The Standard Model, the New Physics & Higgs Factories
Introduction

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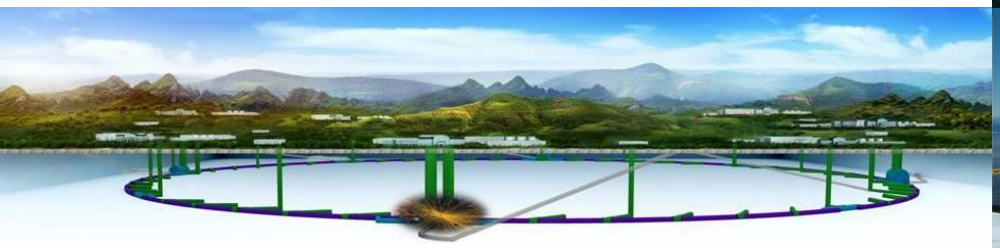
19th Chinese-American Frontiers of Sciences Symposium, 2020



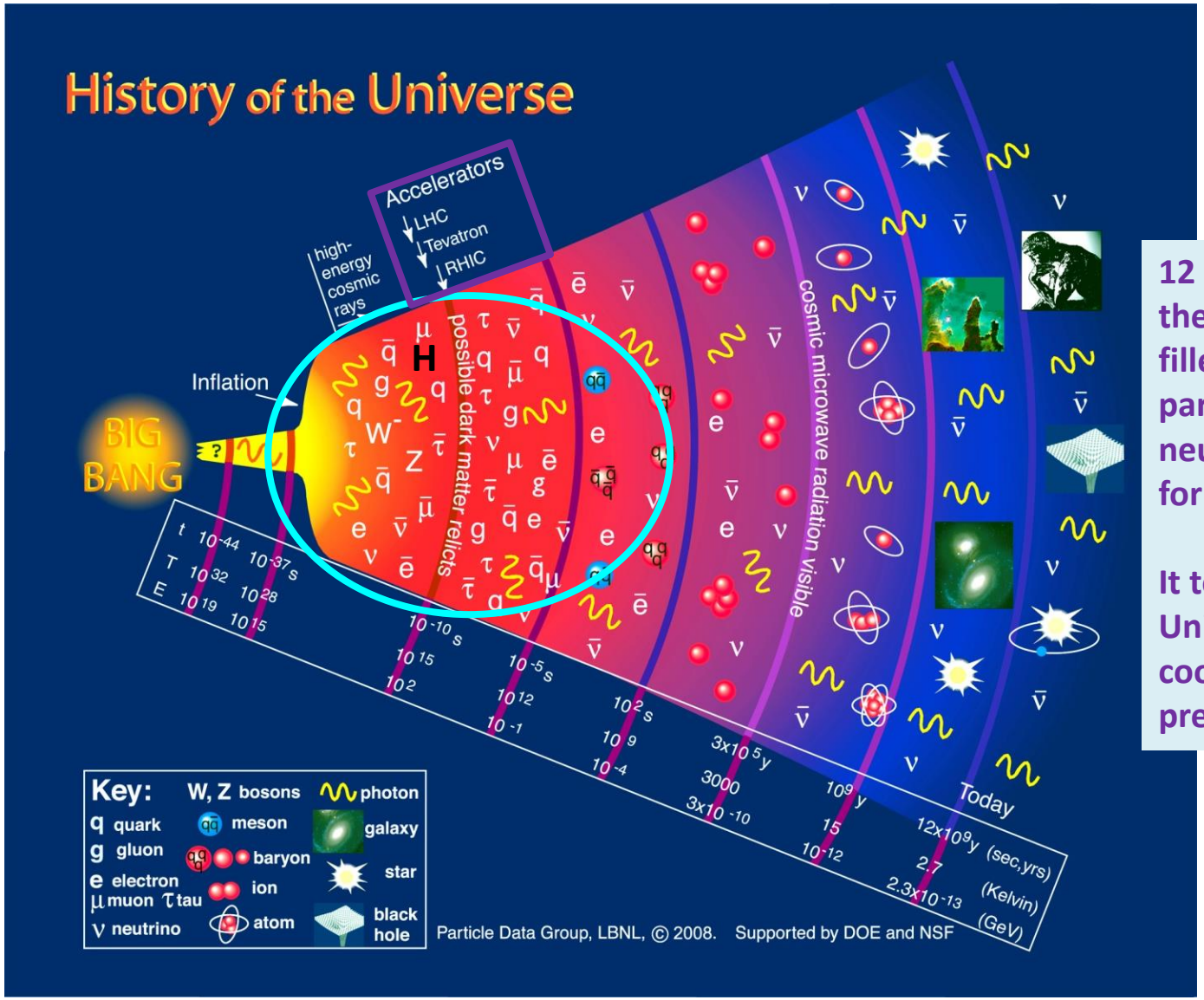
Outline

Prof. QH Cao's presentation covers in depth The Standard Model and New Physics

- The Higgs boson
- Race to discover the Higgs boson
- What can we learn from the Higgs?
- Very large linear and circular accelerators

  Higgs factories
- Circular e^+e^- collider in China - CEPC

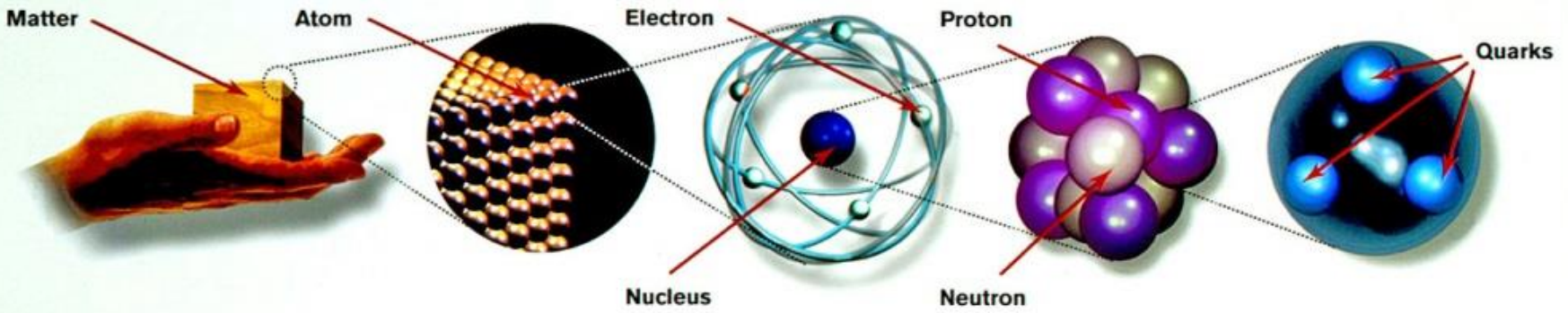
The Universe according to the theory of the Big Bang



12 billions years ago, the Universe was filled with elementary particles, charged leptons, neutrinos, quarks, bosons for mediating interactions.

It took 12 billions for the Universe to expand and cool down to form the present cosmo world.

Elementary Particle Physics



generation / particle	I	II	III	gauge bosons
Quarks	u (0.005)	c (1.5)	t (180)	gluon 1
(mass / strength)	d (0.01)	s (0.2)	b (4.7)	γ 1/1,000
Leptons	e (.0005)	μ (0.106)	τ (1.777)	Z^0 1/10,000
(mass/ strength)	ν_e $<7\times10^{-9}$	ν_μ <.0003	ν_τ <0.03	$W^\pm$

Proton, neutron masses ~ 1 GeV

Nature shows us three generations of quarks, leptons (building blocks) and bosons (mediating forces).

Beautiful symmetry.

91 GeV

80.4 GeV

But their masses are so different – a big problem for physicists

In the Standard Model – particle masses are symmetric to begin with; the data disagree

The Higgs field causes the spontaneous symmetry breaking , through which bosons and fermions acquire different masses ……

The story begins in 1964 . . .

with Englert and Brout; Higgs; Hagen, Guralnik and Kibble

VOLUME 13, NUMBER 9 PHYSICAL REVIEW LETTERS 31 AUGUST 1964

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

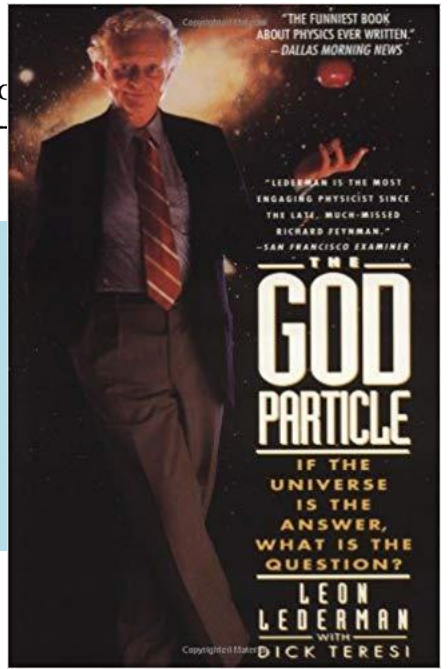
VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19C

