Jinping Neutrino Experiment

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@ Continental Margin in South China:
Multidisciplinary Frontiers in Neutrino Geoscience

Contents

- Neutrino and geo-neutrino detection
- Interest in solar neutrino detection
- China Jinping Underground Laboratory
- Jinping Neutrino Experiment

In this very short history,

Neutrino:

"Concept" -> "Reality" -> "Probe"

Shining Neutrinos

1930 Pauli proposed the neutrino concept

1956 Cowan & Reines observed neutrinos — 1995 Nobel

1962 Find muon neutrinos — 1988 Nobel

1962 R. Davis, solar neutrinos and solar neutrino anomaly

1980s Atmosphere and Supernova neutrinos — 2003 Nobel

2001 Solar neutrino oscillation and matter effect — 2015 Nobel

2012 non-zero mixing angle θ_{13} — 2012 Science breakthrough

2013 ultra high energy neutrinos — 2013 Phys. World breakthrough

Many great discoveries not included in this page.

Non-zero mixing angle θ_{13} is an important corner stone of 2015 Nobel prize. I am greatly honored to be deeply involved in this process.

The mysterious particle - Neutrino

- ν_e, ν_υ, ν_τ, oscillate in propagation

  Different oscillation in matter and vacuum

- Mass < 1 eV

- Interaction weak: ~1x10^{-40} cm^2

  Mean free path ~3x10^{10} km (D_{Earth}=6000 km)

- Neutrino: excellent probe for dense stellar objects, for example, Sun, Earth, Supernova

Large detector and small signal rate

$$N_\nu(E) \sim \Phi_\nu(E) \times \sigma_\nu(E) \times \text{target}$$

1E-40 cm^2

pp collision at 1E-26 cm^2

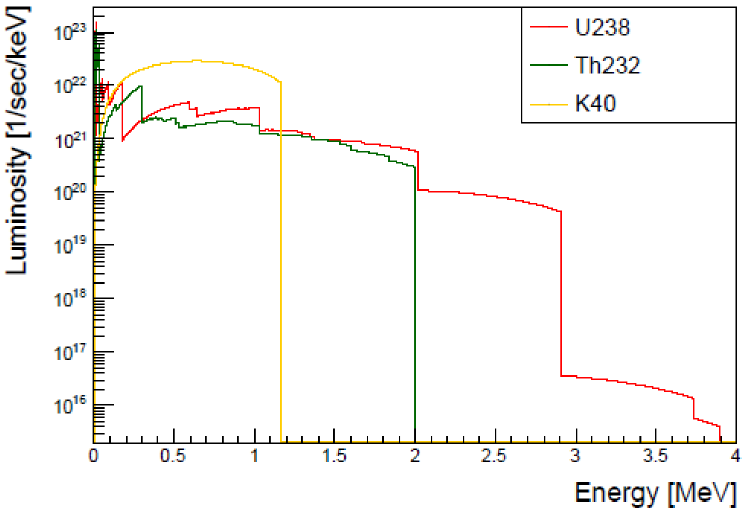
- Large target: kiloton, 10 kiloton, megaton
- Enhance neutrino flux
- Choose process with larger cross-section
- ~10-100 signals/year

Neutrino emission

Categorized by the emission process

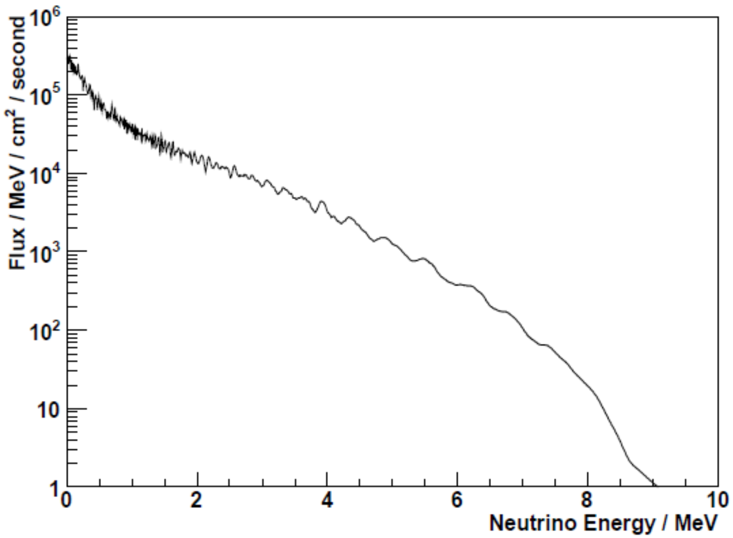
1. Decay process

   β decay，β$^+$ decay,
   U, Th, K decay (chain):
   $\bar{\nu}_e$ emitted
   Enegy < 4 MeV



2. Fission

   U, Th, Pu,
   $\bar{\nu}_e$ emitted
   Energy < 10 MeV

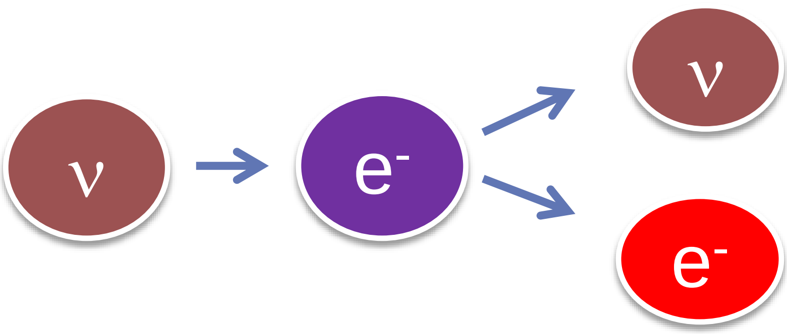


3. Fusion

   ν_e from the Sun

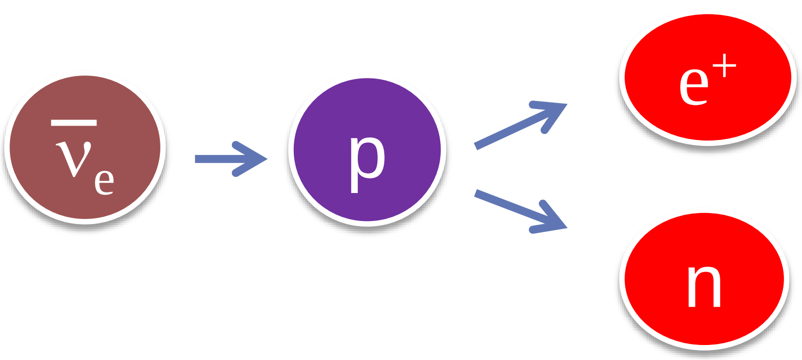
Detection with hydrogen-rich material

Solar neutrino detection



The electron is selected and its energy is measured with liquid scintillator and is related to original neutrino

Geo and supernova neutrino detection



The positron and neutron are selected and positron energy is measured with liquid scintillator.

Detection in liquid scintillator

UV or ionization of charge particle can cause scintillator to emit light.

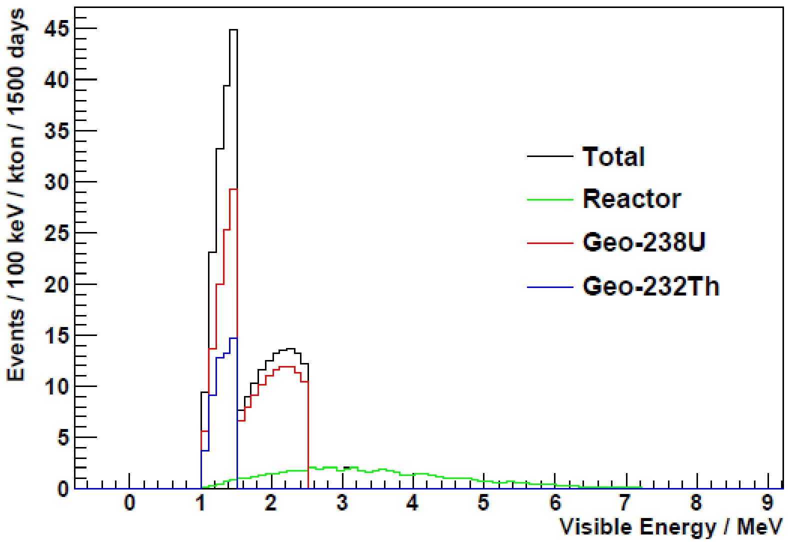
With PMT, the light yield, i.e. energy can be measured.

