Neutrinos:

A window to new Physics

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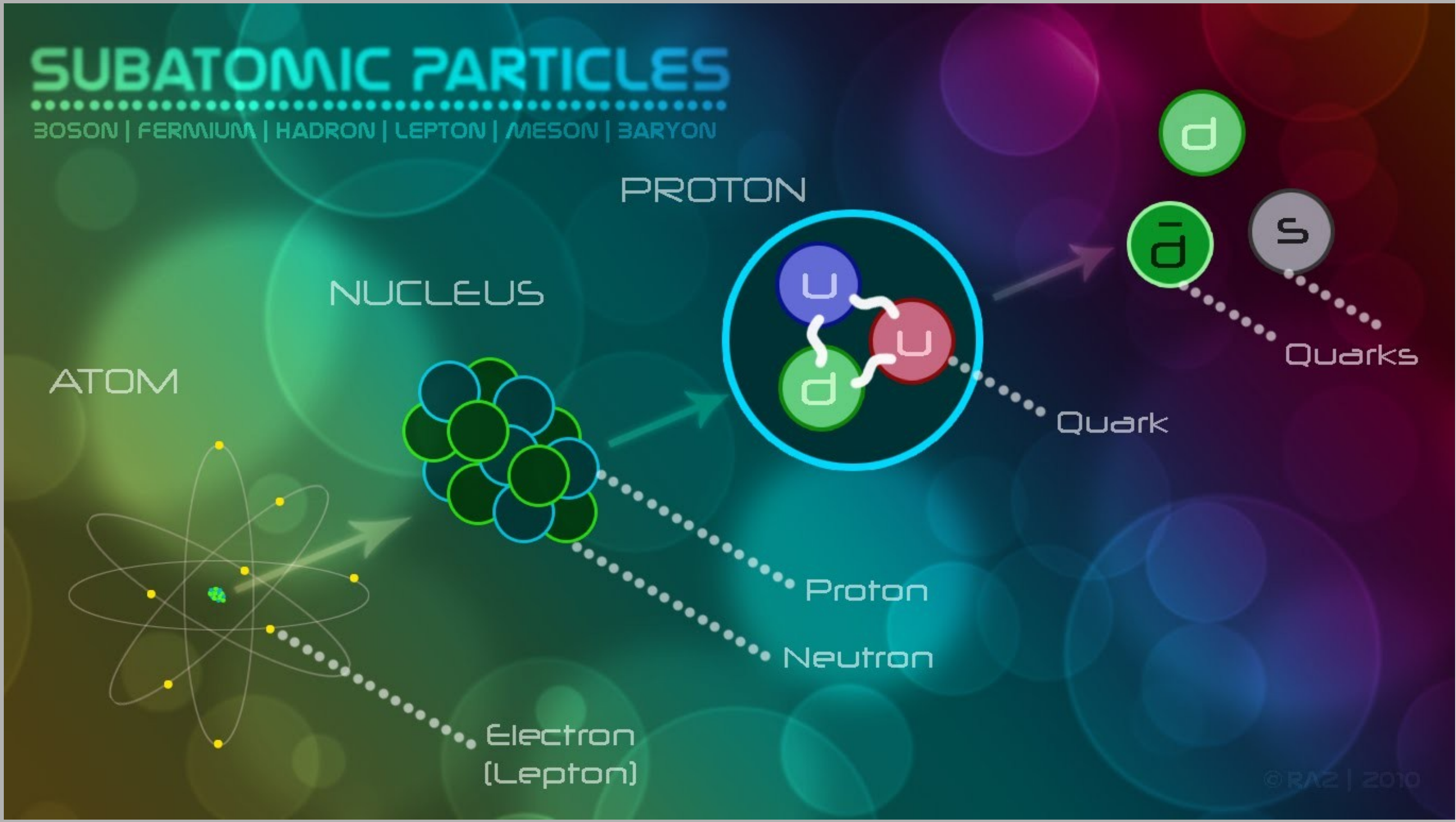
What is Particle Physics?

- Particle Physics is the study of the (subatomic) particles that constitute matter and radiation and their interactions.

Particle Physics is the study of the really, truly, small stuff



Some subatomic particles...

