$X \rightarrow SH \rightarrow \gamma\gamma + leptons$
Unblinding Approval Request Closure

Kaili Zhang, on behalf of ATL-COM-PHYS-2021-718 team

IHEP

30/01/2023

Action Items

- Reply to all comments on CDS
- Include background uncertainties and remove signal uncertainties in the data/MC plots.
- Check the definition of delta R in presence of neutrinos
- Run toys for the problematic regions where you have only 1 event or try to merge regions to avoid needing to run toys, i.e. when you define regions make sure the asymptotic approximation still holds
- Please describe the interpolation and the mass resolution studies in the note
- The EB wants to see Appendix A (statistical analysis) complete before unblinding
- When all of the above is in place, please produce closure slides and send them to HH&HDBS conveners as well as EB. If needed, we will schedule an additional talk, if not we can simply circulate slides.

Reply to all comments on CDS

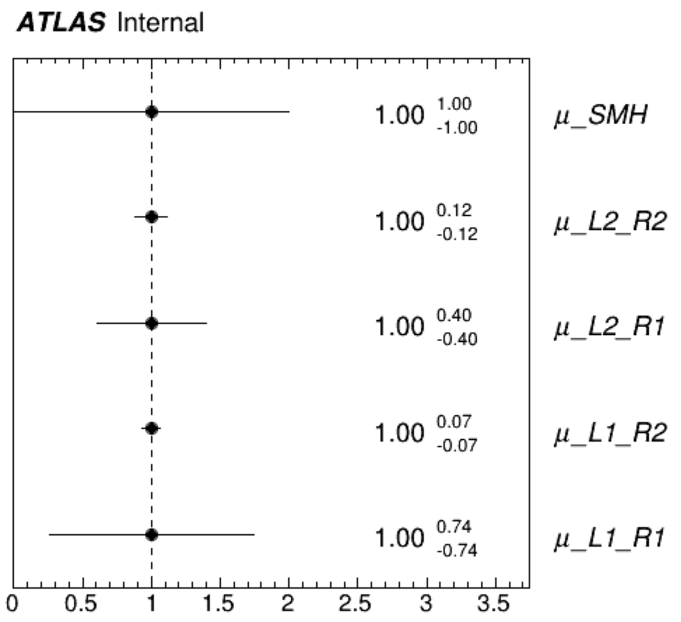
- Reply(1)
- Reply(2)
- All the comments are answered. Very few modifications are marked as purple to be implemented in the draft.
- Frequently asked parts in the draft are written, like theoretical uncertainty, lepton dependence uncertainty, and TMVA configuration.

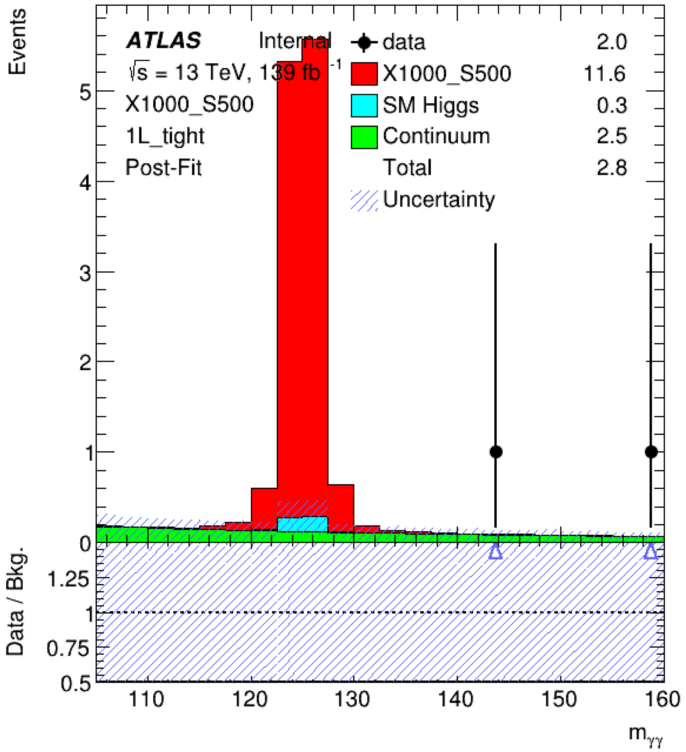
Background normalization factors

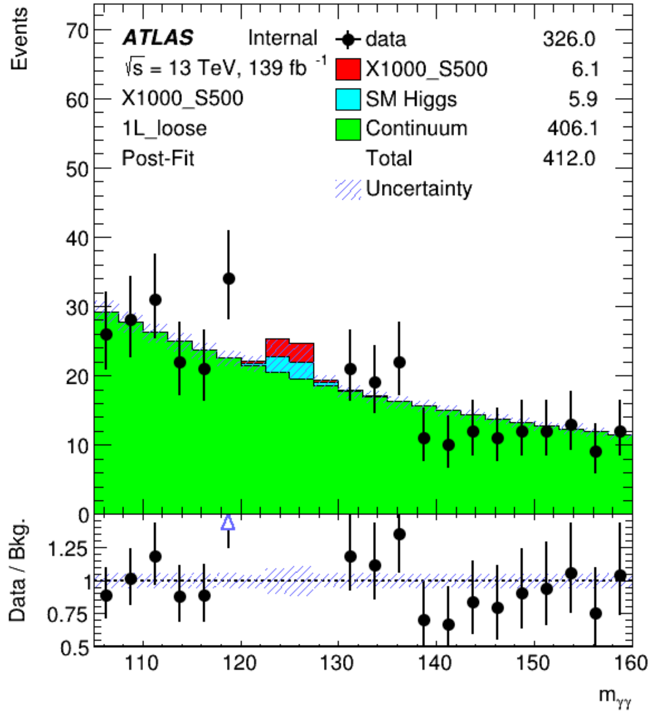
- Include background uncertainties and remove signal uncertainties in the data/MC plots.

->Also been mentioned as background uncertainty. Now included.

- Limit worse ~1%.

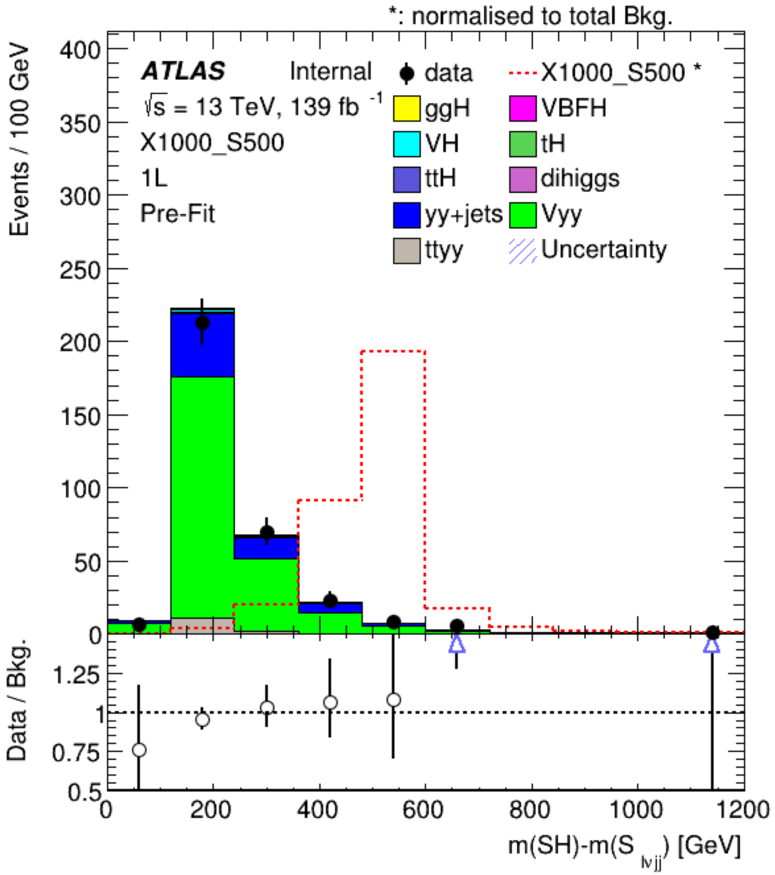


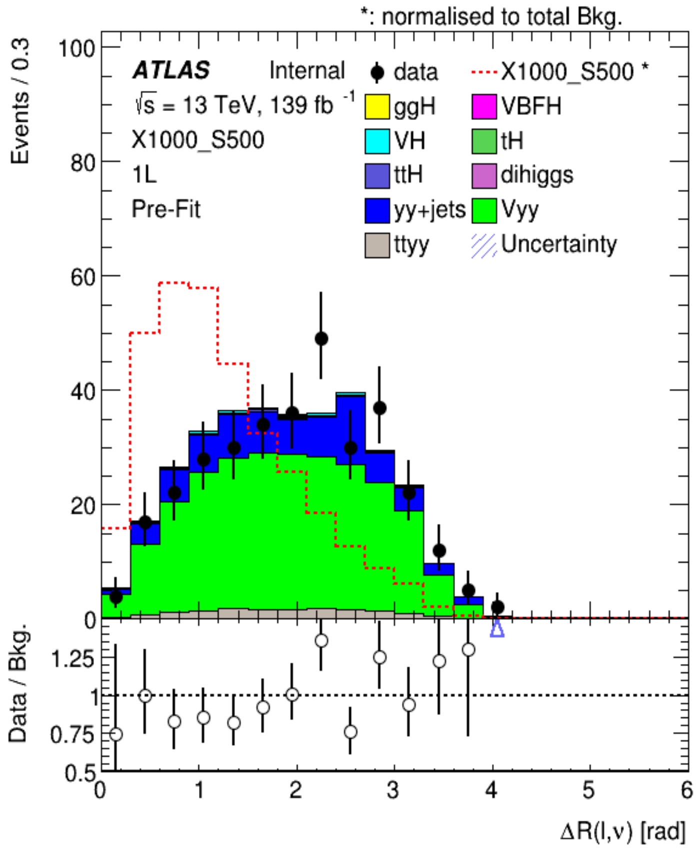




Check neutrinos kinematics

- Pz_neutrinos is fitted by the W mass constraint. Also used in other experiments.
  - No big distortion in these distributions.



