Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Fast neutrons inelastic cross section on ^{28}Si for space applications and fundamental research

Spokespersons: C. Petrone (IFIN-HH) & M.Bacak (CERN &UoM)

V. Alcayne, S. Amaducci, M. Bacak, M. Birch, M. Boromiza, D. Cano-Ott, N. Colonna, L. Cosentino, A. Cristescu, M. Diakaki, P. Finocchiaro, A. Gandhi, D. Jankins, N. Kalantar-Nayestanaki, M. Kavatsyuk, M. Kokkoris, G. Lorusso, C. Neacsu, A. Negret, A. Coman, N. Patronis, C. Petrone, R. Vlastou, T. Wright and the n_TOF Collaboration

Motivation

is the 2nd**-most abundant element on Earth** and …

Technological applications:

- semiconductor industry
- nuclear engineering

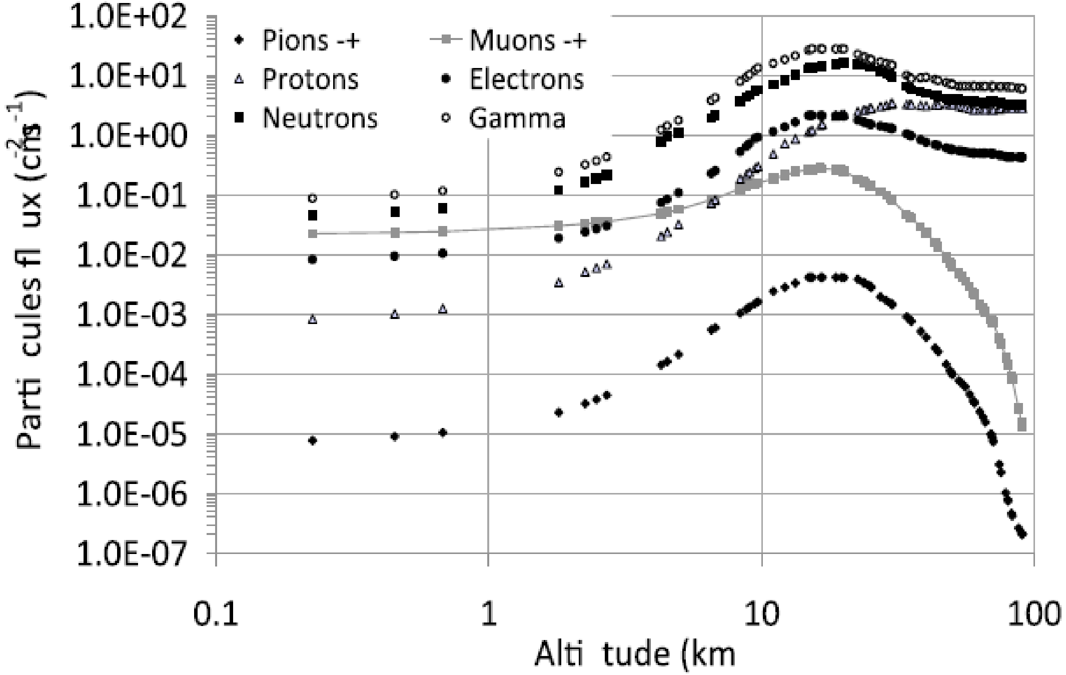
Inelastic cross sections for neutron interactions with silicon:

- reactor modelling
- radiation shielding
- semiconductor radiation damage analysis

Motivation

is the **2nd-most abundant element on Earth** and …

Total flux of particles in the atmosphere with the altitude

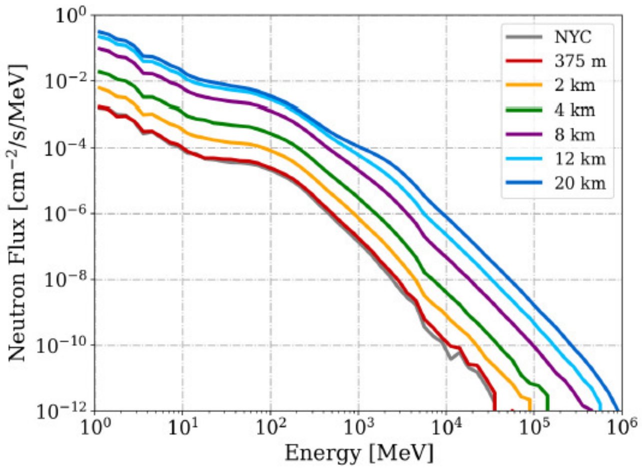


F. Lei, S. Clucas, C. Dyer, P. Truscott, "An atmospheric radiation model based on response matrices generated by detailed Monte Carlo Simulations of cosmic ray interactions", IEEE, Trans. Nucl. Sci.,Volume 51, Issue 6, Part 2, Dec. 2004 Page(s):3442 - 3451

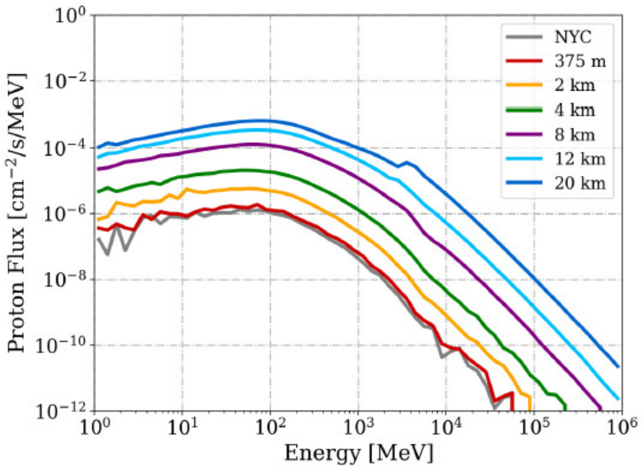
Motivation

is the 2nd-most abundant element on Earth and …

Differential spectra of neutrons (**a**) and protons (**b**) above 1 MeV at different altitudes over Geneva in Switzerland and 1 m above sea level in New York City (NYC).



(a)



(b)

M. Cecchetto *et al*., "Impact of Energy Dependence on Ground Level and Avionic SEE Rate Prediction When Applying Standard Test Procedures", Aerospace 6, (2019) 119

Motivation

is the **2nd-most abundant element on Earth** and …

The contribution of elastic and inelastic scattering to the damage functions of ^{28}Si

Following (n,el) & (n,inel) vacancies and interstitial positions occur in Si lattice sites and act as defects

