UTM-RCNP-JINR Joint collaboration

Muon capture in $^{100}Mo/^{nat}Mo$ and ^{100}Ru at MUSIC (RCNP, Osaka)

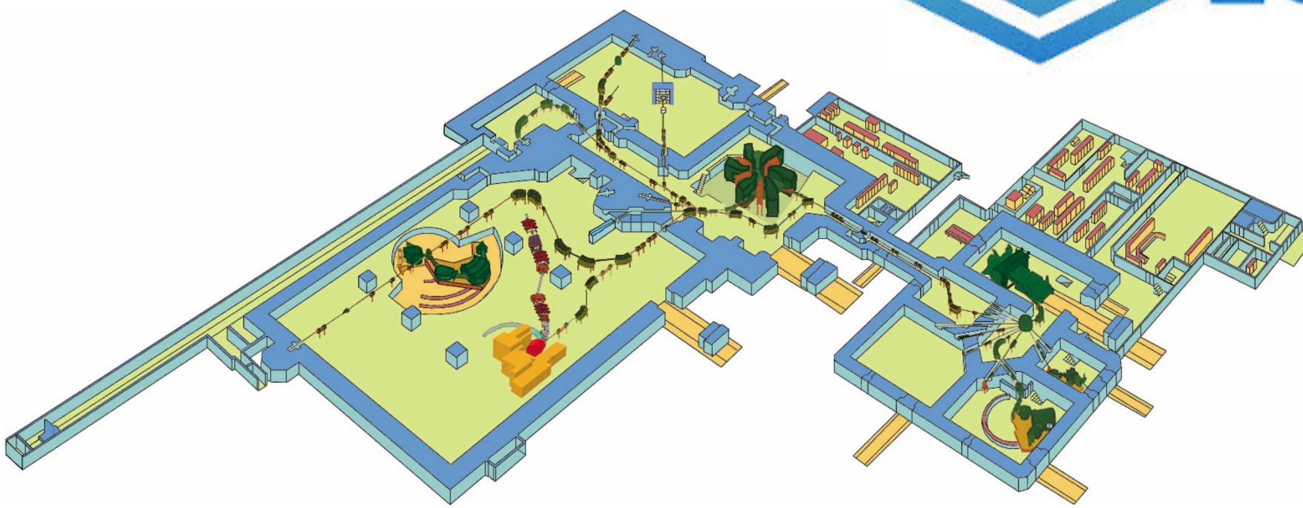
Spokespersons:

Izyan Hazwani Hashim (UTM), Hiroyasu Ejiri (RCNP) and Daniya Zinatulina (JINR)

(On behalf of collaboration)

MEDEX'19

RCNP and E489 experiment

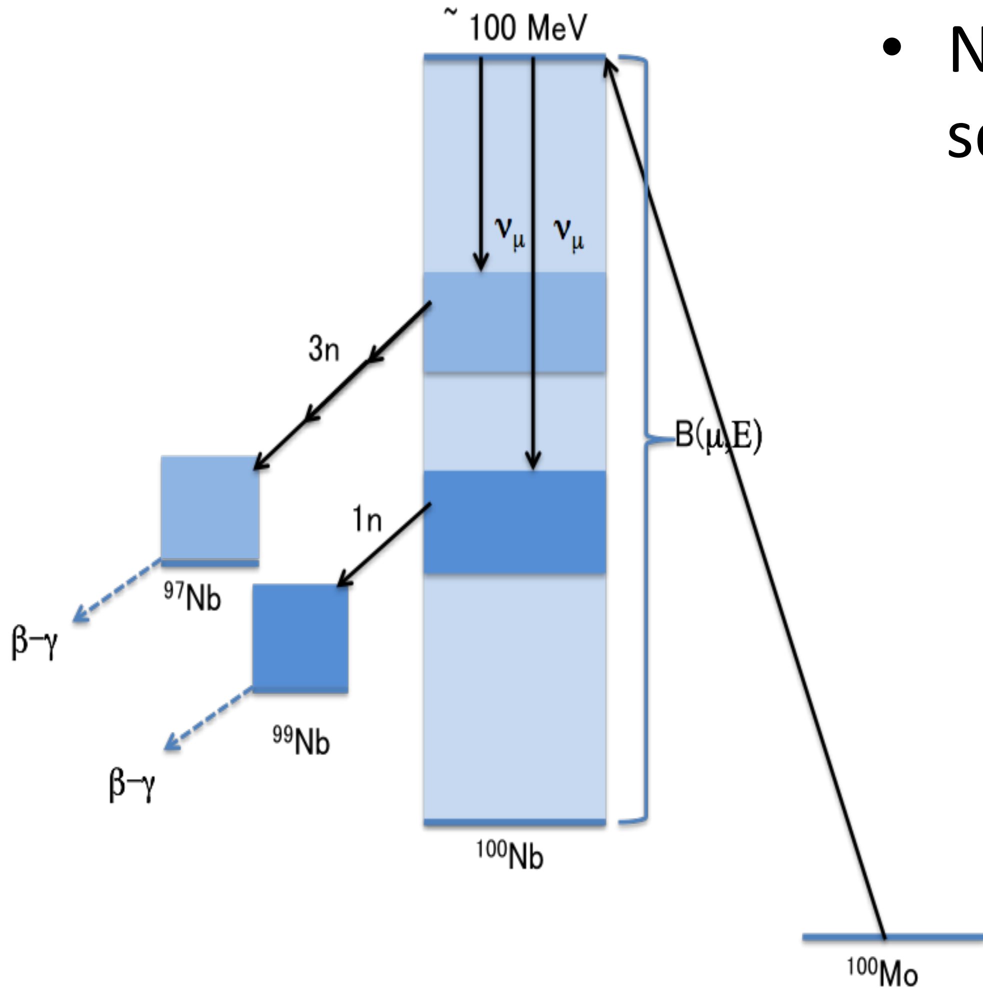


BEAM LINE: MuSIC

BEAM REQUIREMENTS:

Type of particle	proton
Beam energy	400 MeV
Beam intensity	1 μA
Type of particle	muon
Muon momentum	50 MeV/c
Beam intensity	1 μA

Neutrino Nuclear Response

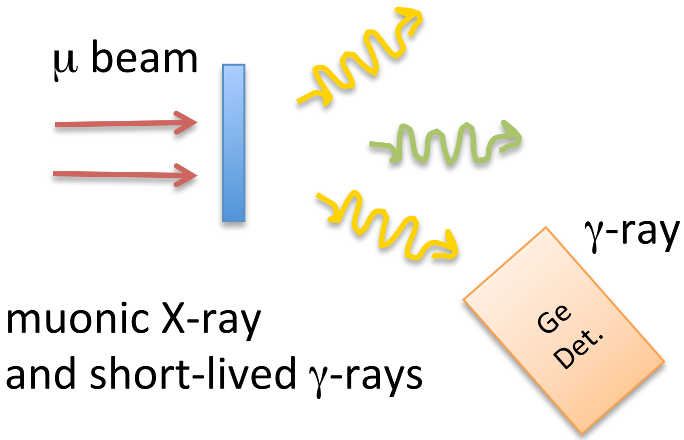


- Neutrino nuclear response is the square of NME of DBD.
  - Effective ν mass can be extracted from the DBD rate and DBD NME.
  - Understanding the nuclear structure information is important to reveal the quenching effect in $M_{0\nu}$.
  - The strength functions B(μ,E) are very sensitive to nucleonic and non-nucleonic correlations.

Experimental data on single beta and muon rates are important to help calculations of DBD NMEs.

Overview of the method

Irradiation of target



Measurement of delayed γ-rays

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

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

Exp. data give the dist. of isotope mass population of the final nuclei after neutron emission.

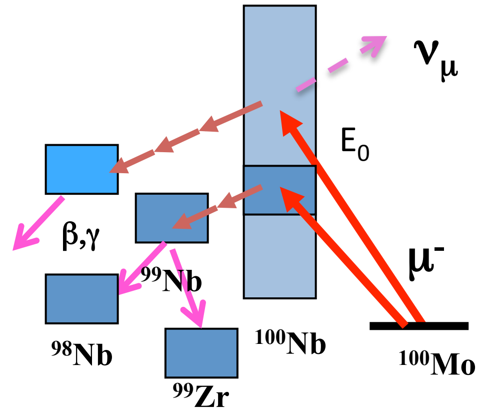
Muon capture reaction

Weak/ neutrino nuclear response

compare

Calculation by proton and neutron emission model

Provides initial capture strength ^{100}Nb after muon capture



Distribution of initial strength can provide the final nuclei isotope population

Relative capture strength

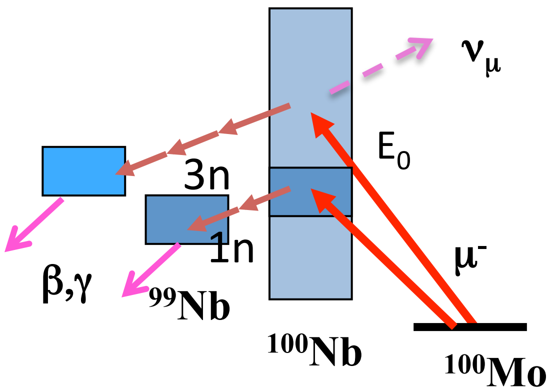
- Provide μ capture rate
- If pnQRPA with g_A can reproduce the μ capture rate or they need to adjust g_A.

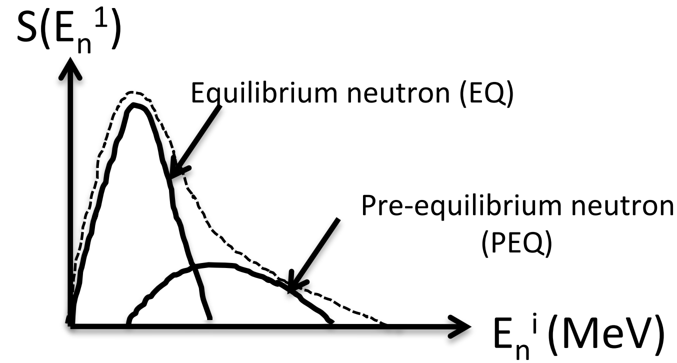
Absolute capture strength

Nuclear matrix element, NME for DBD

- Used adjusted g_A to calculate DBD NME

PRC 97(2018) 014617 (J-PARC 2014)

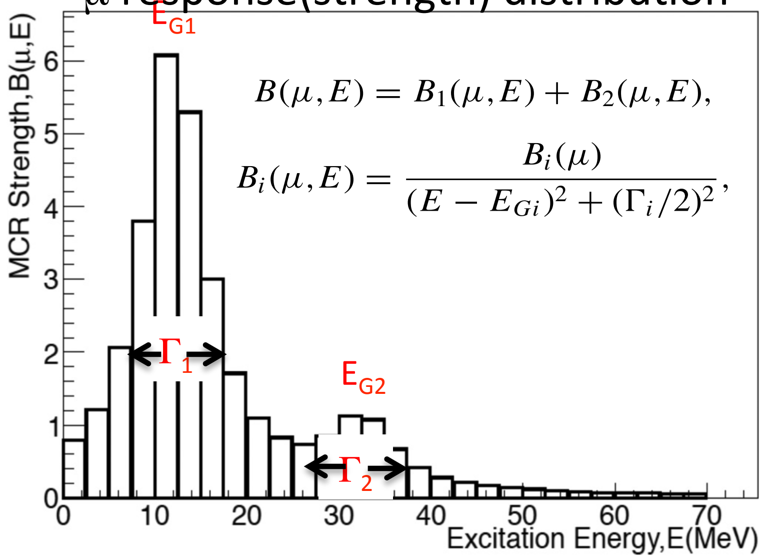




$$S(E_n^1) = k\left[E_n^1 exp\left(-\frac{E_n^1}{T_{\rm EQ}(E)}\right) + pE_n^1 exp\left(-\frac{E_n^1}{T_{\rm PEQ}(E)}\right)\right]$$

