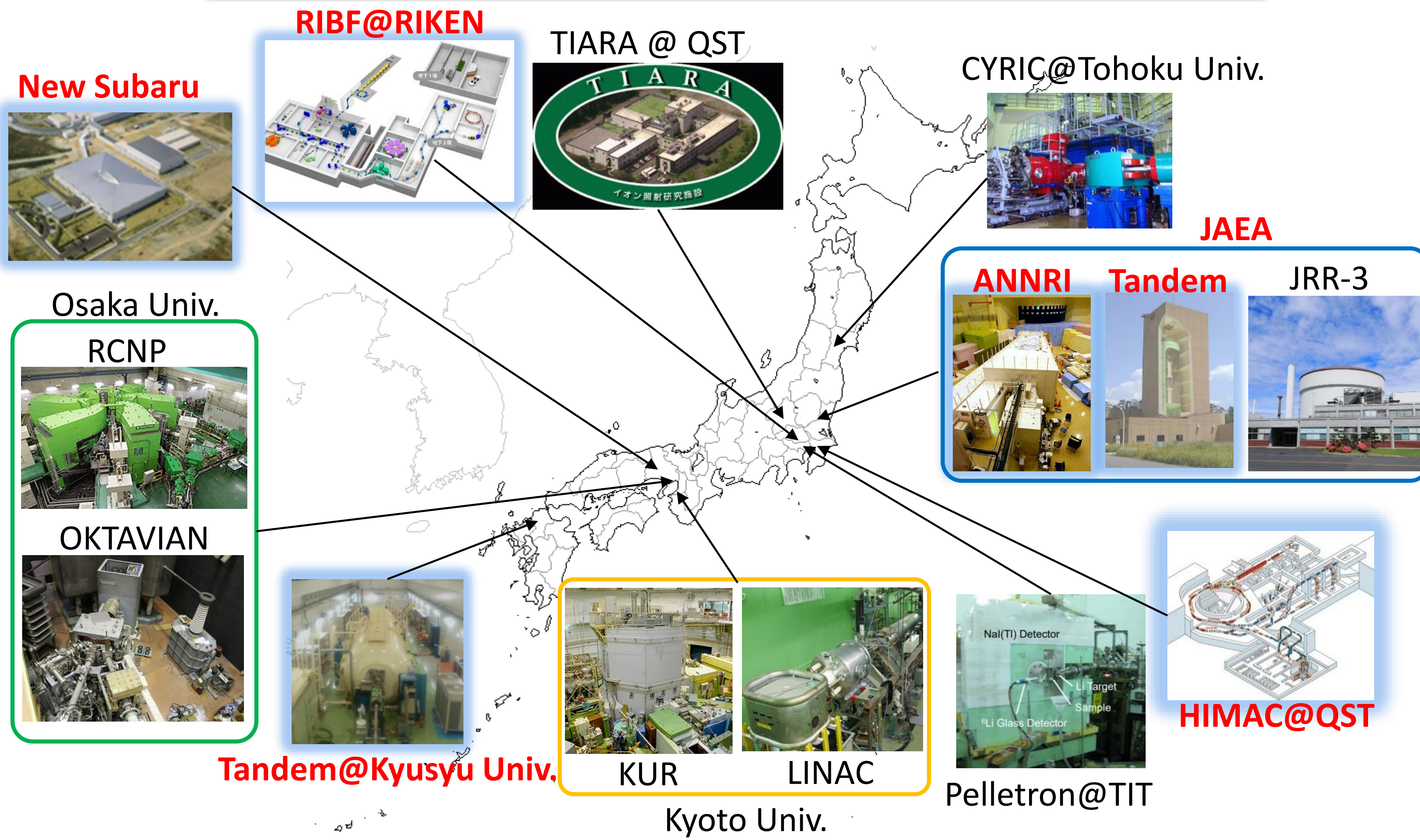
Japanese Activities in Nuclear Data Measurement

Atsushi Kimura

Japan Atomic Energy Agency

Nuclear Data Measurement in Japan

Nuclear Data Measurements have been performed at several accelerator and reactor facilities in Japan



Activities by J-PARC･MLF･ANNRI collaboration in 2018

Japan Atomic Energy Agency

Tokyo Institute of Technology

Kyoto Univ.

Tokyo Tech

KURNS

Contact :

Nuclear Data Center

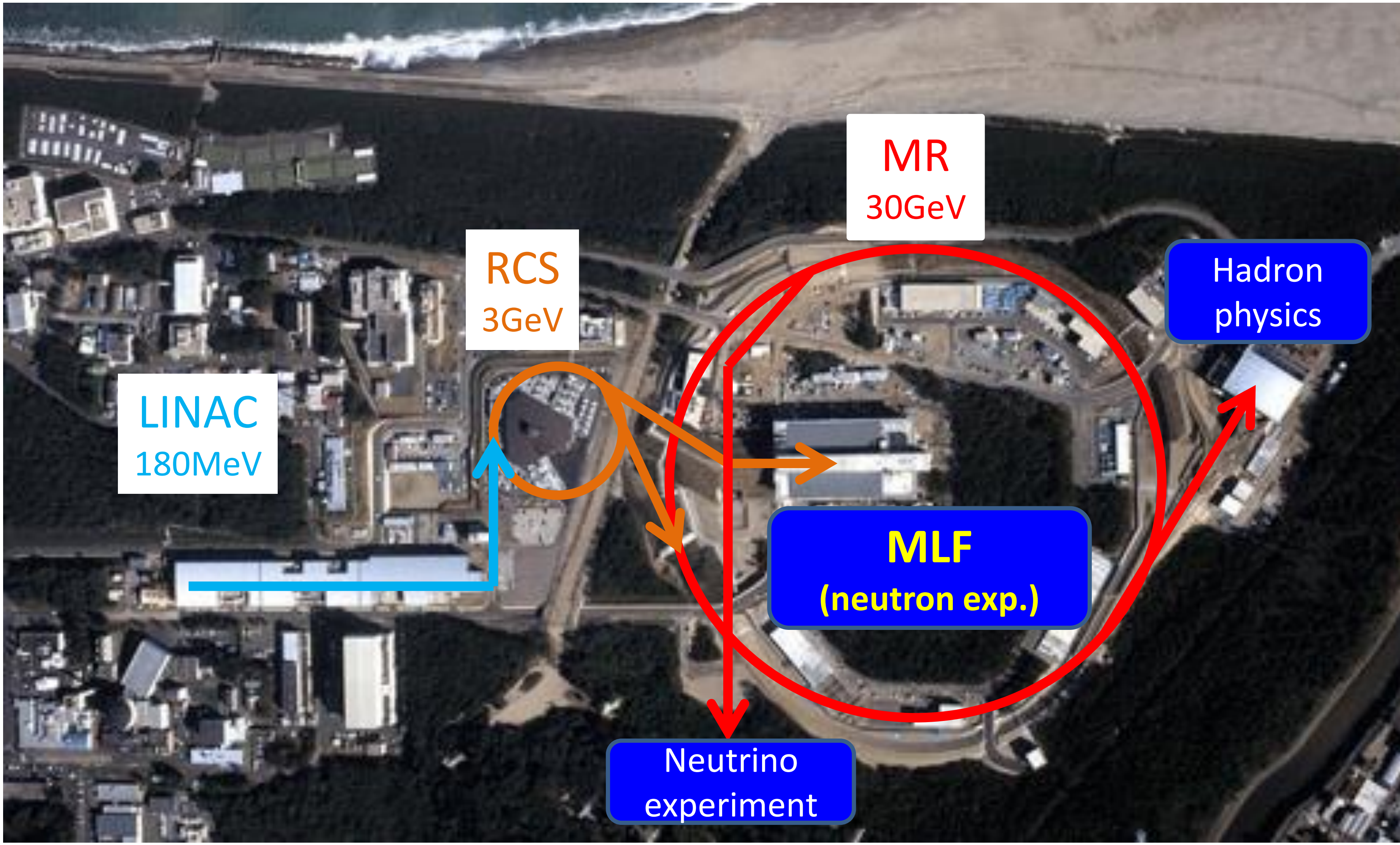
Nuclear Data and Reactor Engineering Division

Nuclear Science and Engineering Center

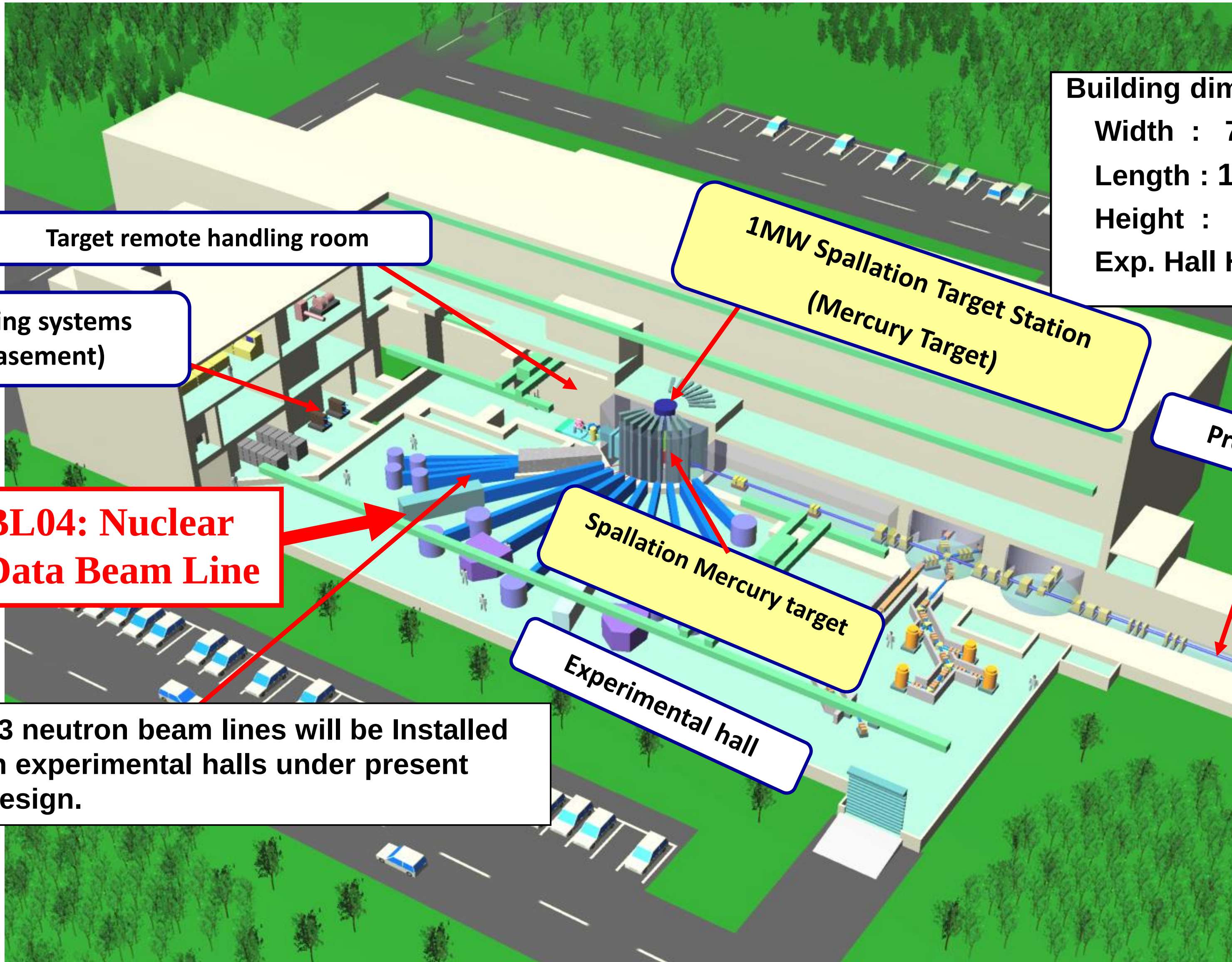
Japan Atomic Energy Agency

Facility

J-PARC : Japan Accelerator Research Complex



J-PARC Materials and Life Science Experimental Facility



Building dimension :

