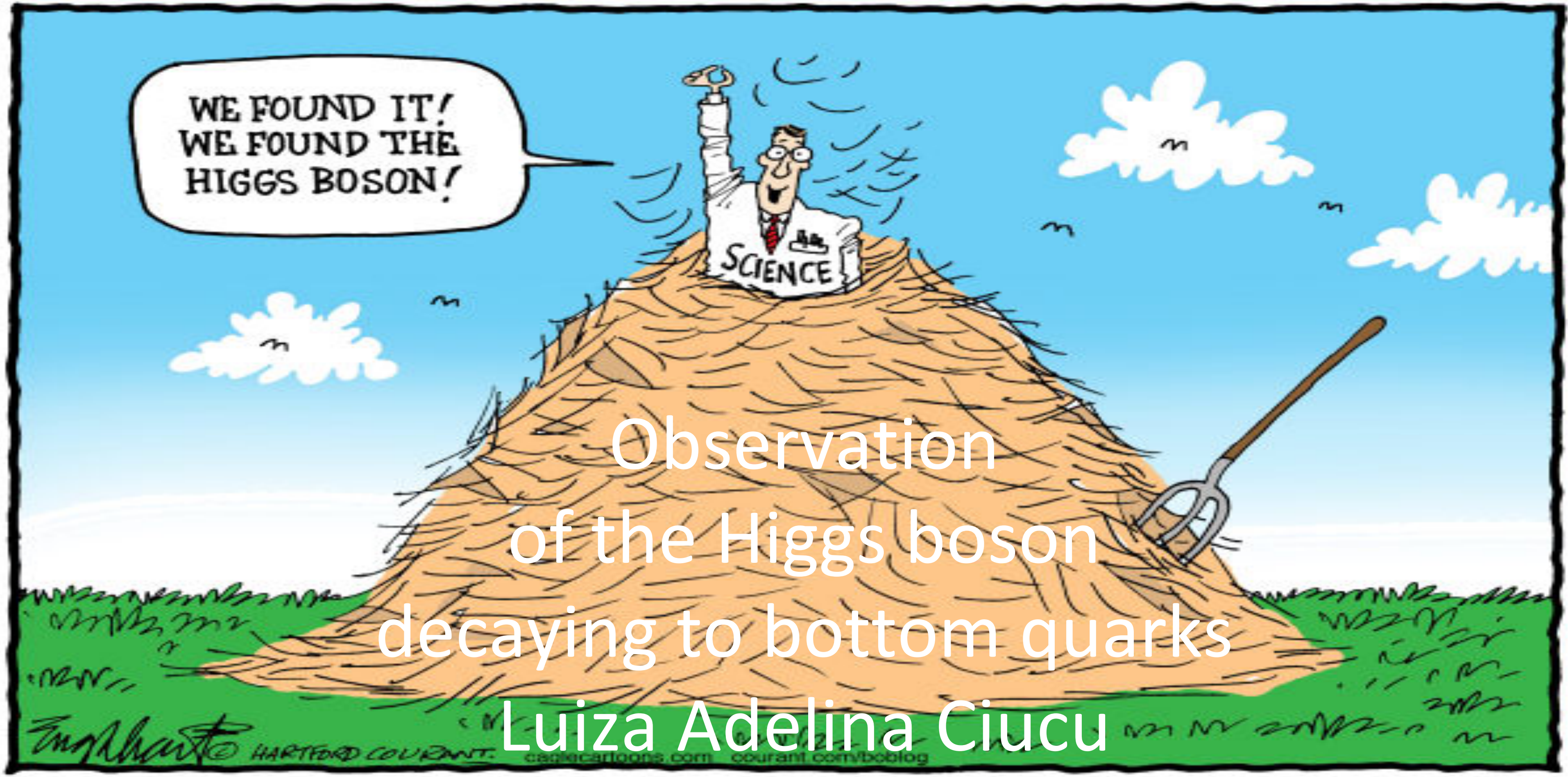
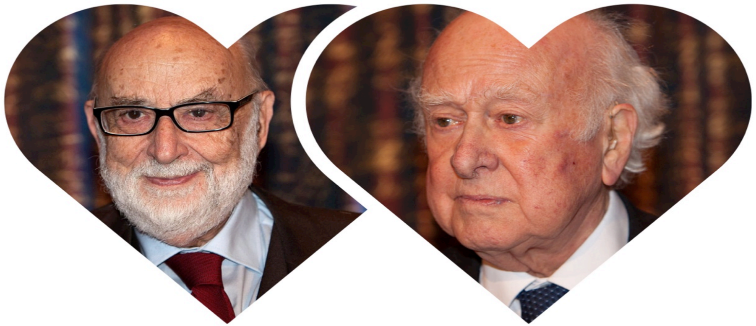


