BSM $H \rightarrow hh \rightarrow WW\gamma\gamma$ search with ATLAS detector

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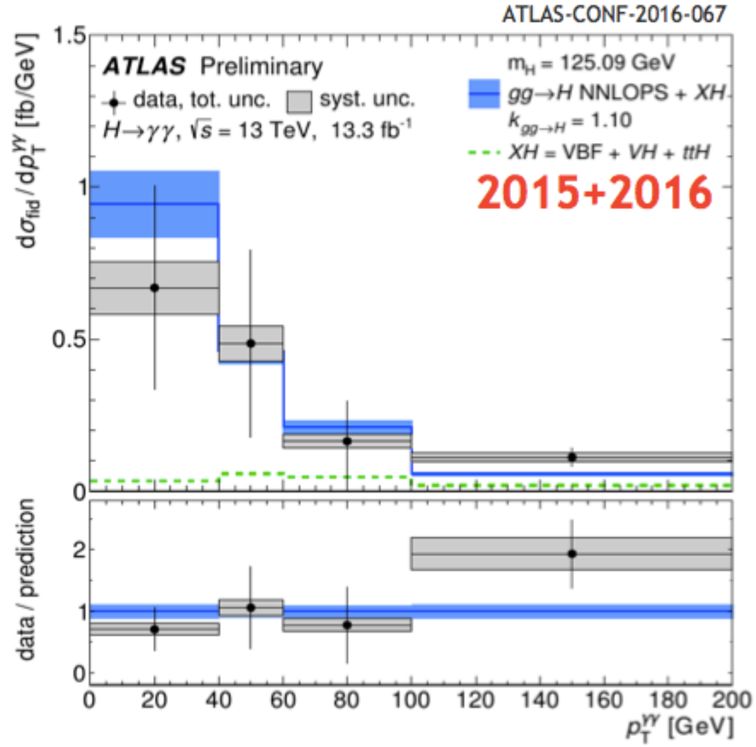
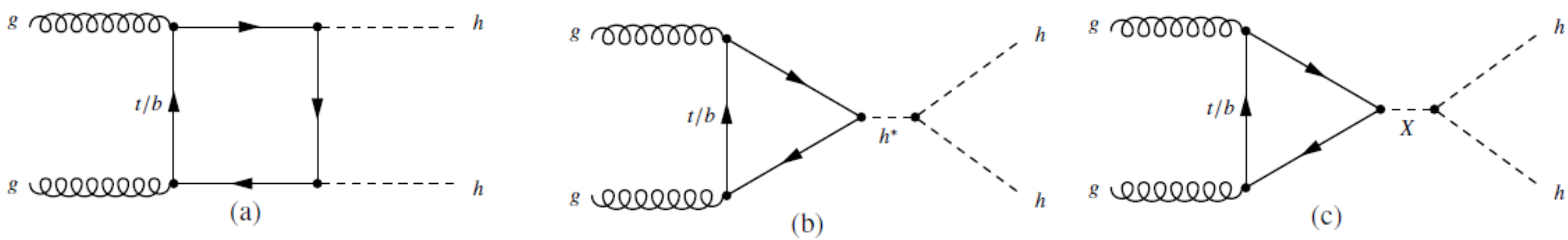
2016年12月16－19日

Motivation

- Higgs pair production has a small Xsection in SM (~33 fb@13TeV).
- BSM can effectively enhance Higgs pair production:
  - ✓ 2HDM, SUSY etc..
- The distribution of pt of Higgs is slightly higher than expected.





Example: two Higgs doublet Model (2HDM)

SM :

$$V = M\,|H|^2 + \frac{\lambda}{2}(H^+H)^2$$

$$\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$$

$$\Phi = \begin{bmatrix} \pi^+ \\ \frac{v+h+i\pi^0}{\sqrt{2}} \end{bmatrix}$$

2HDM :

$$V = M_{11}^2\,|H_1|^2 + M_{22}^2\,|H_2|^2 - M_{12}^2(H_1^+H_2 + H_2^+H_1) + \frac{\lambda_1}{2}(H_1^+H_1)^2 + \frac{\lambda_2}{2}(H_2^+H_2)^2$$

$$+\lambda_3\,|H_1|^2|H_2|^2 + \lambda_4\,|H_1^+H_2|^2 + \frac{\lambda_5}{2}[(H_1^+H_2)^2 + (H_2^+H_1)^2]$$

$$\Phi_a = \begin{pmatrix} \phi_a^+ \\ (v_a + \rho_a + i\eta_a)/\sqrt{2} \end{pmatrix}, \quad a = 1, 2.$$

- For complex SU(2) doublet, there are 8 fields, three used by $W^{+/-}$ Z
- There are five left :   H, h (CP-even), A (CP-odd), $H^{+/-}$
- tanβ is the ratio of the vacuum expectation values of the two doublets.
- α is the mixed angle between H and h (around alignment limit cos(α−β)➔0, h is SM higgs).