Background for Geo neutrinos

- Commercial reactors

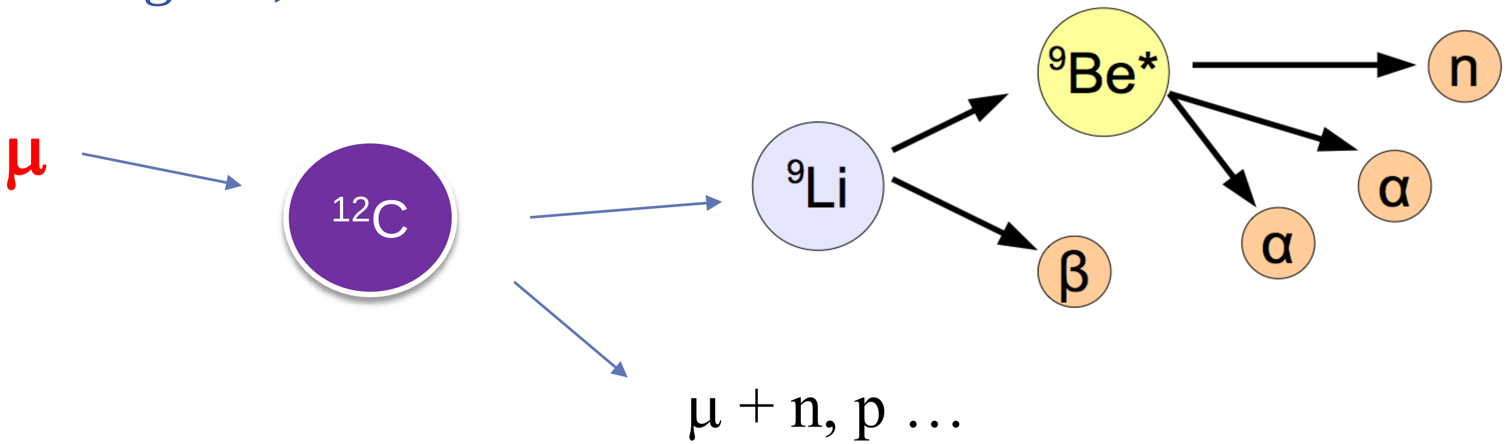
  The same signal, but
  - Broader energy spectrum

  Energy spectra overlap
  - Direction: Currently difficult



- Cosmogenic backgrounds

  Fake signals, fake electron and neutron

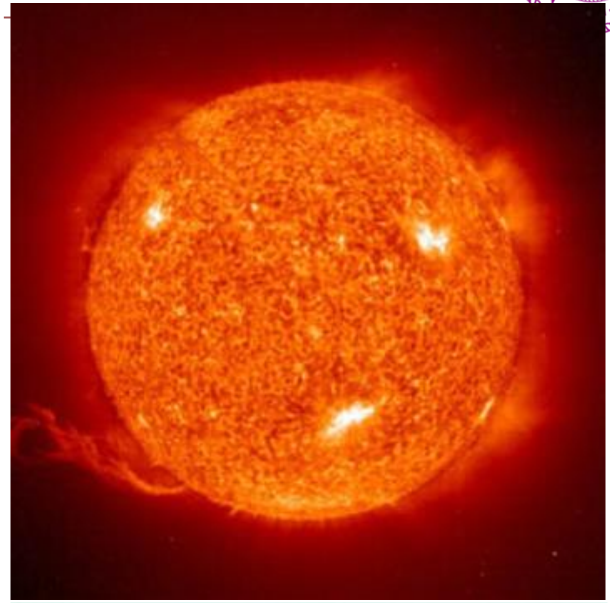


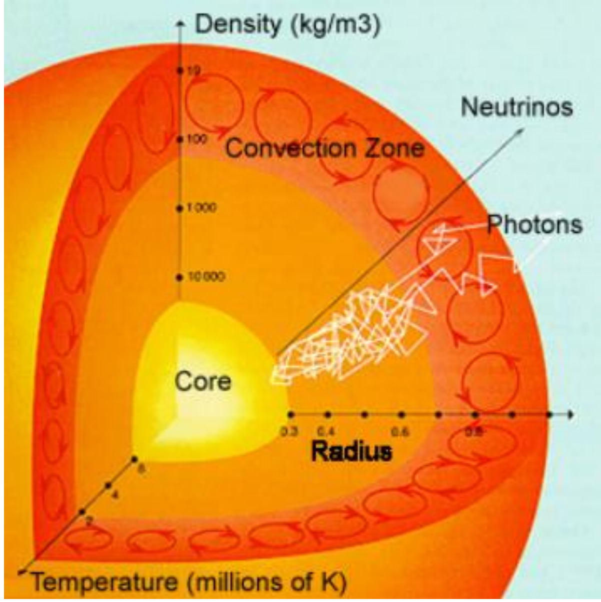
Interest in Solar Neutrinos

Evolution of the Sun – Solar Model

1. **Fueling mechanism:**
   pp chain
   CNO cycle
2. **Energy transmission:**
   Radiation (opacity) inner
   convection outer
3. **Balance of the gravity, radiation, and particle pressure**

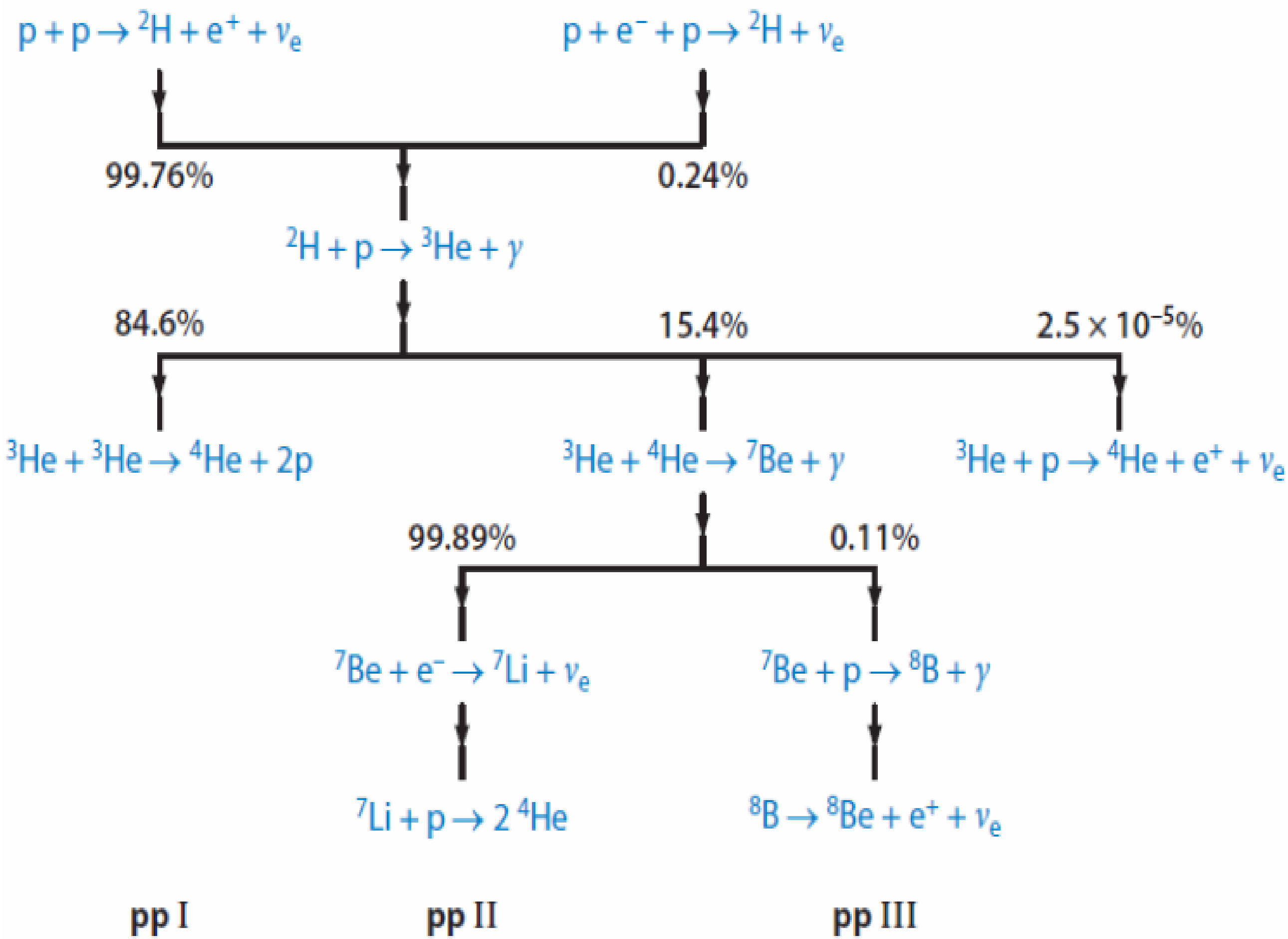
4. **Initial conditions**
   Abundance of H, He, metal elements
   Radius, age, mass …
   <u>Assume: Initial metal fraction = surface fraction = core fraction</u>



