Search for resonances in the 105 to 200 GeV diphoton invariant mass range using 140 fb^{-1} of pp collisions collected at $\sqrt{s}$=13 TeV with the ATLAS detector

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Project description

A search for new spin-0 resonances:

- a blind search in [110,170] GeV m_X range;
- fitting in [105,200] GeV $m_{\gamma\gamma}$ range;
- Use SM Higgs boson samples at different masses to model the signal;
- a production mode independent model:
  - only *ggF* production mode is considered, the others are used to create a systematic uncertainty of efficiency;
  - the signal model is a function of m_H;
- the events selected are pairs of high-pt and isolated photons;
- the events are classified into mutually exclusive categories;
- the signal is modeled fitting simulated *ggF* MC samples in each category;
- the background is fitted from data.

Signal MC samples

Signal h026 *ggF* MC samples obtained by merging and weighting the three flavours (mc16a, mc16d, mc16e) using different m_H resonance masses (110, 125, 130, 140 GeV).

Folder:
/eos/atlas/atlascerngroupdisk/phys-higgs/HSG1/MxAOD/h026/mc16*/Nominal/

Files:

- mc16a.PowhegPy8_NNLOPS_ggH125.MxAODDetailed.e5607_s3126_r9364_p4180_h026.root;
- mc16d.PowhegPy8_NNLOPS_ggH125.MxAODDetailed.e5607_s3126_r10201_p4180_h026.root;
- mc16e.PowhegPy8_NNLOPS_ggH125.MxAODDetailed.e5607_s3126_r10724_p4180_h026.root;
- mc16a.PowhegPy8_NNLOPS_ggH1*0.MxAODDetailed.e7787_s3126_r9364_p4207_h026.root;
- mc16d.PowhegPy8_NNLOPS_ggH1*0.MxAODDetailed.e7787_s3126_r10201_p4207_h026.root;
- mc16e.PowhegPy8_NNLOPS_ggH1*0.MxAODDetailed.e7787_s3126_r10724_p4207_h026.root;

Background MC samples

Background h026 MC samples obtained by merging and weighting the three flavours (mc16a, mc16d, mc16e).

Folder:
/eos/atlas/atlascerngroupdisk/phys-higgs/HSG1/MxAOD/h026/mc16*/Nominal/

Slices: [50,90], [90,175], [175,2000] GeV.

Files:

- mc16a.Sherpa2_diphoton_myy_*_*_AF2.MxAODDetailed.e6452_a875_r9364_p4204_h026.root;
- mc16d.Sherpa2_diphoton_myy_*_*_AF2.MxAODDetailed.e6452_a875_r10201_p4204_h026.root;
- mc16e.Sherpa2_diphoton_myy_*_*_AF2.MxAODDetailed.e6452_a875_r10724_p4204_h026.root;

Prod modes MC samples

Other production modes h026 MC samples obtained by merging and weighting the three flavours (mc16a, mc16d, mc16e) with $m_H = 110$, 125, 130 and 140 GeV.

Prod modes:

prod mode	Generator
VBFH	PowhegPy8EG_NNPDF30_VBFH$<m_H^{mass}>$
ttH	PowhegPy8_ttH$<m_H^{mass}>$
WmH	PowhegPy8_WmH$<m_H^{mass}>$J
WpH	PowhegPy8_WpH$<m_H^{mass}>$J
ZH	PowhegPy8_ZH$<m_H^{mass}>$J

Table: Production modes and their MC generators used in the analysis

Events selection

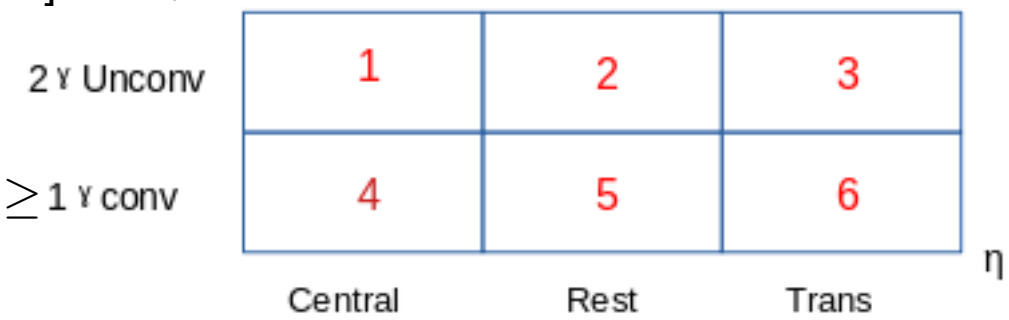
Events selected:

- $|\eta_{S2}| < 2.37$ excluding the crack region $1.37 < |\eta_{S2}| < 1.52$.
- at least two *FixedCutLoose* isolated γ with *Tight* identification;
- leading photon $\rightarrow p_T/m_{\gamma\gamma} > 0.35$;
- sub-leading photon $\rightarrow p_T/m_{\gamma\gamma} > 0.25$;

Categories

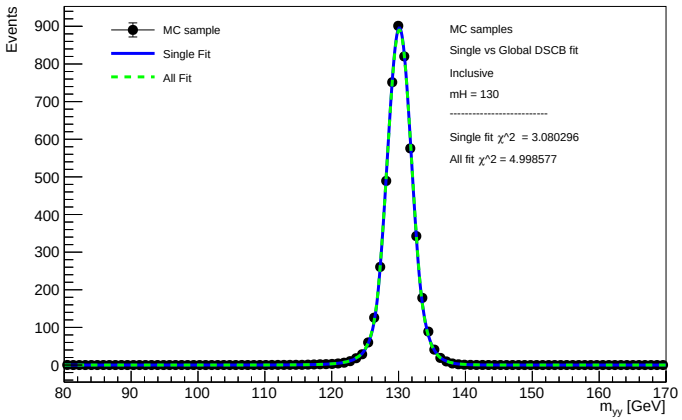
The chosen categorisation (`catConvEta`) is the simplest one and it is based on the photon conversion and $|\eta_{S2}|$.
$\Rightarrow$ Mass categories without the $p^{\gamma\gamma}$ selections

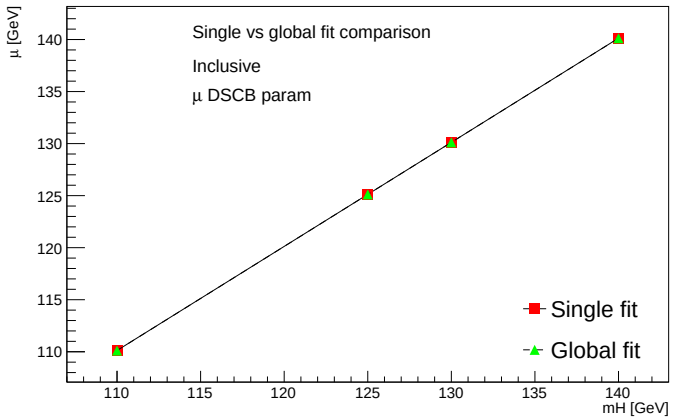
- **2 phs unconv**:
  - $|\eta_{s2}| < 0.75 \rightarrow 1$;
  - $|\eta_{s2}|$ no central and no trans regions $\rightarrow 2$;
  - at least one $|\eta_{s2}|\ \epsilon\ [1.3, 1.75] \rightarrow 3$;
- **at least 1 ph conv**:
  - $|\eta_{s2}| < 0.75 \rightarrow 4$;
  - $|\eta_{s2}|$ no central and no trans regions $\rightarrow 5$;
  - at least one $|\eta_{s2}|\ \epsilon\ [1.3, 1.75] \rightarrow 6$;

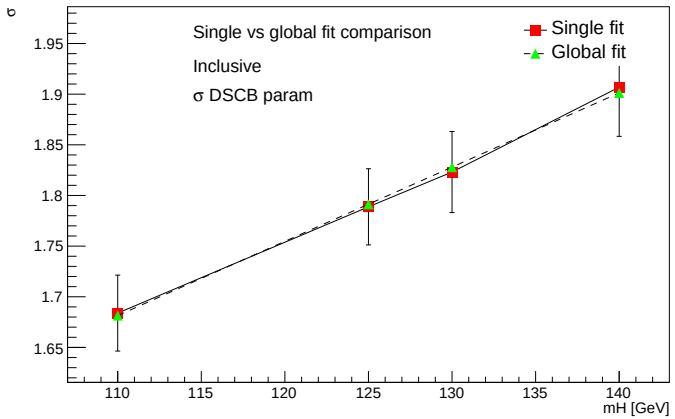


Signal model

- The signal in each category is modeled using simulated MC $H^{SM}_{spin0} \rightarrow \gamma\gamma$ as a function of the mass of the resonance;
- a simultaneous fit is performed on all *ggF* MC samples with different m_H mass, with DSCB parameters as functions of m_H.





