Tohoku Forum for Creativity

Utrecht University

The Higgs Particle, Pivot of the Standard Model of the Subatomic Particles

Gerard 't Hooft,

Public Lecture,

Sendai, April 24, 2015

CERN

European
Center for
Nuclear
Research

LHC

Large
Hadron
Collider

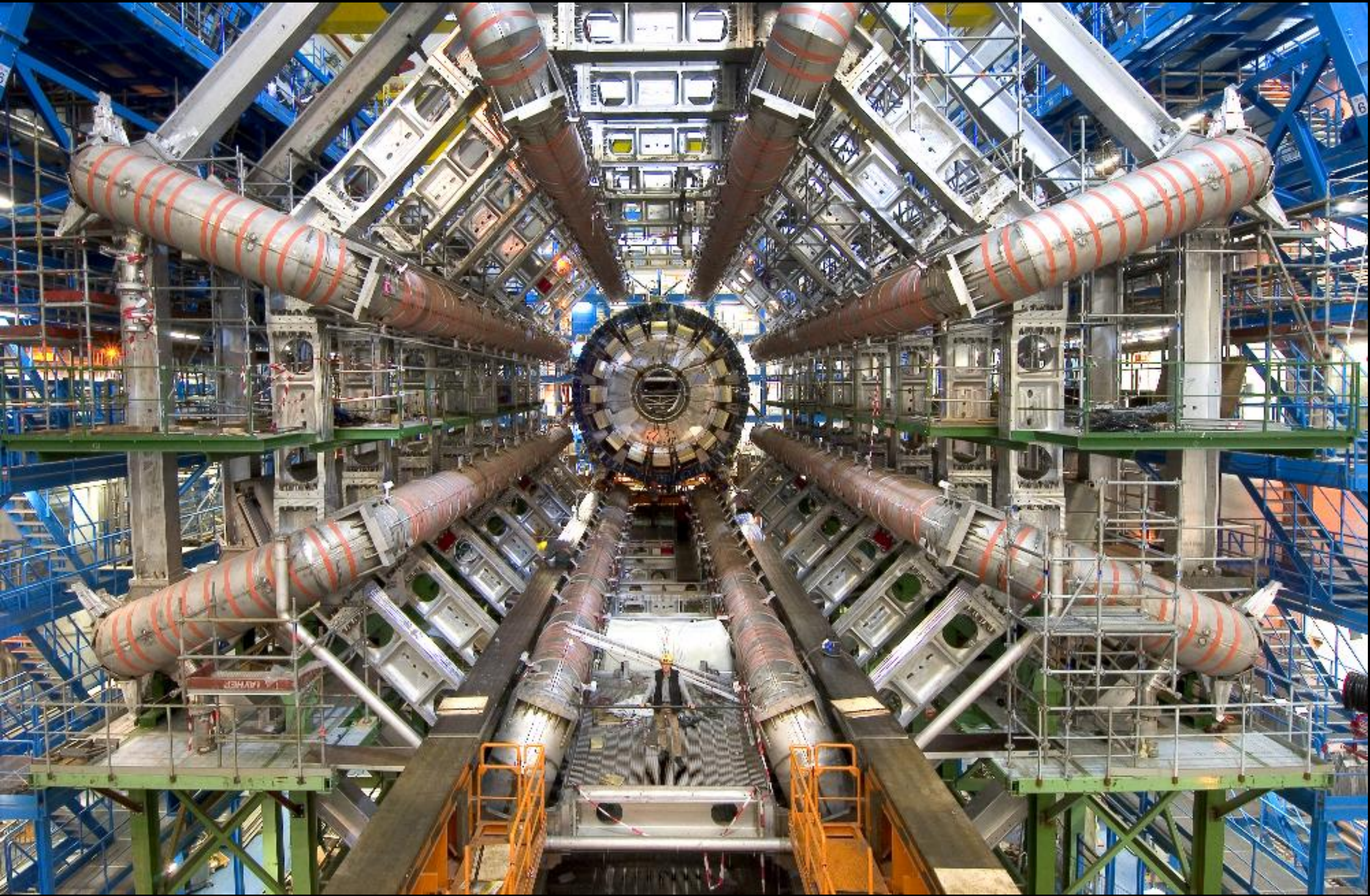
This machine
MICROSCOPE

is the strongest
in the world

Large Hadron Collider, Geneva: 7 + 7 TeV collisions

$$p + p$$

The Atlas Detector



- The accelerator has nearly 10,000 superconducting magnets; main dipoles weigh 35 tons, 15 meters long.

- The magnets are cooled by 130 tons of helium held at 1.9 and 4.2 K

- The accelerator contains about 15,000 M Joules of magnetic energy

- 1200 tons of Nb-Ti superconducting cables were used to wind the magnets

- There is a 0.01% variation in field quality among the 1232 main dipole magnets

One of the first assignments for this machine:

"Find the ***Higgs*** *particle*"

Why do we want such a particle?
What does it have to do with the masses of the other particles?

Why is it called "God Particle" ?

