Analysis Overview:
$X \to Sh \to \gamma\gamma + 1/2L$

Kaili Zhang, on behalf of ANA-HDBS-2021-23 team

IHEP

26/09/2022

Outline

- Int note: CDS:2779977

Current version on CDS: version16.

- Glance
- EB talk: First EB meeting in Feb 2nd.

ATLAS EXPERIMENT

- Introduction
- Data and MC simulation
- Event selection
- BDT optimization
- Background modeling
- Systematic uncertainties
- Expected results

ATLAS EXPERIMENT

ATLAS Note

ANA-HDBS-2021-23-INT1

September 26, 2022

CERN

Draft version 0.7.5

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

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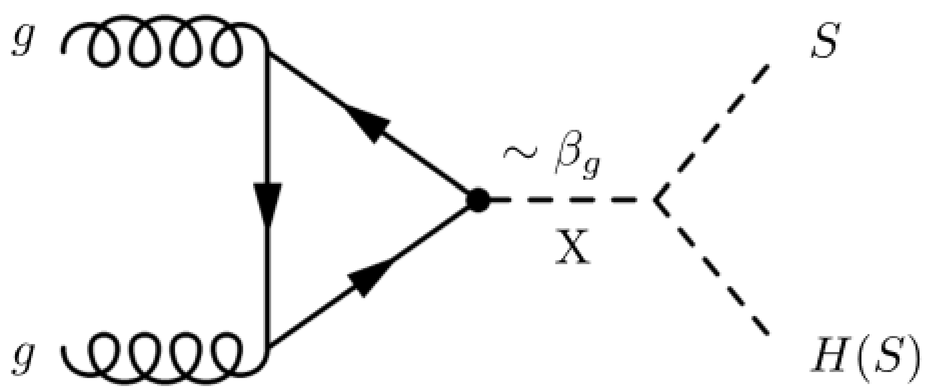
This note presents a search for a new heavy scalar particle X decaying into a Standard Model Higgs boson and a singlet scalar particle S using 139 fb^{-1} of proton-proton collision data at the centre-of-mass energy of 13 TeV recorded with the ATLAS detector at LHC. The explored X mass range varies from 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).

Contents

Introduction



- Extended BSM 2HDM+S model
- X → Sh process would be an alternative model enhancing

  Higgs pair production.

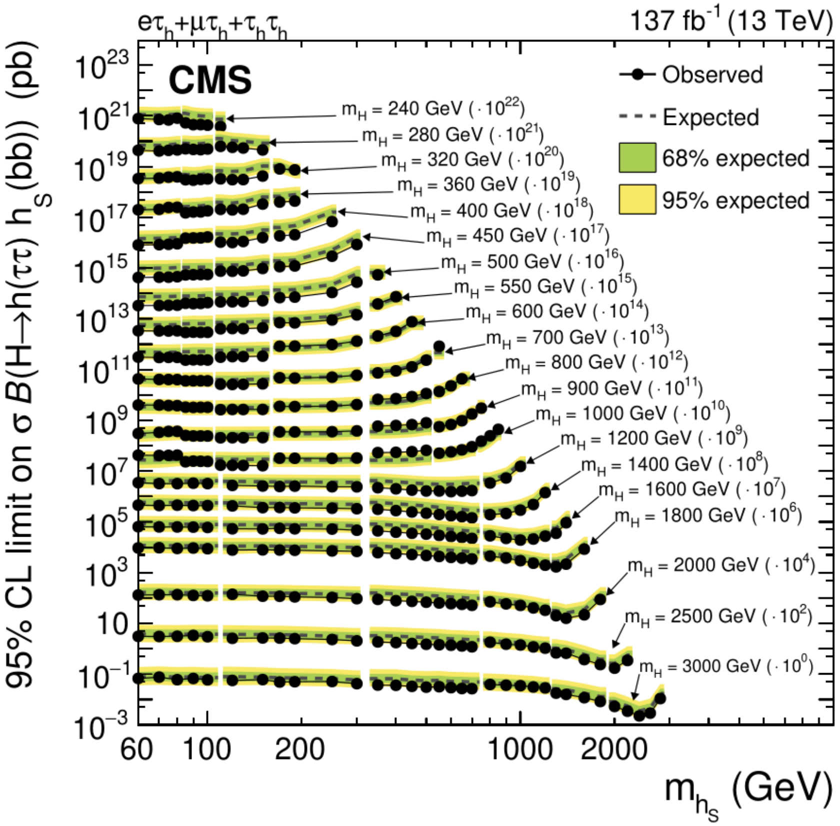
  - Heavy cp-even scalar X into Higgs h + Higgs-like scalar S.
  - For $m_S > m_{125}$, S would decay into WW and ZZ dominantly.

    Multilepton channels benefit from large branch ratio.
  - Higgs diphoton gives excellent clean spectrum and clear signature.

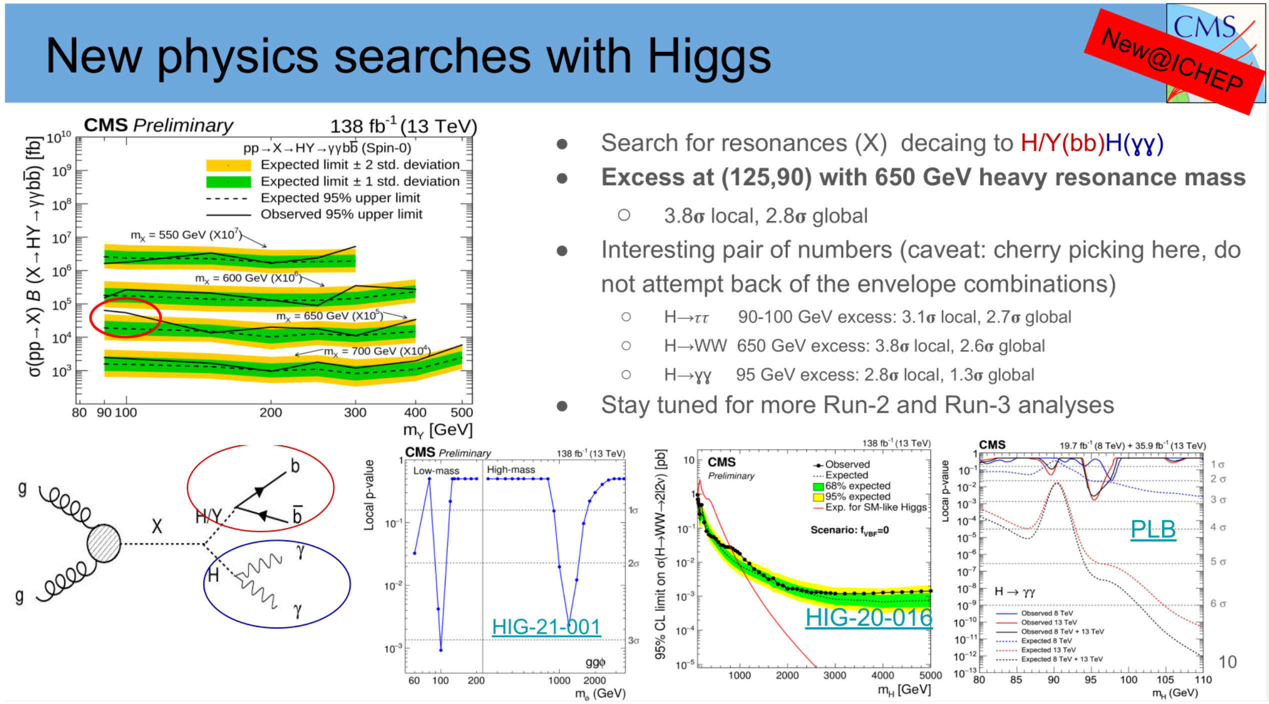
Related work:

More ATLAS SH undergoing……

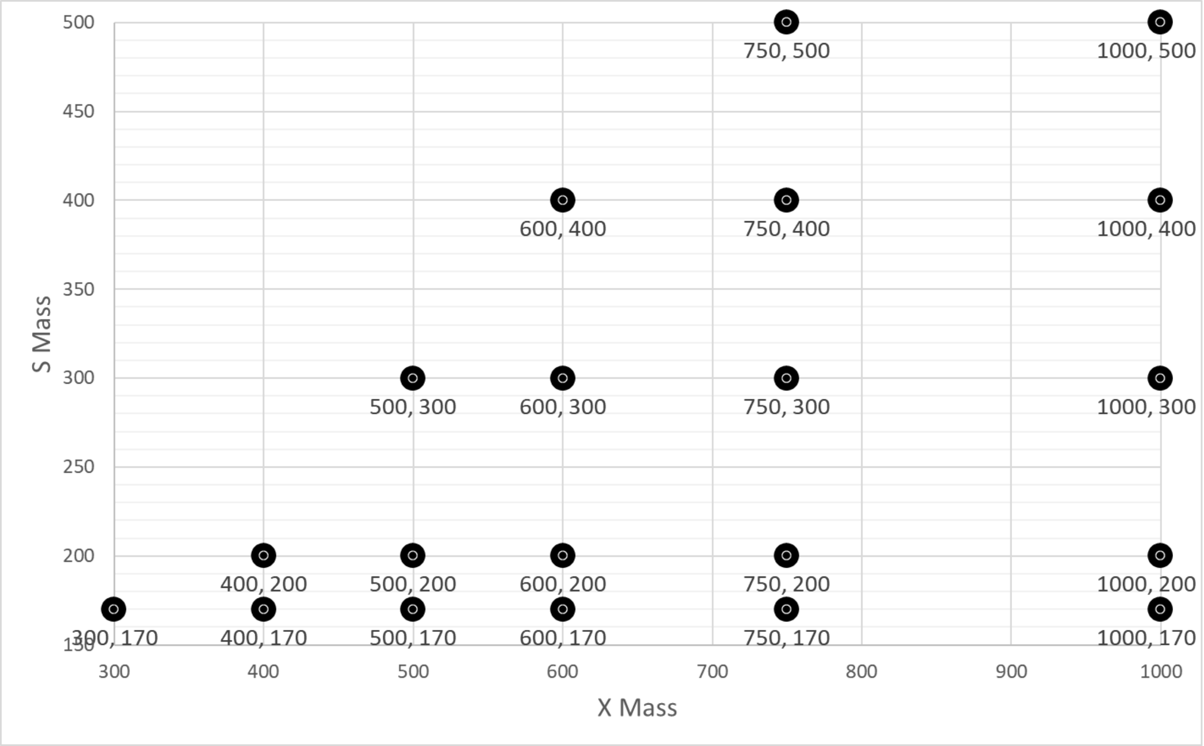
CMS bbtautau: JHEP11(2021)057



CMS ICHEP2022:



Signal X-S Mass Grid



- 20 mass points has been chosen:
- S mass from 170 to 500 GeV
- X mass from 300 to 1000 GeV
  - Signal in LO, PYTHIA8+EVTGEN+A14+NNPDF2.3, AFII.
  - Samples are generated with WW1l, WW2l and ZZ2l, each 200k.
  - Br(S->WW), Br(S->ZZ) considered in the cross talks.
  - Current POI set on $\sigma(pp \to X \to Sh)$. So WW and ZZ are combined with their predicted branch ratio.

