NEUTRINOLESS DOUBLE BETA DECAY AND PHYSICS BEYOND THE STANDARD MODEL

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Plan of Talk

- *Mass and Nature of Neutrinos*
- *Neutrinoless Double Beta Decay*
- *Uncertainties in NTMEs*
- *Physics Beyond the SM*
- *Experimental activities in India*

Static and Dynamic of Massive Properties

(1) Smallness of neutrino mass

(2) Structure of mixing matrix

(3) Nature of neutrinos

(4) Violation of B-L symmetry

(5) Stability of neutrinos

(6) Possible CP-violation in leptonic sector

(7) Interaction of neutrinos

Neutrino Mass and Mixing

(1) Extended Standard model
(enlarged fermion sector, enlarged Higgs sector, Majoron models-spontaneous B-L violation)

(2) Left-right Symmetric model (see-saw)

(3) SU(5), SO(10) and E(6) GUTs

(4) Supersymmetric models

(5) Extradimensions and String theory

Mixing: Democratic, Maximal and Bimaximal

$$m_\nu M_N \approx m_D^2$$

NEUTRINO MASS

(1) Beta Decay

$$m_\nu = \sqrt{\sum_{k=1}^{3} \left| U_{ek}^{(11)} \right|^2 m_k^2}$$

$$= \sqrt{c_{12}^2 c_{13}^2 m_1^2 + c_{13}^2 s_{12}^2 m_2^2 + s_{13}^2 m_3^2}$$

(2) Astrophysical and Cosmological

$$m_\nu = \sum_{k=1}^{3} m_k$$

(3) NDBD

$$\langle m_\nu \rangle = \sum_{k=1}^{3} \left(U_{ek}^{(11)} \right)^2 m_k$$

$$= c_{12}^2 c_{13}^2 e^{2i\alpha_1} m_1^2 + c_{13}^2 s_{12}^2 e^{2i\alpha_2} m_2^2 + s_{13}^2 m_3^2$$

Complementary Experiments

---Neutrino oscillation

---0νββ decay

----Single β decay

----Astrophysical and Cosmological measurements

–--- Role of neutrinos on large scale structure formation

Perspective of ββ decay

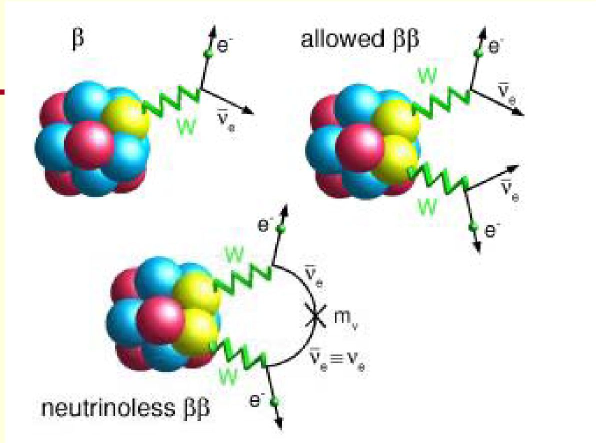
Candidates: 35 $\beta^-\beta^-$, 34 e^+ ββ emitters

Modes: $\beta^-\beta^-$, $\beta^+\beta^+$, $\varepsilon\beta^+$, εε with and without neutrinos, single Majoron and double Majorons

Transitions: $0^+\rightarrow0^+$, $0^+\rightarrow1^+$, $0^+\rightarrow2^+$ etc.

Experimental Study: Decay rates, energy spectrum, angular correlation

Implications of ββ decay



-Lepton number violation

-Dirac or Majorona neutrino

-Origin of neutrino mass

-Mass hierarchy

-Right handed current

-CP violation in lepton sector

Astrophysical: Stellar evolution and Supernova explosion

Cosmological: Big-bang nucleosynthesis, Galaxy formation, dark matter and dark energy

Gauge theoretical models

1 Left-right Symmetric models
2. Sterile neutrinos
3. Majoron models
4. SUSY models
5. Lepto-quark models
6. Compositeness
7. Extra-dimensional Scenario

