General OMC4DBD collaboration on-line meeting, 25 – 26th April 2021

PAUL SCHERRER INSTITUT

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UNIVERSITY OF JYVÄSKYLÄ

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NUCLEAR AND RADIATION PHYSICS

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BVR 53: Progress Report R-20-01.1

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

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Contributions:

- **Paul Sherrer Insitute (PSI),** Switzerland: **A.Knecht, S.M. Vogiatzi** – HPGe detectors, mounting, data taking, administrative work at PSI;
- **Joint Institute for Nuclear Research (JINR)**, Russia: **D. Zinatulina, V. Belov, M. Fomina, K. Gusev, , S. Kazartsev, N. Rumyantseva, E. Shevchik, M. Shirchenko, Yu. Shitov, E. Sushenok, I. Zhitnikov–** management, logistics, setup (targets, HPGe detectors, detectors frame, counters), mounting, data-taking and analysis, publications, theory calculations;
- **Technische Universität München (TUM),** Germany: **E. Bossio, T. Comellato, M. Schwarz, S.Schönert, C. Wiesinger, E. Mondragon** – HPGe detectors, logistics, data taking and analysis LLAMA, software for DAQ;
- **University of Alabama (ALABAMA),** USA: **I.Ostrovskiy, D. Bajpai** – ^{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, G. Araujo, J.Huang** – administrative work, HPGe detector, data-taking and analysis;
- **KU Leuven,** Belgium: **T. Cocolios, M. Heines** – shifts during data taking, mounting, data analysis;
- **Research Center on Nuclear Physics (RCNP),** Osaka University, Japan: **H. Ejiri** – interpretation experimental data for the proton-neutron model, publication preparation;
- **Universiti Teknologi Malaysia (UTM),** Malaysia.: **I.H. Hashim, F. Othman, Zh.W. Ng** – data taking, offline analysis, calculations with proton-neutron model.

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Funding:

- **Joint Institute for Nuclear Research (JINR)**, Russia:

  The project MONUMENT (OMC4DBD) officially supported by JINR

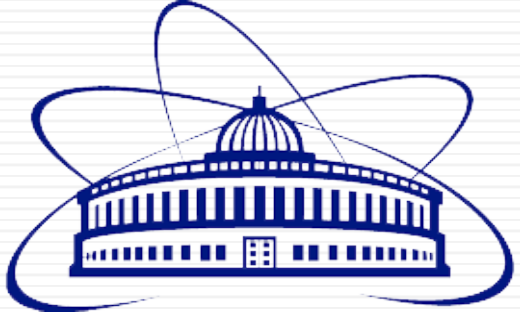
- **Swiss "Research Preparation Grants" in collaboration with Paul Sherrer Insitute (PSI) and JINR**:

  coordinator - **A.Knecht** (materials, equipment, transport expenses and part of accommodation during beam-time)

- **DFG-RFBR grant: "Joint German-Russian Project" (Technische Universität München (TUM) & JINR)**: -> the program was suspended for a while.

  coordinators **S.Schönert (from TUM)** and **D. Zinatulina (from JINR)** (materials, logistics, transportation, supporting PhD student, equipment expenses, part of accommodation during beam-time)

- **Research funding from Ministry of Higher Education Malasia (UTM)** Malaysia.: coordinator - **I.H. Hashim**



Joint Institute for Nuclear Research
Dzhelepov Laboratory of Nuclear Problems

General collaboration meeting, 25 - 26th April 2022

Ordinary Muon Capture (OMC4DBD) measurements in 2021 year at PSI

Daniya Zinatulina

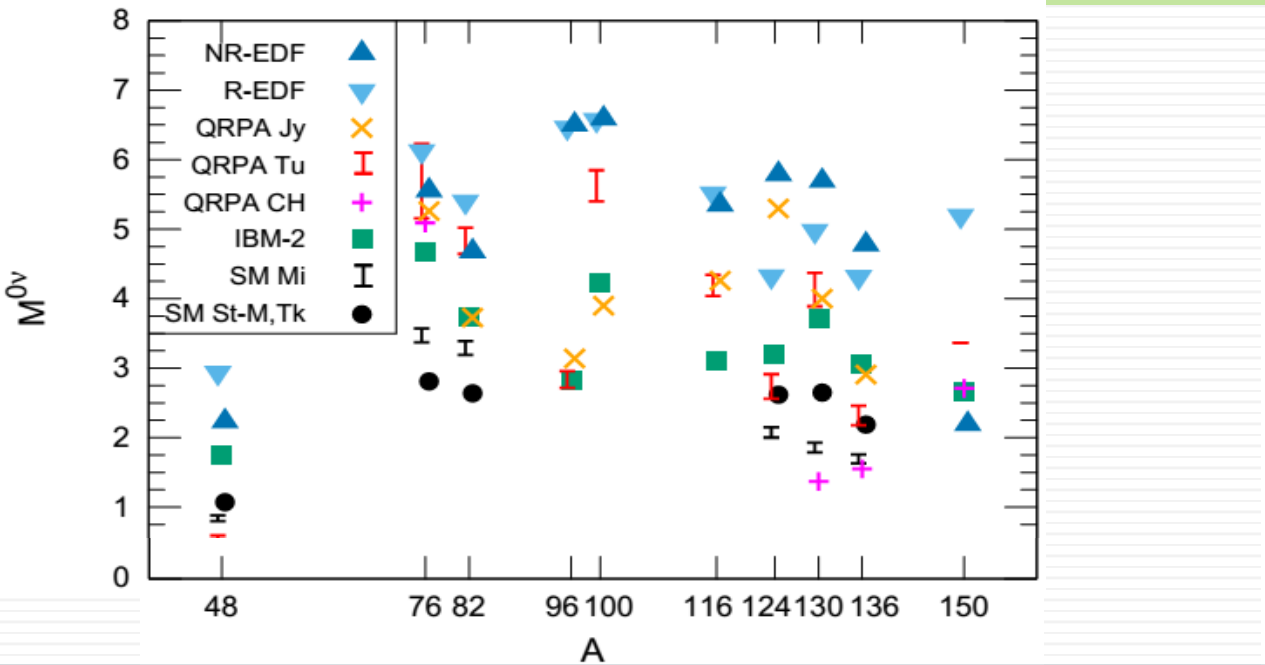
25.04.2022, *ZOOM*

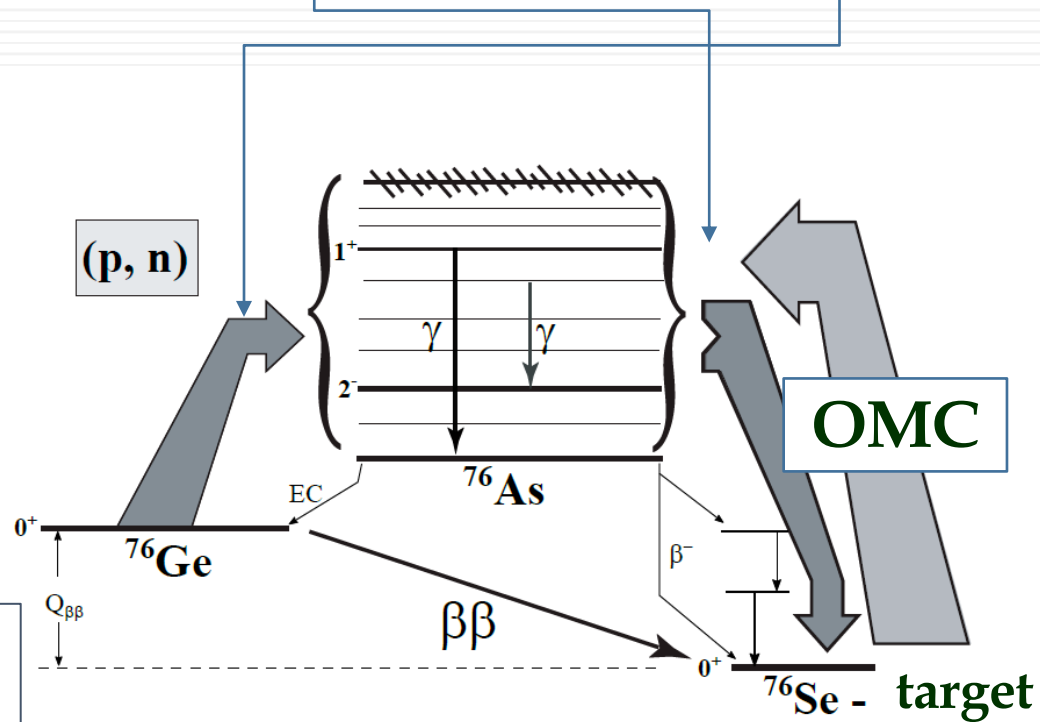
Experimental input for DBD NME calculations

