Jinping Neutrino Experiment

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May 23, 2016

Contents:

Neutrino ---- From a CONCEPT
to REALITY
to a PROBE

Neutrino

Mass < 1 eV (electron 0.5 MeV)
Charge = 0 (electron +/- 1)
Weak interaction only

1931 Pauli proposed to neutrino

1956 Cowan and Reines neutrino observed — 1995 Nobel

1962 Muon neutrino — 1988 Nobel

1962 R. Davis Solar neutrino and problem

1980 Atmosphere neutrino problem and super nova neutrino — 2003 Nobel

2001 Solar neutrino oscillation and matter effect — 2015 Nobel

2012 Daya Bay non-zero θ_{13} — 2012 Science breakthrough

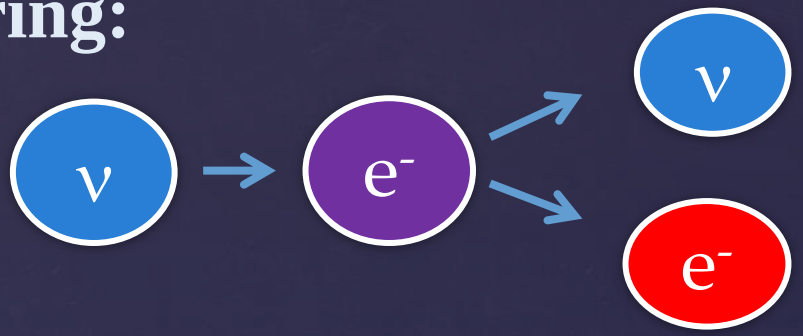
2013 Ultra-high cosmic neutrino — 2013 Phys. World breakthrough

Daya Bay (JUNO) is leading our neutrino research in China

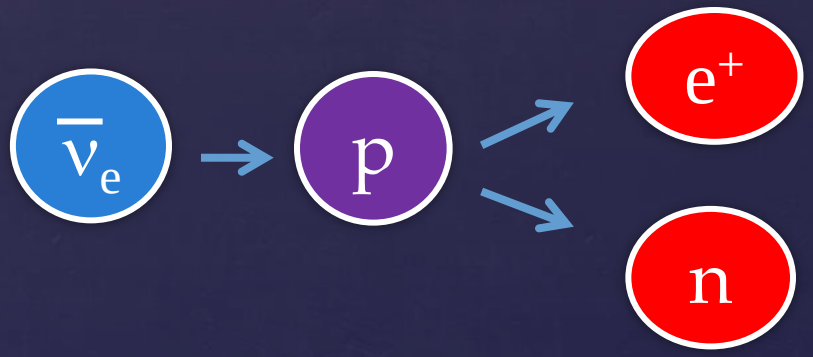
Neutrino Detection

Neutrino is very hard to detect

Neutrino-electron scattering:



Inverse-beta decay:



$$E_{e\pm} \Rightarrow E_{\nu}$$

Detect positron, electron, and neutron

Neutrino may go through 1×10^{17} m without interaction

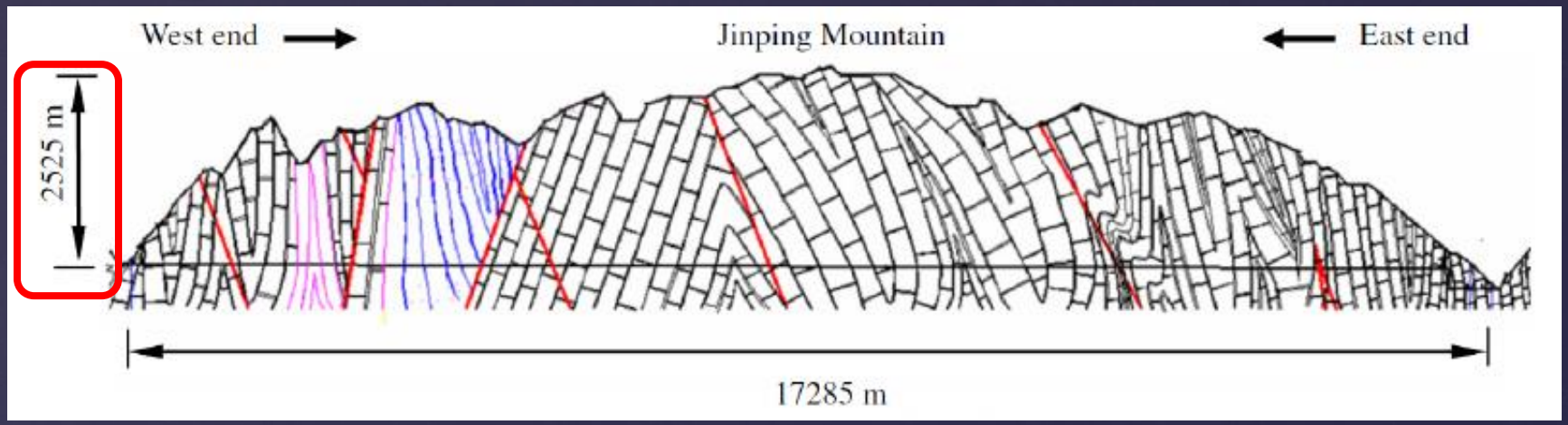
$\Rightarrow$ Large detector
$\Rightarrow$ Low background
  $\Rightarrow$ Deep (Low cosmic-ray muon rate)
  $\Rightarrow$ Clean (Low natural radioactivity)

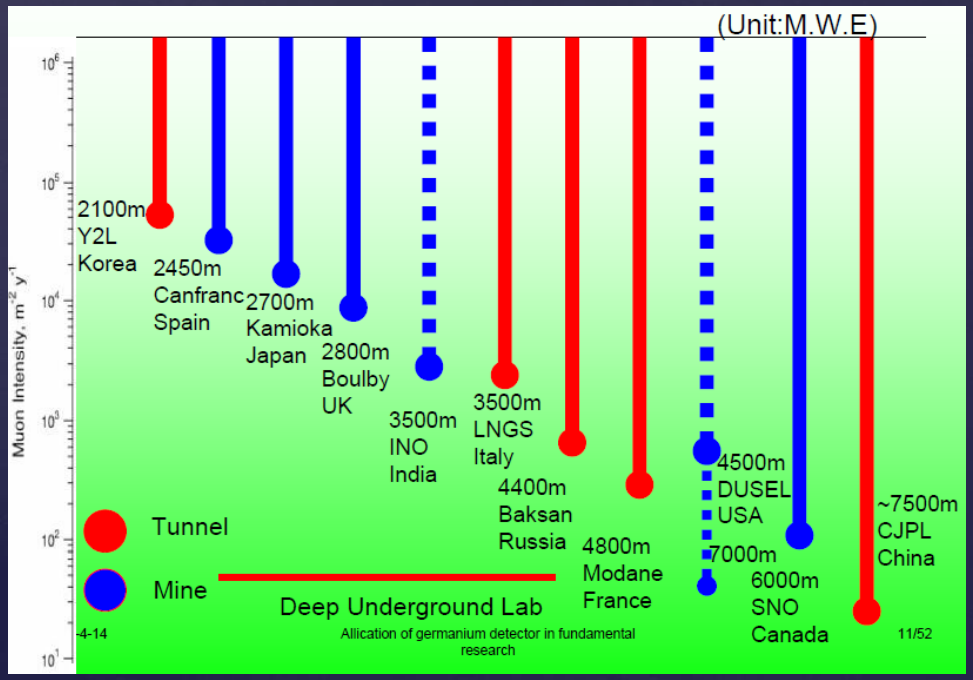
Jinping Neutrino Experiment

China JinPing Laboratory (CJPL)

Flight: Beijing - Xichang (Stop by Chengdu)
Car: Xichang - Jinping (2 hours)

