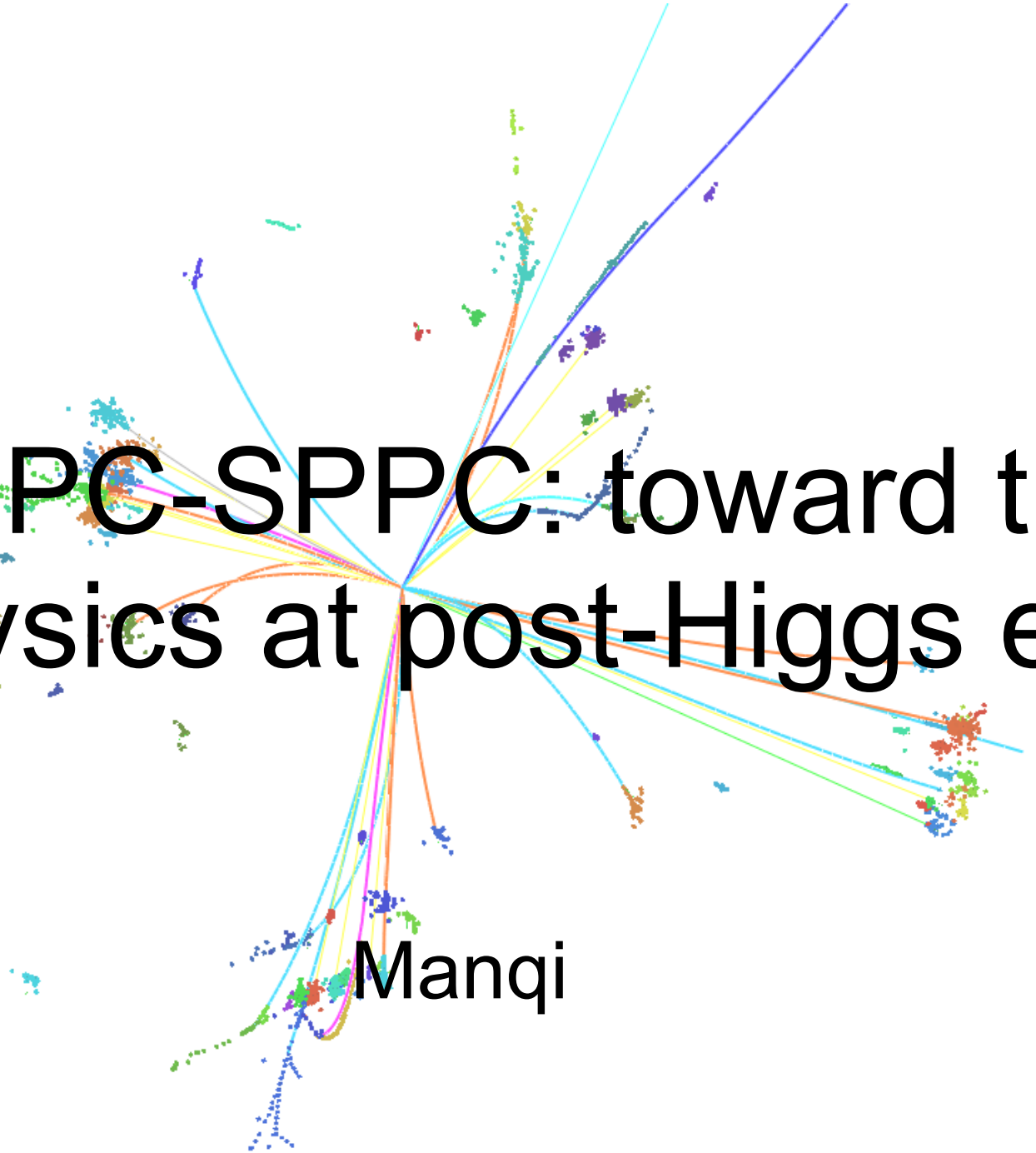
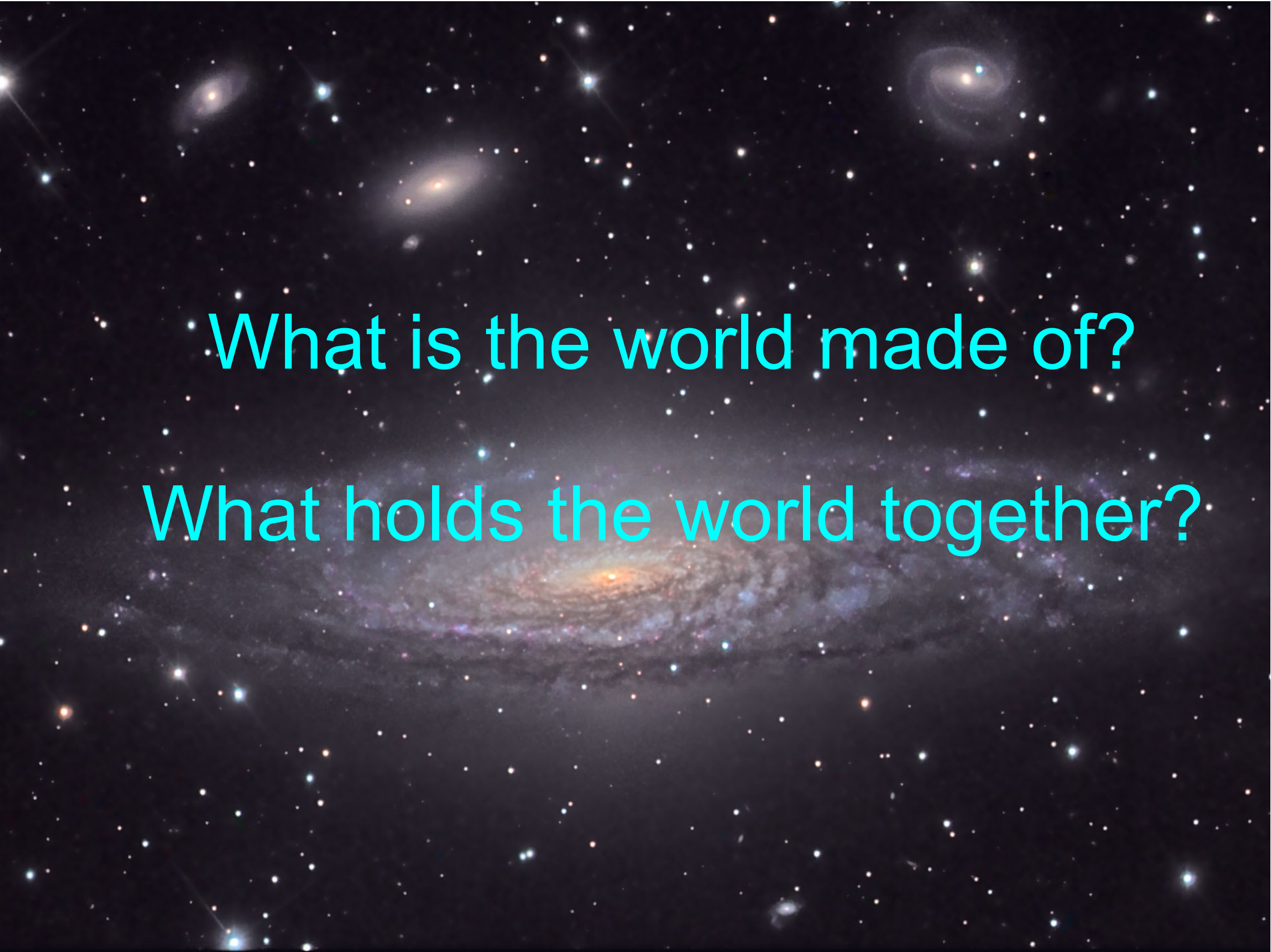
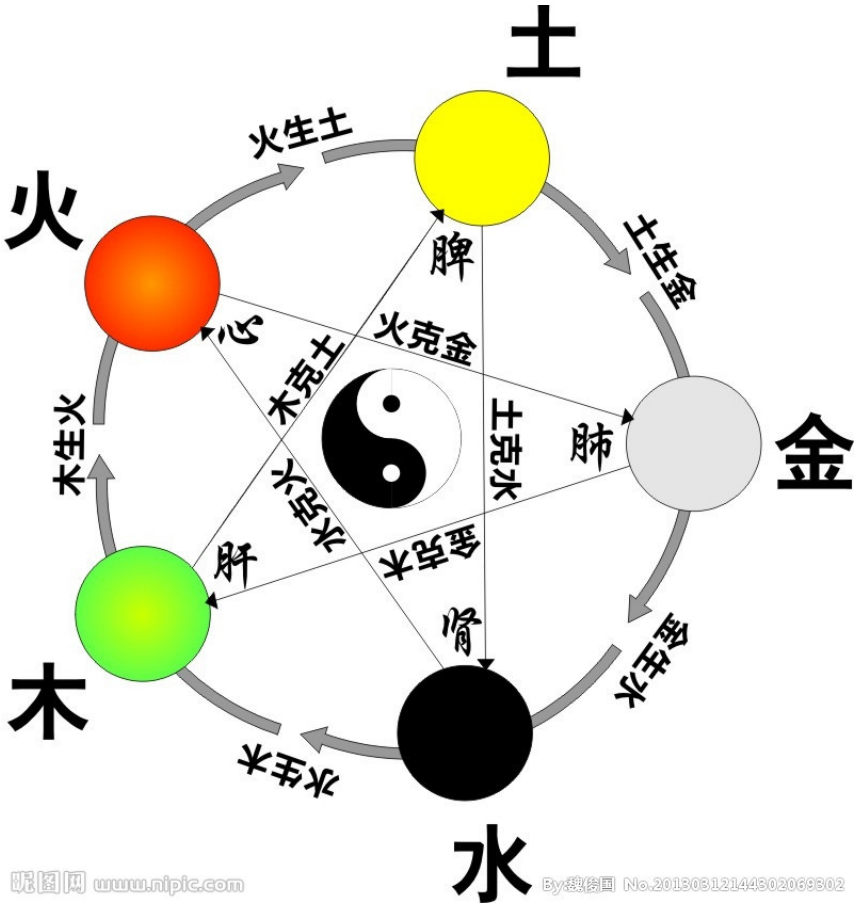


CEPC-SPPC: toward the physics at post-Higgs era

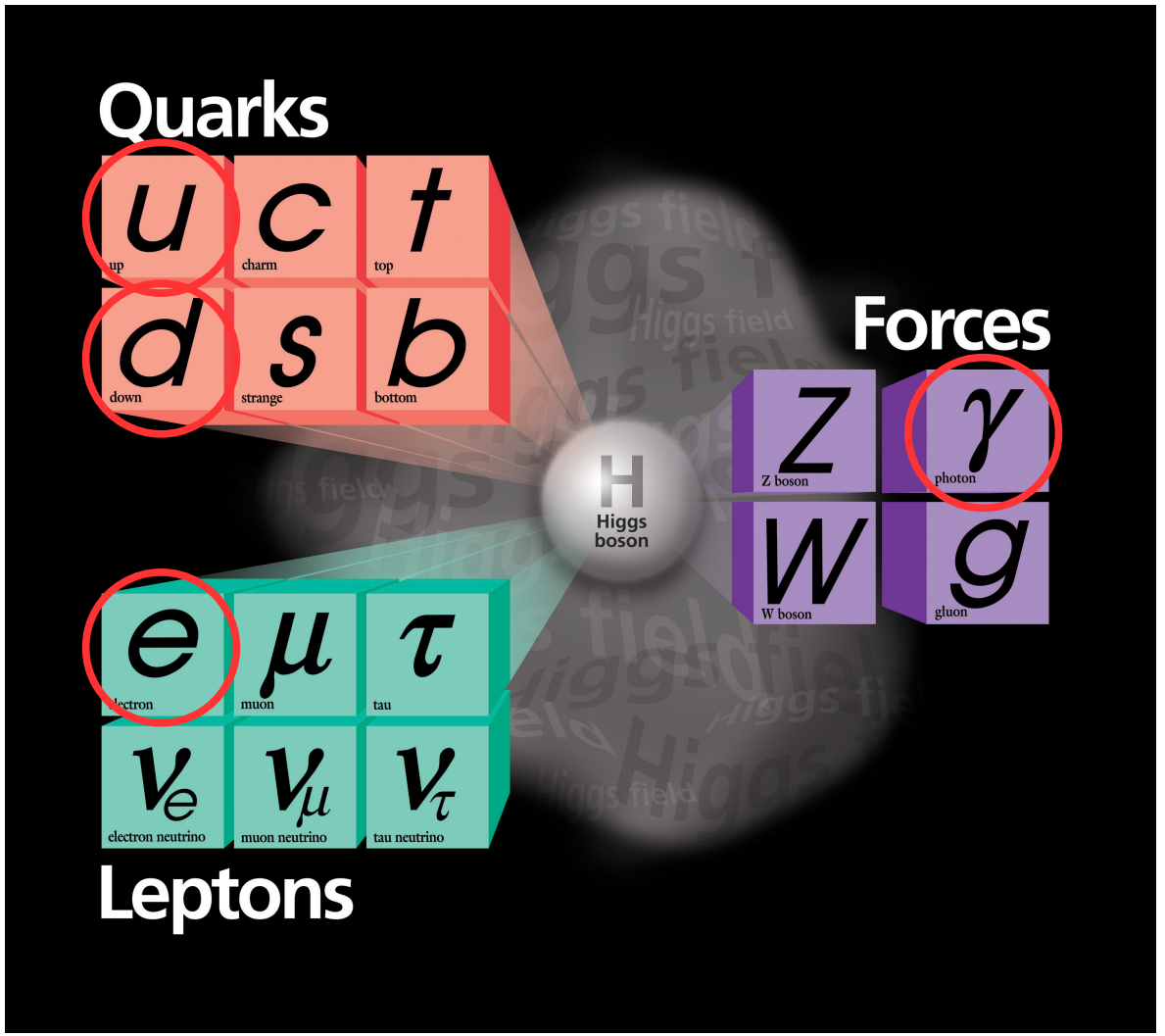
Manqi


What is the world made of?
What holds the world together?

