A Change of Discriminating Variables for v17 $H \rightarrow WW$ Trileptons

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Introduction

I have been trying to think of new ways to improve the $H \rightarrow WW$ trilepton analyses enough to push us over the Standard Model sensitivity threshold as soon as possible. I revised the set of discriminating variables in a way that might help.

Discriminating Variables

WH Analysis

- ΔR(Opp. Sign Close leptons)
- $\not\!\!E_T$
- H_T
- Inv. Mass(Opp. Sign Close leptons)
- $\Delta\phi(2^{\text{nd}}\text{lepton}, \not\!\!E_T)$
- Inv. Mass (3^{rd} lep, $\not\!\!E_T$, Jets)
- m_T(All leptons, jets, $\not\!\!E_T$)
- 2^{nd} lepton p_T
- ΔR(Opp. Sign Futher leptons)
- m_T(all three leptons)
- NJet
- $m_T(3^{\text{rd}}$ lepton, $\not\!\!E_T)$
- Inv. Mass(Lep1, Lep2, $\not\!\!E_T$)
- m_T(all-Leps, $\not\!\!E_T$) (NEW)
- Lepton Type Combinations (NEW)

ZH Analysis

- NJet
- $\not\!\!E_T$
- Lead Jet E_T
- ΔR (W-Lep, Lead Jet)
- $\Delta\phi$(vector sum of leptons, $\not\!\!E_T$)
- m_T(All leptons, jets, $\not\!\!E_T$)
- H_T
- $\Delta\phi(2^{\text{nd}}$ lepton,$\not\!\!E_T)$
- Inv. Mass (3^{rd} lepton, $\not\!\!E_T$, Jets)
- m_T(jets)
- Inv. Mass (W-Lep, $\not\!\!E_T$)
- m_T(W-Lep, $\not\!\!E_T$) (REMOVED)
- Inv. Mass (all three leptons)
- ΔR(Opp. Sign Further leptons)
- $\Delta\phi(Z$-leptons sum, 3^{rd} lep.)(REMOVED)
- ΔR(Opp. Sign Close leptons)
- $\Delta\phi(W$-Lep, $\not\!\!E_T)$ (NEW)
- Lepton Type Combinations (NEW)

Let’s look at the new variables’ distributions:

WH Analysis: m_T(*all*-Leps, $\not\!\!E_T$)

This appears to have helped discriminate against $Z\gamma$ and Fakes a little bit better, despite other similar discriminating variables.