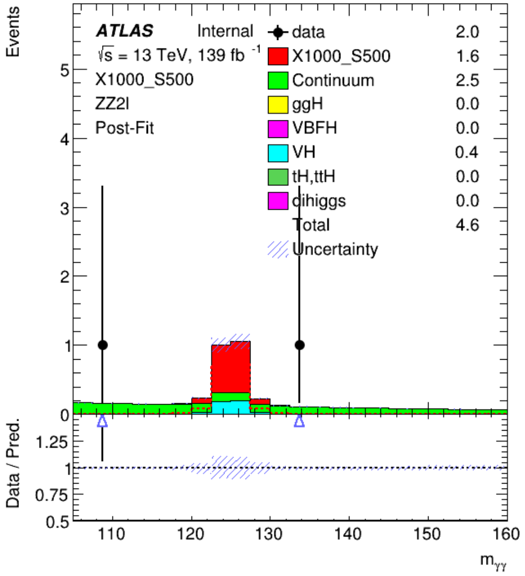


Toy tests

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

- All the channels are tested in toy test, both combined and the Individual channels including WW1e1m and ZZ2l.

  (Considering now the Asimov fit is done, data distribution do not affect the final results; Background normalization factor nominal value exactly at 1.00).

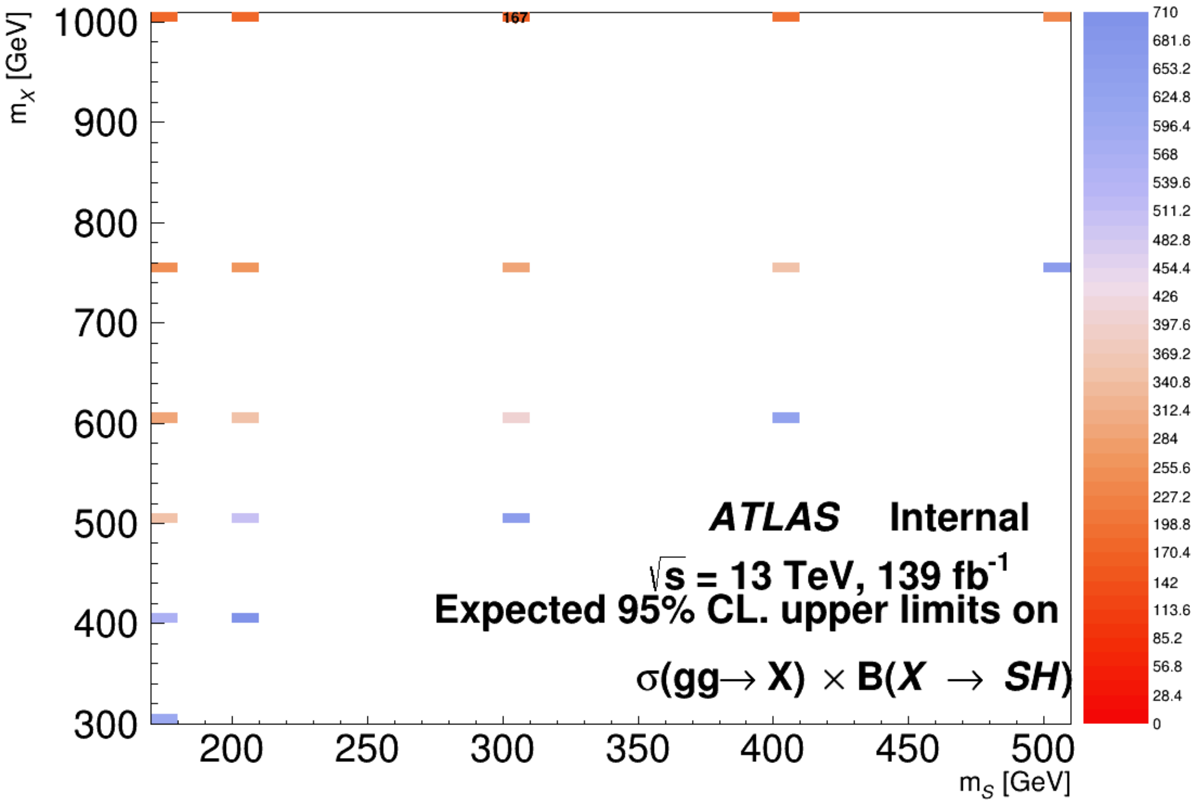


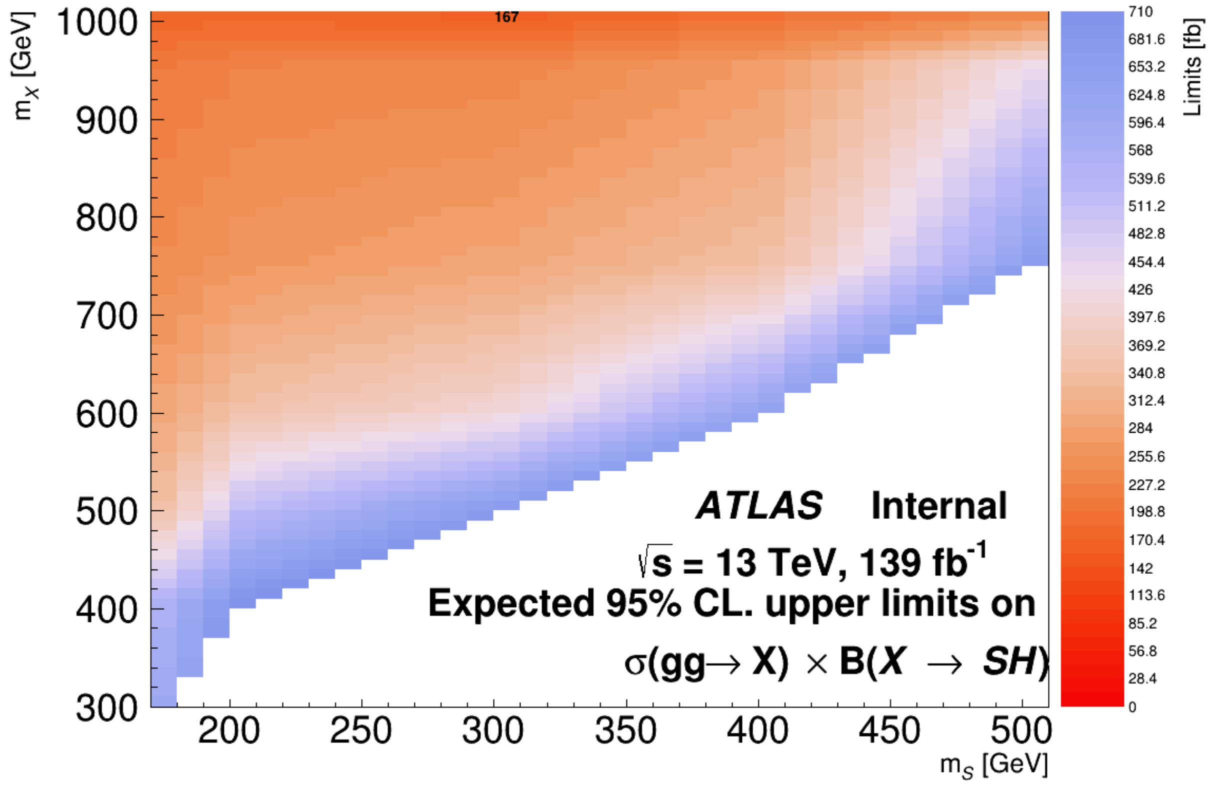
Results consistent in this situation.

Interpolation

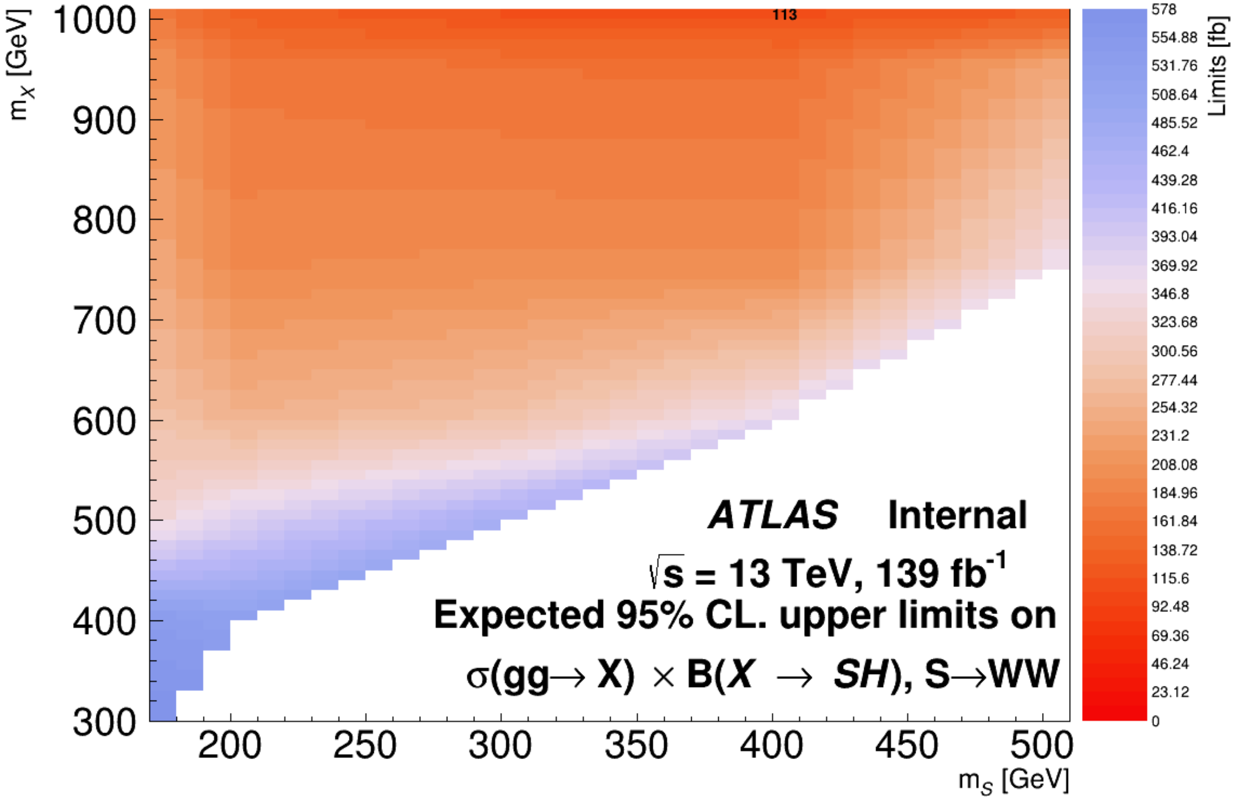
20 points->1600 points
Linear interpolation in log(y) scale.