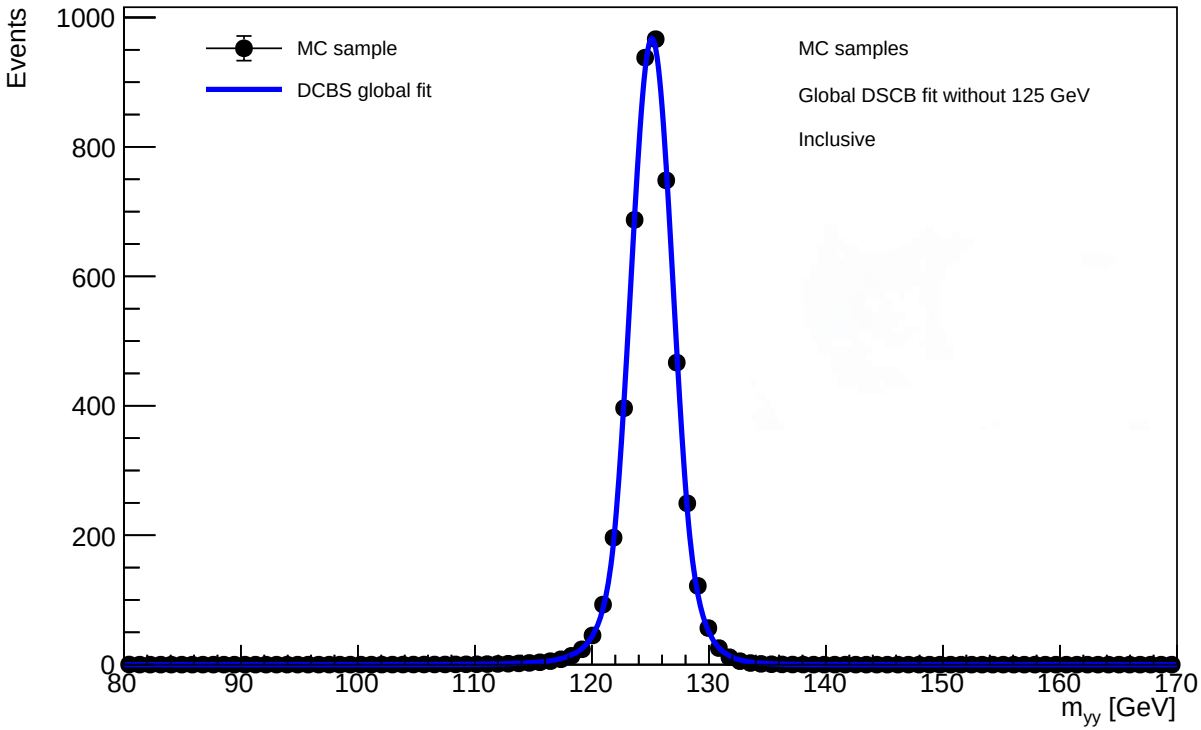


Test signal model

The signal model as a function of resonant mass is tested:

- the simultaneous fit is performed on only *ggF* 110, 130 and 140 GeV MC samples;
- then the model is applied to the MC 125 GeV sample;

$\Rightarrow$ the model is able to fit correctly the MC 125 GeV sample

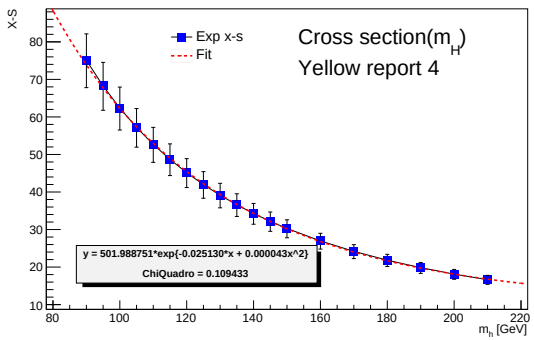


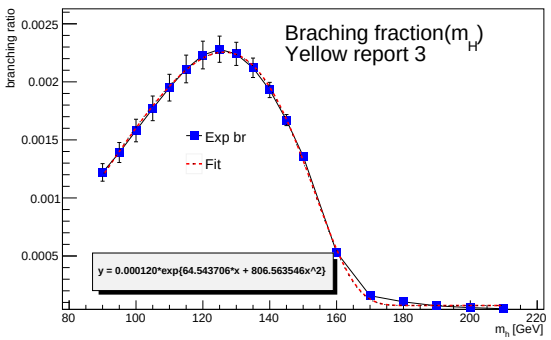
Signal yield

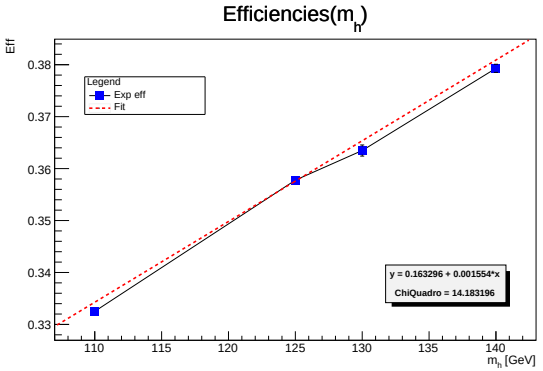
The signal yield in each category is defined as:

$$yield(mH) = xs^{fit}(mH) \cdot eff_{cat}^{fit}(mH) \cdot br^{fit}(mH) \cdot LumiRun2$$