Observation of the Higgs boson decaying to bottom quarks

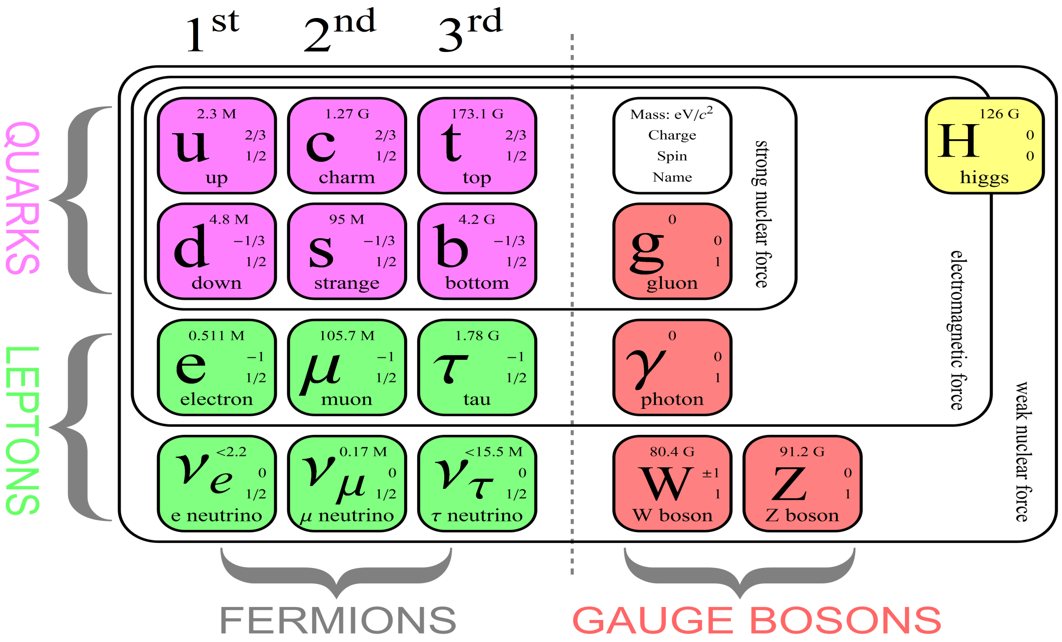
Luiza Adelina Ciucu

One major problem of the Standard Model (SM) was that it could not explain why particles have mass. To solve this, Robert Brout and François Englert and independently Peter Higgs predicted in 1964 the existence of a fundamental field that exists everywhere. An excitation of this field could be observed experimentally as a elementary particle - the famous Higgs Boson.

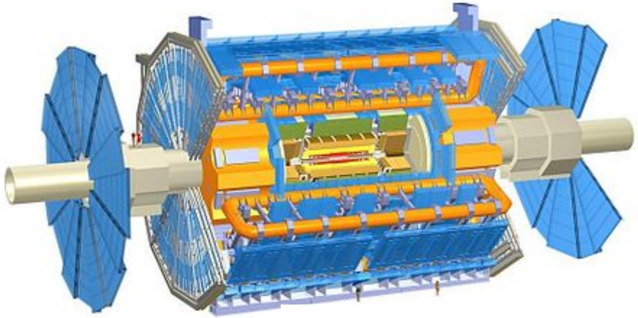


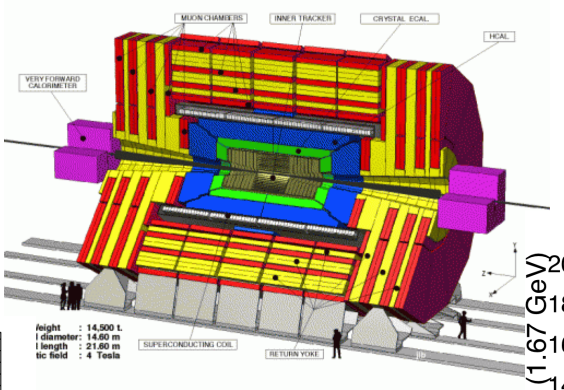
Higgs boson discovered: 2012

Nobel Englert & Higgs: 2013

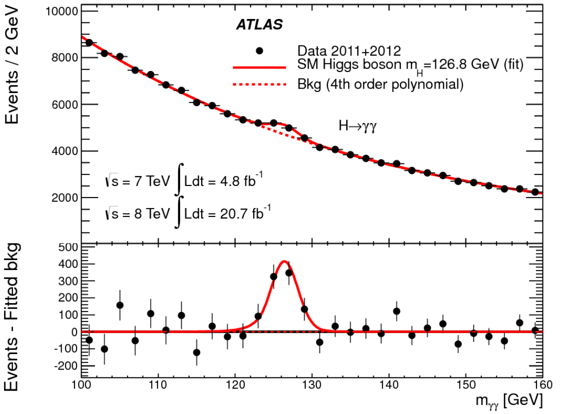


The Higgs boson discovery was done in 2012 at CERN by two independent experiments: ATLAS and CMS, at a mass of 125 GeV. The Higgs boson was produced in a gluon fusion, and decayed to particles that carry the electroweak force: photons, W or Z bosons.

