Update and Neutrino Oscillations Continued

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Update

- Finished installations with IT at Madison
- Starting simulations soon!

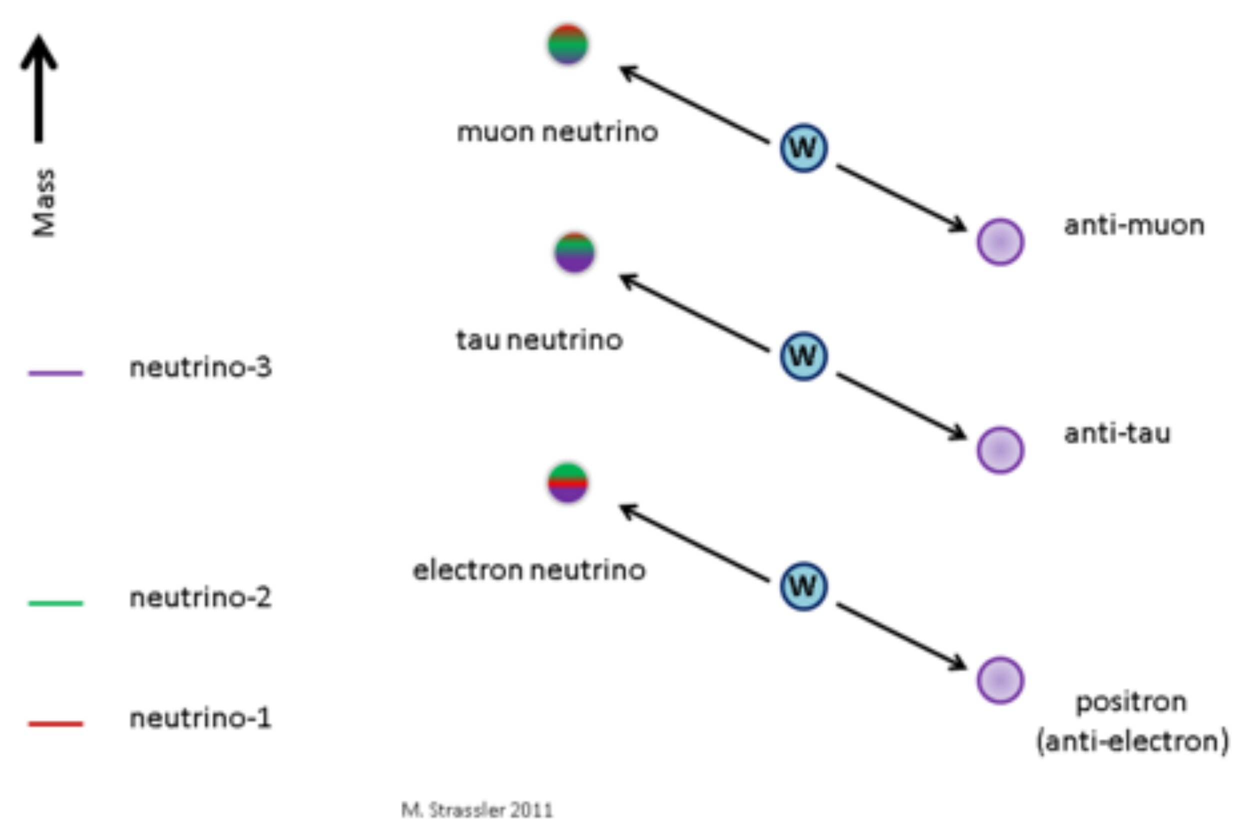
Neutrino Classification

- Because of the wave properties of neutrinos, it makes sense that an oscillation occurs because of certain states out of sync with one anther.

