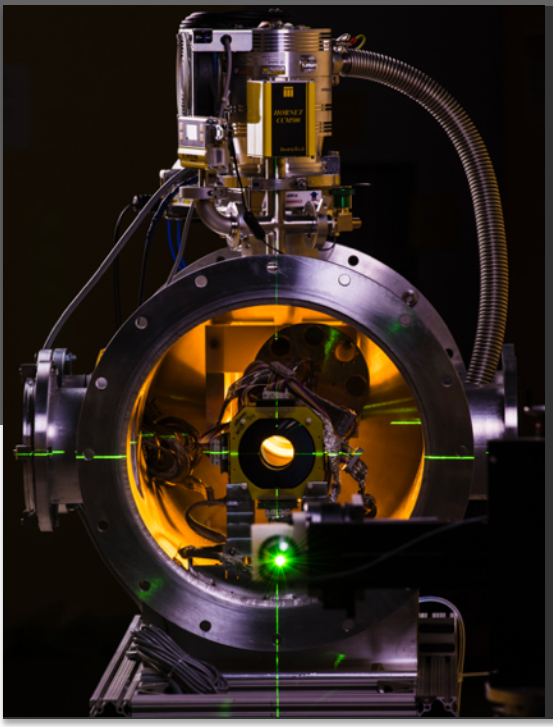
LA-UR-20-XXXXX



# LANL experimental updates on LENZ and DICER in FY20

**LENZ collaboration:** H.Y. Lee, S. Kuvin, B. DiGiovine, A. Georgiadou, D. Votaw, L. Zavorka[&]
**Theory Division:** T. Kawano, M. Herman
**DICER collaboration:** P. Koehler, B. DiGiovine, *et al.*

*US NDP Nuclear Data Week: CSEWG annual meeting*
*Nov. 30 2020*

Los Alamos NATIONAL LABORATORY EST. 1943

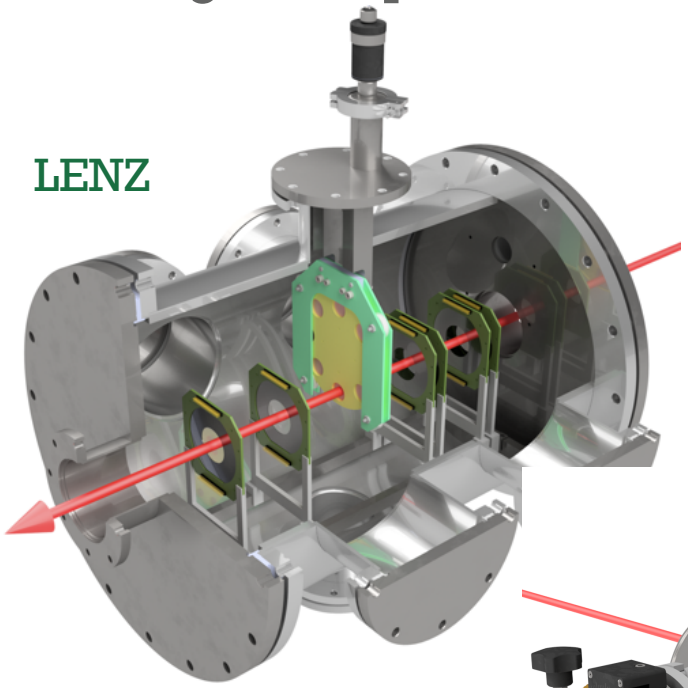
red-postdocs, [&] currently at ORNL

NNSA National Nuclear Security Administration
Managed by Triad National Security for the U.S. Department of Energy's NNSA

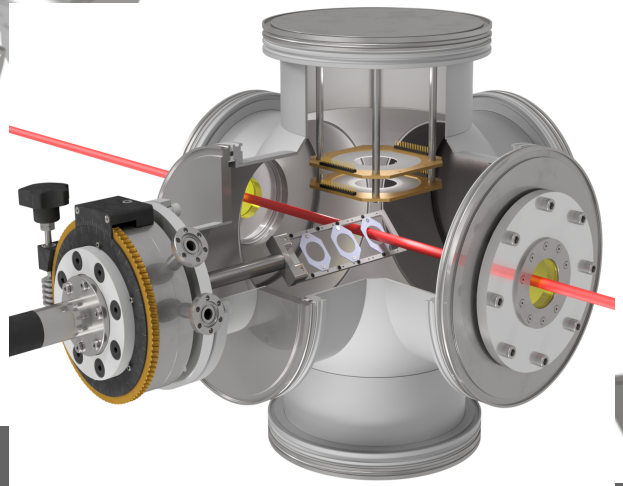
# Contents

- Double differential cross sections on $^{54}$Fe(n,p) and $^{56}$Fe(n,$\alpha$)
- Validation of neutron induced reactions on $^{nat}$C, using an active target at 0.4 MeV < $E_n$ < 22 MeV
- Progress report on $^{56,58,59,60}$Ni(n,p) reaction studies at WNR
- Progress report on DICER project at Lujan Center

