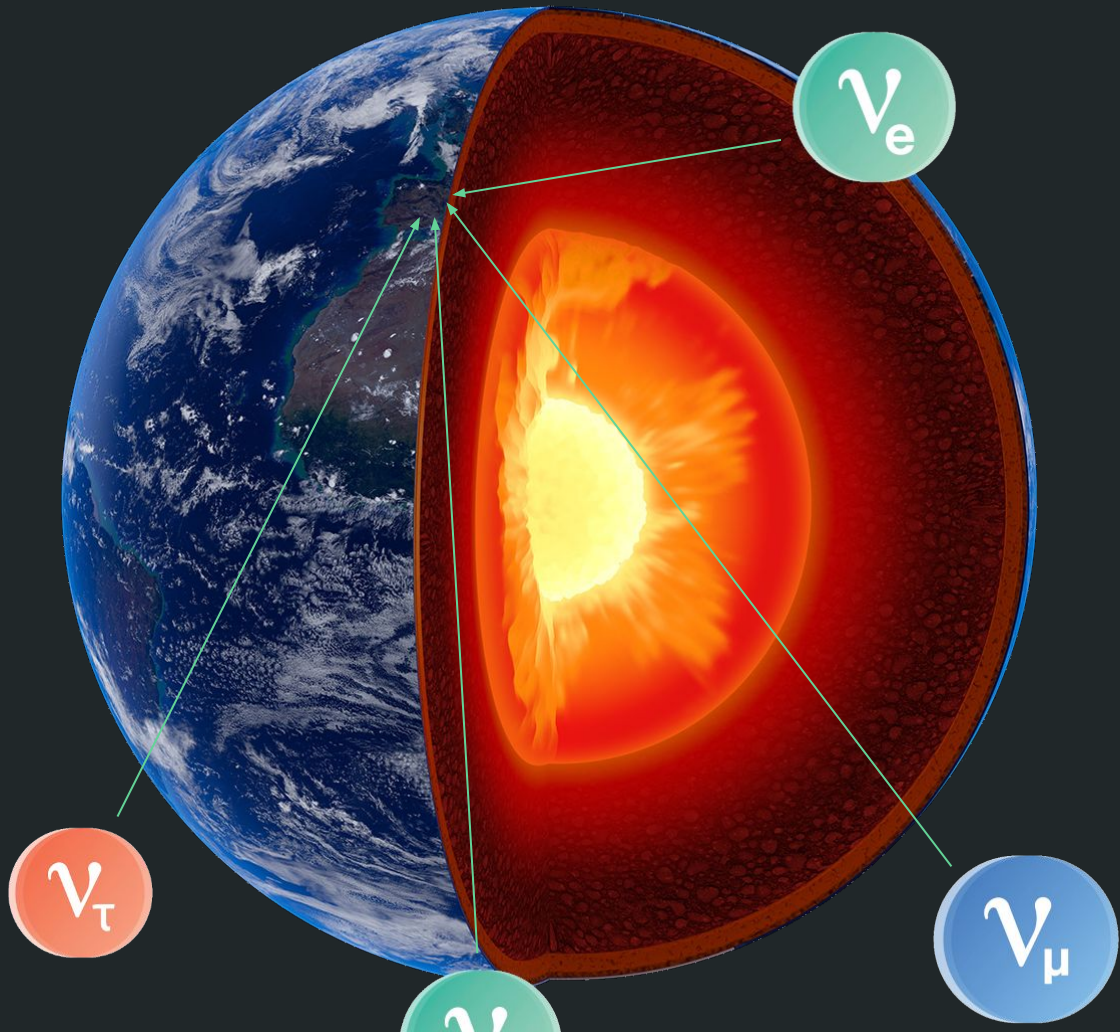
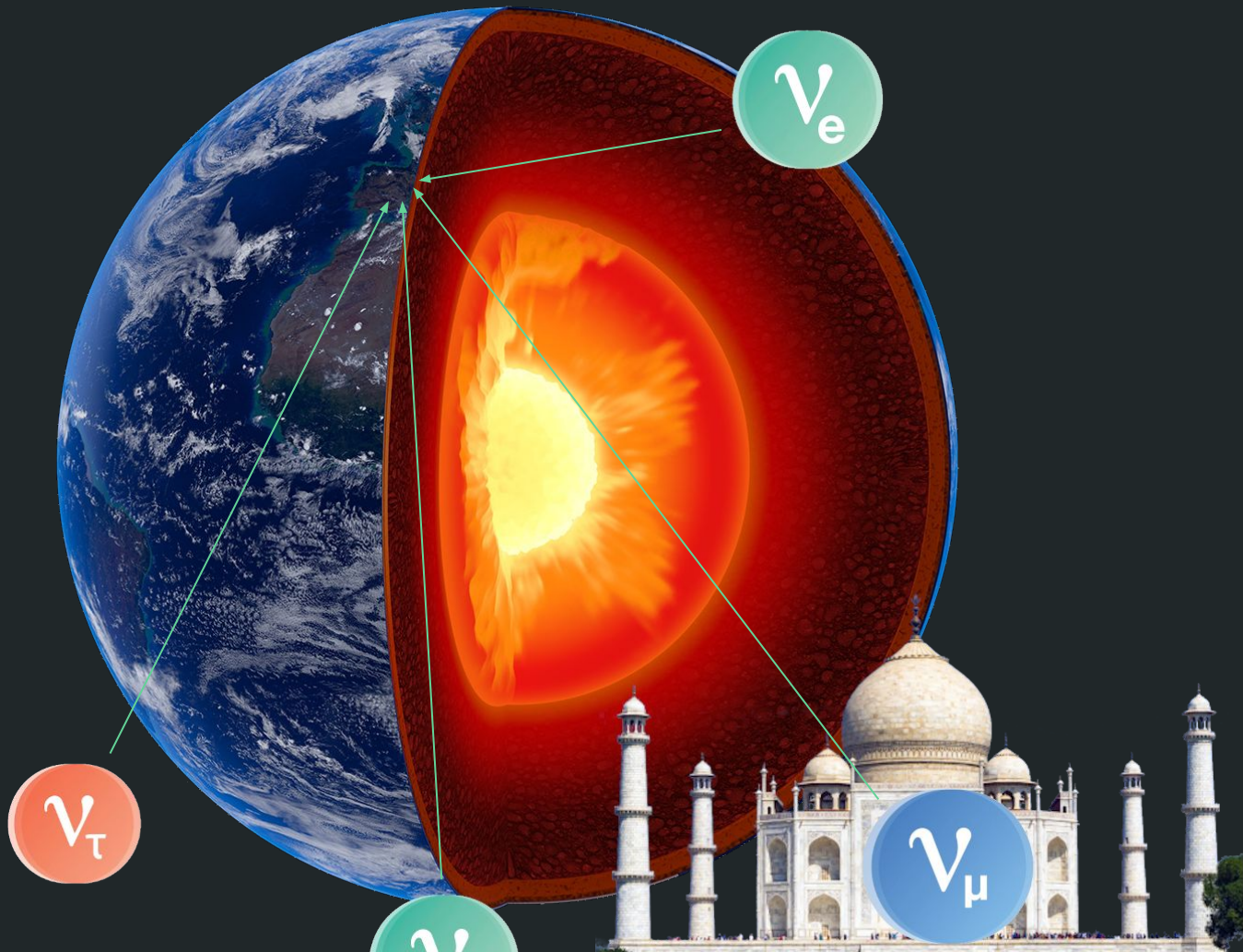