- Width : 70m
- Length : 146m
- Height : 30m
- Exp. Hall Height : 22m

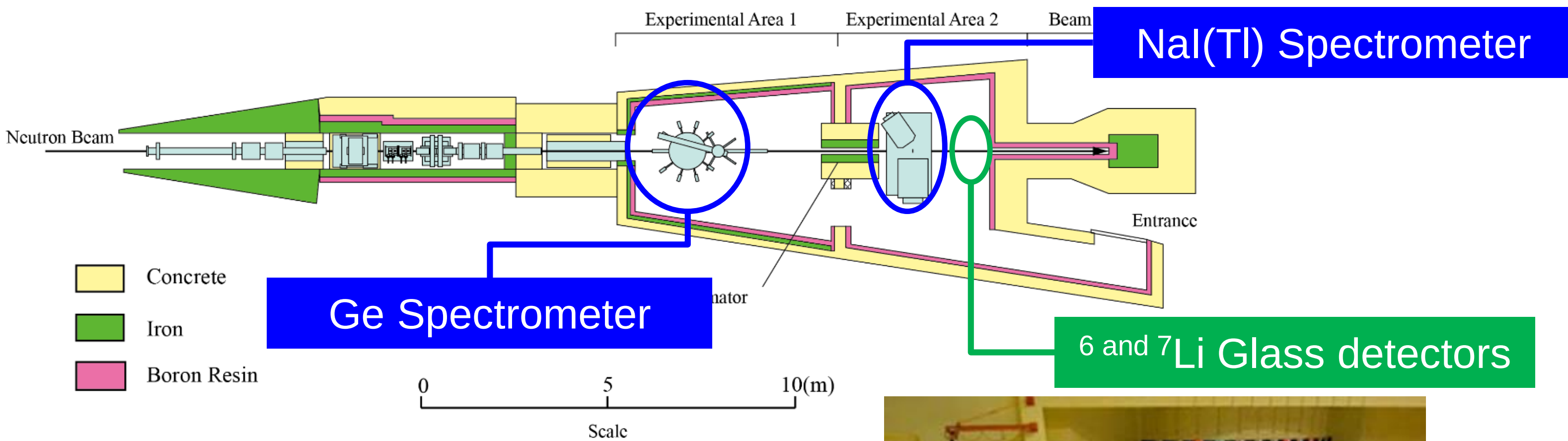
3GeV, proton beam

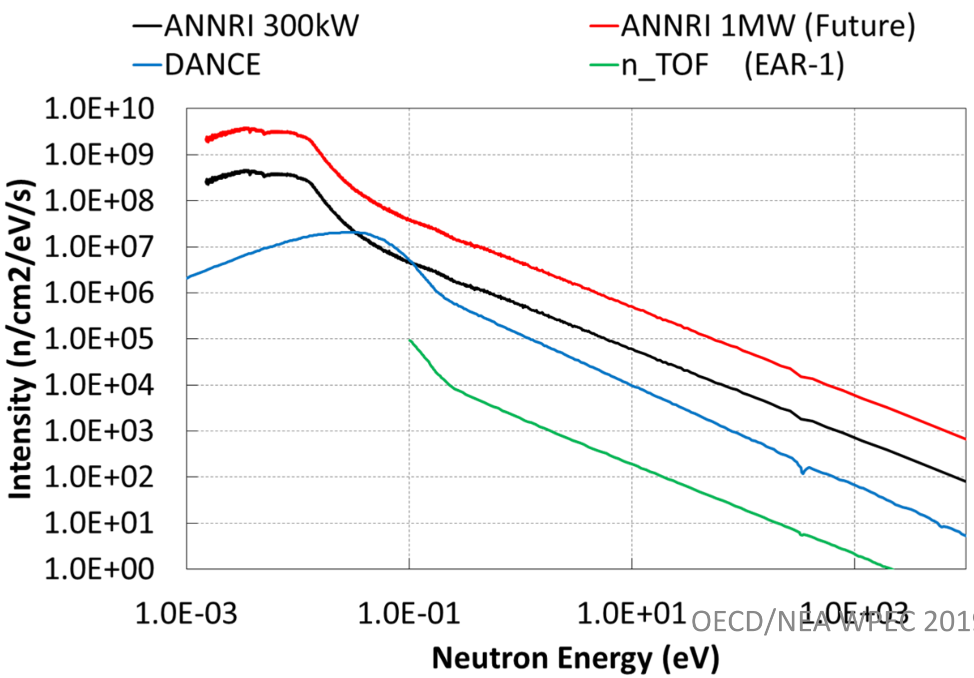
23 neutron beam lines will be Installed in experimental halls under present design.

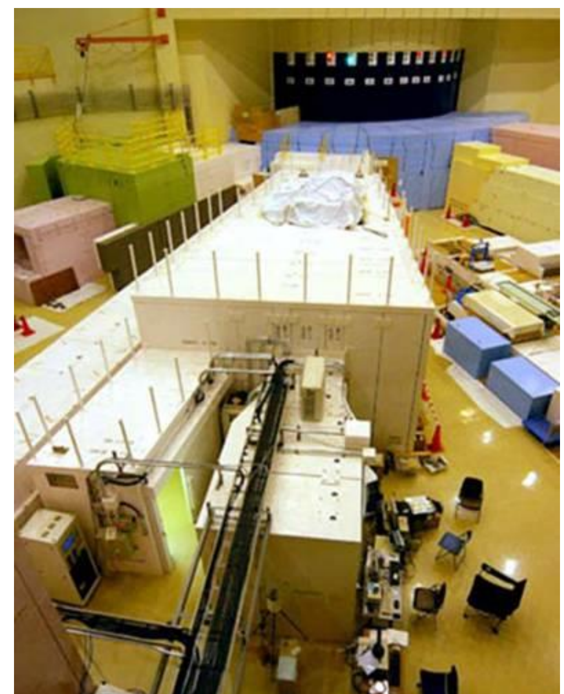
J-PARC MLF, Taken from HP of J-PARC

ANNRI

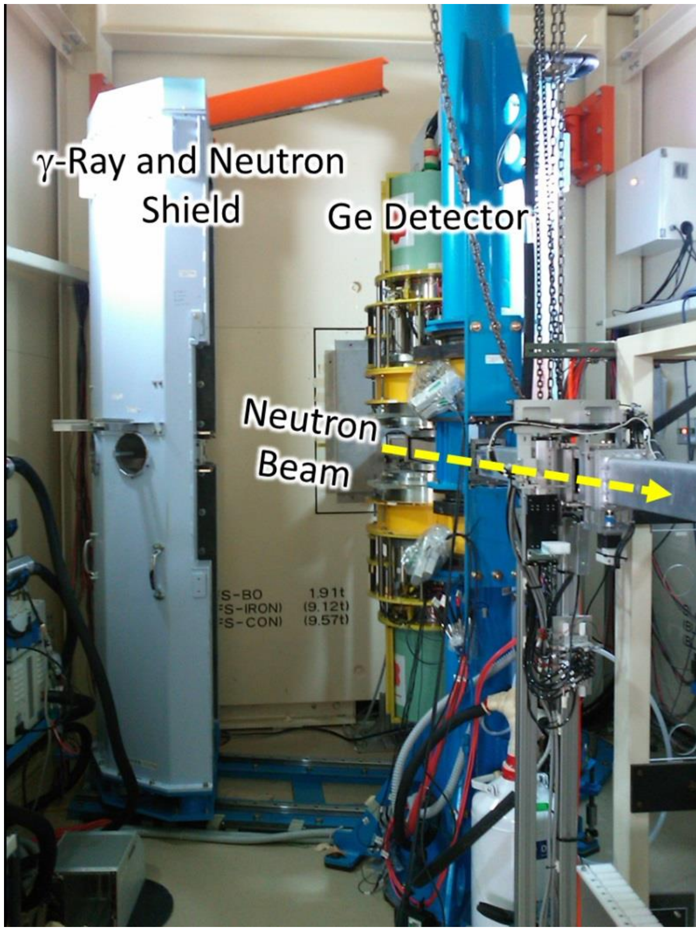
ANNRI (Accurate Neutron Nucleus Measurement Instrument)







Ge Spectrometer

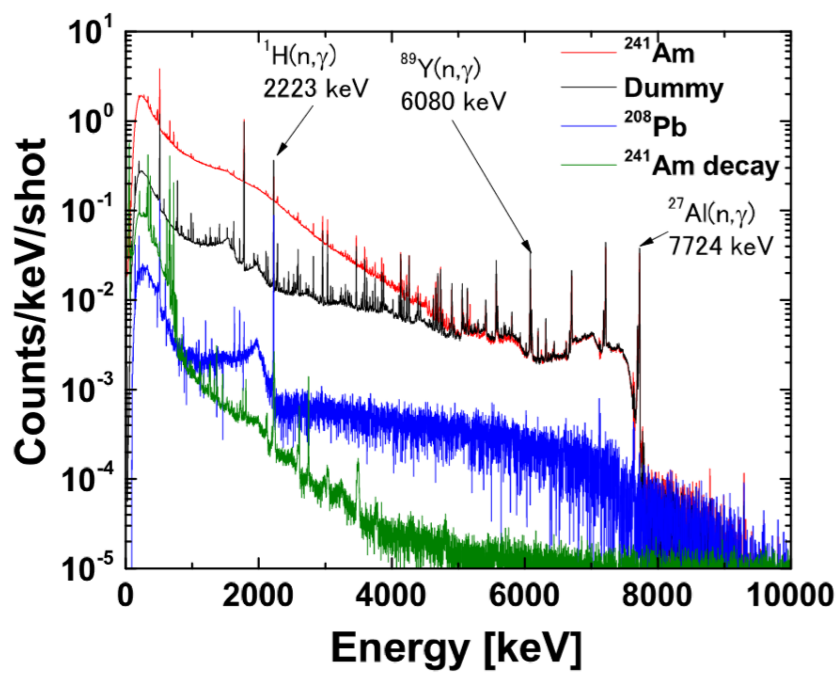


- 2 cluster-Ge detectors
  (7 Ge crystals are installed in the detector)
- 8 coaxial-Ge detectors

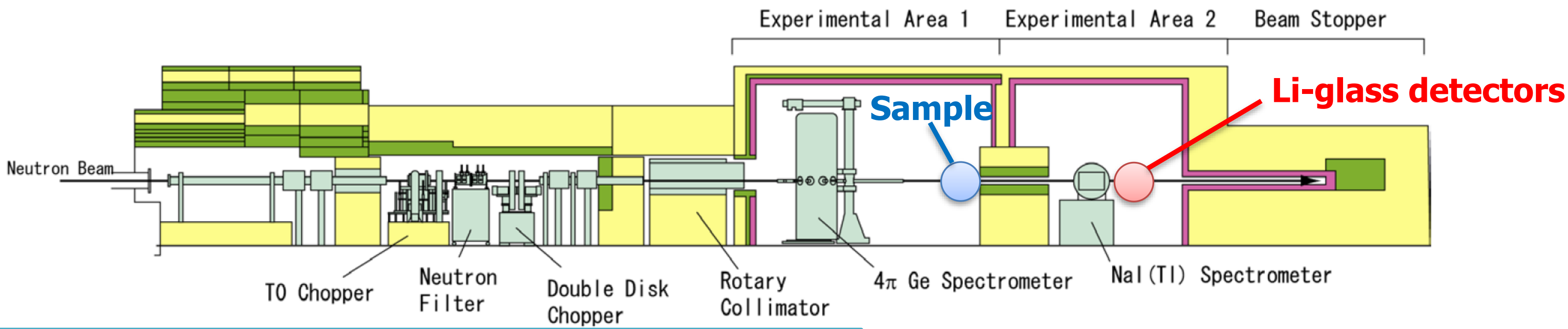
->Peak efficiency for 1.33MeV γ-rays: 3.64 ± 0.11 %

- New DAQ System (CAEN 1724,1720) is installed.

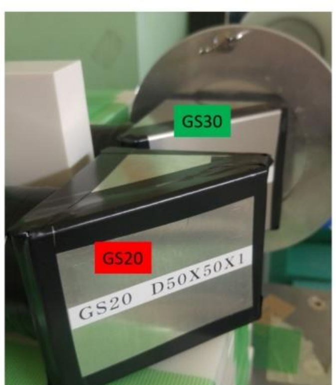
➢ Measurements of neutron capture cross sections of $^{241,243}Am$, $^{137,135}Cs$, $^{244,246}Cm$ and stable isotopes have been finished in recent years.

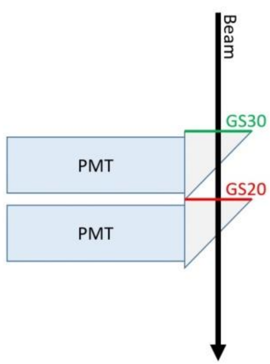


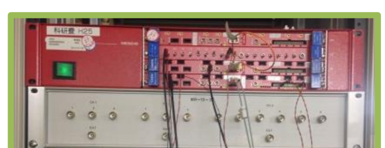
Li Glass detectors for total cross section measurement



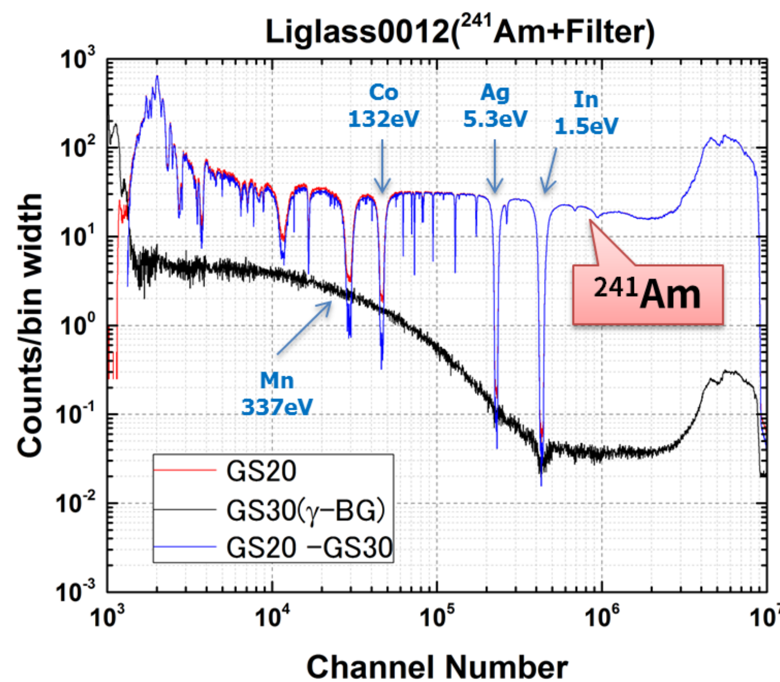
- ^{6}Li-glass scintillation detector for neutron ^{7}Li-glass scintillation detector for B.G. were installed at the flight length of 28.7m
- Measurements of neutron total cross sections of ^{241,243}Am, ^{155,157}Gd and some stable isotopes have been finished.