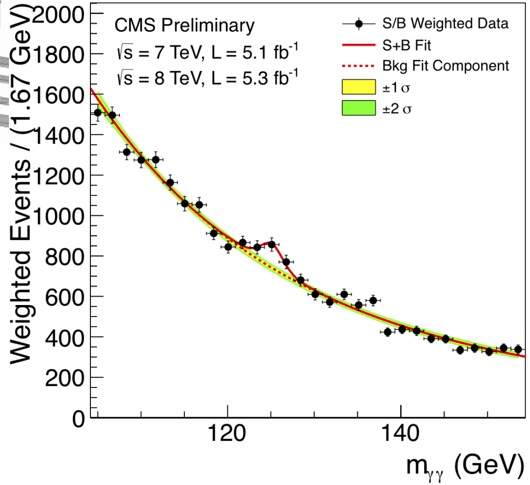




ATLAS
gg->H->γγ

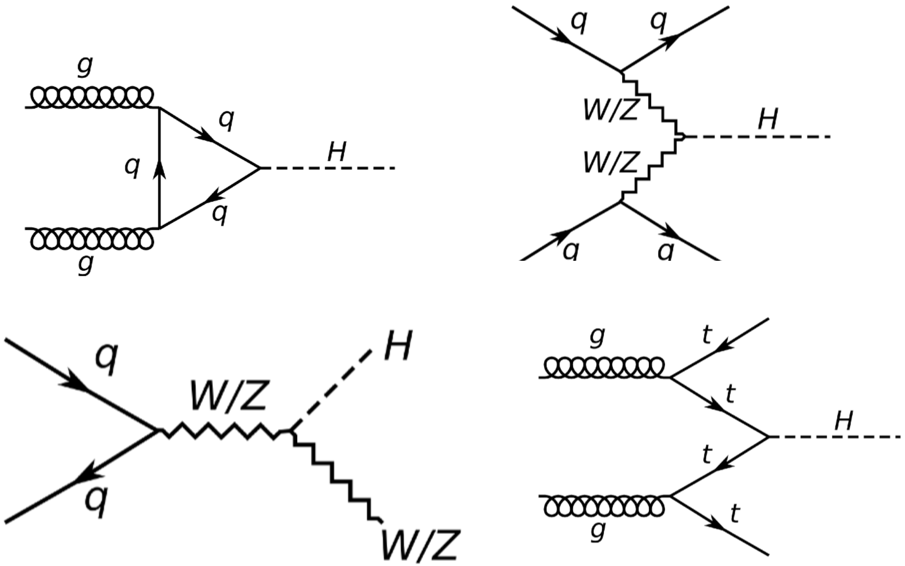


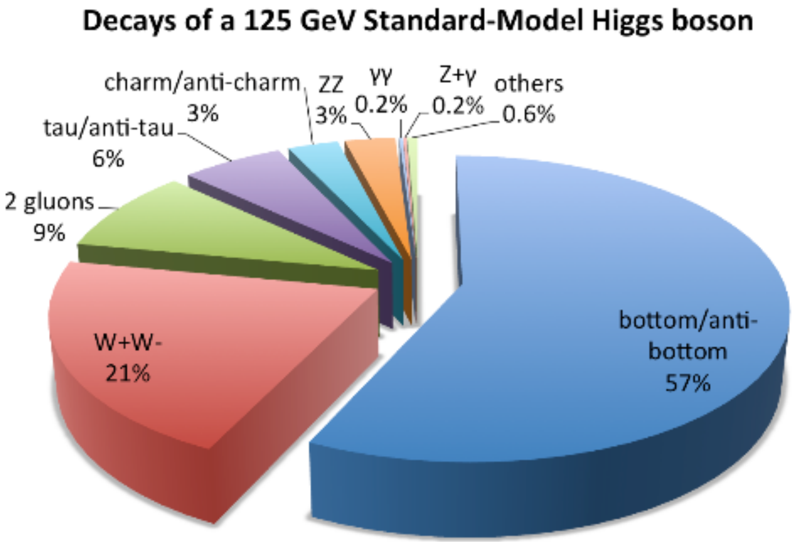
CMS
gg->H->γγ



Is there only one Higgs boson as predicted by the SM?
Or several Higgs boson as predicted by several theories beyond the SM (e.g. supersymmetry) ?
So need to study the Higgs boson and observe all the possible production and decay channels.

