Daya Bay

Notes on Paper:

Observation of electron-antineutrino disappearance at Daya Bay

Mar 2012

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Daya Bay Experiment

- China, north of Hongkong
- Collaboration: China, Taiwan, USA, Czech, Russia
- studies neutrino oscillations and is designed to measure the mixing angle θ_{13}

History

- Neutrino postulated 1939 by W. Pauli

  (explanation of continuous beta decay energy spectrum)
- Neutrino to each lepton Family (ν_e , ν_μ, ν_τ)
- Discovered:
  1956 Cowan and Reines
  1962 Ledermann, Schwartz and Steinberger

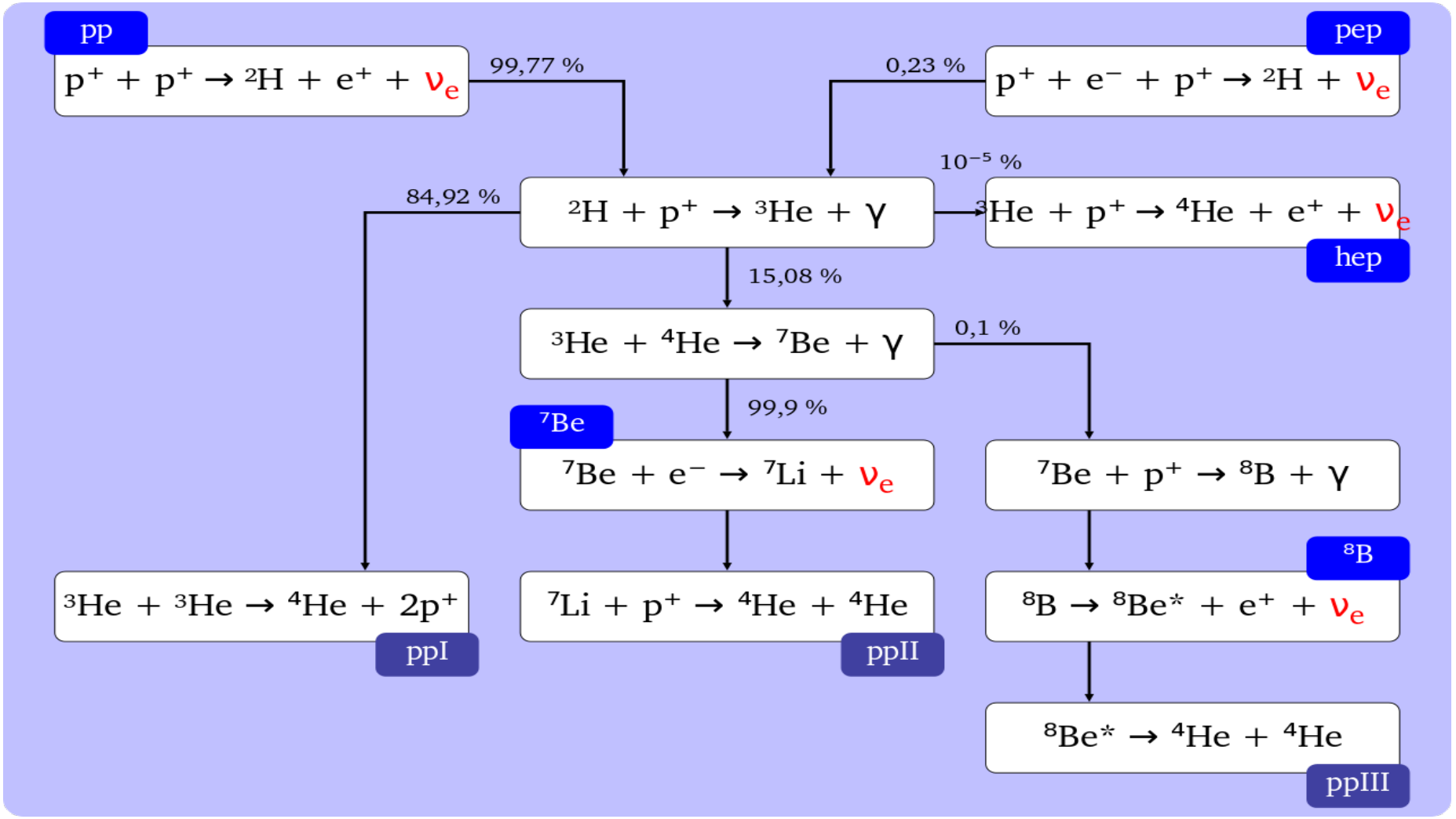
  2000 DONUT collaboration

Neutrinos

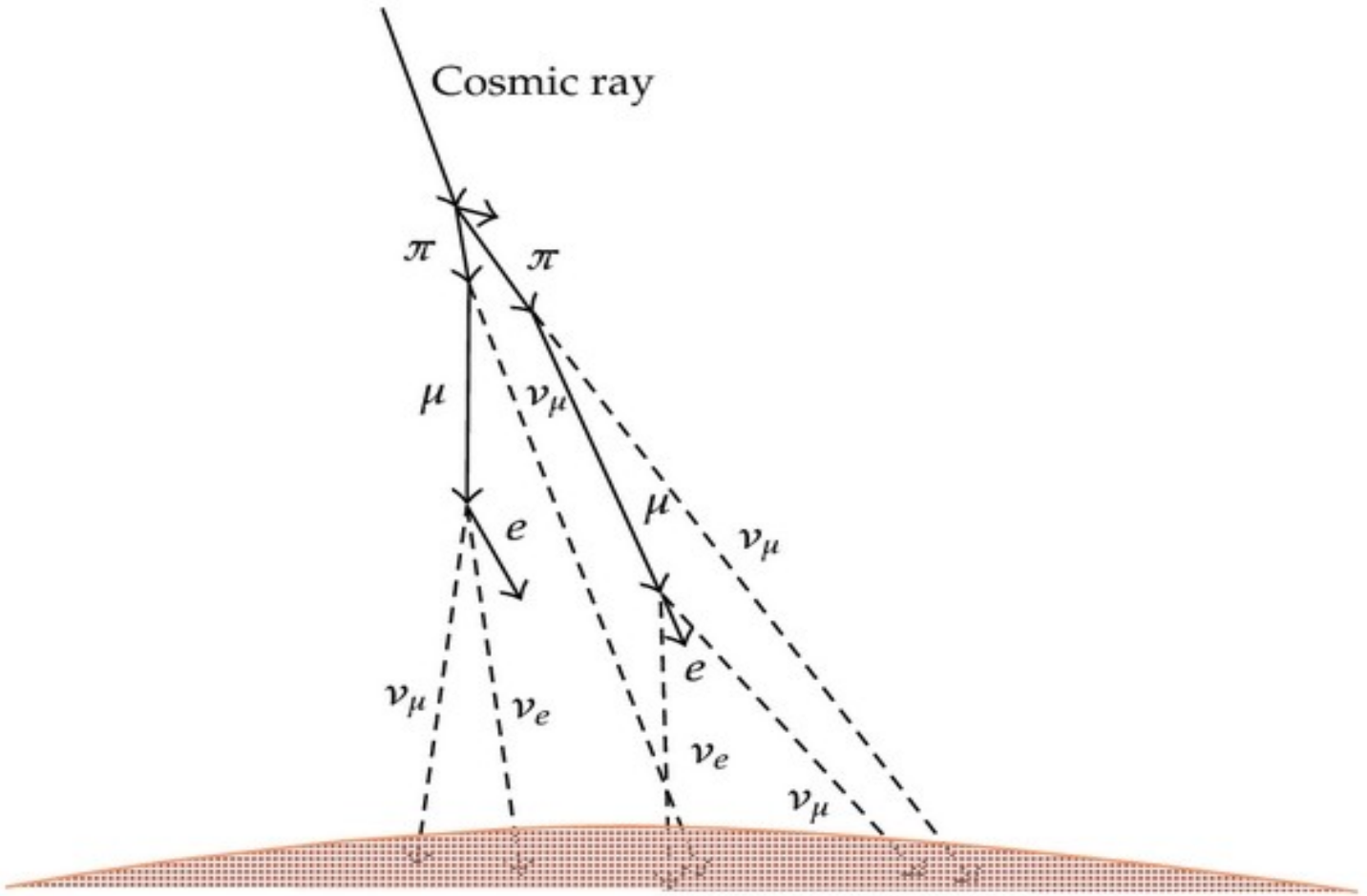
- are only nearly massless
- interact only weakly
- cross-sections around 10^{-40} cm² (photo-production in range of (10^{-28}-10^{-31})cm²)
- Sources of Neutrinos:
  - Solar neutrinos
  - Atmospheric neutrinos
  - Accelerator neutrinos
  - Reactor neutrinos

