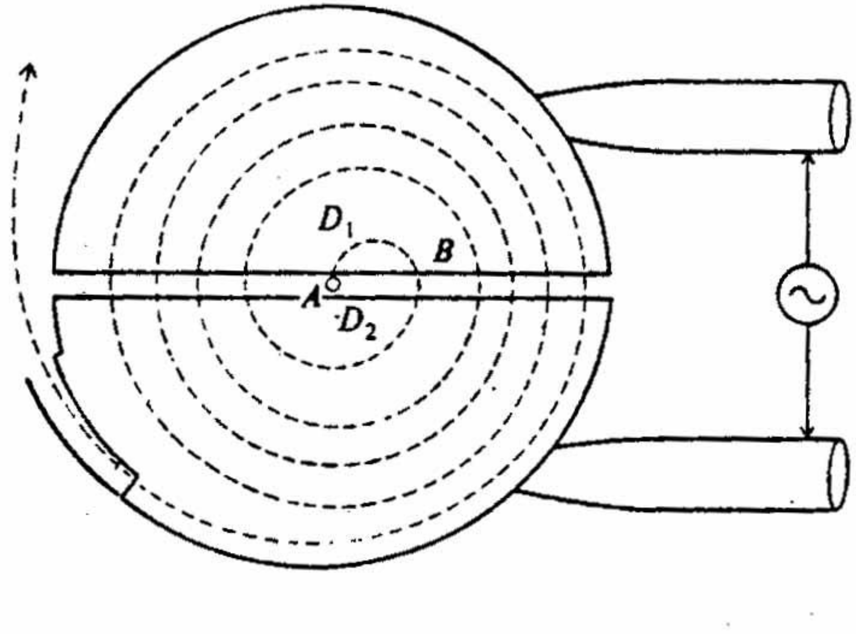
从回旋加速器到费米梦想：

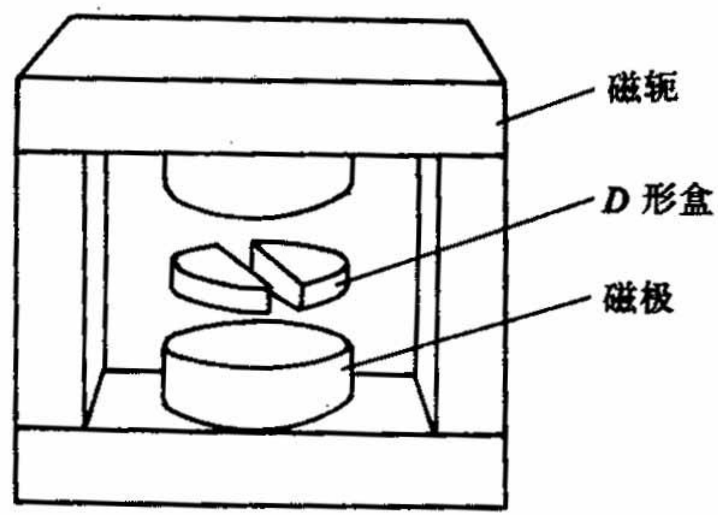
探幽入微之路

1、回旋加速器

密封在真空中的两个金属盒（D_1和D_2）放在电磁铁两极间的强磁场中，两盒间接有交流电源，它在缝隙里的交变电场用以加速带电粒子。



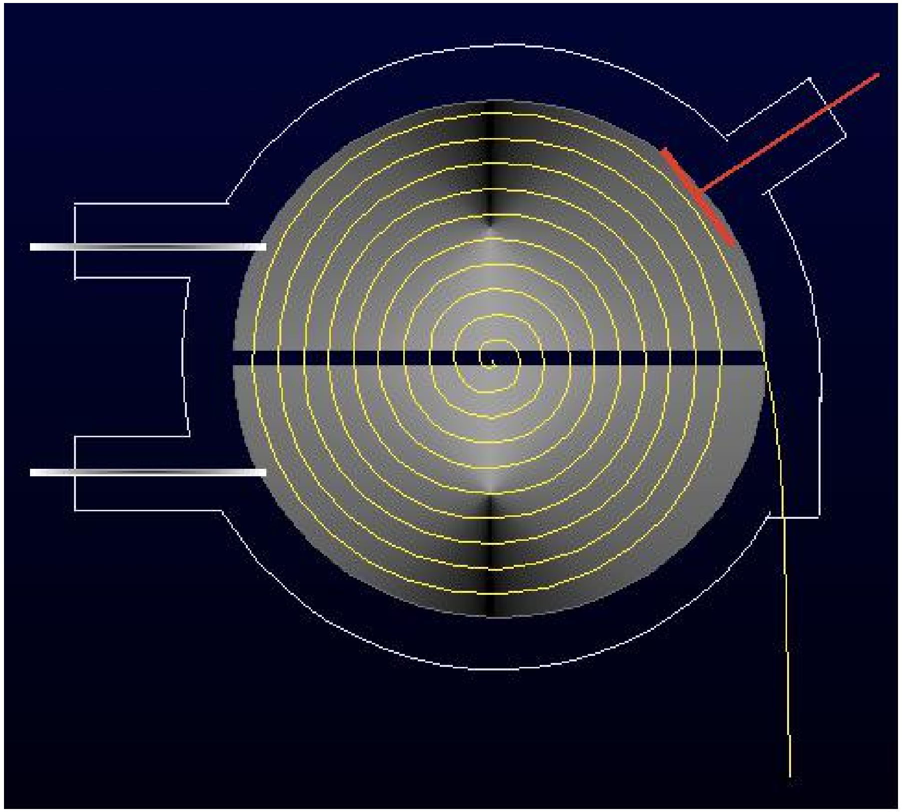
(a)



(b)