- Mass-type and weak type classification are what compose a neutrino

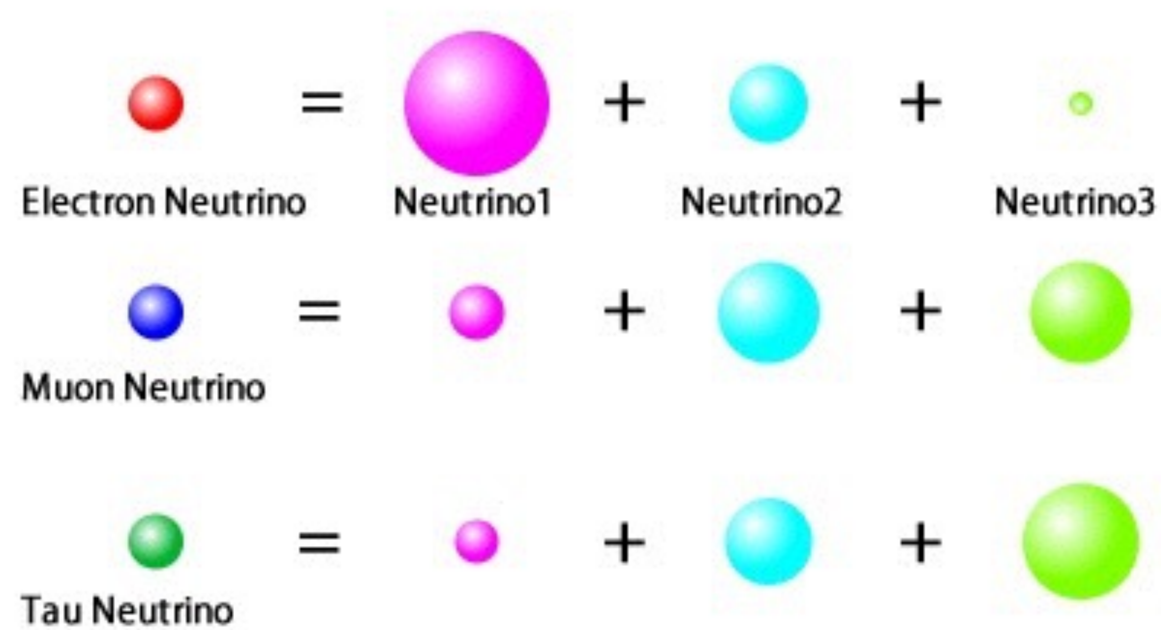
Weak Type

- Connection to charged lepton
- How the neutrino is affected by weak nuclear force, or interaction with W particle.



Mass Type

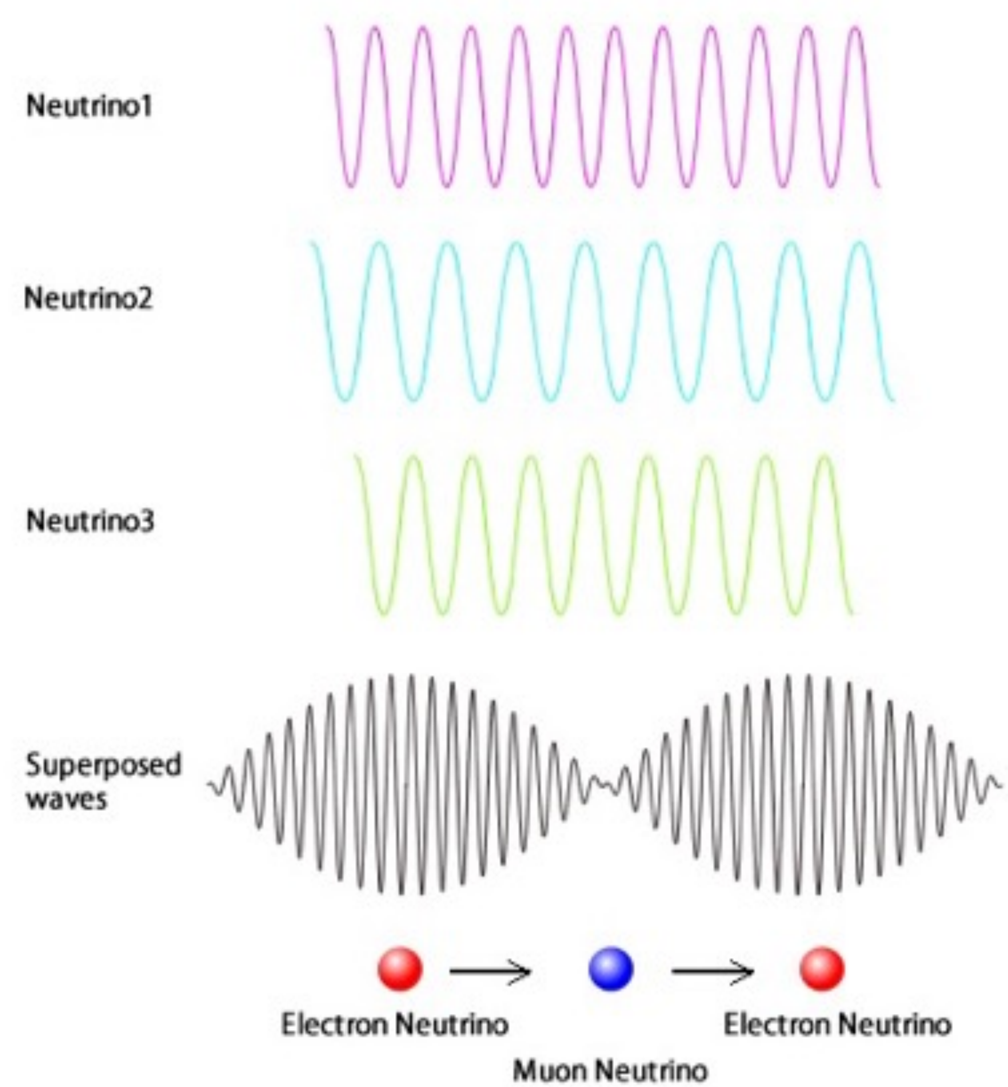
- There are three mass type “levels”, neutrino-1, neutrino-2, and neutrino-3, which, while still largely unknown, are ranked from least to greatest.
- All neutrinos are some combination of these three mass-types.
- Mass types are a superposition of the three weak types, and weak types are a superposition of the mass types.



