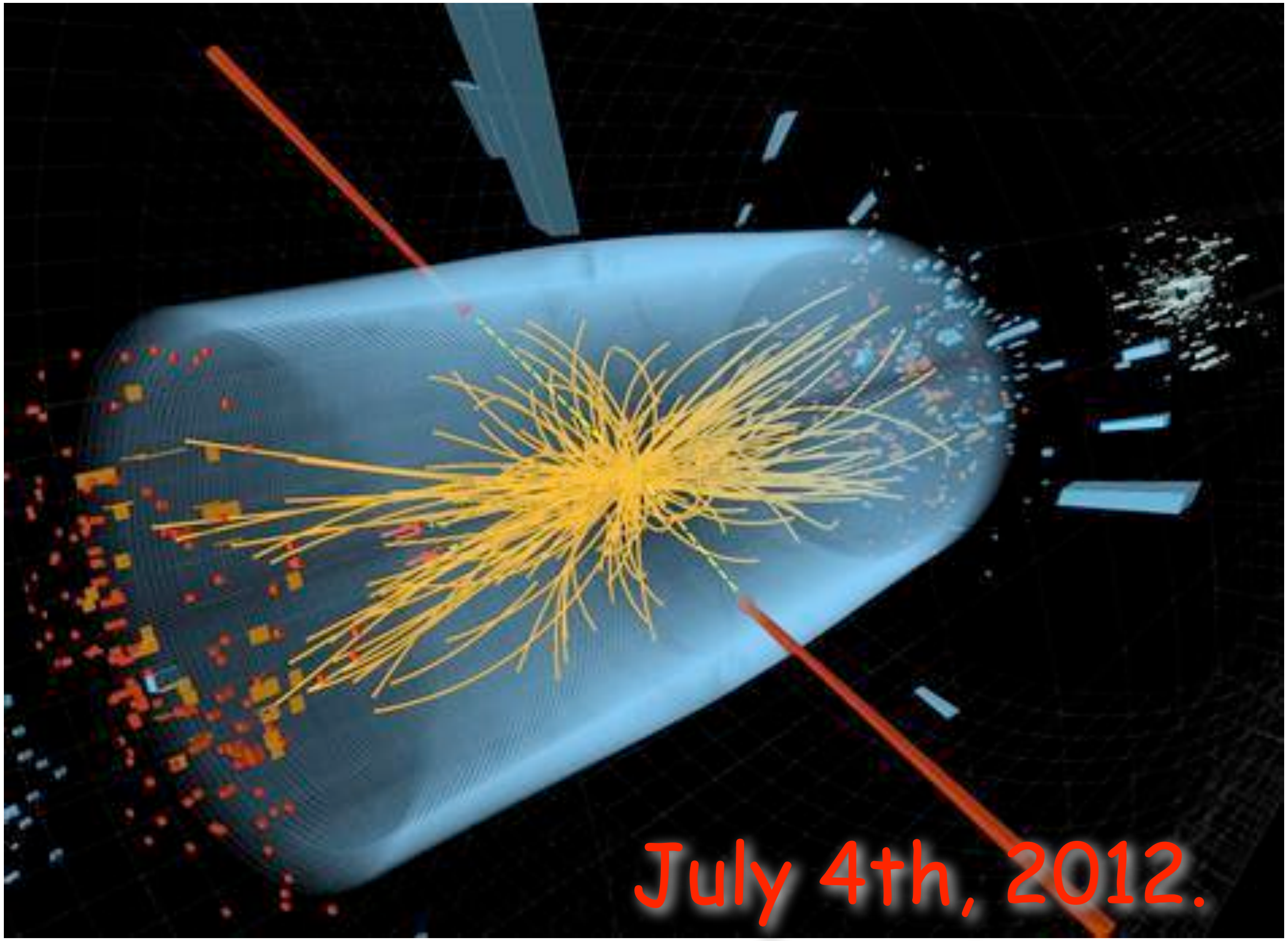
Higgs Factory
Why, How, What?

Shufang Su • U. of Arizona

OSU, October 26, 2022

Higgs discovery



``BREAKTHROUGH of the YEAR'' - Science

Mosaic of the CMS and ATLAS detectors (as in 2007), part of the Large Hadron Collider at CERN. In 2012, research teams used these detectors to fingerprint decay products from the long-sought Higgs boson and determine its mass, successfully testing a key prediction of the standard model of particle physics.

Photos: Maximilien Brice and Claudia Marcelloni/CERN

Celebration!

Hunting the Last Missing Particle of the Standard Model

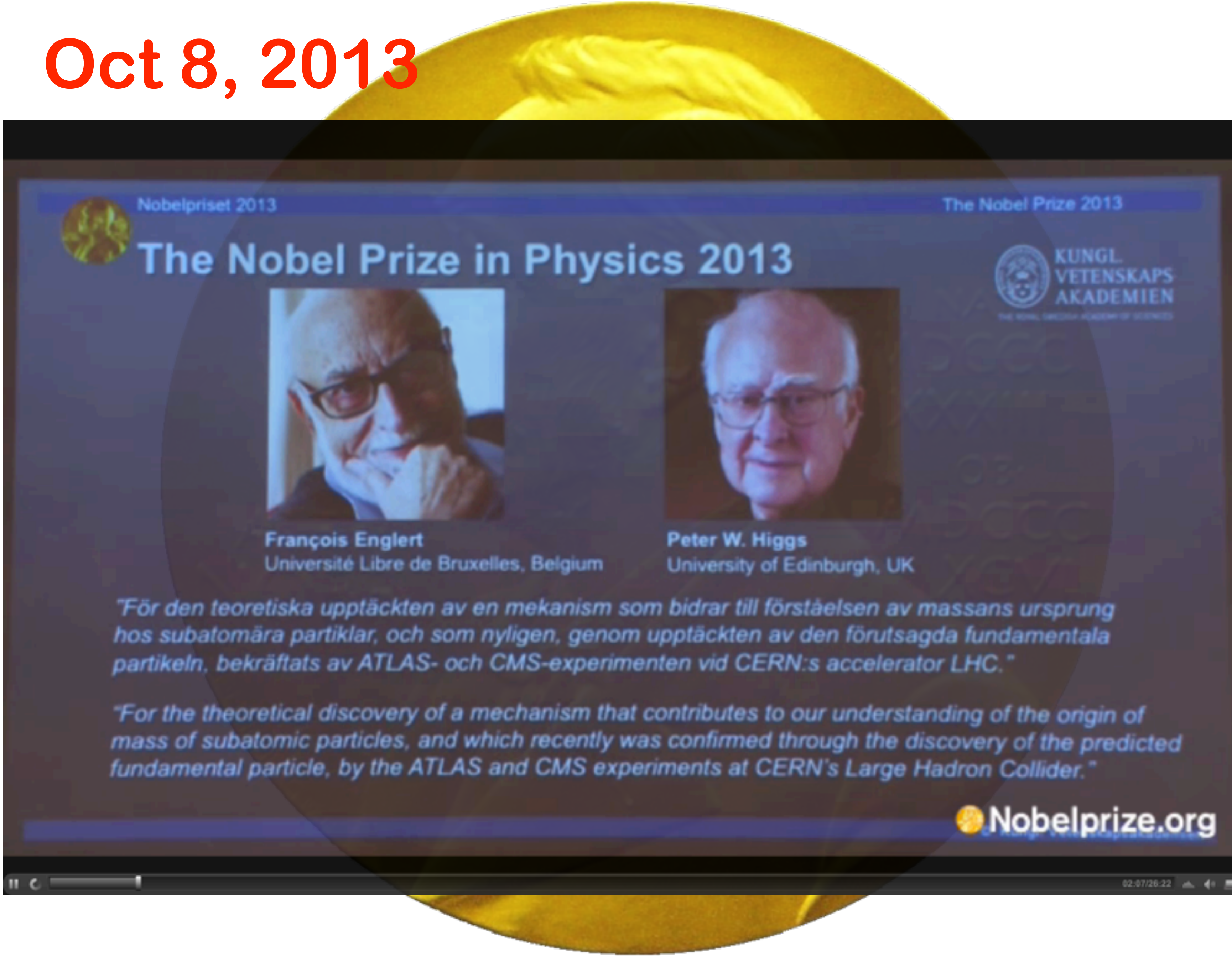
Shufang Su • Caltech

Feb 14, 2003
U Arizona Colloquium
Job Interview

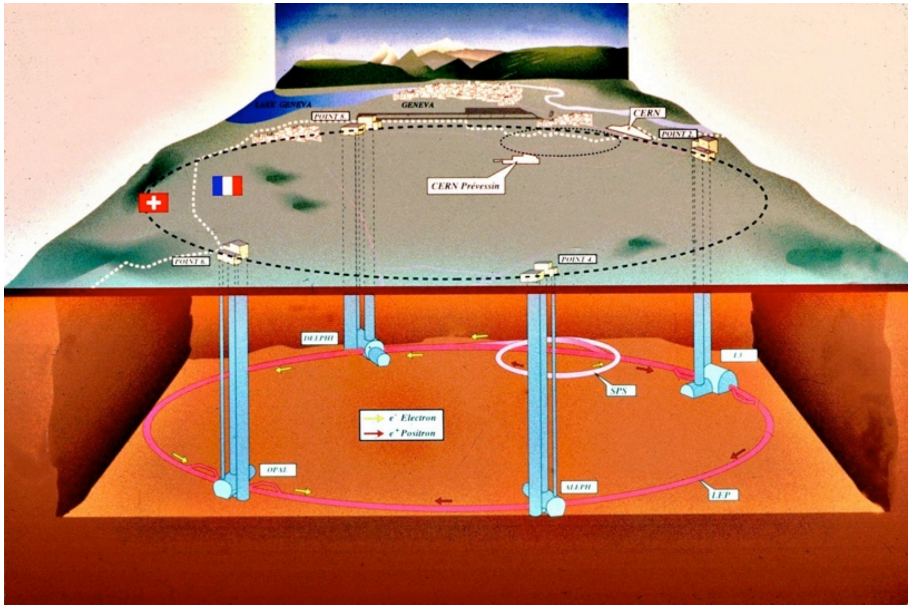
First Hint: Dec 13, 2011

S. Su

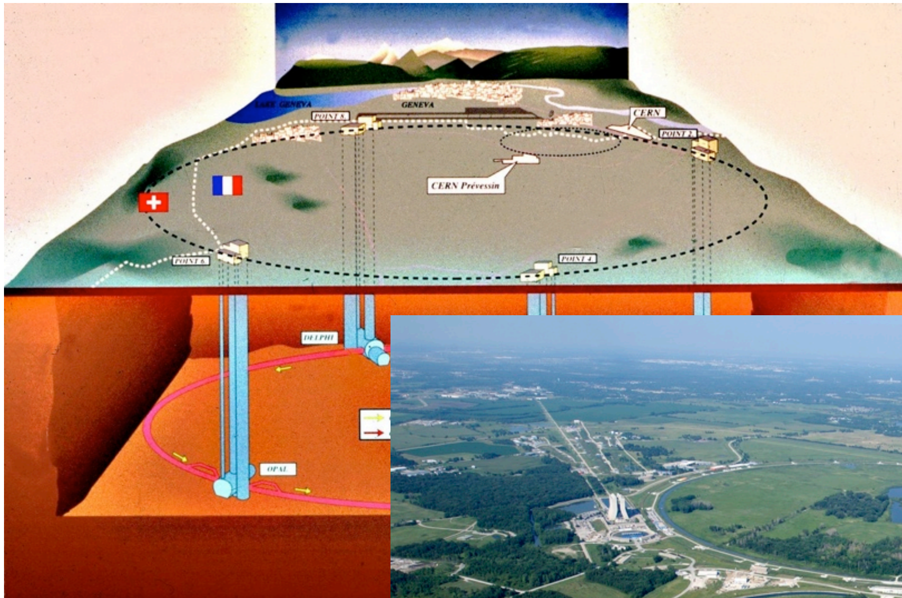
Oct 8, 2013

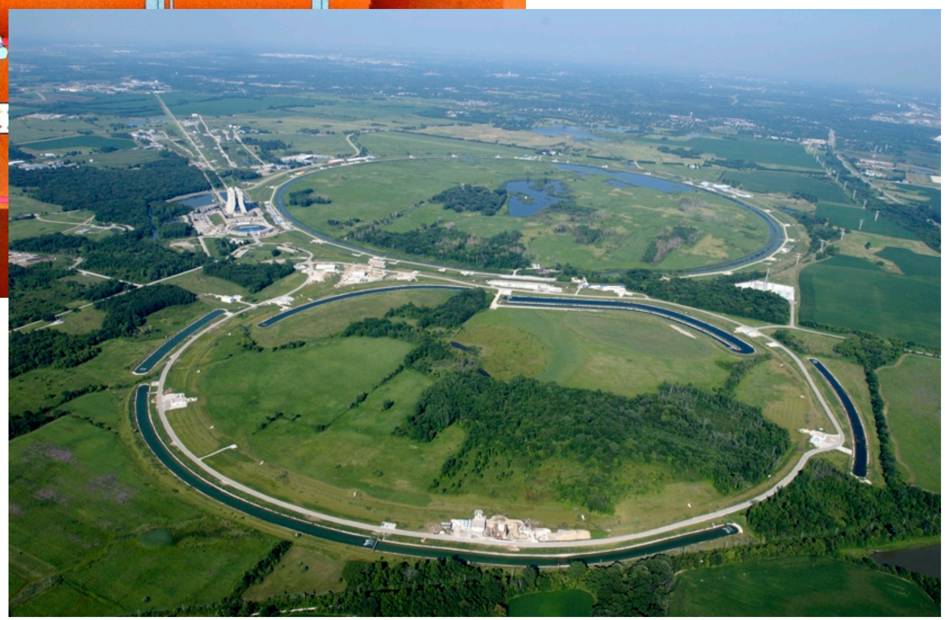

Nobelpriset 2013
The Nobel Prize 2013
The Nobel Prize in Physics 2013
KUNGL. VETENSKAPS AKADEMIEN
François Englert
Université Libre de Bruxelles, Belgium
Peter W. Higgs
University of Edinburgh, UK
"För den teoretiska upptäckten av en mekanism som bidrar till förståelsen av massans ursprung hos subatomära partiklar, och som nyligen, genom upptäckten av den förutsagda fundamentala partikeln, bekräftats av ATLAS- och CMS-experimenten vid CERN:s accelerator LHC."
"For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider."
Nobelprize.org

25 Yrs' Work by thousands experimentalists

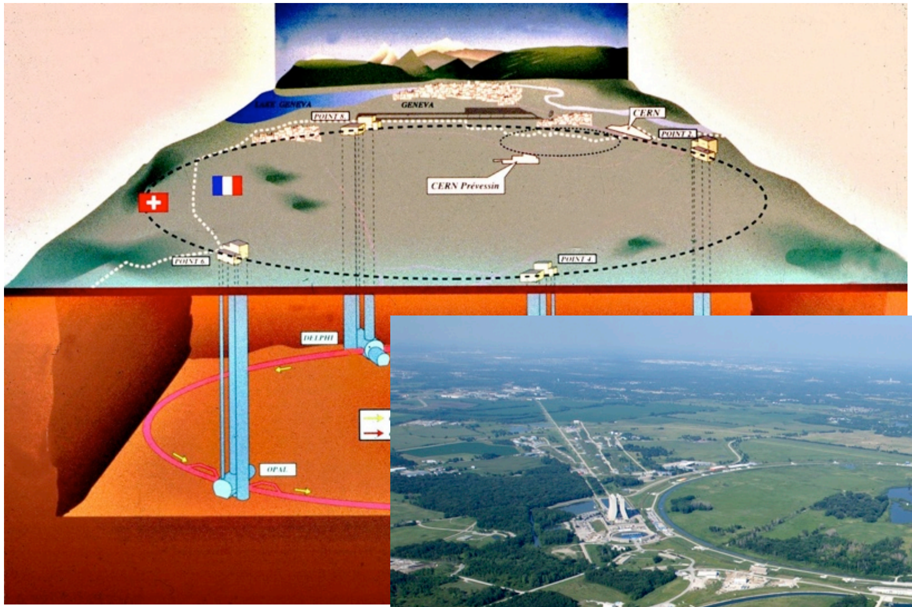


25 Yrs' Work by thousands experimentalists





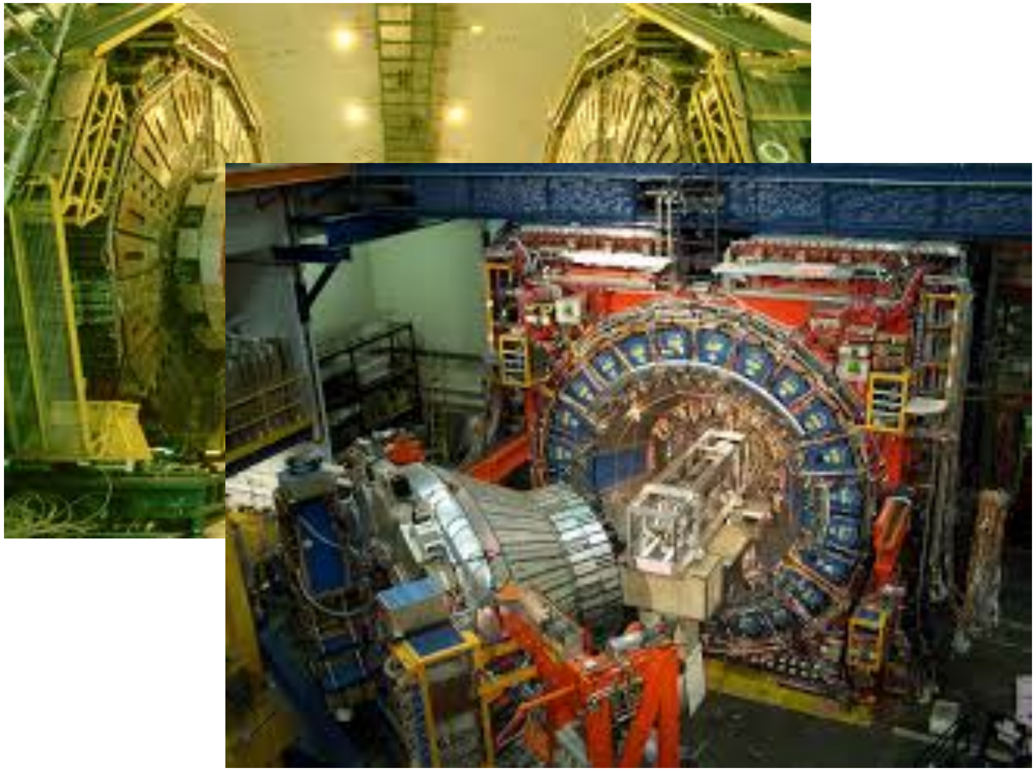
25 Yrs' Work by thousands experimentalists



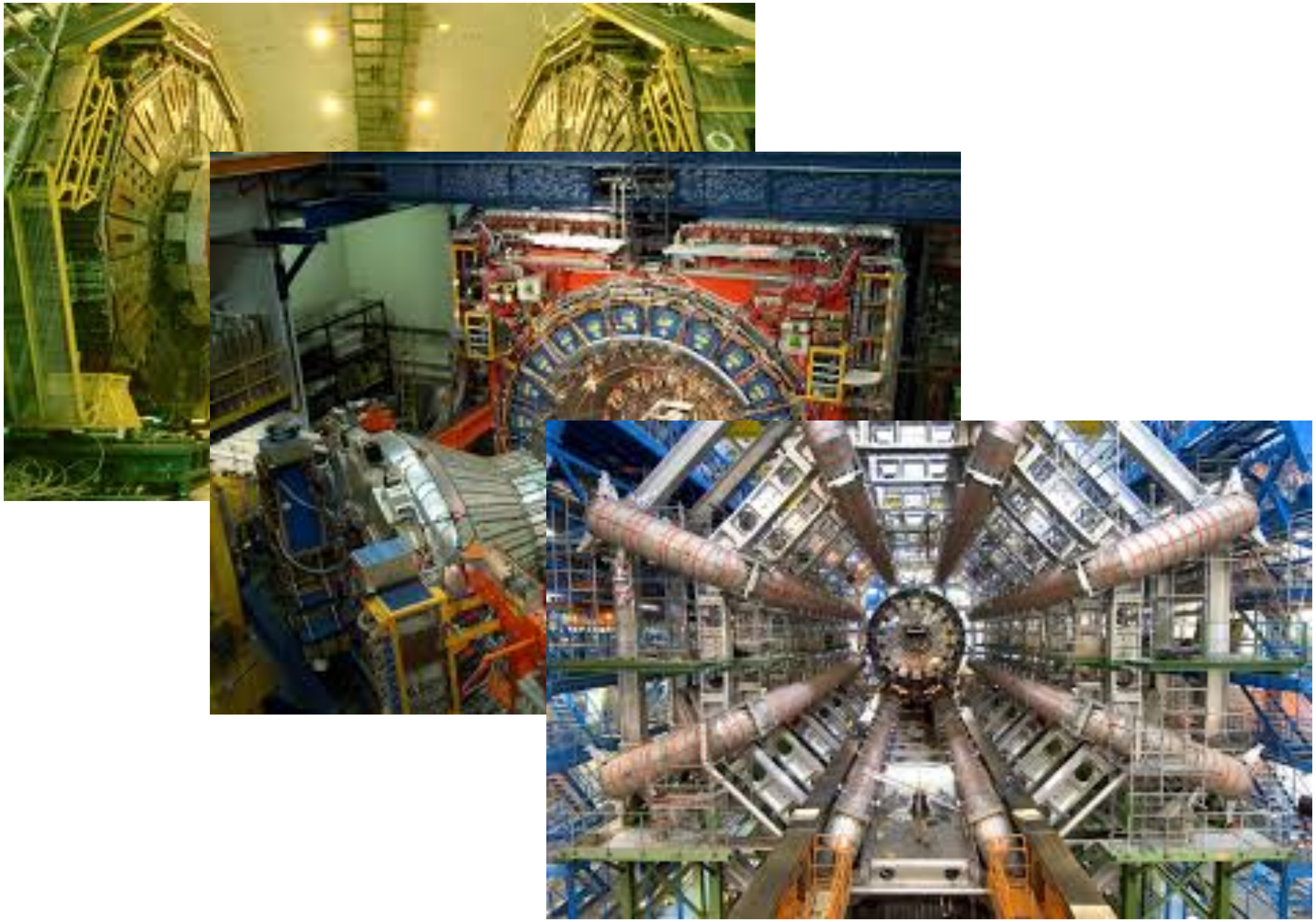
S. Su

25 Yrs' work by thousands experimentalists

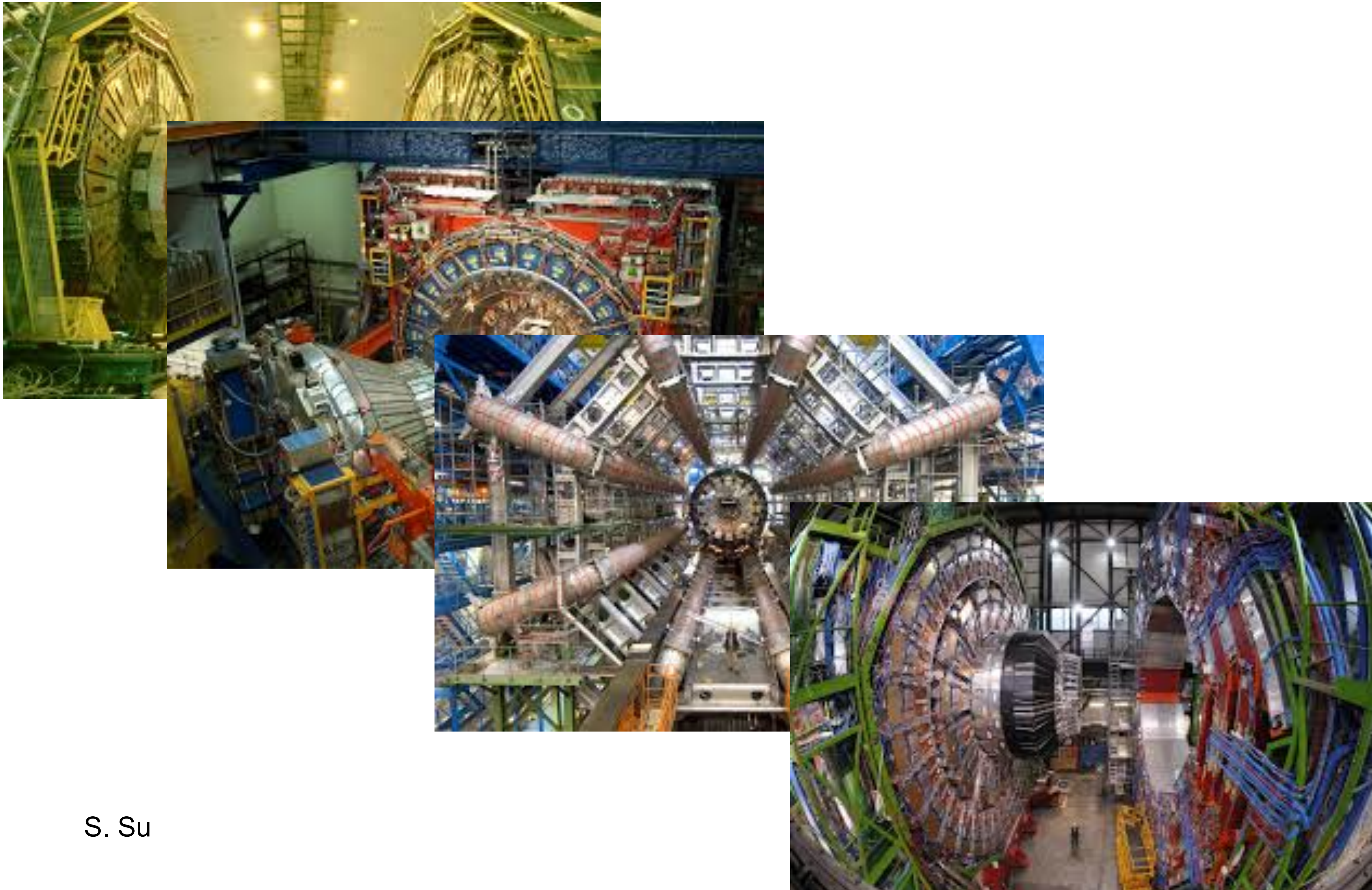
25 Yrs' work by thousands experimentalists



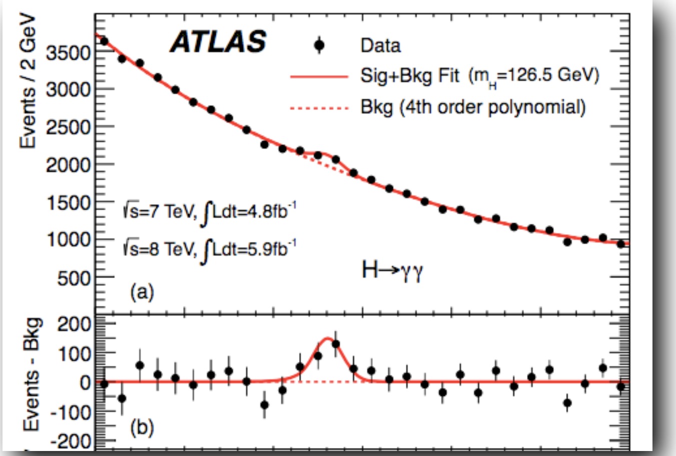
25 Yrs' work by thousands experimentalists

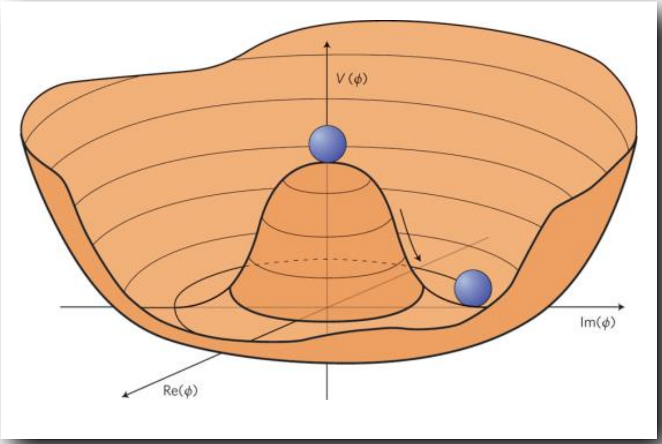


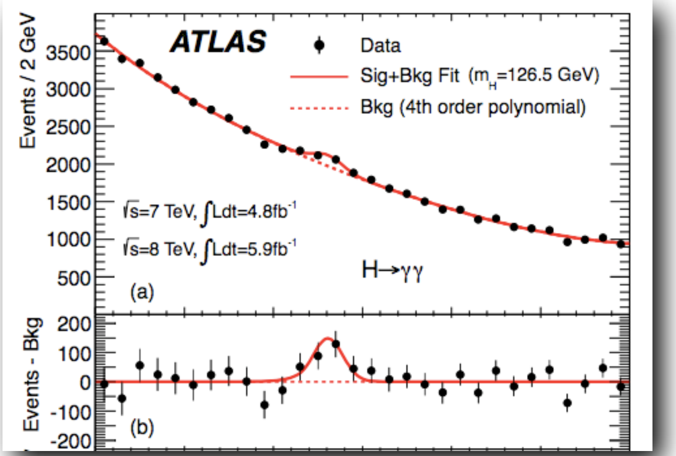
25 Yrs' work by thousands experimentalists

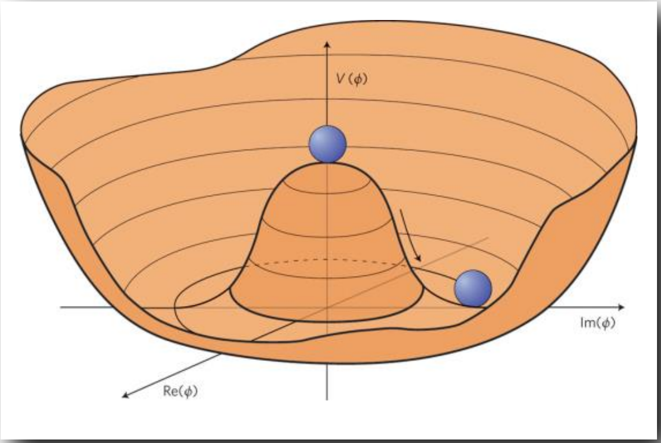


S. Su

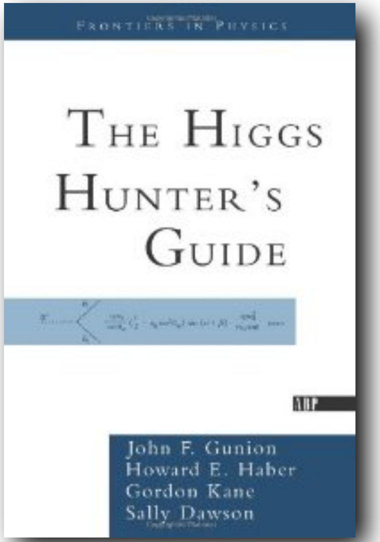

ATLAS
Data
Sig+Bkg Fit (m_H=126.5 GeV)
Bkg (4th order polynomial)
$\sqrt{s}$=7 TeV, $\int Ldt$=4.8fb^{-1}
$\sqrt{s}$=8 TeV, $\int Ldt$=5.9fb^{-1}
H→γγ
(a)
(b)
Events / 2 GeV
Events - Bkg


V (ϕ)
Im(ϕ)
Re(ϕ)

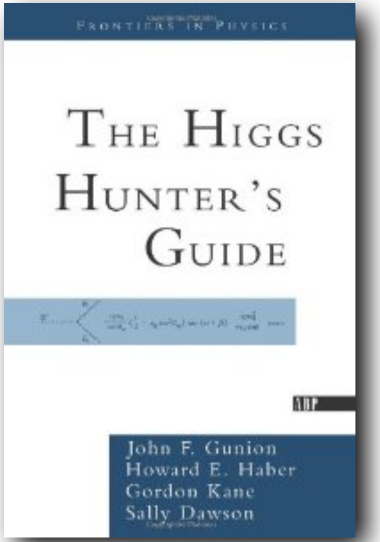

ATLAS
Data
Sig+Bkg Fit (m_H=126.5 GeV)
Bkg (4th order polynomial)
√s=7 TeV, ∫Ldt=4.8fb⁻¹
√s=8 TeV, ∫Ldt=5.9fb⁻¹
H→γγ
(a)
(b)
Events / 2 GeV
Events - Bkg
3500
3000
2500
2000
1500
1000
500
200
100
0
-100
-200

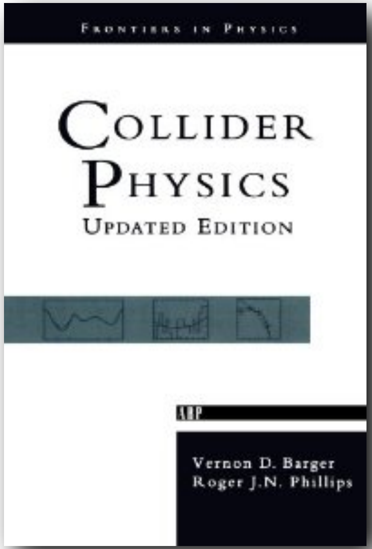

V (ϕ)
Im(ϕ)
Re(ϕ)

