Neutrino Group project

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What are Neutrinos?

- Leptons
- Neutral
- Weakly interacting
- Disputed Small, Non-zero mass
- Three 'Flavours'

Discovery

- 1930 - Theorized
  - Wolfgang Pauli
  - $n^0 \rightarrow p^+ + e^- + \bar{\nu}_e$
- 1956 - Detected
  - Clyde Cowan, Frederick Reines, F. B. Harrison, H. W. Kruse, and A. D. McGuire
  - $\bar{\nu}_e + p^+ \rightarrow n^0 + e^+$

Basis

Interaction

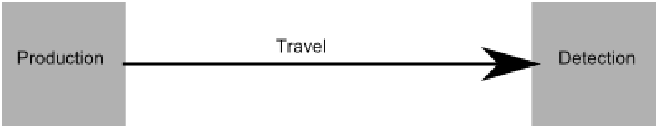
Flavour Basis	Mass Basis
$\|\nu_e\rangle$	$\|\nu_1\rangle$
$\|\nu_\mu\rangle$	$\|\nu_2\rangle$
$\|\nu_\tau\rangle$	$\|\nu_3\rangle$

Pontecorvo-Maki-Nakagawa-Sakata

(PMNS) matrix $$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

Oscillations

- Flavour Basis
  - Detected through interactions
- Mass Basis
  - Mass Eigenstates



- $\nu_e = \alpha \nu_1 + \beta \nu_2 + \gamma \nu_3 \rightarrow A\nu_1 + B\nu_2 + \Gamma \nu_3 \neq \nu_e$

CP violation

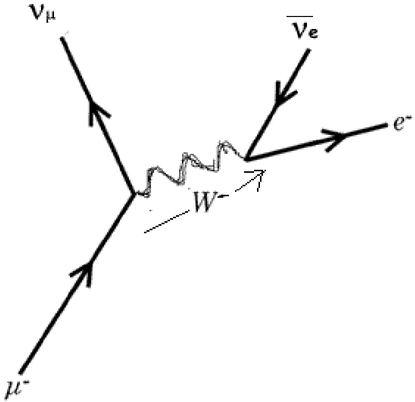
- Charge-Parity Symmetry
- Two possible cases:
  - Dirac
    - Equation implied the existence of antimatter
    - Includes most observable particles
  - Majorana
    - Particle = Antiparticle

CP violation

- Complex phases in mixing matrix
- Dirac case
  - 1 particle: 1 phase
- Majorana Case
  - 3 particle: 3 phase

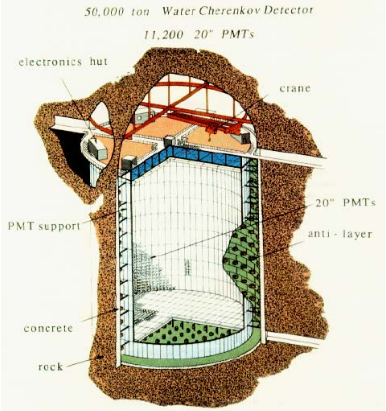
Intro. to atmospheric neutrinos...

- Cosmic ray + our atmosphere = decaying particle + neutrinos
- Muon decay



SuperKamiokande 1998

- Cosmic ray protons + nuclei in the atmosphere = Electron + neutrinos
- Detector: Cerenkov Radiation
- Expectation of 2 muons per electron, measured ratio 1:3 Suggests neutrino oscillation!



- 1/2 the amount of neutrinos going upwards (eg. From the other side of the earth)
- Muon neutrinos change or oscillate to another flavour neutrino
- Most likely $v_\mu \to v_\tau$, neutrino energies not detected by SuperKamiokande.
- MINOS lab-based experiment, 2006, supported SuperKamiokande conclusion.

