A new neutron detection array for cross section measurements at IFIN-HH

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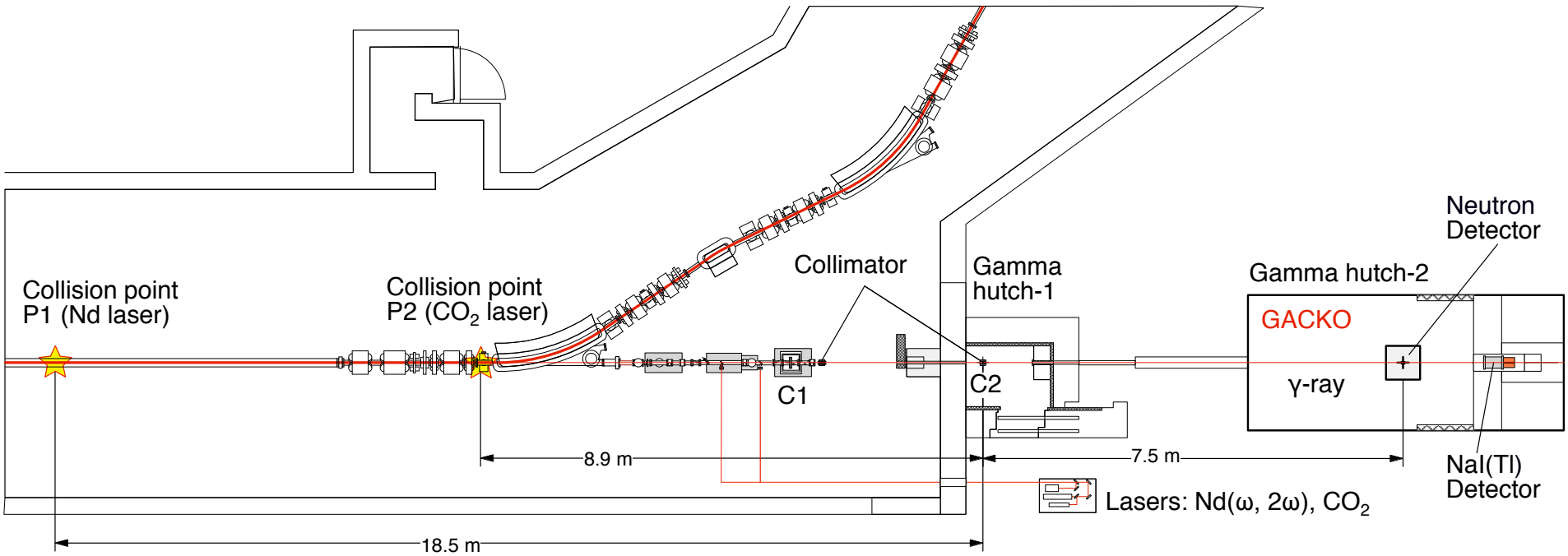
March 08 2024

NewSUBARU synchrotron facility

BL01 LCS γ-ray beam line & GACKO experimental hutch of the Konan University, Kobe, Japan

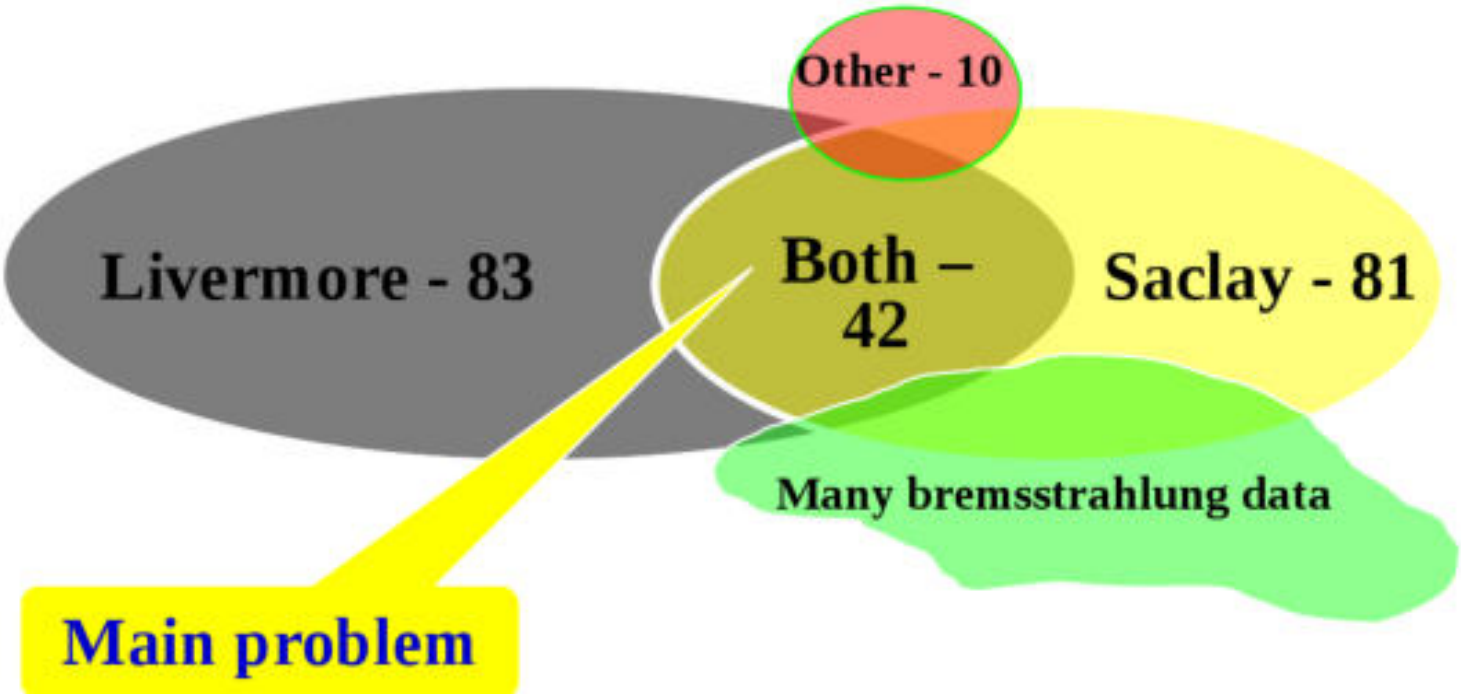


Laser beams are sent head-on against electron beams circulating along a 20 m long straight section of the storage ring. The backscattered γ-ray beam is passed through a double collimation system and sent downstream in the experimental Hutch-2 GACKO (Gamma Collaboration Hutch of Konan University), where the target, neutron detection system and flux and energy profile monitoring systems are placed.

Long standing discrepancies between Saclay and Livermore data sets

The majority of experimental data for partial photonuclear reaction cross sections were obtained at Livermore (USA) and Saclay (France)
Atlas of Photoneutron cross sections obtained with monoenergetic photons
`S.S.Dietrich, B.L.Berman. Atom. Data and Nucl. Data Tables, 38 (1988) 199`
Bermans library: EXFOR entries L0001 – L0059 ($\sim$ 174 data sets)
Large discrepancies between (γ, xn) cross sections measured at the Saclay and Livermore facilities:

- (γ, n) cross sections generally larger at Saclay than at Livermore
- (γ, $2n$) cross sections generally larger at Livermore than at Saclay



Courtesy of V.Varlamov

International Atomic Energy Agency
CRP on Photonuclear Data and Photon Strength Functions

Code F41032; Duration 2016-2019 https://www-nds.iaea.org/CRP-photonuclear/

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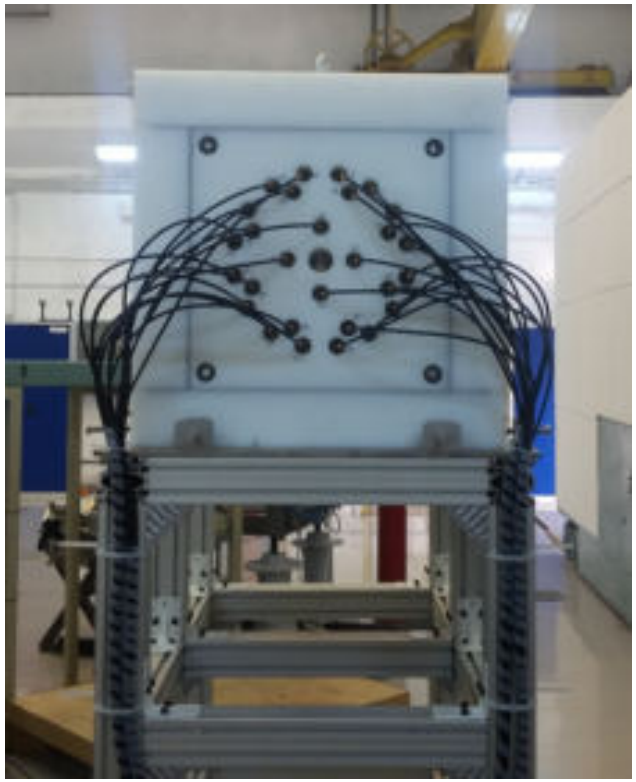
Reference Database of Photon Strength Functions
Database containing all the experimental and global theoretical photon strength functions

- Goriely, et al., Eur.Phys.J. A**55**, 172 (2019)

Updated Photonuclear Data Library
IAEA Photonuclear Data Library 2019

- Kawano, et al., Nuclear Data Sheets **163**, 109 (2020)

