质 量 起 源 粒子物理的认识

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2016年7月11日

质量是什么？ 一个困扰了物理学家几百年的难题—《环球物理》2015-09-11

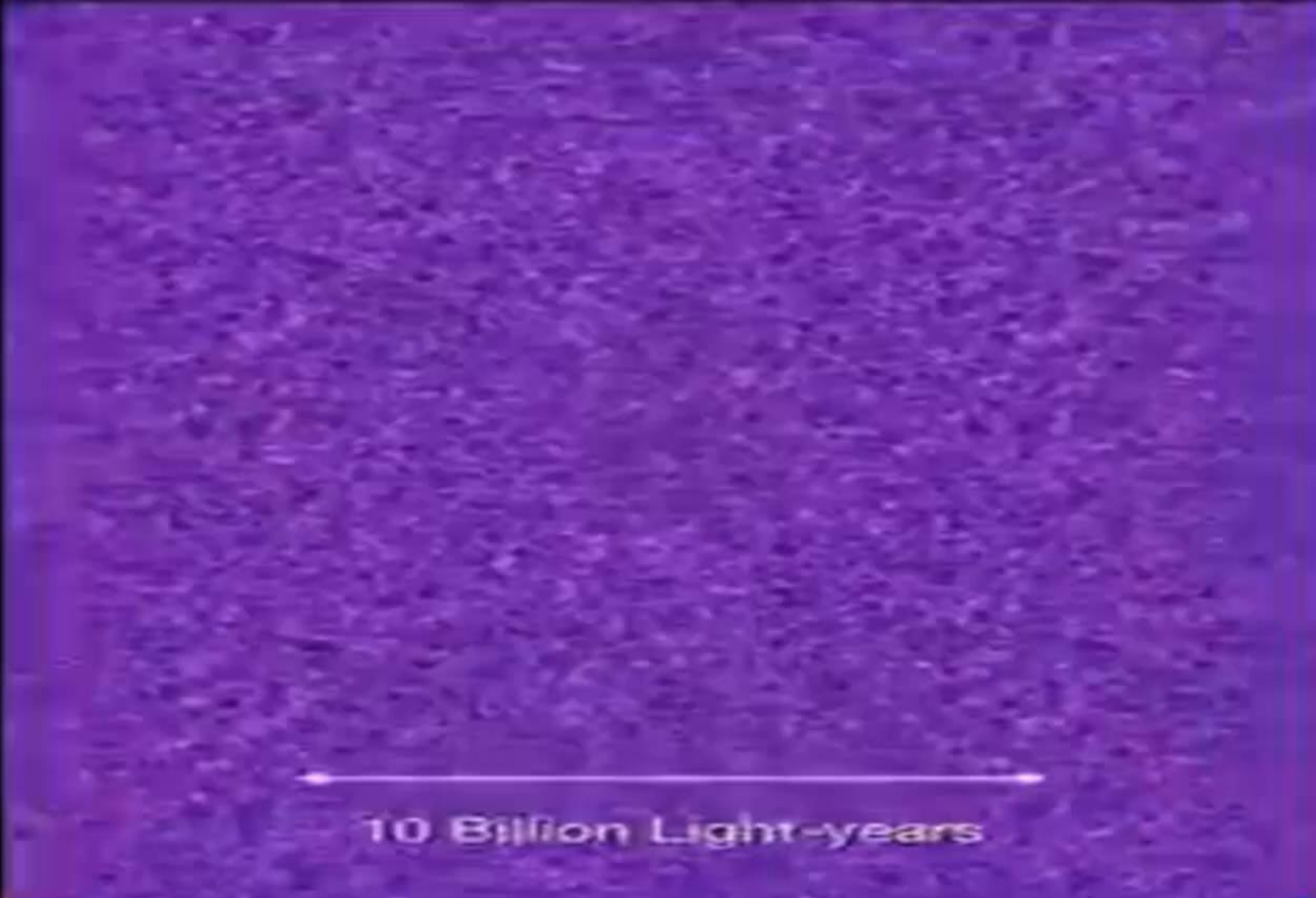
质量就是让一个满载的购物车难于移动的东西

——它的惯性，

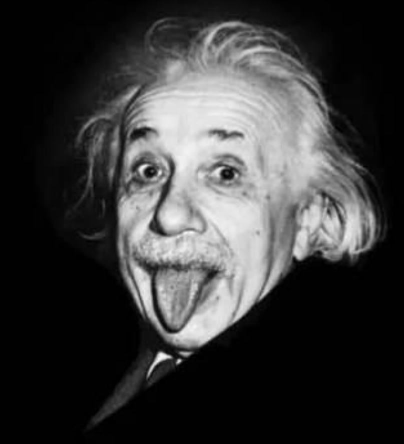
或者也许是让一袋糖或钢琴之类有重量的东西

……

Uniform Universe



能量与质量



$$E=mc^2$$

质量所涉及的基本物理定律

$$F=ma$$

质量起源问题：为什么要有质量？质量为什么取这样的值？它是怎么产生出来的 ？

质量因为我们而存在

真空产生有质量粒子

零质量粒子产生质量

$$F=Gm_1m_2/r^2$$

质量产生与零质量物体

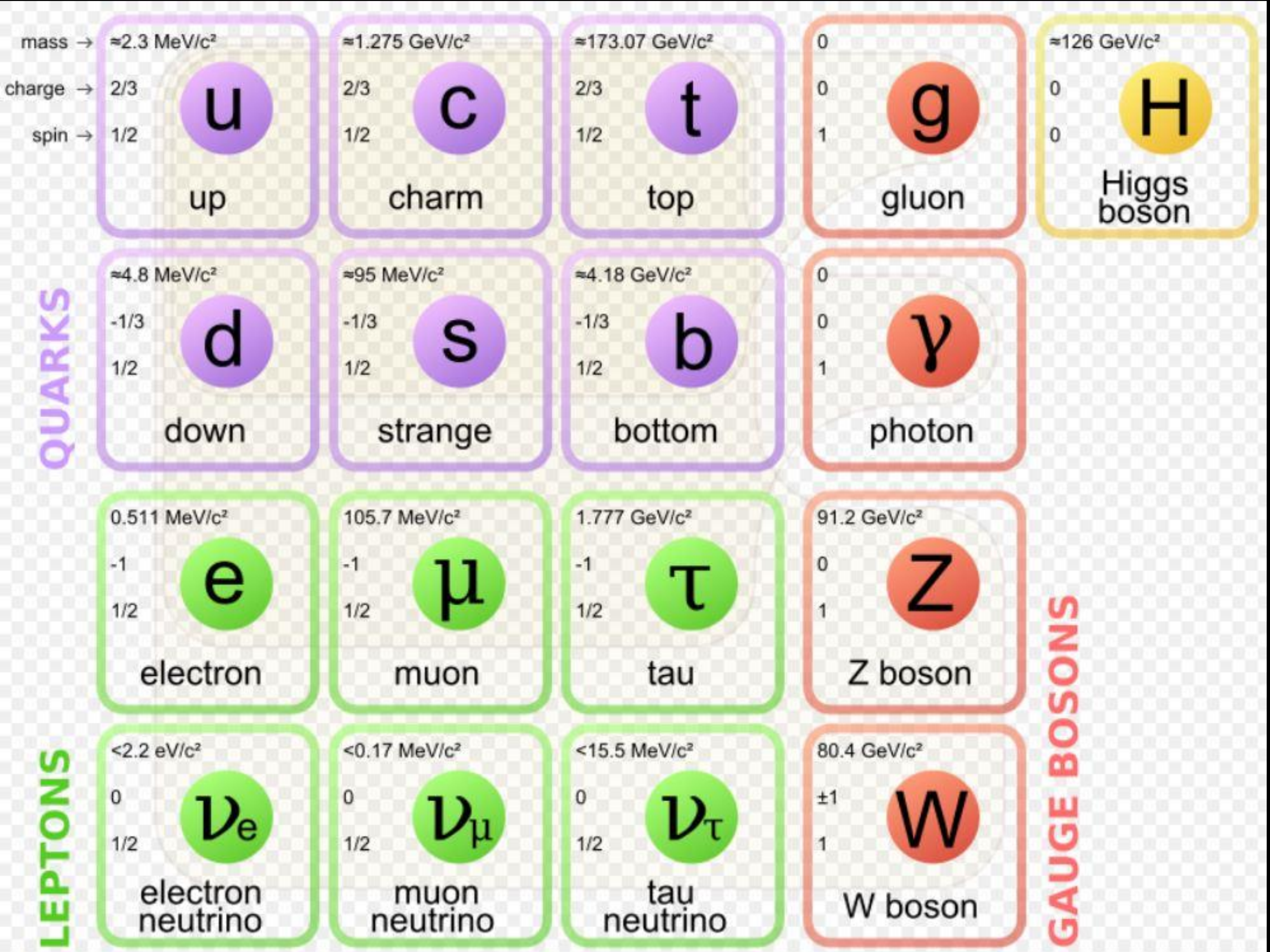
$$T=1/2\ m_0 v^2$$

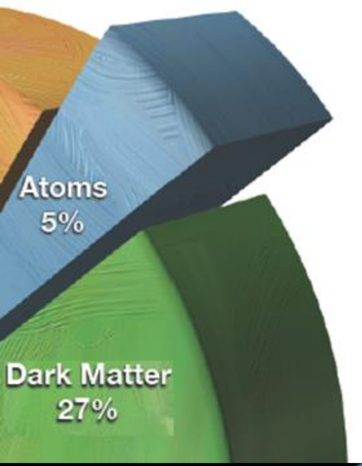
零质量物体一定是相对论性的在经典力学中只能是真空 ！

$$m=m_0/\sqrt{1-v^2/c^2}$$

