OMCs for DBD and astro-neutrino nuclear responses.

(The UTM, RCNP and JINR joint project)

Izyan Hazwani Hashim

Universiti Teknologi Malaysia (UTM)

Mini-NEWS Colloquium (27/11/20)

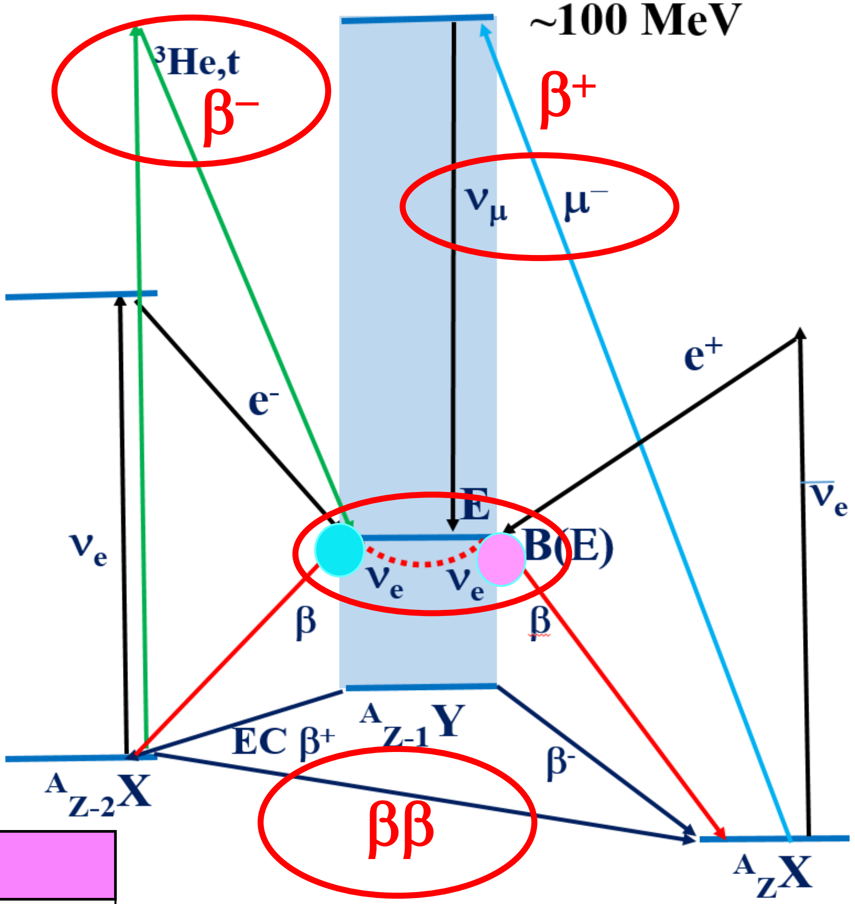
Outline

- OMC for DBD and astro anti-neutrinos responses
- UTM-RCNP-JINR Joint Project (the objectives)
- Briefly the previous experiments offline results
- Publications

Neutrino nuclear responses for DBDs and astro-antineutrino responses

Experiments aim to investigate the fundamental properties of neutrinos:

i. Double beta decays (DBD)
ii. Single Beta decay (SBD)
iii. Inverse beta decay (IBD)



IBD and SBD (EM, weak and nuclear probe)
- investigate the neutrino nuclear responses - simpler way to understand nuclear structure - each probe type investigates different region of interest for nuclear structure studies.

DBD (2νββ or 0νββ)
- observation of nuclear matrix element - extracting the absolute mass of neutrino.

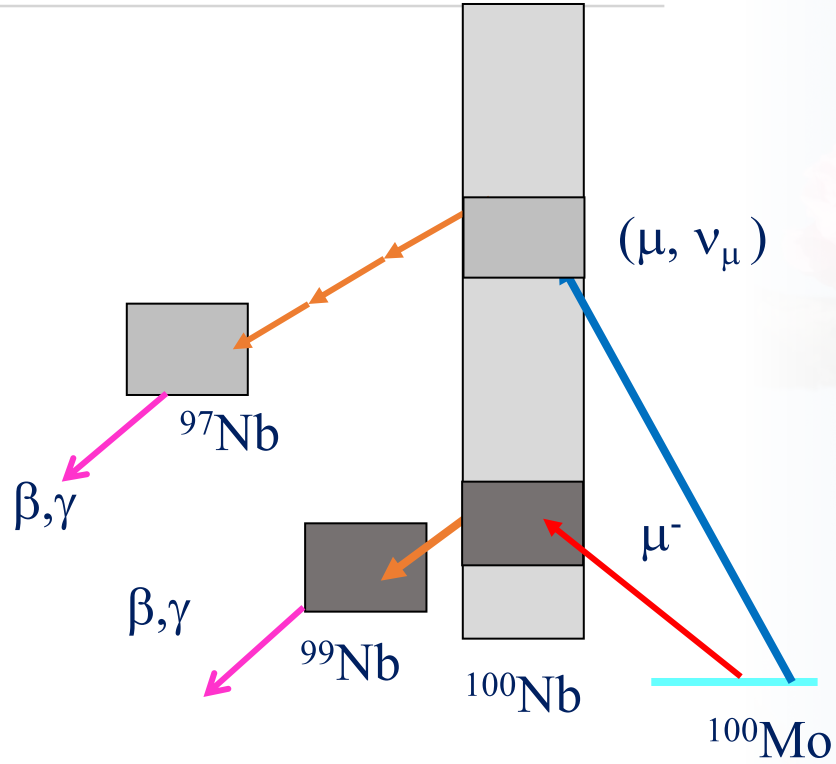
[1] H. Ejiri, Proc. CNNP2017, Catania 2017, IOP Conf. Series, 1056 (2018) 012019.
[2] J. Vergados, H. Ejiri, and F. Simkovic, Rep. Prog. Phys. 75 (2012) 106301.
[3] H.Ejiri, J.Suhonen, K.Zuber Phys. Rep 797 (2019) 1

Nuclear & lepton (μ) CERs for CC and astro-ν and anti-ν responses

- Nuclear and μ CERs cover the large energy (*E*) & momentum (*p*) regions as DBD & astro-ν.
  - P = 100-50 MeV/c
  - E = 0-50 MeV
- Nuclear CER such as (^{3}He,t) reaction is dedicated for β- side ν.
- Lepton (μ) CER like (μ,ν_μ) reaction is dedicated for β+ side anti-ν .
- These reactions are CCs associated with DBD ν-exchange responses, and with astro ν and anti-ν responses

1. H. Ejiri, Proc. CNNP2017, Catania 2017, IOP Conf. Series, 1056 (2018) 012019.
2. I.H. Hashim, H. Ejiri, et al., PRC 97 (2018) 014617
3. I.H. Hashim, H. Ejiri, AAPPS 63ed. (2019) Sept
4. H.Ejiri, J.Suhonen, K.Zuber Phys. Rep 797 (2019) 1

