Joint Institute for Nuclear Research
Dzhelepov Laboratory of Nuclear Problems

Program Advisory Committee for Nuclear Physics, 25th June 2020

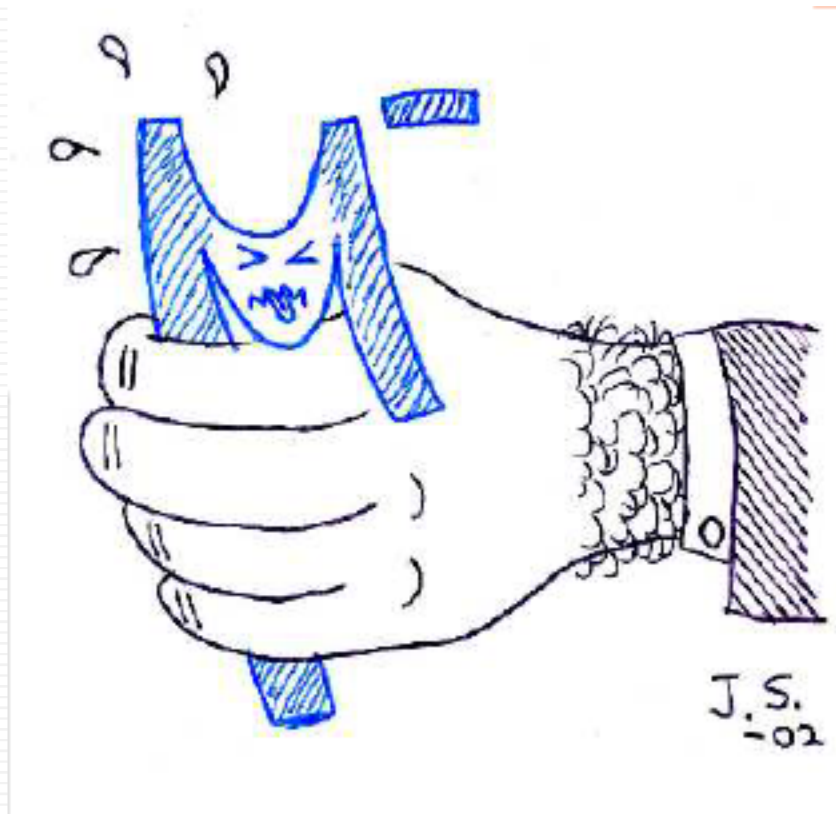
MONUMENT: Muon Ordinary capture for the NUclear Matrix elemENTs in ββ decays

Code of theme: **03-2-1100-2019/2021**

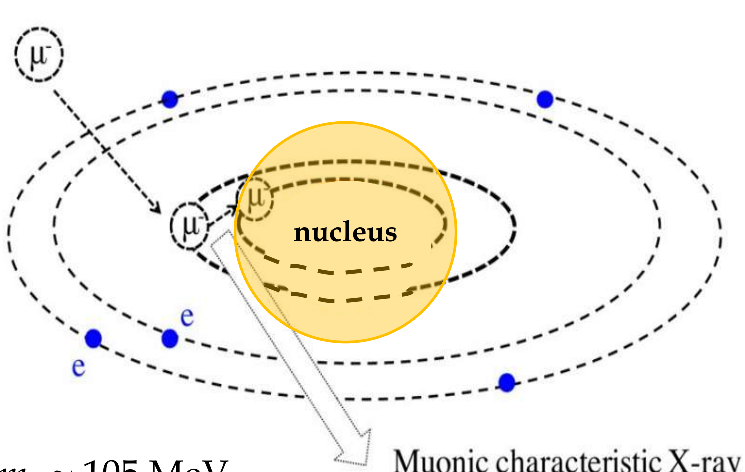
D. Zinatulina, V. Brudanin, K. Gusev, S. Kazarcev, N. Rumyantseva,
M. Shirchenko, E. Shevchik, I. Zhitnikov, M. Fomina, V. Belov, Yu. Shitov

25.06.2020, Dubna

Motivation



Ordinary Muon Capture (OMC)



$m_\mu \sim 105$ MeV

$\mu^- \rightarrow e^- + \nu_e + \nu_\mu$ $\quad \tau_{dec} = 2.2\mu s$

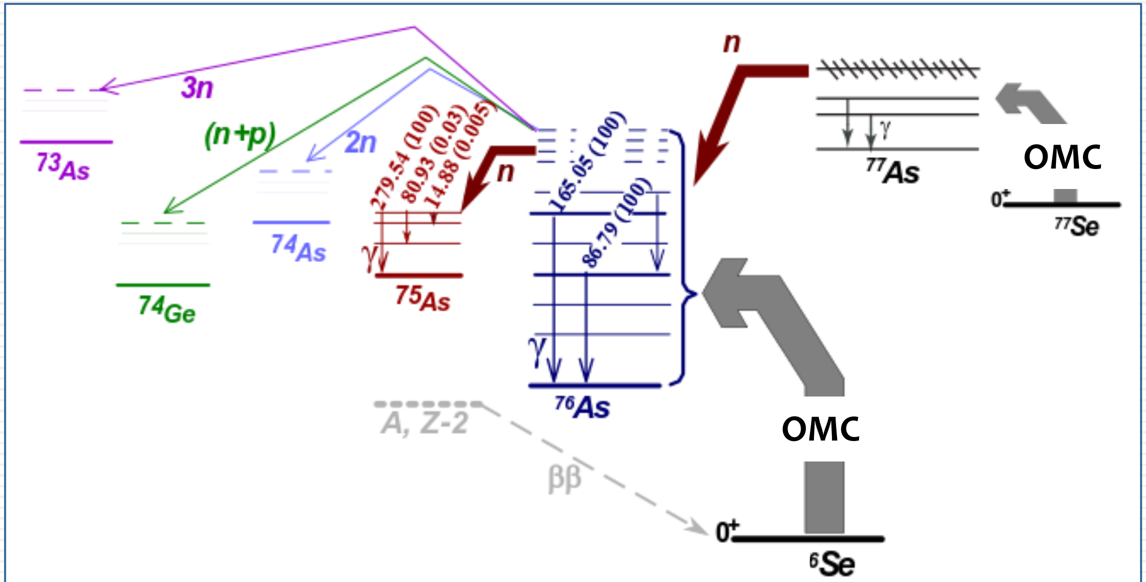
$(A, Z) + \mu^- \rightarrow (A, Z\text{-}1)^* + \nu_\mu$

$\rightarrow (A, Z\text{-}1) + \gamma$

$\rightarrow (A\text{-}1, Z\text{-}1) + \gamma + n$

$\rightarrow (A\text{-}2, Z\text{-}1) + \gamma + 2n$

$\rightarrow (A\text{-}1, Z\text{-}2) + \gamma + n + p$

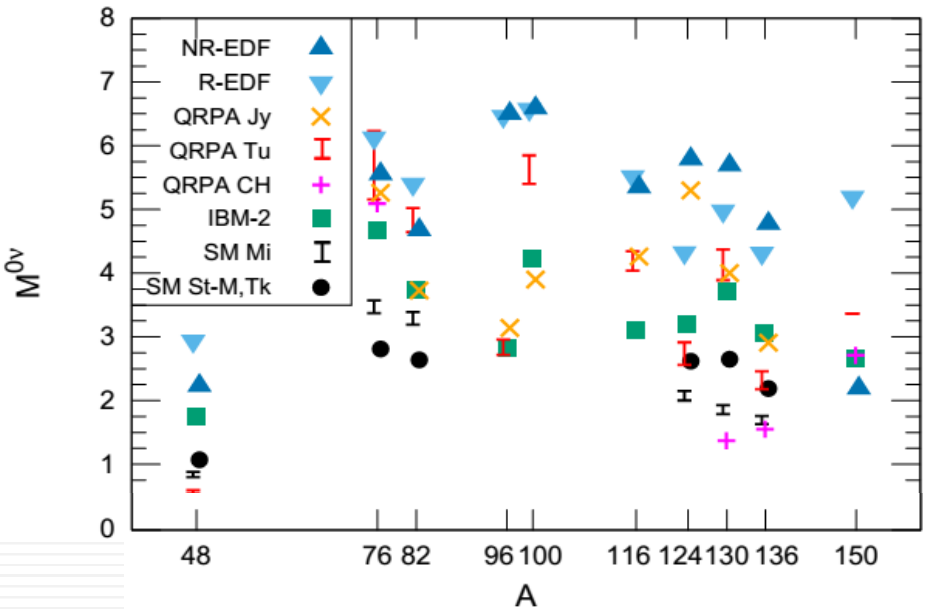


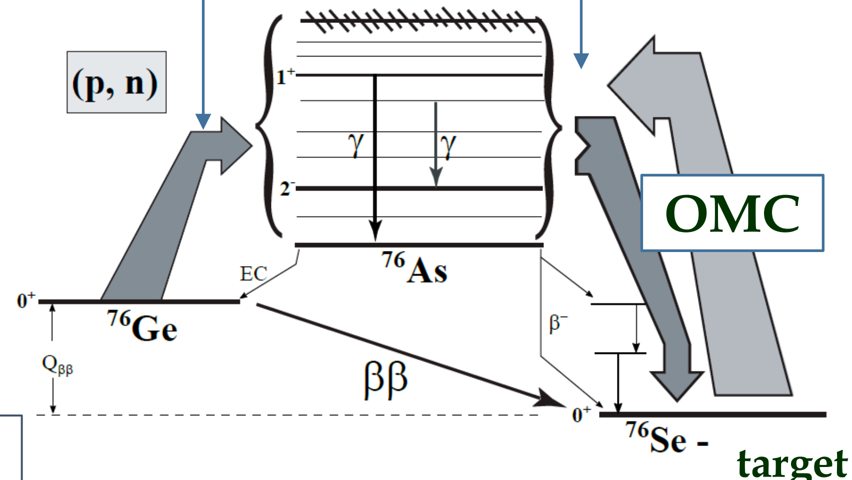
- Muonic cascades (our by-product)
- High momentum transfer (up to 100 MeV) -- High-lying states population
- **Right leg testing for DBD calculations (coupling to charge exchange reactions)**
- g_a – suppression probing -- via capture rates calculations (+ other methods)
- Angular correlations in OMC (Doppler shape of γ-lines)

Experimental input for DBD NME calculations

$$\frac{1}{T_{1/2}^{0\nu}} \propto \underbrace{\left|\sum_i U_{ei}^2 m_i\right|^2}_{\langle m_{\beta\beta}\rangle} G^{0\nu} \underbrace{\left|\langle A,Z+2|S|A,Z\rangle\right|^2}_{M^{0\nu}}$$

$$\langle A,Z+2|S|A,Z\rangle \propto \sum_n \langle Z+2|\hat{H}|Z+1,n\rangle\langle Z+1,n|\hat{H}|Z\rangle$$





