地球中微子物理研讨会

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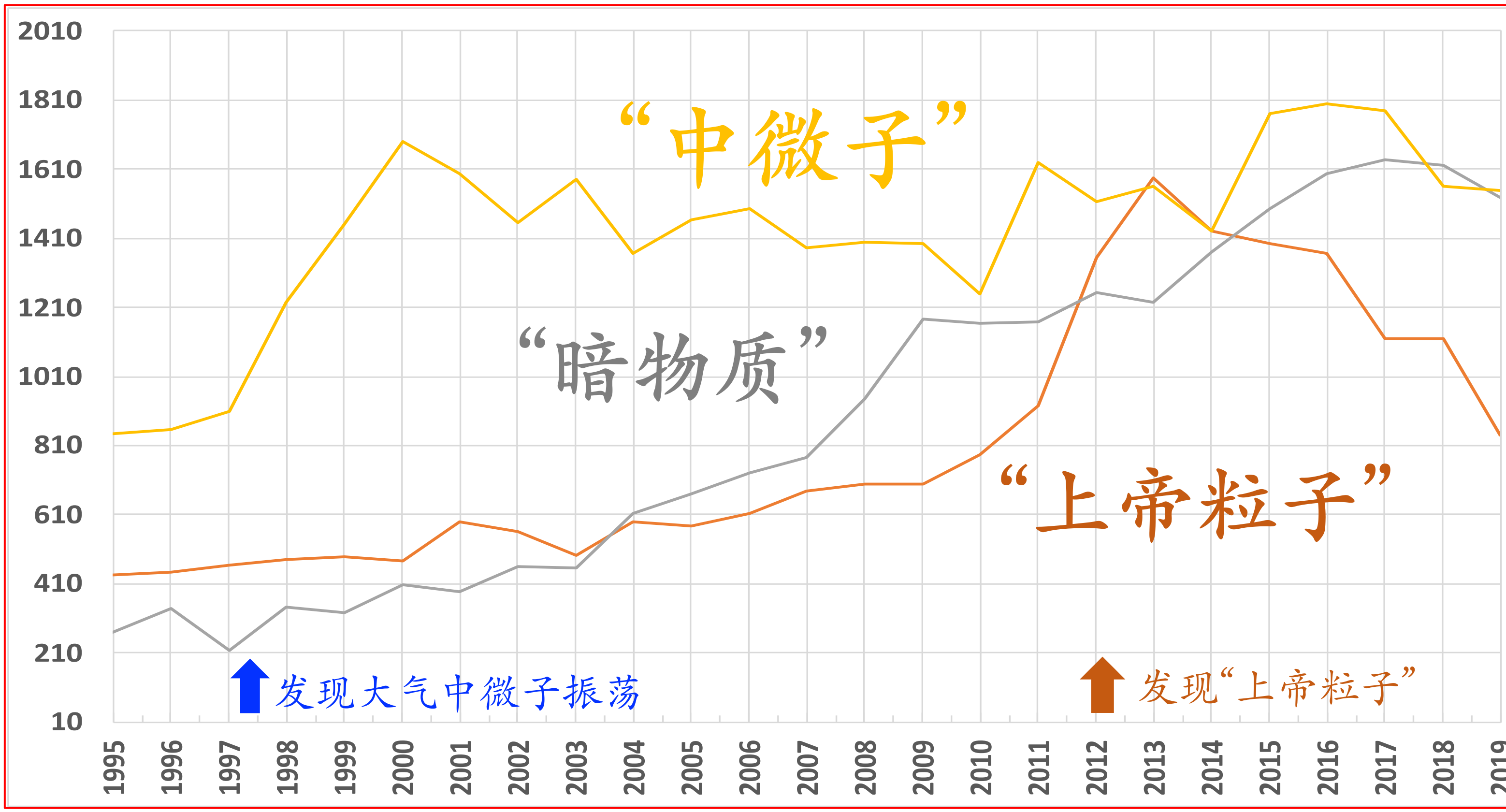
2019.12.20

二十多年粒子物理的发展历程

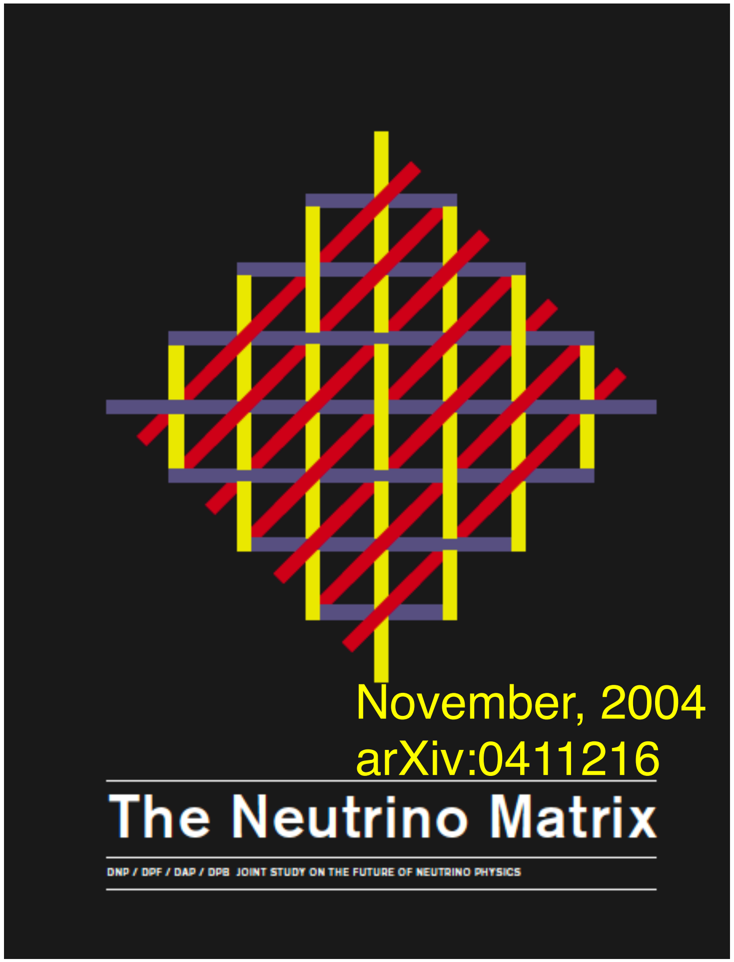
论文数目



发表年份

数据来自 inspirenet.hep

APS关于中微子未来的联合报告



美国物理学会（APS）核物理分部（DNP）/粒子物理与场分部（DPF）/天体物理分部（DAP）/束流物理分部（DPB）关于中微子物理未来的联合研究报告

美国物理学会的四个分部联合就中微子物理学未来研究提出三项建议：

1. 分阶段对无中微子双β衰变进行高灵敏度寻找。
2. 对中微子混合的理解，确定中微子质量谱的特征，并寻找在中微子之间的电荷-宇称（CP）破坏。
3. 开发一个精确测量来自太阳的低能中微子实验。