Muon CER (μ, ν_μ, xnγ)
E+P~100 MeV/c E = 5-50 MeV, P = 95-50 MeV



1. I.H. Hashim, H. Ejiri, et al., PRC 97 (2018) 014617
2. I.H. Hashim, H. Ejiri, AAPPS 63ed. (2019) Sept
3. H.Ejiri, J.Suhonen, K.Zuber Phys. Rep 797 (2019) 1

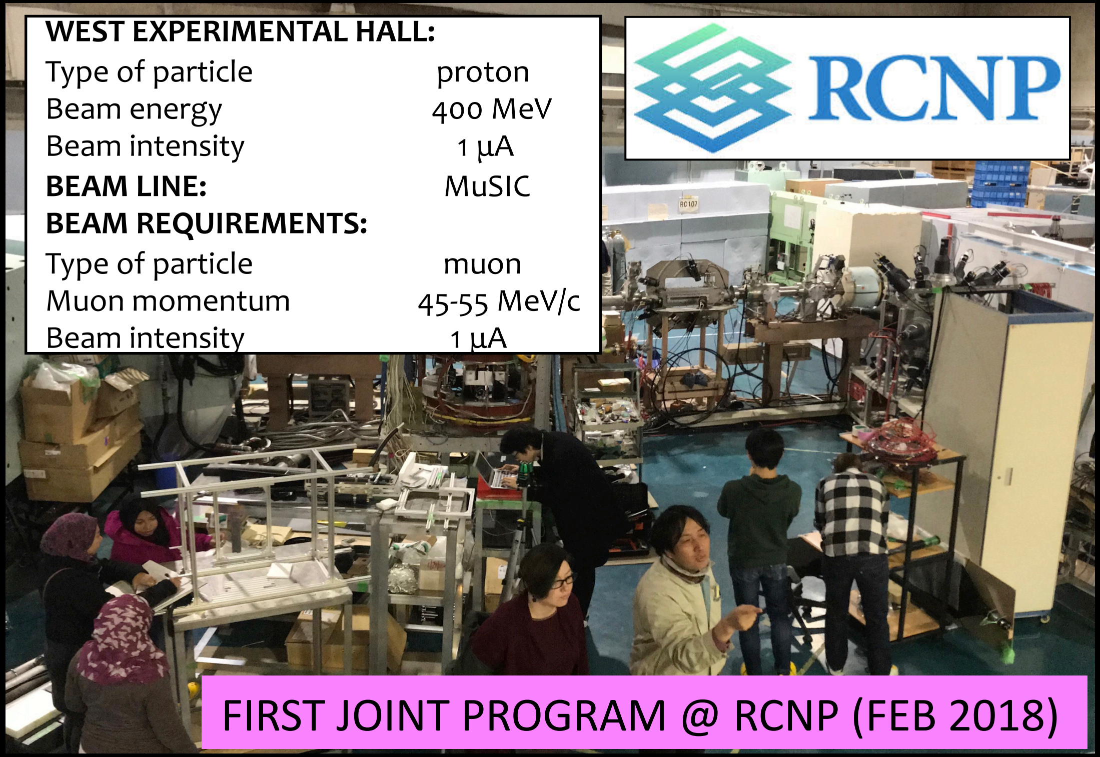
- Muon have high momentum transfer due to its mass compare to an electron.
- Upon emission of highly energetic ν_μ , the remaining nuclei tends to possess certain excitation energy which initiates cascade reaction.
  - Proves by charged particle and neutron emission in light nuclei.
  - Mostly neutron emission in medium-heavy nuclei.
- The muon capture strength distribution B(μ,E) from the remaining excitation energy carries information about nucleonic and non-nucleonic correlations similar to the NME.
  - Collaboration with the theory group, Prof. J. Suhonen and Dr L. Jokiniemi.

UTM-RCNP-JINR joint project

Established in September 2018.

Aim:	Study of the neutrino nuclear response by the Ordinary Muon Capture (OMC) on various double beta decays (DBDs) nuclei.

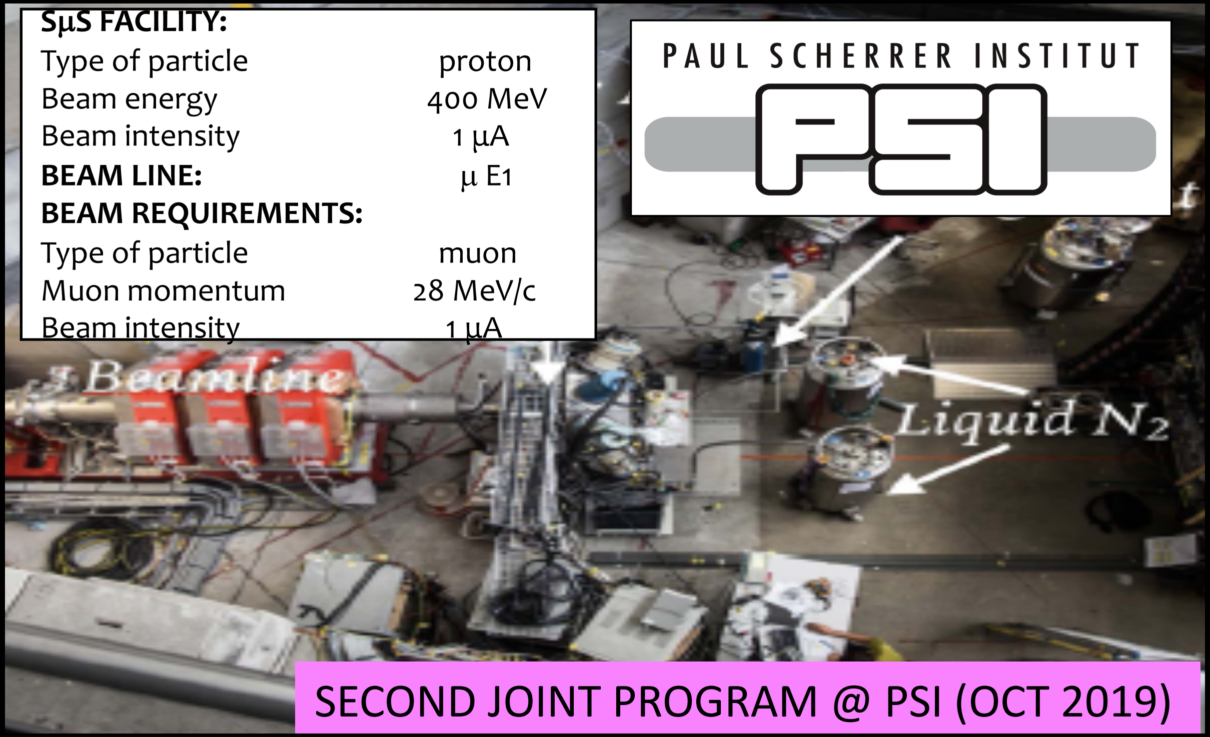
Spokesperson: I.H.Hashim (UTM), H.Ejiri (RCNP), D.Zinatulina (JINR)