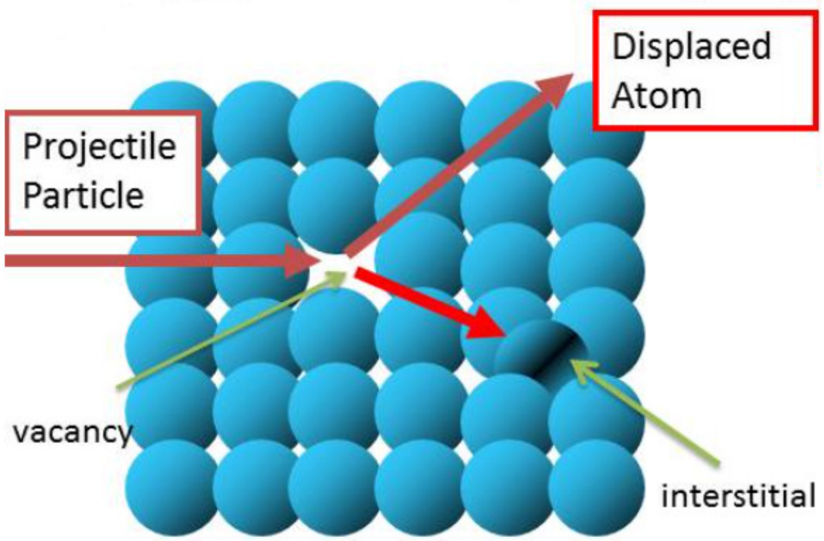
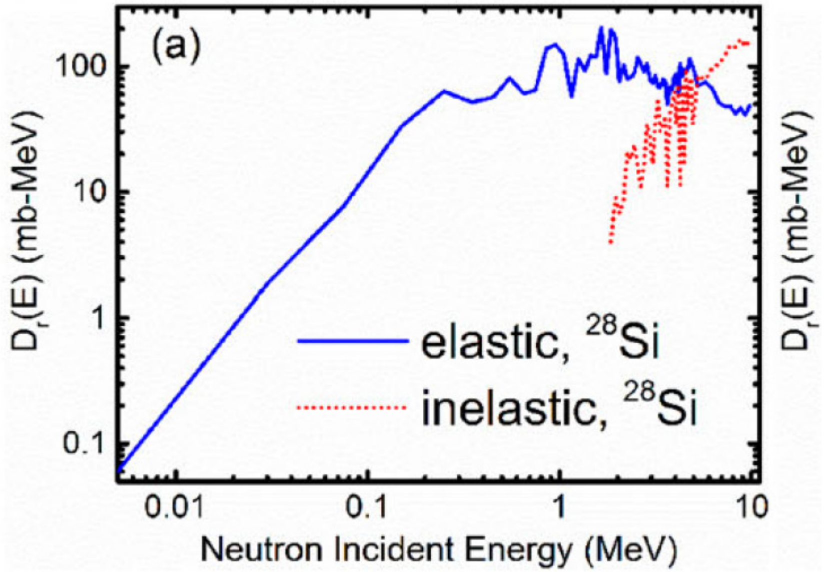


Photo credit: https://www.sr-niel.org/



Y. Baia *et al.*, Radiation Effects and Defects in Solids, 176(5–6), 419–430 (2021)

Motivation

is the 2nd-most abundant element on Earth and 7th-most abundant element in the Universe

Cosmic ray interactions with planetary surfaces.

- Lunar Prospector
- Mars Odyssey
- Mercury → MESSENGER
- Psyche

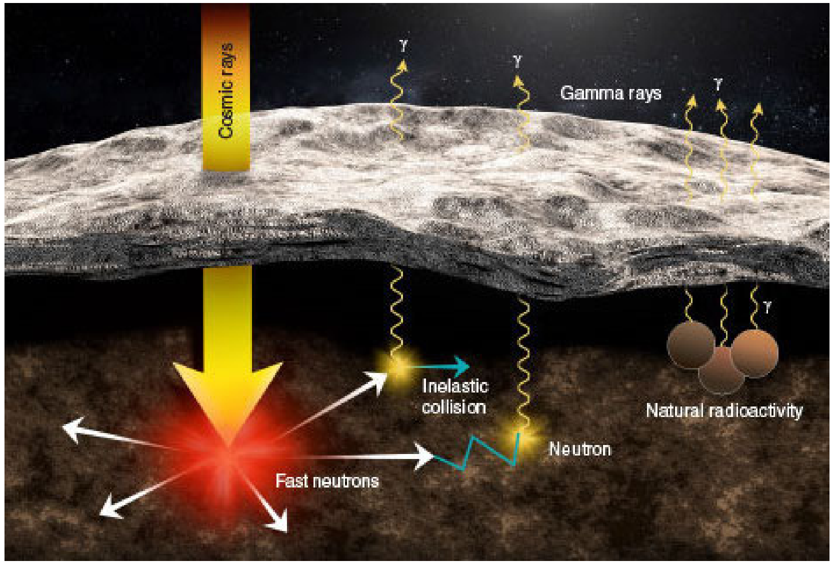


Photo credit: L. Casonhua, "Mini" Device Set to Analyze Mysterious Psyche, (2019).
https://str.llnl.gov/2019-05/burks

Motivation

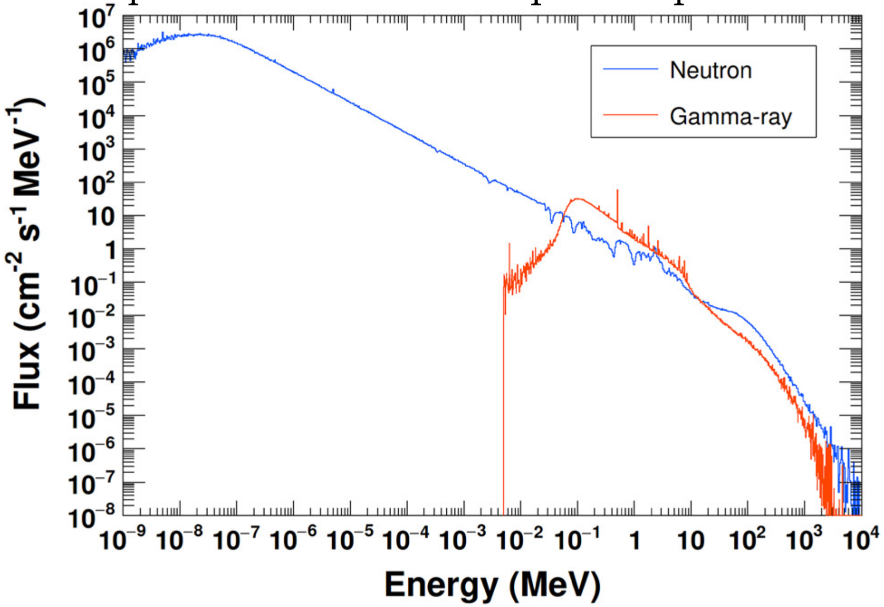
is the 2^{nd}-most abundant element on Earth and 7th-most abundant element in the Universe

3. Nuclear data needs

The highest priority nuclear data need for planetary nuclear spectroscopy is $(n, n'\gamma)$ for H, C, O, N, Na, Mg, Al, Si, P, S, Cl, Ca, Ti, Cr, Mn, Fe, Co, and Ni, from threshold ($\sim$0.1 to $\sim$1 MeV) to $\sim$50 MeV, with less than 5% uncertainty. This overlaps with data needs from safeguards and stewardship applications, where neutrons are used for non-destructive characterization of nuclear waste materials and homeland security applications. The data must be provided to the community via cross section libraries, e.g., ENDF and JENDL, that are compatible with the GEANT4 [228] and MCNP6 [229] transport codes, which are widely used by the planetary nuclear spectroscopy community. Comparisons of laboratory-measured gamma-ray production via neutron inelastic scattering to predictions based on ENDF/B-V to ENDF/B-VII, and ENDF/B-VIII reveal a significant degradation in the accuracy of the secondary gamma-ray energy distributions since the release of ENDF/B-VI [179]. Additionally, cross sections for secondary gamma-generation are also affected.

