Search for a new particle X in the X → HH → γγbb decay channel with the data collected by the ATLAS detector

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Talk for the JRJC 2019

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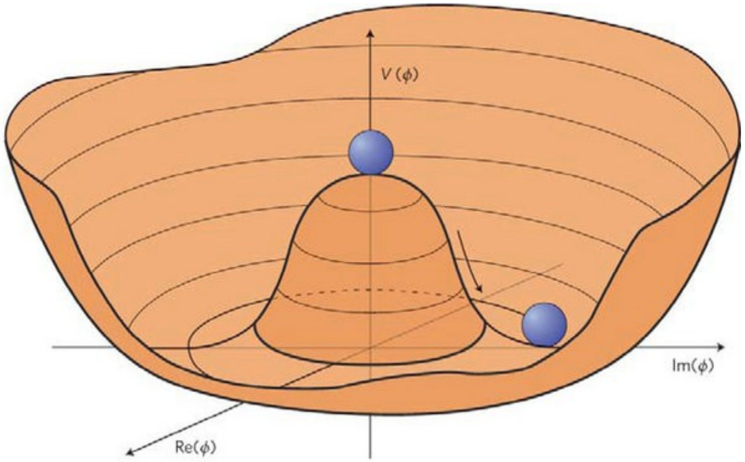
Outline

- Theoretical motivation for the new particle
- Description of the analysis
- Previous result
- New proposal for the analysis
- Ongoing result

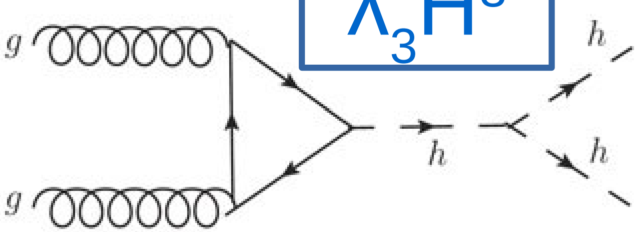
Measurement of the Higgs potential



- Higgs potential : will define the shape of the Mexican hat 

$$V(H) = \mu^2 \varphi^+\varphi^- + \lambda (\varphi^+\varphi^-)^2$$

$\lambda_3 H^3$



- Trilinear coupling :

  with $\lambda_3 = M_H^2/2v$ and $M_H^2 = 2\lambda^* v^2$ where v is the vacuum expected value (246 GeV)

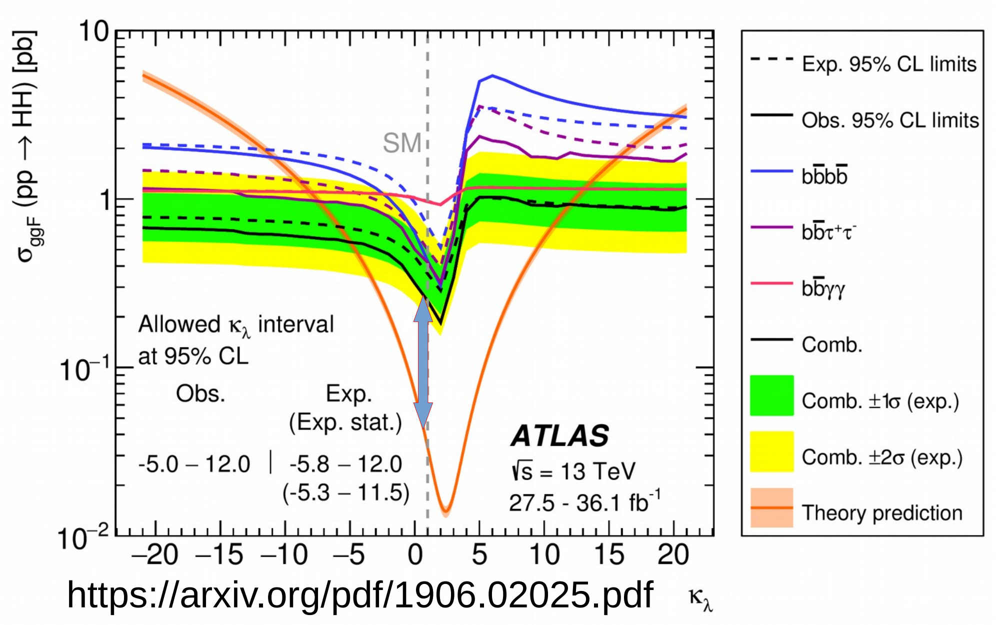
All this leads to $\lambda_3 = \lambda^* v$

Measuring the trilinear coupling will lead to constrain the Higgs potential

Current knowledge of the trilinear coupling

- The production of Higgs pair with the trilinear coupling is 1000 times lower than the cross section of one Higgs.

- The theoretical value is, for now, 10 times lower than the experimental limit → we need more data, the theoretical value will be reached with the help of the HL-LHC (High-lumisity LHC)

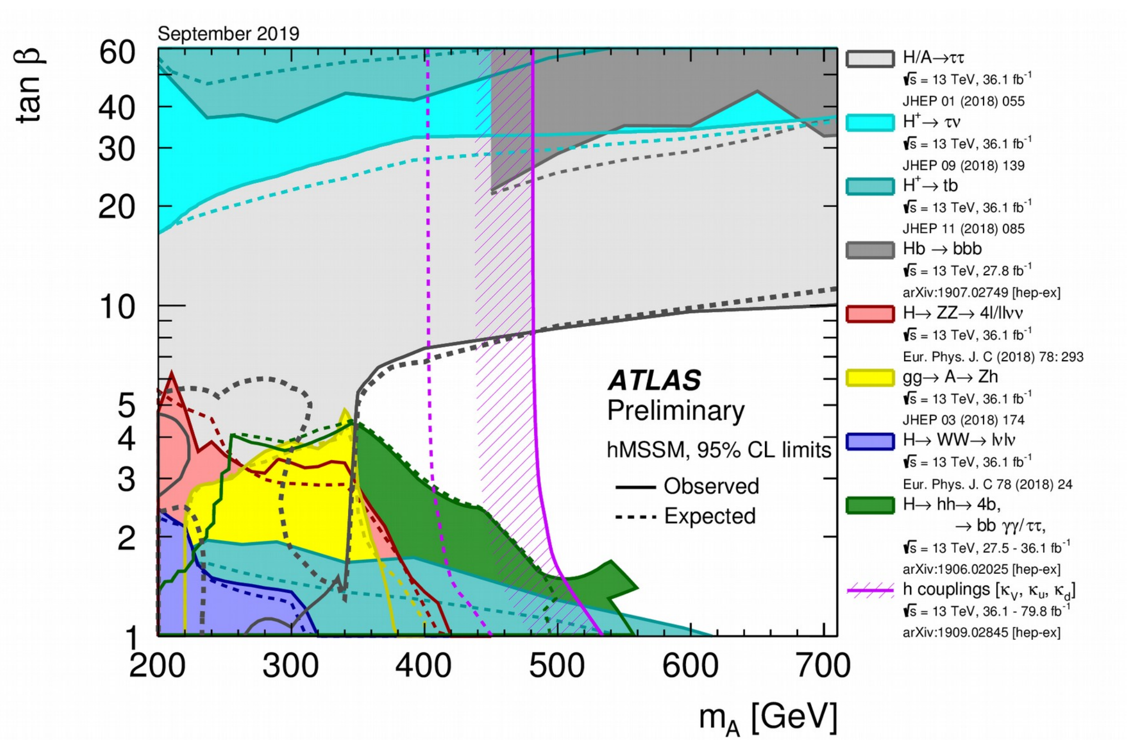


https://arxiv.org/pdf/1906.02025.pdf

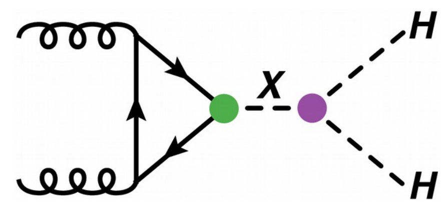
- For now we can only put constraint on the value of λ_3, ($-8.2 < \lambda_3/\lambda_3^{SM} < 13.2$) with λ_3^{SM} being the value predicted by the Standard Model

Motivation of the X->HH

- Huge program of search for a new spin 0 particle in ATLAS, covering many decay channels



