天文学正在发现

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outline

1. 膨胀宇宙的发现

2. 暗物质的发现

3. 暗能量的发现

4. 宇宙微波背景辐射的发现

5. 中微子的发现

6. 引力波的发现

7. 脉冲星的发现

8. 宇宙第一缕曙光的“发现”

一个静谧的午后，我正试图向妈妈解释什么是中微子。

“如果你把大拇指竖起来，每一秒钟，就有700亿中微子从你的拇指中穿过。”

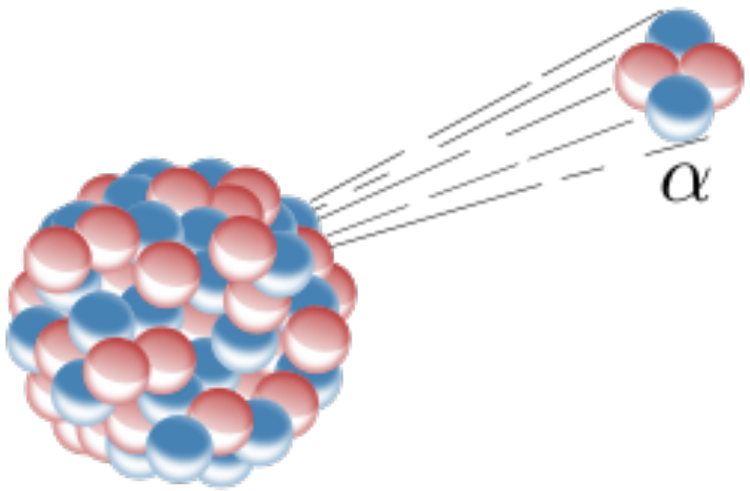
“700亿？！”听到这个数字，妈妈吓了一跳，赶紧把手揣回口袋

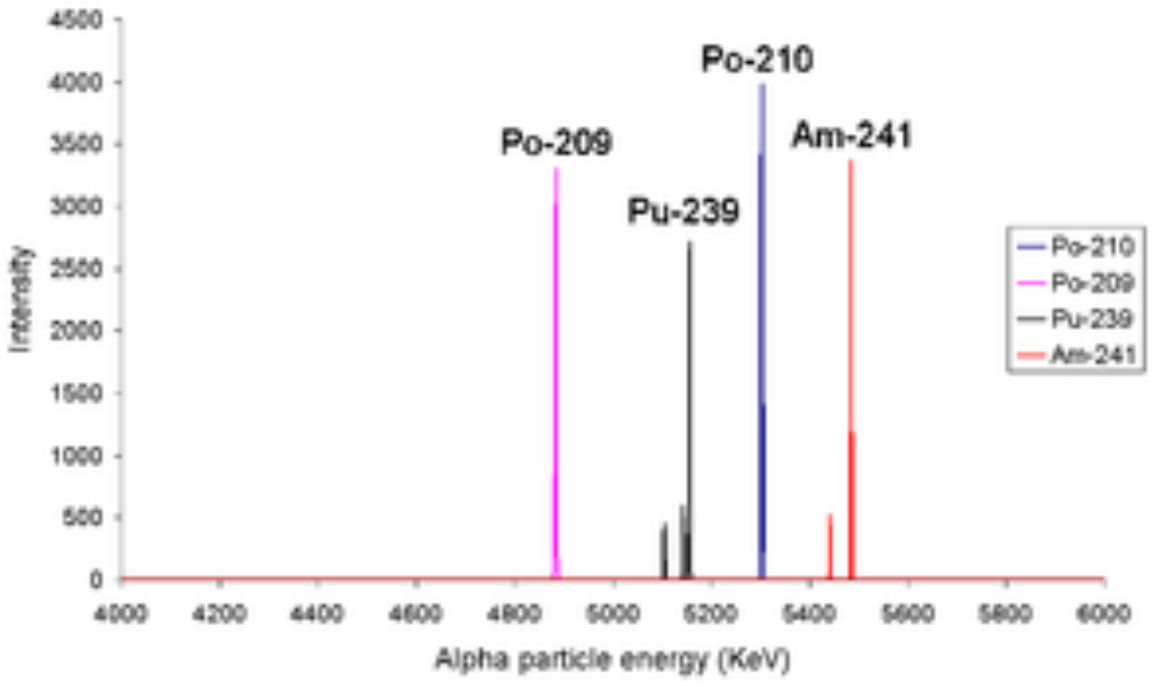
——刘佳@普林斯顿大学

https://zhuanlan.zhihu.com/p/34483368 《撼动宇宙的小粒子——中微子》 | 天问专栏

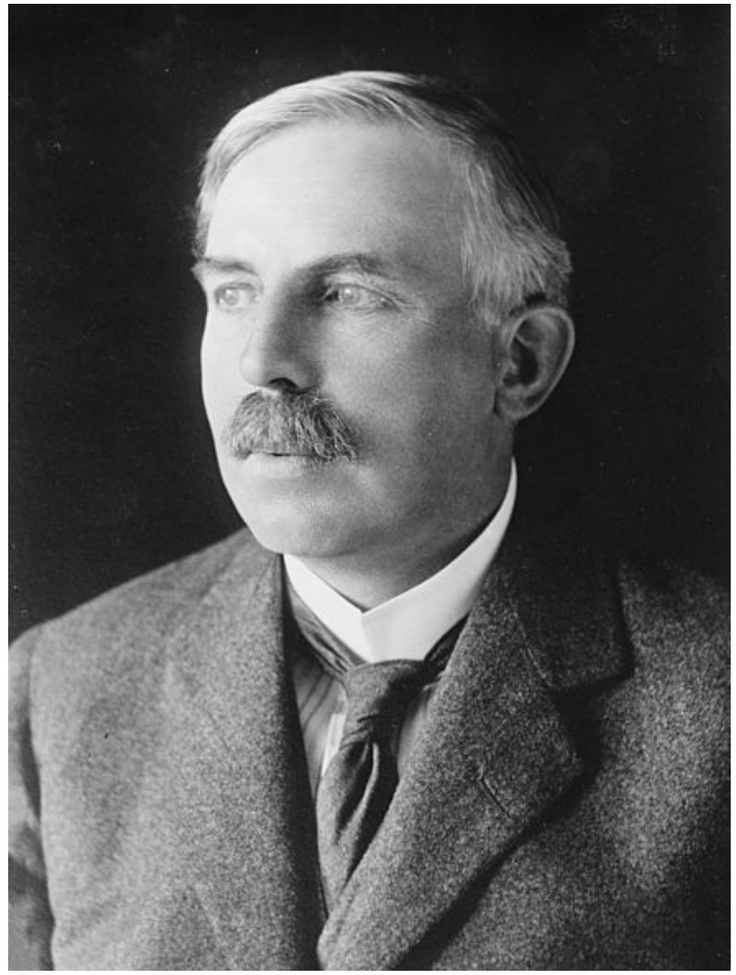
alpha decay

氦核

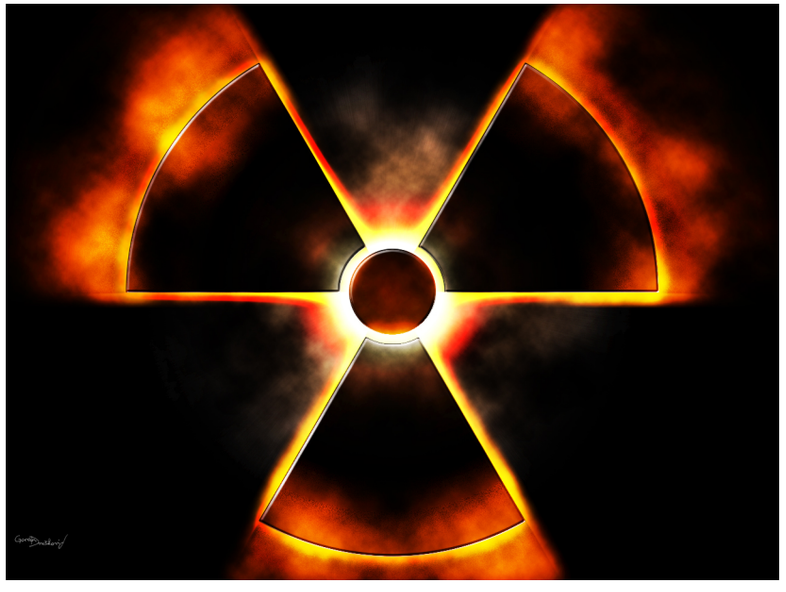




线状谱



卢瑟福

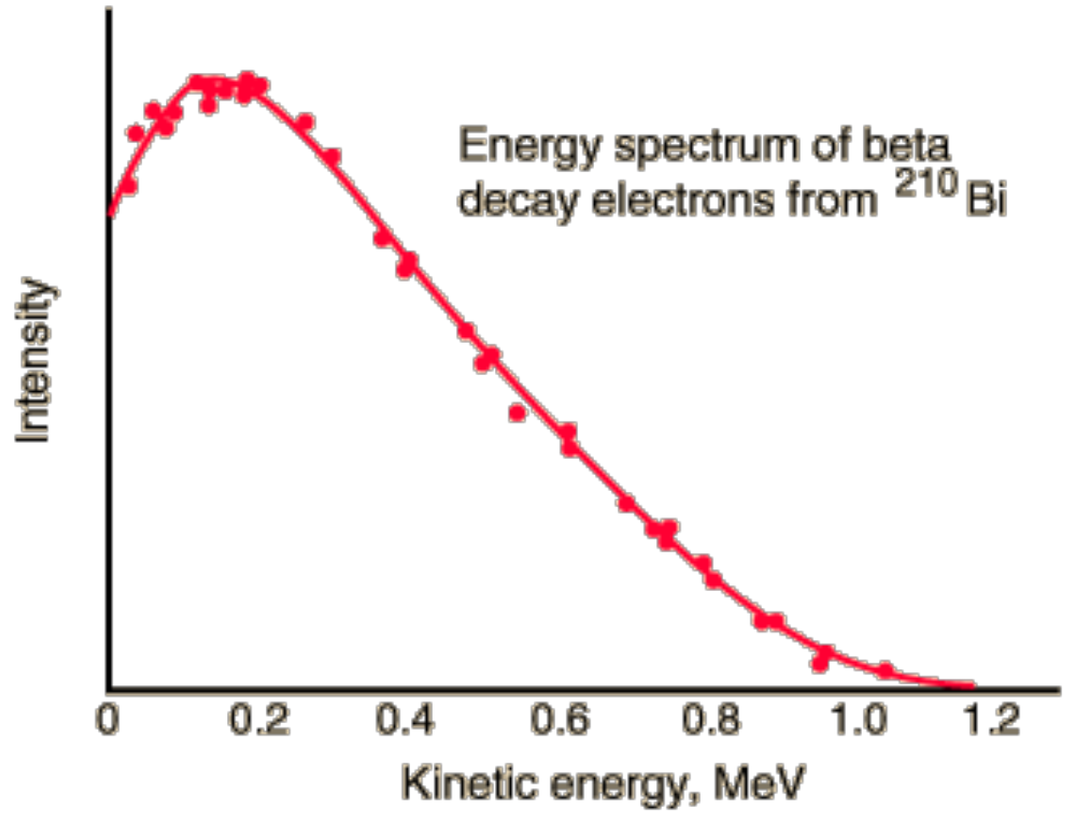


beta decay

1920s Many elements were known to have β-decays: $N_0(A, Z) \rightarrow N(A, Z+1) + e^-$.

