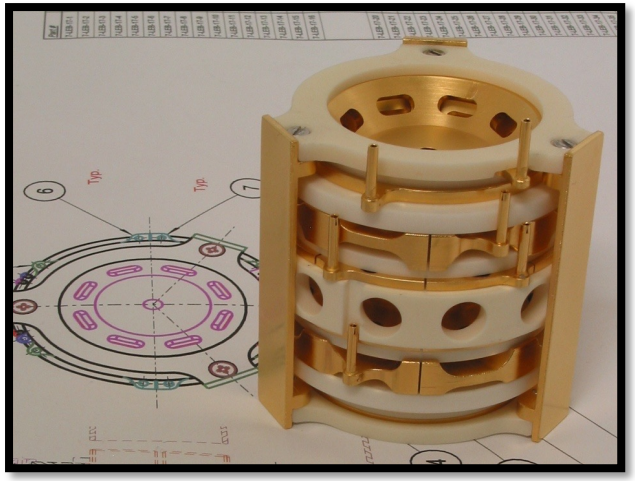


# News From LEBIT

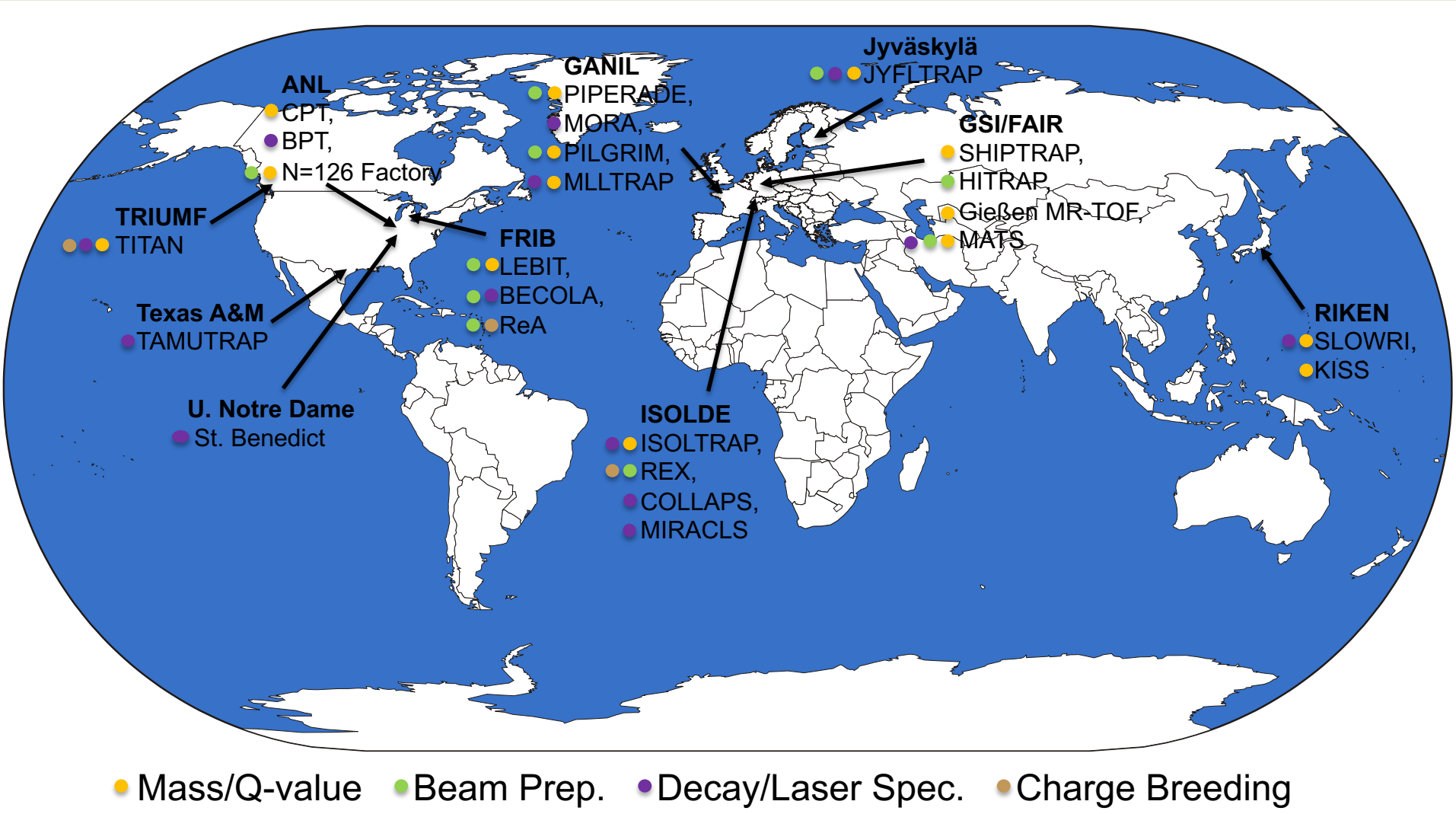
Ryan Ringle

CS Workshop 2023

April 26, 2023

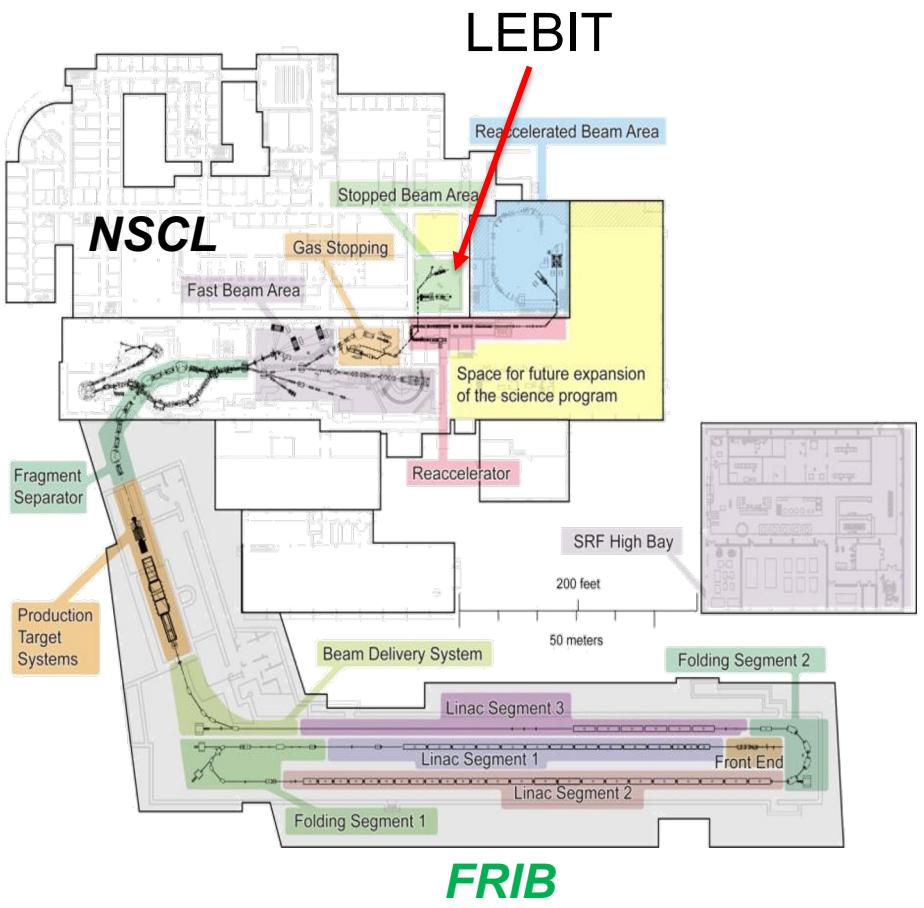
This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