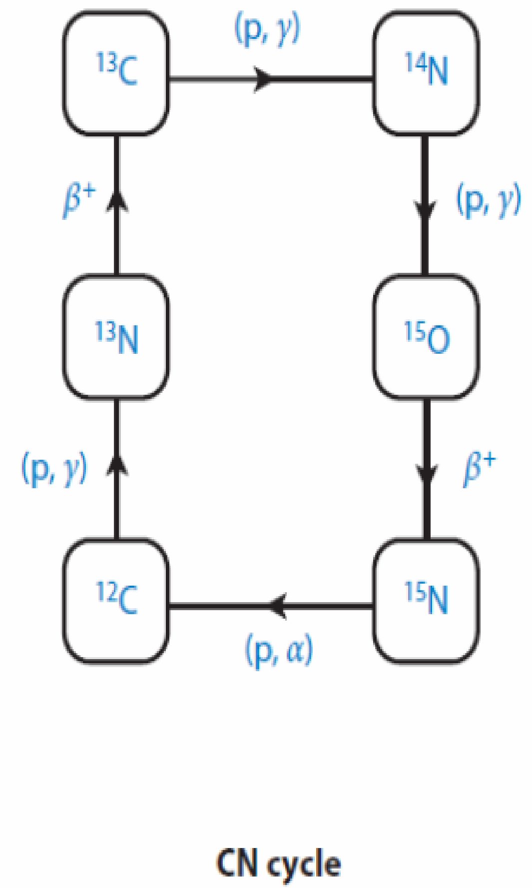


Solar Modal and Neutrino Components

The pp Chain

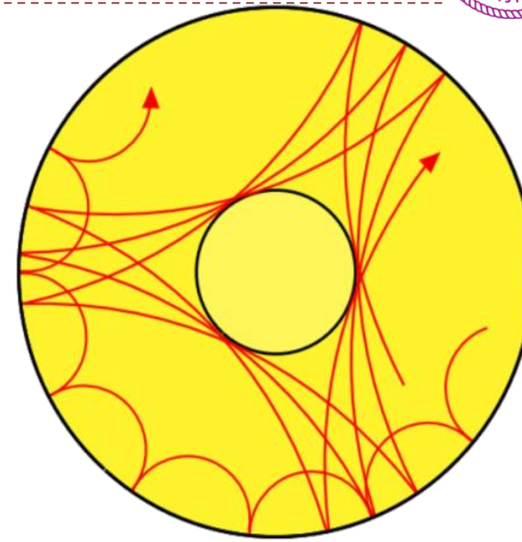


The CNO

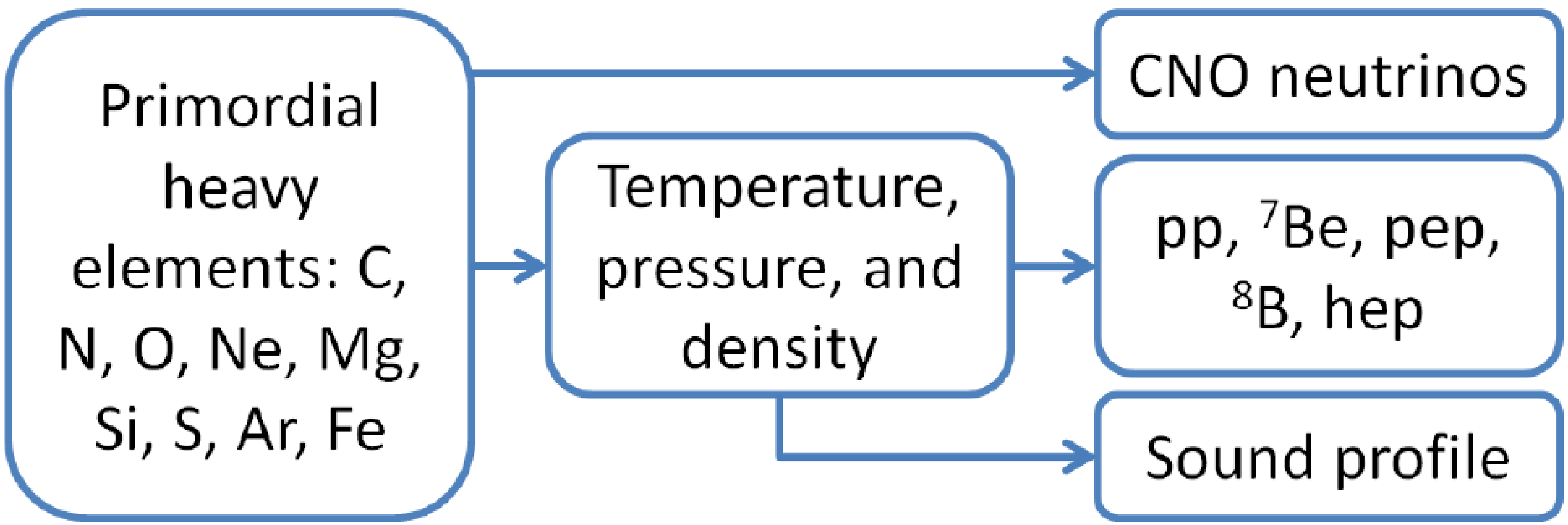


Helioseismology and conflict

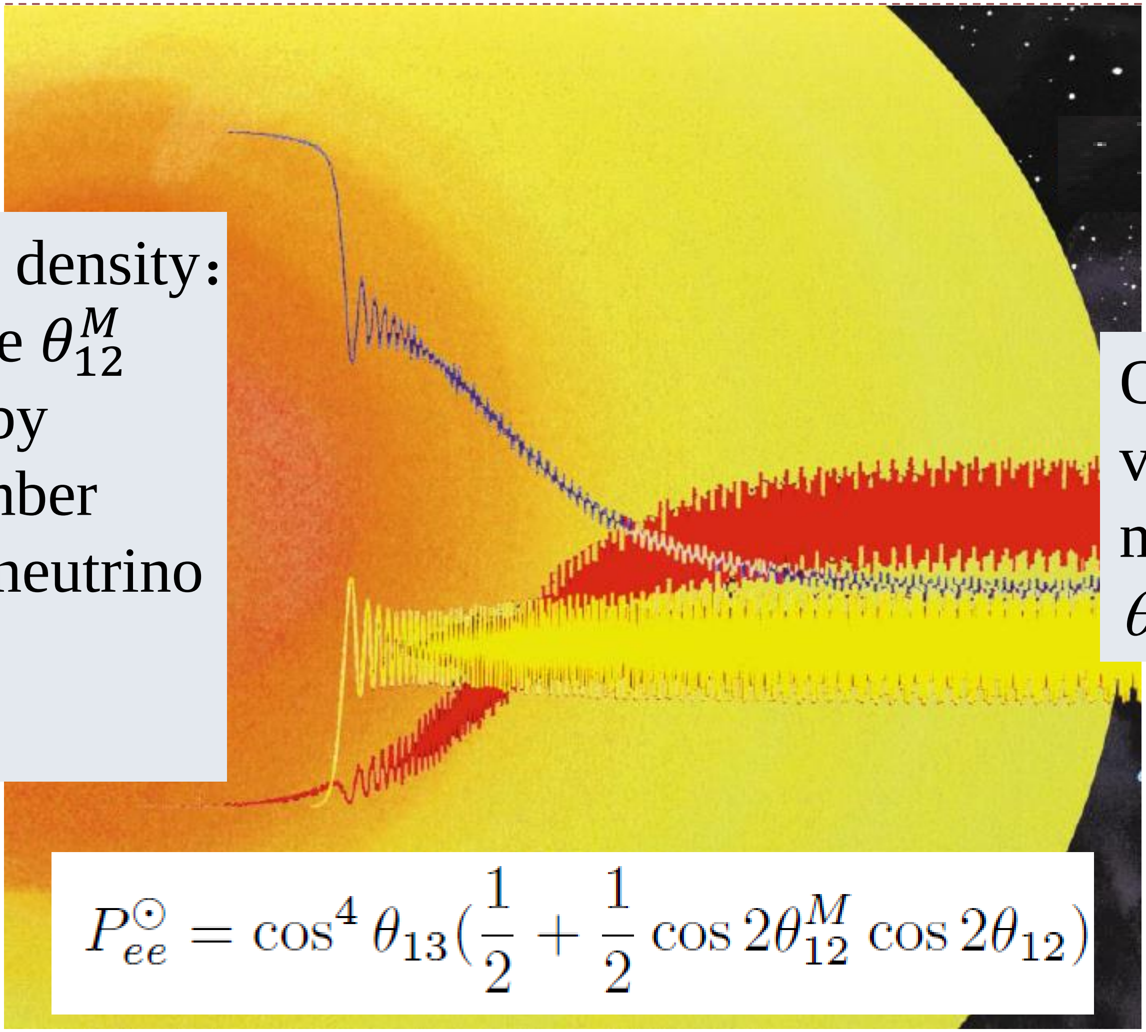
Helioseismology: Solar surface vibration with T=~5 min, v=~0.5 km/s, A=~100 km



New (better) calculation of
Solar model is conflicting with helioseismology measurement: sound speed differ by ~40%



Neutrino oscillation upturn



Center-High density: Mixing angle θ_{12}^{M} determined by electron number density and neutrino energy

Outside: vacuum mixing angle θ_{12}

$$P_{ee}^{\odot} = \cos^4\theta_{13}\left(\frac{1}{2} + \frac{1}{2}\cos 2\theta_{12}^{M}\cos 2\theta_{12}\right)$$