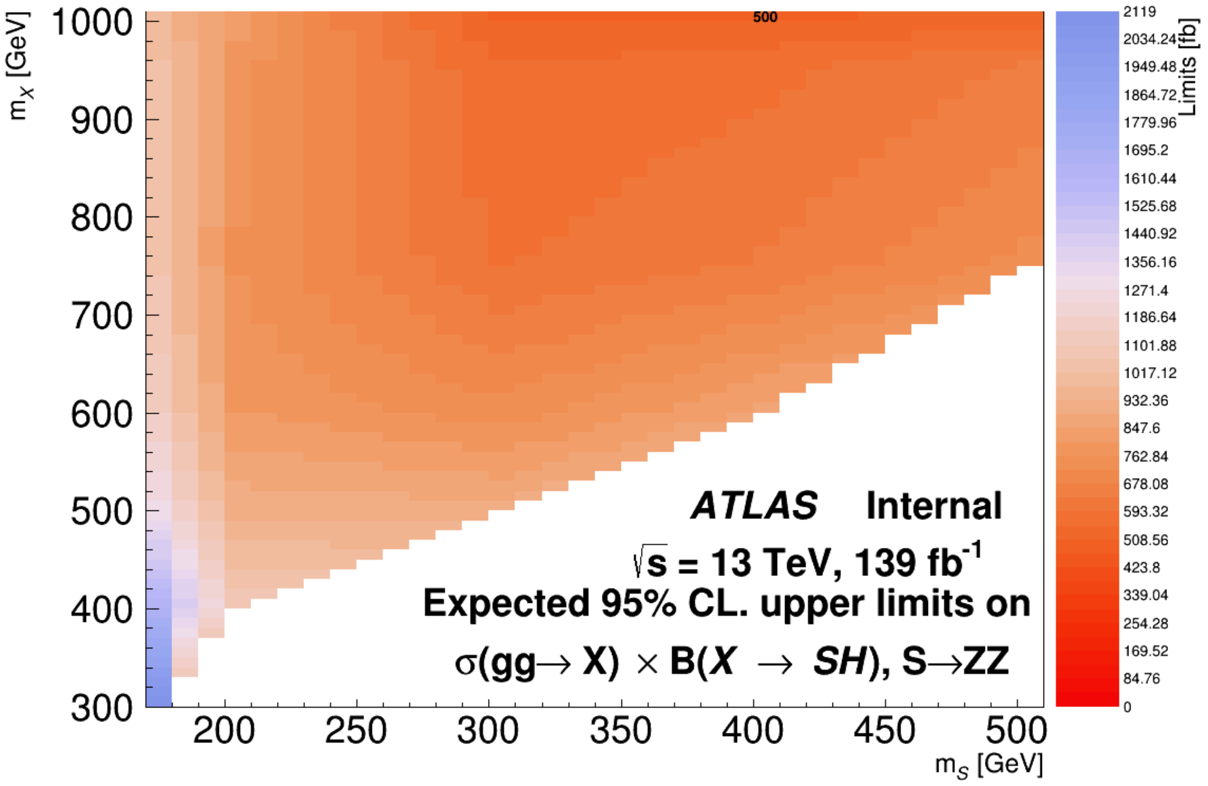
Best point (X1000S300) 167fb.





Interpolation——100% WW/ZZ decay





Issue for mass resolution:

- 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.

Draft status

- The EB wants to see Appendix A (statistical analysis) complete before unblinding

  ->Done.

  Also requiring SS tests, background function forms, lepton dependance uncertainties in the comments. Another Appendix added with A.

- When all of the above is in place, please produce closure slides and send them to HH&HDBS conveners as well as EB. If needed, we will schedule an additional talk, if not we can simply circulate slides.

->Slides and comments are prepared. Draft may need more time to finish all the requirements.

Origin Closure slides in December

Status

- CDS:2779977,version 20. circulated Dec.9;
- Glance
- EB meetings
  - Feb. 2nd
  - Sep. 26th
  - Dec 9th
- EB committee:
- D'ERAMO, Louis (Northern Illinois)
- MAZINI, Rachid (Taipei AS)
- SCHAARSCHMIDT, Jana (Seattle Washington)(Chair)

ATLAS Note

ANA-HDBS-2021-23-INT1

December 9, 2022

Draft version 0.8.1

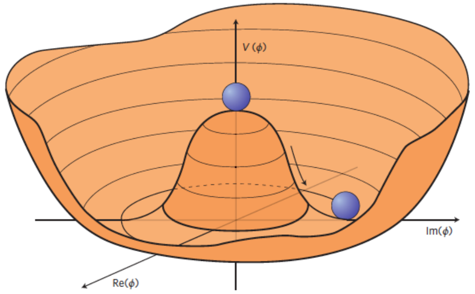
Search for $X \to SH$ model in the final states of two photons and multiple leptons using 139 fb^{-1} of proton-proton collision data at $\sqrt{s}$ = 13 TeV recorded with the ATLAS detector at the LHC

Yaquan Fang[a], Kaili Zhang[a], Zhijun Liang[a], Bo Liu[a], Xinchou Lou[a,c], Xin Shi[a], Qiyu Sha[a], Shuiting Xin[a], Wei-Ming Yao[b], Yesenia Hernandez Jimenez[d], Fangyi Guo[a]

[a]*Institute of High Energy Physics, Chinses Academy of Sciences, Beijing, China*
[b]*Lawrence Berkeley National Laboratory, USA*
[c]*University of Texas at Dallas, USA*
[d]*University of Valencia, Spain*

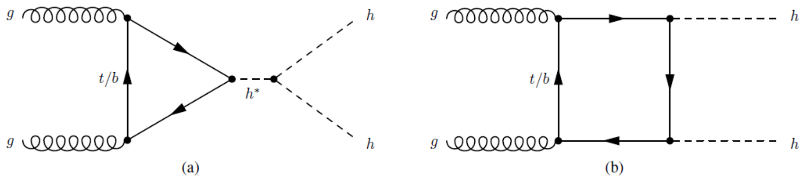
This note presents a search for a new heavy scalar particle X decaying into a Standard Model Higgs boson and a singlet scalar particle S using 139 fb^{-1} of proton-proton collision data at the centre-of-mass energy of 13 TeV recorded with the ATLAS detector at LHC. The explored X mass range varies from 300 GeV to 1000 GeV, with the corresponding S mass range being from 170 GeV to 500 GeV. This search uses the event signature of two photons from the Higgs boson decay and one or two leptons (e or μ) coming from the process of $S \to WW/ZZ$. The observed (expected) upper limits at the 95% confidence level on the cross-section for $gg \to X \to Sh$ assuming the decay of S following the SM prediction is between X fb (167 fb) and Y fb (710 fb).

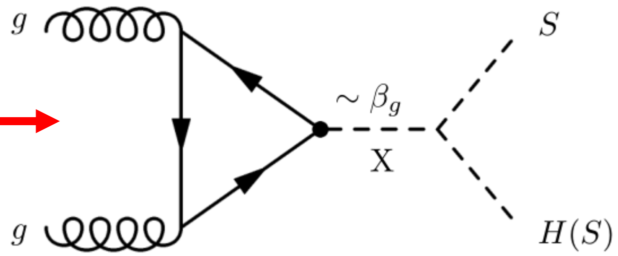
SH model for Higgs couplings



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

$$V(\phi) \rightarrow V(\phi)_{\mathrm{EWSB}} = -\lambda v^2 h^2 - \lambda v h^3 - \frac{1}{4}\lambda h^4 + \mathrm{const.}$$





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:

- bbyy: Phys. Rev. D 106, 5 (2022) pp.052001
- bbbb： (ATLAS-CONF-2022-035)
- bbττ: (arXiv:2209.10910）
- combination: arXiv: 2211.01216

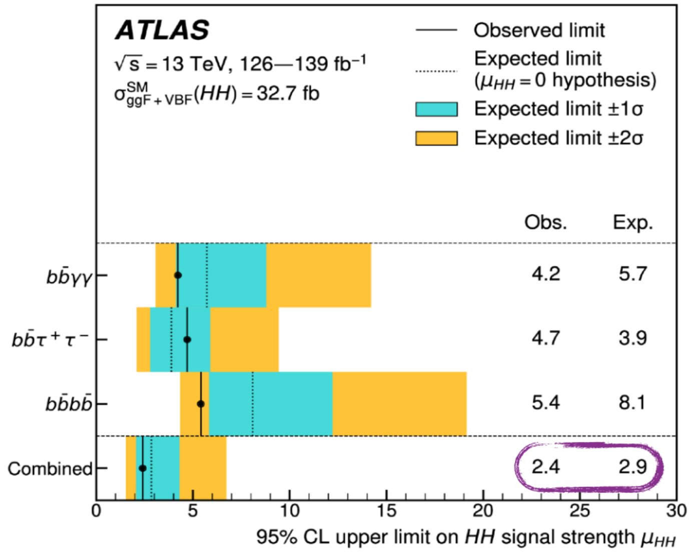
CMS HH:

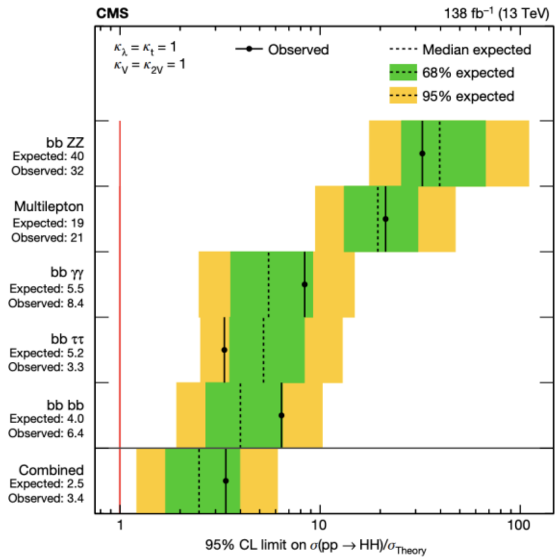
- bbbb: (PRL 129(2022)081802)
- bbyy: (JHEP 03(2021)257)
- bbττ: arXiv:2206.09401
- multilepton: arXiv: 2206.10268
- Wwyy: CMS PAS HIG-21-014
- combination: Nature 607, 60-68 (2022)

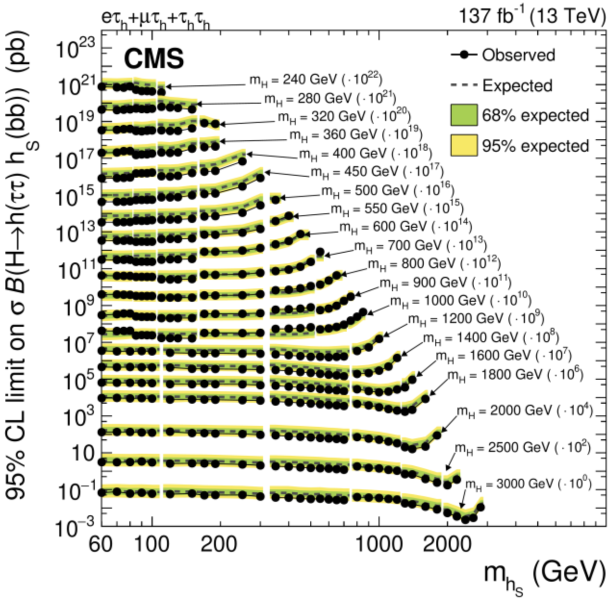
SH:

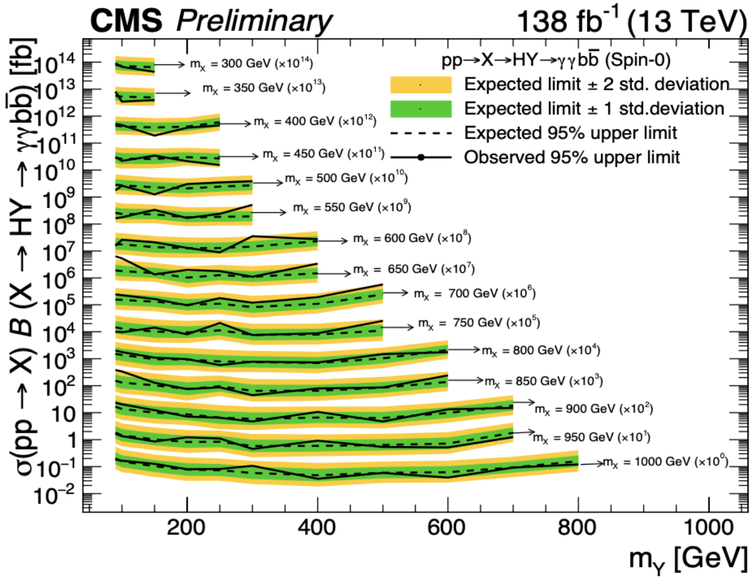
CMS SH->bb$\tau\tau$: JHEP 11 (2021) 057

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





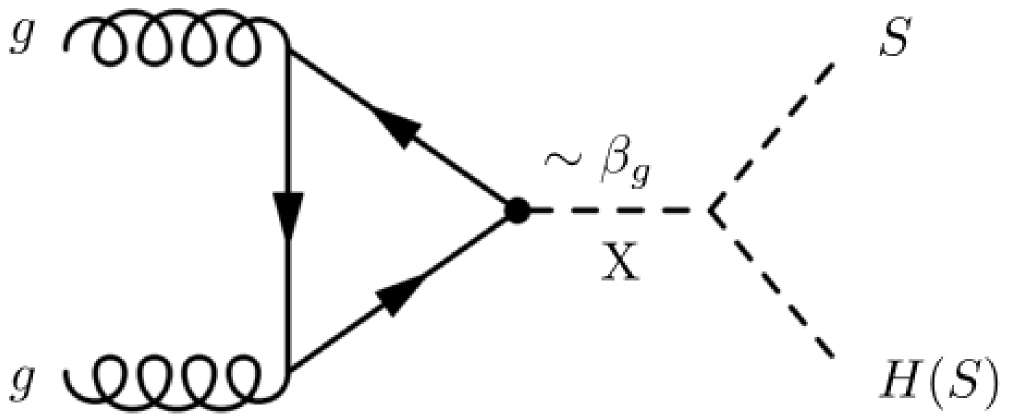




More results for SH are undergoing.

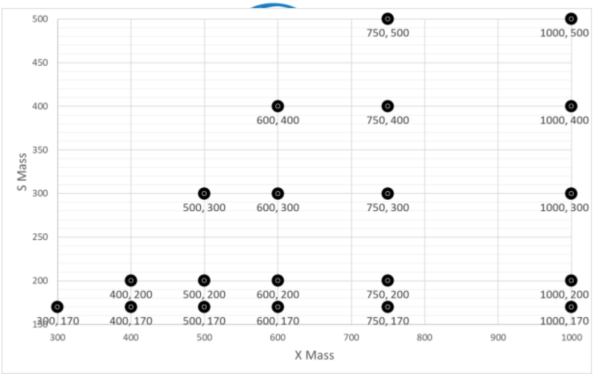
Model & Final states

- 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.

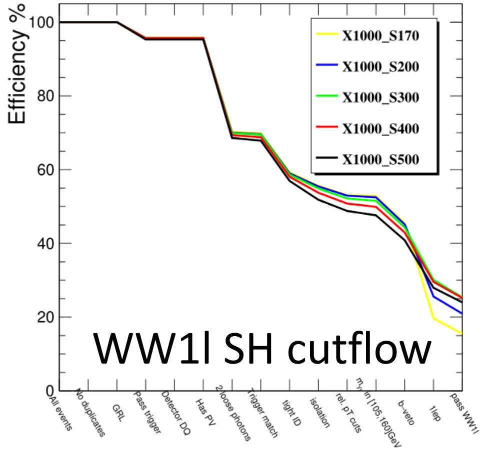


Samples

- 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



(d) m_X = 1000 GeV

Consistent with other Hgam studies.

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

m_S[GeV]	$BR(S \rightarrow WW)$	$BR(S \rightarrow ZZ)$
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_FixedRadIso
  - Hadronic tau not included.

Categories

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

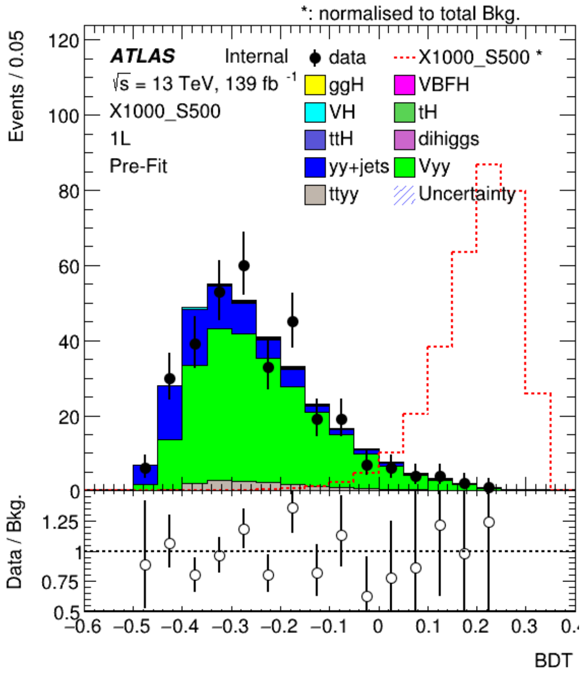
Table 10: Definition of the four channels and the corresponding optimization strategies.

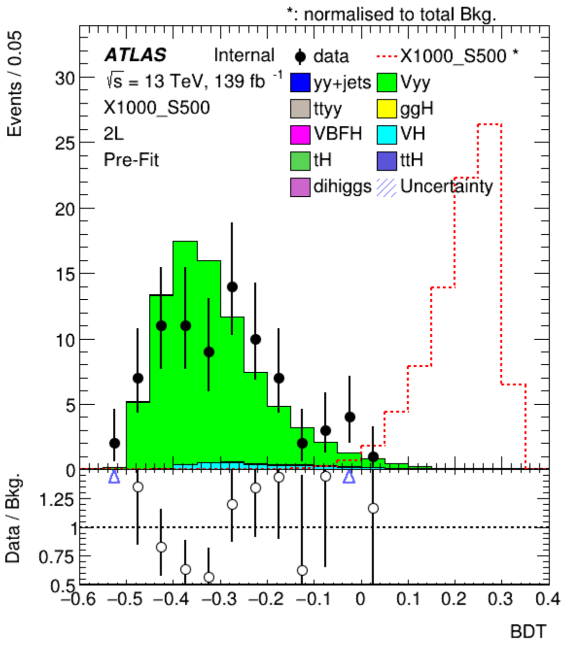
- WW1e1m and ZZ2l are clean enough so directly use as number counting.

- Qiyu use further selections like pt_yy>50GeV, while in SH pt_yy used as BDT training variable, no additional selections applied.