Pheno: G_{Hhh}/G^{SM}_{hhh} in some phase space with 2HDM model

- **PLB755(2016) 509-522**

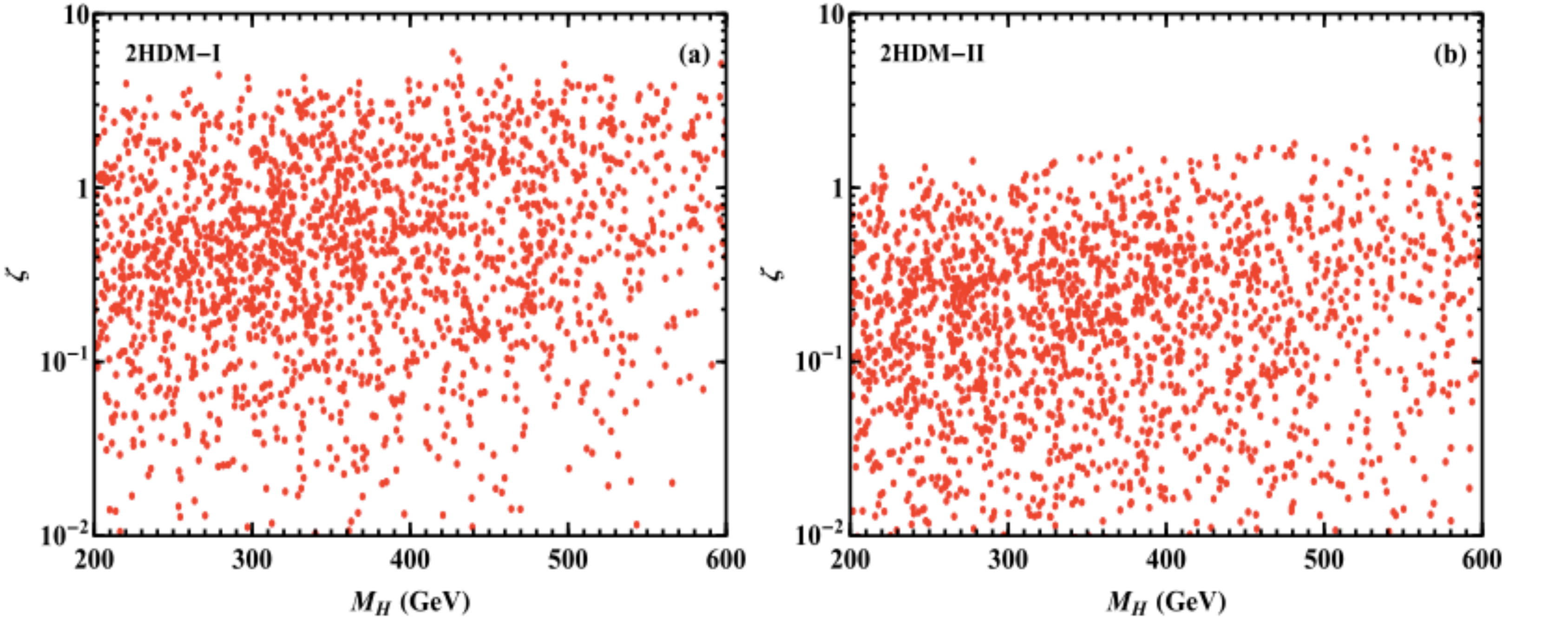


Fig. 1. Parameter space in M_H–ζ plane for 2HDM-I [plot-(a)] and 2HDM-II [plot-(b)], where the red dots present the viable points obeying the consistency requirement of the Higgs potential as explained in the text. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

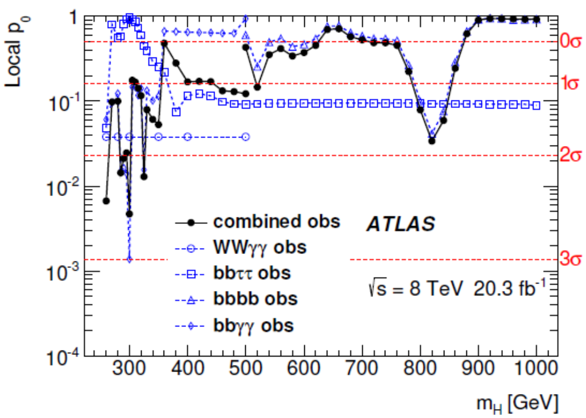
In some phase space, $\sigma \propto (G_{Hhh}/G_{SMhhh})^2$ can be ~10.

