Development of **DAQ Software** for **CULTASK** experiment

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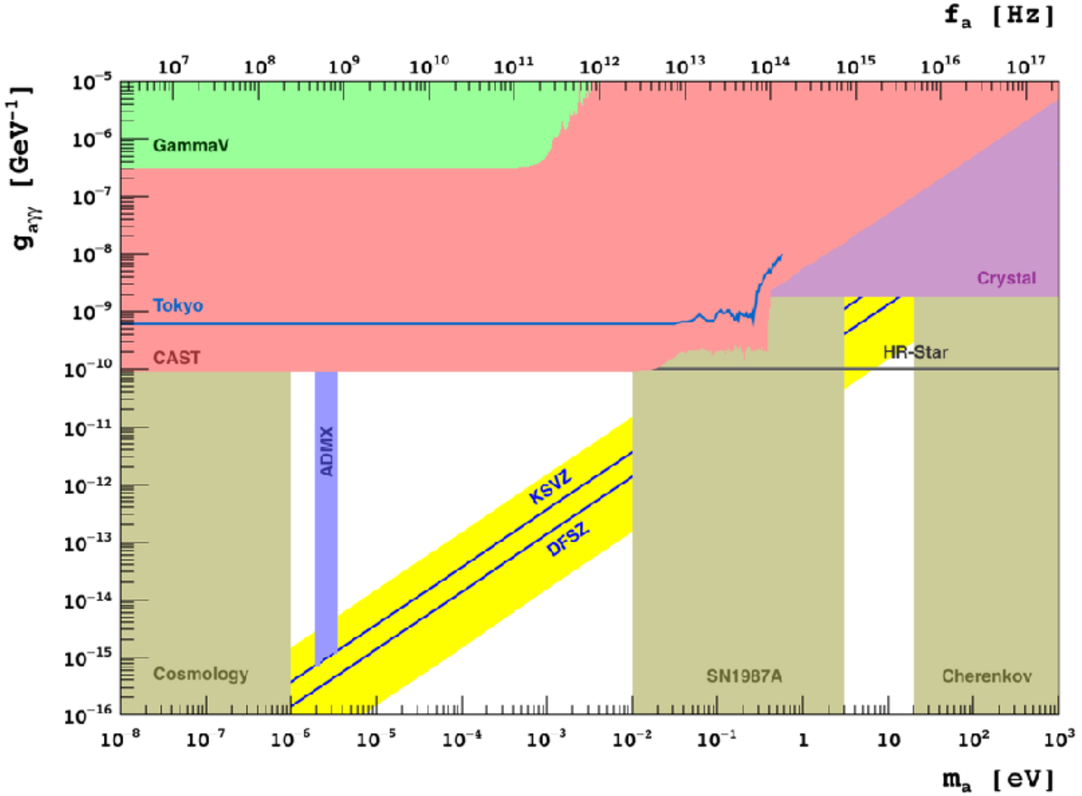
Introduction

- Axion dark matter is a candidate of dark matter to solve the strong *CP* problem
  - Pseudo Goldstone Boson
  - No electric charge
  - Very weakly interacting
  - Small mass (expected to be O(μeV))



- Axion theoretically decays into a photo and a virtual photon under B field
  - Resonant cavity can detect the signal[1]
  - Conversion power (a→γγ)

$$P_a = (9.4 \times 10^{-23}\ \mathrm{W}) \left(\frac{g_\gamma}{0.97}\right)^2 \left(\frac{\rho_a}{0.45\ \mathrm{GeV/cc}}\right) \left(\frac{f_a}{6\ \mathrm{GHz}}\right) \left(\frac{B}{8\ \mathrm{T}}\right)^2 \left(\frac{V}{0.18\ \mathrm{L}}\right) \left(\frac{C_{010}}{0.6}\right) \left(\frac{Q_L}{10^6}\right)$$

  - Scan rate

$$\frac{df_d}{dt} = \frac{14\ \mathrm{MHz}}{\mathrm{year}} \left(\frac{g_\gamma}{0.97}\right)^4 \left(\frac{\rho_a}{0.45\ \mathrm{GeV/cc}}\right)^2 \left(\frac{f}{6\ \mathrm{GHz}}\right)^2 \left(\frac{B}{8\ \mathrm{T}}\right)^4 \left(\frac{V}{0.18\ \mathrm{L}}\right)^2 \left(\frac{C_{010}}{0.6}\right)^2 \frac{Q_L}{Q_a} \left(\frac{4}{\mathrm{SNR}}\right)^2 \left(\frac{4.5\ \mathrm{K}}{T_{\mathrm{sys}}}\right)^2$$

[1] P. Sikivie, Phys. Rev. Lett. 51, 1415 (1983)

CULTASK Experiment

- CULTASK (**C**APP **U**ltra-**L**ow **T**emperature **A**xion **S**earch in **K**orea) is a new axion search experiment
  - To maximize the scan rate:

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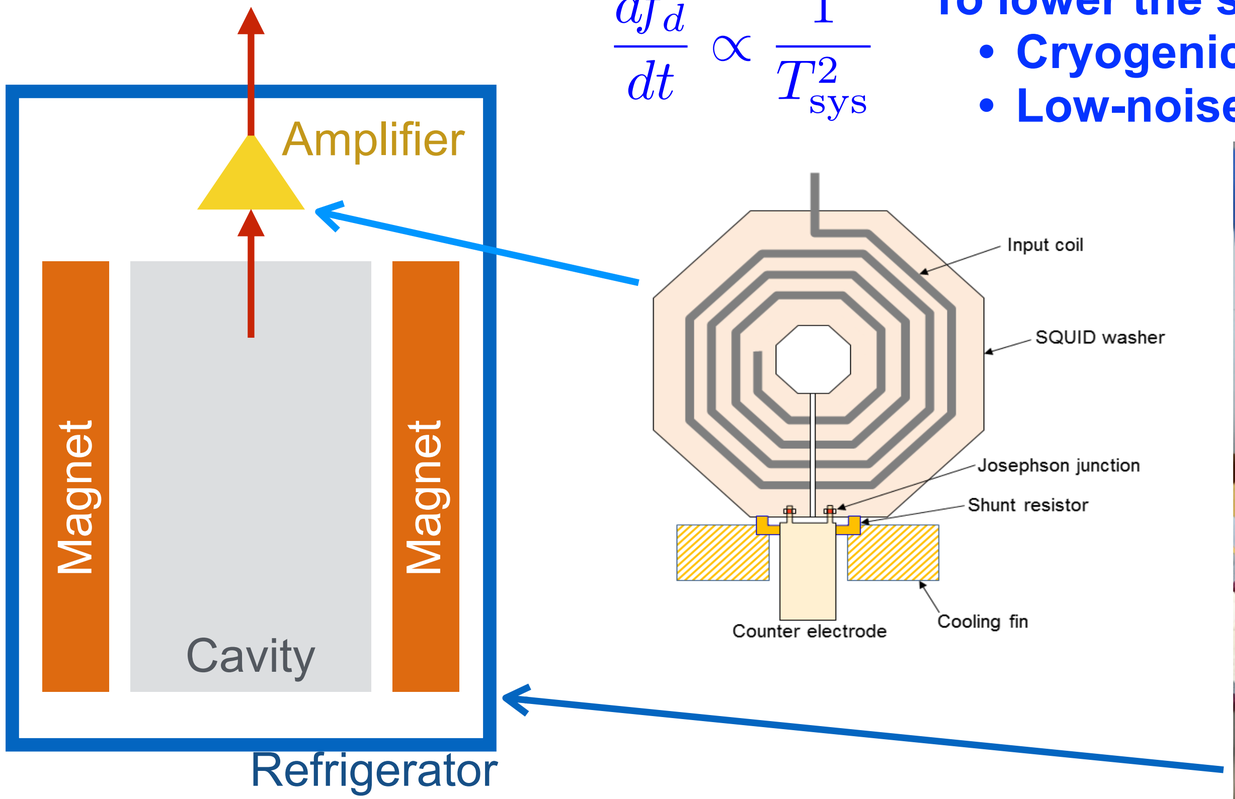
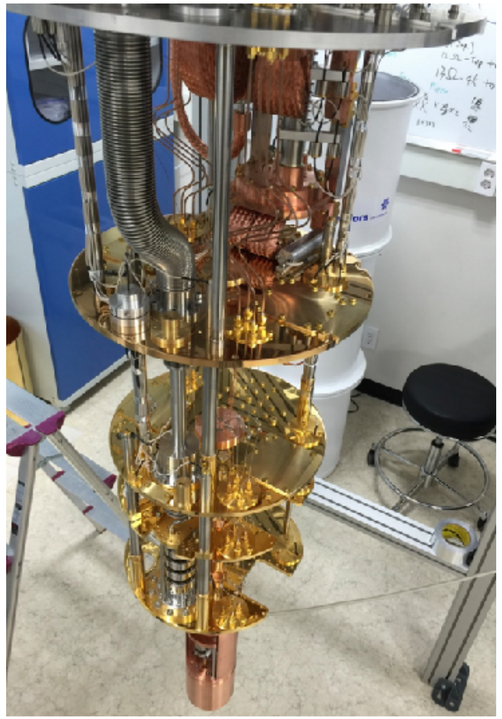
$$\frac{df_d}{dt} \propto \frac{1}{T_{\mathrm{sys}}^2}$$

To lower the system temperature ($T_{sys} = T_{cavity} + T_{amplifier}$):

- **Cryogenics: Dilution refrigerator (< 100 mK)**
- **Low-noise amplifier: SQUID (< 1 K)**





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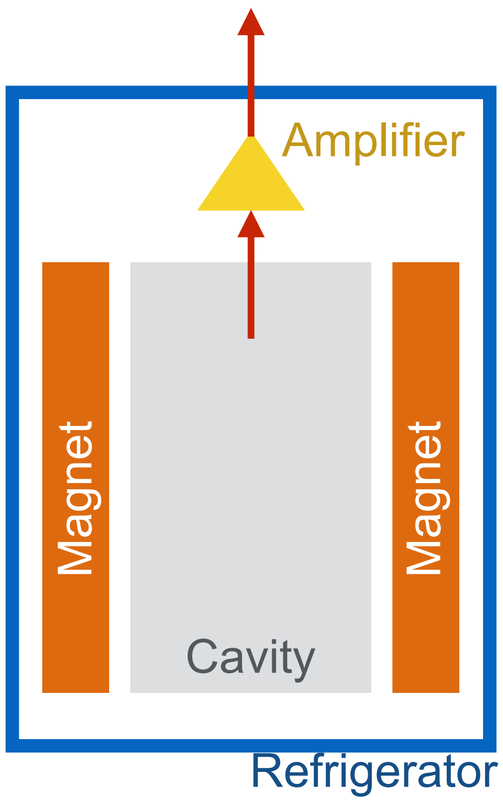