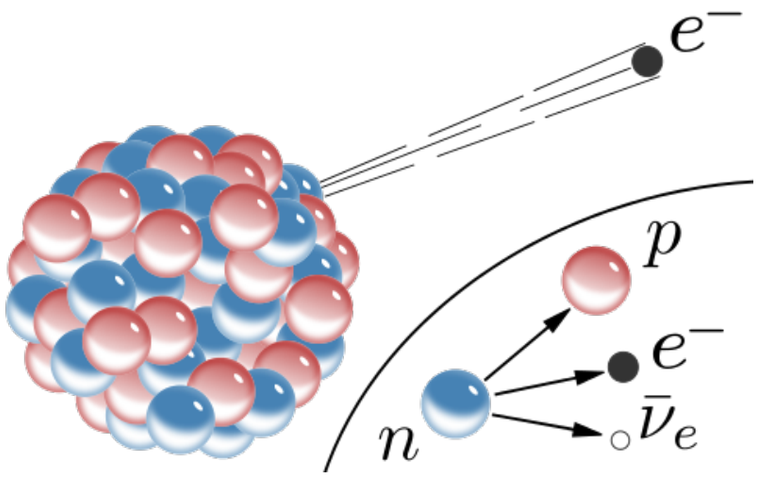
- Energy released was due to a small difference in nuclei masses $E_0 = M_0 - M \sim$ a few MeV
- Measurements of electron energy spectra were controversial:

Problem?



连续谱

Beta decay



free neutron is unstable!

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

rest mass: $m(n) > m(p) + m(e^-) + m(\nu)$

$$m(n) = m(p) + m(e^-) + m(\nu) + \text{kinetic energy}$$

By this process, unstable atoms obtain a more stable ratio of protons to neutrons.

1920s Many elements were known to have β-decays: $N_0(A, Z) \rightarrow N(A, Z+1) + e^-$.

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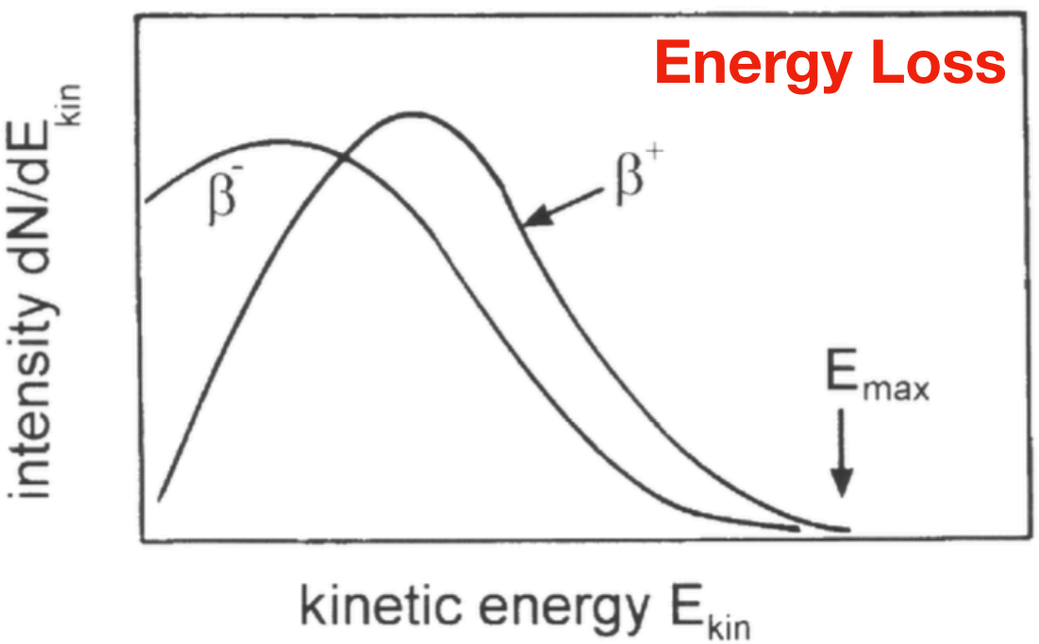
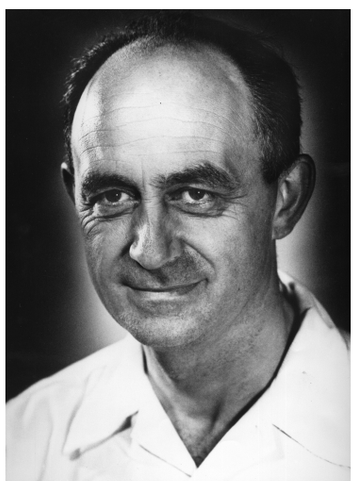


Figure 2: Continuous β^- and β^+ spectra

kinetic energy is shared by electron and neutrino

Why not proton?



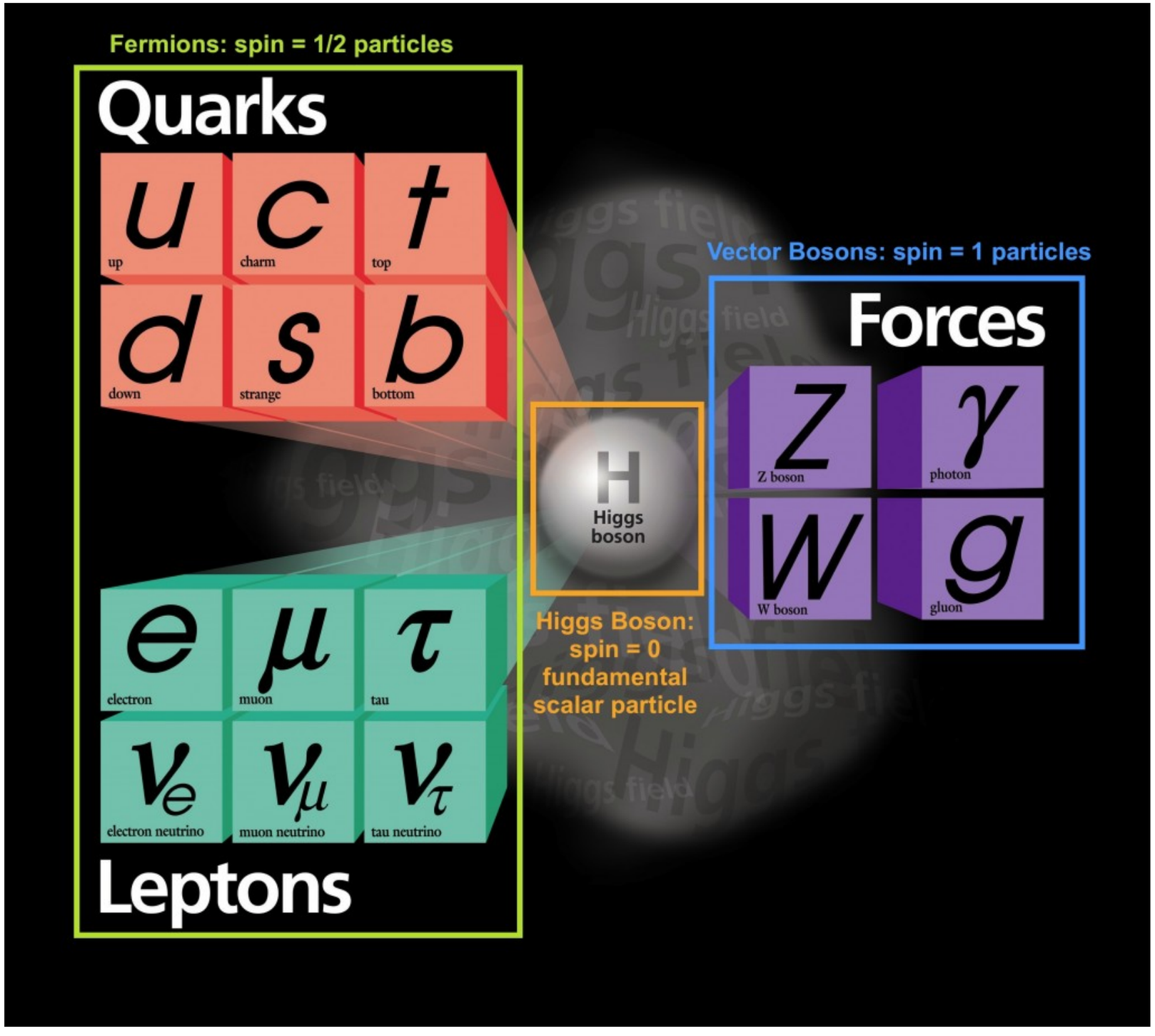
Fermi 🇮🇹

Pauli 🇦🇹

德国的卡尔斯鲁厄氚中微子（KATRIN）实验就是试图通过观测氚原子的β衰变来寻找答案

Q：为什么要这么大?