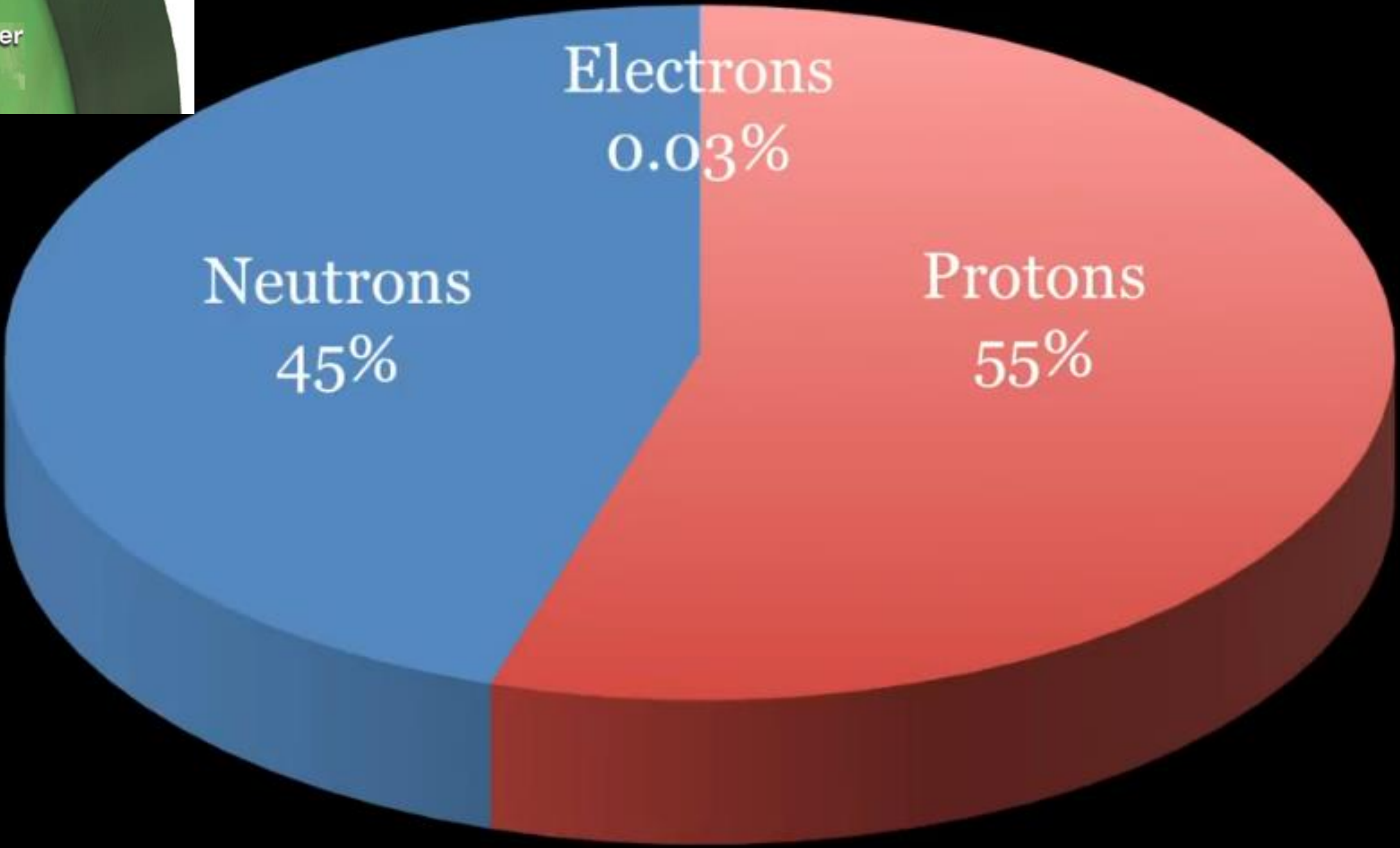
为什么基本粒子要有质量？

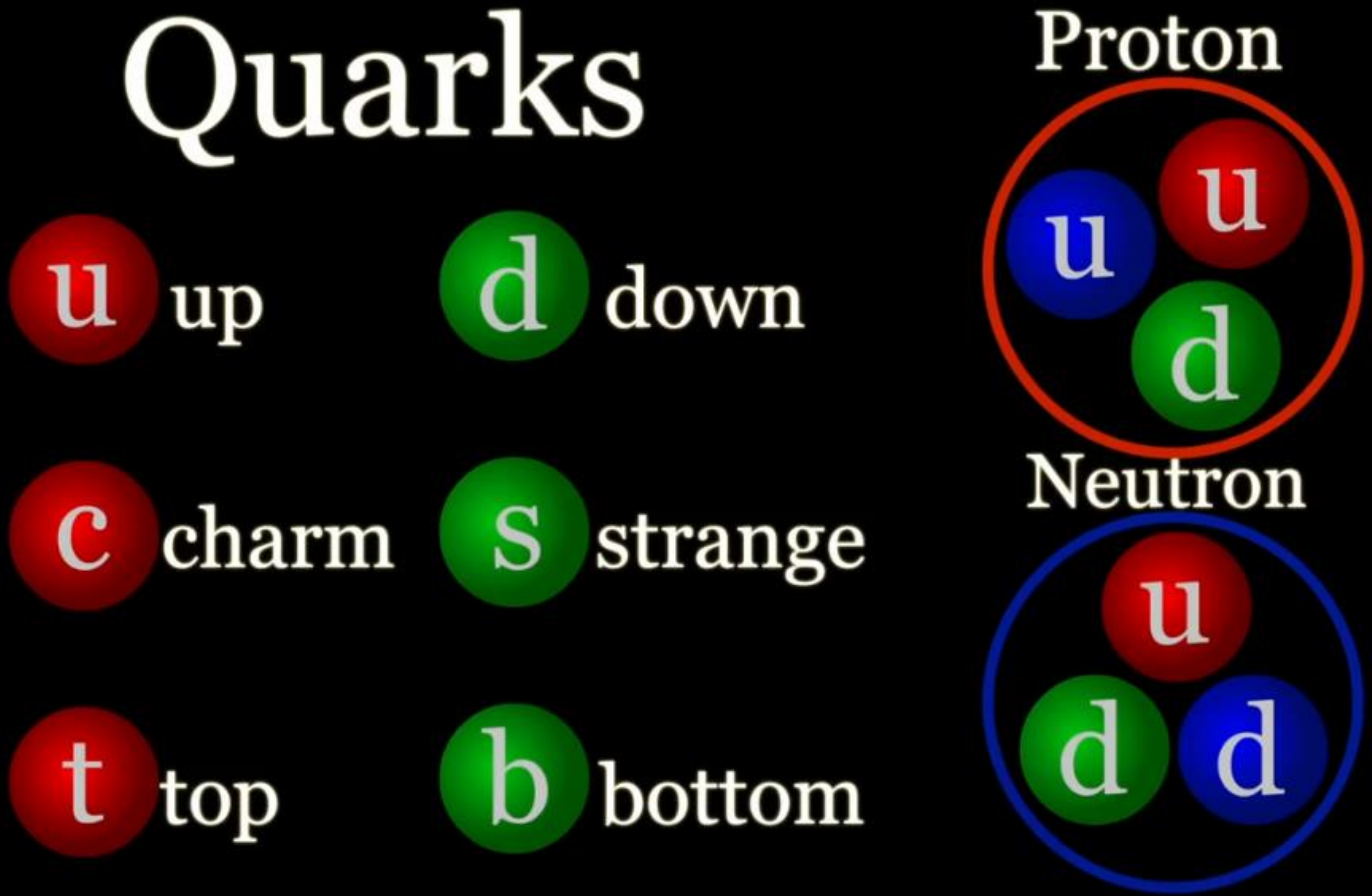
质量为什么取这样的值？


mass →
charge →
spin →
≈2.3 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈173.07 GeV/c²
2/3
1/2
t
top
0
0
1
g
gluon
≈126 GeV/c²
0
0
H
Higgs boson
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
0.511 MeV/c²
-1
1/2
e
electron
105.7 MeV/c²
-1
1/2
μ
muon
1.777 GeV/c²
-1
1/2
τ
tau
91.2 GeV/c²
0
1
Z
Z boson
<2.2 eV/c²
0
1/2
νe
electron neutrino
<0.17 MeV/c²
0
1/2
νμ
muon neutrino
<15.5 MeV/c²
0
1/2
ντ
tau neutrino
80.4 GeV/c²
±1
1
W
W boson
QUARKS
LEPTONS
GAUGE BOSONS