APPEC-2019, Recommendation 6: *The computation of nuclear matrix elements is challenging and currently is affected by an uncertainty which is typically quantified in a factor of 2-3... An enhanced effort is required and a stronger interactions between the particle physics and nuclear community would be highly beneficial. Dedicated experiments may be required.*

g_A – suppression probing -- via capture rates calculations

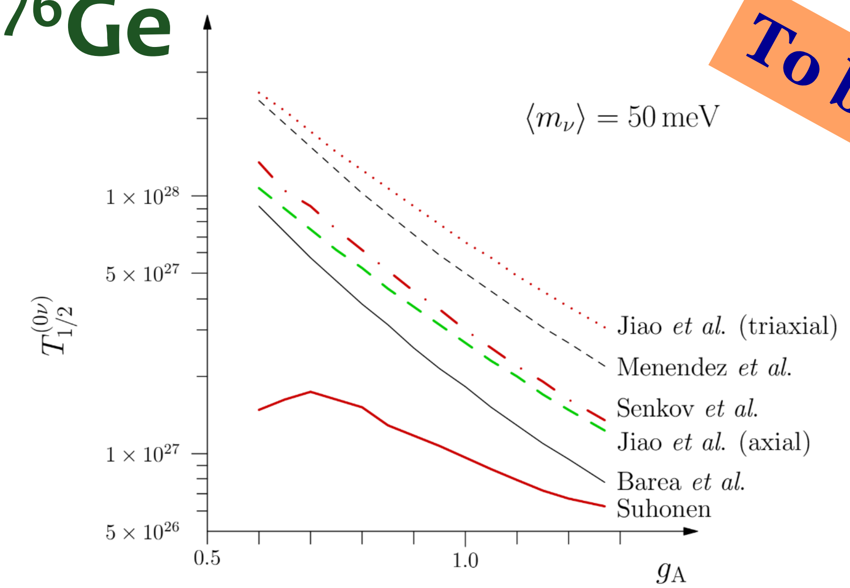
To be, or not to be, that is the quenching…

$$|\mathrm{NME}_{0\nu}|^2 \cong \left|M^{0\nu}_{GTGT}\right|^2 = (g_{a,0\nu})^4 \left|\Sigma_{J^\pi}\left(\langle 0_f^+|O^{0\nu}_{GTGT}|0_i^+\rangle\right)\right|^2$$

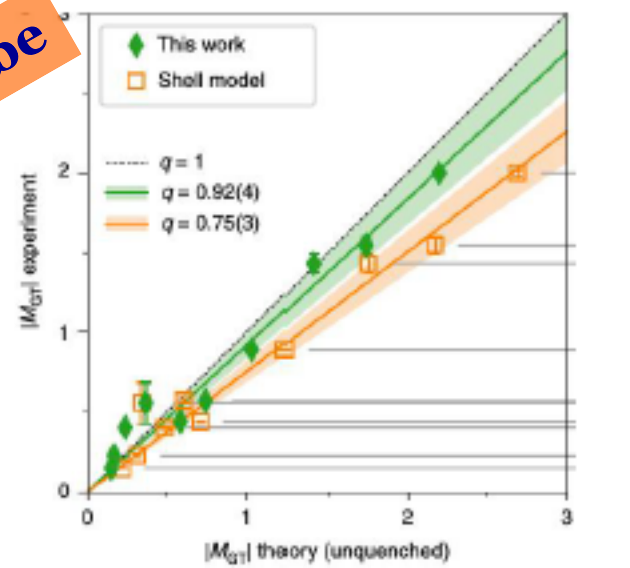
^{76}Ge

To be

or not to be



Jiao et al.: **Phys.Rev. C 96** (2017)054310 (GCM+ISM)
Menendez et al.:**Nucl. Phys.** A818 (2009) 139 (ISM)
Senkov et al.:**Phys. Rev. C 93** (2016) 044334 (ISM)
Barea et al.: **Phys.Rev. C 91** (2015)034304 (IBM-2)
Suhonen: **Phys.Rev. C 96** (2017)055501 (pnQRPA)

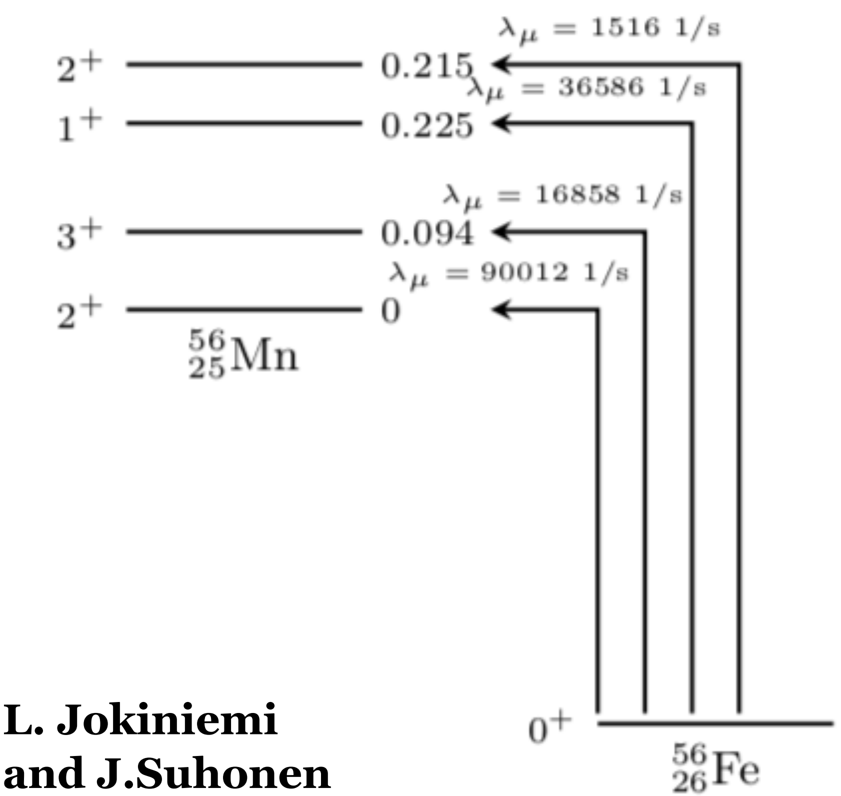


Gysbers et al. Nature Phys. 15 428 (2019)

Ab initio calculations including meson-exchange currents do not need any "quenching"

Testing shell model calculations (^{56}Fe, ^{24}Mg, ^{32}S)

- The level scheme of light nuclei is very well known
- Experiment vs. theory
- Optimization for DBD candidates
- Testing g_A quenching



L. Jokiniemi and J.Suhonen

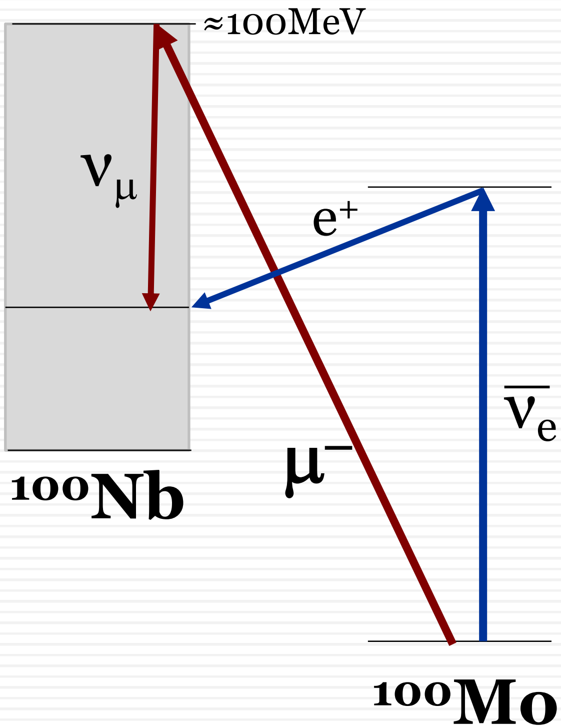
$$\lambda_\mu \approx C(q_i)\sum_{\kappa u}\left|g_V M_V(\kappa,u)+g_A M_A(\kappa,u)+g_P M_P(\kappa,u)\right|^2$$

Astrophysics with ^{100}Mo

- Astro neutrino (including solar and supernovae neutrino study) observation provides evidences for neutrino matter oscillation, nuclear fusion reaction in sun and as tools for probing the supernovae (SN) explosion process

- It was proposed to measure SN antineutrinos on ^{100}Mo (MOON) [1, 2]

- OMC in ^{100}Mo will give experimental input for theoretical calculations of this process



^{100}Mo($\overline{\nu}_e$, e^+)^{100}Nb **(SN)**

^{100}Mo(μ^-, e^+)^{100}Nb **(OMC)**

[1] H.Ejiri, J.Suhonen, K.Zuber. // Phys. Rep 797 (2019) 1 – 102

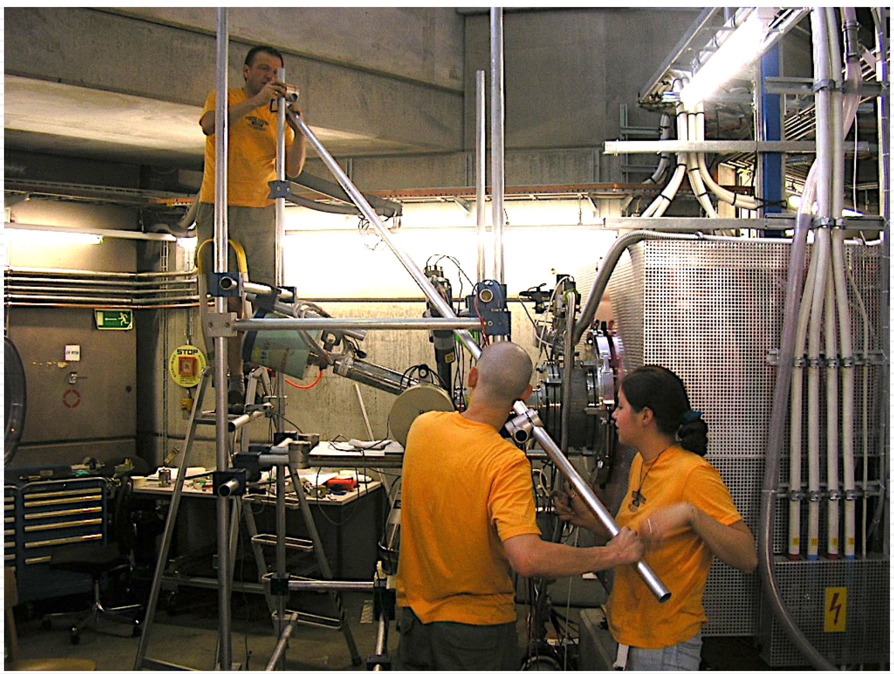
[2] H.Ejiri, J.Engel, N. Kudomi // PLB 530 (2002) 27-32

