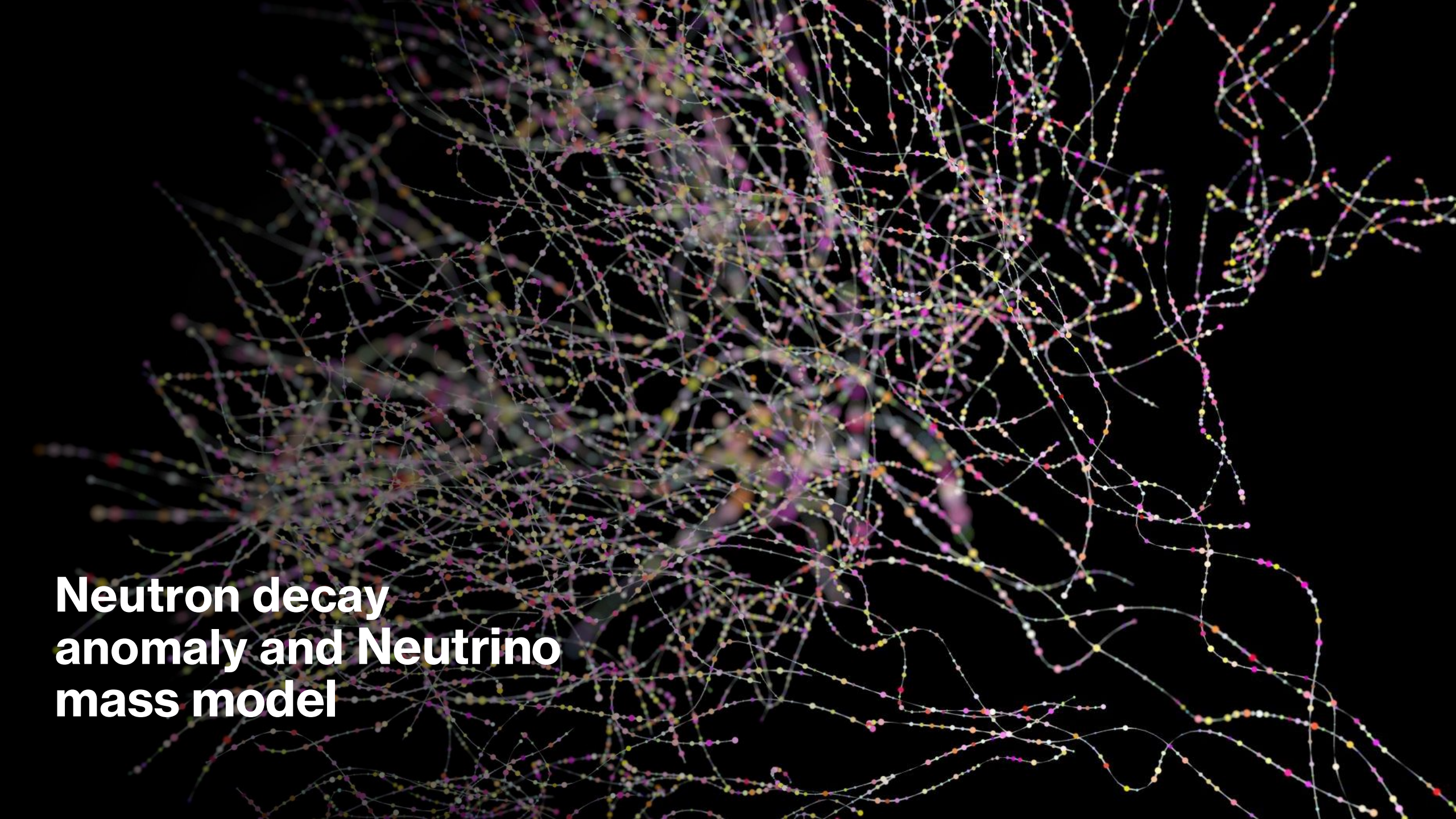
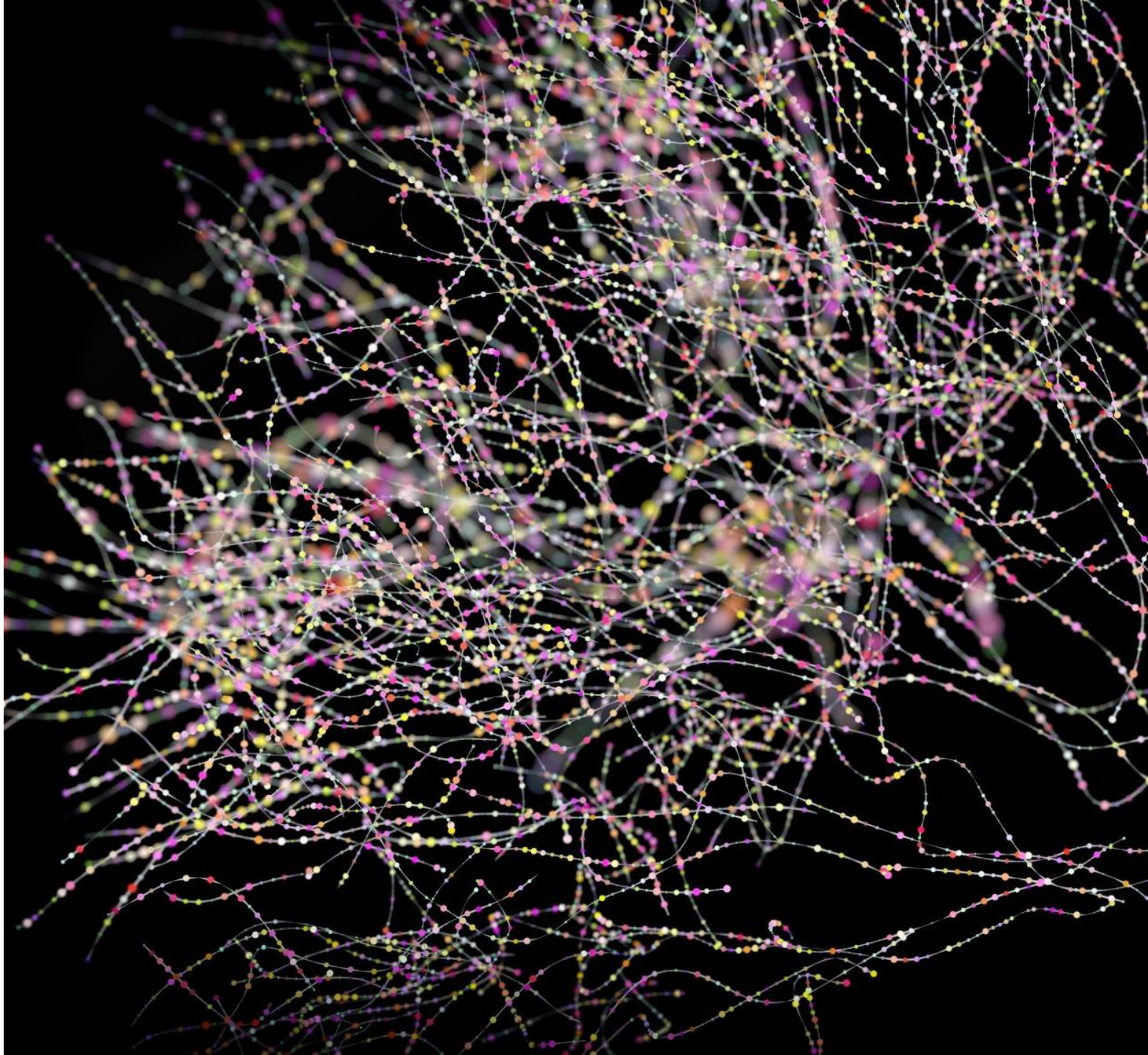
