Higgs Self-Coupling Measurement at the ILC.

Claude-Fabienne Dürig[1], Junping Tian[2], Jenny List[1], Keisuke Fujii[2]

[1]DESY Hamburg, Germany
[2]KEK, Japan

ILD Software and Analysis Meeting, 15.01.2014

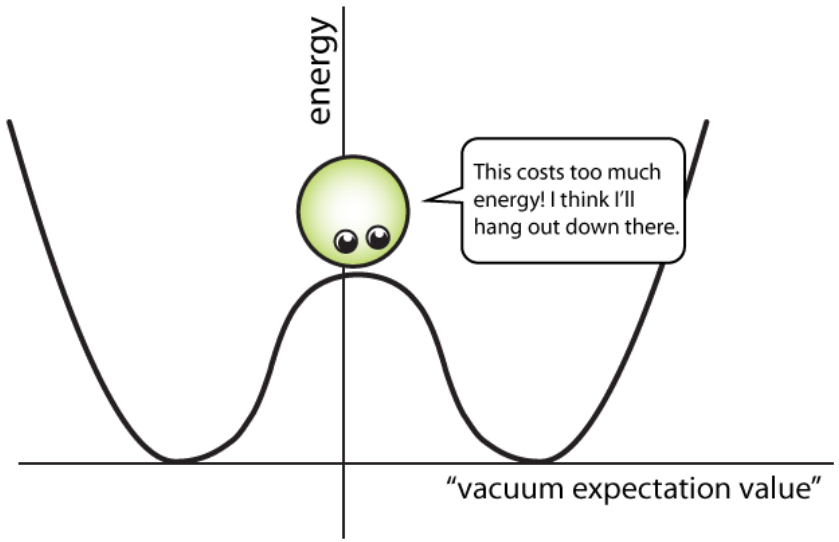
Contents

DESY

Trilinear Higgs self-coupling

- Higgs properties can be measured precisely at ILC (m_H, Γ_H^{tot}, etc.)

  missing: **Higgs potential**, which represents test of EWSB and mass generation



http://www.quantumdiaries.org

Higgs potential after spontaneous symmetry breaking for physical Higgs field:

$$V(\eta_H) = \frac{1}{2} m_H^2 \eta_H^2 + \lambda v \eta_H^3 + \frac{1}{4} \tilde{\lambda} \eta_H^4$$

G_F: Fermi constant

η_H: physical Higgs field

v: vacuum expectation value

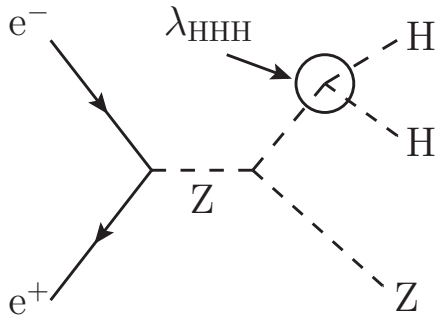
- trilinear λ and quartic $\tilde{\lambda}$ Higgs couplings are defined as:

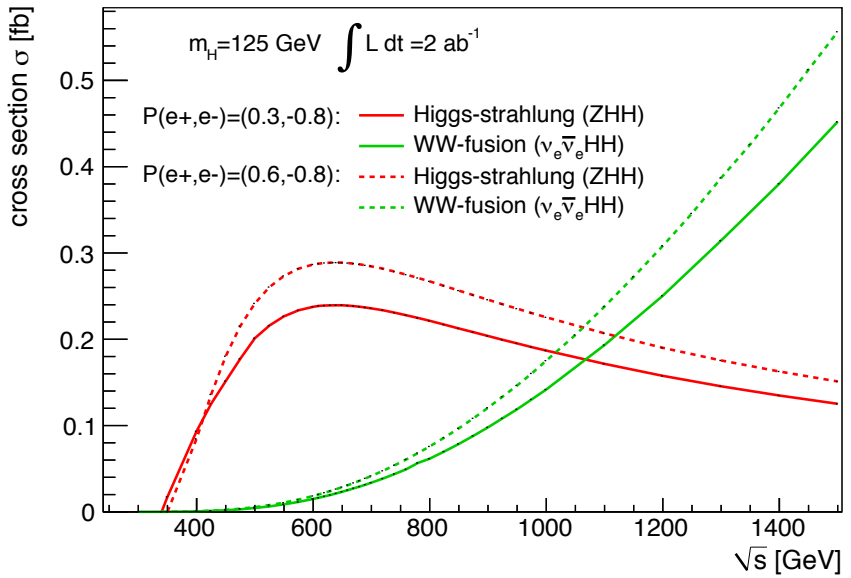
$$\lambda = \tilde{\lambda} = \lambda_{SM} = \frac{m_H^2}{2v^2}$$

- verify the shape of Higgs potential $\longrightarrow$ measure three terms

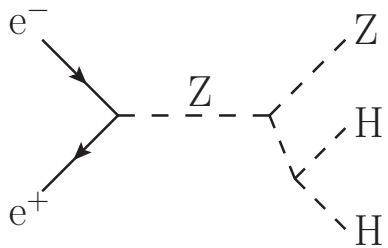
Double Higgs production processes

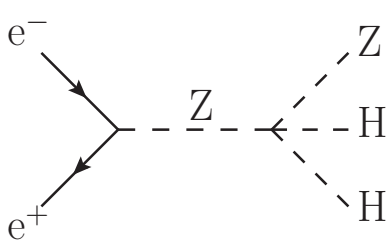
- **Higgs-strahlung**: dominant around $\sqrt{s} = 500$ GeV

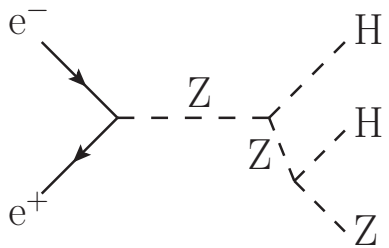




- **irreducible Feynman diagrams** which do not concern Higgs self-coupling



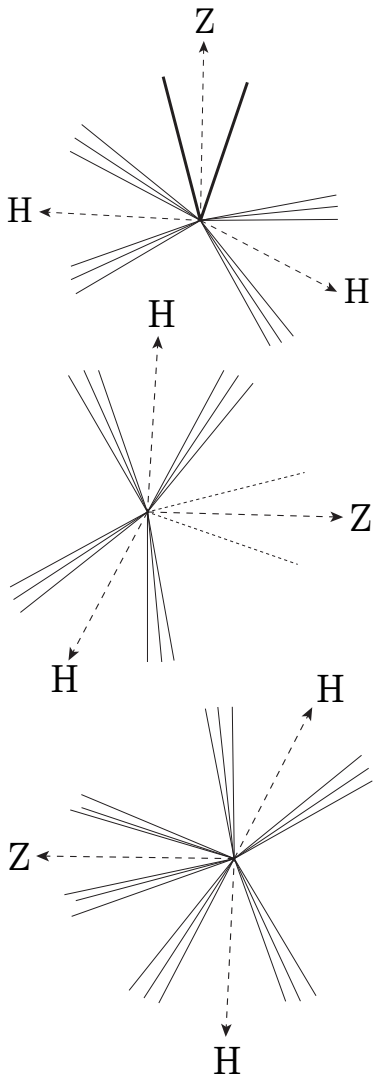




- **Interference** between Higgs self-coupling and irreducible diagrams make measurement complicated

Analysis strategy - Decay Channels

- Measurement at $\sqrt{s} = 500$ GeV and $\mathcal{L} = 2\ \text{ab}^{-1}$ and $m_H = 125$ GeV



$e^+e^- \to ZHH \to l^-l^+HH$

2leptons 4jets mode ($10\% \times 60\% \times 60\% \approx 3.6\%$)

$Z \longrightarrow l\bar{l}$ $H \longrightarrow b\bar{b}$ $H \longrightarrow b\bar{b}$

$e^+e^- \to ZHH \to \nu\bar{\nu}HH$

2neutrino 4jet mode ($20\% \times 60\% \times 60\% \approx 7.2\%$)

$Z \longrightarrow \nu\bar{\nu}$ $H \longrightarrow b\bar{b}$ $H \longrightarrow b\bar{b}$

$e^+e^- \to ZHH \to q\bar{q}HH$

6jets mode ($70\% \times 60\% \times 60\% \approx 25\%$)

$Z \longrightarrow q\bar{q}$ $H \longrightarrow b\bar{b}$ $H \longrightarrow b\bar{b}$

DBD Status for m_H=120 GeV

- Measurement at $\sqrt{s} = 500$ GeV, $\mathcal{L} = 2$ ab^{-1} and $P(e^+e^-) = (0.3, -0.8)$
- here: investigated Higgs mass m_H= 120 GeV

modes	signal	background (tt, ZZ, ZZH, ZZZ)	significance	
			excess	measurement
ZHH $\rightarrow l^-l^+$HH	3.7	4.3	1.5σ	1.1σ
	4.5	6.0	1.5σ	1.2σ
ZHH $\rightarrow \nu\bar{\nu}$HH	8.5	7.9	2.5σ	2.1σ
ZHH $\rightarrow q\bar{q}$HH	13.6	30.7	2.2σ	2.0σ
	18.8	90.6	1.9σ	1.8σ

- cross-section: $\frac{\delta\sigma_{ZHH}}{\sigma_{ZHH}} = 27\%$ ($> 3.5\sigma$) Higgs self-coupling: $\frac{\delta\lambda}{\lambda} = 44\%$

Next steps

- perform analysis with new $m_H = 125$ GeV samples
- consider low-p_T $\gamma\gamma \rightarrow$ hadrons beam induced background
- different starting points for improvement

Selection strategy for leptonic channel

1. select two isolated charged leptons consistent with M_Z

$$|M_{2\text{lep}} - M_z| < 40 \text{ GeV}$$

2. remove low-p_T $\gamma\gamma \rightarrow$ hadrons background
3. force the other reconstructed particles into four jets
4. combine the four jets by choosing combination with smallest χ^2

$$\chi^2 = \frac{(M(j_i j_j) - M(H))^2}{\sigma_H^2} + \frac{(M(j_k j_l) - M(H))^2}{\sigma_H^2}$$

require: $|M_H - 125 \text{ GeV}| < 80 \text{ GeV}$

5. neural net analysis performed separately for signal and each background, output classifiers are used to suppress background

divide background into four different categories:

jets-poor background (llqq)
semileptonic ttbar background (lvbbqq)
full-hadronic background (6-jets and 4-jets)
backgrounds with same final states (ZZH/ZZZ)

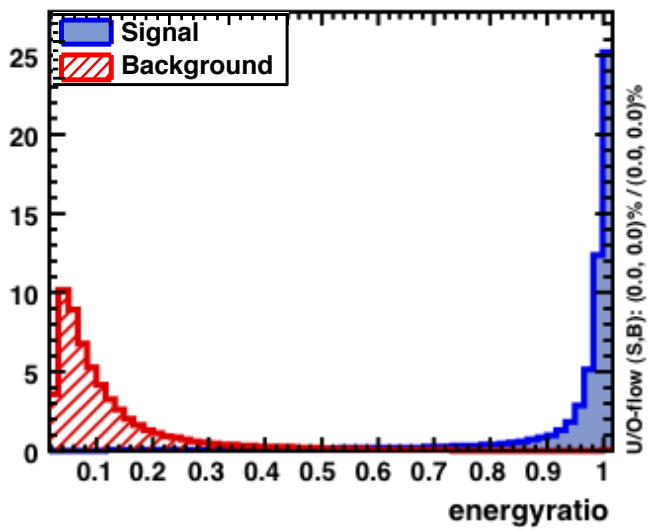
New DiLeptonSelection - Isolation Requirement

old lepton selection - isolation requirement:

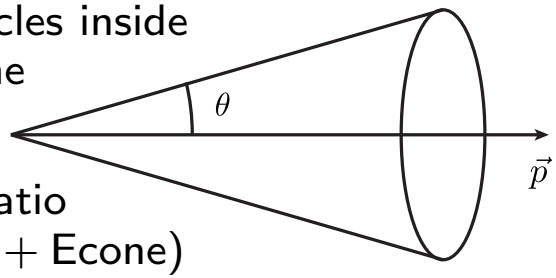
- cut based on energy distributions in calorimeter

new lepton selection - isolation requirement:

- neural net based (MVA)
- train neural net with samples for **signal**: eeHH and μμHH
  background: bbbb and lνbbqq
- MVA output is written to lepton collection, can be optimised in final selection
- **Example of input variable: energyratio**



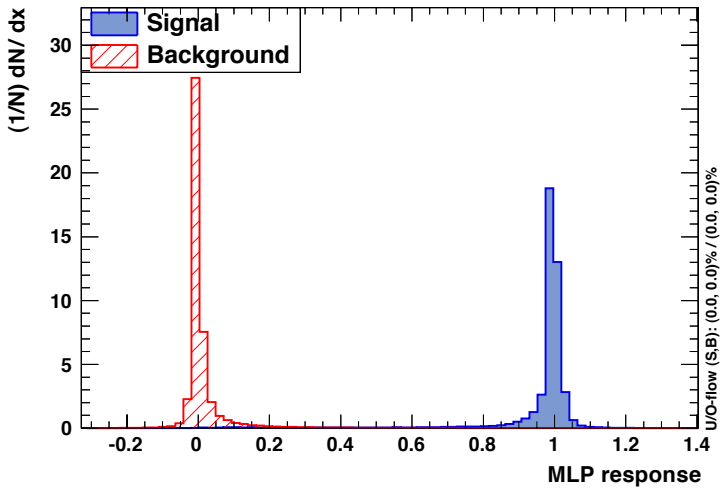
- define cone around direction of rec. particle and sum up energy of particles inside this cone



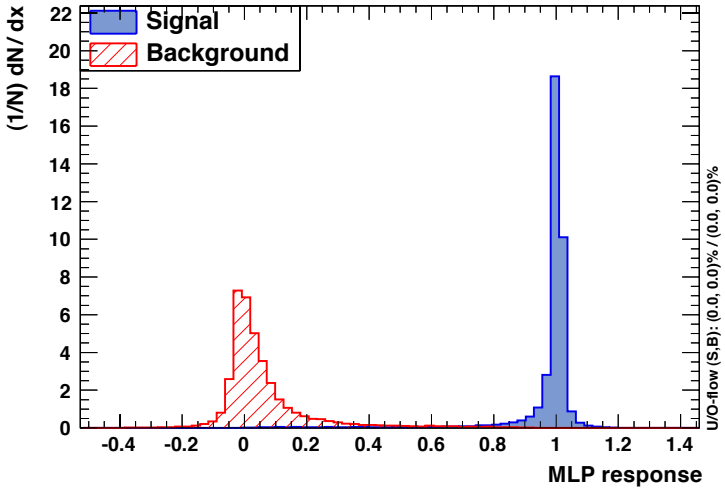
- energyratio is E/(E + Econe)
- isolated lepton has small Econe, so energyratio close to one

New DiLeptonSelection - Isolation Requirement

neural net output for electrons



neural net output for muons



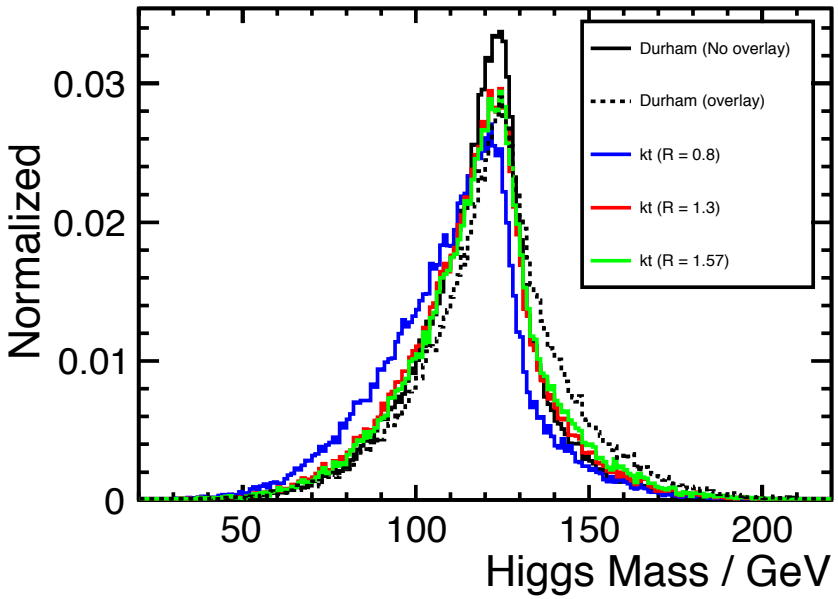
- IsolatedLeptonTaggingProcessor/ZHHll4JLeptonSelectionProcessor → J. Tian

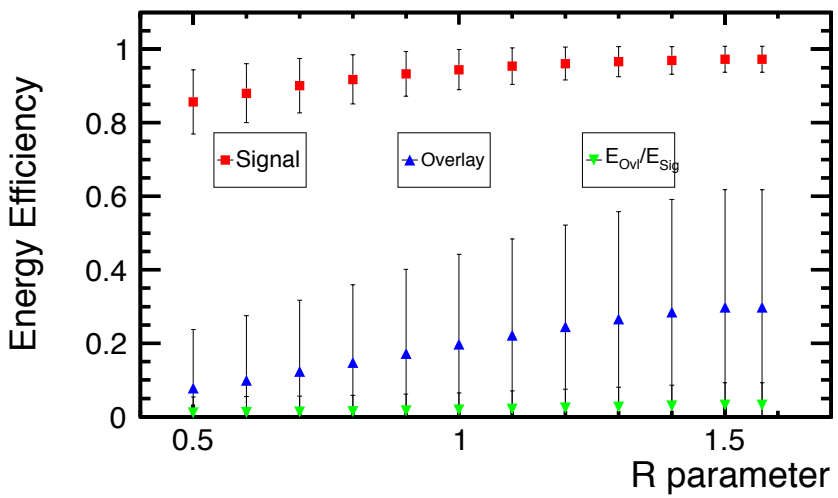
Current Improvement

efficiency (%)	eehh	μμhh	bbbb	eνbbqq	μνbbqq
new selection	86.99	89.11	0.00168	0.315	0.0196
old selection	85.7	88.4	0.028	1.44	0.10

New lepton selection strategy increases signal efficiency.
Suppression of hadronic and one-lepton backgrounds is significantly improved.

Removal of beam induced $\gamma\gamma$ background





- low-p_T $\gamma\gamma \rightarrow$ hadrons overlaid events per interaction:
  $< N_{\gamma\gamma} >= 1.7$
  (ILD/SiD standard, but overestimated)
- apply **FastJetClustering:**
  k_TExclusiveNJets4
  which R-value?
- for R $\geq$ 1.2 almost no increase in signal efficiency but in overlay
- best recovery of bare evts **R = 1.3**
- use only reconstructed particles in these 4 jets for analysis

Lepton channel: preliminary preselection

Preselection for samples with overlaid low-$\mathbf{p_T}$ $\gamma\gamma \rightarrow$ hadrons background

	eeHH	μμHH	eeqqH	μμqqH
expected no. of events	13.50	13.52	75.34	75.53
DiLeptonSelection	11.74	12.05	68.41	67.26
k_T 1.3 ExclusiveNJets4	11.61	12.04	64.66	67.23
combine four jets to two Higgs $\lvert M_H - 125\ \text{GeV}\rvert < 80\ \text{GeV}$	11.09	11.51	62.84	65.24

Comparison to samples without $\gamma\gamma$-overlay

	eeHH	μμHH	eeqqH	μμqqH
expected no. of events	13.50	13.52	75.34	75.53
DiLeptonSelection	11.92	12.83	68.51	67.91
k_T 1.3 ExclusiveNJets4	-	-	-	-
combine four jets to two Higgs $\lvert M_H - 125\ \text{GeV}\rvert < 80\ \text{GeV}$	11.42	12.11	63.75	66.56

Exclusive k_T algorithm recovers event without $\gamma\gamma$-overlay very well.