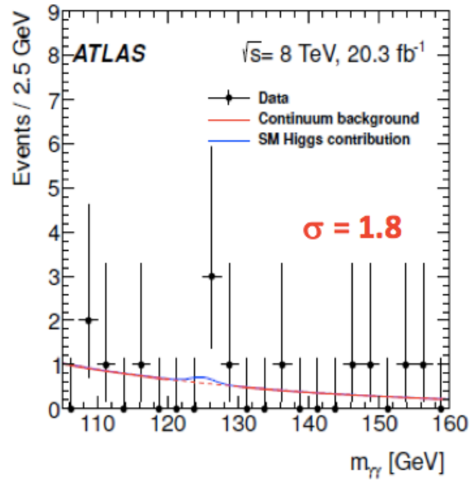
Overview of different channels for H→hh

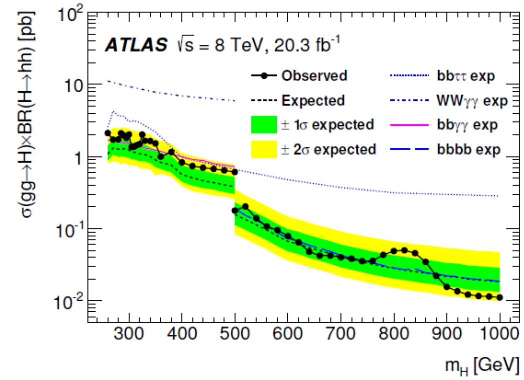
- ***γγbb*** : di-photon provides a decent mass peak and bb can further help to suppress QCD bkg in addition to di-photon requirements.
- **WW(lvqq,lvlv)γγ**: In principle, lvqq is not very sensitive at low mass due to huge QCD; however, di-photon can improve the situation here. Statistics will be low although it is clean; lvlvγγ is expected to be very clear although the statistics will be very low as well.
- ***WWWW***: this channel has no mass peak and cannot be a discovery channel; but the same signed leptonic channel can suppress backgrounds; 3lep is also possible to try
- ***bbtautau***: no mass peak as well, can confirm the result?

Review of LHC RUN1 results: H→hh

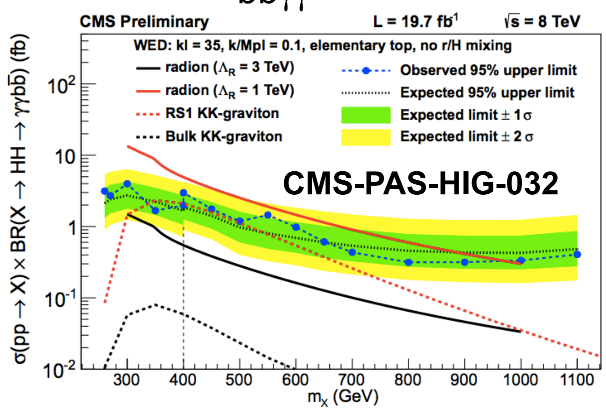
Phys.Rev. D 92, 092004 (2015)



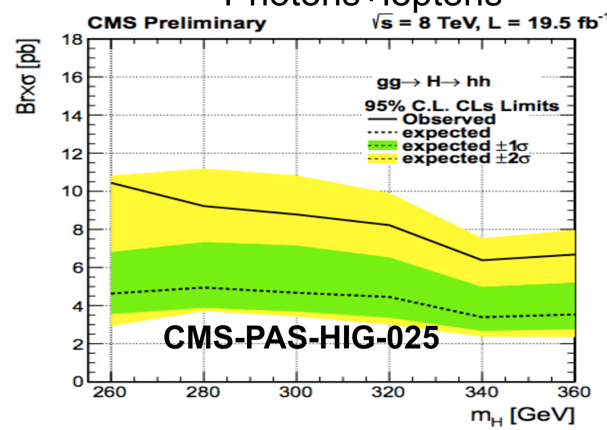




bbγγ



Photons+leptons



- hh->wwγγ was first proposed by us at : **PLB755(2016) 509-522**
- hh->wwγγ together with bbγγ, bbtautau,bbbb are extensively explored with RUN1 data and the results are combined
  - 2.5σ for combined results with 1.8σ from wwγγ.
- CMS didn't see any excess wotj RUN1 data.

Definition of objs and selections

Photons

Two well identified and isolated photons with the following p_T and $m_{\gamma\gamma}$ selections:

$\frac{p_T(\gamma 1)}{m(\gamma\gamma)} \geq 0.35$, $\frac{p_T(\gamma 2)}{m(\gamma\gamma)} \geq 0.25$;

$m(\gamma\gamma) \in [105, 160]$ GeV.