交变电场的周期恰好为回旋周期时 —— 粒子绕过半圈恰好电场反向，粒子又被加速。

因为回旋周期与半径无关，所以粒子可被反复加速。

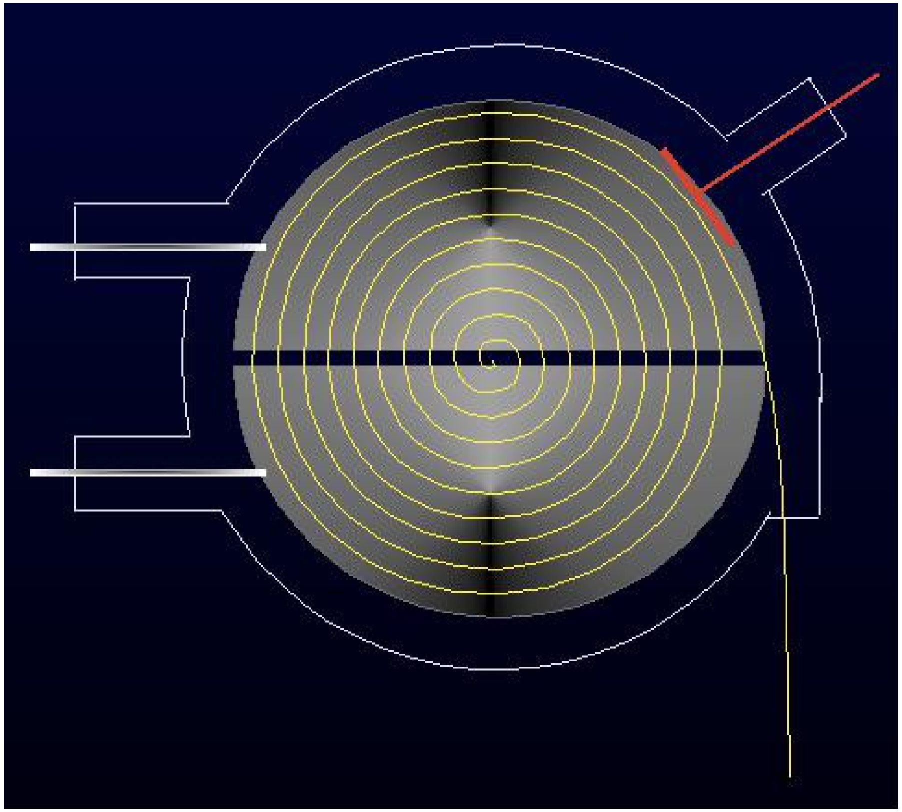


回旋频率 $$f=\frac{1}{T}=\frac{qB}{2\pi m}$$

$$T=2\pi\frac{m}{qB}$$

动画演示

当粒子到达半圆边缘时，粒子的最大速率为（R_0为最大半径）



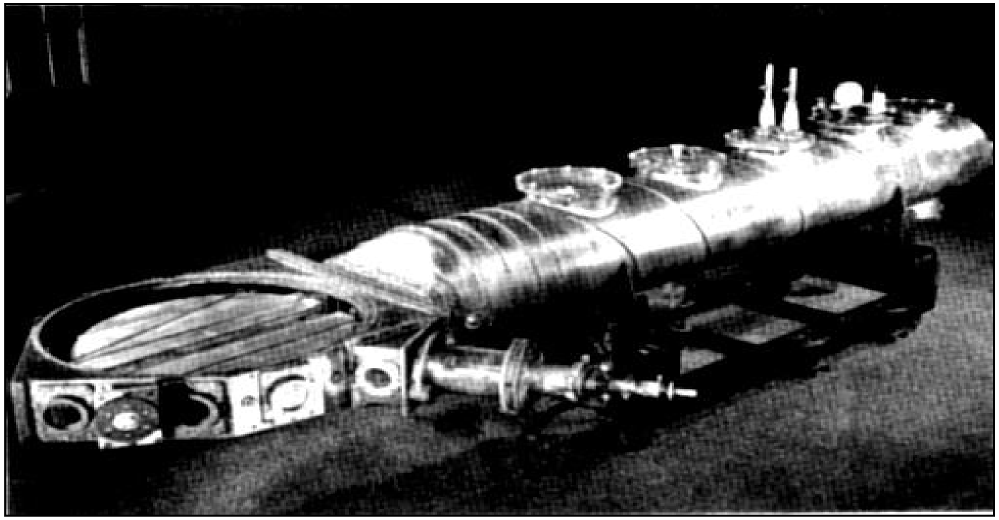
$$v = \frac{qBR_0}{m}$$

$$R = \frac{mv_0}{qB}$$

粒子最大动能

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{BqR_0}{m}\right)^2 = \frac{q^2B^2R_0^2}{2m}$$

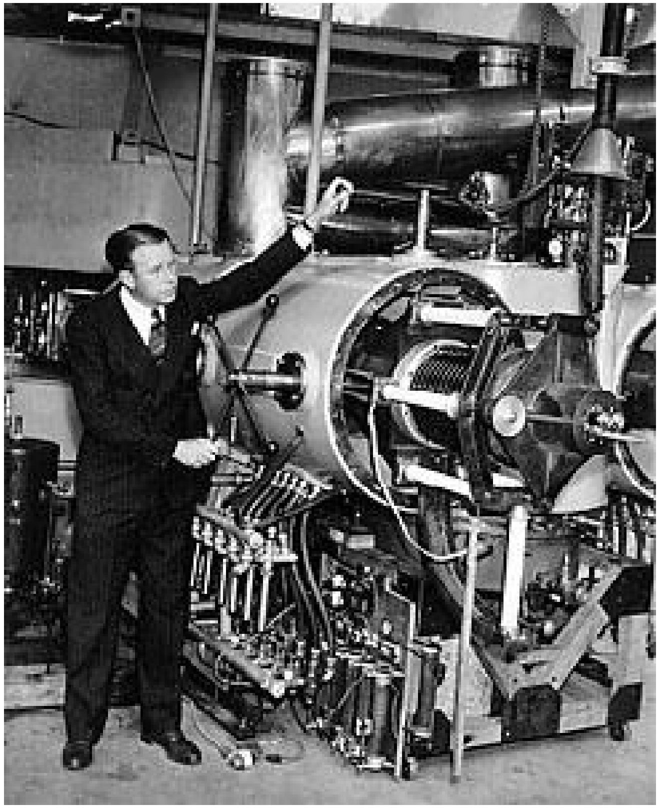
1932年,E.O.Lawrence
建造的第一台回旋加速器

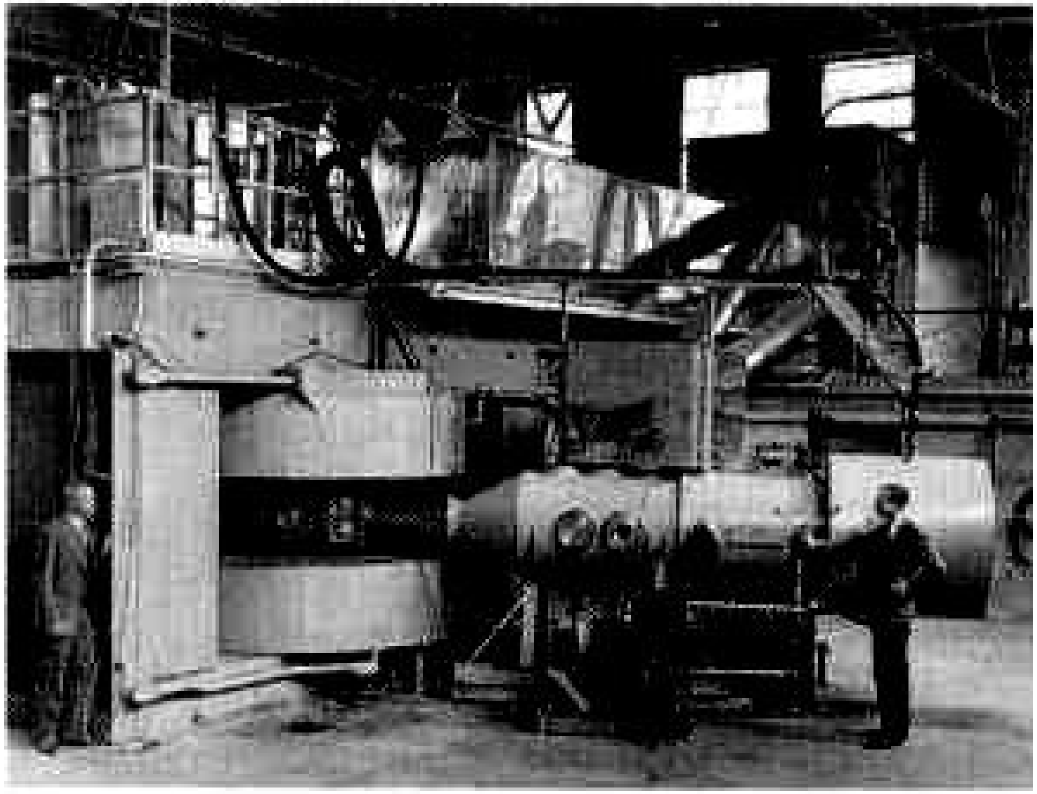


1932年劳伦斯研制第一台回旋加速器的D型室.

此加速器可将质子和氘核加速到0.8MeV的能量

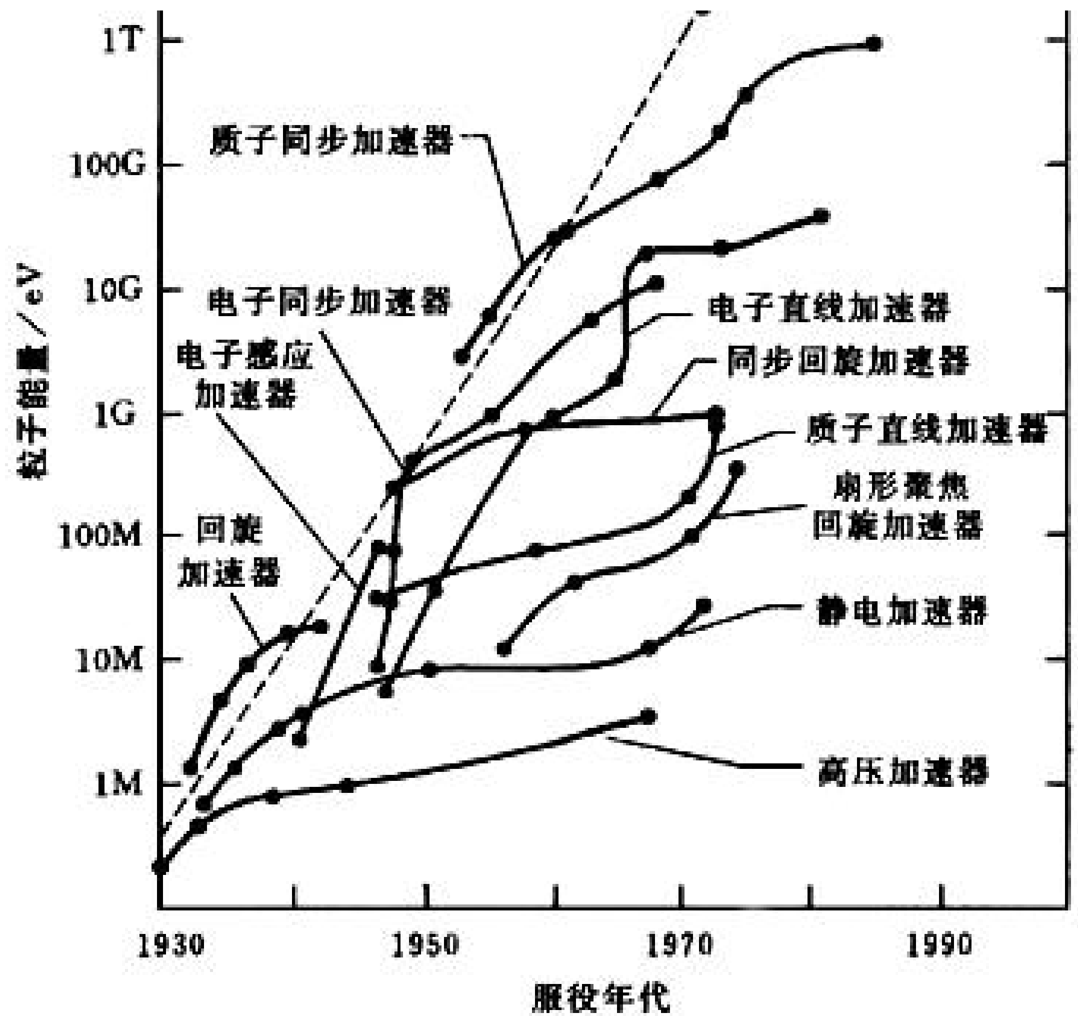
美国物理学家劳伦斯于1934年研制成功第一台实用加速器，于1939年获诺贝尔物理学奖。