WEST EXPERIMENTAL HALL:	
Type of particle	proton
Beam energy	400 MeV
Beam intensity	1 μA
BEAM LINE:	MuSIC
BEAM REQUIREMENTS:	
Type of particle	muon
Muon momentum	45-55 MeV/c
Beam intensity	1 μA

RCNP

FIRST JOINT PROGRAM @ RCNP (FEB 2018)

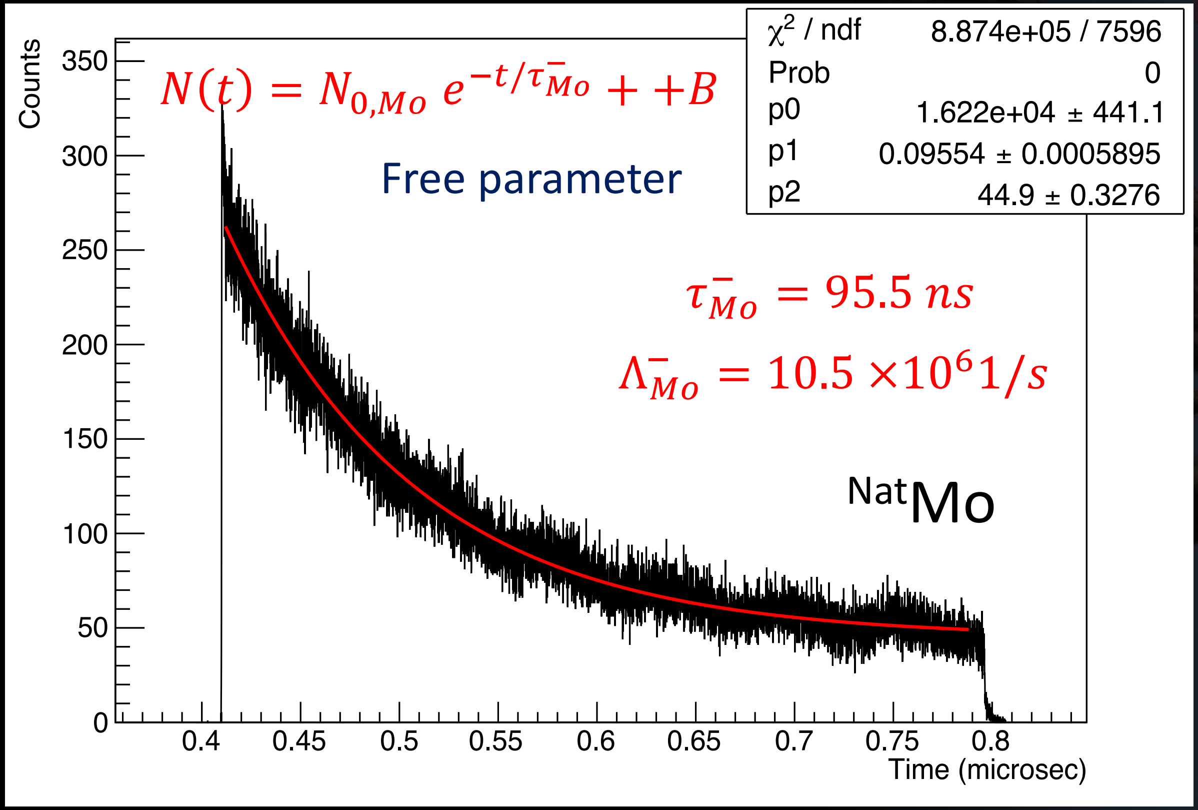


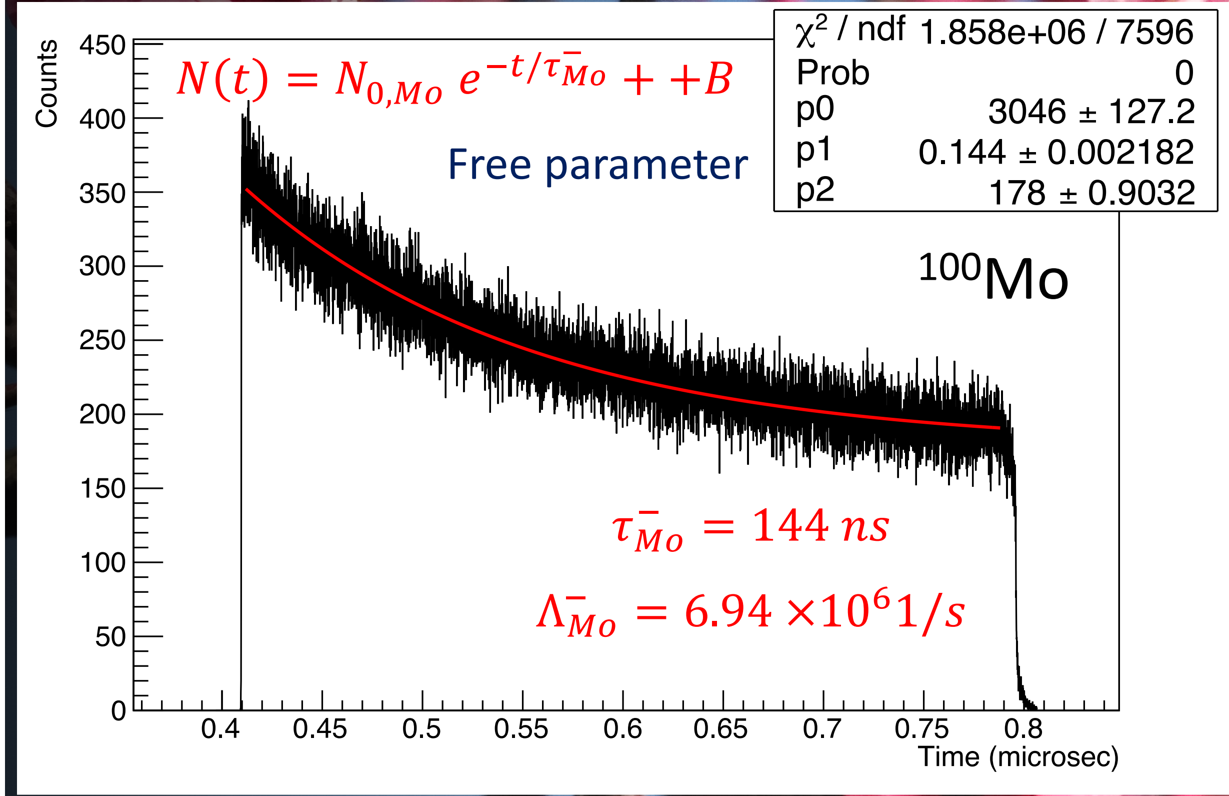
SμS FACILITY:	
Type of particle	proton
Beam energy	400 MeV
Beam intensity	1 μA
BEAM LINE:	μ E1
BEAM REQUIREMENTS:	
Type of particle	muon
Muon momentum	28 MeV/c
Beam intensity	1 μA

PAUL SCHERRER INSTITUT PSI

SECOND JOINT PROGRAM @ PSI (OCT 2019)

