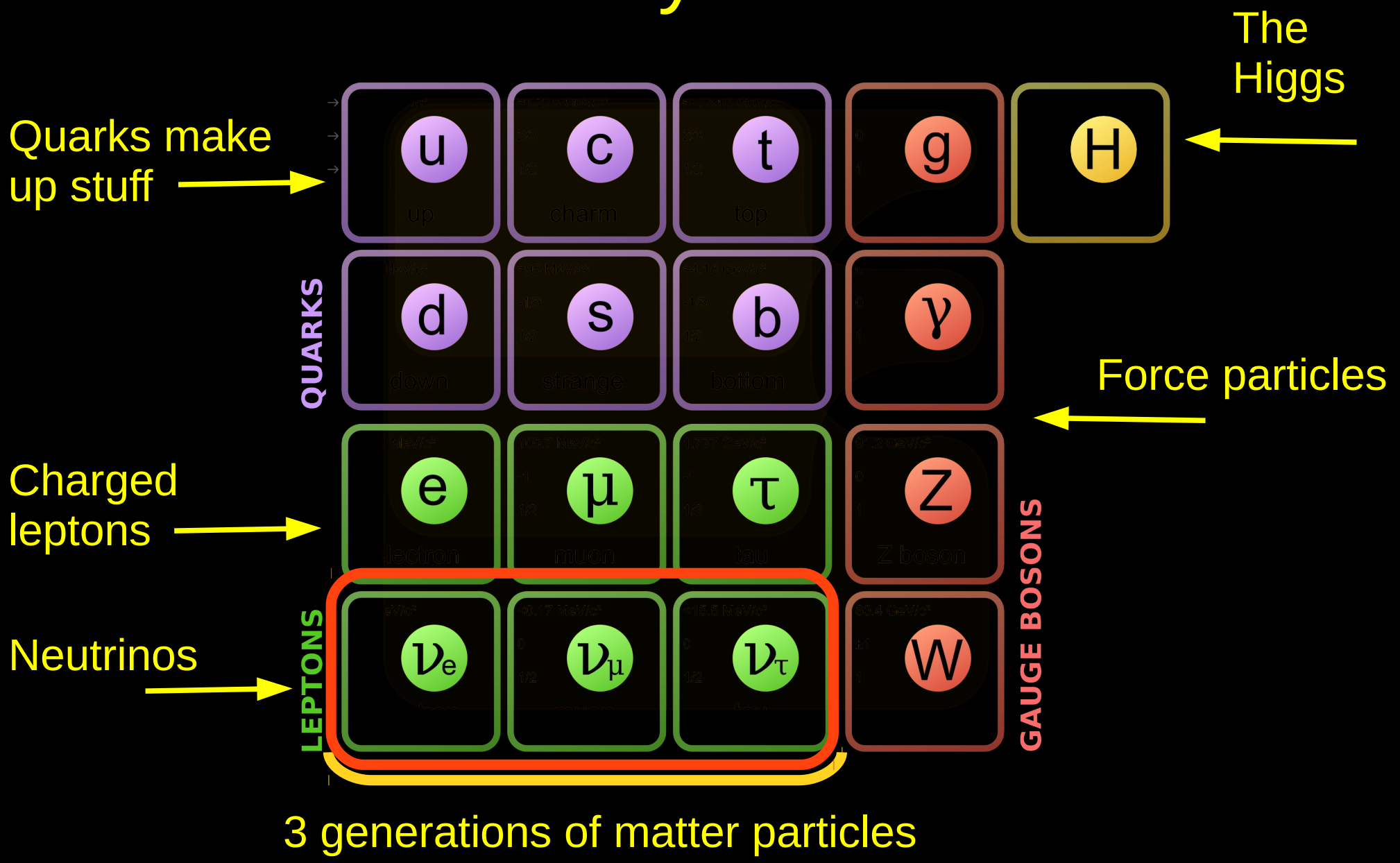
Neutrino Physics

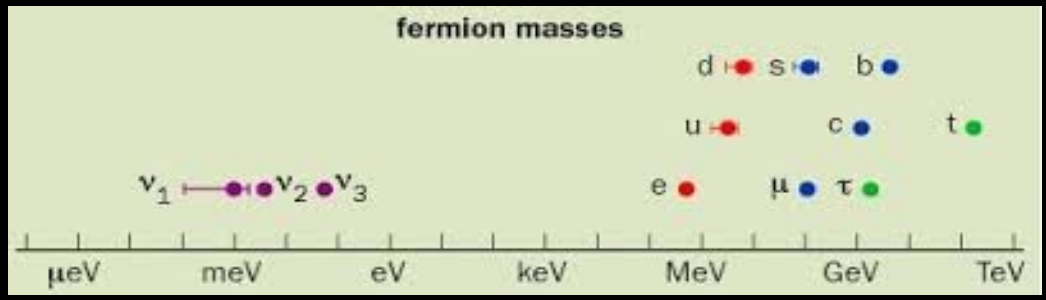
The Standard Model of Particle Physics



Neutrino Properties

Electrically neutral

Very very small mass
(but non-zero)