# Ion Traps at Rare Isotope Beam Facilities



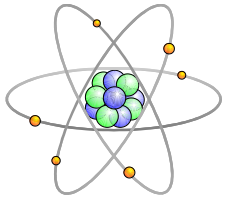
# FRIB – Facility for Rare Isotope Beams
## World-Leading Next-generation Rare Isotope Beam Facility

- $^{80}$Zr was LEBIT's last at NSCL
- FRIB will produce ~1000 NEW isotopes at useful rates (4500 available for study)
  - Higher-energy primary beams (200 MeV/ u for uranium)
  - Ultimate primary beam power of 400 kW
- FRIB delivered first beam to experiments earlier this year.




**2nd call for proposals recently completed**

# Need for Rare Isotope Mass Measurements



= N • ○ + Z • ● + Z • ●

- binding energy

**Relative mass uncertainty**

- ■ $\Delta m/m \leq 10^{-9}$
- ■ $10^{-9} < \Delta m/m \leq 10^{-8}$
- ■ $10^{-8} < \Delta m/m \leq 10^{-7}$
- ■ $10^{-7} < \Delta m/m \leq 10^{-6}$
- ■ $\Delta m/m > 10^{-6}$
- ■ unmeasured

AME20: Huang et al., Chin. Phys. C 45, 030002 (2021)

**SHE studies**
$\Delta m/m < 10^{-6}$

**Tests of Fundamental Interactions**
$\Delta m/m < 10^{-8}$

**Element Synthesis Via rp-Process**
$\Delta m/m \sim 10^{-7}$

*rp-process path*

*r-process path*

**Element Synthesis Via r-Process**
$\Delta m/m \sim 10^{-7}$

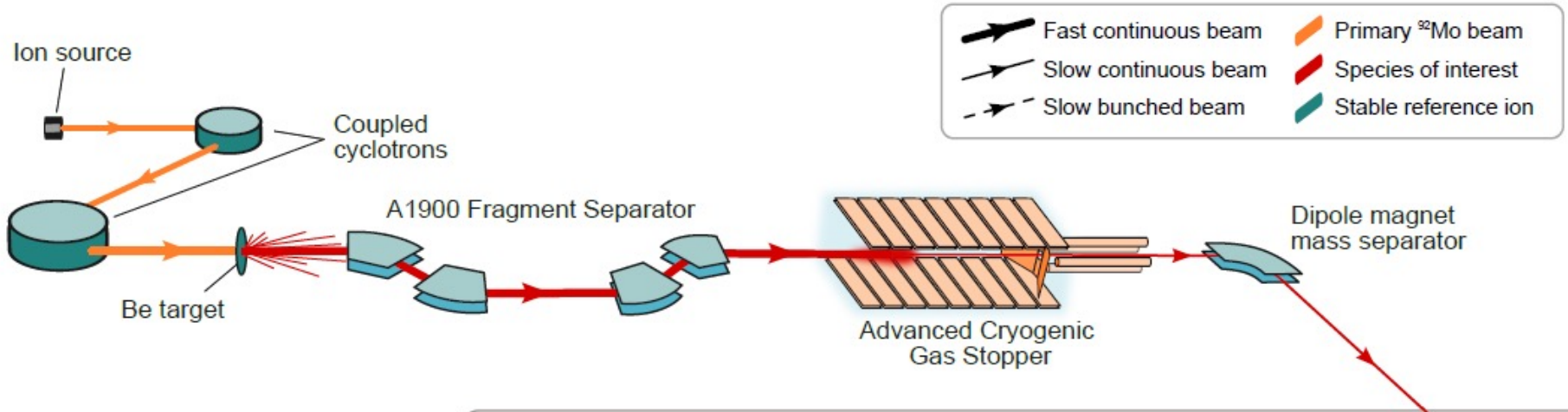
**Evolution of Nuclear Shell Structure**
$\Delta m/m \leq 10^{-6}$

