Direct searches for Beyond Standard Model Higgs sector

(What could we learn about high energy particle physics from the 125 GeV boson)

Teasing the mini-workshop in the BSM Higgs

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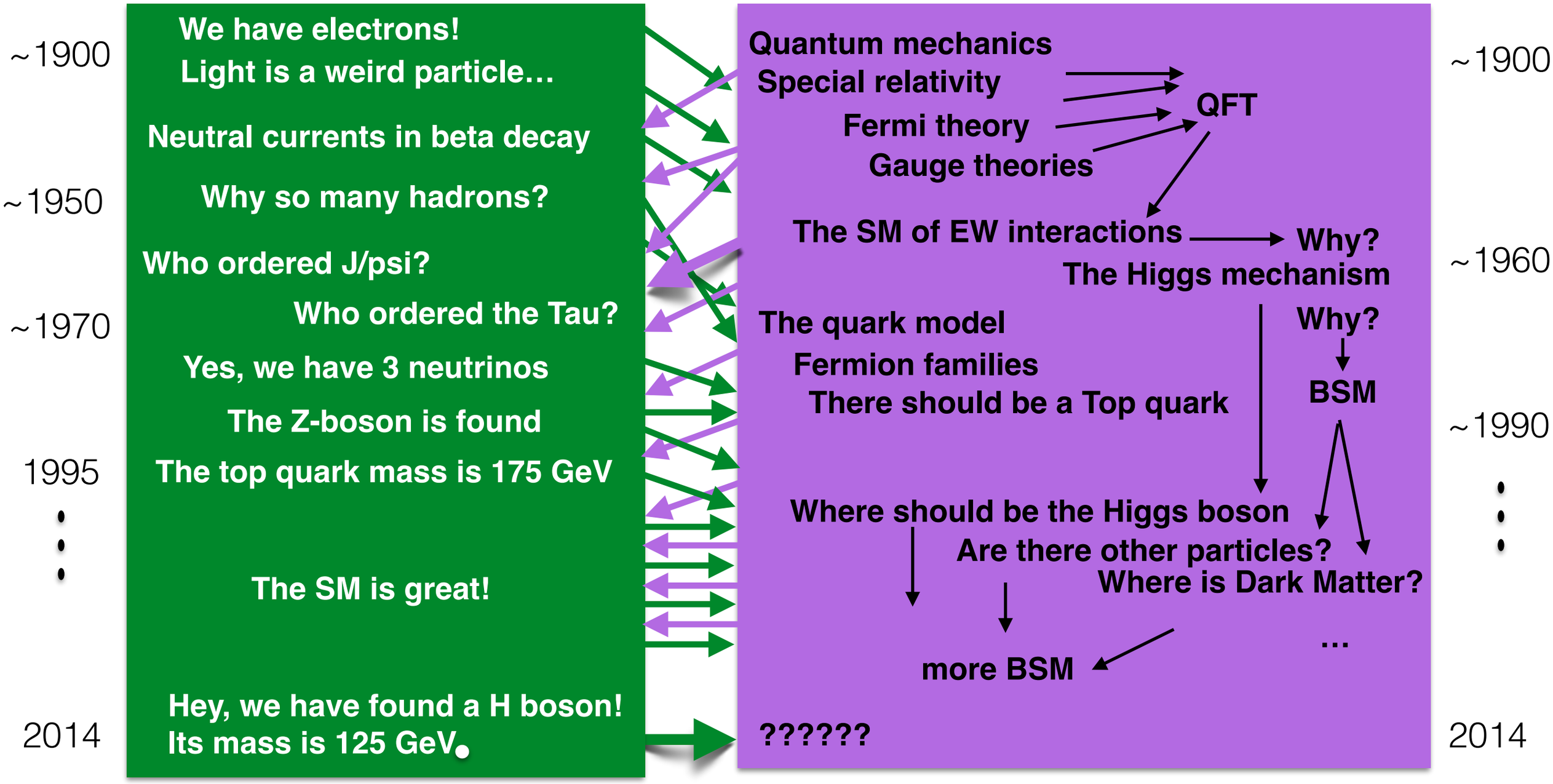
Outline

- Hey, we have a (125 GeV) H boson! Is this the SM one?
- We would like to mention some few things we can learn from it
  - Decay and production
  - Double Higgs production at LHC
- May we have more Higgs bosons?

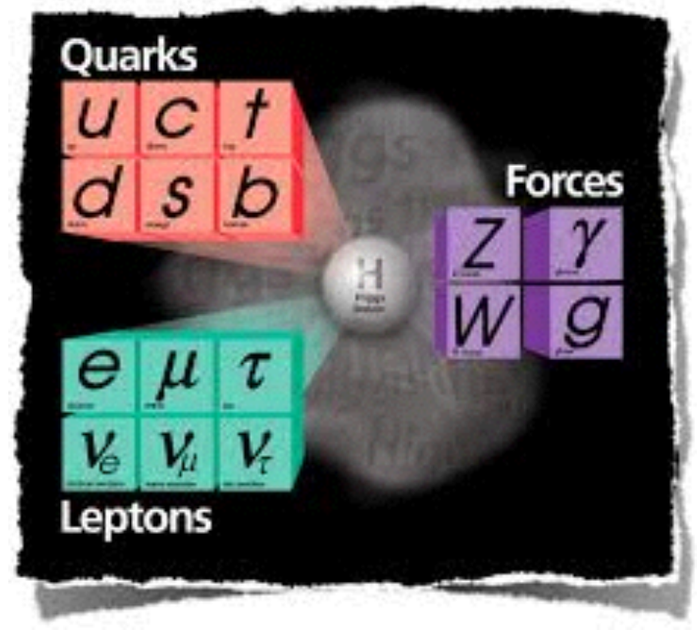
If we try to make a (very coarse) evolution of particle physics