50 Years' work by numerous theorists

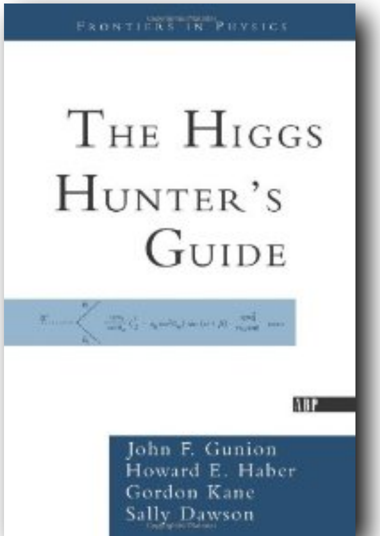


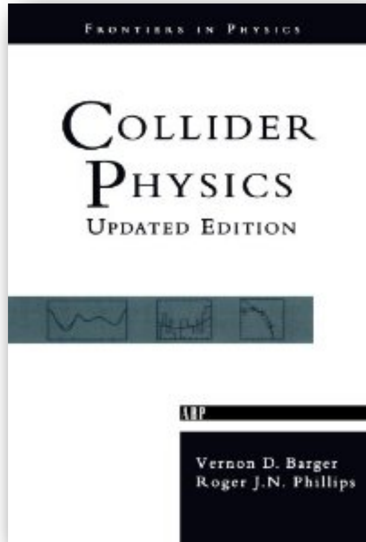
50 Years' work by numerous theorists

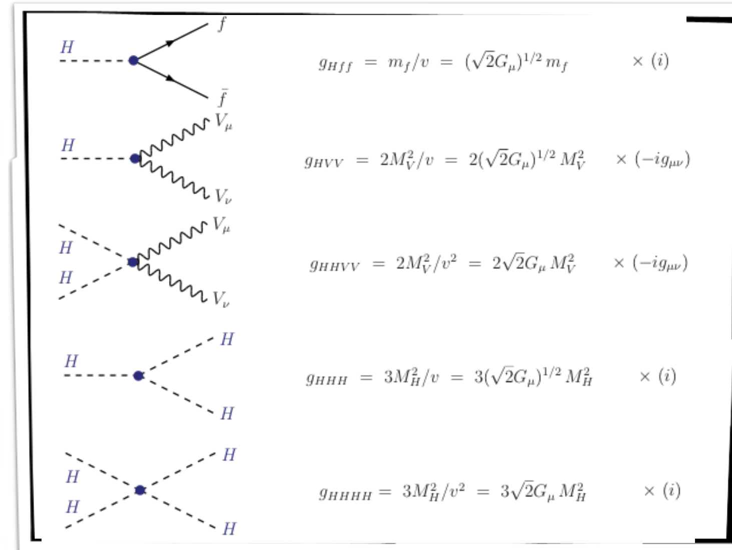




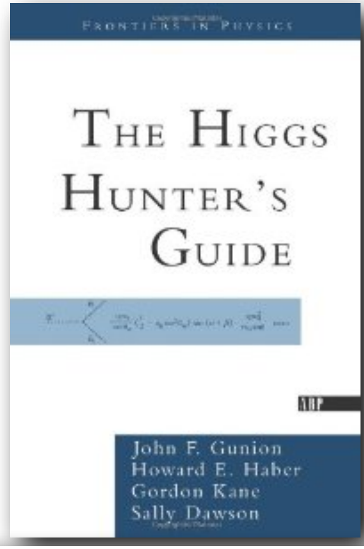
50 Years' work by numerous theorists

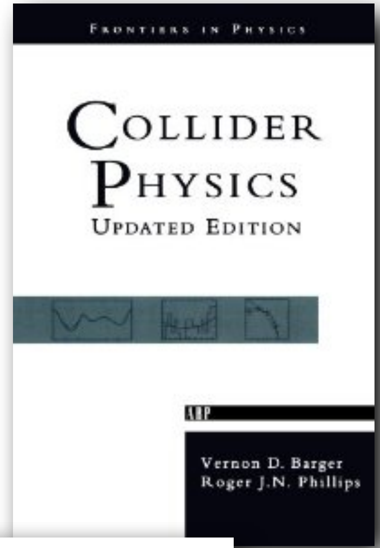


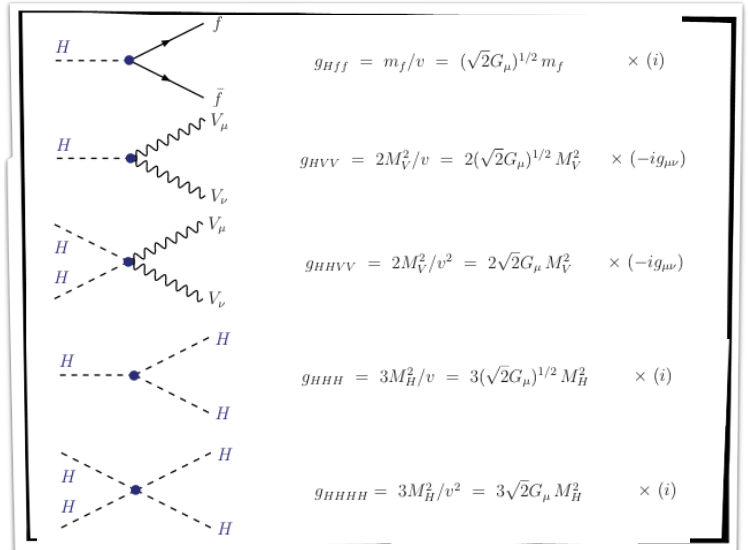


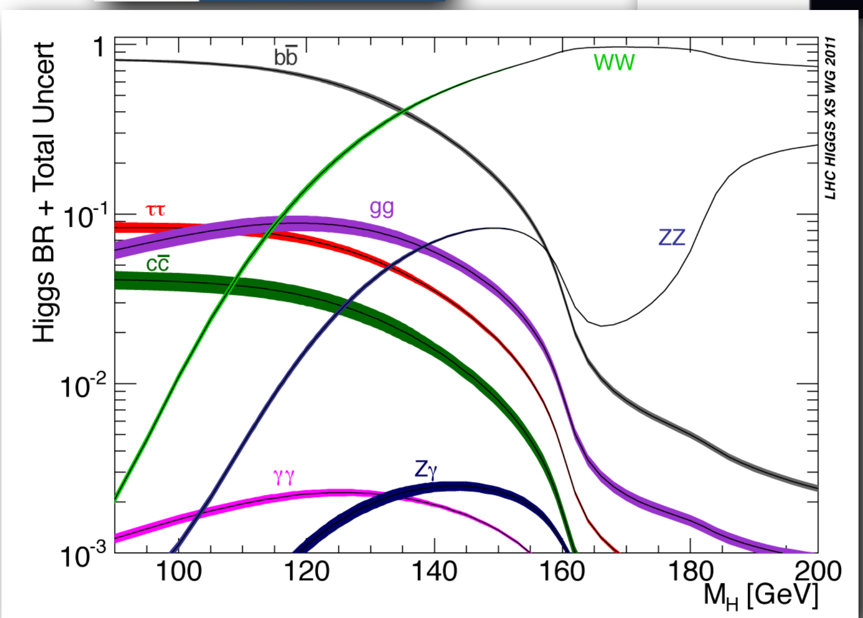


50 Years' work by numerous theorists

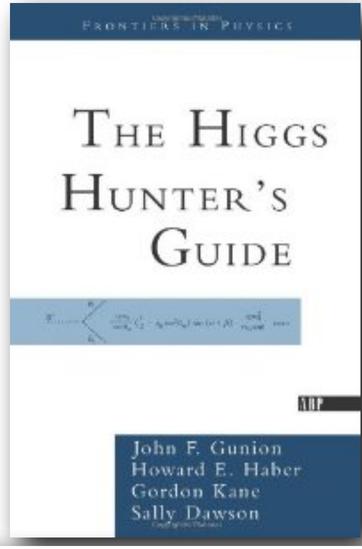


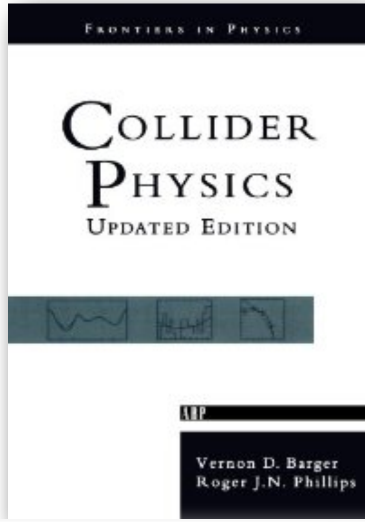


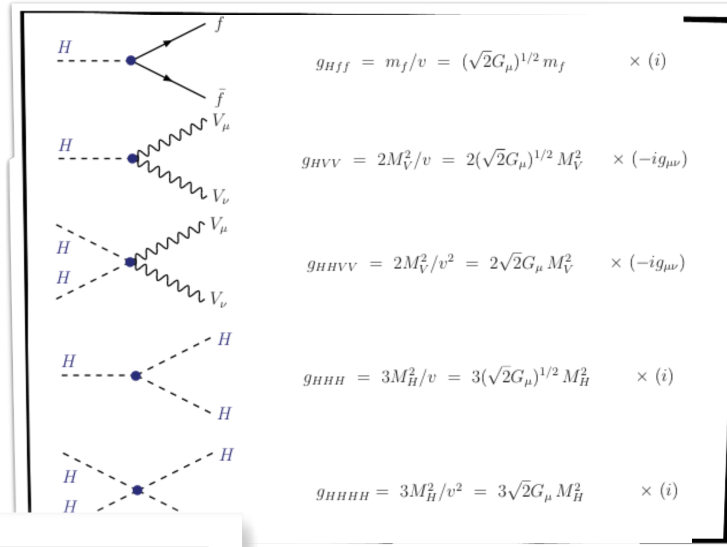


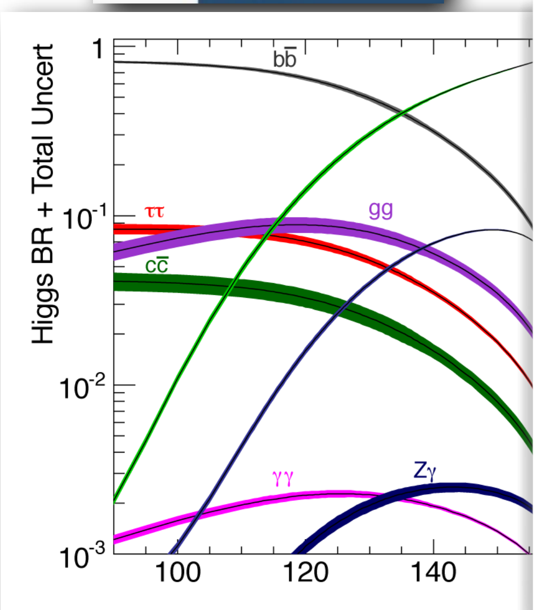


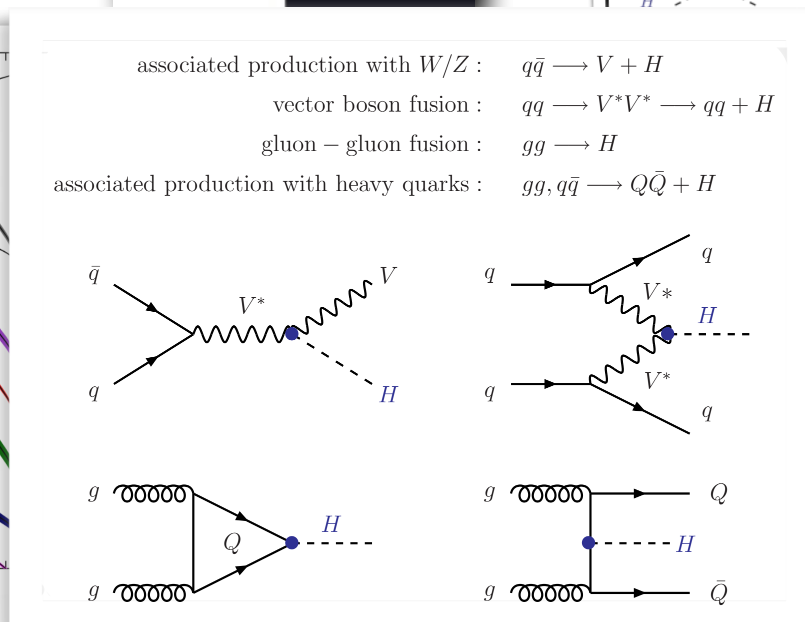
50 Years' work by numerous theorists



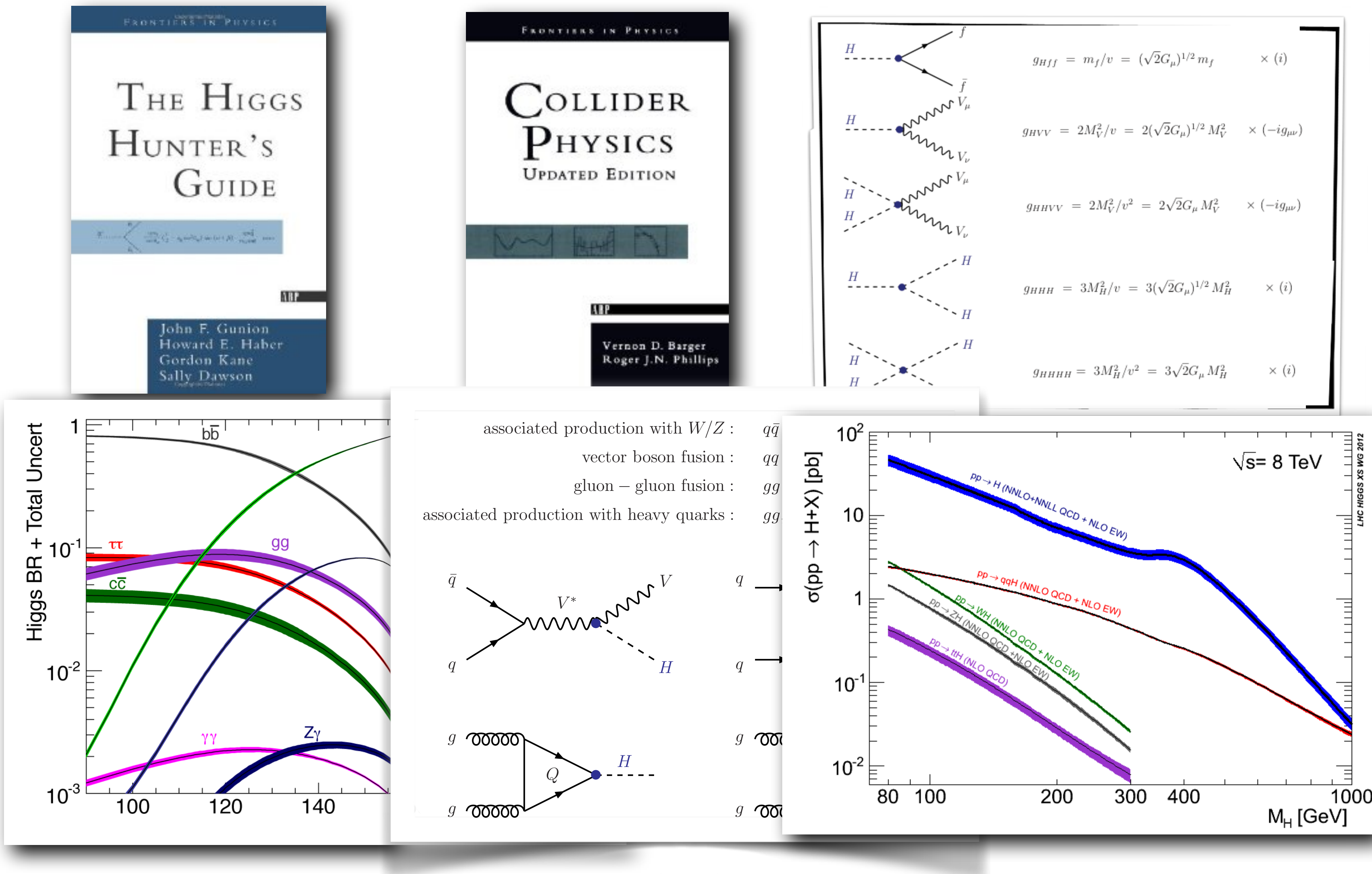








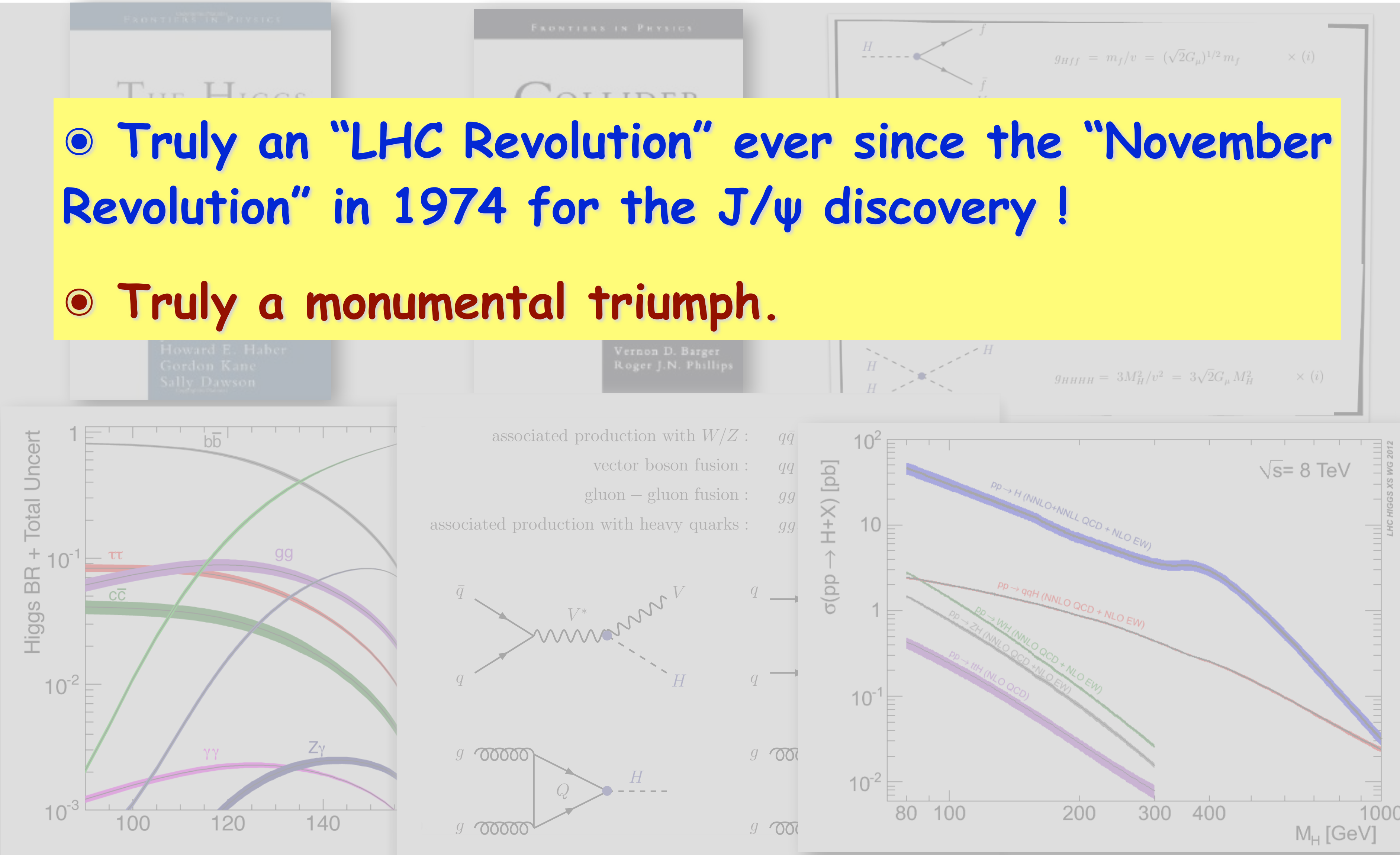
50 Years' work by numerous theorists



50 Years' work by numerous theorists

- Truly an "LHC Revolution" ever since the "November Revolution" in 1974 for the J/ψ discovery !

- Truly a monumental triumph.



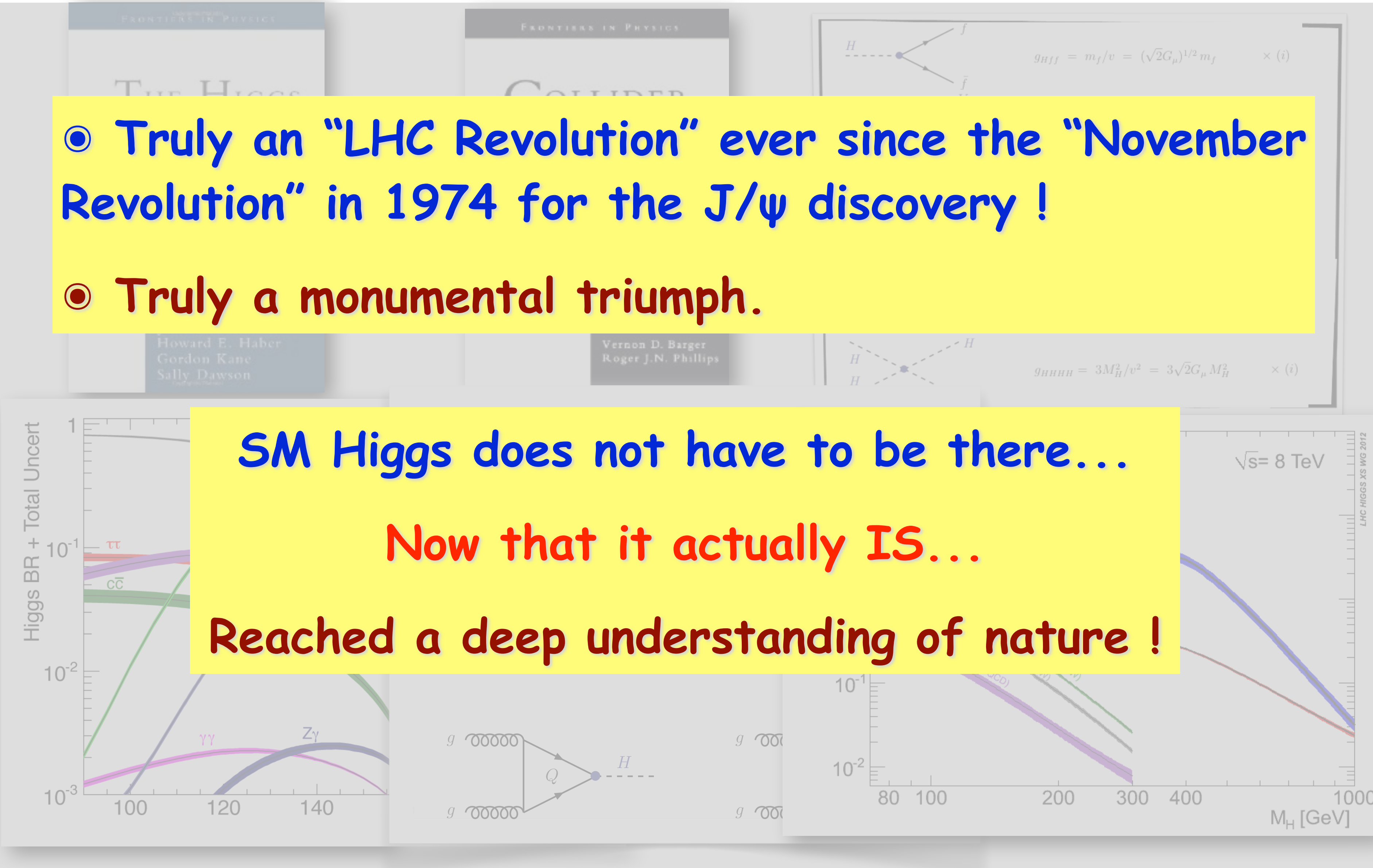
50 Years' work by numerous theorists

- Truly an "LHC Revolution" ever since the "November Revolution" in 1974 for the J/ψ discovery !
- Truly a monumental triumph.

SM Higgs does not have to be there...

Now that it actually IS...

Reached a deep understanding of nature !



Outline

- Why we need a Higgs factory?
- How to make a Higgs factory?
- What we can learn with a Higgs factory?

Why we need a Higgs Factory?

Why we need a Higgs Factory?

To study Higgs, of course!

Why we need a Higgs Factory?

To study Higgs, of course!

Why is it important to study Higgs?

Quiz!!!

Quiz!!!

- Higgs is responsible for the mass of Universe

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

dark matter and dark energies (96% of the Universe)

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

  dark matter and dark energies (96% of the Universe)

- Higgs is responsible for the mass of your and me

  (and 4% of the Universe)

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

  dark matter and dark energies (96% of the Universe)

- ~~Higgs is responsible for the mass of your and me~~

  (and 4% of the Universe)

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

  dark matter and dark energies (96% of the Universe)

- ~~Higgs is responsible for the mass of your and me~~

  (and 4% of the Universe) QCD does it!

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

  dark matter and dark energies (96% of the Universe)

- ~~Higgs is responsible for the mass of your and me~~

  (and 4% of the Universe) QCD does it!

- Higgs is needed for the mass of elementary particles

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

  dark matter and dark energies (96% of the Universe)

- ~~Higgs is responsible for the mass of your and me~~

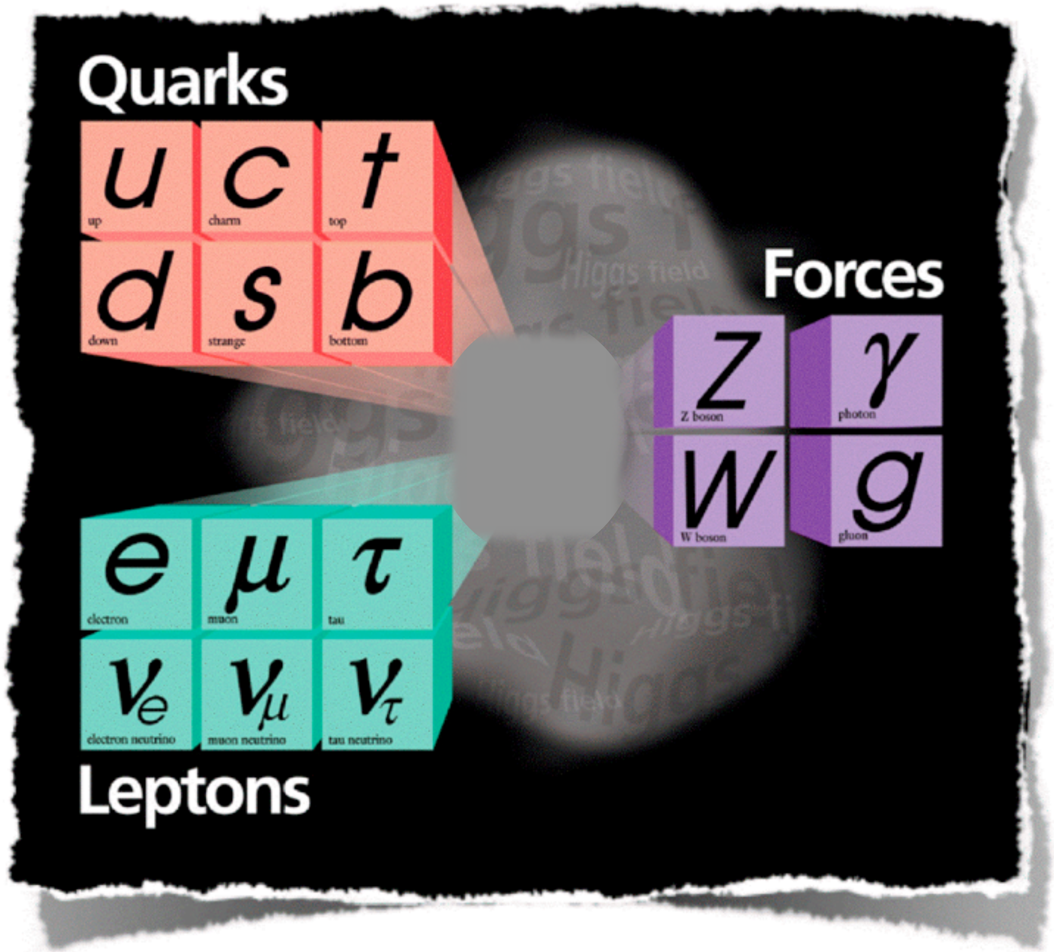
  (and 4% of the Universe) QCD does it!

- Higgs is needed for the mass of elementary particles

  Higgs mechanism: Yes. Higgs particle: No.

Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$

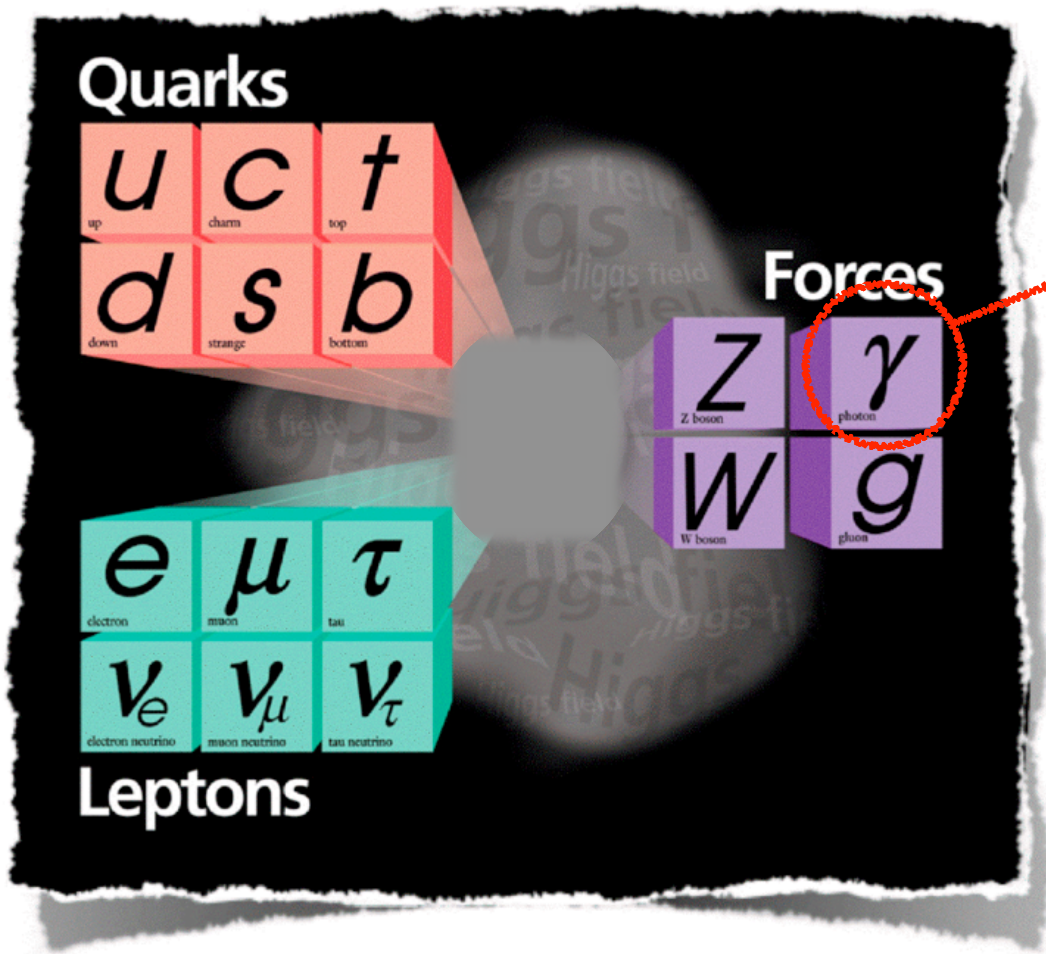


The successful "Standard Model"

Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$

The successful "Standard Model"



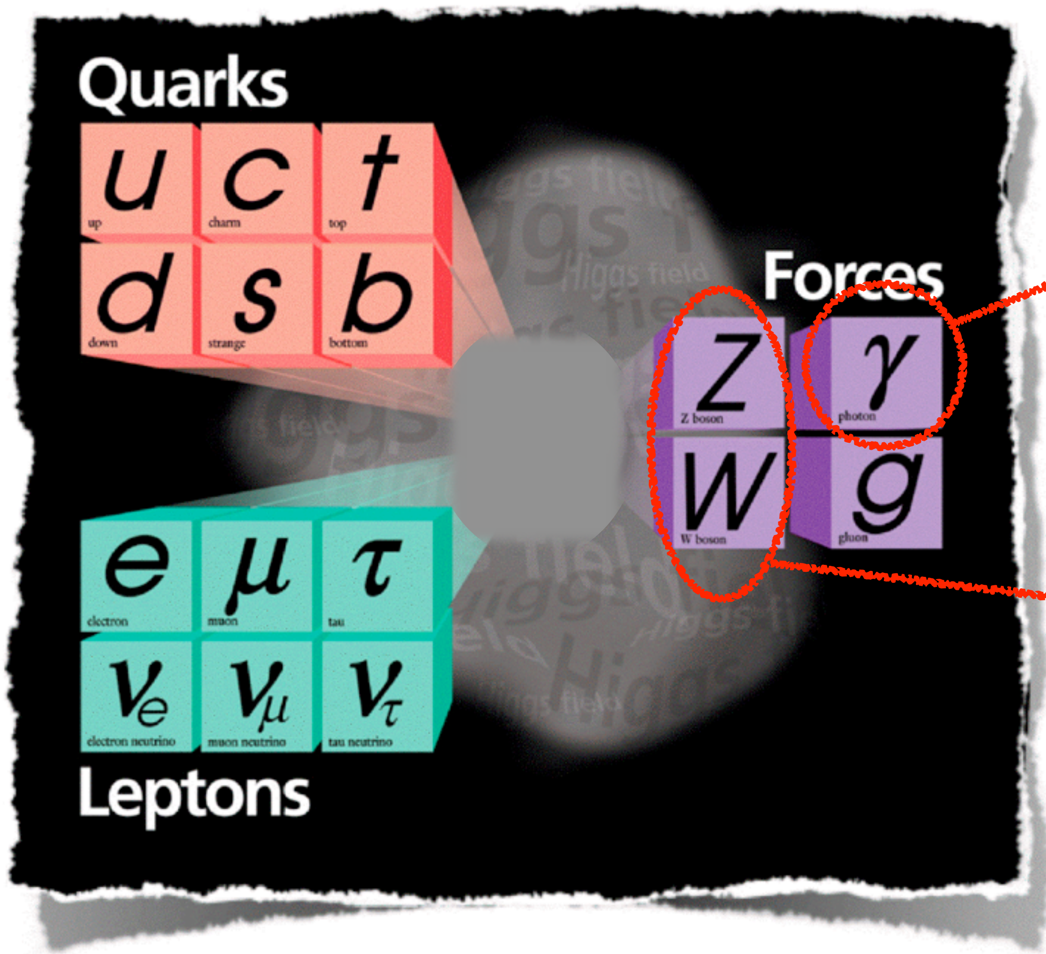
$m_\gamma = 0$

EM: long range force

Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$

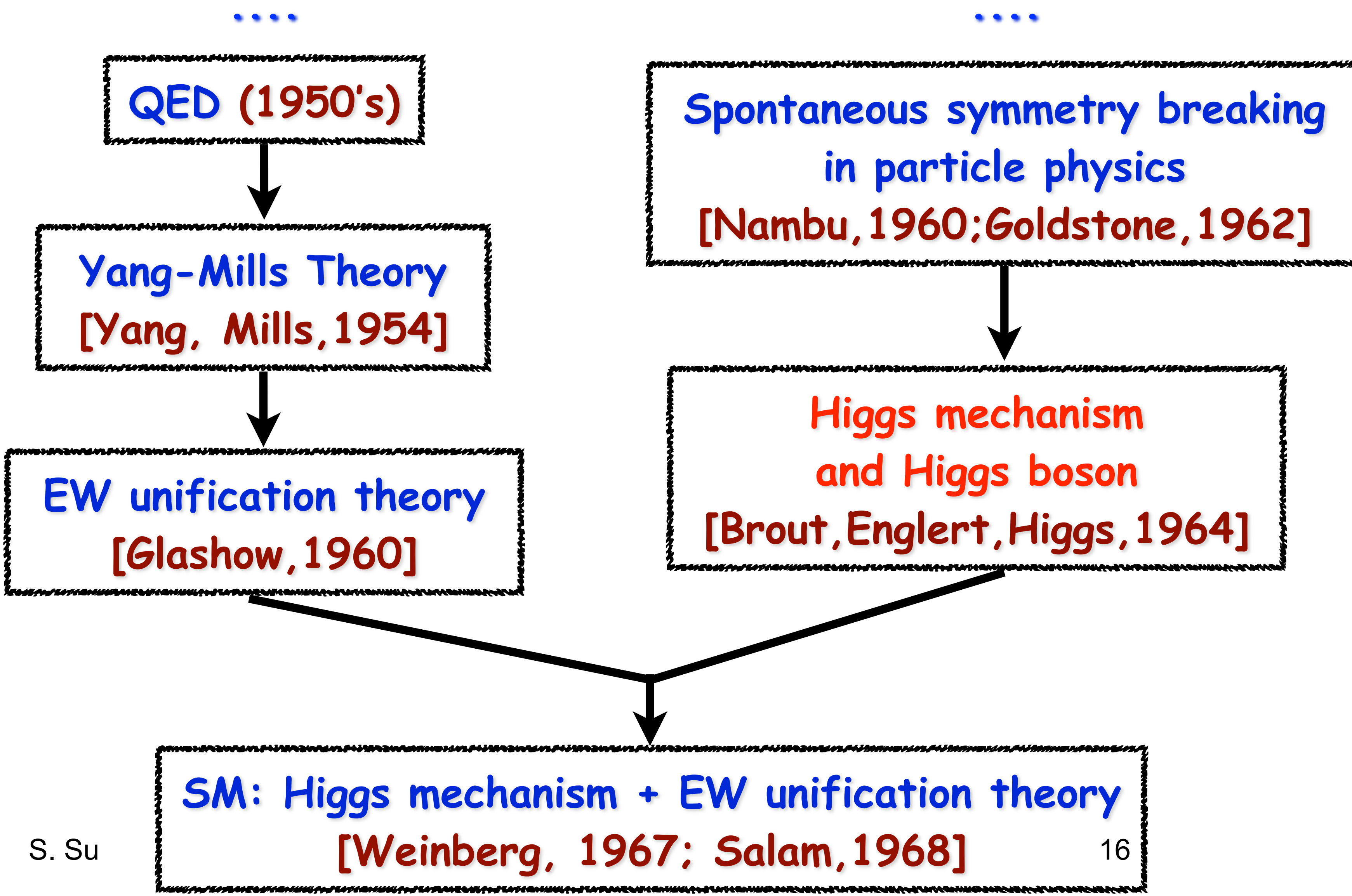
The successful "Standard Model"



$m_\gamma=0$
EM: long range force

$m_{W,Z} \sim 100$ GeV
weak interaction: short range force

Higgs mechanism: historical profile



Higgs mechanism: historical profile

....

