$X \to SH \to \gamma\gamma + leptons$
Unblinding Results

Kaili Zhang, on behalf of $X \to SH \to \gamma\gamma + leptons$ team

IHEP

08/25/2023, HDBS Approval meeting

Note & Paper Status

- Note CDS: [ATL-COM-PHYS-2021-718]
- Paper CDS: [ATL-COM-PHYS-2023-746]
- Glance
- EB committee:
  - D'ERAMO, Louis (Northern Illinois)
  - MAZINI, Rachid (Taipei AS)
  - SCHAARSCHMIDT, Jana (Seattle Washington)(Chair)

Comments and suggestions until Aug 21st has been all answered and included into the draft.

ATLAS Paper

HDBS-2021-23

August 18, 2023

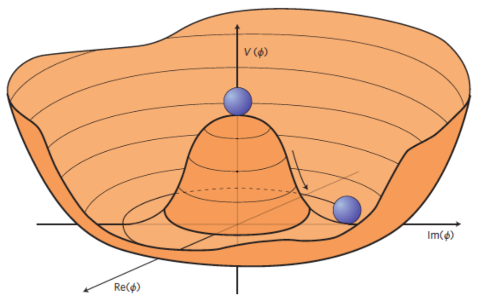
Draft version 1

Search for $X \to SH$ model in final states with two photons and multiple leptons using 139 fb^{-1} of proton-proton collision data at $\sqrt{s}$ = 13 TeV recorded with the ATLAS detector

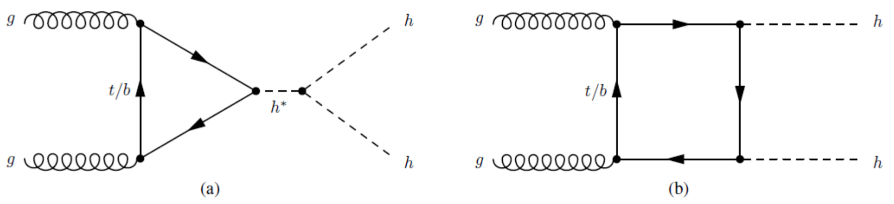
The ATLAS Collaboration

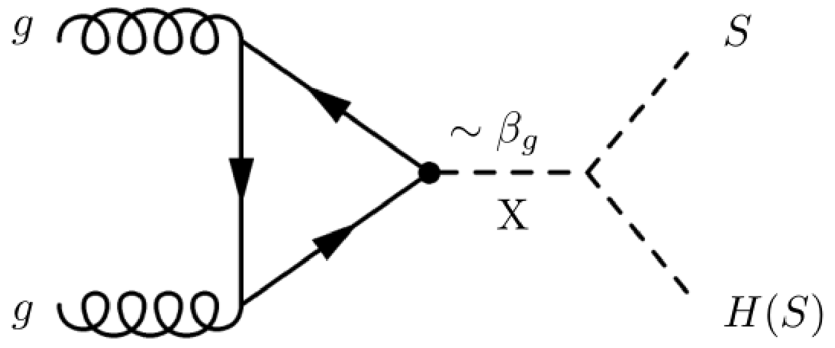
A search for a new heavy scalar particle X decaying to a Standard Model Higgs boson and a singlet scalar particle S using 139 fb^{-1} of proton-proton collision data at the centre-of-mass energy of 13 TeV recorded with the ATLAS detector at the LHC is presented. The explored X mass range varies from 300 GeV to 1 TeV and the S mass ranges from 170 GeV to 500 GeV. The signature of this search is two photons from the Higgs boson decay and one or two leptons (e or μ) attributed to the leptonic decays of vector bosons originating from the S particle: $S \to W^{\pm}W^{\mp}/ZZ$. The observed (expected) upper limits at the 95% confidence level on the cross-section for $gg \to X \to SH$, assuming SM Higgs-like mass-dependent couplings of the S boson, is between 139 fb (183 fb) and 773 fb (946 fb).

SH model for Higgs couplings



SM/BSM Physics → Higgs Potentials → Higgs Self-Coupling → Higgs Pair Production → SH search





X->Sh model, an alternative model enhancing Higgs pair production.

Heavy cp-even scalar X into Higgs h + Higgs-like scalar S.

Current studies for HH/SH

ATLAS HH:

- combination: Phys. Lett. B 843 (2024) 137745
- Multilepton(+yy): ATL-COM-PHYS-2020-229

CMS HH:

- combination: Nature 607, 60-68 (2022)

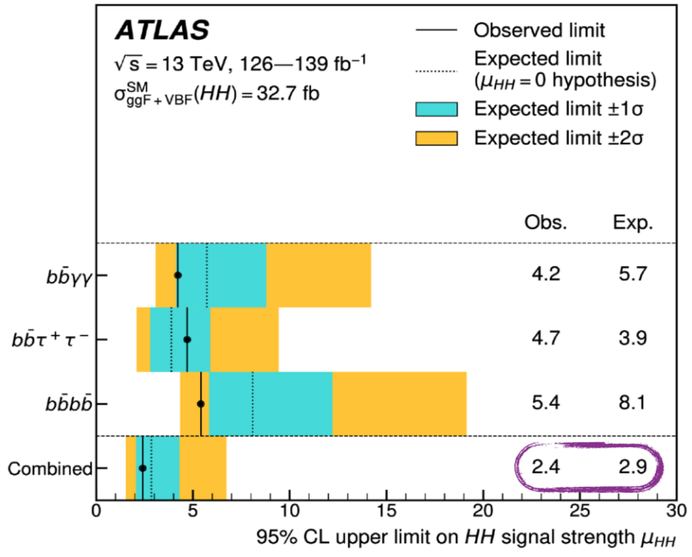
SH:

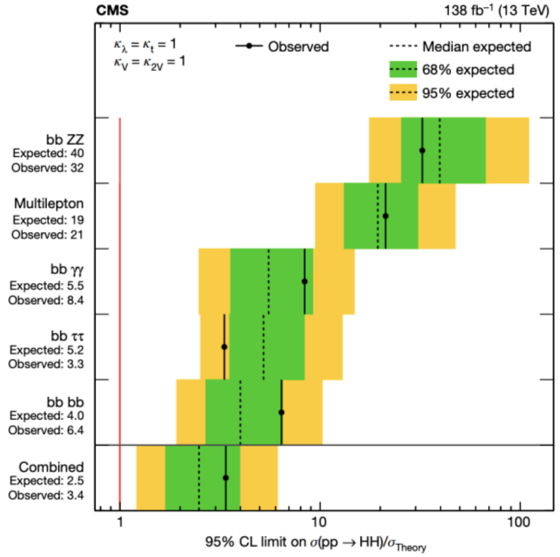
CMS SH->bb$\tau\tau$: JHEP 11 (2021) 057

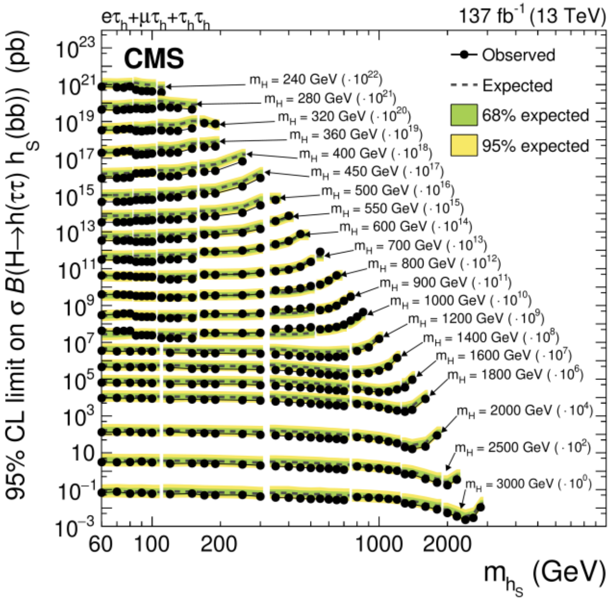
CMS SH->bbyy: CMS PAS HIG-21-011

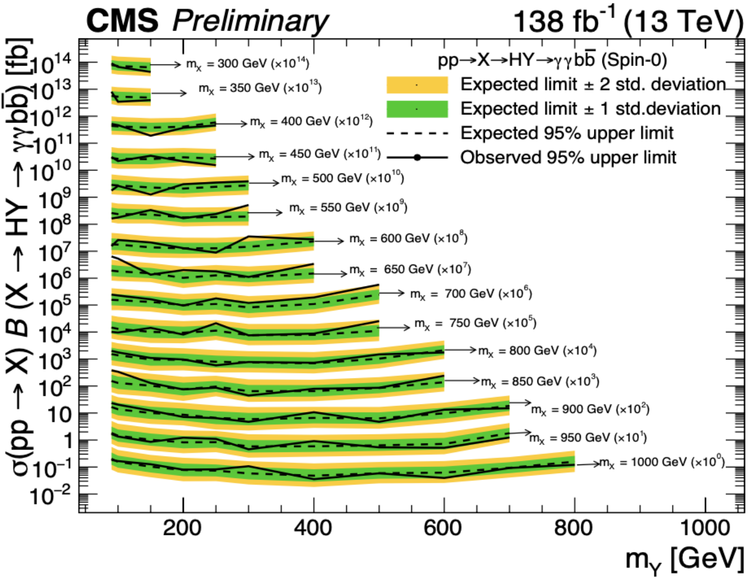
ATLAS SH->VVtautau: ATL-COM-PHYS-2022-1135(JHEP)

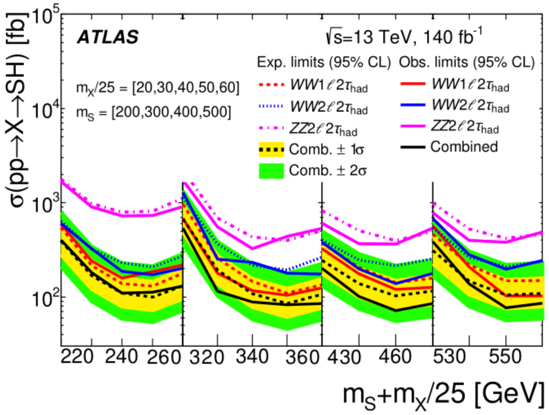
Several other SH studies undergoing;





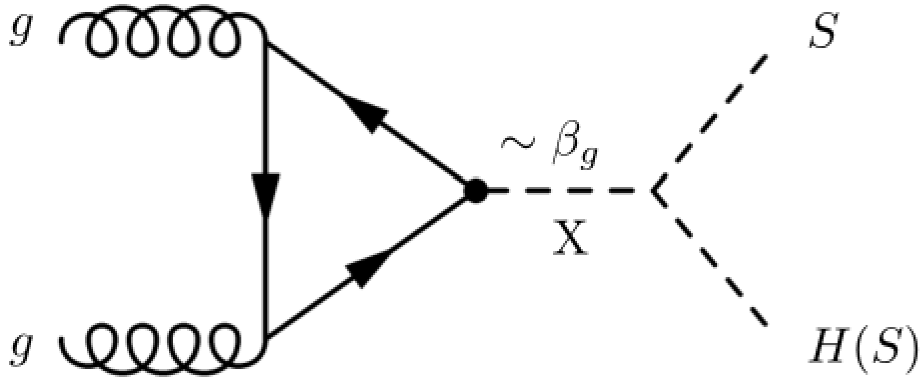






Model & Final states

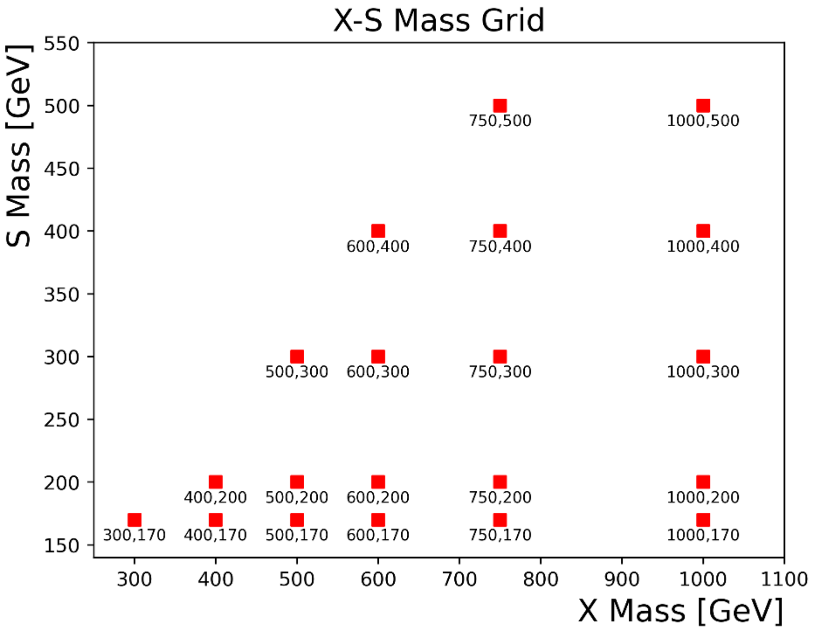
- Expected to be model independent
  - Nominal sample do not rely on BSM assumptions;
  - Results presented as S follow as same decay branch ratio as H.
  - Also S->WW/ZZ 100% results shown for extrapolation.
- If S decay like Higgs, for $m_S > m_{125}$, S would decay into WW and ZZ dominantly.
  - S decay: electron or muon;
  - H125 decay: diphoton, clear spectrum;
- Final states:
  - Diphoton + Multilepton chosen.



Samples

- Data: Official HGam h026, 139ifb, 15-18 full Run2 data.
- Signal
  - SH WW1l, WW2l, ZZ2l, Pythia8.(800938-800997)
- MC:
  - SM Higgs(ggH, VBFH, WH, qqZH, ggZH……)
  - Continuum background: yy+jets, V/VV+yy, $\hat{t}t$+yy.
  - yy+0l, 1l, 2l for bkg shape study;

- 20 mass points has been chosen:
- S mass from 170 to 500 GeV
- X mass from 300 to 1000 GeV



In SH, to mix WW and ZZ signals properly, the decay branching ratio are assumed to be the same as Higgs.

m_S[GeV]	$BR(S \to WW)$	$BR(S \to ZZ)$
170	96.28%	2.44%
200	73.90%	25.68%
300	69.12%	30.72%
400	57.65%	26.90%
500	54.09%	25.86%

General Object definition

All default configuration in HGamframework.(h026, AnalysisBase 21.2.131.), Same as HH-ML.

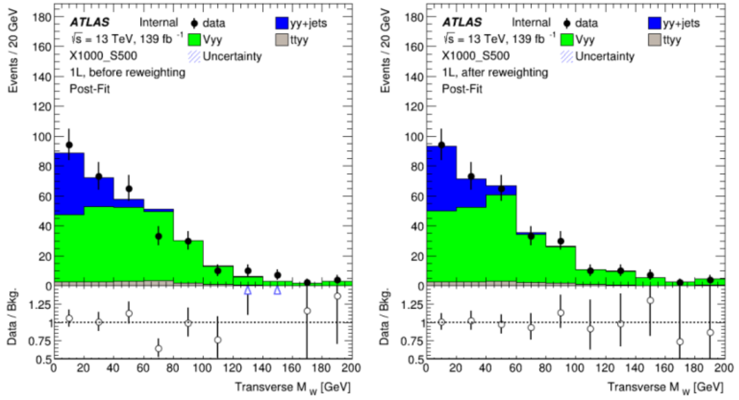
- Good event
  - GRL, Pass the trigger, detector DQ……
- B-veto
  - B-77 veto to avoid the overlap with bb.
- 2 tight photons
  - $\frac{pT_{y1}}{m_{yy}} > 0.35, \frac{pT_{y2}}{m_{yy}} > 0.25, m_{yy} \in (105, 160)$GeV
  - Tight ID, Tight ISO.
- Good lepton
  - e/muon pt>10 GeV;
    - Electron PID: Medium;
    - Electron ISO: FCLoose
    - Muon PID: Medium
    - Muon ISO: PflowLoose_FixedRad
  - Hadronic tau not included.

TMVA Training

Channel	Definition	Optimization strategy
WW1l	1lepton, 2 central jets	BDT
WW2l	2lepton, same flavor, $\|m_{\ell\ell} - m_Z\|$¡10GeV	BDT
WW1e1m	1 electron 1 muon	Cut based
ZZ2l	2lepton, 2 central jets, same flavor, $\|m_{\ell\ell} - m_Z\|$¡10GeV	Cut based

Table 10: Definition of the four channels and the corresponding optimization strategies.

- BDT used for WW 1/2 lepton region
- 4 folds Cross Validation.
- Reweighted MC & data
- Parametrized m_X



(a) (b)

Parameters	Value
BoostType	AdaBoost
AdaBoostBeta	0.5
NTrees	850
MinNodeSize	2.5%
UseBaggedBoost	True
BaggedSampleFraction	0.5
SeparationType	GiniIndex
nCuts	20
MaxDepth	3
NegWeightTreatment	Ignore
UseCrossValidation	True
Nums of Folds	4

Variable	Definition	Separation
Regarding particle X		
$\Delta R(\gamma\gamma, l\nu jj)$	Angular difference between diphoton system (H) and $l\nu jj$ system (S)	0.048
Regarding particle S		
$\Delta R(jj, l\nu)$	Angular difference between dijet system (W_{had}) and $l\nu$ system (W_{lep})	0.089
$p_T^{l\nu jj}$	Transverse momentum of $l\nu jj$ system (S)	0.373
Regarding SM Higgs boson		
$p_T^{\gamma\gamma}$	Transverse momentum of diphoton system (H)	0.484
$\Delta\Phi(\gamma\gamma, l)$	Polar angle difference between di-photon system (H) and signal lepton	0.026
Regarding single W boson from S		
$\Delta R(j, j)$	Angular difference between two jets (W_{had})	0.171
p_T^{jj}	Transverse momentum of di-jet system (W_{had})	0.181
$m_{jj}(m_W)$	Invariant mass of di-jet system whose mass is closest to $m_W(W_{had})$	0.119
$\Delta R(l, E_T^{miss})$	Angular difference between lepton and E_T^{miss} (W_{lep})	0.108
E_T^{miss}	Missing transverse momentum	0.248
p_T^l	Transverse momentum of the single lepton	0.203
$m_T(l\nu)$	Transverse mass of $l + E_T^{miss}$ system (W_{lep})	0.044

Table 11: Variables used for BDT training in WW1l channel and their separation powers.

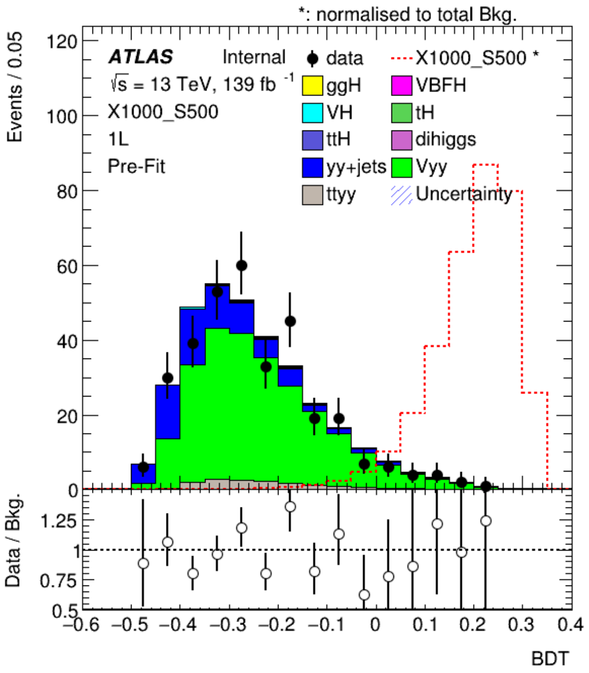
Variable	Definition	Separation
Regarding particle X		
$\Delta R(\gamma\gamma, ll + E_T^{miss})$	Angular difference between diphoton system (H) and $ll + E_T^{miss}$ system (S)	0.031
Regarding particle S		
$\Delta R(l_1 + E_T^{miss}, l_2)$	Angular difference between leading lepton + E_T^{miss} (W_{l1}) and l_2	0.038
Regarding SM Higgs boson		
$p_T^{\gamma\gamma}$	Transverse momentum of diphoton system (H)	0.621
$\Delta\Phi(\gamma\gamma, l_1)$	Polar angle difference between di-photon system (H) and the leading lepton	0.079
Regarding single W boson from S		
$p_T^{l_1}$	Transverse momentum of the leading lepton	0.415
E_T^{miss}	Missing transverse momentum	0.638
$p_T^{l_1+E_T^{miss}}$	Transverse momentum of the leading lepton and E_T^{miss} system	0.533
$m_T(l_1 + E_T^{miss})$	Transverse mass of leading lepton and E_T^{miss} system	0.362
m_{ll}	Invariant mass of di-lepton system	0.358

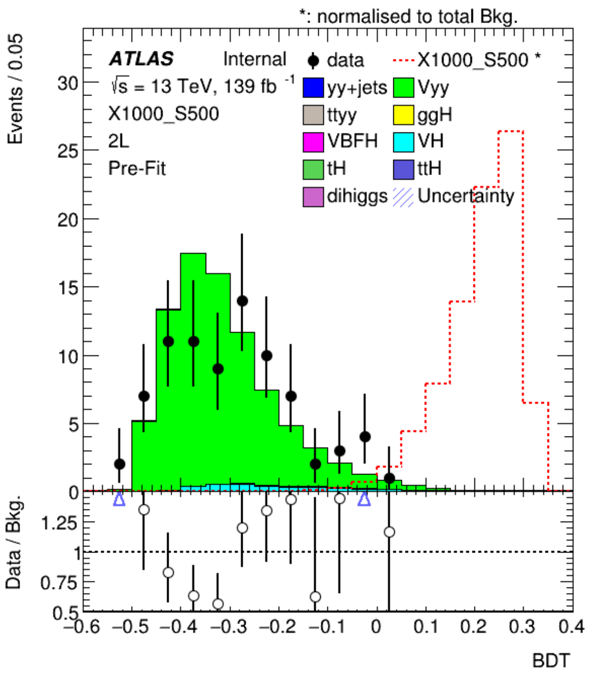
Table 12: Variables used for BDT training in WW2l channel and their separation powers.