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- **Superconducting cavity**

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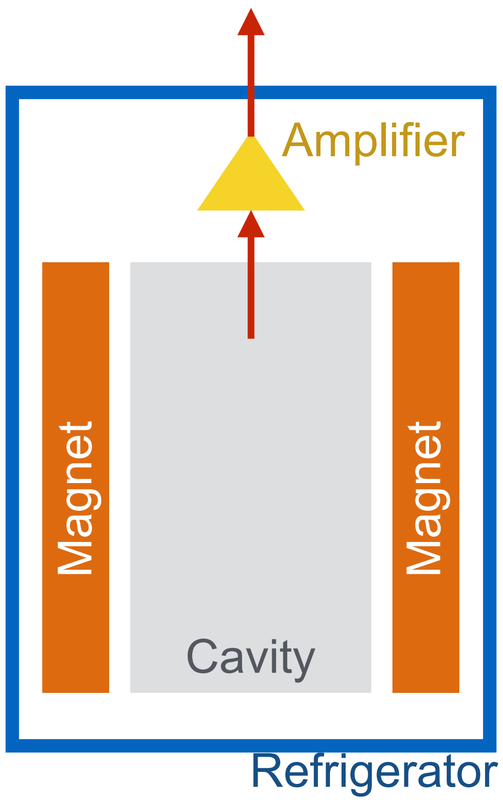

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To maximize the magnetic field:
- **High field superconducting magnet (>25 T) with a large bore size**

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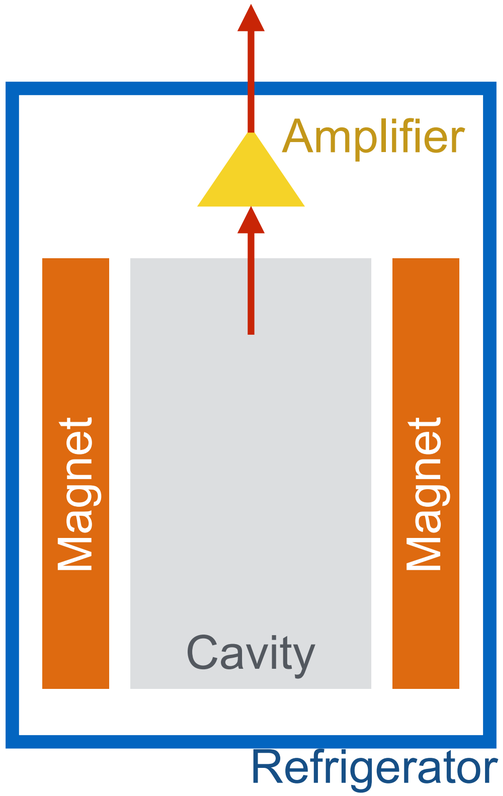

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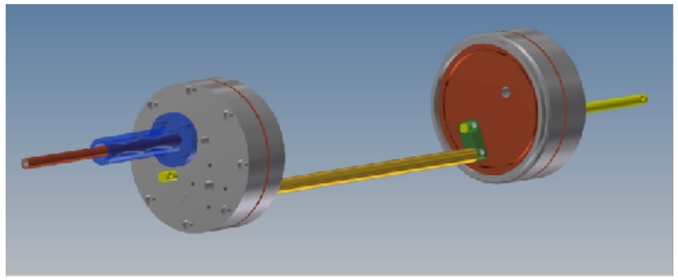
Resonant frequency of the cavity is tuned with a rotating tuning rod

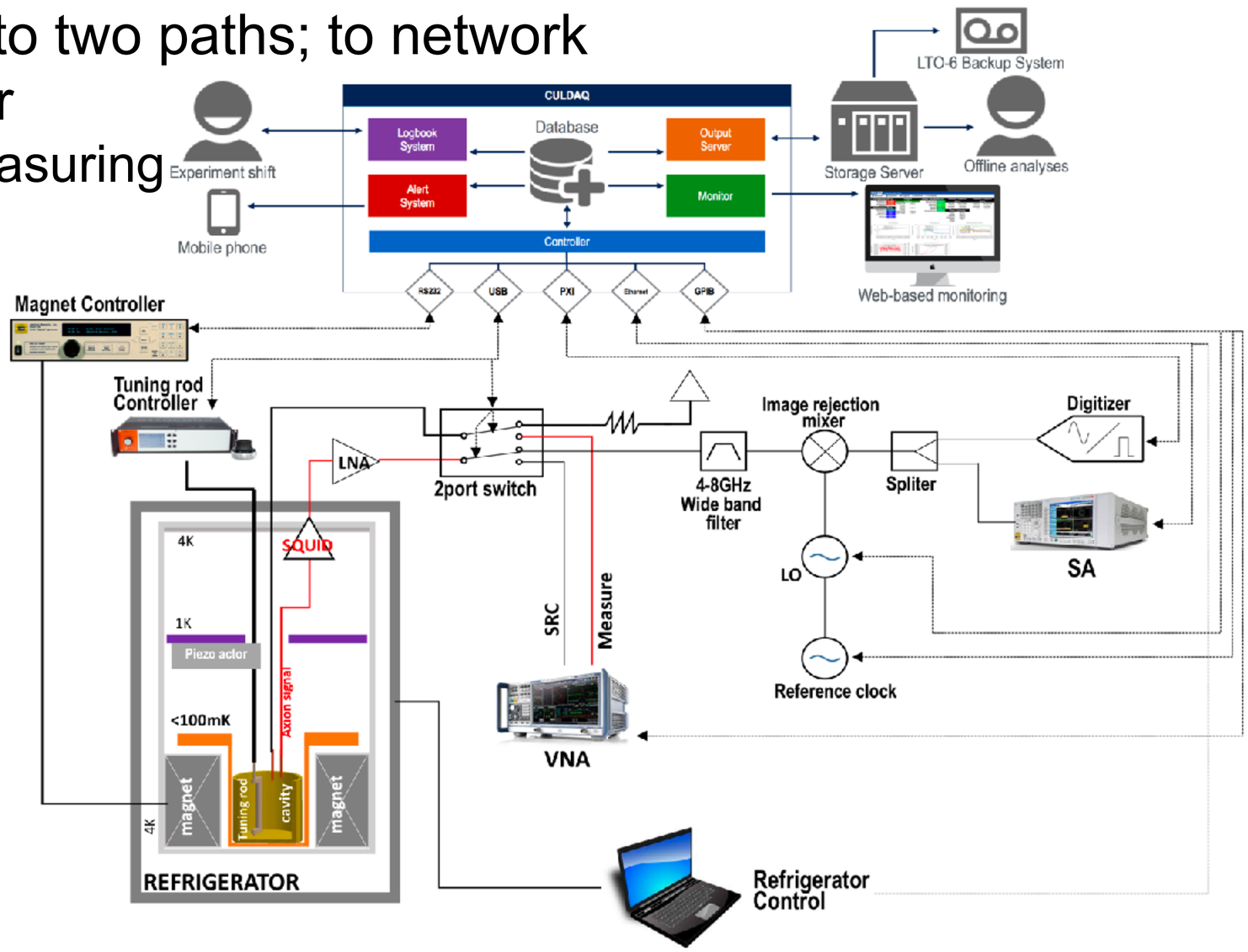


CULTASK Experiment

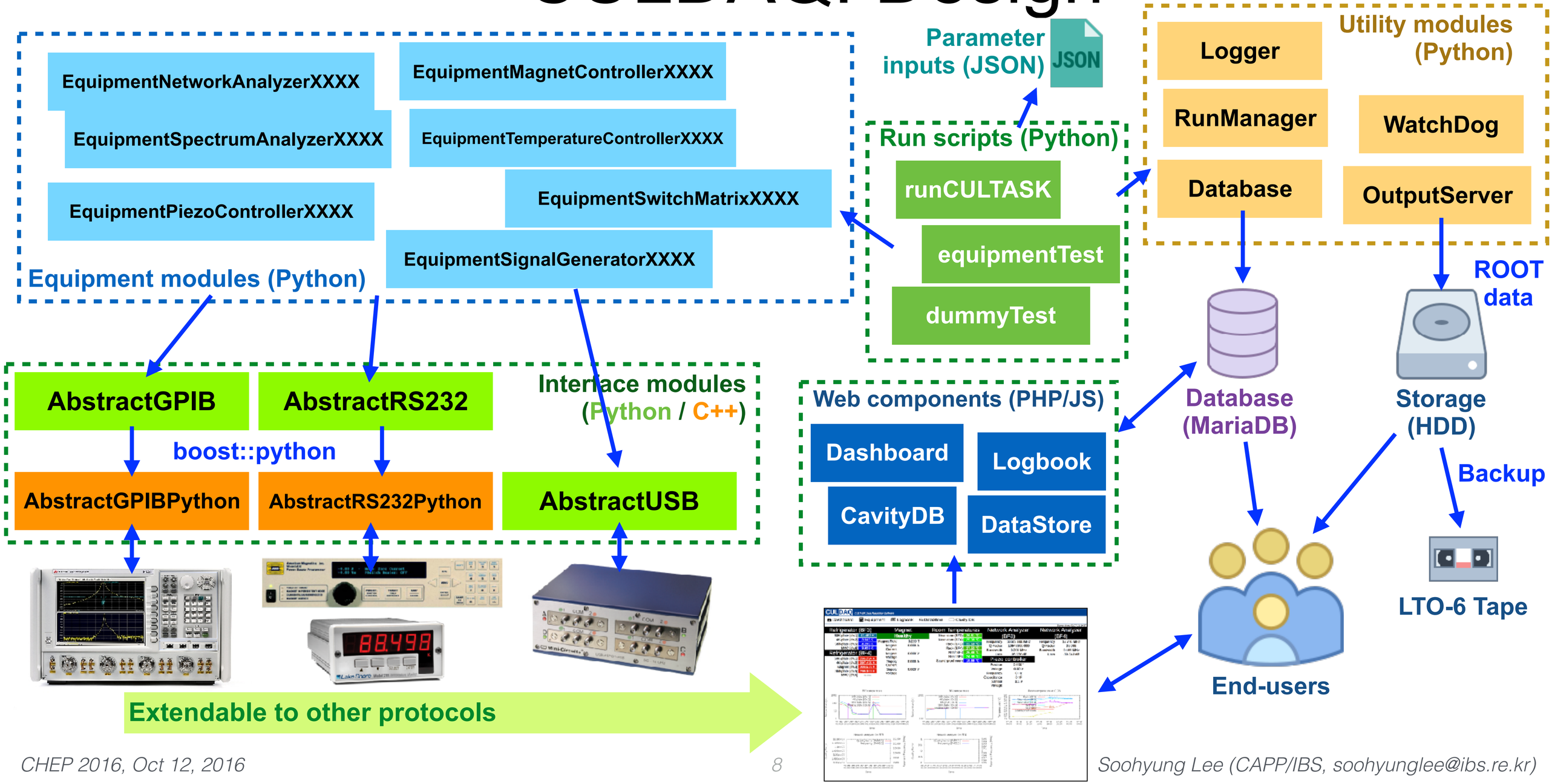
- Microwave cavity is connected to two paths; to network analyzer and spectrum analyzer
  - Network analyzer is used for measuring the cavity performance
  - Spectrum analyzer takes the real data
  - Two paths are switched with mechanical RF switch
  - Tuning rod is rotated by Piezo actuator