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

$$\langle m_{\beta\beta} \rangle \qquad M^{0\nu}$$

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





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

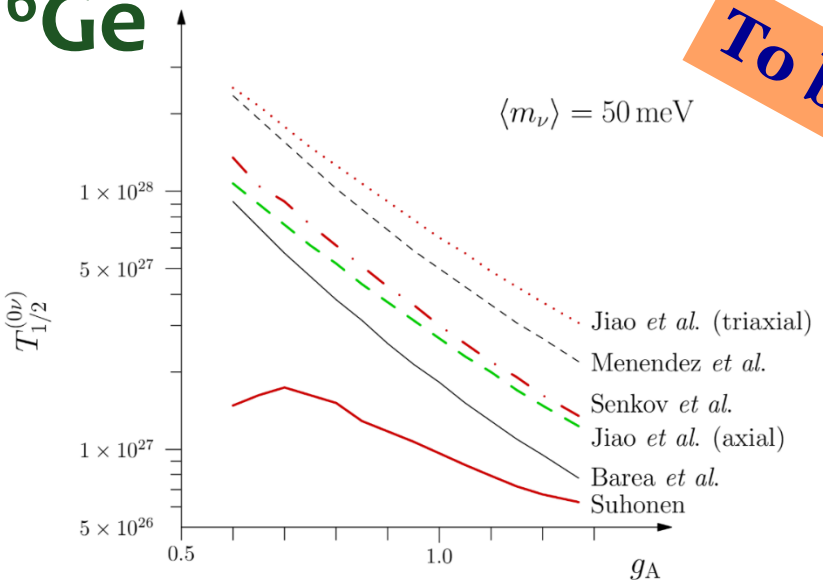
To be, or not to be, that is the quenching…

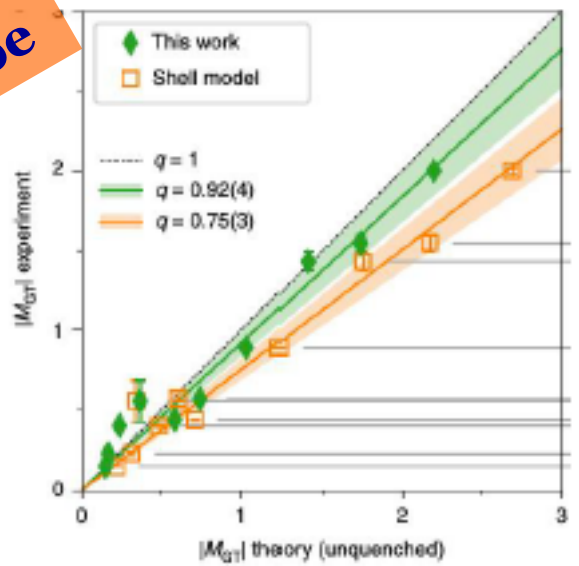
$$|\mathrm{NME}_{0\nu}|^2 \cong \left|M^{0\nu}_{GTGT}\right|^2 = \left(g_{a,0\nu}\right)^4 \left|\Sigma_{J^\pi}\left(\langle 0^+_f | O^{0\nu}_{GTGT} | 0^+_i \rangle\right)\right|^2$$

To be

or not to be

^{76}Ge





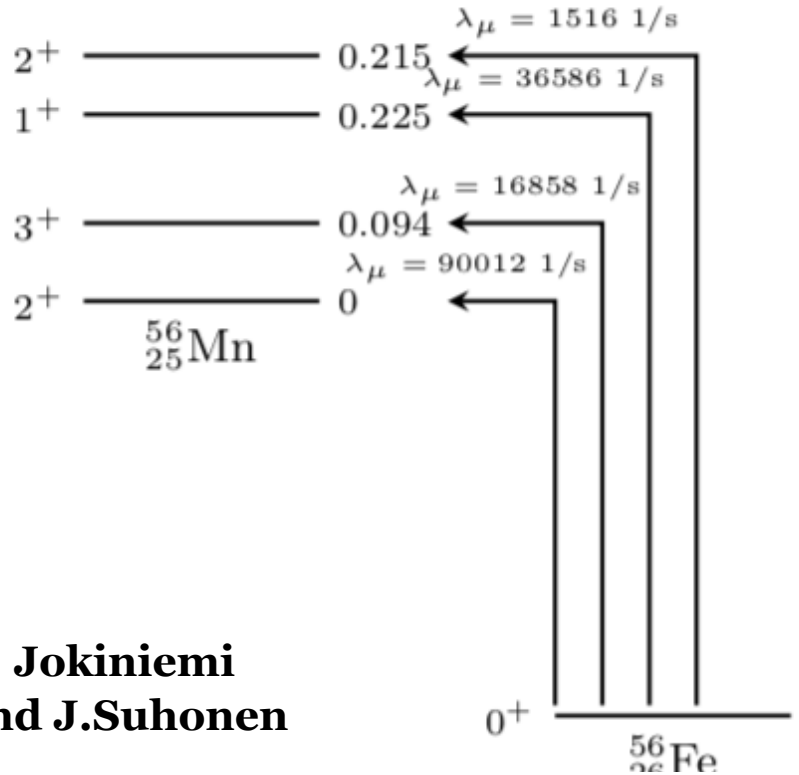
Gysbers et al. Nature Phys. 15 428 (2019)

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

Jiao et al.: **Phys.Rev. C 96** (2017)054310 (GCM+ISM)
Menendez et al.:**Nucl. Phys. A**818 (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)

Testing shell model calculations for ^{56}Fe, ^{24}Mg, ^{32}S (L. Jokiniemi talk in detail)

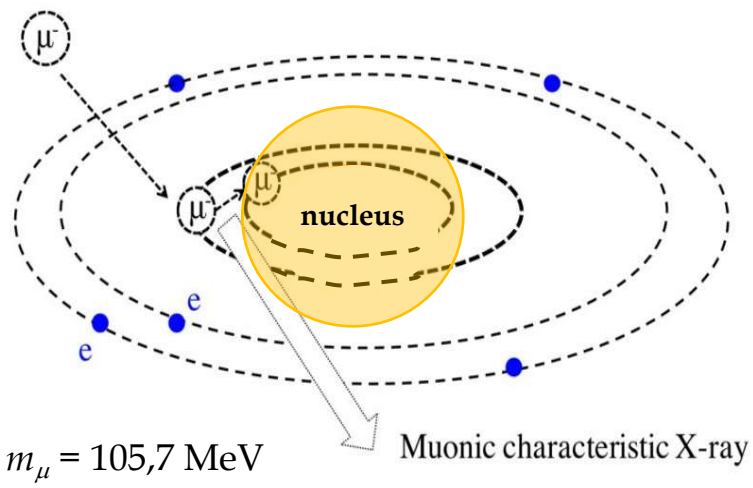
- The level scheme of light nuclei is very well known
- Experiment vs. theory
- Optimization for DBD candidates
- Testing g_A quenching