electron, proton, neutron

higgs, photon, muon, tau, $W^{\pm}$, W^0, Z

neutrinos, kaons, quarks, pions

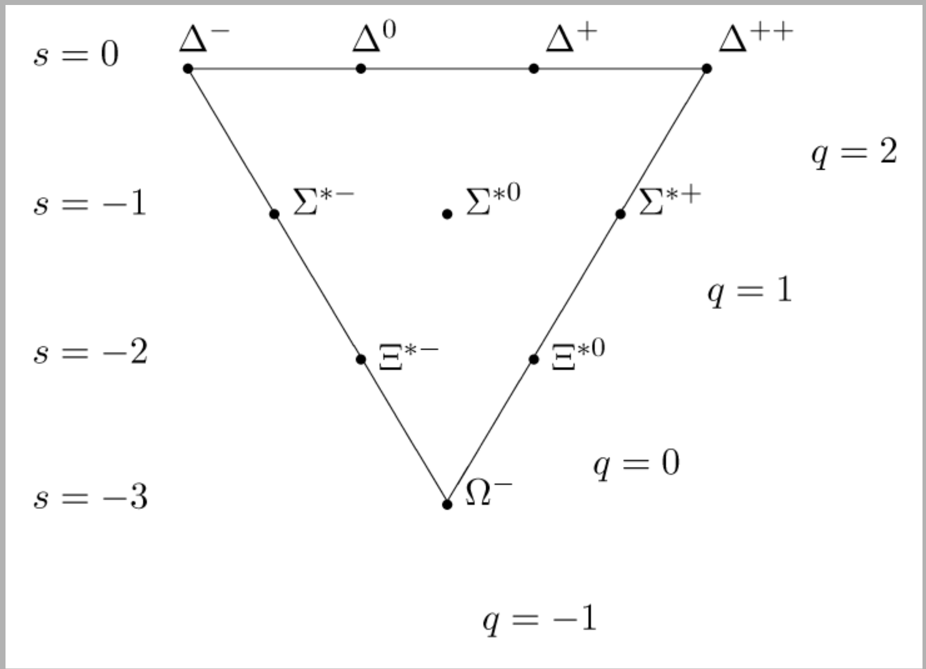
η, η', ω, f_0, a_0, ϕ, h_1

b_1, f_2, ρ, ω_3, ρ_3

$D^{\pm}$, D^0, D^*, $B^{\pm}$, B^0, B^*

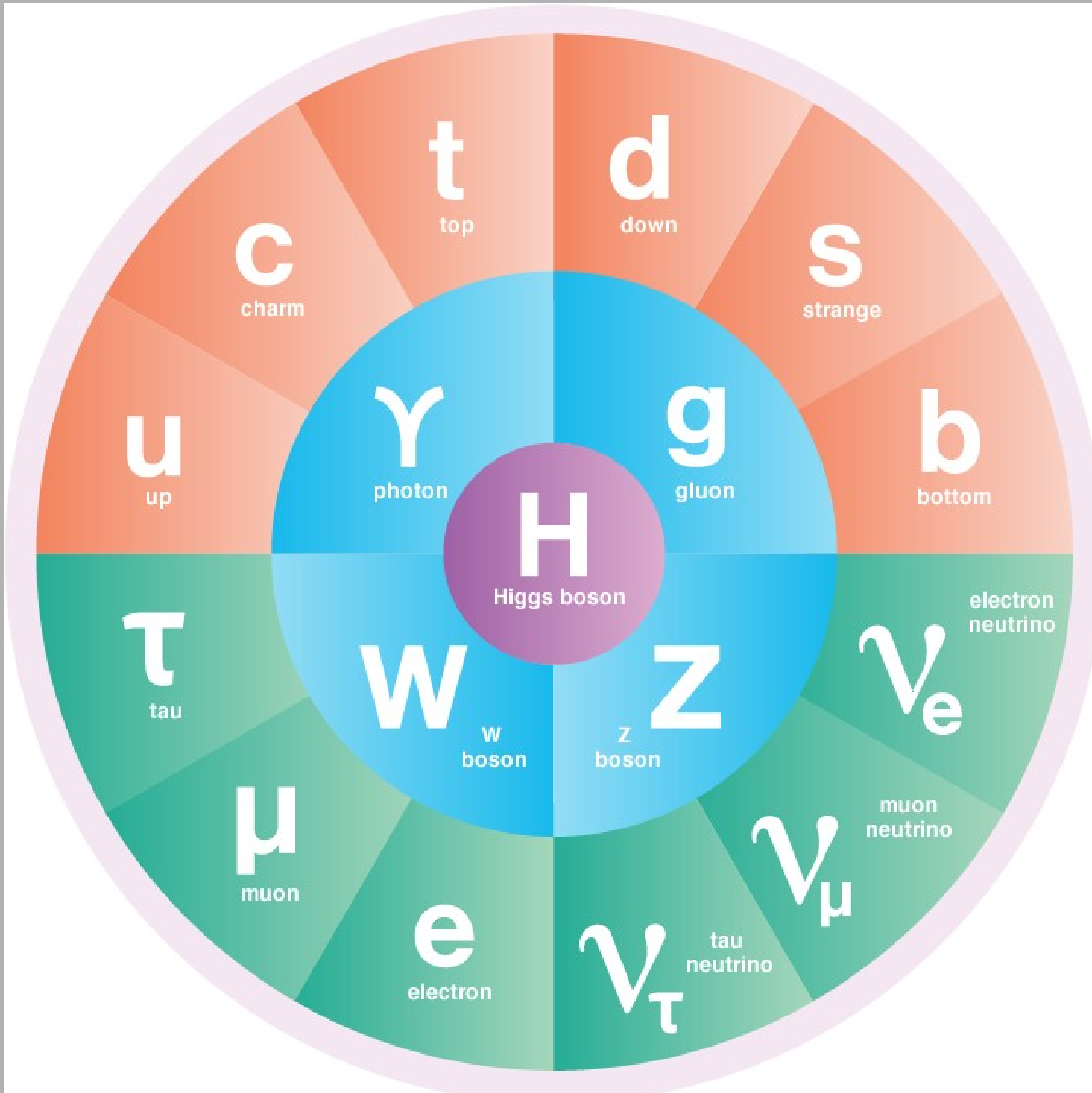
J/ψ, X, [illegible], N, Δ, Λ

$\Sigma^{\pm}$, Σ^0, $\Xi^{\pm}$, Ξ^0, Ω^-



The Standard Model

- Theory that classifies all the subatomic particles and their interactions (except for gravity!).
- Predicted the existence of many particles before they where observed.
- Allows for the calculation of various properties with unprecedented accuracy.
- Explains the composition and properties of all known particles in terms of a small group of elementary particles.