过去十五年进展如何？

Neutrino 2018

1. 无中微子双贝塔衰变实验方面有许多突出的工作，但是依然没有什么发现。
2. 中微子振荡研究成功证明了三代中微子框架，并精确测量混合参数（尤其是θ_{13}）和中微子质量平方差，并看到了中微子质量正排序及非零轻子CP相位迹象。
3. 碳-氮-氧（CNO）循环 与 氦-质子聚变（*hep*）过程产生的太阳中微子尚未观测到，标准太阳模型仍需要精确的检验；太阳中微子从真空振荡区过渡到物质效应区的实验缺失。

中微子还进入了地球科学领域

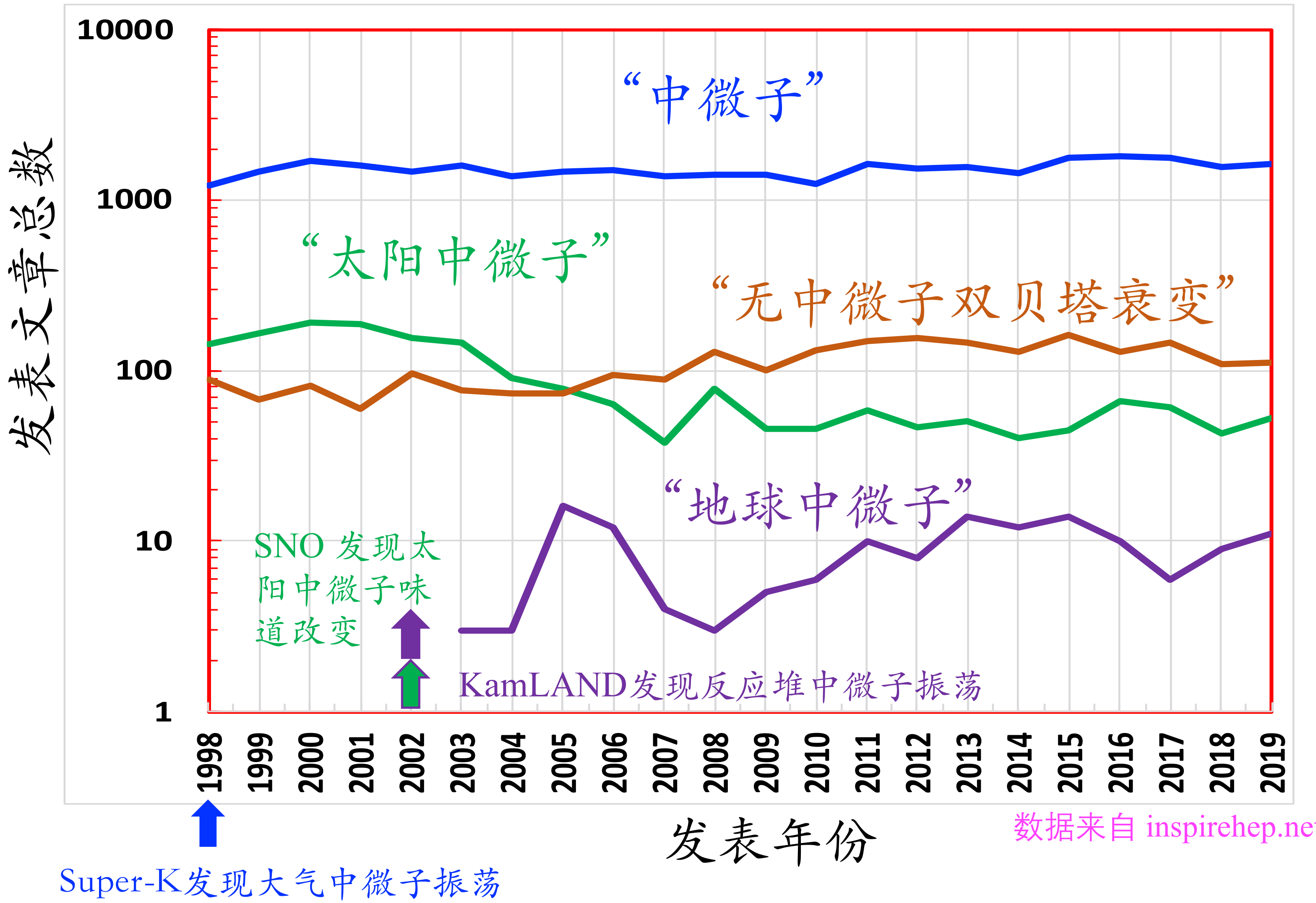
美国国家科学院国家研究理事会2014年指出未来10年出现的7个新的研究机遇：

① 早期的地球
② 热化学内动力和挥发物分布

放射性同位素的形成与产热对地球的影响

③ 断裂作用与变形过程
④ 气候、地表过程、地质构造和深部地球过程之间的相互作用
⑤ 生命、环境和气候间的协同演化
⑥ 水文地貌-生态系统对自然界与人类活动变化的耦合响应
⑦ 陆地环境的生物地球化学和水循环，以及全球变化对它们的影响

各中微子方向研究趋势



10000
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1
发表文章总数
"中微子"
"太阳中微子"
"无中微子双贝塔衰变"
"地球中微子"
SNO 发现太阳中微子味道改变
KamLAND发现反应堆中微子振荡
1998
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数据来自 inspirehep.net
Super-K发现大气中微子振荡

Antineutrino astronomy and geophysics

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Radioactive decays inside the Earth produce antineutrinos that may be detectable at the surface. Their flux and spectrum contain important geophysical information. New detectors need to be developed, discriminating between sources of antineutrinos, including the cosmic-background. The latter can be related to the frequency of supernovas.

That the Earth is a source of antineutrinos was first pointed out by Eders[3] and Marx and co-workers[4–6]. Marx in particular was the first seriously to investigate the detection of terrestrial neutrinos and to recognize the importance of both resonant capture and inverse β decay of terrestrial antineutrinos in detection[4]. But a detailed analysis of the geophysical implications of the problems of measuring the actual flux of terrestrial antineutrinos has not been performed.

Eder 首次提出测量地球中微子

ELSEVIER

Nuclear Physics
Volume 78, Issue 3, April 1966, Pages 657-662

Terrestrial neutrinos

Gernot Eder

⊞ Show more

https://doi.org/10.1016/0029-5582(66)90903-5

Abstract

Arguments are given for a remarkable abundance of radioactive elements within the earth. Methods are discussed in order to measure this abundance by neutrino experiments.

