How It Happens: The Creation and Commissioning of New Experimental Systems

Erin Good

Facility for Rare Isotope Beams

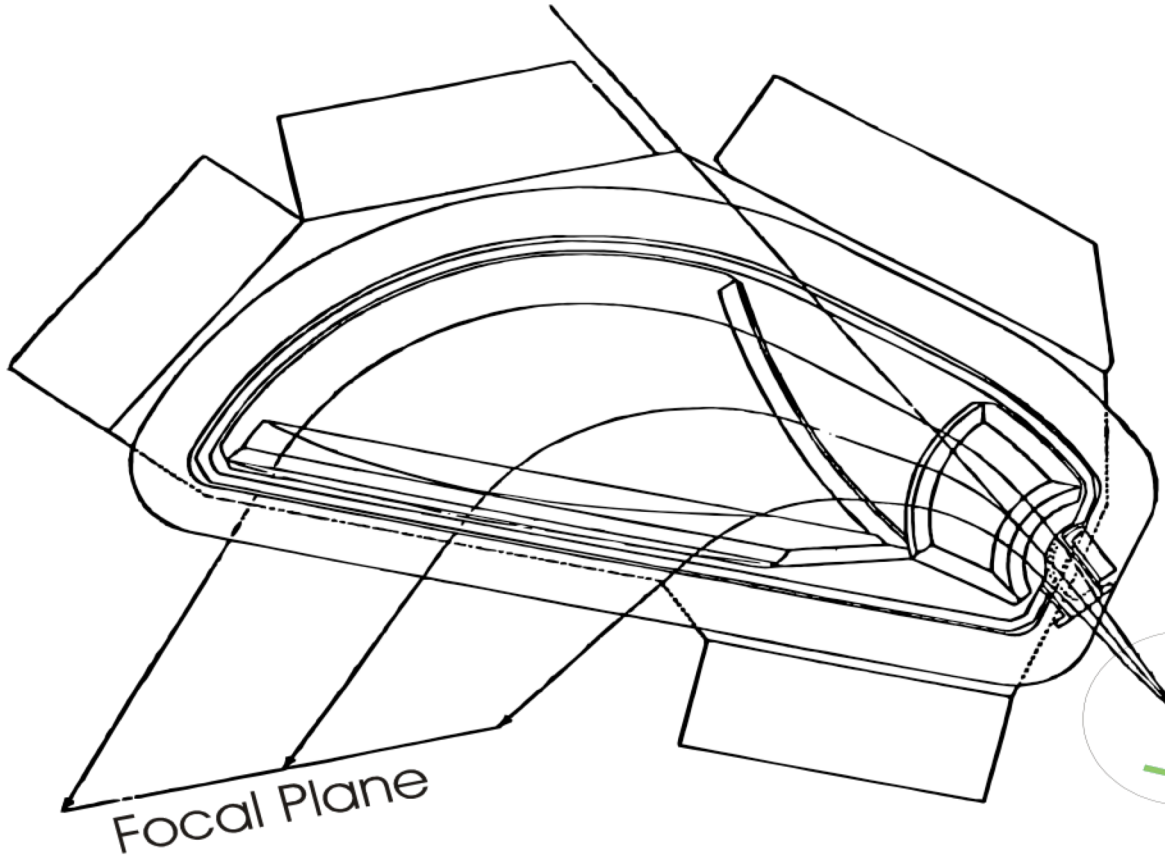
2011: An opportunity arises with the shutdown of the tandem accelerator at Yale's Wright Nuclear Structure Lab

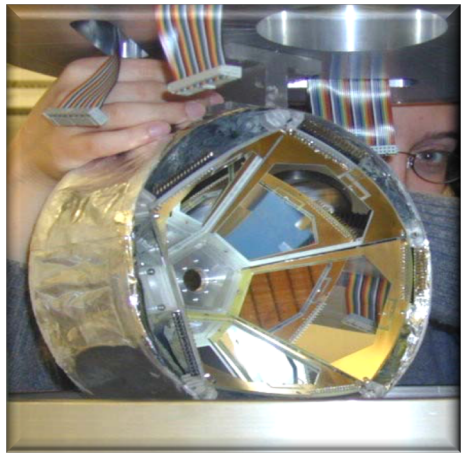
- Catherine Deibel, former Yale grad student and LSU professor hears the news
- Ingo Wiedenhöver, FSU professor that helps run John D. Fox Lab there
- They ask if they can have the old equipment from the lab

Split-Pole Spectrograph (SPS) Setup

Capable of measuring:

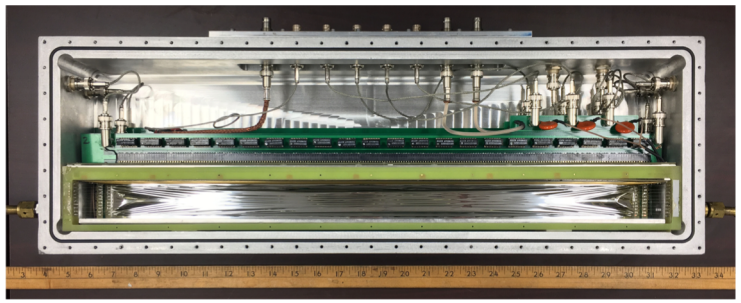
- Excited states in nuclei
- Angular momentum transfers
- Particle decay branching ratios





Charged particle detector:

Gas-filled ionization chamber:
E, ΔE, position



Basics of the SPS

- At Yale, the SPS was used in a robust scientific program utilizing stable beams to measure a variety of nuclear physics quantities
- Indirect measurements are excellent for when cross sections can't be directly measured
- Nuclear properties of astrophysical interest are obtainable via simple transfer reactions

Resonance energies

$$N_A\langle\sigma v\rangle = \frac{1.5399\times10^{11}}{(\mu T_9)^{3/2}}\sum_{res}(\omega\gamma)_{res}\, e^{-11.605E_{res}/T_9} \qquad \left[\frac{\mathrm{cm}^3}{\mathrm{mol}\cdot\mathrm{s}}\right]$$

Angular momentum transfers

$$(\omega\gamma)_{res} = \frac{(2J_{res}+1)}{(2J_A+1)(2J_B+1)}\frac{\Gamma_a\,\Gamma_b}{\Gamma}$$

Charged particle branching ratios

The plan: take the magnet to FSU and upgrade the existing detectors and electronics

Upgrades:

- Redesign the silicon array for higher geometric efficiency: SABRE, the Silicon Array for Branching Ratio Experiments
- New digital electronics for achieving lower thresholds in SABRE

2013: The SPS takes a ride to FSU, applying for grants begins

- Magnet and surplus electronics are loaded onto an 18 wheeler and driven to FSU
- Application for an NSF Major Research Instrumentation grant begins
  - Internal LSU and FSU applications must both be approved first