In the Ancient time



Standard model: building block



- nuclei
  - proton （ uud ）
    - Q = 2/3 * 2 – 1/3 = 1
  - neutron （ udd ）
    - Q = 2/3 - 1/3 * 2 = 0
- electron
- photon
- ...

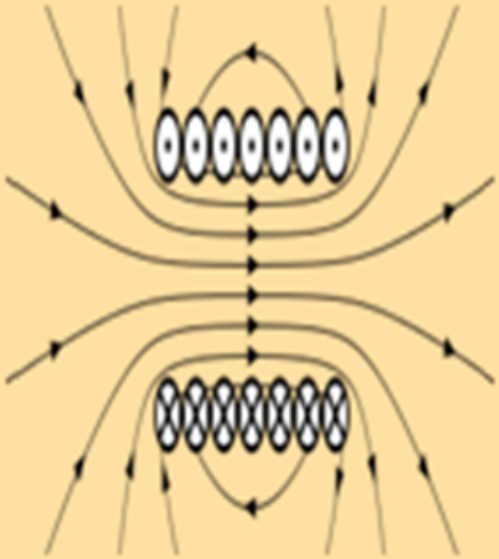
FOUR FUNDAMENTAL FORCES

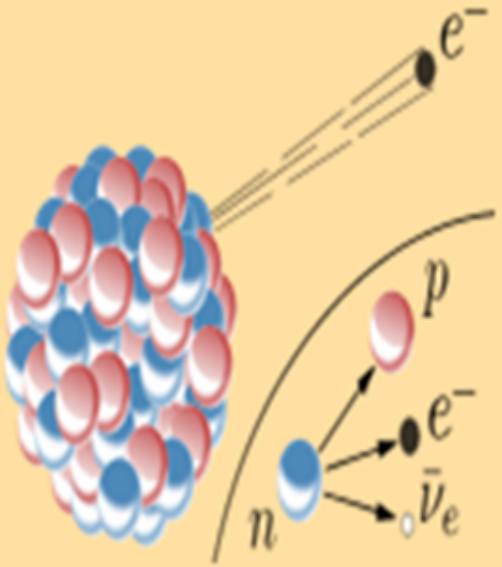
GRAVITATION

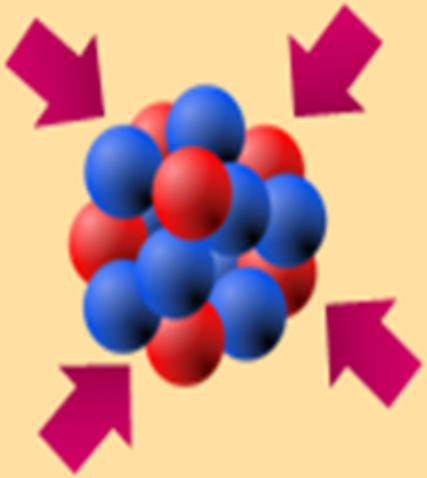
ELECTRO-MAGNETISM

WEAK INTERACTION

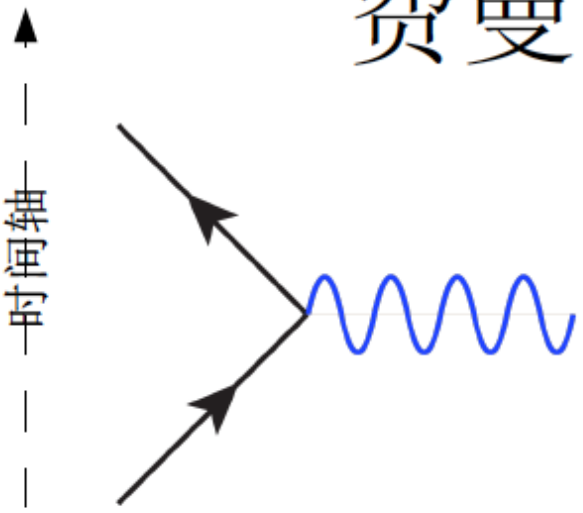
STRONG INTERACTION



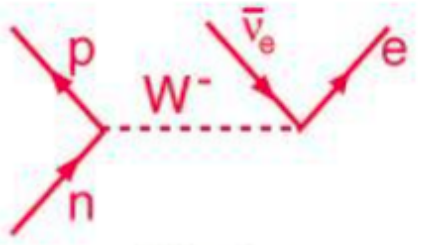




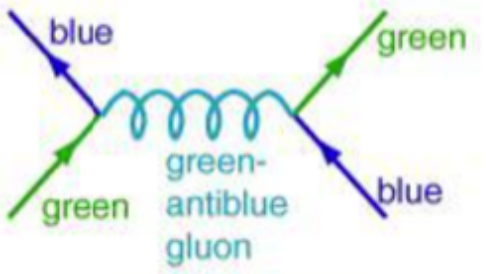
费曼图：定域相互作用



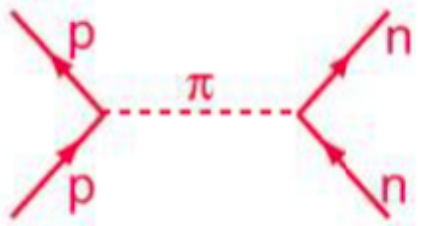
Electromagnetic Interaction



Weak Interaction



between quarks

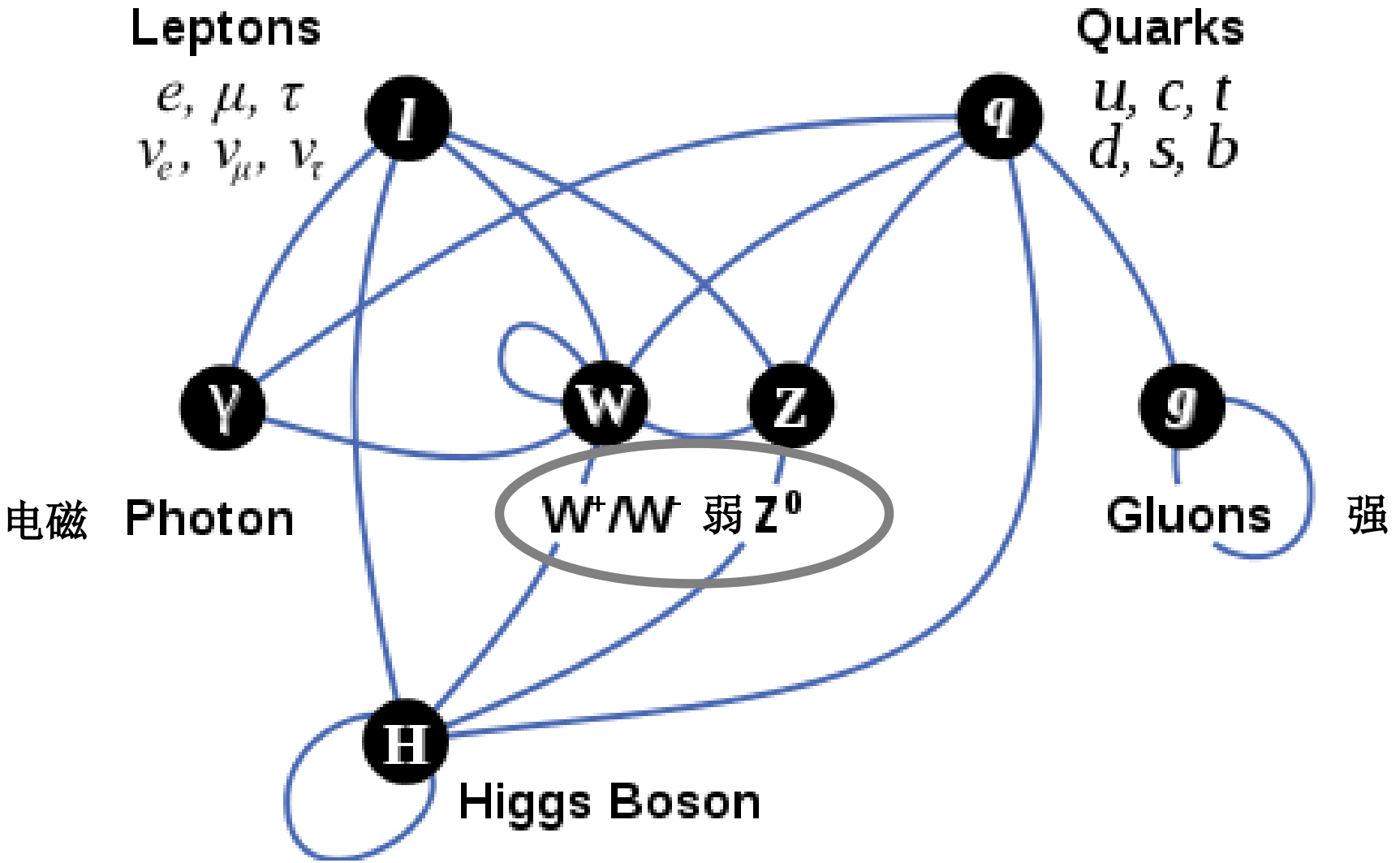


between nucleons

Strong Interaction

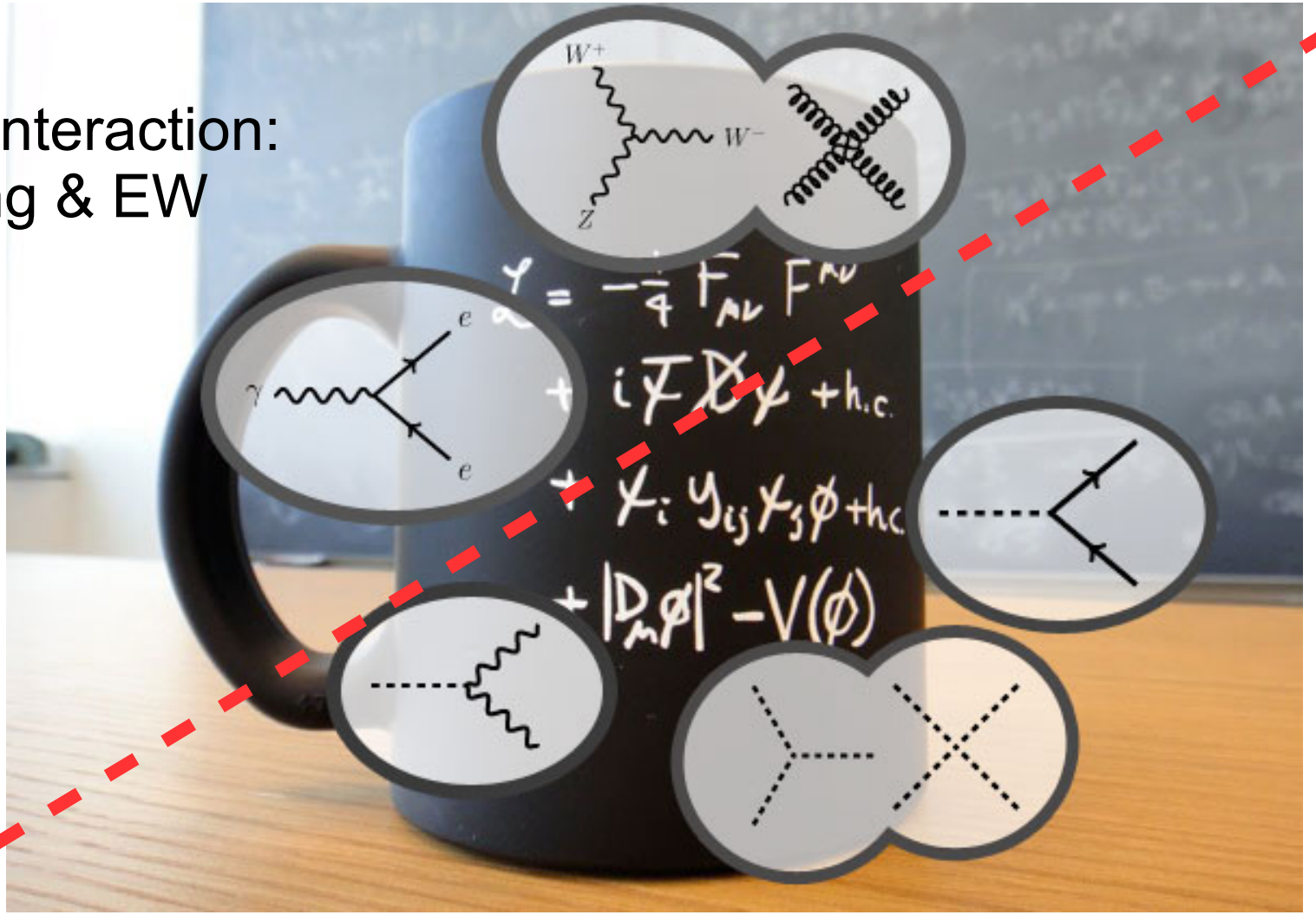
定域相互作用：
相互作用发生在一个时间，一个地点

Standard Model: ingredients & interactions



Standard Model: Interactions

Gauge interaction:
Strong & EW



Higgs related

SM Lagrangian

$$
\begin{aligned}
\mathcal{L} \;=\; & -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{8}tr(\mathbf{W}_{\mu\nu}\mathbf{W}^{\mu\nu}) - \frac{1}{2}tr(\mathbf{G}_{\mu\nu}\mathbf{G}^{\mu\nu}) && \text{(U(1), SU(2) and SU(3) gauge terms)} \\
& + (\bar{\nu}_L, \bar{e}_L)\,\tilde{\sigma}^{\mu} i D_{\mu} \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} + \bar{e}_R \sigma^{\mu} i D_{\mu} e_R + \bar{\nu}_R \sigma^{\mu} i D_{\mu} \nu_R + (\text{h.c.}) && \text{(lepton dynamical term)} \\
& - \frac{\sqrt{2}}{v}\left[(\bar{\nu}_L, \bar{e}_L)\,\phi M^{e} e_R + \bar{e}_R \bar{M}^{e} \bar{\phi} \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \right] && \text{(electron, muon, tauon mass term)} \\
& - \frac{\sqrt{2}}{v}\left[(-\bar{e}_L, \bar{\nu}_L)\,\phi^{*} M^{\nu} \nu_R + \bar{\nu}_R \bar{M}^{\nu} \phi^{T} \begin{pmatrix} -e_L \\ \nu_L \end{pmatrix} \right] && \text{(neutrino mass term)} \\
& + (\bar{u}_L, \bar{d}_L)\,\tilde{\sigma}^{\mu} i D_{\mu} \begin{pmatrix} u_L \\ d_L \end{pmatrix} + \bar{u}_R \sigma^{\mu} i D_{\mu} u_R + \bar{d}_R \sigma^{\mu} i D_{\mu} d_R + (\text{h.c.}) && \text{(quark dynamical term)} \\
& - \frac{\sqrt{2}}{v}\left[(\bar{u}_L, \bar{d}_L)\,\phi M^{d} d_R + \bar{d}_R \bar{M}^{d} \bar{\phi} \begin{pmatrix} u_L \\ d_L \end{pmatrix} \right] && \text{(down, strange, bottom mass term)} \\
& - \frac{\sqrt{2}}{v}\left[(-\bar{d}_L, \bar{u}_L)\,\phi^{*} M^{u} u_R + \bar{u}_R \bar{M}^{u} \phi^{T} \begin{pmatrix} -d_L \\ u_L \end{pmatrix} \right] && \text{(up, charmed, top mass term)} \\
& + \overline{(D_{\mu}\phi)} D^{\mu}\phi - m_h^2 [\bar{\phi}\phi - v^2/2]^2/2v^2. && \text{(Higgs dynamical and mass term)} \qquad (1)
\end{aligned}
$$

