Higgs boson decaying to tau leptons in ATLAS at 13 TeV

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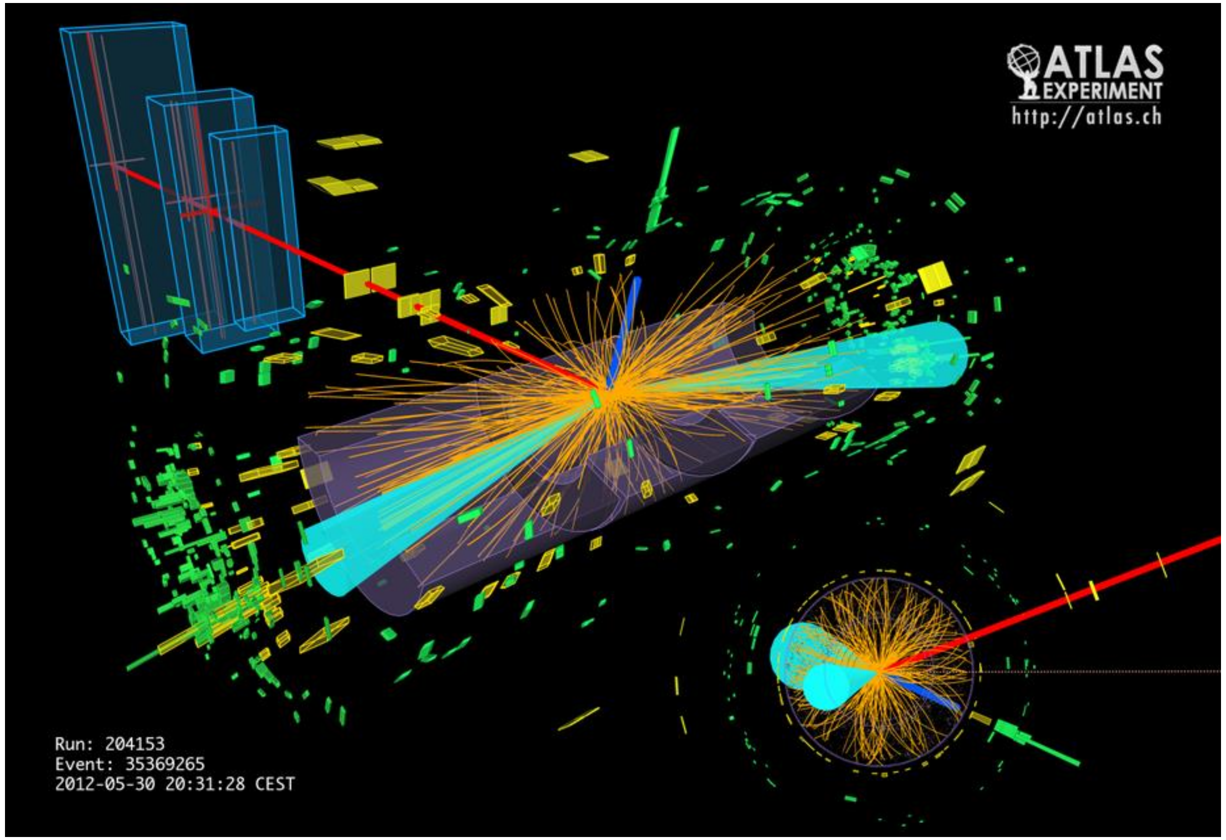
14/09/2016

Taller de Altas Energías
Benasque 2016



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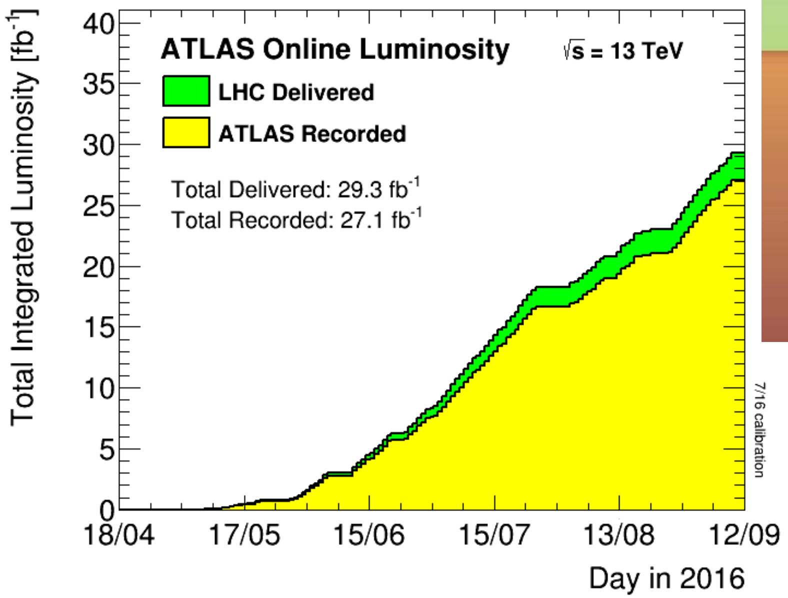
Contents