Fall 2014: NSF Major Research Instrumentation Grant awarded

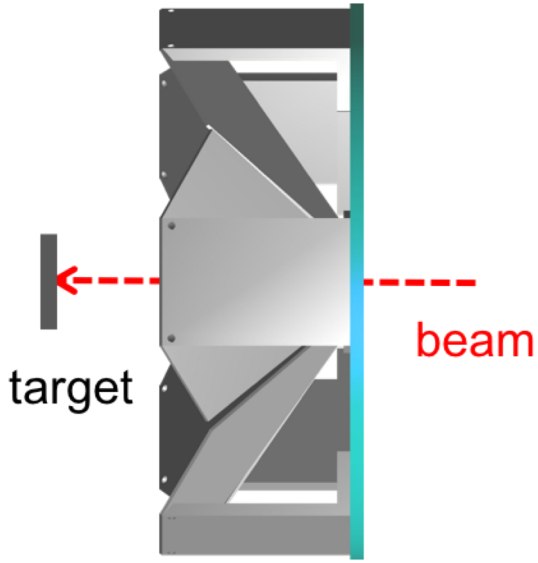
- In collaboration with FSU
- Covers:
  - Installation of SPS
  - SPS support systems (power, gas handling, etc)
  - SABRE detectors and electronics

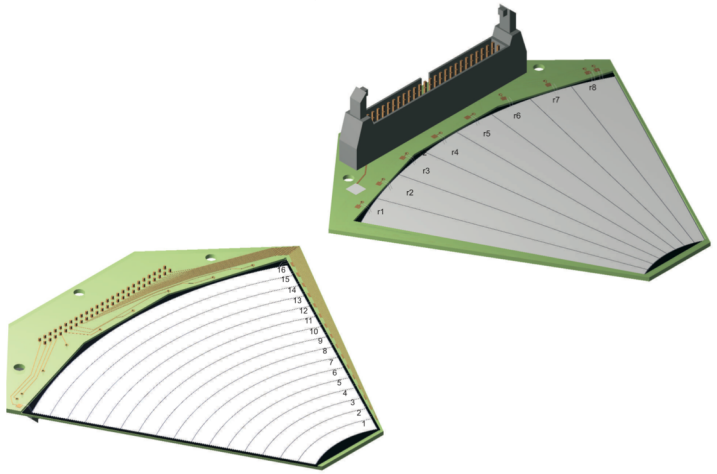
Proposed Project Schedule

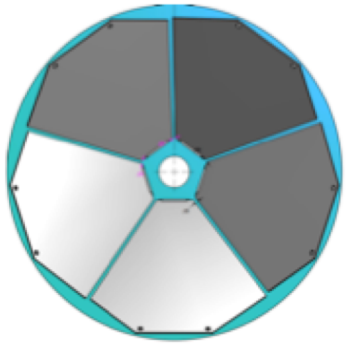
- ✓ Disassembly of magnet and associated equipment and shipment to FSU
  - November 2013
- Detector development at LSU: Fall 2014 – Fall 2016
- Preparation of FSU experimental hall
  - rearrange FSU hall; build new beam line (Winter 2014)
  - pour concrete pedestal (Winter 2015)
- Installation of Magnet at FSU
  - Summer 2016
- First experiments with split-pole at FSU
  - Fall 2016 – Spring 2017
- Far future ideas:
  - gamma detection?
  - gas-filled mode?

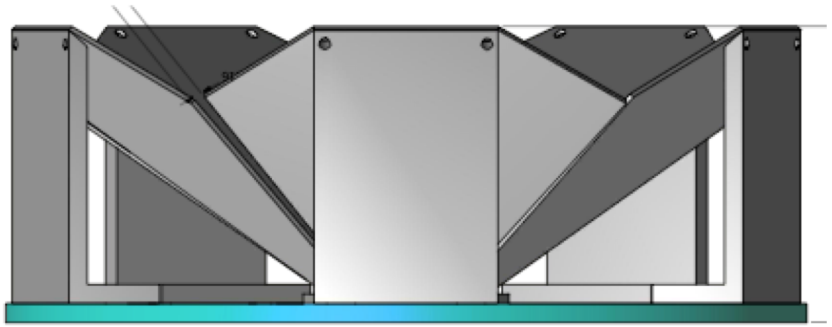
Summer 2015: Designing SABRE at LSU, when I join the project

- Simulate various designs with different detectors for maximum geometric efficiency
  - SABRE doubles efficiency of old array
- Order Si detectors from Micron Semiconductor Ltd, which has a 9 month lead time



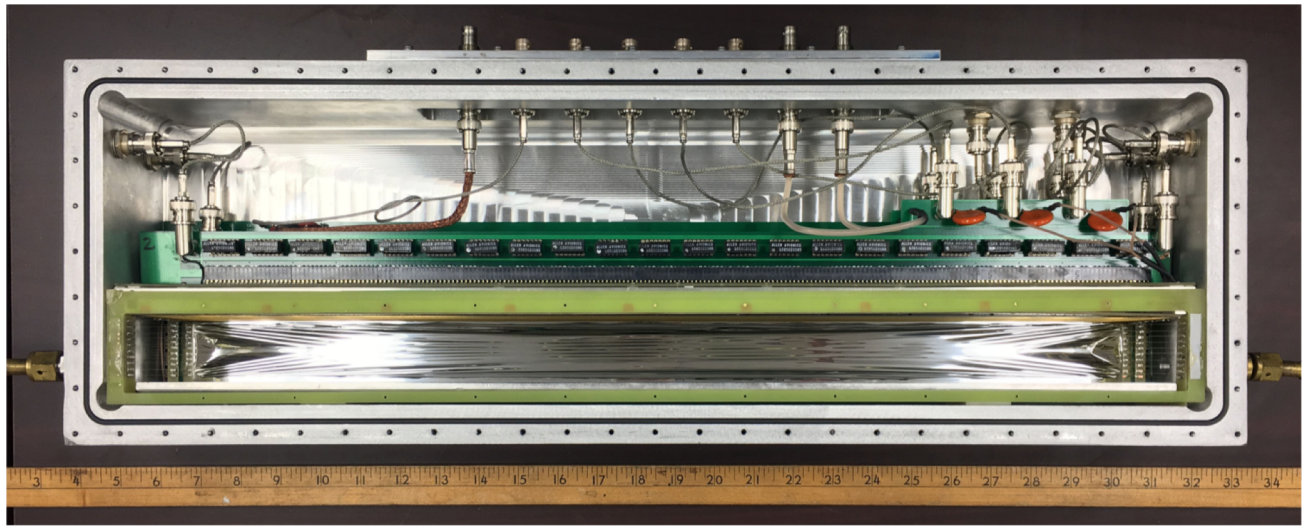






2016: Repairs and testing of the focal plane detector at LSU

- Polishing scratched cathode plate
- Repairing field-shaping wires
- Khang Pham, undergraduate student, did his senior thesis on the focal plane testing
  - Testing various gas pressures and biases
  - Making a sliding source holder to test position sensitivity of detector on the bench