No variable heavily rely on X/S mass value.

BDT Region definition

2 region, tight, loose defined.
At least 2 side band data events in tight region assured.



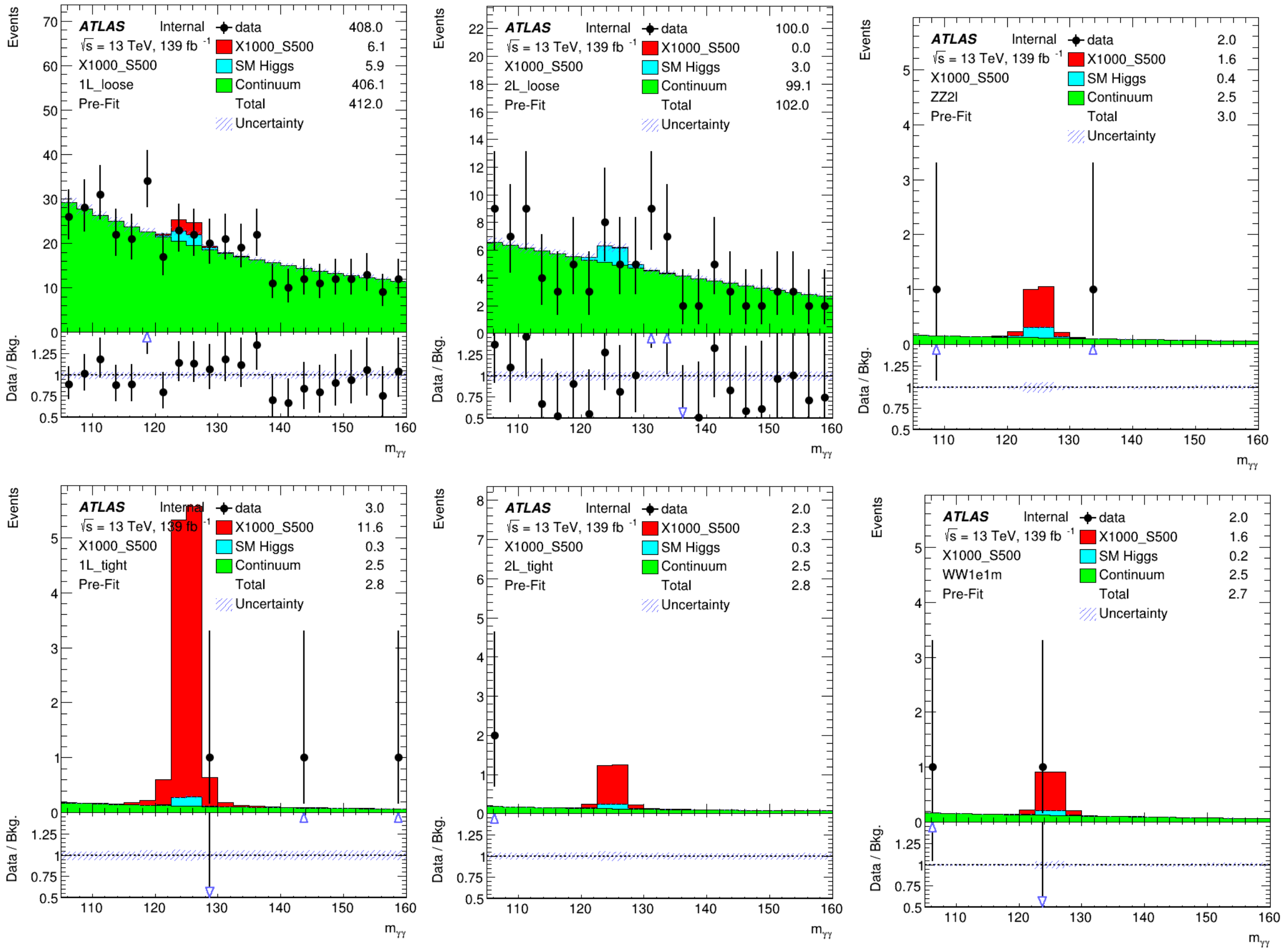


X Mass [GeV]	S Mass [GeV]	WW1L BDT Cut	WW2L BDT Cut
300	170	0.085	0.14
400	170	0.08	0.08
400	200	0.03	0.1
500	170	0.125	0.12
500	200	0.095	0.11
500	300	0.025	0.09
600	170	0.16	0.09
600	200	0.115	0.065
600	300	0.045	0.09
600	400	0.035	0.06
750	170	0.185	0.025
750	200	0.155	0
750	300	0.11	0.035
750	400	0.07	0.065
750	500	0.035	0.065
1000	170	0.155	-0.02
1000	200	0.15	-0.1
1000	300	0.145	-0.03
1000	400	0.115	0.015
1000	500	0.115	0.015

$m_{\gamma\gamma}$ prefit distribution

6 regions in fit: 1l/2l BDT tight/loose, WW1e1m and ZZ2l.

- TRExFitter, binned fitting tool.
  - [105, 160], 22bins.
  - NP threshold: 0.5%.
  - 4 bkg norm factor given;

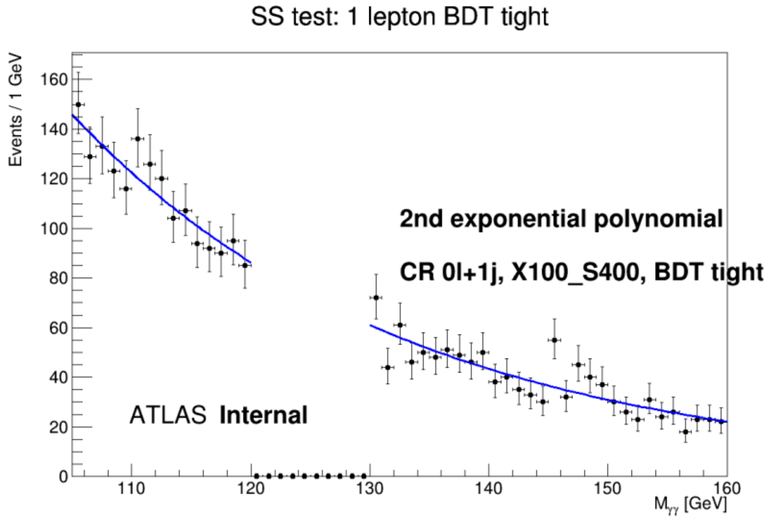


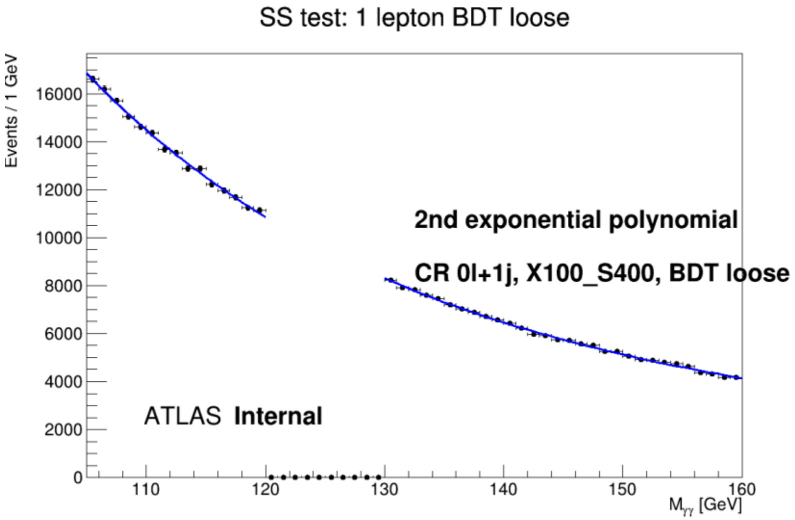
Parameters	Value
MCstatThreshold	0.005
SystPruningNorm	0.005
SystPruningShape	0.005
BlindSRs	FALSE
FitType	SPLUSB
FitRegion	CRSR
LimitType	ASYMPTOTIC
Observed Variable	$m_{\gamma\gamma}$
Variable Range	(105, 160)GeV
Blind Range	(120, 130)GeV
Numebr of bins	22
Bin width	2.5 GeV

Table 24: Summary of configurations used in TRExFitter.

Background Estimation

- Sideband data 0l CR (failed 2 tight photons) shape to simulate yy+1/2l shape.
  - yy+0l+1j to simulate yy+lvjj.
  - yy+0l+2j to simulate yy+lvlv.
- Smooth analytic function used to estimate the signal region in 120-130.
- Bkg yields constrained by sideband data.





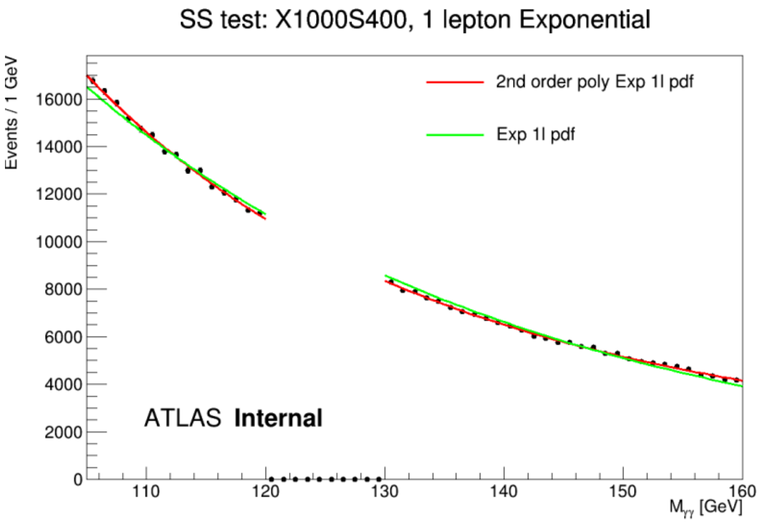
Spurious signals

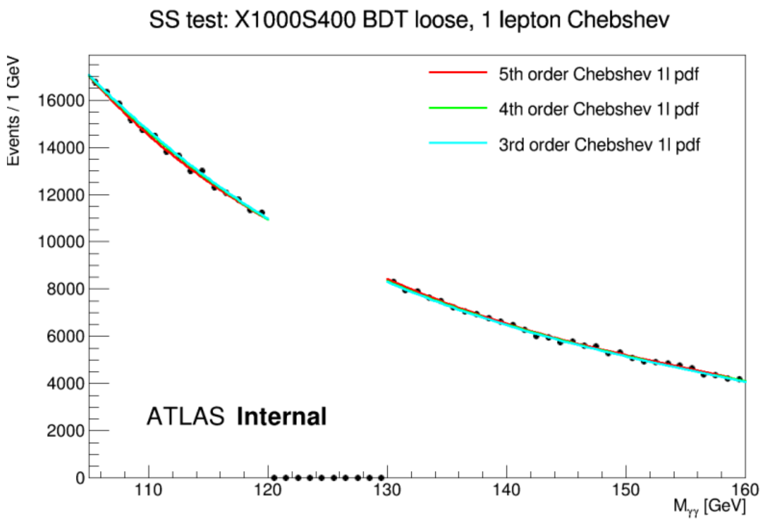
1-lepton case					
Function	Ndof	$\mu_{sp}[\%]$	$Z_{sp}[\%]$	$P(\chi^2)[\%]$	Selected
Exp	1	0.47	9.1	39.06	Yes
ExpPoly2	2	0.39	8.2	41.27	Yes
Cheb3	3	10.2	19.3	18.46	No
Cheb4	4	8.8	21.2	27.23	No
Cheb5	5	6.31	23.3	24.13	No

Table 21: The spuirous signal test result for 1 lepton channel in $m_X = 1000GeV, m_S = 300GeV$, BDT loose region.

- Impact for different background functions tested.
- 2nd order exponential polynomial chosen.
- μ_{SP} used as uncertainty on signal yields.
  - Final impact < 1%.

Chebyshev polynomial functions usually can not pass the criteria; Bernstein is buggy for discontinuous regions. For 1st Exp and 2nd Exp, following the previous practice, 2nd Exp is chosen for 78 out of 80 regions, left 2 use 1st Exp.





Theory uncertainties

- Truth level sample generated to calculate the global change for variations:
  - Madgraph+Pythia8
  - Madgraph+Herwig7

  - In MadGraph, need to specify model name for Herwig: SM_loop_twoscalar.
  - Signal QCD ~13% for X1000S500.
  - All signal, SM single Higgs, dihiggs components in consideration.

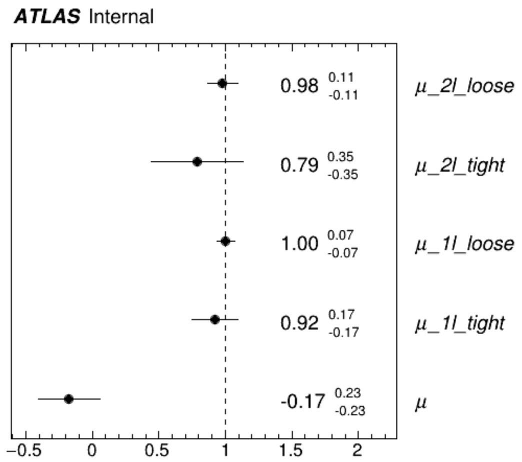
1 lepton region				
Uncertainties	α_S (%)	PDF (%)	QCDup(%)	QCDdown (%)
ggF	3.39	3.67	25.89	-15.97
VBF	0.98	7.96	0.97	-0.52
WmH	0.83	5.78	2.77	-3.20
WpH	0.86	4.99	2.45	-3.08
qqZH	0.88	6.08	3.64	-3.68
ggZH	1.14	3.08	25.83	-19.45
ttH	2.00	5.21	7.39	-9.51
tHbj	0.00	17.01	8.38	-8.63
tHW	0.00	8.30	2.51	-2.02
2 lepton region				
Uncertainties	α_S (%)	PDF (%)	QCDup(%)	QCDdown (%)
ggF	4.37	4.39	38.96	-16.38
VBF	0.70	0.11	1.19	-1.12
WmH	1.02	4.83	1.87	-3.37
WpH	1.17	4.26	5.16	-4.12
qqZH	1.00	5.78	4.67	-3.91
ggZH	1.03	2.97	25.77	-19.41
ttH	1.92	4.87	6.63	-9.59
tHbj	0.00	30.57	9.91	-8.77
tHW	0.00	8.07	5.45	-6.46

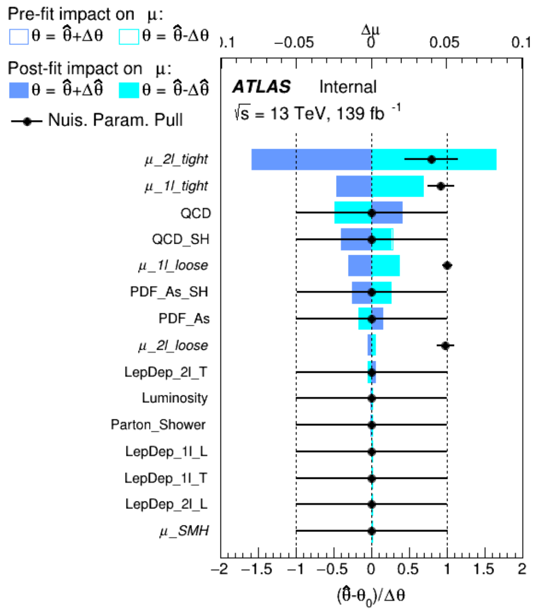
Table 22: SM Higgs theoretical uncertainties for QCD, α_S and PDF variations.

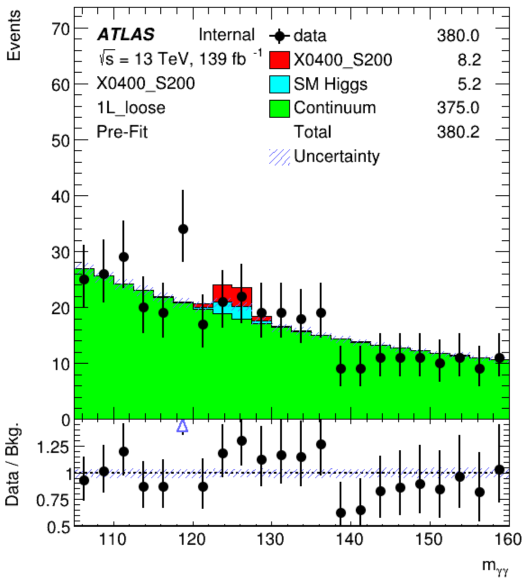
1 lepton region					
Uncertainties	Parton Shower (%)	α_S (%)	PDF (%)	qcdup(%)	qcddown (%)
di-Higgs	2.51	0.93	3.87	13.22	-12.47
2 lepton region					
Uncertainties	Parton Shower (%)	α_S (%)	PDF (%)	qcdup(%)	qcddown (%)
di-Higgs	-2.85	0.93	3.94	13.17	-12.48

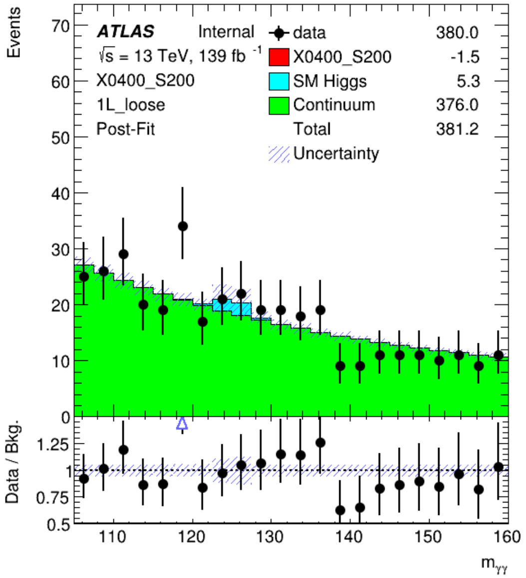
Table 23: Di-Higgs theoretical uncertainties for Parton shower, QCD, α_S and PDF variations.