GEOPHYSICS BY NEUTRINOS*)

G. Marx

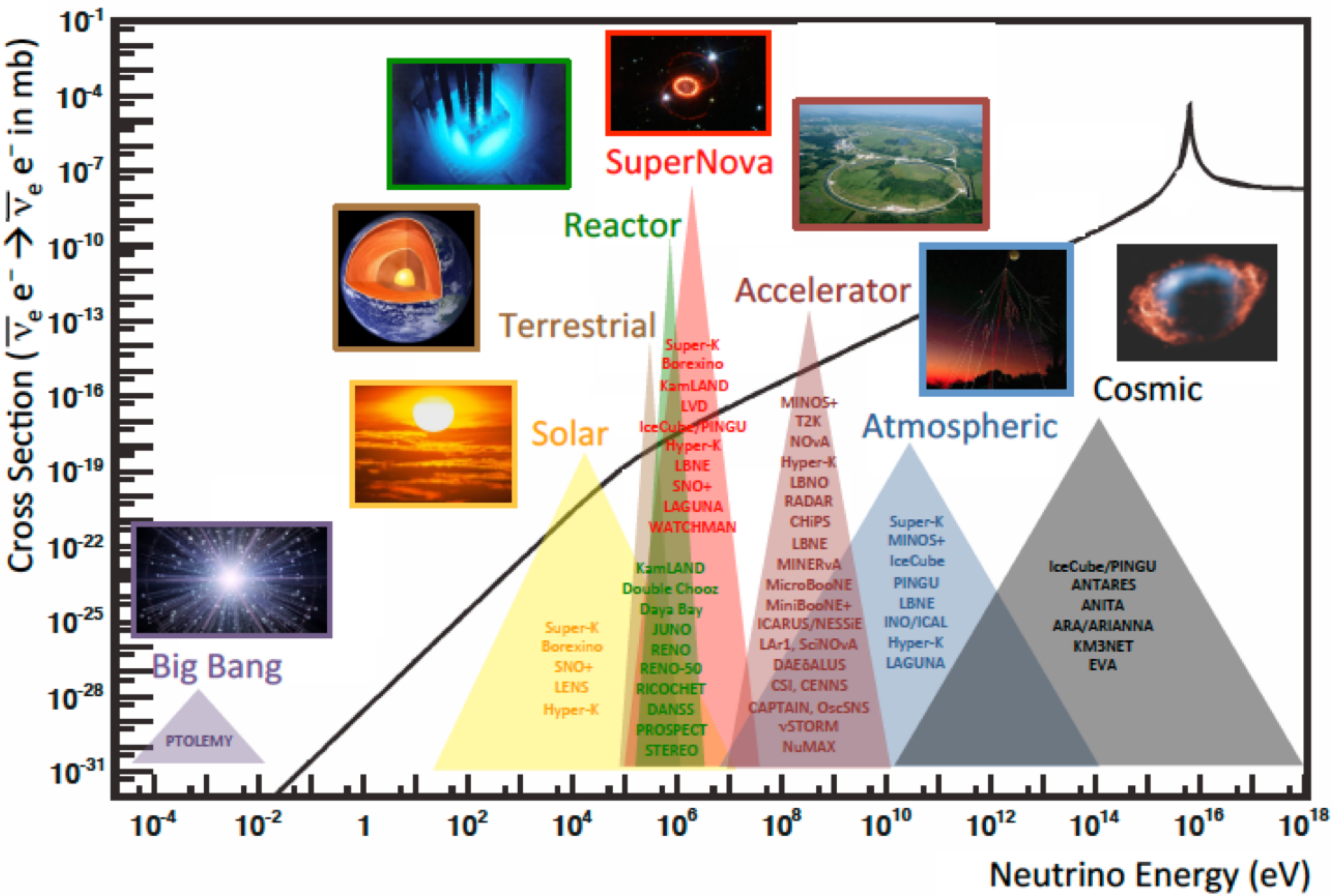
Institute of Theoretical Physics, Roland Eötvös University, Budapest

A review of the possibilities for the chemical exploration of the central regions of the Earth is given, making use of the antineutrino flux produced by natural radioactive isotopes.

1. INTRODUCTION

It was suggested many years ago that the neutrino and antineutrino luminosity of different celestial bodies might provide means of exploring the internal structure of these objects (see e.g. [1]). Due to the enormous mean free path the neutrinos and antineutrinos provide valuable direct information, which is not available with other methods. Searching the Sun with a neutrino telescope is well under way [2]. The present paper is concentrated on the second important task of neutrino physics: the Earth. The idea of observing terrestrial antineutrinos is not a new one [1, 3, 4, 5]. Here a review of different experimental possibilities will be given.

中微子源与中微子实验



Cross Section ($\overline{\nu}_e e^- \rightarrow \overline{\nu}_e e^-$ in mb)
Neutrino Energy (eV)
SuperNova
Reactor
Terrestrial
Accelerator
Solar
Atmospheric
Cosmic
Big Bang
PTOLEMY
Super-K
Borexino
KamLAND
LVD
IceCube/PINGU
Hyper-K
LBNE
SNO+
LAGUNA
WATCHMAN
Super-K
Borexino
SNO+
LENS
Hyper-K
KamLAND
Double Chooz
Daya Bay
JUNO
RENO
RENO-50
RICOCHET
DANSS
PROSPECT
STEREO
MINOS+
T2K
NOvA
Hyper-K
LBNO
RADAR
CHiPS
LBNE
MINERvA
MicroBooNE
MiniBooNE+
ICARUS/NESSiE
LAr1, SciNOvA
DAEδALUS
CSI, CENNS
CAPTAIN, OscSNS
vSTORM
NuMAX
Super-K
MINOS+
IceCube
PINGU
LBNE
INO/ICAL
Hyper-K
LAGUNA
IceCube/PINGU
ANTARES
ANITA
ARA/ARIANNA
KM3NET
EVA