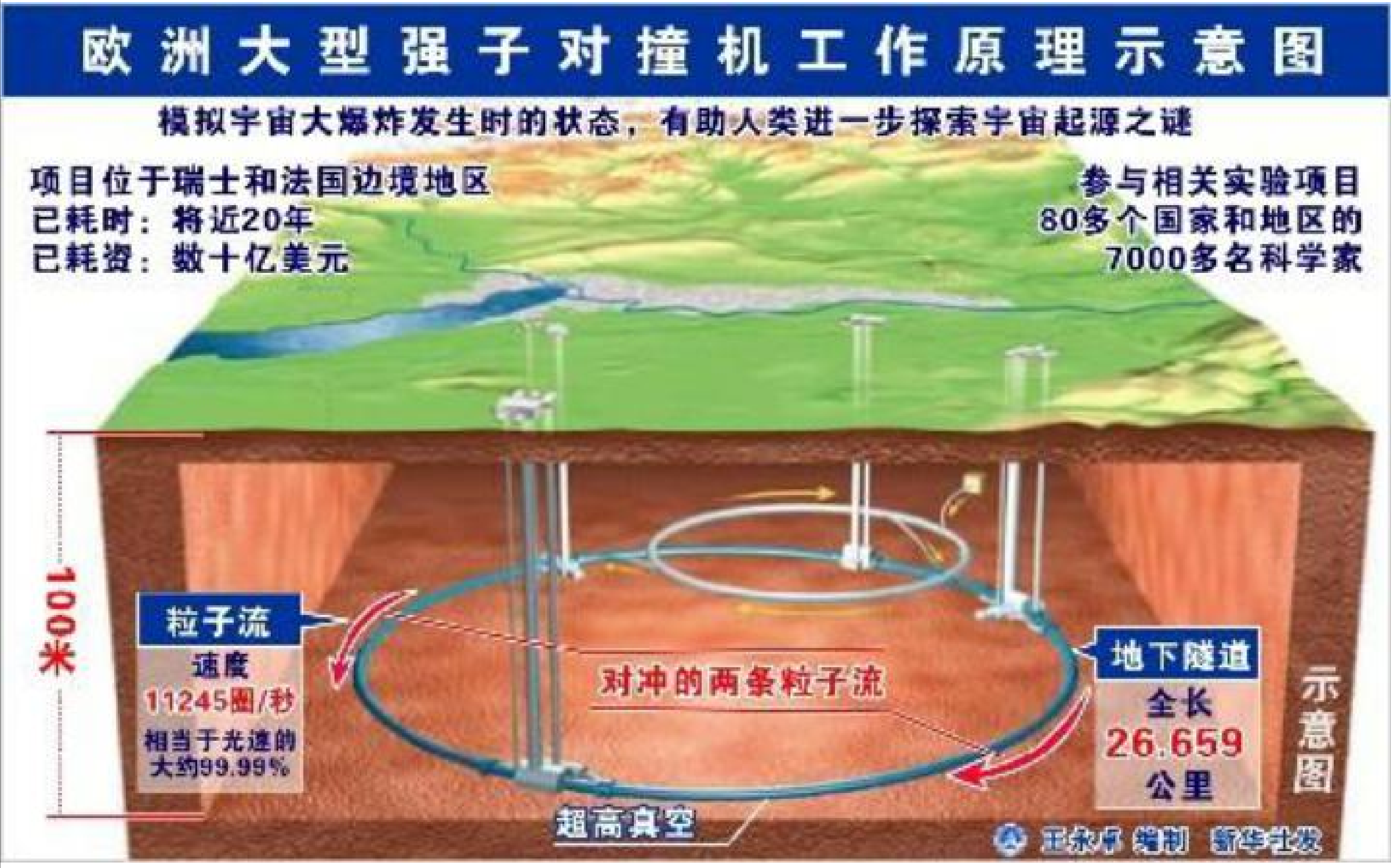


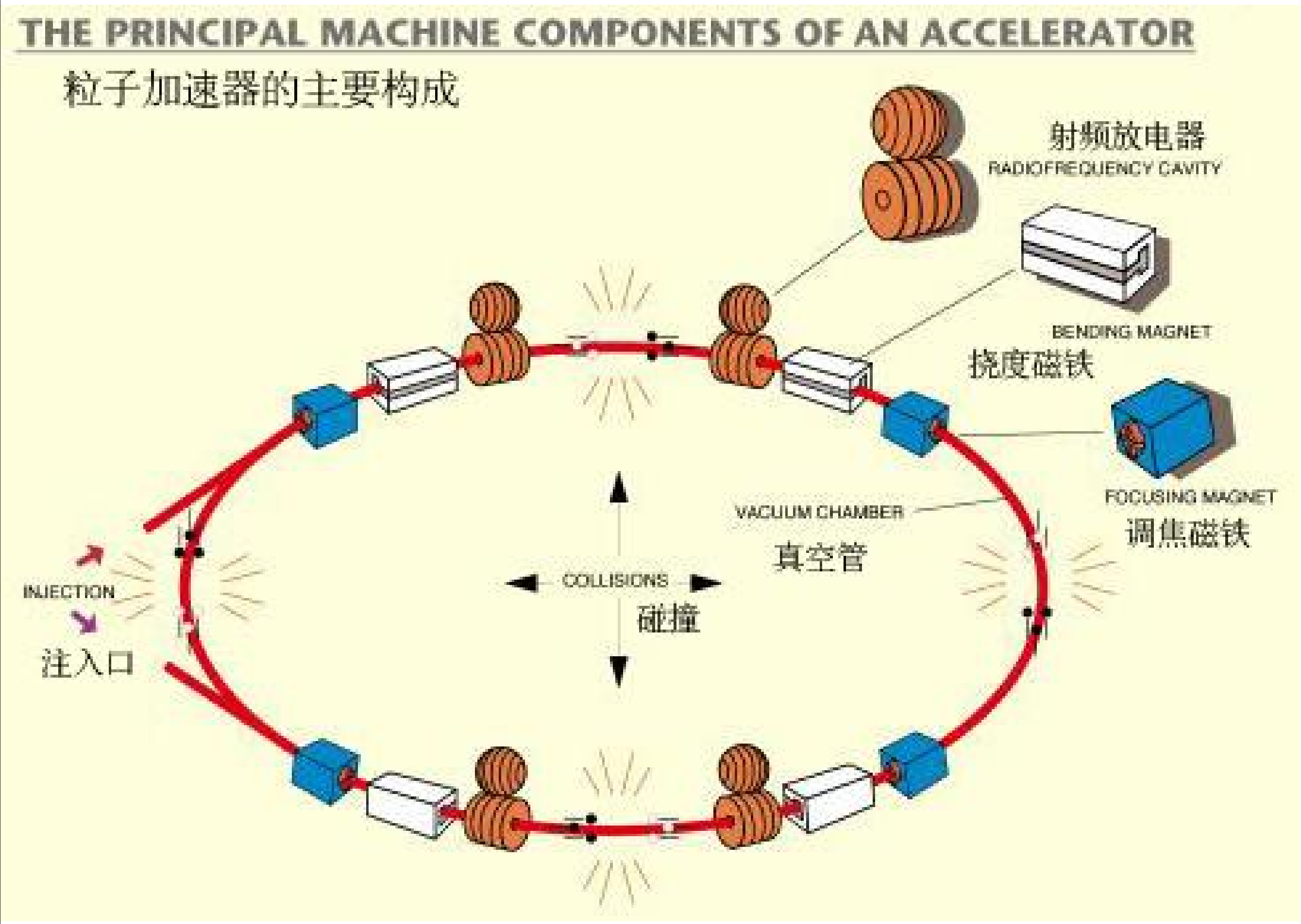
回旋加速器一般只能将质子加速到25MeV左右。

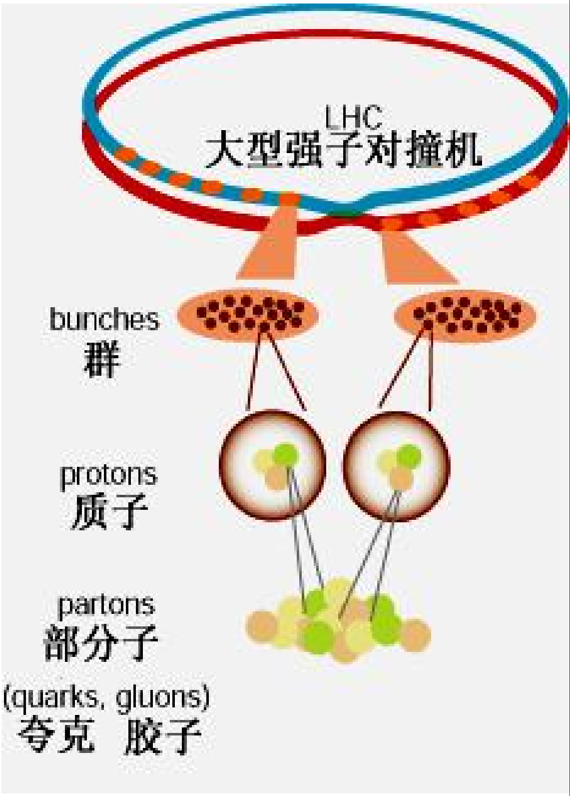
考虑到狭义相对论效应发展的同步回旋加速器可以将提高到1GeV。

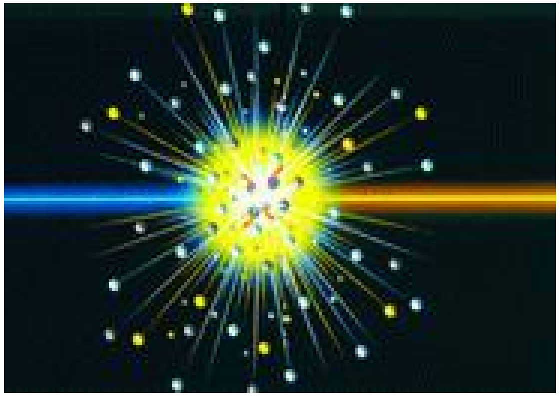


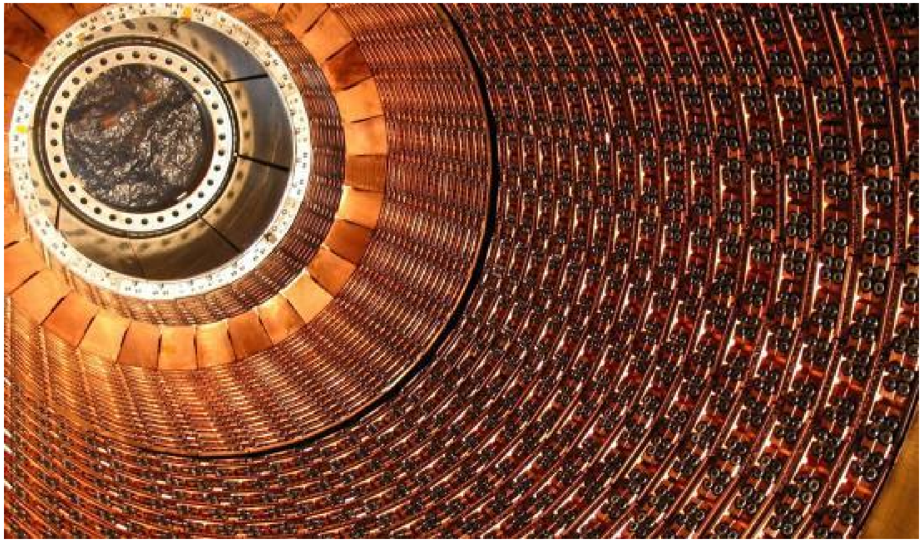