# Ghostbusters!

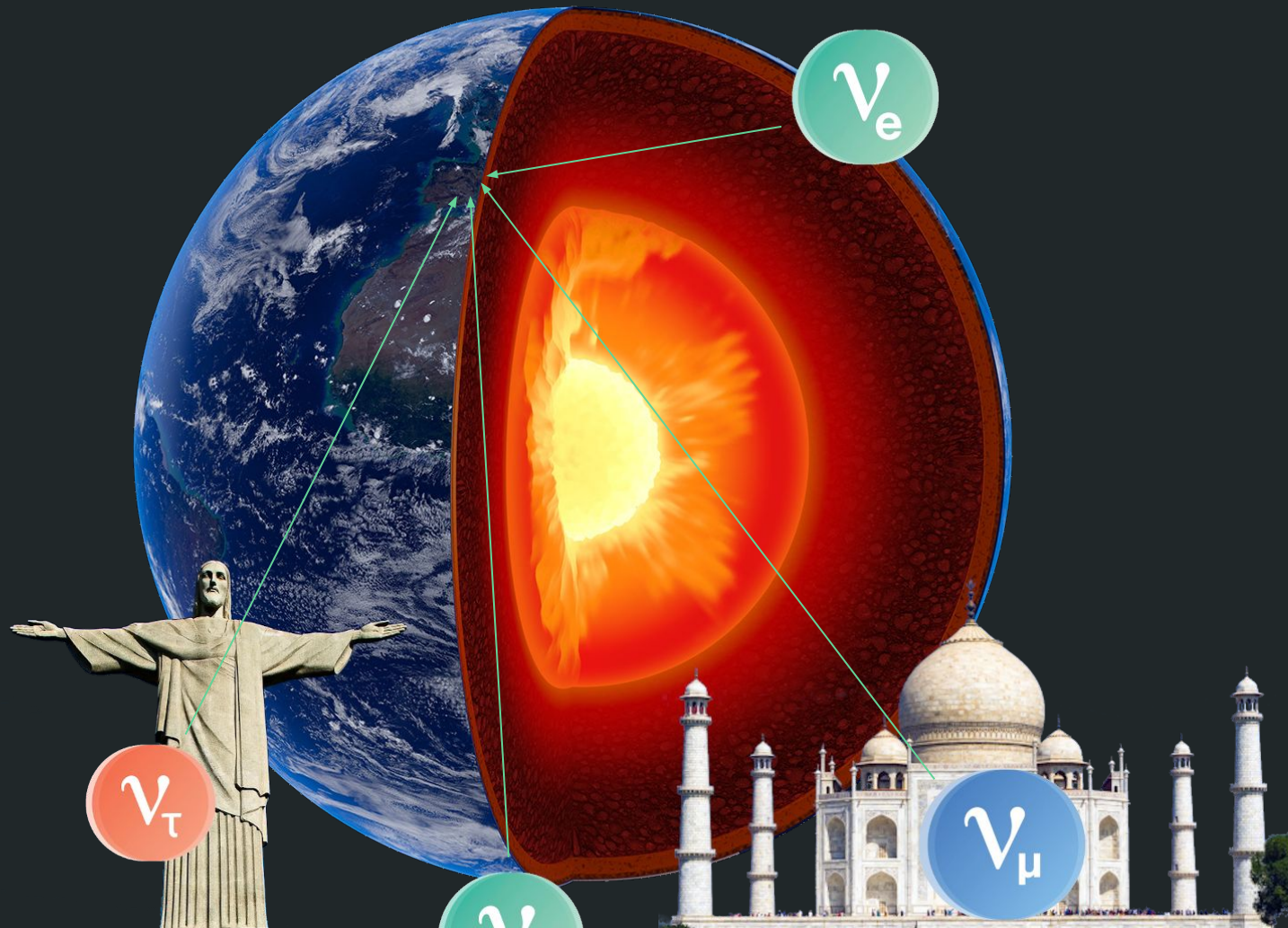
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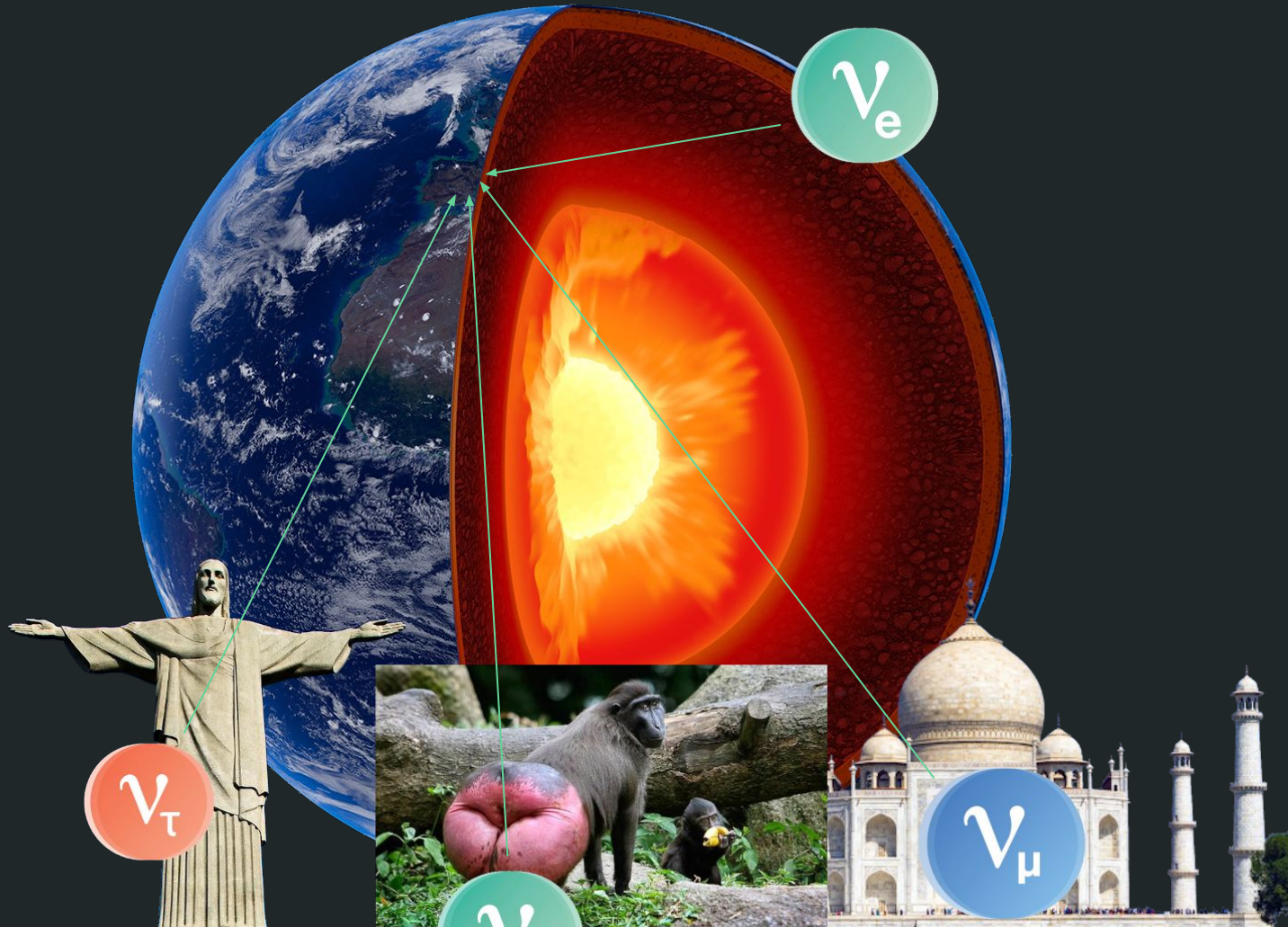
A perspective on neutrino oscillations