Jets

Anti-kt jets with R = 0.4;

$p_T > 25$ GeV; $|\eta| < 2.5$;

Jet Vertex Tagging algorithm (JVT) used to suppress the pileup jets;

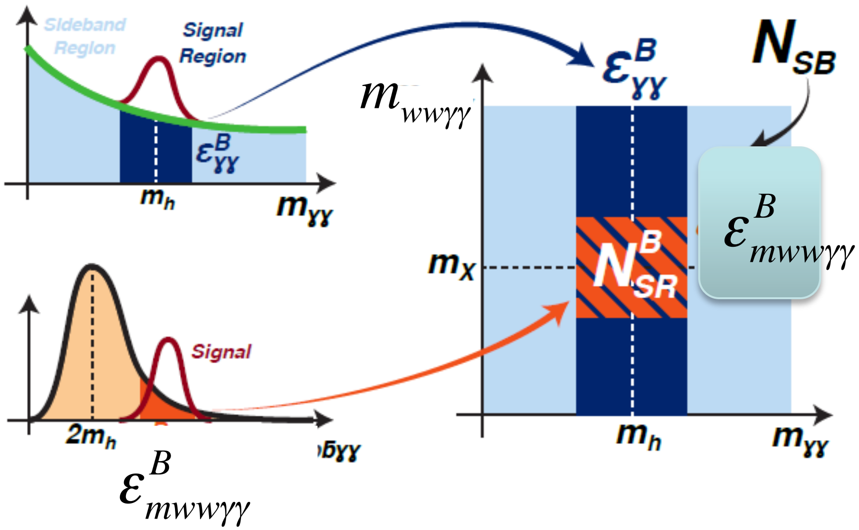
Electrons / Muons

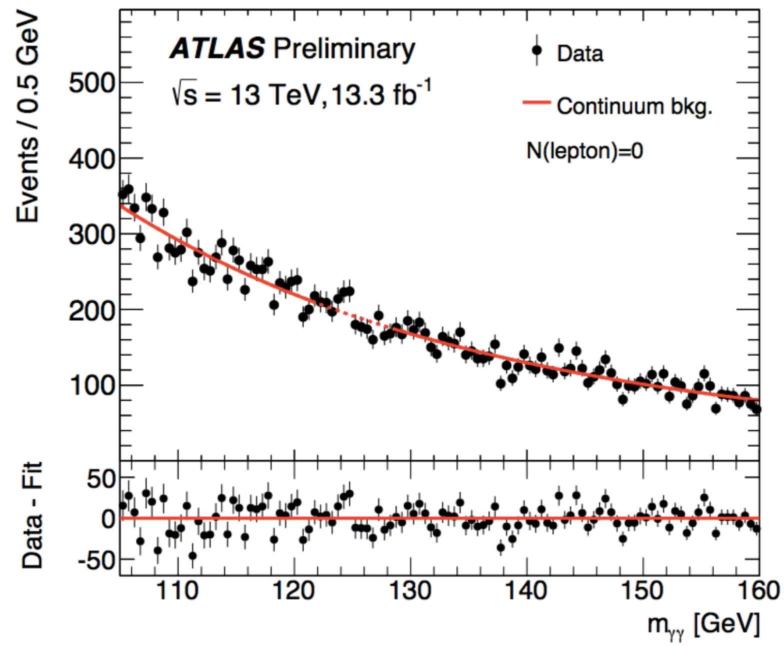
$p_T > 10$ GeV;

Event selection

- Start with the selections aiming at identifying $h \rightarrow \gamma\gamma$ events
- At least two central jets
- B-veto (Working Point: 70%)
- At least one lepton
- Tight mass window (TMW), $|m_{\gamma\gamma} - 125.09| < 2 \times 1.7\ (\sigma_{m_{\gamma\gamma}})$ GeV

Continuous Background estimation





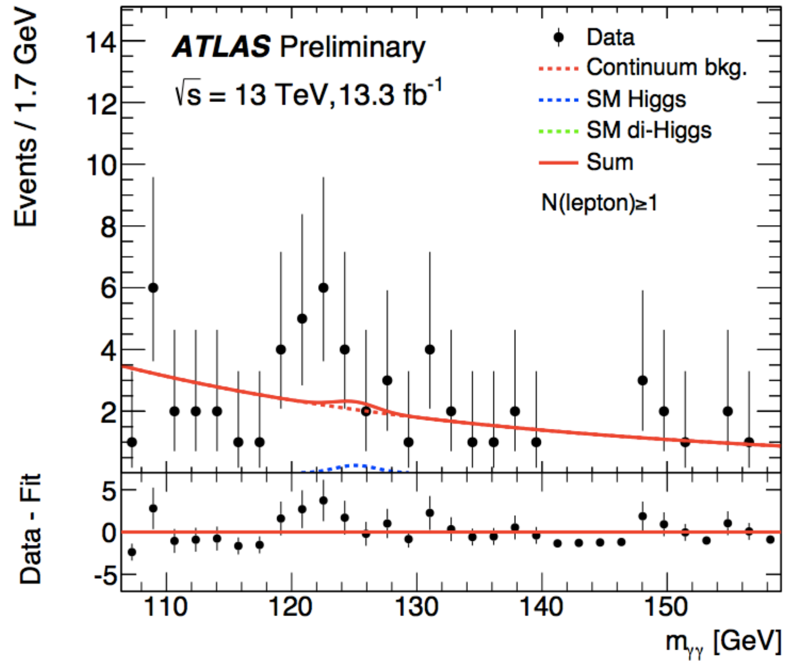
$$N^B_{SR} = N_{SB}\frac{\varepsilon^B_{mww\gamma\gamma}}{1-\varepsilon^B_{m\gamma\gamma}}\varepsilon^B_{mww\gamma\gamma}$$