欧洲核子研究中心CERN，大环是直径27km的大型强子对撞机LHC，中环是质子同步加速器。加速能量为14TeV。

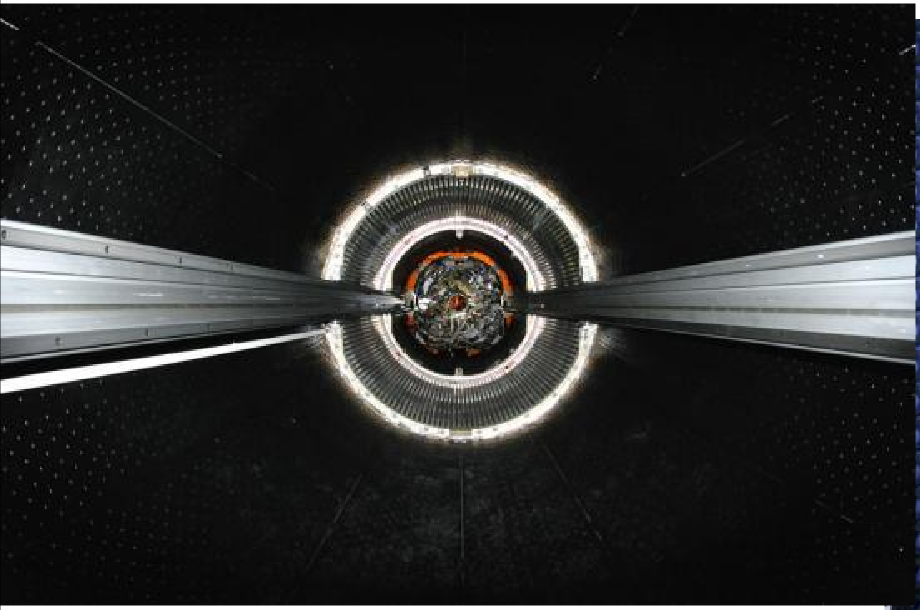

欧洲大型强子对撞机工作原理示意图
模拟宇宙大爆炸发生时的状态，有助人类进一步探索宇宙起源之谜
项目位于瑞士和法国边境地区
已耗时：将近20年
已耗资：数十亿美元
参与相关实验项目
80多个国家和地区的
7000多名科学家
100米
粒子流
速度
11245圈/秒
相当于光速的
大约99.99%
对冲的两条粒子流
地下隧道
全长
26.659
公里
超高真空
示意图
编制 新华社发