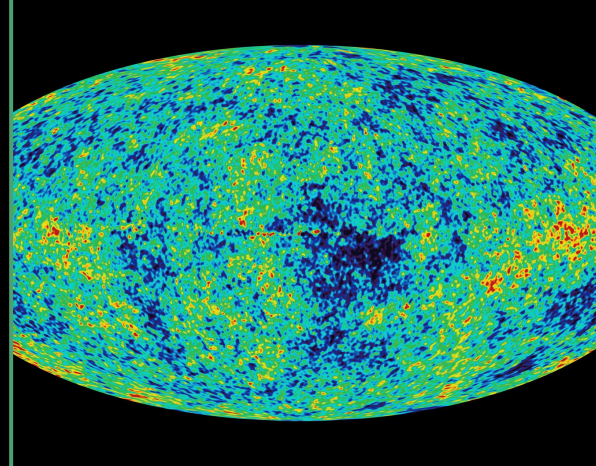
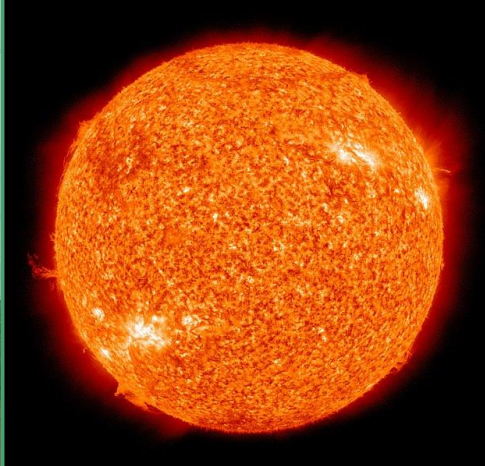
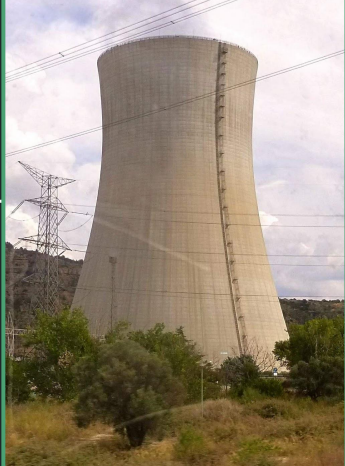
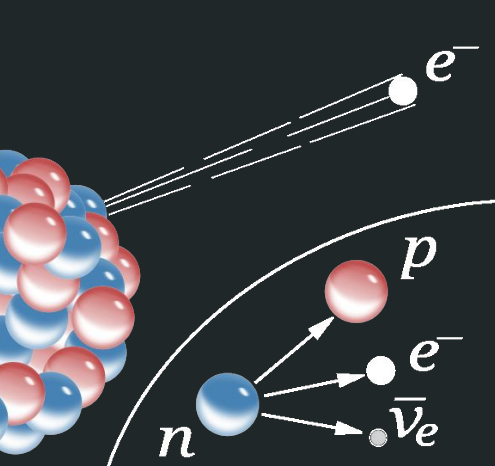