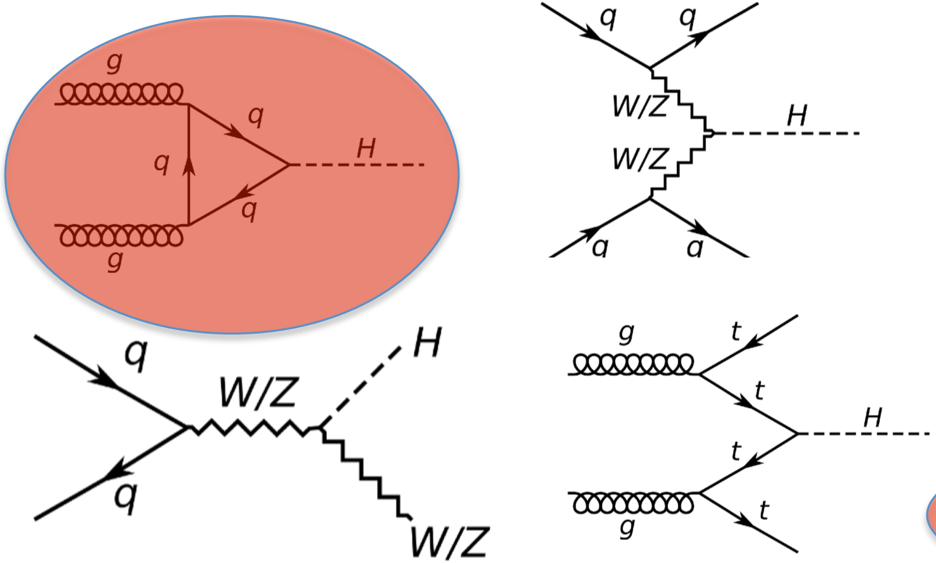
Four production channels

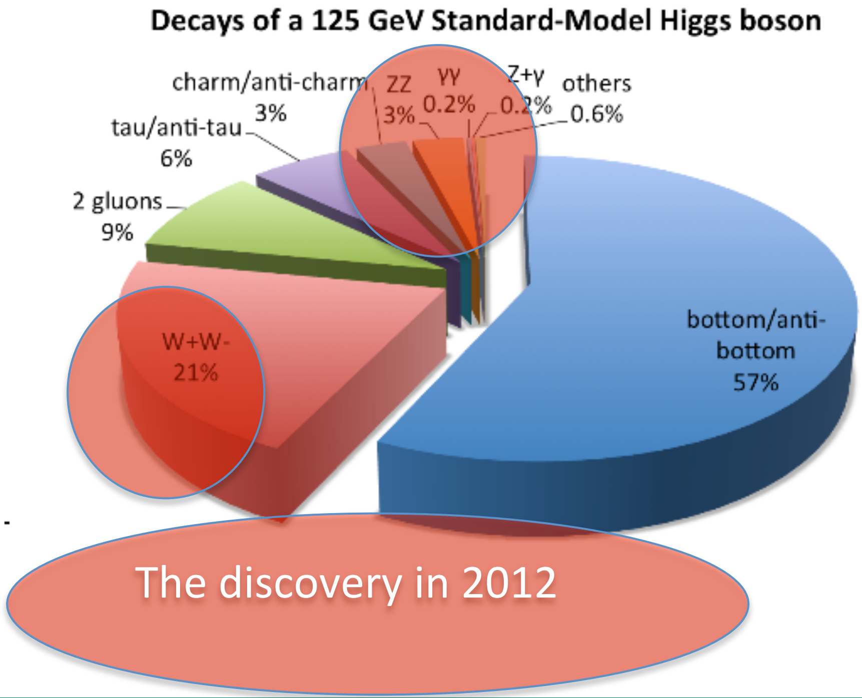




In 2012 the observation used the gluon fusion, and the decays to photons, Z or W bosons.

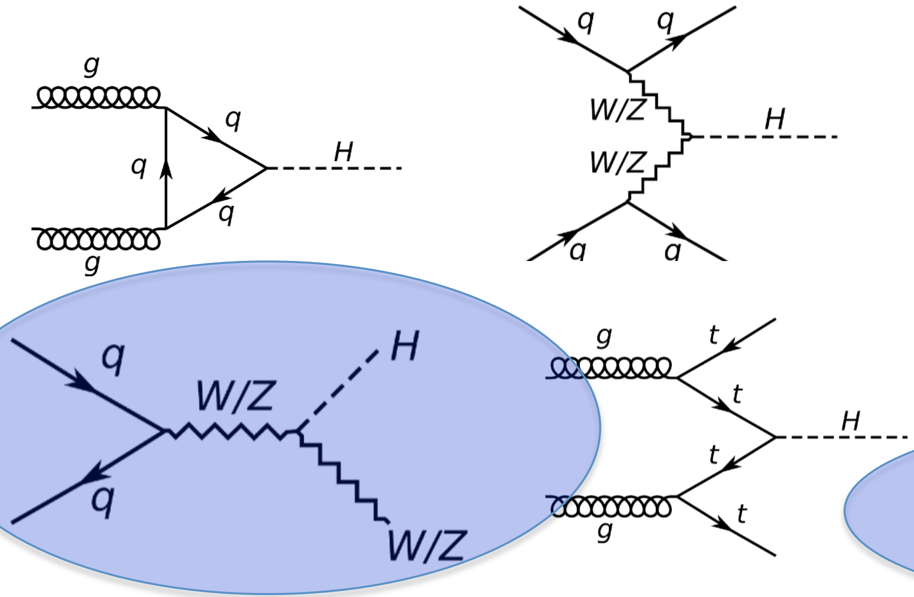
Four production channels

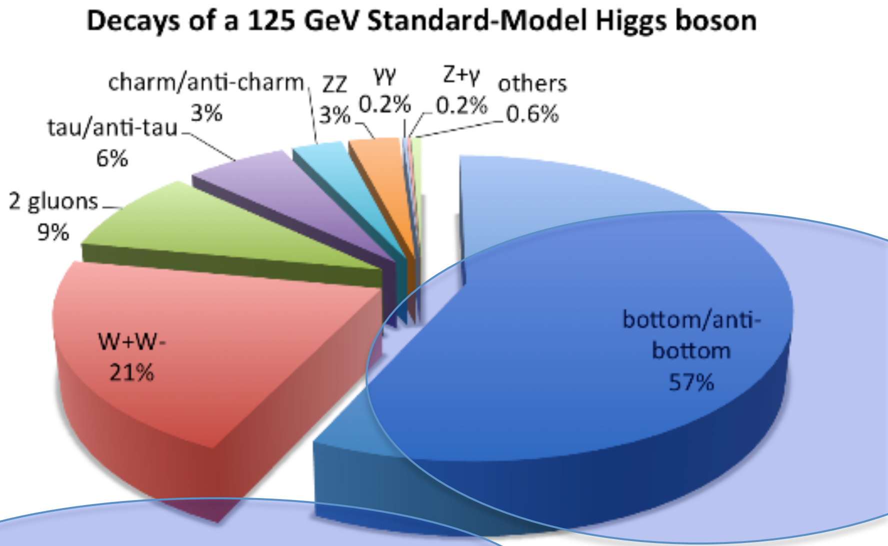




By 2018, there were observed also two more production channels: vector boson fusion and ttH, and the decay to tau leptons. What remained still was the VH production mechanism and the decay to bottom quarks. The search is very hard as colliding protons are made of quarks.

