LA-UR-19-28495
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Title: LENZ at LANSCE: neutron-induced charged-particle reaction studies on radioactive nuclei

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Intended for: CENTAUR Scientific Advisory Committee Meeting, 2019-08-21/2019-08-23 (Los Alamos, New Mexico, United States)

Issued: 2019-08-22

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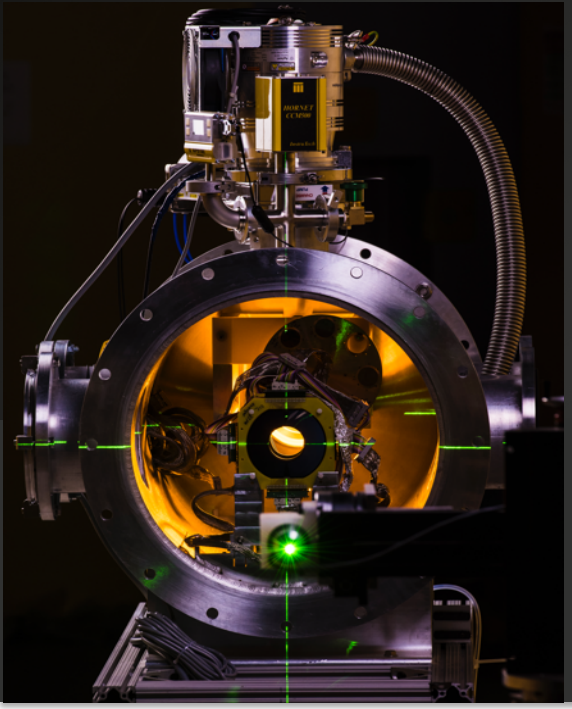

LENZ at LANSCE: neutron-induced charged-particle reaction studies on radioactive nuclei

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Theory Division (T-2): T. Kawano, M. Herman

Chemistry Division (C-IIAC): C. Vermeulen, C. Lledo, E. Birnbaum, M. Brugh, S. Kozimor, V. Mocko, M. Nortier

Korea Atomic Energy Research Institute: H.I. Kim

Central Michigan University: G. Perdikakis, P. Tsintari

North Carolina State U.: C. Frohlich

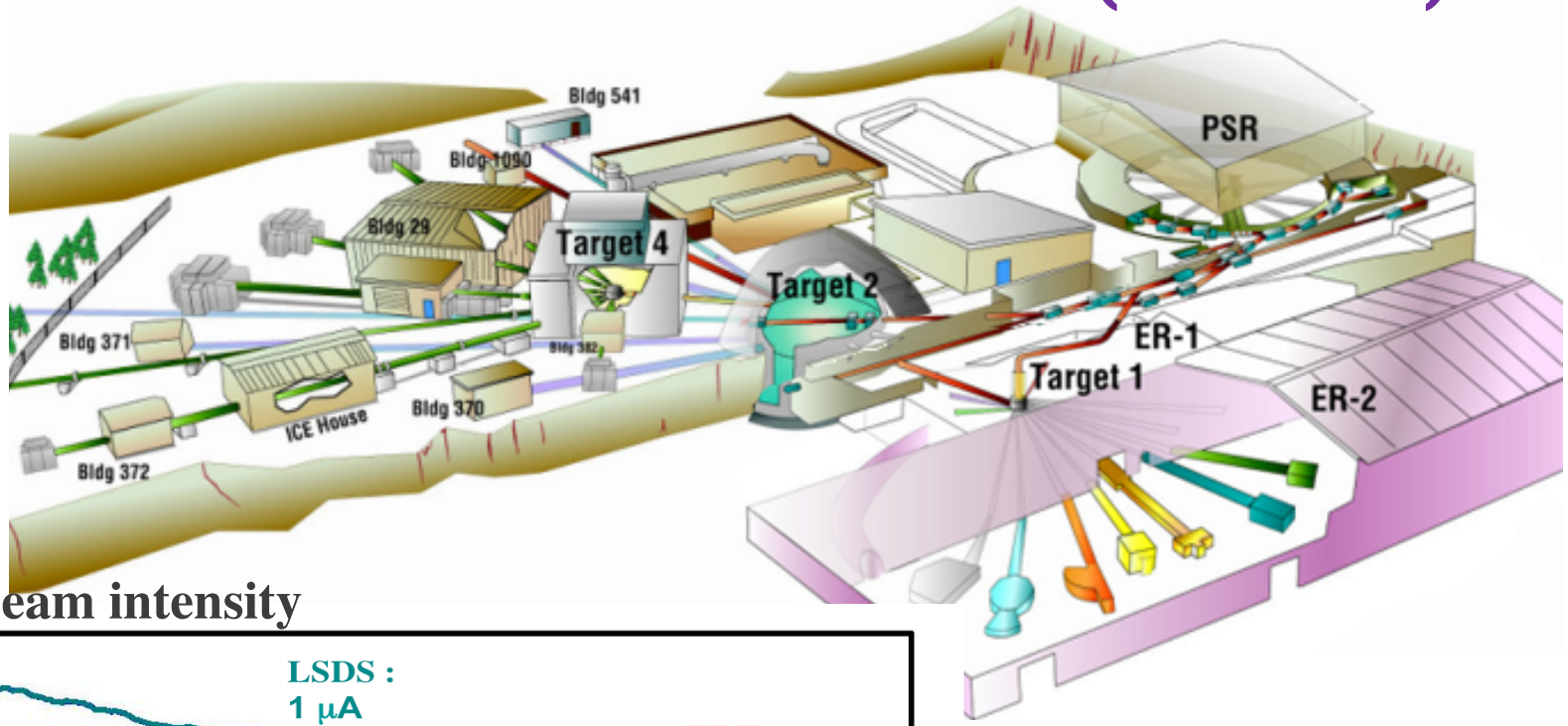
Michigan State U.: M. Grinder

Grad students, postdocs, guest scientists

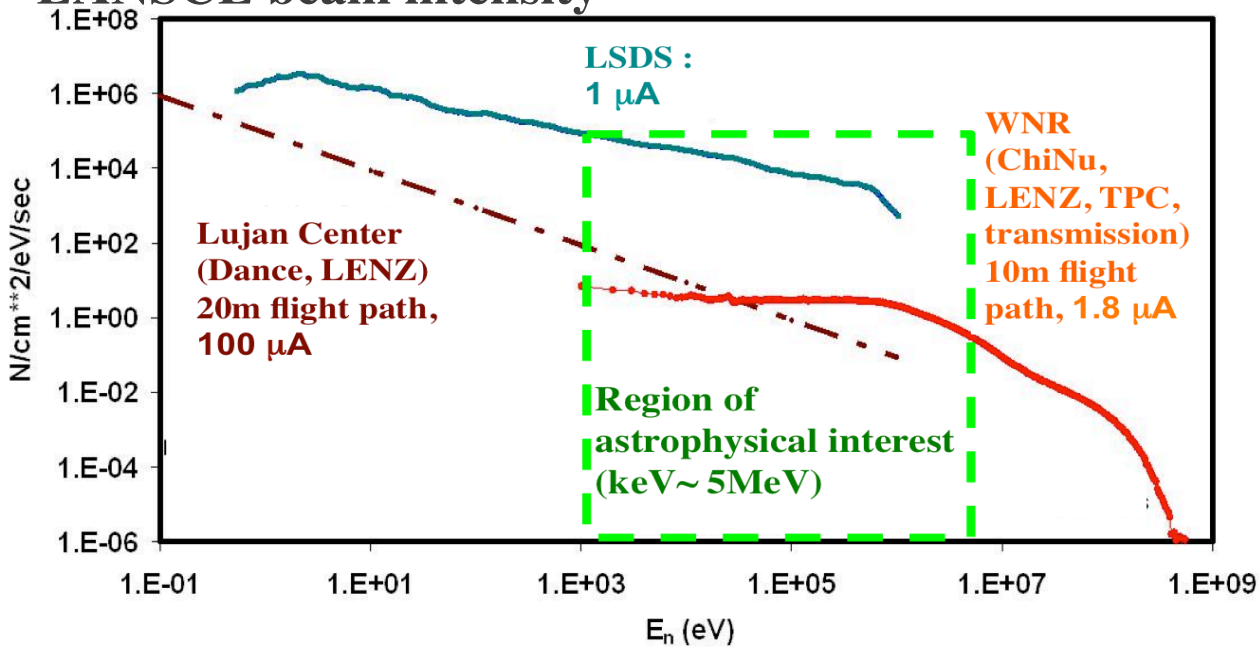
Los Alamos NATIONAL LABORATORY EST. 1943

NNSA National Nuclear Security Administration

Los Alamos Neutron Science Center (LANSCE)