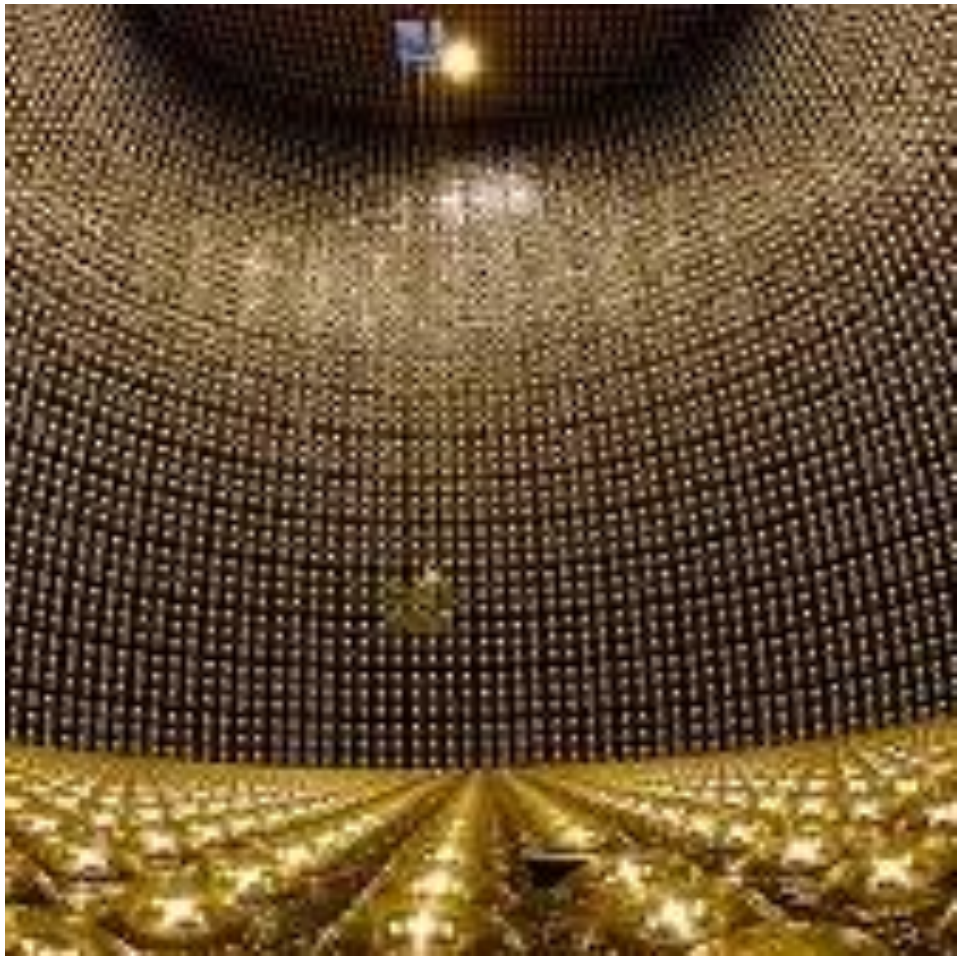

