Virtual depth by active background suppression: The cosmic muon induced background of GERDA Phase II

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- non-standard background sources have to be considered in next generation background-free 0νββ searches

  "Only background-free experiments make efficient use of ββ isotopes"

	background index [cts/(keV·kg·yr)]	
GERDA Phase II	$1.0^{+0.6}_{-0.4} \cdot 10^{-3}$	[1]
next generation	O $(1 \cdot 10^{-5})$	[2]

- deep underground **in-situ production** of radioactive isotopes by cosmic muons generates non-negligible background [3]

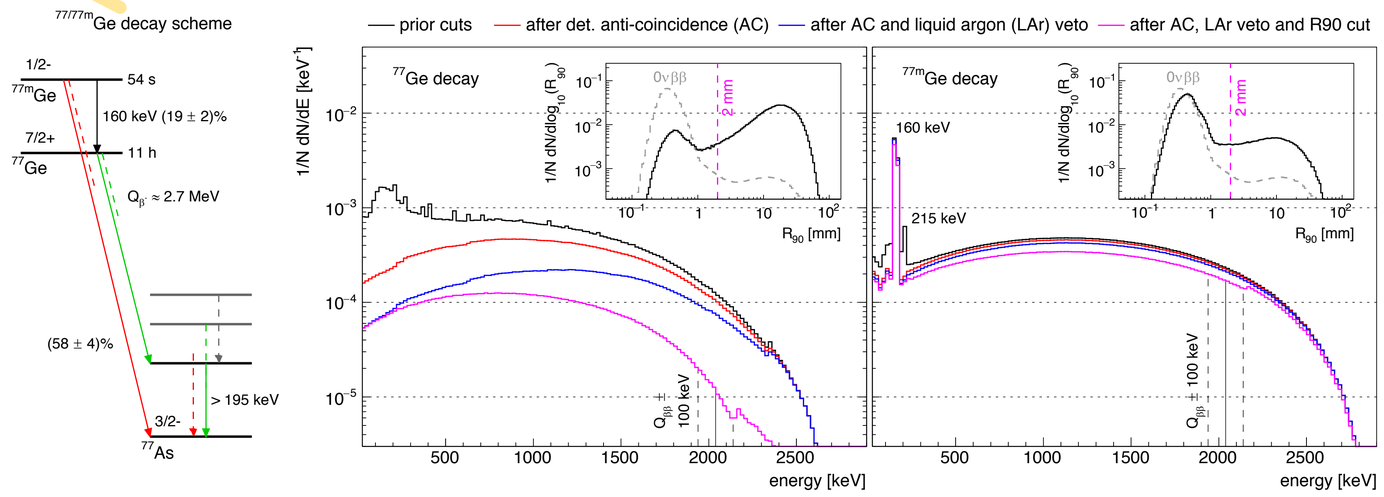
  "How deep is deep enough?"

- $^{76}Ge(n,\gamma)^{77(m)}Ge$ has been identified as critical cosmogenic component for 0νββ searches with germanium [4]
- **distinct features** in $^{77(m)}Ge$ production and decay enable active reduction

  "Virtual depth by active background suppression"

- simulation of cosmic muon induced backgrounds in GERDA Phase II [1] with GEANT4-based MAGE framework [5] can be used as proxy for LEGEND at LNGS [2]