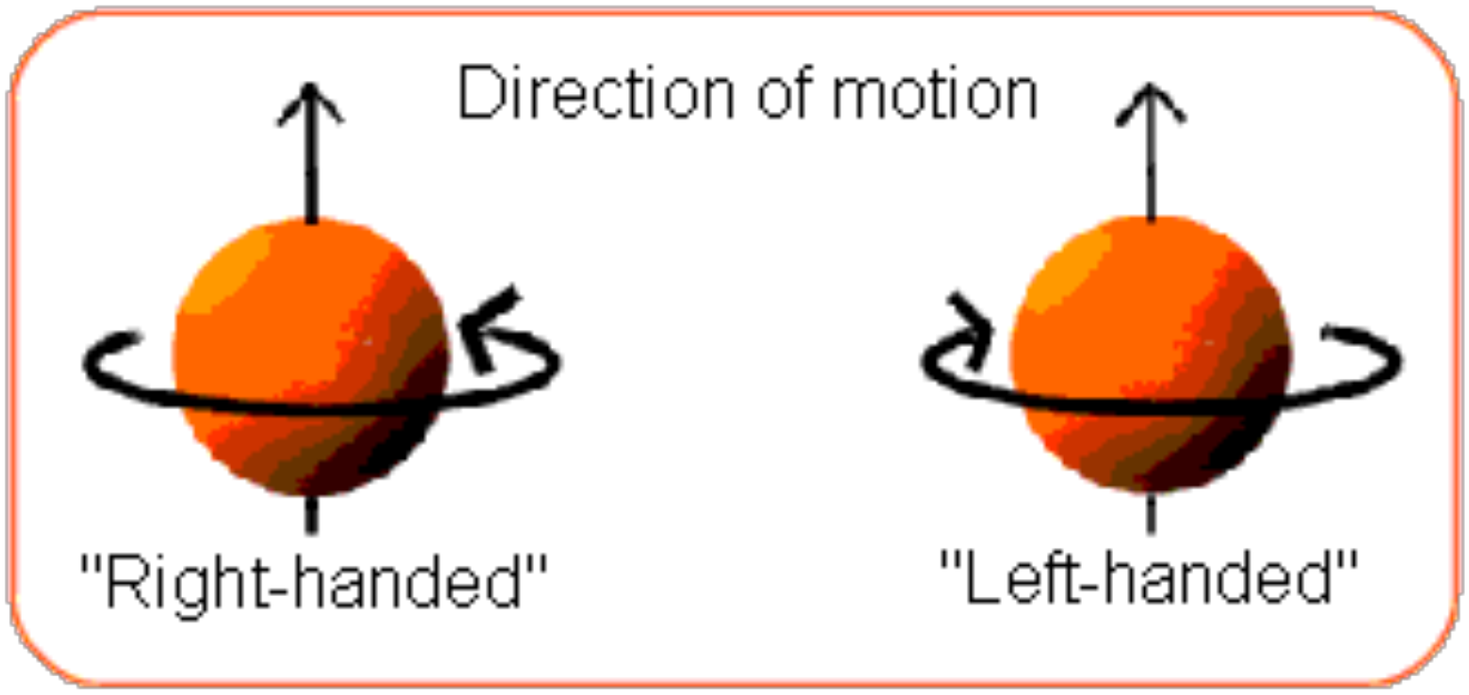
*2006*年*11*月*25*日，特殊制造的卡车正载着*200*吨重的*KATRIN*探测器，小心翼翼地穿过德国小镇符腾堡（*Leopoldshafen*），运往卡尔斯鲁厄科研中心。图片来源：卡尔斯鲁厄科研中心



Particle Standard Model

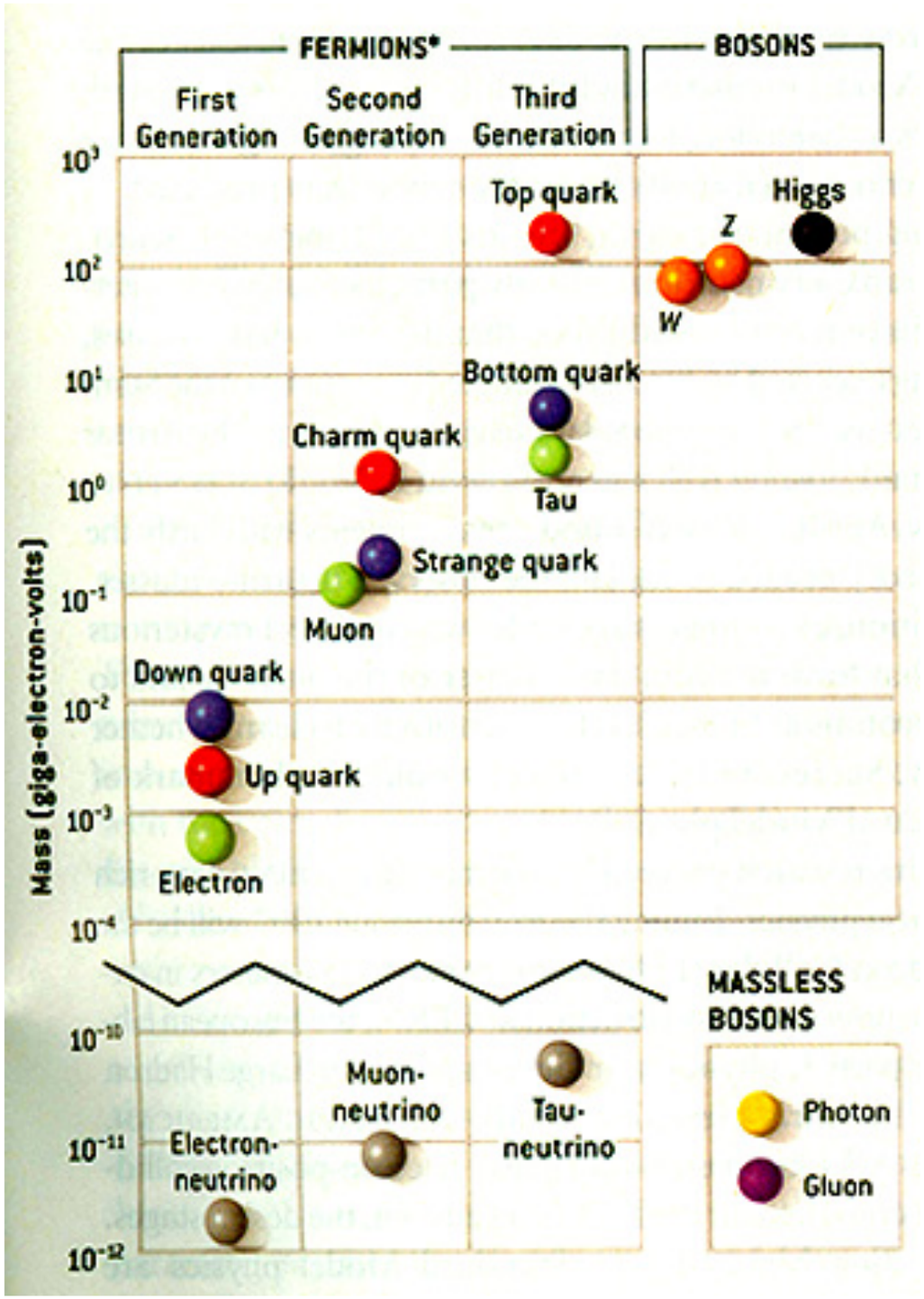
SU(3)*SU(2)*U(1)

neutrino is massless



?

Yes!



Standard Model: only left-handed neutrino and they are **MASSLESS**!