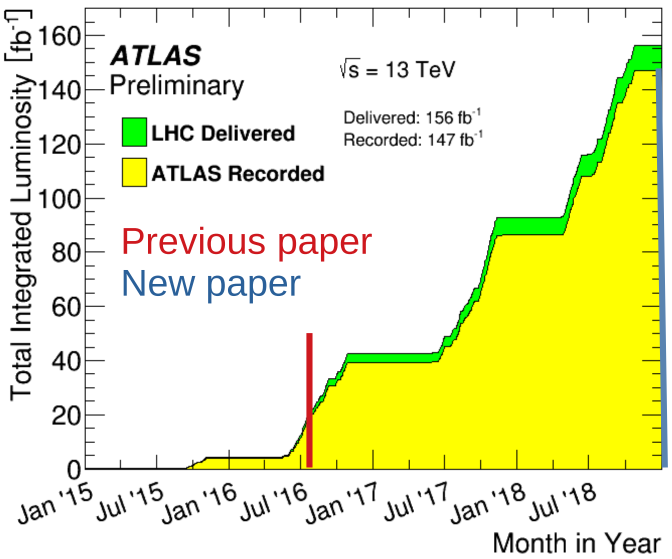
$\tan(\beta) = v_u/v_d$



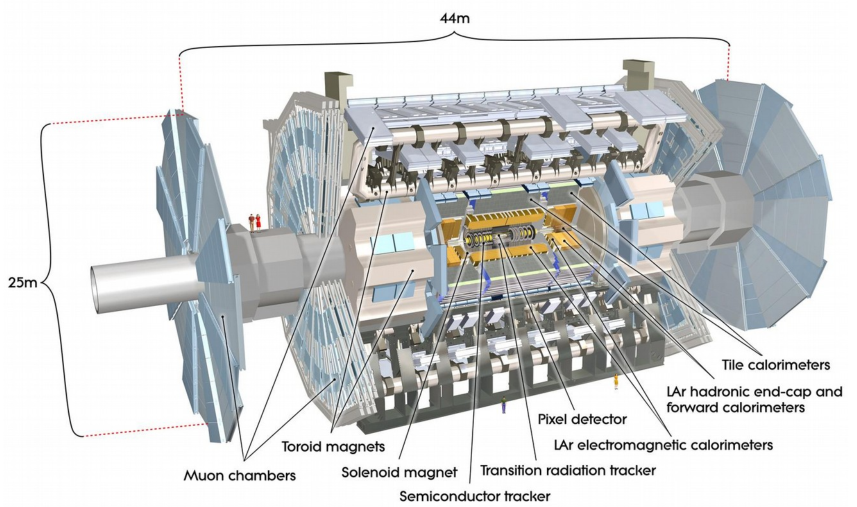
- Many theories predict the existence of a heavy particle decaying into a pair of Higgs boson. Models with two higgs doublets (MSSM, twin Higgs models and composite Higgs models) could explain such particle.

Creation and detection

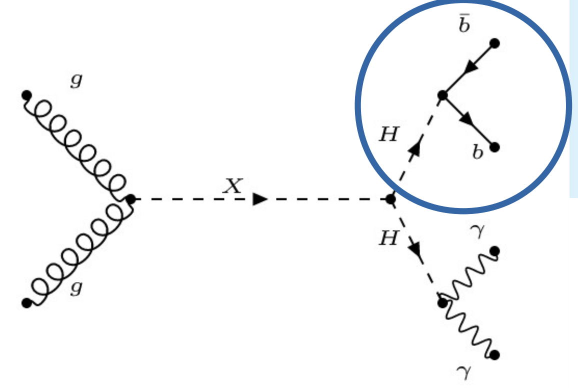
- Proton-proton collision in the LHC
- Last publication was made with a luminosity ($N = \sigma * \mathbf{L}$) of $36fb^{-1}$. We will use all the $140fb^{-1}$ available now for the new paper.
- We will use the data collected by the ATLAS detector



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2



Decay channel X->HH->yybb



Decay of one Higgs boson into a b-quark pair : best branching ratio

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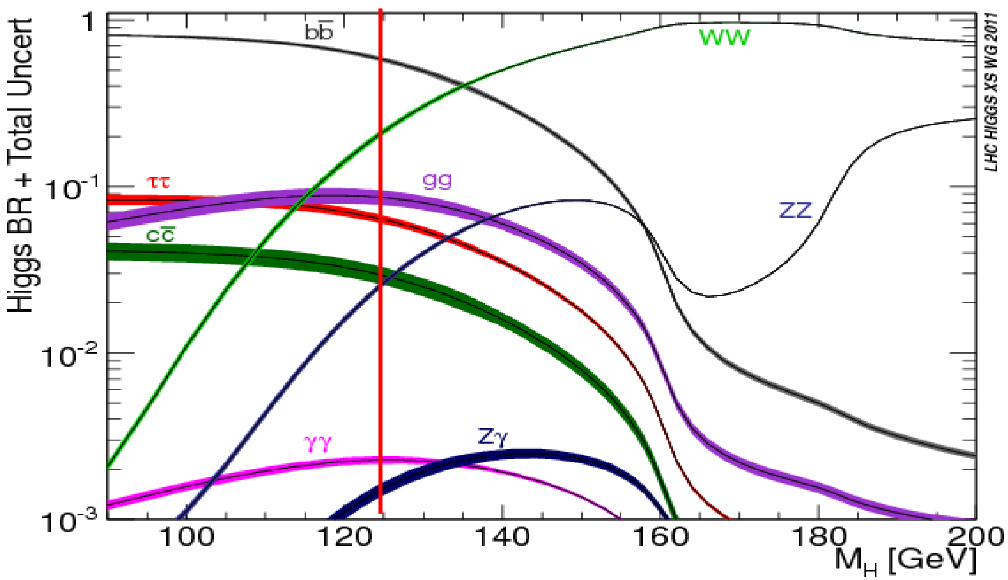

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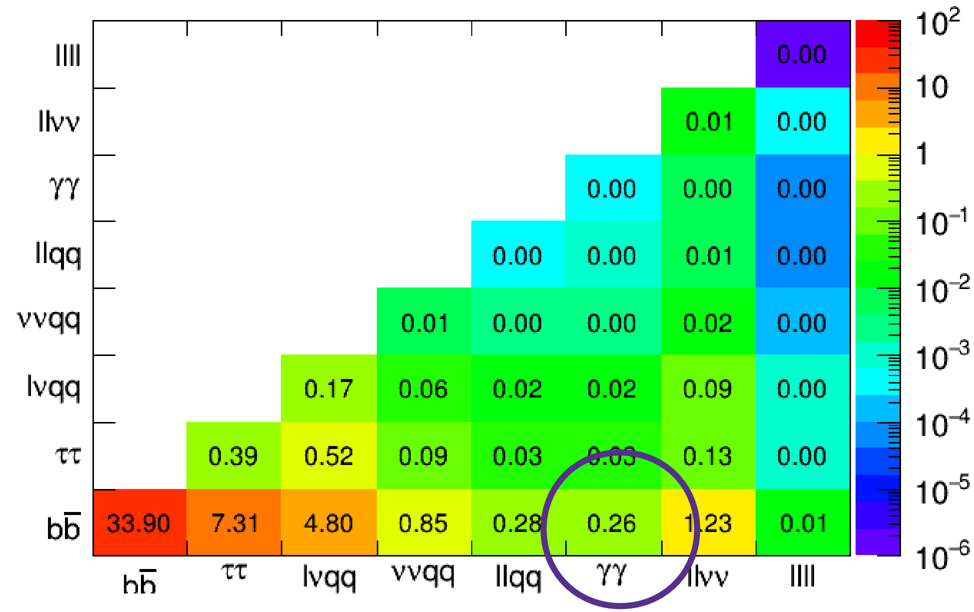
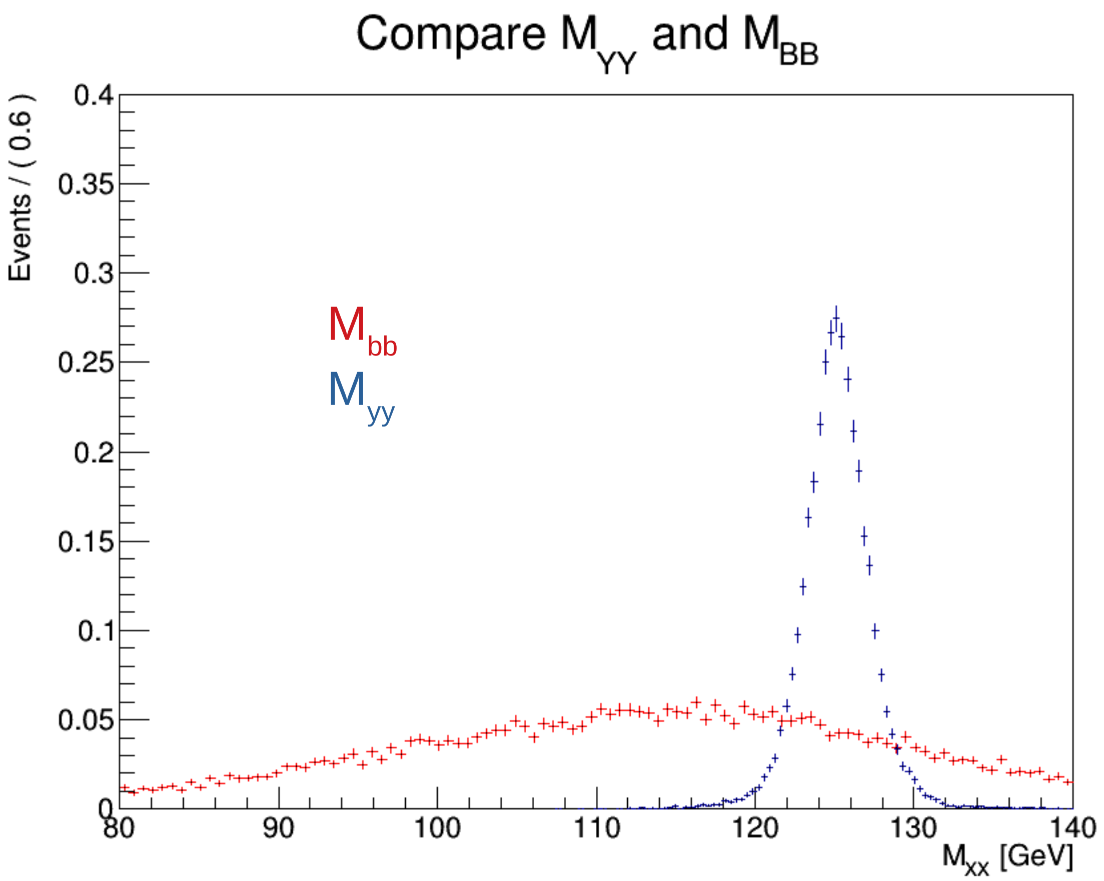
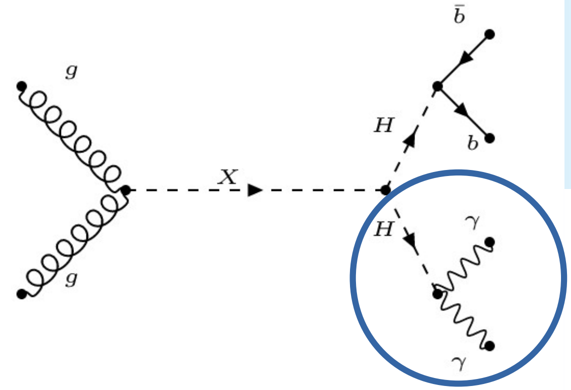


