ANDES: A survey of the physics related to underground labs.

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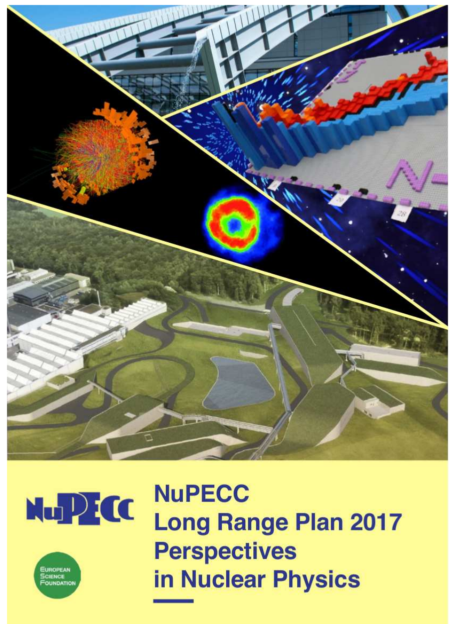
Plan of the talk

- The field in perspective
- The neutrino mass problem
- The two-neutrino and neutrino-less double beta decay
- Neutrino-nucleus scattering
- Constraints on the neutrino mass and W_R mass from LHC-CMS and $0\nu\beta\beta$
- Dark matter
- Supernovae neutrinos, matter formation
- Sterile neutrinos
- High energy neutrinos, GRB
- Decoherence
- Summary

The field in perspective



- How the matter in the Universe was (is) formed ?
- What is the composition of Dark matter?
- Neutrino physics: violation of fundamental symmetries?
- The atomic nucleus as a laboratory: exploring physics at large scale.

Neutrino oscillations

- Building neutrino flavor states from mass eigenstates

$$\nu_l = \sum_i U_{li}\nu_i$$

- Energy of the state

$$E_i \approx pc + \frac{m_i^2 c^4}{2E}$$

- Probability of survival/disappearance

$$P(\nu_l \to \nu_{l'}) = |\ \delta(l,l') + \sum_{i \neq p} U_{l'i}(e^{-i(E_i - E_p)t/\hbar} - 1)U_{li}{}^*\ |^2$$

provided $\frac{({m_i}^2 - {m_p}^2)c^4 L}{2E\hbar c} \geq 1$

Neutrino oscillations

- The existence of neutrino oscillations was demonstrated by experiments conducted at SNO and Kamioka.
- The Swedish Academy rewarded the findings with two Nobel Prices : Koshiba, Davis and Giacconi (2002) and Kajita and Mc Donald (2015)
- Some of the experiments which contributed (and still contribute) to the measurements of neutrino oscillation parameters are K2K, Double CHOOZ, Borexino, MINOS, T2K, Daya Bay.
- Like other underground labs ANDES will certainly be a good option for these large scale experiments.

SNO

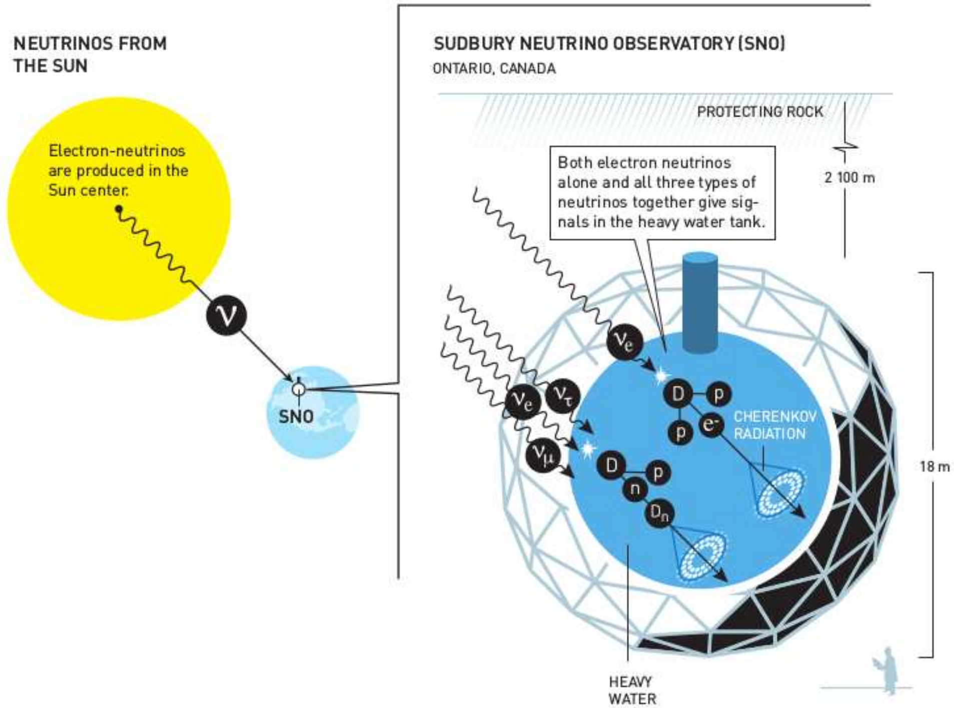


Illustration: © Johan Jarnestad/The Royal Swedish Academy of Sciences

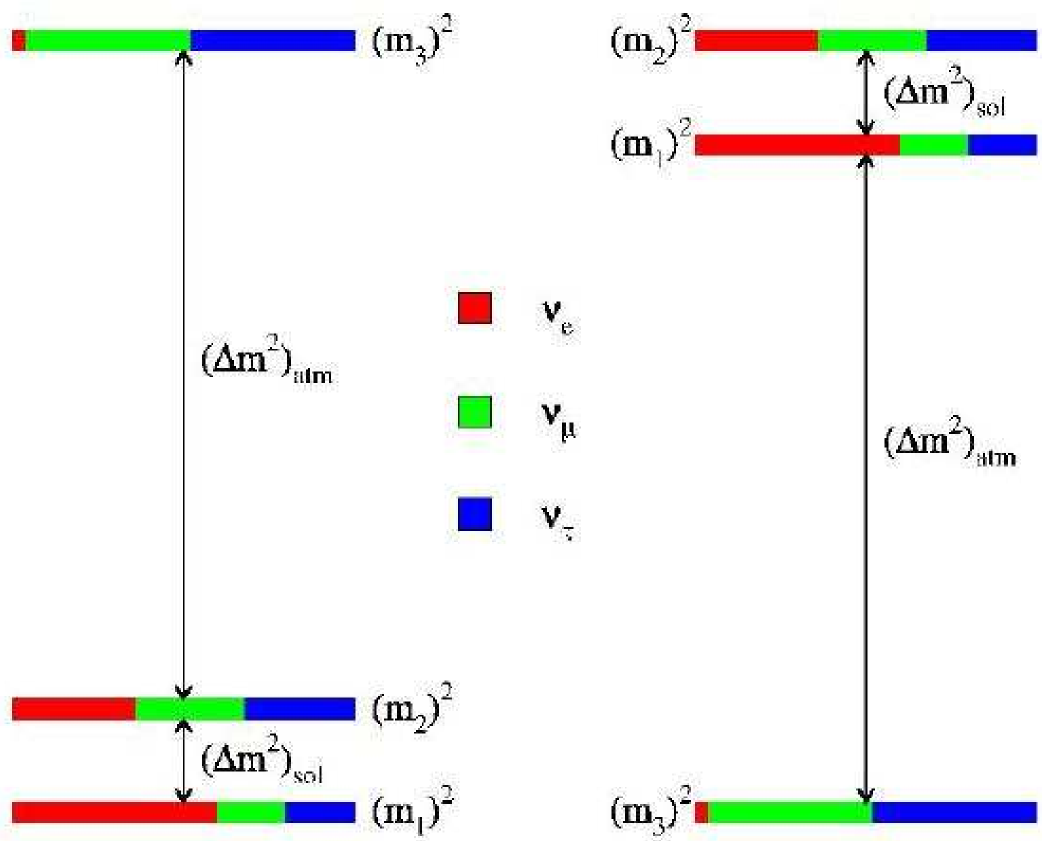
Mixing matrix U

$$U = \begin{pmatrix} c_{13}c_{12} & c_{13}s_{12} & s_{13}e^{-i\delta} \\ -c_{23}s_{12} - s_{23}c_{12}s_{13}e^{i\delta} & c_{23}c_{12} - s_{23}s_{12}s_{13}e^{i\delta} & c_{13}s_{23} \\ s_{23}s_{12} - c_{23}c_{12}s_{13}e^{i\delta} & -s_{23}c_{12} - c_{23}s_{12}s_{13}e^{i\delta} & c_{13}c_{23} \end{pmatrix}$$

$$\begin{aligned} U(Dirac) &= U \\ U(Majorana) &= U diag(e^{i\alpha_1}, e^{i\alpha_2}, 1) \end{aligned}$$