{EQ} {PEQ}

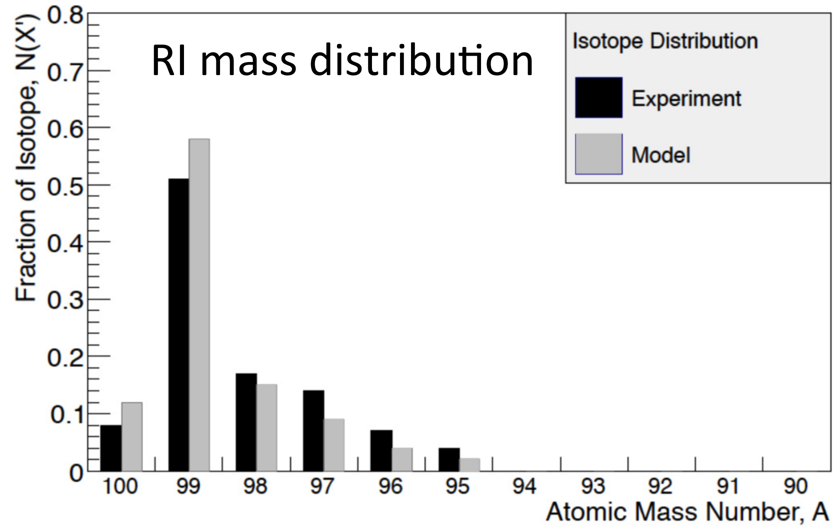
μ response(strength) distribution



$$B(\mu, E) = B_1(\mu, E) + B_2(\mu, E),$$

$$B_i(\mu, E) = \frac{B_i(\mu)}{(E - E_{Gi})^2 + (\Gamma_i/2)^2},$$

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.



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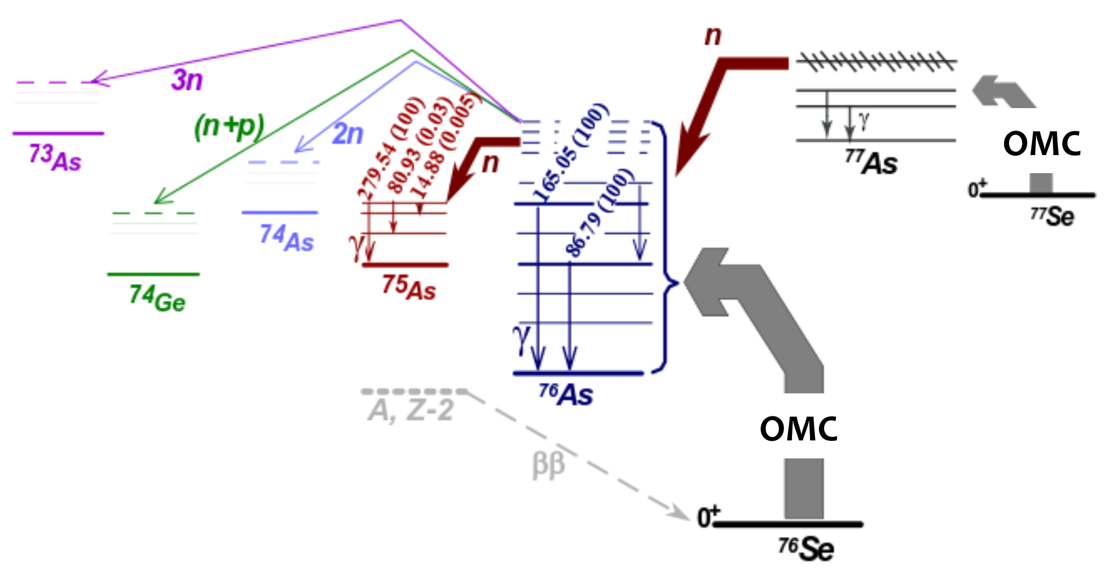
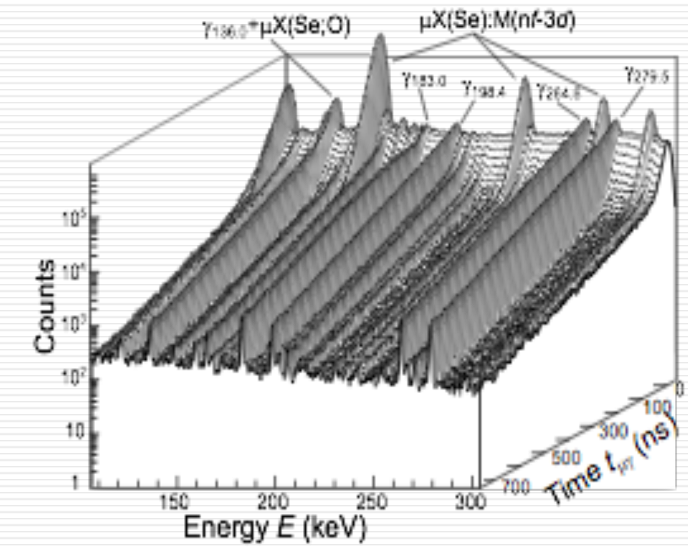
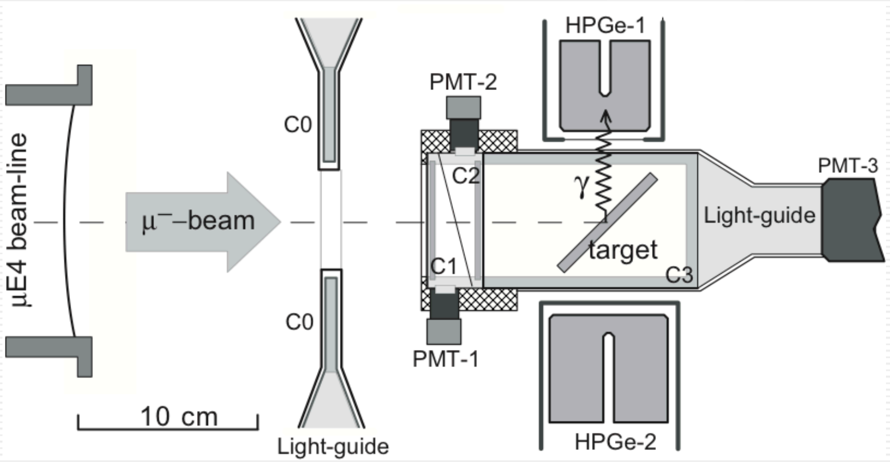
Ordinary Muon Capture (OMC)

$$(A, Z) + \mu^- \rightarrow (A, Z\text{-}1)^* + \nu_\mu$$

$$\rightarrow (A, Z\text{-}1) + \gamma + (0n, 1n, 2n, n\text{+}p, 3n\ldots) \qquad m_\mu \sim 105\ \text{MeV}$$



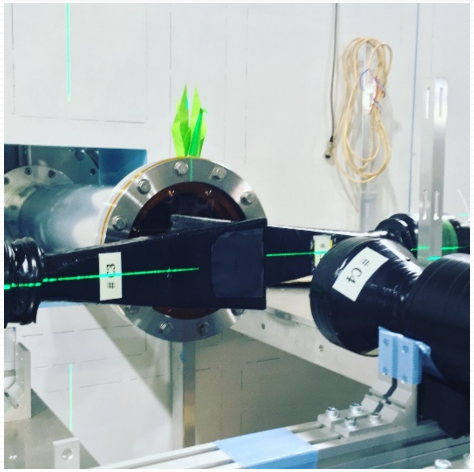


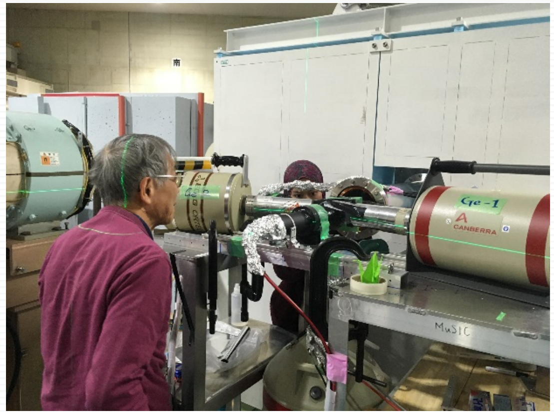


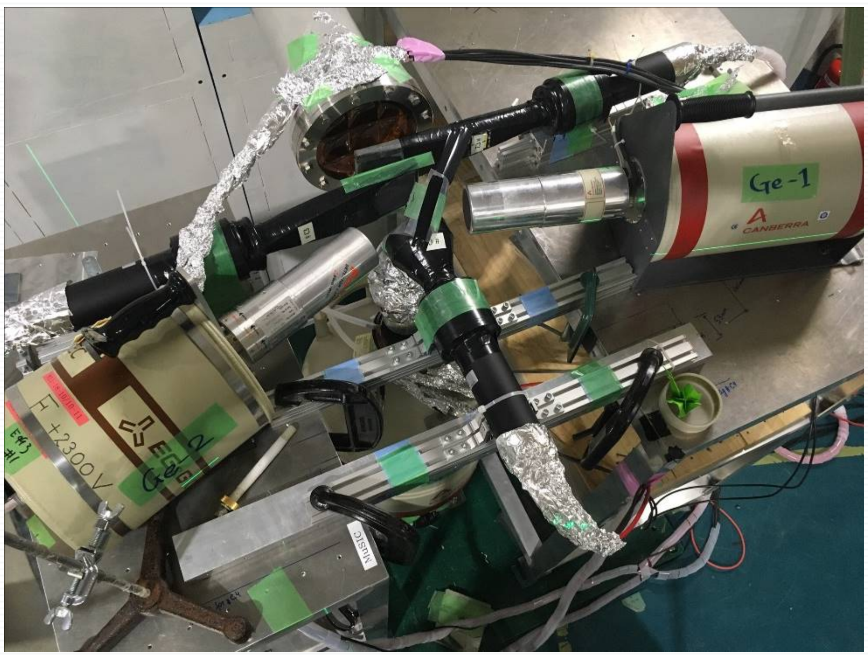
- Set-up adapted to solid and gaseous targets
- (E,t) distribution following OMC in targets
- Yields of short-lived RI during exposure

- PhD thesis of D.Zinatulina (June,2019)
- **PRC 99** (2019) **024327**

E489 experiment (February 2018 y)