https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR2010

Decay channel X->HH->yybb

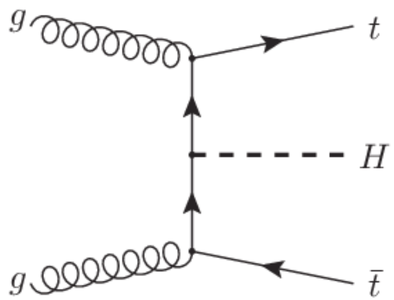




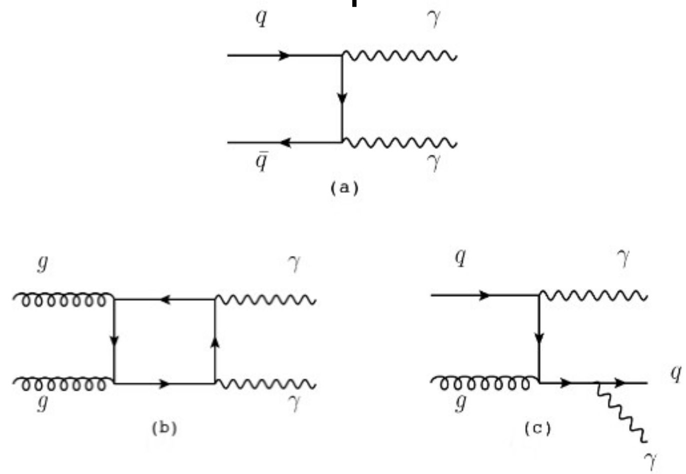
Decay of the other Higgs boson into a photon pair : best resolution and reconstruction efficiency

Background

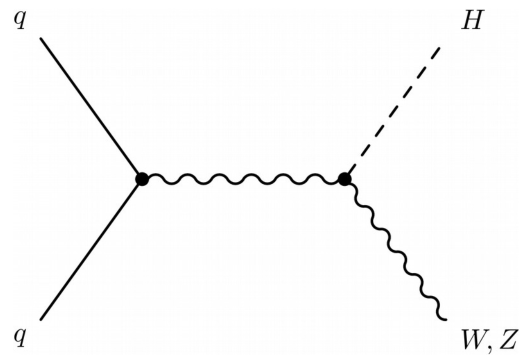
Single Higgs ttH



Continuum diphoton

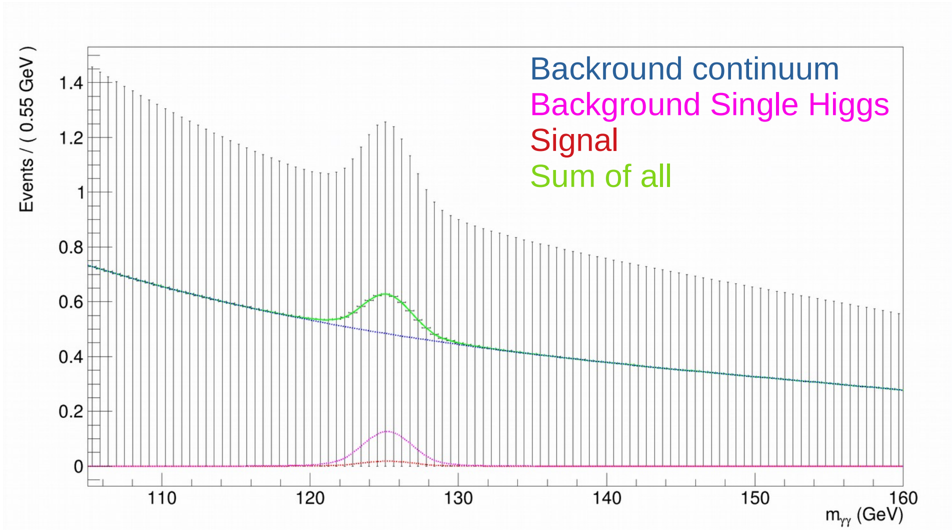


Single Higgs W,Z H



- Presence of background with a higher cross section than our signal. The signal is hidden behind the background, we need to apply selection in order to reduce the ratio background/signal.

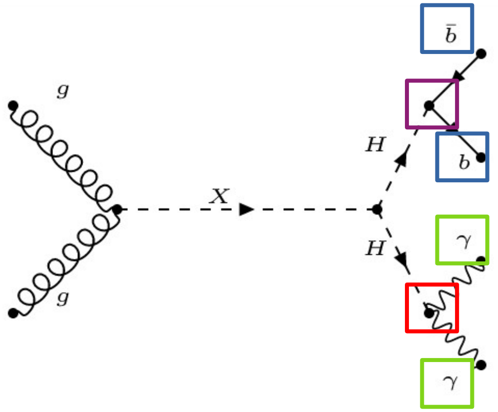
For the Signal at 300 GeV	Number Single Higgs	Number continuum diphoton	Number signal	Ratio S/B
Before the selection	7205.07	229734	5.38	2.27e-05
After the selection	0.98	31.88	3.51	0.11