Theoretical Approaches

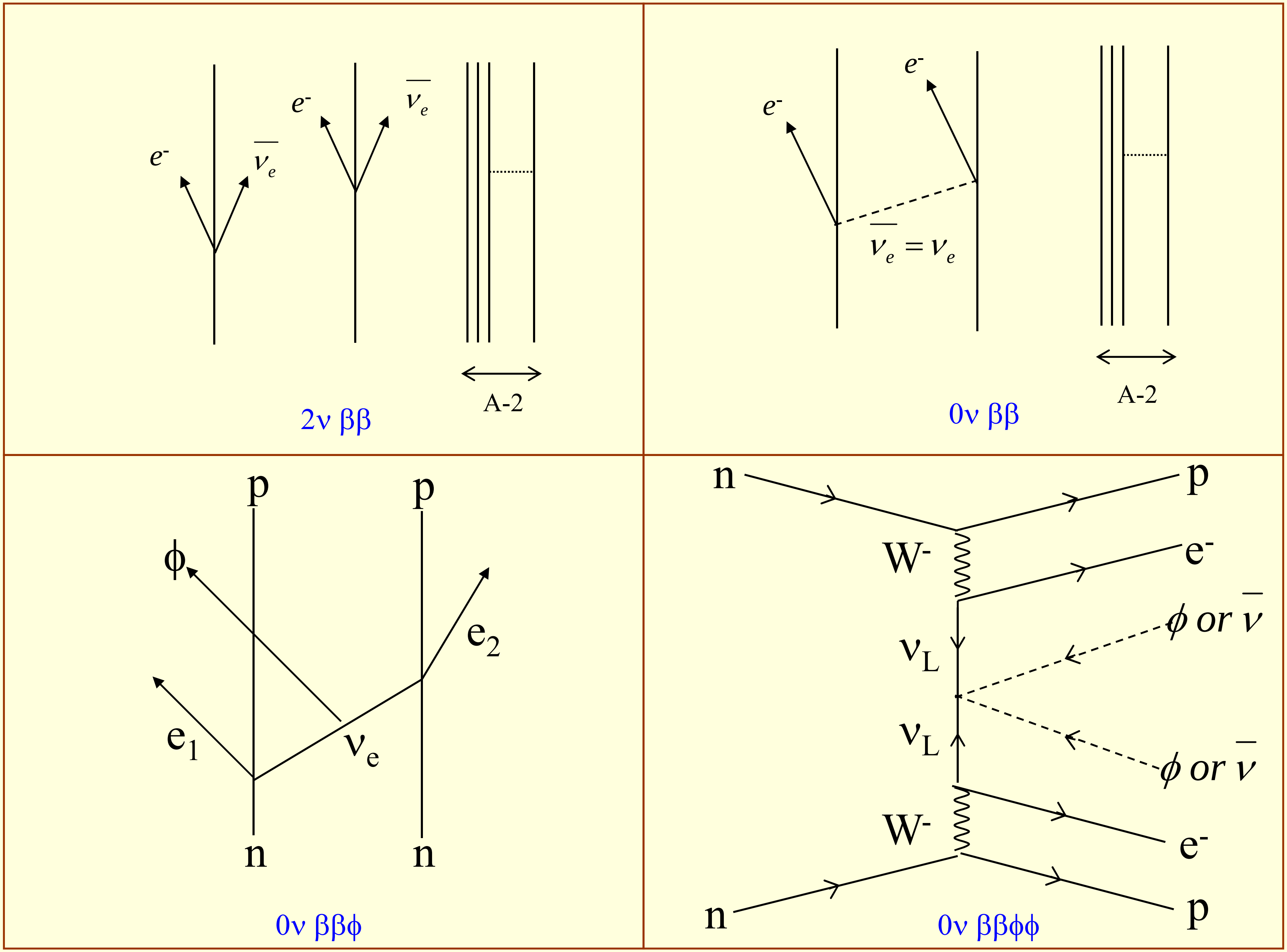
(1) Phenomenological

(2) Quark model

(3) EFT

(4) Chiral EFT

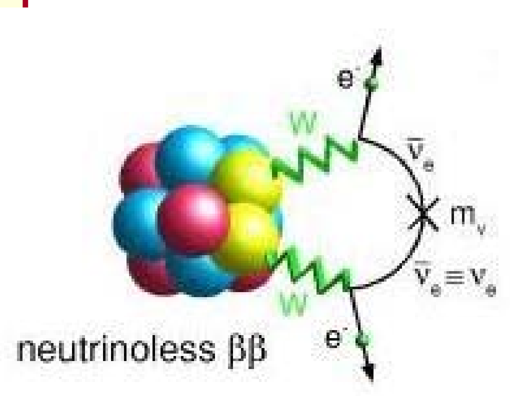
(5) Lorentz invariant description



e^-
$\bar{\nu}_e$
e^-
$\bar{\nu}_e$
A-2
2ν ββ
e^-
e^-
$\bar{\nu}_e = \nu_e$
A-2
0ν ββ
p
p
φ
e_2
e_1
ν_e
n
n
0ν ββφ
n
p
W^-
e^-
ϕ or $\bar{\nu}$
ν_L
ν_L
ϕ or $\bar{\nu}$
W^-
e^-
n
p
0ν ββφφ

$(\beta\beta)_{0\nu}$ Decay (LRSM)

$$\left[T_{1/2}^{0\nu}(0^+ \to 0^+)\right]^{-1} = \left(\frac{\langle m_\nu \rangle}{m_e}\right)^2 C_{mm}^{LL} + \left(\frac{M_p}{\langle M_N \rangle}\right)^2 C_{mm}^{NN} + \left(\frac{\langle m_\nu \rangle}{m_e}\right)\left(\frac{M_p}{\langle M_N \rangle}\right) C_{mm}^{NL}$$
$$+ \left(\frac{\langle m_\nu \rangle}{m_e}\right) \langle \lambda \rangle C_{m\lambda}^{LL} + \left(\frac{\langle m_\nu \rangle}{m_e}\right) \langle \eta \rangle C_{m\eta}^{LL} + \left(\frac{\langle m_\nu \rangle}{m_e}\right) \langle \xi \rangle C_{m\xi}^{NL}$$
$$+ \left(\frac{M_p}{\langle M_N \rangle}\right) \langle \lambda \rangle C_{m\lambda}^{NL} + \left(\frac{M_p}{\langle M_N \rangle}\right) \langle \eta \rangle C_{m\eta}^{NL} + \left(\frac{M_p}{\langle M_N \rangle}\right) \langle \xi \rangle C_{m\xi}^{NN}$$
$$+ \langle \lambda \rangle \langle \eta \rangle C_{\lambda\eta}^{LL} + \langle \lambda \rangle \langle \xi \rangle C_{\lambda\xi}^{NL} + \langle \eta \rangle \langle \xi \rangle C_{\eta\xi}^{NL}$$
$$+ \langle \lambda \rangle^2 C_{\lambda\lambda}^{LL} + \langle \eta \rangle^2 C_{\eta\eta}^{LL} + \langle \xi \rangle^2 C_{\xi\xi}^{NN} \quad (4.2)$$



$$\langle m_\nu \rangle = \sum\nolimits_i' U_{ei}^2 m_i \quad (4.3)$$

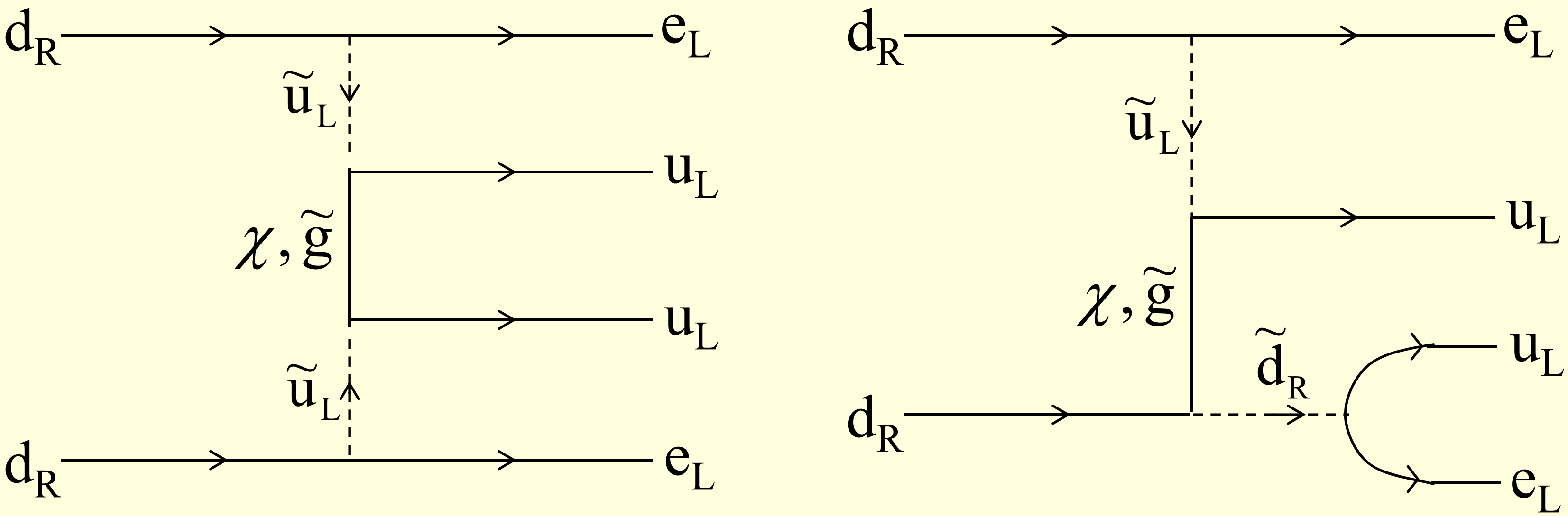
$$\langle \lambda \rangle = \lambda \left| \sum\nolimits_i' \left(\frac{g_V'}{g_V}\right) U_{ei} V_{ei} \right| \quad (4.4)$$

$$\langle \eta \rangle = \eta \left| \sum\nolimits_i' U_{ei} V_{ei} \right| \quad (4.5)$$

$$\langle M_N \rangle^{-1} = \sum\nolimits_i'' U_{ei}^2 m_i^{-1} \quad (4.6)$$

$$\langle \xi \rangle = \left[\lambda^2 + \eta^2 - 2\lambda\eta \left(\frac{M_{GTh} + M_{Fh}}{M_{GTh} - M_{Fh}}\right)\right] \sum\nolimits_i'' V_{ei}^2 \left(\frac{M_p}{m_j}\right) \quad (4.7)$$

SUSY models



$$T_{1/2}^{-1}(0\nu\beta\beta) = G_{01} M_1^{\nu} (m_e R)^{-1} (4\overline{\eta}_{(l)} + \overline{\eta}_{(q)} + \eta_{(q)})^2$$

Majoron models

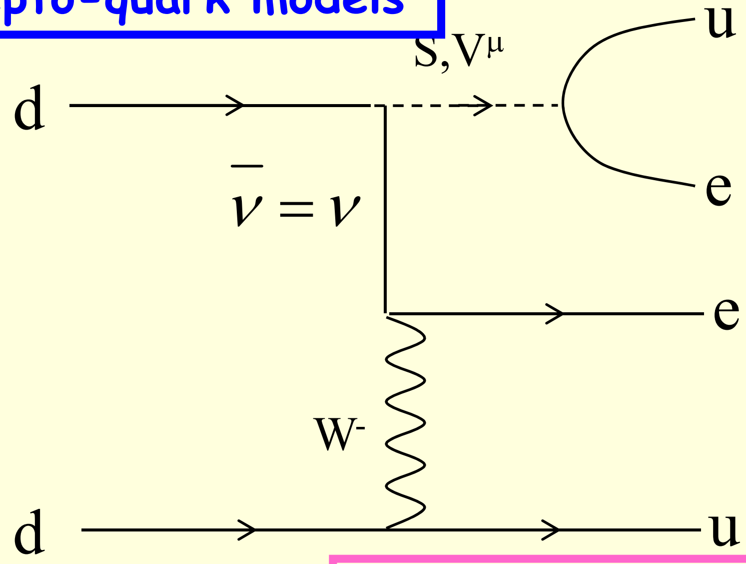
Half-life $T_{1/2}$ of Majoron emitting $0\nu\ \beta\beta$ decay is given by

