

Going underground to look at the sky

The search for invisible neutrinos

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Sawaal-Jawaab
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The search for invisible neutrinos

1 Why look for neutrinos ?

- How does the Sun shine ?
- Where did all the gold come from ?
- What will we learn from neutrinos ?

2 How to look for neutrinos

- Going underground...
- Neutrino mysteries: some solved, some unsolved
- The India-based Neutrino Observatory (INO)

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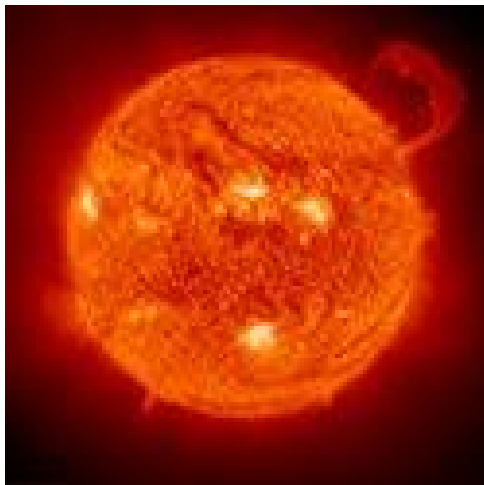
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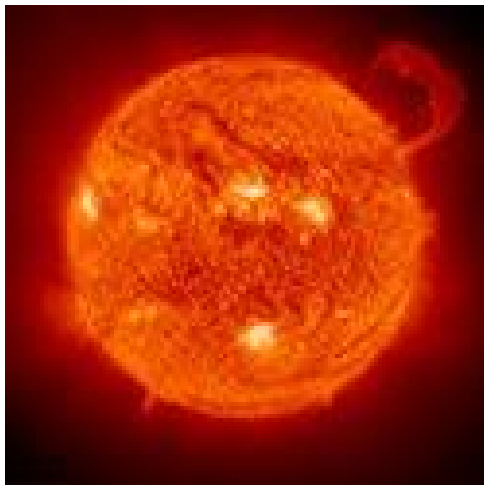
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Burning ball of fire ?

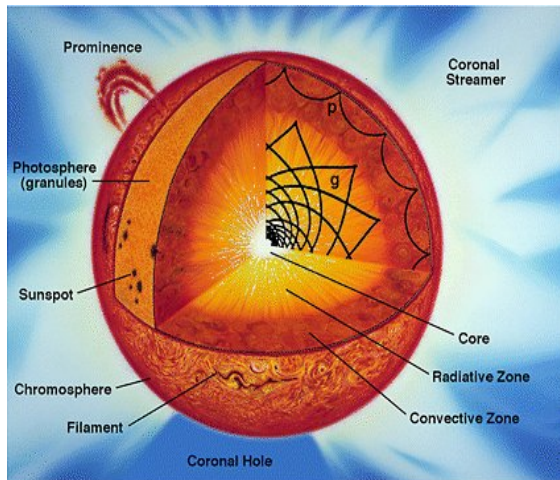


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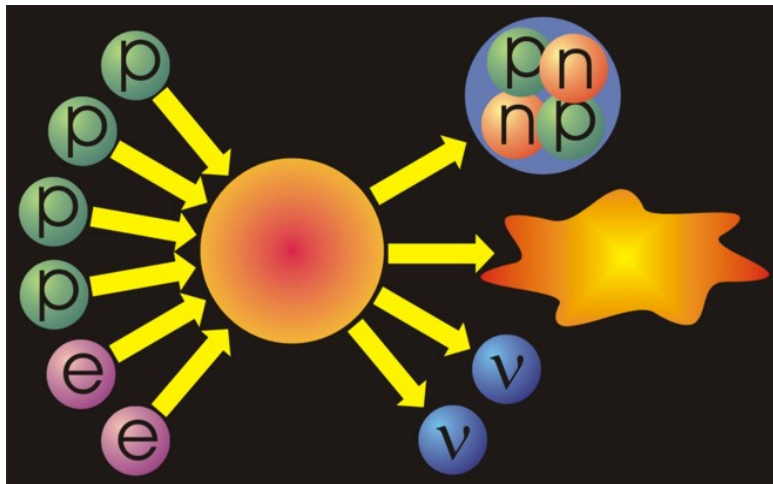
- Would have burnt out in a few thousand years
- But has been around for many more !!