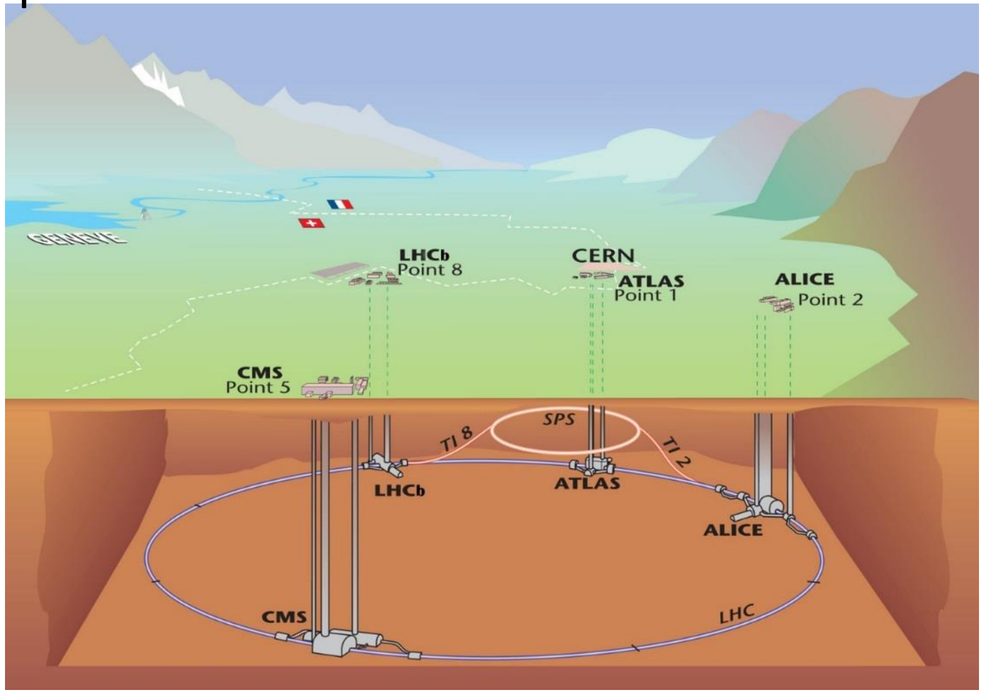
Introduction: LHC

The largest particles collider in the world is the Large Hadron Collider situated in the Franco Swiss border near Geneva. The LHC is designed to collide two proton beams with a center of mass energy of 14 TeV, is a ring with a circumference of 27 Km located 100 meters underground. At nominal luminosity is of 10^{34} cm $^{-2}$ s $^{-1}$, the bunch spacing is 25 ns($\sim$7 m) and each bunch contains about 10^{11} protons.

For Run-2:

- Center of mass energy: $\sqrt{s} = 13$ TeV
- Number of bunches: 2808 bunches
- Bunch space: 25 ns
- Luminosity: 29,3 fb $^{-1}$