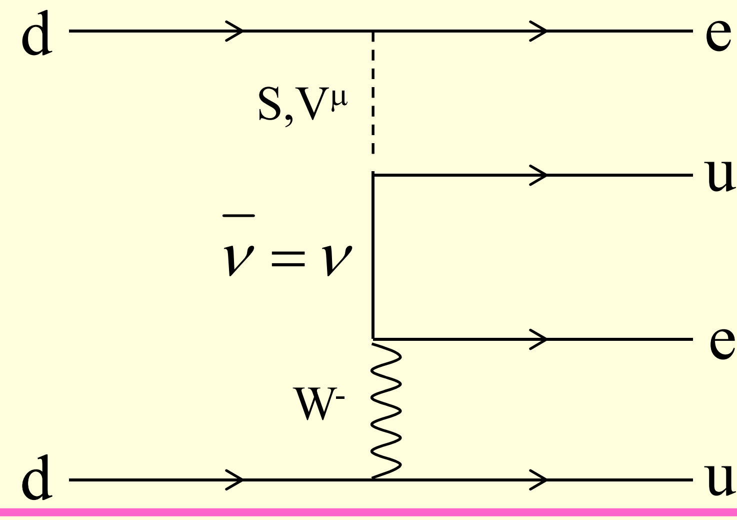
$$[T_{1/2}]^{-1} = \left|\langle g_\alpha \rangle\right|^m . \left|M_\alpha\right|^2 . G_{\beta\beta\alpha}$$

where

$$m = \begin{cases} 2 & 0\nu\beta\beta\phi \\ 4 & 0\nu\beta\beta\phi\phi \end{cases}$$

Lepto-quark models

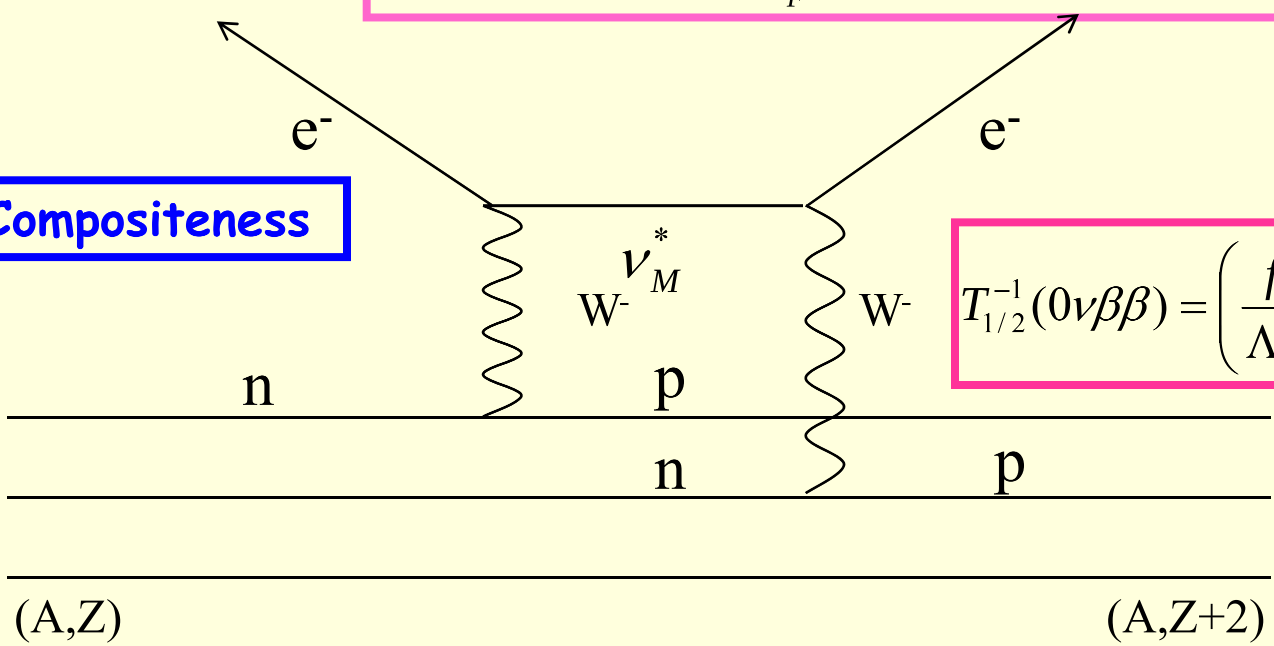




Half-life

$$T_{1/2}^{-1}(0\nu\beta\beta) = |M_{GT}|^2 \frac{2}{G_F^2}[\tilde{C}_1 a^2 + a(\tilde{C}_2 b_R - \sqrt{2}\tilde{C}_3 b_L) + C_4 b_R^2 + 2C_5 b_L^2 - \sqrt{2}C_6 b_L b_R]$$

Compositeness



$$T_{1/2}^{-1}(0\nu\beta\beta) = \left(\frac{f}{\Lambda_c}\right)^{-4} \frac{m_A^8}{M_N^2} \frac{G_{01}}{m_e^2} |M_{FI}|^2 (\eta_L^4 + \eta_R^4)$$

Sterile neutrinos

Half-life $T_{1/2}$:

$$T_{1/2}^{-1}(0\nu\beta\beta) = G_{01}\left| U_{eh}^{2}\frac{m_h}{m_e} M^{0\nu}(m_h)\right|^2$$

U_{eh} is the ν_h-ν_e mixing matrix element and $M^{0\nu}(m_h)$ is the NTME.

Extra-dimensions

$$\langle m \rangle = \frac{1}{\mathcal{M}_{\rm GTF}(m_\nu)} \sum_{n=-\infty}^{\infty} B_{e,n}^2 \, m_{(n)} \left[\mathcal{M}_{\rm GTF}(m_{(n)}) - \mathcal{M}_{\rm GTF}(m_\nu) \right] .$$

$(\beta\beta)_{0\nu}$ Decay

$$[T_{1/2}^{0\nu}(0^+ \to 0^+)]^{-1} = G_{01} \left| \sum_{\alpha} \eta_\alpha M^{(\alpha)} \right|^2$$

where

$$M^{(\alpha)} = M_F^{(\alpha)} + M_{GT}^{(\alpha)} + M_T^{(\alpha)}$$

$and\ \alpha = \text{differentmodes}$

Opearators are long and short ranged.

$$A_L = G_F^2 \frac{M_{ee}^{\nu}}{k^2}$$

and

$$A_H = G_F^2 \frac{M_W^4}{\Lambda^5}$$

$$\mathrm{A}_H / \mathrm{A_L} \approx 1$$

for $M_{ee}^{\nu} \approx 0.1\text{-}0.5\ \mathrm{eV}$

and $\Lambda = 1\ \mathrm{TeV}$

Sources of Uncertainties

(1) Structure of NTMEs

(nonperturbative QCD)

(Simkovic et al., Vergados, Faessler, Civitarese and Suhonen, Mendez)

(2) Assumptions of NRMBTH

(3) Model Specific

(4) g_A

(6) FNS

(7) SRC

Reliability of NTMEs

Models:

SM, QRPA, DQRPA, PHFB, EDF CDFT, IBM

Calculation of as many physical observables as possible

--PRC 41, 1315 (1990)

(1) Yrast spectra

(2) Occupation Numbers

(3) Reduced $B(E2:0^+ \rightarrow 2^+)$ transition

(4) Static quadrupole moments $Q(2^+)$

(5) g-factors $g(2^+)$

(6) $M_{2\nu}$

FNS

(1) Dipole form factor
(2) Structure of nucleons
(3) ……
(4) ……….
……………….