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs **Higgs Boson**

(Received 12 October 1964)

- The Higgs boson was called the "**God Particle**", by late physicst Leon Lederman
- It had been elusive for almost ½ of a century until the LHC discovered it

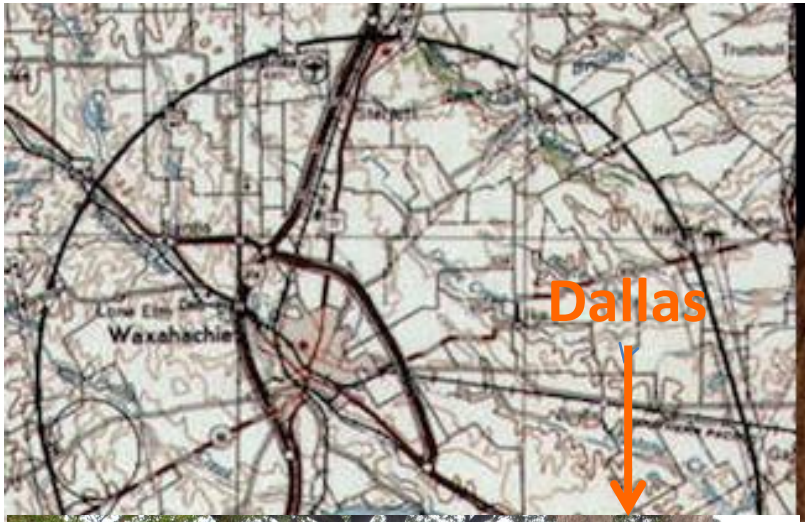


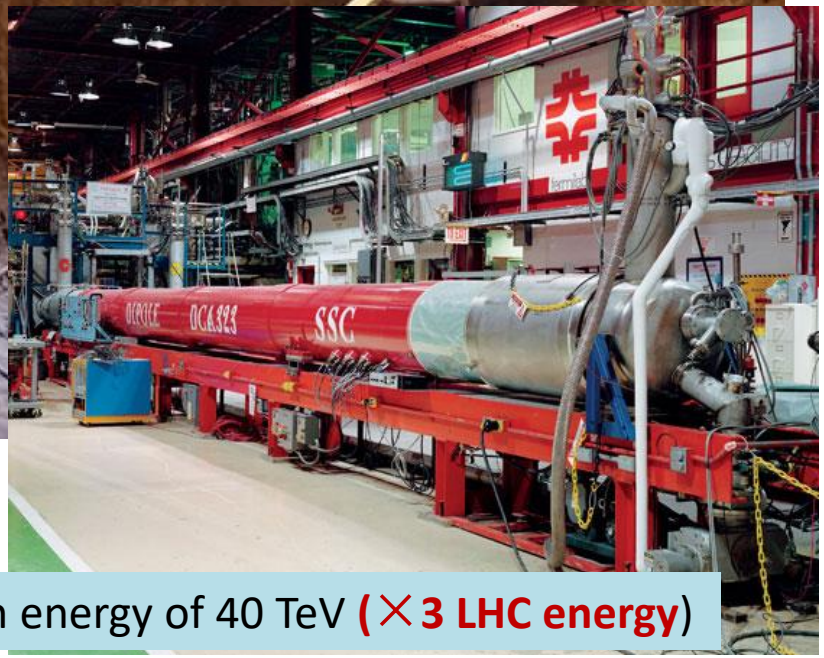
The Higgs boson

Race to discover it

Build accelerators (*"engines of discovery"*) to smash high energy electrons, protons into each other, to produce high energy density, early Universe-like environment, to conduct experiments

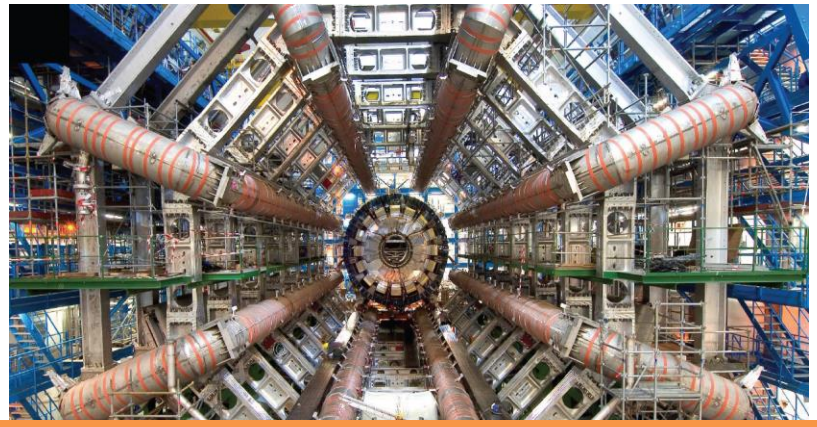
United States: the super collider program – the SSC collider (1990s)



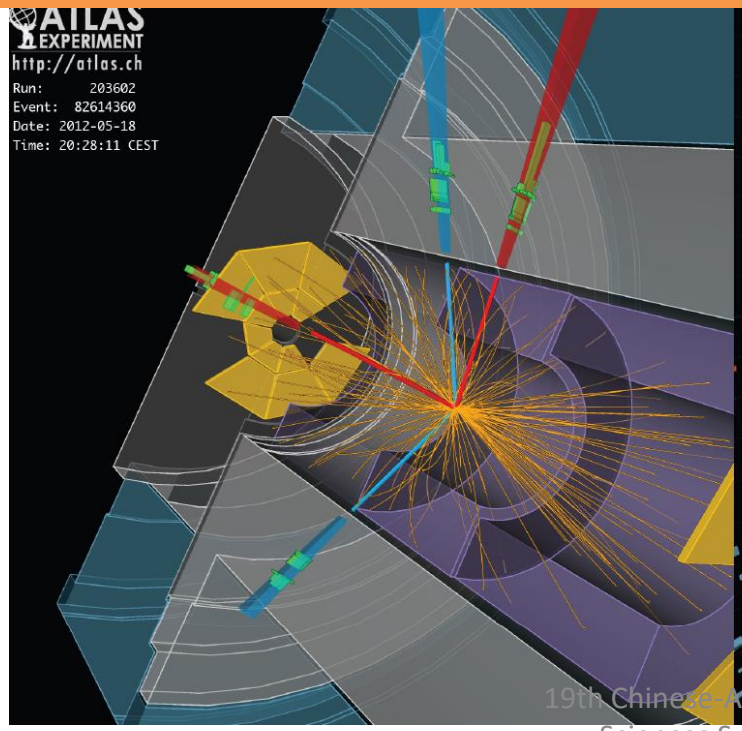


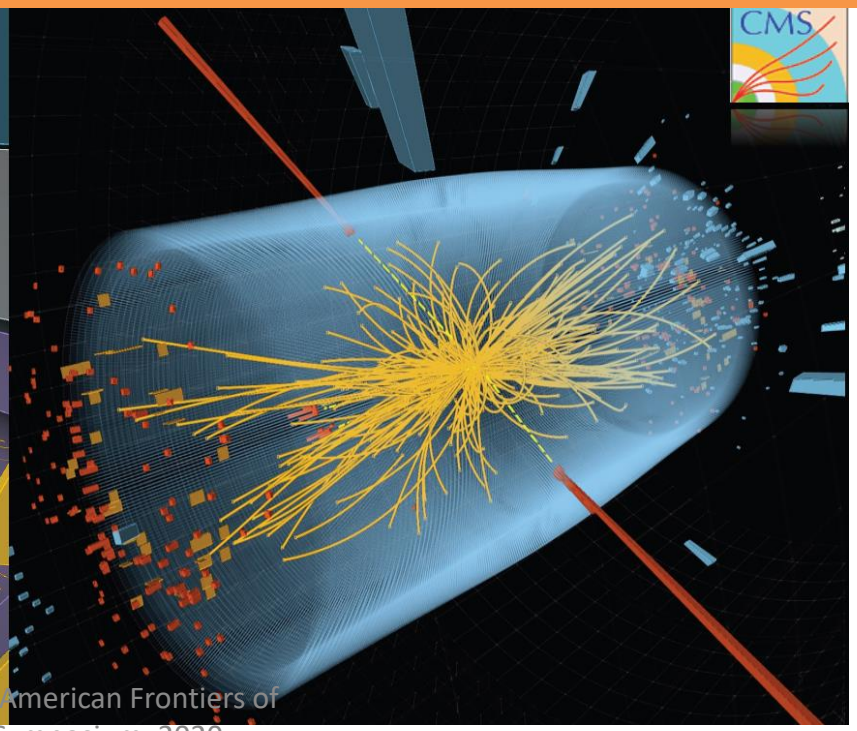
87 km long and a maximum collision energy of 40 TeV (**×3 LHC energy**)