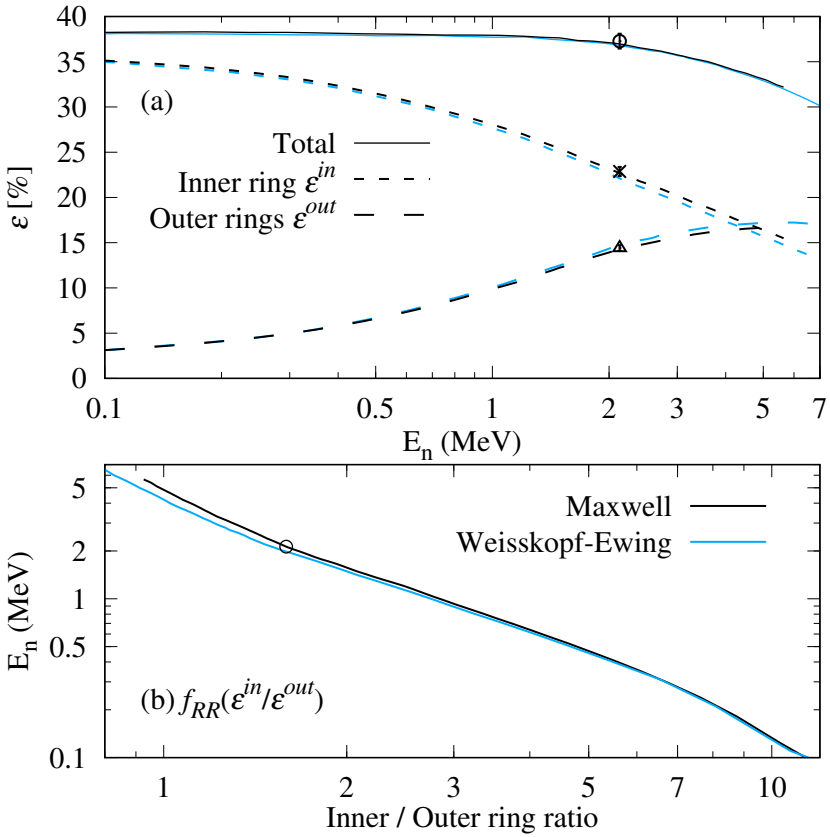
Detector development for ELI-NP and NewSUBARU



ELIGANT detector. Tested at the 9 MV Tandem in 2017. Currently used by the ELI-NP Team at the 9 MV Tandem for charged particle induced reactions cross sections measurements.

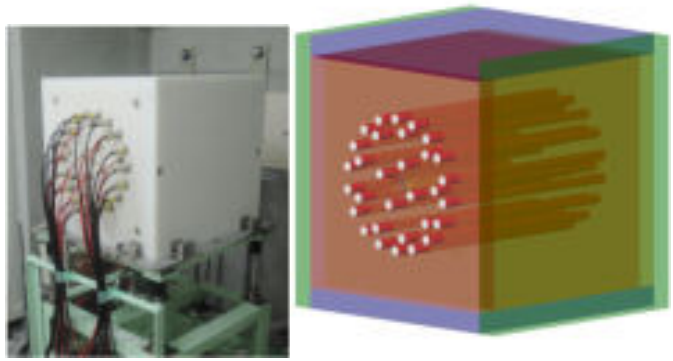
NewSUBARU detector. Used for photoneutron cross sections measurements during 2015-2019.

Neutron multiplicity sorting with a Flat Efficiency neutron detector (FED)



(a) Total detection efficiency (solid) and efficiencies of the inner (dotted) and outer (dashed) rings of the FED obtained by MCNP simulations for Maxwell PFNs spectra (black) (black), neutron evaporation spectra (blue) & experimental ^{252}Cf calibration. (b) Ring ratio curves defined as inner ring / outer rings.

▸ H. Utsunomiya, I. Gheorghe, et. al, NIM A 871, 135-141 (2017)



Flat detector response: average $\langle\varepsilon\rangle_{FED} = 36.5\pm1.6\%$; variation 38 $\sim$ 33% in the 1 keV to 5 MeV energy range typical for evaporation photoneutrons and PFN. Measured cross sections are insensitive to the neutron emission spectra.

neutron fold	efficiency
1 neutron	ε=$\sim$38%
2 neutrons	ε^2=$\sim$14%
3 neutrons	ε^3=$\sim$5.5%
4 neutrons	ε^4=$\sim$2%
i neutrons	ε^i=small

Neutron-multiplicity sorting method

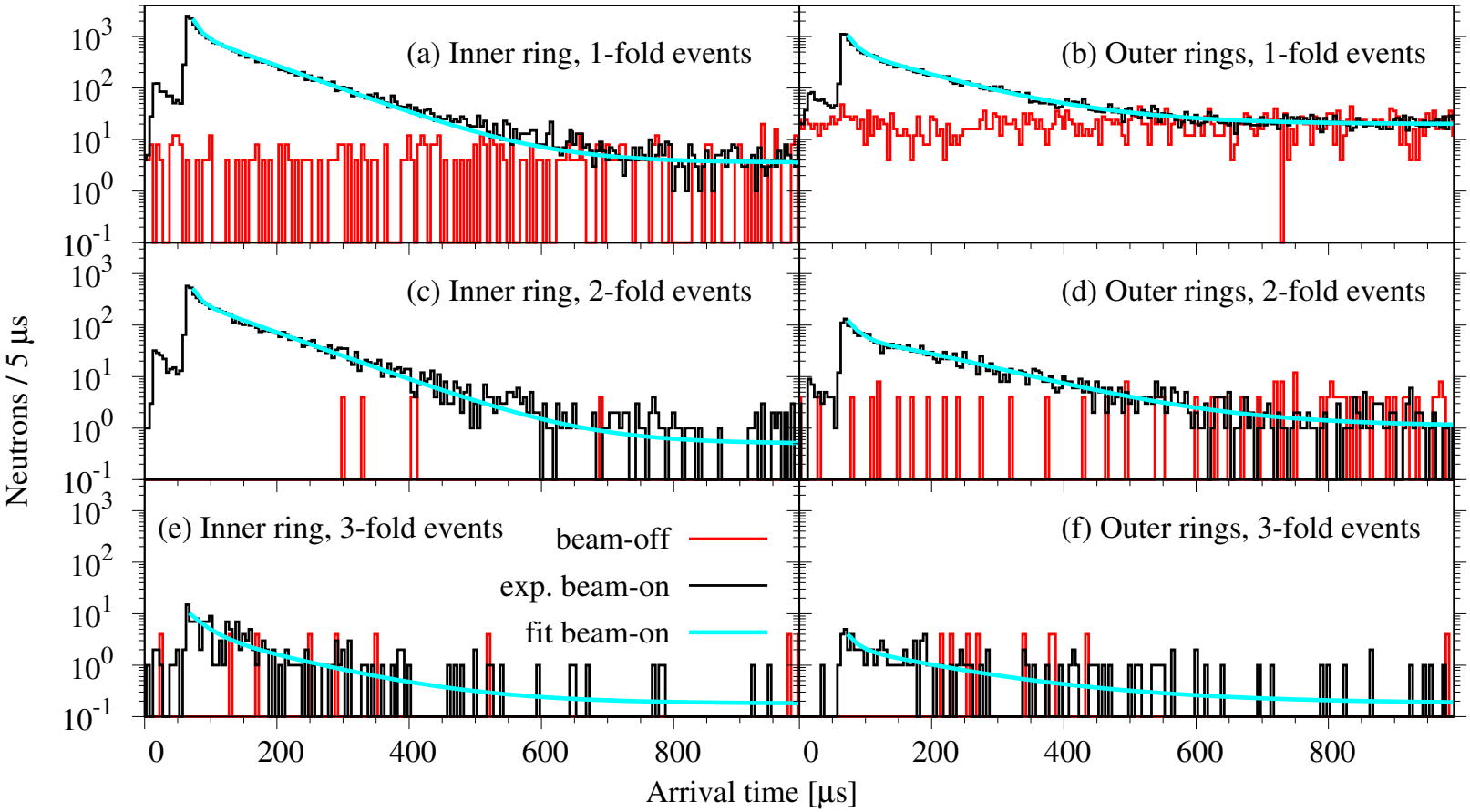


Figure: Arrival-time distributions of neutrons recorded by the FED neutron-multiplicity sorting experiments. Experimental neutron counts recorded during beam-on (black) and beam-off (red) and the best fit to the beam-on distribution (cyan).

NewSUBARU (γ, xn) cross section measurements for IAEA PD CRP

New photoneutron measurements in the Giant Dipole Resonance (GDR):

- quasi-monochromatic Laser Compton scattering (LCS) γ-ray beams
- flat efficiency neutron detector (FED) ▸ H. Utsunomiya, I. Gheorghe, et. al, NIM A 871, 135-141 (2017)

2015	^{209}Bi, ^{9}Be
2016	^{89}Y, ^{169}Tm, ^{197}Au
2017	^{59}Co, ^{165}Ho, ^{181}Ta
2018	^{103}Rh, ^{159}Tb, ^{139}La
2019	^{232}Th, ^{238}U ^{208}Pb, ^{112,116,120,124}Sn

Table: NewSUBARU (γ, xn) cross section measurements.