Data & MC

- Framework: AnalysisBase 21.2.131. HGamFramework h026.
- Data: Official h026, 139ifb, 15-18 full Run2 data.
- MC:
  - SM Higgs(ggH, VBFH, WH, qqZH, ggZH……)
  - SM HH yy+0/1/2l
  - Continuum background: yy+jets, V/VV+yy, $\hat{t}t$+yy.
  - yy+0l, 1l, 2l for bkg shape study;

DSID	Generator	PDF (ME)	PDF+Tune (PS)	Prod. Mode	Events in AOD
343981	NNLOPS + Pythia8	PDF4LHC15	AZNLOCTEQ6	ggH	18.3M
346214	Powheg + Pythia8	PDF4LHC15	AZNLOCTEQ6	VBF	7M
345318	Powheg + Pythia8	PDF4LHC15	AZNLOCTEQ6	W^+H	0.6M
345317	Powheg + Pythia8	PDF4LHC15	AZNLOCTEQ6	W^-H	0.6M
345319	Powheg + Pythia8	PDF4LHC15	AZNLOCTEQ6	$qq \to ZH$	1.5M
345061	Powheg + Pythia8	PDF4LHC15	AZNLOCTEQ6	$gg \to ZH$	0.15M
346525	Powheg + Pythia8	PDF4LHC15	A14NNPDF23	ttH	7.8M
345315	Powheg + Pythia8	PDF4LHC15	A14NNPDF23	bbH	0.299M
346188	MGMCatNLO + PYTHIA8	NNPDF	A14NNPDF23	tHbj	0.4M
346486	MGMCatNLO + PYTHIA8	NNPDF	A14NNPDF23	tHW	0.208M
345868	MGMCatNLO + PYTHIA8			$t\bar{t}\gamma\gamma$ (noallhad)	1.94M
345869	MGMCatNLO + PYTHIA8			$t\bar{t}\gamma\gamma$ (allhad)	1.6M
600542	Powheg + Herwig7	PDF4LHC15		SM Dihiggs $\gamma\gamma$+0L	0.1M
600543	Powheg + Herwig7	PDF4LHC15		SM Dihiggs $\gamma\gamma$+1L	0.5M
600544	Powheg + Herwig7	PDF4LHC15		SM Dihiggs $\gamma\gamma$+2L	0.5M

Table 4: Summary of nominal Single Higgs and di-photon background samples

Event Selection

Common selection criteria in HGam analysis:

- Good event
  - GRL, Pass the trigger, detector DQ……
- 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.
- At least 1 lepton
  - e/muon pt>10 GeV; PID: medium;
    - Hadronic tau not included.
- B-veto
  - B-77 veto to avoid the overlap.

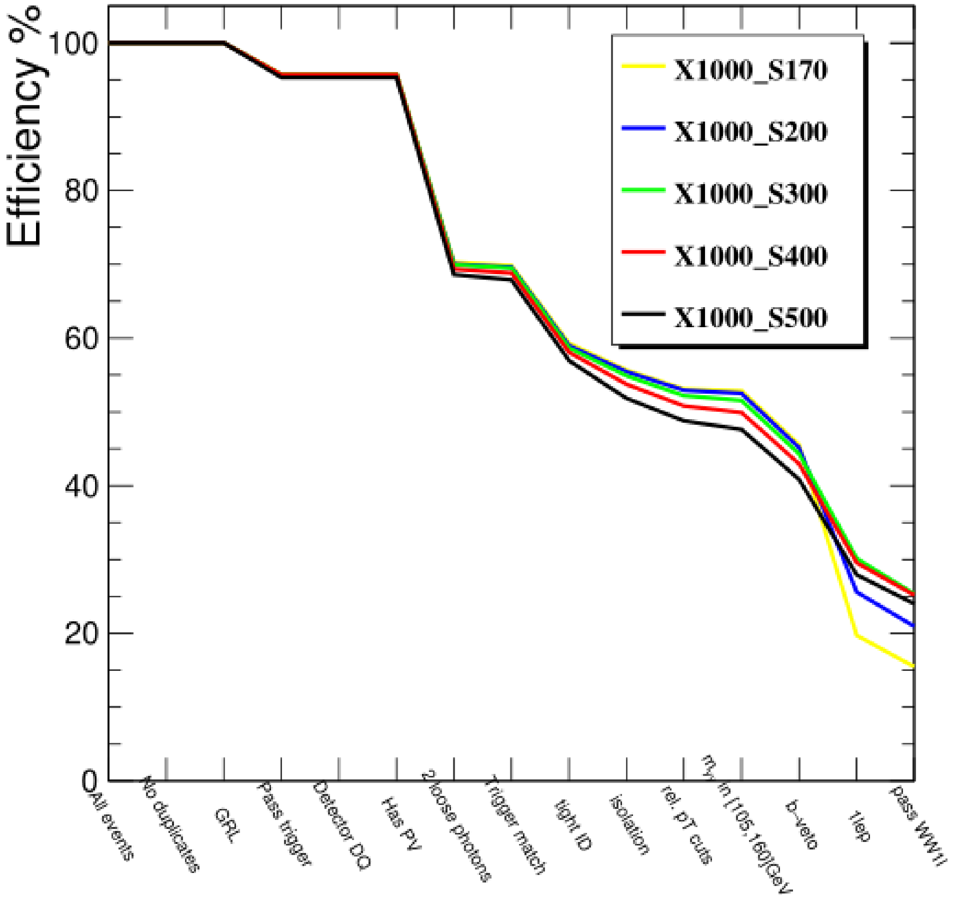
- Regions defined: in total 4.
  - WW1l: 1 e/muon + 2 central jets;
    - Central jet: pt>25 GeV, |eta|<2.5, pass overlap removal;
  - WW2l: 2 same flavor, OS leptons
    - Z-veto, $|m_{ll} - 91| > 10$ GeV

These 2 have enough statistics, use BDT to improve sensitivity.

  - WW1e1m: OS 1 electron 1 muon;
  - ZZ2l: 2 same flavor, OS leptons
    - In Z peak: $|m_{ll} - 91| < 10$ GeV

Limited statistics, used for number counting.

Cutflow: 1l, X1000GeV



(d) m_X = 1000 GeV

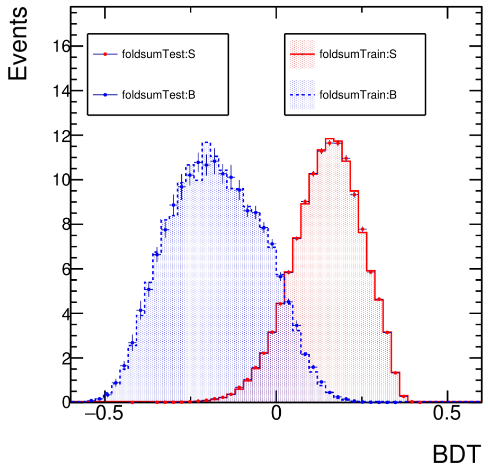
- Typically, X1000 1l signal events
- 70% pass the trigger,
- 45-50% pass the 2 tight photons.
- 45-40% pass b-veto
- 20%(S170) to 30% pass 1 lepton
  - Lepton efficacy >60%.

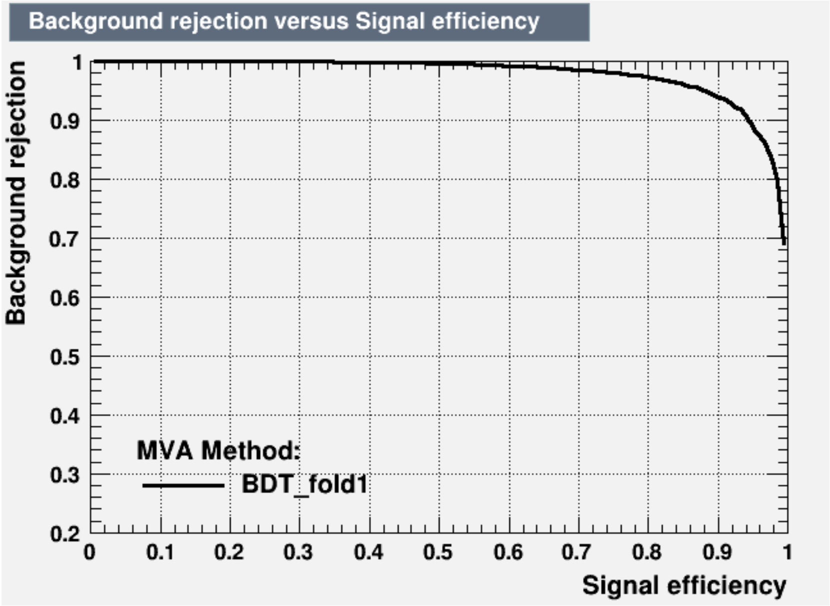
- Ratio from 2lepton fall to 1l is large.

BDT modelling

Chapter 4

- Signal MC, yy+jets, Vyy, ttyy, SM single Higgs and SM dihiggs used.
- Before training, Data/MC consistence is confirmed.
  - Reweighting
- 1 lepton 14 variables and 2lepton 11 variables.
  - Make sure all the variables have small correlation with m_yy.
- Cross validation method + 4 folds
- Parameterized X mass used
  - The true X mass used in the BDT training for signal samples. While background X mass randomly assigned.
  - When applying BDT, background use the corresponding X mass.
  - So 4 BDT trainings, grouped by S mass, have 20 all different BDT outputs for different signals.





BDT variables

Ranking	Variable	Importance
1	$p_T^{\gamma\gamma}$	0.1017
2	$m_{all} - m_{l\nu jj}$	0.0936
3	p_T^{l}	0.0741
4	$E_{\mathrm{T}}^{\mathrm{miss}}$	0.0732
5	$\Delta R(j,j)$	0.0727
6	$\Delta\Phi(\gamma\gamma, l)$	0.0726
7	$\Delta R(l, E_{\mathrm{T}}^{\mathrm{miss}})$	0.0704
8	$\Delta R(jj, l\nu)$	0.0674
9	m_{jj}	0.0633
10	$DeltaR(\gamma\gamma, l\nu jj)$	0.0616
11	p_T^{jj}	0.0594
12	$m_T(l\nu)$	0.0529
13	$p_T^{l\nu jj}$	0.0421

Table 14: Variable importance in WW1l BDT.

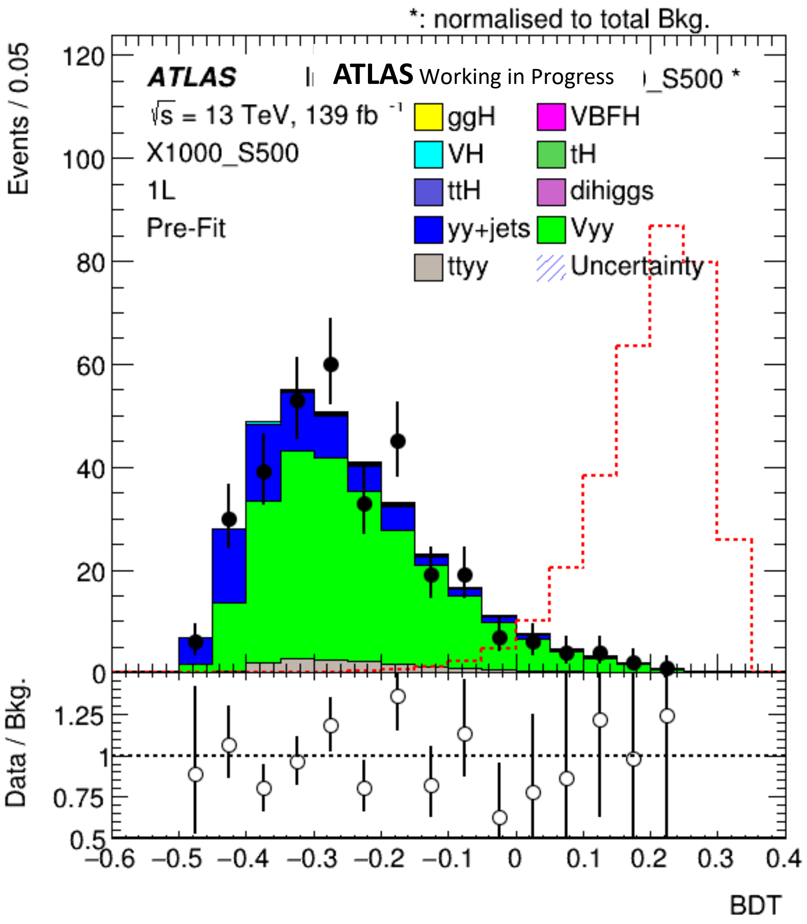
Ranking	Variable	Importance
1	$p_T^{\gamma\gamma}$	0.1077
2	$E_{\mathrm{T}}^{\mathrm{miss}}$	0.1038
3	$\Delta\Phi(\gamma\gamma, l_1)$	0.0939
4	$m_{all} - m_{ll+E_{\mathrm{T}}^{\mathrm{miss}}}$	0.0929
5	$\Delta R(l1, l2)$	0.0885
6	m_{ll}	0.0874
7	$\Delta R(\gamma\gamma, ll + E_{\mathrm{T}}^{\mathrm{miss}})$	0.0782
8	$p_T^{l+E_{\mathrm{T}}^{\mathrm{miss}}}$	0.0739
9	$p_T^{l_1}$	0.0686
10	$m_T(l_1 + E_{\mathrm{T}}^{\mathrm{miss}})$	0.0609