Measurement principle

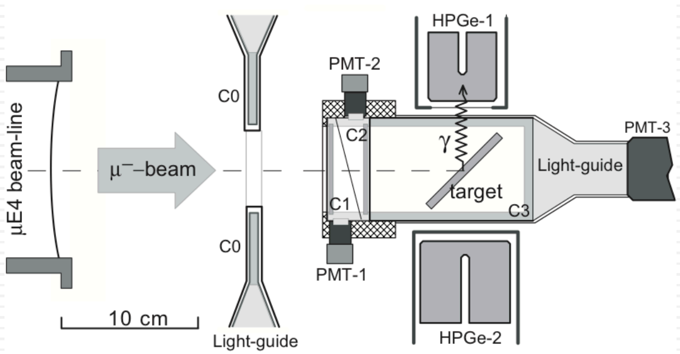

PSI 1998
AC/MC

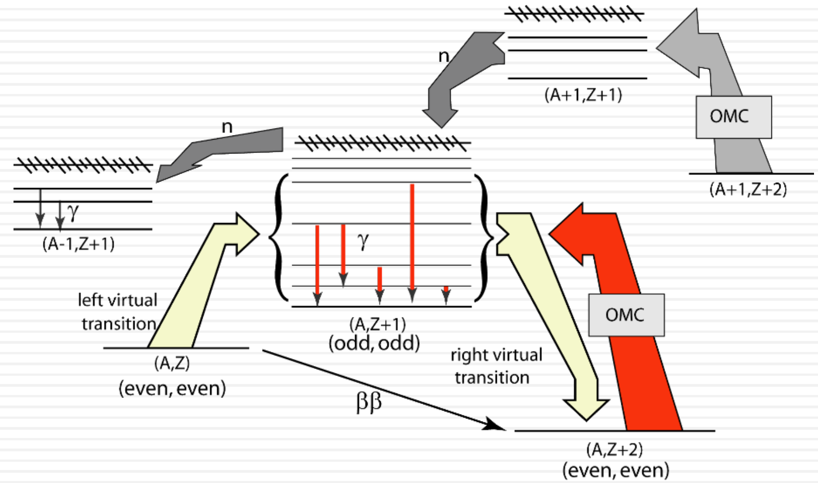
PSI 2006

OMC

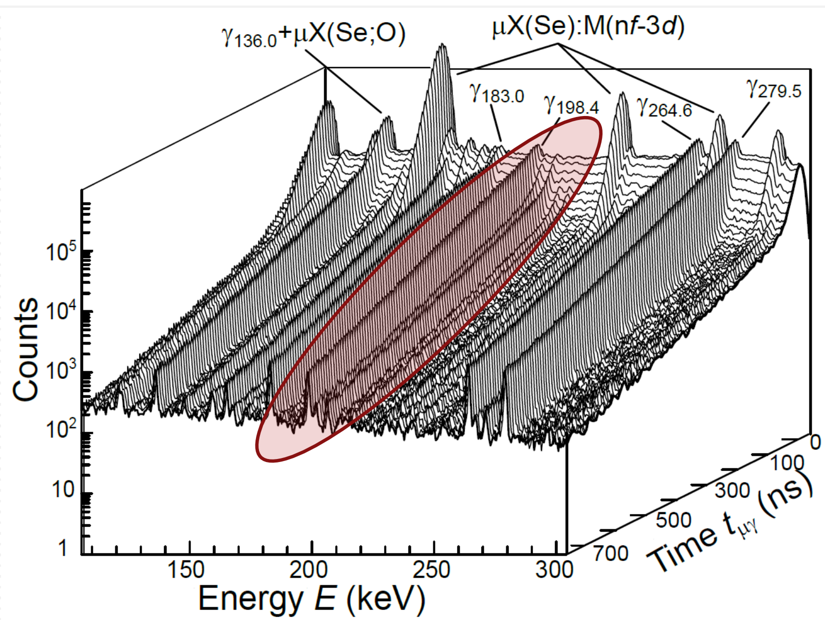


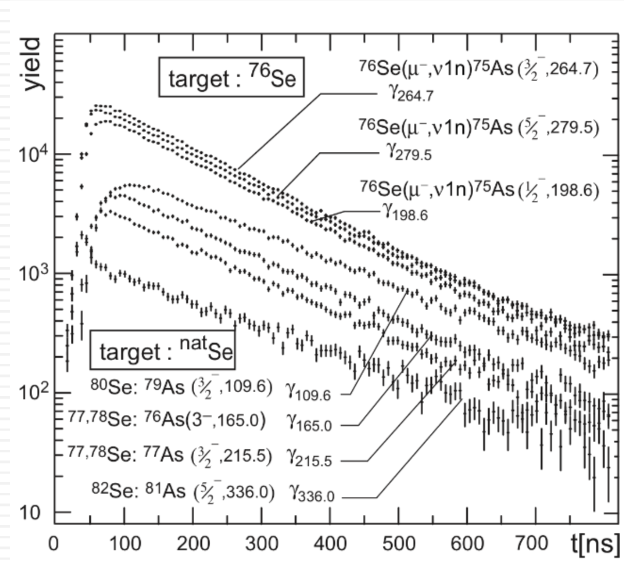
Experimental method of OMC





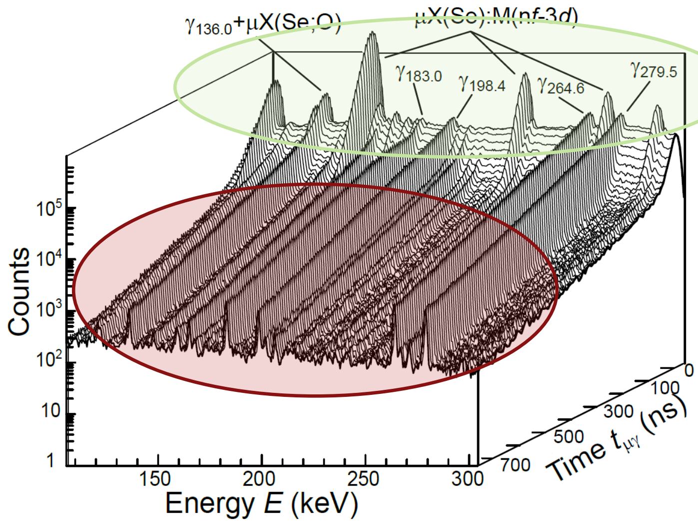
Number of μ-stop = (8 – 25) x 10³ with 20 – 30 MeV/c

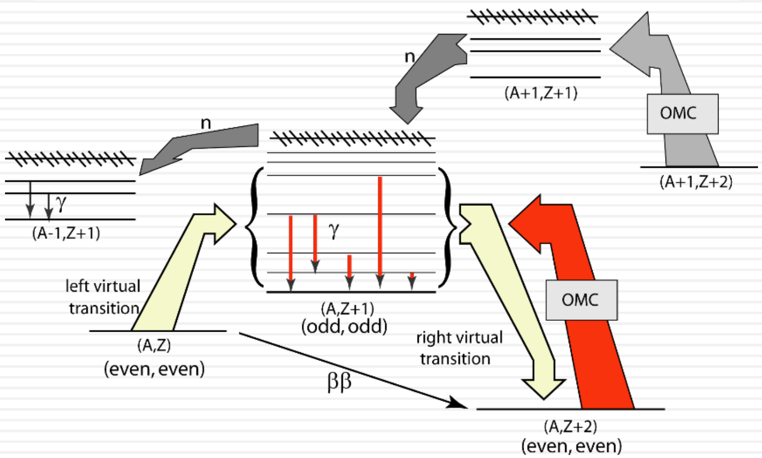


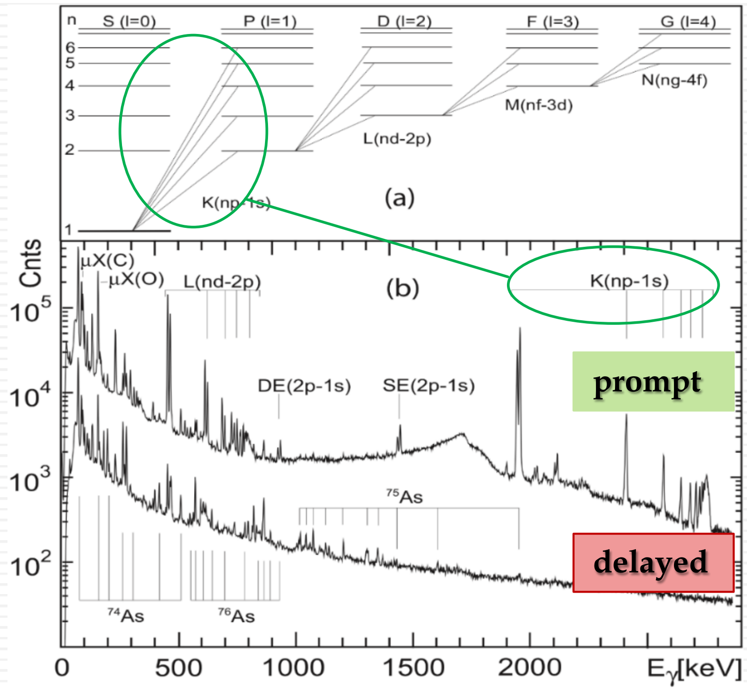


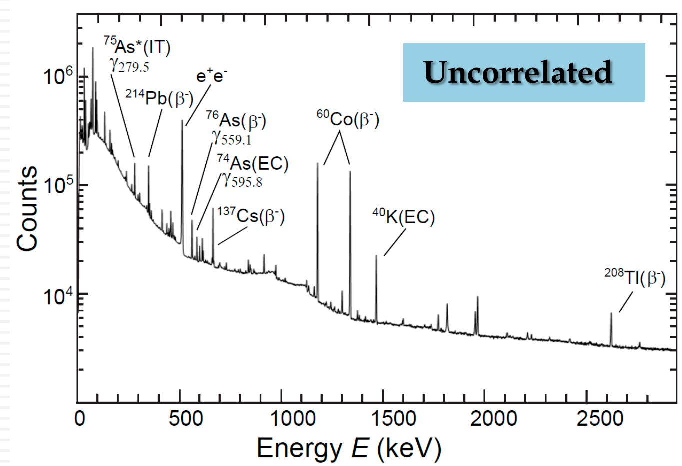
D. Zinatulina, V. Egorov et al. // Phys. Rev. C 99(2019)024327