Lepton channel: NN training after preselection

After preselection:

- fully hadronic background could be removed completely
- remaining: jets-poor background (llqq)
  semileptonic ttbar background (lvbbqq)
  backgrounds similar to signal final state (ZZH/ZZZ)

Train separate neural nets for remaining background types (3 in total)

Input variables: llbb vs llHH

- Z-mass
- thrust
- thrust angle
- Durham param. Y_M and Y_{P2}
- largest cos(Z, 2jets)
- largest 2jet momentum
- number of pfos
- smallest npfos in jet

Input variables: lvbbqq vs llHH

- visible energy
- missing P_T
- angle between 2prompt bjets
- smallest lepton momentum
- mvalepsmall
- rec. W-boson mass
- number of pfos
- Z-mass

Input variables: ZZZ/ZZH vs llHH

- M(H1) when rec. as HH
- M(H2) when rec. as HH
- M(Z) when rec. as ZH
- M(H) when rec. as ZH
- M(Z1) when rec. as ZZ
- M(Z2) when rec. as ZZ
- cosine (ZZH/ZZZ)
- largest mom. (ZZH/ZZZ)

Comparison of NN outputs and input variables from analysis w and w/o overlay in backup

Preliminary cuts electron type - optimised w/o overlay

- **cut1**: $|M_Z - 91\ \text{GeV}| < 32\ \text{GeV}$
- **cut2**: MVAllbb > 0.78
- **cut3**: MVAlvbbqq > 0.62
- **cut4**: bmax3 > 0.2
- **cut5**: MVAllbbbb > 0.25

$ZHH \to l^-l^+HH$	signal	background	significance
DBD study $m_H = 120$ GeV	3.7	4.3	1.1σ
new no overlay optimised	2.79 (2.38)	4.03	1.07σ
new with overlay same cuts	2.78 (2.33)	8.76	0.82σ

	eebb	μμbb	eνbbqq	μνbbqq	τνbbqq	bbqqqq	bbbb	llbbbb	llqqh	bgrd	signal (llbbbb)
expected	284117	49565.7	248454	245936	245708	624060	40234.4	69.51	150.87	$1.74 \cdot 10^6$	40.50
preselection	2697.42	1414.96	519.97	74.97	31.61	4.21	0.38	14.97	129.29	4887.79	23.15 (7.59)
	2660.85	1516.27	509.89	67.88	30.89	4.21	0.38	14.75	128.08	4933.19	22.86 (7.53)
ltype = 11	2697.42	0.09	519.98	1.20	29.15	4.21	0.38	7.36	63.35	3323.14	11.38 (3.75)
	2660.85	0.19	509.98	10.47	27.40	4.21	0.38	7.23	62.81	3273.43	11.24 (3.72)
cut1	2383.93	0.05	426.94	0.34	23.44	1.79	0.29	7.08	62.78	2906.6	11.25 (3.73)
	2375.91	0.09	417.59	0.45	19.68	1.79	0.29	6.96	62.23	2885.02	11.11 (3.69)
cut2	38.13	0	244.99	0.18	12.53	1.79	0.09	4.55	43.52	345.79	8.44 (3.47)
	44.12	0	237.01	0	13.22	1.79	0.085	4.31	42.01	342.54	8.36 (3.38)
cut3	34.11	0	24.05	0	2.94	0.62	0.04	4.31	41.81	107.89	7.89 (3.37)
	41.58	0	41.74	0	3.24	0.62	0.04	4.19	40.79	132.23	7.91 (3.32)
cut4	2.79	0	0.44	0	0.27	0.31	0.04	3.85	8.39	16.09	3.59 (3.02)
	4.29	0	4.38	0	0.27	0.31	0.04	3.74	8.59	21.64	3.59 (2.95)
cut5	0.55	0	0	0	0.02	0.16	0	0.74	2.57	**4.03**	**2.79 (2.38)**
	1.49	0	2.98	0	0.01	0.31	0	0.80	3.16	**8.76**	**2.78 (2.33)**

Preliminary cuts electron type - optimised w overlay

- **cut1**: $|M_Z - 91\ \text{GeV}| < 32\ \text{GeV}$
- **cut2**: MVAllbb > 0.79
- **cut3**: MVAlvbbqq > 0.81
- **cut4**: bmax3 > 0.22
- **cut5**: MVAllbbbb > 0.3

$ZHH \to l^-l^+HH$	signal	background	significance
DBD study $m_H = 120$ GeV	3.7	4.3	1.1σ
new no overlay optimised	2.79 (2.38)	4.03	1.07σ
new with overlay same cuts	2.78 (2.33)	8.76	0.82σ
new with overlay optimized	2.35 (2.03)	4.01	0.93σ

	eebb	μμbb	eνbbqq	μνbbqq	τνbbqq	bbqqqq	bbbb	llbbbb	llqqh	bgrd	signal (llbbbb)
expected	284117	49565.7	248454	245936	245708	624060	40234.4	69.51	150.87	$1.74 \cdot 10^6$	40.50
preselection	2660.85	1516.27	509.89	67.88	30.89	4.21	0.38	14.75	128.08	4933.19	22.86 (7.53)
ltype = 11	2660.85	0.19	509.98	10.47	27.40	4.21	0.38	7.23	62.81	3273.43	11.24 (3.72)
cut1	2375.91	0.09	417.59	0.45	19.68	1.79	0.29	6.96	62.23	2885.02	11.11 (3.69)
cut2	41.67	0	233.267	0	13.01	1.79	0.08	4.25	41.57	335.65	8.29 (3.37)
cut3	37.39	0	24.86	0	2.57	0.62	0.042	4.02	39.26	108.77	7.52 (3.23)
cut4	3.54	0	1.39	0	0.25	0.31	0.04	3.54	7.78	16.87	3.36 (2.81)
cut5	0.84	0	0.46	0	0	0.16	0	0.53	2.02	**4.01**	**2.35 (2.03)**

Neural nets less effective in analysis with overlay
has to be investigated and improved (NN outputs in backup)

Preliminary cuts muon type - optimised w/o overlay

- **cut1**: $|M_Z - 91\ \text{GeV}| < 32\ \text{GeV}$
- **cut2**: MVAllbb > 0.78
- **cut3**: MVAlvbbqq > 0.83
- **cut4**: bmax3 > 0.17
- **cut5**: MVAllbbbb > 0.24

$ZHH \to l^-l^+HH$	signal	background	significance
DBD study $m_H = 120$ GeV	4.5	6.0	1.2σ
new no overlay optimised	3.09 (2.54)	4.89	1.09σ
new with overlay same cuts	3.05 (2.48)	6.50	0.99σ

	eebb	μμbb	eνbbqq	μνbbqq	τνbbqq	bbqqqq	bbbb	llbbbb	llqqh	bgrd	signal (llbbbb)
expected	284117	49565.7	248454	245936	245708	624060	40234.4	69.51	150.87	$1.74 \cdot 10^6$	40.50
preselection	2697.42	1414.96	519.97	74.97	31.61	4.21	0.38	14.97	129.29	4887.79	23.15 (7.59)
	2660.85	1516.27	509.89	67.88	30.89	4.21	0.38	14.75	128.08	4933.19	22.86 (7.53)
ltype = 13	0	1414.86	0	73.77	2.46	0	0	7.61	65.95	1564.65	11.77 (3.84)
	0	1516.07	0	67.41	3.49	0	0	7.51	65.27	1659.76	11.62 (3.81)
cut1	0	1363.42	0	61.69	2.18	0	0	7.39	65.52	1500.2	11.66 (3.82)
	0	1461.81	0	55.27	3.21	0	0	7.28	64.82	1592.39	11.51 (3.78)
cut2	0	35.72	0	30.62	1.55	0	0	4.83	45.13	117.87	8.79 (3.56)
	0	39.141	0	27.98	2.02	0	0	4.57	43.35	117.07	8.69 (3.46)
cut3	0	33.35	0	1.95	0.25	0	0	4.50	42.79	82.85	8.01 (3.43)
	0	37.211	0	3.24	0.25	0	0	4.45	41.85	87.01	8.08 (3.40)
cut4	0	3.224	0	0	0	0	0	4.11	9.38	16.71	3.86 (3.13)
	0	4.89	0	0.45	0	0	0	4.06	9.71	19.13	3.92 (3.10)
cut5	0	1.141	0	0	0	0	0	0.85	2.90	**4.89**	**3.09 (2.54)**
	0	1.64	0	0.45	0	0	0	0.88	3.54	**6.50**	**3.05 (2.48)**

Preliminary cuts muon type - optimised with overlay

- **cut1**: $|M_Z - 91\ \text{GeV}| < 32\ \text{GeV}$
- **cut2**: MVAllbb > 0.79
- **cut3**: MVAlvbbqq > 0.81
- **cut4**: bmax3 > 0.22
- **cut5**: MVAllbbbb > 0.3

$ZHH \to l^-l^+HH$	signal	background	significance
DBD study $m_H = 120$ GeV	4.5	6.0	1.2σ
new no overlay optimised	3.09 (2.54)	4.89	1.09σ
new with overlay same cuts	3.05 (2.48)	6.50	0.99σ
new with overlay optimised	3.01 (2.38)	5.98	1.02σ

	eebb	μμbb	eνbbqq	μνbbqq	τνbbqq	bbqqqq	bbbb	llbbbb	llqqh	bgrd	signal (llbbbb)
expected	284117	49565.7	248454	245936	245708	624060	40234.4	69.51	150.87	$1.74 \cdot 10^6$	40.50
preselection	2660.85	1516.27	509.89	67.88	30.89	4.21	0.38	14.75	128.08	4933.19	22.86 (7.53)
ltype = 13	0	1516.07	0	67.41	3.49	0	0	7.51	65.27	1659.76	11.62 (3.81)
cut1	0	1461.81	0	55.27	3.21	0	0	7.28	64.82	1592.39	11.51 (3.78)
cut2	0	31.81	0	25.32	1.48	0	0	4.15	40.68	103.45	8.28 (3.36)
cut3	0	31.35	0	4.93	0.25	0	0	4.12	40.00	80.66	7.98 (3.34)
cut4	0	5.05	0	0.298	0	0	0	3.86	10.56	19.77	4.12 (3.11)
cut5	0	1.64	0	0.29	0	0	0	0.73	3.31	**5.98**	**3.01 (2.38)**

Neural nets less effective in analysis with overlay
has to be investigated and improved (NN outputs in backup)

Selection strategy for neutrino channel

1. reject events with isolated leptons
2. remove low-p_T $\gamma\gamma \rightarrow$ hadrons background
3. force the other reconstructed particles into four jets
4. combine the four jets by choosing combination with smallest χ^2

$$\chi^2 = \frac{(M(j_i j_j) - M(H))^2}{\sigma_H^2} + \frac{(M(j_k j_l) - M(H))^2}{\sigma_H^2}$$

require: $|M_H - 125\ \text{GeV}| < 80\ \text{GeV}$

5. loose cut on $bmax3 > 0.2$
6. neural net analysis performed separately for signal and each background, output classifiers are used to suppress background

divide background into four different categories:

jets-poor background (vvqq)
semileptonic ttbar background (lvbbqq)
full-hadronic background (6-jets and 4-jets)
backgrounds with same final states (ZZH/ZZZ)

Neutrino channel: preliminary preselection

Preselection for samples with overlaid low-p_T $\gamma\gamma \to$ hadrons background

	$\nu\bar{\nu}$HH	$\nu\bar{\nu}$qqH	$\nu\bar{\nu}$bbbb	$\nu\bar{\nu}$bb	lνbbqq	bbqqqq	bbbb
expected no. of events	80.14	447.01	97.08	272802	740098	624060	40234.3
reject evts with iso leptons	62.95	393.14	95.65	270348.35	240016.16	617460.12	39725.04
k_T 1.3 ExclusiveNJets4	62.53	393.09	95.65	270348.36	240016.13	617460.12	39725.04
$\lvert M_H - 125\ \text{GeV}\rvert < 80\ \text{GeV}$	60.76	384.39	92.12	11063.92	237807.36	559498.11	37327.76
$bmax3 > 0.2$	28.39	74.62	80.89	992.78	40974.54	69697	30921.9

Comparison to samples without $\gamma\gamma$-overlay

	$\nu\bar{\nu}$HH	$\nu\bar{\nu}$qqH	$\nu\bar{\nu}$bbbb	$\nu\bar{\nu}$bb	lνbbqq	bbqqqq	bbbb
expected no. of events	80.14	447.01	97.08	272802	740098	624060	40234.3
reject evts with iso leptons	62.46	392.69	95.58	270371.59	238532.66	617430.18	39714.81
k_T 1.3 ExclusiveNJets4	-	-	-	-	-	-	-
$\lvert M_H - 125\ \text{GeV}\rvert < 80\ \text{GeV}$	61.07	386.45	93.31	8407.49	236087.28	461720.89	37594.43
$bmax3 > 0.2$	28.53	72.27	81.99	545.42	40679.39	65529	31292.4

Exclusive k_T algorithm recovers event without $\gamma\gamma$-overlay very well.

Neutrino channel: NN training after preselection

After preselection:

- train neural nets for: 4jets background (bbbb)
  semileptonic ttbar background (lvbbqq)
  backgrounds similar to signal final state (ZZH/ZZZ)

Input variables: bbbb vs $\nu\nu$HH

- visible energy
- missing pt
- thrust
- M(Z1) when rec. as ZZ
- M(Z2) when rec. as ZZ
- largest 4jet momentum

Input variables: lvbbqq vs $\nu\nu$HH

- missing mass
- Econemax and plmax
- pcmax and coscjmax
- cosbmax
- number of pfos
- mwtt4j
- mh1 and mh2
- mwtt5j, mt1tt5j, mt2tt5j, mjminjets5
- npfosminjets5

Input variables: ZZZ/ZZH vs llHH

- M(Z) when rec. as ZH
- M(H) when rec. as ZH
- M(Z1) when rec. as ZZ
- M(Z2) when rec. as ZZ
- cosine (ZZH)
- cosine (ZZZ)
- largest mom. (ZZH)
- largest mom. (ZZZ)

Comparison of NN outputs and input variables from analysis w and w/o overlay in backup

Preliminary cuts optimised for "without overlay"

- **cut1**: $E_{vis} < 360\ \text{GeV} + 0.83 \cdot P_t^{miss}$, $M_Z < 60\ \text{GeV}$
- **cut2**: $NPFO_{min} > 8$, $M(HH) > 200\ \text{GeV}$, $92\ \text{GeV} < M(H1) < 137\ \text{GeV}$, $94\ \text{GeV} < M(H2) < 135\ \text{GeV}$
- **cut3**: MVAbbbb > 0.89
- **cut4**: MVAlvbbqq > 0.55
- **cut5**: MVAvvbbbb > 0.56
- **cut6**: bmax3 + bmax4 > 1.14

Cuts optimised for "without overlay"
and applied to "with overlay"

	νν̄bb	eν̄bbqq	μν̄bbqq	τν̄bbqq	bbqqqq	bbbb	νν̄bbbb	νν̄qqh	bgrd	signal (νν̄bbbb)
expected	272802	248454	245936	245708	624060	40234.3	97.08	447.01	$1.67 \cdot 10^6$	80.14
preselection	545.42	1787.73	1480.96	37410.7	65529	31292.4	81.98	72.27	138200	28.53 (22.67)
	992.78	1996.63	318.61	38659.3	69697.7	30921.9	80.89	74.63	142742	28.39 (22.38)
cut1 (evis,mpt,mz)	481.01	874.99	855.19	24453.2	1239.64	3699.86	80.36	69.74	31754	27.58 (21.89)
	856.82	914.52	159.96	22609	741.45	2921.47	76.96	67.85	28348	25.89 (20.33)
cut2 (npfo,mh1,mh2)	9.80	196.17	222.99	4616.09	214.25	384.15	10.55	20.62	5674.62	16.61 (14.68)
	10.55	214.91	49.26	4299.18	207.01	316.64	10.02	19.96	5127.53	14.29 (12.65)
cut3 (mvabbbb)	5.51	150.47	174.77	3401.85	56.35	7.51	5.95	15.05	3817.46	14.45 (12.72)
	5.57	171.71	38.39	3330.89	85.41	8.17	5.94	15.03	3661.11	11.86 (10.45)
cut4 (mvalvbbqq)	4.29	34.28	50.38	618.86	23.91	5.06	4.01	8.71	749.47	12.78 (11.43)
	3.75	102.22	19.07	1660.07	65.45	7.43	5.14	12.43	1875.56	11.07 (9.88)
cut5 (mvavvbbbb)	2.46	22.82	35.14	415.19	23.58	4.25	0.67	4.12	508.24	11.01 (9.84)
	3.15	54.55	8.62	910.39	52.08	5.45	0.95	4.14	1039.34	7.79 (6.99)
cut6 (bmax34)	0	0	0.16	0.99	0	1.65	0.27	1.43	**4.52**	**5.26 (5.19)**
	0	0	0	5.75	0.24	1.91	0.37	1.43	**9.69**	**3.86 (3.82)**

Preliminary cuts for neutrino channel with overlay - optimised

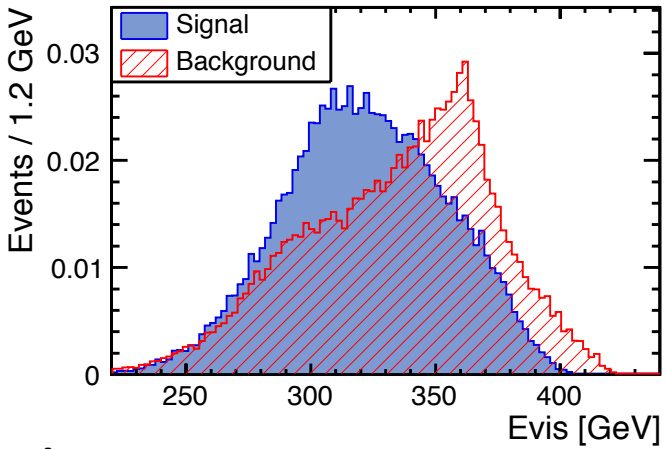
- **cut1**: $E_{\text{vis}} < 373\ \text{GeV} + 0.83 \cdot P_t^{miss}$ $M_Z < 60\ \text{GeV}$
- **cut2**: $Npfos_{min} > 7$, $M(HH) > 200\ \text{GeV}$, $95\ \text{GeV} < M(H1) < 140\ \text{GeV}$, $94\ \text{GeV} < M(H1) < 135\ \text{GeV}$
- **cut3**: MVAbbbb > 0.92
- **cut4**: MVAlvbbqq > 0.67
- **cut5**: MVAvvbbbb > 0.56
- **cut6**: bmax3 + bmax4 > 1.2