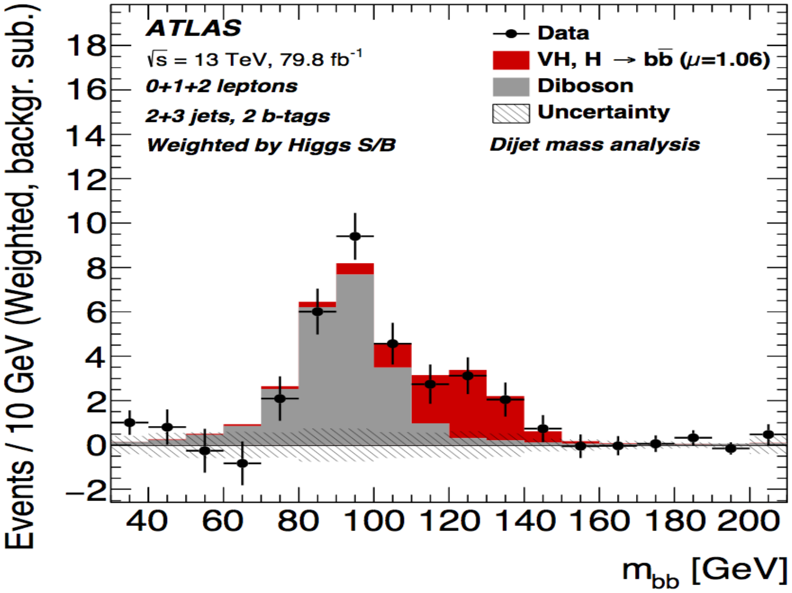
Four production channels

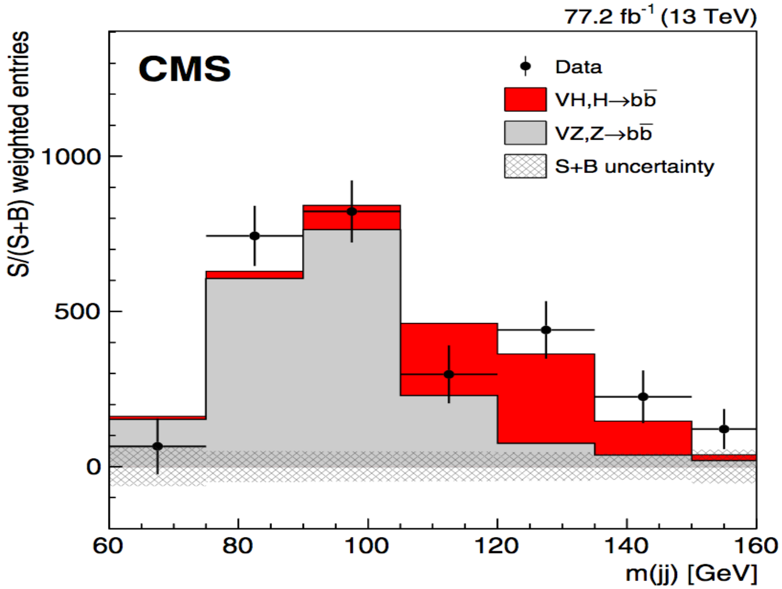




The VH and H->bb Observation in 2018

The final plots of these very complex data analyses:
simulation of diboson background in grey W+Z(Z->bb) or Z+Z(Z->bb) with a bump at 90 GeV,
simulation of the Higgs boson signal (red) with a bump at 125 GeV,
and the **data points in black,** which agree very well with the background and signal.