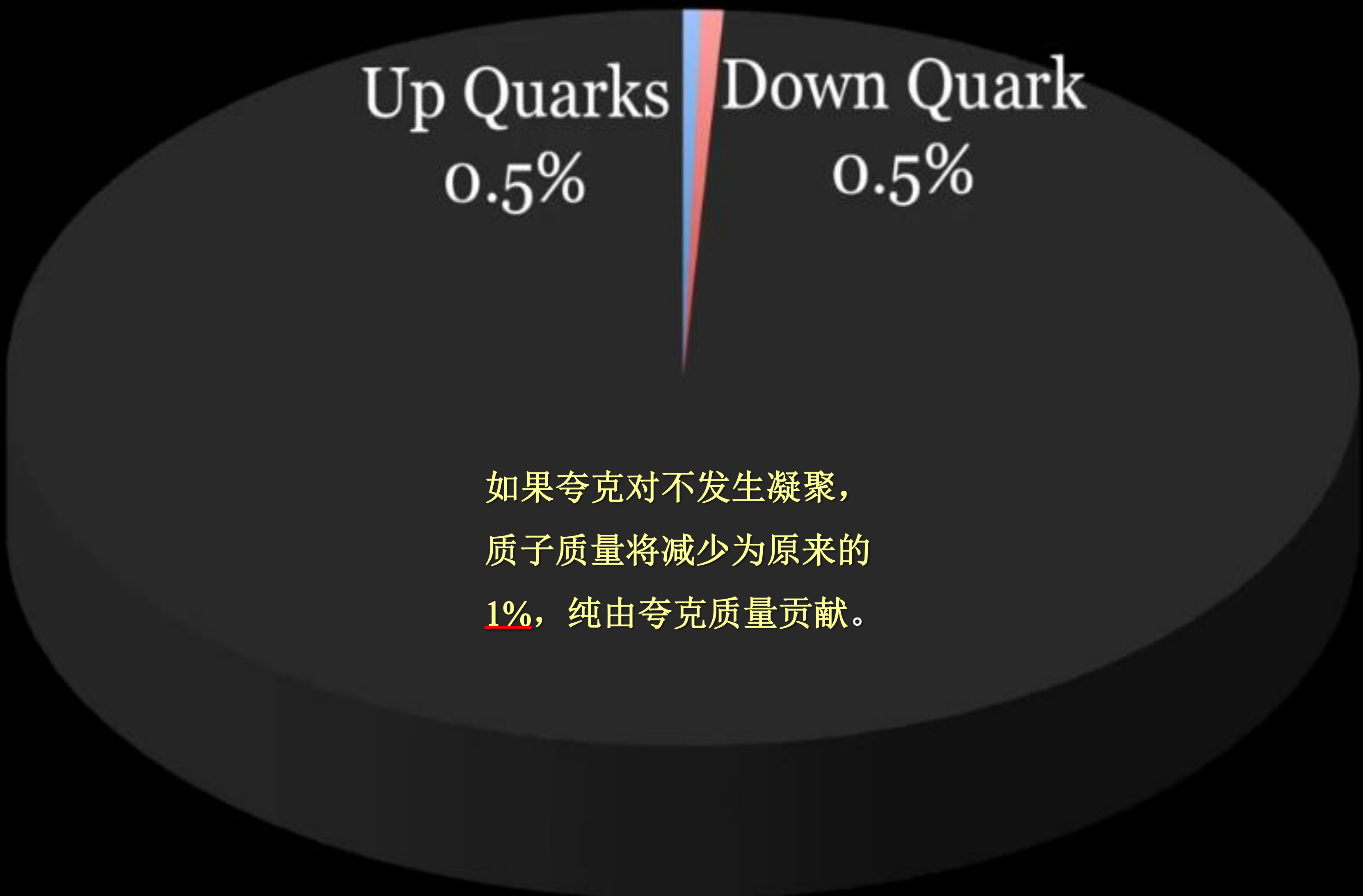


Mass of a Human Body

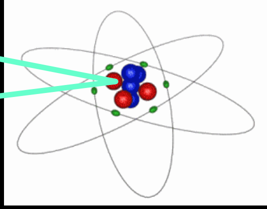



Quarks
u up
d down
c charm
s strange
t top
b bottom
Proton
u u d
Neutron
u d d

Mass of a Proton

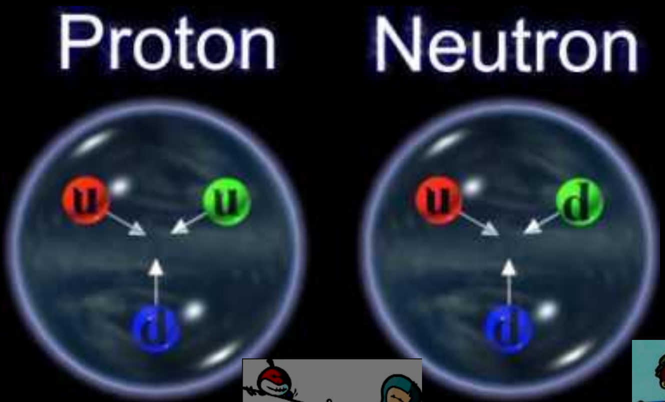


如果夸克对不发生凝聚，
质子质量将减少为原来的
1%，纯由夸克质量贡献。



u、d质量影响π介子质量，因而影响核力力程，进而直接影响原子核的大小

夸克和电子的质量



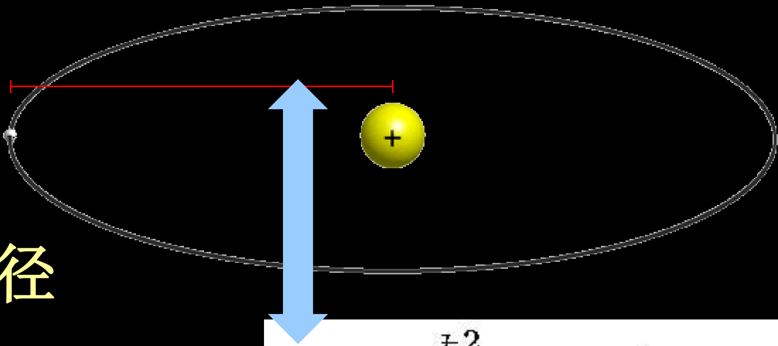
质子中子质量差的两个竞争机制：

(1) 电磁质量　(2) 夸克质量

m_u=1.5-3.3MeV m_d=3.5-6MeV Q_u=2/3　Q_d= −1/3

夸克 无质量 导致质子不稳定

Q_P=1 m_p=938.27MeV m_N=939.57MeV　Q_N=0



Me=0.51MeV 电子 无质量 导致无穷玻尔半径

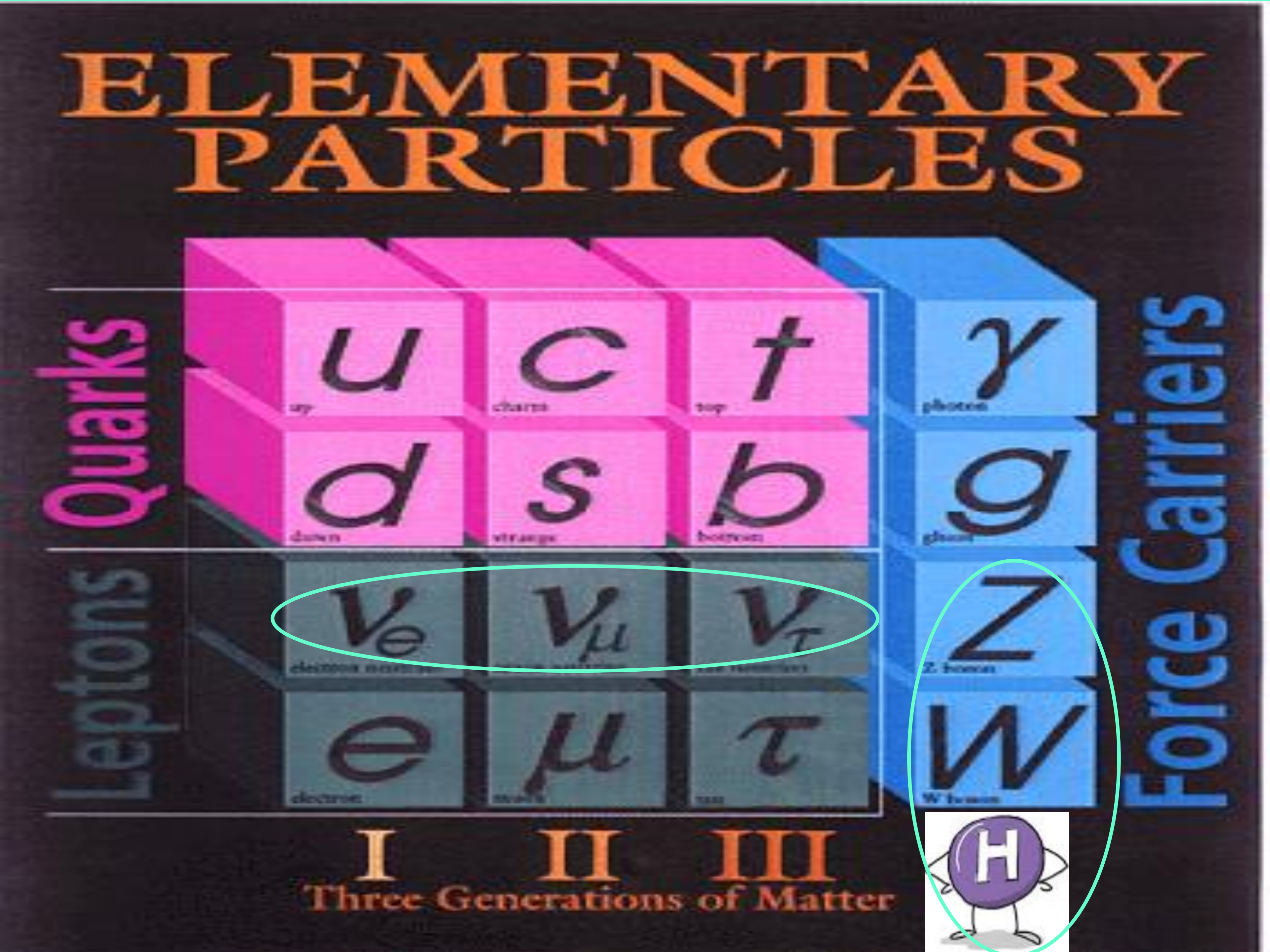
♣ 夸克、电子无质量导致原子无法形成 玻尔半径:

$$a_0 = \frac{\hbar^2}{me^2} \xrightarrow{m\to 0} \infty$$

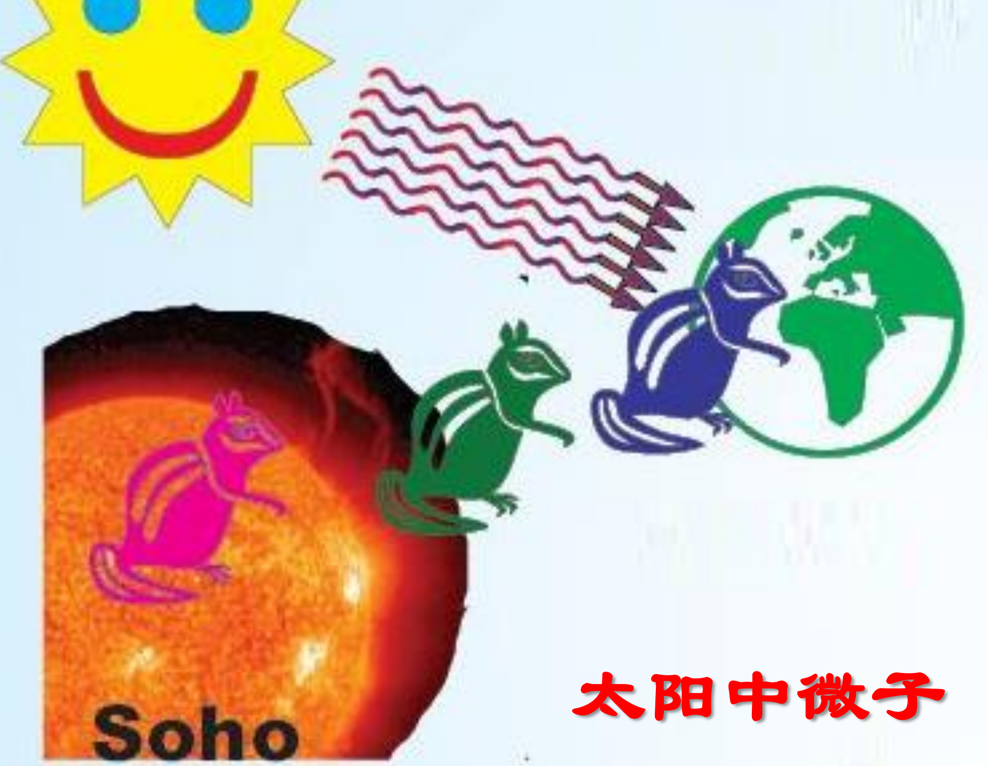
♣ 没有分子，没有化学，没有生物，没有人类 ……

电子质量的变化直接影响原子的大小

您的“质量”虽与基本粒子质量 大致 无关，但您的“尺寸”确与其相关

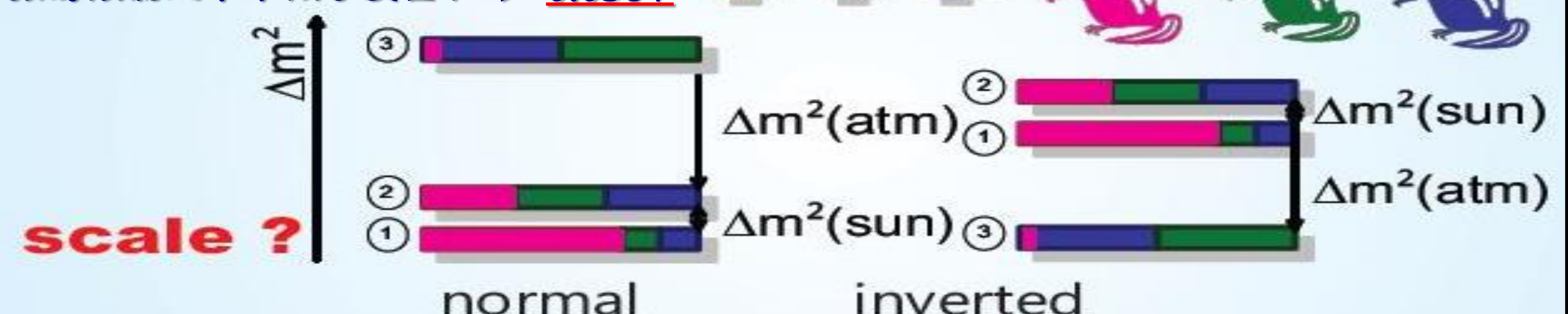

ELEMENTARY PARTICLES
Quarks
Leptons
Force Carriers
u
c
t
γ
d
s
b
g
ν_e
ν_μ
ν_τ
Z
e
μ
τ
W
charm
top
photon
down
strange
bottom
gluon
Z boson
electron
muon
tau
W boson
H
I
II
III
Three Generations of Matter