	ννbb	eνbbqq	μνbbqq	τνbbqq	bbqqqq	bbbb	ννbbbb	ννqqh	bgrd	signal (ννbbbb)
expected	272802	248454	245936	245708	624060	40234.3	97.08	447.01	$1.67 \cdot 10^6$	80.14
preselection	992.78	1996.63	318.61	38659.3	69697.7	40921.9	80.89	74.63	142742	28.39 (22.38)
cut1	862.421	995.118	171.55	24672.2	1301.68	3607.56	77.89	69.33	31757.8	26.63 (20.93)
cut2	12.41	250.19	49.81	5156.49	379.23	371.17	9.59	19.39	6248.29	15.11 (13.33)
cut3	5.57	181.48	36.65	3502.48	90.98	6.51	5.23	13.86	3842.77	11.51 (10.12)
cut4	4.35	67.72	11.47	1220.41	57.45	5.14	4.07	9.66	1380.26	9.96 (8.92)
cut5	3.75	37.49	4.5	697.34	45.1	4.15	0.82	3.42	796.58	7.12 (6.39)
cut6	0	0	0	1.07	0.12	1.41	0.28	1.08	**3.96**	**3.26 (3.23)**

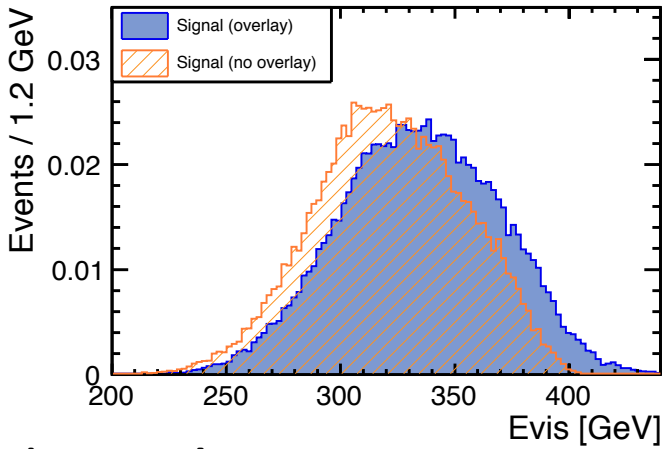
Neural nets less effective in analysis with overlay
has to be investigated and improved (NN outputs in backup)
tau background needs better handling

Example: Neural Net bbbb vs. $\nu\nu$HH

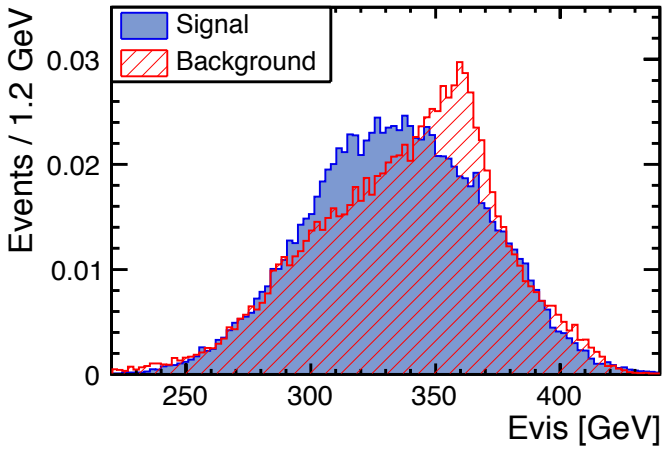
no overlay



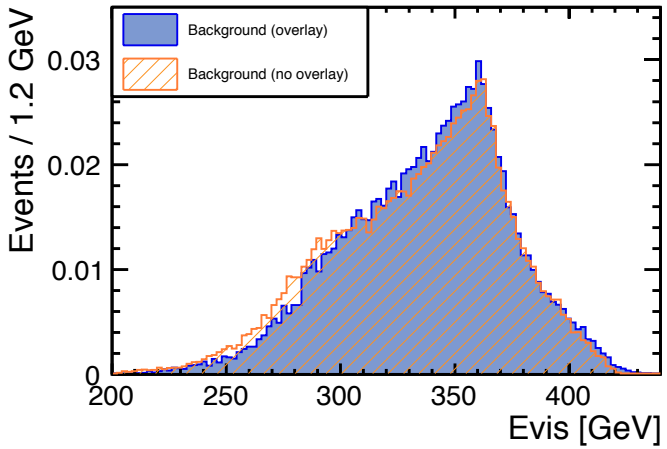
signal



overlay



background



Differences need to be investigated and understood!

DESY

Summary and Outlook

- updated lepton and neutrino channel for $m_H = 125$ GeV
  $\longrightarrow$ slightly less signal (σ,BR)
- new isolation lepton finding
- addition of $\gamma\gamma$-overlay
  $\longrightarrow$ removal with FastJetClustering exclusive k_T-algorithm
  $\longrightarrow$ some neural net input variables worse
  $\longrightarrow$ neutrino channel: τ, *Evis* ?
- status for $m_H = 125$ GeV without overlay and with overlay

modes	signal	background (tt, ZZ, ZZH, ZZZ)
$ZHH \to l^- l^+ HH$	2.79 (2.38)	4.03
	3.09 (2.54)	4.89
$ZHH \to \nu\bar{\nu}HH$	5.26 (5.19)	4.52

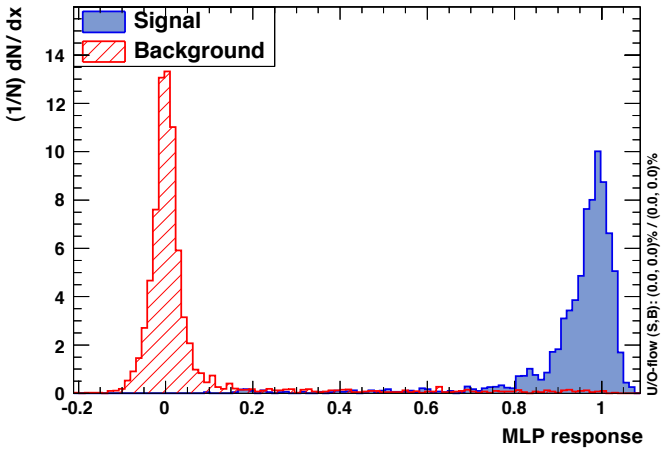
modes	signal	background (tt, ZZ, ZZH, ZZZ)
$ZHH \to l^- l^+ HH$	2.35 (2.03)	4.01
	3.01 (2.38)	5.98
$ZHH \to \nu\bar{\nu}HH$	3.26 (3.23)	3.96

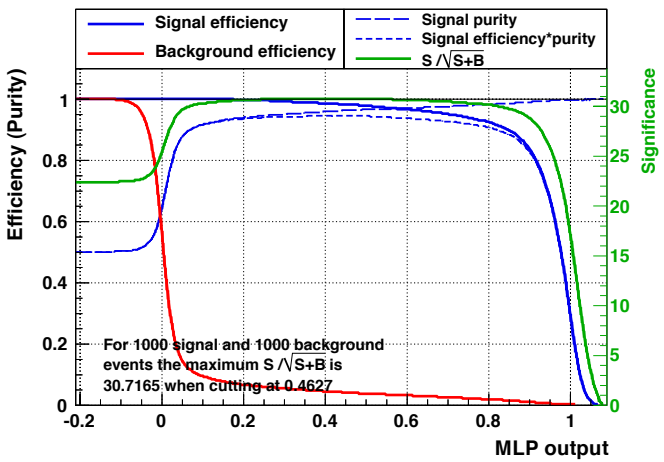
- reproduce entire analysis for $m_H = 125$ GeV
- improve neural net training and understand differences
- investigate kinematic fitting
- optimise the analysis strategy (current selections are optimised for ZHH, not for the self-coupling diagram)

BACKUP SLIDES

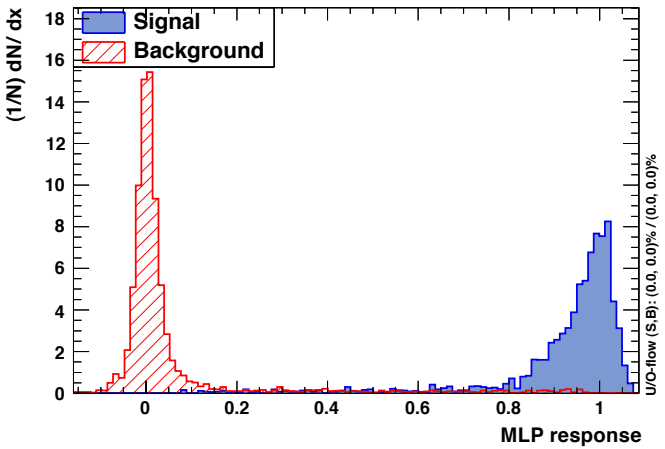
Neural Net training: llbb vs. llHH

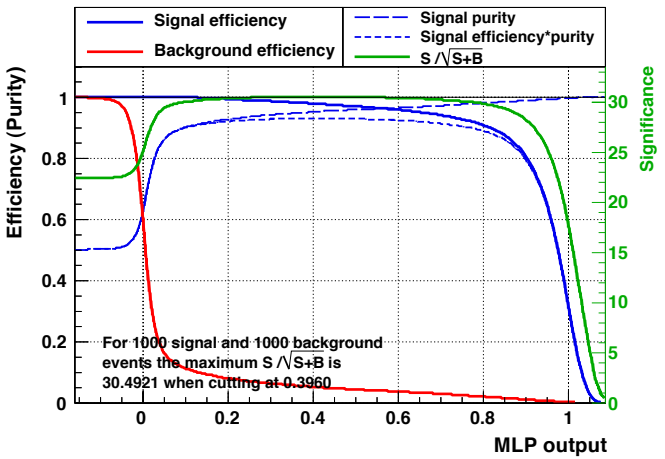
samples without overlay





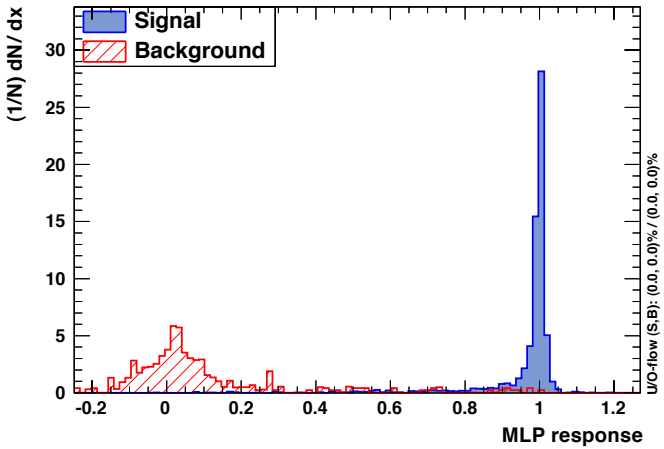
samples with overlay

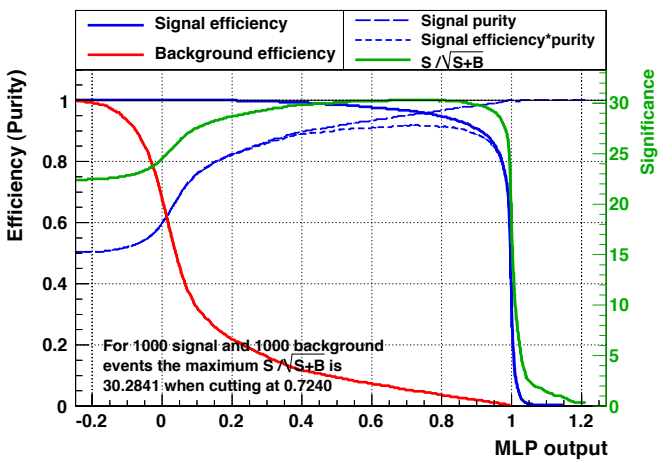




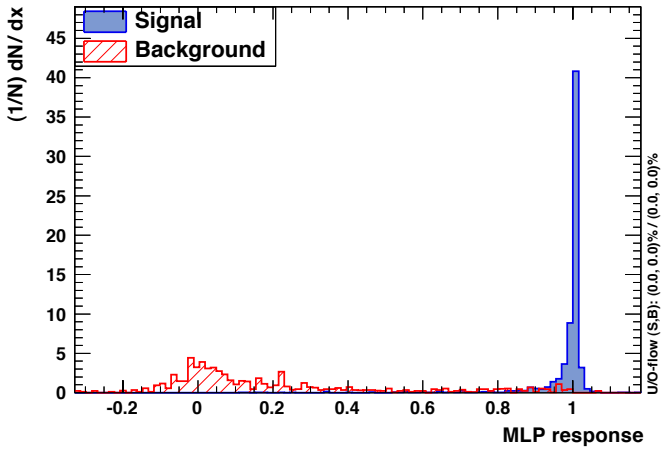
Neural Net training: lvbbqq vs. llHH

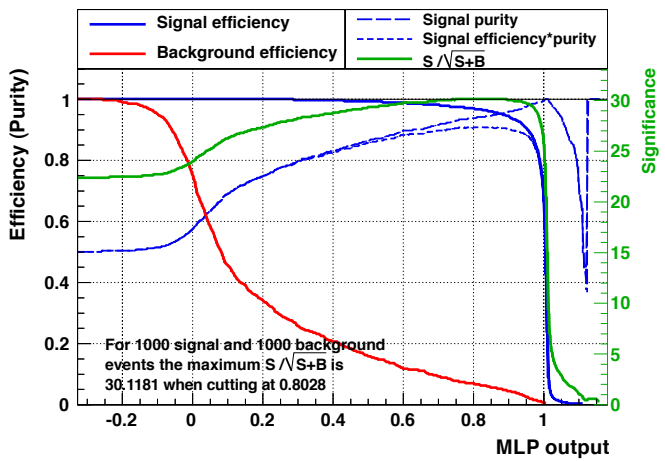
samples without overlay





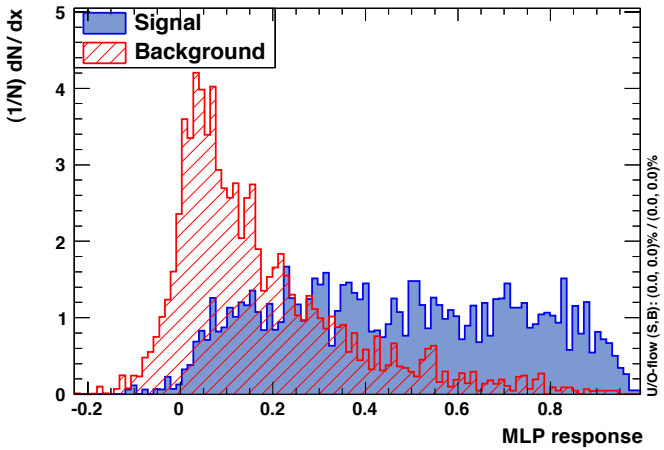
samples with overlay

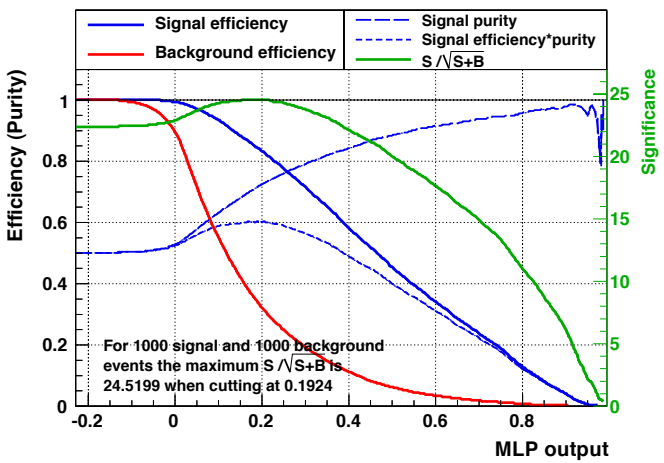




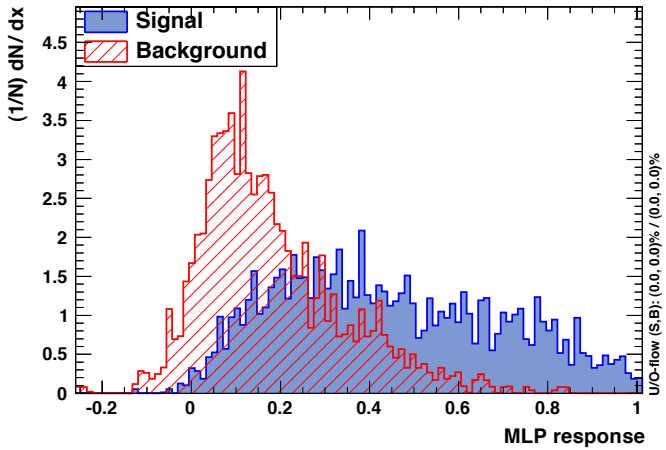
Neural Net training: ZZZ/ZZH vs. llHH

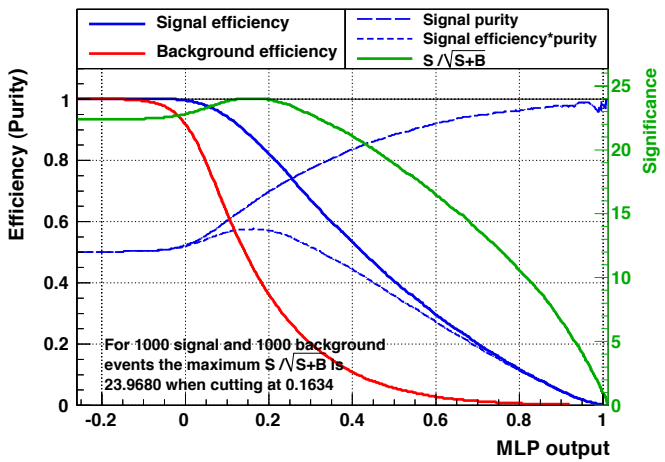
samples without overlay





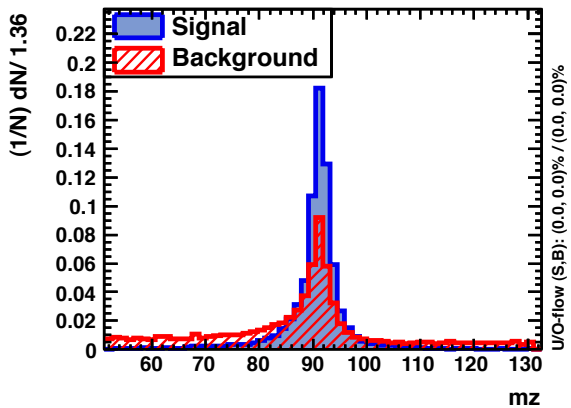
samples with overlay

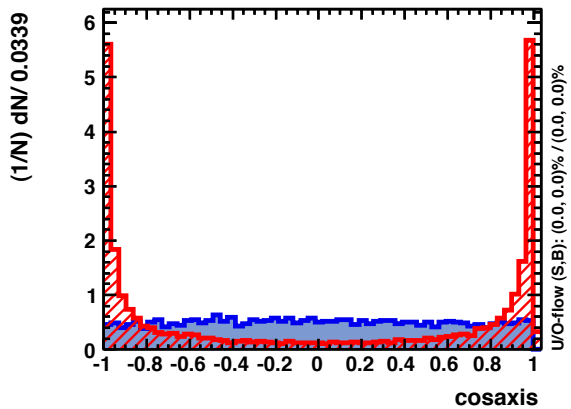


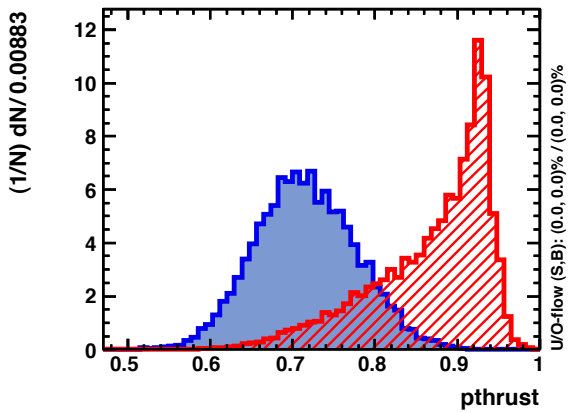


NN training: Input variables llbb vs llHH (1)