Neutron decay
anomaly and Neutrino
mass model

Outline

- 1 : Neutrino mass problem
- 2 : Neutron lifetime anomaly
- 3 : Neutrino mass model





Neutrino mass problem

Neutrino only have left hand:

1950's:

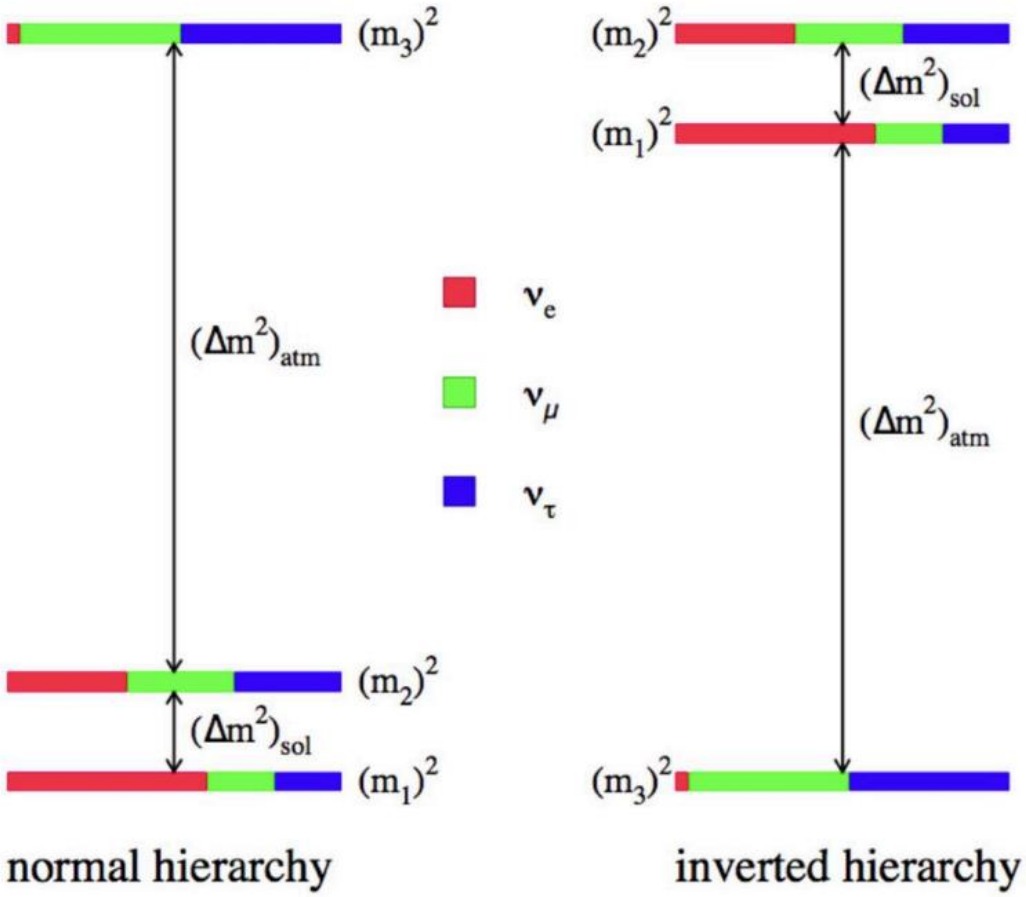
$$e^- + Eu^{152} \rightarrow Sm^{*152} + \nu_e$$
$$\downarrow$$
$$\gamma$$

M. Goldhaber, L. Grodzins, and A. W. Sunyar

$$\mathcal{L}_D = -m_D(\overline{\nu}_R\ \nu_L + \overline{\nu}_L\ \nu_R)$$

$$m_D = 0\ ?$$

Neutrino oscillation:



$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}U_{1e} & U_{2e} & U_{3e}\\ U_{1\mu} & U_{2\mu} & U_{3\mu}\\ U_{1\tau} & U_{2\tau} & U_{3\tau}\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

$$\nu_e = U_{1e}\nu_1 + U_{2e}\nu_2 + U_{3e}\nu_3$$

$$\nu_\mu = U_{1\mu}\nu_1 + U_{2\mu}\nu_2 + U_{3\mu}\nu_3$$

$$\nu_\tau = U_{1\tau}\nu_1 + U_{2\tau}\nu_2 + U_{3\tau}\nu_3$$

$$P(\nu_\alpha \to \nu_\beta) = sin^2(2\theta)sin^2(\frac{\Delta m^2}{4E}L)$$

$$\Delta m^2_{31} \approx \Delta m^2_{32} = m_3^2 - m_2^2 \approx 2.5 \times 10^{-3} eV^2$$

$$\Delta m^2_{21} = m_2^2 - m_1^2 \approx 7.4 \times 10^{-5} eV^2$$

$m_1?$ $m_2?$ $m_3?$

Neutrino only have left handed:

1950's:

$$e^- + Eu^{152} \rightarrow Sm^{*152} + \nu_e$$
$$\downarrow$$
$$\gamma$$

M. Goldhaber, L. Grodzins, and A. W. Sunyar

$$\mathcal{L}_D = -m_D(\overline{\nu}_R\ \nu_L + \overline{\nu}_L\ \nu_R)$$

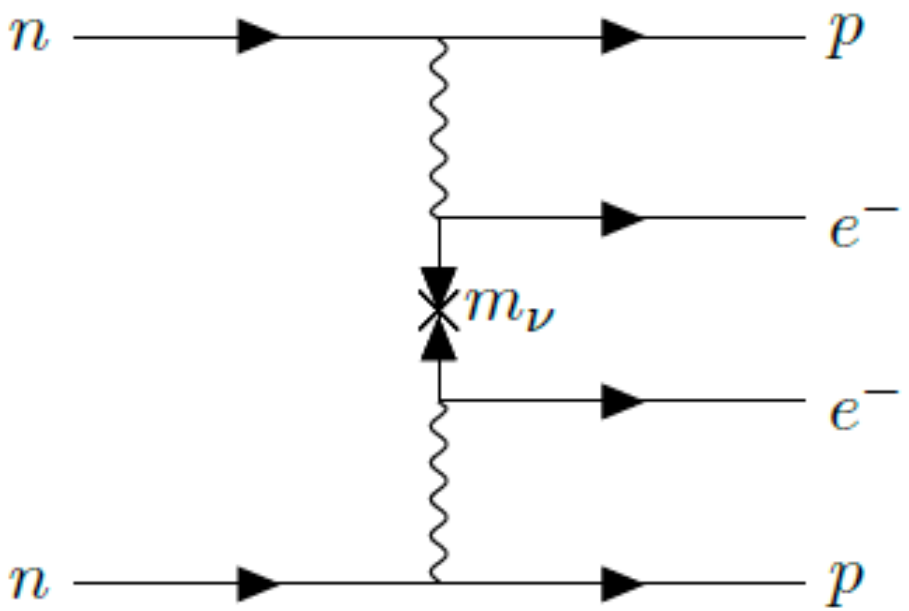
$$m_D = 0$$

$$\mathcal{L}_M = -\frac{1}{2}M(\overline{\nu}_L^c\ \nu_L + \overline{\nu}_L\nu_L^c) \qquad \nu^c = i\gamma^2\gamma^0\nu^*$$