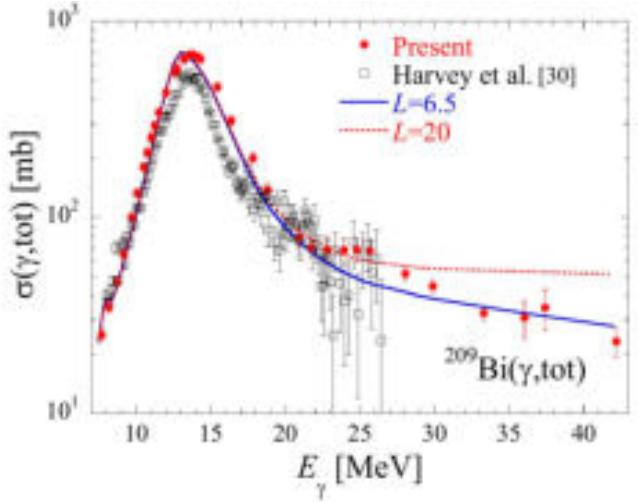
Measurements performed within the **PHOENIX** Collaboration coordinated by **Prof. Hiroaki Utsunomiya, Konan Univ. Japan**

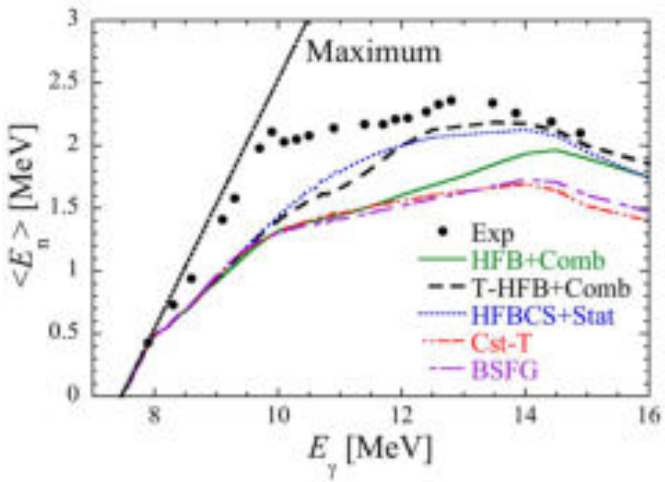
NewSUBARU Japan, SINP China, IFIN-HH Romania, MSU Russia, Oslo University Norway, TU Darmstadt Germany, Universite Libre de Bruxelles Belgium.

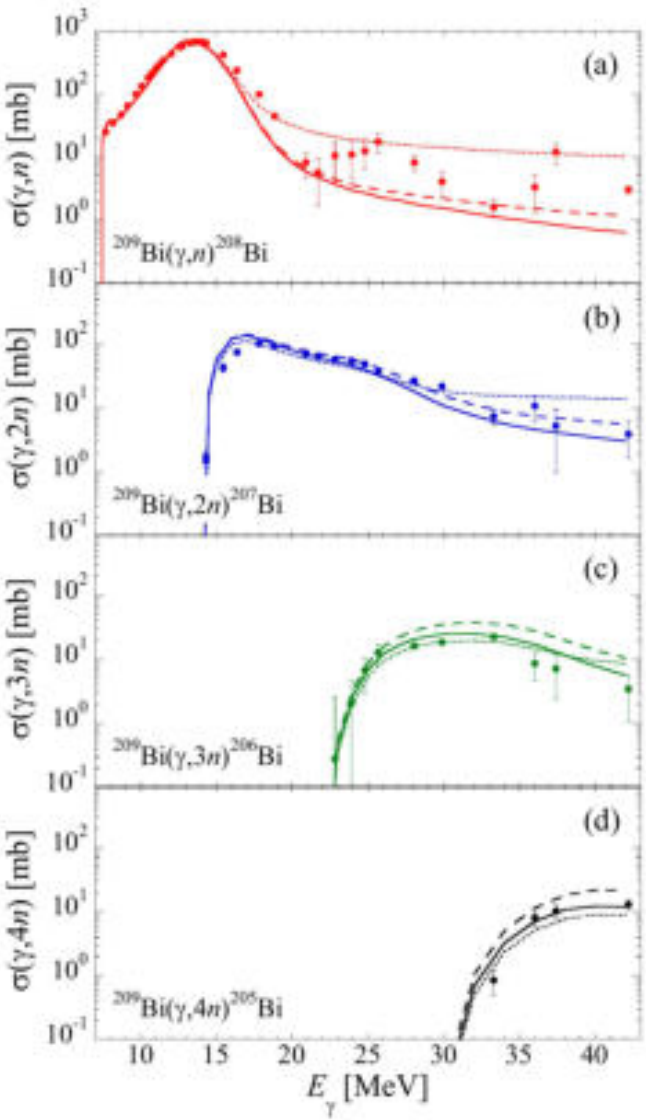
Results delivered to the IAEA CRP on Updating the Photonuclear Data Library ▸ Kawano, et al., Nuclear Data Sheets **163**, 109 (2020)

- NewSUBARU (γ, xn) data selected for producing the updated IAEA evaluations. *IFIN-HH evaluations adopted for ^{89}Y, ^{169}Tm, ^{59}Co, ^{165}Ho, ^{181}Ta, ^{103}Rh, ^{159}Tb.*
- have been the basis of recent theoretical calculations: ▸ S.Goriely et al. PRC 102, 064309 (2020)

IAEA CRP data – ^{209}Bi(γ, xn) data

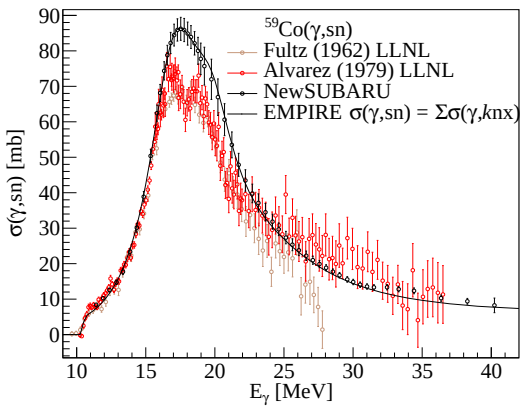


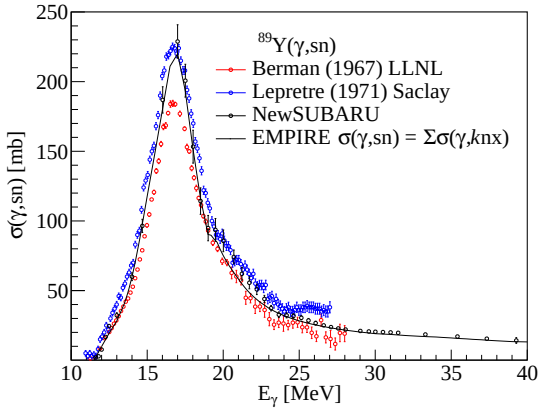


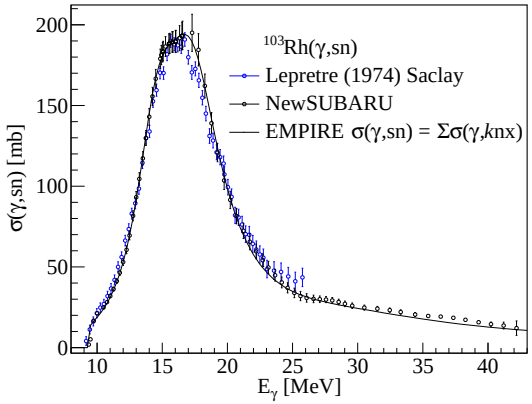


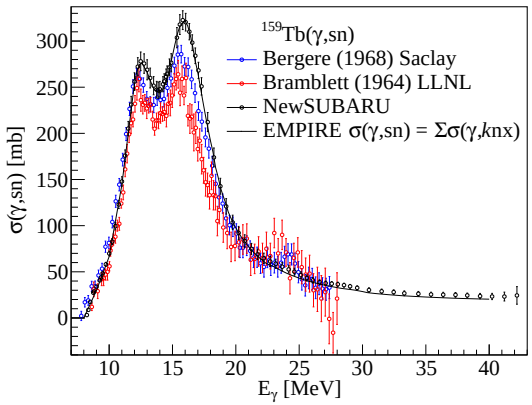
- I.Gheorghe, H.Utsunomiya et al. Phys. Rev. C 96, 044604 (2017)
- Erratum 99, 059901(E) (2019)

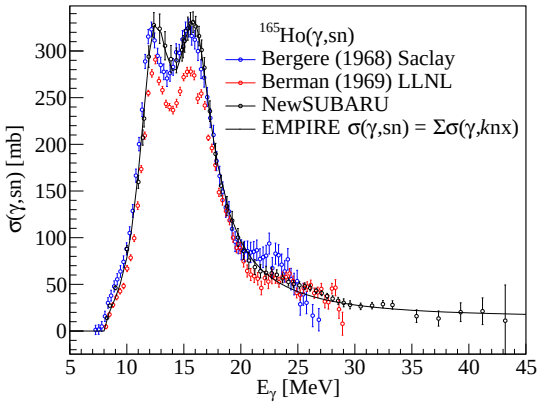
IAEA CRP data – T.Kawano et al. Nuclear Data Sheets 163 (2020) 109