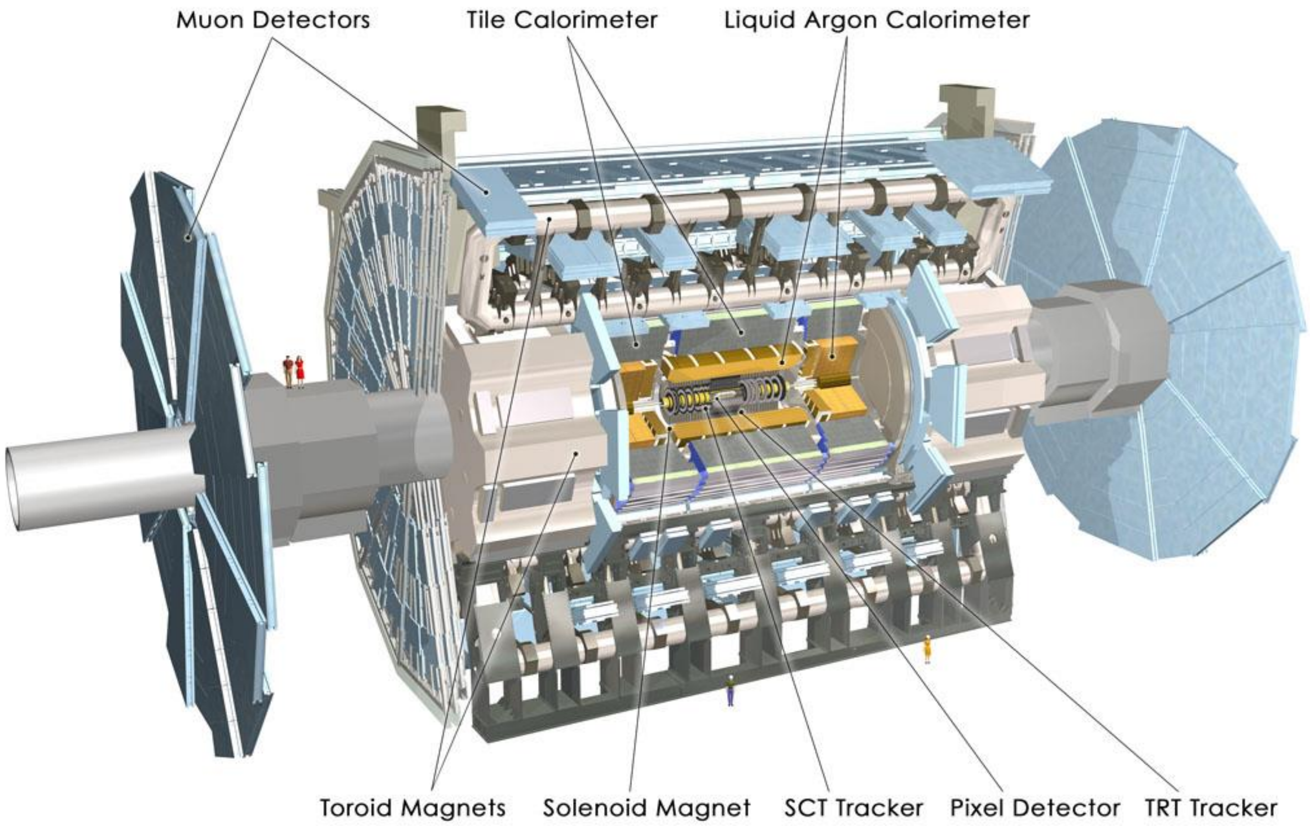




Introduction: ATLAS

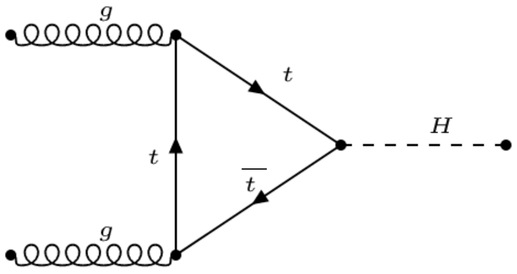
One of the four experiments located at the LHC is ATLAS (A Toroidal LHC Apparatus). The ATLAS detector is 44 meters wide, 22 meter high and weights nearly to 7000 Tons. The ATLAS detector consists of three main components:

- **Inner detector**: momentum precision $\frac{\sigma}{p_T} = 0{,}05\% p_T \oplus 1\%$, with a coverage $|\eta| < 2{,}5$.
- **Two calorimeters**: LAr calorimeter with resolution $\frac{\sigma}{E} = 10\%/\sqrt{E} \oplus 0{,}7\%$, and TileCal with precision $\frac{\sigma}{E} = 50\%/\sqrt{E} \oplus 3\%$
- **Muon Spectrometer**: where the main function is the precise measurement of the muon tracks, with precision 2% for 100 GeV

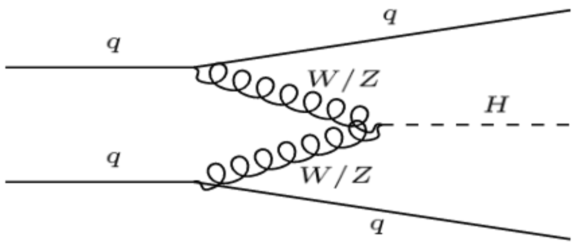


Higgs $\rightarrow \tau_{lep}\tau_{lep}$

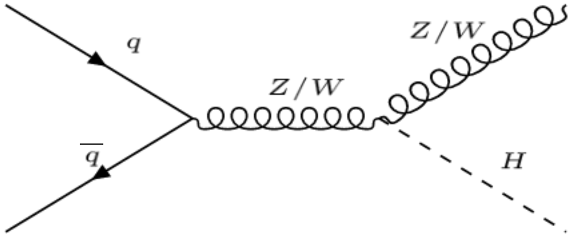
The main production modes for Higgs boson used in this analysis are:



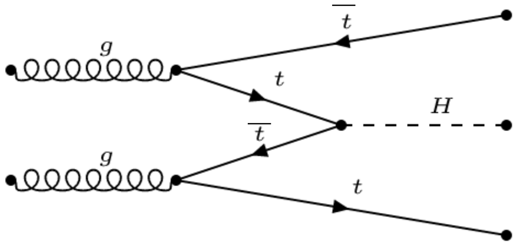
ggF production (88%)



VBF production (7%)

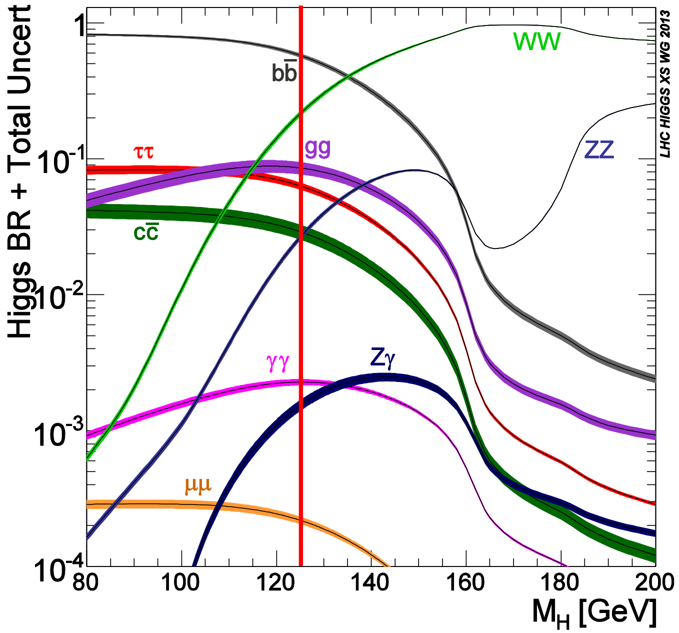


VH production (4%)

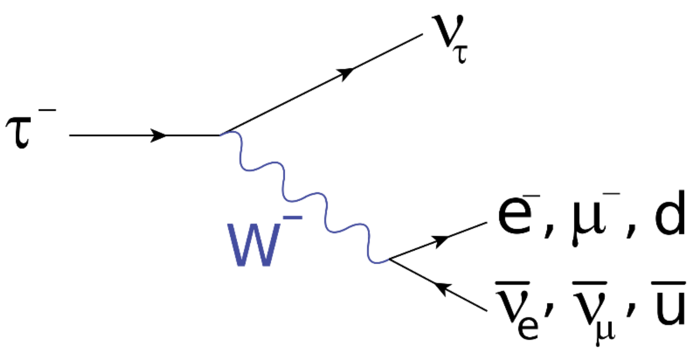


ttH production (1%)

Decay channels for the Higgs boson are shown below:



Decay channels for the tau lepton:



The same analysis has been done for Run I with a significance of **4.5 standard deviations** (1).