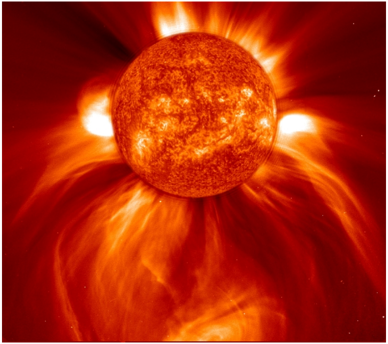
IMB Detector 1982-1991

- Proton Decay & neutrino observatory
- Detector: Cerenkov Radiation
- Can tell the direction of neutrinos
- Most famous discovery: 8×10^{58} neutrinos from Supernova 1987a

MACRO 1989-2000

- Gravitational Collapse
- Detector:
  Scintillator / Streamer
- Sensitivity determined by background events
- Estimate neutrino energy ~ 4 and ~ 50 GeV
- Results: $\nu_\mu \to \nu_\tau$

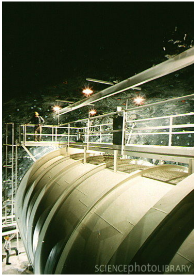
Solar Neutrinos- Come from this (You may have heard of it)



- Neutrinos are produced in core
- Travel time to Earth $\approx$ 8 minutes
- Produces two hundred trillion trillion trillion neutrinos per second!
- Neutrinos possess $0 - 20$ MeV of energy
- 91 % of solar neutrinos originate from proton - proton chain

Reaction examples: Hydrogen + Hydrogen $\rightarrow$ Deuterium + Positron + Neutrino Beryllium 7 + Positron $\rightarrow$ Lithium 7 +Neutrino

First Detection - Homestake experiment 1969-1993



- Contains 100,000 gallons of perchloroethlyene
- Located 4800 feet below ground in Homestake Gold Mine, South Dakota
- First to successfully detect and count Solar Neutrinos

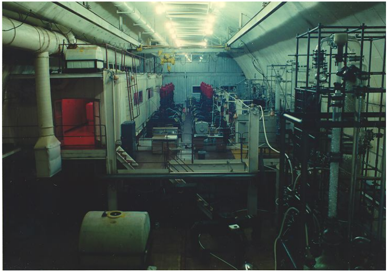
Reaction used for detection:
Neutrino + Chlorine 37 → Electron + Argon 37
Only detects high energy neutrinos

The Solar Neutrino Problem:
Only 30% of predicted neutrinos detected
Where are the rest?

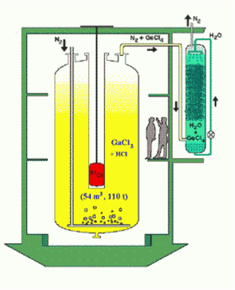
SAGE - Caucaus Mountains, Russia (1989-2010)

Reaction used:
Gallium 71 + Neutrino → Germanium + Electron

- Detected low energy neutrinos (approx.
- Atoms of Germanium individually counted via decay
- Predicted 50 - 60% of neutrinos from Sun
- Only sensitive to Electron neutrinos



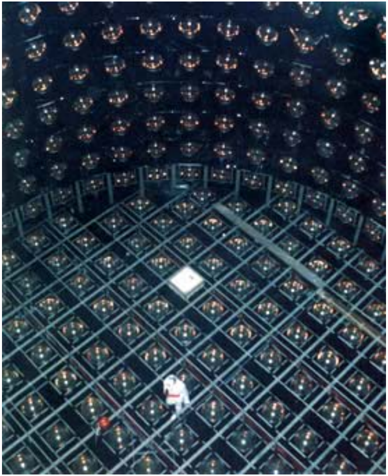
Gallex - Italy (1991-1997)



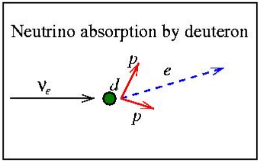
- Located deep underground inside Gran Sasso
- 54 cubic metre tank filled with gallium based solution
- Detection threshold -233.2

- Reaction: Neutrino + Gallium 71 $\rightarrow$ Germanium + Electron
- Like SAGE, only sensitive to