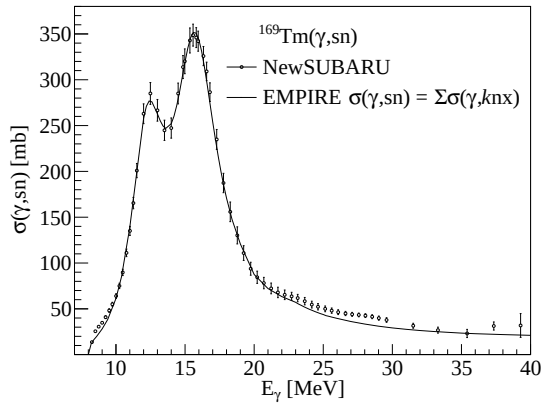


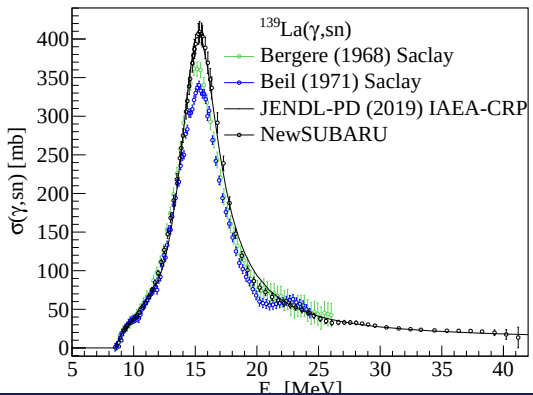


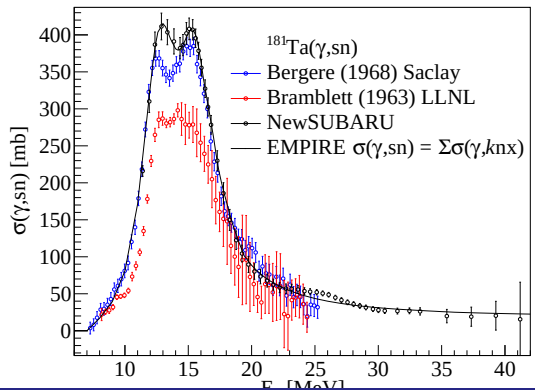


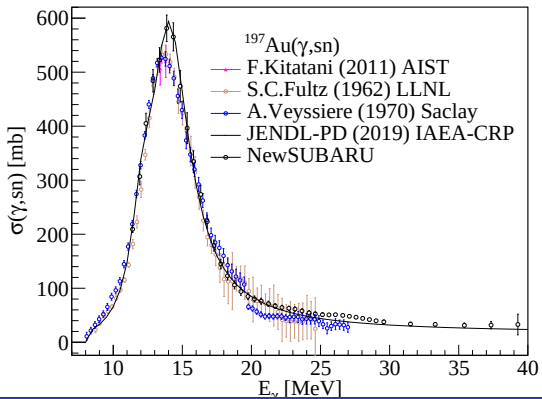




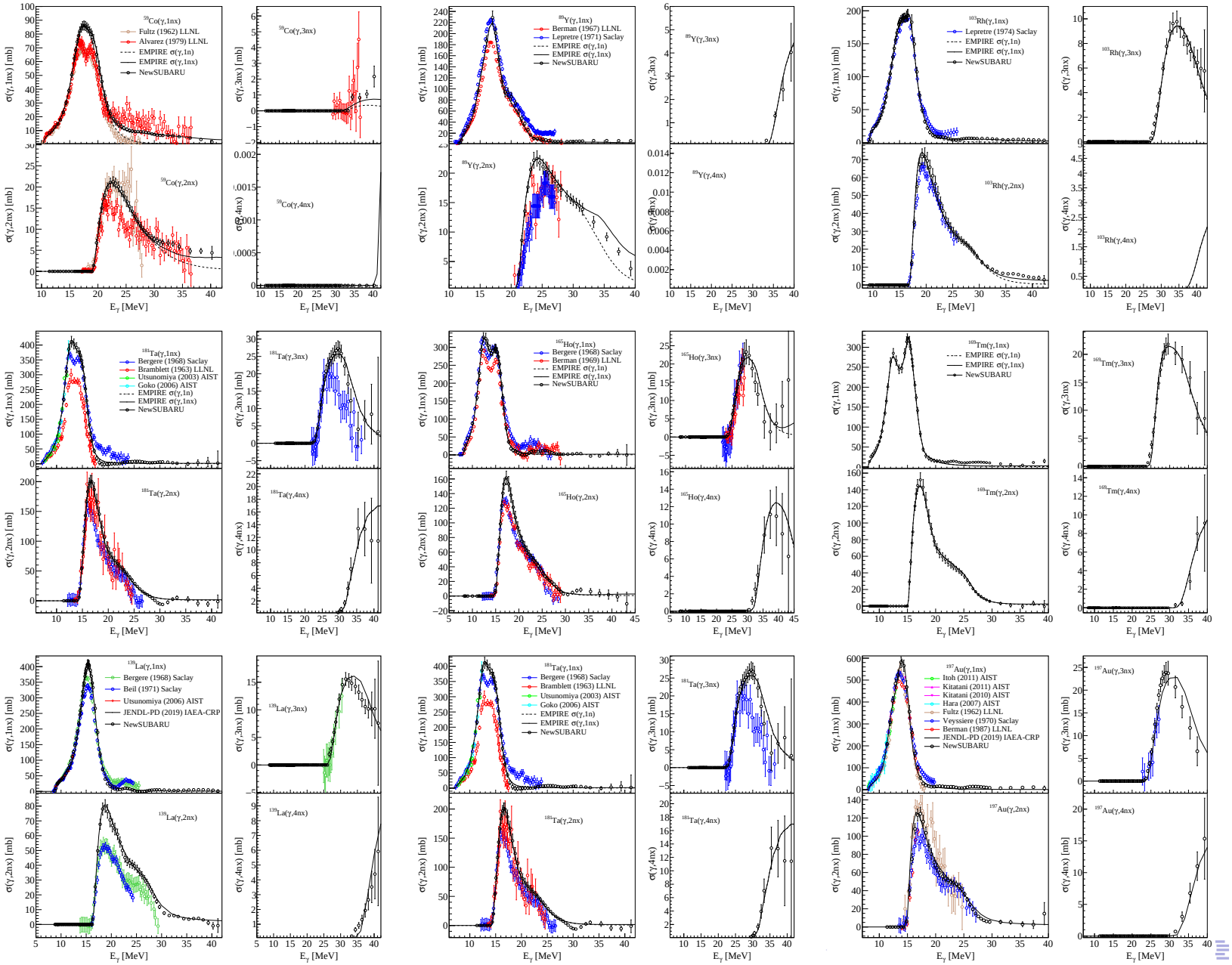








IAEA CRP data – T.Kawano et al. Nuclear Data Sheets 163 (2020) 109



NewSUBARU (γ, xn) cross section measurements *following* IAEA PD CRP

Improved data analysis techniques:

- Monte Carlo model of quasi-monochromatic LCS γ-ray beams:
  - D. Filipescu et al., Spectral distribution and flux of LCS γ-ray beams, NIM A **1047**, 167885 (2023), arXiv:2211.14650
  - D. Filipescu, Monte Carlo simulation of polarization effects in LCS on relativistic electrons, JINST **17** P11006 (2022), arXiv:2210.14669
  - Takashi Ari-Izumi et al., Spatial distribution of collimated LCS γ-ray beams, JINST **18** T06005 (2023), arXiv:2304.08935
- Multiple-firing neutron multiplicity sorting: I. Gheorghe, H. Utsunomiya, et. al, NIMA 1019, 165867 (2021)

New measurements in the GDR energy region:

2015	^{209}Bi, ^{9}Be
2016	^{89}Y, ^{169}Tm, ^{197}Au
2017	^{59}Co, ^{165}Ho, ^{181}Ta
2018	^{103}Rh, ^{159}Tb, ^{139}La
2019	**^{232}Th, ^{238}U** **^{208}Pb,** ^{112,116,120,124}Sn

Table: NewSUBARU (γ, xn) cross section measurements.

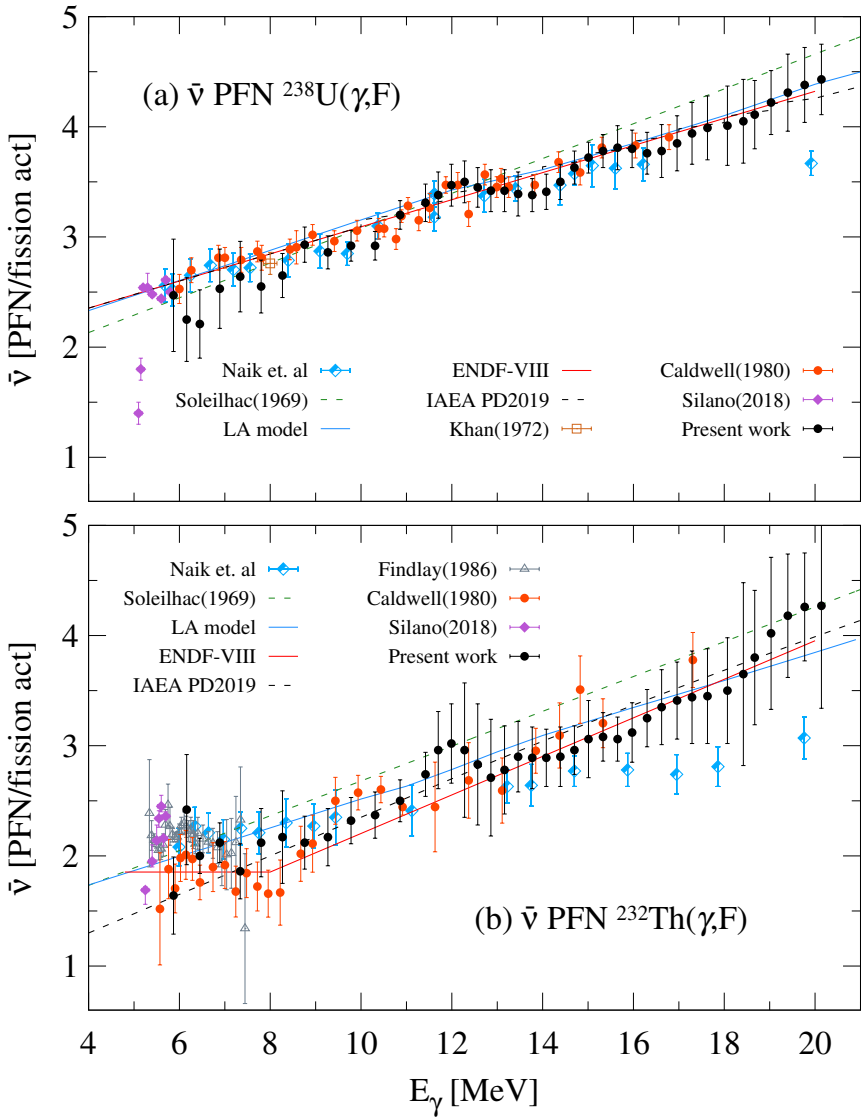
- Photoneutron and photofission measurements on ^{232}Th, ^{238}U Oct 2019
- **^{208}Pb**, ^{112}Sn, ^{116}Sn, ^{120}Sn, ^{124}Sn Nov-Dec 2019 Campaign initiated by TUD group of Thomas Aumann.