Experimental method of OMC





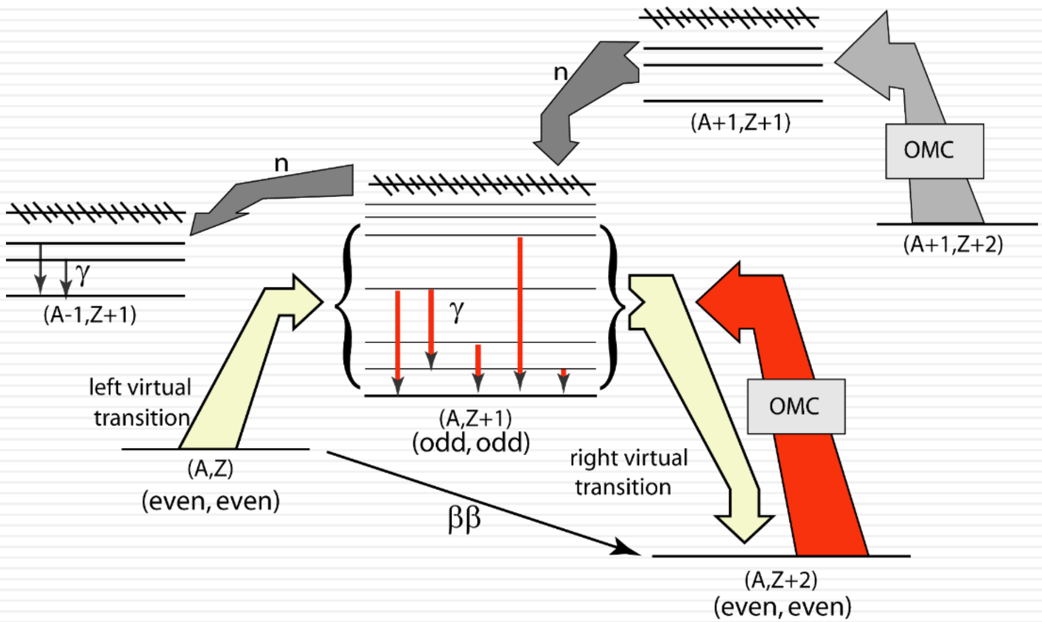




All results have been published in 9 different journals also the main article with methods is - >

D. Zinatulina, V. Egorov et al. // Phys. Rev. C 99(2019)024327

Comparison of experimental OMC results with theoretical calculations



OMC in ^{76}Se

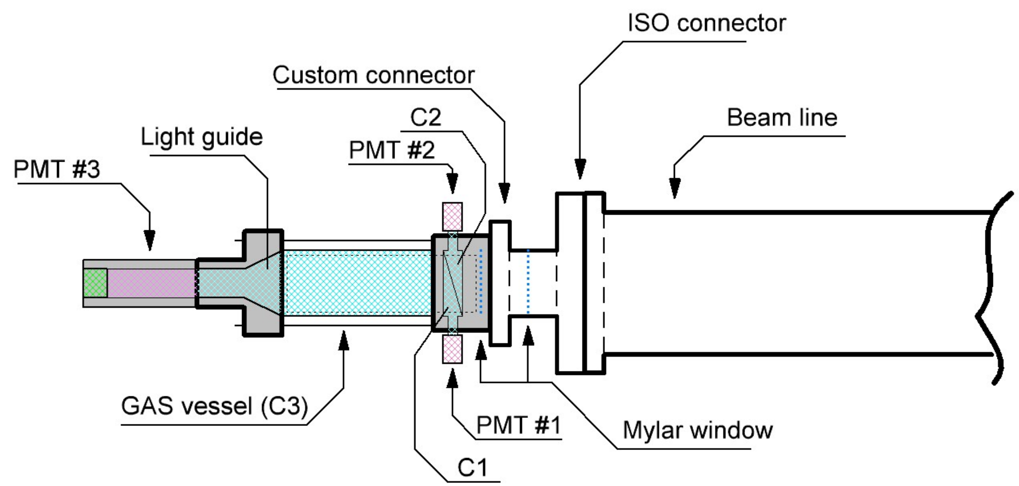
J^π	OMC rate (1/s) Exp.[A]	pnQRPA[B]
0^+	5120	414
1^+	218 240	236 595
1^-	31 360	28 991
2^+	120 960	114 016
2^-	145 920 + g.s.	177 802
3^+	60 160	55 355
3^-	53 120	34 836
4^+	-	2797
4^-	30 080	23 897

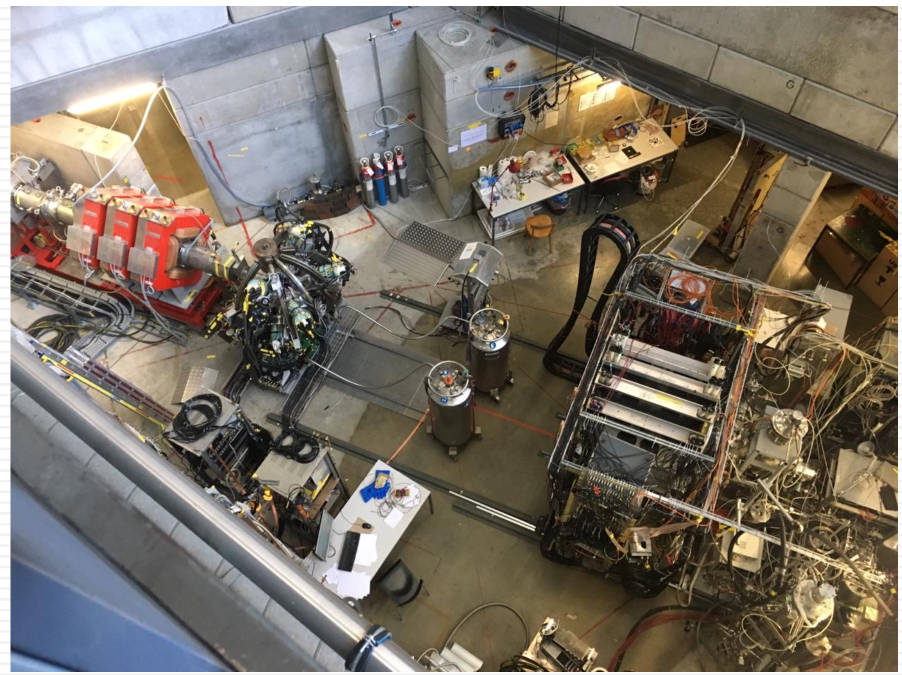
A) **D. Zinatulina, V. Egorov et al. // Phys. Rev. C 99 (2019) 024327**

B) **L. Jokiniemi, J. Suhonen // Phys. Rev. C 100 (2019) 014619**

Preliminary/ proposed measurements

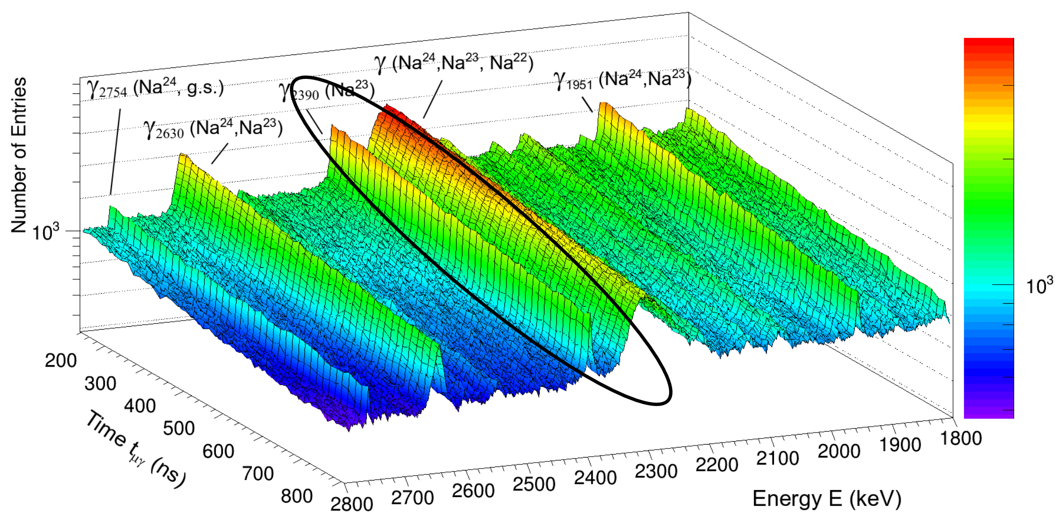
Preliminary measurements in 2019

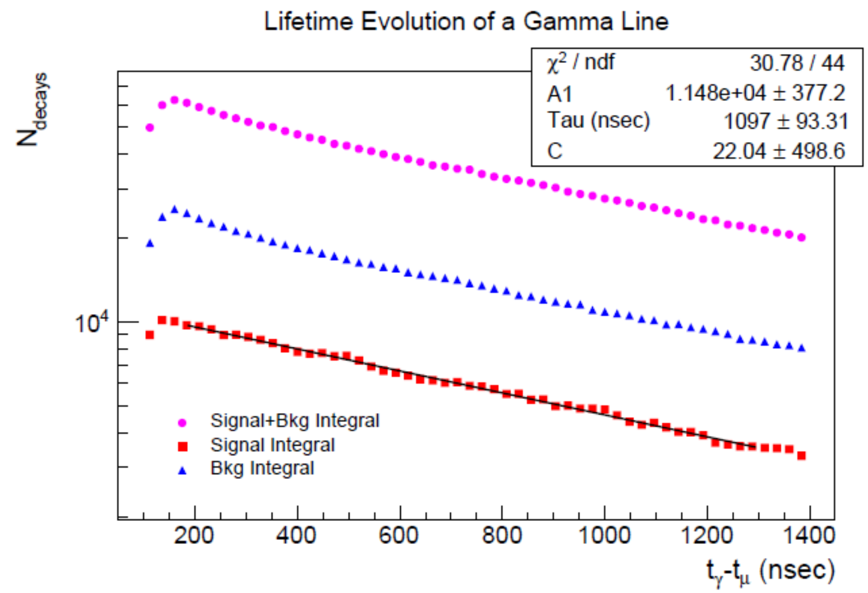




0ν2β-decay	0ν2β-Exper-ts	OMC targets	Quant-ty
^{82}Se	NEMO3, SuperNEMO, Lucifer(R&D)	^{82}Kr (99.9%)	1 l (1.7 atm.)
^{130}Te	Cuore 0/Cuore, SNO+	^{130}Xe (99.9%)	1 l (1.7 atm.)
---	Testing shell model for NME	^{24}Mg (99.85%)	2 g

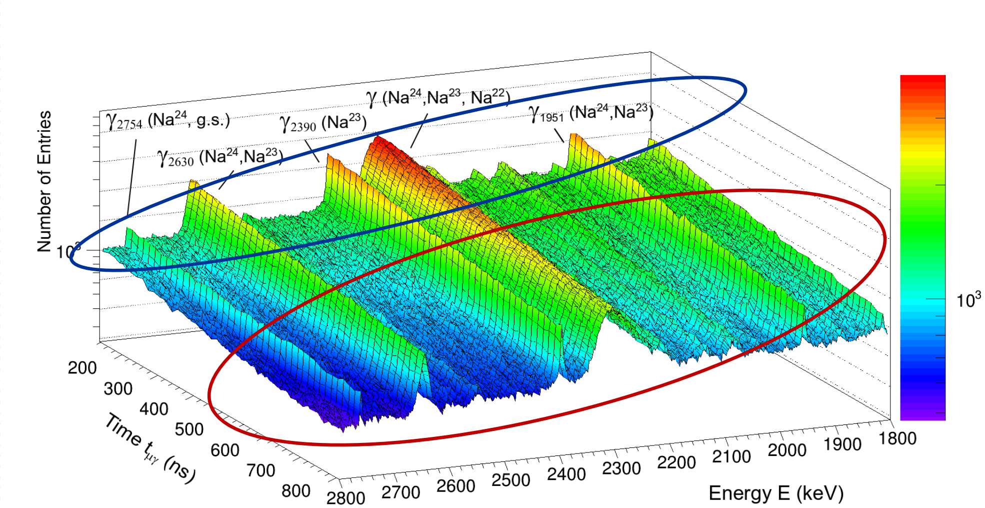
Preliminary 2019 results: *(E, t)* distribution of the correlated events following μ-capture in ^{24}Mg target