QED (1950's)

Yang-Mills Theory
[Yang, Mills,1954]

EW unification theory
[Glashow,1960]

....

Spontaneous symmetry breaking
in particle physics
[Nambu,1960;Goldstone,1962]

Higgs mechanism
and Higgs boson
[Brout,Englert,Higgs,1964]

SM: Higgs mechanism + EW unification theory
[Weinberg, 1967; Salam,1968]

Higgs mechanism: historical profile

....

QED (1950's)

↓

Yang-Mills Theory
[Yang, Mills, 1954]

↓

EW unification theory
[Glashow, 1960]

....

Spontaneous symmetry breaking
in particle physics
[Nambu, 1960; Goldstone, 1962]

↓

Higgs mechanism
and Higgs boson
[Brout, Englert, Higgs, 1964]

↓

SM: Higgs mechanism + EW unification theory
[Weinberg, 1967; Salam, 1968]

Higgs mechanism: historical profile

....

QED (1950's)

↓

Yang-Mills Theory
[Yang, Mills, 1954]

↓

EW unification theory
[Glashow, 1960]

....

Spontaneous symmetry breaking
in particle physics
[Nambu, 1960; Goldstone, 1962]

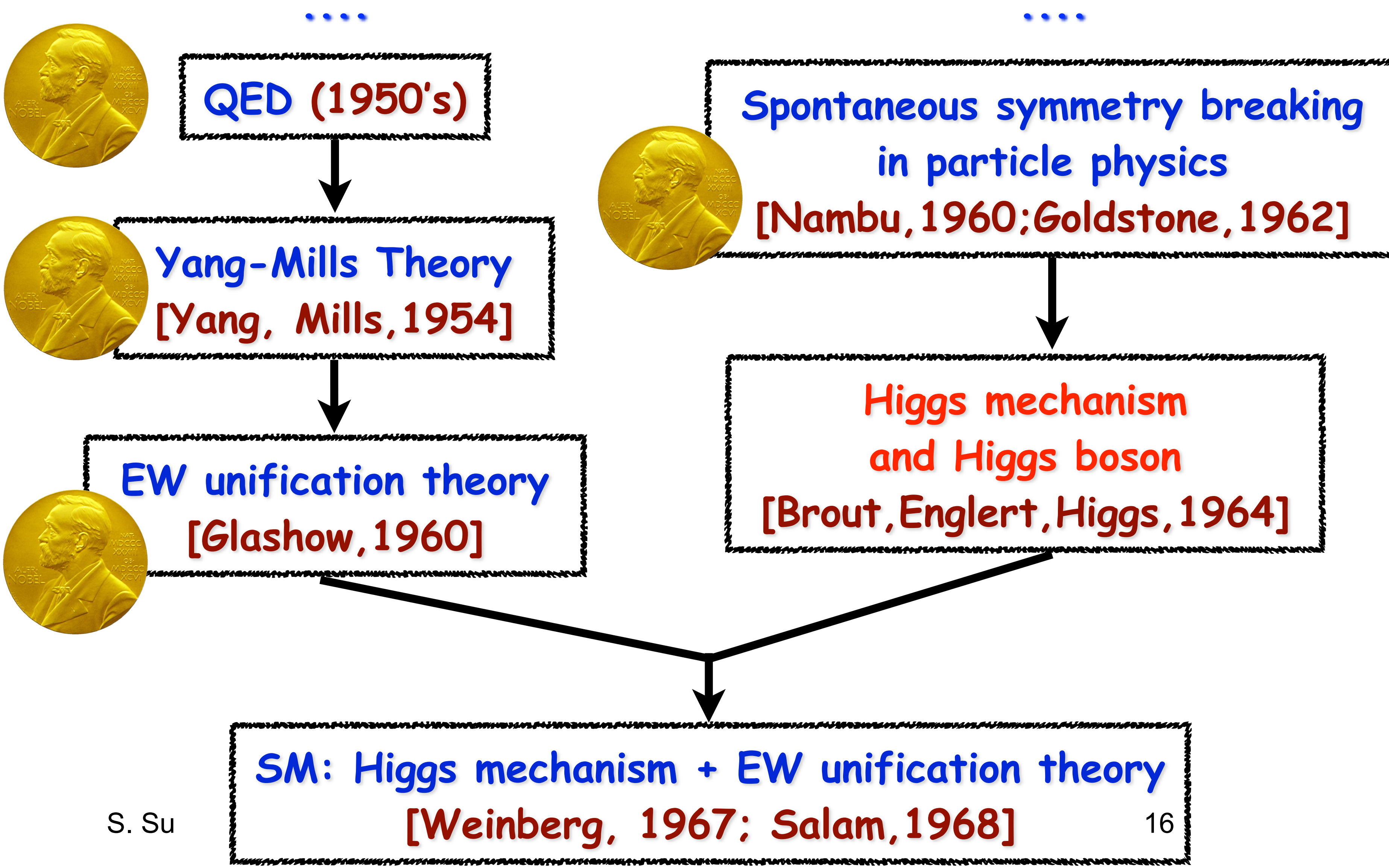
↓

Higgs mechanism
and Higgs boson
[Brout, Englert, Higgs, 1964]

↓

SM: Higgs mechanism + EW unification theory
[Weinberg, 1967; Salam, 1968]

Higgs mechanism: historical profile



Higgs mechanism: historical profile

....

QED (1950's)

↓

Yang-Mills Theory
[Yang, Mills, 1954]

↓

EW unification theory
[Glashow, 1960]

....

Spontaneous symmetry breaking
in particle physics
[Nambu, 1960; Goldstone, 1962]

↓

Higgs mechanism
and Higgs boson
[Brout, Englert, Higgs, 1964]

↓

SM: Higgs mechanism + EW unification theory
[Weinberg, 1967; Salam, 1968]

Higgs mechanism: historical profile

....

QED (1950's)

↓

Yang-Mills Theory
[Yang, Mills, 1954]

↓

EW unification theory
[Glashow, 1960]

....

Spontaneous symmetry breaking in particle physics
[Nambu, 1960; Goldstone, 1962]

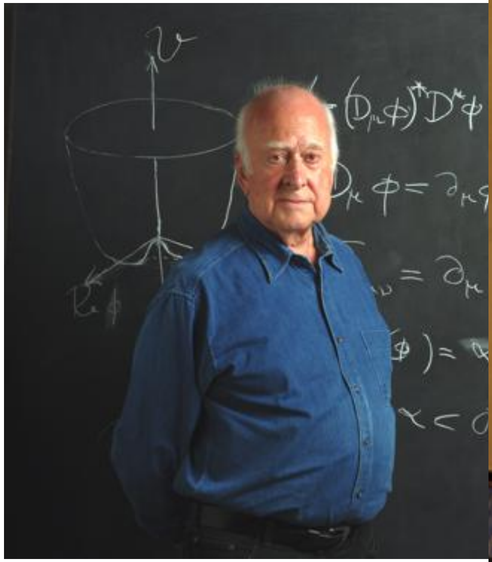
↓

Higgs mechanism and Higgs boson
[Brout, Englert, Higgs, 1964]

↓

SM: Higgs mechanism + EW unification theory
[Weinberg, 1967; Salam, 1968]

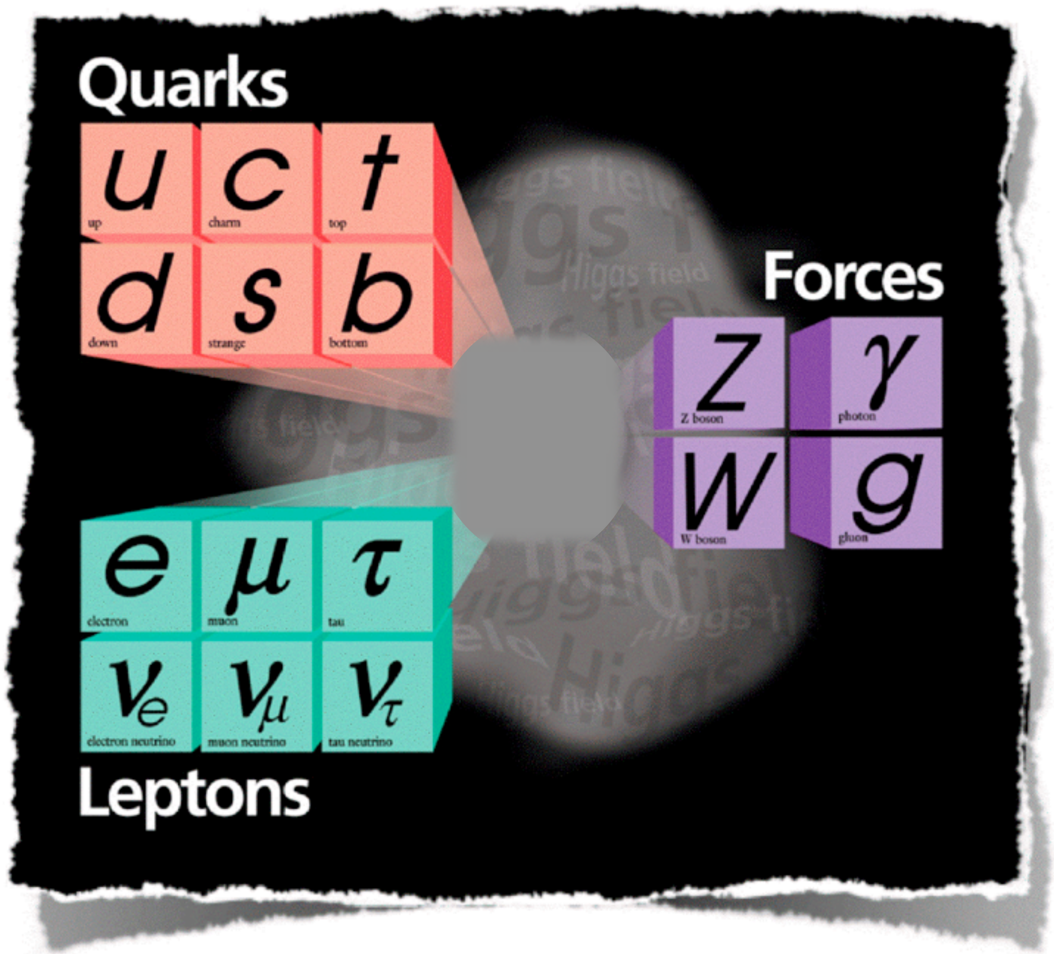
Higgs Mechanism (1964)



S. Su

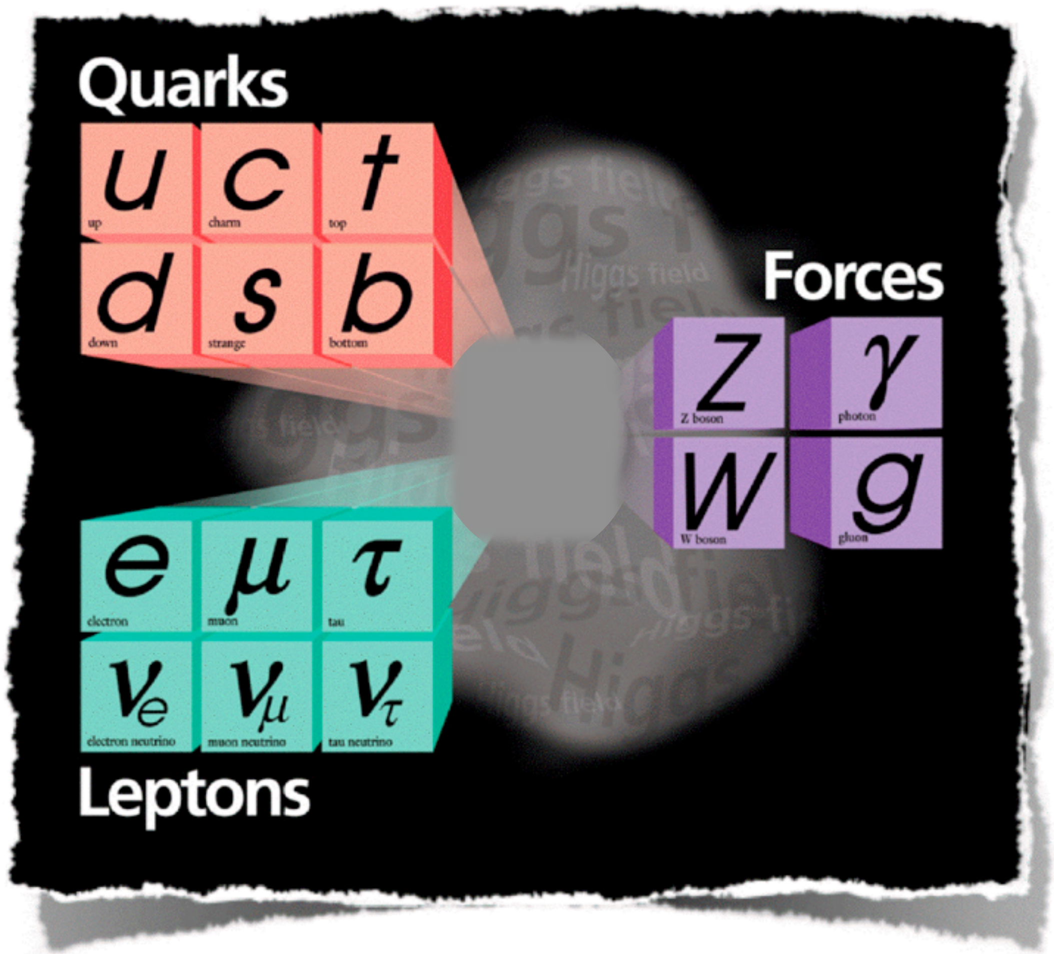
Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$



Elementary particles

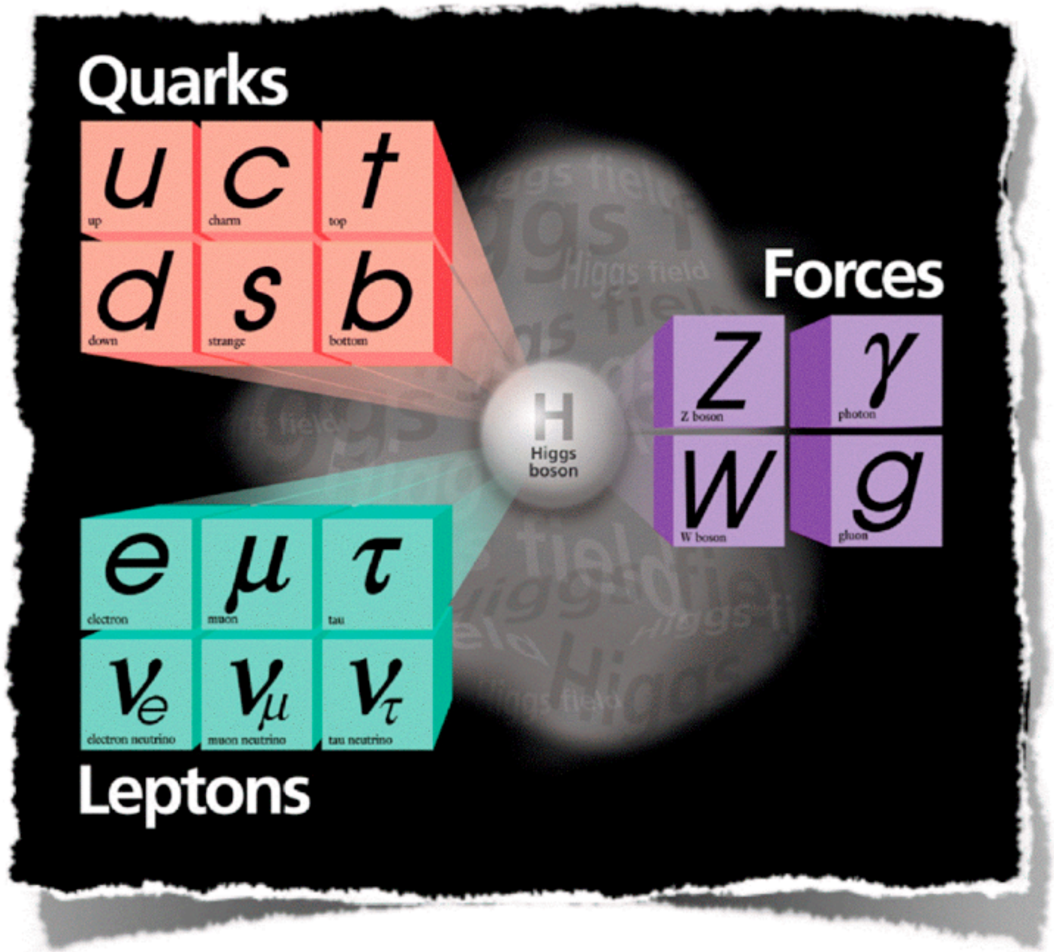
$SU(3)_c \times SU(2)_L \times U(1)_Y$



Higgs (mechanism) !

Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$

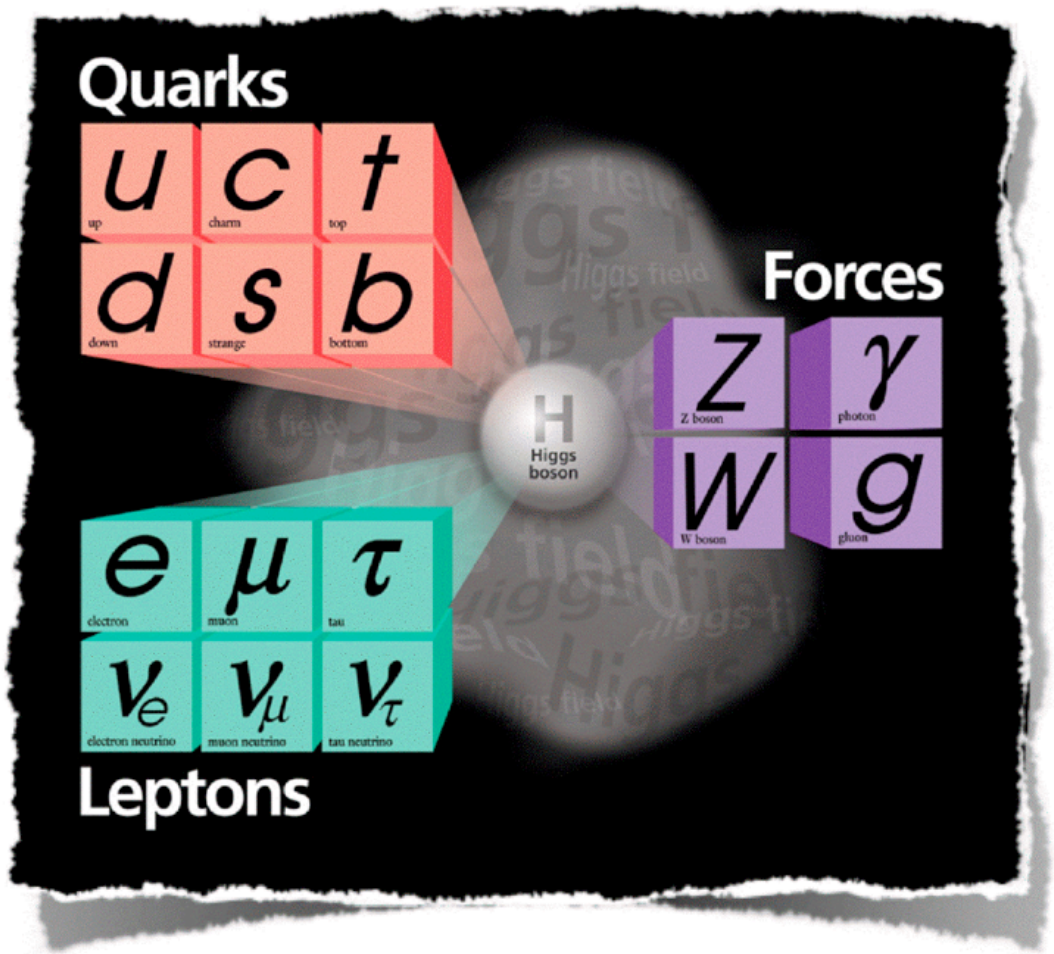


Higgs (mechanism) !

- Higgs mechanism

Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$



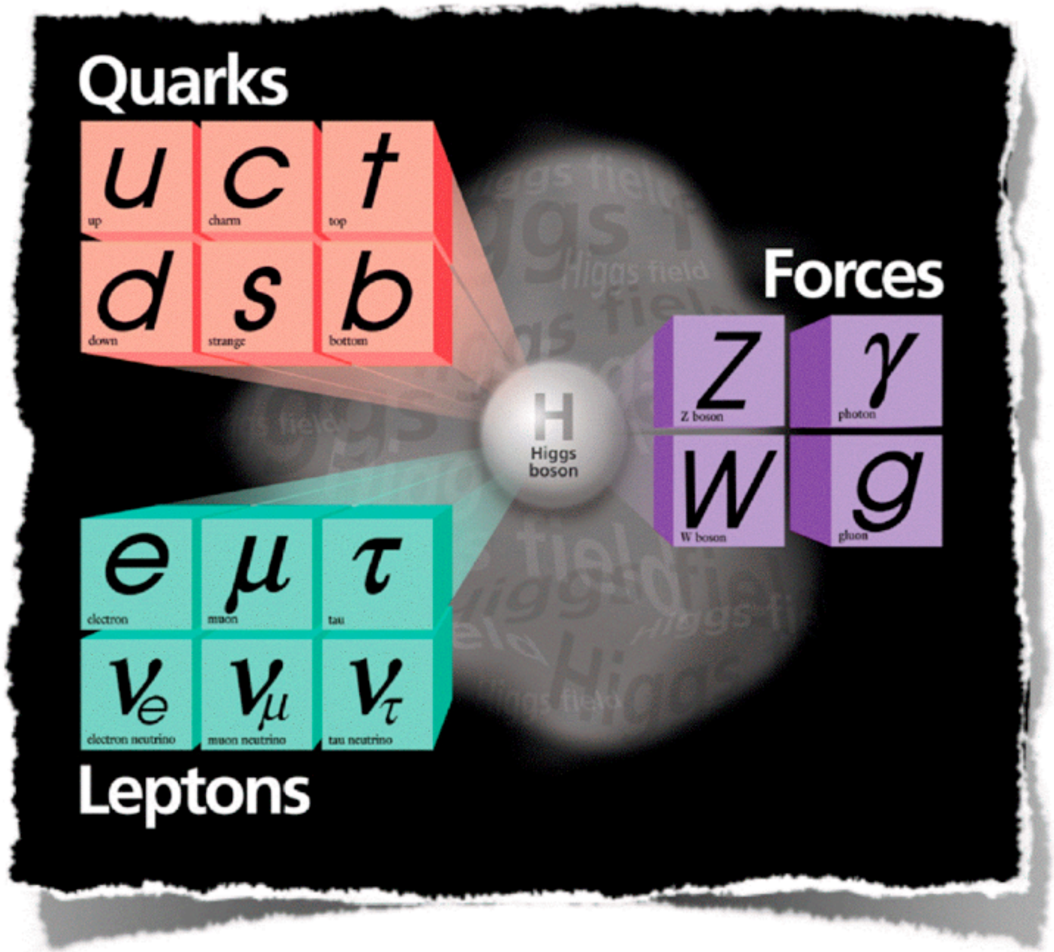
Higgs (mechanism) !

- Higgs mechanism

break electroweak symmetry spontaneously.

Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$



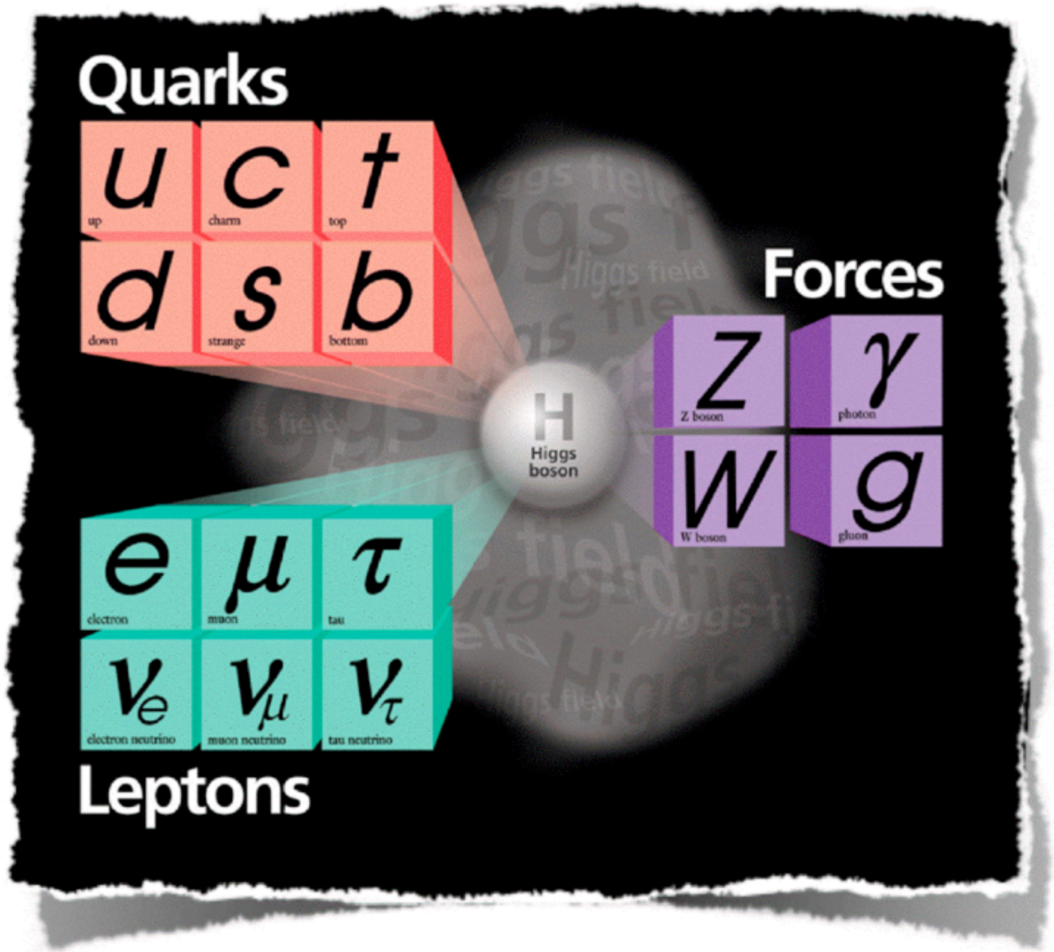
Higgs (mechanism) !

- Higgs mechanism

break electroweak symmetry spontaneously.

Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$



Higgs (mechanism) !

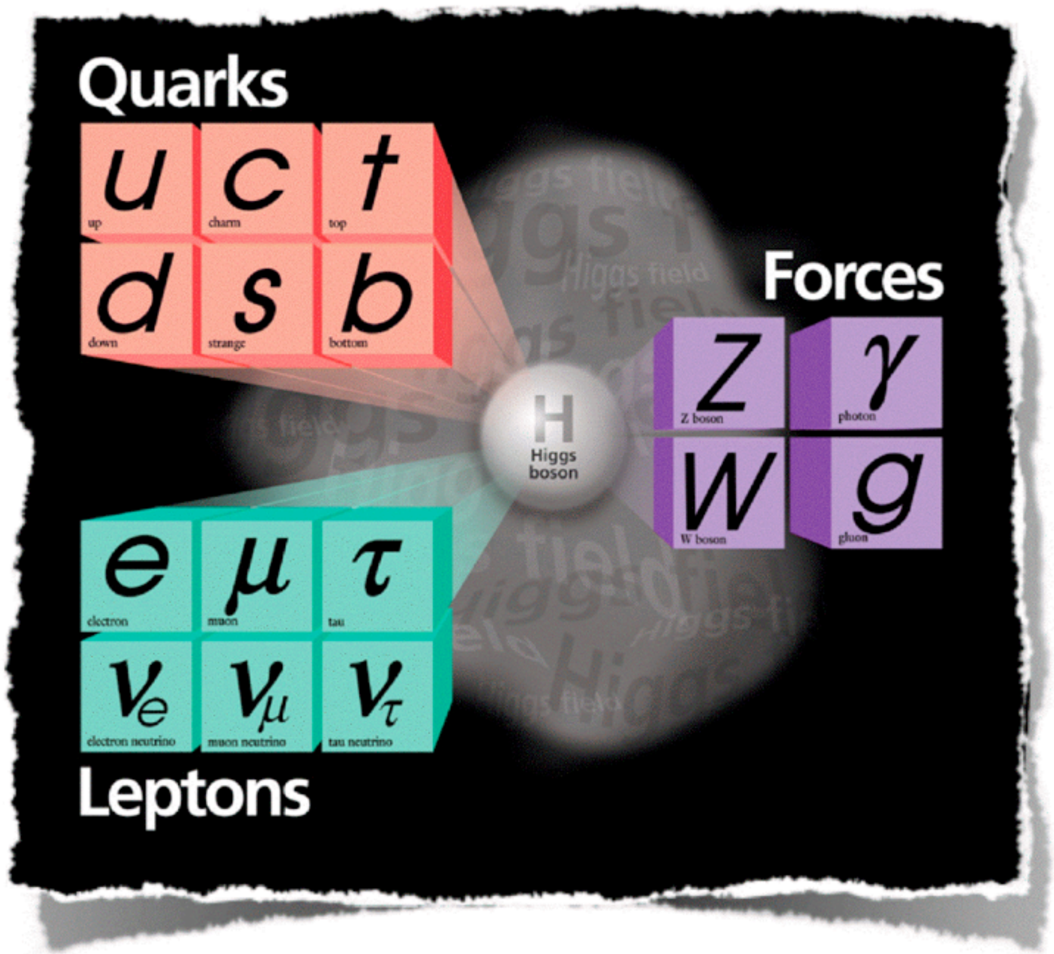
- Higgs mechanism

break electroweak symmetry spontaneously.

- Higgs field gives mass to e, W, Z,...

Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$



Higgs (mechanism) !

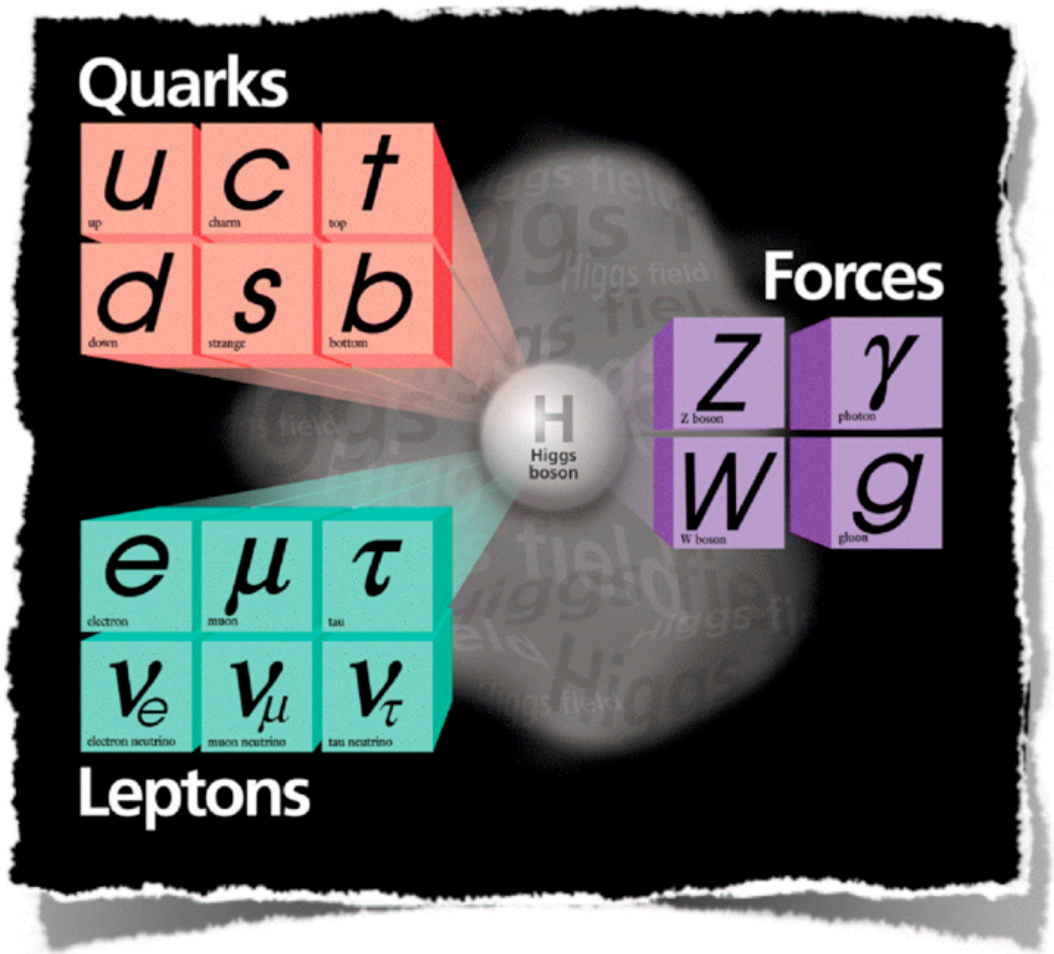
- Higgs mechanism

break electroweak symmetry spontaneously.

- Higgs field gives mass to e, W, Z,...

Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$



Higgs (mechanism) !

- Higgs mechanism

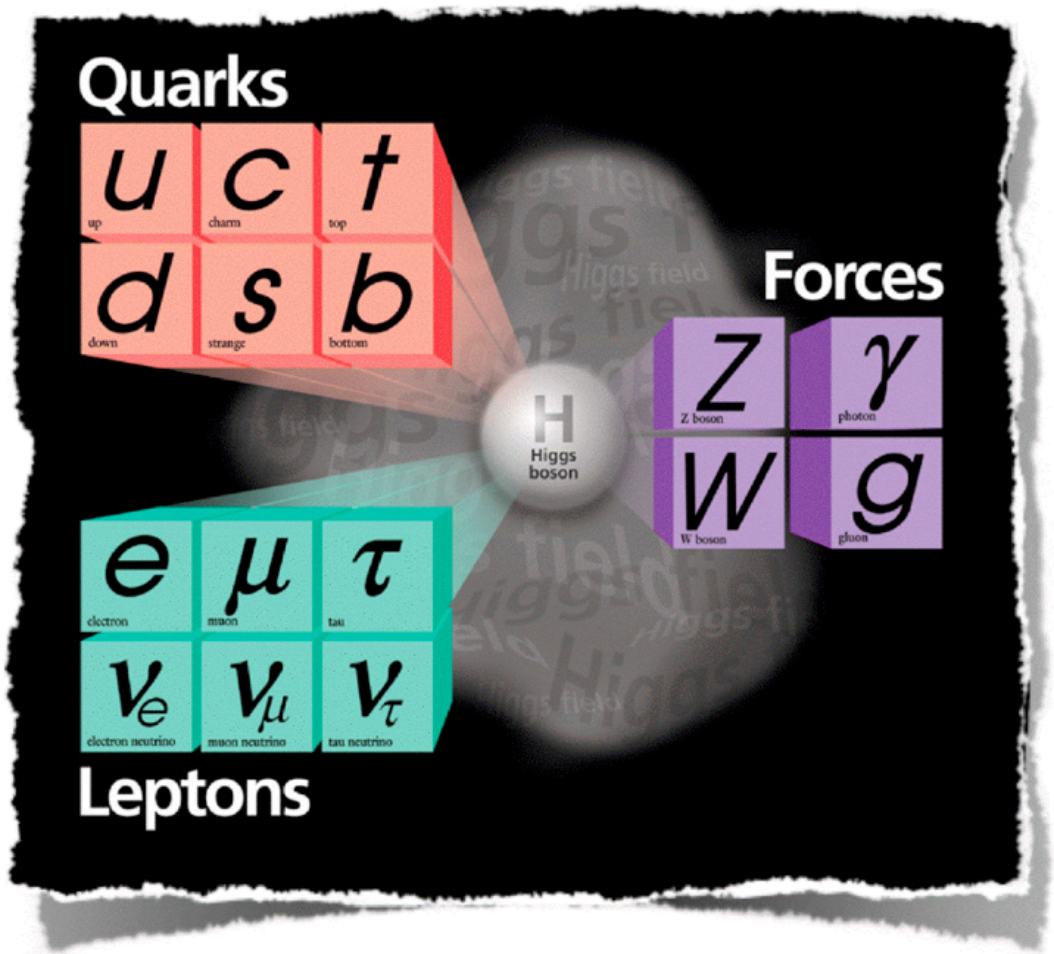
break electroweak symmetry spontaneously.