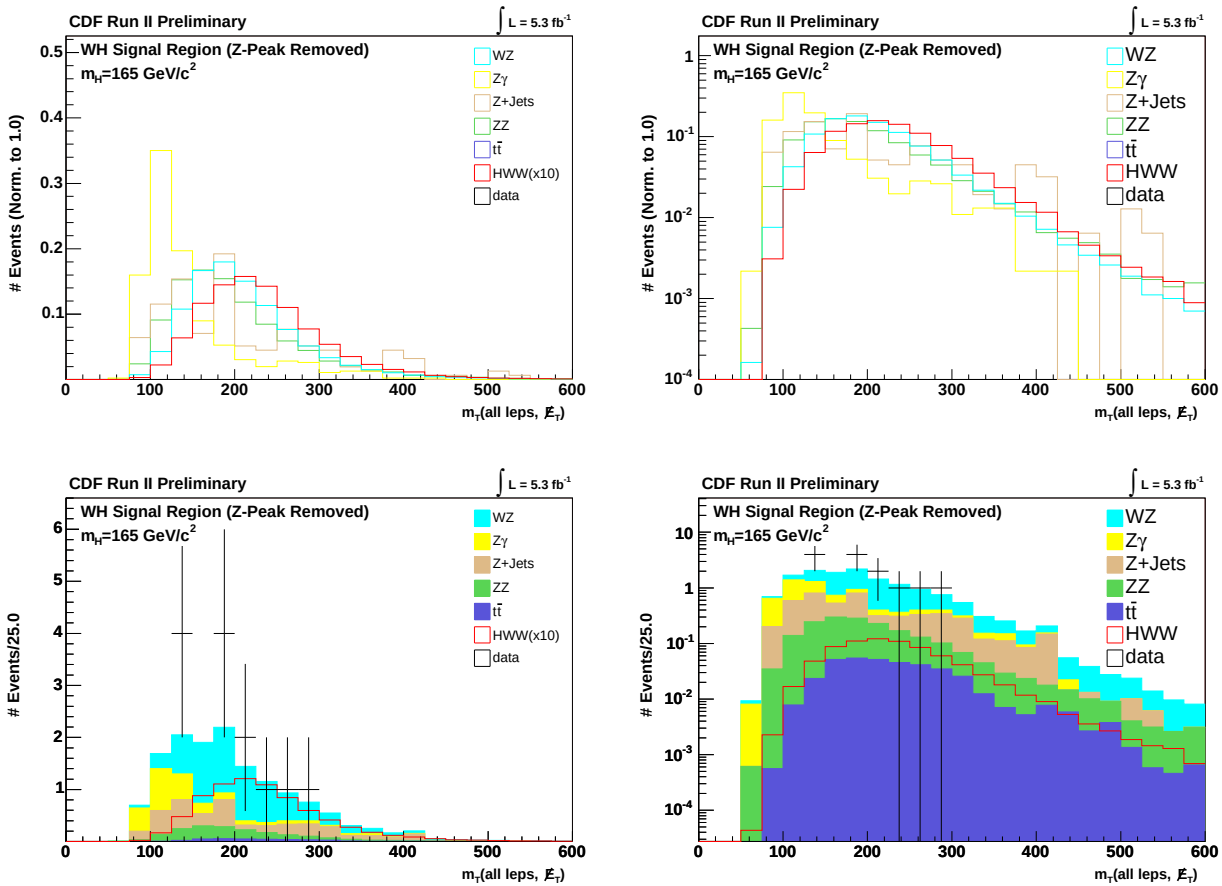

Figure: New variable for the *WH* trilepton analysis

WH Analysis: Trilepton Combinations

There appear to be many features in here to decipher. One is the preference for $Z\gamma$ to be *eet*, possibly because the converted photon tends to show as an unspecified track (?). Although, $Z\gamma$ also seems adverse to muons overall in this Z-peak-removed region. Mostly, I'm hoping to improve discrimination against WZ, such as the switch in preference between *eee* and *ee*μ.

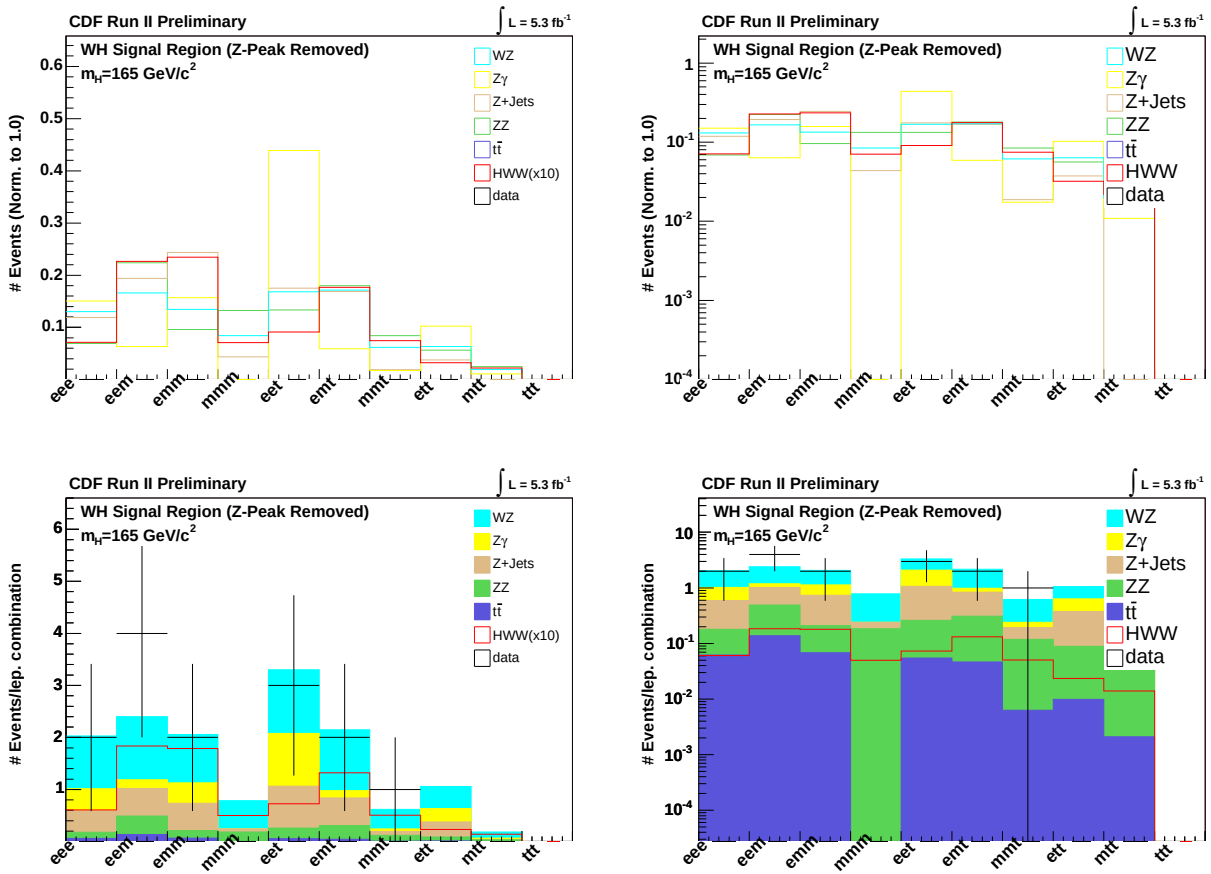

Figure: New variable for the *WH* trilepton analysis

ZH Analysis: $\Delta\phi(W\text{-Lep}, \not\!\!E_T)$

This provides more discrimination against Fakes, ZZ, and $Z\gamma$.