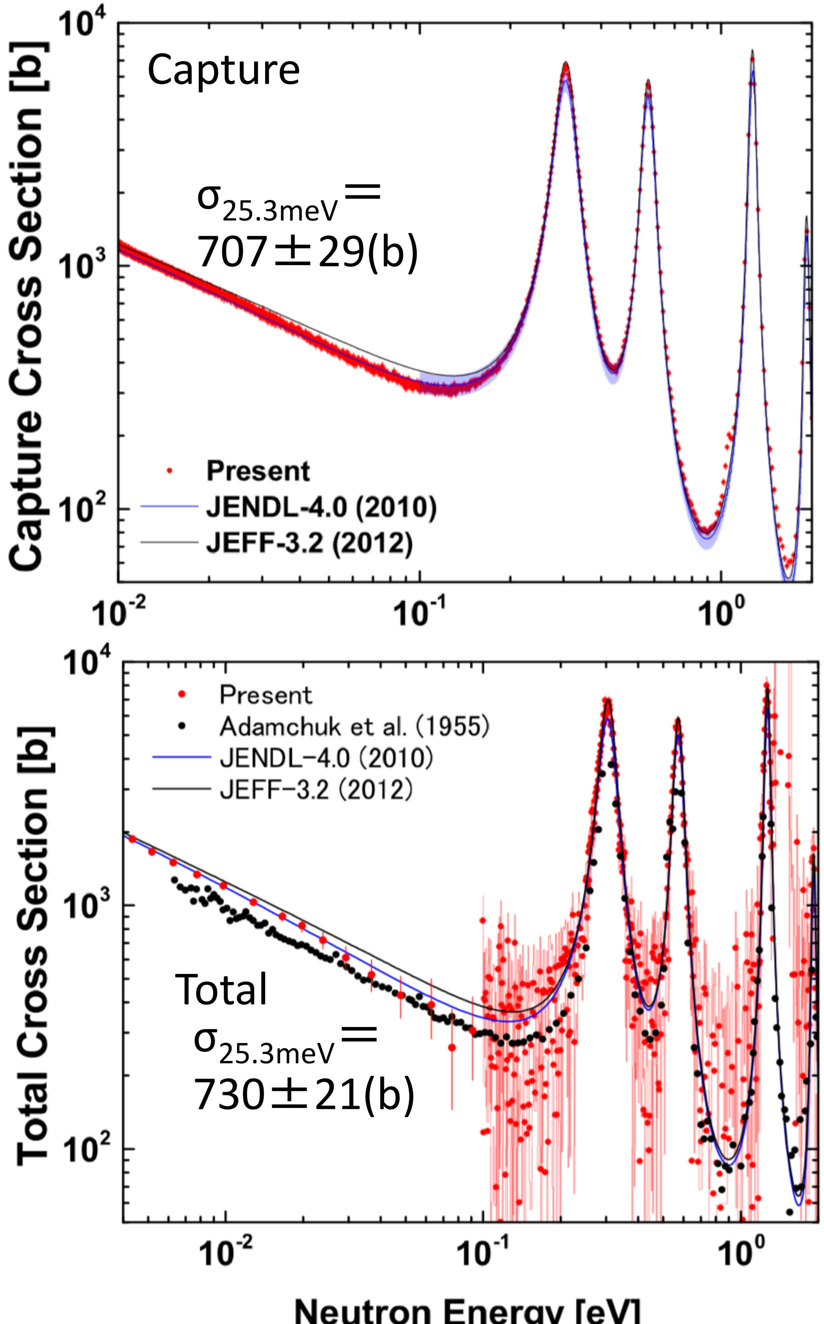


DAQ
(CAEN V1720)



TOF spectra for ^{241}Am

Selected results in 2018: Total and Capture cross section of ^{241}Am



K. Terada, et. Al.,
JNST, Vol.55, No.10, pp.1198-1211

Sample:
^{241}Am 957.4±0.5 [MBq]

Activity of ^{241}Am was determined with an uncertainty of **0.45%** using a calorimetric method.

Capture: 10meV～100eV
Ge detectors with PHWT were applied.
$\sigma_{25.3meV}$=707±29(b) ...4.0% Unc.
⇒ Self-shielding of ^{10}B: 2.3%
Extrapolation of PH spectra: 2.9%

Total: 10meV~2eV
$\sigma_{25.3meV}$=730±21(b) ...2.9% Unc.
⇒Sample diameter: 2%

^{243}Am measurements were published in 2019 (JNST, Vol.56, No.6, pp.479-492)

Activities at JAEA Tandem Accelerator Facility

Contact :
Katsuhisa Nishio
Advanced Science Research Center
Japan Atomic Energy Agency

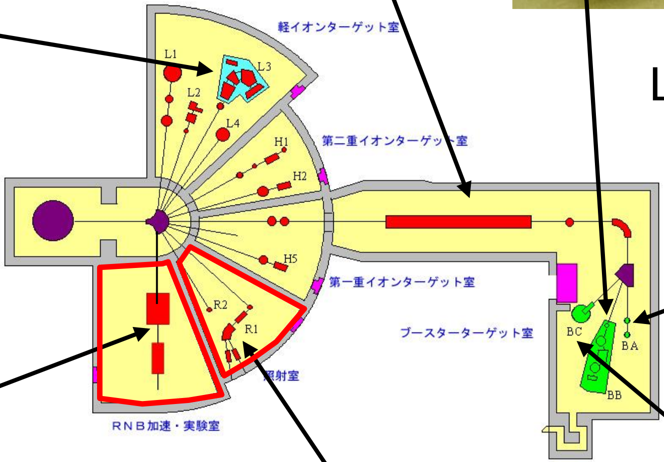
20 MV

Equipment at the JAEA Tandem Accelerator Facility

Magnetic Spectrograph

Booster Liniac

Recoil Mass Separator



Large Scattering Chamber

In-beam fission setup (surrogate reaction)

ISOL

Ge-detector array

Radioactive materials can be used
Th, U, Np, Pu, Am, Cm, Bk, Cf, Es

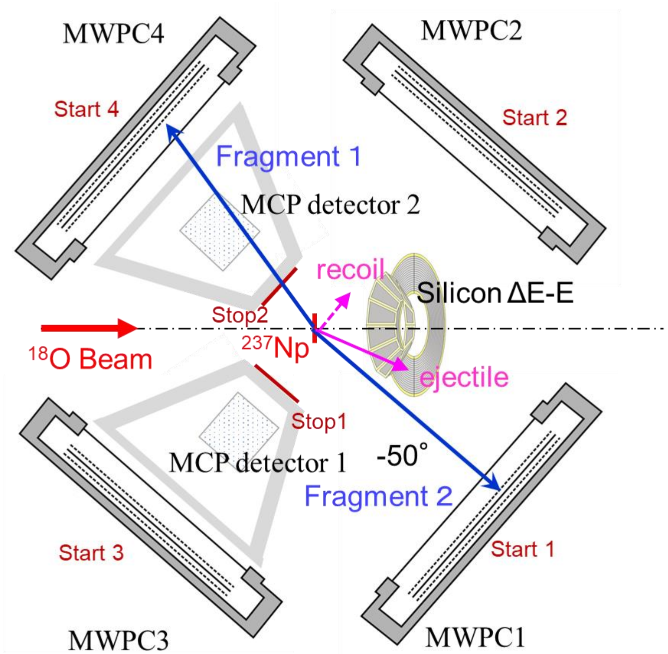
Surrogate Reactions for Fission Data

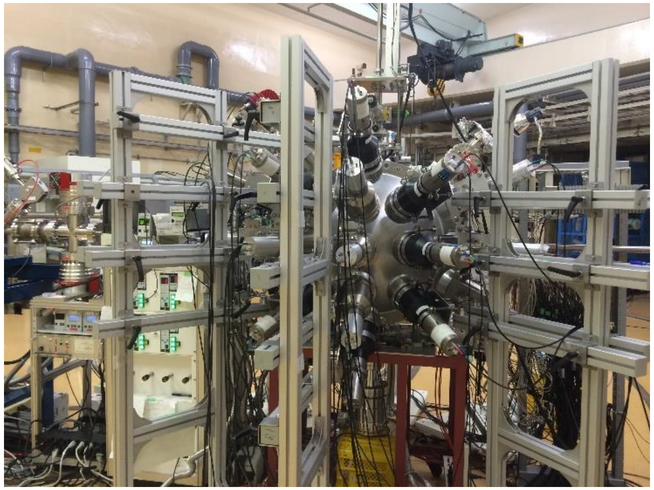
Method Using multi-nucleon transfer reactions, excited compound nuclides are populated.
The multi-nucleon transfer channels of $^{18}O + ^{237}Np$ were used.

- The populated nuclides and excited energy are Identified by detecting recoiled particles with silicon ΔE-E detectors.
- Both fission fragments (double-velocity measurement) are detected using multi-wire proportional counters and micro-channel plate (MCP) based timing detectors.
- Coincidence with prompt neutrons (liquid scintillation detectors with n/g discrimination technique).

Obtained Data

- Fission cross sections
- Fission fragment mass distribution
- Prompt neutron multiplicity and energy spectra





Array of 33 liquid scintillators (d5"x t2") around the fission chamber (Planning to add 12 detectors.)

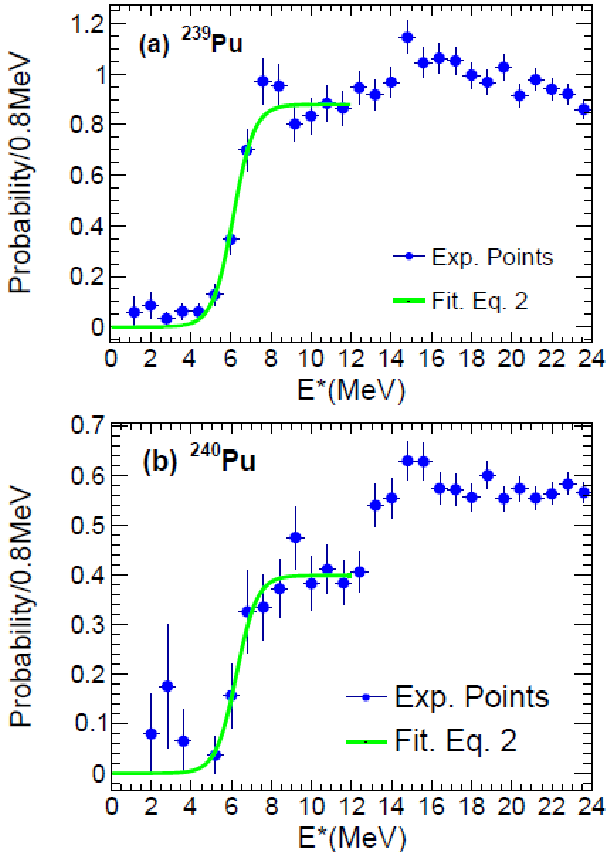
R. Léguillon *et al*., Phys. Lett. B **761,** 125 (2016).
K. Hirose *et al*., Phys. Rev. Lett. **119**, 222501 (2017).

Selected Results in 2018

from surrogate fission setup

Fission barrier heights were determined for nuclei, ^{239}Np, ^{239,240}Pu in the multi-nucleon transfer channels of ^{18}O + ^{237}Np. The results agree with the literature data, validating our method to determine the fission barrier.

