ATLAS e la scoperta del bosone di Higgs

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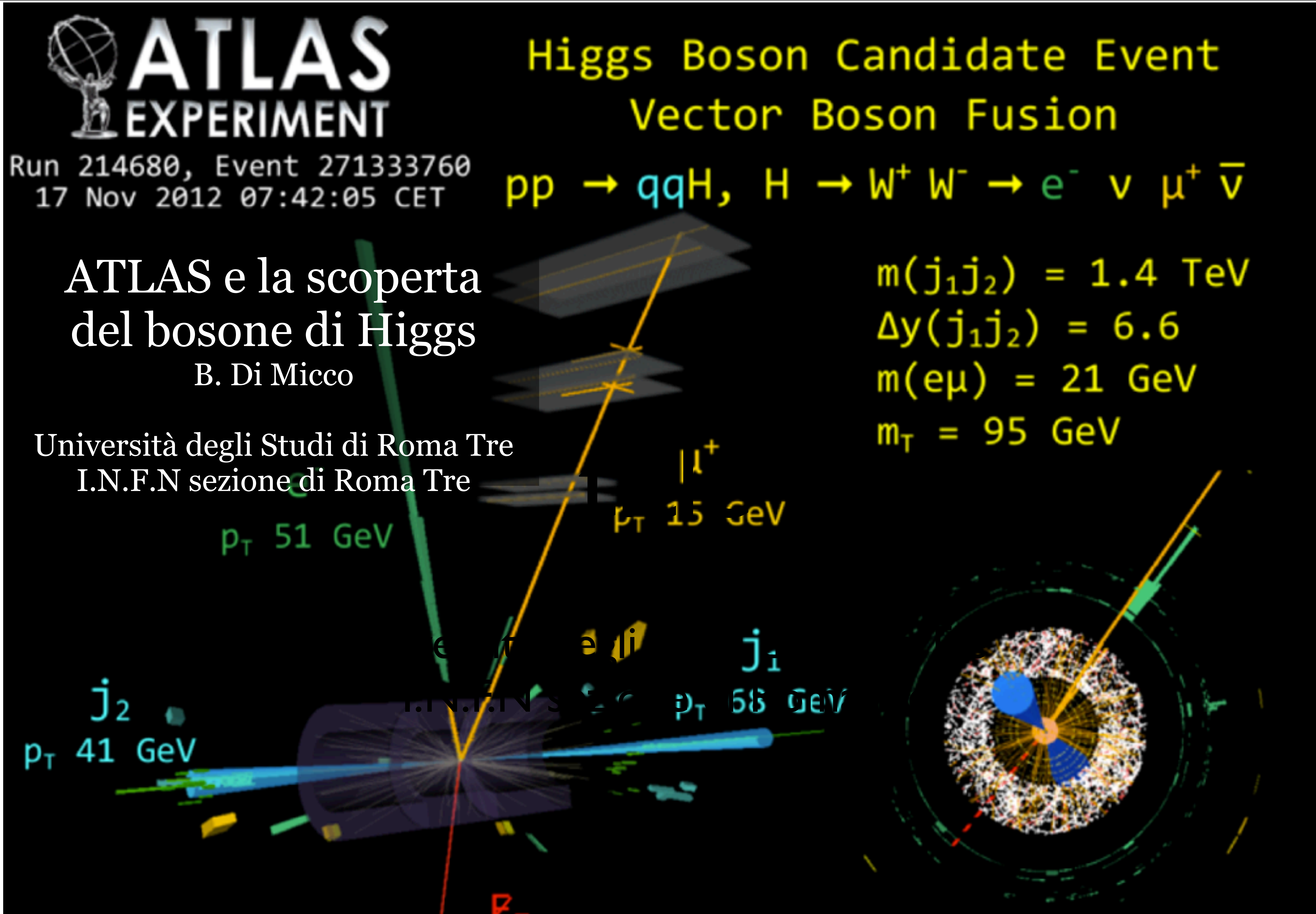
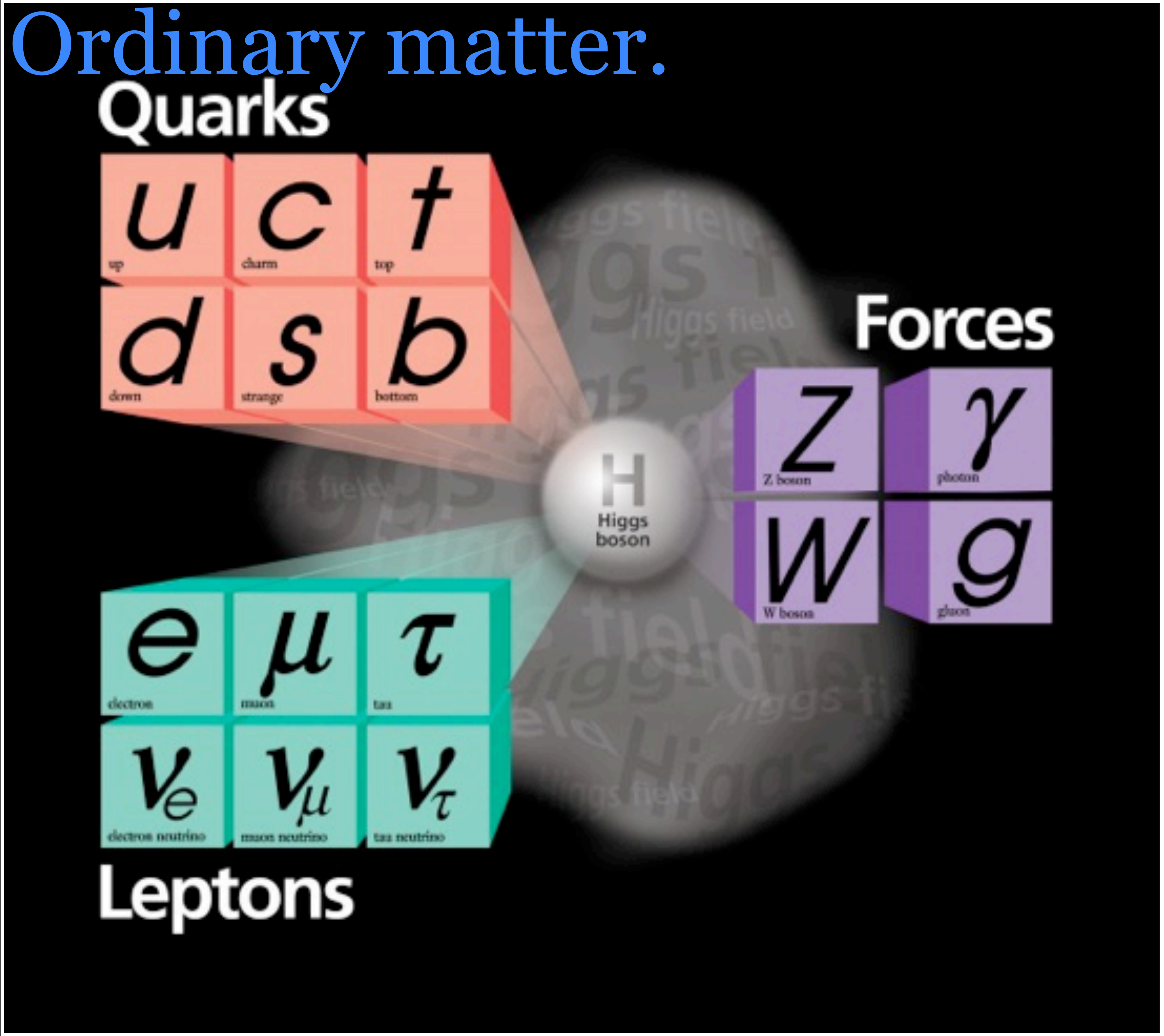


The Standard Model of particle physics

Ordinary matter.



The ordinary matter is made of protons, neutrons and electrons.

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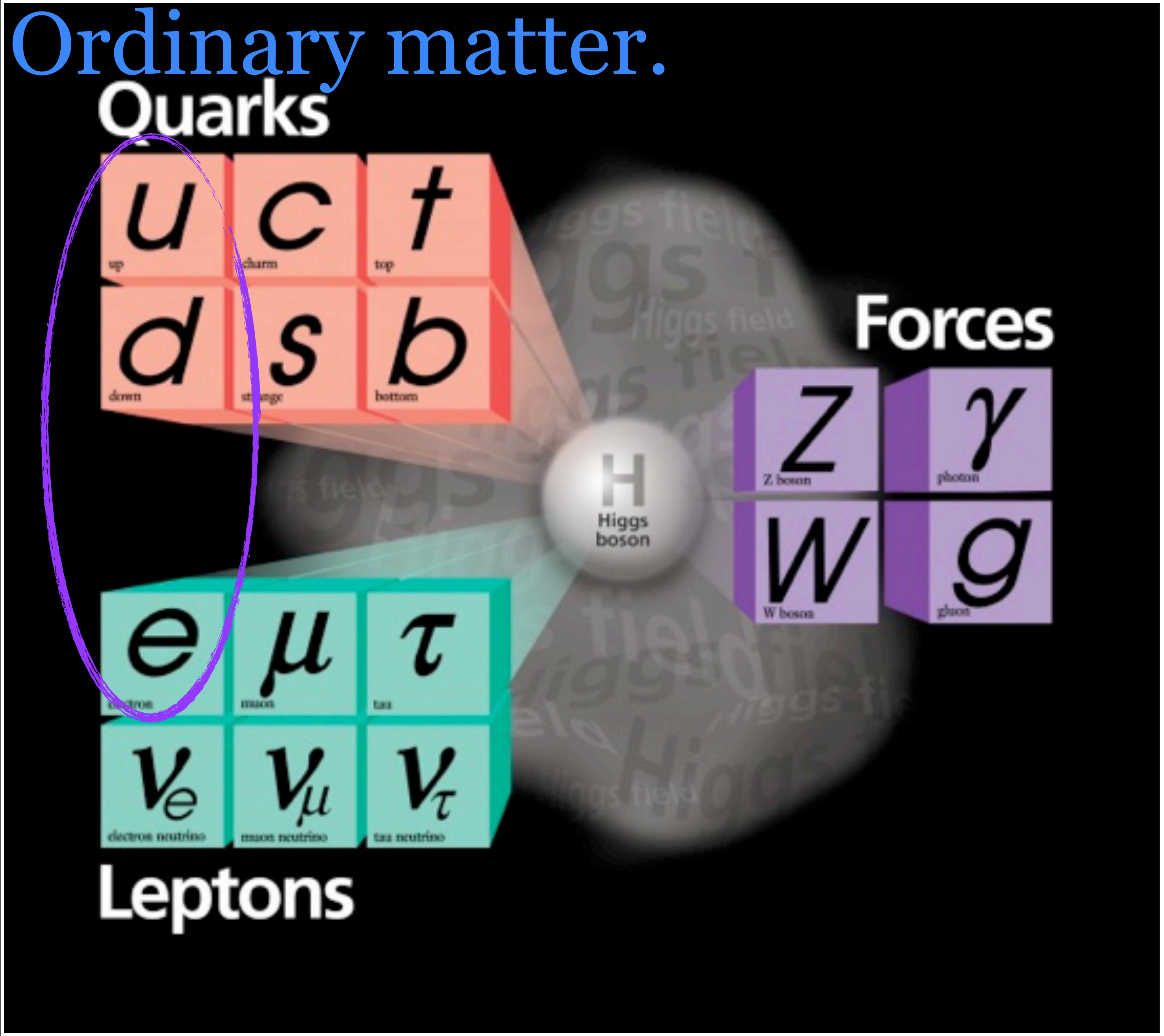

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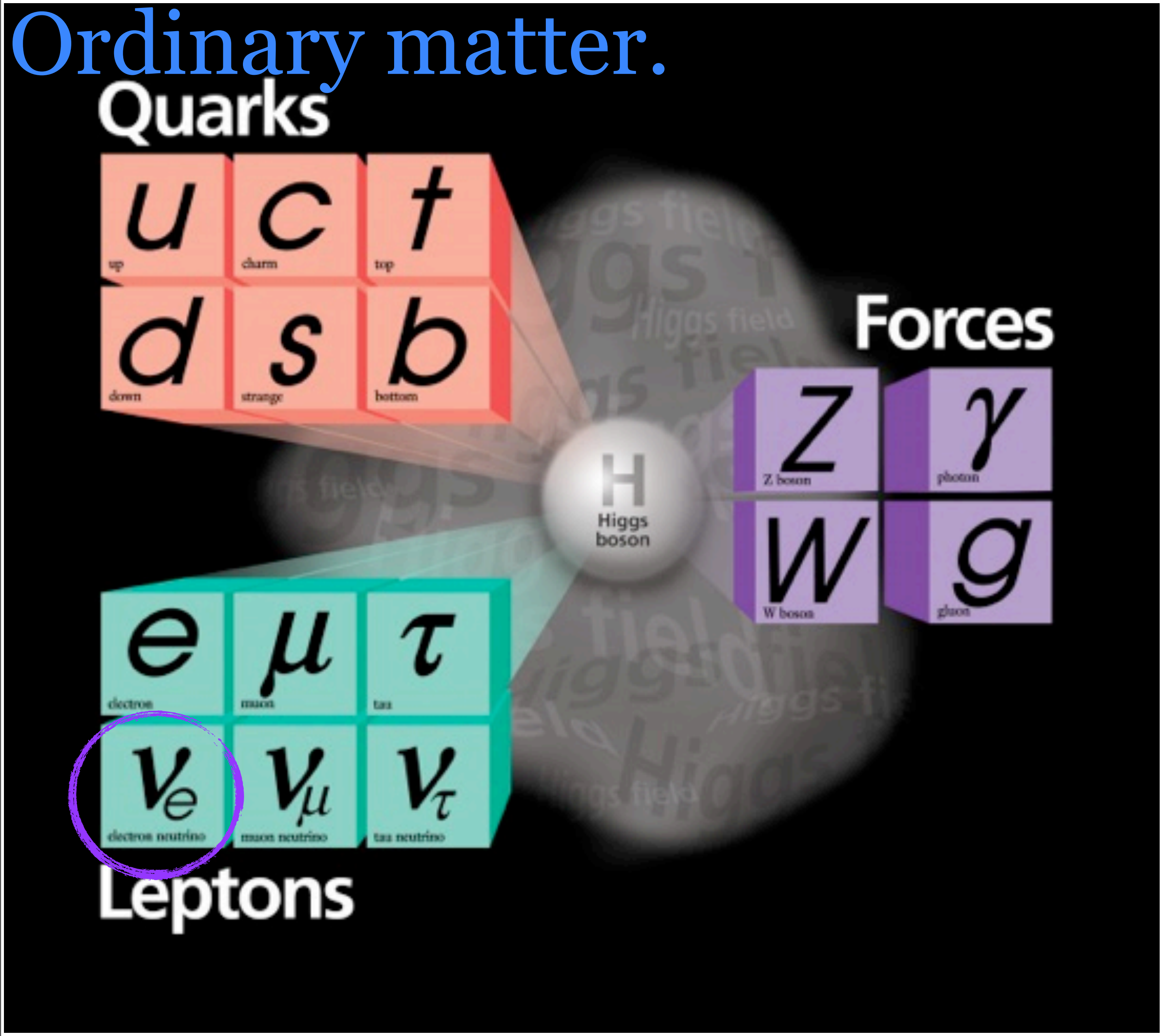

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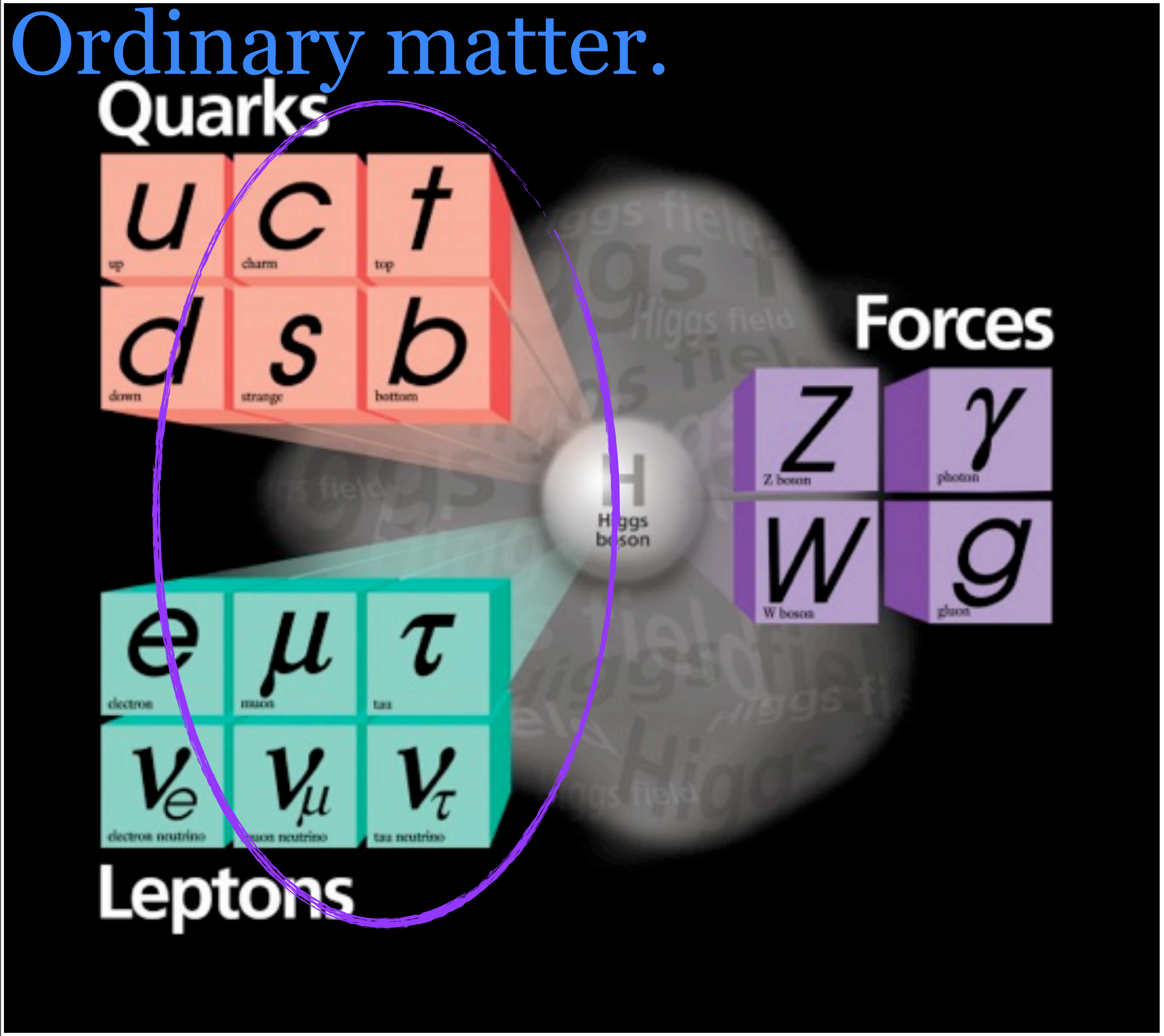

