Muon-gamma spectroscopy for neutrino nuclear responses

I.H.Hashim[1], H.Ejiri2, S.A.Hamzah[1], S.S.Saroni[1], A.Sato[3], T.Shima[2], Y.Kuno[3], A.Shinohara[4], K.Ninomiya[4], K.Takahisa[2].

1 Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, MALAYSIA
2 Research Center of Nuclear Physics, Osaka University, 10-1 Mihogaoka, Ibaraki, Osaka 567-0047, JAPAN
3 Department of Physics, Graduate School of Science, Osaka University, Toyonaka-shi, Osaka 560-0043, JAPAN
4 Department of Chemistry, Graduate School of Science, Osaka University, Toyonaka-shi, Osaka 560-0043, JAPAN

Objectives:

1) To study the prompt gamma and X-ray as the product of muon capture reaction on ^{100}Mo and ^{100}Ru
2) To study the delayed gamma ray as the product of muon capture reaction on ^{100}Ru
3) To determine the absolute lifetime of muon capture on ^{100}Mo and ^{100}Ru

Introduction:

Neutrino nuclear responses (square of nuclear matrix elements) are crucial for neutrino studies in nuclei by measuring double beta decays and astro neutrino nuclear interactions. The matrix element is given by the sum of products of β- and β+ matrix elements. Theoretical calculations of the weak responses (matrix elements) are very challenging since they are very sensitive to nuclear correlations and nuclear medium effects. Thus experimental studies of them are very valuable.

Recently nuclear responses of M(β-) have been studied extensively by using high energy-resolution (^{3}He,t) experiments at RCNP. On the other hand those of M(β+) are hard because of no high energy-resolution nuclear probes. While EM probe does not directly contribute to the neutrino nuclear response.

So far nuclear γ rays from muon capture reactions were measured to study the nuclear reaction mechanisms. Prompt γ-rays from bound states excited by μ capture ^{A}X(μ,γ)^{A}Y reactions were investigated to study β+ responses for low lying bound states [1,2]. Here it is hard to extract the β+ strengths to individual states.

It has been pointed out in 1972[3], and also in 2000's [4] that μ capture reactions are used to get the β+ responses.

1) The β+ strengths are obtained by measuring prompt and delayed γ rays from (μ, xn) reactions with x being the number of the emitted neutrons.
2) Unique features of the μ capture reactions are the large branch of the μ capture (Br≅1),
3) The wide range of the excitation region of $0 \le E_x \le 70$ MeV, and the momentum transfer of q=50-150 MeV/c.
4) The energy and the momentum involved are just the same orders of magnitude as those of 0νββ-ν and the astro-ν responses.