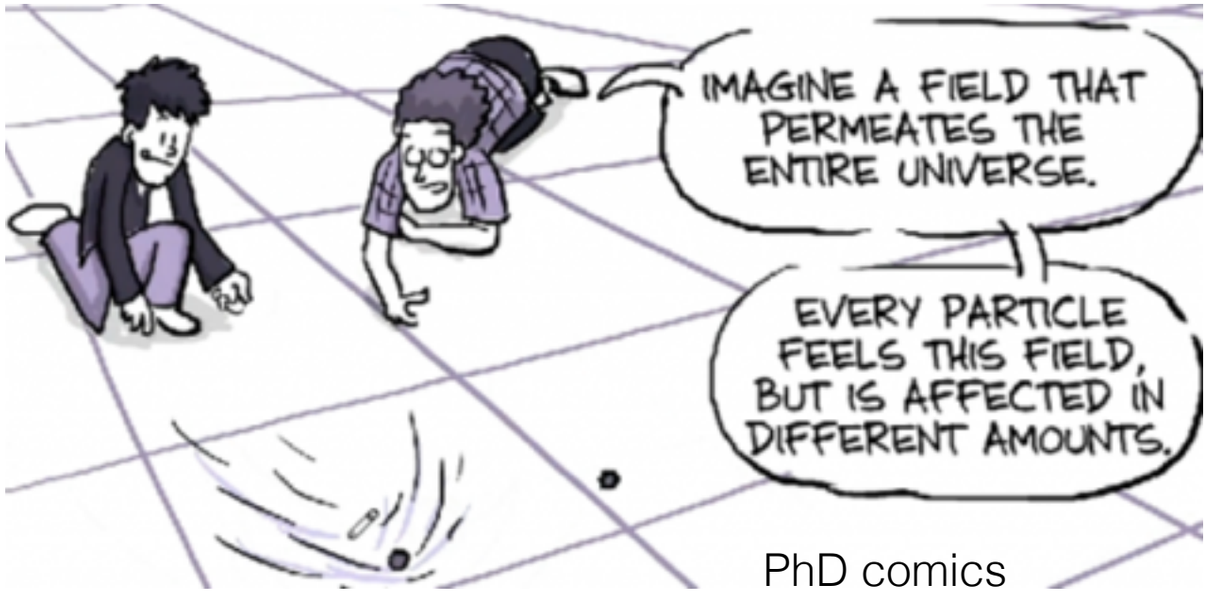
Since its beginning particle physics has been a synergy of experimental and theoretical discoveries



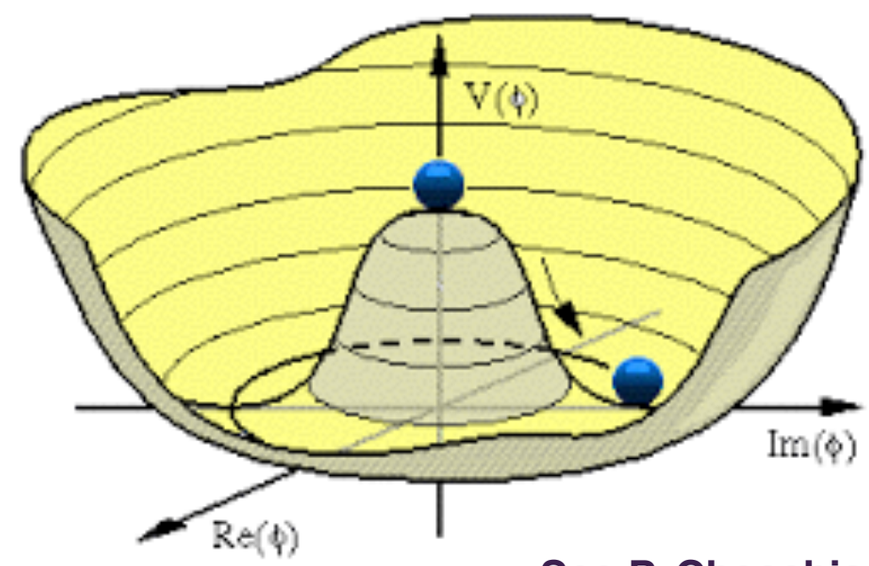
* (B)SM = (Beyond the) Standard Model (of Elementary Particles)

Why is the H boson an interesting guy?





