Normal hierarchyを探索可能なdouble-beta実験
と
ニュートリノ混合行列のユニタリティ検証実験

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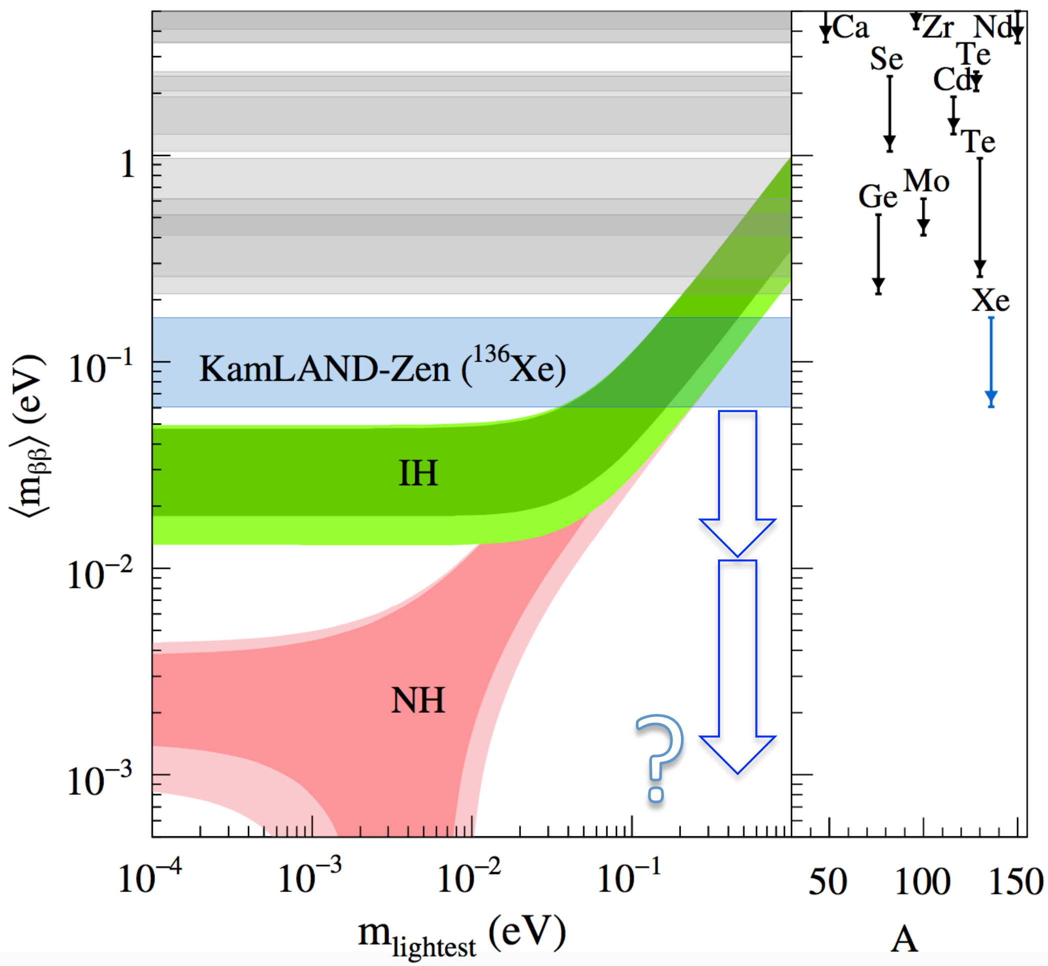
- No question about the importance of 0ν2β decay search



KamLAND-Zen Collaboration PRL117, 082503 (2016)