Isotope	Reference	B_f(MeV)(inner, outer)
^{239}Np	This work: (^{237}Np(^{18}O,^{16}O)^{239}Np)	5.86 ± 0.09
	RIPL3 [15]	—
	^{238}U(^{3}He,d)^{239}Np [12]	5.85 ± 0.30, 5.50 ± 0.30
^{239}Pu	This work: (^{237}Np(^{18}O,^{16}N)^{239}Pu)	6.14 ± 0.12
	RIPL3 [15]	6.20, 5.70
^{240}Pu	This work: (^{237}Np(^{18}O,^{15}N)^{240}Pu)	6.25 ± 0.32
	RIPL3 [15]	6.05 , 5.15
	^{238}Pu(t,p)^{240}Pu [11]	5.80 ± 0.20, 5.45 ± 0.20



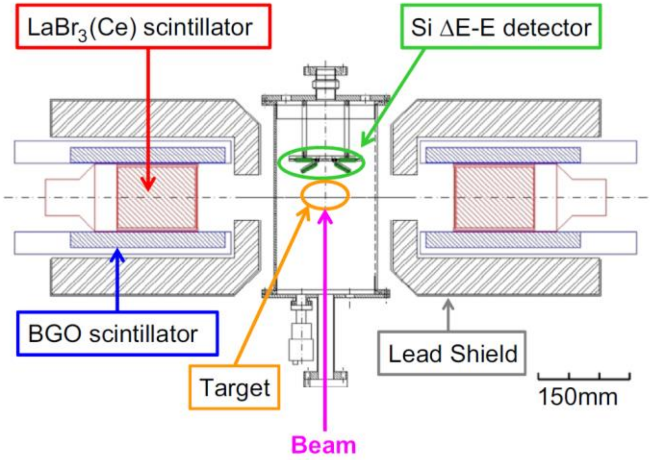
K.R. Kean et al., Phys. Rev. C, accepted.

Surrogate Reactions for Capture Cross Sections

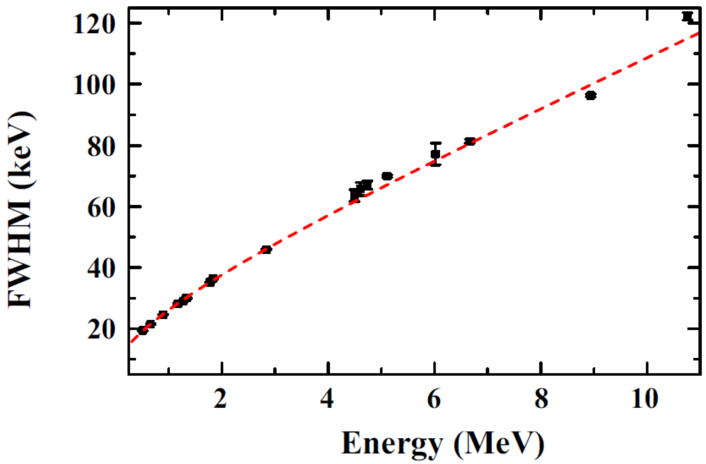
Method

- Populate excited compound nuclides using multi-nucleon transfer reactions.
  Identification of nucleus and its excitation energy is given by silicon ΔE-E detectors
- Gamma-rays emitted in the deexcitation process are detected by two anti-Compton $LaBr_3$(Ce) spectrometers.

$LaBr_3$(Ce)



Detector setup for the surrogate capture measurement.



Energy Resolution

H. Makii *et al*., Nucl. Instrum. Meth. A, **797**, 83 (2015).
S. Q. Yan et al., Phys. Rev. C, **94**, 015804 (2016).

Selected Results

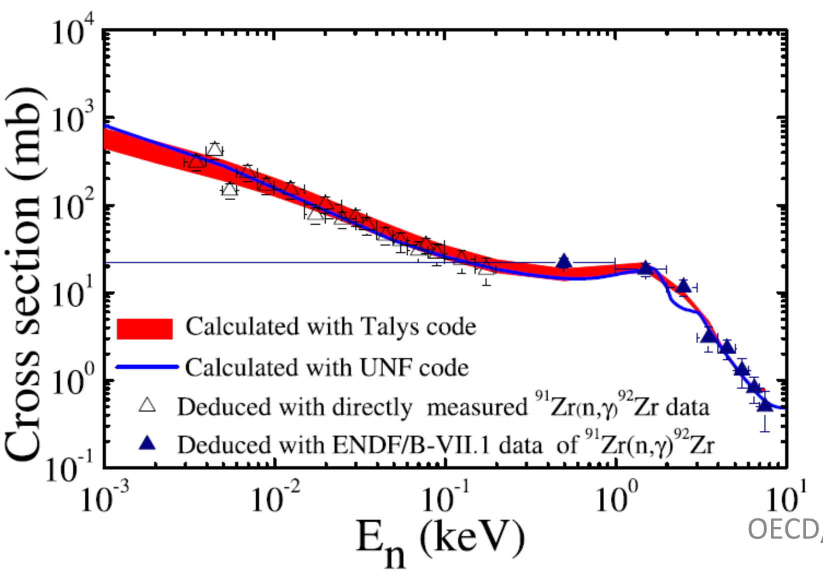
from surrogate capture setup

The Astrophysical Journal, 848:98 (8pp), 2017 October 20
https://doi.org/10.3847/1538-4357/aa8c74

CrossMark

The ^{95}Zr(n, γ)^{96}Zr Cross Section from the Surrogate Ratio Method and Its Effect on *s*-process Nucleosynthesis

S. Q. Yan (颜胜权)[1], Z. H. Li (李志宏)[1], Y. B. Wang (王友宝)[1], K. Nishio[2], M. Lugaro[3,4], A. I. Karakas[4], H. Makii[2], P. Mohr[5,6], J. Su (俊苏)[1], Y. J. Li (李云居)[1], I. Nishinaka[2], K. Hirose[2], Y. L. Han (韩银录)[1], R. Orlandi[2], Y. P. Shen (谌阳平)[1], B. Guo (冰郭)[1], S. Zeng (晟曾)[1], G. Lian (钢连)[1], Y. S. Chen (陈永寿)[1], and W. P. Liu (柳卫平)[1]
[1] China Institute of Atomic Energy, P.O. Box 275(10), Beijing 102413, P. R. China; panyu@ciae.ac.cn
[2] Japan Atomic Energy Agency, Tokai, Naka, Ibaraki 319-1195, Japan
[3] Konkoly Observatory, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, 1121 Budapest, Hungary; maria.lugaro@csfk.mta.hu
[4] Monash Centre for Astrophysics, School of Physics and Astronomy, Monash University, Clayton, VIC 3800, Australia
[5] Institute for Nuclear Research (ATOMKI), H-4001 Debrecen, Hungary
[6] Diakonie-Klinikum, D-74523 Schwäbisch Hall, Germany
Received 2017 May 14; revised 2017 September 10; accepted 2017 September 11; published 2017 October 17



Measurement of *p/d* induced isotopic cross sections by inverse kinematics technique at RIBF

Team :

RIKEN Nishina Center
Kyushu Univ.
CNS, Tokyo Univ.
Tokyo Tech.

Contact person :

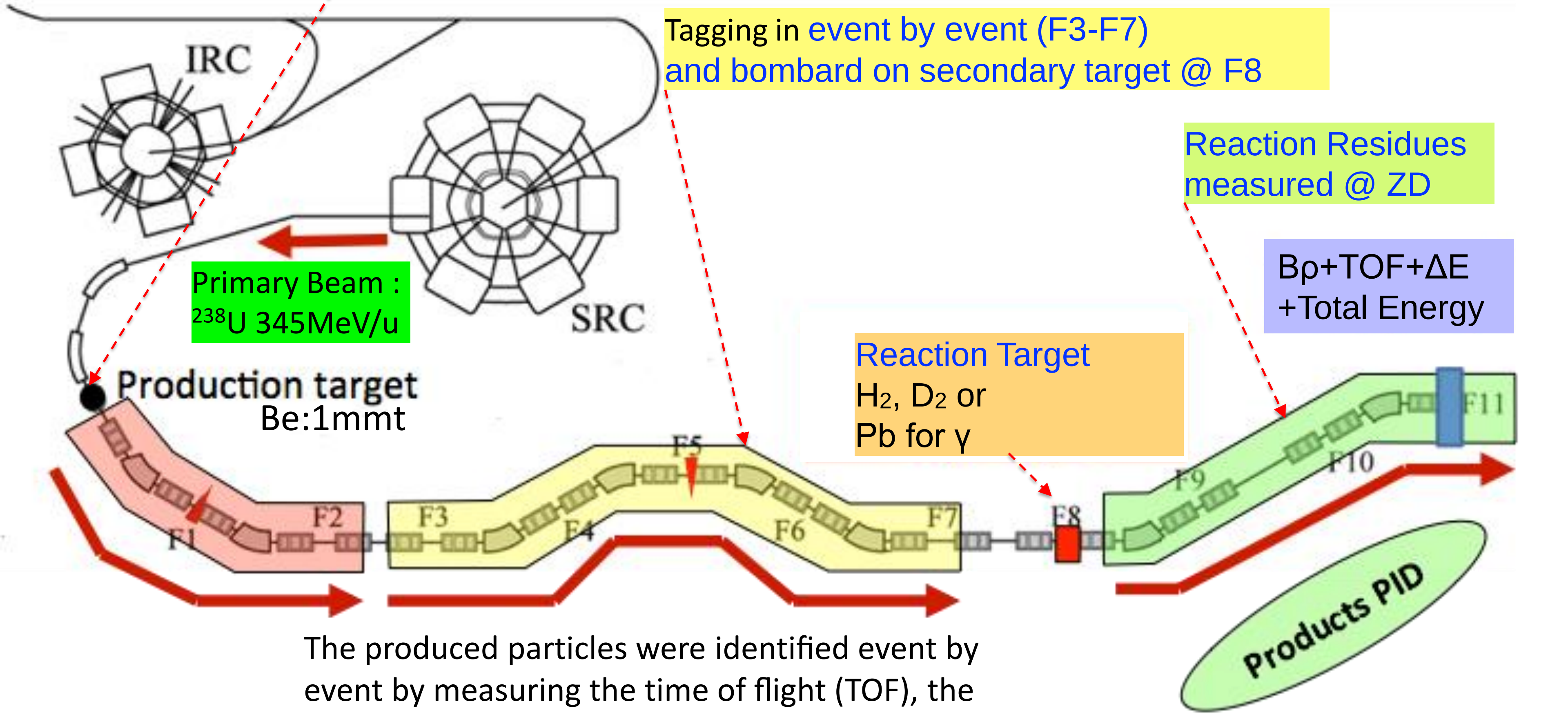
Hideaki Otsu(RNC)

Supported by ImPACT Program of CSTI
(Cabinet Office, Government of Japan)

Experiment @ RIBF

Secondary beam energy	Beam Selection	Reaction Residue ID
200, 100, 50 MeV/u	BigRIPS	ZeroDegree
30, 20 MeV/u	BigRIPS + OEDO	SHARAQ D1

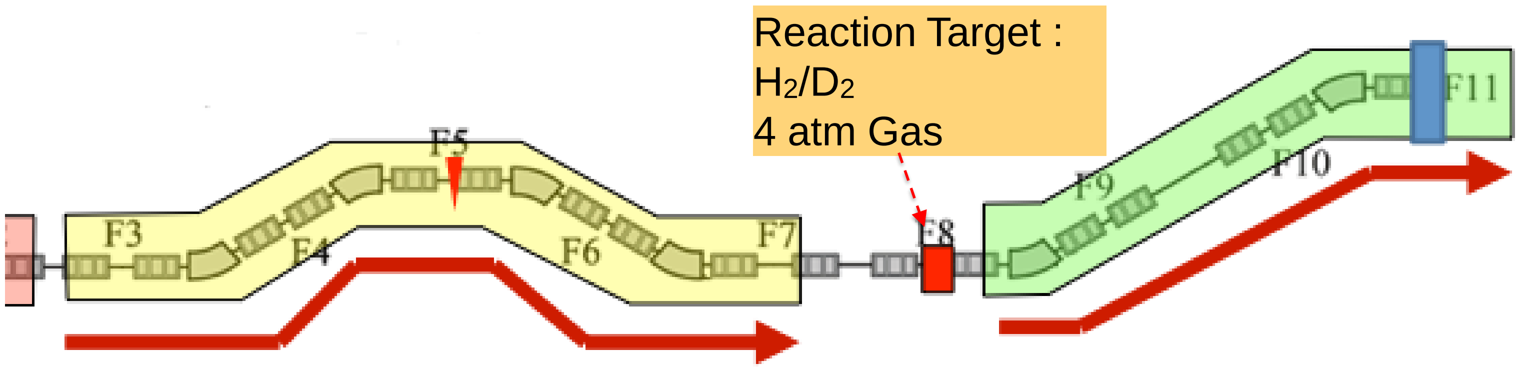
LLFP : ^{107}Pd, $^{93}Zr(+^{90}Sr)$, $^{135(+137)}Cs$, ^{79}Se
produced as secondary beam