Backup

- p p Reaction Solar neutrinos

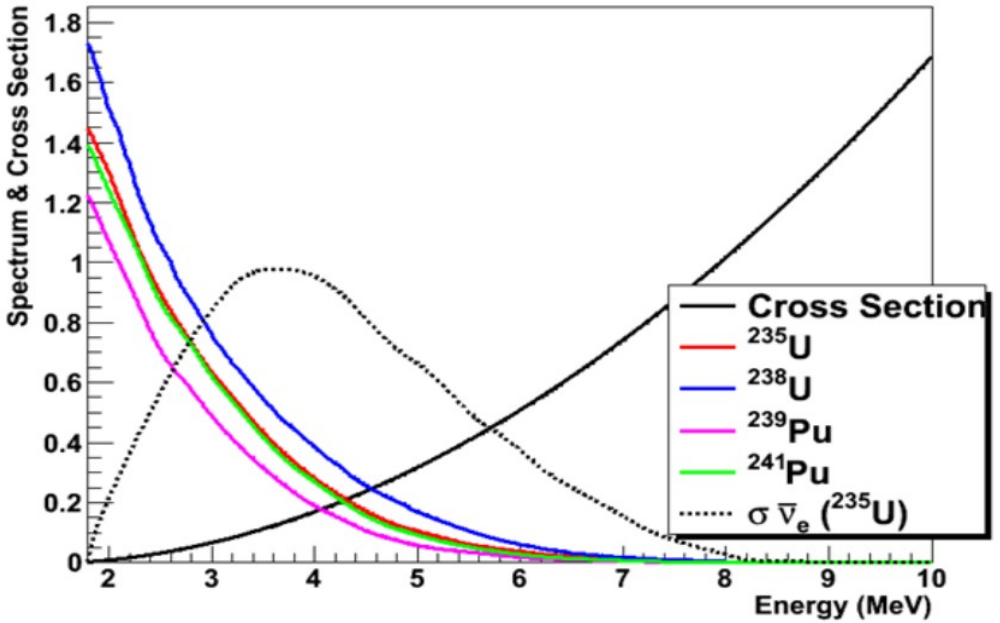


- Cosmic Neutrinos



Reactor Neutrinos

- Pure electron anti neutrino source
- $2*10^{20}$ /s/core isotropically
- 235U, 239Pu, 241Pu,238U
- Energy below 10 MeV



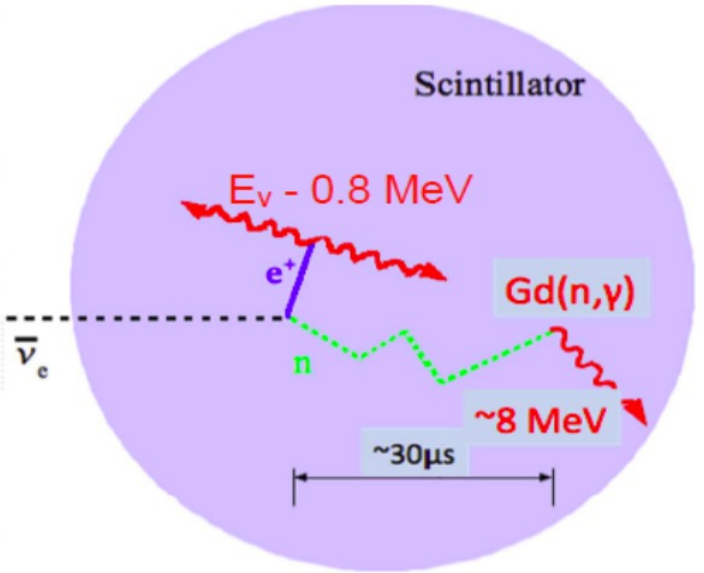


Fig. 1. (Left) $\bar{\nu}_e$ energy spectra (four curves with negative slopes) for ^{235}U, ^{238}U, ^{239}Pu, and ^{241}Pu are shown. The curve with positive slope represents the cross section of the inverse beta decay (IBD) process. The convoluted IBD spectrum, seen in experiments, is shown as the dotted line. (Right) The detecting principle of IBD is shown.