- Higgs field gives mass to e, W, Z,...

- The remaining Higgs boson

Elementary particles

$SU(3)_c \times SU(2)_L \times U(1)_Y$



Higgs (mechanism) !

- Higgs mechanism

break electroweak symmetry spontaneously.

- Higgs field gives mass to e, W, Z,...

- The remaining Higgs boson

  spin 0 scalar

Mass generation

Higgs Mechanism DOES NOT require a Higgs boson!

Mass generation

Higgs Mechanism DOES NOT require a Higgs boson!

Higgs Mechanism: If a LOCAL gauge symmetry is spontaneously broken, then the gauge boson acquires a mass by absorbing the Goldstone mode.

Mass generation

Higgs Mechanism DOES NOT require a Higgs boson!

Higgs Mechanism: If a LOCAL gauge symmetry is spontaneously broken, then the gauge boson acquires a mass by absorbing the Goldstone mode.

The predicted Higgs boson is the left-over particle!

Mass generation

Higgs Mechanism DOES NOT require a Higgs boson!

Higgs Mechanism: If a LOCAL gauge symmetry is spontaneously broken, then the gauge boson acquires a mass by absorbing the Goldstone mode.

The predicted Higgs boson is the left-over particle!

Higgs field → **4 =**

Mass generation

Higgs Mechanism DOES NOT require a Higgs boson!

Higgs Mechanism: If a LOCAL gauge symmetry is spontaneously broken, then the gauge boson acquires a mass by absorbing the Goldstone mode.

The predicted Higgs boson is the left-over particle!

Higgs field → 4 = 3

longitudinal modes of W^+, W^-, Z

Mass generation

Higgs Mechanism DOES NOT require a Higgs boson!

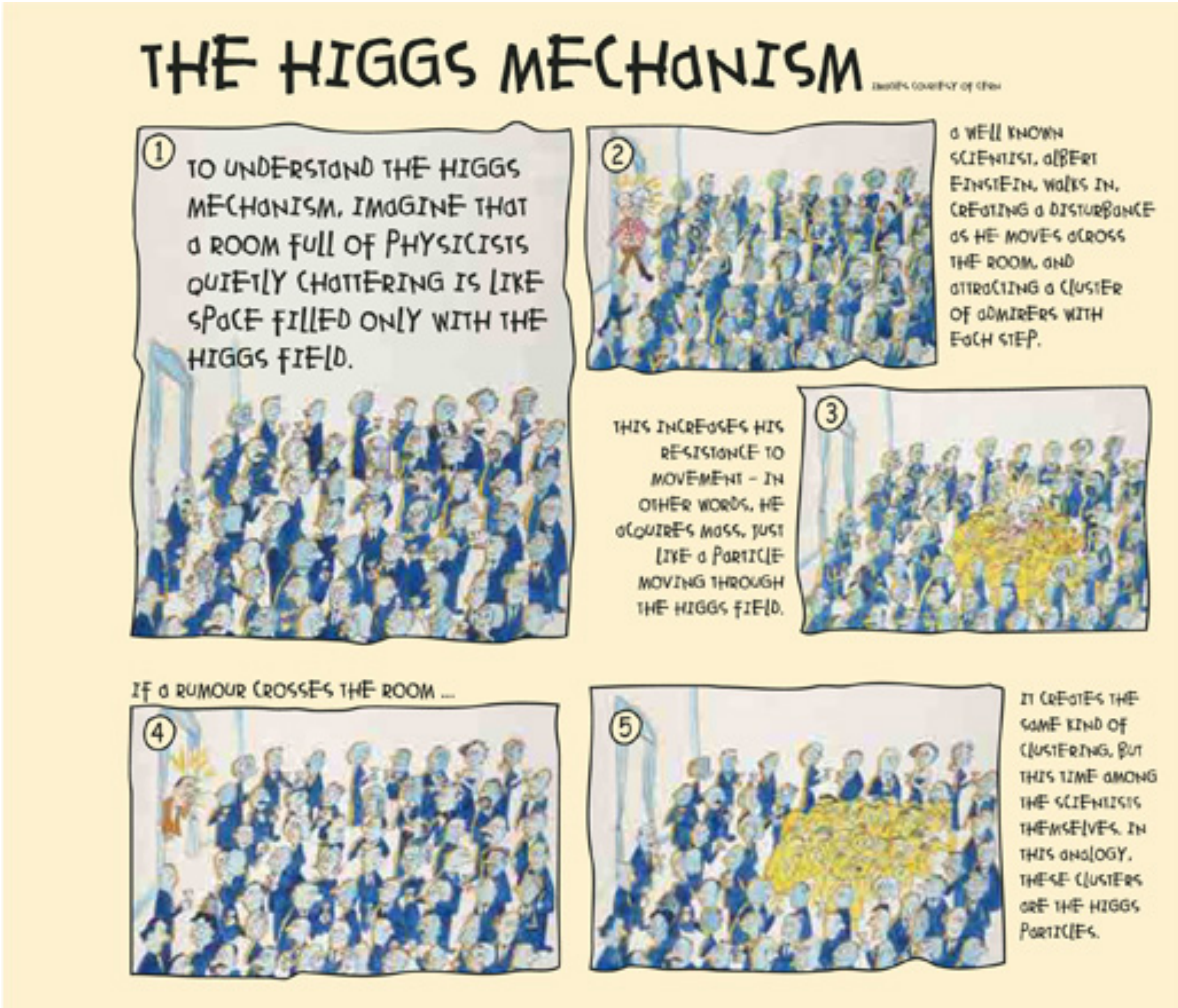
Higgs Mechanism: If a LOCAL gauge symmetry is spontaneously broken, then the gauge boson acquires a mass by absorbing the Goldstone mode.

The predicted Higgs boson is the left-over particle!

Higgs field → **4 = 3 + 1**

↑ 3: longitudinal modes of W^+, W^-, Z

↑ 1: physical Higgs Boson


THE HIGGS MECHANISM
1
TO UNDERSTAND THE HIGGS MECHANISM, IMAGINE THAT A ROOM FULL OF PHYSICISTS QUIETLY CHATTERING IS LIKE SPACE FILLED ONLY WITH THE HIGGS FIELD.
2
A WELL KNOWN SCIENTIST, ALBERT EINSTEIN, WALKS IN, CREATING A DISTURBANCE AS HE MOVES ACROSS THE ROOM, AND ATTRACTING A CLUSTER OF ADMIRERS WITH EACH STEP.
3
THIS INCREASES HIS RESISTANCE TO MOVEMENT – IN OTHER WORDS, HE ACQUIRES MASS, JUST LIKE A PARTICLE MOVING THROUGH THE HIGGS FIELD.
IF A RUMOUR CROSSES THE ROOM ...
4
5
IT CREATES THE SAME KIND OF CLUSTERING, BUT THIS TIME AMONG THE SCIENTISTS THEMSELVES. IN THIS ANALOGY, THESE CLUSTERS ARE THE HIGGS PARTICLES.

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

  dark matter and dark energies (96% of the Universe)

- ~~Higgs is responsible for the mass of your and me~~

  (and 4% of the Universe) QCD does it!

- Higgs is needed for the mass of elementary particles

  Higgs mechanism: Yes. Higgs particle: No.

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

  dark matter and dark energies (96% of the Universe)

- ~~Higgs is responsible for the mass of your and me~~

  (and 4% of the Universe) QCD does it!

- Higgs is needed for the mass of elementary particles

  Higgs mechanism: Yes. Higgs particle: No.

- SM is now complete with the discovery of the Higgs

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

  dark matter and dark energies (96% of the Universe)

- ~~Higgs is responsible for the mass of your and me~~

  (and 4% of the Universe) QCD does it!

- Higgs is needed for the mass of elementary particles

  Higgs mechanism: Yes. Higgs particle: No.

- SM is now complete with the discovery of the Higgs

..... THE END.

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

  dark matter and dark energies (96% of the Universe)

- ~~Higgs is responsible for the mass of your and me~~
  (and 4% of the Universe) QCD does it!

- Higgs is needed for the mass of elementary particles

  Higgs mechanism: Yes. Higgs particle: No.

- SM is now complete with the discovery of the Higgs

..... ~~THE END.~~

Quiz!!!

- ~~Higgs is responsible for the mass of Universe~~

  dark matter and dark energies (96% of the Universe)

- ~~Higgs is responsible for the mass of your and me~~

  (and 4% of the Universe) QCD does it!

- Higgs is needed for the mass of elementary particles

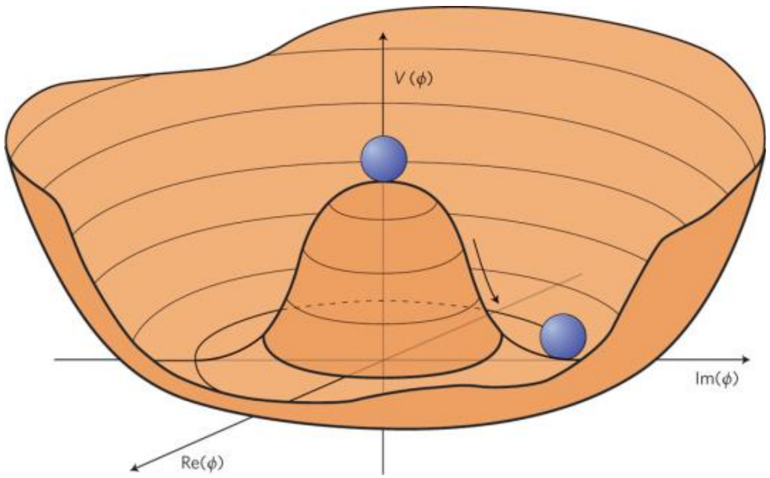
  Higgs mechanism: Yes. Higgs particle: No.

- SM is now complete with the discovery of the Higgs

..... ~~THE END.~~ Beginning of a new Era !!!

On the theory side…

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV



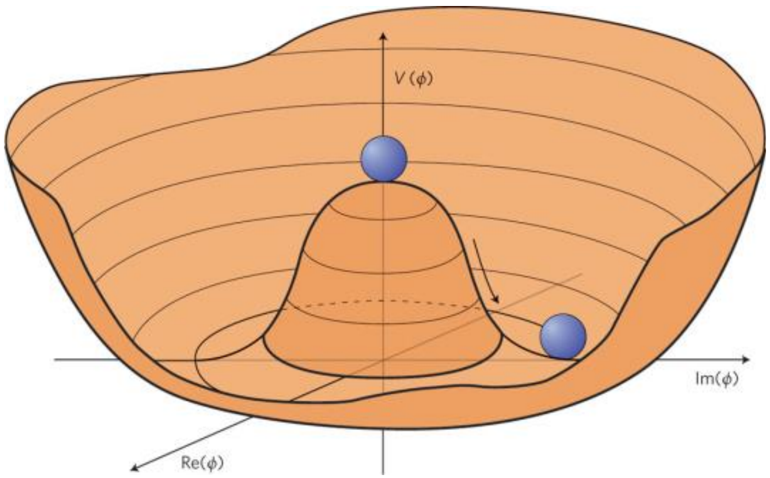
$$V(\phi) = \frac{1}{2}\mu_h^2\phi^2 + \frac{\lambda}{4}\phi^4$$

$$\langle\phi\rangle \equiv v \neq 0 \quad \rightarrow \quad m_W = g_W \frac{v}{2}$$

$$M_H^2 = -2\mu^2 = 2\lambda v^2$$

On the theory side…

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV



$$V(\phi) = \frac{1}{2}\mu_h^2\phi^2 + \frac{\lambda}{4}\phi^4$$

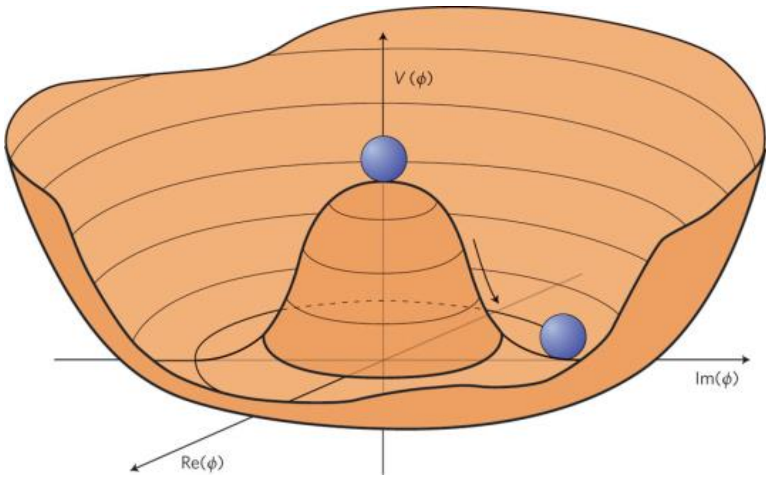
$$\langle\phi\rangle \equiv v \neq 0 \quad \rightarrow \; m_W = g_W \frac{v}{2}$$

$$M_H^2 = -2\mu^2 = 2\lambda v^2$$

- μ_h, λ measured, not predicted. $\lambda \sim 1/8$, A new force?

On the theory side...

light, weakly coupled boson: m_h = 125-126 GeV, $\Gamma < 1$ GeV



$$V(\phi) = \frac{1}{2}\mu_h^2\phi^2 + \frac{\lambda}{4}\phi^4$$

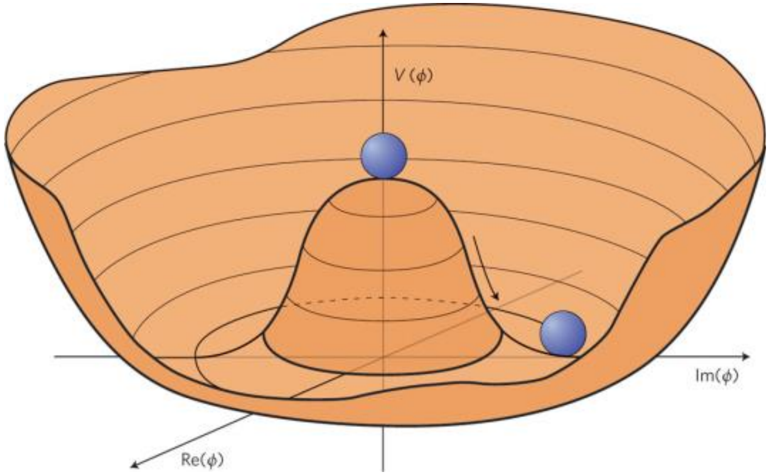
$$\langle\phi\rangle \equiv v \neq 0 \quad \rightarrow \quad m_W = g_W \frac{v}{2}$$

$$M_H^2 = -2\mu^2 = 2\lambda v^2$$

- μ_h, λ measured, not predicted. $\lambda \sim 1/8$, A new force?
- like phase-transition in superconductor, however,

On the theory side...

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV



$$V(\phi) = \frac{1}{2}\mu_h^2\phi^2 + \frac{\lambda}{4}\phi^4$$

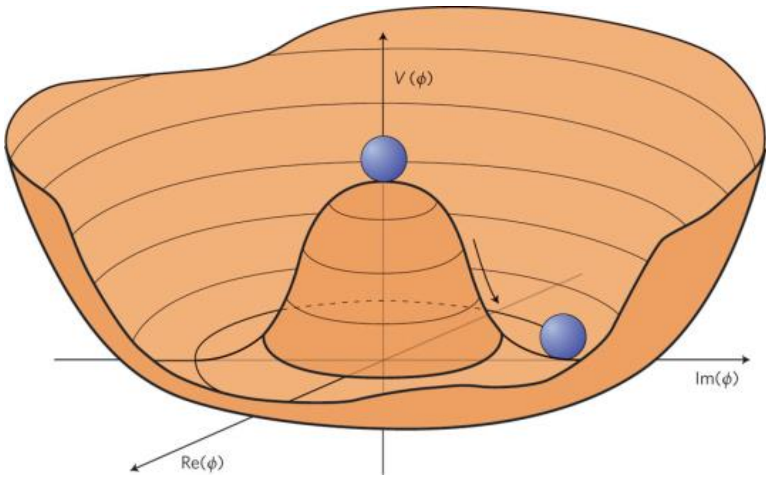
$$\langle\phi\rangle \equiv v \neq 0 \quad \rightarrow \; m_W = g_W\frac{v}{2}$$

$$M_H^2 = -2\mu^2 = 2\lambda v^2$$

- μ_h, λ measured, not predicted. λ ~ 1/8, A new force?
- like phase-transition in superconductor, however,
  - ➡ not in known material

On the theory side...

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV



$$V(\phi) = \frac{1}{2}\mu_h^2\phi^2 + \frac{\lambda}{4}\phi^4$$

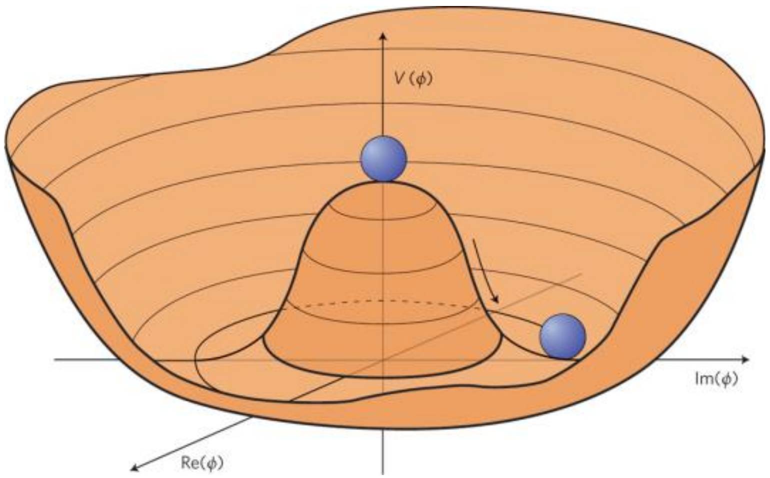
$$\langle\phi\rangle \equiv v \neq 0 \quad \rightarrow \quad m_W = g_W\frac{v}{2}$$

$$M_H^2 = -2\mu^2 = 2\lambda v^2$$

- μ_h, λ measured, not predicted. $\lambda \sim 1/8$, A new force?
- like phase-transition in superconductor, however,
  - ➡ not in known material
  - ➡ nobody dials the temperature from outside

On the theory side…

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV



$$V(\phi) = \frac{1}{2}\mu_h^2\phi^2 + \frac{\lambda}{4}\phi^4$$

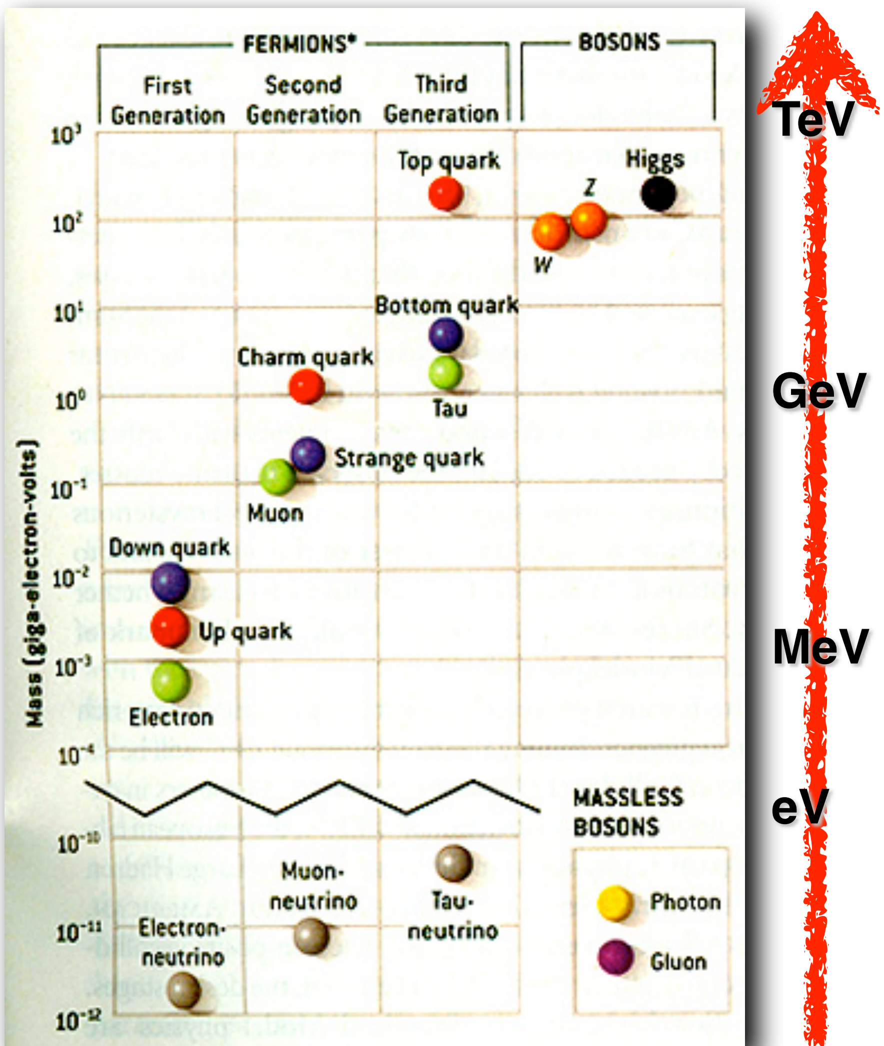
$$\langle\phi\rangle \equiv v \neq 0 \quad \rightarrow \quad m_W = g_W \frac{v}{2}$$

$$M_H^2 = -2\mu^2 = 2\lambda v^2$$

- μ_h, λ measured, not predicted. $\lambda \sim 1/8$, A new force?
- like phase-transition in superconductor, however,
  - ➡ not in known material
  - ➡ nobody dials the temperature from outside
- parameters in V need to come from an (unknown) fundamental theory

Standard Model

Image credit: Gordon Kane, Scientific American, June 2003.

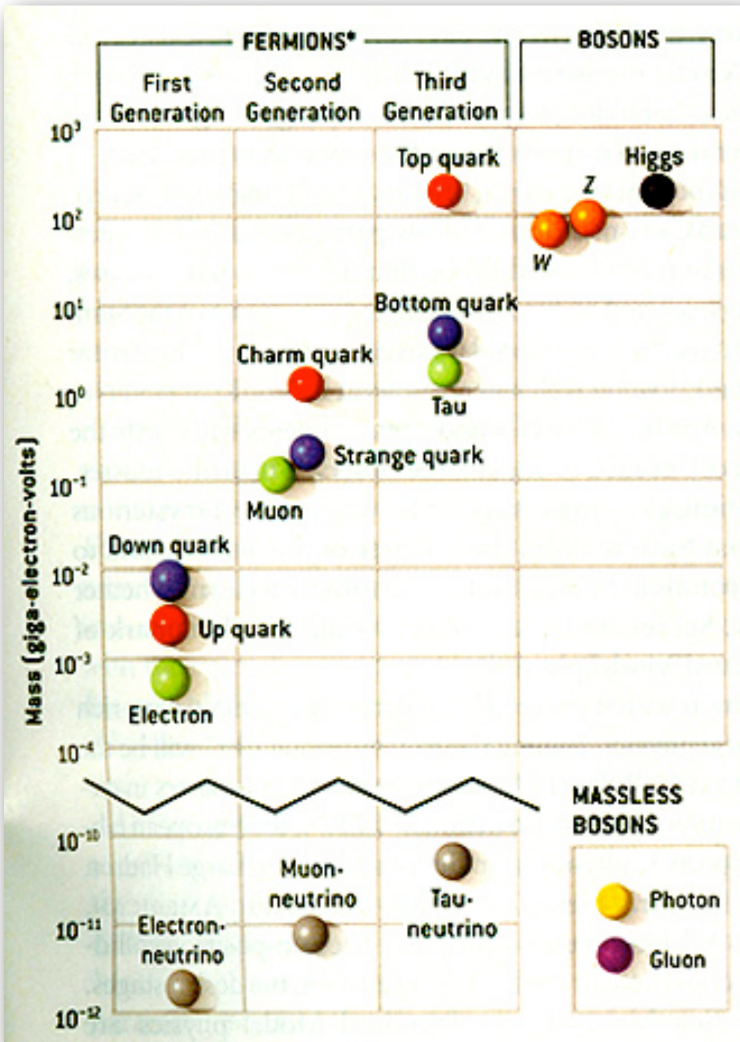


$\lambda_q \sim m_q/v$

All couplings and parameters of the Higgs sector is determined in the SM.

Standard Model

Image credit: Gordon Kane, Scientific American, June 2003.



$\lambda_q \sim m_q/v$

All couplings and parameters of the Higgs sector is determined in the SM.

To compare with measurements high precise needed!

- clean environments
- lots of Higgs

➡ **Higgs factory!**

A light SM Higgs is puzzling...

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

A light SM Higgs is puzzling...

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

Higgs: a new kind of elementary particle!

A light SM Higgs is puzzling...

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

Higgs: a new kind of elementary particle!

Nothing protects its mass.

A light SM Higgs is puzzling...

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

Higgs: a new kind of elementary particle!

Nothing protects its mass.

→ New physics beyond the SM

On the exp side…

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV

S. Su

On the exp side…

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV

Experimentally …

On the exp side...

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV

Experimentally ...

On the exp side...

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV

Experimentally ...

- Is it a SM Higgs? Mass, width, spin, coupling, CP,...

On the exp side...

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV

Experimentally ...

- Is it a SM Higgs? Mass, width, spin, coupling, CP,...
- Is there more than one Higgs boson?

On the exp side…

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV

Experimentally …

- Is it a SM Higgs? Mass, width, spin, coupling, CP,…
- Is there more than one Higgs boson?
- Does this H decay to other things unexpected?

On the exp side...

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV

Experimentally ...

- Is it a SM Higgs? Mass, width, spin, coupling, CP,...
- Is there more than one Higgs boson?
- Does this H decay to other things unexpected?
- Can we use H to look for new physics?

S. Su

On the exp side…

light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV

Experimentally ...

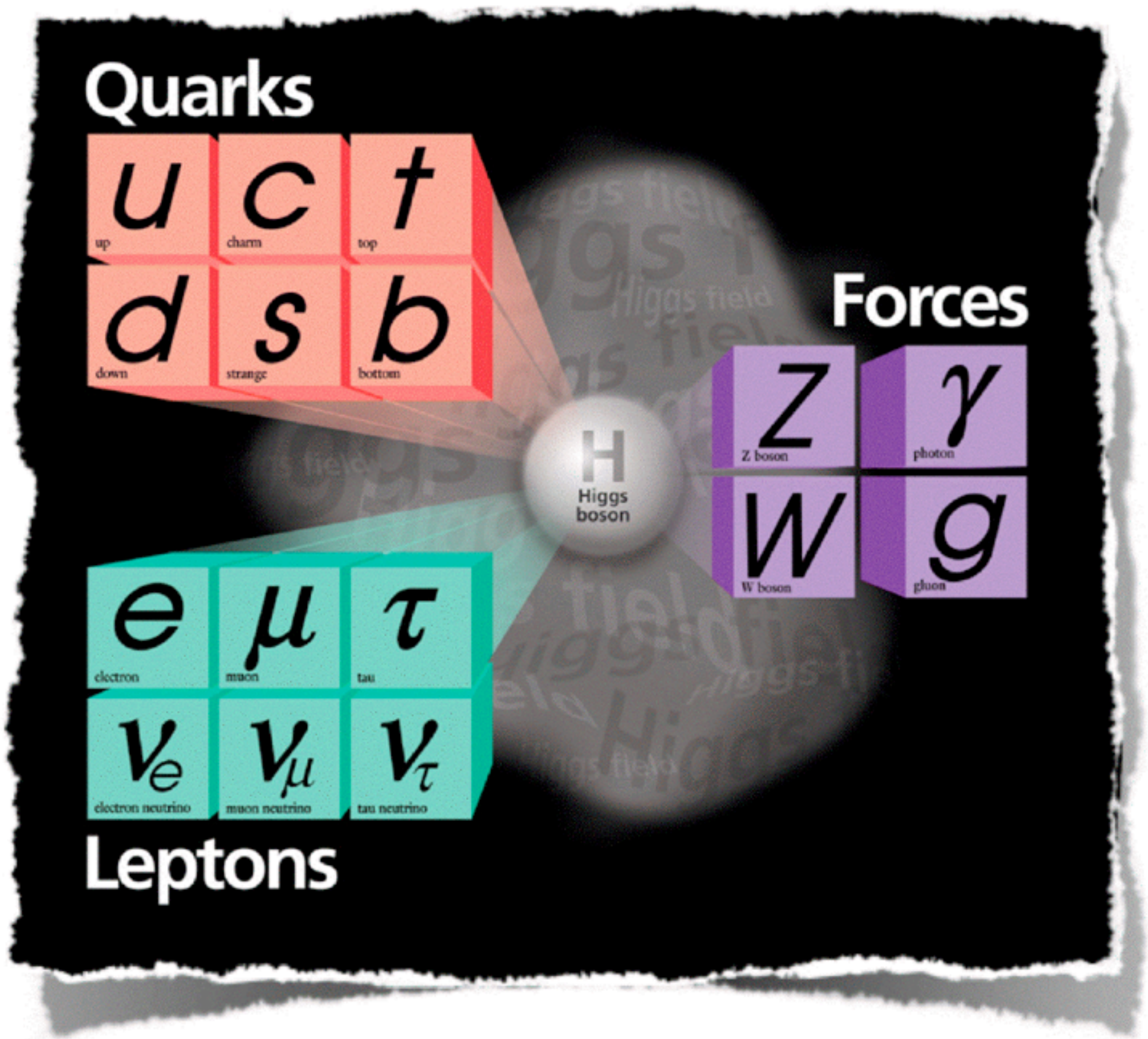
- Is it a SM Higgs? Mass, width, spin, coupling, CP,...
- Is there more than one Higgs boson?
- Does this H decay to other things unexpected?
- Can we use H to look for new physics?
- Where is new physics? top partners? Dark matter?

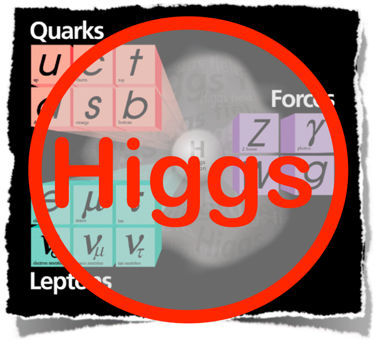
On the exp side...

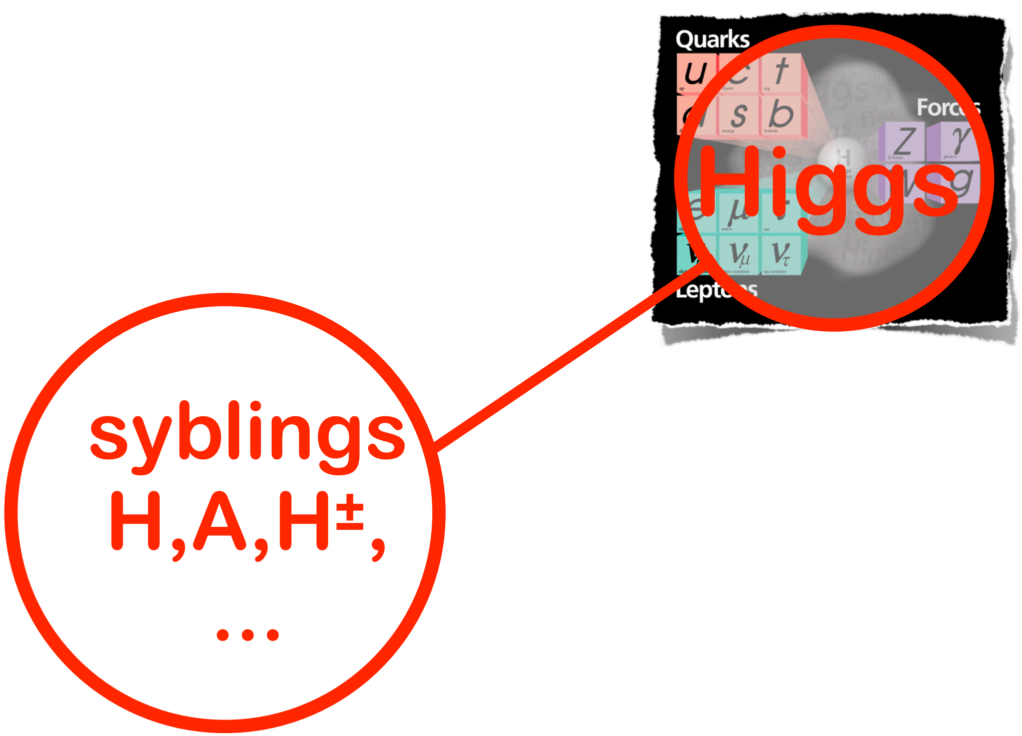
light, weakly coupled boson: m_h = 125-126 GeV, Γ < 1 GeV

Experimentally ...

- Is it a SM Higgs? Mass, width, spin, coupling, CP,...
- Is there more than one Higgs boson?
- Does this H decay to other things unexpected?
- Can we use H to look for new physics?
- Where is new physics? top partners? Dark matter?
- ...