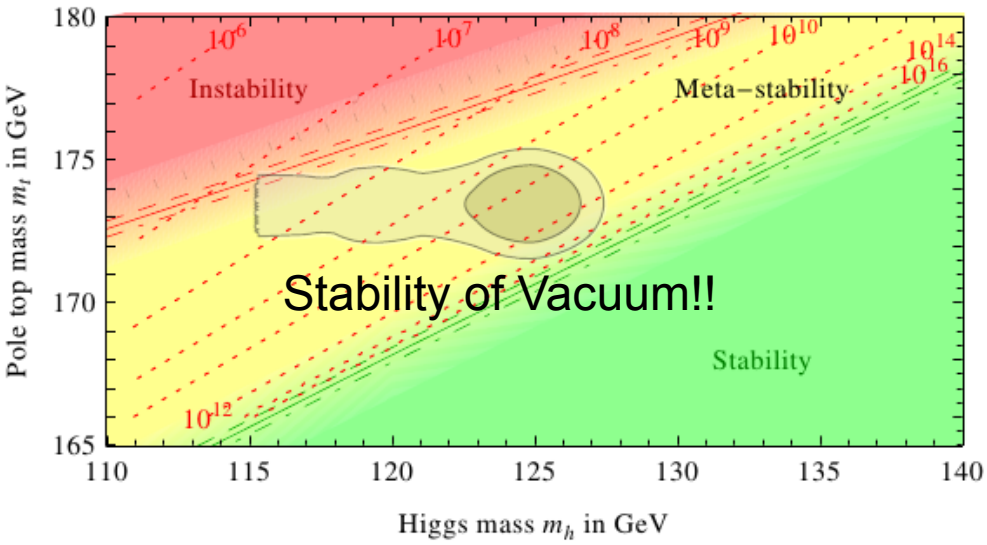
The SM Parameters & the Higgs

- 9 fermion masses (+ 3 m_ν)
- 3 CKM mixing angles + 1 phase (+ 3+1 for $m_\nu \neq 0$)
- 1 electromagnetic coupling constant α
- 1 strong coupling constant α_s
- 1 weak coupling constant $G_F = 1.16637(1) \times 10^{-5}\,\mathrm{GeV}^{-2}$
- 1 Z^0 mass $m_Z = 91.1876(21)\ \mathrm{GeV}/c^2$
- 1 Higgs mass

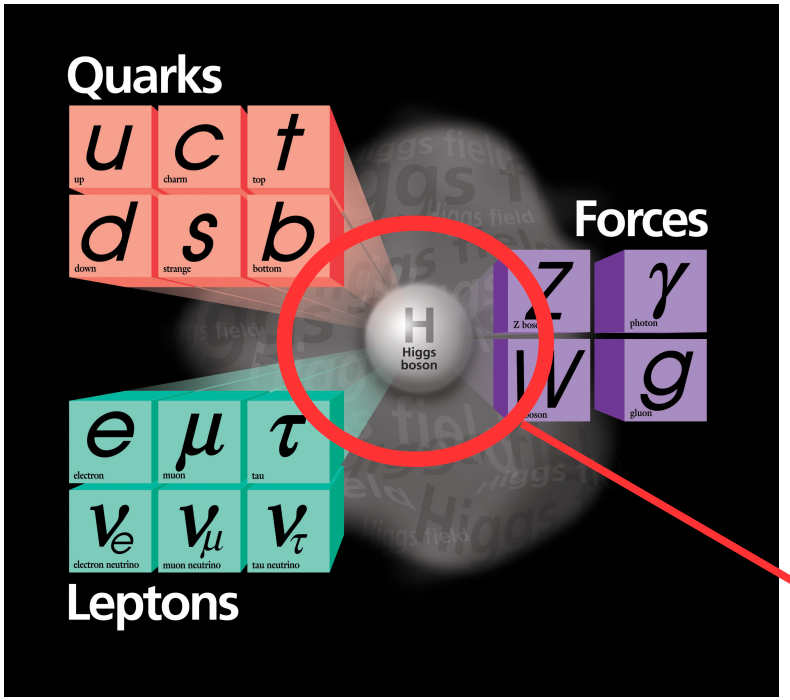
The Only Scalar Particle
Correlated with most of the SM Unknowns:
Theoretical defects & hand-put parameters

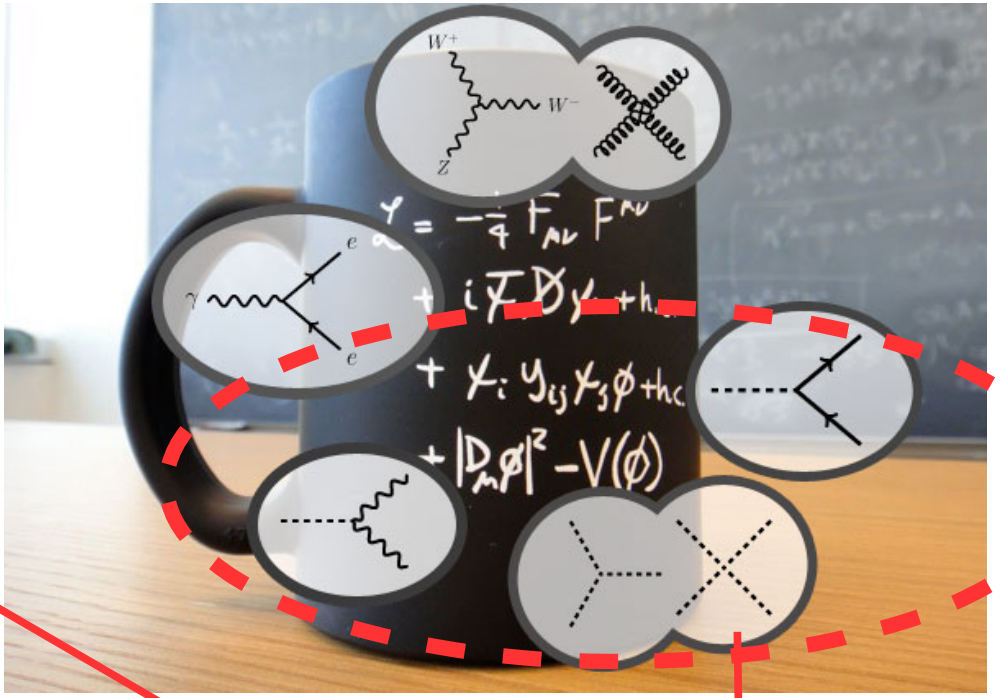
Higgs boson: New Interactions

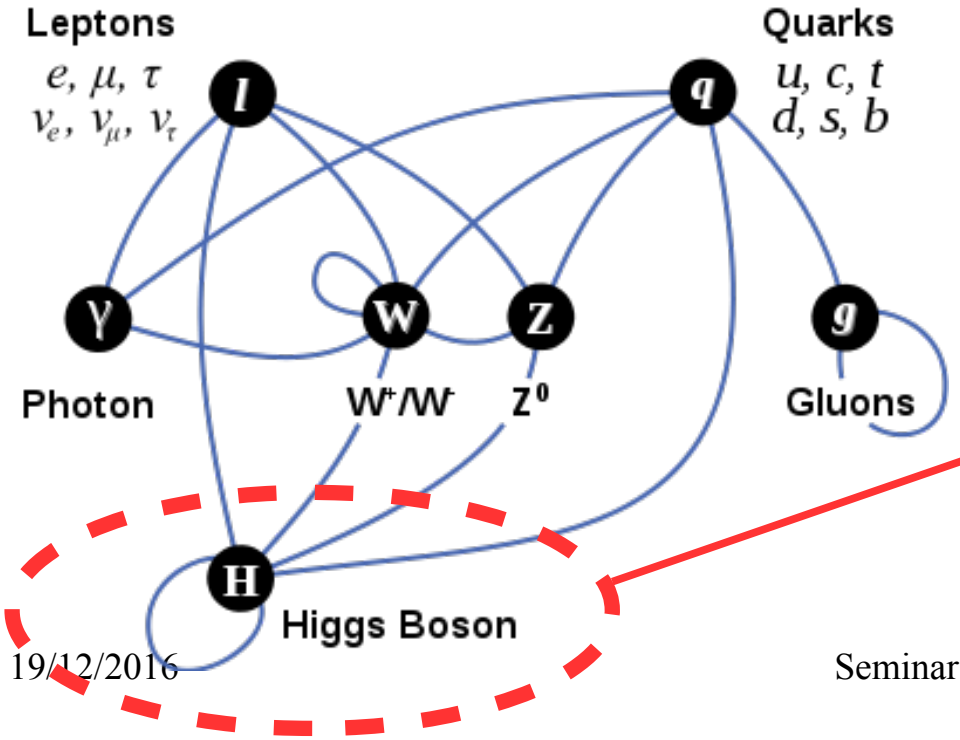
- Yukawa Interaction: determine the mass of fermion ,
  - Mass(u) < mass(d): stability of proton
  - Mass of electron: scale of atom
  - Mass of top quark
  - ...



- Higgs Mechanism
  - Mass of Higgs boson (itself)
  - Mass of W, Z: Range & Strength of the weak interaction
  - ...


Quarks
u c t
up charm top
d s b
down strange bottom
Forces
Z γ
photon
W g
gluon
H
Higgs boson
e μ τ
electron muon tau
νe νμ ντ
electron neutrino muon neutrino tau neutrino
Leptons



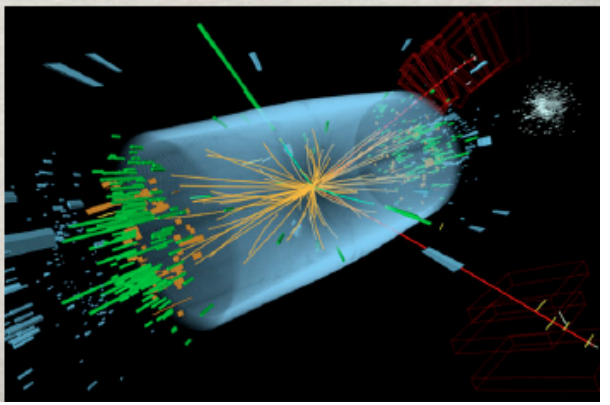

Leptons
e, μ, τ
νe, νμ, ντ
l
Quarks
u, c, t
d, s, b
q
γ
W
Z
g
Photon
W+/W-
Z0
Gluons
H
Higgs Boson