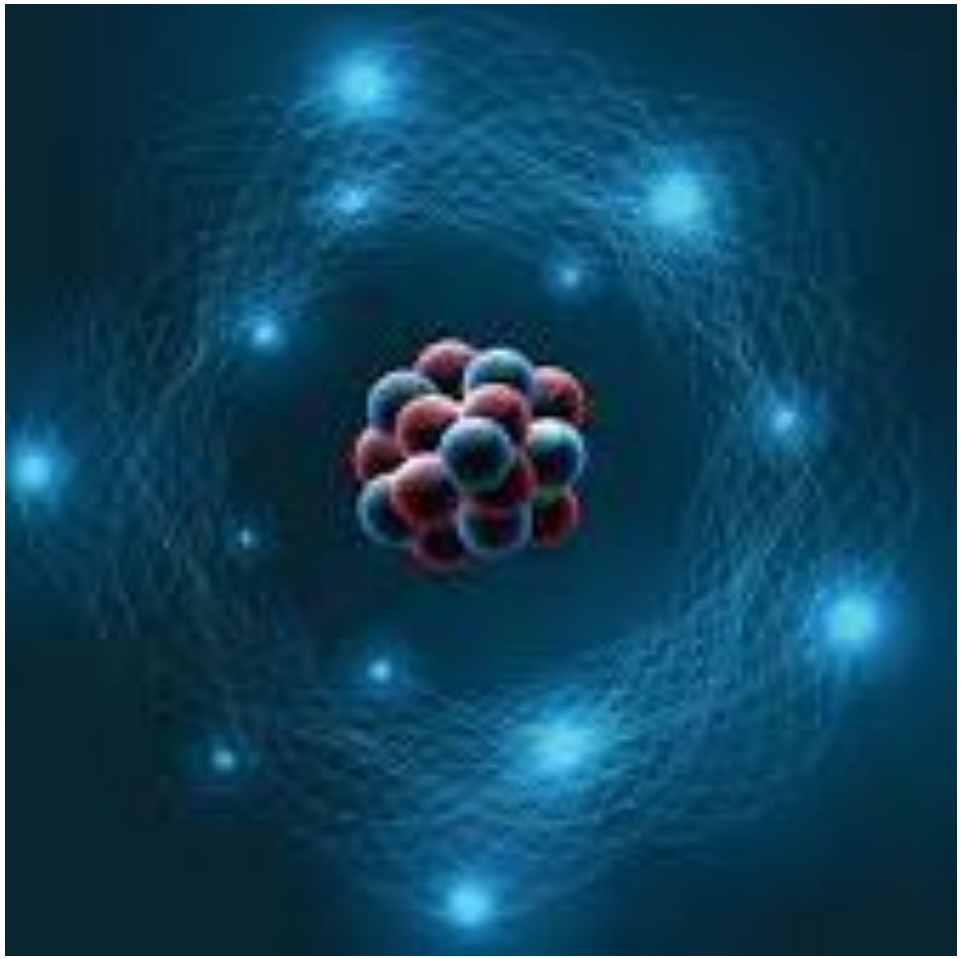
Neutrinoless double beta decay:

Majorana

Not yet observed!



$0\nu\beta\beta$



Neutron lifetime anomaly

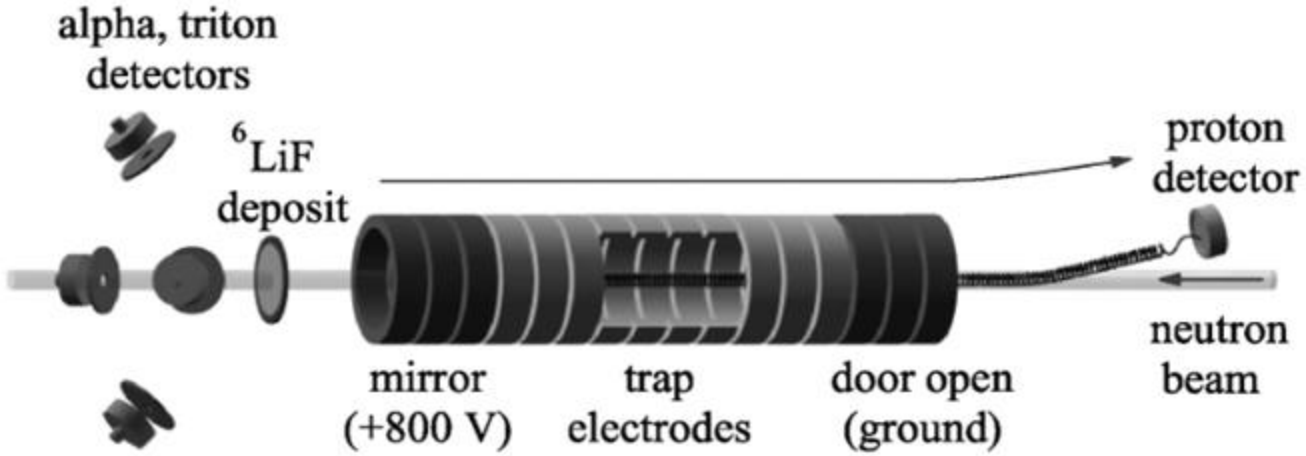
$$n \rightarrow P^+ + e^- + \bar{\nu}_e :$$

$$\mathcal{M} = \frac{G_F}{\sqrt{2}} V_{ud} g_V \left[\bar{p}\gamma_\mu n - \lambda \bar{p}\gamma_5\gamma_\mu n\right]\left[\bar{e}\gamma^\mu(1-\gamma_5)\upsilon\right]$$

