The SECAR Recoil Separator

Mackenzie Smith

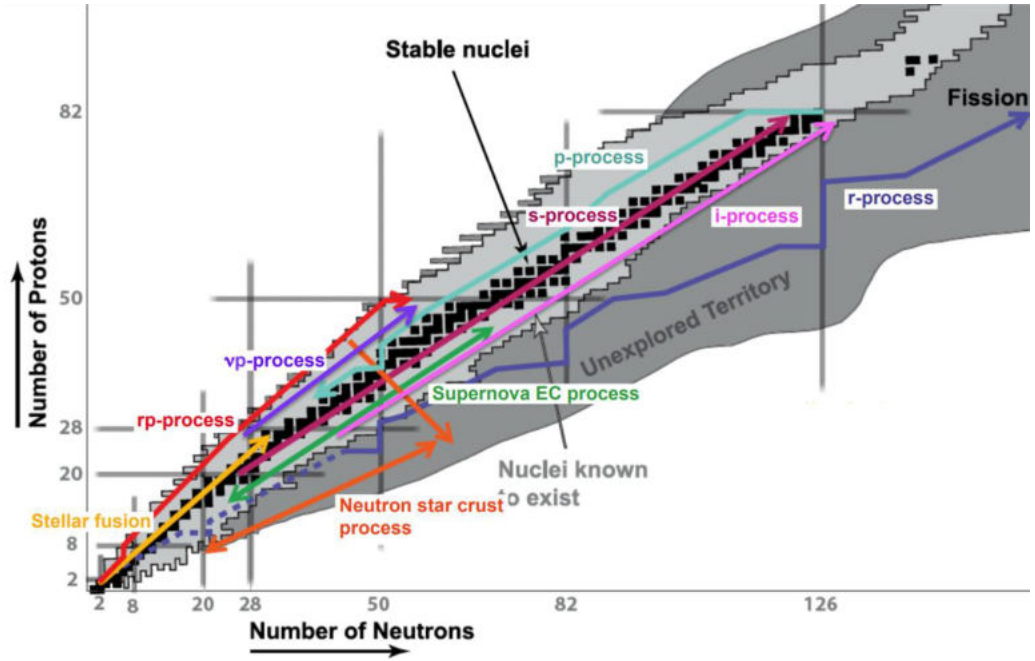
19th Rußbach School on Nuclear Astrophysics

8 March 2024

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB), which is a DOE Office of Science User Facility, under Award Number DE-SC0000661.

Scientific Motivation

- To measure the capture reaction rates of radioactive nuclei with hydrogen or helium to understand observations of astrophysical phenomena and address open question in nuclear physics