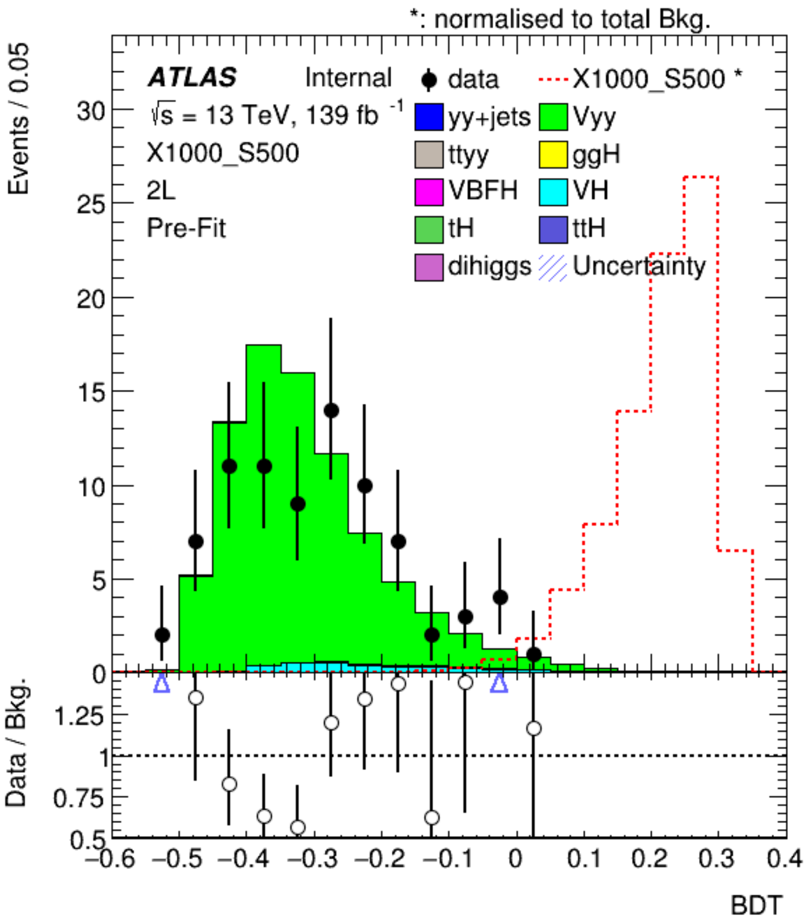
Table 15: Variable importance in WW2l BDT.

BDT outputs

Clear separation between signal and MC/sideband data.
Consistence between MC and sideband data.

Appendix D for all BDT results.



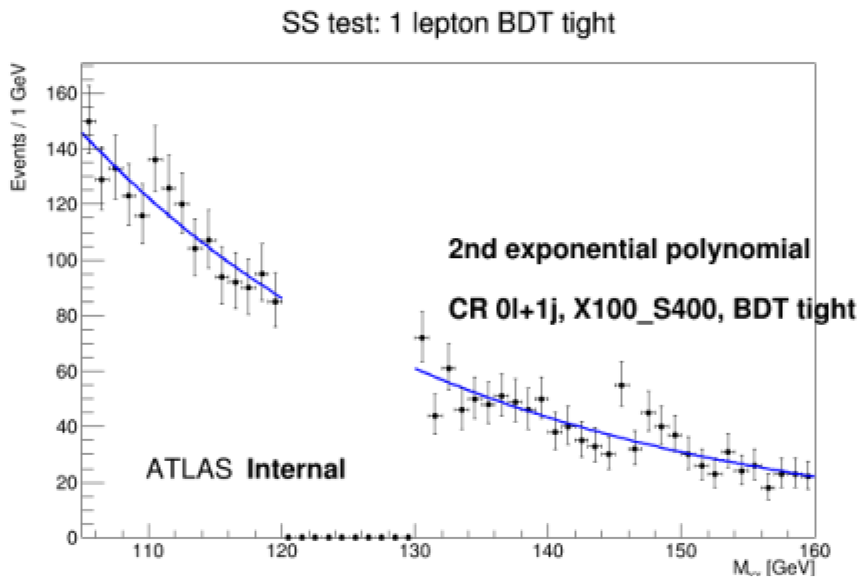


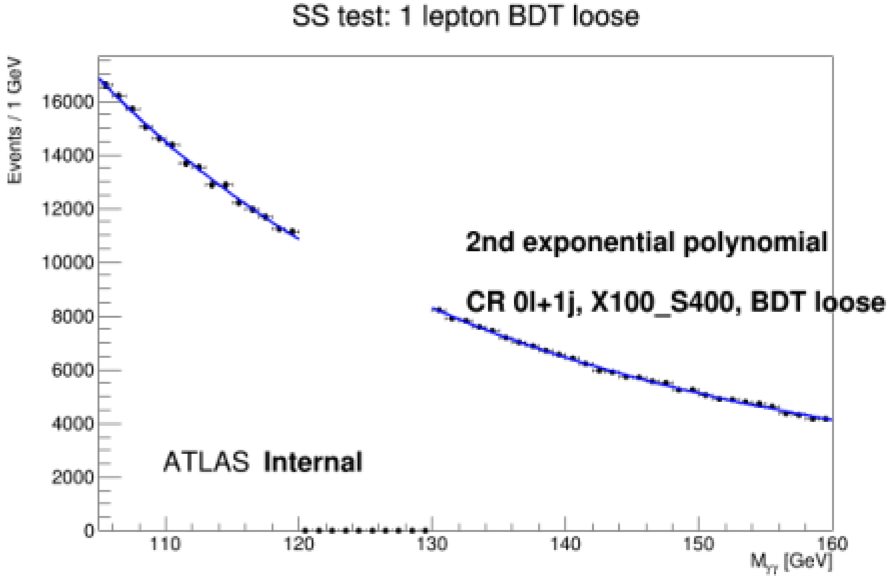
X Mass [GeV]	S Mass [GeV]	WW1L BDT Cut	WW2L BDT Cut
300	170	0.09	0.155
400	170	0.08	0.145
400	200	0.03	0.13
500	170	0.125	0.165
500	200	0.095	0.14
500	300	0.025	0.115
600	170	0.16	0.115
600	200	0.115	0.085
600	300	0.045	0.11
600	400	0.035	0.1
750	170	0.21	0.03
750	200	0.155	0.035
750	300	0.11	0.06
750	400	0.085	0.11
750	500	0.035	0.11
1000	170	0.185	-0.01
1000	200	0.195	-0.04
1000	300	0.165	0.005
1000	400	0.125	0.04
1000	500	0.125	0.04

For tight region, cut value will be optimized to confirm at least 1 sideband left.

Background modeling: shape

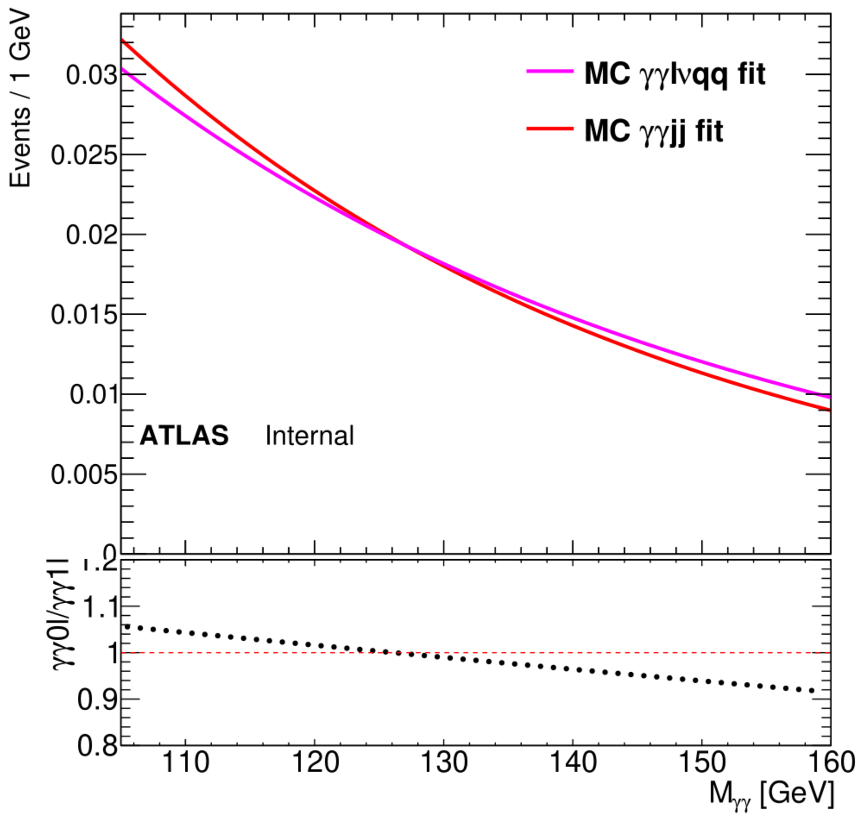
Chapter 5.2





- Use 0 lepton data side-band control region as continuum background shape.
- BDT tight/loose region use different shape
  - In BDT training, fake jet as lepton.
- Background shape simulated from the smooth shape
- Background yield scaled from the sideband data.

Lepton Dependance



Use sideband 0l to simulate bkg.

Use MC yy+0l/1l/2l shape to study uncertainty.

Use all bins(105, 160) to calculate the derivation.

(Conservative)

<3% in background shape, both 1l and 2l.

Low impact in final signal strength.

(Simplified) Spurious signal test

- Directly use signal histogram. SS test-> impact of different bkg function.
  - Fit the S+B histogram with $(\mu S + B)$ to B only shape. Here μS =expected yield, not initial 1pb.
  - Requiring relaxed template

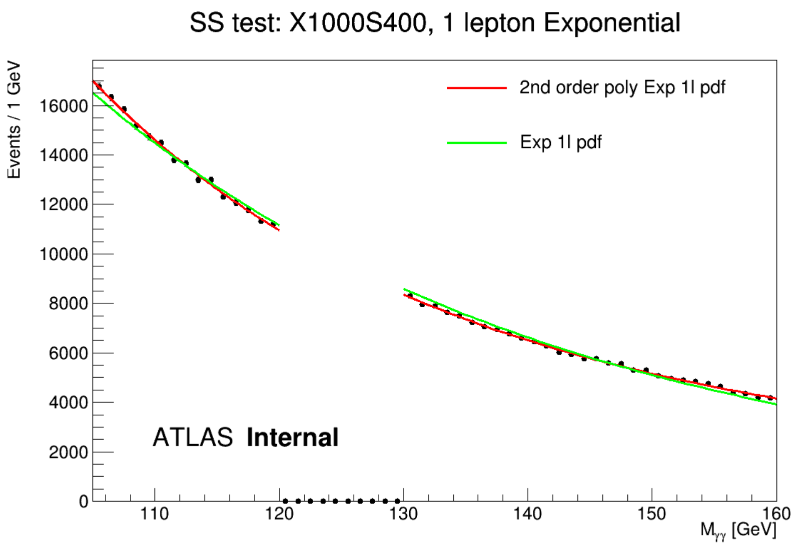
$\mu = \frac{S_{ss}}{S_{ref}}$<0.1, $\frac{S_{ss}}{\delta S_{ref}}$<0.2 p($\chi^2$)>5%