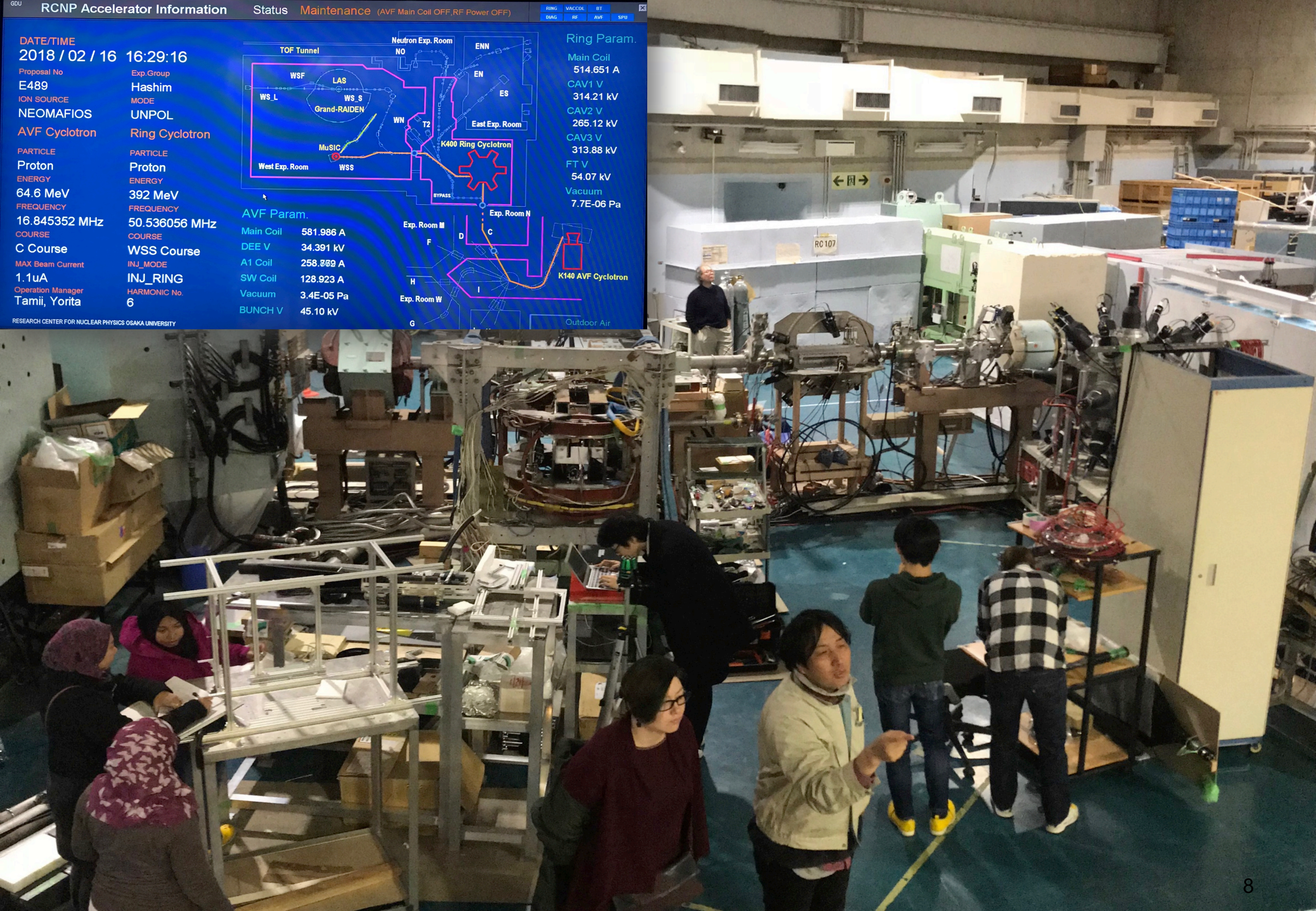




E489 collaboration:

I.H. Hashim [1], D .Zinatulina[3],
H. Ejiri[2], A.Sato[2], M. Shirchenko[3], S.A.Hamzah[1],
F.Othman[2], K.Ninomiya[2], T.Shima[2], K. Takahisa[2],
D.Tomono[2], Y.Kawashima[2] and V. Egorov[3]

[1] Universiti Teknologi Malaysia, Malaysia
[2] Research Center for Nuclear Problems, Osaka University, Osaka, Japan
[3] Joint Institute for Nuclear Research, Russia, Dubna


GDU
RCNP Accelerator Information
Status
Maintenance (AVF Main Coil OFF,RF Power OFF)
RING VACCOL BT
DIAG RF AVF SPU
DATE/TIME
2018 / 02 / 16 16:29:16
Proposal No
E489
Exp.Group
Hashim
ION SOURCE
NEOMAFIOS
MODE
UNPOL
AVF Cyclotron
Ring Cyclotron
PARTICLE
Proton
PARTICLE
Proton
ENERGY
64.6 MeV
ENERGY
392 MeV
FREQUENCY
16.845352 MHz
FREQUENCY
50.536056 MHz
COURSE
C Course
COURSE
WSS Course
MAX Beam Current
1.1uA
INJ_MODE
INJ_RING
Operation Manager
Tamii, Yorita
HARMONIC No.
6
RESEARCH CENTER FOR NUCLEAR PHYSICS OSAKA UNIVERSITY
TOF Tunnel
Neutron Exp. Room
NO
ENN
EN
ES
WSF
LAS
WS_L
WS_S
Grand-RAIDEN
WN
T2
East Exp. Room
K400 Ring Cyclotron
MuSIC
West Exp. Room
WSS
BYPASS
Exp. Room N
Exp. Room M
D
C
F
H
I
Exp. Room W
G
K140 AVF Cyclotron
Outdoor Air
AVF Param.
Main Coil 581.986 A
DEE V 34.391 kV
A1 Coil
SW Coil 128.923 A
Vacuum 3.4E-05 Pa
BUNCH V 45.10 kV
Ring Param.
Main Coil
514.651 A
CAV1 V
314.21 kV
CAV2 V
265.12 kV
CAV3 V
313.88 kV
FT V
54.07 kV
Vacuum
7.7E-06 Pa
RC107

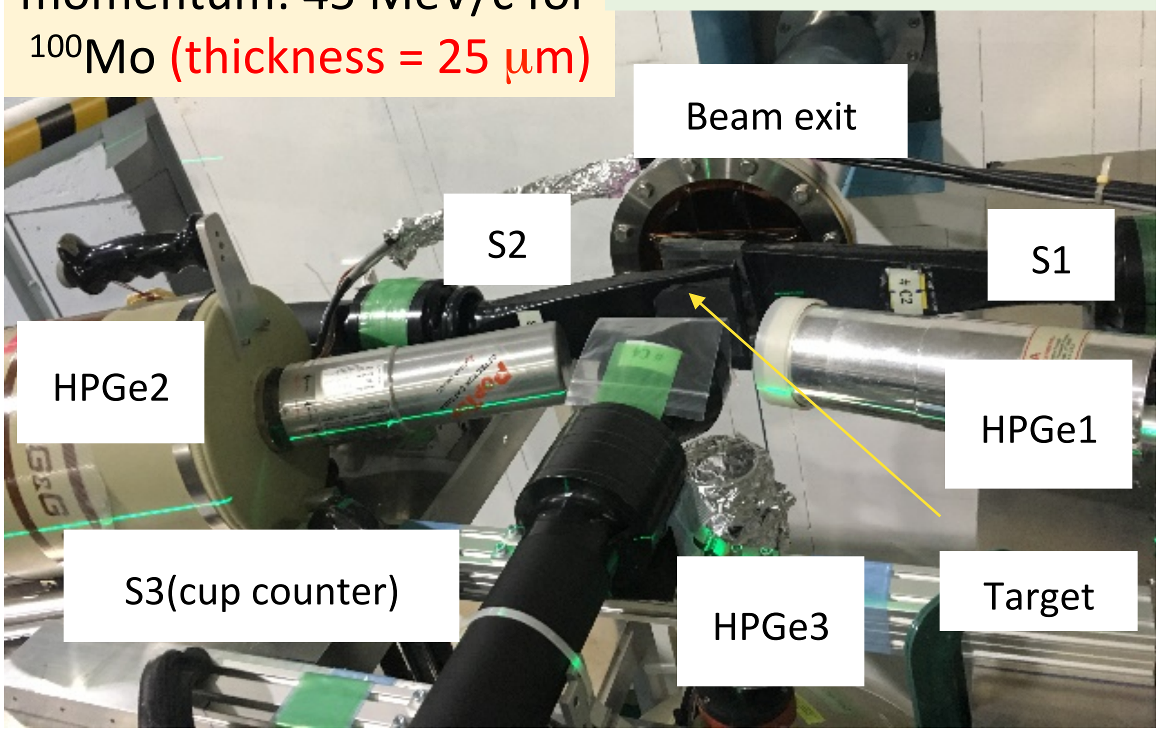
Long-term preparations and tricks for the muon beam-time

First Joint Program

- Officially established in September 2018.
- E489 Beamtime at Osaka University (Feb 2018).

Negative muon momentum: 45 MeV/c for ^{100}Mo (thickness = 25 μm)

Irradiation time:
100Mo (15hours)