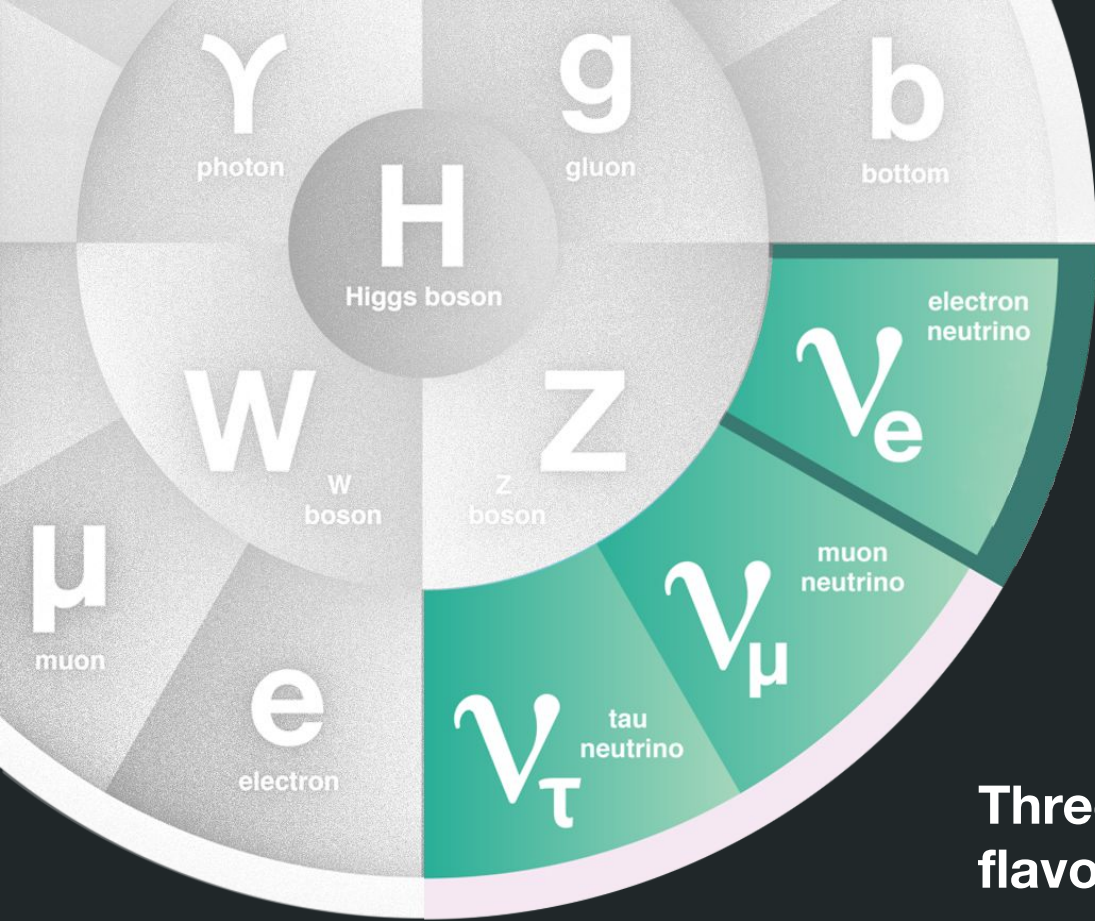
**Single beta  
decay**

**Nuclear  
reactors**

**The Sun  
(and stars)**

**Neutrino Cosmic  
Background**

...and many more!