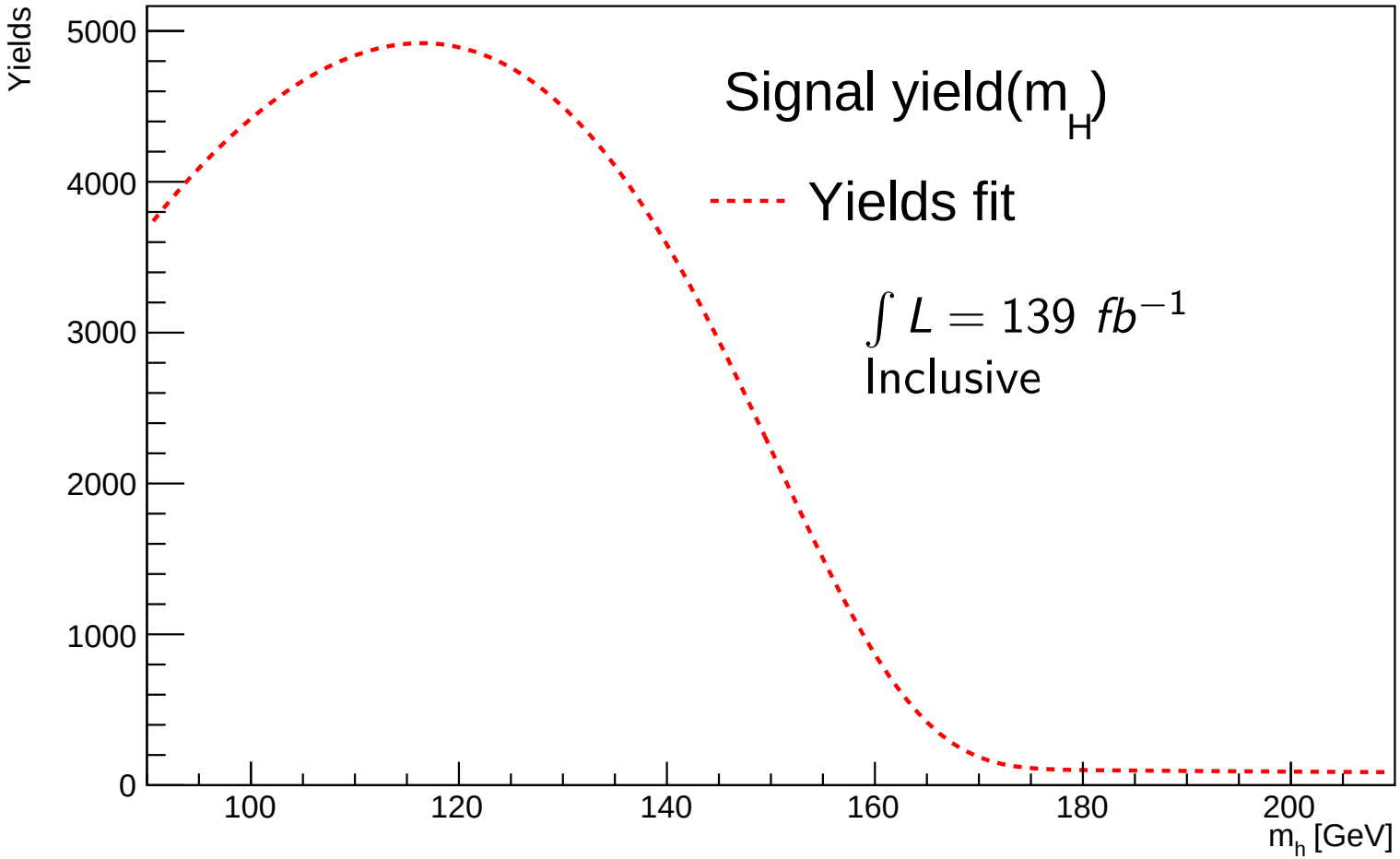
- $xs^{fit}(mH) = 501.988751 \cdot \exp\left(-0.025130 \cdot m_H + 0.000043 \cdot m_H^2\right)$;
- $br^{fit}(mH) = 0.000120 \cdot \exp\left(64.543706 \cdot m_H + 806.563546 \cdot m_H^2\right)$;
- $eff_{cat}^{fit}(mH) = A^{cat} + B^{cat} \cdot m_H \Leftarrow$ Using only ggF MC samples.





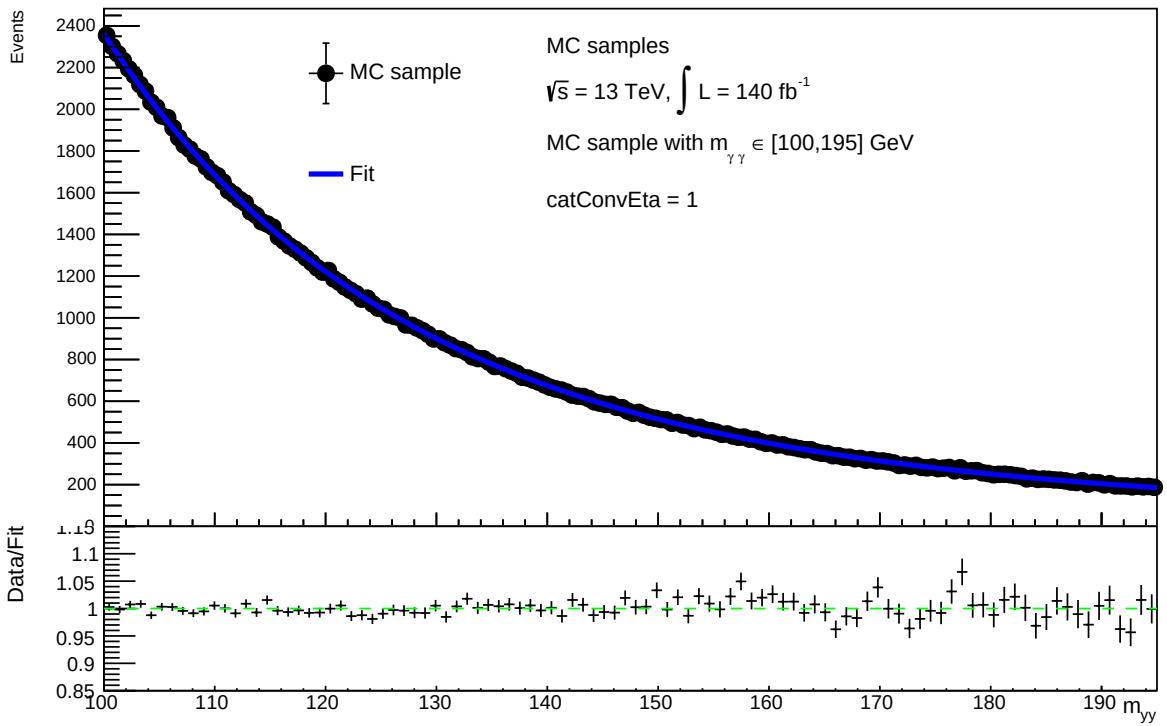


Signal yield



Background model

- The background in each category is described by a smoothly falling function whose normalization and shape parameters will be determined from data;
- A simple exp(poly2) fit is used for the creation of the background model;
- The functional form is tested using MC samples.



Global DSCB σ

cat	110 GeV	125 GeV	130 GeV	140 GeV
inclusive	1.68147	1.79136	1.828	1.90126
1	1.38117	1.47621	1.50789	1.57125
2	1.60006	1.7092	1.74558	1.81833
3	1.88956	2.06138	2.11865	2.23319
4	1.51839	1.61354	1.64526	1.7087
5	1.86199	1.97005	2.00607	2.07811
6	2.20815	2.40964	2.4768	2.61112

Table: DSCB global fit σ

Sig/$\sqrt{Bkg}$ comp

cat	110 GeV	125 GeV	130 GeV	140 GeV
inclusive	9.01245	11.9472	11.8646	9.27702
1	4.58345	6.10029	6.08811	4.81662
2	4.57152	6.00591	6.05181	4.71381
3	2.26846	2.90856	2.85756	2.2402
4	3.41611	4.58159	4.53164	3.61815
5	4.35575	5.78824	5.72445	4.51255
6	2.66065	3.45109	3.4146	2.68388
Sum	9.20729	12.1716	12.1169	9.54441

Table: Number of signal and $\sqrt{bkg}$ events ratio in [peak-3σ,peak+3σ] GeV interval

Syst unc MC sample

Systematic uncertainties are obtained only using h026 MC sample with 125 GeV mass, merging and weighting the three flavours (mc16a, mc16d, mc16e).