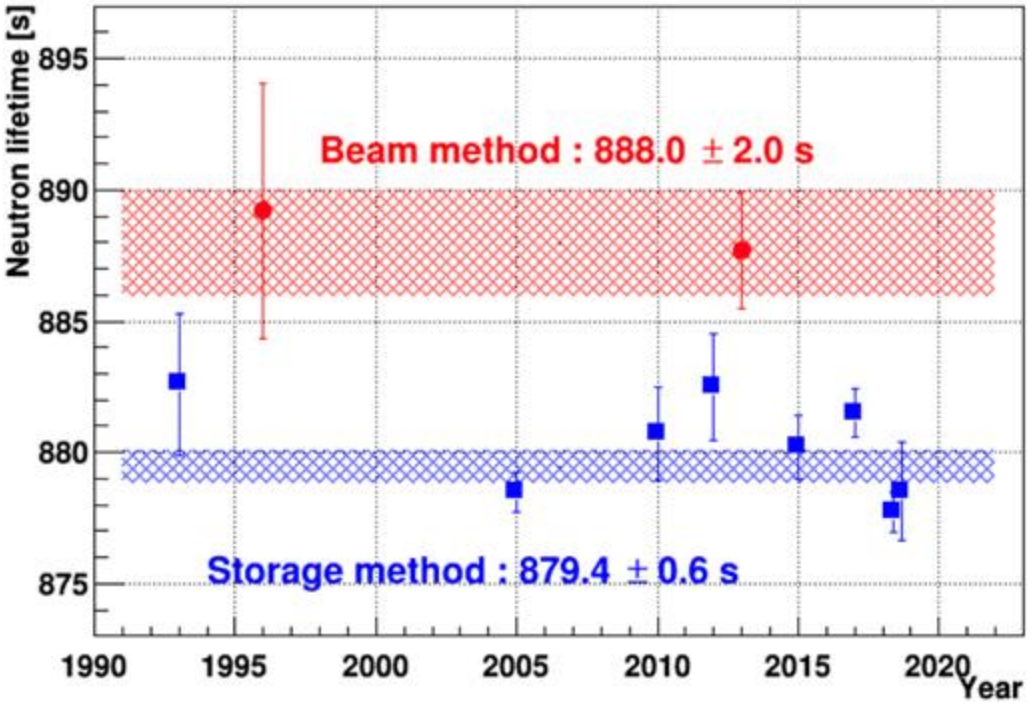
$$\tau_n = \frac{4908.7}{|V_{ud}|^2(1+3\lambda^2)} \approx 875.3 - 891.2\ s$$

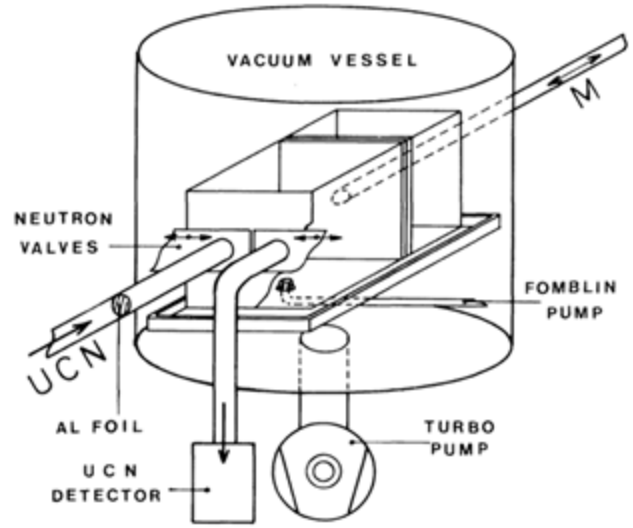
axial-vector to vector coupling ratio: $\lambda \approx -1.273 \pm 0.0023$

matrix element giving by PDG: $|V_{ud}| \approx 0.974 \pm 0.00021$



[1]: https://doi.org/10.1103/PhysRevLett.91.152302





[2]:https://doi.org/10.1103/PhysRevLett.63.593

$$n \rightarrow P^+ + e^- + \bar{\nu}_e :$$

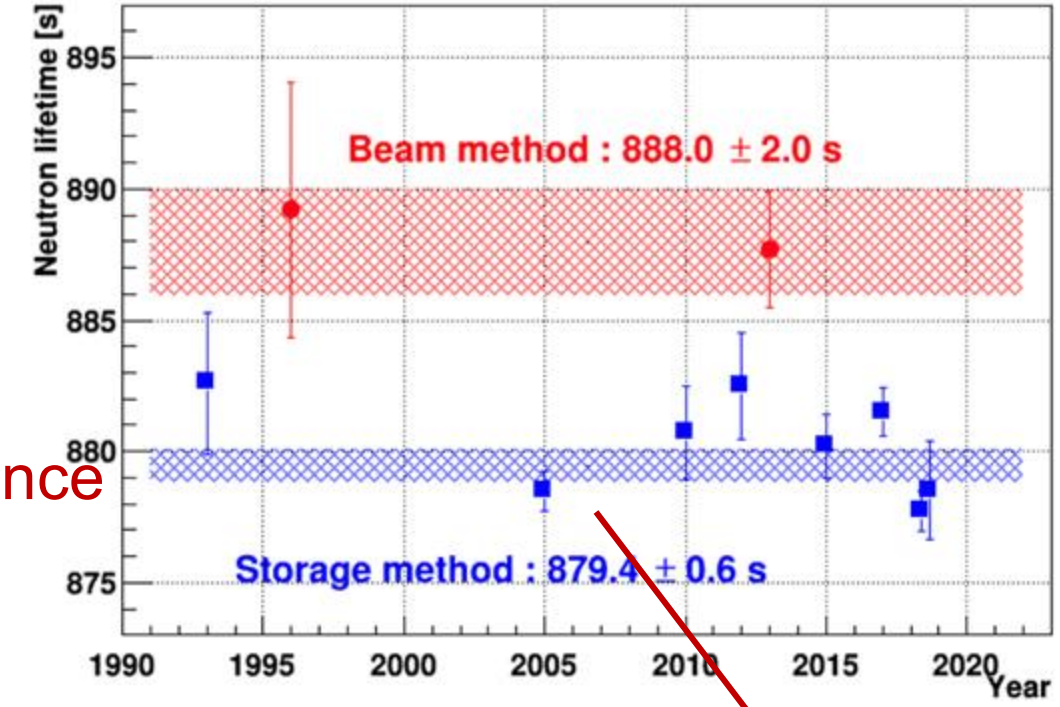
$$\mathcal{M} = \frac{G_F}{\sqrt{2}} V_{ud} g_V \left[\bar{p}\gamma_\mu n - \lambda \bar{p}\gamma_5\gamma_\mu n\right]\left[\bar{e}\gamma^\mu(1-\gamma_5)\upsilon\right]$$