K. Kolos *et al.*, "**Current nuclear data needs for applications**"
PHYSICAL REVIEW RESEARCH **4**, 021001 (2022)

The calculated neutron and γ-ray energy spectra for the Apollo 16 returned sample composition

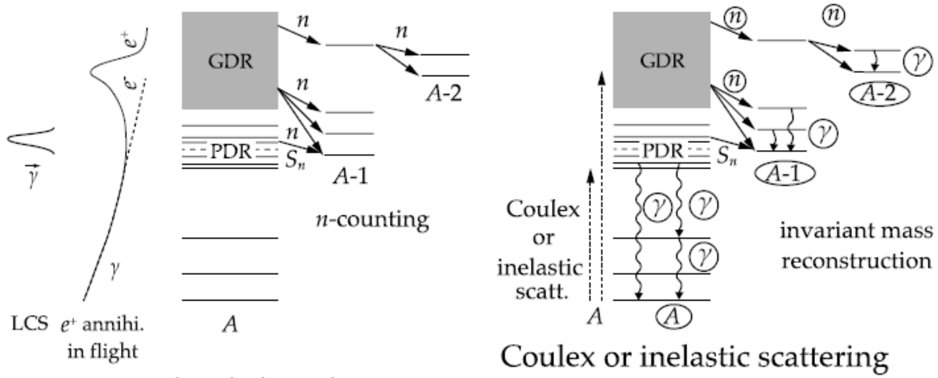


M. Naito, H. Kusano, S. Kodaira, "Global dose distributions of neutrons and gamma-rays on the Moon", Nature Sci Rep 13, 13275 (2023)

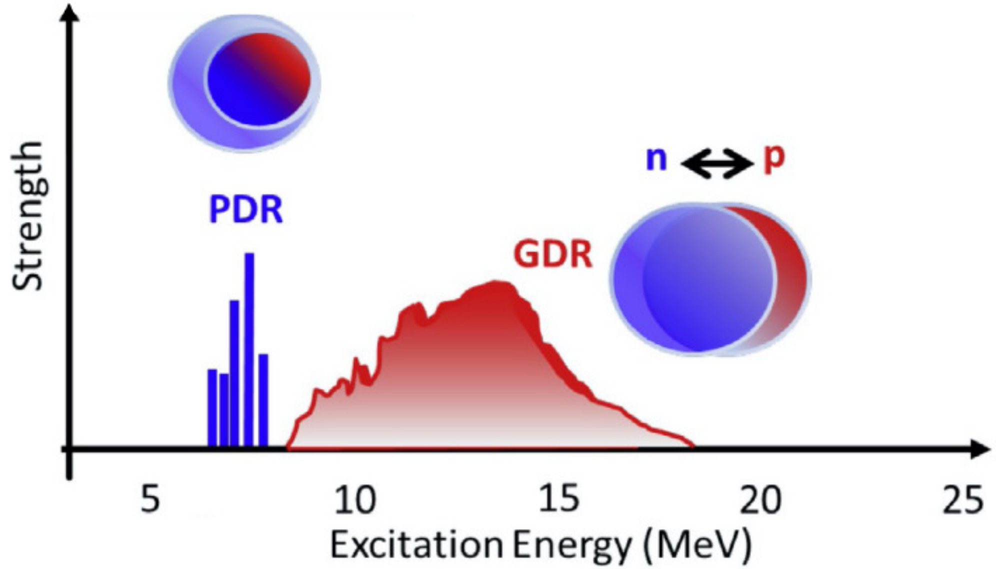
Motivation

(n,n') to probe Giant dipole response - exploratory

- Relative dipole oscillation between *p* and *n*
- Macroscopically Damping: due to viscosity between the *p* and *n* fluids



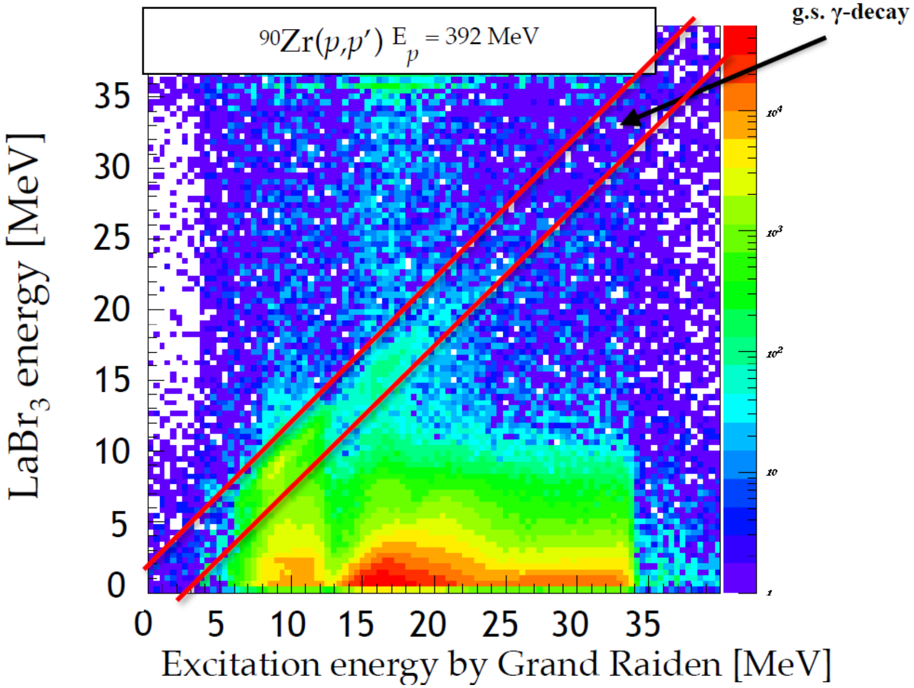
(γ, n), (γ, xn)



A. Bracco *et al.* Prog. Part. Nucl. Phys. 106 (2019)

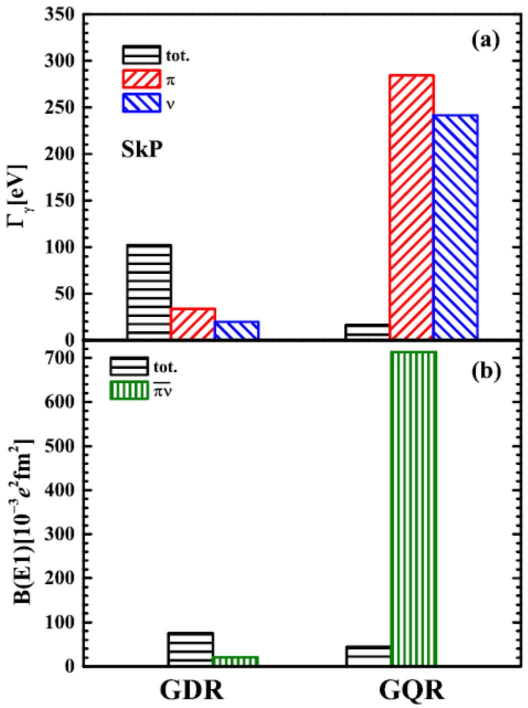
Motivation

(n,n') to probe Giant dipole response - exploratory



A. Tamii et al., PANDORA project and Gamma Emission from Giant Dipole Resonances, 9th Workshop on Nuclear Level Density and Gamma Strength, May 27-31, 2024, Oslo