- In many ways this is the best theory we have.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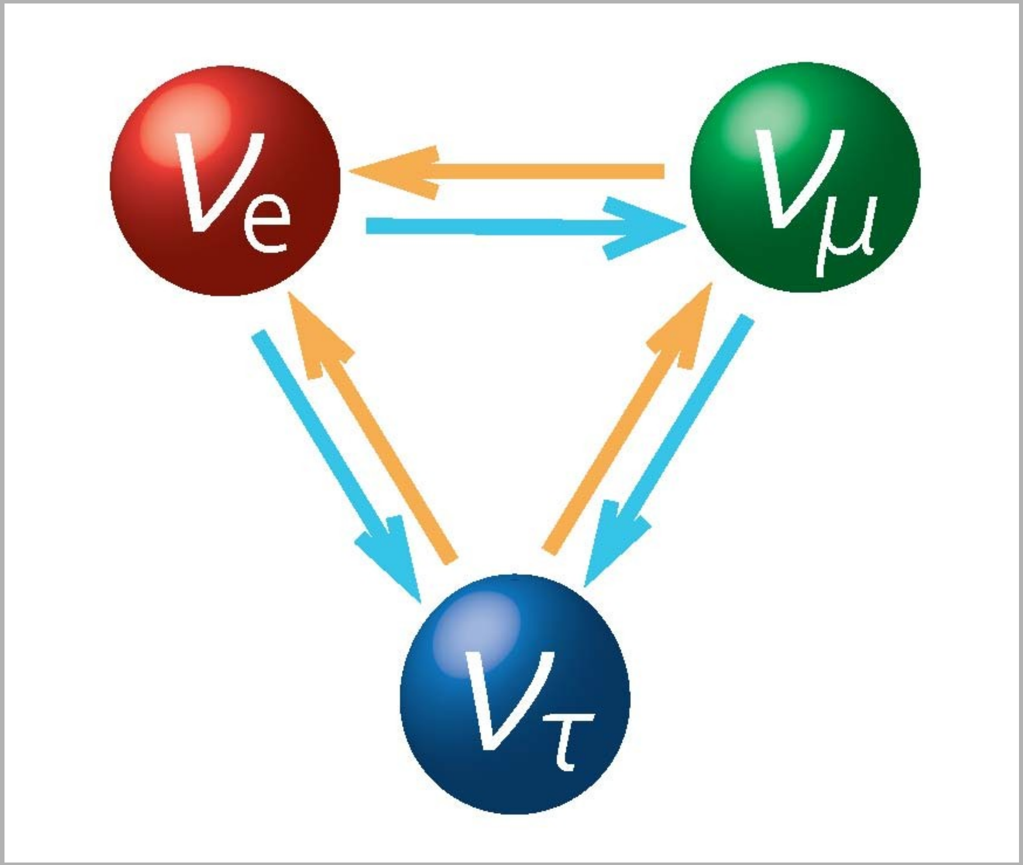
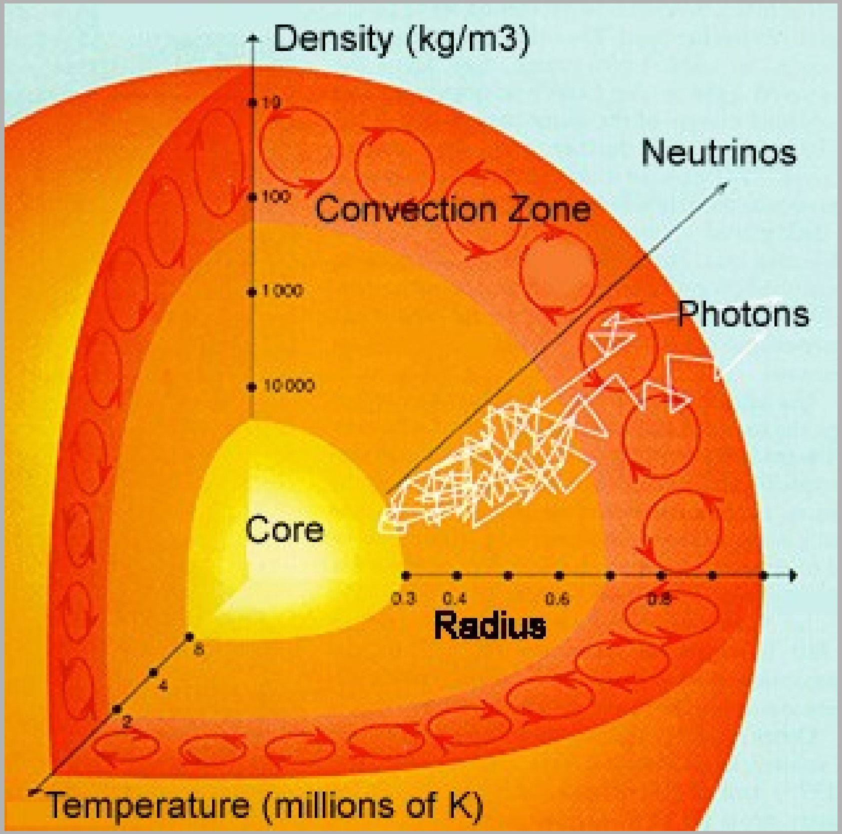
Some information about neutrinos

- There are three types of neutrinos

  - electron – neutrinos
  - muon – neutrinos
  - tau - neutrinos



neutrinos interact **very** weakly



Neutrinos have no electric charge.

Neutrinos have no color.

photons generated at the core of the Sun can take 10^6 years to cross the surface, neutrinos make the trip in a few seconds!

So far all these properties can be nicely accommodated in the Standard Model.