兆电子伏能区中微子物理

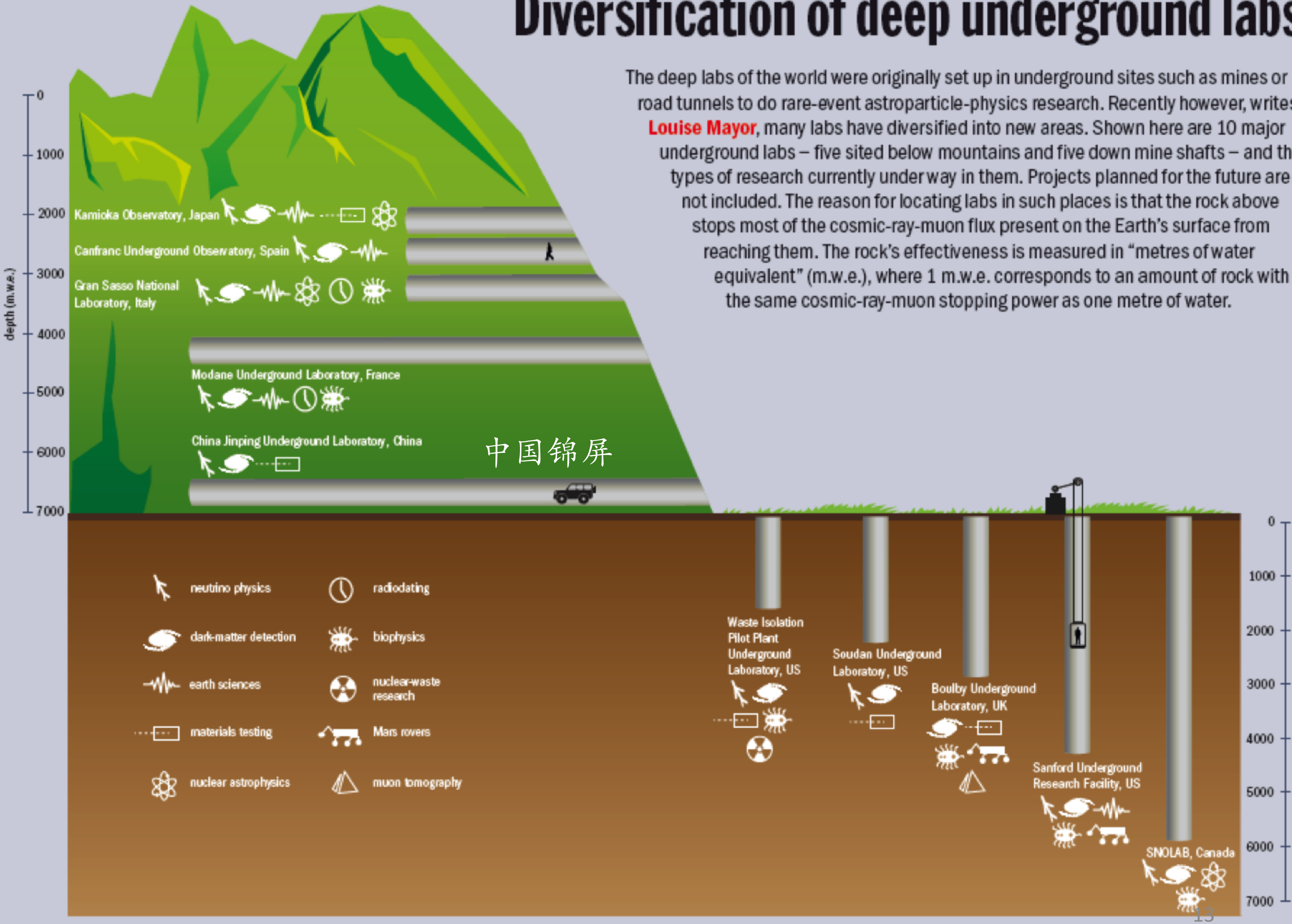
- ✓ 反应堆中微子（中微子振荡参数、质量排序）
  - ➢ θ_{13} 与Δm^2_{ee}(大亚湾···); θ_{12}、Δm^2_{12}与中微子质量排序（JUNO)
- ✓ 太阳中微子（标准太阳模型、振荡曲线、高温主序星)
  - ➢ 寻找碳-氮-氧循环中微子（锦屏、Borexino、Thiea)
  - ➢ 寻找*hep*中微子（HK、DUNE)
  - ➢ 研究太阳中微子如何从真空振荡过渡到物质效应区（锦屏、SK，SNO，HK，JUNO？）
  - ➢ 太阳中微子在地球的物质效应（HK)
- ✓ 地球中微子（地球的起源、热流的来源、内部组成)
  - ➢ 地壳/地幔通量（锦屏、Borexino、KamLAND、JUNO)
  - ➢ 铀/钍比（锦屏)
- ✓ 超新星中微子
  - ➢ 寻找爆发与遗迹中微子（锦屏、SK、JUNO，DUNE，HK)

为什么要到地下？

如果 SNO 实验室不是设在 2 公里地下，宇宙线会让探测器像北极光那样时刻都在闪闪发光！

Diversification of deep underground labs

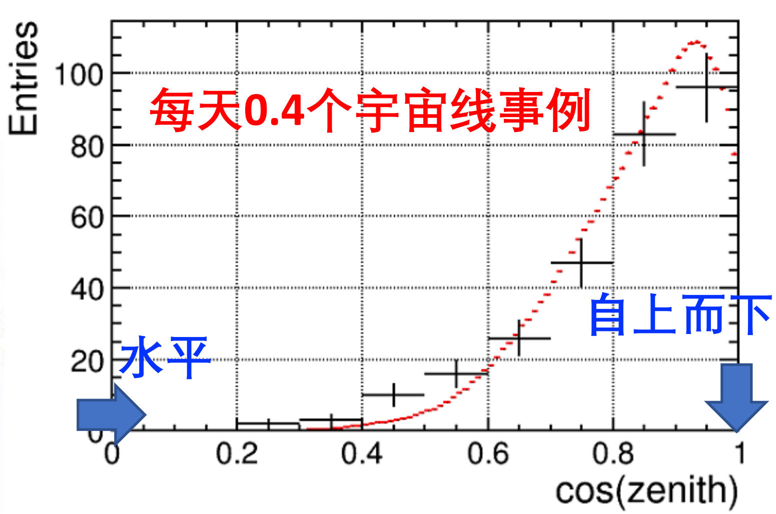
The deep labs of the world were originally set up in underground sites such as mines or road tunnels to do rare-event astroparticle-physics research. Recently however, writes **Louise Mayor**, many labs have diversified into new areas. Shown here are 10 major underground labs – five sited below mountains and five down mine shafts – and the types of research currently under way in them. Projects planned for the future are not included. The reason for locating labs in such places is that the rock above stops most of the cosmic-ray-muon flux present on the Earth's surface from reaching them. The rock's effectiveness is measured in "metres of water equivalent" (m.w.e.), where 1 m.w.e. corresponds to an amount of rock with the same cosmic-ray-muon stopping power as one metre of water.