Proton number *Z*

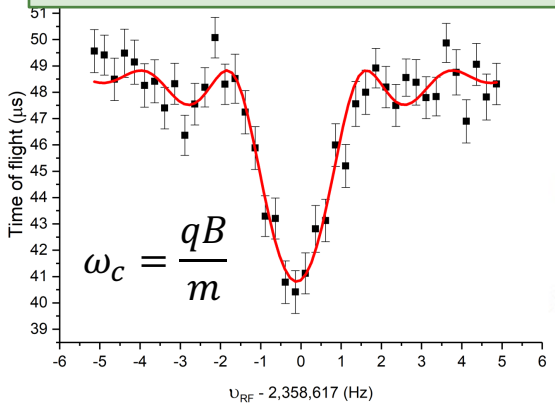
Neutron number *N*

**LEBIT uses Penning trap mass spectrometry for mass measurements of rare isotopes**

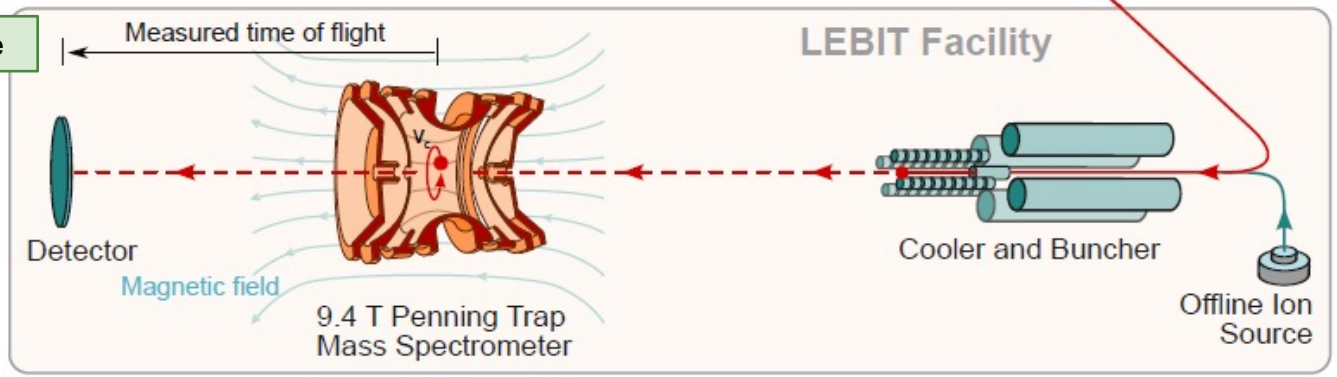
# Rare Isotope Production at the NSCL and Delivery to LEBIT




Time-of-flight ion cyclotron resonance




König et al. IJMSIP 142, 95 (1995)




Ringle et al. NIM A 604, 536 (2009)

Schwarz et al. NIM A 816, 131 (2016)

# LEBIT Experiment

Ringle et al., Int. J. Mass Spectrom. 349, 87 (2013)

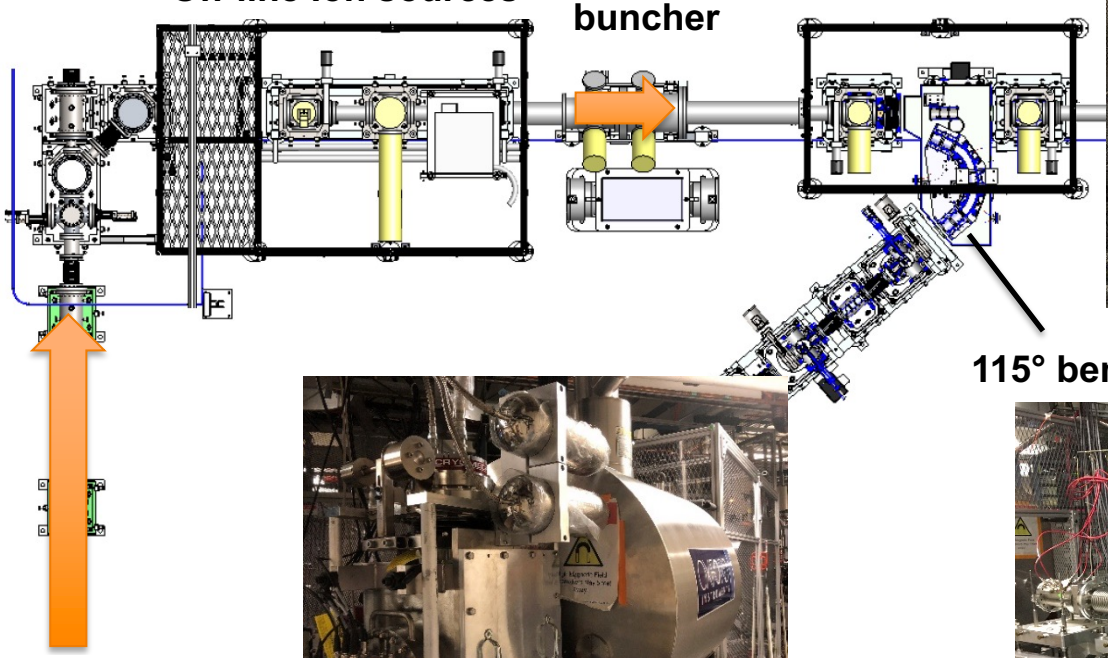
Ringle et al. NIM A 604, 536 (2009)

Schwarz et al. NIM A 816, 131 (2016)

**Off-line Ion sources**

**RFQ cooler buncher**

**9.4 T Penning Trap (TOF-ICR, PI-ICR)**

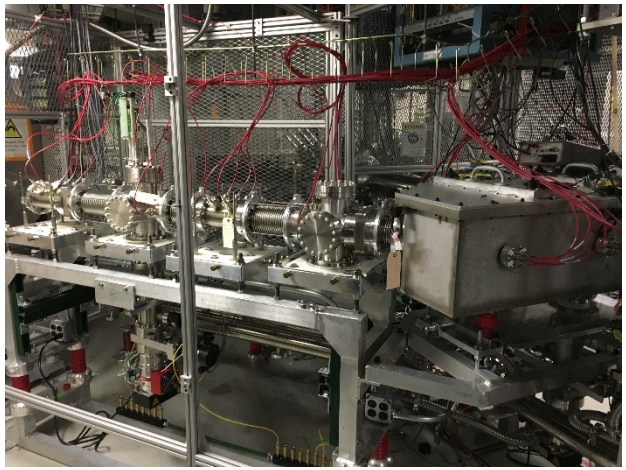


**Rare isotope beam (On-line source)**

**7 T SIPT (Narrowband FT-ICR)**

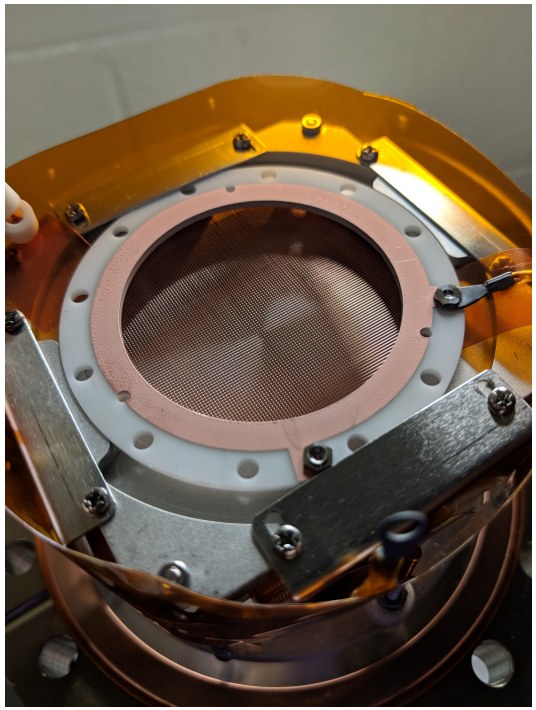
Hamaker et al. Hyp. Int. 240, 34 (2019)