- Dilution refrigerator cools down the cavity to ~O(10) mK

- 8T magnet is installed



CULDAQ: Design



CULDAQ: Control Flow

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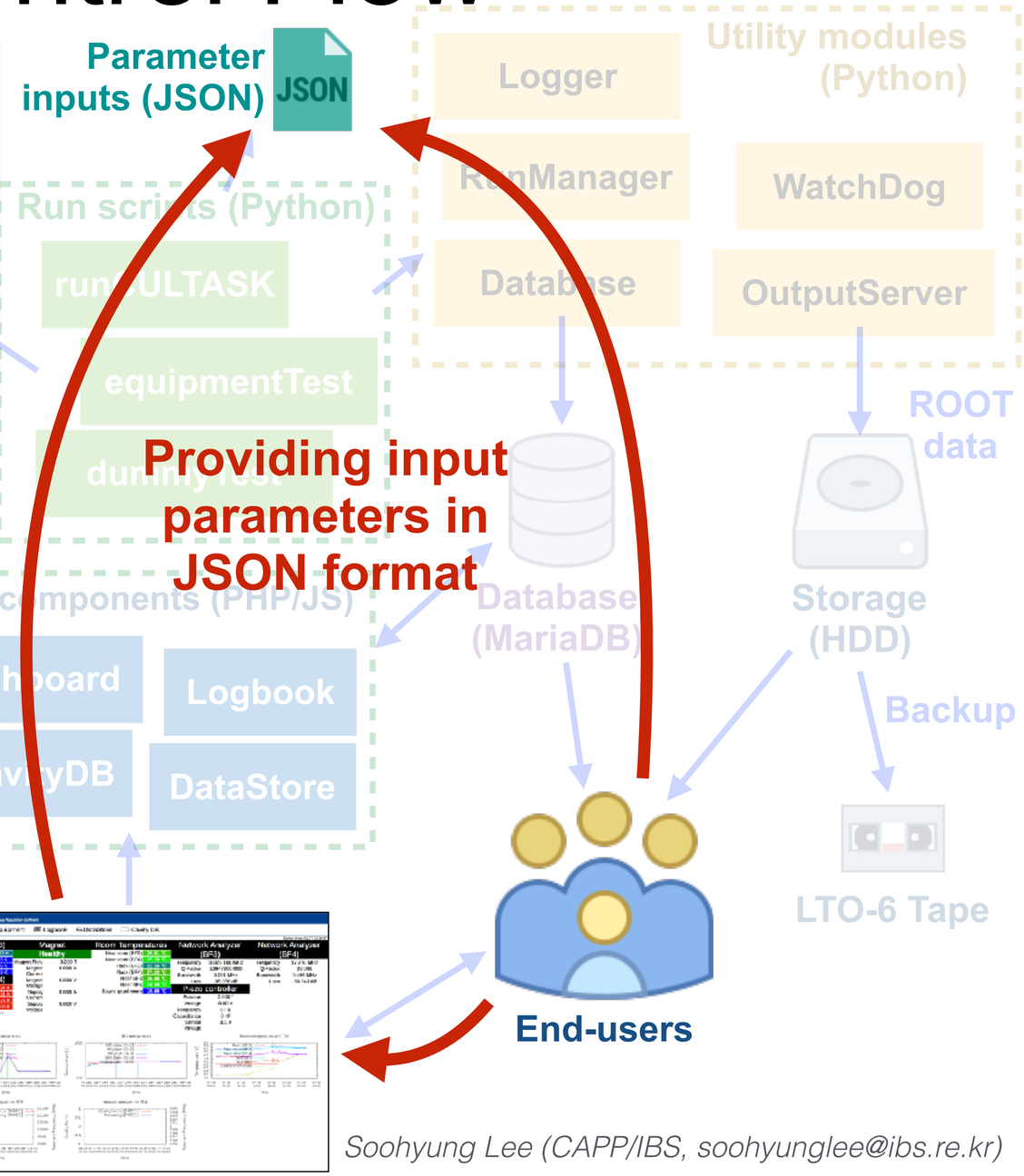

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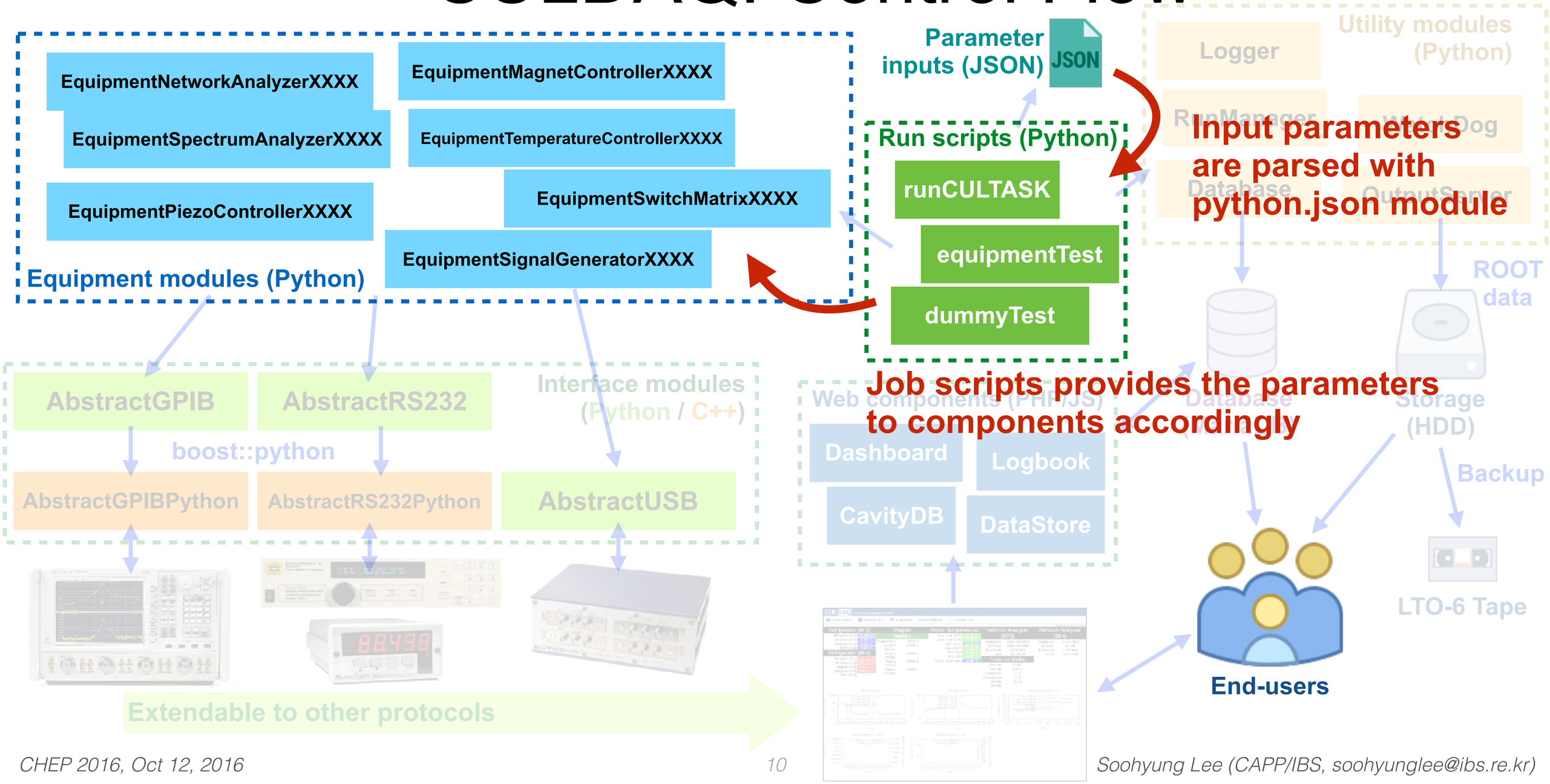