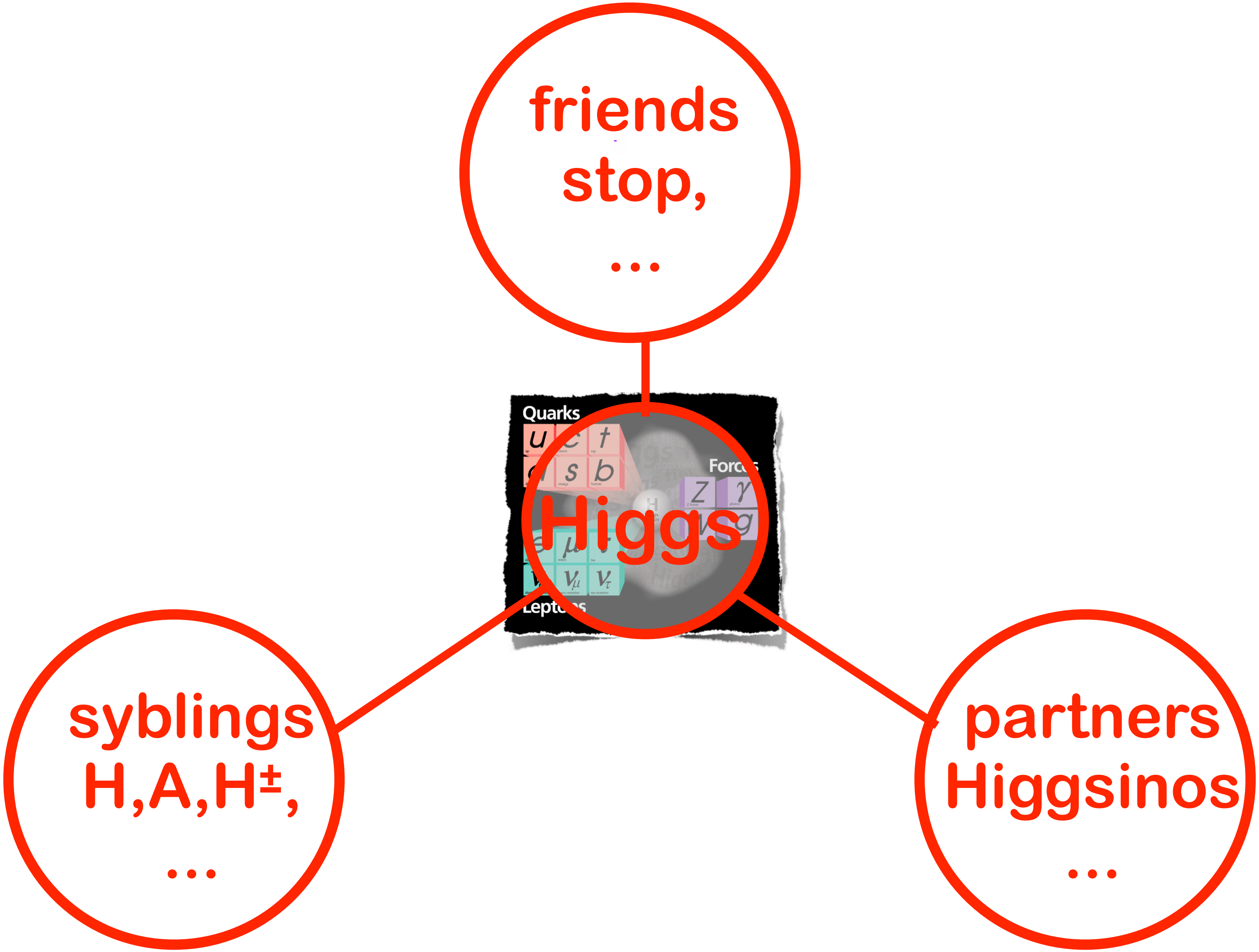

Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
H
Higgs boson
e
electron
μ
muon
τ
tau
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
Leptons
Higgs field


Quarks
Forces
Leptons
Higgs

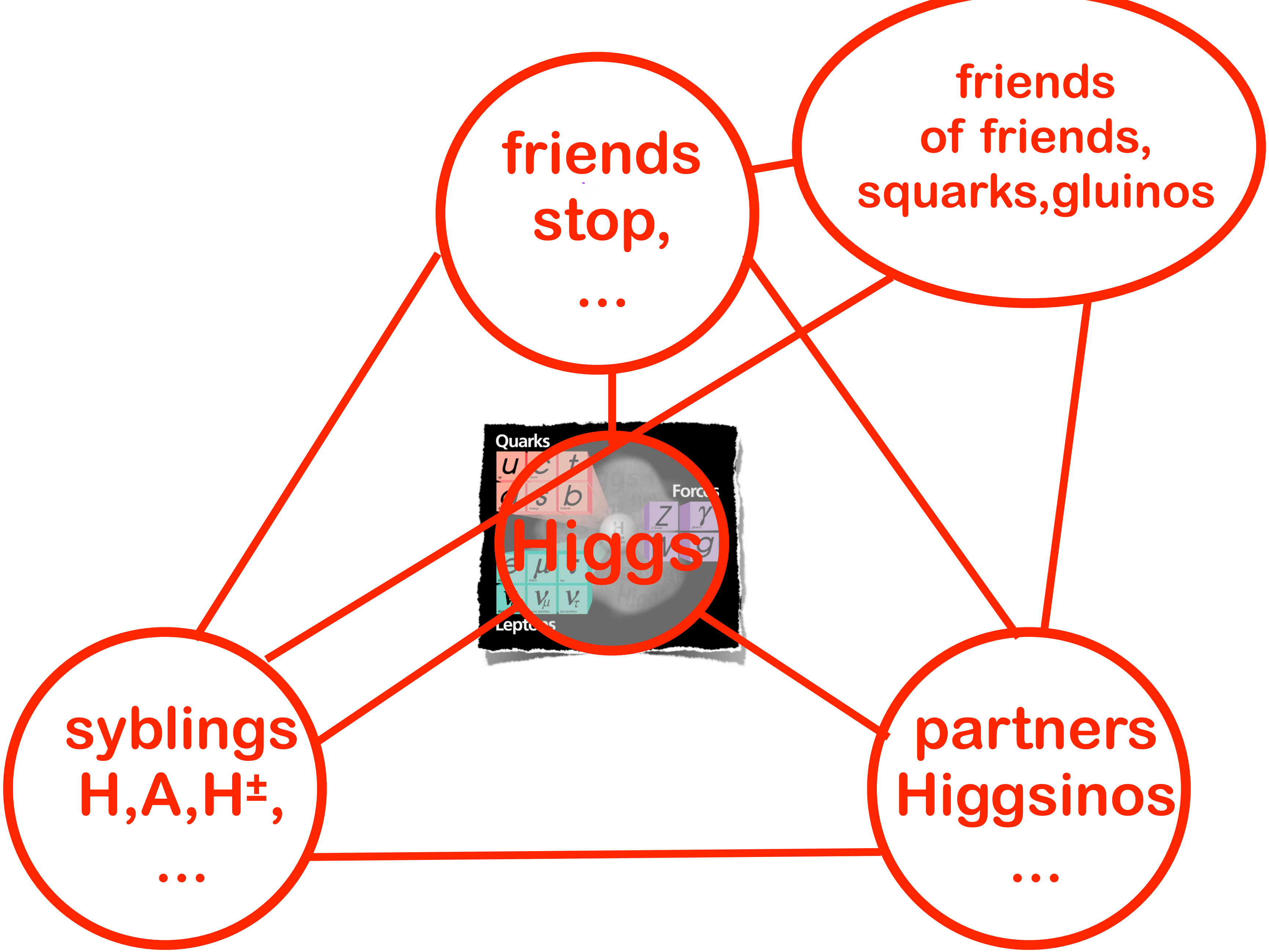


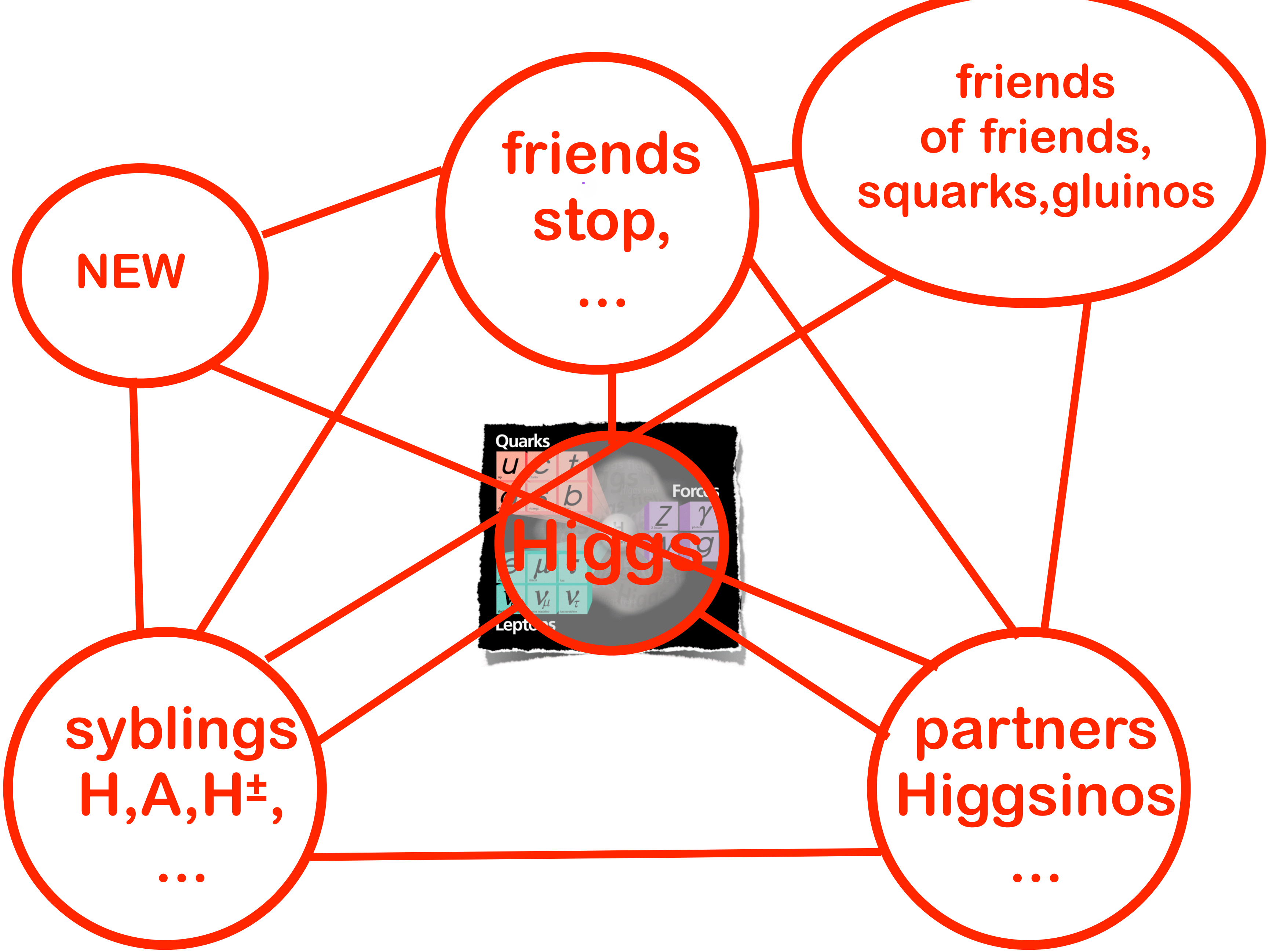
Quarks
Higgs
syblings
H,A,H±,
...

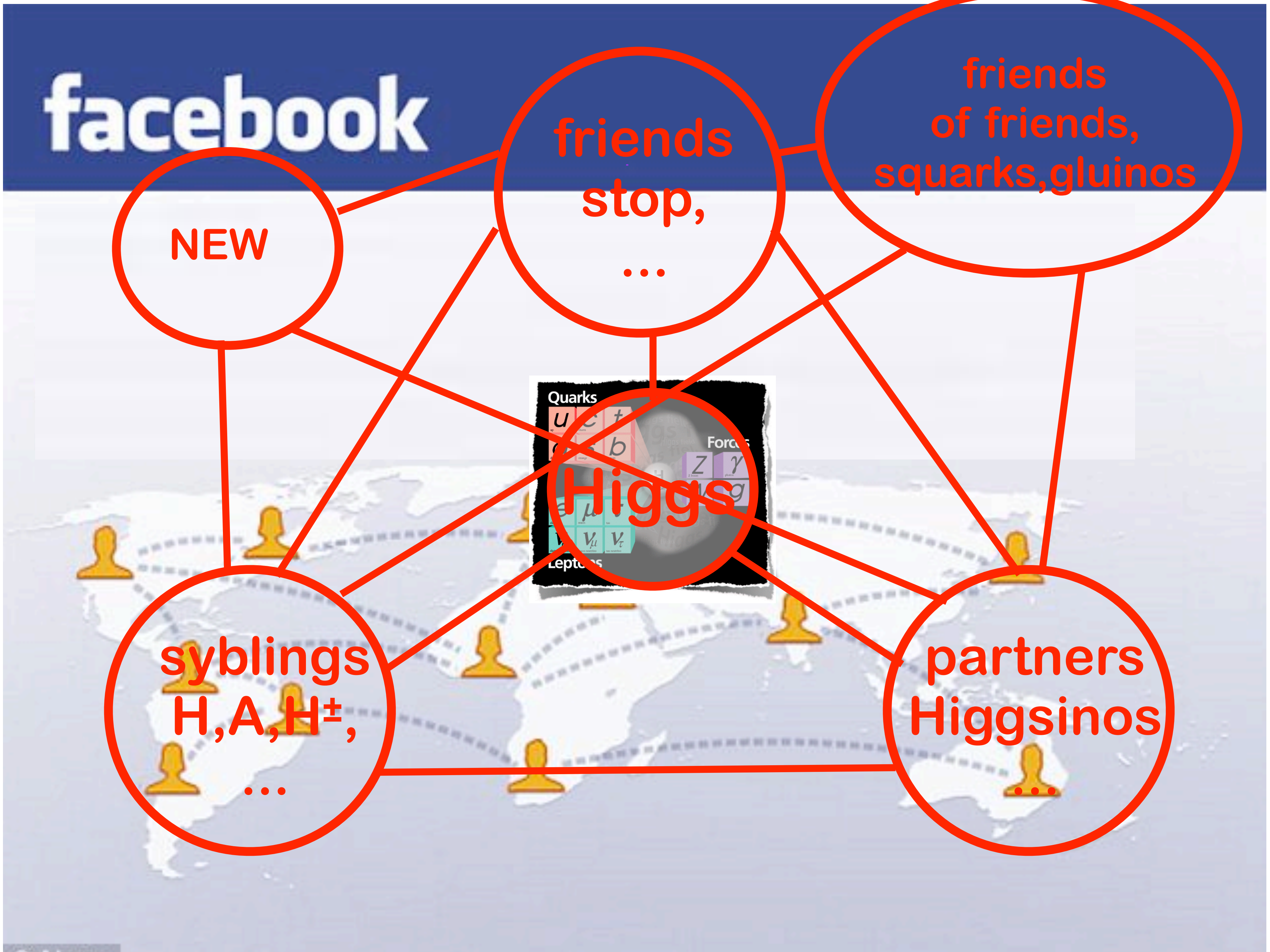

Quarks
Higgs
syblings
H,A,H±,
...
partners
Higgsinos
...


friends
stop,
...
Quarks
Higgs
syblings
H,A,H±,
...
partners
Higgsinos
...


friends
stop,
...
friends
of friends,
squarks,gluinos
Higgs
Quarks
syblings
H,A,H±,
...
partners
Higgsinos
...

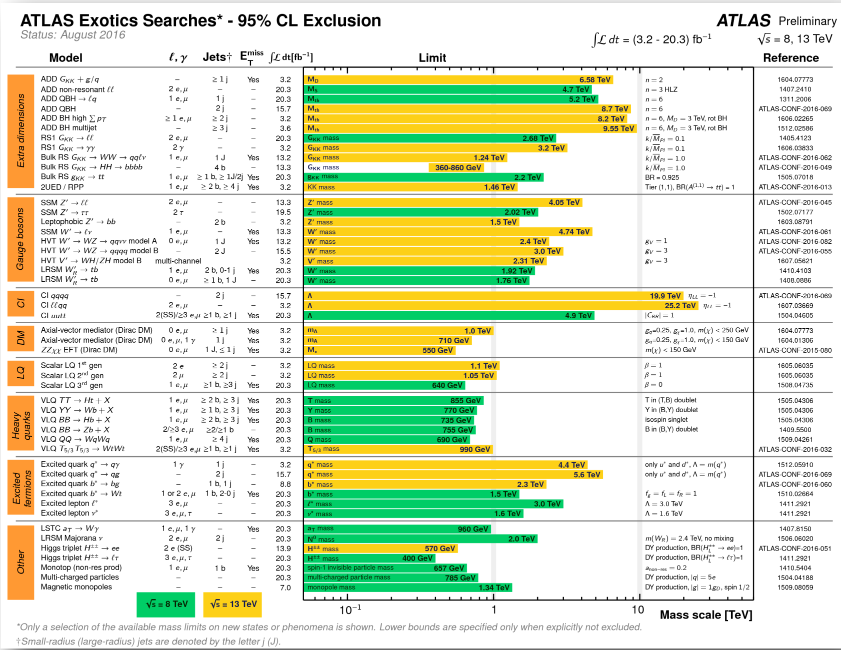

friends
stop,
...
friends
of friends,
squarks,gluinos
Quarks
Higgs
syblings
H,A,H±,
...
partners
Higgsinos
...


friends
of friends,
squarks,gluinos
friends
stop,
...
NEW
Higgs
Quarks
syblings
H,A,H±,
...
partners
Higgsinos
...

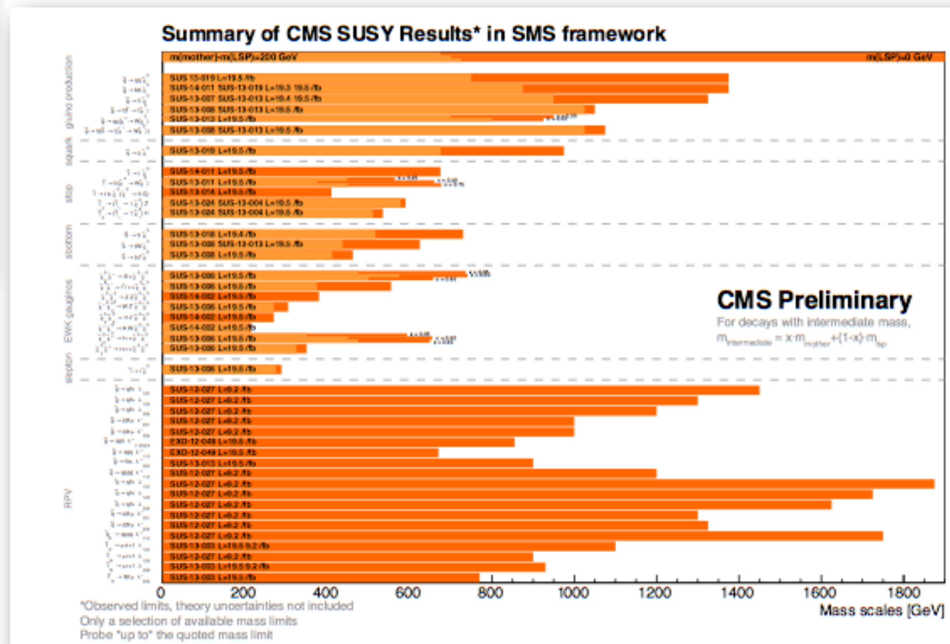

facebook
friends
stop,
...
friends
of friends,
squarks,gluinos
NEW
Quarks
Higgs
syblings
H,A,H±,
...
partners
Higgsinos
...

facebook
friends
friends
of friends,
uinos
W, Z
W, Z
Higgs Boson
Add Friend
Message
Timeline
About
Photos
Friends 9 Mutual
More
About
To see what he shares with friends, send him a friend request.
Add Friend
9 Mutual Friends
Work and Education
CERN
Scalar elementary particle · Geneva, Switzerland · Jan 1980 to present
Fermi National Accelerator Laboratory
European Center for Nuclear Research
CERN
Places Lived
France
Italy
Geneva, Switzerland
Hometown
Basic Information
Birthday September 29, 1954
Gender Male
rs
nos

New Physics Searches



ATLAS exotic

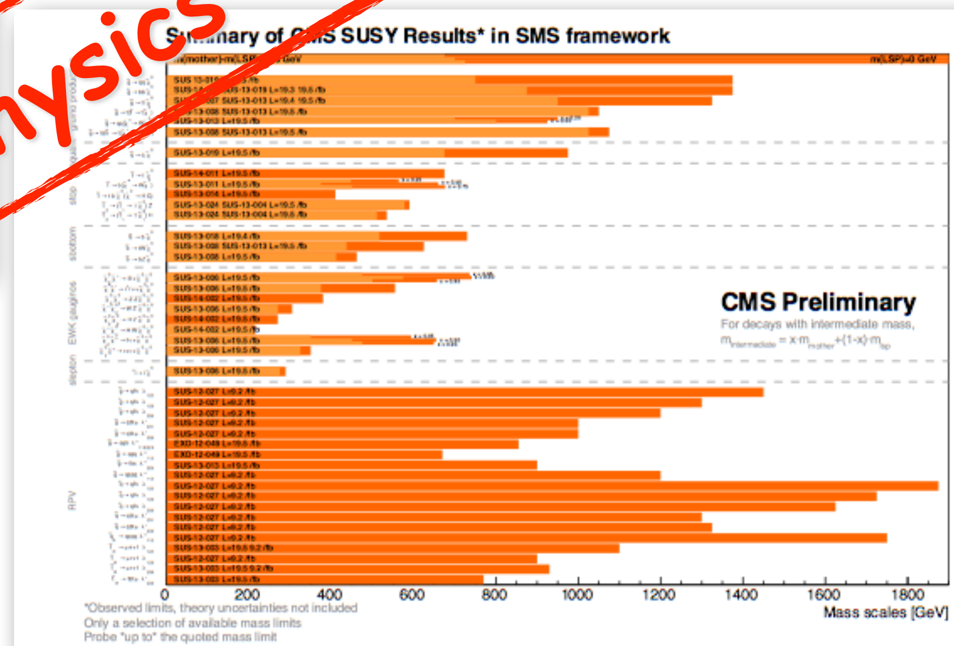


CMS SUSY

New Physics Searches

ATLAS exotic

No New Physics Yet!

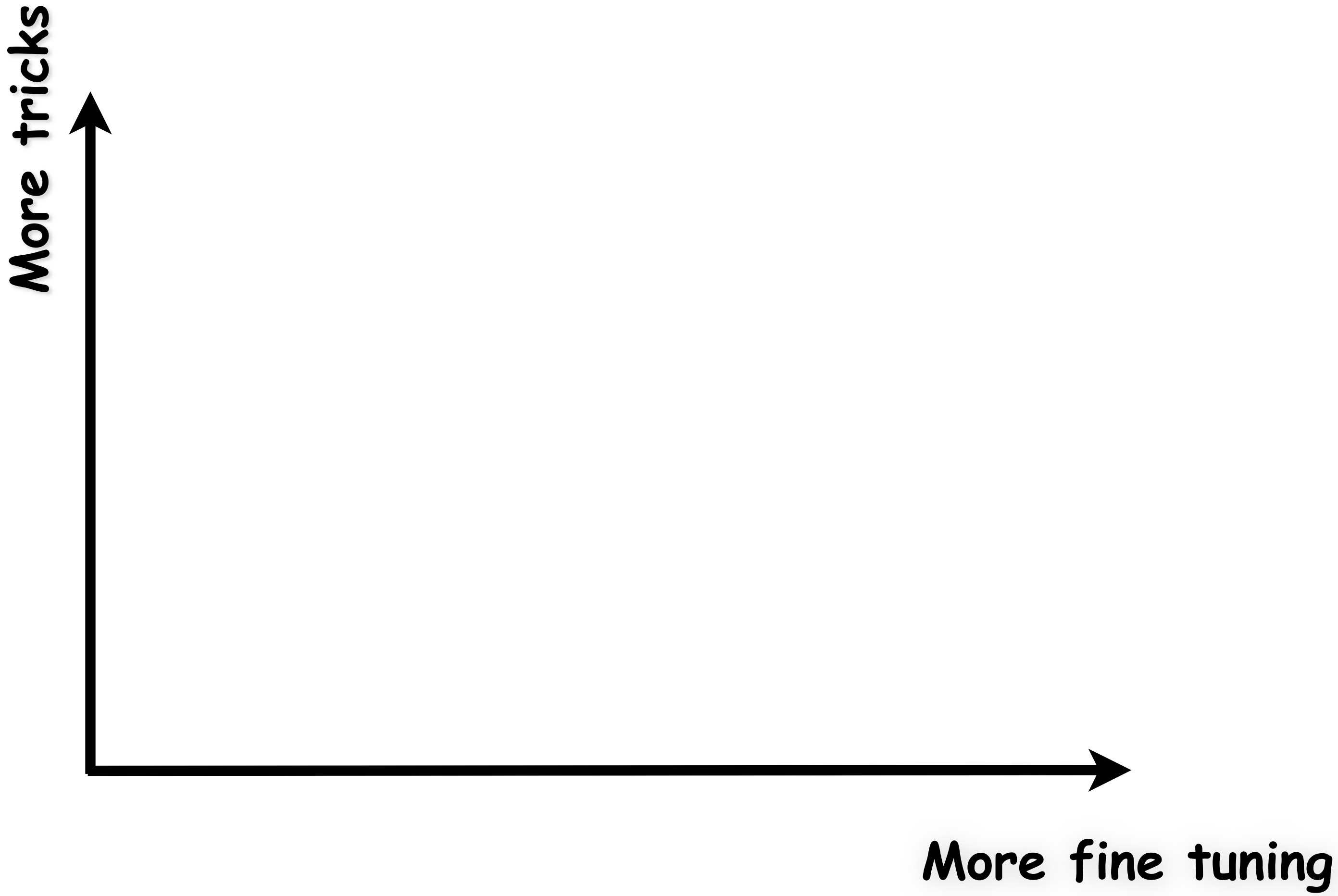


CMS SUSY

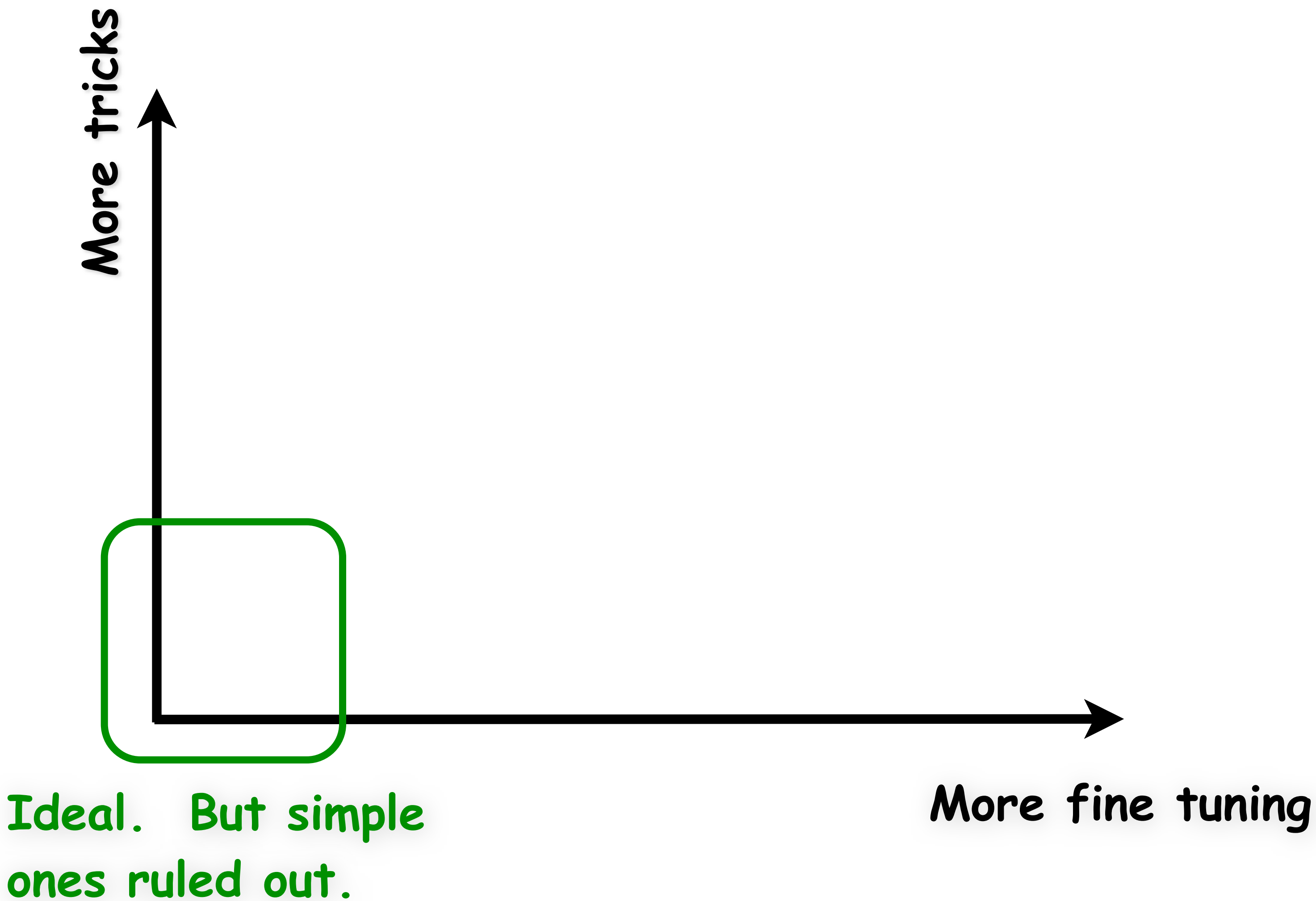
Where Are We Now?

- Our wish list has not change much from 10 years ago.
- Discovery of Higgs
  - ➡ Exclude technicolor
  - ➡ Narrow down parameter space
- Non-discovery of anything else
  - ➡ New physics gets heavier
  - ➡ A bit uncomfortable, big picture unchanged

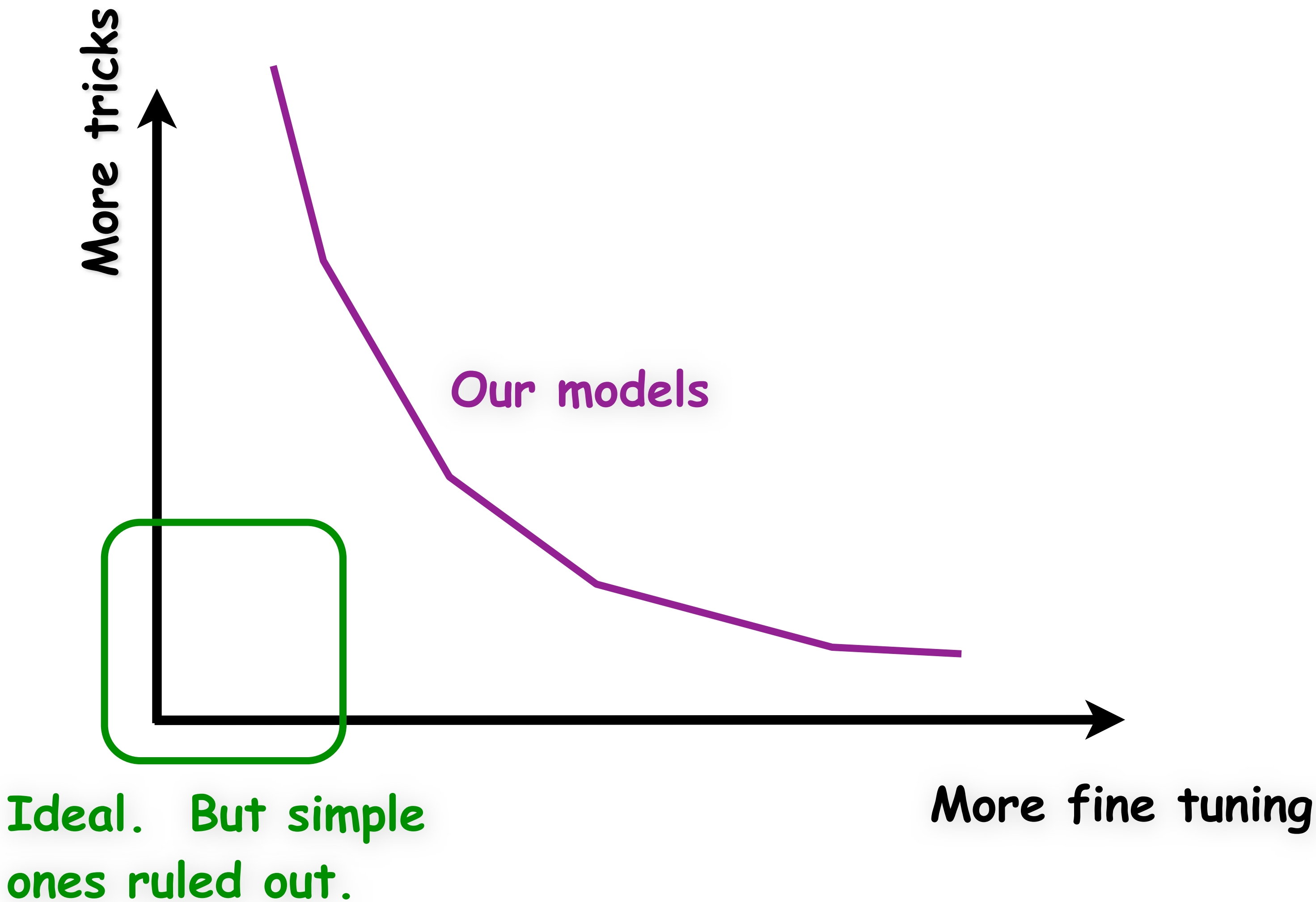
What Do Theorists Say?



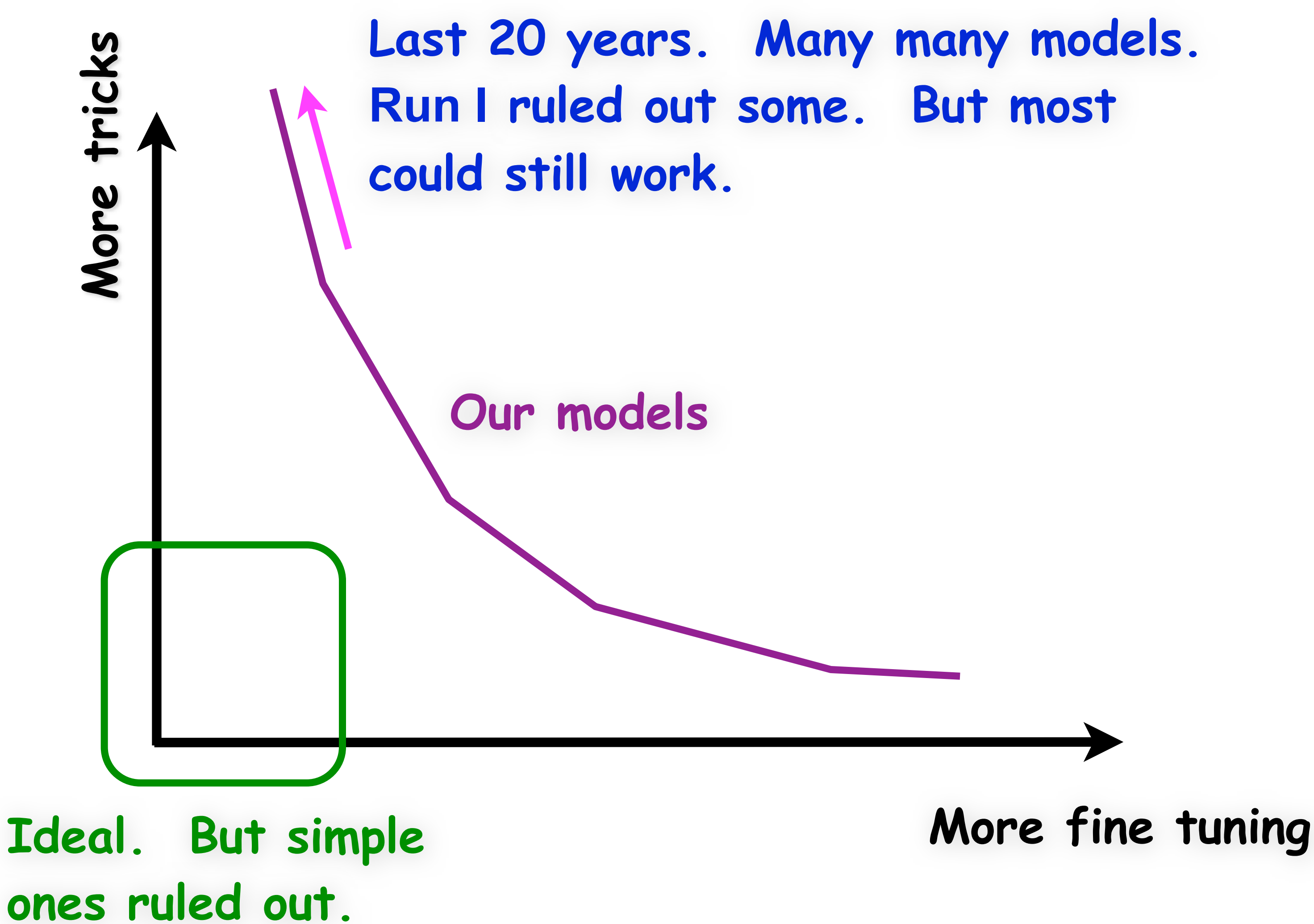
What Do Theorists Say?