Theoretical description

- Neutrino Oscillations describable by
  - Three mixing angles
  - A phase of the Pontecorvo-Maki-Nakagawi-Sakata matrix
  - Two mass squared differences

- Survival probability of $\bar{\nu}_e$:

  $P_{sur}=1-\sin^2 2\theta_{13}\sin^2(1.267\Delta m^2_{31}\, L/E)$

  E is $\bar{\nu}_e$ Energy; L distance source detector;

Measurement of $\bar{\nu}_e$

- Detection via inverse beta decay (IBD)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

positron rapidly annihilates (prompt) while neutron thermalizes before capture (delayed signal)

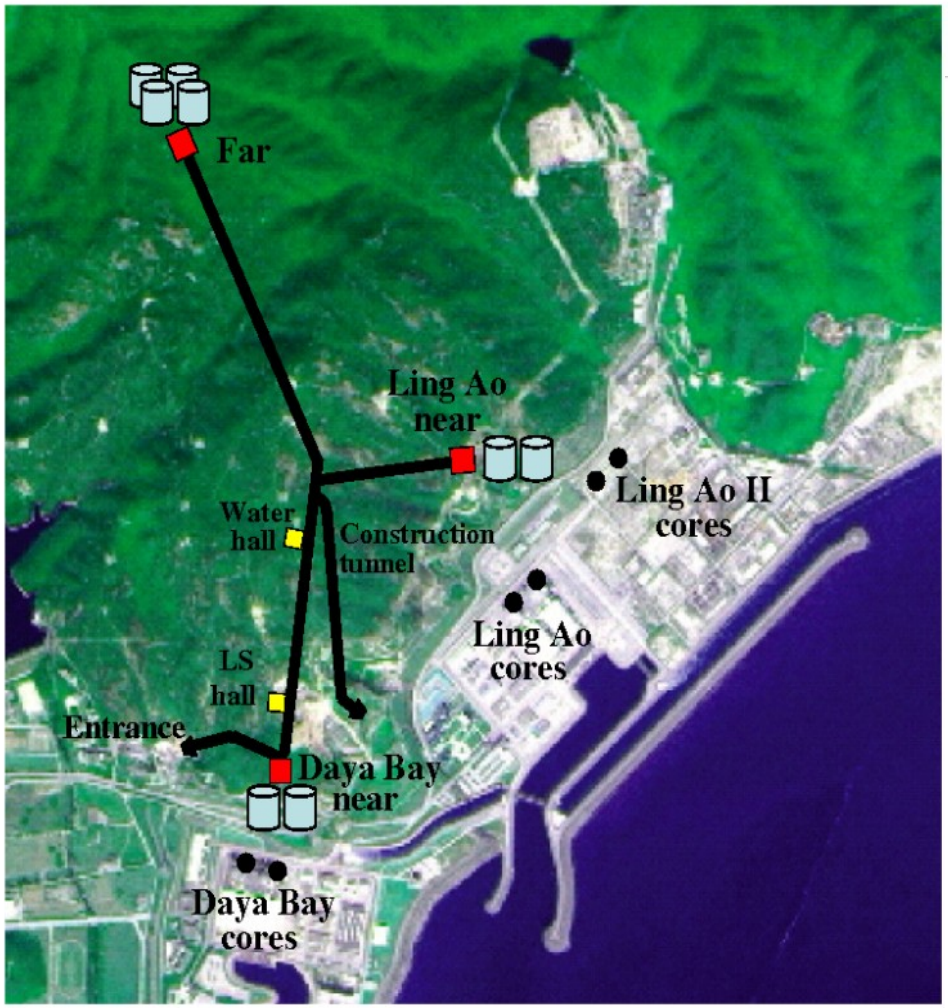
$$N_{\text{det}} = \frac{N_p}{4\pi L^2} \int \epsilon \sigma P_{\text{sur}}(E, L, \theta_{13}) S \, dE$$