Folder:
/eos/atlas/atlascerngroupdisk/phys-higgs/HSG1/MxAOD/h026/mc16*/PhotonSys/

Files:

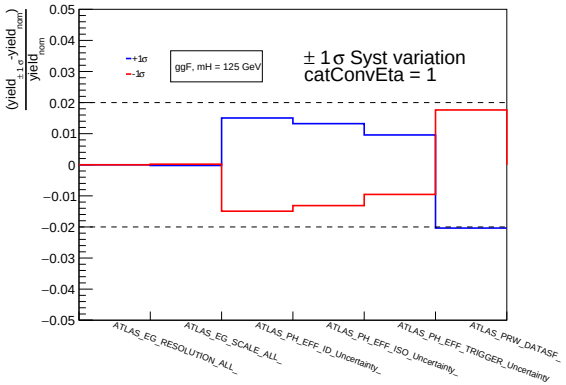
- mc16a.PowhegPy8_NNLOPS_ggH125.MxAODPhotonSys.e5607_s3126_r9364_p4180_h026.root;
- mc16d.PowhegPy8_NNLOPS_ggH125.MxAODPhotonSys.e5607_s3126_r10201_p4180_h026.root;
- mc16e.PowhegPy8_NNLOPS_ggH125.MxAODPhotonSys.e5607_s3126_r10724_p4180_h026.root;

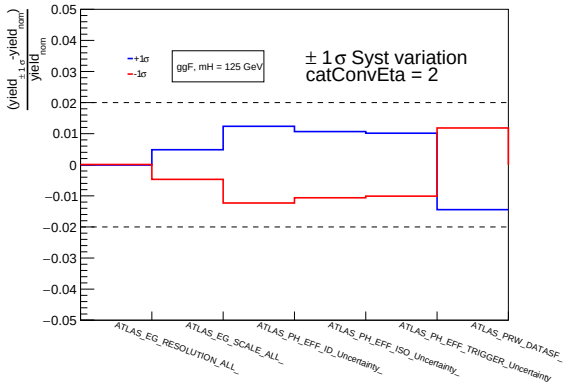
Yield systematic uncertainty

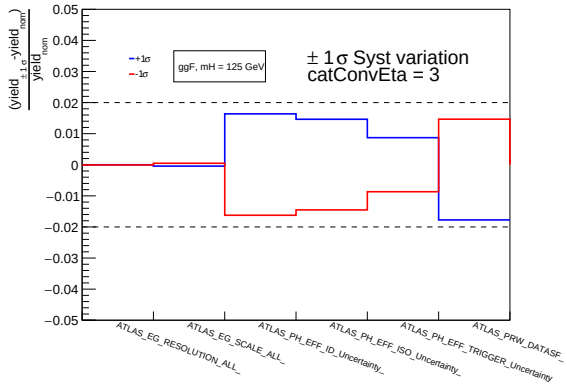
The systematic uncertainties inserted in model are:

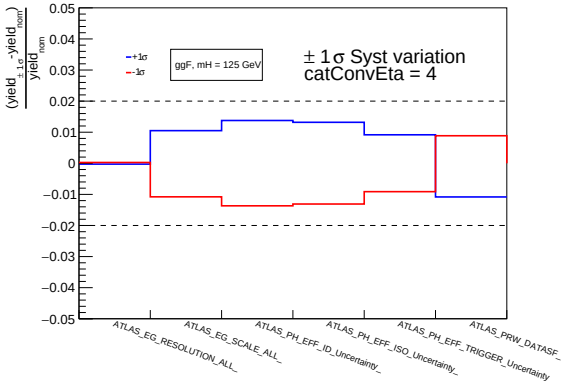
- Yield $\rightarrow \pm 1\sigma$ variations:
  - ATLAS_EG_RESOLUTION_ALL;
  - ATLAS_EG_SCALE_ALL;
  - ATLAS_PH_EFF_ID_Uncertainty;
  - ATLAS_PH_EFF_ISO_Uncertainty;
  - ATLAS_PH_EFF_TRIGGER_Uncertainty;
  - ATLAS_PRW_DATASF;

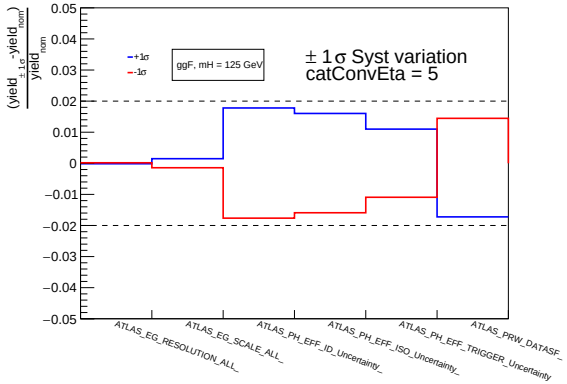
Yield systematic uncertainty

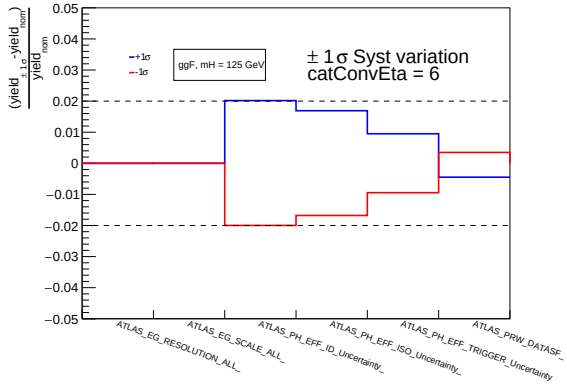








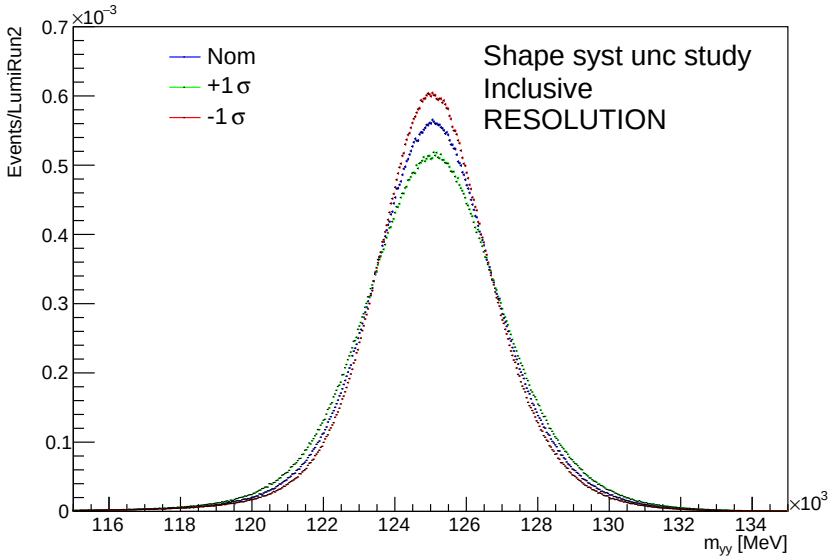




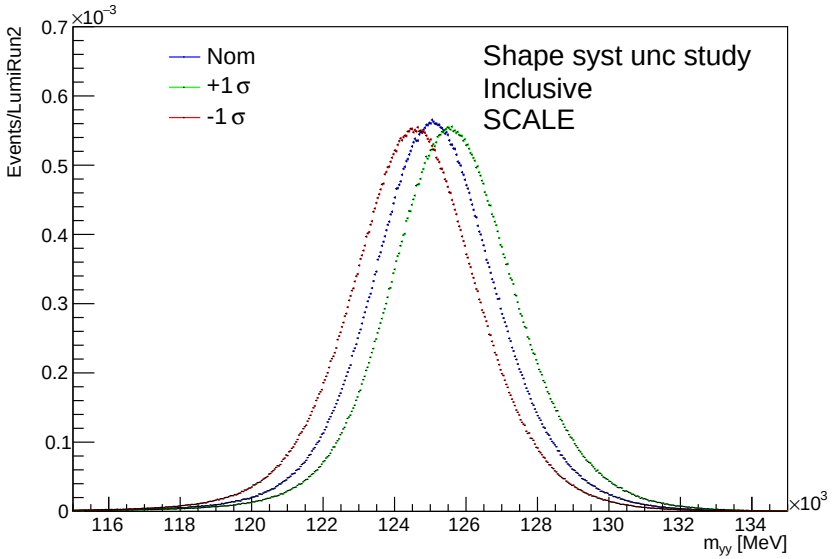
Shape systematic uncertainty

The Shape systematic uncertainty inserted in model are:

- Shape $\rightarrow \pm 1\sigma$ variations:
  - ATLAS_EG_RESOLUTION_ALL;
  - ATLAS_EG_SCALE_ALL;



$$\delta\sigma_c(\pm 1\sigma) = \frac{IQR_c(\pm 1\sigma)}{IQR_c}$$



$$\delta\mu_c(\pm 1\sigma) = \frac{<m_{\gamma\gamma}>_c(\pm 1\sigma)}{<m_{\gamma\gamma}>_c}$$

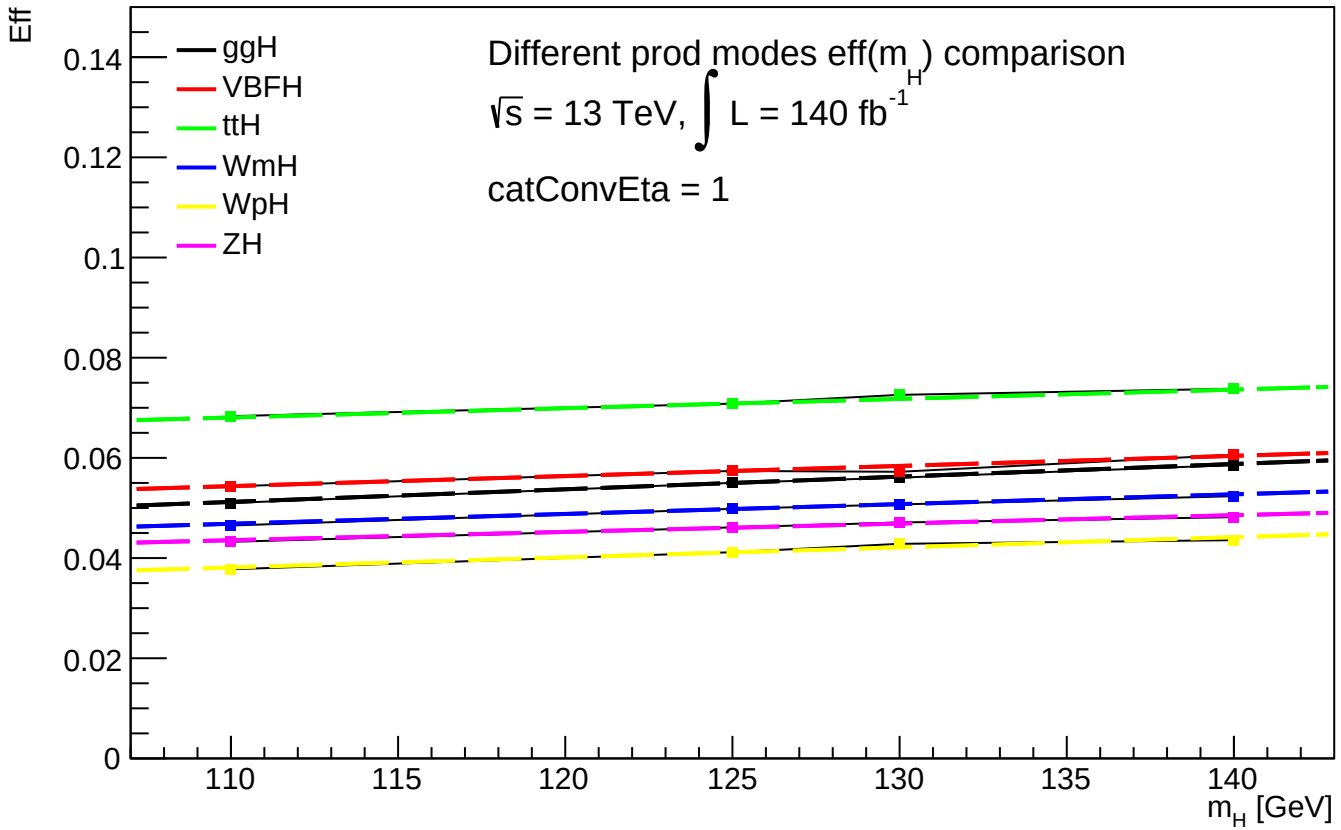
$\pm 1\sigma$ var Shape uncertainty

	ATLAS_EG_RESOLUTION_ALL		ATLAS_EG_SCALE_ALL	
	$+1\sigma$	-1σ	$+1\sigma$	-1σ
no	0.0870621	-0.0673568	0.00442256	-0.00442571
1	0.0878635	-0.0483741	0.00261243	-0.00261395
2	0.144179	-0.0783765	0.00319399	-0.00318967
3	0.0847722	-0.0719211	0.00489874	-0.00490499
4	0.130348	-0.106281	0.00581507	-0.00581681
5	0.118665	-0.116413	0.00935759	-0.00937977
6	0.0728903	-0.0417185	0.00280711	-0.00280223

Table: $\pm 1\sigma$ var shape unc for each category

Prod modes systematic uncertainty

Production modes efficiencies fitted using a linear fit function of m_H.



Prod modes systematic uncertainty

The production modes systematic uncertainty inserted in model is:

- max $\frac{|eff_{prod}^{fit} - eff_{ggF}^{fit}|}{eff_{ggF}^{fit}}$ for each category

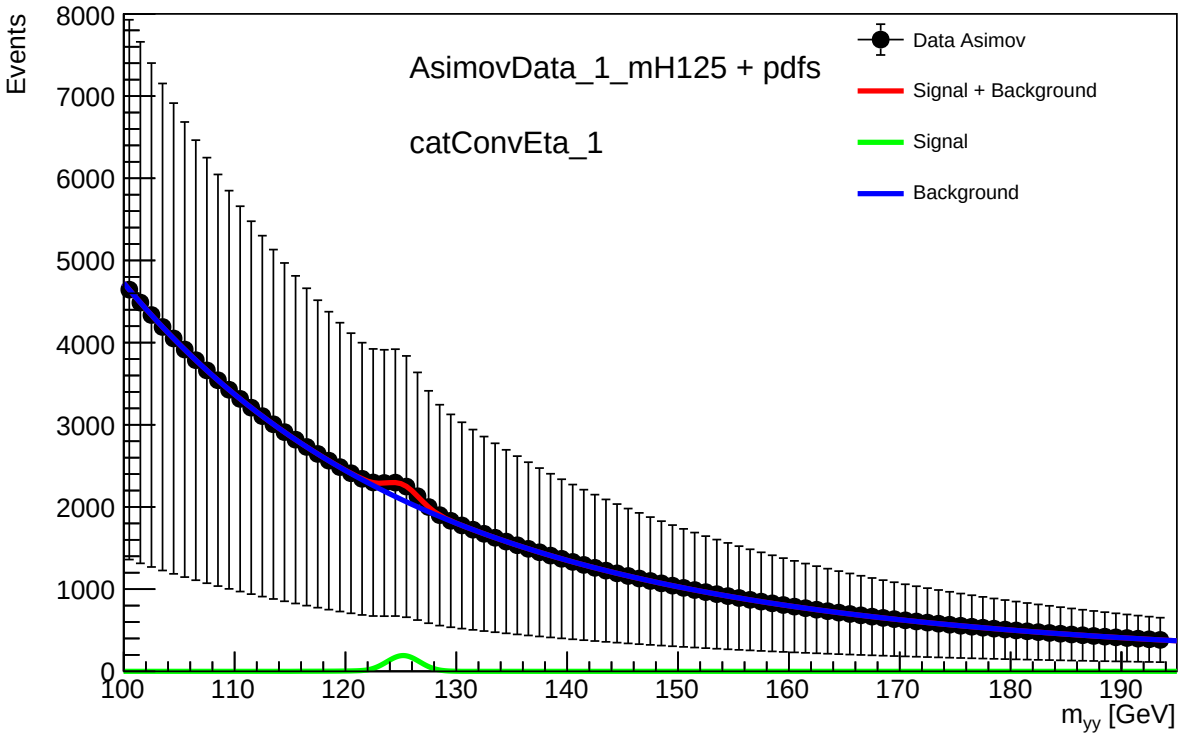
	110 GeV	125 GeV	130 GeV	140 GeV	Max$\rightarrow \sigma$
no	0.163719	0.158653	0.157113	0.154228	0.163719
1	0.329207	0.28836	0.275966	0.252775	0.329207
2	0.168929	0.172123	0.173095	0.174916	0.174916
3	0.134046	0.127847	0.125924	0.122273	0.134046
4	0.343184	0.309866	0.299803	0.281032	0.343184
5	0.136881	0.12726	0.124344	0.118891	0.136881
6	0.114249	0.135306	0.14171	0.153712	0.153712