L. Jokiniemi and J.Suhonen

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

What do we get from the Ordinary Muon Capture (OMC)?



m_μ = 105,7 MeV

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

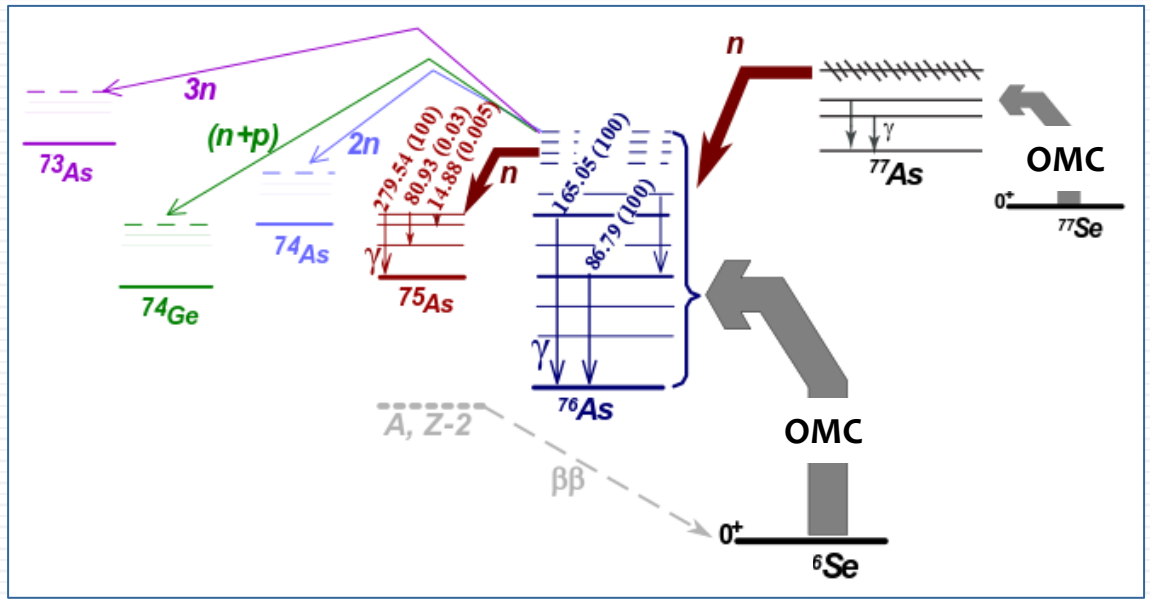
$(A, Z) + \mu^- \rightarrow (A, Z\text{-}1)^* + \nu_\mu$

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

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

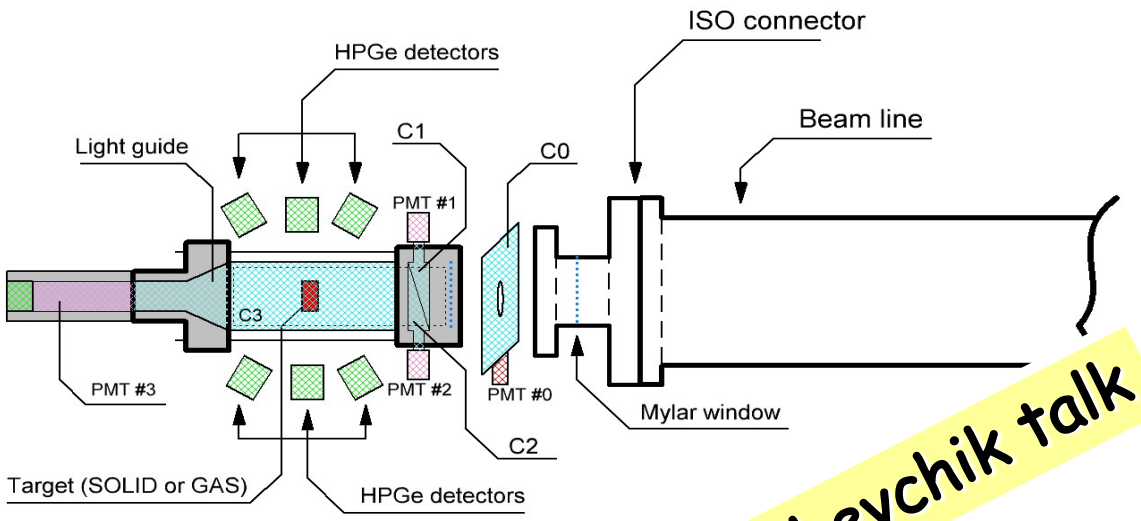
$\rightarrow (A\text{-}2, Z\text{-}1) + \gamma + 2n$

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

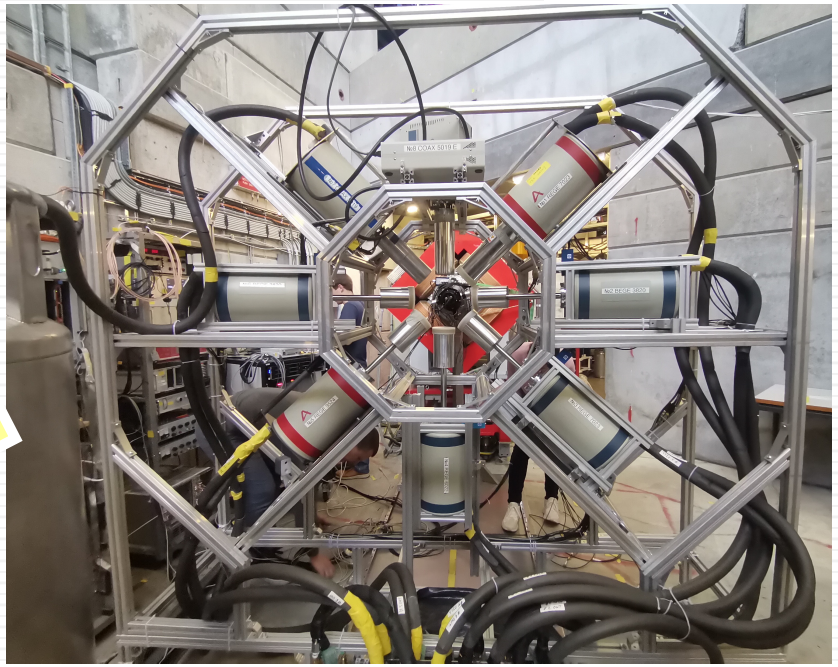


- ✓ **Muonic cascades** (our by-product)
- ➢ High momentum transfer (up to 100 MeV) – High-lying states population
- ✓ **Partial capture rates**
- ✓ **The radioactive production rates (yelds of isotopes/ isomers)**