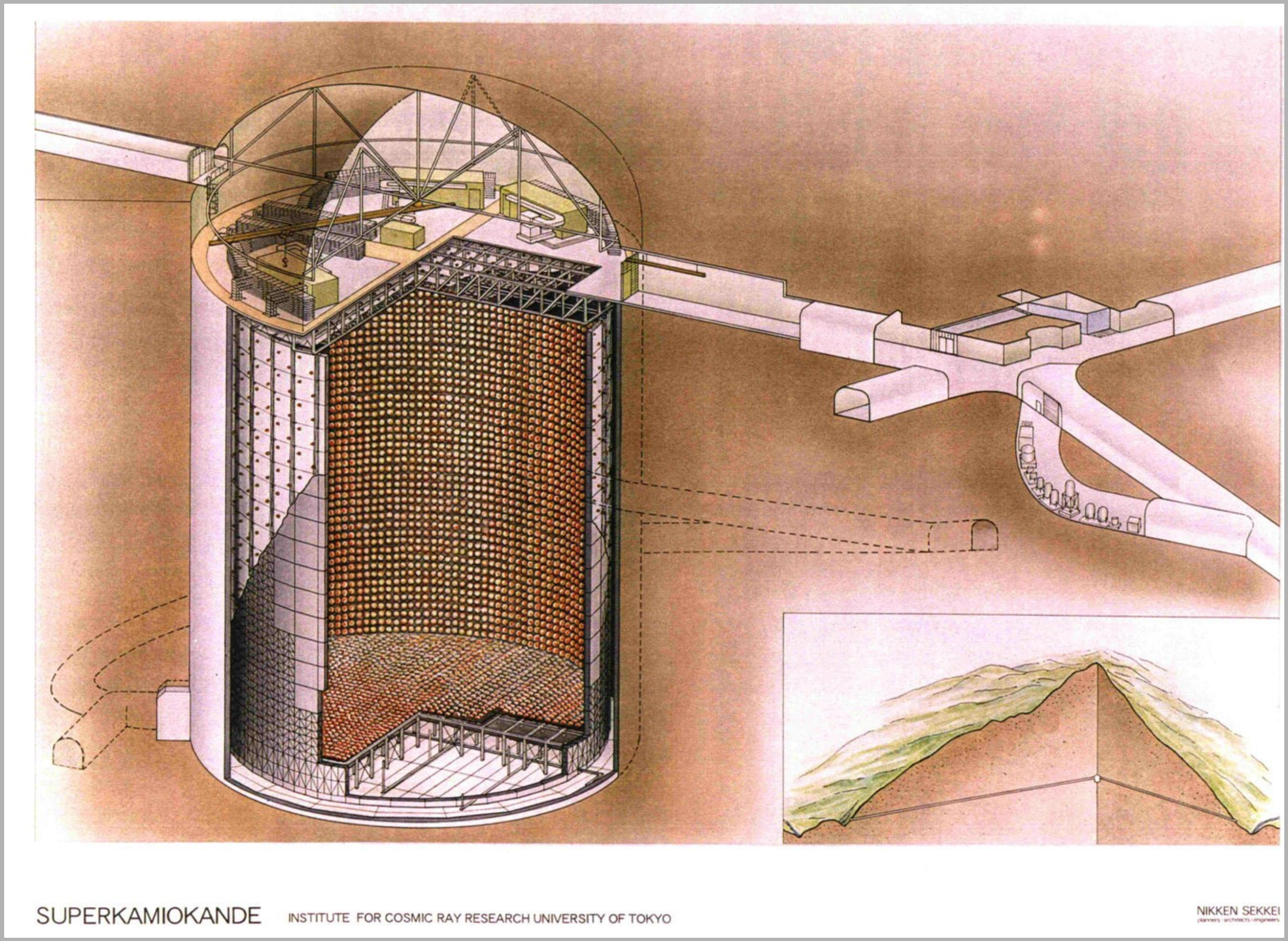
One more thing.

According to the Standard Model neutrinos are massless, like photons.

The Solar Neutrino Problem

- In the late 1960s several experiments found that the number of electron neutrinos arriving from the Sun was between one third and one half the number predicted by the Standard Solar Model (which assumed massless neutrinos).
- Astrophysicists blamed the Particle physicists and the Particle physicists blamed the Astrophysicists.
- This went on for about 30 years!
- Many possible solutions were proposed during this time.
- In 1998 the first strong experimental results came in...

The Super-Kamiokande



- Neutrino observatory under Mount Kamioka, Japan
- Consists of a cylindrical stainless steel tank holding 50,000 tons of ultrapure water.
- In 1998 produced results cosistent with (atmospheric) muon-neutrinos changing into tau-neutrinos.

- The phenomenon of muon-neutrinos changing into tau-neutrinos in called neutrino oscillations.

- This result is very difficult to explain with massless neutrinos.

- Then in 2002, while physicists were still trying to make sense of these results new results came in...