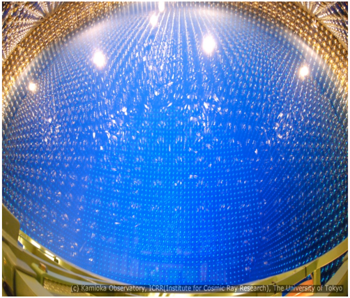
Kamiokande - Gifu, Japan (1985)

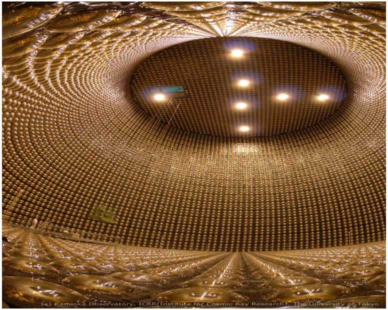


- Located 1km underground
- Water cherenkov detector - PMTs detect emitted light from neutrino reaction
- 3000 tons of pure water acted as a target
- Detected neutrinos from a supernova (1987)



Superkamiokande - Gifu, Japan (1996-present)

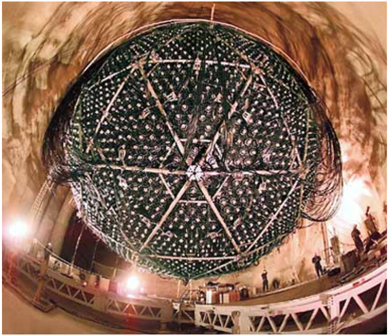




- Sequel to Kamiokande - large water cherenkov detector
- 50000 tons of pure water act as a target
- Direction of incident neutrinos can be obtained

- Located 1000m under a mountain
- Results showed early indication of neutrino oscillations

SNO - Creighton Mine, Sudbury, Ontario, Canada (2000-present)



- Located 6800 feet underground
- Heavy water cherenkov light detector (1000 tonnes of heavy water)
- First to detect all three varieties of neutrino
- Could have detected a supernova in our galaxy

Neutrino Problem - SOLVED!

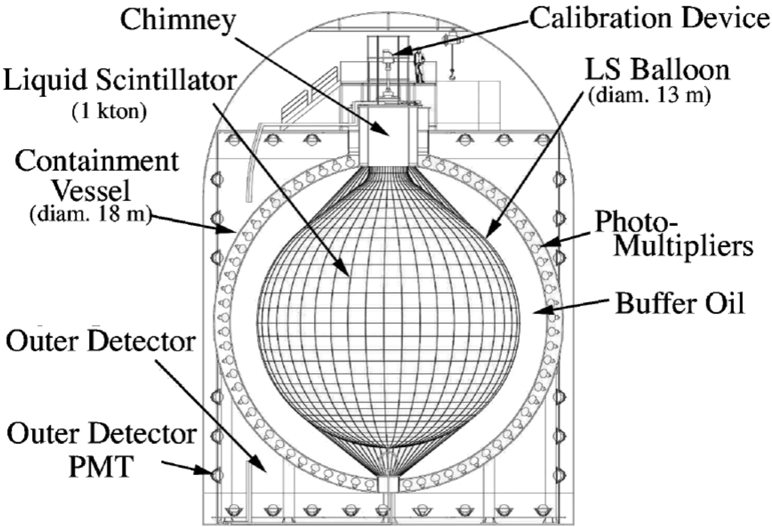
Results showed:

- First clear evidence of neutrino oscillation
- Implies that neutrinos have a non zero mass
- Flux measured agreed with Standard model

KamLAND

- I have been studying the KamLAND neutrino detector, where neutrino oscillation was first proved.
- Abstract: KamLAND measured the flux of electron neutrinos from nuclear reactors. The experiment lasted 145.1 days and recorded the ratio of Beta decay events to the expected number without disappearance.
- $$\bar{\nu}_e + p \rightarrow e + n$$