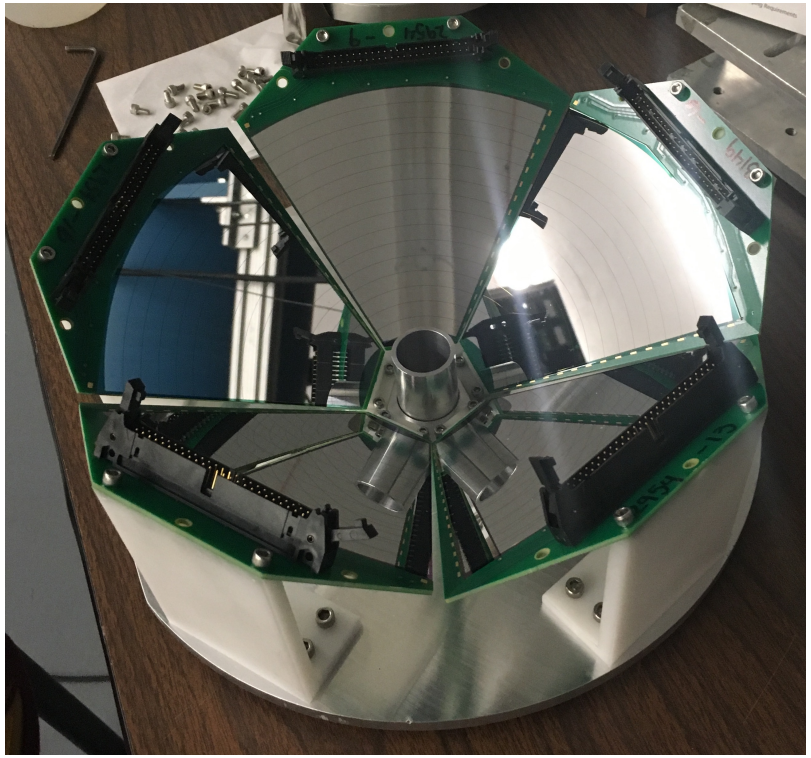


2016: The John D. Fox Lab at FSU gets a fancy new floor and concrete pedestal

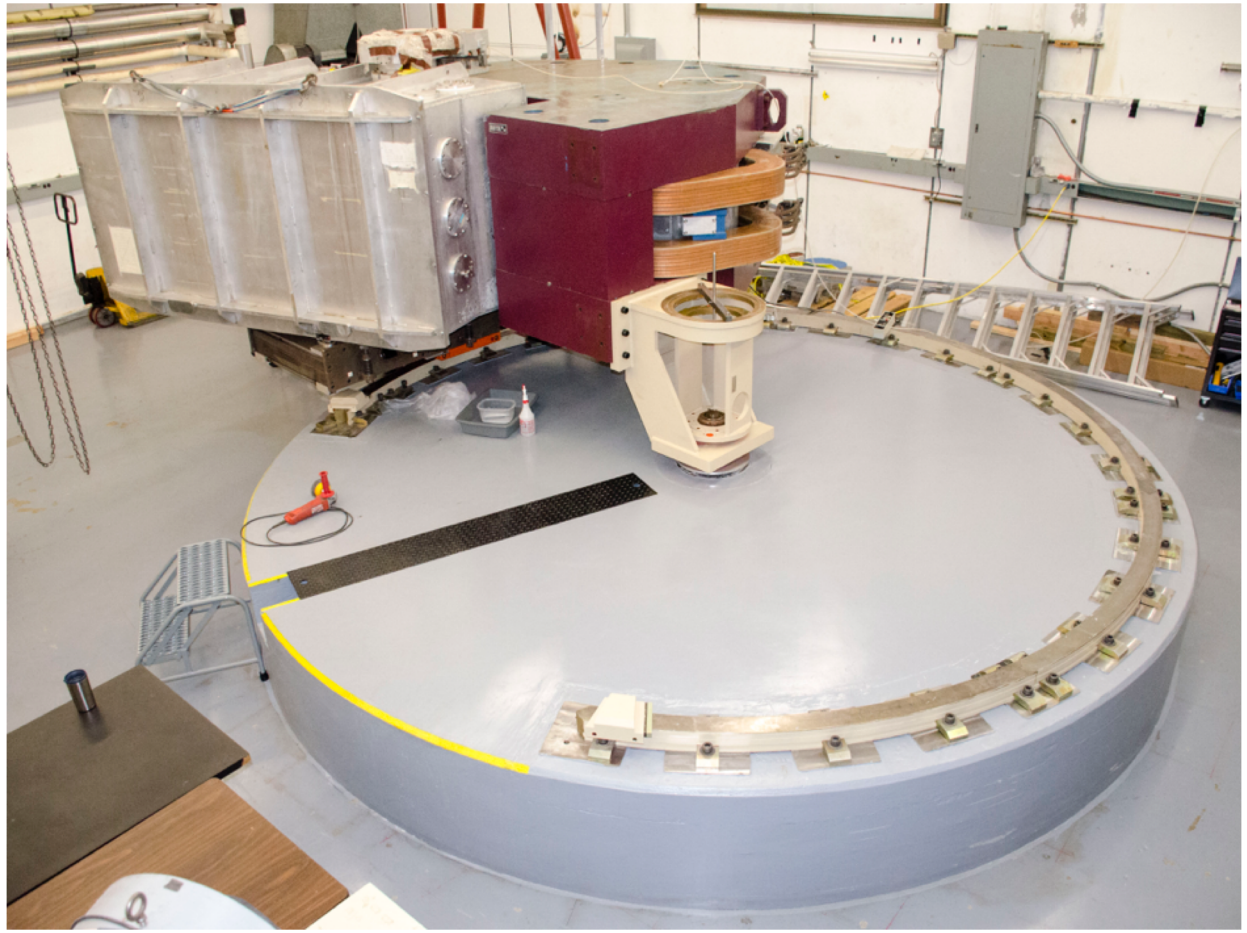
- Spring 2016: outside contractor drills test piles in the floor for the concrete pedestal to support the SPS; final engineering plans are made for the floor
- Summer 2016: many more support piles are drilled for the floor and the concrete pedestal is laid by outside contractor

2016: Fabrication of SABRE mount at LSU

- Created CAD drawings of all parts
- CAD drawings submitted to LSU machine shop for fabrication
- Close work with machine shop to make small adjustments to mount to make detectors fit