PhD comics

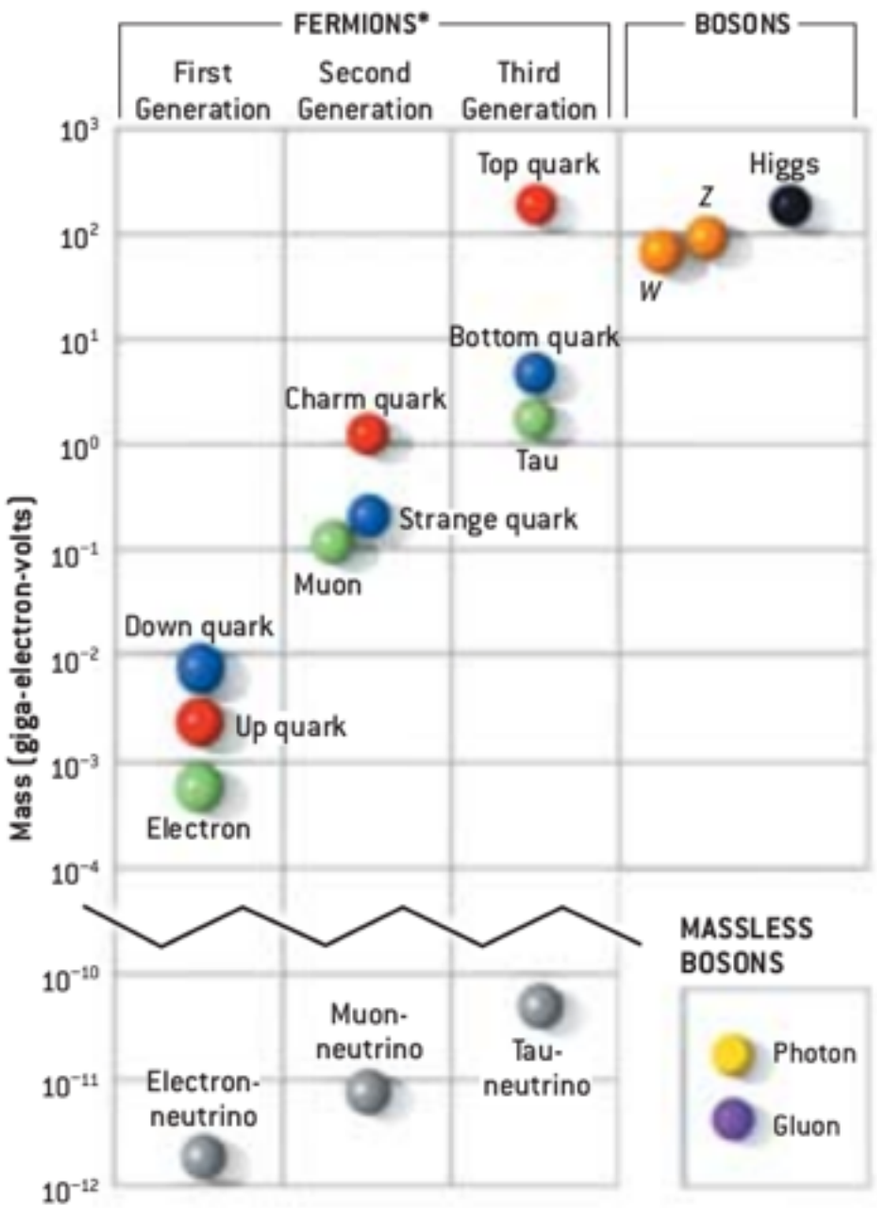


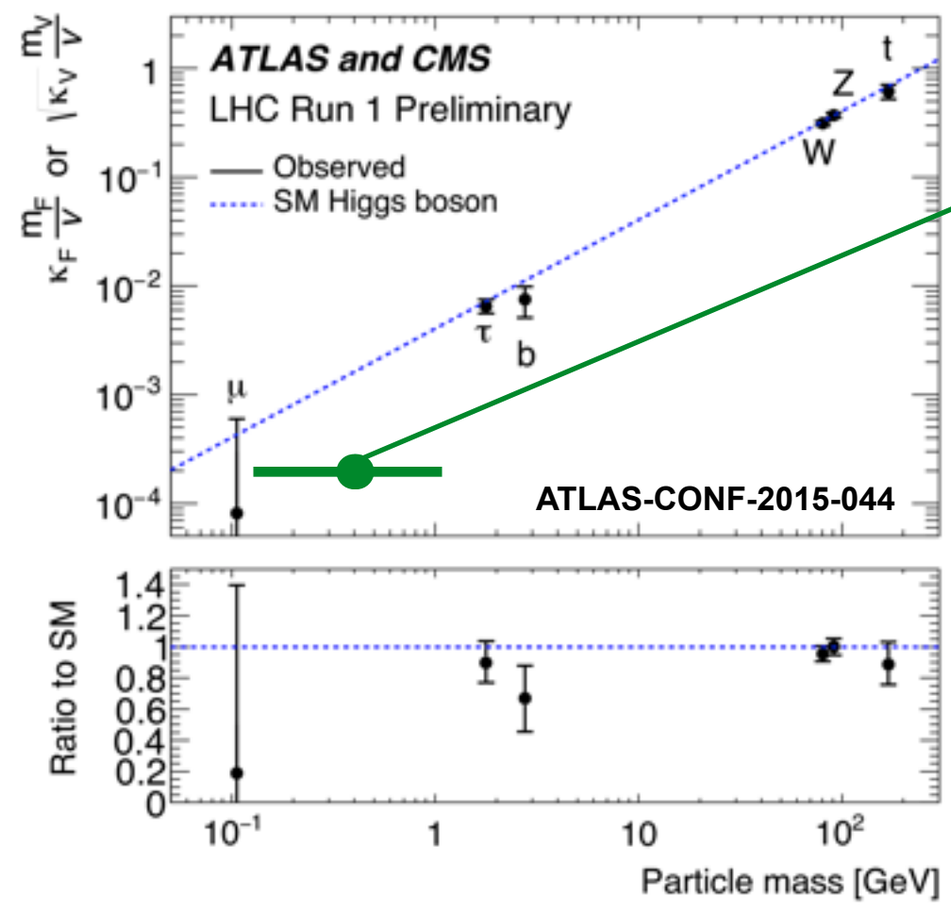
See P. Checchia talk

If there are new forces and new particles they should be connected to the H boson.
Let's look have a closer look on it!

Do we have a SM 125 Higgs boson? Decays.

- In the SM, we expect the Higgs boson to be a spin-0 CP-even boson, that couples with other particles with strength proportional to their masses





something is missing here

To detect H decays to light quarks at LHC is very difficult. In principle there is no handle to distinguish those decays from the huge QCD Background….