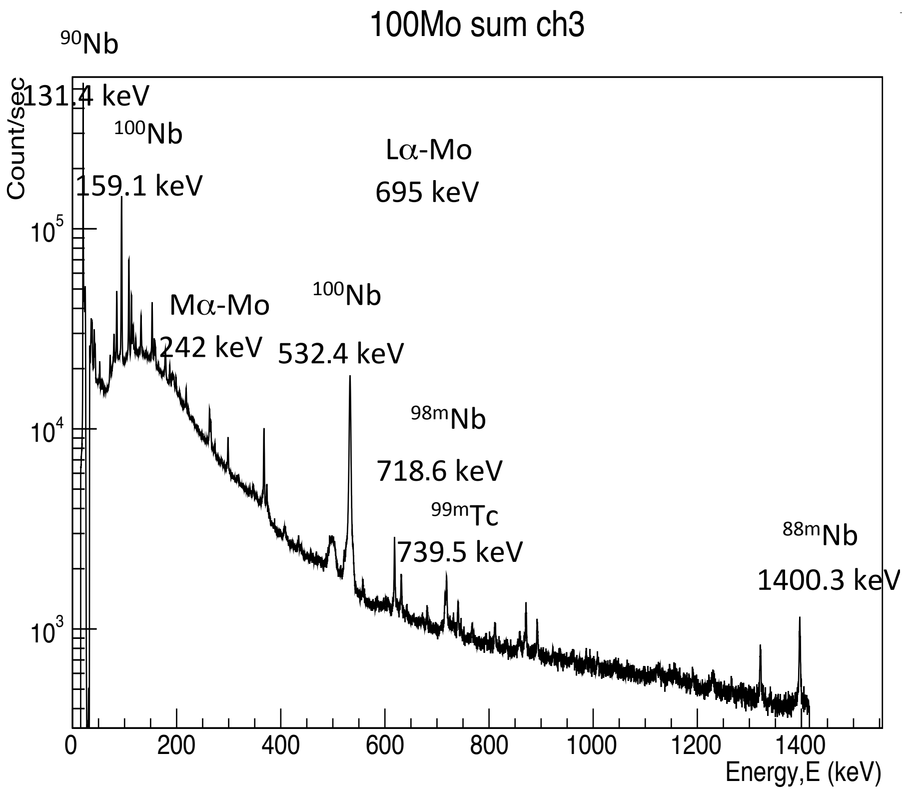


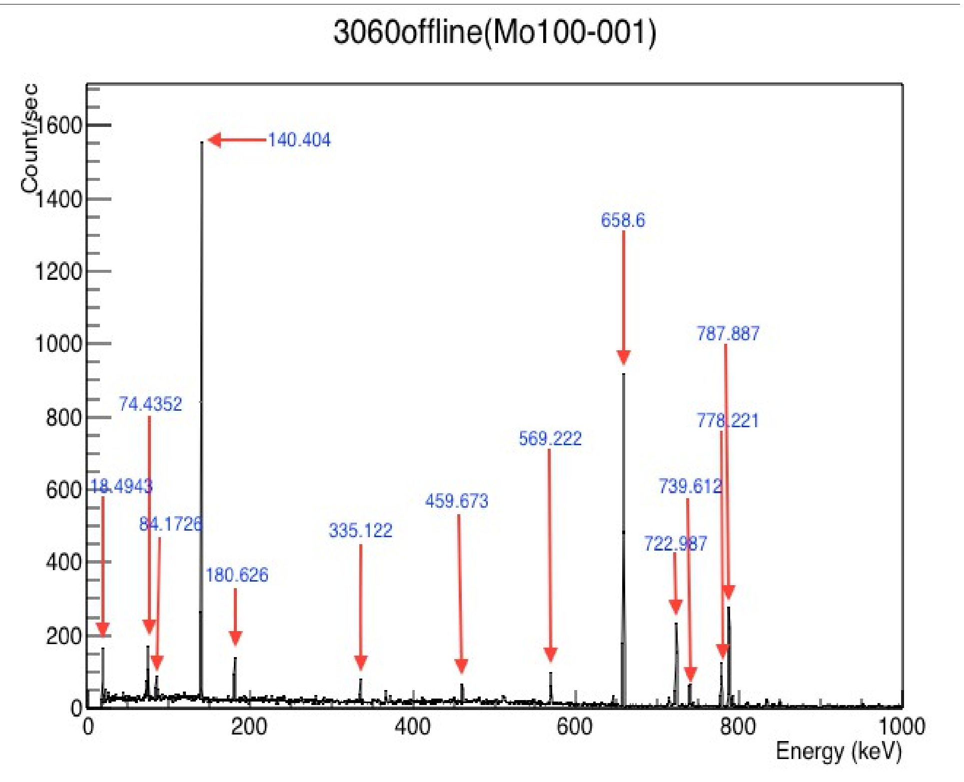
3 trigger counters with (S1•S2×S3)logic
To observe muon stopping event

HPGe
To measure x-ray and gamma ray

^{100}Mo (thin films)	**Natural Ruthenium**
Natural Molybdenum	Natural Selenium

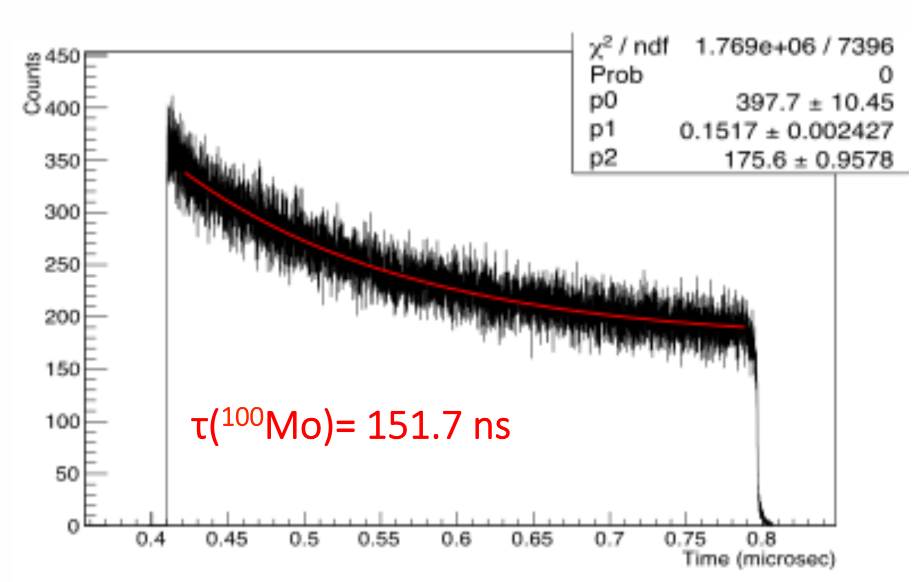
Preliminary results of the on-line E489 measurement

