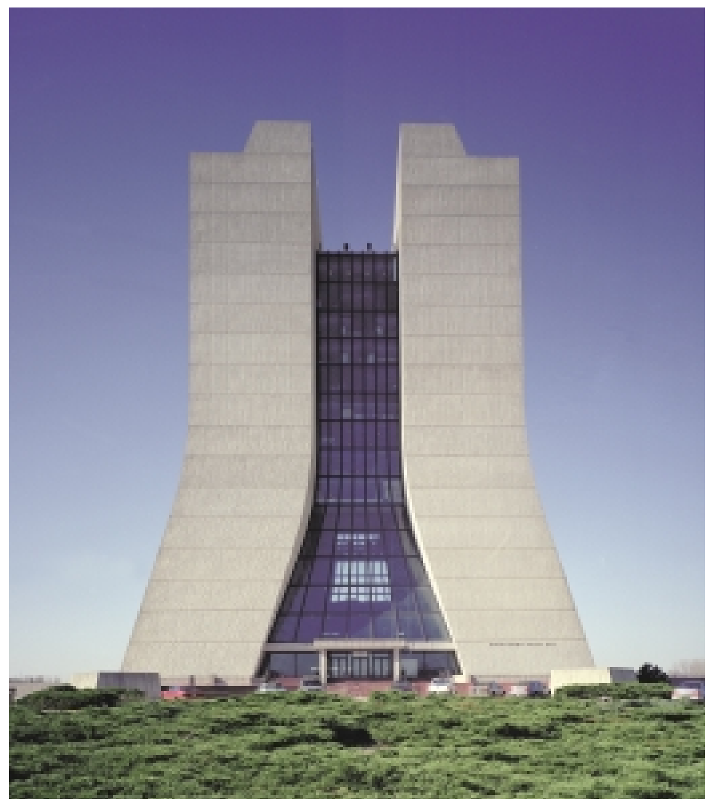
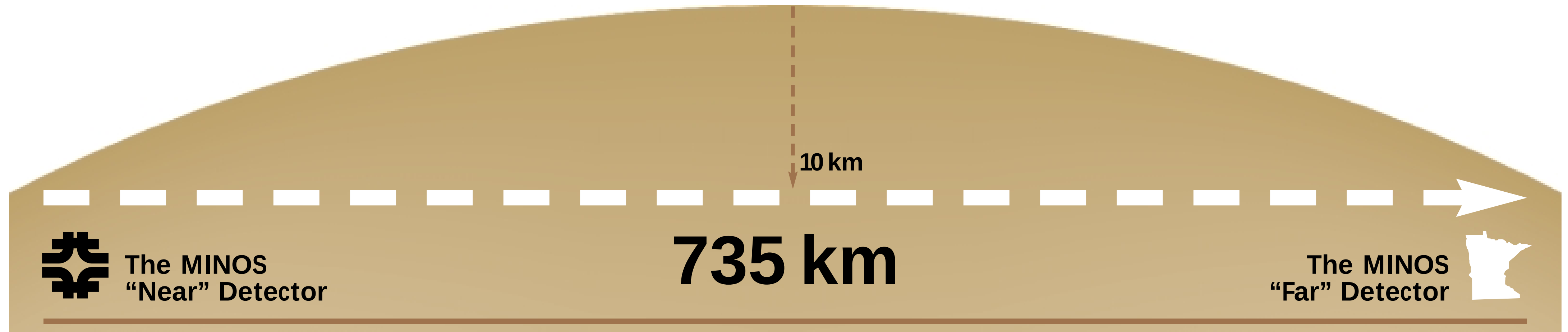
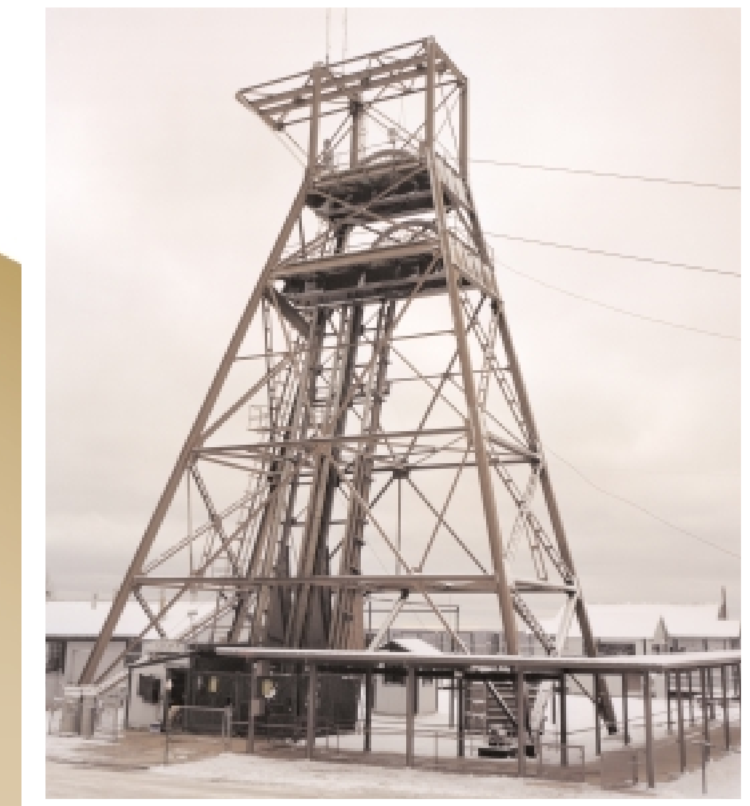
# Can Neutrinos CHANGE Flavor?