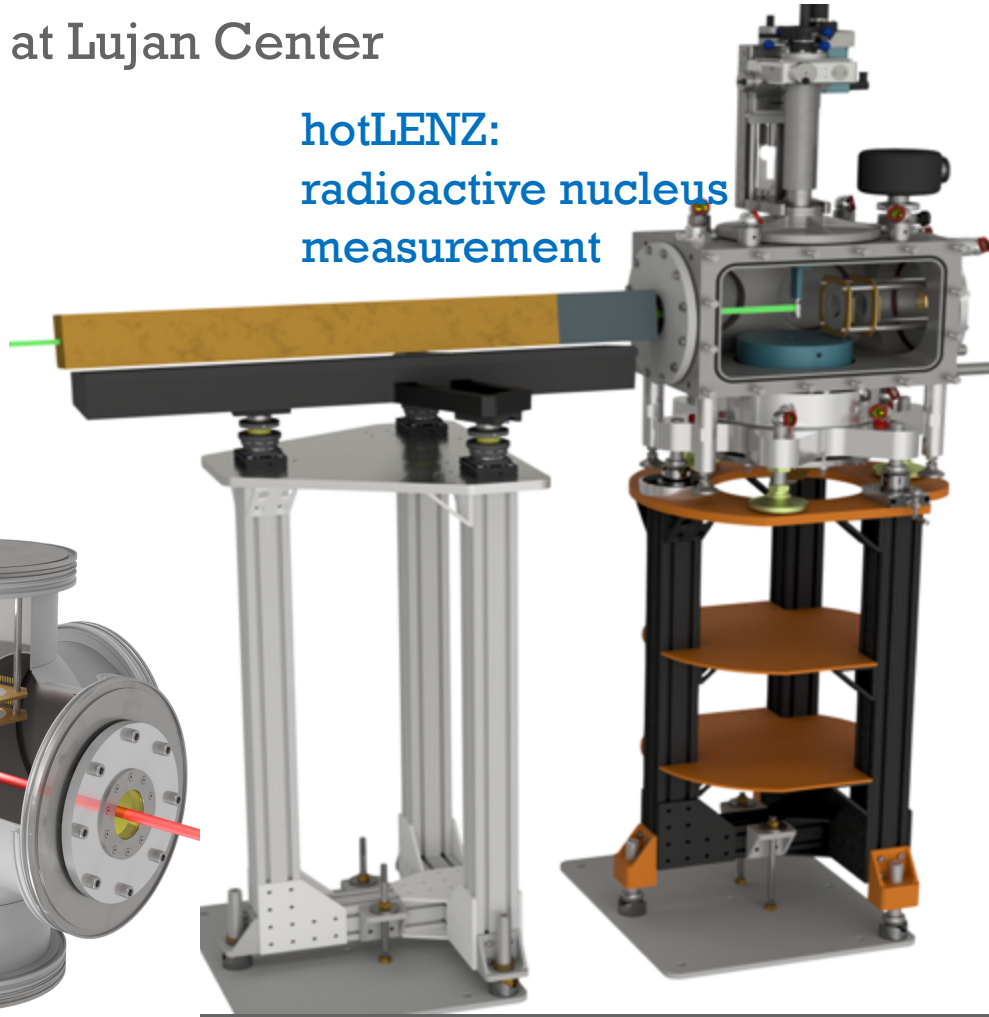
LENZ



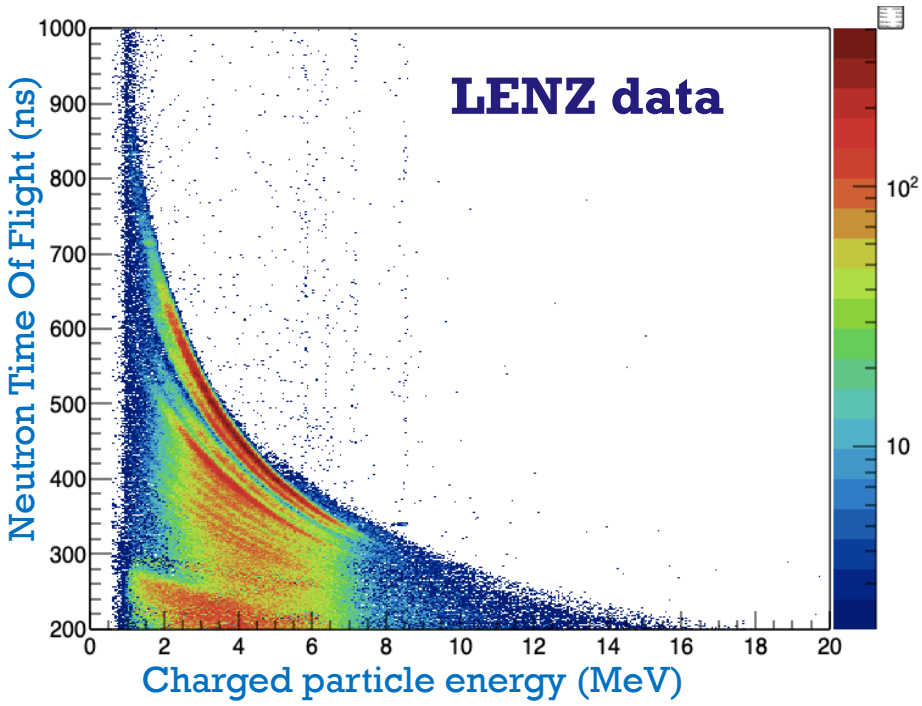
ALSOLENZ:
around 90-deg.
measurement

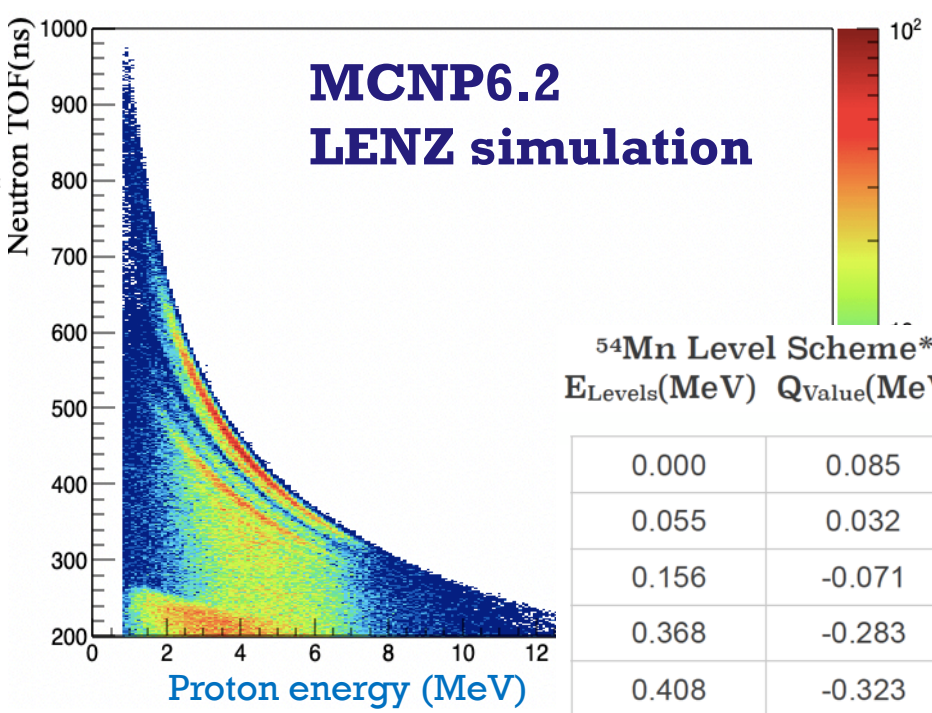


hotLENZ:
radioactive nucleus
measurement



# $^{54}Fe(n,p)^{54}Mn$ yield comparison with MCNP simulation




$^{54}$Mn Level Scheme*

| $E_{Levels}$(MeV) | $Q_{value}$(MeV) |
|---|---|
| 0.000 | 0.085 |
| 0.055 | 0.032 |
| 0.156 | -0.071 |
| 0.368 | -0.283 |
| 0.408 | -0.323 |
| 0.839 | -0.754 |
| 1.009 | -0.924 |
| 1.073 | -0.988 |
| 1.137 | -1.052 |
| 1.375 | -1.290 |
| 1.392 | -1.307 |
| 1.454 | -1.369 |
| 1.461 | -1.376 |
| 1.508 | -1.423 |
| ... | |

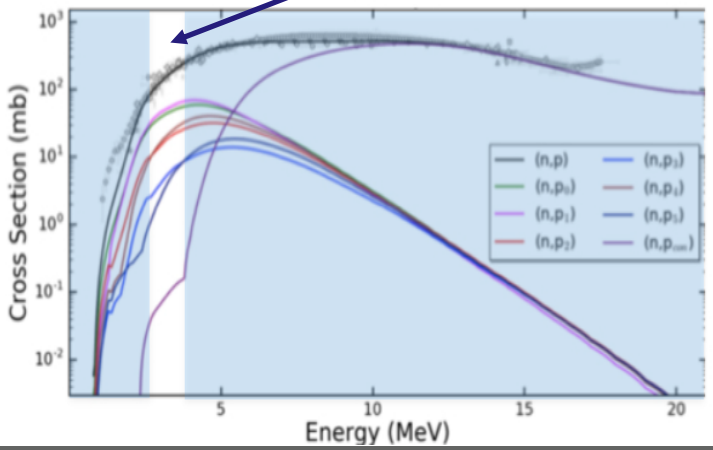
*from ENSDF

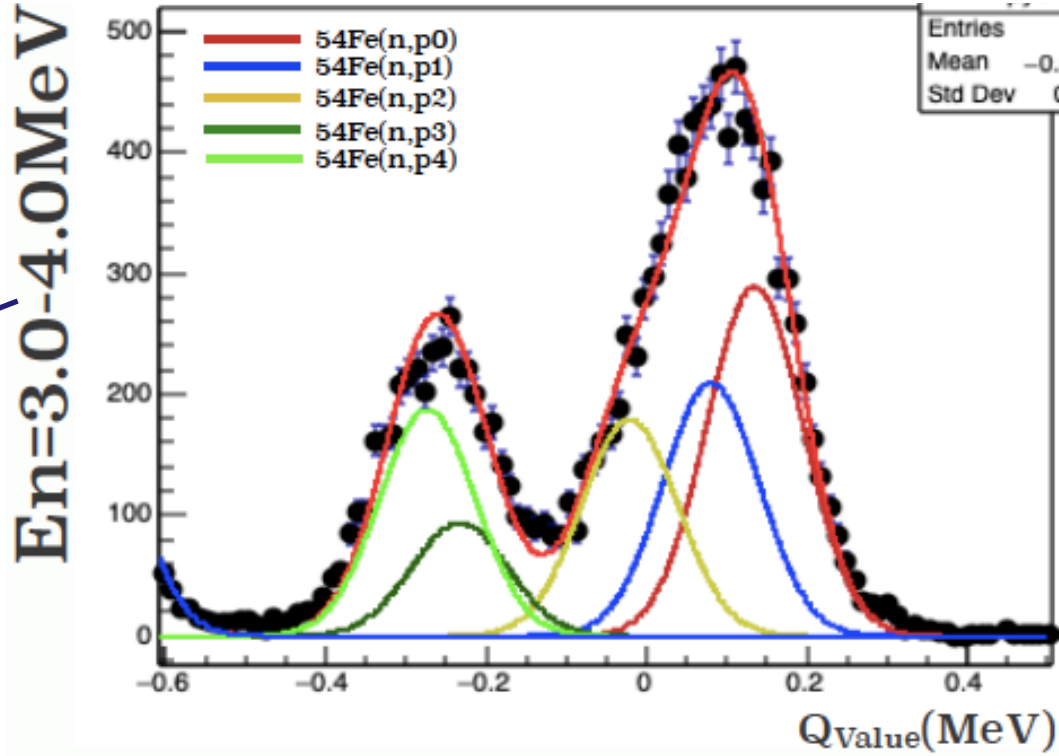
- Experiment: Background reactions are subtracted
- MCNP simul.:
  -Neutrons produced by spallation, are tracked at flight path 15R
  -Charged particles are tracked in LENZ/ALSOLENZ chambers and during post-processing, PTRAC outputs are used for reconstructing experimental observables