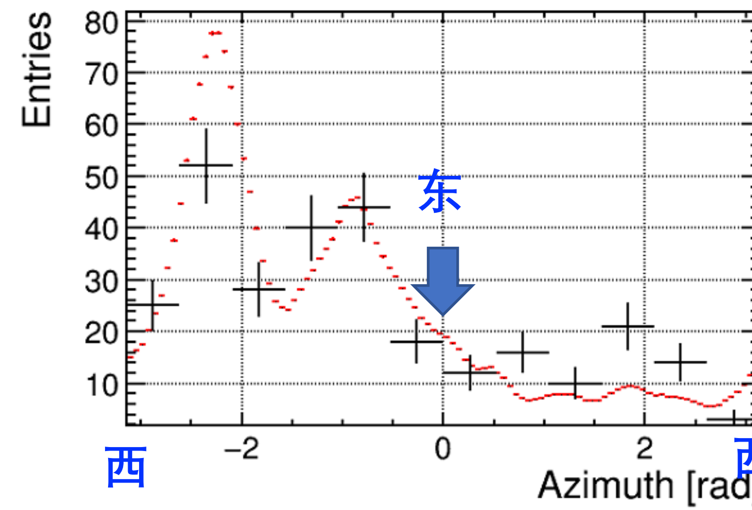


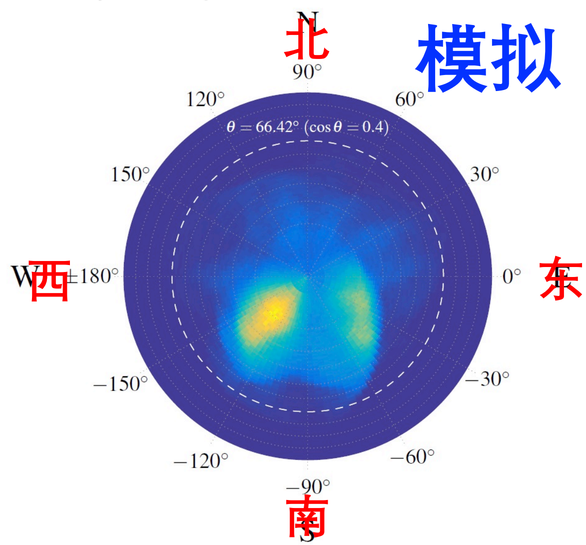
Physics World May 2015

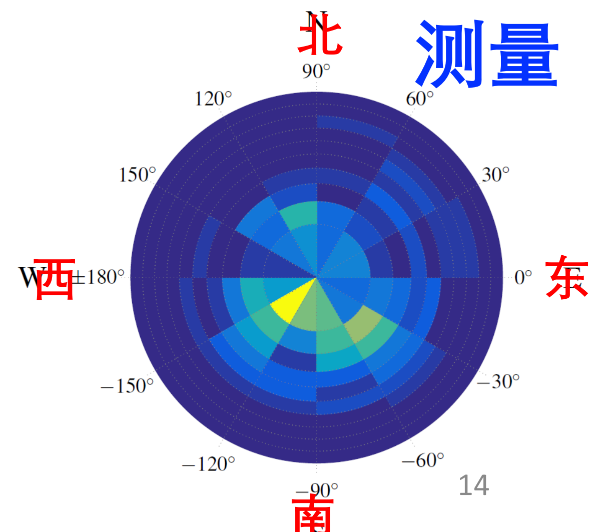
锦屏地下实验室宇宙线测量

宇宙线通量：$(3.57 \pm 0.21_{stat} \pm 0.19_{sys}) \times 10^{-10}\ cm^{-2}s^{-1}$





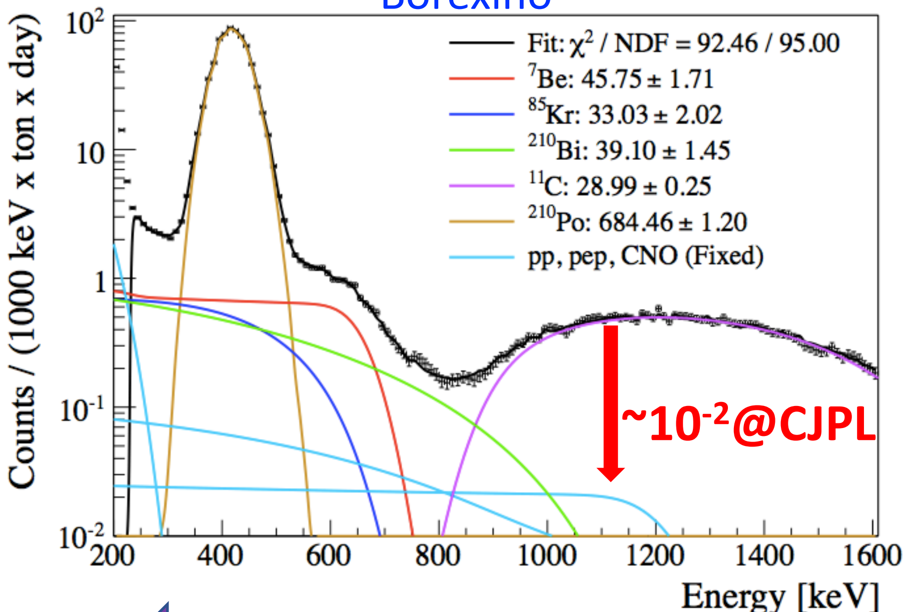




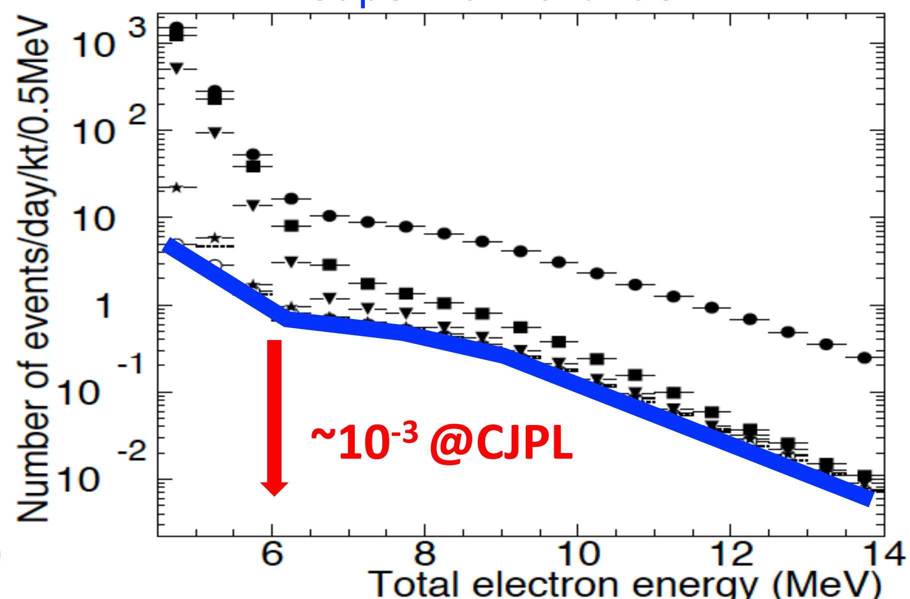
锦屏优势一：埋深大

太阳中微子探测 $\nu_e + e^- \rightarrow \nu_e + e^-$

Borexino



Super-Kamiokande



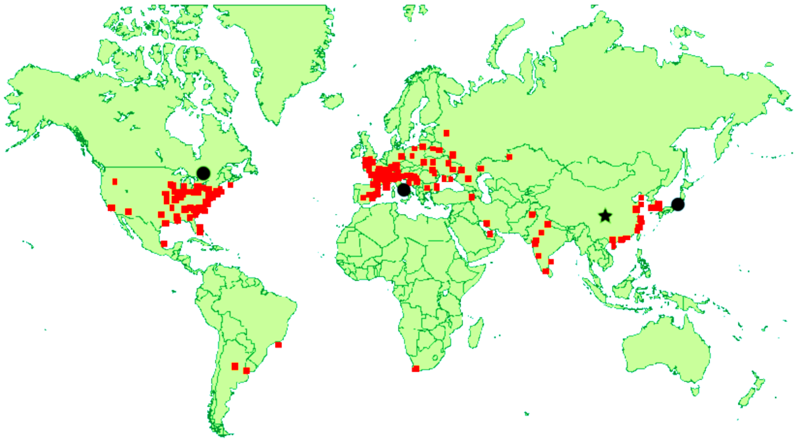
① 外部本底(光电倍增管, 岩石…)

② 内部本底 (^{222}Rn…)