Table: abs(eff_{prod}^{fit} - eff_{ggH}^{fit})/ eff_{ggH}^{fit}

Asimov Data

In order to test the model two Asimov dataset have been created:

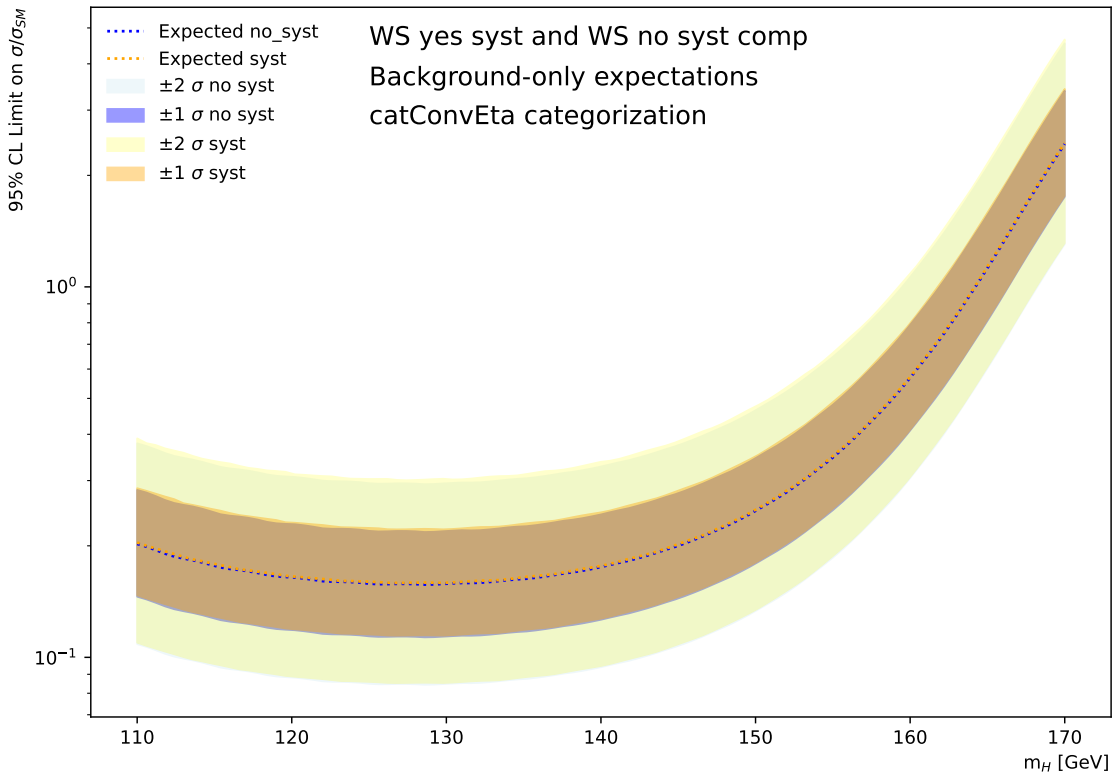
- AsimovData_1_mH125: a dataset with both background and signal with a signal strength μ=1 and m_H=125.09 GeV;
- AsimovData_0: a dataset with only background $\rightarrow$ μ=0.



- $\mu = 1$;
- $m_H = 125.09$ GeV;
- $\mu^{fit} = 0.994 \pm 0.097$;
- $m_H^{fit} = 125.109 \pm 0.229$ GeV;

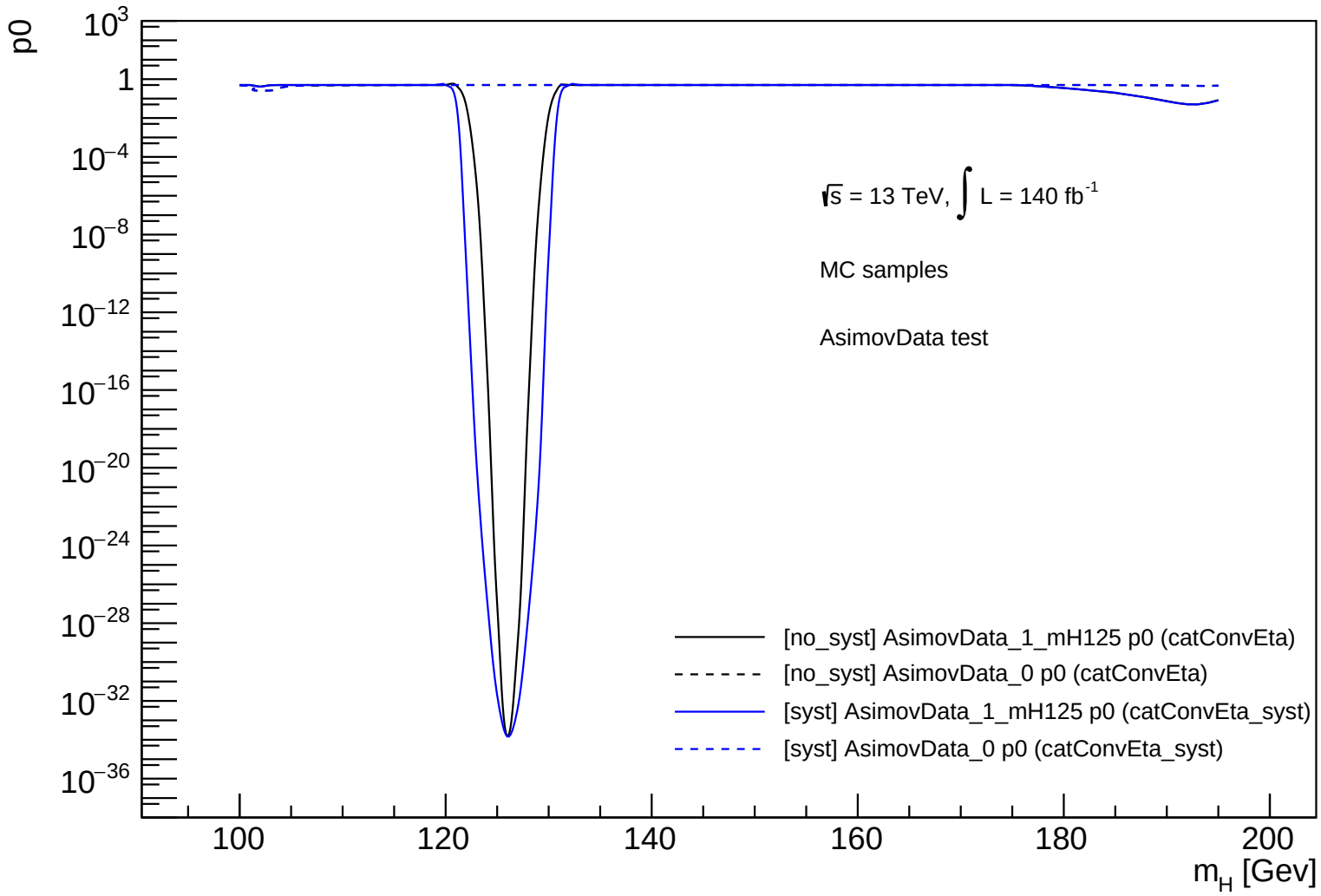
Expected Results

Systematic analysis impact



The inclusion of systematic uncertainties makes the analysis worse by a factor of $<2\%$.