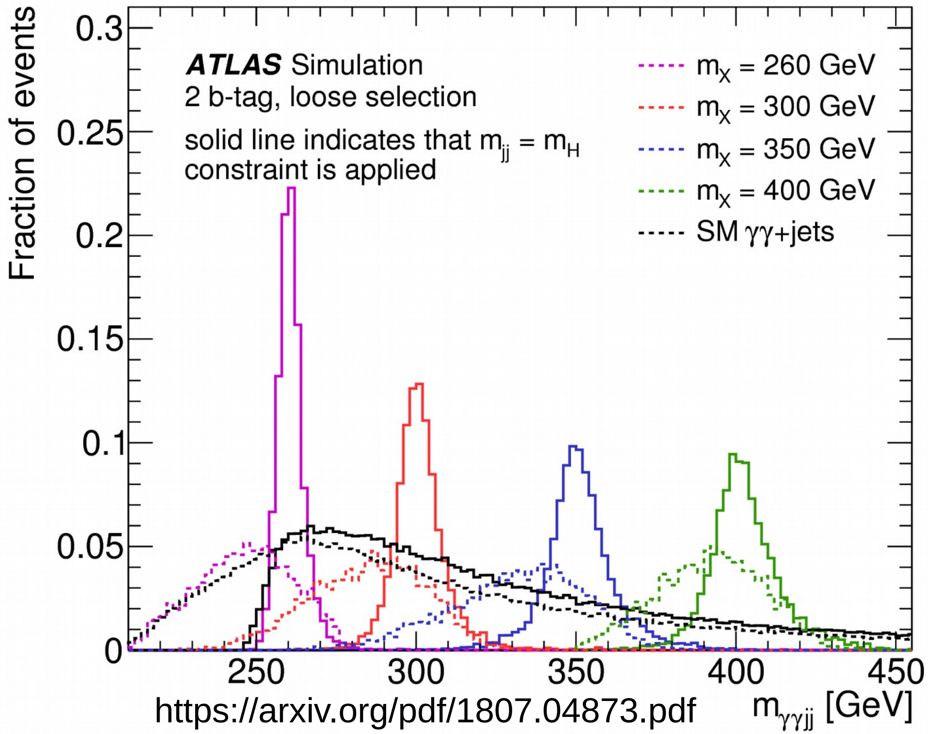


Fit of the background and signal

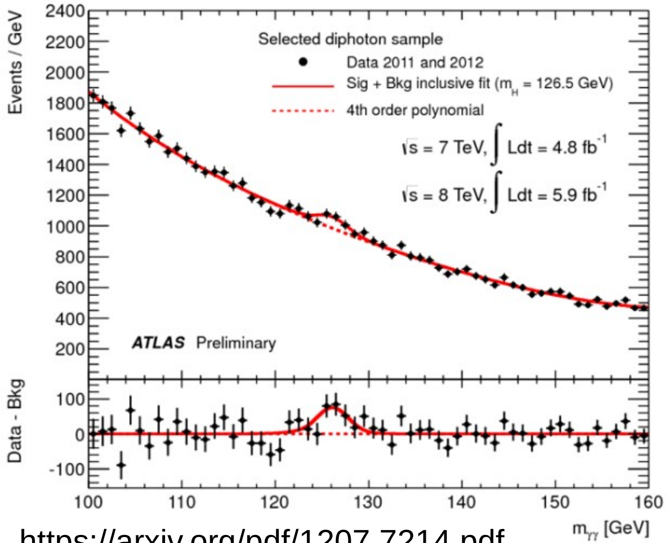
- Once the selections are applied we search functions that fit the expected shape of the background and the signal

Selections :
- asking for two identified photons
- asking fot two identified b-jets
- kinematic selection on the photons and the diphoton invariant mass
- kinematic selection on the jets and the dijets invariant mass





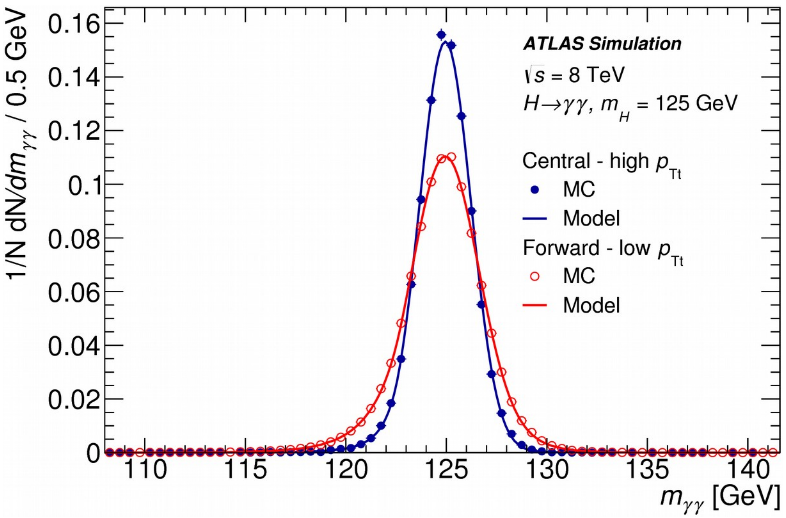
How to do a search like the H->yy ?



https://arxiv.org/pdf/1207.7214.pdf

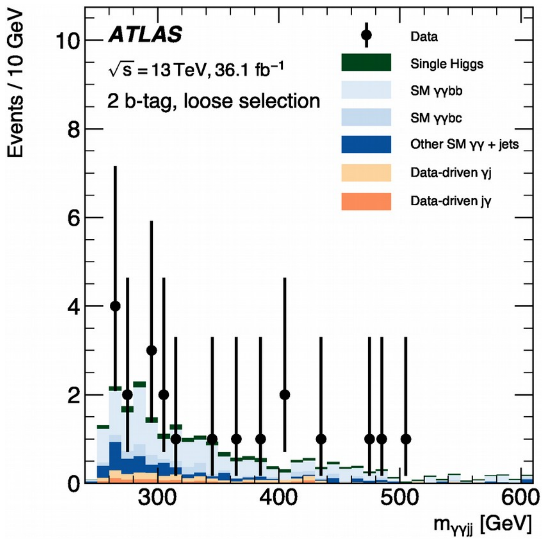
We search for in bump in the data compared to the bakground only hyphothesis.
Once we find one we search the best background+ signal Hypothesis that fit the Data

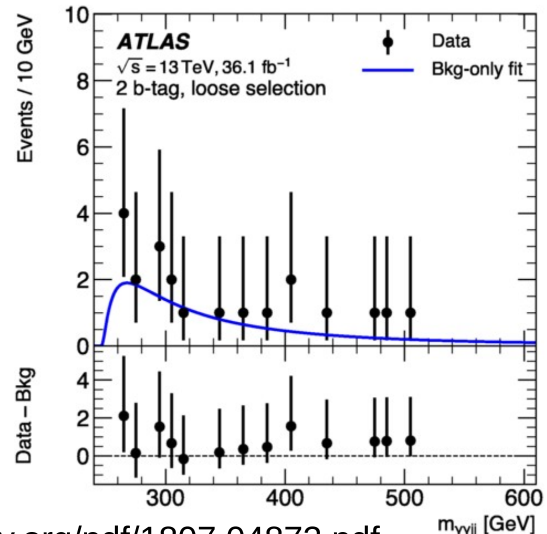
- Example of the Higgs boson discovery by ATLAS
- Dash line :
  Fit of the data with the background only hypothesis
- Full line :
  Fit of the data with the background+signal hypothesis



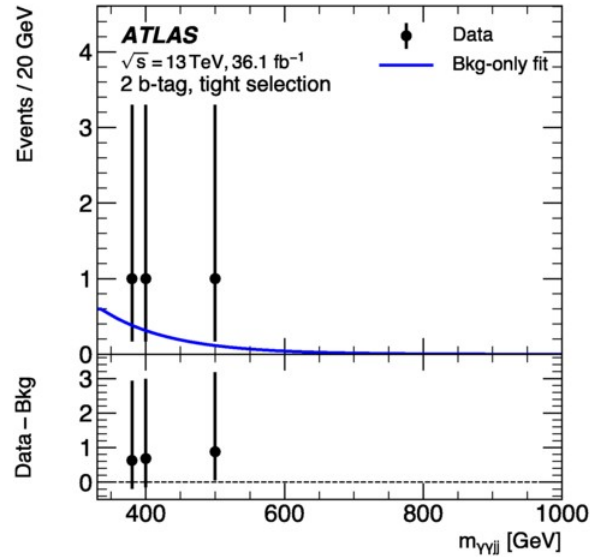
Previous result

- Result of the 2016 analysis :
  No huge differences between the data and the background only hypothesis (No bump). Our fits are limited by the low number of events in the tail.