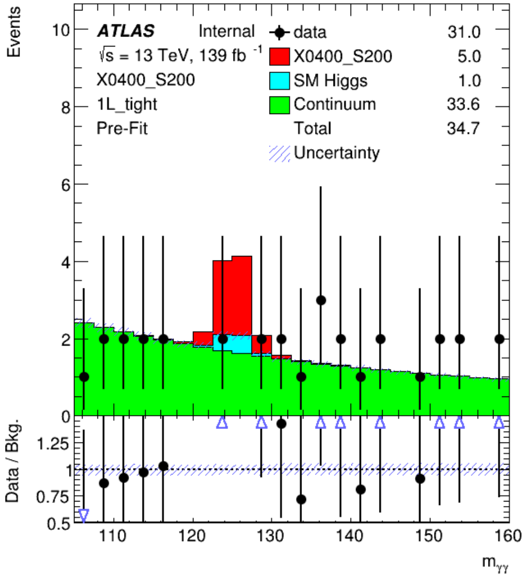
Unblinding: Low mass X400S200

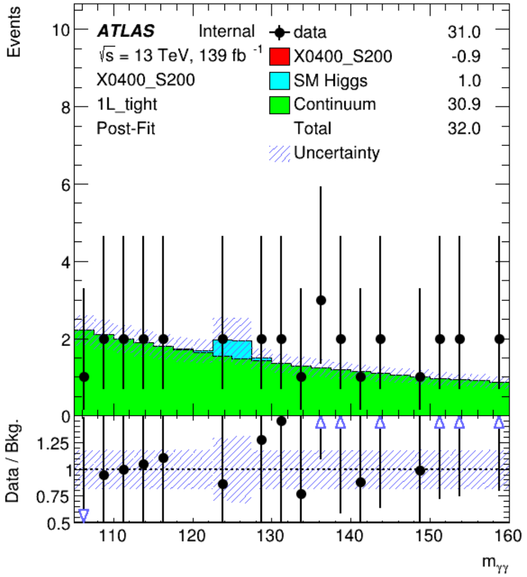




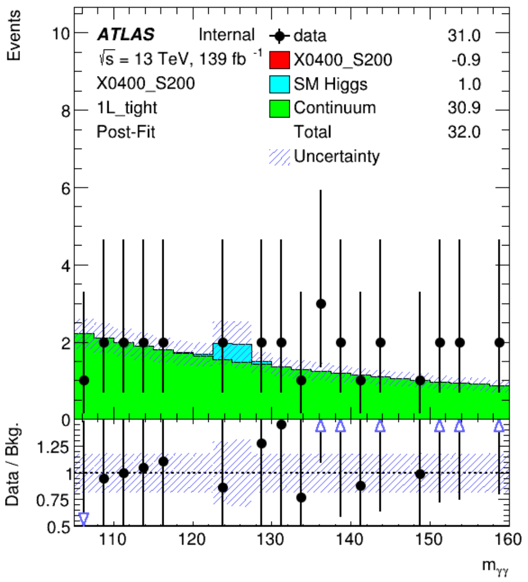


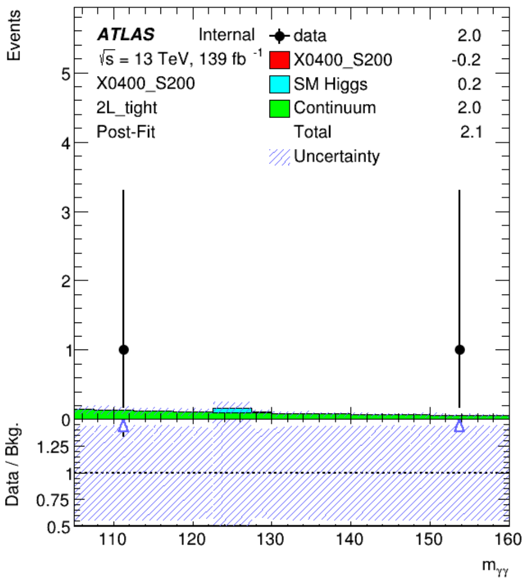


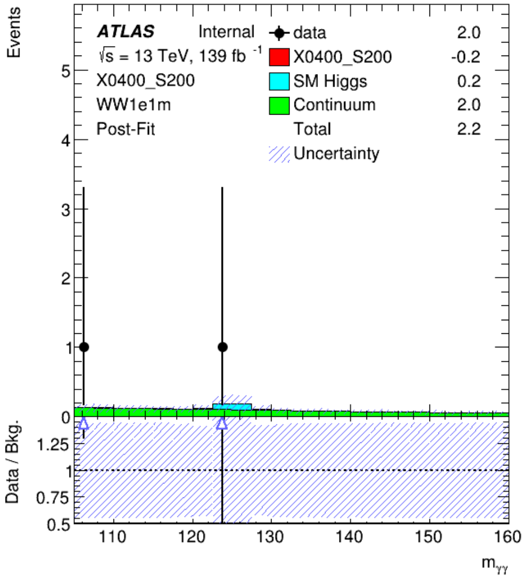


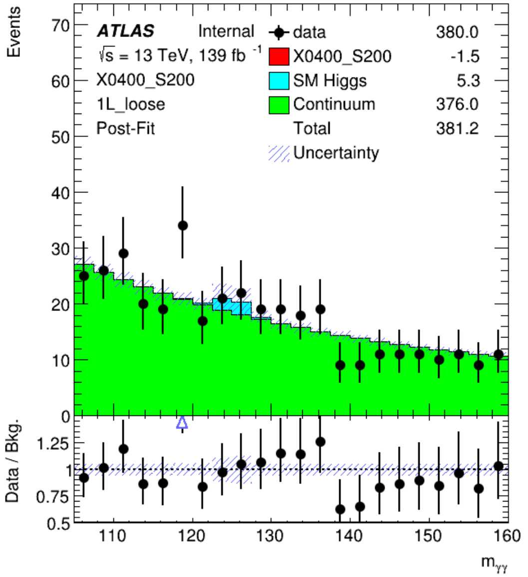


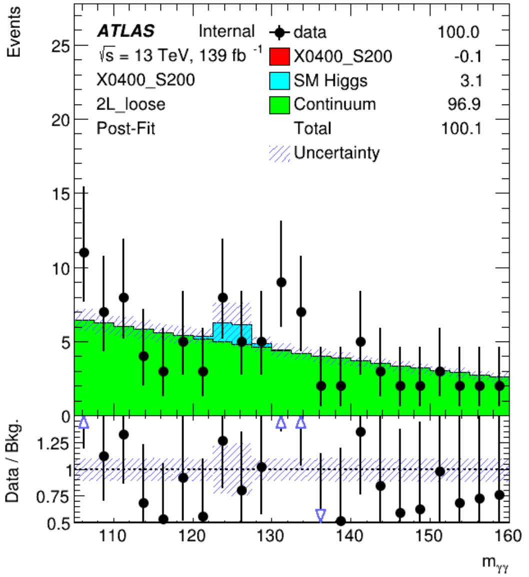
X400S200 regions

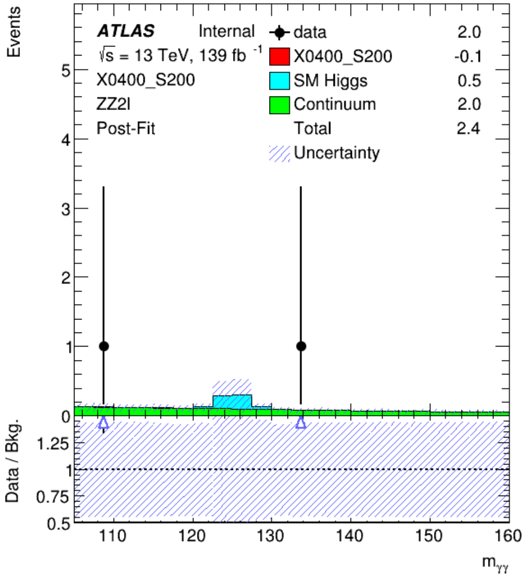




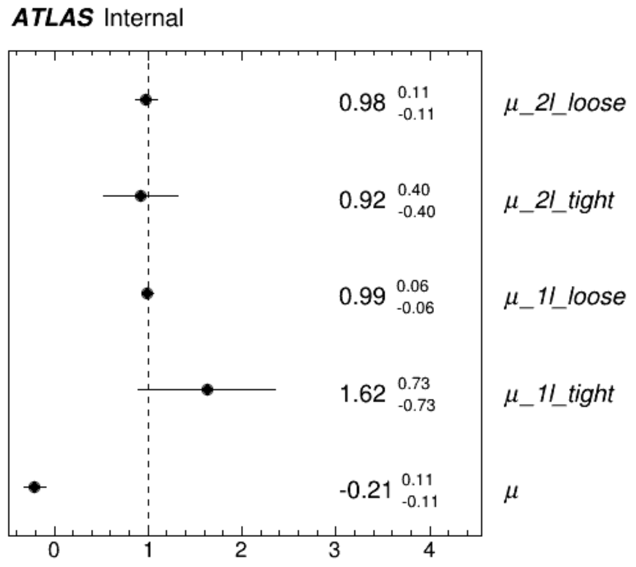


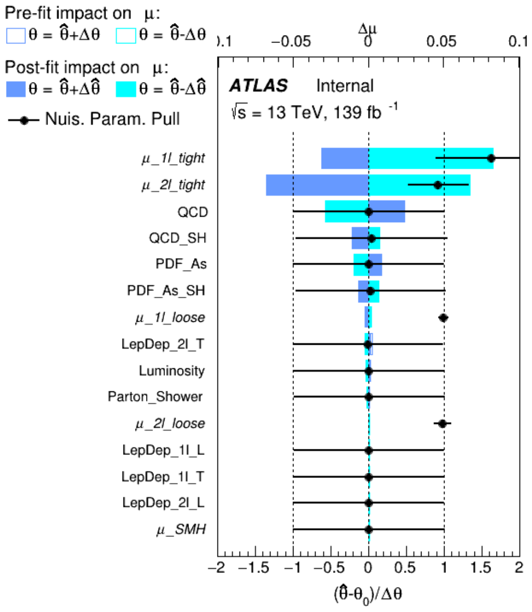


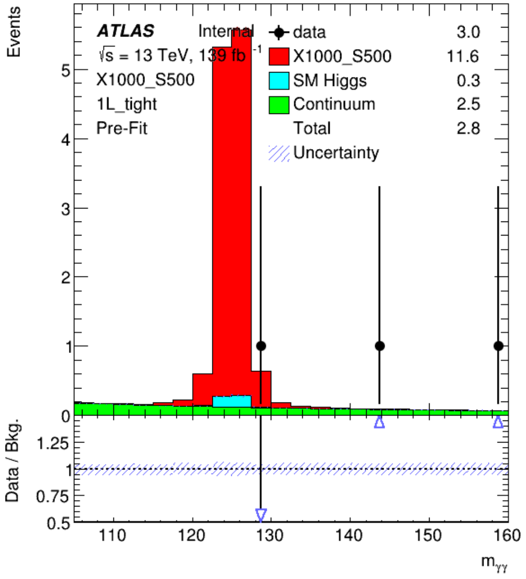


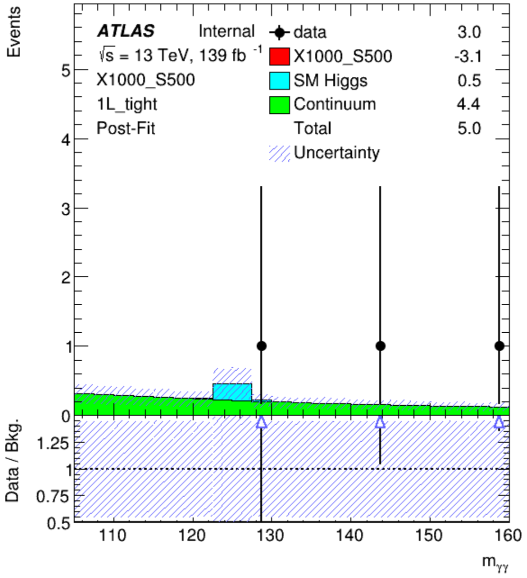


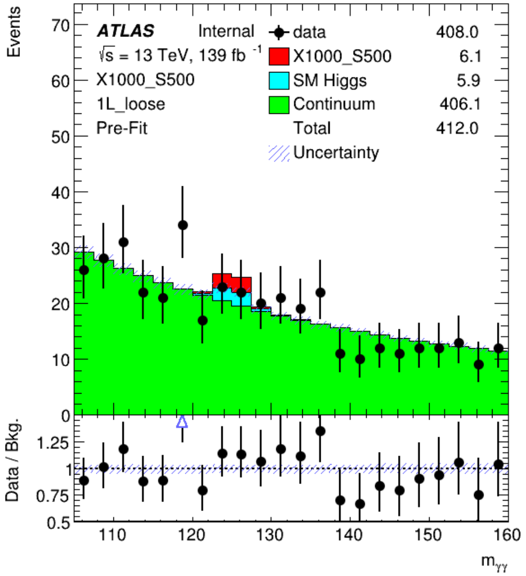
Unblinding: High mass X1000S500

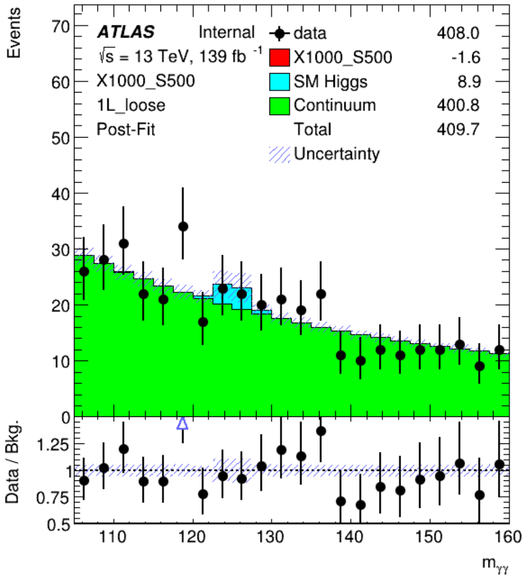




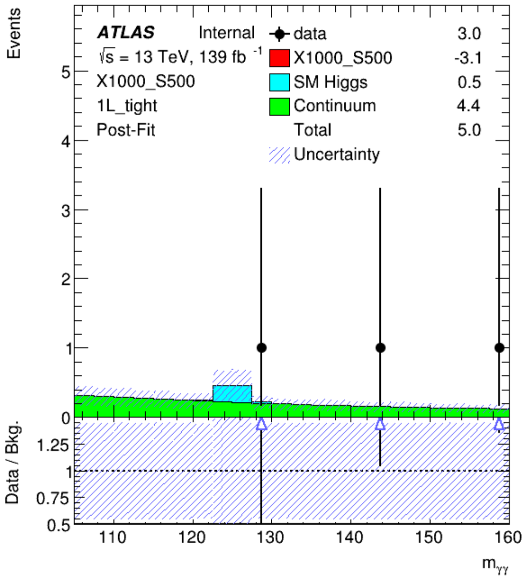


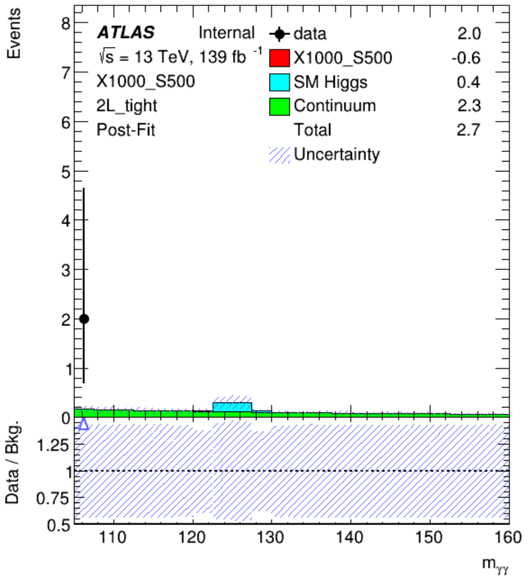


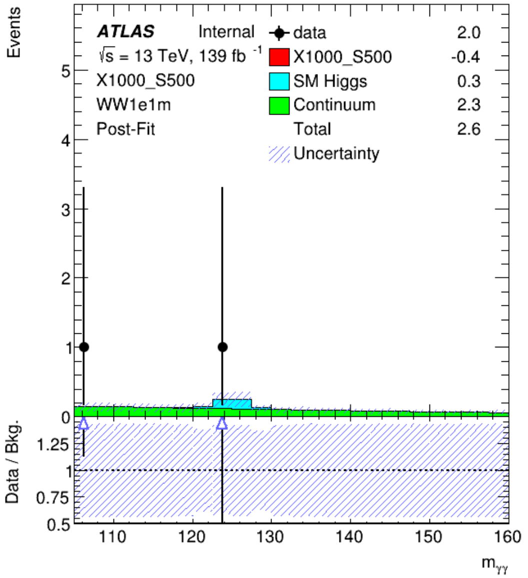


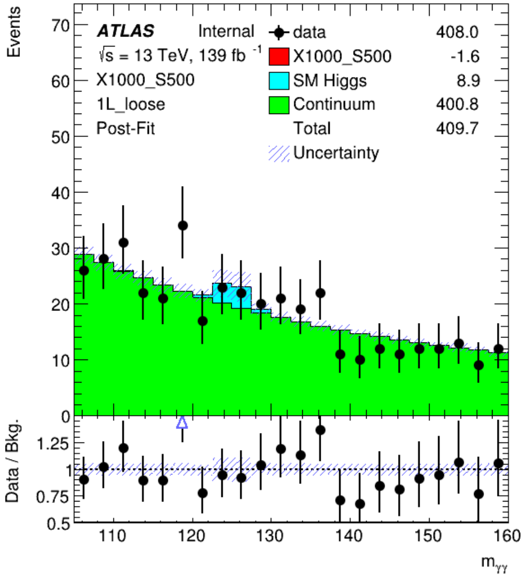


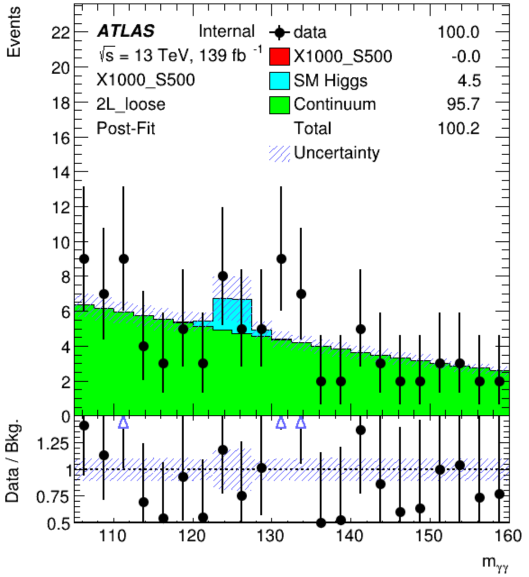
X1000S500 regions

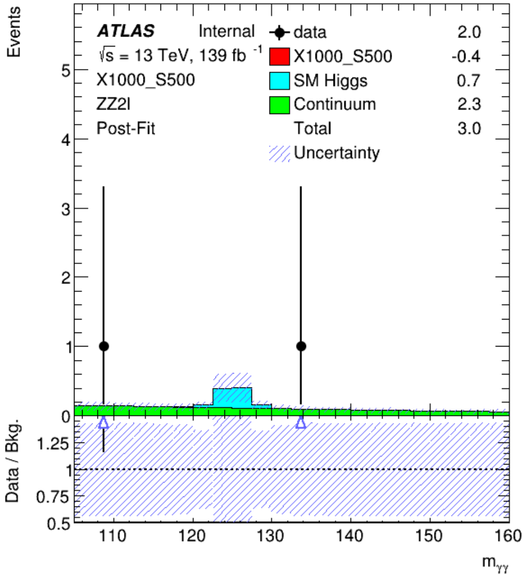










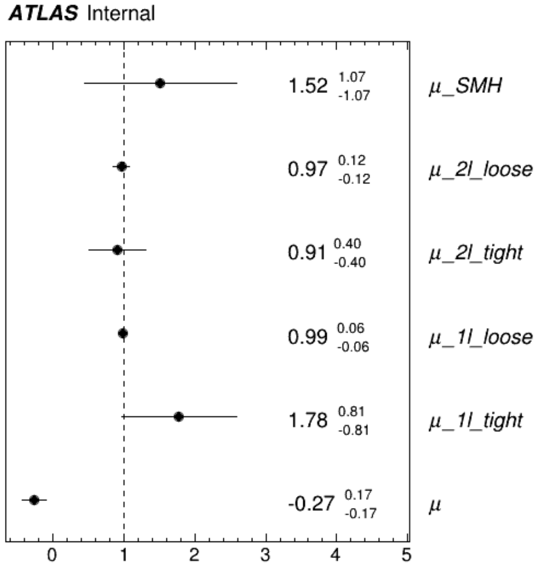


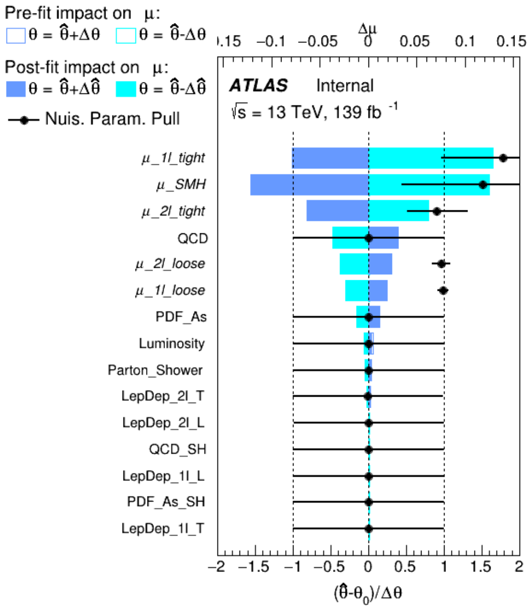
SM_Higgs normalization

- One factor assigned to SM Higgs(ggH, VBFH, WH, qqZH, ggZH……)
  - Fix or float?
- Maximum difference 6% on limit for 20 mass points
  - Fixing is always better.
- If float, usually norm factor around 1
- Corresponding to different assumption

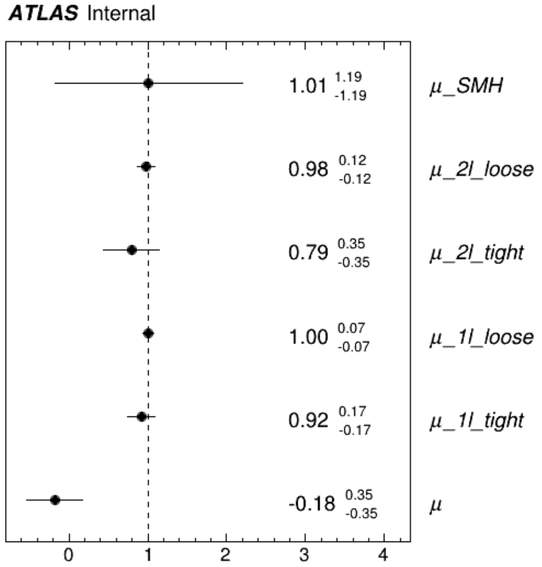
- Choose to fix SM_higgs to 1.
  - Very strong anti-correlation with signal
  - 20 mass points will lead to different normalization.
  - Use theoretical uncertainties to constrain SM_higgs (9% QCD and 6% PDF_As)

