GAIAS

GAxIal Analysis with Scintillators

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The "quenching" of g_A

- A major challenge in interpreting the results of 0νββ-decay experiments lies in the accurate calculation of nuclear matrix elements (NMEs). The 0νββ-decay probability is:

$$\left[T_{1/2}(0\nu)\right]^{-1} = G_{0\nu}\left(g_A^{eff}\right)^4 |M_{0\nu}|^2 \left|\frac{\langle m_\nu \rangle}{m_e}\right|^2$$

$M_{0\nu}$ nuclear matrix element
g_A^{eff} eff. axial-vector coup. const.
$G_{0\nu}$ phase-space factor
m_e electron mass
$\langle m_\nu \rangle$ effective Majorana mass of the ν

- The effective value of the axial-vector coupling constant, g_A^{eff}, in nuclear environments is a key sources of uncertainty in $\langle m_\nu \rangle$ calculations
- While the free-nucleon value of g_A is well known (g_A = *1.276*), experimental data suggest that g_A is quenched in nuclei, with effective values ranging in 0.5-1.0 depending on the nuclear mass and the theoretical model employed
- The "quenching" of g_A has profound consequences:
    - it can reduce the predicted decay rate by more than an order of magnitude, it affects the sensitivity of current and future 0νββ experiments and the interpretation of 0νββ experiments in terms of the neutrino mass
    - Understanding the origin and magnitude of this quenching is therefore essential for the design and optimization of next-generation detectors, as well as for the extraction of reliable constraints on neutrino properties.

Forbidden non-unique beta decays

- The most sensitive probe of g_A^{eff} is represented by Forbidden Non-Unique (FNU) beta decays
- g_A^{eff} can be studied through precise measurements of the beta spectral shape
- By selecting isotopes with high branching ratios and well-understood nuclear structure, it is possible to extract g_A^{eff} with minimal model dependence
- Crystal scintillators are suitable detectors to measure with high-accuracy the beta spectral shape having the possibility to incorporate beta-emitting isotopes directly into the crystal bulk, low energy threshold, high enough energy resolution, high detection efficiency and control of possible systematic uncertainties

β-transitions of interest sensitive to g_A^{eff}

Transition	Forbidness	Q_β (keV) δ (%)	Half-life	Activity [1]	Possible scintillator, Note
^{113}Cd → ^{113}In	$1/2^+ \rightarrow 9/2^+$ (100%, 4 FNU)	323.84(27) 12.2227(7)	8.04(5) $\times 10^{15}$ yr	1.8 mBq/g of Cd	$CdWO_4$
^{113m}Cd → ^{113}In	$11/2^- \rightarrow 9/2^+$ (~100%, 1 FNU)	587.38(27) Synthetic	13.58(32) yr	65-130 mBq/g of $^{106}CdWO_4$	$^{106}CdWO_4$
^{87}Rb → ^{87}Sr	$3/2^- \rightarrow 9/2^+$ (100%, 3 FNU)	282.275(6) 27.83(2)	4.97(3)$\times 10^{10}$ yr	867 Bq/g of Rb	CsI(Na,Rb), NaI(Tl,Rb)
^{99}Tc → ^{99}Ru	$9/2^+ \rightarrow 5/2^+$ (100%, 2 FNU)	297.5(9) Synthetic	2.111(12) $\times 10^5$ yr	6.33×10^8 Bq/g of ^{99}Tc	NaI(Tl,^{99}Tc), CsI(Na,^{99}Tc)
^{115}In → ^{115}Sn	$9/2^+ \rightarrow 1/2^+$ (100%, 4 FNU)	497.489(10) 95.719(52)	4.41(25) $\times 10^{14}$ yr	0.25 Bq/g of In	CsI(In), $LiInSe_2$, InI
^{210}Bi → ^{210}Po	$1^- \rightarrow 0^+$ (100%, 1 FNU)	1162.2(8) daughter of ^{210}Pb (^{238}U chain)	5.012(5) d	4.6×10^{15} Bq/g of ^{210}Bi	$CaWO_4$, PbI_2
^{135}Cs → ^{135}Ba	$7/2^+ \rightarrow 3/2^+$ (100%, 2 FNU)	268.70(29) Synthetic	2.3(3)×10^6 yr	4.3×10^7 Bq/g of ^{135}Cs	CsI(Tl)
^{137}Cs → ^{135}Ba	$7/2^+ \rightarrow 3/2^+$ (5.6%, 2 FNU)	1175.63(17) Synthetic	30.04(4) y	3.2×10^{12} Bq/g of ^{137}Cs	CsI(Tl)
^{129}I → ^{129}Xe	$7/2^+ \rightarrow 3/2^+$ (100%, 2 FNU)	189(3) (10^{-13}-10^{-12})	1.57(4)×10^7 yr	0.7-7 μBq/g of I	CsI
^{36}Cl → ^{36}Ar	$2^+ \rightarrow 0^+$ (98.1%, 2 FNU)	709.53(4) (~7×10^{-13})	3.013(15)×10^5 yr	≈1 mBq/g of Cl	$CeCl_3$
^{214}Bi → ^{214}Po	$1^- \rightarrow 0^+$ (19.2%, 1 FNU)	3269(11) daughter of ^{226}Ra (^{238}U chain)	19.71(2) min	1.6×10^{18} Bq/g of ^{214}Bi	$CaWO_4$, NaI(Tl), CsI(Tl), SrI_2(Eu), $LaCl_3$, …,
^{74}As → ^{74}Se	$2^- \rightarrow 2^+$ (15.4%, 1 FNU)	1352.8(18) Synthetic	17.77(2) d	3.7×10^{15} Bq/g of ^{74}As	Highly effective organic scintillation material with an external synthetic source
^{94}Nb → ^{94}Mo	$6^+ \rightarrow 4^+$ (100%, 2 FNU)	2045.0(15) Synthetic	2.03(16)×10^4yr	6.9×10^9 Bq/g of ^{94}Nb	Highly effective organic scintillation material with an external synthetic source