https://arxiv.org/pdf/1807.04873.pdf



- We then reinterpret our result as limit in the cross section

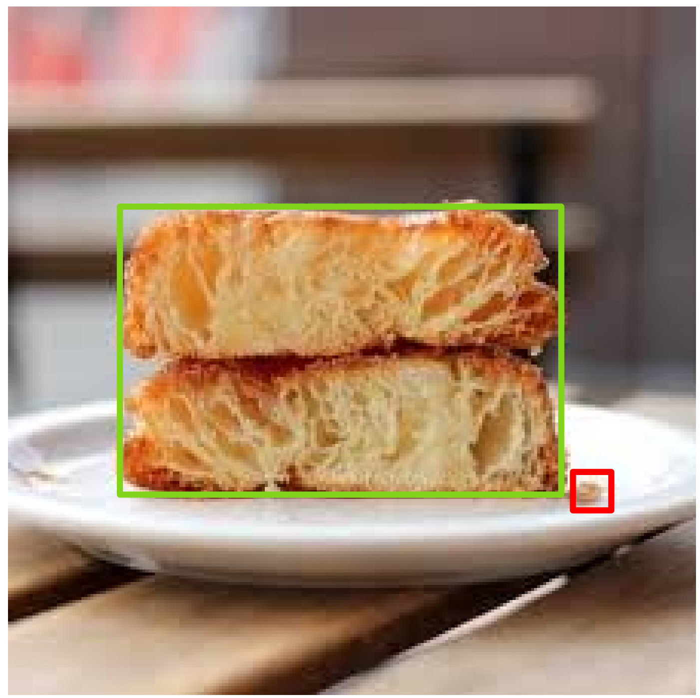
Cross section of a Kouign Amann

Limit on the cross section of a Kouign Amann

Limit over the time

Limit of the cross section

Limit after tasting it



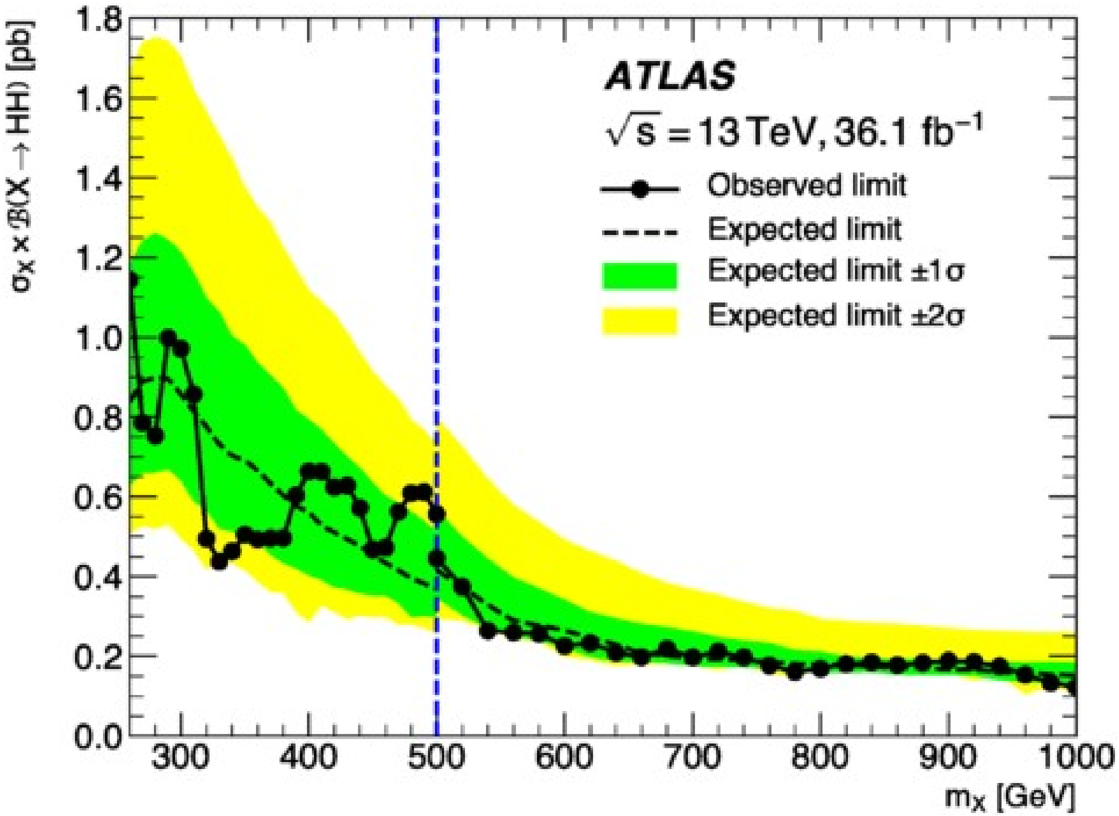
Due to the tastiness and the fatness (lots of butter) it is likely that the cross section will just reduced to almost 0 !!!!

TAKE CARE !!!! YOUR CROSS SECTION MAY INCREASE !!!!!!

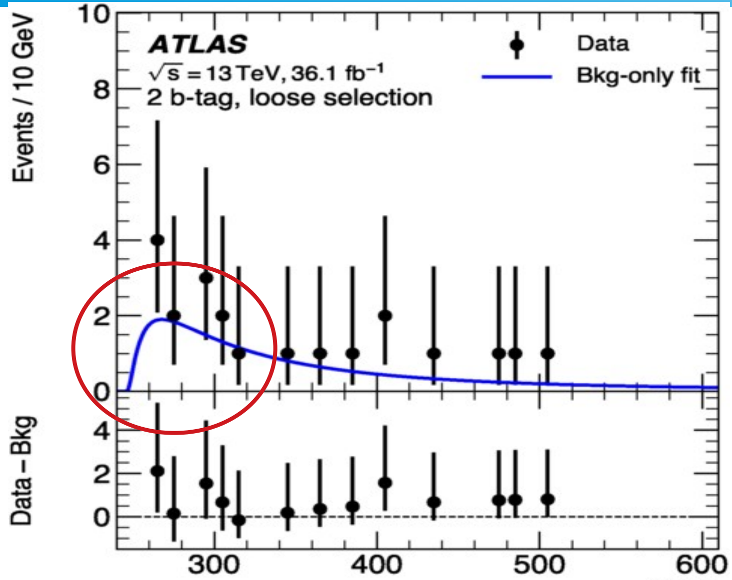
Limit over the cross section

- Limit at 95% confidence level of the cross section of the X→HH decay.

Everything that is over this line is excluded at 95% → no signal with a cross section over this line exist

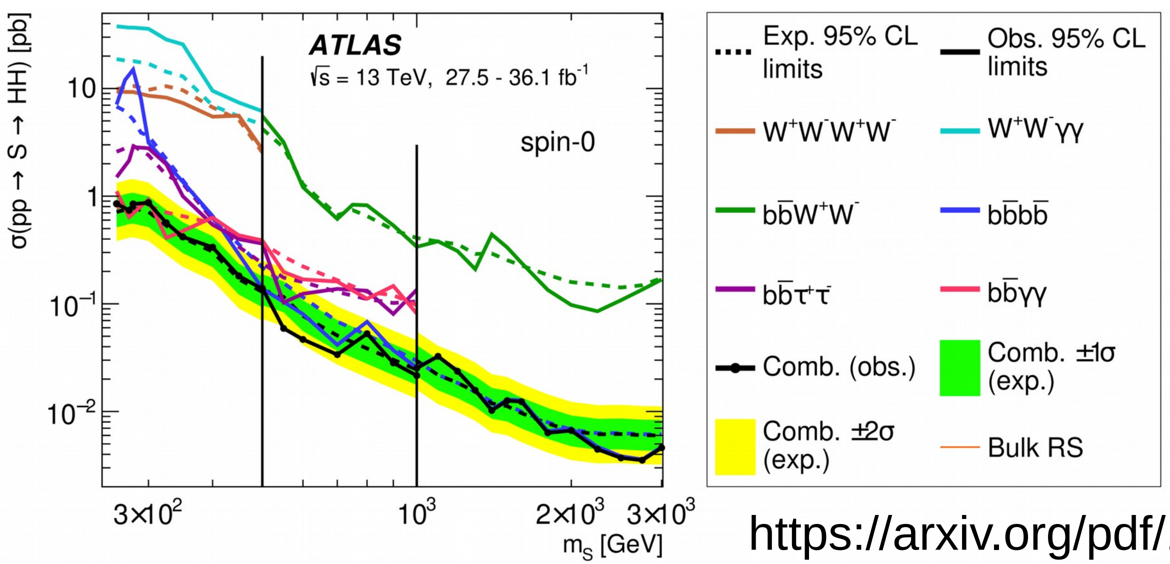


Limitation of this technique



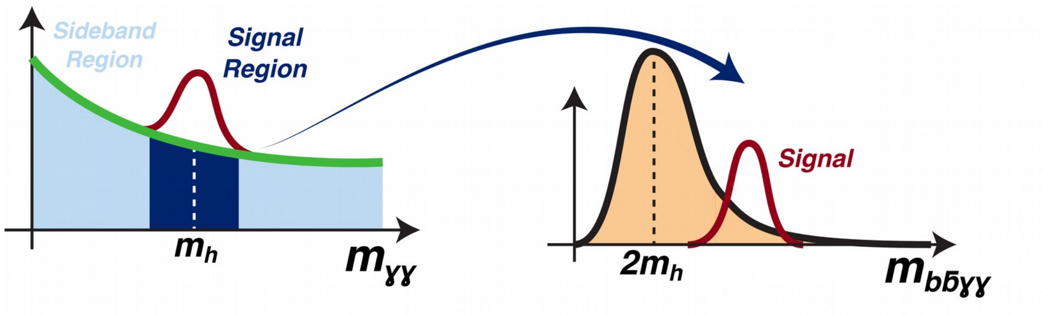
https://arxiv.org/pdf/1807.04873.pdf

- Presence of a kinematic "turn-on" make it hard to fit specifically at low mass
- But it's at low mass that the yybb is the most important