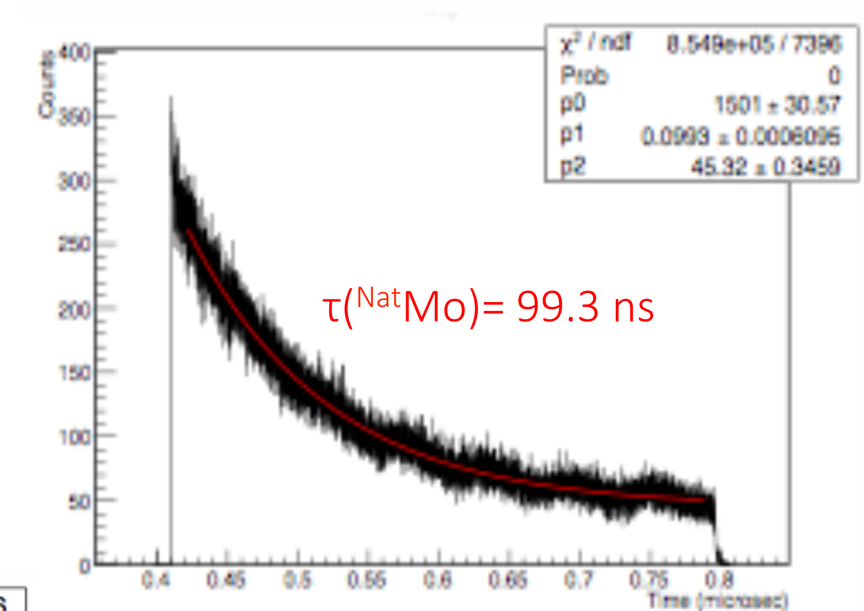


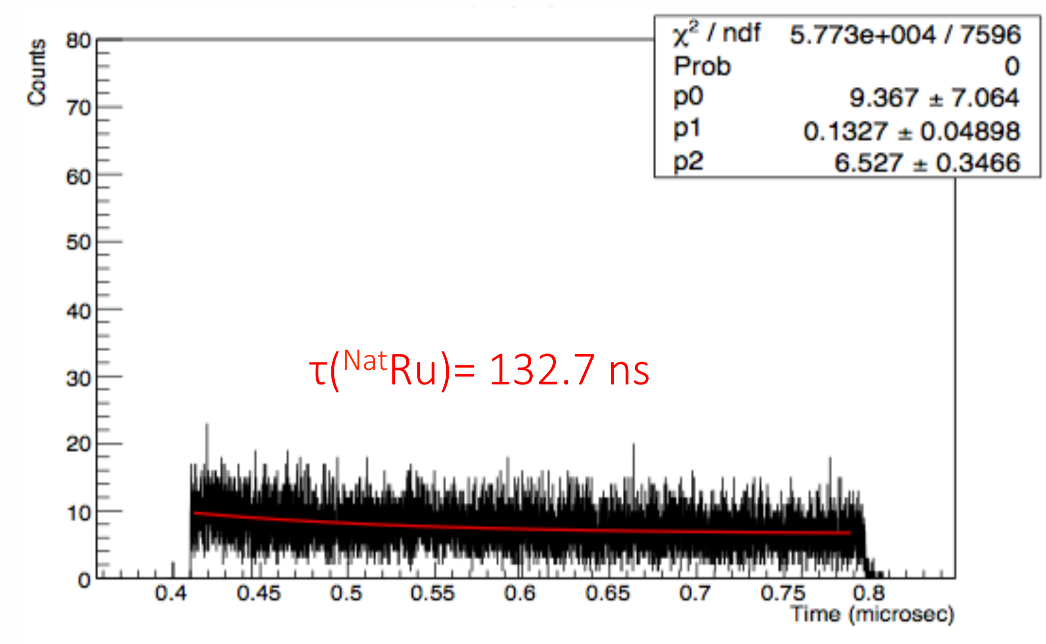


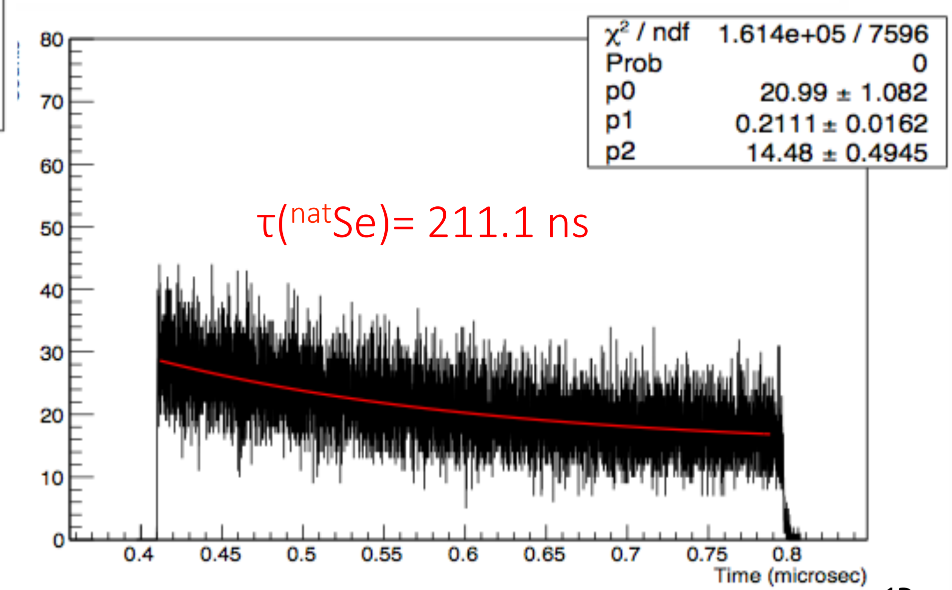
The analyses are under progress

Time distribution of μ-decay electrones







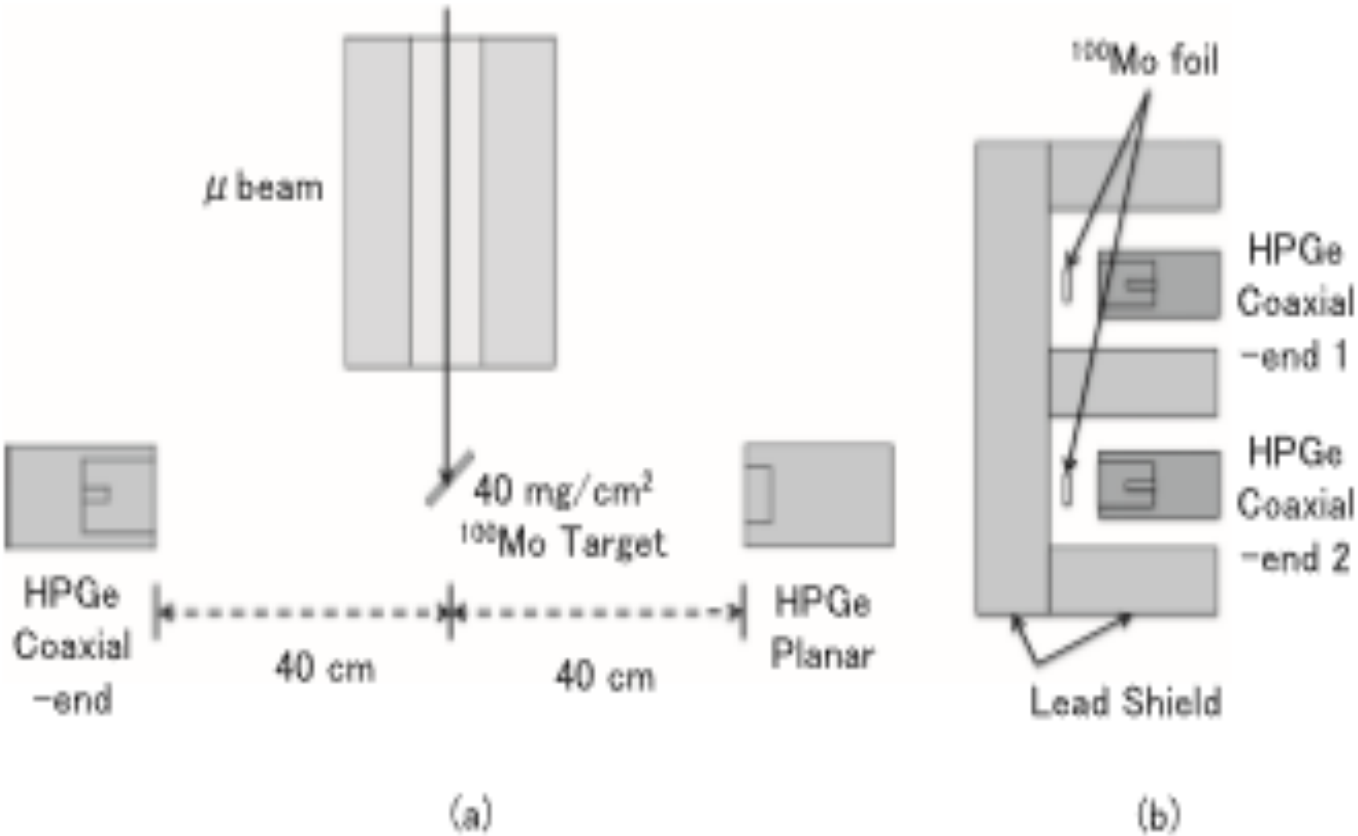


Present absolute lifetime measurement

Isotope, A	Present work	Previous experimental work	Calculation [Primakoff 1959]
^{100}Mo	**151.7(24) ns**	N/A	130 ns
^{Nat}Mo	**99.3(61) ns**	105 ns [Suzuki 1987]	114 ns
^{Nat}Ru	**132.7(49) ns**	N/A	109 ns
^{Nat}Se	**211.1(16) ns**	208.2(68) ns [PRC99(2019)024327]	239 ns

- Comparison of present mean life, previous experimental work (Suzuki & Zinatulina) life time, and Primakoff mean life.

Muon Irradiation @ J-PARC Experiment



(a) Online setup for the γ rays with half-lived 0 to 1.5 hours.

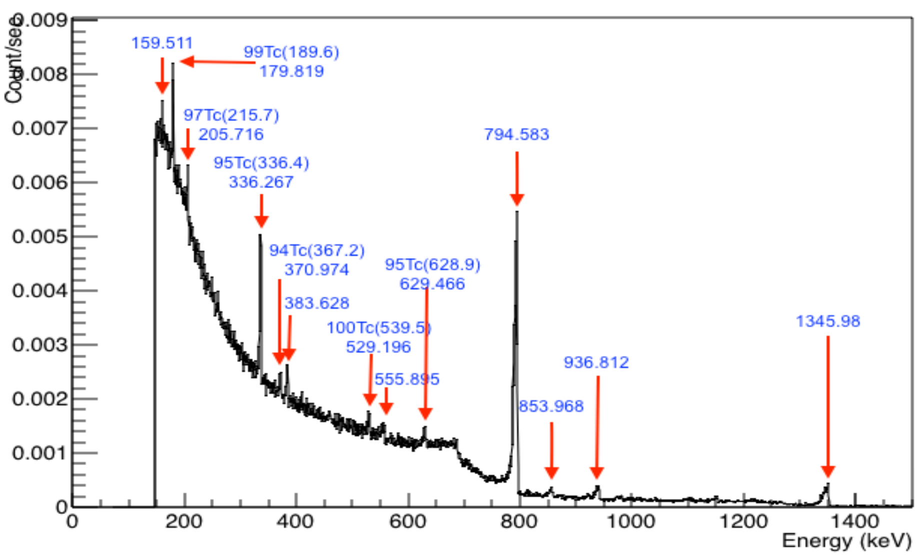
(b) Off-line setup for the delayed γ rays with half-lived 0.5 hours onwards.

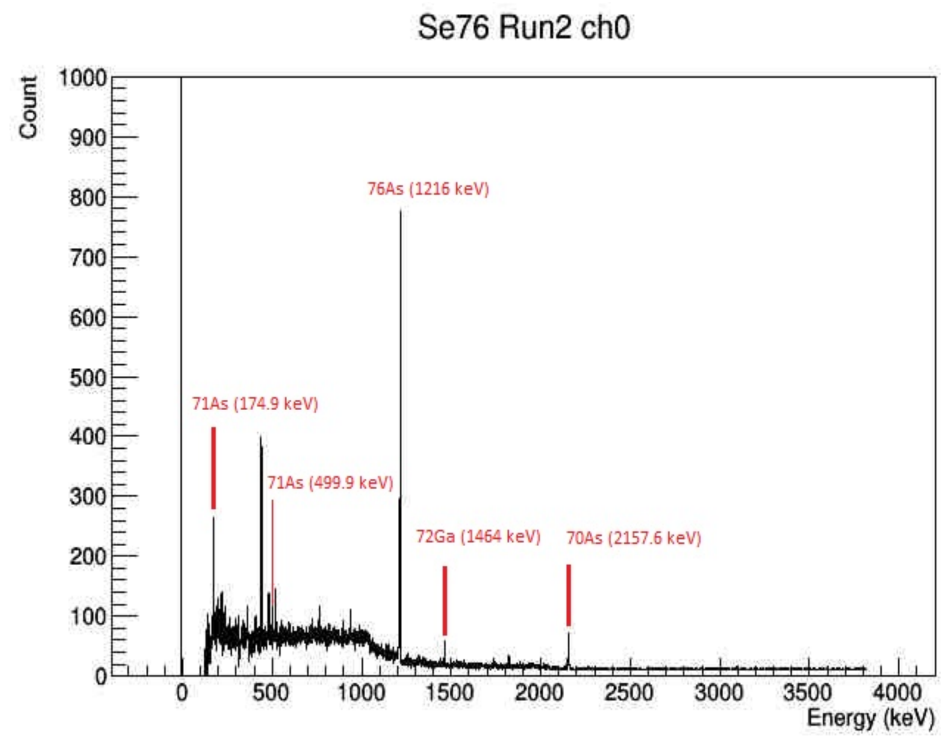
I. H. Hashim PhD Thesis Osaka 2015I.
I. H. Hashim H. Ejiri , 2015. MXG16,
I. H. Hashim H. Ejiri , et al PR C 97 2018

RI distribution by prompt and delayed γ-rays (under progress)

- To determine the partial capture rates from prompt gamma.
- To evaluate GR peaks from proton and neutron emission model by comparison of short lived and long-lived RI gamma rays.

^{nat}Ru (off-line)





Summary:

- Experimental studies of OMCs absolute lifetime on some $0\nu\beta\beta$ nuclei have been done at RCNP 2018 and the analysis is still on going.

- Neutron emission from OMC on enriched nuclei gives almost 90-95% RI production rate;

- All information of OMC is very useful for the β^+ side of DBD NME's and astro-antineutrino investigations.

➢ Approved beam-time for next solid targets **^{136}Ba/^{nat}Ba** и **^{76}Se/^{nat}Se** (1 week, RCNP, 2020 y).

➢ Gas targets ^{130}Xe and ^{82}Kr will be investigated with μX group at PSI (Villigen, Switzerland, October 2019)

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Thank you for your attention!

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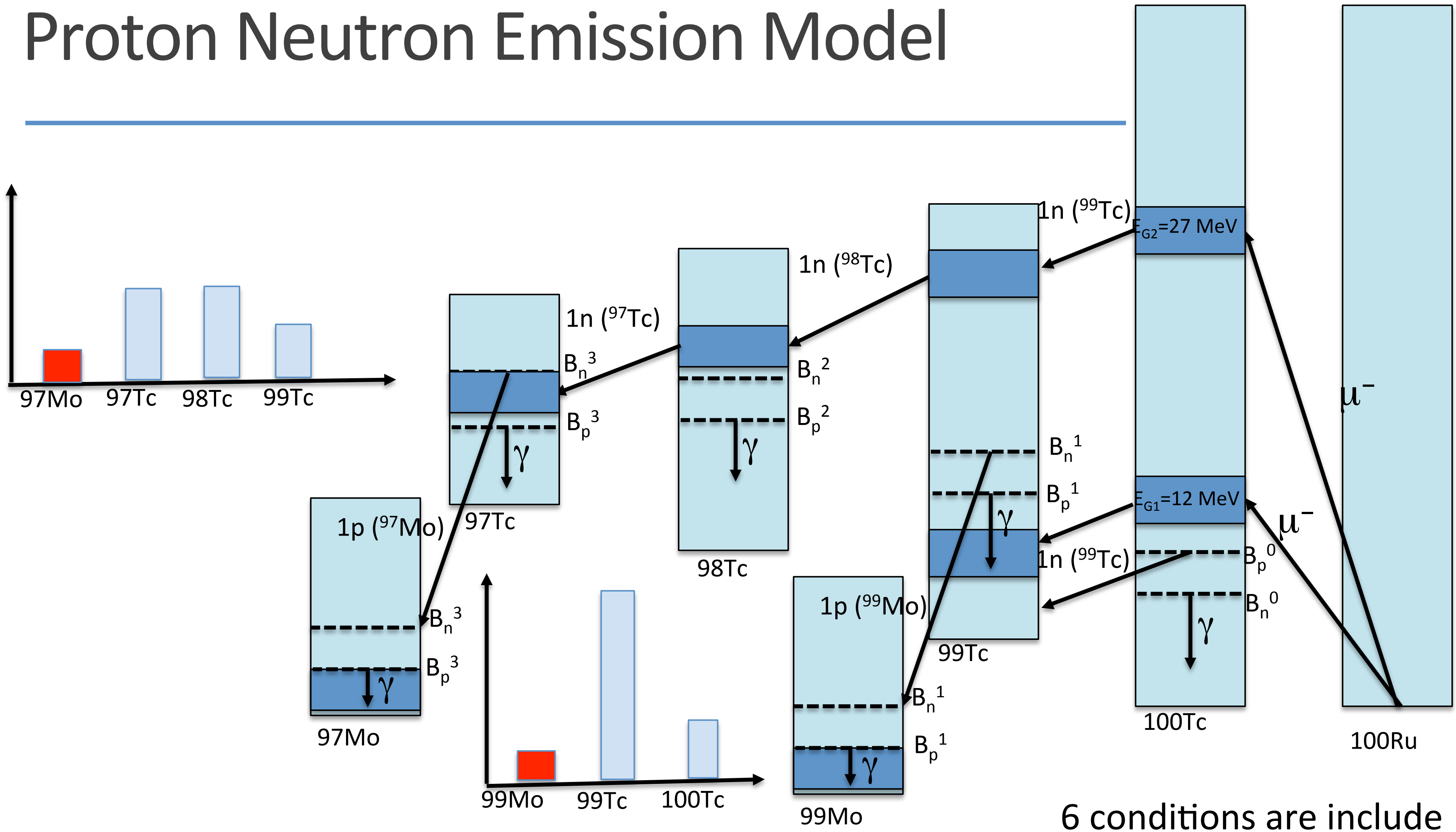
BACK SLIDES

Proton Neutron Emission Model



6 conditions are include in current PNEM.