The structure of the Sun



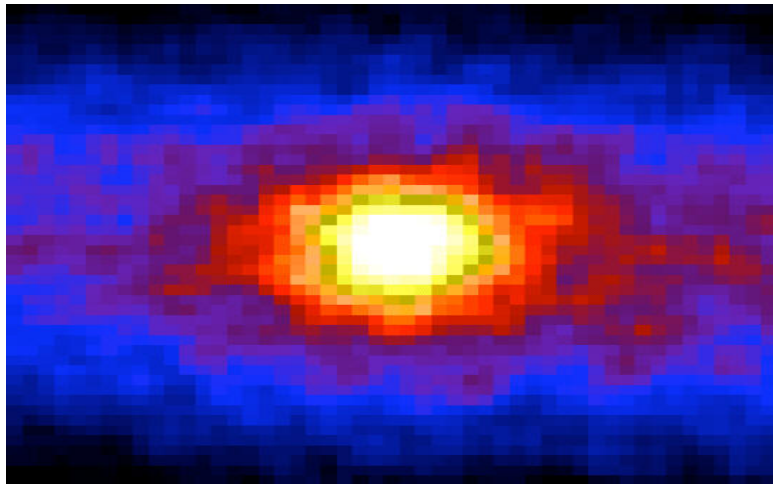
It is a nuclear reactor !

The nuclear reactions



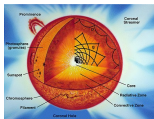
How do we know this ? Can we see some evidence ?

Neutrinos from the Sun: tiny point particles

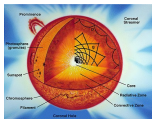


- Can indeed see neutrinos from the Sun now !

Neutrinos from the Sun



Neutrinos from the Sun

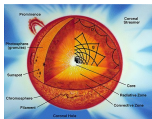


A very very large number of neutrinos

About hundred trillion through our body per second

Hundred trillion = 100 000 000 000 000

Neutrinos from the Sun



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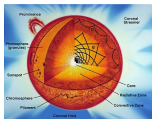
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Neutrinos during night = Neutrinos during day

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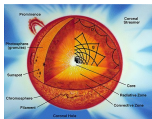
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Reach us directly from the core of the Sun

Light from the Sun's core cannot reach us directly

Neutrinos from the Sun



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Why do we not notice them ?

Three questions, the same answer



- Why did the *roti* burn ?
- Why did the betel leaves (*paan*) rot ?
- Why could the horse not run ?

Three questions, the same answer



- Why did the *roti* burn ?
- Why did the betel leaves (*paan*) rot ?
- Why could the horse not run ?

Because they were not moved !

Three questions about neutrinos



Pauli

Dirac

- Why do we not notice neutrinos passing through us?
- Why do neutrinos from the Sun reach us during night ?
- Why can we see “inside” the sun with neutrinos ?

Three questions about neutrinos



Pauli Dirac

- Why do we not notice neutrinos passing through us?
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Because neutrinos interact extremely weakly !

The most weakly interacting particles

Stopping radiation with lead shielding

- Stopping α, β, γ radiation: 50 cm

The most weakly interacting particles

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- Why can we see “inside” the sun with neutrinos ?
Neutrinos pass through the Sun without interacting

.... Neutrinos play a crucial role in the Sun shining !

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Many forms of gold: origin ?