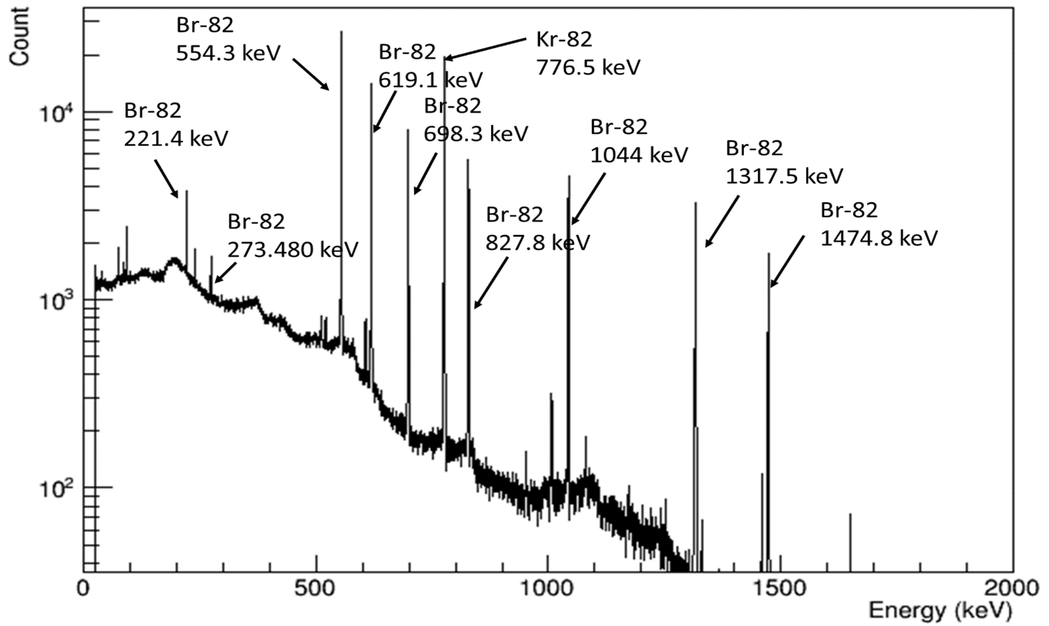
E489 Experiment @ RCNP status

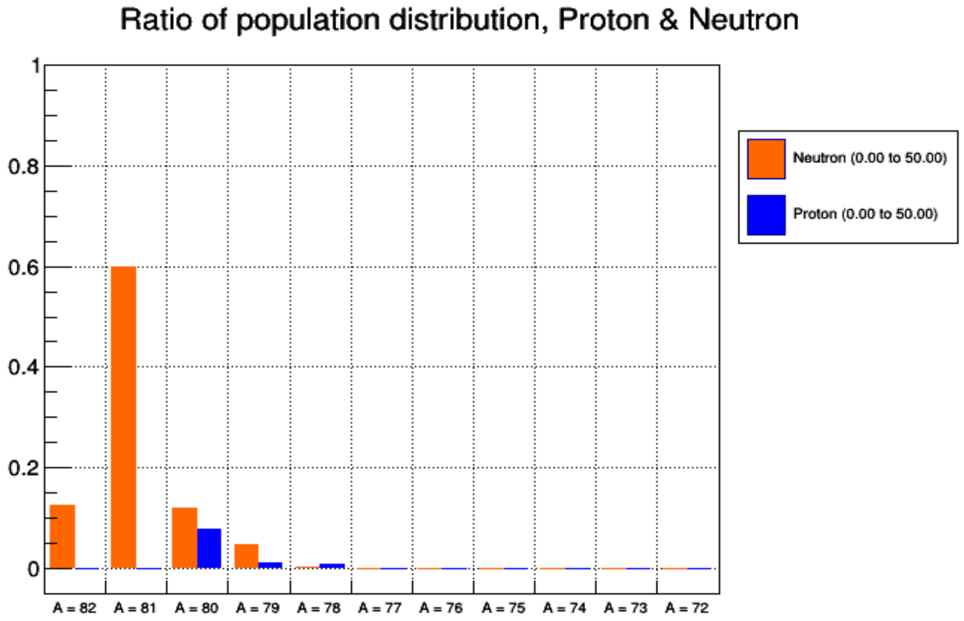




- Primakoff estimates ^{100}Mo lifetime is larger than ^{Nat}Mo. by a factor 130/100 = 1.3 (ours is about a factor of 144/95.5 = 1.5).
- Both experimental observation shows greater capture rate value compare to the one reported in Primakoff's.
- **Repetitive measurement will be done @PSI soon.**

Experiment @ μE1 PSI status





Target	PSI experiment		PNEM estimation	
	event	N(RI)	event	Percentage (%)
^{24}Mg	(μ,0n)	2.89 x 10^{11}	(μ,0n)	0.06
	(μ,1n)		(μ,1n)	0.66
	(μ,2n1p)		(μ,2n1p)	0.25
	(μ,3n1p)		(μ,3n1p)	0.04
	(μ,4n1p)		(μ,4n1p)	0.01
	(μ,5n)		(μ,5n)	<0.01
^{82}Kr	(μ,0n)	5.39 x 10^{7}	(μ,0n)	0.13
	(μ,1n)		(μ,1n)	0.6
	(μ,2n1p)		(μ,2n1p)	0.2
	(μ,3n1p)		(μ,3n1p)	0.09
	(μ,4n1p)		(μ,4n1p)	0.06
	(μ,5n)		(μ,5n)	<0.01
^{130}Xe	(μ,0n)	1.54 x 10^{7}	(μ,0n)	0.12
	(μ,1n)		(μ,1n)	0.55
	(μ,2n1p)		(μ,2n1p)	0.23
	(μ,3n1p)		(μ,3n1p)	0.1
	(μ,4n1p)		(μ,4n1p)	0.04
	(μ,5n)		(μ,5n)	0.01

Overview

1.0 Muon Irradiation experiment

muonic X-ray, electrons, prompt γ-rays, short-lived and delayed γ-rays

1.1 Measurement of short-lived and delayed RI γ-rays

$$^{100}\text{Mo} + \mu^- \rightarrow \text{Nb}^* + \nu_\mu + xn$$

$$\text{Nb}^* + \beta^- + \overline{\nu}_e + \gamma$$

Exp. data give the RIs production rate of the final nuclei after neutron and proton emission.