目前仍不能完全理解中微子 <u>为什么要有质量</u>！



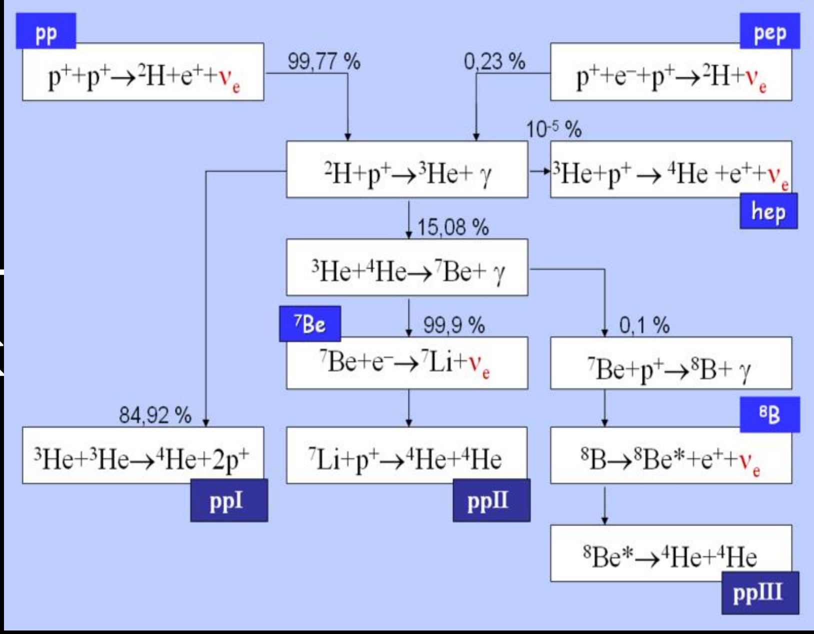
宇宙学限制三个中微子质量和 < <u>0.12eV</u>

振荡限制三个中微子质量和 > <u>0.05eV</u>



若它们太小，导致夸克质量过小，质子中子质量仍会倒置

反之，质子中子质量差过大，导致不存在重核



质子、中子：轻夸克、电子质量重要

重夸克、陶子、缪子都应比第一代重

为什么传递弱作用力的 W、Z粒子质量也那么重要？

直接联系Higgs

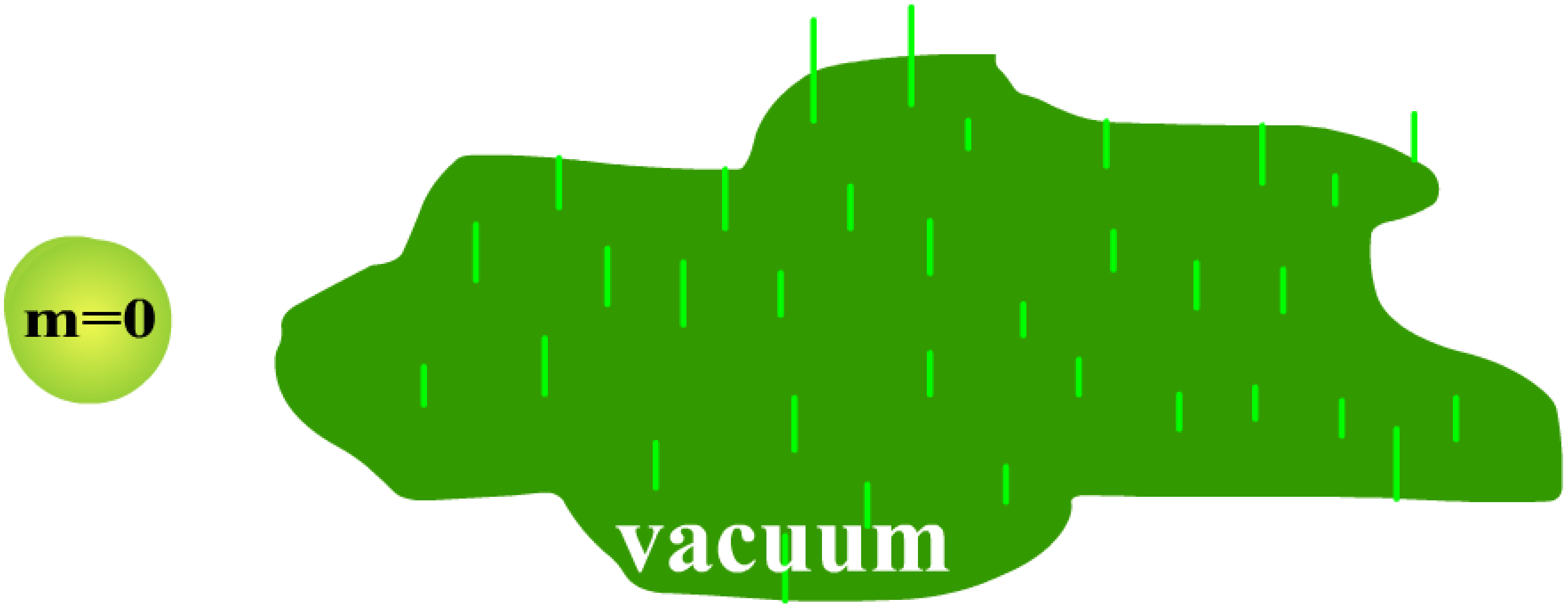
它使弱力很弱 导致目前太阳中质子聚变成 氦的过程相对缓慢

If you were a proton in the sun at its birth, today, 5 billion years later, there would still be only a 50:50 chance that you had undergone fusion