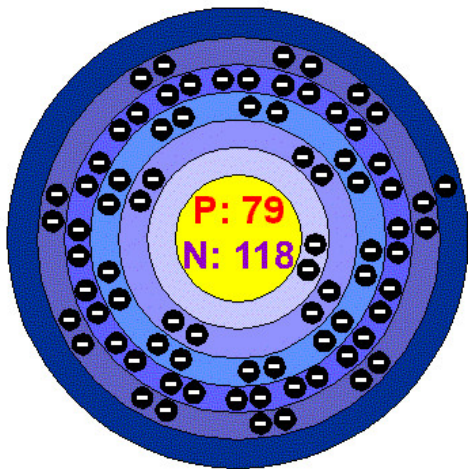


The gold mine



But where did the gold in the mines come from ?

The essence of gold



Why is it a big deal to make gold ?

- Elements have to be made, starting from hydrogen, by nuclear fusion inside stars

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- Even the intense temperature and pressure inside stars cannot make elements heavier than iron (26 protons, 30 neutrons)

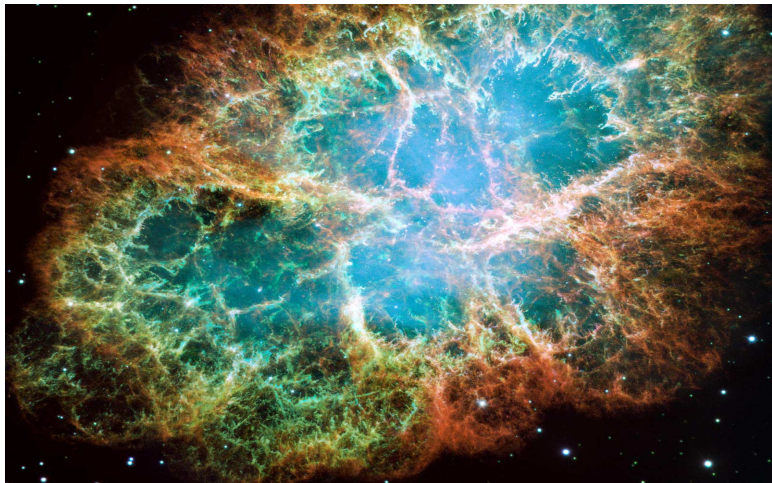
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- Even the intense temperature and pressure inside stars cannot make elements heavier than iron (26 protons, 30 neutrons)
- Gold has 79 protons and 118 neutrons. How is this possible ?
- There is just one phenomenon we know in nature that can do this...

A supernova !



Crab nebula, Supernova seen exploding in 1054

So that's the story...

- Once upon a time, there was a big star, which exploded (supernova)
- The exploded material travelled far and wide in the galaxies
- It is from this material that the solar system was made.
- We are, literally, “Stardust”

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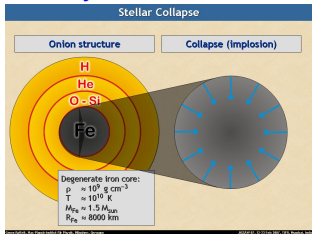
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But, how does a supernova explode ?

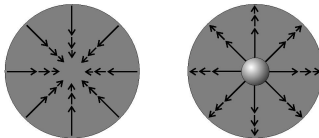
(This is now a search to understand where we came from.)

Supernova: the death of a star

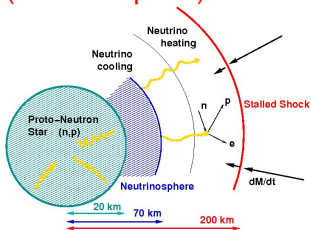
Gravity \Rightarrow



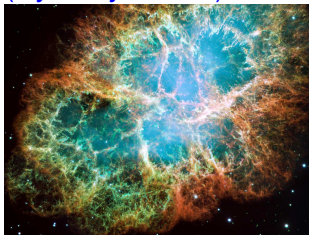
Strong nuclear force \Rightarrow



Weak nuclear force
(Neutrino push) \Rightarrow



Electromagnetism
(Hydrodynamics) \Rightarrow



(Crab nebula, SN seen in 1054)