Majorana phases do not enter in the analysis of neutrino oscillations

Neutrino Mass Hierarchy



The neutrino mass does not result from the Higgs mechanism

Best global fit

Parameter	Normal (H)	Inverted (H)
$\sin^2(\theta_{12})$	0.304(+0.013,-0.012)	0.304(+0.013,-0.012)
$\sin^2(\theta_{23})$	0.412(+0.012,-0.028)	0.579(+0.025,-0.032)
$\sin^2(\theta_{13})$	0.0218(+0.001,-0.001)	0.0219(+0.001,-0.001)
$\delta(^\circ)$	306(+39,-70)	254(+63,-62)
$\Delta m^2_S(10^{-5}eV^2)$	7.50(+0.19,-0.17)	7.50(+0.19,-0.17)
$\Delta m^2_{atm}(10^{-3}eV^2)$	2.457(+0.047,-0.047)	2.449(+0.048,-0.047)

Oscillation parameters. Systematic measurements are needed to set more stringent constraints on these values

Sterile neutrinos

If we assume other mass eigenstates, the previous expressions will look like

- flavor eigenstates

$$\nu_\alpha = \sum_i^{3+ns} U_{\alpha i}\nu_i \qquad \alpha = e, \mu, \tau, s_1, s_2..s_{ns}$$

- Probability of survival/disappearance with sterile neutrinos

$$P(\nu_\alpha \to \nu_{\alpha'}) = \delta(\alpha,\alpha') - 4\sum_i \mid U_{\alpha i}\mid^2(\delta(\alpha,\alpha') - \mid U_{\alpha i}\mid^2)\sin^2(\Delta_{pi})$$

$$+8\sum_{i>k} ReU_{\alpha' i}U_{\alpha i}{}^* U_{\alpha' k}{}^* U_{\alpha k}\cos(\Delta_{pi}-\Delta_{pk})\sin(\Delta_{pi})\sin(\Delta_{pk})$$

$$+8\sum_{i>k} ImU_{\alpha' i}U_{\alpha i}{}^* U_{\alpha' k}{}^* U_{\alpha k}\sin(\Delta_{pi})\sin(\Delta_{pk})$$

Sterile neutrinos

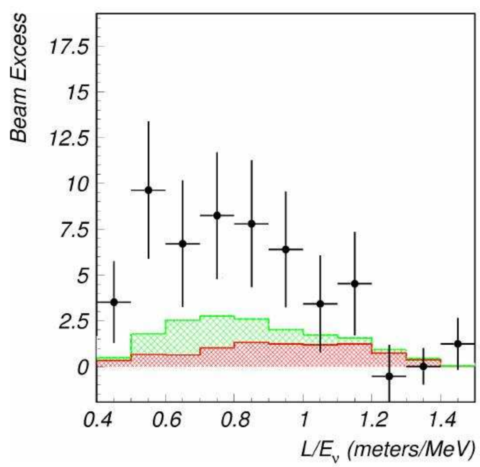
KARMEN, LNSD, MiniBooNe, Gallex, Reactor electron neutrino anomaly

light sterile neutrino: $\Delta m^2_{14} \approx 1.3 \;\; eV^2 \;\;\; \sin^2(2\theta_{14}) \approx 0.04$

LSND

[PRL 75 (1995) 2650; PRC 54 (1996) 2685; PRL 77 (1996) 3082; PRD 64 (2001) 112007]

$\bar{\nu}_\mu \to \bar{\nu}_e \qquad 20\,\text{MeV} \leq E \leq 52.8\,\text{MeV}$



- Well-known and pure source of $\bar{\nu}_\mu$

$p + \text{target} \to \pi^+ \xrightarrow{\text{at rest}} \mu^+ + \nu_\mu$

$\mu^+ \xrightarrow[\text{at rest}]{} e^+ + \nu_e + \bar{\nu}_\mu$

$L \simeq 30\,\text{m}$

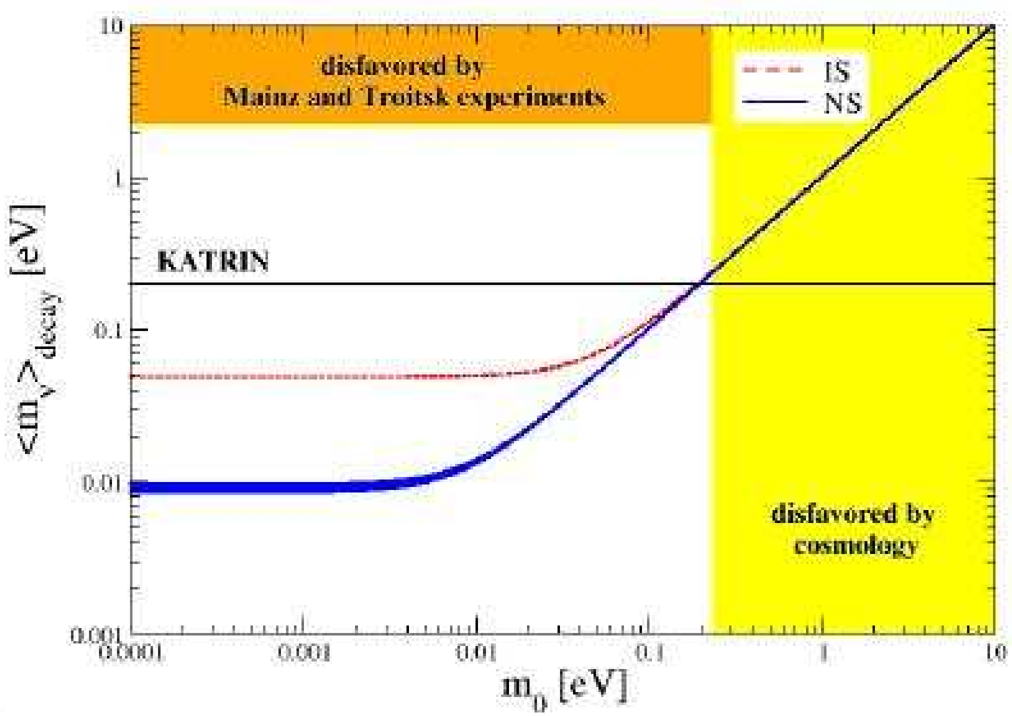
$\bar{\nu}_e + p \to n + e^+$

Well-known detection process of $\bar{\nu}_e$

- $\approx 3.8\sigma$ excess
- But signal not seen by KARMEN at $L \simeq 18\,\text{m}$ with the same method

[PRD 65 (2002) 112001]