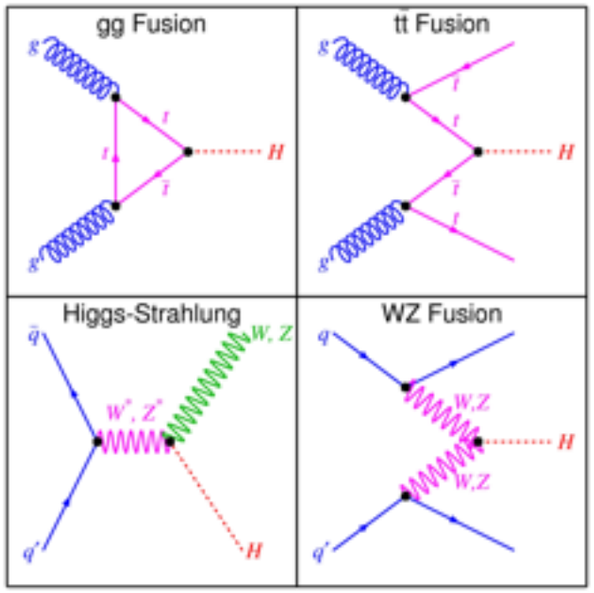
… but it is not impossible

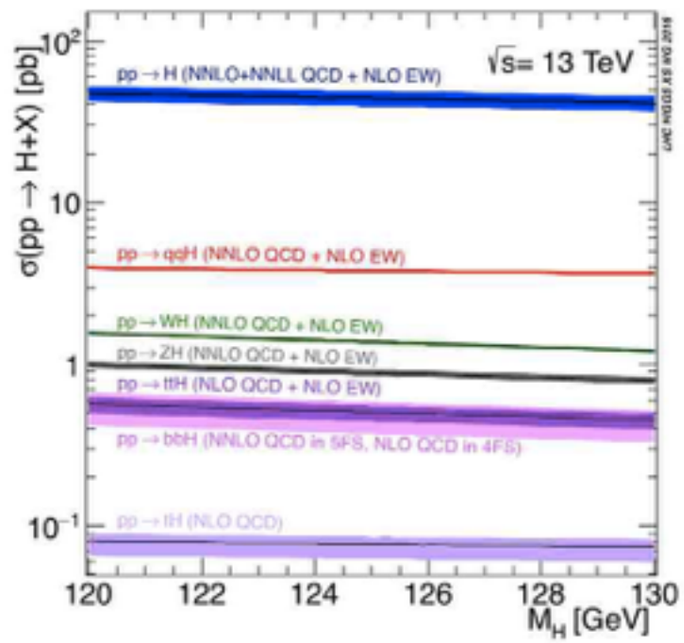
Taggers for jets originally from light quarks are a possibility and can help to fill the gap!

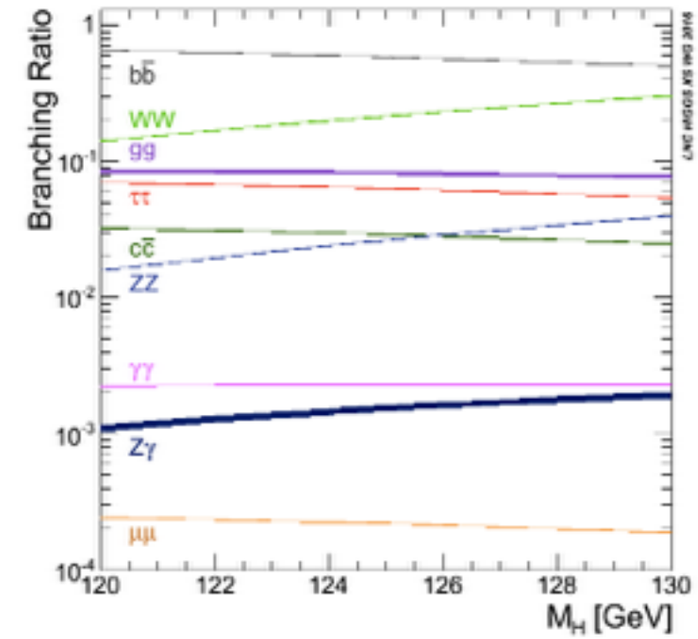
See E. Stamou talk

Do we have a SM 125 Higgs boson? Production.

Main production and decays modes very well predicted at LHC:







Deviations of the SM (as presented in the last slide) are usually measured assuming an effective Lagrangian, truncated up to dimension 6 operators, and under the hypothesis of no other new particle.

Now that we have found the H boson, we can can return and ask:
How much we can trust this assumption?

$$
\begin{aligned}
\mathcal{L}_{\rm EFT} = & \mathcal{L}_{\rm SM} + \frac{\bar{c}_H}{2v^2}\,\partial^\mu(\phi^\dagger\phi)\,\partial_\mu(\phi^\dagger\phi) + \frac{\bar{c}_T}{2v^2}\,(\phi^\dagger \overleftrightarrow{D}^\mu \phi)\,(\phi^\dagger \overleftrightarrow{D}_\mu \phi) - \frac{\bar{c}_6\lambda}{v^2}(\phi^\dagger\phi)^3 \\
& + \frac{ig\bar{c}_W}{2m_W^2}\,(\phi^\dagger \sigma^k \overleftrightarrow{D}^\mu \phi)\,D^\nu W^k{}_{\mu\nu} + \frac{ig'\bar{c}_B}{2m_W^2}\,(\phi^\dagger \overleftrightarrow{D}^\mu \phi)\,\partial^\nu B_{\mu\nu} \\
& + \frac{ig\,\bar{c}_{HW}}{m_W^2}\,(D^\mu\phi^\dagger)\,\sigma^k\,(D^\nu\phi)\,W^k_{\mu\nu} + \frac{ig'\bar{c}_{HB}}{m_W^2}(D^\mu\phi^\dagger)\,(D^\nu\phi)\,B_{\mu\nu} \\
& + \frac{g'^2\bar{c}_\gamma}{m_W^2}\,(\phi^\dagger\phi)\,B_{\mu\nu}\,B^{\mu\nu} + \frac{g_s^2\bar{c}_g}{m_W^2}\,(\phi^\dagger\phi)\,G^A_{\mu\nu}\,G^{\mu\nu\,A} \\
& - \left[\frac{\bar{c}_u}{v^2}\,y_u\,(\phi^\dagger\phi)(\phi^\dagger\cdot\overline{Q}_L)\,u_R + \frac{\bar{c}_d}{v^2}\,y_d\,(\phi^\dagger\phi)(\phi\,\overline{Q}_L)\,d_R + \frac{\bar{c}_\ell}{v^2}\,y_\ell\,(\phi^\dagger\phi)(\phi\,\overline{L}_L)\,\ell_R + \text{h.c.}\right].
\end{aligned}
$$