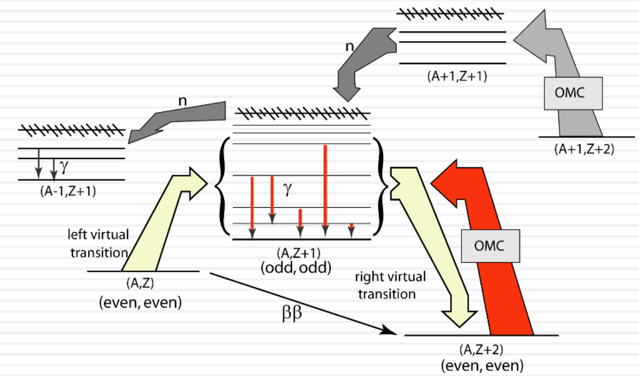


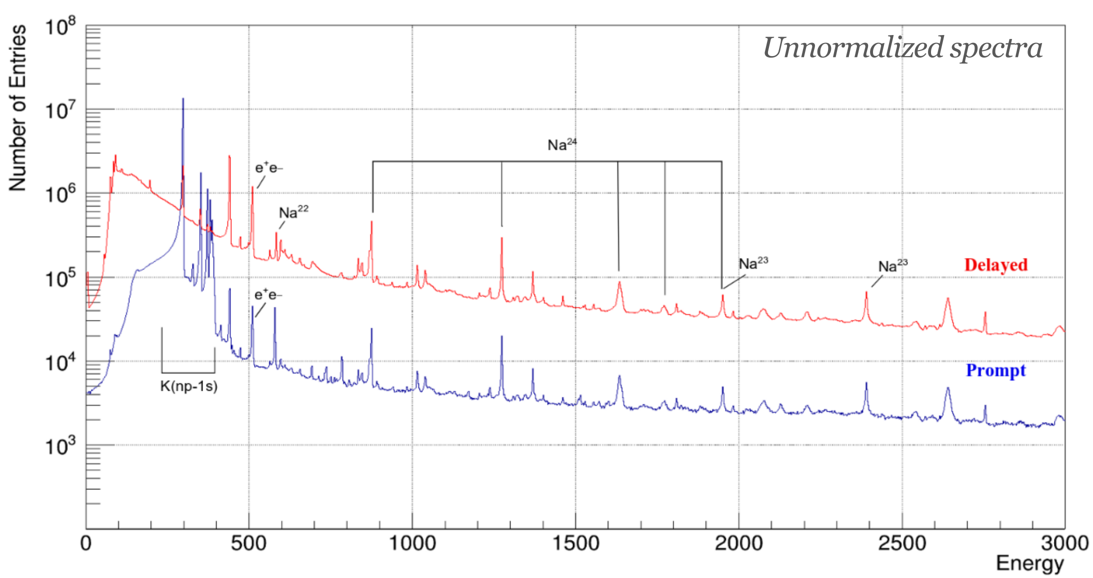


Time evolution of the 2390.6 keV γ-line, following OMC in ^{24}Mg.

Preliminary 2019 results: *(E, t)* distribution of the correlated events following μ-capture in ^{24}Mg target







- $t_{\mu\gamma}$ = 0-50 ns: μX-cascades (**Prompt** spectra) – normalization, identification, composition of the surrounded materials and target itself;
- $t_{\mu\gamma}$ = 50-700 ns: γ-radiation following OMC (**Delayed** spectra) – partial m-capture rates – strength function of the right side;
- T >> $t_{\mu\gamma}$: background radiation (**Uncorrelated** spectra) – calibration of the det-s, identification, yields of short-lived RI during exposure

Proposal for BVR 51

OMC4DBD: ordinary muon capture as a probe of properties of double beta decay processes

V. Brudanin[1], L. Baudis[2], V. Belov[1], T. Comellato[3], T. Cocolios[4], H. Ejiri[5], M. Fomina[1], I.H. Hashim[6], K.Gusev[1,3], L. Jokiniemi[7], S. Kazartsev[1,8], A. Knecht[9], F. Othman[6], I. Ostrovskiy[10], N.Rumyantseva[1], M. Schwarz[3], S.Schönert [3], M. Shirchenko[1], E. Shevchik[1], Yu. Shitov[1],J. Suhonen[7], S.M. Vogiatzi[9,11], C. Wiesinger[3], I. Zhitnikov[1], and D. Zinatulina[1]

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[5]Research Center on Nuclear Physics, Osaka University, Ibaraki, Osaka, Japan
[6]Department of Physics, Universiti Teknologi Malaysia, Johor Bahru, Malaysia.
[7]Department of Physics, University of Jyväskylä, Jyväskylä, Finland.
[8]Voronezh State University, Voronezh, Russia.
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[10]Department of Physics and Astronomy, University of Alabama, Tuscaloosa, AL, USA
[11]ETH Zurich, Switzerland

Open Users Meeting BV51, 29.01.2020

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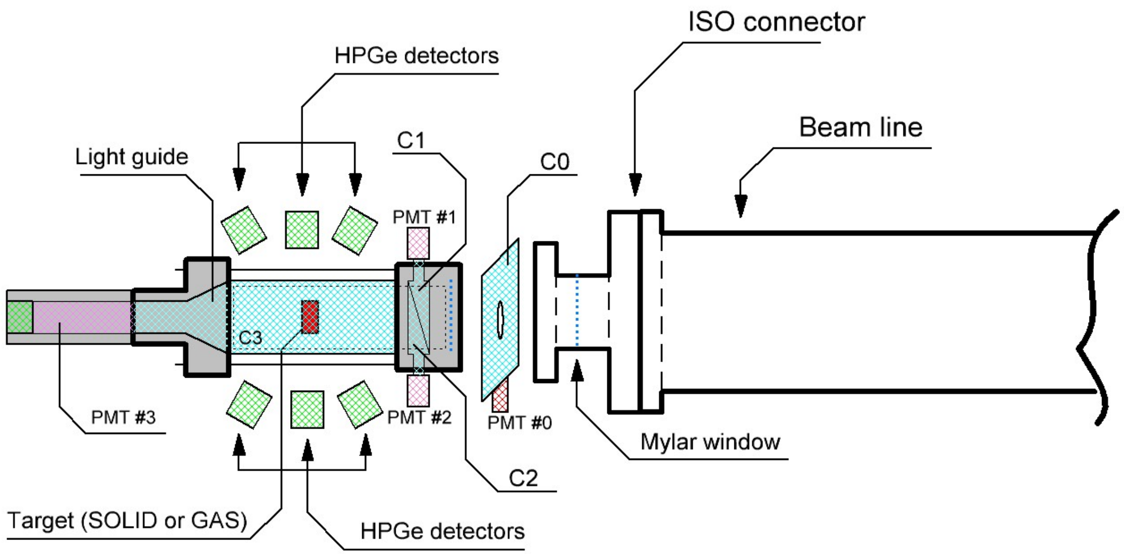
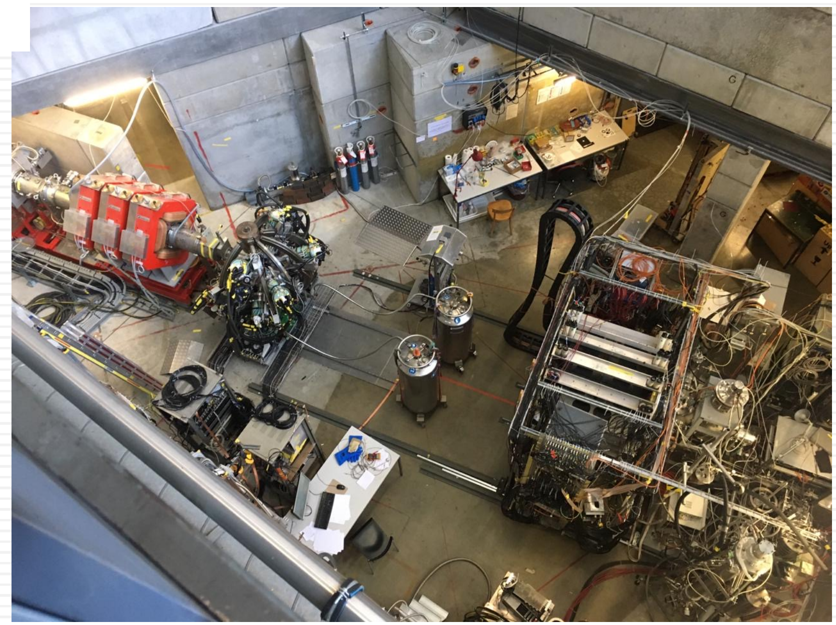
UTM UNIVERSITI TEKNOLOGI MALAYSIA
THE UNIVERSITY OF ALABAMA
KU LEUVEN NUCLEAR AND RADIATION PHYSICS
ETH zürich
RCNP