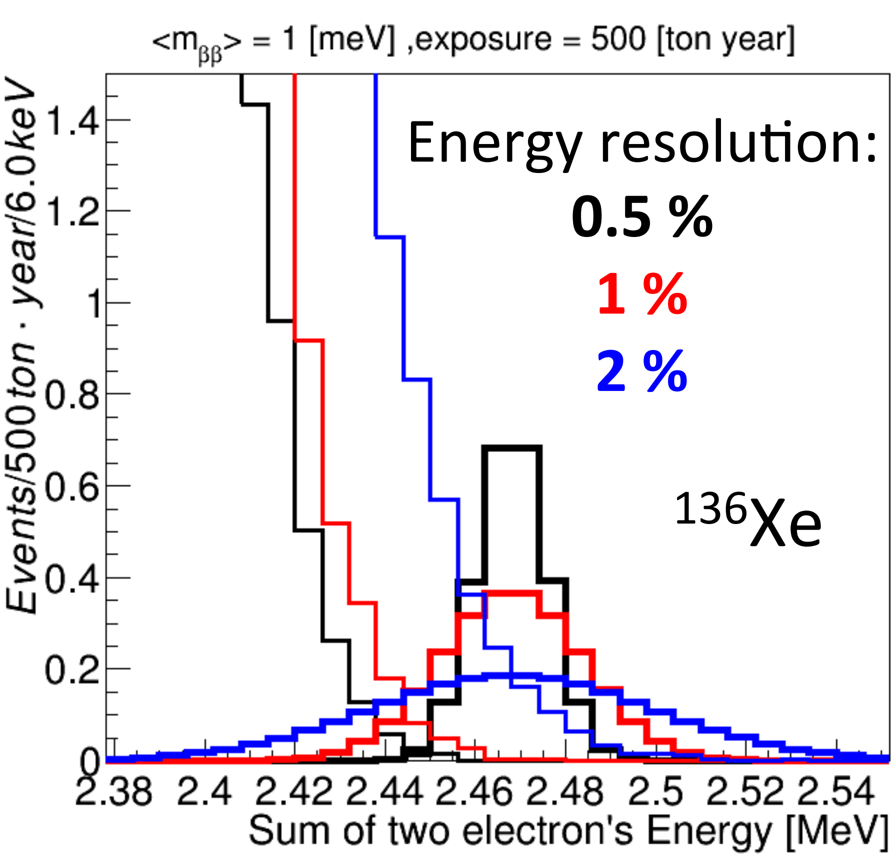
- KamLAND-zen and other projects aim to test M vs. D with IH
- What is minimum requirement to reach 1meV?

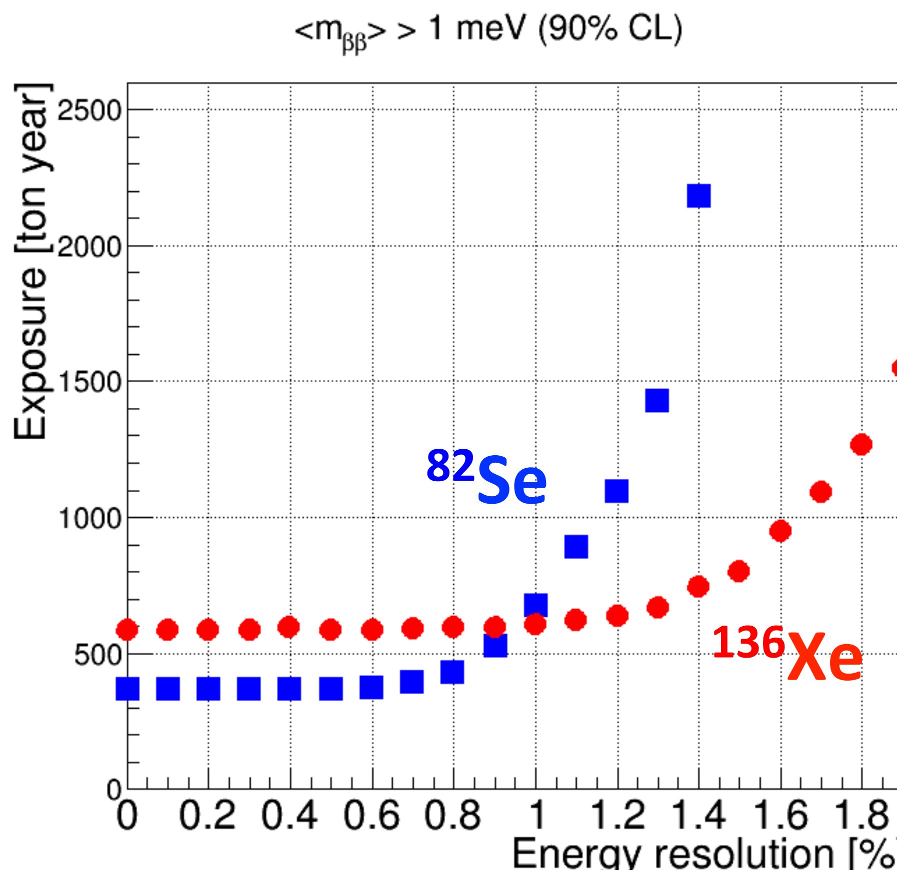
Plot from Dai Hamabe (TokyoTech)
0v2β and 2v2β decay calculated using DECAY0 code provided by V. Tretyak