1.2 Measurement of partial capture rates

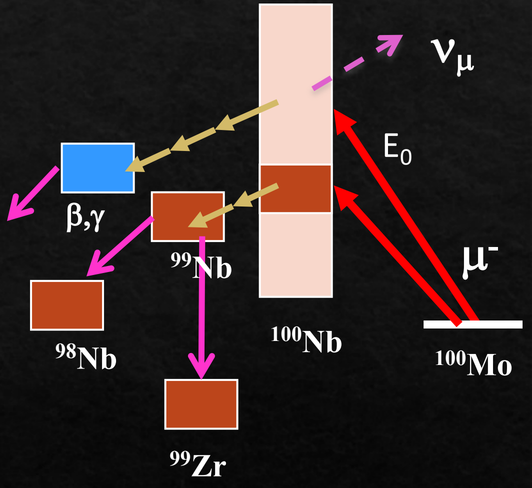
$$\lambda_T = 1/\tau = \lambda_C + H\lambda_{free}$$

Exp. data give the gamma emission spectrum from bound states. Obtain the partial capture rates and calculate the total capture rate for improvise the g_A and g_p parameter from pn-QRPA calculation. (Daniya's talk)

2.0 Proton and neutron emission model

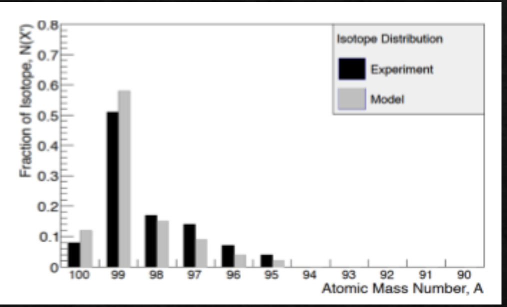
Reproduces the Ris production rate distribution

- Adjust the PEQ and EQ neutron emission process
- Adjust the probability of neutron and proton emission
- Provides μ capture strength ^{100}Nb after muon capture

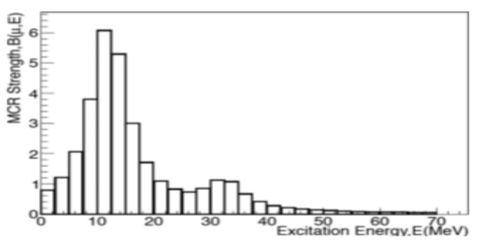


compare

Output 1: RI Production Rates



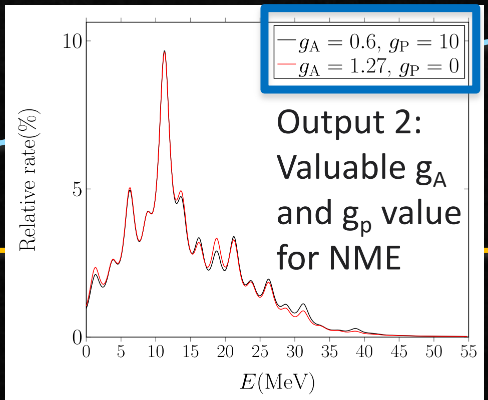
Output 2: Muon Capture Strength



Absolute capture strength

compare

Output 1: Muon Capture Strength



Output 2: Valuable g_A and g_p value for NME

3.0 pn-QRPA calculation

Reproduces the μ capture strength from experiment using pn-QRPA.

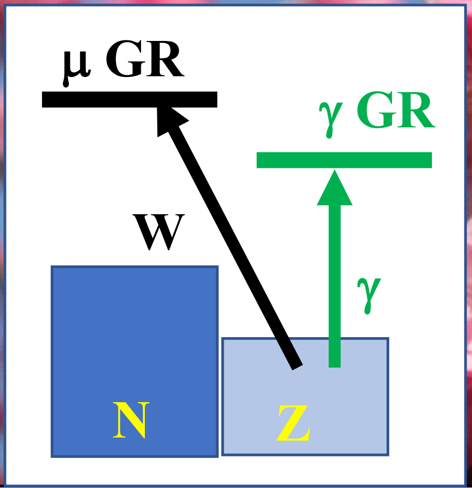
- Adjust the pn-QRPA with g_A , g_p and g_A/g_p ratio can reproduce the μ capture strength.

Repeat experiment with other nuclei to understand the effect of

1. GR peak in μ capture strength,
2. g_A and g_p parameter on nuclear structure.

Nuclear matrix element (NME) for DBD

Muon Capture Isotope Detection/Production (MuCID) - *J. Phys. Soc. Japan, 82 (2013) 044202*

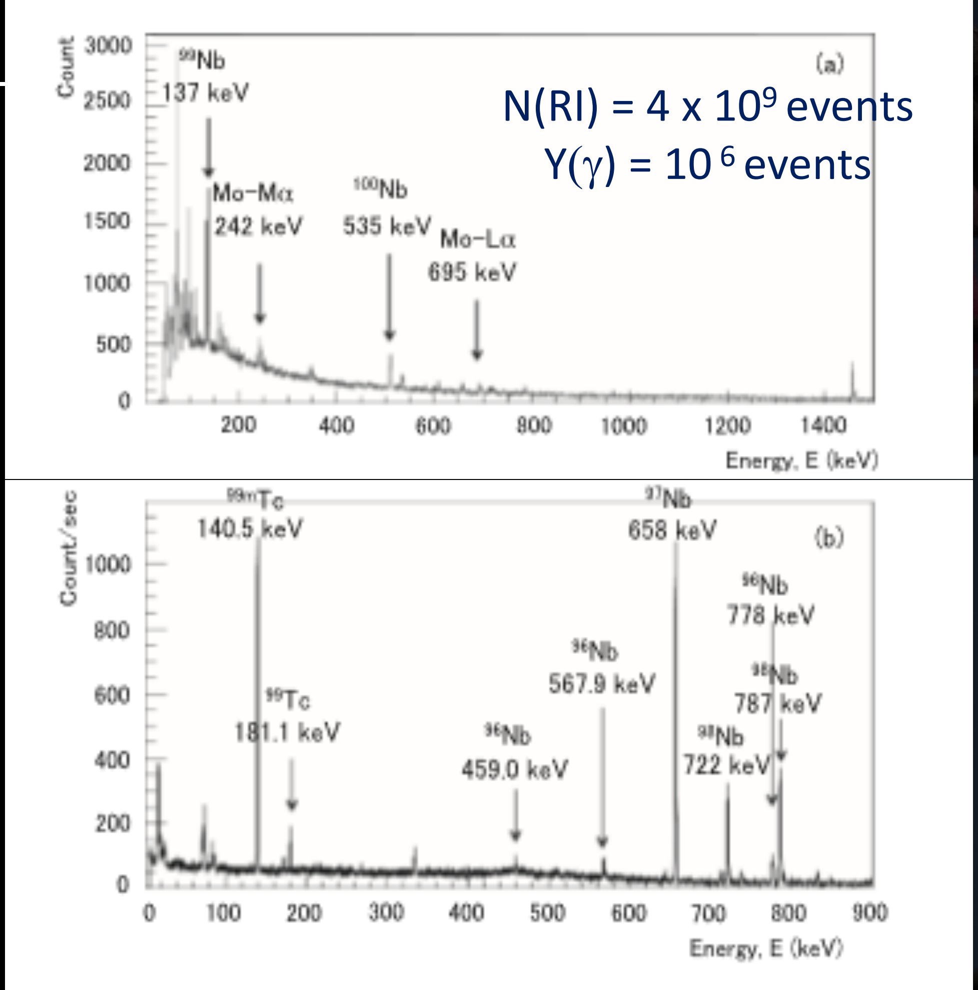


- MuCID/MuCIP is a reliable method in producing radioisotopes (RIs) with X_{Z-1}^{A-x} where x = 0,1,2…5 especially for environmental and biomedical applications.
- Other method using (n,γ) and (γ,n) reactions are complimentary methods.