THE
HIGGS
BOSON
H

弗朗索瓦•恩格勒 和 彼得•希格斯共享2013年物理学诺奖：

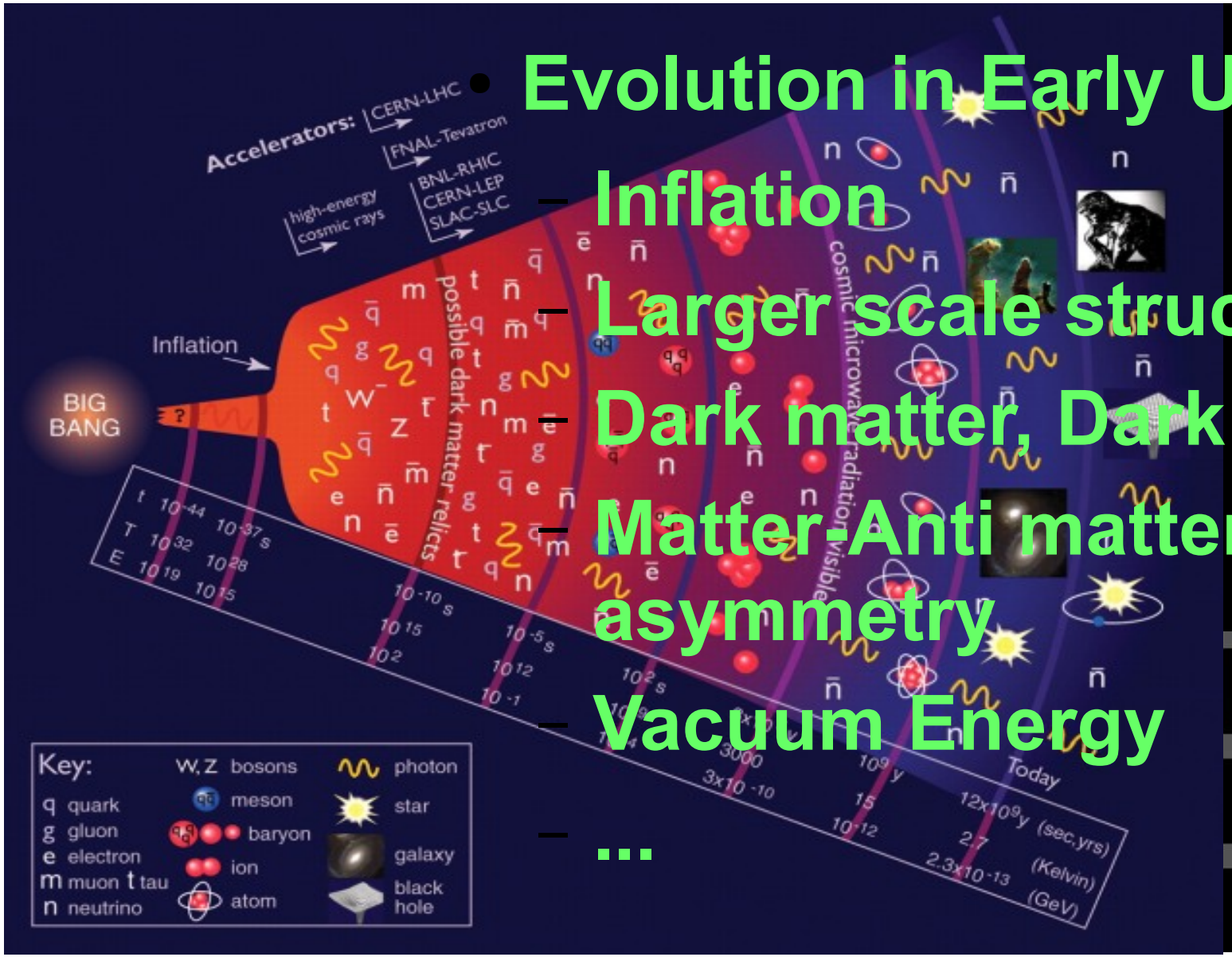
欧洲核子研究中心（CERN）的
“大型强子对撞机”（LHC）发现了“希格斯粒子”，
从而验证了恩格勒－希格斯等人的*基本粒子质量起源*的理论机制（对称性的自发破缺）。

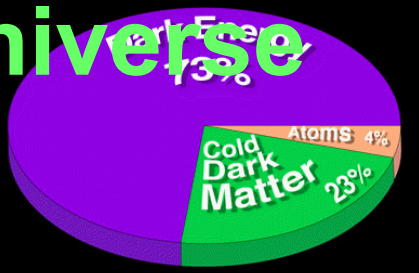
这是几十年来物理学基础研究中
最重大的成果之一！ 3

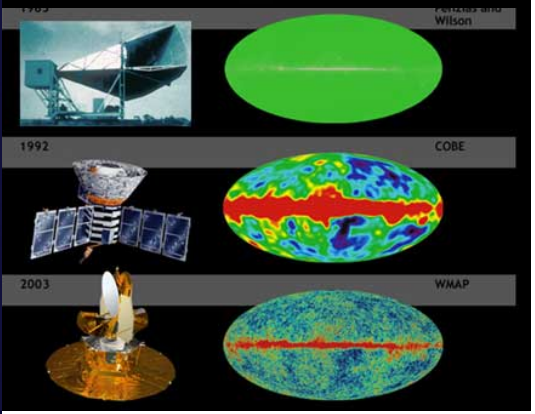


Beyond SM Phenomenas

- Evolution in Early Universe
  - Inflation
  - Larger scale structure
  - Dark matter, Dark energy
  - Matter-Anti matter asymmetry
  - Vacuum Energy
  - ...







Higgs boson: Extremely important

- The unique Scalar particle in the SM
- Correlated with all “unknown” in the SM
- Determines new interactions
- Determines many important features of visible world
- ...
- **Maybe also responsible for several key feature in the evolution of the early universe**

What's the nature of Higgs boson???


Higgs

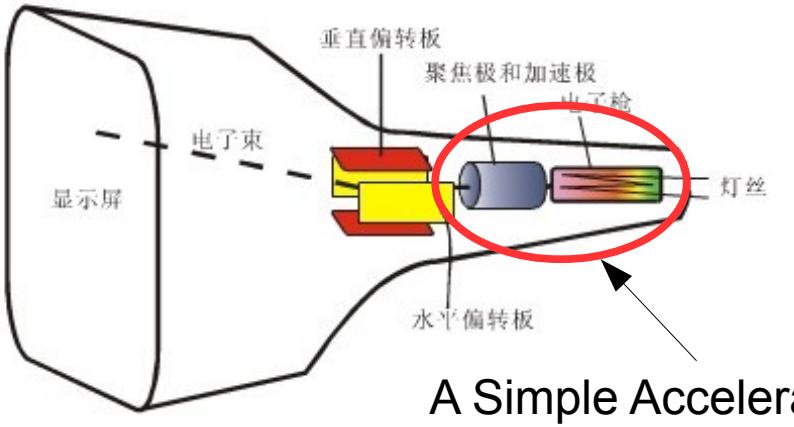
Accelerator & Detector

Accelerator, make the “events”

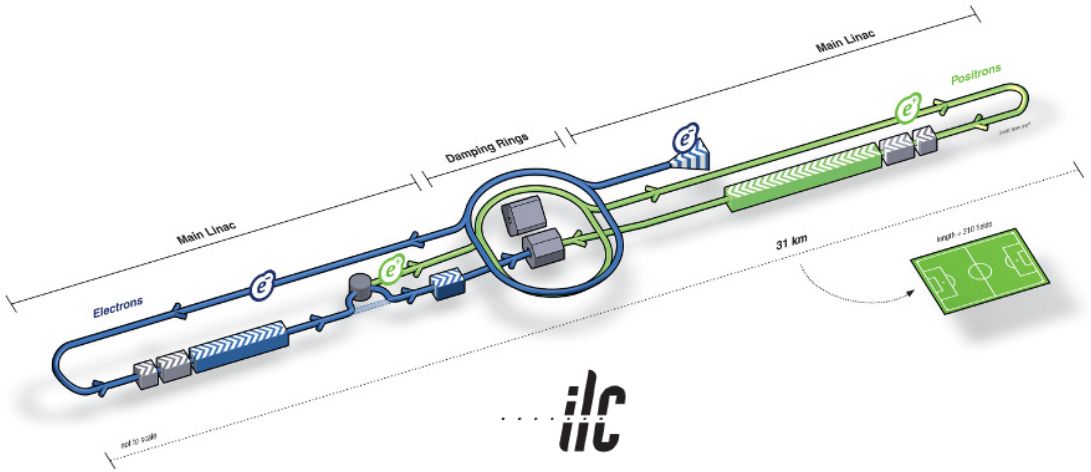
Accelerator the particle, and group/zip
Them into very small bunches...

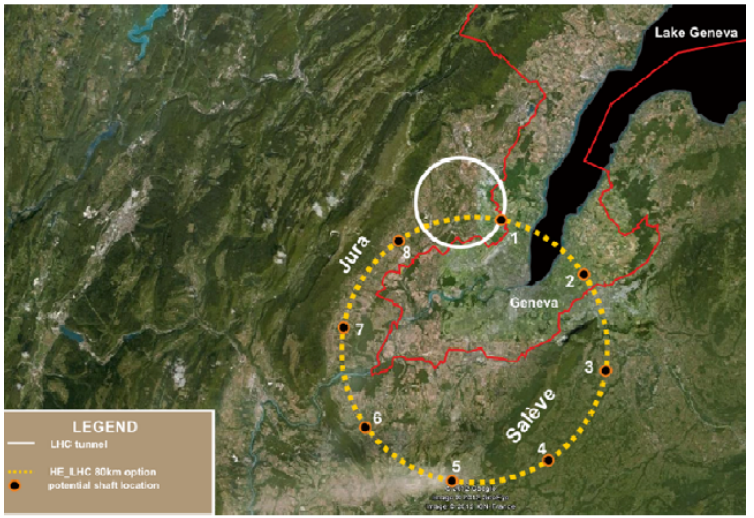
Diversity: electron-positron colliders, Proton colliders, Muon colliders, Photon collider, Heavy ion colliders, ...