- Observables: m_{yy}
- Blinded region: 120 GeV<m_{yy}<130 GeV
- Sideband region: [105, 120]∪ [130, 160] GeV

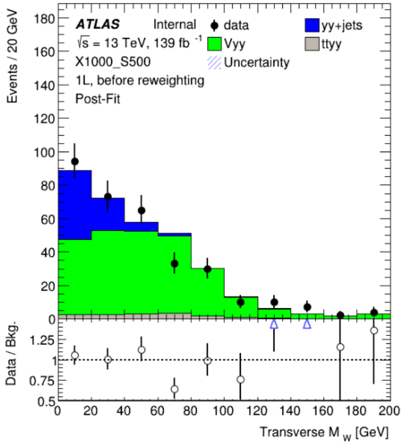
TMVA Training



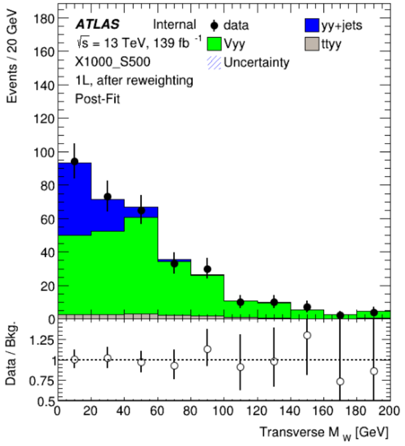


- BDT used
- 4 folds Cross Validation.
- Training on reweighted continuum backgrounds+single Higgs+Dihiggs vs signals.

In this plot, continuum backgrounds+single Higgs+dihiggs are shown in sideband region, while dashed signals is the normalized signal in signal region.



(a)



(b)

TMVA variables

- Parametrized m_X
  - X mass used in training to get 20 different outputs, but small impact.

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.

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

No variable heavily rely on X/S mass value.

BDT cut value configuration

- 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

- Impact for different threshold studied. from threshold 2-10.

Threshold	1	2	3	5	6	7	8	9	10
Limit increase	100%	103.7%	105.2%	108.1%	109.8%	110.3%	111.5%	113.4%	114.4%
Cut value	0.12	0.115	0.1	0.095	0.08	0.07	0.065	0.055	0.05

Table 17: Relative limit change for different sideband data entry threshold in (m_X, m_S) = (1000, 400) GeV WW1l channel.

Threshold	1	2	3	4	5	6	7	8	9	10
Limit increase	100%	103.1%	105.3%	106.4%	110.2%	109.6%	112.8%	112.7%	114.0%	115.3%
Cut value	0.165	0.15	0.135	0.1	0.09	0.06	0.05	0.045	0.025	0.15

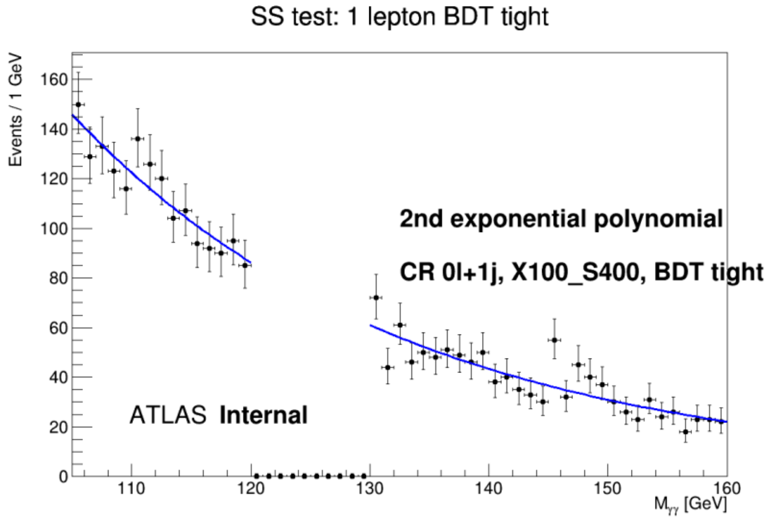
Table 18: Relative limit change for different sideband data entry threshold in (m_X, m_S) = (1000, 170) GeV WW1l channel.

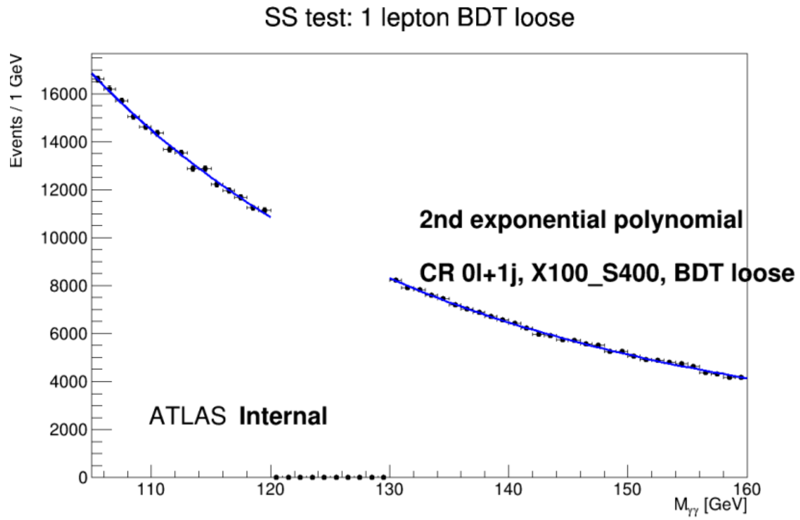
Threshold	1	2	3	4	5	6	7	8	9	11
Limit change	100%	106.9%	99.5%	78.7%	80.4%	83.1%	90.5%	93.3%	92.4%	98.4%
Cut value	0.195	0.185	0.165	0.105	0.09	0.08	0.075	0.07	0.065	0.055

Table 19: Relative limit change for different sideband data entry threshold in (m_X, m_S) = (750, 200) GeV WW1L channel

Background Estimation

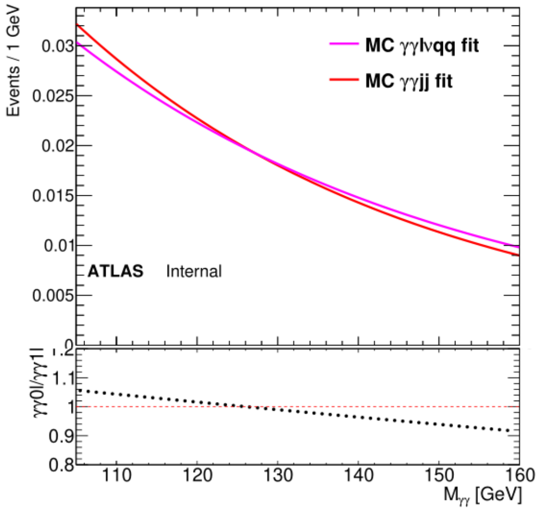
- General idea:
  - Using sideband data 0l CR (failed 2 tight photons) shape to simulate yy+1/2l shape.
  - Use sideband data yy+0l+1j to simulate yy+lvjj.
  - Use yy+0l+2j to simulate yy+lvlv.
  - Smooth analytic function used to estimate the signal region in 120-130.
- Bkg yields scaled to sideband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

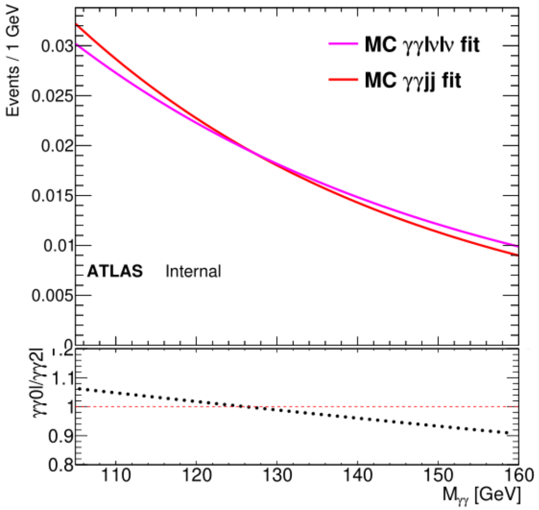




Lepton dependence

- Lepton dependence uncertainty value calculate from MC comparison(yyjj, yylvjj, yyllvv), generator in Madgraph+Pythia8.





- Chi square value in 45 bins.
- Uncertainty apply on the background yields.

X1000S500: Lepton dependence	**BDT tight**	**BDT loose**
1L	8.98%	5.26%
2L	7.38%	5.47%

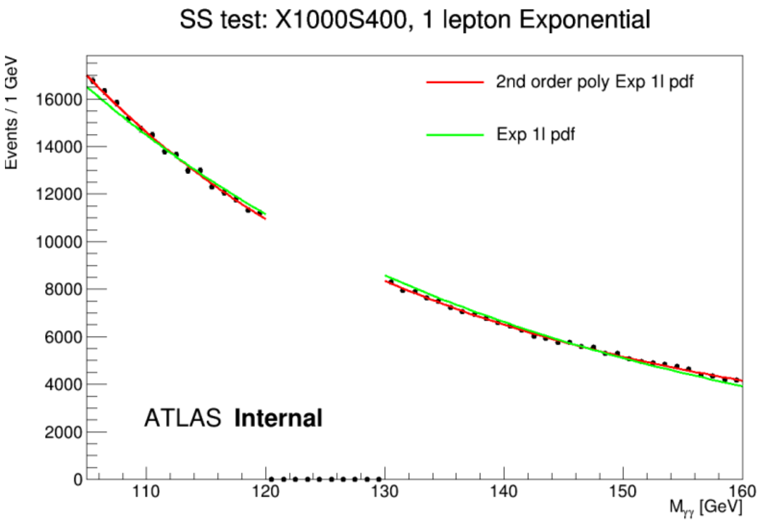
Spurious signals

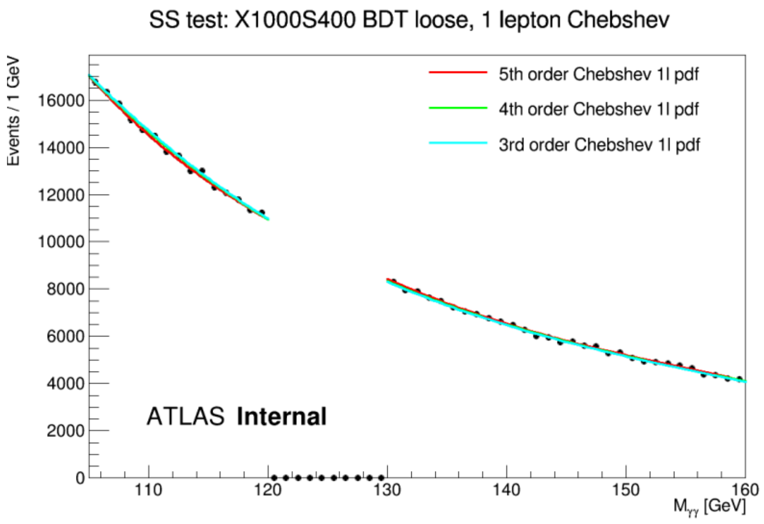
- Impact for different background functions tested.
- 2nd order exponential polynomial chosen.
- μ_{SP} used as uncertainty on signal yields.