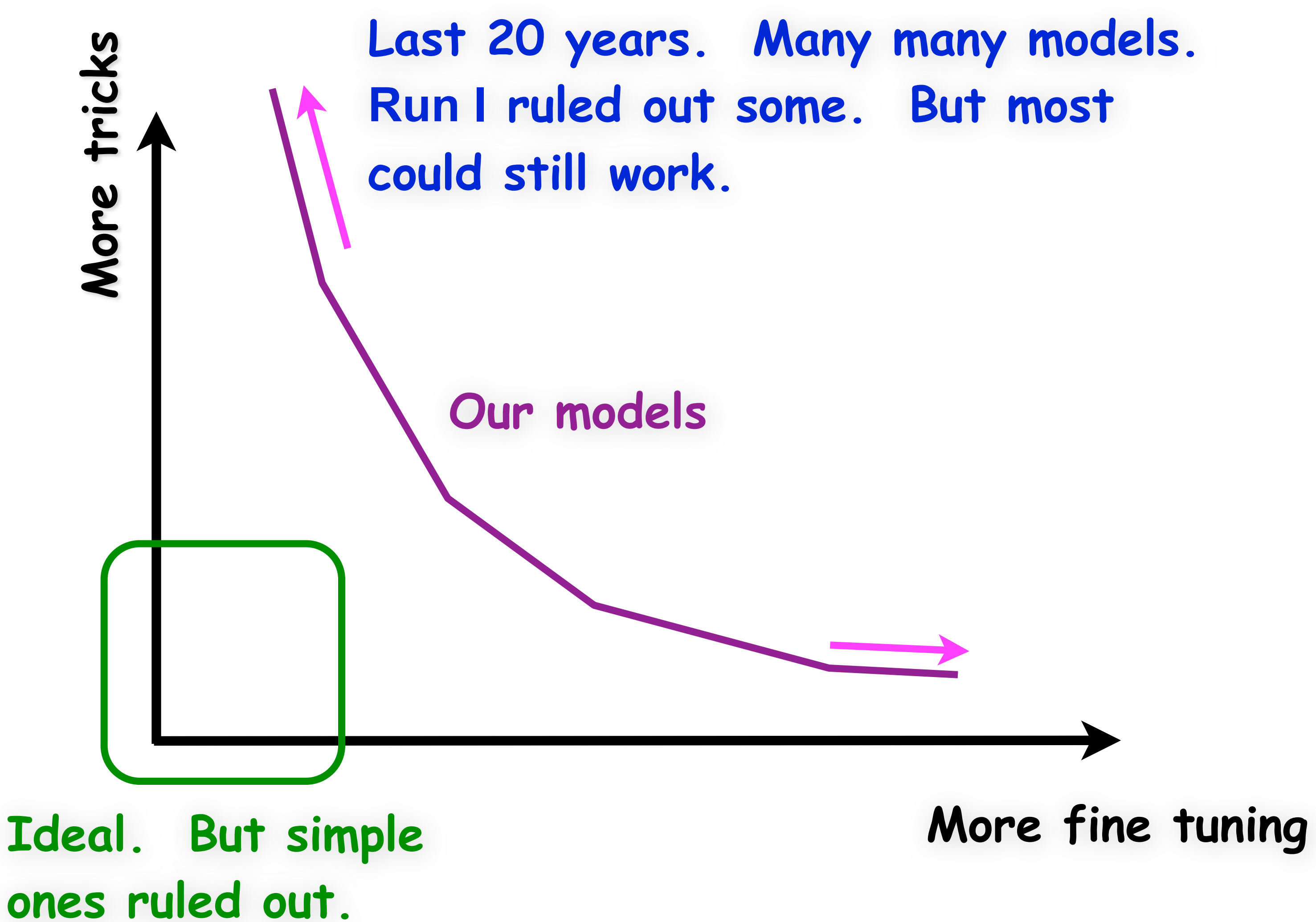
What Do Theorists Say?



What Do Theorists Say?



What Do Theorists Say?



Current and Future Colliders

<u>Where is New Physics?</u> larger mass? Small Coupling? Both?

- Indirect search

e+e-

- direct search

pp

Current and Future Colliders

Where is New Physics? larger mass? Small Coupling? Both?

- Indirect search

  e+e-

- direct search

  pp

→ E_{cm}

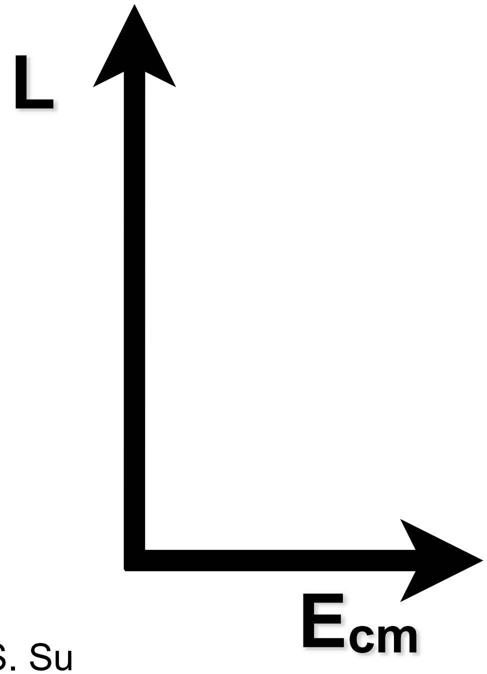
Current and Future Colliders

Where is New Physics? larger mass? Small Coupling? Both?

- Indirect search
- direct search

e+e-

pp



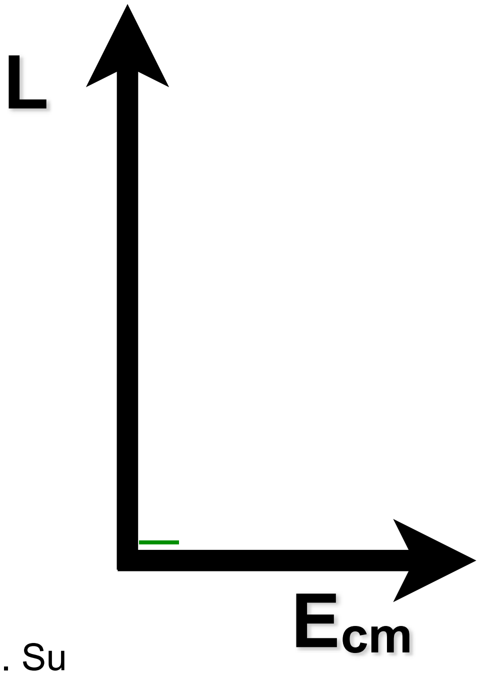
Current and Future Colliders

Where is New Physics? larger mass? Small Coupling? Both?

- Indirect search
- direct search

e+e-

pp



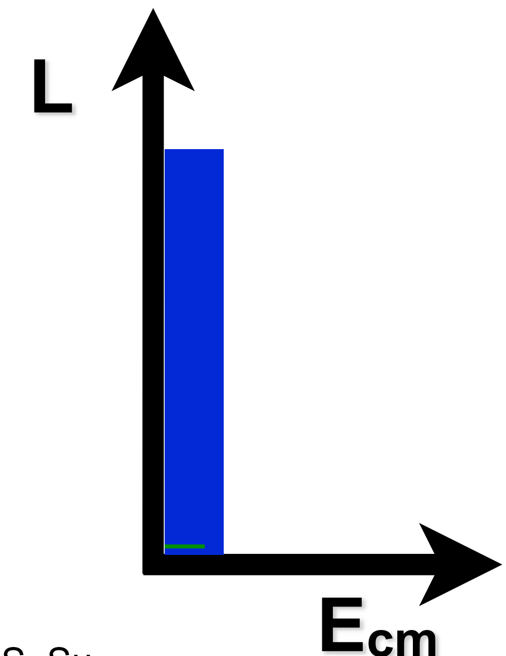
Current and Future Colliders

Where is New Physics? larger mass? Small Coupling? Both?

- Indirect search
- direct search

e+e-

pp



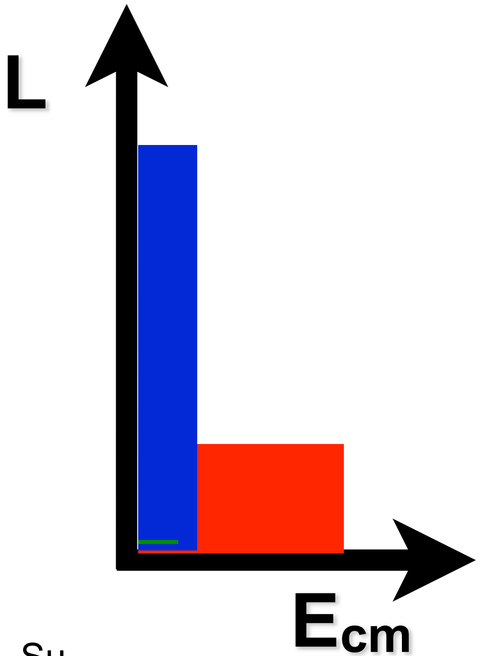
Current and Future Colliders

Where is New Physics? larger mass? Small Coupling? Both?

- Indirect search
- direct search

e+e-

pp



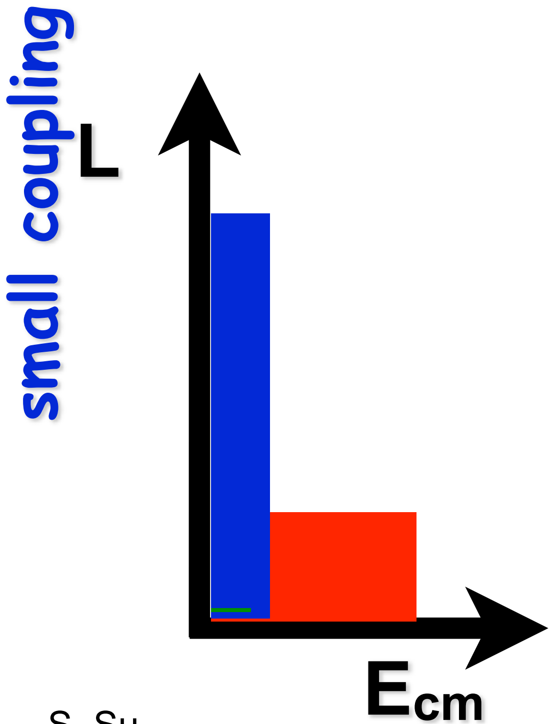
Current and Future Colliders

<u>Where is New Physics?</u> larger mass? Small Coupling? Both?

- Indirect search
- direct search

e+e-

pp



Current and Future Colliders

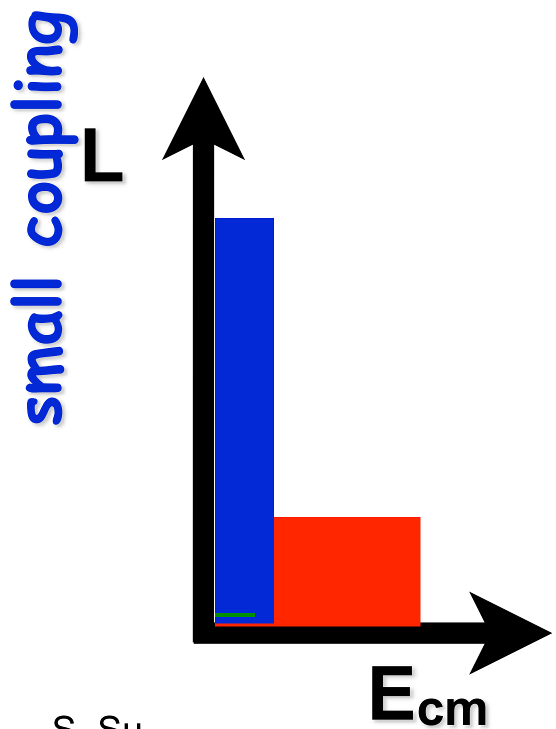
Where is New Physics? larger mass? Small Coupling? Both?

- Indirect search

e+e-

- direct search

pp

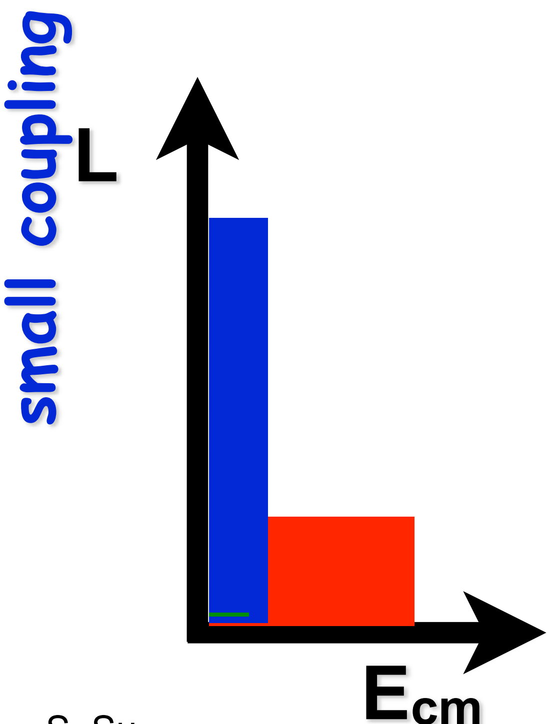


Current and Future Colliders

Where is New Physics? larger mass? Small Coupling? Both?

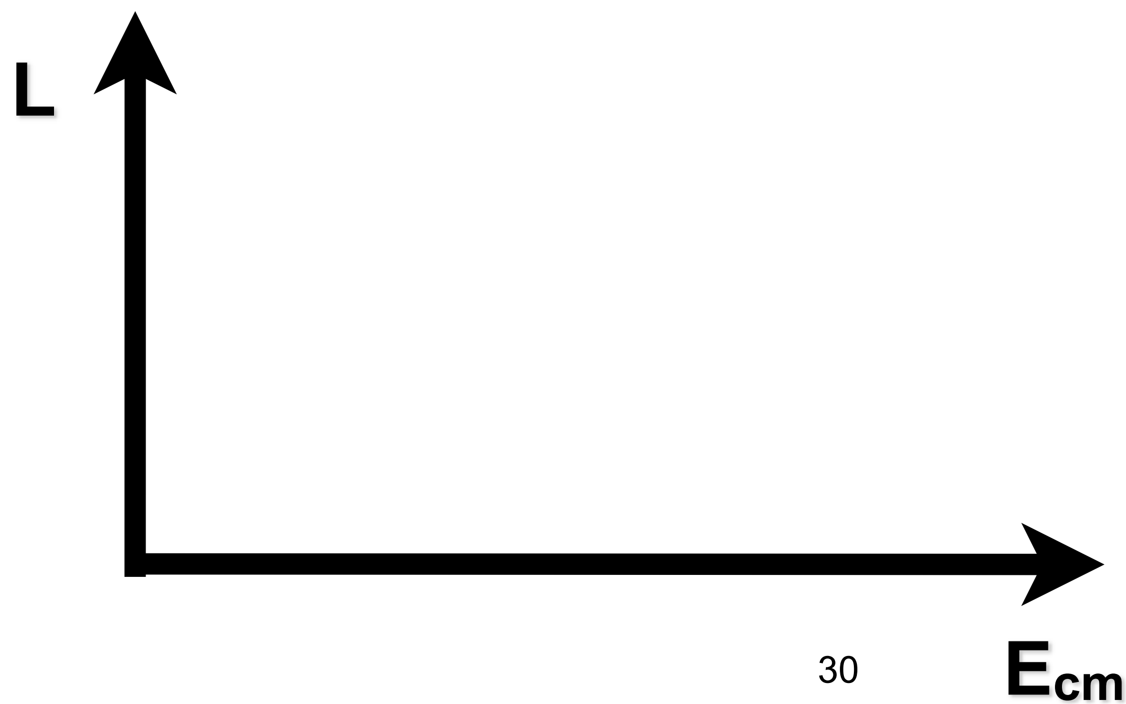
- Indirect search

e+e-



- direct search

pp



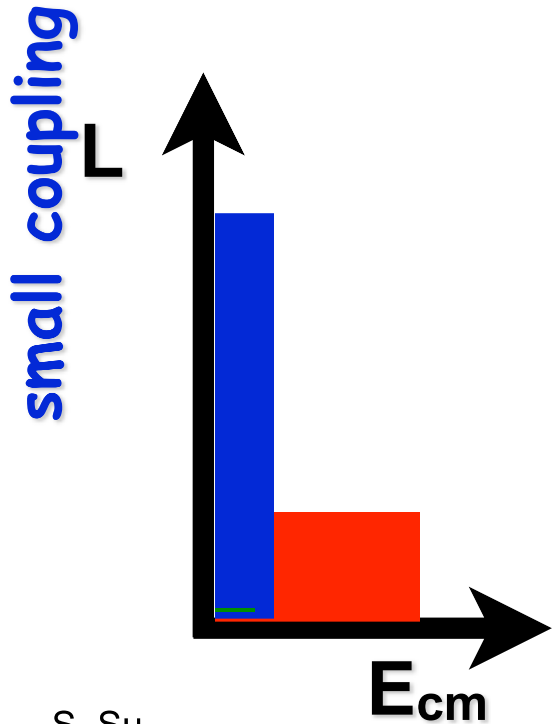
Current and Future Colliders

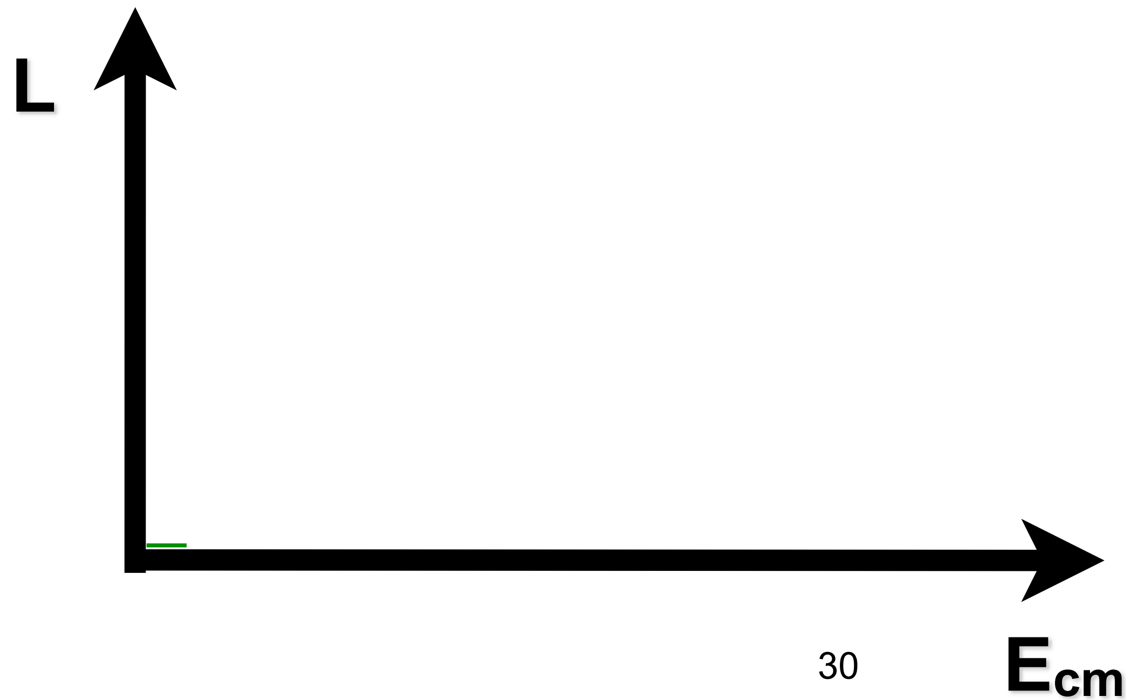
Where is New Physics? larger mass? Small Coupling? Both?

- Indirect search
- direct search

e+e-

pp



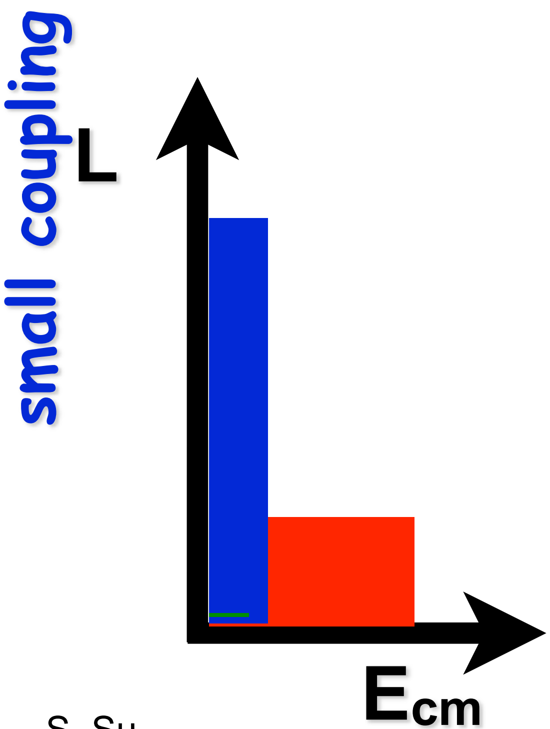


Current and Future Colliders

<u>Where is New Physics?</u> larger mass? Small Coupling? Both?

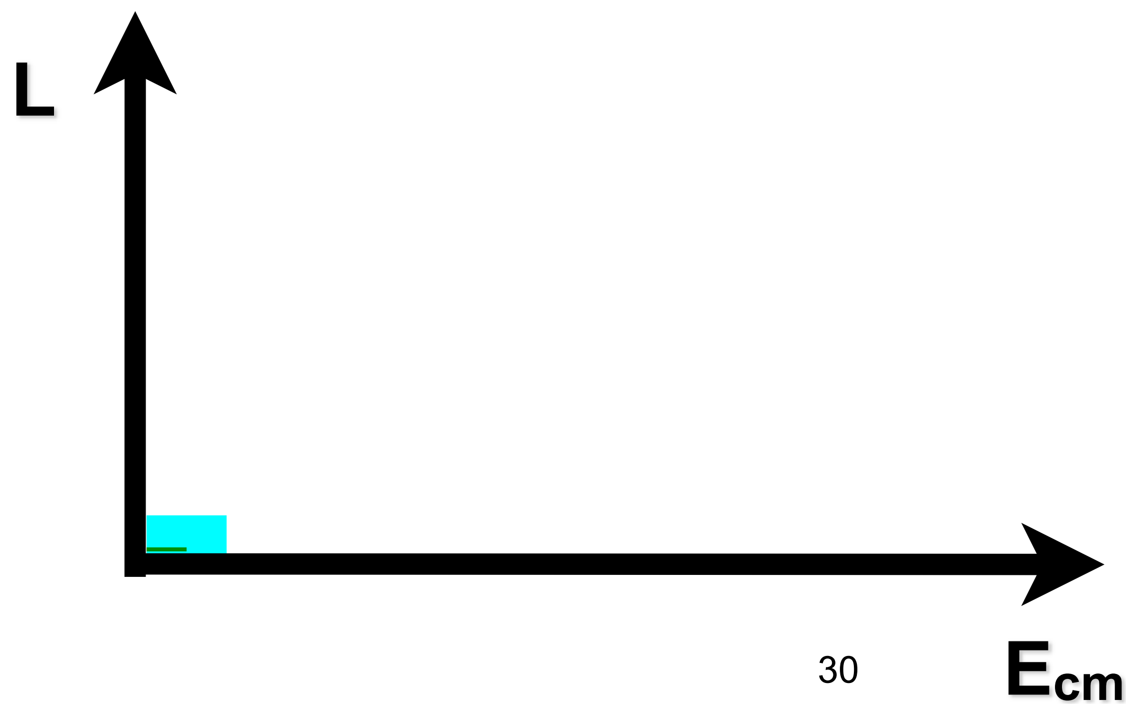
- Indirect search

e+e-



- direct search

pp

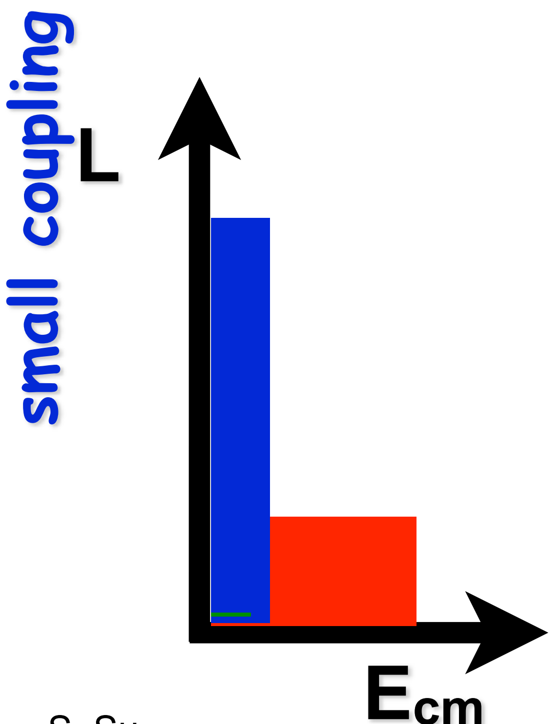


Current and Future Colliders

<u>Where is New Physics?</u> larger mass? Small Coupling? Both?

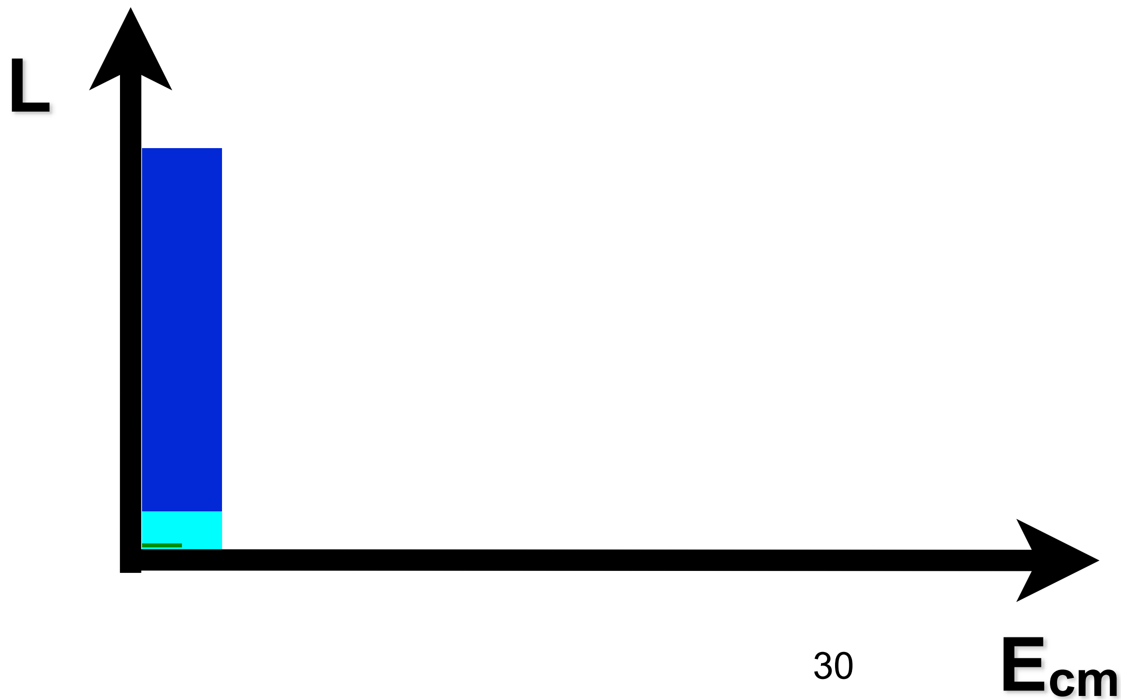
- Indirect search

e+e-



- direct search

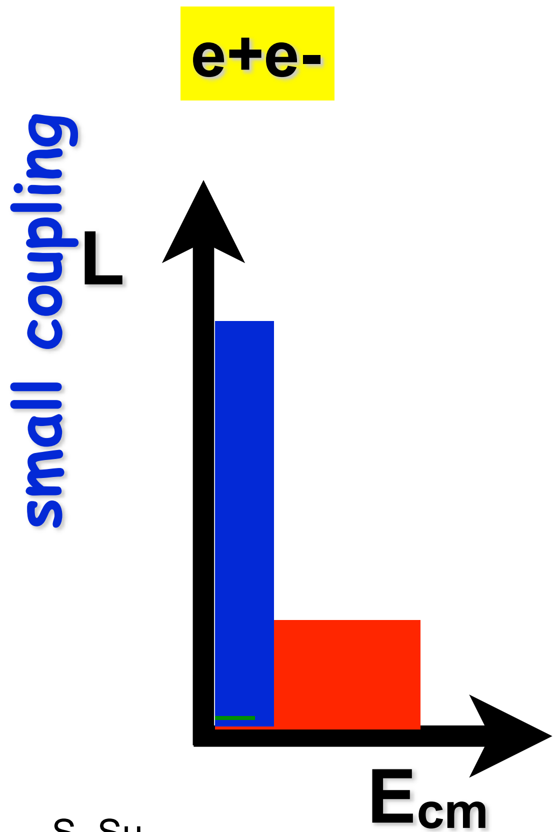
pp

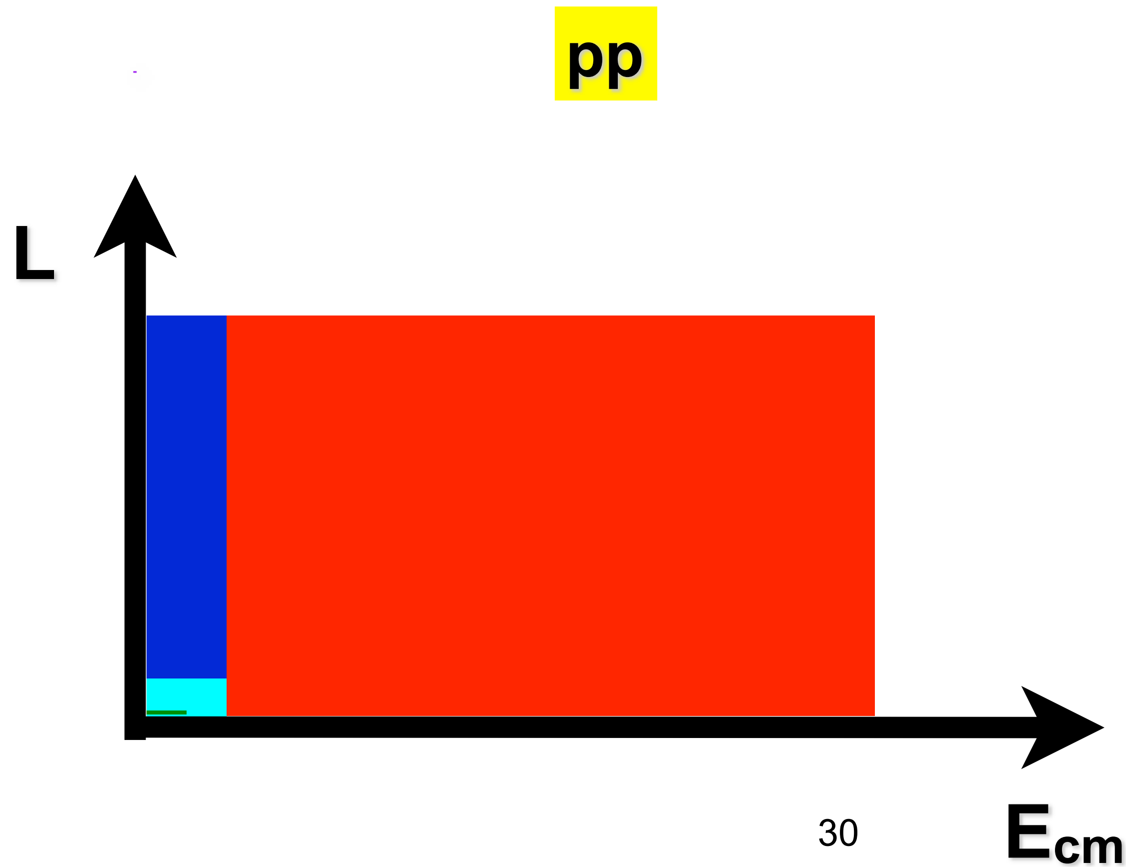


Current and Future Colliders

Where is New Physics? larger mass? Small Coupling? Both?

- Indirect search
- direct search

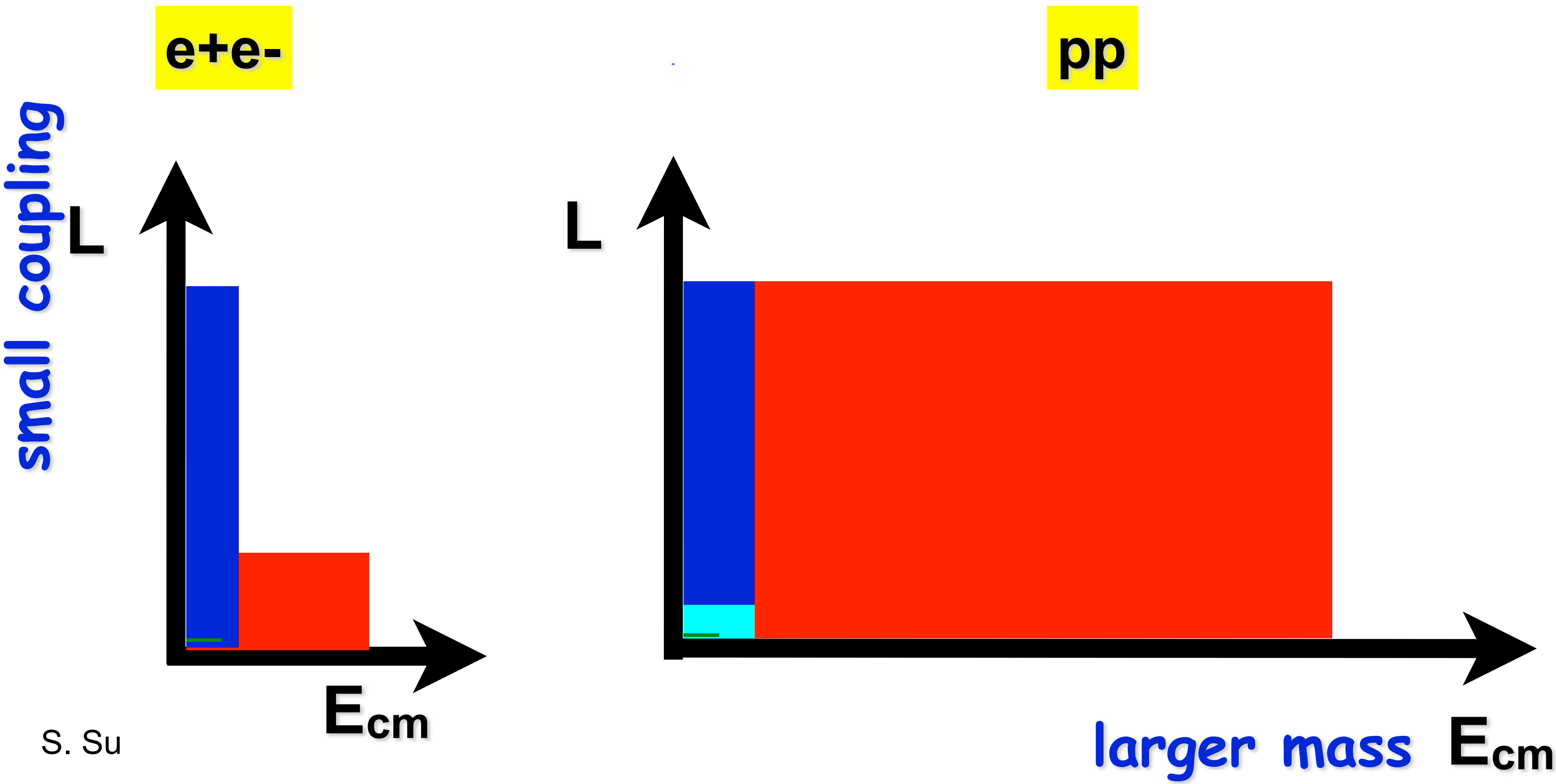




Current and Future Colliders

Where is New Physics? larger mass? Small Coupling? Both?