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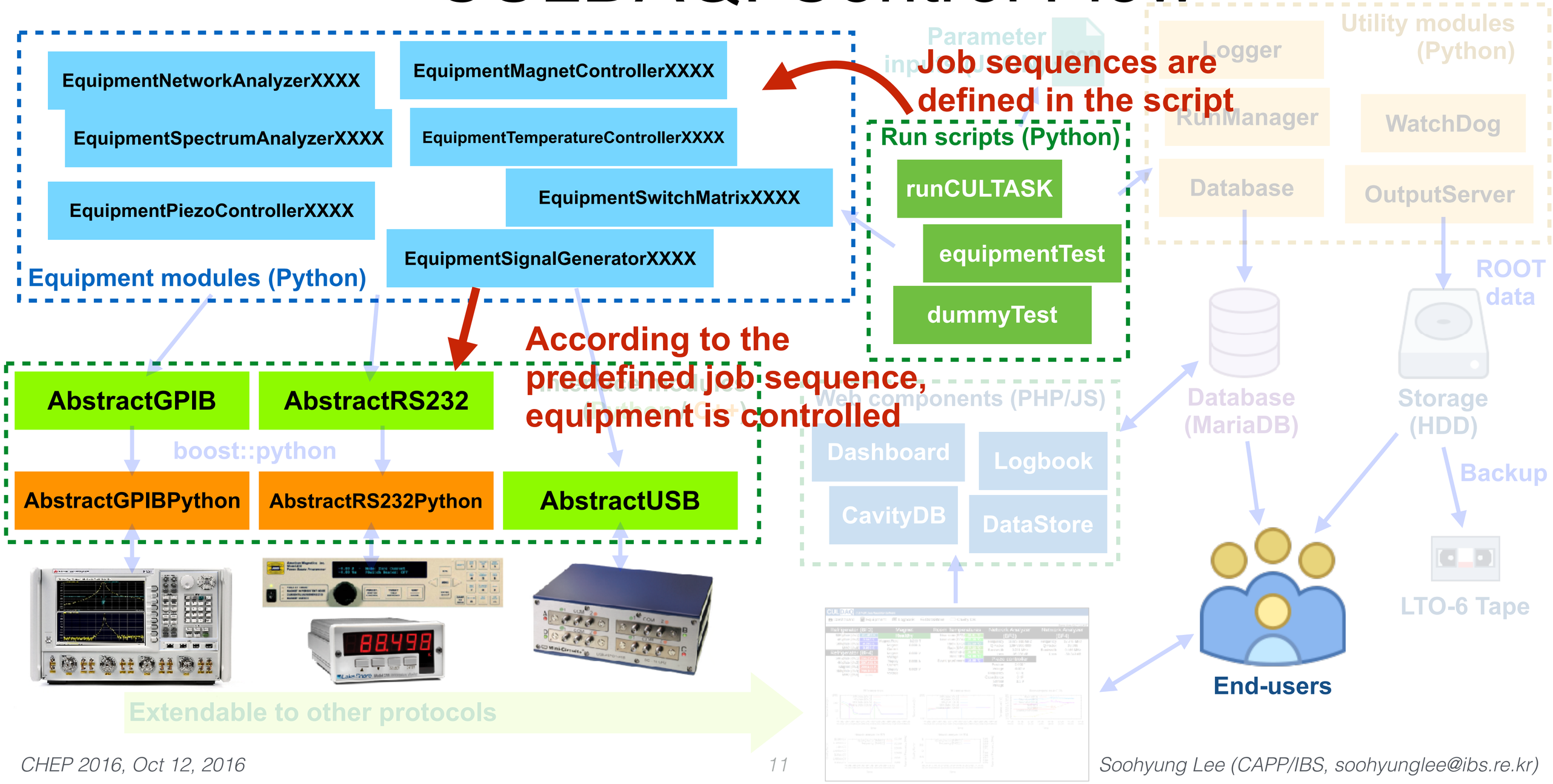
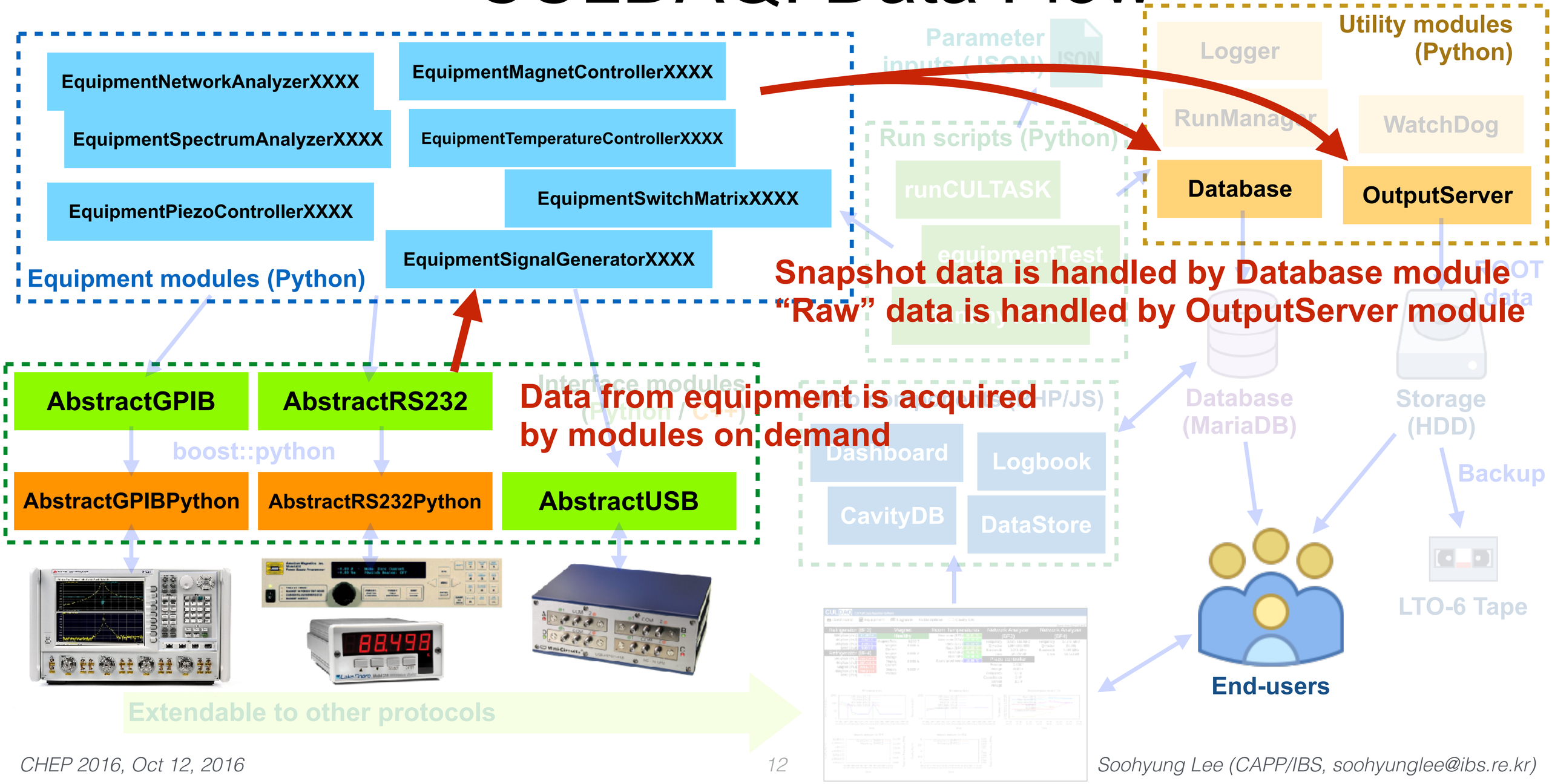


CULDAQ: Data Flow



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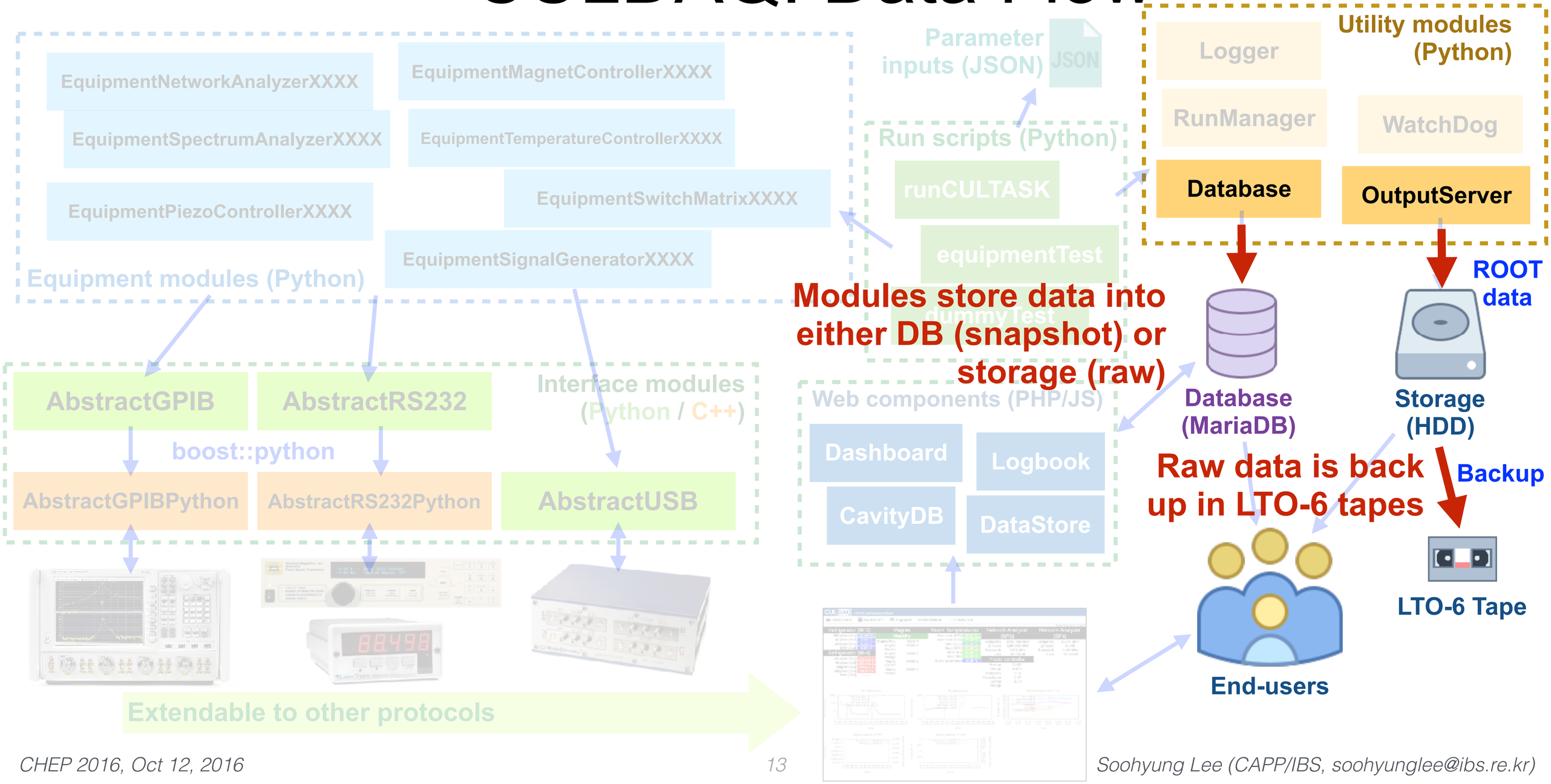

