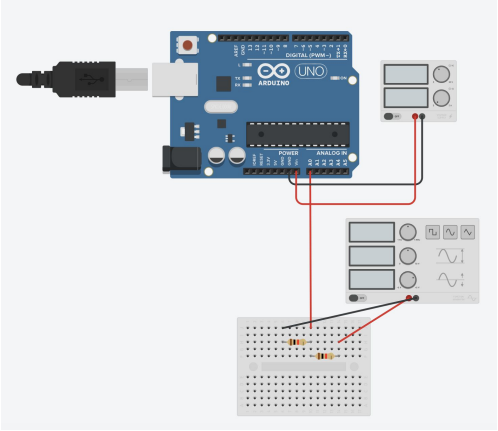
Woodstock compressor and pressure readout

Coming soon: Alert system!

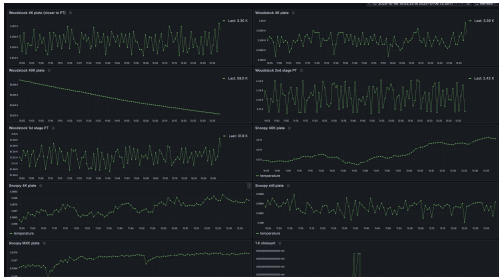
Local DAQ team has been working closely with cryostat team to deploy slow monitoring systems for Woodstock

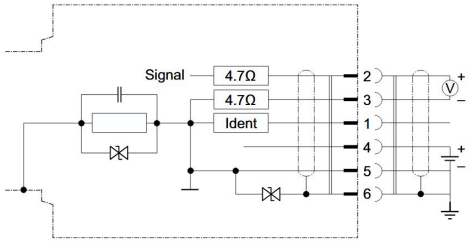
Slow monitoring data is monitored using **Grafana dashboards**

- Temperature, pressure, and heater logging
- Compressor monitoring



TinkerCAD rendering of Arduino readout



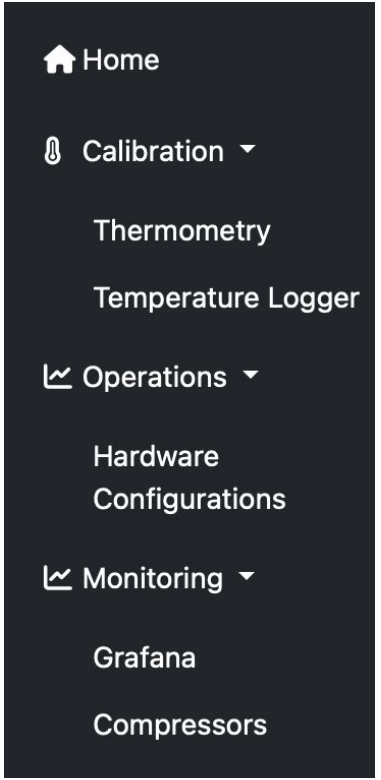


DMRadio-50L Internal Website: http://171.64.108.119/home/

The website is the centralized resource hub for all remote controls and operation within 50L – accessible with VPN!

Existing functionality:

- User registration and role-based access
- Registering thermometers and pressure gauges, recording thermometer calibrations, saving thermometry configurations for cooldowns