Neutrino mass limits from tritium beta decay and Planck

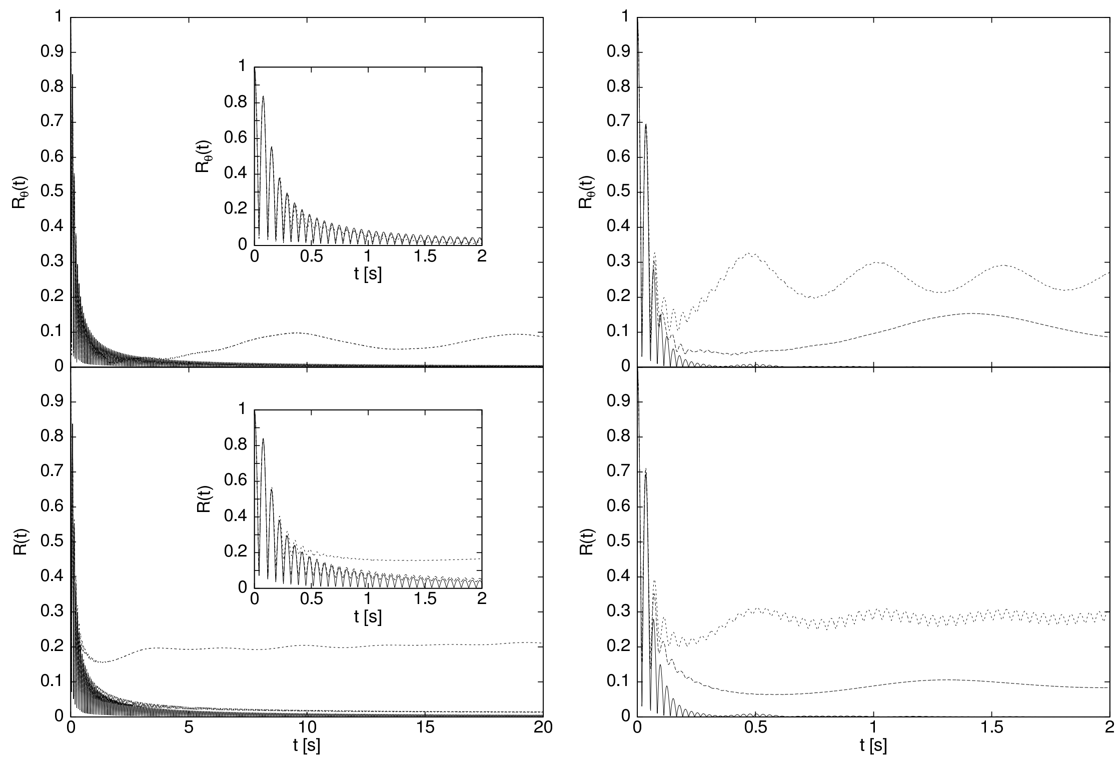


Tritium beta decay: $m_\beta^2 = \sum_i \mid U_{ei} \mid^2 m_i^2$

Mainz and Troitsk results: $\rightarrow m_\beta$ < 2.3 eV (Mainz) 2.05 eV (Troitsk)

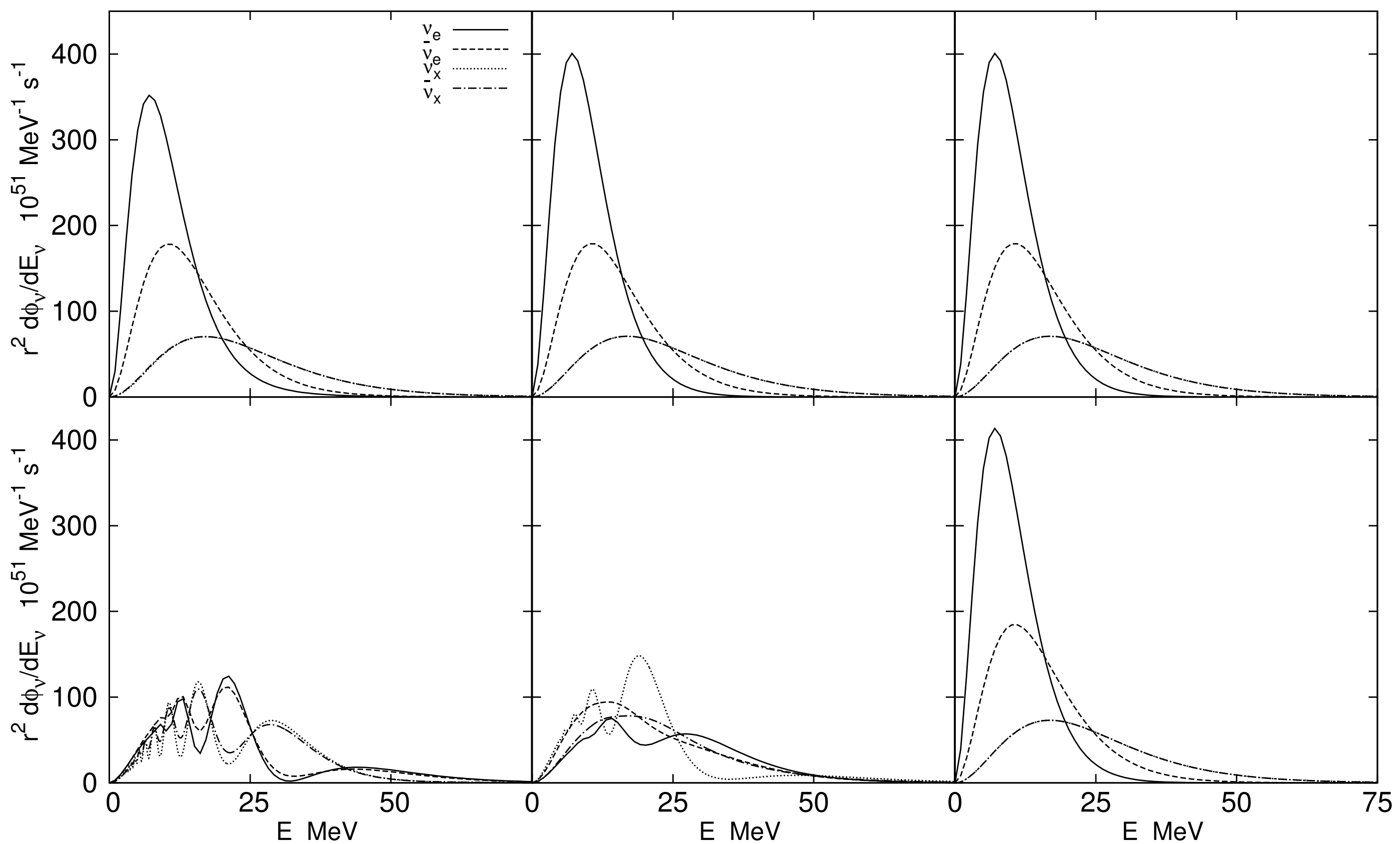
From Cosmology: $< m_\nu >= \sum_i m_i$ Planck result: $< m_\nu > < 0.23$ eV

Decoherence in cosmic neutrino fluxes



Left: order parameter as a function of time (neutrinos from a microquasar's jet).
Right order parameter as a function of time (neutrino from a windy microquasar).