到目前为止，**唯一**的，**确信**的，

超出标准粒子物理模型的证据

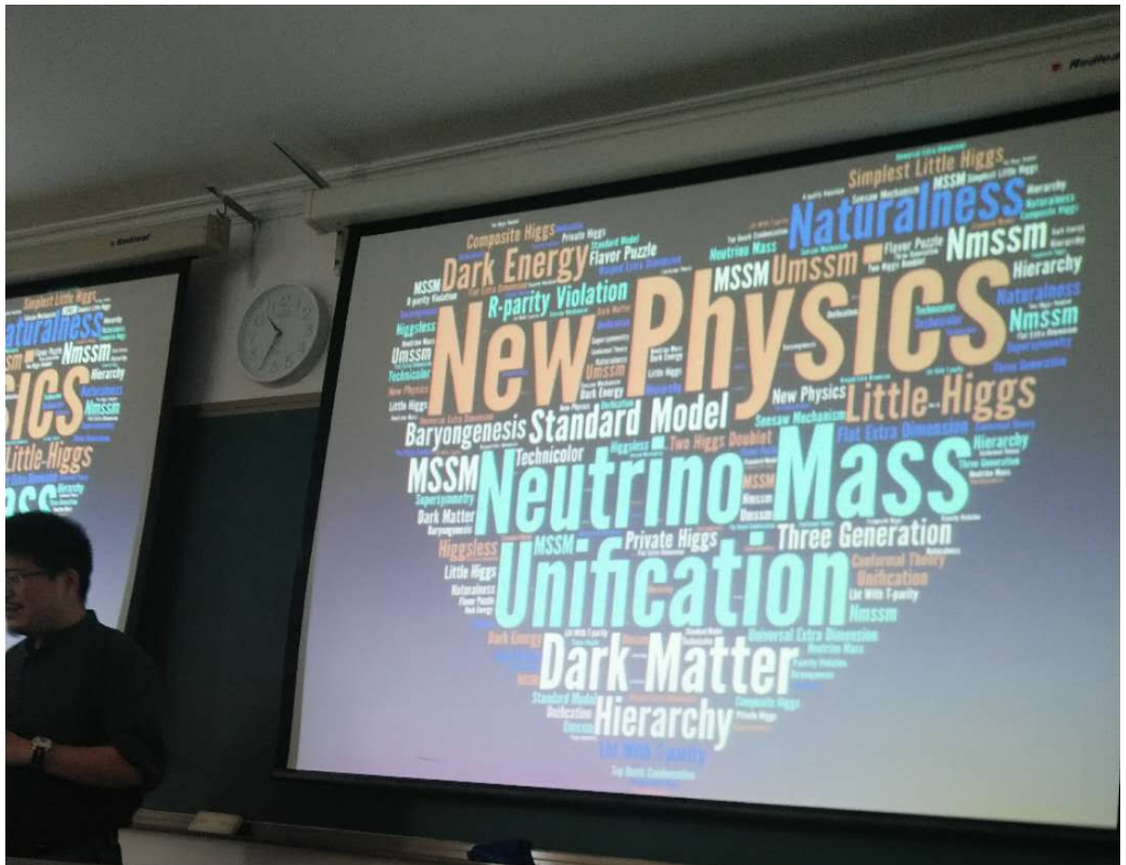
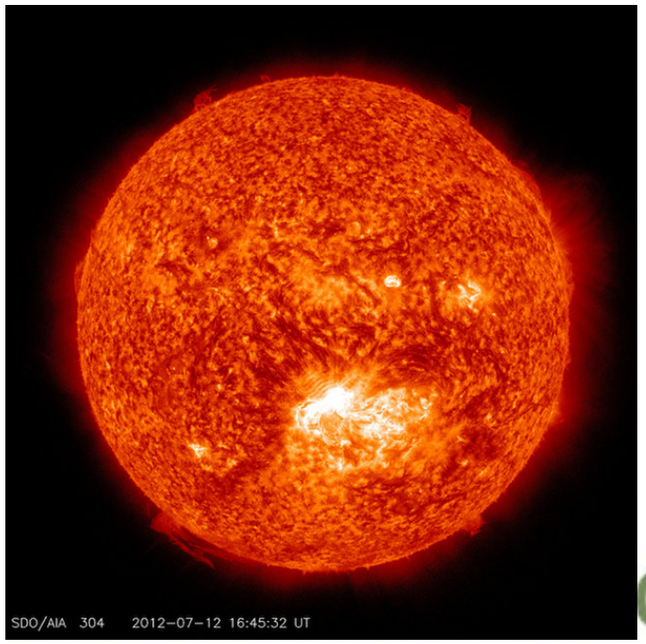
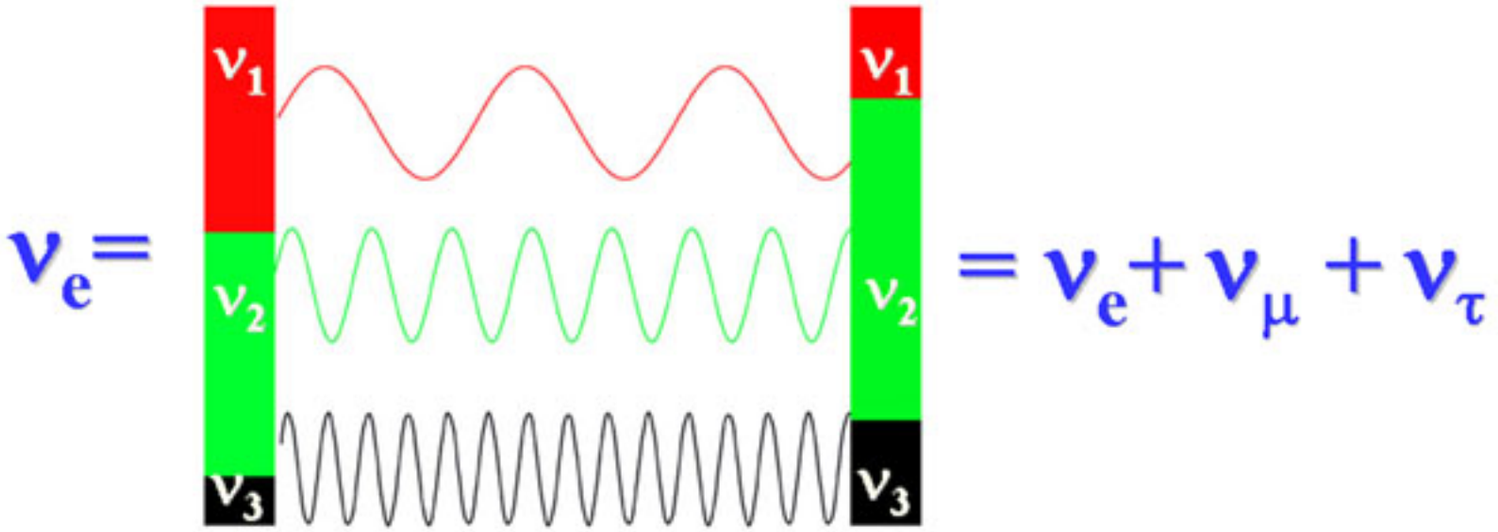


Illustration: © Johan Jarnestad/The Royal Swedish Academy of Sciences

solar neutrino problem

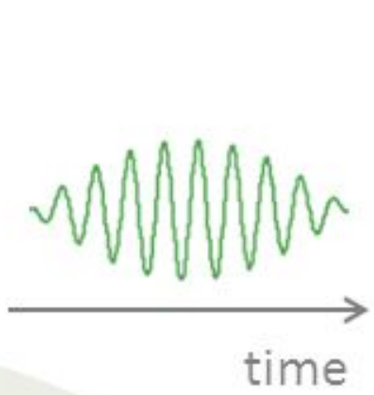


味道本征态 != 质量本征态



cillation

The flavor of neutrino changes periodically as it propagates

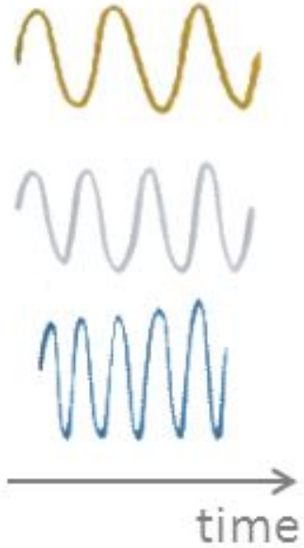


$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{PMNS} \times \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix} \begin{matrix} (m_1) \\ (m_2) \\ (m_3) \end{matrix}$$

Flavor eigenstates

Mixing matrix (PMNS matrix)

mass eigenstates



described by mixing angles θ_{12}, θ_{23}, θ_{13} and CP phase δ_{CP}

$\sim 34^\circ, \sim 45^\circ, \sim 9^\circ$ Unknown!

ν oscillation also depends on $\Delta m^2_{ij} = m^2_i - m^2_j$

$\Delta m^2_{21} \sim 7.5\times10^{-5}$, $|\Delta m^2_{32}| \sim 2.3\times10^{-3}$ eV^2

Questions:

王贻芳@ihep

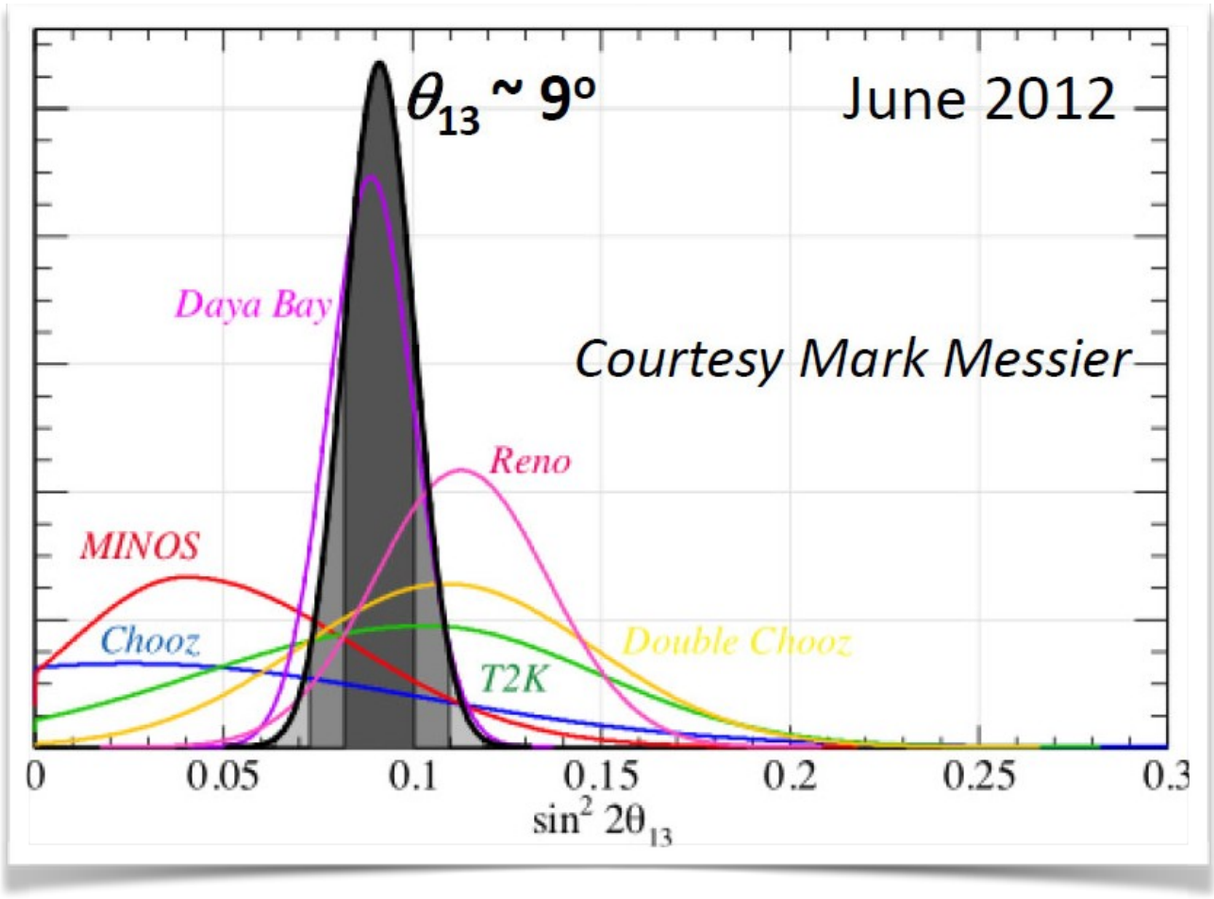
中国**首次**领导

基础科学领域

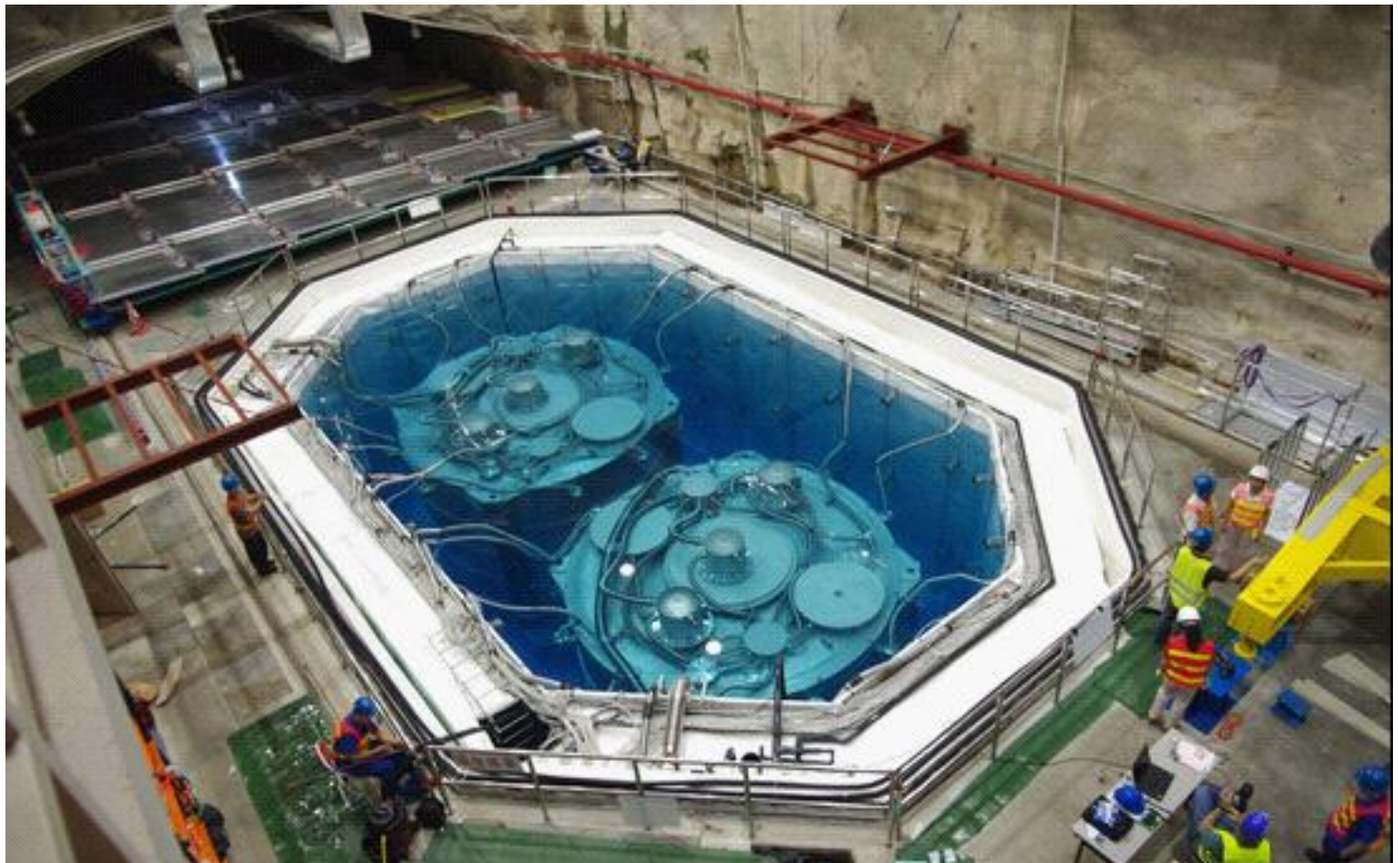
的大型合作项目

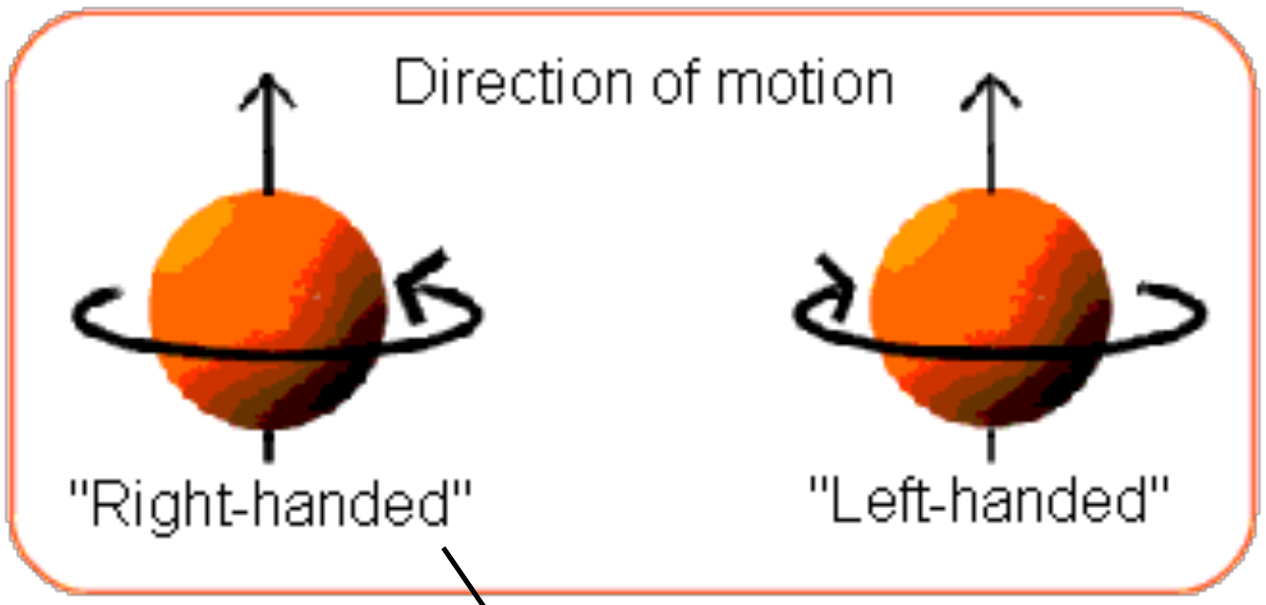
并作出**国际领先**

的工作！



DaYa BAY





sterile neutrino?

Dark Matter candidate!

Neutrino Astronomy

blue glory of nuclear
reactor under the water

The speed of source of the light (charged particle) is greater than light

A common analogy is the sonic boom of a supersonic aircraft or bullet. The sound waves generated by the supersonic body propagate at the speed of sound itself; as such, the waves travel slower than the speeding object and cannot propagate forward from the body, instead forming a shock front. In a similar way, a charged particle can generate a light shock wave as it travels through an insulator.