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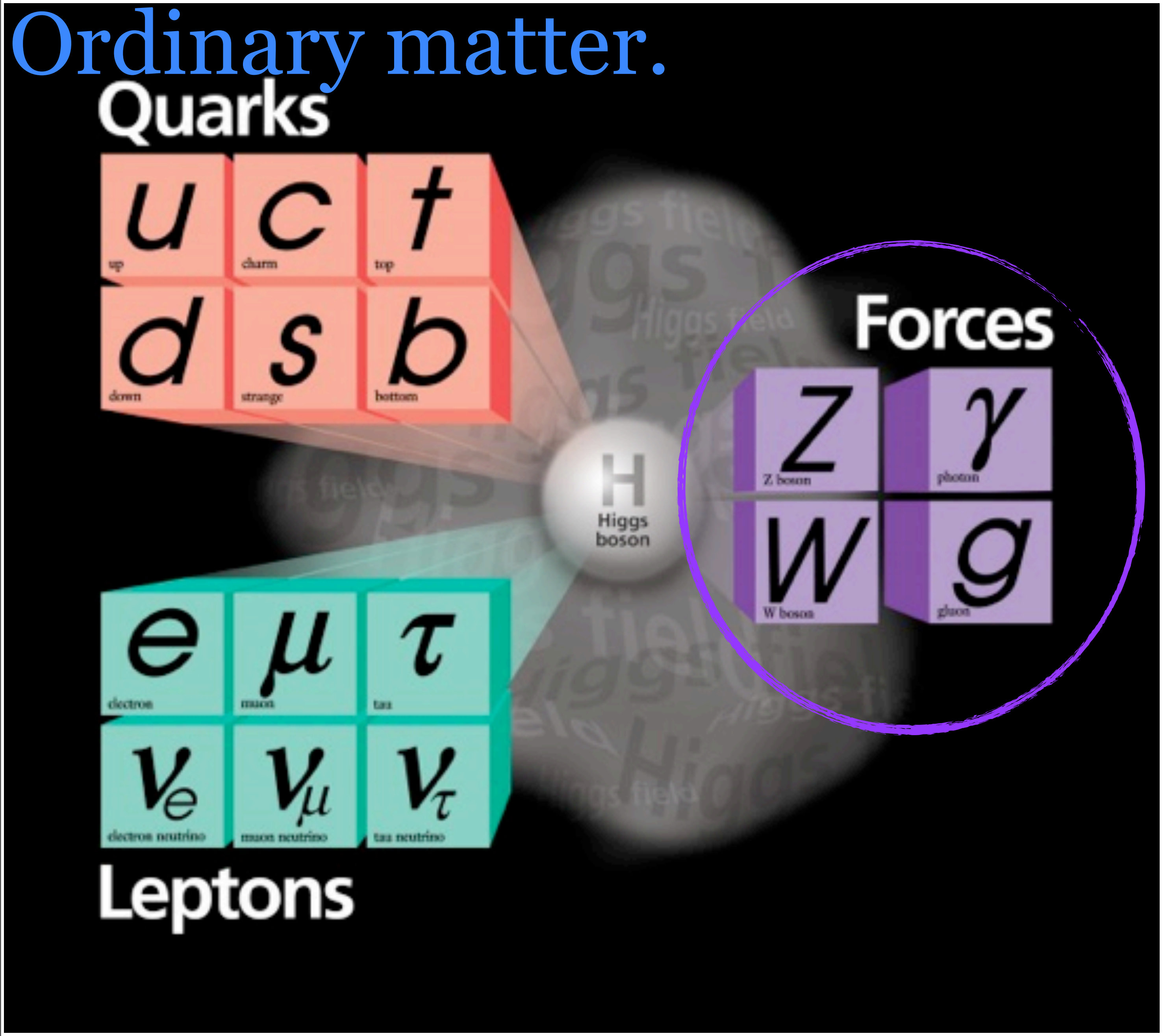

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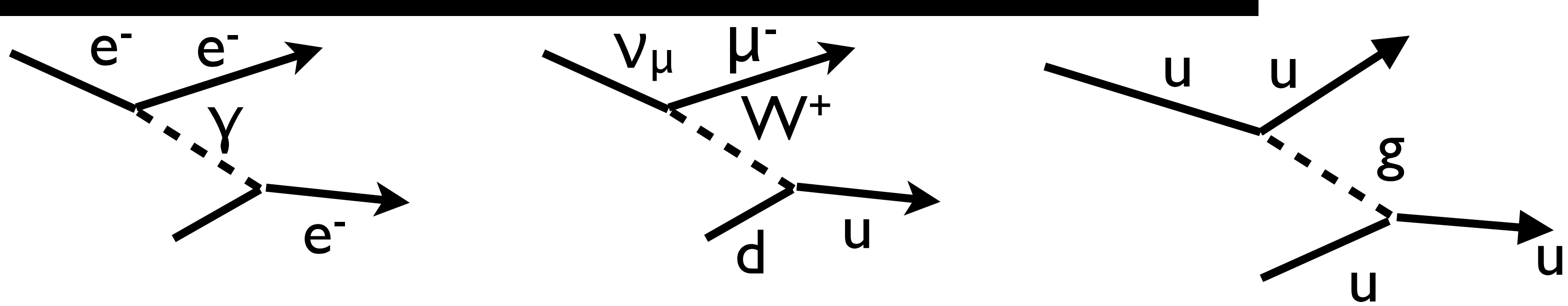
Particles interact by exchanging vector bosons (called force mediators)



Particle physics studies elementary particles and their interactions.

The diagrams are used to give a representation of interacting particles and the force mediators.

The Standard Model Lagrangian

γ,W,Z

g

$$\mathcal{L} = -\frac{1}{4g'^4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4g^2}W^a_{\mu\nu}W^{\mu\nu a} - \frac{1}{4g_s^2}G^a_{\mu\nu}G^{\mu\nu a}$$
$$+\bar{Q}_i i\not{D}Q_i + \bar{u}_i i\not{D}u_i + \bar{d}_i i\not{D}d_i + \bar{L}_i i\not{D}L_i + \bar{e}_i i\not{D}e_i$$
$$+(Y_u^{ij}\bar{Q}_i u_j H + Y_d^{ij}\bar{Q}_i d_j H + Y_l^{ij}\bar{L}_i e_j H + c.c.)$$
$$-\lambda(H^\dagger H)^2 + \lambda v^2 H^\dagger H$$

Matter interaction

Higgs

The standard model lagrangian is able to describe all non gravitational phenomena. Before LHC only one particle was missing from the observation: the Higgs boson.

The mathematics (statistics, diffrential equations and complex matrices algebra are used in particle physics to quantify the phenomena and produce predictions)

What is the Higgs boson and why we need it?

From Galileo to Popper we define a scientific theory if it is able to predict quantitative observables that can be tested in order to falisify the thoery.

In other words the theory must be predictive, it must be able to predict phenomena using a finite number of inputs (like masses of paricles, strenght of the interactions and so on).

Particle physics is a quantum field theory that is able to give predictions through perturbative expansions, unfortunately when doing perturbative calculations some quantities become divergent and a regularisation procedure must be adopted, this procedure is called “renormalisation”.

In the “renormalisation” procedure divergences are absorbed with the redefinition of the “fundamental” constants of the theory (like masses, electric charge and so on). In renormalisable theories the number of constants needed to do this job is finite and constant at any order of the perturbative expantion, in non -renormalisable theories more and more constants need to be added at each order (i.e. when the calculation becomes more and more accurate).

Non renormalisable theory have a limited predictive power, because accurate predictions need more and more “fundamental” constants, limiting the model to a description of nature more than a theory of nature.

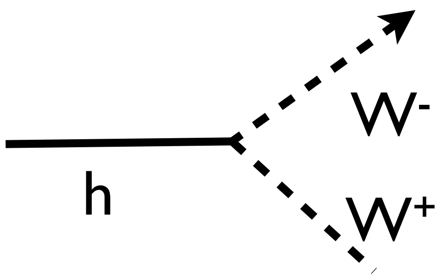
The theory of the γ,W and Z interactions where W and Z bosons have a non zero mass is not renormalisable, W and Z bosons should be massless to have a renormalisable theory,
but from experimental measurements their masses are 80 times and 90 times larger than the proton mass.

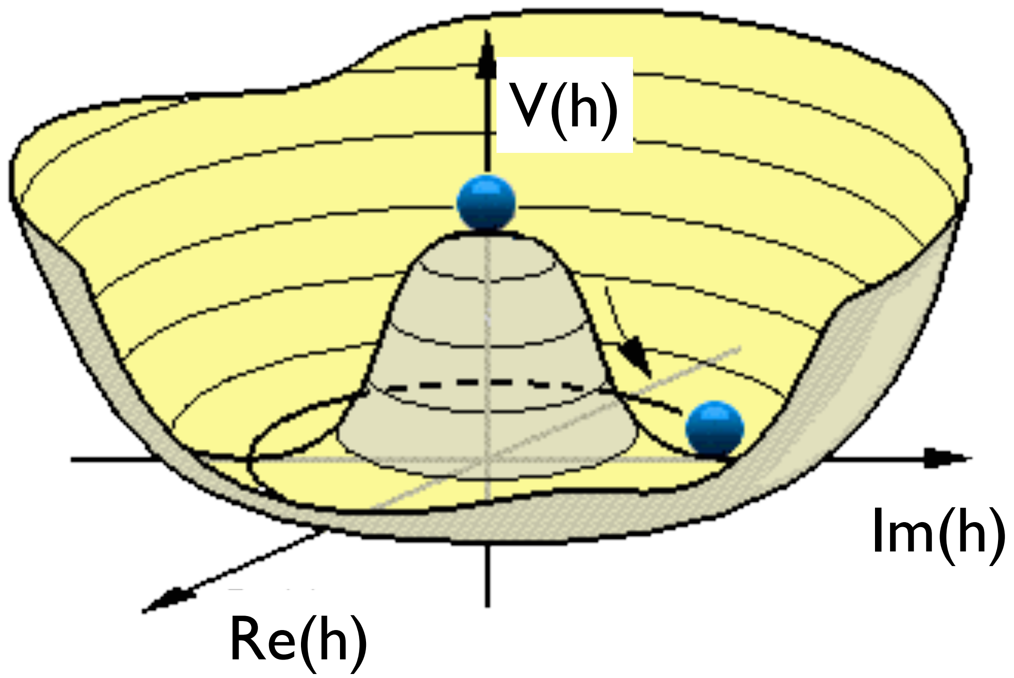
Vector boson mass term

Lagrangian

$L \sim m_W^2 W^+ W^-$ Non renormalisable mass term.

$L \sim h W^+ W^-$ Renormalisable interaction term.





$$V(h) = \lambda \left(|h_0|^2 - h^2 \right)$$

At the minimum Im h = 0, Re h = h_0 (convention), for which we can write h = $h_0 + \eta$

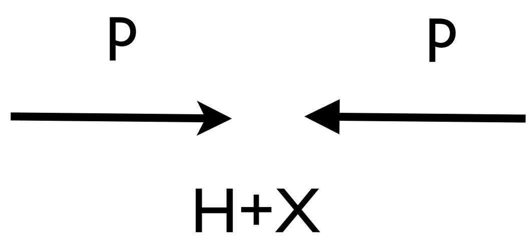
$$L \sim h_0 W^+ W^- + \eta W^+ W^-$$

We have now introduced a mass term, but L is still normalisable thanks to the presence of the extra interaction of the "remnent" Higgs field and the W's.

The Higgs mechanism is the simplest mechanism able to do the job, we can build more complex ways to solve the problem, but the economicity was always one of the driving requirement of the Standard Model building.

The Higgs boson is also not a "prediction" of the standard model, but a requirement, needed to make it a "nice" renormalisable theory. Why nature should follow the caprice of the man mind is still a mistery. The predictions is that its coupling to W, Z and top particles are fixed by their masses, so the SM fully predicts its production rate and decay, and we can try to falsify it.

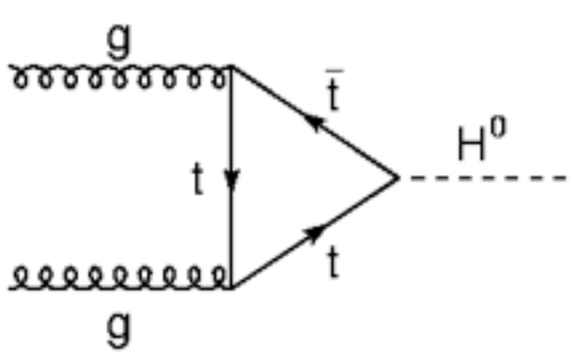
Higgs production.



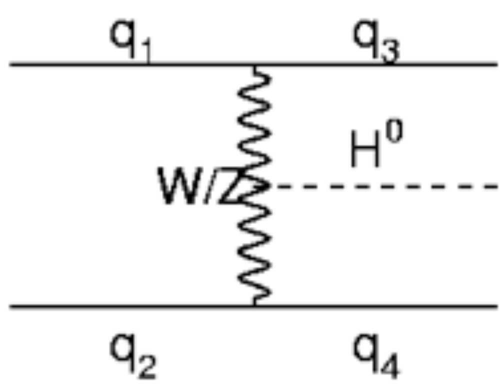
The Higgs is produced in pp cllisions alone or together with other particle gluons, quarks, W and Z bosons.

The proton is made of ~50% gluons and 50% quarks.