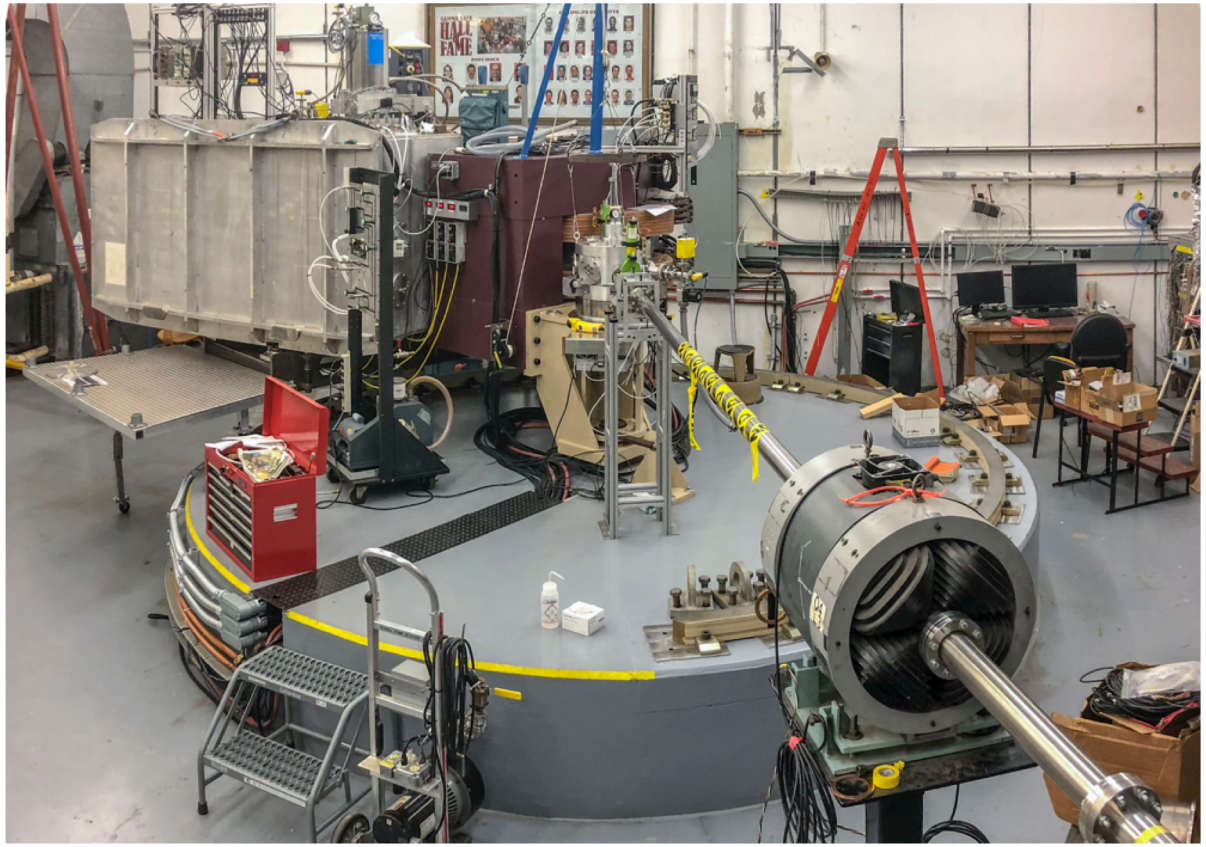
January 2017: The SPS is installed at FSU



- Placed on rotating pedestal
- Still has no gas handling, electronics systems, or beamline

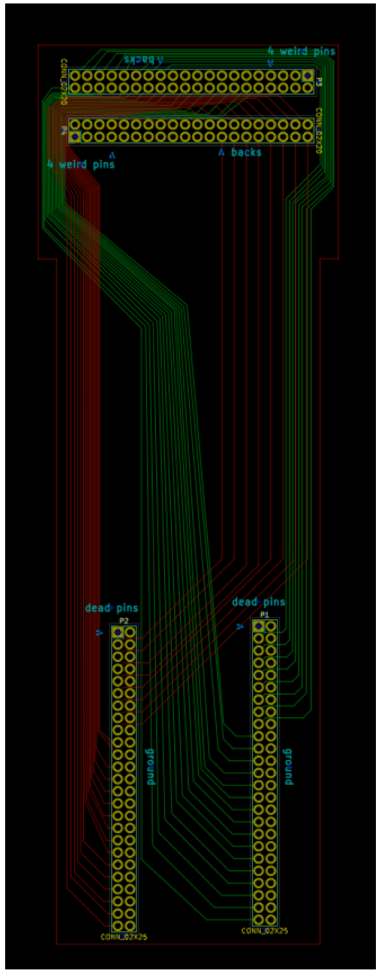
2017-2018: Support systems, target chamber, and beamline installations at FSU

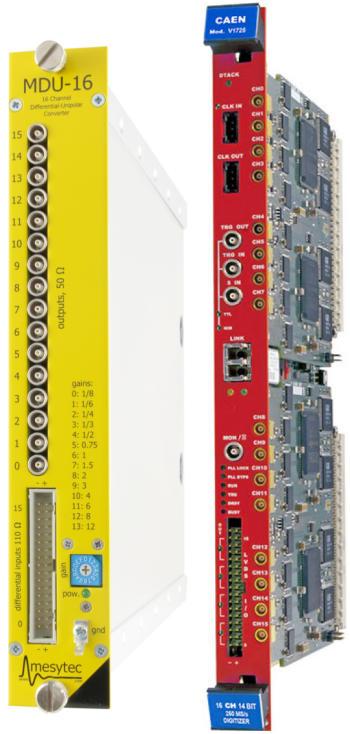
- Magnet power supply is connected to SPS
- Target chamber and crane for lid installed
- Gas handling for magnet and target chamber installed
- Beamline and target chamber installed and aligned



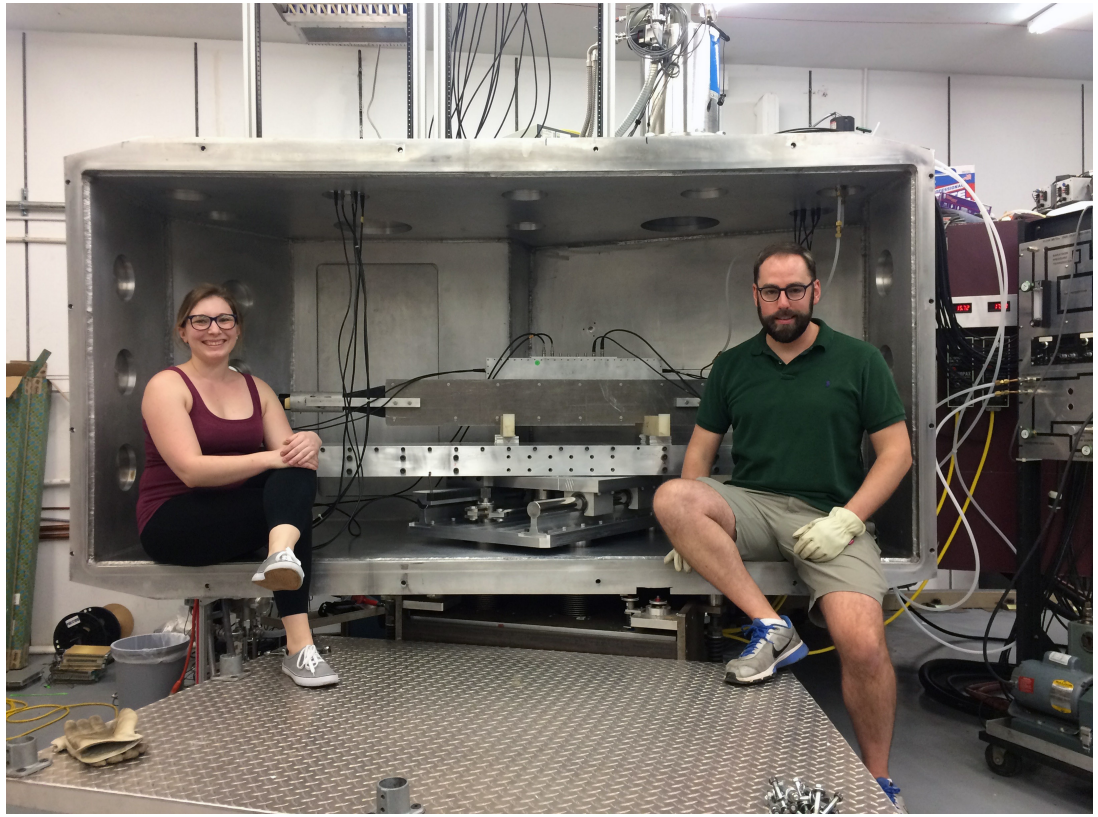
2017-2018: Preamp box building, ordering electronics modules, and digitizer testing at LSU