Proposed measurements in 2020

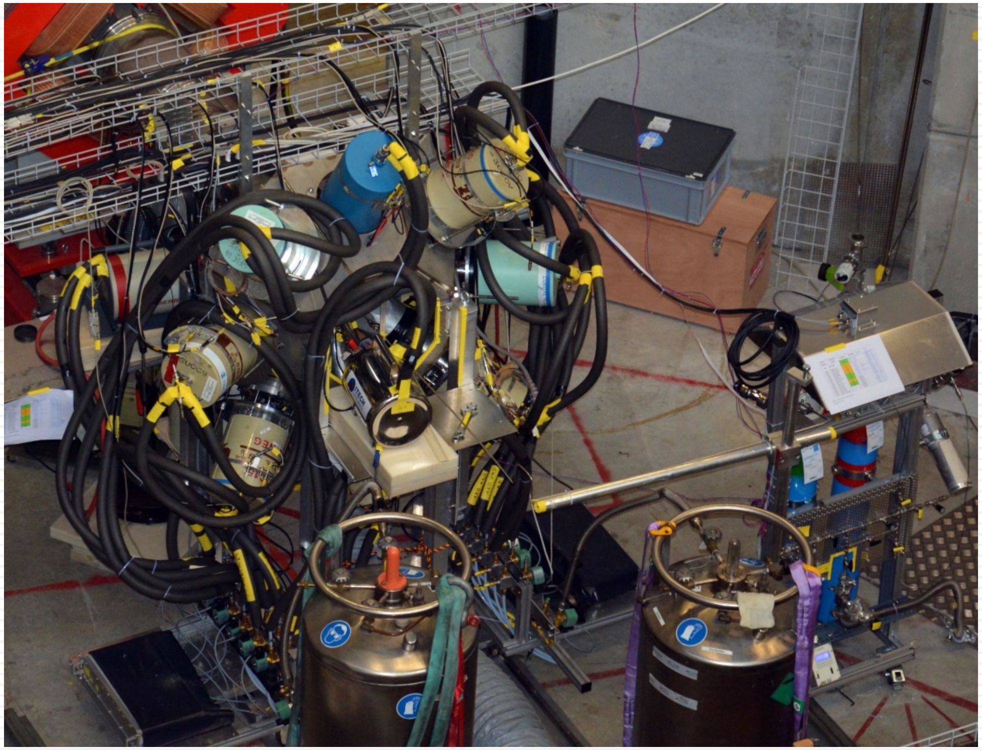




0ν2β-decay	0ν2β-Exper-ts	OMC targets	Quant-ty
^{136}Xe	nEXO, KamLAND2-Zen, NEXT, DARWIN, PandaX-III	^{136}Ba (95.27%)	2 g
---	---	^{nat}Ba	2 g

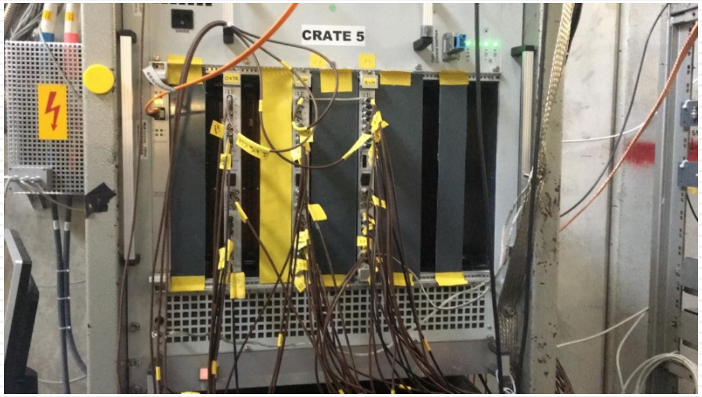
Detection system and DAQ

- **Set of 8 HPGe detectors :**
  4 n-type: 2 low-energy-region (PSI+UZH) + 2 coaxial (PSI+JINR(has to be procured))
  4 p-type: 2 BEGe (TUM+UZH) + 1(2) inverted coaxial (TUM+JINR(going to be procured after 2020 campaign))
  In addition we have 2 p-type coaxial detectors which can be used as back-up



- **Beam profile control**
- **C0** (aperture defining veto counter)
- **C1-C2** (pass-through counters)
- **C3** (cup-like counter)

- **DAQ:** 2 SIS 3310 digitizers@250 MHz
  MIDAS DAQ
  MIDAS slow control
  Online analysis
  Data backup



Objectives and estimated results:

- The present project is extended to DBD nuclei in the atomic mass number region between 70 to 140;

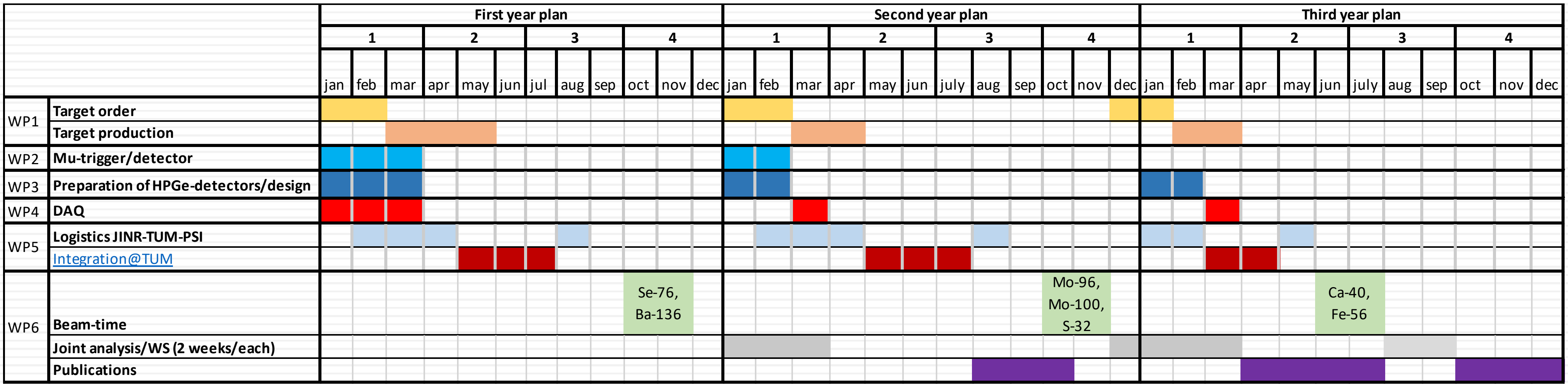
Target	Enrichment	Main purpose	Year
^{136}Ba	95.27 %	Partial cap.rates for NME for DBD	2021
^{nat}Ba	--	Identification for enriched Ba	2021
^{100}Mo	99.8 %	Astroneutrinos	2022
^{96}Mo	99.78 %	Partial cap.rates for NME for DBD	2022
^{nat}Mo	--	Identification for enriched Mo	2022
^{76}Se	99.7 %	Partial cap.rates for NME for DBD	2021
^{40}Ca	99.81 %	g_A testing with SM	2023
^{56}Fe	99.9 %	g_A testing with SM	2023
^{32}S	99.95 %	g_A testing with SM	2023

Objectives and estimated results:

We propose to carry out a research program which includes three beam time periods at the πE1 beam line of PSI over three years to pursue the following scientific objectives:

- Measurement of the total muon capture rates in the isotopically enriched isotopes ^{96}Mo, ^{100}Mo, ^{40}Ca, ^{56}Fe and ^{32}S. The measurements relate to the NME calculations for the DBD of ^{96}Zr (first stage for the extraction partial capture rates). The ^{100}Mo total capture rates is required for the investigation of astro-physical neutrino properties. The measurements of the total muon capture rates of last three isotopes - ^{40}Ca, ^{56}Fe and ^{32}S - are instrumental to extract the partial capture probabilities in order to test nuclear shell model (SM) calculations. Publication in Nucl.Phys.A is foreseen.
- Extraction of the partial muon capture rates to the bound states in ^{76}As, ^{96}Nb, ^{100}Nb, ^{40}K, ^{56}Mn and ^{32}P following OMC in ^{76}Se, ^{96}Mo, ^{100}Mo, ^{40}Ca, ^{56}Fe and ^{32}S, respectively. Comparison with the calculated nuclear matrix elements which will be carried out by theory groups (not funded through this proposal). We plan for a joint publication with theory colleagues in a high-impact journal, such as Phys. Rev. C.
- The radioactive production rates will be compared with the proton and neutron emission model to derive the muon-capture strength function and the associated giant resonance (GR) peak. These results will be compared with recent theoretical results. Separate publications, in either Nucl. Phys. A or Phys. Rev. C, are anticipated for these theory/experiment comparisons.
- The muonic X-rays spectra measured in OMC will be implemented to the already existing Mesoroentgen electronic catalogue (muxrays.jinr.ru).

Detailed project plan:



WP1 - Procurement of target material and production of target cells;

WP2 - Production and characterization of muon trigger, beam profile;

WP3 - HPGe detectors (cryostats, detector holders design, constructive production)

WP4 - Data acquisition system (accommodation to setup, software optimization)

WP5 - Detector integration at TUM (testing of the detectors, setup, DAQ with detectors)

WP6 - Data taking at PSI, processing and off-line analysis, publications

Project MONUMENT Form No. 26

Expenditures, resources, financing sources			Costs (k$) Resource Require-ments	Proposals of the Laboratory on the distribution of finances and resou-s		
				1st yr	2nd yr	3rd yr
Expenditures		Target materials (enriched stable isotopes, holders for the target, target itself)	40	16	8	16
		Materials for the muon veto counters (scintillators, PMTs,WLS fibers, adapters, SiPMs, mechanics)	18	15	3	0
		Components and materials for R&D (optic glue, cables, connectors, instruments, etc.)	5	2	3	0
		HPGe detectors	130	75	55	0
		Electronics for the detectors and mu-trigger (VME- and NIM-crates and devices, PC and additional hard disks for data)	34	20	12	2
		Total	**227**	**128**	**81**	**18**
Requi-d resourc e-s	Standard hour	Resources of – Laboratory design bureau – Laboratory experimental workshop	300 600	100 200	100 200	100 200
Financing sources	Budg etary reso urces	**Budget expenditures including foreign-currency resources.**	**227**	**128**	**81**	**18**
	External resource s	*Contributions by collaborators.* *Grants* *(these funds are not currently guaranteed)*	*20* *15*	*10* *15*	*5* *5*	*5* *5*

Project MONUMENT Form No. 29

NN	Expenditure items	Full cost	1st yr	2nd yr	3rd yr
	Direct expenses for the Project				
1.	Computer connection	$ 6 k	2	2	2
2.	Design bureau	300 std hours	100	100	100
3.	Experimental Workshop	600 std hours	200	200	200
4.	Materials	$ 63 k	33	14	16
5.	Equipment	$ 164 k	95	67	2
6.	Transportation of equipment	$ 30 k	10	10	10
7.	Collaboration meetings and workshops	$ 15 k	5	5	5
8.	Travel allowance, including: a) non-rouble zone countries b) rouble zone countries c) protocol-based	$ 100 k $ 100 k - -	35 35 - -	35 35 - - -	30 30 - -
	Total direct expenses:	**$ 378 k**	**180**	**133**	**65**

JINR group participation :

Name	Catego-ry	Responsibilities	Full Time Equivalent (FTE)
V.V. Belov	junior researcher	MC simulation, data analysis	0.4
V.B. Brudanin	Head of department	Administrative work, coordinator	0.2
K. N. Gusev	senior researcher	HPGe detector's array coordinator , logistics, mounting, testing	0.4
I.V. Zhitnikov	junior researcher	Data analysis	0.3
D. R. Zinatulina	senior researcher	Management and participation in all works	1.0
S.V. Kazarcev	junior researcher	Muon trigger system, mounting, data taking	0.6
N.S. Rumyantseva	junior researcher	Data taking and data analysis	0.6
M. V. Fomina	junior researcher	Preparation, logistics, data analysis	0.3
M.V. Shirchenko	senior researcher	Deputy leader, data analysis coordinator	1.0
Yu.A. Shitov	Head of sector	Data taking and data analysis	0.3
E.A. Shevchik	senior engineer	Detector array and holders design, muon trigger, beam profile control	0.5
Total FTE (engineers): 0.5, Total FTE (Scientific): 5.1, TOTAL FTE: 5.6			

SWOT analysis:

The major **strengths** of the project:

- using isotopically enriched elements as targets for muon capture;
- using a monochromatic and narrow-collimated negative muon beam;
- using the beam profile monitoring system;
- using the active muon trigger;
- using a data acquisition system (DAQ) on fast flash ADC;
- normalization by the number of incoming muons stopped in each chemical element;
- precision measurement of time (due to fast scintillator counters) and energy distributions of γ-rays using a set of HPGe detectors of various volumes with high energy resolution.