SRC

(1) Jastrow correlations (Miller-Spencer, CCM)
(2) UCOM
(3) CCM (Argonne and CD-Bonn)
(4) FhCh
(5) Meson exchange

Uncertainties in NTMEs

(1) Spread (Vogel)
(2) Global average (Bahcall, Avignone III)
(3) Model independent (Bilenky and Grifols)
(4) Model specific (Tuebingen, Jyväskylä)
(5) Engel's proposal

Deformation Effects

(1) NTMEs are large for a pair of spherical nuclei.

(2) With small admixture of quadrupolar correlations, NTMEs are almost constant and suppressed in realistic situations.

(3) NTMEs are large for identical deformations of parent and daughter nuclei.

(4) Sizes of NTMEs are reduced with the increase in deformations of parent and daughter nuclei.

(5) The deformation effects are equally important for $(\beta\beta)_{2\nu}$ and $(\beta\beta)_{0\nu}$ modes so far as nuclear structure aspect of $\beta\beta$ decay is concerned.

EPJA 23, 223 (2005); EPJA 28, 27 (2006); EPJA 33, 375 (2007),

PRC 78, 054302 (2008); PRC 80, 044303 (2009), EPL 86, 32001 (2009),

JPG 37, 055108 (2010)

Calculated [5] and experimental deformation parameter β_2 [6].

Nuclei	Case	β_2 $(Th.)$	β_2 $(Exp.)$	Nuclei	Case	β_2 $(Th.)$	β_2 $(Exp.)$
^{94}Zr	(a)	0.100	0.090±0.010	^{94}Mo	(a)	0.161	0.1509±0.0015
	(b)	0.110			(b)	0.161	
^{96}Zr	(a)	0.085	0.080±0.017	^{96}Mo	(a)	0.191	0.1720±0.0016
	(b)	0.087			(b)	0.186	
^{98}Mo	(a)	0.158	0.1683±0.0028	^{98}Ru	(a)	0.205	0.1947±0.0030
	(b)	0.162			(b)	0.194	
^{100}Mo	(a)	0.231	0.2309±0.0022	^{100}Ru	(a)	0.214	0.2148±0.0011
	(b)	0.226			(b)	0.214	
^{104}Ru	(a)	0.285	0.2707±0.0020	^{104}Pd	(a)	0.216	0.209±0.007
	(b)	0.282			(b)	0.219	
^{110}Pd	(a)	0.216	0.257±0.006	^{110}Cd	(a)	0.196	0.1770±0.0039
	(b)	0.214			(b)	0.191	
^{128}Te	(a)	0.136	0.1363±0.0011	^{128}Xe	(a)	0.192	0.1836±0.0049
	(b)	0.136			(b)	0.181	
^{130}Te	(a)	0.117	0.1184±0.0014	^{130}Xe	(a)	0.166	0.169±0.007
	(b)	0.120			(b)	0.163	
^{150}Nd	(a)	0.276	0.2853±0.0021	^{150}Sm	(a)	0.238	0.1931±0.0021
	(b)	0.279			(b)	0.241	

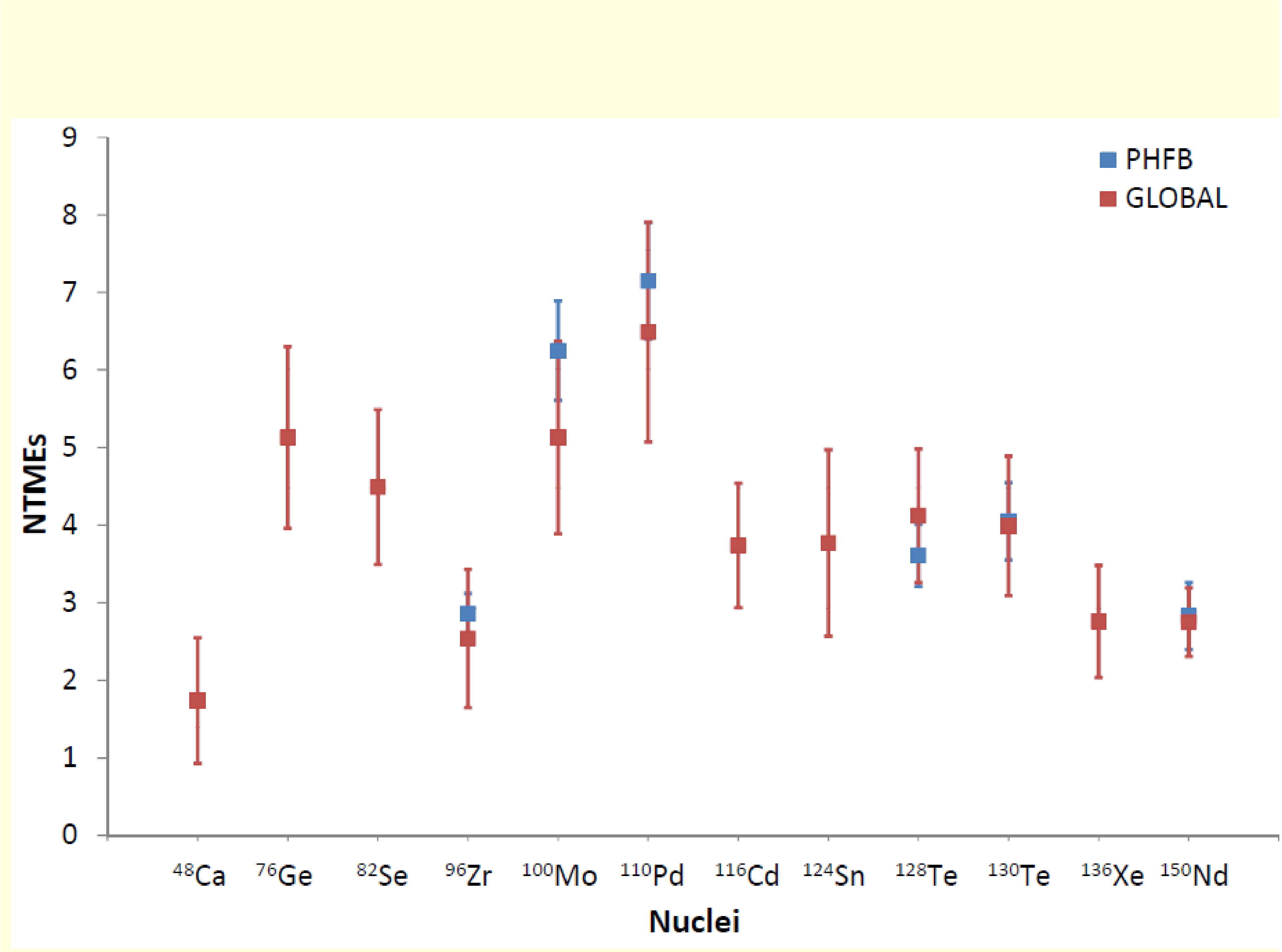
Uncertainties in NTMEs

NTMEs and uncetainties of short and long ranged operators.

