Neutrino University - Intro

What is a neutrino?

Standard Model

QUARKS	u	c	t	LEPTONS	ν_e	ν_μ	ν_τ
	d	s	b		e^-	μ^-	τ^-

Force carriers
- γ
- W/Z
- g

p, n $\rightarrow$ j

Scalars: H

Crux of ν!

$\boxed{\text{Weak interactions only}}$

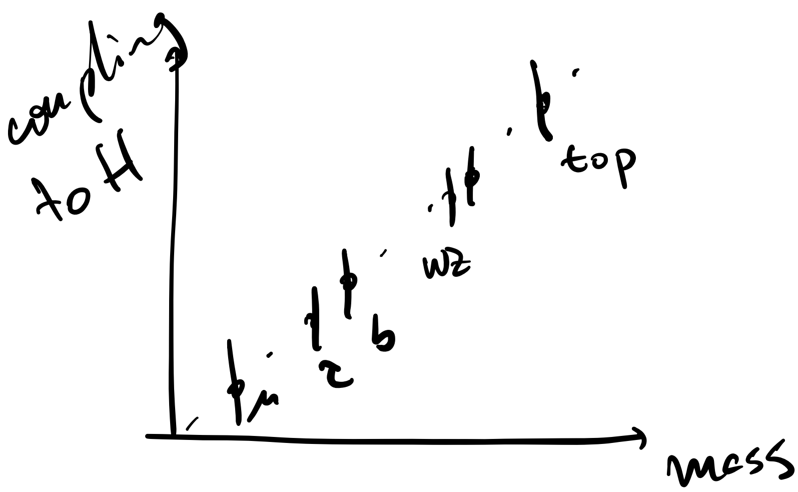
$$\mathcal{L} = m\bar{\psi}_L \psi_R \longrightarrow \bar{\psi}_L H \psi_R \longrightarrow m\bar{\psi}_L\psi_R$$