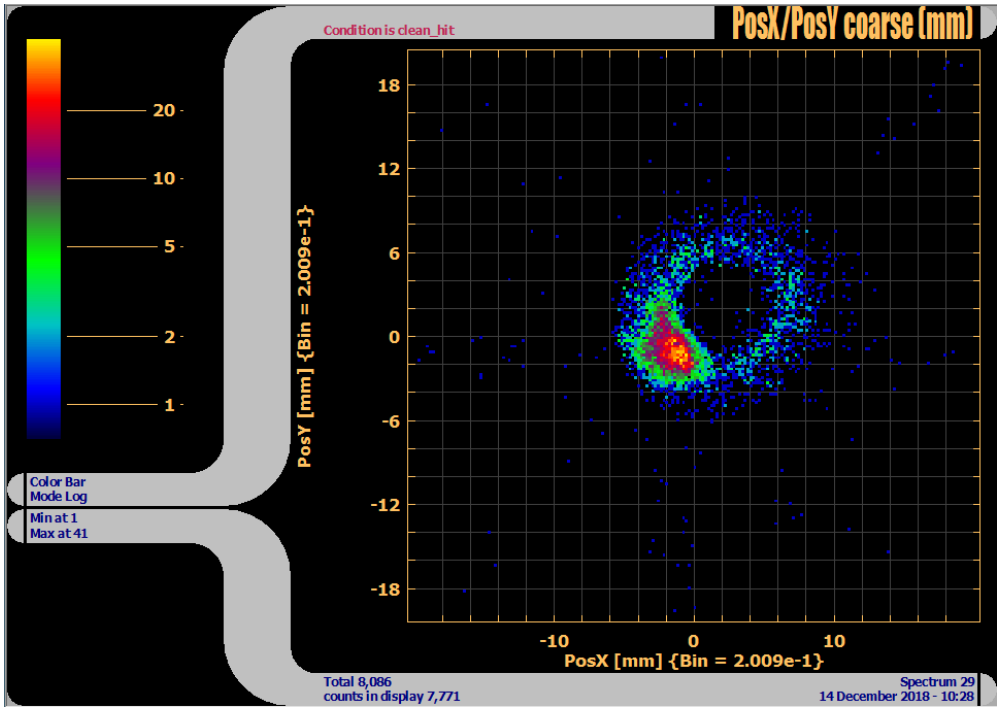
**115° bender + electrostatic quadrupoles**



# Phase Imaging Ion Cyclotron Resonance (PI-ICR) Demonstrated increase over TOF-ICR

- Mass measurement precision of rare, short-lived isotopes is limited by half life (resolving power) and production rate (statistics)
  - PI-ICR[1] can achieve a significantly higher resolving power than TOF-ICR, yielding the same mass precision with fewer ions.
  - Measures the phase accumulation of ions in the trap as opposed to the time of flight.

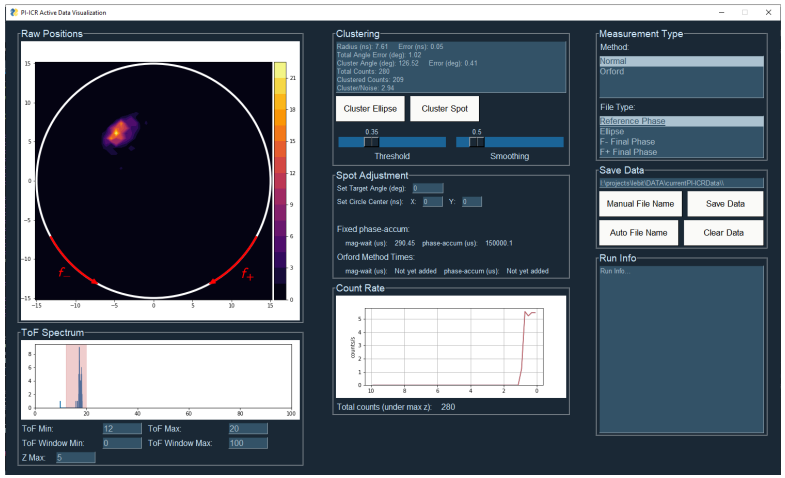







1. S. Eliseev *et al*. PRL, **110,** 082501 (2013)

# PI-ICR at LEBIT

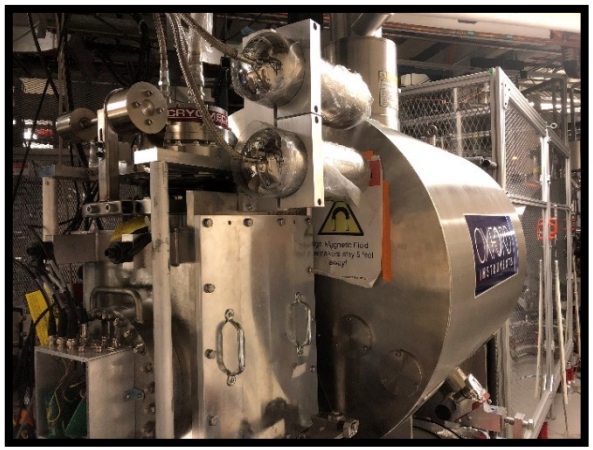



- Fully commissioned and functional
  - Timing resolution and jitter of NI FPGA currently not good enough
  - Using delay in 2-channel AFG for critical timing
  - What do others do?
- First measurements of rare isotopes performed
  - Checking for common sources of systematics
- Fully integrate into LEBIT control system
  - Tie-in to CS archiver so that data files are written out just like original TOF-ICR files
  - Event-by-event publishing of data to DIM variables for real-time visualization in MM
- Python-based visualization and analysis tools created

- ***Need to move to CS++ (probably prior to successor) to get everything tied together.***
- ***Scott Campbell coming to GSI in Fall for 3 months***

# Single Ion Penning Trap (SIPT) Towards Ultimate Sensitivity

- Motivation: expand reach on the nuclear chart by allowing measurements of ions with very low production rates
  - Traditional methods → destructive methods, require ≥ 100 ions
  - FT-ICR method → nondestructive method, allows a complete measurement with only a few ions



