

Vts results for ESPP

March 20, 2025

Aaron Wiedl, Xunwu Zuo



Outline



Main messages:

- Vts analysis fully redone. Results improved by a lot.
- Can consider as “finalized”, except one issue in bkg MC affect certain categories (mitigated in current analysis)

Structure of this presentation:

- Overview of analysis steps
- Results
- (In backup) summary of changes wrt previous version



Analysis overview

Samples and selection



Samples (detail in backup)

- Signal: all decay modes of $t\bar{t} \rightarrow WbWs$
- Backgrounds: $t\bar{t} \rightarrow WbWb, Z, WW, ZZ, \text{Higgs}, WWZ$

Event selection

- Require exactly 1 s-tagged jet and 1 b-tagged jet
- Further divide into **10 categories** based on **number of objects:** $e, \mu, \text{hadronic } \tau, \text{ and tagged jets}$
 - dilep_0tau, dilep_1tau, dilep_2tau
 - semilep_0tau_ud, semilep_0tau_cs,
 - semilep_1tau_ud, semilep_1tau_cs,
 - dihad_ud_only, dihad_udcs, dihad_cs_only,

e/μ selection

- $p_\ell > 20 \text{ GeV}$
- $\text{ISO}_{R<0.5} > 0.25$

jet selection

- anti-kt R=0.5
- $E_J > 15 \text{ GeV}$
- $m_J < 50 \text{ GeV}$
- $\tau\text{-score} < 0.5$
- flavor tag if score > 0.5

τ selection

- anti-kt R=0.5 jet
- $E_J > 15 \text{ GeV}$
- $m_J < 5 \text{ GeV}$
- $\tau\text{-score} > 0.5$

Issue in bkg MC



In bkg $t\bar{t} \rightarrow WbWb$ samples, **only negatively charged τ^-** are generated, processes involving positive τ^+ are not.

```
alias lep = e1:e2:e3
alias neut = n1:n2:n2
alias Lep = E1:E2:E3
alias Neut = N1:N2:N3
me = 0
mmu = 0
mtau = 0

process proc = e1, E1 => (Lep, neut, b, lep, Neut, B)
                        {$restrictions = "3+4~W+ && 6+7~W- && 3+4+5~t && 6+7+8~tbar"}
```

Example card

Spotted 2 days ago, actions at the moment:

- Exact reason under investigation
 - Related to “mtau = 0” (taus are fine in signal samples, where mtau is kept nonzero)
- More samples being generated
- Event weight adjusted account for the missing processes

events with 0 tau	events with 1 tau	events with 2 taus
proper xsec	xsec * 2	no event in MC

With these fixes, results in following slides should be valid.

- Mask all categories involving taus from analysis

Event yields



- Table here just for completeness, more discussion in [later slides](#)

Category	dilep_0tau	dilep_1tau	dilep_2tau	semilep_0tau_ud	semilep_0tau_cs	semilep_1tau_ud	semilep_1tau_cs	dihad_ud_only	dihad_udcs	dihad_cs_only
sig modes										
dilep_0tau	109.535	5.879	0.078	0.570	0.003	0.018	0.000	0.000	0.000	0.000
dilep_1tau	10.561	59.169	1.611	0.583	0.024	0.136	0.001	0.000	0.000	0.000
dilep_2tau	0.234	3.699	7.954	0.020	0.002	0.112	0.004	0.000	0.000	0.000
semilep_0tau_ud	0.000	0.097	0.003	247.336	1.269	6.613	0.028	2.289	0.045	0.000
semilep_0tau_cs	0.000	0.043	0.000	32.103	78.878	0.825	1.960	0.250	0.674	0.003
semilep_1tau_ud	0.000	0.010	0.016	16.048	0.084	57.744	0.315	1.840	0.420	0.002
semilep_1tau_cs	0.000	0.003	0.009	2.017	5.023	7.349	18.715	0.205	0.767	0.030
dihad_ud_only	0.000	0.000	0.000	0.001	0.000	0.107	0.000	150.641	4.266	0.005
dihad_udcs	0.000	0.000	0.000	0.001	0.000	0.060	0.024	40.614	105.374	0.458
dihad_cs_only	0.000	0.000	0.000	0.000	0.000	0.011	0.008	2.672	18.875	10.944
bkg modes										
dilep	269.367	160.893	5.993	20.703	0.437	0.704	0.053	0.057	0.000	0.000
semilep_ud	0.953	15.479	7.031	1824.440	119.457	539.586	38.093	95.711	15.923	0.164
semilep_cs	10.987	175.139	49.010	1041.961	544.038	319.480	172.539	27.745	35.177	0.601
dihad	0.000	0.000	0.000	19.898	5.798	82.496	26.964	3875.943	3238.026	235.444
Z	7.423	0.770	3.341	9.535	1.560	21.652	2.758	244.427	66.382	0.815
WW	7.610	155.869	27.059	133.884	5.919	104.007	24.522	542.301	372.057	5.637
ZZ	29.291	20.201	14.216	11.943	2.189	14.825	3.353	57.722	42.370	0.527
higgs	19.766	13.118	7.361	43.130	4.872	17.604	3.387	138.186	122.021	1.802
WWZ	0.593	0.094	0.009	5.067	0.053	0.602	0.000	2.193	0.406	0.004