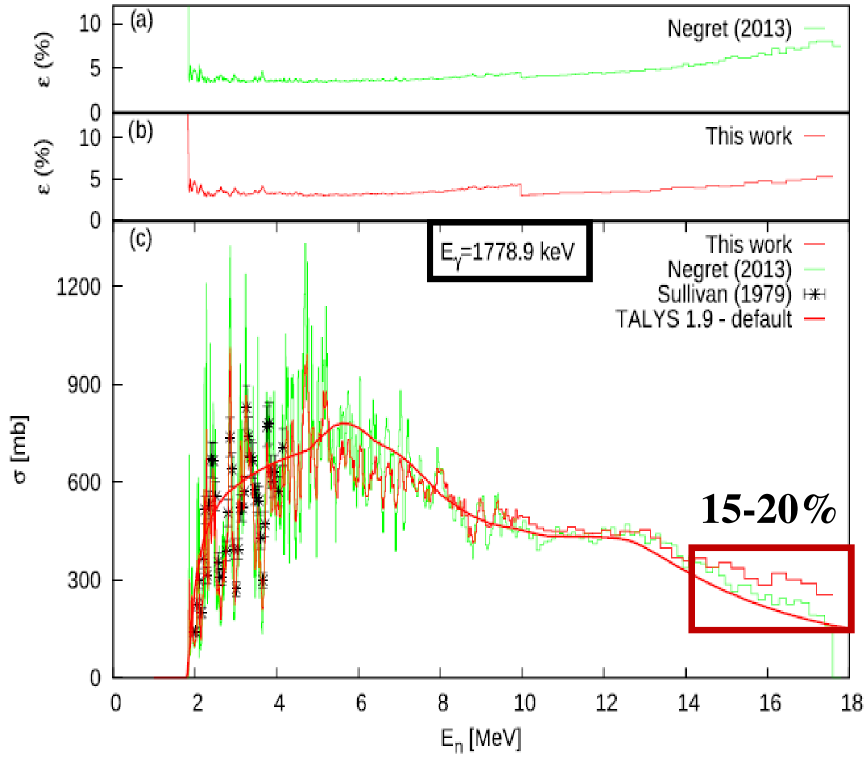
Comparison of the γ -decay widths and decay probabilities B(E1) for transition between GDR→2^+ and GQR → 3^- in ^{208}Pb.



W. L. Lv, Y. F. Niu, G. Colo Learning about the structure of giant resonances from their γ decay, Pys Rev. C 103, 064321 (2021)

Existing data sets in literature

- N. Sullivan *et al.*, *Neutron Inelastic Scattering in Silicon-28 to 4.15 MeV*, Nucl. Sci. Eng. 70, 294 (1979)
- A.Negret *et al.*, *Cross sections for inelastic scattering of neutrons on ^{28}Si and comparison with the ^{25}Mg(α,n)^{28}Si reaction*, PRC 88, 034604 (2013)
- M. Boromiza *et al.*, *Nucleon inelastic scattering cross sections on ^{16}O and ^{28}Si*, PRC 101, 024604 (2020)
- A.P.D. Ramirez *et al.*, *Neutron elastic and inelastic cross section measurements on silicon from 0.8–8 MeV*, Nucl. Phys. A 1024, 122474 (2022)



M. Boromiza *et al.*, PRC 101, 024604 (2020)

$LaBr_3(Ce)$ tests @ n_TOF

5 $LaBr_3(Ce)$ detectors:

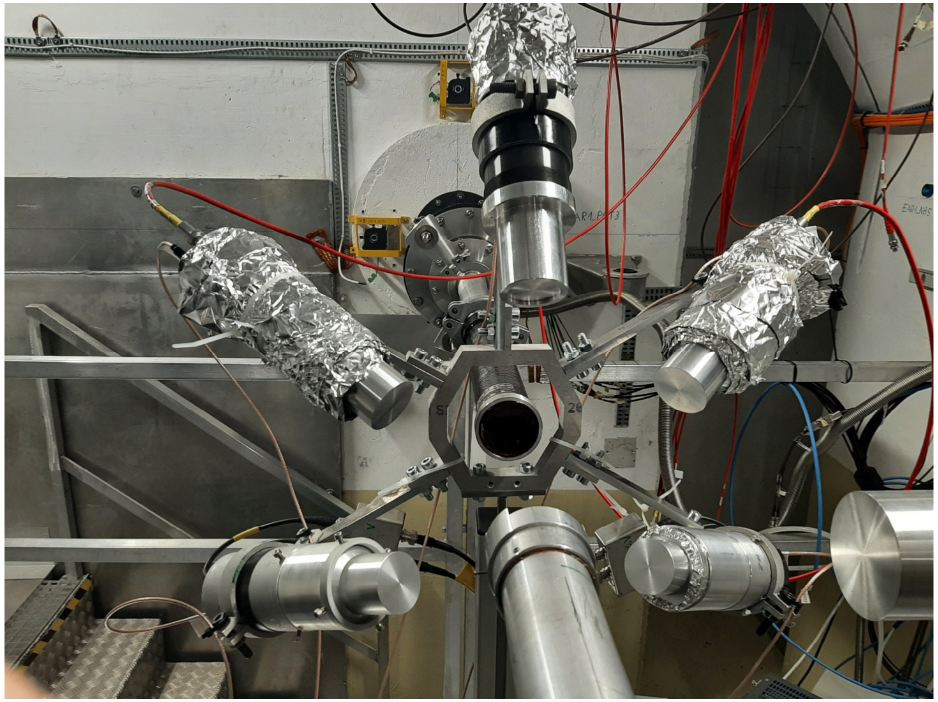
- 1 PMT ET Electronics –gating option
- 2 PMT Hamamatsu R6231 & passive VD
- 2 PMT Hamamatsu R6231 & active VD