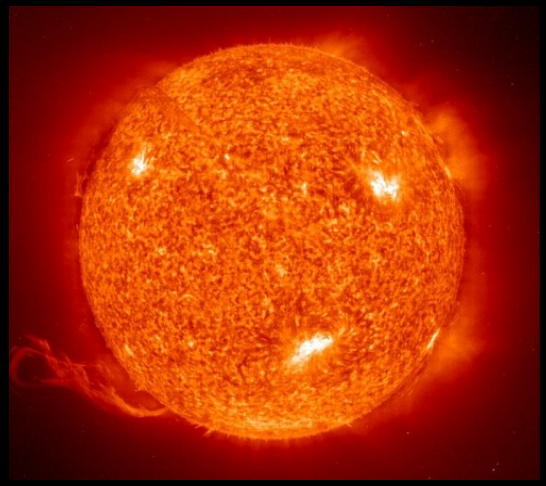
They are the most common particle in the universe

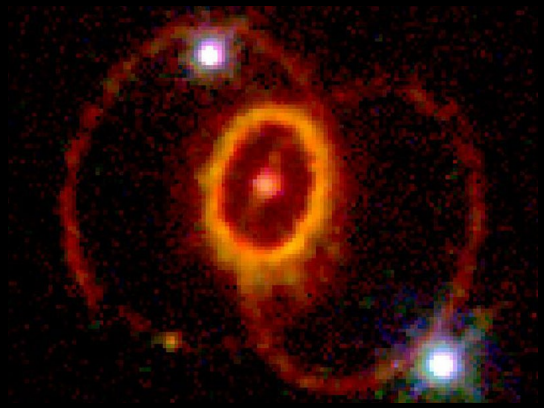
Neutrino Sources

The Big Bang
300 ν/cm^3

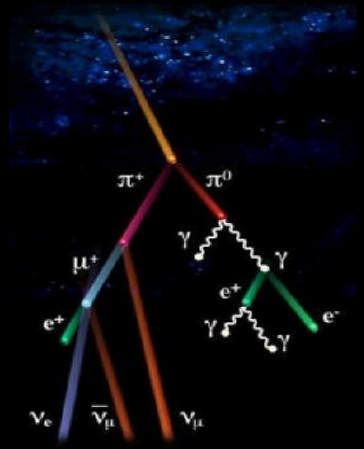
Accelerators and Reactors
10^{20} ν/s

The Sun
10^{11} $\nu/cm^2/s$

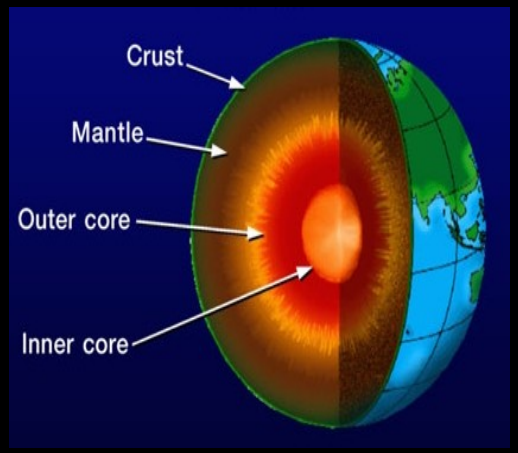




Astrophysics
(Supernovae)



Cosmic
Rays
1 $\nu/cm^2/s$



Radioactive decay
in the earth
10^6 $\nu/cm^2/s$

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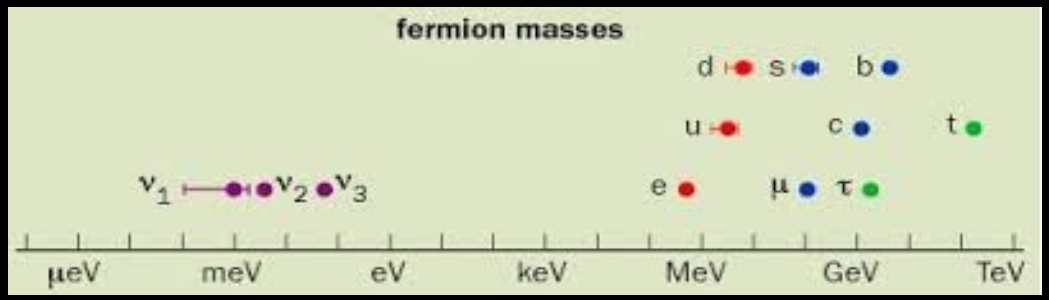


They are the most common particle in the universe

They only interact through the weak interaction

To a neutrino a planet is just a wisp of fog

Roughly 100 trillion go through you every second

You can never detect the neutrinos - just what they do when they interact in our detectors.