Configuration: Linear & Circular

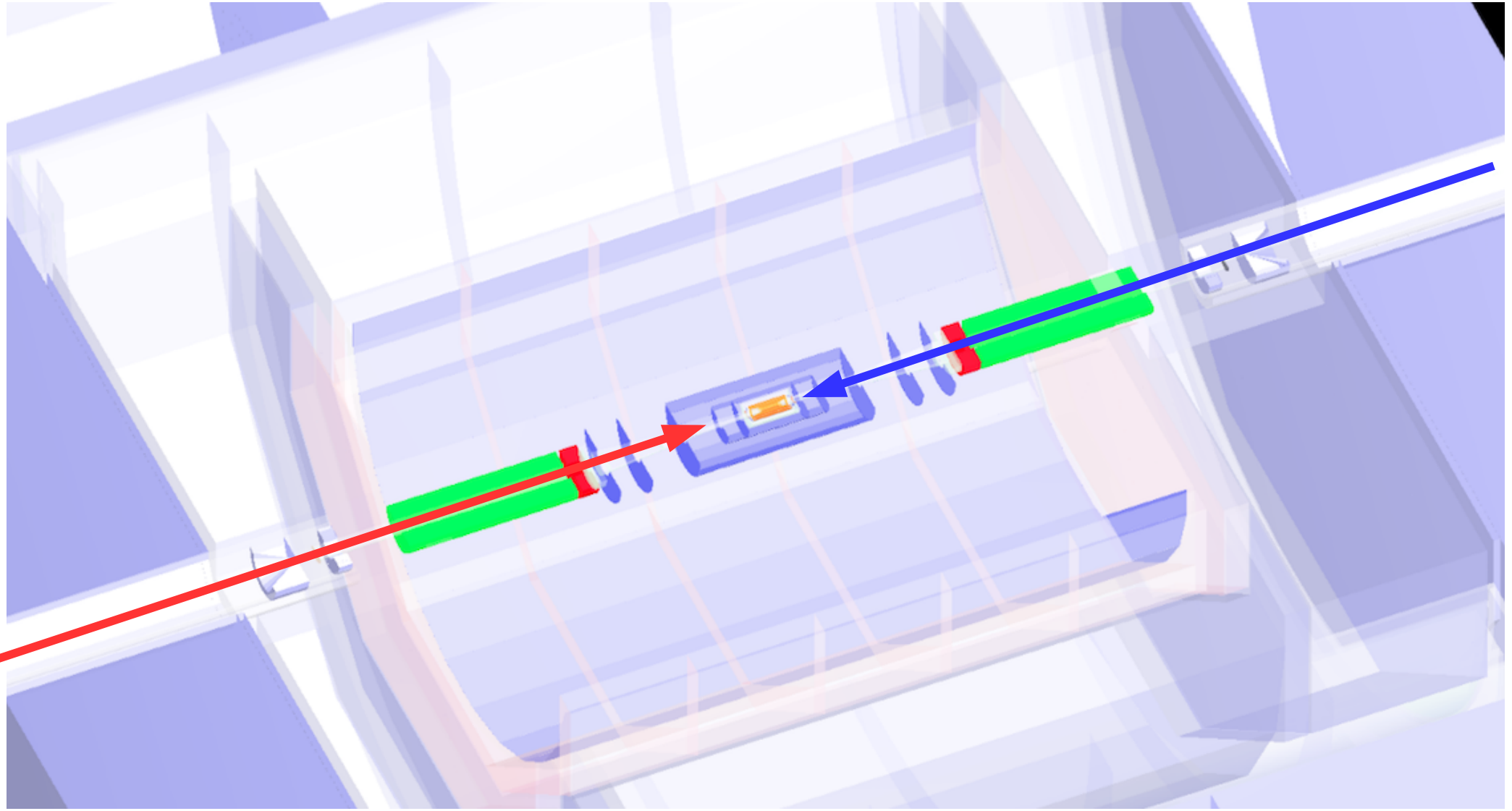


A Simple Accelerator



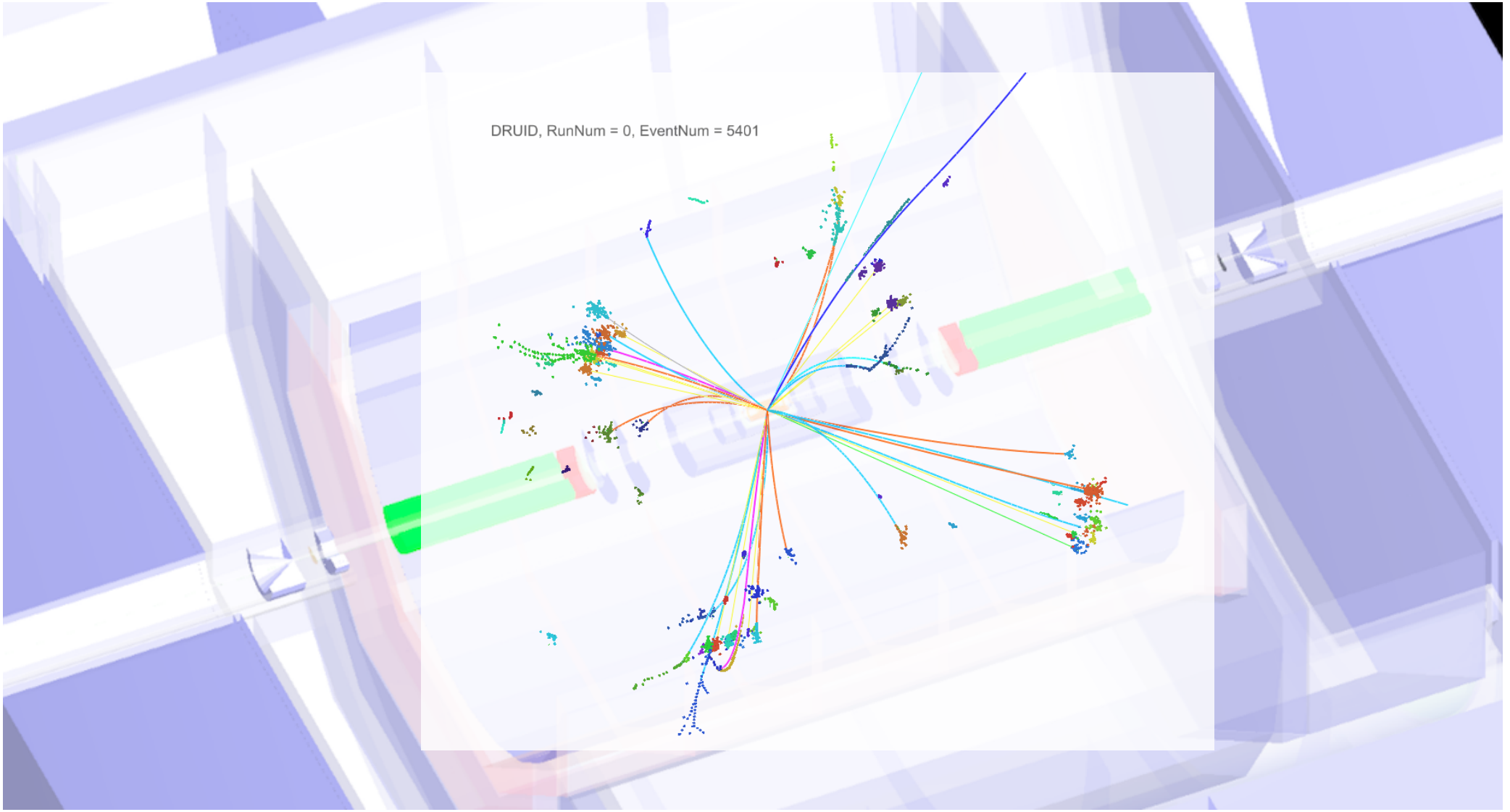


Detector

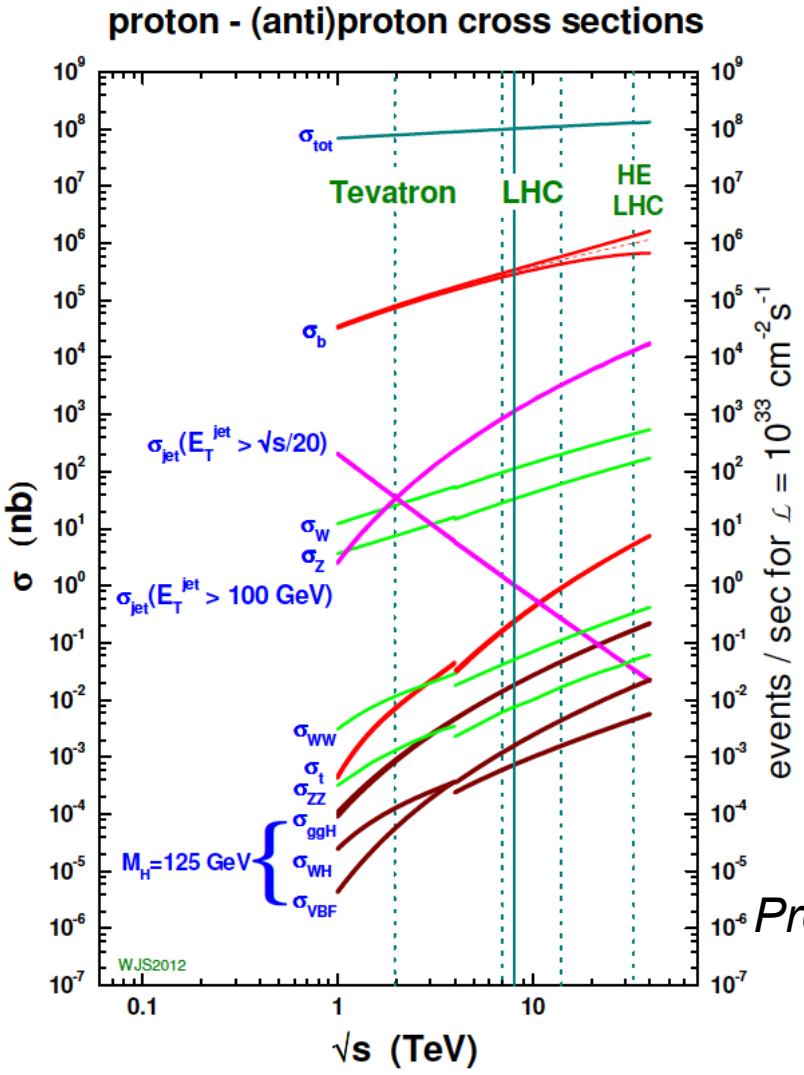


高能对撞机上探测器的尺寸 ~ 10 米

Physics Events

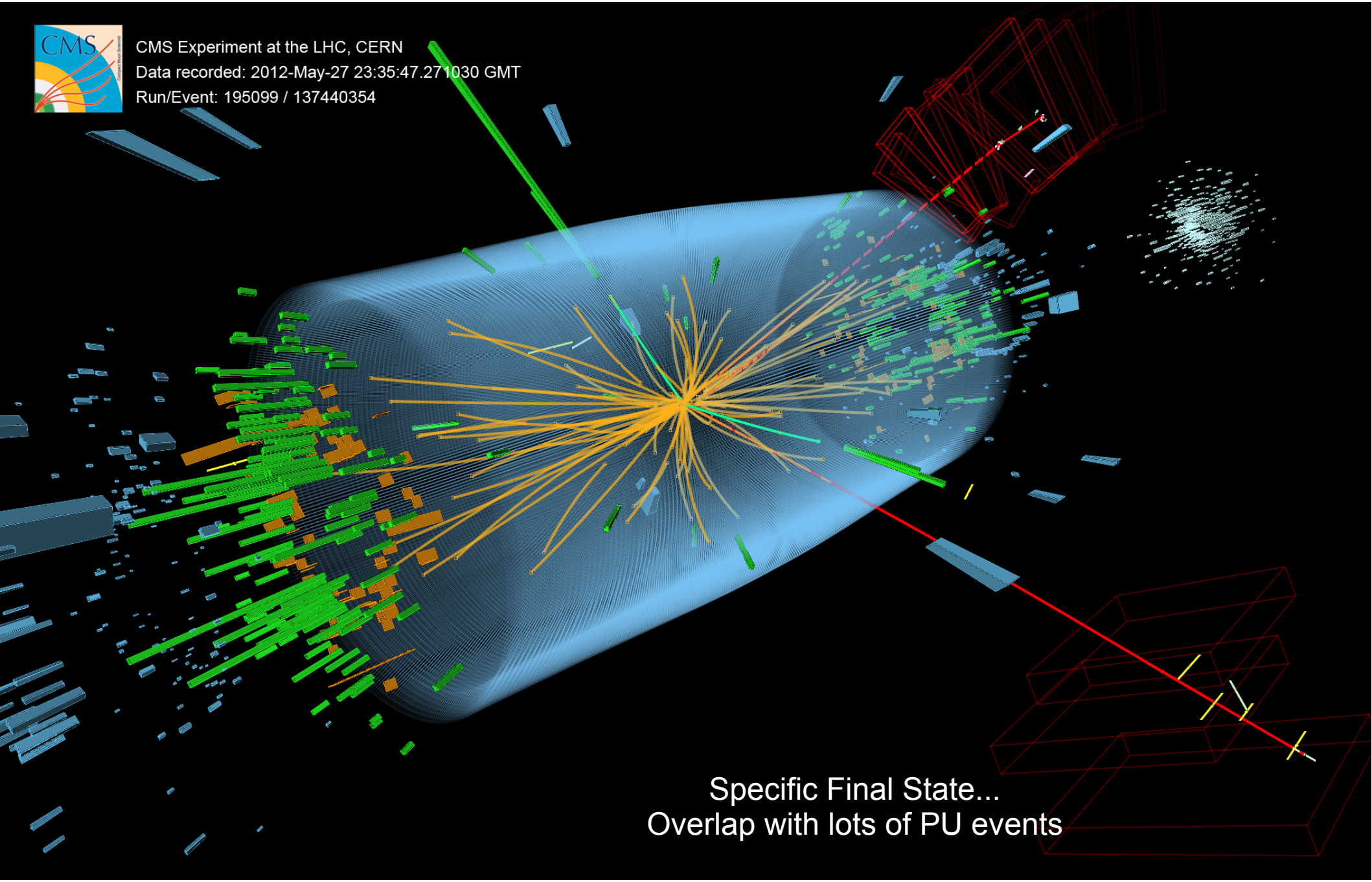


Higgs @ LHC



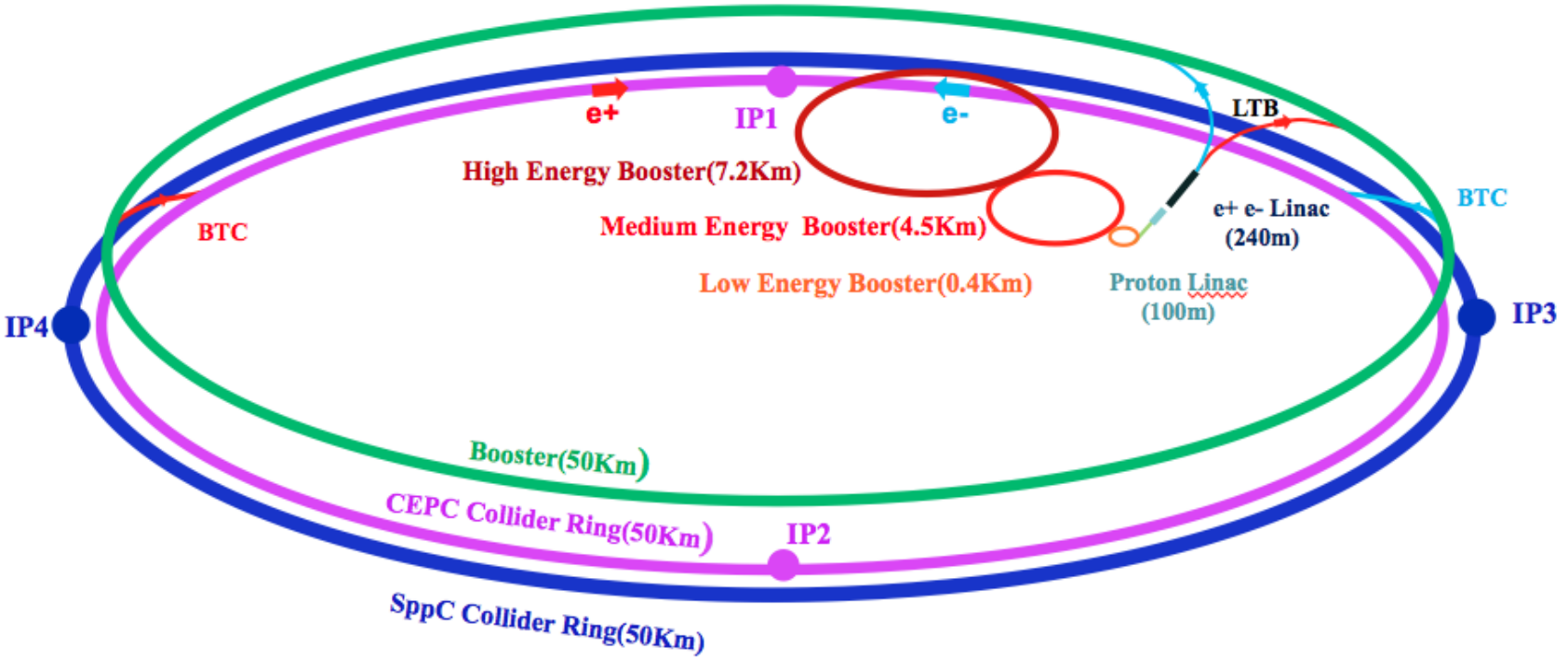
Proton-Proton collider: Huge background (one Higgs boson Generated for 10B collisions...)

Low reconstruction(finding) efficiency

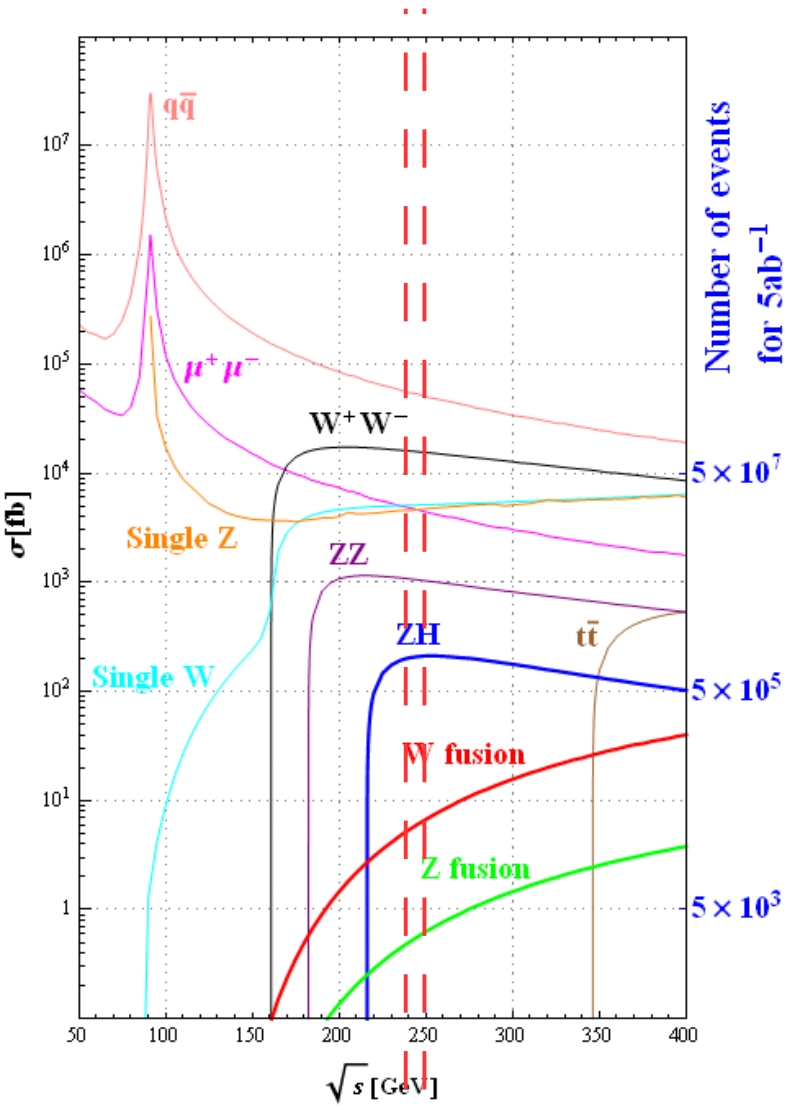

CMS Experiment at the LHC, CERN
Data recorded: 2012-May-27 23:35:47.271030 GMT
Run/Event: 195099 / 137440354
Specific Final State...
Overlap with lots of PU events

CEPC: a precise Higgs factory

- Higgs mass ~ 125 GeV, it is possible to build a Circular e+e- Higgs factory (CEPC), followed by a proton collider (SPPC) in the same tunnel
- Looking for Hints (from Higgs) at CEPC → direct search at SPPC
- CEPC: 1 M Higgs boson + 10 Billion Z bosons...