Neutrino's fluxes in core collapse supernovae

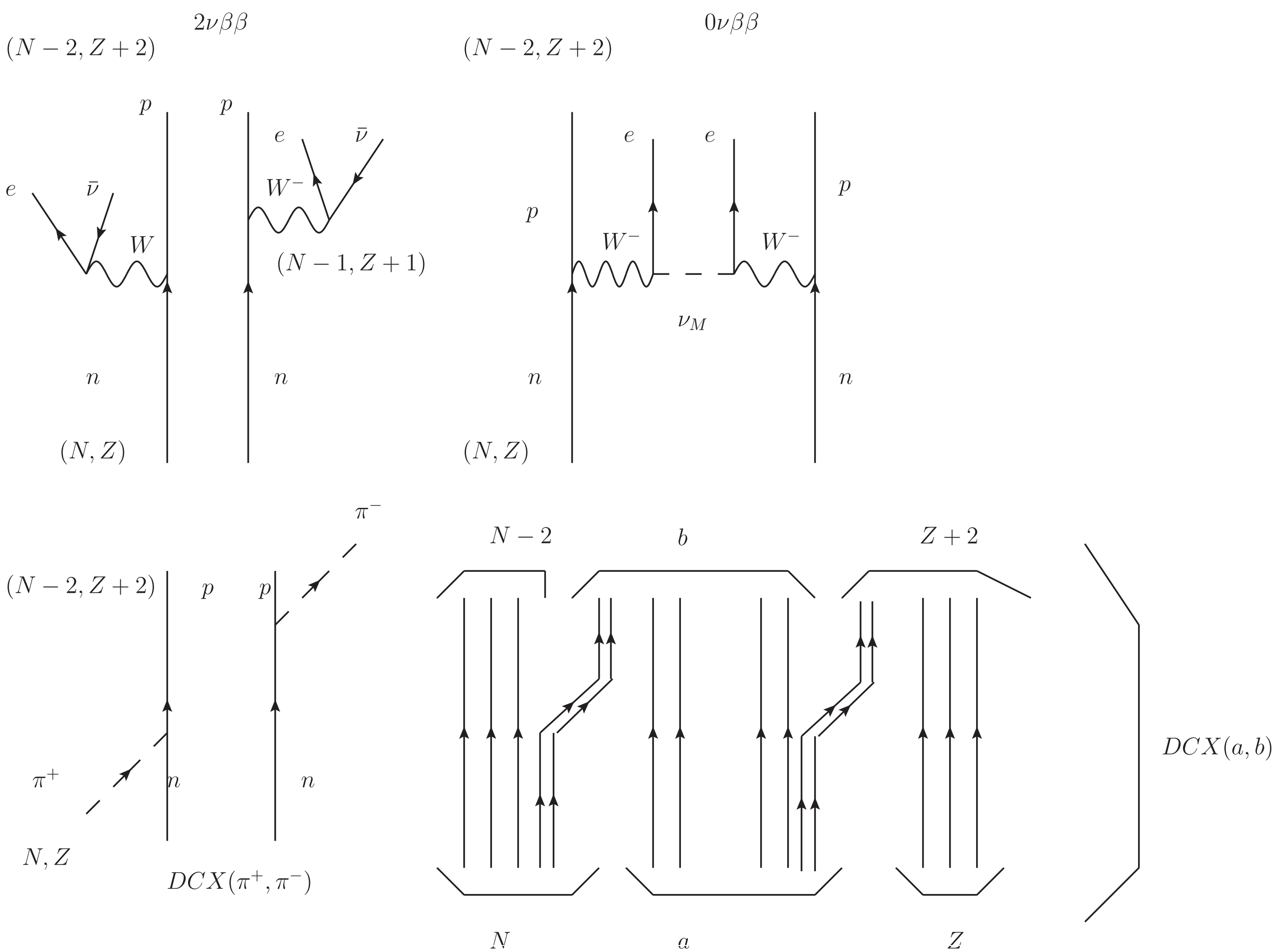


Open questions

- Lepton number non-conservation
- Nature of the neutrino: Majorana or Dirac
- Light/heavy mass ratio in the seesaw mechanism
- Absolute mass scale
- Mass hierarchy
- CP violation in the lepton sector
- Minimal extension of the Standard Model ($SU(2)_R U(1)_{(B-L)}$)
- Limits on the couplings to the singlet-scalar Majoron

This questions may be answered in the near future by the measurements of the Nuclear Double Beta Decay

Nuclear Double beta decay



The NUMEN project (F. Cappuzzello et al.EPJ A 51 (2015) 145) LNS (Catania) offers a nice new possibility of testing both DBD and DCX observables

About the $2\nu\beta\beta - decay$

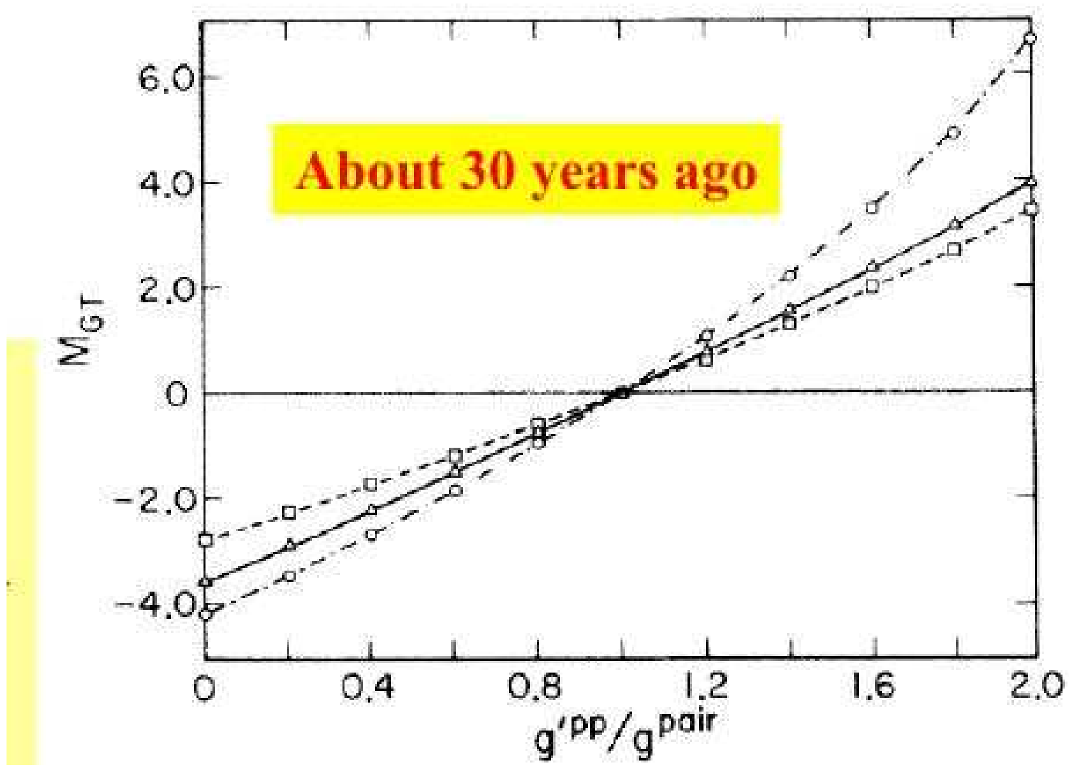
- It is a rare decay (N,Z) $\rightarrow$ (N-2,Z+2)+2 electrons
- It is allowed in the Standard Model since it conserves lepton number
- Does not tell us if the neutrinos are Dirac or Majorana particles
- It has been measured in various nuclei
- Its long half-life tell us that the nuclear physics component of it is strongly suppressed.
- The suppression is related to isospin and Pauli blocking effects in nuclei.

Basic definitions ($2\nu\beta\beta - decays$)

$$\left[t_{1/2}^{(2\nu)}(0_i^+ \to J_f^+)\right]^{-1} = G^{(2\nu)}(J)\left|M^{(2\nu)}(J)\right|^2$$

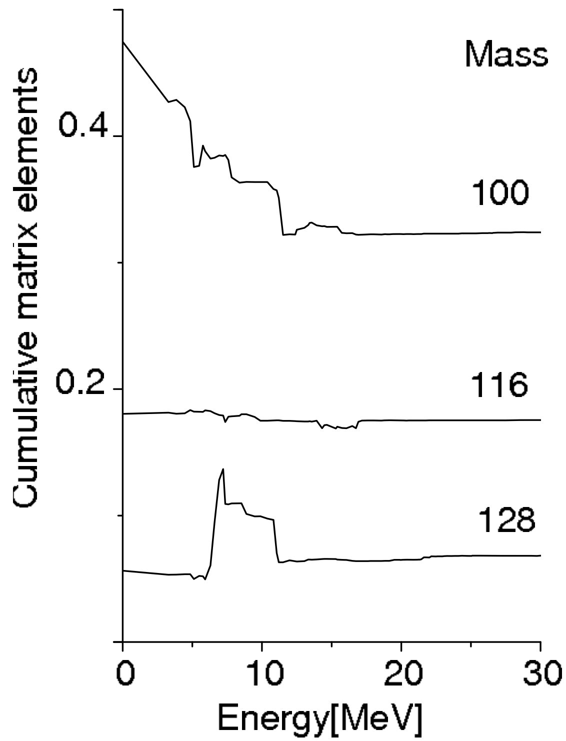
$$M^{(2\nu)}(J) = \sum_{k_1 k_2} \frac{M_{\rm F}^J(1_{k_1}^+)\langle 1_{k_1}^+|1_{k_2}^+\rangle M_{\rm I}(1_{k_2}^+)}{\left(\frac{1}{2}\Delta + \frac{1}{2}[E(1_{k_1}^+) + \tilde{E}(1_{k_1}^+)] - M_i c^2\right)/m_{\rm e}c^2} \; .$$

The peculiar behavior of $M^{(2\nu)}$



The matrix element is strongly suppressed due to particle-particle interactions in the nucleus.