$$\tau_n = \frac{4908.7}{|V_{ud}|^2(1+3\lambda^2)} \approx 875.3 - 891.2\ s$$

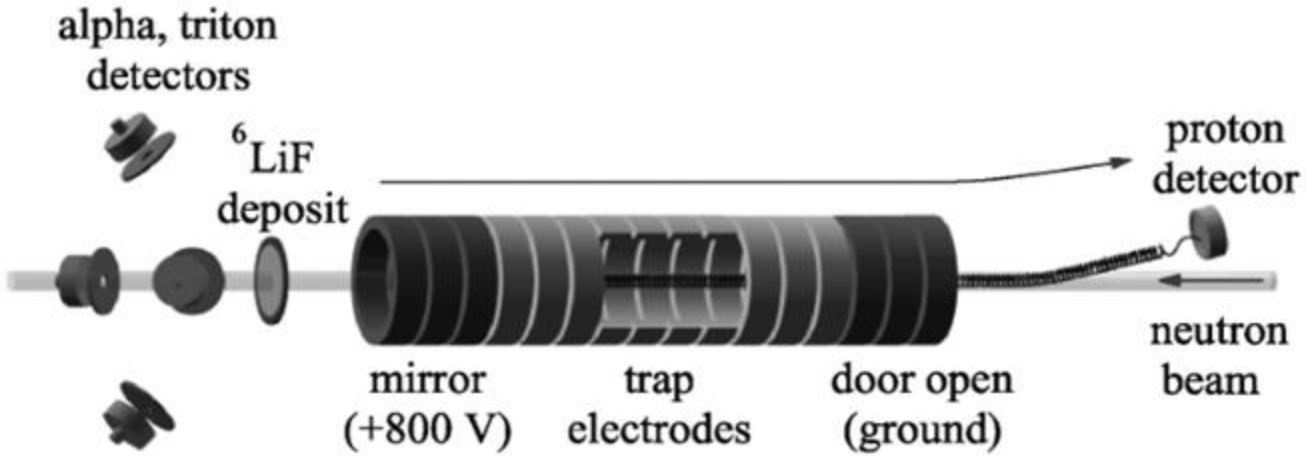
3σ Difference

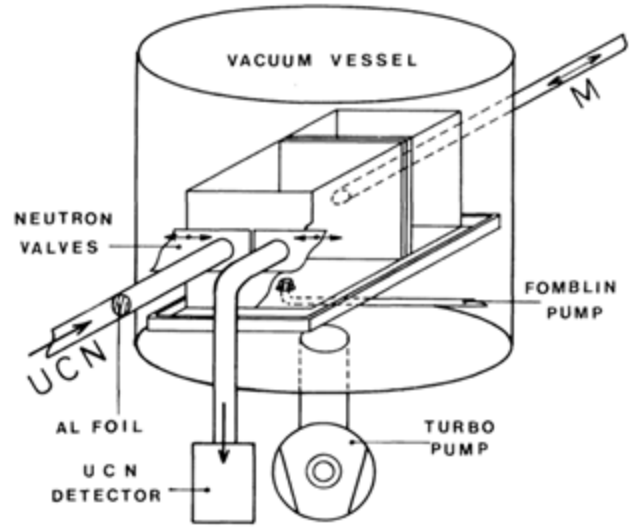
axial-vector to vector coupling ratio: $\lambda \approx -1.273 \pm 0.0023$

matrix element giving by PDG: $|V_{ud}| \approx 0.974 \pm 0.00021$



2σ Difference





4σ

[1]: https://doi.org/10.1103/PhysRevLett.91.152302

[2]:https://doi.org/10.1103/PhysRevLett.63.593

$$\tau_n^{bottel}, \tau_n^{beam} = \frac{\tau_n}{Br(n \rightarrow P^+ + e^- + anything)}$$

$$\Gamma_n \cong 7.5 \times 10^{-28} GeV$$

$$\Delta\Gamma_n^{exp} = \left(\frac{\tau_n^{beam} - \tau_n^{bottle}}{\tau_n^{beam}\tau_n^{bottel}}\right)$$