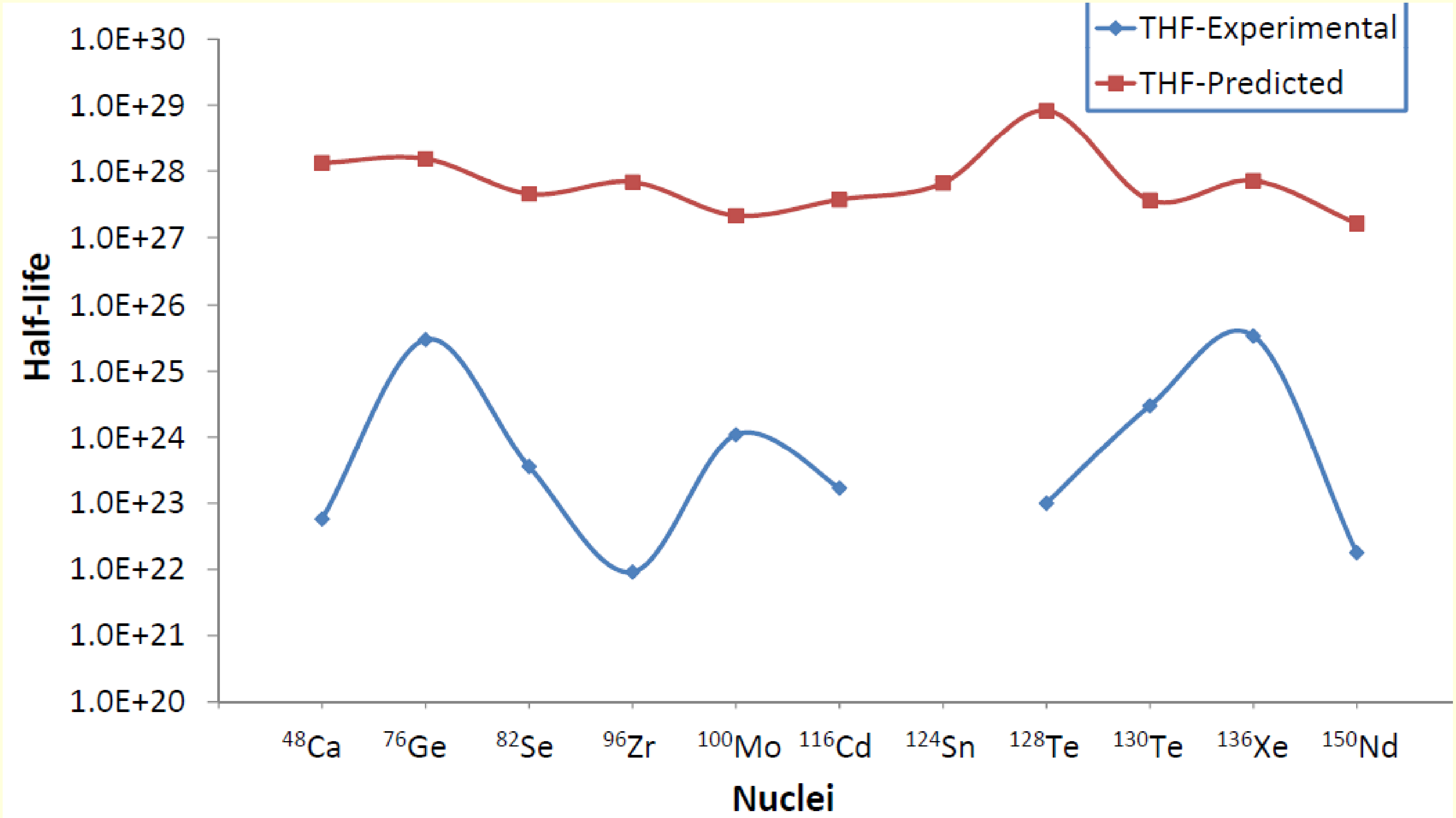
Nuclei	^{96}Zr	^{100}Mo	^{128}Te	^{130}Te	^{150}Nd	Error(%)
$M^{(0\nu)}$	2.86±0.26	6.25±0.64	3.61±0.40	4.05±0.50	2.83±0.43	9–15
$M_N^{(\tilde{q}\nu)}(bag)$	34.2±12.8	78.2±25.1	46.7±16.9	56.3±16.4	31.4±11.0	32–37
$M_N^{(\tilde{q}\nu)}(nrqm)$	81.5±24.9	174.0±49.3	104.4±32.3	117.0±31.8	70.5±21.7	22–49
$M_\pi^{(\tilde{q}\nu)}$	219.5± 20.1	486.9± 49.9	305.4±30.7	318.4±30.1	213.5±31.6	9–15
$M_{CL}^{(\chi)}$	0.60±0.06	1.21±0.12	0.26±0.03	0.69±0.08	0.63±0.10	9–15
$M_{CR}^{(\chi)}\times 10^3$	1.64±0.15	3.02±0.29	0.23±0.02	1.47 ±0.17	1.71± 0.25	9–15
$M_{w2}^{(\chi)}\times 10^4$	0.74±0.06	1.25±0.14	0.10±0.01	0.65 ±0.13	0.77±0.1	7–21
$M_{w2}^{(\chi)}\times 10^4$	2.52±0.19	3.60±0.40	0.03±0.004	1.38± 0.29	2.77 ±0.45	7–21
$M^{(0N)}$	100.53±36.89	206.75 ±73.08	126.83± 46.34	136.39± 46.92	85.55± 31.45	34–37

PHFB model specific and global uncetainties NTMEs.

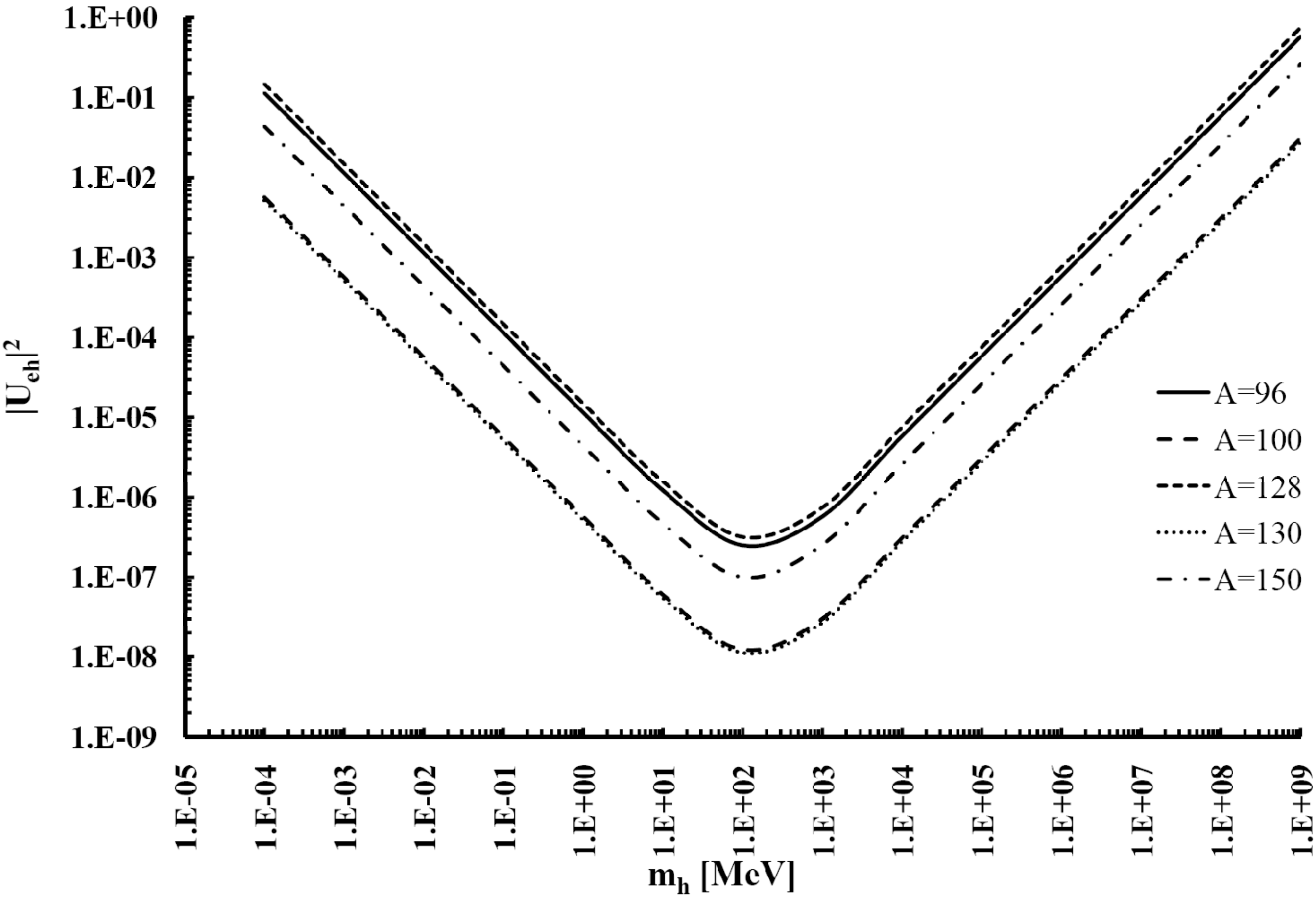
Nuclei	PHFB	Error(%)	Global	Error(%)	$T_{1/2}^{(0\nu)}(yr)$	$\langle m_\nu \rangle$	$T_{1/2}^{(0\nu)}(yr)$ $\langle m_\nu \rangle = 0.01$ e
^{48}Ca			1.74± 0.81	46.44	5.8×10^{22}	4.80	1.33×10^{28}
^{76}Ge			5.13 ±1.17	22.84	3.0×10^{25}	0.23	1.53×10^{28}
^{82}Se			4.49 ±1.00	22.22	3.6×10^{23}	3.55	4.54×10^{27}
^{96}Zr	2.86±0.26	9.26	2.54 ±0.89	35.03	9.2×10^{21}	8.60	6.81×10^{27}
^{100}Mo	6.25±0.64	10.20	5.13 ±1.24	24.13	1.1×10^{24}	0.44	2.14×10^{27}
^{110}Pd	7.15±0.75	10.54	6.49 ±1.42	21.87	6.0×10^{17}	852	4.36×10^{27}
^{116}Cd			3.74± 0.80	21.44	1.7×10^{23}	1.48	3.72×10^{27}
^{124}Sn			3.77 ±1.20	31.86			6.60×10^{27}
^{128}Te	3.61±0.40	10.94	4.12± 0.86	20.98	1.0×10^{23}	8.71	8.34×10^{28}
^{130}Te	4.05±0.50	12.29	3.99±0.90	22.43	3.0×10^{24}	0.35	3.66×10^{27}
^{136}Xe			2.76 ±0.72	26.02	3.4×10^{25}	0.14	7.14×10^{27}
^{150}Nd	2.83±0.43	15.22	2.75 ±0.44	16.46	1.8×10^{22}	3.01	1.63×10^{27}