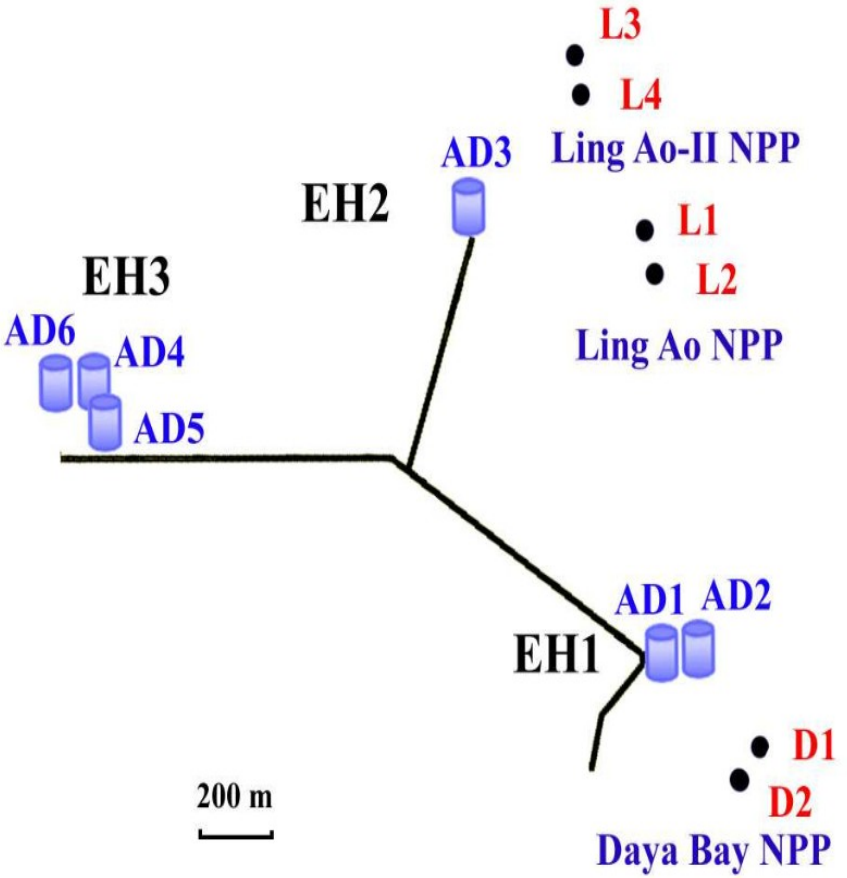
Design of the experiment

- 6 Reactor cores, Daya Bay I, II and Lingao I-IV
- Total thermal power of 17.4 GW
- Two near under ground sites, each two anti-neutrino detectors.
- Far side with four anti-neutrino detectors

  (2014, paper 2012 only three and near side one and two)