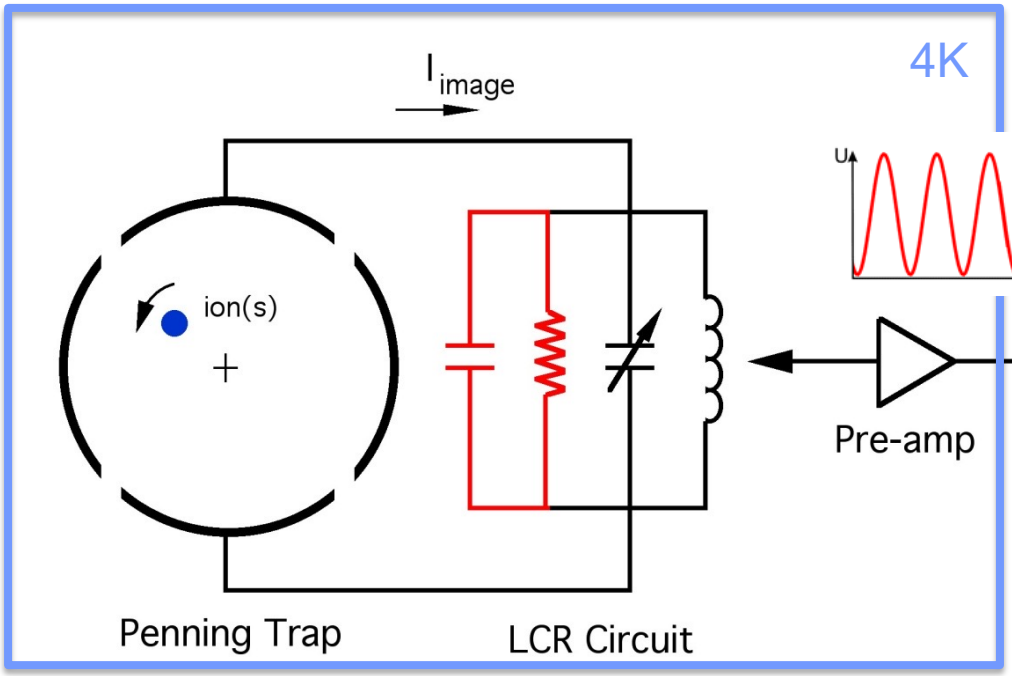
- A path towards exotic nuclei
  - $^{100}$Sn and $^{78}$Ni considered “holy grails” for nuclear structure studies
    - $^{100}$Sn: Heaviest N=Z doubly-magic
    - $^{78}$Ni: Most neutron-rich doubly-magic
  - Expected rates ≤1 ion per minute with first FRIB beams to LEBIT

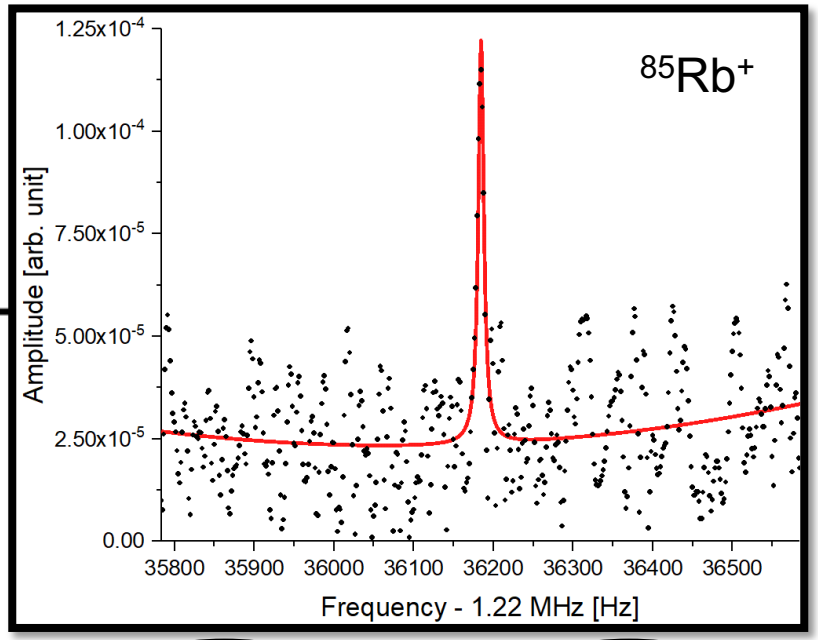
**SIPT will allow measurements that are otherwise impossible due to low rates.**

# Narrowband FT-ICR Detection
# Complete Mass Measurements with Only One Ion

**FT-ICR**
**Fourier Transform Ion Cyclotron Resonance**

**Enables high-precision mass measurements of rare isotopes produced at low rates.**




***Weak Signal ~fA***

***Amplify signal & suppress noise***

***Analyze***

***Determine Ion Frequency***

Marshall et al. Mass Spectrom. Rev. 88, 1 (1998)

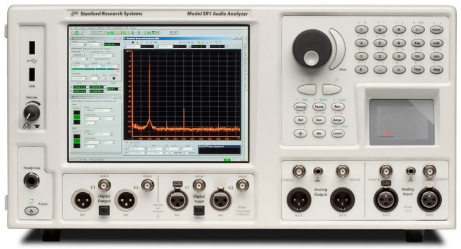
# SIPT & PI-ICR: CS Hardware Integration/Changes

- Function Generators (Keysight 33509)
  - Burst mode
  - Toggle output
  - Multi-channel delays for precision timing

- Power Supplies
  - Homebrew and ISEG (controlled by PLC)
  - Stahl Electronics – Low Noise Voltage Supply (RS-485)