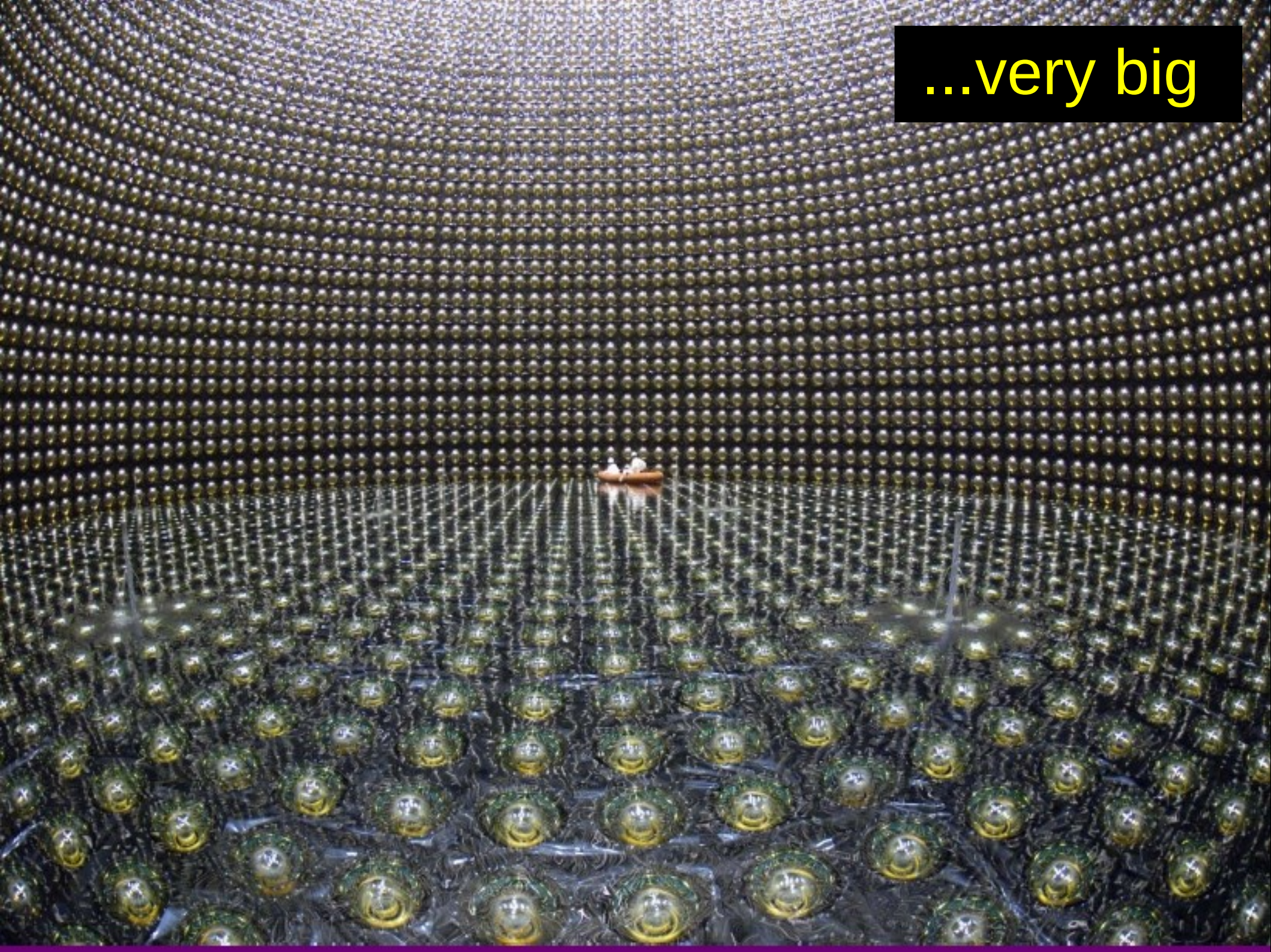
Neutrino Detections =

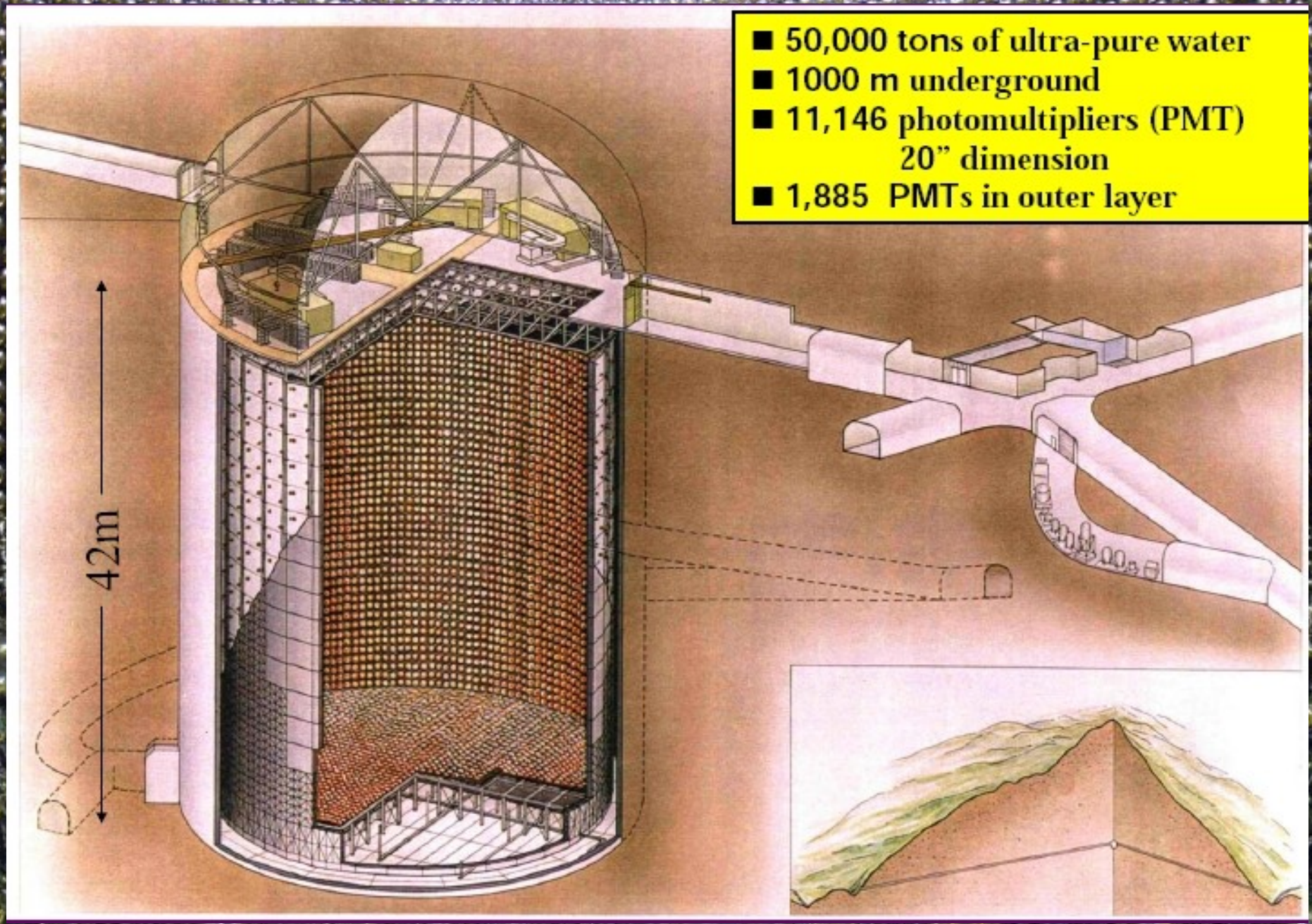
Probability of a neutrino to interact $\times$