(1) https://cds.cern.ch/record/1982276?ln=es

Background

As the final state there are two light leptons (muons or electrons), the background that we have to consider are the particles that its decay are leptons, then we divide the background in these sub categories:

- *Top backgrounds*: which contains $t\bar{t}$, $t\bar{t}+\text{boson}$ and $single-top$ processes.

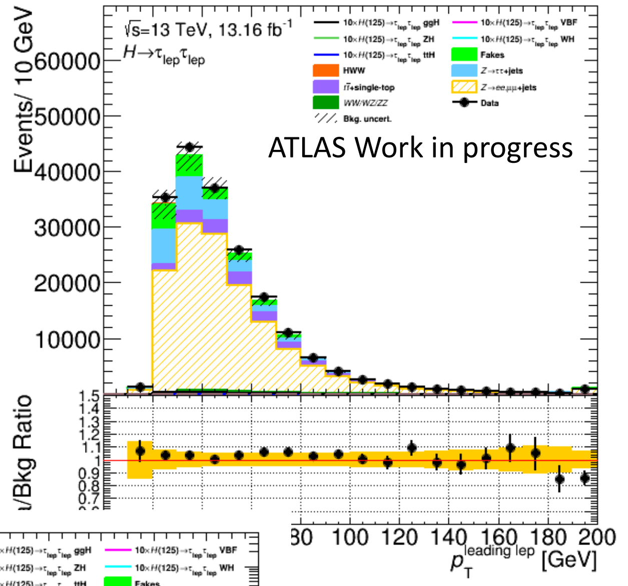
- The *Diboson backgrounds*: which contains WW, WWW, $WWjj$, Z, WZ, ZZ, WWZ and ZZZ processes.

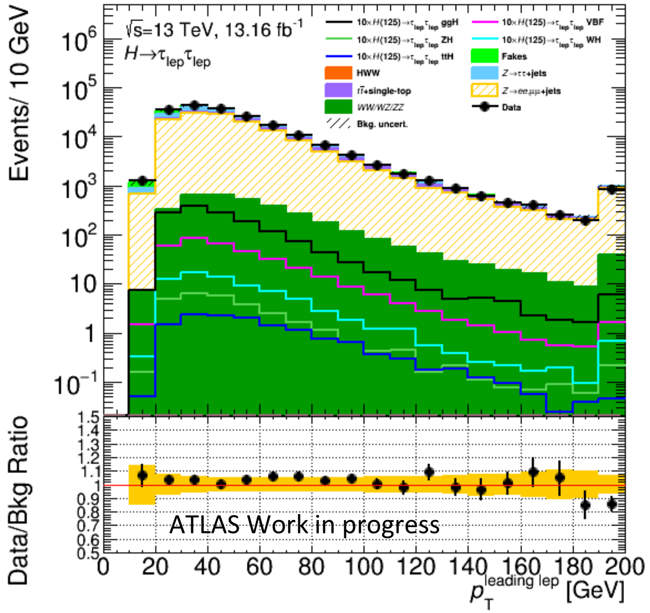
- The Z_{light} category: which contains $\text{Z}+jets$ decaying to ee or μμ.

- The Z_{taus} category: which contains $\text{Z}+jets$ decaying to $\tau\tau$

- The Higgs backgrounds: which contains the Higgs boson decaying to WW mostly

- The fake leptons background: (it is a template sample) which contains $multi-jets$ as well as $W+jets$ and $W\gamma$, that can pass the selection criteria if jets or leptons from hadrons decays are misidentified as prompt leptons.





Event Selection

To enhance the signal and reduce the background, different cuts are applied for each event. The event selection that we have so far is:

Preselection cutflow:

- One or more primary vertex
- At least two selected leptons ($n_{elec} + n_{muon} = 2$)
- No medium taus (to reduce the misidentified particles)
- A trigger selection (different triggers for 2015 or 2016 data)
- Opposite signs leptons (the charge have to be conserved)