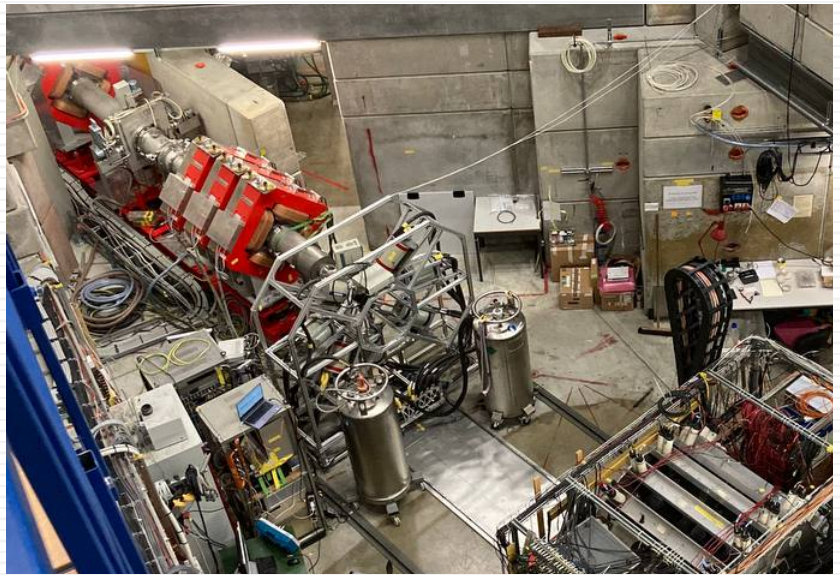
OMC measurements in 2021



E. Shevchik talk



0n2β-decay	0n2β-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
^{76}Ge	LEGEND	^{76}Se (99.97%)	2 g



Detection system and DAQ

Set of 8 HPGe detectors :

4 large-volume n-type coaxial detectors (REGe detectors) with thin beryllium entrance windows. Three detectors from PSI and one from TUM.

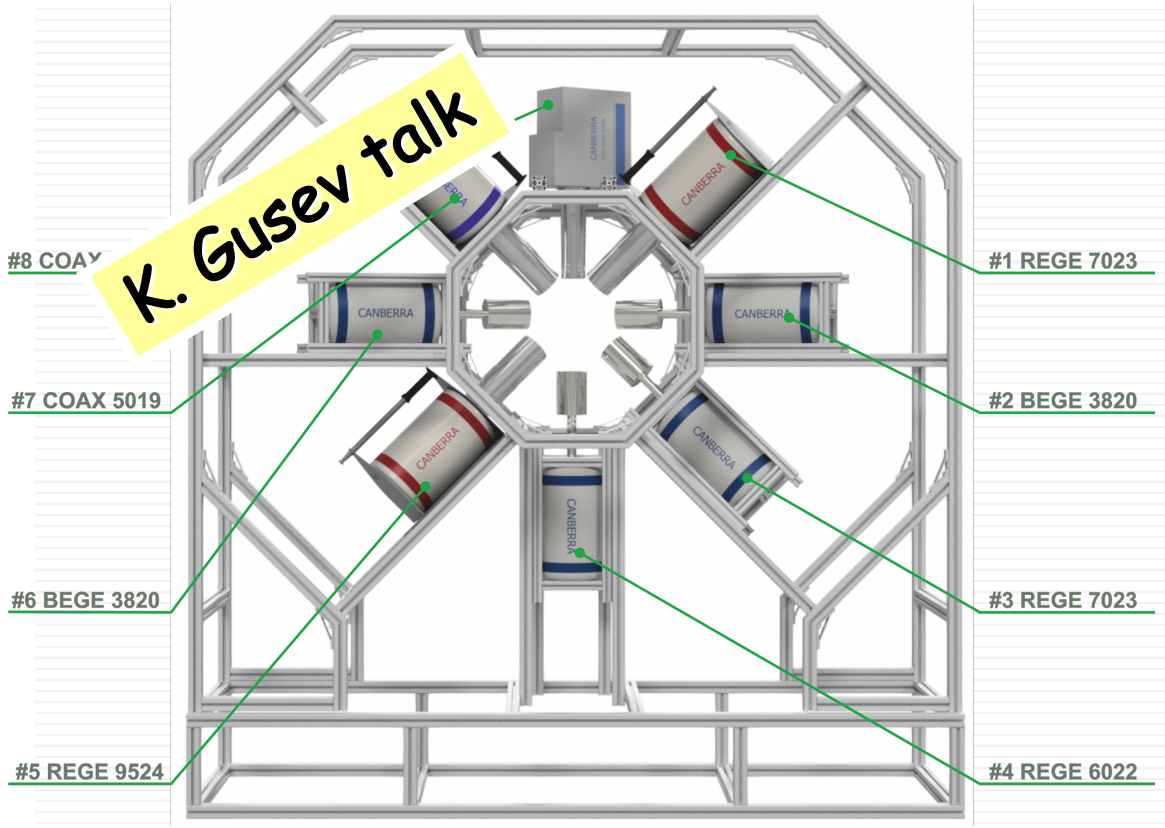
2 large-volume p-type coaxial detectors (COAX detectors), both from JINR.

2 relatively large-volume p-type BEGe detectors with thin beryllium entrance windows, both from PSI.

C0 (aperture defining veto counter)

C1-C2 (pass-through counters)

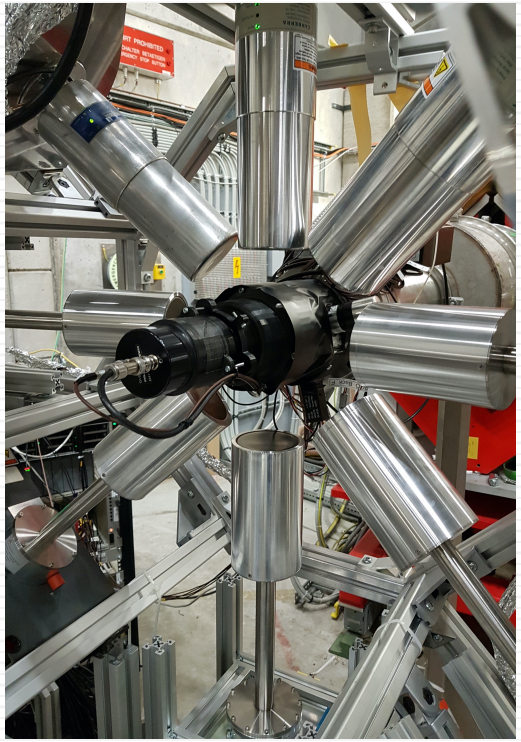
C3 (cup-like counter)

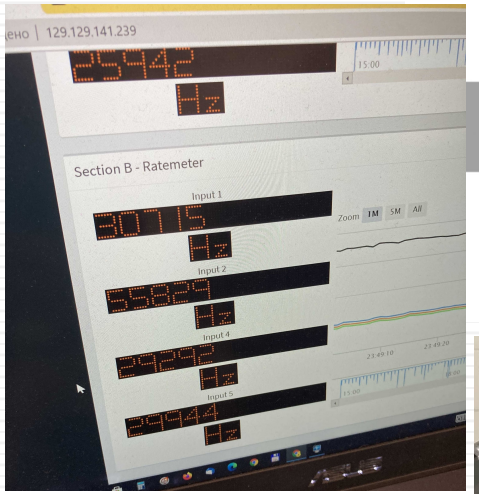


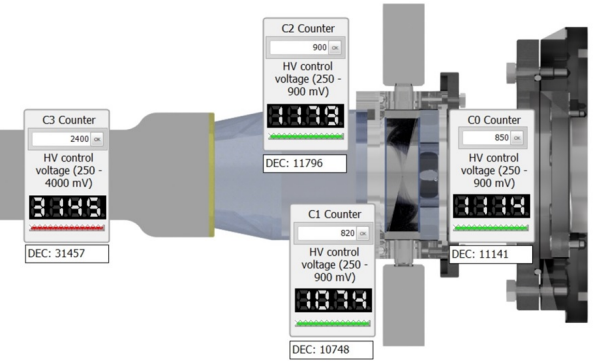
DAQ: 2 digitizers@250 MHz of MIDAS DAQ and LLAMA DAQ switched on in parallel (works independently)