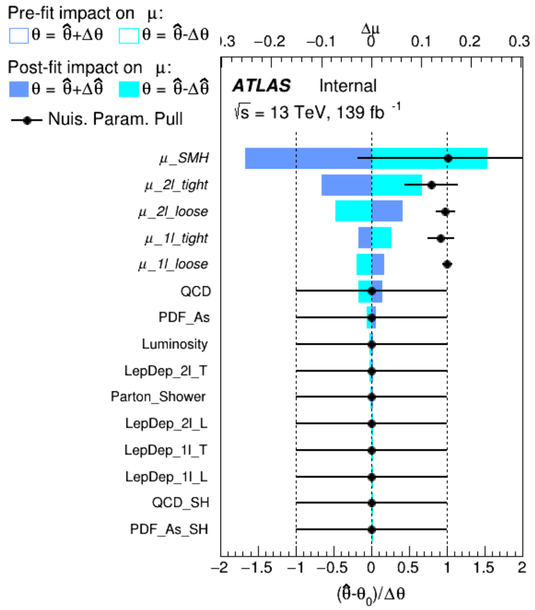
Float SM_Higgs: X1000S500, X400S200





X1000S500

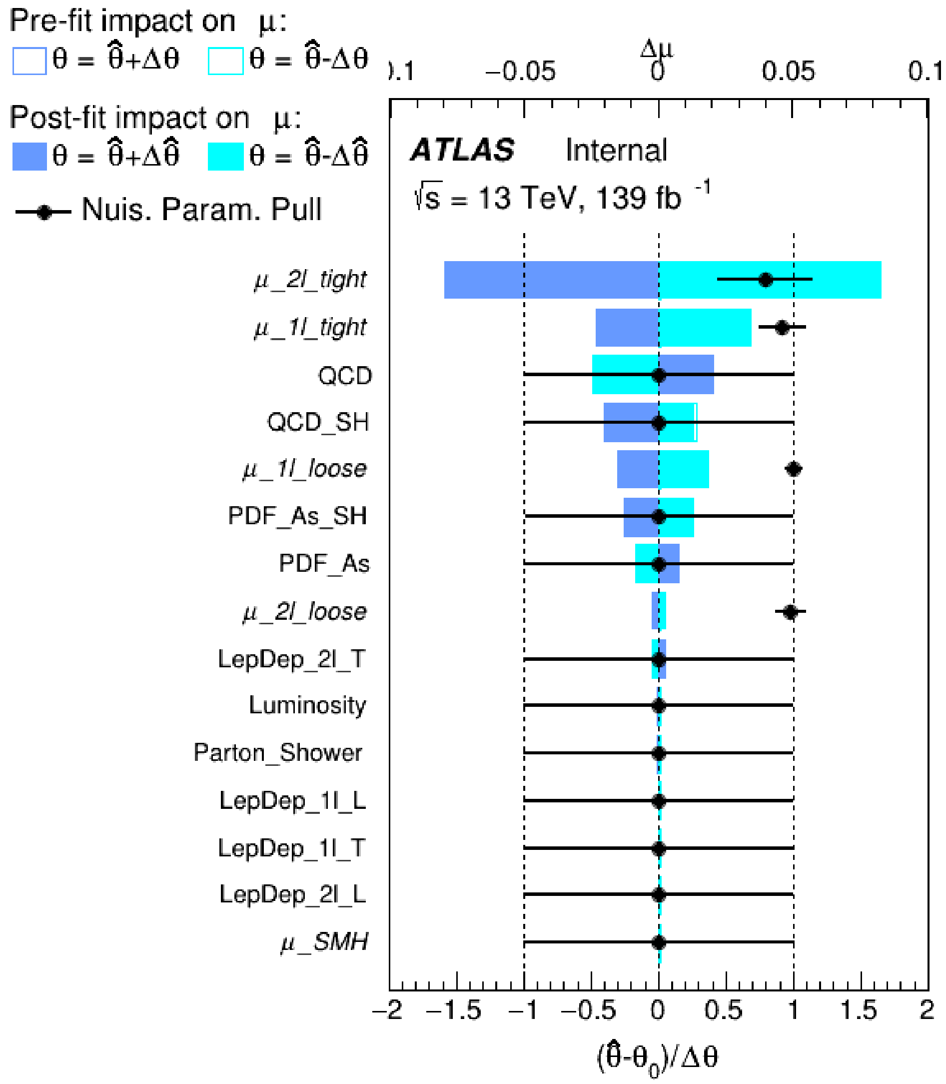




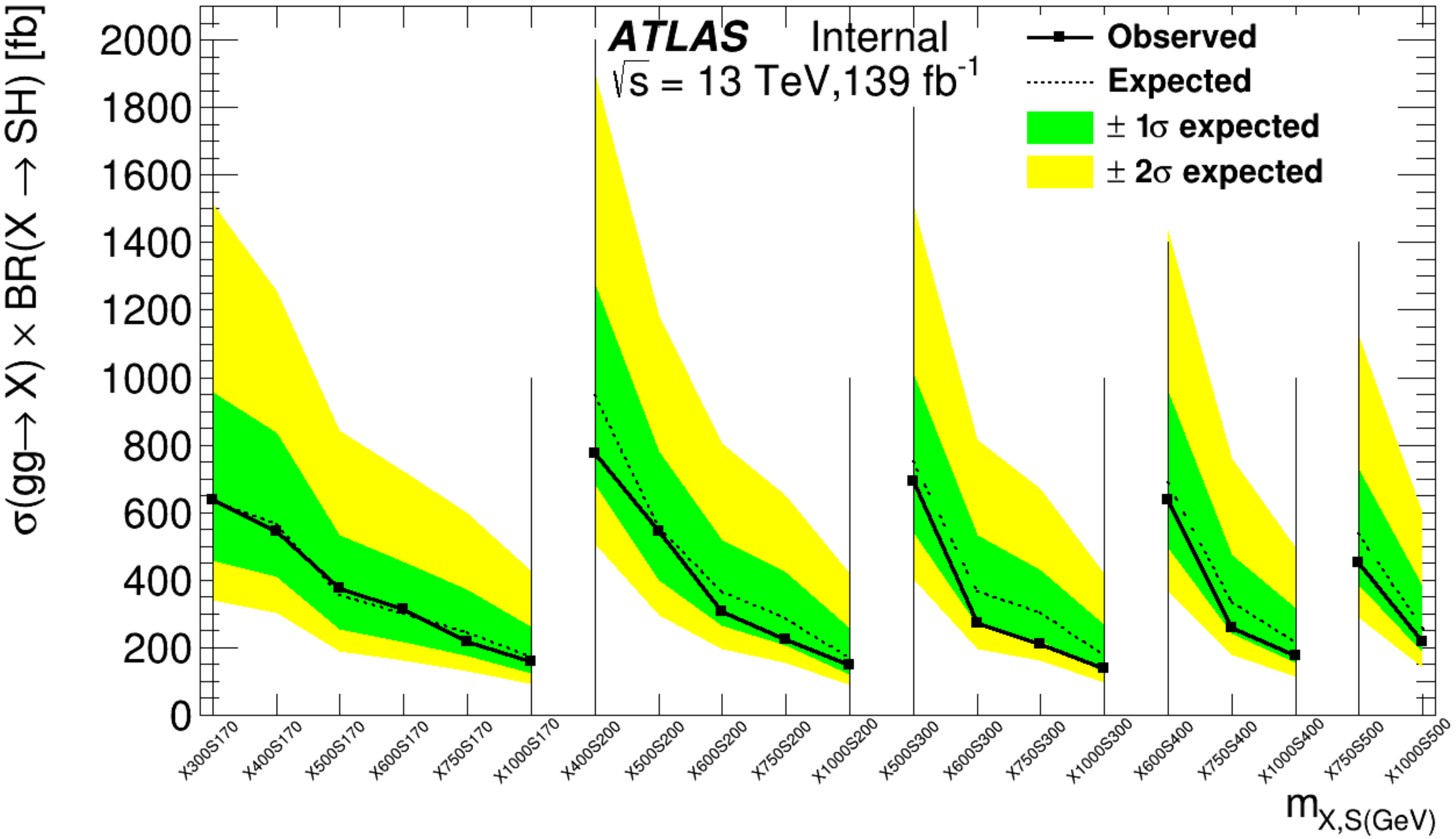
X400S200

Experimental uncertainties

- For experimental NPs, though >100 NPs in study
- Most of them are vetoed by the 0.5% threshold.
  - Typical value for EG_Scale_All: 1*10^-3.
- Before unblinding, Egamma uncertainties can enter the fit;
  - With unblinding, all those NPs are vetoed.



Limit: along S mass



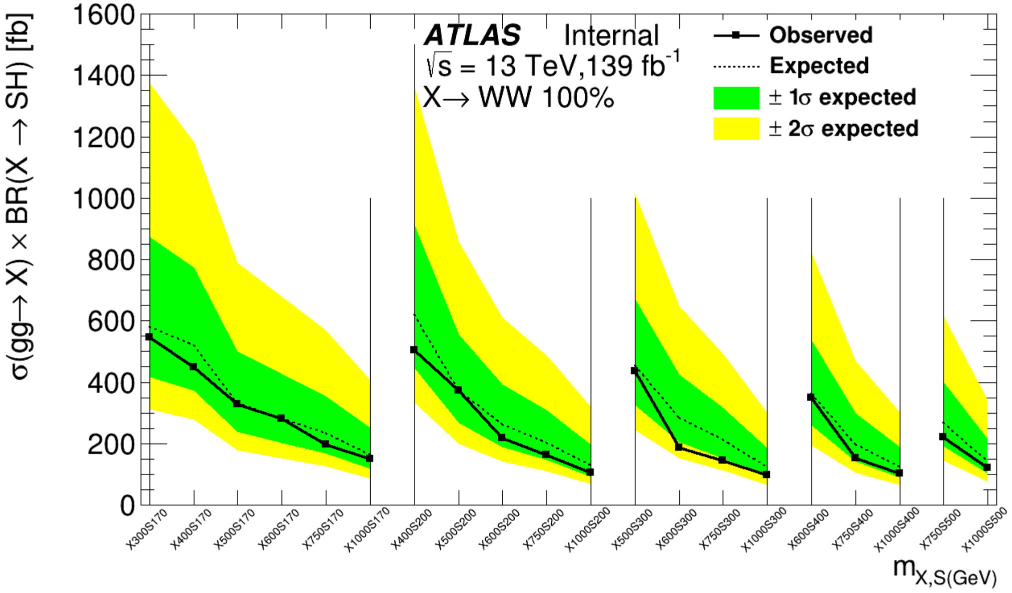
Limit Table

(fb)	X300S170	X400S170	X400S200	X500S170	X500S200	X500S300	X600S170	X600S200	X600S300	X600S400
Exp	634	566	946	354	555	751	299	366	366	688
Obs	636	543	773	377	544	690	314	306	271	636
+1	958	836	1279	534	783	1011	454	519	535	961
+2	1516	1256	1901	843	1183	1513	724	806	817	1437
-1	457	408	682	255	400	541	216	264	264	496
-2	340	304	508	190	298	403	161	196	196	369
	X750S170	X750S200	X750S300	X750S400	X750S500	X1000S170	X1000S200	X1000S300	X1000S400	X1000S500
Exp	244	286	304	336	537	171	169	183	214	260
Obs	215	225	209	259	452	157	149	139	175	218
+1	372	424	430	476	730	262	258	279	318	381
+2	598	651	672	762	1127	426	419	450	497	598
-1	176	206	219	242	387	123	121	132	154	187
-2	131	153	163	180	288	92	90	98	115	139

Results for S 100% to WW/ZZ.

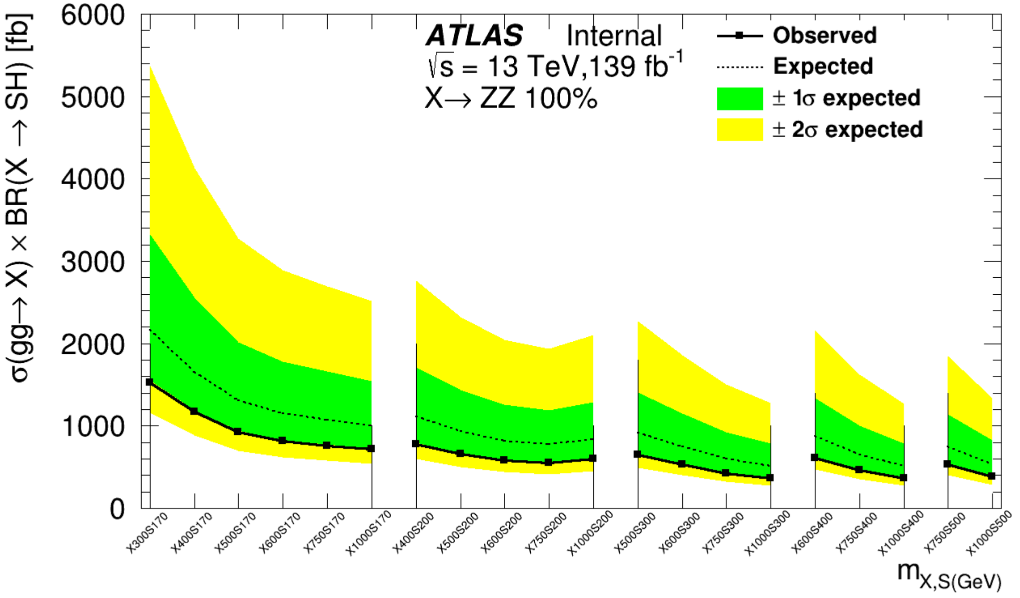
For the convenience for theorists, other than SM Higgs-like decay, 100% decay to WW/ZZ given.
BDT cut value stay the same as SM predictions, but scale the yields to 100% WW/ZZ.

WW:



100% WW have better limits for larger yields.

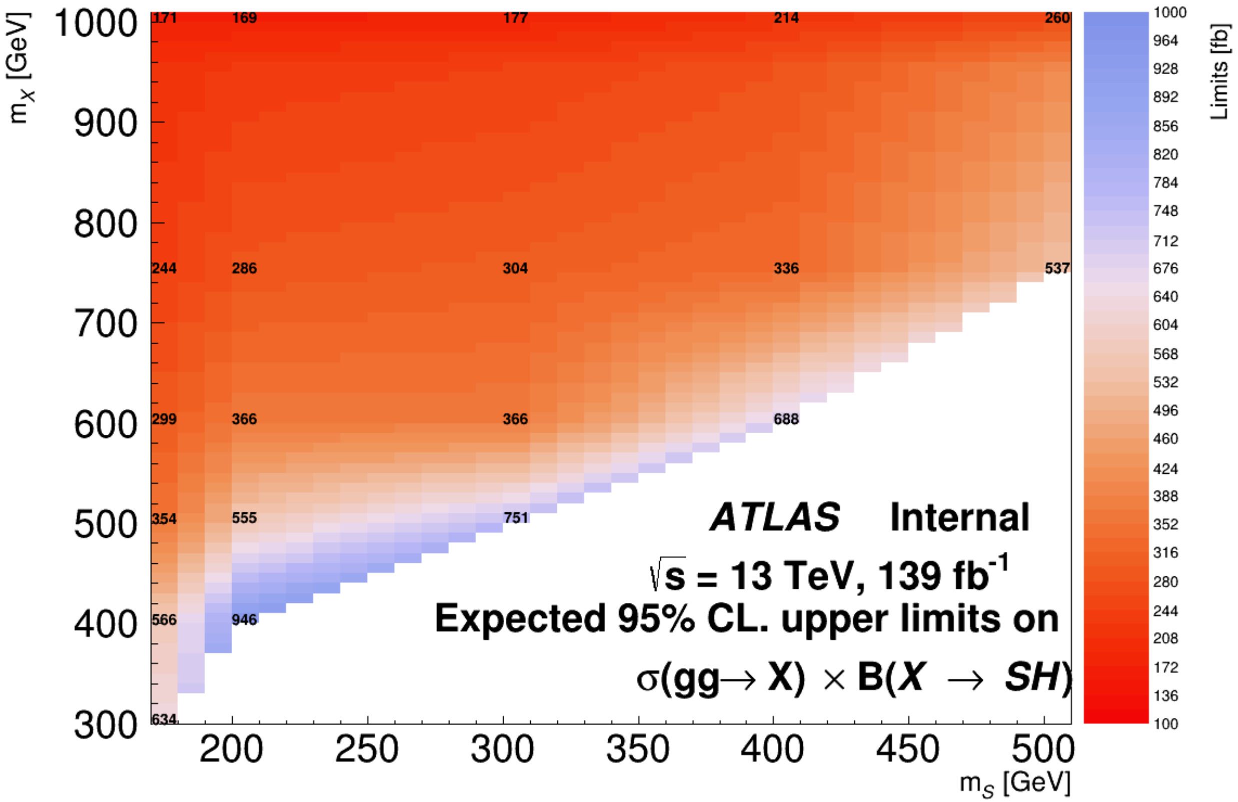
ZZ:

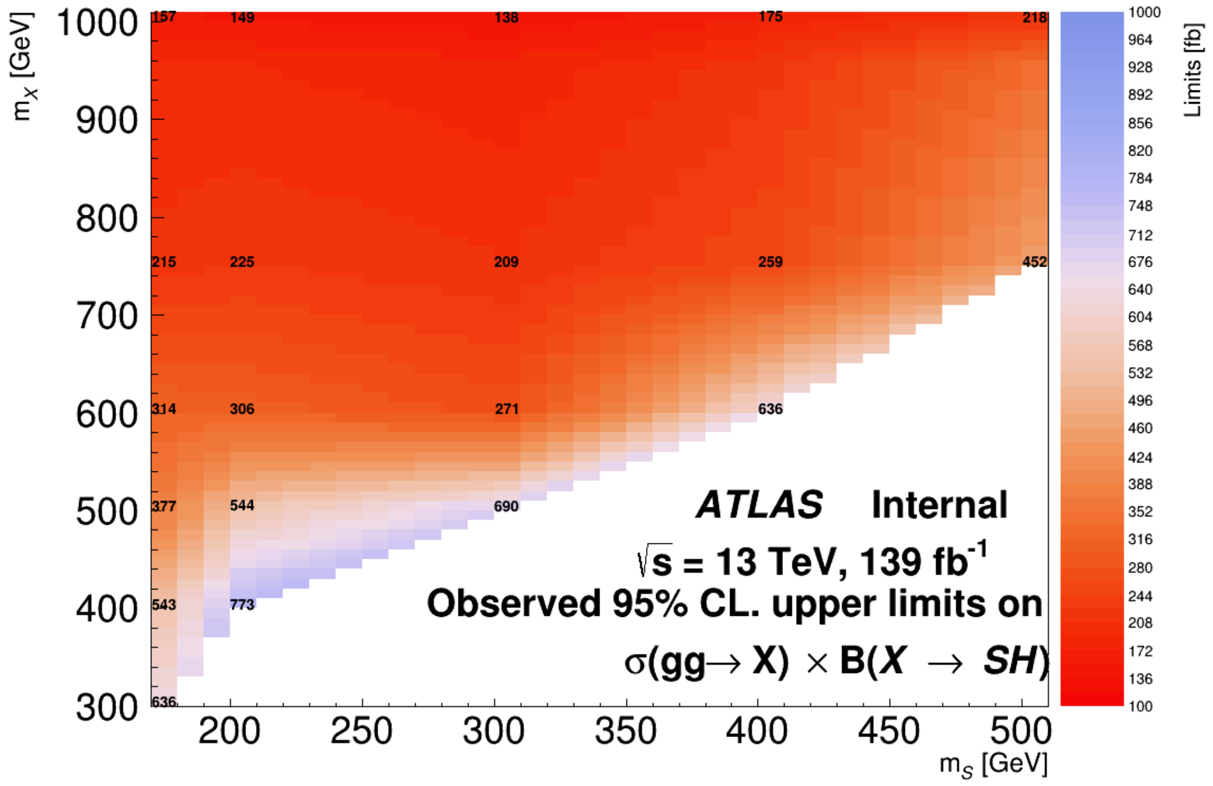


ZZ suffered from limited selection efficacy.

Interpolation

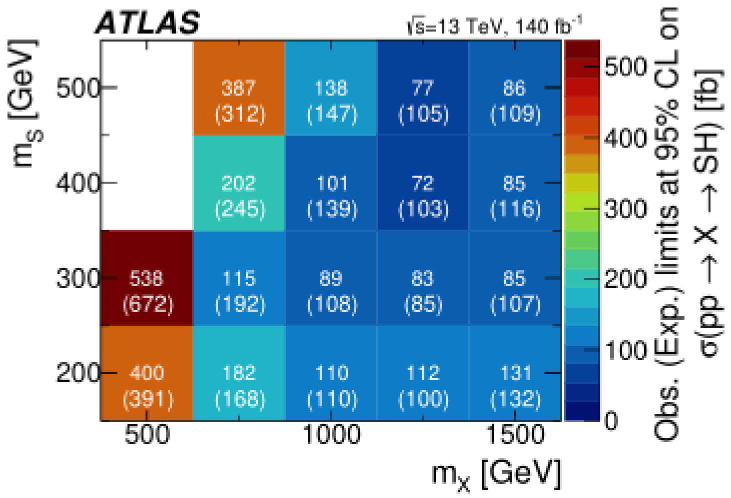
Use bisect linear interpolation to conver the whole X-S plane.
Best point: X1000S300.