**Three *conserved* flavors**

$|\psi\rangle$ 

A quantum state

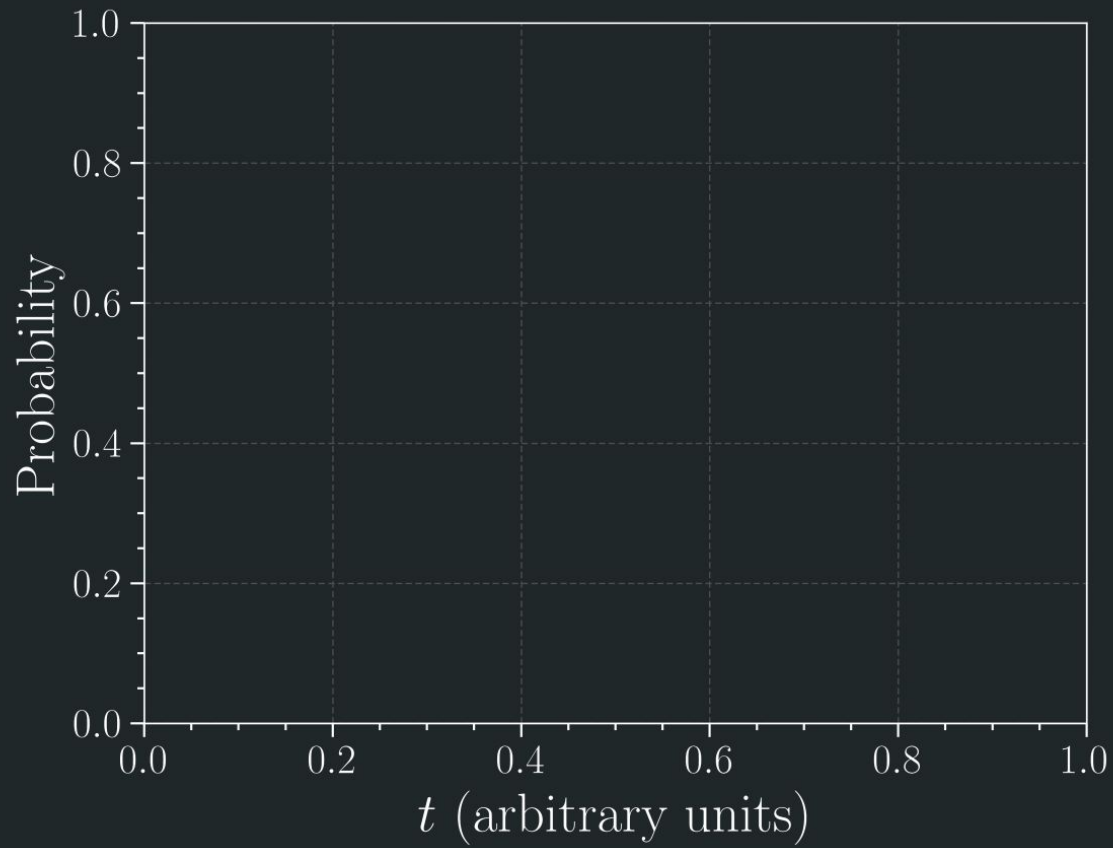


$$|\psi\rangle = |E_0\rangle + |E_1\rangle$$

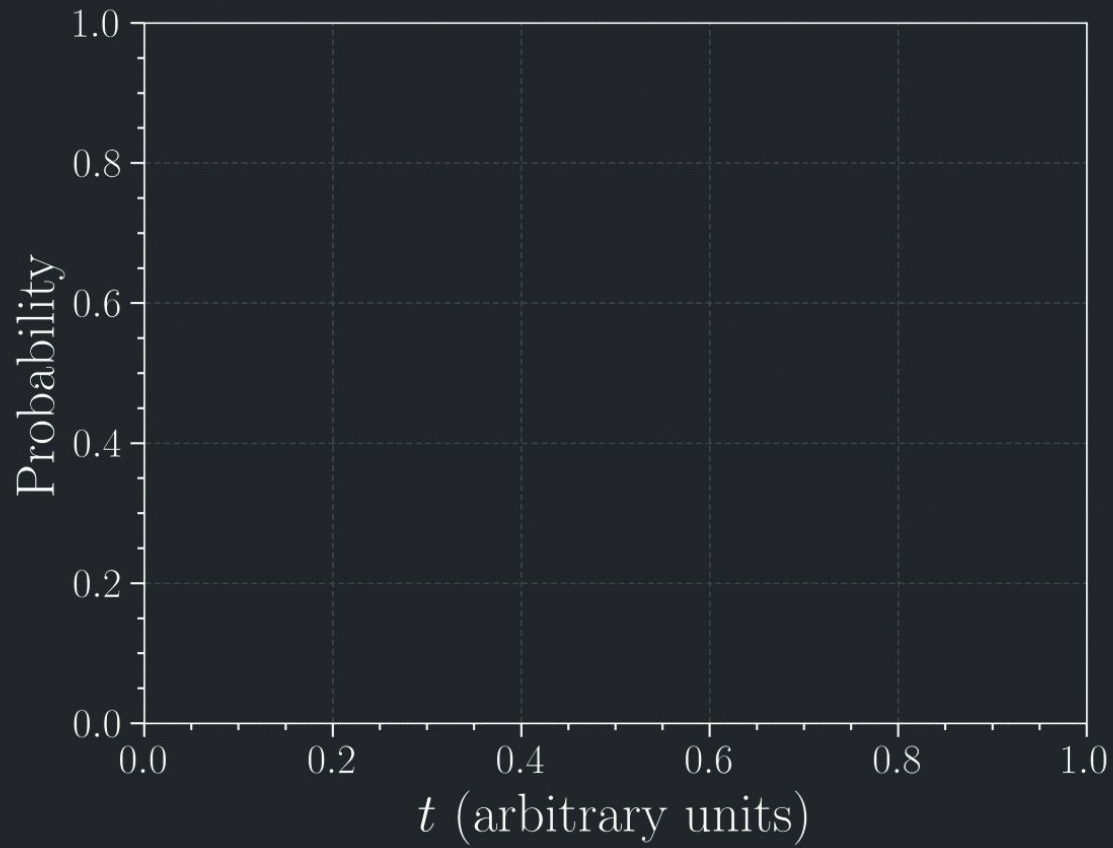
A quantum state,  
which is not an energy eigenstate,

$$|\psi(t)\rangle = e^{iE_0t} |E_0\rangle + e^{iE_1t} |E_1\rangle$$

A quantum state,  
which is not an energy eigenstate,  
evolves in time.

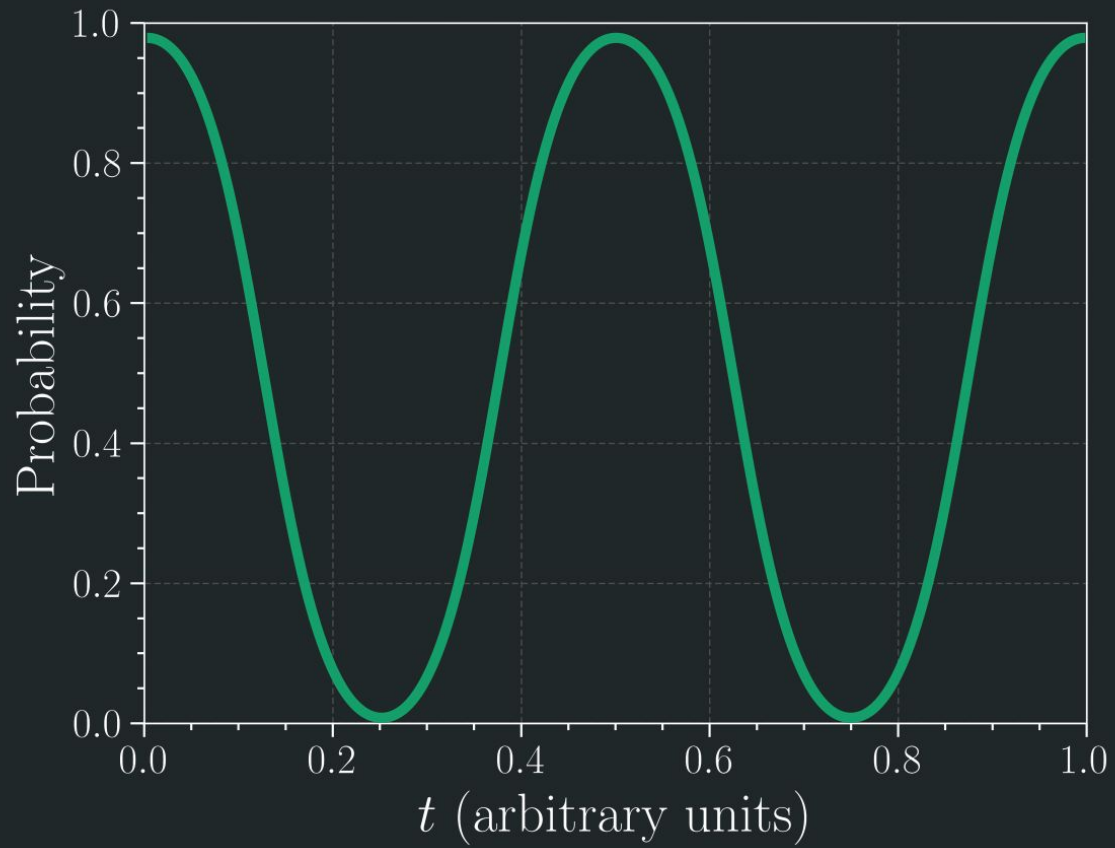


$|\psi\rangle$



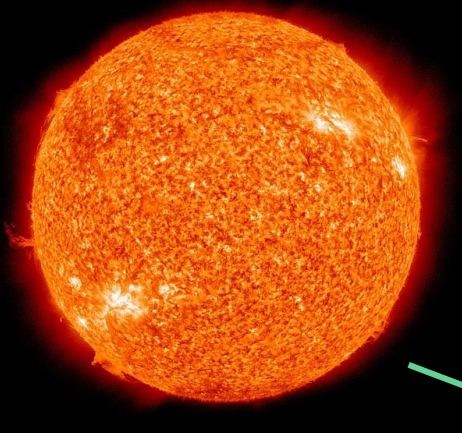
$|\psi\rangle$



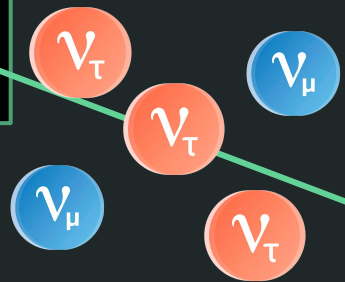


$|\psi\rangle$

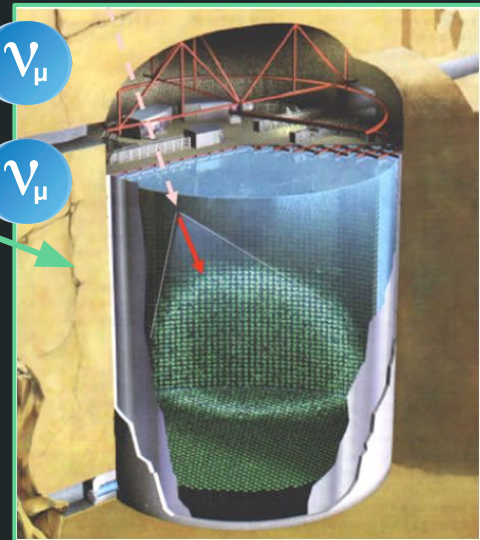
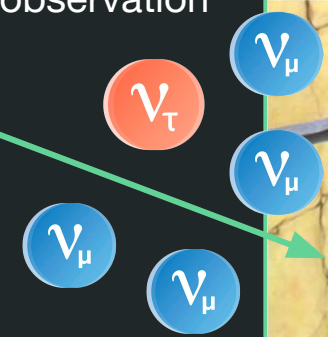
# Can this phenomenon happen to neutrinos?