* If going through the Earth, the survival probability will change ~3%

The basic questions of the Sun

The mechanism of solar evolution

- CNO neutrinos not discovered

  1% in the Sun, but major fueling process for high temperature stars

- CNO neutrinos: a direct probe of the core of the Sun

  Study solar metal element fraction, resolve the conflict

- Understand our closest star

Neutrino oscillation

- Solar neutrino oscillation

  Transition from vacuum to matter oscillation

- Precise measurement and new physics

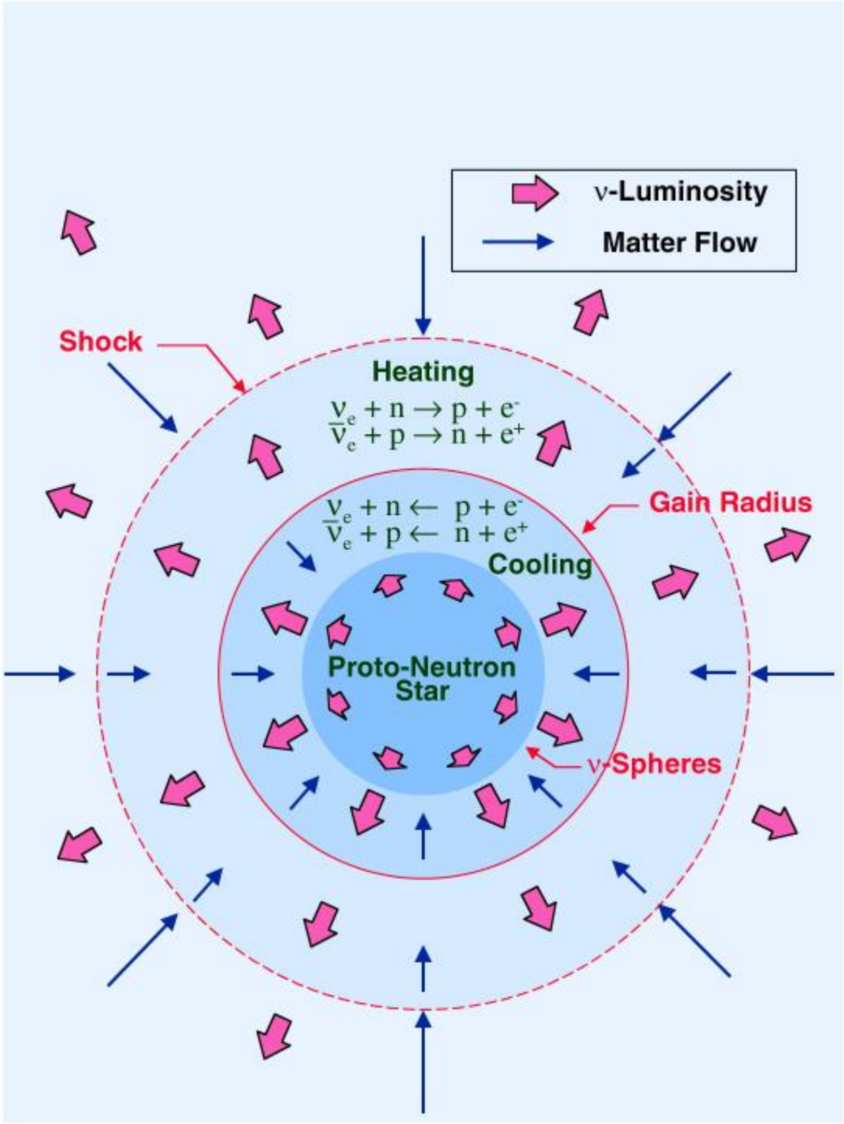
Supernova relic neutrinos

1. Supernova burst neutrino:
   1987a supernova neutrinos were observed

2. Diffused supernova neutrino background
   Accumulated background from far distance and time

<u>SRN: A finger print of star formation rate and star evolution mechanism.</u>

<u>SRN: Not discovered!</u>

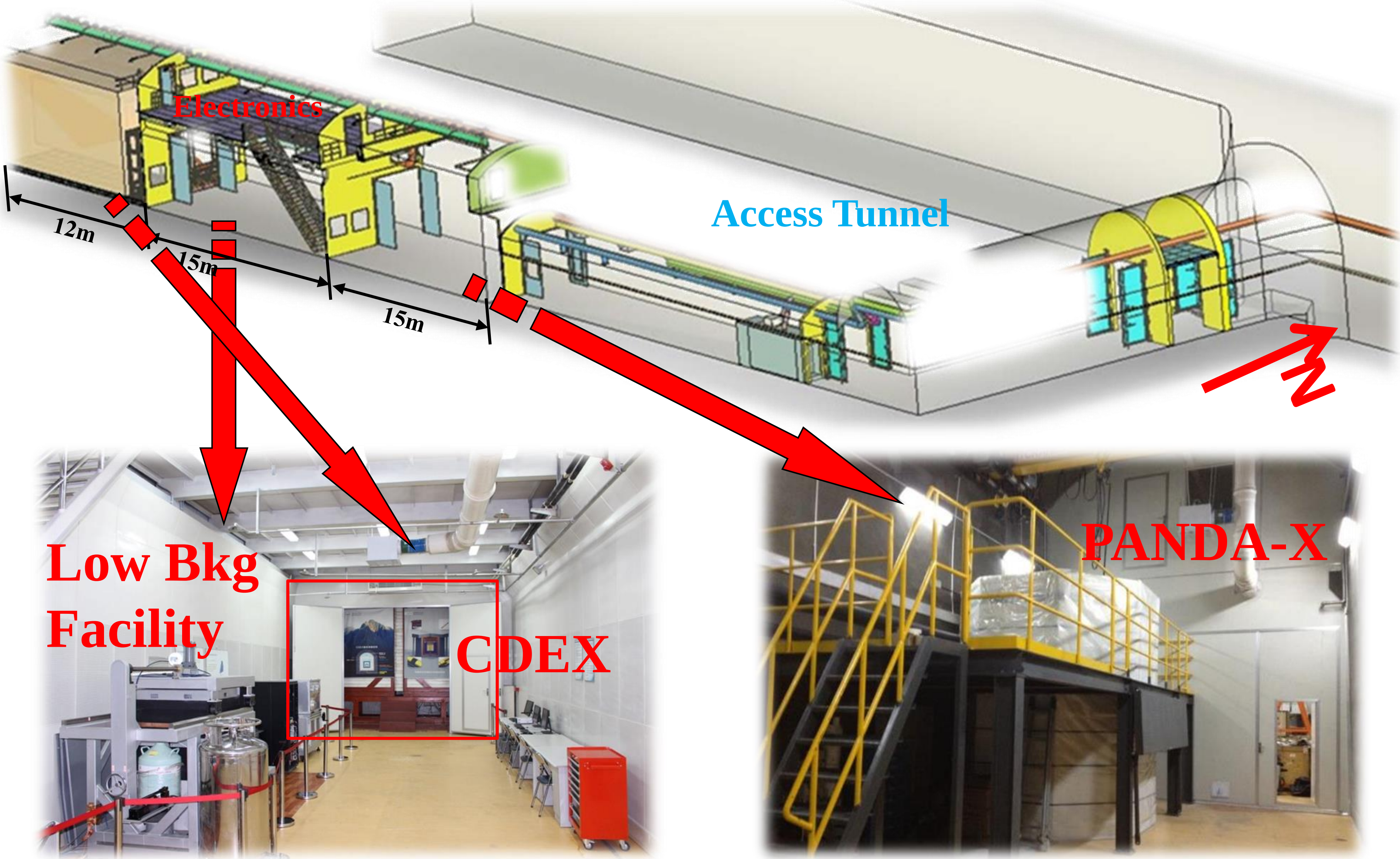


China Jinping Underground Laboratory

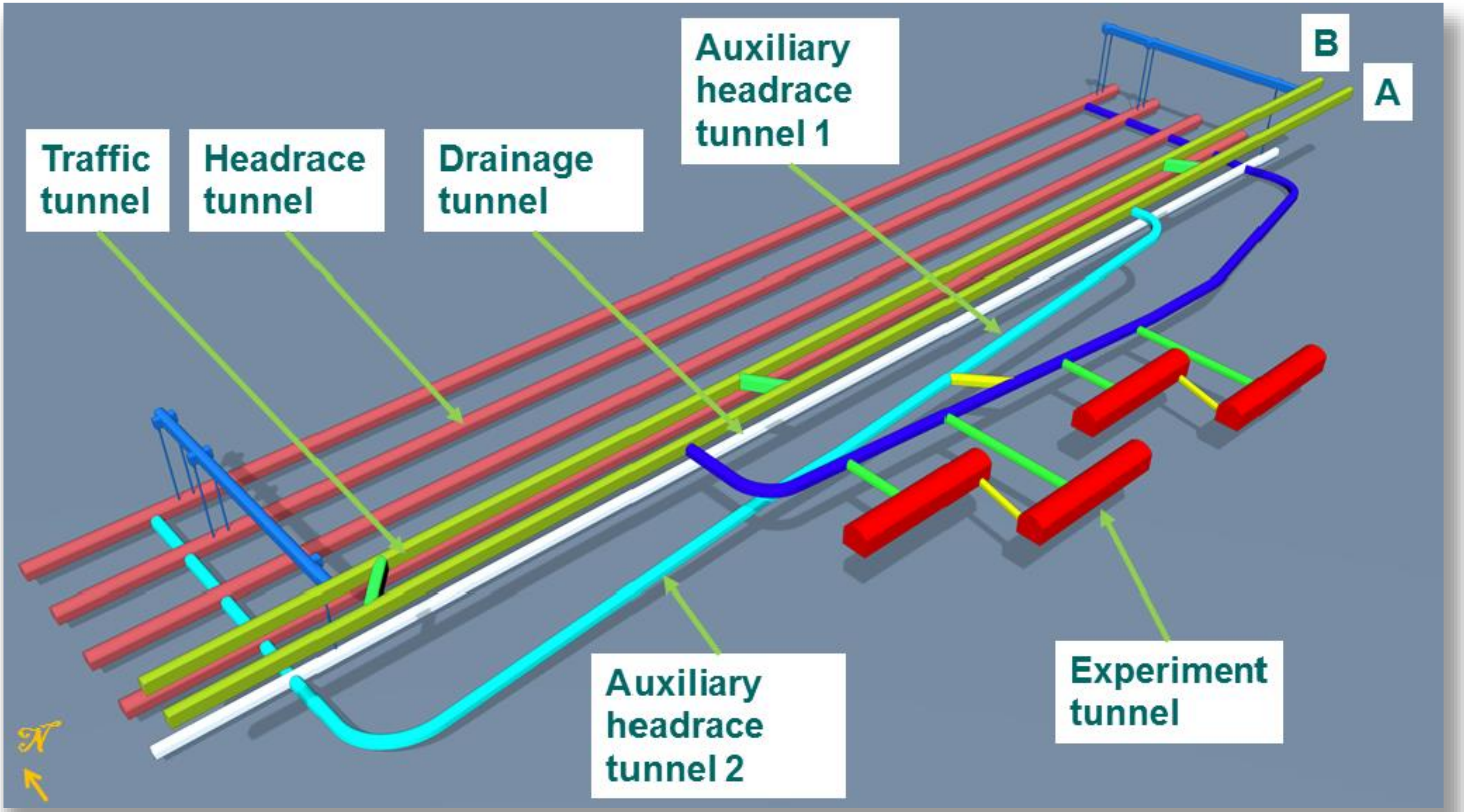
Jinping's location

Right next to the Himalayas

CJPL-I and Dark Matter Exp.