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A view from the Hubble telescope



The Hubble Deep Field North  HUBBLESITE.org

The world without neutrinos

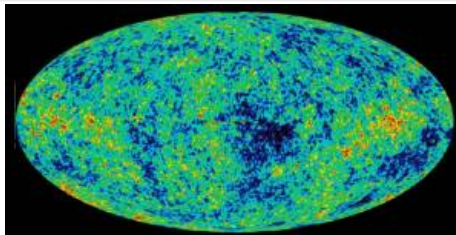
The world without neutrinos

Role of neutrinos in creating atoms

Neutrinos helped create the matter-antimatter asymmetry, without which, no atoms, no stars, no planets, no galaxies

The second-most abundant particles in the universe

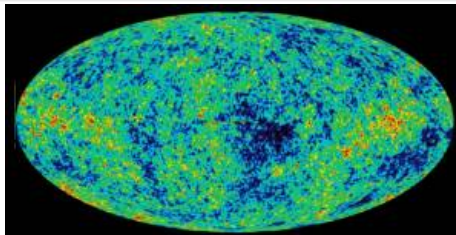
Even empty space between galaxies is full of light and neutrinos!



- Cosmic microwave background: 400 photons/ cm³
Temperature: ~ 3 K
- Tell us about the universe when it was *only* 400,000 years old (Now it is $\sim 14\,000\,000\,000$ years old.)

The second-most abundant particles in the universe

Even empty space between galaxies is full of light and neutrinos!



- Cosmic microwave background: 400 photons/cm^3
Temperature: $\sim 3 \text{ K}$
- Tell us about the universe when it was *only* 400,000 years old (Now it is $\sim 14\,000\,000\,000$ years old.)
- Cosmic neutrino background: $300 \text{ neutrinos/cm}^3$
Temperature: $\sim 2 \text{ K}$
- Can tell us about the universe when it was 0.18 sec old !

Neutrinos as messengers

- No bending in magnetic fields \Rightarrow
point back to the source
- Minimal obstruction / scattering \Rightarrow
can arrive directly from regions from where light cannot come.

Neutrinos everywhere

Where do Neutrinos Appear in Nature?



Earth Crust
(Natural
Radioactivity)



Sun



Nuclear Reactors



Supernovae
(Stellar Collapse)

SN 1987A ✓



Particle Accelerators

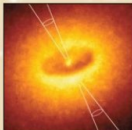


Cosmic Big Bang
(Today $330 \nu / \text{cm}^3$)

Indirect Evidence



Earth Atmosphere
(Cosmic Rays)

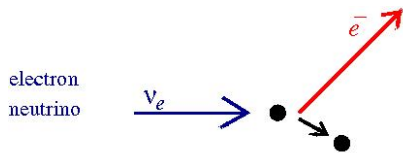


Astrophysical
Accelerators

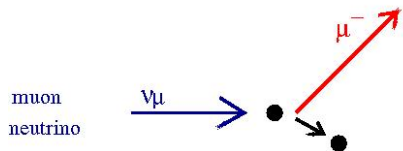
Soon ?

Three kinds of neutrinos:

ν_e ν_μ ν_τ

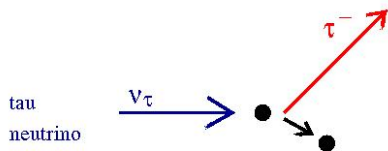


electron



muon

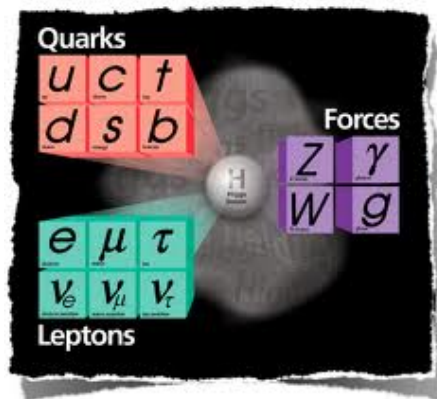
200 times heavier than electron



tau

3500 times heavier than electron

The Standard Model of Particle Physics



- 3 neutrinos:
 ν_e, ν_μ, ν_τ
- chargeless
- spin 1/2
- almost massless
(at least a million times lighter than electrons)
- only weak interactions