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.

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.





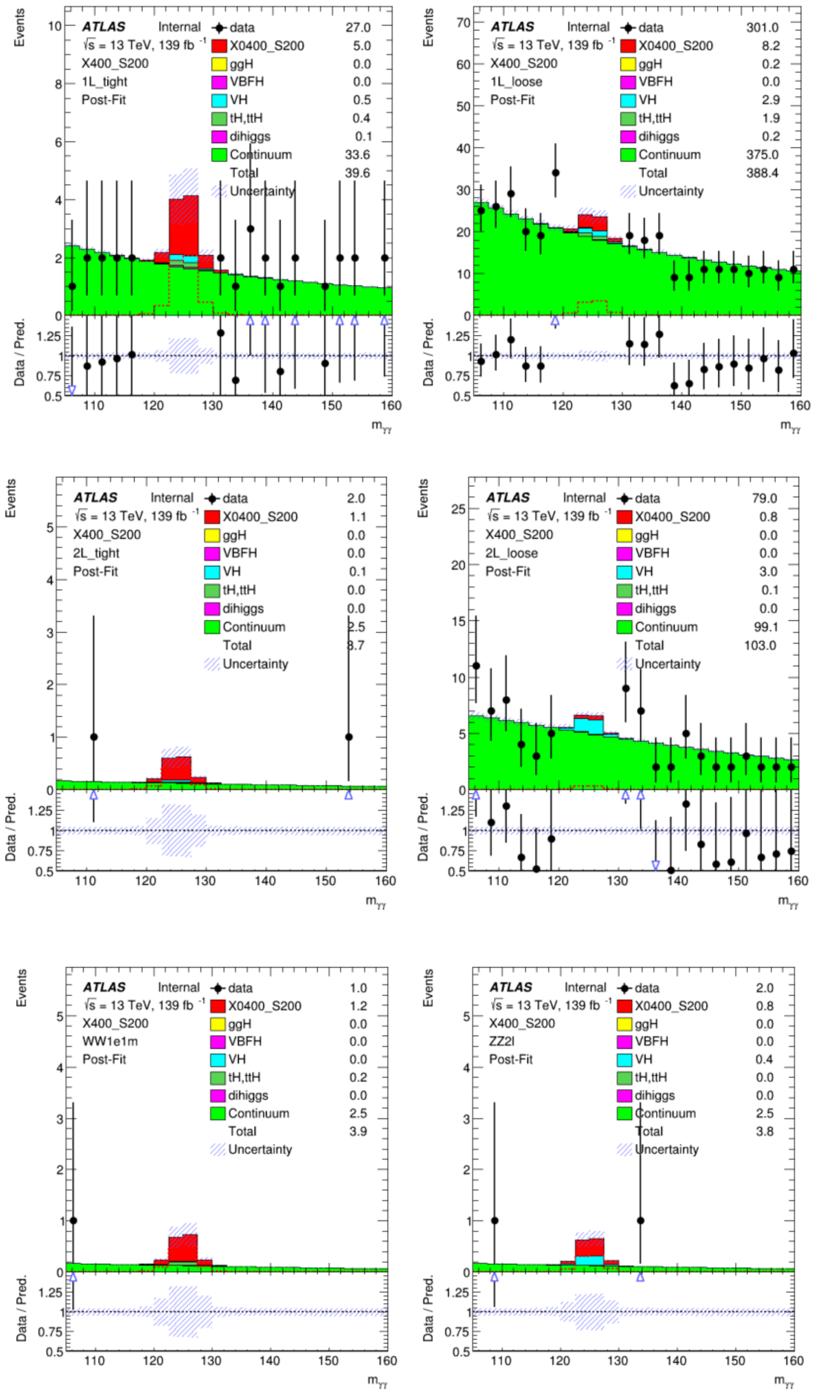
Both lepton dependance and spurious signals varied for different X-S mass points, 1l and 2l, and bdt tight and loose.
(80 in total)

m_{yy} distribution

- Use TRExFitter, one binned fitting tool.
  - Suffered from limited statistics.
  - No need to parametrized signal shape
  - [105, 160], 25bins.

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.



Theory uncertainties

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

  - In Madgraph, it is necessary to point out the BSM model name. Using SM_loop_twoscalar.
  - Current signal QCD is the dominant uncertainty source, ~13% for X1000S500.

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.

Dihiggs Results from Qiyu.

Systematic uncertainties

- Followed Dihiggs scenarios, >100 NPs included.
- While there are no explicit selections on objects for photons and leptons, most NPs do not change m_{yy} shape and yield.
- Pruning threshold 0.5%, usually only Egamma, lumi, DATASF NPs passed.
- Analysis dominates by statistics.

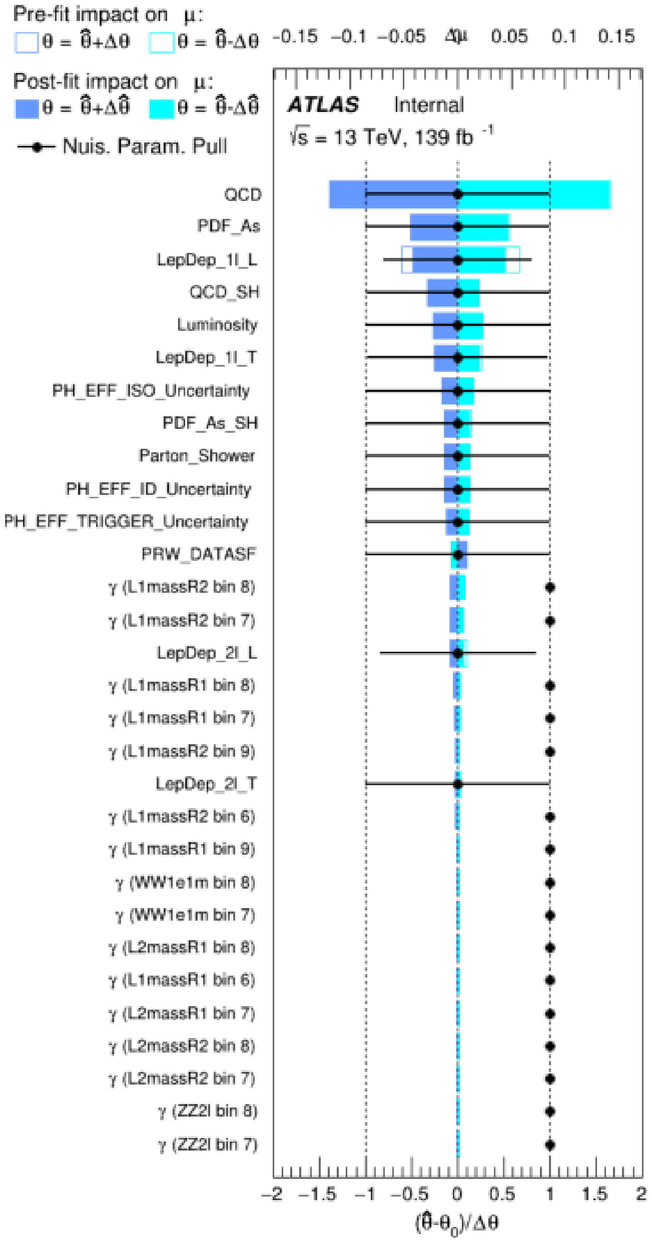
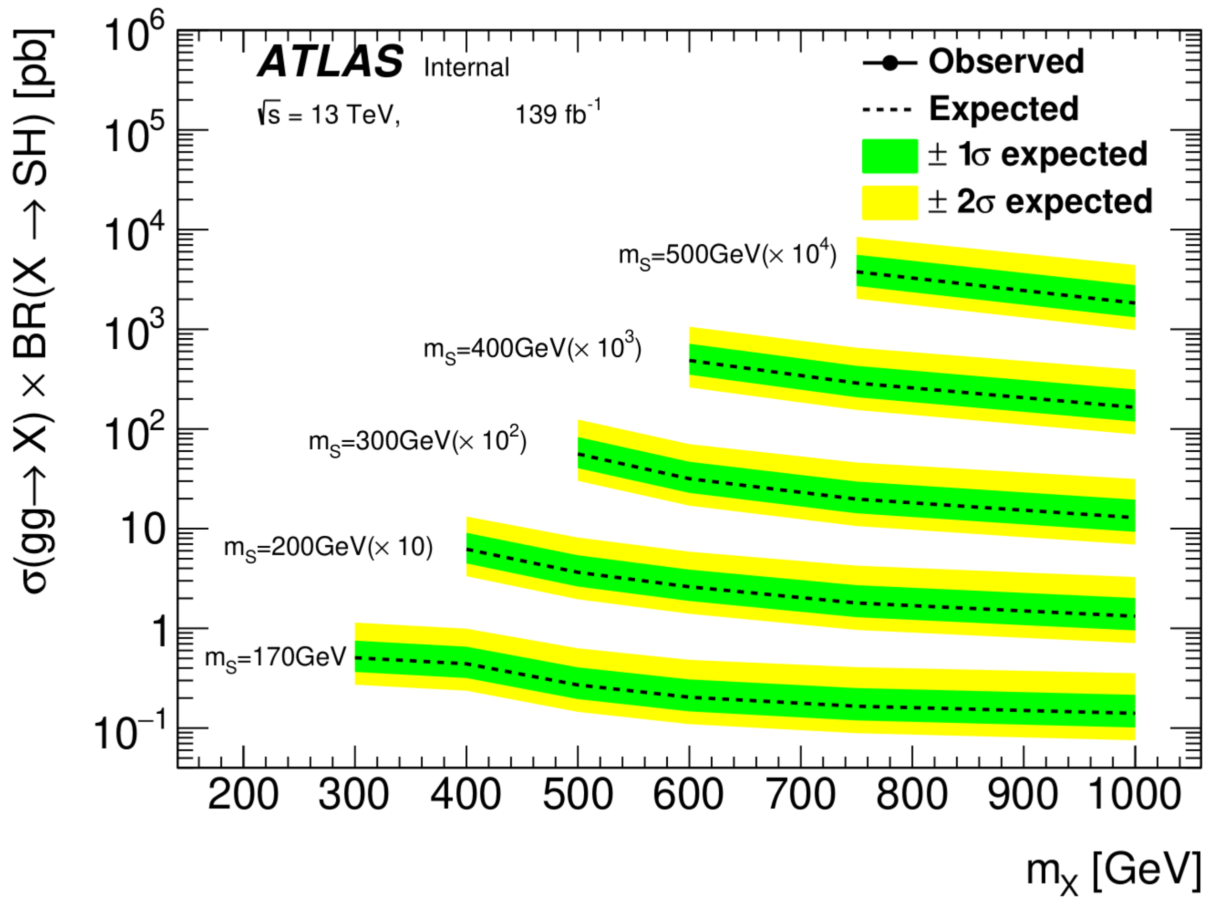