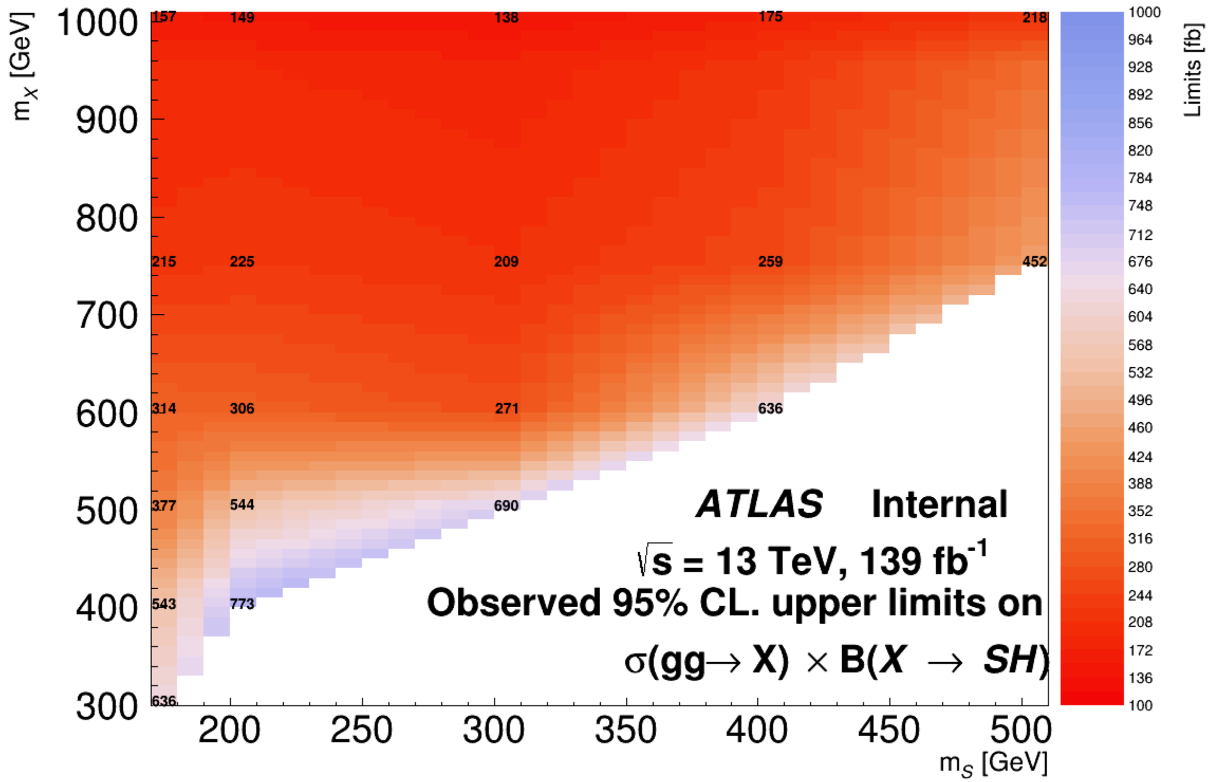




Comparison with other analysis

X1000S200, observed 149fb for VVyy and 110fb for VVtautau.
X1000S300, observed 138fb for VVyy and 89fb for VVtautau.
Also in the same order of magnitude with CMS results.



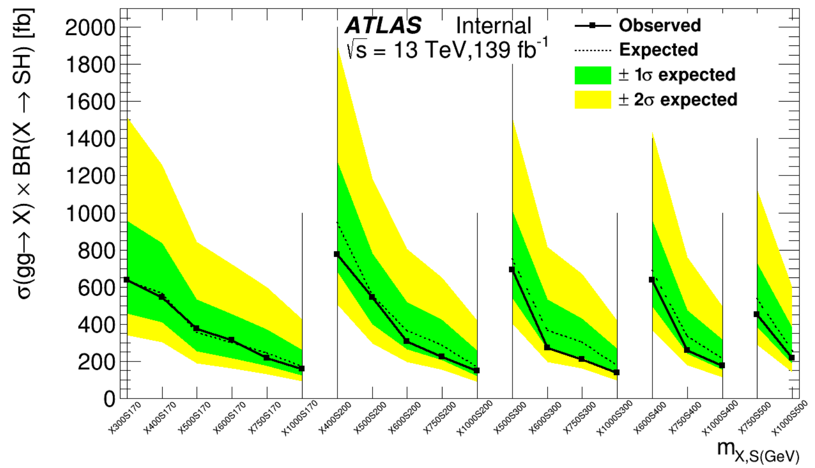


Summary

- $X \rightarrow SH \ \rightarrow \gamma\gamma + leptons$ unblinding results and observed limit shown
  - Best limit given on X1000S300.
  - Results comparable with other SH studies.

- Unblinding results will be soon implemented in to the draft and paper.

(fb)	X300S170	X400S170	X400S200	X500S170	X500S200	X500S300	X600S170	X600S200	X600S300	X600S400
Exp	634	566	946	354	555	751	299	366	366	688
Obs	636	543	773	377	544	690	314	306	271	636
+1	958	836	1279	534	783	1011	454	519	535	961
+2	1516	1256	1901	843	1183	1513	724	806	817	1437
-1	457	408	682	255	400	541	216	264	264	496
-2	340	304	508	190	298	403	161	196	196	369
	X750S170	X750S200	X750S300	X750S400	X750S500	X1000S170	X1000S200	X1000S300	X1000S400	X1000S500
Exp	244	286	304	336	537	171	169	183	214	260
Obs	215	225	209	259	452	157	149	139	175	218
+1	372	424	430	476	730	262	258	279	318	381
+2	598	651	672	762	1127	426	419	450	497	598
-1	176	206	219	242	387	123	121	132	154	187
-2	131	153	163	180	288	92	90	98	115	139



Backups

WW ZZ results

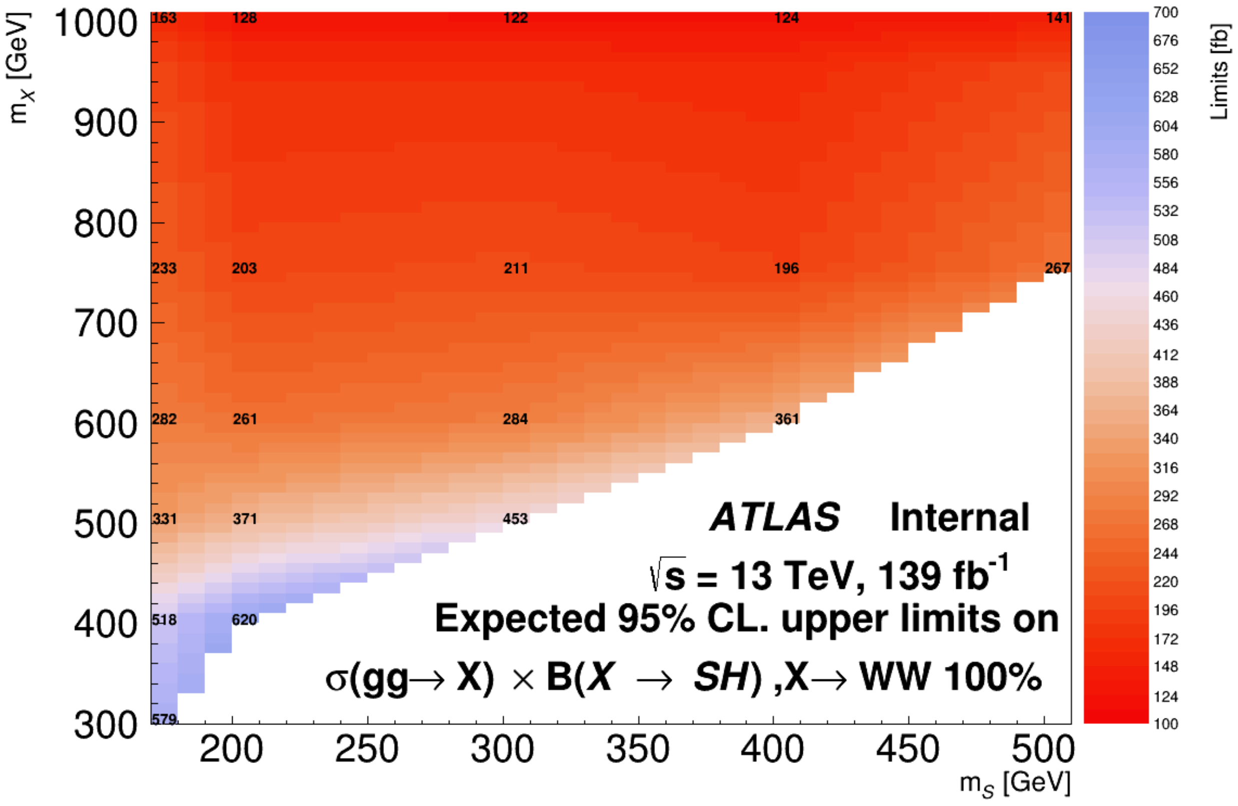
m_X [GeV]	$m_S[GeV]$	Expected [fb]	Observed [fb]	$+1\sigma$ [fb]	$+2\sigma$ [fb]	-1σ [fb]	-2σ [fb]
300	170	579	546	874	1374	417	311
400	170	518	448	774	1184	373	278
500	170	331	327	502	790	239	178
600	170	282	280	428	679	203	151
750	170	233	196	355	569	168	125
1000	170	163	149	251	408	118	88
400	200	620	505	913	1363	446	333
500	200	371	374	557	859	268	199
600	200	261	216	394	611	188	140
750	200	203	162	308	488	146	109
1000	200	128	106	196	319	92	69
500	300	453	436	673	1015	327	243
600	300	284	185	425	649	205	153
750	300	211	144	318	493	152	113
1000	300	122	96	187	301	88	66
600	400	361	350	539	824	260	194
750	400	196	151	298	470	142	105
1000	400	124	103	189	302	89	66
750	500	267	220	401	615	192	143
1000	500	141	121	214	341	101	75

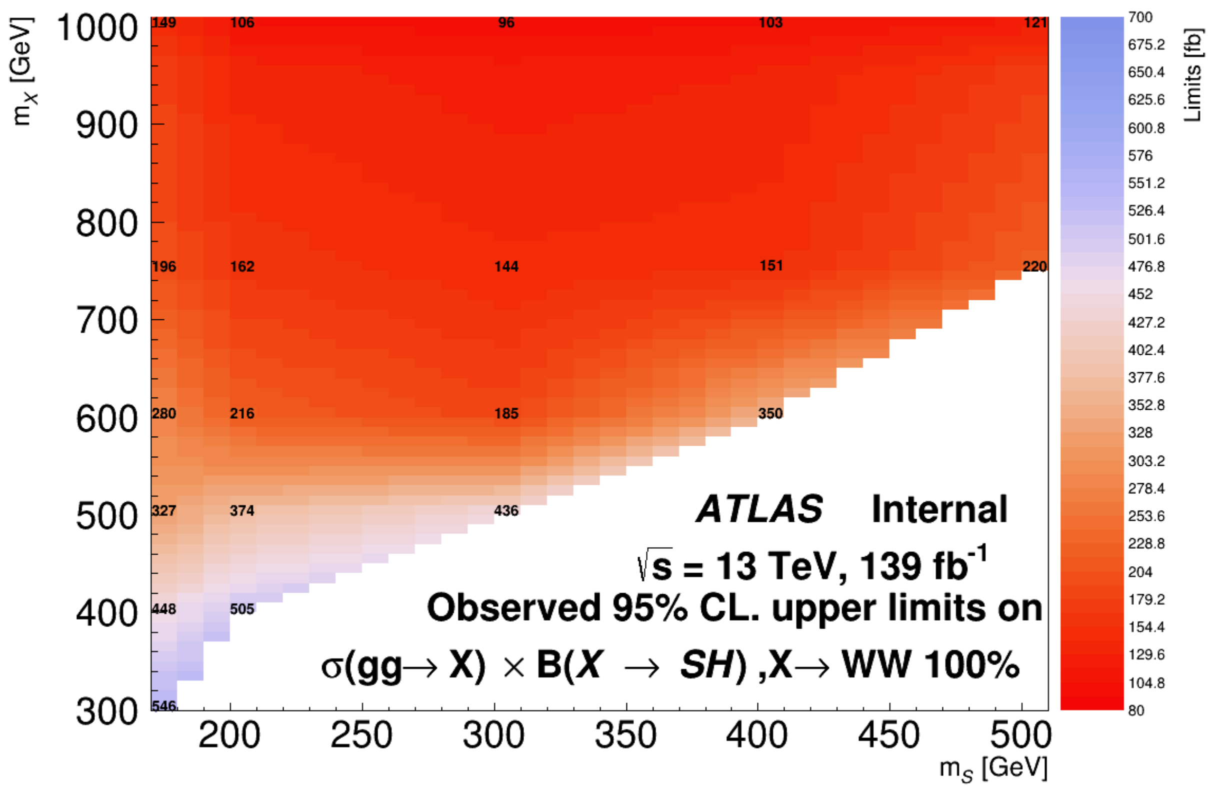
Table 28: Upper limits at the 95% confidence level for the cross-section of the gluon fusion production of the resonance $X \to SH$ and the S particle is assumed to decay fully to WW.

m_X [GeV]	$m_S[GeV]$	Expected [fb]	Observed [fb]	$+1\sigma$ [fb]	$+2\sigma$ [fb]	-1σ [fb]	-2σ [fb]
300	170	2161	1522	3326	5373	1557	1160
400	170	1657	1166	2554	4130	1194	889
500	170	1109	923	1709	2763	799	595
600	170	1309	816	2019	3275	943	703
750	170	933	761	1435	2324	672	501
1000	170	917	718	1409	2277	661	492
400	200	1152	779	1780	2895	830	618
500	200	820	663	1261	2045	591	440
600	200	746	584	1147	1859	538	400
750	200	871	555	1337	2161	628	468
1000	200	1075	605	1659	2696	774	577
500	300	774	649	1192	1936	558	415
600	300	601	528	925	1502	433	322
750	300	651	427	1000	1623	469	349
1000	300	745	366	1145	1854	537	400
600	400	1002	612	1548	2521	722	538
750	400	839	462	1293	2105	605	450
1000	400	509	364	784	1276	367	273
750	500	508	529	782	1273	366	273
1000	500	535	383	824	1339	386	287

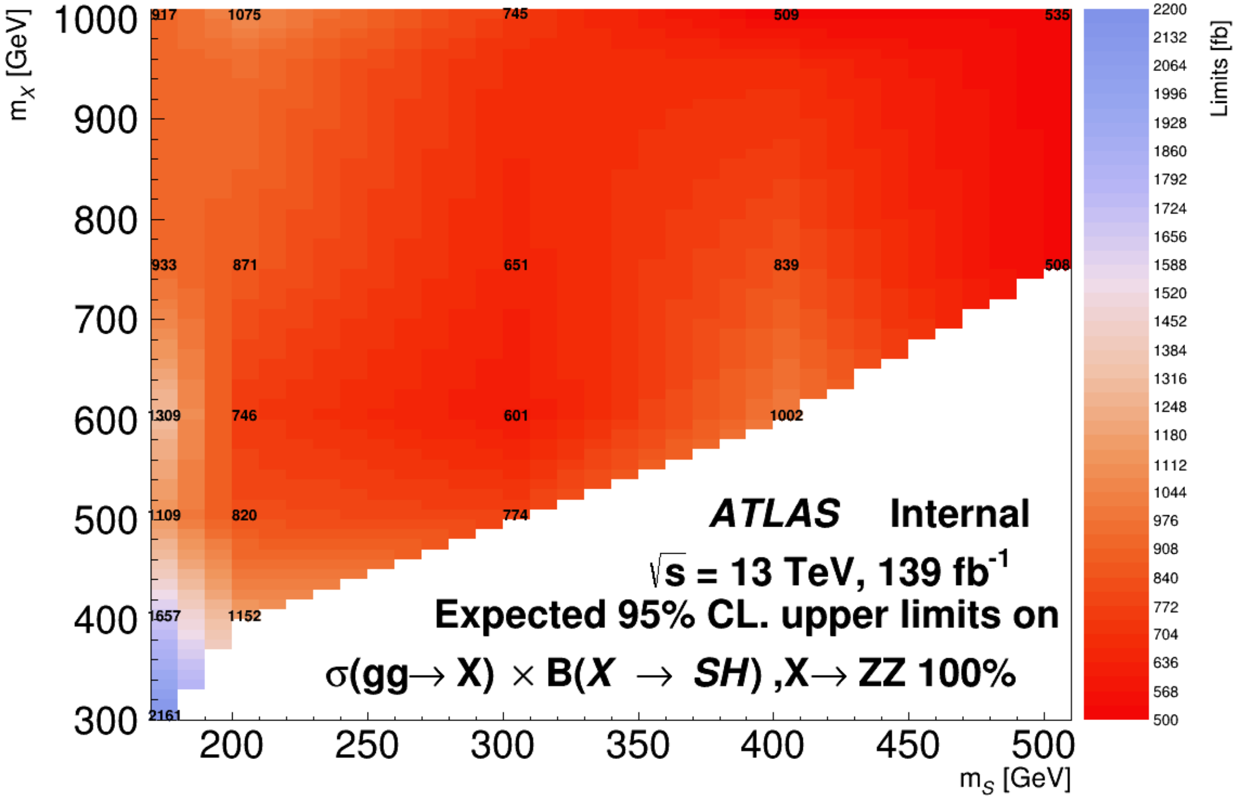
Table 29: Upper limits at the 95% confidence level for the cross-section of the gluon fusion production of the resonance $X \to SH$ and the S particle is assumed to decay fully to ZZ.