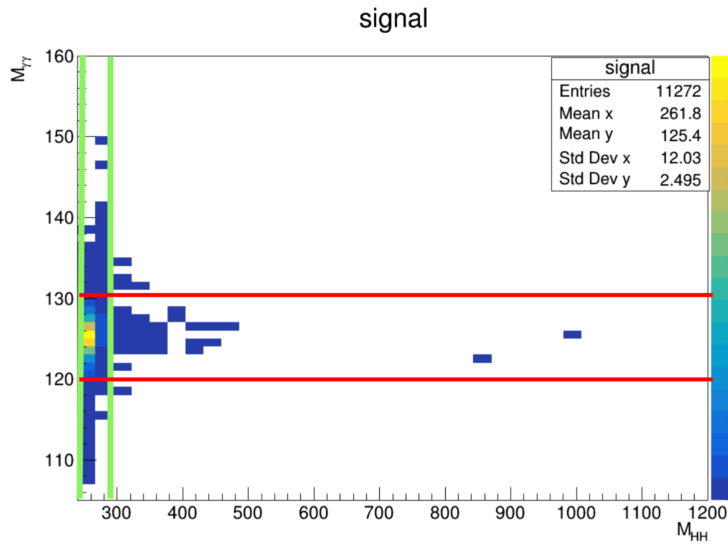
https://arxiv.org/pdf/1906.02025.pdf

New methodology

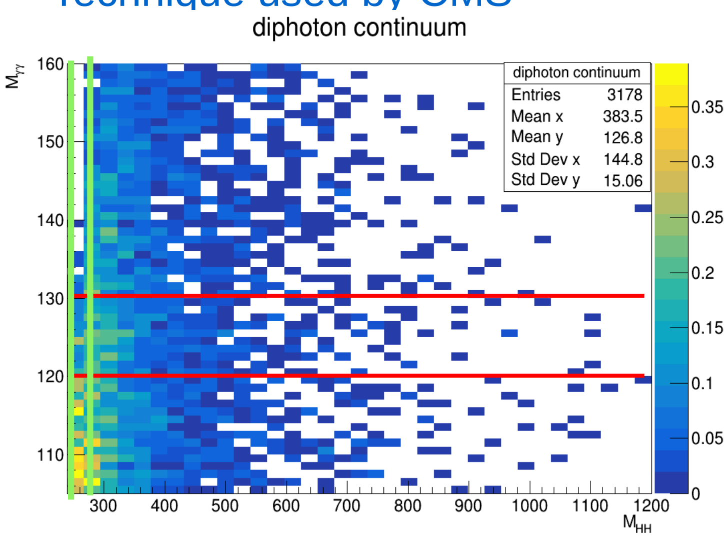


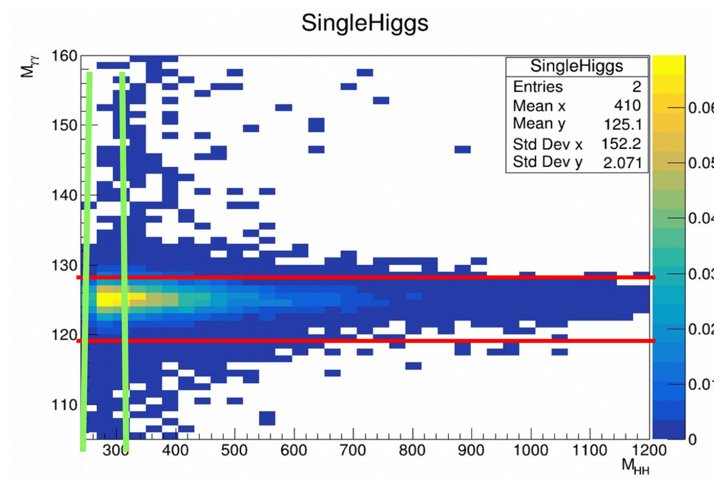
-Current Cut in m_{yy}

-New cut in m_{HH}



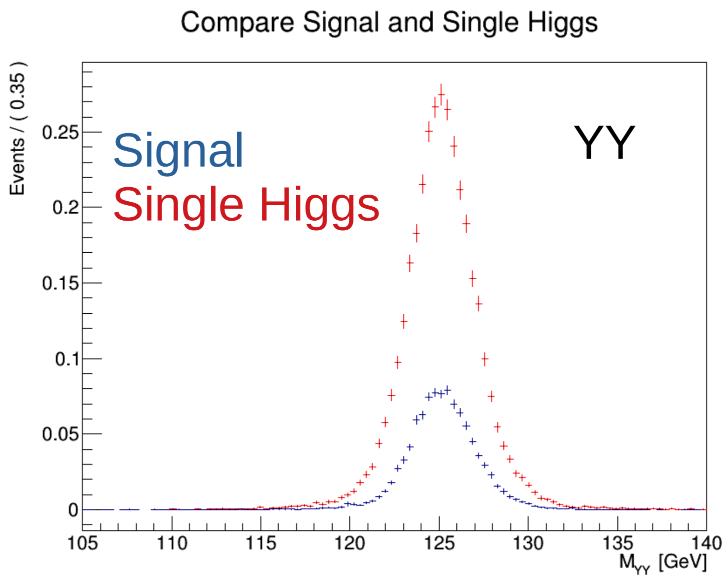
- More data help to develop more advance technique
- First change : from a fit on M_{HH} with a cut on M_{yy} to a fit on M_{yy} with a cut on M_{HH}
- Technique used by CMS