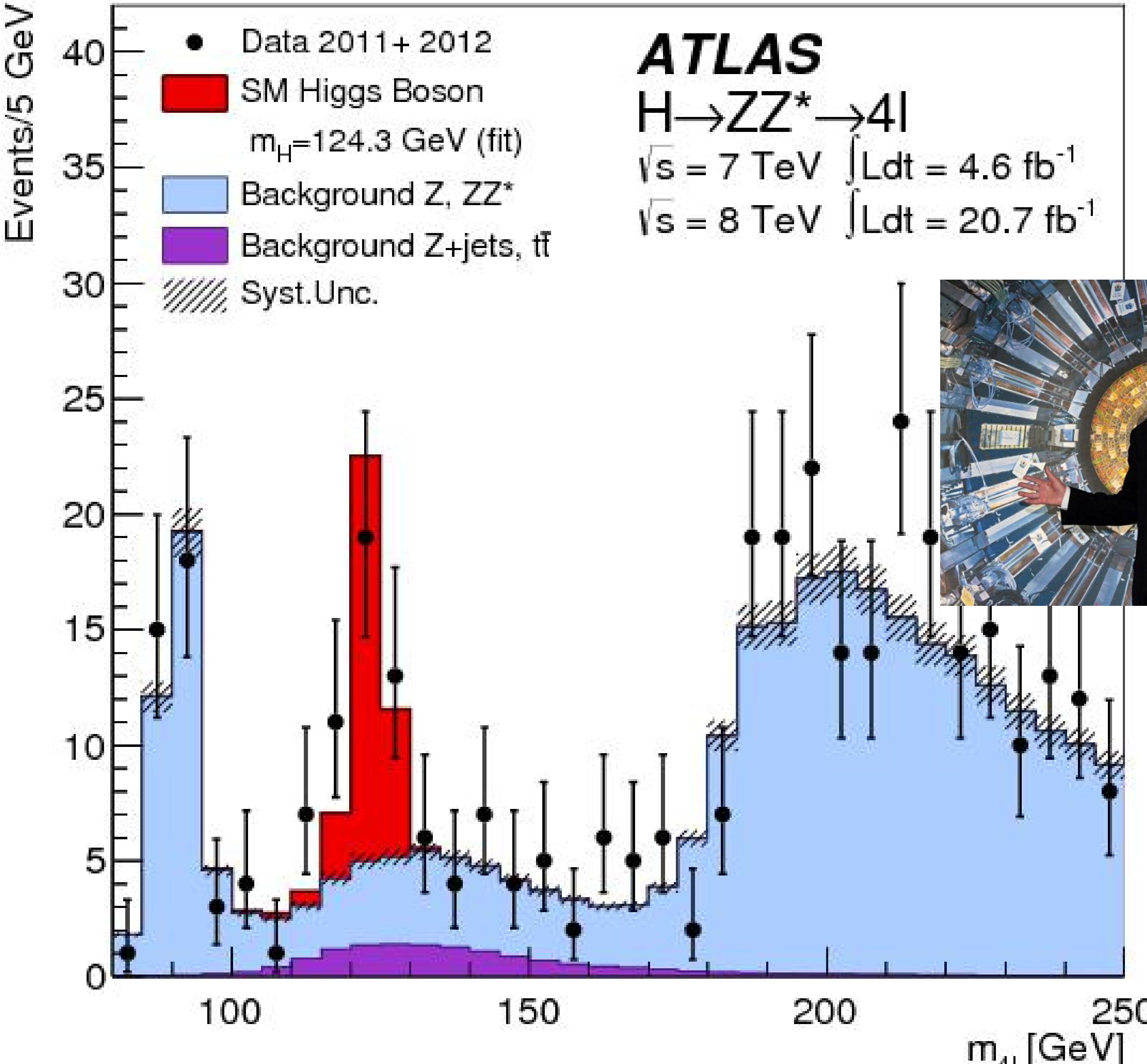

THE PRINCIPAL MACHINE COMPONENTS OF AN ACCELERATOR
粒子加速器的主要构成
射频放电器
RADIOFREQUENCY CAVITY
BENDING MAGNET
挠度磁铁
FOCUSING MAGNET
调焦磁铁
VACUUM CHAMBER
真空管
COLLISIONS
碰撞
INJECTION
注入口


LHC
大型强子对撞机
bunches
群
protons
质子
partons
部分子
(quarks, gluons)
夸克 胶子

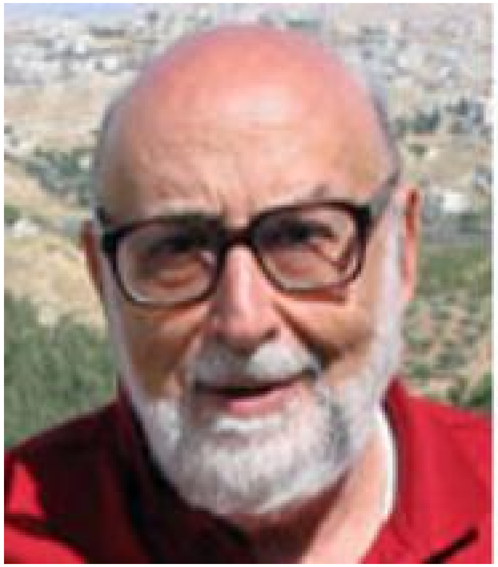


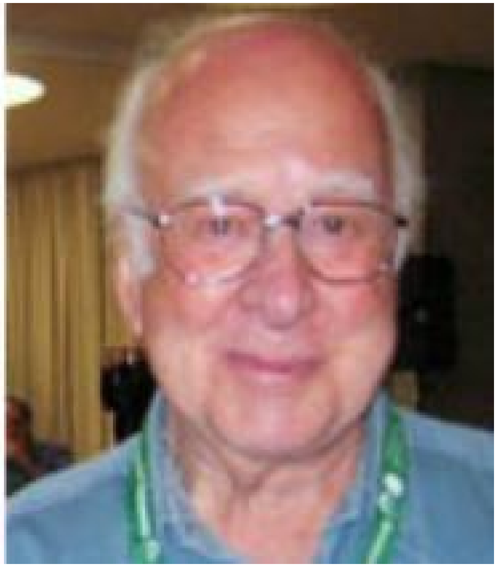


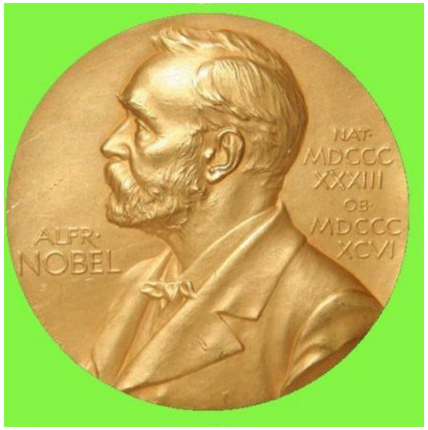




Events/5 GeV
Data 2011+ 2012
SM Higgs Boson
m_H=124.3 GeV (fit)
Background Z, ZZ*
Background Z+jets, $t\bar{t}$
Syst.Unc.
ATLAS
$H \rightarrow ZZ^* \rightarrow 4l$
$\sqrt{s}$ = 7 TeV $\int Ldt$ = 4.6 fb^{-1}
$\sqrt{s}$ = 8 TeV $\int Ldt$ = 20.7 fb^{-1}
0
5
10
15
20
25
30
35
40
100
150
200
250
m_{4l} [GeV]

Francois Englert和Peter W. Higgs的发现获得2013年诺贝尔物理学奖





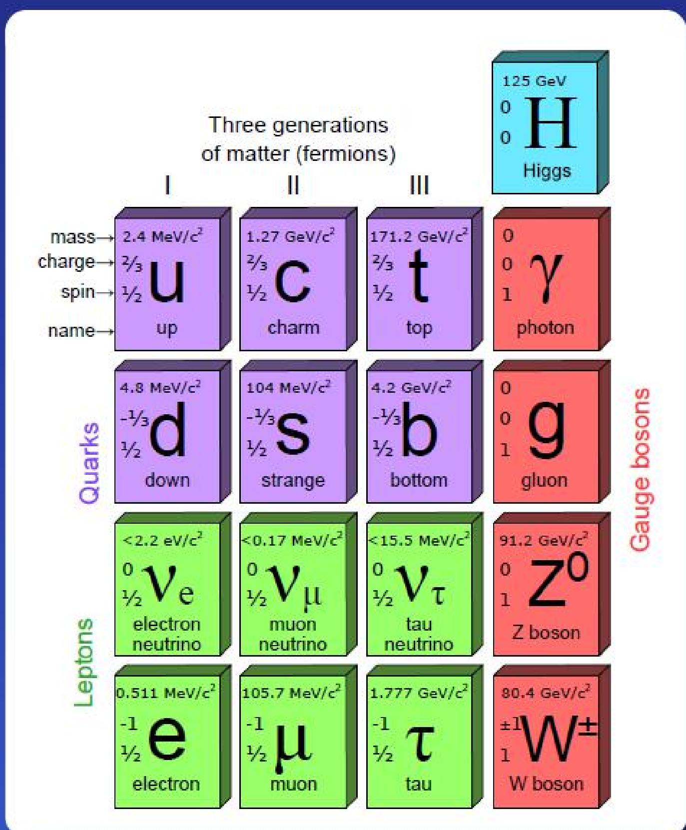


标准粒子模型理论中共预言了62种基本粒子的存在，希格斯玻色子正是该理论依赖的基石。作为物质的质量之源, Higgs粒子被叫做“上帝粒子”

The Standard Model

Binding of nuclei and radioactivity require two additional short-range forces:

- **Strong Interactions**: Keep nucleus bound.
- **Week interactions**: Allow beta decay of nuclei



3 families of matter (chiral fermions)

$$\text{Quarks}: \quad Q_L \equiv \begin{pmatrix} u_L \\ d_L \end{pmatrix}, \; d_R \, , \; u_R$$

$$\text{Leptons}: \quad L_L \equiv \begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix}, \; e_R \, , \; \nu_R?$$

3 types of gauge bosons (spin 1)

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

- Strong (8 masless gluons, g)
- Electromag. (1 massless photon γ)
- Weak (3 massive Z, W^+, W^-)