- Custom PCB feedthroughs designed, ordered, and constructed for SABRE
- LSU preamp boxes modified and built for SABRE
- Various digitizer models tested
- SABRE electronics ordered:
  - Digitizers
  - MDU modules
  - Cabling
  - DAQ computer

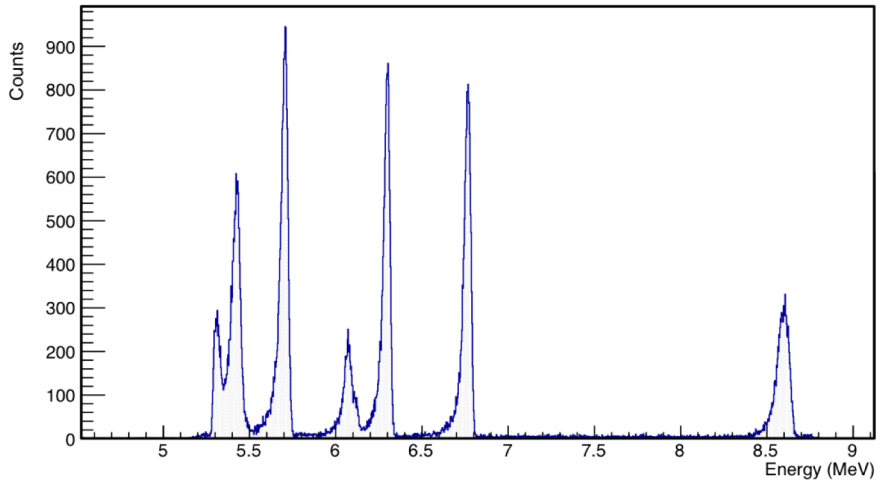




February 2018: Focal Plane detector installed and tested (no beam)

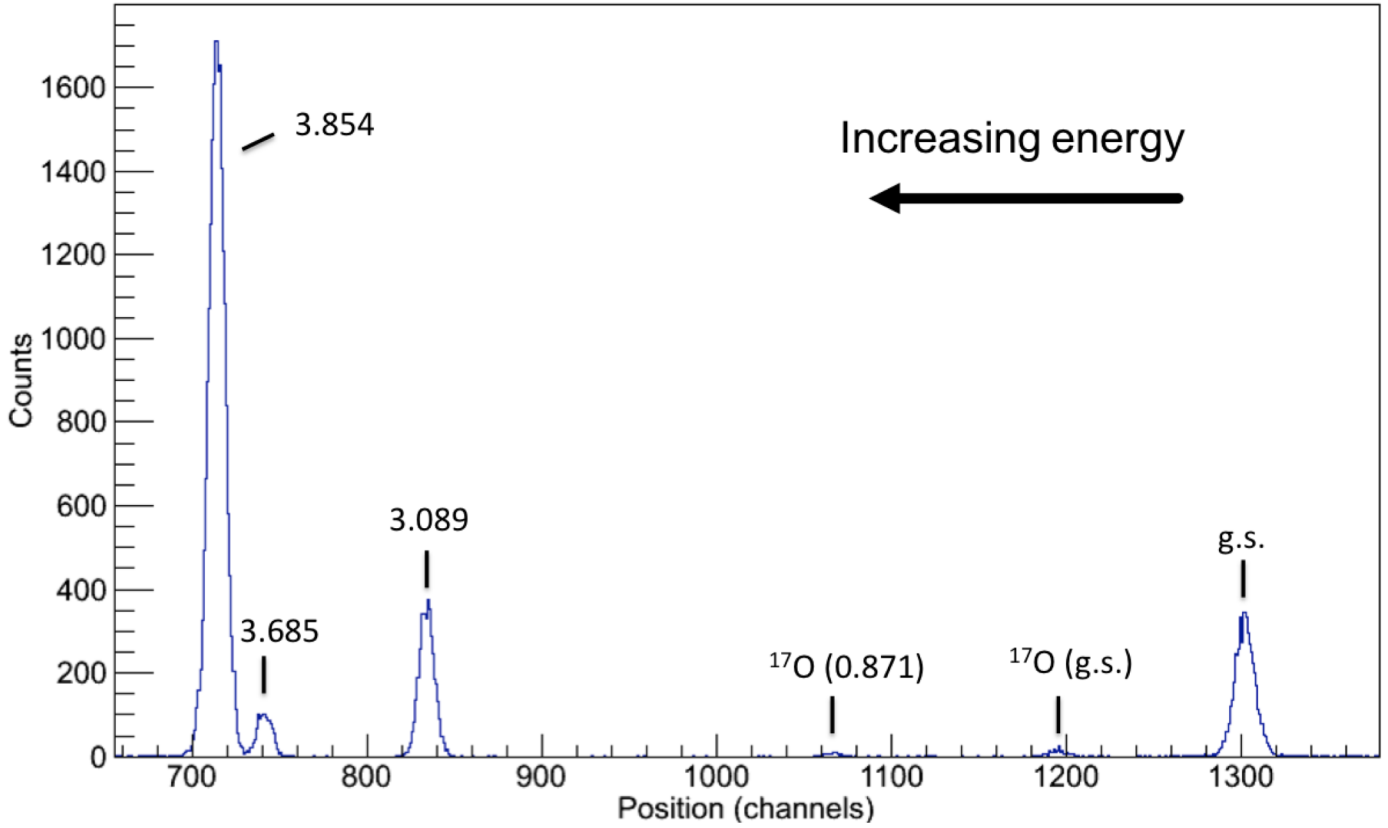


- Gas handling system and electronics installed
- SPS set to about 5.8 kG and focal plane detector tested to see ^{228}Th alpha source



Summer 2018: SPS and focal plane commissioning

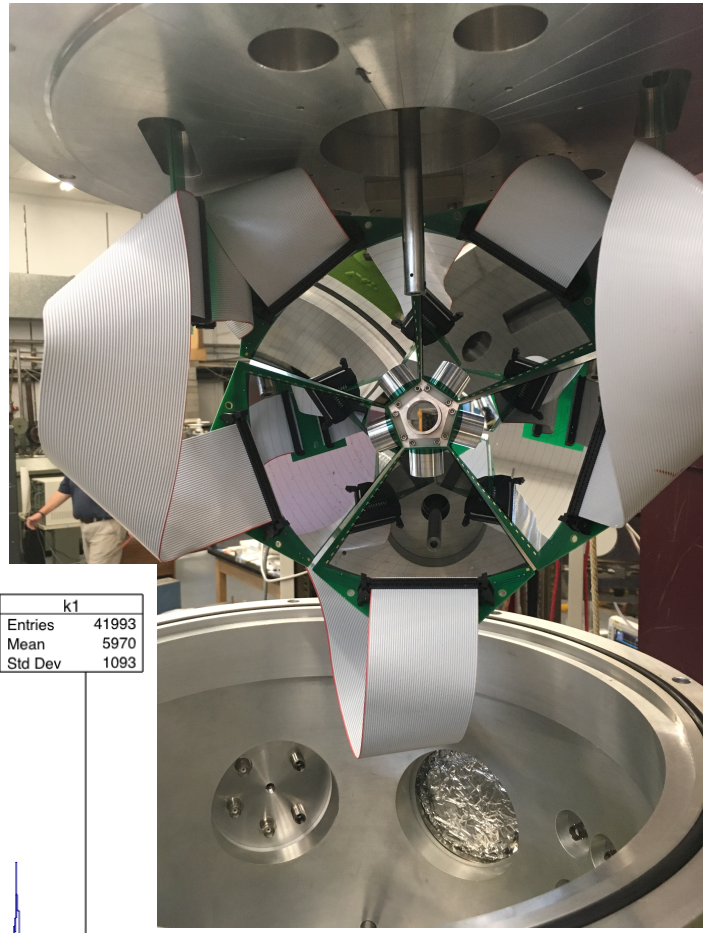
- $^{12}C(d, p)^{13}C$ reaction
  - Well known states in ^{13}C populated
- 16-MeV deuteron beam
- 200-μg/cm^2 thick ^{12}C target
- Achieved 35 keV FWHM resolution, comparable to when it was at Yale