SSC would have discovered the Higgs boson in the US – had it not been cancelled

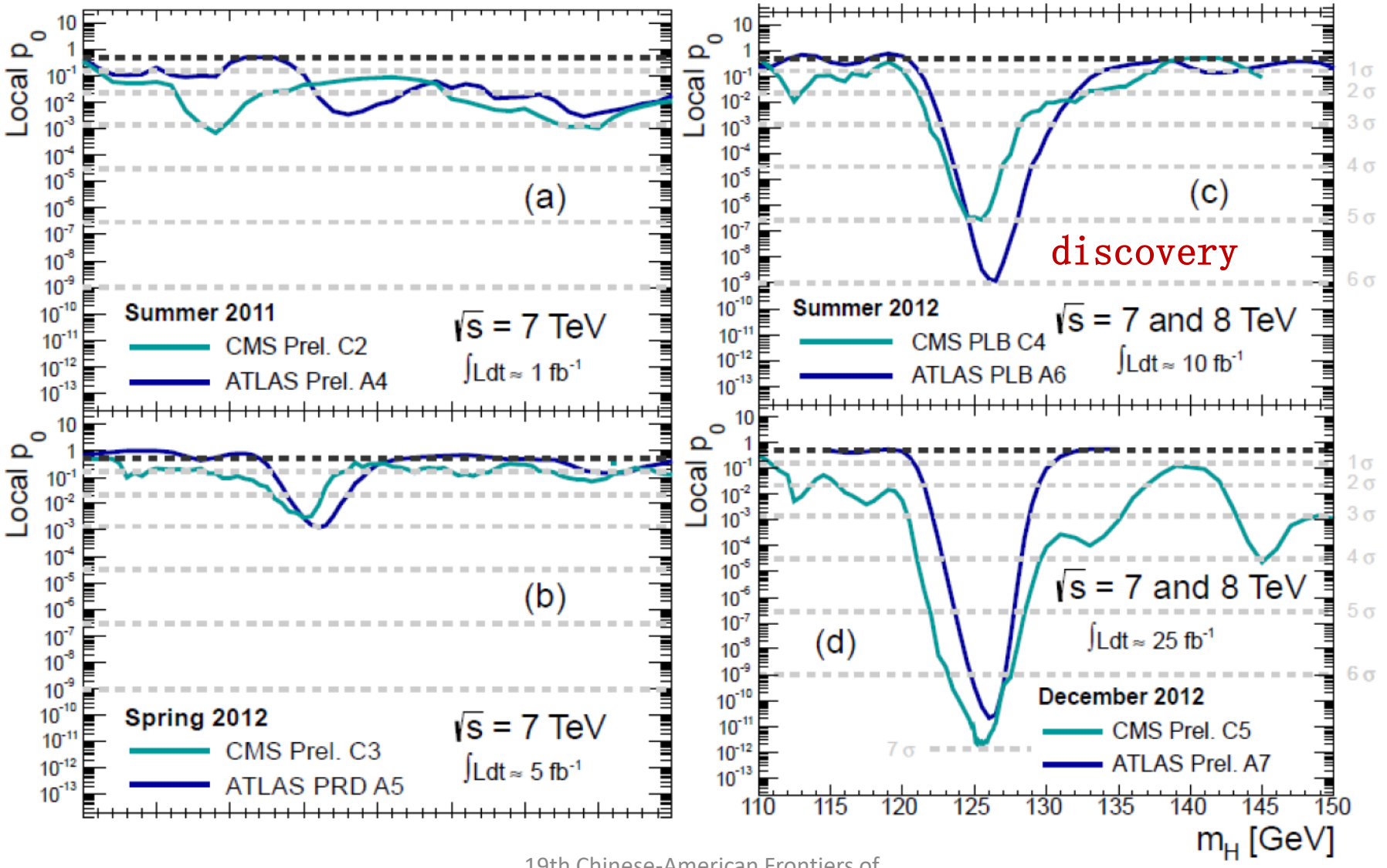


July 4, 2012 was a milestone in the history of particle physics – Higgs was discovered at both ATLAS and CMS at CERN.