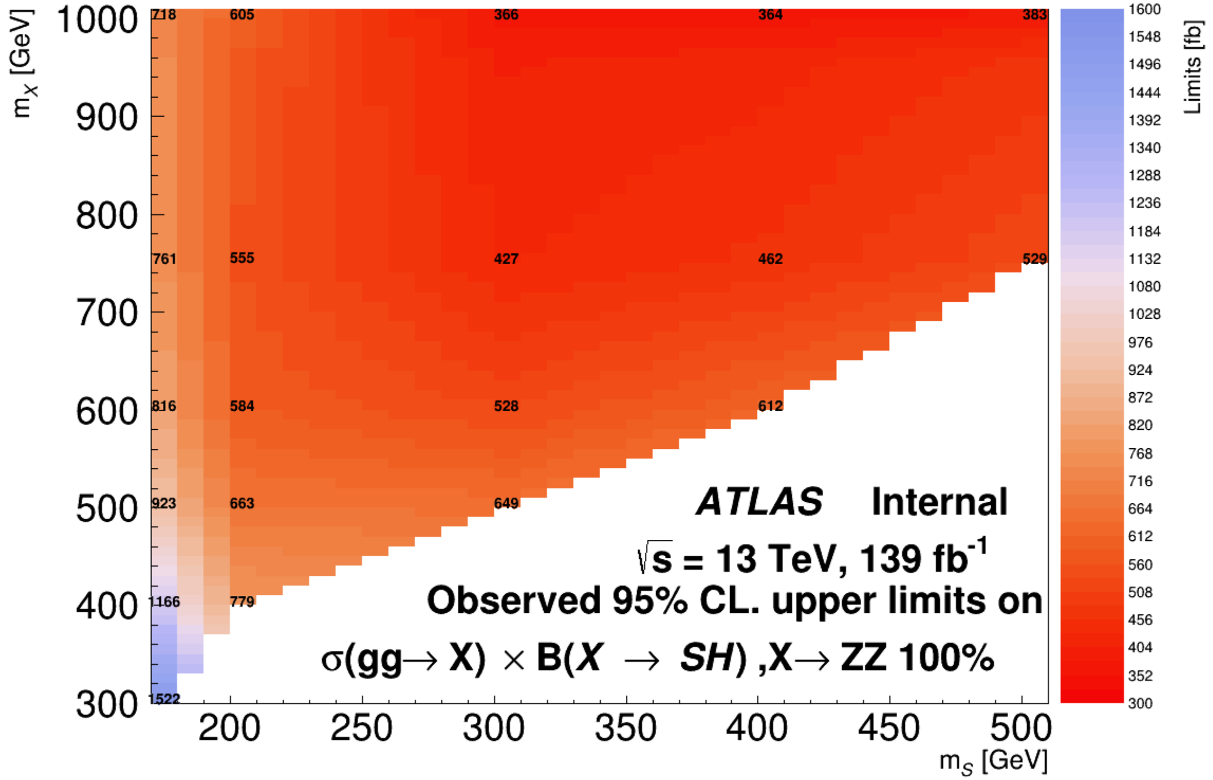
Interpolation on WW



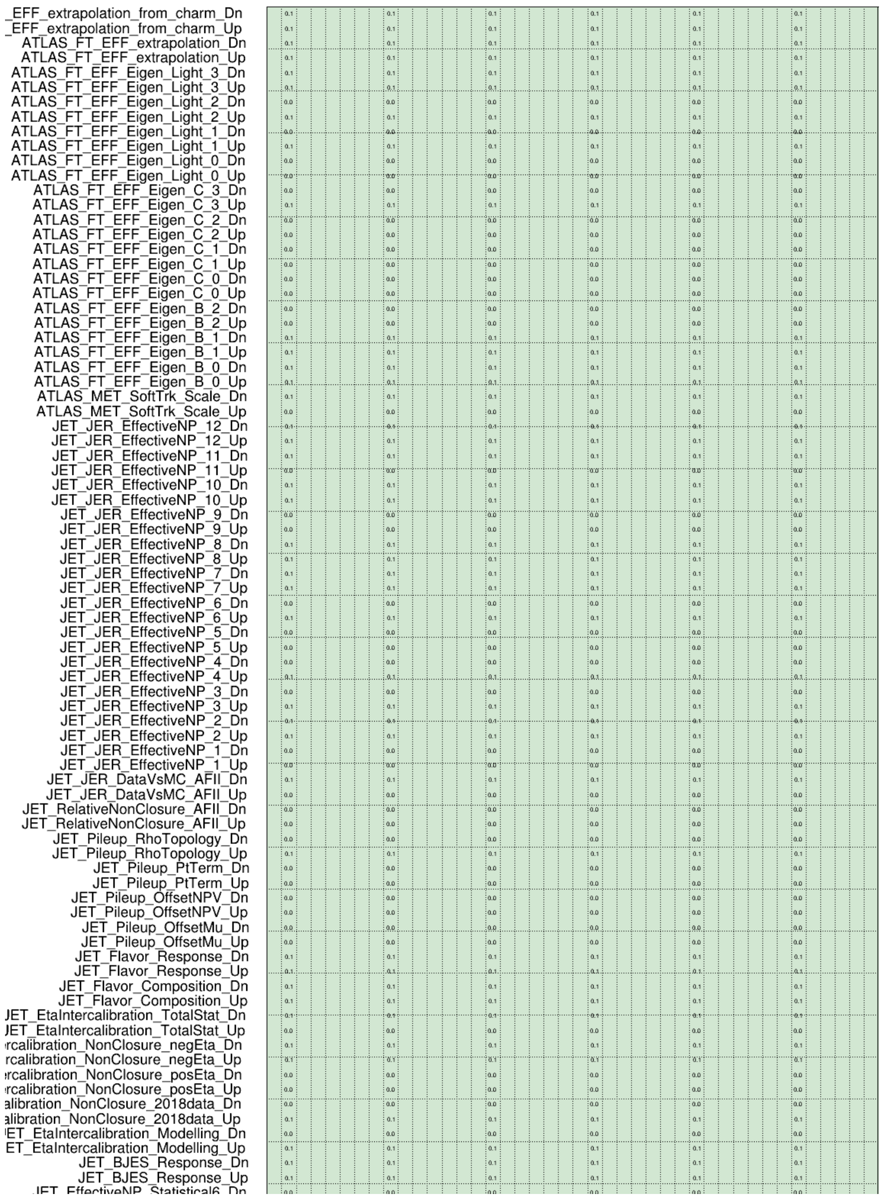


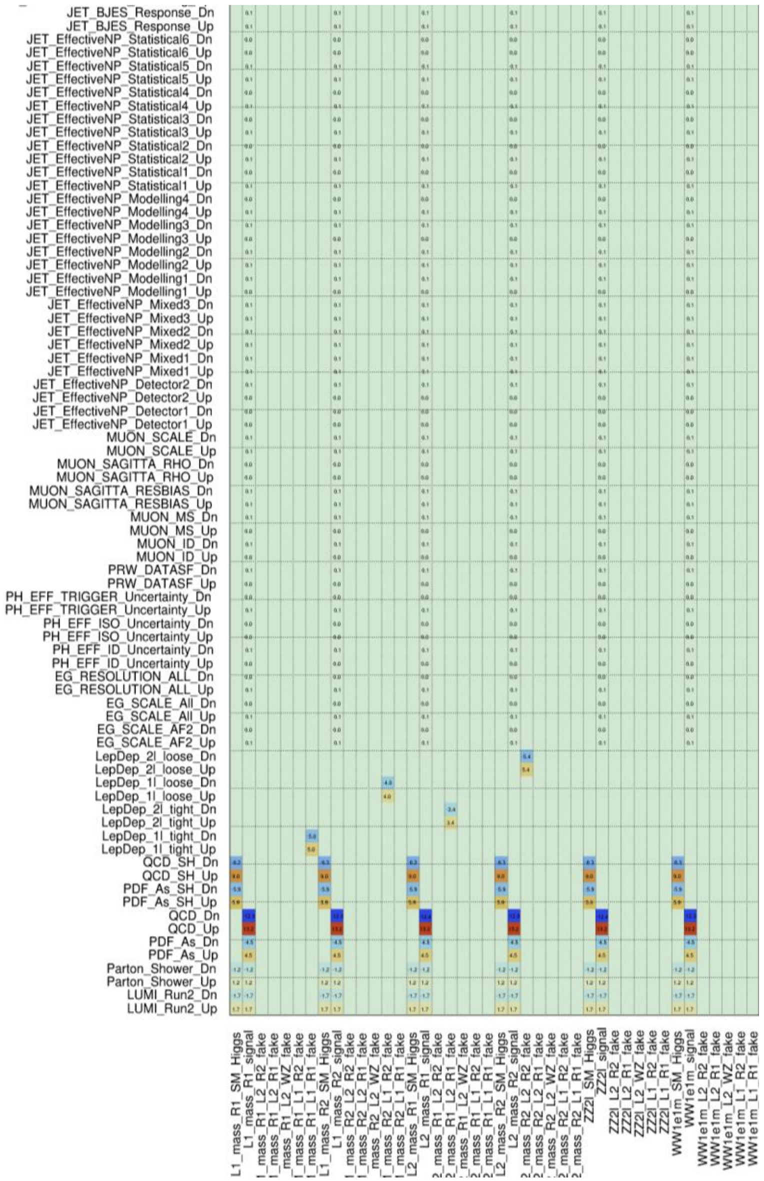
Interpolation on ZZ





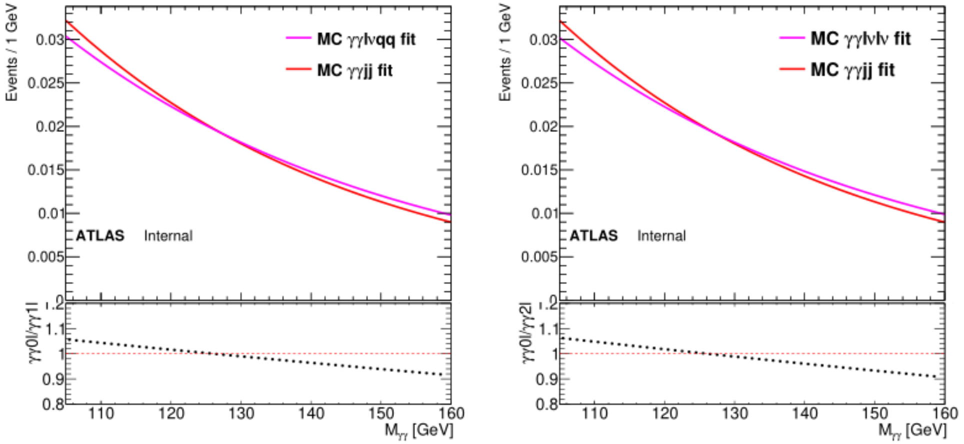
NPs vetoed by 0.5%

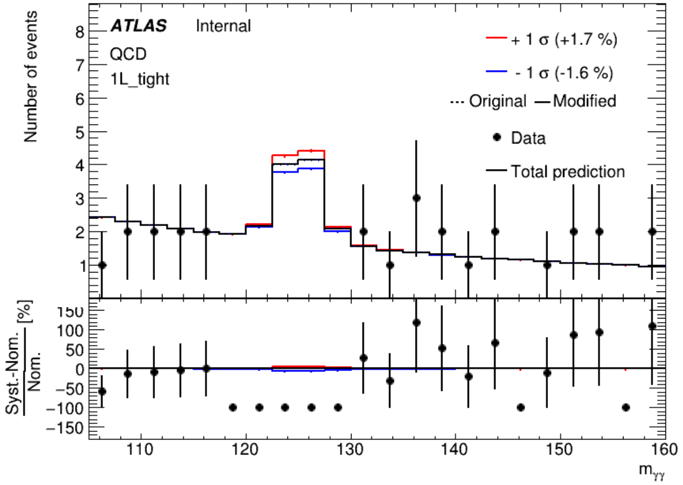




Bin by bin lepton dependance uncertainty

- Instead to calculate χ^2
- Histogram variations directly imported
- This lead to smaller uncertainty.
  - (For left plot, the uncertainty now is 1.3%).





Nominal and varied shape are automatically compared and the impact included.

Signal cutflows

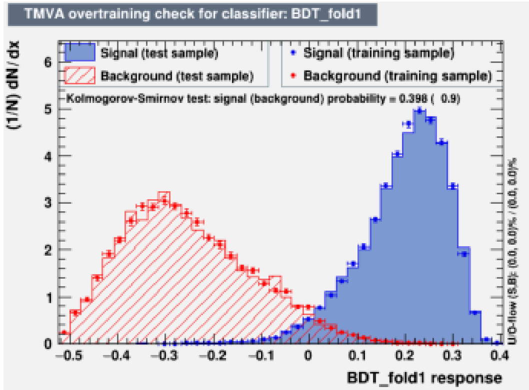
m_X	300	400	400	500	500	500	600	600	600	600
m_S	170	170	200	170	200	300	170	200	300	400
WW1l, DSID	800943	800944	800945	800946	800947	800948	800949	800950	800951	800952
All events	100	100	100	100	100	100	100	100	100	100
No duplicates	100	100	100	100	100	100	100	100	100	100
GRL	100	100	100	100	100	100	100	100	100	100
Pass trigger	77.56	82.25	81.14	88.92	88.45	83.35	91.86	91.69	90.37	84.82
Detector DQ	77.56	82.25	81.14	88.92	88.45	83.35	91.86	91.69	90.37	84.82
Has PV	77.56	82.25	81.14	88.92	88.45	83.35	91.86	91.69	90.37	84.82
2 loose photons	58.57	59.26	59.46	60.98	61.10	61.23	63.06	63.11	62.69	62.65
Trigger match	53.29	54.64	54.12	58.45	58.19	55.83	61.60	61.46	60.02	57.10
tight ID	45.04	46.47	46.07	49.67	49.36	47.09	52.24	52.01	50.49	47.84
isolation	36.73	39.99	38.98	44.28	43.61	39.70	47.45	46.98	44.37	40.26
rel. pT cuts	34.16	35.51	34.57	39.95	39.10	35.11	43.62	43.15	39.97	35.50
m_{yy} in [105, 160]GeV	33.81	35.18	34.16	39.51	38.59	34.34	43.21	42.64	39.11	34.43
b-veto	30.75	31.49	30.52	34.97	34.19	30.35	38.03	37.52	34.18	30.19
At least 1lep	19.32	19.81	20.30	21.27	22.71	20.67	21.92	24.46	23.73	20.55
pass WW1l	11.01	13.12	13.85	15.20	16.58	16.11	16.27	18.60	18.92	16.95
WW2l, DSID	800963	800964	800965	800966	800967	800968	800969	800970	800971	800972
All events	100	100	100	100	100	100	100	100	100	100
No duplicates	100	100	100	100	100	100	100	100	100	100
GRL	100	100	100	100	100	100	100	100	100	100
Pass trigger	84.51	87.68	87.25	91.92	91.75	89.45	93.83	93.99	93.39	91.03
Detector DQ	84.51	87.68	87.25	91.92	91.75	89.45	93.83	93.99	93.39	91.03
Has PV	84.51	87.68	87.25	91.92	91.75	89.45	93.83	93.99	93.39	91.03
2 loose photons	58.15	57.75	58.43	59.10	58.94	60.23	60.91	60.68	60.45	61.59
Trigger match	53.03	53.45	53.28	56.75	56.22	55.25	59.63	59.21	58.15	56.72
tight ID	45.22	45.74	45.55	48.59	48.07	47.34	50.94	50.69	49.77	48.45
isolation	38.12	39.65	39.06	43.23	42.55	40.57	45.96	45.60	43.99	41.37
rel. pT cuts	35.49	34.90	34.68	38.88	38.01	35.87	42.10	41.73	39.45	36.56
m_{yy} in [105, 160]GeV	34.79	34.22	33.88	38.02	36.96	34.43	41.17	40.68	37.95	34.67
b-veto	33.56	32.74	32.39	36.23	35.17	32.95	39.05	38.65	36.08	32.96
At least 2lep	17.14	18.06	18.12	20.55	20.72	19.45	22.16	23.23	22.35	20.15
pass WW2l	17.01	17.90	17.60	20.34	20.09	18.95	21.90	22.44	21.73	19.76
pass ZZ2l	0.07	0.10	0.43	0.13	0.52	0.40	0.14	0.65	0.46	0.23
WW2l-em	8.46	8.91	8.85	10.17	10.27	9.64	10.96	11.50	11.02	10.03
fall to 1lepton category	11.93	10.51	10.99	11.07	11.14	10.93	11.54	11.82	11.33	10.58
ZZ2l, DSID	800983	800984	800985	800986	800987	800988	800989	800990	800991	800992
All events	100	100	100	100	100	100	100	100	100	100
No duplicates	100	100	100	100	100	100	100	100	100	100
GRL	100	100	100	100	100	100	100	100	100	100
Pass trigger	77.68	81.12	80.26	87.03	86.52	81.65	89.98	89.82	88.24	82.69
Detector DQ	77.68	81.12	80.26	87.03	86.52	81.65	89.98	89.82	88.24	82.69
Has PV	77.68	81.12	80.26	87.03	86.52	81.65	89.98	89.82	88.24	82.69
2 loose photons	53.42	53.66	54.13	54.92	55.21	55.79	56.92	57.19	56.96	57.33
Trigger match	48.43	49.46	49.14	52.63	52.49	50.88	55.57	55.65	54.47	52.29
tight ID	40.75	41.91	41.52	44.61	44.41	42.81	46.87	46.93	45.85	43.71
isolation	32.83	35.78	34.68	39.36	38.81	35.77	42.31	42.05	39.74	36.32
rel. pT cuts	30.54	31.61	30.81	35.43	34.77	31.78	38.92	38.53	35.90	32.00
m_{yy} in [105, 160]GeV	29.93	30.98	30.14	34.67	33.94	30.73	38.17	37.69	34.73	30.70
b-veto	25.04	24.53	23.71	26.65	25.77	22.89	28.65	28.14	25.25	21.89
At least 2lep	12.82	12.97	12.87	13.79	13.86	13.75	14.16	14.69	15.67	13.50
pass WW2l	10.13	9.66	6.13	9.94	6.21	5.69	9.99	6.26	6.18	5.16
pass ZZ2l	2.64	3.24	6.68	3.77	7.60	7.99	4.08	8.35	9.40	8.25
WW2l-em	0.07	0.09	0.08	0.09	0.09	0.13	0.11	0.11	0.14	0.11
fall to 1lepton category	8.52	8.06	7.69	8.76	8.32	6.26	9.56	9.20	6.33	5.53

Table 28: Efficiencies in percent for event selection for signals.

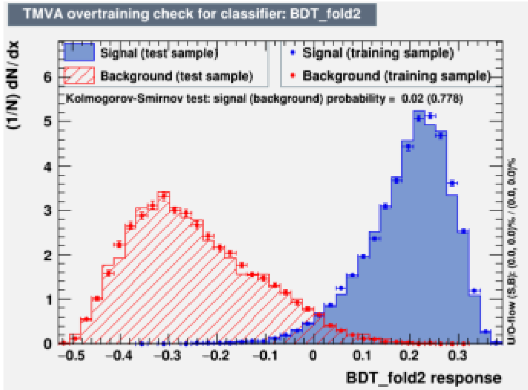
X	750	750	750	750	750	1000	1000	1000	1000	1000
S	170	200	300	400	500	170	200	300	400	500
WW1l, DSID	800953	800954	800955	800956	800957	800938	800939	800940	800941	800942
All events	100	100	100	100	100	100	100	100	100	100
No duplicates	100	100	100	100	100	100	100	100	100	100
GRL	100	100	100	100	100	100	100	100	100	100
Pass trigger	93.90	93.92	93.60	92.95	90.06	95.70	95.56	95.69	95.69	95.31
Detector DQ	93.90	93.92	93.60	92.95	90.06	95.70	95.56	95.69	95.69	95.31
Has PV	93.90	93.92	93.60	92.95	90.06	95.70	95.56	95.69	95.69	95.31
2 loose photons	66.12	65.98	65.50	64.81	63.87	70.26	70.03	69.93	69.35	68.60
Trigger match	65.35	65.15	64.43	63.04	60.41	69.85	69.62	69.50	68.81	67.87
tight ID	55.30	55.05	54.46	52.80	50.27	59.30	58.99	58.67	58.08	56.94
isolation	51.01	50.75	49.51	46.92	43.19	55.65	55.44	54.89	53.74	51.84
rel. pT cuts	47.92	47.61	46.04	43.00	38.47	53.12	52.95	52.20	50.81	48.79
m_{yy} in [105, 160]GeV	47.57	47.12	45.22	41.89	37.09	52.87	52.51	51.55	49.92	47.62
b-veto	41.45	41.08	39.16	36.33	32.17	45.53	45.14	44.30	42.94	40.86
1lep	21.69	25.62	27.08	24.90	21.87	19.71	25.60	30.14	29.57	27.95
pass WW1l	16.62	20.31	22.32	20.98	18.68	15.49	20.95	25.37	25.19	24.01
WW2l, DSID	800973	800974	800975	800976	800977	800958	800959	800960	800961	800962
All events	100	100	100	100	100	100	100	100	100	100
No duplicates	100	100	100	100	100	100	100	100	100	100
GRL	100	100	100	100	100	100	100	100	100	100
Pass trigger	95.43	95.31	95.49	95.37	94.10	96.61	96.77	96.84	96.88	96.82
Detector DQ	95.43	95.31	95.49	95.37	94.10	96.61	96.77	96.84	96.88	96.82
Has PV	95.43	95.31	95.49	95.37	94.10	96.61	96.77	96.84	96.88	96.82
2 loose photons	63.62	63.33	63.21	62.85	62.67	67.11	67.07	67.16	66.86	66.30
Trigger match	62.94	62.62	62.21	61.51	59.53	66.77	66.70	66.76	66.37	65.70
tight ID	53.72	53.75	53.21	52.64	50.85	57.43	57.28	57.33	56.91	56.27
isolation	49.43	49.29	48.39	47.13	44.22	53.56	53.49	53.36	52.56	51.50
rel. pT cuts	46.18	46.00	44.78	42.90	39.40	50.90	50.75	50.38	49.46	48.15
m_{yy} in [105, 160]GeV	45.32	44.96	43.35	40.95	37.02	50.16	49.81	49.12	47.84	46.02
b-veto	42.79	42.47	41.01	38.49	35.14	46.94	46.63	46.05	44.92	43.22
At least 2lep	23.96	25.67	26.20	24.56	22.24	24.54	28.04	29.91	29.17	28.33
pass WW2l	23.65	24.75	25.38	24.11	21.87	24.14	26.97	28.89	28.49	27.84
pass ZZ2l	0.17	0.74	0.63	0.29	0.16	0.22	0.86	0.80	0.42	0.22
WW2l-em	11.90	12.65	12.93	12.22	11.08	12.22	13.90	14.75	14.40	14.12
fall to 1lepton category	12.27	12.52	12.14	11.62	10.76	13.54	13.04	12.99	12.88	12.34
ZZ2l, DSID	800993	800994	800995	800996	800997	800978	800979	800980	800981	800982
All events	100	100	100	100	100	100	100	100	100	100
No duplicates	100	100	100	100	100	100	100	100	100	100
GRL	100	100	100	100	100	100	100	100	100	100
Pass trigger	92.35	92.38	91.98	90.73	87.54	94.41	94.56	94.45	94.11	93.63
Detector DQ	92.35	92.38	91.98	90.73	87.54	94.41	94.56	94.45	94.11	93.63
Has PV	92.35	92.38	91.98	90.73	87.54	94.41	94.56	94.45	94.11	93.63
2 loose photons	59.89	60.04	59.63	59.11	58.35	63.46	63.58	63.61	63.33	62.62
Trigger match	59.27	59.25	58.55	57.46	55.16	63.09	63.17	63.14	62.80	61.87
tight ID	49.98	50.14	49.17	48.08	45.78	53.39	53.43	53.22	52.85	51.68
isolation	45.90	46.00	44.42	42.29	38.80	49.83	49.88	49.41	48.66	46.80
rel. pT cuts	42.91	42.97	41.25	38.70	34.58	47.48	47.40	46.85	46.02	43.98
m_{yy} in [105, 160]GeV	42.22	42.23	40.22	37.43	33.09	46.95	46.78	45.99	44.92	42.68
b-veto	30.66	30.57	28.53	26.06	22.68	33.10	32.64	31.58	30.64	28.72
At least 2lep	13.68	14.63	17.85	16.51	14.55	12.22	13.08	19.37	19.46	18.42
pass WW2l	9.64	6.18	6.58	5.93	5.20	8.72	5.85	6.76	6.58	6.17
pass ZZ2l	3.95	8.36	11.15	10.48	9.25	3.39	7.12	12.48	12.72	12.14
WW2l-em	0.11	0.13	0.17	0.18	0.16	0.12	0.10	0.20	0.21	0.21
fall to 1lepton category	10.88	10.59	6.77	5.98	5.06	12.07	12.17	7.12	6.21	5.84

Table 29: Efficiencies in percent for event selection for signals.(Continued)

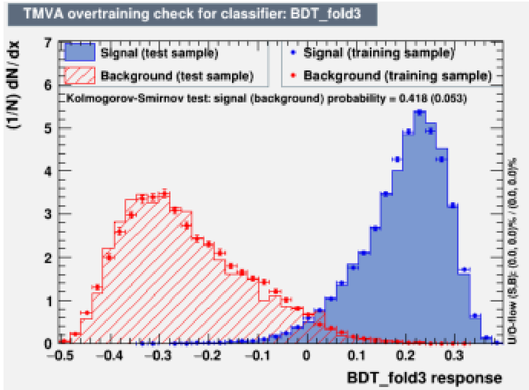
BDT Overtraining



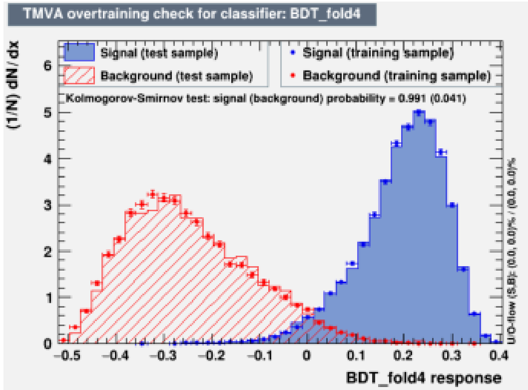
(a) fold1



(b) fold2



(c) fold3



(d) fold4

Figure 16: The overtraining plots with ks test values for 4 individual folds in 2 leptons $m_S \geq 400$ GeV group.