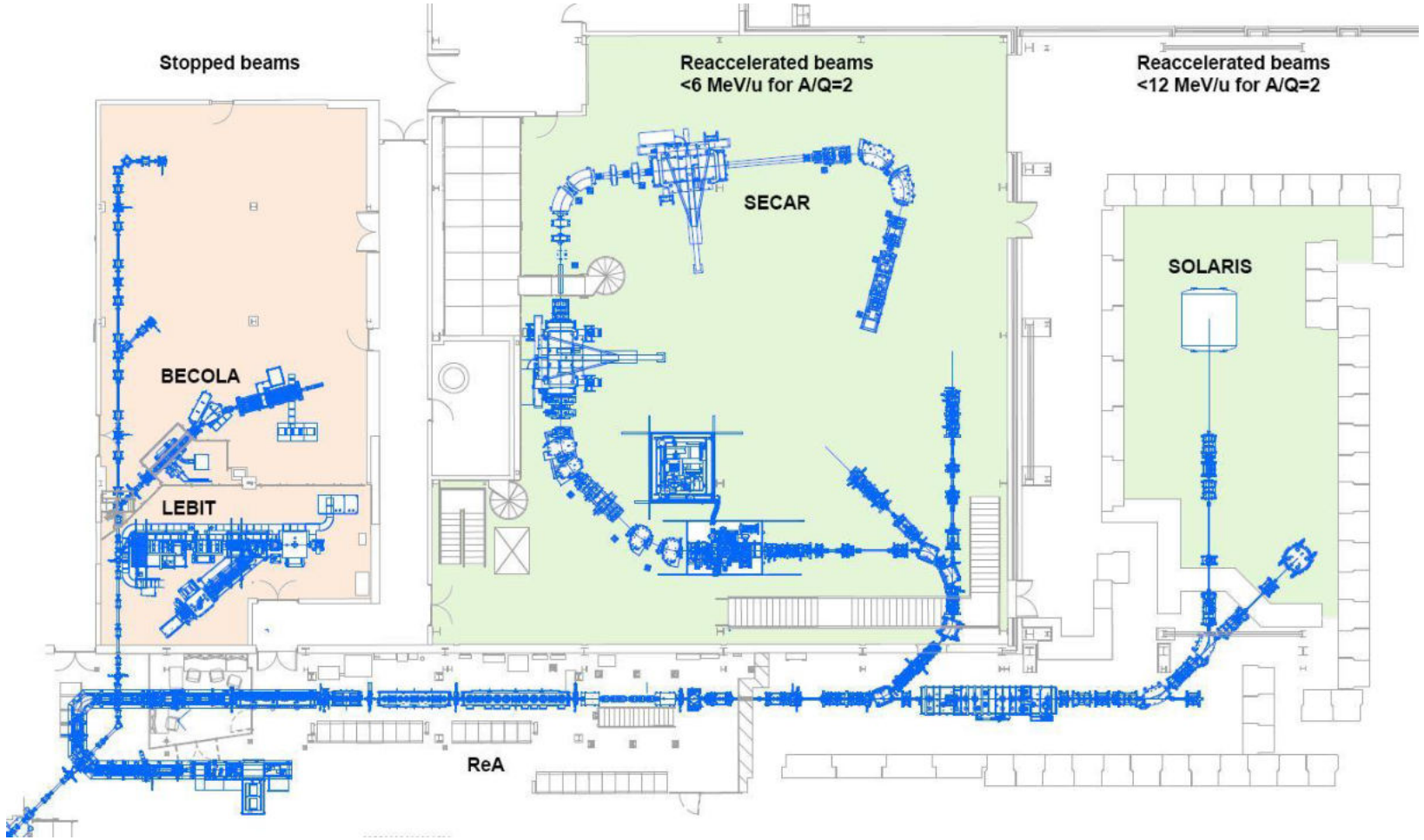


Core-Collapse Supernovae (CCSNe)

Classical Novae

Type I X-Ray Bursts

Reaccelerated Beams from the Facility for Rare Isotope Beams (FRIB)

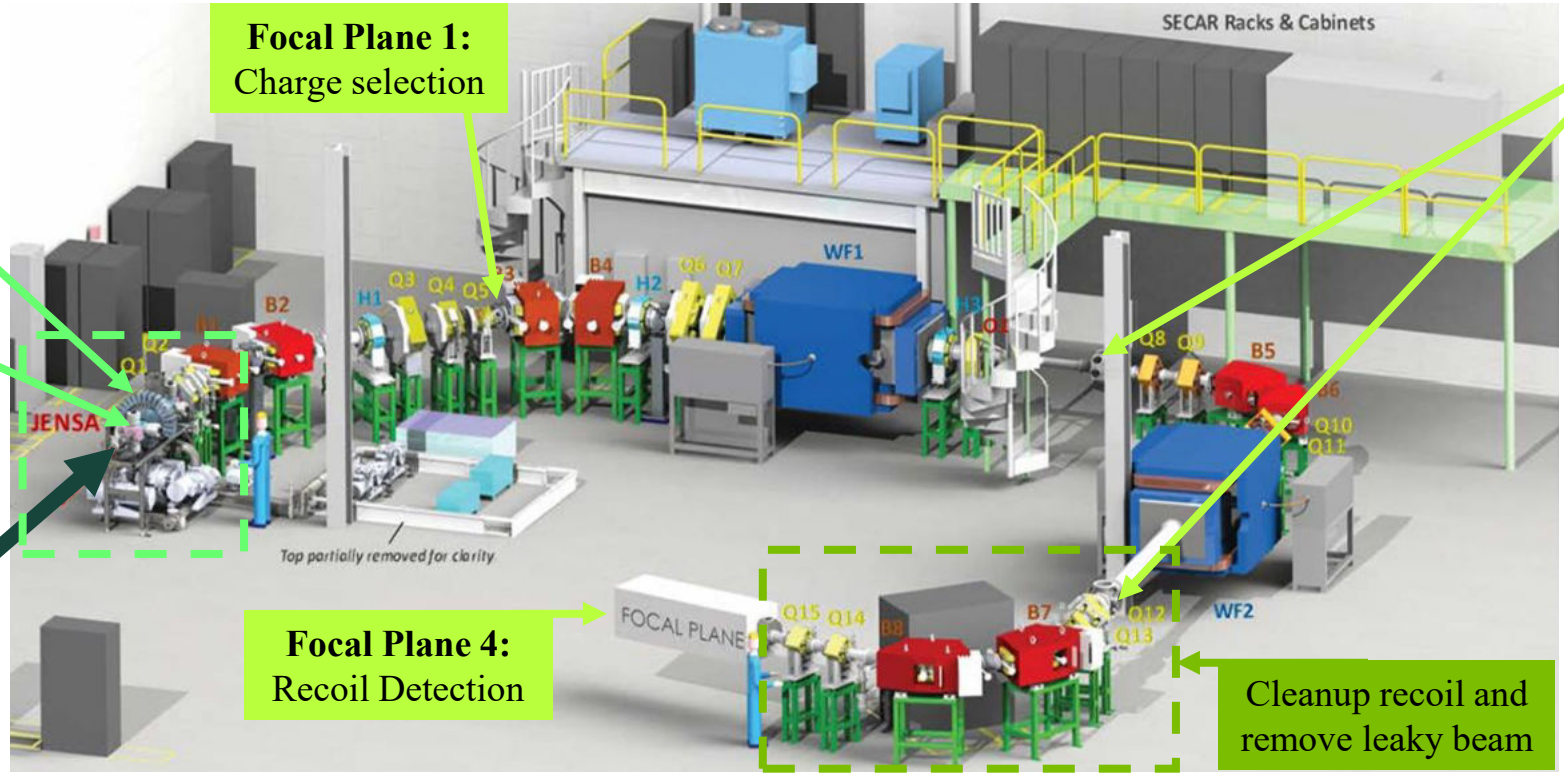


SECAR Layout

γ-ray, neutron, and scattering detectors (e.g., BGO Array)