# $^{54}$Fe(n,p) LENZ data analysis

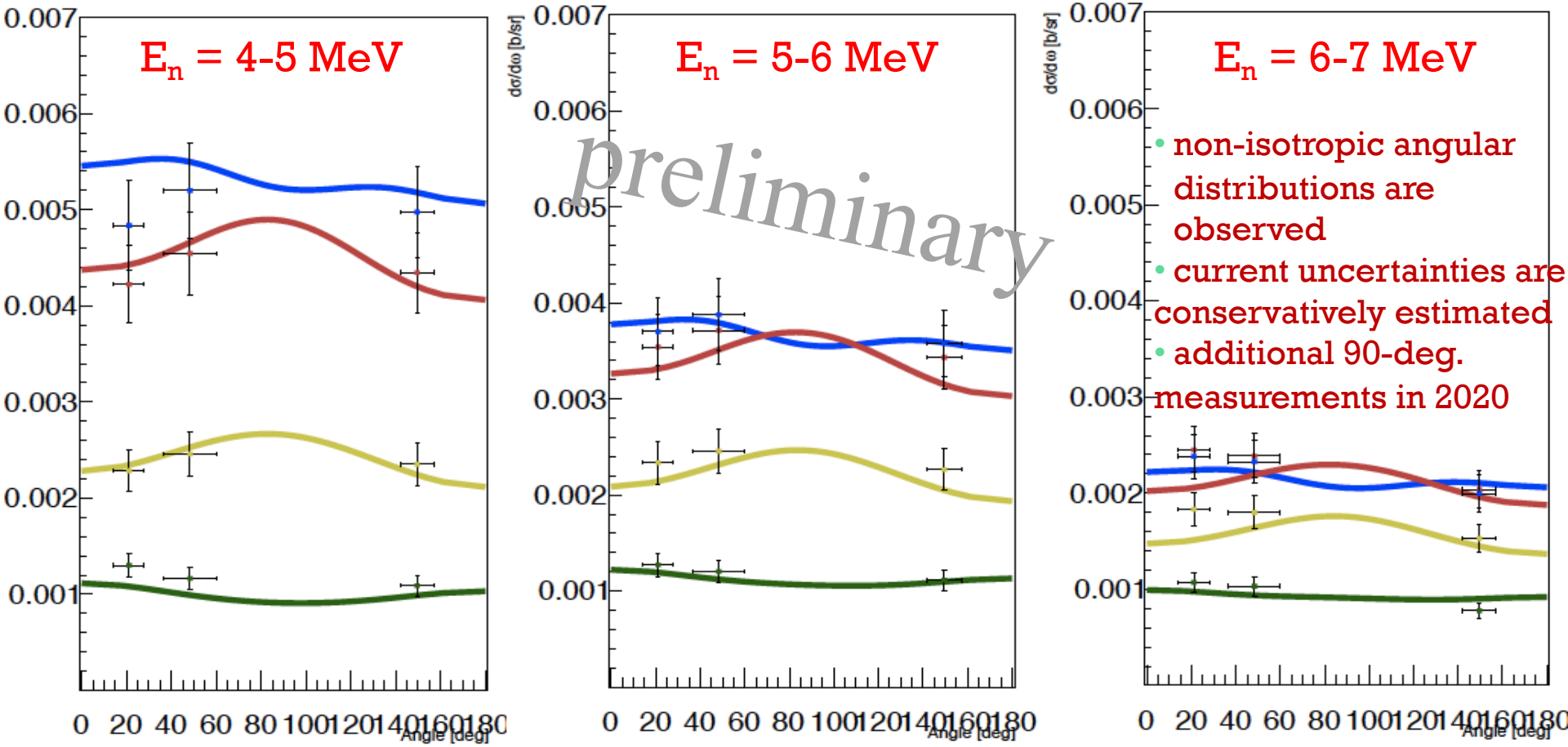
A thick $^{54}$Fe foil (2.2 mg/cm$^2$) and a high level density in $^{54}$Mn resulted in substantial experimental Q-value resolutions, therefore the rigid peak fitting procedure is applied with simulation/measurement-guided constraints.

1. fixed centroids from ENDSF
2. measurement-constrained range of widths
3. relative ratios to populate discrete states, adopted from ENDF-B/VIII.0



# $^{54}$Fe(n,p) angular distributions ($d\sigma/d\Omega$ (b/sr) vs. $\theta_{lab}$ (deg))




- non-isotropic angular distributions are observed
- current uncertainties are conservatively estimated
- additional 90-deg. measurements in 2020