**If we can detect neutrinos changing from one flavor to another, then we know that they have mass.**

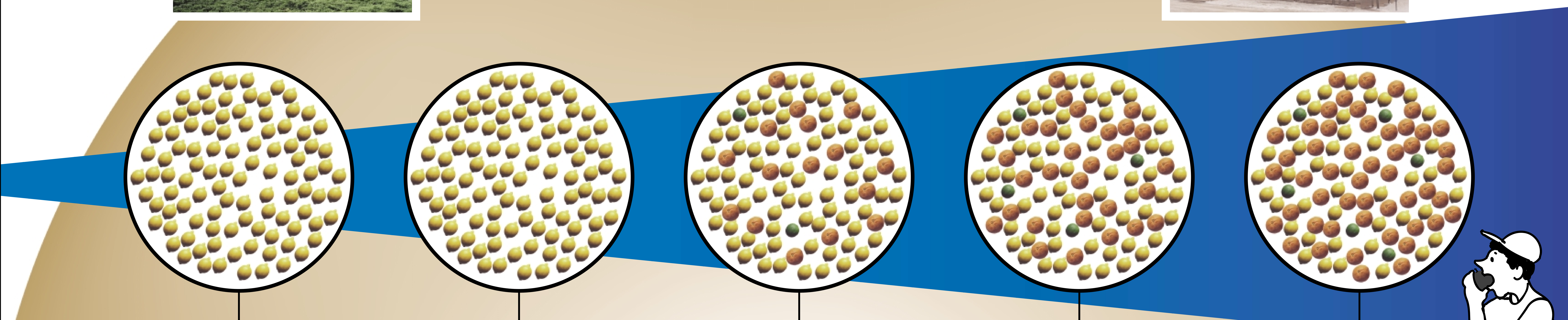
Neutrinos start at Fermilab...





...and, *two* milliseconds later, arrive at the Soudan Mine.



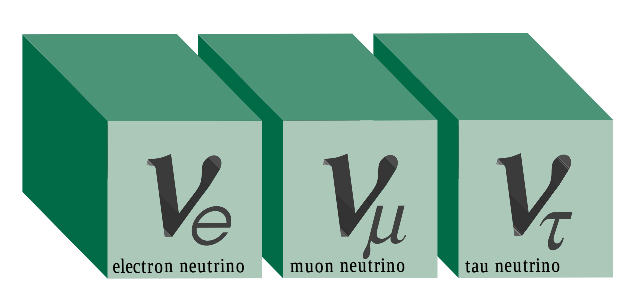
**1.** A beam of protons strikes a target, creating a beam of pions and kaons, which decay into a beam of muon neutrinos ($\nu_\mu$). The fruits in the circle represent the proportion of muon neutrinos (lemon) that oscillate into tau (orange) and electron (lime) neutrinos.

**2.** The MINOS "near" detector measures the rate, energy spectrum and flavor composition of the NuMI neutrino beam immediately after the neutrinos are produced and before any oscillations can take place.

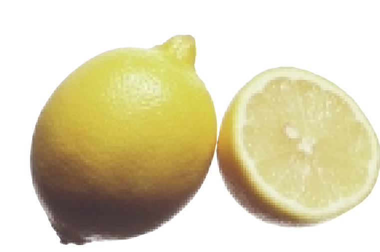
**3.** Assuming that the neutrino oscillation length is great, muon neutrinos will not oscillate significantly until they travel well beyond the Fermilab site. In this example, a fraction of the muon neutrino beam has transformed into tau neutrinos (orange). If the oscillation potential is great, this fraction will be significant. Note that very few muon neutrinos have oscillated into electron neutrinos (lime), because the oscillation potential is small, or the oscillation length is very great.

Distances not to scale.

**4.** The MINOS "far" detector is located 735 kilometers from Fermilab, in Soudan, Minnesota. The neutrino beam diverges and becomes less intense as it travels away from the source. However, the long distance from the source allows the muon neutrinos more length to transform into tau neutrinos, though not enough distance to transform into a significant number of electron neutrinos.

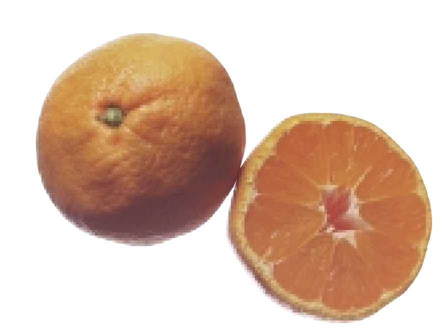



**Neutrinos come in three flavors: electron, muon and tau. Each one has a charged partner particle, an electron, a muon or a tau lepton. Here, a muon neutrino is a lemon, an electron neutrino is a lime and a tau neutrino is an orange.**



muon neutrino ($\nu_\mu$)

electron neutrino ($\nu_e$)



tau neutrino ($\nu_\tau$)

**About 10,000 billion neutrinos from the sun pass through this square every second.**

Neutrinos@FERMILAB

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