Large Scale Neutrino Detectors

ANTARES
La-Seyne-sur-Mer, France

NEMO
Catania, Italy

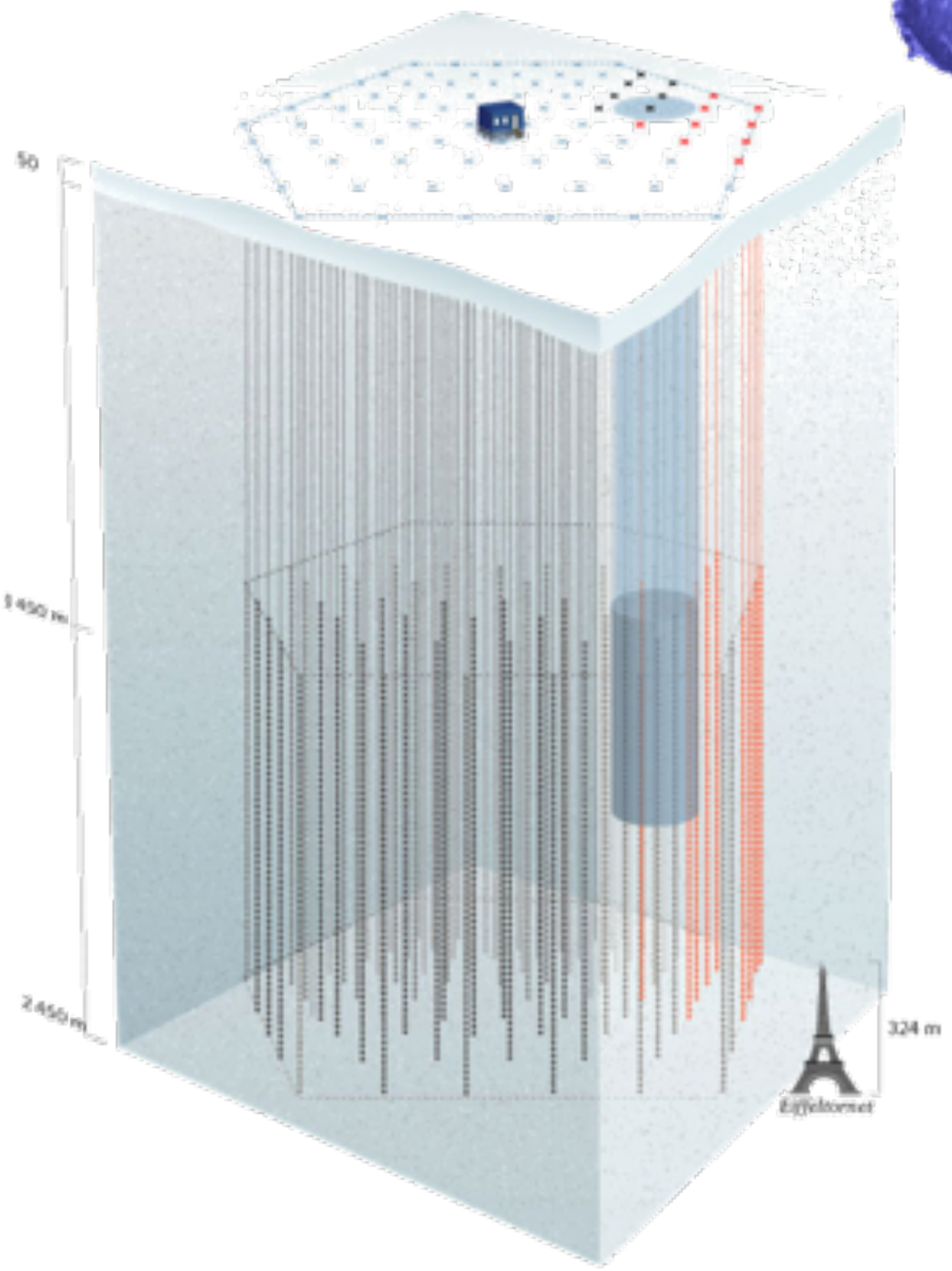
NESTOR
Pylos, Greece

BAIKAL
Russia

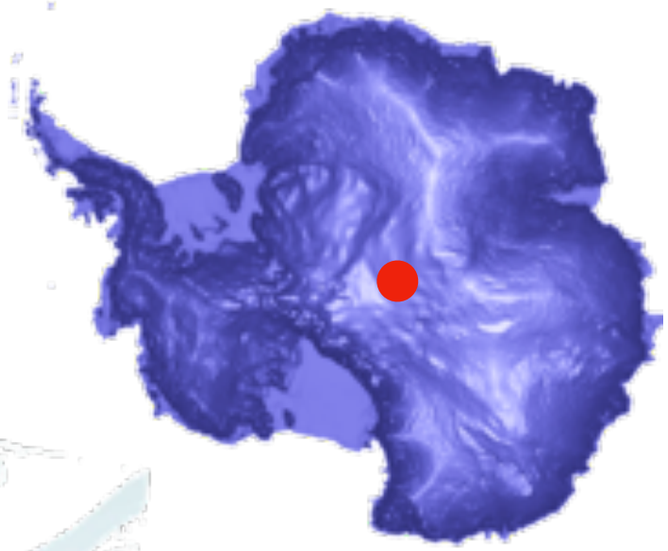
IceCube, South Pole, Antarctica

Post-it Notes

See Talks in this Session

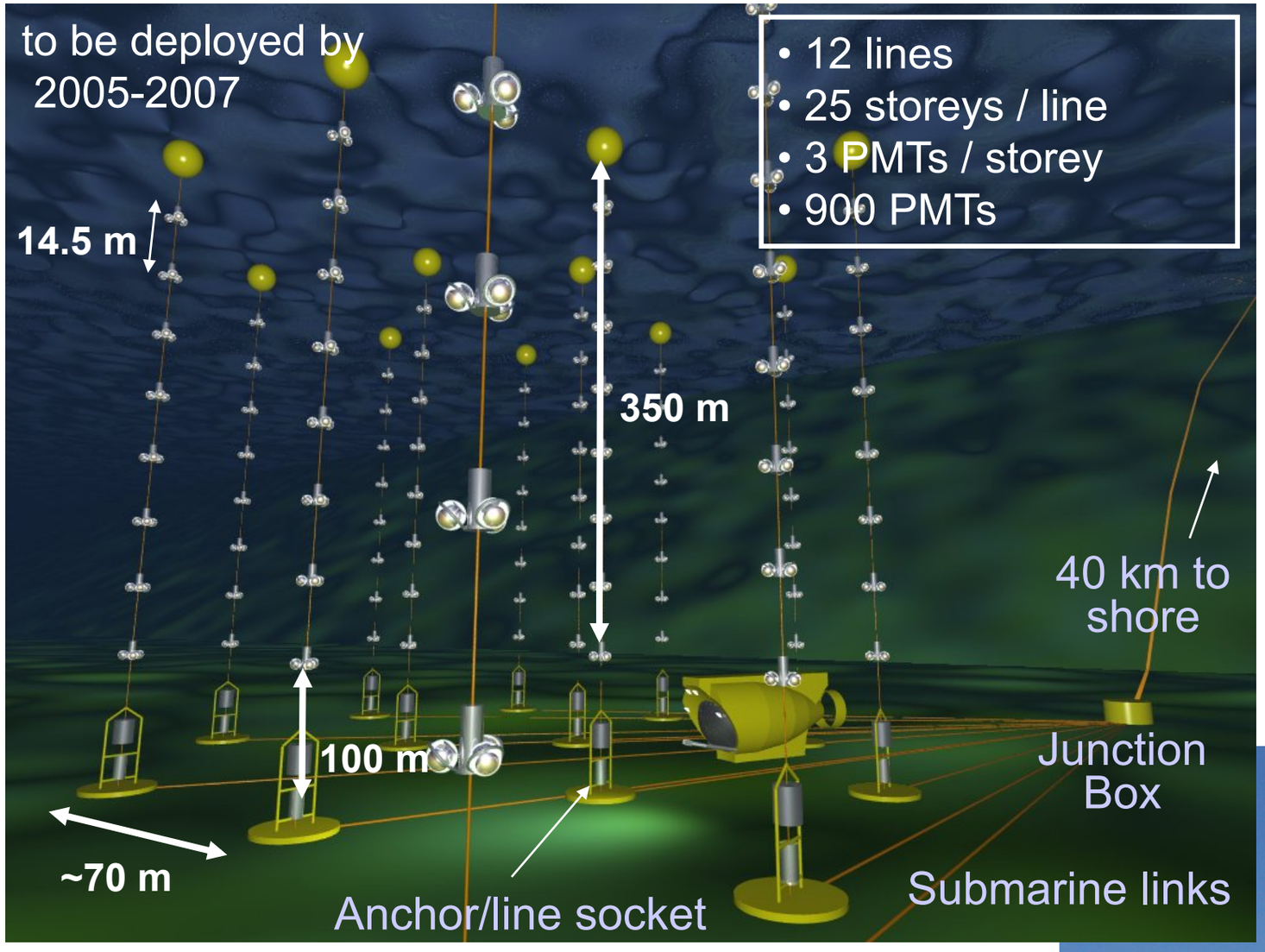


ICECUBE

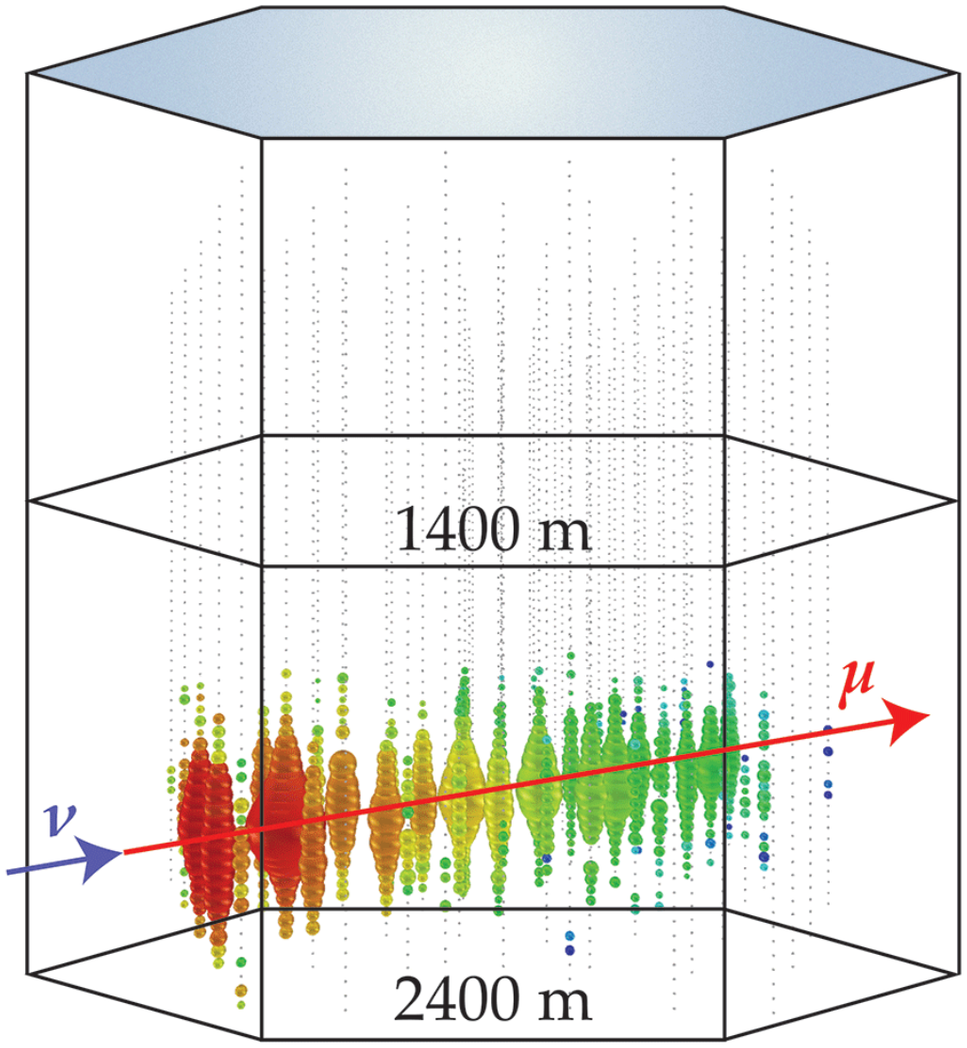


水立方

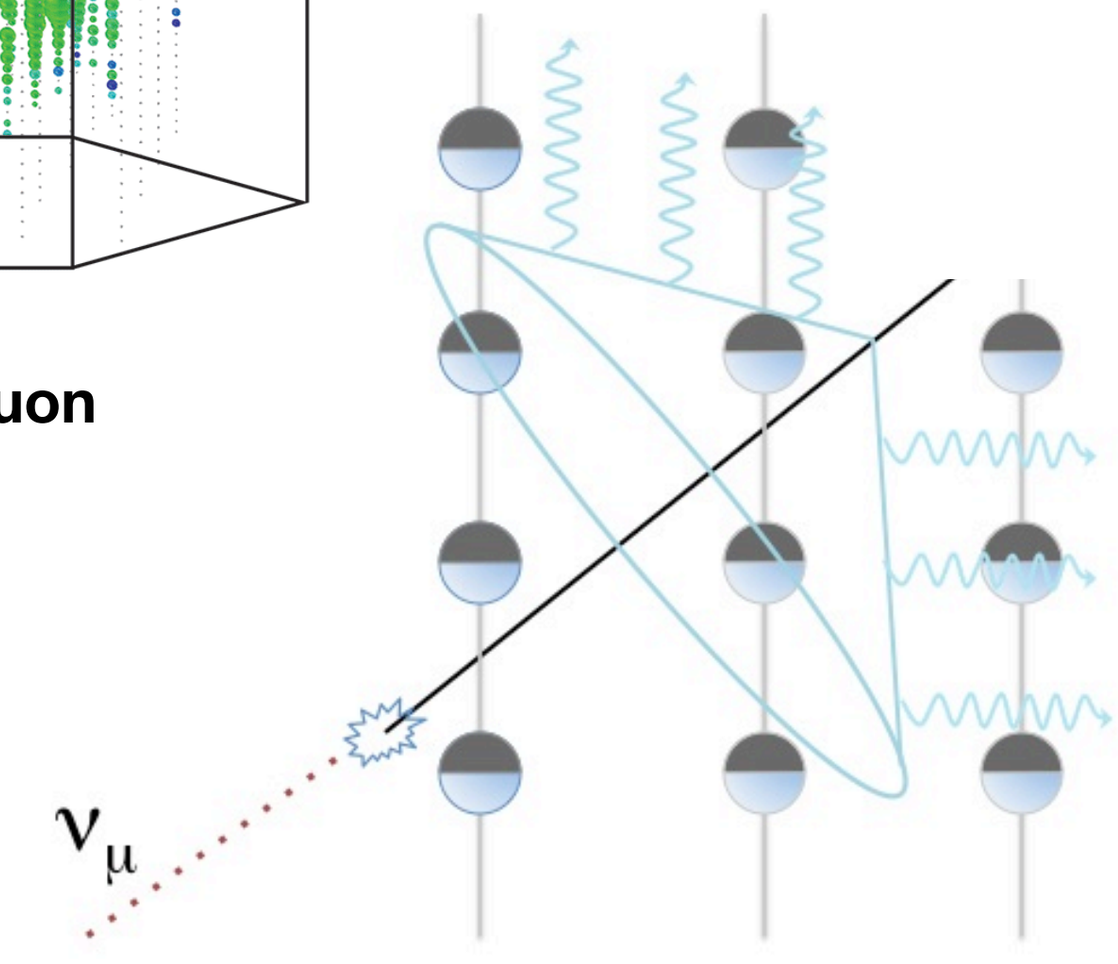
ANTARES is installing a 0.1 km^2 demonstrator detector close to Toulon