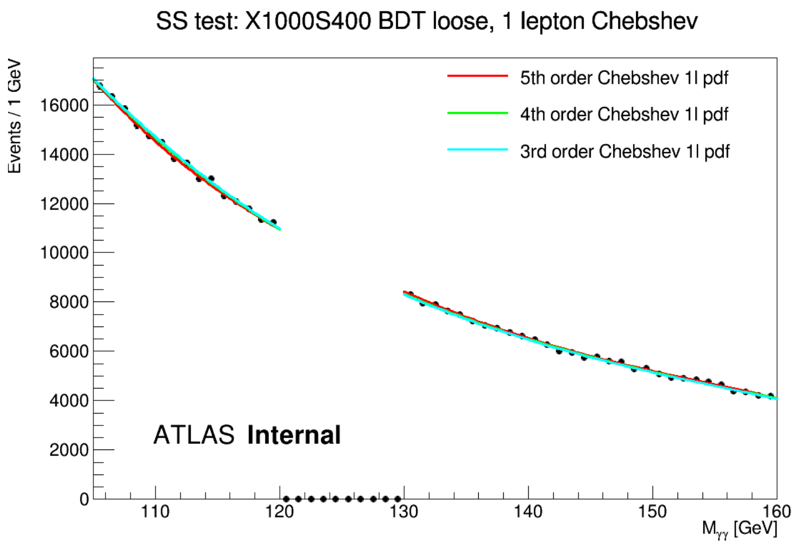
1-lepton case					
Function	Ndof	μ_{sp}[%]	Z_{sp}[%]	$P(\chi^2)$[%]	Selected
Exp	1	0.47	9.1	39.06	Yes
ExpPoly2	2	0.39	8.2	41.27	Yes
Cheb3	3	10.2	19.3	18.46	No
Cheb4	4	8.8	21.2	27.23	No
Cheb5	5	6.31	23.3	24.13	No

Table 18: The spuirous signal test result for 1 lepton channel in $m_X = 1000GeV, m_S = 300GeV$, BDT loose region.

Among Functions: Exp, 2nd Exp, cheb.

In 80 different shapes, Cheb fails in mu test, 78 shapes use 2nd Exp and 2 use Exp.

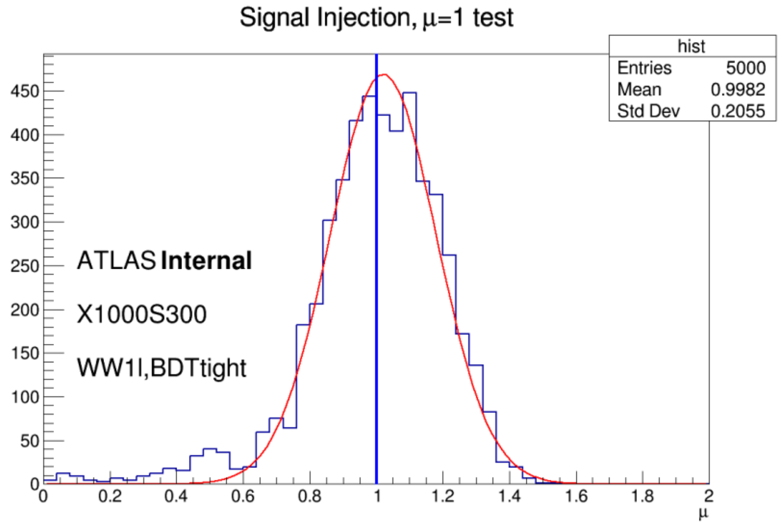


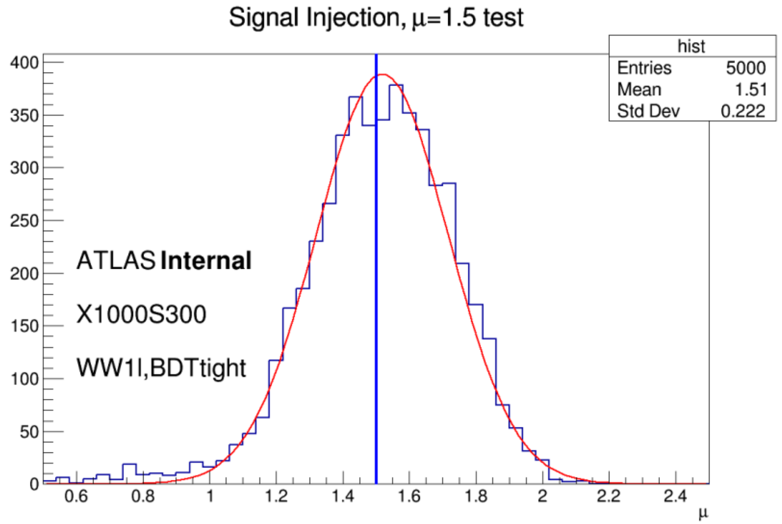


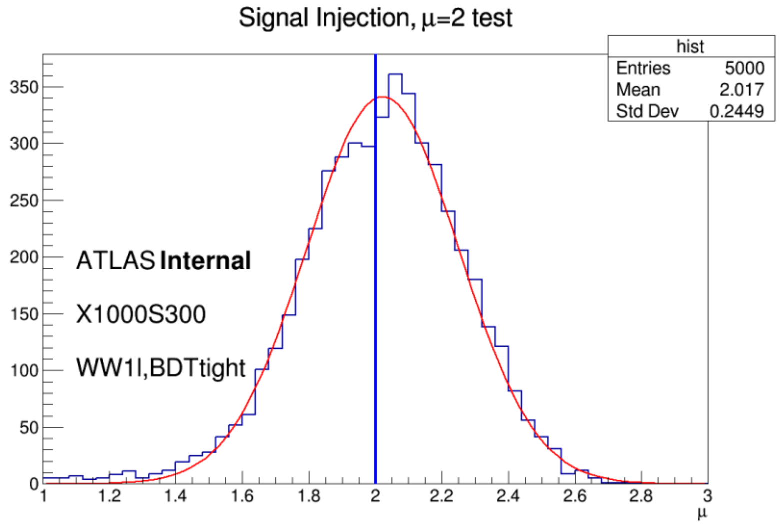
Signal injection test

Appendix G

Choose $\mu = 1, 1.5, 2$ to S+B histogram to check the robustness.

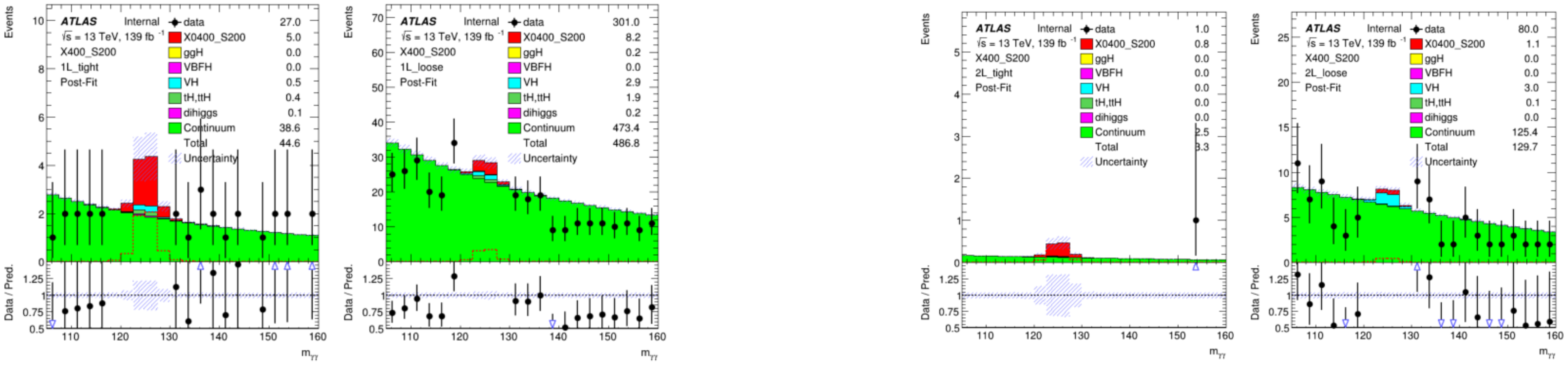






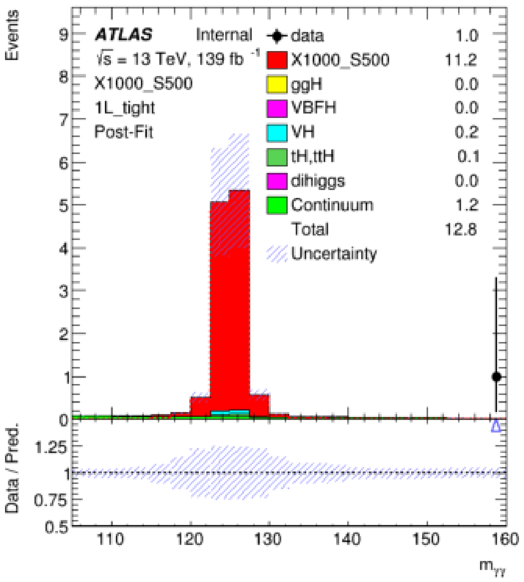
Fit framework

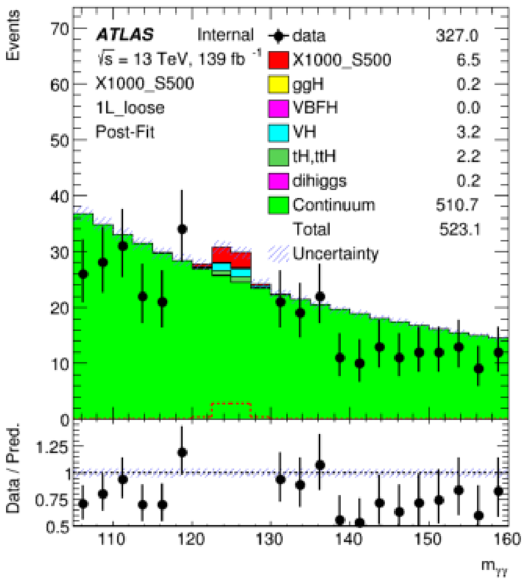
- As limited statistics, we prefer using binned fit with tool TRExFitter.
  - Fit region among m_yy[105, 160]GeV for 22 bins. Bin width 2.5GeV.
    - A bit larger than natural photon resolution.
  - A smaller bin width and narrower range [120, 130] is tried. No significant difference.
  - All systematics would convert to the variation of the shape and yields by bin contents.