Experimental setup

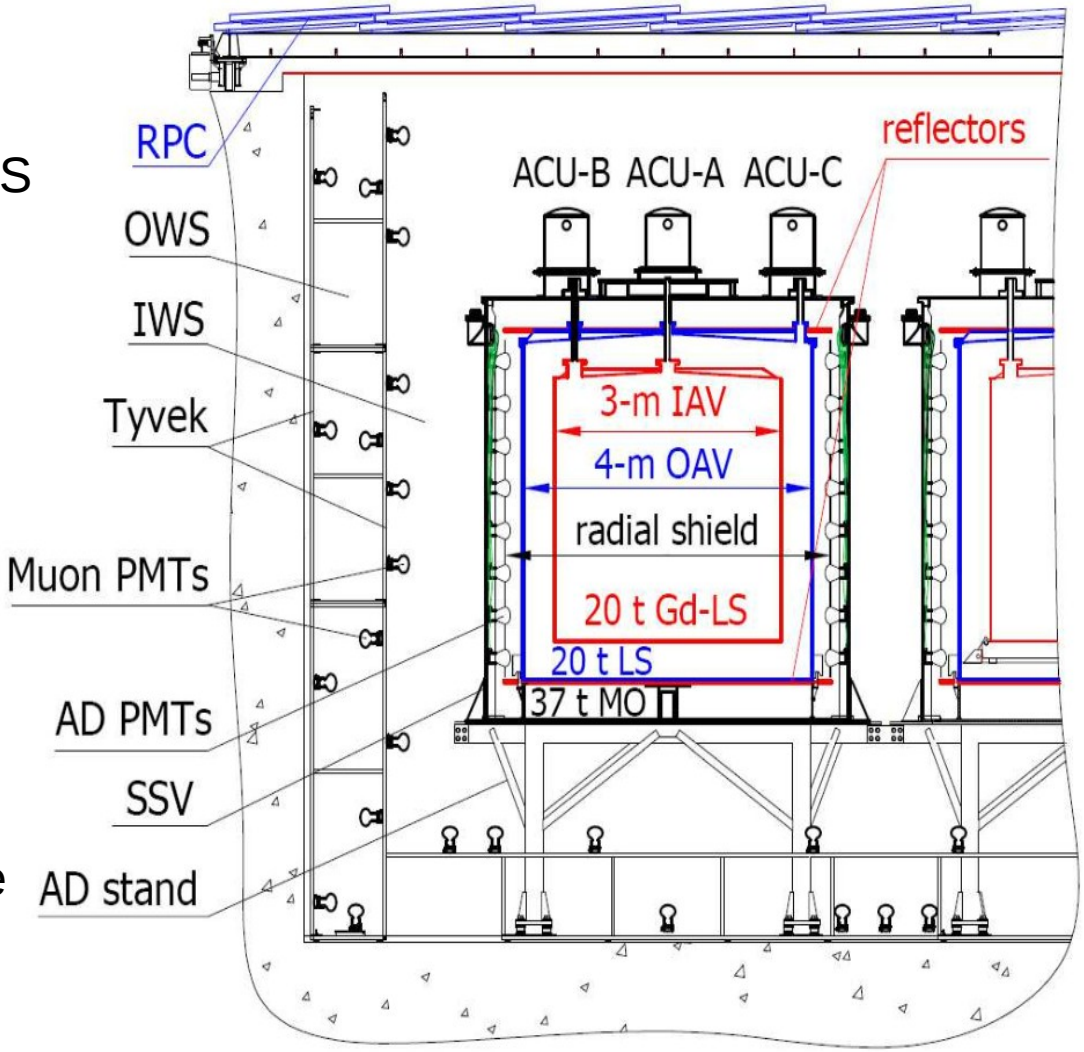




The antineutrino Detector

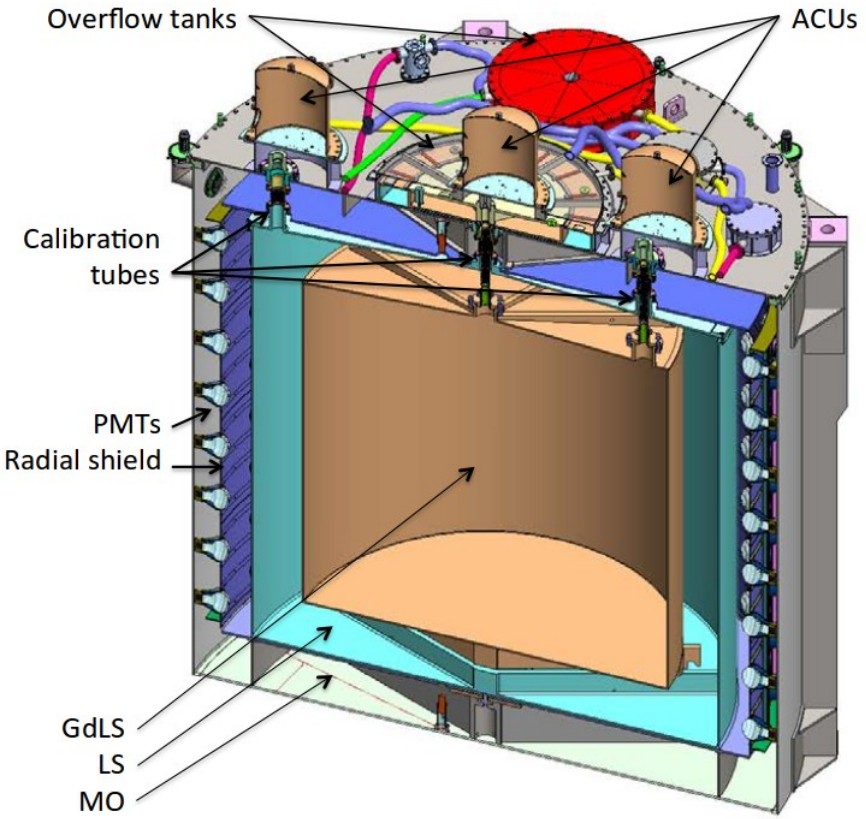
- Inverse beta decay $p+\bar{\nu}_e \rightarrow n+ e^+$
- 3 zone design
  - Innermost 20t 0.1% by weight Gd-LS (antineutrinotarget)
  - Middle volume 21t of undoped LS (gamma catcher)->better energy resolution
  - Outer volume 37t of mineral oil (for optical homogenity and schielding