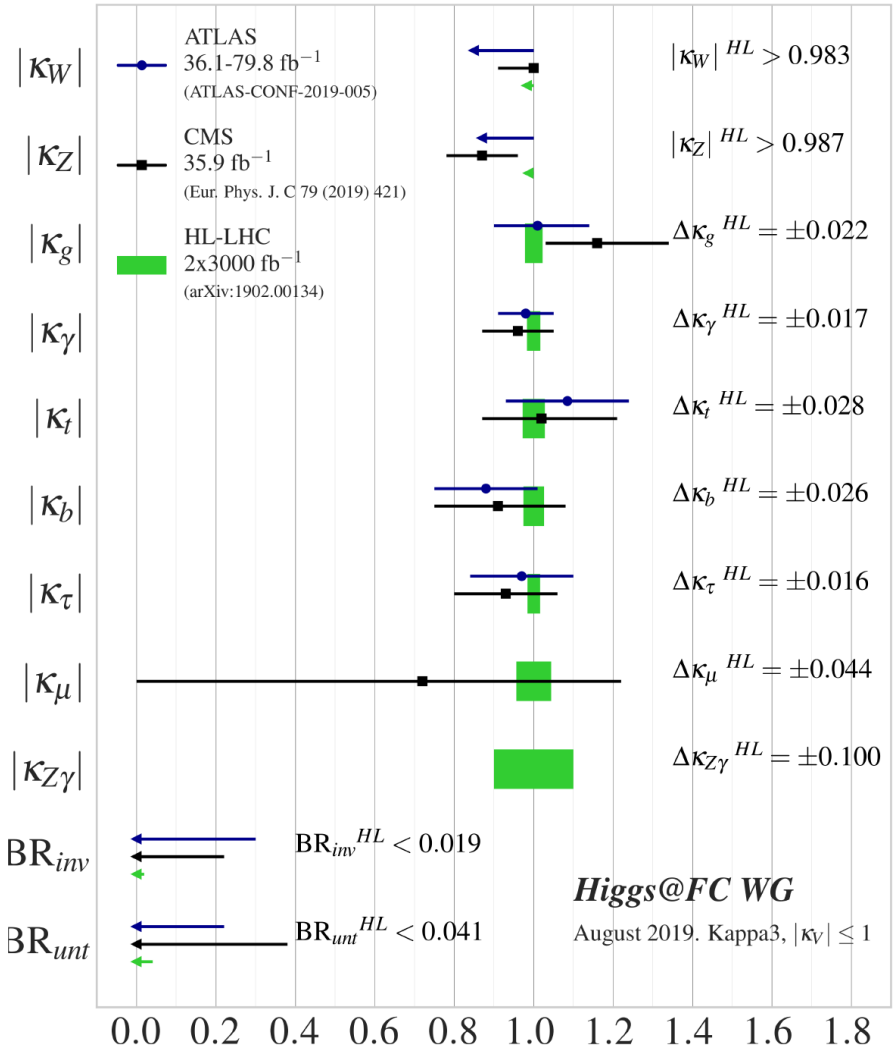


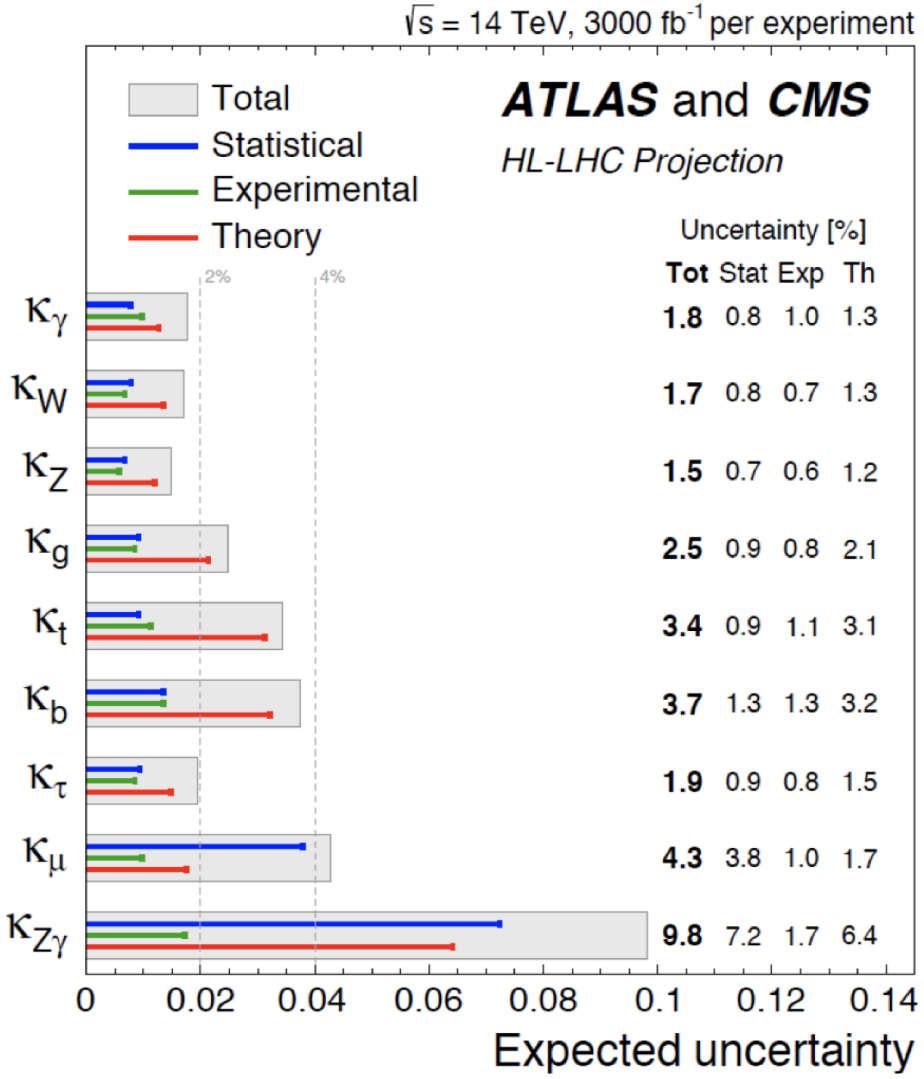


Discovery of new particle at the Large Hadron Collider



Higgs precisions at the Large Hadron Collider

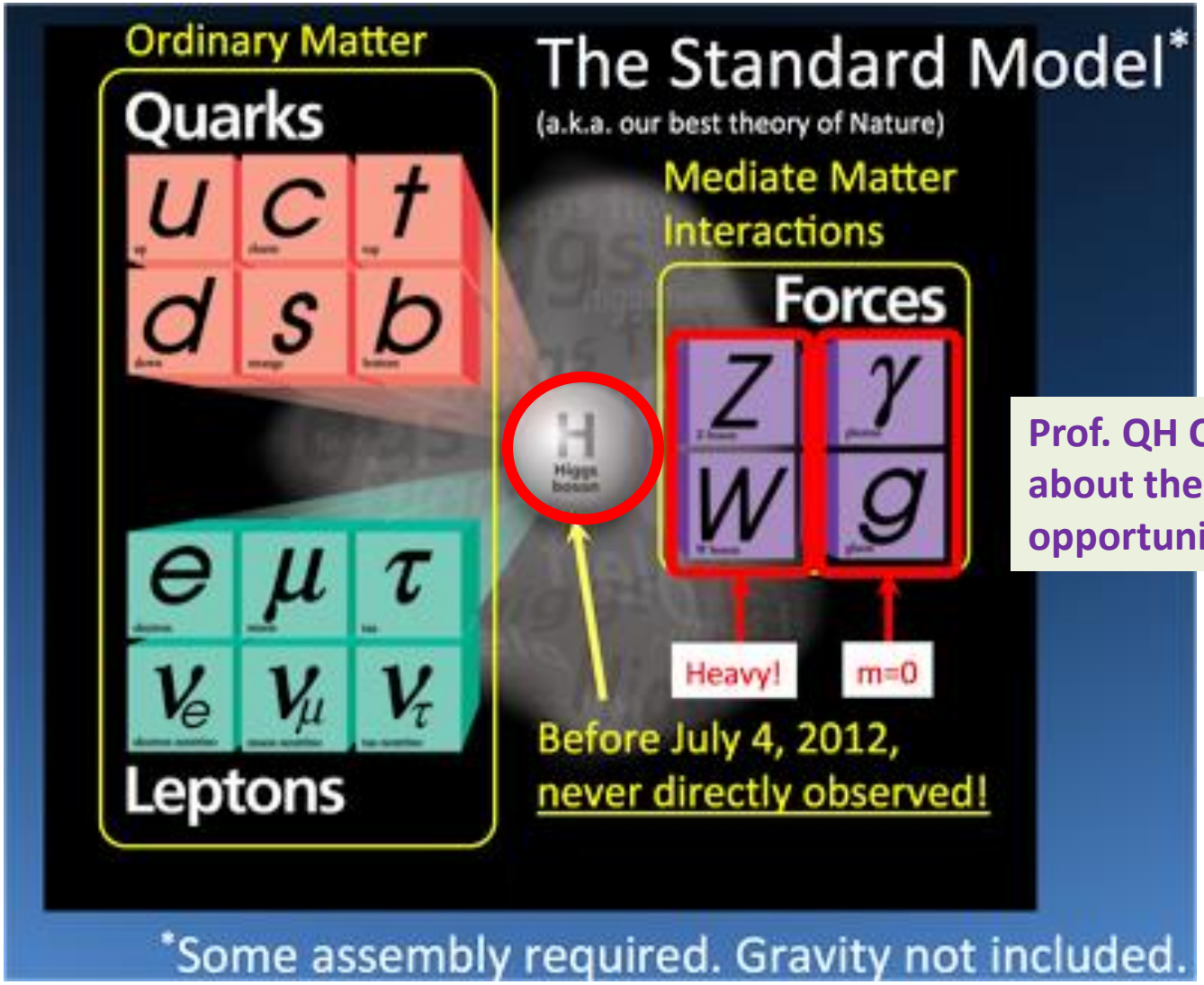




The Higgs boson

What can we learn from it?

Elementary Particle Physics



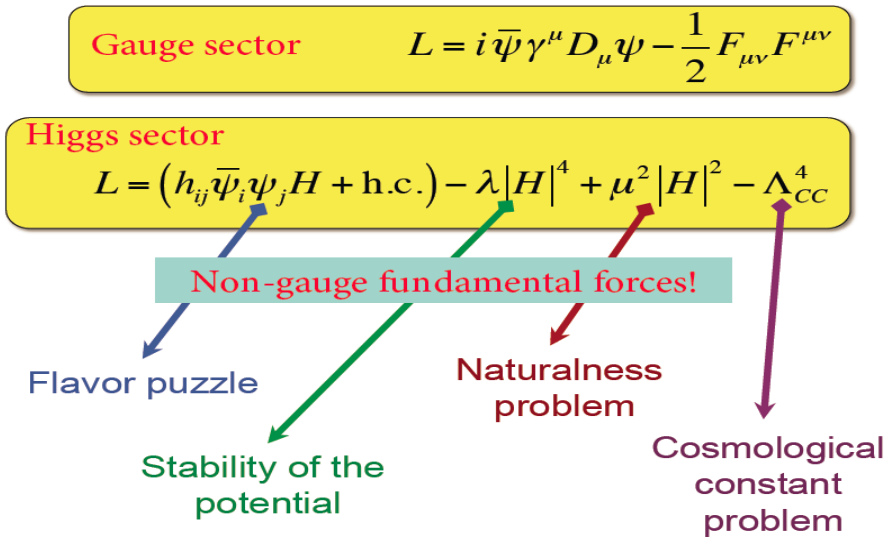
Prof. QH Cao will tell us about the physics opportunities

Higgs interacts with all fermions & W,Z bosons;

- **Does it interact with dark matter/new particles/new physical world?**
- **Is the Higgs a portal to the new world?**

The cases for high energy e^+e^- colliders

- **The Higgs – only spin-0 elementary particle**
- **Very special:**



particle	spin
quark: u, d,...	1/2
lepton: e...	1/2
photon	1
W,Z	1
gluon	1
Higgs	0

The Higgs may hold keys to the unknowns

- **Question:**
  - **The properties of the Higgs**

    is it elementary? any partners? EW phase-transition? ...

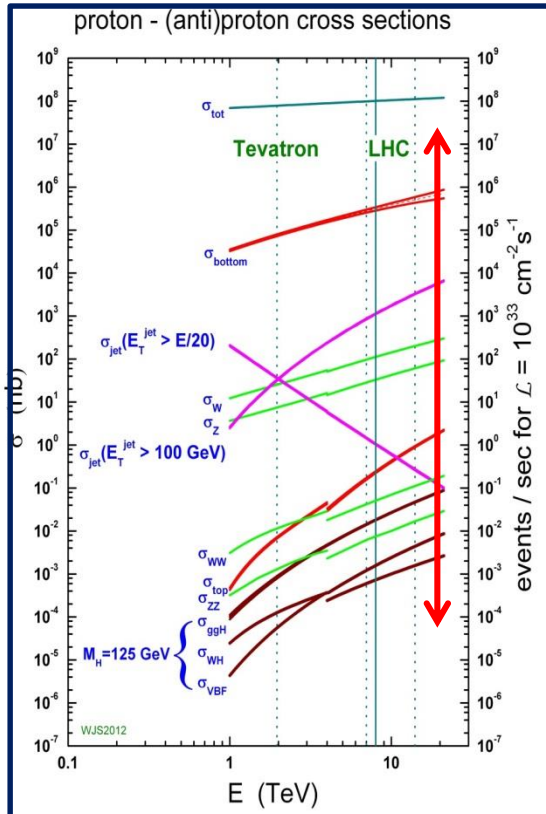
    self-coupling, Yukawa coupling, new properties?