Design of CJPL-II



	CJPL-I	CJPL-II
Rock Work	4000 m^3	131000m^3

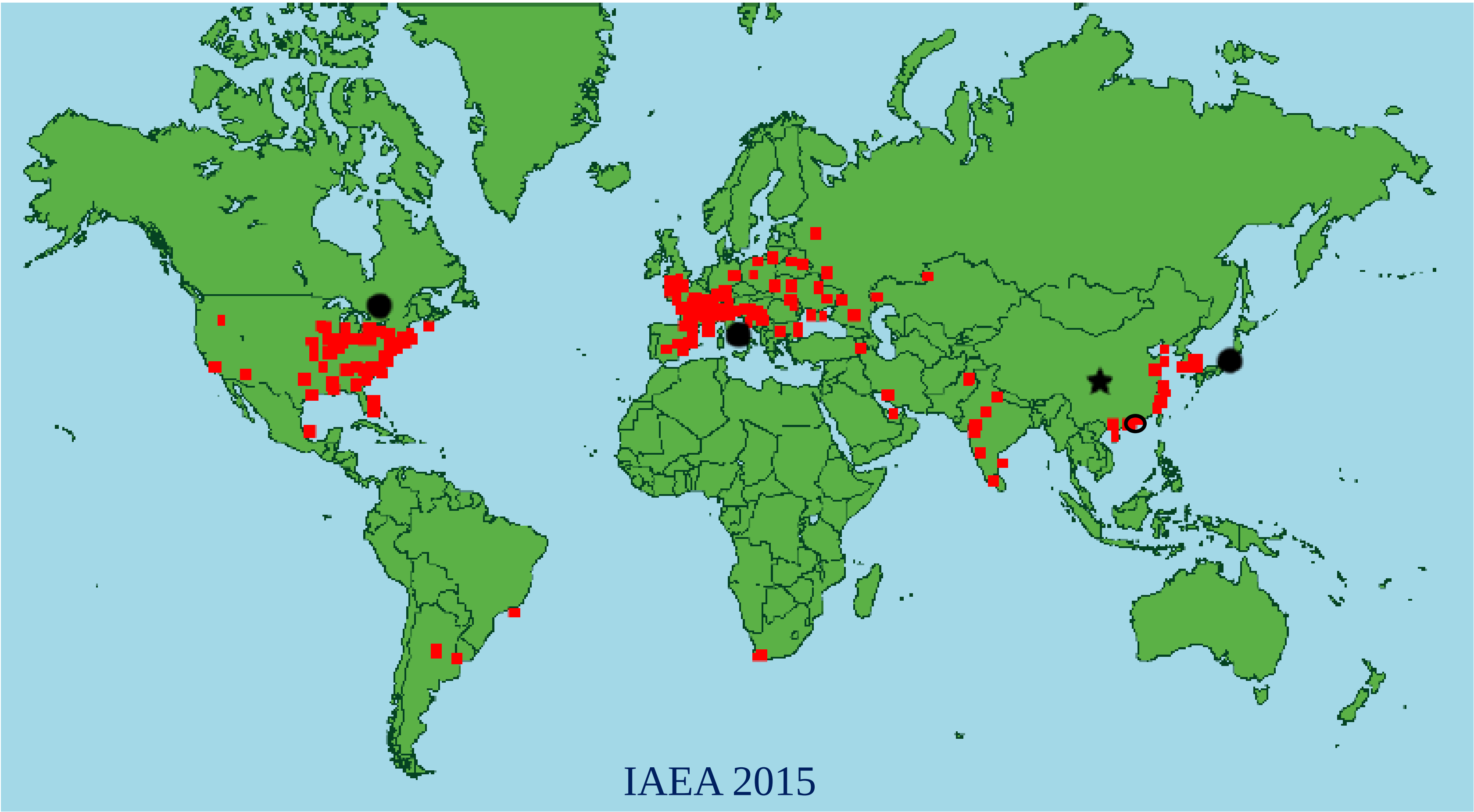
CJPL-II Current status

4 halls,
14x14x60 m^3
8 laboratories

CDEX foundation pit

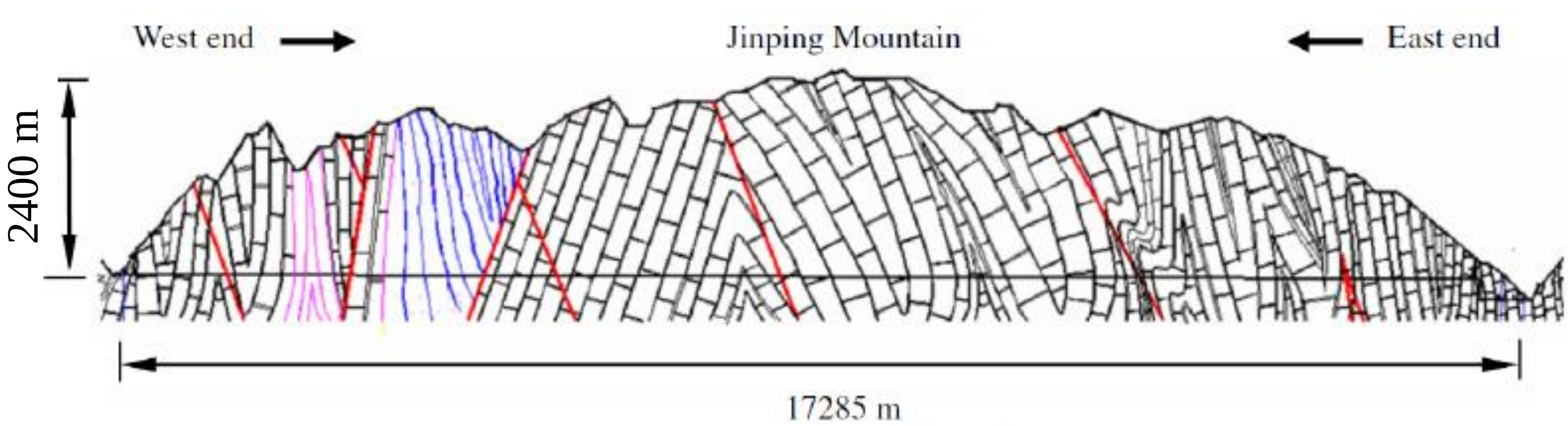
PandaX foundation pits

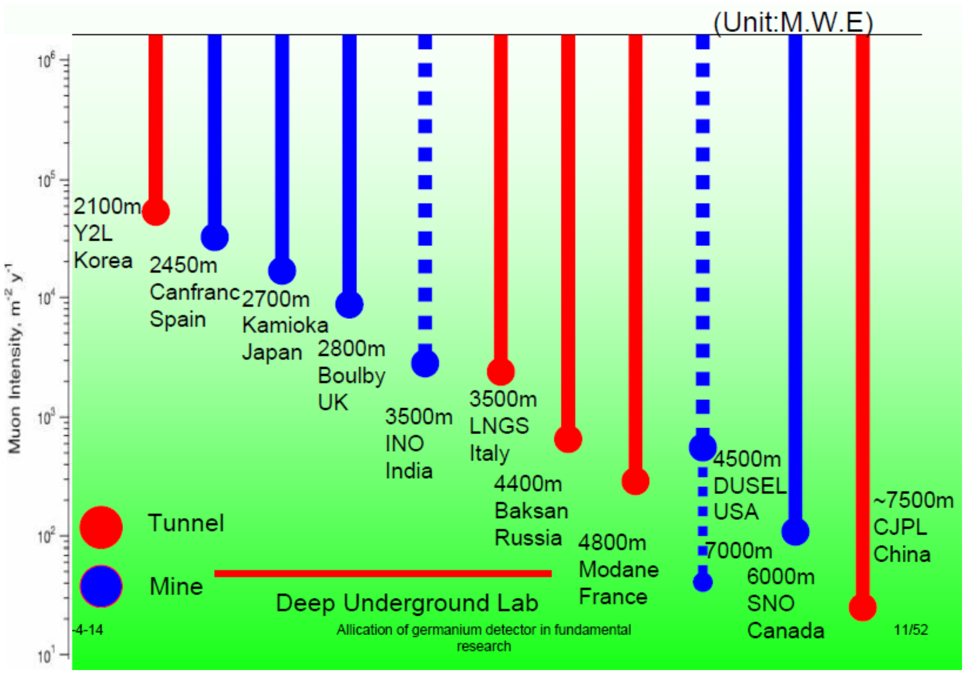
Reactor Neutrino Background



Closest reactor 1200 km

Depth and Muon Flux

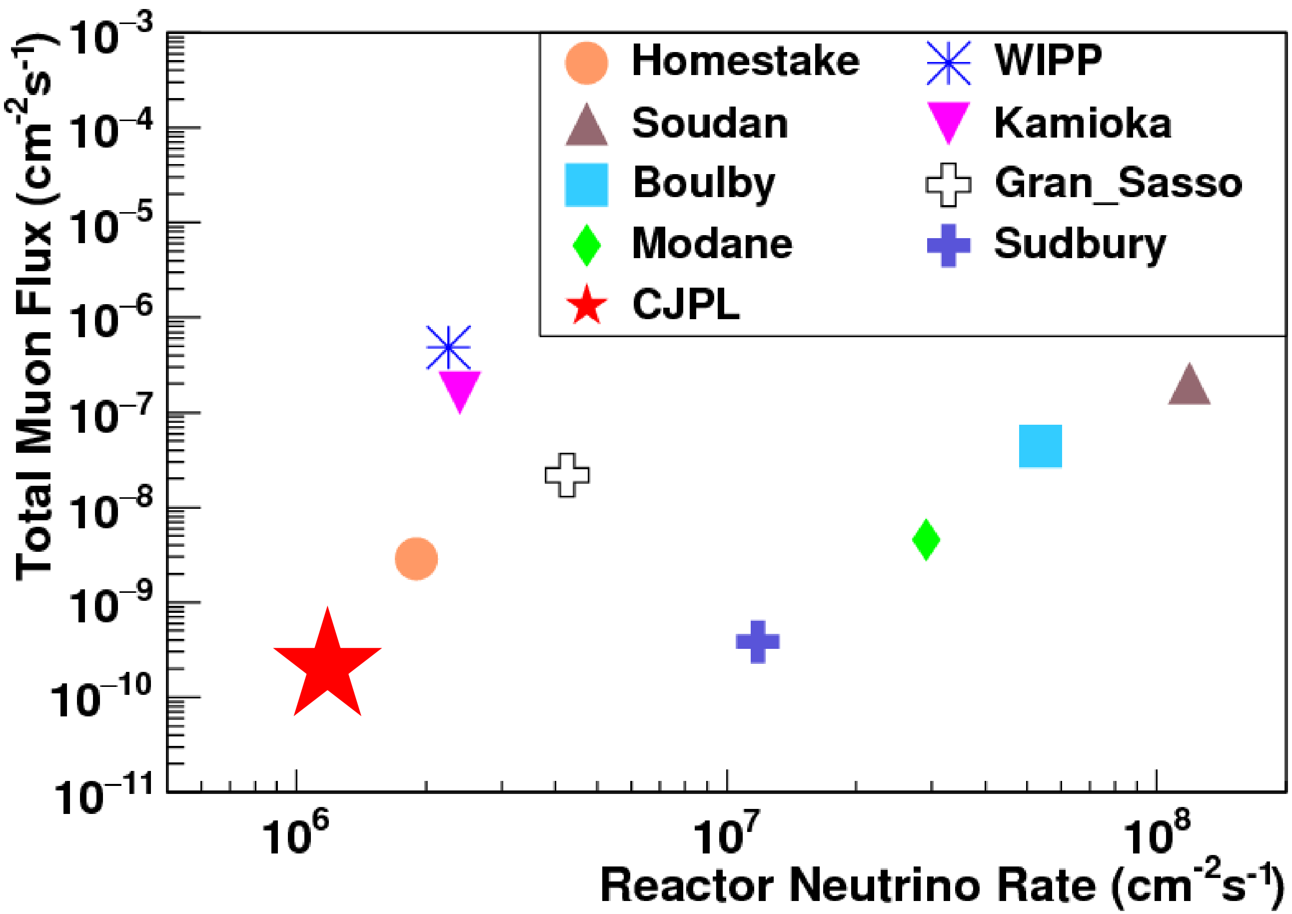




Muon and related background

- 1/200 of LNGS
- 1/2 of SNOLAB

An ideal site for low background neutrino Exp.



Jinping Neutrino Experiment

Jinping Neutrino Experiment Proposal

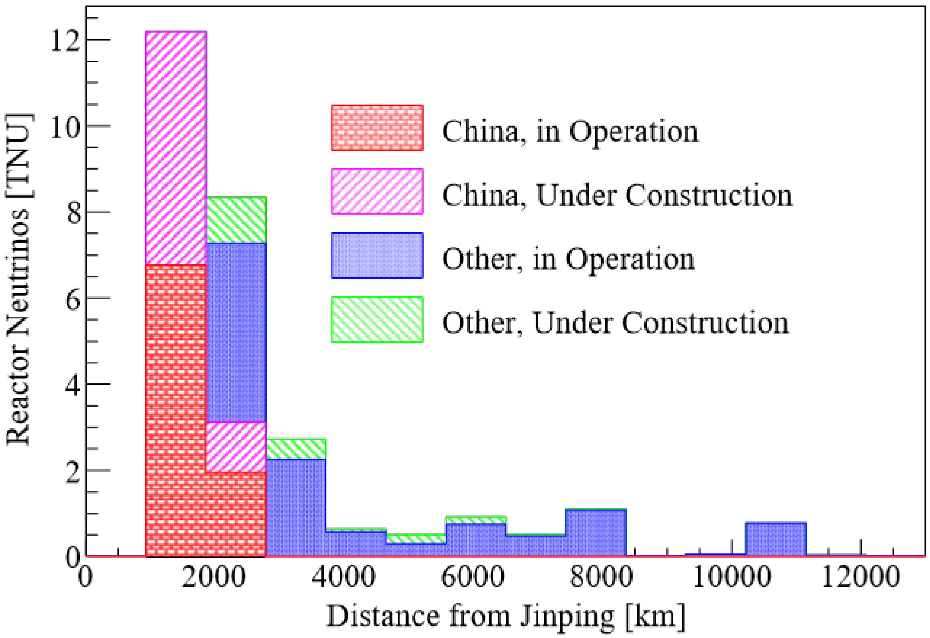
With 2 kton fiducial mass for solar neutrino (equivalently 3 kton for geo and supernova relic neutrinos)

1. Discover CNO neutrinos
2. Solar ν oscillation