Depth and Muon Flux

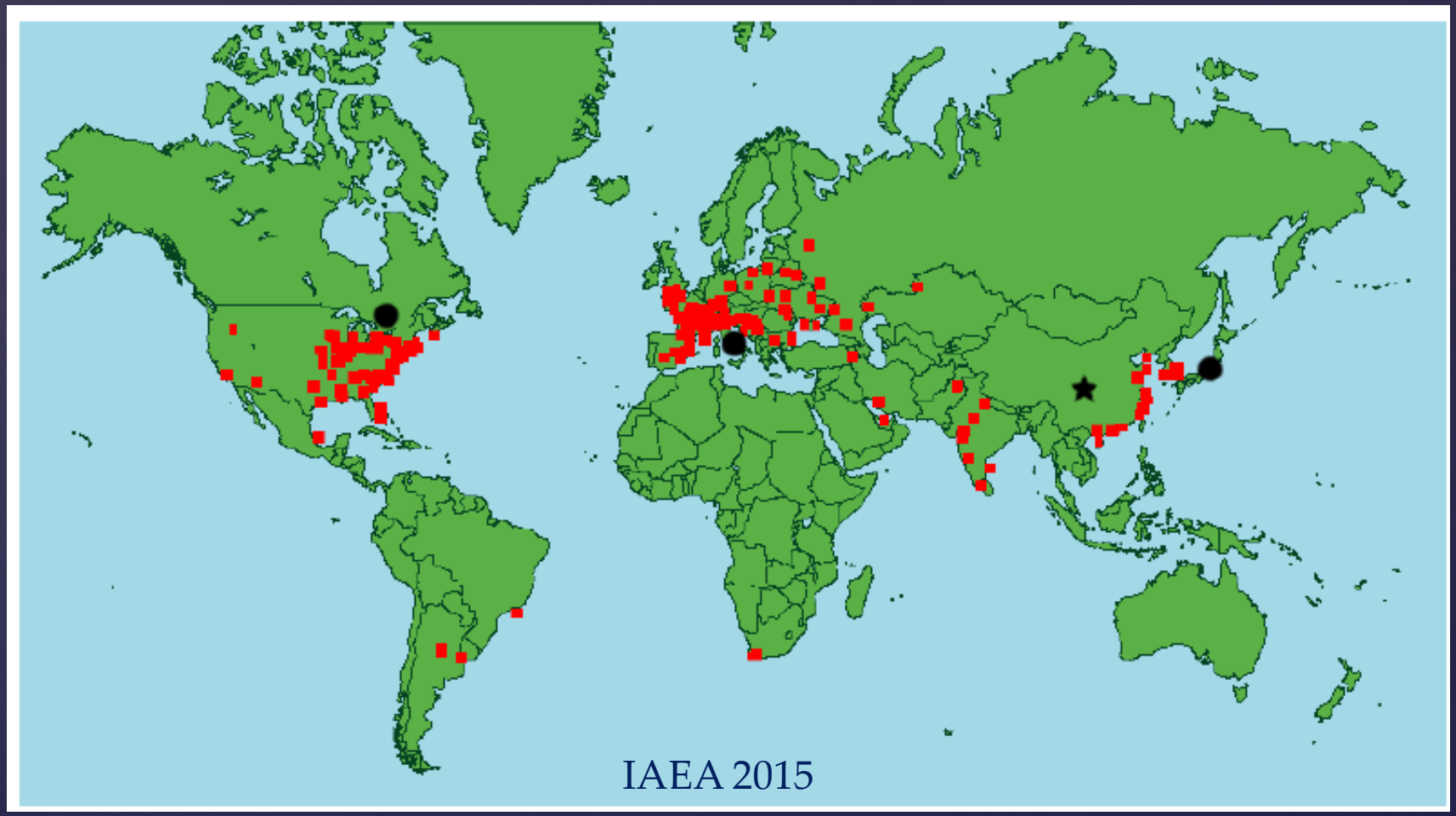




1/200 of LNGS

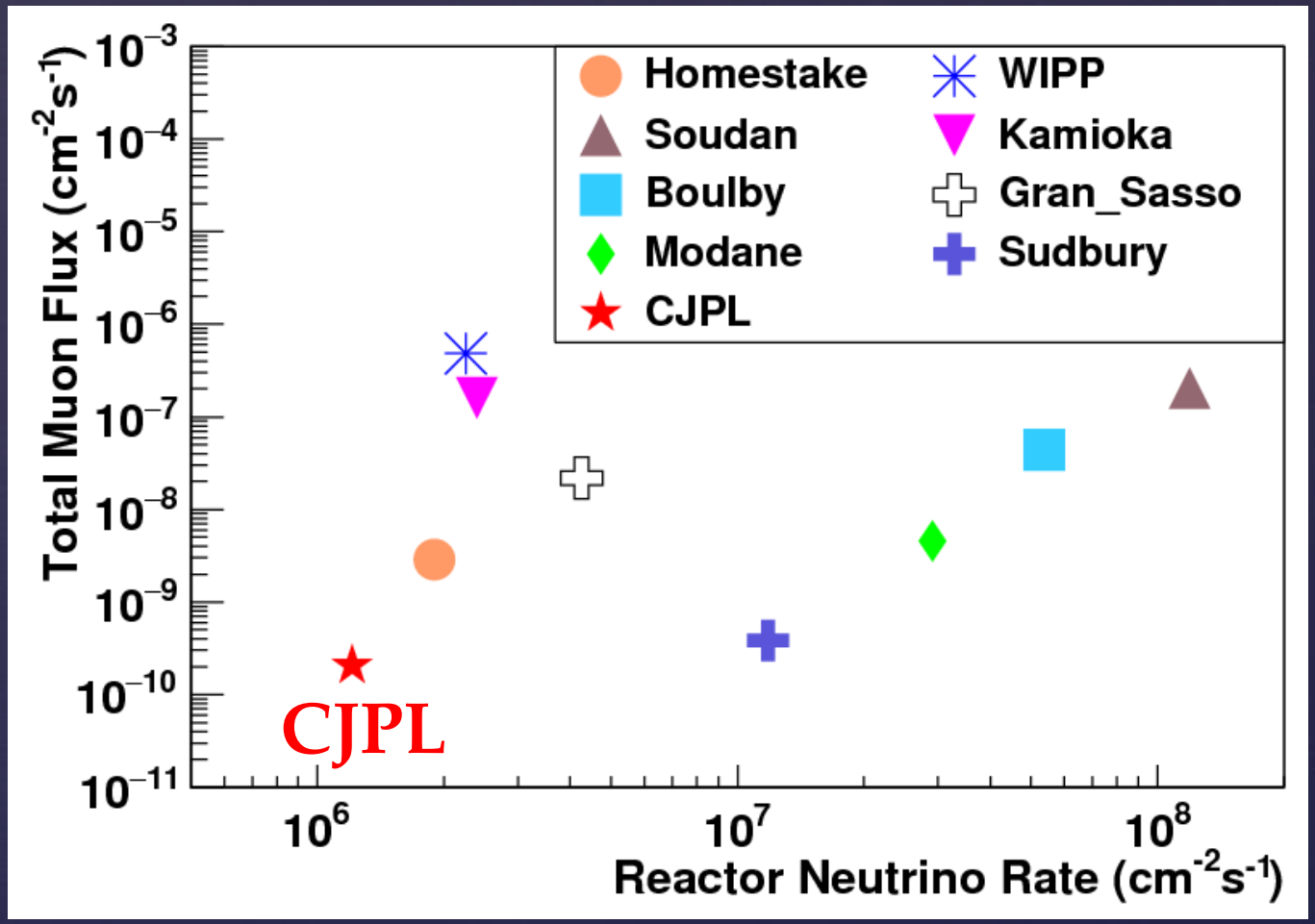
1/2 of SNOLAB

Reactor Neutrino Background

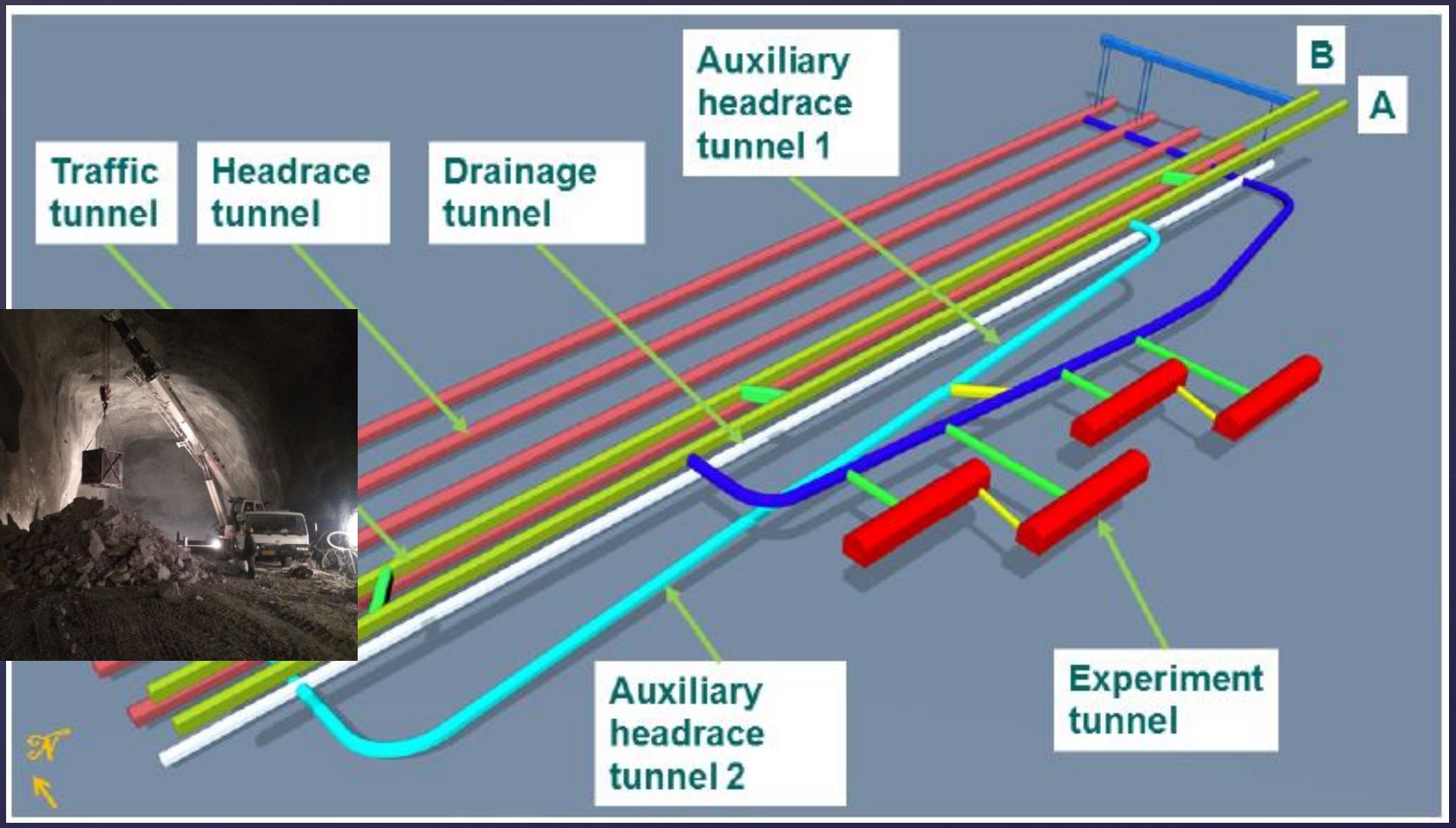


Closest reactor 1200 km

Ideal for Low Background Experiments

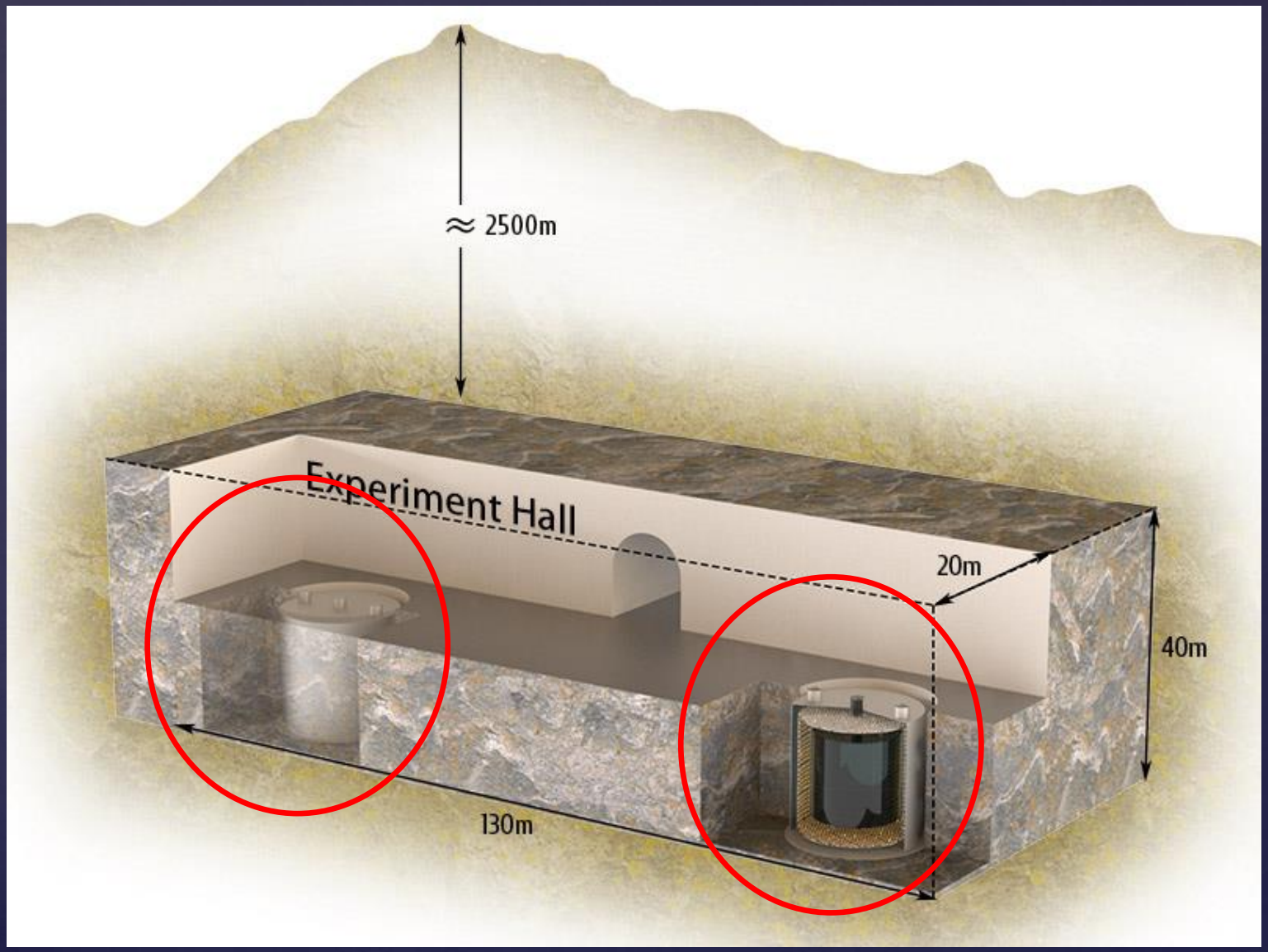


CJPL Phase II

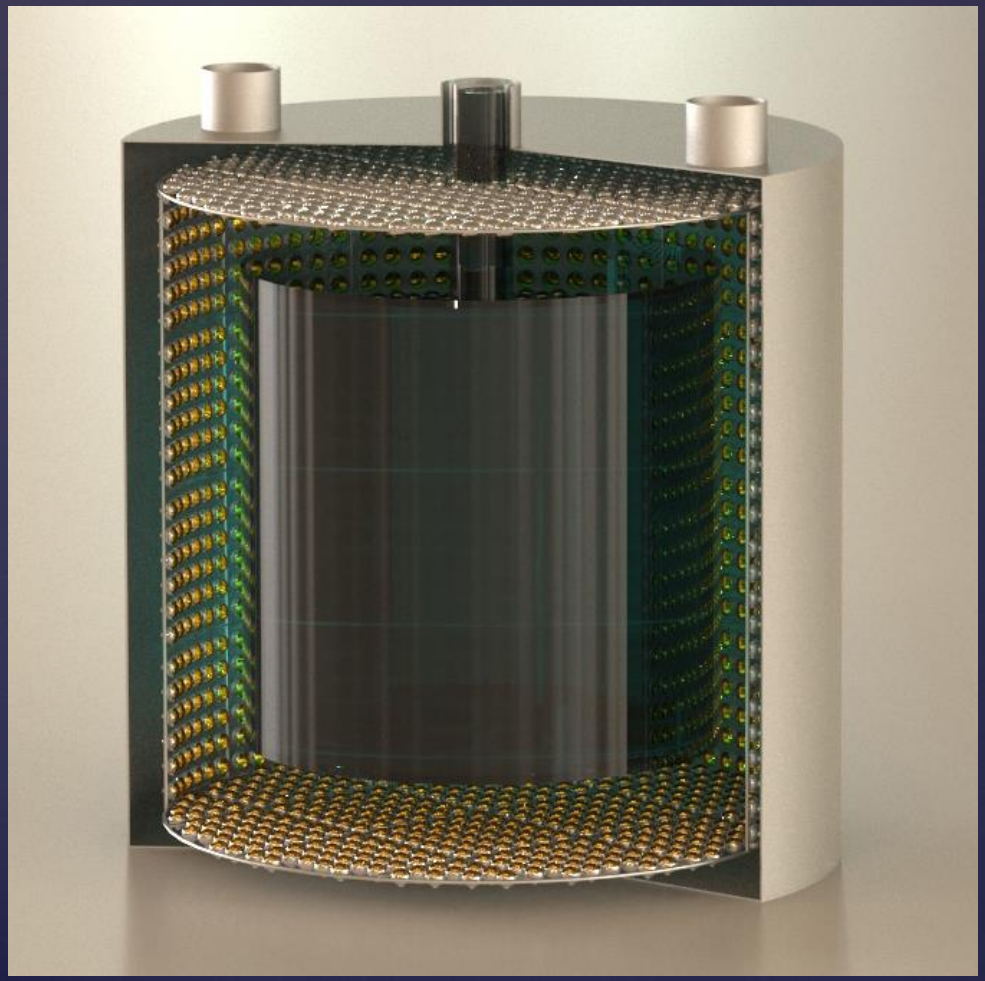


Each hall > $12 \times 12 \times 130$ m^3
(Minimal dimension is more important than total space)