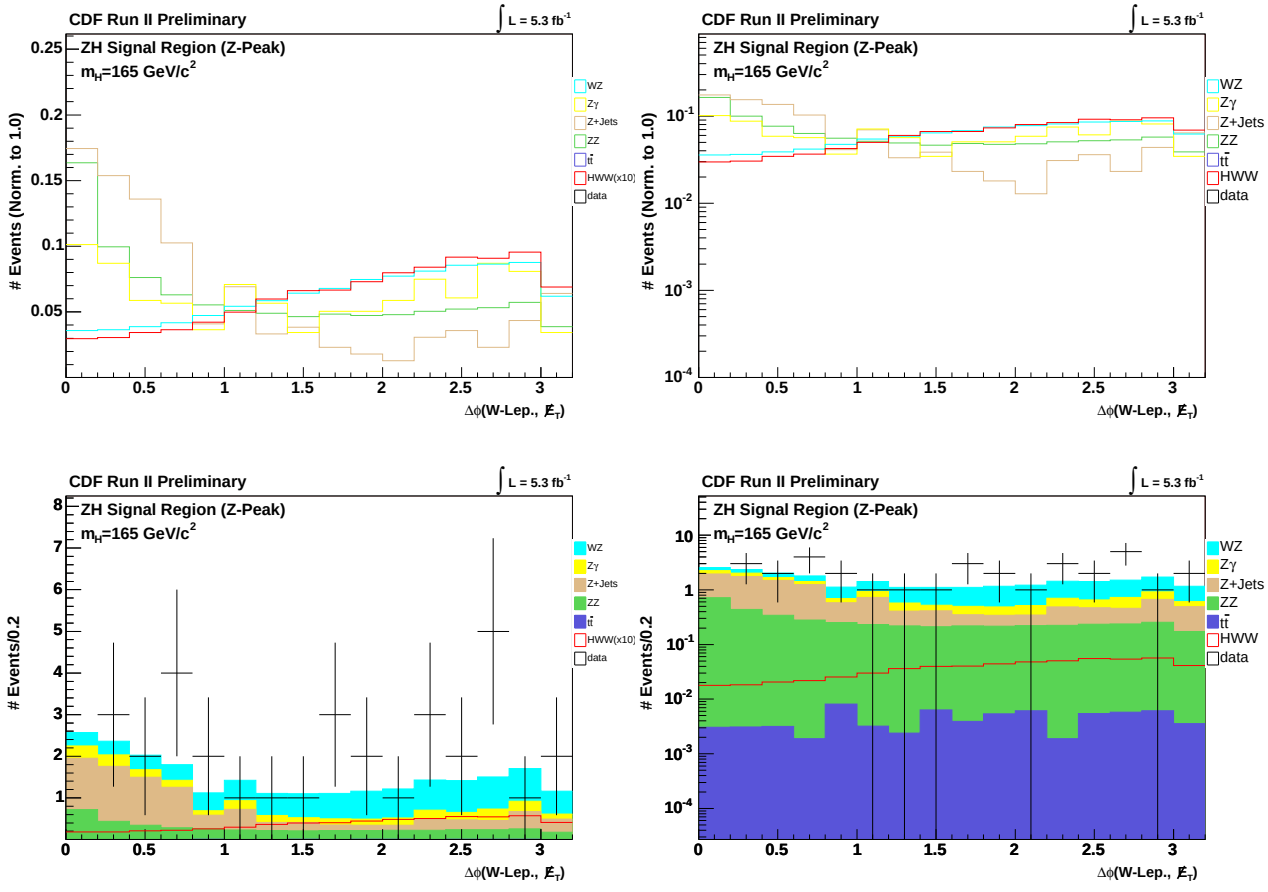

Figure: New variable for the ZH trilepton analysis

ZH Analysis: Trilepton Combinations

The signal appears to be roughly flat along with *WZ* and *ZZ*, unfortunately. However, there is solid structure for $Z\gamma$ and Fakes.