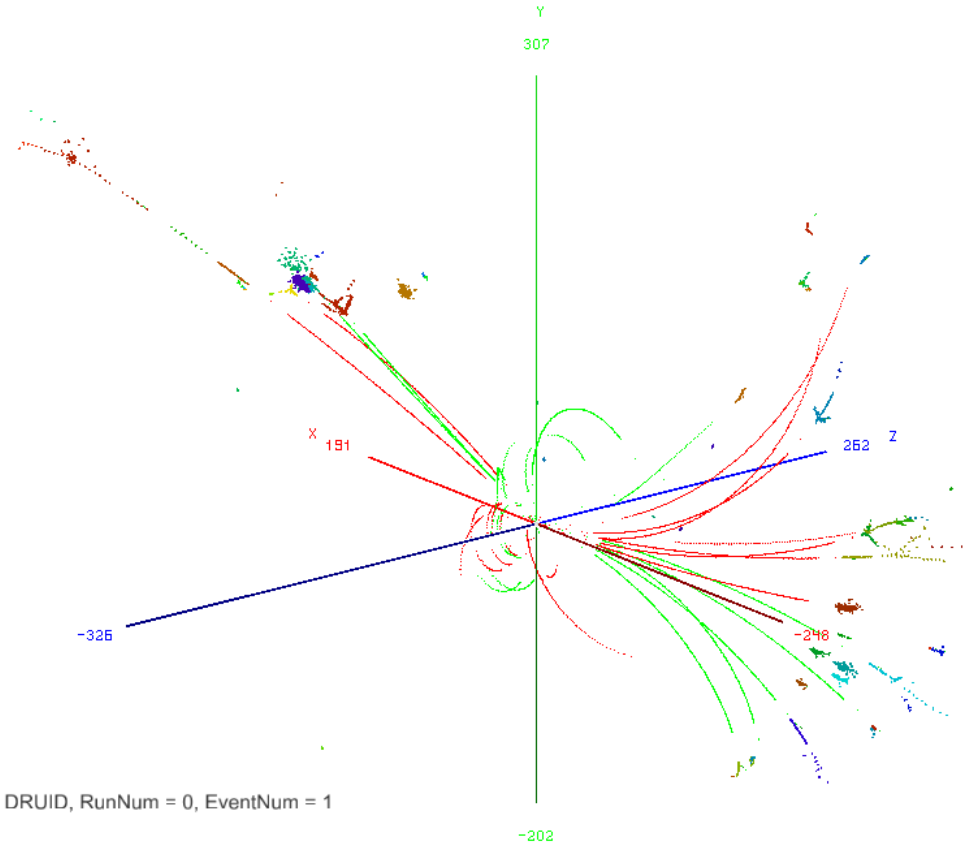


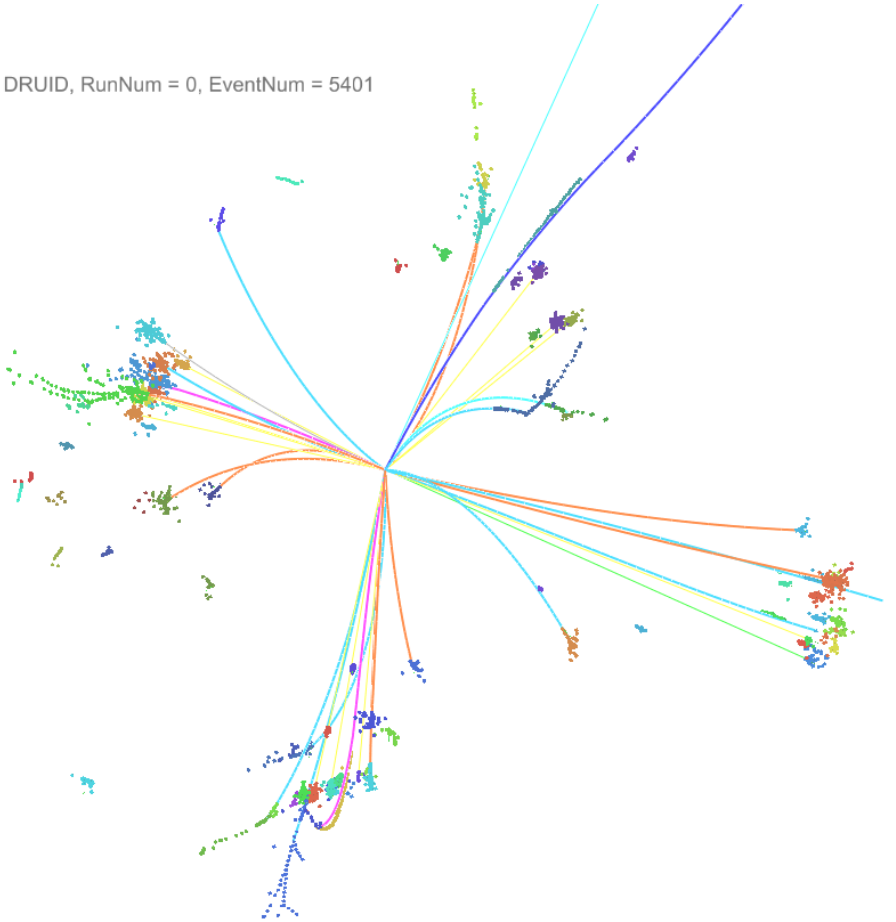
Higgs @ CEPC



One Higgs boson for every 1000 physics events

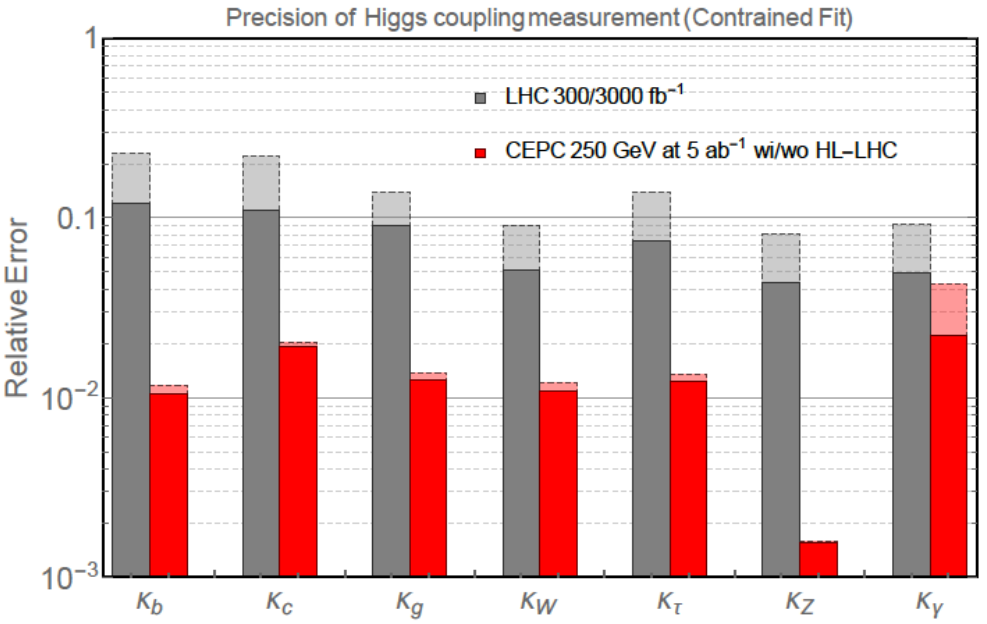
Main observables: Higgs boson mass, quantum number, **σ(ZH)**, branching ratio -> Absolute value of Higgs width & Higgs couplings

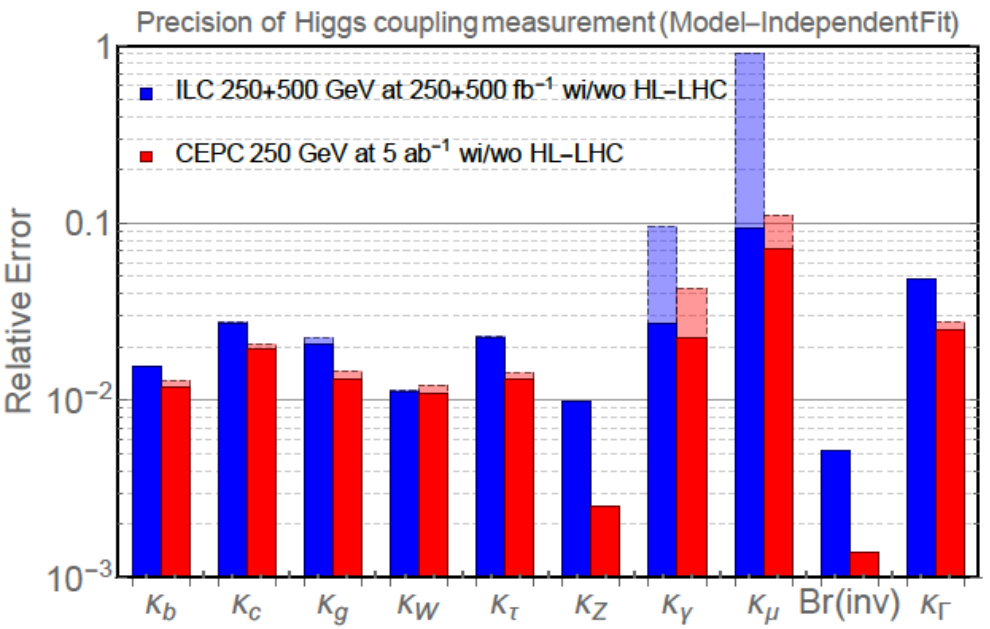




Sim Higgs @ CEPC

Higgs boson Measurement





	Productivity	Efficiency	Comments
LHC	Run 1: 10^6 Run 2/HL: $10^{7\text{-}8}$	~o(10^{-3})	Huge background, larger uncertainty, relative measurement
CEPC	10^6	~o(1)	Absolute measurement at Extremely clean environment

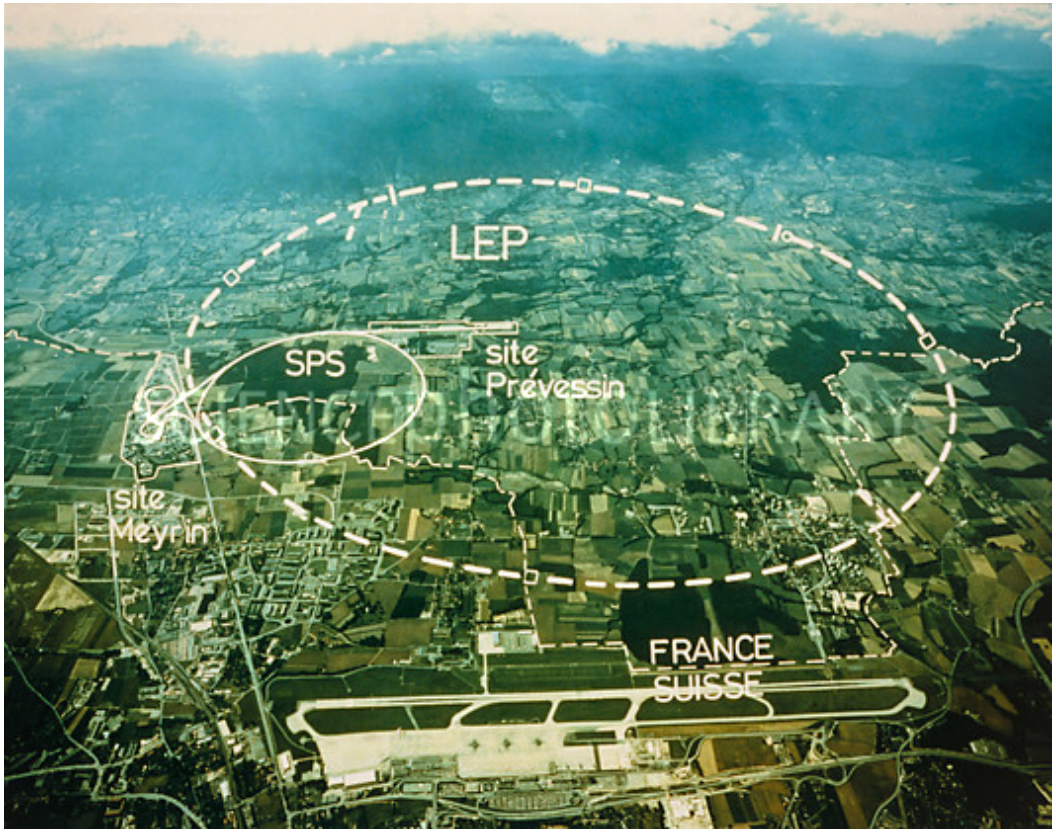
Higgs particle & Dark Matter

CEPC would report an Higgs to DM signal If Br(H->DM)>0.1%

- *CEPC could measure the Higgs width to 3% relative uncertainty, which is a discovery window for any NP that has impact on Higgs decay behavior*

A Historical Review of the Higgs Discovery

Precision measurement: telescope



Precision measurement at Low Energy Region could reflect the physics At High Energy Region

LEP determines the possible Higgs boson mass range

Limites sur la masse du Higgs

→ direct searches at LEP

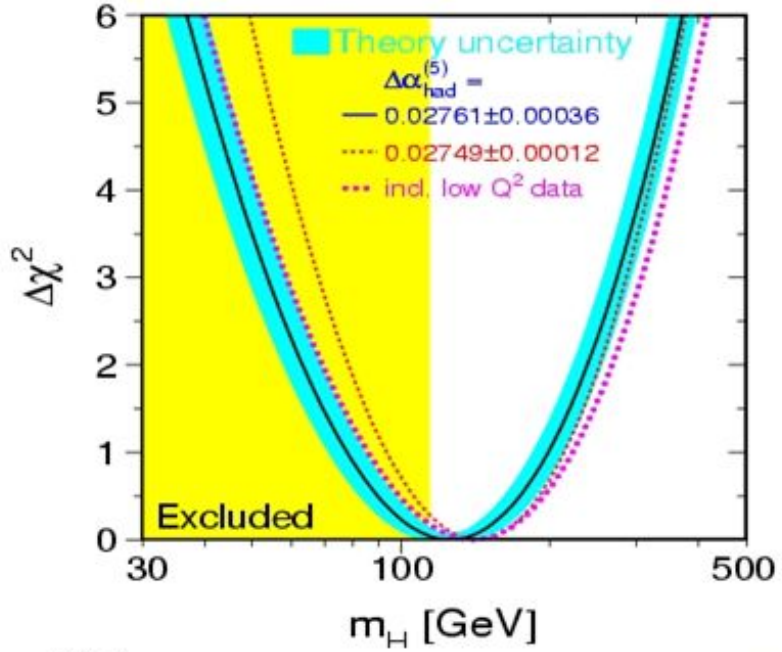
$M_H > 114$ GeV at 95% C.L.