Collaboration on the ^{238}U and ^{232}Th study – Filipescu et al. arXiv:2402.13333

- Hiroaki Utsunomiya, Takashi Ari-izumi (*Konan University, Japan*)
- Dan Filipescu, Ioana Gheorghe (*IFIN-HH, Romania*)
- Stephane Goriely (*Université Libre de Bruxelles, Belgium*)
- Anabella Tudora (*University of Bucharest, Bucharest, Romania*)
- Gongtao Fan, Hongwei Wang (*SLEGS, Shanghai Advanced Research Institute, Chinese Academy of Sciences, China*)
- Katsuhisa Nishio, Fumi Suzaki, Kentaro Hirose (*Advanced Science Research Center, Japan Atomic Energy Agency, Japan*)
- Tsutomu Ohtsuki, Makoto Inagaki (*Institute for Integrated Radiation and Nuclear Science, Kyoto University, Japan*)
- Konstantin Stopani (*Lomonosov Moscow State University, Russia*)
- Yiu-Wing Lui (*Cyclotron Institute, Texas A&M, USA*)
- Takaharu Otsuka (*Tokyo University, RIKEN, Japan*)
- Shuji Miyamoto (*LASTI, University of Hyogo, Japan*)

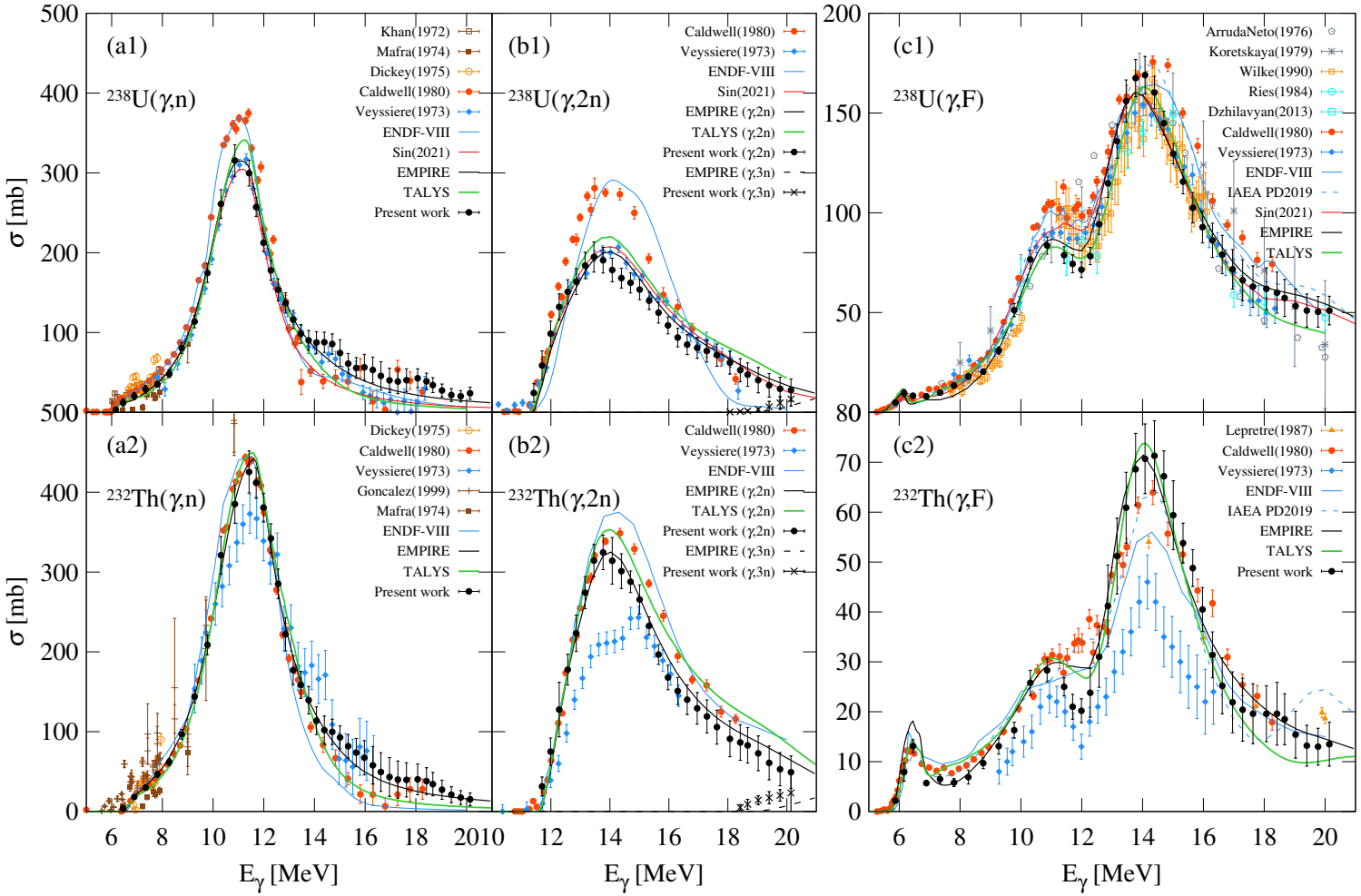
^{238}U and ^{232}Th mean PFN multiplicities – ▸ Filipescu et al. arXiv:2402.13333

Dependence with incident photon energy for the mean PFN multiplicities in the photofission reactions on (a) ^{238}U and (b) ^{232}Th. The present results (full black dots) are compared with recent HIγS LCS γ-ray beam data of ▸ Silano (PhysRevC.98.054609) (purple full diamonds), Livermore positron in flight annihilation data (full red dots), capture γ-ray data (brown symbols) and bremsstrahlung data (gray open triangle). The blue solid lines show the systematic linear dependences deduced from neutron-induced fission experiments by Soleilhac et al. and used by the Saclay group in the data reduction. The full black lines are predictions obtained through calculations in the frame of the most probable fragmentation approach with the Los Alamos model.



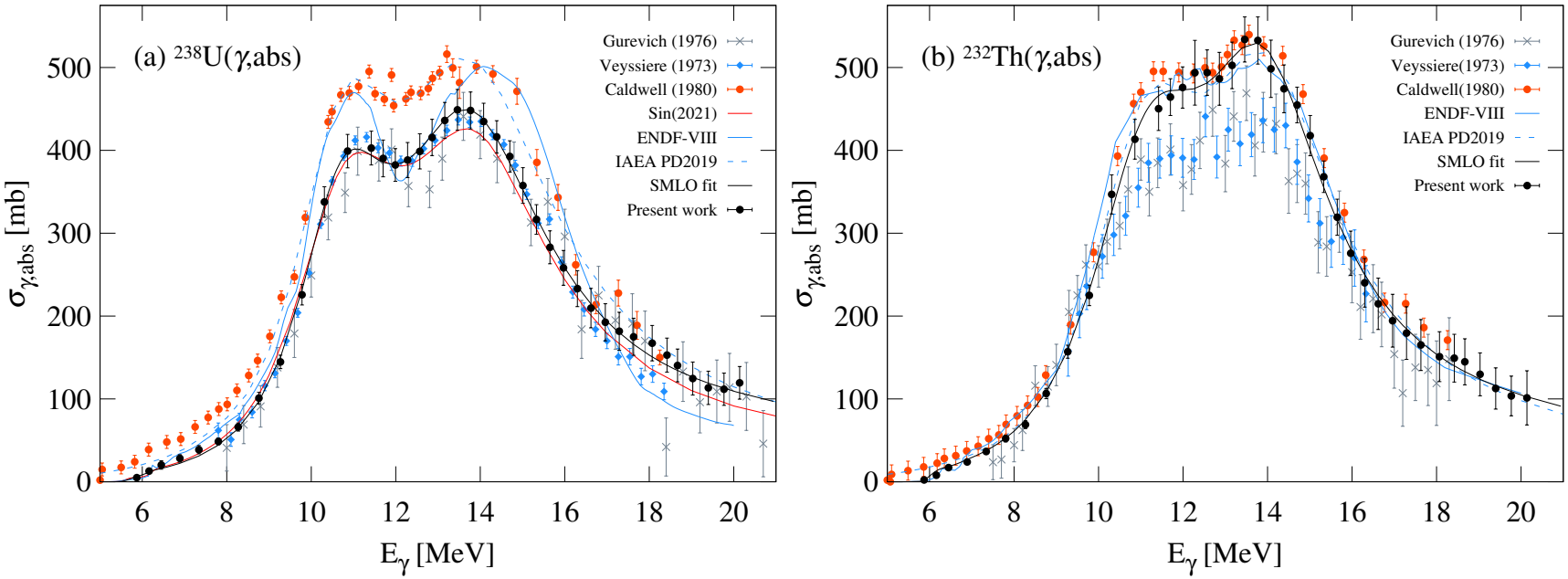
^{238}U and ^{232}Th photoneutron and photofission cross sections –