We need precision measurements on the Higgs (<1%)

The Great Collider

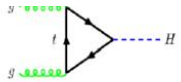
Higgs Factory - Very Large Accelerators

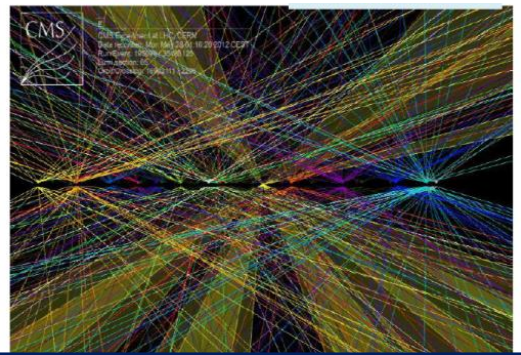
The cases for high energy e^+e^- colliders



LHC –

- large Higgs cross section
- 150M Higgs per exp.
- dominated by QCD events
- **S**(H)/**B**(All) 10^{-10}
- Pile-up and jet overlap
- Not knowing $(\overrightarrow{P_H}, E_H)_{initial}$



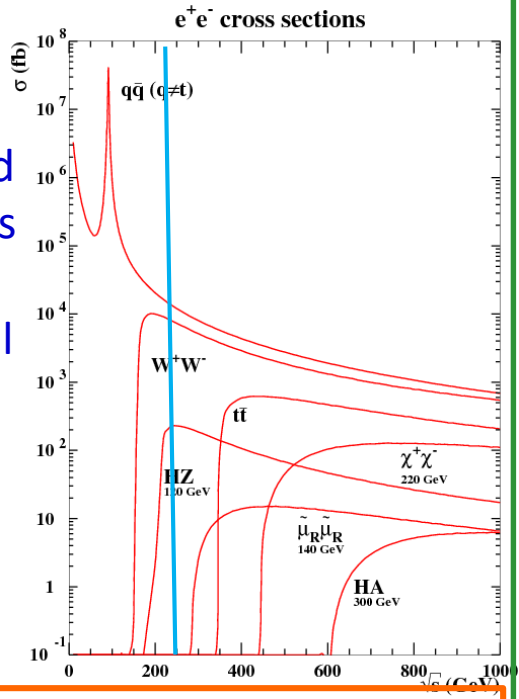


Precisions on H couplings

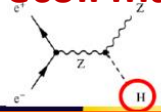
~(5-10)% expected

e^+e^- collider –

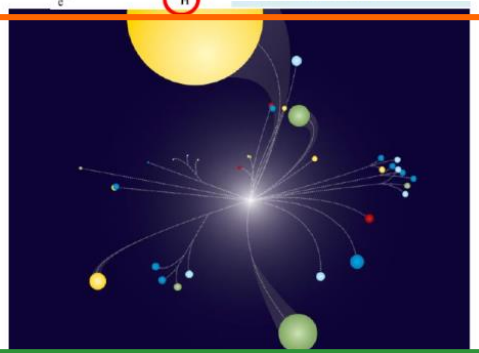
- Higgs cross section, predicted with (sub)% levels
- Know $(\overrightarrow{P_H}, E_H)_{initial}$ allowing for recoil mass reconst.
- Clean events
- low Higgs cross section



unbiased H sample can be selected by way of recoil mass against the Z boson



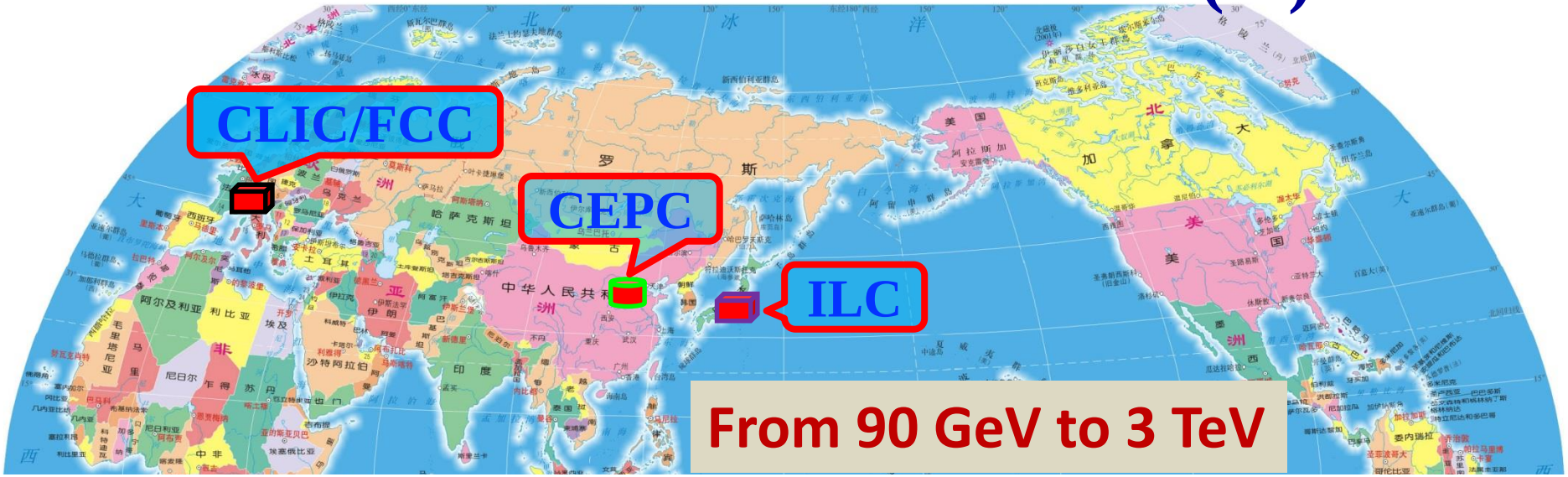
$$M^2_{H\to FS} = (\sqrt{S} - E_Z)^2 - |\vec{P}_Z|^2$$



Precisions on H couplings

~1% or less expected

ILC/CLIC and CEPC/FCC(ee)



3TeV (CLIC)

(+ BSM physics, …)

250-500GeV 1TeV (ILC)

Linear Colliders

(Higgs, $t\bar{t}$, …)

90-250GeV (CEPC,FCC-ee)

Circular Colliders

upgradable to a pp collider → 100 TeV!

(H, W, Z, t,…)

Progress and updates - CEPC CDR

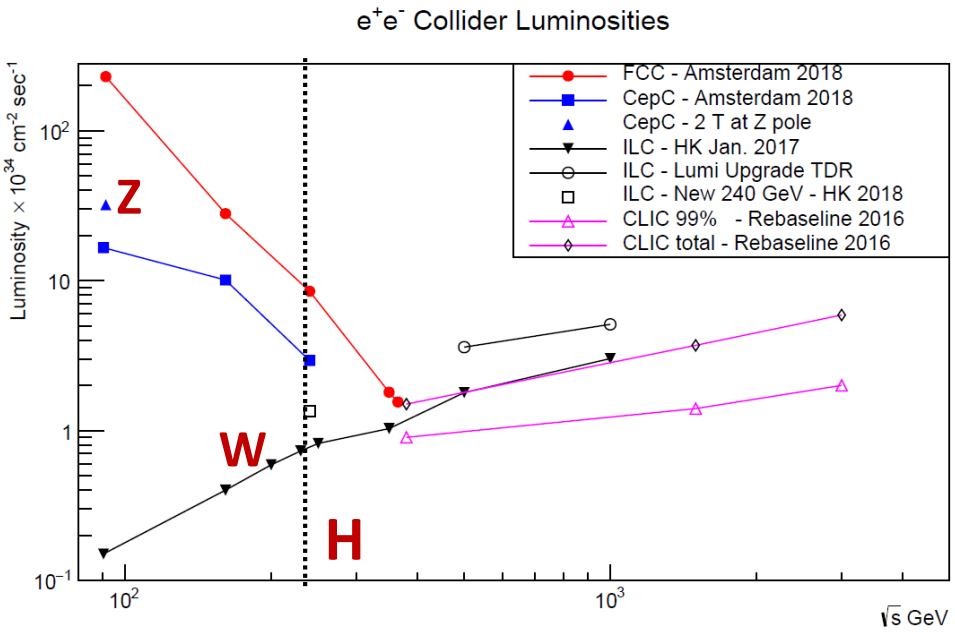
Luminosity vs. CM energy

Circular:

offers higher lumi. @ LE
⇒unprecedented Z,W,+H program
mature technology

very long term: pp upgrade path

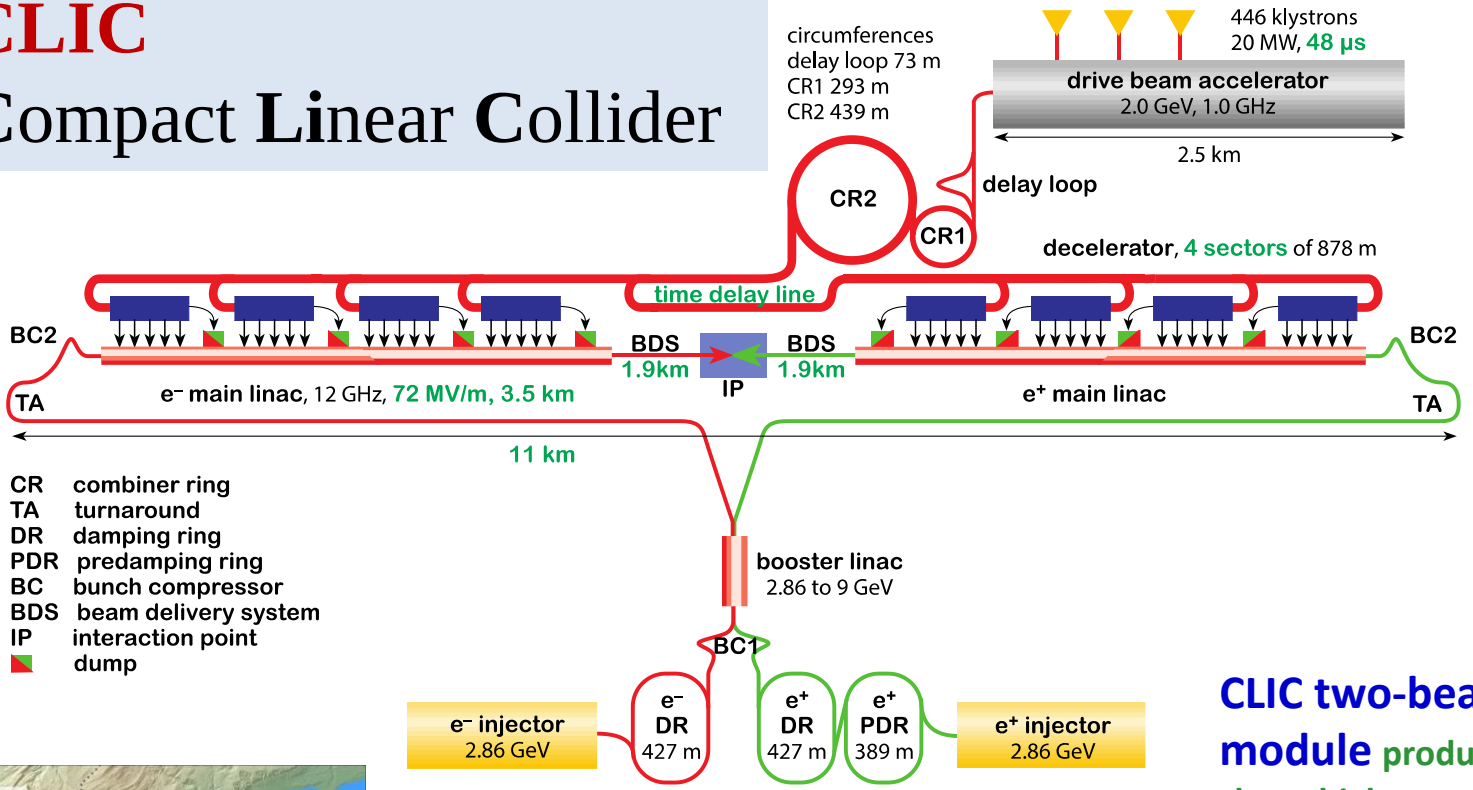
Linear:
very impressive Higgs precision
better at higher energies, or only option for VHE

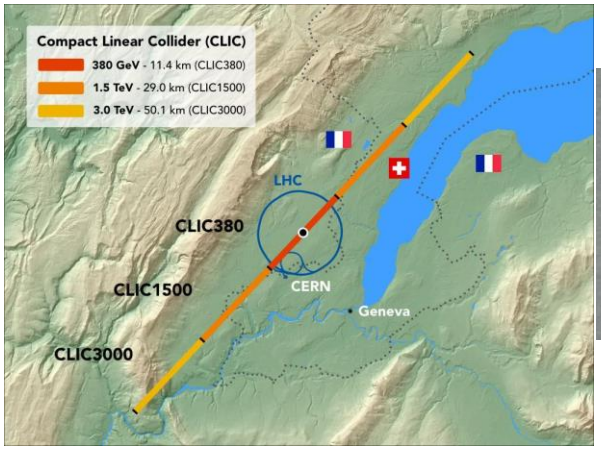


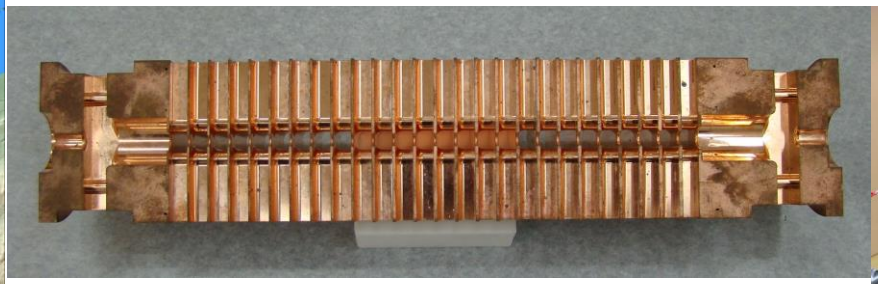
F. Bedeschi, INFN-Pisa

circular & linear colliders are ideally complementary to each other

CLIC
Compact Linear Collider

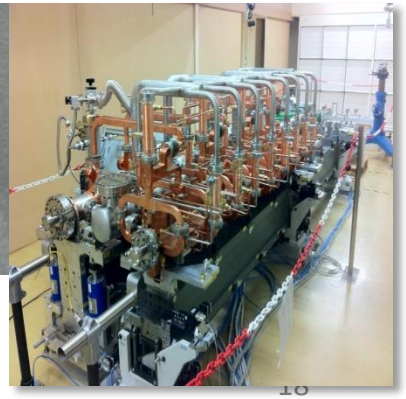






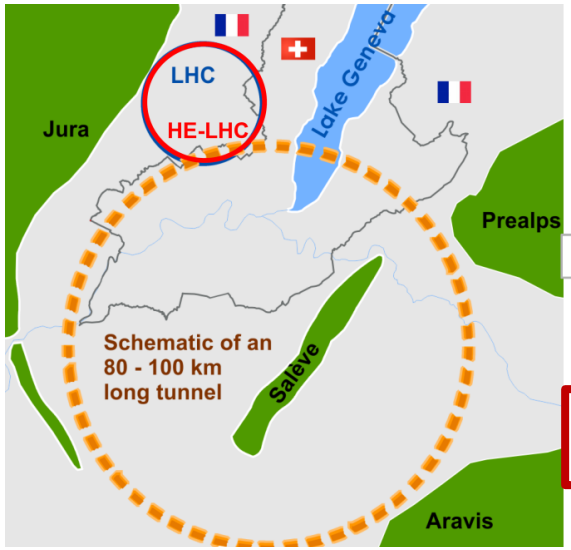
accelerating structure

high gradient makes machine cheap



CLIC two-beam module produces short, high power RF pulse

FCC(ee): Future Circular Collider

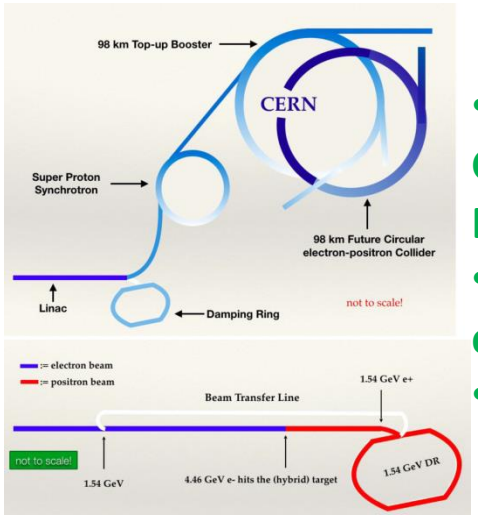


International FCC collaboration (CERN as host lab) to study:

- ***pp*-collider (*FCC-hh*)**
  → long-term goal, defining infrastructure requirements