+ ???

What happens to the signal of a H boson if we have higher order operators or additional particles?

What would be the impact in the experimental searches?

See J. Brehmer talk

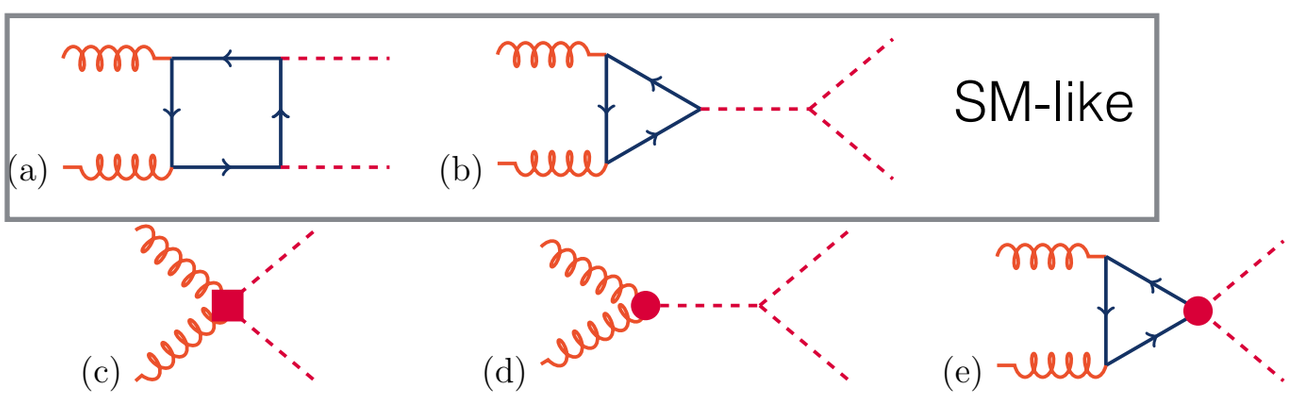
Do we have a SM 125 Higgs boson? The H potential

Driving the Higgs mechanism is the H boson trilinear coupling
Fixing the mass of the H boson the trilinear coupling is fixed,
=> and therefore a SM parameter to be measured.

Like for instance in single production the channel most promising is the gluon fusion (GF).

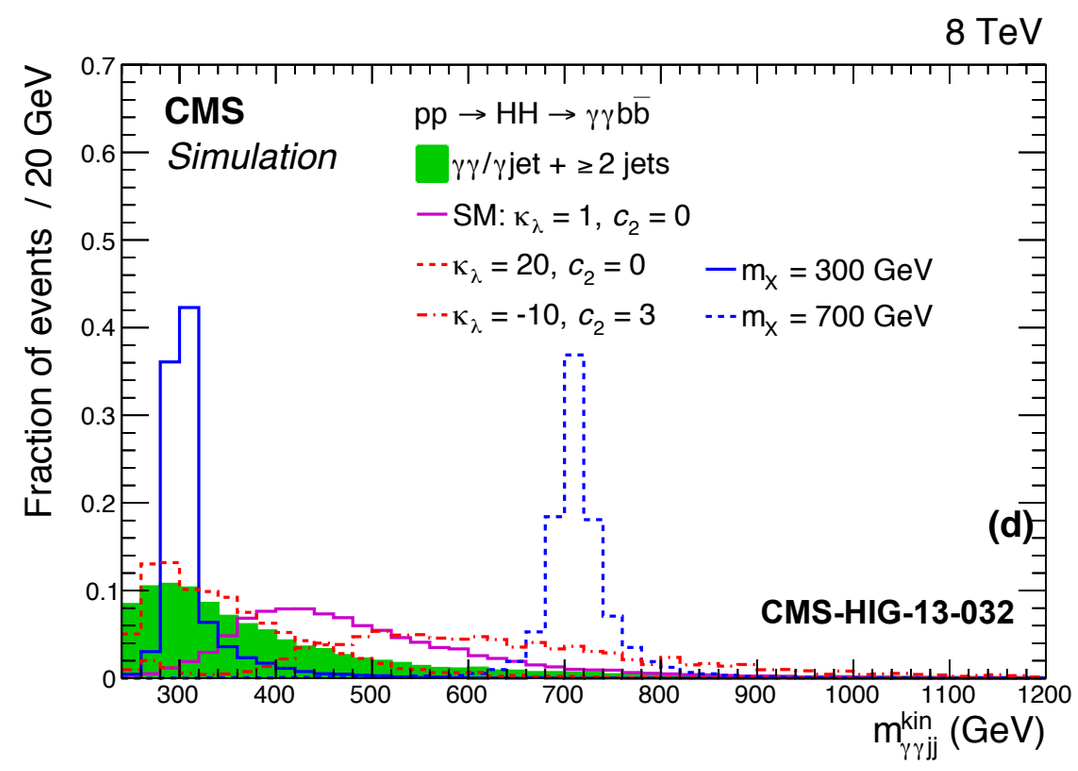
If the H potential is not like in the SM the measurement is not so simple to perform

Example: In composite models, if we consider up to dimension 6 operators the GF production receives new contributions. And the signal topology is modified.