JENSA or Extended Gas Target

Reaccelerated beam enters SECAR



Focal Plane 1: Charge selection

Focal Planes 2 & 3: Wien Filters separate recoils by $\frac{\text{mass}}{\text{velocity}}$

Focal Plane 4: Recoil Detection

Cleanup recoil and remove leaky beam

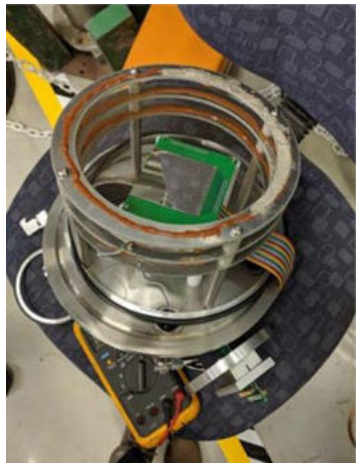
Elements:

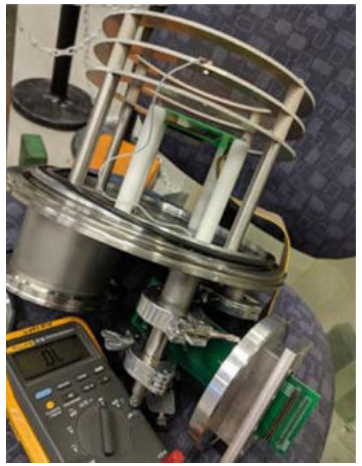
- **Dipole (× 8)**
- **Quadrupole (× 15)**
- **Hexapole (× 3)** or **Octopole (× 1)**
- **Wien Filter (× 2)**
- **Focal Plane (FP; × 4)**

The **SE**parator for **CA**pture **R**eactions (**SECAR**) is designed to directly measure capture reactions in inverse kinematics

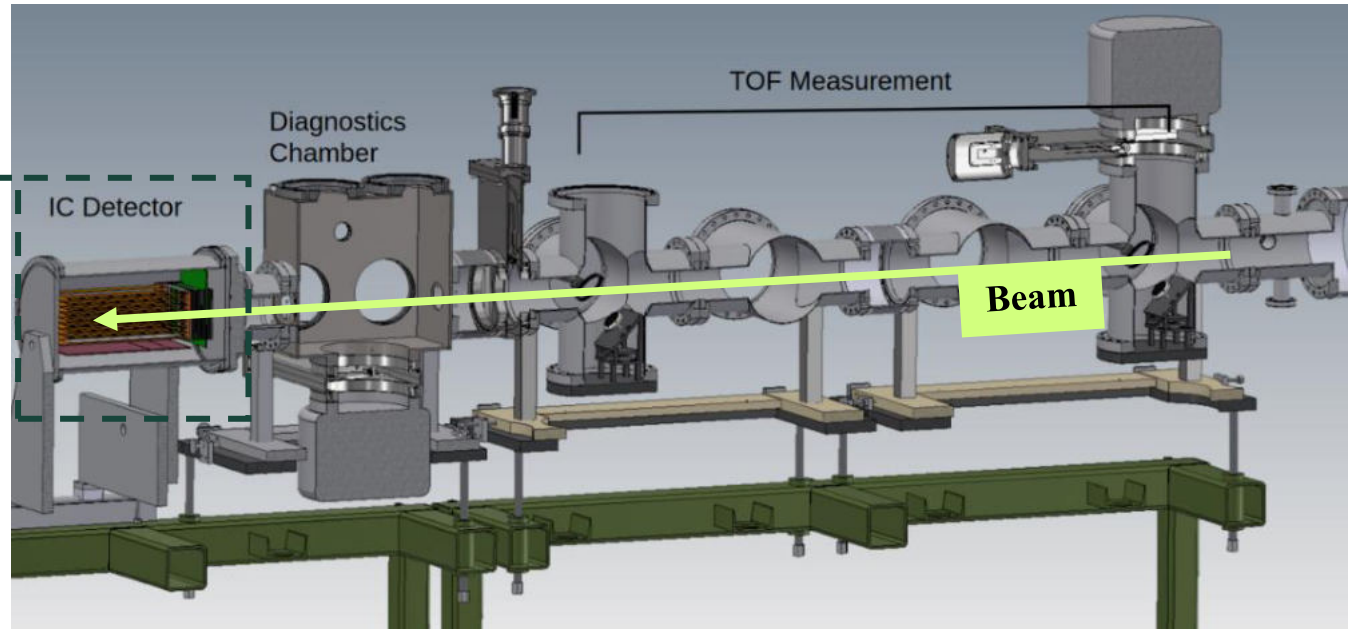
Focal Plane (FP) Detectors for Additional Separation