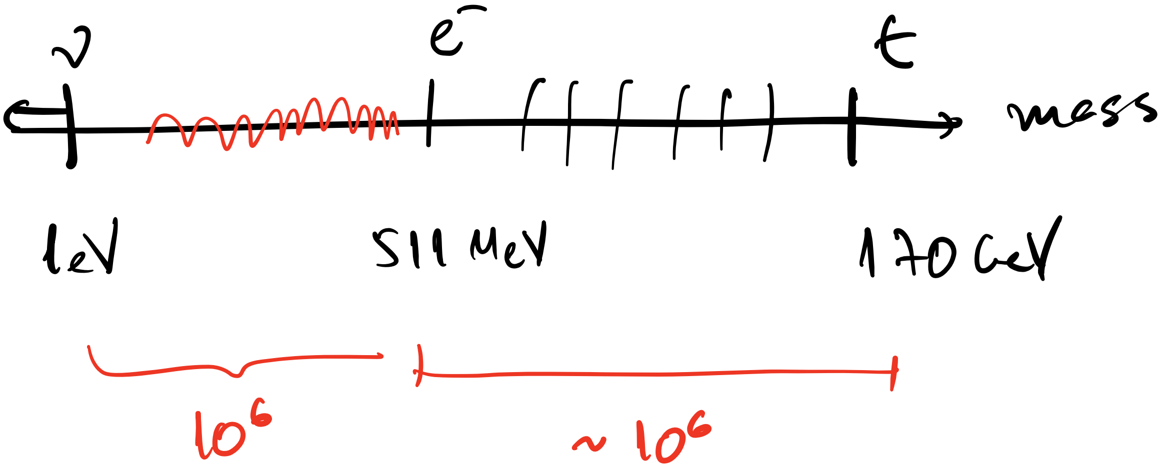
weak

not weak

Invariant

ν_R



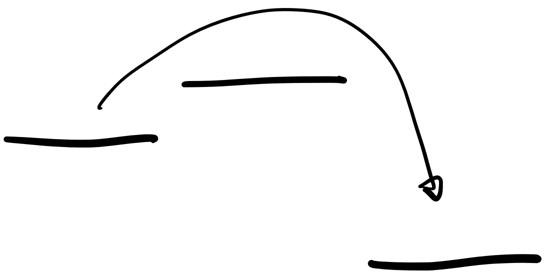


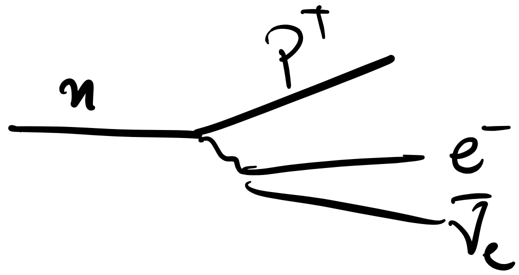
Matter - antimatter

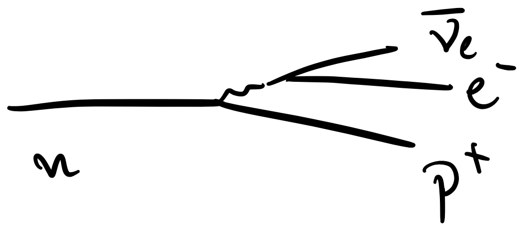
$$\overset{+1}{p^+}\ \overset{-1}{e^-}$$