Flux of neutrinos $\times$

Number of target atoms

Detectors need to be big...

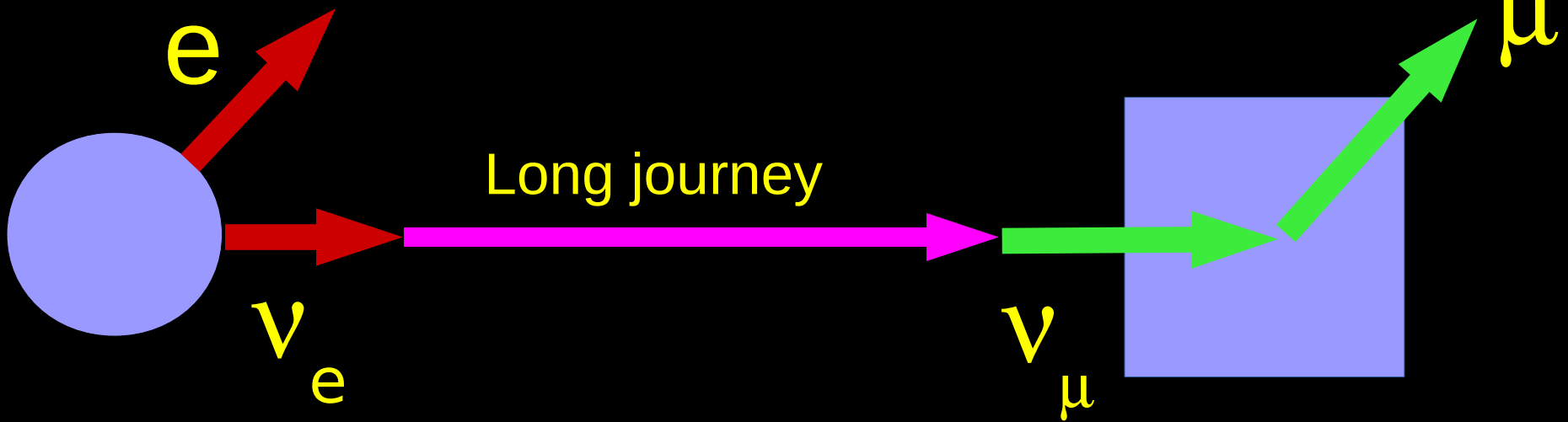

...very big

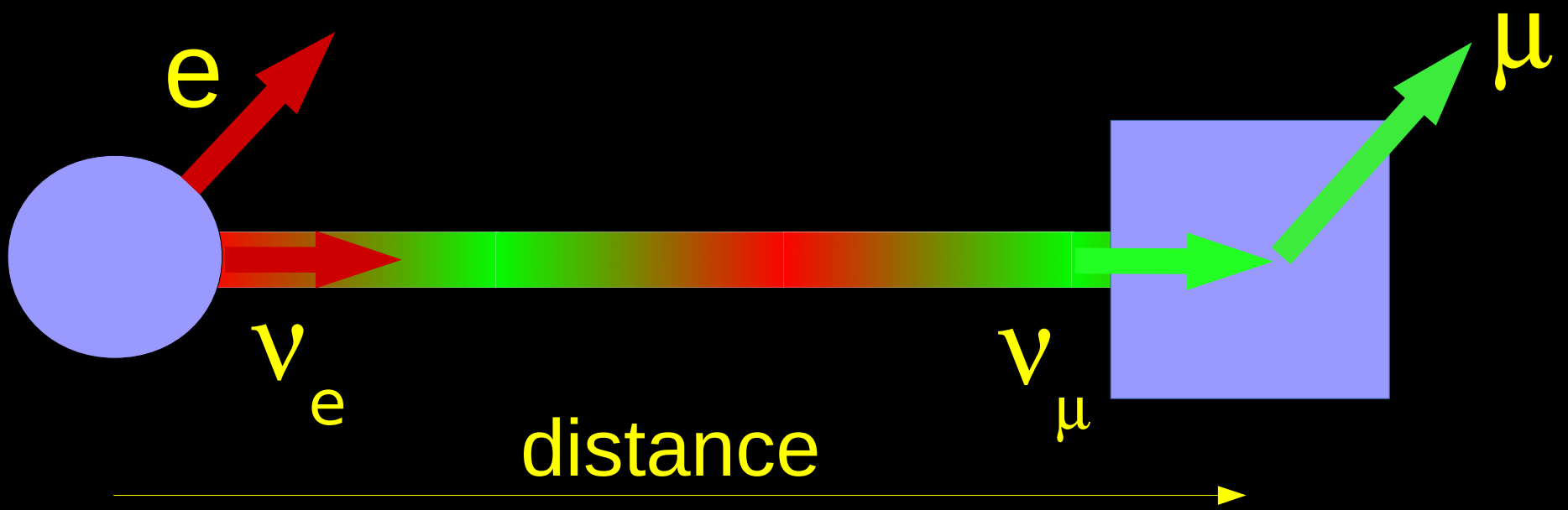

■ 50,000 tons of ultra-pure water
■ 1000 m underground