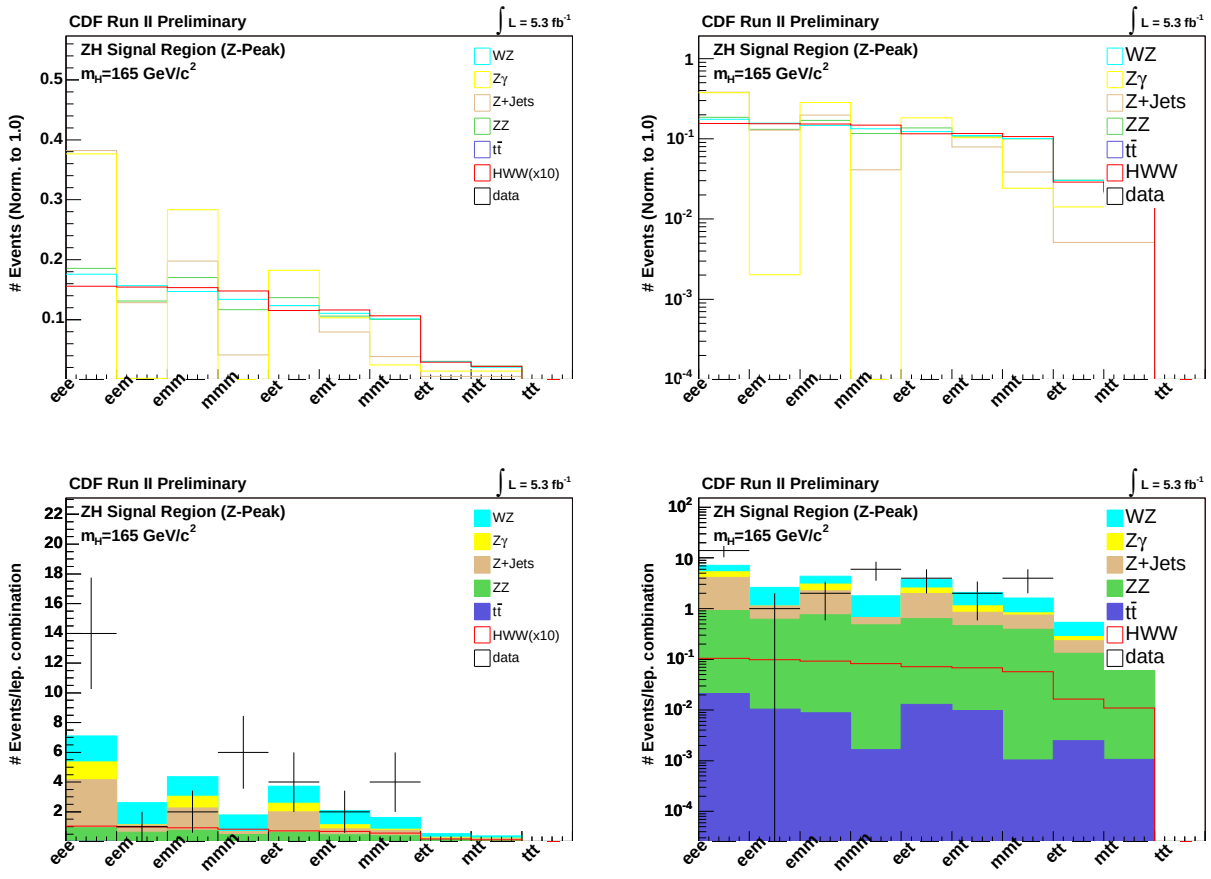

Figure: New variable for the *ZH* trilepton analysis

Now let’s see how these changes affected the neural network score:

WH Analysis NN Score

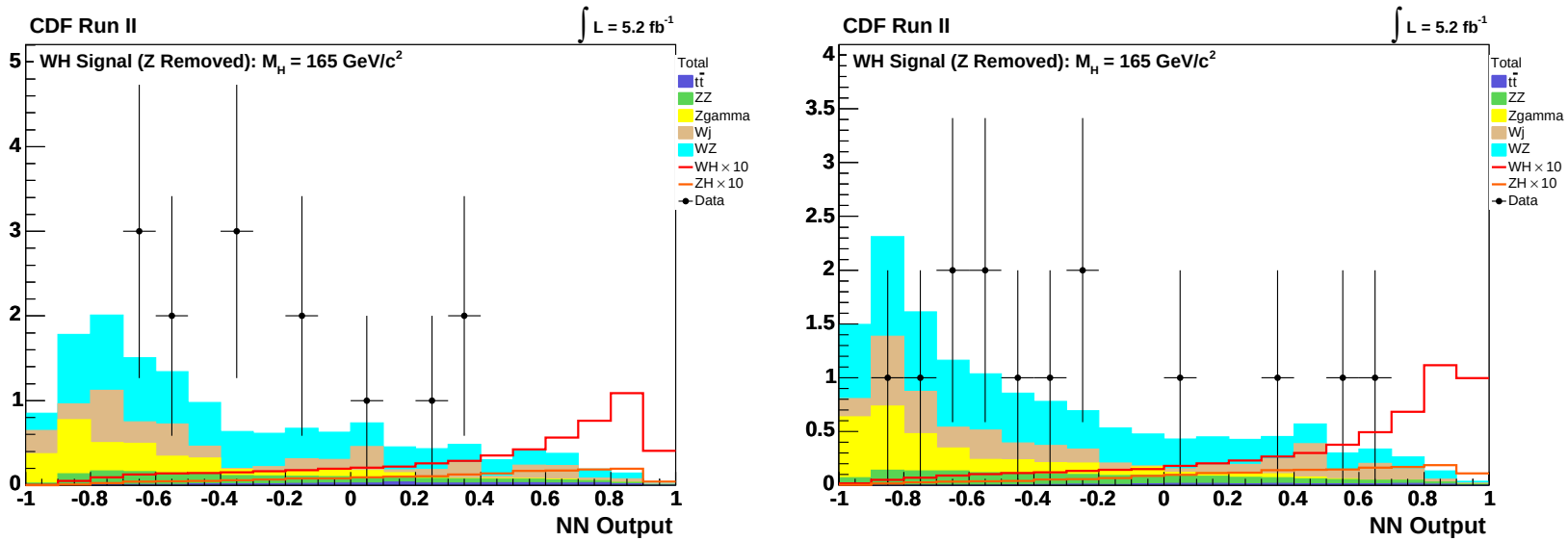

Figure: Left plot is OLD (from January), right plot is the NEW score. We see better discrimination between signal and background, but strangely the data does become more spread out in the signal region. The expected limit improves a little ($\sim$ 4% near $m_H = 165\mathrm{GeV}$), but the observed limit stays about the same.