Signal efficiency

x axis: truth of decay

y axis: reco selection category

- Each cell shows fraction per column (truth), reflecting acceptance and reconstruction efficiency
 - E.g. $\epsilon(2 \text{ leptons}) = 75\%$, $\epsilon(2 \text{ jets}) = 71\%$
- Last column is the fraction of diagonal yield wrt its row. I.e. the accuracy of reco categories.

Overall,

- Tau efficiency lower than expected (to check)
- Good selection accuracy

Confusion matrix

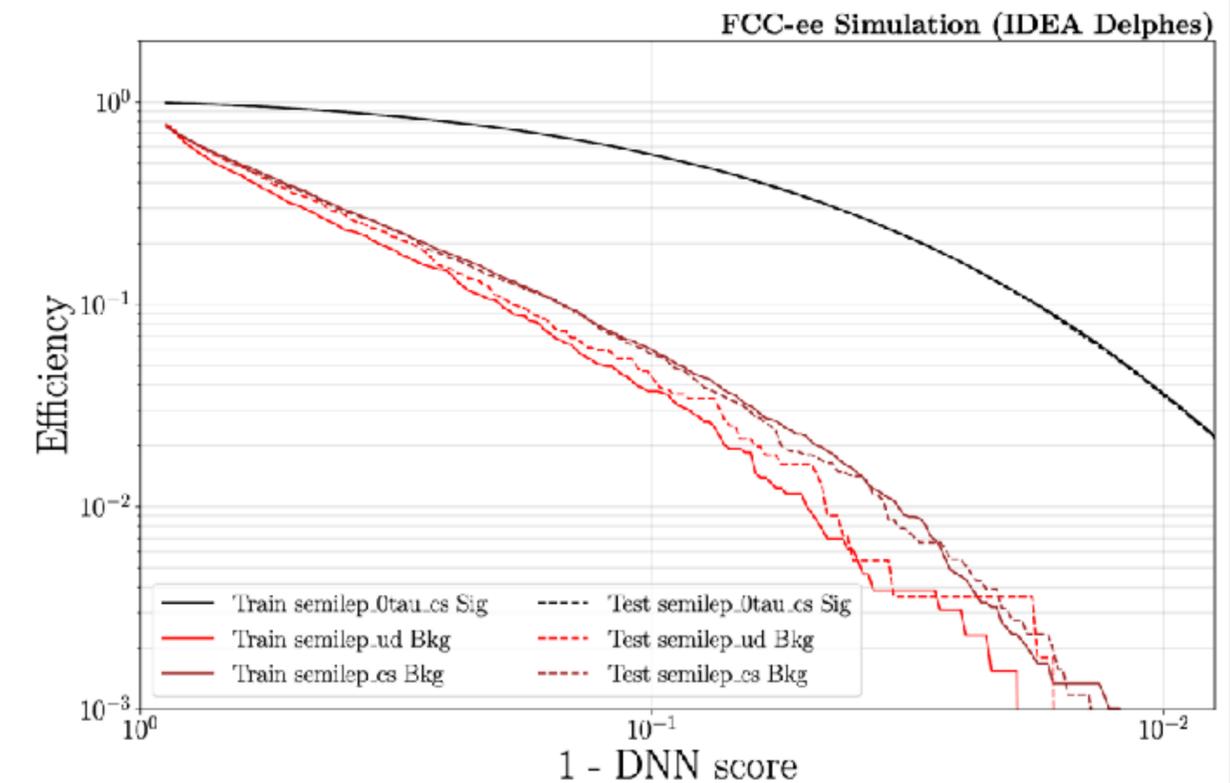
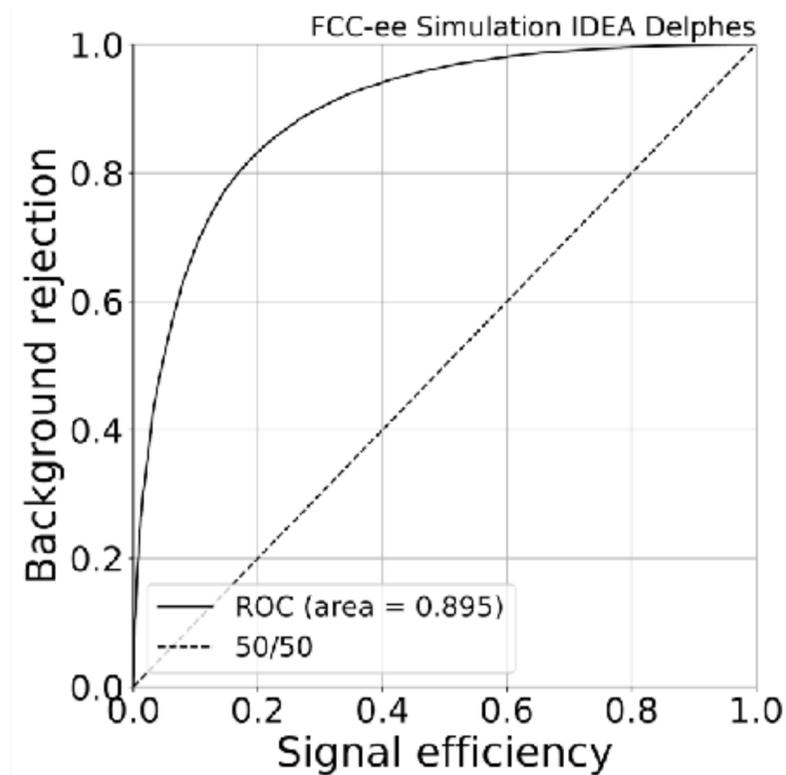
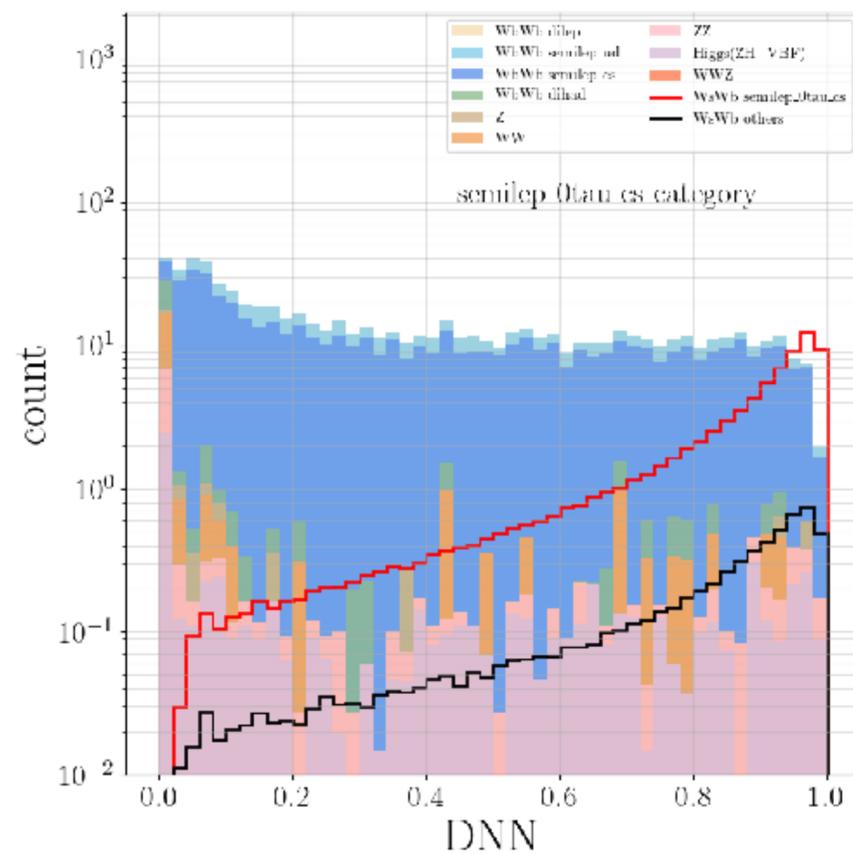
unselected	783145.0 42.40%	823650.0 61.34%	155926.0 74.37%	2599703.0 50.33%	2146525.0 53.94%	3381.0 57.22%	1779081.0 68.84%	1413879.0 71.12%	2170.0 73.34%	1945937.0 54.02%	3092864.0 54.34%	1115424.0 57.35%	8621.0 57.65%	0.00%
dilep_0tau	997653.0 54.02%	94164.0 7.01%	1902.0 0.91%	30.0 0.00%	38.0 0.00%			4.0 0.00%						91.21%
dilep_1tau	56660.0 3.07%	398522.0 29.58%	15037.0 7.55%	6358.0 0.12%	3105.0 0.08%	3.0 0.05%	453.0 0.02%	232.0 0.01%	1.0 0.03%					82.79%