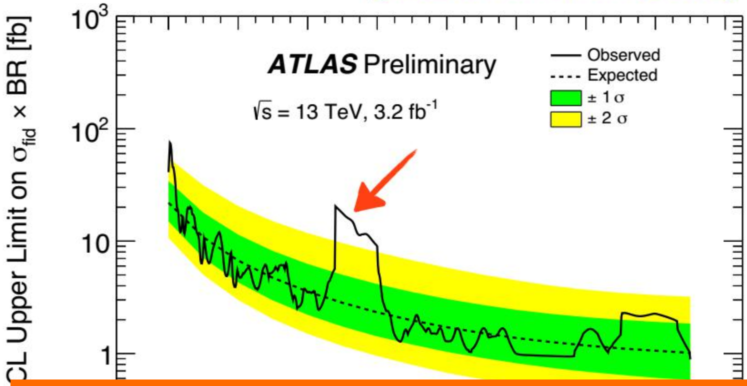
1 Higgs boson (spin 0) needed for SSB

$$
\begin{aligned}
\mathcal{L} \;=\; & -\frac{1}{4}\sum_{C=1}^{8} G^{C}_{\mu\nu}G^{C\mu\nu} \;-\; \frac{1}{4}\sum_{a=1}^{3} W^{a}_{\mu\nu}W^{a\mu\nu} \;-\; \frac{1}{4}\,B_{\mu\nu}B^{\mu\nu} \\
& + \; D^{\mu}H^{\dagger}\,D_{\mu}H \;-\; V(H^{\dagger}H) \\
& + \sum_{n,i,\alpha} iQ^{\dagger}_{ni\alpha}\bar{\sigma}^{\mu}D_{\mu}Q^{i\alpha}_{n} + \sum_{n,i} iU^{\dagger i}_{n}\bar{\sigma}^{\mu}D_{\mu}U_{ni} \;+ \sum_{n,i} iD^{\dagger i}_{n}\bar{\sigma}^{\mu}D_{\mu}D_{ni} \\
& + \sum_{n,\alpha} iL^{\dagger}_{n\alpha}\bar{\sigma}^{\mu}D_{\mu}L^{\alpha}_{n} + \sum_{n} iE_{n}\bar{\sigma}^{\mu}D_{\mu}E_{n} \\
& + \; \mathcal{L}_{\text{Yukawa}} \;+\; \mathcal{L}_{LLHH}\,.
\end{aligned}
$$

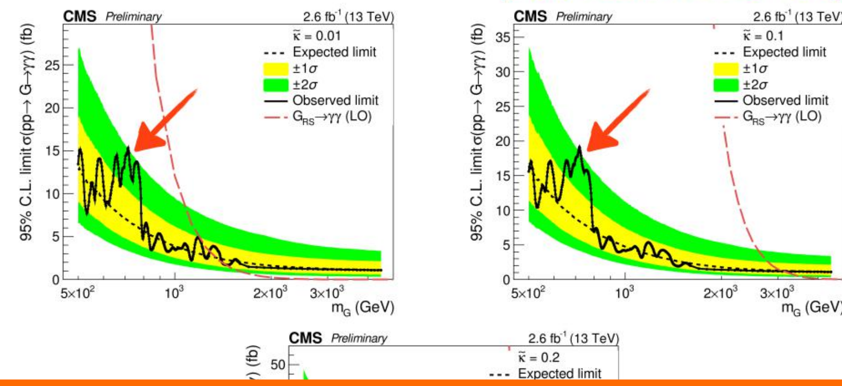
Here $G^{C}_{\mu\nu}$, $W^{a}_{\mu\nu}$, and $B_{\mu\nu}$ are canonically normalized tension fields for the $SU(3)$, $SU(2)$, and $U(1)$ gauge symmetries,

$$
\begin{aligned}
G^{C}_{\mu\nu} \;&=\; \partial_{\mu}G^{C}_{\nu} \;-\; \partial_{\nu}G^{C}_{\mu} \;-\; g_{3}f^{CDE}G^{D}_{\mu}G^{E}_{\nu}\,, \\
W^{a}_{\mu\nu} \;&=\; \partial_{\mu}W^{a}_{\nu} \;-\; \partial_{\nu}W^{a}_{\mu} \;-\; g_{2}F\epsilon^{abc}W^{b}_{\mu}W^{c}_{\nu}\,, \\
B_{\mu\nu} \;&=\; \partial_{\mu}B_{\nu} \;-\; \partial_{\nu}B_{\mu}\,,
\end{aligned}
\tag{9}
$$

[ATLAS-CONF-2015-081]



[CMS-PAS-EXO-15-004]



Intro: 750 GeV diphoton excess awakens!!

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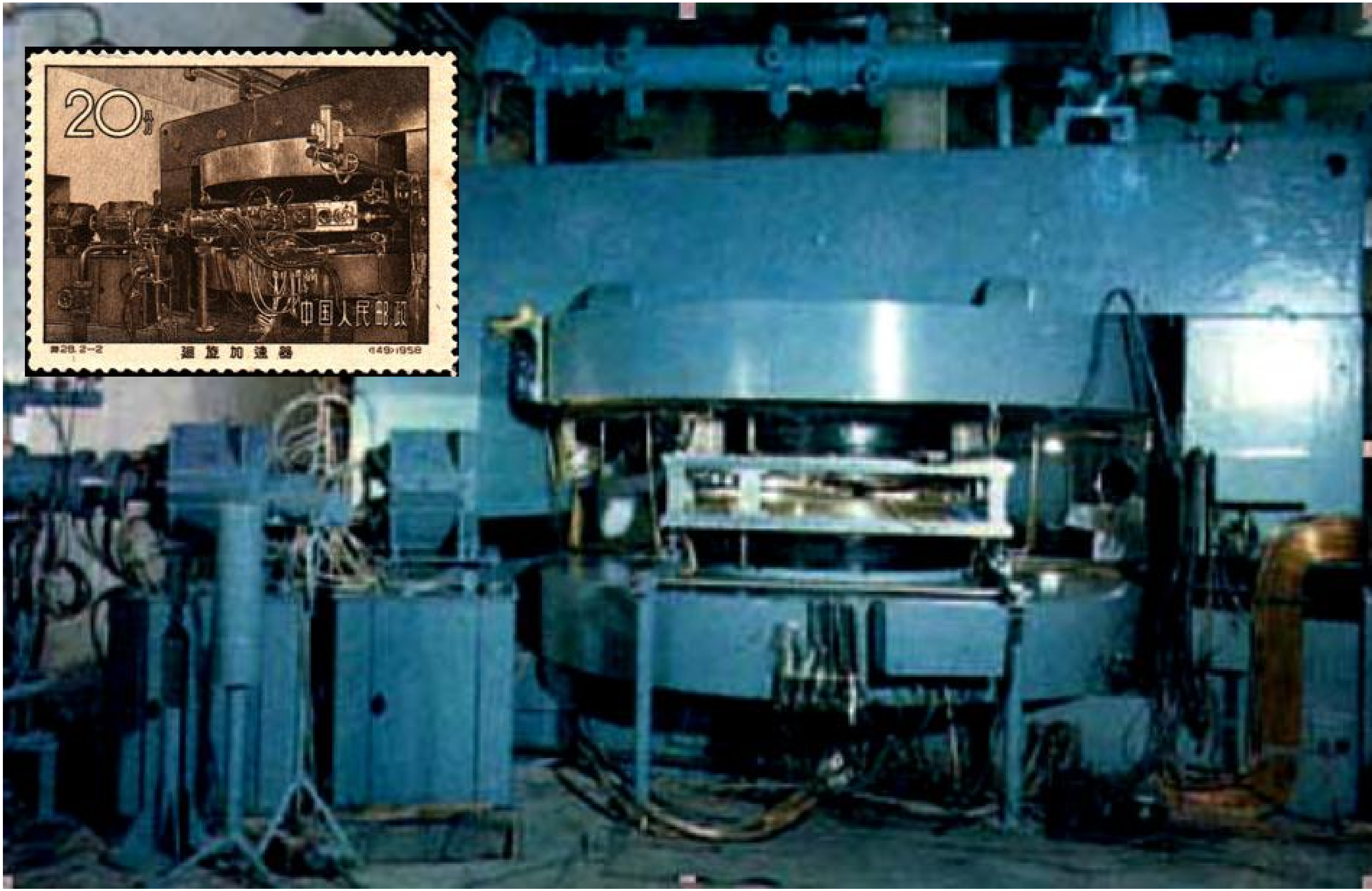
探索基础物理学的未解之谜