ZH Analysis NN Score

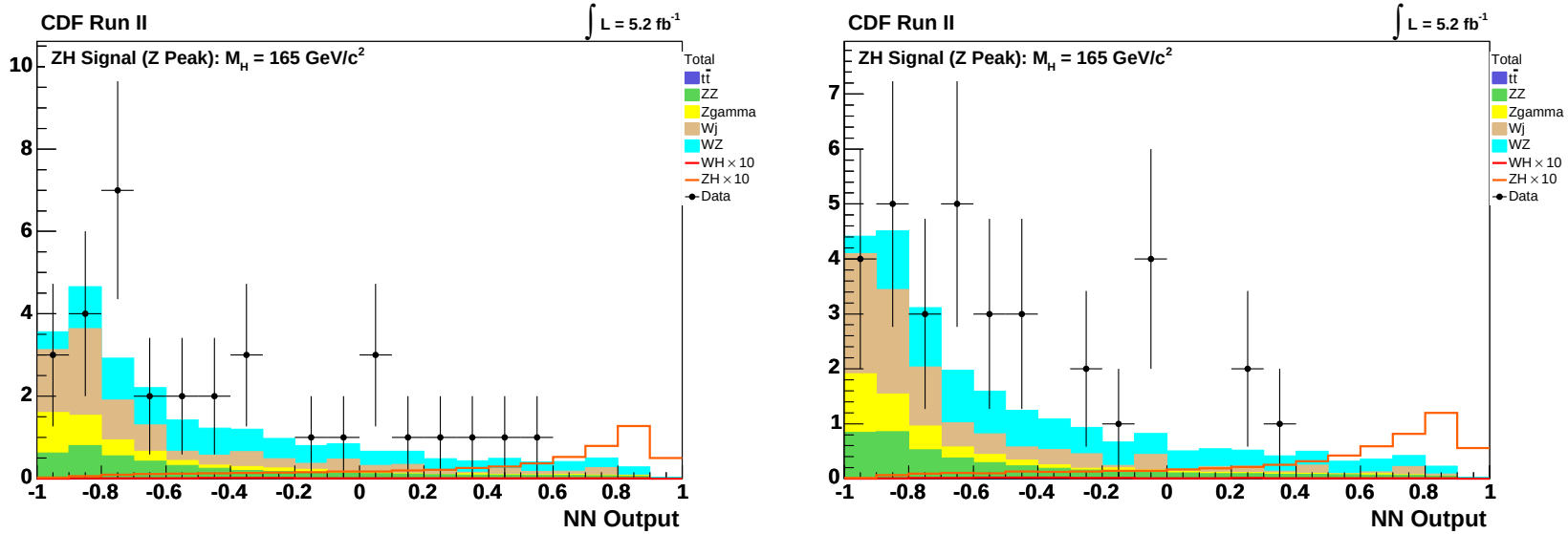

Figure: Left plot is OLD (from January), right plot is the NEW score. We see more promising improvements here. The background is pushed to the far left region better (mostly the Fakes, but there does seem to be a better data-to-*WZ* ratio in the signal region) and there are only three data events with NN score > 0.0 rather than seven.

Let’s look at the old and new limit tables for comparison.

OLD *WH* Analysis Limits

Limits	110	115	120	125	130	135	140	145	150	155
$+2\sigma/\sigma_{SM}$	171	96.5	64.3	43.4	32.9	27.4	24.3	21.2	19.5	17.3
$+1\sigma/\sigma_{SM}$	121	69.4	45.8	31.0	23.4	19.5	17.1	15.1	13.9	12.4
Median$/\sigma_{SM}$	**85.2**	**49.1**	**32.5**	**21.8**	**16.5**	**13.7**	**12.0**	**10.6**	**9.73**	**8.77**
$-1\sigma/\sigma_{SM}$	62.3	35.6	23.7	16.0	12.0	9.96	8.69	7.62	7.14	6.56
$-2\sigma/\sigma_{SM}$	49.2	27.9	18.4	12.5	9.47	7.70	6.80	5.96	5.64	5.29
Observed$/\sigma_{SM}$	**83.4**	**48.3**	**35.2**	**25.2**	**18.2**	**15.4**	**13.6**	**12.2**	**11.0**	**9.62**

Limits	160	165	170	175	180	185	190	195	200	
$+2\sigma/\sigma_{SM}$	15.7	16.0	17.7	20.6	23.9	29.5	35.1	40.7	47.4	
$+1\sigma/\sigma_{SM}$	11.2	11.4	12.8	14.6	16.9	20.9	25.1	29.3	33.3	
Median$/\sigma_{SM}$	**7.99**	**8.16**	**9.16**	**10.3**	**11.9**	**14.9**	**17.9**	**20.7**	**23.3**	
$-1\sigma/\sigma_{SM}$	5.96	6.14	6.84	7.70	8.87	11.0	13.3	15.2	17.1	
$-2\sigma/\sigma_{SM}$	4.82	4.95	5.57	6.19	7.15	8.81	10.7	12.2	13.7	
Observed$/\sigma_{SM}$	**8.87**	**8.65**	**10.1**	**12.0**	**14.2**	**16.4**	**19.7**	**25.2**	**26.8**	

Table: *WH* trilepton analysis limits for 5.3fb^{-1}.