GAIAS scientific perspectives

The project will focus in sequence on:

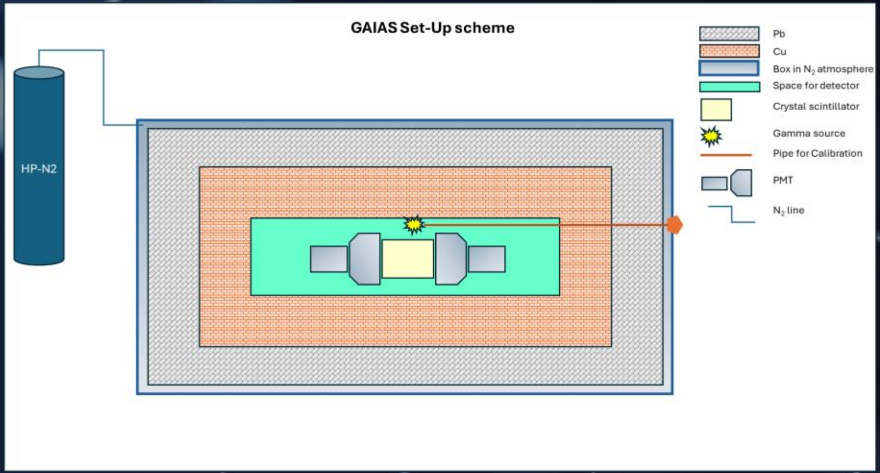
- **^{113}Cd** is naturally present in $CdWO_4$ crystal scintillators; **^{113m}Cd** is in the enriched $^{106}CdWO_4$ scintillator
- **^{87}Rb**, and **^{99}Tc**: promising candidates for custom crystal growth as **CsI(Na,Rb)** and **NaI(Tl,Tc)**.
- R&D for investigating the feasibility of procurement of beta-emitting isotopes such as ^{137}Cs, ^{135}Cs and ^{36}Cl to incorporate as controlled contaminants during crystal synthesis.

Crystal Scintillator	Beta decay of interest	Feasibility
$CdWO_4$	^{113}Cd	Ready
$^{106}CdWO_4$	^{113m}Cd	Ready
CsI(Na,Rb)	^{87}Rb	Potential (preliminary R&D started)
NaI(Tl,Rb)	^{87}Rb	Potential
NaI(Tl,Tc)	^{99}Tc	Potential
$CeCl_3$	^{36}Cl	Potential
PbI_2	^{210}Bi, ^{214}Bi	Potential
CsI(Tl)	^{135}Cs, ^{137}Cs	Challenging
SrI_2(Eu), CsI	^{129}I	Challenging
…	…	…

- Nuclides present in a scintillator as a result of contamination (natural or artificial) by their parent nuclides (^{210}Bi, ^{214}Bi).
- Feasibility assessment for more challenging isotopes with very short half-lives, including, for example, ^{74}As.

The experimental set-up

- Scintillating crystals: $CdWO_4$, $^{106}CdWO_4$, CsI(Na, Rb), and potentially NaI(Tl, Tc) and $CeCl_3$, …:
    - High light yield and energy resolution, low non-proportionality of response
    - Flexibility in incorporating or doping isotopes of interest
    - Suitability for long-term operation in low-background environments
- The activity of the beta emitter isotopes will be at a level of <100 Bq.
- The experiment will be conducted in a low-background environment at the INFN Gran Sasso National Laboratory (LNGS): ultra-low radiation conditions, reduced background, collection of high-statistics beta spectra within a relatively short time, stable and controlled conditions



- Length size of the crystals ≈ few cm
- The detector system will fit into a volume of 60 cm x 15 cm x 15 cm, surrounded by a passive shield
- The experimental setup is compact and can be hosted in a dedicated clean and temperature-controlled room at LNGS

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Capitolo	Descrizione	Richiesta (kE)	Totale (kE)
CONSUMO	• Guanti, Tute, Cavi e consumabili per laboratorio • Sviluppo di cristalli di CdWO4	2.0 20.0	22.0
MISSIONI	Missioni presso LNGS	4.0	4.0
TOTALE			26

Name	Position	Percentage
Riccardo Cerulli (RN, RL)	Primo Ricercatore	50%
Vincenzo Caracciolo	Professore Associato	20%
Pierluigi Belli	Dirigente di Ricerca	95%
Fedor Danevich	Contratto di Ricerca INFN	100%
Alice Leoncini	AdR Universitario	40%
Mattia Atzori Corona	AdR INFN	30%
Vittorio Merlo	Associato Senior	100%
Andrea Bussolotti	Tecnico INFN	50%
Ricercatori 7		FTE = 4,35
Tecnici 1		