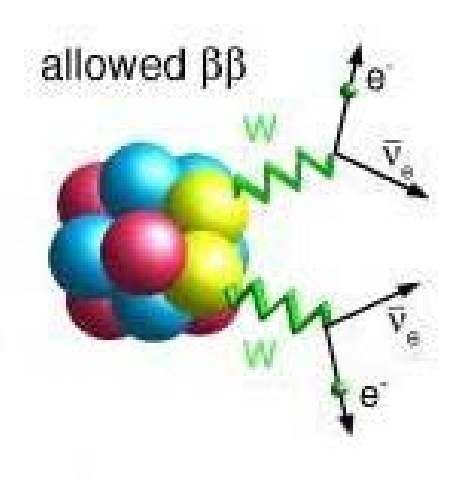
PHFB
GLOBAL
NTMEs
0
1
2
3
4
5
6
7
8
9
^{48}Ca
^{76}Ge
^{82}Se
^{96}Zr
^{100}Mo
^{110}Pd
^{116}Cd
^{124}Sn
^{128}Te
^{130}Te
^{136}Xe
^{150}Nd
Nuclei


THF-Experimental
THF-Predicted
Half-life
1.0E+30
1.0E+29
1.0E+28
1.0E+27
1.0E+26
1.0E+25
1.0E+24
1.0E+23
1.0E+22
1.0E+21
1.0E+20
48Ca
76Ge
82Se
96Zr
100Mo
116Cd
124Sn
128Te
130Te
136Xe
150Nd
Nuclei

Sterile Majorona Neutrinos



Standard Model and Beyond



Barabash et al.

$$Time\ dependence\ of\ G_F \quad \Delta G_F / G_F \quad \approx \quad -0.1$$

$$Bosonic\ \ neutrino \qquad \mathrm{Sin}^2\chi < 0.6$$

J. S. Diaz

Lorentz and *CPT Violation*

Modification of electron sum spectrum $(2\nu\beta\beta)$

Angular correlations $(0\nu\beta\beta)$

Parameters of gauge theoretical models

Physics beyond the standard model ($T^{0\nu}_{1/2} > 3.0 \times 10^{25}$ yr)

Parameters			Limits
Effective Majorana neutrino mass	$\langle m_\nu \rangle$	$<$	$0.23\ eV$
L-R Coupling constant	$\langle \eta \rangle$	$<$	3.18×10^{-9}
R-R Coupling constant	$\langle \lambda \rangle$	$<$	5.73×10^{-7}
Heavy Neutrino mass	$\langle M_N \rangle$	$>$	$9.46 \times 10^{7}\ GeV$
	$\langle \xi \rangle$	$<$	9.16×10^{-9}
Mass of W_R	m_{W_R}	$>$	$1.44 \left(\frac{\langle m_N^{(V)} \rangle}{1\ TeV} \right)^{-1/4}$
	$\tan\langle \xi \rangle$		$3.12 \times 10^{-3} \left(\frac{\langle m_N^{(V)} \rangle}{1\ TeV} \right)^{1/2}$
Neutrino-Majoron coupling	$\langle g_m \rangle$	$<$	8.2×10^{-5}
R-parity violation	ζ	$<$	1.43×10^{-5}
Compositeness scale	$\lvert f \rvert$	$<$	2.72
Excited Majoron neutrino mass	$\langle m_N \rangle$	$>$	$433\ GeV$
Leptoquark-Higgs coupling	ϵ_I	$<$	$1.16 \times 10^{-9} \left(\frac{M_I}{100\ GeV} \right)^2$
	$\alpha_I^{(L)}$	$<$	$1.51 \times 10^{-10} \left(\frac{M_I}{100\ GeV} \right)^2$
	$\alpha_I^{(R)}$	$<$	$3.82 \times 10^{-8} \left(\frac{M_I}{100\ GeV} \right)^2$
VLI	δv	$<$	4×10^{-16}

Physics @ LHC

$(i) e^- e^- \to W^- W^-$

$(ii) e^- e^\pm \to H^- H^\pm$

$(iii) e^\pm e^\pm \to H^\pm H^\pm$

$(iv) t \to b W^- l_i^+ l_j^+$

$(v) W^+ \to J J' l_i^+ l_j^+$

A non-observation of eejj-like events in the future LHC run at $\sqrt{s} = 11$ TeV would rule out all but the pure leptoquark contribution as the dominat mode to $0\nu\beta\beta$ decay.

EXPERMENTAL ACTIVITIES IN INDIA

INO Collaboration

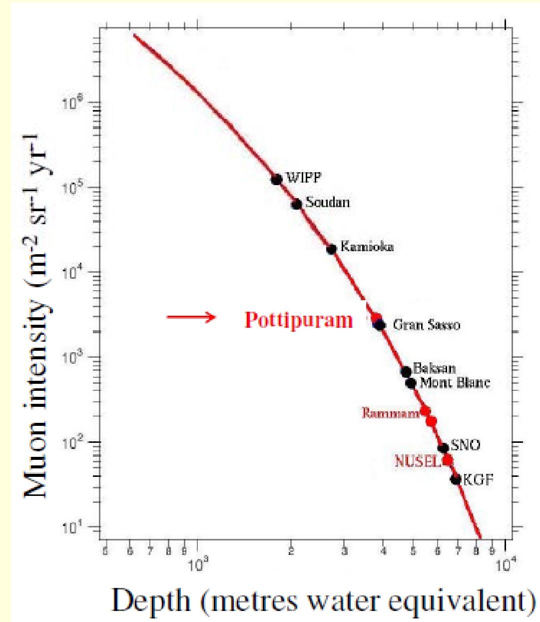
Ahmadabad: Physical Research Lab.
Aligarh: Aligarh Muslim University
Allahabad: HRI
Bhubaneswar: Institute of Physics
Calicut: University of Calicut
Chandigarh: Panjab University
Chennai: IIT, Madras IMSc
Delhi: University of Delhi
Guwahati: IIT, Guwahati
Hawaii (USA): University of Hawaii
Indore: IIT, Indore
Jammu: University of Jammu
Kalpakkam: IGCAR
Kolkata: Ramakrishna Mission Vivekananda University, SINP, VECC, University of Calcutta
Lucknow: Lucknow University
Madurai: American College
Mumbai: BARC, IIT, Bombay TIFR
Mysore: University of Mysore
Sambalpur: Sambalpur University
Srinagar: University of Kashmir
Varanasi: Banaras Hindu University