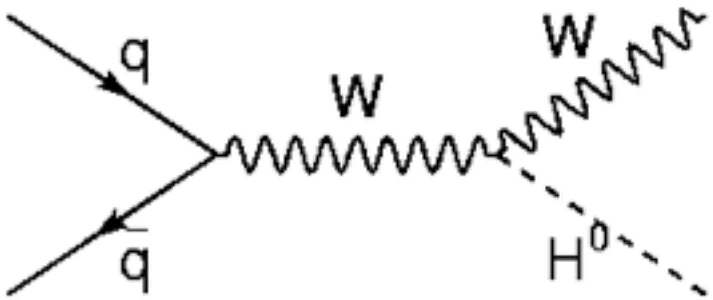
Gluon fusion

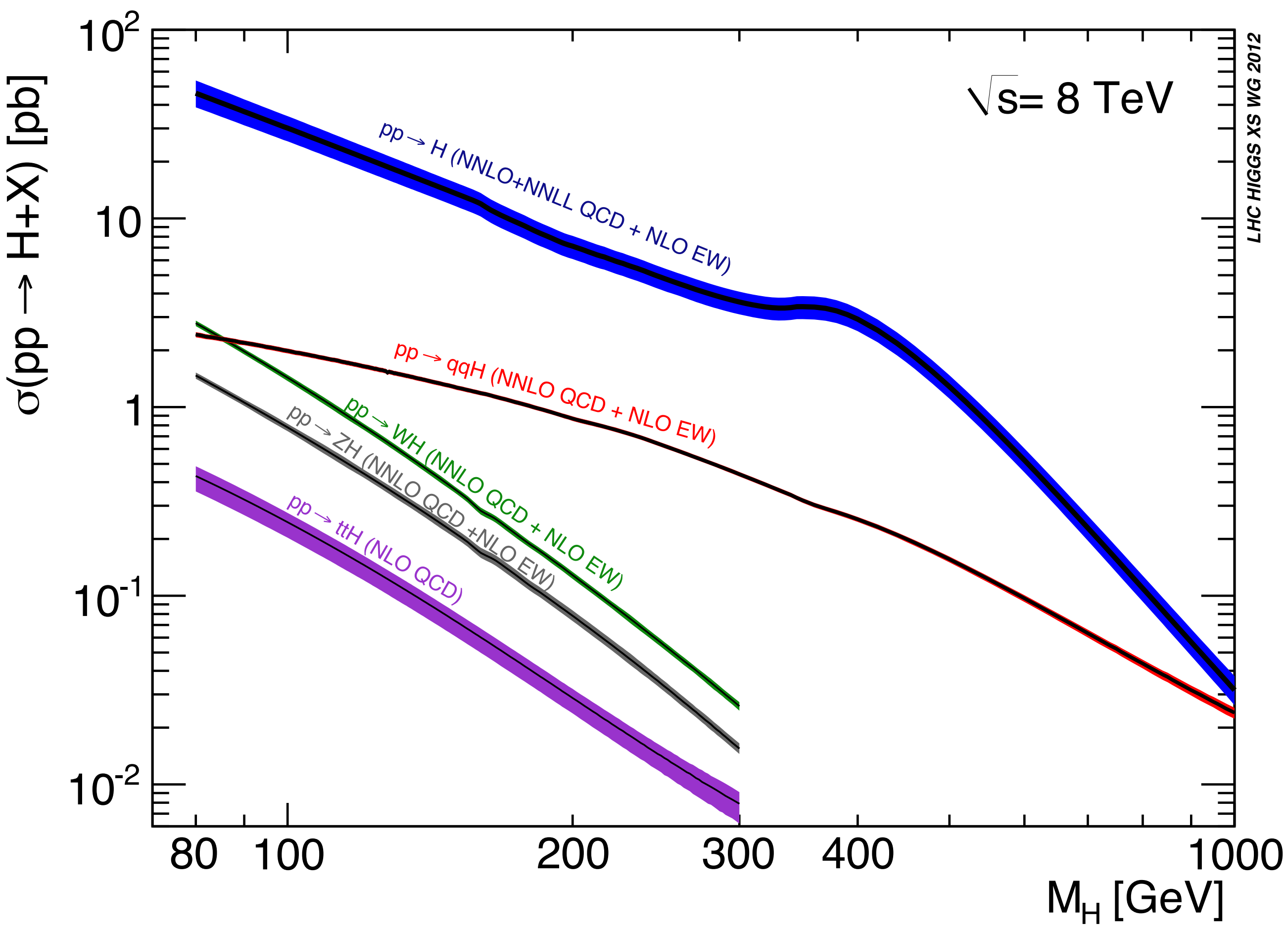


Vector boson fusion



Associate production

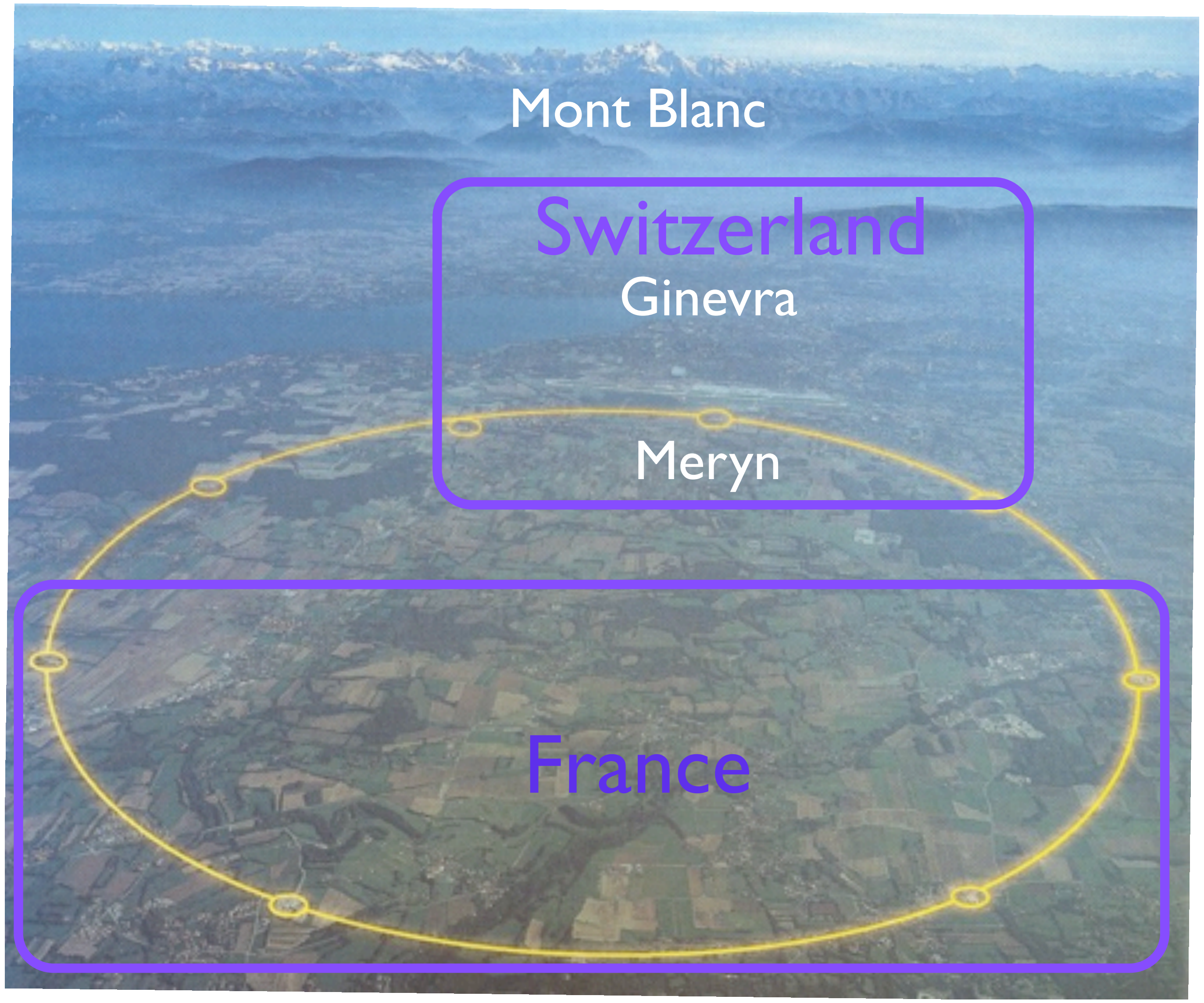


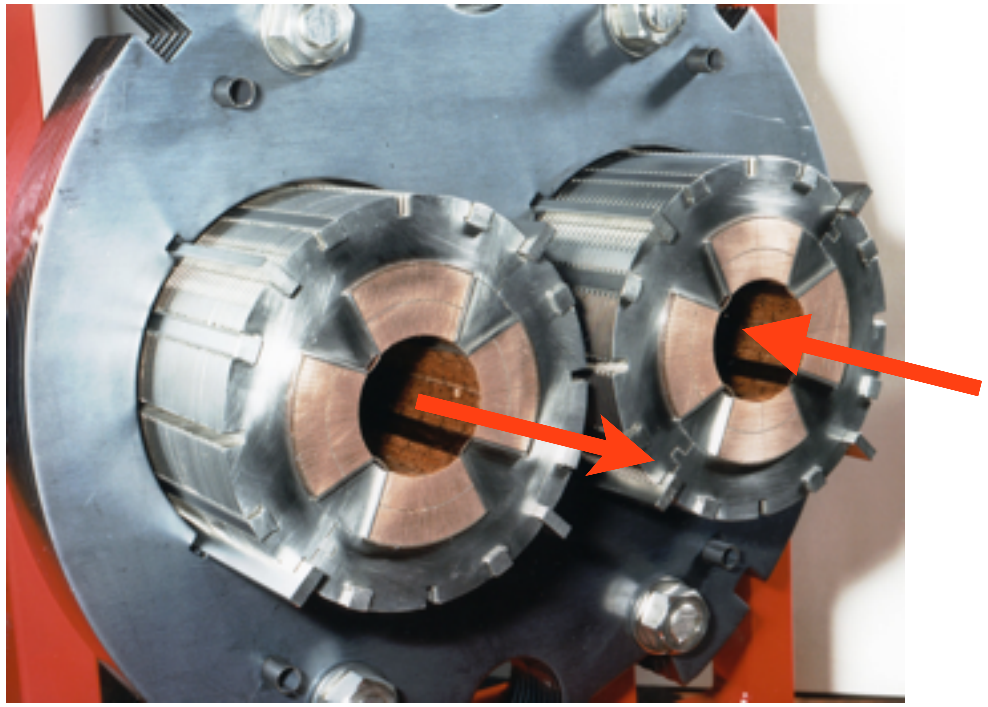


The mass of the Higgs is a free paramter of the Standard Model, but given the mass the production probability is completely frozen by the known couplings of the Higgs to W/Z and t particles given by their measured masses.

The search has been performed in the full LHC explorable range, even if limit were imposed from direct search (m_H > 114 GeV) and indirect measurements m_H < 200 GeV.

The Large Hadron Collider





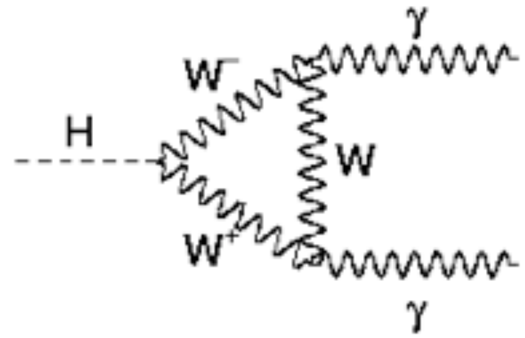
- Length 27 km;
- Proton energy 14 TeV (project) 8 TeV (maximum up to now);
- The maximum energy is fixed by the magnet bending power 8.3T, the circumference of the ring and the effective length occupied by the magnets (2/3)

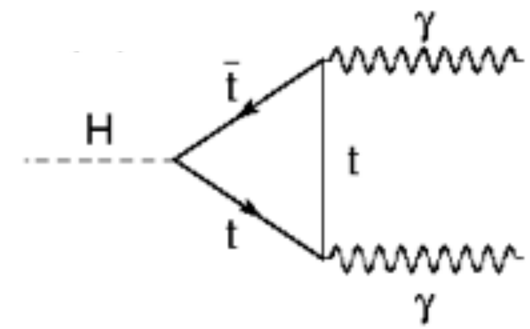
The Higgs discovery decays.

$H \rightarrow \gamma\gamma$

$H \rightarrow ZZ \rightarrow 4l\ (e,\mu,\tau)$

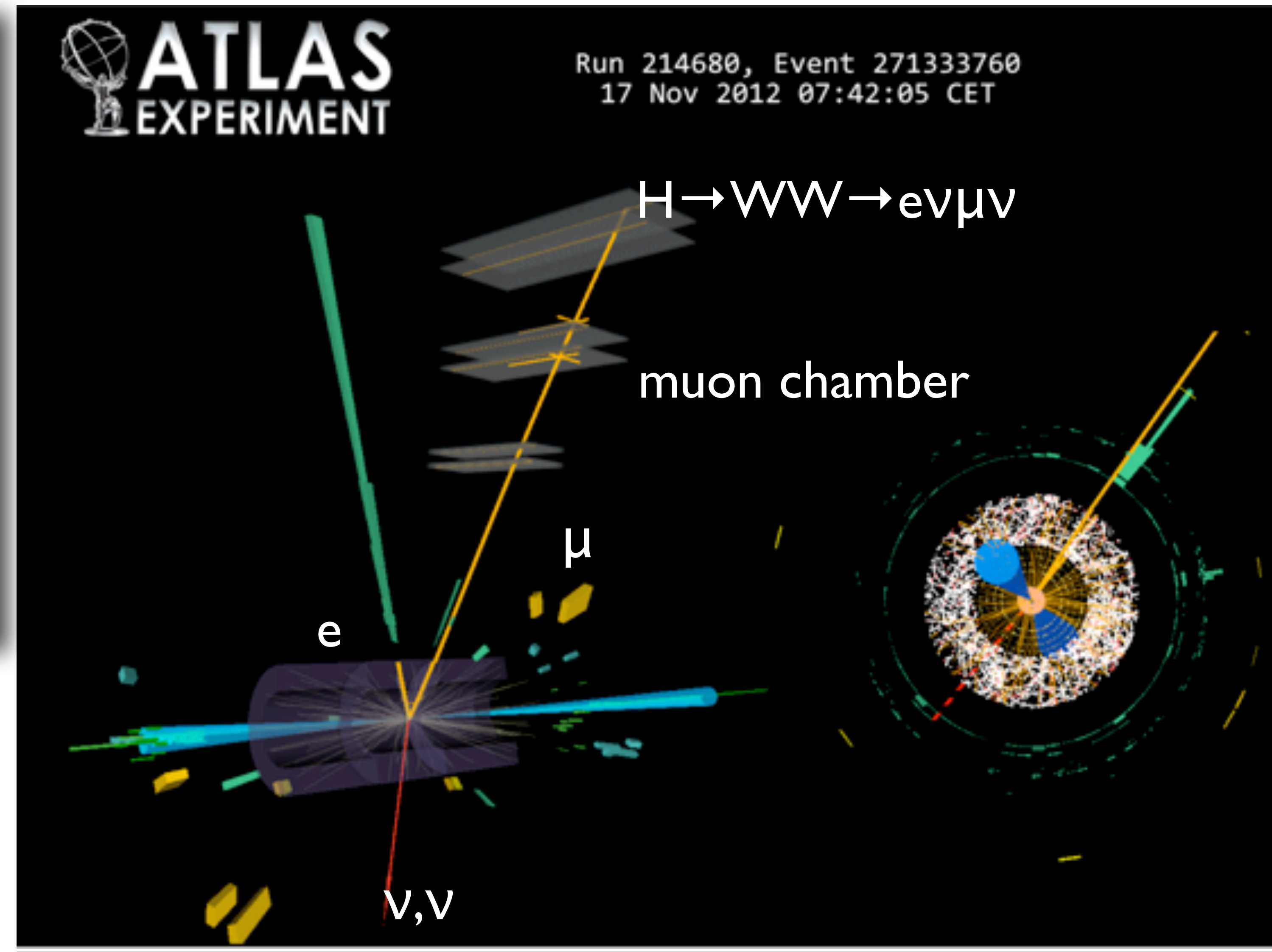
$H \rightarrow W^+W^- \rightarrow l^+\nu l^-\bar{\nu}\ (e,\mu,\tau)$





Higgs WG Subgroups

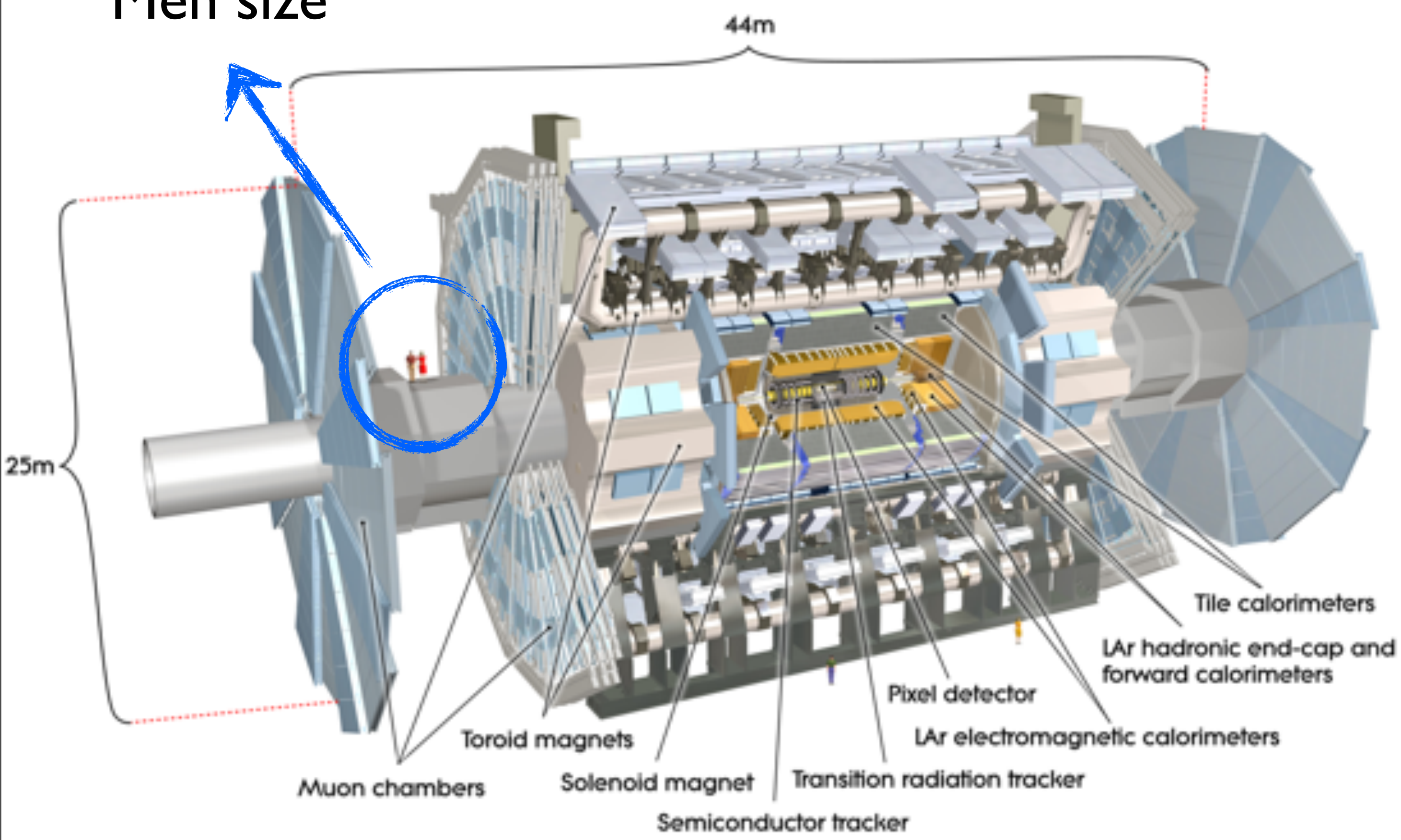
Sub-Group	Conveners	Main Topics
HP	Leandro Nisati	Higgs Prospects and Upgrade
HSG1	Kerstin Tackman	DiPhotonand Zgamma
	Krisztian Peters	
HSG2	Christos Anastopoulos	ZZ and ZH(invisible)
	Stefano Rosati	
HSG3	Biagio di Micco	WW and VBF H(inivisible)
	Pierre Savard	



- World wide collaboration with 3500 physicists
- Roma Tre activity mainly in the muon system construction and the H→WW analysis
- H→WW group involve the work ~ 150 active physicists

The ATLAS detector and collaboration

Men size



One Monitored Drift Tube chamber of the muon spectrometer constructed at Roma Trea

R & D

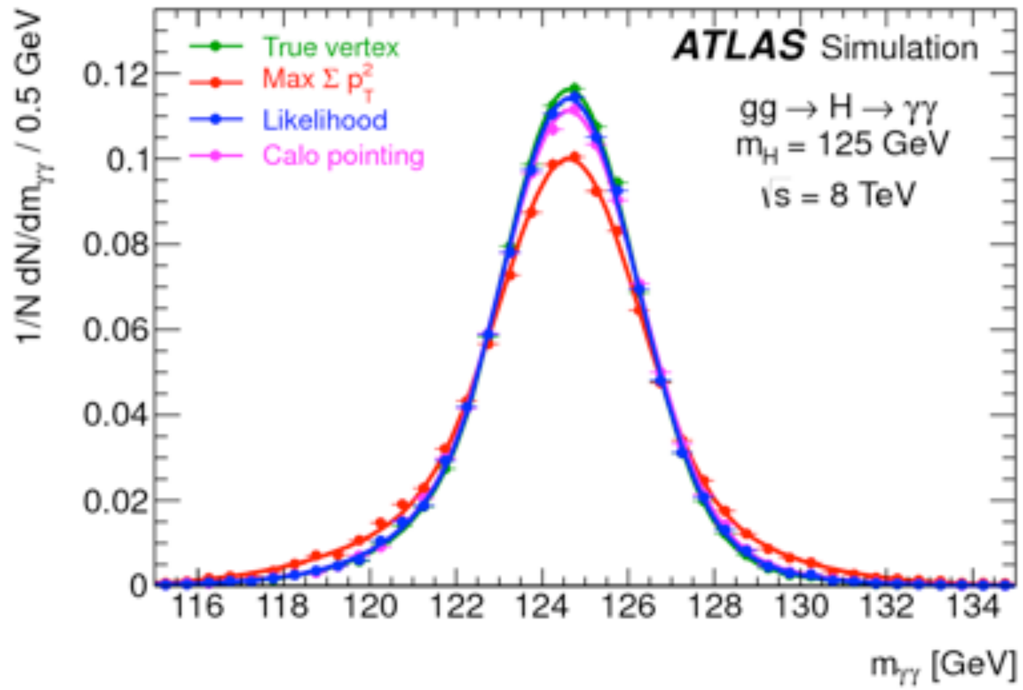
The search strategy in the γγ and ZZ channels

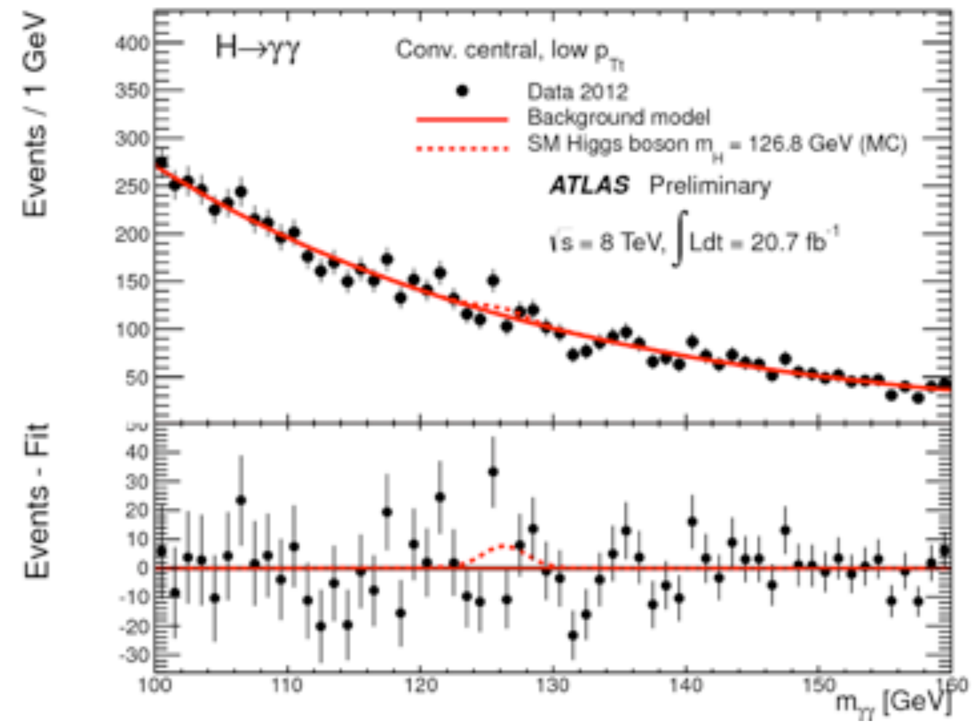
H→γγ

The signal has a sharp peak at the Higgs mass.

The background has a smooth falling shape,and it is fit to data with a smooth function.

Photons can be fully reconstructed, from the energy and direction of the photons we can build the mass of the decaying particle.