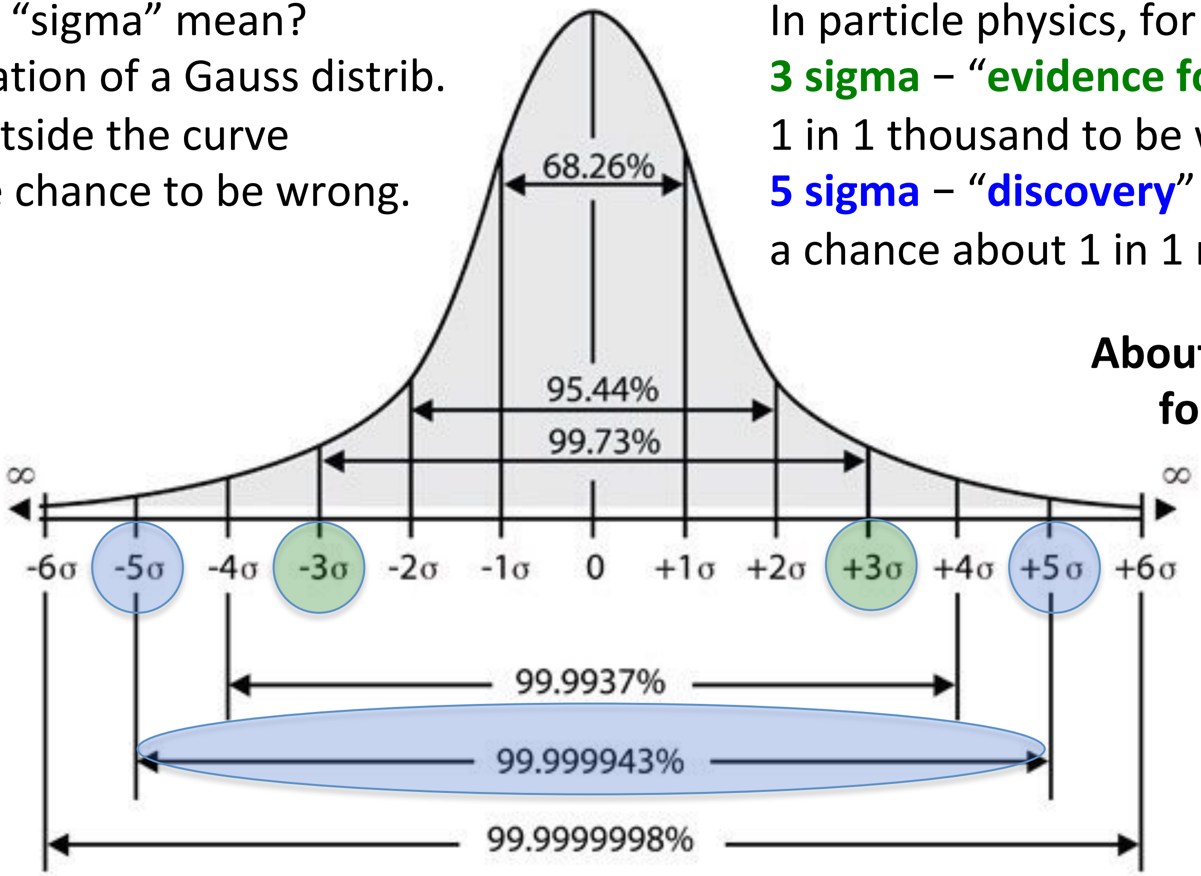




From the data error bars we can estimate the number of sigma: 5 -> observation!

But what does "sigma" mean?
Standard deviation of a Gauss distrib.
Percentage outside the curve represents the chance to be wrong.

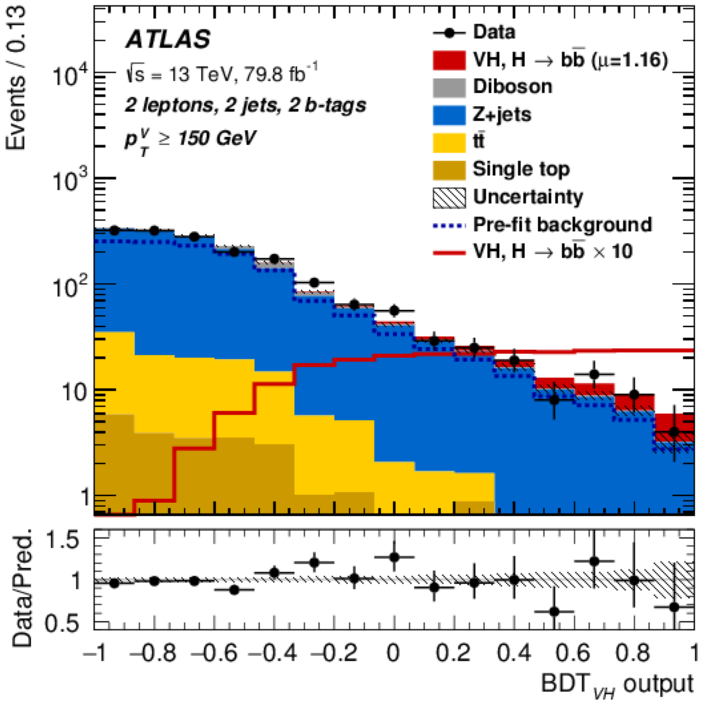
In particle physics, for discoveries we use:
3 sigma – "**evidence for**", a chance about 1 in 1 thousand to be wrong
5 sigma – "**discovery**" or "**observation**", a chance about 1 in 1 million to be wrong



About 15 years history for the Hbb search:

* 2004 – start at Tevatron
* 2011 – evidence at Tevatron
* 2017 – evidence at ATLAS and CMS
* 2018 – observation at ATLAS and CMS

But how was the observation of 5 sigma been obtained by both ATLAS and CMS?
One key ingredient was using machine learning (artificial intelligence), to separate better the Higgs boson signals and the various SM processes. A gain of 25%, or 4 sigma -> 5 sigma.