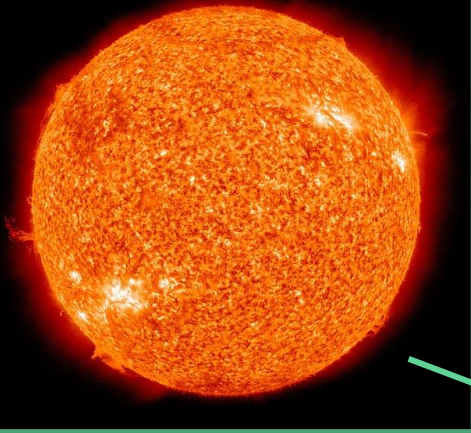
Theoretical prediction



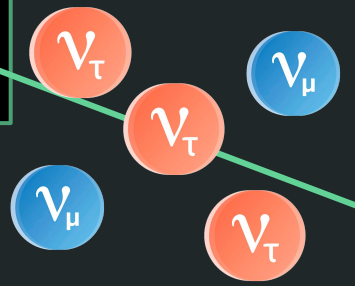
Experimental observation



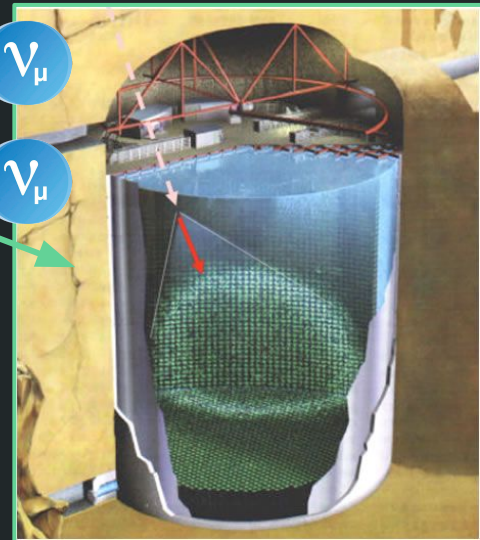
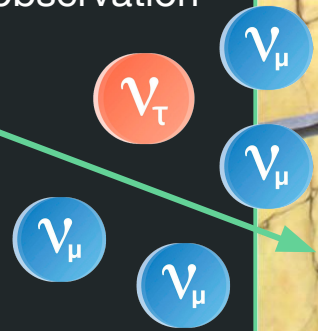
The process shown here is just an oversimplified example, don't take it literally.



Theoretical prediction

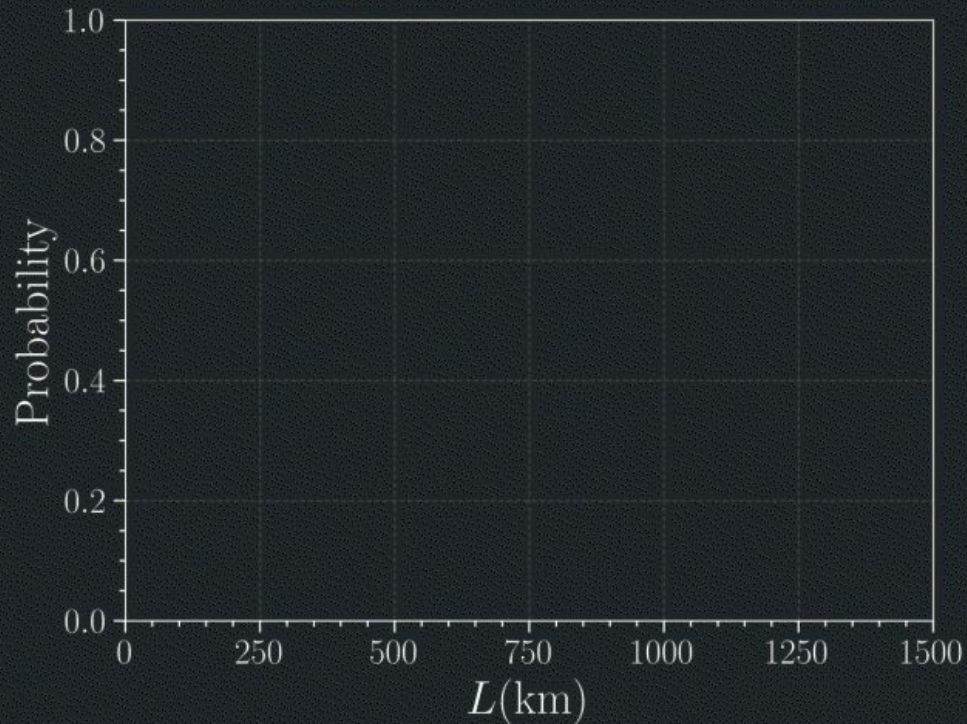


Experimental observation



Something is missing!