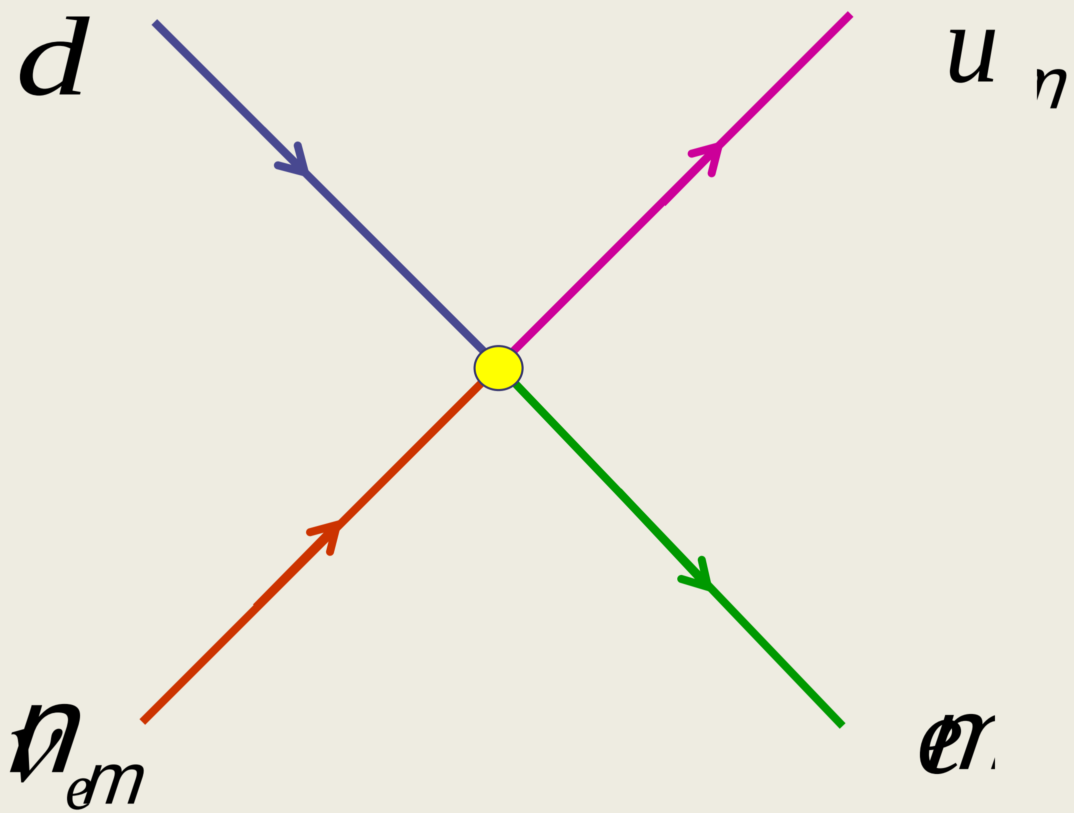
The story is more complicated
– and much more interesting ! – than the religious story

The Higgs particle is a product of ***theory*** !

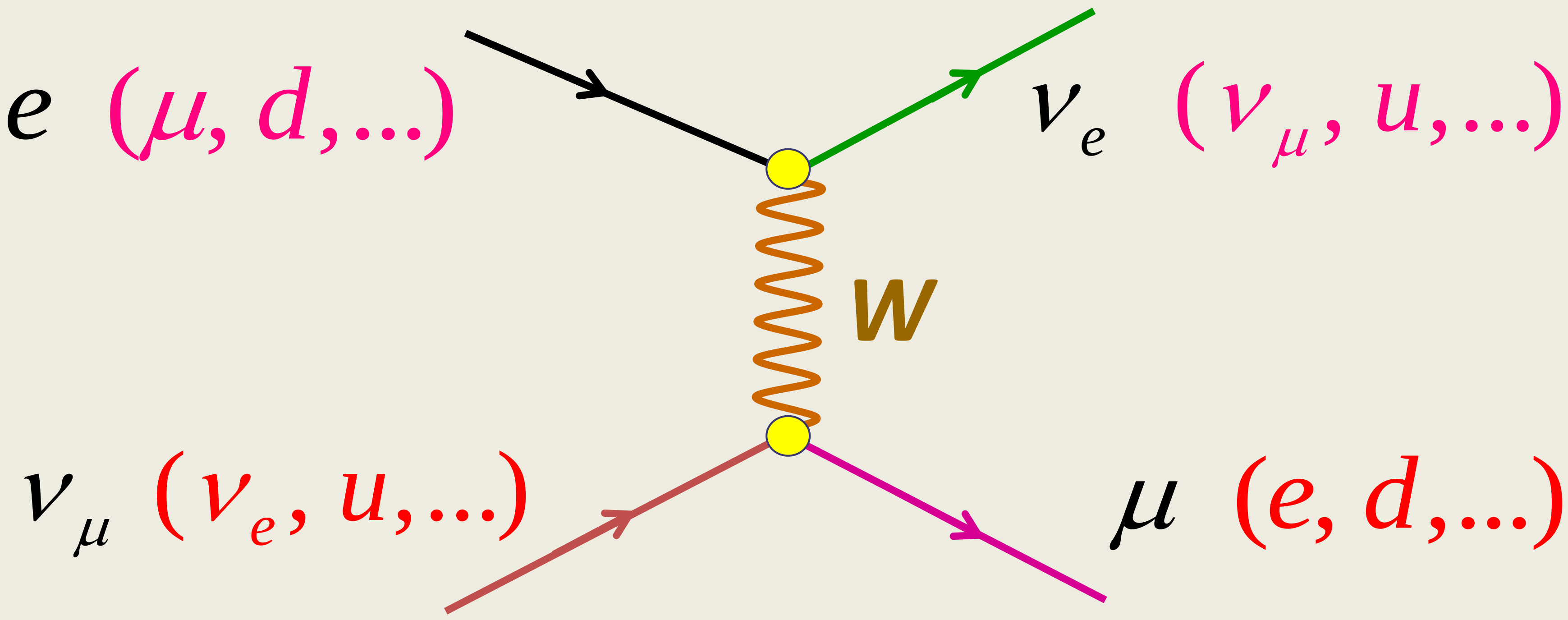
Not only **mass**, but also: ***spin*** !

The Weak Force

The fundamental FERMI interaction

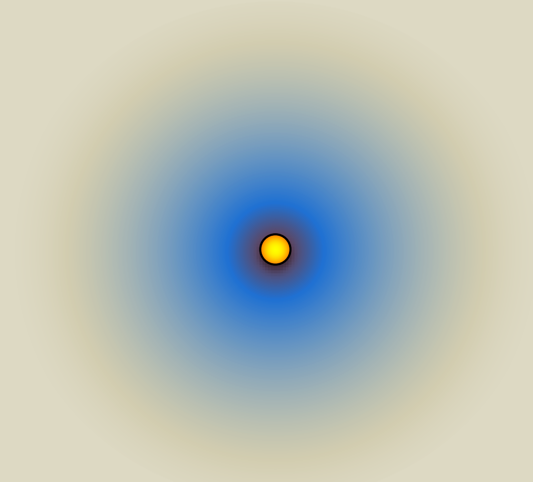


The
INTERMEDIATE VECTOR BOSON



The carrier of the weak force would have more spin degrees of freedom than a Yang-Mills photon,