NEW *WH* Analysis Limits

Limits	110	115	120	125	130	135	140	145	150	155
$+2\sigma/\sigma_{SM}$	163	93.6	60.5	41.6	31.7	25.4	22.9	20.0	18.6	16.9
$+1\sigma/\sigma_{SM}$	115	66.1	43.1	29.6	22.8	18.2	16.1	14.1	13.1	12.1
Median$/\sigma_{SM}$	**82.2**	**47.1**	**30.5**	**21.2**	**16.2**	**12.9**	**11.4**	**9.99**	**9.32**	**8.59**
$-1\sigma/\sigma_{SM}$	61.0	34.8	22.4	15.5	11.9	9.52	8.39	7.41	6.97	6.44
$-2\sigma/\sigma_{SM}$	48.7	27.8	17.9	12.3	9.41	7.59	6.70	5.97	5.57	5.23
Observed$/\sigma_{SM}$	**76.4**	**43.9**	**29.2**	**22.4**	**17.4**	**13.6**	**12.6**	**11.0**	**10.2**	**9.61**

Limits	160	165	170	175	180	185	190	195	200	
$+2\sigma/\sigma_{SM}$	15.1	15.4	17.9	19.7	23.1	29.6	35.3	40.3	45.4	
$+1\sigma/\sigma_{SM}$	10.7	11.0	12.8	14.0	16.6	20.8	25.2	28.7	32.7	
Median$/\sigma_{SM}$	**7.74**	**7.85**	**9.12**	**9.89**	**11.7**	**14.7**	**17.9**	**20.2**	**23.2**	
$-1\sigma/\sigma_{SM}$	5.91	5.95	6.79	7.52	8.78	10.9	13.3	15.0	17.1	
$-2\sigma/\sigma_{SM}$	4.83	4.93	5.65	6.16	7.28	8.79	10.7	12.1	13.7	
Observed$/\sigma_{SM}$	**8.80**	**9.24**	**10.2**	**11.0**	**14.2**	**18.3**	**22.0**	**26.0**	**29.5**	

Table: *WH* trilepton analysis limits for 5.3fb^{-1}. At $m_H = 165\text{GeV}$, there is about 4% improvement in expected limits, but no improvement in observed limits.

OLD *ZH* Analysis Limits

Limits	110	115	120	125	130	135	140	145	150	155
$+2\sigma/\sigma_{SM}$	296	173	103	71.0	52.9	41.5	34.2	28.6	26.8	24.3
$+1\sigma/\sigma_{SM}$	210	122.6	74.0	50.4	37.0	29.7	24.2	20.4	18.8	17.4
Median$/\sigma_{SM}$	**148**	**85.2**	**51.6**	**35.4**	**25.8**	**20.7**	**16.9**	**14.5**	**13.3**	**12.3**
$-1\sigma/\sigma_{SM}$	106	60.8	36.9	25.5	18.6	14.9	12.3	10.5	9.75	9.06
$-2\sigma/\sigma_{SM}$	80.4	45.7	27.9	19.3	14.3	11.3	9.65	8.33	7.64	7.15
Observed$/\sigma_{SM}$	**204**	**121**	**78.2**	**52.8**	**43.2**	**34.4**	**28.6**	**23.1**	**22.9**	**20.9**

Limits	160	165	170	175	180	185	190	195	200	
$+2\sigma/\sigma_{SM}$	22.6	21.9	23.9	25.7	28.3	34.1	39.4	43.6	48.4	
$+1\sigma/\sigma_{SM}$	15.9	15.7	17.2	18.3	20.2	24.1	28.1	30.7	33.7	
Median$/\sigma_{SM}$	**11.3**	**11.1**	**12.2**	**13.0**	**14.3**	**17.2**	**20.0**	**21.9**	**23.9**	
$-1\sigma/\sigma_{SM}$	8.38	8.33	9.04	9.73	10.6	12.8	15.0	16.2	17.9	
$-2\sigma/\sigma_{SM}$	6.73	6.75	7.33	7.85	8.66	10.4	12.2	13.2	14.6	
Observed$/\sigma_{SM}$	**15.2**	**13.9**	**18.0**	**17.8**	**21.7**	**25.3**	**32.8**	**33.2**	**35.7**	

Table: *ZH* trilepton analysis limits for 5.3fb^{-1}.

NEW *ZH* Analysis Limits

Limits	110	115	120	125	130	135	140	145	150	155
$+2\sigma/\sigma_{SM}$	275	154	96.1	66.4	49.0	38.5	32.4	28.3	26.0	24.1
$+1\sigma/\sigma_{SM}$	193	109	68.3	47.1	34.8	27.8	22.8	20.0	18.3	16.9
Median$/\sigma_{SM}$	**135**	**76.7**	**47.7**	**33.0**	**24.5**	**19.5**	**16.2**	**14.1**	**12.8**	**12.0**
$-1\sigma/\sigma_{SM}$	97.5	55.6	34.5	23.8	17.7	14.1	11.8	10.3	9.40	8.83
$-2\sigma/\sigma_{SM}$	75.7	42.8	26.7	18.5	13.7	11.0	9.21	8.17	7.44	7.05
Observed$/\sigma_{SM}$	**193**	**105**	**72.7**	**47.8**	**35.3**	**29.3**	**22.5**	**24.1**	**18.3**	**15.4**