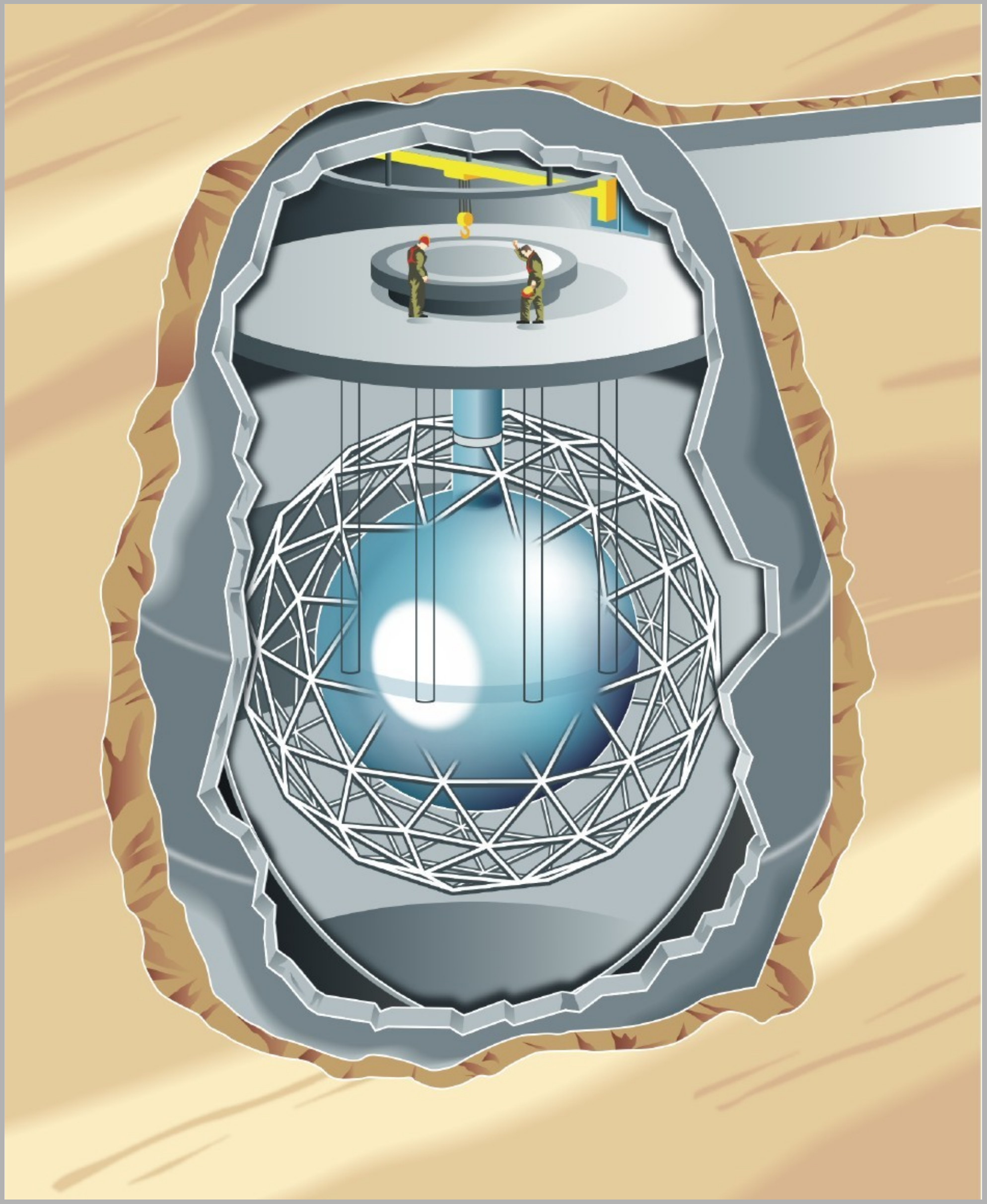
The Sudbury Neutrino Observatory (SNO)

- Neutrino observatory located in Creighton's mine in Sudbury, Ontario, Canada.

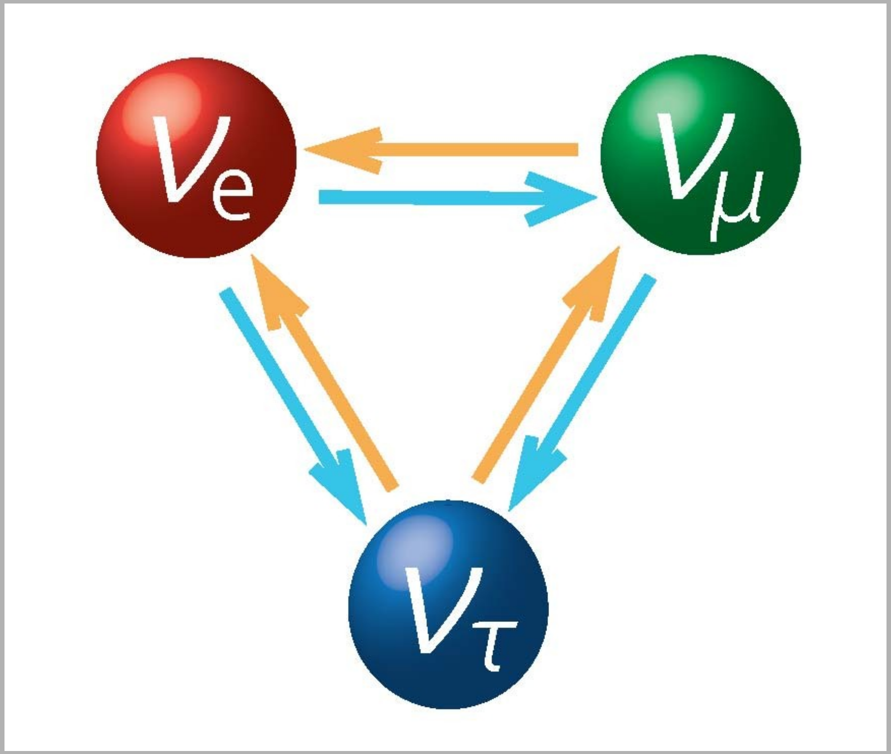
- The SNO detector consisted of 1,000 tons of heavy water in an acrylic vessel.