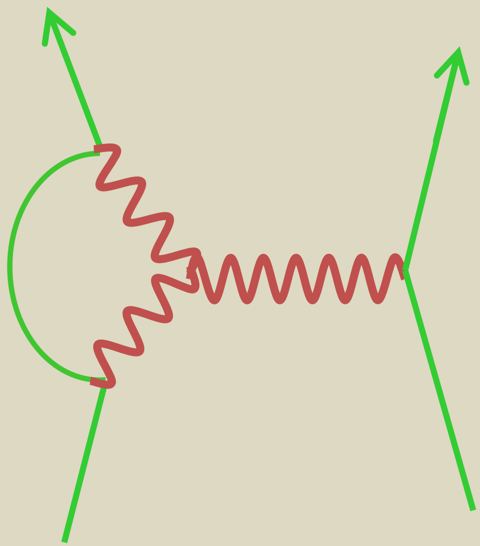
and that’s why the theory did not work

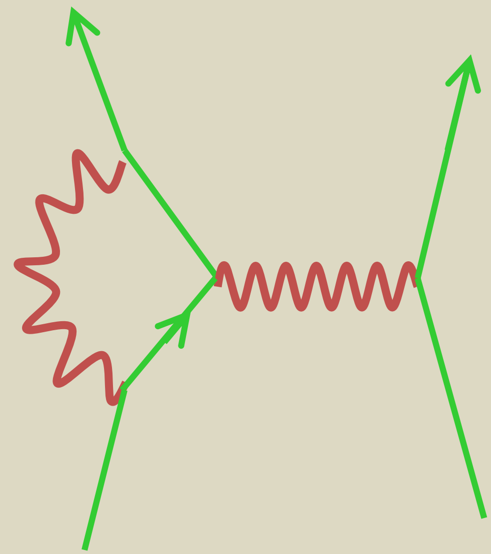


Particles get self-energy, and thus also self-mass, through the forces that they exert themselves. This self-energy is **infinite** for particles with mass, but it is **zero** for a photon-like particle.

How do we get a particle with **finite** mass?

In the calculations, it looked like this:

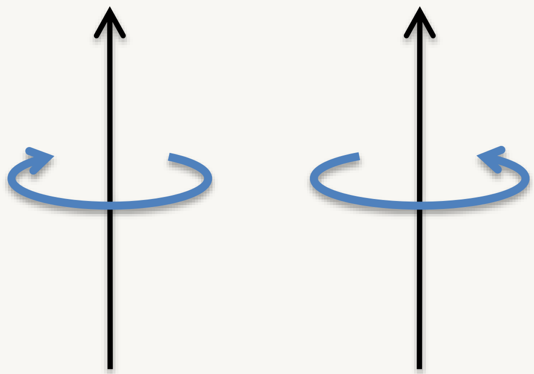




M. Veltman

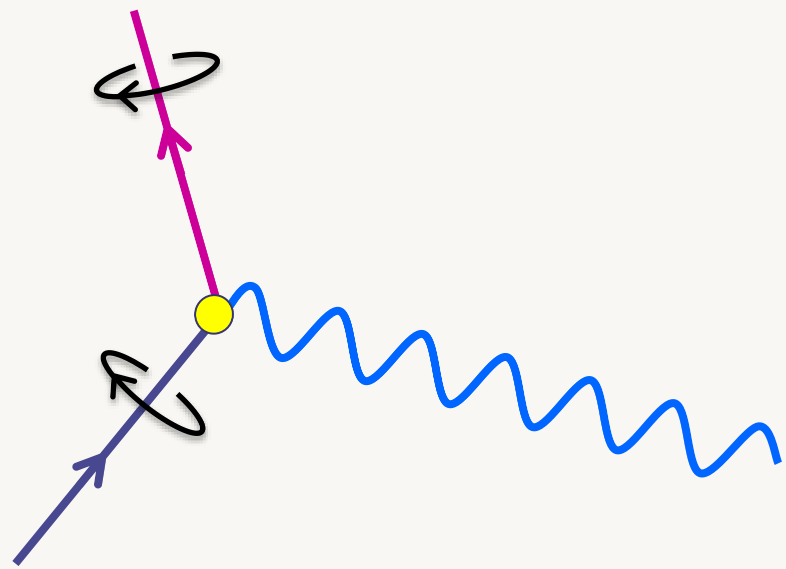
These interactions would become “infinitely strong” !

Such a theory, Field theory, would become useless !