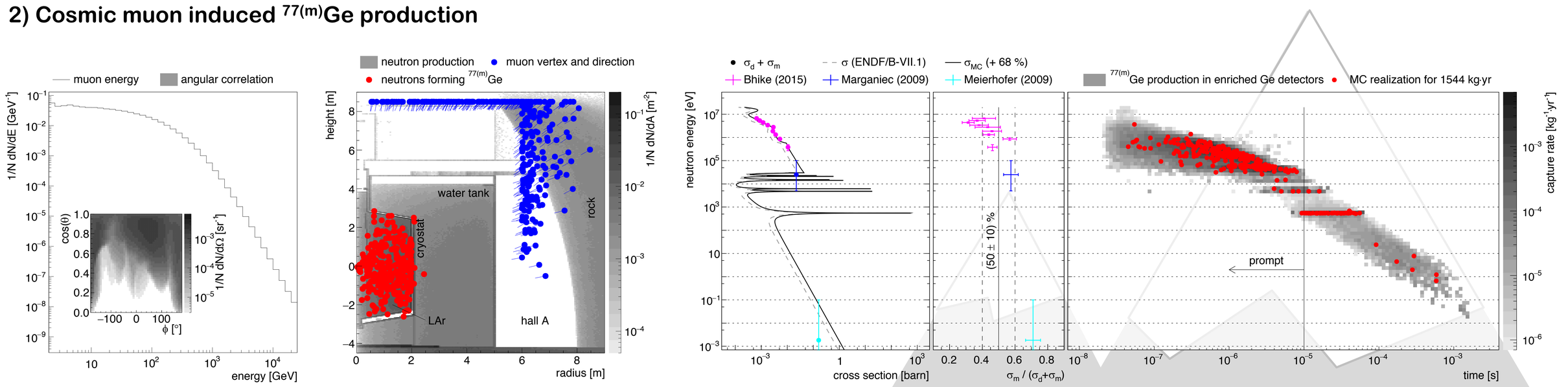
1) Active suppression of $^{77(m)}Ge$ decays



- ^{77m}Ge: **ground state decay dominates**
- ^{77}Ge: **ground state transition is spin suppressed**
- effective modelling of active suppression by
  - 150 keV coincident energy deposition threshold for **liquid argon** (LAr) veto
  - 2 mm 90% energy deposition cluster radius for pulse shape discrimination (**PSD**):

	^{77}Ge [10^{-5} keV^{-1}]	^{77m}Ge [10^{-5} keV^{-1}]
prior cuts	12.6	23.3
… after AC	10.5	22.4
… after LAr veto	7.5	21.2
… after R90	1.2	17.0

2) Cosmic muon induced $^{77(m)}Ge$ production



- underground muon flux in Hall A of LNGS is obtained by MUSUN [6]
- simulation of **1 · 10⁸ muons** with mean energy of 270 GeV and angular correlation
- 43.4 yr or 1544 kg·yr of GERDA Phase II data

- **neutron production**/propagation in GERDA setup
- cosmic muon induced neutron flux at germanium array is 1.6 $m^{-2}\,h^{-1}$

  "Only neutrons from inner cryostat volume contribute to the 77(m)Ge production"

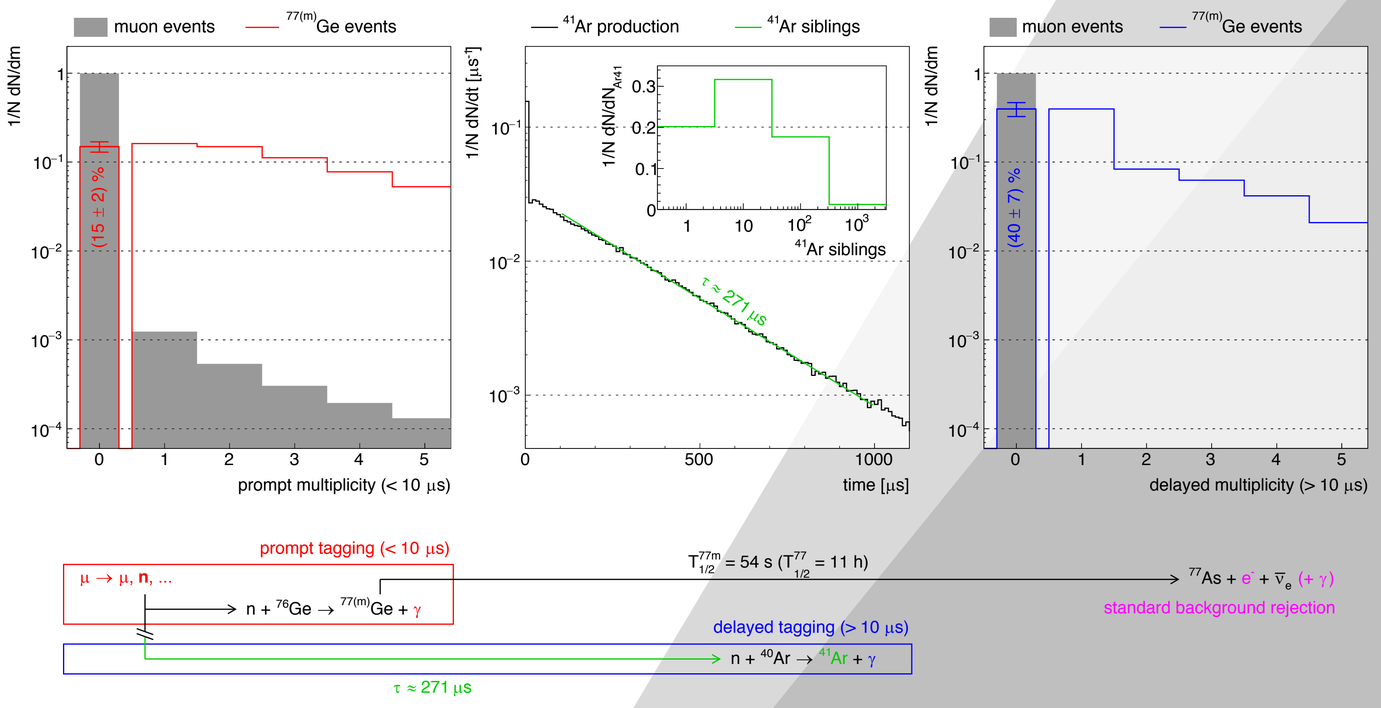
- recent measurements [7] show that ENDF/B-VII.1 does not include full ^{77m}Ge production, increased Monte Carlo cross section is used
- at higher neutron energies ^{77g}Ge is favored, equal ^{77g}Ge to ^{77m}Ge production is assumed