LANSCE beam intensity



LANSCE beam energy

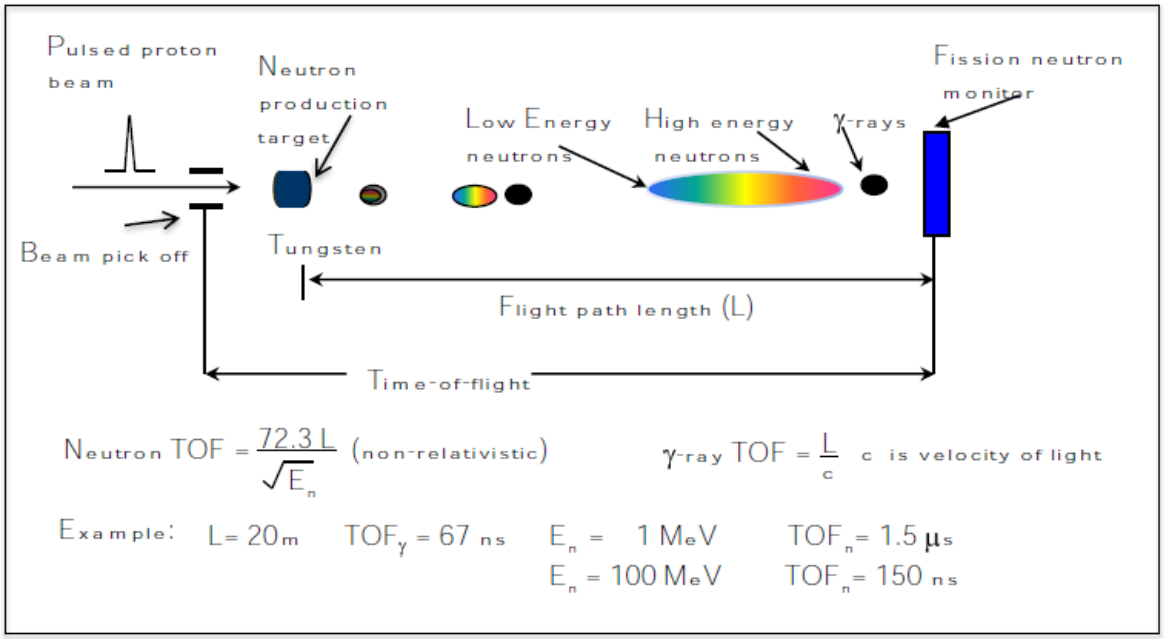
Lujan Center

-thermal ~ 100 keV

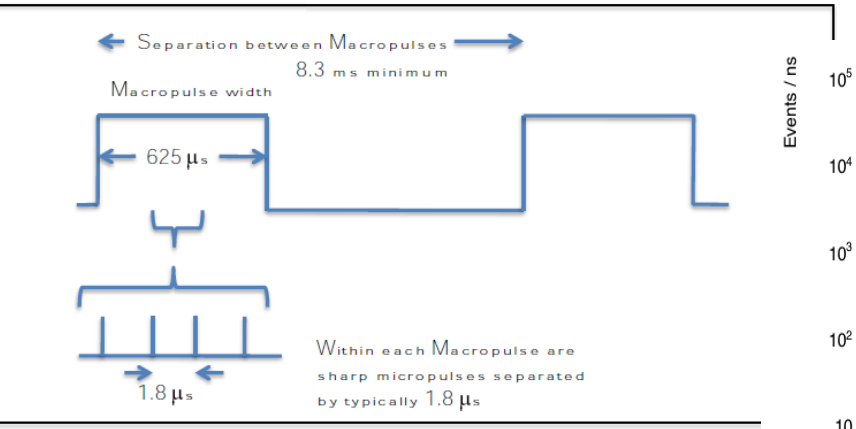
Weapons Neutron Research

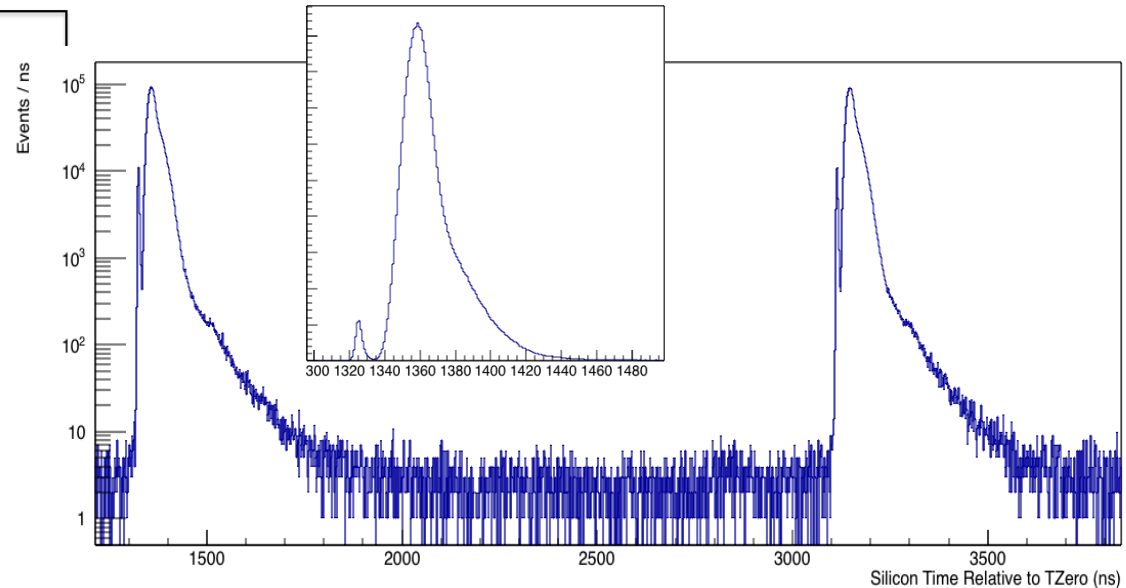
-100 keV ~ 600 MeV

Weapons Neutron Research: Time of Flight (TOF) facility

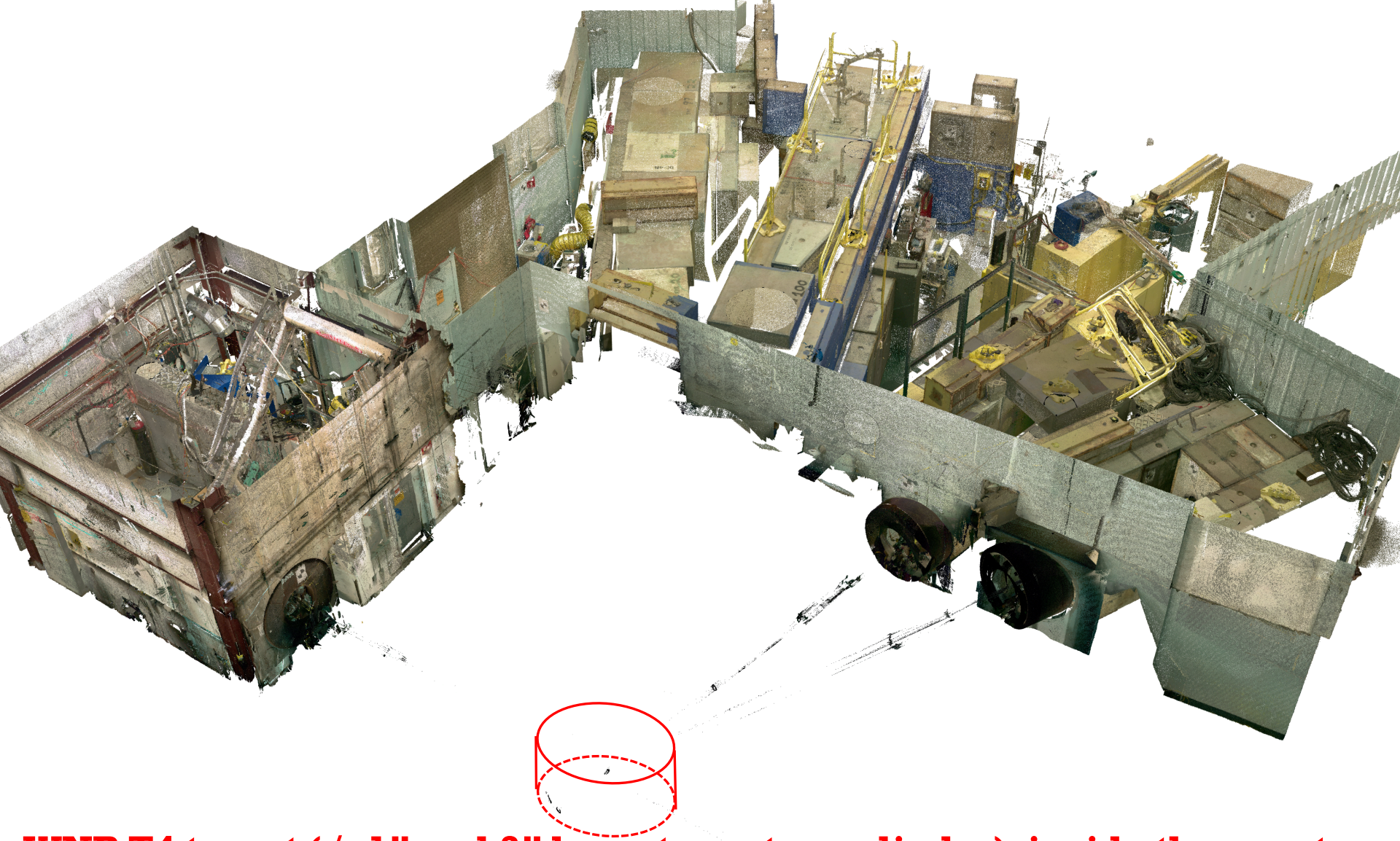


- TOF of neutron at the detection relative to the T0 (proton pickup time before impinging the W production target, provides neutron energy
- Neutron energy resolution and range are determined by timing resolution and flight path length



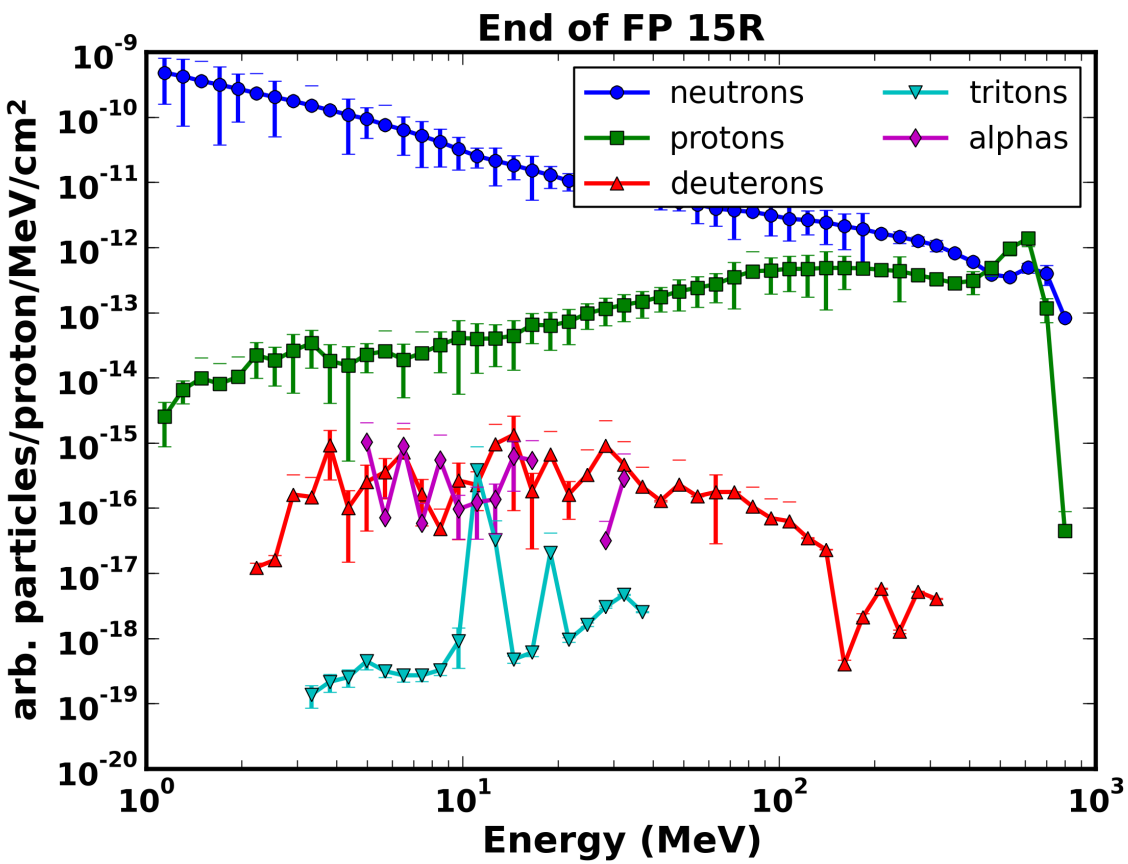


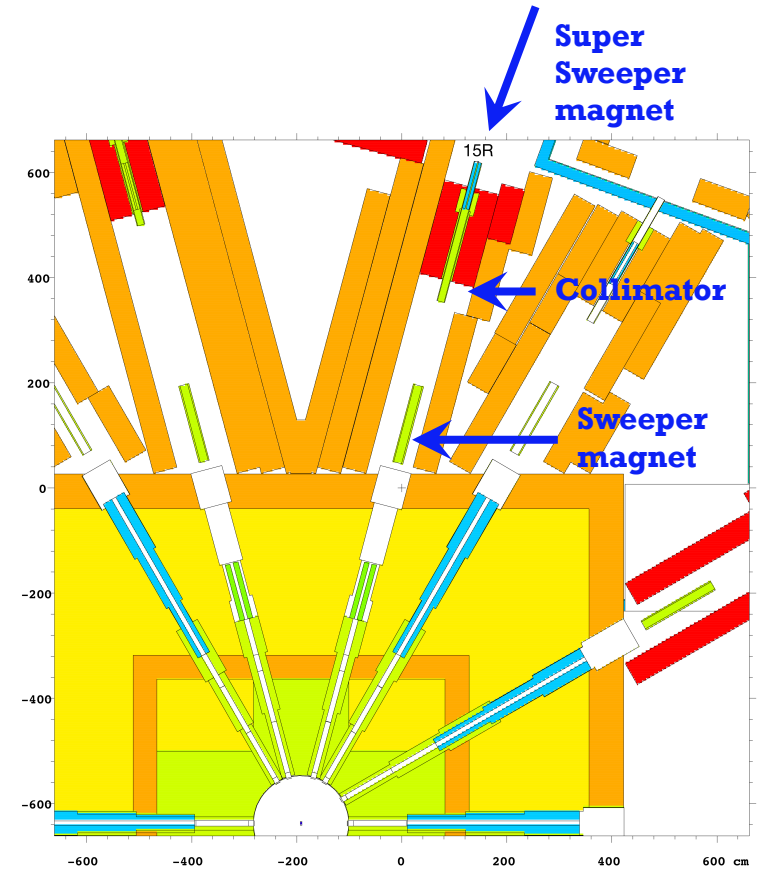
WNR facility survey with LIDAR measurements