The peculiar behavior of $M^{(2\nu)}$



It can be tested experimentally, by measuring the energy dependence of the strength distribution in (p,n) reactions

Experimental results

Recommended values for half-lives:

[A.S.B. Nucl. Phys. A 935 (2015) 52]

- ^{48}Ca - $(4.4^{+0.6}_{-0.5})\cdot 10^{19}$ y
- ^{76}Ge – $(1.65^{+0.14}_{-0.12})\cdot 10^{21}$ y
- ^{82}Se – $(0.92 \pm 0.07)\cdot 10^{20}$ y
- ^{96}Zr – $(2.3 \pm 0.2)\cdot 10^{19}$ y
- ^{100}Mo – $(7.1 \pm 0.4)\cdot 10^{18}$ y
- ^{100}Mo – ^{100}Ru (0^+_1) – $(6.7^{+0.5}_{-0.4})\cdot 10^{20}$ y
- ^{116}Cd – $(2.87 \pm 0.13)\cdot 10^{19}$ y
- ^{128}Te(geo) – $(2.0 \pm 0.3)\cdot 10^{24}$ y
- ^{130}Te – $(6.9 \pm 1.3)\cdot 10^{20}$ y
- ^{136}Xe – $(2.19 \pm 0.06)\cdot 10^{21}$ y
- ^{150}Nd - $(8.2 \pm 0.9)\cdot 10^{18}$ y
- ^{150}Nd – ^{150}Sm (0^+_1) – $(1.2^{+0.3}_{-0.2})\cdot 10^{20}$ y
- ^{238}U(rad) - $(2.0 \pm 0.6)\cdot 10^{21}$ y
- ECEC(2ν): ^{130}Ba(geo) - $\sim 10^{21}$ y

$0\nu\beta\beta$

$$t_{1/2}^{(0\nu)} = g^{(0\nu)} \left| M^{(0\nu)\prime} \right|^{-2} \left(|\langle m_\nu \rangle| [\mathrm{eV}] \right)^{-2}$$

$$\langle m_\nu \rangle = \sum_j \lambda_j^{\mathrm{CP}} m_j |U_{\mathrm{e}j}|^2 \, .$$

$$M^{(0\nu)\prime} = \left(\frac{g_{\mathrm{A}}}{g_{\mathrm{A}}^{\mathrm{b}}} \right)^2 \left[M_{\mathrm{GT}}^{(0\nu)} - \left(\frac{g_{\mathrm{V}}}{g_{\mathrm{A}}} \right)^2 M_{\mathrm{F}}^{(0\nu)} + M_{\mathrm{T}}^{(0\nu)} \right]$$

$$M_{\mathrm{F}}^{(0\nu)} = \sum_k (0_f^+ || \sum_{mn} h_{\mathrm{F}}(r_{mn}, E_k) || 0_i^+) \, , \quad r_{mn} = |\mathbf{r}_m - \mathbf{r}_n| \, ,$$

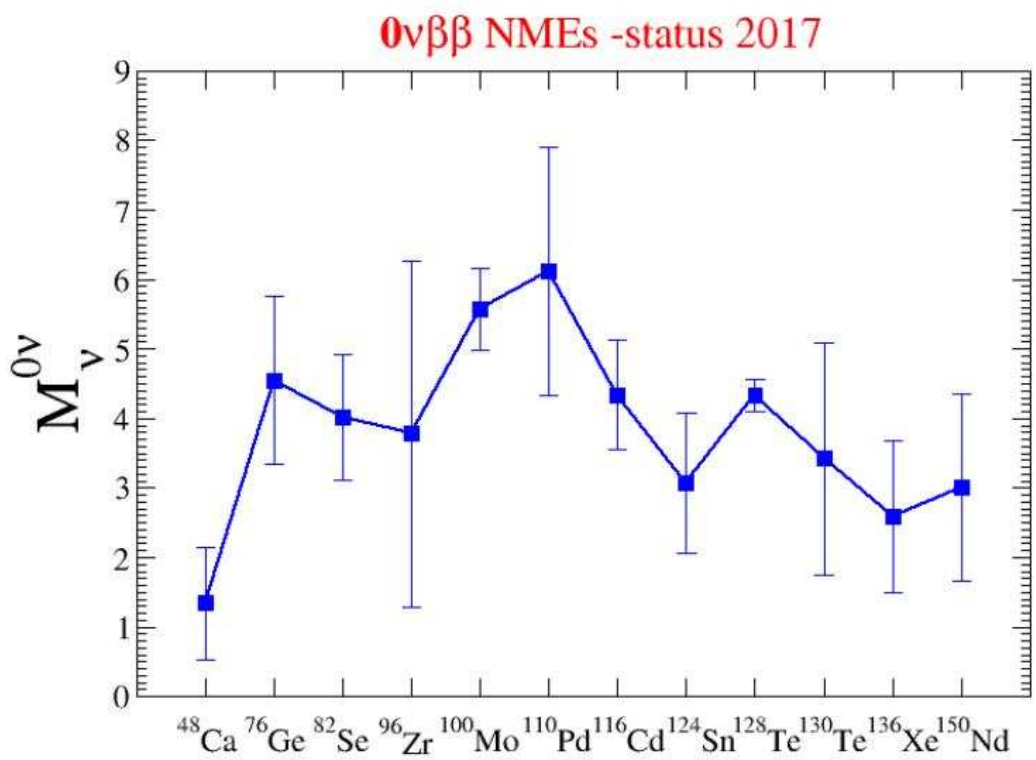
$$M_{\mathrm{GT}}^{(0\nu)} = \sum_k (0_f^+ || \sum_{mn} h_{\mathrm{GT}}(r_{mn}, E_k) (\boldsymbol{\sigma}_m \cdot \boldsymbol{\sigma}_n) || 0_i^+) \, ,$$

Calculated ground-state-to-ground-state NMEs for $g_A = 1.25$. The last line summarizes the overall magnitude and the associated dispersion of the NMEs of the cited nuclear model (without ^{48}Ca included).

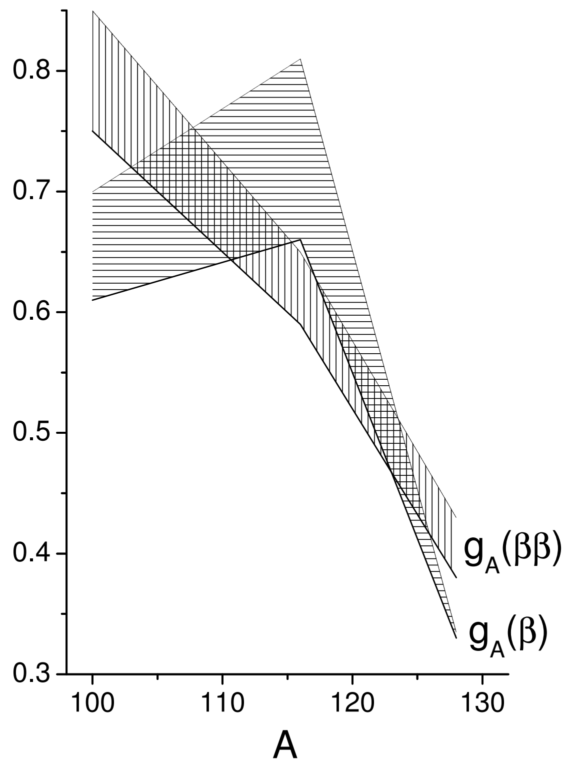
Transition	pnQRPA(U)	EDF(U)	ISM(U)	PHFB(U)
^{48}Ca $\rightarrow$ ^{48}Ti	-	2.37	0.85	-
^{76}Ge $\rightarrow$ ^{76}Se	5.18 ± 0.54	4.60	2.81	-
^{82}Se $\rightarrow$ ^{82}Kr	4.20 ± 0.35	4.22	2.64	-
^{96}Zr $\rightarrow$ ^{96}Mo	3.12	5.65	-	3.32 ± 0.12
^{100}Mo $\rightarrow$ ^{100}Ru	3.93	5.08	-	7.22 ± 0.50
^{110}Pd $\rightarrow$ ^{110}Cd	5.63 ± 0.49	-	-	8.23 ± 0.62
^{116}Cd $\rightarrow$ ^{116}Sn	3.93	4.72	-	-
^{124}Sn $\rightarrow$ ^{124}Te	4.57 ± 1.33	4.81	2.62	-
^{128}Te $\rightarrow$ ^{128}Xe	5.26 ± 0.40	4.11	2.88	4.22 ± 0.31
^{130}Te $\rightarrow$ ^{130}Xe	4.76 ± 0.41	5.13	2.65	4.66 ± 0.43
^{136}Xe $\rightarrow$ ^{136}Ba	3.16 ± 0.25	4.20	2.19	-
Overall NME	4.37 ± 0.86	4.72 ± 0.51	2.63 ± 0.24	5.53 ± 2.09