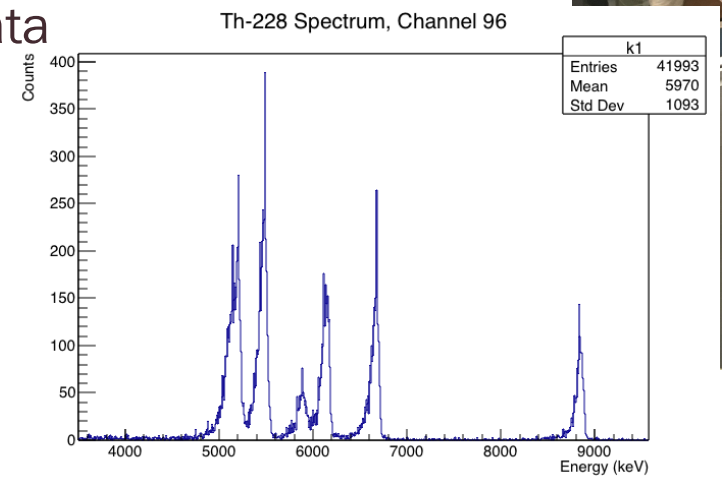


Fall 2018 – Summer 2019: Installation of SABRE in target chamber and first tests with alpha source

Many trips to FSU over this time:

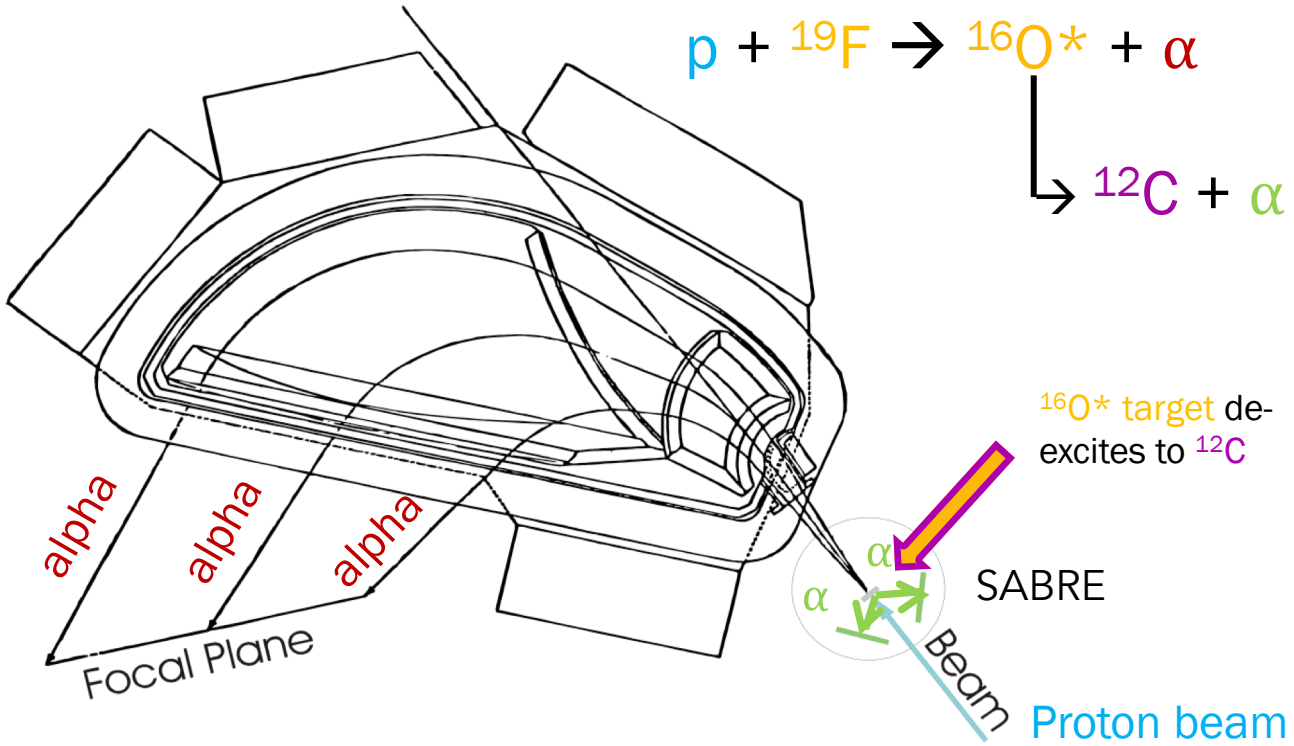
- Alignment of array with beamline
- Making cables for installation and installing all electronics
- Setup of planned data acquisition system (NSCLDAQ) and transition to new data acquisition system (CoMPASS)
- Transfer of focal plane detector to digital electronics

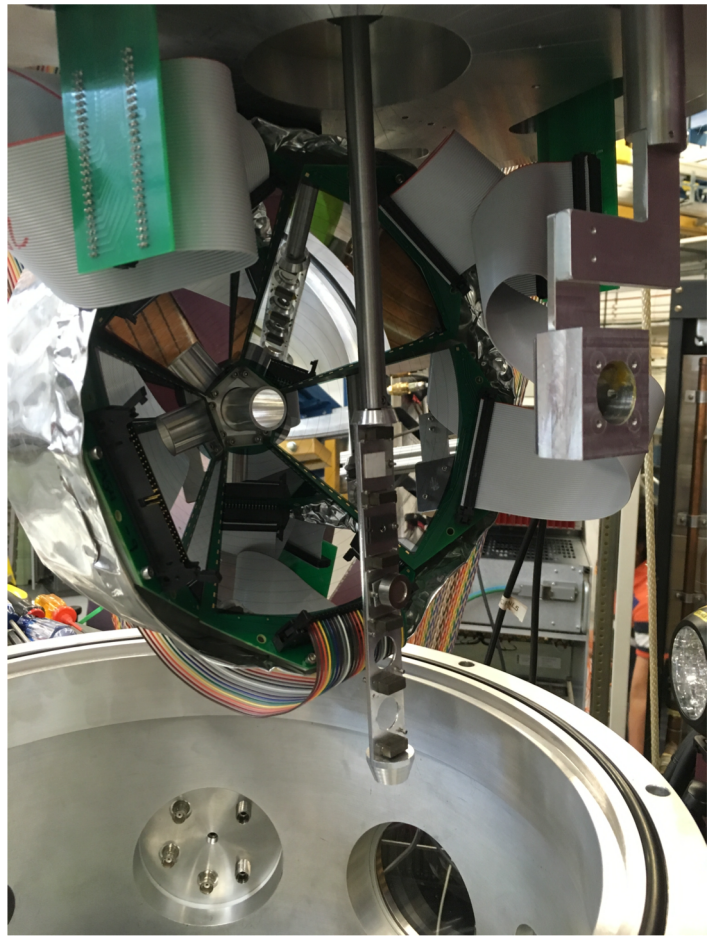




Fall 2019: Commissioning run of the SPS with SABRE

- Looking at known 100% α-particle branching ratios of states in ^{16}O via the $^{19}F(p,\alpha)^{16}O^{*}(\alpha)^{12}C$ reaction