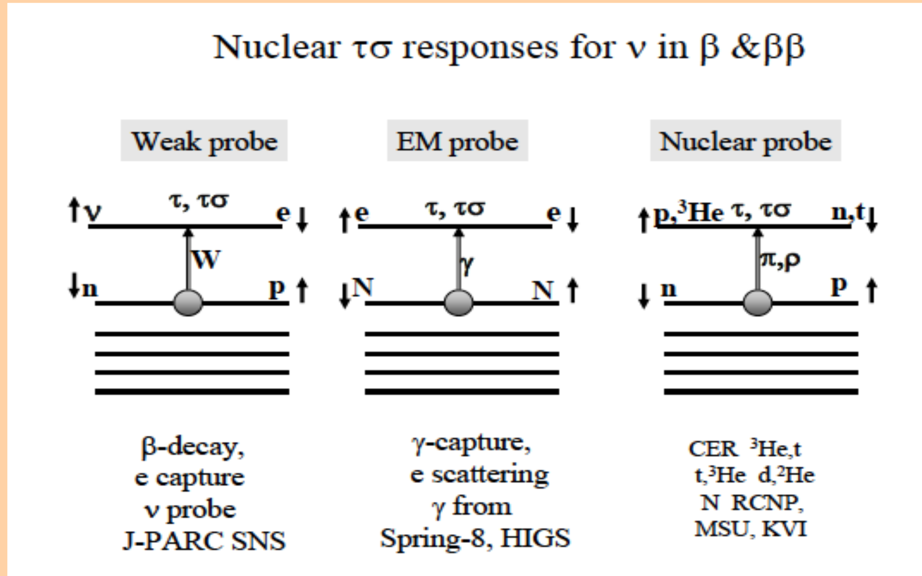
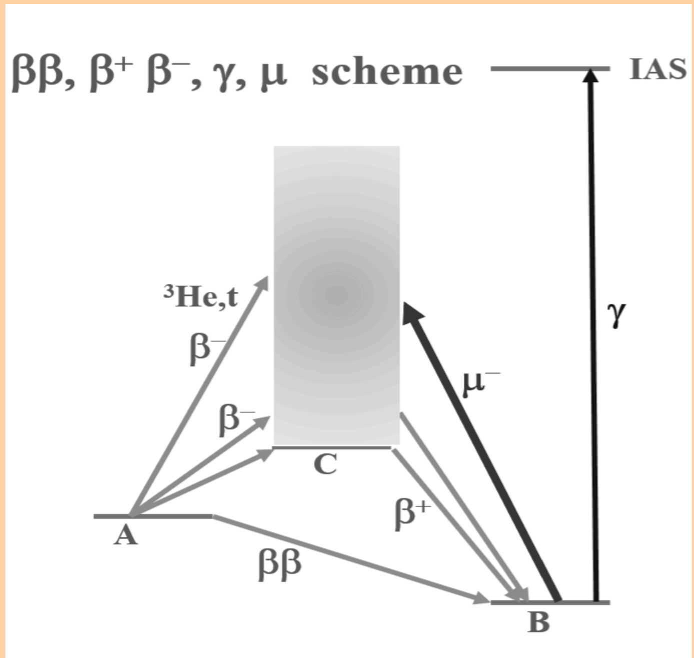
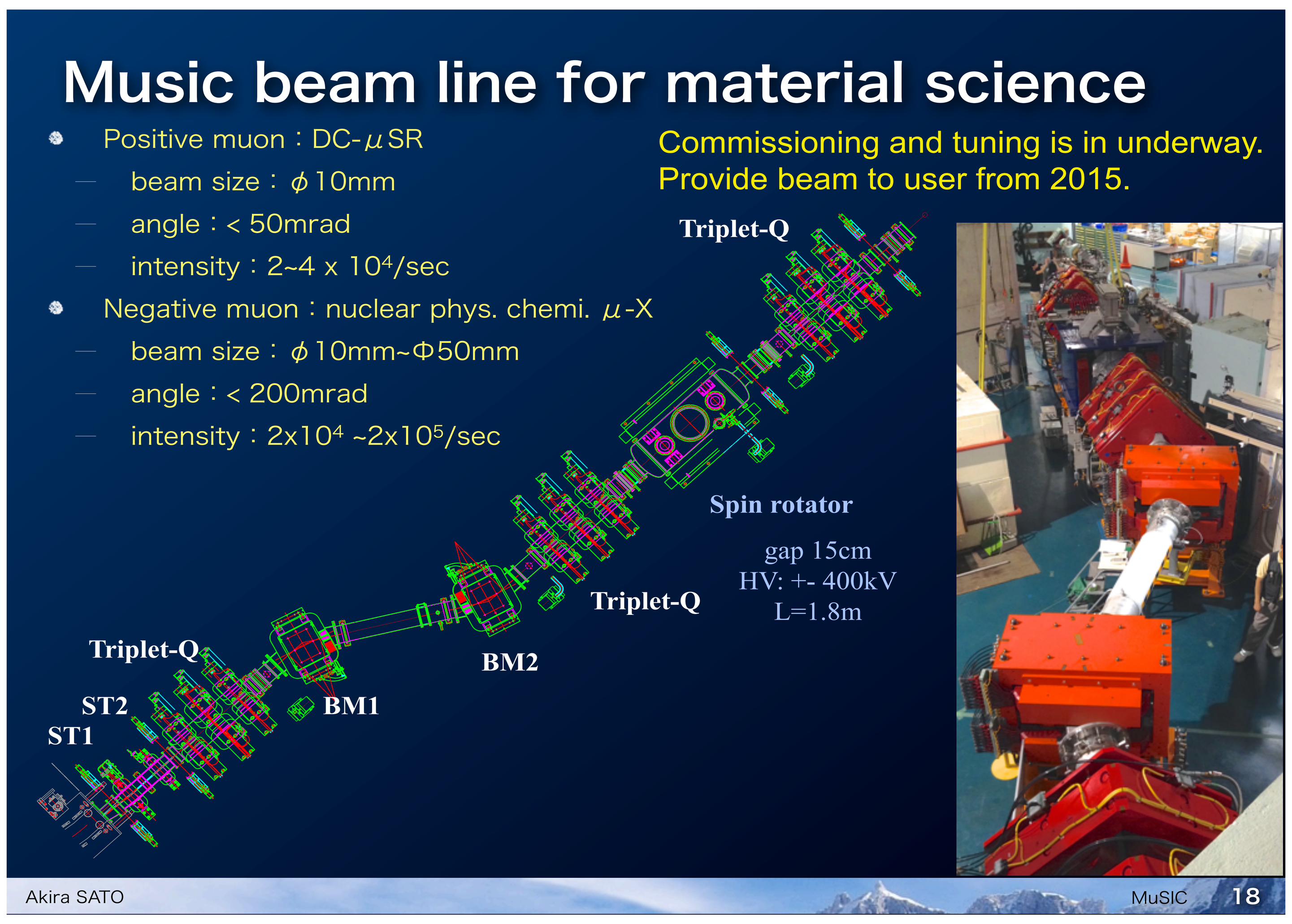