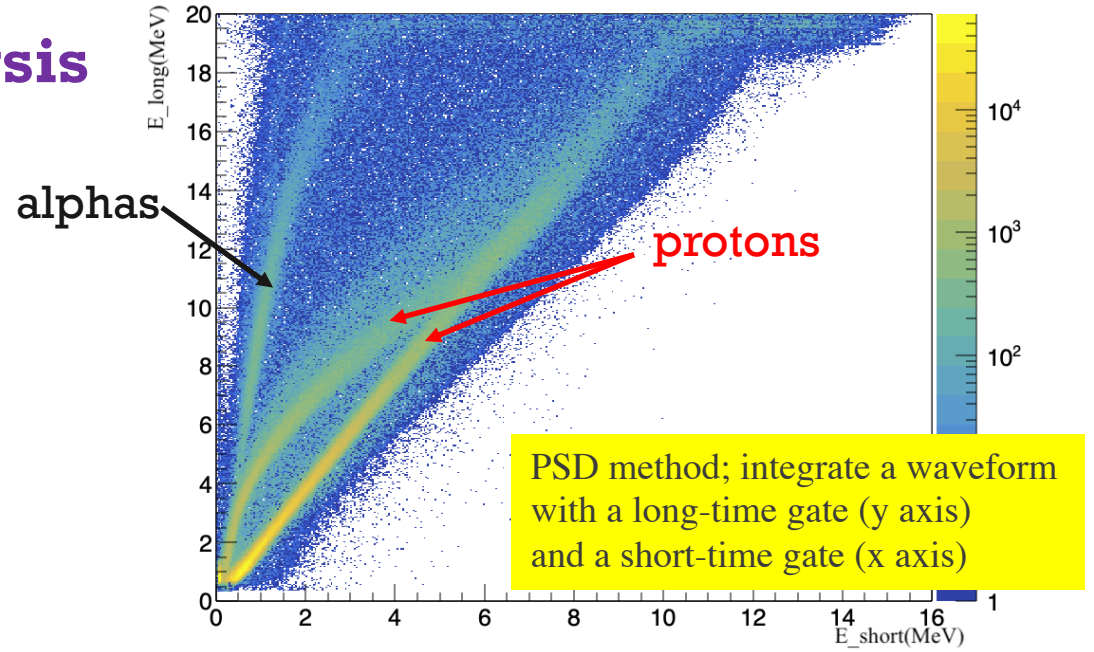
*-dots are LENZ measurements*

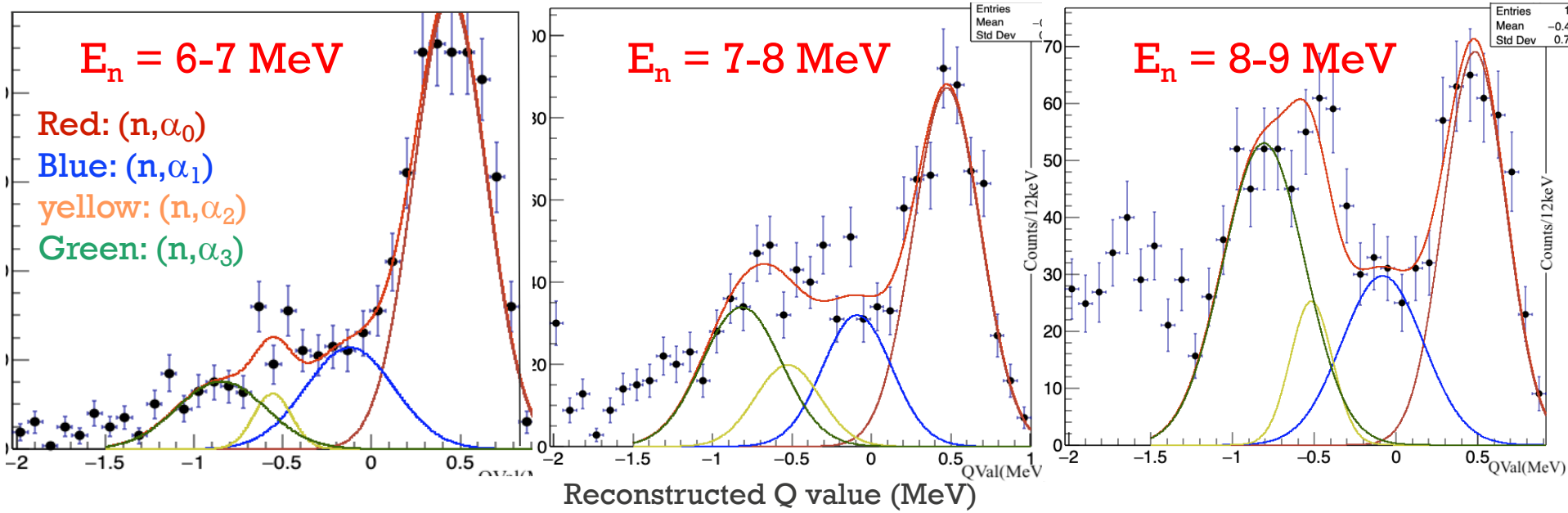
*-Solid lines show newly calculated angular distributions, where Legendre coefficients are explicitly calculated. Details of this work will be presented by H.I. Kim in Evaluation Session.*

Red: $(n,p_0)$, Blue: $(n,p_1)$, Yellow: $(n,p_2)$, Green: $(n,p_3)$

# $^{56}$Fe(n,α) LENZ data analysis

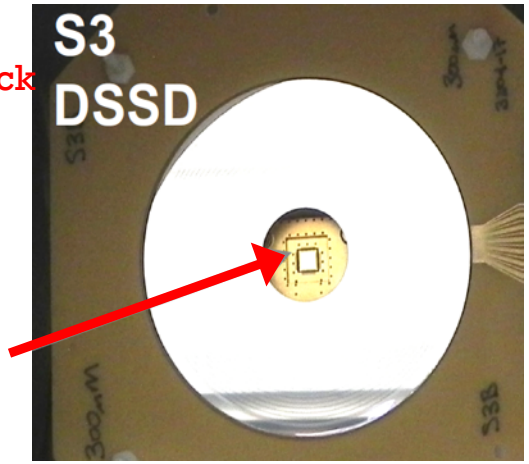
After performing Pulse Shape Discrimination (PSD) method, alpha reaction yields are plotted for (n,$\alpha_0$), (n,$\alpha_1$), (n,$\alpha_2$), … fitting procedures for obtaining discrete cross sections

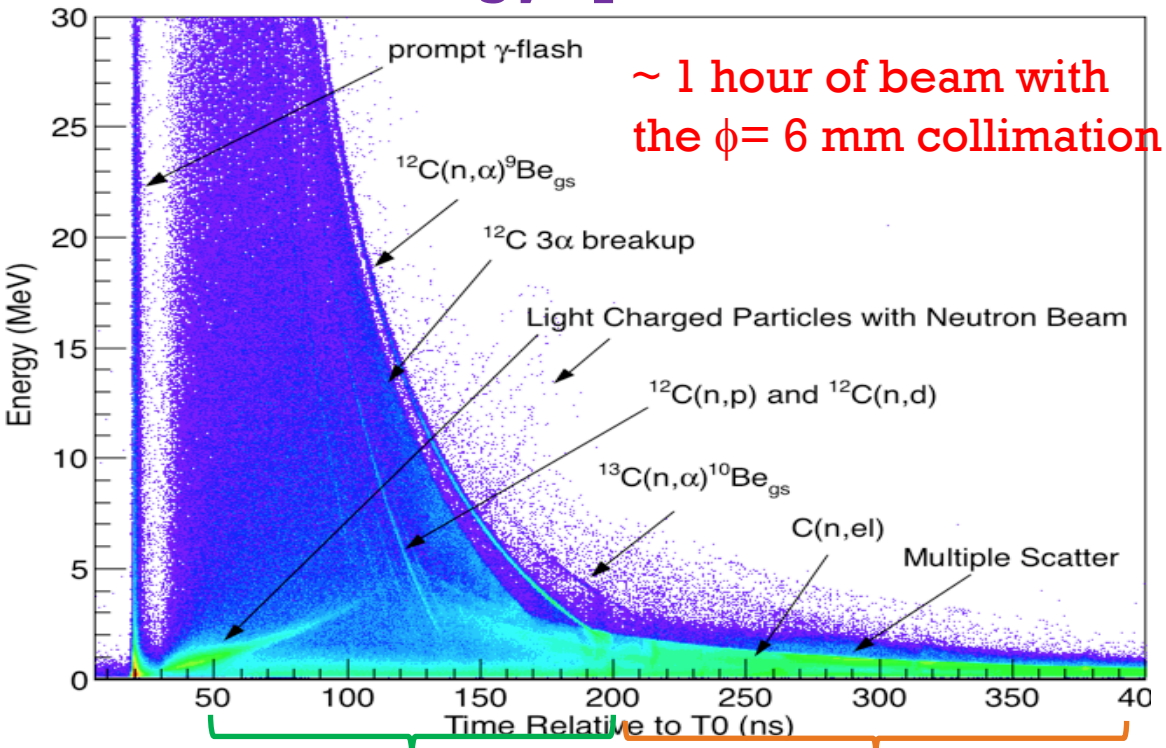


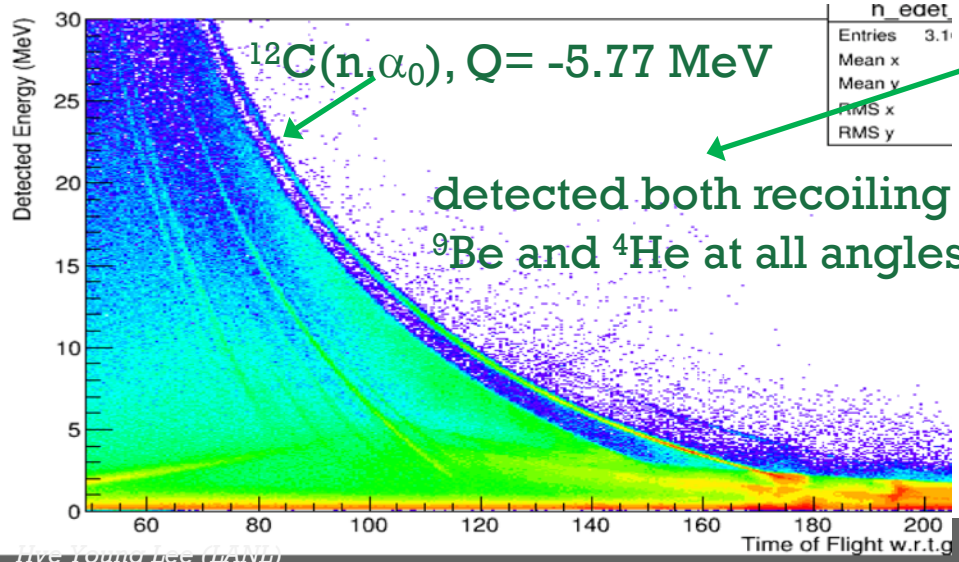
# Diamond detector response function: energy spectrum taken with neutrons from 90L WNR