Overall $0\nu\beta\beta$ NME gs-gs transitions

Ranges of values of the overall nuclear matrix elements for $0\nu\beta\beta$ ground state to ground state transitions

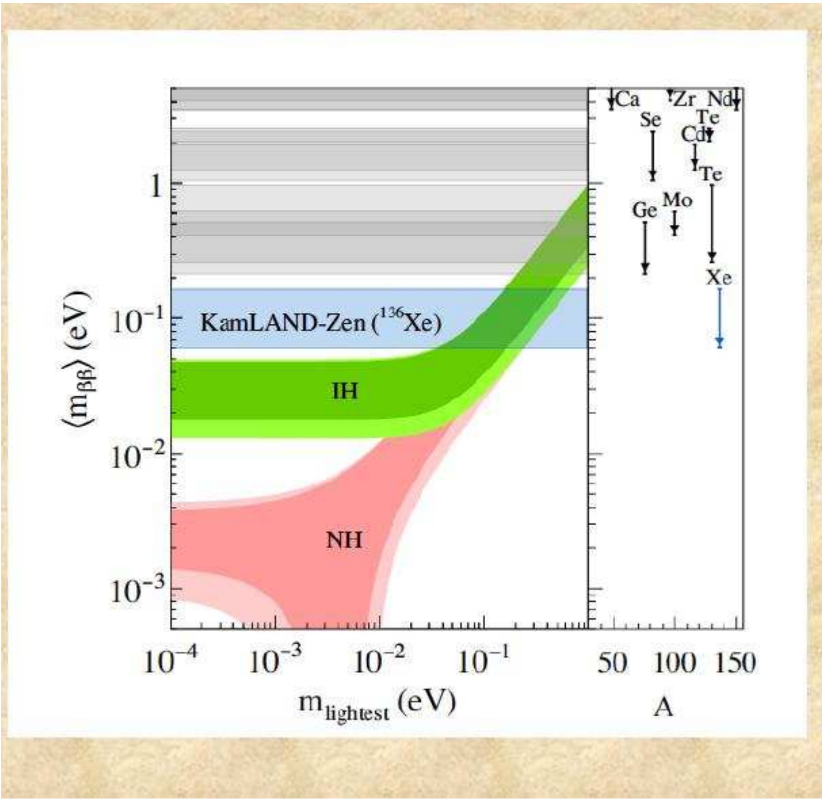


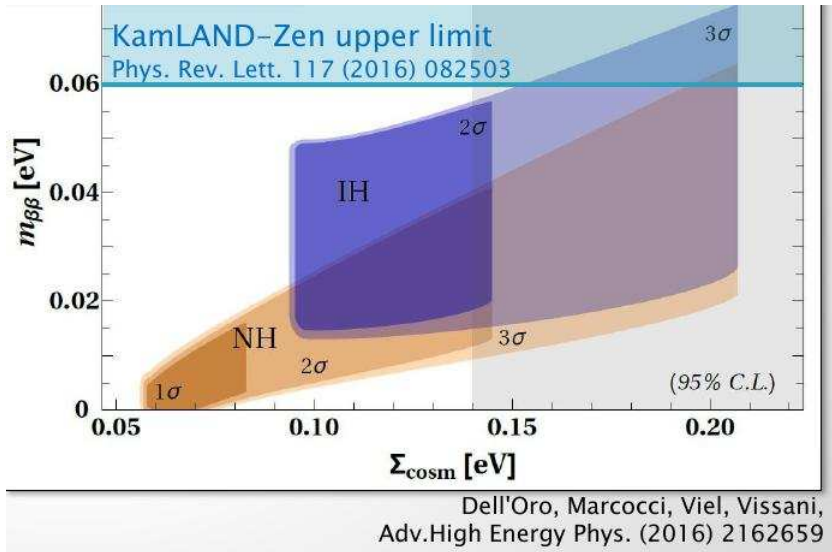
Effective values of g_A



The situation is unclear and it calls for a systematic study of media-effects upon single-beta decays, particularly for highly forbidden decays

Exploring the mass hierarchy





The KamLAND experiment is exploring a mass region very near the I.H , with present uper limits of 61-160 meV

RL currents from LHC and $0\nu\beta\beta$ decay

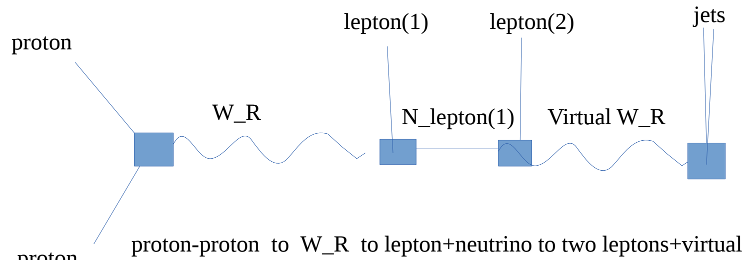
The left-right and right-right electroweak interactions (Hamiltonian density)

$$h_{\mathrm{W}} = \frac{G}{\sqrt{2}} \cos\theta_{\mathrm{CKM}} \left(j_{\mathrm{L}} J_{\mathrm{L}}^{\dagger} + \eta j_{\mathrm{R}} J_{\mathrm{L}}^{\dagger} + \lambda j_{\mathrm{R}} J_{\mathrm{R}}^{\dagger} \right) + \mathrm{h.c.}\ ,$$

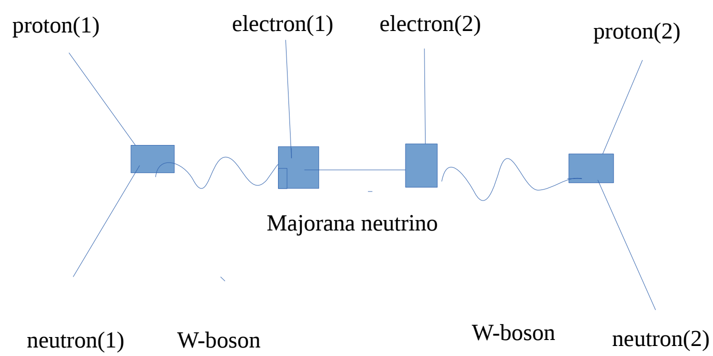
$$\begin{aligned} \mathrm{W_L} &= \mathrm{W_1} \cos\zeta - \mathrm{W_2} \sin\zeta \\ \mathrm{W_R} &= \mathrm{W_1} \sin\zeta + \mathrm{W_2} \cos\zeta \end{aligned}$$

$$\begin{aligned} \left[T_{1/2}^{(0\nu)} \right]^{-1} &= C_{mm}^{(0\nu)} \left(\frac{\langle m_\nu \rangle}{m_{\mathrm{e}}} \right)^2 + C_{m\lambda}^{(0\nu)} \langle \lambda \rangle \left(\frac{\langle m_\nu \rangle}{m_{\mathrm{e}}} \right) \\ &+ C_{m\eta}^{(0\nu)} \langle \eta \rangle \left(\frac{\langle m_\nu \rangle}{m_{\mathrm{e}}} \right) + C_{\lambda\lambda}^{(0\nu)} \langle \lambda \rangle^2 \\ &+ C_{\eta\eta}^{(0\nu)} \langle \eta \rangle^2 + C_{\lambda\eta}^{(0\nu)} \langle \eta \rangle \langle \lambda \rangle \end{aligned}$$

Same Physics



proton-proton to W_R to lepton+neutrino to two leptons+virtual W_R to two-leptons and quark-antiquark pairs.