$^{24}Mg(n,n')$ reaction

➢0.75mm thickness

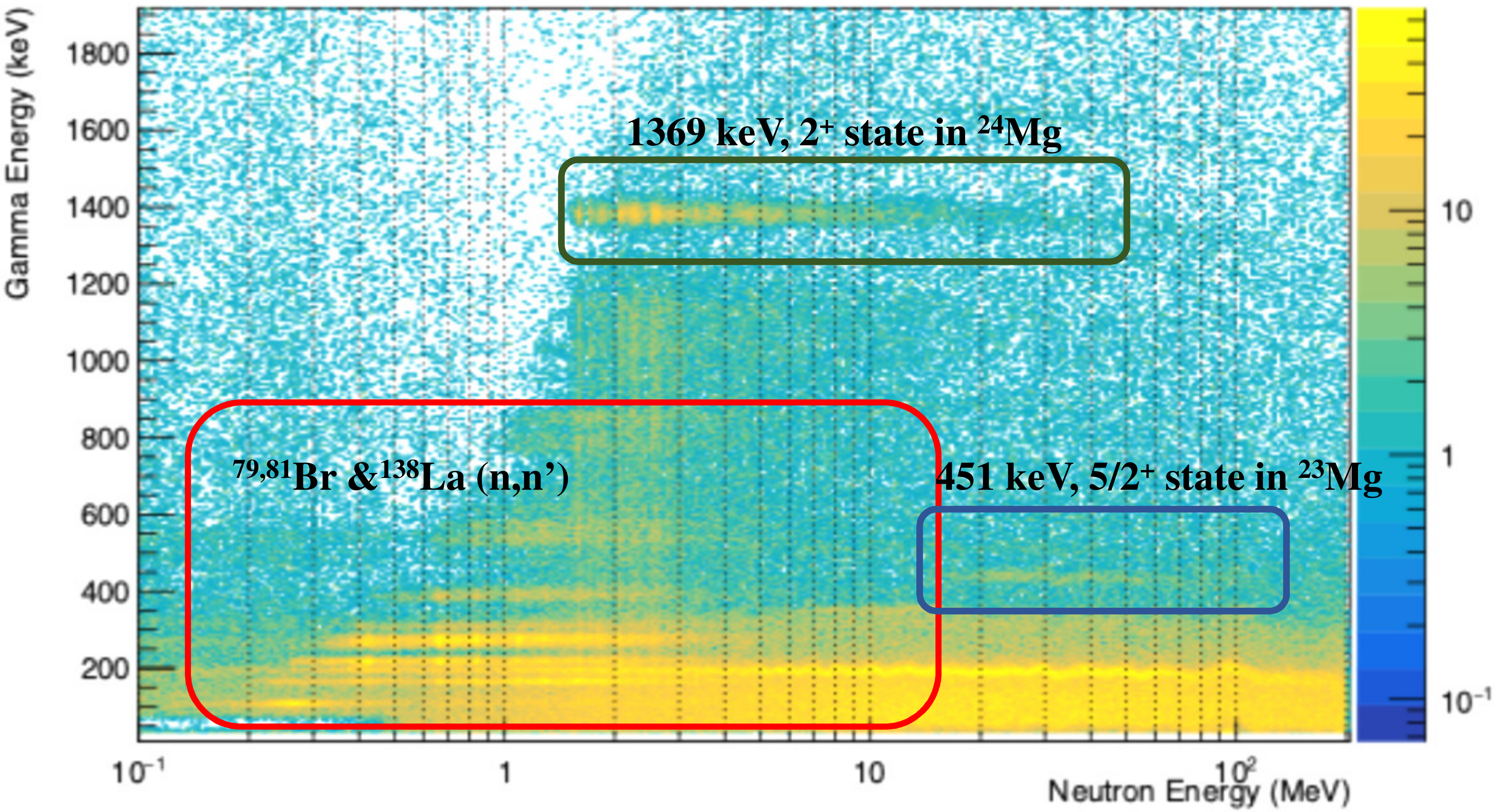
➢15 cm sample-detectors distance

➢~6 days of beam time



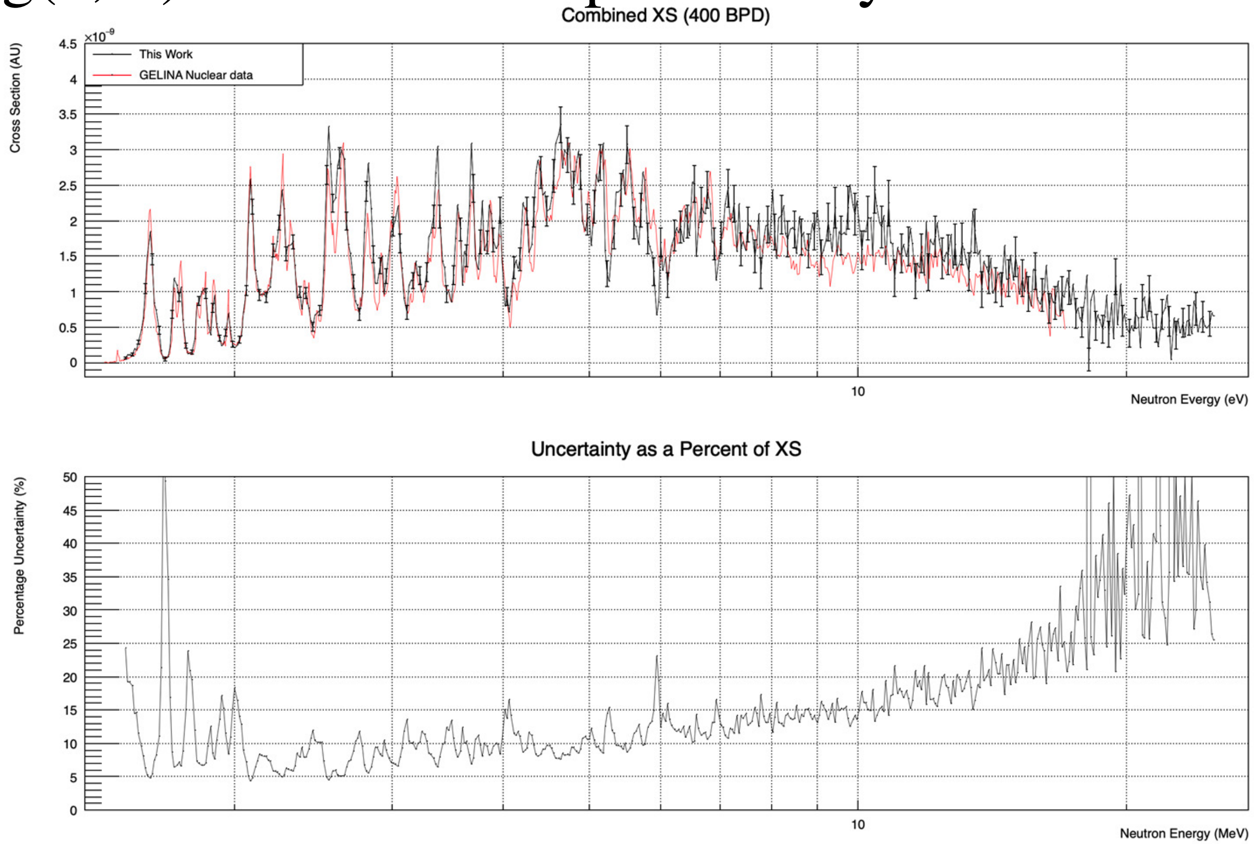
LaBr$_3$(Ce) tests @n_TOF

^{24}Mg(n,n') γ-ray spectrum



LaBr$_3$(Ce) tests @n_TOF

^{24}Mg(n,n') cross section –preliminary results from M. Birch

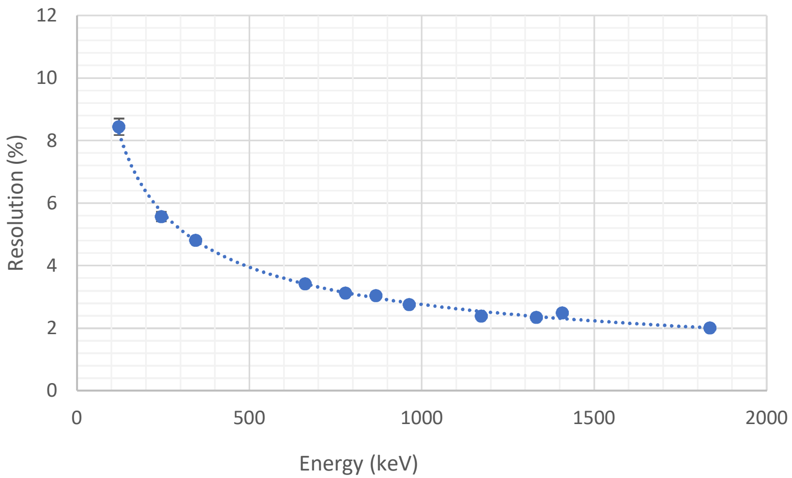


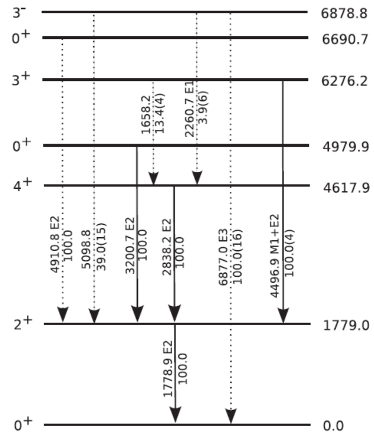
^{28}Si(n,n') challenges

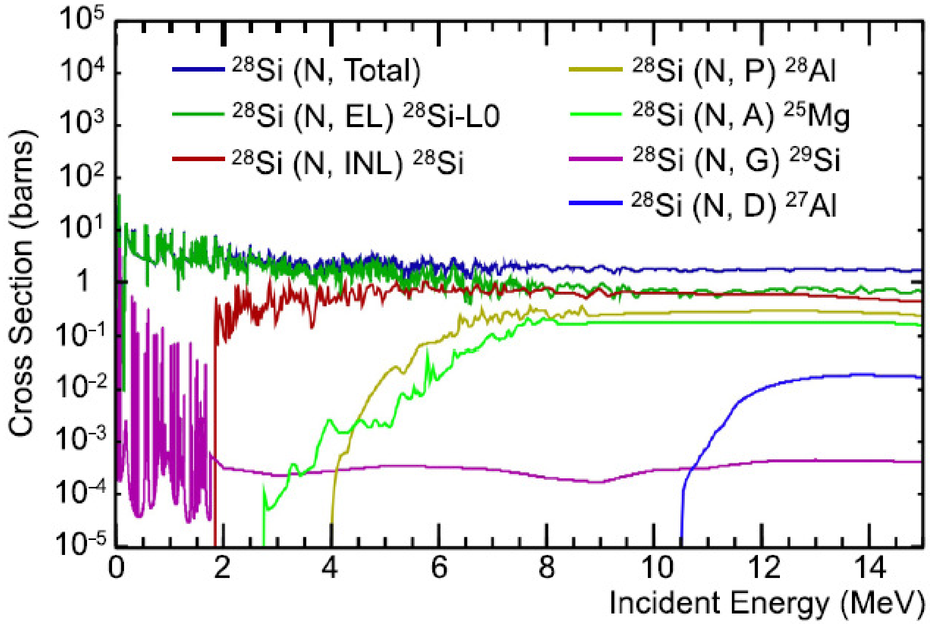