■ 11,146 photomultipliers (PMT)
20" dimension
■ 1,885 PMTs in outer layer
42m

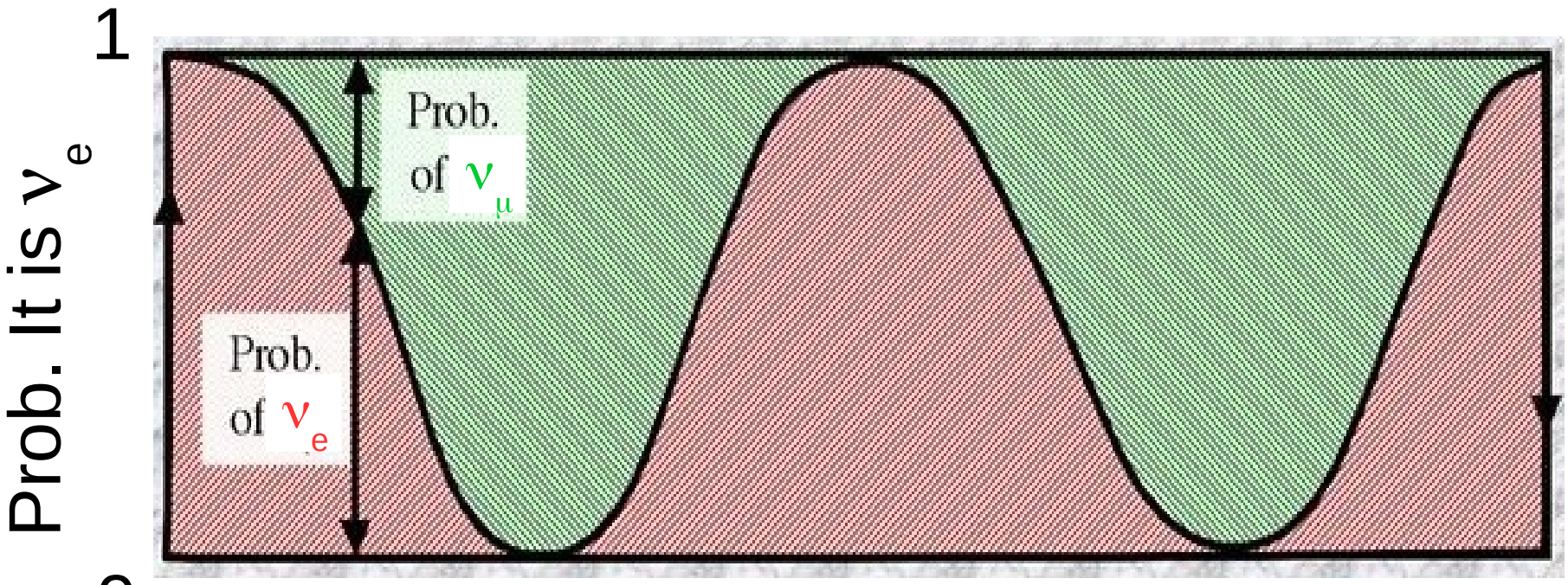
Neutrinos : Particles In Disguise

Neutrinos are relaxed about identity. They can change type as they propagate from point to point.