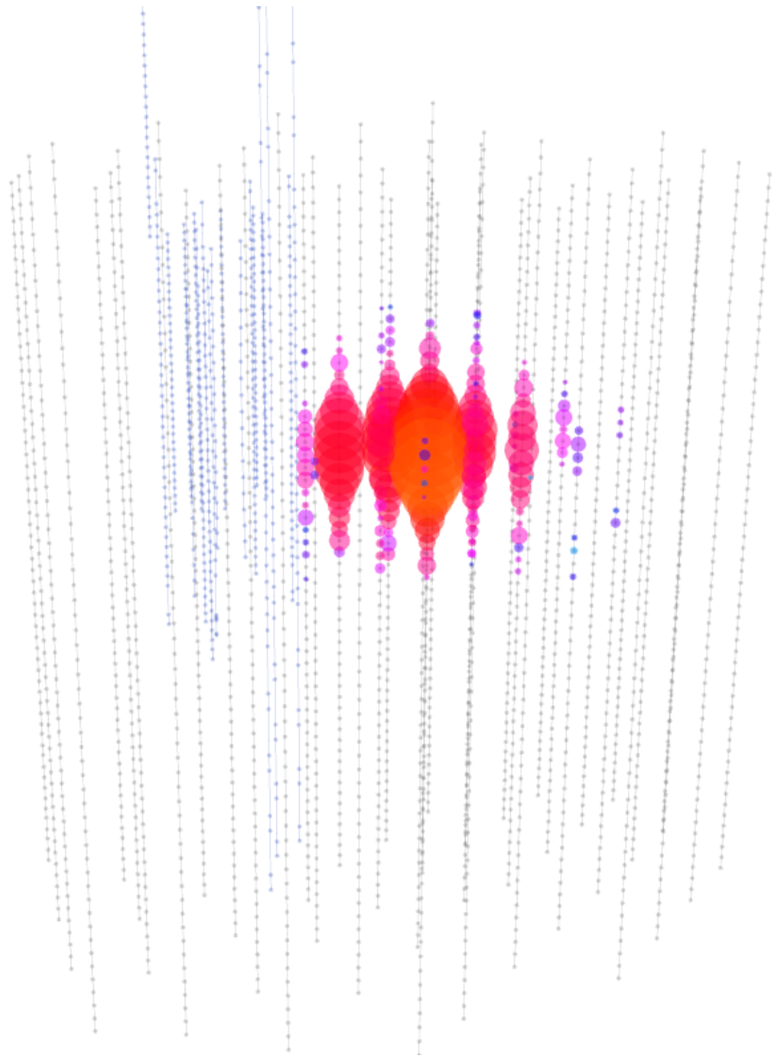


ANTARES deployed Line 1 in February. 2006.