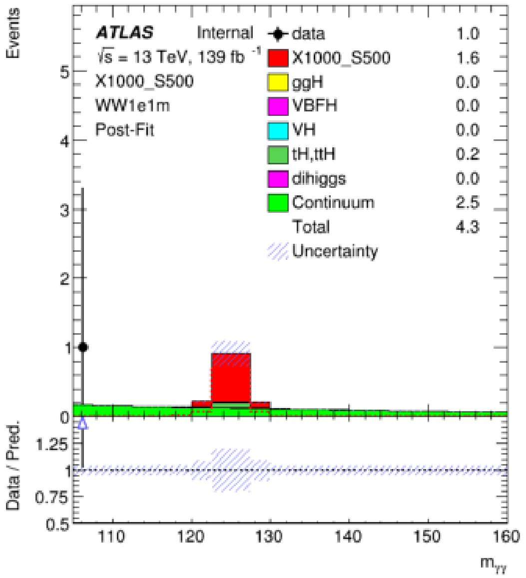


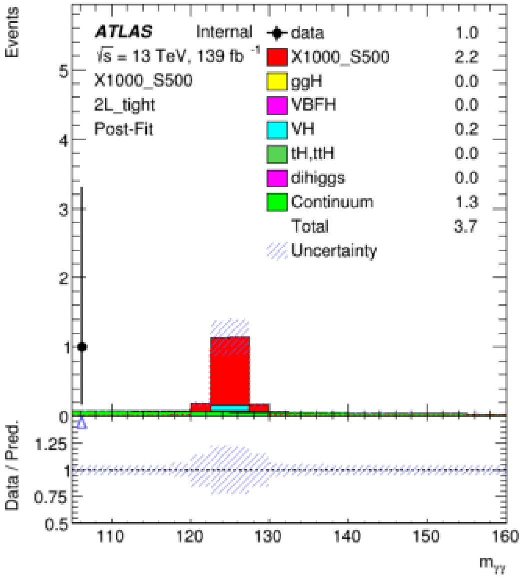
(a) (b) (c) (d)

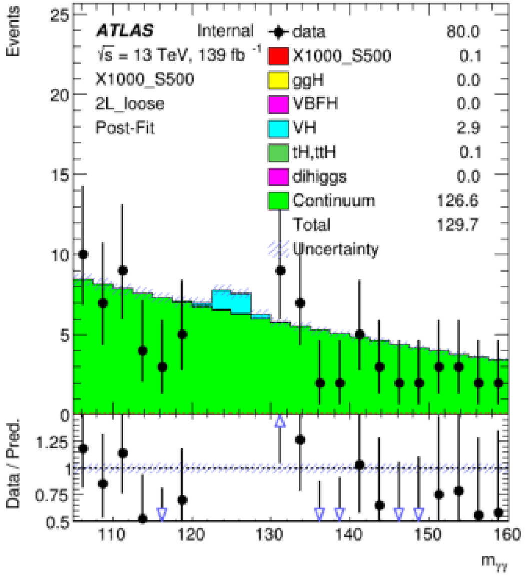
High mass points

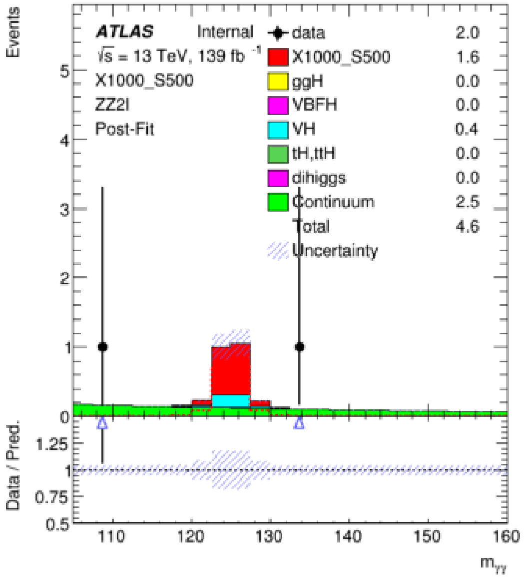








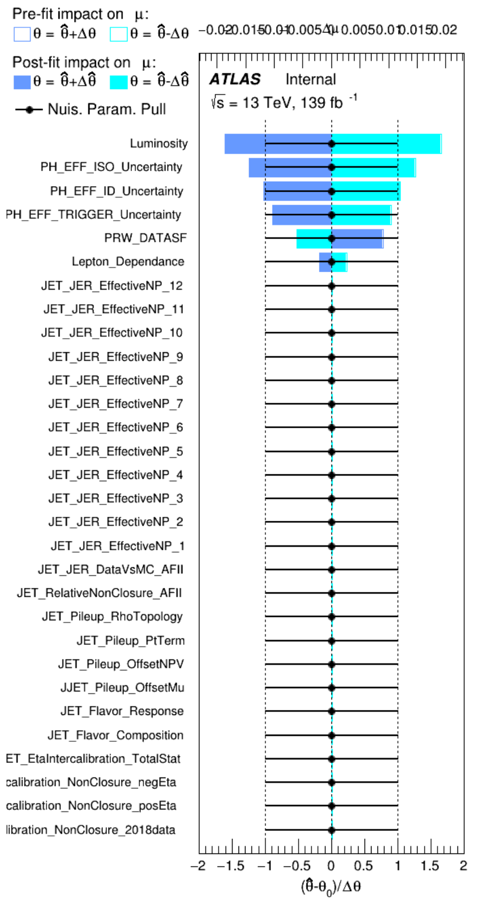




Systematics

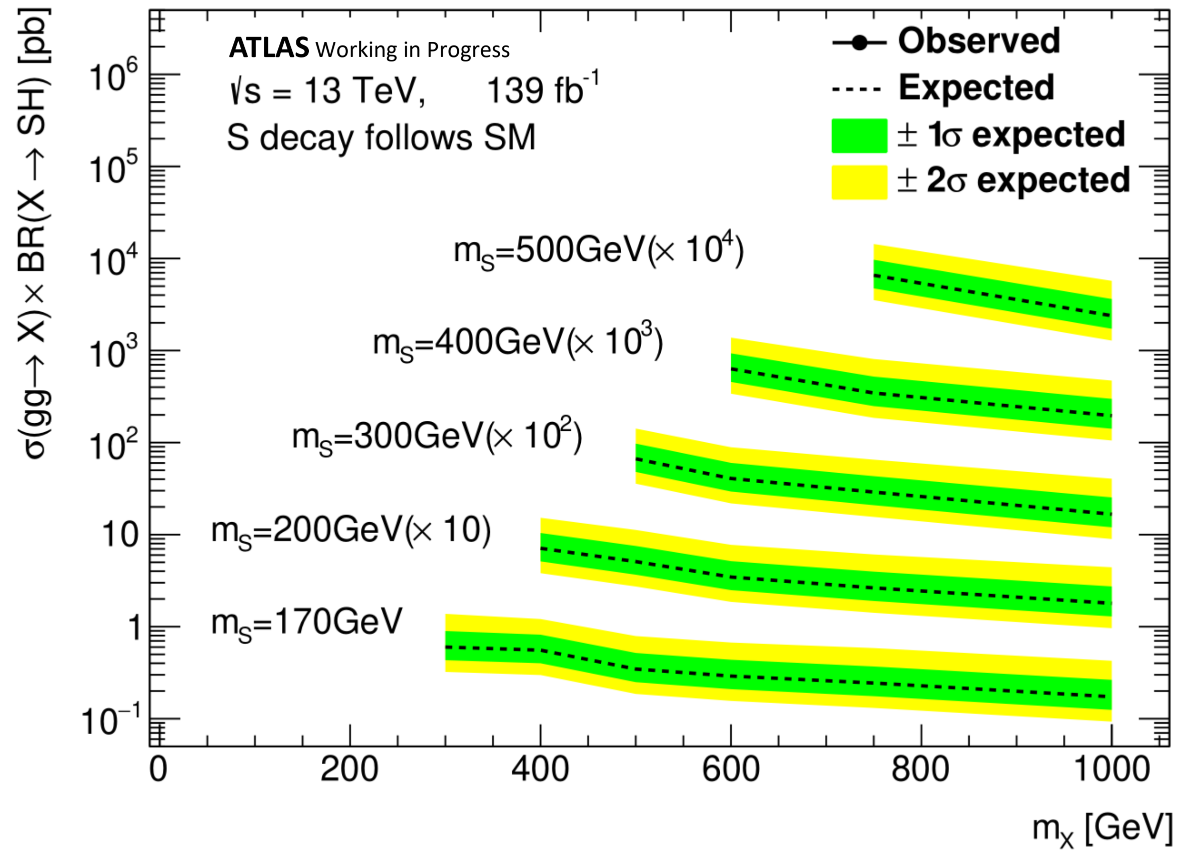
```
Systematic: EG_SCALE_AF2
  Title:     EG_SCALE_AF2
  Type: HISTO
  Samples: *_signal
  Regions: L1_*
  NtupleFileUp:    "sys"
  NtupleFileDown: "sys"
  NtupleNameUp:    "EG_SCALE_AF2__1up"
  NtupleNameDown: "EG_SCALE_AF2__1down"
  WeightSufUp: "weight"
  WeightSufDown: "weight"
```

- CP systematics agree with dihiggs combination scenario
  - SH signal, single higgs and dihiggs samples CP variation included.
  - Egamma, Flavor, leptons, MET, Jet, Taus CP included.
    - Both histo shape variation and weight variation included.
  - Most of CPs have minimal impact. Vetoed by the threshold 0.5%.
    - Changed to 0.05%, ~20 to 30 NPs will enter the fit. Small impact.
    - Only Egamma matters.
  - SS test and lepton dependance uncertainties included.



Fit results: SM condition

WW1l dominant;
Best point X1000,S300: 167fb.



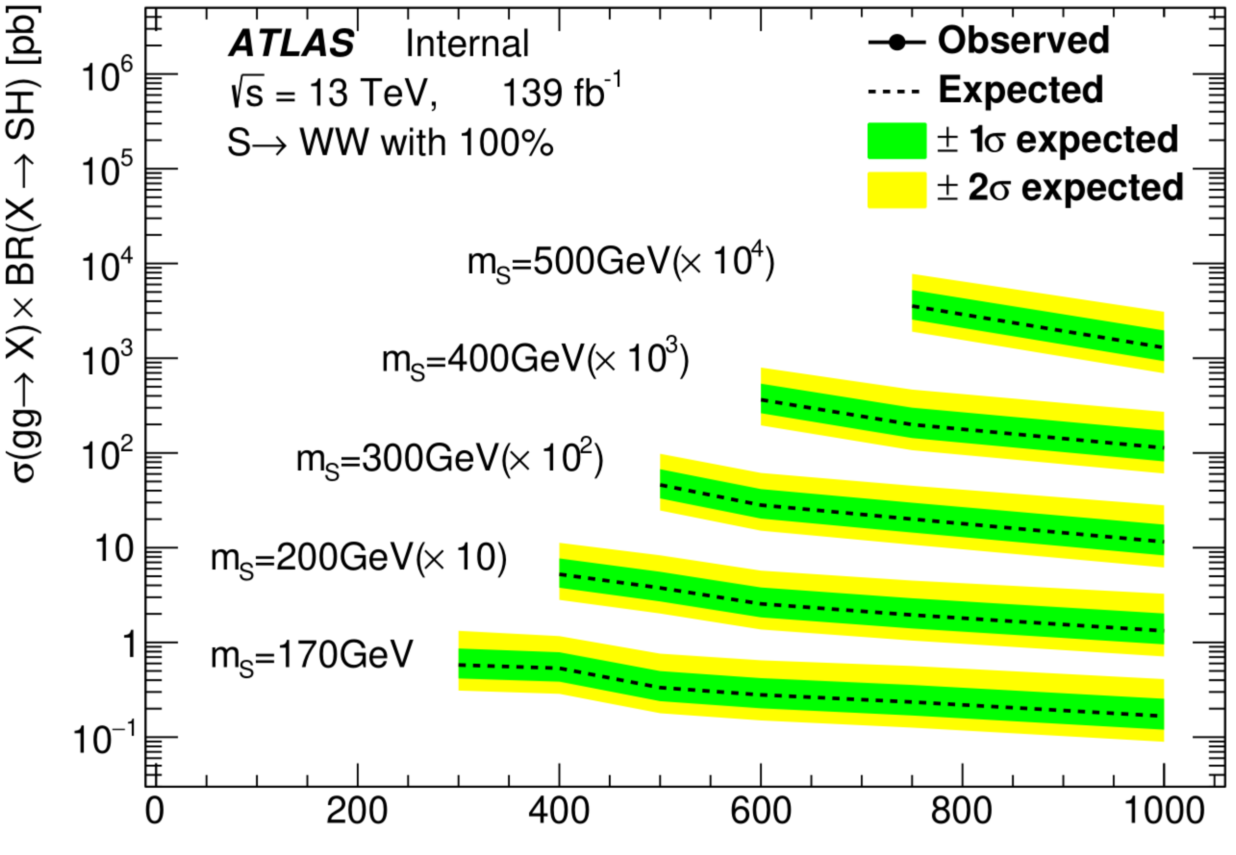
(though not a good way to show)

m_X [GeV]	$m_S[GeV]$	$+2\sigma$ [pb]	$+1\sigma$ [pb]	Median [pb]	-1σ [pb]	-2σ [pb]
300	170	0.600	0.896	0.600	0.433	0.322
400	170	0.555	0.819	0.555	0.400	0.298
400	200	0.710	1.041	0.710	0.512	0.381
500	170	0.346	0.518	0.346	0.250	0.186
500	200	0.509	0.754	0.509	0.367	0.273
500	300	0.666	0.974	0.666	0.480	0.357
600	170	0.291	0.437	0.291	0.209	0.156
600	200	0.346	0.514	0.346	0.249	0.186
600	300	0.407	0.601	0.407	0.294	0.219
600	400	0.632	0.933	0.632	0.456	0.339
750	170	0.244	0.369	0.244	0.176	0.131
750	200	0.264	0.396	0.264	0.190	0.142
750	300	0.290	0.432	0.290	0.209	0.156
750	400	0.345	0.521	0.345	0.249	0.185
750	500	0.657	0.968	0.657	0.474	0.353
1000	170	0.173	0.264	0.173	0.125	0.093
1000	200	0.179	0.273	0.179	0.129	0.096
1000	300	0.167	0.254	0.167	0.120	0.089
1000	400	0.196	0.298	0.196	0.141	0.105
1000	500	0.239	0.363	0.239	0.172	0.128