- Filipescu et al. arXiv:2402.13333



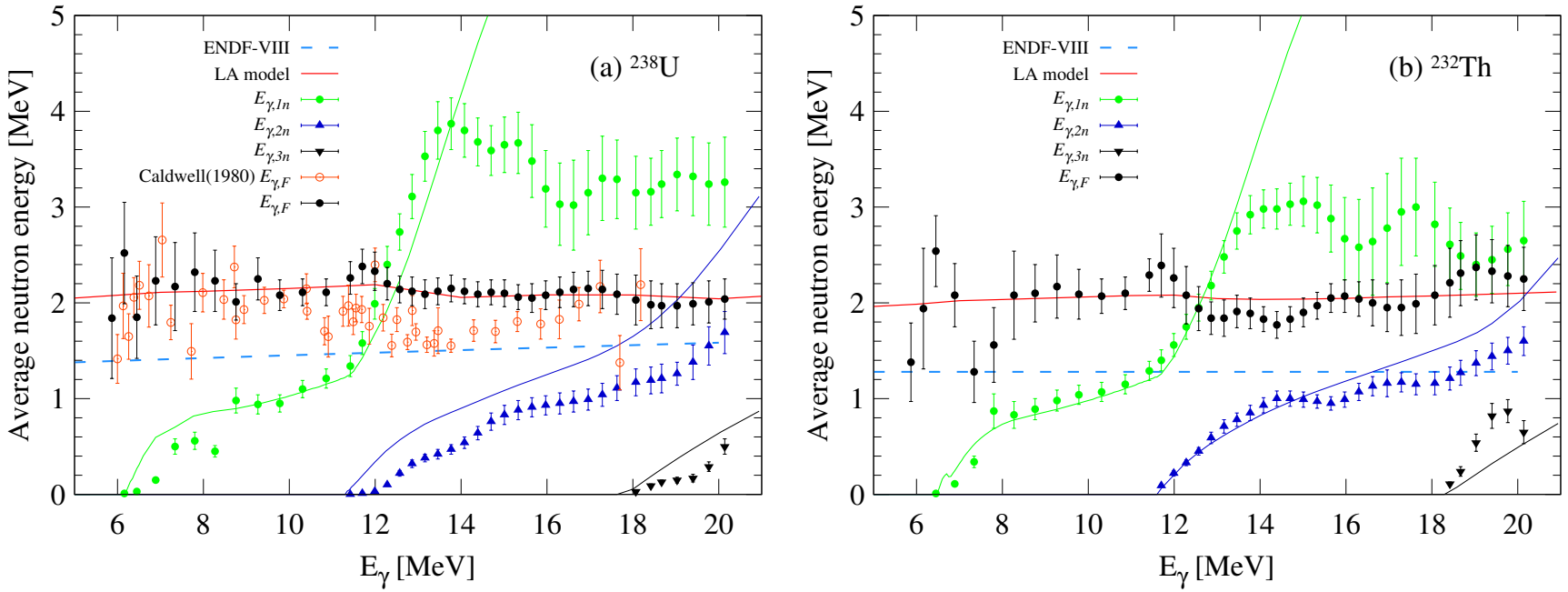
Present results (black dots) and existing data obtained with positron in flight annihilation beams at Saclay (blue full diamonds), Livermore (red full dots), Giessen (yellow full dots) and Moscow (yellow full square), bremsstrahlung beams (gray), bremsstrahlung monochromators (green), capture γ-rays (brown).

$$\sigma_{\gamma,\,abs} = \sigma_{\gamma,\,n} + \sigma_{\gamma,\,2n} + \sigma_{\gamma,\,3n} + \sigma_{\gamma,\,F}$$



Present photon absorbtion cross sections for (a) ^{238}U and (b) ^{232}Th compared with existing data obtained with positron in flight annihilation beams at Saclay - Veyssiere NPA **199**, 45 (1973) (blue full diamonds) and at Livermore - Caldwell PRC **21**, 1215 (1980) (red full dots), with bremsstrahlung beams (gray) and also with recent statistical model calculations ▸ M.Sin PRC 103, 054605 (2021)

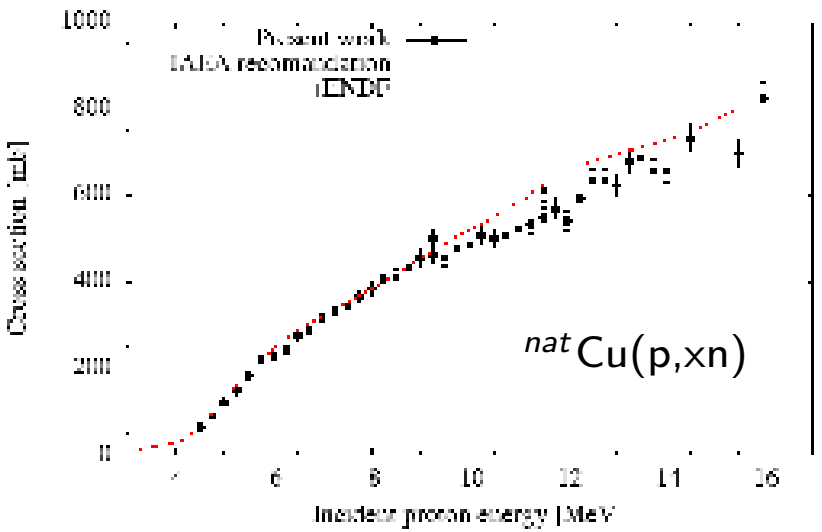
^{238}U and ^{232}Th average energies of PFNs – ▸ Filipescu et al. arXiv:2402.13333

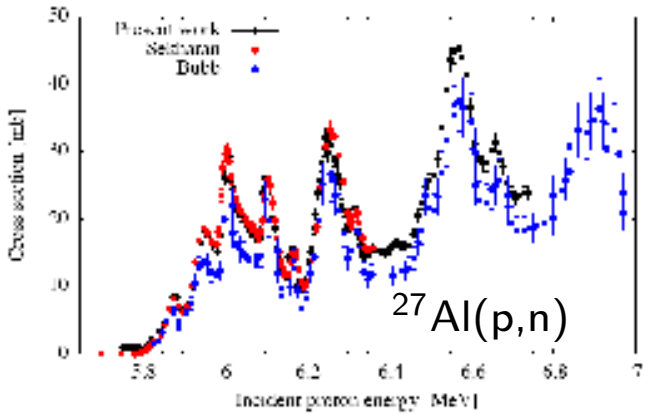


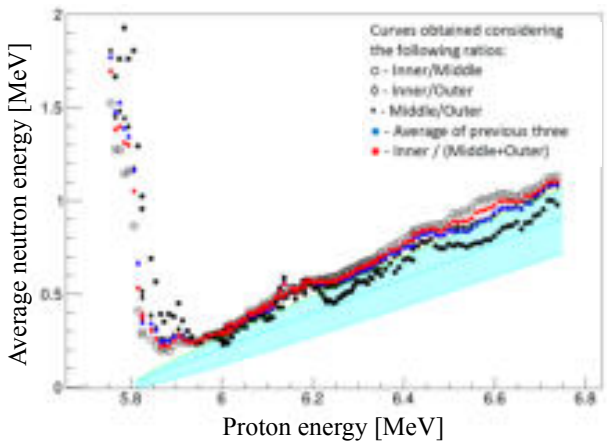
Average energies of neutrons emitted in photon induced reactions on (a) ^{238}U and (b) ^{232}Th. $E_{\gamma,n}$ average energy of neutrons emitted in (γ, n) reactions (green dots), $E_{\gamma,2n}$ for (γ, $2n$) neutrons (blue triangles) and $E_{\gamma,3n}$ for (γ, $3n$) neutrons (black triangles) are compared with results of present EMPIRE statistical model calculations (solid lines in corresponding color for each reaction). Present $E_{\gamma,F}$ PFNs energies (black dots) are compared to the ENDF/B-VIII.0 evaluation (dashed blue lines) and LA model predictions (red lines), and, for ^{238}U, also to the results of Caldwell et al. PRC **21**, 1215 (1980) (empty red dots).

ELIGANT-TN array commissioning experiment at Bucharest 9 MV Tandem

- measured neutron production cross sections for proton induced reactions on ^{nat}Cu and ^{27}Al.
- ^{nat}Cu(p, xn) investigated in the 4.5–14 MeV energy range with 250 keV steps. The low energy measurements below 10 MeV served to validate the detection efficiency calibration against monitor $^{nat}Cu(p, n)$ cross sections.
- ^{27}Al(p, n) investigated in the 5.8 MeV to 6.75 MeV energy range with 5 keV steps.







C. Clisu, I. Gheorghe, D. Filipescu, et al., Cross section measurements of low-energy charged particle induced reactions using moderated neutron counter arrays,

▸ EPJ Web of Conf. 284 01015 (2023)

New neutron detection system development at the 3&9 MV IFIN Tandem

A new neutron detection array of moderated ^{3}He proportional counters is being developed for nuclear astrophysics experiments at the 3 MV and 9 MV Tandem facilities of the Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, Romania.

49 ^{3}He Reuter-Stokes (General Electric) counters:

- RS-P4-0810-104 (10 atm)
- RS-P4-0810-109 (4 atm)

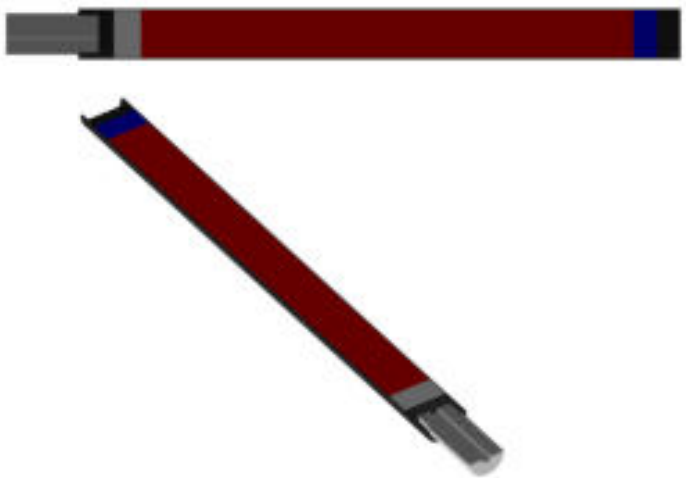


Figure: GEANT4 implementation.