DMRadio-50L Internal Website: http://171.64.108.119/home/

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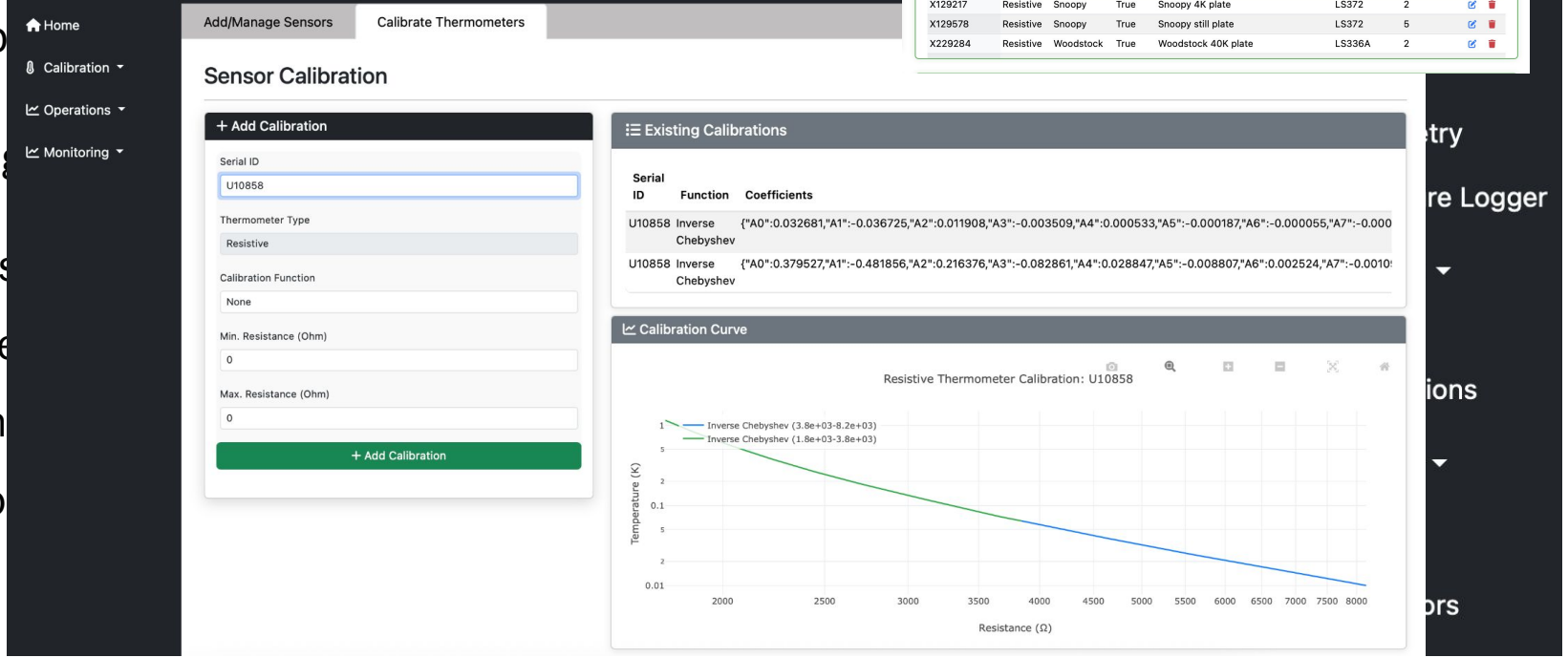
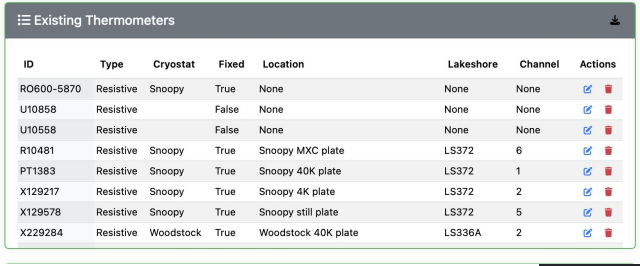
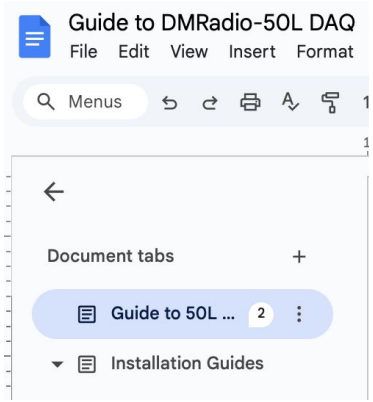




DAQ resources are meant to support *all* collaborators

Considerable DAQ effort put towards developing tutorials and resources, refactoring software and creating accessible entry points, and writing documentation!