Limits	160	165	170	175	180	185	190	195	200	
$+2\sigma/\sigma_{SM}$	21.0	20.9	22.8	24.9	27.1	33.7	38.9	43.5	47.1	
$+1\sigma/\sigma_{SM}$	15.0	15.0	16.3	17.9	19.7	23.8	27.8	30.9	33.3	
Median$/\sigma_{SM}$	**10.7**	**10.6**	**11.6**	**12.7**	**14.0**	**16.9**	**19.8**	**21.9**	**23.9**	
$-1\sigma/\sigma_{SM}$	7.98	7.99	8.77	9.54	10.5	12.6	14.8	16.3	17.9	
$-2\sigma/\sigma_{SM}$	6.54	6.61	7.27	7.84	8.60	10.4	12.1	13.4	14.8	
Observed$/\sigma_{SM}$	**12.4**	**10.8**	**14.2**	**13.1**	**18.5**	**21.9**	**28.4**	**31.1**	**37.3**	

Table: *ZH* trilepton analysis limits for 5.3fb^{-1}. At $m_H = 165\text{GeV}$, there is about 4.5% improvement in expected limits and 20% improvement in observed limits, probably due to the reduction of data events in the signal region of the NN score.

OLD Trilepton Analysis Limits

Limits	110	115	120	125	130	135	140	145	150	155
$+2\sigma/\sigma_{SM}$	140	80.4	51.6	35.4	26.0	21.6	18.4	15.7	14.6	12.8
$+1\sigma/\sigma_{SM}$	99.5	57.0	37.1	25.1	18.7	15.2	13.0	11.2	10.4	9.15
Median$/\sigma_{SM}$	**69.7**	**40.1**	**25.8**	**17.6**	**13.0**	**10.7**	**9.08**	**7.79**	**7.26**	**6.40**
$-1\sigma/\sigma_{SM}$	50.4	29.0	18.8	12.6	9.32	7.64	6.56	5.65	5.25	4.68
$-2\sigma/\sigma_{SM}$	38.6	22.1	14.1	9.68	7.11	5.80	4.96	4.30	4.05	3.66
Observed$/\sigma_{SM}$	**76.0**	**44.1**	**32.3**	**22.5**	**17.4**	**14.4**	**12.3**	**10.4**	**9.99**	**8.61**

Limits	160	165	170	175	180	185	190	195	200	
$+2\sigma/\sigma_{SM}$	11.4	11.5	12.8	14.0	16.2	19.6	23.5	26.2	30.0	
$+1\sigma/\sigma_{SM}$	8.37	8.10	9.19	10.1	11.5	14.0	16.7	18.8	21.4	
Median$/\sigma_{SM}$	**5.86**	**5.78**	**6.50**	**7.19**	**8.07**	**9.96**	**11.7**	**13.3**	**15.0**	
$-1\sigma/\sigma_{SM}$	4.31	4.26	4.77	5.24	5.92	7.28	8.56	9.67	10.9	
$-2\sigma/\sigma_{SM}$	3.38	3.42	3.77	4.09	4.71	5.73	6.71	7.58	8.47	
Observed$/\sigma_{SM}$	**6.58**	**5.99**	**7.83**	**8.61**	**10.8**	**12.3**	**16.1**	**18.7**	**19.5**	

Table: Combined trilepton analysis limits for 5.3fb^{-1}.

NEW Trilepton Analysis Limits

Limits	110	115	120	125	130	135	140	145	150	155
$+2\sigma/\sigma_{SM}$	129	74.0	47.8	33.7	25.0	20.1	16.8	14.9	13.6	12.5
$+1\sigma/\sigma_{SM}$	93.2	52.9	33.9	23.8	17.8	14.2	12.0	10.5	9.78	8.87
Median$/\sigma_{SM}$	**65.7**	**37.5**	**24.0**	**16.6**	**12.5**	**9.96**	**8.46**	**7.42**	**6.88**	**6.27**
$-1\sigma/\sigma_{SM}$	47.6	27.2	17.5	12.0	9.13	7.25	6.17	5.44	5.01	4.63
$-2\sigma/\sigma_{SM}$	36.9	21.2	13.6	9.25	7.08	5.57	4.79	4.26	3.92	3.65
Observed$/\sigma_{SM}$	**63.9**	**36.6**	**24.4**	**17.4**	**14.4**	**11.4**	**10.2**	**8.36**	**8.19**	**6.66**

Limits	160	165	170	175	180	185	190	195	200	
$+2\sigma/\sigma_{SM}$	10.6	10.7	12.6	13.5	15.4	19.4	23.0	25.9	29.1	
$+1\sigma/\sigma_{SM}$	7.59	7.75	8.87	9.68	11.1	13.8	16.6	18.5	20.9	
Median$/\sigma_{SM}$	**5.44**	**5.47**	**6.32**	**6.88**	**7.91**	**9.74**	**11.7**	**13.1**	**14.8**	
$-1\sigma/\sigma_{SM}$	4.06	4.13	4.65	5.08	5.81	7.20	8.61	9.63	10.7	
$-2\sigma/\sigma_{SM}$	3.26	3.35	3.73	4.10	4.69	5.77	6.87	7.65	8.52	
Observed$/\sigma_{SM}$	**5.82**	**5.33**	**6.63**	**6.90**	**9.55**	**11.8**	**16.0**	**19.2**	**21.8**	

Table: Combined trilepton analysis limits for 5.3fb^{-1}. In the combined $H \to WW$ trilepton limits, at $m_H = 165\text{GeV}$ there is a 5.4% improvement in the expected limits and an 11% improvement in the observed limits.