WNR T4 target (ϕ=1” and 3” long, tungsten cylinder) inside the crypt

MCNP simulation of WNR neutron production via spallation

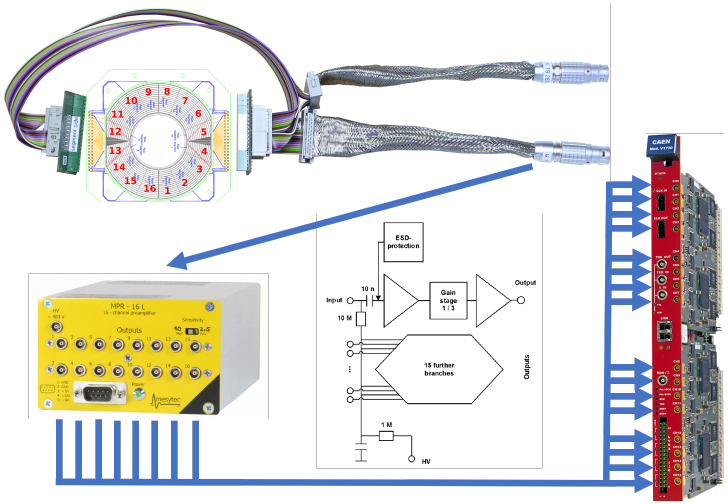




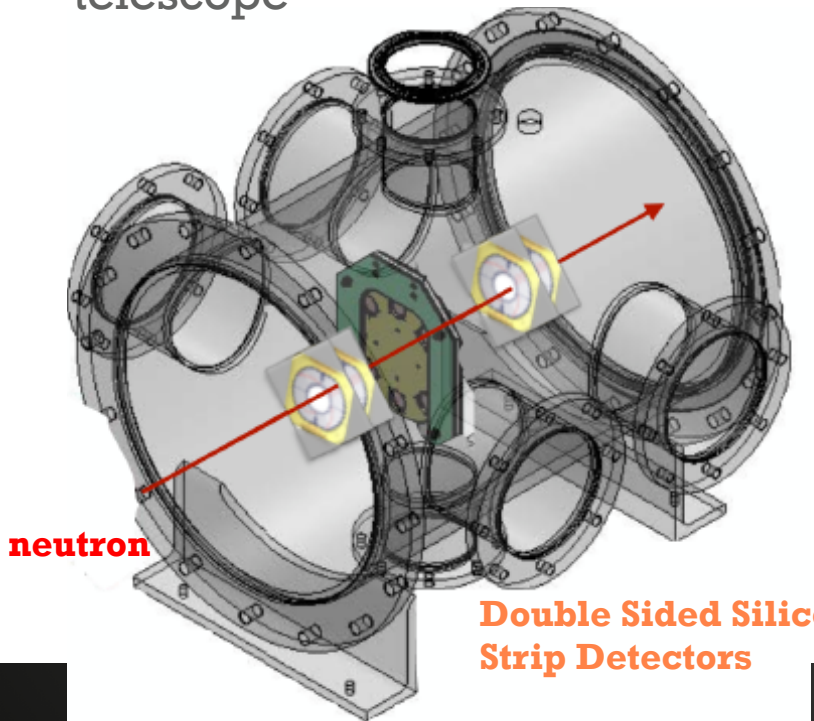
- Precise mapping of the WNR facility for improving the fidelity of MCNP modeling
- Sweeper & Super-sweeper will be used to reduce background at forward angles
- This improved MCNP modeling would be used optimizing new experiments with better predictive power in systematic uncertainties, backgrounds, etc.

Low Energy (n,z) (LENZ): Direct measurement of double differential cross sections

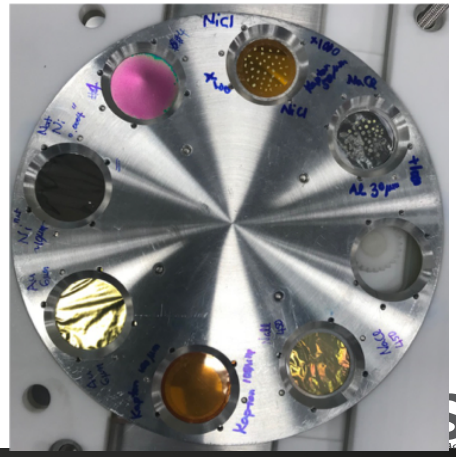
- Designed for measuring (n,z) reactions simultaneously with a large detection coverage and a low detection threshold for various applications, using solid targets & digitizers
- Twin Frisch grid ionization chamber coupled with silicon strip detectors to measures angles and energies of charged particles as a telescope



Post processing of digitized waveforms enables high selectivity for signals and high-quality data based on redundant information and preserving raw data

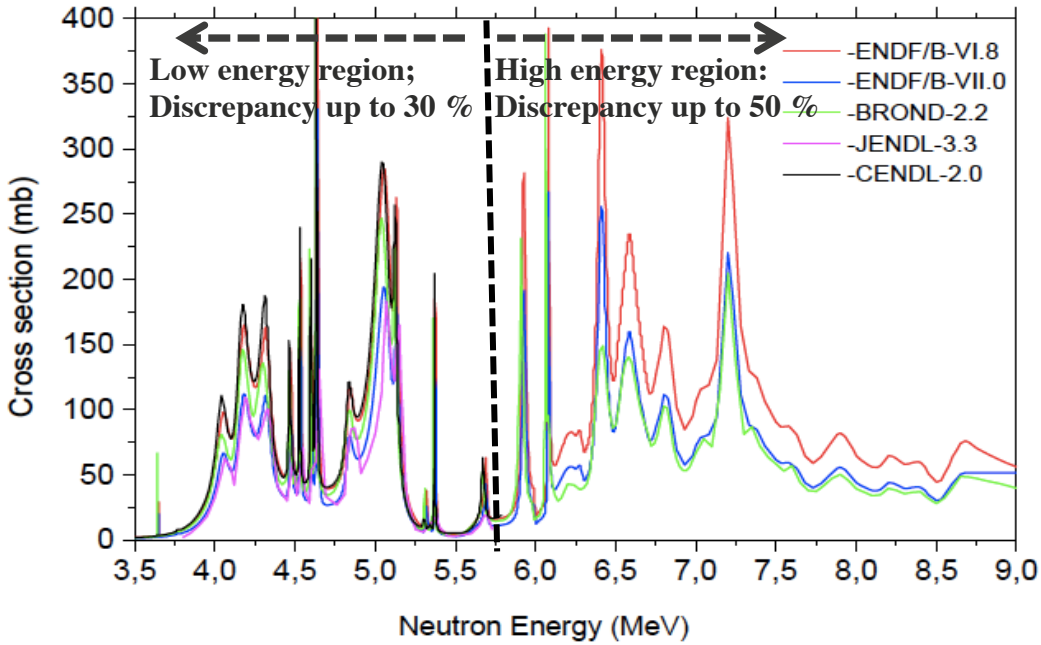


Instead of gas targets, we developed solid & thin-film target fabrications for reducing systematic uncertainty



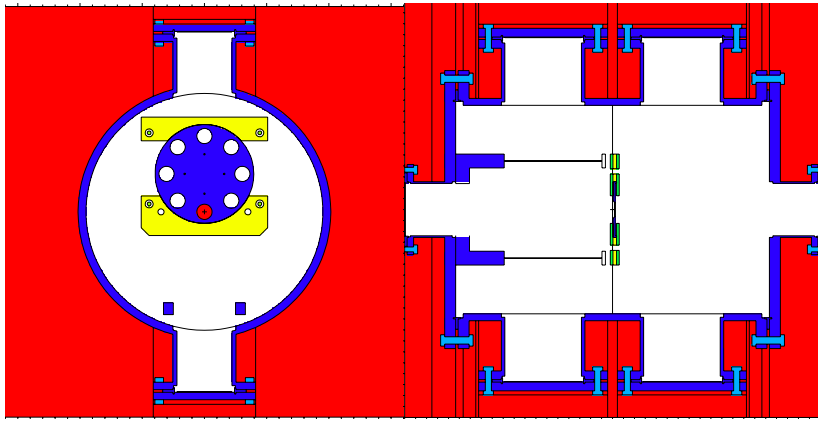
High precision measurements of charged particles are interest for nuclear application at LANL

- Current evaluations on the $^{16}O(n,\alpha)$ reaction differ by 30-50 %, requiring new data
- For the case of reactors, mostly used UOX and MOX fuels contain lots of oxygen
- New LENZ measurement at LANSCE with advanced analysis method will provide an independent data set with reduced systematic uncertainties in the neutron energy range of interest



NEMEA-7, 5-8 November 2013, Geel, Belgium

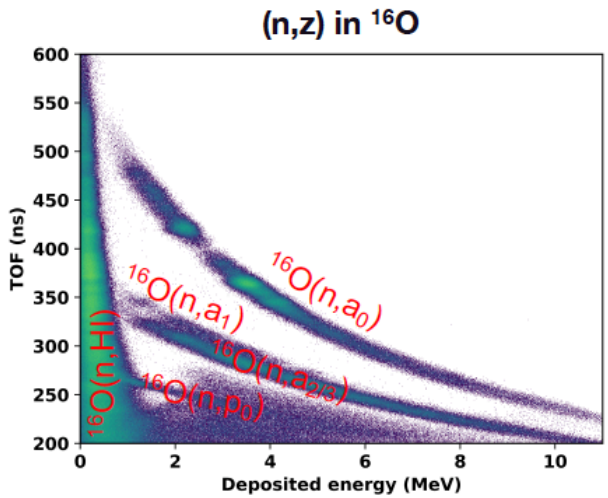
LENZ geometry is modeled using the MCNP6: PTRAC (Particle TRACk output) simulates LENZ experimental observables including energy, timing, point of collisions, reaction types, etc.