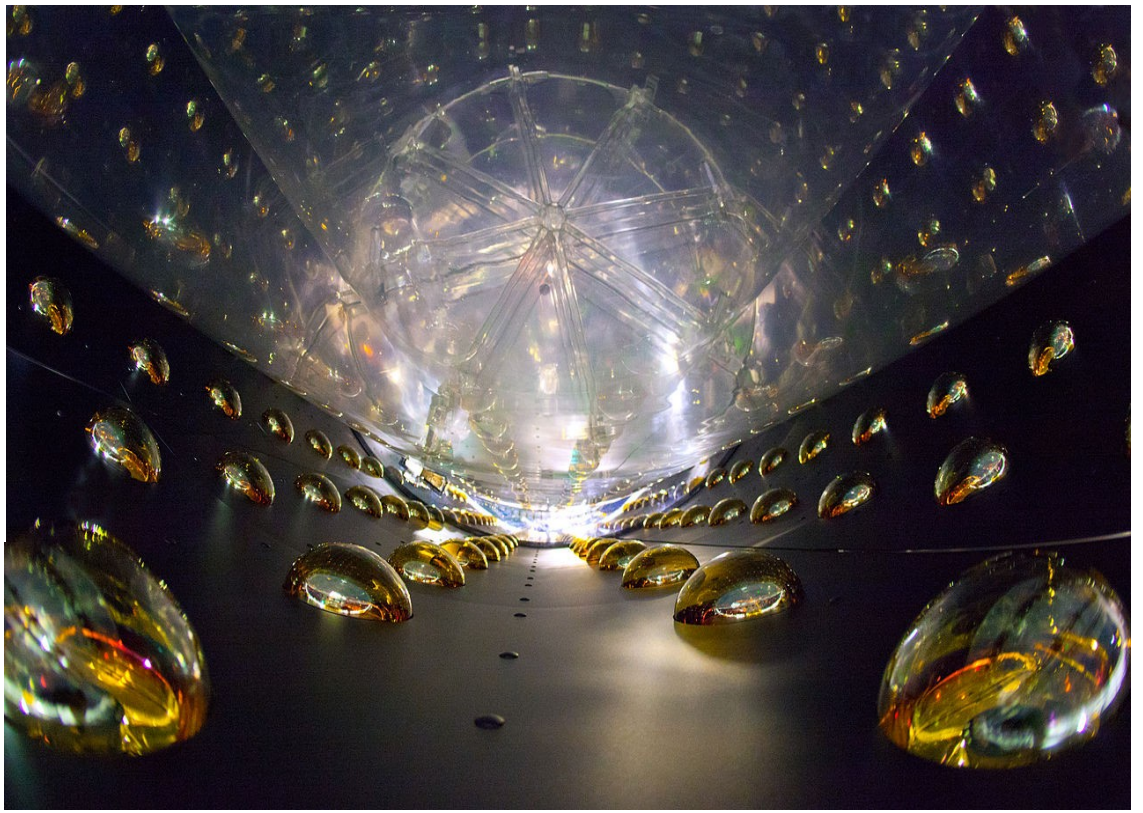
3 Automated Calibration units
- led (PM gain/timing)
- ^{68}Ge source (IBD threshold calib)
- ^{60}Co source (energy scale)
- ^{241}Am-^{13}C neutron source (n capture on Gd and H to Gd capture ratio)