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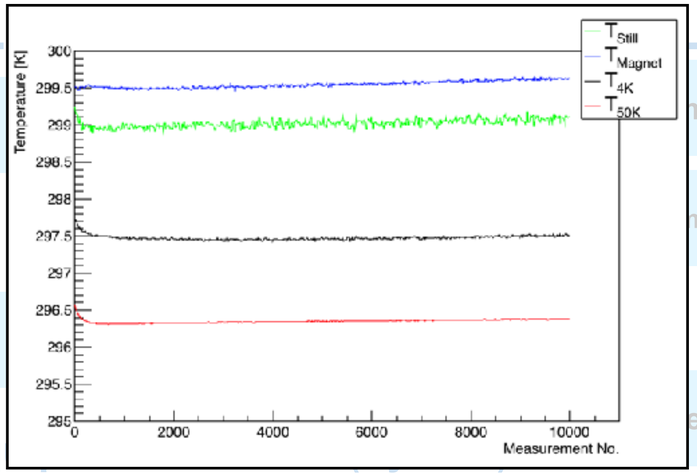
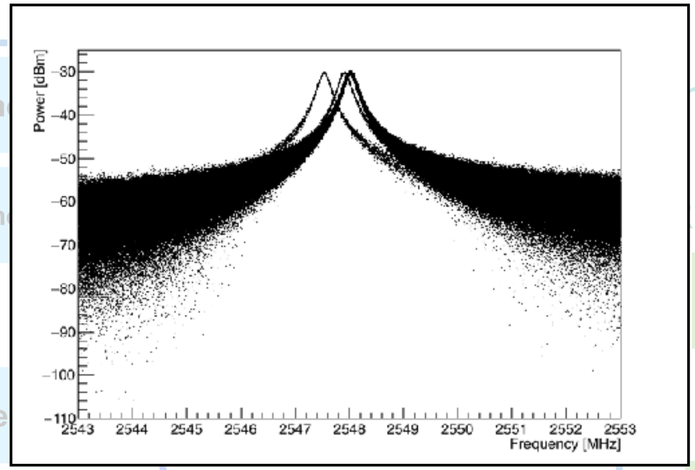
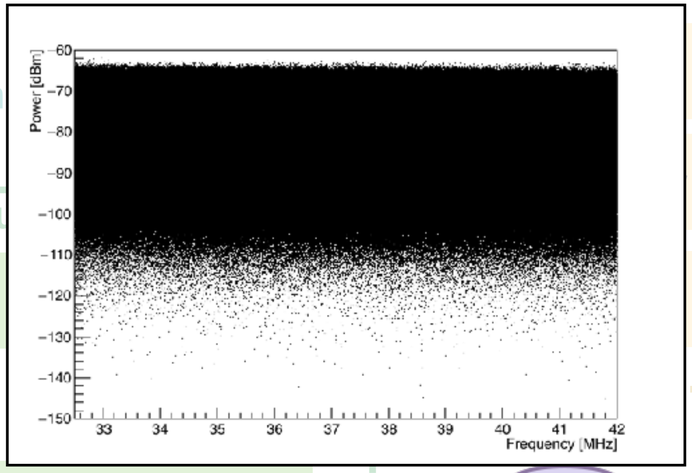






Utility modules (Python)

WatchDog

OutputServer

ROOT data

Snapshot data is used for online monitoring

Database (MariaDB)

Storage (HDD)

Backup

LTO-6 Tape

Web components (PHP/JS)

Dashboard

Logbook

CavityDB

DataStore

AbstractGPIB

AbstractRS232

Interface modules (Python / C++)

boost::python

AbstractGPIBPython

AbstractRS232Python

AbstractUSB

Web components display online monitoring

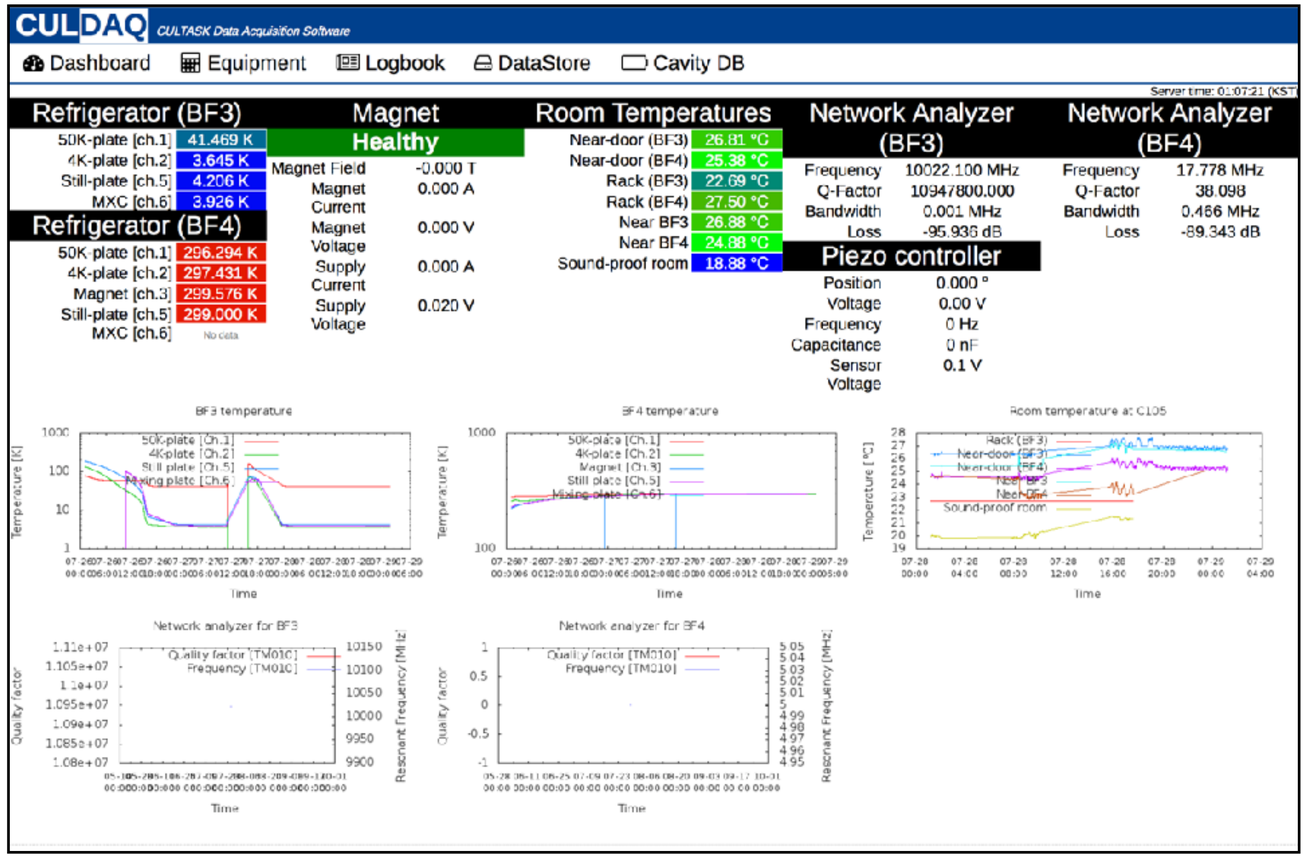
End-users

End-users analyze data with ROOT

Extendable to other protocols

CULDAQ: Monitoring

- Web modules are developed with:
  - PHP5 (CodeIgniter[1]), JavaScript (jquery[2], D3.js[3], NVD3.js[4]), HTML5, CSS3 (HTML KickStart[5], FontAwesome[6]), SQL (MariaDB[7])
  - Currently it monitors:
    - Room temperatures in the lab
    - Cryo-temperatures in refrigerators
    - Variables related magnet
    - snapshot data from network analyzers
    - Variables from piezo controller
  - Variables and plots are self-refreshing individually with jquery
  - More variables and plots on the way



[1] www.codeigniter.com [2] www.jquery.com [3] www.d3js.org [4] www.nvd3.org
[5] www.99lime.com [6] www.fontawesome.io [7] www.mariadb.com

CULDAQ: Extra Features

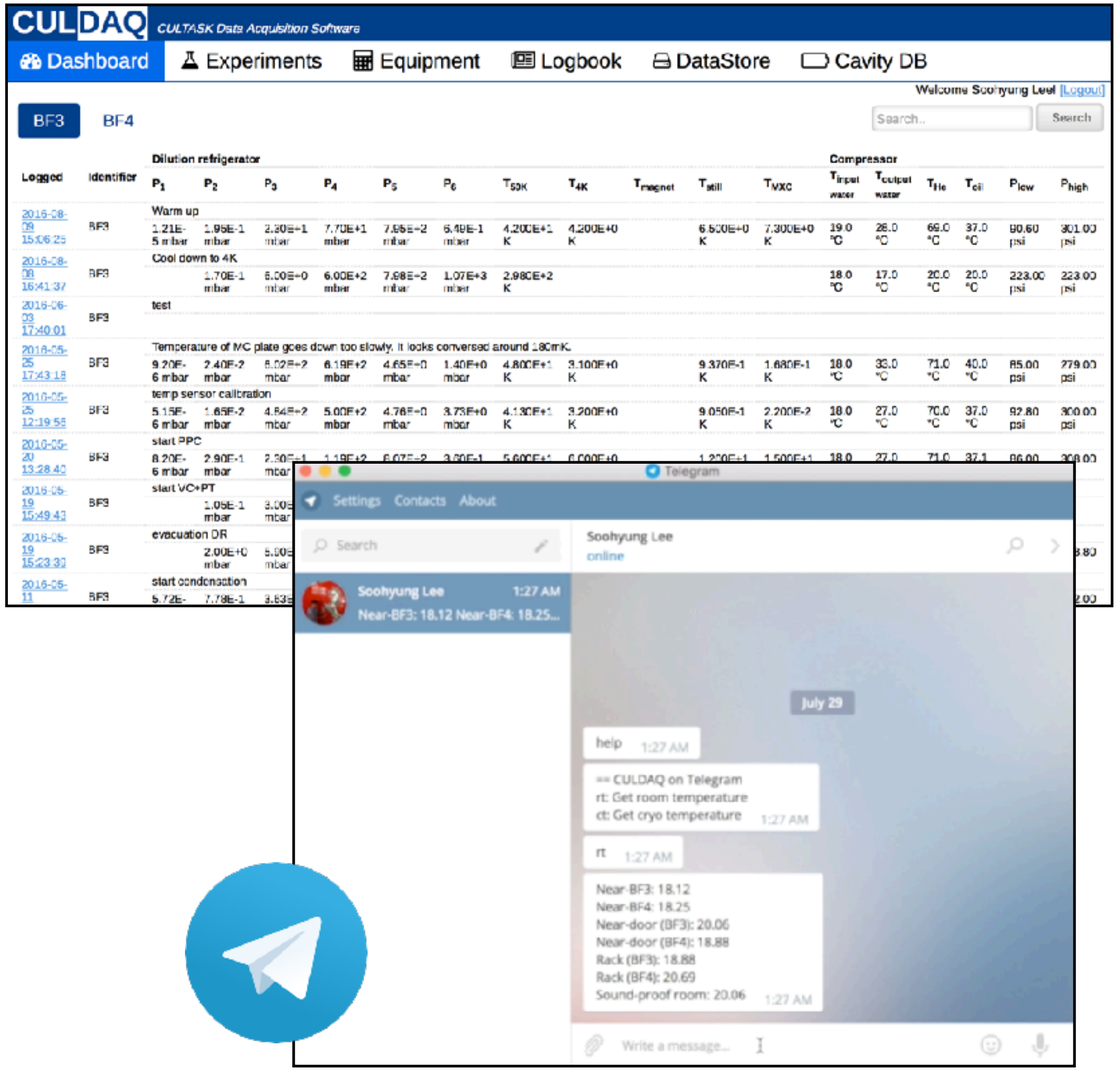
- More functions are supported on the same framework (mostly under development)

