PANDORA Project

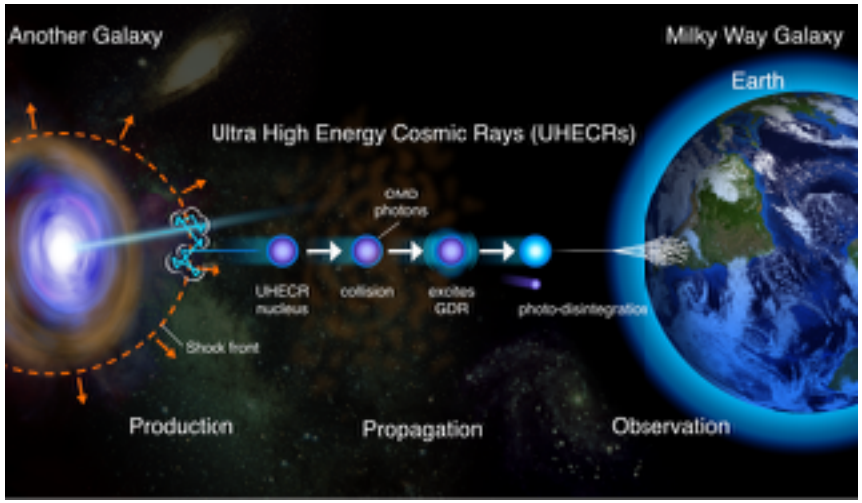
Photo-**A**bsorption of **N**uclei and **D**ecay **O**bservation for **R**eactions in **A**strophysics

Purpose:

- Systematic measurement of photo-nuclear reactions for stable nuclei up to the Fe-Ni mass region
- Photo-absorption cross section and p, n, α, γ decay branching ratios in the GDR region
- Development of theoretical models
- Description of the energy and mass evolution of UHECR nuclei by photo-nuclear reactions in intergalactic space as well as the evaluation of nuclear model uncertainty

Organization

- >100 international collaborators
- experimental facilities: RCNP, iThemba LABS, ELI-NP, …
- theoretical models: AMD, large scale shell model, mean field models (RPA/EDF), ab initio model
- UHECR propagation simulations



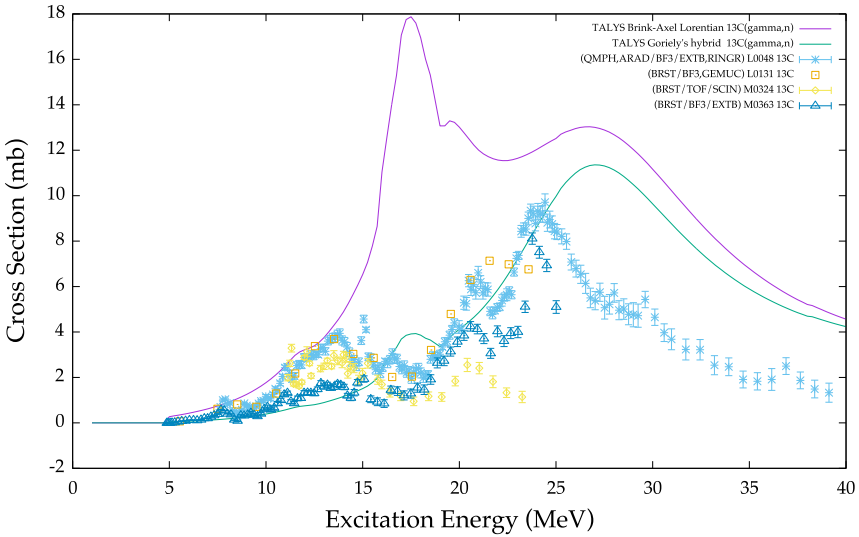
White paper: A. Tamii et al., EPJA59, 208 (2023)

UHECR simulation: E. Kido et al., Astropart. Phys. 152, 102866 (2023).