Figure 36: Rankings including systematics and gammas for (m_X, m_S)=(400,200) GeV mass

X400S200 NP ranking.

Expect Results for S decay like SM.



m_X [GeV]	$m_S[GeV]$	$+2\sigma$ [pb]	$+1\sigma$ [pb]	Median [pb]	-1σ [pb]	-2σ [pb]
300	170	1.360	0.896	0.604	0.435	0.324
400	170	1.130	0.762	0.517	0.372	0.277
400	200	1.636	1.138	0.786	0.567	0.422
500	170	0.756	0.493	0.330	0.238	0.177
500	200	1.020	0.683	0.462	0.333	0.248
500	300	0.666	0.974	0.666	0.480	0.357
600	170	0.651	0.420	0.280	0.201	0.150
600	200	0.745	0.496	0.335	0.241	0.180
600	300	0.842	0.571	0.389	0.280	0.209
600	400	1.248	0.844	0.574	0.414	0.308
750	170	0.567	0.366	0.243	0.175	0.130
750	200	0.572	0.369	0.246	0.177	0.132
750	300	0.631	0.429	0.290	0.209	0.155
750	400	0.820	0.547	0.370	0.266	0.198
750	500	1.020	0.687	0.466	0.336	0.250
1000	170	0.421	0.267	0.176	0.127	0.094
1000	200	0.401	0.254	0.168	0.121	0.090
1000	300	0.404	0.260	0.173	0.125	0.093
1000	400	0.471	0.303	0.201	0.145	0.108
1000	500	0.565	0.365	0.243	0.175	0.130

Table 27: 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 to WW/ZZ following the SM prediction.

Best channel in (X1000, S200): 168fb.

Expect results for S 100% to WW/ZZ.

BDT cut value stay the same as SM predictions,
but scale the yields to 100% WW/ZZ.

WW:

m_X [GeV]	$m_S[GeV]$	$+2\sigma$ [pb]	$+1\sigma$ [pb]	Median [pb]	-1σ [pb]	-2σ [pb]
300	170	1.327	0.863	0.578	0.417	0.310
400	170	1.166	0.788	0.535	0.385	0.287
400	200	1.126	0.769	0.524	0.378	0.281
500	170	0.762	0.499	0.333	0.240	0.179
500	200	0.831	0.557	0.376	0.271	0.202
500	300	0.981	0.673	0.460	0.332	0.247
600	170	0.648	0.420	0.280	0.202	0.150
600	200	0.573	0.380	0.256	0.184	0.137
600	300	0.615	0.416	0.282	0.203	0.151
600	400	0.796	0.538	0.364	0.263	0.196
750	170	0.564	0.356	0.235	0.169	0.126
750	200	0.450	0.293	0.195	0.140	0.105
750	300	0.450	0.298	0.200	0.144	0.108
750	400	0.466	0.300	0.199	0.144	0.107
750	500	0.776	0.523	0.355	0.256	0.191
1000	170	0.410	0.254	0.167	0.120	0.089
1000	200	0.326	0.202	0.133	0.096	0.071
1000	300	0.280	0.175	0.115	0.083	0.062
1000	400	0.272	0.172	0.113	0.081	0.061
1000	500	0.309	0.196	0.129	0.093	0.069

ZZ:

m_X [GeV]	$m_S[GeV]$	$+2\sigma$ [pb]	$+1\sigma$ [pb]	Median [pb]	-1σ [pb]	-2σ [pb]
300	170	5.059	3.230	2.119	1.527	1.137
400	170	3.875	2.469	1.620	1.167	0.870
400	200	2.597	1.656	1.088	0.784	0.584
500	170	3.075	1.953	1.280	0.923	0.687
500	200	2.187	1.392	0.915	0.659	0.491
500	300	2.142	1.366	0.900	0.648	0.483
600	170	2.725	1.726	1.130	0.814	0.606
600	200	1.926	1.223	0.803	0.579	0.431
600	300	1.753	1.113	0.732	0.527	0.393
600	400	2.036	1.297	0.854	0.615	0.458
750	170	2.537	1.606	1.050	0.757	0.564
750	200	1.825	1.155	0.758	0.547	0.407
750	300	1.417	0.898	0.589	0.425	0.316
750	400	1.532	0.972	0.639	0.460	0.343
750	500	1.749	1.112	0.731	0.527	0.393
1000	170	2.384	1.499	0.983	0.708	0.527
1000	200	1.999	1.260	0.825	0.594	0.443
1000	300	1.216	0.766	0.502	0.362	0.270
1000	400	1.209	0.762	0.500	0.360	0.268
1000	500	1.272	0.803	0.526	0.379	0.282

100% WW have better limits for larger yields.

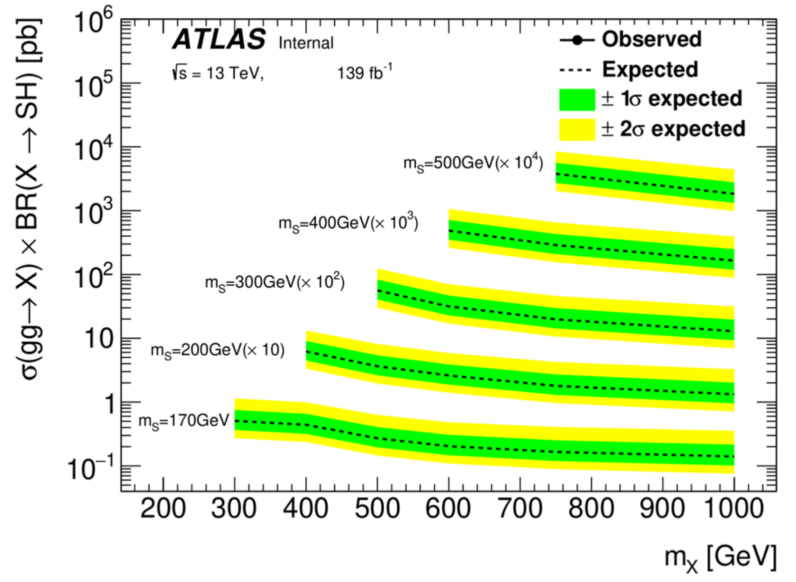
CDS's comment since Dec 9th:

- We received many nice comments in CDS, thank you all!
  - https://docs.google.com/document/d/1Gwua1dWgyDFbYqGpTkY0PZTaXSR_pfgZfRGjxzqwQml/edit?usp=sharing
  - More than 100 suggestions from 9 different people;
- To avoid confusing, the updated draft, including Appendix A and the reply for comments will be done after this approval meeting.

Summary

- We are ready for unblinding.
  - Currently best channel in X1000S200, for 168fb.

- Unfinished task:
  - Check for theoretical uncertainty
  - Check for Interpolation
  - Comments received on CDS.