# Neutrino oscillations: the neutrino flavor changes during propagation

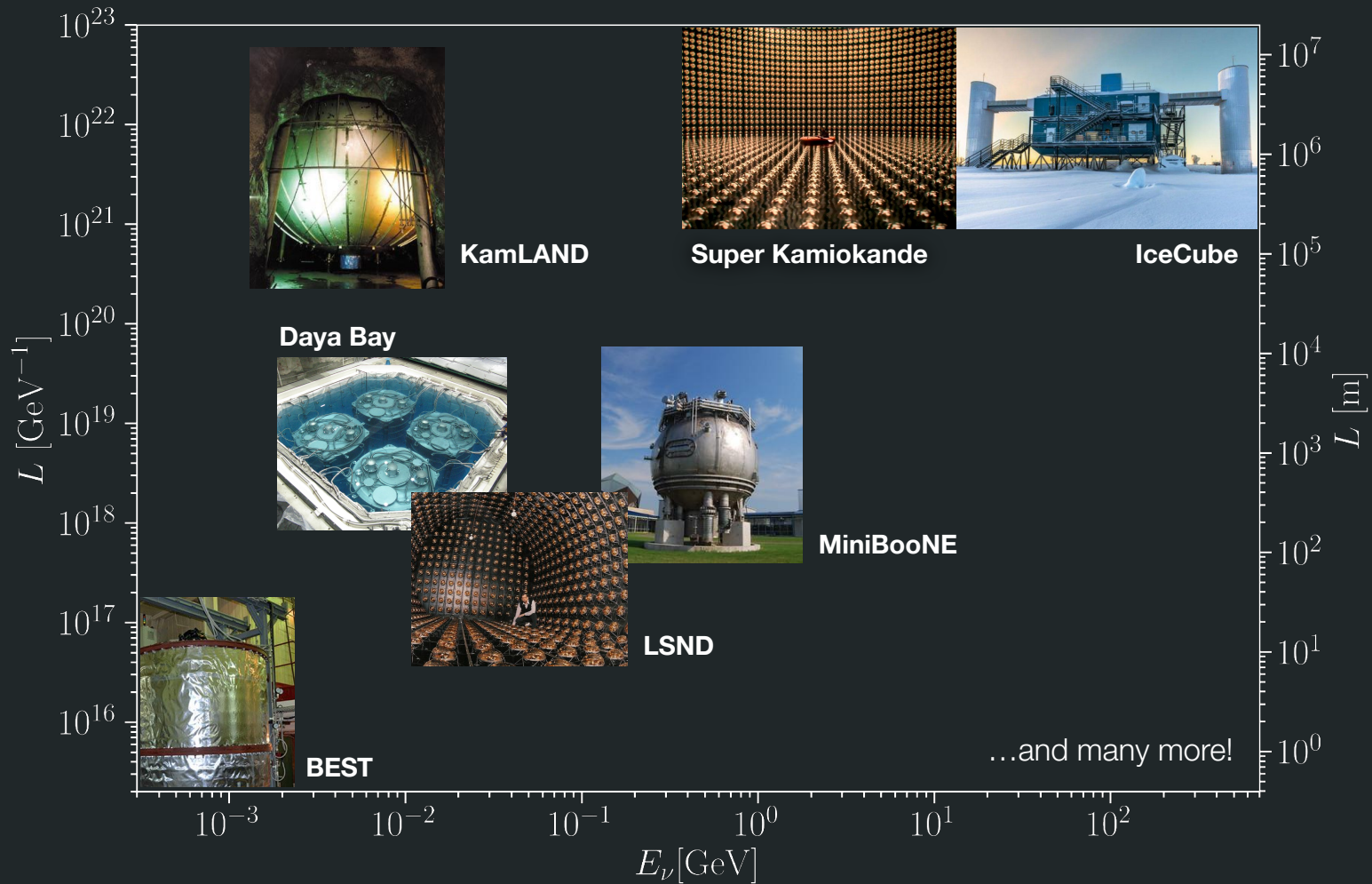




# Flavor eigenstates are not energy eigenstates.

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And therefore, neutrinos have different mass.  
This affects a lot of interdisciplinary physics!



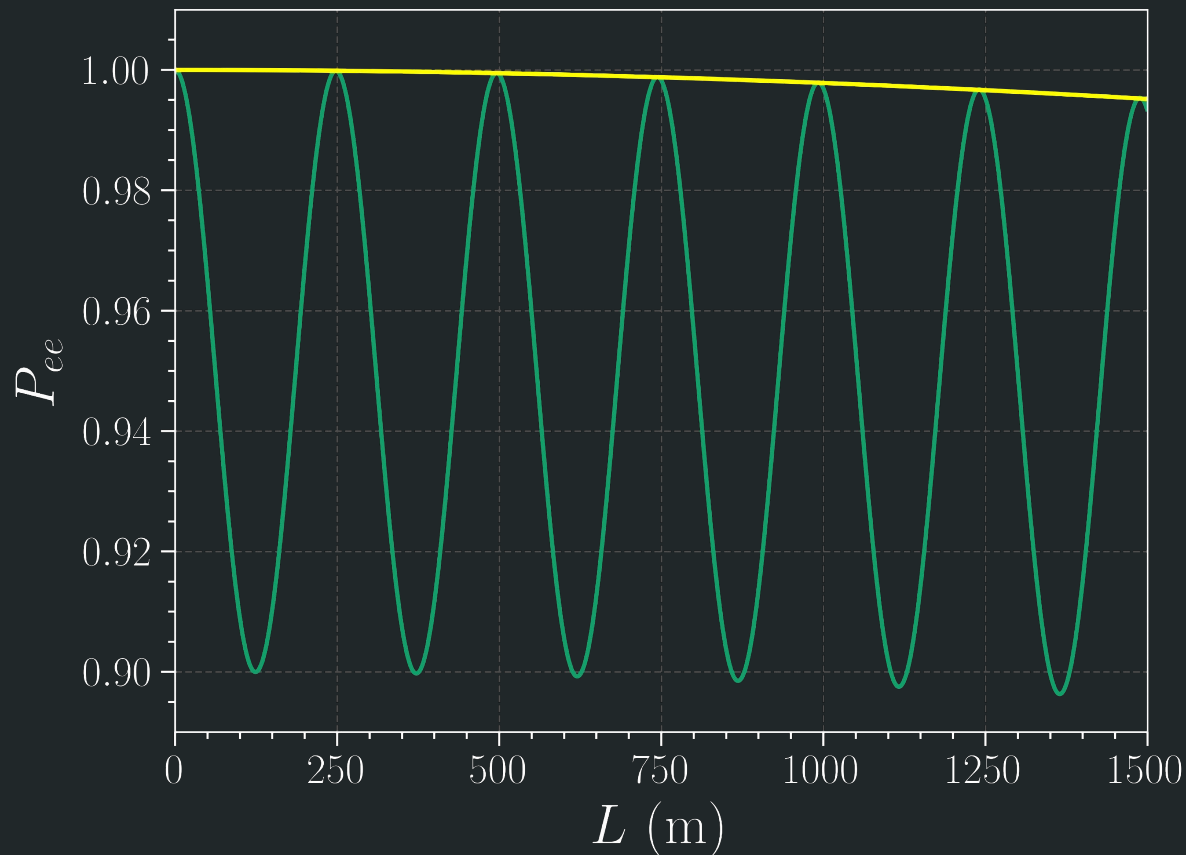


**The LSND anomaly:  
a hint of a sterile neutrino?**

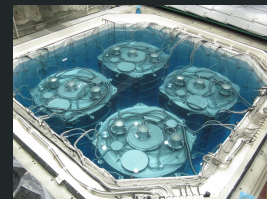


$$E_\nu = 20.0 \text{ MeV}, \quad \Delta m_{41}^2 = 0.2 \text{ eV}^2, \quad \sin^2 2\theta_{14} = 0.1$$