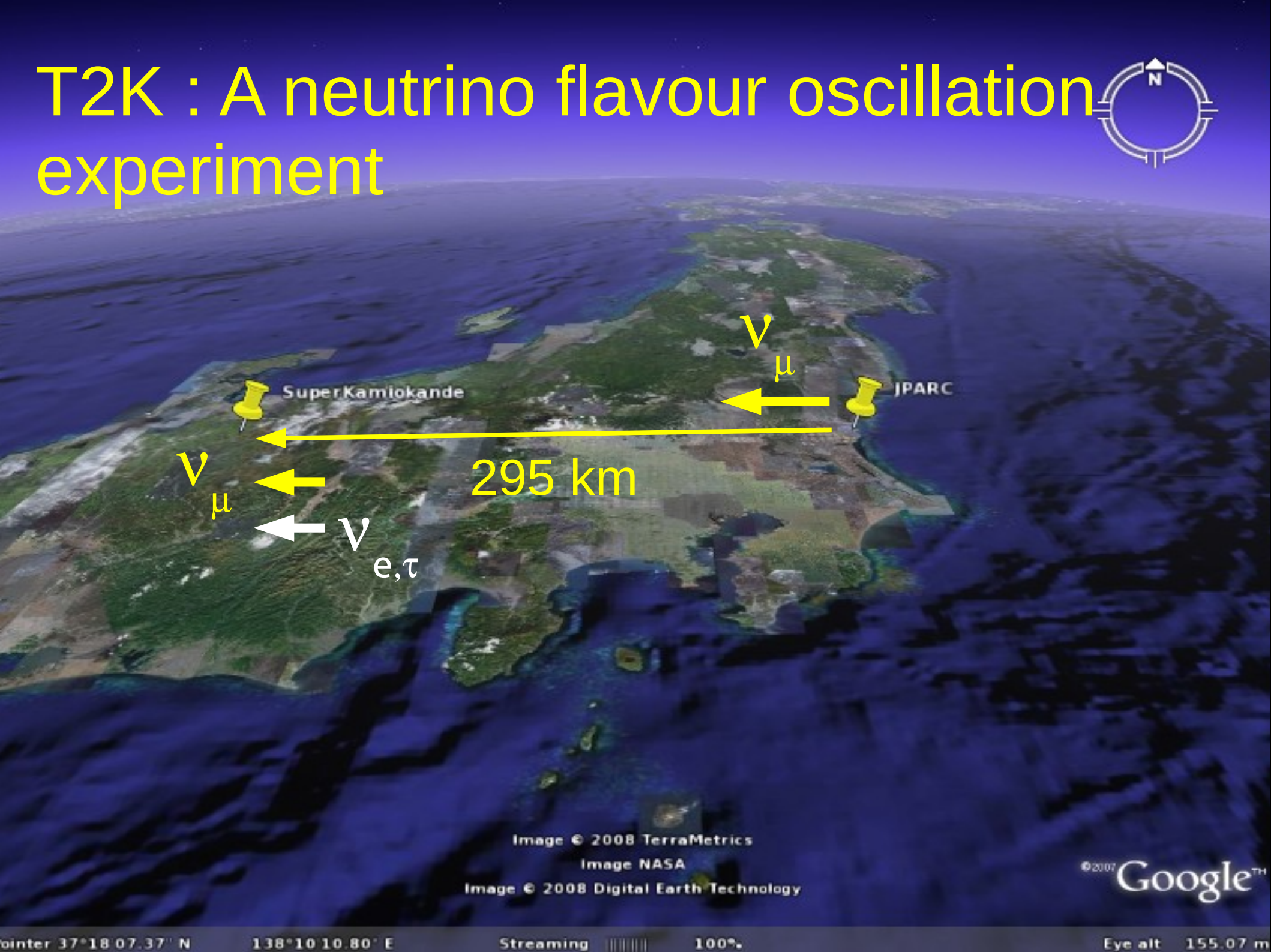
They can only do this if they have mass.




e
μ
ν_e
ν_μ
distance


1
0
Prob. It is ν_e
Prob. of ν_μ
Prob. of ν_e
Distance Travelled

T2K : A neutrino flavour oscillation experiment



Why study them?

Neutrinos are cool...

Why study them?

Why study them?

Why is the universe dominated by matter and not anti-matter?

The way neutrinos (and anti-neutrinos) change flavour could help answer this question.