Oscillation Process

- As a neutrino propagates through space, the quantum mechanical phases of the three mass states advance at slightly different rates due to the slight differences in frequency.

- Overlapping can cause the formation of a different type of neutrino



Neutrino Oscillations

mixing relationship between flavor and mass eigenstates

$$\begin{pmatrix} \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$

Allowing the mass states to propagate at different frequencies

From the time - dependent Schrödinger equation :

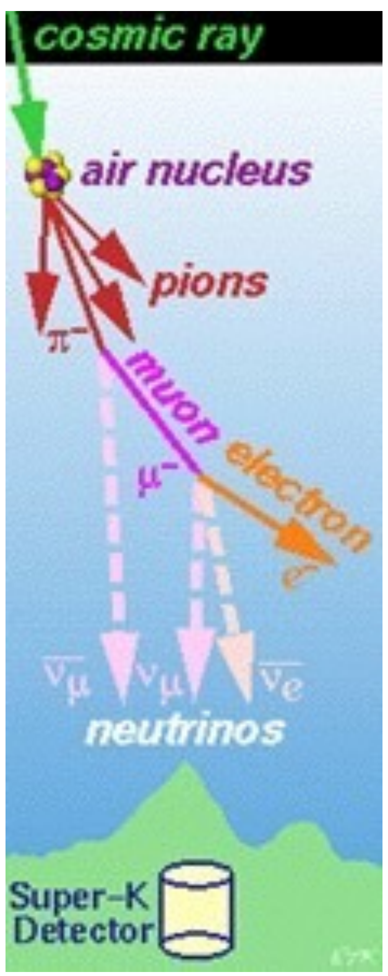
$$\begin{pmatrix} \nu_1(\vec{x},t) \\ \nu_2(\vec{x},t) \end{pmatrix} = e^{i\vec{p}\cdot\vec{x}} \begin{pmatrix} e^{-iE_1 t}\,|\nu_1(0)\rangle \\ e^{-iE_2 t}\,|\nu_2(0)\rangle \end{pmatrix} = e^{i\vec{p}\cdot\vec{x}} \begin{pmatrix} e^{-iE_1 t} & 0 \\ 0 & e^{-iE_2 t} \end{pmatrix} \begin{pmatrix} |\nu_1(0)\rangle \\ |\nu_2(0)\rangle \end{pmatrix}$$