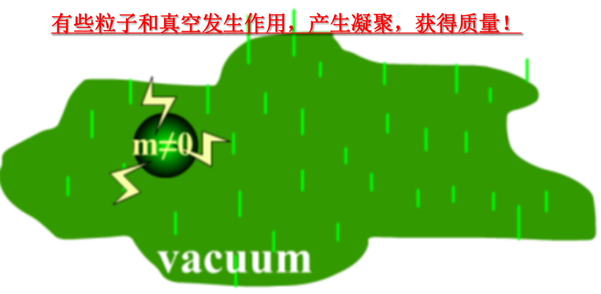
人类产生和进化才有充分的时间 ！

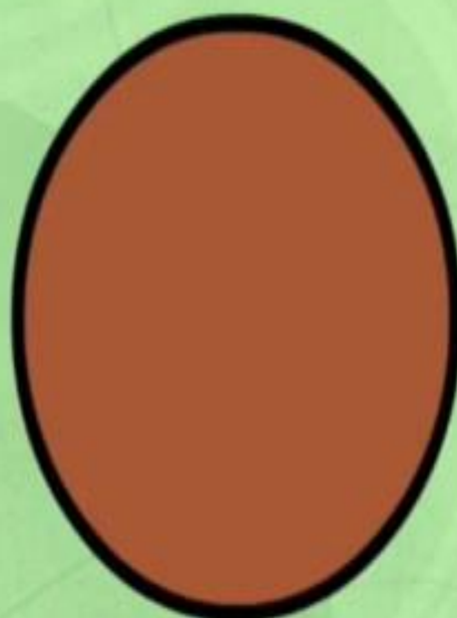
我们多少知道为什么标准模型的粒子要有质量！但基本不知道质量为什么取现在的值？

基本粒子质量如何产生？


m=0
vacuum

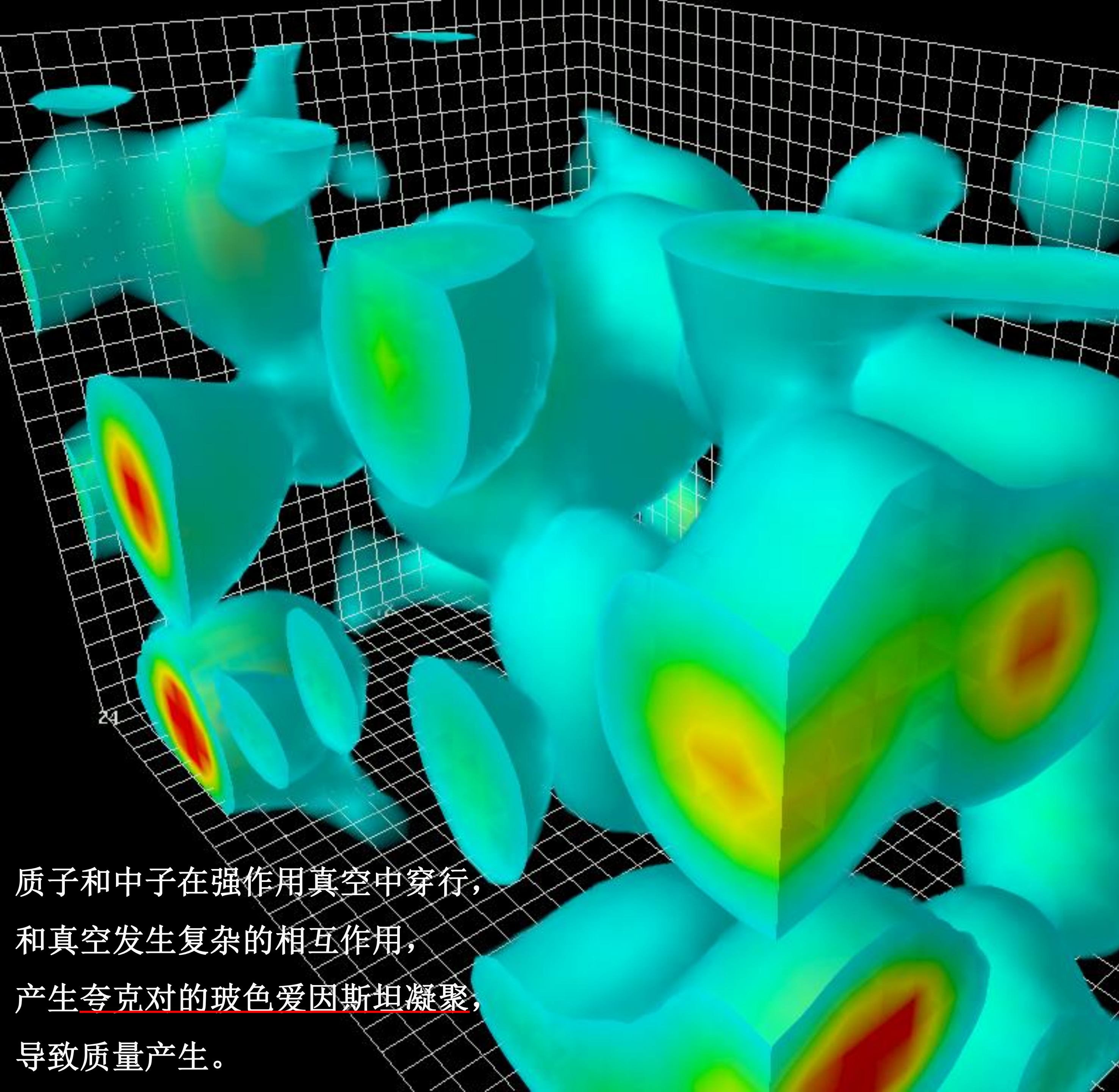
有些粒子和真空中的希格斯场无作用，保持无质量！

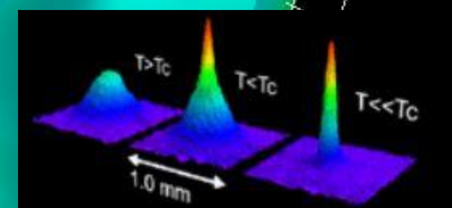




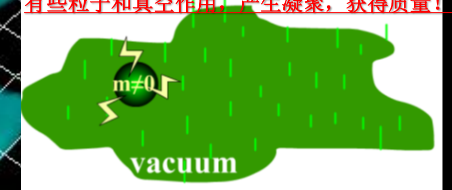
Massless

希格斯场自己还可能会激发出粒子,它是希格斯场存在的标志！





$$M_N = g < \bar{q}q >$$



质子和中子在强作用真空中穿行，

和真空发生复杂的相互作用，

产生夸克对的玻色爱因斯坦凝聚，

导致质量产生。

这些粒子和真空作用时能否获得

质量取决于某种 **对称性是否破缺**

手征对称性 夸克、带电轻子　　**规范对称性** 规范粒子

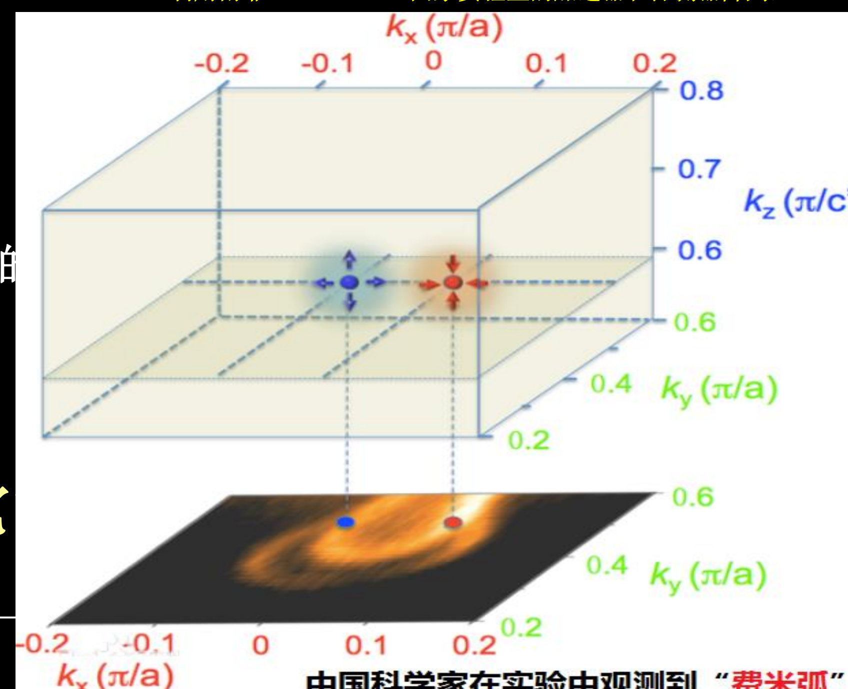
？？？ 中微子、希格斯粒子

自旋1/2的基本粒子费米子

研究 自旋1/2基本粒子 质量的起源

等价于

最近，来自山东大学（威海）、北京大学、北京航空航天大学、中科院理论物理所、清华大学和南非、匈牙利等国的科学家，利用南非iThemba LABS国家实验室的加速器和探测器阵列，



研究 自旋1/2基本粒子 可能具有的

自旋1/2基本粒子质量的有无 它

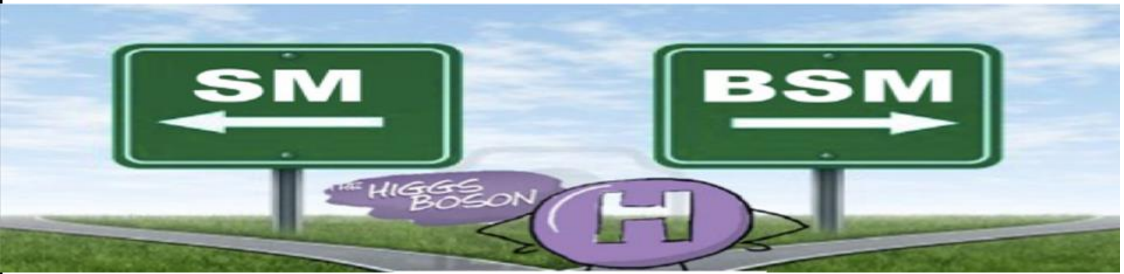
自旋≥1的粒子

$$m^2 tr(A_\mu A^\mu) \qquad A_\mu \Rightarrow A'_\mu = UA_\mu U^{-1} + \frac{i}{g} U\partial_\mu U^{-1}$$

研究 **自旋≥1粒子 质量的起源**

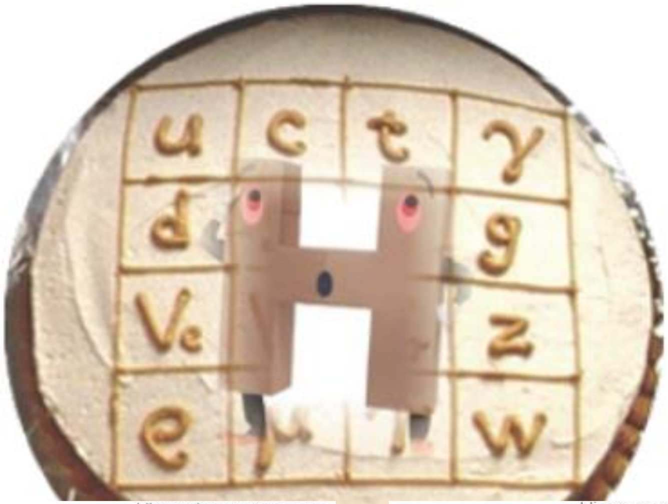
等价于

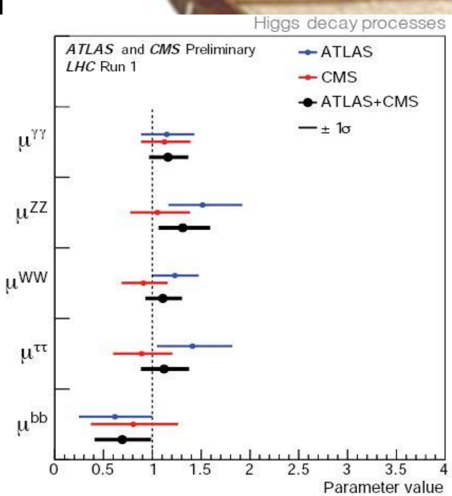
研究 **自旋≥1粒子** 可能具有的 **规范对称性的破缺**

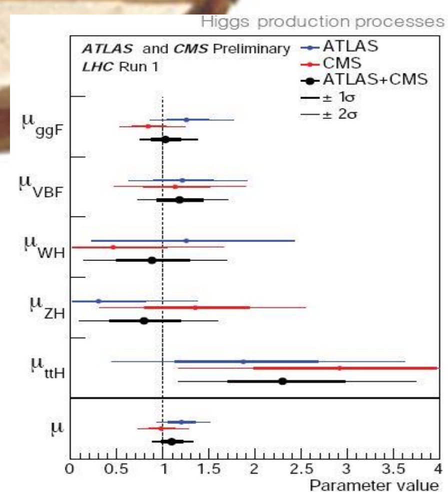


We found Higgs

需要它产生质量标度，但不知怎么来的！ 标度对称性？







We have the theory, but now we'd like to understand <u>why it is like it is</u>

We could discover plenty

We could discover nothing

XXVII International Symposium on Lepton Photon Interactions at High Energies

17–22 Aug 2015 Slovenia

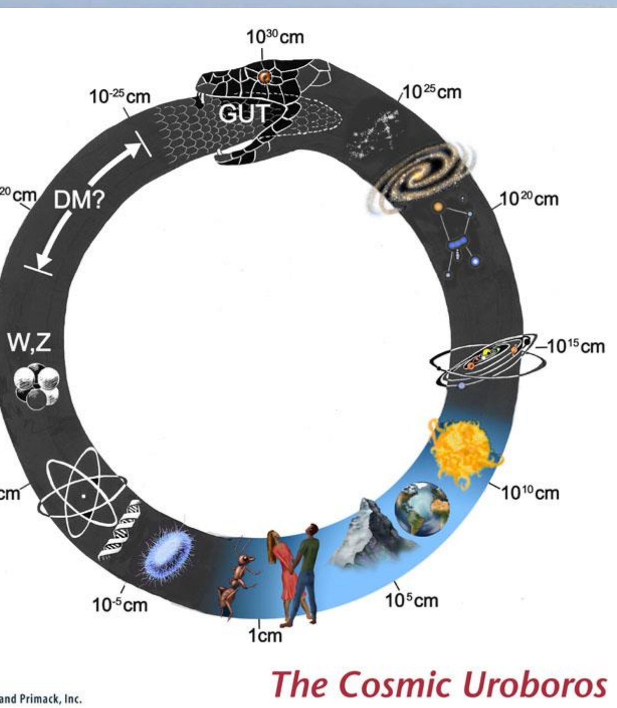
New Physics：Dusk or Dawn ?