Jinping Neutrino Experiment

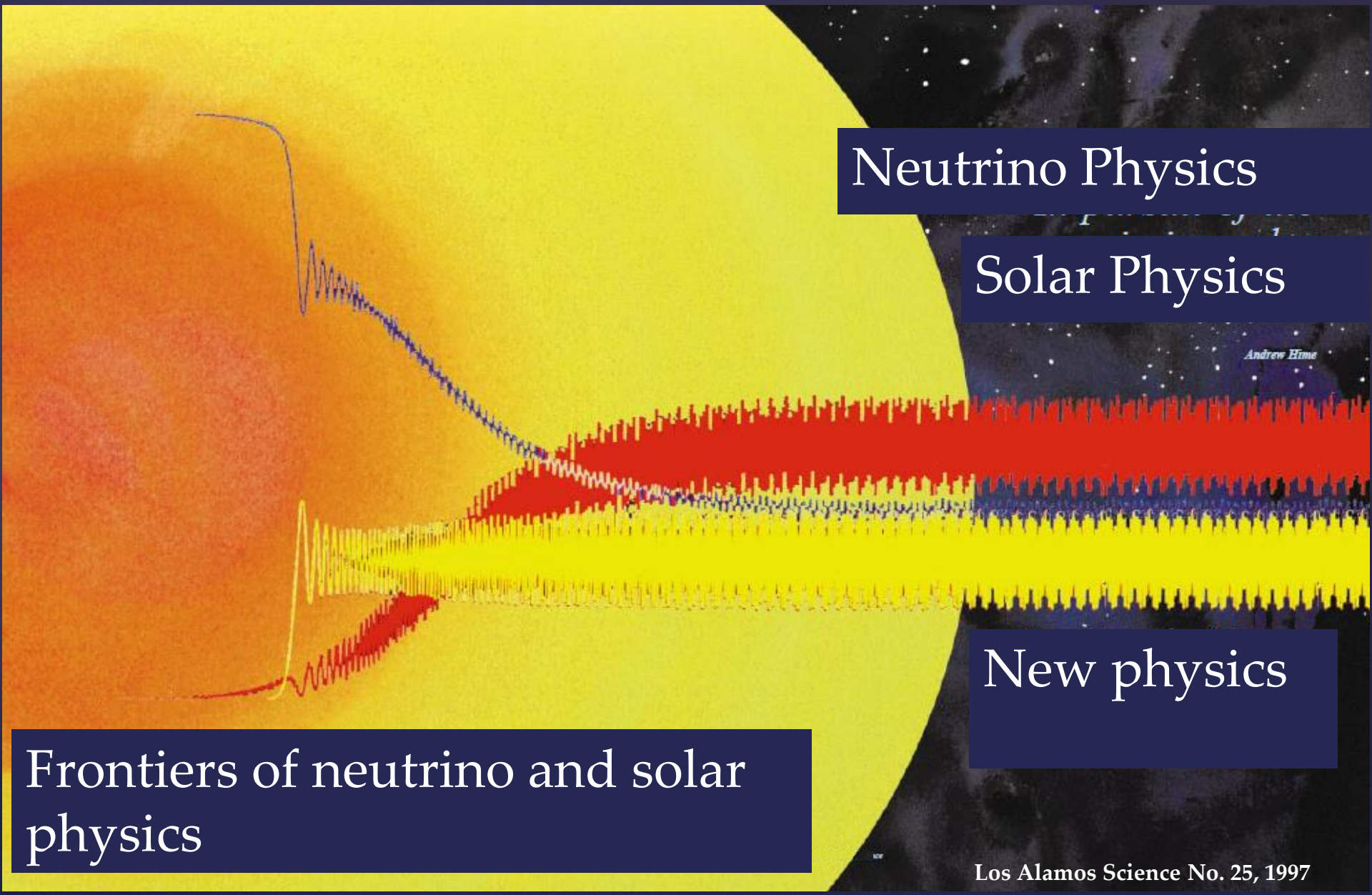


Neutrino Detector Concept



- For solar neutrino: Effective volume 1000 ton/det, total 2000 ton
- For geo-neutrino and supernova: Effective volume 1500 ton/det, total 3000 ton

Solar Neutrino Physics


Neutrino Physics
Solar Physics
Andrew Hime
New physics
Frontiers of neutrino and solar physics
Los Alamos Science No. 25, 1997

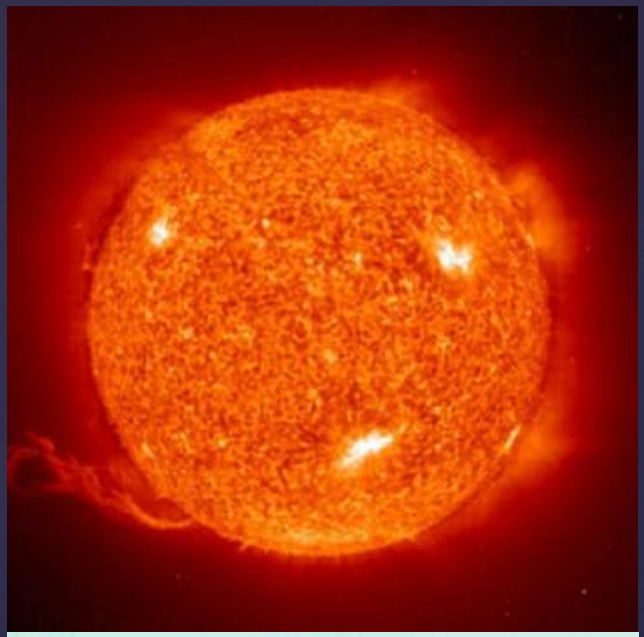
Standard Solar Model

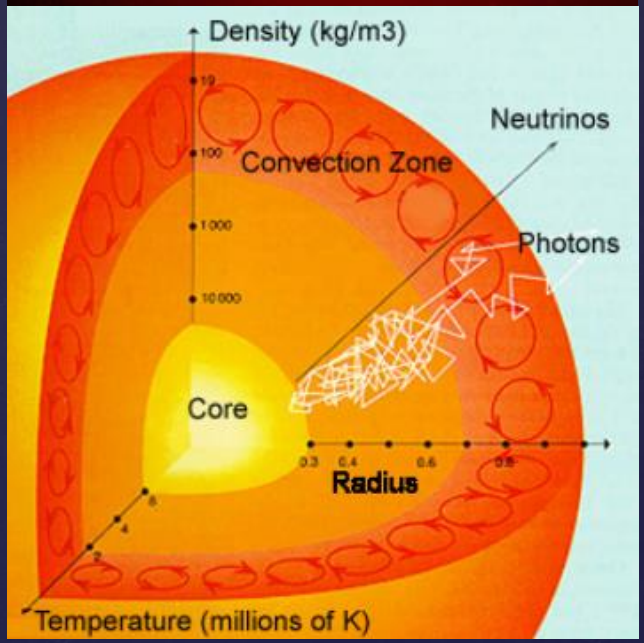
1. **Fueling mechanism：**
   pp chain
   CNO cycle

2. **Energy transmission：**
   Radiation - transparency
   convection

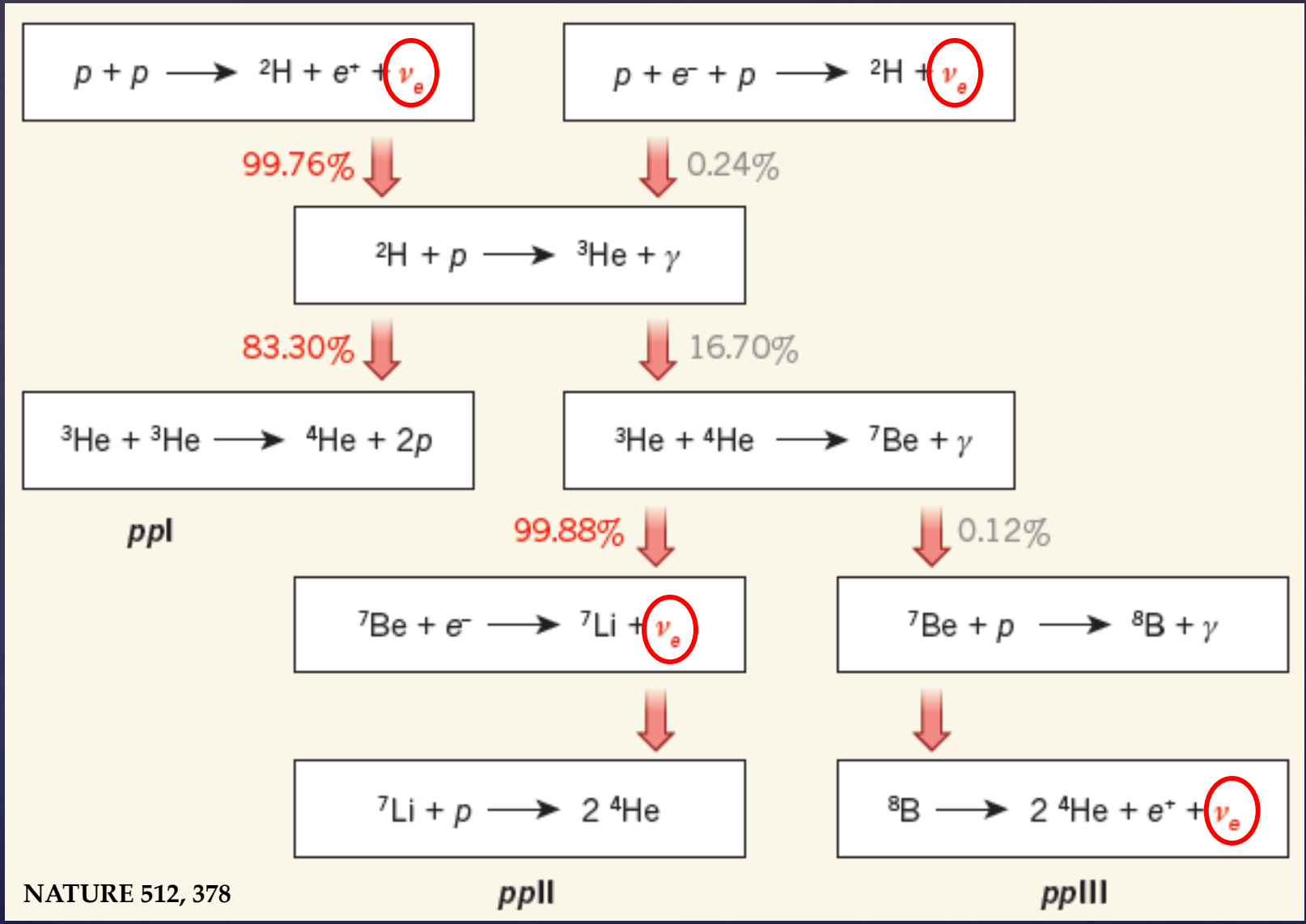
3. **Balance of the gravity, radiation, and particle pressure**

4. **Initial conditions**
   Abundance of H, He, metal elements
   Radius, age, mass …