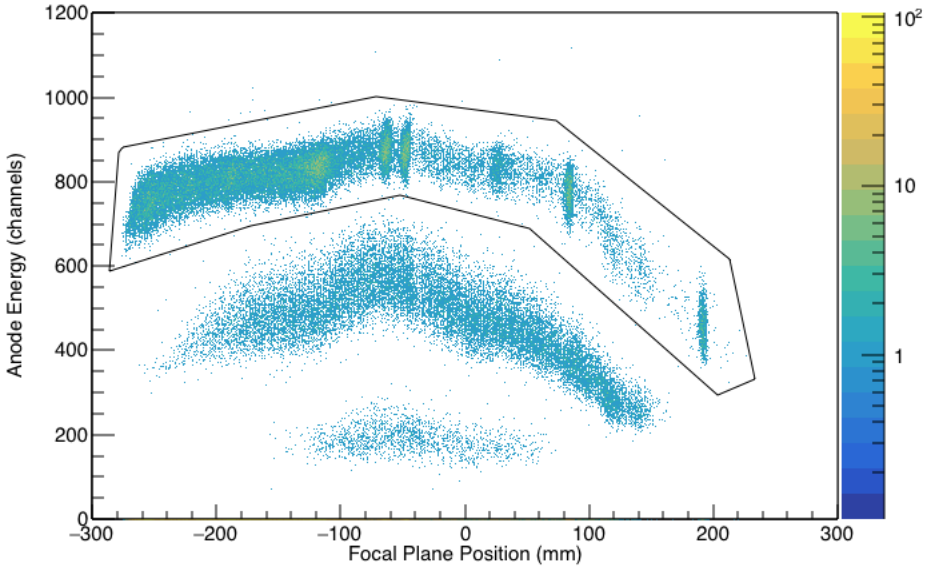




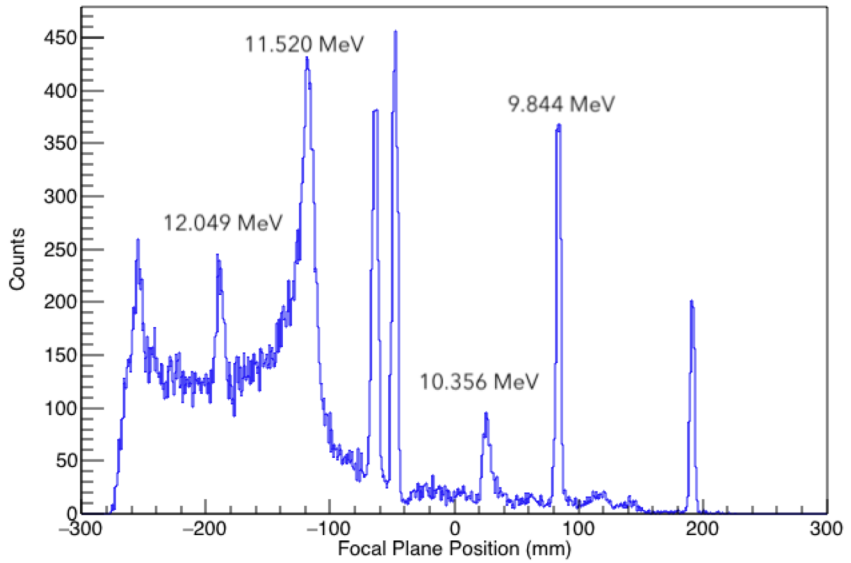
SABRE commissioning experiment analysis

- Looking at known 100% α-particle branching ratios of states in ^{16}O via the $^{19}F(p,\alpha)^{16}O^{*}(\alpha)^{12}C$ reaction

1. Plot focal plane position versus energy loss in focal plane to identify alpha particles



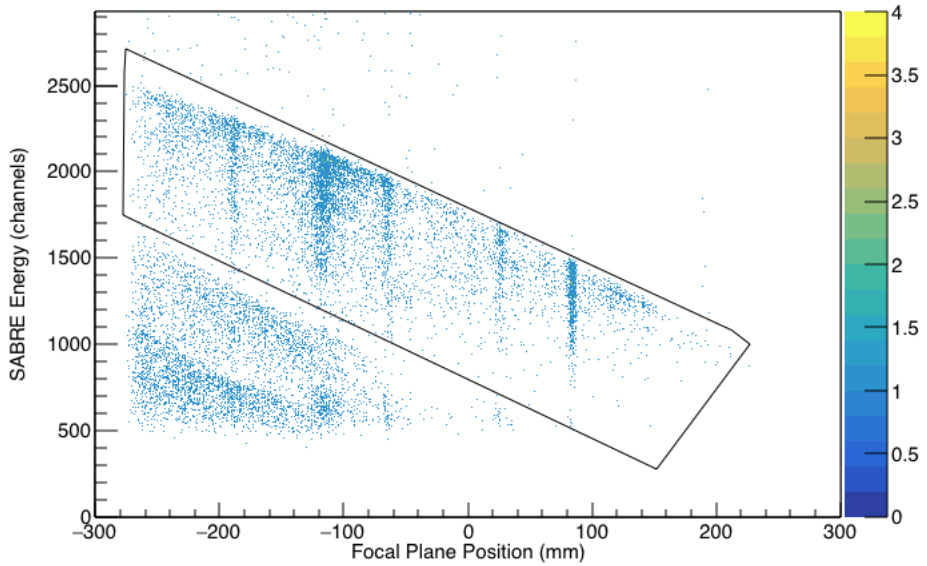
2. Project this cut onto the focal plane position axis (x axis) and integrate counts in peaks of interest