$$\varepsilon^B_{mww\gamma\gamma} = 13.64\%$$

- A number counting analysis is used for the analysis considering low statistics.
- Sideband of the di-photon is used to extract $\varepsilon^B_{mww\gamma\gamma}$
  - Different control regions are used to validate.
- High statistical sideband sample gg+2jets (in lepton requirement) is pragmatically used.

Results

Process	Number of events	
Continuum background	7.26	± 1.23
SM single-Higgs	0.616	± 0.115
SM di-Higgs	0.0187	± 0.00224
Observed	15	



The events within 125.07+/-2σ GeV mass window are listed in the above table.
The dominant background is still from continuum background.
From the right plot, the statistical fluctuation is still significant.

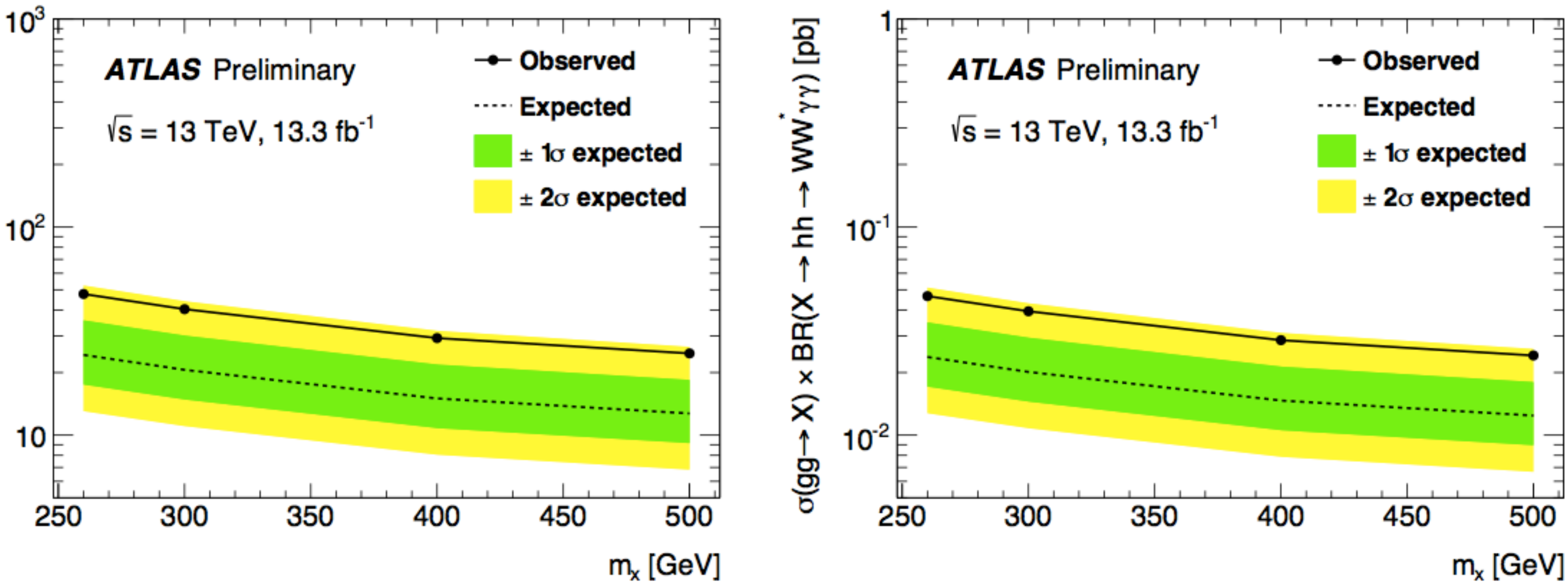
Systematics

Trigger		0.4	0.4	0.4	-
Pileup re-weighting		0.8	0.2	1.8	-
Event statistics		2.0	1.8	2.7	14.7
Photon	energy resolution	2.0	1.8	1.2	-
	energy scale	4.2	4.1	1.6	-
	identification	4.2	4.2	4.2	-
	isolation	1.0	1.0	1.1	-
Jet	energy resolution	0.8	0.2	8.0	-
	energy scale	3.5	3.5	5.2	-
b-tagging	b-jets	0.06	0.05	5.4	-
	c-jets	0.5	0.5	0.3	-
	light jets	0.4	0.4	0.4	-
	extrapolation	0.006	0.06	0.8	-
Lepton	electron	0.7	0.7	0.7	-
	muon	0.3	0.3	0.6	-
$\epsilon_{\gamma\gamma}$	lepton dependence	-	-	-	7.4
	background modelling	-	-	-	3.8
	sideband definition	-	-	-	1.2
	statistics on $\epsilon_{\gamma\gamma}$	-	-	-	1.3
Theory	PDF	(2.1)	-	2.2	-
	α_S	(2.3)	-	1.5	-
	scale	(6.0)	-	3.7	-
	HEFT	(5.0)	-	-	-
	jet multiplicity	-	-	12.5	-

The most dominant resource of the systematics comes from the statistical uncertainty of continuum background.