[1] H.Ejiri, I.H. Hashim. Private Comm. 2018
[2] I.H. Hashim. F.Soberi, F.Ibrahim. Private Comm. 2019

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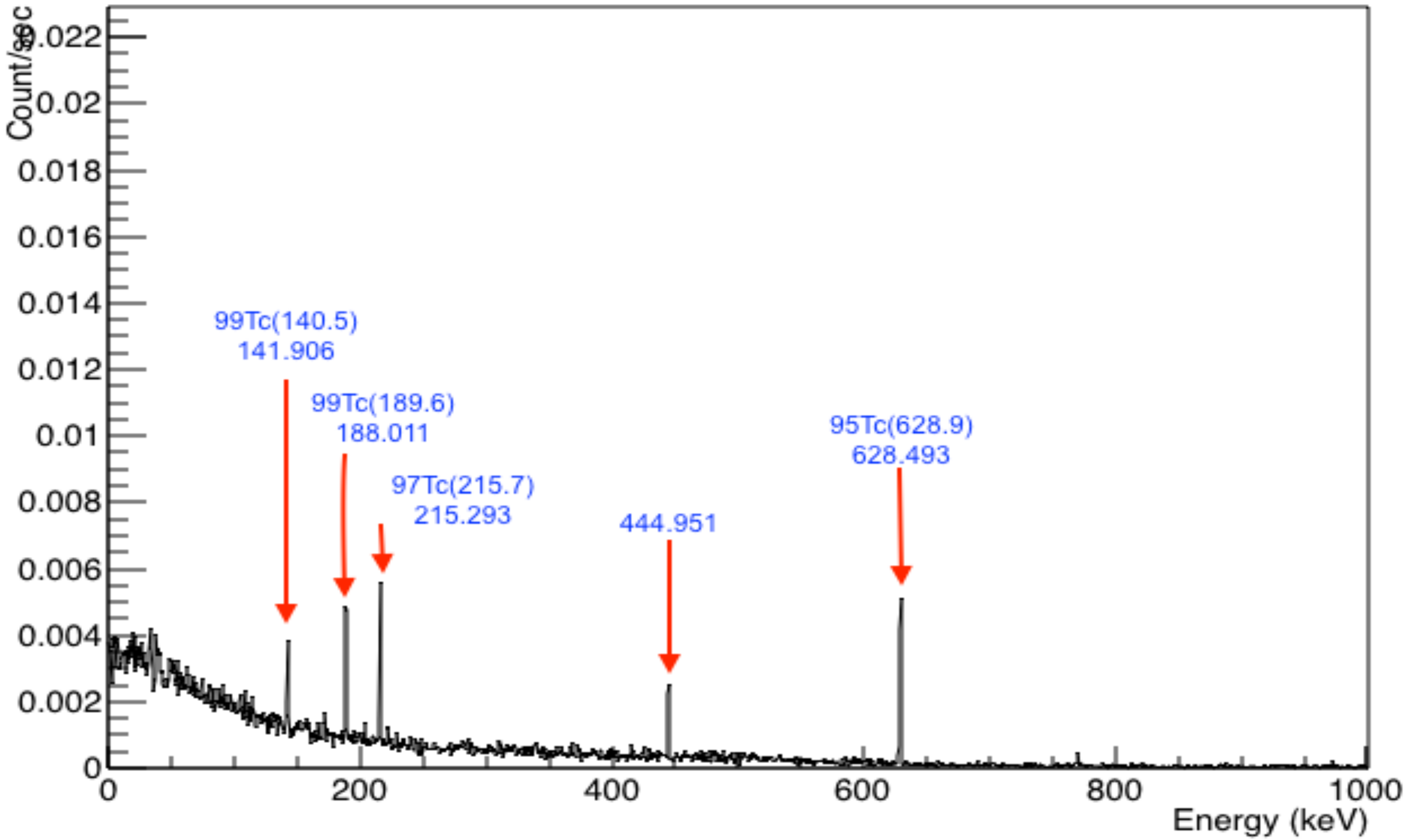
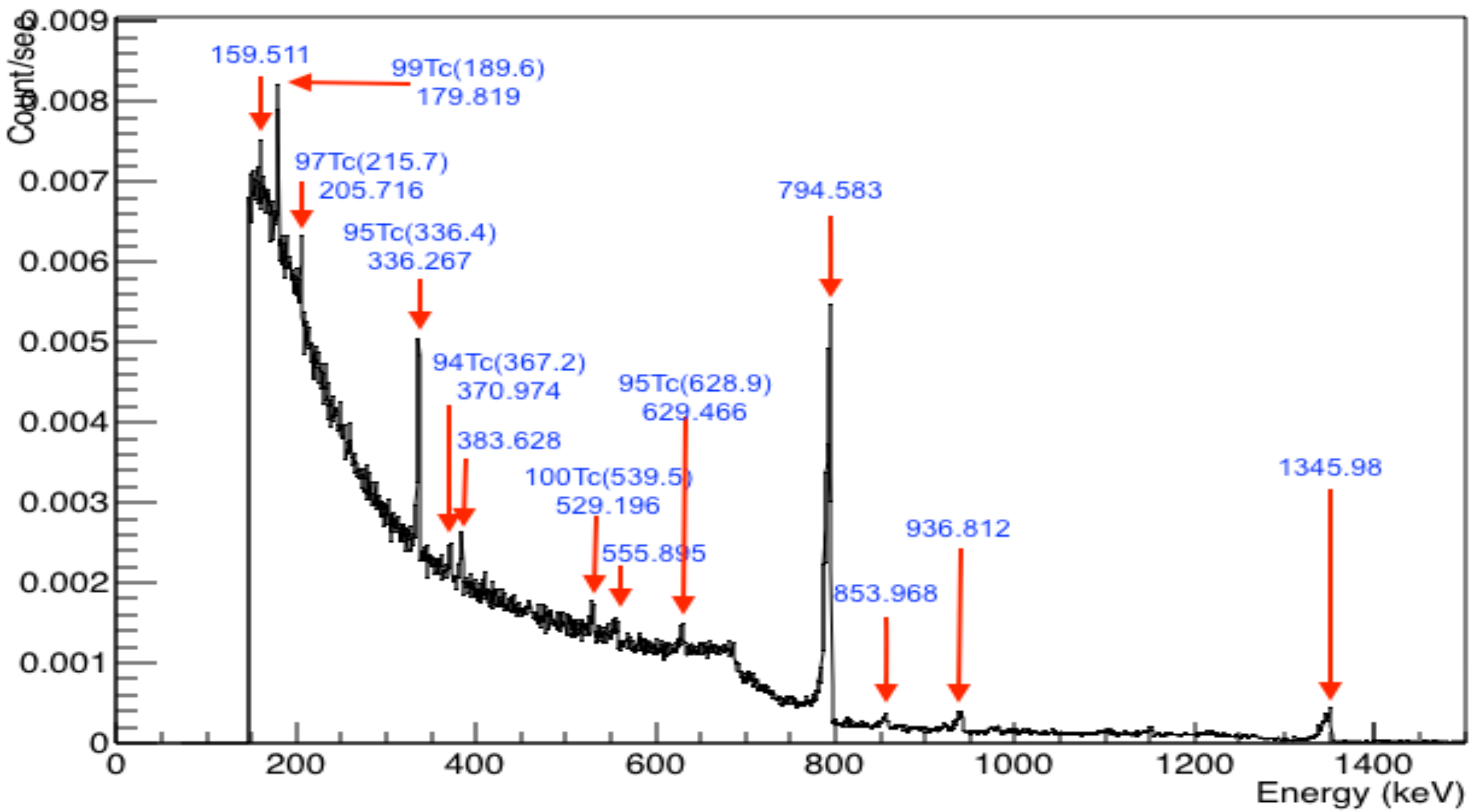
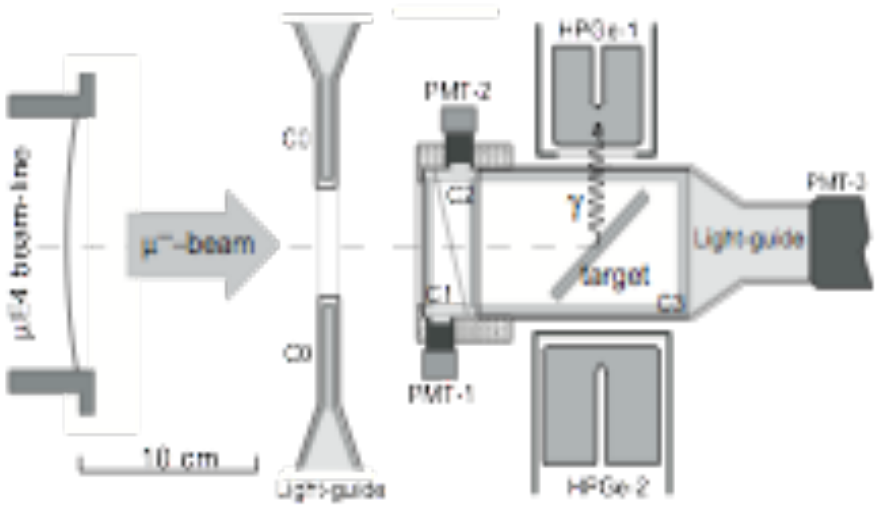
Poptop Det (Runat)