dilep_2tau	776.0 0.04%	10874.0 0.81%	33323.0 15.89%	215.0 0.00%	114.0 0.00%		1563.0 0.06%	779.0 0.04%		5.0 0.00%	3.0 0.00%	1.0 0.00%		69.93%
semilep_0tau_ud	7223.0 0.39%	7697.0 0.57%	274.0 0.13%	2103233.0 40.72%	376064.0 9.45%	451.0 7.63%	136559.0 5.20%	24189.0 1.22%	24.0 0.01%	257.0 0.01%	122.0 0.00%	22.0 0.00%	1.0 0.01%	79.18%
semilep_0tau_cs	1228.0 0.07%	5898.0 0.44%	233.0 0.11%	351049.0 6.80%	1379235.0 34.56%	1986.0 33.61%	22518.0 0.88%	59354.0 4.49%	133.0 4.49%	86.0 0.00%	302.0 0.01%	85.0 0.00%	1.0 0.01%	74.46%
semilep_1tau_ud	189.0 0.01%	1517.0 0.11%	1080.0 0.52%	58978.0 1.14%	10420.0 0.26%	8.0 0.14%	490646.0 18.99%	35611.0 4.31%	107.0 3.62%	15371.0 0.43%	7148.0 0.13%	1064.0 0.05%	9.0 0.06%	73.00%
semilep_1tau_cs	37.0 0.00%	391.0 0.03%	868.0 0.41%	9821.0 0.19%	36733.0 0.92%	48.0 0.01%	84182.0 3.26%	322910.0 16.24%	171.0 5.92%	3196.0 0.09%	14908.0 0.26%	2806.0 0.14%	28.0 0.19%	67.78%