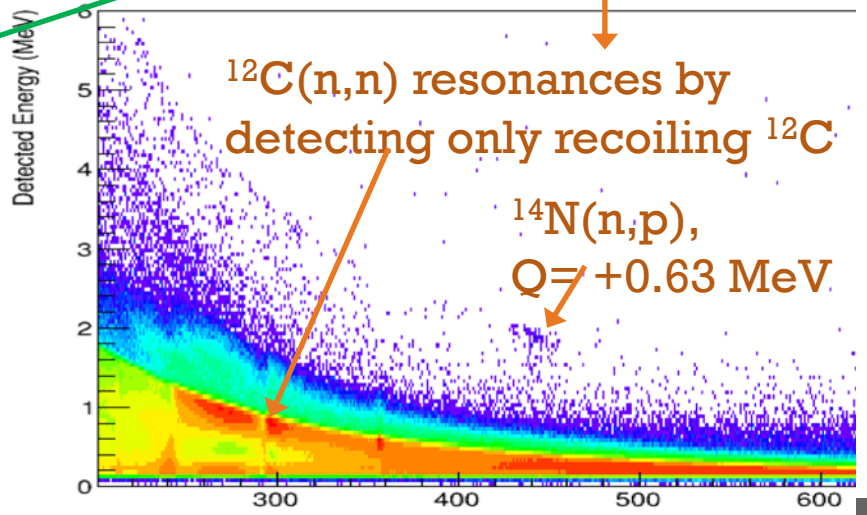
4 X4 mm², 500 μm thick chemical vapor deposition (CVD) Diamond detector



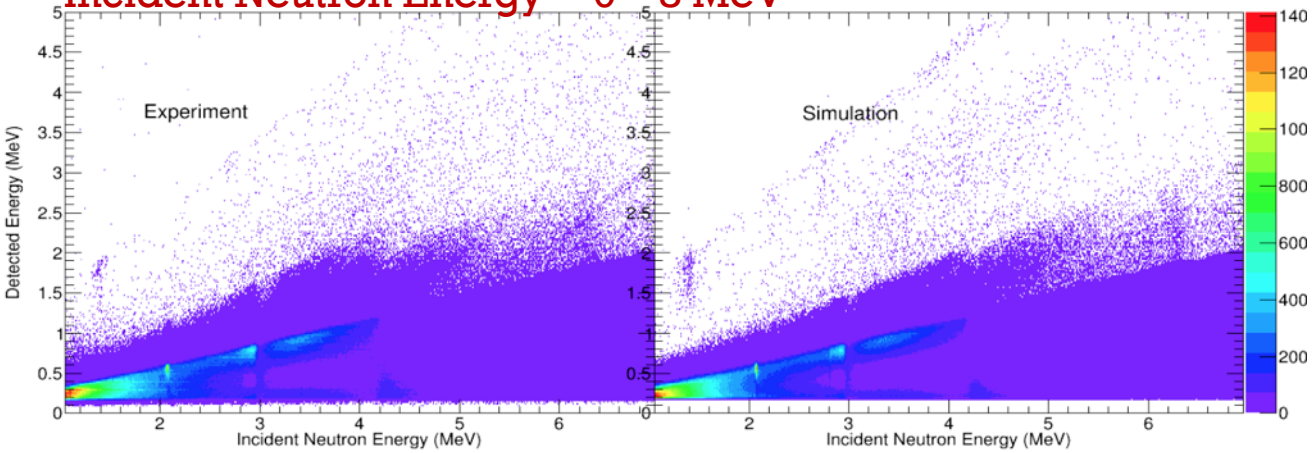

~ 1 hour of beam with the ϕ= 6 mm collimation



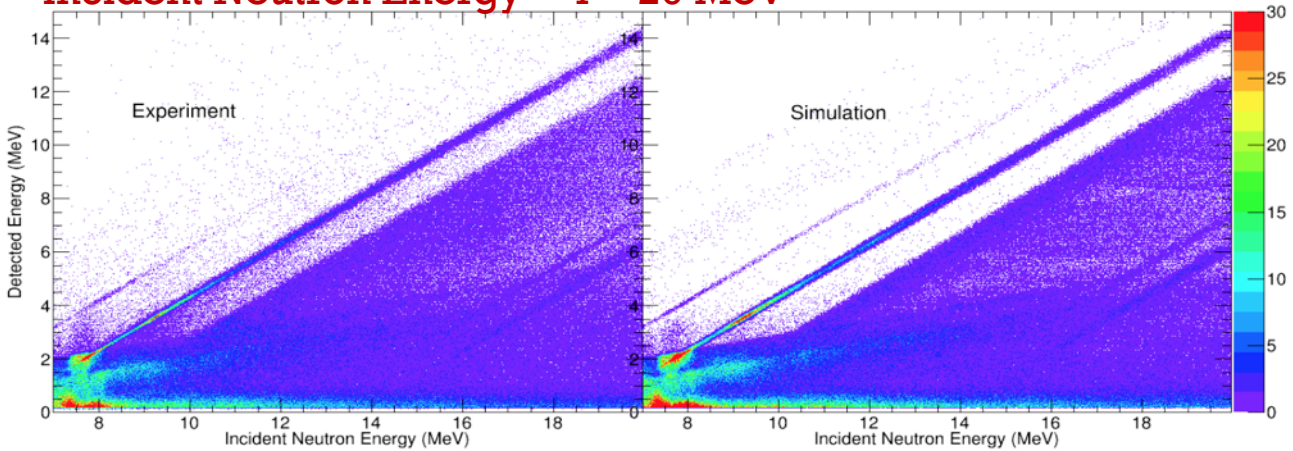



# Diamond data- Forward Propagation Analysis using Geant

## Incident Neutron Energy = 0 – 8 MeV




## Incident Neutron Energy = 7 – 20 MeV

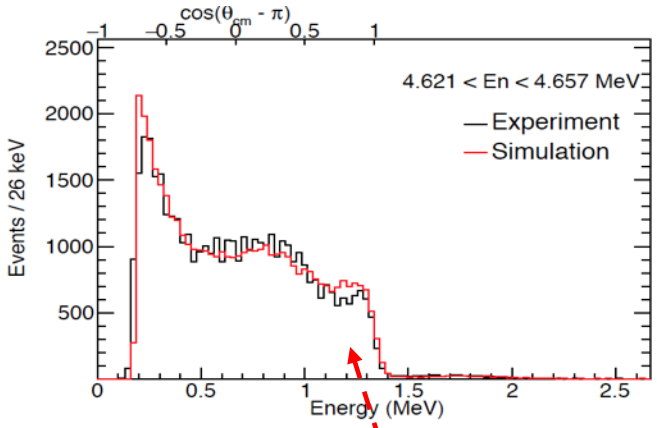


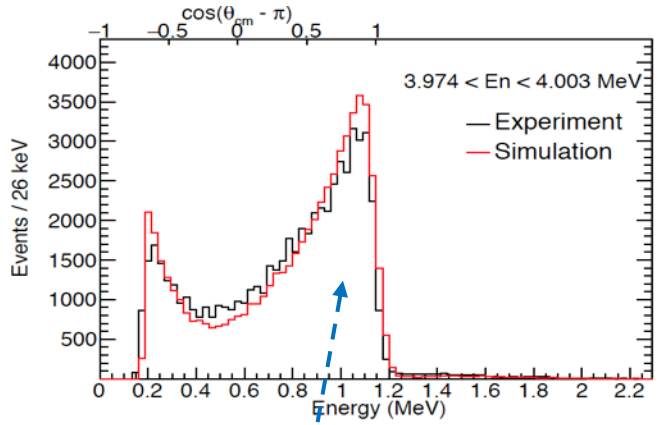

Geant4:
-ENDF-B.VIII.0 library
-Multi-step process of the $^{12}C$ breakup into 3 $\alpha$'s, $^{12}C(n,n\alpha)^{8}Be \rightarrow \alpha+\alpha$, default $\gamma$-decay of excited states in $^{12}C$ above alpha separation energy, etc.
-set the environment variable to use NRESP package