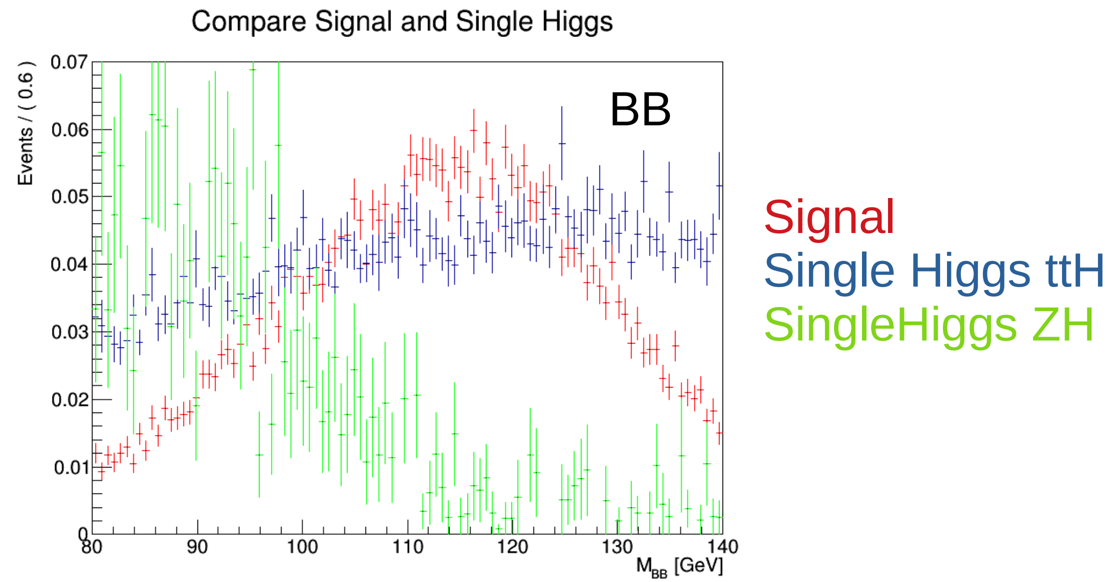


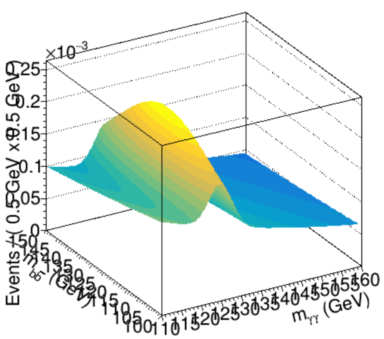


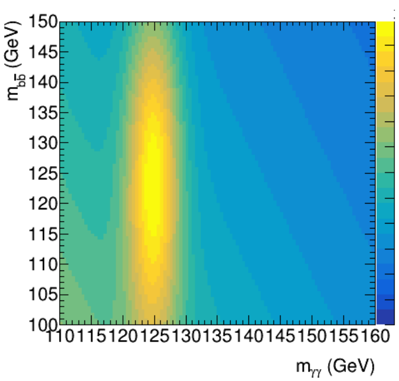
Using 2D fit

- Second change : from a 1D fit on M_{yy} to a 2D fit on M_{yy}*M_{bb}





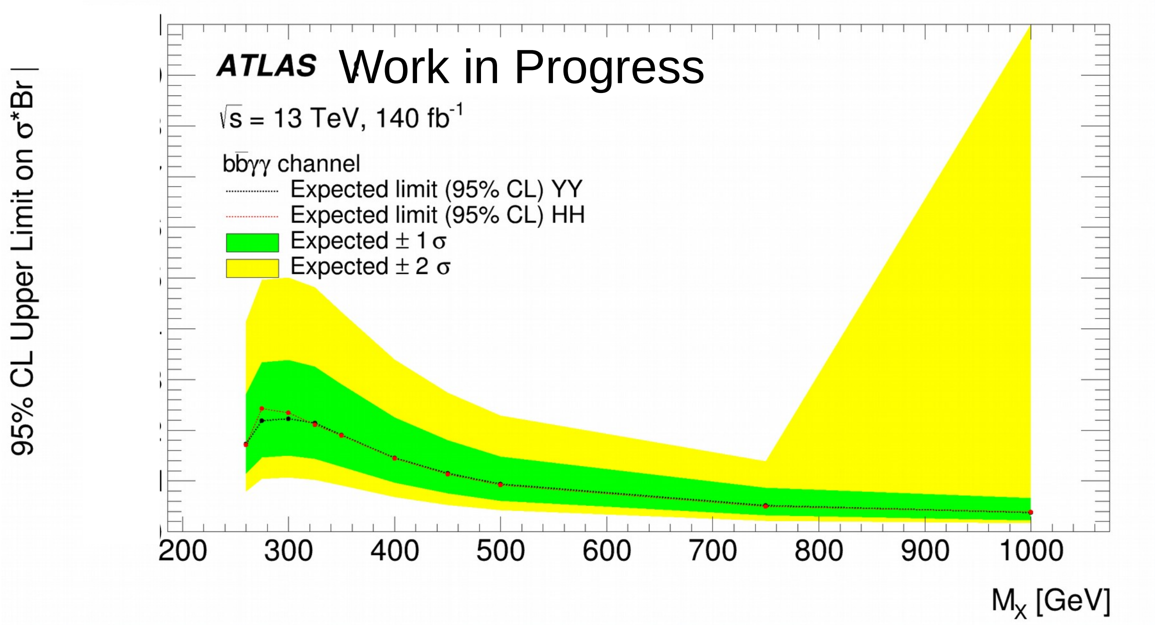




Improvement could be made using the fact that the shape of the SingleHiggs background peak differ as function of the decay channel

The 2D method could also be used for the SM measurement

My ongoing result



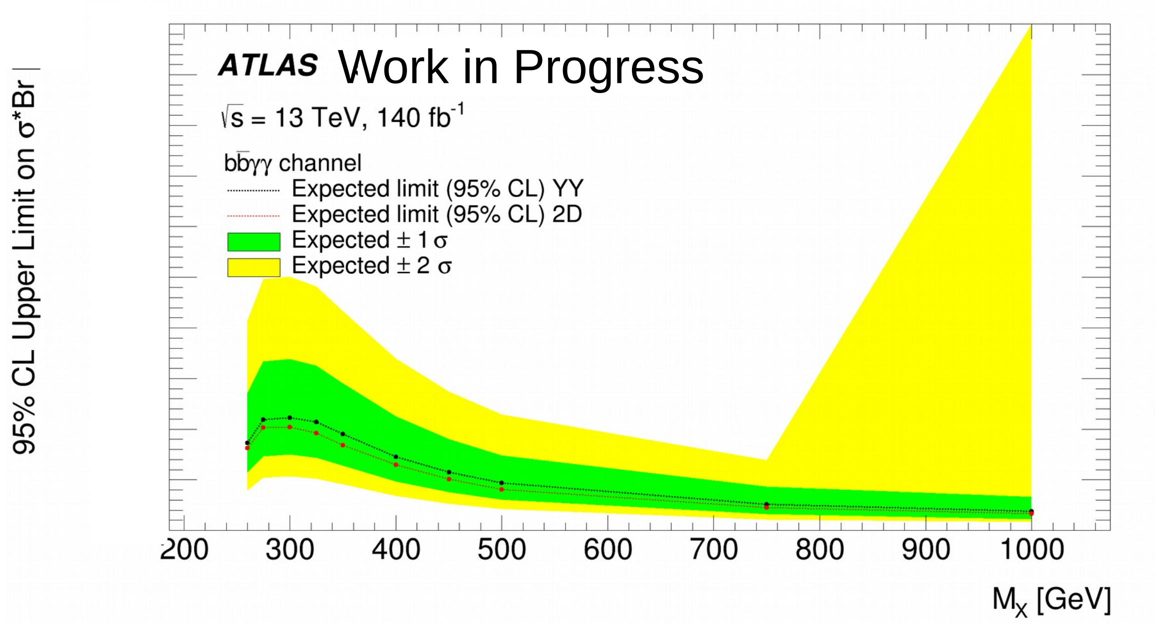
YY : using the 1D fit on M_{yy}

HH : using the 1D fit on M_{HH}
(method of the previous paper)

For limit result : the lower the better

- We already see an improvement using the YY fit method comparing to the first method.
This improvement is more present for low mass where this channel is the most important

My ongoing result



YY : using the 1D fit on M_{yy}

2D : using the 2D fit on M_{yy}*M_{bb}

For limit result : the lower the better

- There is an even better improvement using the 2D fit comparing the the YY fit.

Conclusion

- Already some improvement have been shown using new methodology in this analysis
- There are some work to be done to compute the uncertainties and some parametrization (to get the limit between the mass point)
- The result that will be published in 2020 will be the reference until the end of the run-3 in 2024

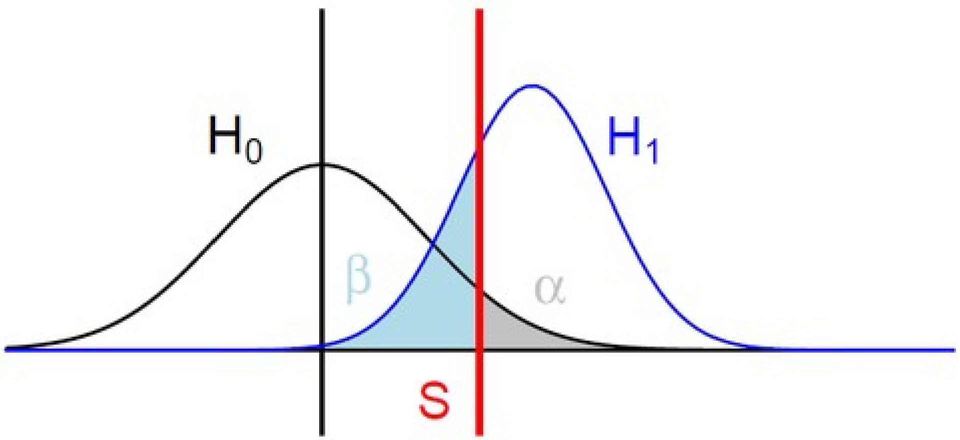
The End

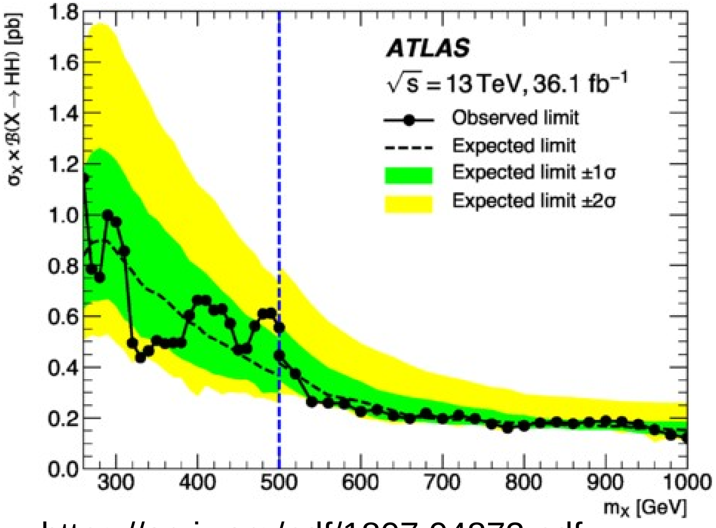
THANK YOU !!!!!!