- This experiment detected all types of neutrinos* coming from the Sun.

- It was found that about 35% of the arriving solar neutrinos are electron – neutrinos with the others being muon – or tau – neutrinos.



- Combining these results two conclusions can be reached:
  - The astrophysicists were right…
  - Neutrinos oscillate between different flavors.



It turns out that the best, simplest way to explain neutrino oscillations is assuming that neutrinos have mass.

This means that the Standard Model, our best, most fundamental theory of nature is incomplete or not completely correct.

This is great news!

New Physics!

The Nobel Prize in Physics 2015 was awarded to Takaaki Kajita and Arthur McDonald, the directors of the Super-Kamiokande and SNO collaborations respectively.

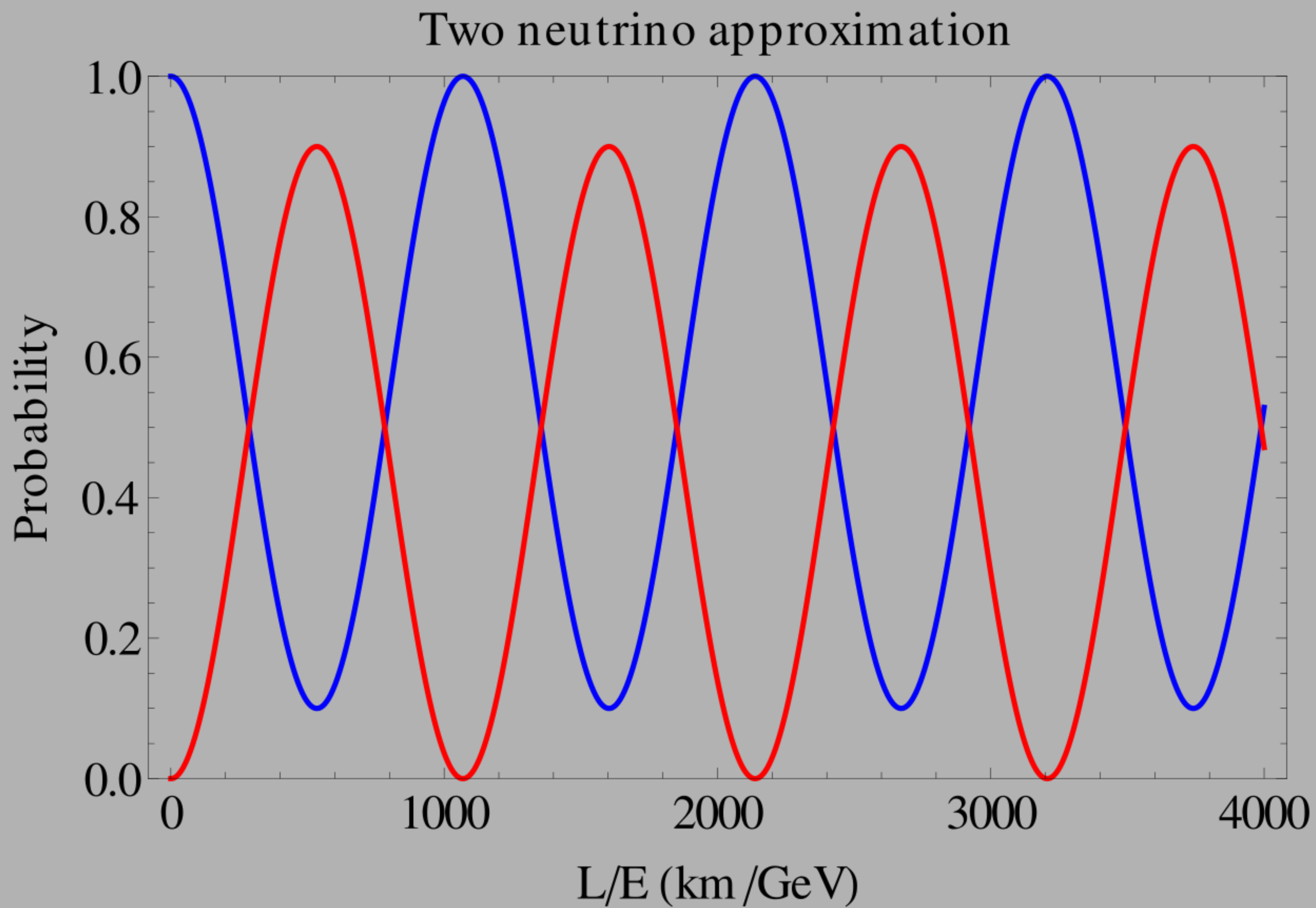
“for the discovery of neutrino oscillations, which show that neutrinos have mass”

Neutrino Oscillations

- Purely quantum mechanical phenomenon with no classical analog.
- Quantum Mechanics is very, very different from Classical Physics. It is…
  - Probabilistic
  - Subjective
- The three types of neutrinos can be classified in two different ways
  - By how interaction: electron-neutrino, muon-neutrino, tau-neutrino
  - By their mass: neutrino-1, neutrino-2, neutrino-3
- Quantum Mechanics does not allow one to assign a direct, one to one relation between these classifications. This means that it is meaningless to ask what is the mass of, say, an electron-neutrino. It does not have a well defined mass!

- It can be shown that when neutrinos travel there is a probability that they can be detected in a different flavor than the one they where measured in.

- This probability depends on the difference of the square of the masses of the neutrinos.