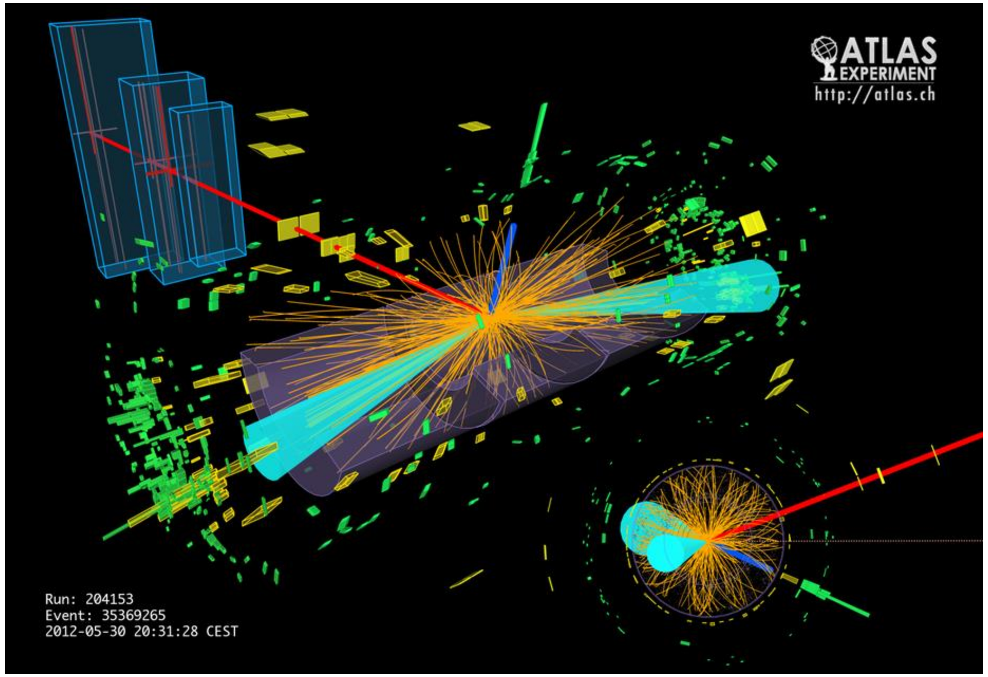


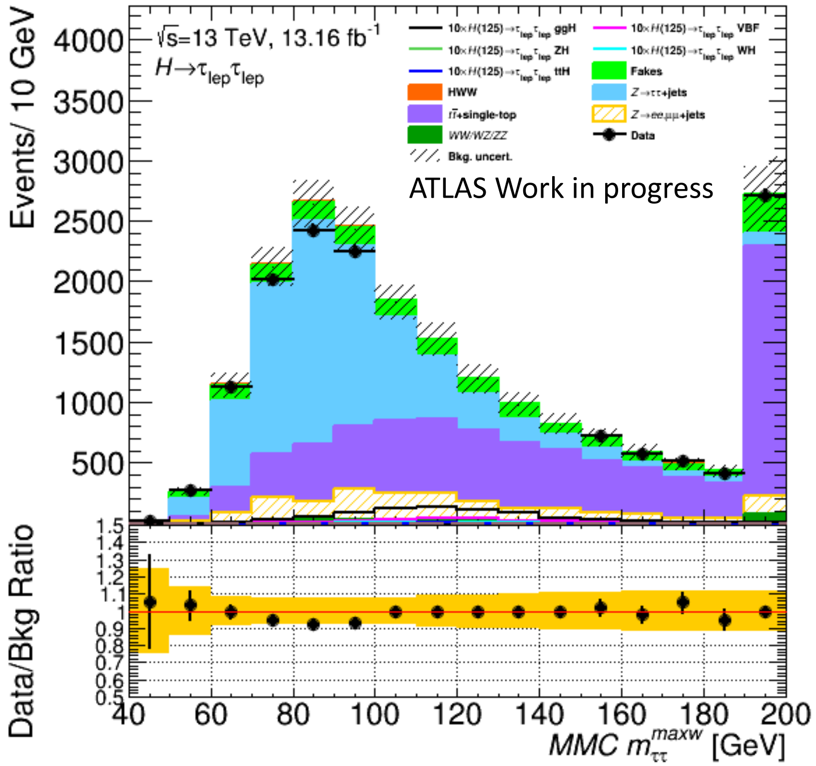
Fig 1: Event display of candidate Higgs boson decaying into a tau lepton and anti-tau lepton in ATLAS detector

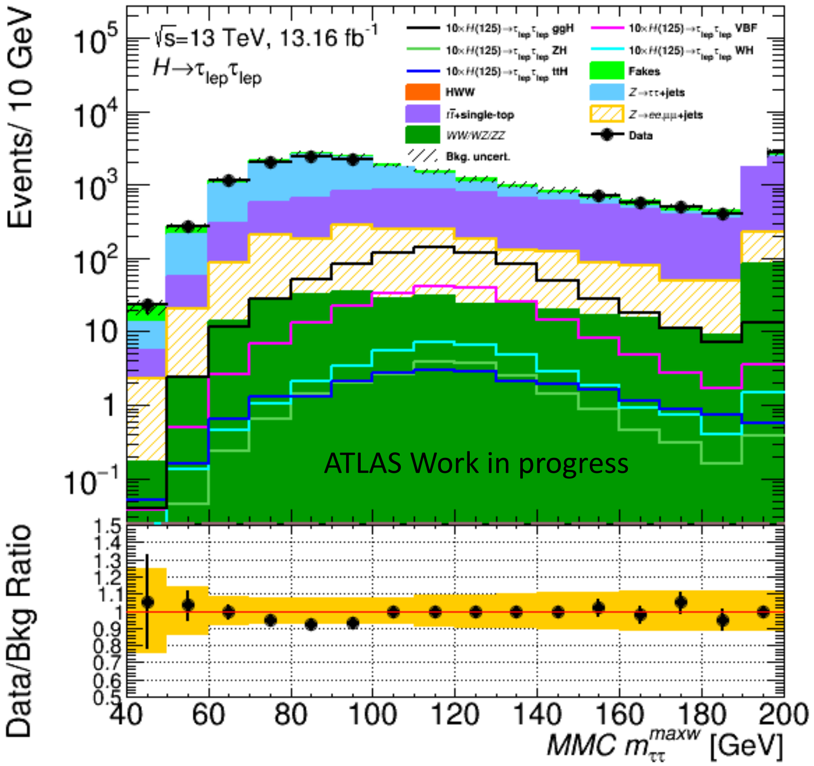
Event selection:

- Leptons p_T restrictions: $p_T^{lead} + p_T^{sublead} > 35$ GeV
- Visible mass cuts (sf: $30 < m_{ll} < 70$ and for df: $30 < m_{ll} < 100$ GeV)
- Leading jet $p_T > 40$ GeV
- MET cuts (sf: $met > 40$ GeV and df: $met > 20$ GeV)
- Collinear approximation
- Angular cut: $\Delta\phi < 2.5$

Distributions

With all these cuts useful to increase the signal over the background, a very preliminary results can be studied:

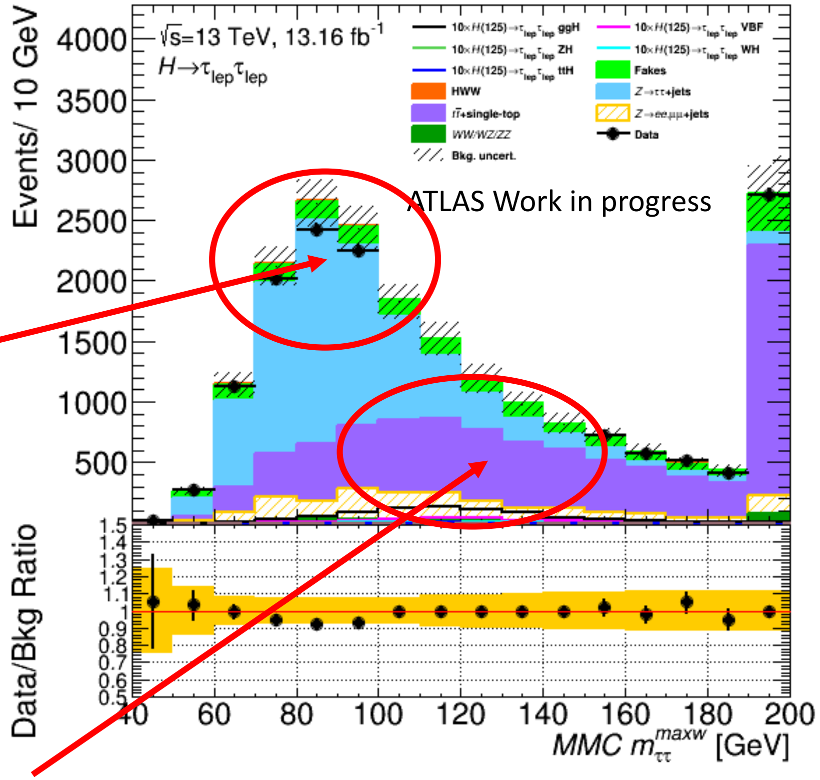


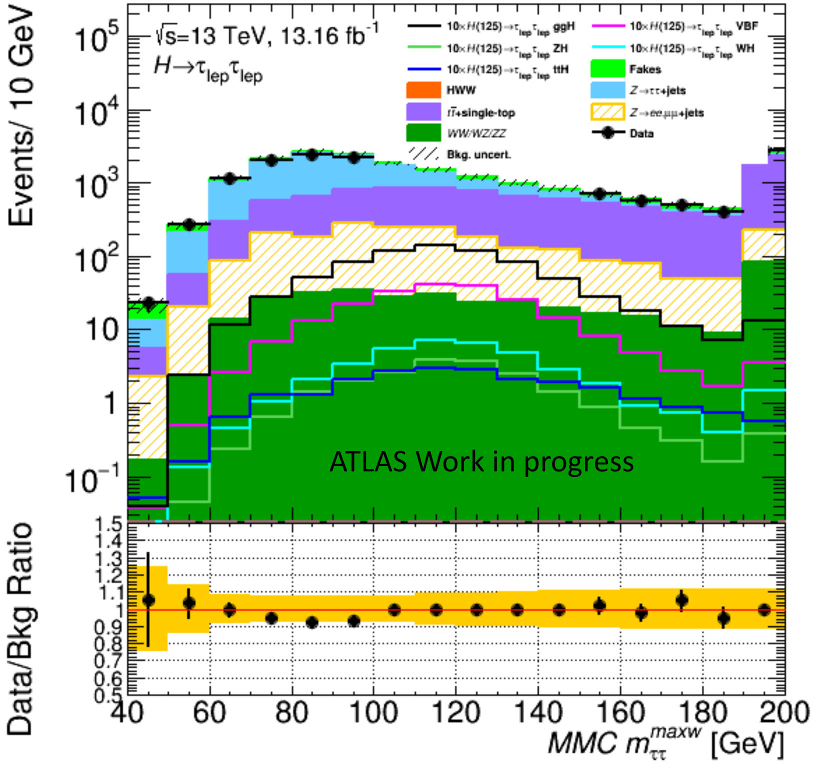


Distributions

With all these cuts useful to increase the signal over the background, a very preliminary results can be studied:

Under investigation, maybe need a reweight in the $Z_{\tau\tau}$ sample?