3. Precise geoneutrino flux measurement and U/Th ratio
4. Study SRN

Geoneutrino consideration input

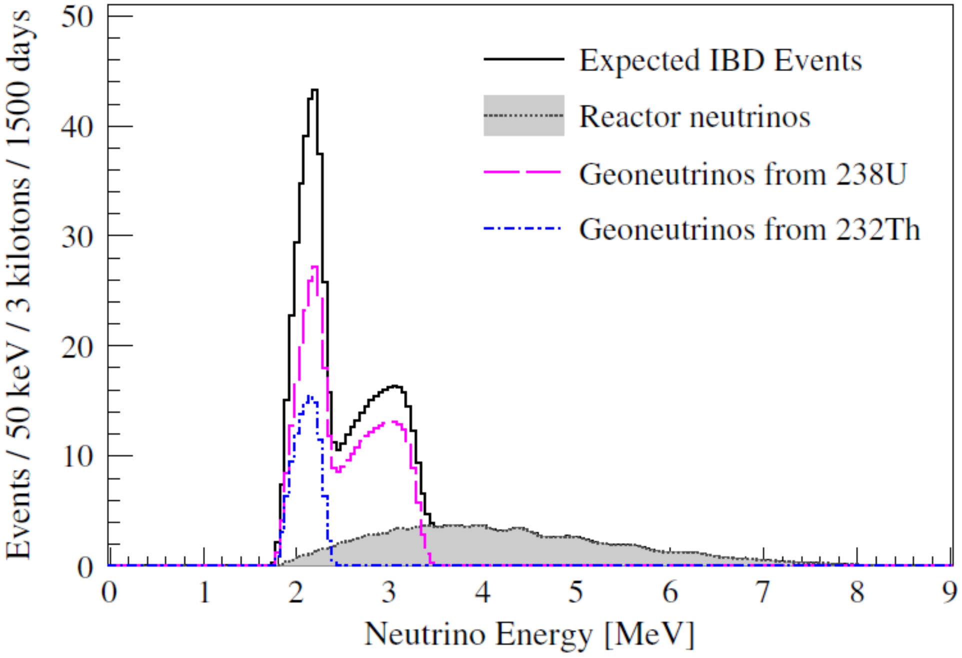
- Geoneutrino flux
- Neutrino oscillation
- neutrino spectrum from U and Th
- Inverse beta decay cross-section
- Number of H
- Background
  1. Reactors
  2. Cosmogenic background (depth)

$$\phi(i) = \frac{X\lambda N_A}{\mu} n_\nu \int\int\int \frac{A(\vec{r}')\rho(\vec{r}')}{4\pi|\vec{r}' - \vec{r}|^2} P_{ee} d\vec{r}'.$$



Prediction: IBD Events at Jinping

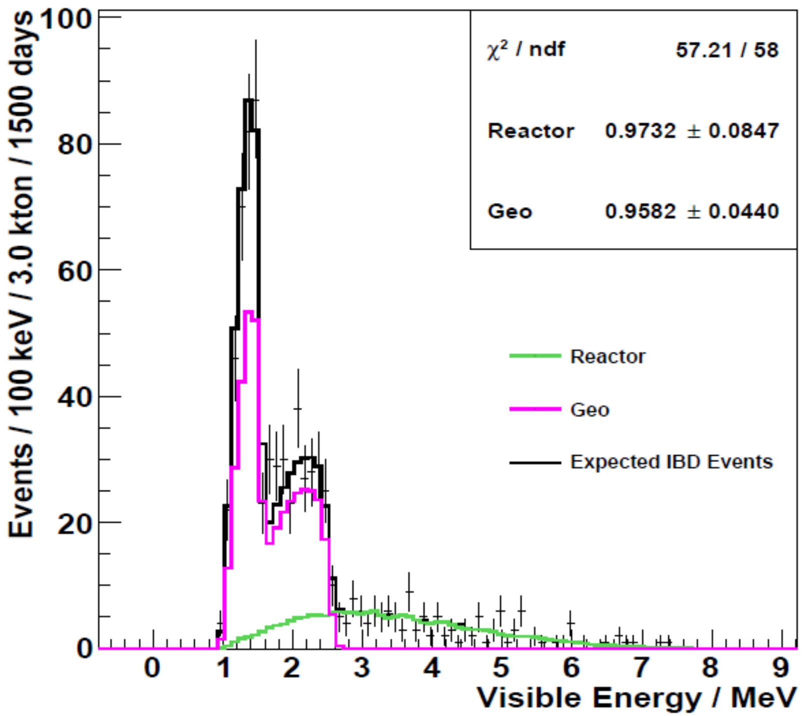
- Detector:
  - 3 kton
  - 1500 days
  - 500 p.e.
- Signal/Background ratio:
  - SER: < 3.3 MeV

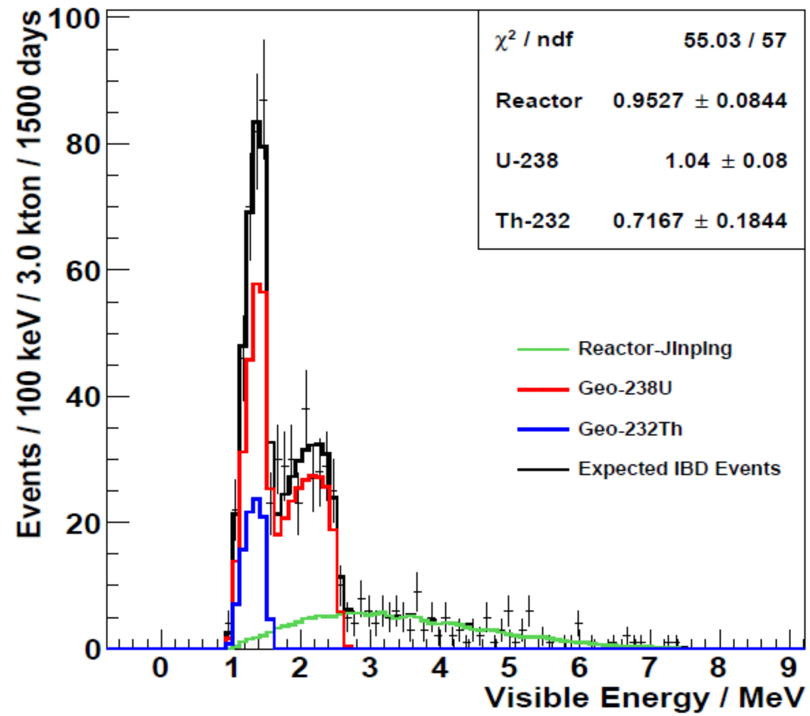


	Geoneutrino			Reactor	
	^{238}U	^{232}Th	Total	FER	SER
Event Rate (TNU)	46.7	12.7	59.4	27.8	6.8
Total Events	414.5	113.6	527.3	246.8	60.4