Figure 1: Nuclear τσ responses for ν in β and ββ

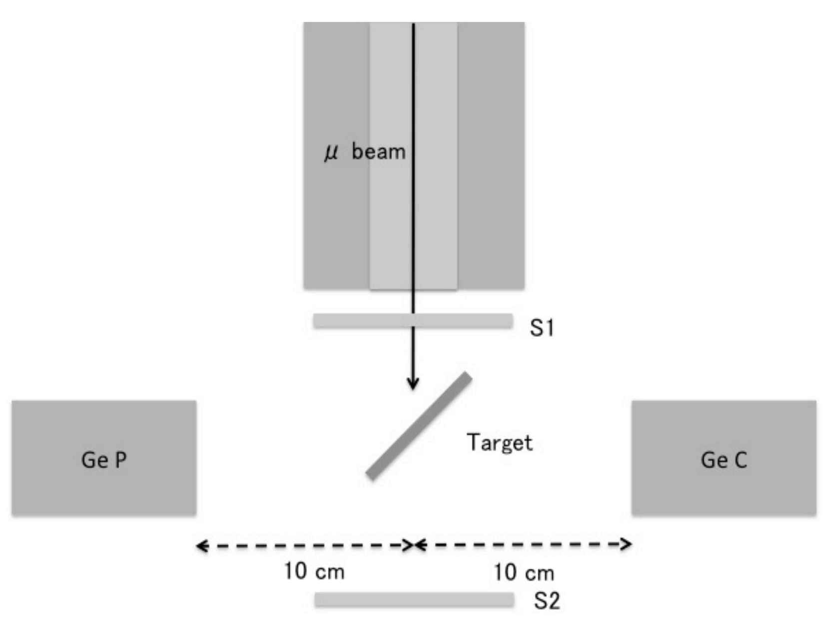


The present experiment studies the gross β+ strength distribution as a function of the excitation energy up to around 70 MeV by measuring the isotope x distribution of the reaction ^{A}X(μ, xn)$^{A-x}$Y, where $^{A-x}$Y and x are identified by measuring γ rays from $^{A-x}$Y. The feasibility of the low energy μ probe for ν response studies has been demonstrated by using the pulsed μ probes from MUSE at J-PARC [5].