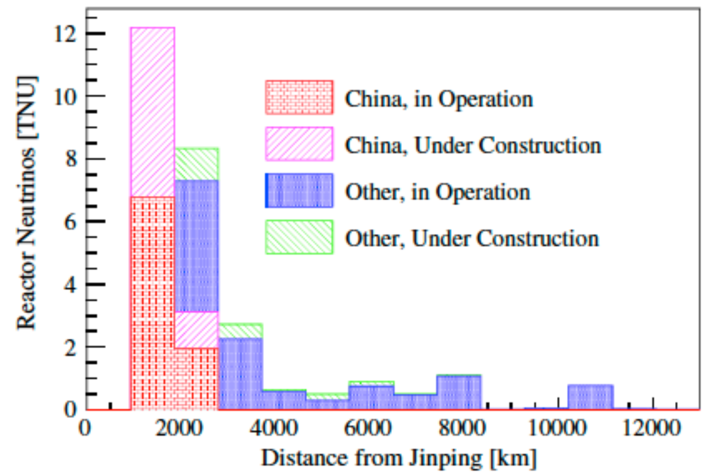
③ 宇宙线诱导放射性本底 ^{11}C、^{10}C、^{11}Be

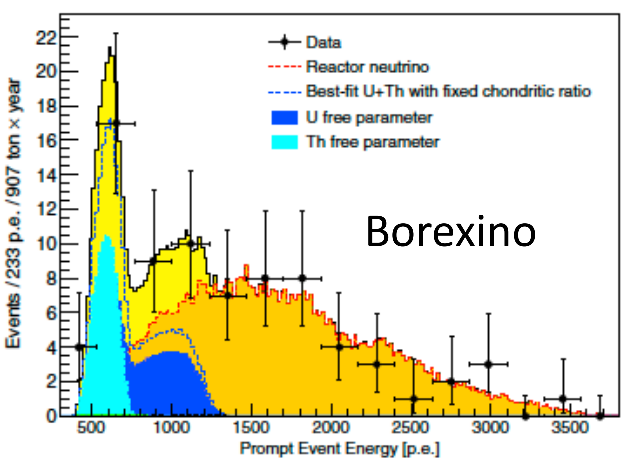
锦屏优势二：离核电站远

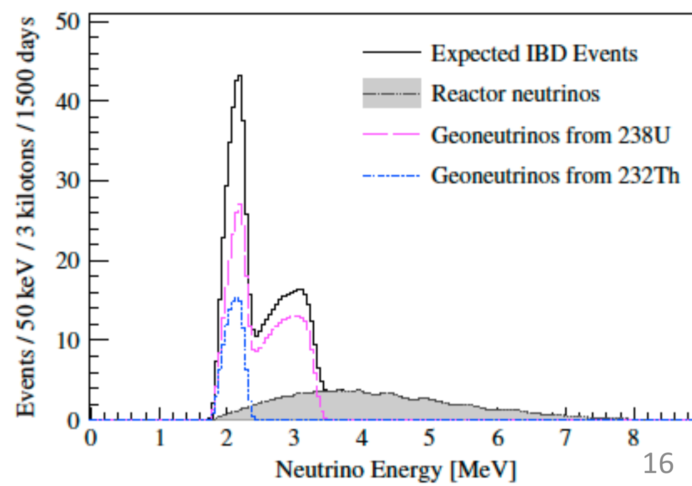
为测量地球中的铀/钍比提供了可能



国际原子能机构 2015数据

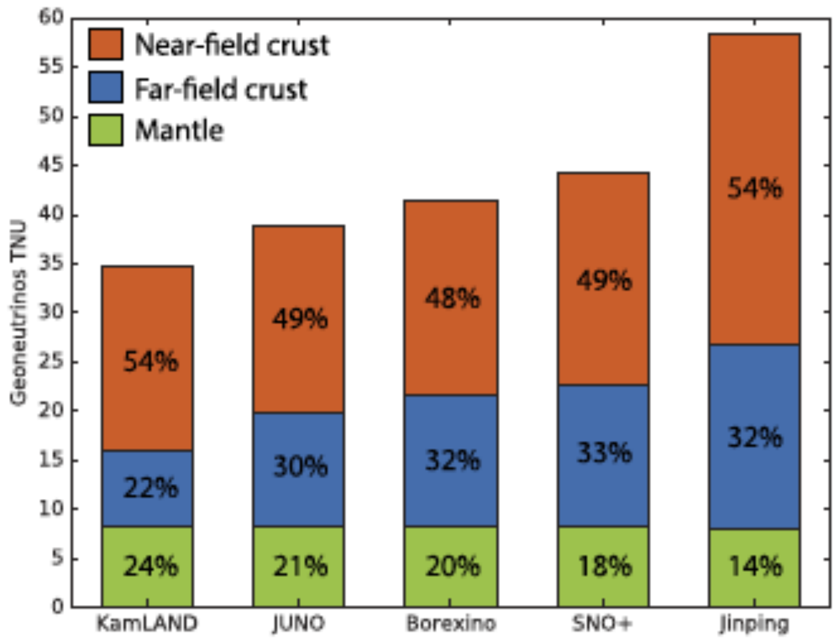


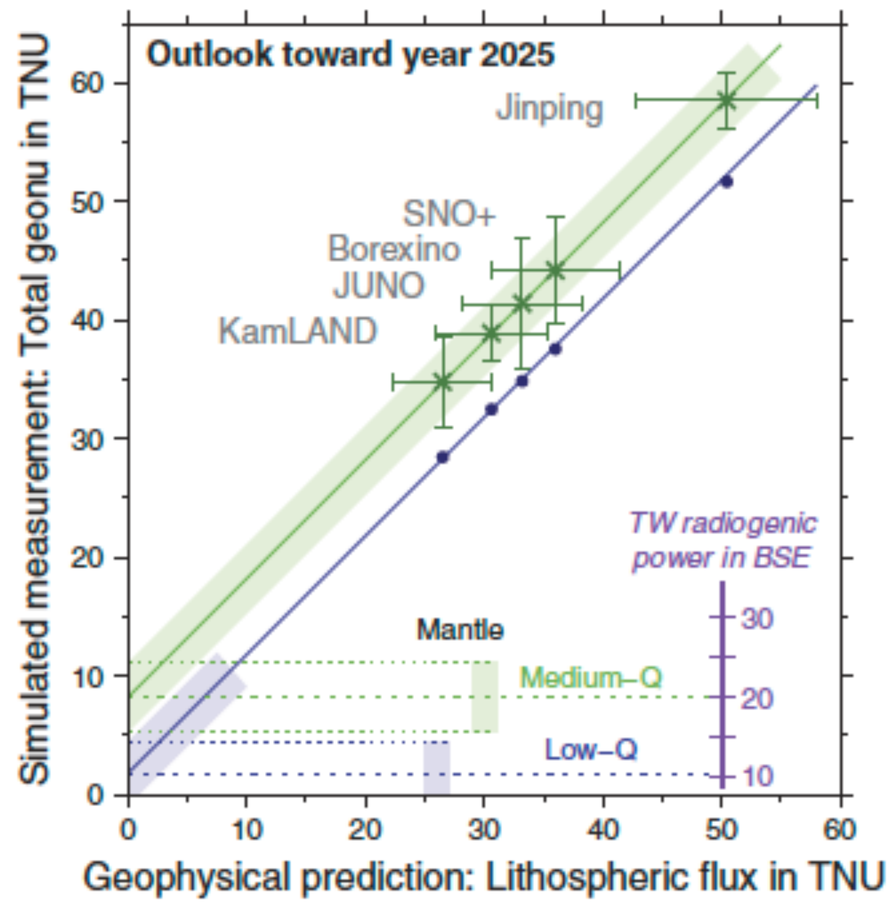




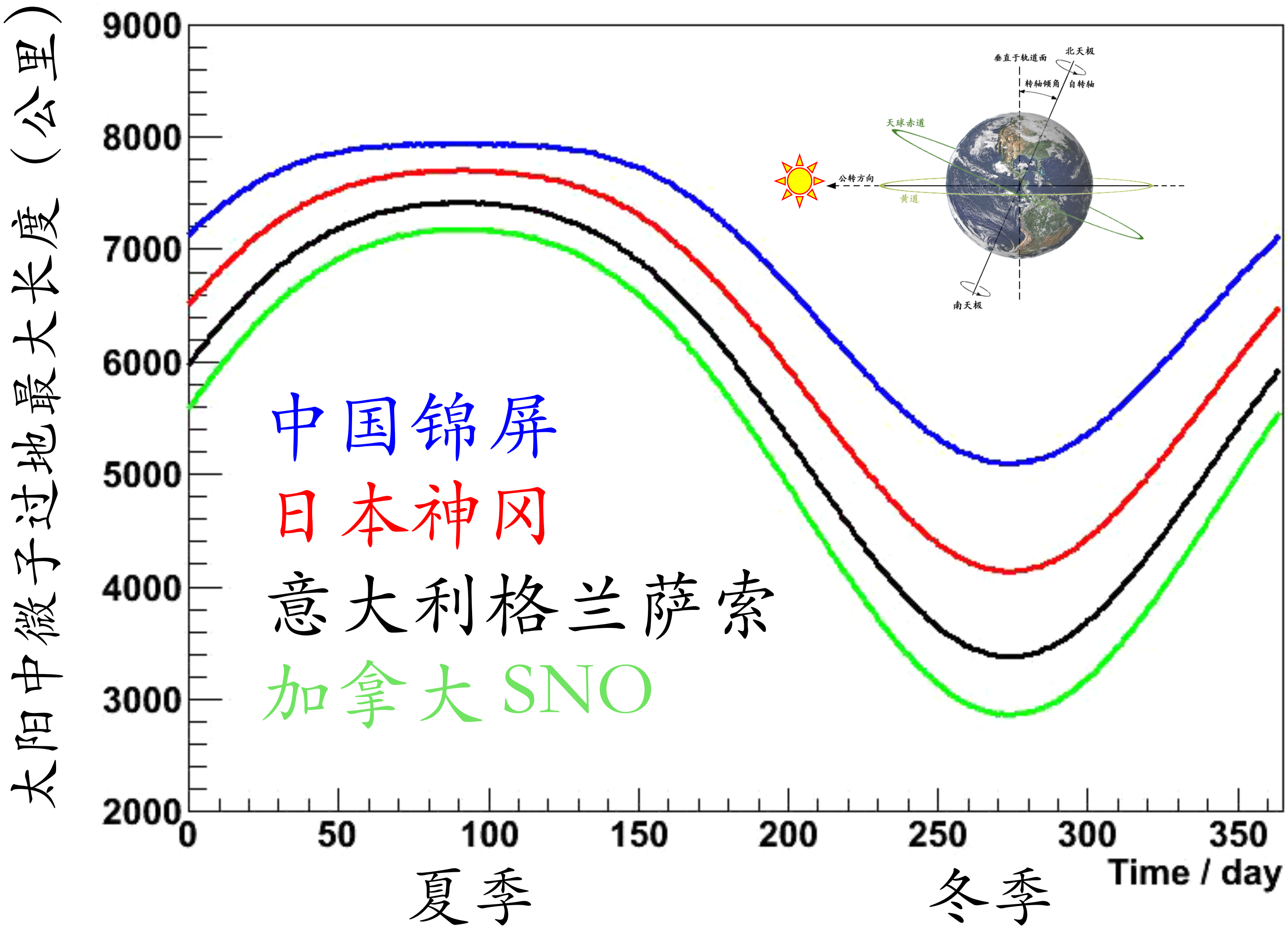