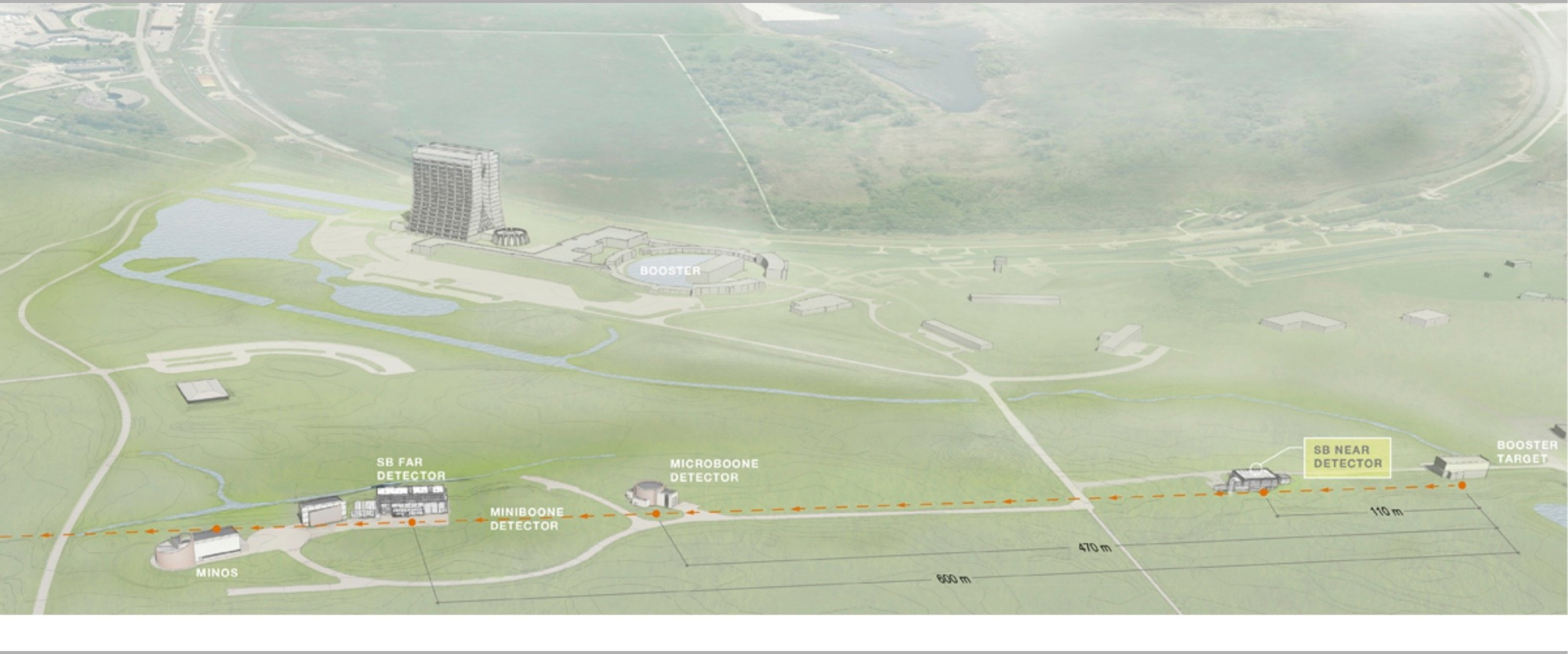
There are still many things we don't know about neutrinos,

- What is the mass hierarchy?
- Why do they have such small masses?, what exactly are their masses?
- Are there more types of neutrinos?
- What kind of mass do they have?
- What are their phases?

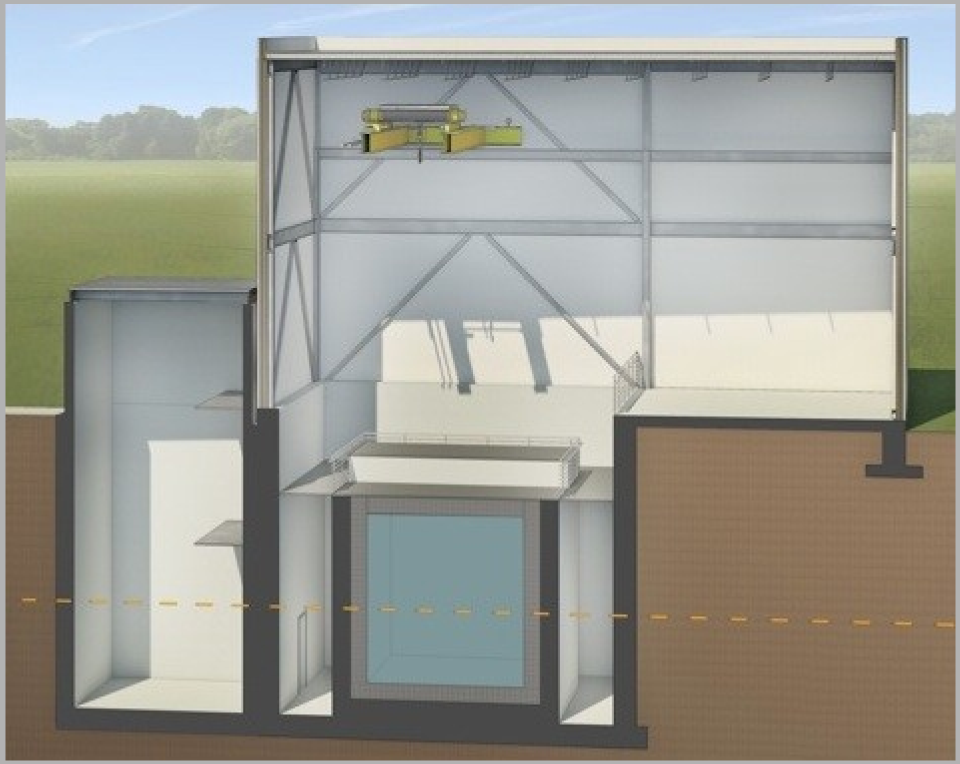
- A new generation of precision neutrino experiments are being designed to answer these questions.
- The High Energy group in the Physics Department of the UPRM is involved in two of these efforts
  - Short baseline near detector (SBND), which is part of the Short Baseline Program
  - Deep underground neutrino experiment (DUNE)