Correlation matrix

X1000S500

ATLAS Internal

	μ	Luminosity	LepDep_1l	LepDep_1l	LepDep_2l	LepDep_2l	PDF_As	PDF_As_SH	PH_EFF_ID_Uncertainty	PH_EFF_ISO_Uncertainty	PH_EFF_TRIGGER_Uncertainty	PRW_DATASF	Parton_Shower	QCD	QCD_SH
μ	100.0	-6.3	-3.5	-0.7	0.0	-0.3	-15.4	-1.8	-4.1	-5.0	-3.5	2.6	-4.0	-43.6	-2.4
Luminosity	-6.3	100.0	-0.2	0.0	-0.2	-0.0	-0.0	-0.1	0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.1
LepDep_1l	-3.5	-0.2	100.0	0.0	0.0	0.0	-0.0	-0.8	0.0	-0.0	0.0	0.0	-0.0	-0.1	-1.0
LepDep_1l	-0.7	0.0	0.0	100.0	0.0	0.0	0.0	0.0	-0.0	-0.0	-0.0	-0.0	0.0	0.0	0.0
LepDep_2l	0.0	-0.2	0.0	0.0	100.0	0.0	-0.0	-0.7	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.9
LepDep_2l	-0.3	-0.0	0.0	0.0	0.0	100.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
PDF_As	-15.4	-0.0	-0.0	0.0	-0.0	-0.0	100.0	-0.0	-0.0	-0.0	-0.0	-0.0	0.0	-0.0	-0.0
PDF_As_SH	-1.8	-0.1	-0.8	0.0	-0.7	-0.0	-0.0	100.0	0.0	0.0	0.0	0.0	-0.0	-0.0	-0.4
PH_EFF_ID_Uncertainty	-4.1	0.0	0.0	-0.0	-0.0	-0.0	-0.0	0.0	100.0	-0.0	0.0	-0.0	0.0	0.0	-0.0
PH_EFF_ISO_Uncertainty	-5.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	0.0	-0.0	100.0	-0.0	-0.0	-0.0	0.0	-0.0
PH_EFF_TRIGGER_Uncertainty	-3.5	-0.0	0.0	-0.0	-0.0	-0.0	-0.0	0.0	0.0	-0.0	100.0	-0.0	-0.0	0.0	-0.0
PRW_DATASF	2.6	-0.0	0.0	-0.0	-0.0	-0.0	-0.0	0.0	-0.0	-0.0	-0.0	100.0	0.0	-0.0	0.0
Parton_Shower	-4.0	-0.0	-0.0	0.0	-0.0	-0.0	0.0	-0.0	0.0	-0.0	-0.0	0.0	100.0	-0.0	-0.0
QCD	-43.6	-0.0	-0.1	0.0	-0.0	-0.0	-0.0	-0.0	0.0	0.0	0.0	-0.0	-0.0	100.0	-0.0
QCD_SH	-2.4	-0.1	-1.0	0.0	-0.9	-0.0	-0.0	-0.4	-0.0	-0.0	-0.0	0.0	-0.0	-0.0	100.0

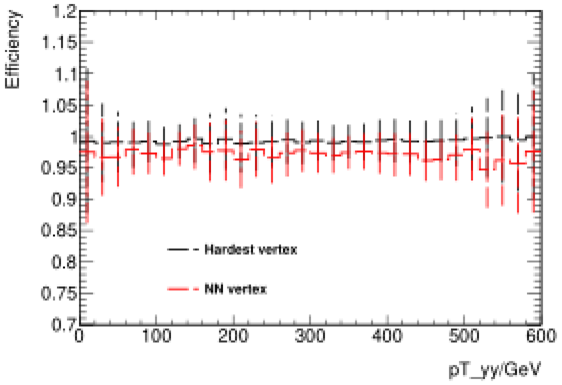
X400S200

ATLAS Internal

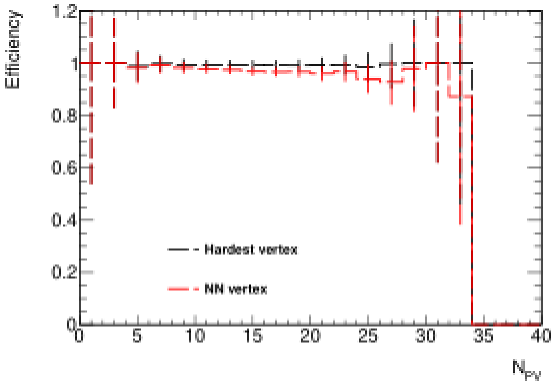
	μ	Luminosity	LepDep_1l_L	LepDep_1l_T	LepDep_2l_L	LepDep_2l_T	PDF_As	PDF_As_SH	PH_EFF_ID_Uncertainty	PH_EFF_ISO_Uncertainty	PH_EFF_TRIGGER_Uncertainty	PRW_DATASF	Parton_Shower	QCD	QCD_SH
μ	100.0	-4.7	-9.1	-4.4	-1.5	-0.5	-9.6	-2.6	-2.5	-3.0	-2.2	1.6	-2.5	-27.1	-5.0
Luminosity	-4.7	100.0	-0.1	0.0	-0.2	0.0	0.0	-0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
LepDep_1l_L	-9.1	-0.1	100.0	0.4	0.2	0.0	-0.0	-0.2	0.0	0.0	0.0	-0.0	-0.0	-0.0	-0.5
LepDep_1l_T	-4.4	0.0	0.4	100.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1
LepDep_2l_L	-1.5	-0.2	0.2	0.1	100.0	0.0	-0.0	-0.5	0.0	0.0	0.0	0.0	-0.0	-0.0	-0.9
LepDep_2l_T	-0.5	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	-0.0	0.0	0.0	0.0
PDF_As	-9.6	0.0	-0.0	0.0	-0.0	0.0	100.0	-0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.0
PDF_As_SH	-2.6	-0.0	-0.2	0.1	-0.5	0.0	-0.0	100.0	-0.0	0.0	-0.0	0.0	-0.0	-0.0	-0.2
PH_EFF_ID_Uncertainty	-2.5	0.0	0.0	0.0	0.0	0.0	0.0	-0.0	100.0	0.0	0.0	-0.0	0.0	0.0	0.0
PH_EFF_ISO_Uncertainty	-3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	-0.0	0.0	0.0	-0.0
PH_EFF_TRIGGER_Uncertainty	-2.2	0.0	0.0	0.0	0.0	0.0	0.0	-0.0	0.0	0.0	100.0	-0.0	0.0	0.0	0.0
PRW_DATASF	1.6	0.0	-0.0	0.0	0.0	-0.0	0.0	0.0	-0.0	-0.0	-0.0	100.0	-0.0	-0.0	-0.0
Parton_Shower	-2.5	0.0	-0.0	0.0	-0.0	0.0	0.0	-0.0	0.0	0.0	0.0	-0.0	100.0	0.0	-0.0
QCD	-27.1	0.0	-0.0	0.0	-0.0	0.0	0.0	-0.0	0.0	0.0	0.0	-0.0	0.0	100.0	-0.0
QCD_SH	-5.0	-0.1	-0.5	0.1	-0.9	0.0	-0.0	-0.2	0.0	-0.0	0.0	-0.0	-0.0	-0.0	100.0

Vertex check

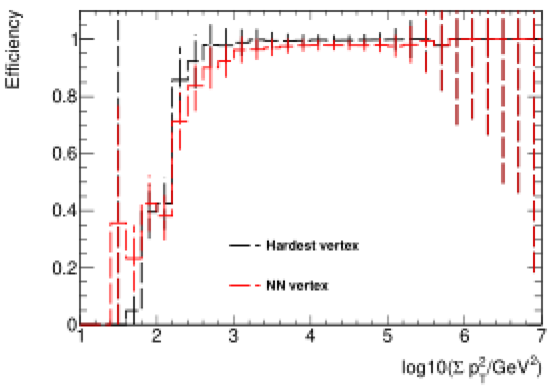
- Hgam usually use NN vertex while with leptons, it is possible to use the hardest vertex.



(a) $p_T^{\gamma\gamma}$



(b) N_{PV}



(c) $log(\Sigma p_T^2)$

Toy limits & signal injections

	$+2\sigma$	$+1\sigma$	Median	-1σ	-2σ
Asymptotic	0.348	0.227	0.152	0.109	0.081
toy	10.00	0.215	0.153	0.116	0.097

Table 30: The expected limits of the search $m_X = 1000$ GeV, $m_S = 300$ GeV with asymptotic and toy.

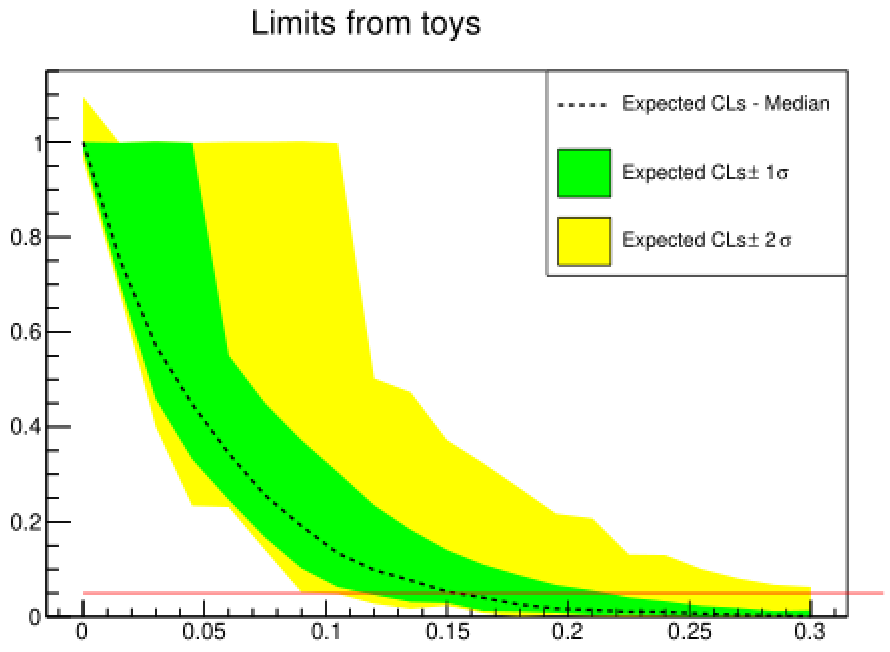
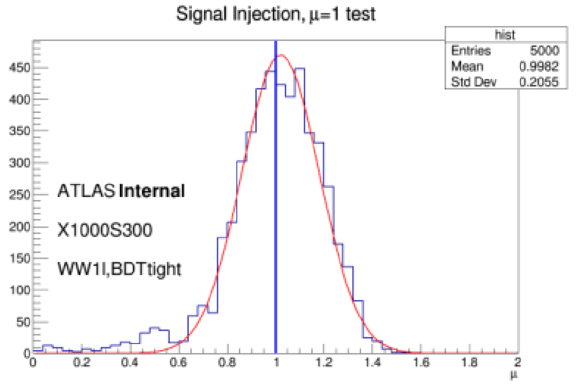
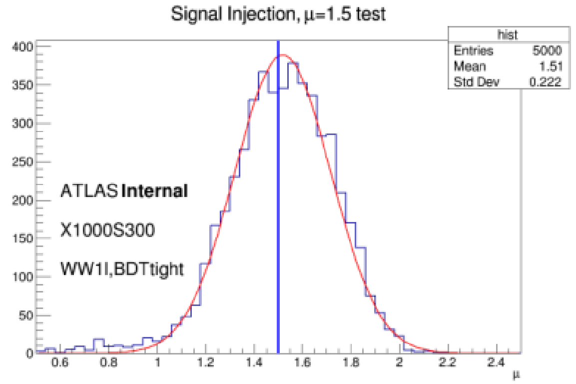


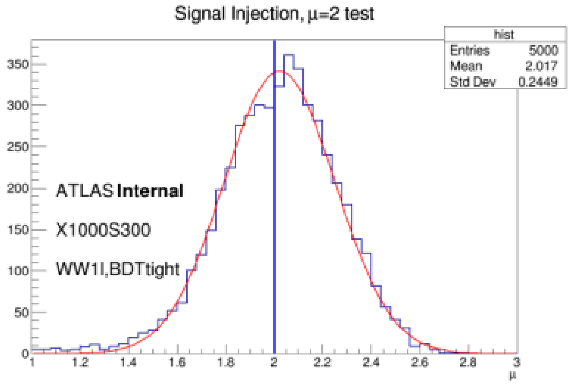
Figure 91: The expected limits of the search $m_X = 1000$ GeV, $m_S = 300$ GeV with toy.



(a)

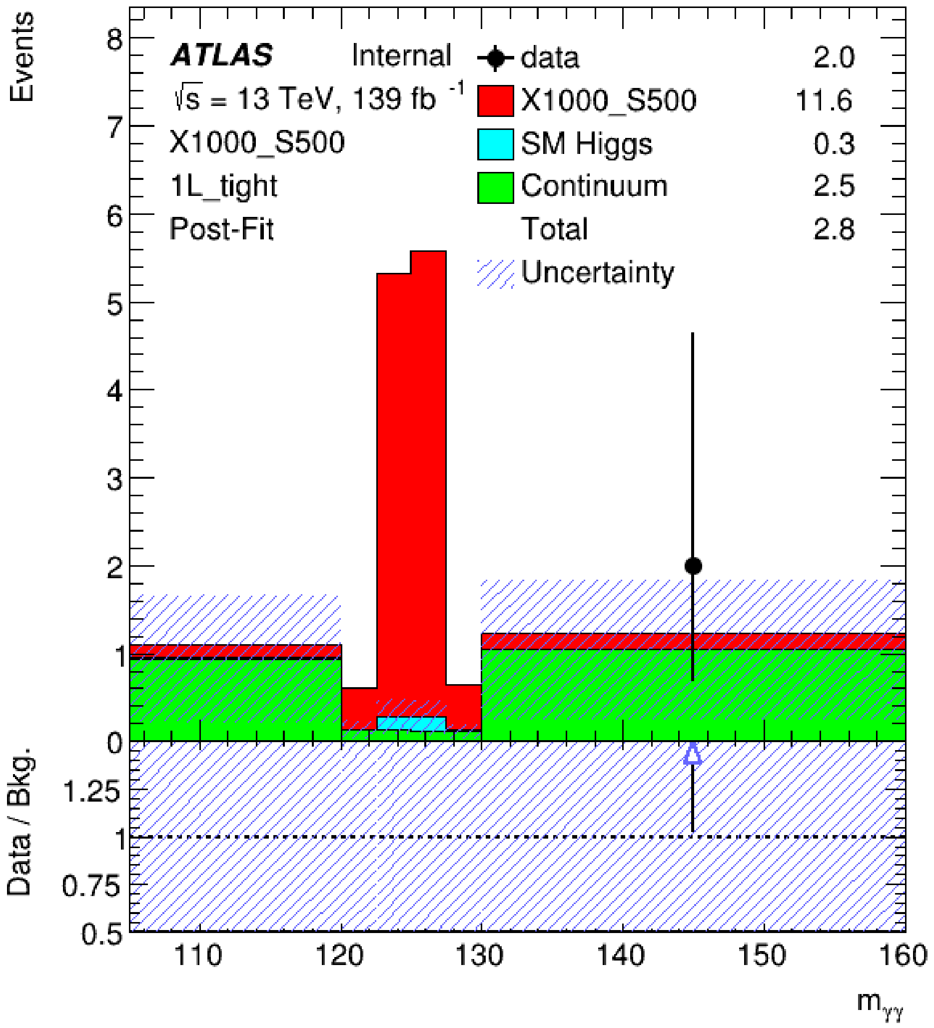


(b)



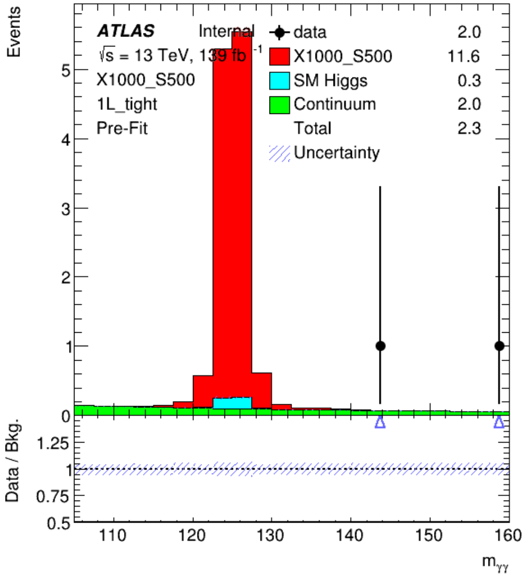
(c)

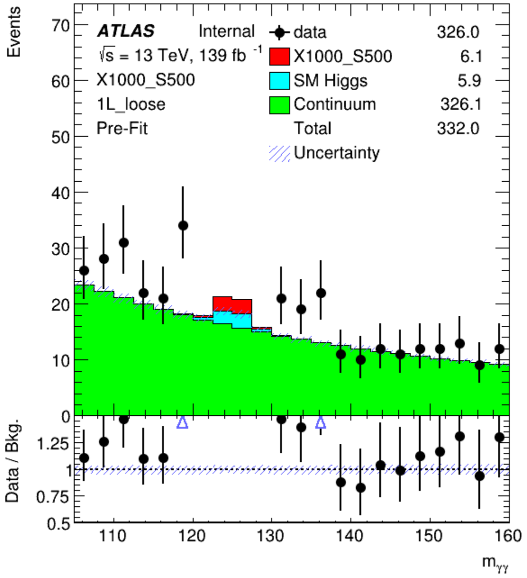
3 bin test



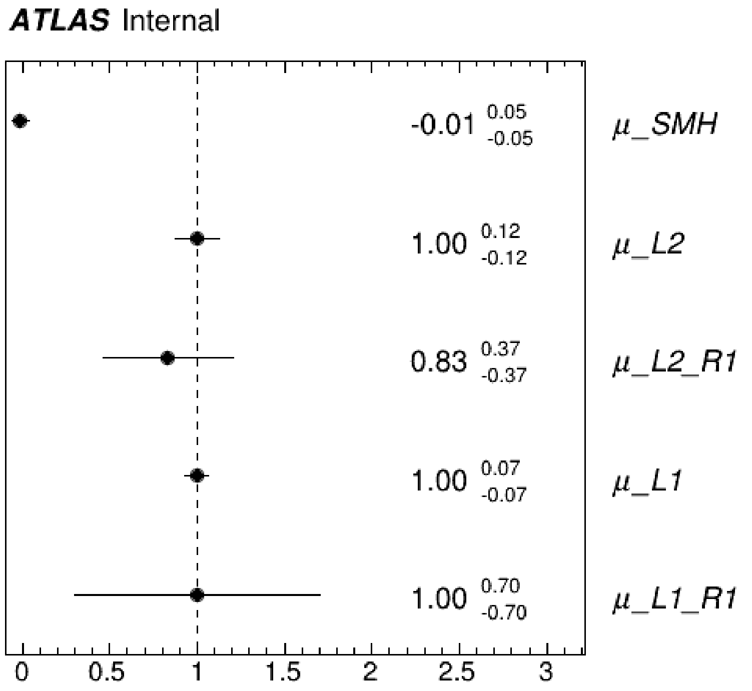
- Rebinning to 3 bins, the limit change is in 1%.
- It turned out the shape information is very small in this analysis.