Weaknesses of the project:

- strong decrease of the detection efficiency in the energy range above 3-4 MeV;
- large contribution of statistical measurement uncertainty into the final balance of the partial capture rates for the corresponding states of the daughter nucleus;
- imperfection of the calculated NME models for muon capture at the moment, which may cause an incorrect interpretation of the experimental results from the point of view of the calculated models.

Potential competitors to our project in the coming years could be only previously conducted measurements of the (n,p) and (p,n) charge-exchange reactions.

Conclusions and outlook:

- OMC is the sensitive tool to probe properties of DBD process. It is based on mature experimental technique successfully developed during many years, which demonstrates satisfactory agreement between experimental and theoretical data;

- The unique information obtained at OMC will provide a significant experimental contribution to the theory of ββ decay and astropartical physics researches. In particular, in case of observed 0νββ decay the **OMC results will help improve nuclear matrix elements calculations to define the effective Majorana neutrino mass.** Leading ββ decay theorists have shown serious interest in obtaining this new experimental information;

- An intensive multi-year PSI beam research program was proposed:

  -- In **2021 year** the ^{136}Ba/^{nat}Ba and ^{76}Se will be measured at πE1-2 PSI beamline for 3 weeks

  -- In **2022 year** the ^{100}Mo, ^{96}Mo and ^{32}S will be measured at πE1-2 PSI beamline for 4 weeks

  -- In **2023 year** the ^{40}Ca, ^{56}Fe will be measured at πE1-2 PSI beamline for 3 weeks

Back Slides

Contributions:

- Paul Sherrer Insitute (PSI), Switzerland: A.Knecht, S.M. Vogiatzi – mounting, data taking, administrative work at PSI, data analysis;
- Technische Universität München (TUM), Germany: T. Comellato, M. Schwarz, S.Schönert, C. Wiesinger – HPGE detectors, logistics, holders for the detectors, data taking and analysis, software for DAQ;
- University of Alabama (ALABAMA), USA: I.Ostrovskiy – ^{136}Ba, data taking, publication preparation;
- University of Jyväskylä, Finland: I.Suhonen, L. Jokiniemi – NME calculations, interpretation experimental data with NME models, publications;
- Physik-Institut, University of Zurich (ETH),Switzerland: L.Baudis – administrative work, HPGe detector;
- KU Leuven, Belgium: T. Cocolios – shifts during data taking, mounting;
- Research Center on Nuclear Physics (RCNP), Osaka University, Japan:H. Ejiri – offline analysis, interpretation experimental data to the proton-neutron model, publication preparation;
- Universiti Teknologi Malaysia (UTM), Malaysia.:I.H. Hashim, F. Othman – data taking, offline analysis, calculations with proton-neutron model.

μX collaboration and JINR group

Addendum to proposal R-16-01.1 ("Muon capture on double beta decay nuclei of ^{130}Xe, ^{82}Kr and ^{24}Mg to study neutrino nuclear responses")

A. Adamczak[1], A. Antognini[2,3], N. Berger[4], T. Cocolios[5], R. Dressler[2], C. Du¨llmann[4], R. Eichler[2], P. Indelicato[6], K. Jungmann[7], K. Kirch[2,3], A. Knecht[2], J. Krauth[4], J. Nuber[2], A. Papa[2], R. Pohl[4], M. Pospelov[8,9], E. Rapisarda[2], D. Renisch[4], P. Reiter[10], N. Ritjoho[2,3], S. Roccia[11], N. Severijns[5], A. Skawran[2,3], S. Vogiatzi[2], F. Wauters[4], and L. Willmann[7]

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[2]Paul Scherrer Institut, Villigen, Switzerland
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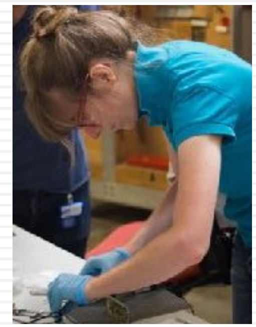
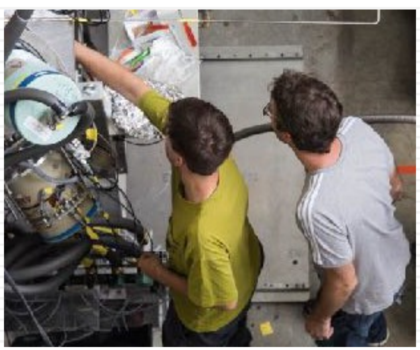
[6]LKB Paris, France
[7]University of Groningen, The Netherlands
[8]University of Victoria, Canada
[9]Perimeter Institute, Waterloo, Canada
[10]Institut fu¨r Kernphysik, Universita¨t zu Ko¨ln, Germany
[11]CSNSM, Universit´e Paris Sud, CNRS/IN2P3, Orsay Campus, France

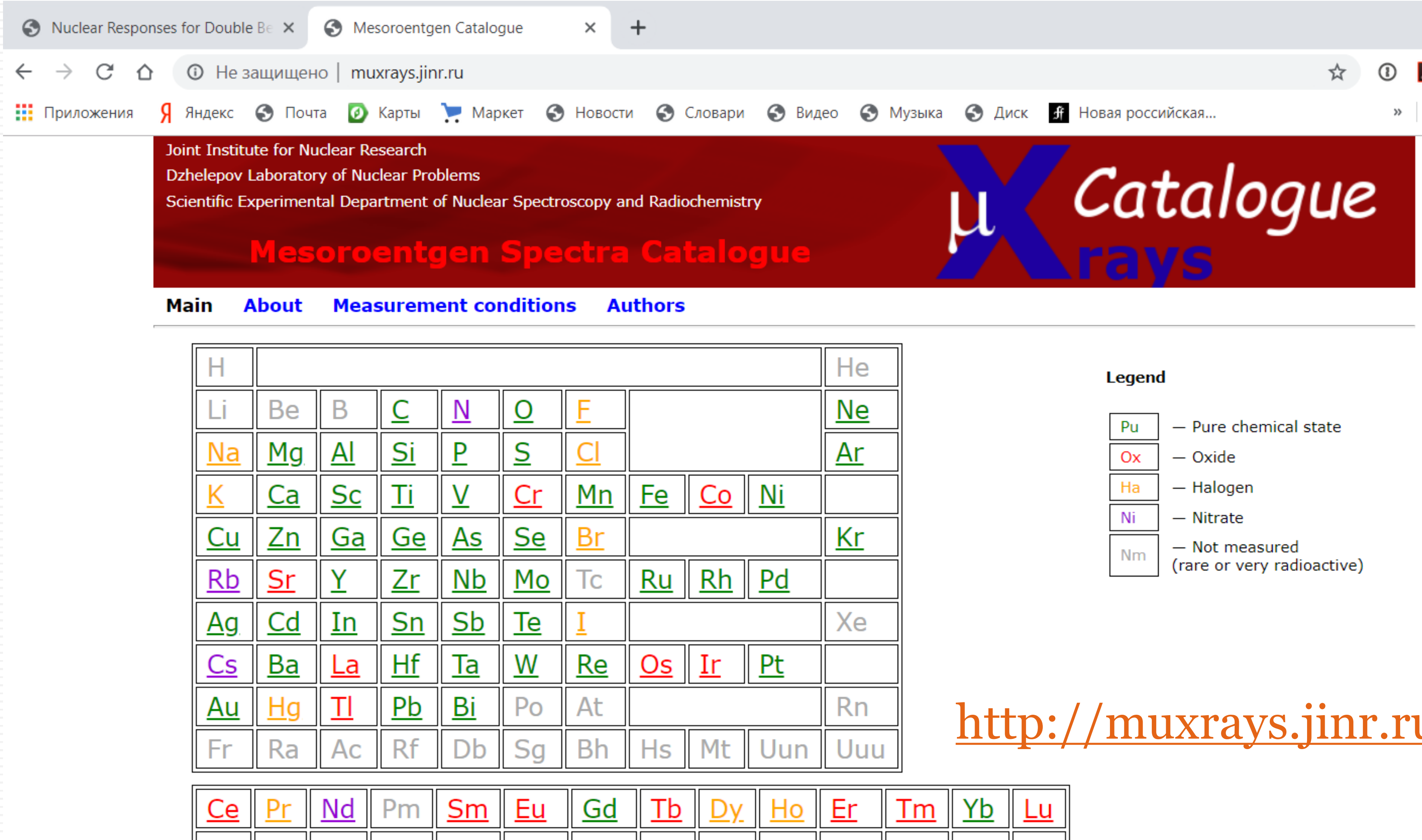








Muonic X-rays Catalogue



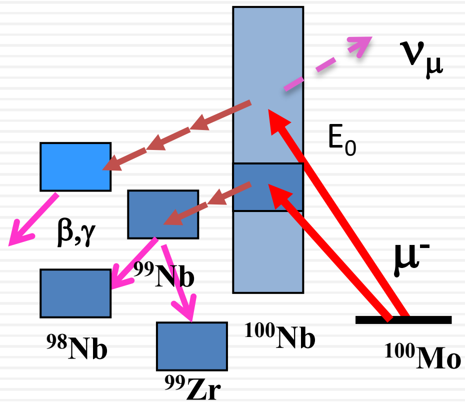
http://muxrays.jinr.ru/

More than 75 chemical elements, PSI, μE1 и μE4 (The information from the μX-ray spectra catalogue is important! (It helps us to identify γ-lines, background, and gives correct selection of the targets and construction materials for different experiments with muons)

Publications:

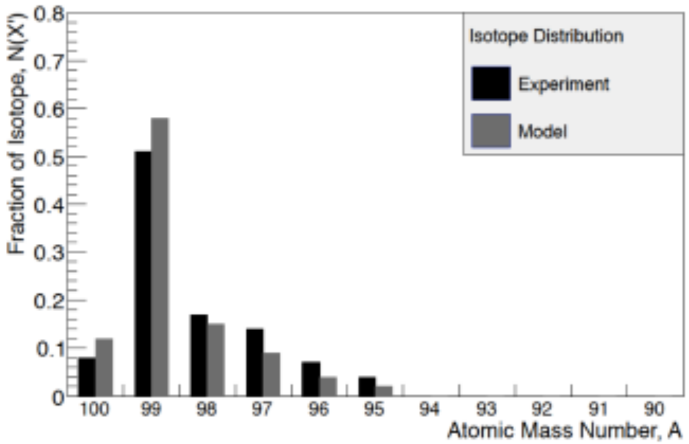
1. Ordinary muon capture studies for the matrix elements in $\beta\beta$ decay / *D. Zinatulina, V. Brudanin, V. Egorov et al.* // Phys. Rev. C . - 2019 . - Feb . - Vol. 99 . - P. 024327.
2. μCR42β: Muon capture rates for double-beta decay / *V. G. Egorov, V. B. Brudanin, K. Ya. Gromov et al.* // Czechoslovak Journal of Physics . - 2006 . - May . - Vol. 56, no. 5 . - Pp. 453–457.
3. Ordinary muon capture (OMC) studies by means of γ-spectroscopy / *D. Zinatulina, V. Brudanin, V. Egorov et al.* // AIP Conf. Proc . - 2017 . - Vol. 1894, no. 1 . - P. 020028.
4. Muon capture in Ti, Se, Kr, Cd and Sm / *D. Zinatulina, K. Gromov, V. Brudanin et al.* // AIP Conf. Proc . - 2007 . - Vol. 942 . - Pp. 91–95.
5. OMC studies for the matrix elements in $\beta\beta$ decay / *D. Zinatulina, V. Brudanin, Ch. Briançon et al.* // AIP Conf. Proc . - 2013 . - Vol. 1572 . - Pp. 122–125.
6. Muon capture rates in Se and Cd isotopes / *D. R. Zinatulina, K. Ya. Gromov, V. B. Brudanin et al.* // Bulletin of the Russian Academy of Sciences: Physics . - 2008 . - Jun . - Vol. 72, no. 6 . - Pp. 737–743.
7. Negative-muon capture in ^{150}Sm / *D. R. Zinatulina, Ch. Briançon, V. B. Brudanin et al.* // Bulletin of the Russian Academy of Sciences: Physics . - 2010 . - Jun . - Vol. 74, no. 6 . - Pp. 825–828.
8. Electronic catalogue of muonic X-rays / *D. Zinatulina, Ch. Briançon, V. Brudanin et al.* // EPJ Web Conf . - 2018 . - Vol. 177 . - P. 03006.
9. Электронный каталог мезорентгеновских спектров излучения/ *Д. Зинатулина* //Ядерная Физика. - 2019. - Vol. 82, no. 3. - Pp. 228-234.

Comparison experimental OMC results with theoretical calculations

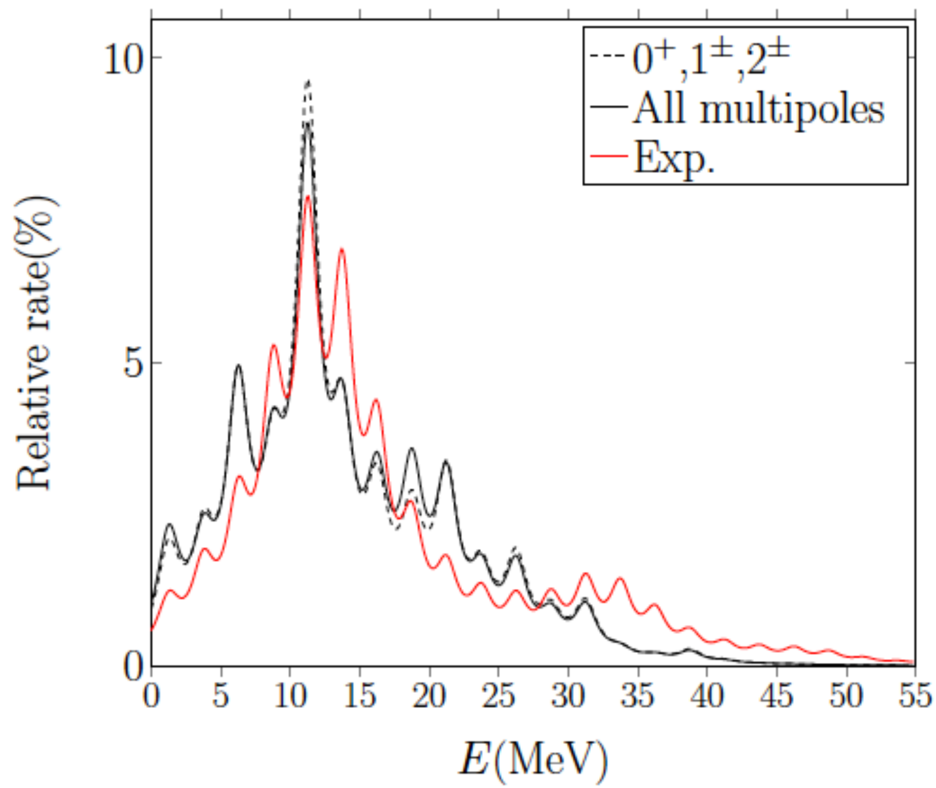


OMC in ^{100}Mo

Calculation by proton and neutron emission model provides initial capture strength ^{100}Nb after muon capture



Population of RI $^{100-x}$Nb isotopes after muon capture on ^{100}Mo.



Comparison of the measured and computed relative OMC capture rates for the OMC on ^{100}Mo. Two theoretical distributions are shown, the total one and the one containing the main contributing multipolarities.

Distribution of initial strength can provide the final nuclei isotope population (**PRC 97(2018) 014617 (J-PARC 2014)**)

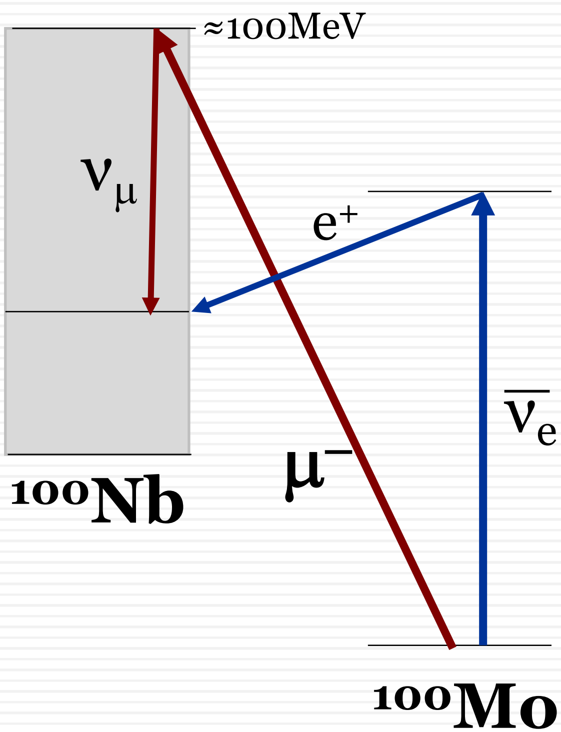
L. Jokiniemi, J. Suhonen, H. Ejiri, and I.H. Hashim, Phys. Lett. B 794 (2019) 143

Astrophysics with ^{100}Mo

- Astro neutrino (including solar and supernovae neutrino study) observation provides evidences for neutrino matter oscillation, nuclear fusion reaction in sun and as tools for probing the supernovae (SN) explosion process

- It was proposed to measure SN antineutrinos on ^{100}Mo (MOON) [1, 2]

- OMC in ^{100}Mo will give experimental input for theoretical calculations of this process



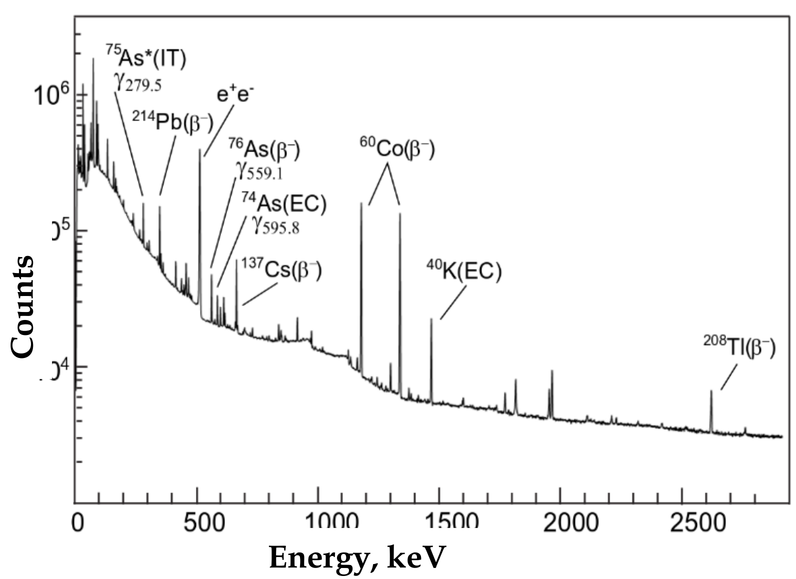
^{100}Mo($\bar{\nu}_e$, e^+)^{100}Nb (SN)

^{100}Mo(μ^-, e^+)^{100}Nb (OMC)

[1] H.Ejiri, J.Suhonen, K.Zuber. // Phys. Rep 797 (2019) 1 – 102

[2] H.Ejiri, J.Engel, N. Kudomi // PLB 530 (2002) 27-32

Results measured with U-spectra in ^{76}Se and ^{150}Sm



Isotope	Decay type	$T_{1/2}$	$\lambda_{cap}(xn)$ (10^6 s^{-1})	P_{cap}
^{76}As	β^-	26.3 h	0.86(3)	13.65(255)
^{75m}As	IT	17.6 ms	0.41(7)	6.5(11)
^{75}As	stable		unmeasured	
^{74}As	β^-, EC	17.8 d	1.1(2)	17.5(32)
^{73}As	EC	80.3 d	unmeasured	
^{72}As	β^+	26 h	0.15(3)	2.4(5)
^{71}As	β^+	65.3 h	0.061(18)	0.96(28)
^{75m}Ge	IT	48 s	0.047(13)	0.75(21)
^{75}Ge	β^-	82.8 min	0.054(2)	0.86(3)
^{71m}Ge	IT	20 ms	0.020(3)	0.32(5)
^{74}Ga	β^-	8.1 min	0.026(6)	0.40(9)
^{72}Ga	β^-	14.1 h	0.026(7)	0.40(11)
				$\sum$=43.7(43)
^{150}Pm	β^-	2.68 h	1.45(11)	12.3(9)
^{149m}Pm	IT	35 μs	1.80(31)	15.3(26)
^{149}Pm	β^-	53.1 h	2.93(60)	24.9(51)
^{148}Pm	β^-	5.37 d	0.77(26)	6.6(22)
^{148m}Pm	IT	41.3 d	0.10(2)	0.85(17)
^{148m}Pm	β^-	41.3 d	0.21(6)	1.79(51)
^{149}Nd	β^-	1.73 h	0.78(35)	6.6(29)
^{148}Nd	stable		unmeasured	
				$\sum$=68.3(69)

Background radiation (**Uncorrelated** spectra) –

- calibration of the det-s,
- identification,
- yields of short-lived RI during exposure