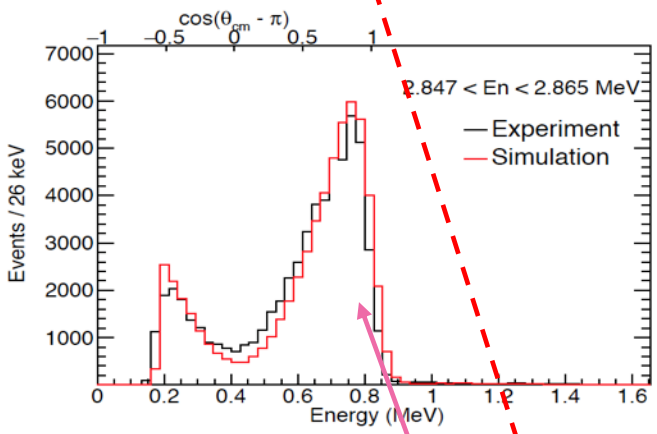
Neutron elastic scattering on $^{12}C$: the energy of the scattered neutron is sensitive to the scattering angle, the angular distribution of the outgoing neutron leaves an imprint of the missing energy on the detected $^{12}C$ recoil energy ($E_{det}$)

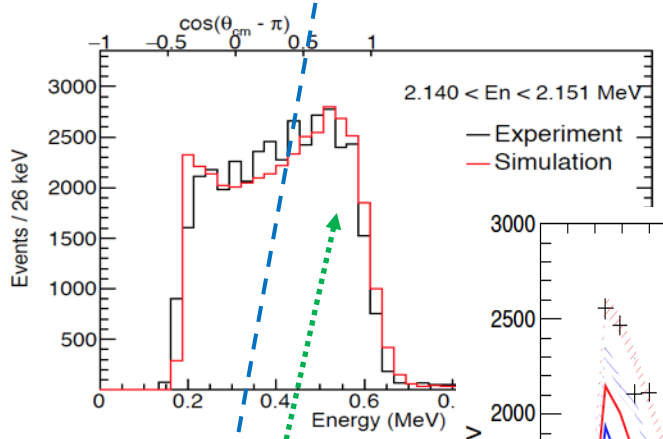
$$cos(\theta_{cm}) = 1 - \left( \frac{E_{det}}{E_n} \frac{(M_n + M_{12_C})^2}{(2M_n M_{12_C})} \right)$$

# Diamond data- validation of $^{nat}C(n,x)$ reactions: Elastic Scattering

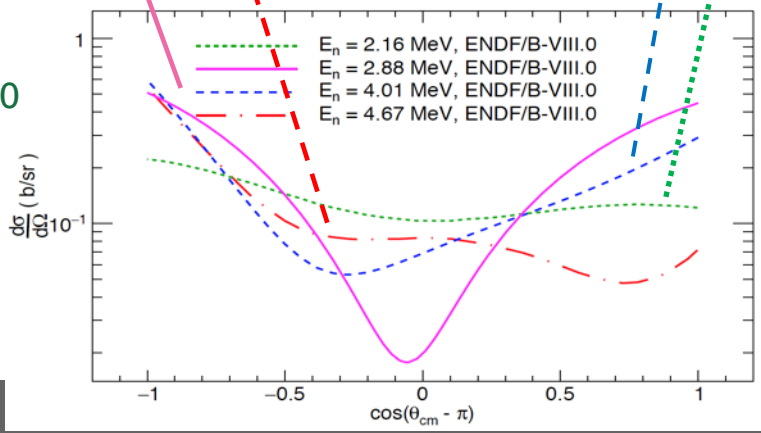


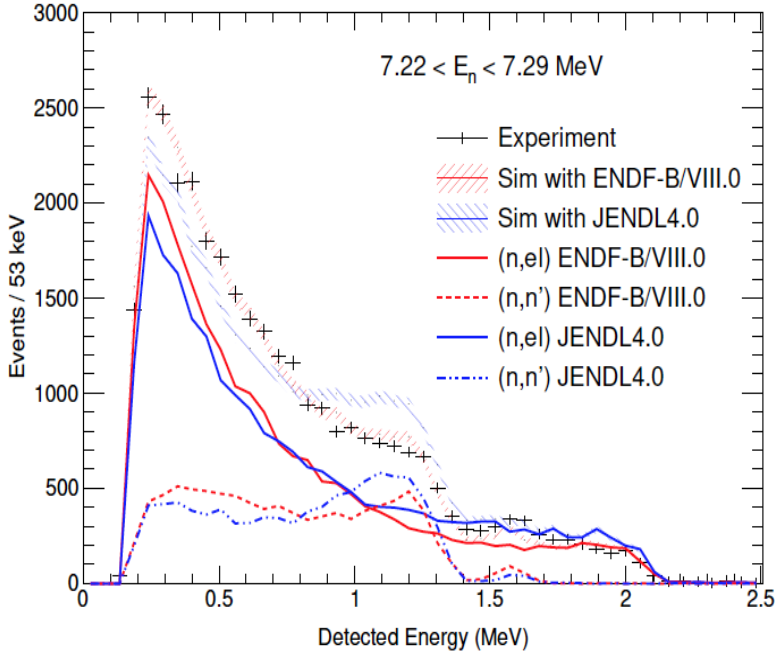




$^{12}C(n,el)$: ENDF-B/VIII.0 angular distributions

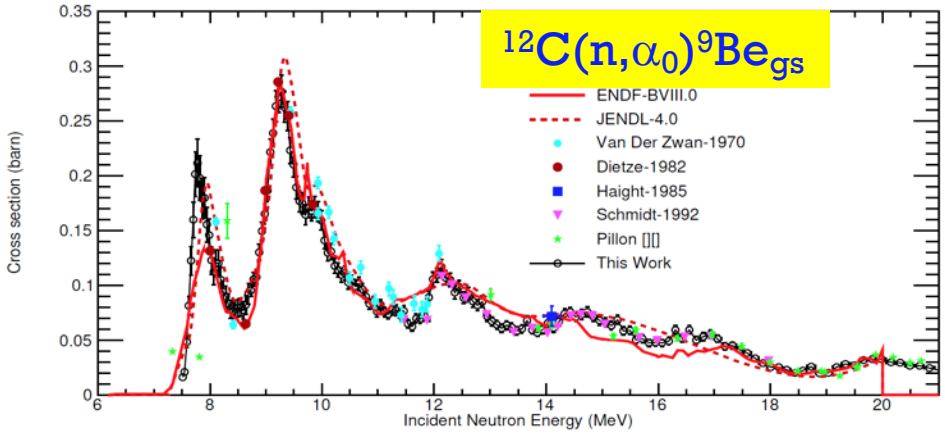



Without completely disentangle elastic channels from inelastic channels, a pulse height spectrum could validate different evaluations. Our data is better reproduced when simulation used the ENDF8 evaluation for elastic scattering and inelastic scattering.