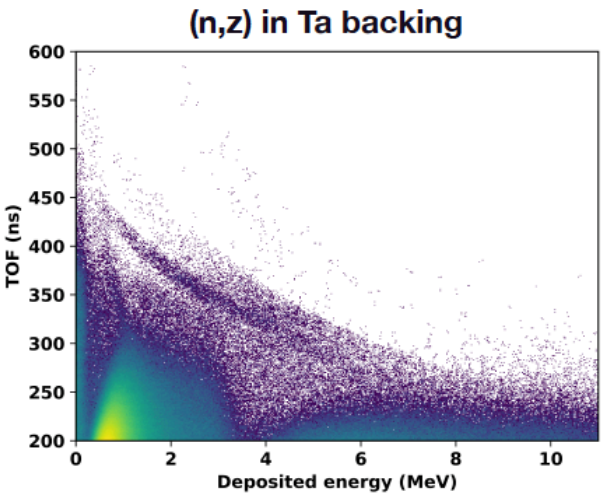


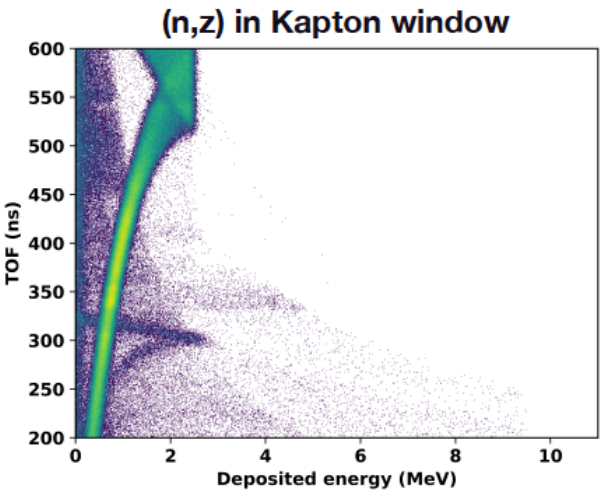
LENZ: $^{16}O(n,z)$ simulation

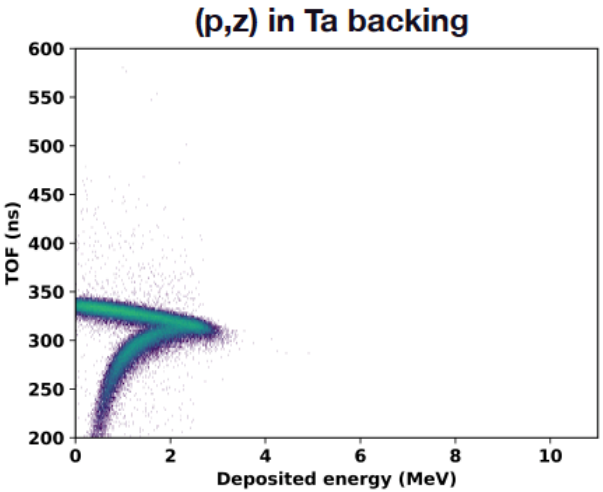
Slide from L. Zavorka

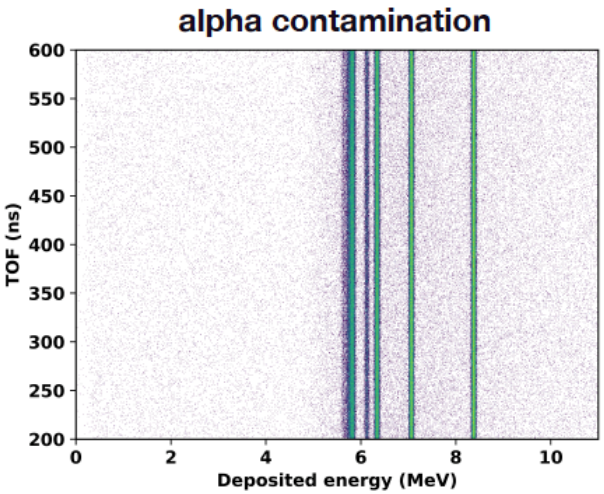
- 4000 A thick ^{16}O target with Ta backing
- 60 um Si detector at 3.4 cm from the target
- Covering 35 – 55 degree angle
- h, d, t, a, HI tracked