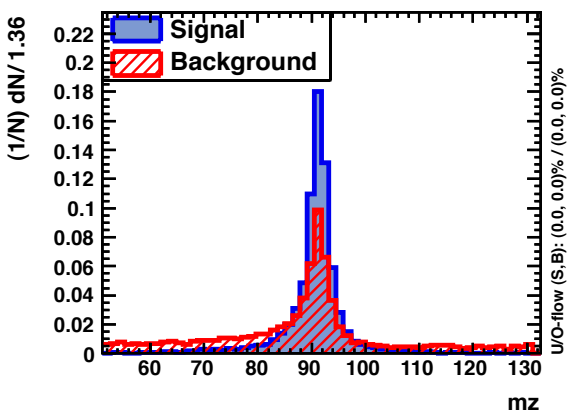
samples without overlay

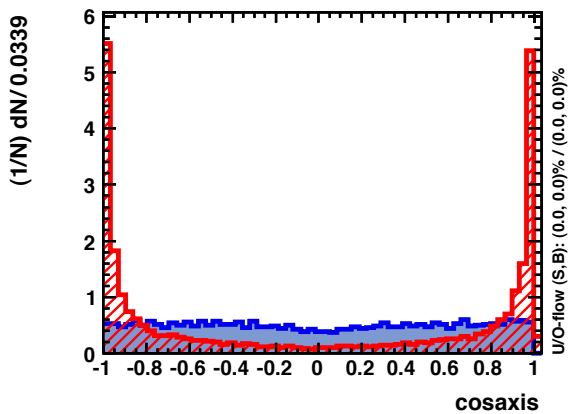


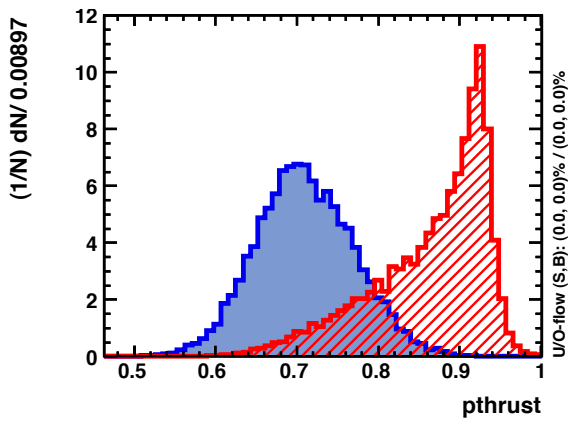




samples with overlay

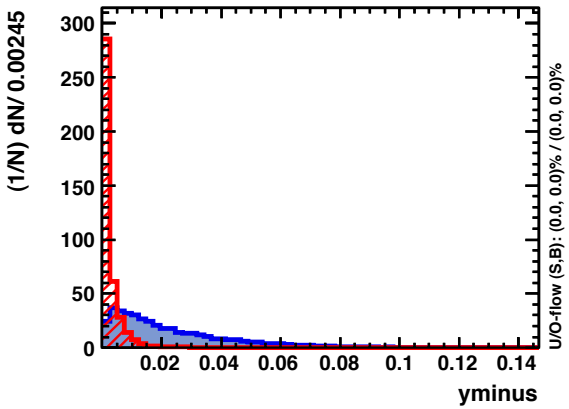


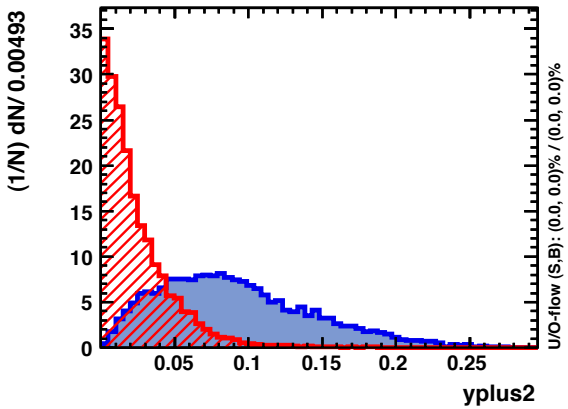


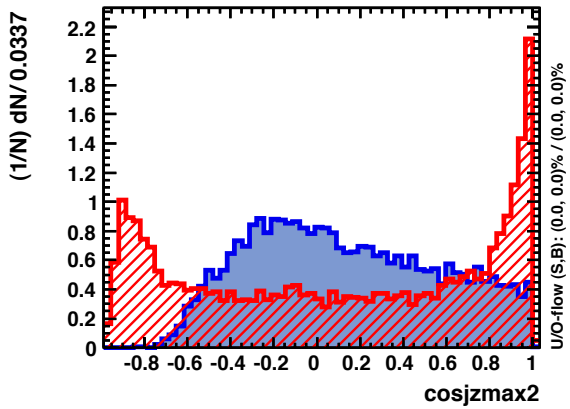


NN training: Input variables llbb vs llHH (2)

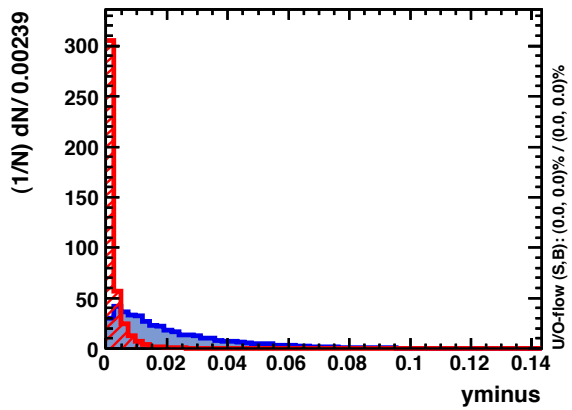
samples without overlay

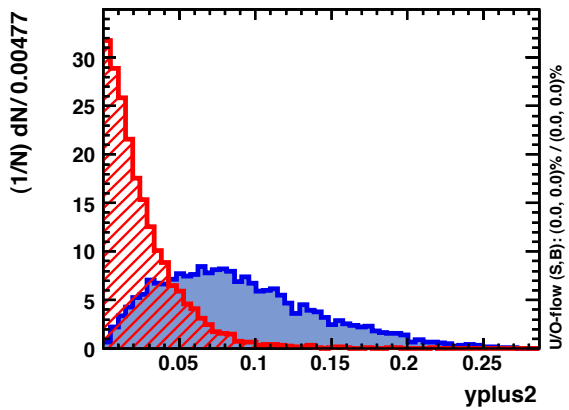


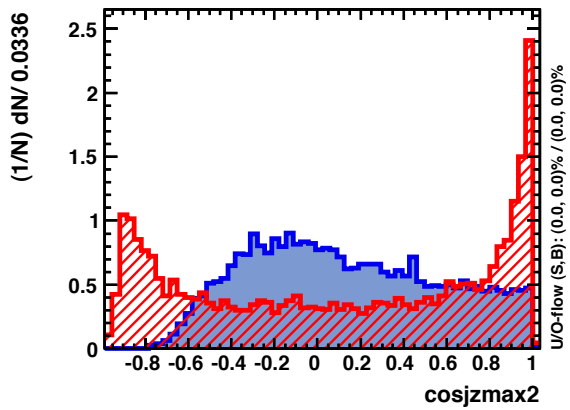




samples with overlay

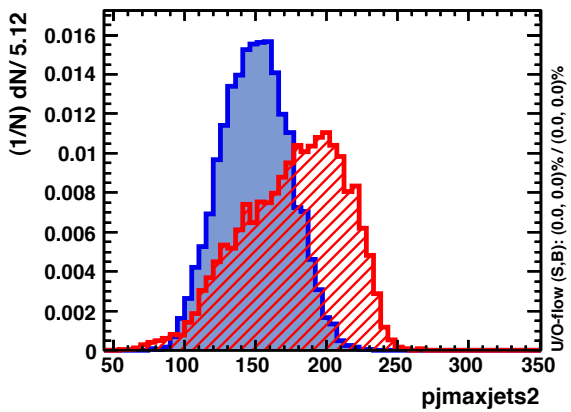


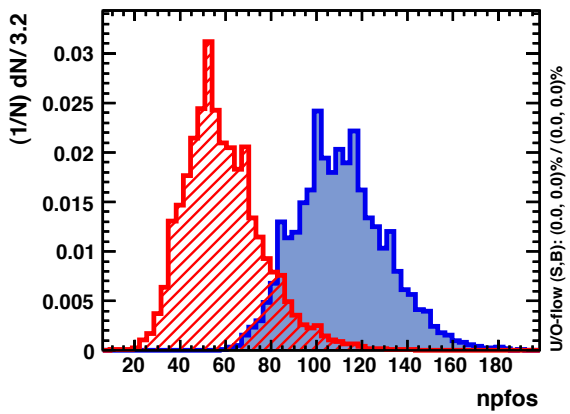


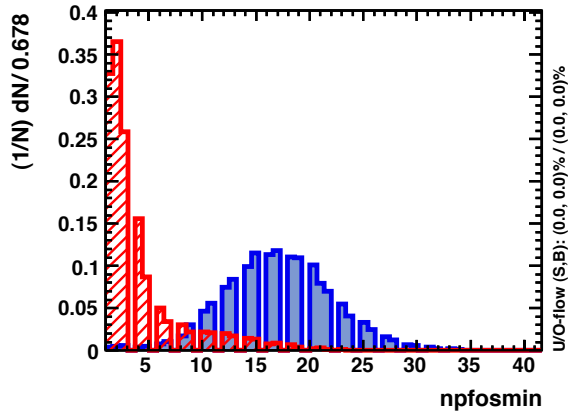


NN training: Input variables llbb vs llHH (3)

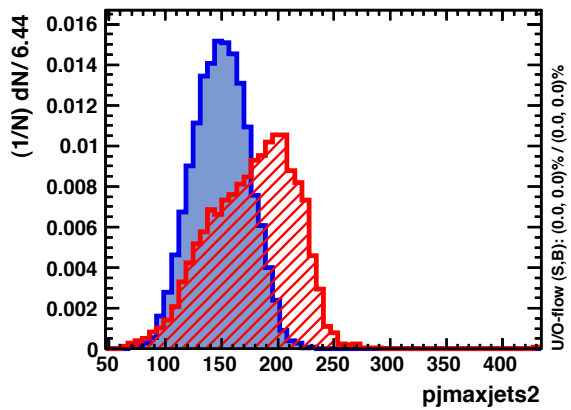
samples without overlay

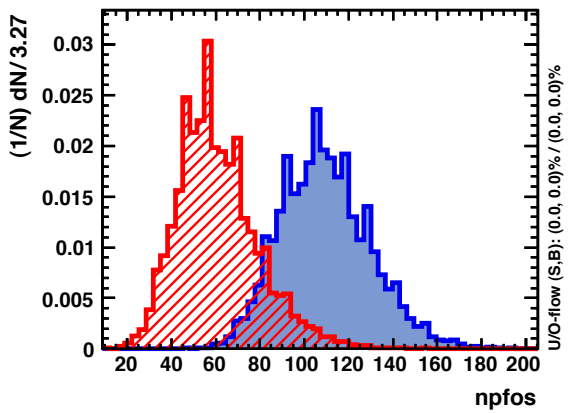


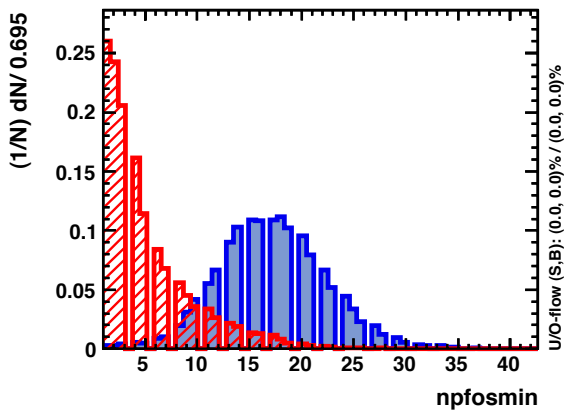




samples with overlay

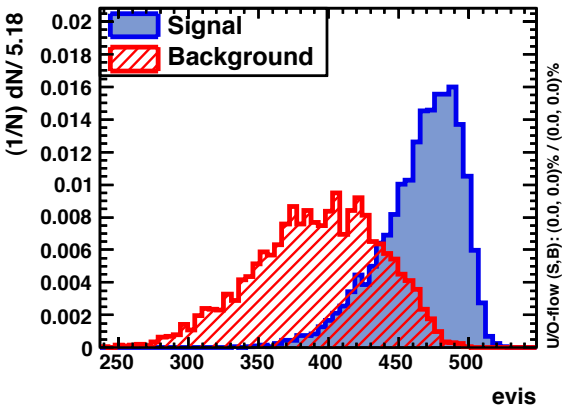


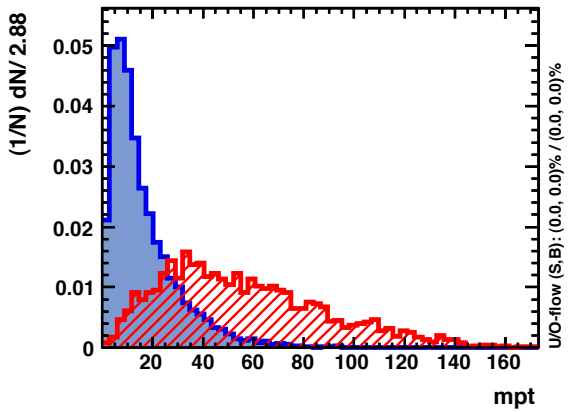


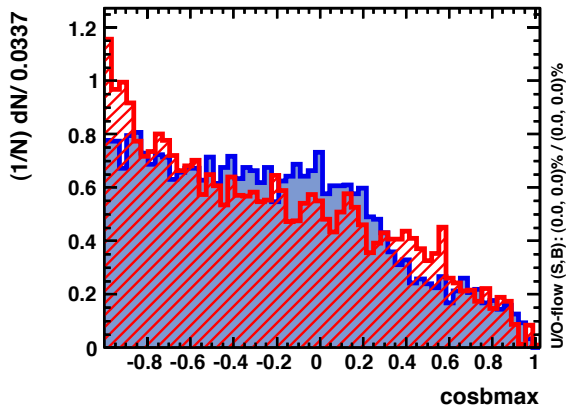


NN training: Input variables lvbbqq vs llHH (1)

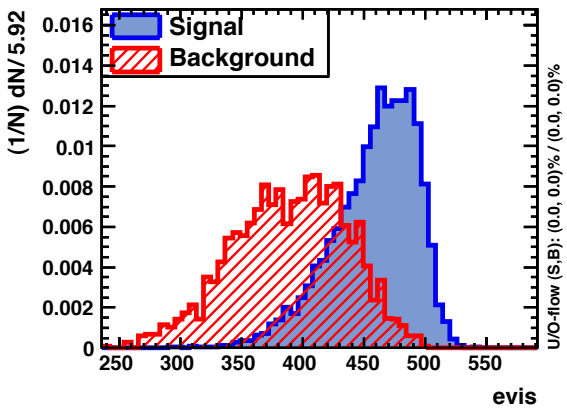
samples without overlay

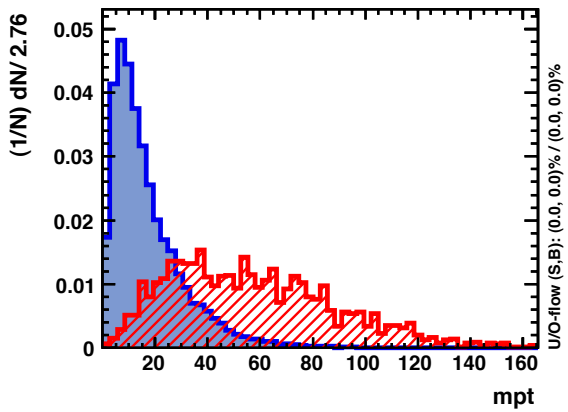


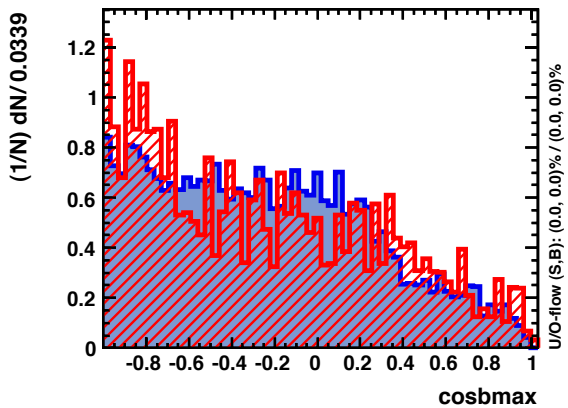




samples with overlay

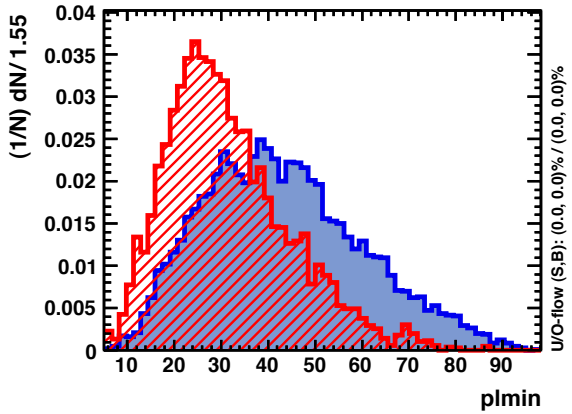


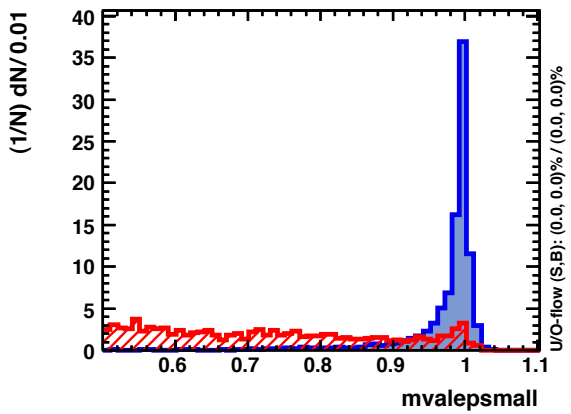


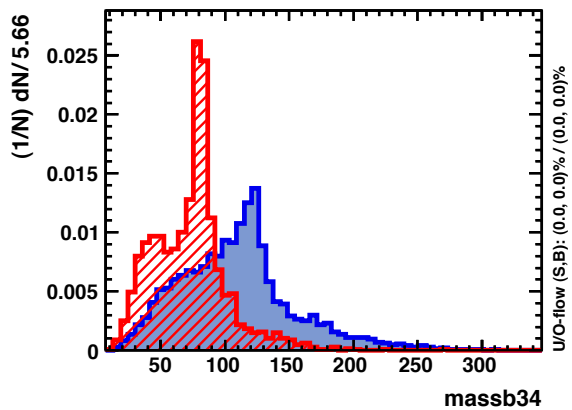


NN training: Input variables lvbbqq vs llHH (2)