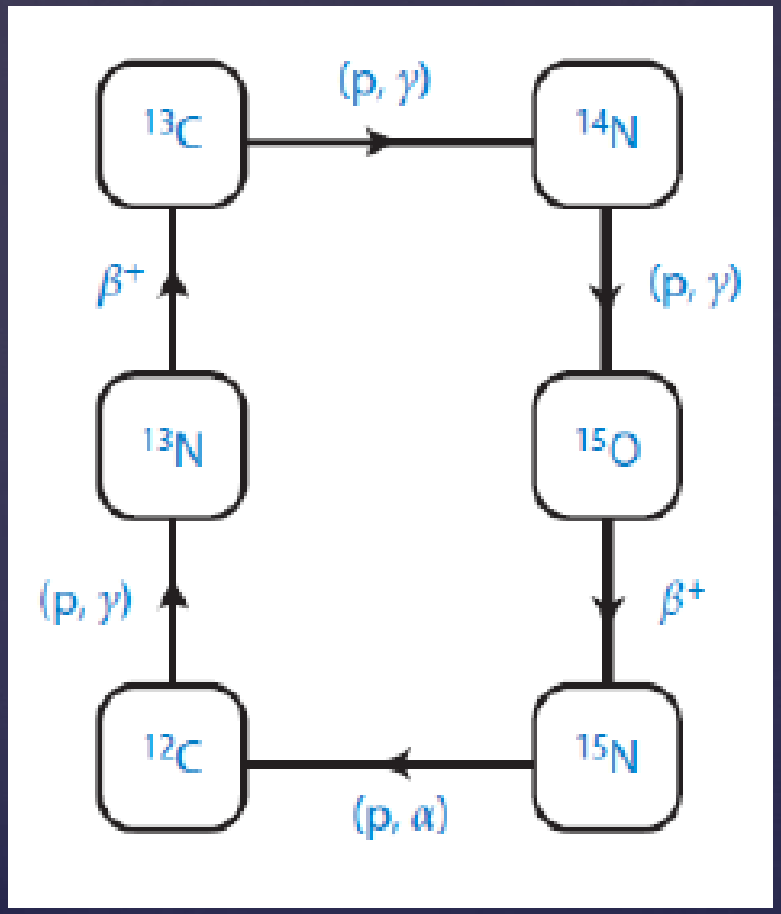


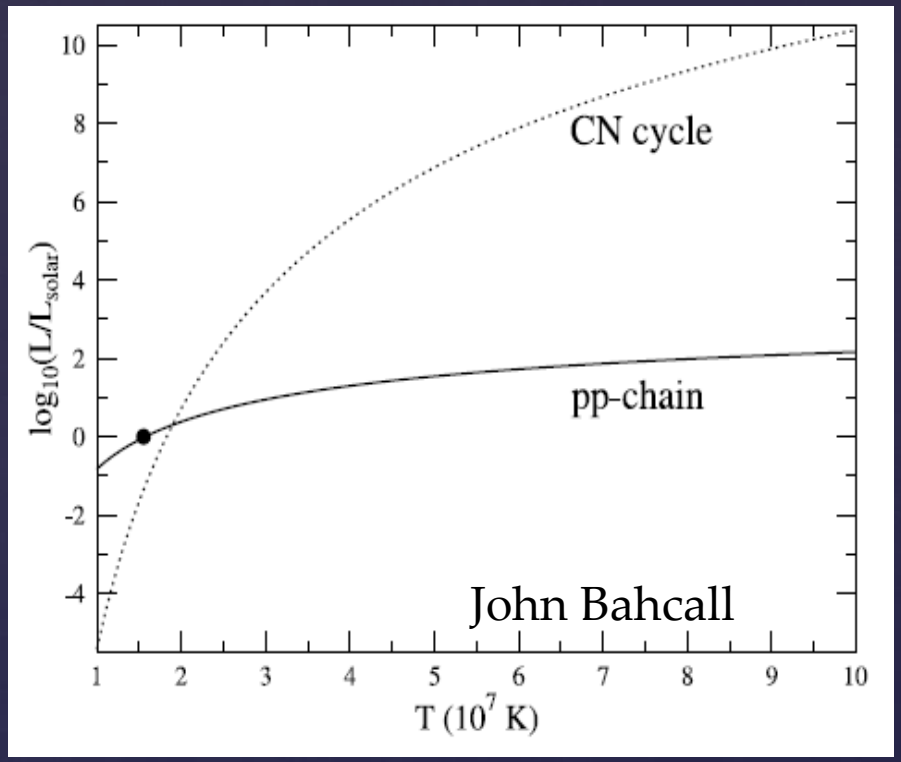


Neutrino Generation: pp chain



Neutrino generation: CNO Cycle

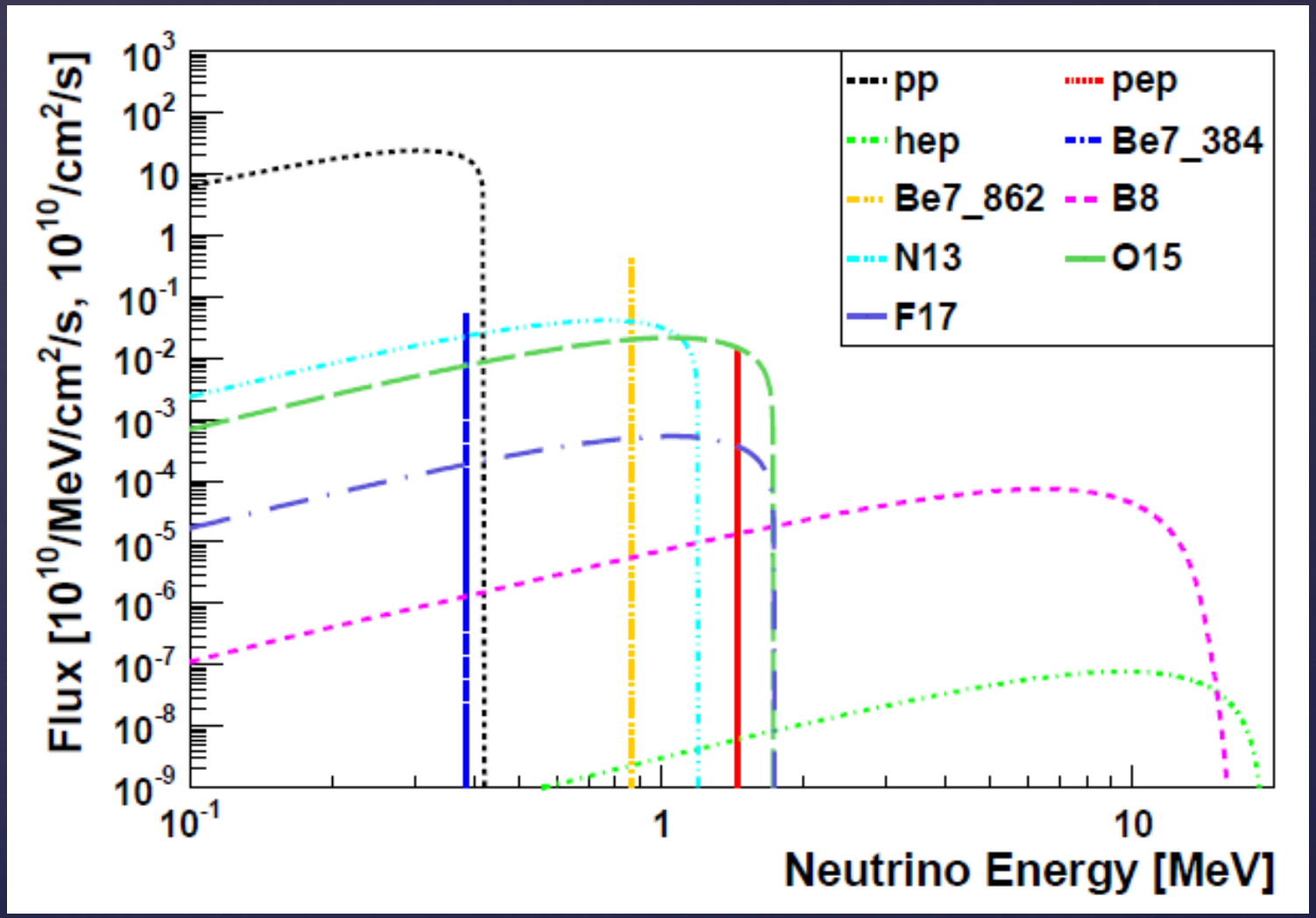




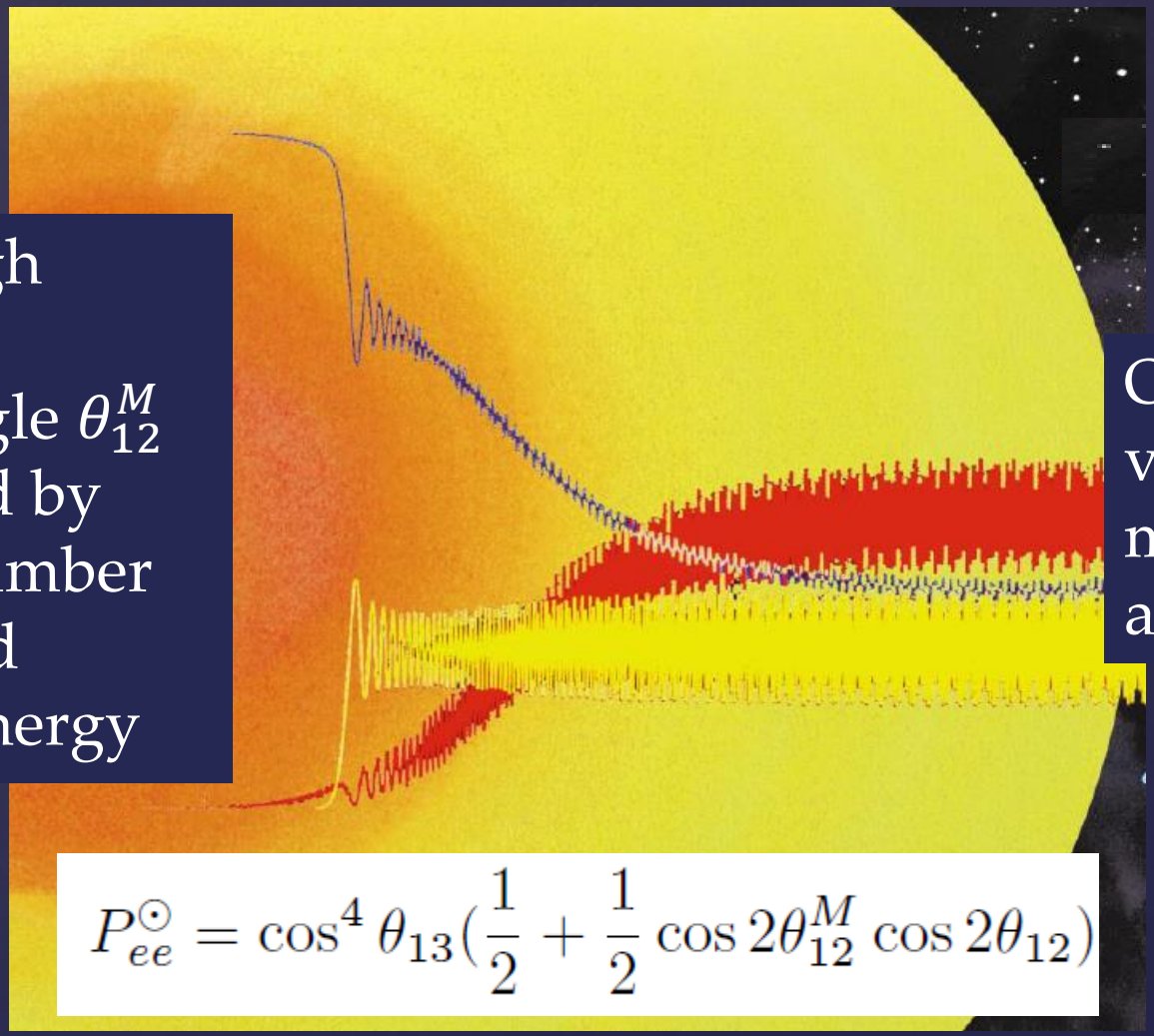
***pp* chain: Main process for the Sun**

CNO cycle: Main process for high temperature stars

Solar neutrino spectrum



Solar Neutrino Oscillation and Propagation



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

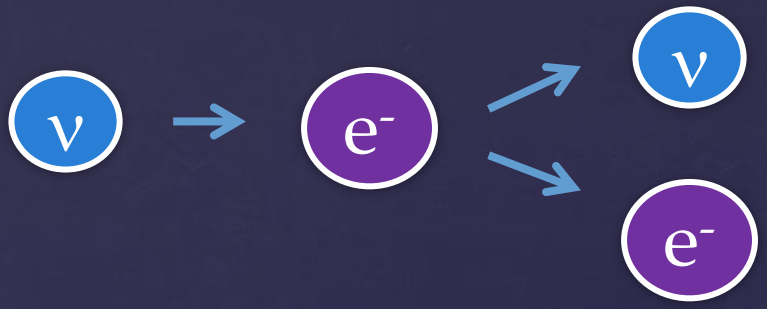
Outside: vacuum mixing angle θ_{12}

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

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

Solar Neutrino Detection

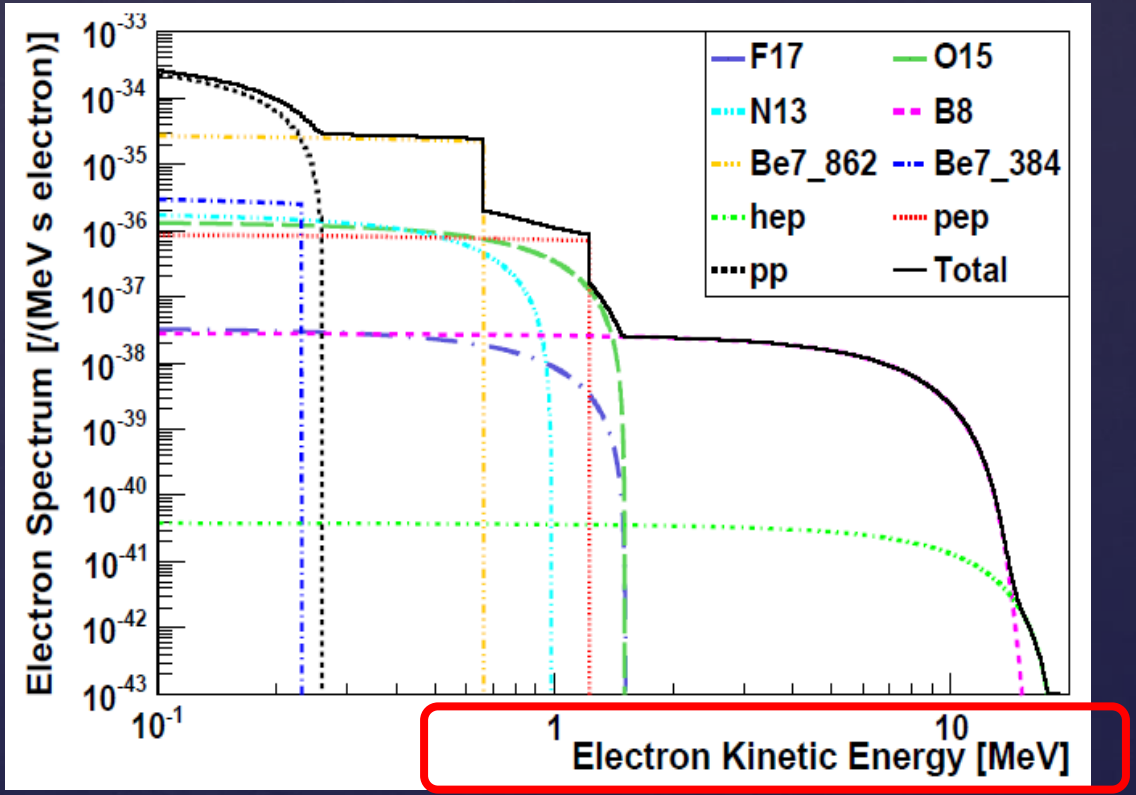
Neutrino-electron scattering



Measure the rates and spectra of recoiling electron, and suppress all possible backgrounds.

Solar Neutrino Detection

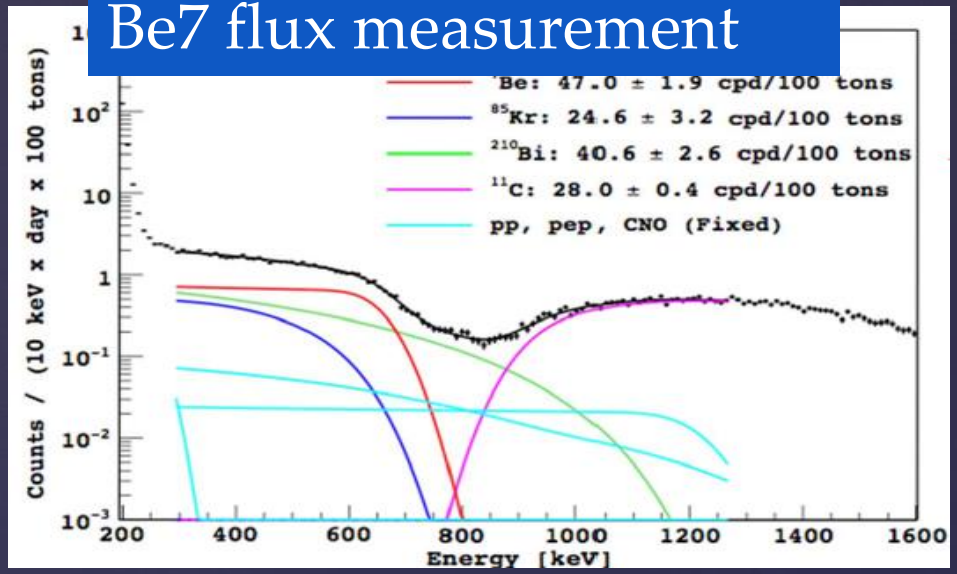
Recoiling electron rates and spectra



Current Detection Issues

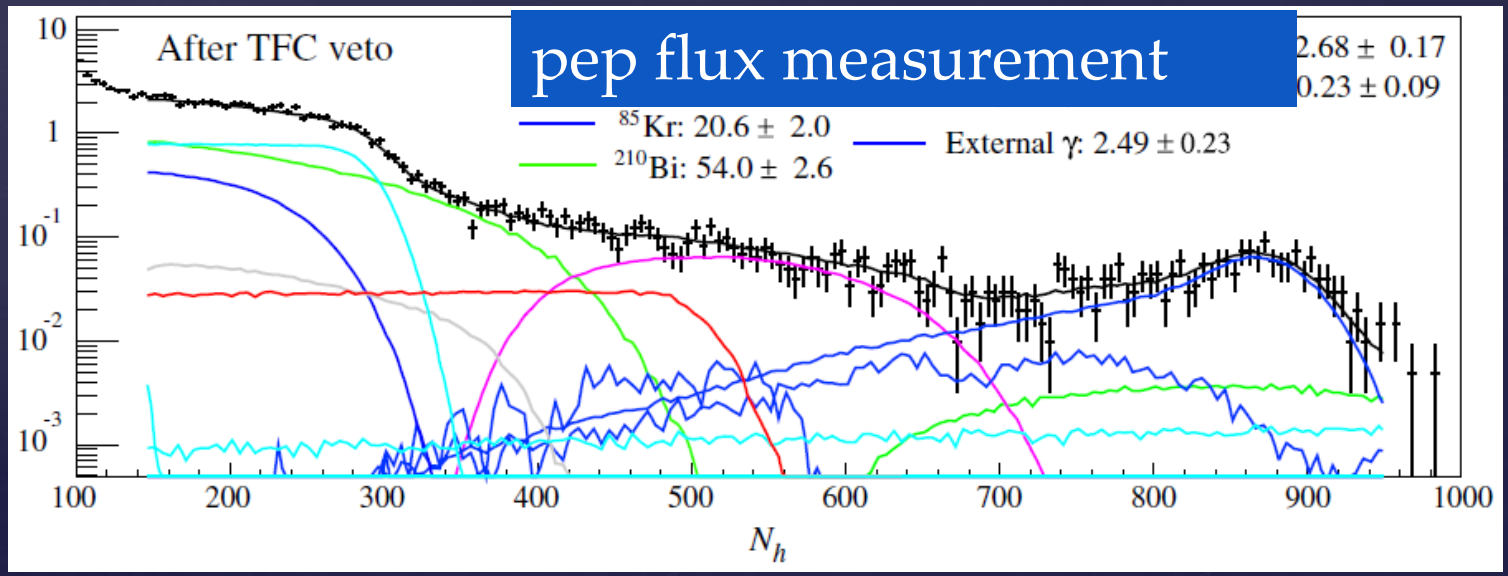
Borexino Exp.