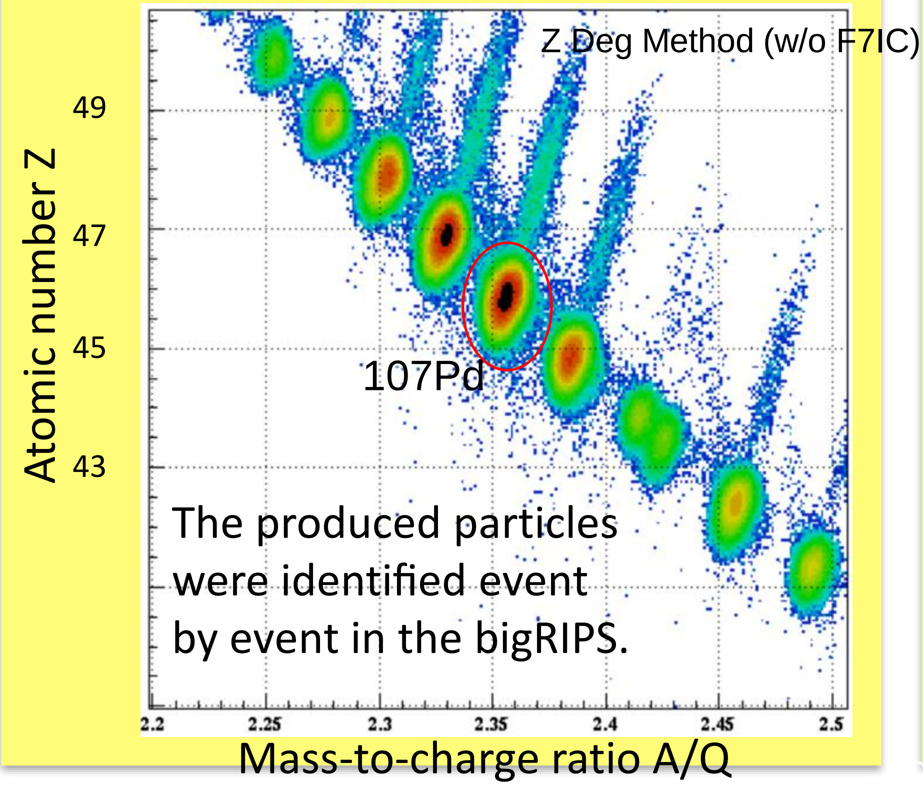
The produced particles were identified event by event by measuring the time of flight (TOF), the magnetic rigidity (Bρ), and the energy loss (ΔE)

BigRIPS **ZeroDegree**

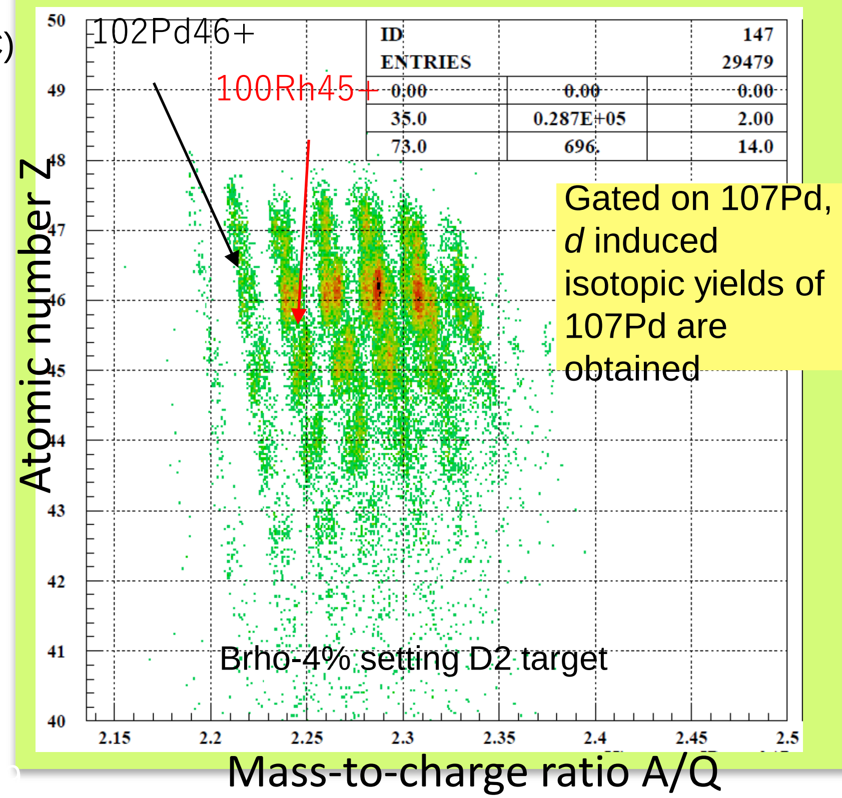
Results (Yield determination to each isotope)



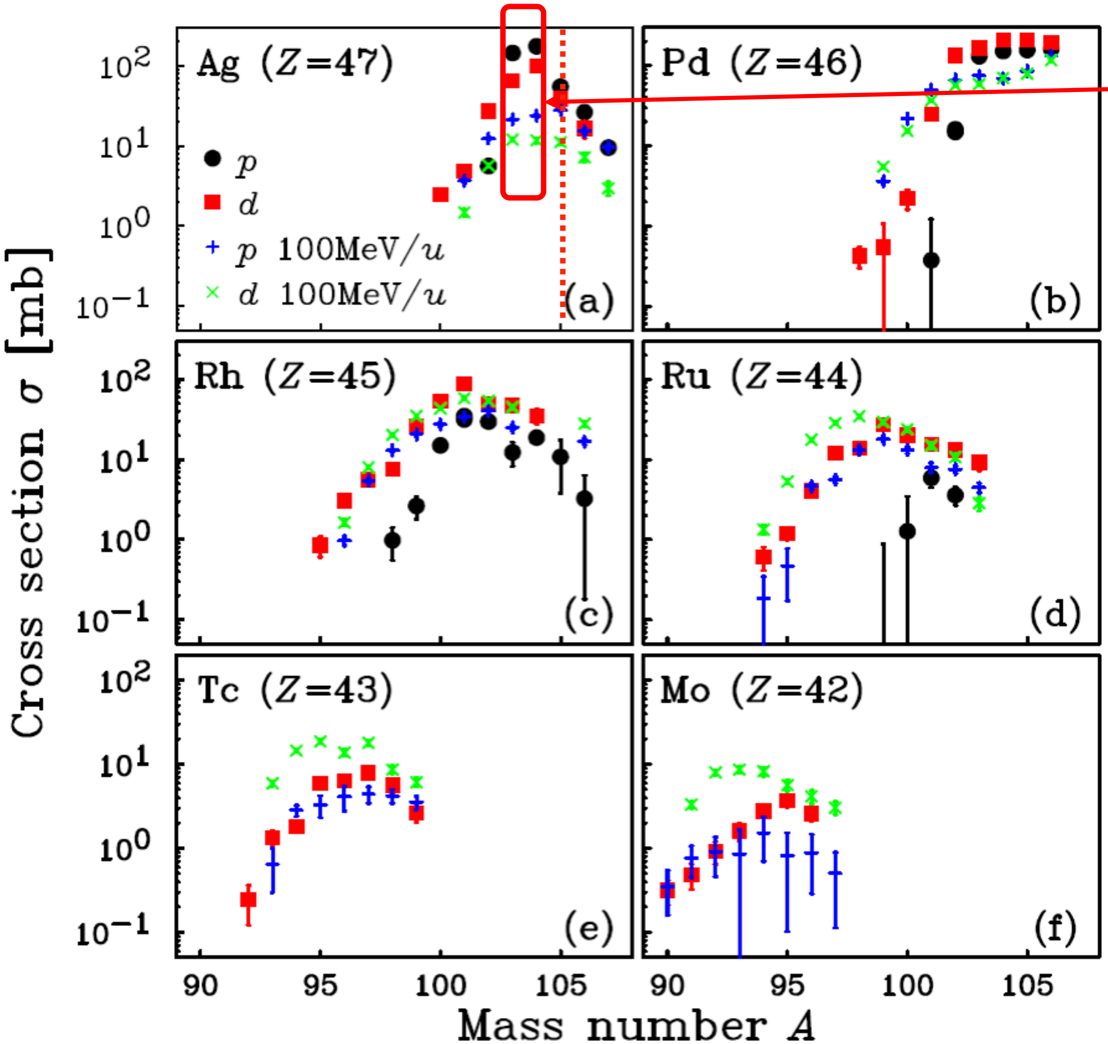
Secondary Beam Selection



Reaction Residue ID



Recent results of isotopic cross sections for ^{107}Pd@ 50 MeV/u



Large enhancement @^{103,104}Ag

^{107}Pd (p/d,xn) channel is enhanced comparison to 100MeV/u.

Importance of
proton induced fusion
and
deuteron induced
complete and incomplete fusion
(followed by neutron evapolation)

Results @Z=45, 44, 43, 42
Similar trend on
d 50 MeV/u and p 100 MeV
(Same kinetic energy)

H. Wang, et. al., Comm. Phys. to be published.

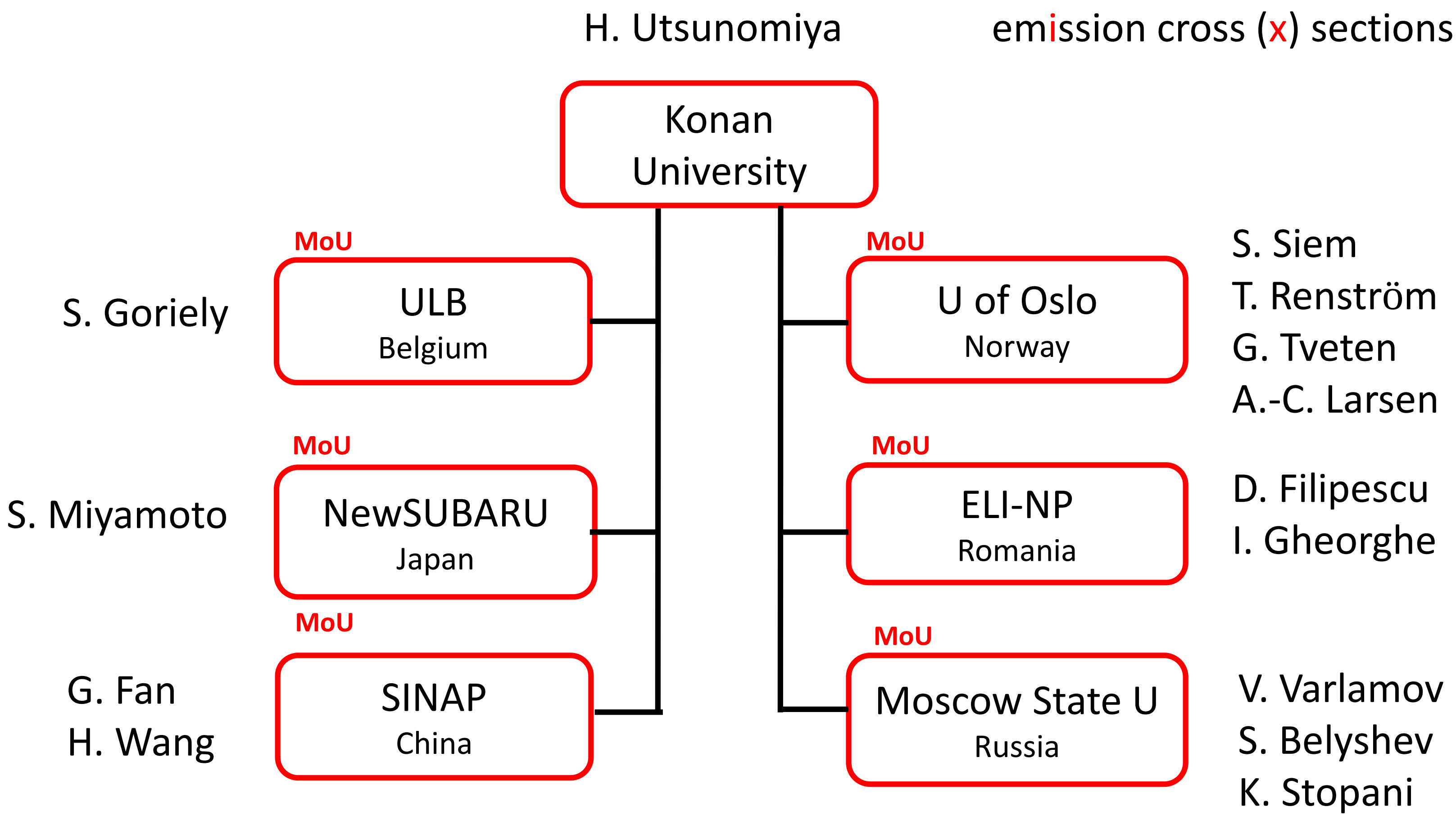
Activities at Ko-nan Univ.