$$^{28}Al \xrightarrow{\beta^-, T_{1/2}=2.25\ min} {}^{28}Si$$

Polluting contributions:

- 1779 keV line: 1763 and 1793 keV γ-rays in ^{25}Mg
- 2838 keV transition: 2828 keV γ-ray ^{25}Mg







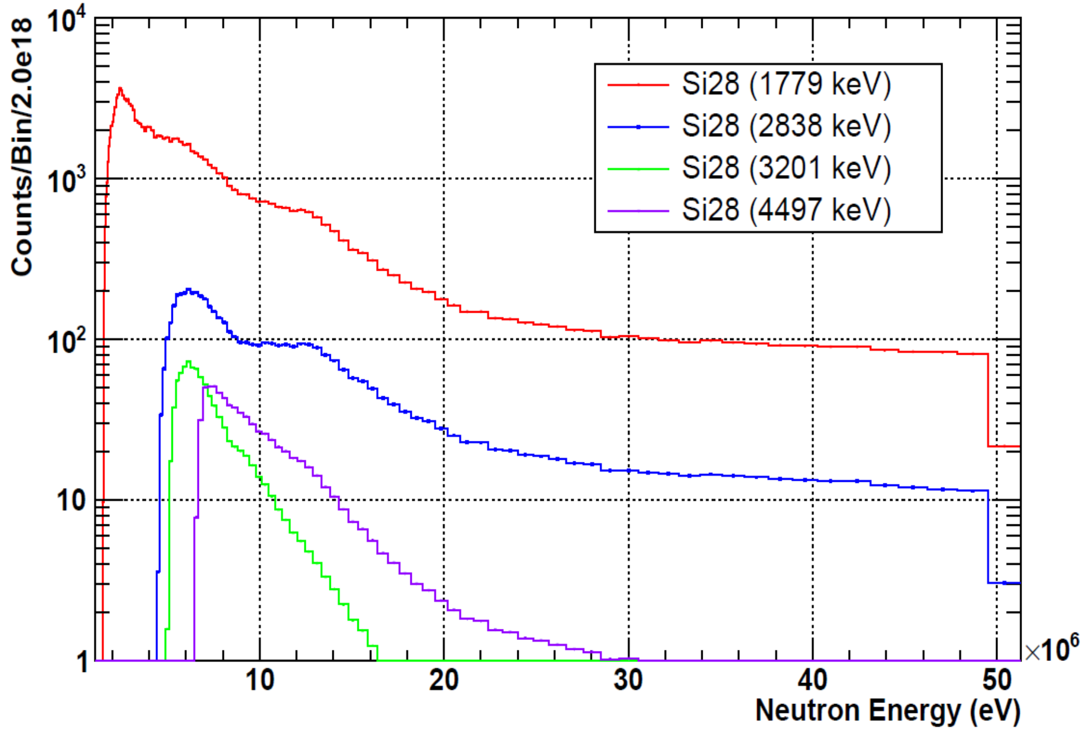
^{28}Si(n,n') Beam time request

Expected count rate:

- TALYS theoretical calculations
- ^{28}Si enriched sample of 1mm thickness
- 5 LaBr3(Ce) detectors (1.5"X2" crystal)
- 17cm detector-sample distance
- 60bpd