Be7 flux measurement



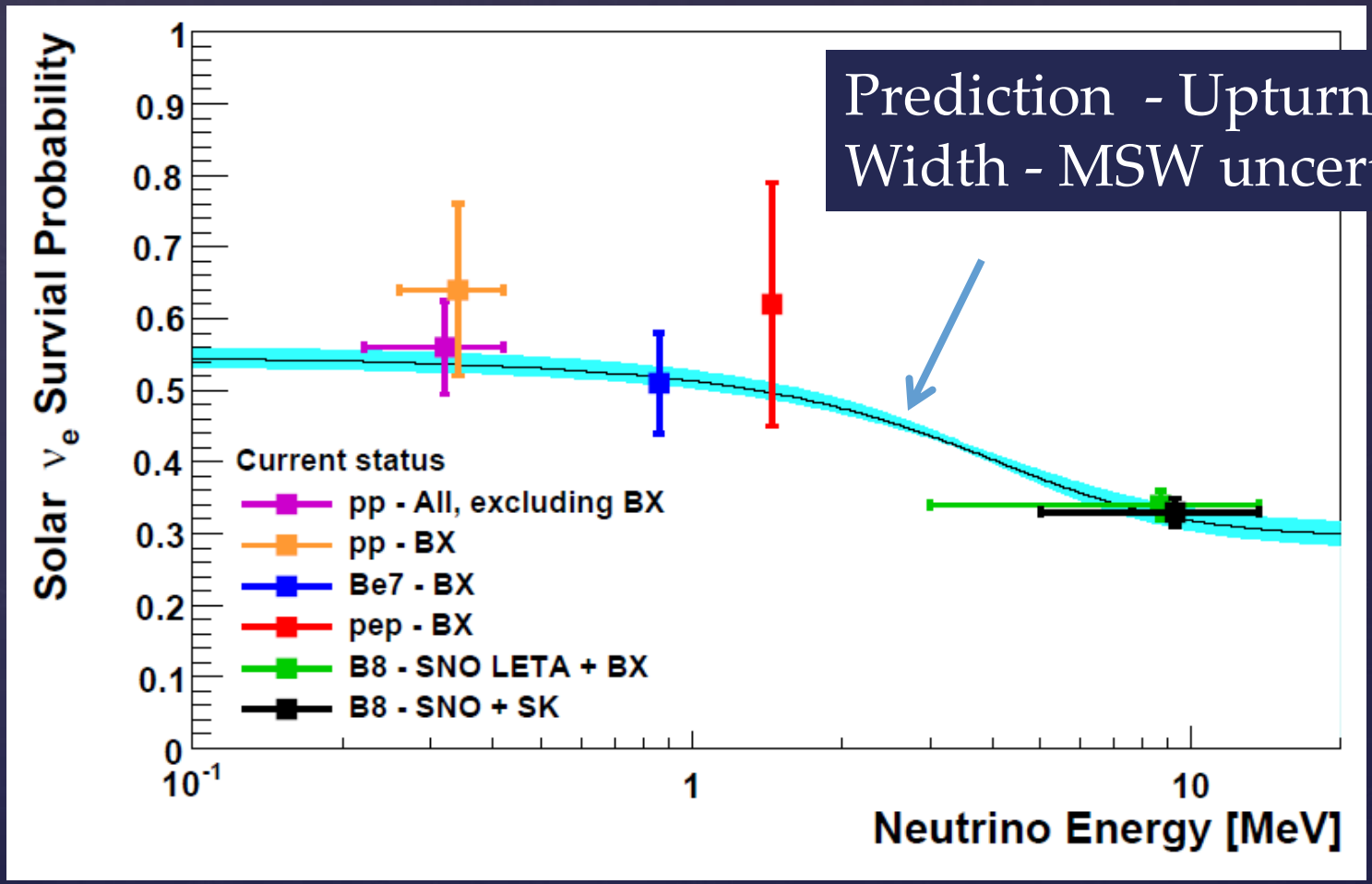
1. **Cosmi-ray muon induced ^{11}C, ^{10}C**
2. **^{210}Bi**
3. **External γ**

pep flux measurement

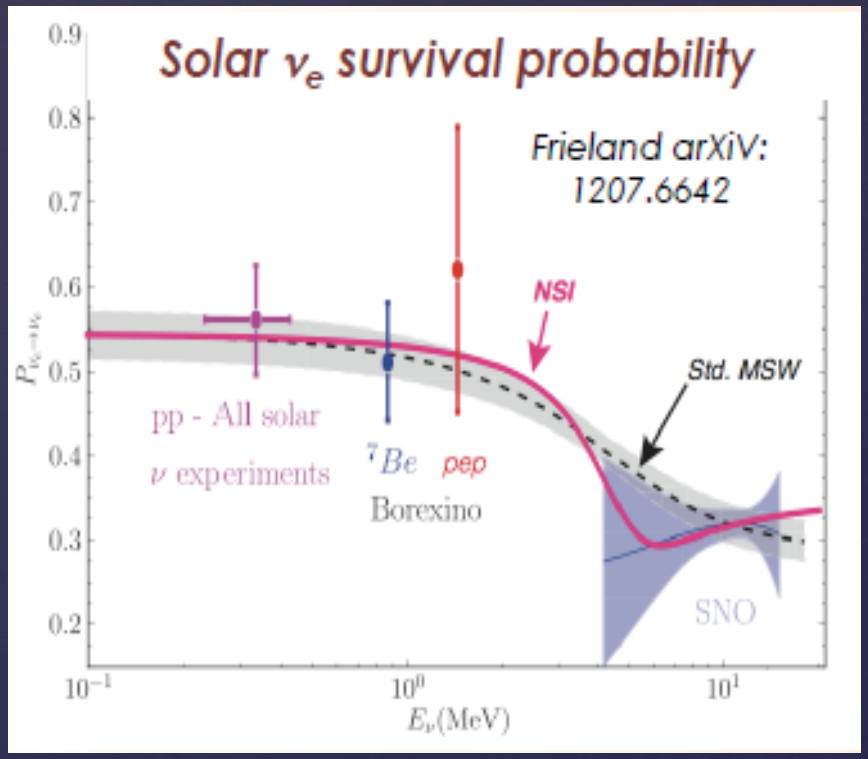


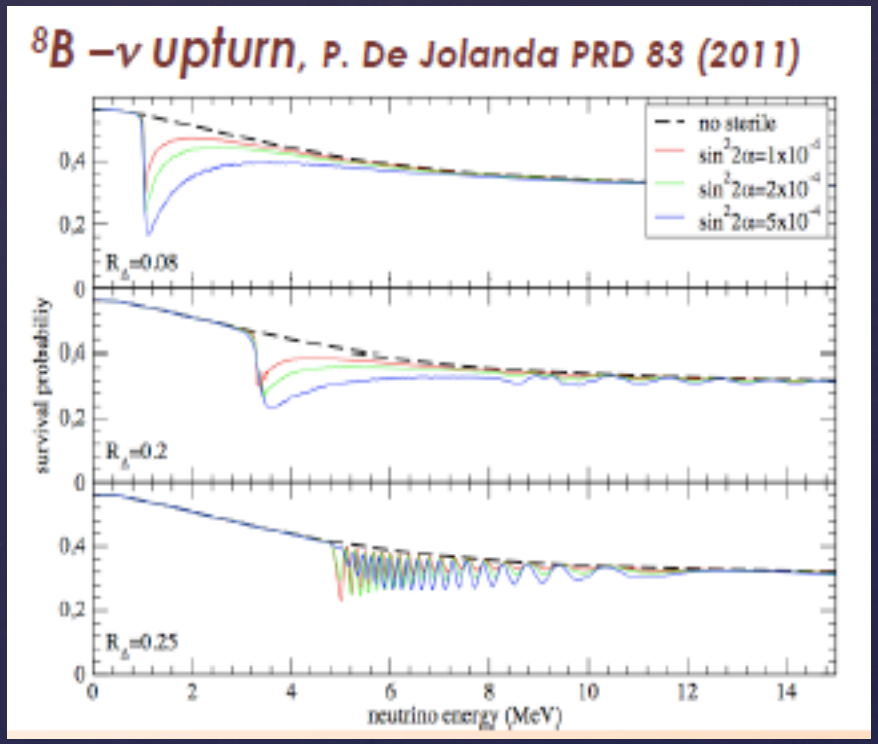
Current Status of Solar Neutrino Measurement

Question 1. CNO、hep are not detected pep with a poor precision



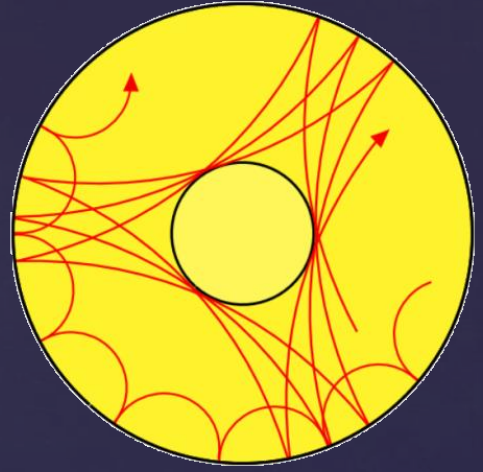
Question 2. MSW effect is loosely constrained



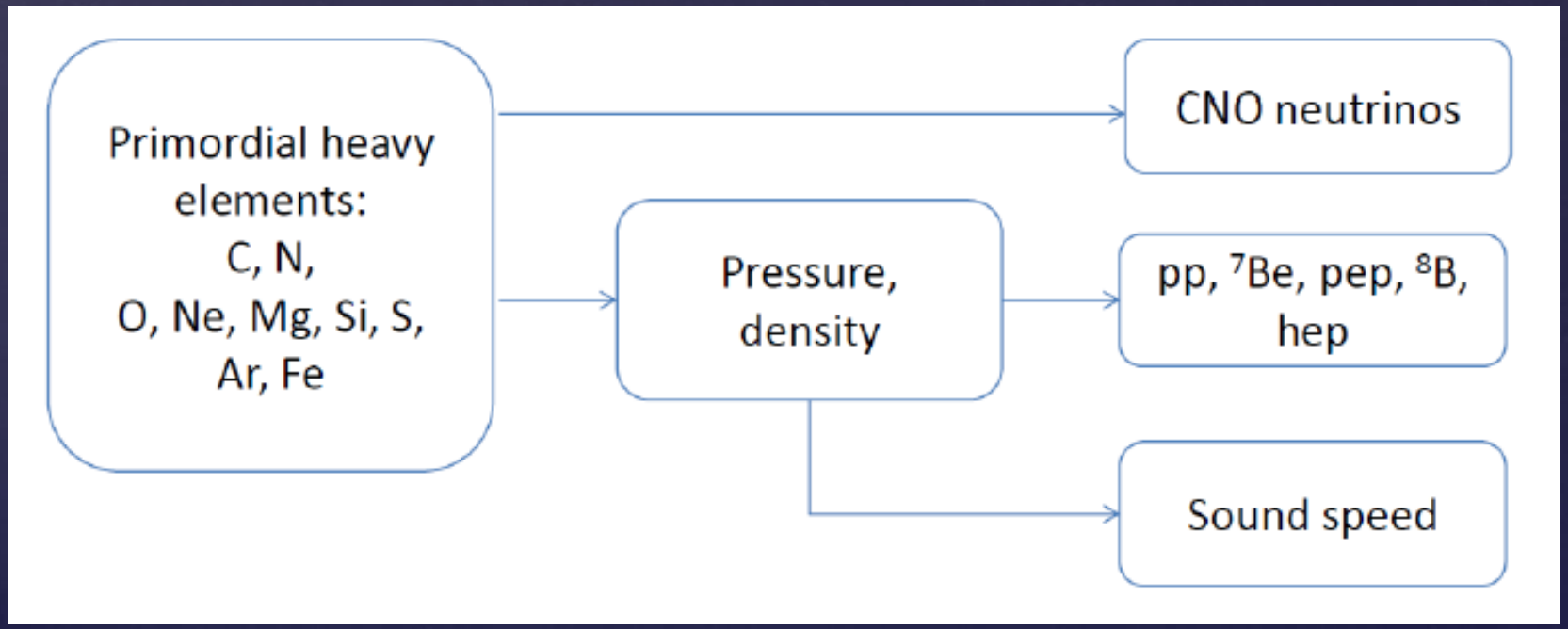


New physics:
non-standard interaction, sterile neutrino etc.
Expect high precision solar mixing measurement,