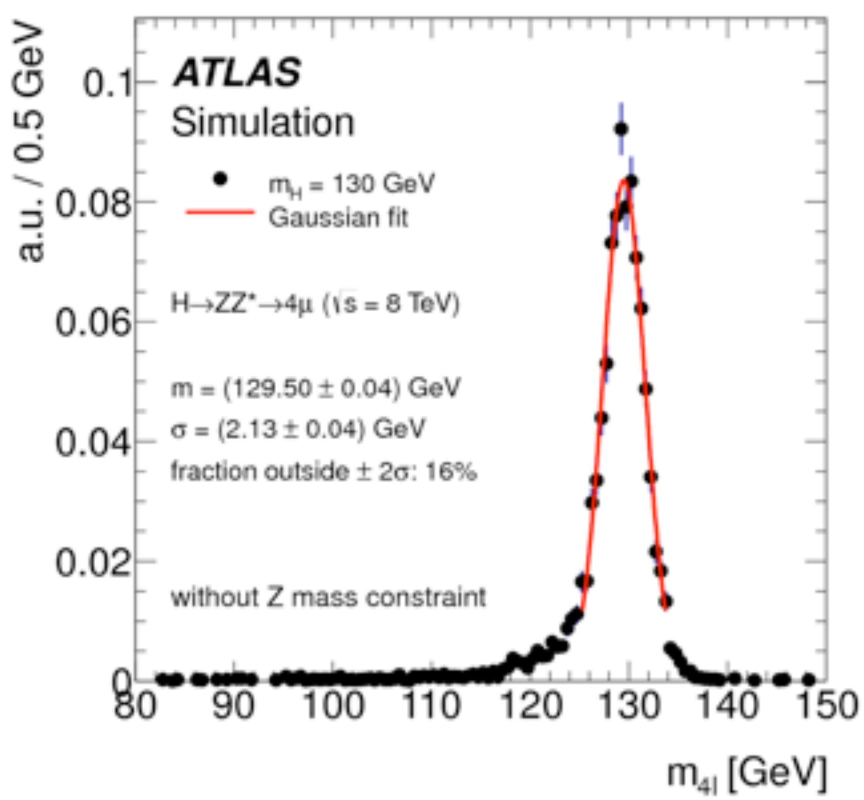


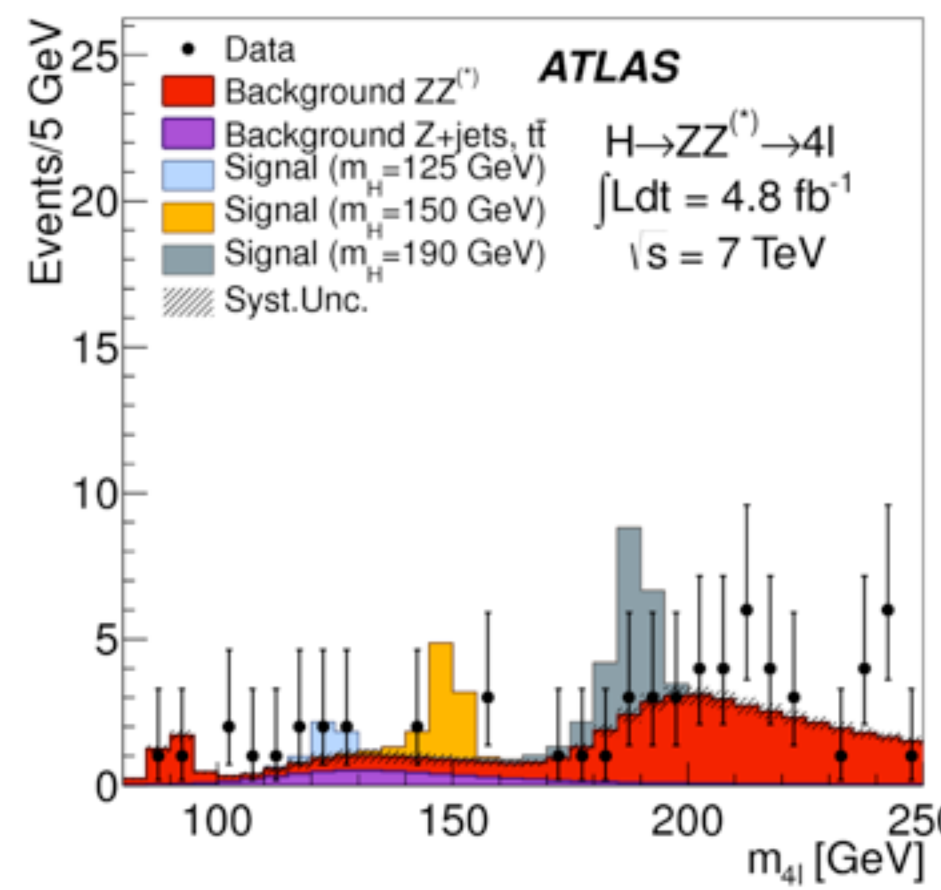


H→ZZ→4l

Leptons like e and μ can be fully reconstructed and the Higgs mass can be determined from m_{4l} mass.

The background has a complex shape and must be estimated using detector simulation.





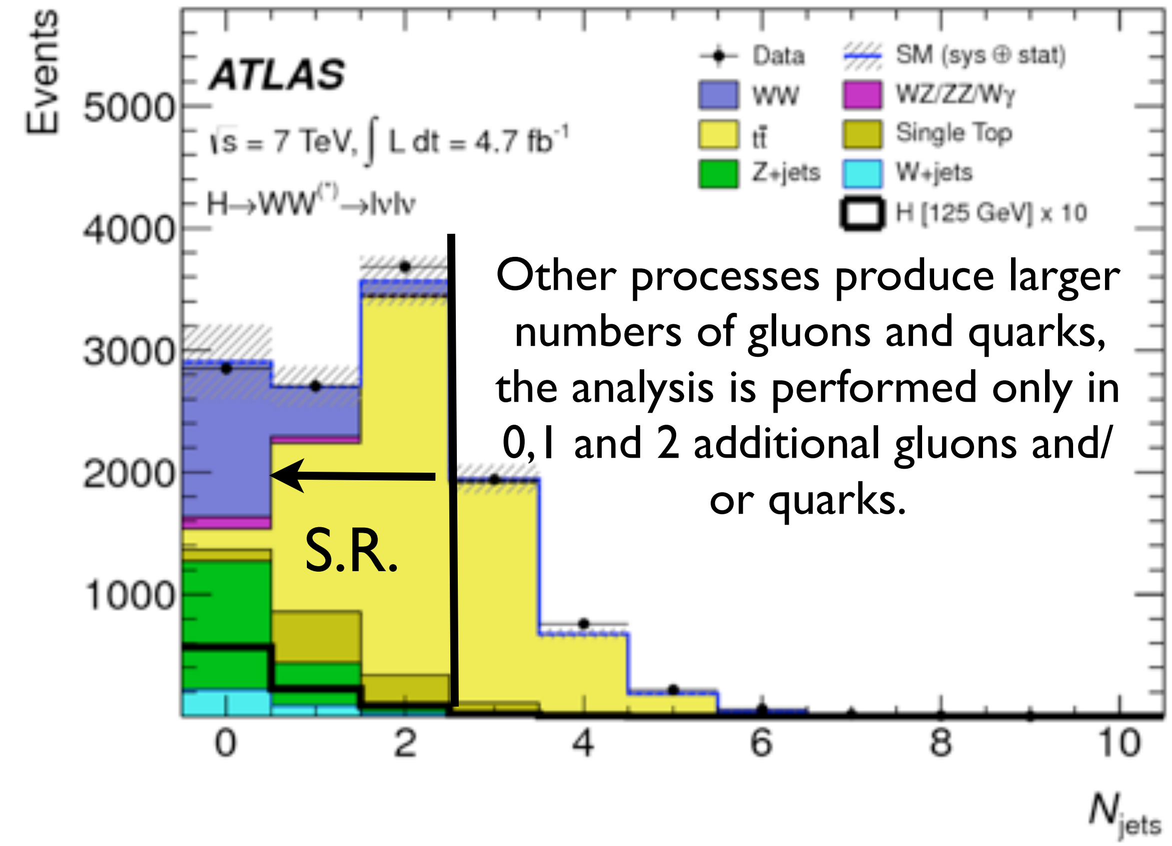
The search strategy in the WW channel.

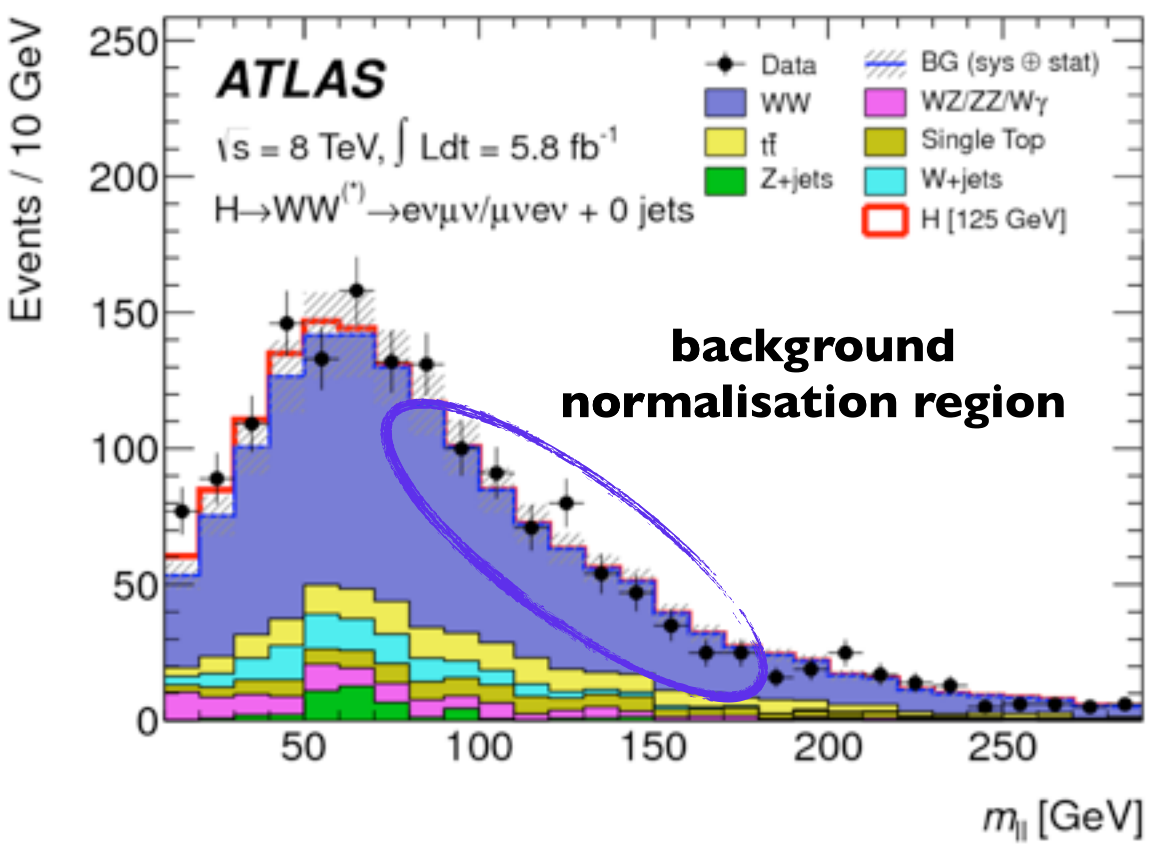
$H \rightarrow W^+W^- \rightarrow l^+\nu l^-\nu$ (l=e,μ)

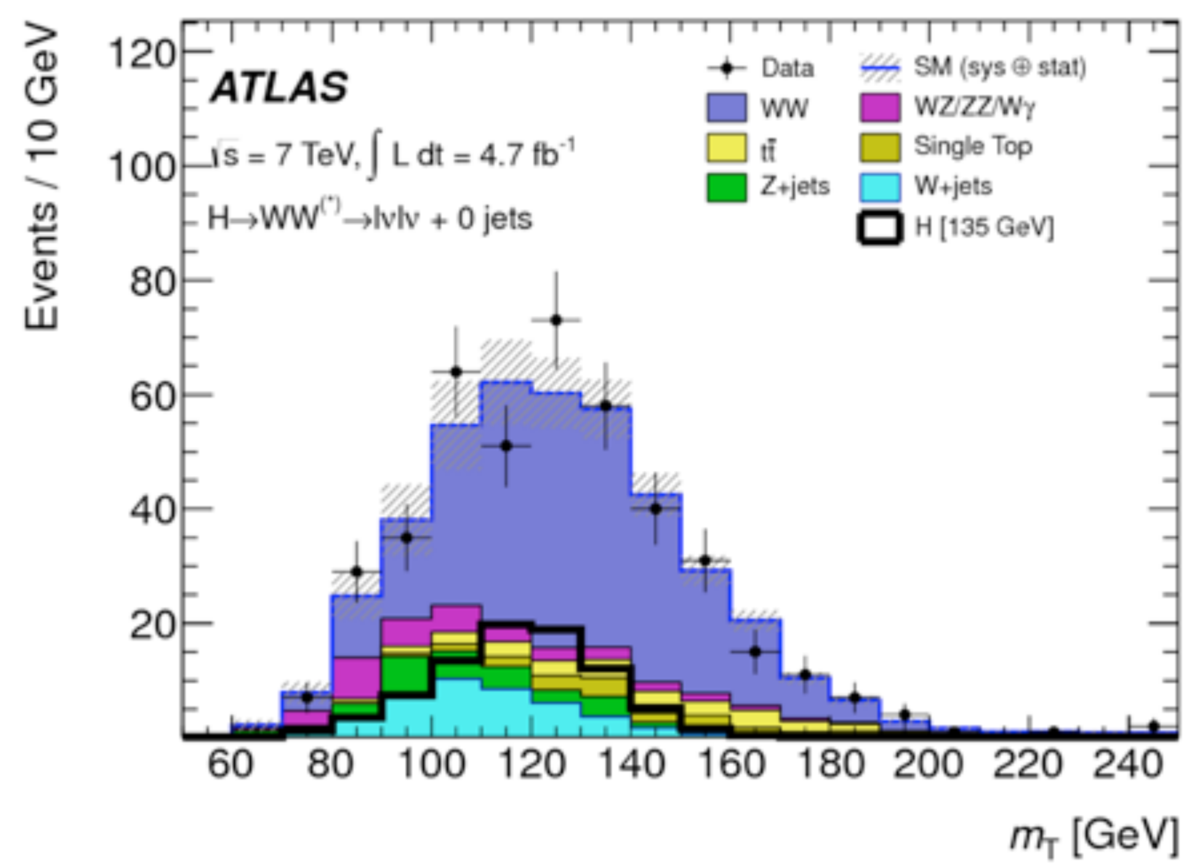
- The energy and direction of the neutrinos can be reconstructed only partially, imposing that the sum of the components in the plane orthogonal to the beam axis is null. The reconstructed quantity is the Missing E_T.

- The channel has a large irreducible background from $pp \rightarrow WW \rightarrow l\nu l\nu$, the characteristics of the H decay brings m_{ll} at small values, allowing to fit both the background and the signal yield.

- Low resolution mass can still be reconstructed without using the component along the beam of the neutrinos momenta (transverse mass)

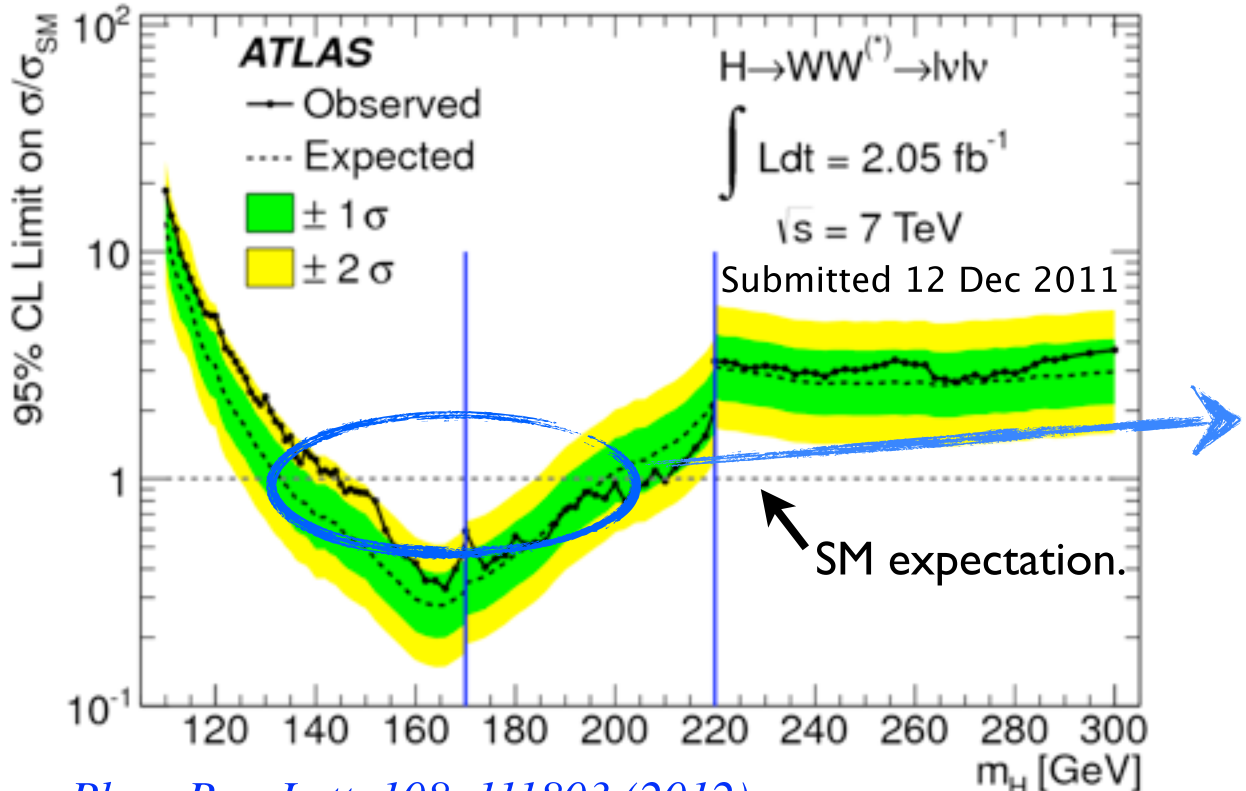






First search results.