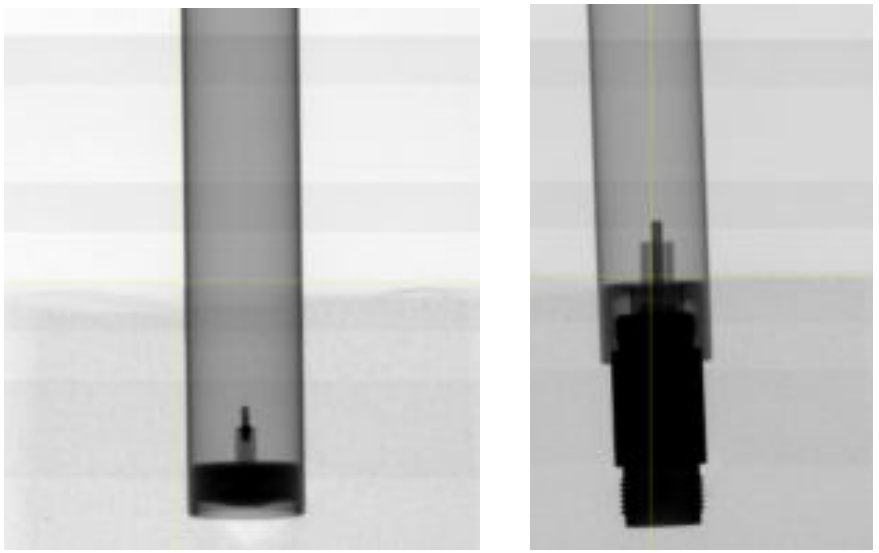
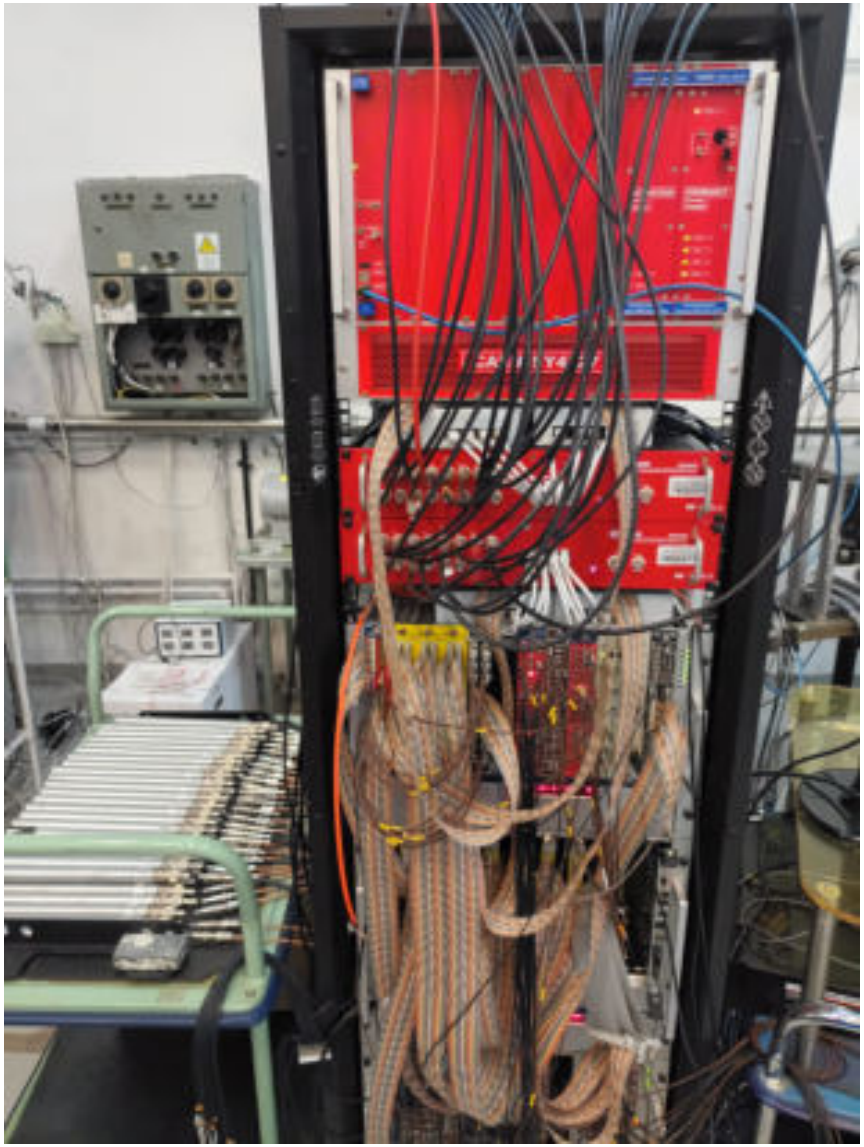


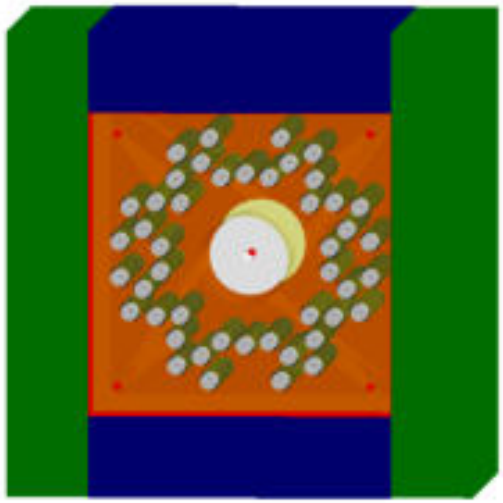
Figure: ^{3}He counter X-ray scan.



Analog DAQ system.

Figure: ^{3}He counters spectra for PuBe source.

Present moderator matrix



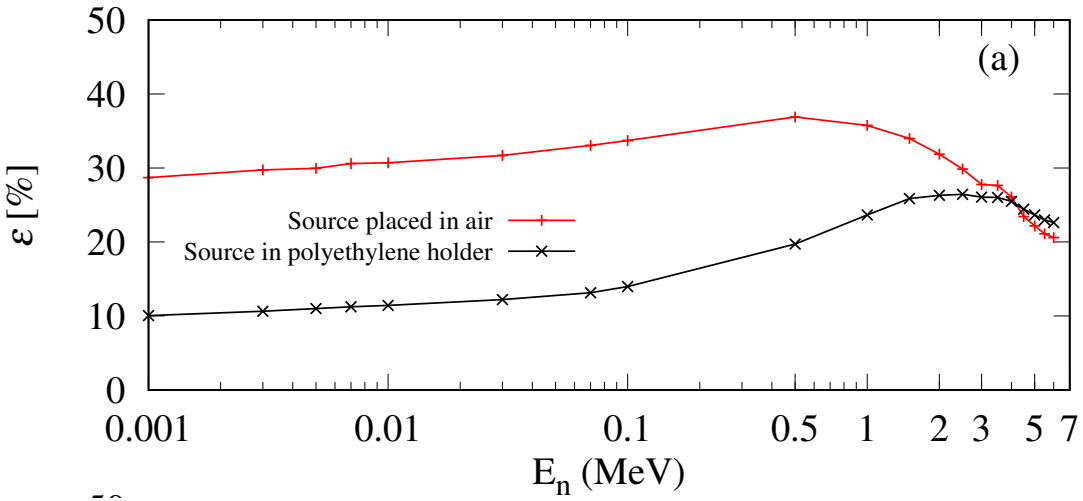


Figure: Total detection efficiency with source placed in air (red) and in a polyethylene cylindrical holder (black).

Geant4 efficiency simulations.

The optimum geometric configuration for a high-and-flat detection efficiency is investigated through Geant4 simulations.