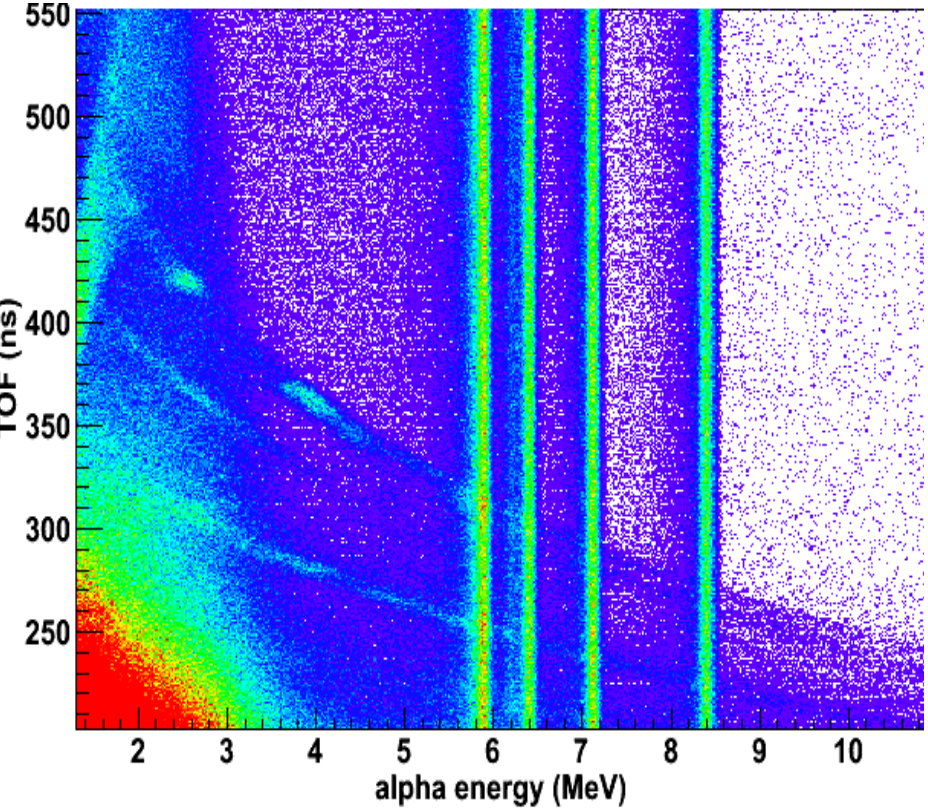




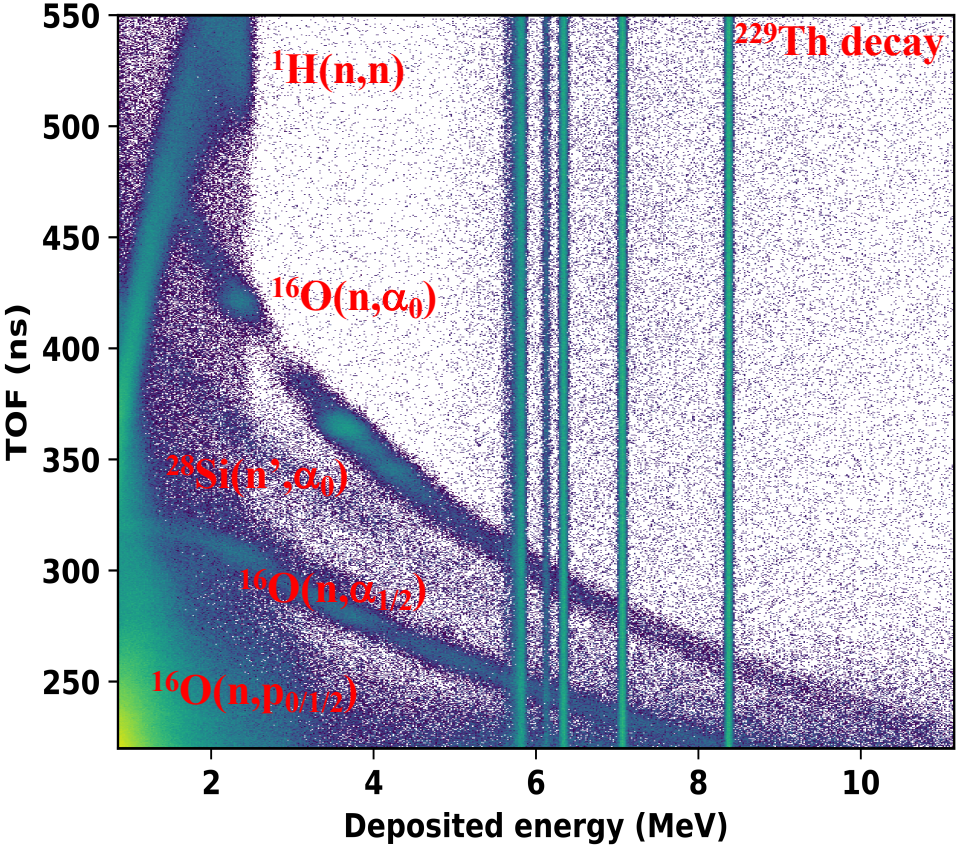


$^{16}O(n,\alpha)$ yield comparison with MCNP

LENZ data

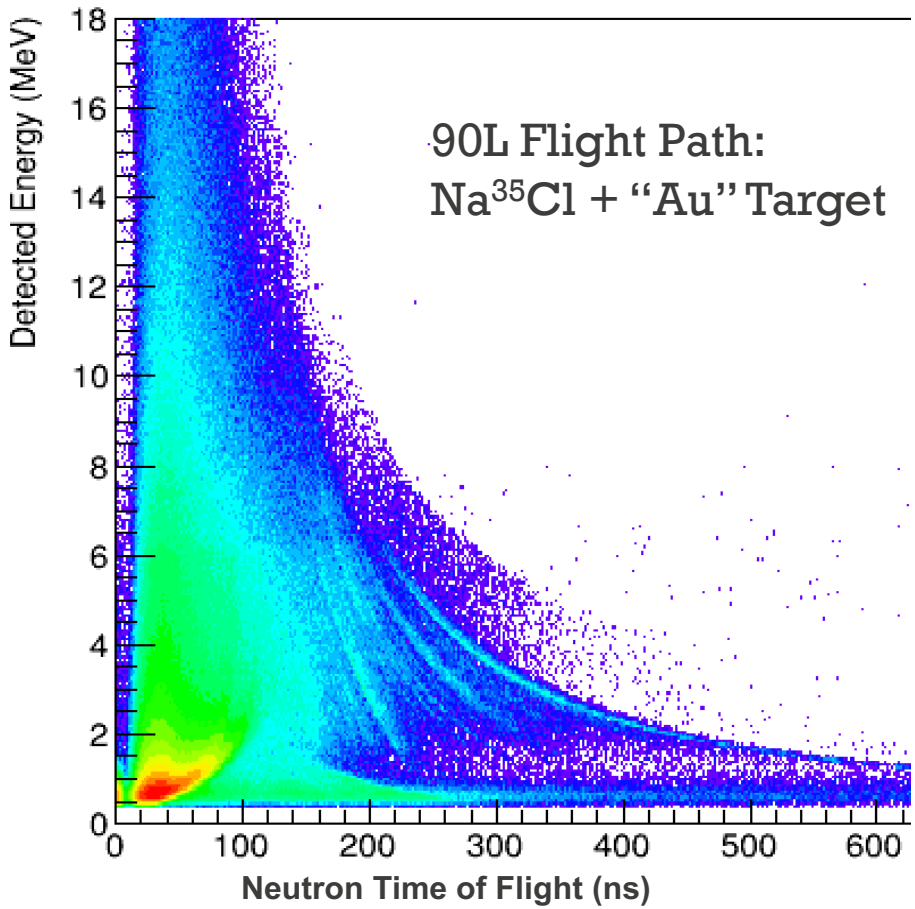


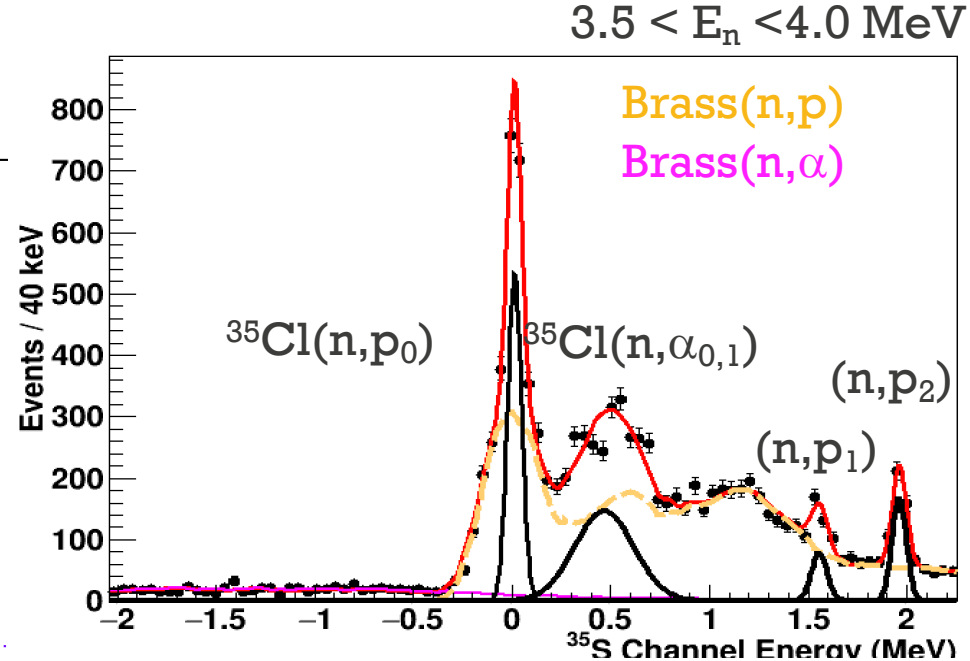
MCNP simulation

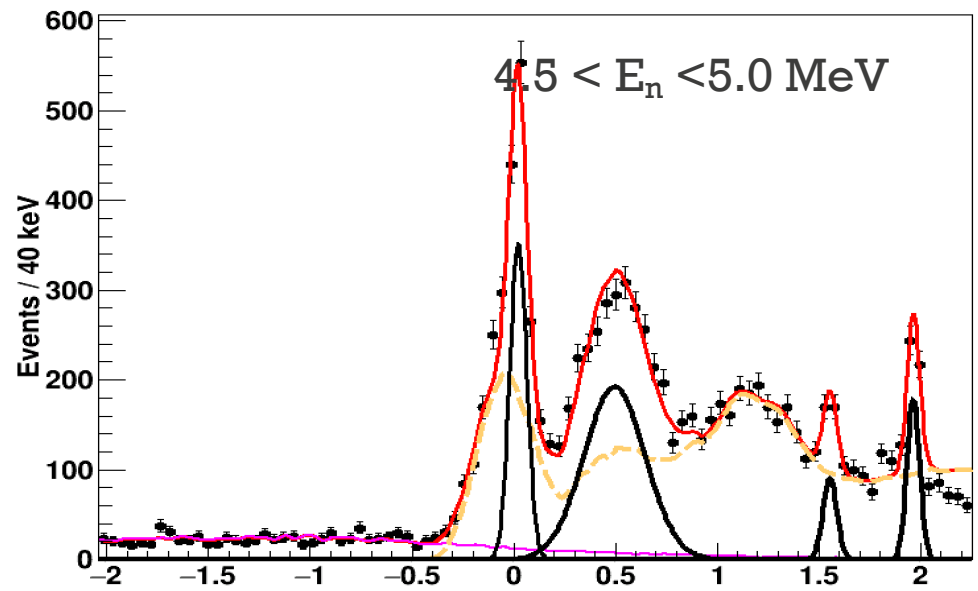


- LENZ data was taken using a 65 micron thick silicon strip detector in 2016
- Forward Propagation Analysis is being progressed to deduce $^{16}O(n,\alpha)$ reaction cross section, by sampling different cross sections within the parameter uncertainty boundary

LENZ Measurement of $^{35}Cl(n,p)^{35}S$ at LANSCE

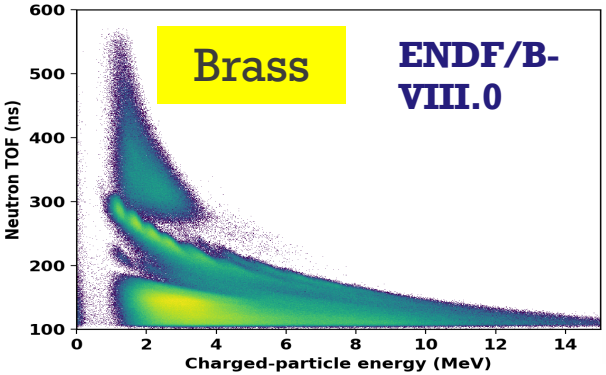


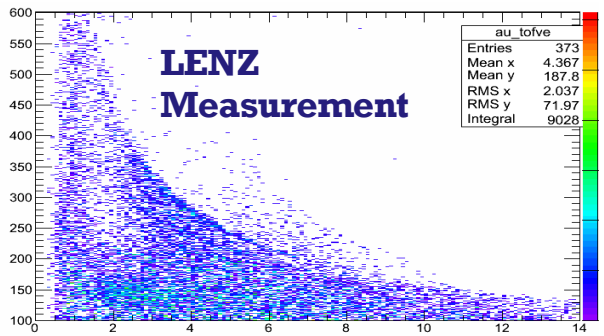


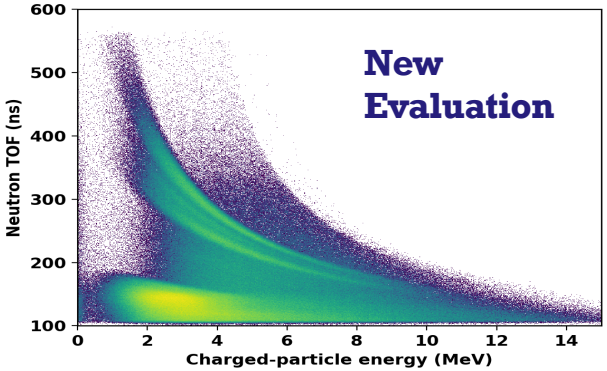


New data evaluation for improving charged particle outputs

- New double-differential cross sections (DDX MF6) for charged-particle production
- New angular distributions for (n,p) and (n,a)
- New data include discrete gamma-rays

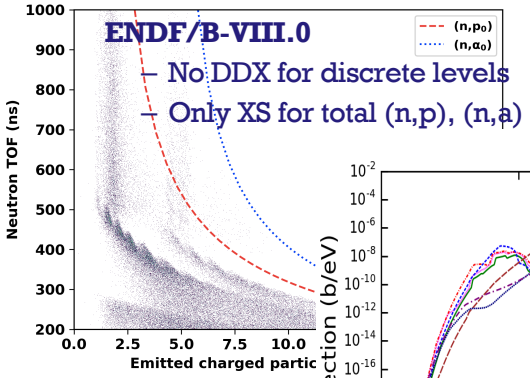


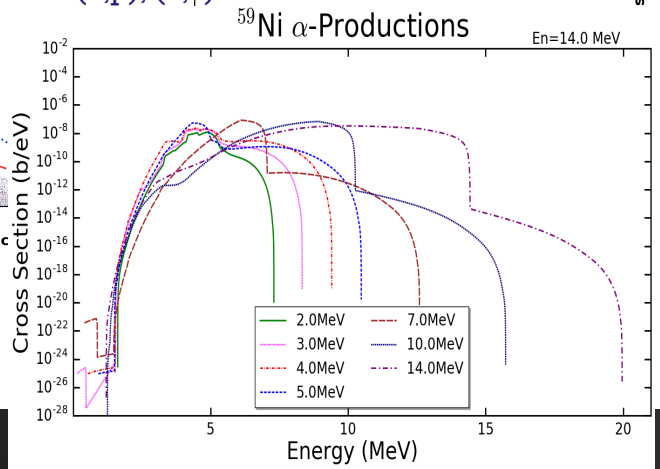


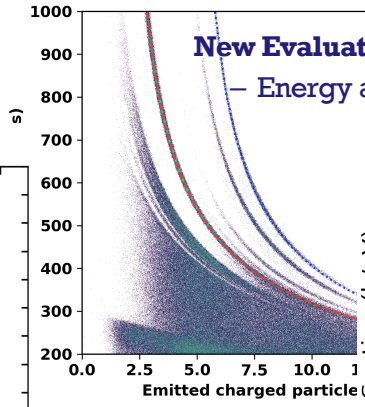


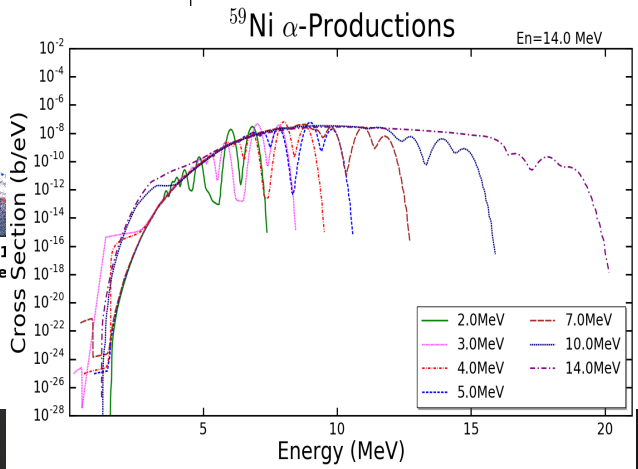
Radioactive Ni-59

No data available. LENZ is scheduled to take data in 2019 runcycle









Submitted to Nucl. Instr. Meth. A

New Evaluation on Angular Distributions and Energy Spectra for Neutron-Induced Charged-Particle Measurements

H.I. Kim[a,b], H.Y. Lee[b,*], A. Georgiadou[b], S. Kuvin[b], L. Zavorka[b], T. Kawano[c], M.W. Herman[c]