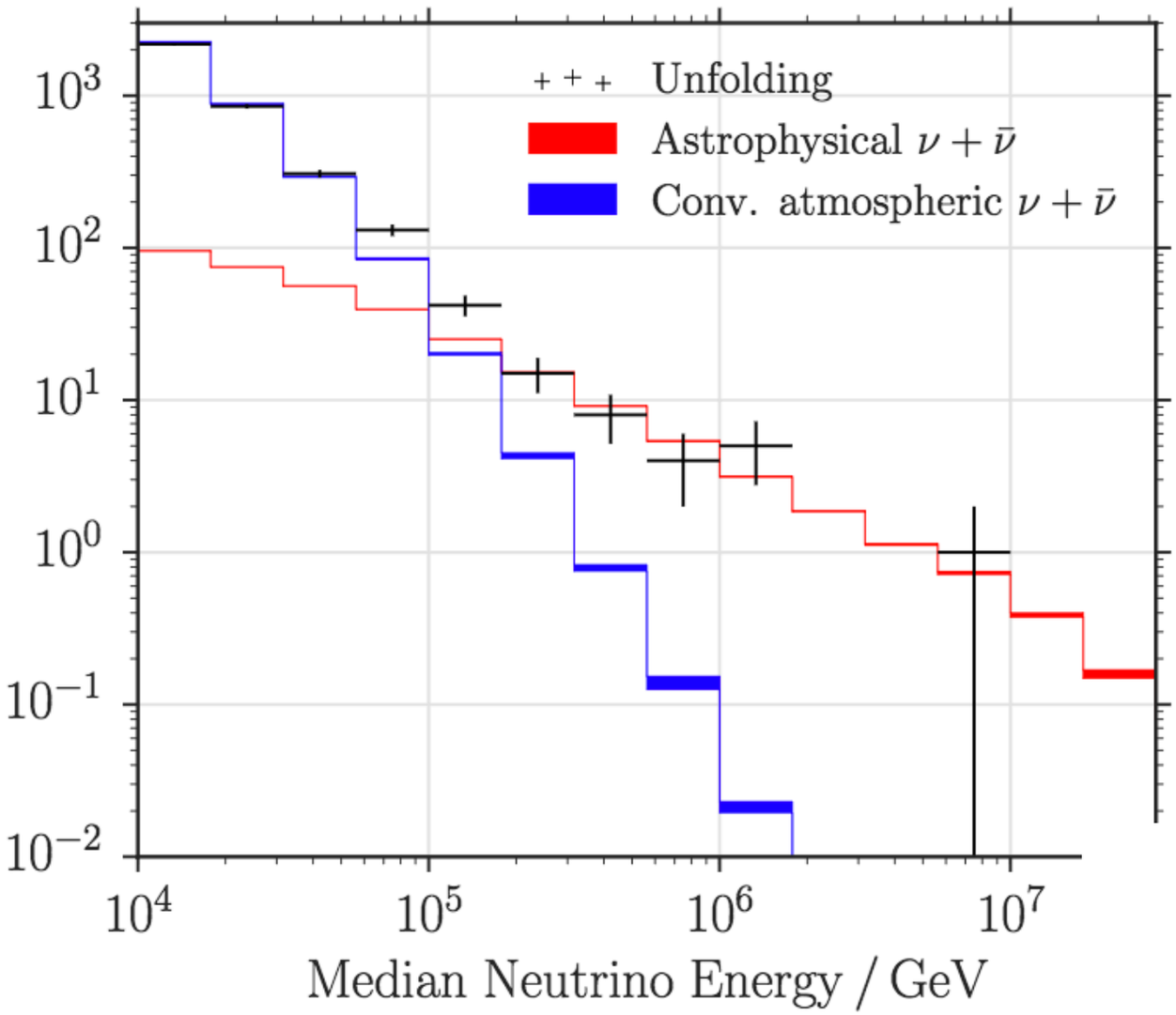
track-like event: muon

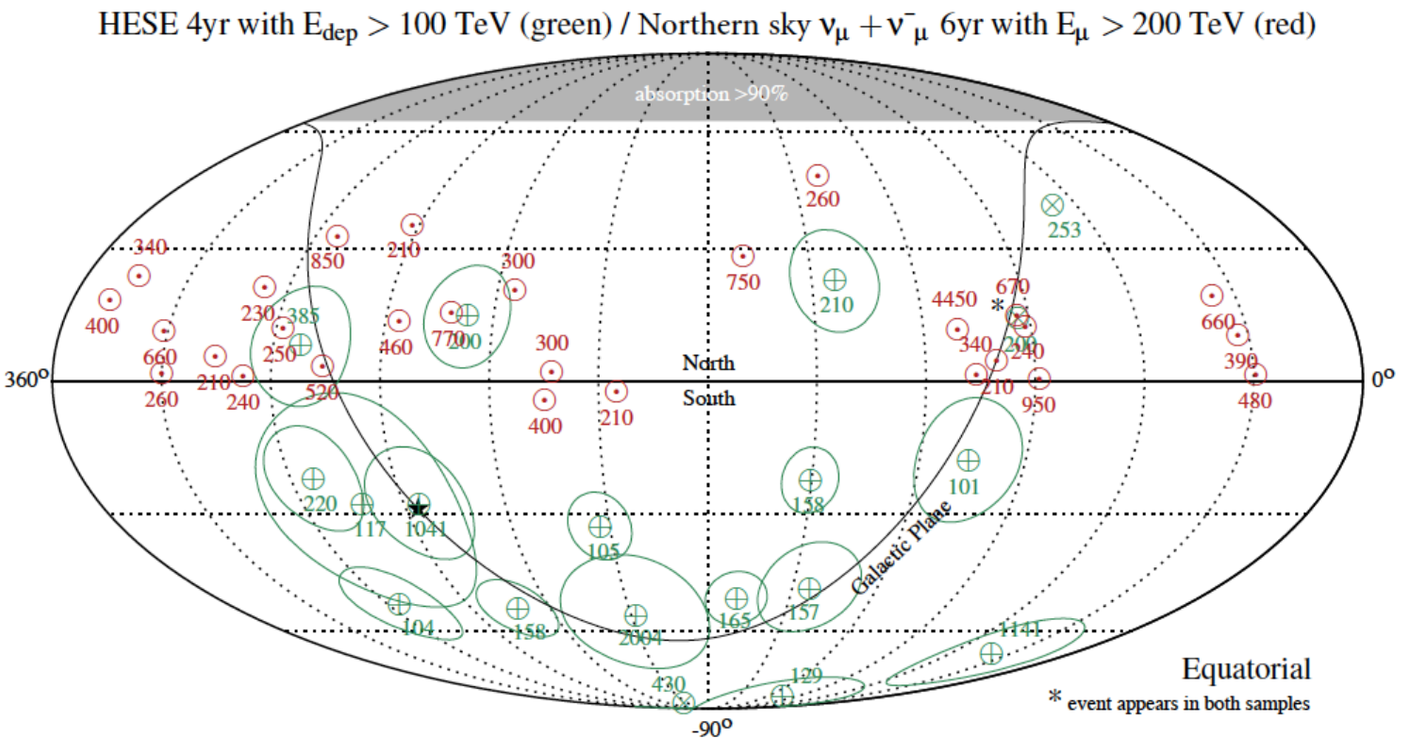




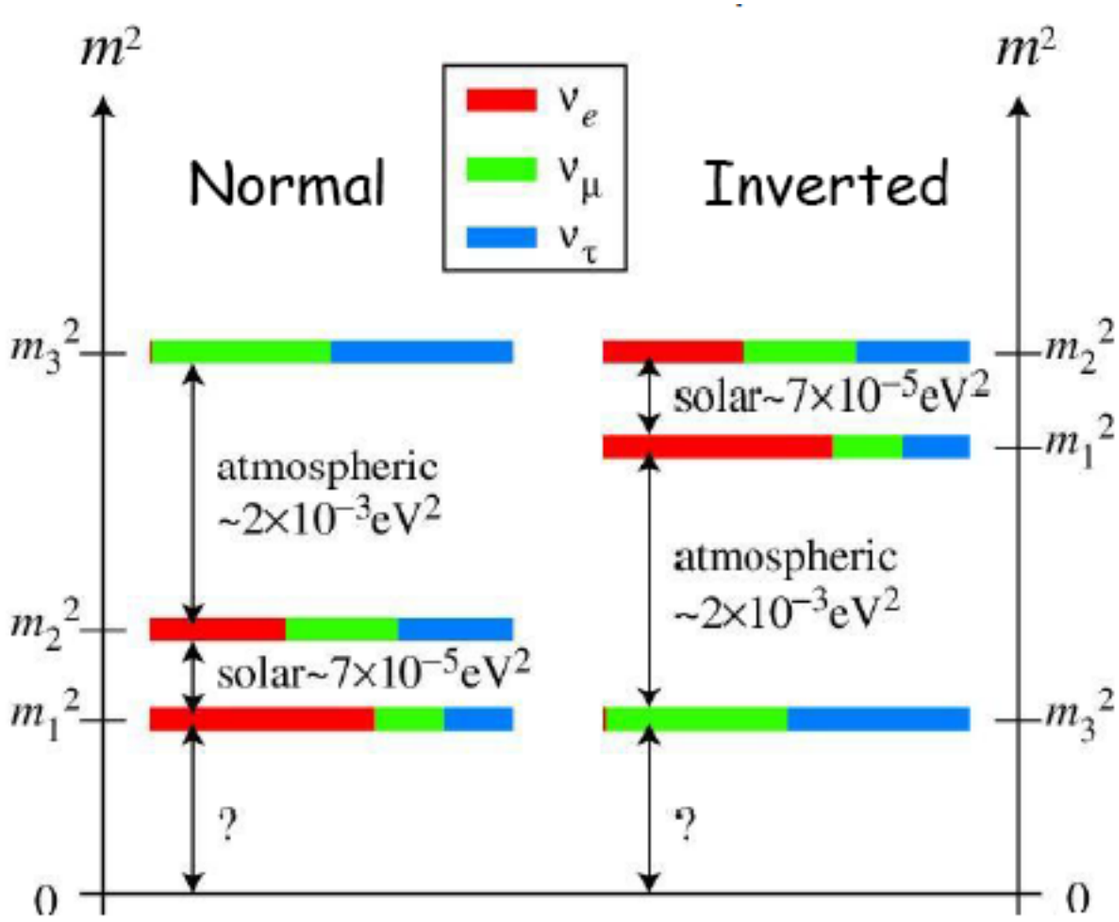
cascade-like event: tau

ICECUBE——中微子天文台





Neutrino Cosmology



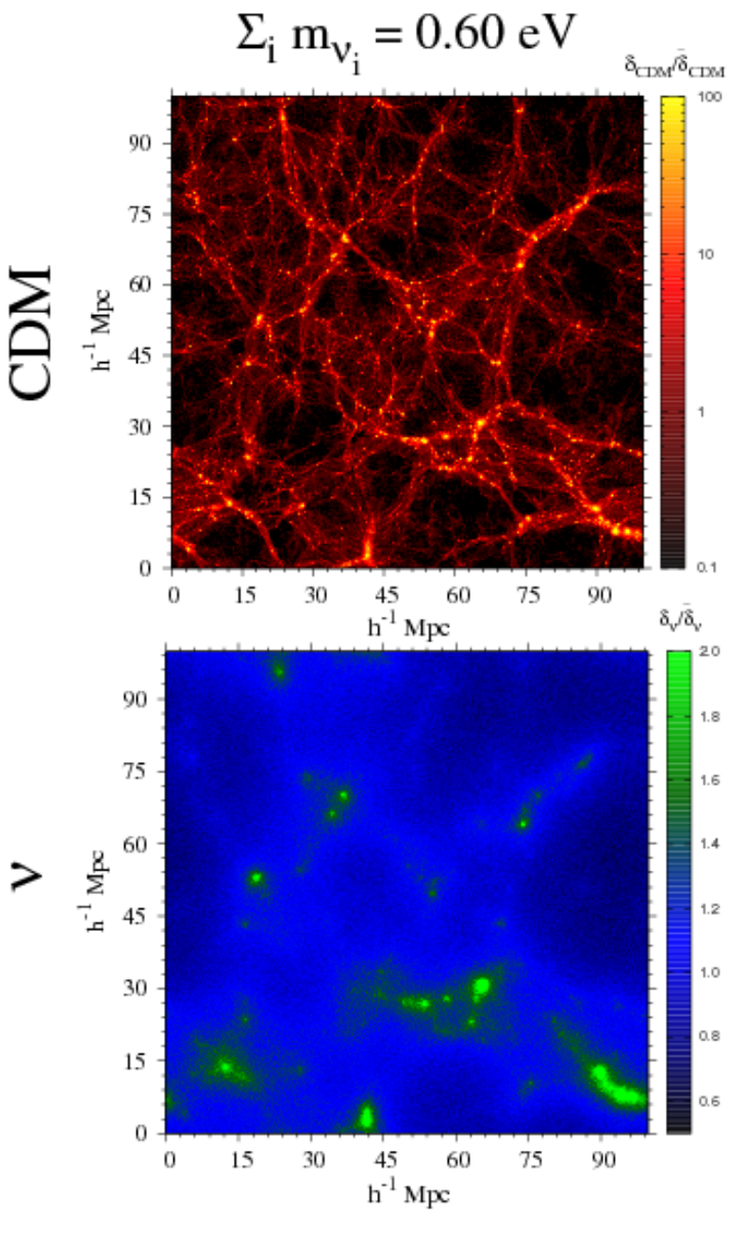
中微子的直接探测试验只能测量其质量差，**不能**很好地确定其**总质量**

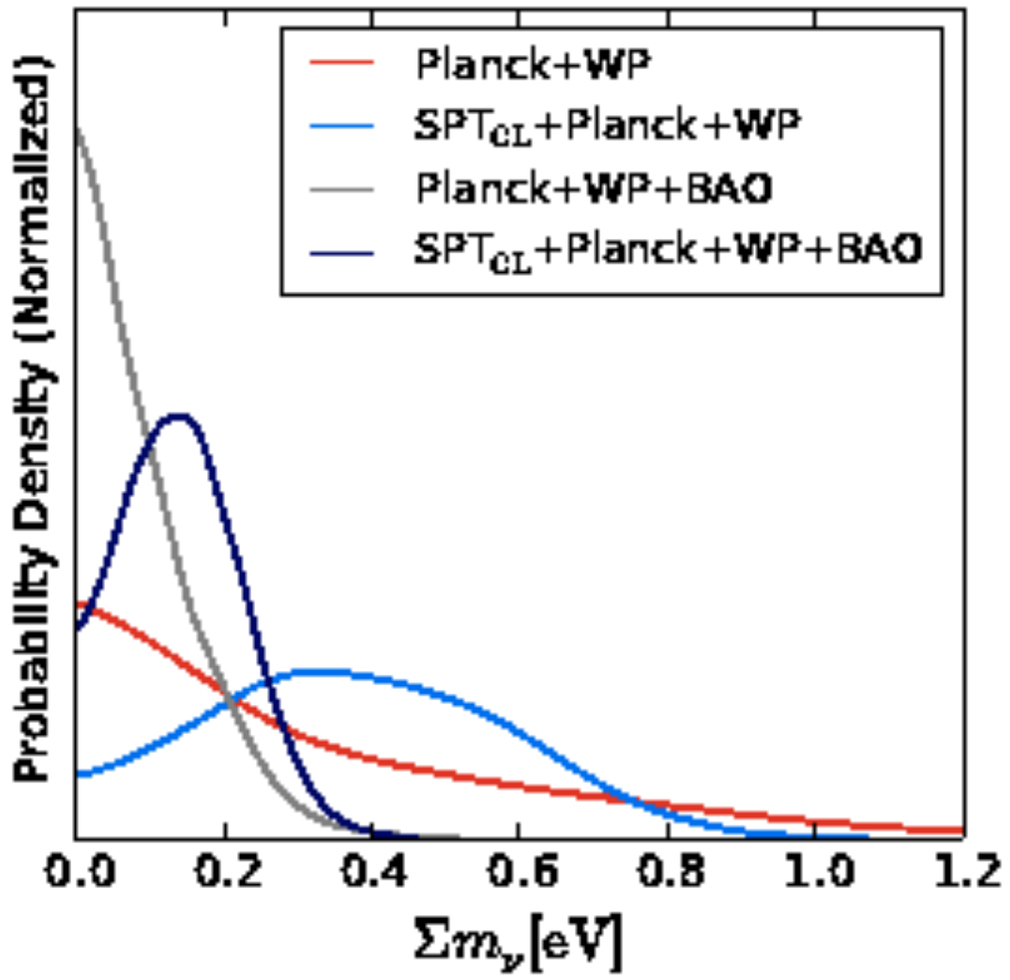
但，宇宙学实验数据**可以**很好地测量其总质量！

WHY?

$$\frac{\Omega_\nu}{\Omega_{\rm cdm}} \sim 0.005$$

$$\Omega_\nu = \frac{\Sigma m}{94 h^2 {\rm eV}}$$





Problem-9: 综述一下中微子物理相关领域所获的诺贝尔奖