Placed inside purity water (shield and Cerenkow[cosmic muons])
Resistive plate chamber above (additional muon tagging)

Antineutrino Detector





Before Daya Bay

- CHOOZ 90% confidence-level upper limit of 0.17

- T2K, Minos, Double Chooz: indication non-zero Θ_{13}

Result

- **Daya Bay:**

  $\sin^2 2\Theta_{13}$=0.092+-0.016(stat)+-0.005(sys)

  Significance of 5.2 standard deviations

  (rate only analysis)

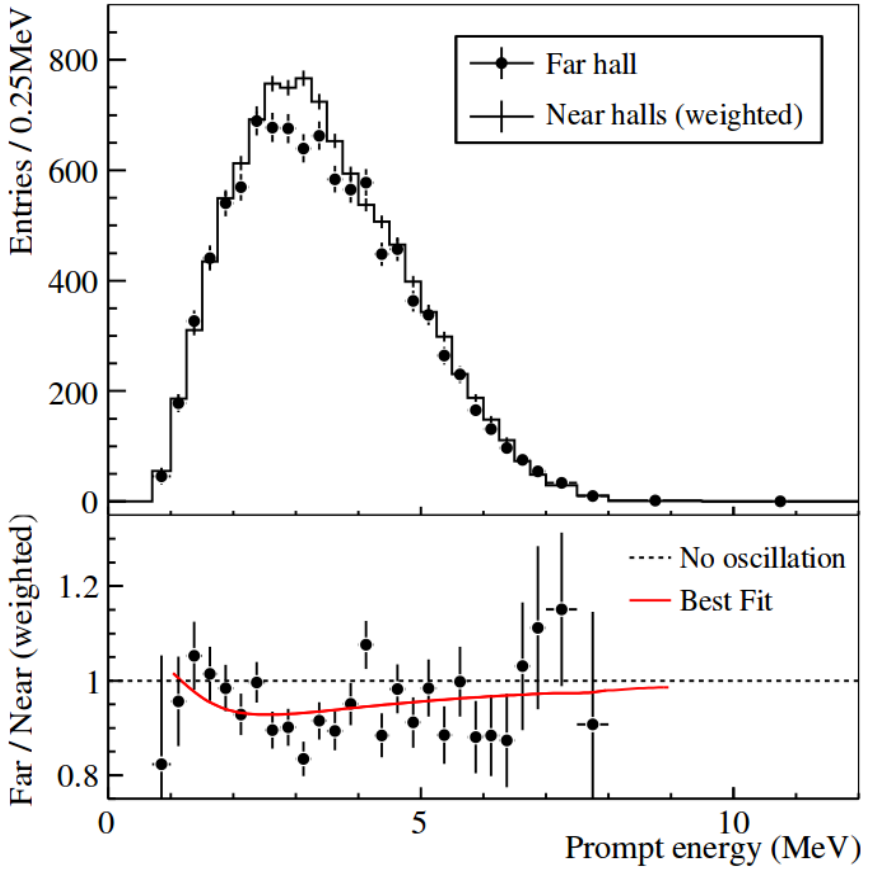


FIG. 5. Top: Measured prompt energy spectrum of the far hall (sum of three ADs) compared with the no-oscillation prediction from the measurements of the two near halls. Spectra were background subtracted. Uncertainties are statistical only. Bottom: The ratio of measured and predicted no-oscillation spectra. The red curve is the best-fit solution with $\sin^2 2\theta_{13} = 0.092$ obtained from the rate-only analysis. The dashed line is the no-oscillation prediction.

Future

- 2016 Breakthrough Prize in Fundamental Physics (3 million US$)
- Precession measurement of Δm_{ee}^2 to about 2.5%

THE END

Additional papers

- []Observation of electron-antineutrino disappearance at Daya Bay, Mar 2012, Phys.Rev.Lett. 108 (2012) 171803
- [] Reactor Neutrino Experiments: Θ_{13} and Beyond (Modern Physics Letter A)
- []Symmetry Magazine – A joint Fermilab/SLAC publication
- []The Daya Bay Antineutrino Detector, Wikimedia commons, public domain