$$\cong 7.1 \times 10^{-30} Gev$$

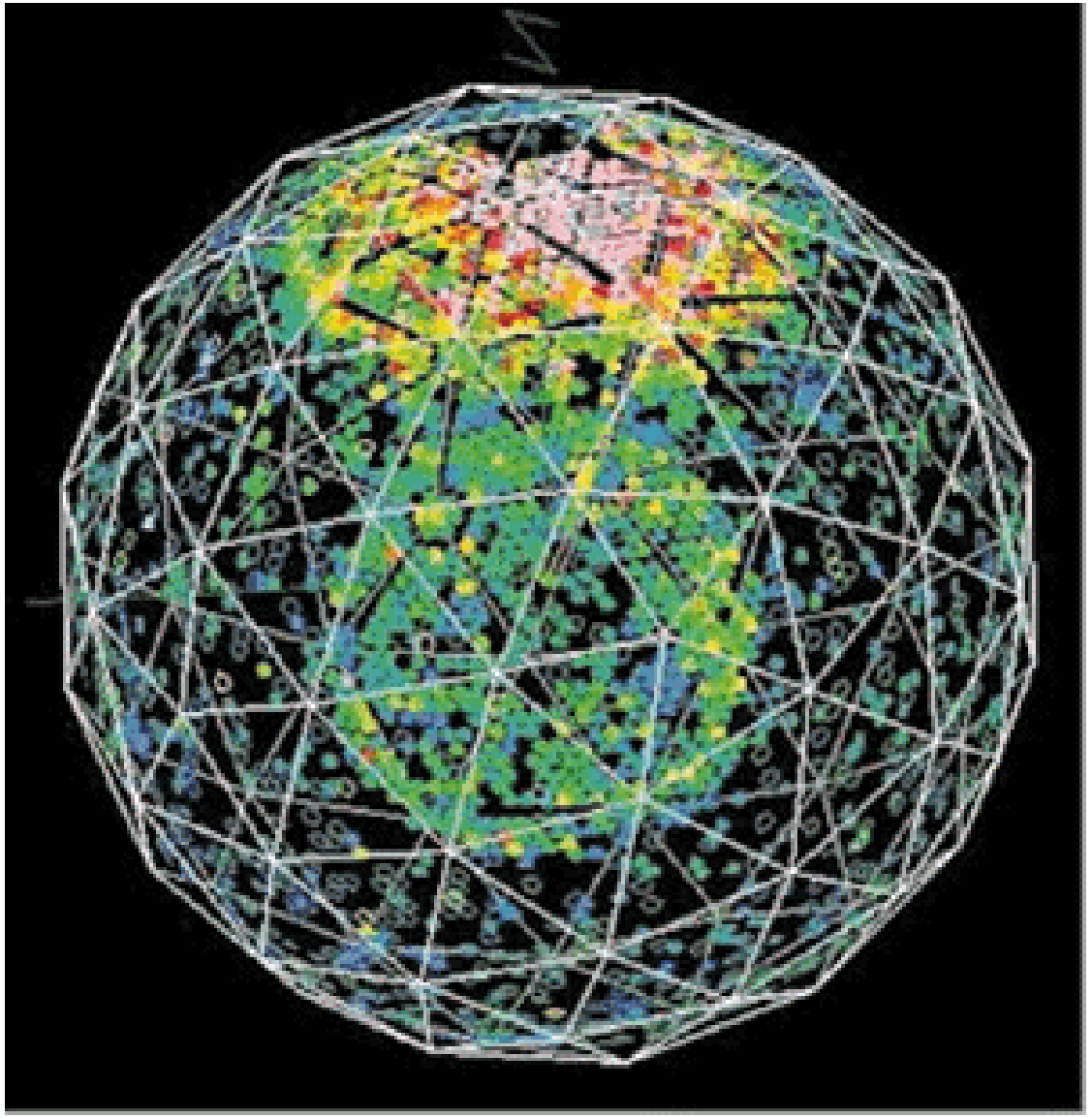
$$\tau_n^{beam} - \tau_n^{bottle} = \Delta\tau_n \cong 8.4\ s$$

$$\frac{\Delta\Gamma_n^{exp}}{\Gamma_n} \approx 1\% \rightarrow Br(n \rightarrow P^+ + e^- + anything) \approx 99\%$$

Proposals:

$$n \rightarrow invisible + visible \qquad n \rightarrow invisible$$

[3]: https://doi.org/10.1103/PhysRevLett.120.191801



Neutrino mass model

$n \rightarrow invisible$

$$D_\mu = \partial_\mu - ig' A'_\mu$$

$$\mathcal{L}_{total} = \mathcal{L}_{eff} + \mathcal{L}_{Higgs} + \mathcal{L}_{Yukawa}$$

$$Z_{\mu\nu} = \partial_\mu A'_\nu - \partial_\nu A'_\mu$$

$$\mathcal{L}_{eff} = \bar{\chi}\left(i\gamma^\mu D_\mu - m_\chi\right)\chi + \bar{n}\left(i\gamma^\mu \partial - m_n + \mu_n \sigma^{\mu\nu} F_{\mu\nu}\right)n - \delta m \overline{n_R}\chi_L + h.c$$

$B - L$

particle	$SU_L(2)$	$U_Y(1)$	$U'(1)$
$\begin{pmatrix}\nu_i \\ L_i\end{pmatrix}$	2	-1	0
$\begin{pmatrix}p \\ n\end{pmatrix}$	2	1	-1
$\begin{pmatrix}\phi^+ \\ \phi^0\end{pmatrix}$	2	1	0
S_1	1	0	1
S_2	1	0	-1
$\begin{pmatrix}\chi^0 \\ \chi^-\end{pmatrix}$	2	-1	1

$$-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{\varepsilon}{2}F_{\mu\nu}Z^{\mu\nu} - \frac{1}{4}Z_{\mu\nu}Z^{\mu\nu}$$

$$\mathcal{L}_{Higgs} = (D^\mu \Phi)^\dagger \left(D_\mu \Phi\right) - V(\phi, S_1, S_2)$$

$$\mathcal{L}_{Yukawa} = g_{ij}\bar{l_L} S_2 \chi + h.c$$

$$\Delta\Gamma_n^{exp} \cong 7.1 \times 10^{-30} GeV$$

$$\mathcal{L}_{eff} \to \Gamma(n \to \chi A') \cong \frac{g'^2(\delta m)^2 m_n}{8\pi m_{A'}^2 x(1-r^2)^{\frac{3}{2}}} \cong 7.1 \times 10^{-30} GeV$$