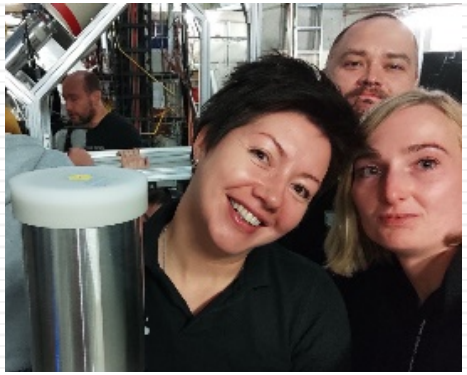
MIDAS slow control
Online analysis, data backup

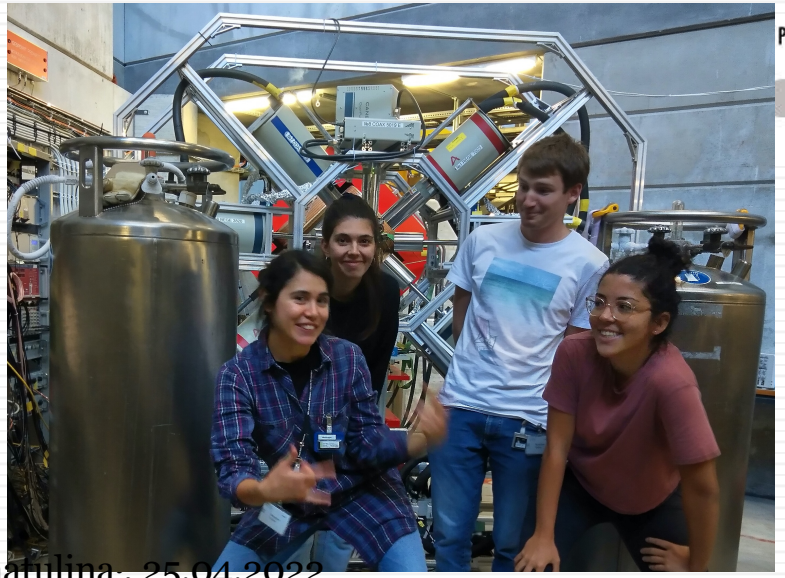
Measurements in 2021











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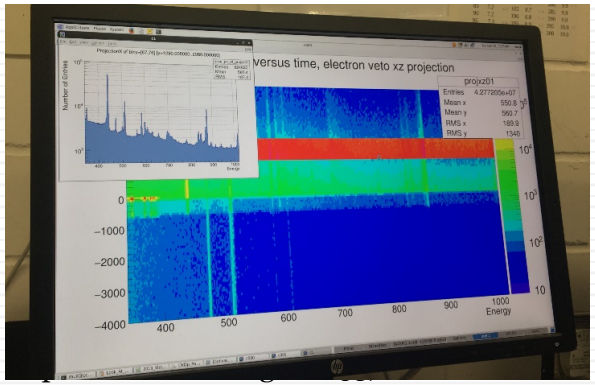
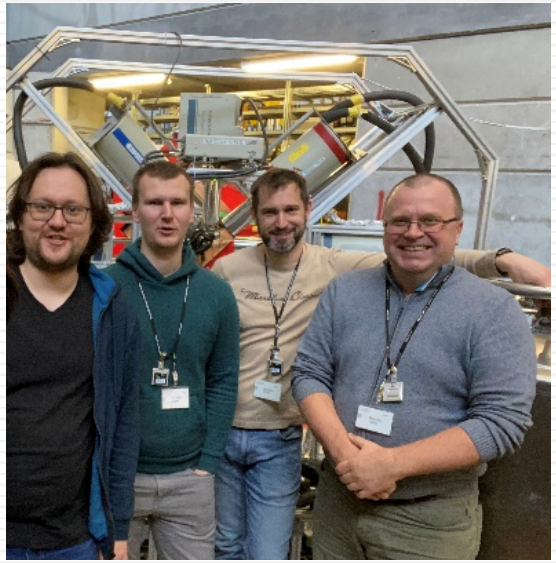
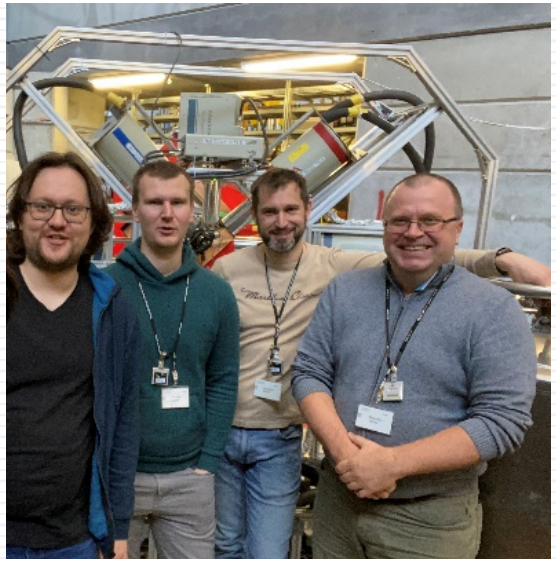
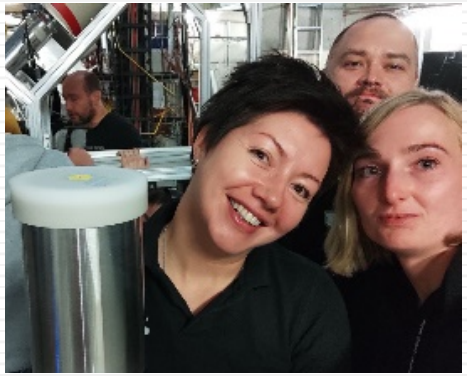
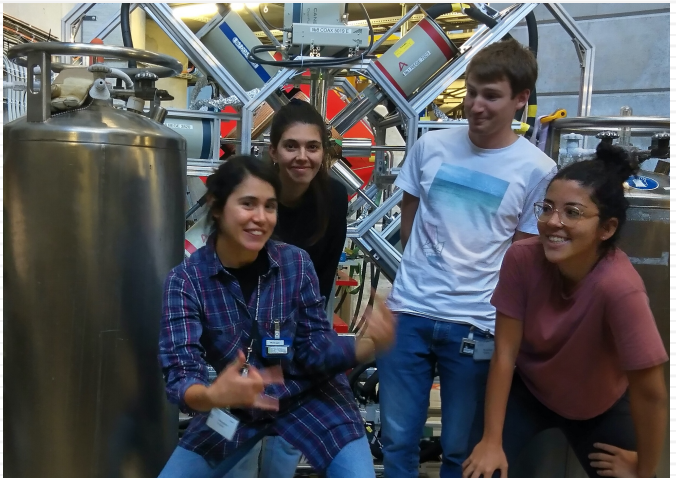