If we consider specific composite model theories, how much we can expect anomalous couplings to variate?

See R. Grober talk



We will discuss the first results of the ATLAS and CMS searches

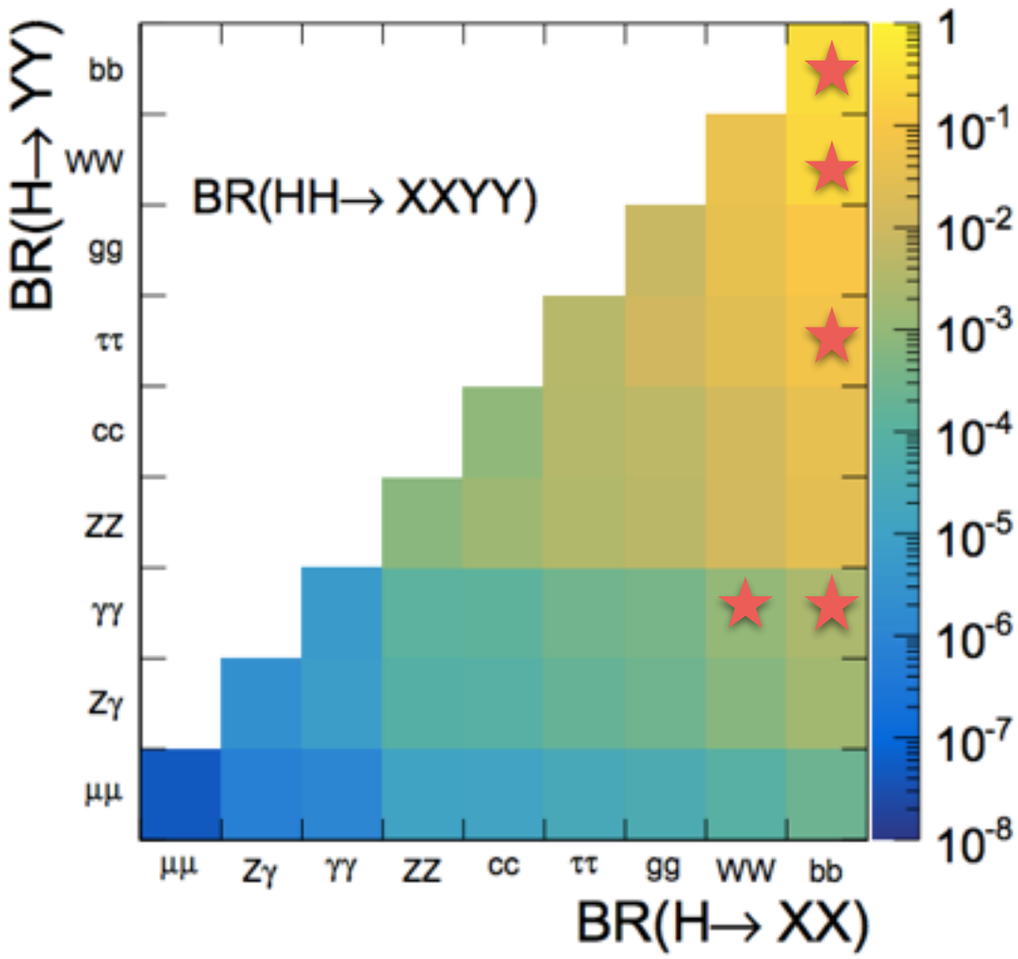
See X. Sun and A. Pozdnyakov talk

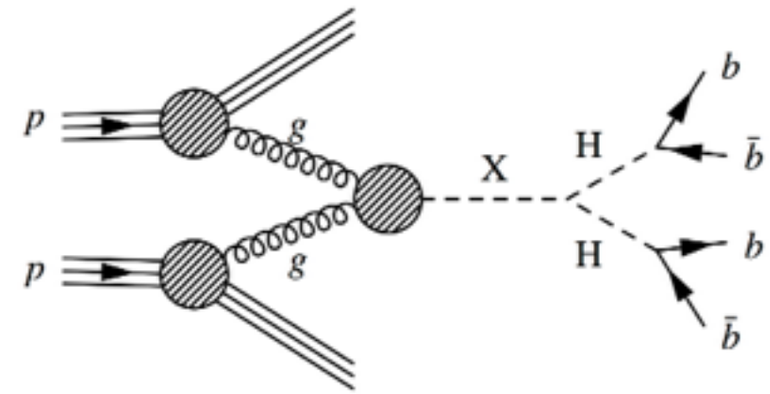
The 125 GeV Higgs can be part of a bigger Higgs sector

If this is the case, now we know that at least one of the neutral components of the Higgs sector have a mass of 125 GeV