[a] *Nuclear Data Center, Korea Atomic Energy Research Institute, Yuseong-gu, Daejeon, Korea*
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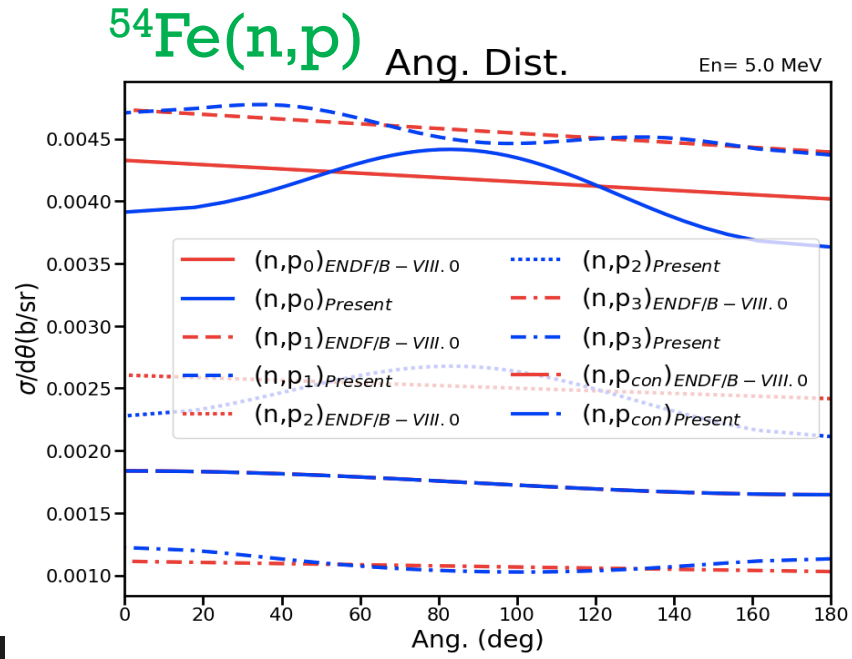
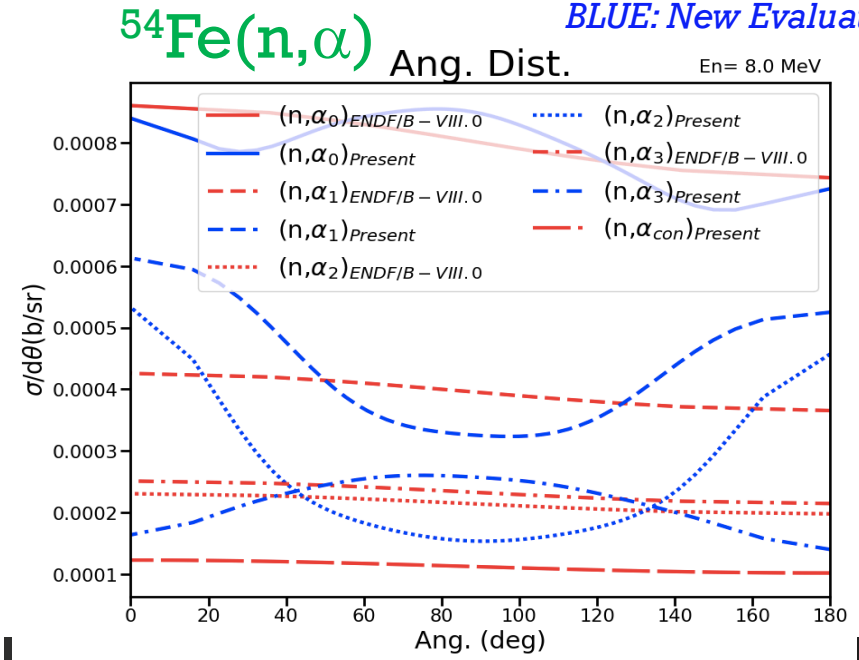
[c] *Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM, 87545, USA*

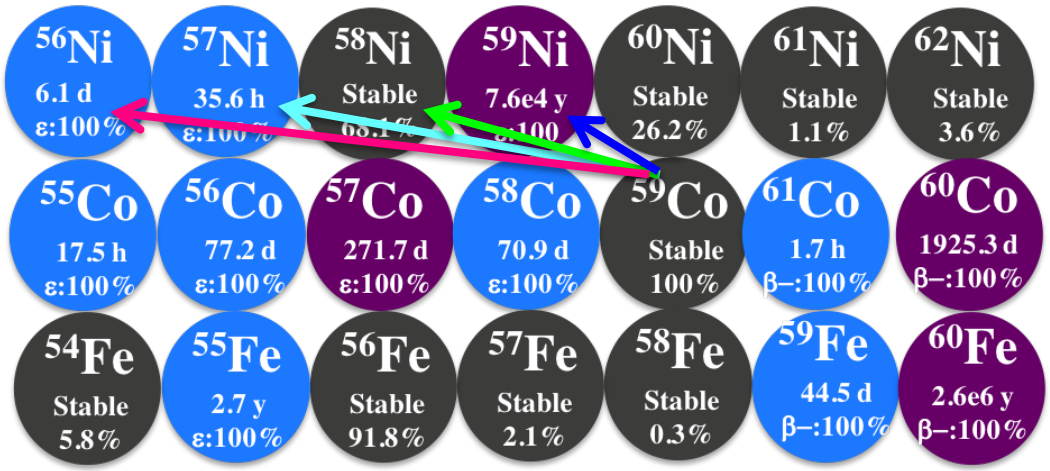
Anisotropy due to angular momentum couplings

RED: ENDF.VIII-0
BLUE: New Evaluation

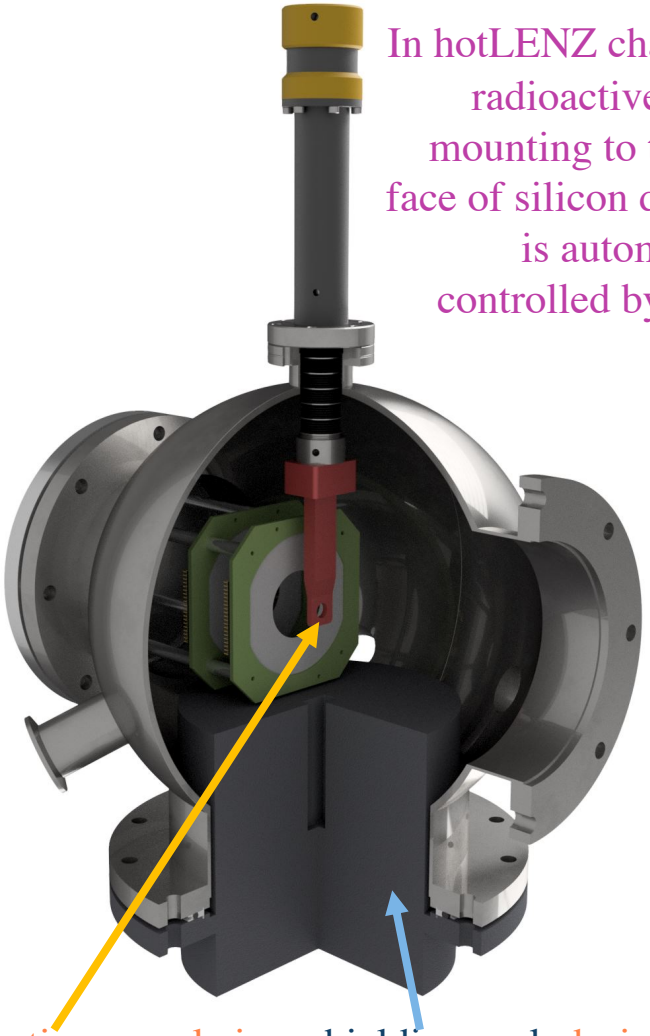




Pinning Down the Neutrino-Proton Process Importance in Heavy Element Production via Reaction Studies on Radioactive ^{56}Ni



- For the interest of heavy ion production via neutrino-proton process in explosive supernovae, knowing the ^{56}Ni(n,p) reaction cross section is crucial
- Until now, this direct measurement was impossible, due to the limited access to radioactive targets and unavailable neutrons
- *First and the only effort in the world*



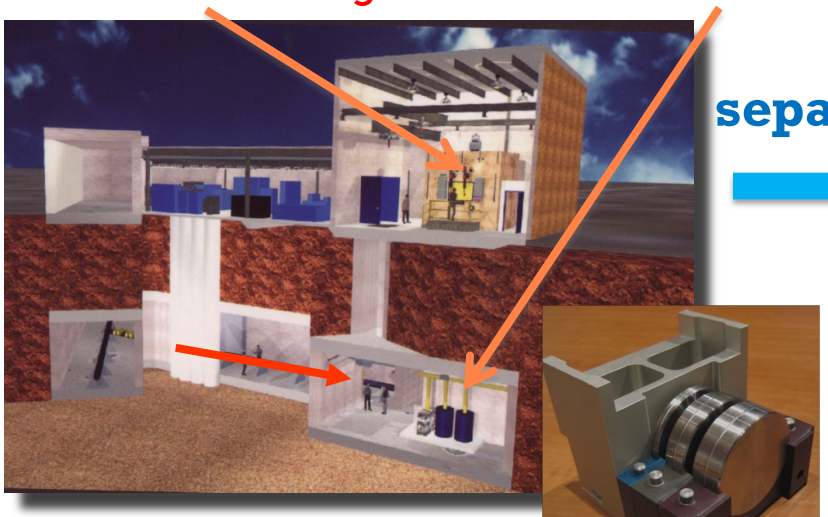
In hotLENZ chamber, a radioactive sample mounting to the front face of silicon detectors is automatically controlled by remote system

Radioactive sample in a shielding cask during transportation and a resting spot in WNR flight path

Isotope irradiation at IPF and chemical separation, fabrication at TA48

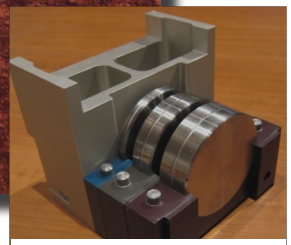
Hot Cell

Target Irradiation Chamber



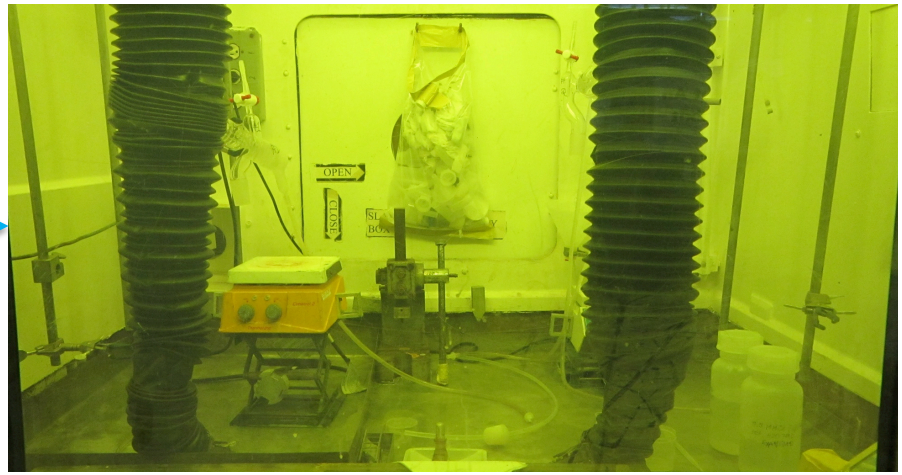
100 MeV (230 μA) H^+

Proton irradiation



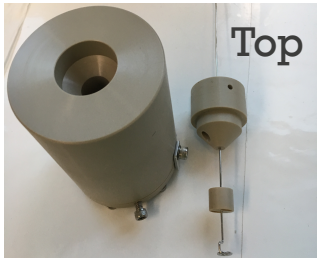
3 Stack Target Irradiation

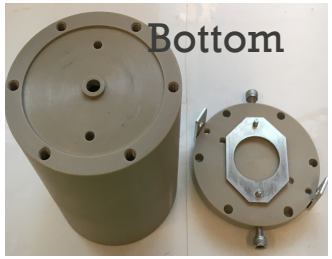
separation



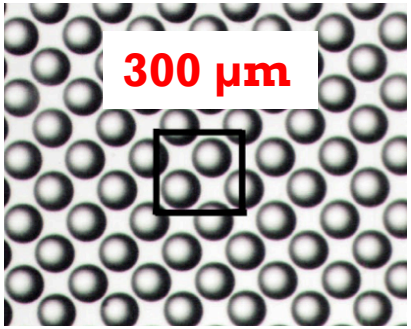
The Hot Cell Facility in TA48 consists of 13 hot cells for radiochemical purification. Isotopes of interest are isolated from targets using remote manipulators and standard wet chemistry techniques such as ion exchange chromatography.