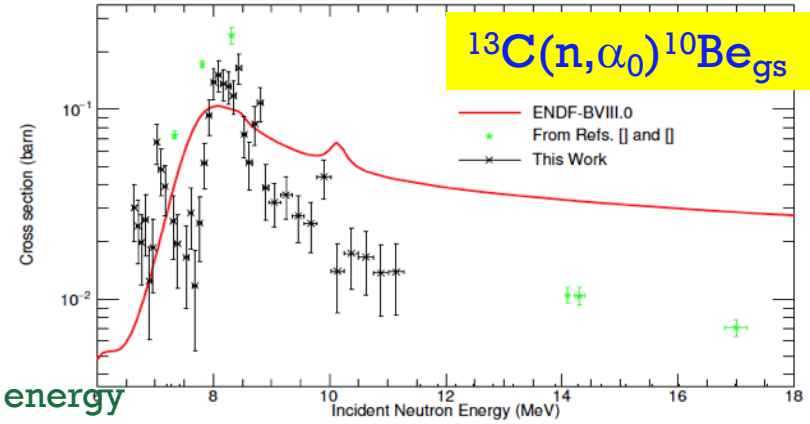


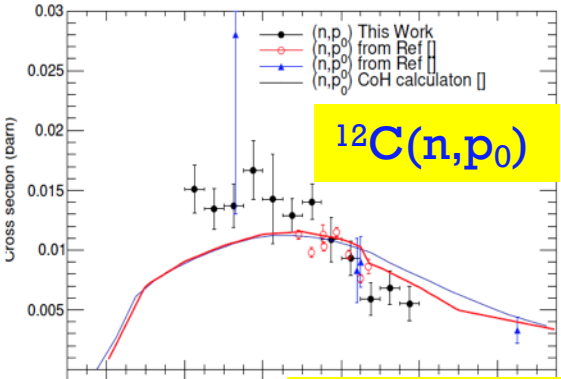
# Diamond data- $^{12,13}C(n,z)$ reaction evaluation

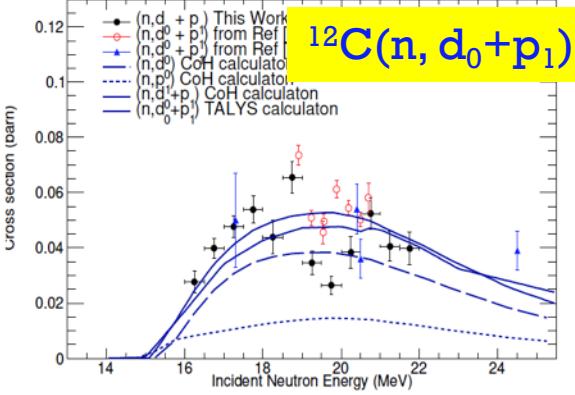
Black dots: LANSCE data



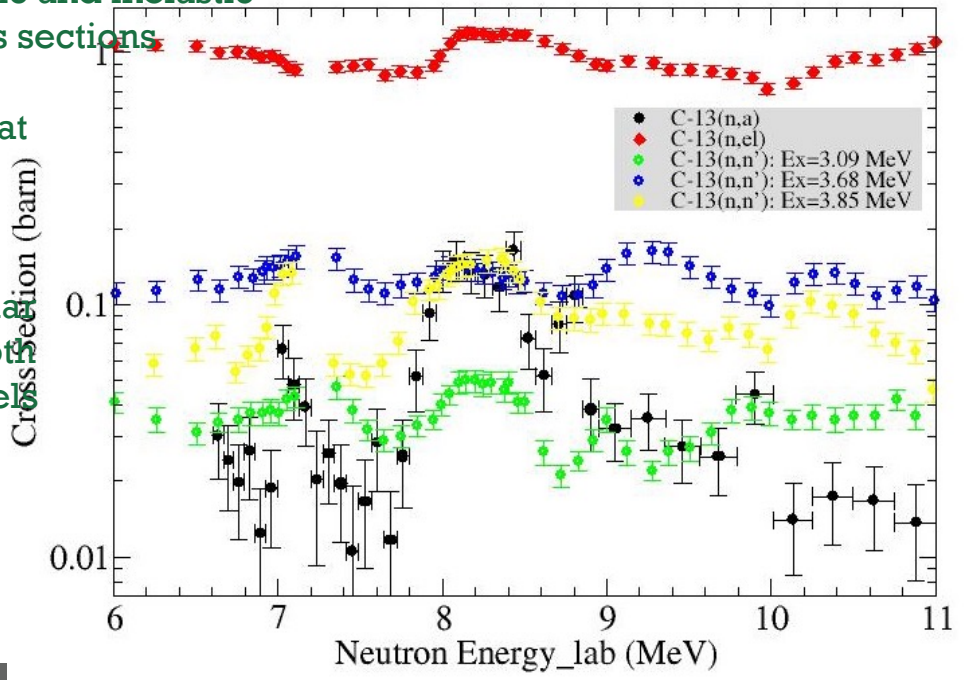

*"Validation of neutron induced reactions on natural carbon using an active target at neutron energies from 0.4 to 22 MeV at LANSCE", S. A. Kuvin, H. Y. Lee, B. DiGiovine, A. Georgiadou, and D. Votaw, Phys. Rev. C (in preparation)*



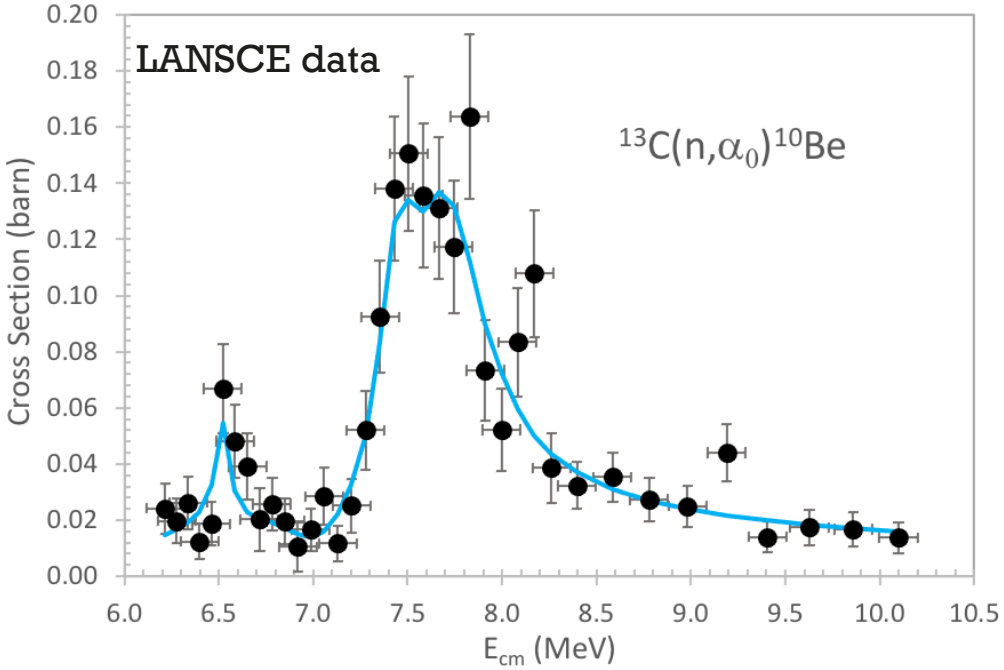



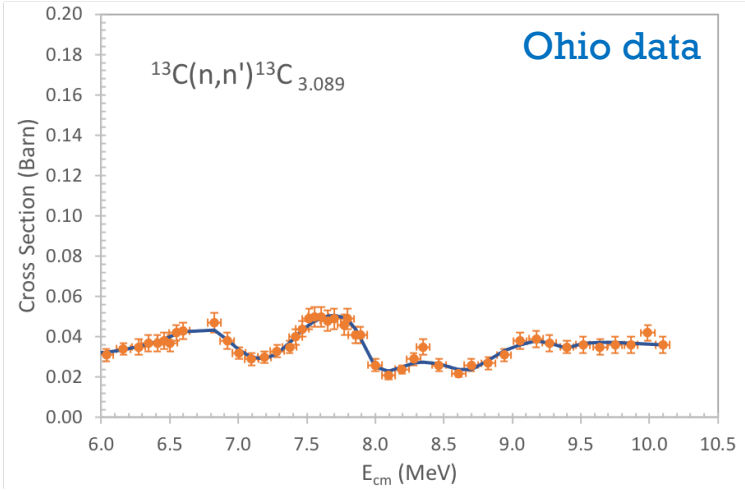

For the relevant LANSCE energy range, the elastic and inelastic scattering cross sections (Resler 1989 measurements at Ohio U.) are compared with the $^{13}C(n,\alpha_0)$. Presented similar structures in both reaction channels