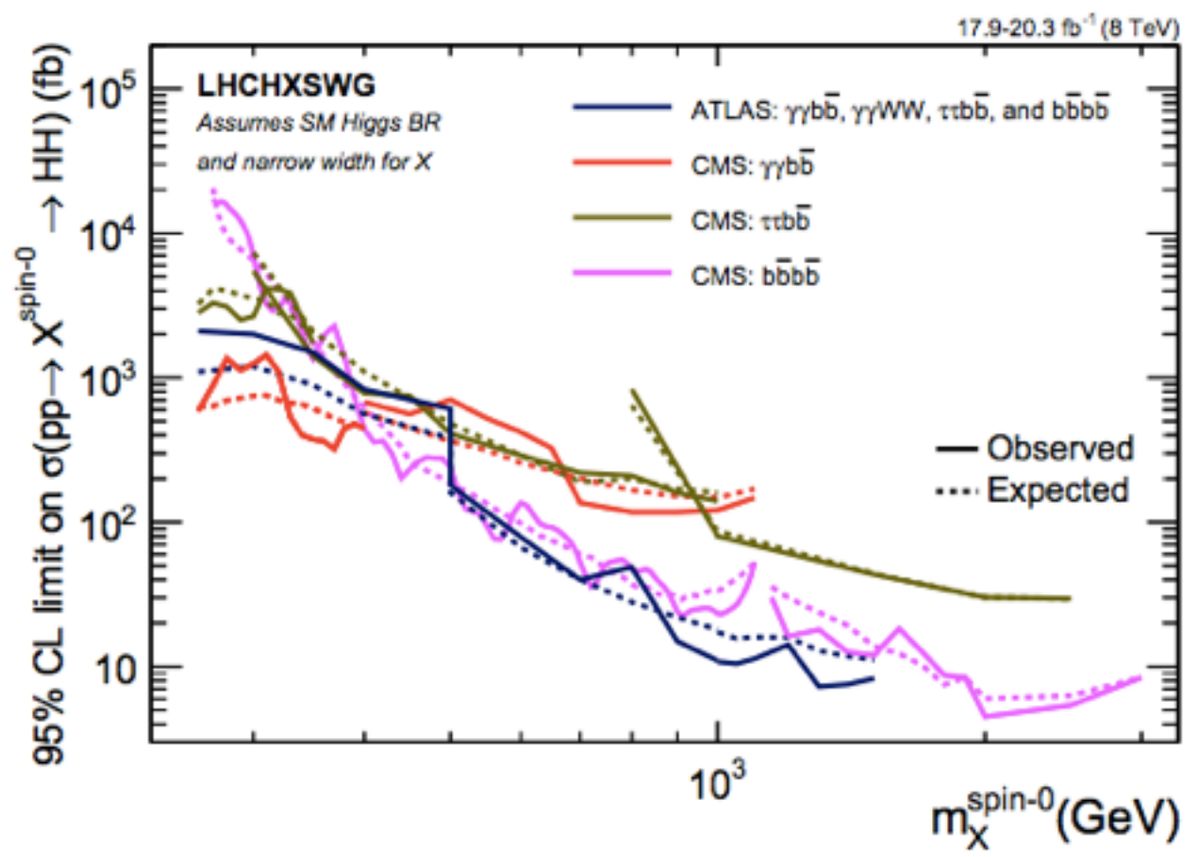
Searching for heavy Higgs bosons decaying to a pair of 125 GeV bosons

Resonances that are somehow connected with the EWSB may decay with considerable rate to a pair of H bosons.





Status after the LHC Run 1:



★ **The run 2 searches will also be summarized in X. Sun and A. Pozdnyakov talks**

Higgs extended sectors and the Supersymmetry

One of the most popular scenarios to a Higgs extended sector is the case of a 2HDM, that is the case of Minimal Supersymmetry Model

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} \quad H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix}$$

The Higgs sector with two doublets have as H bosons four physical states:

$$h^0, H^0, A^0, H^\pm$$

If we want to understand just the Higgs sector of the theory one can built smart parametrizations, knowing the mass of one of the neutral component should be 125 GeV.

- We have the power to relate all the searches for the Heavy H bosons

One example of such parametrization is called hMSSM

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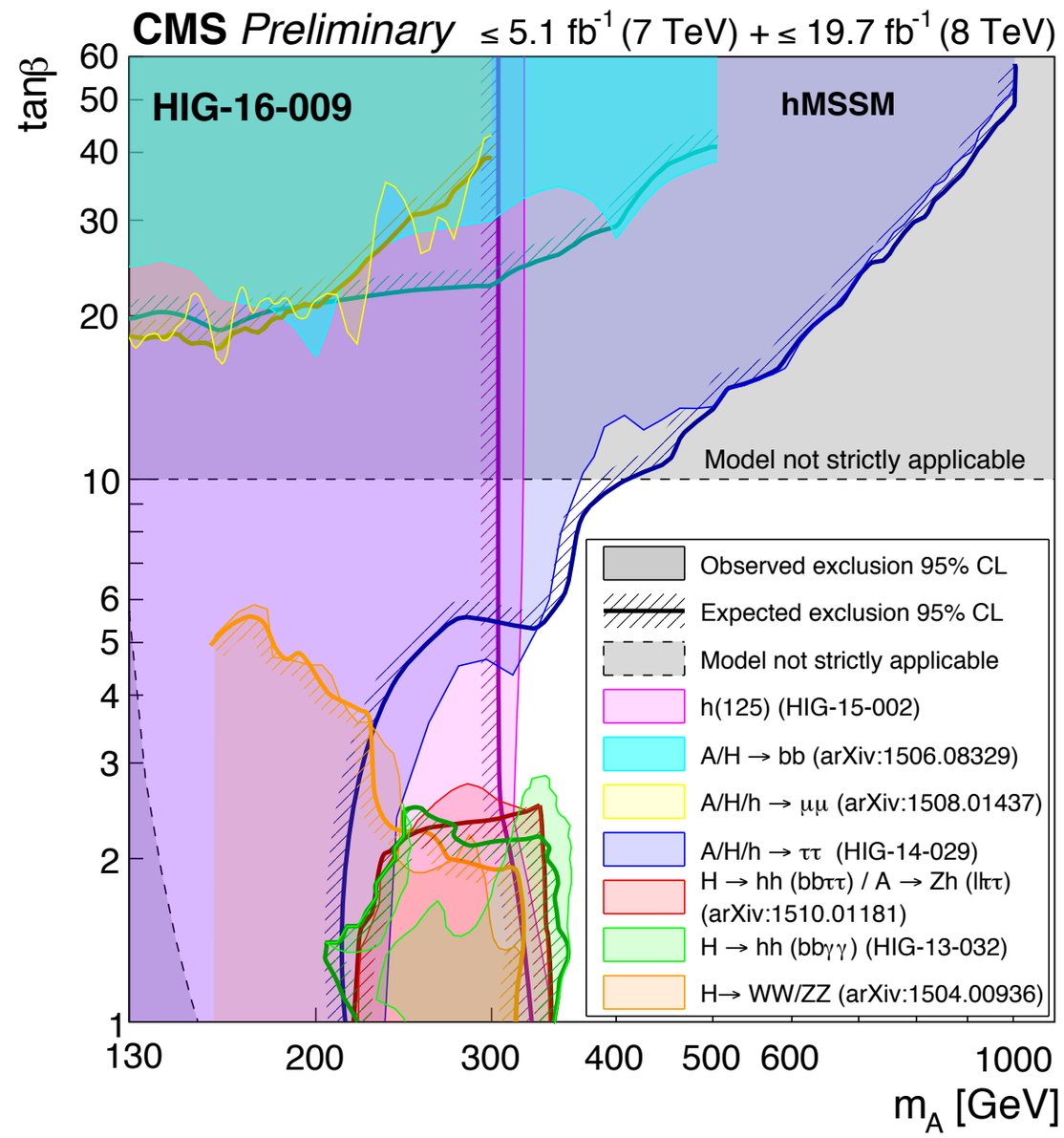