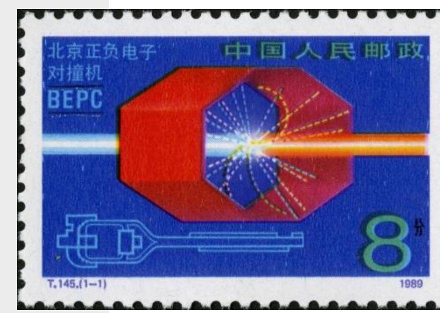
- 粒子是否有相对应的超对称（SUSY）粒子存在？
- 有更高维度的空间(Kaluza-Klein theory, extra-dimensions）存在吗？
- 是否可以探测到和弦论预言有关的物理现象？
- 为何物质与反物质是不对称的？
- 宇宙有96%的质量是目前天文学上无法观测到的（暗物质），这些到底是什么？
- 为何万有引力比起其他三个基本作用力（电磁力，强作用力，弱作用力）差了这么多个数量级？
- 微型黑洞是否存在？
- 是否存在超出标准模型的物理？
- 模拟早期宇宙的物理性质
- ……

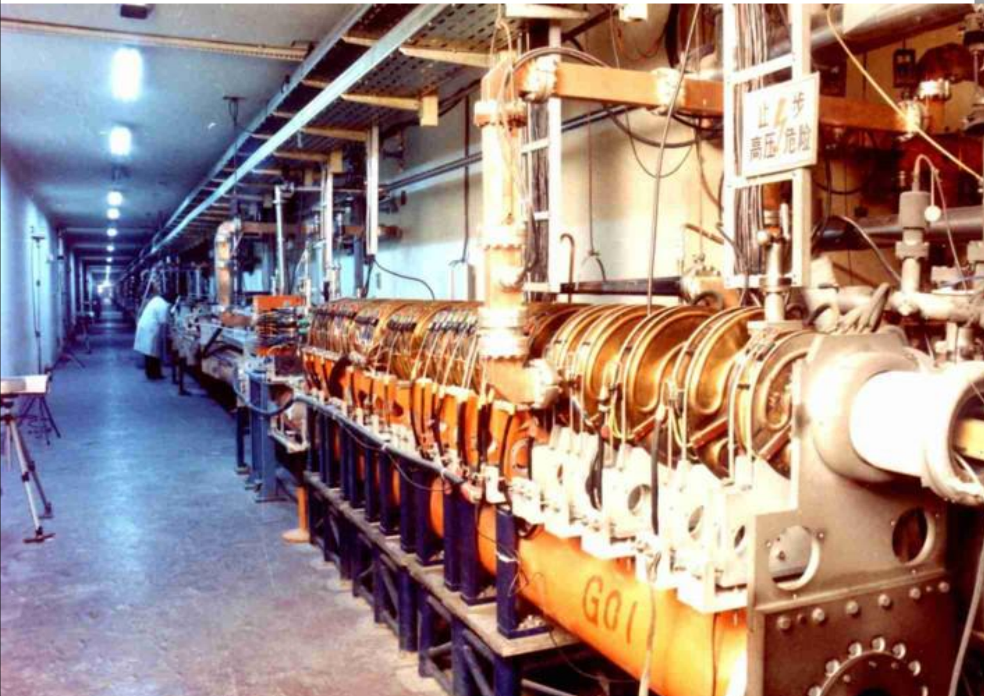
3、 中国的加速器

1958年6月30号中国第一个回旋加速器建成



北京正负电子对撞机: 长度0.24公里，加速能量1-1.15GeV，改造后能量最大为4Gev

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高压危险
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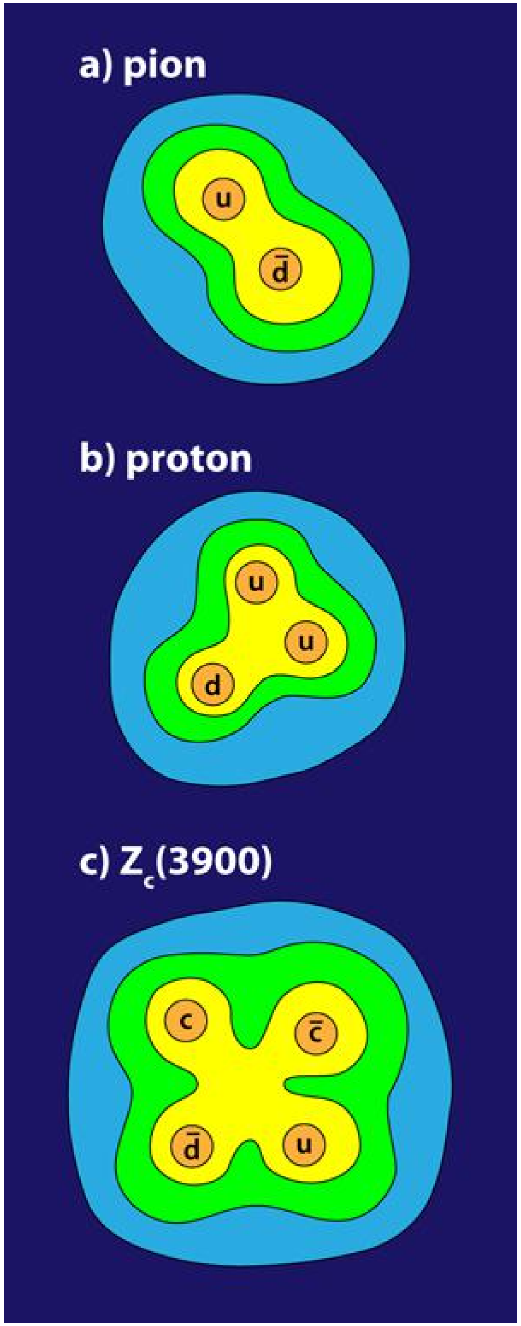
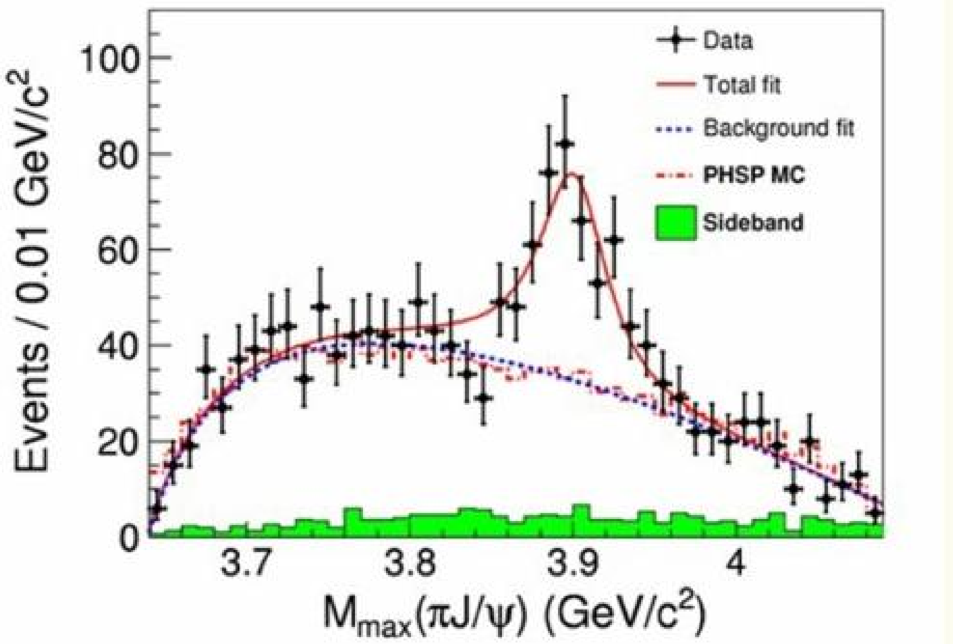
XINHUANET


2013年中国电子对撞机发现4夸克物质





四夸克物质Zc（3900）的共振结构

Study of $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ and Observation of a Charged Charmoniumlike State at Belle

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The cross section for $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ between 3.8 and 5.5 GeV is measured with a 967 fb^{-1} data sample collected by the Belle detector at or near the $\Upsilon(nS)$ $(n = 1, 2, \ldots, 5)$ resonances. The $Y(4260)$ state is observed, and its resonance parameters are determined. In addition, an excess of $\pi^+\pi^- J/\psi$ production around 4 GeV is observed. This feature can be described by a Breit-Wigner parametrization with properties that are consistent with the $Y(4008)$ state that was previously reported by Belle. In a study of $Y(4260) \rightarrow \pi^+\pi^- J/\psi$ decays, a structure is observed in the $M(\pi^\pm J/\psi)$ mass spectrum with 5.2σ significance, with mass $M = (3894.5 \pm 6.6 \pm 4.5)$ MeV$/c^2$ and width $\Gamma = (63 \pm 24 \pm 26)$ MeV$/c^2$, where the errors are statistical and systematic, respectively. This structure can be interpreted as a new charged charmoniumlike state.