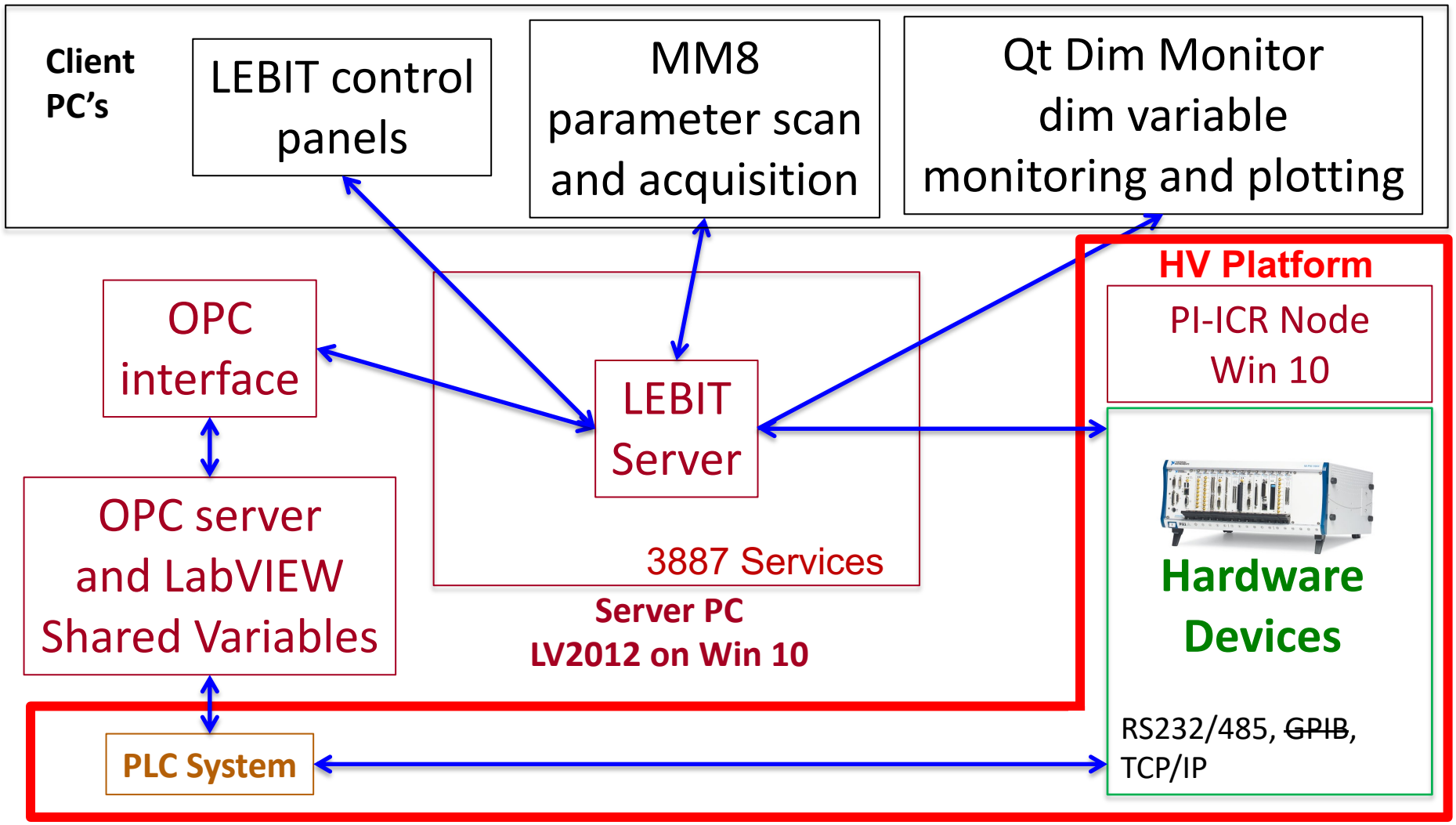
- Cryogenic Level Monitor
  - Oxford LM211S (SIPT)
  - Cryomagnetics LM510 (LEBIT)
- Temperature Monitor (Lakeshore Model 218)


- FFT
  - ~~Stanford research SR1 Audio Analyzer~~ (too slow)
  - NI PXI-5922 scope card