Even for those who are not in this picture :)

CLs Method

- H0: backround only hypothesis
- H1: background+signal hypothesis
- S : value measured
- α: accepting H1 whereas H0 is true (highlightling at 3 σ and 5 σ)
- β: accepting H0 whereas H1 is true (treshold : β <0.05 this value will fix the value for our limit)





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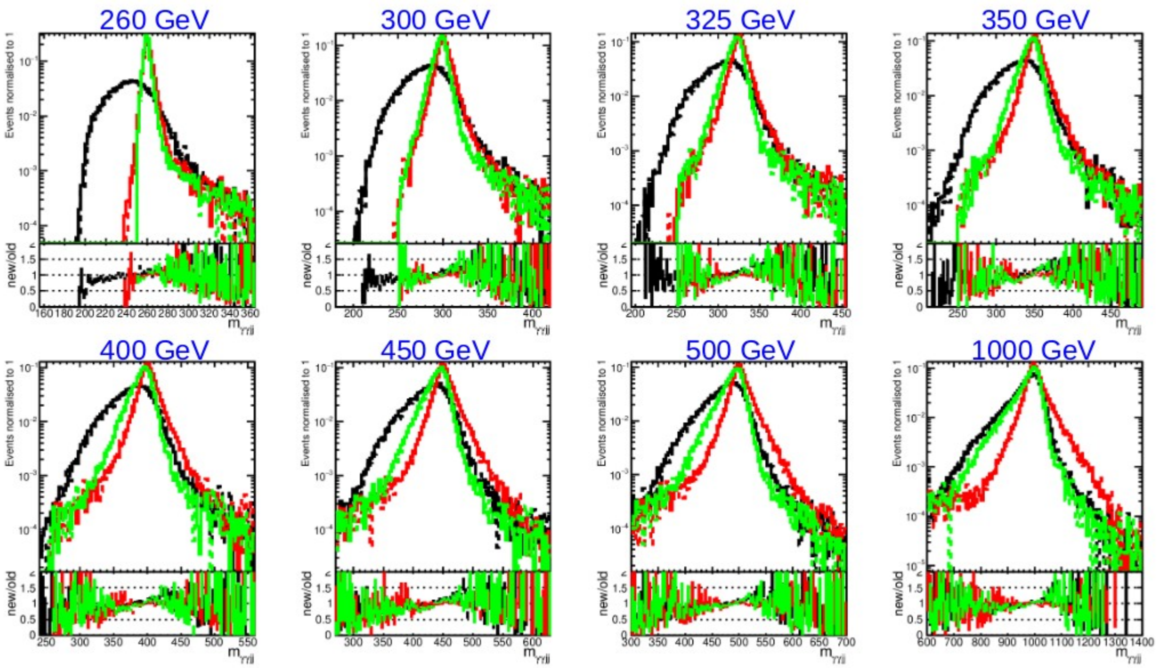
Redefinition if the diHiggs invariant mass

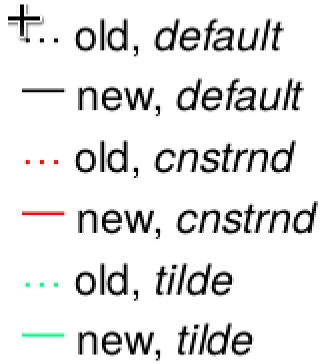
- We want to use correction on the diHiggs invariant mass to reduce the spread of the signal



Old = bb.M + yy.M

Cnstrnd = $bb_{cnstrnd}$.M + yy.M (the one used for now)
with $bb_{cnstrnd}$ = bb/bb.M *125

Tilde = yybb.M – yy.M – bb.M +250

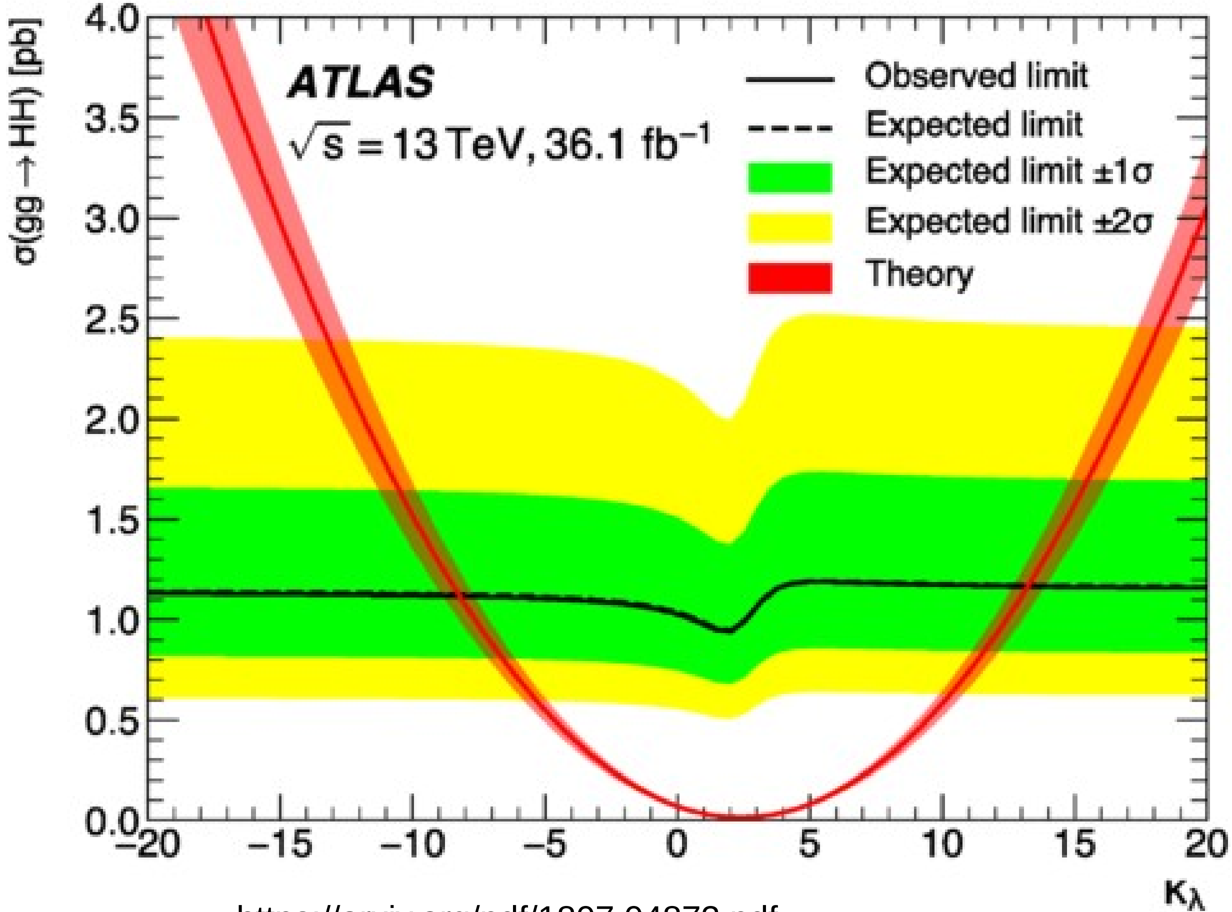


Backup : b-tagging and photon identification

- There are some parameter used to characterize each type of particle then we use an MVA to discriminate the type of the particle.
- We can choose the MVA cut depending on how clean we want our signal to be.
  (tighter discriminant → cleaner signal)

Backup non-resonant result

- $\kappa_\lambda = \lambda_3/\lambda_3^{SM}$



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Possible new physics

Model	Higgs Spectrum	Possible Higgs pair final states from resonant production
RxSM SM+real singlet	`dark phase': H_SM, DM `broken phase´: H_SM, S	DM DM H_SM H_SM, SS
CxSM SM+complex singlet	`dark phase´: H_SM,S,DM `broken phase´: H_SM,H1, H2	H_SM H_SM, SS, DM DM H_SM H_SM, H1 H1, H2H2, H1 H2, H_SM H1
2HDM 2 Higgs doublets	CP-conserving: H_SM,H,A	H_SM H_SM, HH
MSSM 2 Higgs doublets, SUSY!	CP-conserving: H_SM,H,A	H_SM H_SM no HH (due to constraints)
C2HDM 3 Higgses mix	CP-violating: H_SM,H1, H2	H_SM H_SM, H1 H1, H2 H2 H1 H2, H_SM H1
N2HDM 2 doublets, 1 real singlet	H_SM,H1,H2,A	H_SM H_SM, H1 H1, H2 H2 H_SM H1, H1 H2
NMSSM SUSY! 2 doublets + 1complex singlet	H_SM,H1,H2,A1,A2	H_SM H_SM, H1 H1, H_SM H1, H_SM A1 A1 H1 (no H1 H2, A1 H2 due to conststraints)