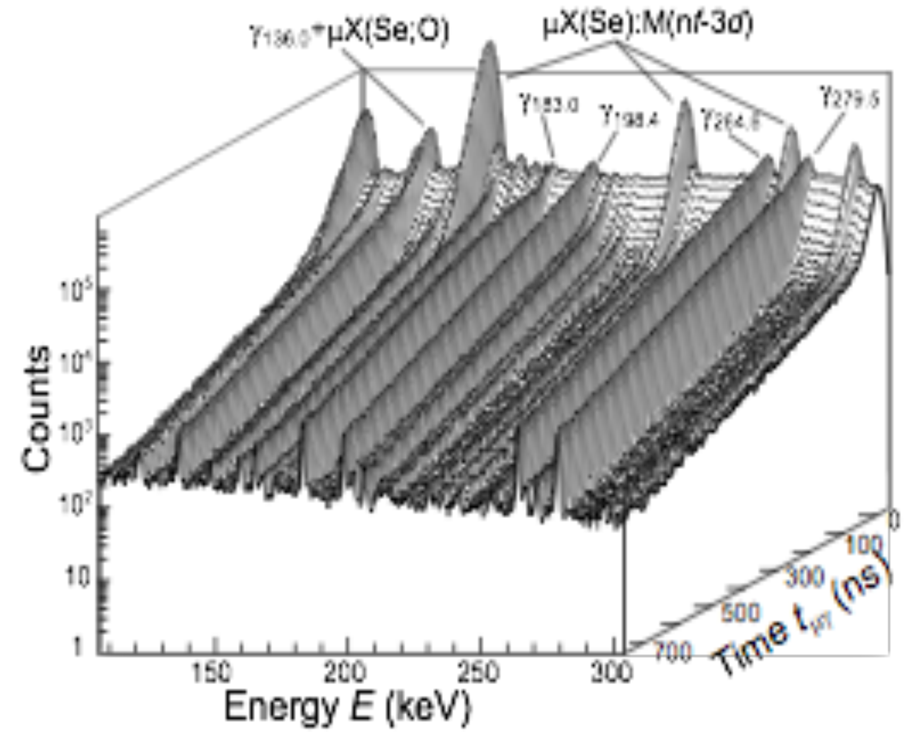


Fukushima Det (RuNat)



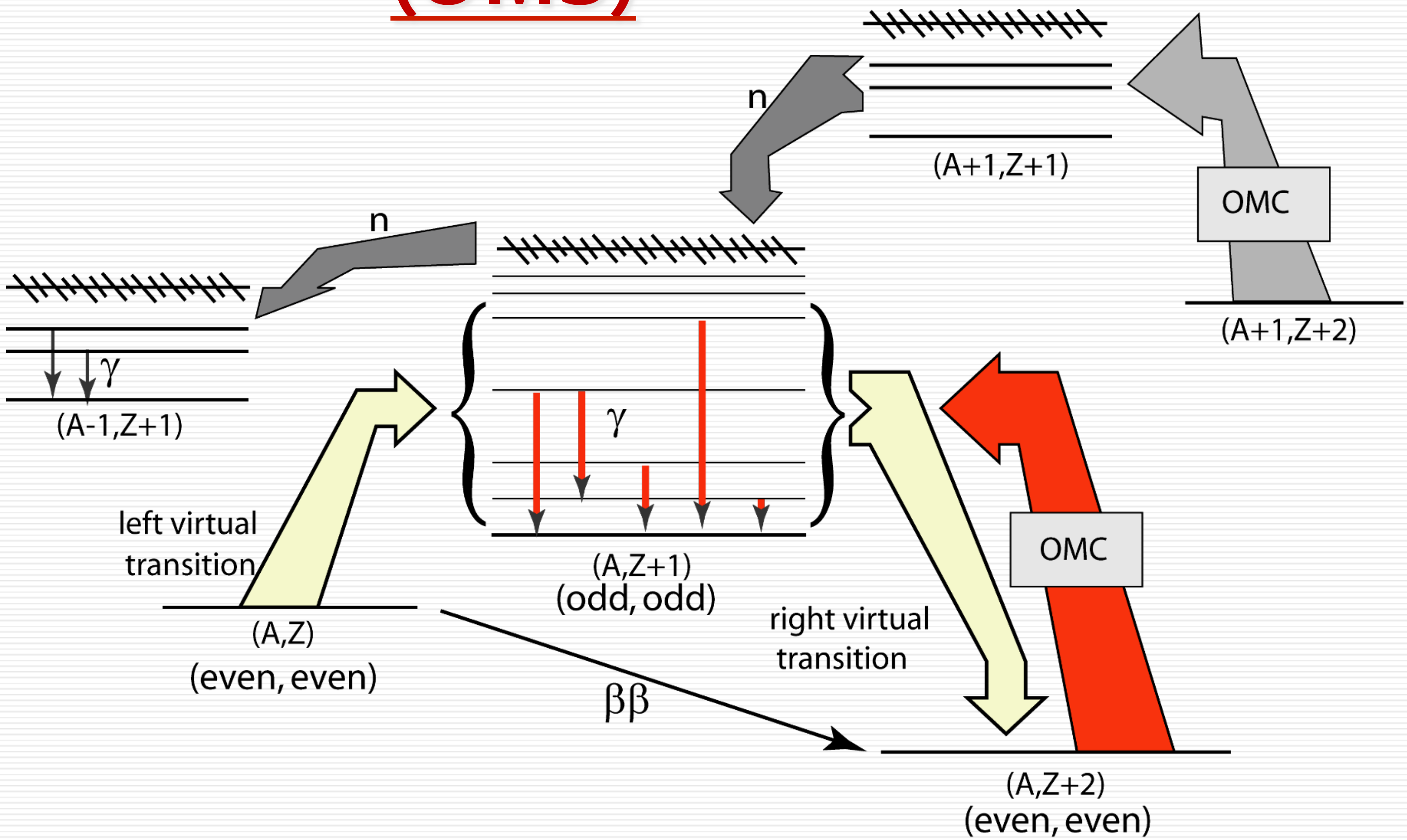


target	enr-ment	composition	element mass	thickness mg/cm^2
^{82}Kr	99.9%	Kr gas	1.0 l (1 atm.)	37.3
^{nat}Kr	–	Kr gas	1.0 l (1 atm.)	37.3
^{130}Xe	99.9%	Xe gas	1.0 l (1 atm.)	37.3
^{nat}Xe	–	Xe gas	1.0 l (1 atm.)	37.3
^{24}Mg	99.89%	MgO powder	1.0 g	250



[1] D. Zinatulina et al. Phys. Rev. C 99 (2019) 024327.

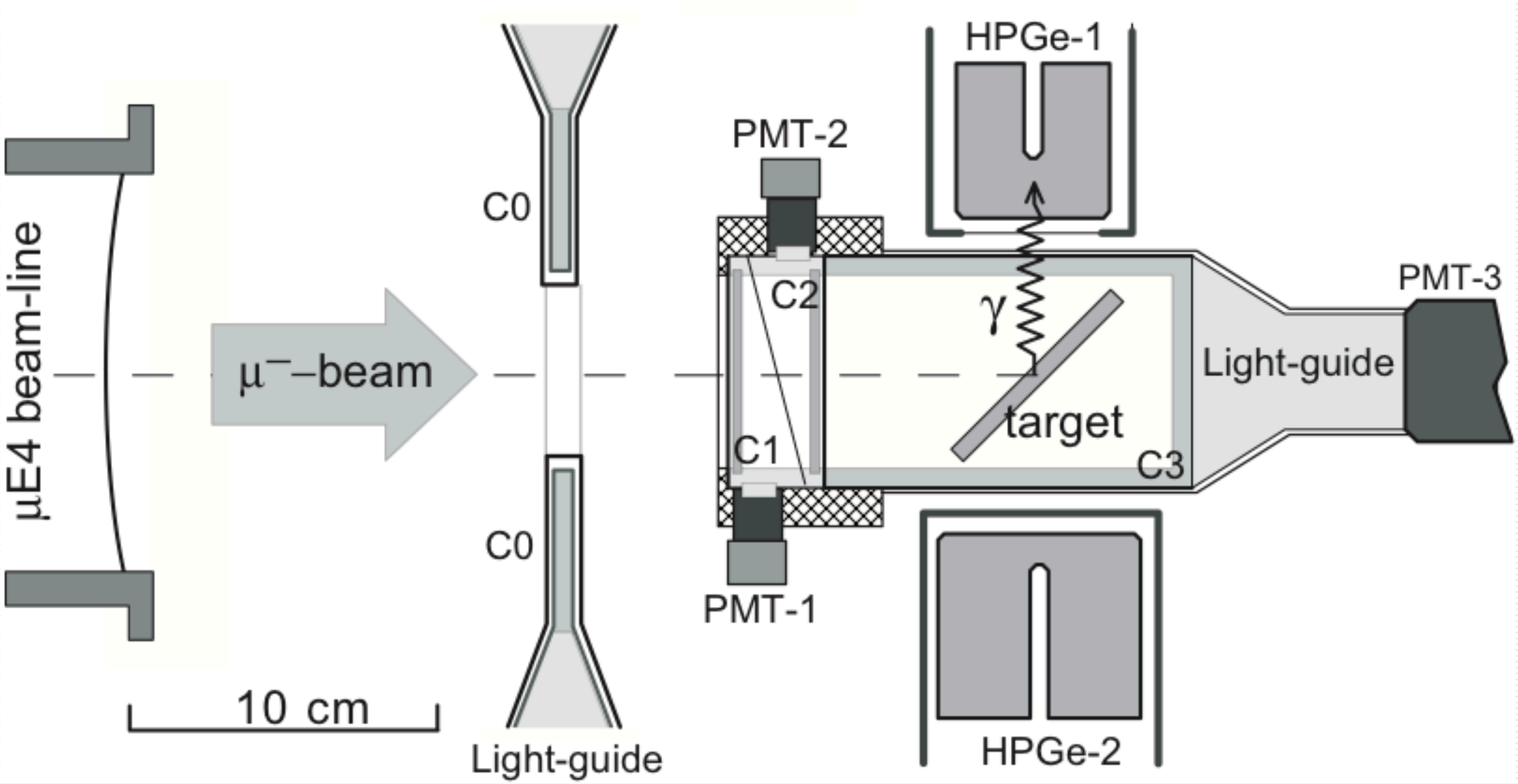
Обычный мюонный захват (ОМЗ)



ОМЗ (0n): $\mu^- + (A, Z) \rightarrow (A, Z\text{-}1)^* + \nu_\mu \rightarrow (A, Z\text{-}1) + \gamma$, $m_\mu \sim 100$ MeV

2β-распад	2β-эксперименты	Мишени ОМЗ	Статус
^{76}Ge	GerdaI/II, Majorana Demonstrator	^{76}Se	2004 (PSI)
^{48}Ca	TGV, NEMO3, Candles III	^{48}Ti	2002 (PSI)
^{106}Cd	TGV	^{106}Cd	2004 (PSI)
^{82}Se	NEMO3, SuperNEMO, Lucifer(R&D)	^{82}Kr	2006 (PSI)
^{100}Mo	NEMO3, AMoRE(R&D), LUMINEU(R&D)	^{100}Ru	2018 (RCNP)
^{116}Cd	NEMO3, Cobra	^{116}Sn	2002
^{150}Nd	SuperNEMO, DCBA(R&D)	^{150}Sm	2002, 2006
^{136}Xe	EXO200, Kamland-Zen, NEXT	^{136}Ba	2019 (RCNP)
^{130}Te	Cuore 0/Cuore, SNO+	^{130}Xe	2019 (PSI)?