Measurements in 2021



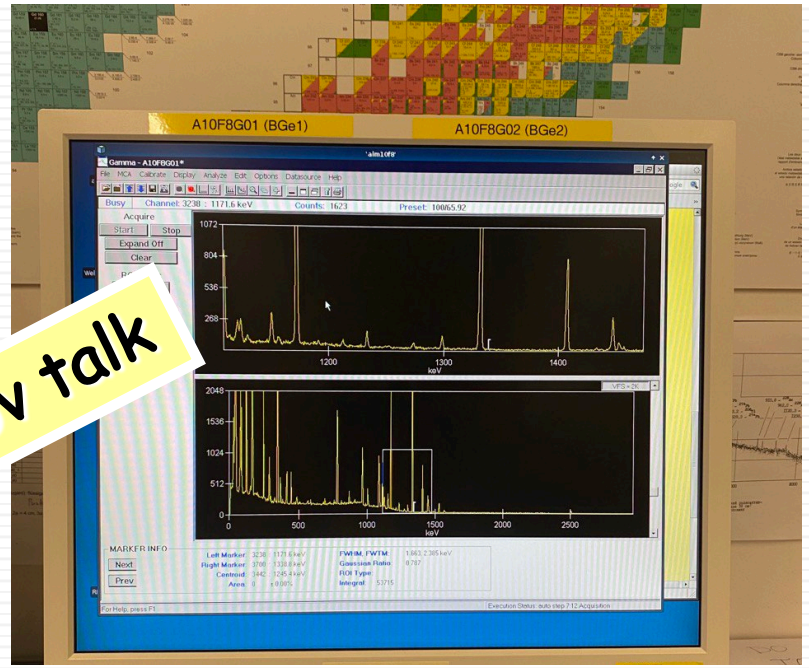


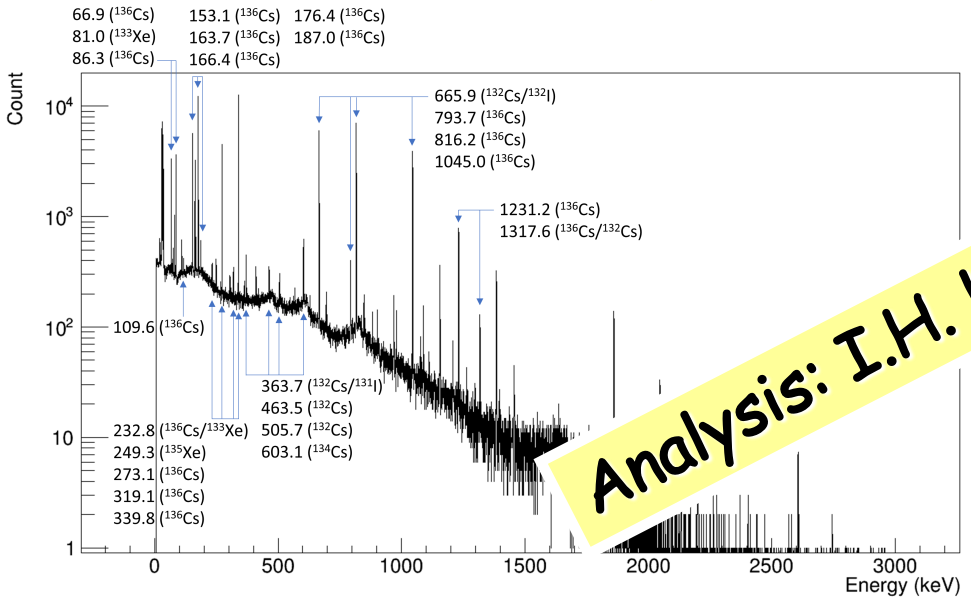


Step	Time
Equipment delivery	6.10.2021
Assembling and tuning of the setup	7.10.2021-11.10.2021
Calibration runs	11.10.2021-12.10.2021
^{nat}Ba measurements	12.10.2021-15.10.2021
^{136}Ba	20.10.2021-24.10.2021
Calibration runs	25.10.2021
^{nat}Se measurements	26.10.2021-28.10.2021
^{76}Se measurements	29.10.2021-3.11.2021
Calibration runs	4.11.2021
^{136}Ba measurements	5.11.2021-7.11.2021
Calibration runs	7.11.2021
Deconstruction	8.11.2021-10.11.2021

Off-line measurements @ LRC PSI

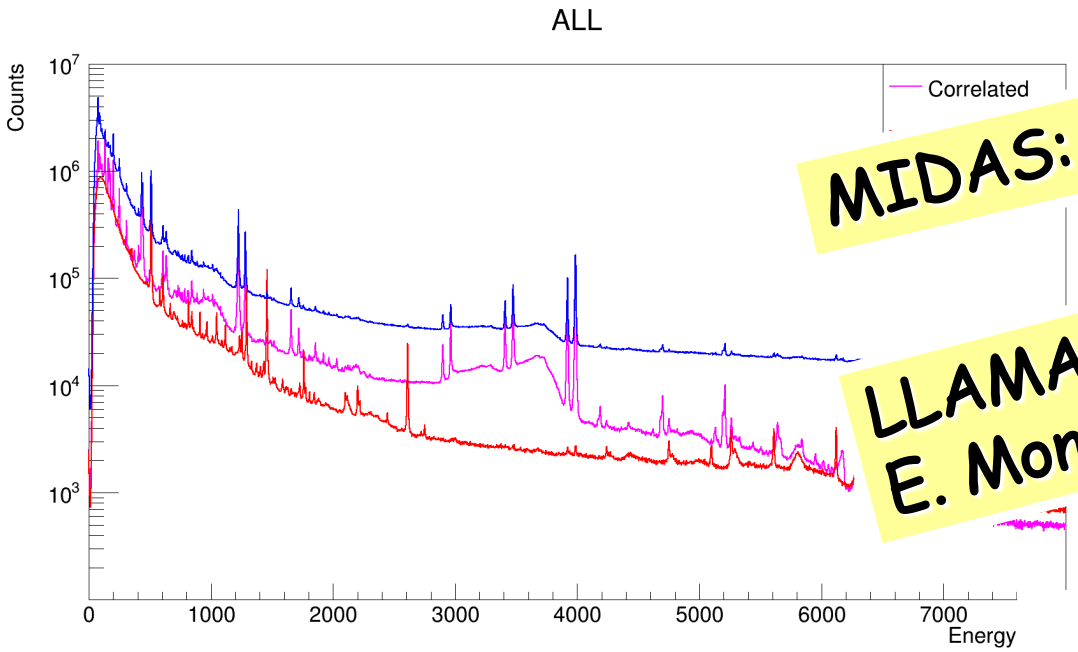
Meas-ts: V. Belov talk





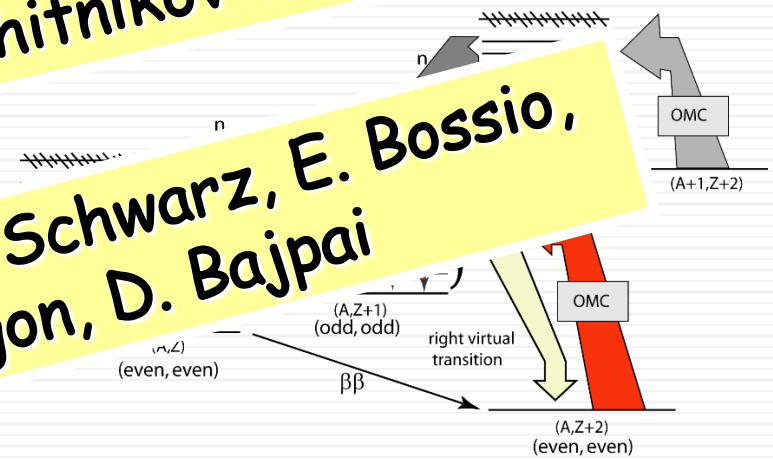
Analysis: I.H. Hashim& talk

Preliminary 2021 analysis of ^{136}Ba:

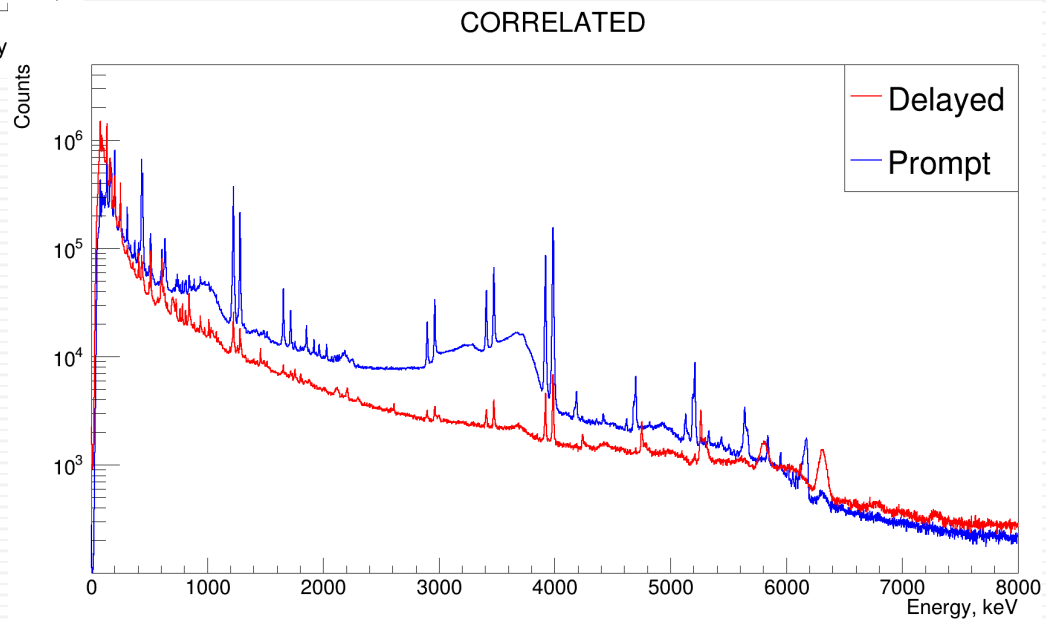


MIDAS: I. Zhitnikov talk

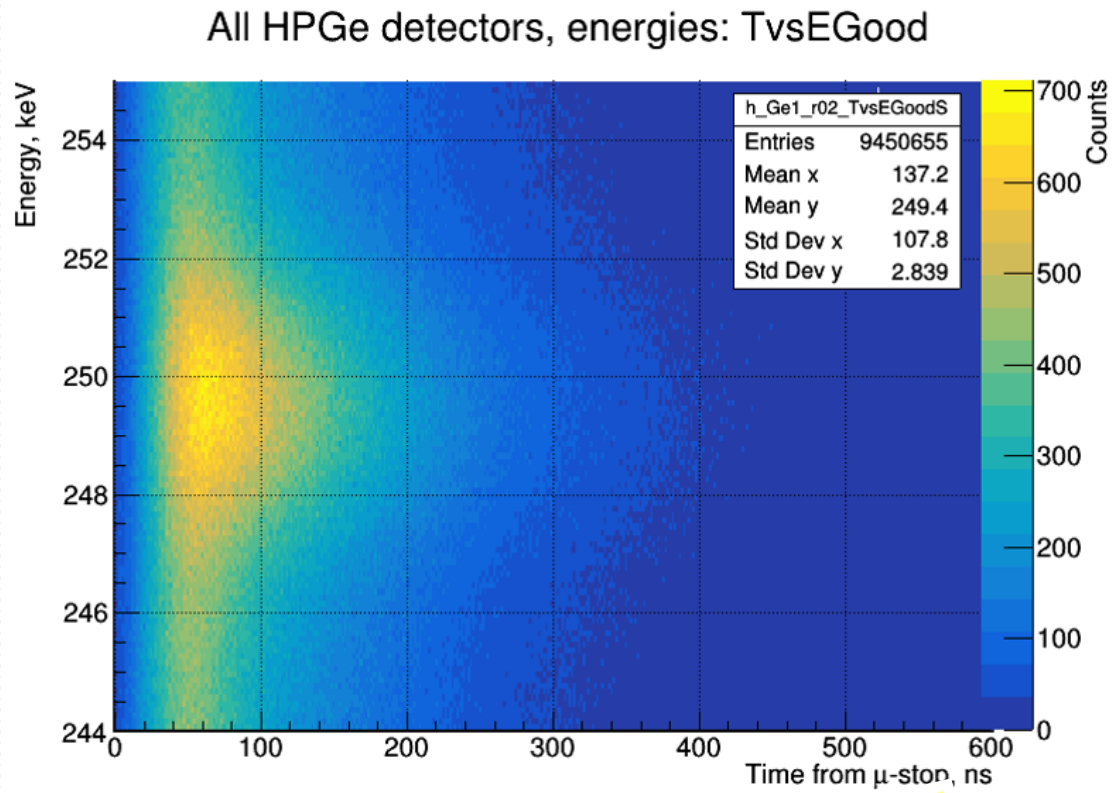
LLAMA: M. Schwarz, E. Bossio, E. Mondragon, D. Bajpai



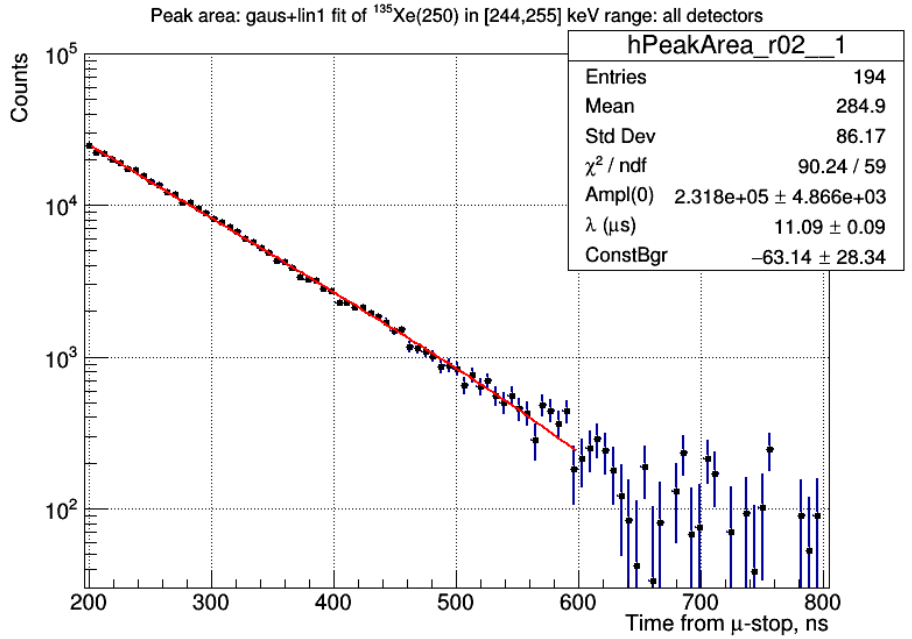
- $t_{\mu\gamma}$ = -100+1500 ns: μX and γ-radiation following OMC (**Correlated** spectra) – normalization, identification, composition of the surrounded materials and target itself;
- T >> $t_{\mu\gamma}$: background radiation (**Uncorrelated** spectra) – calibration of the det-s, identification, yields of short-lived RI during exposure
- HPGe events with the main trigger and an additional trigger from any of the C counters during the selected time window form **the Rejected spectra**



Preliminary 2021 results: *(E, t)* distribution of the correlated events following μ-capture in ^{136}Ba target