India-based Neutrino Observatory (INO)

an underground laboratory

9°57′14.3″N 77°16′47.56″E

Bodi West Hills, Theni district



Physics Motivation at INO

(1) ICAL
(2) NDBD
(3) DINO

Cavern set in Charnockite rock under 1580 m peak, 1289 m Vertical cover, 1000 m all-round

The INdia-based TIN detector (TIN.TIN)
Initiative for DBD experiment in India

Proposal for an experiment at site of the INO (India-based neutrino Observatory)

^{124}Sn (Q =2288.1 ± 1.6 keV)

- Sn has $T_C \sim 3.7$ K
- Electronic specific heat falls off exponentially below T_C
- Only lattice specific heat ($\sim T^3$) present below ~ 500 mK
- Z=50 shell is closed
- Simple metallurgy

^{124}Sn: $T_{1/2} > (0.8\text{-}1.2) \times 10^{21}$ yrs Nucl. Phys. A **807,** 269(2008)

Cryogen free dilution refrigerator installed at TIFR

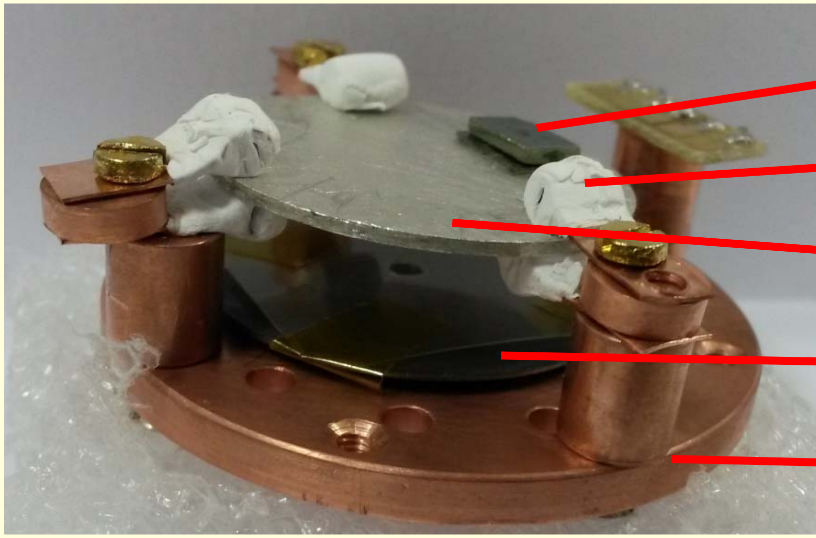
Base Temp. ~7 mK

cooling power
1.4 mW@120mK

V. Singh et. al. Pramana ***81*** *(2013) 719*

http://www.tifr.res.in/~tin.tin/

Bolometer Detector – Initial Tests



NTD Ge sensor (made in India)