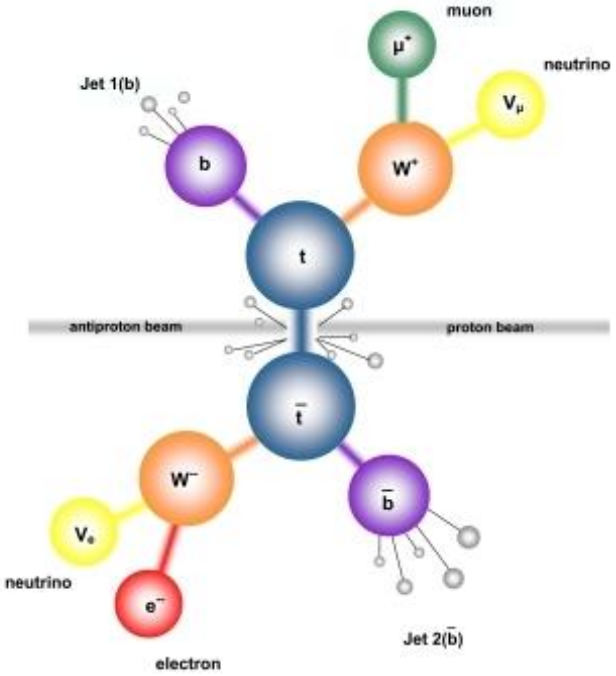


In the signal region the top background is the dominating sample.

How can I reduce it?

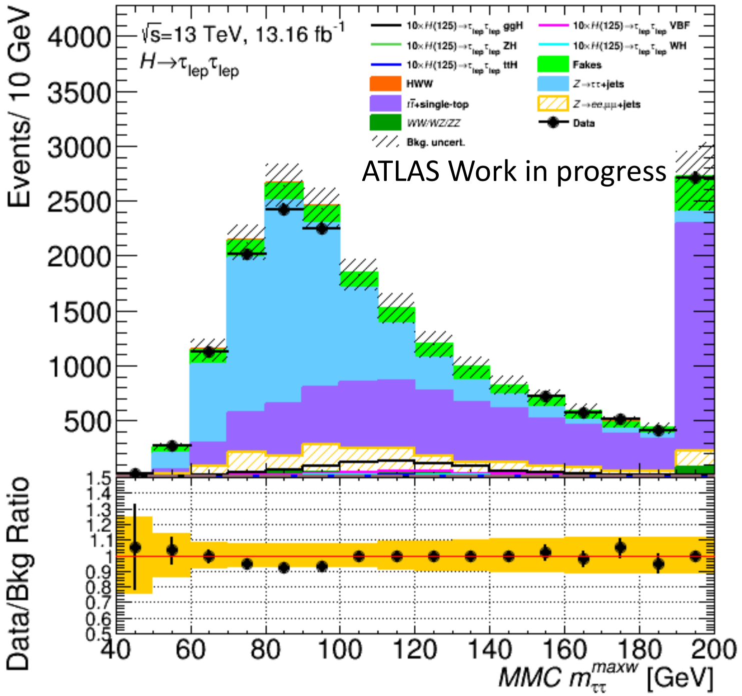
Distributions

A simplest way to reduce the top background is to know the decay modes of the top-quark:

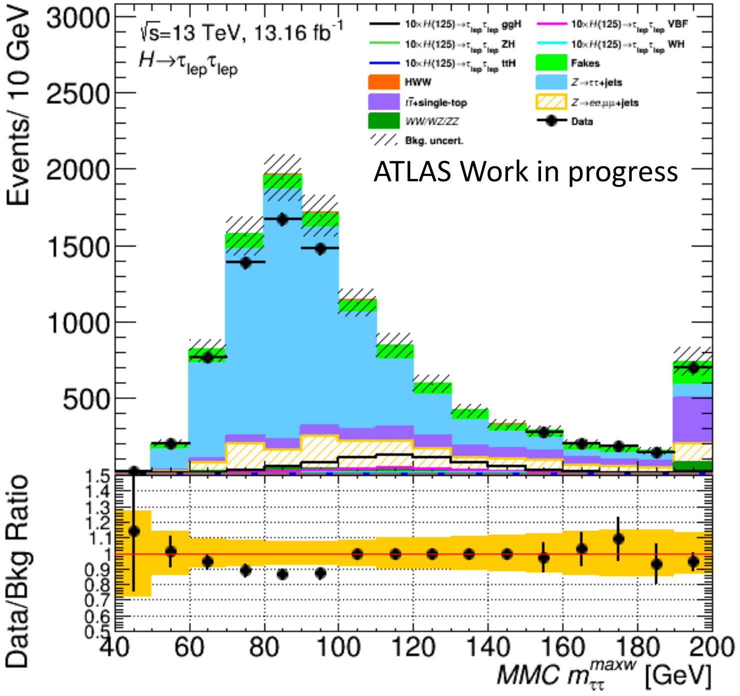


- It have two leptons in the final state and **also two b-jets…**

Wait..! Two b-jets!? Why don't throw away every event with b-jets?