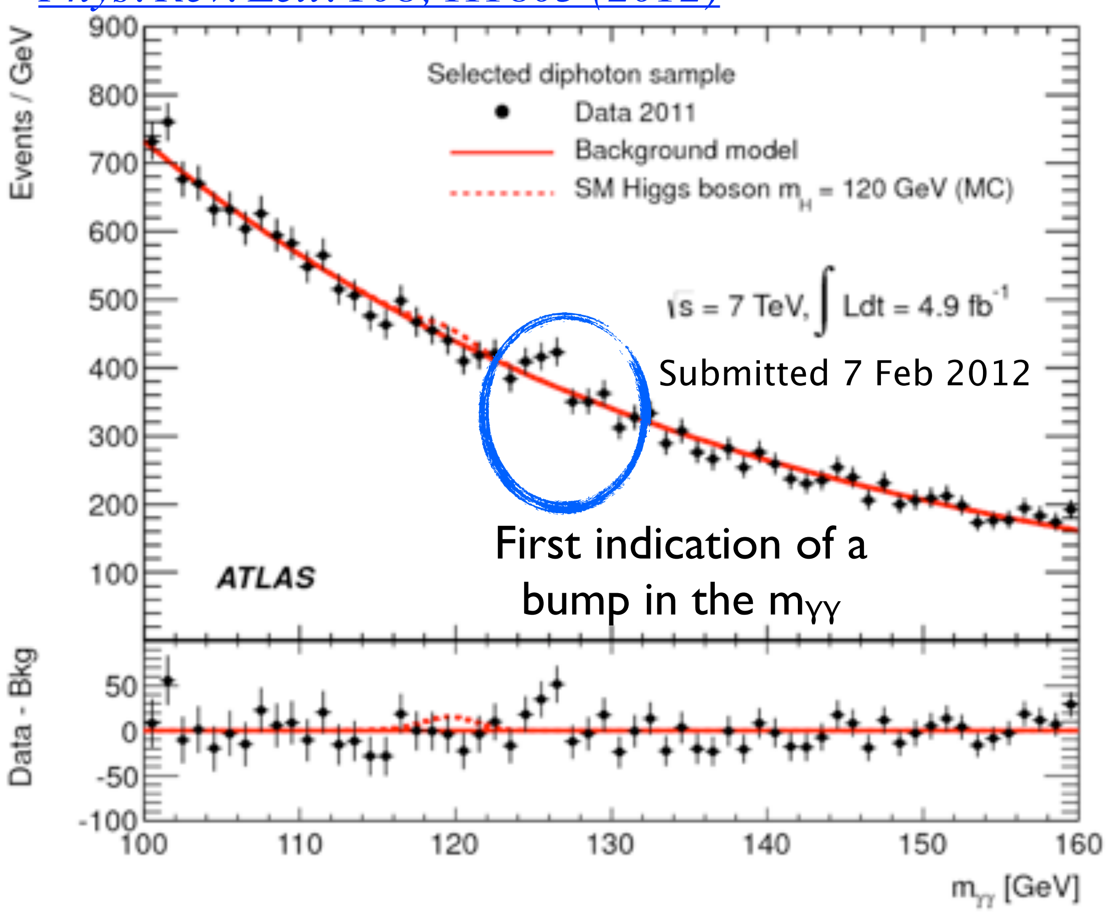
[Phys. Rev. Lett. 108, 111802 (2012)](#)



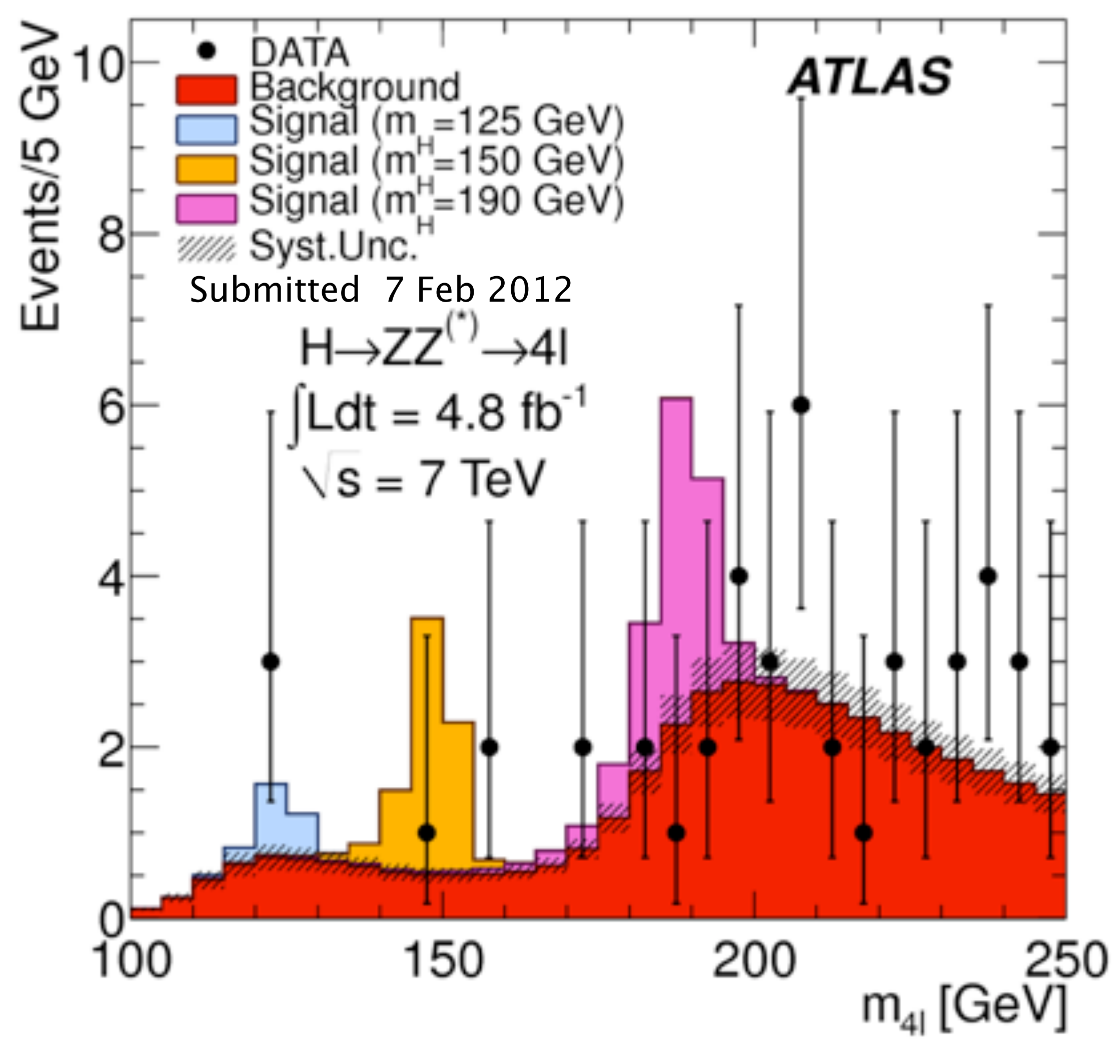
- The signal is excluded @95% C.L. if the probability that the observed data are obtained by an underfluctuation of the event yield is less than 5%.

Large exclusion in the region preferred by the SM indirect tests. Slight excess in the low mass region m_H < 145 GeV.

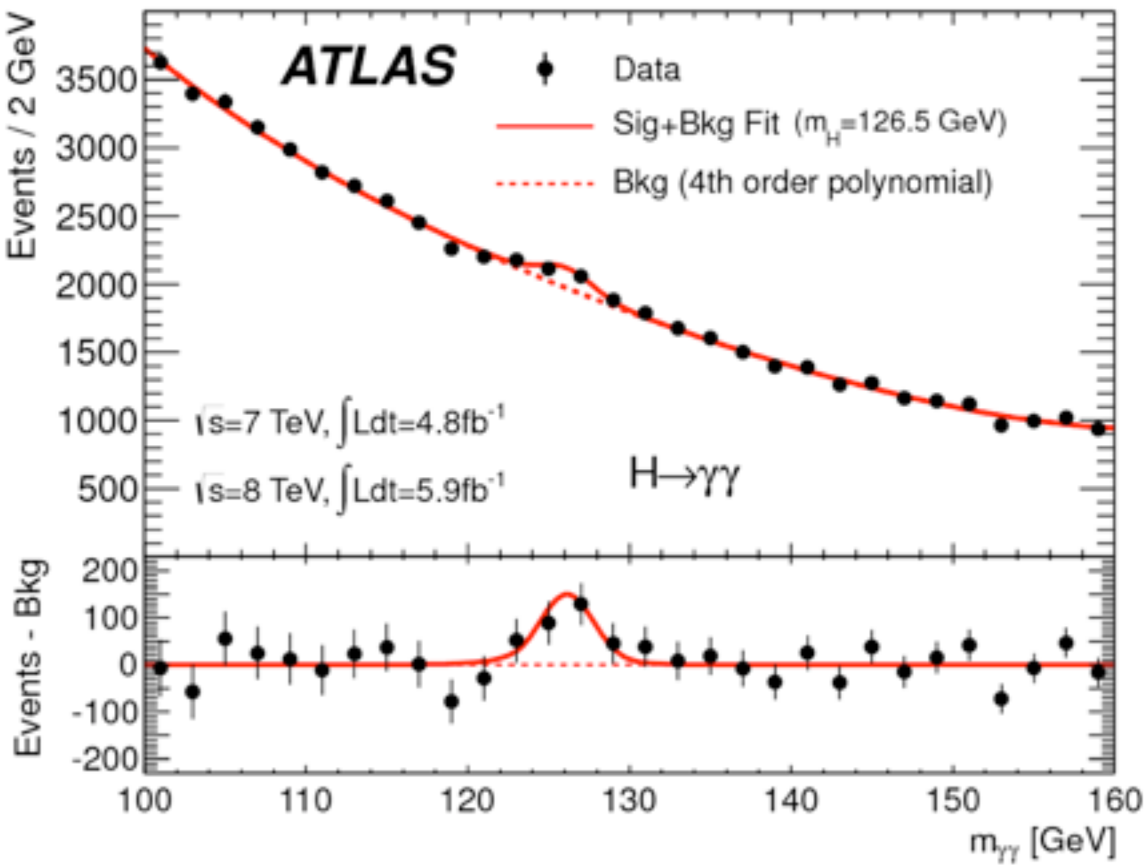
[Phys. Rev. Lett. 108, 111803 (2012)](#)

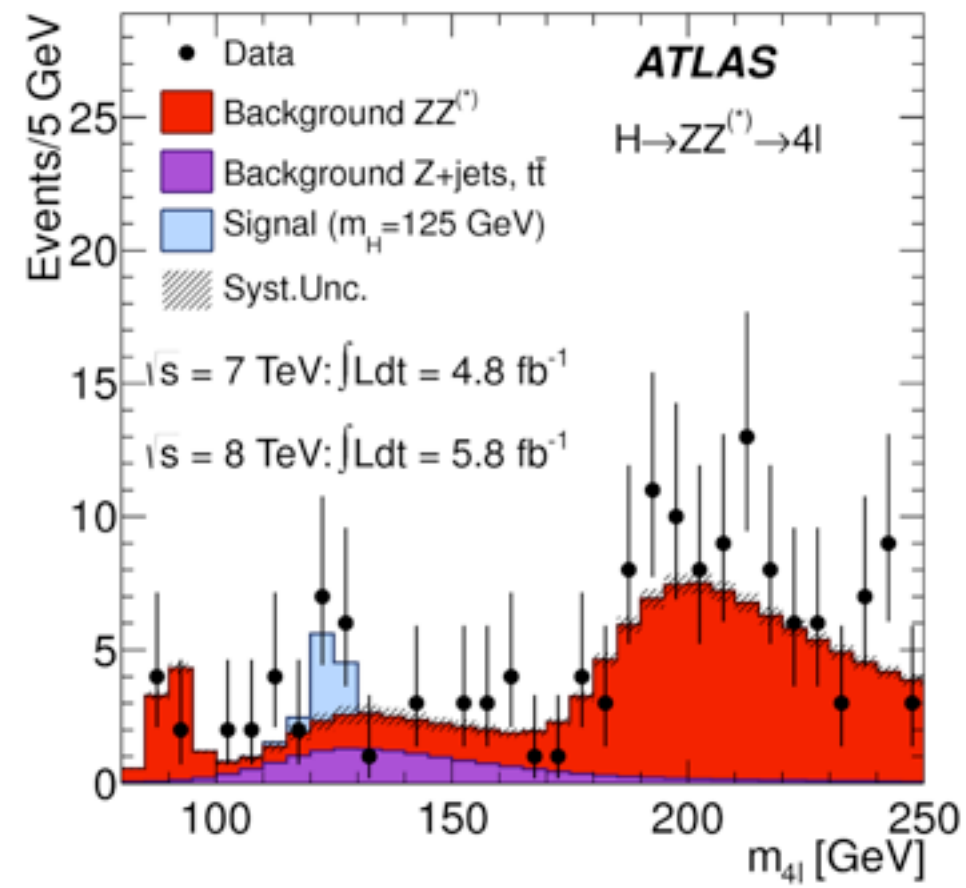


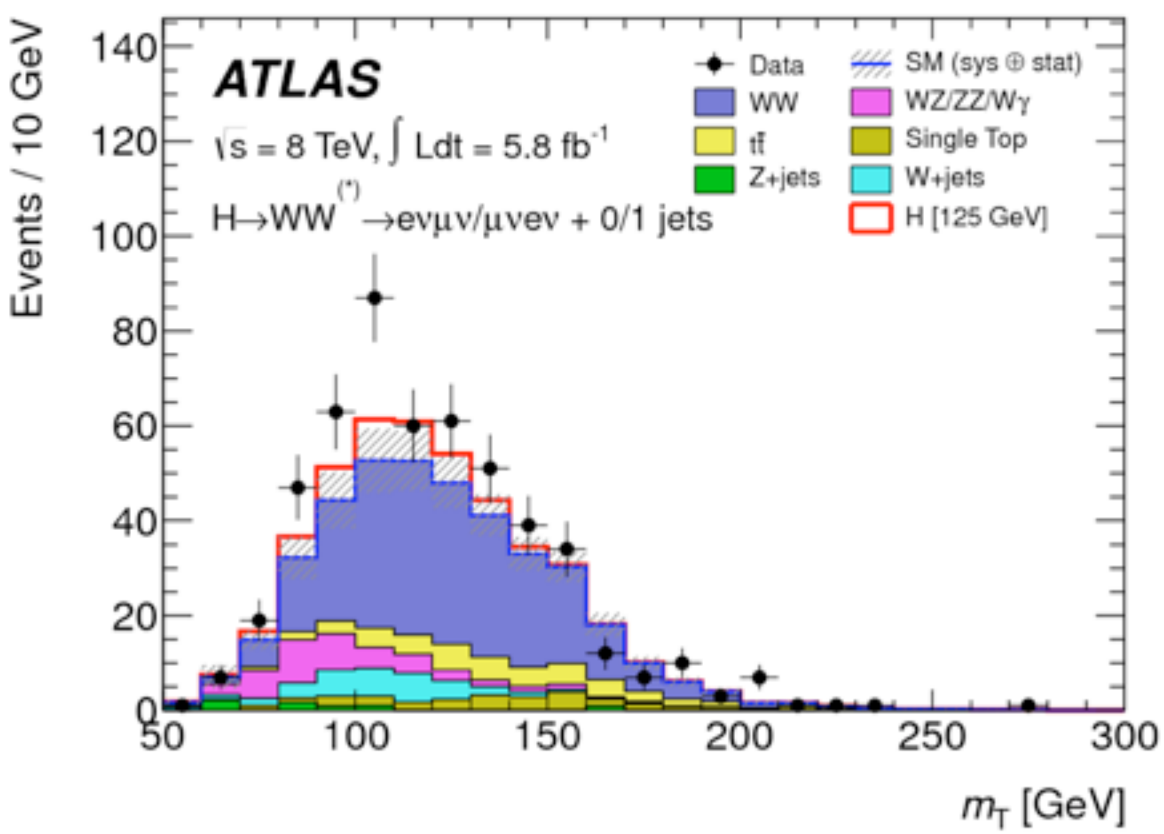
[Phys.Lett. B710 (2012) 383-402](#)



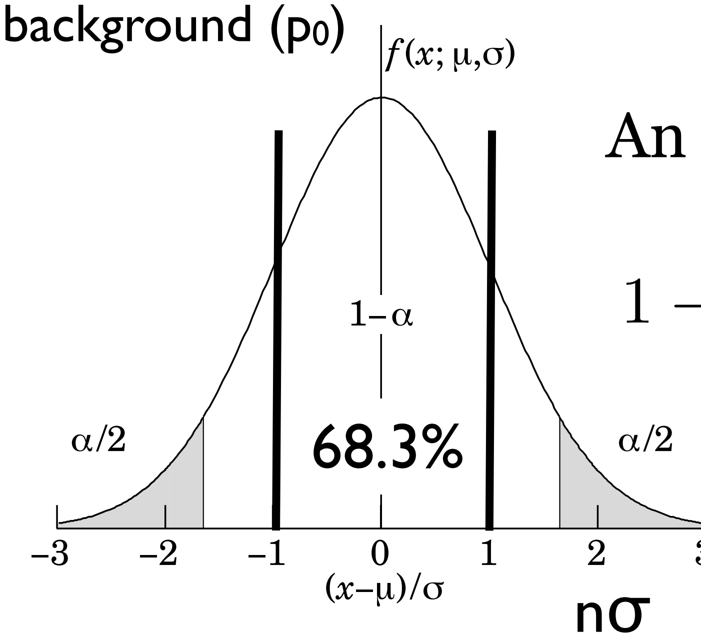
The discovery paper.







An excess of events has been observed in all three channels, the excess is quantified as the probability that such configuration is given by an overfluctuation of the background (p_0)