Challenge of Helioseismology



Question 3. New (better) calculation of Solar model is conflicting with helioseismology measurement



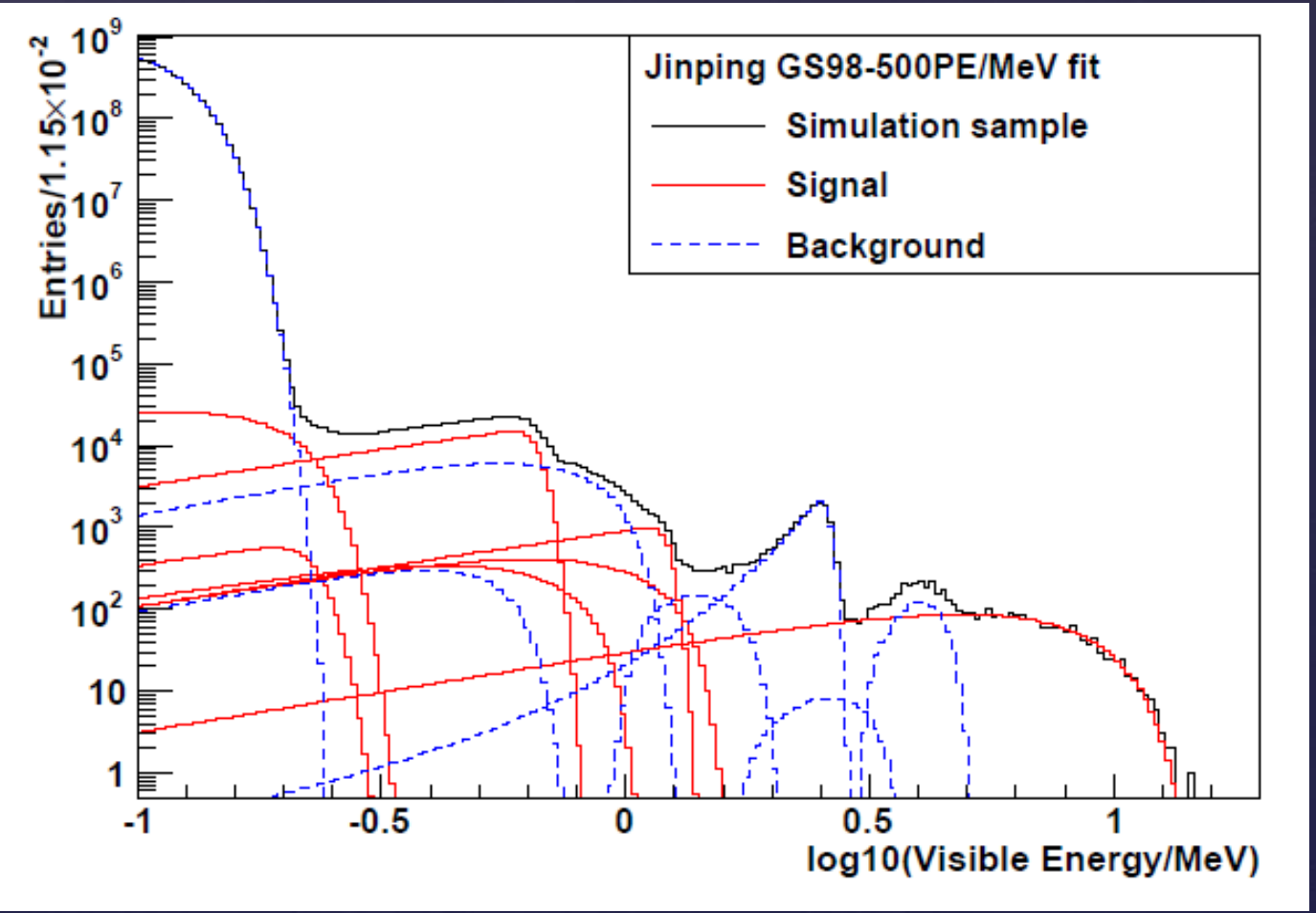
Summary for Solar Neutrino Physics

1. **MNS+MSW**
   - **Matter effect, upturn**
   - **New physics: sterile neutrino, non-standard interaction, etc.**
   - **Matter effect on Earth**
   - Improve solar Δm^2_{12} measurement

2. **Solar Model**
   - **CNO、hep are not detected, pep with a poor precision**
   - **Metallicity problem**
   - **Solar neutrino luminosity**

Preliminary study for Jinping

Consider radioactive background as Borexino but with Jinping overburden



Statistical Sensitivity Scan

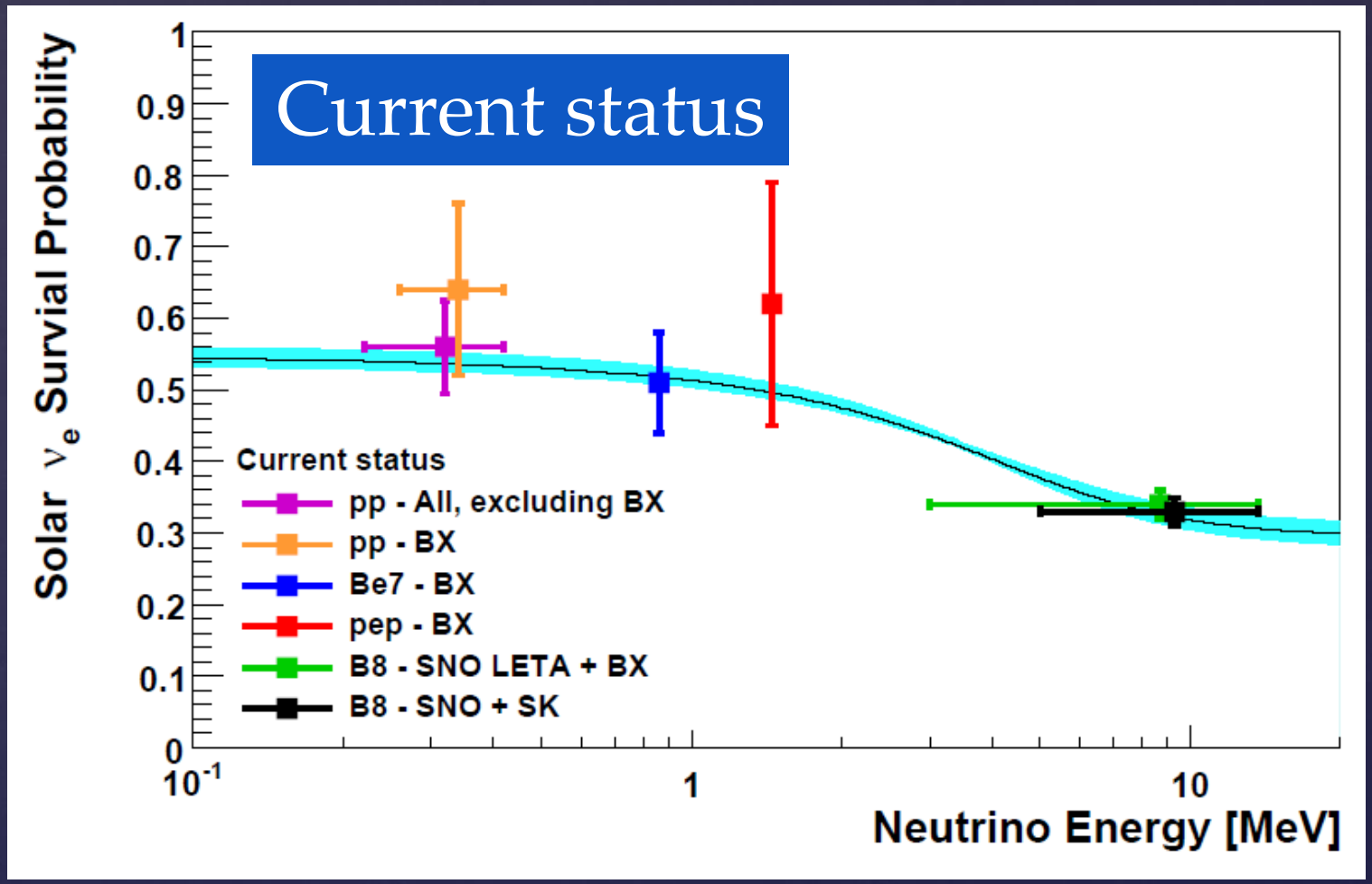
	Neutrino component	Energy resolution 200 PE/MeV	500 PE/MeV	1000 PE/MeV
Fiducial mass 1000 ton	pp	0.02	0.007	0.005
	^{7}Be	0.007	0.006	0.005
	pep	0.07	0.05	0.04
	^{13}N	NA	0.5 (NA)	0.3 (0.4)
	^{15}O	0.3	0.2 (0.4)	0.1 (0.2)
	^{8}B	0.02	0.02	0.02
Fiducial mass 2000 ton	pp	0.01	0.005	0.004
	^{7}Be	0.005	0.004	0.004
	pep	0.06	0.03	0.03
	^{13}N	0.4	0.3	0.2 (0.3)
	^{15}O	0.2	0.1	0.08 (0.1)
	^{8}B	0.02	0.02	0.02
Fiducial mass 4000 ton	pp	0.01	0.004	0.003
	^{7}Be	0.004	0.003	0.003
	pep	0.04	0.03	0.02
	^{13}N	0.3	0.2 (0.3)	0.2 (0.3)
	^{15}O	0.1 (0.2)	0.07 (0.1)	0.06 (0.09)
	^{8}B	0.01	0.01	0.01

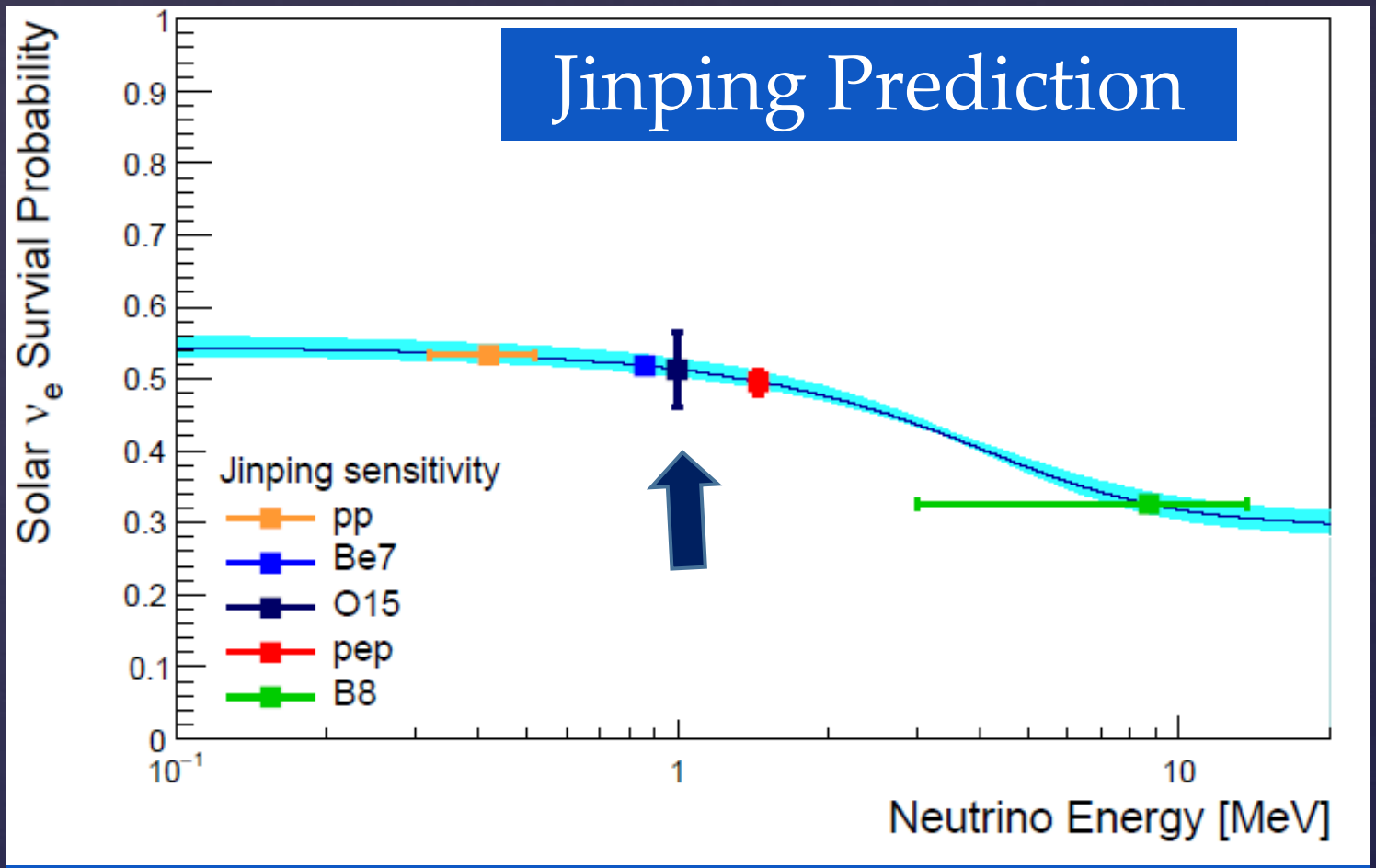
relative error, 0.33 means 3σ

Key systematic uncertainy

- **Based on the experience of Daya Bay and Borexino experiments**
- **Effective volume 1%**
- **Energy scale uncertainty induced flux uncertainty 1%**
- **Total systematic uncertainty 1.5%**