"Captures appear mainly prompt and at non-thermal neutron energies"

- $^{77(m)}Ge$ production rate: **(0.21 ± 0.01) nuclei/(kg·yr)**

	^{77}Ge	^{77m}Ge	combined
background index [cts/(keV·kg·yr)]	$(1.5 \pm 0.2) \cdot 10^{-6}$	$(1.8 \pm 0.4) \cdot 10^{-5}$	$(2.0 \pm 0.4) \cdot 10^{-5}$

3) $^{77(m)}Ge$ rejection by delayed coincidence



- (85 ± 2)% of $^{77(m)}Ge$ events show **prompt coincidences** (<10 μs) between muon veto and germanium detectors
- 6 min dead-time leads to < 4% life-time reduction

- coincidences are partially produced by **sibling captures** in the array surroundings

  "Large neutron multiplicities allow to tag events with accompanying isotope production"

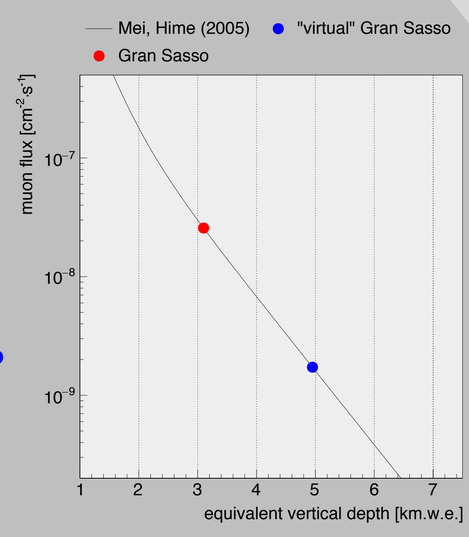
- (60 ± 7)% of $^{77(m)}Ge$ events show **delayed coincidences**
- sequence of **prompt** and **delayed** tagging combined with "standard" **prompt coincidence rejection**

4) Virtual depth by active background suppression

- active suppression can be translated into an **effective muon flux reduction** for a certain cosmogenic background
- other cosmogenics than $^{77(m)}Ge$ have only minor contribution

  "The virtual overburden of GERDA Phase II corresponds to about 5000 m.w.e."

- early stage design considerations open up possibilities for further improvements



background index [cts/(keV·kg·yr)]	
$^{77(m)}Ge$	**$(4.0 \pm 0.4) \cdot 10^{-5}$**
… after AC, LAr veto, PSD	$(2.0 \pm 0.4) \cdot 10^{-5}$
… after delayed coincidence	**$(2.7 \pm 0.3) \cdot 10^{-6}$**

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