p0 Scan


p0
10^{3}
1
10^{-4}
10^{-8}
10^{-12}
10^{-16}
10^{-20}
10^{-24}
10^{-28}
10^{-32}
10^{-36}
100
120
140
160
180
200
m_H [Gev]
$\sqrt{s}$ = 13 TeV, $\int$ L = 140 fb^{-1}
MC samples
AsimovData test
[no_syst] AsimovData_1_mH125 p0 (catConvEta)
[no_syst] AsimovData_0 p0 (catConvEta)
[syst] AsimovData_1_mH125 p0 (catConvEta_syst)
[syst] AsimovData_0 p0 (catConvEta_syst)

Conclusions

- Almost all analysis building blocks ready:
  - the signal model as a function of the m_H works;
  - baseline categorisation to avoid prod-mode dependence provides a small improvement;
  - the expected p_0 and limits look ok;
- Future improvements:
  - update to h027 or h028;
  - the XS from Yellow Report 4 and the BR from Yellow Report 3;
  - evaluate the feasibility to improve the categorisation (prod mode systematics vs performance)
  - spurious signal test to choose the background function;
  - include background from SM Higgs in the model;
  - look at the data;

Backup

Alternative categorisation

A stronger categorisation has been tested, using the 2012 Higgs discovery categories (`catMass_Run1`) based on the photon conversion, $|\eta_{S2}|$ and $p_{Tt_{\gamma\gamma}}$. Due to the different production modes $p_{Tt_{\gamma\gamma}}$ distribution, Run1 mass categorization would produce values of $\sigma_{prodmods}$ up to $\sim$600%.

	110 GeV	125 GeV	130 GeV	140 GeV
no	0.163719	0.158653	0.157113	0.154228
1	0.473474	0.501648	0.510308	0.526655
2	6.10882	5.75791	5.66206	5.49417
3	0.389534	0.454923	0.475167	0.513567
4	4.19079	4.09942	4.07578	4.03563
5	0.134046	0.127847	0.125924	0.122273
6	0.483679	0.49864	0.503204	0.511778
7	5.89377	5.83035	5.81268	5.78134
8	0.415306	0.477397	0.496536	0.532731
9	4.08364	3.94033	3.90303	3.83948
10	0.114249	0.135306	0.14171	0.153712

Table: abs(eff^{fit}_{prod} - eff^{fit}_{ggH})/ eff^{fit}_{ggH}

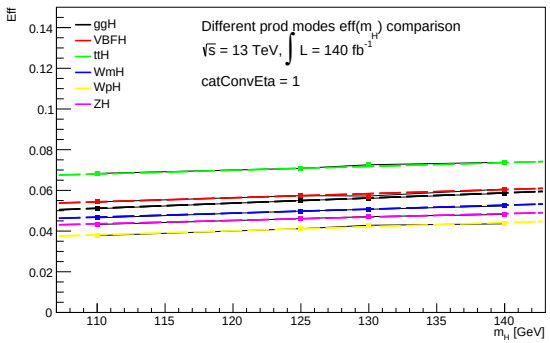
$\pm 1\sigma$ var Yield uncertainty

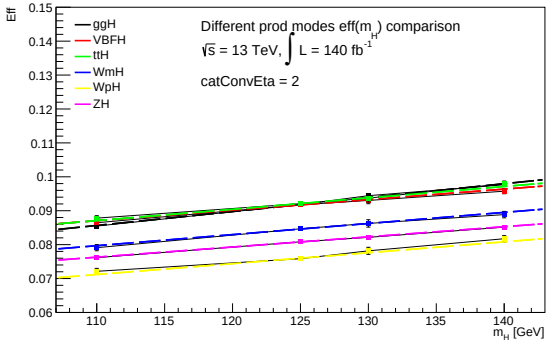
Signal	no		1		2		3	
	$+1\sigma$	-1σ	$+1\sigma$	-1σ	$+1\sigma$	-1σ	$+1\sigma$	-1σ
ATLAS_EG_RESOLUTION_ALL	-3.40462e-05	3.3878e-05	-6.11058e-06	-7.58219e-07	-9.1139e-05	8.79852e-05	6.57836e-06	-4.91537e-05
ATLAS_EG_SCALE_AF2	0	0	0	0	0	0	0	0
ATLAS_EG_SCALE_ALL	0.000678601	-0.000679522	-0.000232135	0.000188235	0.00483447	-0.0046946	-0.000428294	0.000482657
ATLAS_PH_EFF_ID_Uncertainty	0.0178653	-0.0177085	0.015046	-0.0149364	0.0123724	-0.0122983	0.0163719	-0.0162403
ATLAS_PH_EFF_ISO_Uncertainty	0.0164459	-0.0163114	0.0132218	-0.0131345	0.0106729	-0.0106168	0.0146318	-0.0145239
ATLAS_PH_EFF_TRIGGER_Uncertainty	0.00959862	-0.00954776	0.00958805	-0.00954001	0.0101478	-0.0100931	0.00871426	-0.00867415
ATLAS_PRW_DATASF_	-0.0160675	0.0134036	-0.0203614	0.0176278	-0.0144369	0.0118348	-0.0177415	0.0146681

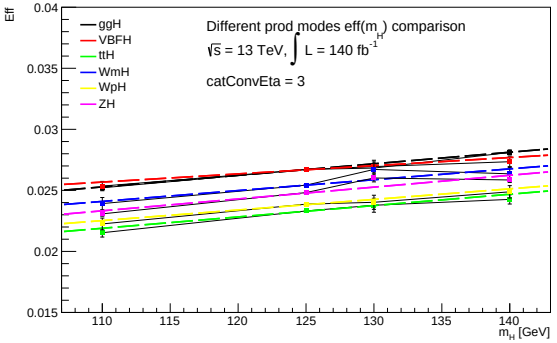
Signal	4		5		6	
	$+1\sigma$	-1σ	$+1\sigma$	-1σ	$+1\sigma$	-1σ
ATLAS_EG_RESOLUTION_ALL	-0.000263193	0.000263654	-0.00014322	0.000170178	1.5645e-05	-4.38881e-05
ATLAS_EG_SCALE_AF2	0	0	0	0	0	0
ATLAS_EG_SCALE_ALL	0.010503	-0.0107856	0.0014803	-0.00142847	1.11065e-05	-1.46545e-05
ATLAS_PH_EFF_ID_Uncertainty	0.013768	-0.0136748	0.0177965	-0.017642	0.0201687	-0.0199793
ATLAS_PH_EFF_ISO_Uncertainty	0.0131856	-0.0130982	0.0160314	-0.0159049	0.0169114	-0.0167773
ATLAS_PH_EFF_TRIGGER_Uncertainty	0.00916871	-0.00912181	0.0109943	-0.0109264	0.00950289	-0.00945582
ATLAS_PRW_DATASF	-0.0108232	0.00886235	-0.0172345	0.0144609	-0.00446197	0.00349614

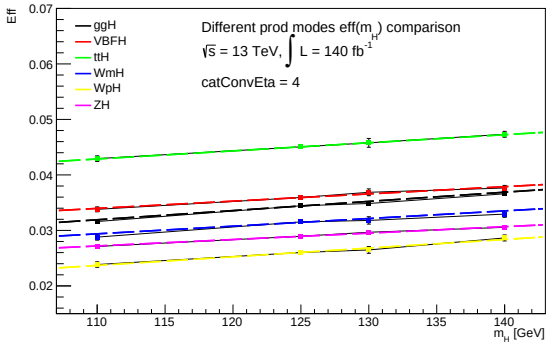
Table: $\pm 1\sigma$ var yield unc for each category