Finally, here's the comparison plot between the v17 trilepton limits in January and now.

$H \rightarrow WW$ Trilepton Limits

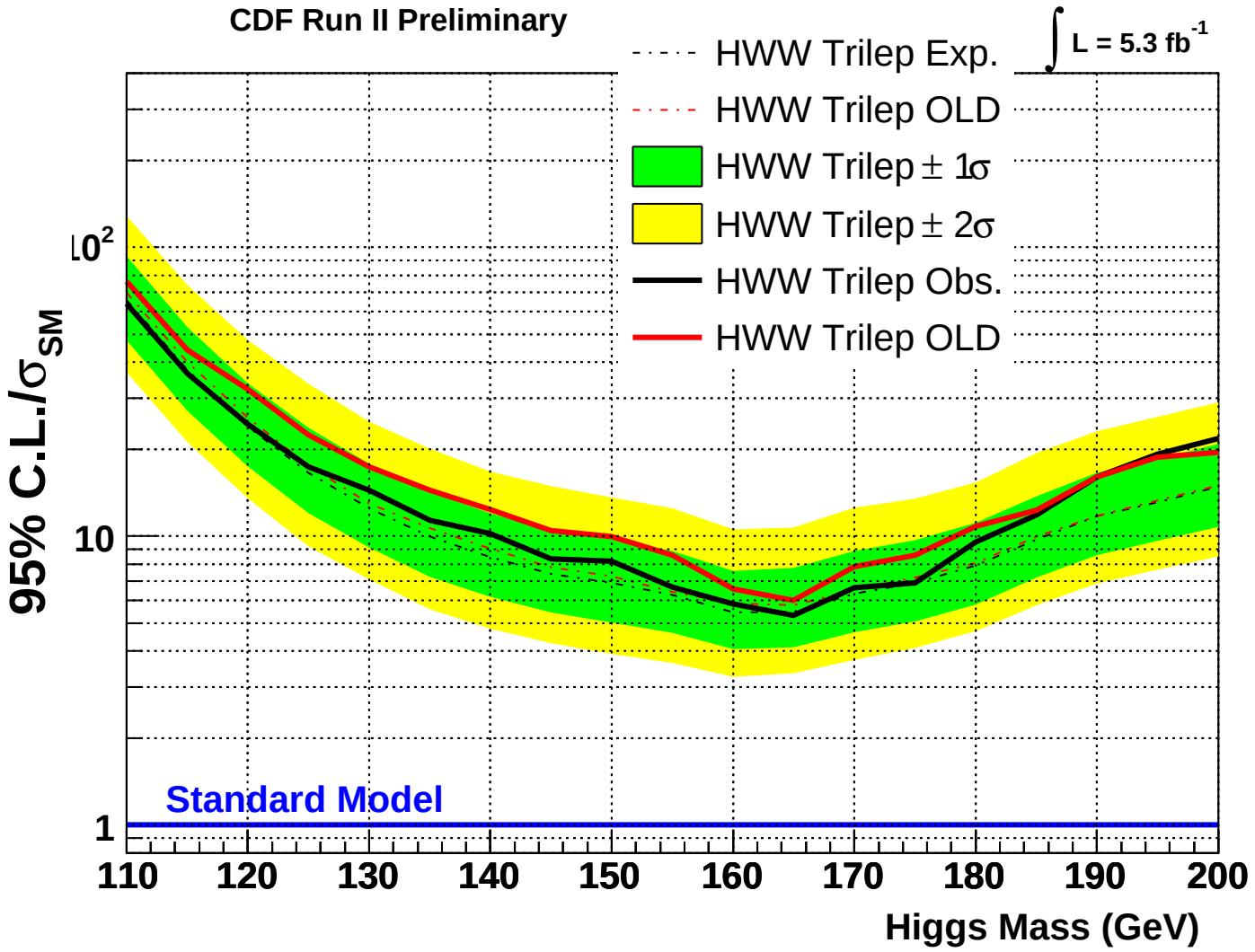

Figure: Comparison plot between the v17 trilepton limits in January, and now with the new discriminating variable list.

Conclusions

- Better separation has improved the observed limits.
- This change does include the change in systematic errors since January, most of which became slightly worse.
- This does still include the $Z\gamma$ 17% scale down similar to $W\gamma$. Repealing this scale down has recently been decided and new templates will have to be made before making a new $H \rightarrow WW$ combination with this change to the trileptons. For the sake of making a more consistent comparison, I waited to make this change.
- The new variables used should still be relevant for these two trilepton regions when revised to accommodate Geumbong's trilepton analysis. I'm still working on that.
- Another expected improvement: I'm nearly finished with a new WZ-trilepton cross section measurement. This has not been done since 1.1fb^{-1} and WZ is the largest background in both of my trilepton regions, so maybe it will help reduce some systematic errors. I still need to figure out how to change *WWFit* into a *WZFit* to extract the cross section measurement.