→ precision EW fits (winter 2005)

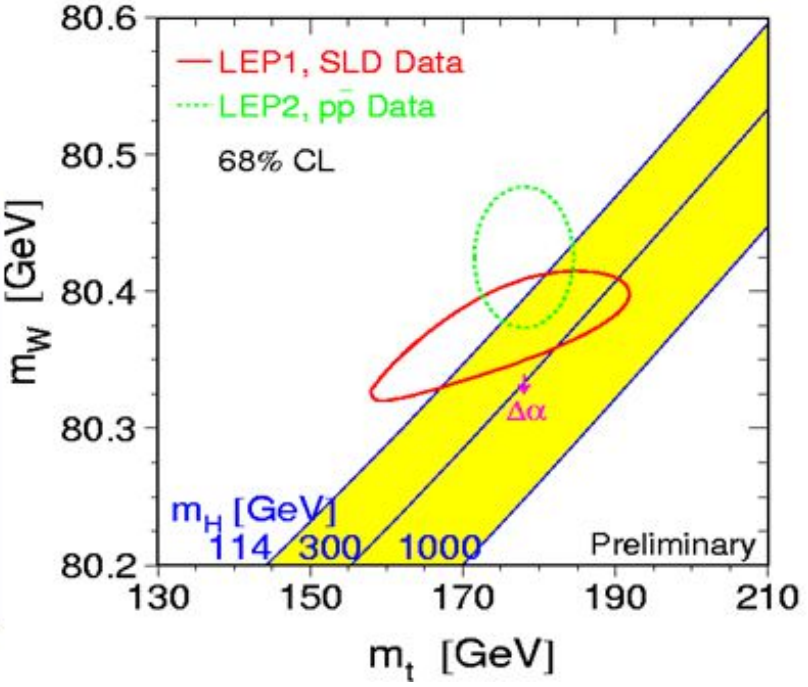
$M_H = 126^{+73}_{-48}$ GeV

$M_H \leq 280$ GeV @ 95% C.L.

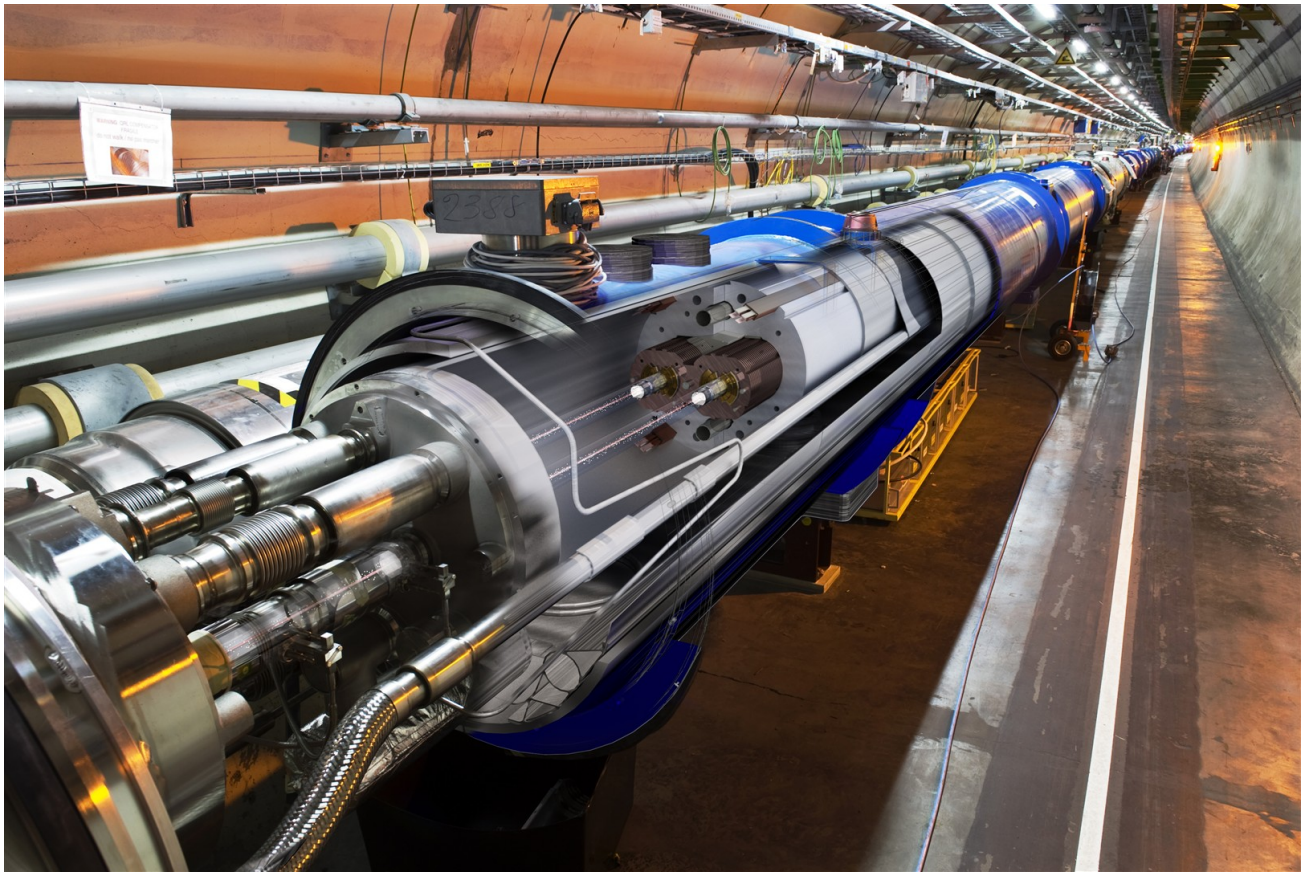
→ **Light Higgs favored**



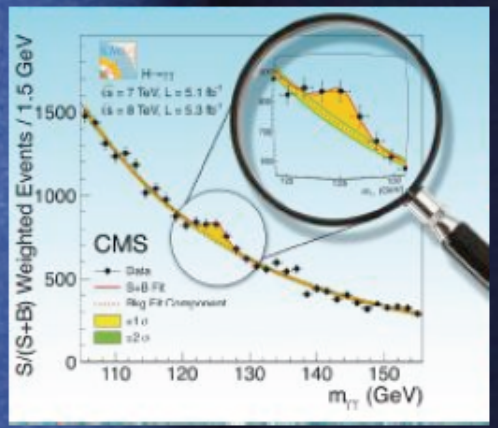
Tevatron provides:
Precision measurements of m_{top} & M_W
and
Direct searches:
→ SM Higgs
→ non-SM Higgs

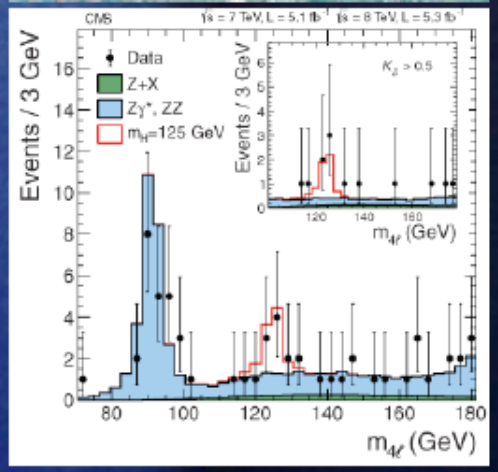


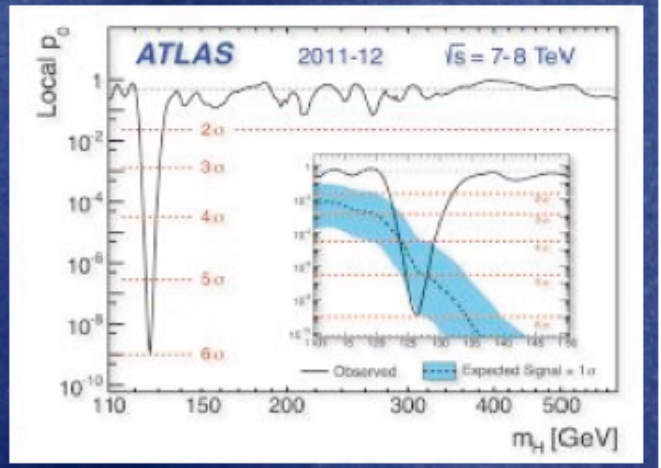
Direct measurement: voyage ship



Increase the c.m.s energy, and directly measure the new Physics/new phenomena


CMS
S/(S+B) Weighted Events / 1.5 GeV
$m_{\gamma\gamma}$ (GeV)


CMS
Data
Z+X
$Z\gamma^*$, ZZ
m_H=125 GeV
Events / 3 GeV
$m_{4\ell}$ (GeV)


ATLAS
2011-12
$\sqrt{s}$ = 7-8 TeV
Local p_0
Observed
Expected Signal + 1σ
m_H [GeV]

CEPC-SPPC

- Higgs factory: 1 M Higgs boson
- EW factory： 10 B Z boons
- Potential Discovery machine toward： Dark Matter, Exotic Higgs behavior, Higgs width...

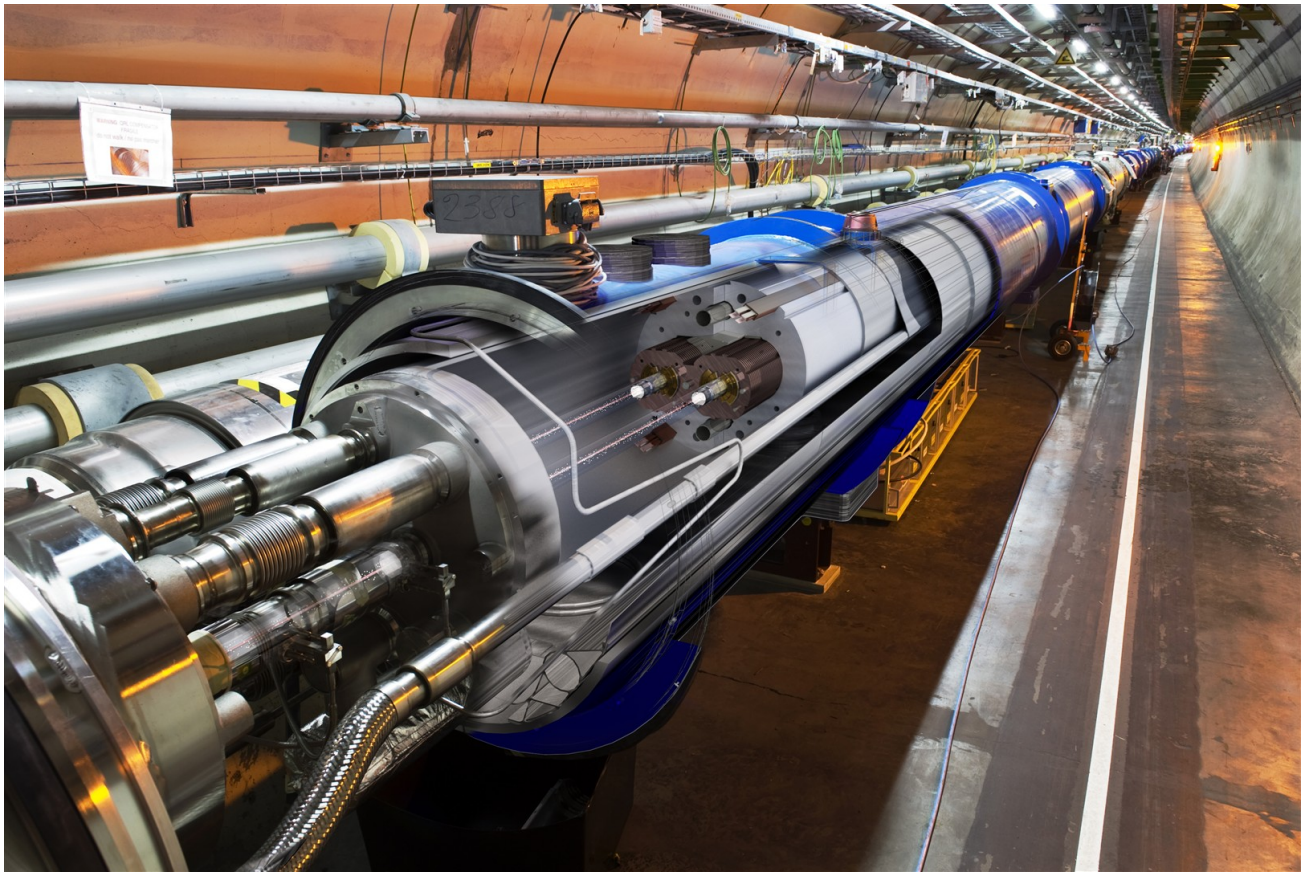
- Could be upgraded to SPPC, a proton collider with c.m.s energy of 100 TeV.