- Logbook
  - Automatic logging the parameters, e.g., refrigerator operation
  - Additional notes are made by shifters

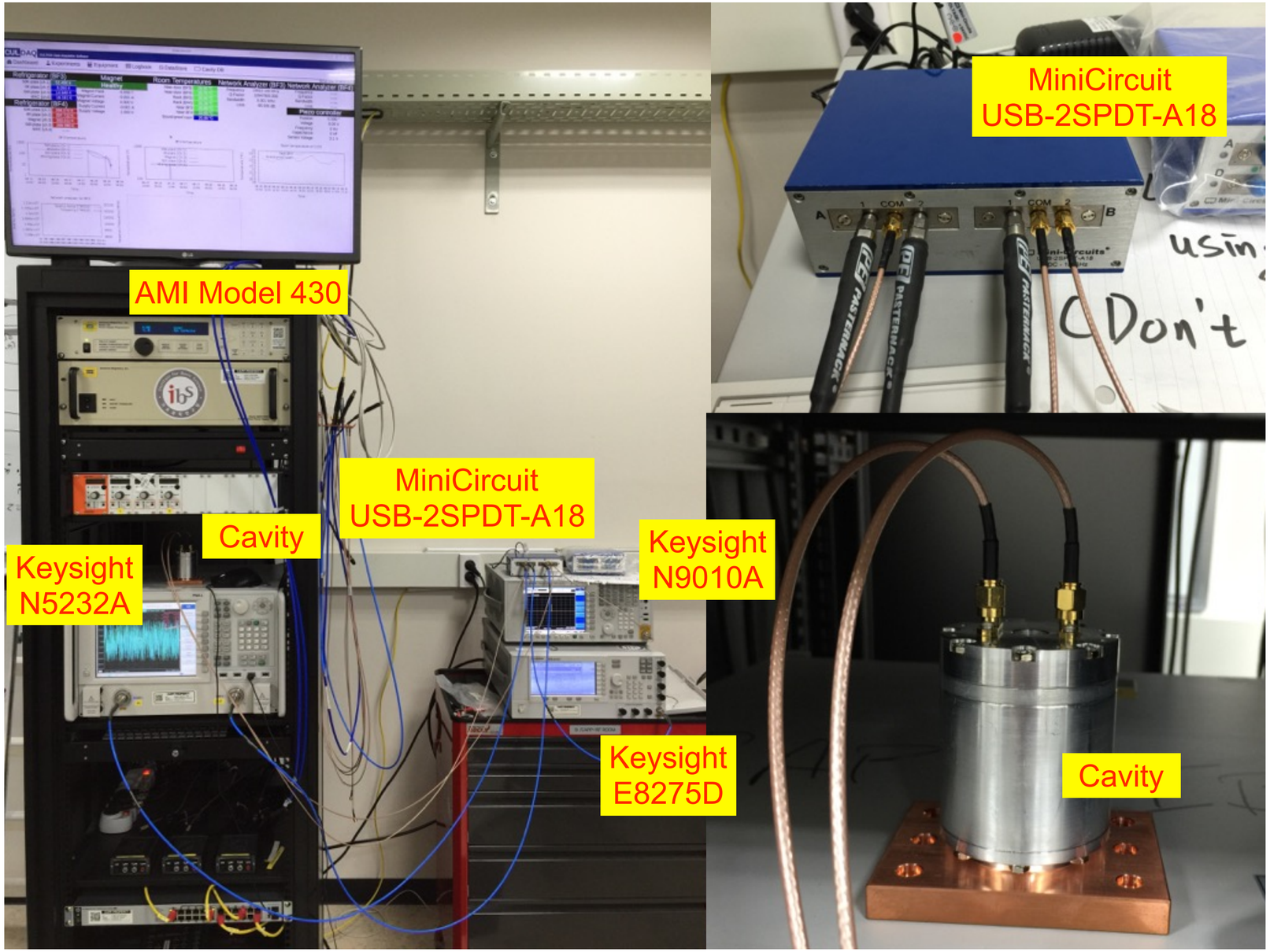
- DataStore
  - Provides an organized way to access data taken from the experiment

- Cavity database
  - Database of all the cavities fabricated

- Alert system (Telegram)
  - Alarm system for critical events, e.g., exceptional temperatures of refrigerator, magnet quench, etc



CULDAQ Testbed



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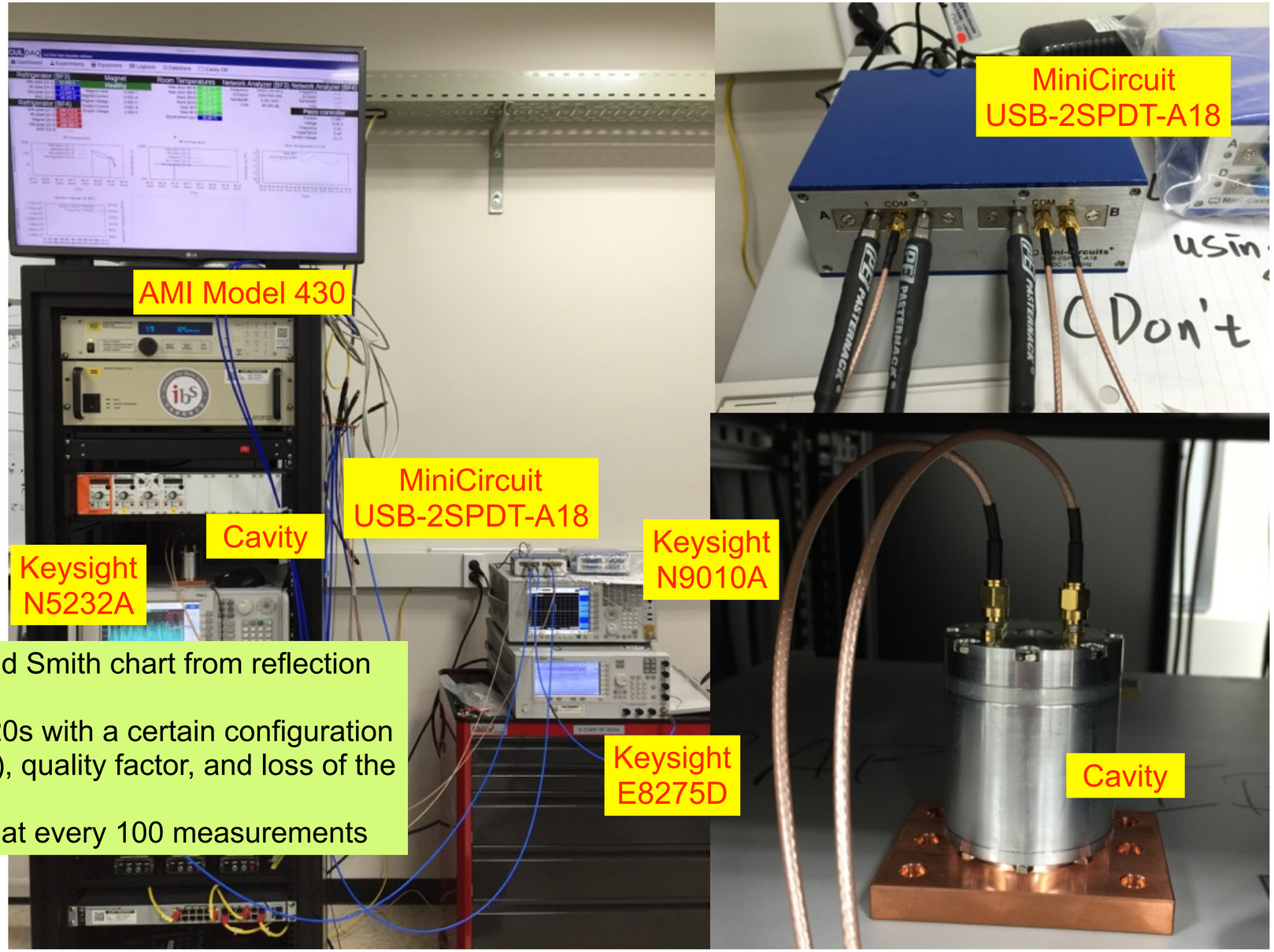

- Measures power spectra and Smith chart from reflection (S_{11}) and transmission (S_{21})
- One measurement takes ~20s with a certain configuration
- Resonant frequency (TM_{010}), quality factor, and loss of the test cavity are also taken
- Observables are measured at every 100 measurements