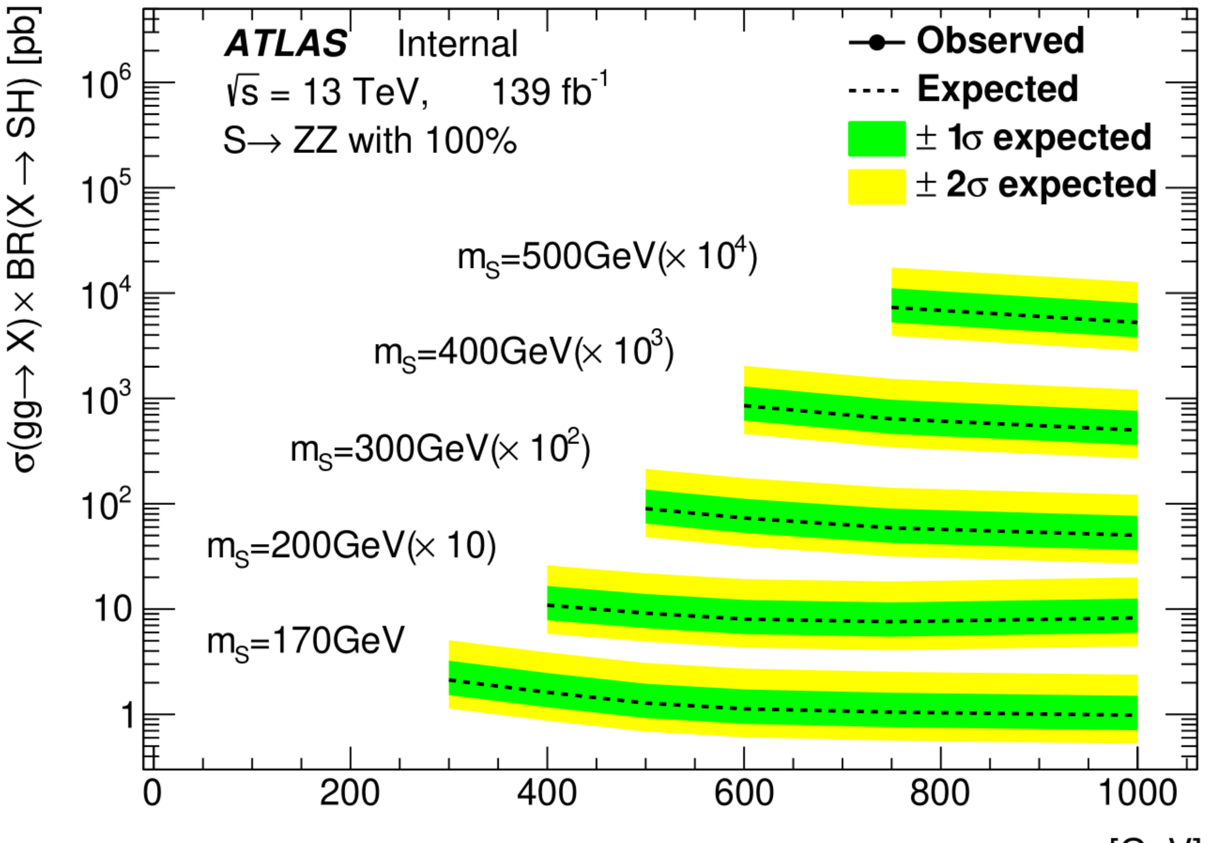
Table 22: Upper limits at the 95% confidence level for the cross-section of the gluon fusion production of the resonance $X \to SH$ and the S particle is assumed to decay to WW/ZZ following the SM prediction.

100% WW and ZZ:

BDT training and cut not optimized to these assumptions;
For crosstalks, ZZ to WW no contribution, WW to ZZ <5%.



Best point X1000,S400: 113fb.
100% WW have larger yields so better than SM assumption.



Best point X1000,S400: 500fb.
3 times worse than SM assumption due to limited yields.

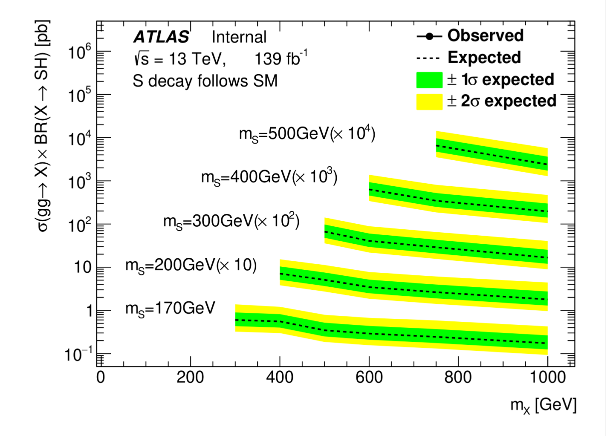
Unfinished task

Chapter 6.1

- Theoretical/Parton Shower uncertainty
  - Currently SH do not have official recommendation yet
  - Herwig SH sample with some technical issue; LHAPDF under study
  - Current temporary solution: only considering X.

M_X	+Theory(%)	-Theory(%)	TH Gaussian(%)	+-(PDF+a_s)
300	1.5	-3.2	+-1.8	+-3.0
400	1.6	-3.3	+-1.9	+-3.1
500	1.7	-3.4	+-2.0	+-3.2
600	1.8	-3.6	+-2.1	+-3.5
750	2.0	-3.7	+-2.1	+-3.8
1000	2.2	-4.0	+-2.3	+-5.2

- 2d interpolation
  - Extract lines to plane



Major questions raised in First EB

- Questions in February
  - Replies
  - Changes all updated in current version draft.

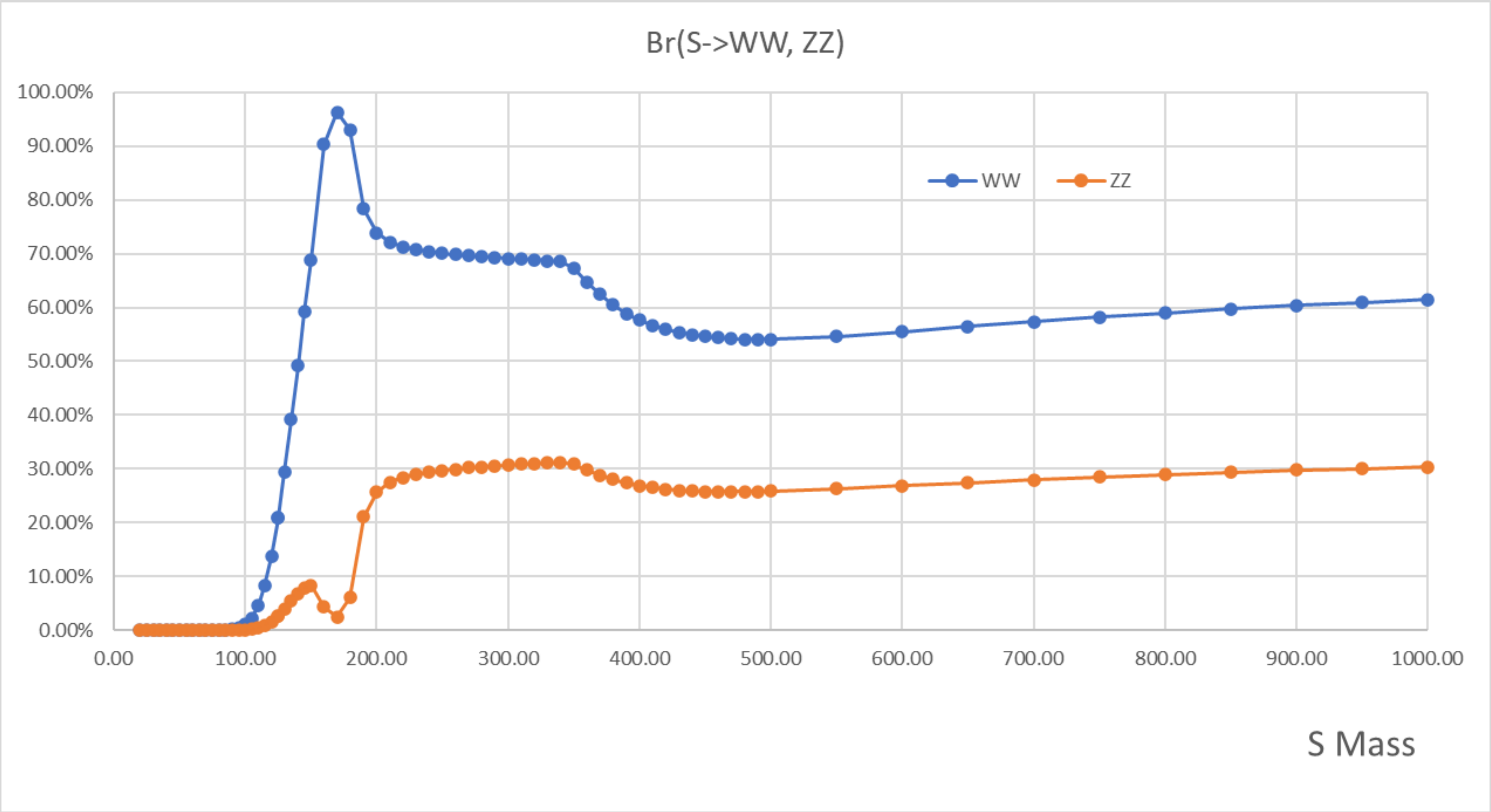
- Toy limits
- Correlation between mass and BDT
- Vertex check

Appendix

Why best on X1000, S300?

Br(S->WW) is much larger, for S300 than S4/500.

CERN YR4, (without NLO EW corrections)
among S[170, 500], WW and ZZ are dominant decays.



Signal Selection Eff.

Note: As 1l eff~60%, the ratio 2l fall to 1l is not small.