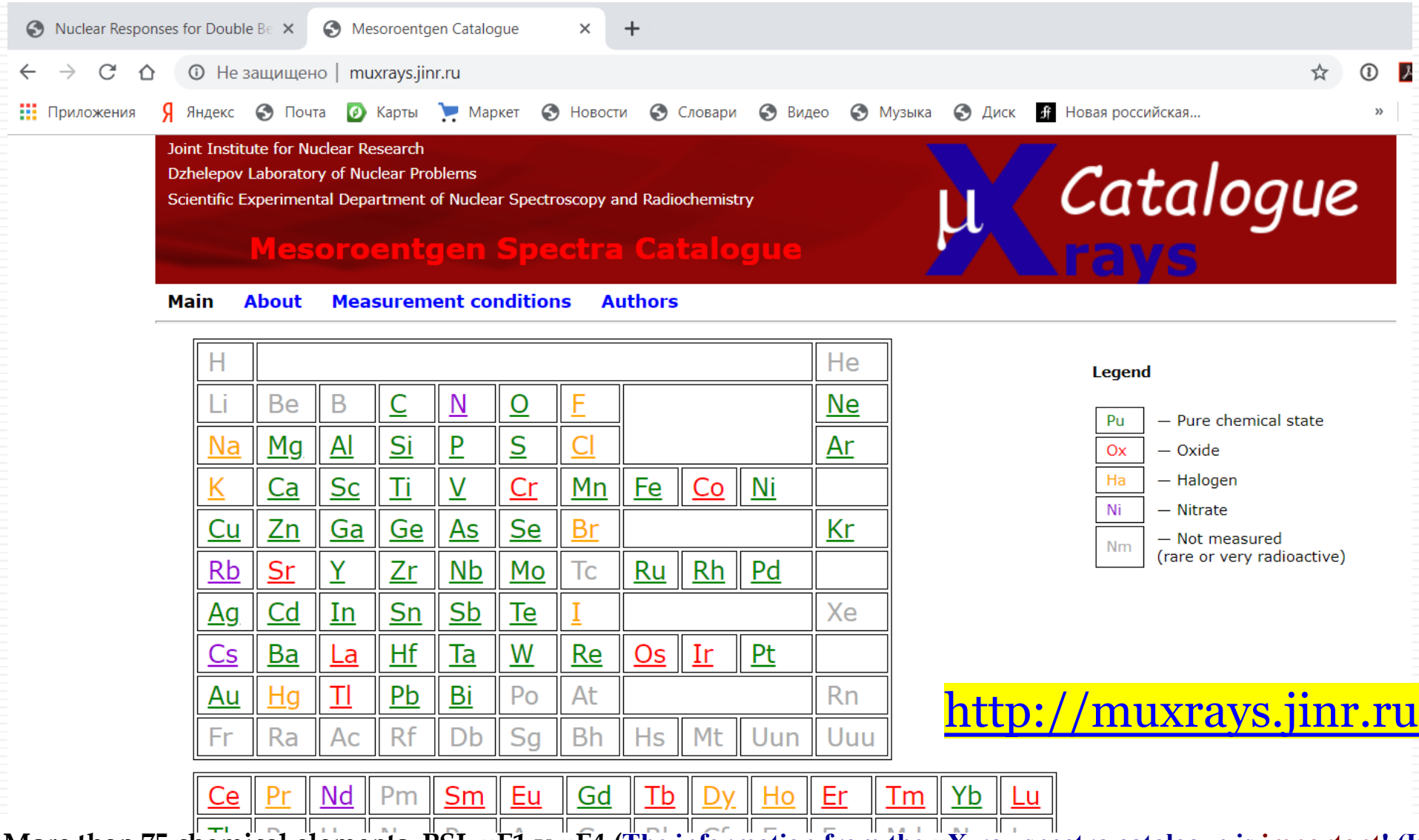


Yu. Shitov talk



Time evolution of the 249.7 keV γ-line, following OMC in ^{136}Ba.
The corresponding decay constant, λ_{tot} *is* $11.1\ \mu s^{-1}$ *and the mean lifetime,* τ *, is* ***90 ns.***

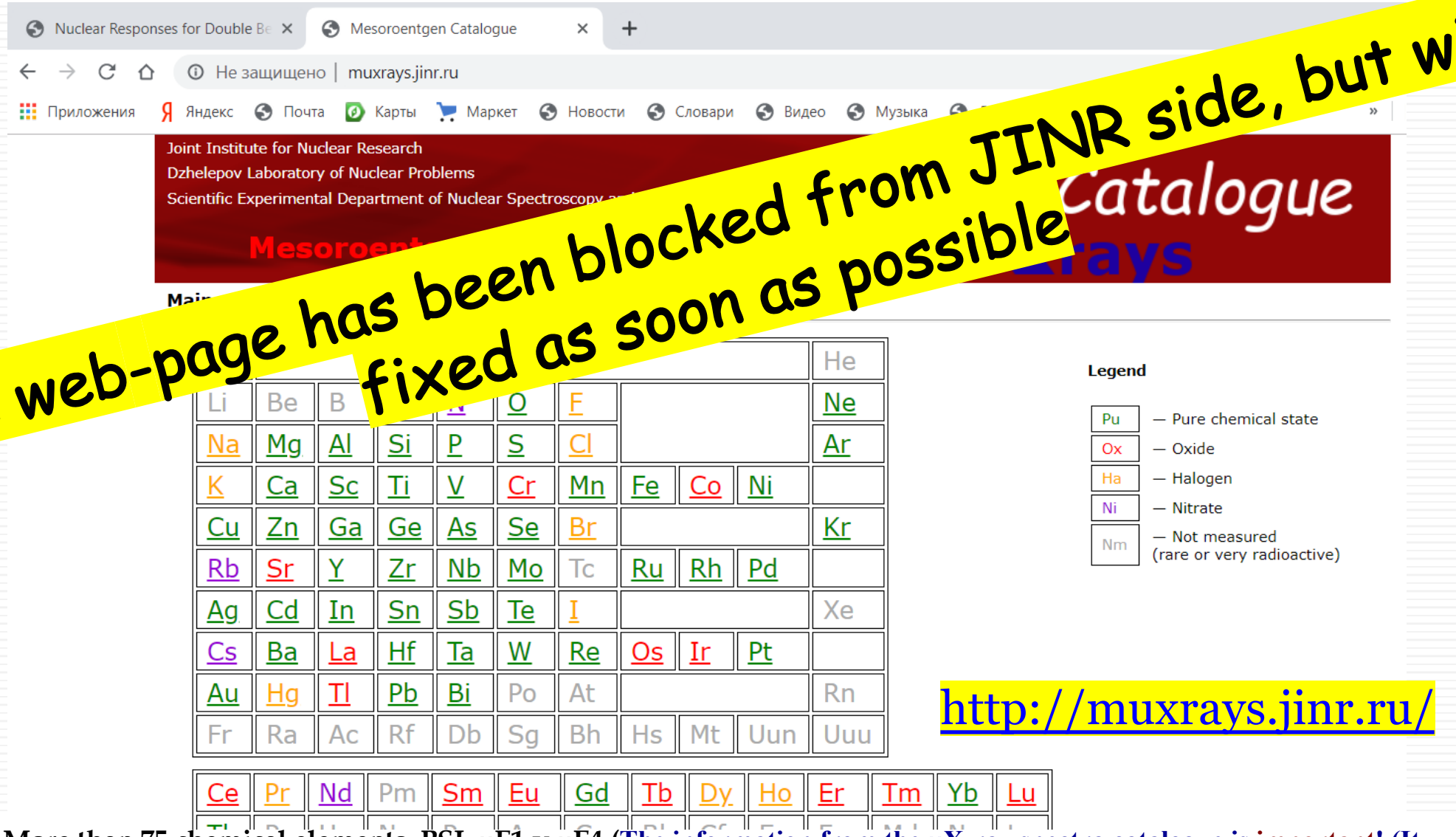
Muonic X-rays Catalogue



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)

Muonic X-rays Catalogue



The web-page has been blocked from JINR side, but will fixed as soon as possible

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)

Plans and upcoming 2022 beam-time @ PSI