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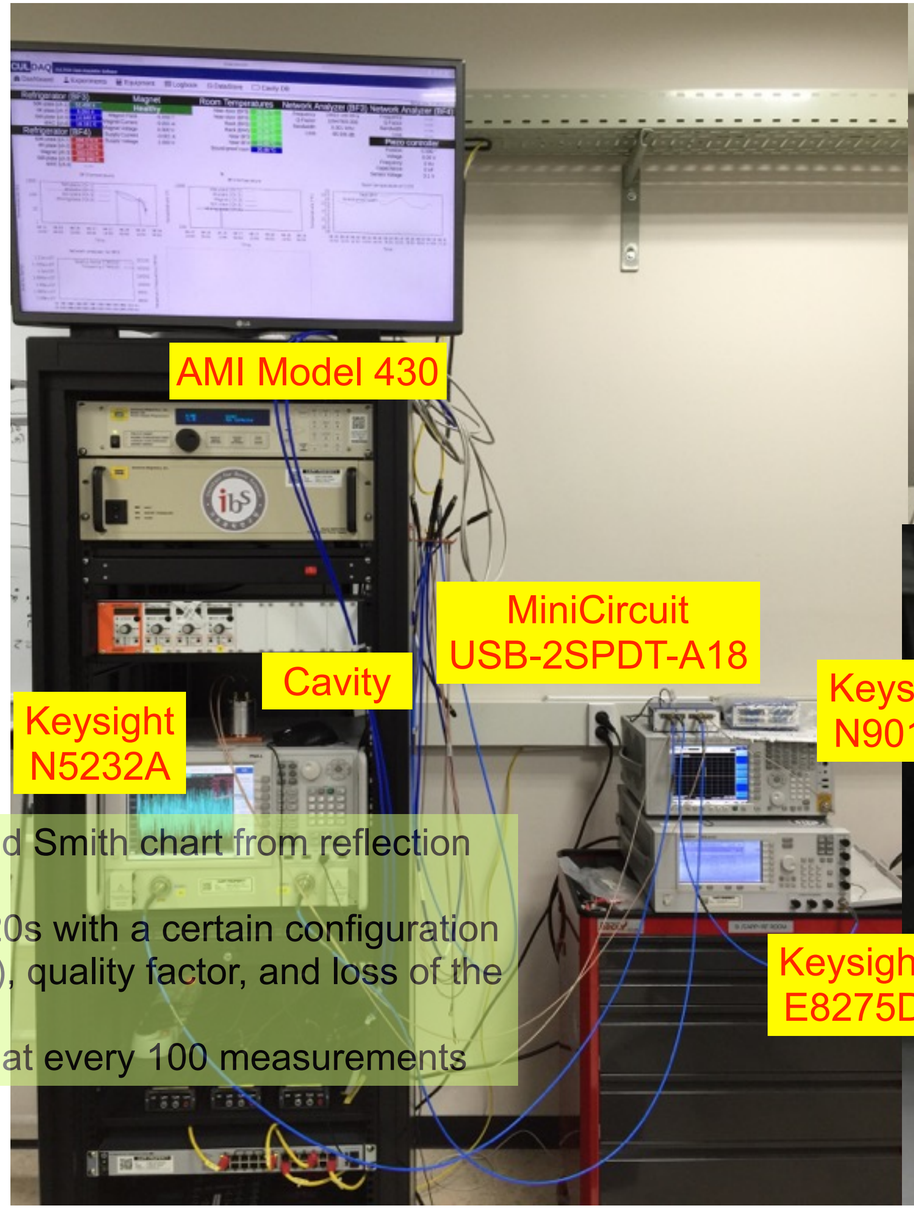

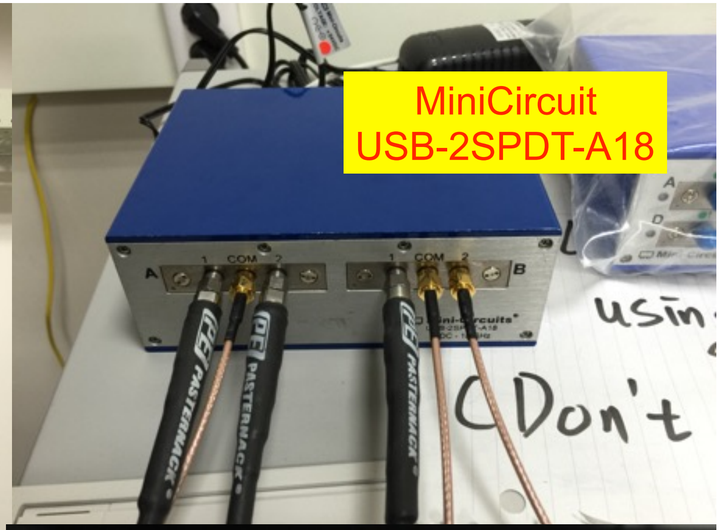

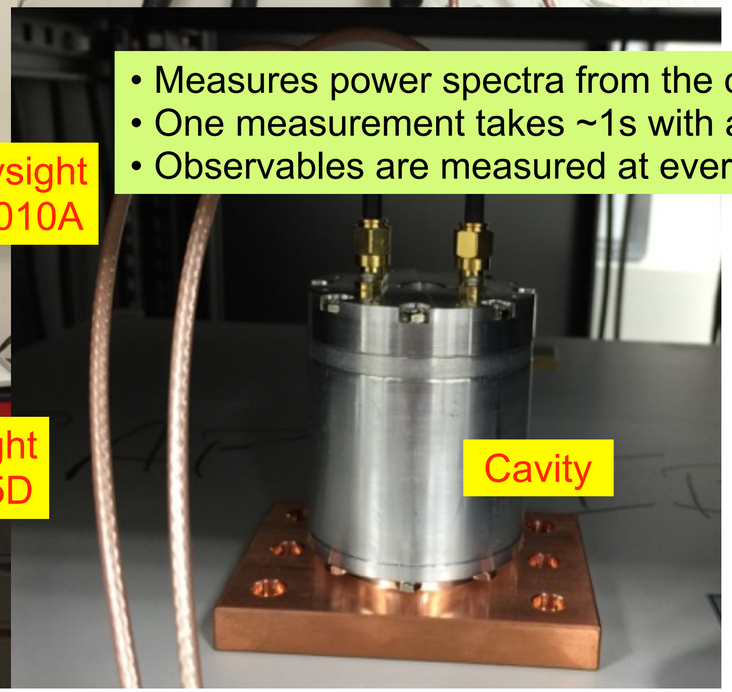

- Measures power spectra from the cavity
- One measurement takes ~1s with a certain configuration
- Observables are measured at every measurement

- Measures power spectra and Smith chart from reflection (S_{11}) and transmission (S_{21})
- One measurement takes ~20s with a certain configuration
- Resonant frequency (TM_{010}), quality factor, and loss of the test cavity are also taken
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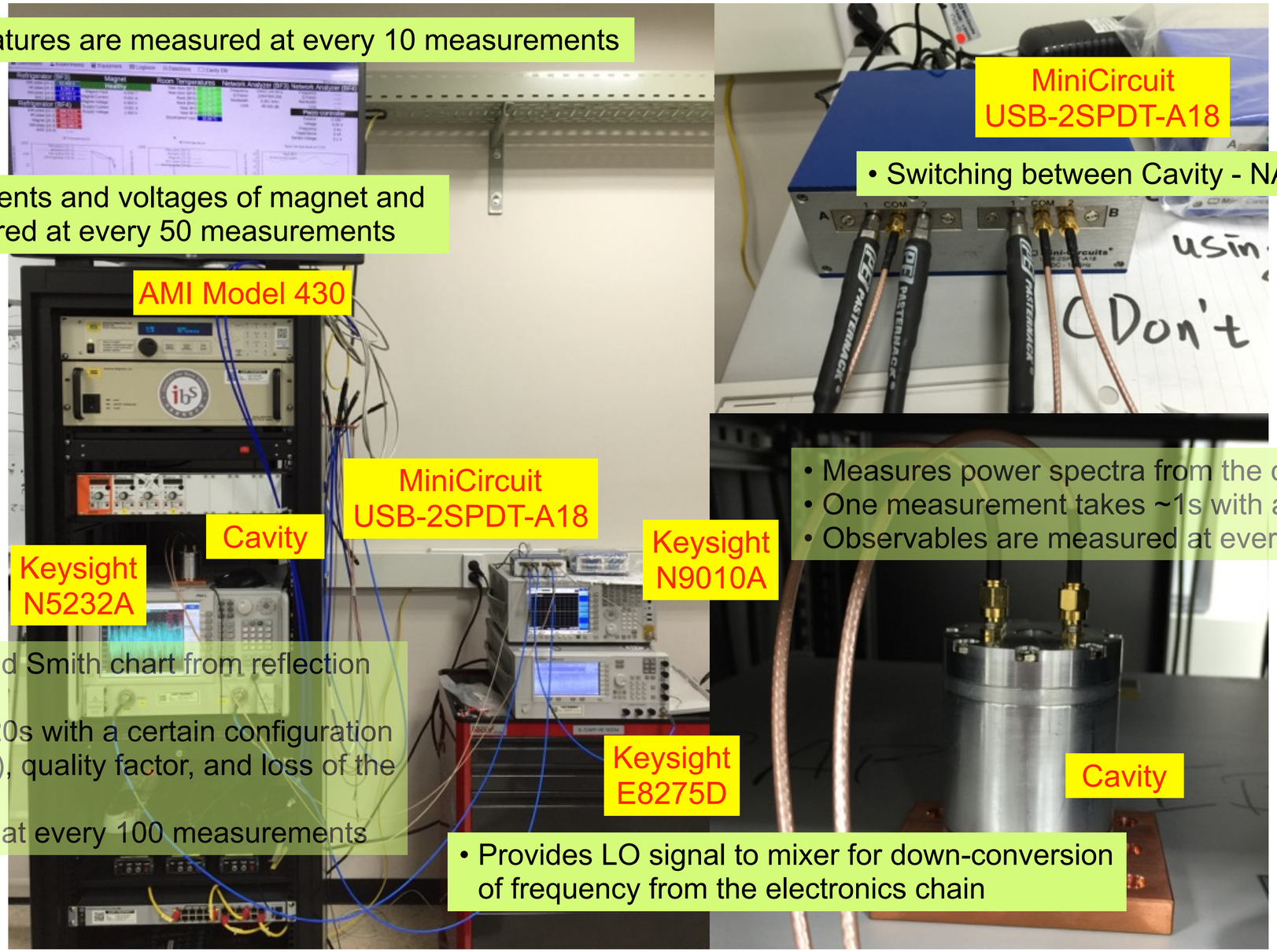
CULDAQ Testbed

- Cryo-temperatures are measured at every 10 measurements
- Observables (B field, currents and voltages of magnet and power supply) are measured at every 50 measurements



- Switching between Cavity - NA and Cavity - SA

- Measures power spectra from the cavity
- One measurement takes ~1s with a certain configuration
- Observables are measured at every measurement