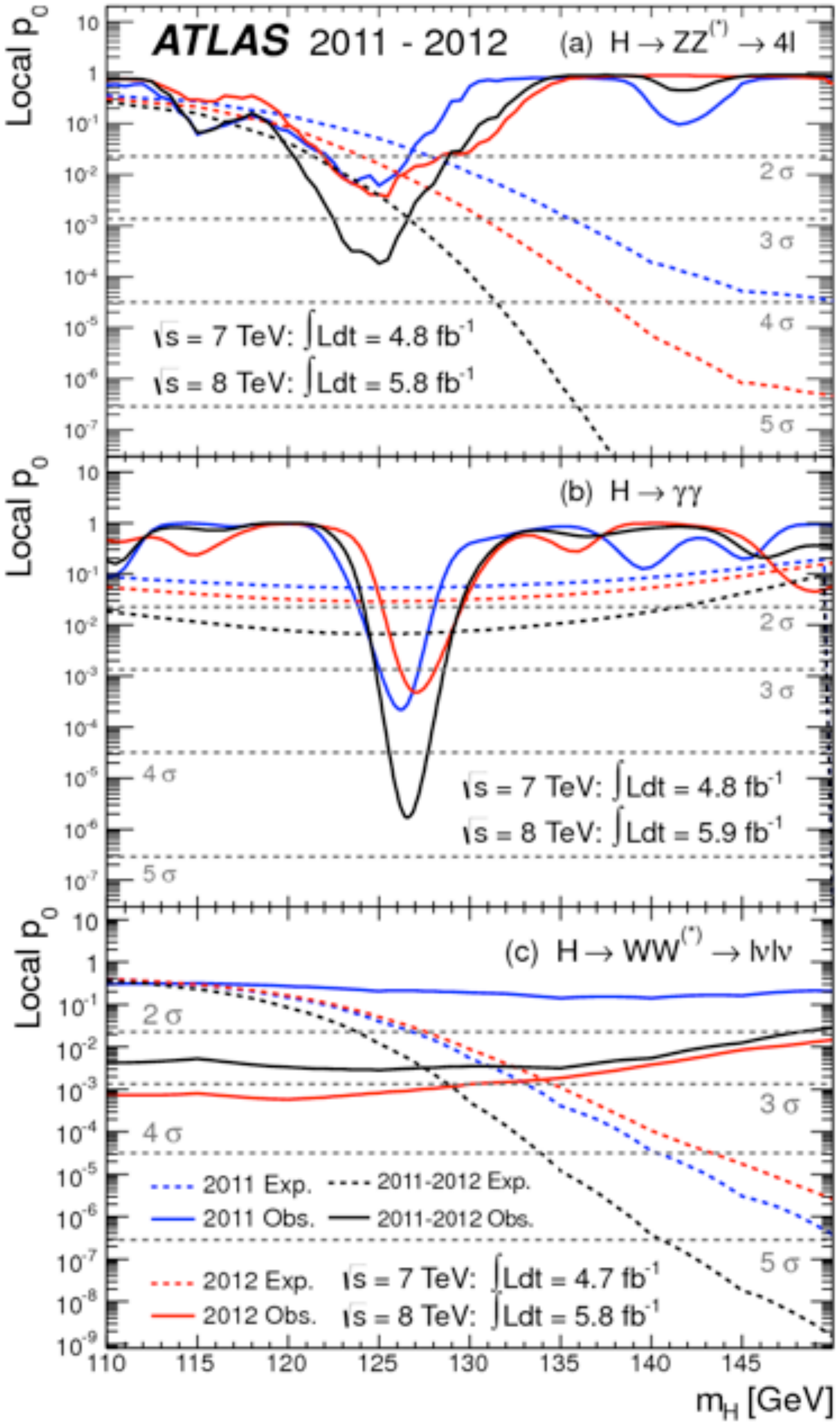


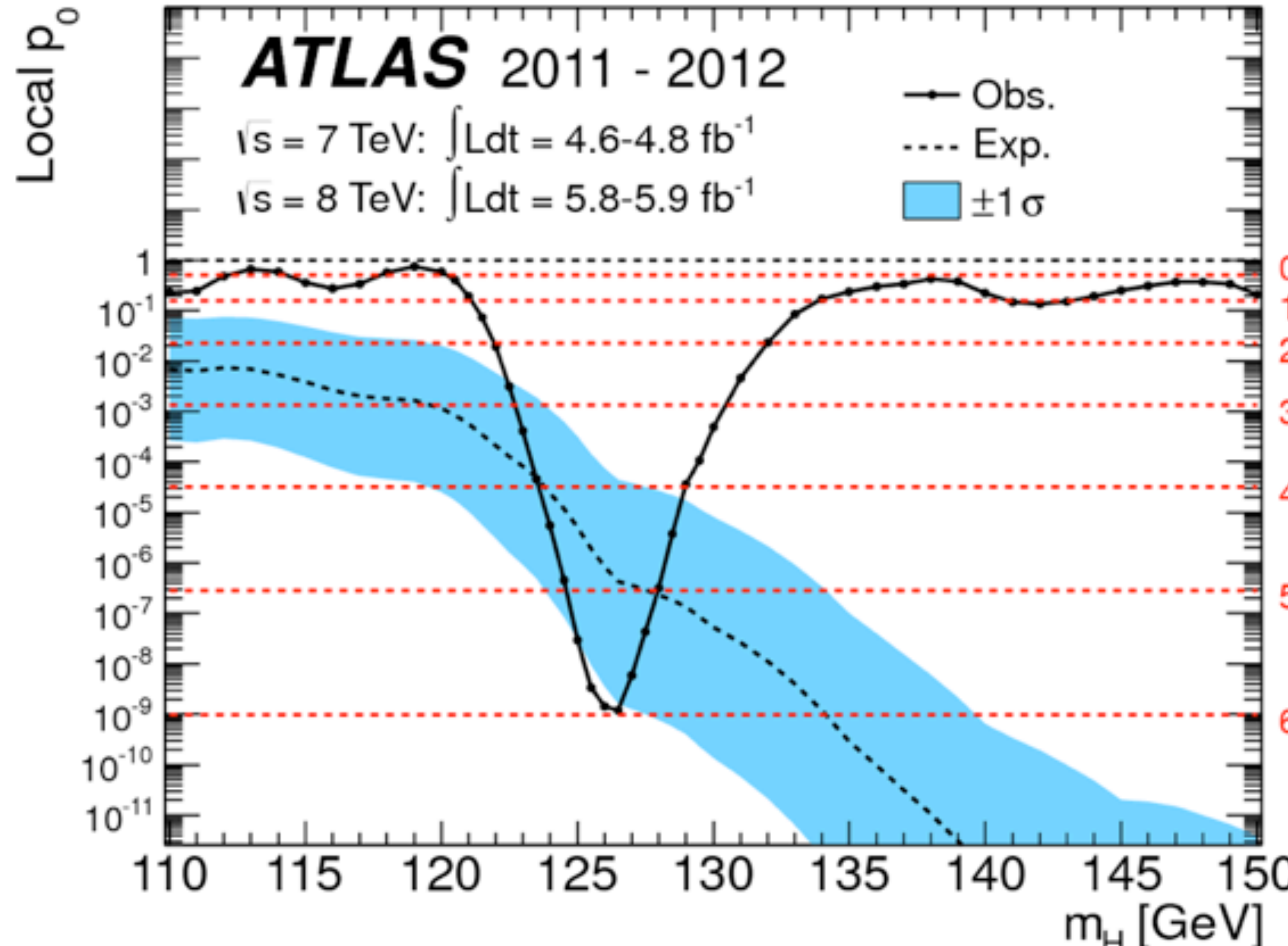
An observation is at $n\sigma$ if:

$$1 - \int_{-\infty}^{n\sigma} f(x;\mu,\sigma)dx = p_0$$

Statistical analysis

Phys. Lett. B 716 (2012) 1-29





To claim a discovery the probability that an excess in data is due to a background fluctuation must be smaller than 2.8×10^{-7} (5σ).

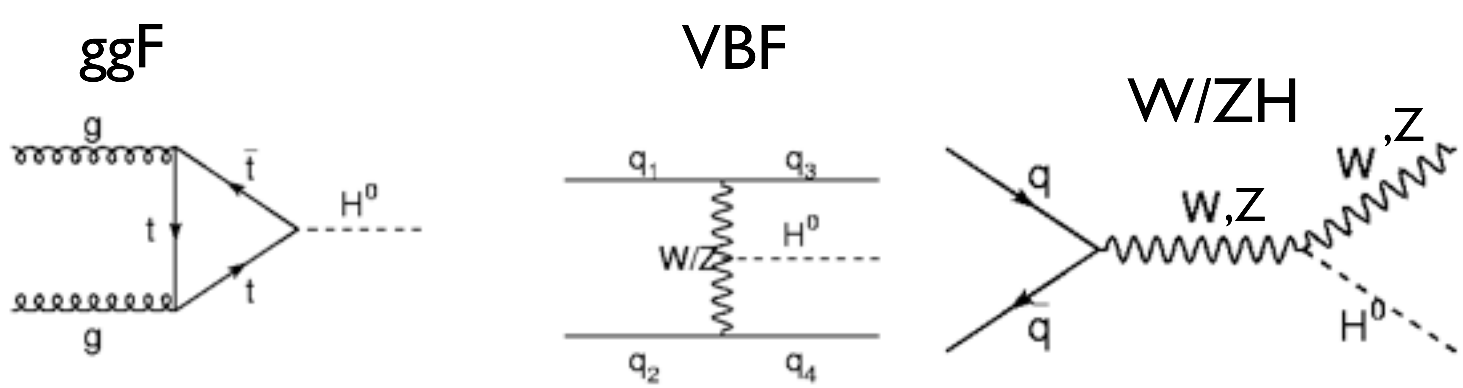
ATLAS reached 6σ evidence, with such probability being $1/10^9$. In the summer 2012 the observation of a new particle was found, but is it really the Higgs boson?

Probing the nature of the observed resonance.

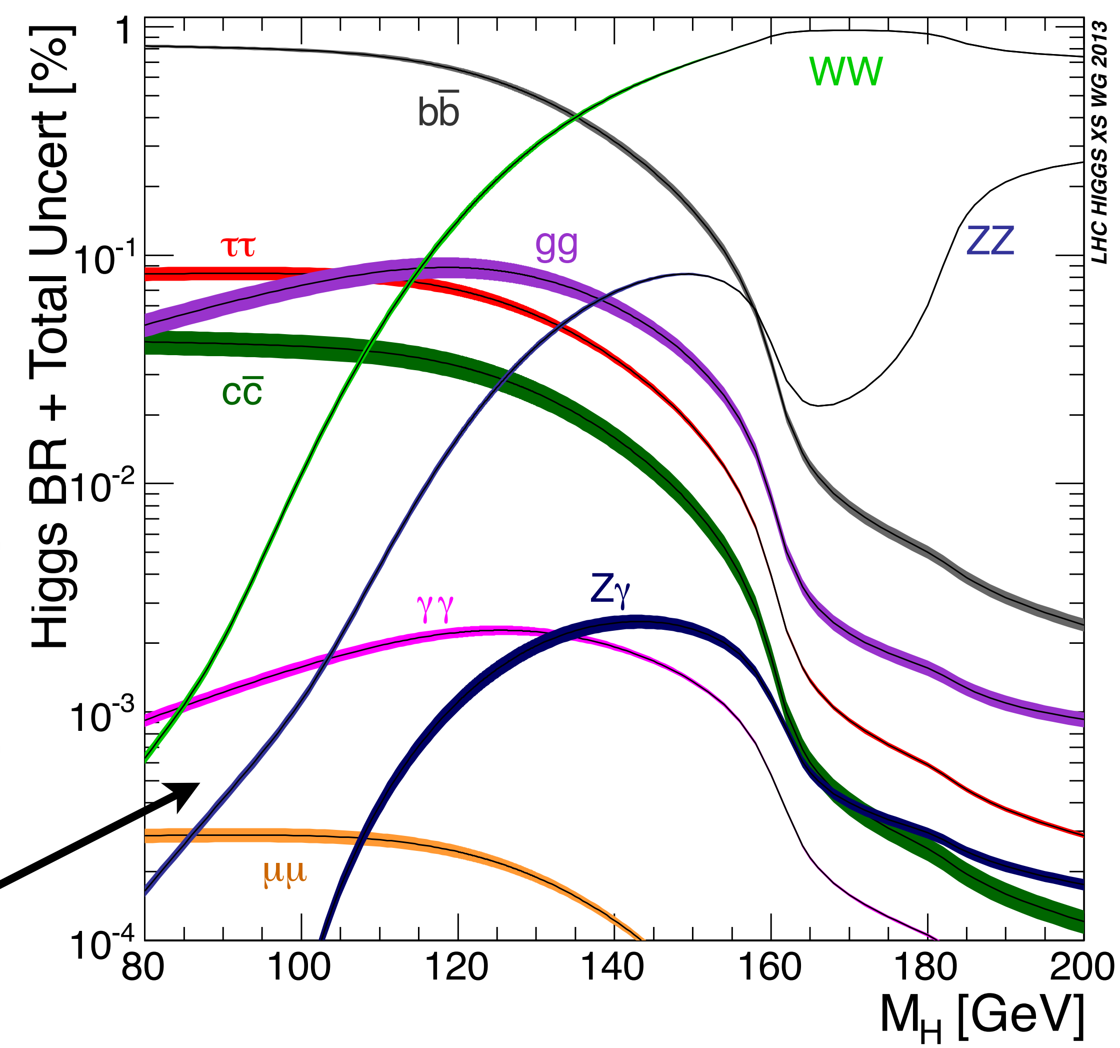
Last year we had enough data to understand that there was something, but we needed more data to find what it was.

The Standard Model has a large predictive power for the Higgs behviour.

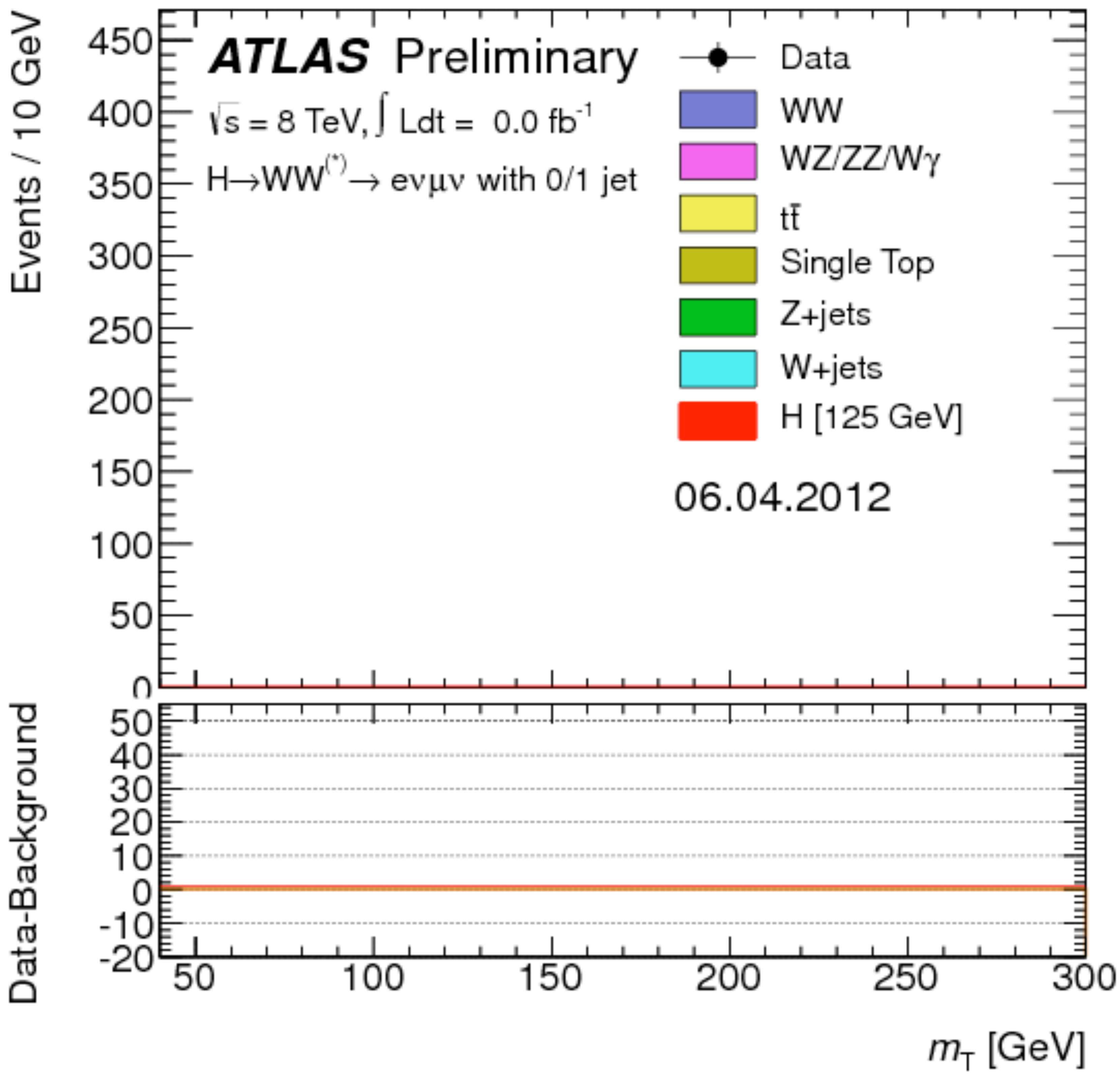
- we know it's spin and parity 0^+
- we know the production rate and the production mechanism (ggF and VBF)

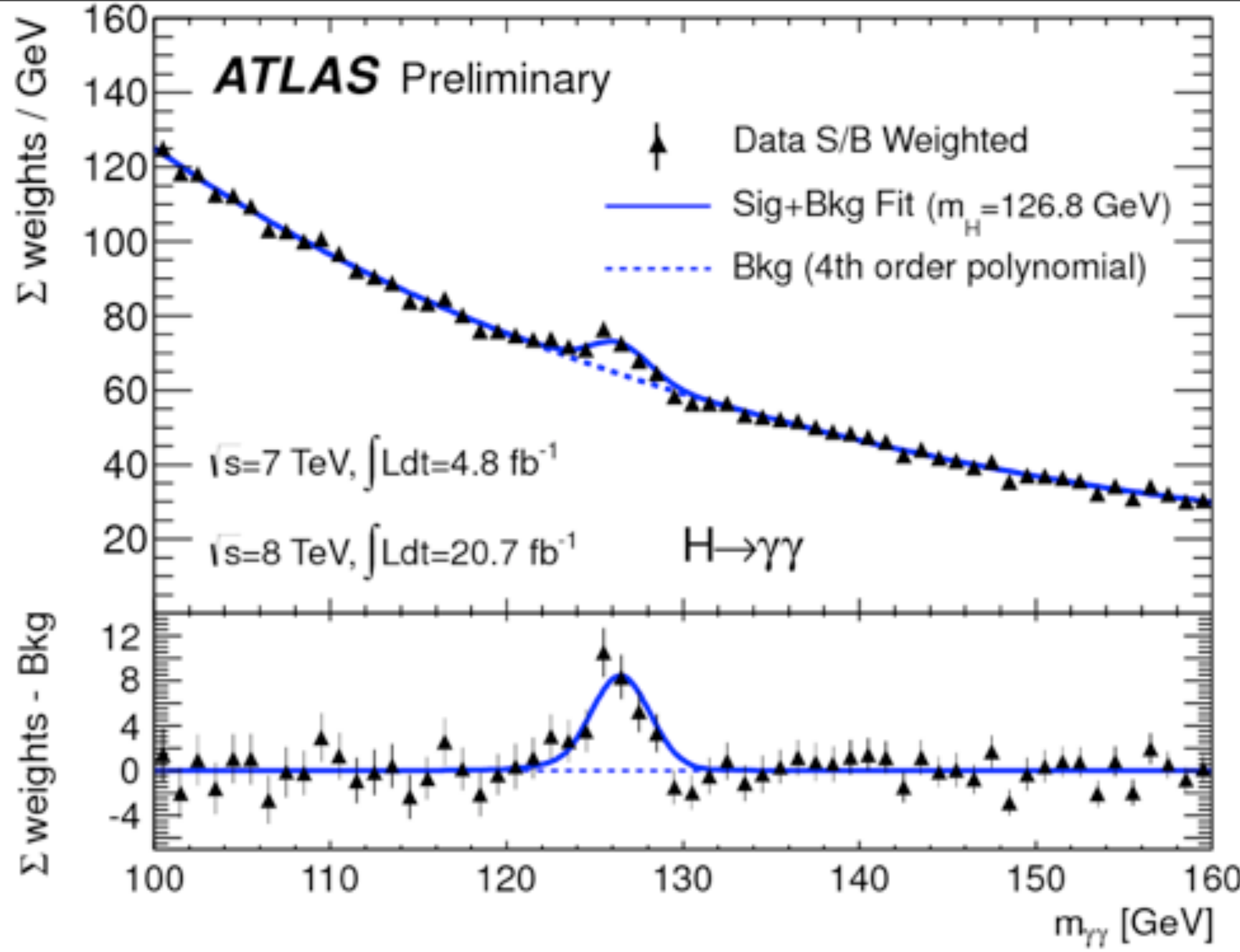


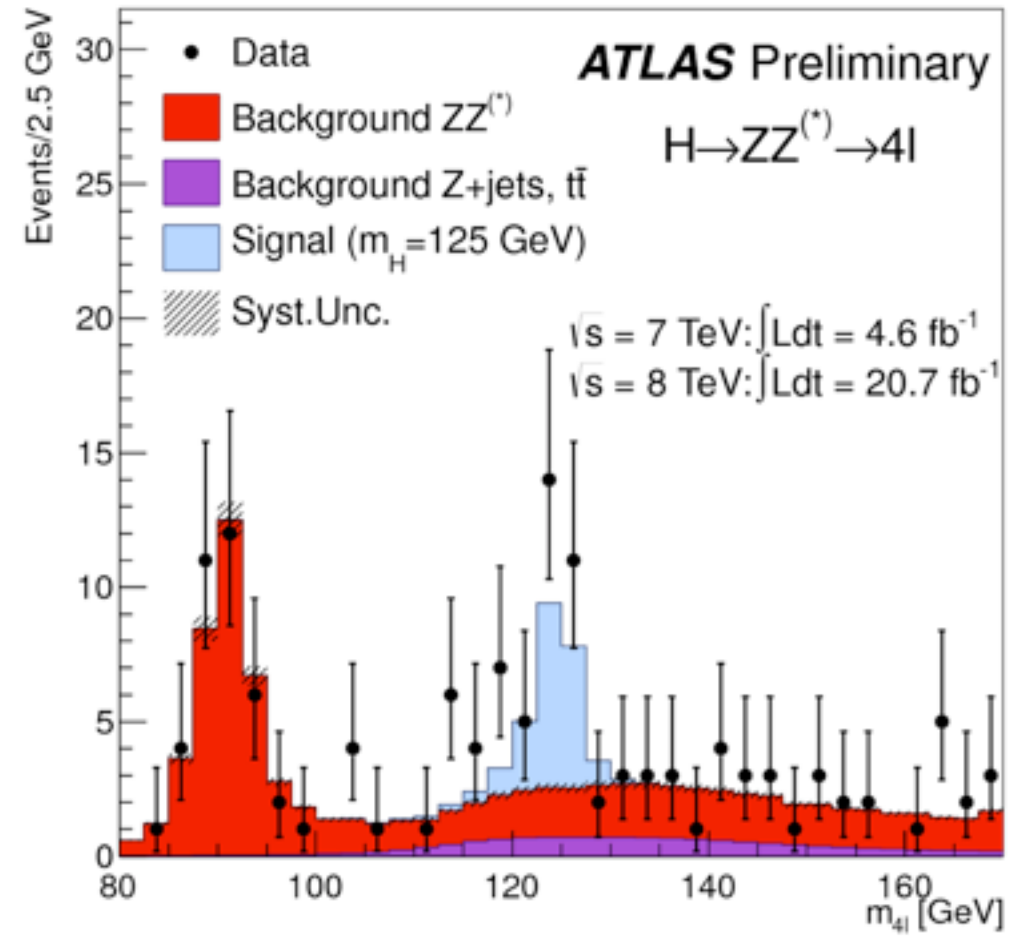
- we know the decay probability in each sub-channel