The Detector



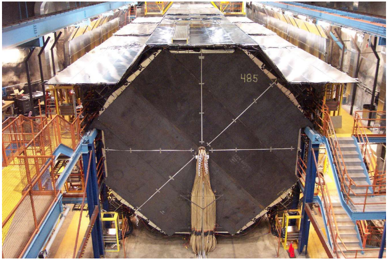
Process

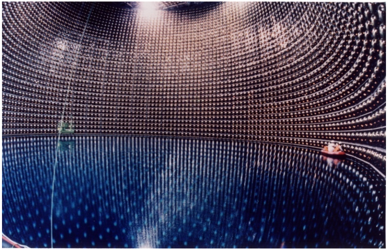
- Calibration
- Background radiation
- Final values

Results

- 99.95 % confidence that there is some neutrino disappearance
- 93 % confidence the disappearance is caused by neutrino oscillation

Particle Accelerators





Experiments

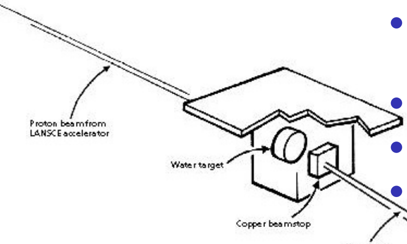
- LSND
  Liquid Scintillator
  Neutrino Detector
- MiniBooNE
  Booster Neutrino
  Experiment

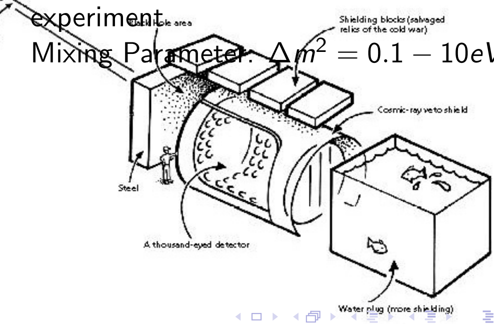
- K2K
  KEK to Kamiokande
- T2K
  Tokai to Kamiokande
- MINOS
  Main Injector
  Neutrino Oscillation
  Search

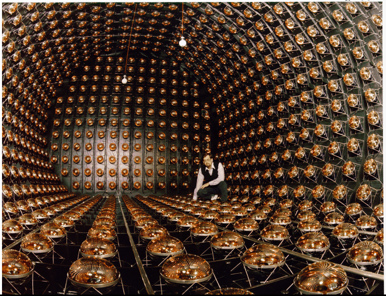
Liquid Scintillation Neutrino Detector

- Commissioned to look for evidence of neutrino oscillation
- short baseline at just 30m
- Neutrino energy of $\sim 20 - 53 MeV$
- 1.8×10^{23} protons on target over lifetime of experiment

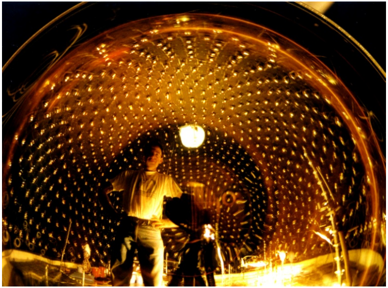
Mixing Parameter: $\Delta m^2 = 0.1 - 10 eV^2$





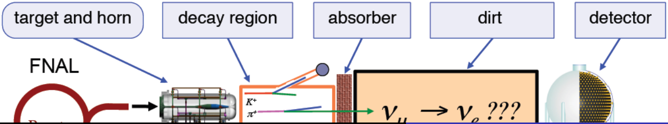


MiniBooNE

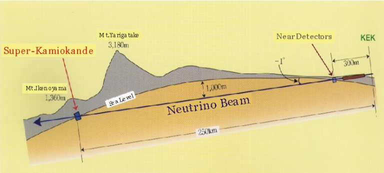


- Oscillation probability:
  $P = 4|U|^2|U|^2 Sin^2(1.27\Delta m^2_{41} L/E) = sin^2(\theta) sin^2(1.27\Delta m^2 L/E)$
- MiniBooNE designed with higher beam energy and longer baseline than LSND
- But L/E kept similar to investigate their results