- Indirect search
- direct search

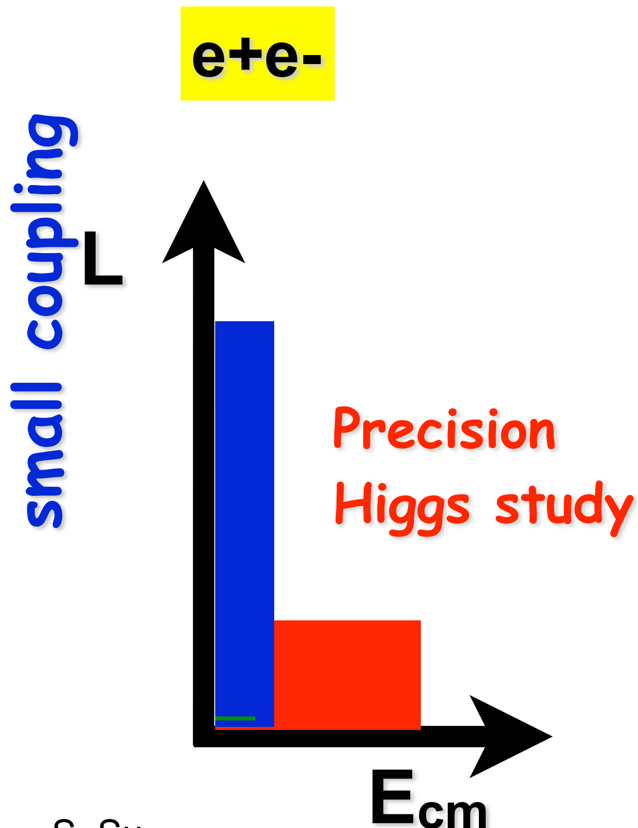


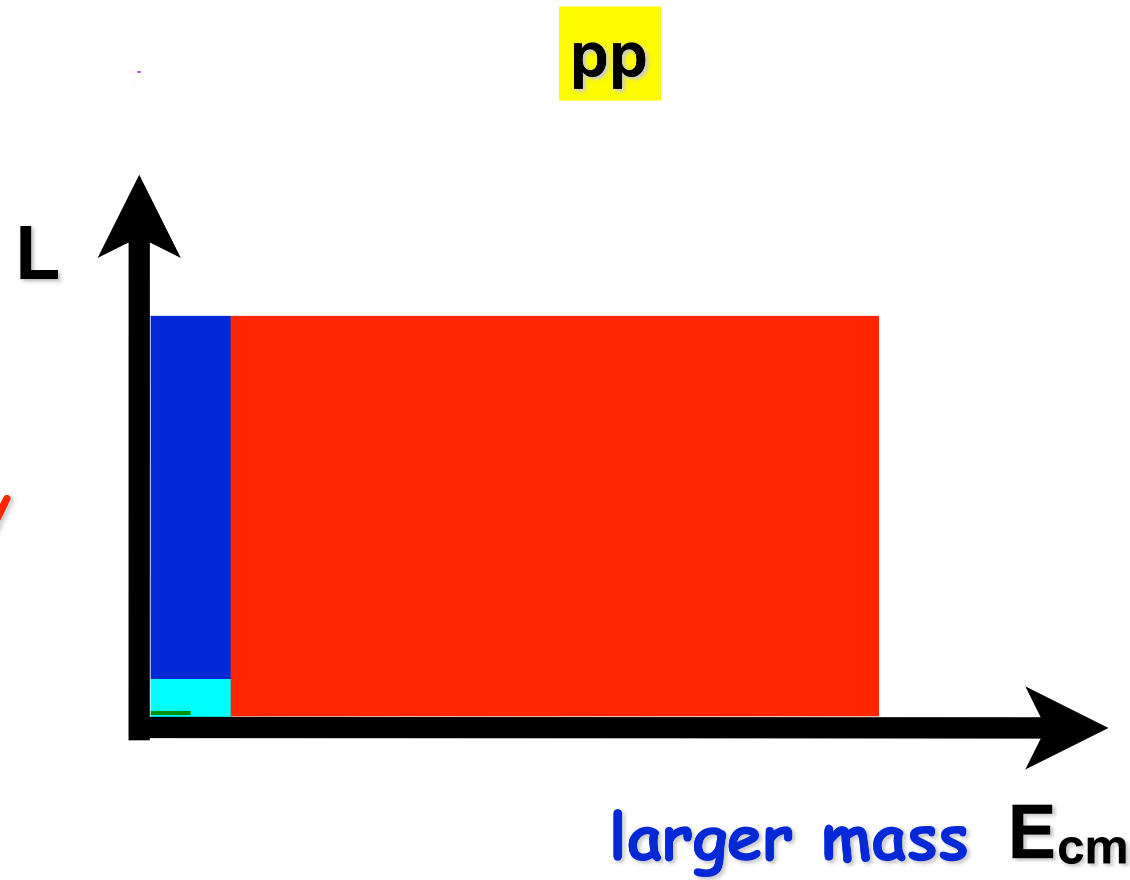
S. Su

Current and Future Colliders

Where is New Physics? larger mass? Small Coupling? Both?

- Indirect search
- direct search





S. Su

How to Make a Higgs Factory?

LHC

- pp collider, 27 km
- 7 TeV beam

0.99999999 c

- stored energy:

~ Giga Joule

LHC

- **stored energy:**

~ Giga Joule

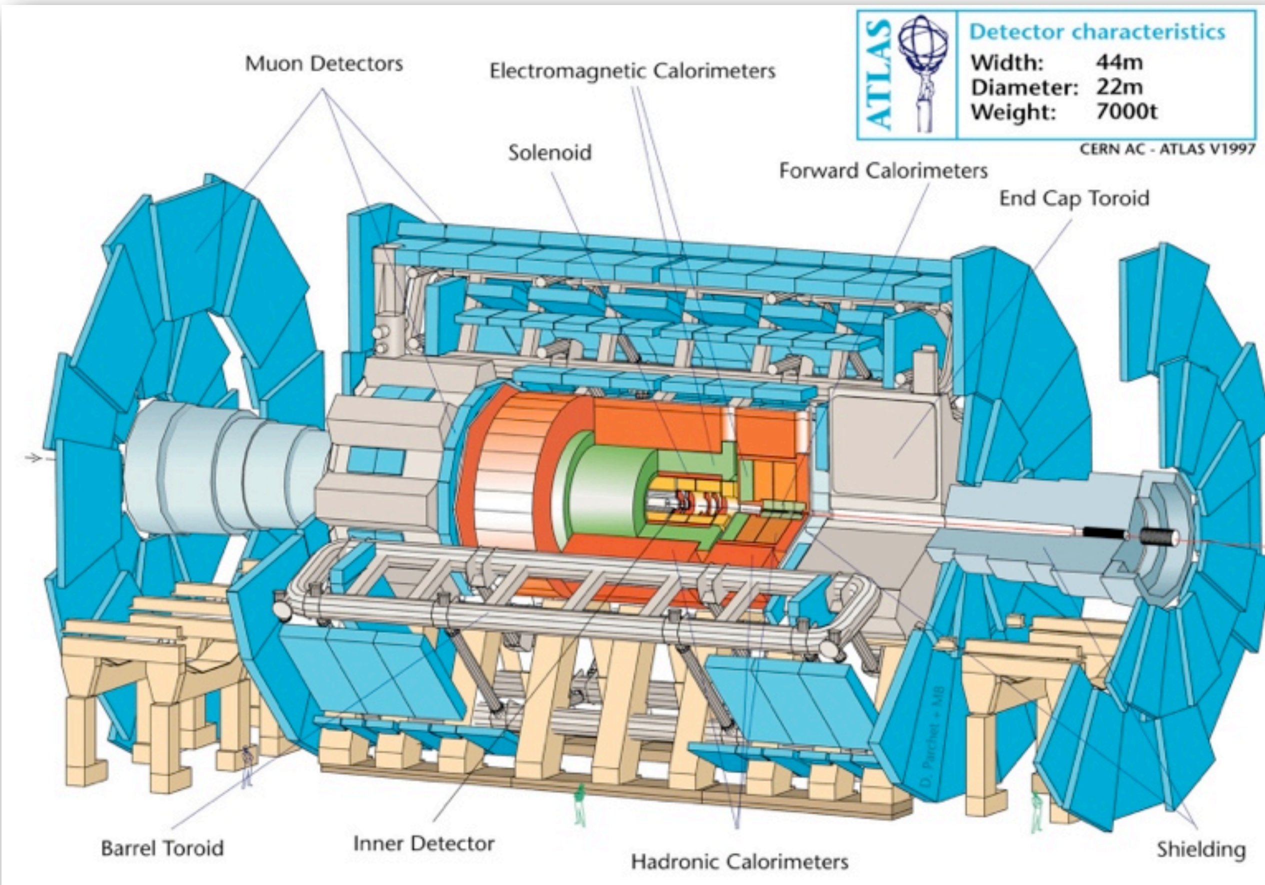
LHC

- **stored energy:**

  ~ Giga Joule

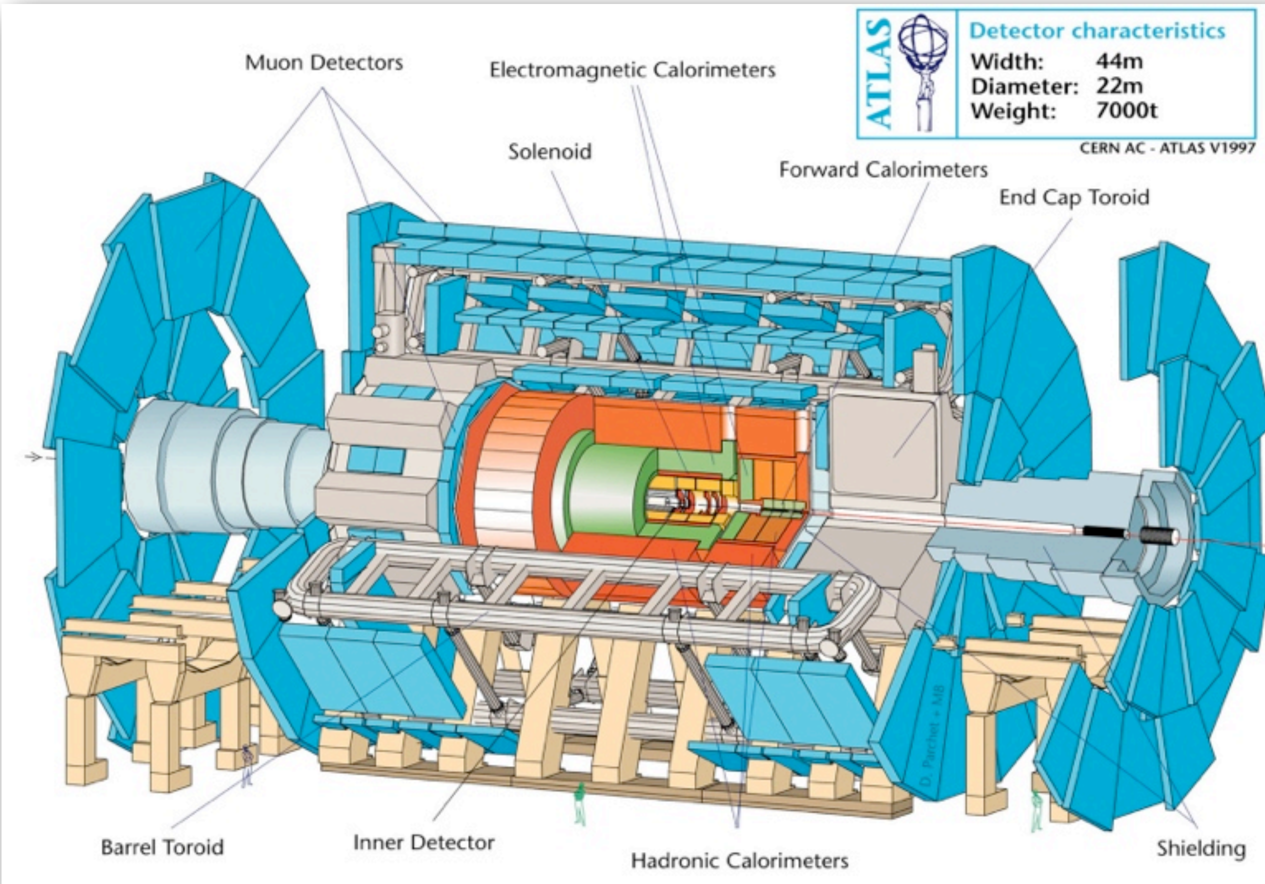
Highest energy, probing smallest distance (10^{-10} nm)

Particle Detector



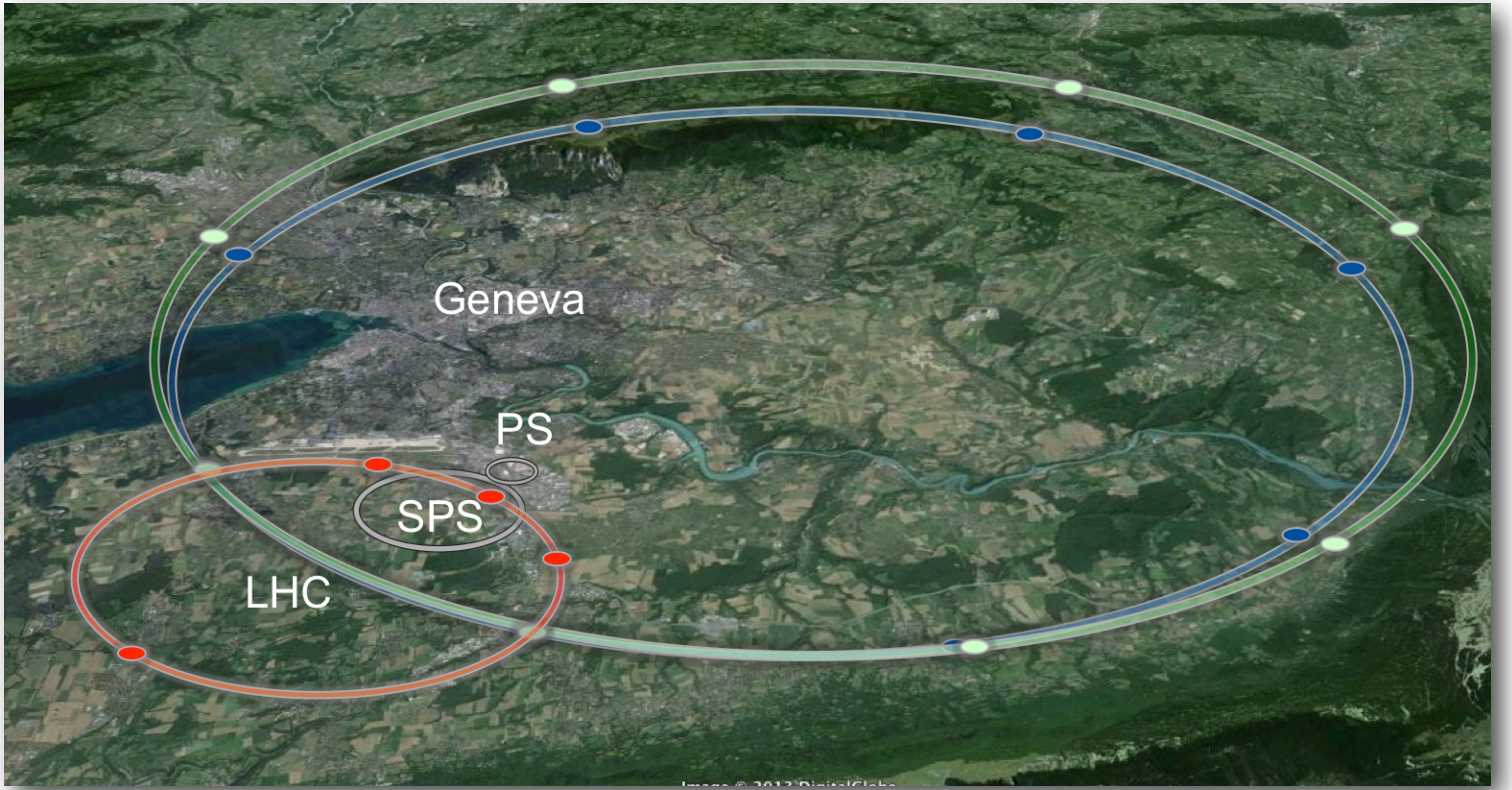
- **150 MP**
- **600 million snapshots / second**