Where $x = \frac{m_n - m_\chi}{m_n}, r = \frac{m_{A'}}{m_\chi - m_n}$

937.900 MeV(Be stability) < m_χ < 938.783 MeV $(m_p + m_e)$

$M(Z,A) - M(Z,A-1) < M_f < M_n$

$M_{Li}(3,6) - M_{Li}(3,5) = 933.9MeV$

$M_{Be}(4,9) - M_{Be}(4,8) = 937.9MeV$

$M_B(5,10) - M_B(5,9) = 931.1MeV$

[4]:https://doi.org/10.48550/arXiv.1803.04961

$$\mathcal{L}_{Higss} = (D^{\mu}\Phi)^{\dagger}\left(D_{\mu}\Phi\right) - V(\phi, S_1, S_2)$$

$$V(\phi, S_1, S_2) = m_{\phi}^2\phi^{\dagger}\phi + m_{s_1}^2 {S_1}^{\dagger}S_1 + m_{s_2}^2 {S_2}^{\dagger}S_2$$

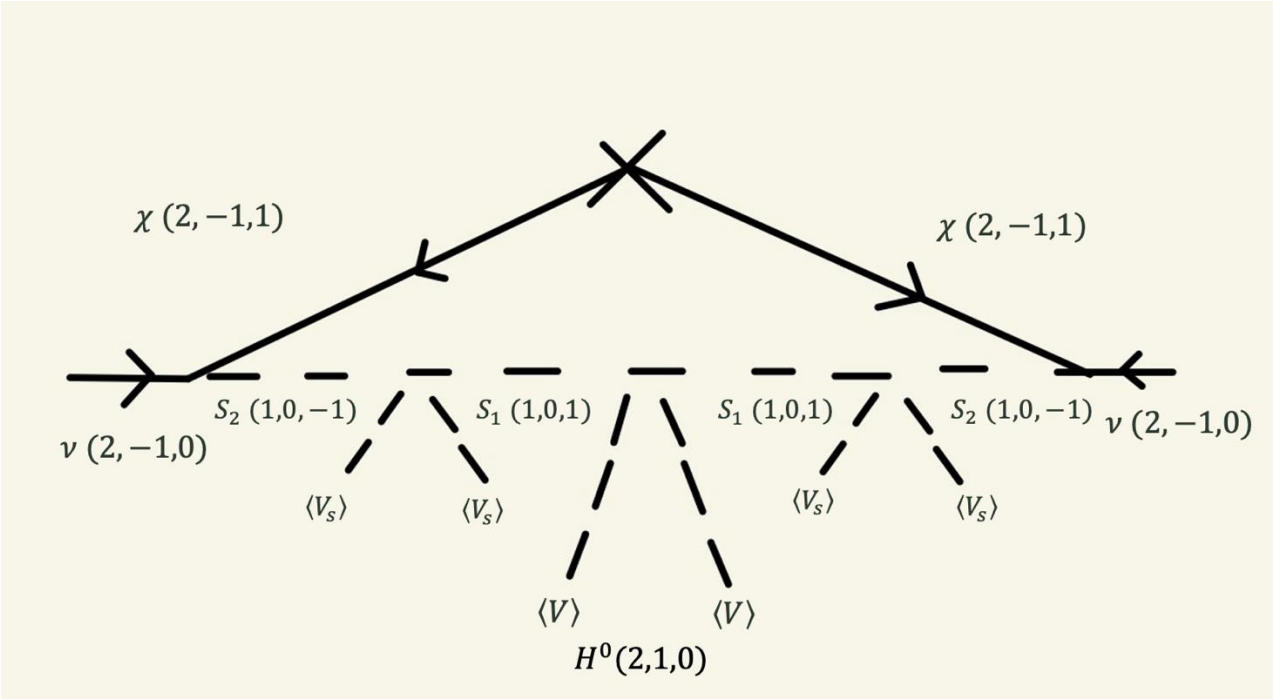
$$+\lambda_1(\phi^{\dagger}\phi)^2 + \lambda_2({S_1}^{\dagger}S_1)^2 + \lambda_3({S_2}^{\dagger}S_2)^2$$

$$+\lambda_4\left(\phi^{\dagger}\phi\right)\left({S_1}^{\dagger}S_1\right) + \lambda_5\left(\phi^{\dagger}\phi\right)\left({S_2}^{\dagger}S_2\right) + \lambda_6\left({S_1}^{\dagger}S_1\right)\left({S_2}^{\dagger}S_2\right)$$

$$+\lambda_7\left(\phi^{\dagger}S_1\right)\left({S_1}^{\dagger}\phi\right) + \lambda_8\left(\phi^{\dagger}S_2\right)\left({S_2}^{\dagger}\phi\right) + \lambda_9\left({S_1}^{\dagger}S_2\right)\left({S_2}^{\dagger}S_1\right)$$

$$+\frac{\lambda_{10}}{2}\left[\left(\phi^{\dagger}S_1\right)^2 + h.c\right] + \frac{\lambda_{11}}{2}\left[\left(\phi^{\dagger}S_2\right)^2 + h.c\right] + \frac{\lambda_{12}}{2}\left[\left({S_1}^{\dagger}S_2\right)^2 + h.c\right]$$

$$\mathcal{L}_{Yukawa} = g_{ij}\overline{l_{L_i}}S_2\chi_j + h.c$$



$$m_\nu^{ij} = \sum_k \frac{g_{ik}g_{jk}M_\chi}{16\pi^2}\left[\frac{M_{S_1}^2}{M_{S_1}^2 - M_\chi^2} ln\frac{M_{S_1}^2}{M_\chi^2} + \frac{M_{S_2}^2}{M_{S_2}^2 - M_\chi^2} ln\frac{M_{S_2}^2}{M_\chi^2}\right]$$

Preliminary results :