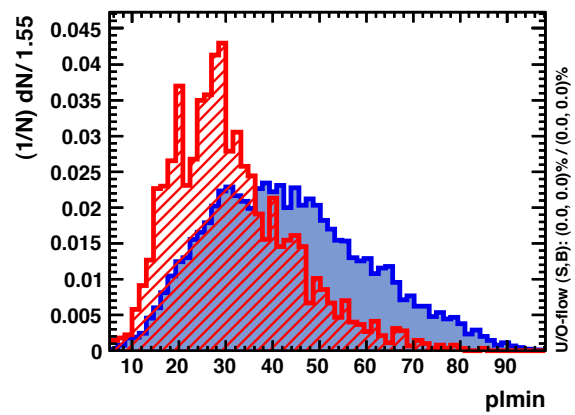
samples without overlay

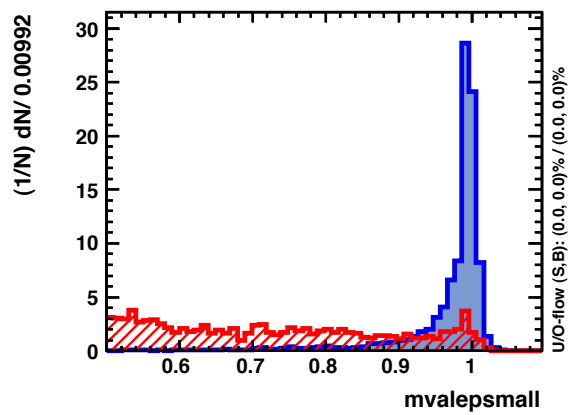


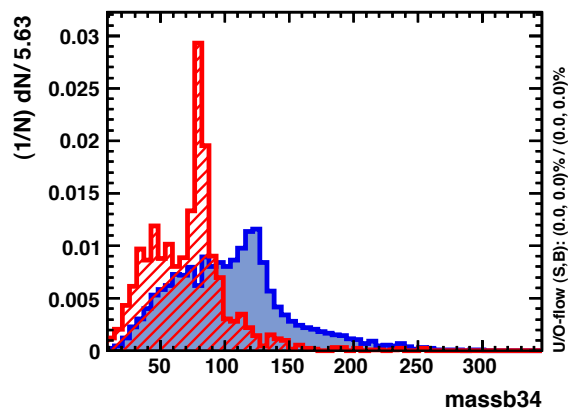




samples with overlay

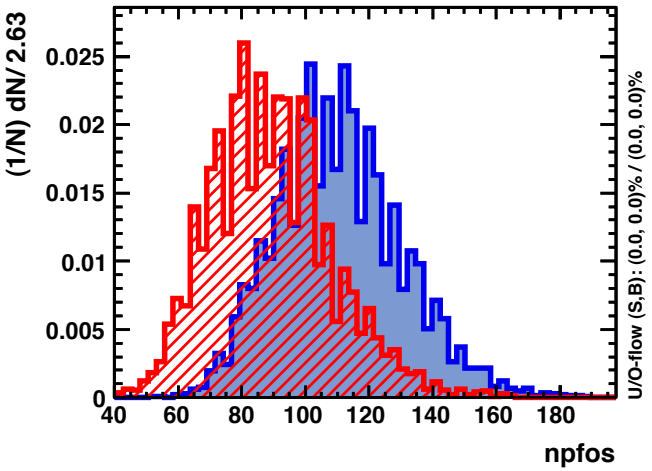


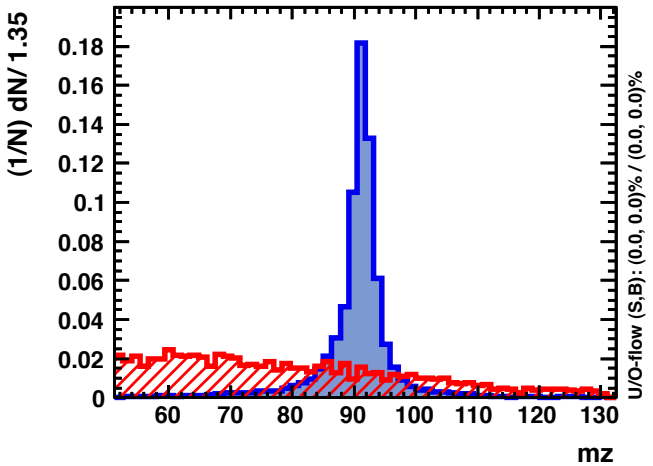




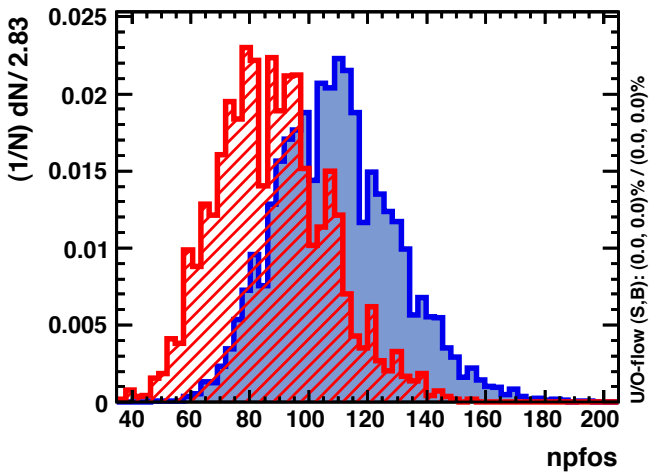
NN training: Input variables lvbbqq vs llHH (3)

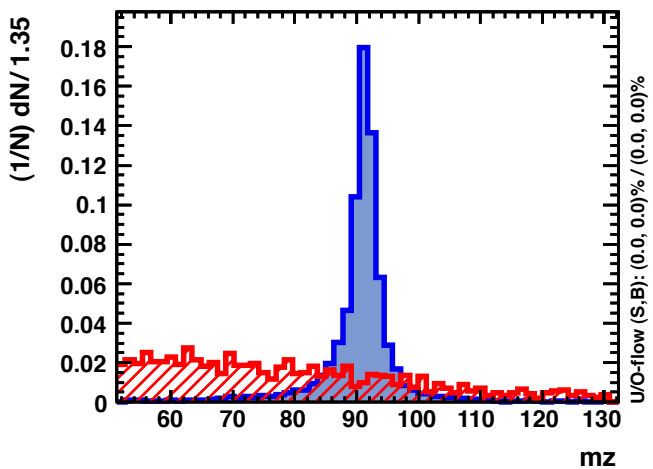
samples without overlay





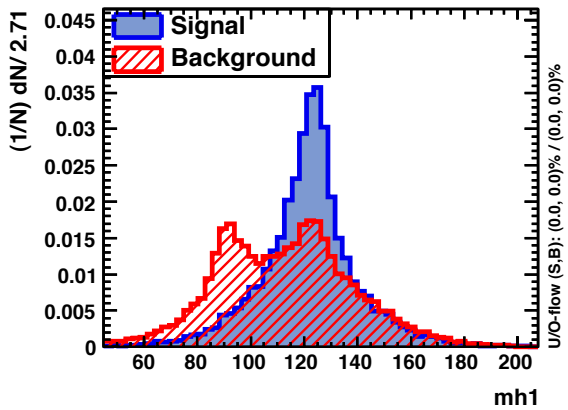
samples with overlay

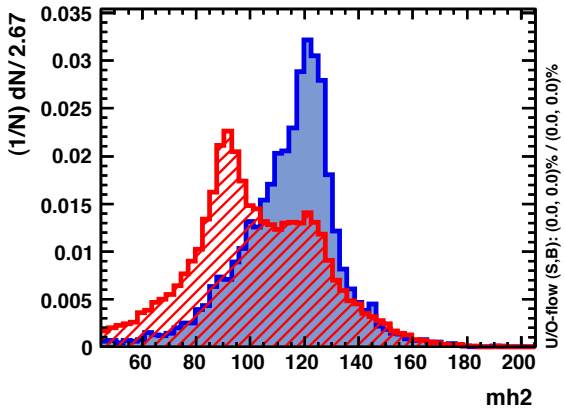


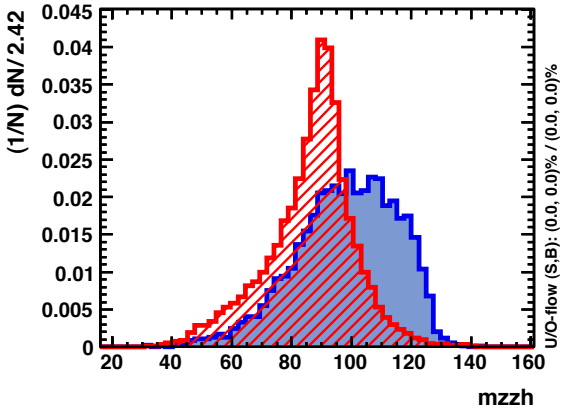


NN training: Input variables llbbbb/ZZH vs llHH (1)

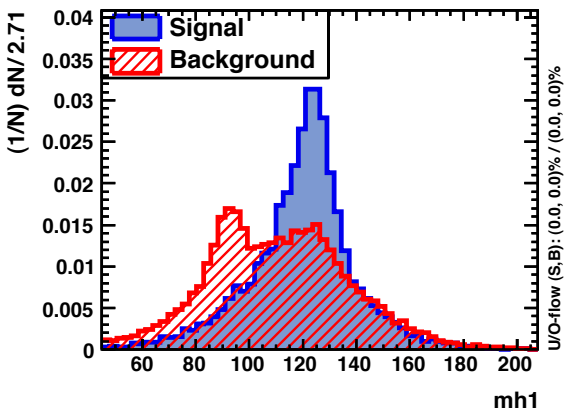
samples without overlay

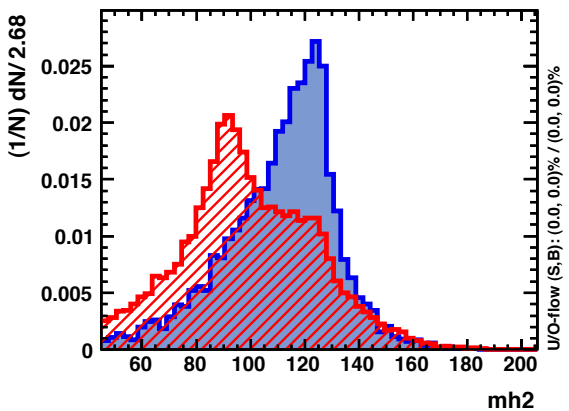


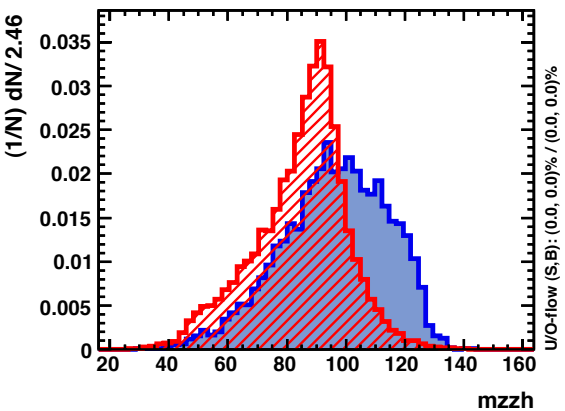




samples with overlay

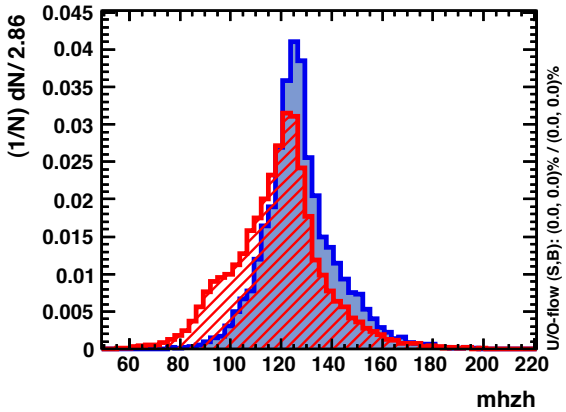


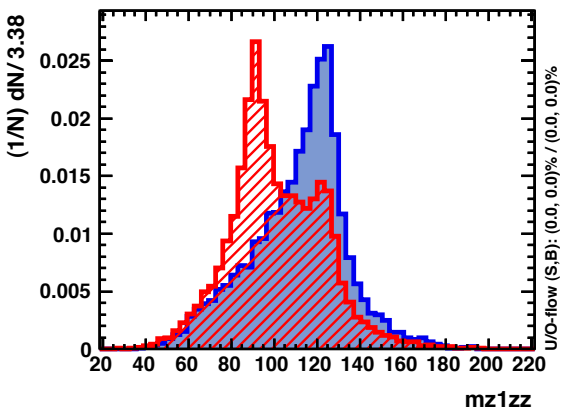


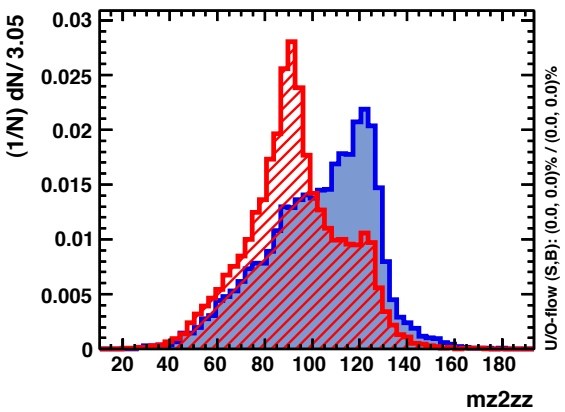


NN training: Input variables llbbbb/ZZH vs llHH (2)

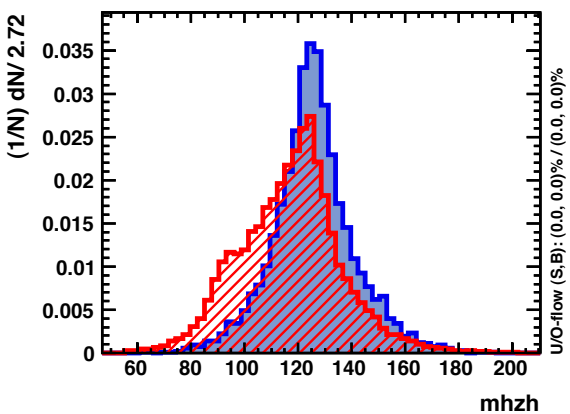
samples without overlay

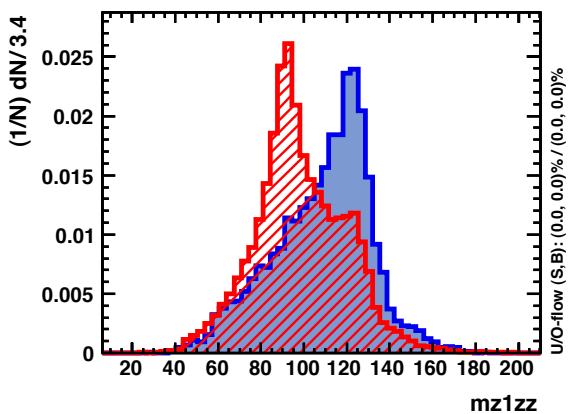


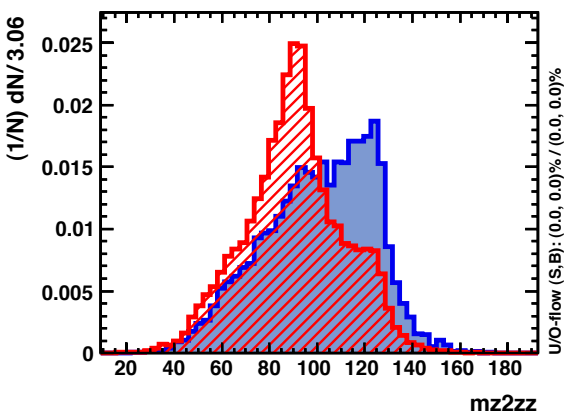




samples with overlay

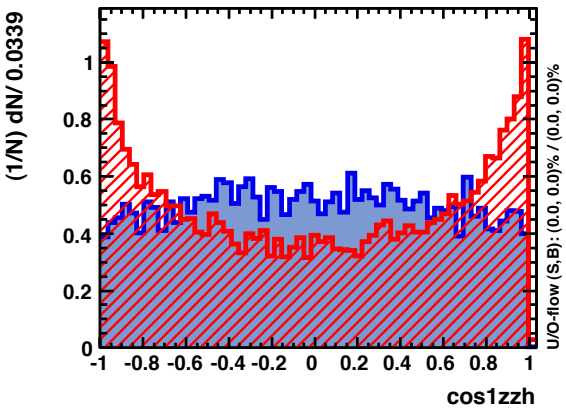


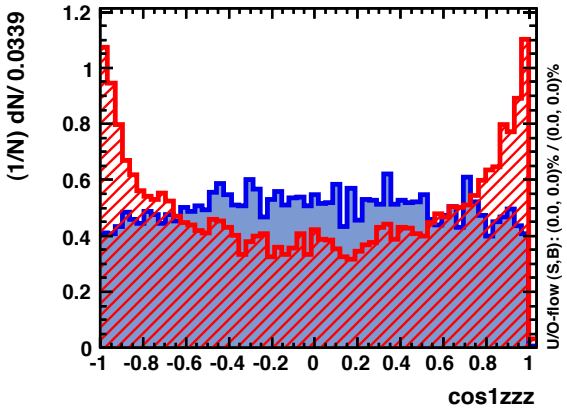


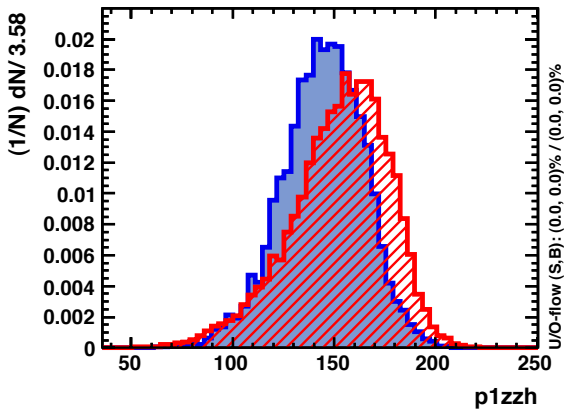


NN training: Input variables llbbbb/ZZH vs llHH (3)