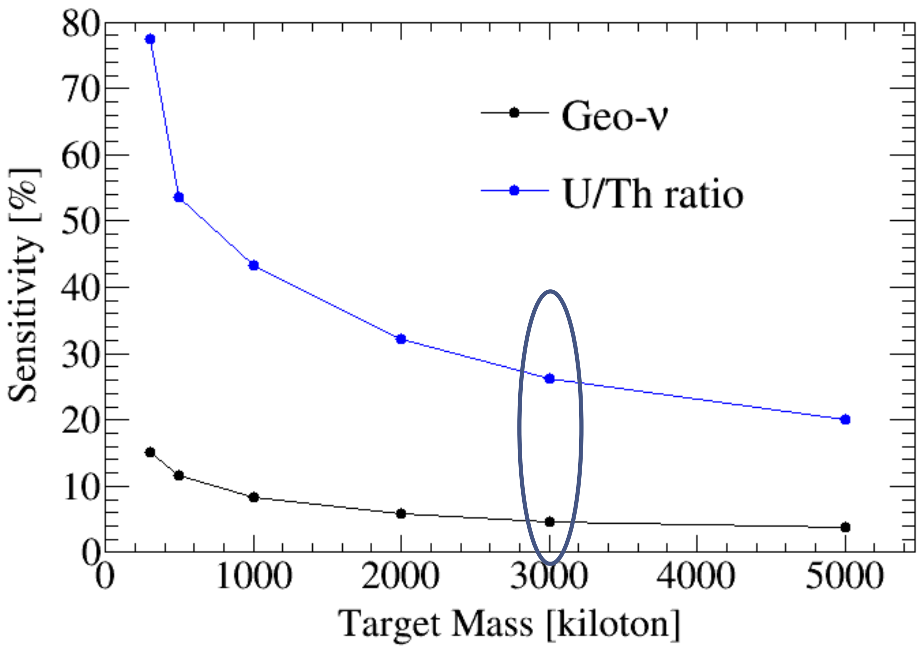
Extract Geo-neutrino signal

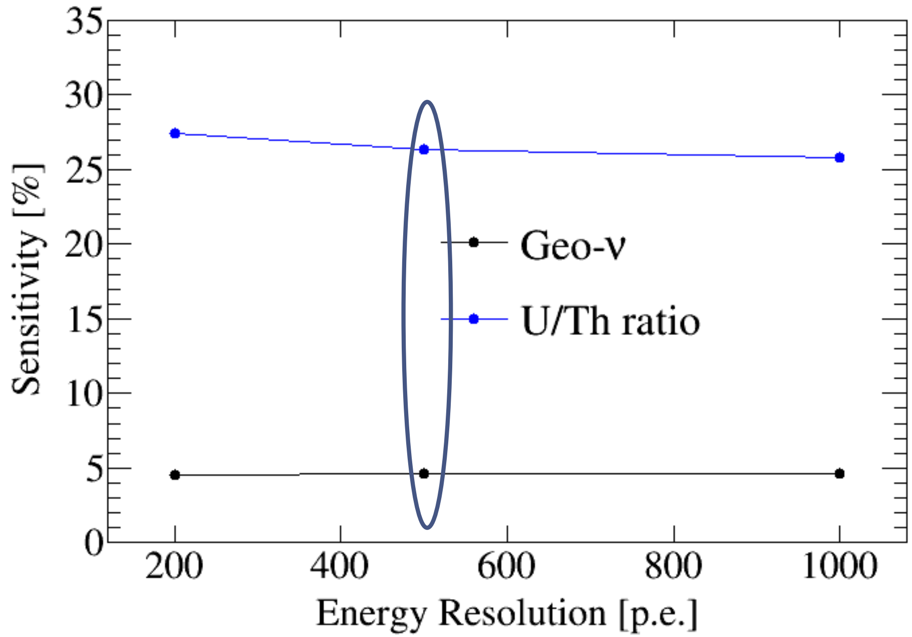
- We fit the energy spectrum of all candidates with Geo-neutrino signal shapes (U, Th chains) and reactor neutrino shapes, get the amount of U and Th





Predicted Sensitivity:





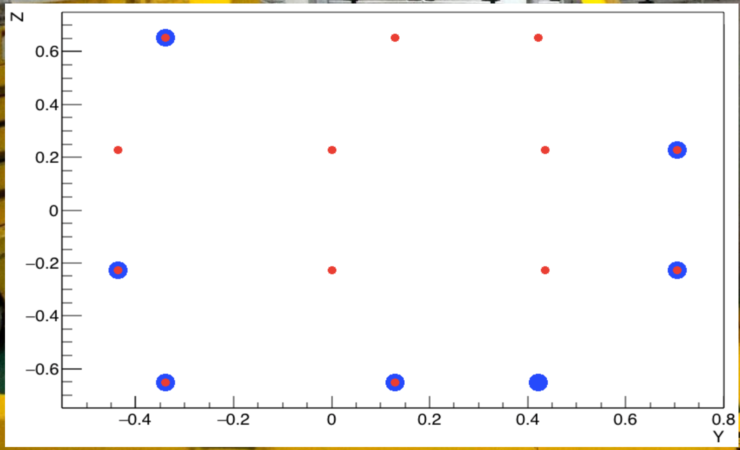
- ❑ Detector size (for fixed live-time of 1,500 days) makes a difference.
- ❑ Sensitivity of geoneutrinos does not depend on energy resolution.

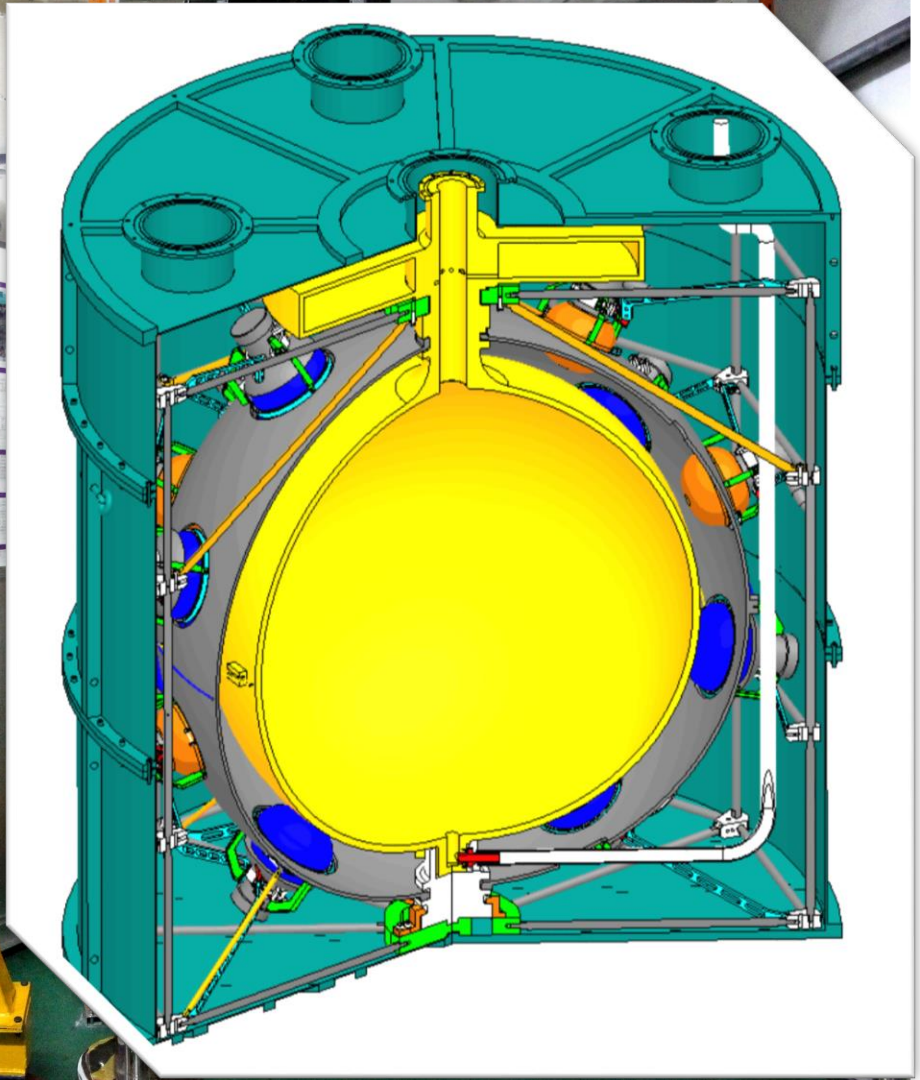
To get a conclusion of mantle neutrinos, we need an estimation of crust contributions.