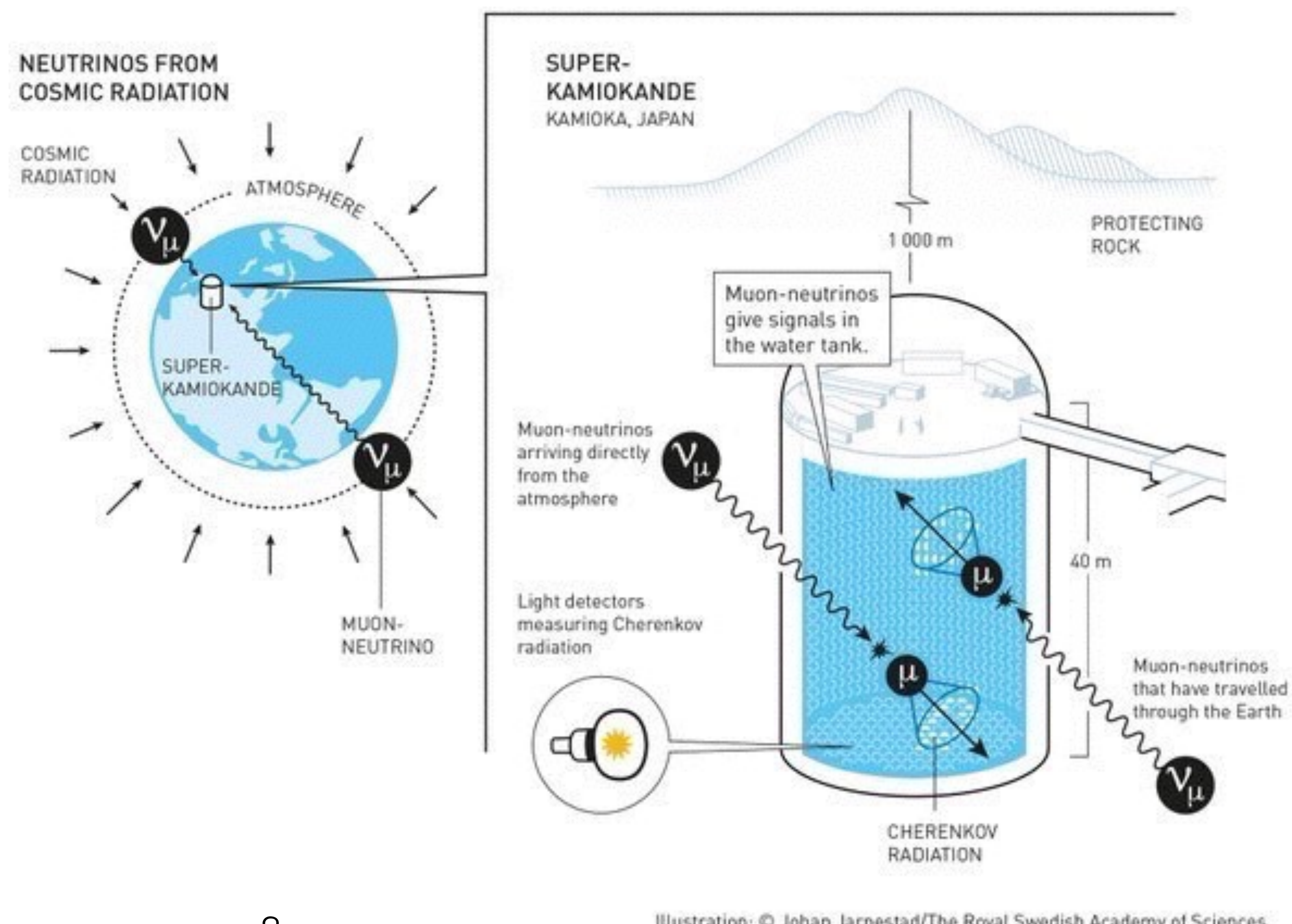
Momentum required
for oscillation

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

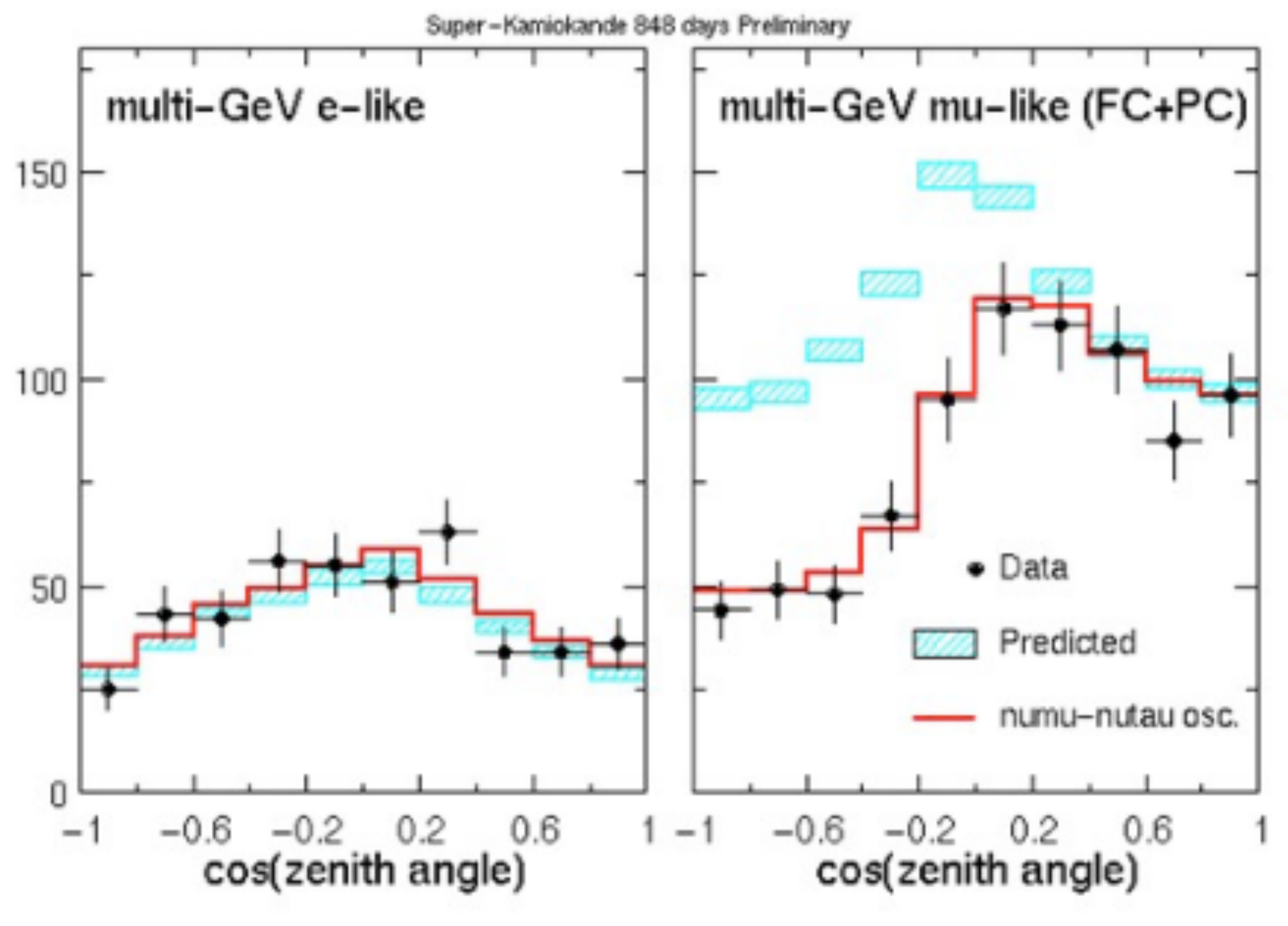
Super-Kamiokande

- 2000 ft underground
- 50,000 tonne tank of ultra-pure water



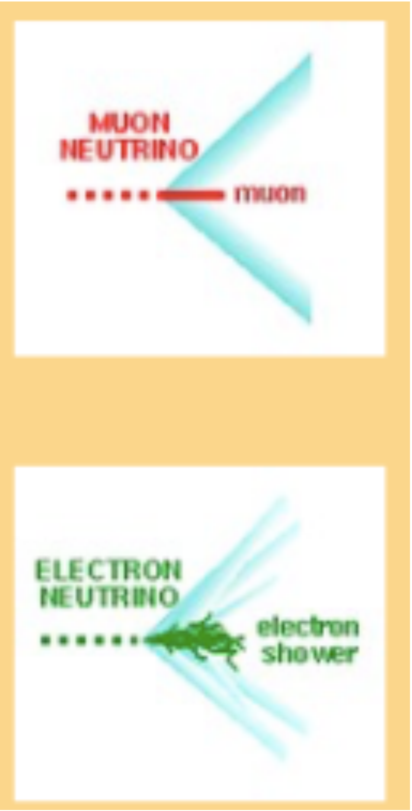


Muon neutrino deficit



This graph is a preliminary result based on the current full data-set; details of the analysis of high energy events based on the first 414 days of data were published in Phys. Lett. B436(1998)p.33 (hep-ex/9805006).