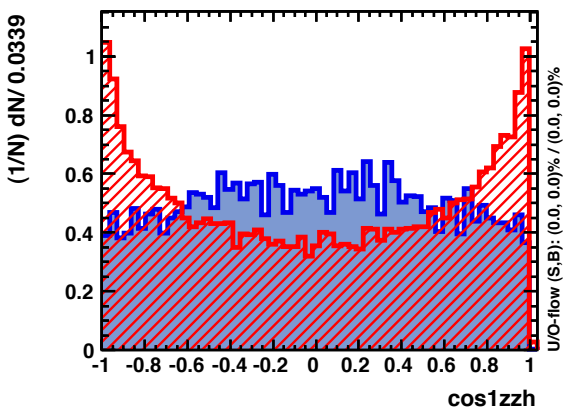
samples without overlay

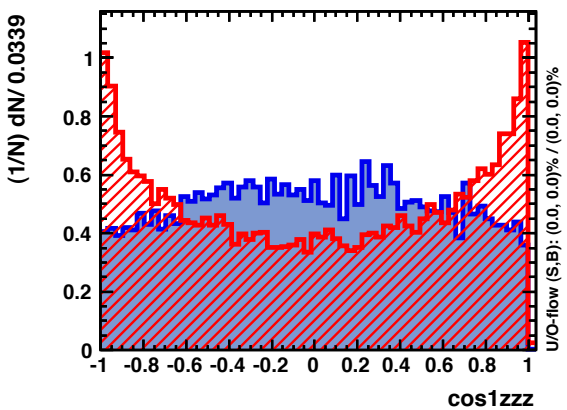


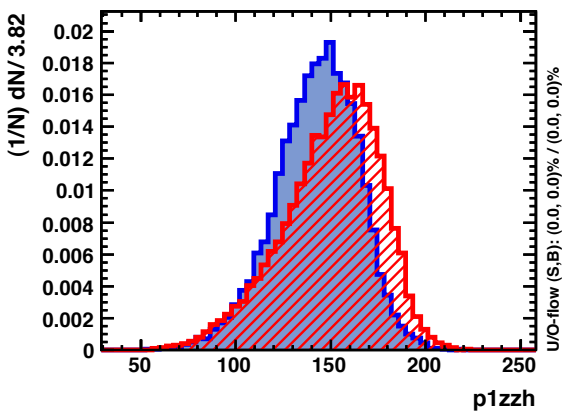




samples with overlay

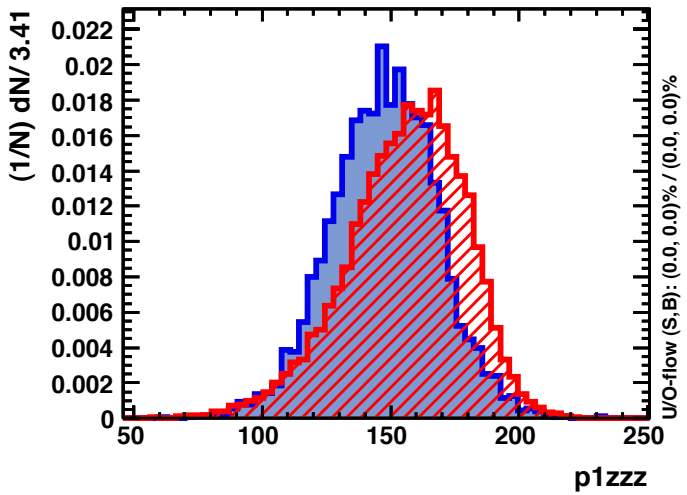




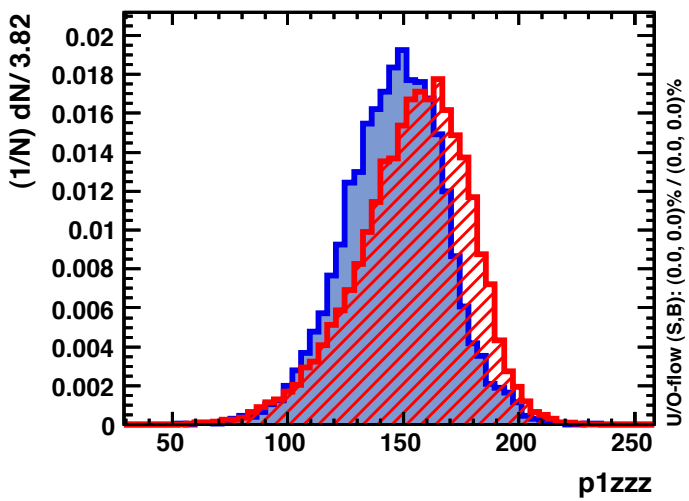


NN training: Input variables llbbbb/ZZH vs llHH (4)

samples without overlay

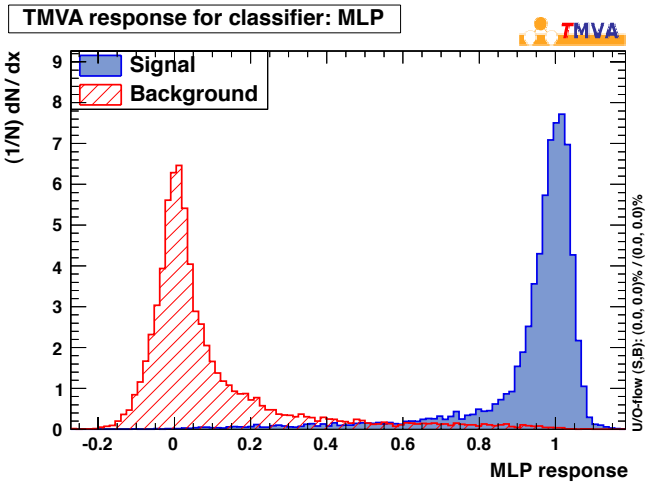


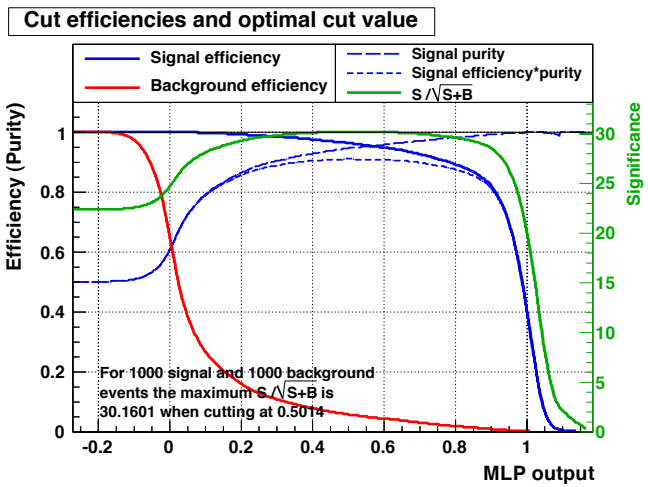
samples with overlay



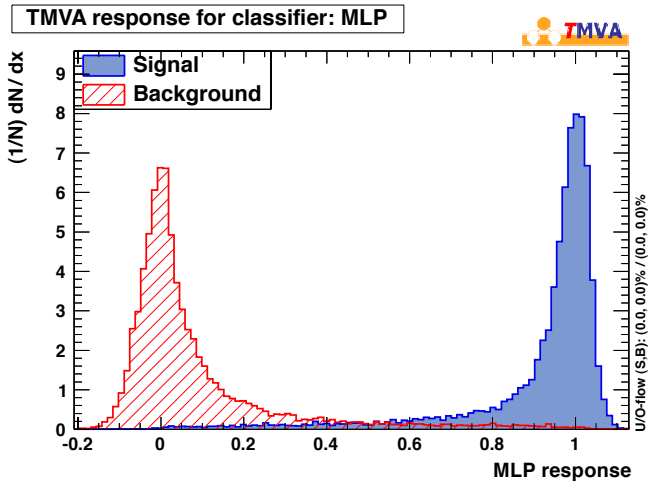
Neural Net training: bbbb vs. $\nu\nu$HH

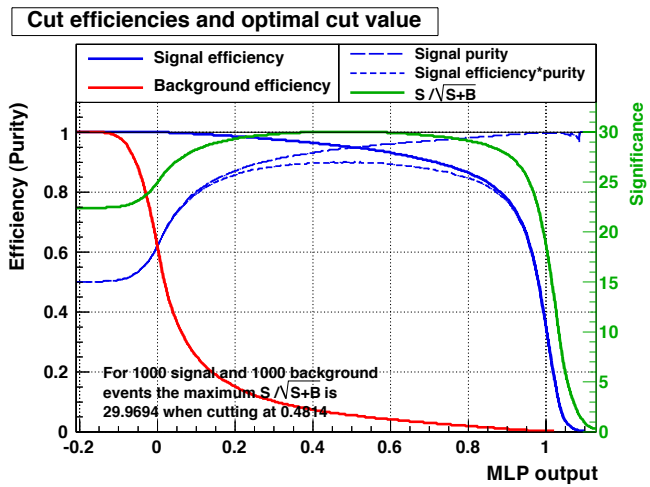
samples without overlay





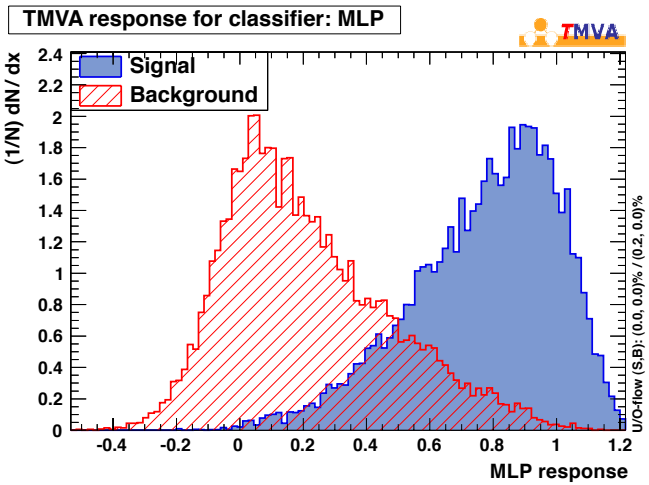
samples with overlay

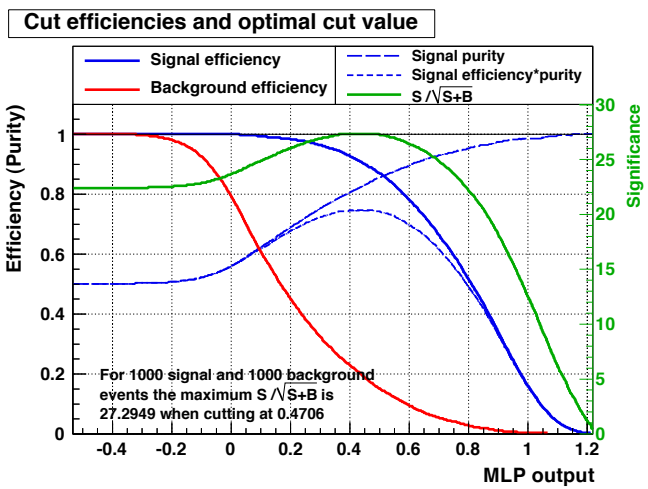




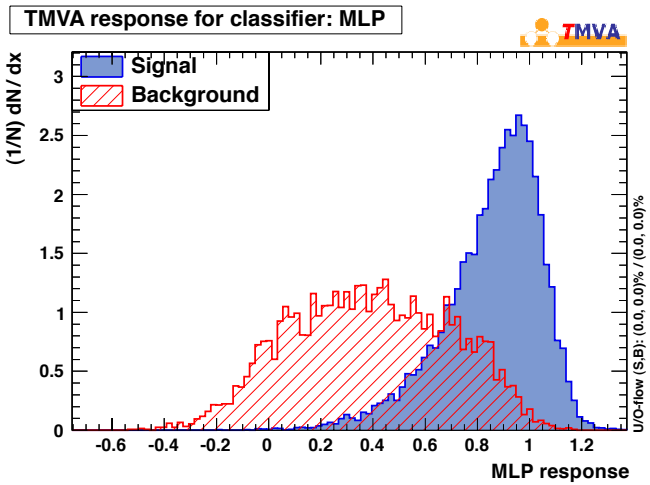
Neural Net training: lvbbqq vs. $\nu\nu$HH

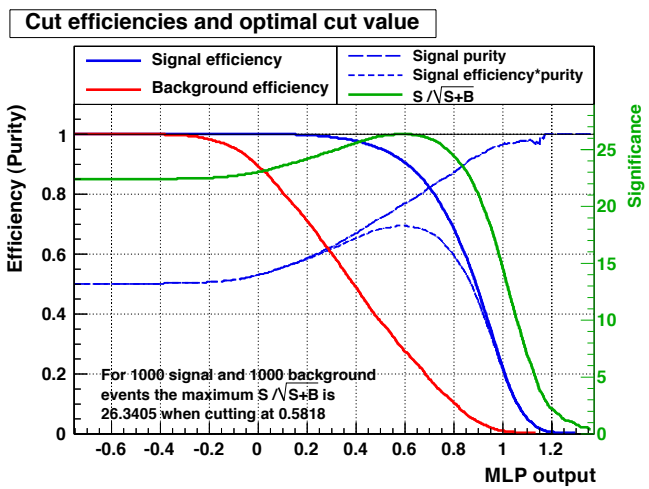
samples without overlay





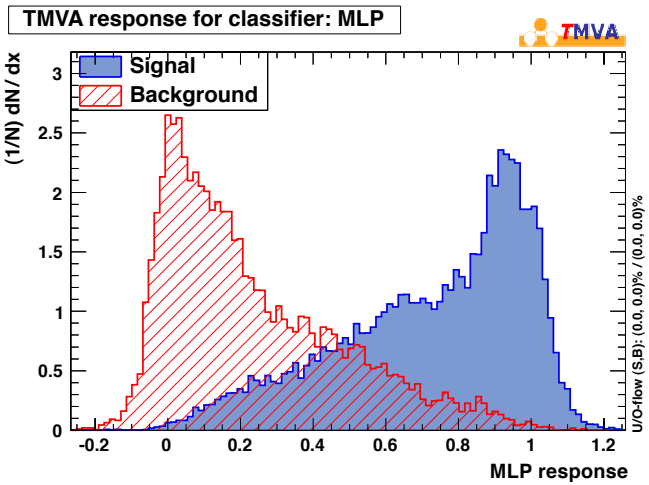
samples with overlay

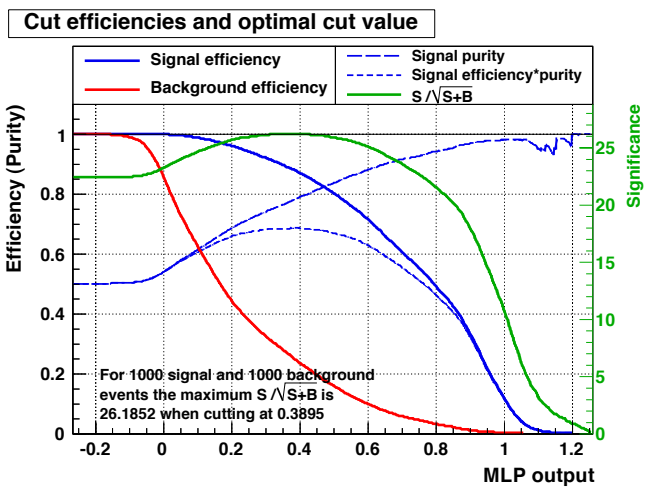




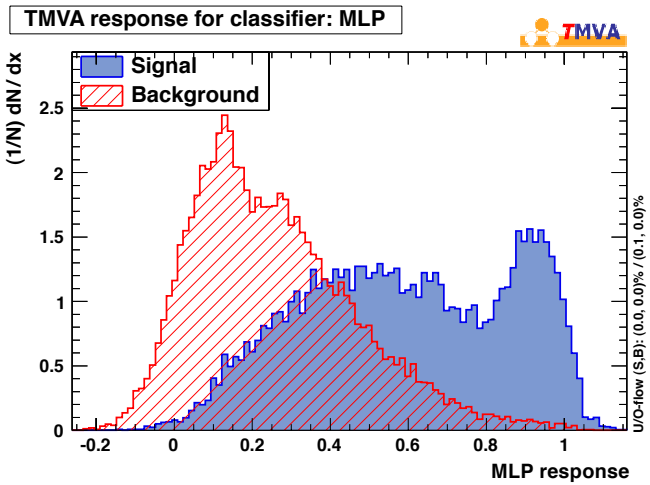
Neural Net training: ZZZ/ZZH vs. $\nu\nu$HH

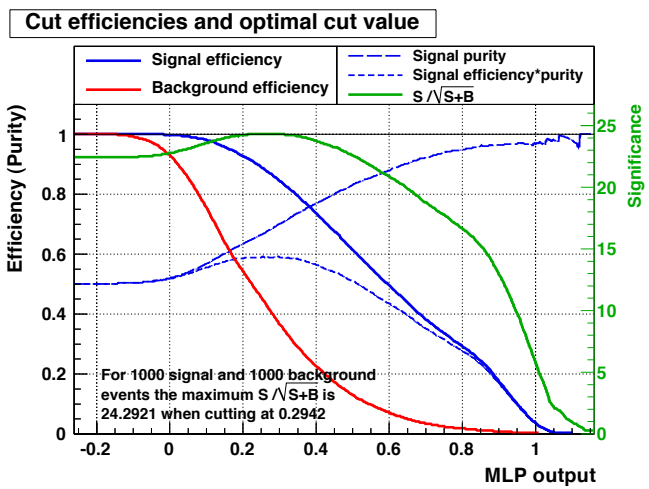
samples without overlay





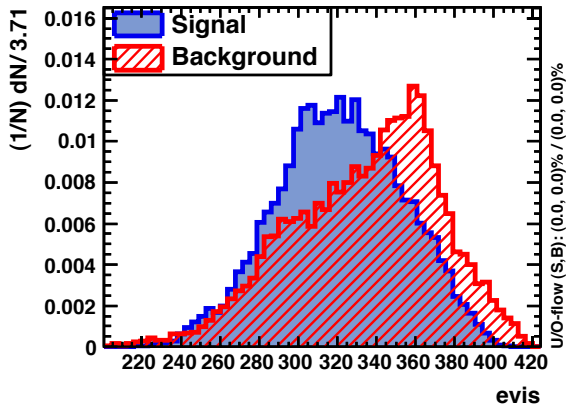
samples with overlay

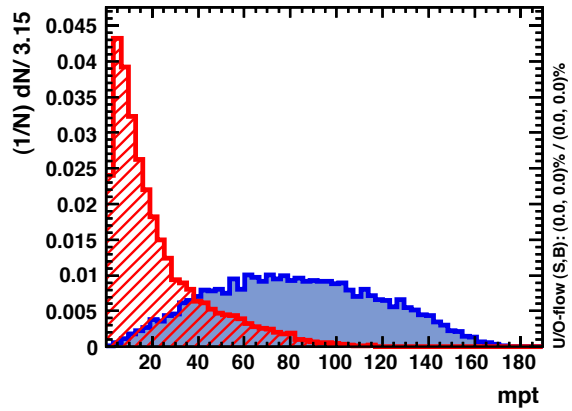


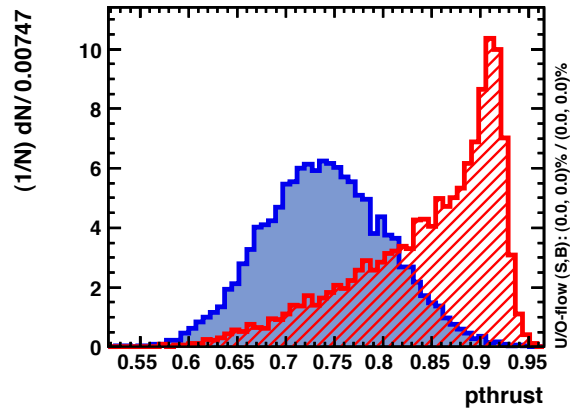


NN training: Input variables bbbb vs vvHH (1)