- 3 detectors rings: 110°, 150° & 90°

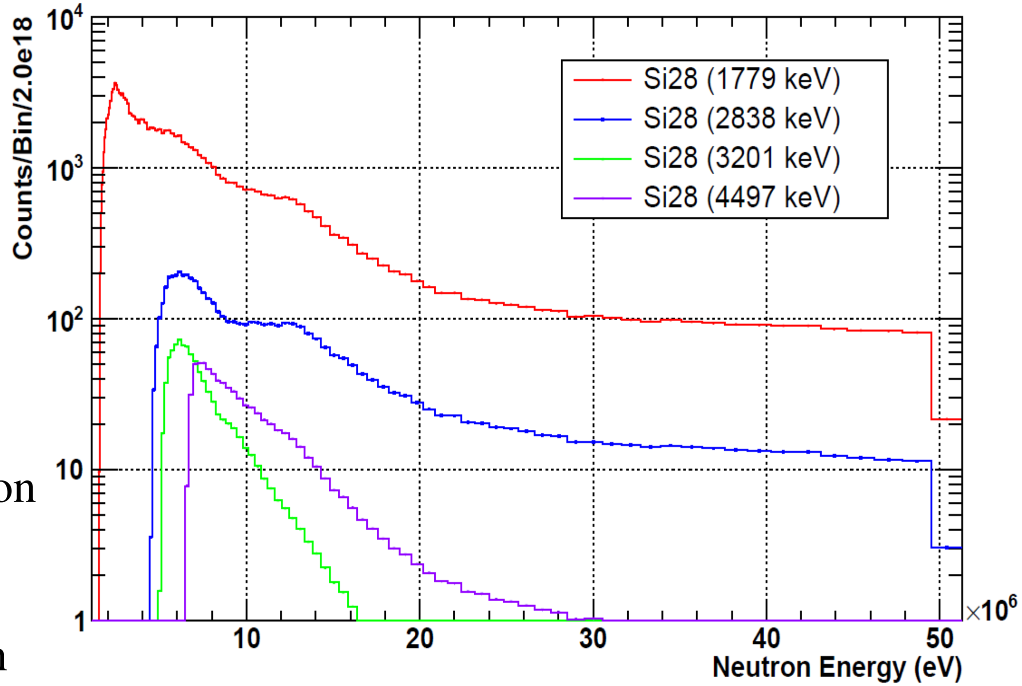
Summary of requested protons: 2 ▪ 10^{18} in EAR1



^{28}Si(n,n’) Conclusions

Expected count rate:

- ➢ 15MeV<E_n<20MeV ε_σ~7%
- ➢ 20MeV<E_n<50MeV ε_σ~10%



Important for:

- ✓ ***Resolve the two conflicting*** measurements from GELINA
- ✓ Extract for the ***first time*** the cross section up to 50MeV

- ➢ ***Fast neutron damage*** on electronic devices based on silicon (airplanes/space shifts/ weather balloons/ satellites etc.)
- ➢ ***Planetary exploration*** studies
- ➢ ***Signature of GDR*** excitation on the 1779keV γ production cross section→ exploratory study (by-product)

Summary of requested protons: 2 ・ 10^{18} in EAR1

Thank you for your attention!

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Fast neutrons inelastic cross section on ^{28}Si for space applications and fundamental research

September 26, 2024

V. Alcayne[1], S. Amaducci[2], M. Bacak[3,4], M. Birch[4], M. Boromiza[5], D. Cano-Ott[1], N. Colonna[6], L. Cosentino[2], A. Cristescu[5], M. Diakaki[7], P. Finocchiaro[2], A. Gandhi[5], D. Jankins[8], N. Kalantar-Nayestanaki[9], M. Kavatsyuk[9], M. Kokkoris[7], G. Lorusso[10], C. Neacsu[5], A. Negret[5], A. Coman[5], N. Patronis[11], C. Petrone[5], R. Vlastou[7], T. Wright[4] and the n_TOF Collaboration[12]

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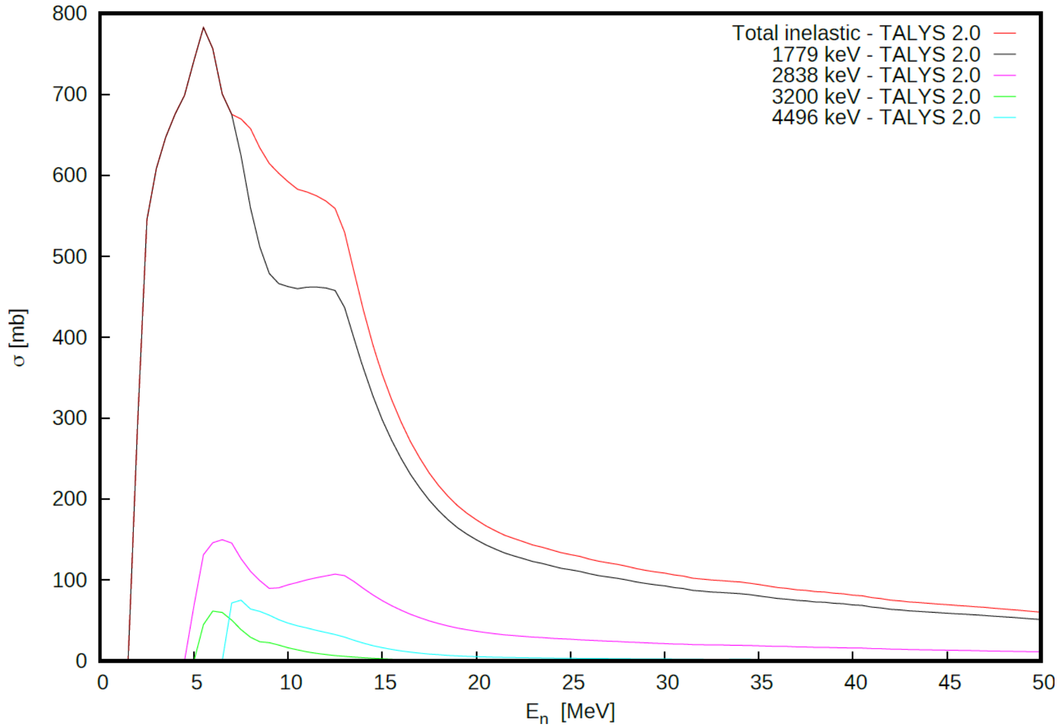
[4]*University of Manchester, United Kingdom*
[5]*Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, Romania*
[6]*Instituto Nazionale di Fisica Nucleare, Sezione di Bari, Italy*
[7]*National Technical University of Athens, Greece*
[8]*University of York, York, UK*
[9]*ESRIG, University of Groningen, Groningen, Netherlands*
[10]*National Physical Laboratory, UK*
[11]*University of Ioannina, Greece*
[12]*www.cern.ch/ntof*

Spokesperson: C. Petrone (cristina.petrone@nipne.ro), M. Bacak (michael.bacak@cern.ch)
Technical coordinator: O. Aberle (oliver.aberle@cern.ch)

Abstract: As one of the most abundant elements in the Universe, silicon plays a key role in a wide variety of applications in industry, electronics, nuclear engineering or space exploration. These applications require precise, reliable and extended cross section data sets on the neutron-induced inelastic channel on ^{28}Si from threshold up to several tens of MeV. Following up on recent efforts on the development of $LaBr_3$(Ce) detectors for studying high neutron energy-induced reactions by means of γ-ray spectroscopy, we are confident that these kind of neutron energies are achievable at n_TOF. To that end, the current proposal aims to measure high-resolution, time of flight data for the neutron inelastic channel on ^{28}Si from threshold up to 50 MeV, where no data exist.