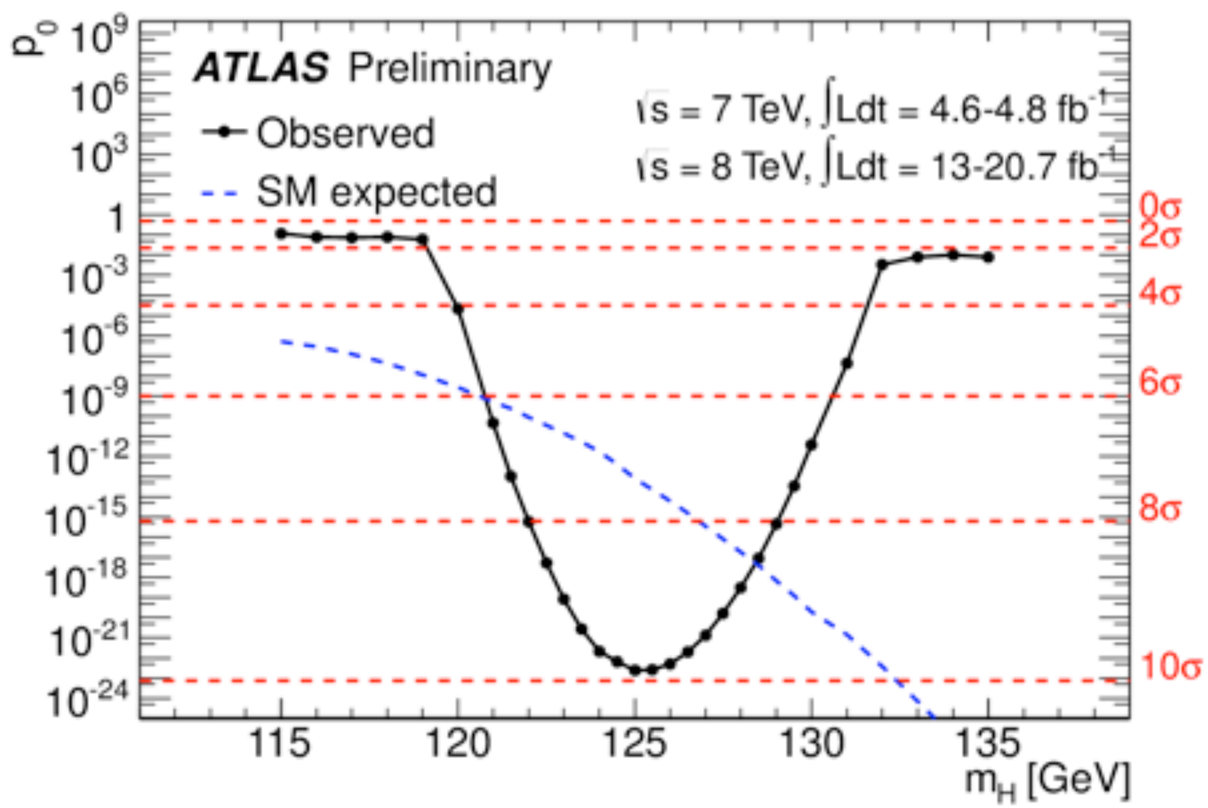


Data with the full dataset, presented at Moriond 2013





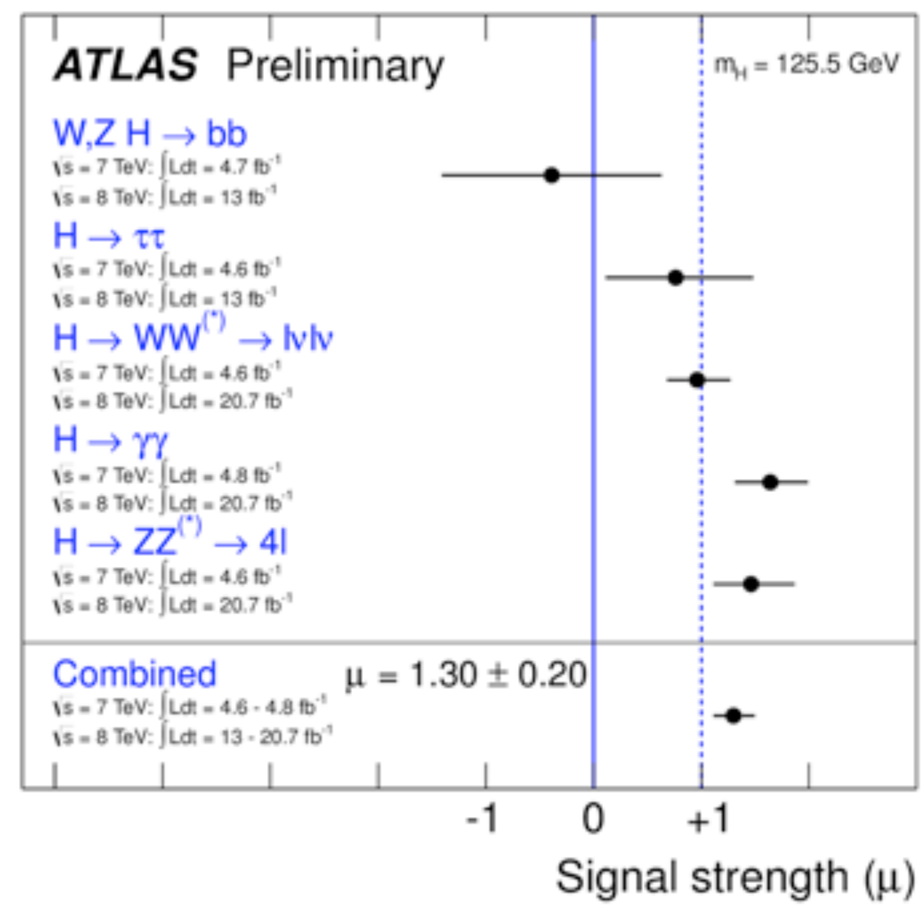




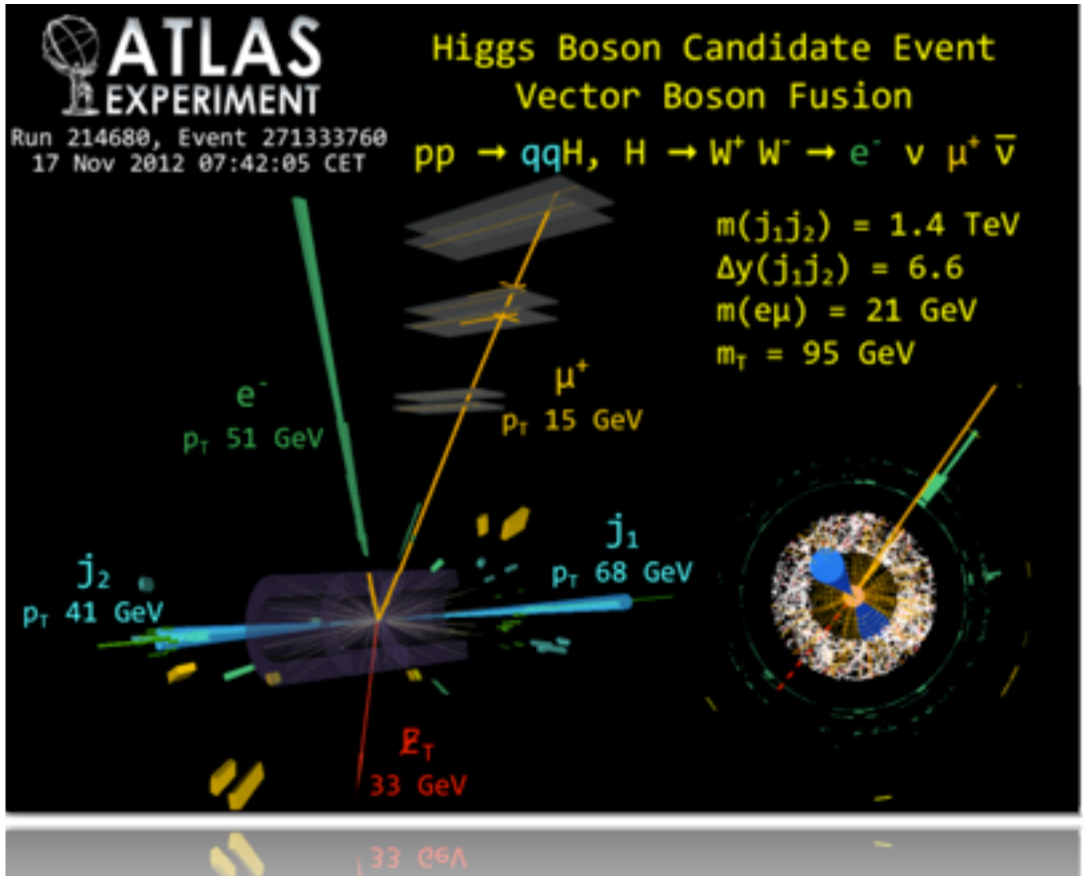
$$\mu = \frac{\text{observed yield}}{\text{expected yield}}$$

The yield in all channels is compatibe with the SM expectation.

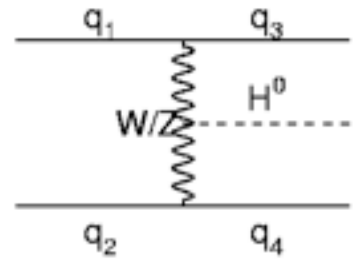
Slight excess in the γγ and ZZ channel, combined result compatible with the SM @7% level.



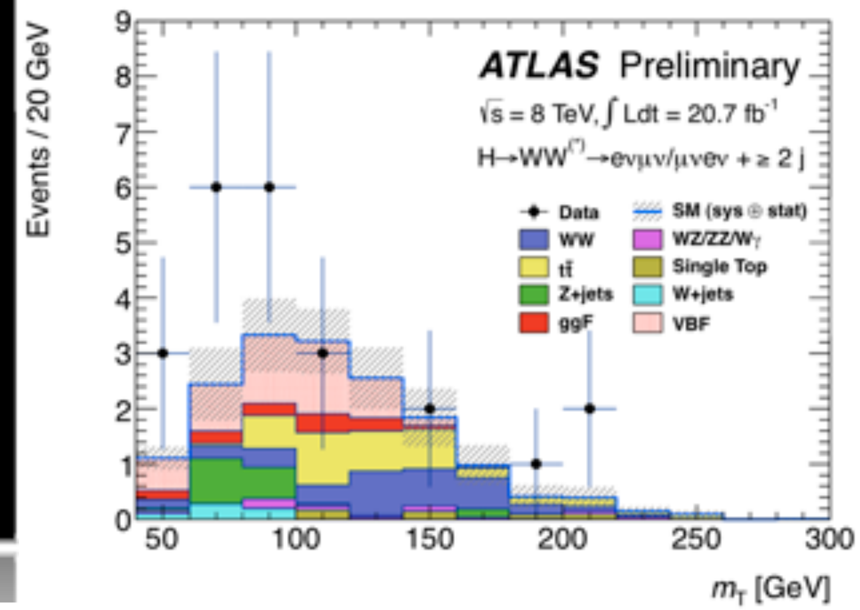
Probe of the production mechanism

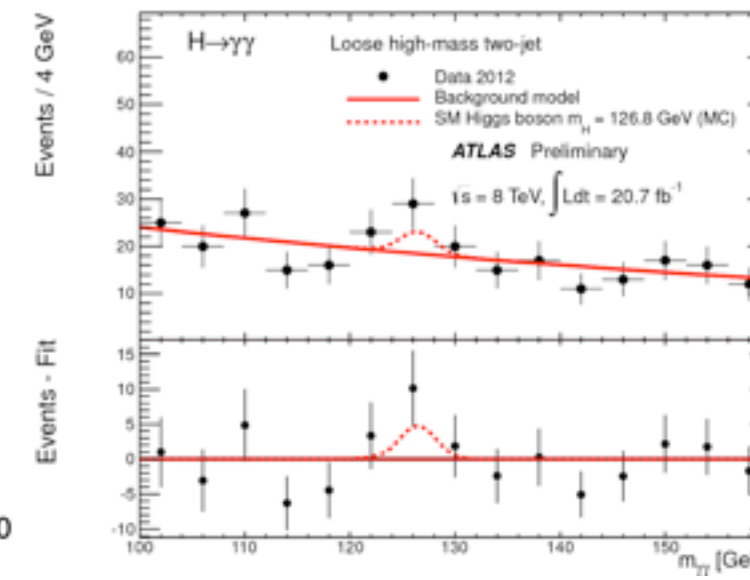


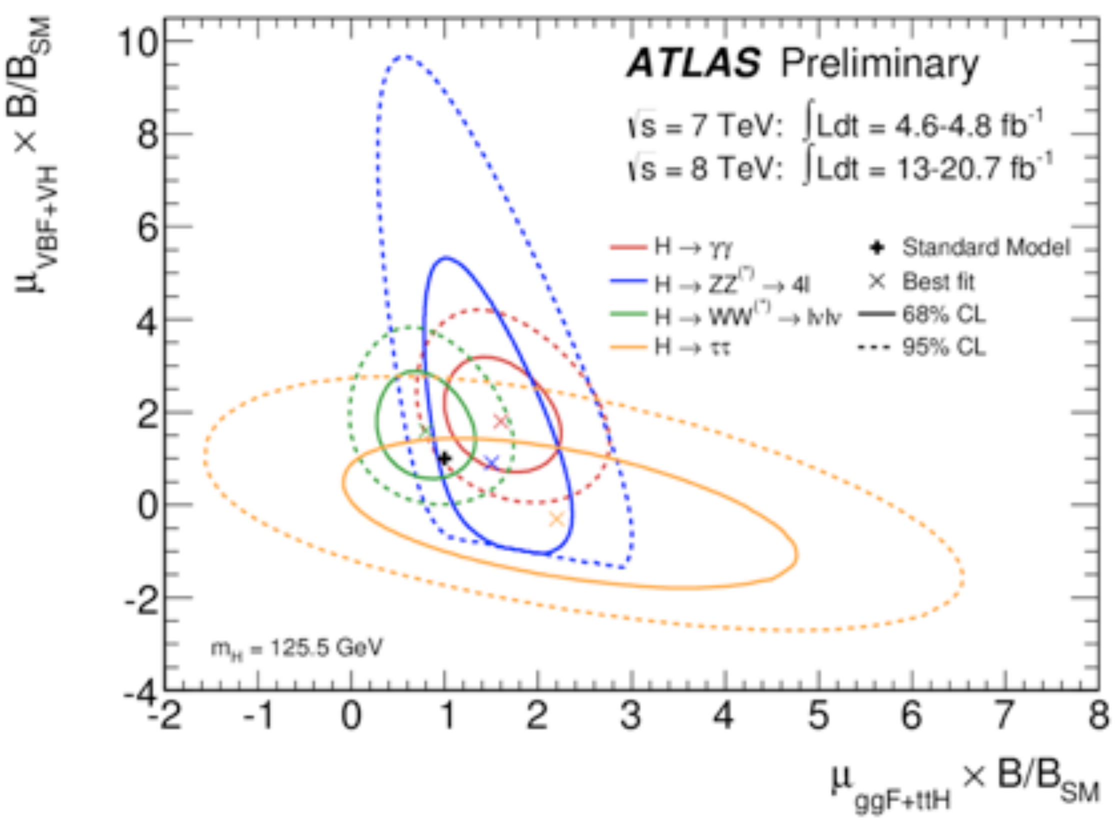
VBF

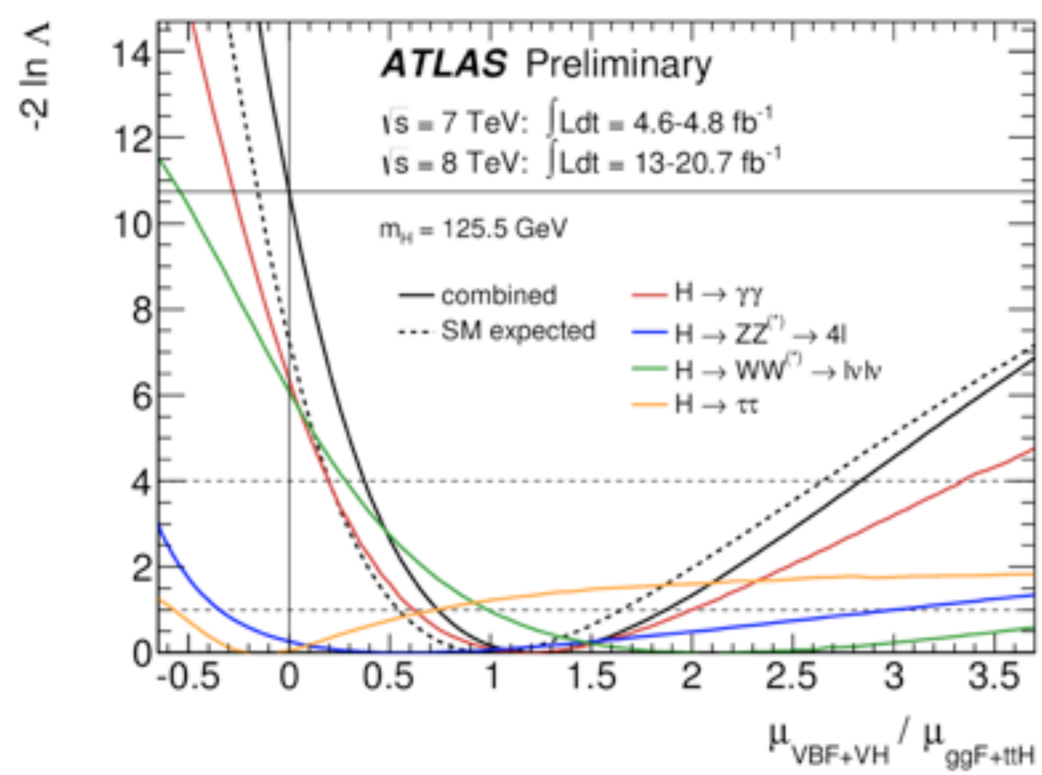


The two outcoming quarks produce large energy deposits in the forward part of the detector, selecting events with this topology enrichs the VBF componenet.