- >500 ton mass of double-beta decay source
- <1% energy resolution

⇒ about 2 event/year expected with 500 ton·yr

- Background should be below this level
  → PID (e/α, e/γ, 2 electron tracks) necessary





Unitarity of neutrino mixing matrix (no specific model assumed)

$U^{\dagger}U = \mathbf{1} \quad \Rightarrow$

$$\left|U_{e1}\right|^2 + \left|U_{e2}\right|^2 + \left|U_{e3}\right|^2 = 1$$

and for μ and τ

$$U_{e1}U_{\mu 1}^* + U_{e2}U_{\mu 2}^* + U_{e3}U_{\mu 3}^* = 0$$

and for μ,τ and e,τ

$$\left|U_{e1}\right|^2 + \left|U_{\mu 1}\right|^2 + \left|U_{\tau 1}\right|^2 = 1$$

and for 2 and 3

$$U_{e1}U_{e2}^* + U_{\mu 1}U_{\mu 2}^* + U_{\tau 1}U_{\tau 2}^* = 0$$

and for 2,3 and 1,3

Not straightforward to measure due to degeneracy of mass squared differences (oscillation length)

$$\Delta m_{21}^2 << \Delta m_{31}^2 \sim \Delta m_{32}^2$$

Direct test

$$|U_{e1}|^2 + |U_{e2}|^2 + |U_{e3}|^2 = 1$$

KamLAND: $4|U_{e1}|^2 |U_{e2}|^2$

DC, Daya Bay, RENO: $4|U_{e3}|^2 \left(|U_{e1}|^2 + |U_{e2}|^2\right)$

Solar (with MSW): $|U_{e2}|^2$

$$1 - |U_{e1}|^2 + |U_{e2}|^2 + |U_{e3}|^2 < \ \sim 0.04$$

Other direct test?

$$\left|U_{\mu 1}\right|^2 + \left|U_{\mu 2}\right|^2 + \left|U_{\mu 3}\right|^2 = 1$$

ν_μ disappearance ($\Delta m^2_{31(32)}$): $4\left|U_{\mu 3}\right|^2 \left(\left|U_{\mu 1}\right|^2 + \left|U_{\mu 2}\right|^2\right)$

⇒ LBL, atmospheric

ν_μ disappearance (Δm^2_{21}): $4\left|U_{\mu 1}\right|^2 \left|U_{\mu 2}\right|^2$

⇒ atmospheric sub-GeV ν_μ?
disappearance canceled by $\nu_e \rightarrow \nu_\mu$ as ν_μ/ν_e~2
need to understand flux precisely

Alternative approach (indirect)

- Test consistency of mixing angle from different oscillation modes
  - Discrepancy indicates violation of unitarity due to e.g. mixing of 4th neutrino
- θ_{13}
  - From disappearance ($\nu_e \rightarrow \nu_e$): Reactor
  - From appearance ($\nu_\mu \rightarrow \nu_e$): LBL, atmospheric
- θ_{23}
  - From disappearance ($\nu_\mu \rightarrow \nu_\mu$): LBL, atmospheric
  - From appearance ($\nu_\mu \rightarrow \nu_\tau$): Atmospheric, LBL