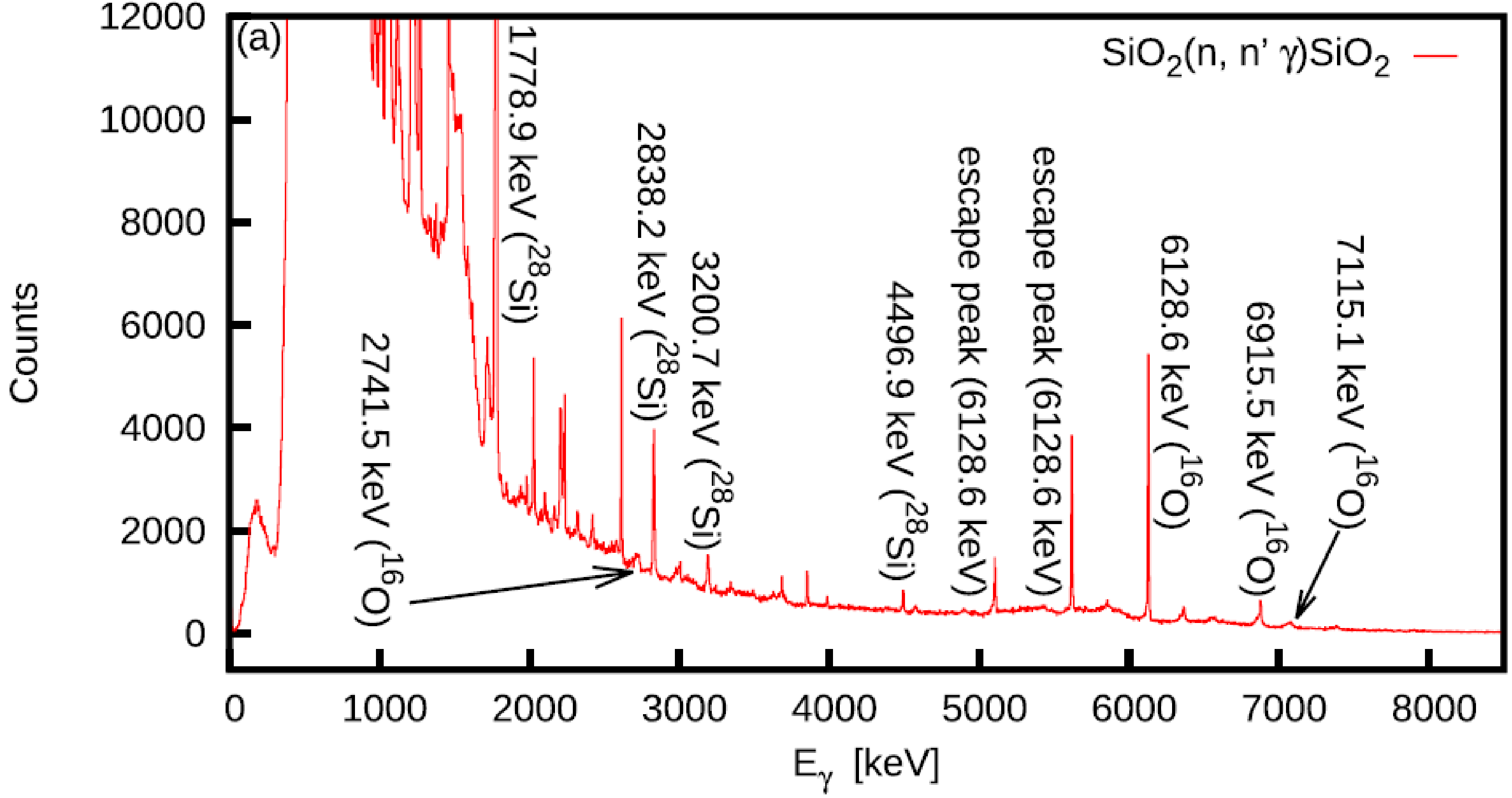
Requested protons: $2{\cdot}10^{18}$ protons on target
Experimental Area: EAR1

TALYS default cross sections

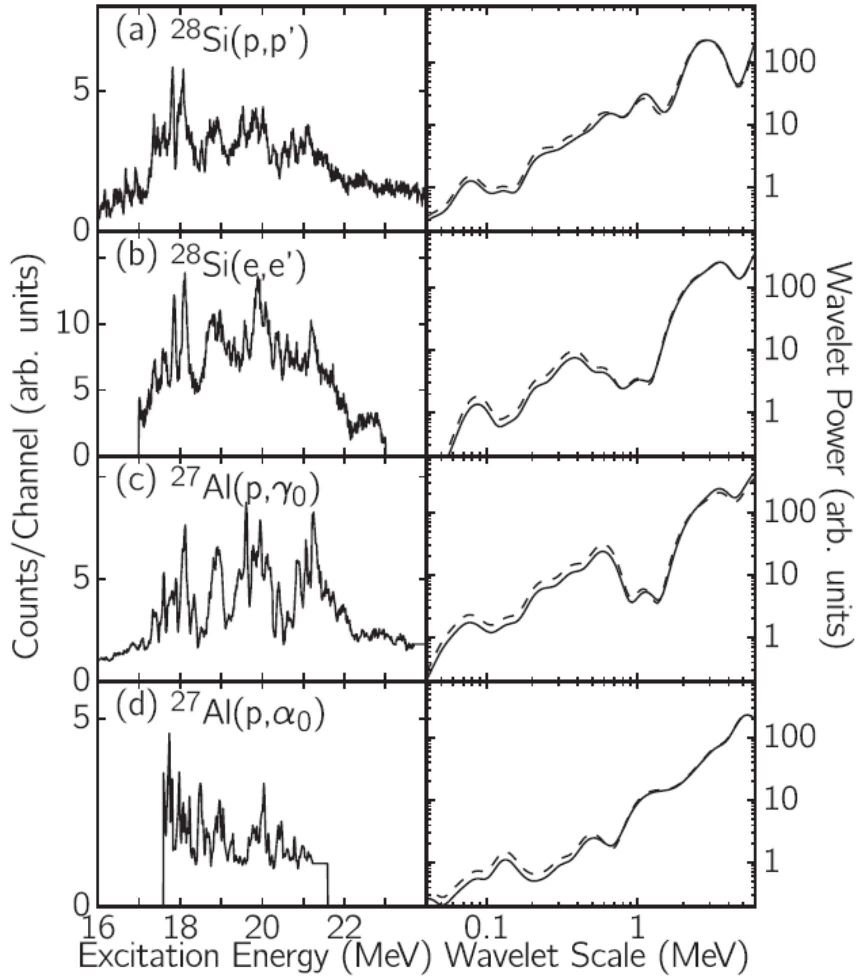


A. Koning *et al*., TALYS: modeling of nuclear reactions, Eur. Phys. J. A (2023) 59:131

GAINS spectrum- M. Boromiza et al, PRC **101**, 024604 (2020)



GDR studies in ^{28}Si



R. W. Fearick *et al.*, Origin of fine structure of the giant dipole resonance in sd-shell nuclei, PRC 97, 044325 (2018)