One-ton prototype at CJPL-I

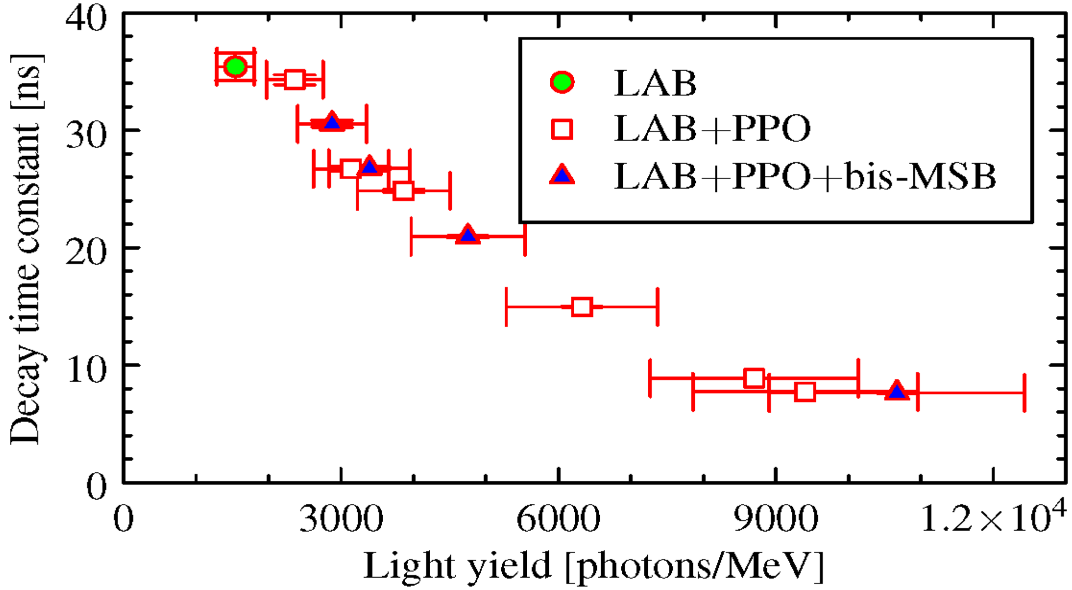
One-ton prototype at CJPL-I

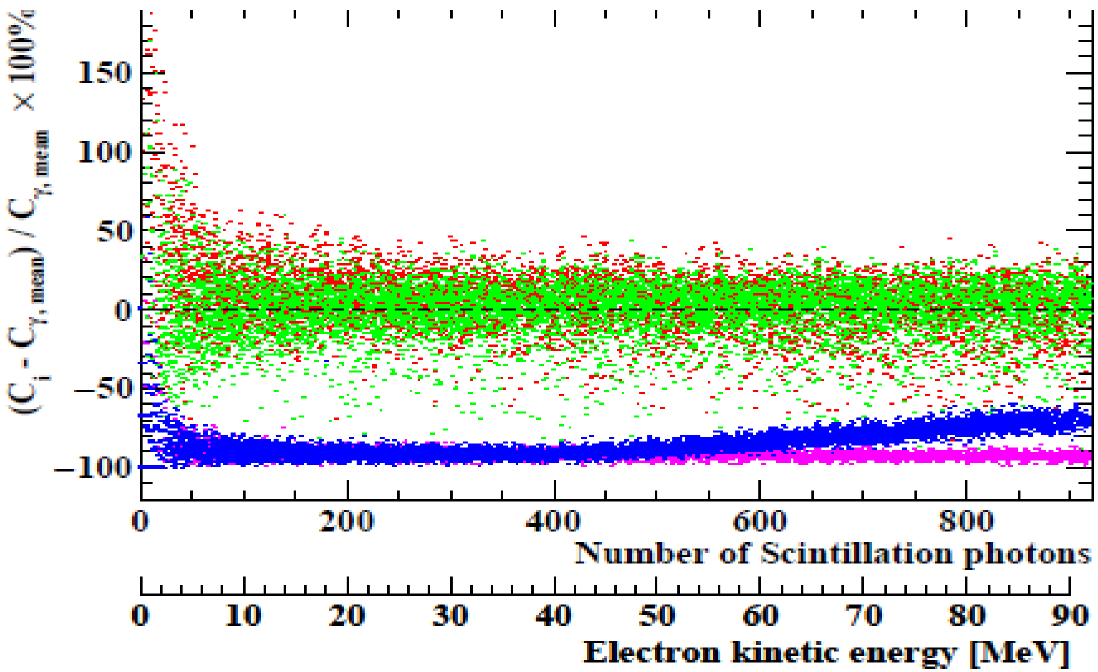
- Taking data with water
- Cherenkov events identified
- Next, water – liquid Cherenkov scintillator replacement





New: Liquid Cherenkov Scintillator





- Distinguish Cherenkov and scintillation light
- Reasonable light yield

- Directionality (> 5MeV)
- Particle identification (mainly for electron, muon, proton, minor effect for gamma and positron)

Useful for proton decay, 0νββ search, and ADS neutrino etc.

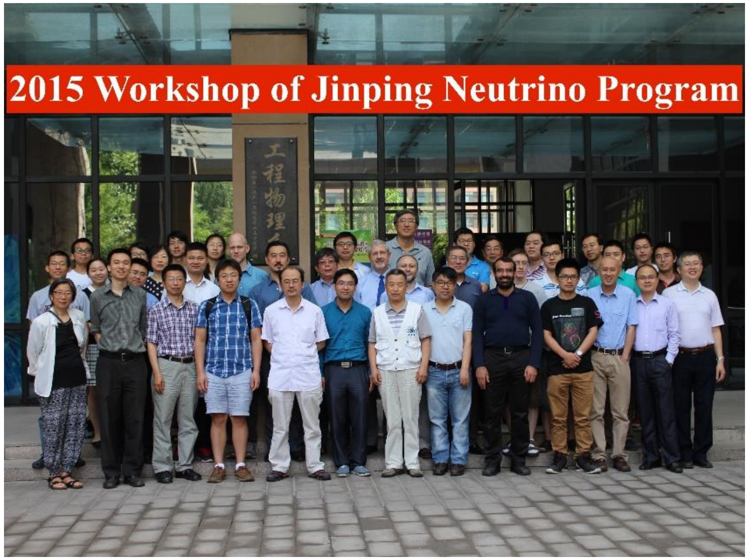
Other R&D activities

- 100% coverage, 98% efficiency PMT reflector
- Low background stainless steel
- Simulation and analysis software
- Rock damage zone
- Mechanical studies
- Electromagnetic Calorimeter function
- PMT property measuemernt
- Low background technology research

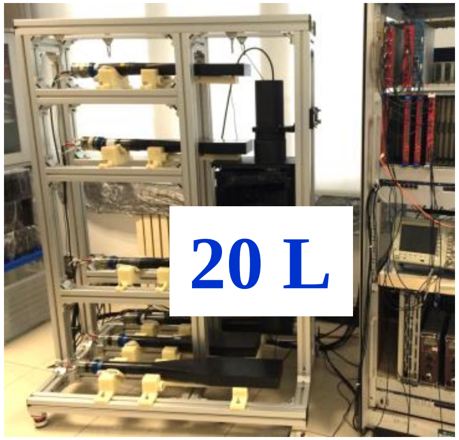
- A lot of more by our pre-collaboration members are not mentioned here.

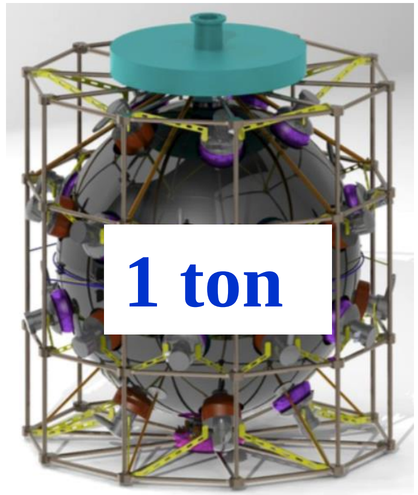
Meeting and Pre-collaboration

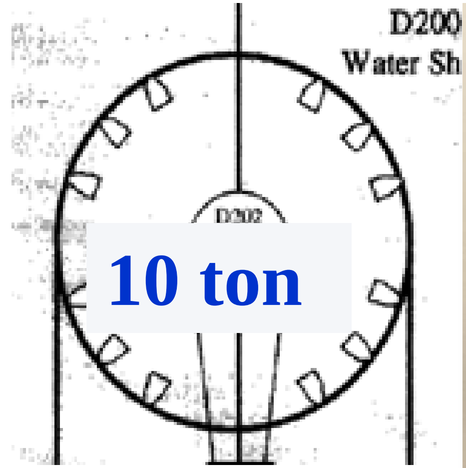
1. 2015, 2017 two international workshops
2. Pre-collaboration: Tsinghua, SYSU, Queen's University, UCAS, Guangxi University, Shandong University, BNL, University of Maryland, Technische Universität Dresden, Mainz University, Charles University, University of Michigan, Tohoku University, Nanjing University, Wuhan University

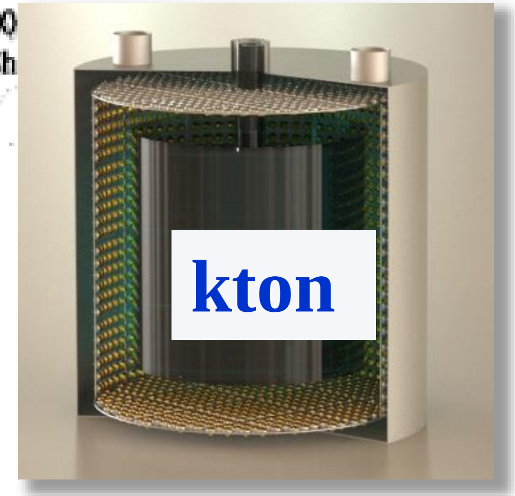


Plan









1. A ~10-ton prototype will be build next for testing the final plan for PMT, liquid Cherenkov scintillator, structure etc.

2. kton detector is in schedule

Conclusion

- Many basic questions for solar, geo, and supernova relic neutrino detections are unsolved.
- Jinping will provide complementary measurement with JUNO, for example, geoneutrinos.
- Many R&D efforts: liquid Cherenkov scintillator, 1-ton prototype, etc.
- Hope to probe deep in the future

More details can be found at http://jinping.hep.tsinghua.edu.cn/

Thank you for your attention.