Neutrino Physics with the INO-ICAL detector

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Neutrino Oscillations

In the Standard Model, neutrinos are massless. However, recent experiments have shown that neutrinos change their identities in time as they travel. This is possible only if the neutrinos have mass. The process of changing their identities/flavors is called oscillation and is a quantum mechanical phenomenon. Neutrino oscillations take place due to the fact that flavor eigen states differ from the mass eigen states. In fact, the flavor eigen states ν_α can be written as a superposition of mass eigen states ν_i as

$$|\nu_\alpha\rangle = \Sigma\, U_{\alpha i}|\nu_i\rangle$$

$U_{\alpha i}$ is the mixing matrix which contains the probabilities of a particular flavor eigen state α to be in a mass eigen state i. For two flavor oscillations the mixing matrix is:

$$U = \begin{vmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{vmatrix}$$

The probability of finding a neutrino which is initially in a flavor α to be in a flavor β in two flavor scenario is given by,

$$P(\nu_\alpha \to \nu_\beta) = \sin^2 2\theta sin^2[1.27\Delta m^2(L/E)]$$

θ is called the mixing angle and Δm is called the mass difference. The aim of neutrino oscillation experiments is to measure the probability $P(\nu_\alpha \to \nu_\beta)$ as a function of L/E and thus get the mixing angles and the mass differences.

In the three flavor case, there are three mixing angles θ_{13}, θ_{23} and θ_{12} and three mass differences Δm^2_{12} (solar), Δm^2_{23} and Δm^2_{13} (atmospheric). INO will measure Δm^2_{13} and due to its capability of distinguishing between neutrino and anti-neutrino interactions, will also measure the sign of Δm^2_{13}.

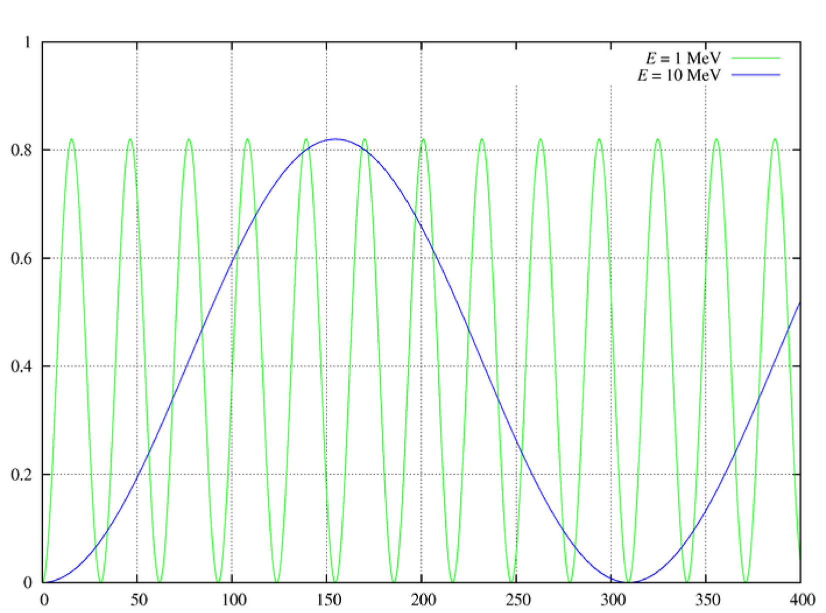


Figure: A sample calculation of the oscillation probabilty ($\nu_e \to \nu_\mu$) for two energies 1 MeV (green) 10 MeV (blue).

The Standard Model

In the quest to understand the fundamental building blocks of nature man has zoomed his understanding of the atom to see they are made of further smaller particles called quarks and electrons. The Standard Model summarizes the current knowledge of fundamental particles in the universe and their interactions with each other.