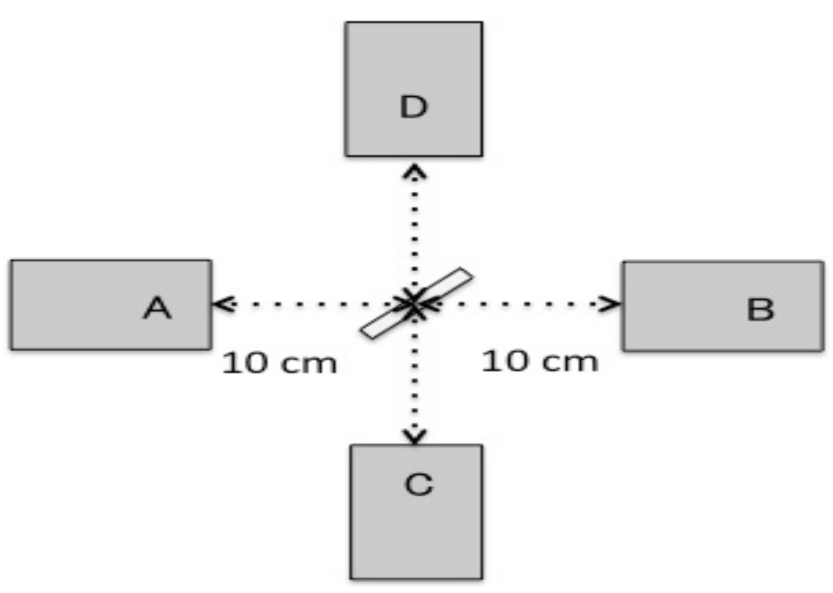
Methodology:



(a) The prompt gamma and X-ray and the absolute lifetime measurement.



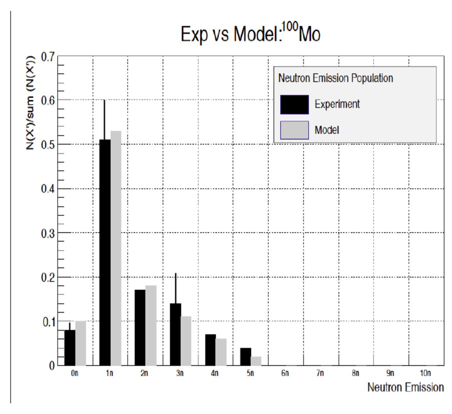
(b) The delayed gamma measurement for ^{100}Ru isotopes



Expected results:

(a) ^{100}Mo(μ,xn)$^{100-x}$Nb

A	RI (half-life)	Gamma ray Energy (keV)
100	Nb(1.5s)-Mo	535.0
99	Nb-Mo(66h)-Tc	140.5, 181.0, 739.5
	*Tc(6h)-Tc	
98	Nb(0.9h)-Mo	722.0, 787.1
97	Nb(1.2h)-Mo	657.9
96	Nb(23.3h)-Mo	459.8, 569.0, 778.1
95	Nb(86.6h)-Mo	765.3



(b) ^{100}Ru(μ,xn)$^{100-x}$Hf

A	RI (half-life)	Gamma ray Energy (keV)
100	Tc(15s)-Ru	539.5, 590.8
99	Tc(6h)-Ru	140.5, 189.6
97	Tc(67.9h)-Ru	215.7, 324.5
95	Tc(1.64h)-Ru	336.4, 628.9
94	Tc(0.86h)-Ru	367.2

Remarks:

- The present experiment elucidates gross features of weak responses (β+ strength distributions) with $J^{\pm}= 0^{\pm}, 1^{\pm}, 2^{\pm}$, in E = 0-70 MeV for isotopes of ^{100}Ru and ^{100}Mo. They are used to get and/or to evaluate the 0νββ responses ($M_{0\nu}$) and astro–ν responses for medium heavy nuclei.
- The present experiment is extended to other nuclei in the wide atomic mass number (A) region between 40 to 230. The gross features of the weak strength depend smoothly with the mass number.
- Finally we note that the RI γ-ray analyses associated with (μ,xn) reactions are used to detect/assay impurities and small components of nuclear isotopes, which are interesting from scientific and/or historical view points, as Resonant Photo nuclear-reaction for Isotope Detection (RPID) [7] and Muon Capture Isotope Detection (MuCID) is presented in ref. [8].

References:

[1] V. Egorov. Czechoslovak J Phys. 56 453-457 (2006).
[2] K.Ya (2013), JINR DLP
[3] H. Ejiri, Proc. EM interactions, Sendai. (1972).
[4] D.F. Measday Physics Reports 354, 243 (2001).
[5] I. Hashim PhD thesis, Osaka University (2014)
[6] A. Sato, et al., Proc. IPAC2011, San Sebastian, Spain, 820 (2011).
[7] H. Ejiri and T. Shima, Phys. Rev. ST 15, 024701 (2012).
[8] H. Ejiri, et al. Journal of the Physical Society of Japan 82 044202 (2013).