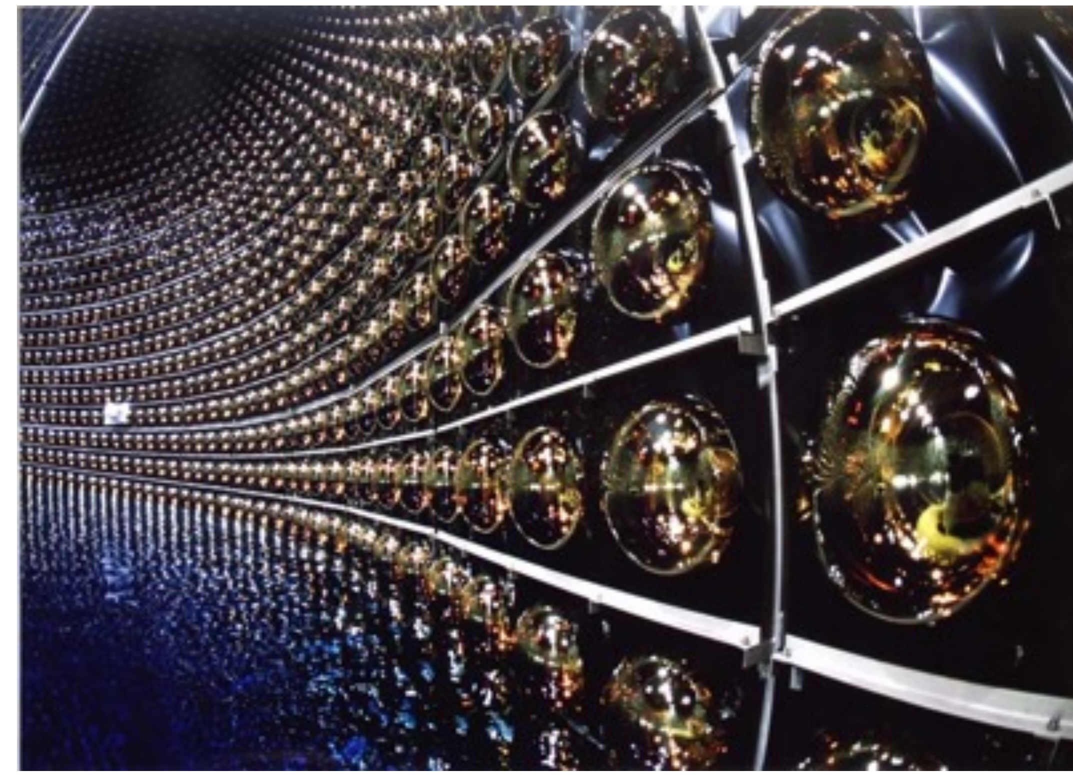
Neutrino Interaction



- Neutrino strikes a quark in an oxygen nucleus, gets a charge and becomes either a muon or electron —->
- energetically charged elementary particle emits Cherenkov radiation

Oscillation data with…

- Around 12000, photomultiplier tubes to measure:
  - Amount of light reaching it
  - Time of arrival
  - These measurements to reconstruct energy and starting position



  - Ring pattern of C-light
    - sharp edges=muon
    - fuzzy, blurred edges=electron

Additional evidence

- Muon neutrinos also interact in the rock around and below the detector. Because cosmic rays cannot penetrate the earth from below, any upward-going muons must be neutrino induced. However, the rate of low and high energy events, and their angular distribution, were in poor agreement with the standard prediction, but in good agreement with the hypothesis of neutrino oscillations.