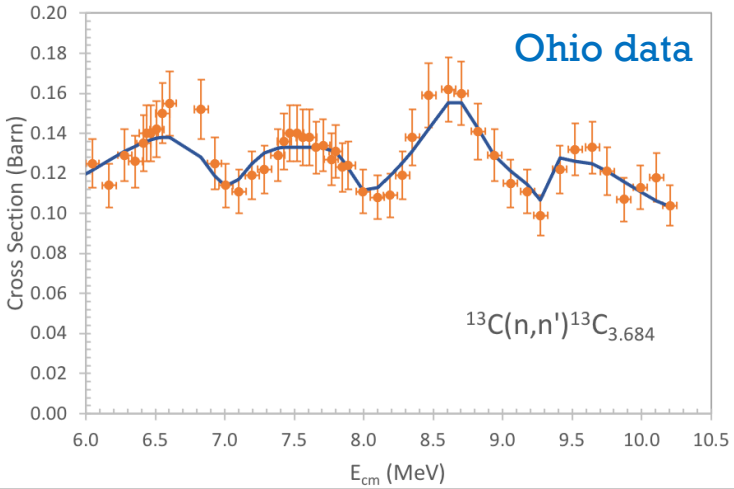


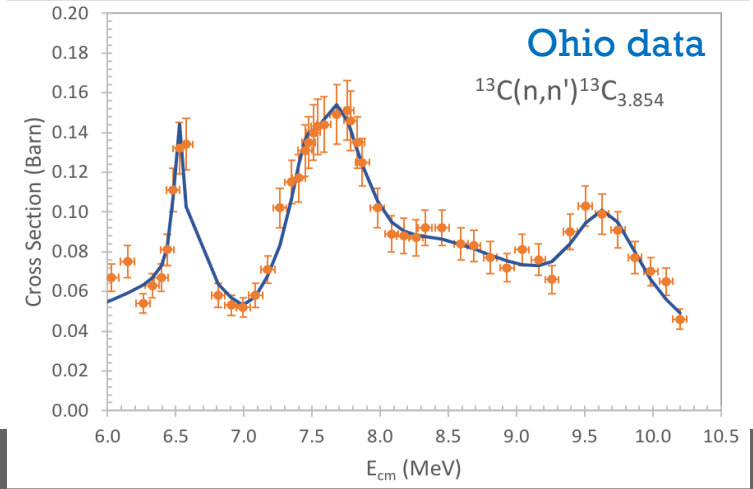
# Diamond data- R-matrix analysis on $^{13}C(n,\alpha_0)$: *(preliminary)*

-Used the AZURE code with initial parameters guided by the ENDF R-matrix evaluation
-Still progressing in fitting the $(n,\alpha_0)$ data by varying parameters and different available reaction data sets



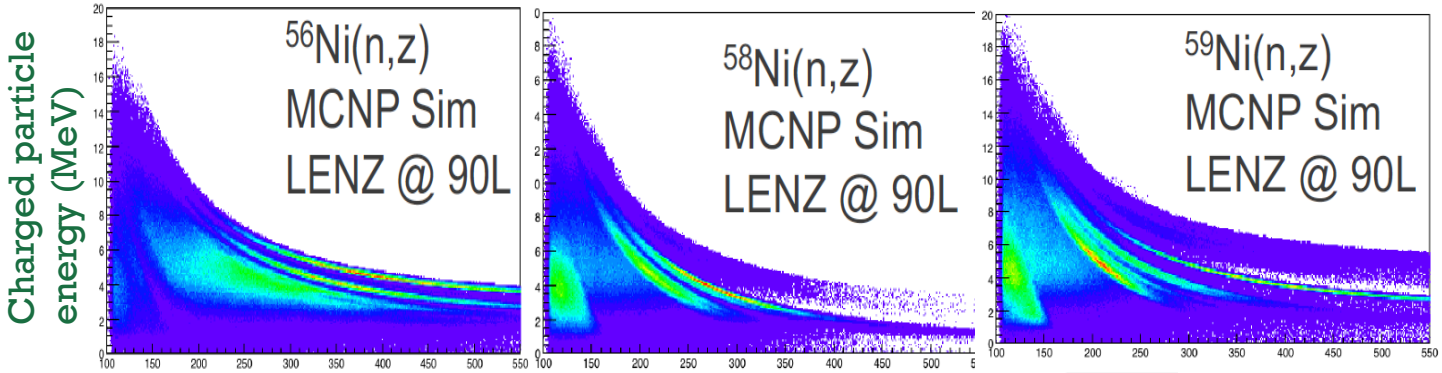



# $^{56,58,59,60}$Ni(n,z) LENZ data status

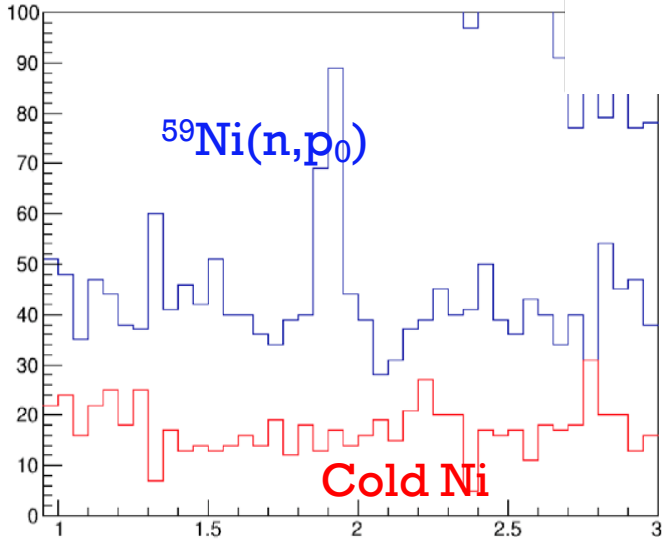
- $^{59}$Ni(n,p) and (n,a) LENZ data: analysis is underway and an additional measurement with a thicker target (91 μg/cm2) is scheduled in Dec 2020 @ 15R
- $^{58}$Ni(n,p) and (n,a) LENZ data: analysis is underway, largest stable background
- $^{60}$Ni(n,p) and (n,a) LENZ data: analysis is underway
- $^{56}$Ni(n,p) hotLENZ data: scheduled to run with IPF target in beam in Dec. 2020 @ 90L

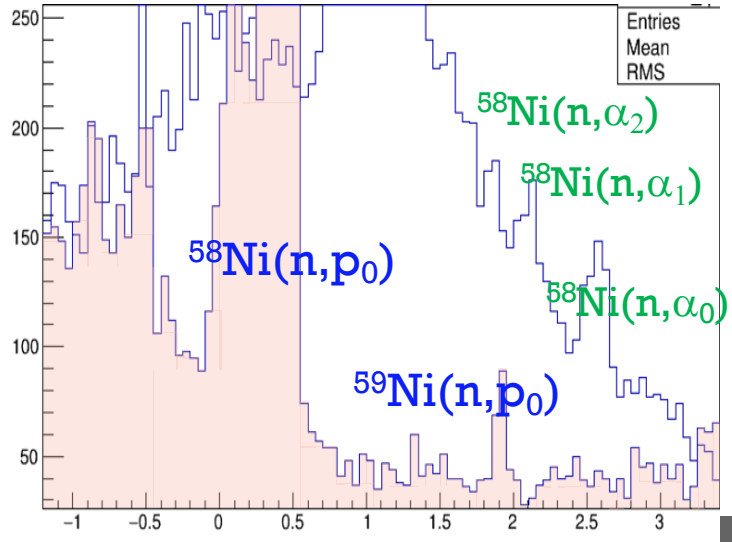



$^{56, 58,59}$Ni(n,p) yield estimates using MCNP6 & new evaluations

$^{59}$Ni(n,p): 2019 LENZ data, using IPF produced, radioactive target ~ 1 μg of $^{59}$Ni with ~100s μg of $^{58}$Ni

-Used Pulse Shape Discrimination method to distinguish a and p



# PI: Paul Koehler

## DICER Update

- 1-mm-diameter binocular collimator system installed and successfully tested
  **Measurements on $^{95}$Mo and $^{209}$Bi in agreement with previous results**
  **Cuts experiment time in half and minimizes required sample**
- Three acceptable chemistries for $^{88}$Zr sample identified
  **DICER experiment scheduled for summer 2021**
- Completed DICER measurement with liquid argon sample
  **Motivated by DUNE neutrino experiment, led by UC Davis**