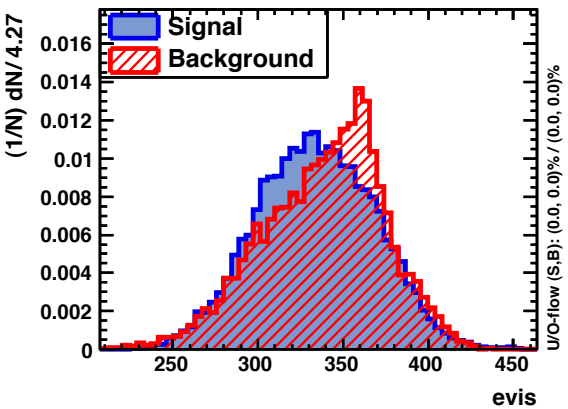
samples without overlay

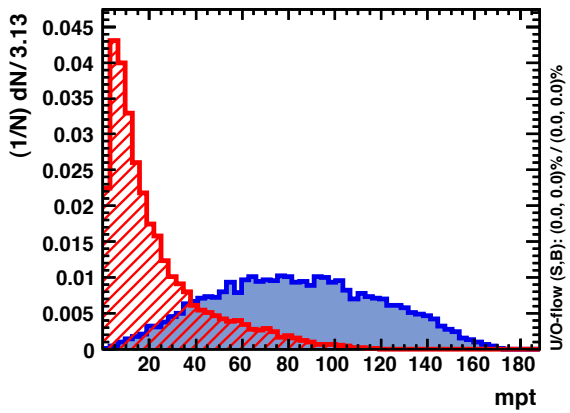


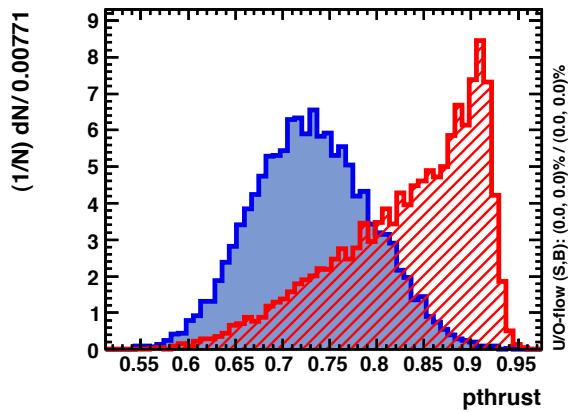




samples with overlay

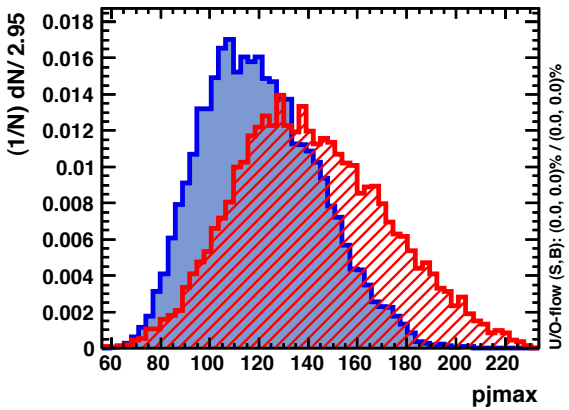


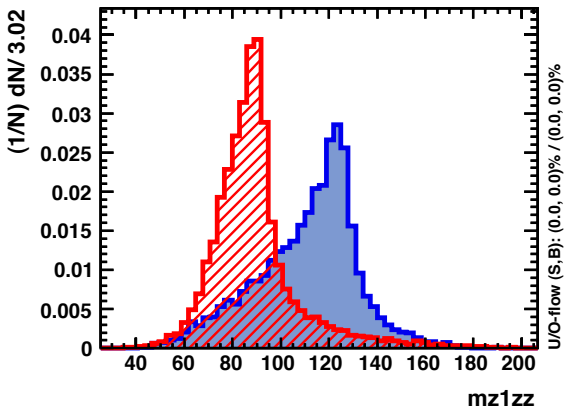


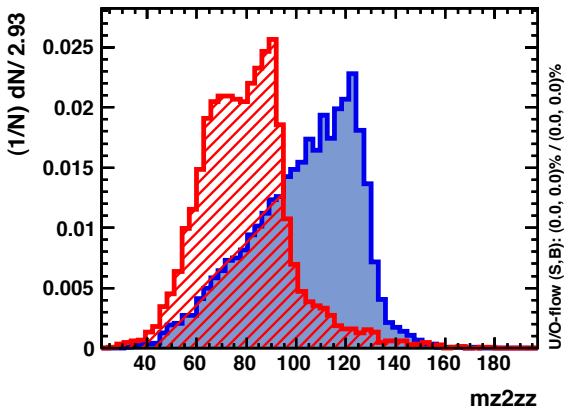


NN training: Input variables bbbb vs vvHH (2)

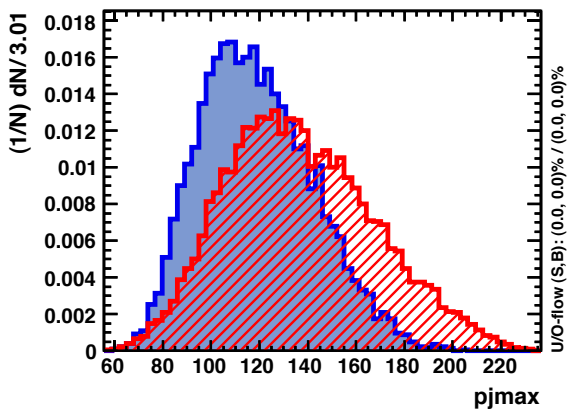
samples without overlay

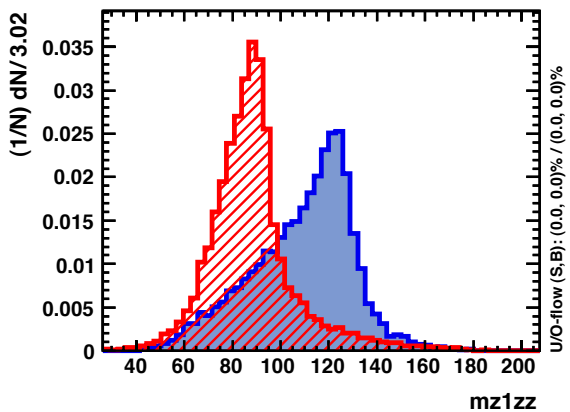


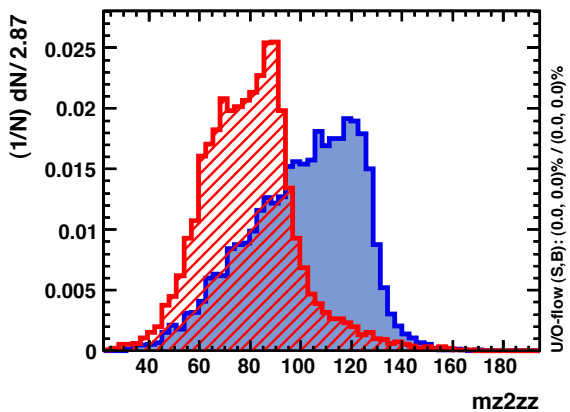




samples with overlay

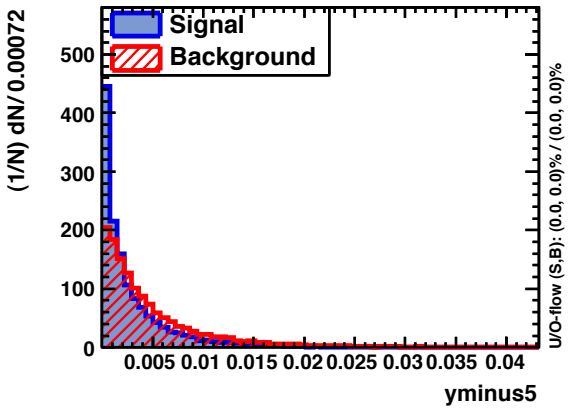


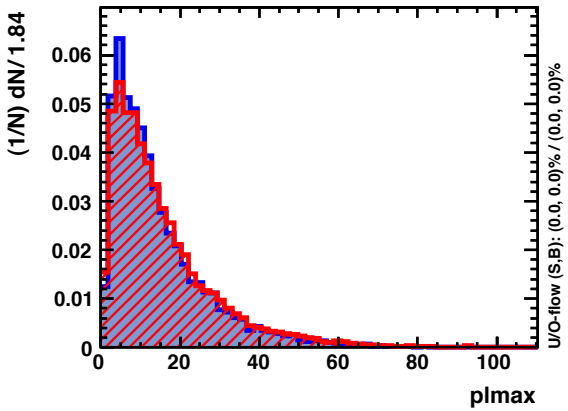


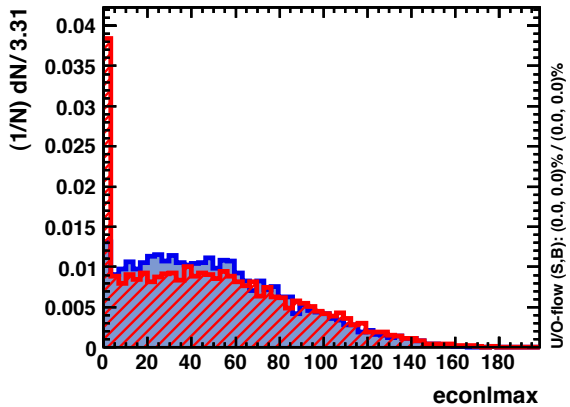


NN training: Input variables lvbbqq vs vvHH (1)

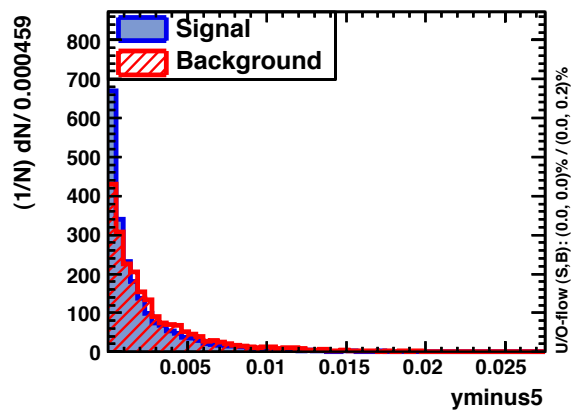
samples without overlay

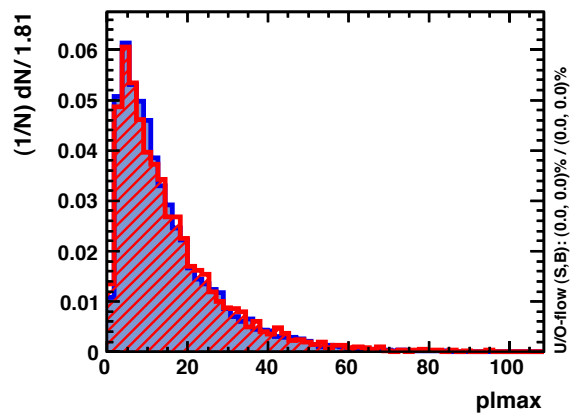


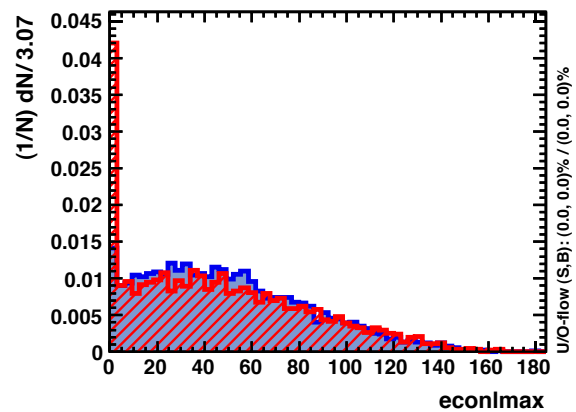




samples with overlay

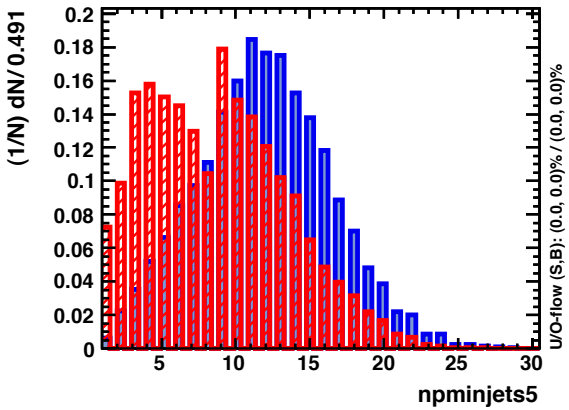


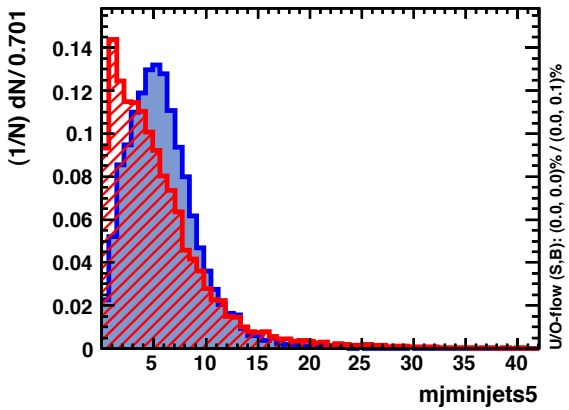


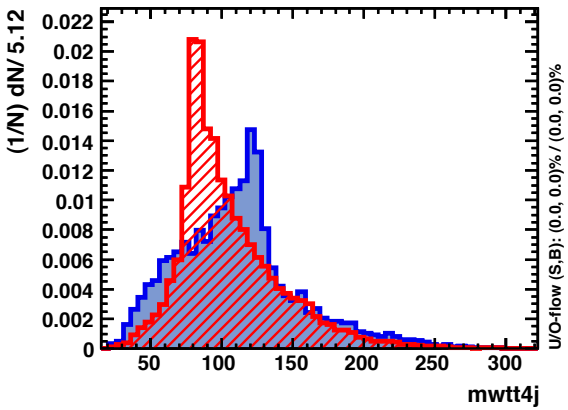


NN training: Input variables lvbbqq vs vvHH (2)

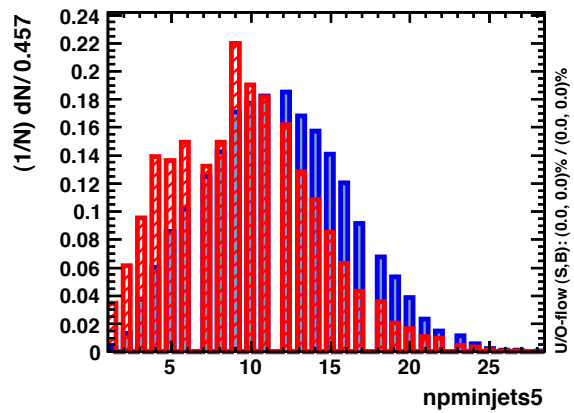
samples without overlay

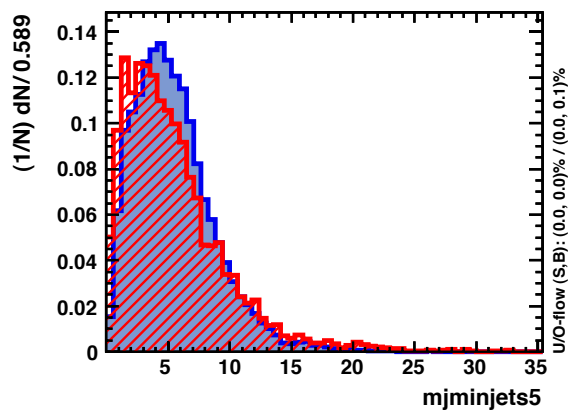


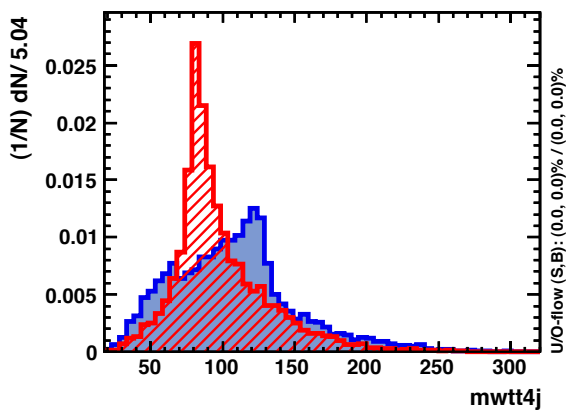




samples with overlay

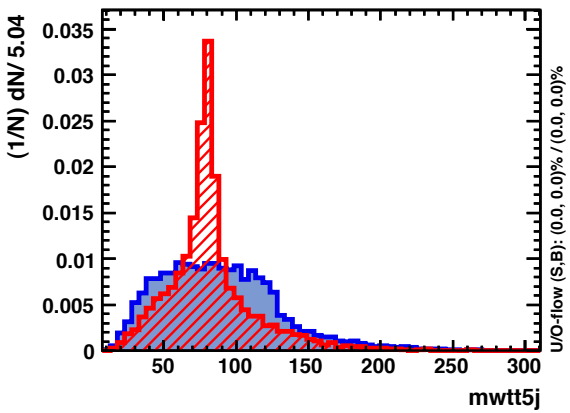


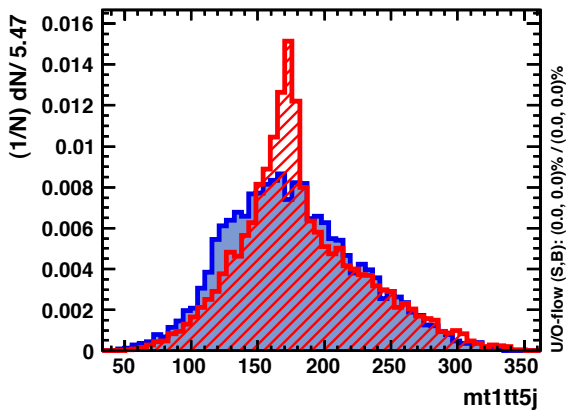


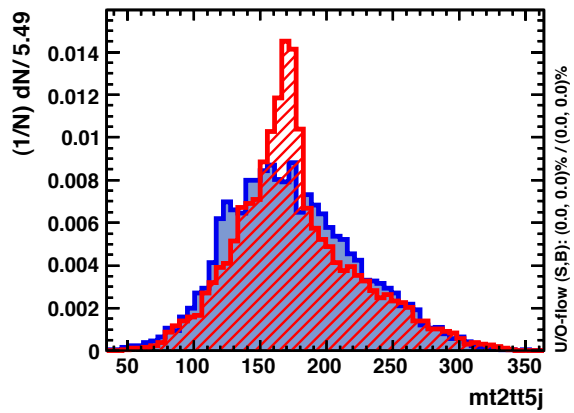


NN training: Input variables lvbbqq vs vvHH (3)