玛雅历2012.12.21结束后

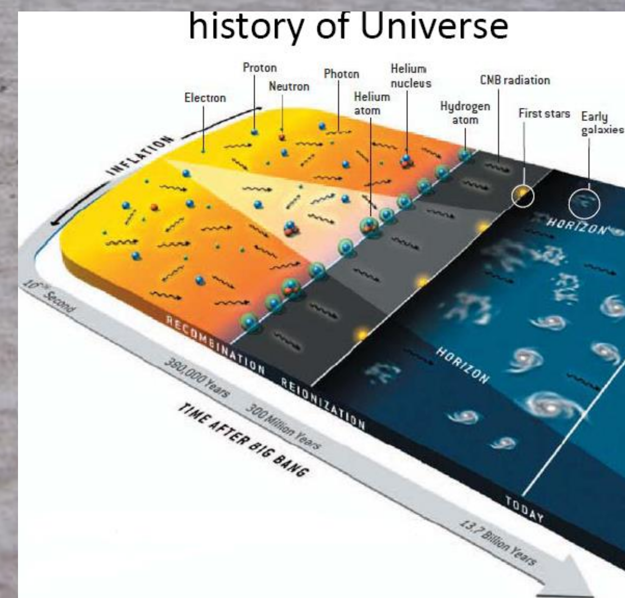
开启了 后希格斯 时代

1974：c quark observed （SLAC,BNI
1974-77：τ lepton observed （SLAC)
1977：b quark observed （FNAL)
1983：W and Z observed （CERN)
1995：t quark observed （FNAL)
2000：ν_τ observed FNAL)
2012：H observed （CERN）
2024：dark matter？

1974：Binary Pulsar
1987：Supernova
1992：Cosmic Microwave Backgroun
1998：Universe expanding
~~2014：Polarization of CMB~~
2016：Gravitation Wave



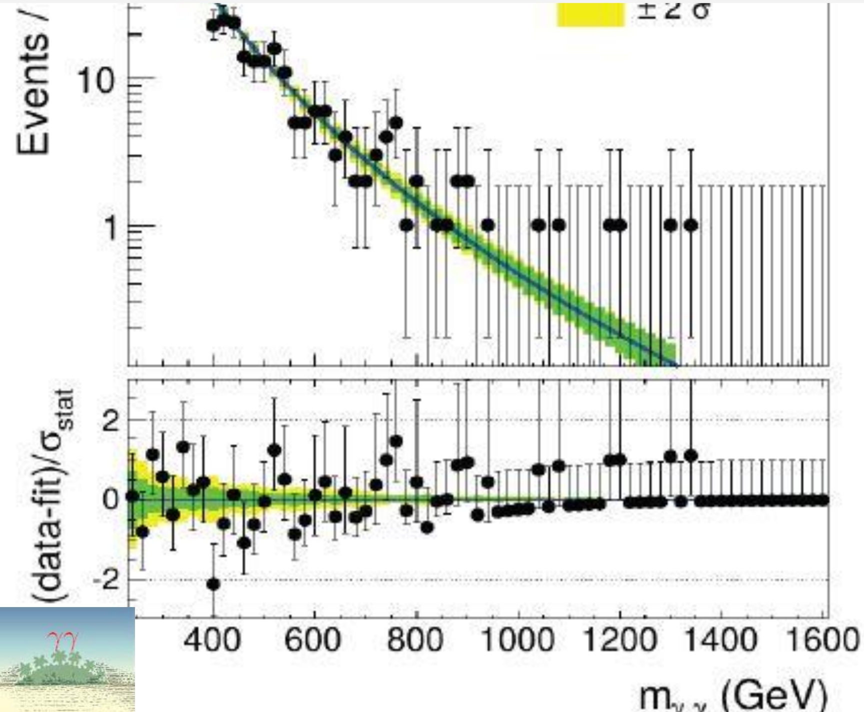
The Cosmic Uroboros

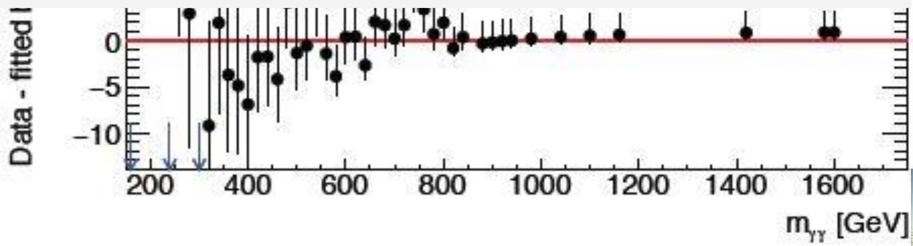


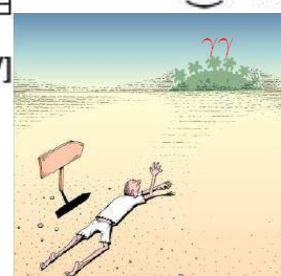
ICHEP2016CHICAGO

38th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

AUGUST 3 - 10, 2016
CHICAGO







The Gold Rush: [INSPIRES][list]

Date	papers
16 Dec	10
25 Dec	101
1 Jan	137
1 Feb	212
1 Mar	263
1 Apr	?

Why is this around the EW scale?

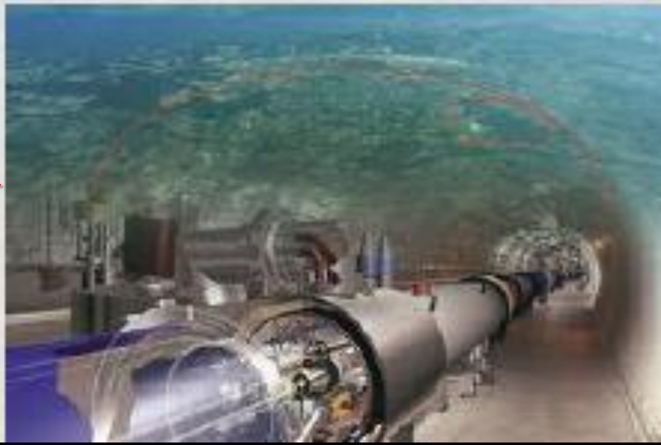
What points to?

Was expected?

What else we can expect?

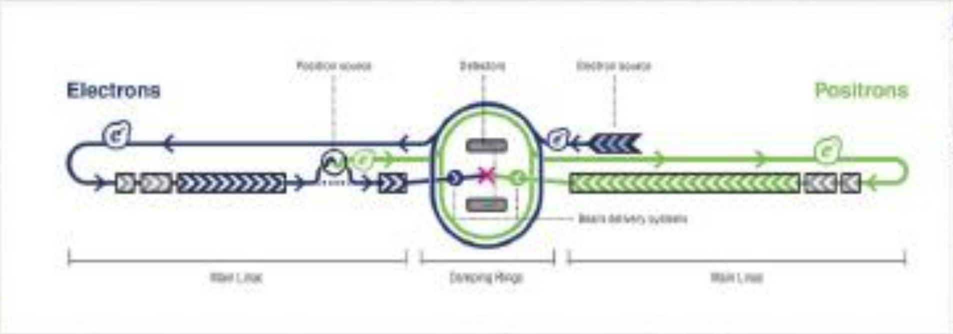
pp colliders:

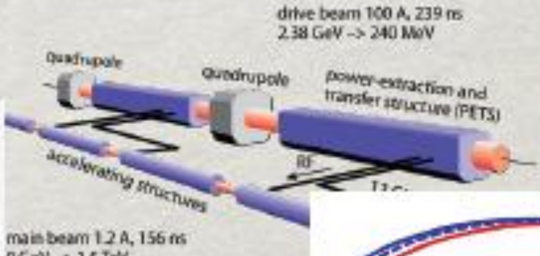
- LHC at 14 TeV with 300 fb^{-1} 现在才1/10的数据！
- HL-LHC at 14 TeV with 3000 fb^{-1}
- HE-LHC at 33 TeV and VLHC at 100 TeV

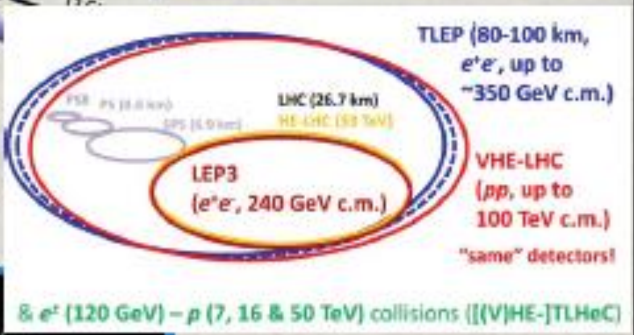


e^+e^- colliders:

- Linear: ILC 250/500/1000 GeV, CLIC 350/1400/3000 GeV
- Circular: TLEP @ 240 and 350 GeV

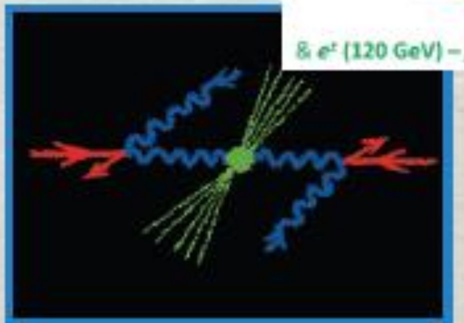






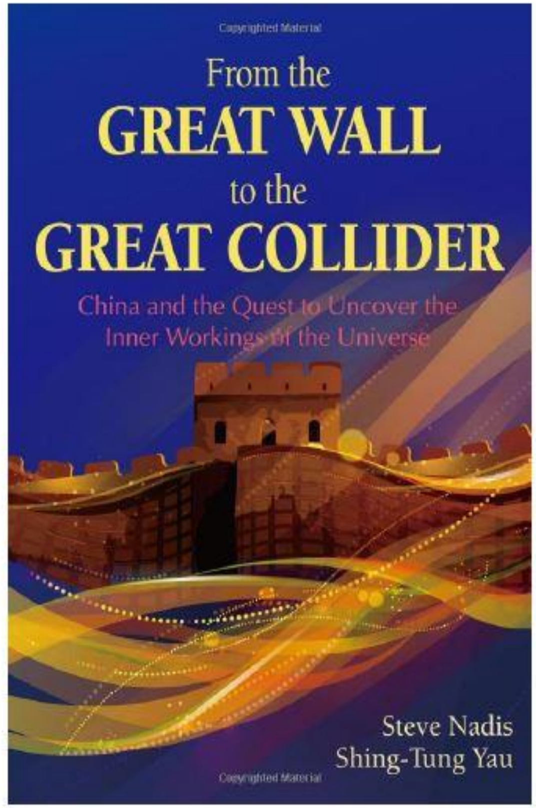
Others:

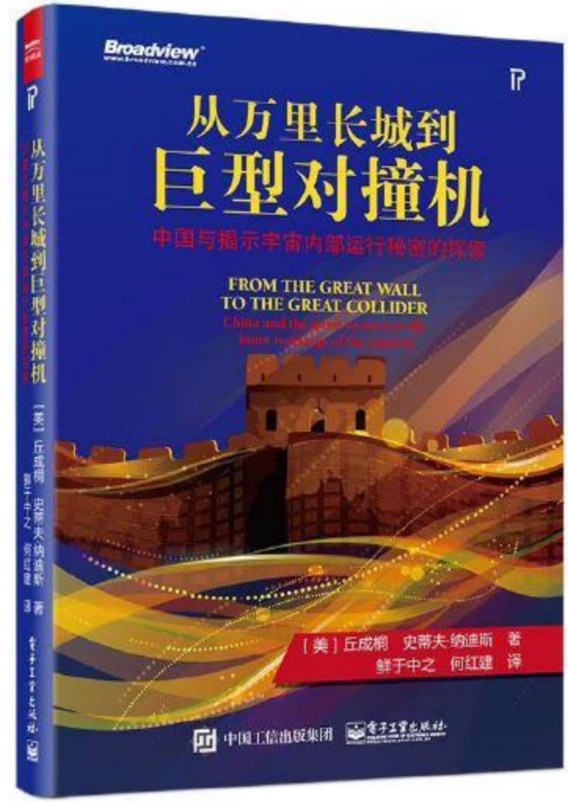
- $\mu^+\mu^-$ collider
- $\gamma\gamma$ collider

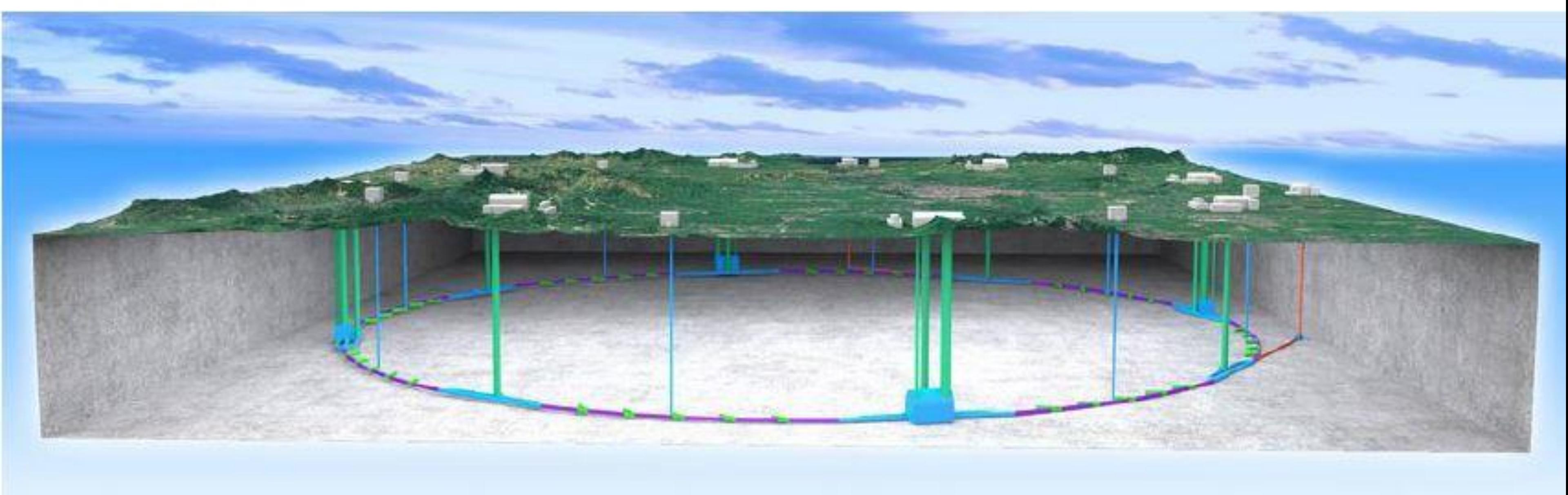


Timeline (dream)

- **CPEC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-15
      - **Pre-CDR for R&D funding request**
    - R&D: 2016-2020
    - Engineering Design: 2015-2020
  - Construction: 2021-2027
  - Data taking: 2028-2035
- **SppC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-2020
    - R&D: 2020-2030
    - Engineering Design: 2030-2035
  - Construction: 2035-2042
  - Data taking: 2042 -







The TeV frontier must be attacked from several fronts

Moriond EW 2016-Theory Summary

2016.3.12-19，La Thuile in Aosta, Italy

Epilogue

It was the best of times,
It was the worst of times,
...
It was the spring of hope,
It was the winter of despair
A Tale of Two Cities

- After the Higgs, we start a very different **phase** in particle physics:

  We could discover plenty,
  we could discover nothing…

- Most important fronts are covered to explore TeV territory

- While waiting experimentalists to tell us what is there at the TeV, we continue our program of **computing the SM predictions**, & also profiting from our *vivid* imagination to find **new routes to BSM**

- Several anomalies give some hope e.g. S(750 GeV)

(hope is not another *Yeti*)

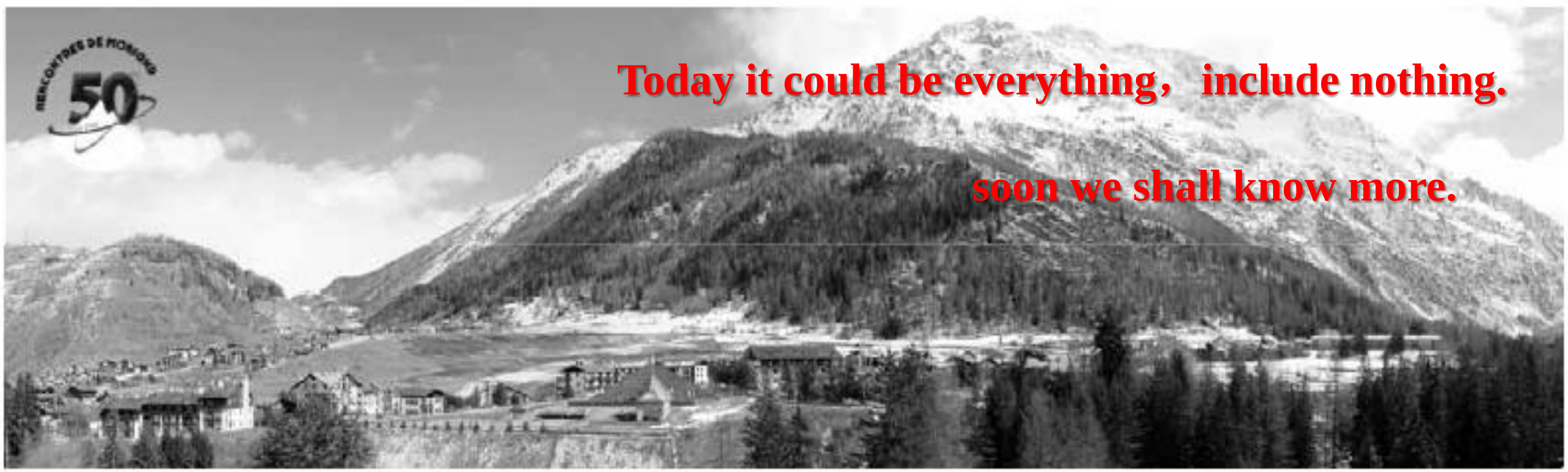
Thank you!

and to all that made possible another successful Moriond!

Moriond EW (51st edition) has been memorable

It exhibited once again the challenges today's experimental physics takes on and overcomes

- The discovery of the Higgs boson required the construction of a huge accelerator and ultra-sophisticated particle detectors to find the events buried under 10^{12} times larger backgrounds
- The direct observation of gravitational waves required to measure over 4 km a relative length deformation two hundred times smaller than the size of a proton.
- Similar things can be said about neutrino physics, dark matter searches, etc. It is breathtaking.
- Accomplishing these measurements requires great ideas, visionary leadership, long-term support by governments & society, innovative & highest quality hardware and software, computing resources, operational & maintenance support, precise & unbiased analysis — and above all: dedication
- Given what we have seen this week, I have no worry. We live in an extraordinary period for fundamental experimental research in physics




谢 谢
SM