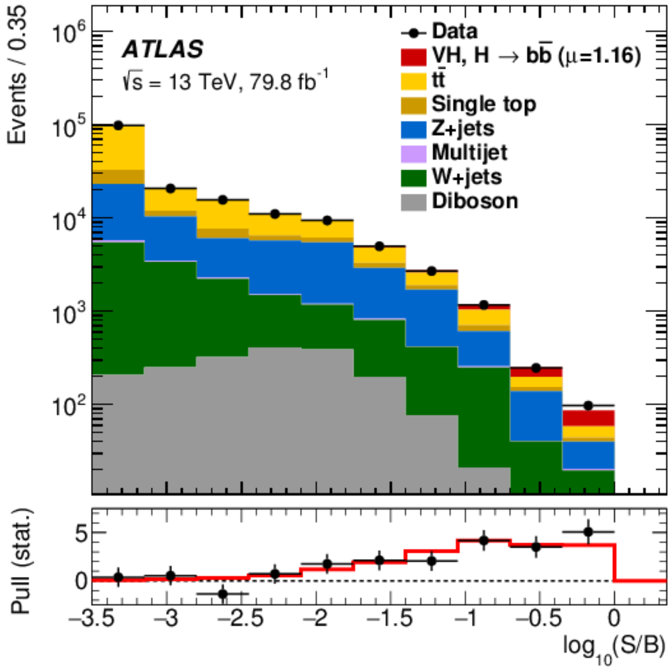


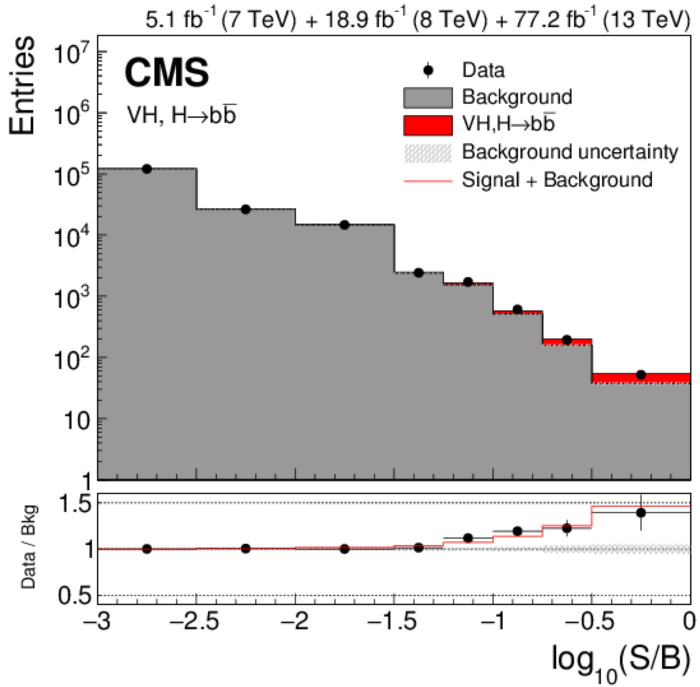
Same machine learning algorithm at ATLAS and CMS: boosted decision trees.

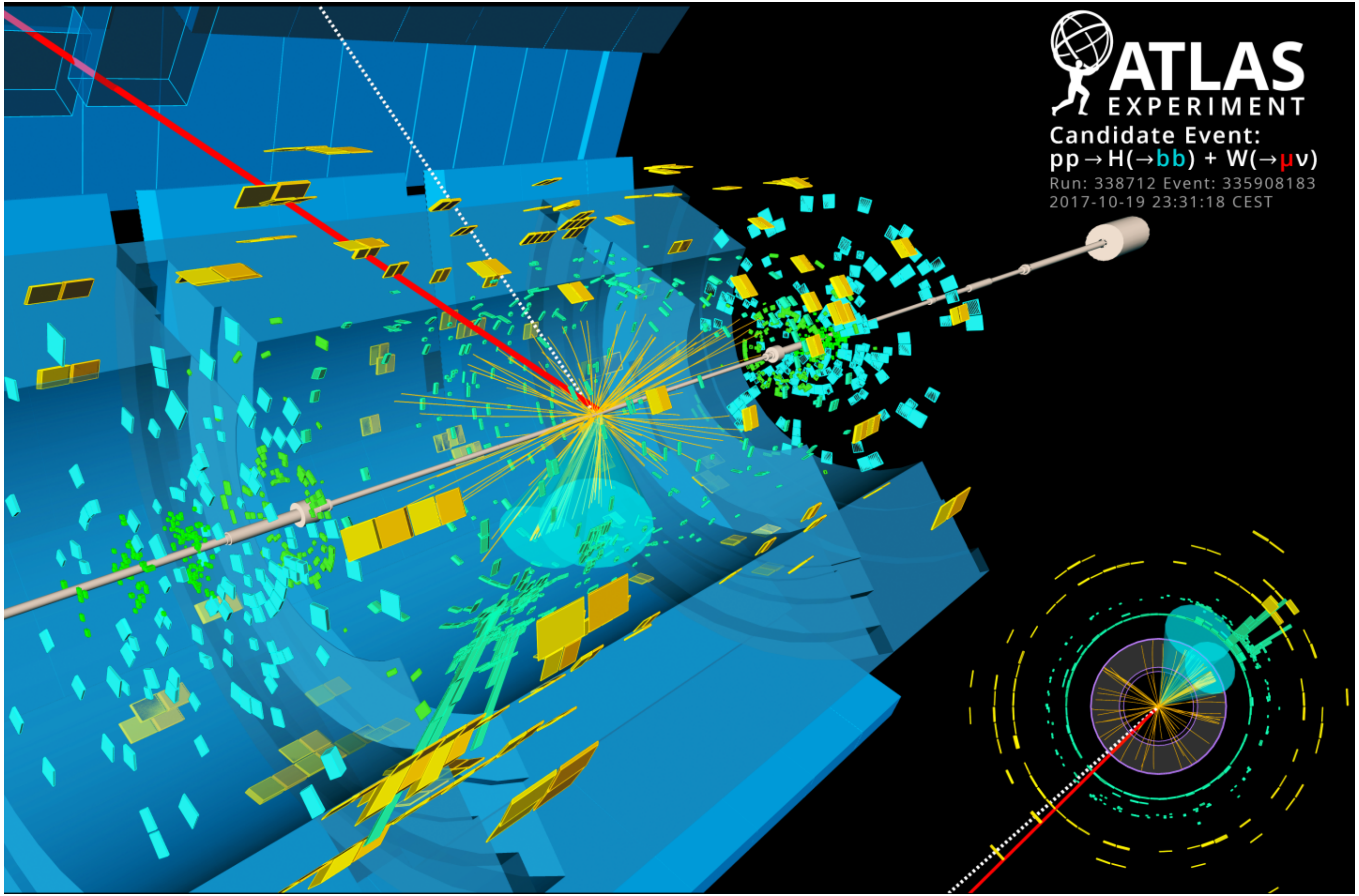
As a result, signal in red peaks to the right, while backgrounds peak on left, making it easier to separate signal and bkg,