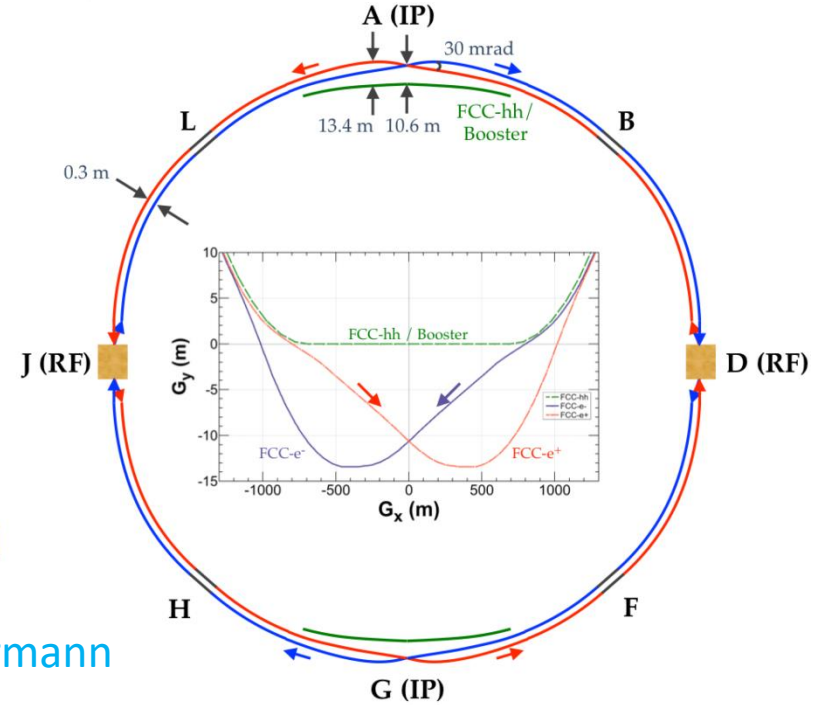
~16 T ⇒ 100 TeV *pp* in 100 km

- **~100 km tunnel infrastructure** in Geneva area, site specific
- **e^+e^- collider (*FCC-ee*),** as potential first step
- **HE-LHC** with *FCC-hh* technology



- **Injection of 20 GeV beams to Booster;**
- **Interleaved filling of e+/e- ;**
- **Continuous top-up**

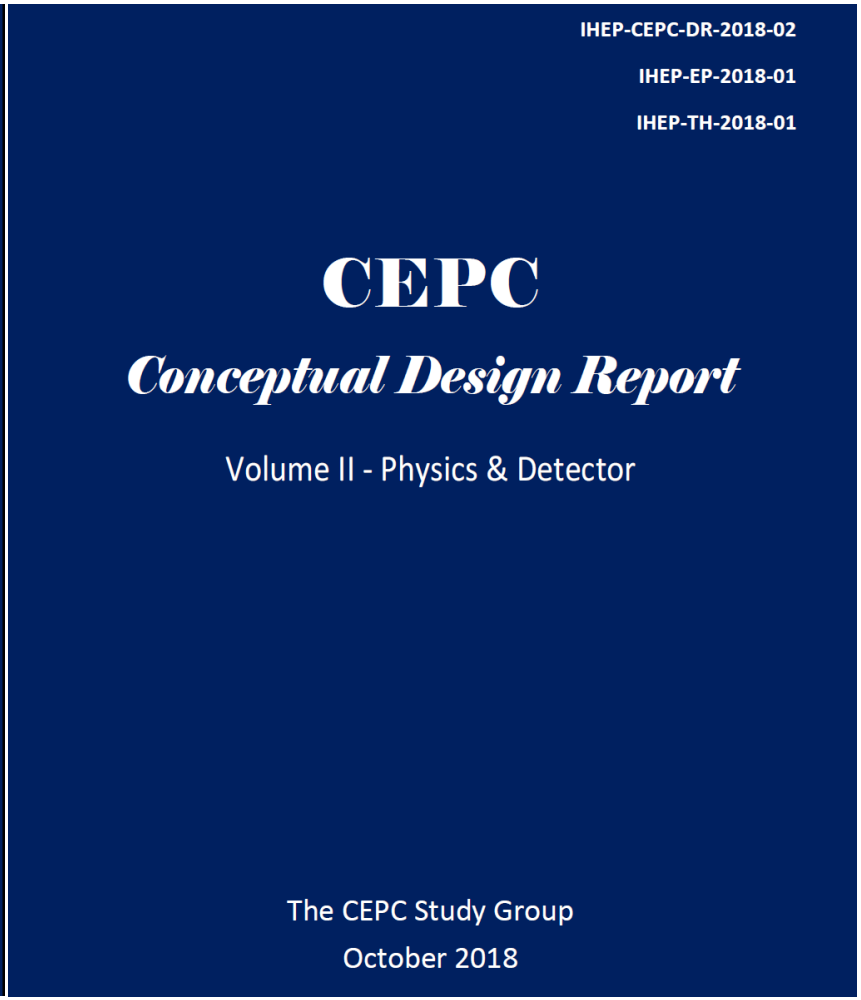
- **Double ring** e+ e- collider ~100 km
- **Follows footprint of FCC-hh**, except around IPs
- **Asymmetric IR layout and optics** to limit synchrotron radiation towards the detector
- **2 IPs, large** horizontal crossing angle **30 mrad, crab-waist optics**
- **Synchrotron radiation power 50 MW/beam** at all beam energies
- **Top-up injection** scheme for high luminosity
- Requires **booster synchrotron in collider tunnel**



M. Benedikt & F. Zimmermann

CEPC: Circular Electron Positron Collider

Conceptual Design Reports released on November 15, 2018



http://cepc.ihep.ac.cn/

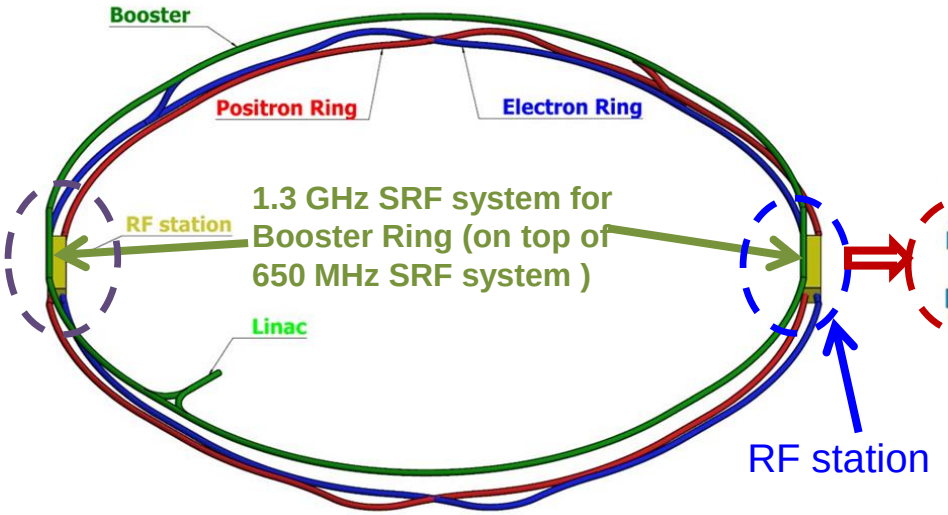
Conceptual Design Reports released on November 15, 2018

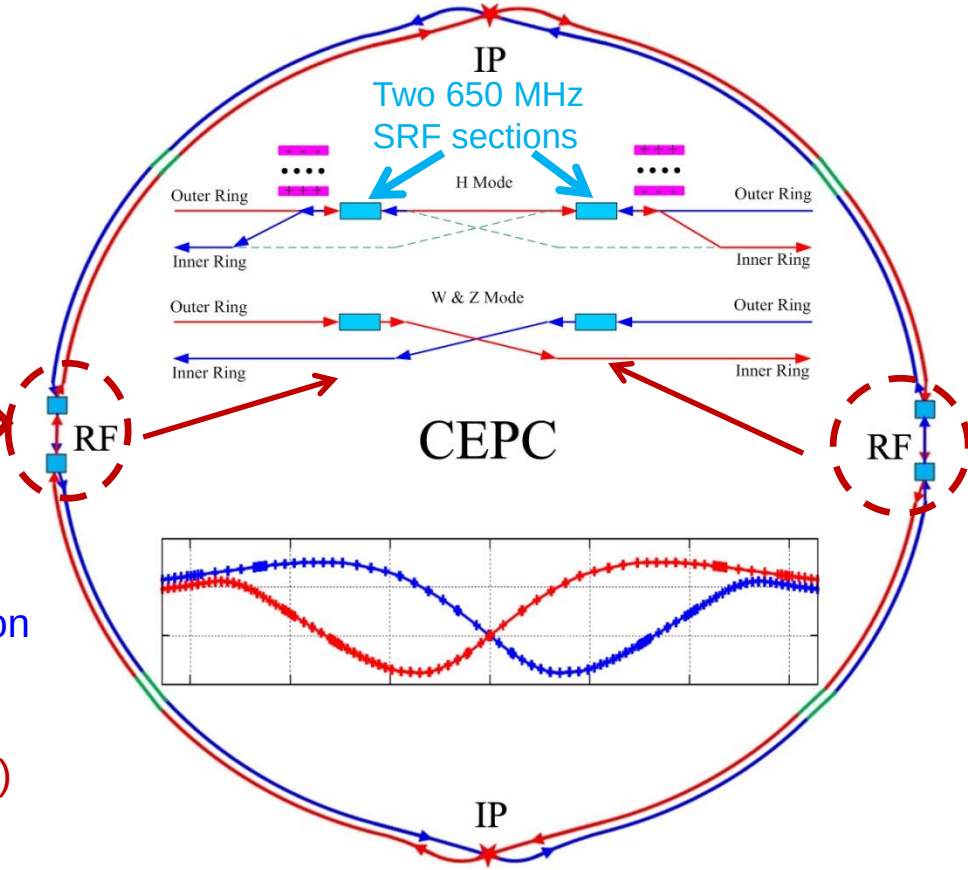
CDR Volumes 1 (Accelerator) and 2 (Physics-Detector) , are available at

http://cepc.ihep.ac.cn/

CEPC: Circular Electron Positron Collider

- 336 650MHz 2-cell cavities for Collider Ring + 96 1.3GHz 9-cell cavities for Booster Ring
- All those cavities are distributed equally to two RF stations.
- For Collider Ring, each RF station consists of two SRF sections.