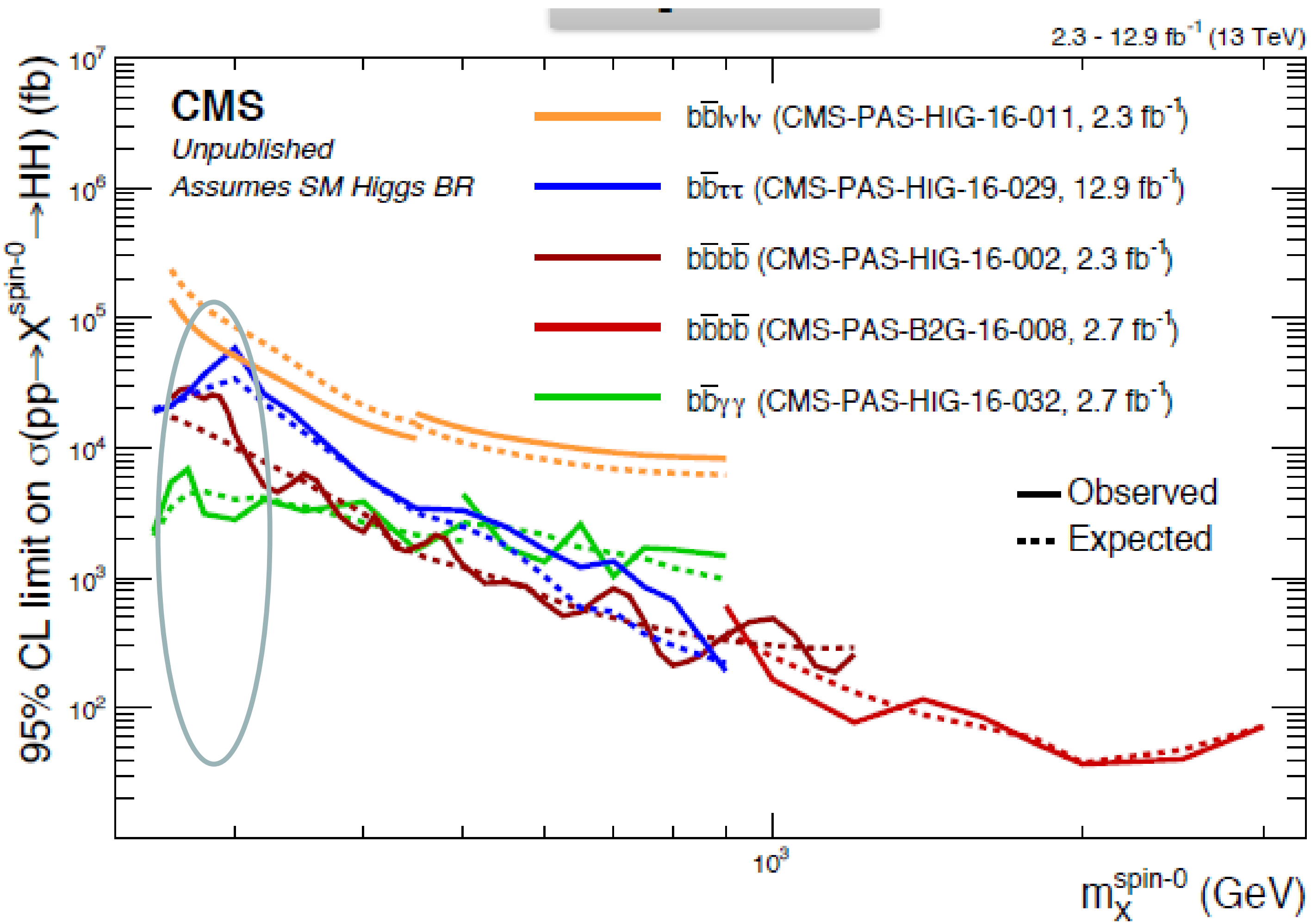
Limits

ICHEP: ATLAS-CONF-2016-071



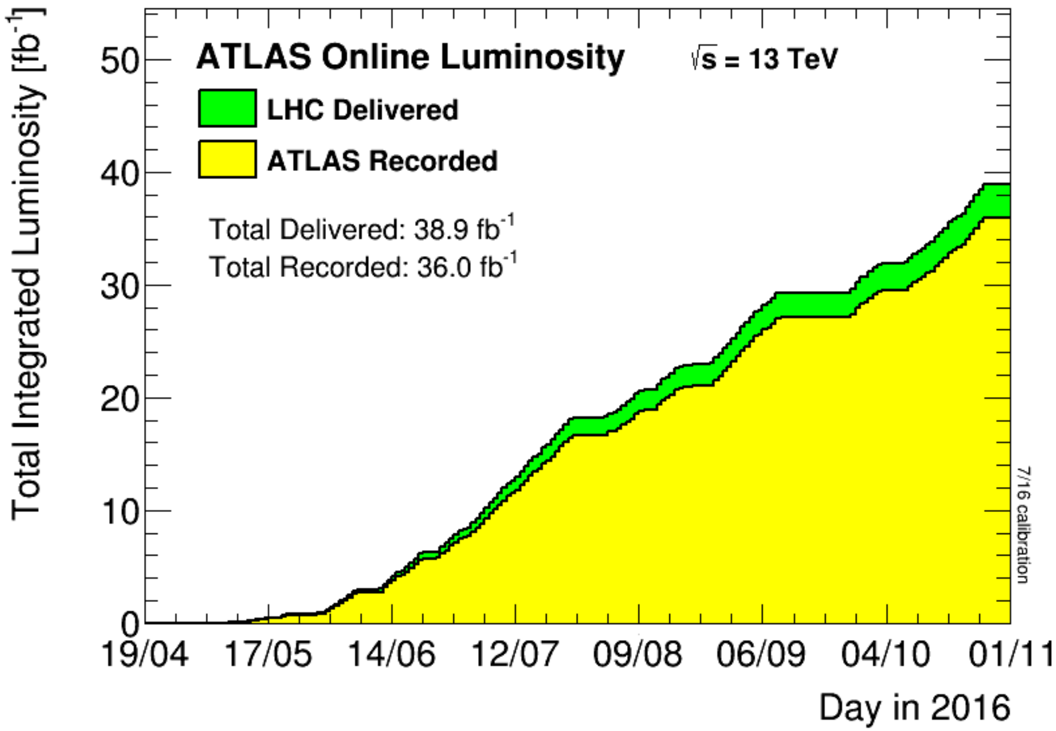
- ➢ The selections are mass independent; the differences of the limits are mainly due to the variations of the signal efficiencies.
- ➢ No obvious new signal has been seen:
  the deviations between observed limits and expected limits are around 2σ.