锦屏优势三：地壳厚

对测量地慢放射性元素产热贡献大



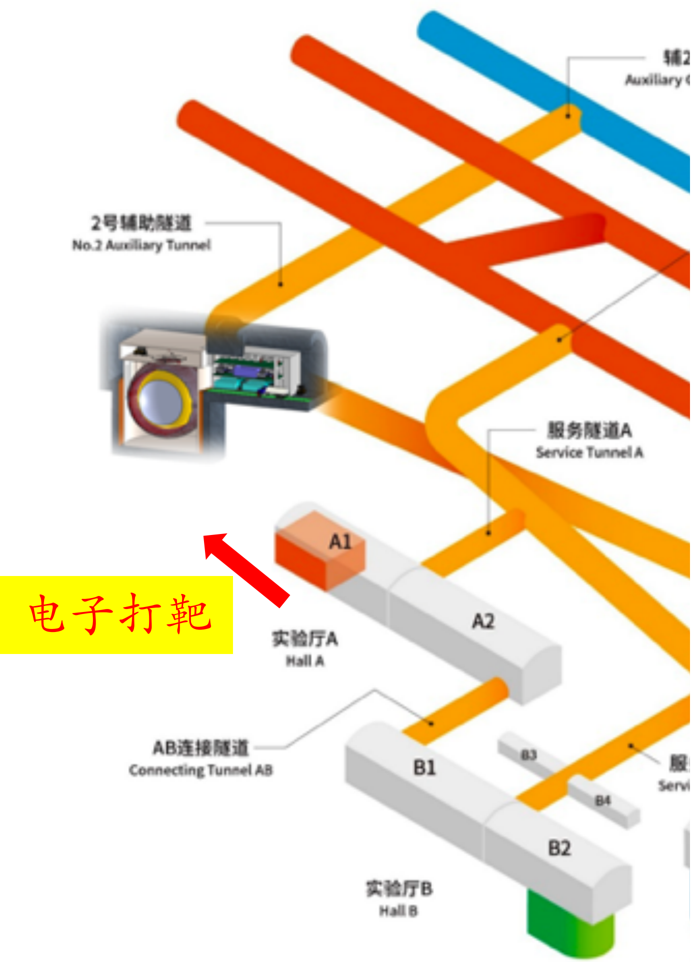


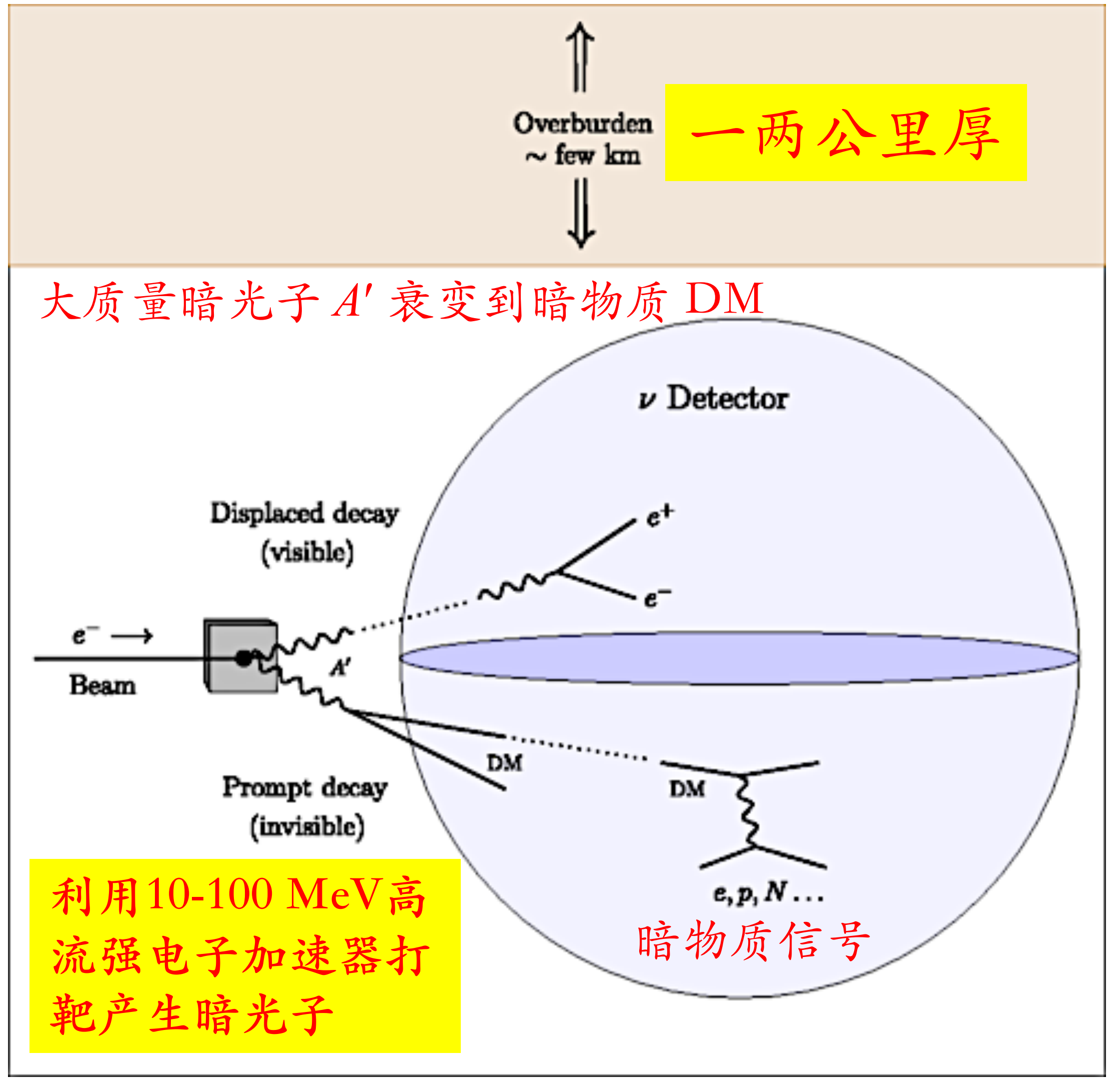
锦屏优势四：低纬度



太阳中微子过地最大长度（公里）
9000
8000
7000
6000
5000
4000
3000
2000
0
50
100
150
200
250
300
350
Time / day
夏季
冬季
中国锦屏
日本神冈
意大利格兰萨索
加拿大SNO
垂直于轨道面
北天极
转轴倾角
自转轴
天球赤道
公转方向
黄道
南天极

锦屏优势五：兆电子伏暗物质





锦屏国际顾问委员会意见

2014年 IAC 报告

“...IAC认为，最初旨在探测地球中微子的千吨级闪烁探测器可能是CJPL中微子科学的第一步，原则上类似于Borexino和KamLAND，前提是上述研究得出了积极的结论，并利用合作学会的每一个减少环境本底的技巧，以及随后转成的新实验，包括双贝塔衰变探测器的掺杂技术。”

2016年 IAC 报告

“...IAC强烈支持该项目，因为CJPL在减少本底方面具有相当大的优势。我们不知道在埋深如此大的地方还有其他实验，因此这显示了CJPL的优势。此外，这个项目的科学目标是令人信服的。...”

2018年 IAC 报告

“...在中微子实验方面，CJPL 的竞争者很少，优势明显...”

谢谢！
请多提宝贵意见！