SRF system location of CEPC (two RF stations)

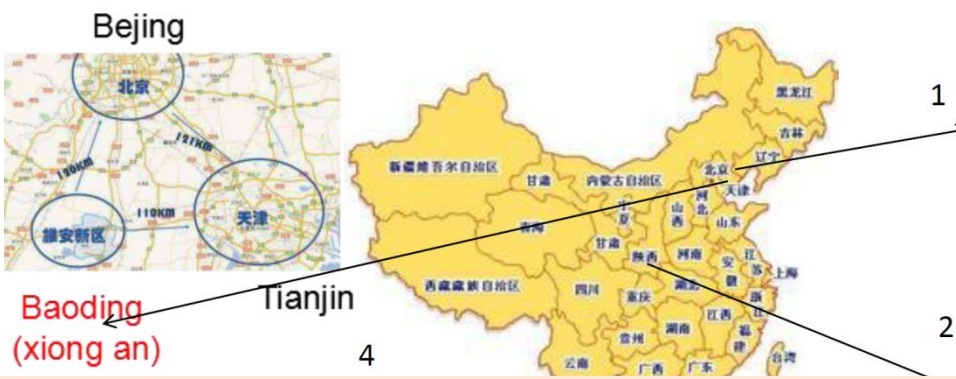
Layout of 650 MHz SRF system for Collider Ring

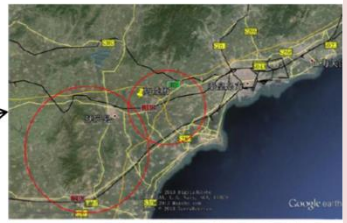
Layout -hardware satisfying both Z and H programs

$L \geq 2\times10^{34}cm^{-2}s^{-1}$ (at E_{cm}=240 GeV)

$L \geq 1\times10^{34}cm^{-2}s^{-1}$ (at E_{cm}=91 GeV)

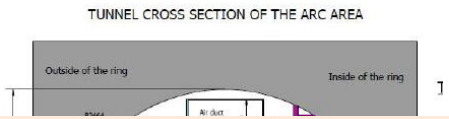
CEPC: Circular Electron Positron Collider





- ✓ site visits & study
- ✓ facility deign
- ✓ construction plan

....



CEPC is conducting country wide site visits and study. Local government agencies are very receptive and supportive to CEPC. CDR study is based on site 1 (Qing Huang Dao).

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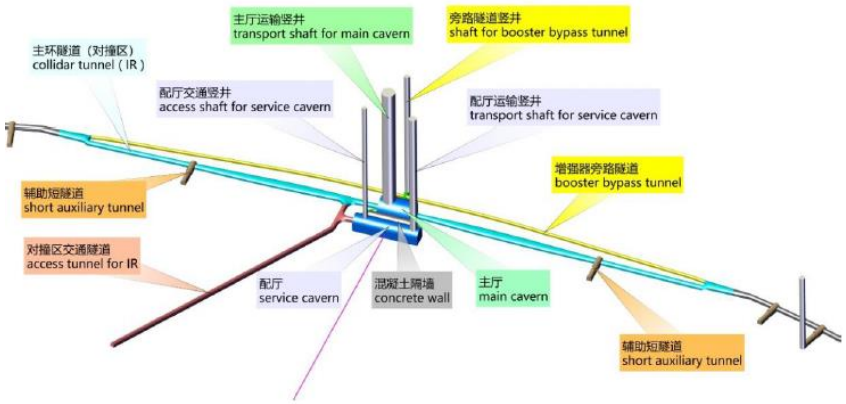
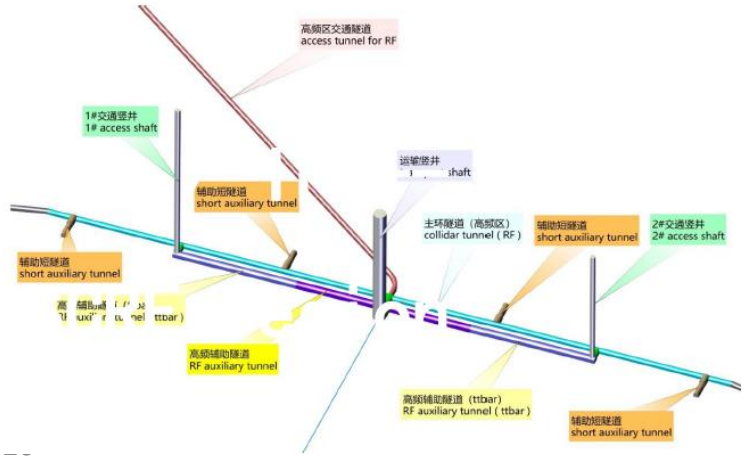
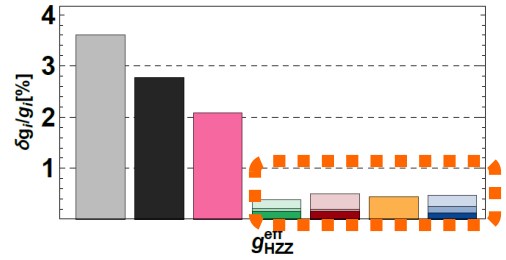
CEPC Interaction Region

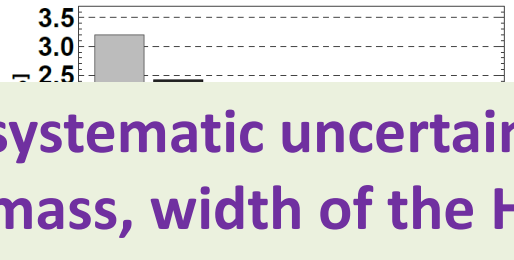


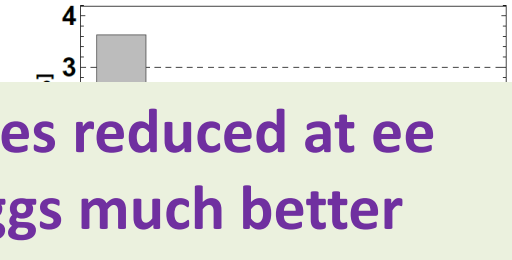
CEPC Injection Region

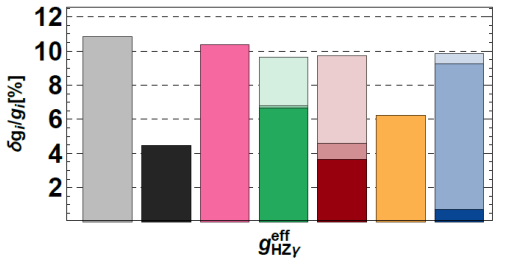


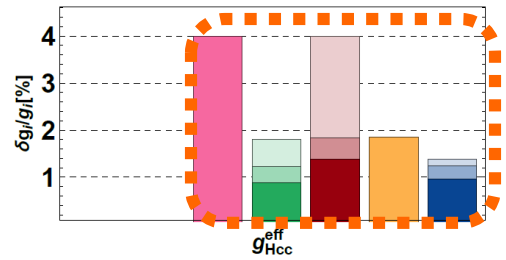
Higgs precisions at the Higgs factories

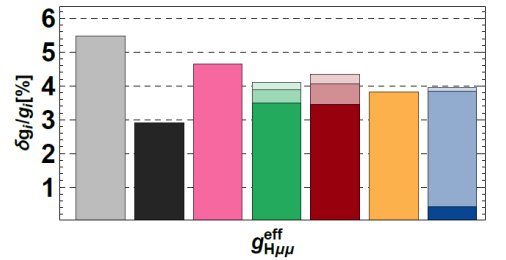


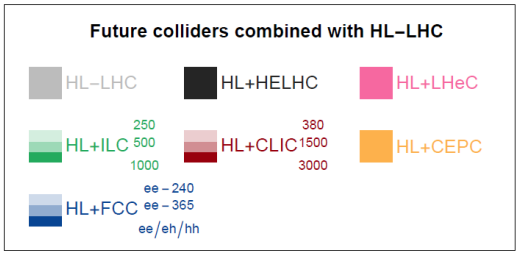












systematic uncertainties reduced at ee
mass, width of the Higgs much better
invisible ~ possibly dark matter
……
portal for probing new physics beyond the Standard Model with ~1-2 orders of magnitude in sensitivities

Acknowledgement

Special thanks to
the ILC,CLIC,FCC and CEPC groups