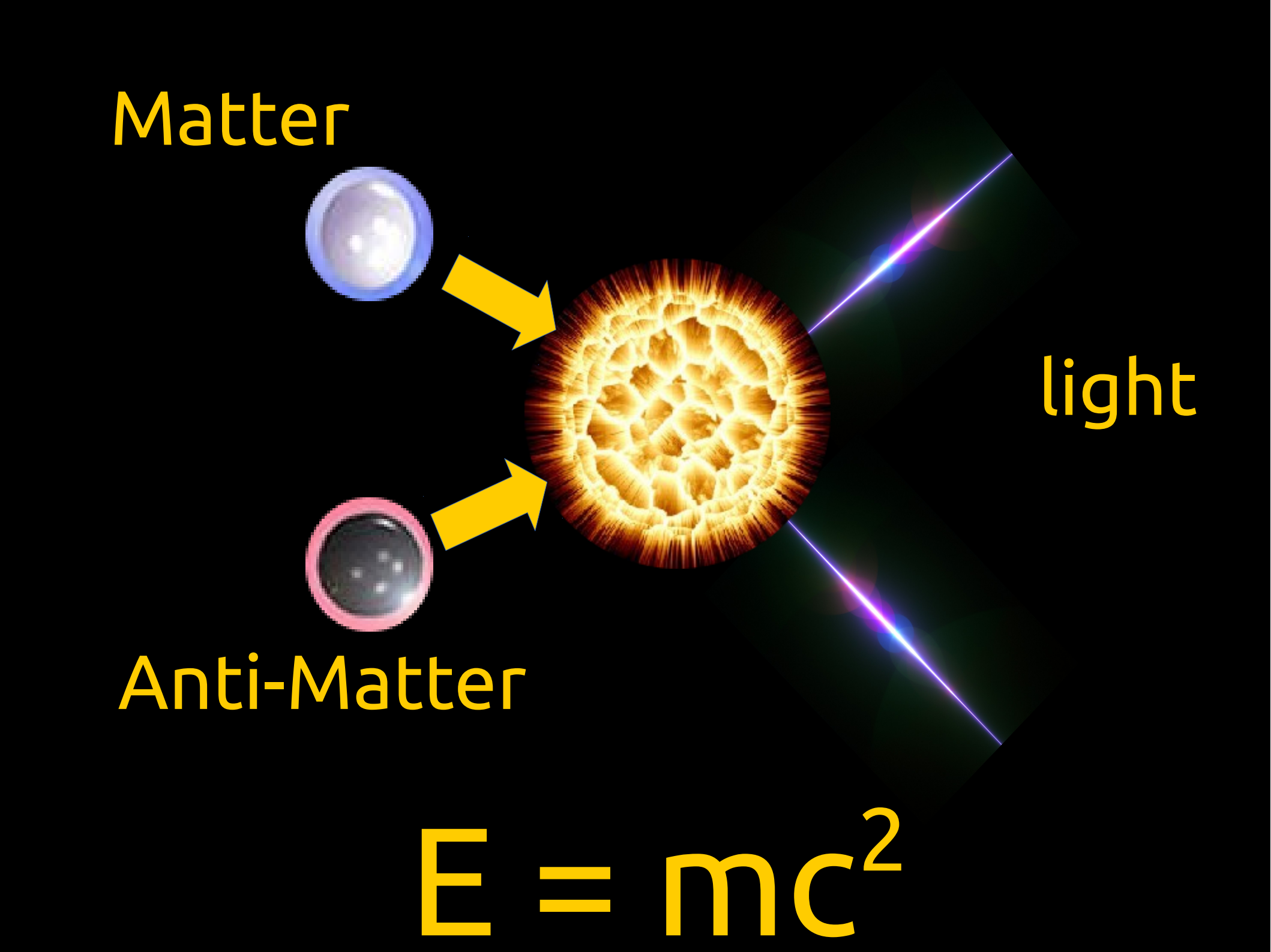
Summary

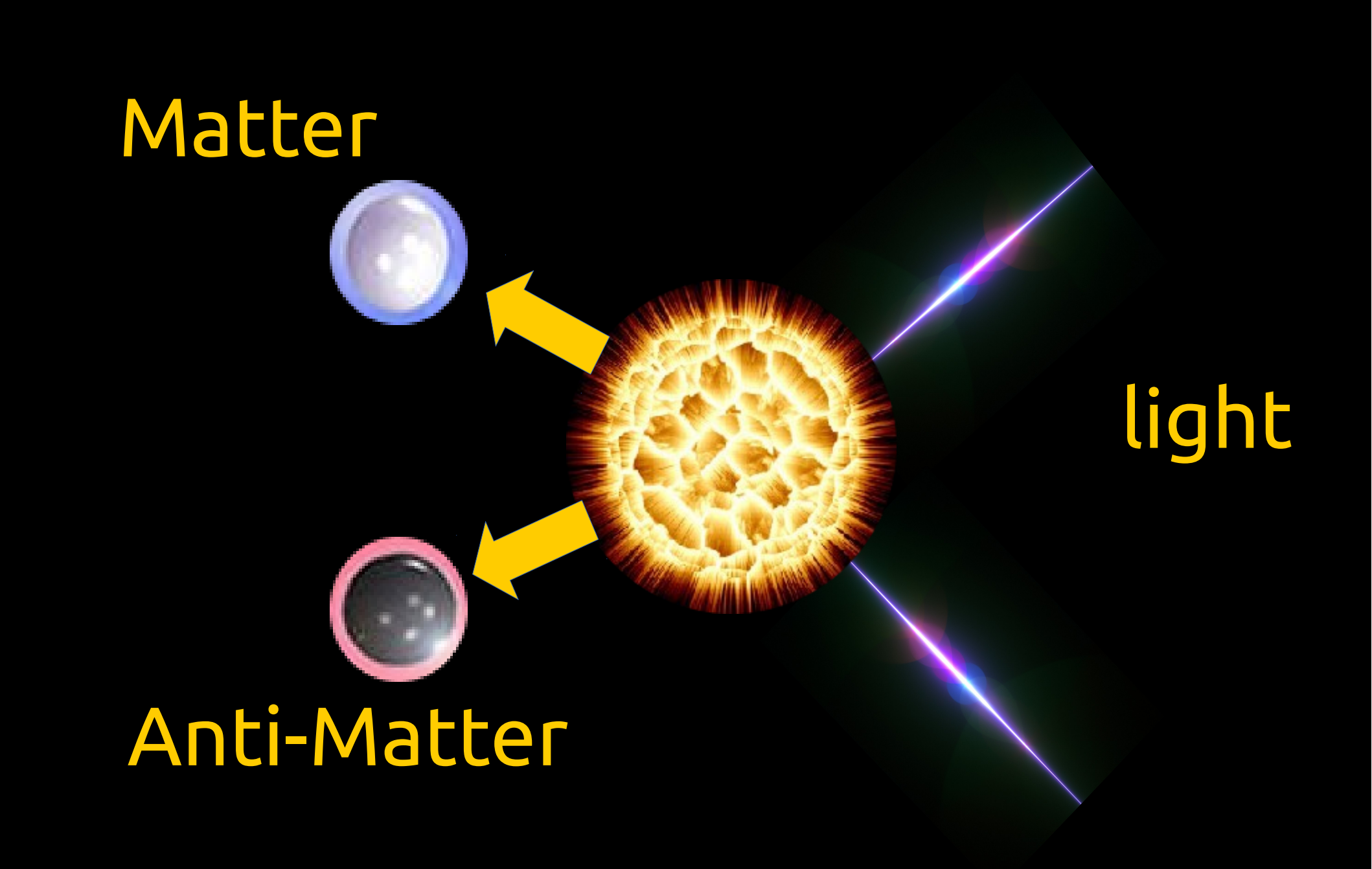
Neutrinos are cool!

"The chances of a neutrino actually hitting something as it travels through all this howling emptiness are roughly comparable to that of dropping a ball bearing at random from a cruising 747 and hitting, say, an egg sandwich."