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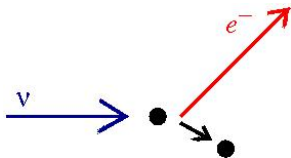
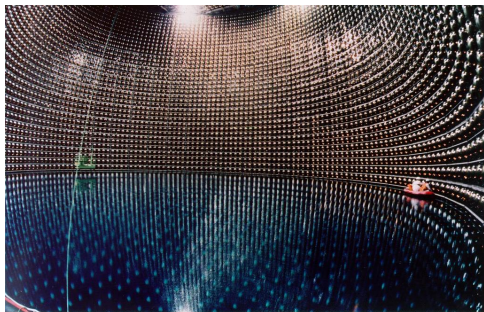
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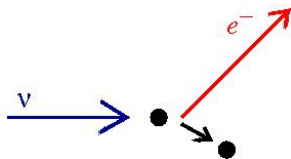
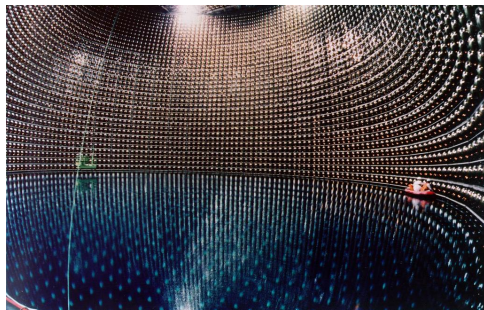
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SuperKamiokande: 50 000 000 litres of water

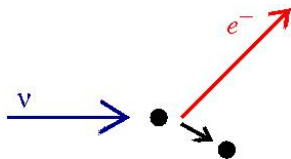
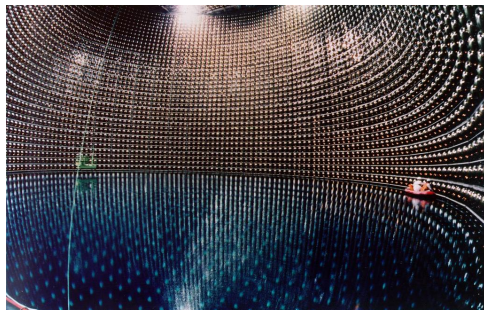


SuperKamiokande: 50 000 000 litres of water



- Neutrinos passing through SK per day: 10^{25}
- Neutrino interactions in SK per day: 5-10

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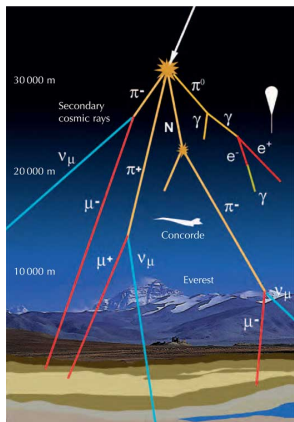


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Recipe for observing neutrinos

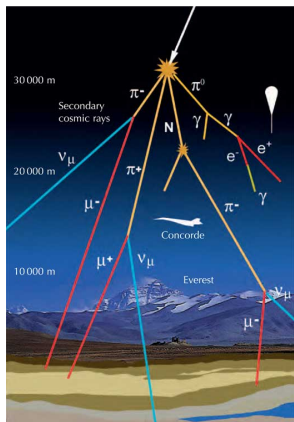
- **Go deep underground**
- Build very large detectors
- Wait for a very long time