- FP 1-4 used to determine the size and distribution of the beam spot
- FP 4 detects particles and provides further separation between recoils and leaky beam





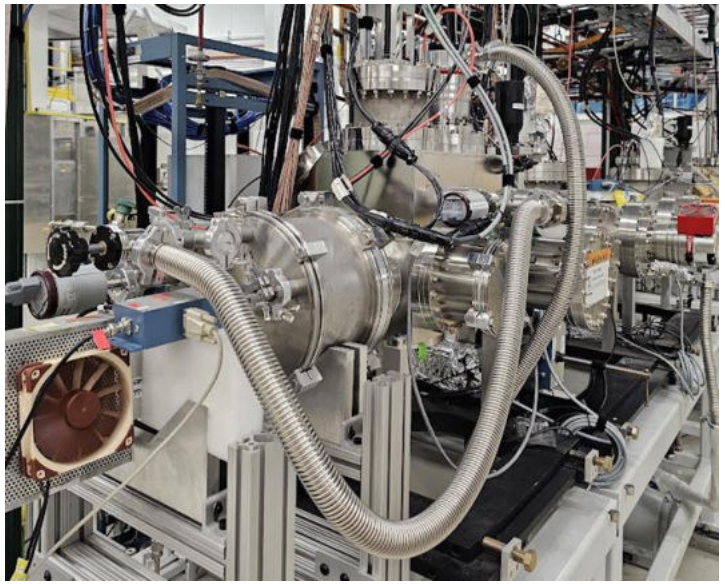
Hybrid Ionization Chamber (IC) and
Double-Sided Silicon Strip Detector (DSSD)

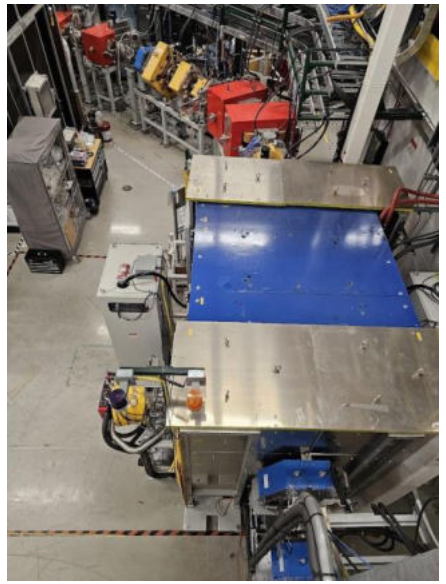


Focal plane detection system at FP 4

SECAR Status

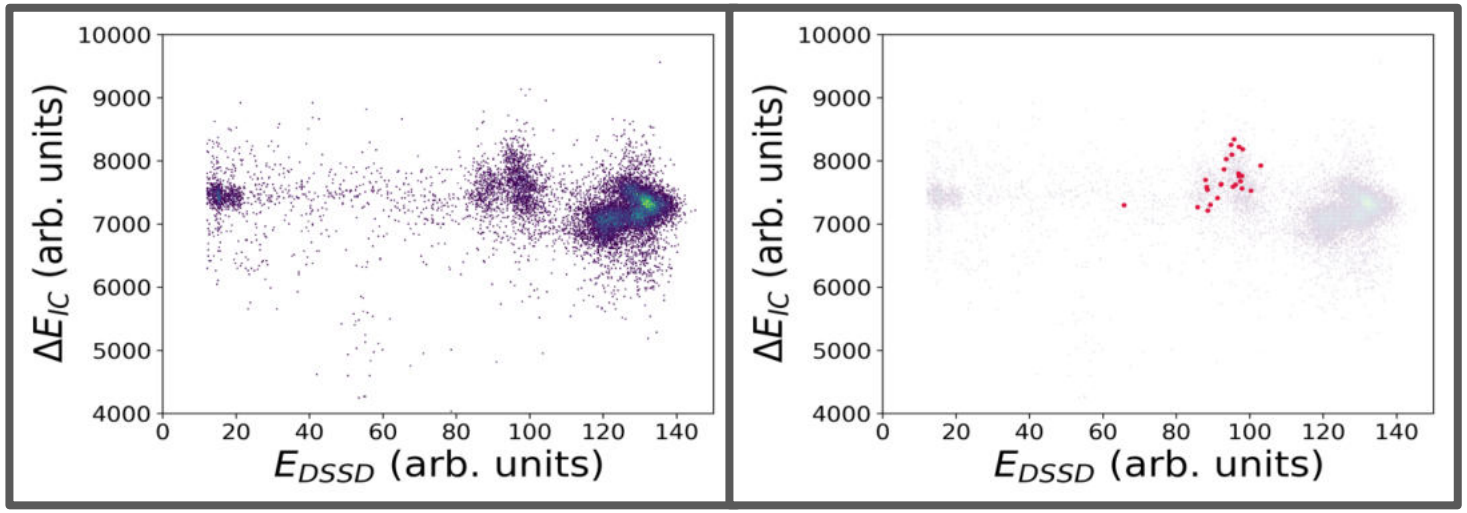
- Construction project completed in September 2021
- First experiments performed at NSCL for (α, n) and (p, n)
- Ongoing test experiments for (p, γ) at FRIB