fabrication





1.Electrodeposition: Developed an optimized electodeposition device to be used in the Hot Cell with radioactive samples for uniformity & no impurity



2. Micro-jet printing: Developing a NEW small-quantity radioactive target fabrication method, which manipulates tiny drops using a transducer for fluid at ambient pressure with 100 % efficiency, introducing some impurities

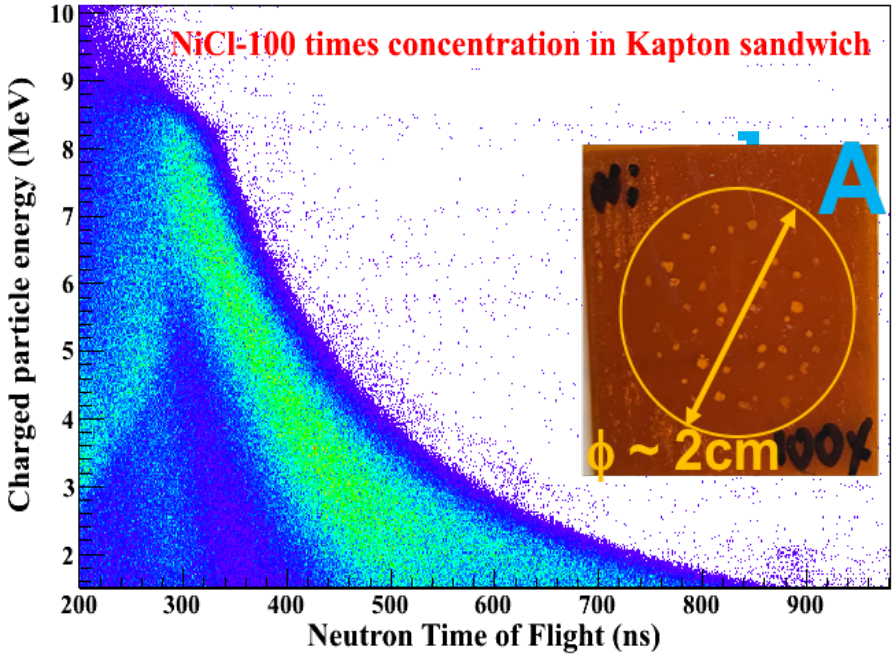
Target fabrication by Isotope Production Facility

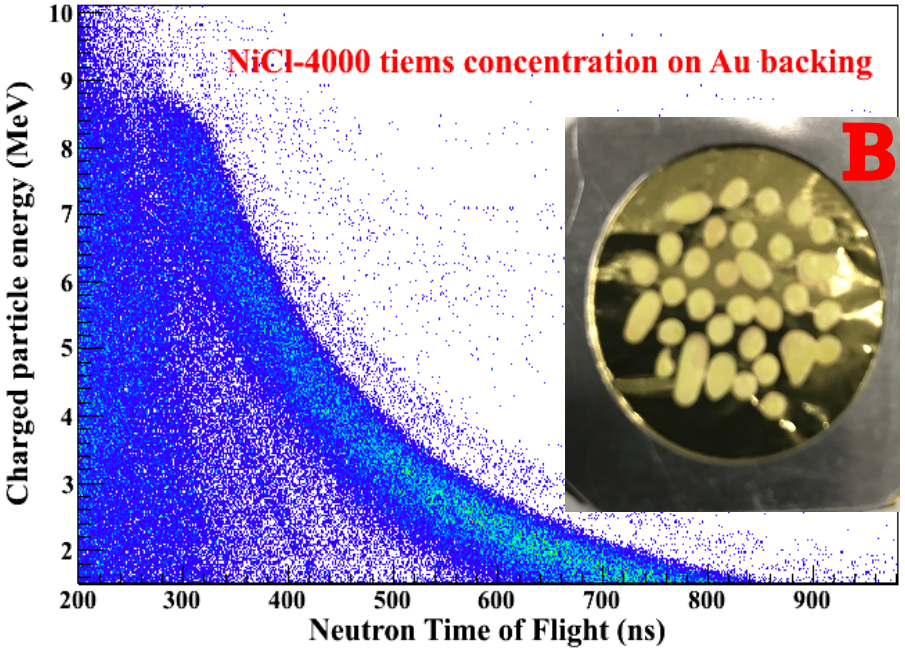
- $NiCl_2$-6(H_2O) samples were made by manually dispensing a solution using a micropipette on a different backing materials
- Improving signal-to-noise ratio is crucial

For the flight path of the LENZ location, the TOF at 1000 ns corresponds ~ 1MeV neutrons and the TOF at 510 ns, ~ 4 MeV neutrons

100 times more concentrated solution than that of the final radioactive sample inside double-layered Kapton foils (each Kapton tape is 50 micron thick)

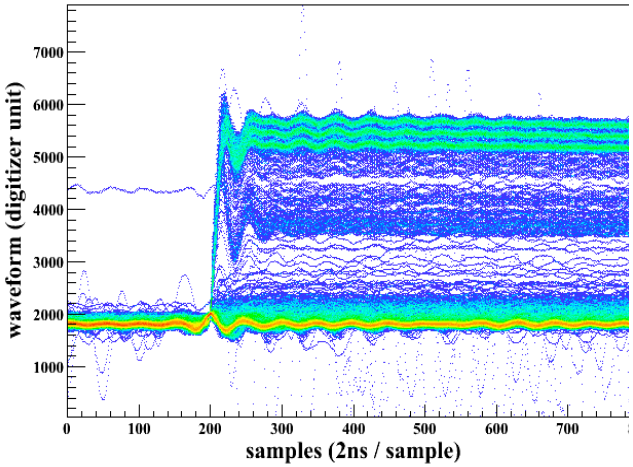
4000 times more concentrated solution that of the final radioactive sample on the 6 micron thick Brass foil.



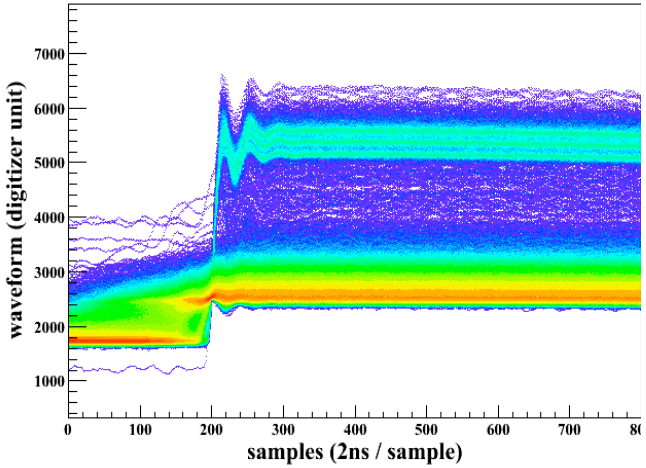


Waveform Analysis to Investigate Radiation Effect on detectors' performance

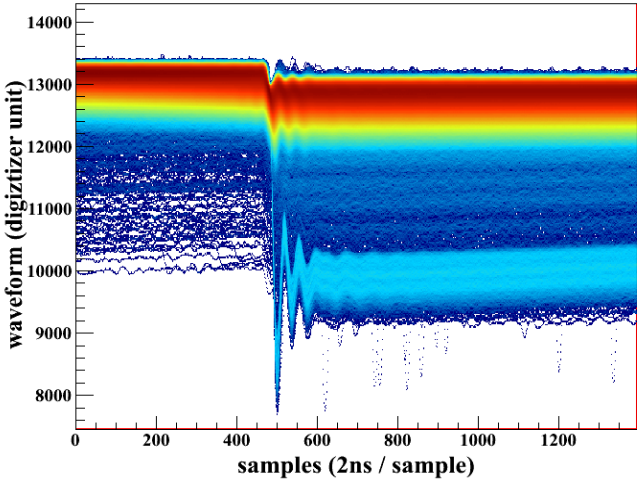
Mixed ^{239}Pu-^{241}Am-^{244}Cm source



55 μCi ^{82}Sr sample with the mixed source

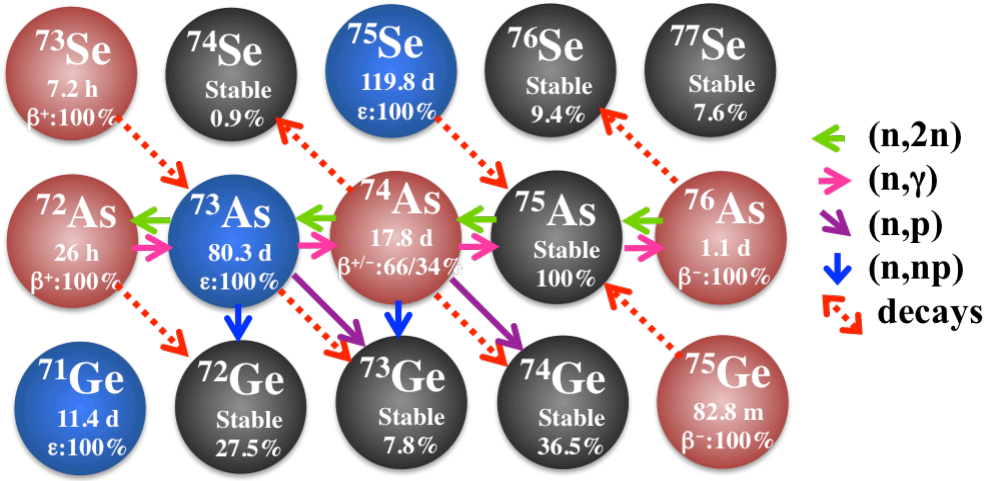


450 μCi ^{82}Sr sample with the mixed source

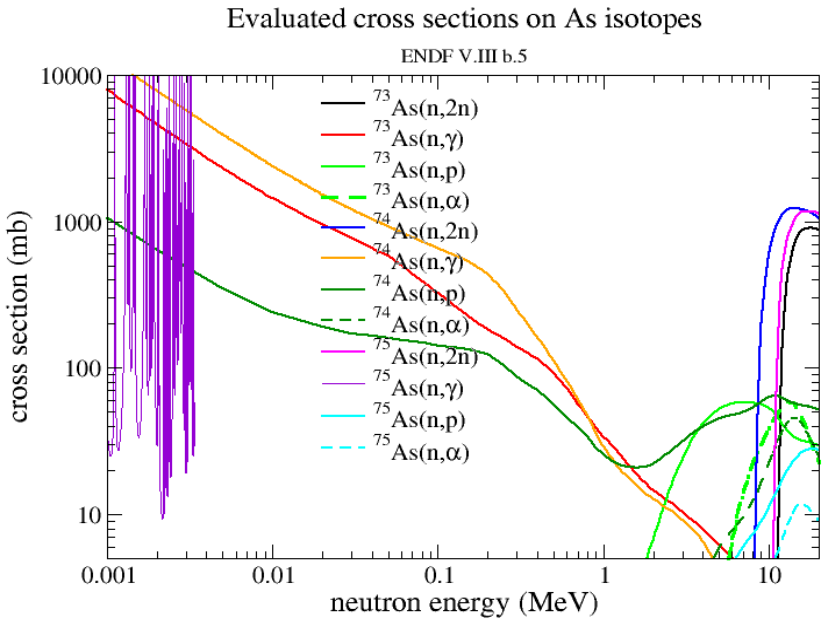


- Beta decays make small energy deposit in a silicon detector, causing pile ups for causing energy resolutions worse
- Can be improved by optimizing the silicon thickness and waveform analysis to be able to handle high throughput rate and pile up corrections
- Enhancing throughput rate by optimizing triggering method and on-board processing
- Also investigate diamond detectors for radiation resilience