dihad_ud_only	1.0 0.00%	11.0 0.00%	4.0 0.00%	28254.0 0.55%	5599.0 0.14%	7.0 0.12%	31839.0 1.23%	7352.0 0.37%	4.0 0.14%	1305033.0 36.23%	494135.0 8.68%	51599.0 2.65%	704.0 4.71%	67.81%
dihad_udcs	1.0 0.00%	10.0 0.00%	10.0 0.00%	6538.0 0.13%	17896.0 0.45%	21.0 0.36%	31946.0 1.24%	25255.0 1.27%	16.0 0.54%	303842.0 8.43%	1769080.0 31.08%	277860.0 14.29%	3319.0 22.19%	72.63%
dihad_cs_only		2.0 0.00%	5.0 0.00%	751.0 0.01%	3126.0 0.09%	4.0 0.07%	5301.0 0.21%	18478.0 0.93%	33.0 1.12%	28499.0 0.79%	312975.0 5.50%	495941.0 25.50%	2271.0 15.19%	57.16%
sum_col	1846914 54.02%	1342736 29.68%	209662 15.89%	5164930 40.72%	3979155 34.66%	5909 0.00%	2584198 18.99%	1988043 16.24%	2959 0.00%	3602226 36.23%	5691537 31.08%	1944802 25.50%	14954 0.00%	
	45.98%	70.32%	84.11%	59.28%	65.34%	100.00%	81.01%	83.76%	100.00%	63.77%	68.92%	74.50%	100.00%	
	dilep_0tau	dilep_1tau	dilep_2tau	semilep_0tau_ud	semilep_0tau_cs	semilep_0tau_CKMmix	semilep_1tau_ud	semilep_1tau_cs	semilep_1tau_CKMmix	dihad_ud_only	dihad_udcs	dihad_cs_only	dihad_CKMmix	cat_accuracy
	Actual													