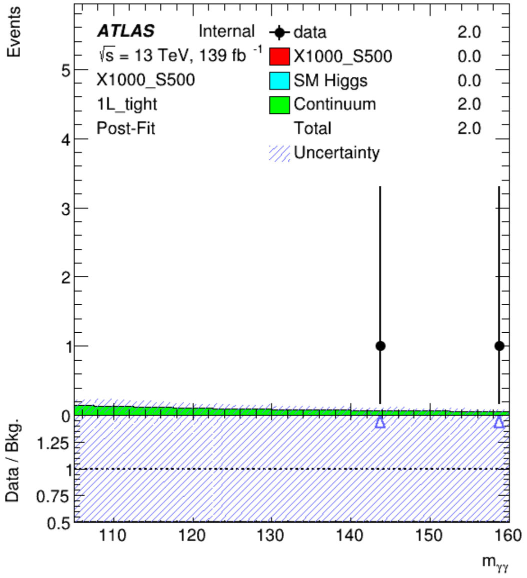
Sideband fit, Bonly:

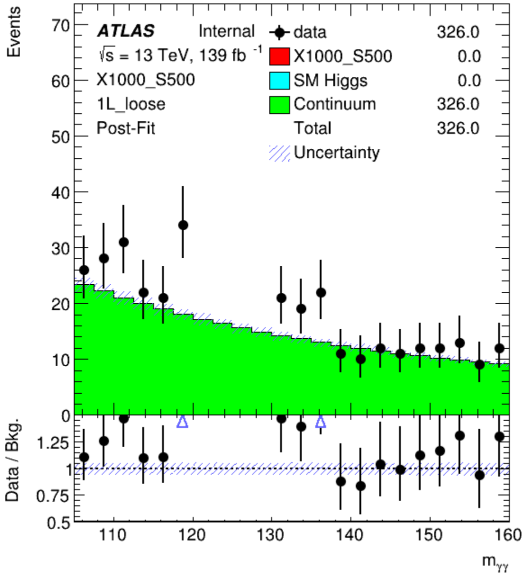




Bkg only fit only provide pull, no NP ranking plot.

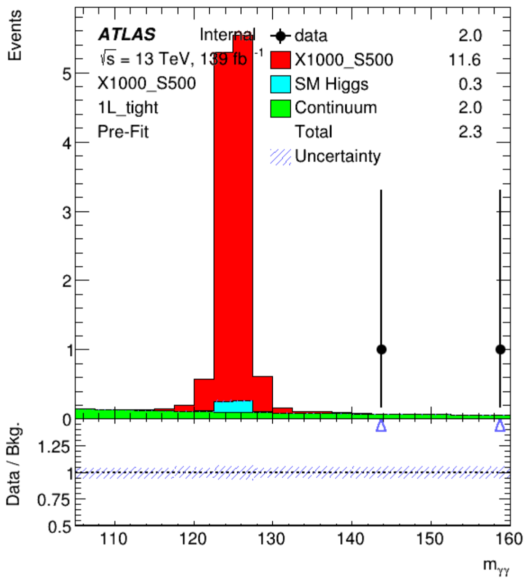




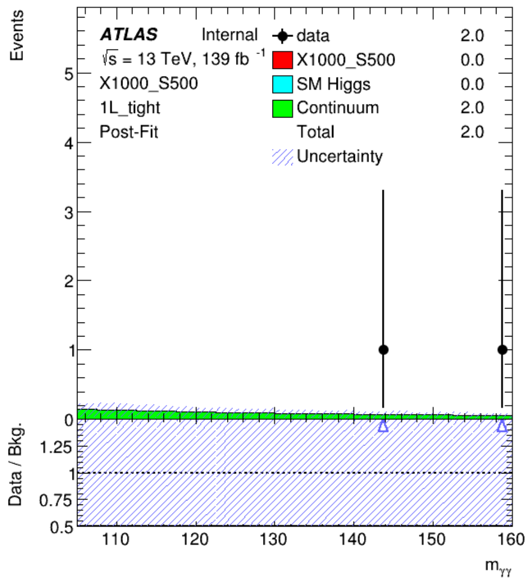


Comparison: mass distribution

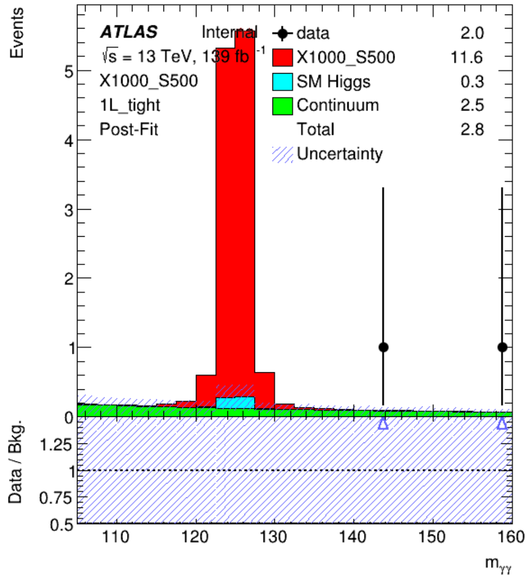
Limit ~191fb. Close.



Sideband Fit:
Zero signal and fit model is stable.

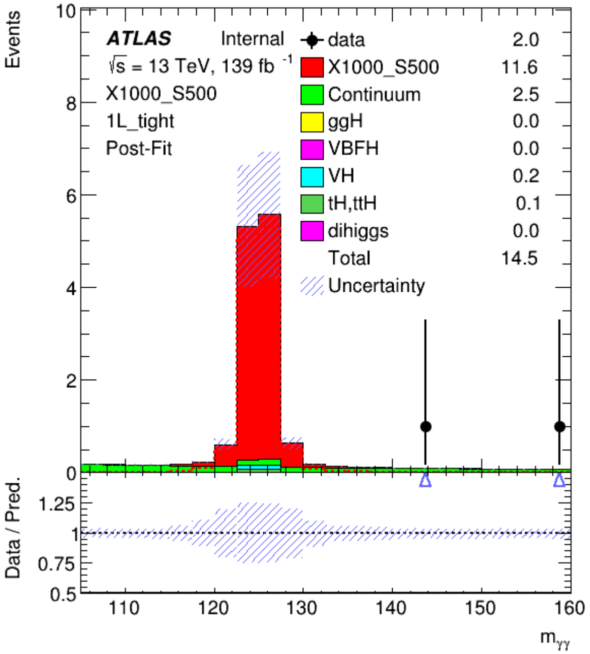


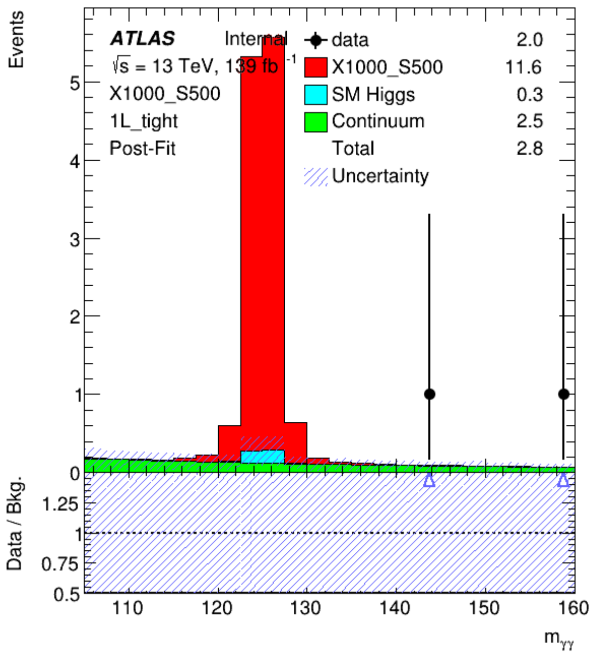
Asimov Fit:

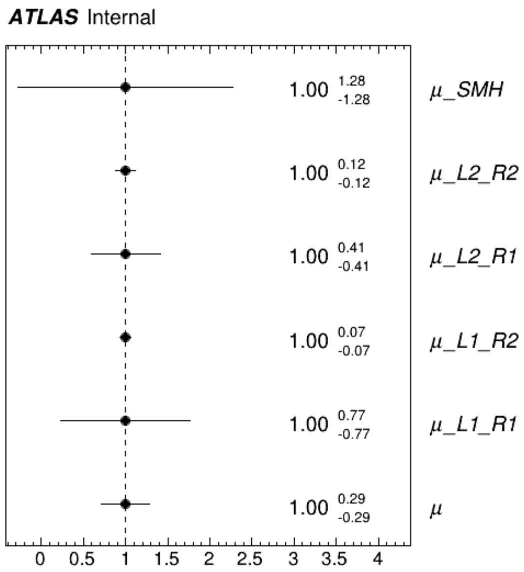


We have finished all the requirements and looking forward for the unblinding.

Background normalization uncertainty







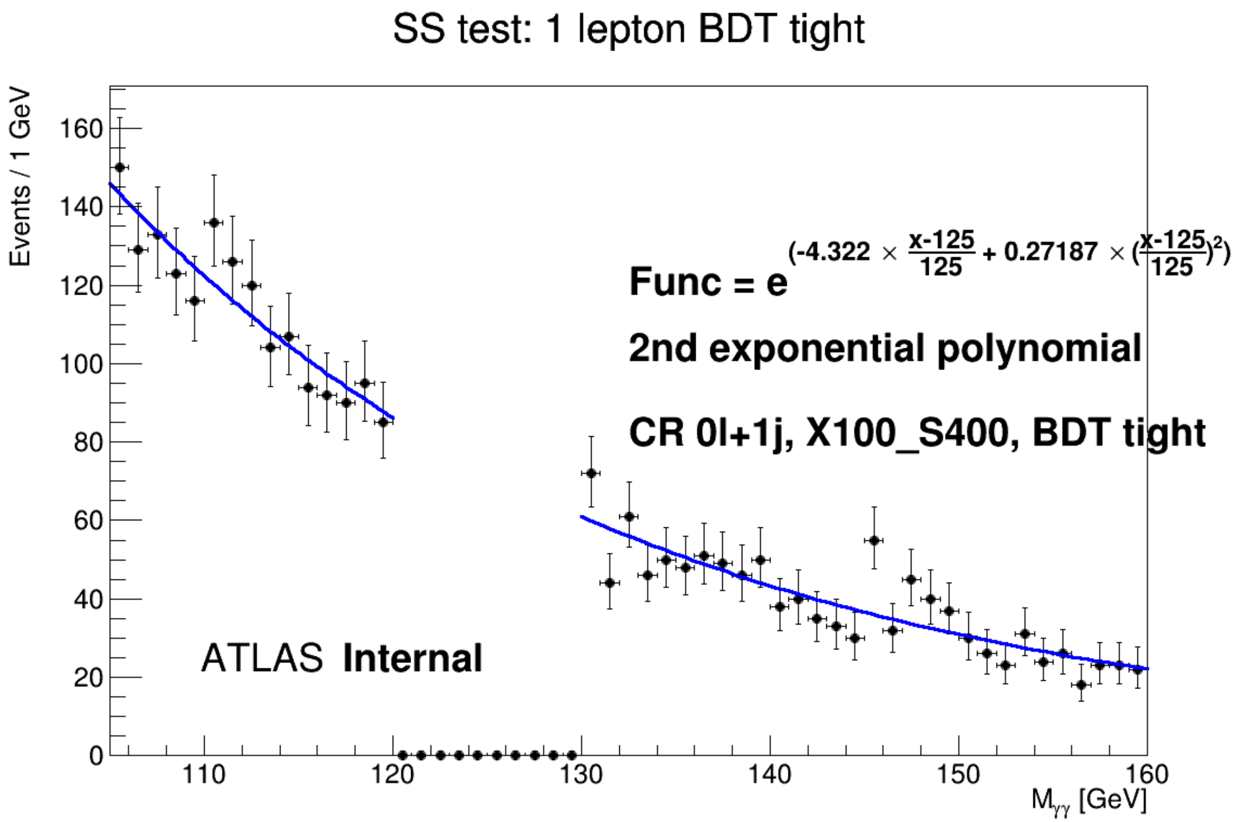
In the past, only signal strength is float in the fit, but the normalization factor for other components are fixed to 1.
In this plot, 1l BDT tight region include 77% continuum background uncertainty.
Generally, this lead to ~1-2% limit reduction.

Sideband data fit

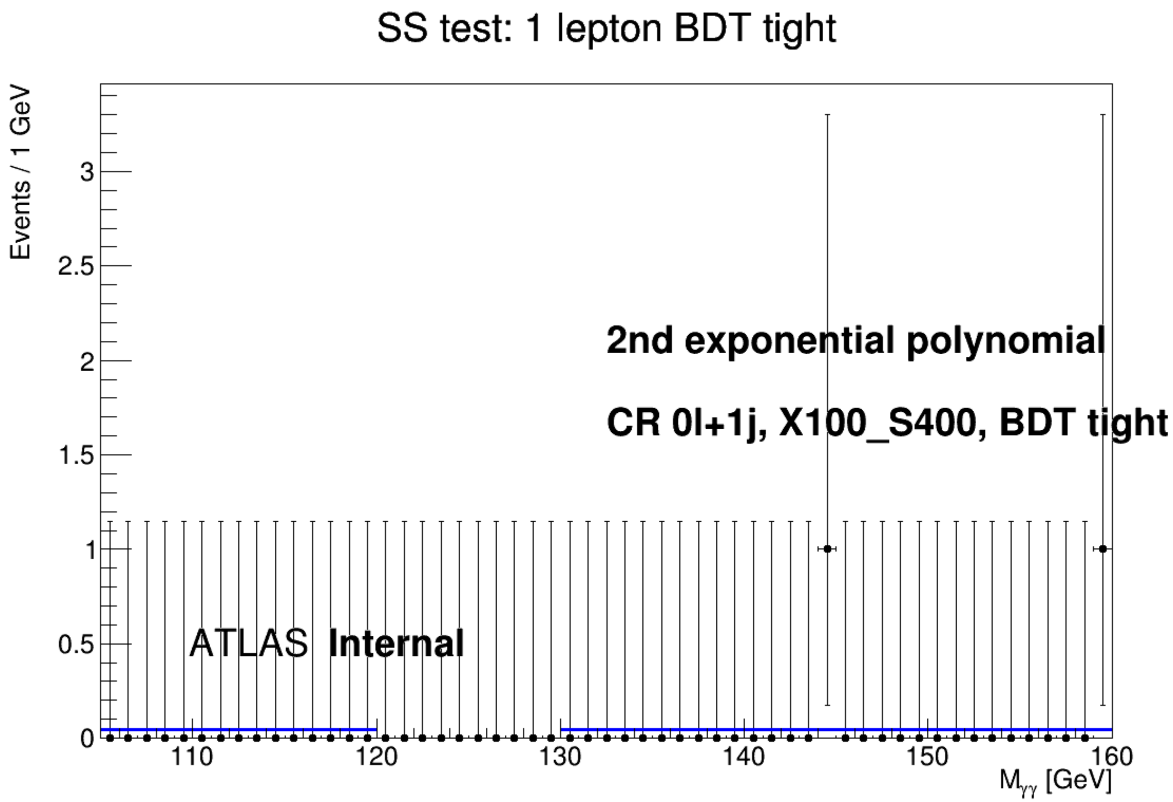
Only 2 events in sideband,
Here the shape is forced to be left side higher, right side lower.

it looks like one straight line/uniform distribution.

Fit by CR



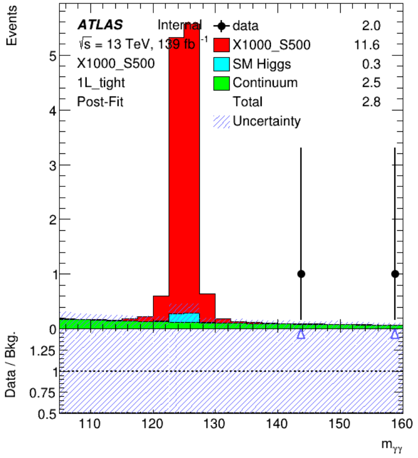
Fit by Sideband



Toys tests: stability test

```
Limit: "myLimit"
  LimitType: TOYS
  SplusBToys: 5000
  BonlyToys: 5000
  ScanMin: 0
  ScanMax: 0.5
  ScanSteps: 0.05
  LimitBlind: TRUE
```

- For all mass points and all sub-channels, toy tests are done.
- In these Asimov toy tests, even for both signal and background yields<10, the limit deviation between toy/asymptotic <20%.
  - Combined limit including all channels, difference <12%.
- The fit model itself is stable and consistent in these statistics limited situation.



Issue for mass resolution/running mass:

- EB asked to think about running X/S mass.
- Currently, this analysis do not sensitive to different X and S mass.
  - All the events are kept as long as 2 tight photons and 1 good leptons obtained.
  - In BDT training, no variable is heavily rely on X and S kinematics.
  - For one mass point, like X750S200, to pass the selections for X600S200, the difference is cut value

X Mass [GeV]	S Mass [GeV]	WW1L BDT Cut	WW2L BDT Cut
300	170	0.085	0.14
400	170	0.08	0.08
400	200	0.03	0.1
500	170	0.125	0.12
500	200	0.095	0.11
500	300	0.025	0.09
600	170	0.16	0.09
600	200	0.115	0.065
600	300	0.045	0.09
600	400	0.035	0.06
750	170	0.185	0.025
750	200	0.155	0
750	300	0.11	0.035
750	400	0.07	0.065
750	500	0.035	0.065
1000	170	0.155	-0.02
1000	200	0.15	-0.1
1000	300	0.145	-0.03
1000	400	0.115	0.015
1000	500	0.115	0.015

As we tested the different threshold sideband data for limits, The limit may varied for cut value but the final impact on limits is acceptable. If the X-S mass is running, our selections are efficient to find the sensitivity. Which is, it is possible for us to do extrapolation for running X-S mass.

Validation for interpolation

- Use [600, 300], [1000, 300] to interpolate [750, 300]:
  - 290 (Real)
  - 291.417 (Interpolated)

- Use [600, 200], [1000, 200] to interpolate [750, 200]:
  - 264 (Real)
  - 270.235 (Interpolated)

  - For phase limited cases, the deviation will be large.
  - Results for (600, 400) ~20% uncertainty.

Background functions

- In SS tests, Chebyshev polynomials is vetoed.
- Both 1^{st} exp and 2^{nd} exp can pass the tests but most of them 2^{nd} exp has better benchmarks for mu_sp. So 78 of 80 of them choose exppoly2.
- Among 78 of 80 functions, 2^{nd} order exp is best in the SS benchmark.
    - Left 2 use 1^{st} exp.
- After check, with ~1000 events left in 0l CR region,
    - I can confirm always smooth down shape and no peak around 120 GeV.

Background function fit on sideband data.

- In SH analysis, the continuum background do not rely on the side band data. Instead, control region with more events used.

- If using sideband data, one need to fix shape to confirm the function is always left higher, and right side lower. Then the deviation is small.

- If use sideband data to determine the shape, there is the example from bbyy group.

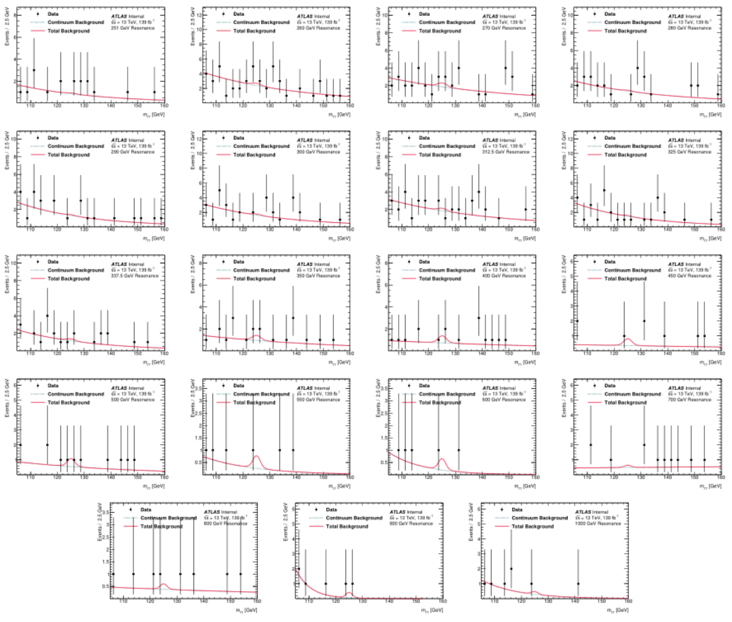


Figure 57: Background only fit to data for each resonance

Single Higgs Parton shower uncertainty

- Similar as HH-ML, h027 MxAOD samples used to obtain the single Higgs theoretical uncertainties.
- $\epsilon = \dfrac{\epsilon_{after}^{Herwig}}{\epsilon_{before}^{Herwig}} \bigg/ \dfrac{\epsilon_{after}^{Pythia}}{\epsilon_{before}^{Pythia}} - 1,$

Where before= initial total sum of weights
After cut=After selection(2 tight photons and 1 good leptons)

- For all single Higgs components, yields variation ~8%. Impact on signal yield <2%.

Peak at 1l loose myy=115 GeV: binning issue

55 bins; deviation in 2 sigma.