Экспериментальная установка (PSI)

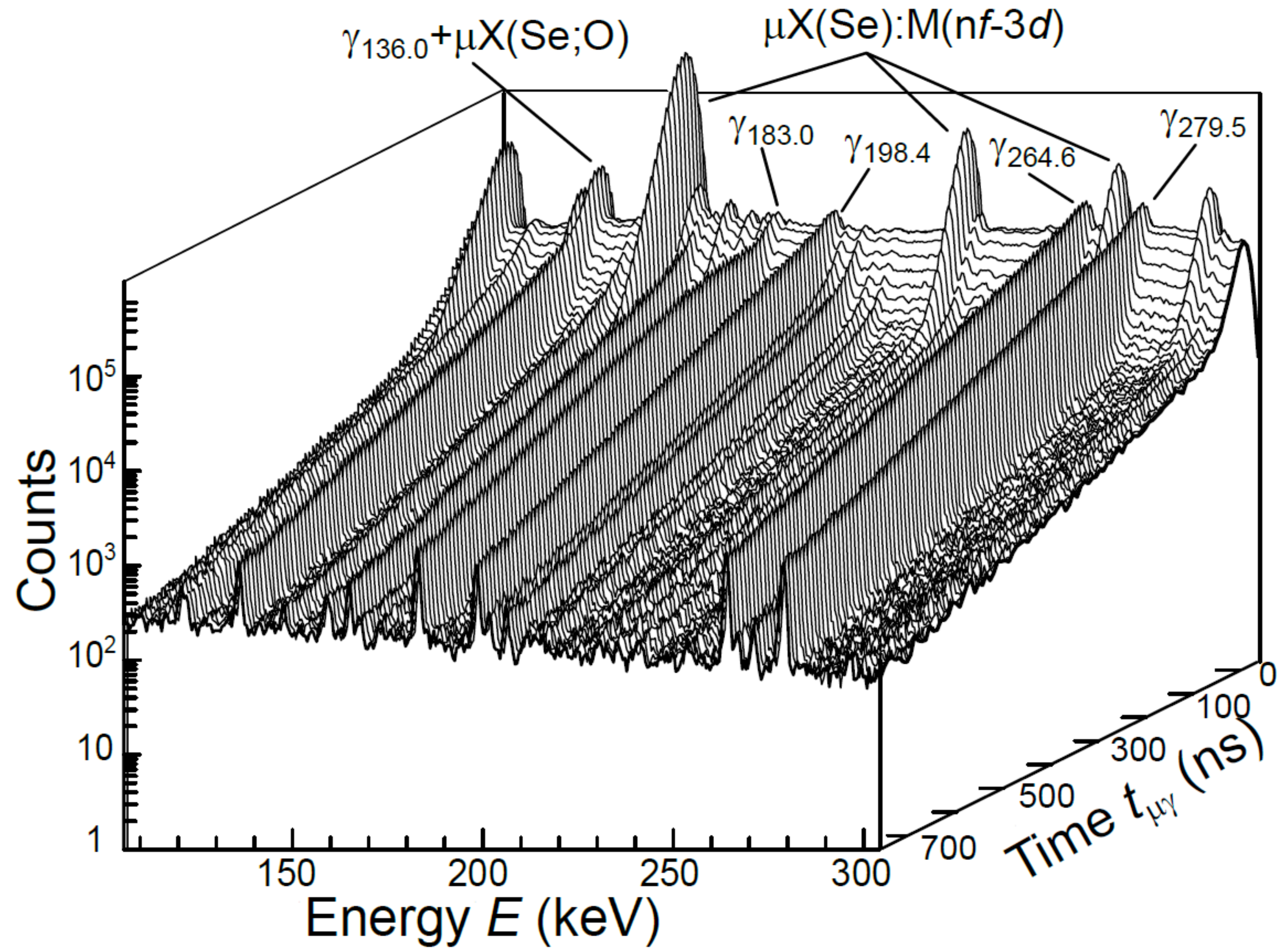


$$\mu_{stop} = \overline{C0} \wedge C1 \wedge C2 \wedge \overline{C3}$$

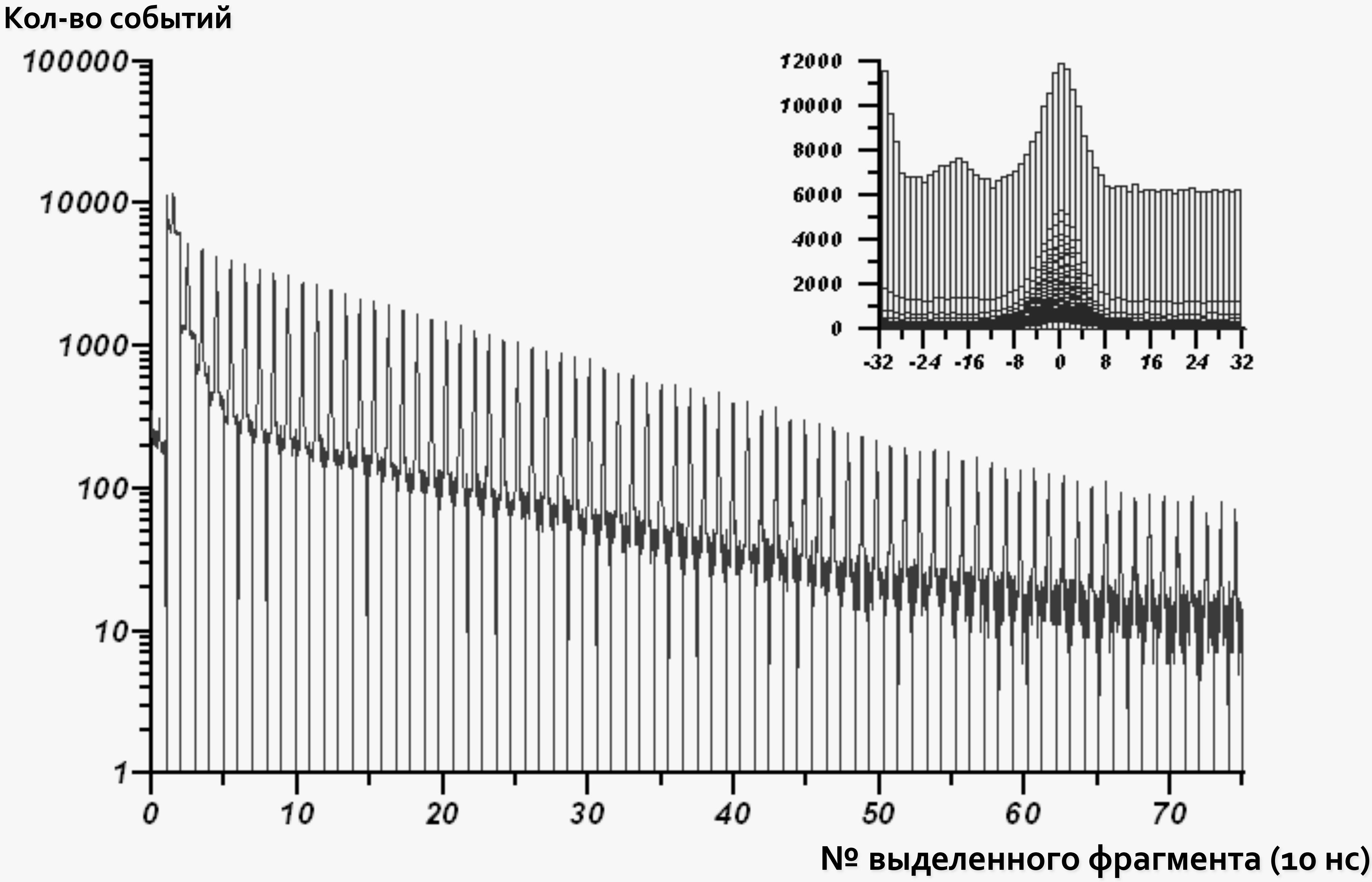
Количество μ-stop = (8 – 25) x 10³ с 20 – 30 MeB/c

PSI, 2006

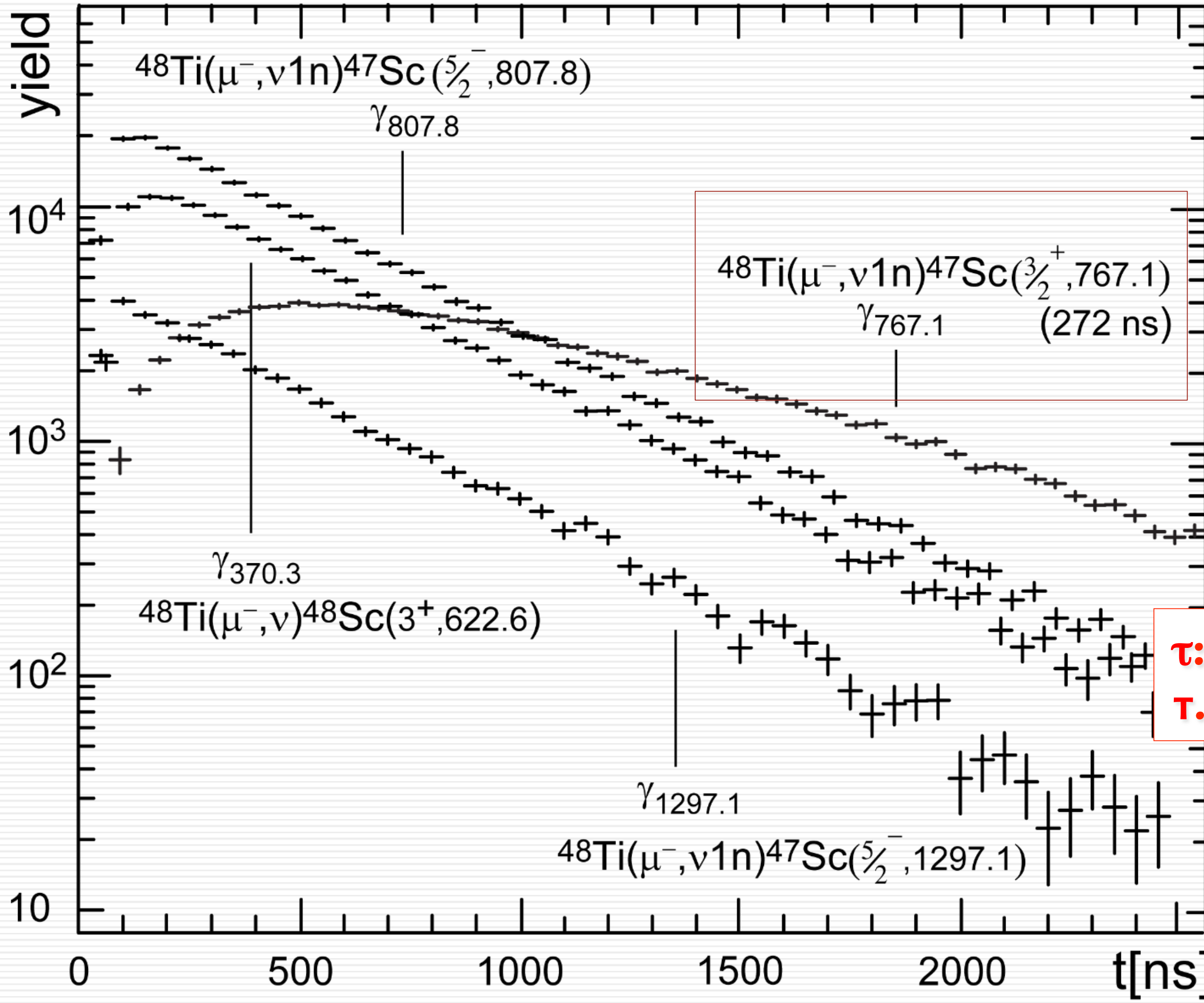
(E, t) распределение при μ-захвате в мишени ^{76}Se



Метод временной эволюции γ-линии



Полные скорости m-захвата в ^{48}Ti



τ: 361.1 нс

т.е., λ_{cap} = 2.32 μс$^{-1}$