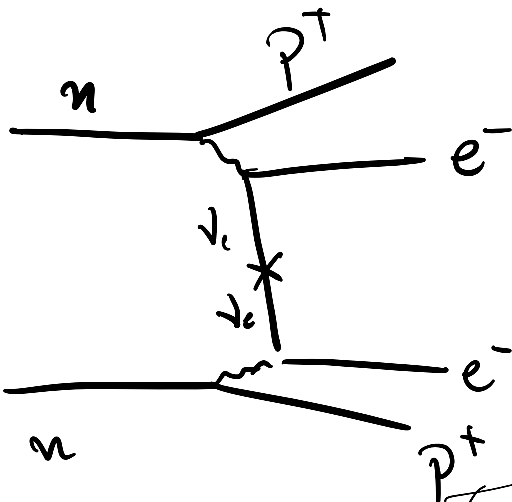
$$n \to p^+ e^- \bar{\nu}_e$$

Majorana $\nu = \nu^c$



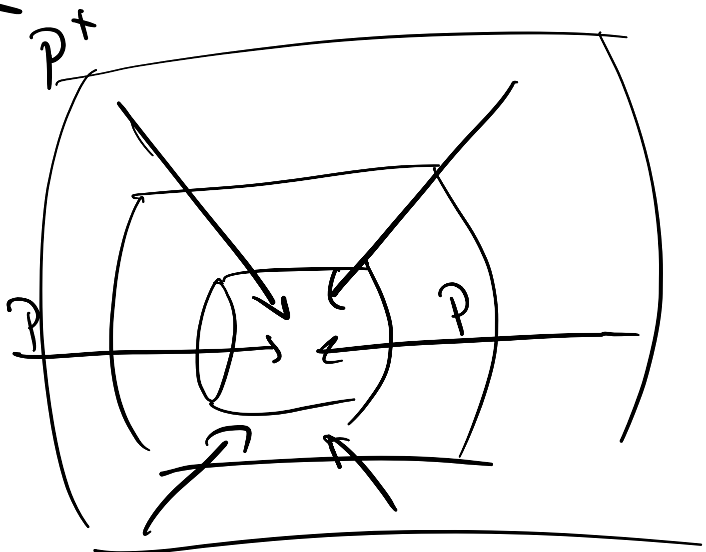






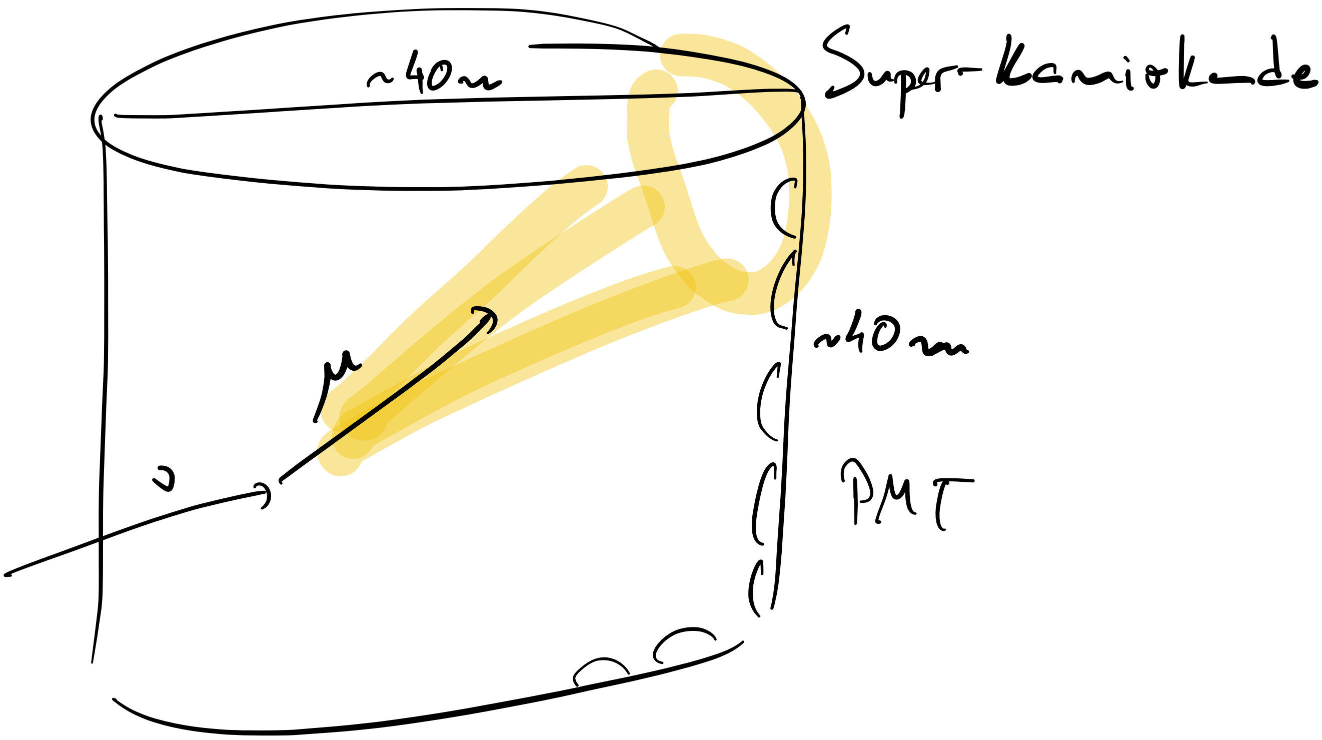
$0\nu\beta\beta$

Experimental

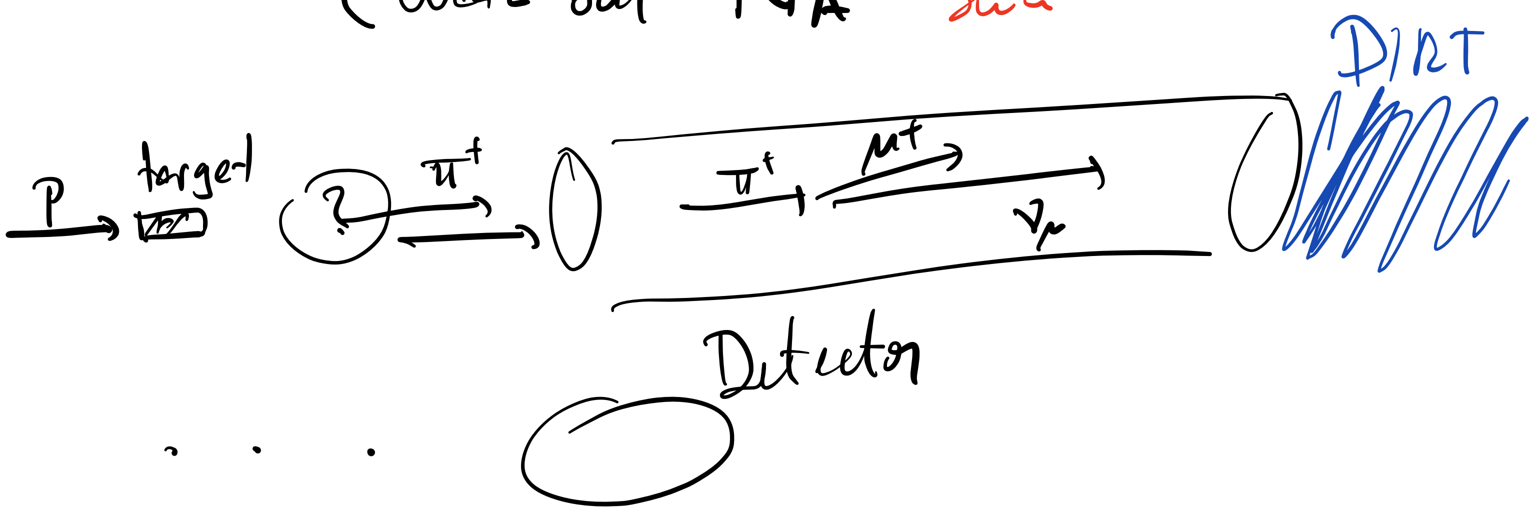


$\sigma(1\,\text{GeV}) \sim 10^{-38}\,\text{cm}^2$

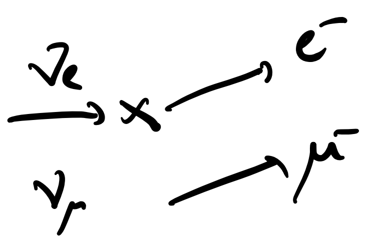
$$\lambda = \frac{1}{\sigma n} = \frac{1}{10^{-38}\,\text{cm}^2\ 10^{24}/\text{cm}^3} = 10^{14}\,\text{cm}$$



Production $\begin{cases} \text{Strong!} \\ \text{Weak but } N_A \end{cases}$ Sun



Oscillations



$$|\nu_e\rangle = \sum_i U_{ei}^* |\nu_i\rangle$$

$$i\frac{\partial}{\partial t}|\psi\rangle = H|\psi\rangle$$

$t = L$ $\quad \boxed{c=1}$ $\quad \underline{}$ $t=1$

$$|\psi(t)\rangle = e^{iHt}|\psi\rangle$$

$$A(\nu_\alpha \to \nu_\beta) = \langle \nu_\beta | e^{iHt} | \nu_\alpha\rangle$$

$e^{iE_k t}$