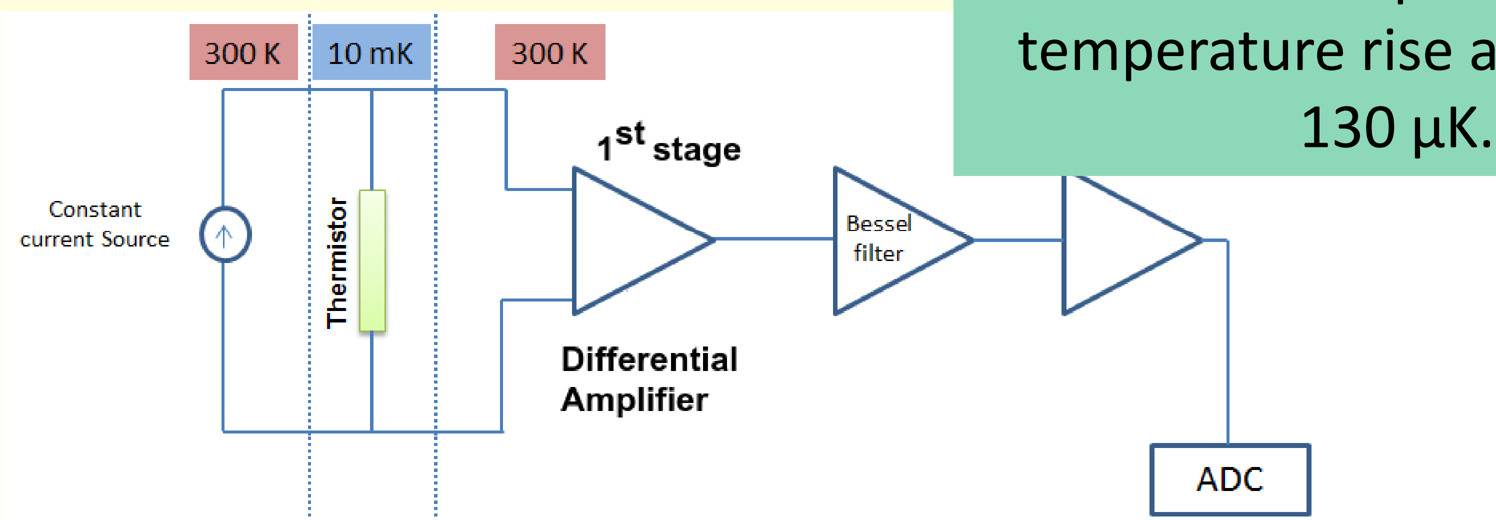
Teflon : weak thermal link

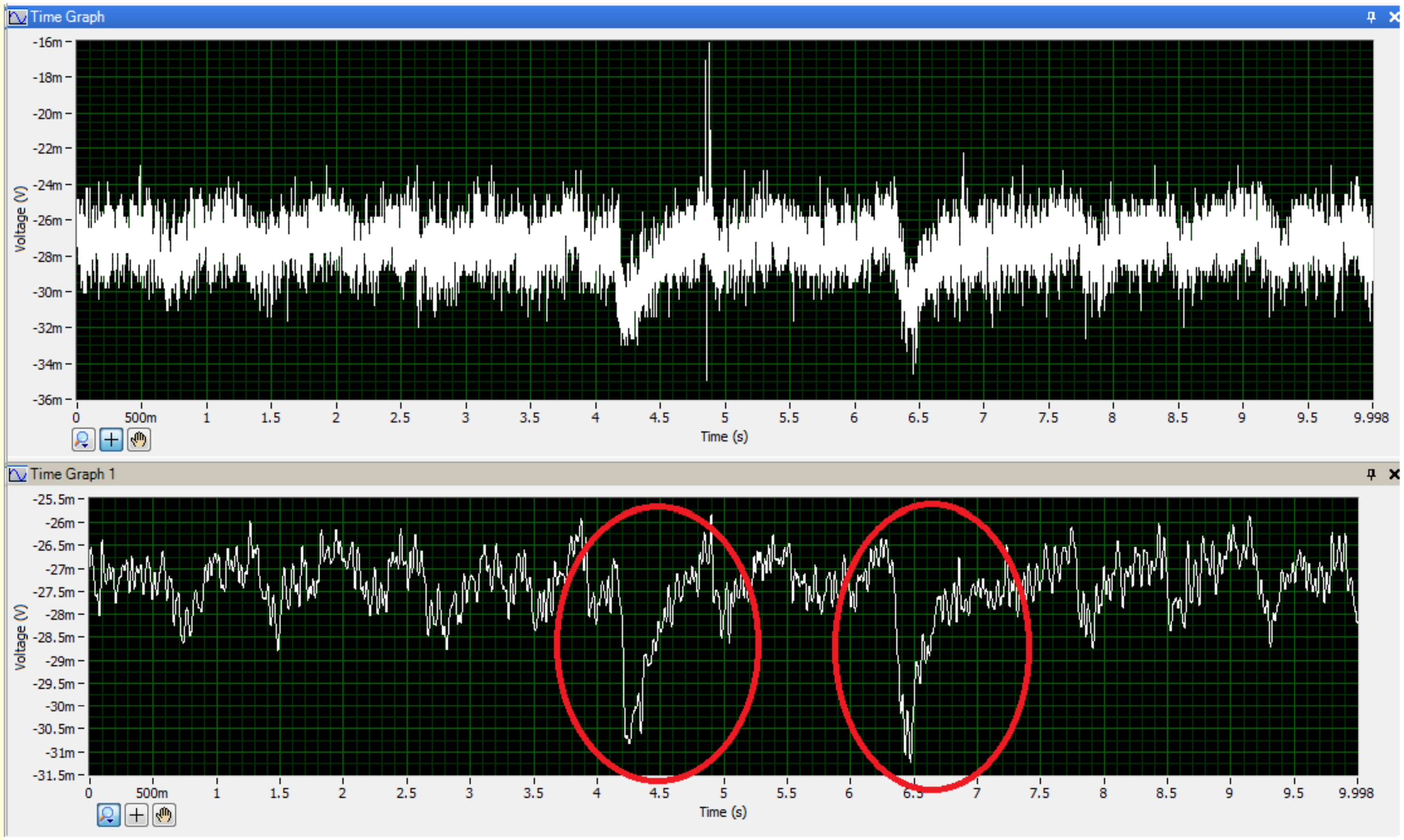
Tin ~ 3.3 g

Am-Pu alpha source (5.5 MeV)

Copper : Thermal Bath

For 5.5 MeV alpha - expected temperature rise at 100 mK ~ 130 μK.



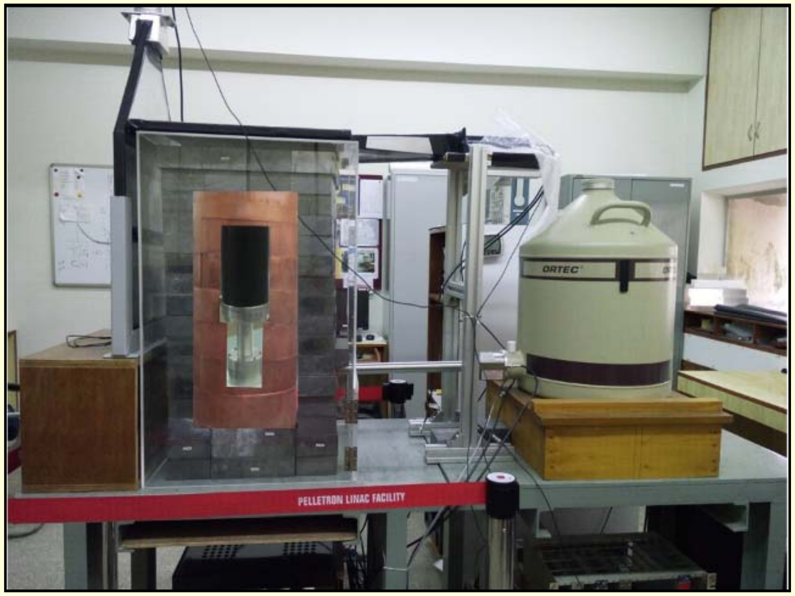


RAW SIGNAL
after gain ~ 100.

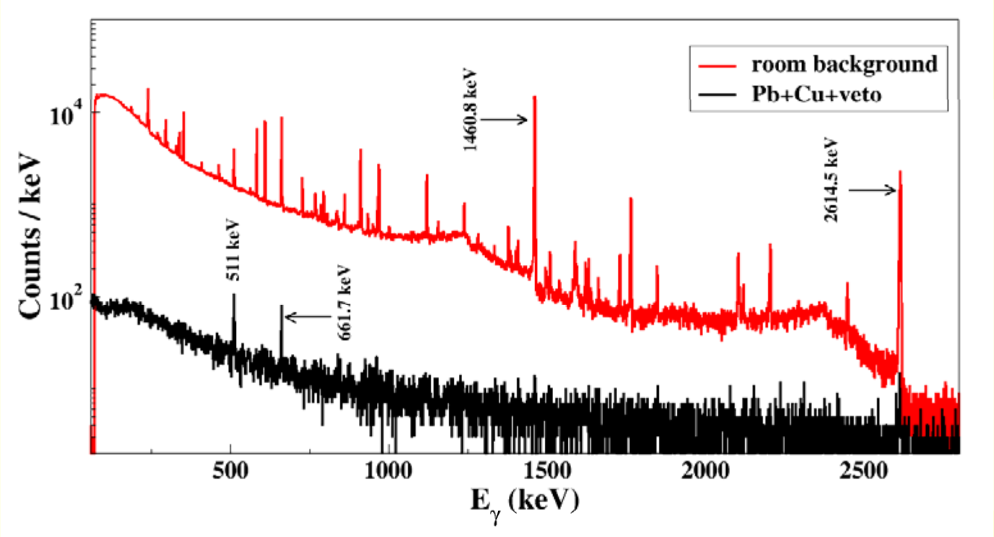
Filtered Signal
(Cutoff ~ 30 Hz)

- Thermal pulses are characterized by sharp rise time and very slow decay time.
- Since the pulses are slow high frequency noise can be filtered
- Count rate matched with the alpha source.
- Need to improve on Signal to Noise ratio to achieve good resolution and generate an energy spectrum.

Low Background Counting Facility (Tiles)



TiLES with Cu +low activity shield and muon veto



Background Gamma ray spectra with and without veto

Sensitivity of the setup:

0.04mBq/g for ^{40}K ~ 1ppm
0.004mBq/g for ^{232}Th ~1 ppt

- **Screening of materials and their selection on the basis of radio purity levels**
- **Rare decay studies**

N. Dokania *et al.*, NIM A **745** (2014) 119-127

Future Goal…

After prototype demonstration

Build a large scale detector (~ 1 ton) at INO lab

(3 phases: 100 Kg, 500 Kg, 1000 Kg)

$F_n = G^{0\nu} |M^{0\nu}|^2$ *= 8.611 × $10^{-13}\ y^{-1}$ (PHFB) (Rath et al.)*

= 6.205 × $10^{-14}\ y^{-1}$ (SM)

With 90 % enrichment, 0.2% energy resolution at $Q_{\beta\beta}$, background ~ 0.01 counts/ keV. kg.y and 1 year observation time

Phase	Mass (kg)	$T_{1/2}$ (y) [68% C.L.]	<$m_{\beta\beta}$> eV
I	100	8.6×10^{25}	0.06-0.22
II	500	1.9×10^{26}	0.04-0.15
III	1000	2.7×10^{26}	0.03-0.12

- KamLANDZen + EXO : $T^{0\nu}_{1/2} > 3.4 \times 10^{25}\ y$ **(90% C.L.), <$m_{\beta\beta}$> < 0.12-0.25 eV**
  (PRL 110 (2013) 062502)
- GERDA : $T^{0\nu}_{1/2} > 2.1 \times 10^{25}\ y$ **(90% C.L.), <$m_{\beta\beta}$> < 0.2-0.4 eV**
  (PRL 111 (2013) 122503)

Tin.Tin Collaboration

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Thanks to

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"A poet once said 'The whole universe is in a glass of wine.' We will probably never know in what sense he meant that, for poets do not write to be understood. But it is true that if we look at a glass closely enough we see the entire universe.

Thanks a lot for your indulgence