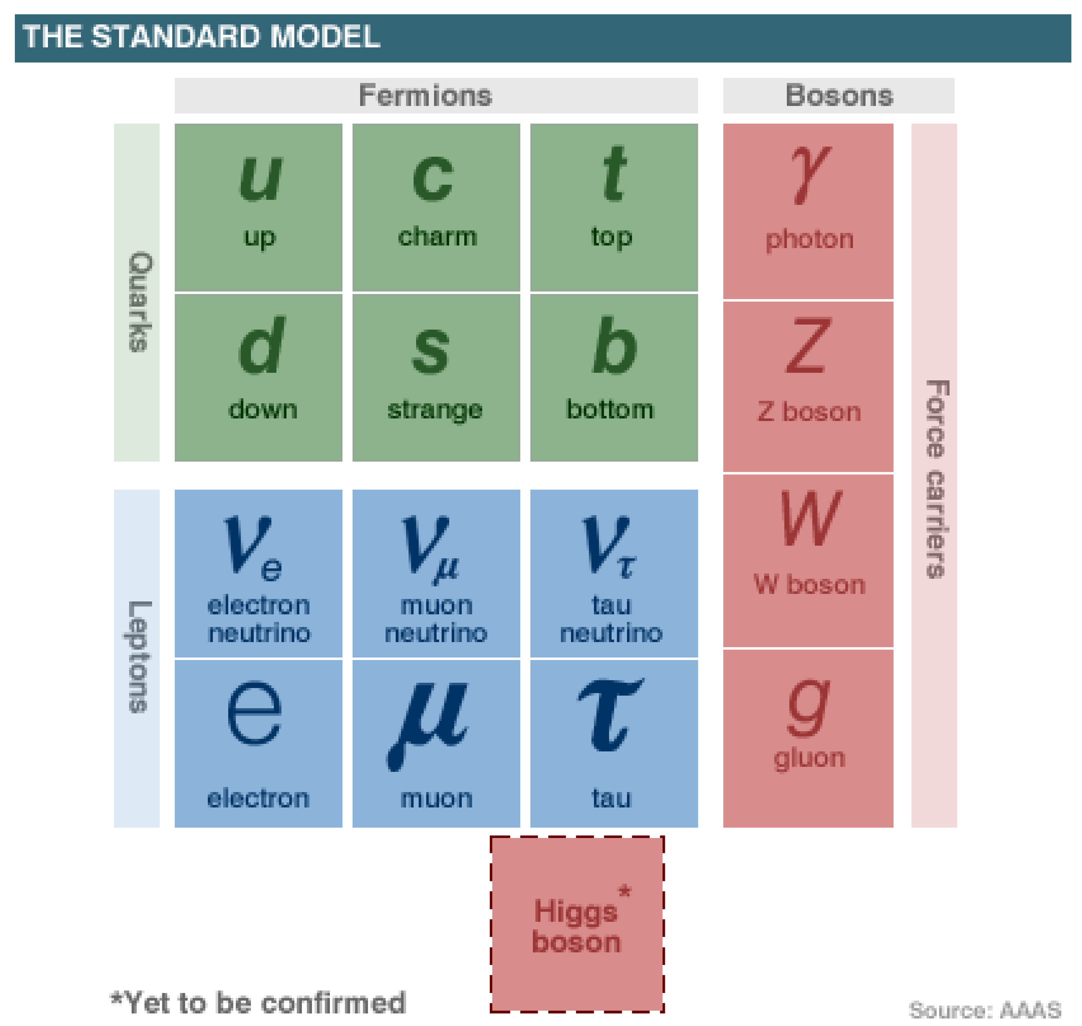
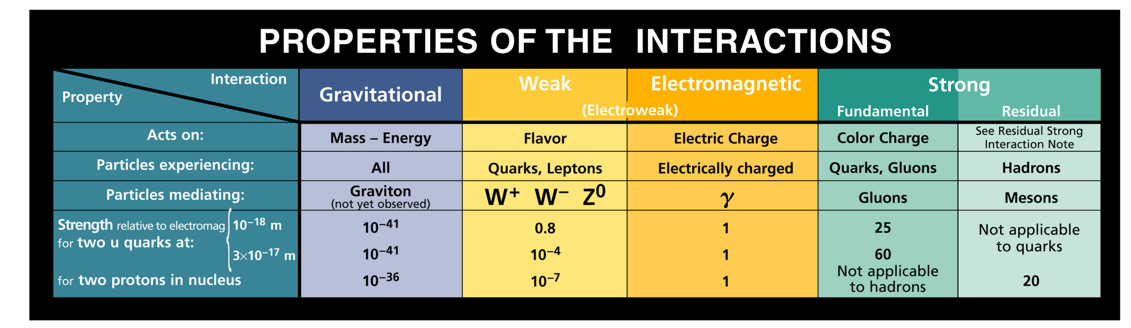


Figure: The fundamental particles in the Standard Model. Neutrinos belong to the family of leptons.



PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

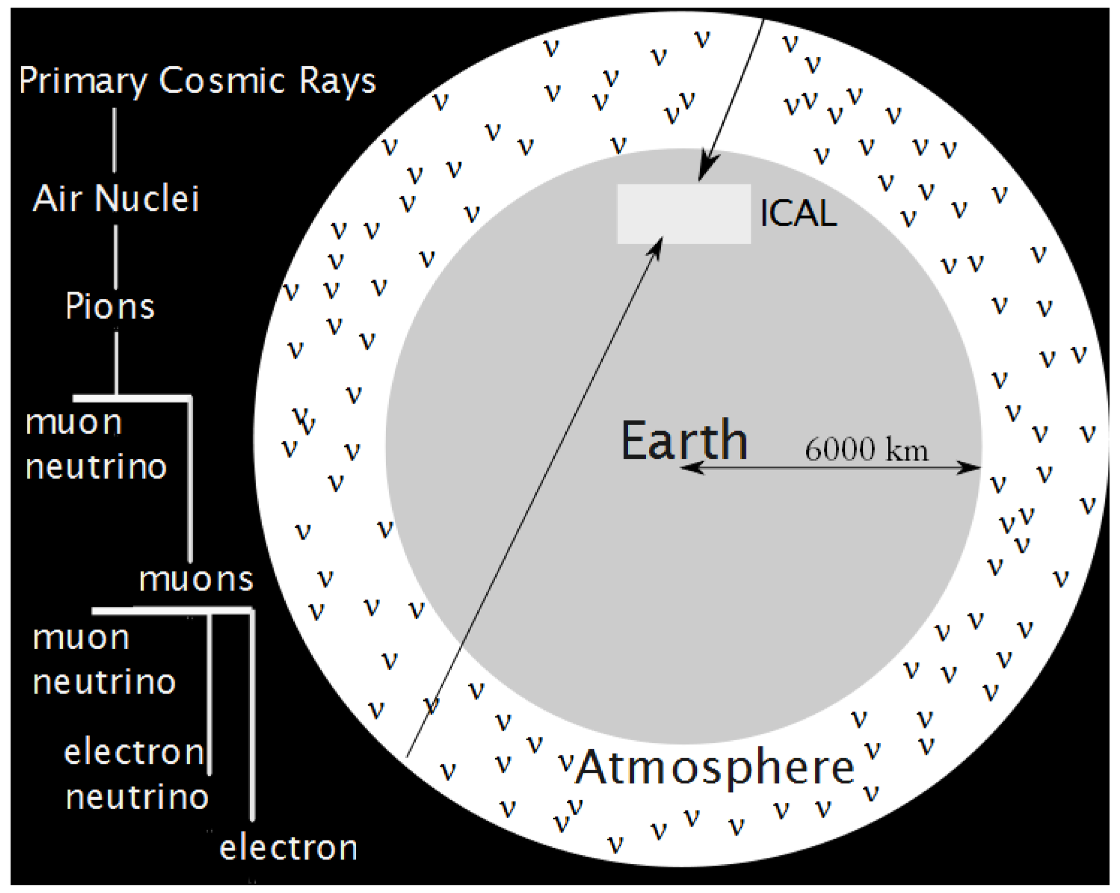
Figure: The fundamental forces of nature. Neutrinos interact via the weak force.

About Neutrinos

Neutrinos are chargeless, almost massless and carry a spin of 1/2. They are naturally produced in the Sun and other astronomical objects. Neutrinos are also produced in the atmosphere as a result of collisions of cosmic rays. INO-ICAL will study these atmospheric neutrinos in the first phase and in the later phase receive beam of neutrinos produced by accelerators.

Neutrino Oscillation Studies with INO-ICAL

The INO project will construct a magnetic Iron calorimeter (ICAL) with Resistive Plate Chambers (RPC) as active detector elements to study neutrino oscillations. This massive detector (50 kton) has been designed to achieve a statistically significant number of neutrino interactions in a reasonable time frame with good energy and angular resolution to measure L/E with an accuracy better than half the modulation period. This detector will be placed inside a mountain to be shielded from cosmic rays.



Primary cosmic rays are the main sources of atmospheric neutrinos which contain mostly muon neutrinos and electron neutrinos in the ratio 2:1. The probability of a neutrino oscillating from one flavor to another depends on the distance the neutrino has traveled L and on its energy E. The neutrinos coming from the top the earth, having traveled less distance to reach the detector, have a lesser probability to oscillate into another flavor than the neutrinos that travel through the earth to reach the detector. Thus a measurement of the ratio of the neutrinos coming from the top to the neutrinos coming from the bottom is a direct measure of the oscillation probability.

Simulation of ICAL

With advancing computational technology and our understanding of laws of nature, it is possible to imitate real physical world scenario on a computer. This is called simulation. Most of the experiments are preceded by these simulation studies in order to understand the detector better and to provide a test bench to test the analysis tools developed.

- Simulation of Atmospheric Neutrinos: Using existing theoretical models, the flux of neutrinos and the secondary particles generated due to their interaction with matter are simulated using a computer. We use the NUANCE package for this purpose.
- Simulation of the Detector: The next step is to simulate the propagation of the generated secondary particles through our detector giving the detector parameters as input to the computer. We use the GEANT4 package for this purpose. As the particle passes through the detector, different interactions leave different signatures (or tracks) in them which are further analyzed.
- Track Reconstruction: From the law of conservation of energy, the energy of the neutrino is shared by the secondary particles produced by it. The energy of the neutrino can thus be reconstructed from the energy of the secondary particles.
- Physics Analysis: After reconstructing the parameters of neutrino, this data is analyzed in order to help understand the physics reach of INO detector. Simulation studies also help us to optimize the parameters of the detector.

Contact

Visit us at www.ino.tifr.res.in or write to nkm@tifr.res.in for more information on this project

Some of the pictures shown in this poster were picked from the web. The work of the original authors is hereby acknowledged.