Isotope	μ reaction	RI (half life)	Comments on (γ, n)
^{54}Fe	(μ, 2n)	^{52}Mn (5.59 d)	^{53}Fe: short life
^{56}Fe	(μ, 0n)	^{56}Mn (2.58 h)	^{55}Fe: no γ
^{65}Cu	(μ, 0n)	^{65}Ni (2.5h)	^{64}Cu: 12.7 h
^{90}Zr	(μ, 0n)	^{90}Y (64.1 h)	^{89}Zr: 78.4 h
^{92}Zr	(μ, 0n)	^{92}Y (3.54 h)	^{91}Zr: stable
^{99}Tc	(μ, 0n)	^{99}Mo (65.9 h)	^{98}Tc: long life
^{109}Ag	(μ, 0n)	^{109}Pd (13.7 h)	^{108}Ag: short/ long life
^{128}Te	(μ, 1n)	^{127}Sb (3.85 d)	^{127}Te: 9.4 h, 109 d
^{187}Re	(μ, 0n)	^{187}W (23.7 h)	^{186}Re: 90.6 h
^{197}Au	(μ, 0n)	^{197}Pt (18.3 h)	^{196}Au: 6.18 d
^{233}U	(μ, 0n)	^{233}Pa (27.0 d)	^{232}U: long life
^{235}U	(μ, 1n)	^{234}Pa (6.7 h)	^{234}U: long life
^{239}Pu	(μ, 0n)	^{239}Np (2.36 d)	^{238}Pu: long life
^{240}Pu	(μ, 0n)	^{240}Np (1.03 h)	^{239}Pu: long life

1. H. Ejiri, I. H. Hashim, et al. J. Phys. Soc. Japan, 82 (2013) 044202.
2. I.H. Hashim, H. Ejiri, AAPPS 63ed. (2019) June

Muon capture for neutrino nuclear and astro-ν response
- *PRC 97 (2018) 014617*



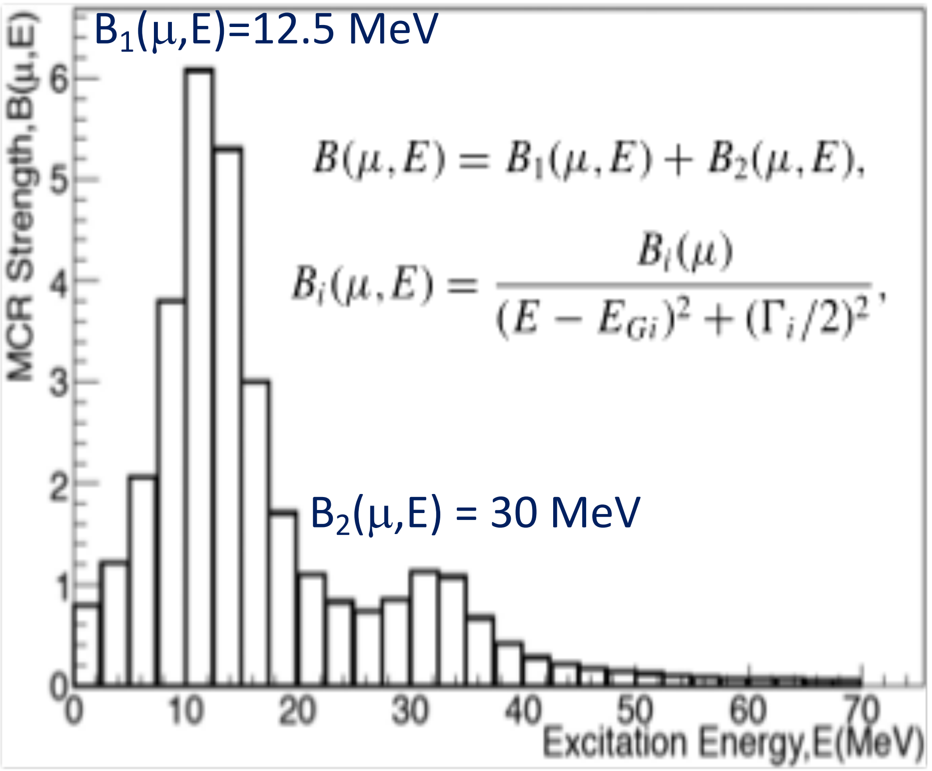
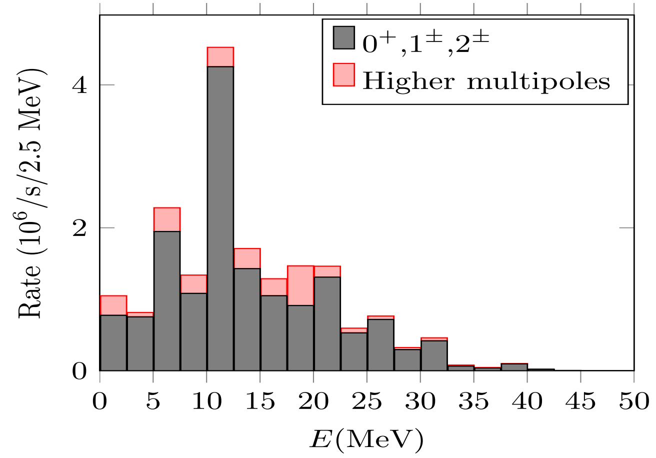
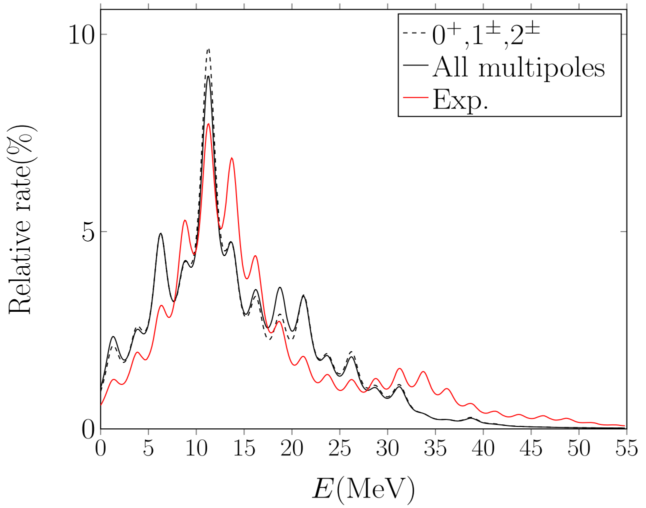


FIG. 6. The OMC strength distribution suggested from the experimental RI distribution. E_{G1} and E_{G2} are the OMC GRs at around 12 MeV and 30 MeV.