Issues in Photo-nuclear Reaction Data and Predictions of light nuclei

- Lack of data especially for charged particle decays
- Large inconsistency among experimental data
- Insufficient predicting power of theoretical models

typical example: $^{13}C(\gamma,n)$



$^{13}C(\gamma, xn)$ data and model predictions

Challenges to theoretical models

Nuclear Structure

- stronger shell effect
- nuclear deformation
- nucleon correlations:
  α clustering, *np* pairing, tensor correlation,…

Decay Calculation

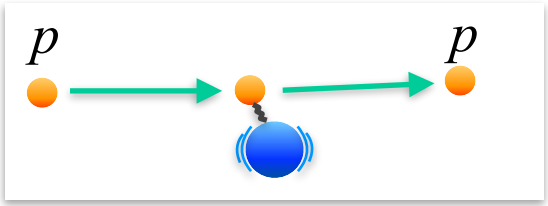
- direct and pre-equilibrium decay process in addition to statistical (compound) decays
- isospin selection rule in α-decay

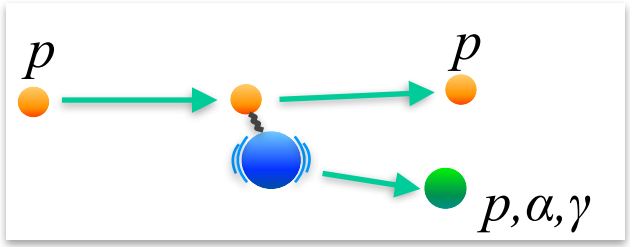
Even the α-decay branching ratio from IVGDR in ^{16}O is not known yet!

Modern Techniques for Photo-Nuclear Reaction Measurement
two complimentary methods

Virtual photo excitation by proton scattering (RCNP, iThemba)

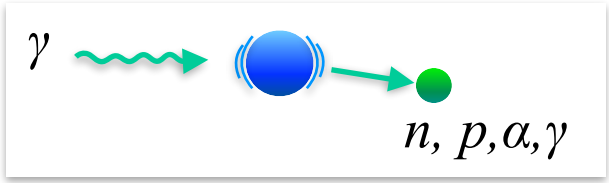
- Missing mass method by Coulomb excitation
- good for inclusive cross section
  applicable for p,α,γ decays





Real photo excitation (ELI-NP)

- Real photon beam by laser-Compton scattering
- individual decay channels
  good for absolute normalization
  applicable also for *n* and *xn* decays in addition to p,α,γ



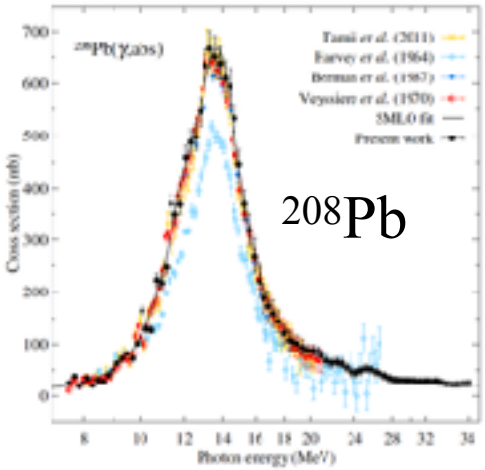
almost perfect consistency

Virtual photon at RCNP

AT et al., PRL2011

Real photon at NewSUBARU

I. Gheorghe et al, PRC2024



Targets

measurement of 10-20 target nuclei with theoretical model developments in coming 5-7 years

σ_{abs} distribution and decay branching ratios within 10% accuracy

Target nuclei

- ^{12}C, ^{16}O, and ^{27}Al — first cases, alpha decay, reference target
- ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B — light nuclei
- (^{20}Ne), ^{24}Mg, ^{28}Si, ^{32}S, (^{36}Ar), ^{40}Ca — N=Z nuclei, α-cluster effect, deformation
- ^{26}Mg, ^{48}Ca, ^{56}Fe — N>Z nuclei
- ^{13}C, ^{14}N, ^{51}V — odd and odd-odd nuclei
- ^{18}O, ^{48}Ca, ^{64}Ni — (γ,xn), multi-nucleon emission