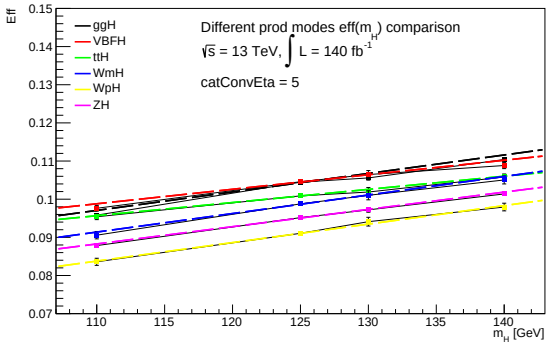
Prod modes systematic uncertainty

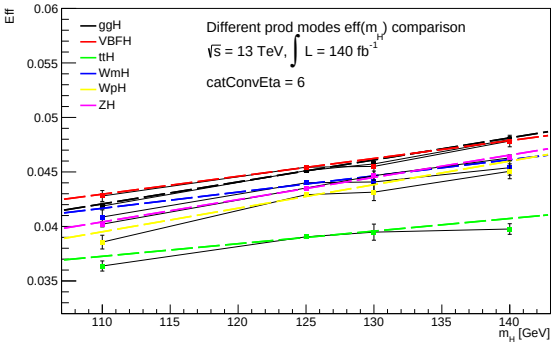




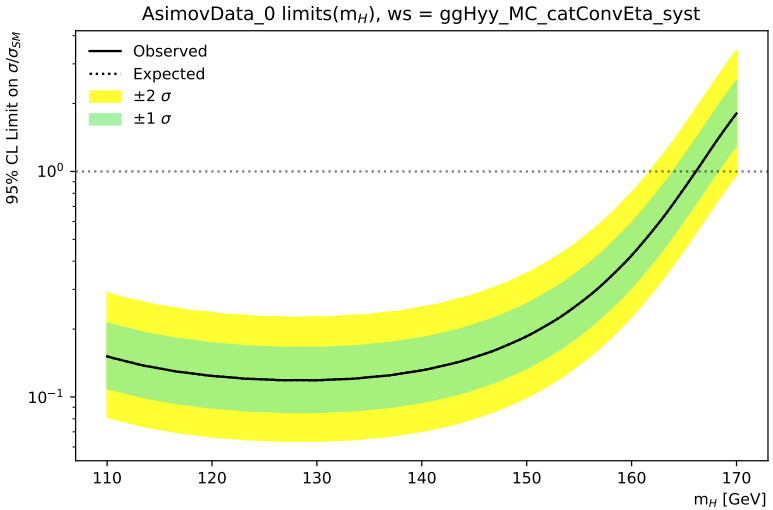


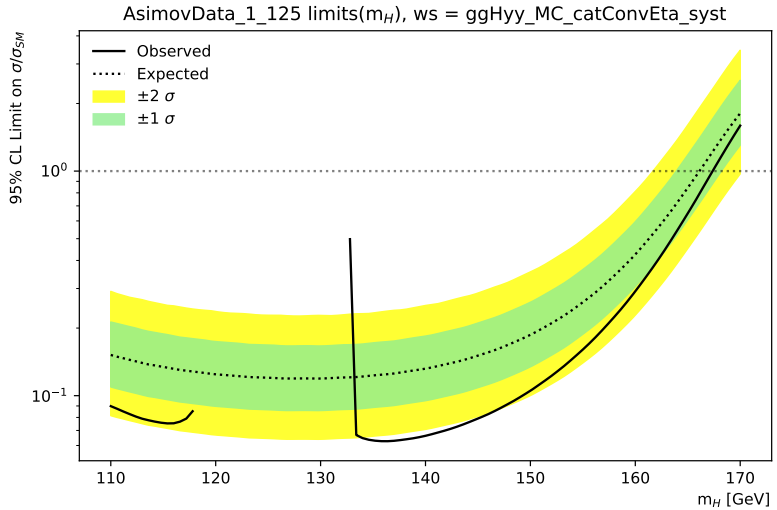






Limits

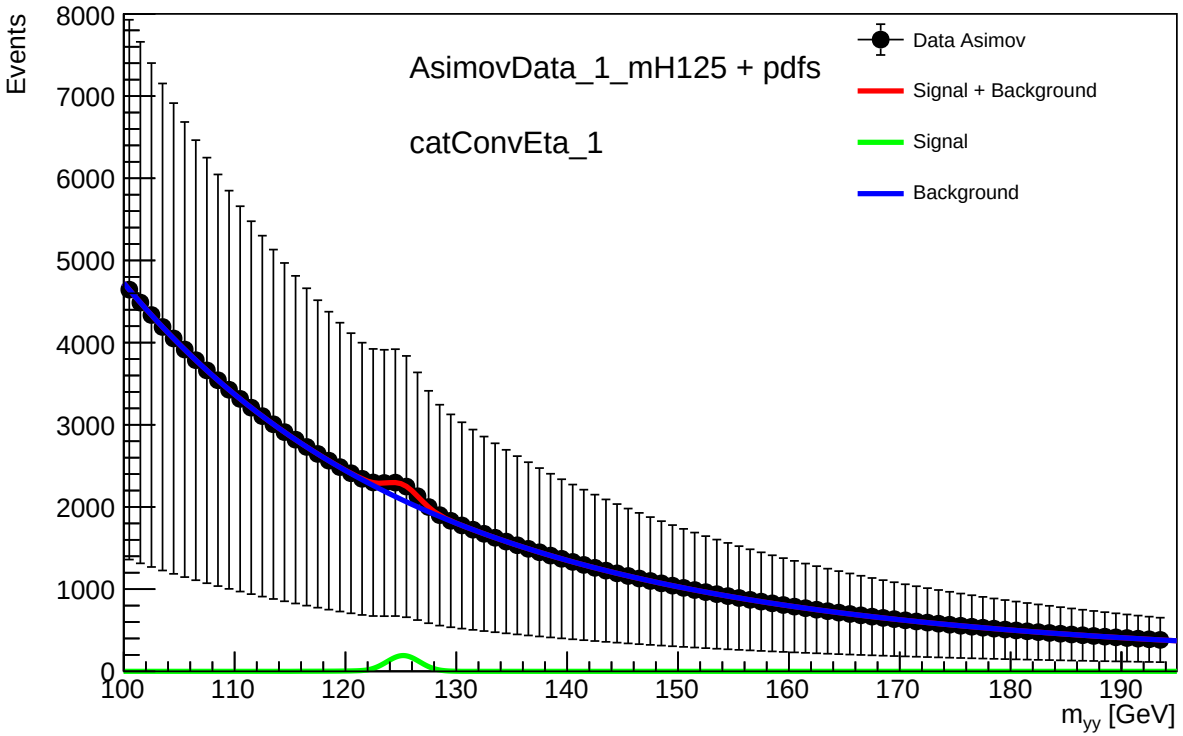

AsimovData_0 limits(m_H), ws = ggHyy_MC_catConvEta_syst
Observed
Expected
±2 σ
±1 σ
95% CL Limit on σ/σ_{SM}
10^0
10^{-1}
110
120
130
140
150
160
170
m_H [GeV]


AsimovData_1_125 limits(m_H), ws = ggHyy_MC_catConvEta_syst
Observed
Expected
±2 σ
±1 σ
95% CL Limit on σ/σ_{SM}
10^0
10^{-1}
110
120
130
140
150
160
170
m_H [GeV]

Asimov Data no syst

In order to test the model two Asimov dataset have been created:

- AsimovData_1_mH125: a dataset with both background and signal with a signal strength μ=1 and m_H=125.09 GeV;
- AsimovData_0: a dataset with only background $\rightarrow$ μ=0.



- $\mu = 1$;
- $m_H = 125.09$ GeV;
- $\mu^{fit} = 0.997 \pm 0.121$;
- $m_H^{fit} = 125.098 \pm 0.886$ GeV;