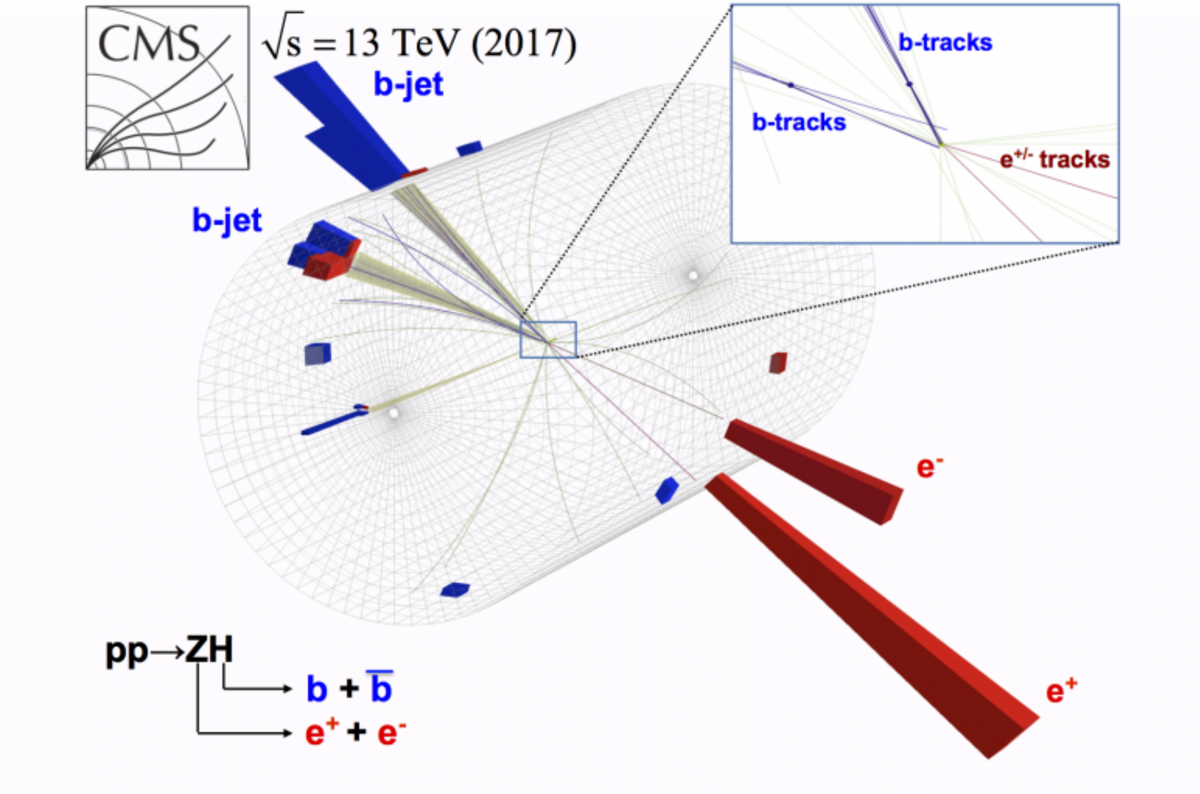
and thus 4 sigma -> 5 sigma (discovery!)

These analysis are very complex, using several independent regions of phase space.
Combining based on the signal to background ratio (S/B).
Signal is to the right, background to the left.
In the bottom pads, the **data in black** reproduce very well the **simulated signal prediction in red**.






ATLAS
EXPERIMENT
Candidate Event:
pp → H(→bb) + W(→μν)
Run: 338712 Event: 335908183
2017-10-19 23:31:18 CEST


CMS
$\sqrt{s} = 13$ TeV (2017)
b-jet
b-jet
b-tracks
b-tracks
$e^{+/-}$ tracks
e^-
e^+
pp→ZH
$b + \bar{b}$
$e^+ + e^-$

Bibliography

ATLAS paper
CMS paper

ATLAS press release
CMS press release
CERN press release

Conclusion: after a 15 year quest, two observations have been made from just one analysis: 1) the VH associated production; 2) the Higgs boson decay to bottom quarks (H->bb).

With this observation of VH, H->bb,
all the major Higgs boson production
and decay channels have been observed.

The next Higgs observations are expected to be:

- the decay of Higgs boson to muons
- productions of two Higgs bosons together.

These processes are so rare, it may need a 5-10 years (Run-3 and the Run-4 data taking).

ATLAS and CMS persevere in studying better the properties of the Higgs boson.
Maybe it will turn out that it is not the SM Higgs boson after all!
Stay tuned to news from CERN!