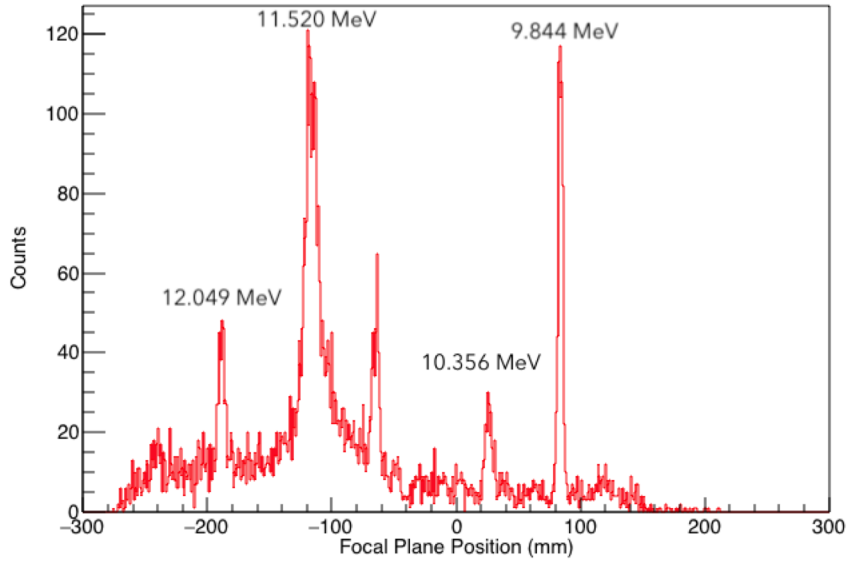
SABRE commissioning experiment analysis

- Looking at known 100% α-particle branching ratios of states in ^{16}O via the $^{19}F(p,\alpha)^{16}O^{*}(\alpha)^{12}C$ reaction

3. Plot focal plane position versus SABRE energy to find alphas that decay into SABRE



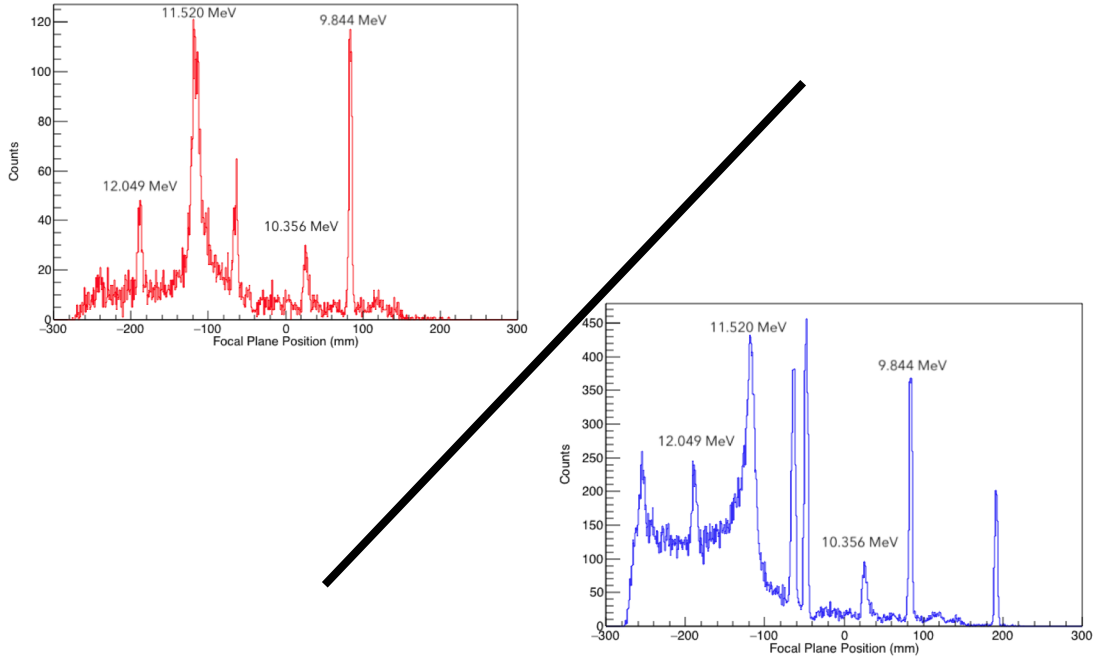
4. Project this cut onto the focal plane position axis (x axis) and integrate counts in peaks of interest



SABRE commissioning experiment analysis

- Looking at known 100% α-particle branching ratios of states in ^{16}O via the $^{19}F(p,\alpha)^{16}O^{*}(\alpha)^{12}C$ reaction

5. Divide SABRE counts over focal plane counts to get branching ratio not corrected for geometric efficiency



6. Compare these measured values to a simulation of geometric efficiency. If they agree, the measured branching ratios match!

	Branching Ratio Not Corrected for Geometric Efficiency	
Excitation Energy	Calculated	Measured
9.844 MeV	27.2(32) %	31.5(14) %
10.356 MeV	25.7(19) %	25.6(33) %
11.520 MeV	25.0(26) %	28.7(14) %
12.049 MeV	30.2(31) %	31.5(46) %

2019-2020: Analysis of commissioning data and first experimental runs

- Further improvements to the digital data acquisition scheme are made during this time
- Further physical shielding and biasing applied to SABRE to deter electrons and heavy particle backscatter
- Eventbuilding pipeline continually improved
- Experiments:
  - Study of branching ratios for the $^{26}Al^{g,m}(p, \gamma)^{27}Si$ reaction in classical novae
  - Study of highly excited states in ^{9}B via $^{10}B(^{3}He,\alpha)^{9}B$ of importance to relative abundances of ^{7}Li in BBN calculations
  - Low-lying resonances in ^{9}B using SABRE as a coincidence array
  - Examining interference effects between two resonant states in ^{13}N via $^{12}C(^{3}He,d)^{13}N$ at 20 and 40 degrees in the SE-SPS

2021: Publication of NIM article

- This publication is the announcement of the SE-SPS and SABRE in a journal
- SE-SPS collaboration had to finalize the name: Super Enge Split-Pole Spectrograph

ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

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SABRE: The Silicon Array for Branching Ratio Experiments

E.C. Good [a], B. Sudarsan [a], K.T. Macon [a], C.M. Deibel [a], L.T. Baby [b], J.C. Blackmon [a], C. Benetti [b], J.C. Esparza [b], N. Gerken [b], K. Hanselman [b], G.W. McCann [b], A.B. Morelock [b], J.F. Perello [b], K.H. Pham [a], E. Rubino [b], E. Temanson [b], I. Wiedenhöver [b]

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To conclude…

Proposed Project Schedule

- ✓ Disassembly of magnet and associated equipment and shipment to FSU
  - November 2013
- Detector development at LSU: Fall 2014 – Fall 2016
- Preparation of FSU experimental hall
  - rearrange FSU hall; build new beam line (Winter 2014)
  - pour concrete pedestal (Winter 2015)
- Installation of Magnet at FSU
  - Summer 2016
- First experiments with split-pole at FSU
  - Fall 2016 – Spring 2017
- Far future ideas:
  - gamma detection?
  - gas-filled mode?

- The proposed project timeline is never as quick as you plan for!
- First experiments with just the SPS were in 2018
- First SABRE experiments were in late 2019

However,

- SABRE and the SE-SPS are now running regularly for a number of experiments for nuclear structure and astrophysics applications
- We achieve lower thresholds and higher rates with the new setup

Many thanks

Everyone from LSU and FSU that helped to plan this project and worked on the commissioning run:

B. Sudarsan, K.T. Macon, C.M. Deibel, L.T. Baby, J.C. Blackmon, C. Benetti, J.C. Esparza, N. Gerken, K. Hanselman, G.W. McCann, A.B. Morelock, J.F. Perello, K.H. Pham, E. Rubino, E. Temanson, I. Wiedenhöver

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