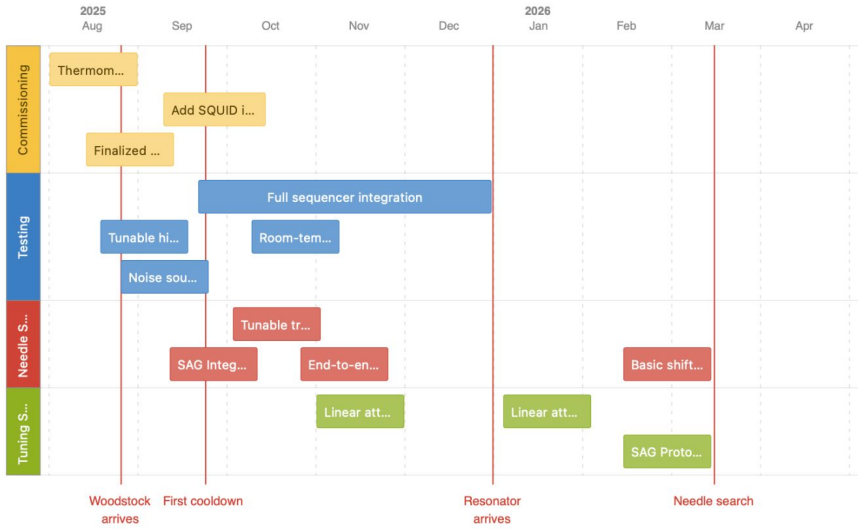


	Casual Users	Intermediate Users	Advanced Users
Expected Usage	- Remote monitoring - Shifter duties - Log access	- Remote operation - Scripts for automating testing	- Software development - Data management - Full analysis pipeline
Available Resources	- Grafana - Website	- Quick Start tutorials - Python interfaces with hardware drivers and database (*in progress*)	- Full Github access to dmr-software - Development guides (*in progress*)

Everyone should have immediate access to critical experimental infrastructure *without* needing to interface with low-level software

Enormous progress has been made towards building a DAQ that will enable us to quickly transition to data-taking

There is more to do – but we have a lot of momentum and a good plan going forward!



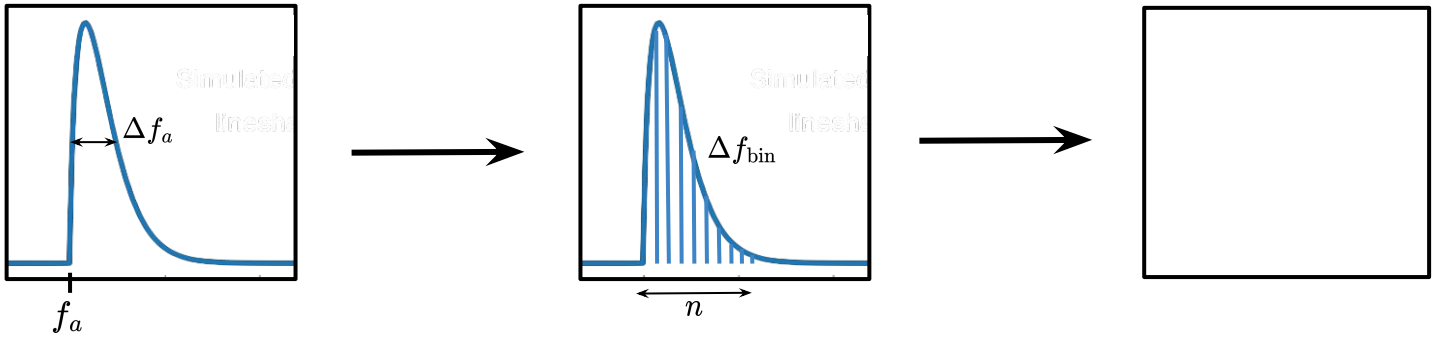
Special thanks to everyone on the DAQ team:

MIT: Lindley Winslow, Jessica Fry, Kenny Vetter, Sergio Cuadra

Stanford/SLAC: Kevin Wells, Alex Droster, Chelsea Bartram, Andrew Yi, Pam Stark, Barkotel Zemenu, Noah Haile

LBNL/UBerkeley: Chiara Salemi, Shreya Puranam

DAQ vs Run Plan



DAQ Plan

- What digitizer parameters should we use across the 50L frequency range?
- When and how often should calibrations should be performed?

Run Plan

- How long do we spend in each region of frequency space?
- How does this translate into limits on $g_{a\gamma\gamma}$?