$$= \sum_{jk} \langle \nu_j | U_{\beta j}\, e^{iHt}\, U_{\alpha k}^* | \nu_k\rangle$$

$\langle \nu_j | \nu_k\rangle = \delta_{jk}$

$$E^2 = p^2 + m^2$$

$$E \simeq p + \frac{m^2}{2p}$$

$$E_i = p + \frac{m_i^2}{2p}$$

$$= \sum_j U_{\beta j} U_{\alpha j}^* \exp\left(i\frac{m_j^2 L}{2E}\right)$$

Two flavors

$$|\nu_\mu\rangle = \cos\theta|\nu_1\rangle + \sin\theta|\nu_2\rangle$$
$$|\nu_\tau\rangle = -\sin\theta|\nu_1\rangle + \cos\theta|\nu_2\rangle$$

$$\Delta m^2 = m_2^2 - m_1^2$$

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

$\hbar c = 0.2\,\mathrm{GeV\,fm}$

$$\frac{\Delta m^2 L}{4E} = \frac{\Delta m^2}{eV^2}\,\frac{L}{Km}\,\frac{GeV}{E}\,\underbrace{\frac{eV^2\,Km}{4\,GeV}}$$

$$1.27 \frac{\Delta m^2}{eV^2} \frac{L}{Km} \frac{GeV}{E} \sim \frac{\pi}{2}$$

$$\frac{eV^2 Km}{4\,GeV} \quad \frac{1}{0.2\,GeV\,fm}$$

$= 1.27$

$\Delta m^2 \sim 2.5 \times 10^{-3} eV^2$

GeV

$\Rightarrow L \sim 1000\,K$