Cosmic rays: muon background and neutrinos



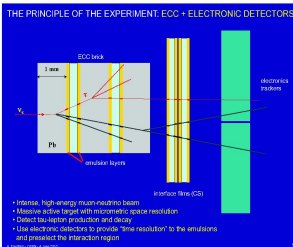
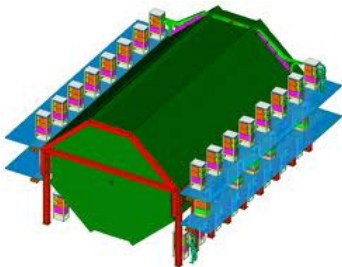
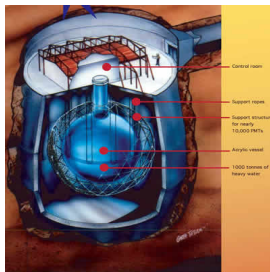
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- All muons interact, only one in 1 000 000 000 000 000 000 neutrinos interact
- At the Earth surface, neutrinos get lost among muons !

Cosmic rays: muon background and neutrinos



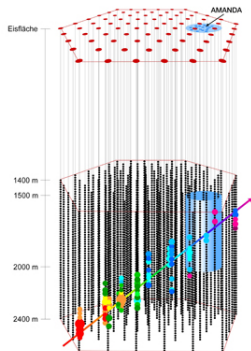
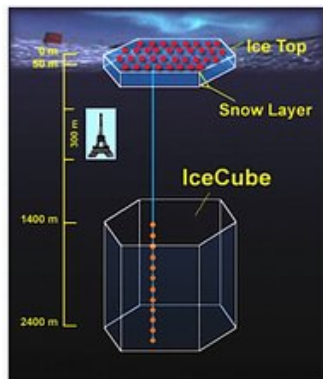
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- Underground, muons get absorbed but neutrinos do not
- Have to go ~ 1 km underground for a clean environment

Some neutrino detectors



Common feature: all underground

Below the antarctic ice: Gigaton IceCube



1 000 000 000 000 litres of ice

- Looks at neutrinos coming from below
- The whole Earth acts as a shield from cosmic muons

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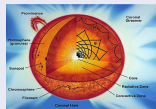
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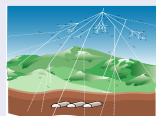
The long-term mysteries \Rightarrow neutrino oscillations

Solar neutrino mystery: 1960s – 2002



- Only about half the expected ν_e observed!

Atmospheric neutrino mystery: 1980s – 1998



- Half the ν_μ lost in the Earth!

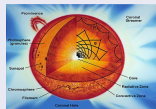
Reactor neutrino experiments



- **Breaking news of 2012-13:
10% of reactor $\bar{\nu}_e$ are lost !**

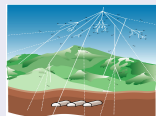
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Three questions, the same answer



ν conference participants

- Why did half the ν_e from the sun become ν_μ/ν_τ ?
- Why did half the ν_μ from the atmosphere become ν_τ ?
- Why did 10% $\bar{\nu}_e$ from the reactors become $\bar{\nu}_\mu/\bar{\nu}_\tau$?

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Because neutrinos have different masses and they mix !



Quantum Mechanics

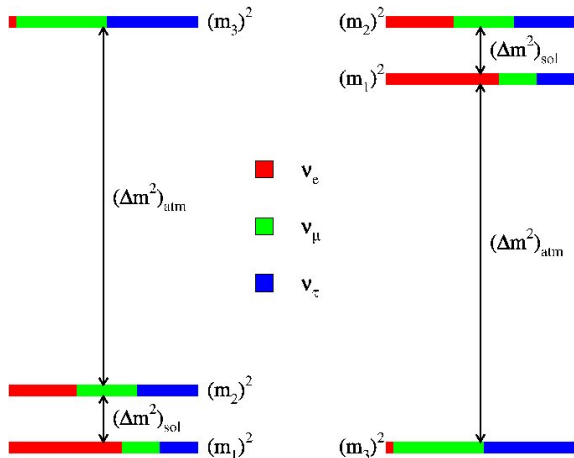
What is meant by neutrino mixing ?