Backups

Signal cutflows

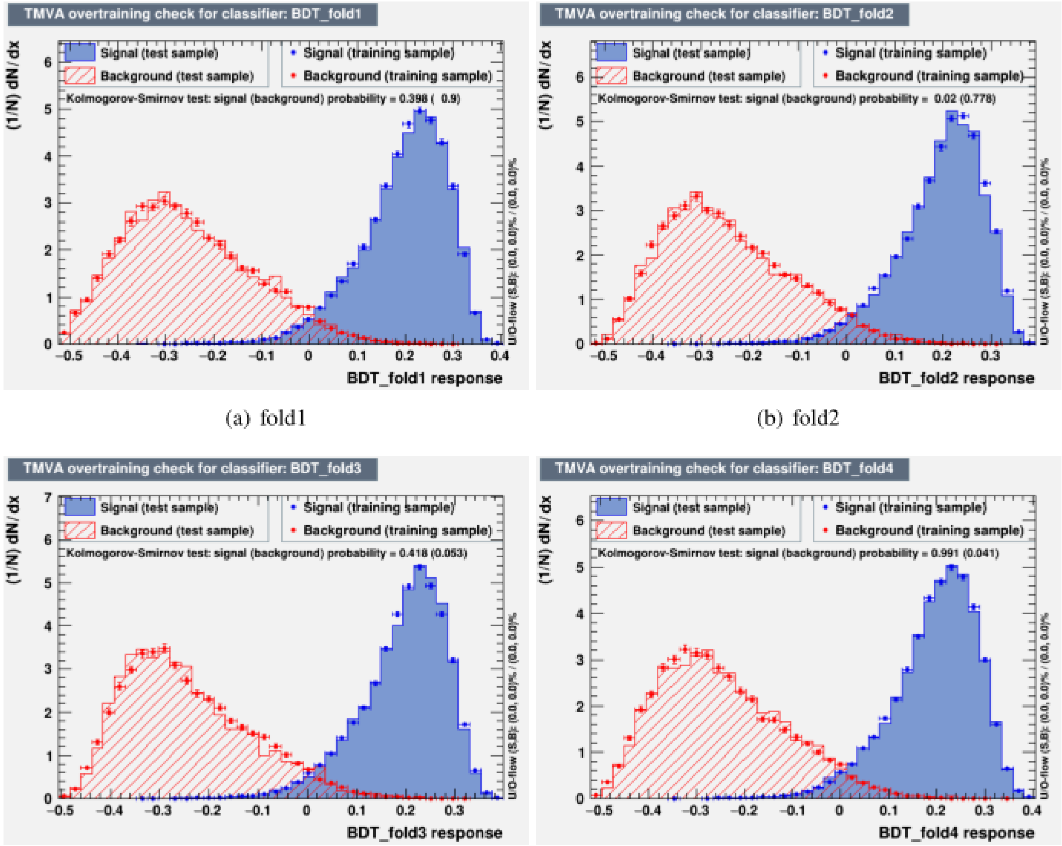
m_X	300	400	400	500	500	500	600	600	600	600
m_S	170	170	200	170	200	300	170	200	300	400
WW1l, DSID	800943	800944	800945	800946	800947	800948	800949	800950	800951	800952
All events	100	100	100	100	100	100	100	100	100	100
No duplicates	100	100	100	100	100	100	100	100	100	100
GRL	100	100	100	100	100	100	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

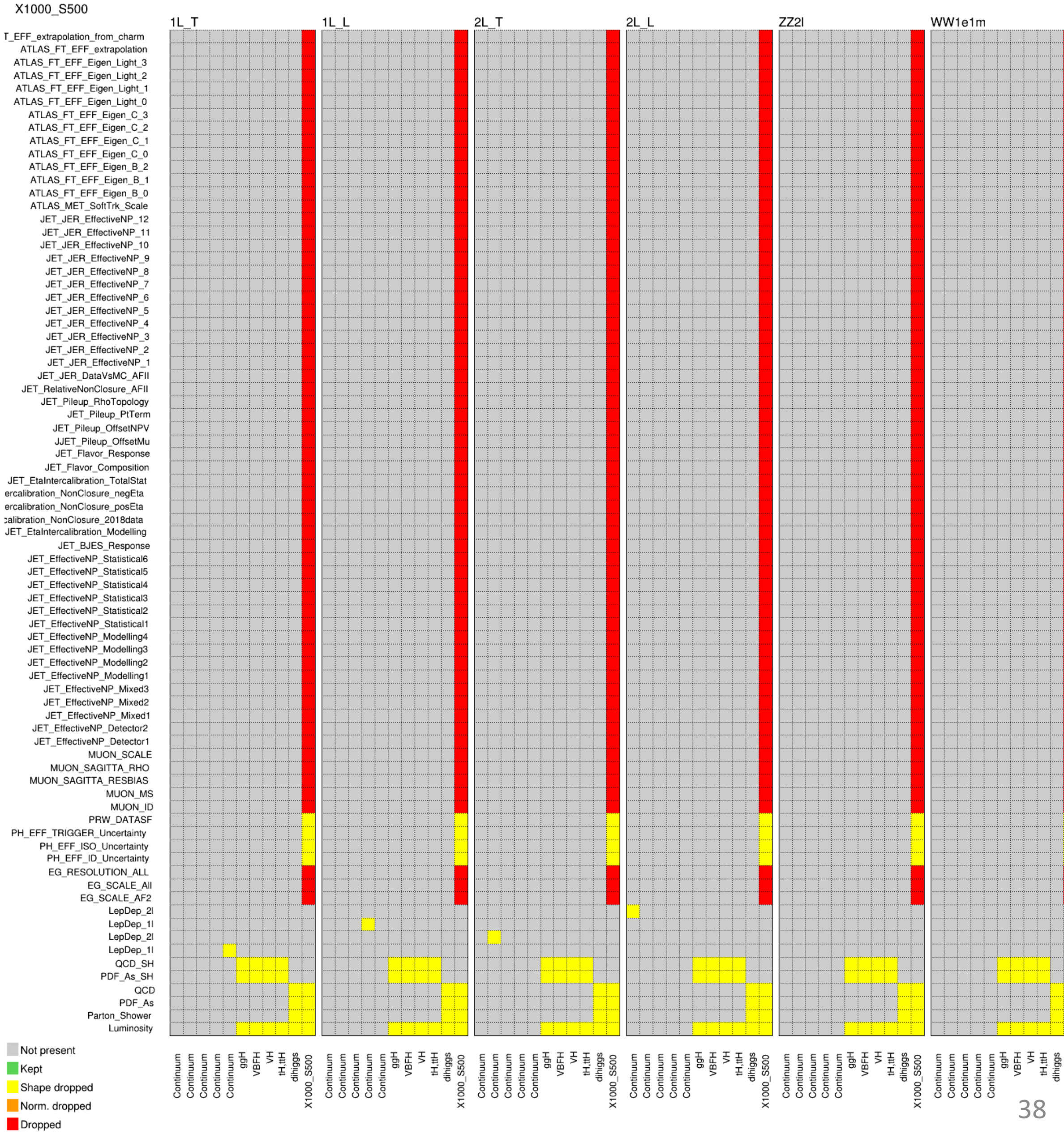
X400S200

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

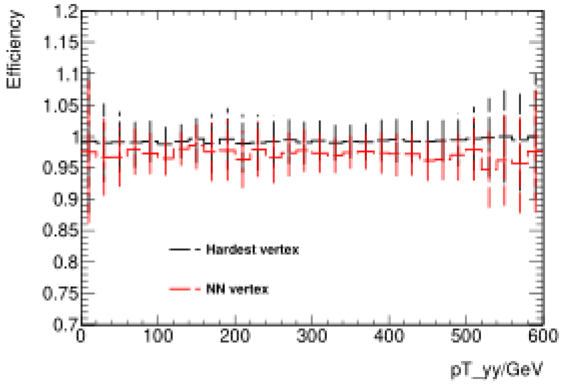
Pruning situations for X1000S500

Most of the NPs are pruned by 0.5% threshold.

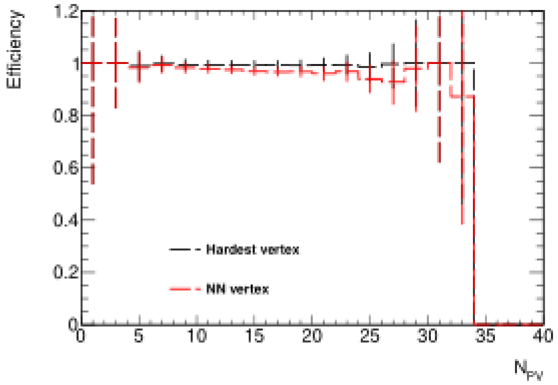


Vertex check

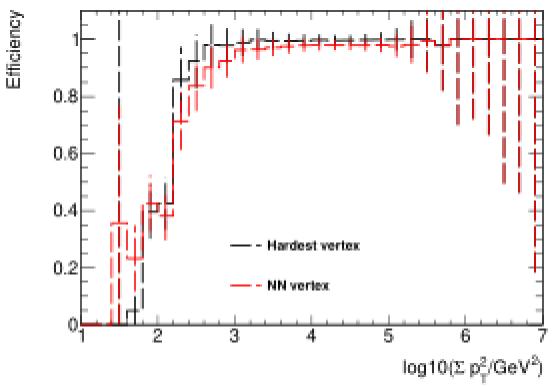
- Hgam usually use NN vertex while with leptons, it is possible to use the hardest vertex.



(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.

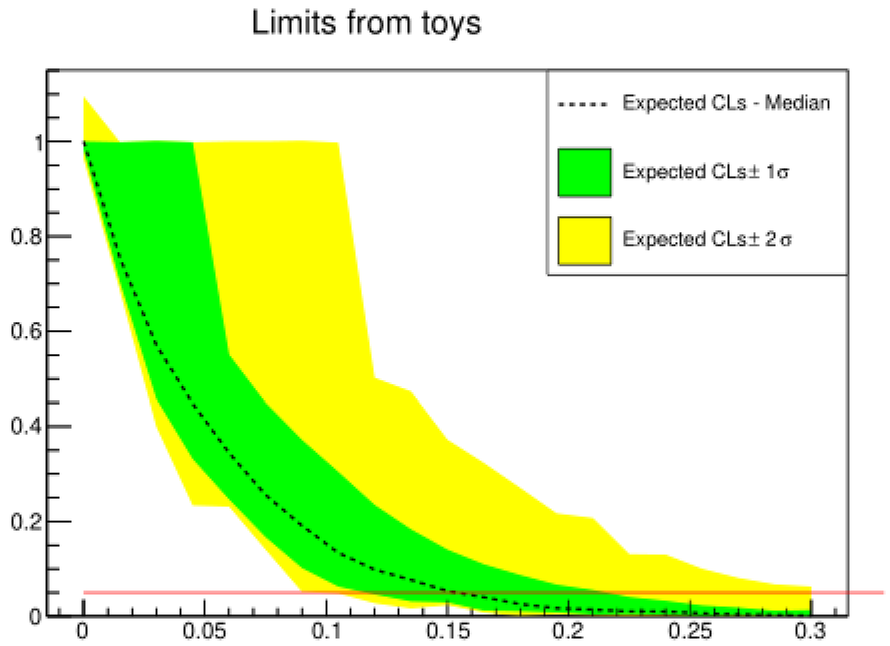


Figure 91: The expected limits of the search m_X = 1000 GeV, m_S = 300 GeV with toy.