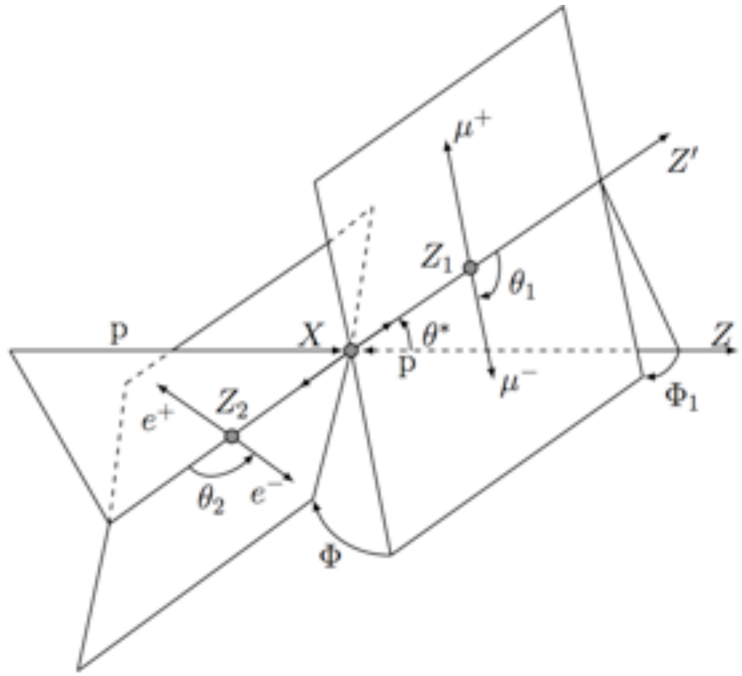


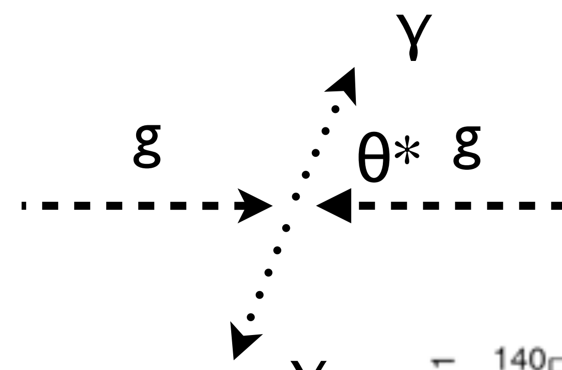
VBF production observed at 3σ level.

VH production still under study (large involvement of Roma Tre in this channel), Domizia being the responsible of the analysis.

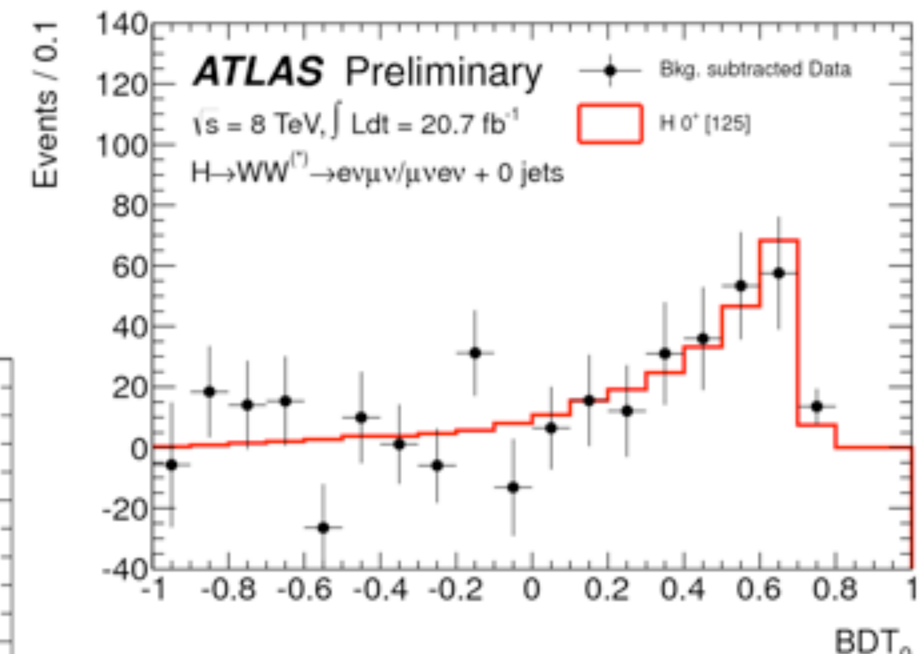
Determination of the spin and parity quantum numbers

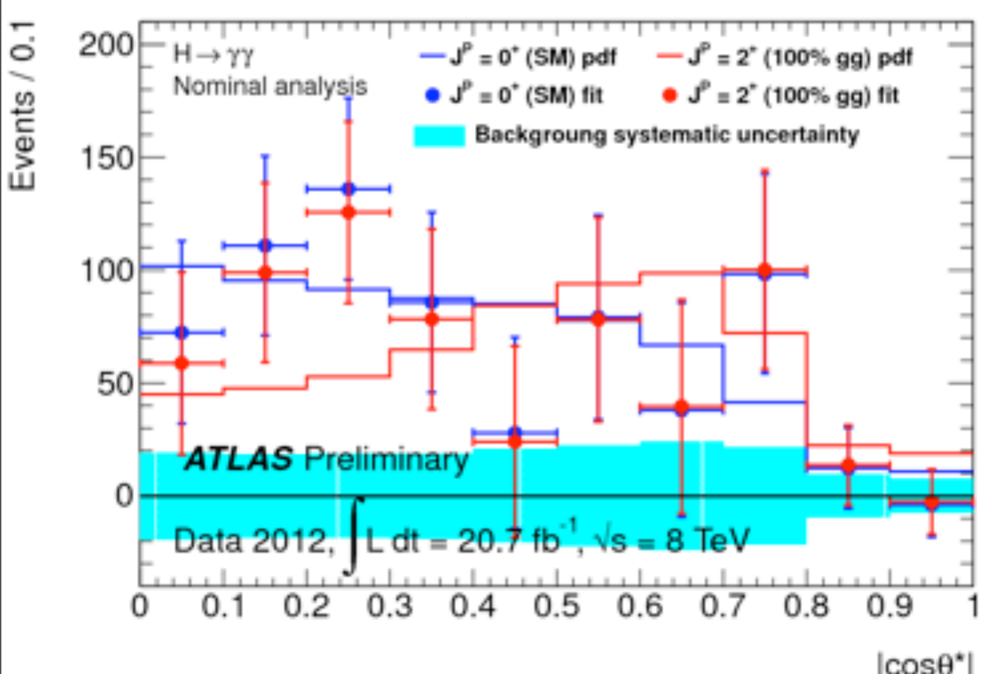
The spin can be determined using the angular distributions of the decay products in WW and ZZ.

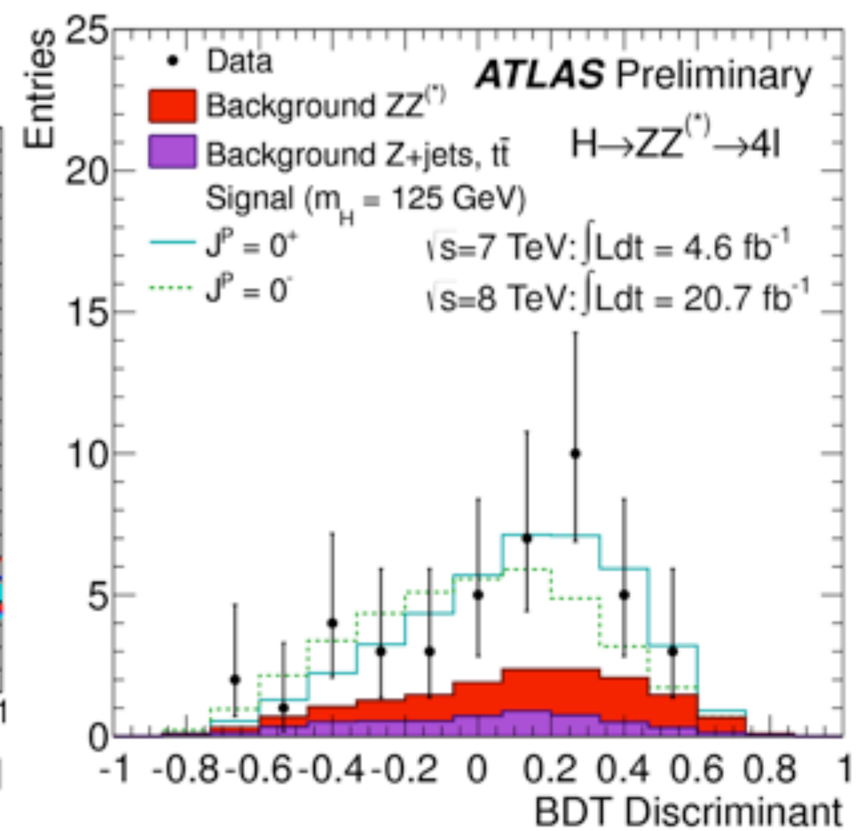


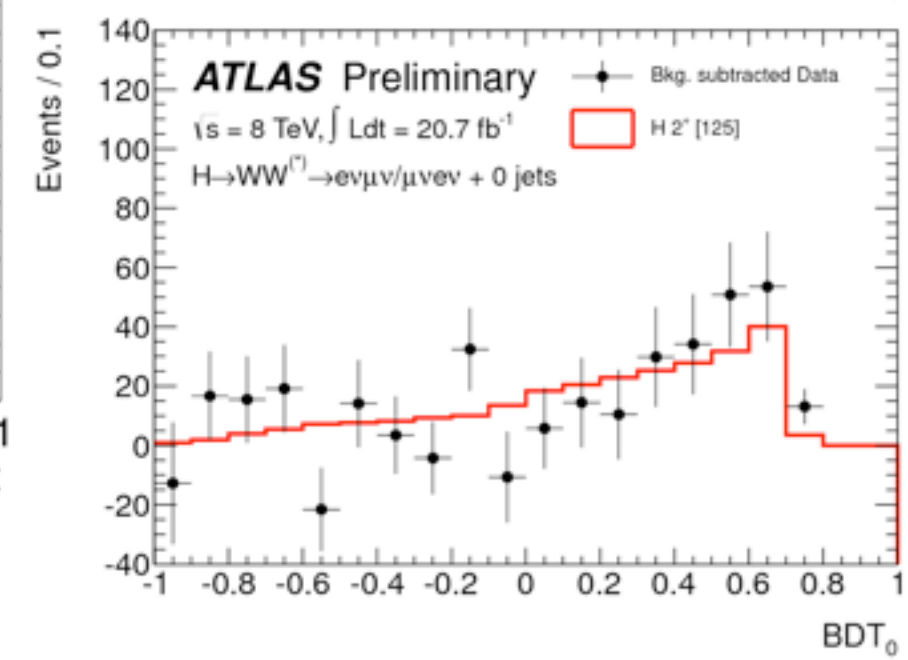


Using the angle respect to the beam axis in the H reference frame for H→γγ

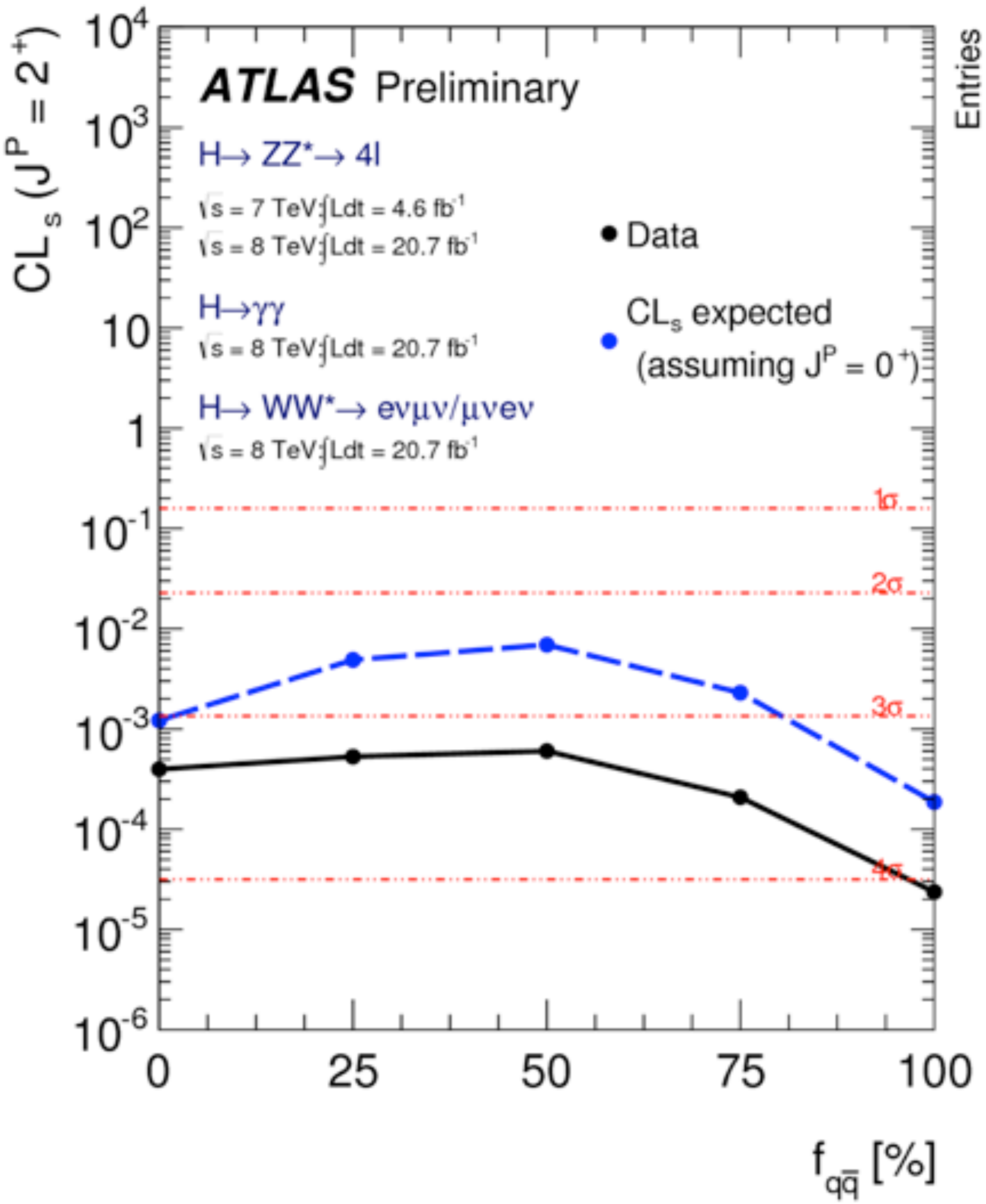


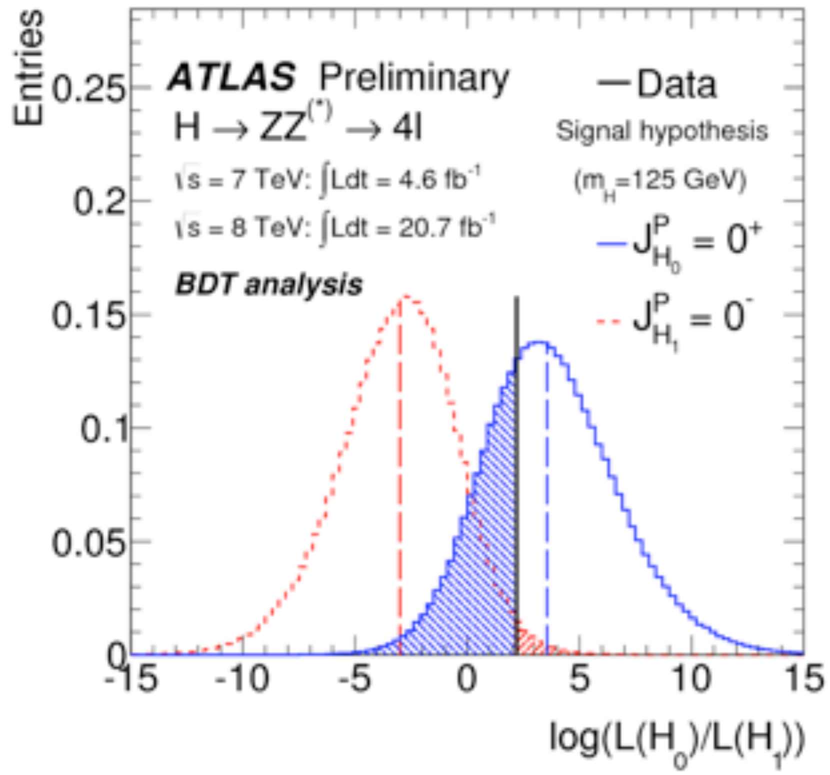


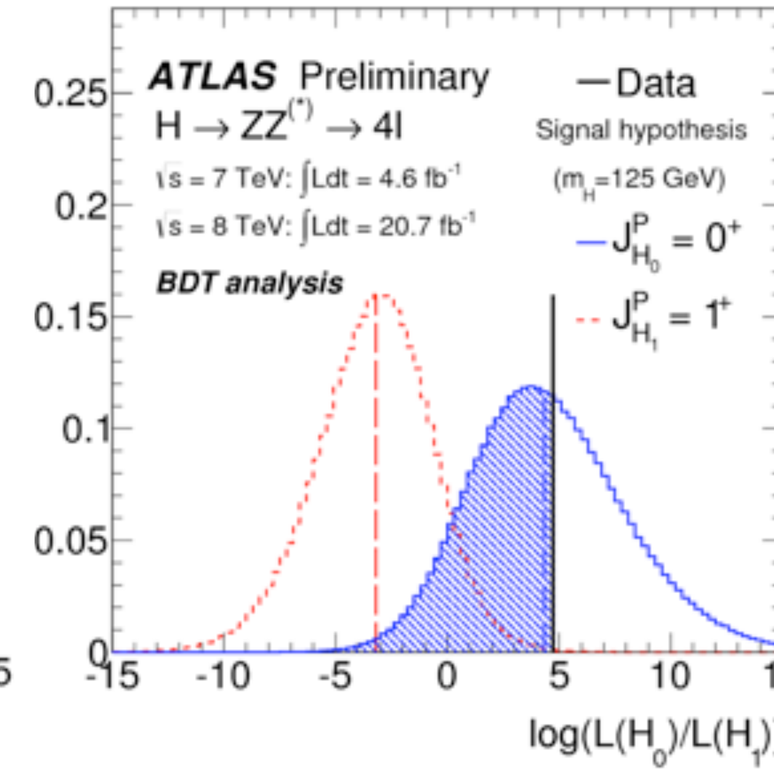




Spin and parity determination.







		BDT analysis			
		tested J^P for an assumed 0^+		tested 0^+ for an assumed J^P	CL_S
		expected	observed	observed*	
0^-	p_0	0.0037	0.015	0.31	0.022
1^+	p_0	0.0016	0.001	0.55	0.002
1^-	p_0	0.0038	0.051	0.15	0.060