- Measures power spectra and Smith chart from reflection (S_{11}) and transmission (S_{21})
- One measurement takes ~20s with a certain configuration
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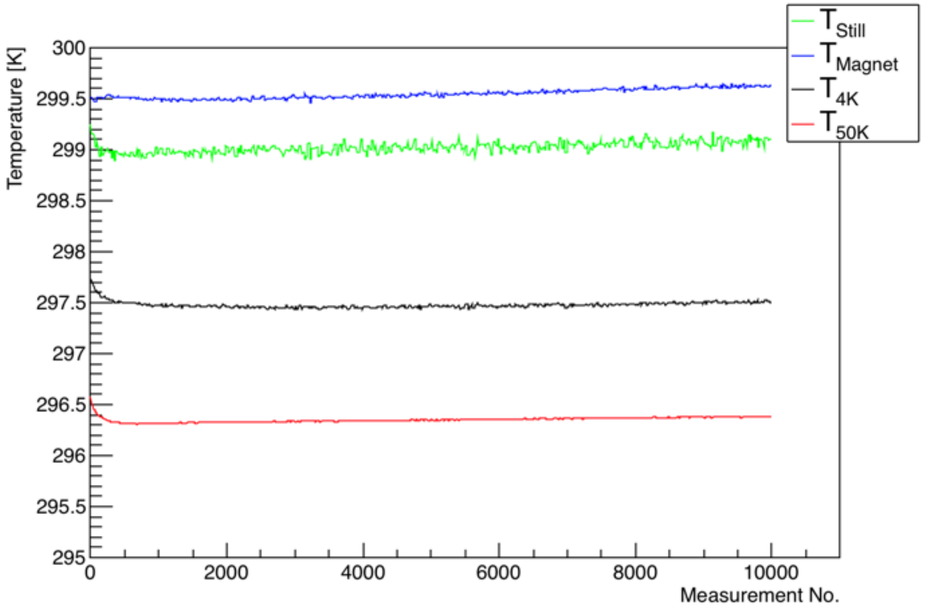
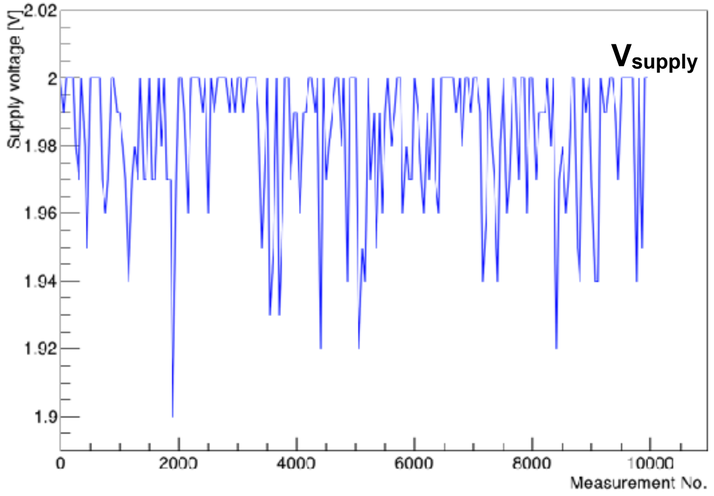
- Observables are measured at every 100 measurements

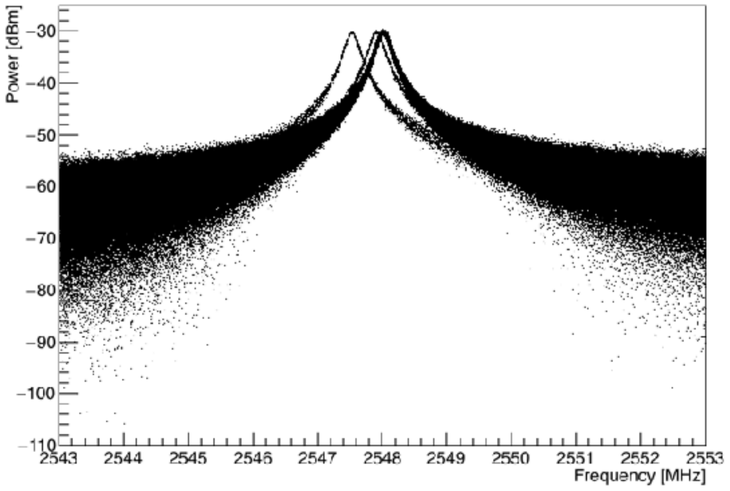
- Provides LO signal to mixer for down-conversion of frequency from the electronics chain

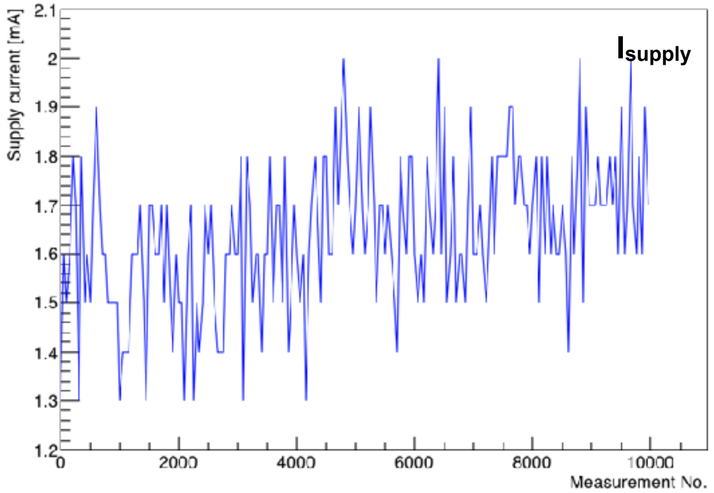
Data from the Test

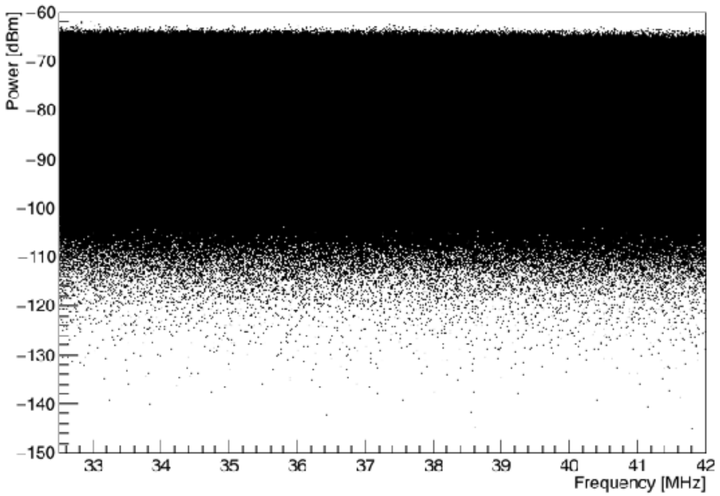
- No cool-down, no magnetic field (engineering run to test electronics chain and operation of CULDAQ)







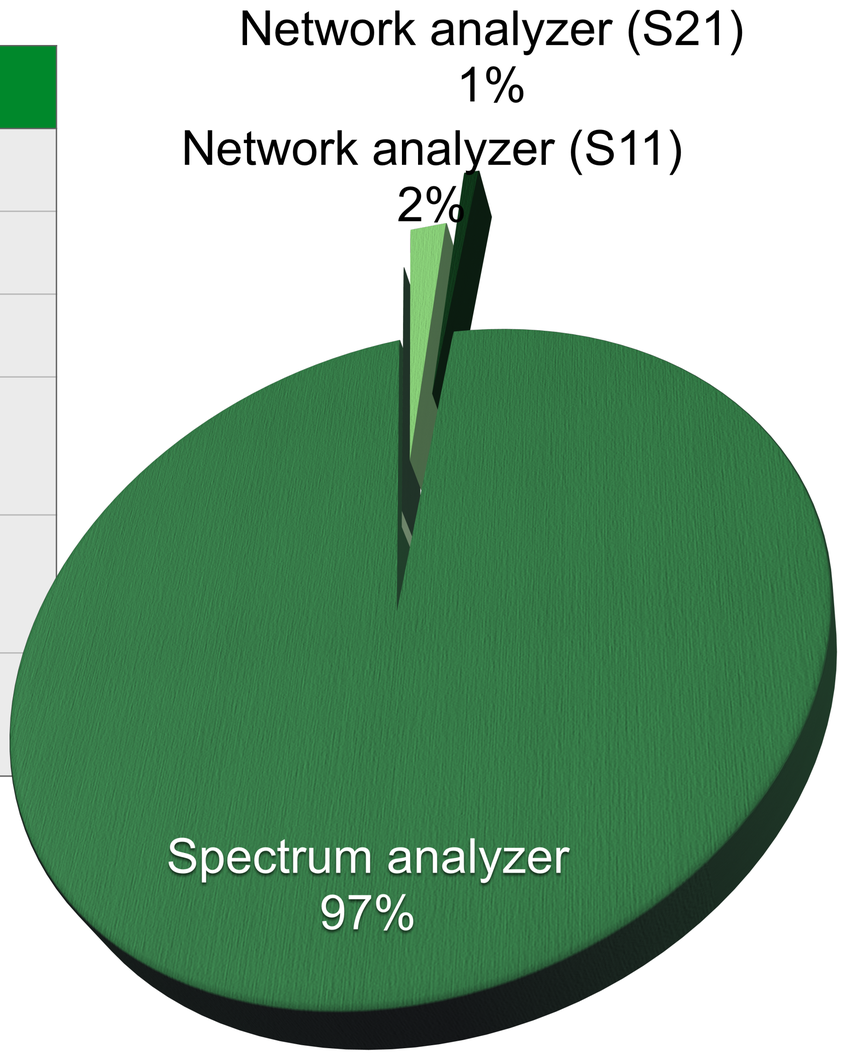




Data Size Breakdowns

- Raw data of a run with 10,000 measurements: ~ 670 MB

Category	# of entries	File size
Run metadata	10,000	~ 17 kB
Cryo-temperatures	1,000	~ 7 kB
Magnet data	200	~ 3 kB
Network analyzer data [Reflection (S_{11})]	100 measurements * 10,001 sweep points = 1,000,100	~ 12 MB
Network analyzer data [Transmission (S_{21})]	100 measurements * 10,001 sweep points = 1,000,100	~ 5 MB
Spectrum analyzer data	10,000 measurements * 10,001 sweep points = 100,010,000	~ 655 MB



- As the experiment gets more realistic, the breakdowns will change

Status and Plans

- The experiment is still in R&D stage
  - Essential functions of CULDAQ are functioning
  - The experiment may require additional features, but it won't be challenging in the current configurations
  - Extra features are under development
  - Developments of offline processing and data analysis are also being planned and considered

- Experiment at a single frequency under 8T magnet will starts in a month
  - Higher magnets (>20T) are coming in years

Summary

- CULTASK is a new experiment to search axion dark matter
  - In R&D stage for the moment
  - To reach the sensitivity we desire, all the parameters of the experiment are being studied and developed

- CULDAQ is DAQ software for the CULTASK experiment
  - Beyond the data acquisition, it also provides further useful features
  - Essential parts have developed and more features are on the way

- CULTASK is about to start its first run
  - As the development goes, better sensitivity will be achieved