Hiroaki Utsunomiya
Konan University

KONAN

Progress report on the PHOENIX* Collaboration

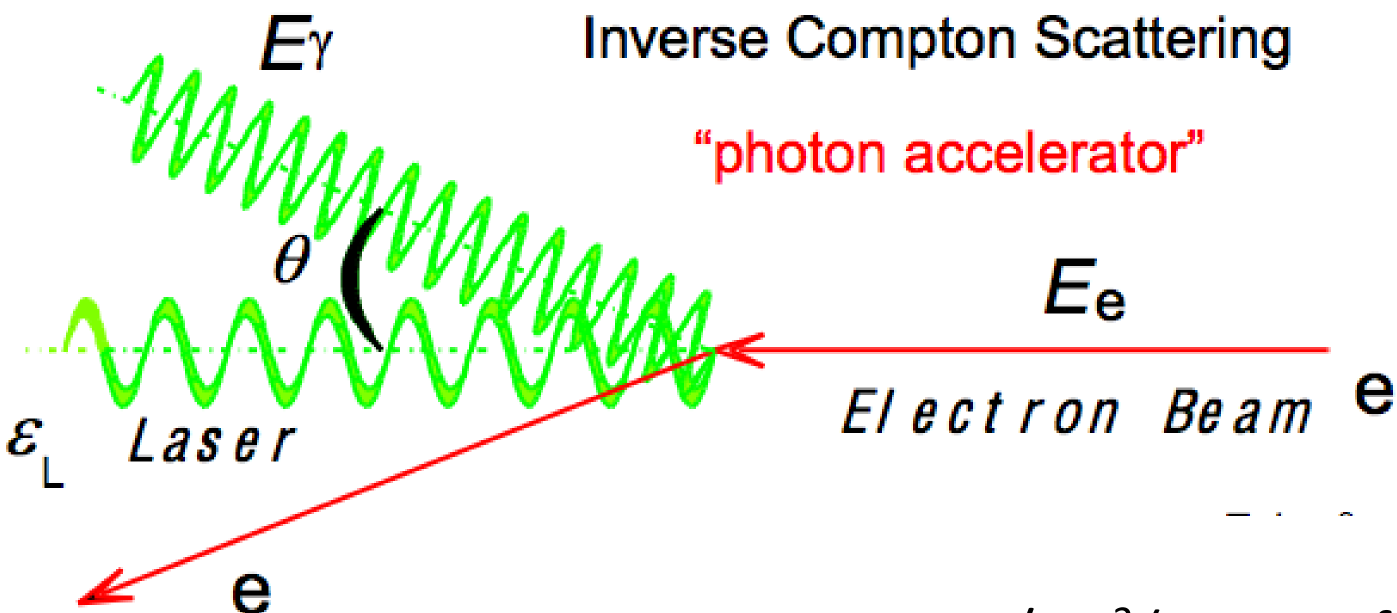
*Photo-excitation and neutron emission cross (x) sections



As a part of IAEA-CRP F41032 5 year-project (2016-2020)


SPring8
SACLA
1 GeV e- Linac
NewSUBARU
MeV γ

Laser Compton scattering



$$E_\gamma = \frac{4\gamma^2\varepsilon_L}{1+(\gamma\theta)^2+4\gamma\varepsilon_L/(mc^2)}$$

$$E_\gamma \approx 4\gamma^2\varepsilon_L$$

$$\Delta E/E \cong \left\{\left(\frac{2\Delta E_e}{E_e}\right)^2 + \gamma^4(\theta_e^2+\theta_c^2)^2\right\}^{1/2}$$

γ= E_e/mc^2 (Lorentz factor)

$\sim$ 2 x 10^3 for E_e=1 GeV

Energy amplification

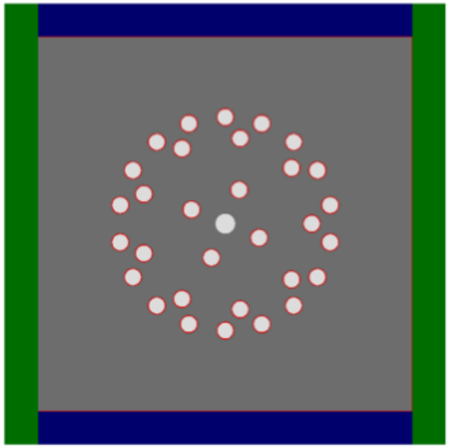
$$E_\gamma / \varepsilon_L \approx 4\gamma^2 \sim 1.6\times10^7$$

$\varepsilon_L \sim$ 1eV

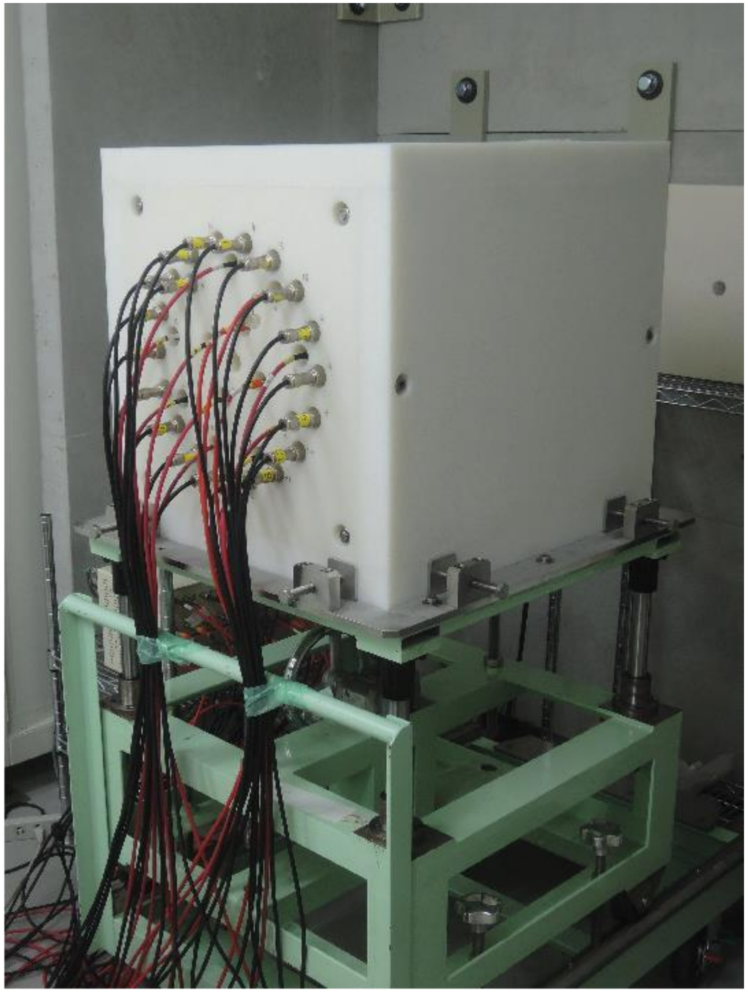
$E_\gamma \sim$ 16 MeV

Flat-efficiency neutron detector

H. Utsunomiya et al., Nucl. Instrum. Meth. A 871 (2017) 135-141.



Configuration	^{3}He counters	Distance [cm]
Ring 1	4	5.5
Ring 2	9	13.0
Ring 3	18	16.0
Total	31	



Data Acquisition

	(γ, xn) cross sections	(γ, 1n) cross sections
2015	209Bi, 9Be	203Tl, 205Tl, 89Y
2016	197Au, 169Tm, 89Y	192Os, 185Re, 138Ba, 137Ba, 64Ni, 61Ni, 60Ni, 58Ni, 13C
2017	181Ta, 165Ho, 59Co	184W, 183W, 182W, 68Zn, 66Zn, 64Zn
2018	159Tb, 139La, 103Rh	160Gd, 158Gd, 157Gd, 156Gd

All Data taking: Done

All evaluations: Done

2019 Submission of the updated photonuclear data library to Nuclear Data Sheet and the reference database of photon strength functions to European Physical Journal A

2020 Publications

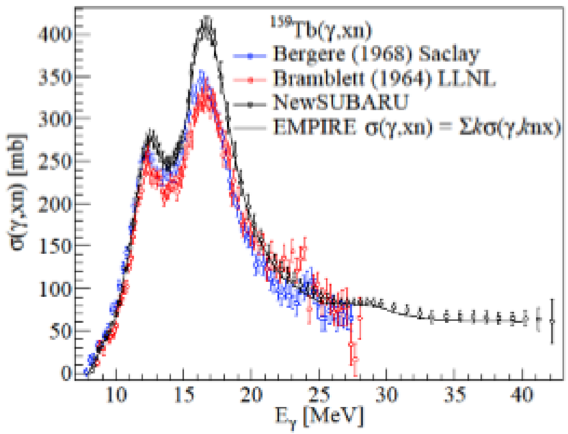
IAEA-CRP F41032

Selected Results

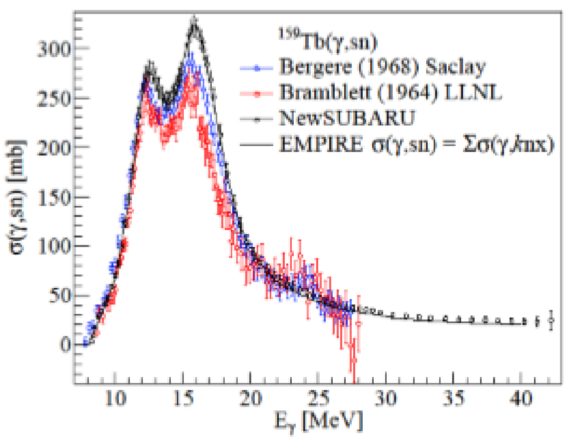
159Tb

IAEA-CRP Data
Evaluation: EMPIRE

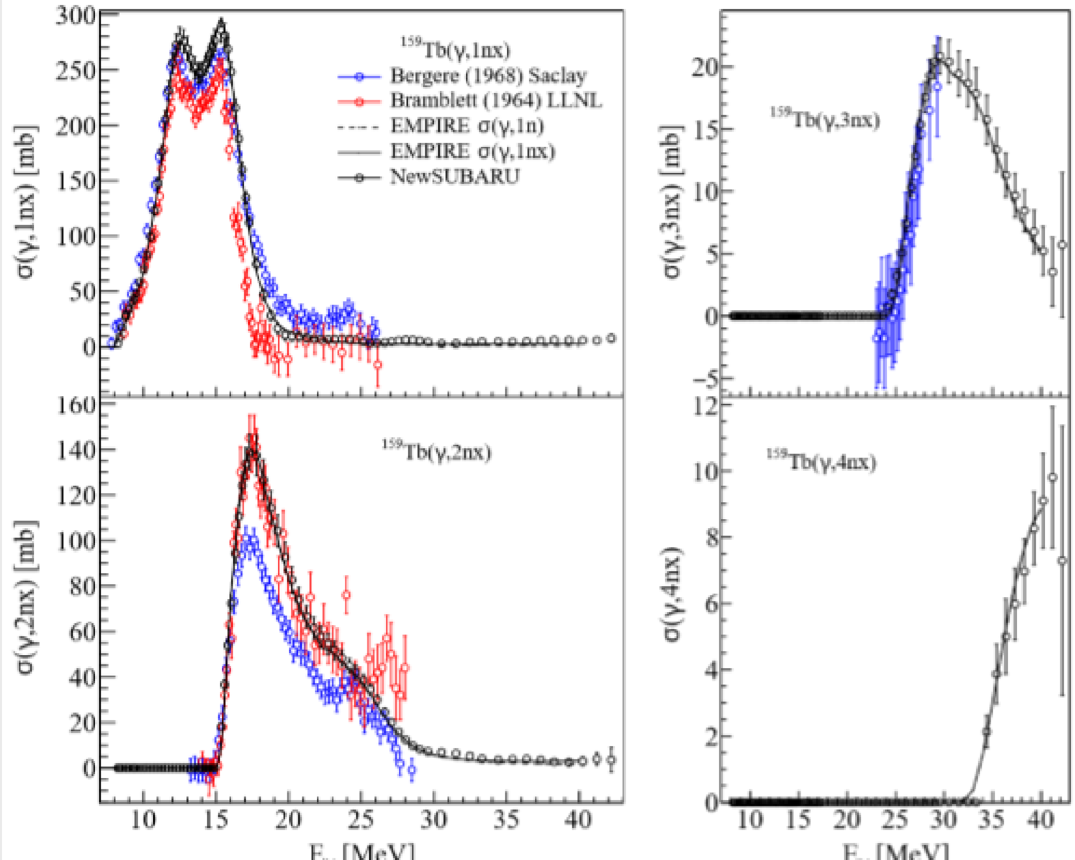
Neutron yield cross sections: $\sum_i i \cdot \sigma(\gamma, inx)$



Total cross sections: $\sum_i \sigma(\gamma, inx)$



Partial cross sections: $\sigma(\gamma, inx)$



Activities at National Institutes for Quantum and Radiological Science and Technology (QST)

LCS Gamma-Ray Research Group
Contact: Toshiyuki Shizuma
shizuma.toshiyuki@qst.go.jp

QST

Measurements of nuclear resonance fluorescence (NRF) using polarized and unpolarized photon beams

Facilities:

NewSUBARU (Univ. of Hyogo), HIγS (Duke University), γELBE (HZDR)

NRF takes place via only electro-magnetic interaction:

✓Model independent extraction of transition strength
✓Selective excitation of dipole states
✓Unambiguous spin and parity determination (1^- or 1^+) using a polarized photon beam

Experimental Setup at NewSUBARU

Example

Electrons

Energy: 600-1500MeV

Current: Max.250mA

Laser

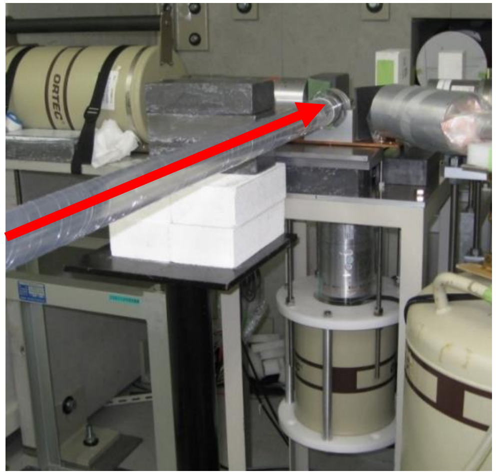
Nd:YVO_4 l=1064nm

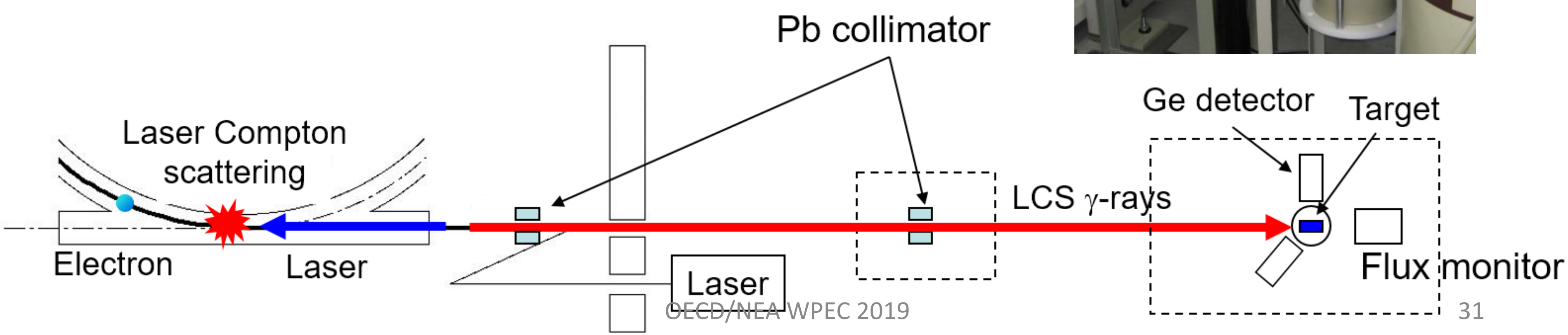
Power: 20W

LCS γ-ray beam

Max. energy: 6-39MeV

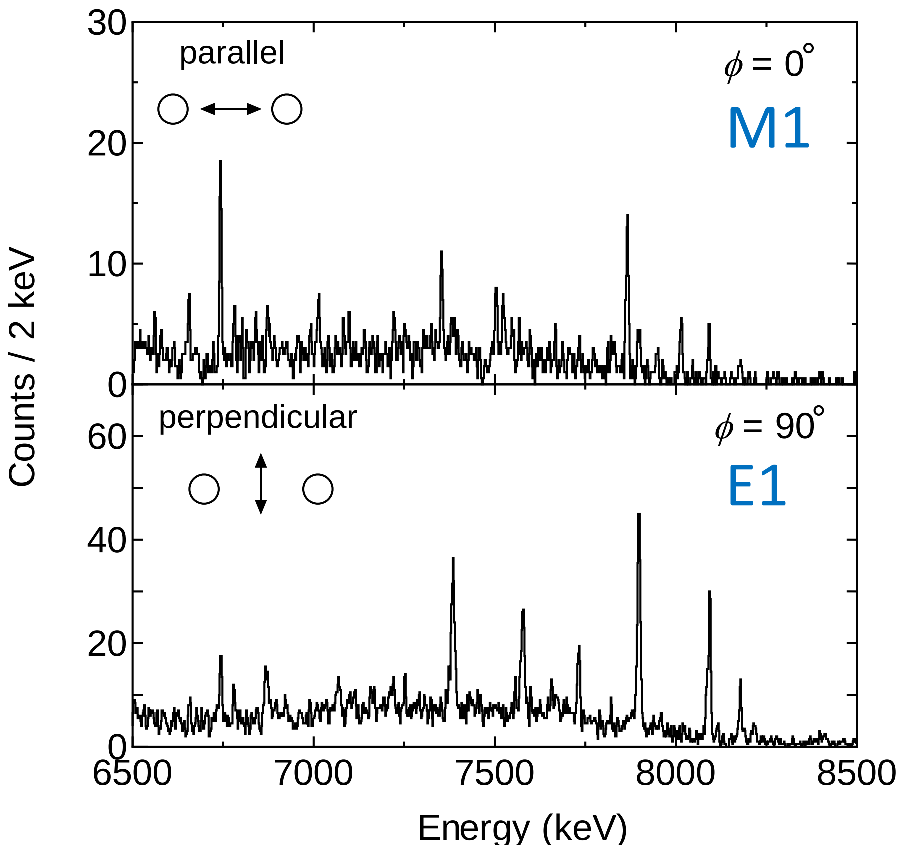
Ave. flux: ～6×10^5/s



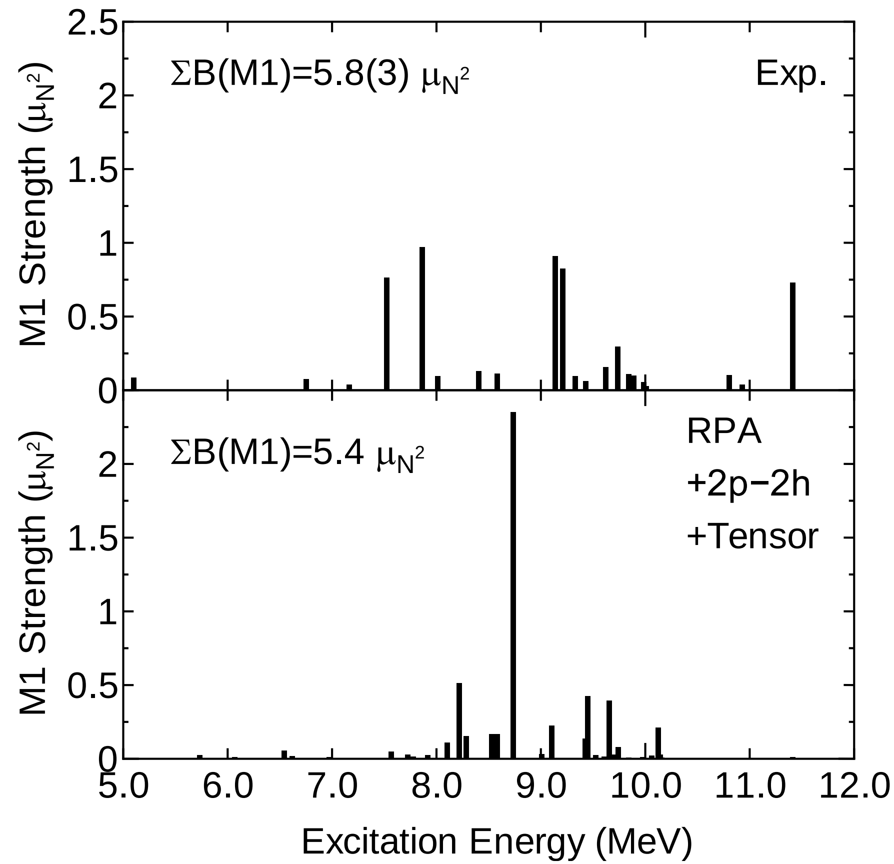


Results of NRF measurements for ^{52}Cr

Typical NRF spectrum



Measured M1 strength compared with RPA calculations



T.Shizuma et al., PRC 96, 044316 (2017).

Neutron Production DDX from Heavy-Ion Interactions @ NIRS-HIMAC

Team:

a) Department of Applied Quantum Physics and Nuclear Engineering, Kyushu University
b) Hiroshima University
c) National Institute of Radiological Sciences of National Institute for Quantum and Radiological Science and Technology
d) Sungkyunkwan University
e) Myongji University

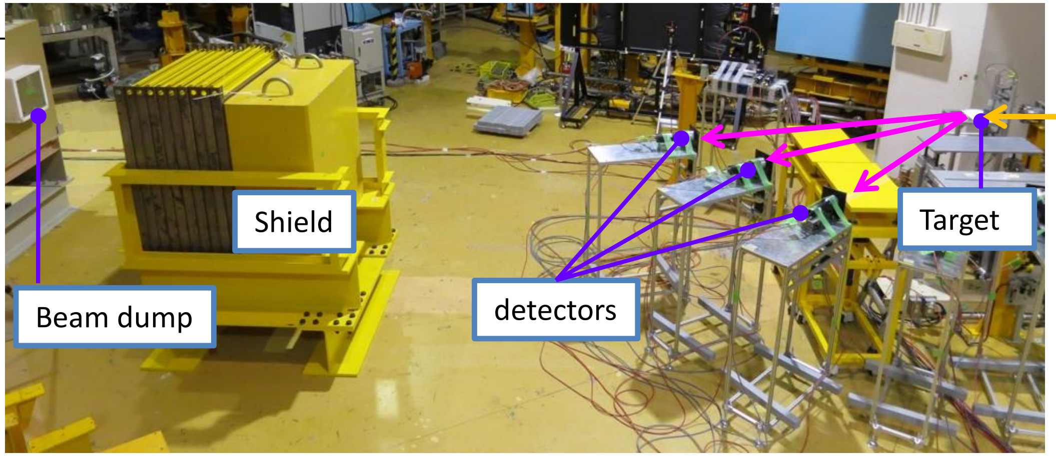
Contact:

Nobuhiro SHIGYO, Kyushu University

Neutron DDX from Heavy-Ion Interactions @ QST-NIRS-HIMAC

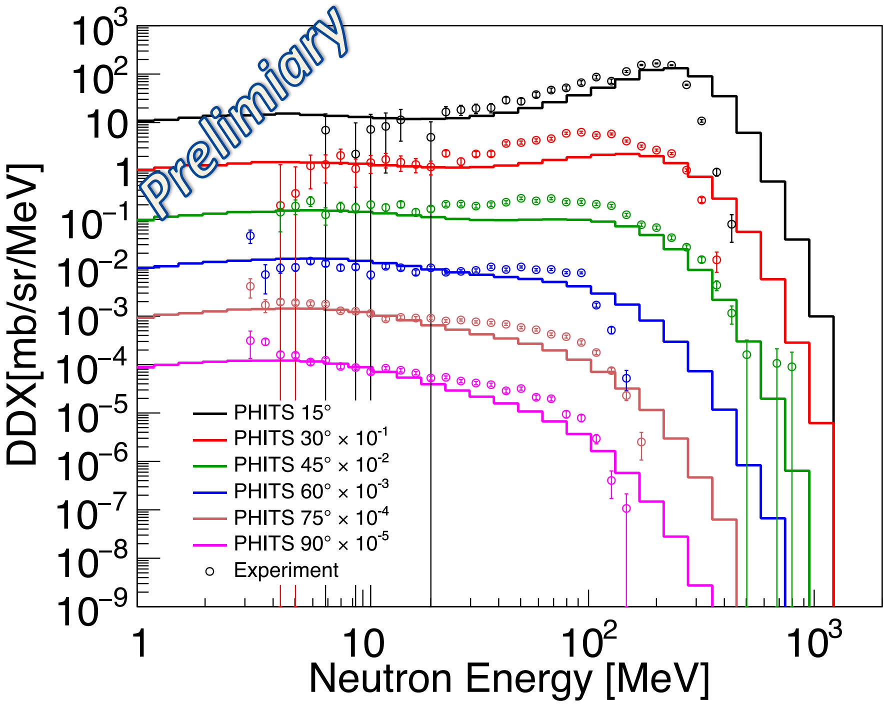
- Kyushu U., Hiroshima U., QST-NIRS, Sungkyunkwan U, Myongji U

- Systematic neutron cross sections for shielding design



Experimental setup at HIMAC

290 MeV/u Xe(C, xn) DDX



290 MeV/u Xe(C, xn) DDX

- HIMAC PH2 beam line
- Beam: 290 MeV/u Xe, ~10^5 pps
- Target: C
- Detection: **Liquid Scintillator** NE213, EJ301 + TOF
- Directions: 15˚ - 90˚

Neutron production from thick targets bombarded by 13.4-MeV deuterons

Contact person:

Yukinobu Watanabe, Kyushu University

九州大学
KYUSHU UNIVERSITY

Background and Purpose

- Neutron production from deuteron-induced reactions has been proposed as a candidate of **accelerator-based neutron source for various applications** such as transmutation of radioactive waste and production of medical radioisotopes.