DNN training

- 3 hidden layers ($2 \times \text{\#inputs} \rightarrow 4 \times \text{\#inputs} \rightarrow 8$)
- For tt processes (sig and bkg), independent events for training, testing, and statistical analysis
- For other bkg, training and testing events are also used for analysis.
- DNN output used for signal fit

example plots in semilep_0tau_cs category

complete results at https://etpwww.etp.kit.edu/~xzuo/Vts_plots/20250319_2249/





Results

Results



- Binned likelihood fit on DNN output with Asimov dataset
- Only take categories without taus. → Not affected by bkg issue
- Consider 1% bkg norm uncertainty to be the nominal case
- **6.3% relative uncertainty on $\mathcal{B}(t \rightarrow Ws)$**

Fit config	Free bkg	bkg $\pm 20\%$	bkg $\pm 5\%$	bkg $\pm 2\%$	bkg $\pm 1\%$
category					
dilep_0tau	14.5%	12.4%	12.0%	11.9%	11.8%
semilep_0tau_ud	13.2%	10.8%	10.2%	9.9%	9.7%
semilep_0tau_cs	30.3%	18.9%	18.3%	17.8%	17.7%
dihad_ud_only	25.4%	20.2%	19.8%	19.1%	18.6%
dihad_udcs	32.4%	26.0%	25.6%	24.7%	24.1%
dihad_cs_only	108%	83.1%	78.4%	76.5%	76.2%
combined	6.8%	6.6%	6.5%	6.4%	6.3%

Results



- To get a sense of the precision in tau-related categories
- xsec effect from bkg issue properly mitigated, kinematic effects not necessarily
- Sizable gain from tau-categories
 - But not a game changer for physics interpretation
 - Suggestion: not include taus before new samples are ready

Fit config	Free bkg	bkg $\pm 20\%$	bkg $\pm 5\%$	bkg $\pm 2\%$	bkg $\pm 1\%$
category					
dilep_0tau	14.5%	12.4%	12.0%	11.9%	11.8%
semilep_0tau_ud	13.2%	10.8%	10.2%	9.9%	9.7%
semilep_0tau_cs	30.3%	18.9%	18.3%	17.8%	17.7%
dihad_ud_only	25.4%	20.2%	19.8%	19.1%	18.6%
dihad_udcs	32.4%	26.0%	25.6%	24.7%	24.1%
dihad_cs_only	108%	83.1%	78.4%	76.5%	76.2%
combined	6.8%	6.6%	6.5%	6.4%	6.3%

Fit config	bkg $\pm 1\%$
category	
dilep_0tau	11.8%
dilep_1tau	18.2%
semilep_0tau_ud	9.7%
semilep_0tau_cs	17.7%
semilep_1tau_ud	19.8%
semilep_1tau_cs	37.8%
dihad_ud_only	18.6%
dihad_udcs	24.1%
dihad_cs_only	76.2%
combined	5.6%

Conclusions and Next steps



Measurement of $\mathcal{B}(t \rightarrow Ws)$ at 365 GeV

- Analysis fully revised
- Nominal combined precision of 6.3%, and additional gain from tau-categories

For ESPP

- Finish analysis note \rightarrow this week
- If new bkg samples in time, rerun and include tau-categories \rightarrow next week
- Other interesting comparisons?

After ESPP

- Rerun as a simultaneous measurement of $\mathcal{B}(t \rightarrow Ws)$ and $\mathcal{B}(t \rightarrow Wb)$
- More studies on jet clustering and tagging performance
- Publication



Backups

Sample considered



Sig: SM $t \rightarrow Ws$ decay

- wzp6_ee_SM_tt_tWsTWb_tlepTall_ecm365
- wzp6_ee_SM_tt_tWsTWb_tlightTall_ecm365
- wzp6_ee_SM_tt_tWsTWb_theavyTall_ecm365
- wzp6_ee_SM_tt_tWbTWs_tallTlep_ecm365
- wzp6_ee_SM_tt_tWbTWs_tallTlight_ecm365
- wzp6_ee_SM_tt_tWbTWs_tallTheavy_ecm365

Bkg: SM $t \rightarrow Wb$ samples

- wzp6_ee_SM_tt_tlepTlep_noCKMmix_keepPollInfo_ecm365
- wzp6_ee_SM_tt_thadThad_noCKMmix_keepPollInfo_ecm365
- wzp6_ee_SM_tt_tlepThad_noCKMmix_keepPollInfo_ecm365
- wzp6_ee_SM_tt_thadTlep_noCKMmix_keepPollInfo_ecm365