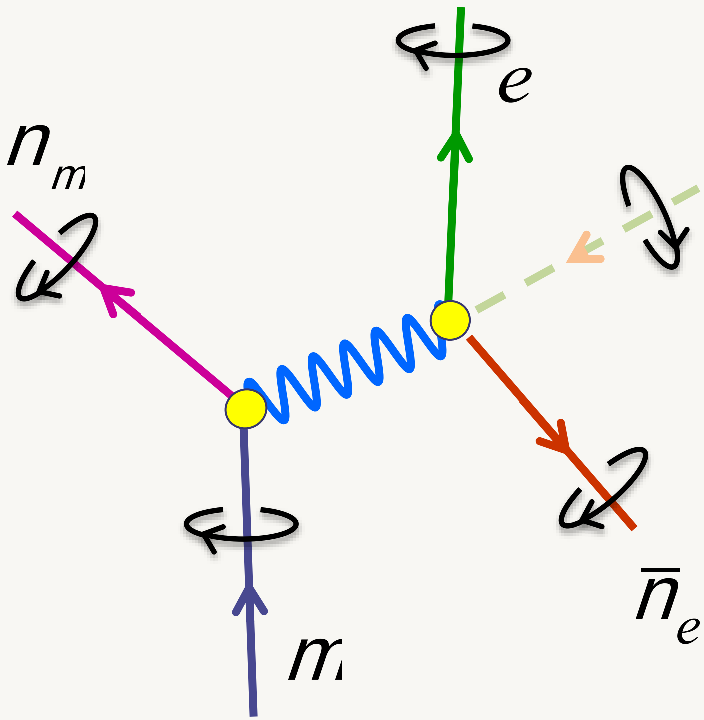
Helicity =

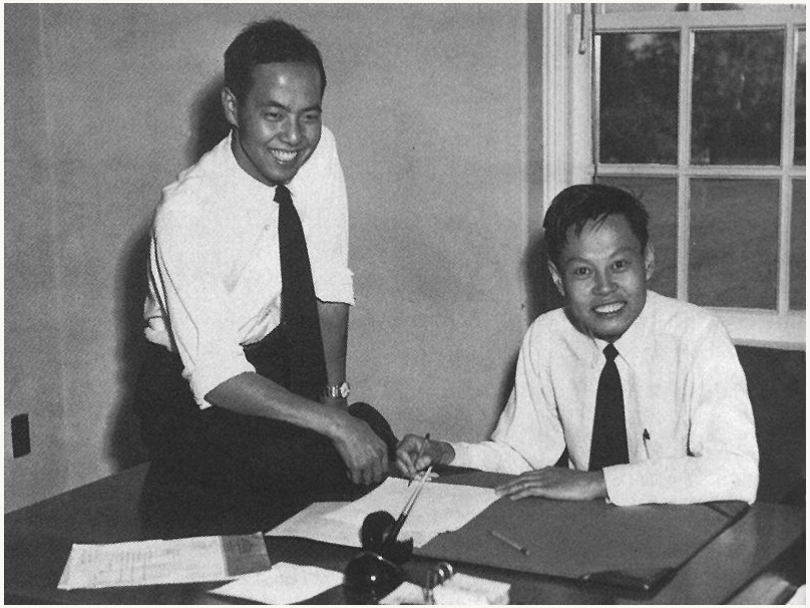
Spin w.r.t. rotation axis parallel to direction of motion



If a *weak force* acts on a massless particle, its helicity <u>stays the same</u>.

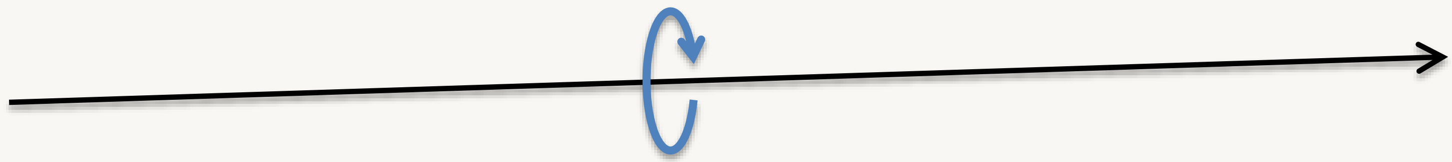
Fundamental discovery by T.D. Lee and C.N. Yang in 1956: left helicity and right helicity have **different weak charges**!





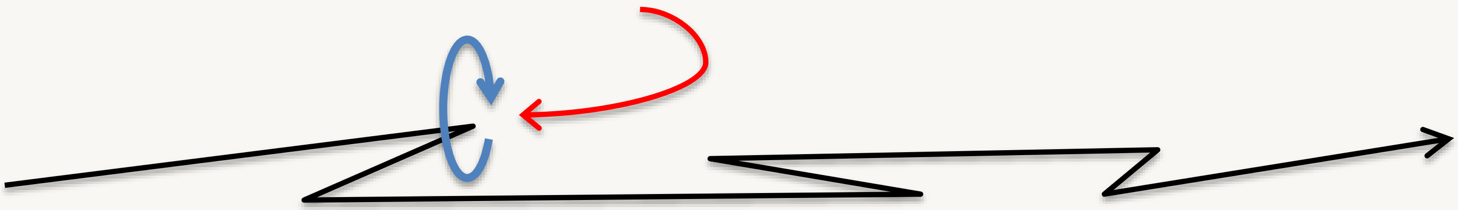
left – right asymmetry !

The weak force cannot flip the helicity

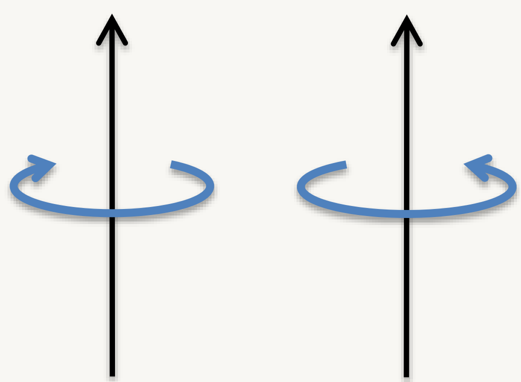


Massless particle: *always goes with speed of light* and its spin axis is always parallel to direction of motion