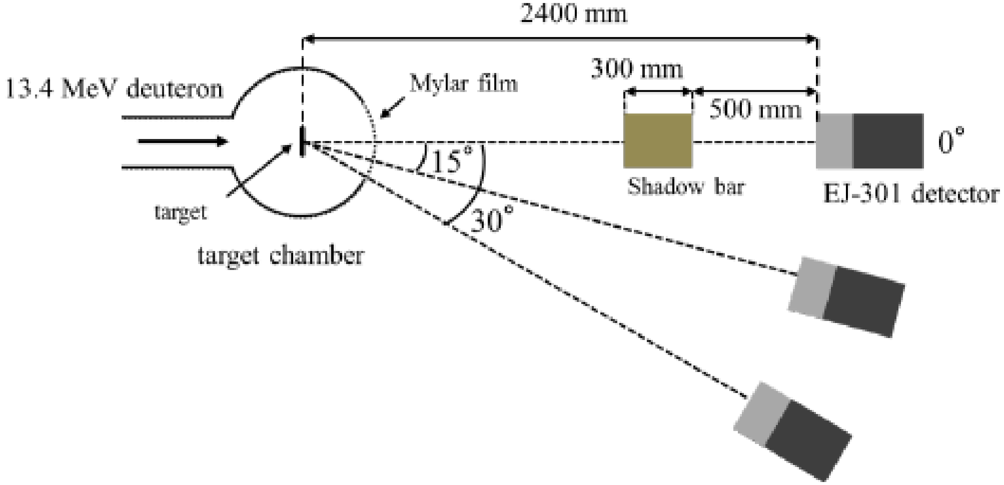
- For the design of such neutron sources, comprehensive knowledge of **deuteron-induced reactions is essential**. So far, experimental data of **thick target neutron yields (TTNYs)** have been obtained at deuteron energies below 10 MeV and theoretical model analyses have been performed in Kyushu University.

- M. Drosg et al. have focused on neutron production with triton irradiation and recently measured triton-induced TTNYs (t-TTNYs) from some target materials by 20.22-MeV triton irradiation. To compare deuteron-induced TTNYs (d-TTNYs) with t-TTNYs at the same incident energy per nucleon and the same target materials, **we have conducted a new measurement of d-TTNYs at the incident energy of 13.4 MeV, or 6.7 MeV/nucleon**, and analyzed them with theoretical models.

Experiment @Kyushu U.

Measurement of double-differential thick target neutron yields from 13.4-MeV deuteron bombardment using an unfolding method:

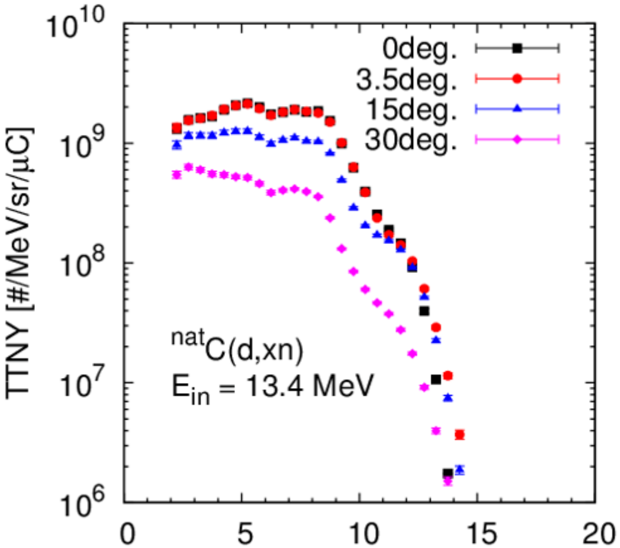
- **Facility: 8-MV Tandem accelerator at CABAS, Kyushu U.**
- **Targets: Thick LiF, C, Si, Ni, Mo, and Ta**
- **Emission angles : 0, 3.5, 15, and 30 degrees for C, 0, 15, and 30 for LiF, and 0 degree for the other targets,**
- **Detector: Liquid Scintillator EJ301 (2" in dia. & 2" thick)**

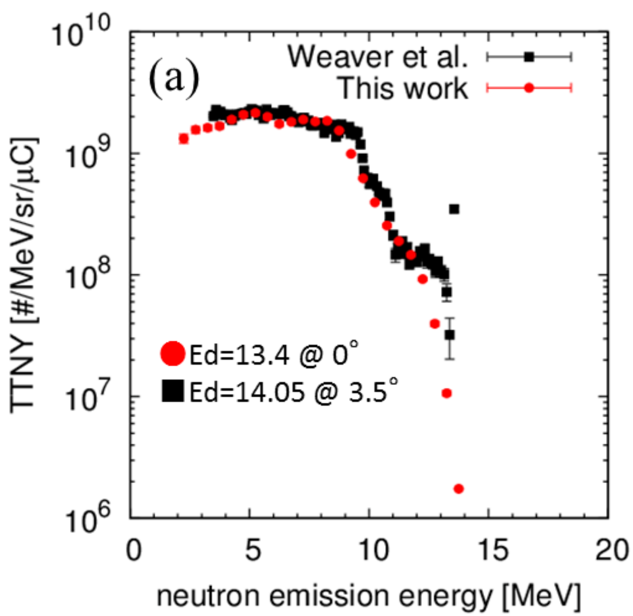


Experimental setup @ Kyushu U

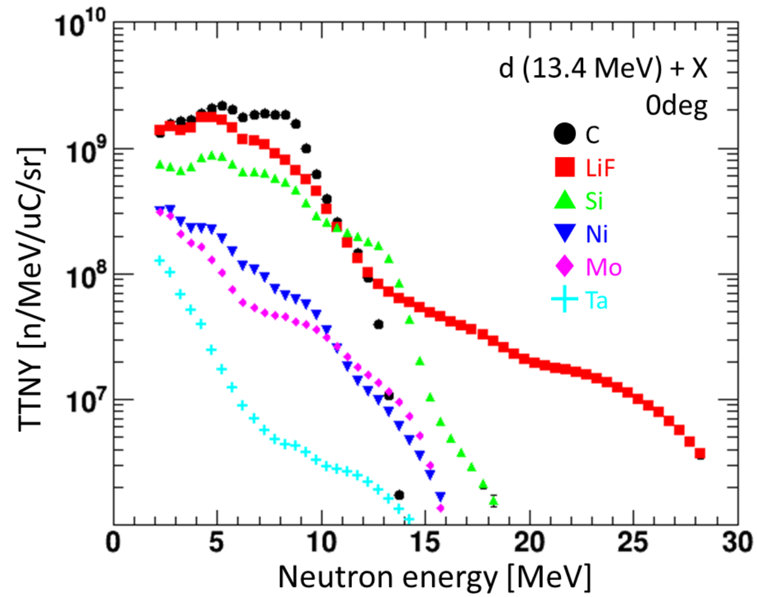
Experimental Results

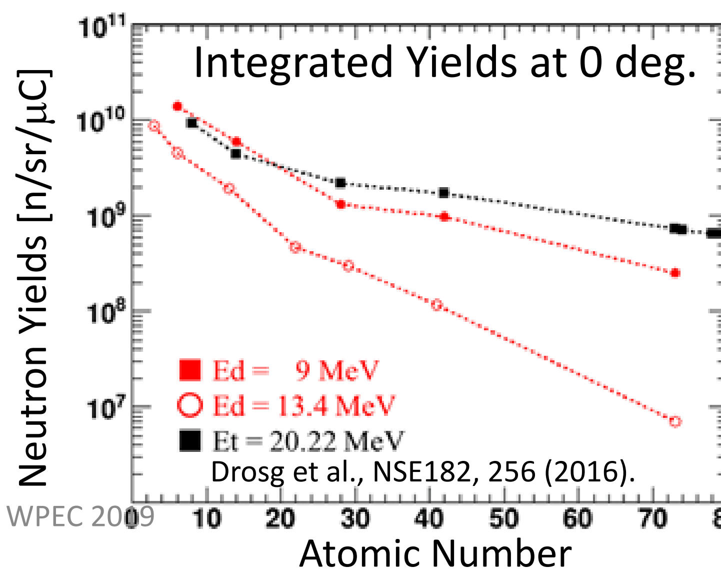
C@ 0, 3.5, 15, 30 deg.





C, LiF, Si, Ni, Mo, Ta@ 0deg.





Neutron TTY from α Induced Reaction @ RIKEN

Team:

a) Department of Applied Quantum Physics and Nuclear Engineering, Kyushu University
b) RIKEN Nishina Center
c) High Energy Accelerator Research Organization (KEK)

Contact:

Nobuhiro SHIGYO, Kyushu University

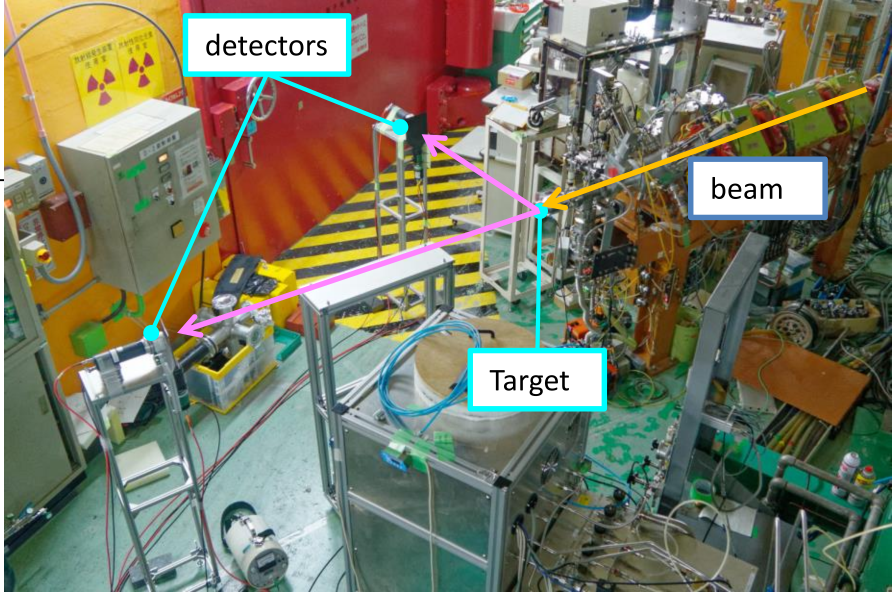
Neutron TTY @ RIKEN

- Kyushu U., RIKEN Nishina Center, KEK

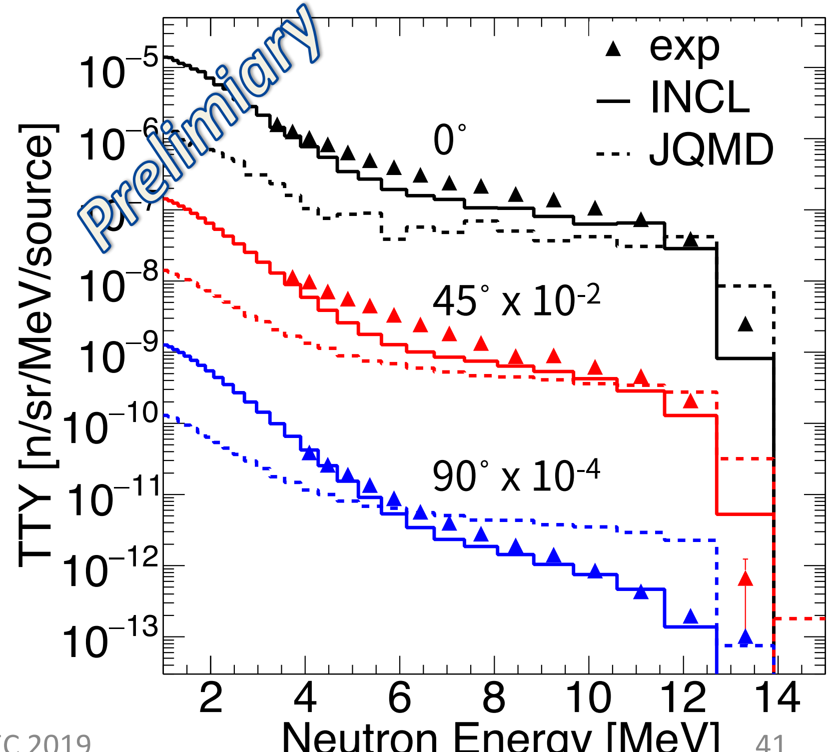
- Neutron thick target yields for shielding design

- AVF cyclotron E7B course
- Beam: 7 MeV/u α, 30 pnA
- Target: Bi
- Detection: EJ301 + TOF
- Directions: 0˚, 45˚, 90˚

- INCL model better than QMD model in PHITS



Experimental setup at RIKEN



7 MeV/u α(Bi, xn) TTY

Thank you for your attention!!