CEPC : New Sea Map
Extra Dimension?
Dark matter?
Composed Higgs?
Vacuum Phase Transition?
SUSY?
Toward Unknown!!


Baron Kelvin: Nineteenth century clouds
over the dynamical theory of heat and light
...
21th century: Higgs clouds over the SM
Let's sail!

谢谢大家

Higgs discovery at LHC

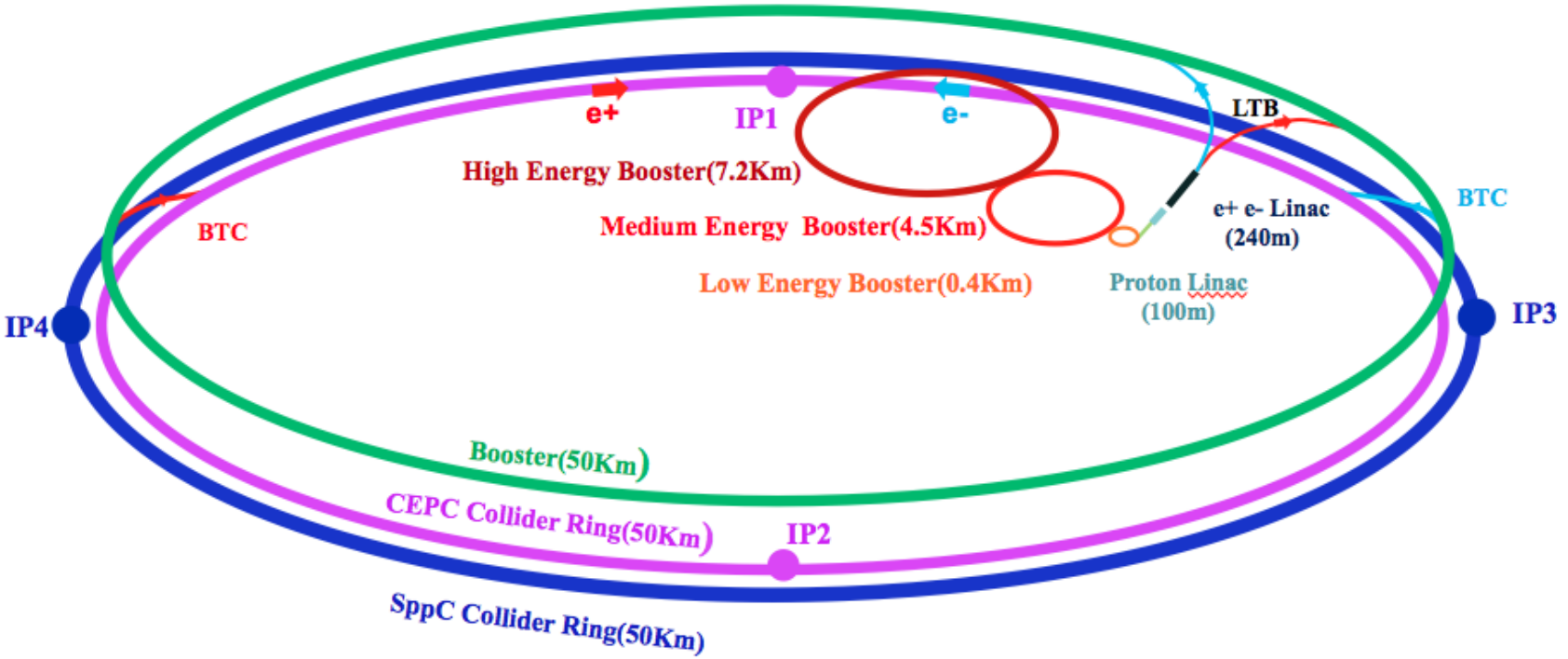


Increase the c.m.s energy!!

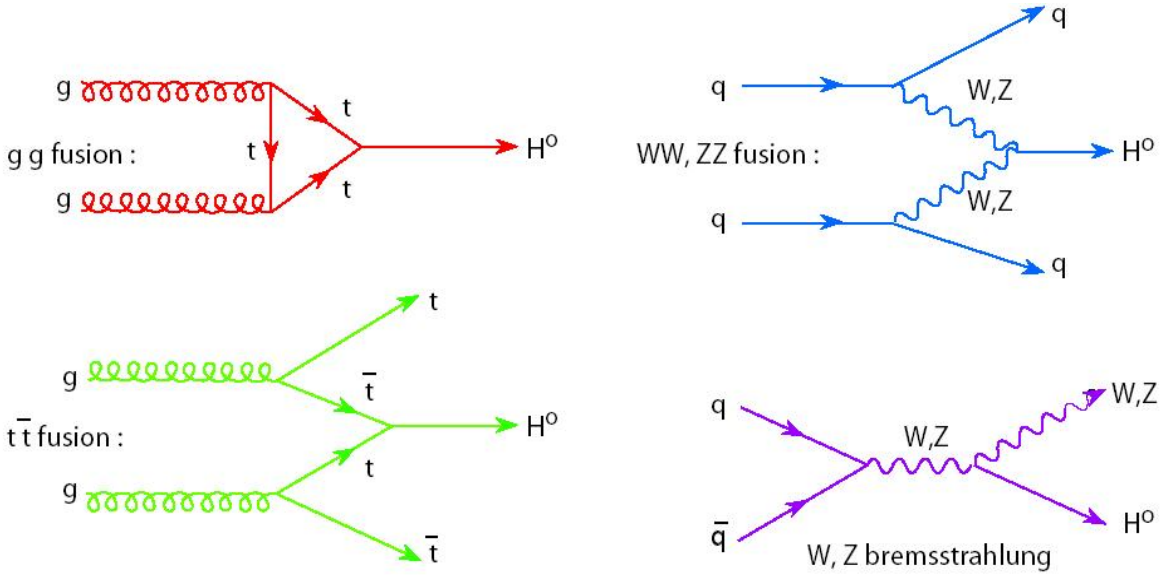
天问

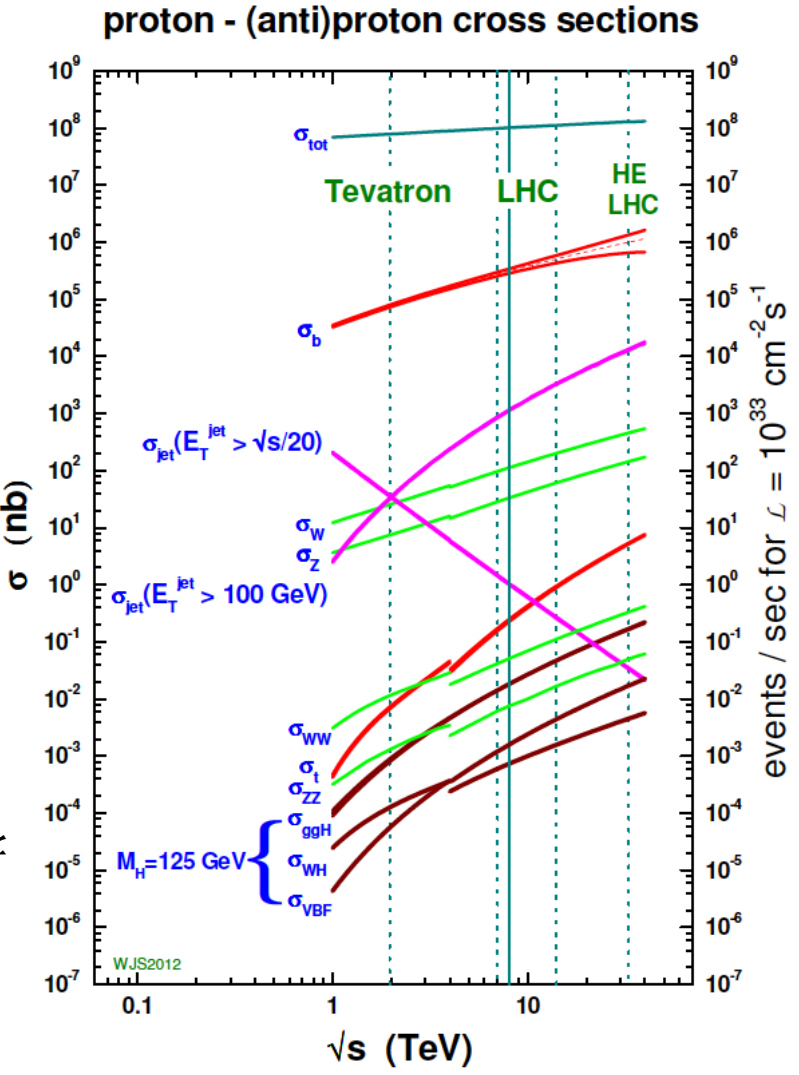
Key: a precise Higgs factory

- Higgs mass ~ 125 GeV, it is possible to build a Circular e+e- Higgs factory (CEPC), followed by a proton collider (SPPC) in the same tunnel
- Looking for Hints (from Higgs) at CEPC → direct search at SPPC



Higgs @ LHC



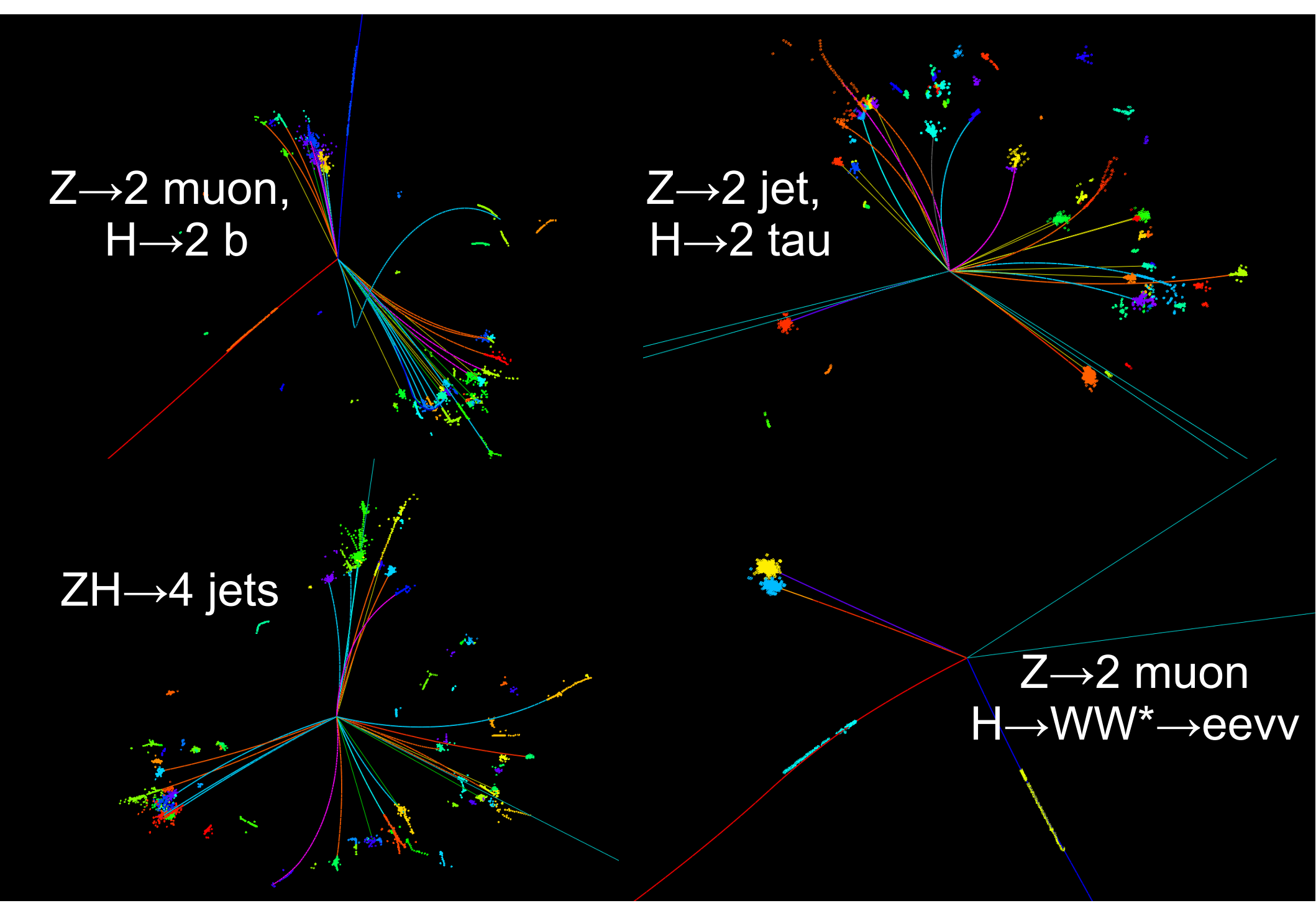


质子对撞机：Higgs 粒子产额很高（LHC 上已产生 100 万量级的Higgs 粒子），然而探测效率极低

海量本底：约 100 亿 -1000 亿次对撞中只要一个Higgs 粒子

无法实现绝对测量

$$\sigma(AA \to H \to BB) \sim g^2(HAA) g^2(HBB) / \Gamma_{total}$$


Z→2 muon,
H→2 b
Z→2 jet,
H→2 tau
ZH→4 jets
Z→2 muon
H→WW*→eevv