**Source**  
L = 0 m



**Detector**  
L ~ 1500 m



— With sterile      — Only standard

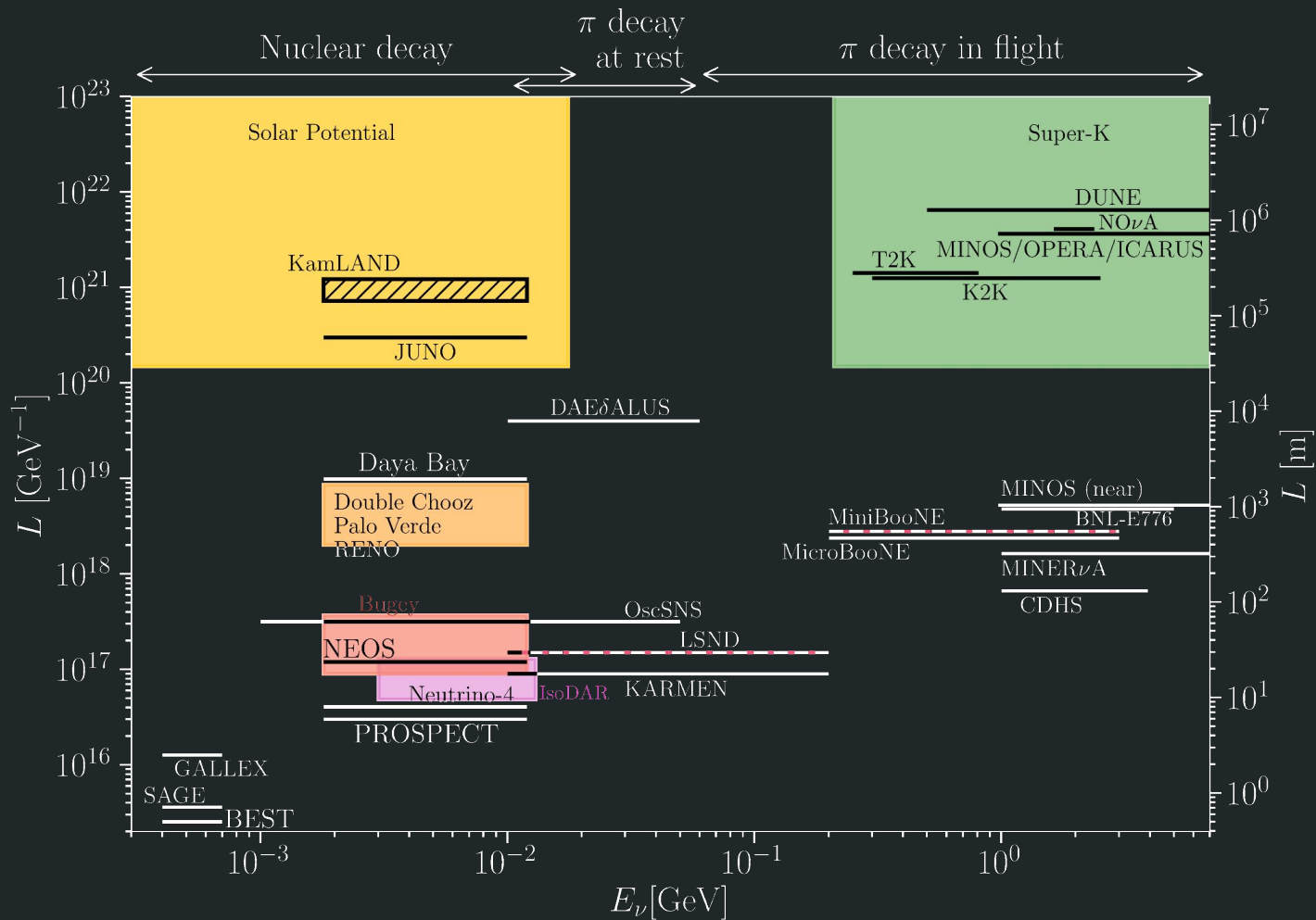


# The sterile neutrino

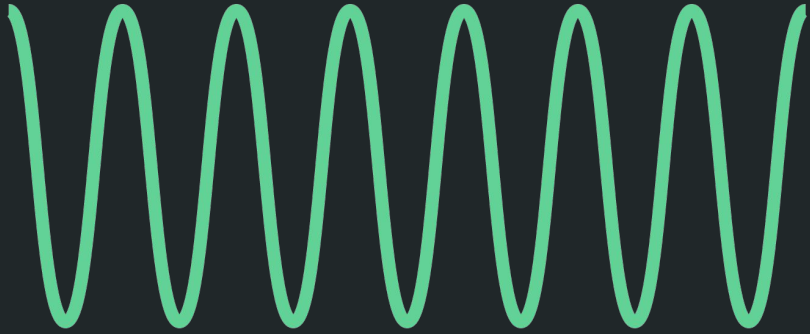
A new mass eigenstate to add a new oscillation frequency.

This new eigenstate must correspond to a new “flavor”: the sterile neutrino.

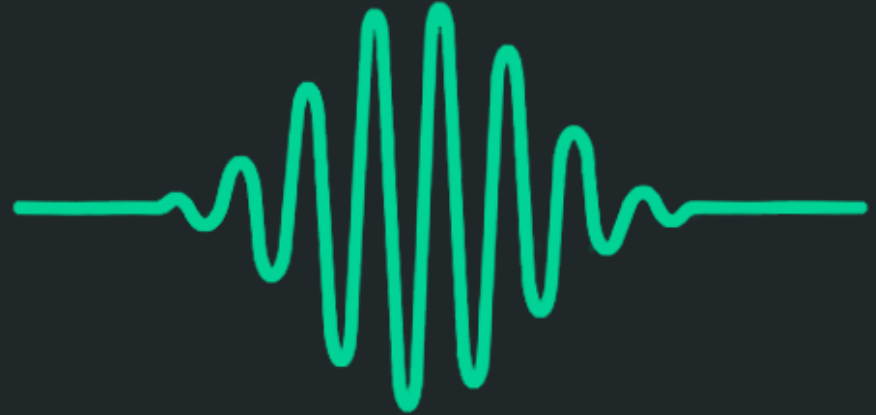
No weak interaction, only visible through oscillations (or gravity).



**Plane wave**



**Wave packet**



The **plane wave approximation** may not be valid for sterile neutrinos. **Wave packets** are needed.

**Standard quantum-mechanics can reduce  
the tension between some experiments.**

**Please, feel free to ask any question :)**