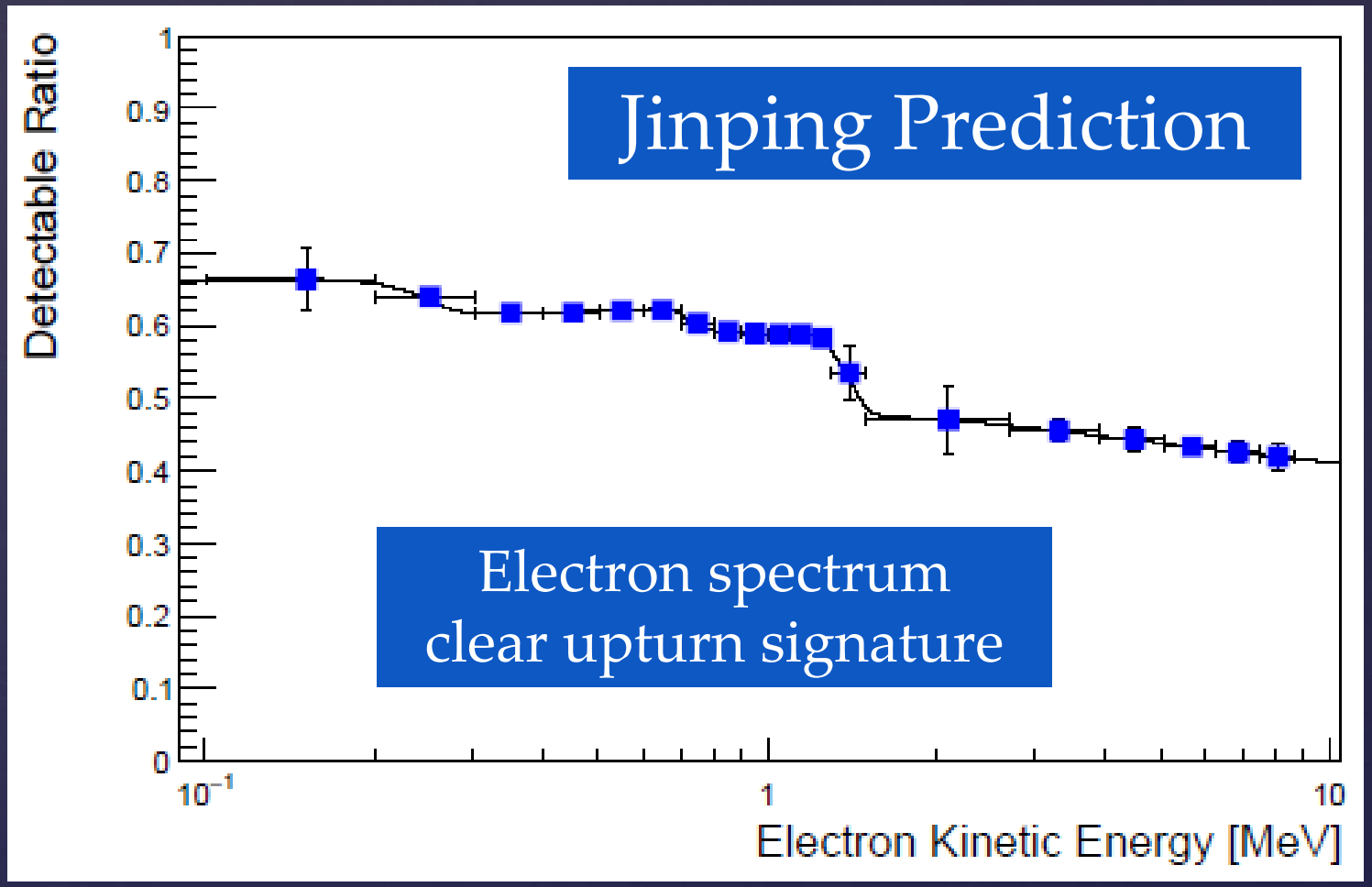
Comparison


Current status
Solar ν_e Survial Probability
Neutrino Energy [MeV]
Current status
pp - All, excluding BX
pp - BX
Be7 - BX
pep - BX
B8 - SNO LETA + BX
B8 - SNO + SK
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
10^{-1}
1
10



Discovery of CNO
Metallicity problem: 7.6 σ (no theory uncertainty)

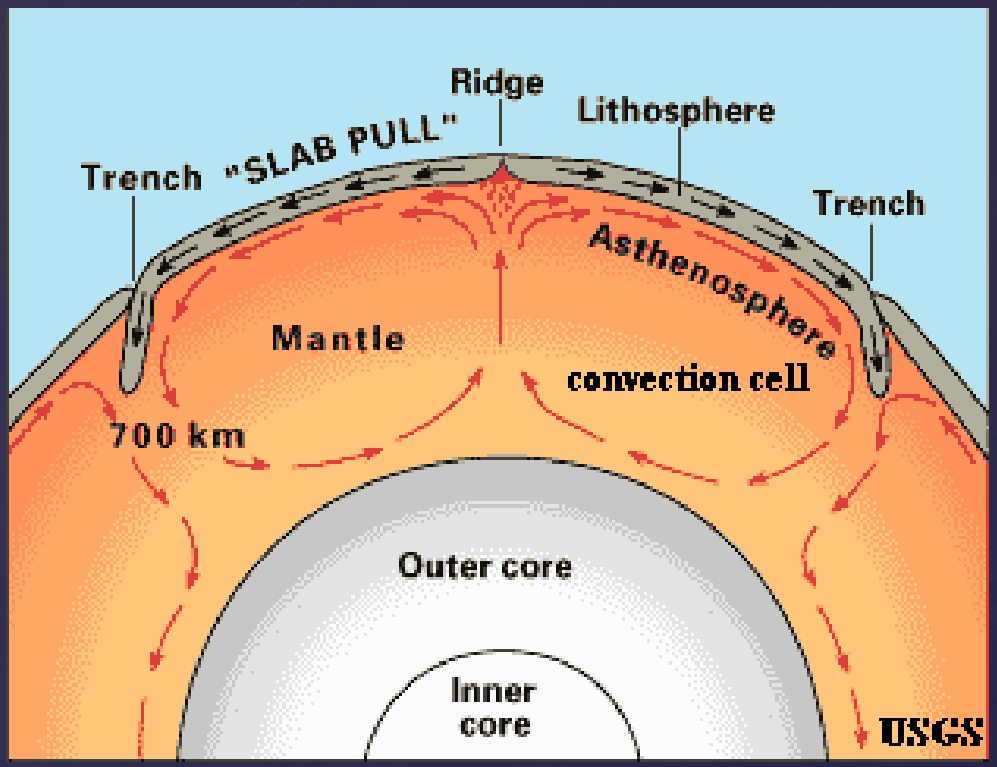
Comparison


Jinping Prediction
Electron spectrum
clear upturn signature
Detectable Ratio
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10^{-1}
1
10
Electron Kinetic Energy [MeV]

Geoneutrino

板块运动的原动力？

- 地球引力塌缩势能？
- 地球内部的核衰变，核裂变？



目前的知识：

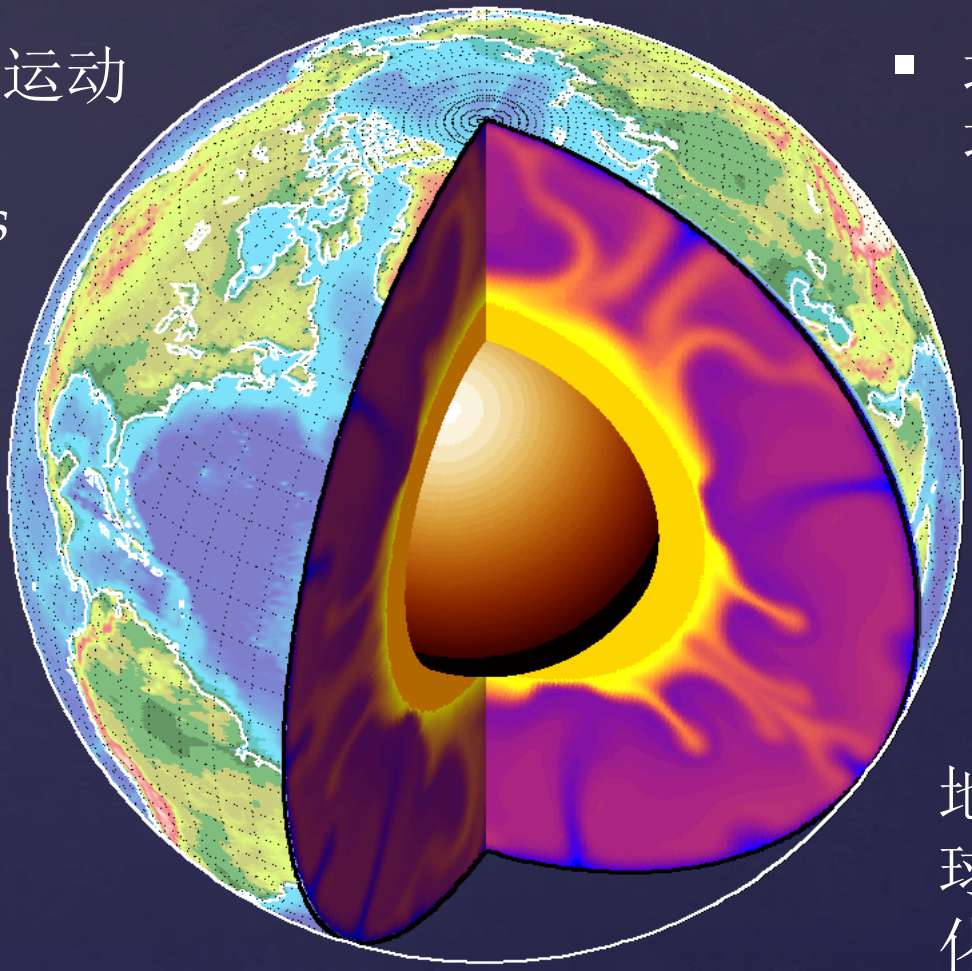
- 全球地热测量47±3 TW
- 对核衰变热的预期：
  - Cosmochemichal模型：10 TW
  - Geodynamical模型：15-30 TW
  - Geochemical模型：20 TW
- 地球中微子实验测量10-30 TW之间

答案：

- 我们还在消耗地球形成之初的引力势能
- 核衰变情形基本未知
- 需要测量地球中微子

地球中微子，地球运动模型

- 地热，板块运动原动力？
  核素衰变 *vs* 原初塌缩引力势能



- 地核内有核反应堆吗？

- 热产生放射性元素的地下分布
- 地壳中微子
- 地幔中微子

- 地球的原初构成成分？

地球动力学，地球化学，与陨石化学

Geoneutrino Detection

Solar:
electron-neutrino
Geo:
electron-antineutrino

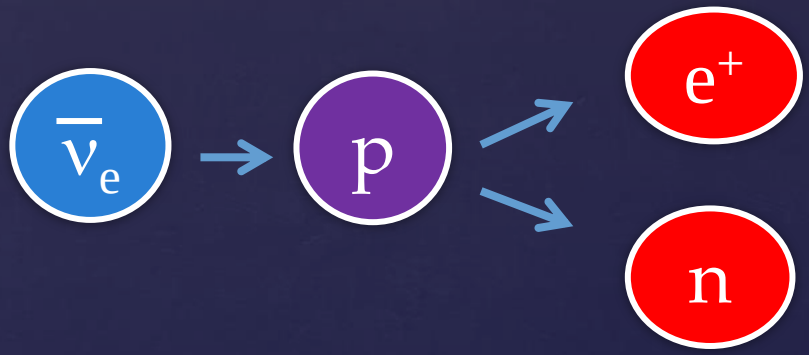
Solar and geoneutrino are distinguishable.

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

Prompt signal $e^+ + e^- \rightarrow \gamma s$

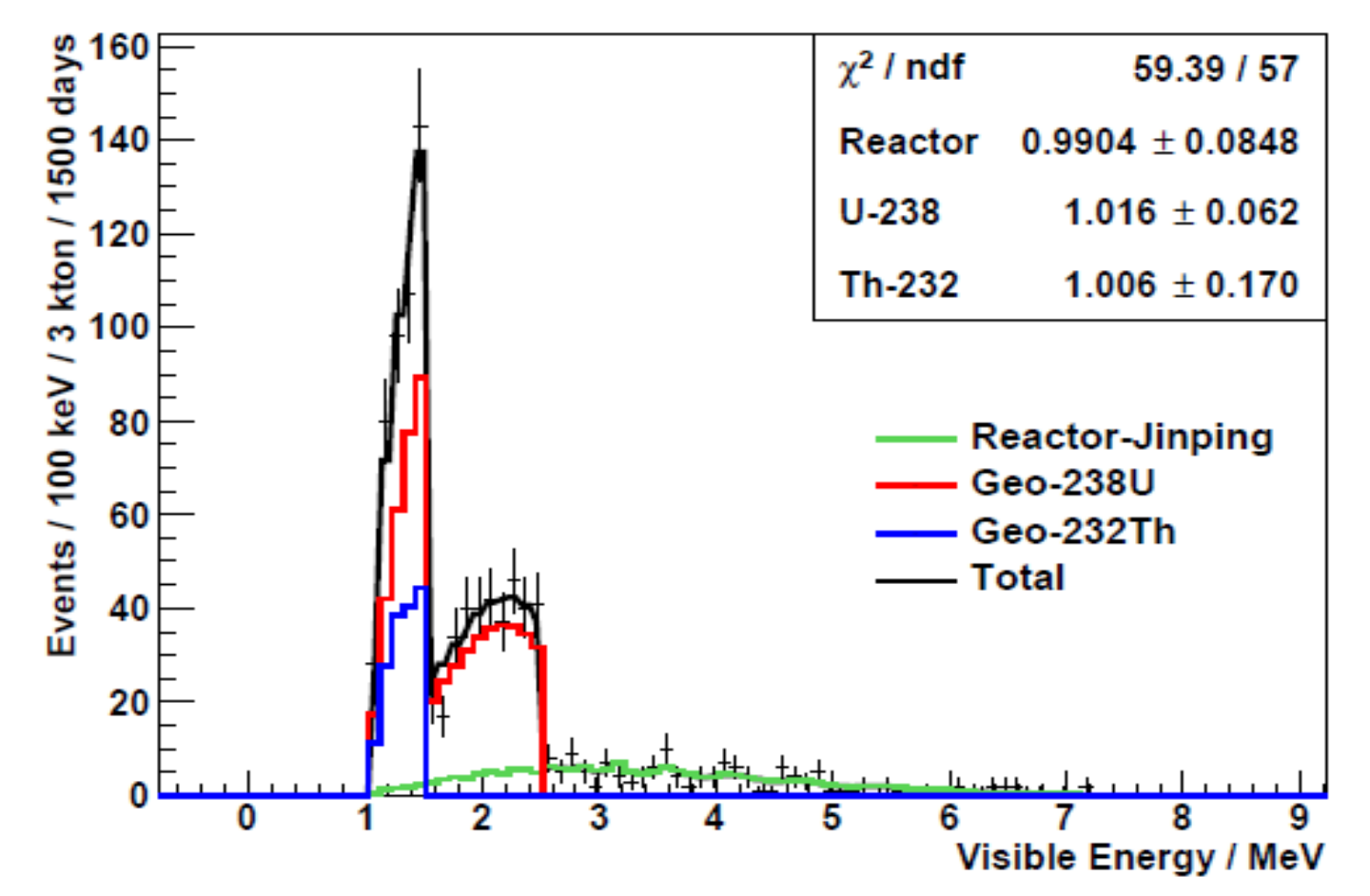
Delayed signal $n + p \rightarrow D + \gamma$ 2.2 MeV 200 μs