Pinning down the strength function for ordinary muon capture on ^{100}Mo

- *Physics Letters B 794 (2019) 143–147*





Approximately 80 − 90% of the total capture rate consists of transitions to the lowest multi- poles, and the rest 10 − 20% comes from the transitions to higher multipoles.

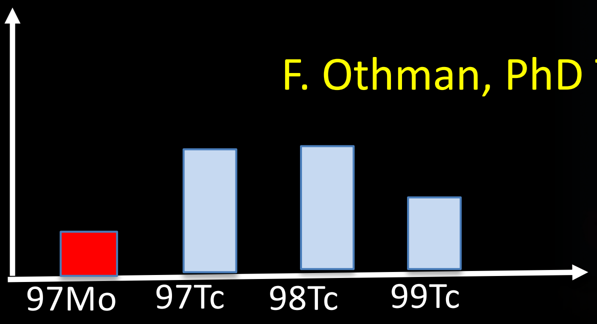
There is a strong peak, GR1, around 10 − 12.5 MeV and tails on both sides, but experimentally we observed the evidence of GR2 around 30 MeV.

Exp. summed strength and NME $S(\mu) = \int B(\mu,E)\, dE = 0.146 \pm 0.03$, thus $M(\mu) = S(\mu)^{1/2} = 0.38 \pm 0.04$.

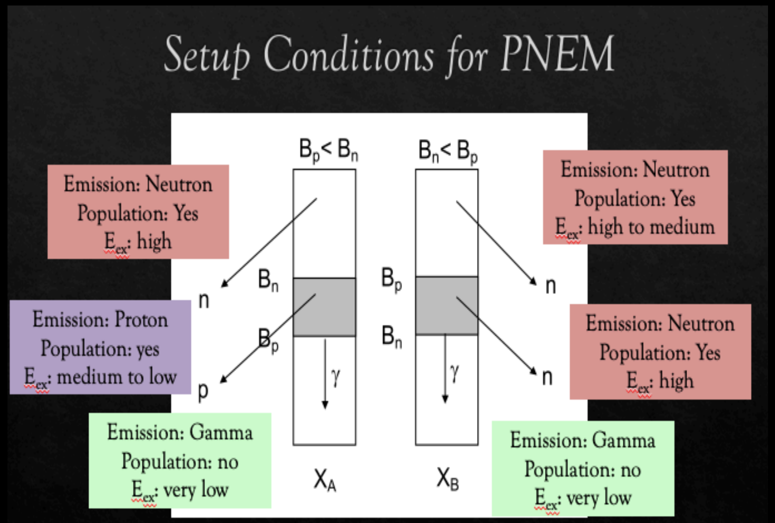
The Primakoff's value is smaller than the theoretical rates, thus L. Jokiniemi $S(\mu)$ suggests a quenched $g_A^{eff} \sim 0.5$
taking μ-renormalization, $k_{NM} = g_A^{eff} / g_A \sim 0.4$)

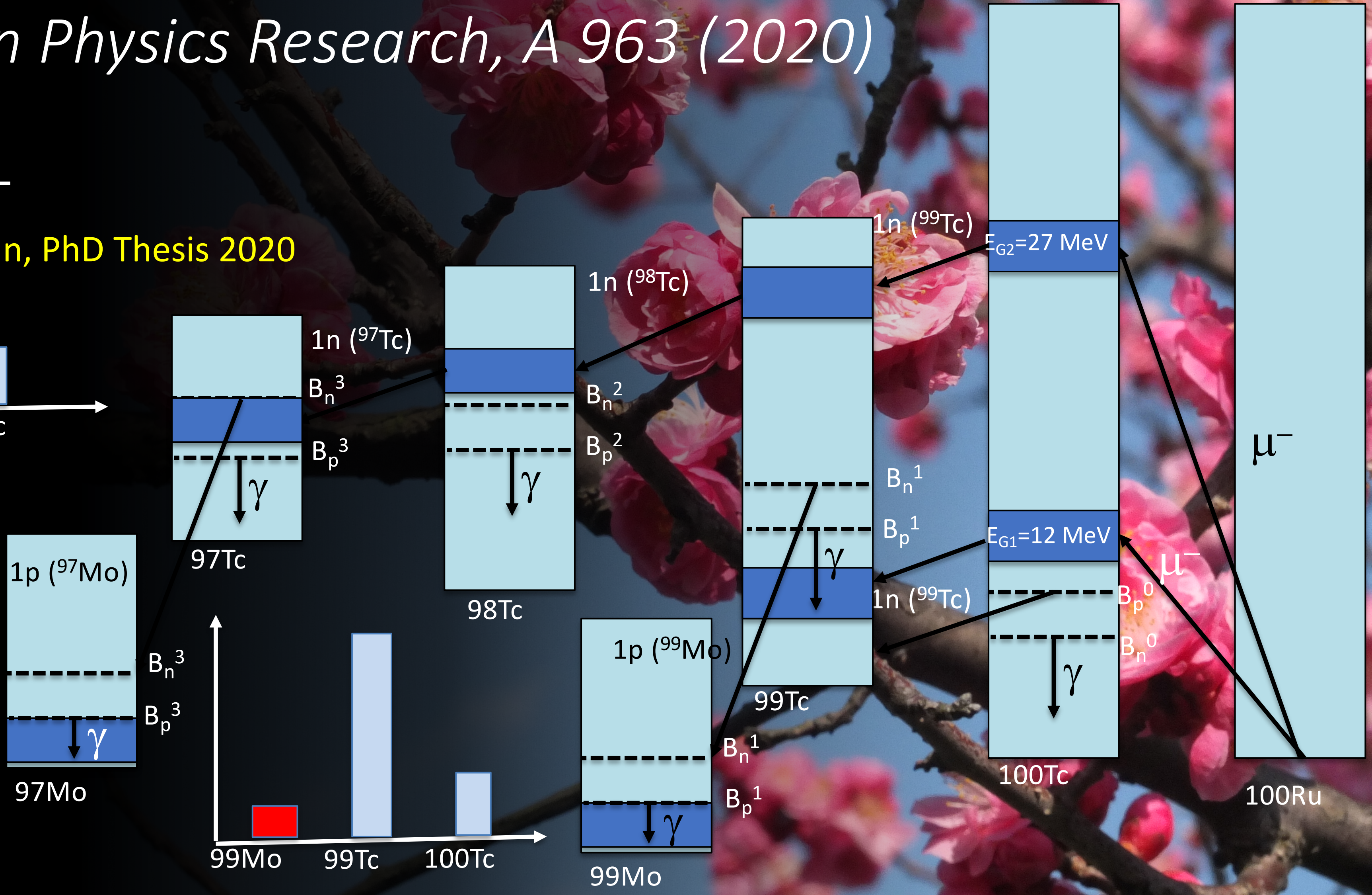
L. Jokiniemi, J. Suhonen, H.Ejiri, I.H. Hashim, F.Othman, Private comm, Muon Workshop 2018.