ν_e, ν_μ, ν_τ do not have fixed masses !!

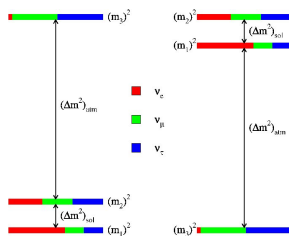
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Mixing of $\nu_e, \nu_\mu, \nu_\tau \Rightarrow \nu_1, \nu_2, \nu_3$ (These have fixed masses!)



Still open mysteries about neutrino masses



- Mass ordering: Normal or Inverted ?
- What are the absolute neutrino masses ?
- Are there more than 3 neutrinos ?
- Do neutrinos behave differently than antineutrinos ?
- Can neutrinos be their own antiparticles ?

The search for invisible neutrinos

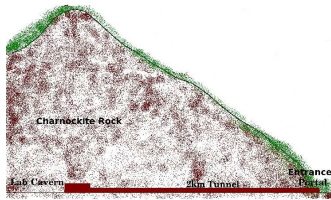
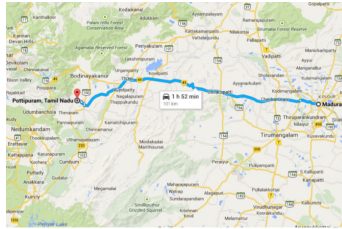
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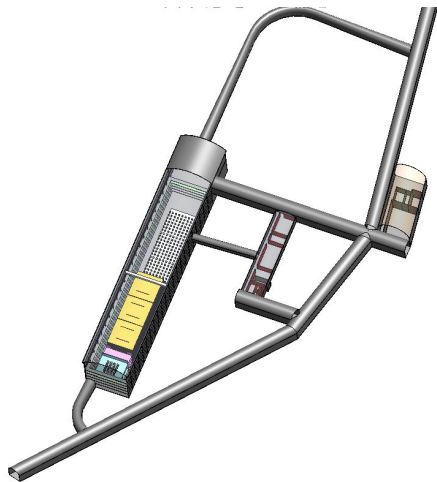
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The location



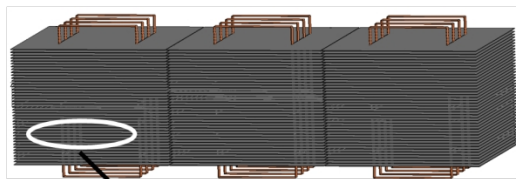
- In a tunnel below a peak (Bodi West Hills, near Madurai)
- 1 km rock coverage from all sides

The cavern plan



- Largest cavern: 132 m x 26 m x 20 m
- Other smaller sensitive experiments possible (dark matter etc.)

The iron calorimeter (ICAL) experiment



5.6 cm thick iron plate

4 cm air gap for RPC detector

India-based Neutrino Observatory

- The world's largest electromagnet:
50 kiloton of magnetized iron (50 000 000 kg)
- Can distinguish neutrinos from antineutrinos
- Determining mass ordering from atmospheric neutrinos

INO: an opportunity

- The largest (planned) experimental facility in India
- Combines expertise of physicists and engineers, from more than 25 universities, research institutes, and industry
- Many opportunities available for students
- Inter-Institutional Centre for High Energy Physics (**IICHEP**) to be established at Madurai
- Please visit <http://www.ino.tifr.res.in>

After all....



"ONE HUNDRED MILLION NEUTRINOS ARE PASSING THROUGH OUR BODIES EVERY SECOND, AND WE'RE WORRIED ABOUT THE PRICE OF COFFEE."

After all....



TRILLION

"ONE HUNDRED **MILLION** NEUTRINOS ARE PASSING THROUGH OUR BODIES EVERY SECOND, AND WE'RE WORRIED ABOUT THE PRICE OF COFFEE."