Enhancing our understanding of radiochemistry diagnostics, through "high quality" data on radioactive nuclei

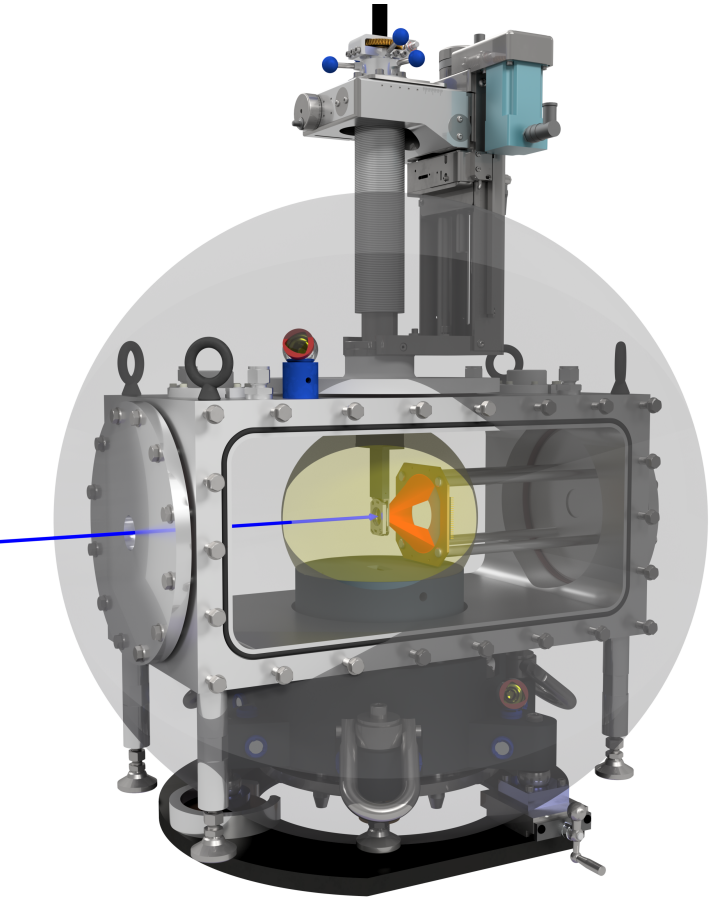


Only LANL can perform this study by producing short-lived radioactive samples at IPF and carrying out nuclear reaction studies at LANLSE

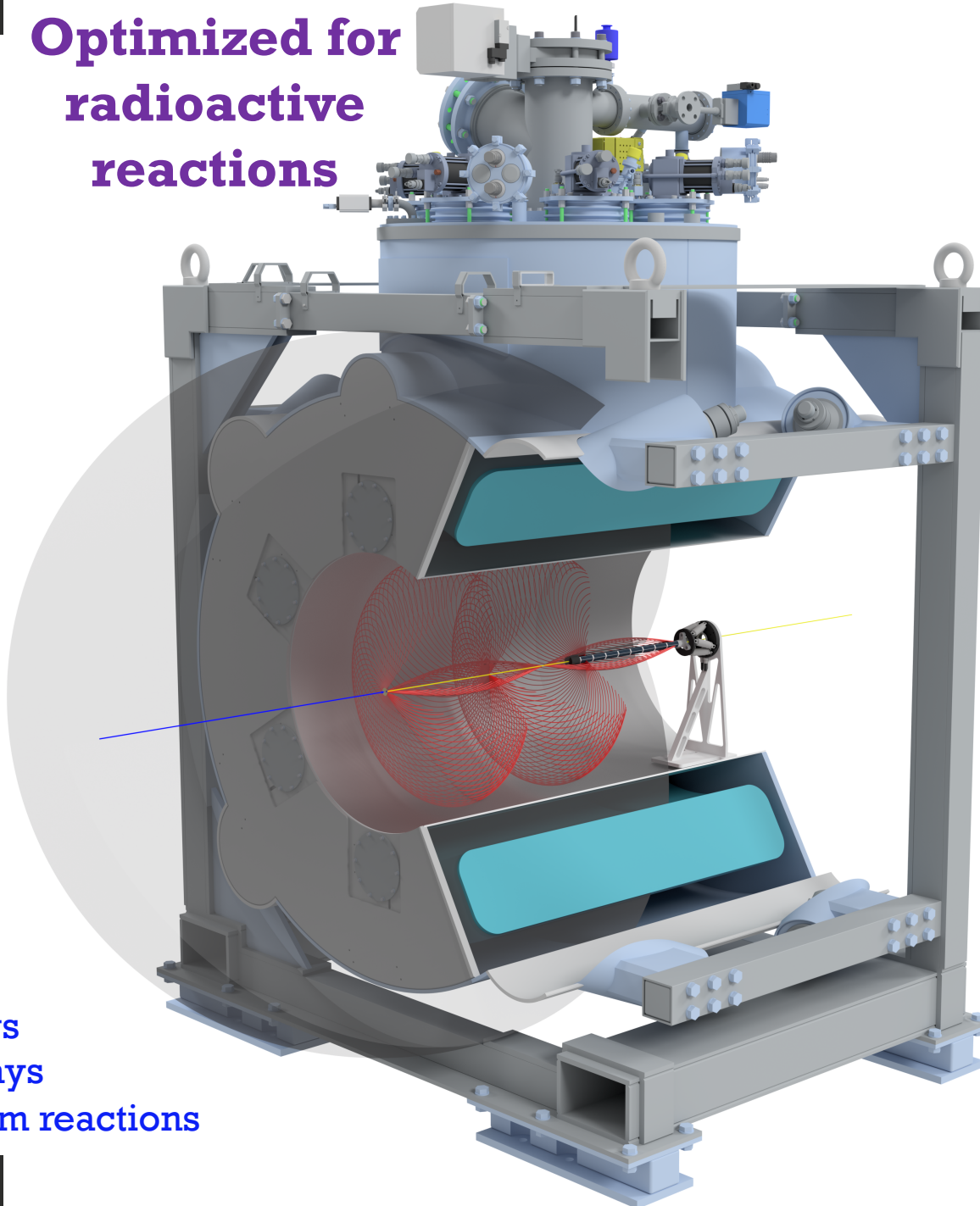


- Until now, this direct measurement was difficult, due to the limited access to radioactive targets and available neutrons
- Upon completion of LDRD-ER (PI by Lee, FY18-20), the capability of producing radioactive samples and measuring their reaction cross sections at LANSCE will be demonstrated
- Many *New & First radioactive* nuclei measurements will be generated for better nuclear data evaluation

Conventional (n,Z) studies



Optimized for radioactive reactions

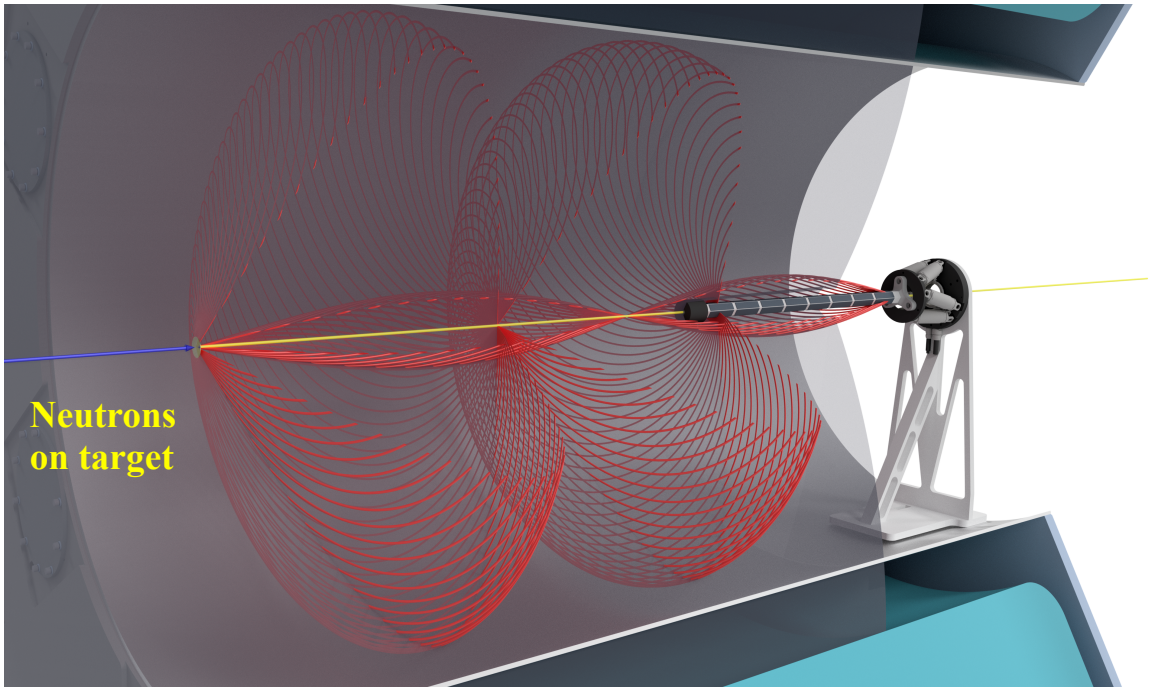


Blue line: LANSCE neutron beam
Yellow sphere: intrinsic beta decays
Gray sphere: intrinsic gamma decays
Red envelop: charged particles from reactions

5T Solenoid is here at LANSCE

Bore diameter = 90 cm
Bore length = 1.4 meters
Magnetic Field = 5 Tesla

Under the axial B filed, Betas swirl inside the hollow tube



- **Charged particles emitted at different angles intersect the detector at different locations in beam direction**
- **Different charged particles are identified by cyclotron period**

Summary and Outlook

- LENZ measurements will provide high-quality differential data for better understanding of nuclear modeling for applications, with close collaboration of improving on nuclear reaction modeling and evaluations.
- LANSCE with Isotope Production Facility is the *only* place in the world to perform neutron-induced nuclear reaction studies directly on "short-lived" radioactive nuclei
- Extending experimental capability to unstable nuclei certainly enhance our reach to benefit nuclear astrophysics, radiochemistry diagnostics, nuclear forensics, etc.
- Complete information obtained by this proposed high-quality measurements on stable and radioactive nuclei will directly be used for the in-depth nuclear reaction modeling in close collaboration with a reaction modelers, under the DOE-Office of Science, the US Nuclear Data Program, and the continuous tie through the international nuclear data community.