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
$m_{\gamma\gamma}$ 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
$m_{\gamma\gamma}$ 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
$m_{\gamma\gamma}$ 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 6: 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
$m_{\gamma\gamma}$ 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
$m_{\gamma\gamma}$ 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
$m_{\gamma\gamma}$ 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 7: Efficiencies in percent for event selection for signals.(Continued)

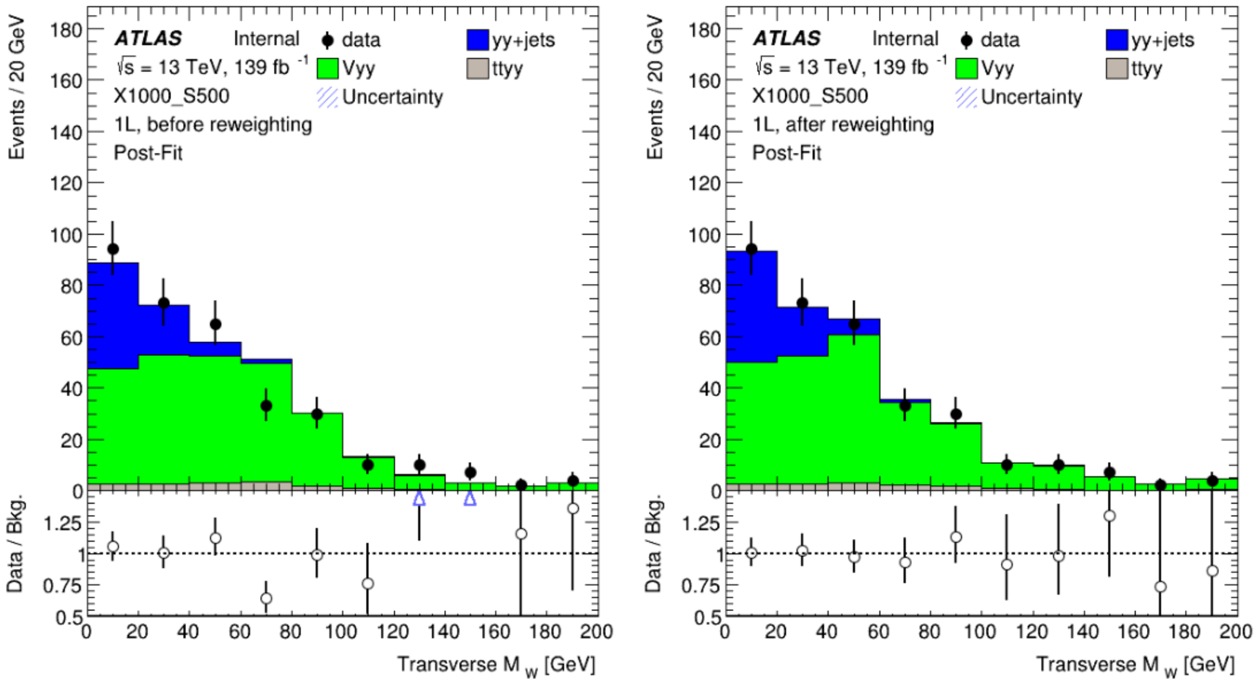
Appendix A.

Sideband Data/MC consistence

Appendix C.

ATLAS EXPERIMENT

- As our limited side data yield, we use yy+jets(known as “Sherpa”) and Vyy, ttyy continuum MC in the BDT training.
- Behavior between MC and sideband data need to be guaranteed.
- After tuning, The discrepancy between data and MC would be acceptable.

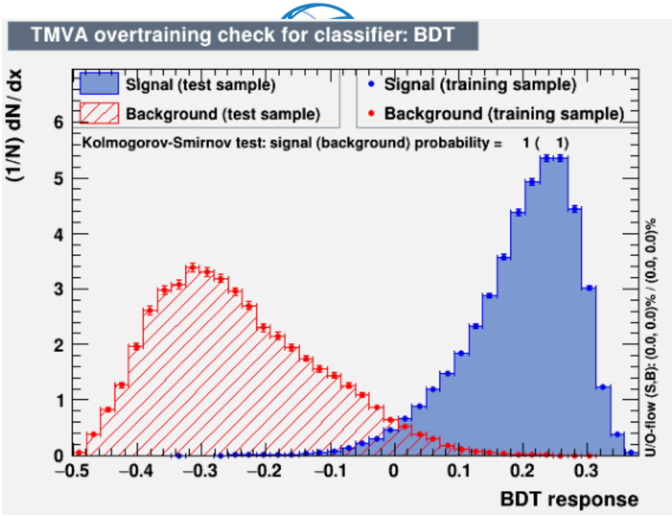


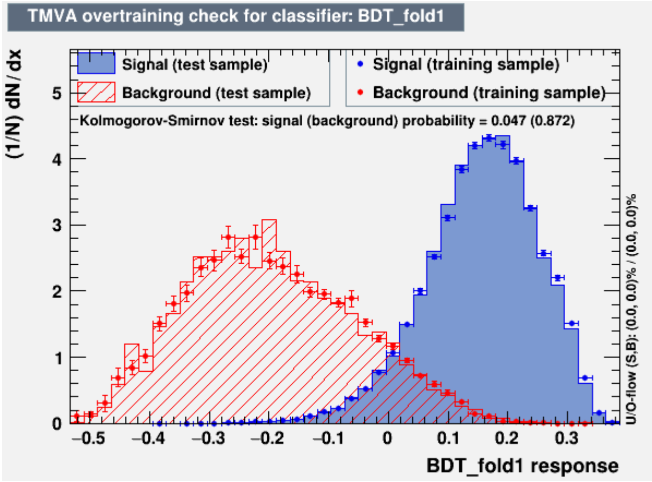
(a) (b)

TMVA: ks=1 issue

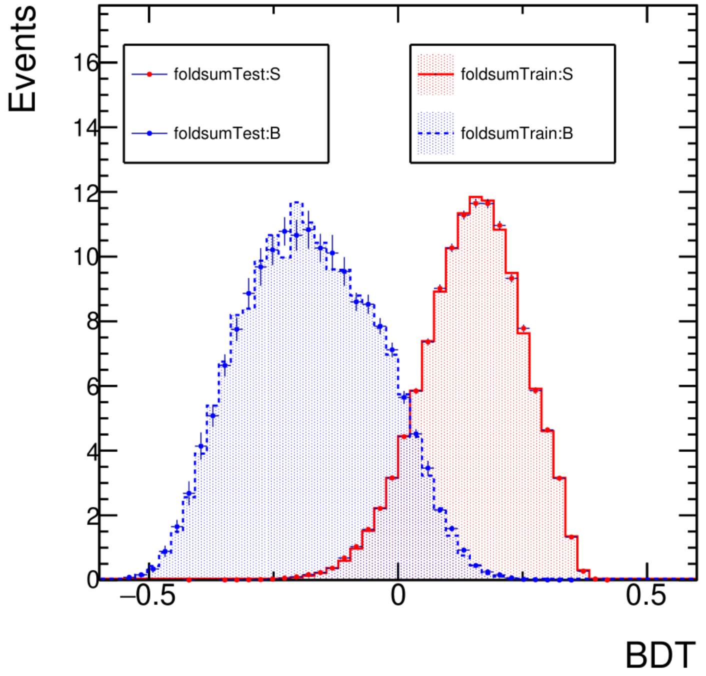
- Reference：
  - Guide: https://root.cern.ch/download/doc/tmva/TMVAUsersGuide.pdf
  - Source code: Tmva/src/CrossValidation.cxx, CvSplit.cxx, MethodCrossValidation.cxx

- We can confirm:
  - 4 folds ABCD, CV train BCD then test on A; train ABC then test on D, etc. When applying, only one fold information would apply to one individual event.
  - The training sample itself never use in testing. No over-fitting issue.
  - On the other side, this ks=1 sample is not used in the TMVA application. This sample is only used to test the performance.
  - Instead, we decided to display the individual fold ks plot to avoid the confusing.



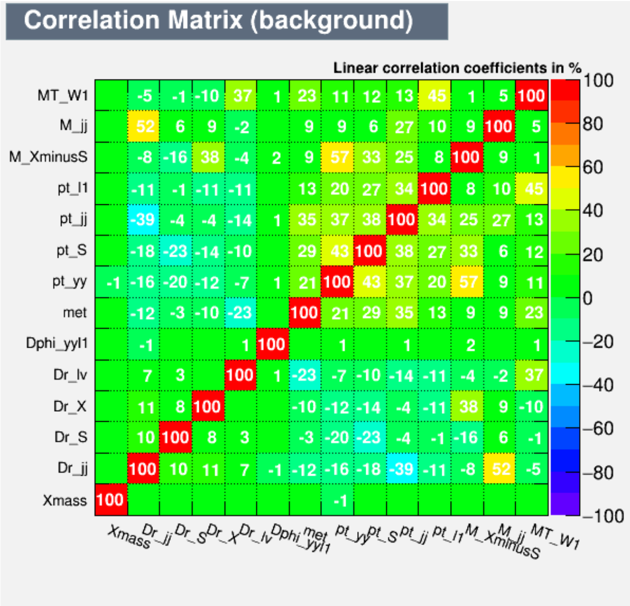


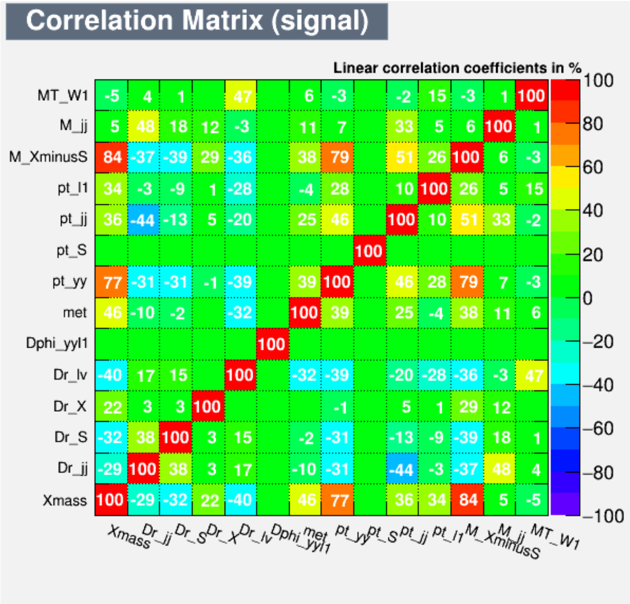
Alternative way to show overtraining:



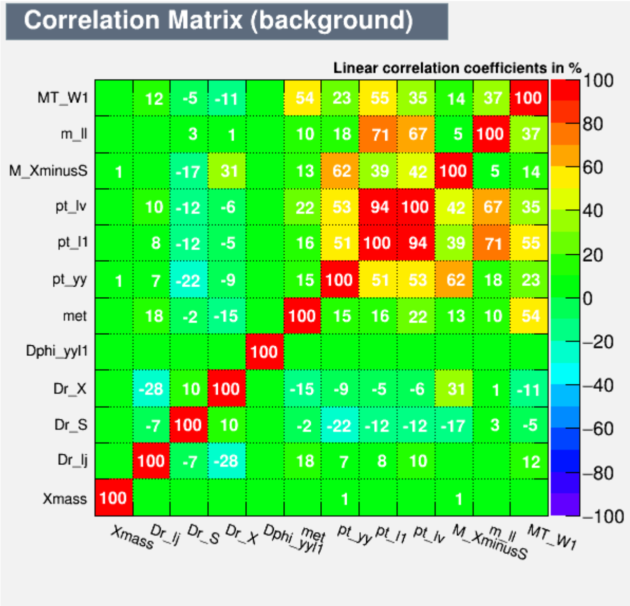
- Sum the individual fold test/training sample together, (scale 1/3) would be the better example for overtraining tests.
- The combined sample and the individual sample share different weights.
- KS tests not exactly to 1. There is no over-training issue.
- Also it showed that the individual fold TMVA ROC is consistent with the combined one.