Particle Detector



- 150 MP
- 600 million snapshots / second
- 7000 scientists
- $10 billion

FCC

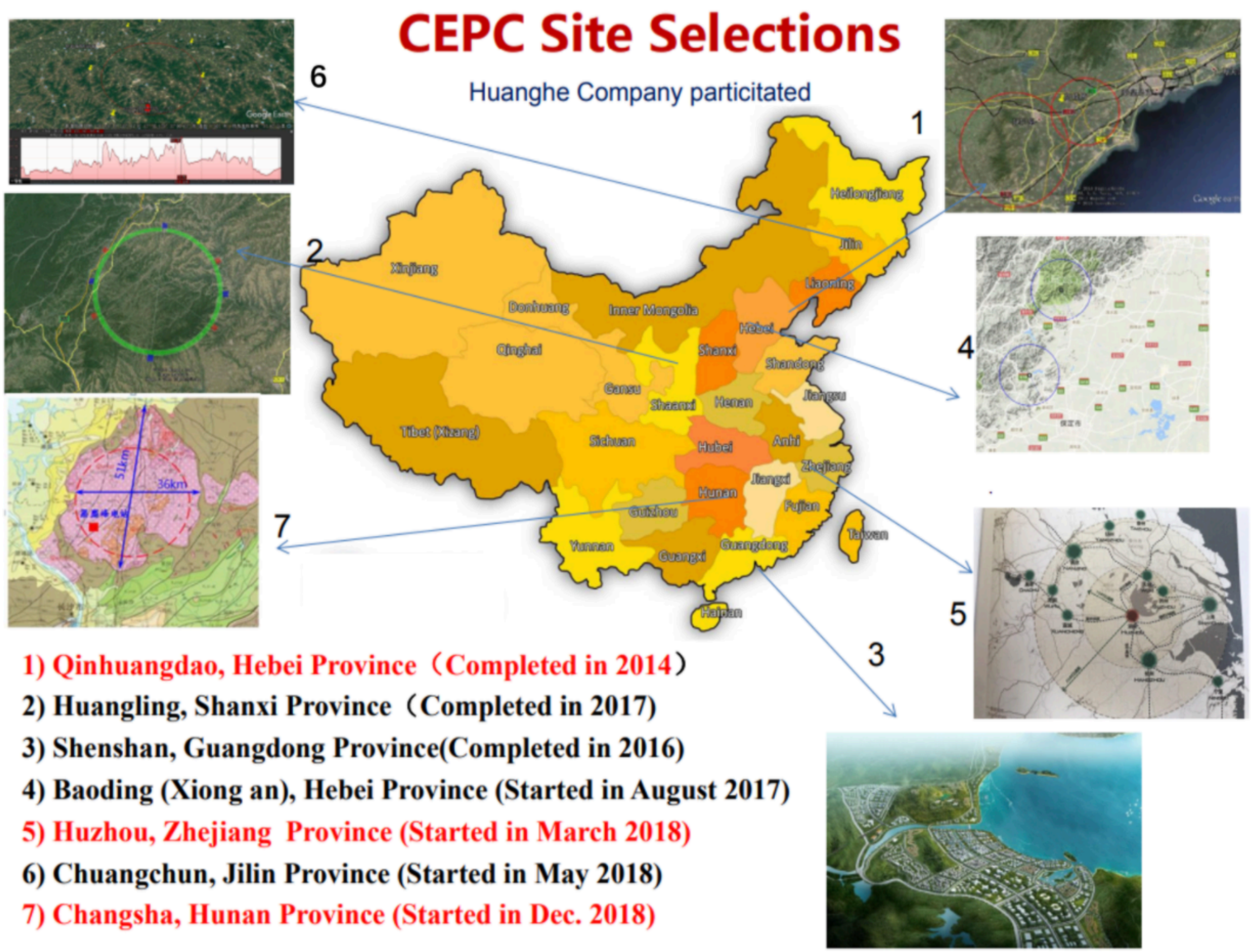


HE-LHC
27 km, 20T
33 TeV

FCC-ee
80/100 km
90 - 400 GeV

FCC-hh
80 /100 km, 16/20T
100 TeV

CEPC-SPPC



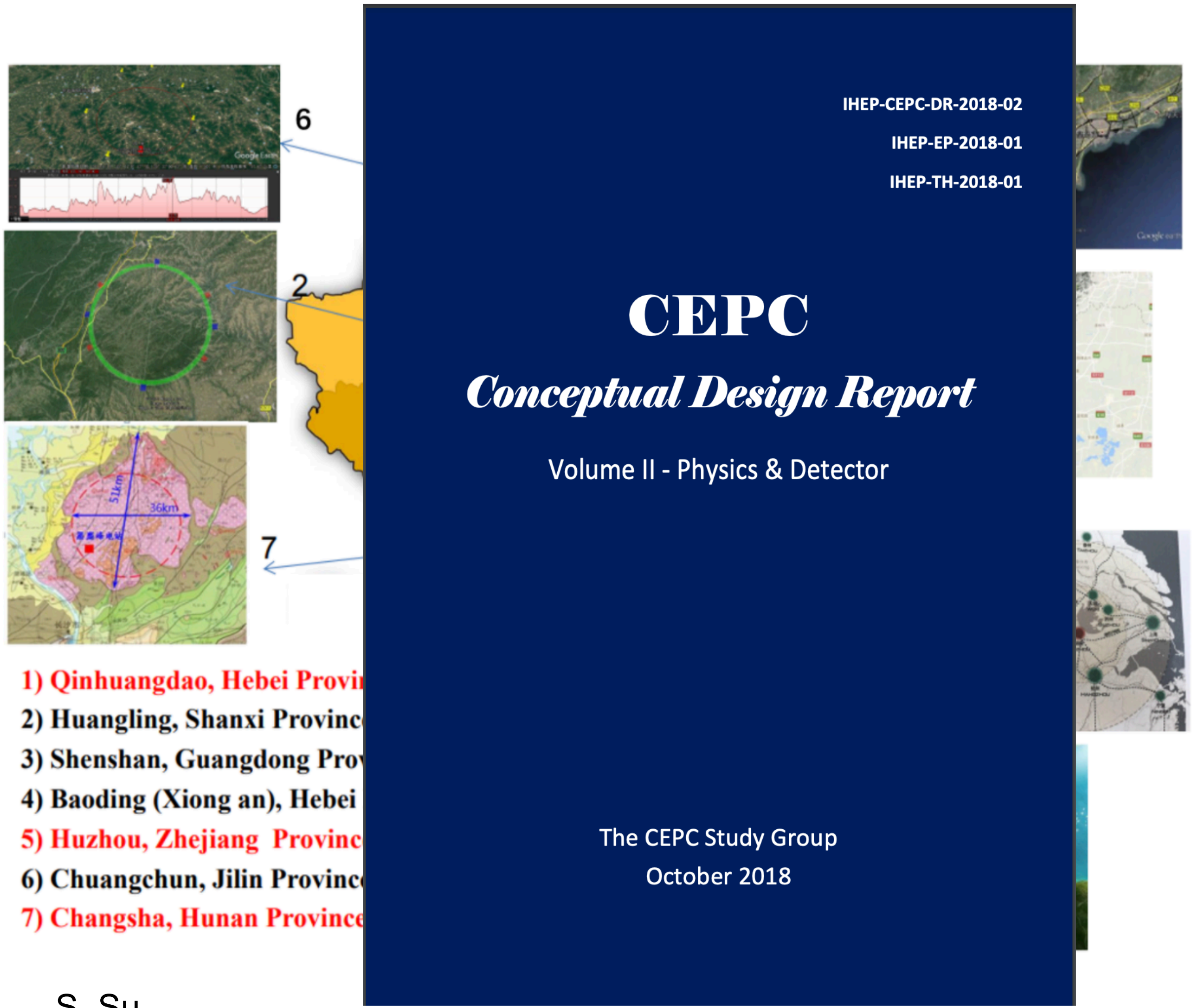
CEPC

e+e-: 240 GeV

SPPC

pp: 70-100 TeV

CEPC-SPPC



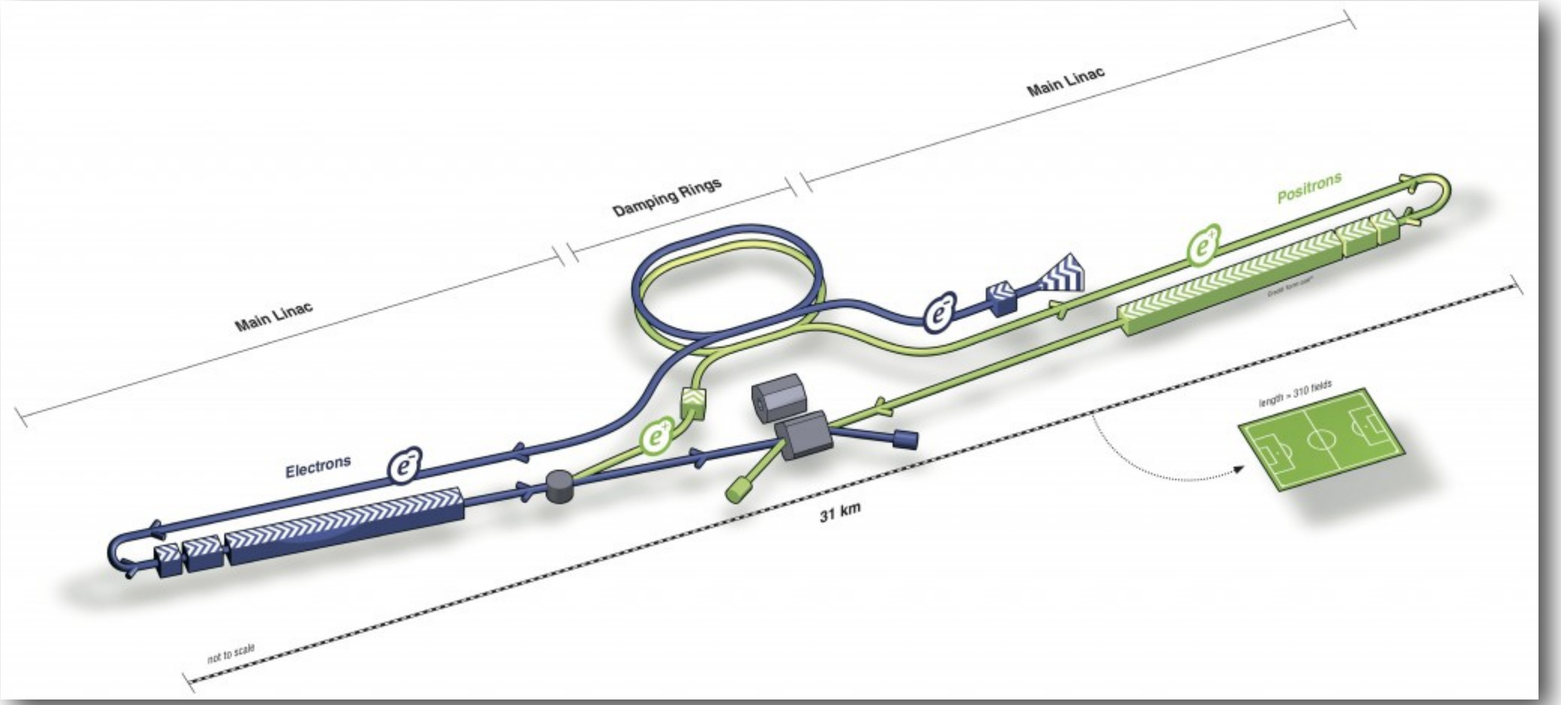
CEPC

e+e-: 240 GeV

SPPC

pp: 70-100 TeV

ILC

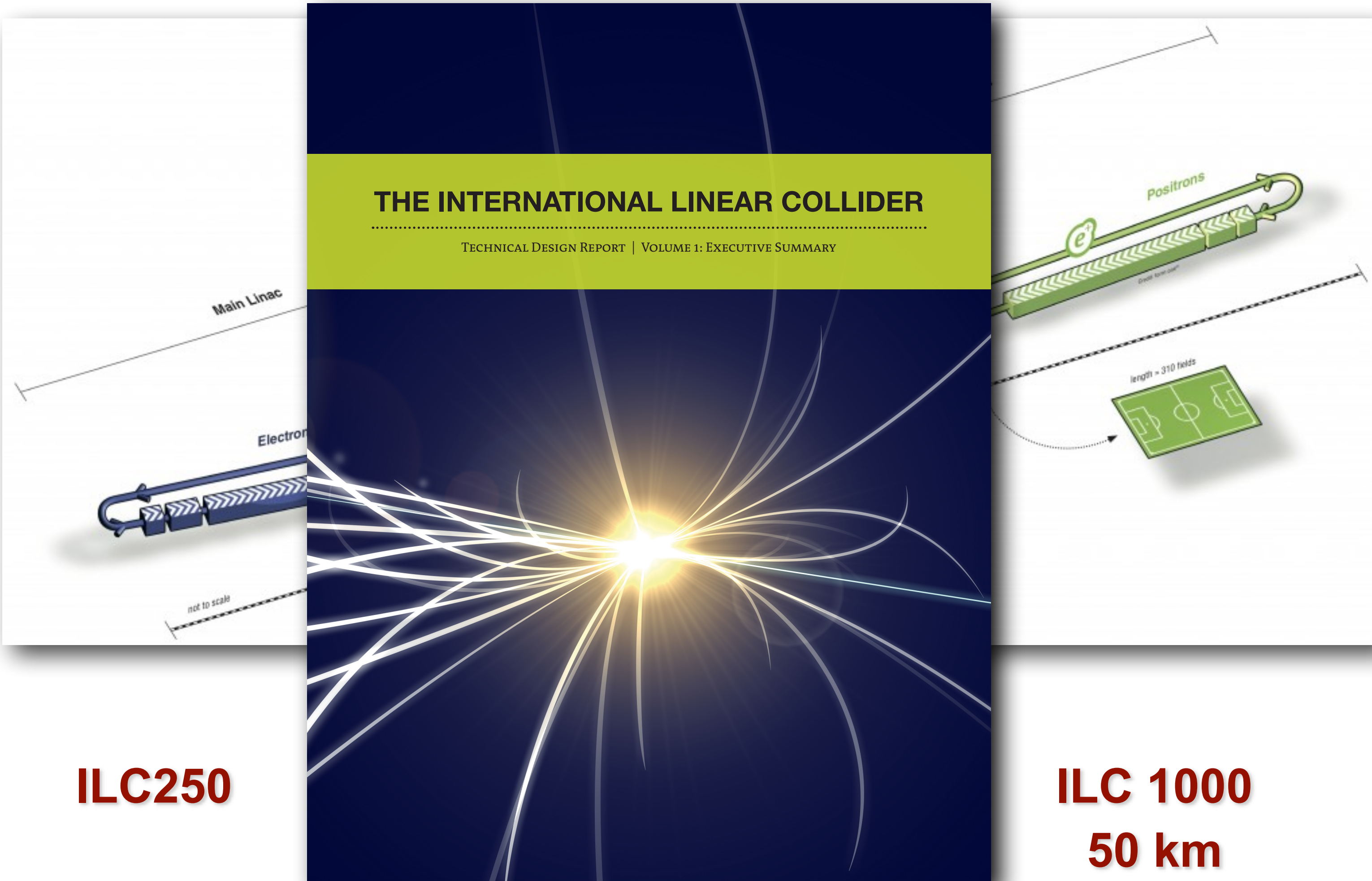


ILC250

ILC 500
31 km

ILC 1000
50 km

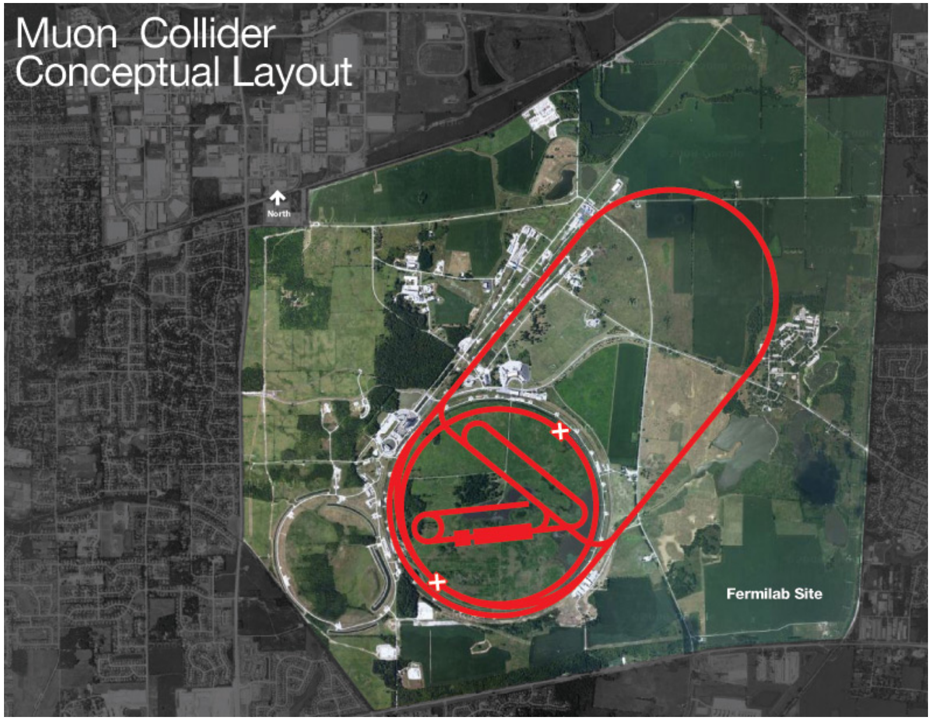
ILC



ILC250

ILC 1000
50 km

Muon Collider



$m_\mu \sim 200\ m_e$

- unique combination of higher energy and clean environment
- smaller ring

How to make a Higgs

e+e- collider

μ+μ- collider

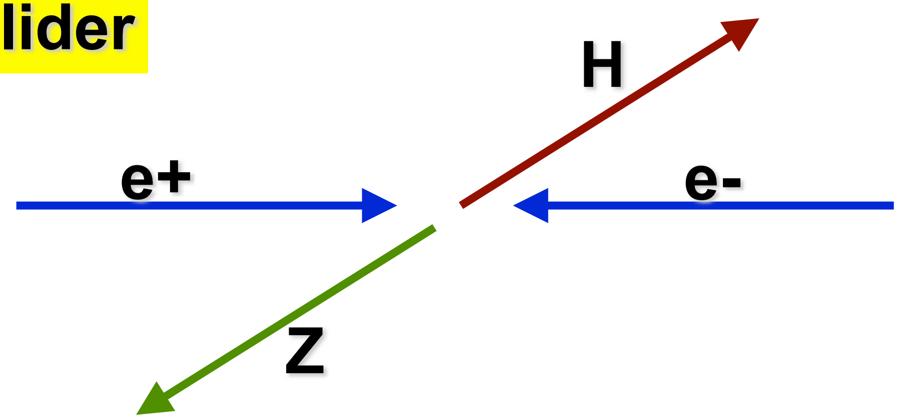
How to make a Higgs

e+e- collider

μ+μ- collider

How to make a Higgs

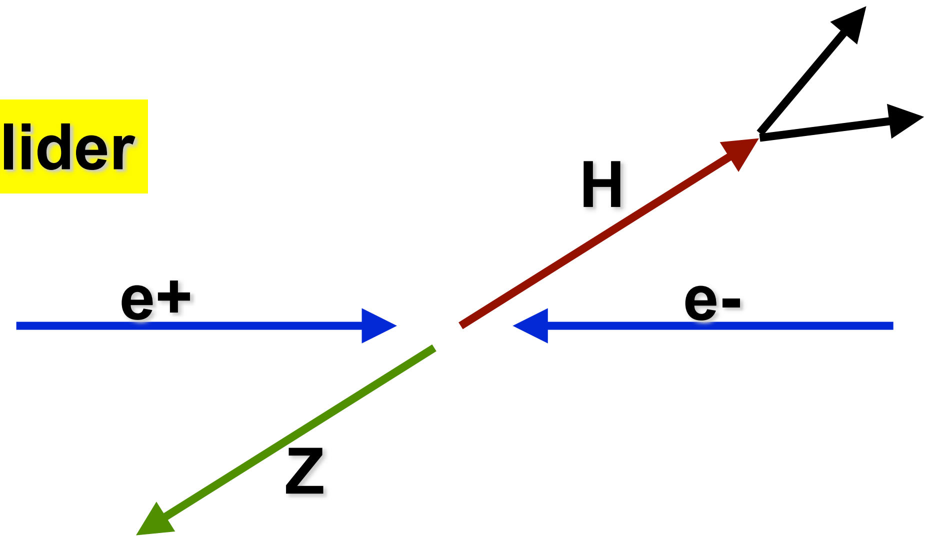
e+e- collider



μ+μ- collider

How to make a Higgs

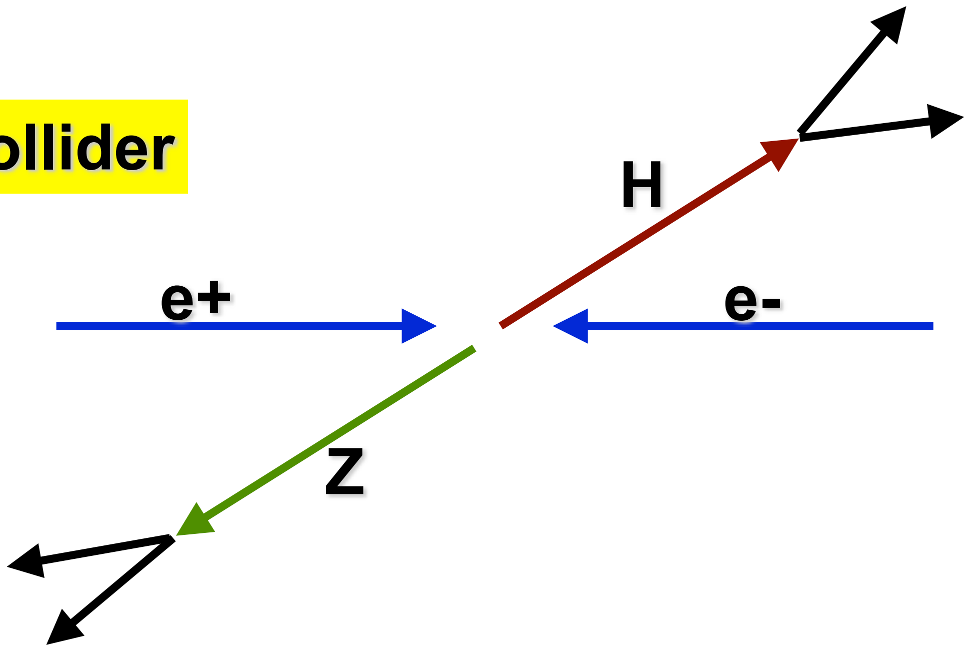
e+e- collider



μ+μ- collider

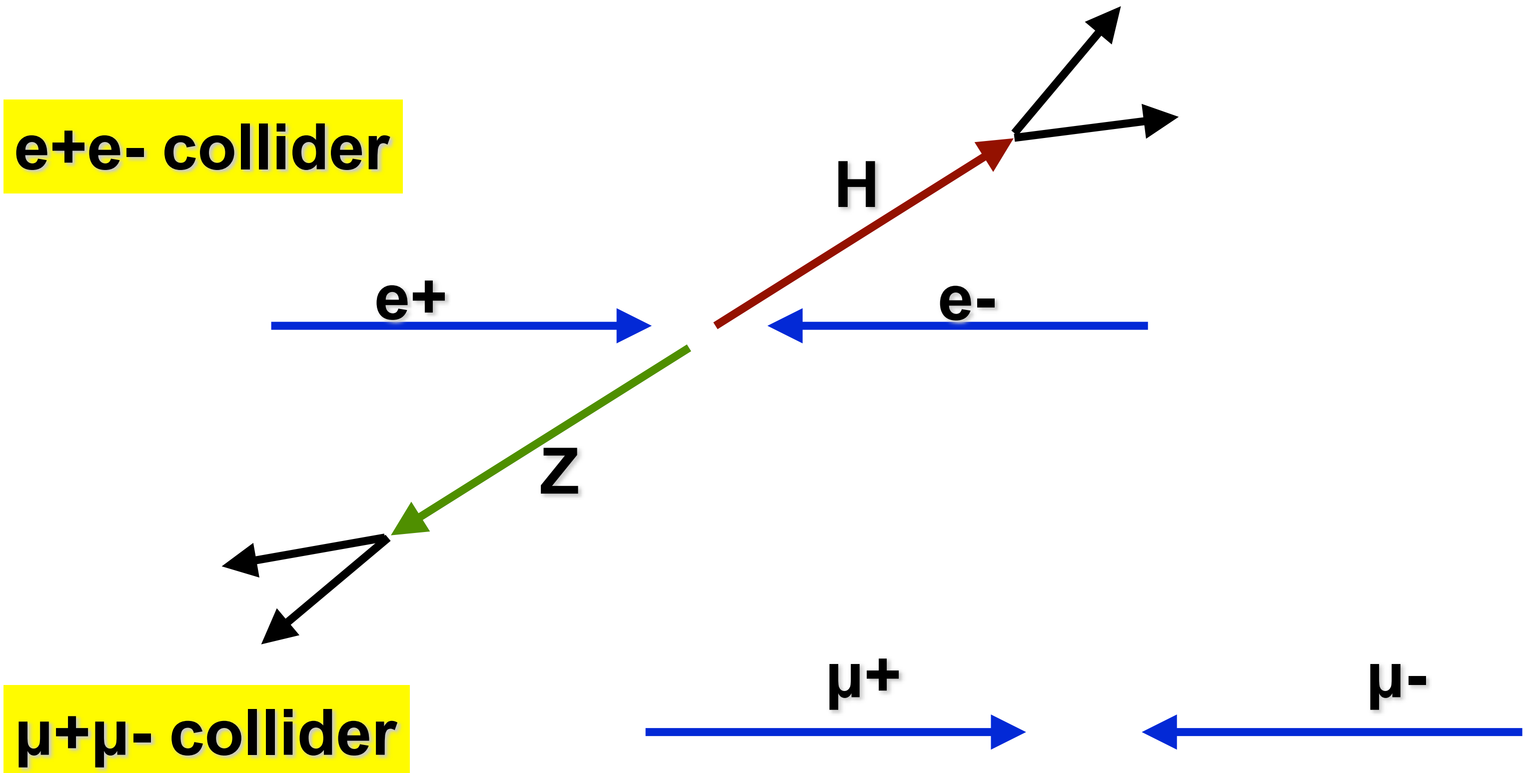
How to make a Higgs

e+e- collider

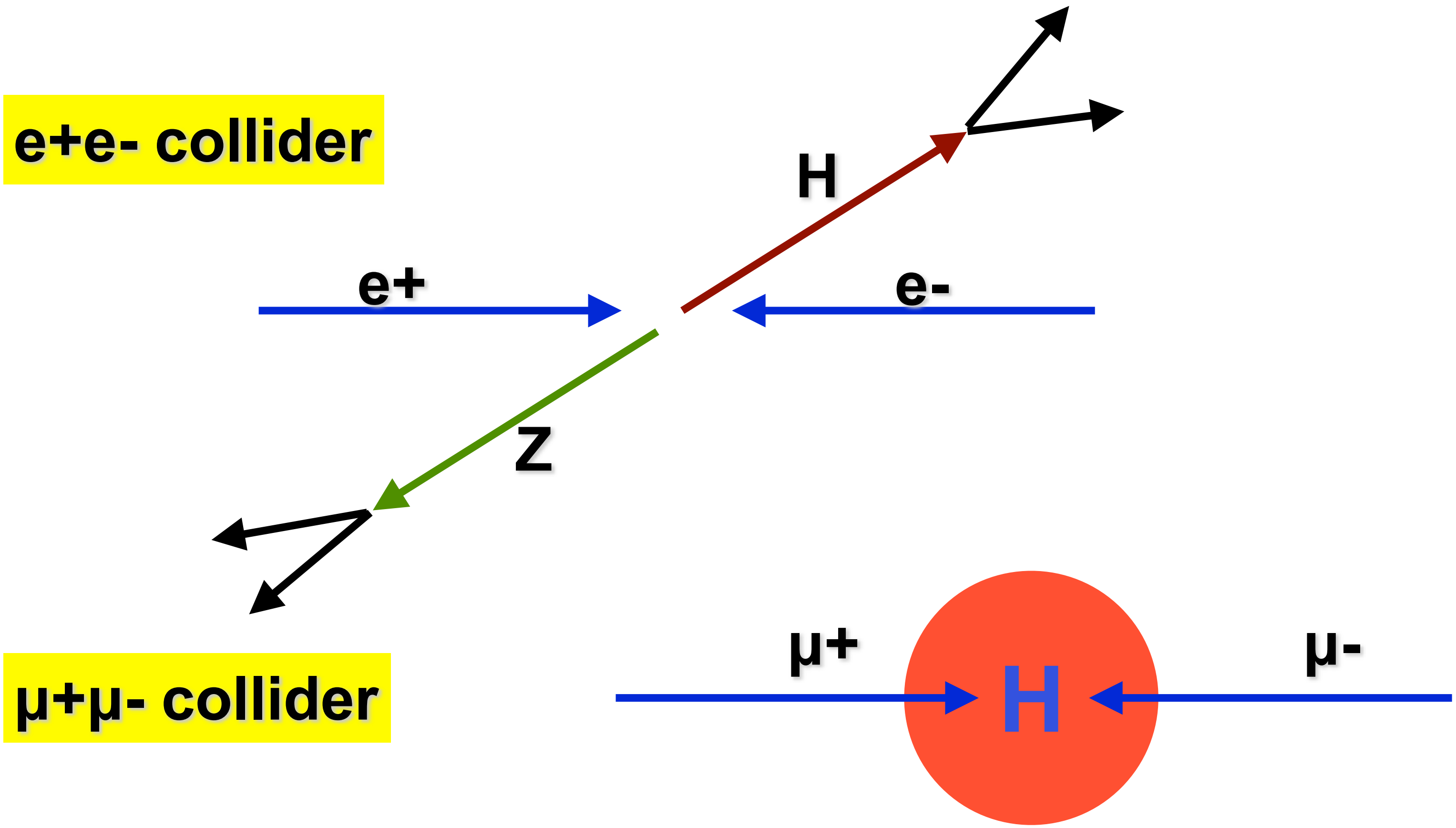


μ+μ- collider

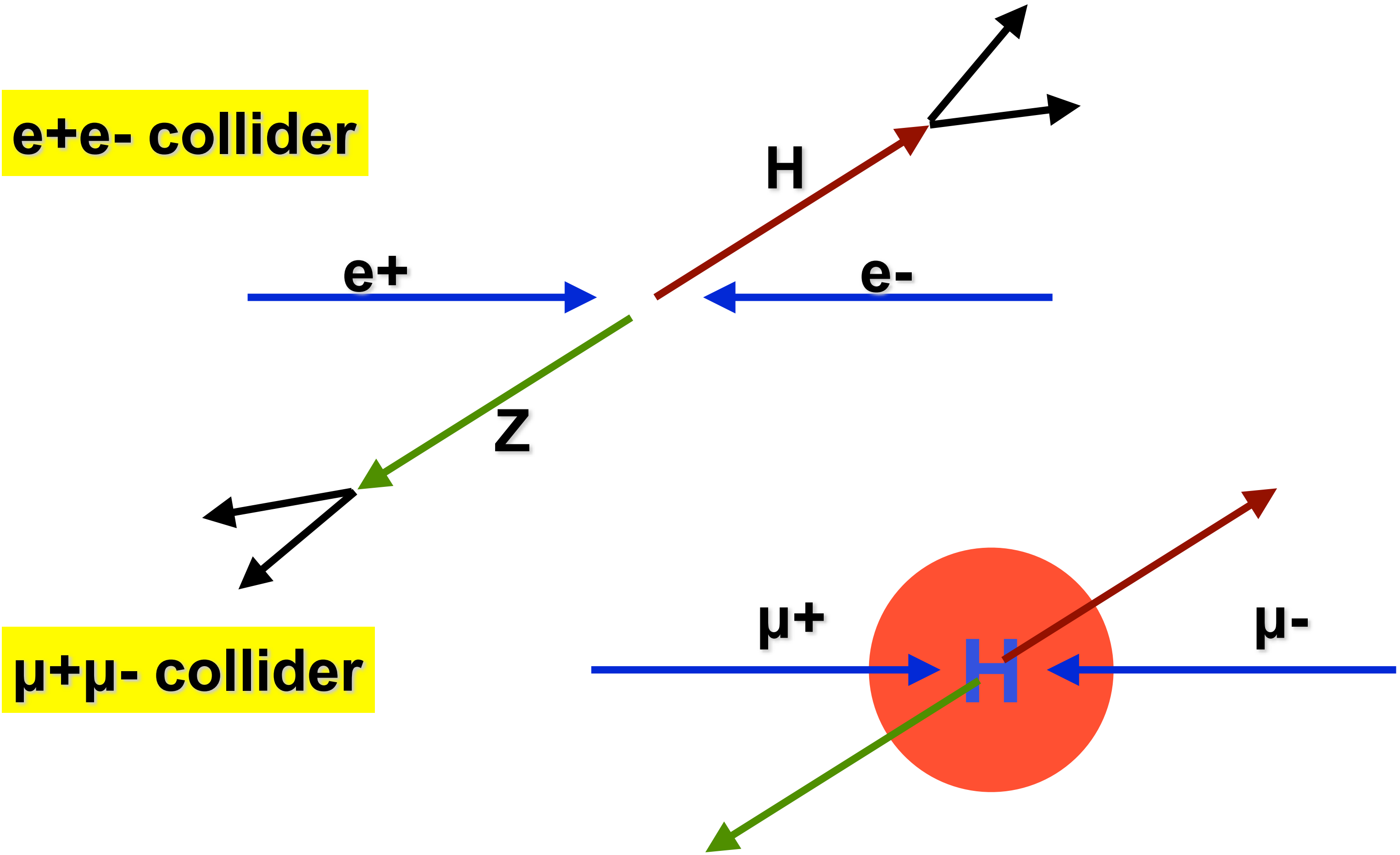
How to make a Higgs



How to make a Higgs



How to make a Higgs



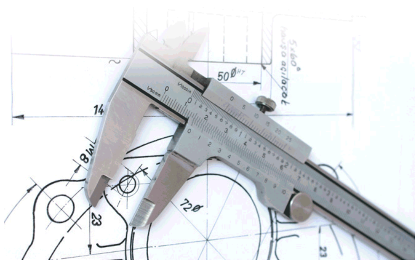
What we can learn with a Higgs Factory?

Higgs Factory

- SM physics

- dark matter

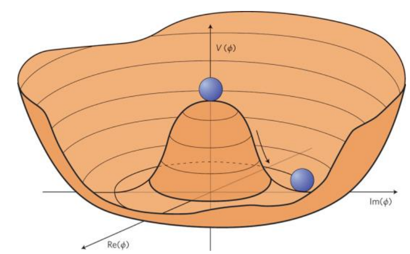
- precision tests



- Higgs-related

- other BSM

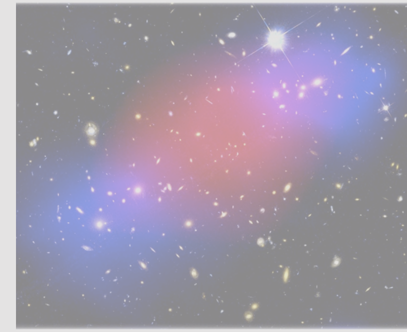
- Cosmo connection



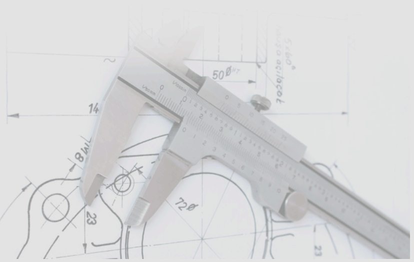
Higgs Factory

- SM physics

- dark matter



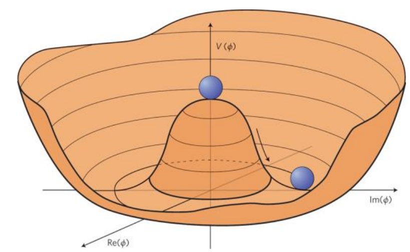
- precision tests



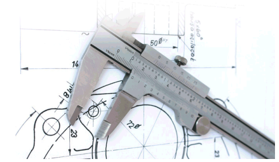
- Higgs-related

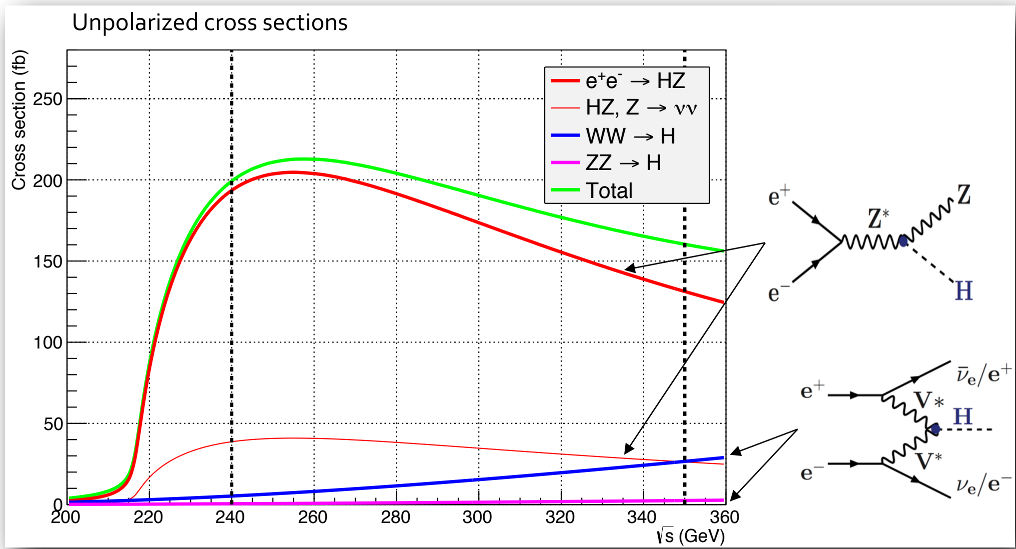
- other BSM

- Cosmo connection



Higgs Production @ e+e-



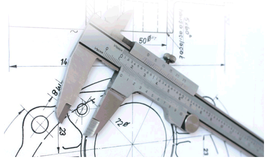


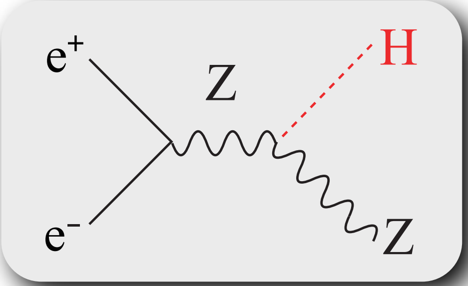
$$\sigma(e^+e^- \to H + X) \times BR(H \to YY)$$

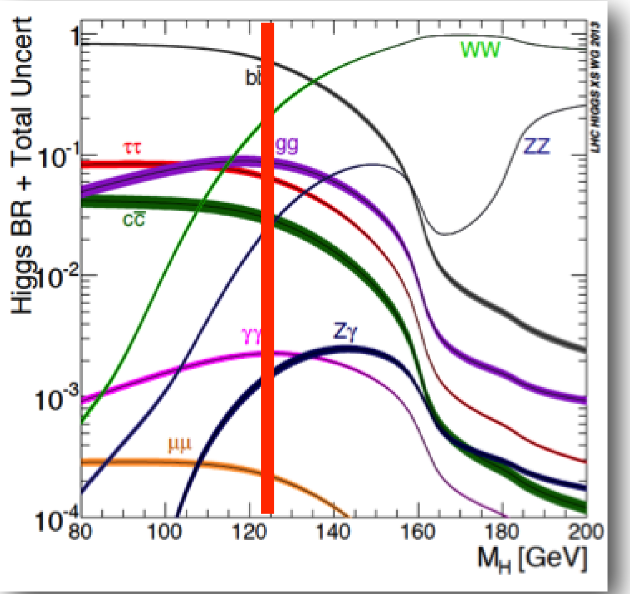
Y=b,c,g,W,Z,γ,τ,μ

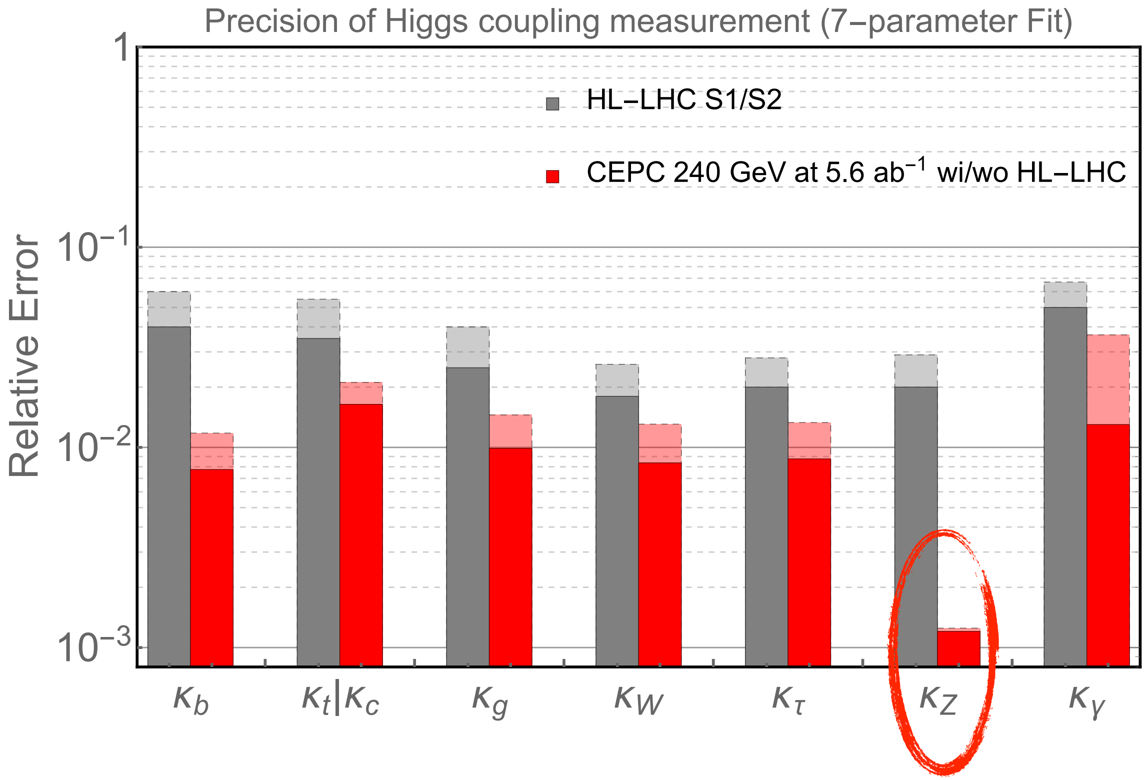
- **Determine all Higgs couplings (model-independent)**
- **Infer Higgs total decay width**
- **probe invisible Higgs decay**

Higgs Precision Measurement

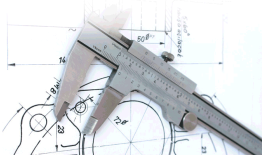




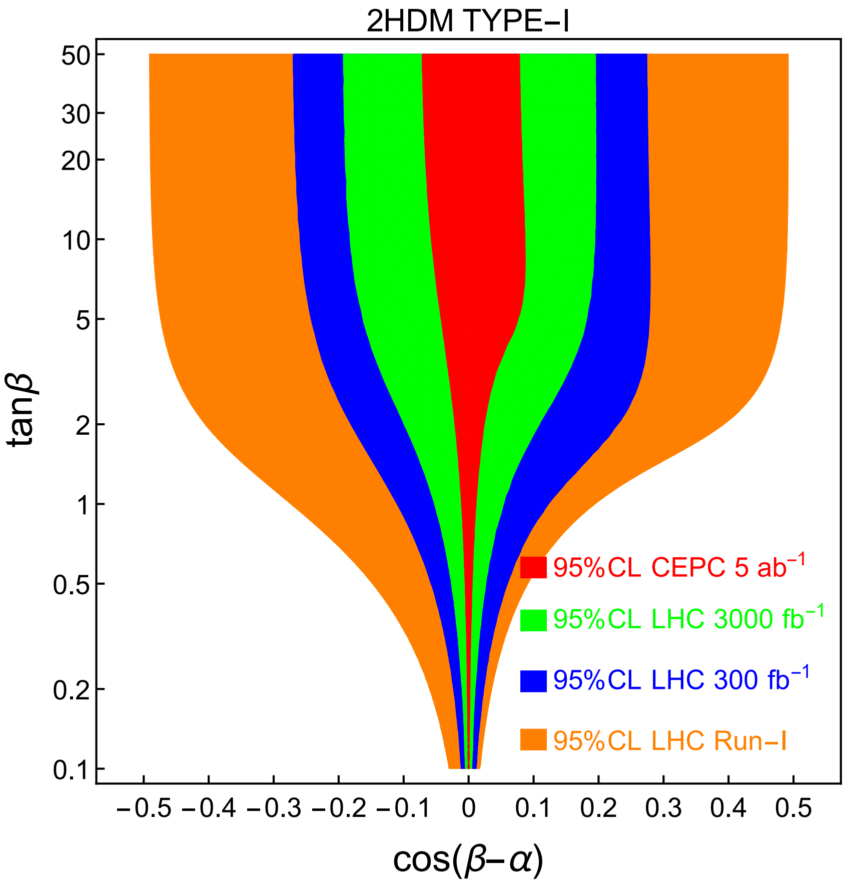


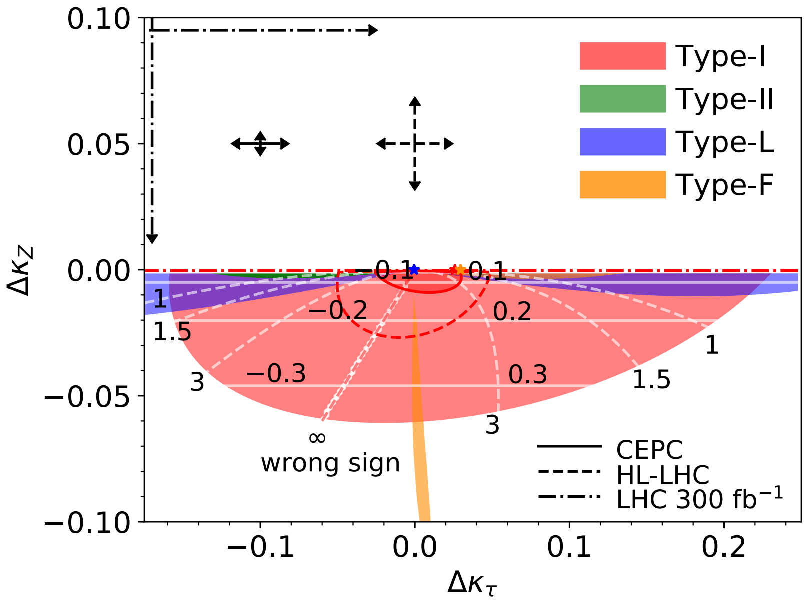


Tree-level 2HDM fit



2HDM, LHC/CEPC fit

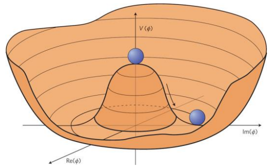


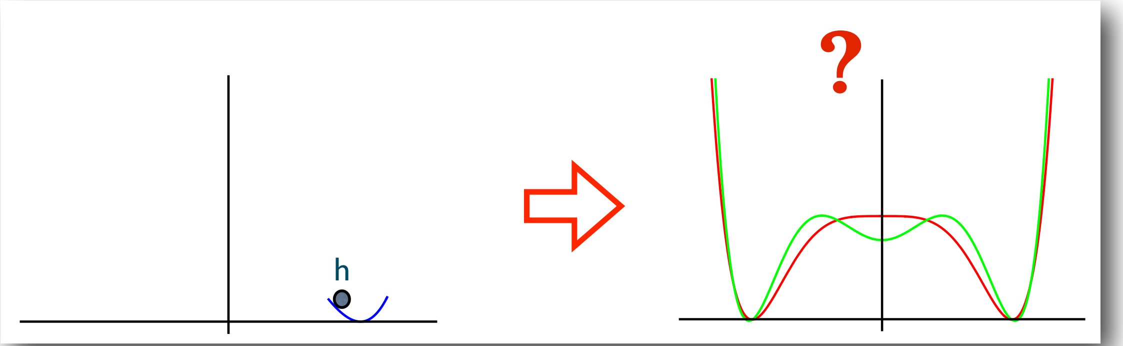


Han, Li, SS, Su, Wu (2020)

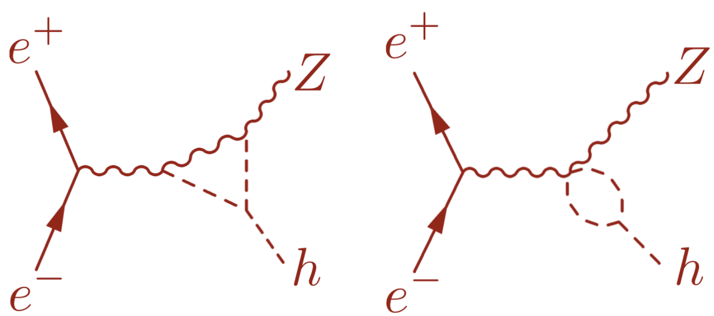
Gu, Li, Liu, SS, Su (2017)

EW baryogenesis





- baryon asymmetry ⬅ baryogenesis ⬅ strong 1st order EWPT
- SM: 125 GeV, 2nd order EWPT ➡ no EW baryogenesis
- BSM with strong 1st order EWPT ➡ large deviation in HHH
  - ➡ HHH > 20% or more, 100 TeV pp
  - ➡ ggH coupling, LHC
  - ➡ HZZ coupling, e+e-



Conclusion

- The discovery of Higgs is a remarkable triumph in particle physics
- A light weakly coupled Higgs argues for new physics beyond SM
- Search for new physics calls for both high precision machine and high energy machine
- Higgs factory: precise measurement of Higgs properties
  - Higgs coupling to sub-percent level
  - indirect approach for new physics beyond the SM
  - cosmo connection, dark matter, SM physics…

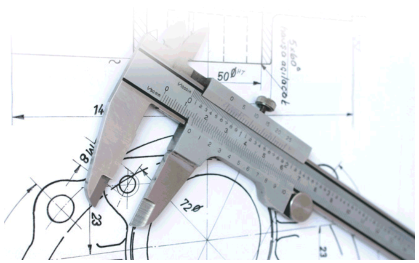
- SM physics

- dark matter

Higgs Factories

An exciting journey ahead of us!

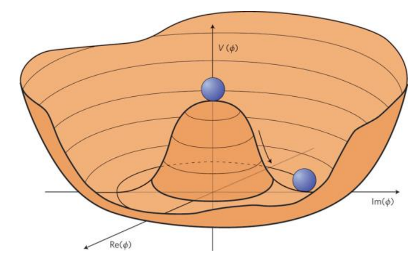
- precision tests



- Higgs-related

- other BSM

- Cosmo connection



Snowmass 2021

DPF community planning exercise

- Snowmass Frontiers

- Energy Frontier
- Neutrino Physics Frontier
- Rare Processes and Precision
- Cosmic Frontier
- Theory Frontier
- Accelerator Frontier
- Instrumentation Frontier
- Computational Frontier
- Underground Facilities
- Community Engagement
- Snowmass Liaisons

Physics

→

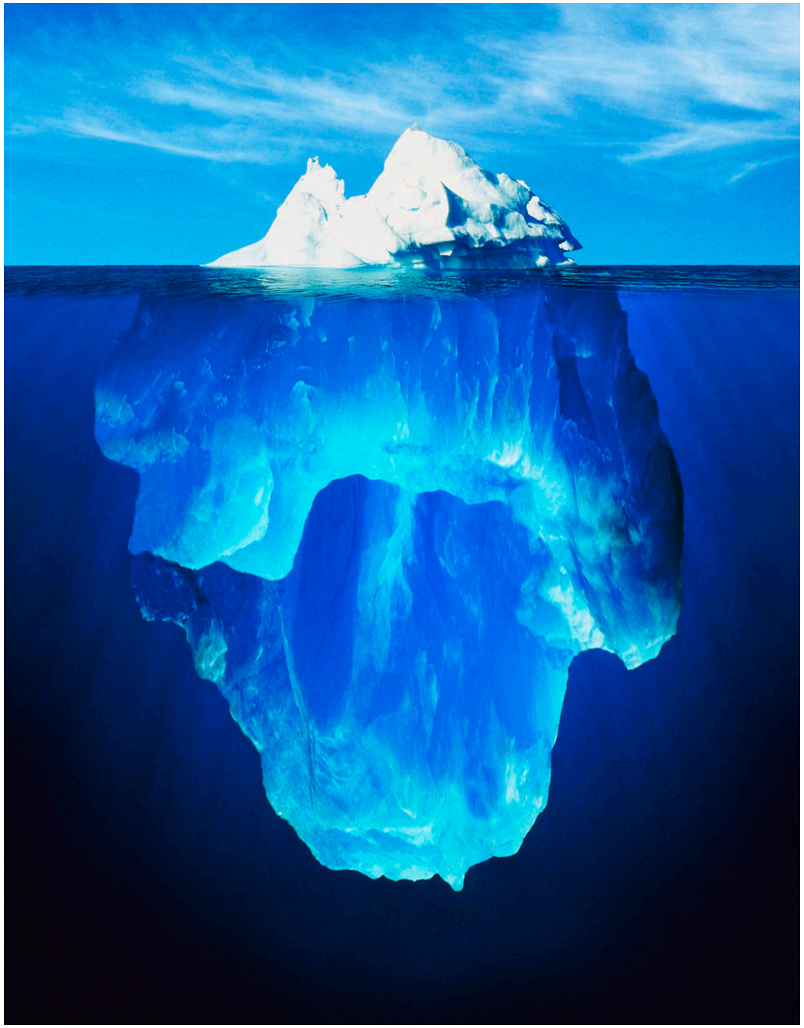
P5
Particle Physics Project Prioritization Panel

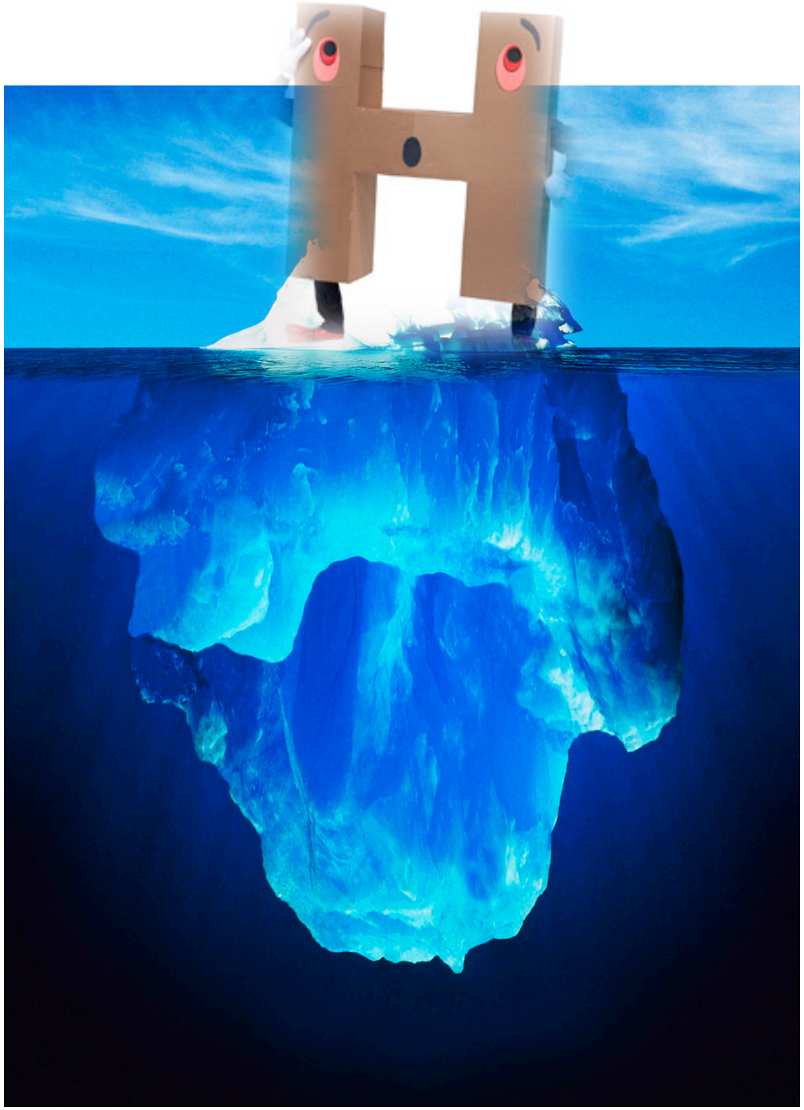
↓

HEPAP
High Energy Physics Advisory Panel

↓

US Government
Funding Agency





Beginning of new era ...

Beginning of new era ...

Thank you !