Proton Neutron Emission Model Calculation - *INuclear Inst. and Methods in Physics Research, A 963 (2020) 163749*

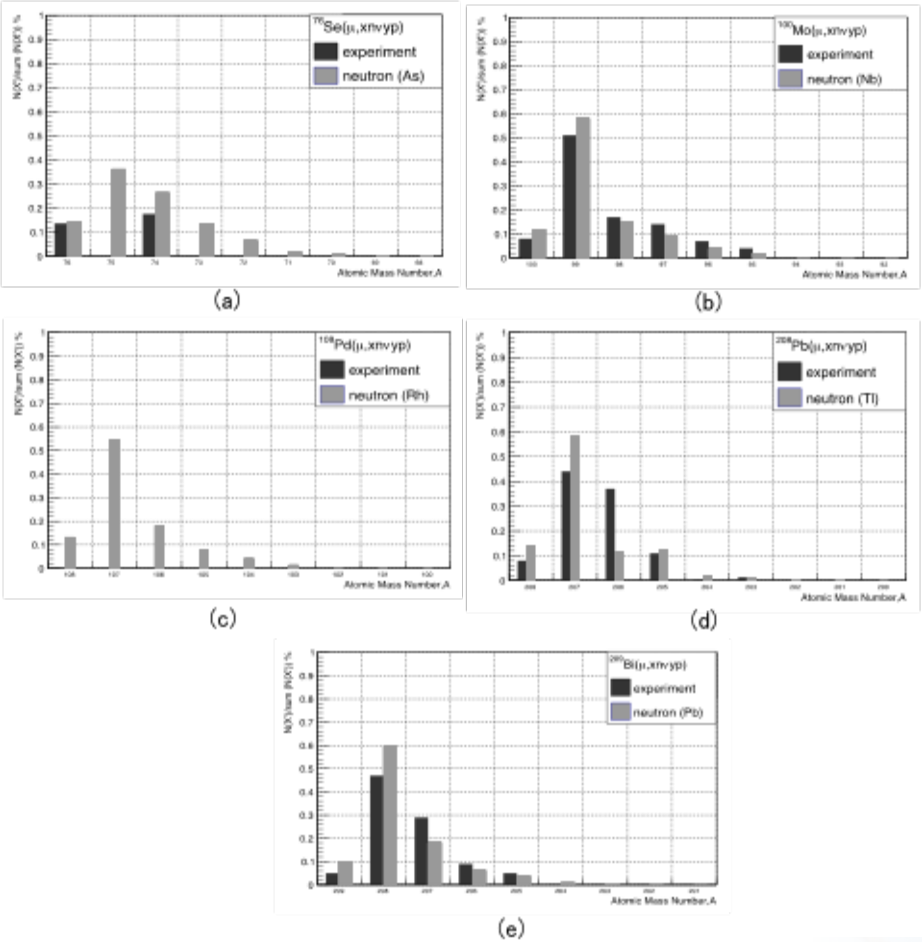


F. Othman, PhD Thesis 2020

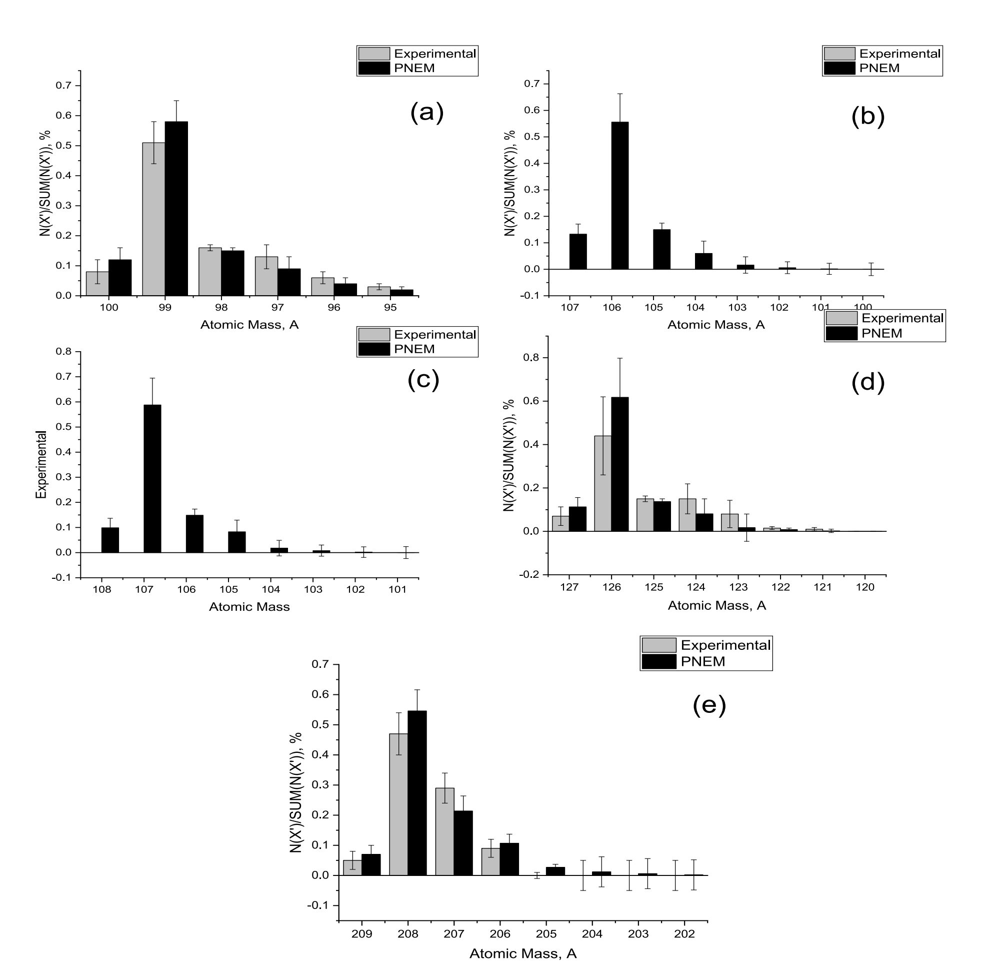




NEM vs PNEM calculation



Neutron emission model (NEM) 2014



Proton neutron emission model (PNEM) 2020

The μ-GR around 12-14 MeV was found for nuclei with 100<A<209.

The OMC rate = 6.7 $\pm$ 1.3x10^6/sec.

Relationship between GR peak energy with A

$$E_{G1} = 30\ A^{-1/5}$$

$$E_{G2} = 75\ A^{-1/5}$$

I.H.Hashim, PhD Thesis 2014

Remarks and conclusion

- OMC is a lepton-sector charge exchange reaction via the weak boson and is shown to be used for the study neutrino nuclear responses that are relevant to 0νββ and astro-neutrino reactions.
- OMC is crucial method for RIs detection and production suitable for biomedical and environmental applications.
- The joint program so far have study several nuclei including Mo, Se, Mg, Kr and Xe.
  - Experimental analysis @RCNP and final checking have been done for publication purposes.
  - Experimental analysis @PSI is under progress.
  - Further comparison with pn-QRPA calculation to obtain the g_A and g_A^{eff} for the anti-neutrino sector.