- More Timing channels controllable through MM

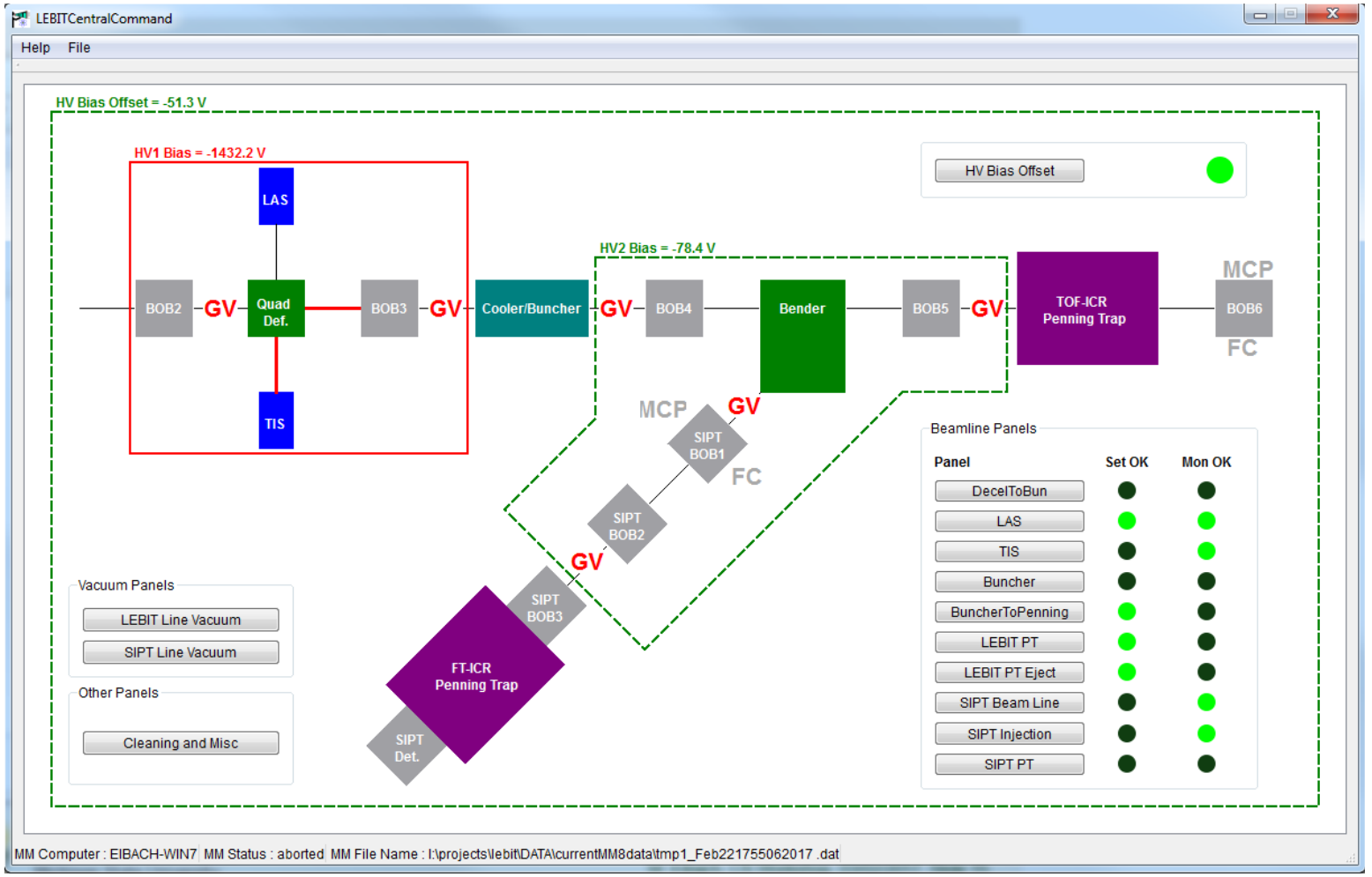
# CS at LEBIT - Structure



# LEBIT Control Panels

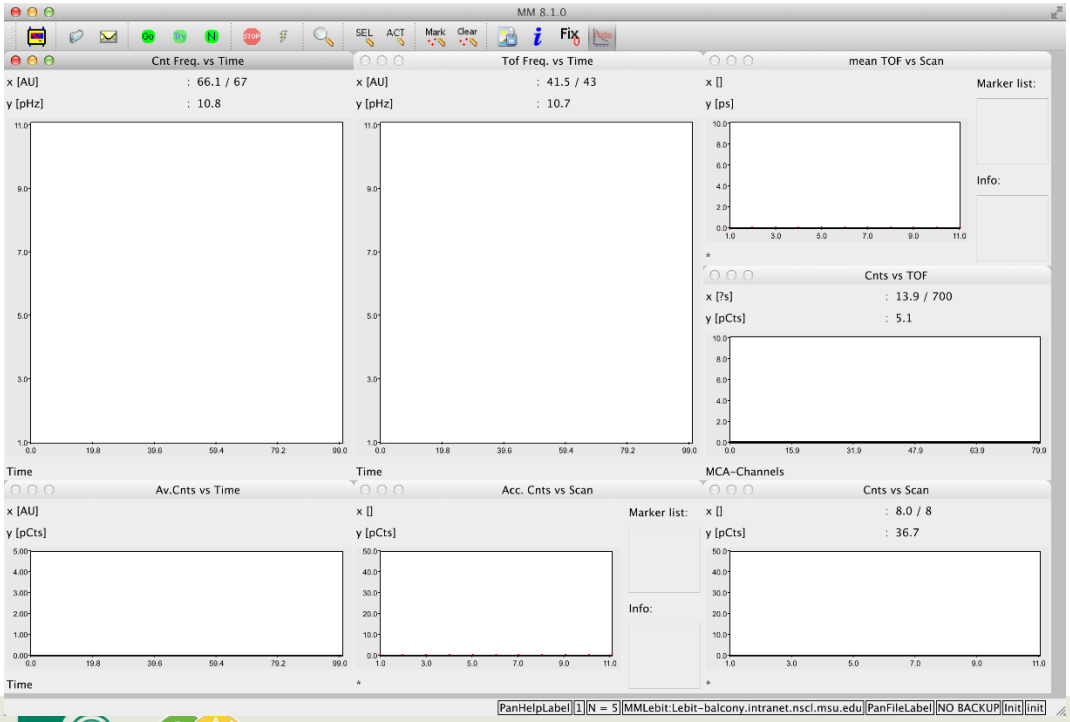
## used to display and change DIM variables

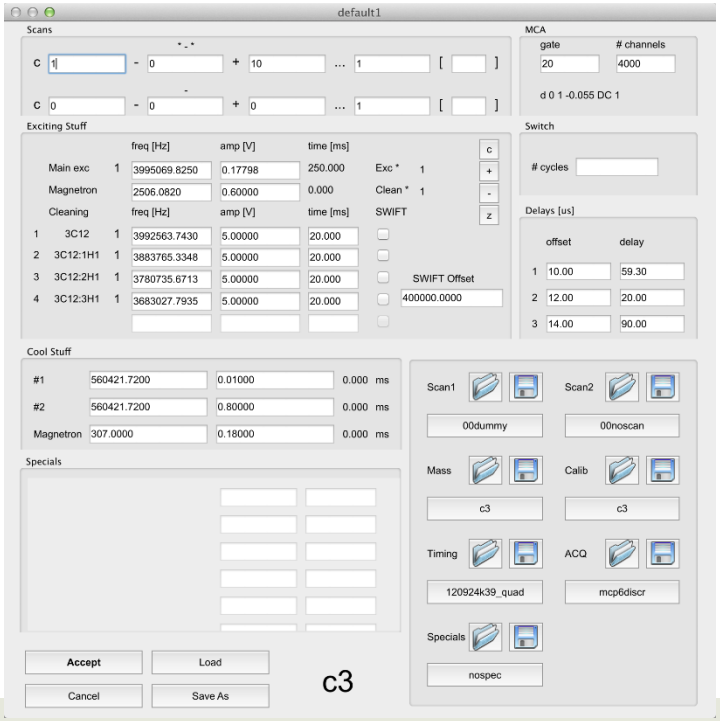
- Written in Qt 6 using C++ dim interface



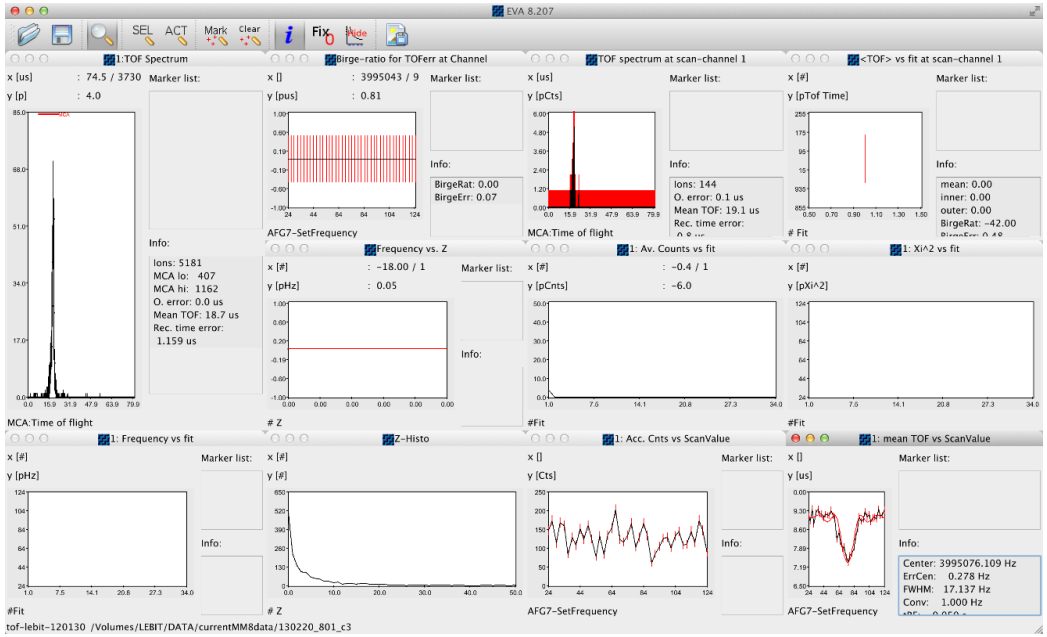
# Mass Measure (MM8)