Experimental Results for ^{86}Kr (α, xn) $^{88\text{-}89}$Sr

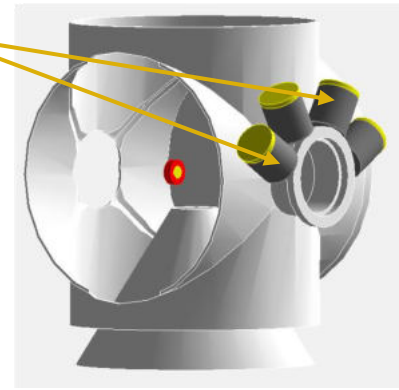
- An important reaction for the weak r-process in CCSNe
- First SECAR experiment, performed with the Jet Experiments in Nuclear Structure and Astrophysics (JENSA)



JENSA

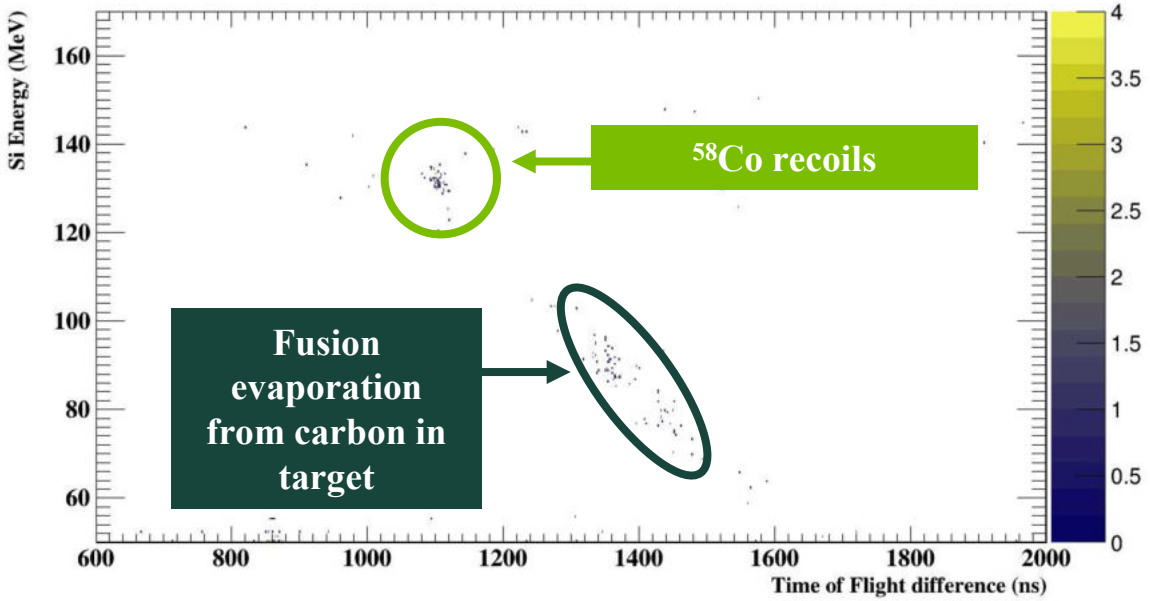
K. Chipps, U. Greife, K. Schmidt, et al.

Liquid scintillators for neutron detection

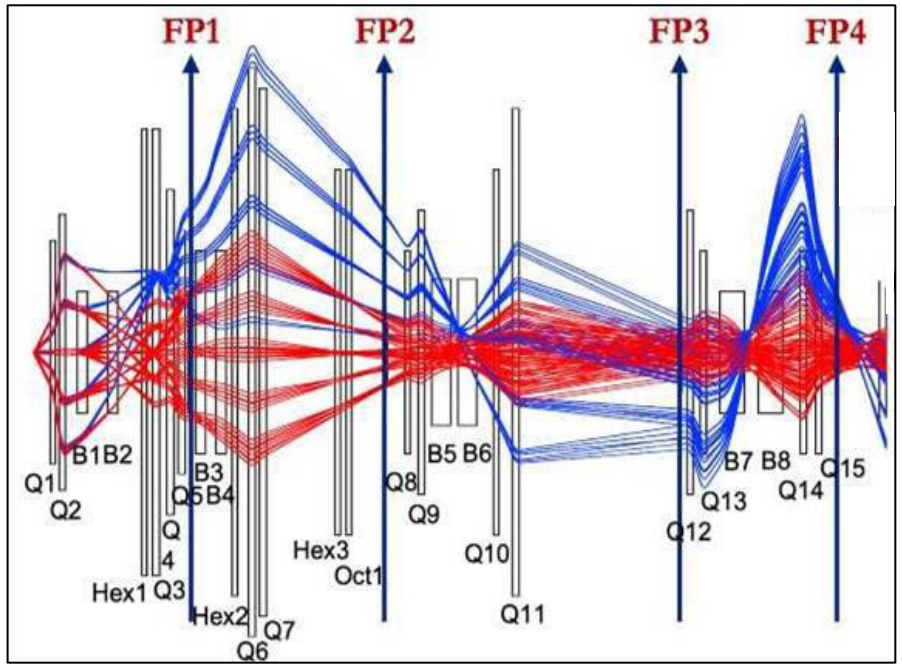


Experimental Results for ^{58}Fe (p, n) ^{58}Co

- Test experiment for inverse νp-process reaction
- Relevant to νp-process and core-collapse supernovae
- SECAR capable of separating recoils of similar mass using p/q difference