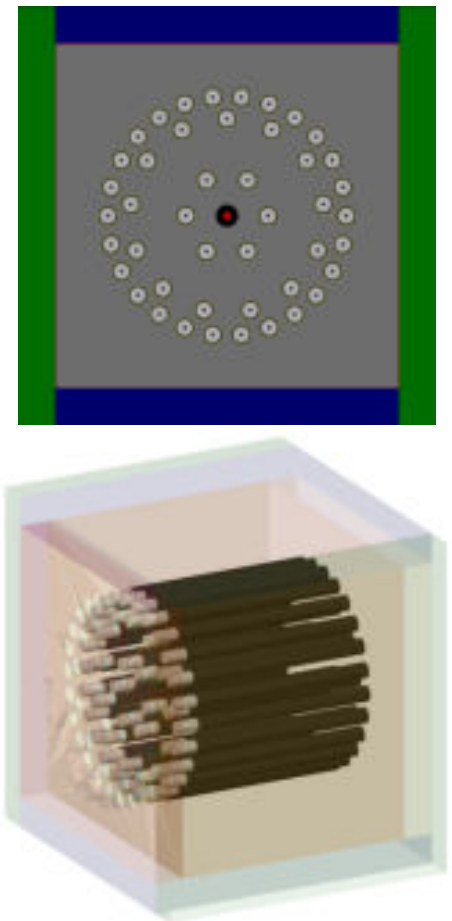
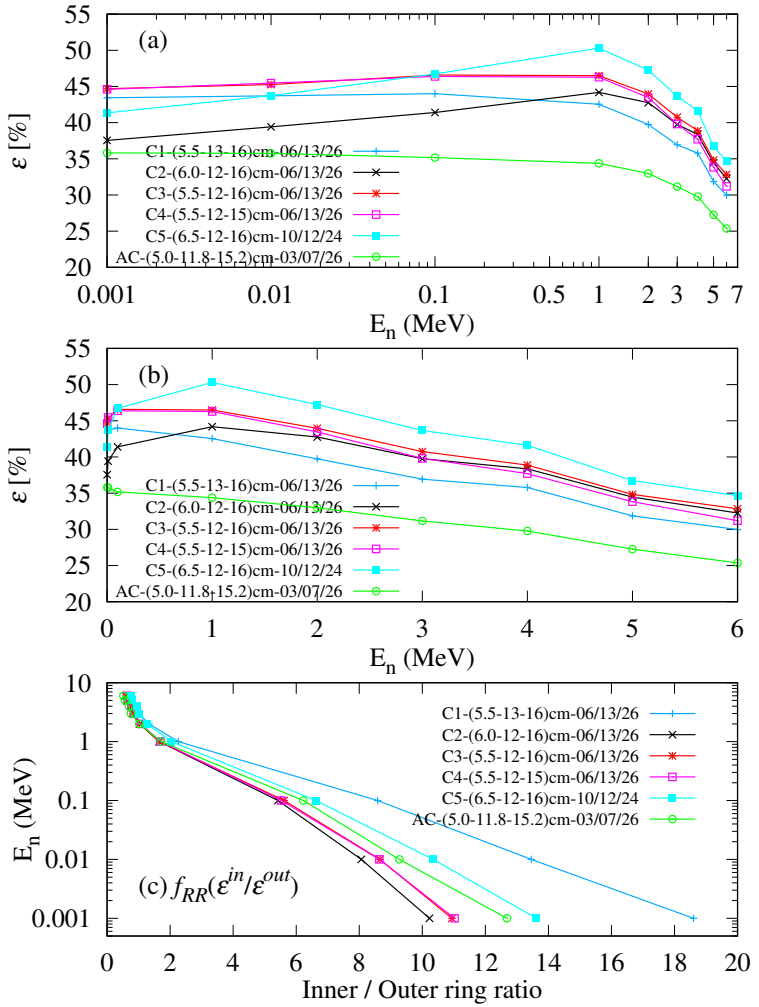


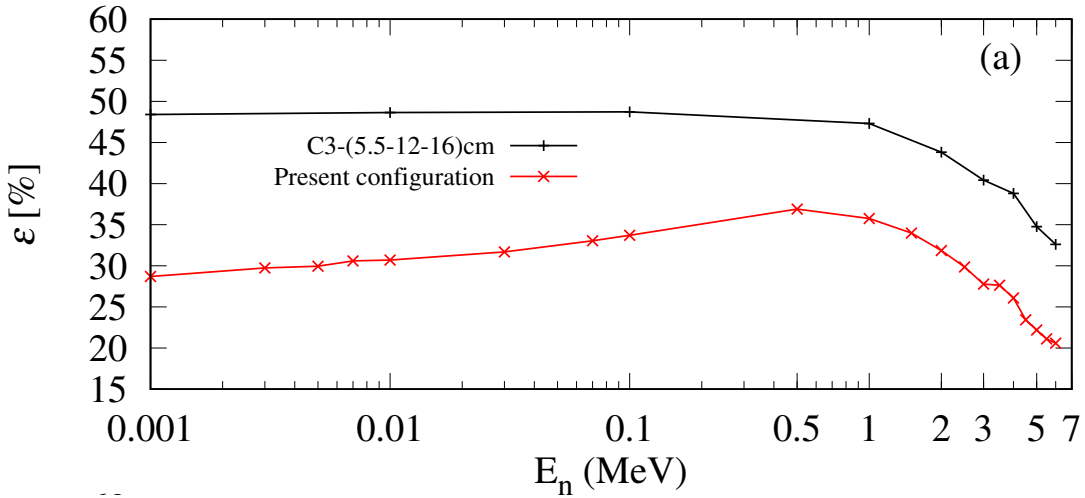
Figure: GEANT4 implementation of moderator and counters.



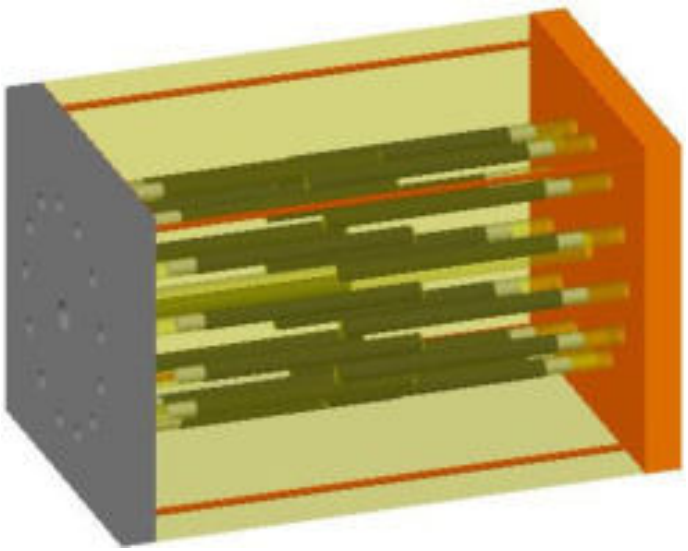
Work in progress

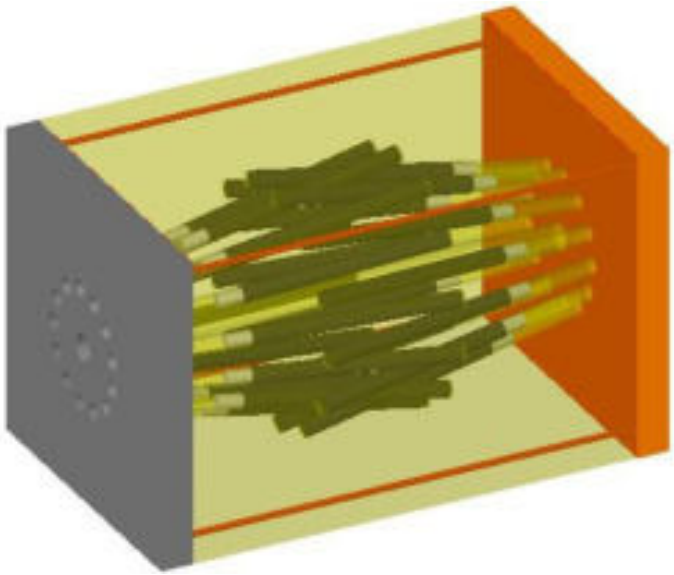
Timeline for 2024:

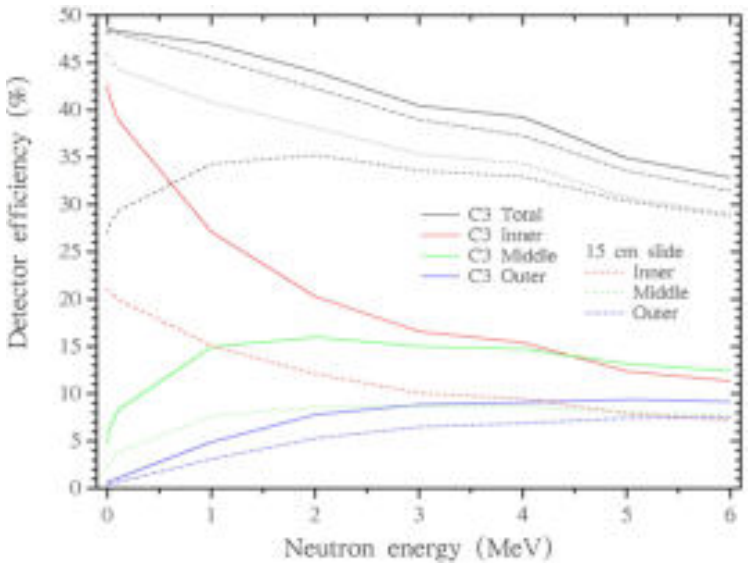
1. Finalize moderator design by end of April
2. Machine moderator by end of August
3. Test the detection array in November

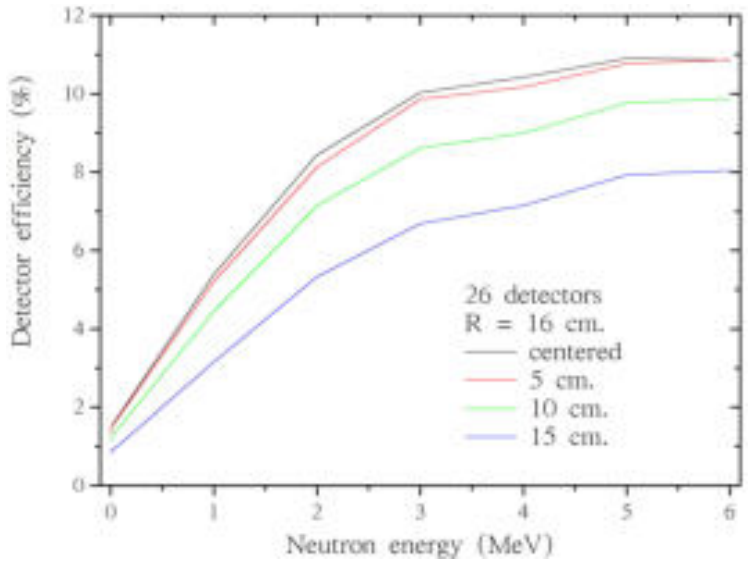


Work in progress









Work in progress

CAEN 5560 Digitizer
Based on Xilinx Zinq-7000
128 Channels
14-bit
125 MS/s
Differential inputs
Communication: USB 3.0, Optical Link, Ethernet

Open FPGA algorithm development using CAEN Sci-Compiller software.

- allows to develop and compile the firmware code using graphical blocks
- automatically generates the VHDL firmware code
- it generates C/C++/C#/Python driver libraries

Thank you for your attention!