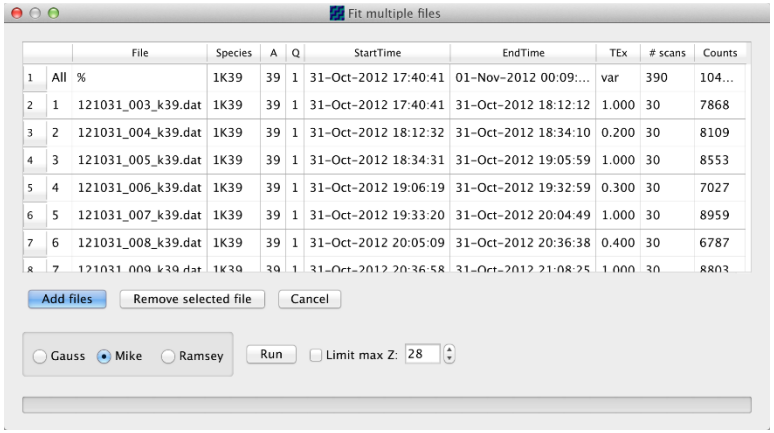
- MM8 developed using Qt 6 – tested on MacOS & Windows 10
- Scripting capabilities – tested with Python
- Some minor visual bugs, but fully functional
- FT-ICR supported
- **Future functionality – visualization of PI-ICR?**



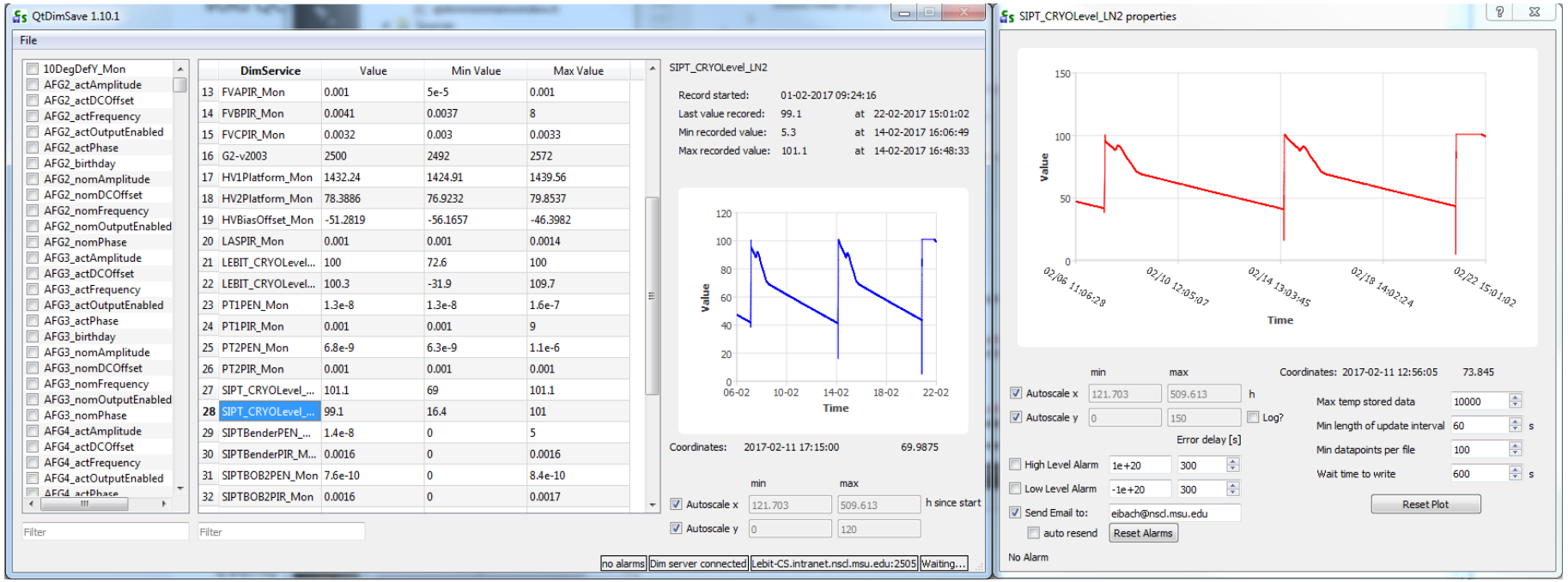
# Eva 8.3.0.5 - Status?




- General purpose TOF-ICR analysis
- Eva 8 based on Qt 6 – tested on MacOS & Windows 10
- Multiple fit functionality and no-doubles function
- Important bugfix: start and end time in .ft2 and .log file were the same
- **Future functionality – PI-ICR, FT-ICR (EvaFFT developed as stopgap)?**

# QtDimSave




- Logging and Saving of Dim service values
- Based on Qt 5.7 – tested on Windows 10
- Alarm handling and email notification

# Summary and Outlook

- LEBIT has been a happy CS user for the last 20 years
- Last upgrade of LEBIT CS was in 2013
- Need to upgrade to CS++ in the near future
  - Windows 10 end-of-life currently scheduled for October 14, 2025
  - Most likely we'll be forced to upgrade to the next lab standard (Windows 11?)
- Fully support move away from LabVIEW
  - Want to upgrade to CS++ first for plenty of buffer
  - FRIB coming online means LEBIT has plenty of life left in it
- Excited to see what comes next!

Many thanks to Holger and Dennis