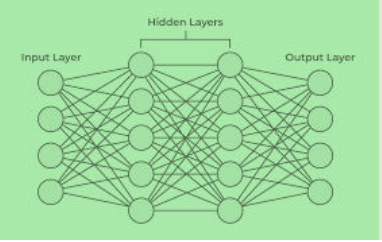


^{58}Co Recoils
^{58}Fe Leaky Beam

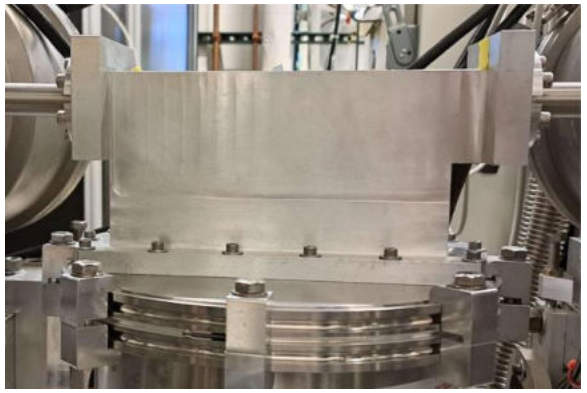
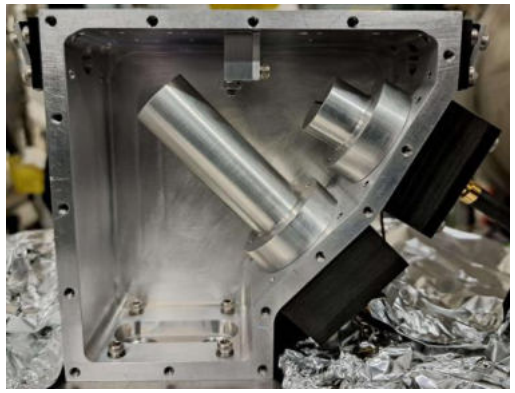
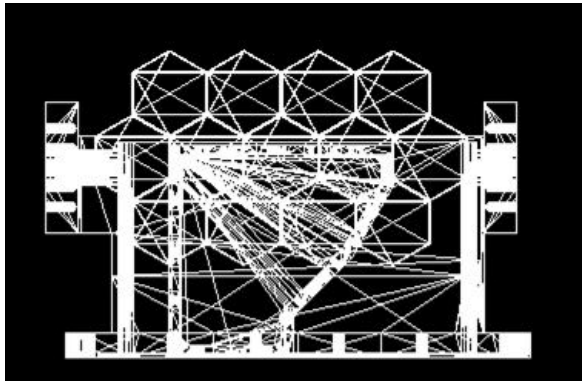
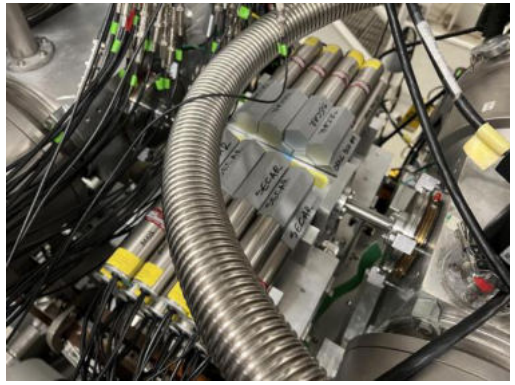