Douglas Adams-Mostly Harmless

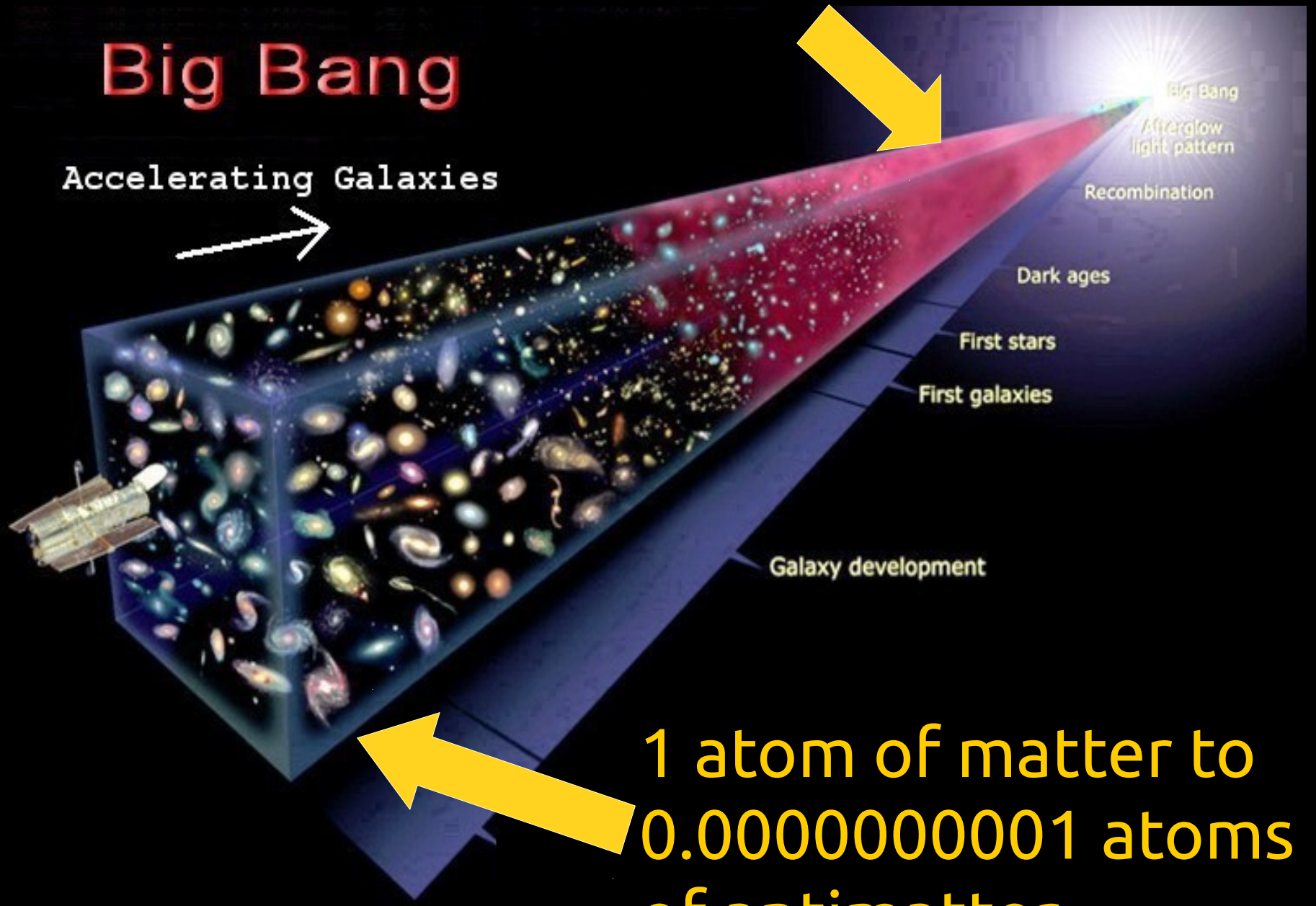
The chances of this happening is about 1 part in 10^{14}


Matter
light
Anti-Matter
E = mc²



The reverse reaction should also happen with the same probability

Equal amounts of
matter and antimatter



1 atom of matter to
0.0000000001 atoms
of antimatter

It's Quantum.....

$$|\nu_\alpha> = \sum_{i=1}^{3} U_{\alpha i} |\nu_i>$$ where $U_{\alpha i}$ is a unitary matrix

$$|\nu_k(t,x\ )> = e^{i(E_k t - p_k x)} |\nu_k(0,0)> \ \rightarrow\ P(\nu_\alpha(0,0) \rightarrow \nu_\beta(t,x\ )) = |<\nu_\beta(t,x\ )|\nu_\alpha(0,0)>|^2$$

$$|<\nu_\beta(t,x\ )|\nu_\alpha(0,0)>|^2 = \sum_k \sum_j U_{\alpha k} U^*_{\alpha j} U_{\beta k} U^*_{\beta j} e^{i((E_j - E_k)t - (p_j - p_k)x)}$$

$$(E_j - E_i)t - (p_j - p_i)x = (\sqrt{p_j^2 + m_j^2} - \sqrt{p_i^2 + m_i^2})x - (p_j - p_i)x =$$

$$(p_j(1 + \frac{1}{2}\frac{m_j^2}{p_j}) - p_i(1 + \frac{1}{2}\frac{m_i^2}{p_i})) \approx \frac{\Delta m_{ij}^2}{4E}$$

$$U = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \longrightarrow P(\nu_\alpha(0,0) \rightarrow \nu_\beta(t,x\ )) = \sin^2(2\theta)\sin^2(\frac{\Delta m_{12}^2 L}{4E})$$