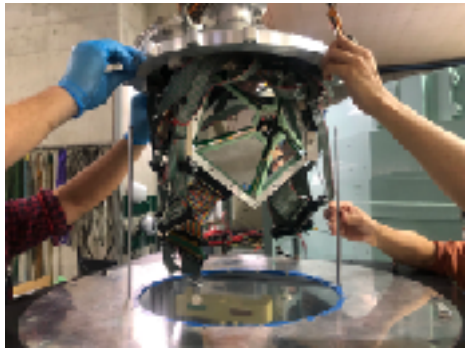
measured in the first exp. at RCNP (2023)

proposal accepted

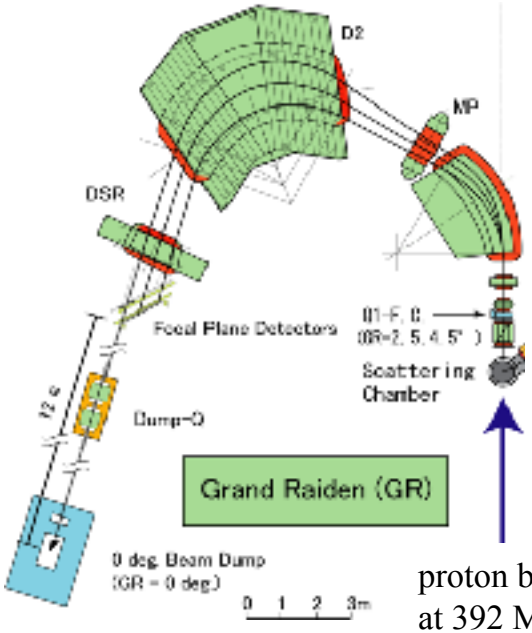
First PANDORA Experiment at RCNP, Oct. 2023

Grand Raiden Spectrometer (Left)

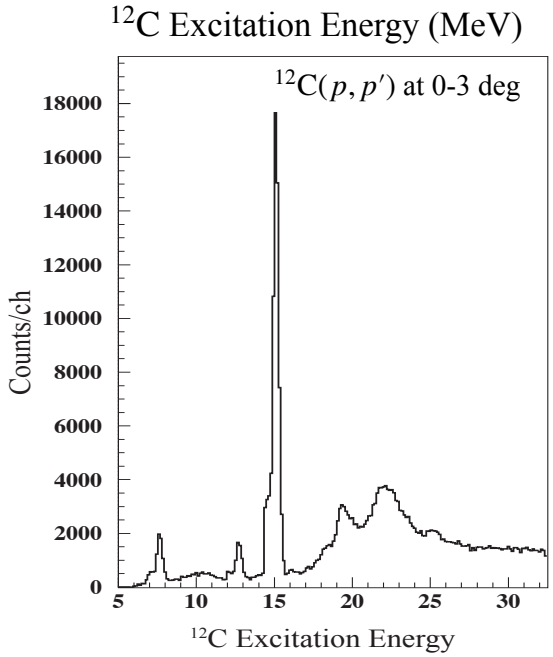
LaBr3 gamma detectors (red)

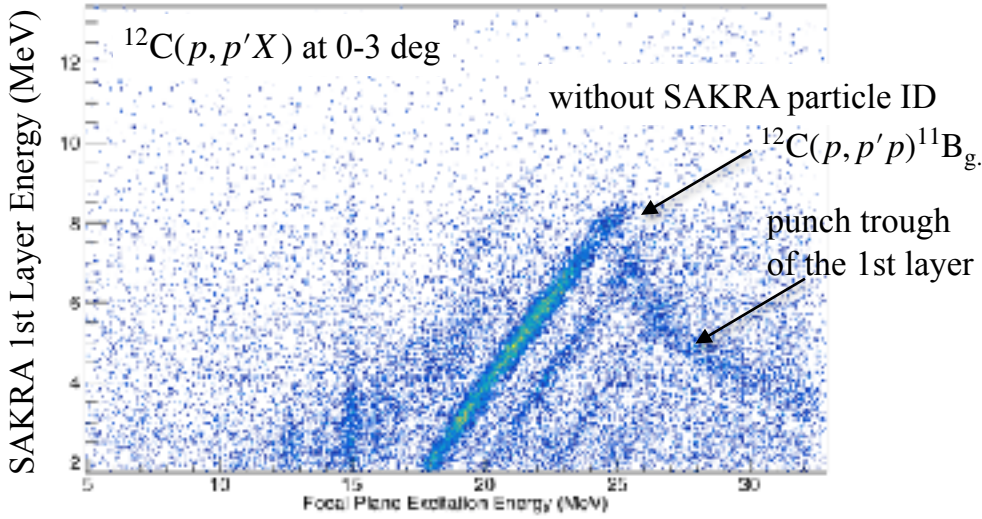


SAKRA silicon strip detectors



proton beam
at 392 MeV





^{12}C Excitation Energy (MeV) by Grand Raiden