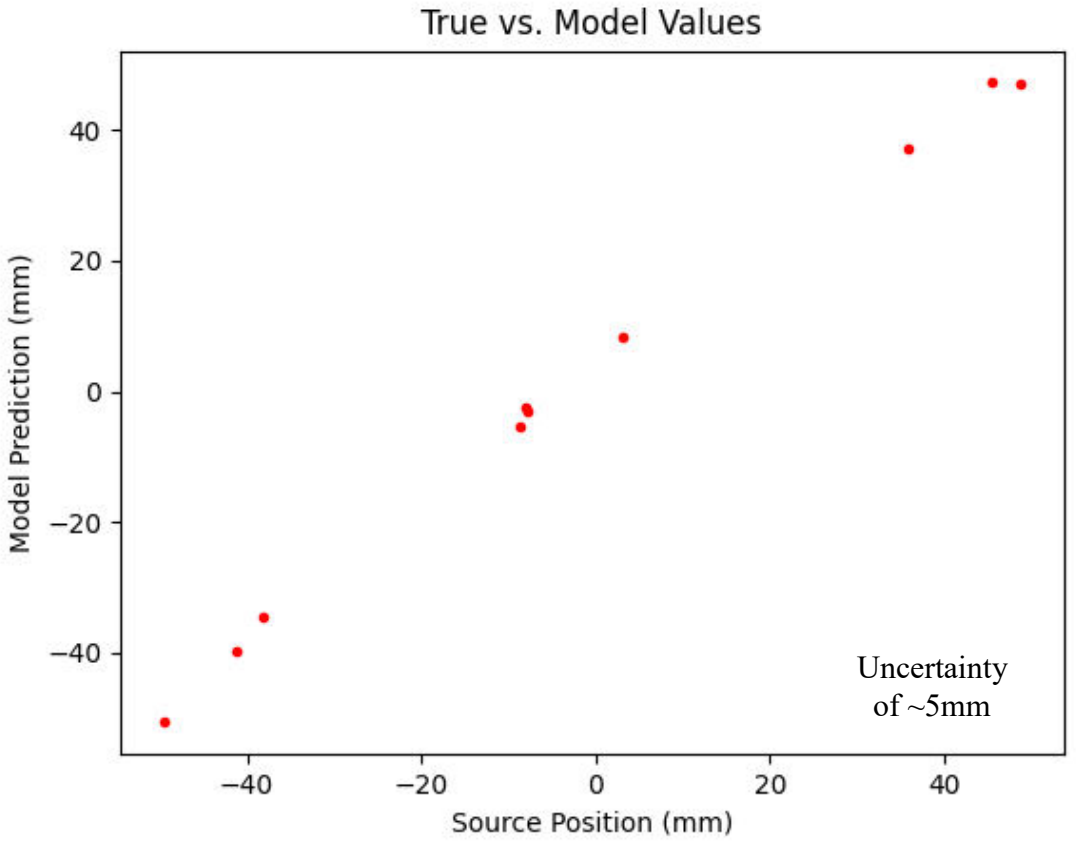
P. Tsintari et al., 2023

Neural Network to Determine Resonance Position with Windowless Extended Gas Target



Windowless Extended Gas Target



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SECAR Core Group

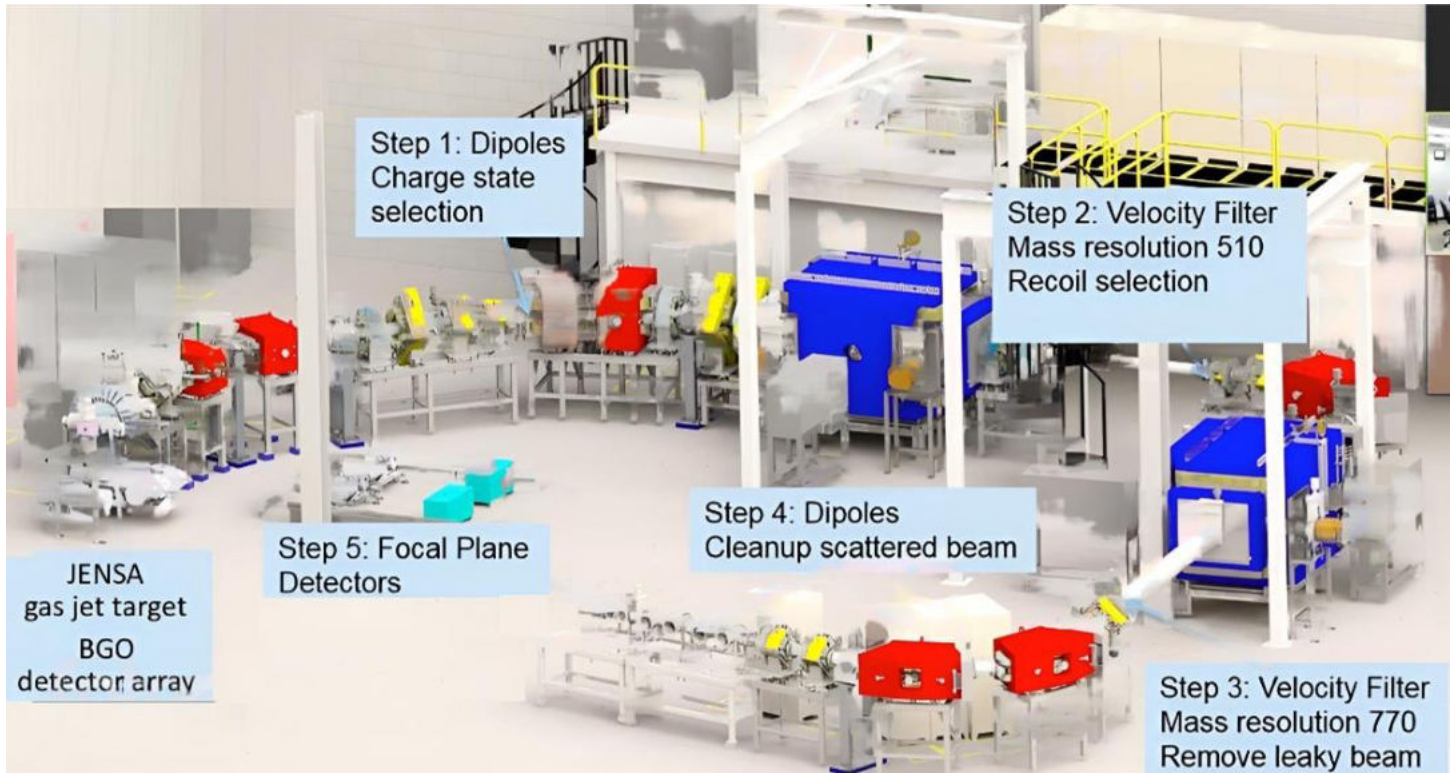
Mackenzie Smith[1,2,3], G. Berg[4,5], J. Blackmon[6], K. Chipps[7], M. Couder[4,5], C. Deibel[6], U. Greife[8], F. Montes[2,3], H. Schatz[1,2,3], K. Setoodehnia[2], M. Smith[7], R. Garg[1,2,3], K. Hermansen[1,2,3], A. Hood[9], R. Jain[1,2,3], S. Miskovich[1,2,3], T. Ruland[6], C. Tinson[1,2,3], P. Tsintari[2,10], L. Wagner[1,2,3]