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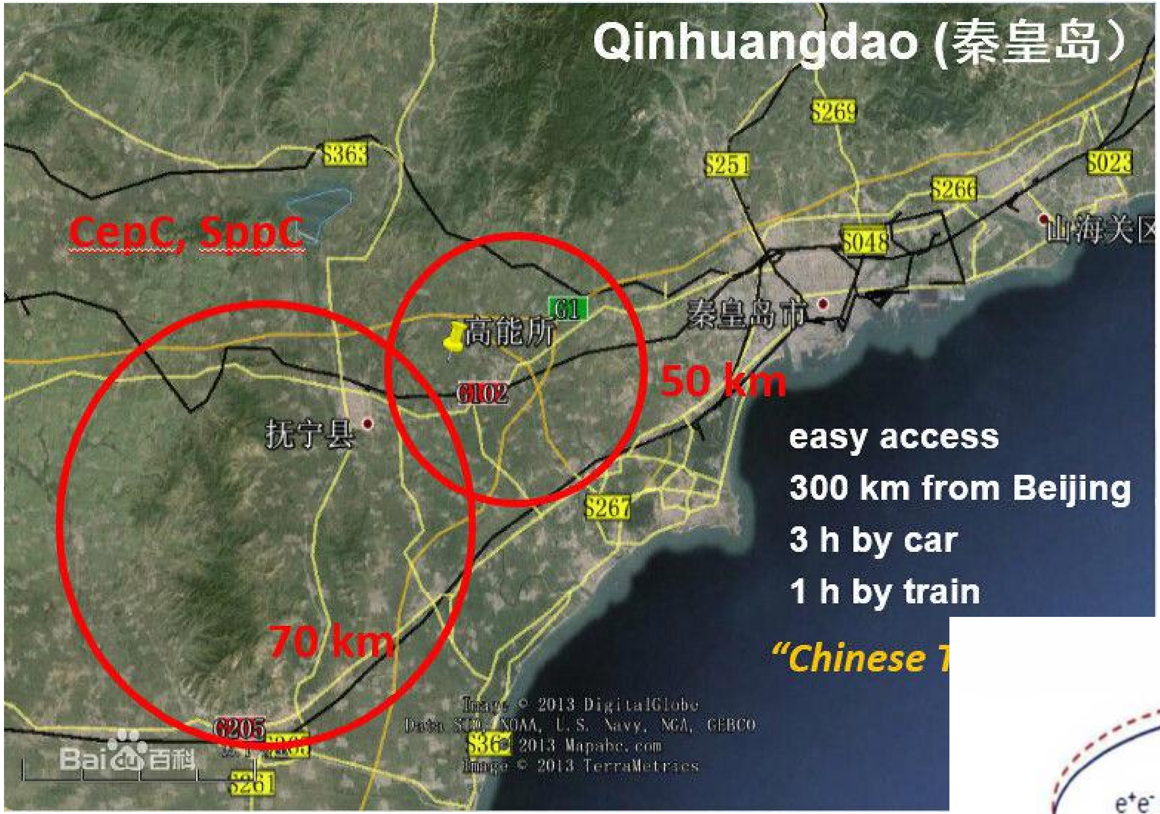
$Y(4260)$ state was first observed by the *BABAR* ration in the initial-state-radiation (ISR) process $\rightarrow \gamma_{\rm ISR}\pi^+\pi^- J/\psi$ [1] and then confirmed by the [2] and Belle experiments [3] using the same technique. Subsequently, a charged $Z(4430)^\pm$ charmoniumlike state was reported in the $\pi^\pm\psi(2S)$ invariant mass spectrum of $B \rightarrow K\pi^\pm\psi(2S)$ [4] and two $Z^\pm$ states were observed in the $\pi^\pm\chi_{c1}$ invariant mass distribution of

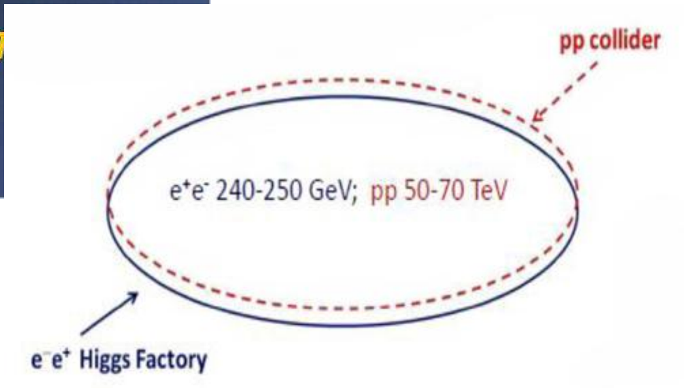
中国的“大型对撞机”大辩论

在规划中，CEPC-SPPC项目将在50-100公里长的地下环形通道内，利用相同的隧道，建造两座超级对撞机：正负电子对撞机和质子对撞机。

该质子对撞机和LHC相似，都在环形通道内使用质子进行对撞。但该对撞机的通道长度将是LHC的2-4倍，对撞能级可达70-100TeV或100-140TeV，远超LHC的14TeV。中科院高能所建议的超大对撞机预算将高于200亿美元（1335亿人民币）。

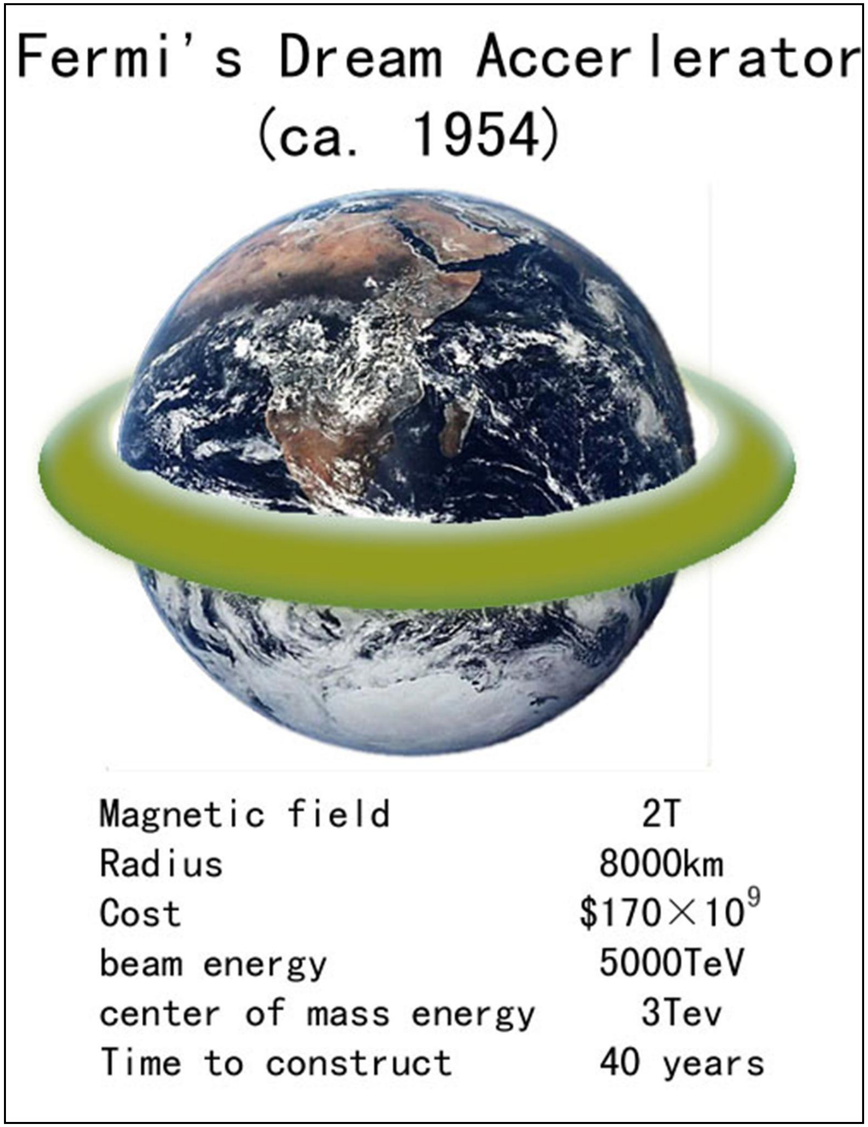
环形正负电子对撞机 （25TeV）
超级质子对撞机 （50-70TeV）





费米梦想

费米曾在1954年提出环绕地球建一台加速器的设想，称为费米的梦。其能量可达数千TeV。



谢谢！