$n + Gd \rightarrow Gd^* \rightarrow Gd + \gamma s$ 8/8.5 MeV 30 μs



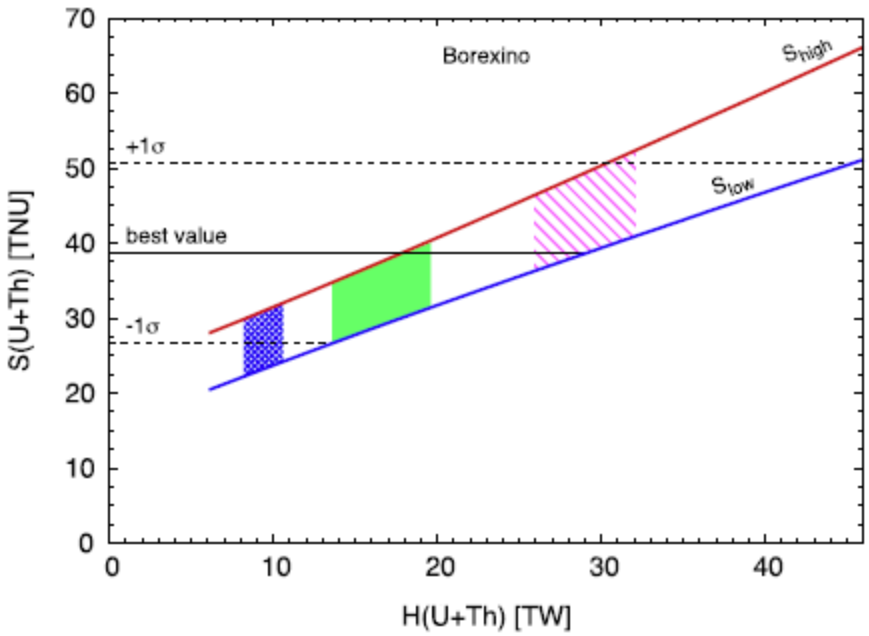
Geoneutrino and background spectra

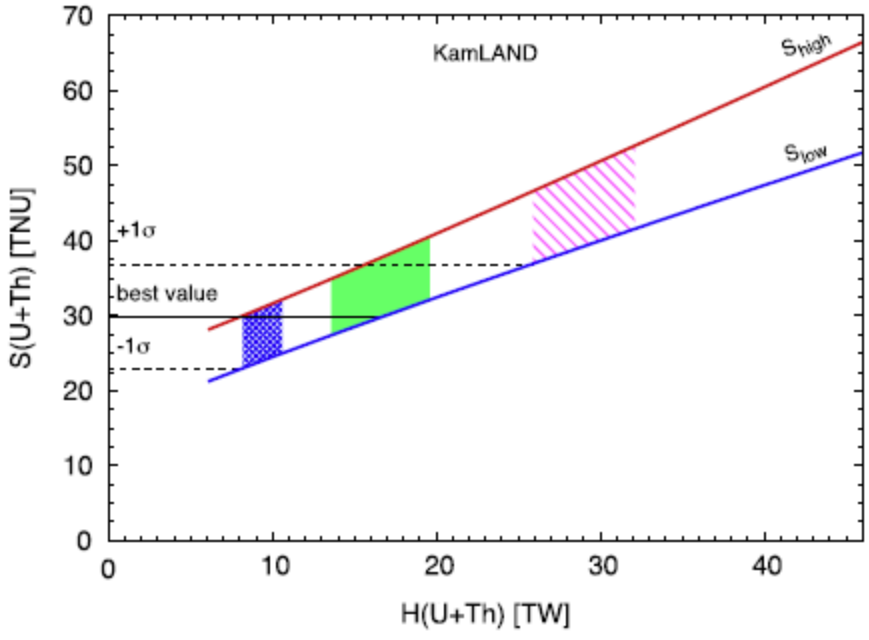
U: 37 /y/kton, Th: 9/y/kton vs Bkg: 6/y/kton
U/Th can be determined to 10%.



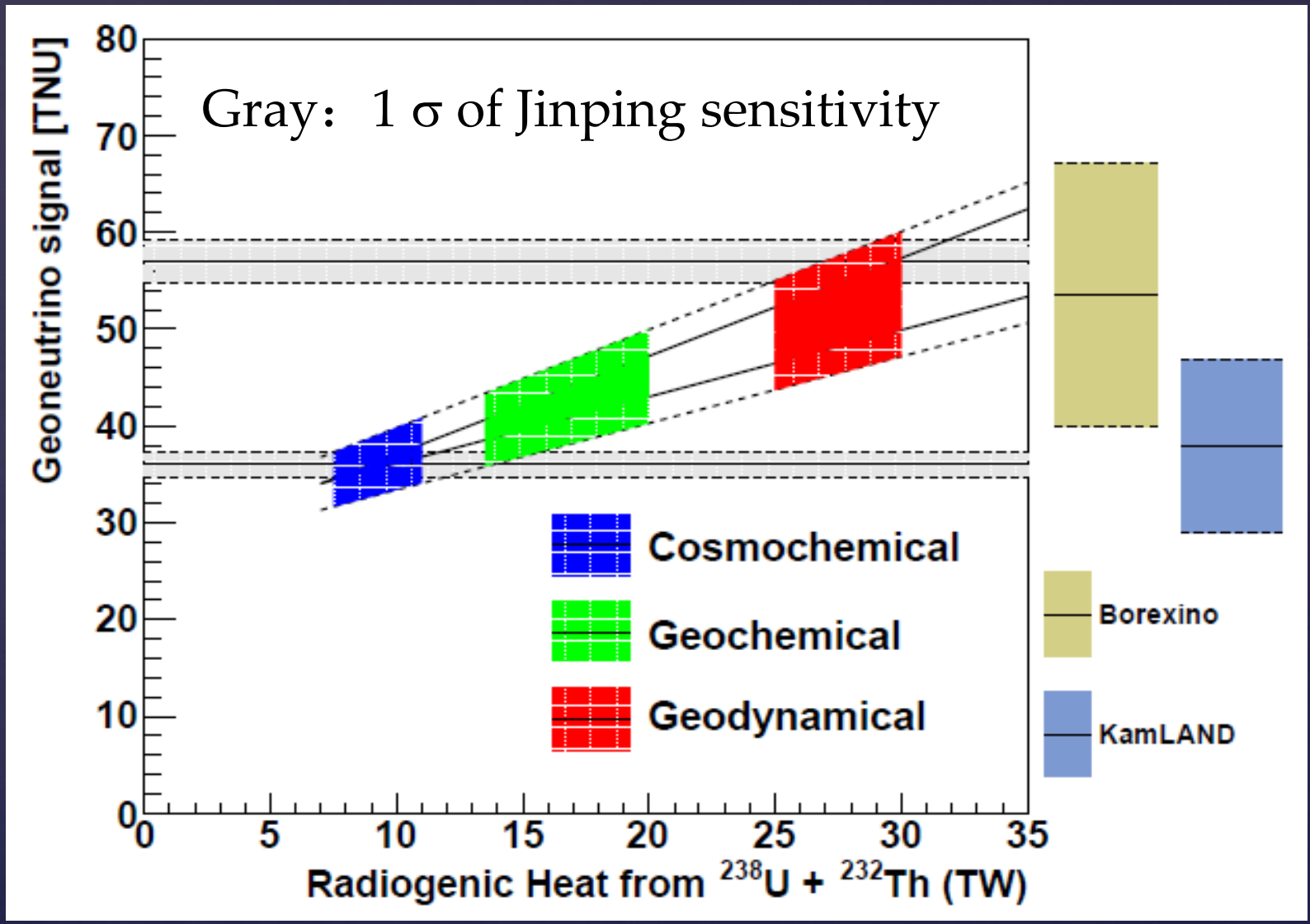
The current status of geoneutrino study

The major reactor background is avoid at Jinping.

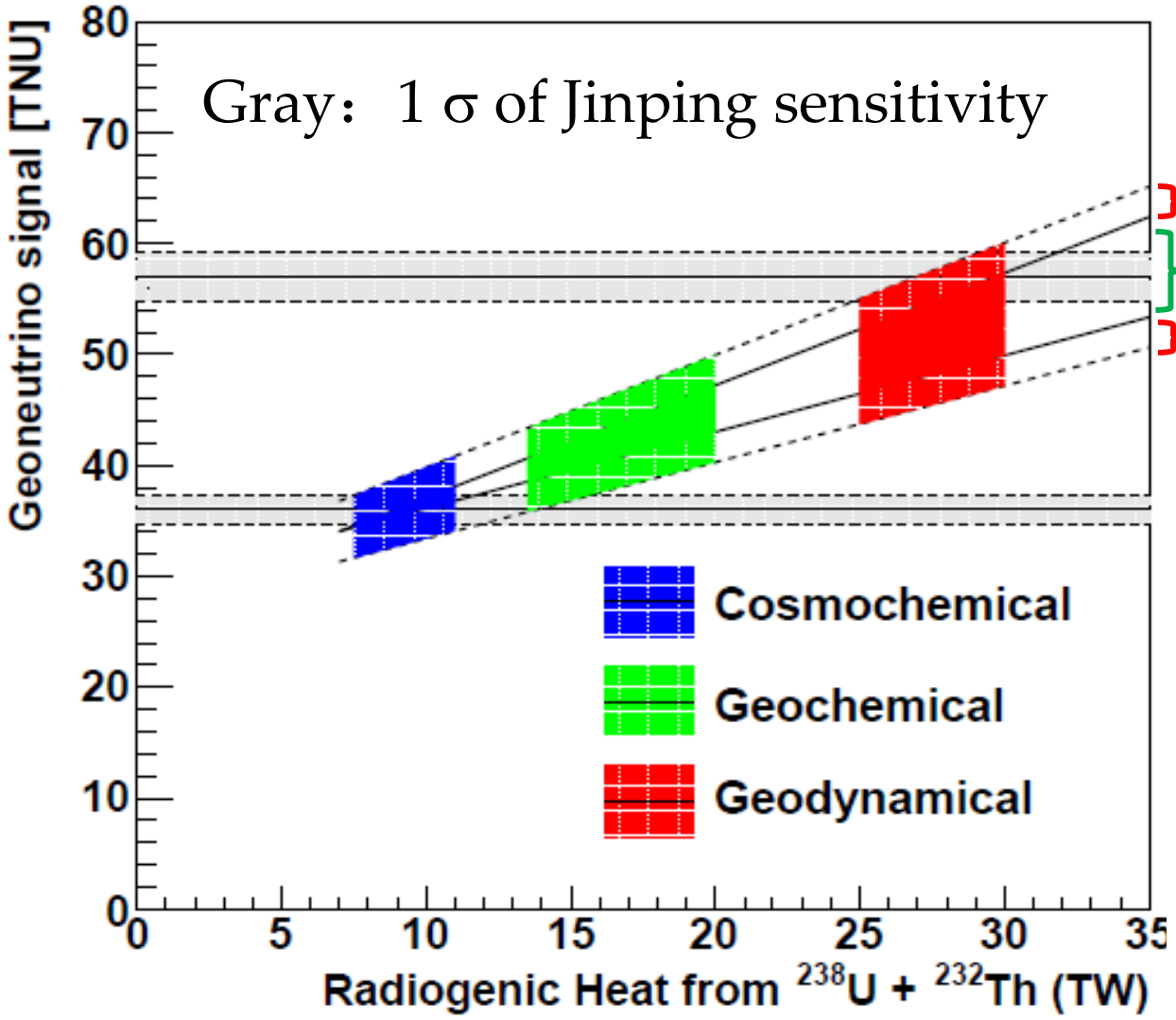




Prediction of Jinping



Major uncertainties



1. Crust geoneutrino measurement uncertainty

2. Mantel geoneutrino spacial distribution

Summary of Geoneutrino study

1. **With collaboration with geoscientist, Jinping can distinguish geo-predictions of heat productions**

2. **Measure the ratio of U/Th**

3. **Probe unknown geo-reactors**

Summary

1. **Experiment improvement**
   - 2000 ton (Borexino ~100 ton)
   - ^{11}C, ^{10}C (200 times less than Borexino)
   - Low background PMT
   - Total systematic 1.5%
2. **Expectation for Neutrino and Solar physics**
   - Precision measurement of Solar neutrino flux
   - Discover CNO neutrino
   - Precision test of MNS+MSW, upturn
   - Study solar metallicity problem
3. **Geo-science**
   - Distinguish geo-prediciton models for heat production
   - Precise U/Th ratio
4. **Supernova relic neutrino (in progress)**

Thank you.

More detail can be found in arXiv:1602.01733