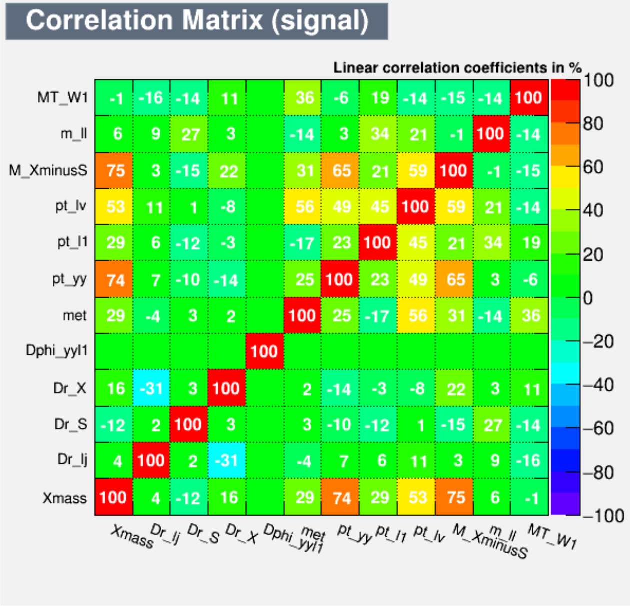
BDT Variable Correlation





1 lepton bkg: S400 signal



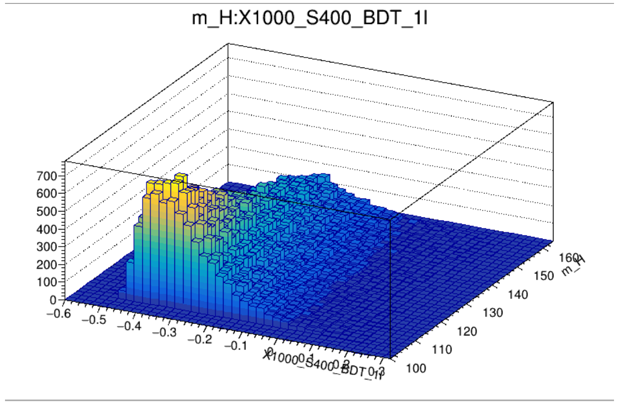


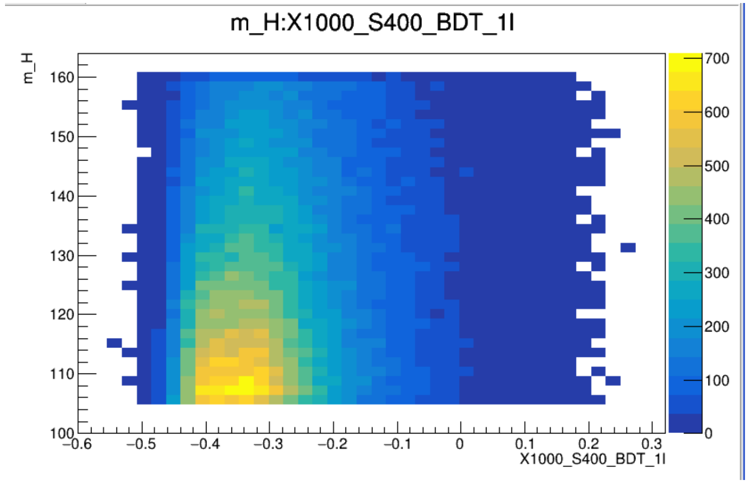
2 lepton bkg: S400 signal

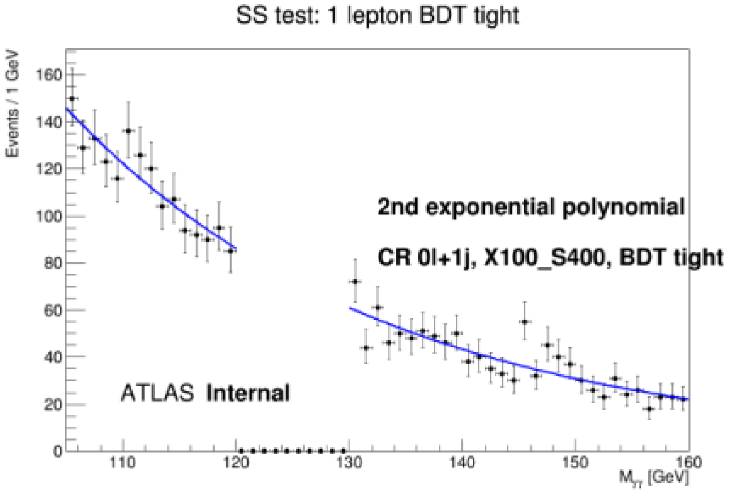
Signal and background hold different behavior.

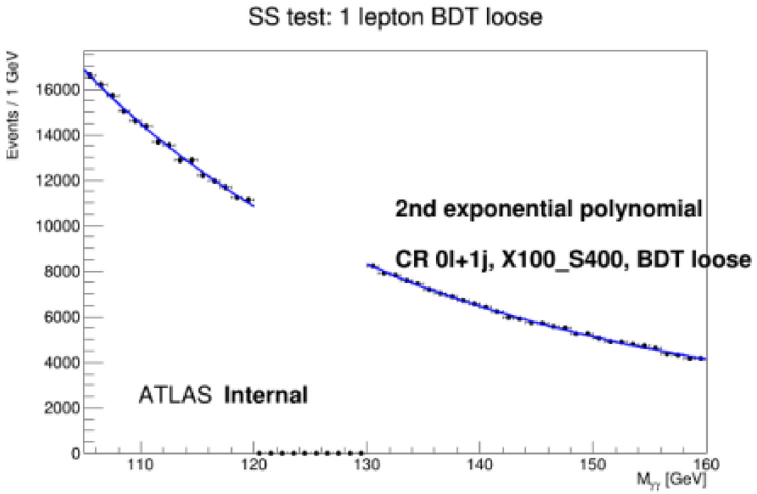
Correlation between mass and BDT

1l	data	signal	2l	data	signal
X1000_S170	-6.08%	-0.24%	X1000_S170	-7.27%	-0.74%
X1000_S200	0.66%	-0.40%	X1000_S200	3.90%	0.87%
X1000_S300	-0.31%	0.55%	X1000_S300	1.82%	1.62%
X1000_S400	3.95%	0.83%	X1000_S400	4.88%	2.22%
X1000_S500	3.55%	-0.57%	X1000_S500	4.32%	2.59%
X0300_S170	2.22%	-0.97%	X0300_S170	-0.22%	-1.70%
X0400_S170	5.44%	1.03%	X0400_S170	4.50%	3.59%
X0400_S200	5.46%	0.08%	X0400_S200	4.17%	4.79%
X0500_S170	5.93%	0.20%	X0500_S170	0.59%	1.25%
X0500_S200	2.57%	-0.82%	X0500_S200	-3.54%	0.75%
X0500_S300	6.40%	1.91%	X0500_S300	4.17%	4.65%
X0600_S170	6.11%	0.41%	X0600_S170	4.02%	4.19%
X0600_S200	8.06%	0.16%	X0600_S200	0.91%	1.92%
X0600_S300	6.66%	-0.12%	X0600_S300	-2.77%	0.81%
X0600_S400	6.66%	-0.12%	X0600_S400	-2.77%	0.81%
X0750_S170	7.19%	1.52%	X0750_S170	4.29%	3.07%
X0750_S200	6.41%	1.93%	X0750_S200	3.94%	3.32%
X0750_S300	8.64%	2.00%	X0750_S300	0.72%	2.46%
X0750_S400	9.13%	-0.09%	X0750_S400	-3.01%	1.10%
X0750_S500	9.13%	-0.09%	X0750_S500	-3.01%	1.10%





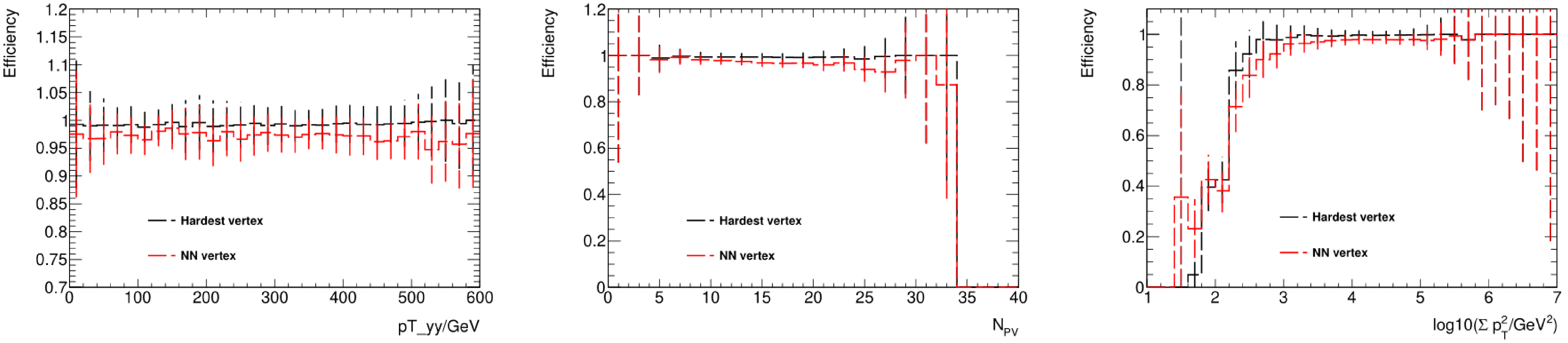




Though small correlation,
We do found the shape for tight/loose regions are different. Use different shape to fit.

Diphoton vertex efficiency

Compare the performance between hardest vertex(default) and NN(used in Hgam)



(a) $p_T^{\gamma\gamma}$ (b) N_{PV} (c) $log(\Sigma p_T^2)$

Figure 77: Efficiency of selecting a correct vertex by two approaches as a function of variables.

Toy limits test

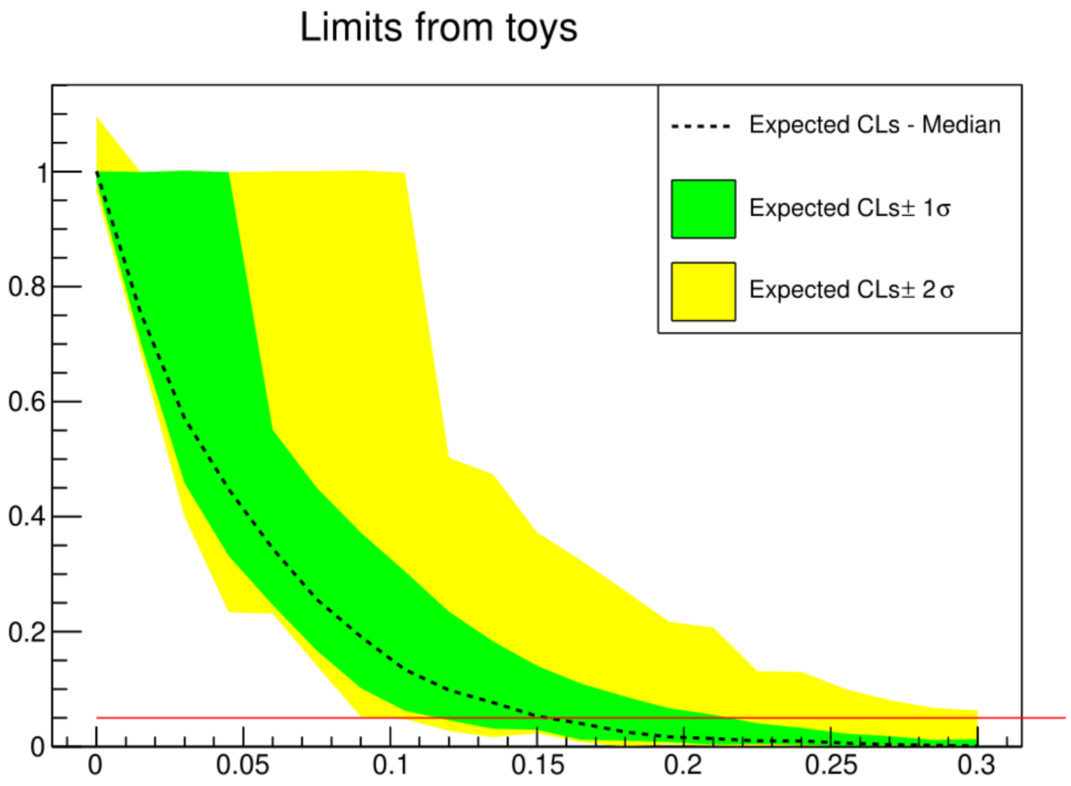


Figure 79: The expected limits of the search m_X = 1000 GeV, m_S = 300 GeV with toy.

	$+2\sigma$	$+1\sigma$	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 25: The expected limits of the search m_X = 1000 GeV, m_S = 300 GeV with asymptotic and toy.