Short Baseline Program

- SBND
- MicroBooNE
- ICARUS-T600



SBND



- The SBND will be one of three liquid argon neutrino detectors sitting in the Booster Neutrino Bean (BNB) at Fermilab.
- SBND is a 112 ton volume liquid argon time projection chamber (TPC) to be located 110 m from the BNB neutrino source.
- The purpose of this detector is to make high precision measurements of the un-oscillated content of the booster neutrino beam.
- This will allow studies of neutrino-argon interactions in the GeV range with unprecedented precision.

At the UPRM we have joined this collaboration and have started work on the simulation of various particles through the time projection chambers of the SBND and on the study of the emission properties of liquid argon excimers. Our group has proposed to

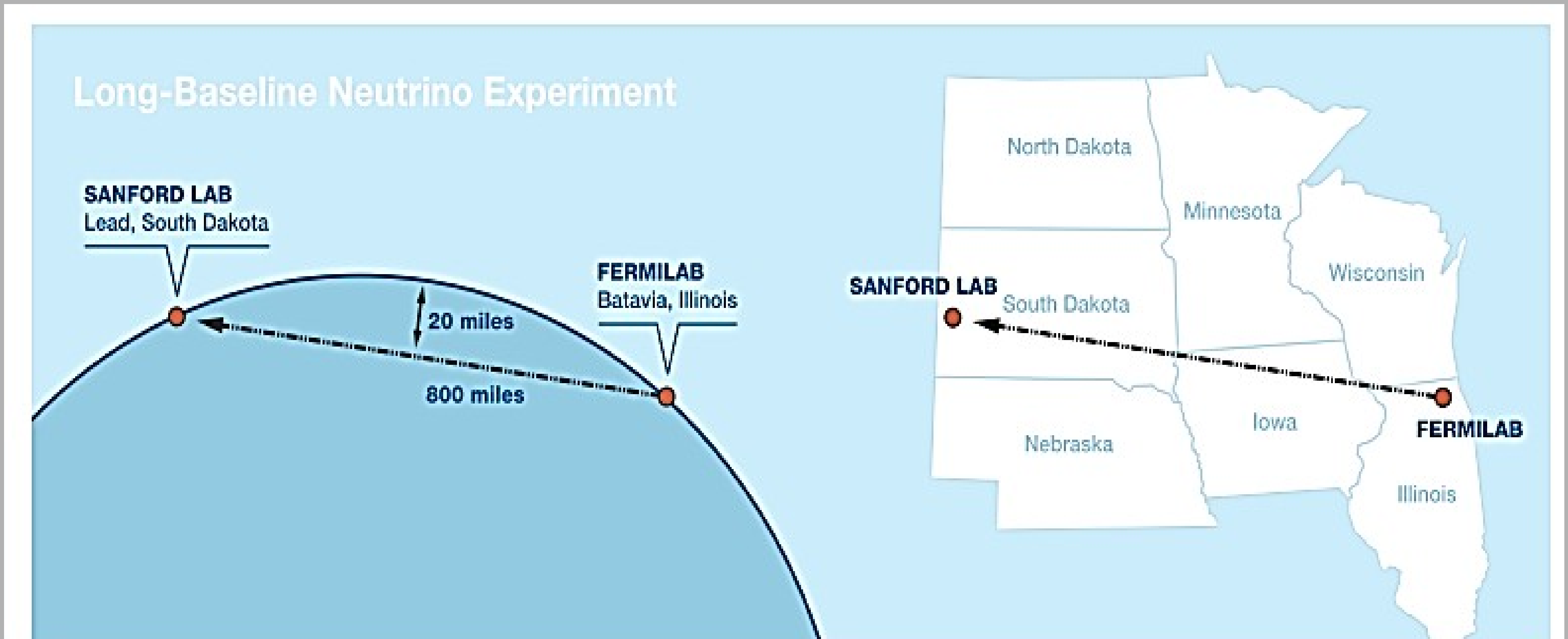
- Continue their work on the integration of the tracking and reconstruction software to SBND.

- Study elastic neutrino – electron interactions to measure the weak mixing angle and the neutrino magnetic moment. Precision measurements of both of these parameters are necessary to determine possible deviations from the Standard Model predictions and to uncover important information about the nature of neutrino masses.

- Continue the work on quantum mechanical calculations on the emission properties of argon excimers in the in the infrared (IR) region of the electromagnetic spectrum. The results of these calculations coupled with experiments being performed at Fermilab could have important consequences in future neutrino detector technologies.

DUNE

- From Fermilab and intense neutrino beam will travel 800 miles through the Earth before striking the target at the Stanford Underground Research Facility located in Lead, South Dakota.
- The far detector will be a 40000 ton liquid argon cryogenic detector.
- This experiment will allow, amongst other things, precision measurements of various neutrino oscillation parameters.
- The neutrino detection technology and the software used to simulate, collect and analyze data in the DUNE collaboration will be the same as the one used in the Shot Baseline Program.



Thank you for your attention!