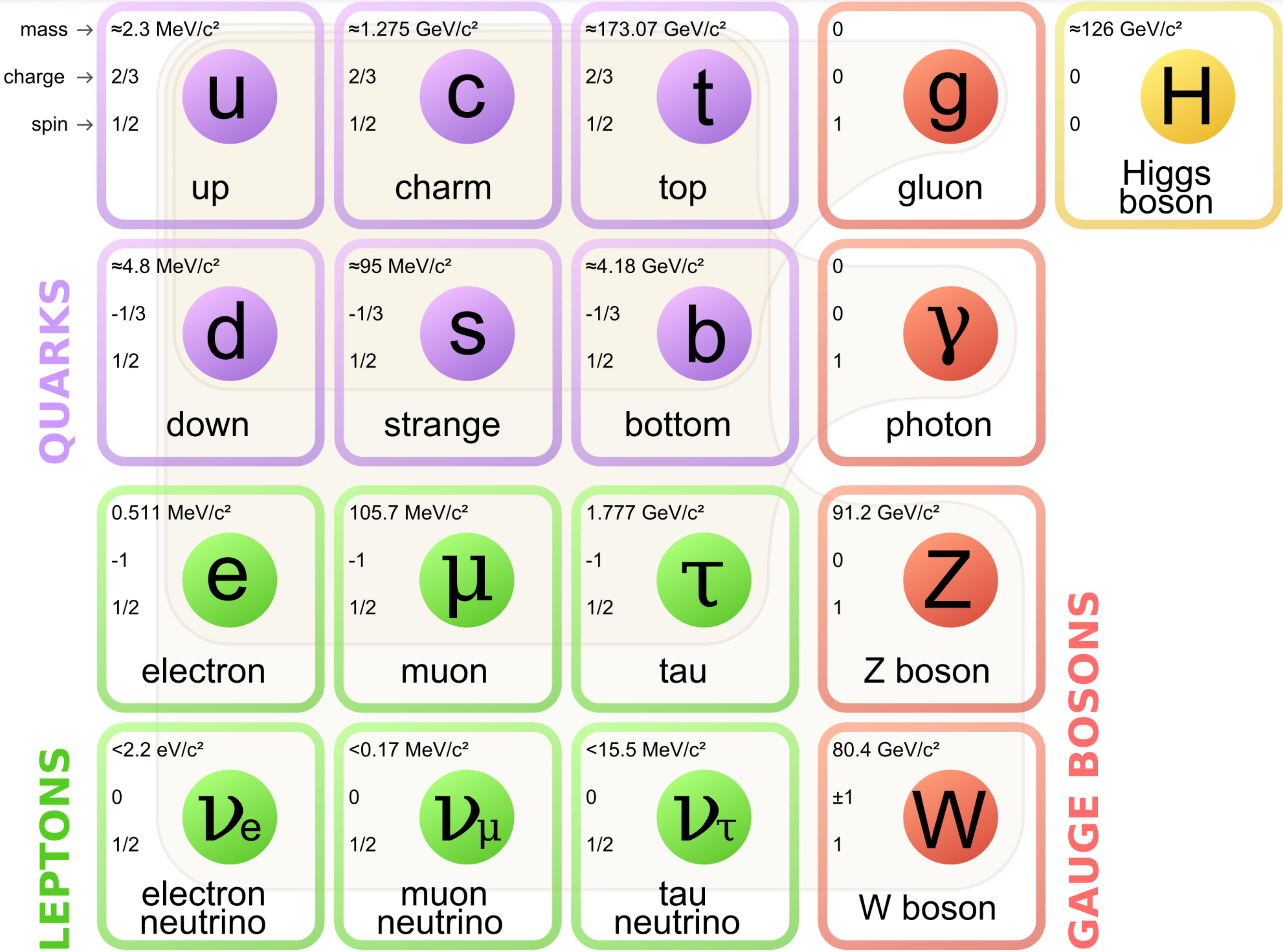
Before



After

Bonus

Bonus


mass →
charge →
spin →
≈2.3 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈173.07 GeV/c²
2/3
1/2
t
top
0
0
1
g
gluon
≈126 GeV/c²
0
0
H
Higgs boson
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
QUARKS
0.511 MeV/c²
-1
1/2
e
electron
105.7 MeV/c²
-1
1/2
μ
muon
1.777 GeV/c²
-1
1/2
τ
tau
91.2 GeV/c²
0
1
Z
Z boson
<2.2 eV/c²
0
1/2
νe
electron neutrino
<0.17 MeV/c²
0
1/2
νμ
muon neutrino
<15.5 MeV/c²
0
1/2
ντ
tau neutrino
80.4 GeV/c²
±1
1
W
W boson
LEPTONS
GAUGE BOSONS

Bonus

Different kind of reconstructed masses:

Transverse Mass:

$$m_T = \sqrt{2p_T^{lead}\, E_T^{miss}\,(1 - \cos(\Delta\phi(l, E_T^{miss}))}$$

Visible Mass:

$$m_{\tau\tau}^{vis} = \sqrt{p_T^{lead} + p_T^{sublead}}$$

Missing Mass Calculator (MMC): http://arxiv.org/abs/1012.4686

$$M_{\tau_i}^2 = m_{miss_i}^2 + m_{vis_i}^2 + 2\sqrt{p_{vis_i}^2 + m_{vis_i}^2}\sqrt{p_{mis_i}^2 + m_{mis_i}^2} - 2p_{mis_i}p_{vis_i}\cos(\Delta\theta_{vm_i})$$

$$E_{T_j} = p_{mis_1}\sin(\theta_{mis_1})\cos(\phi_{mis_1}) + p_{mis_2}\sin(\theta_{mis_2})\cos(\phi_{mis_2})$$

where i=1,2 runs for the two leptons and j=x,y axis.

Bonus