Neutrinoless double beta decay with LL , LR and RR interactions

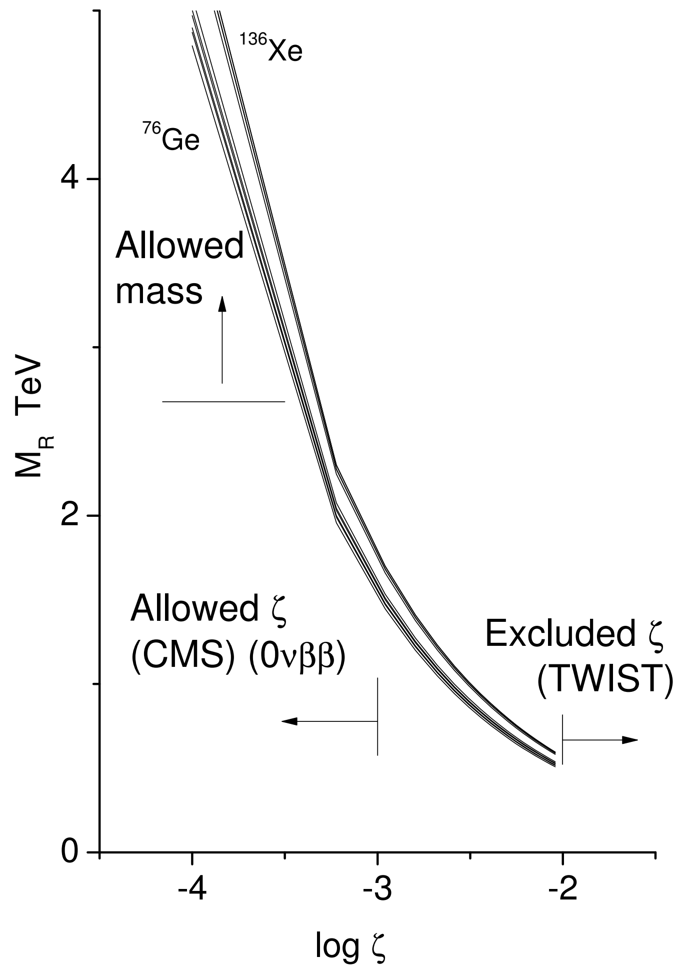
$$\frac{M_L}{M_R} = \sqrt{\frac{(\alpha - \tan\zeta)\tan\zeta}{(1+\alpha\tan\zeta)}}$$

$$\alpha = \langle\lambda\rangle/\langle\eta\rangle$$

Case	$C^{(0\nu)}_{mm}$	$C^{(0\nu)}_{m\lambda}$	$C^{(0\nu)}_{m\eta}$	$C^{(0\nu)}_{\lambda\lambda}$	$C^{(0\nu)}_{\eta\eta}$	$C^{(0\nu)}_{\lambda\eta}$
^{76}Ge	$1.33(-13)$	$-6.77(-14)$	$2.58(-11)$	$1.76(-13)$	$4.88(-9)$	$-9.54(-14)$
^{136}Xe	$9.40(-13)$	$-6.02(-13)$	$1.49(-10)$	$2.18(-12)$	$2.92(-8)$	$-1.25(-12)$

Case	Half-life limit (10^{25}yr)	$\langle m_\nu\rangle_{\max}$ (eV)	$\langle\lambda\rangle_{\max}$	$\langle\eta\rangle_{\max}$	$\frac{\langle\lambda\rangle_{\max}}{\langle\eta\rangle_{\max}}$
^{76}Ge	2.5	0.325	$0.431(-6)$	$0.286(-8)$	$1.507(2)$
^{136}Xe	1.1	0.182	$0.197(-6)$	$0.176(-8)$	$1.119(2)$
	1.9	0.138	$0.150(-6)$	$0.134(-8)$	$1.119(2)$

Mass of the right-handed boson



Compatibility of the results for W_R and the neutrino mass

- The results show that a mass $\mathrm{M_R}$ of the order of 3 TeV, for the right handed boson, and a mixing angle ζ of the order of 10^{-3}, are compatible with the measured $0\nu\beta\beta$ half-life limits and with the extracted upper limit of the average neutrino mass.
- These values may be ultimately explored at large by the $0\nu\beta\beta$ experiments, in conjunction with the ATLAS and CMS measurements.
- In the event of possitive evidences about the existence of neutrinoless double beta decay, the understanding of the mechanism (nucleonic or non-nucleonic) will depend upon the advances in the calculation of the nuclear matrix elements and of the related particle physics theory.

Present and future experiments: a short list

- Several double beta decay experiments have been taking data with quantities of enriched isotopes around or above 100 kg and plans are under way for tonne-scale experiments. These efforts revolve around several isotopes and use a broad array of detection techniques (KamLAND-ZEN, SNO+, EXO-200/nEXO, GERDA, CUORE, SuperNEMO, COBRA, Majorana) .
- Experiments of such scale make enormous demands on the progress and reliability of the nuclear matrix elements calculations.
- The research in the field of special modes of $\beta^-\beta^-$, such as $\beta^+\beta^+$ or 2νECEC starts to be more and more interesting from experimental and theoretical points of view (e.g. COBRA, TGV)
- Further development of the theory of such processes is crucial for continuation of the experimental activities in this field.

Current and planned $0\nu\beta\beta$ –experiments

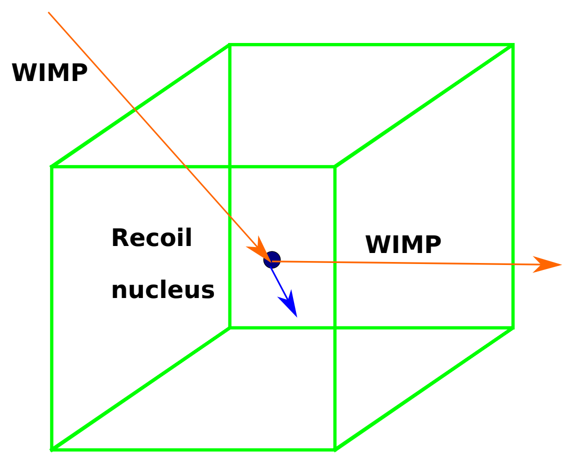
Experiment	Isotope	Lab
GERDA	^{76}Ge	LNGS [Italy]
CUORE	^{130}Te	LNGS [Italy]
Majorana	^{76}Ge	SURF [USA]
KamLAND-Zen	^{136}Xe	Kamioka [Japan]
EXO/nEXO	^{136}Xe	WIPP [USA]
CUPID - Lucifer	^{82}Se, ^{100}Mo	LNGS [Italy]
SNO+	^{130}Te	Sudbury [Canada]
SuperNEMO	^{82}Se (or others)	LSM [France]
CANDLES	^{48}Ca	Kamioka [Japan]
COBRA	^{116}Cd	LNGS [Italy]
DCBA	many	[Japan]
AMoRe	^{100}Mo	[Korea]
MOON	^{100}Mo	[Japan]
PandaX-III	^{136}Xe	[China]

About Dark Matter detection

- The observations of Zwicky and Rubin and Ford (Helv. Phys. Acta 6, 110 (1933)) and V. C. Rubin and W. K. Ford, Jr., (Astrophys. J. 159, 379 (1970)) demonstrate the existence of dark matter.
- An electrically neutral WIMP is the most probable candidate for cold DM. The estimates of the mass of the WIMP vary from 1 GeV to 10 TeV.
- Interacts weakly and gravitationally with the ordinary matter but does not interact electromagnetically and/or strongly with other particles.
- It is assumed that the DM in the Galactic Halo is composed mostly by WIMP with velocities which obey Maxwell-Boltzmann distribution function.

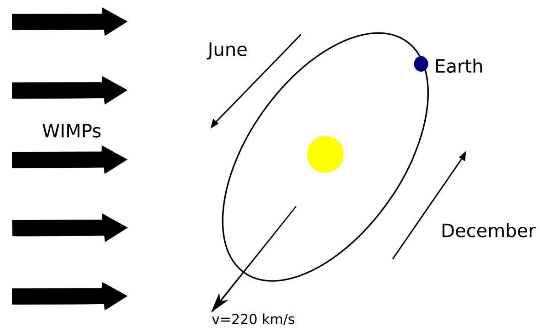
Detection methods

- Direct detection: Search the energy deposited in a detector of low threshold, when the WIMP is scattered by a nucleus. (DAMA, CRESST, CoGeNT, CDMS, XENON,SABRE, DM-ICE.)



- Indirect detection: Energetic neutrinos, from the nucleus of the Sun and Earth, produced by the annihilation of WIMPs. They may be detected with neutrino telescopes (IceCube, ANTARES, HESS).