- ➢ More data will tell us the further story…

CMS Run2 results



In some region around 250-300 GeV, expected and observed limits are inconsistent.

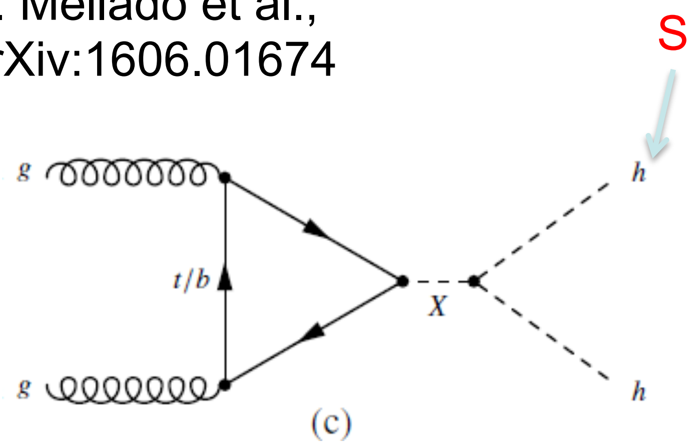
Plans after ICHECP



- With 36 fb^{-1} data, we can better exploited this channel with reasonable statistics.
- More different channels can be investigated.
- Aim at some publication in Moriond, 2017.