Helicity must ***flip***



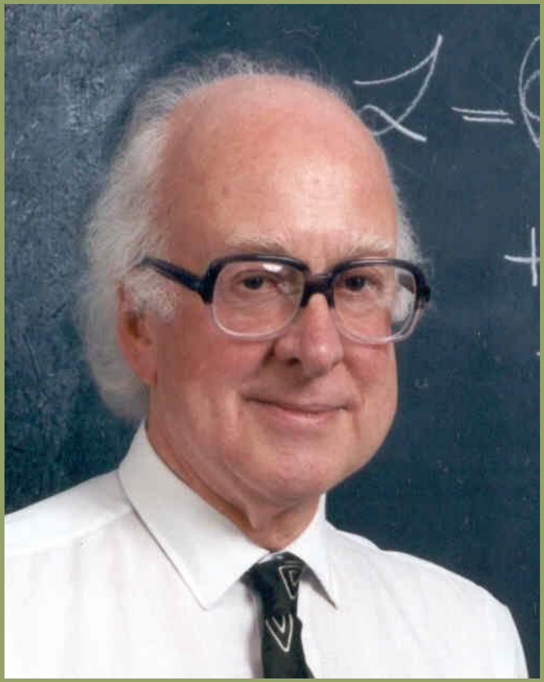
Particle with mass: *goes slower*



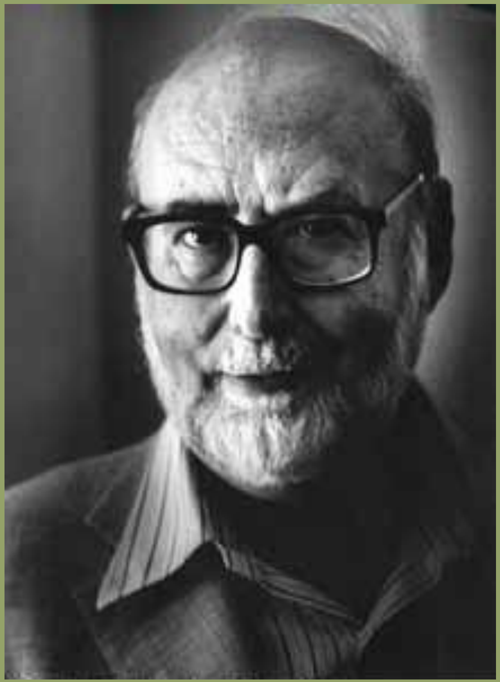
Helicity =

Spin w.r.t. rotation axis parallel to direction of motion

Massive particle continuously flips its helicity



Peter Higgs



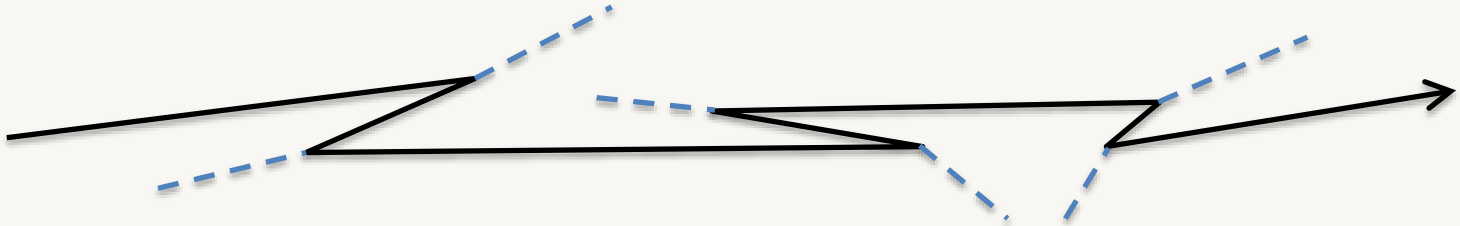
Fr. Englert

Robert Brout

They proposed *Spontaneous Symmetry Breaking*.

Complete symmetry → particle without mass

By spontaneous symmetry breaking you can get mass.

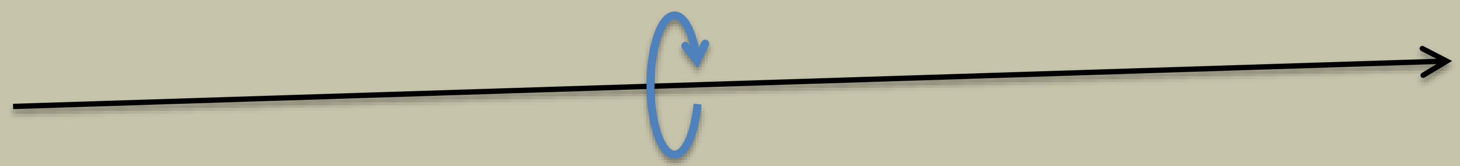


Particle with mass

a particle that can
disappear into empty space:
the Higgs particle
.

It does carry along the weak charges, and so these are no longer conserved.

Now, helicity can flip !!

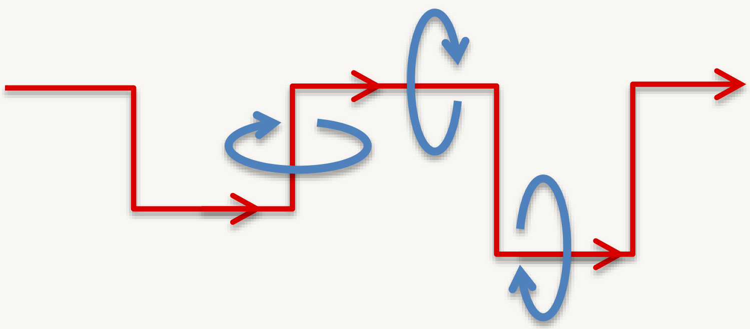


A photon, the particle of light, also goes with the speed of light. It can only spin along the axis parallel to its motion, either left or right.

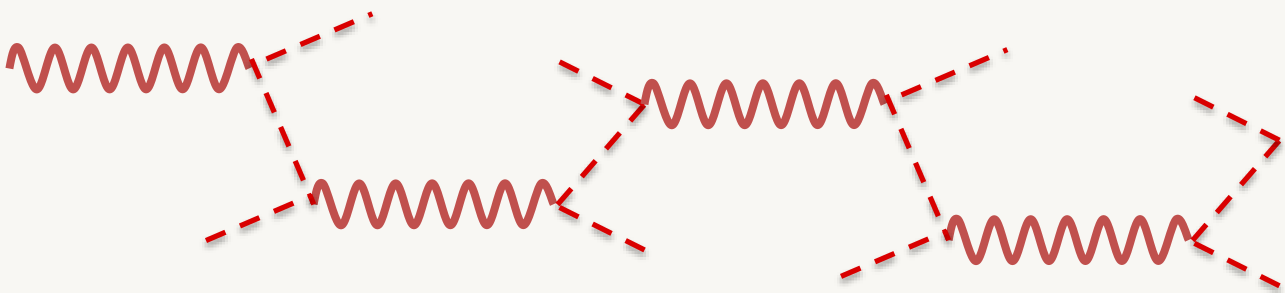
The carrier of the weak force would have more spin degrees of freedom than a photon,

and that's why the earlier calculations did not make sense …

The weak force carrier, is like a photon, but the force has much shorter range, therefore, the weak carrier must slow down, and carry mass. Massive photons can spin around 3 possible axes.