See S. Snyder talk

Searching for heavy Higgs bosons (or generic heavy resonances) at LHC

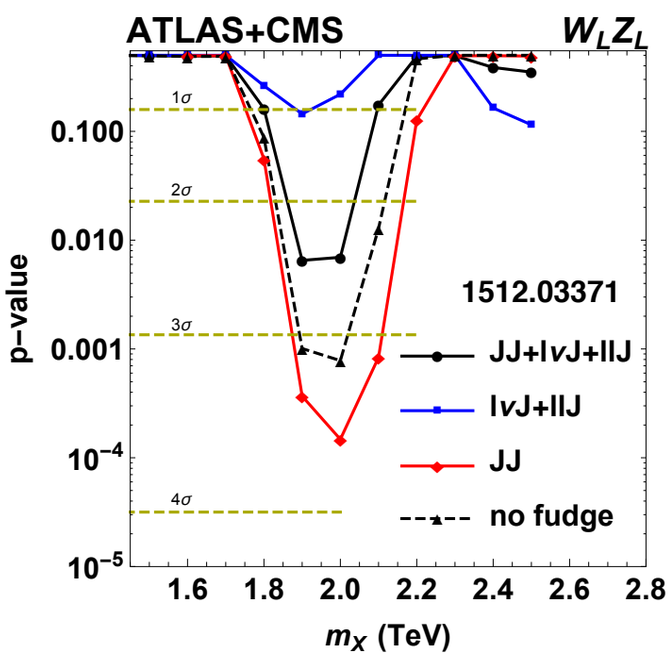
We can do classification of signal by kinematics.

The relevant informations to define for searches for resonances in single channels are:

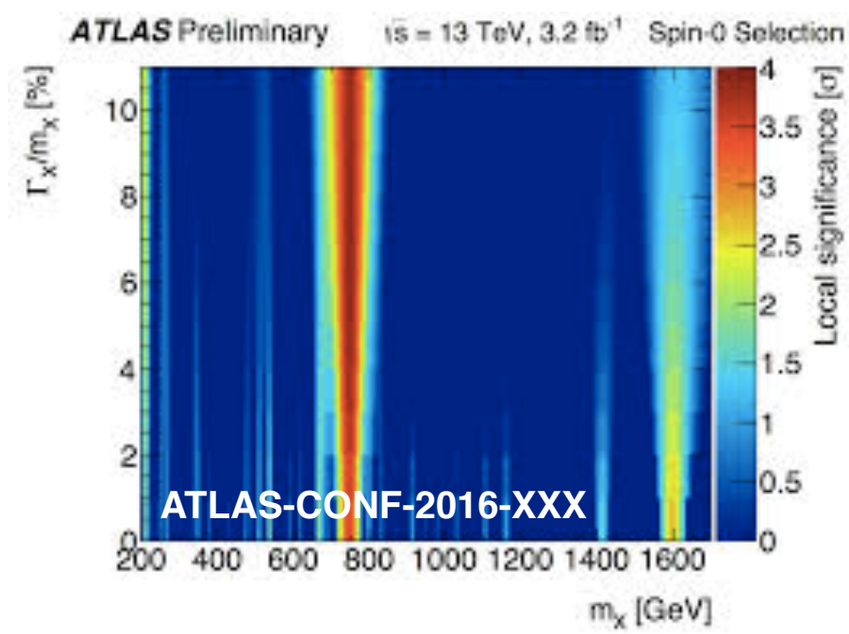
- Its production mode and spin-parity
- Its mass and width, that can be calculated from the free parameters the theory

We had (at least) two hints of new resonances in the last 6 months !

Run 1



Run 2



See M. Quittnat and F. Malek talks

How are the other channels looking in the same mass range of the diphoton hint?

See G. Halladjian talk

Even if all hints them disappear to not come back, we had learned a lot about resonances characterization and matching interpretations in different models!

See A. Carmona talk

Summary

A new world of potential for discovering New Physics at the LHC opened with the discovery of the 125 GeV boson

For more doubts, attend the 'BSM Higgs' workshop in the 11th july!