LSND:	E ~30 MeV	L ~30 m	L/E ~1
MiniBooNE:	E ~500 MeV	L ~500 m	L/E ~1

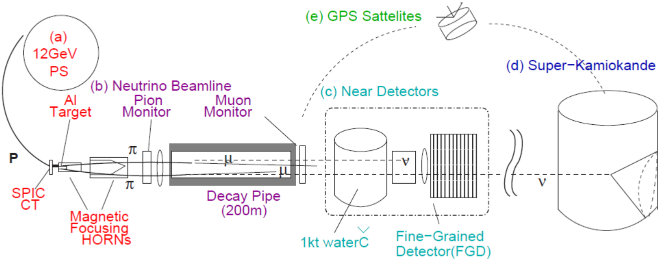


KEK to Kamiokande



- 1999-2004
- K2K has a long baseline of 250km
- 12GeV proton beam produces the neutrinos with energy 1.3GeV

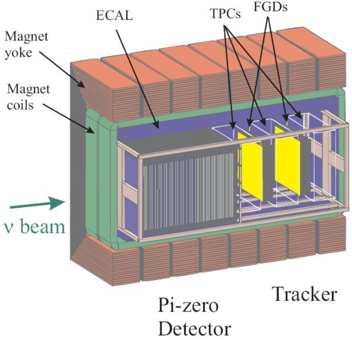
$1.9 \leq \Delta m^2 \leq 3.6 MeV^2$

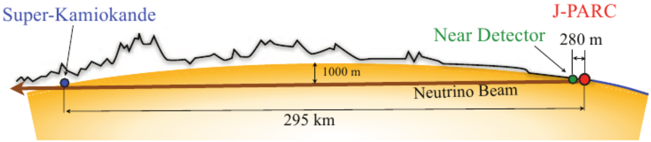


Tokai to Kamiokande

- Jan 2010 - present
- 295km baseline
- Uncontaminated beam, $<$ 1.3GeV

$2.1 \leq \Delta m^2 \leq 3.4 MeV^2$
With 90% confidence level

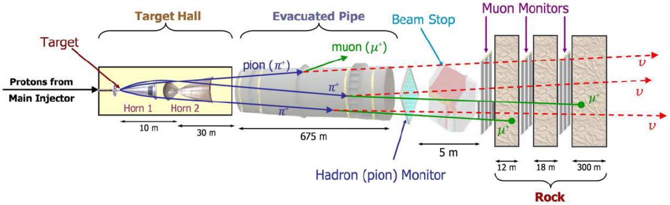




MINOS

- Feb 2005 - present
- 120 GeV proton beam
- 735km long baseline experiment

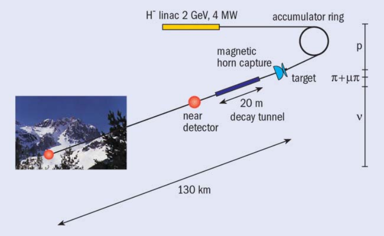
$\Delta m^2 = 2.43 \pm 0.13 MeV^2$

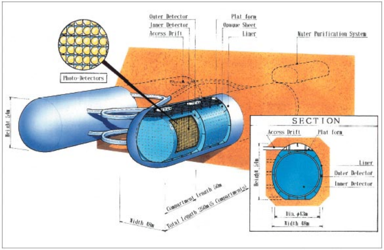


Future

T2K- Due to continue

MINOS- Ongoing



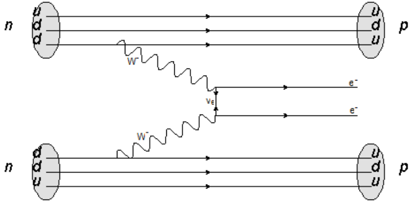


Upcoming Experiments

- KATRIN
  - Scheduled to start in 2013
  - Measure neutrino masses to 0.2eV accuracy
- T2K
  - Uses Superkamiokande detector
  - Aims to measure $v_\mu \rightarrow v_e$
- NOvA
  - Scheduled to start in 2013
  - Study $v_\mu \rightarrow v_e$
  - Measure neutrino masses
  - CP symmetry

Beyond the Standard model

- Neutrino masses
- Neutrinoless $\beta\beta$ decay



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