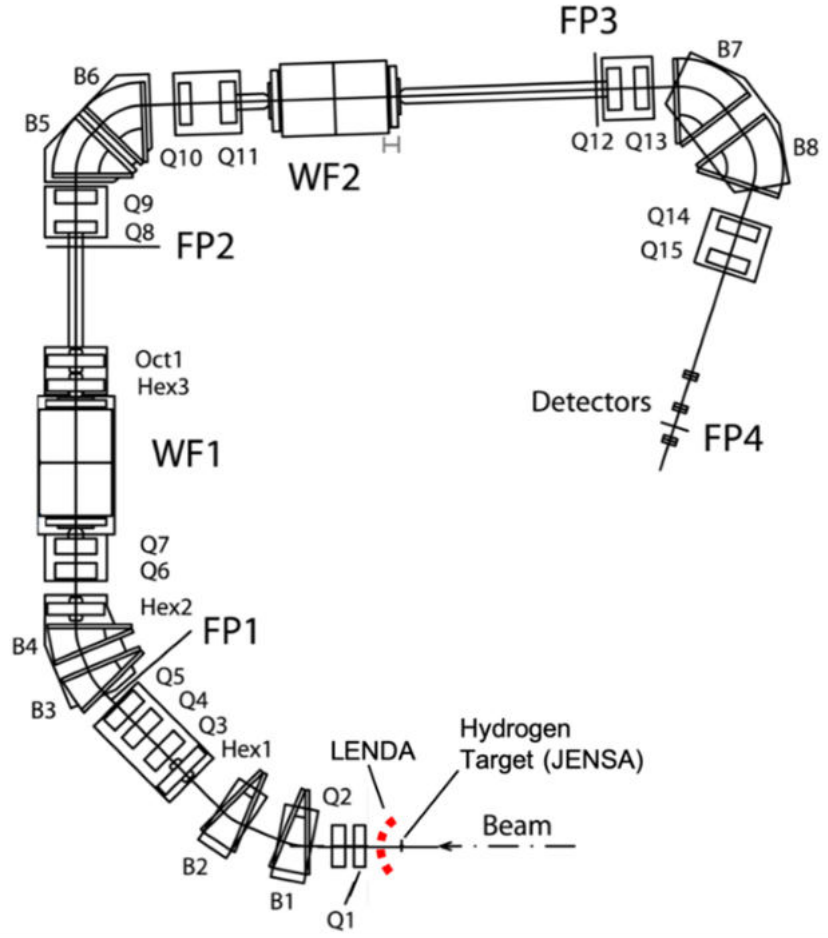
1. Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA **2.** Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA **3.** The Joint Institute for Nuclear Astrophysics, Michigan State University, East Lansing, Michigan 48824, USA **4.** Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556, USA **5.** The Joint Institute for Nuclear Astrophysics, University of Notre Dame, Notre Dame, Indiana 46556, USA **6.** Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803, USA **7.** Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA **8.** Department of Physics, Colorado School of Mines, Golden, CO 80401, USA **9.** Cyclotron Institute, Texas A&M University, College Station, Texas 77843, USA **10.** Department of Physics, Central Michigan University, Mt Pleasant, Michigan 48859, USA

Conclusions

- SECAR has been established at FRIB and first experiments have been performed
  - SECAR has demonstrated the ability to directly measure capture reactions in inverse kinematics for both $(\alpha, \mathrm{x}n)$ and (p, n) reactions
  - Test experiments for upcoming (p, γ) measurements are ongoing
- Ongoing neural network development for resonance position
  - Source measurements in the lab and from GEANT4 simulations
- Future plans:
  - Hydrogen operation for (p, γ) reactions with extended gas target
  - Four FRIB approved experiments

SECAR Layout (Option 1)





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