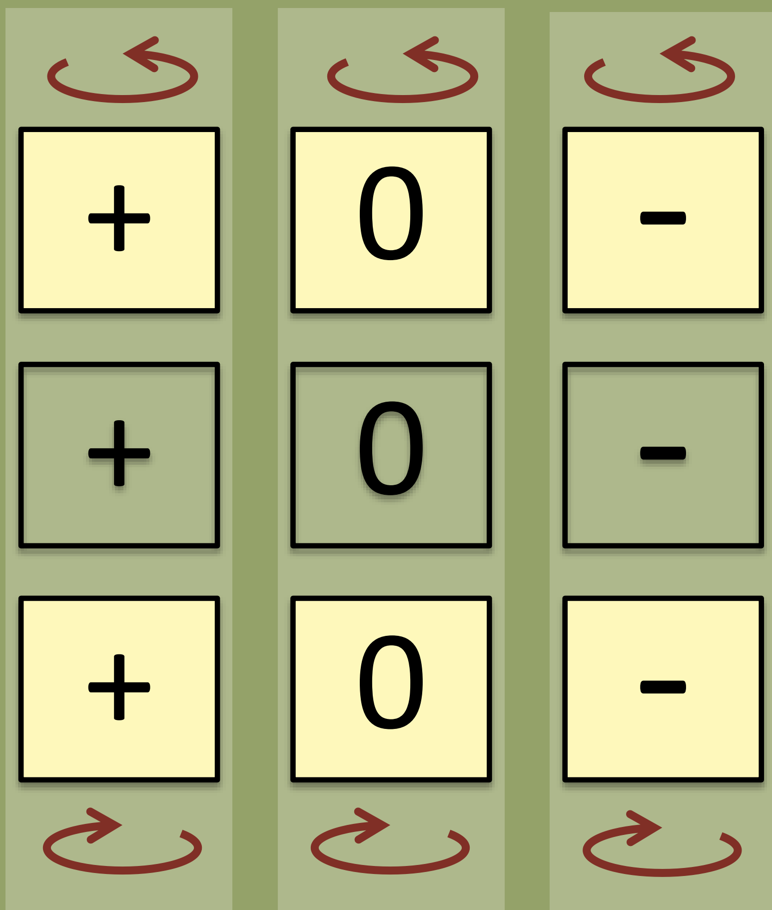


This is how the Higgs particle can take the place of a photon, giving it 3 spin modes!



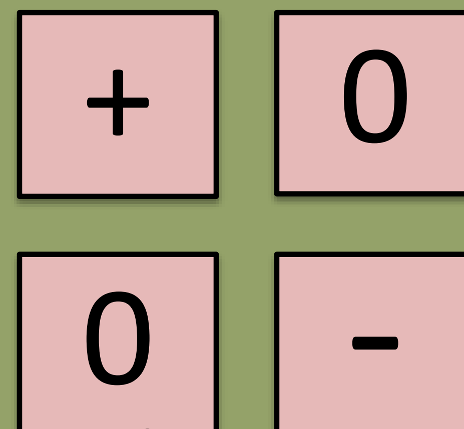
massive particles

Weak ~~photons~~



Particle without spin

One spinless particle remains: the **Higgs**

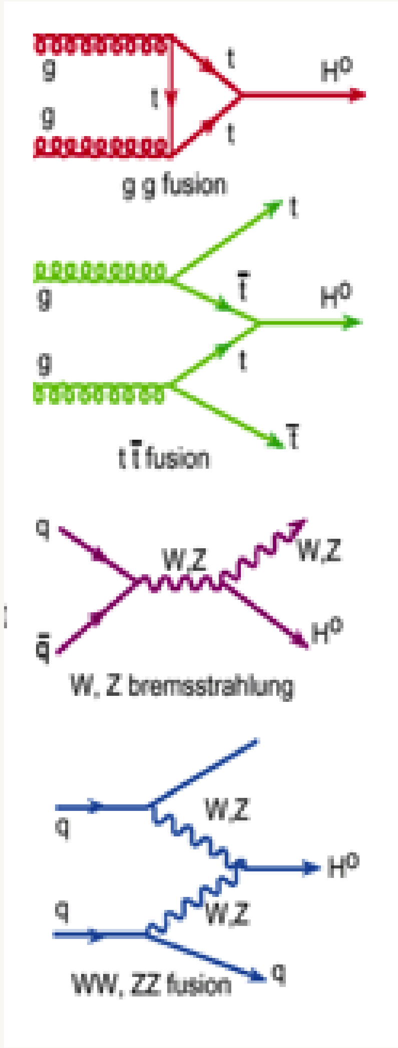


In spontaneous symmetry breaking the photon gets mass

Does the Higgs particle now “create” mass?

is it a **God particle** ??

Experimentally, what one (tries to) observe:



$$H^0 \longrightarrow ZZ$$

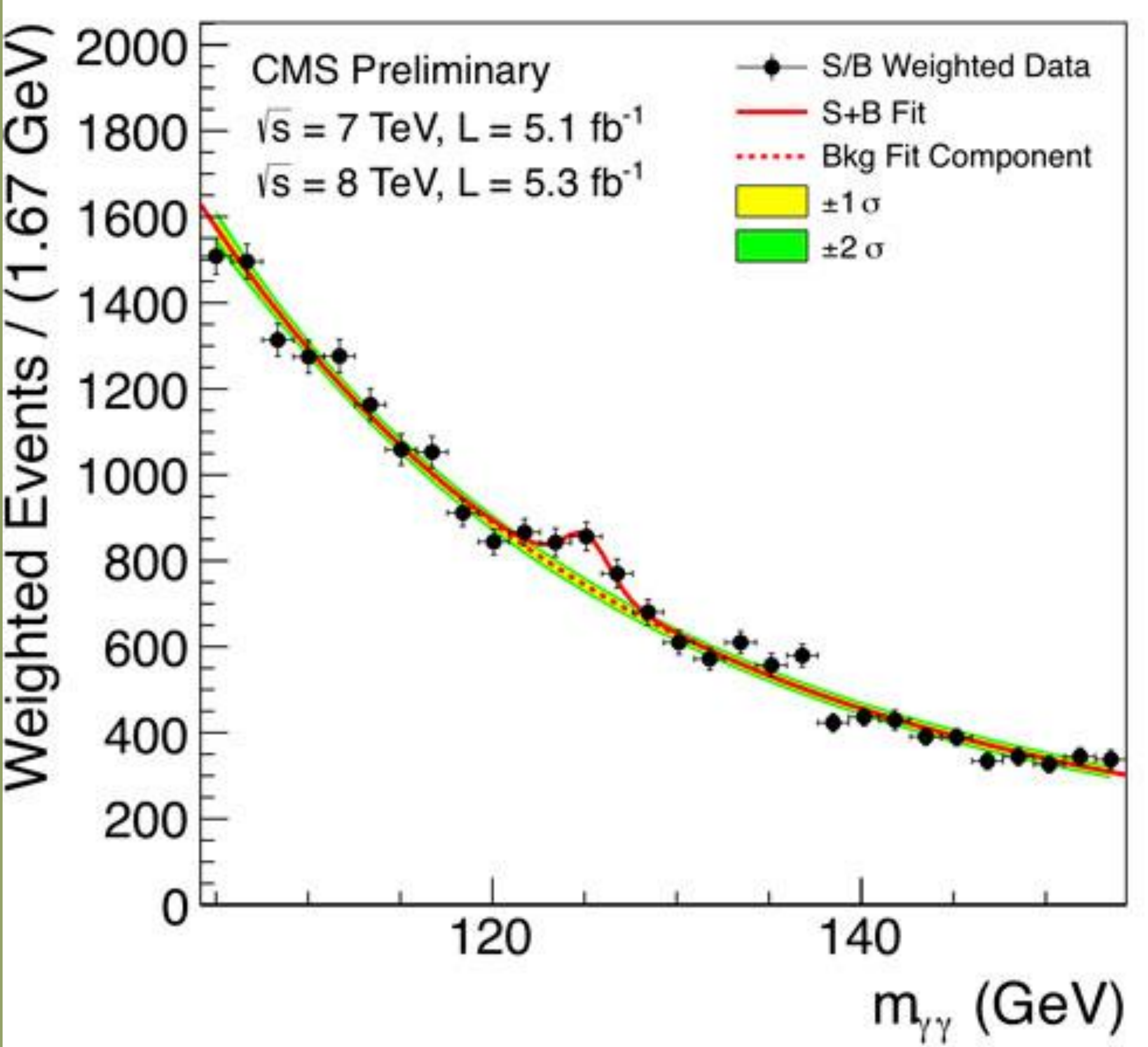
$$H^0 \longrightarrow WW$$

$$H^0 \longrightarrow b\bar{b}$$

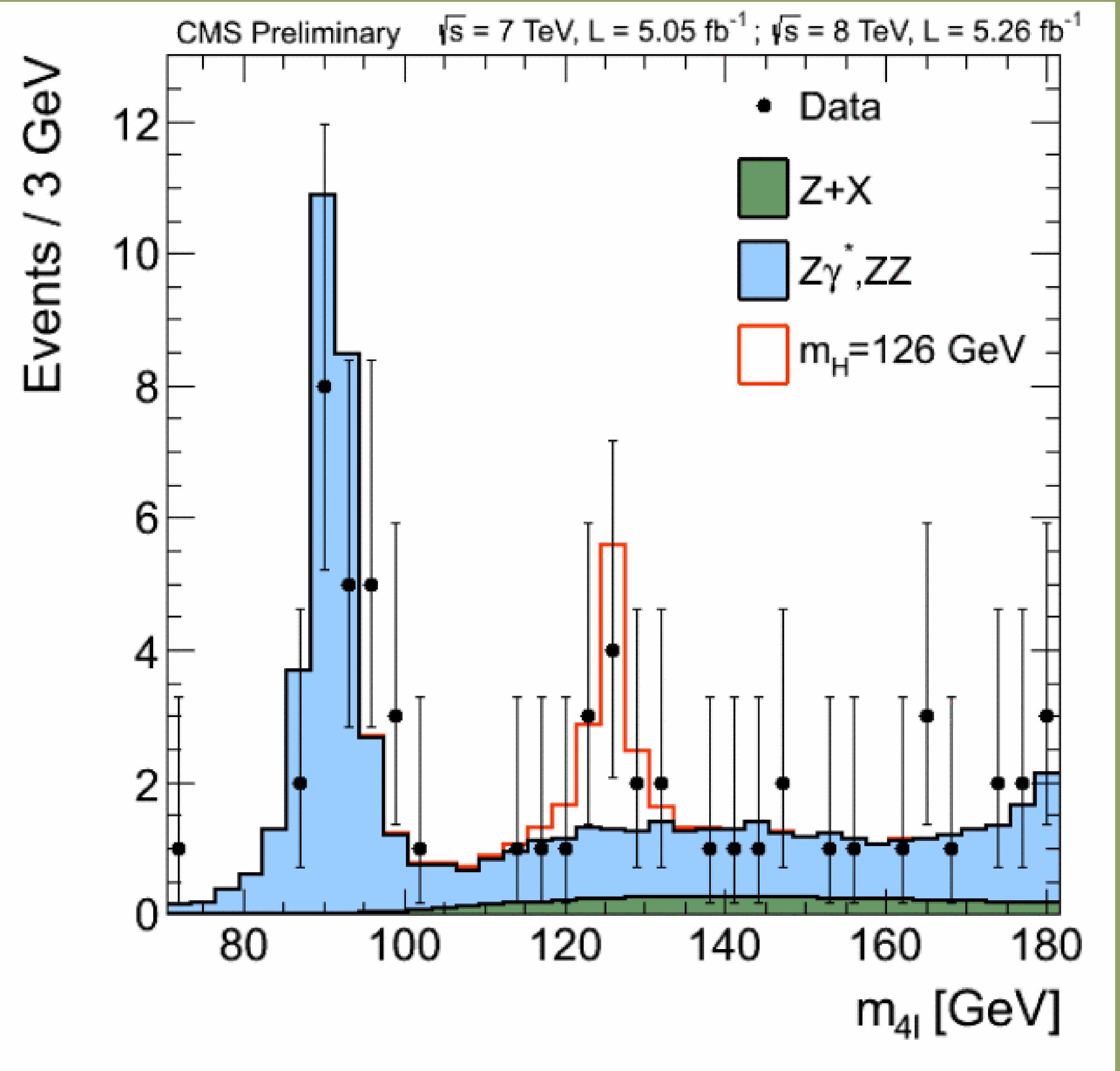
$$H^0 \longrightarrow t\,\bar{t}$$

$$H^0 \longrightarrow gg$$

Only one out of 1000 000 000 000 collisions produces a Higgs ...