Modulation effect



- The flux of the dark matter should vary annually.
- The diurnal modulation of the amplitude depends on the location.
- Measurement of northern and southern laboratories will help to refine parameters of DM
- Extremely low signal-to-noise rates: direct-detection experiments need to be performed in low-background conditions.
- To confirm a positive signal data with the same type of detectors should be collected in different laboratories

Recoil rate

$$\frac{dR}{dE_{\rm nr}} = \frac{\sigma(q)}{2m_\chi \mu^2}\rho_\chi \eta(E_{\rm nr}, t)$$

This equation has three factors:

- $2m_\chi \mu^2 \rightarrow$ Dependence on the WIMP and nuclear masses.
- $\rho_\chi \eta(E_{\rm nr}, t) \rightarrow$ Dependence with the energy and time $\rightarrow$ Astrophysics.
- $\sigma(q) \rightarrow$ Dependence with the energy $\rightarrow$ Particle physics.

Coordinates of the Underground Labs.

Laboratory	ϕ_0	λ_0
LNGS	$42°27'$ N	$13°34'$ E
SUL	$47°48'$ N	$92°14'$ W
ANDES	$30°15'$ S	$69°53'$ W
SUPL	$37°3'$ S	$142°46'$ E
South Pole	$89°59'$ S	$139°16'$ E

Annual and diurnal modulation rates

We can write the recoil rate in terms of the annual and diurnal modulation rates as

$$\frac{dR}{dE_{\rm nr}} \simeq S_0 + S_{\rm m}(E_{\rm nr})\cos(w(t-\tilde{t_0})) + S_{\rm d}(E_{\rm nr})\cos(w_{\rm rot}(t'-t_{\rm d})).$$

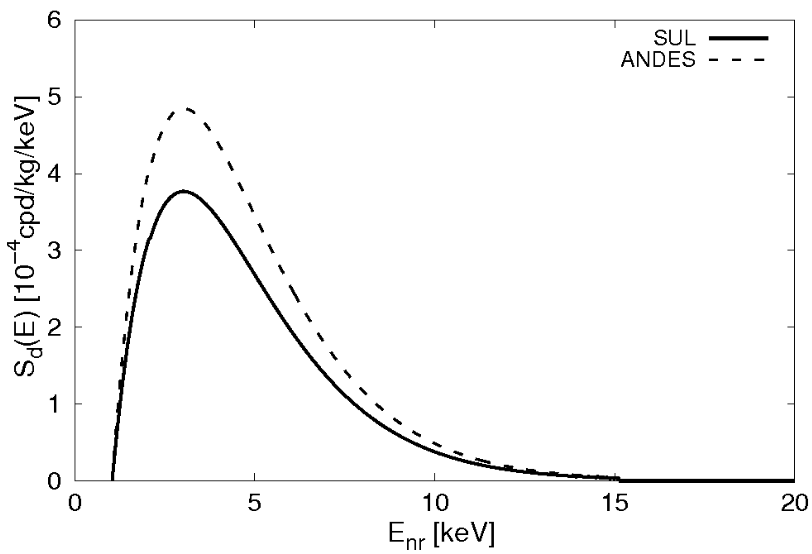
Annual modulation:

$$S_{\rm m}(E_{\rm nr}) = \frac{\rho_\chi}{m_\chi}\frac{\sigma_0}{2\mu^2}F^2(q)v_{\rm rev}^{\oplus}A_{\rm m}\left.\frac{\partial\eta}{\partial v_{\rm lab}}\right|_{\tilde{t_0};t_{\rm d}}$$

Diurnal modulation:

$$S_{\rm d}(E_{\rm nr}) = \frac{\rho_\chi}{m_\chi}\frac{\sigma_0}{2\mu^2}F^2(q)v_{\rm rot}^{\oplus}A_{\rm d}\left.\frac{\partial\eta}{\partial v_{\rm lab}}\right|_{\tilde{t_0};t_{\rm d}}$$

Results: Ge Detector's

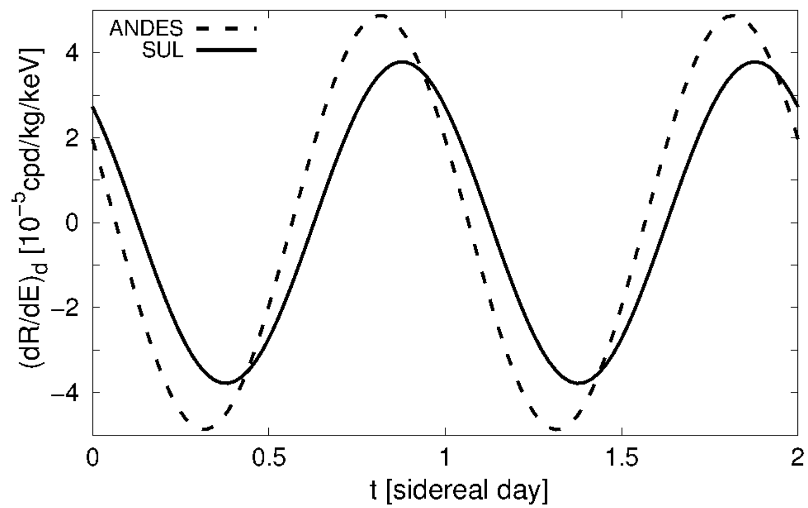


Diurnal modulation amplitude as a function of the recoil energy, in units of cpd Kg^{-1} keV^{-1}.

Parameters:

- $\sigma_s^{SI} = 2.0 \;\; 10^{-15} fm^2$
- m_χ=10 GeV

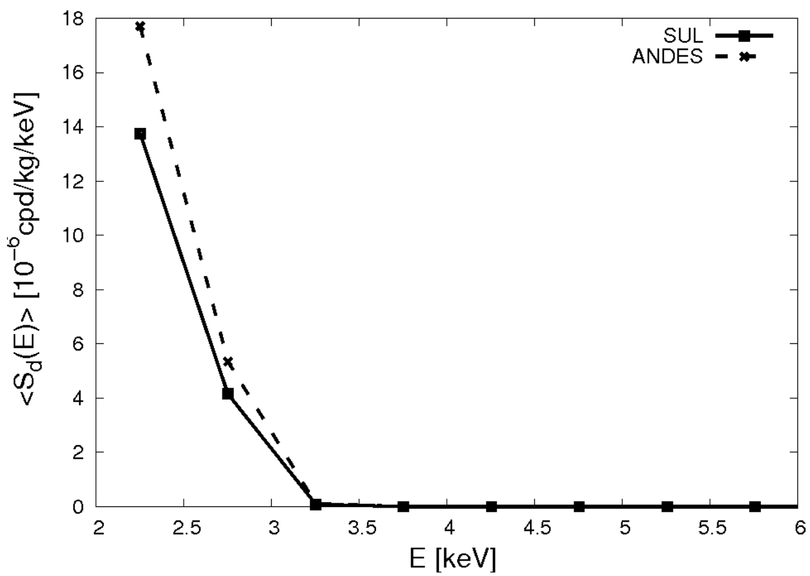
Results: Ge Detector's



Diurnal modulation as a function of the sidereal time (in days) for an energy E = 2 keV .

- Shift between the calculated signals.
- The amplitude of the modulation is larger for the case of the ANDES laboratory.

Results: Ge Detector's



At the maximum, the results for ANDES are larger by a factor of the order of 1.29, respect to the results of SUL.

$$< S_{\rm d} >= \frac{1}{E_2 - E_1} \int_{E_1}^{E_2} S_{\rm d}(E_{\rm nr}) dE_{\rm nr}$$

Summary

- The amplitudes for modulations and recoil-rates, for two different detectors, NaI and Ge, and for the best-fit values of the WIMP mass and cross section, depend on the location of the detector on the Earth.
- The value of the average diurnal modulation, for NaI and Ge detectors placed in ANDES, is larger than the values of detectors placed in other labs.
- The enhancement of the signals correlates with the ratio of the latitude's cosine of the sites.

The research in ANDES: a view

- The neutrino puzzle is not yet solved and future experiments in ANDES may play an important role in the quest for the solutions.
- ANDES may host modulus of extended detectors, like Majorana and Super-Nemo, and in due time build its own Double Beta Decay Experiment. A good candidate will be the decay of ^{128,130}Te
- More refined measurements of the neutrino oscillation parameters in ANDES may be planned in view of the space available for large detectors.
- DAMA like experiments in ANDES may confirm the findings of experiments performed in the northern hemisphere. The location of ANDES is very convenient for it.
- The activities around ANDES, both in theory and experiments, will certainly give a great impulse to physics, astrophysics and detector-technology.
- ANDES should not be a repository but a generator of new and challenging experiments.

Thanks for your attention