Other possibility

B. Mellado et al.,
arXiv:1606.01674



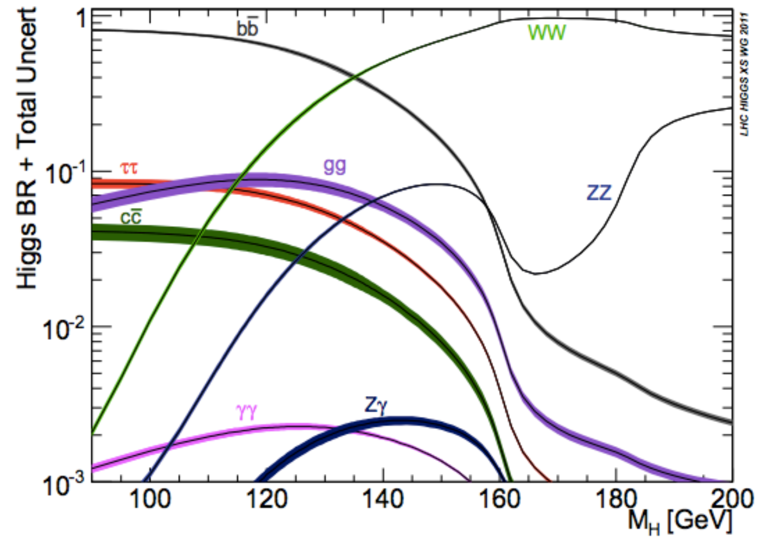
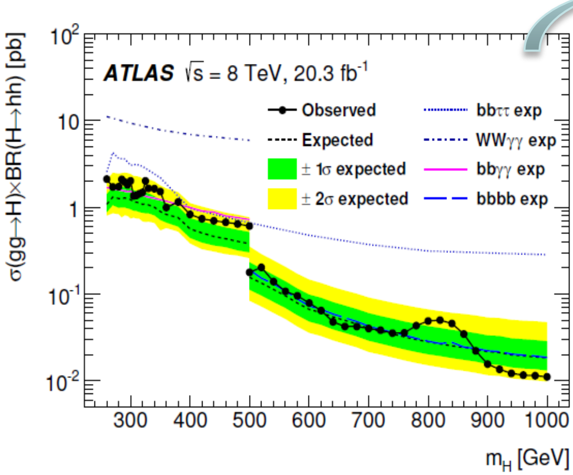
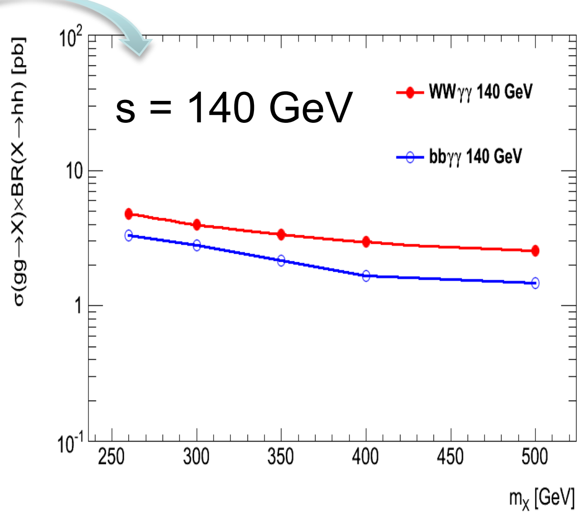
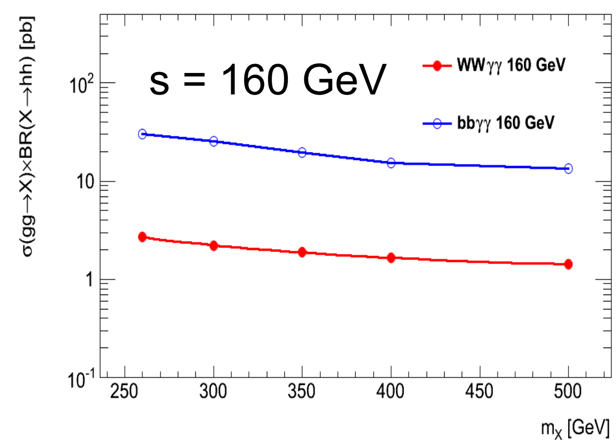


FIG. 1: Higgs branching ratios and their uncertainties for the low mass range.

Rescale Br







- Replace one or two h's with scalar particle s which is not coupled with SM.
- So the s particle is not observed in RUN1 and can be higher than the mass of Higgs (125 GeV).
- γγWW can be more sensitive than γγbb if replacing one h with s for higher mass values.

Conclusion

- Although Higgs discovered in LHC is consistent with SM, there are still motivation to explore new physics such as diHiggs at LHC.
  - MSSM, 2HDM
- Di-Higgs searches with RUN1 data have been extensively studied with the ATLAS detector.
  - 2.5σ was observed with the combination of bb$\gamma\gamma$, bbtautau,ww$\gamma\gamma$…
- The study of $H \rightarrow hh \rightarrow WW\gamma\gamma$ has been did not show significant excess.
  - Slight excess with 2σ has been seen.
- With full 2016 data, it is possible to have more interesting results.

back up