CMS Preliminary
√s = 7 TeV, L = 5.1 fb-1
√s = 8 TeV, L = 5.3 fb-1
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1 σ
±2 σ
Weighted Events / (1.67 GeV)
mγγ (GeV)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
120
140

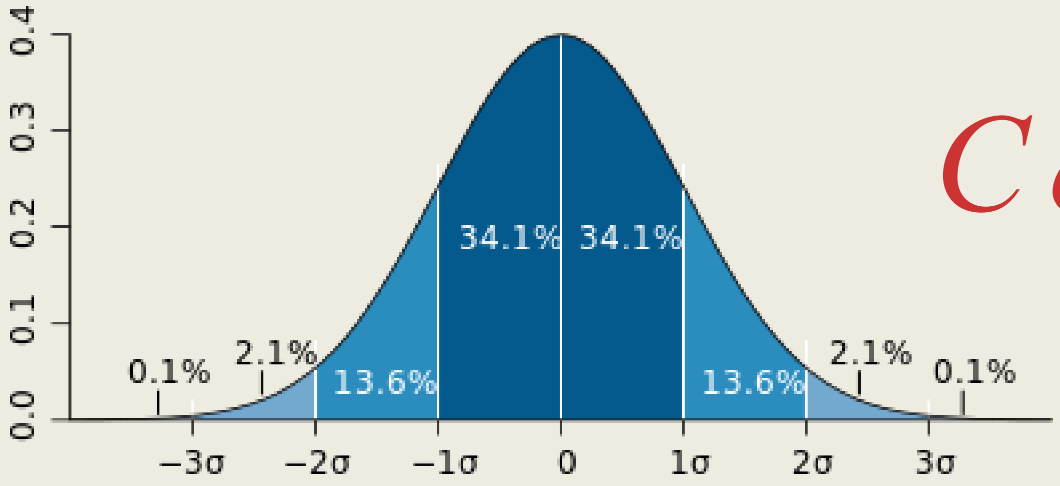


CMS Preliminary √s = 7 TeV, L = 5.05 fb-1 ; √s = 8 TeV, L = 5.26 fb-1
Events / 3 GeV
Data
Z+X
Zγ*,ZZ
mH=126 GeV
0
2
4
6
8
10
12
80
100
120
140
160
180
m4l [GeV]

To establish whether an observation is statistically significant, we use the mathematics of probabilities:

the Gauss curve

$$C e^{-\frac{1}{2}\left(\frac{x - x_0}{s}\right)^2}$$



If there is a result that deviates 5 σ or more from the expected value (probability 1 / 1 744 278), then one may call this a "discovery" (it is unlikely that this would be just a coincidence)

But you must be sure of your value for σ !

The Standard model

leptons quarks

gluons

τ-neutrino top

III

tau bottom

μ-neutrino charm

II

tau strange

e-neutrino up

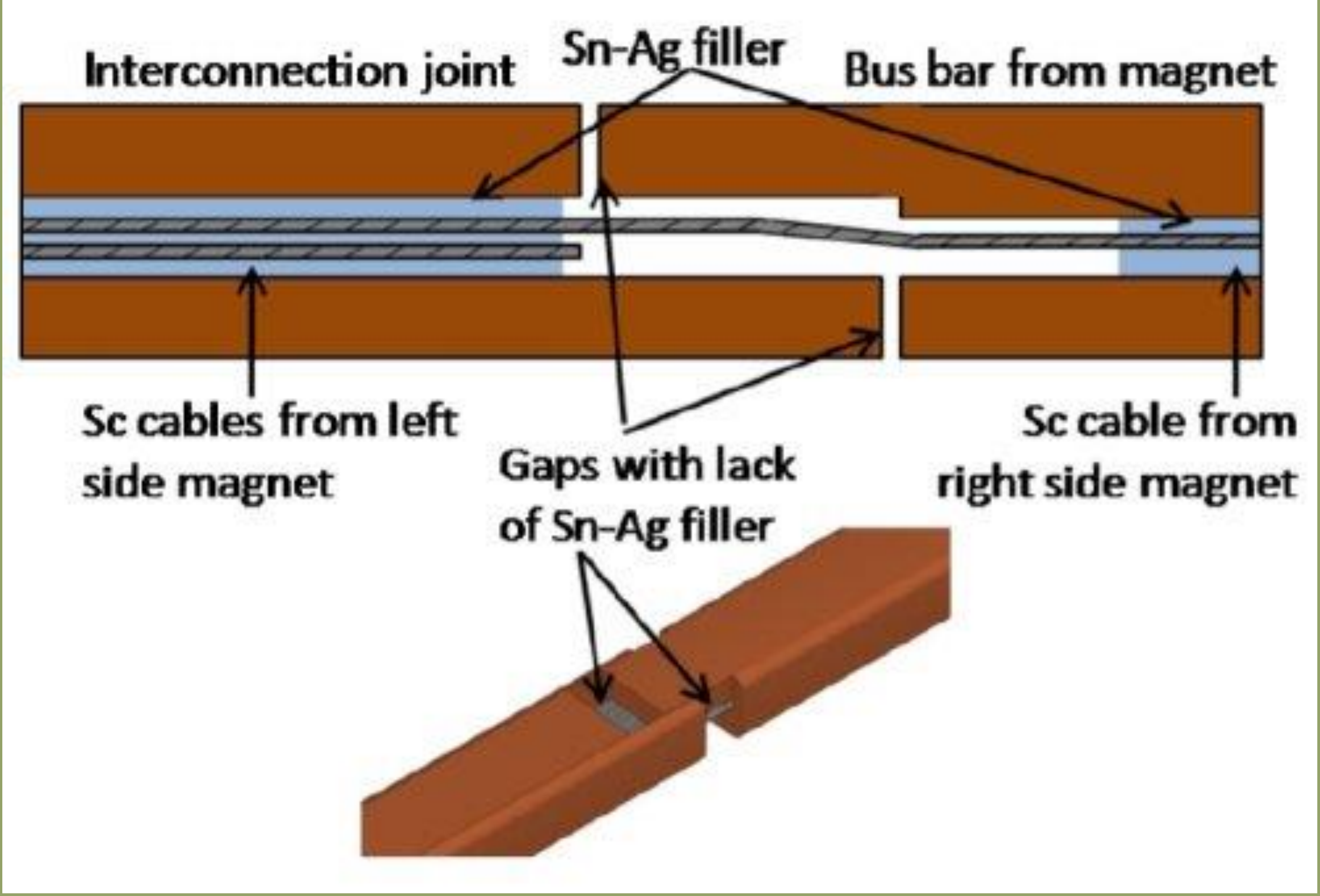
I

electron down

Higgs

Weak EM

Sept. 19, 2008


Interconnection joint
Sn-Ag filler
Bus bar from magnet
Sc cables from left side magnet
Gaps with lack of Sn-Ag filler
Sc cable from right side magnet

What trick was used by

the Book Keeper of the Universe

?

THE END