Bkg: other SM processes

WW

- p8_ee_WW_ecm365

Z

- p8_ee_Zbb_ecm365
- wzp6_ee_tautau_ecm365

ZZ

- p8_ee_ZZ_ecm365

Higgs

- wzp6_ee_bbH_ecm365
- wzp6_ee_ccH_ecm365
- wzp6_ee_ssH_ecm365
- wzp6_ee_qqH_ecm365
- wzp6_ee_tautauH_ecm365
- wzp6_ee_mumuH_ecm365
- wzp6_ee_eeH_ecm365
- wzp6_ee_nunuH_ecm365

WWZ

- wzp6_ee_WWZ_Zbb_ecm365



Breakdown of changes

Summary of changes



- Different categorization strategy
 - consider τ final states
 - explicit categories for fully hadronic cases
 - “new” version of PNet ([tagging performance seems better](#))
- Updated normalization for samples
 - Raw event count for tt samples ($\sim 20\%$ higher normalization)
 - Total luminosity (2.5 \rightarrow 3.0 ab^{-1})
- Better MVA discriminator
 - DNN instead of BDT (big improvement in hadronic channels)

tt raw event count



In Whizard samples,

- tt processes are generated with all possible phase space, and mediator are later defined by matching to resonance mass windows

```
process proc = e1, E1 => (Lep, neut, b, lep, Neut, B)
                      {$restrictions = "3+4~W+ && 6+7~W- && 3+4+5~t && 6+7+8~tbar"}
```

- In about 17% of tt events, not enough generator top or W are found. (Reason to be better understood)
- In previous analysis, events without 2 gen tops and 2 gen Ws are filtered out, but still counted in the total raw MC events, which are used for event weight calculation.
- In current analysis, these events are kept out for both analysis and event weight calculation (**effectively 17% larger event yield** for tt, both sig and bkg)

Luminosity and normalization



For tt events

- Normalized to total expected number = 2 million (previously 1.9 million)

For other backgrounds

- Normalized with xsec from sample dict, to total lumi of 3.0 ab⁻¹ (previously 2.5)

Event selection

Event categories

Old

- **dilep**: exactly 2 leptons, 2 jets
- **semilep_ud**: exactly 1 leptons, 4 jets (sb+ud)
- **semilep_cs**: exactly 1 leptons, 4 jets (sb+cs)
- **dihad**: exactly 0 lepton, 6 jets

- About **40%** of **dileptonic** events involves hadronic τ decays
- About **22%** of **semileptonic** events involves hadronic τ decays

Some categories have one-to-one correspondence, can be compared

Event categories

New

- Based on number of leptons (e/μ), hadronic τ , and jets
- **dilep_0tau**, dilep_1tau, dilep_2tau
- **semilep_0tau_ud**, semilep_0tau_cs,
- **semilep_1tau_ud**, semilep_1tau_cs,
- **dihad_ud_only**, **dihad_udcs**, **dihad_cs_only**,

Event yield



category	dilep		semilep_ud		semilep_cs		dihad	
process	new	old	new	old	new	old	new	old
sig dilep	120.1	101.2	1.17	1.20	0.03	0.09	0	0
sig semi_ud	0	0	263.4	208.7	1.35	2.47	4.5	3.68
sig semi_cs	0	0	34.1	20.2	83.9	90.7	1.8	1.9
sig dihad	0	0	0	0	0	0	332	298
bkg dilep	269.4	536	20.7	220	0.437	44	0.06	0.87
bkg semi	11.9	2.94	2866.3	4205.1	663.5	1571.7	175	794.2
bkg dihad	0	0	19.9	9.45	5.80	3.53	7349	8694
bkg WW+ZZ+ZH	56.6	609.2	188.9	504.7	12.9	158.1	1280	2963.2
bkg Z + WWZ	8.0	-	14.6	-	1.61	-	314	-

- Signal yields in ballpark agreement
- bkg yields in general became (much) lower

Seems new PNet training has lower fake s-tag rate (to confirm)

Training performance



- Training performance not better than before
- New training is more reliable
 - More bkg events, with event weight properly applied
 - Tested for overtraining
 - Independent events for fits

AUR	dilep	semilep_ud	semilep_cs
this version	0.937	0.929	0.895
previous analysis	0.964	0.889	0.932