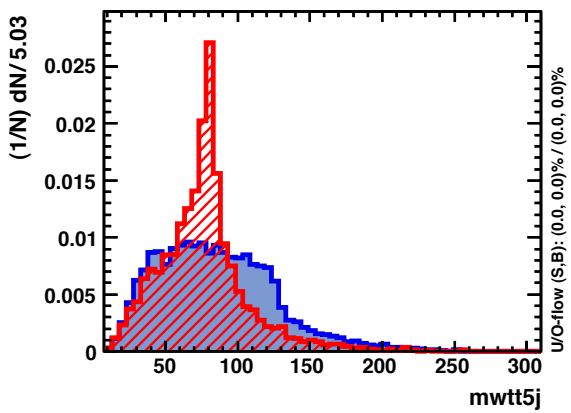
samples without overlay

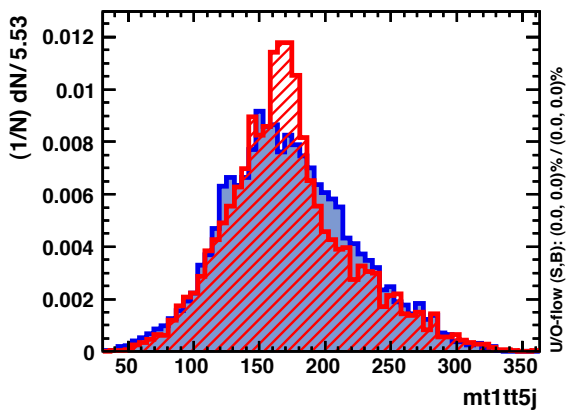


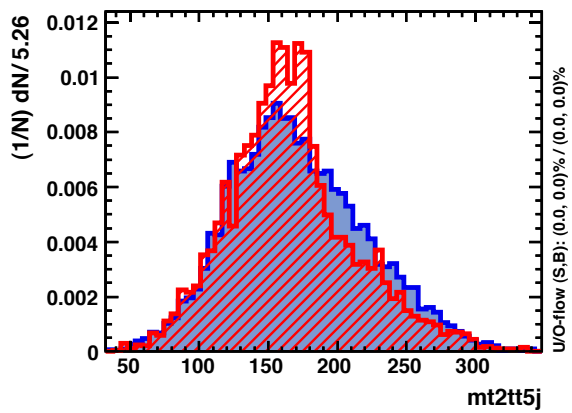




samples with overlay

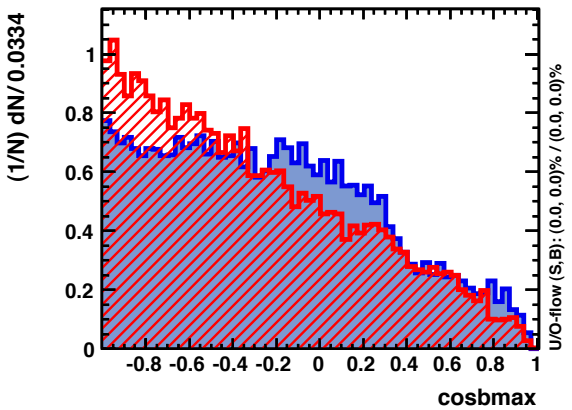


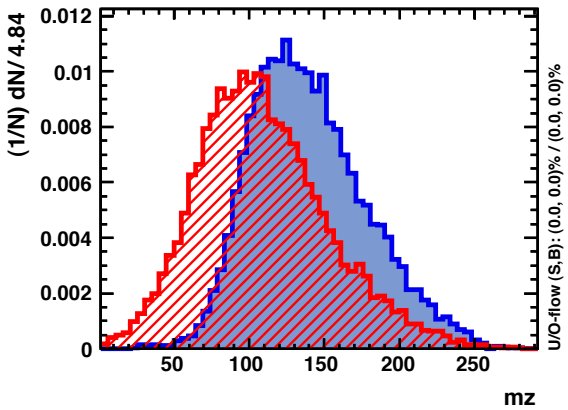


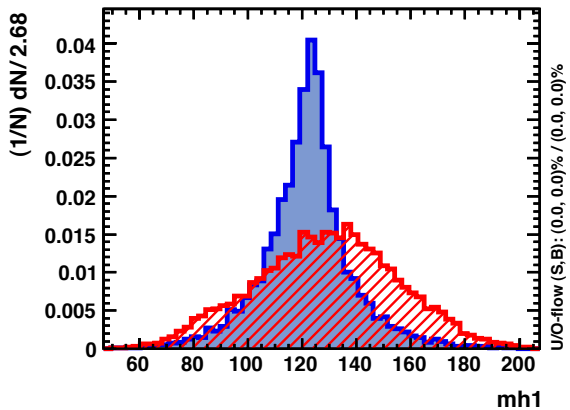


NN training: Input variables lvbbqq vs vvHH (4)

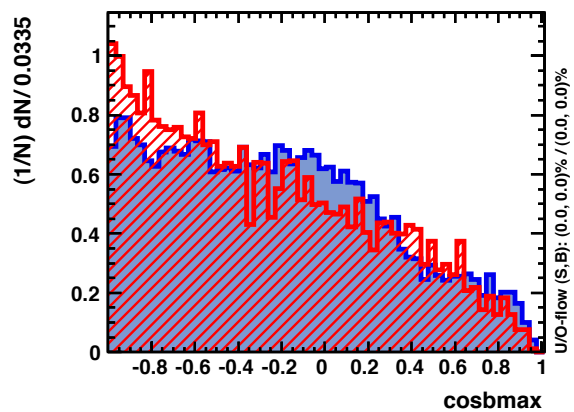
samples without overlay

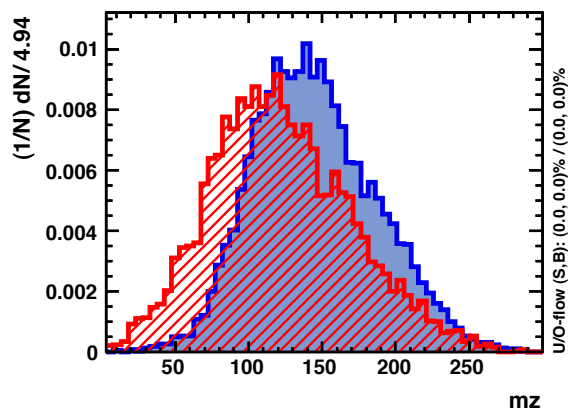


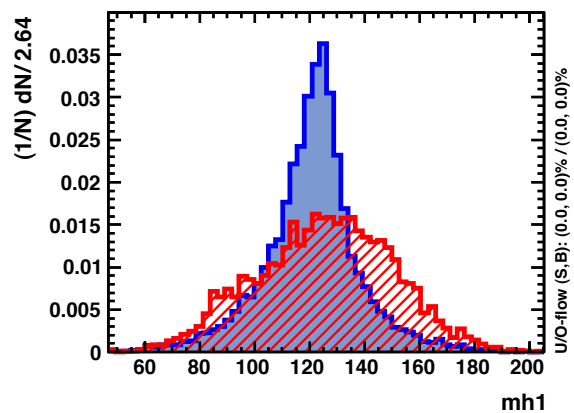




samples with overlay

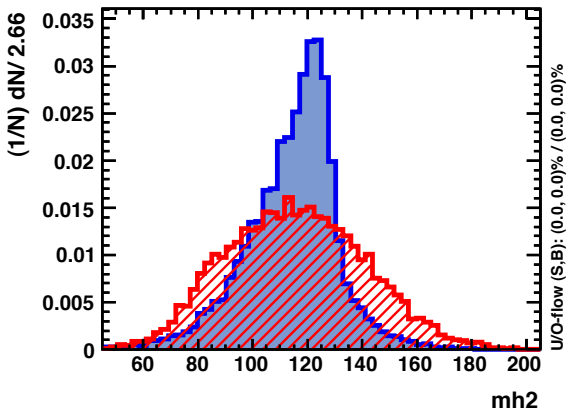


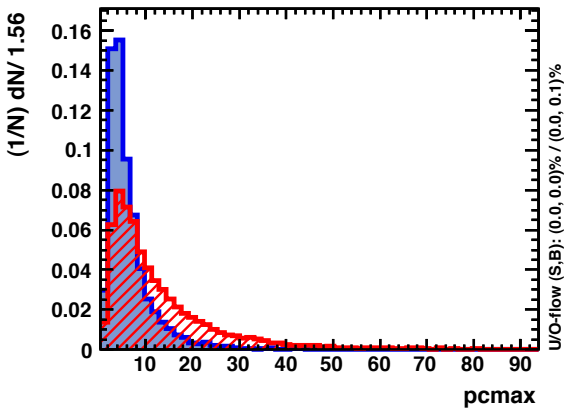


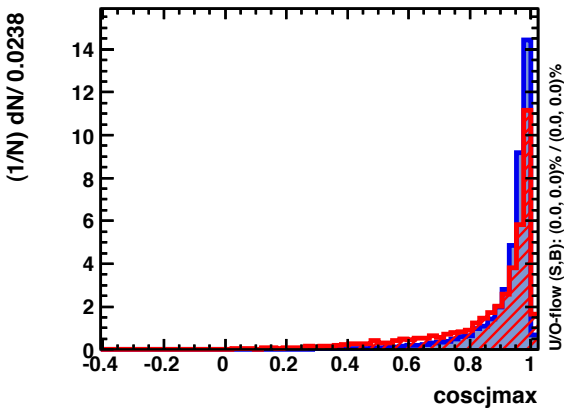


NN training: Input variables lvbbqq vs vvHH (5)

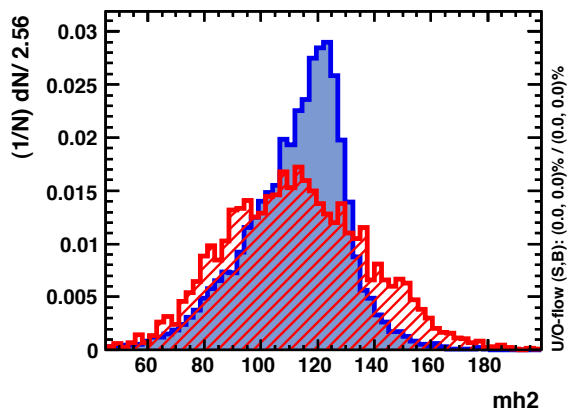
samples without overlay

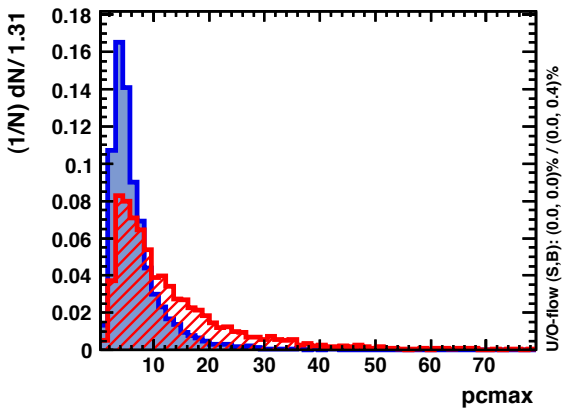


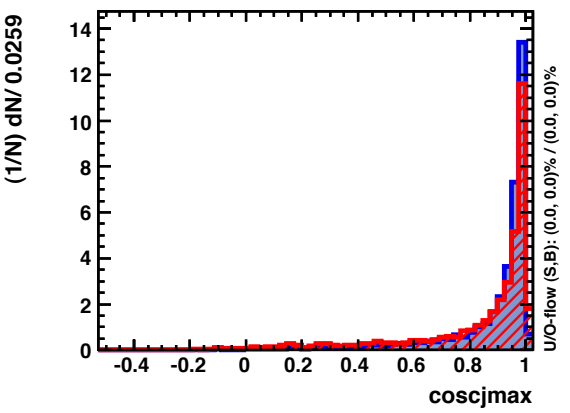




samples with overlay

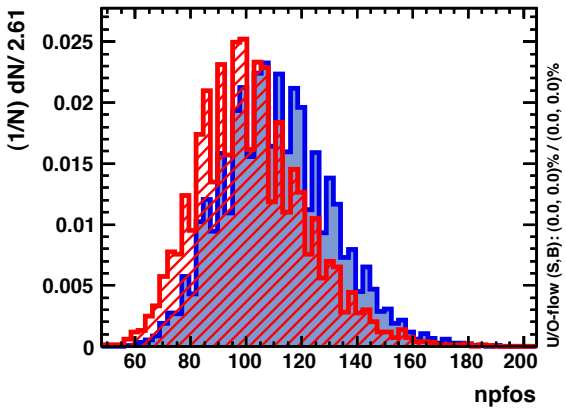




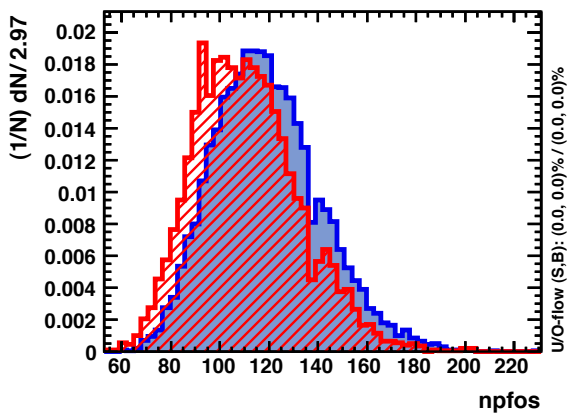


NN training: Input variables lvbbqq vs vvHH (6)

samples without overlay

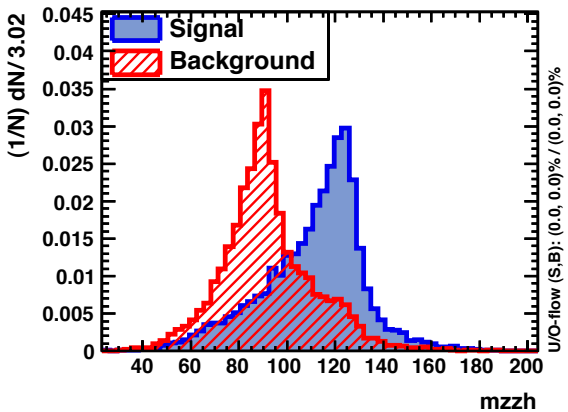


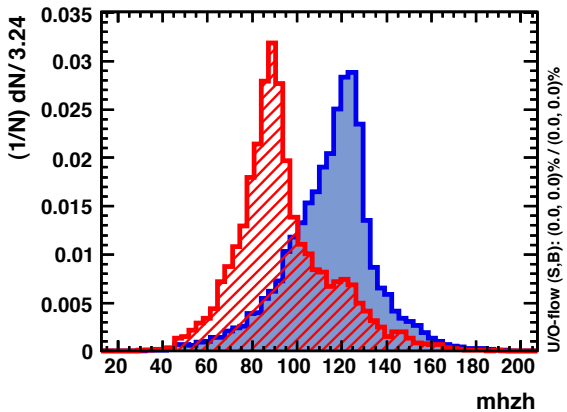
samples with overlay

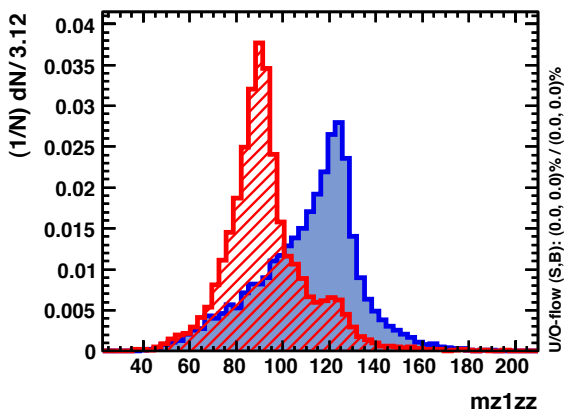


NN training: Input variables ZZZ/ZZH vs vvHH (1)

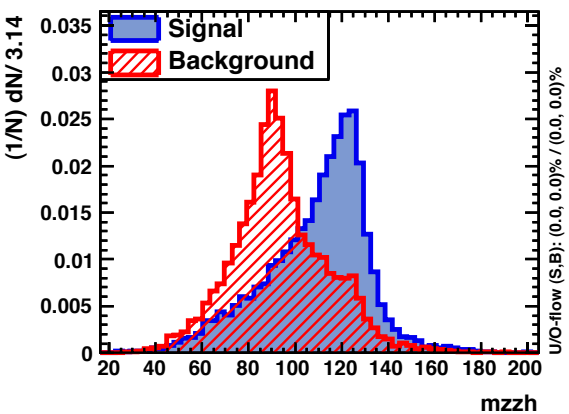
samples without overlay

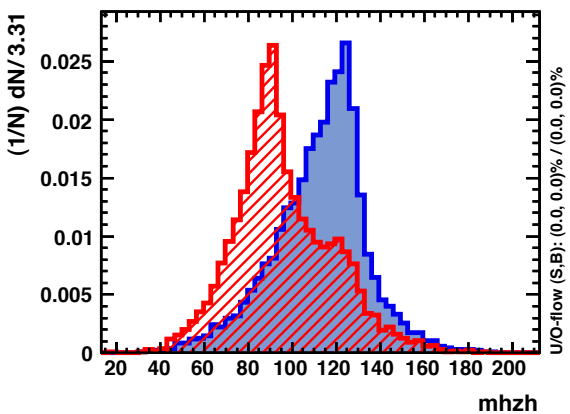


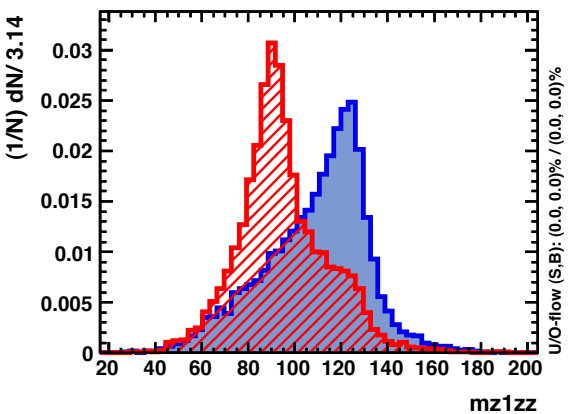




samples with overlay

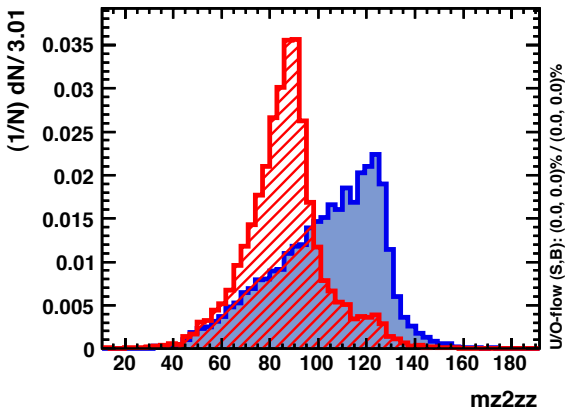


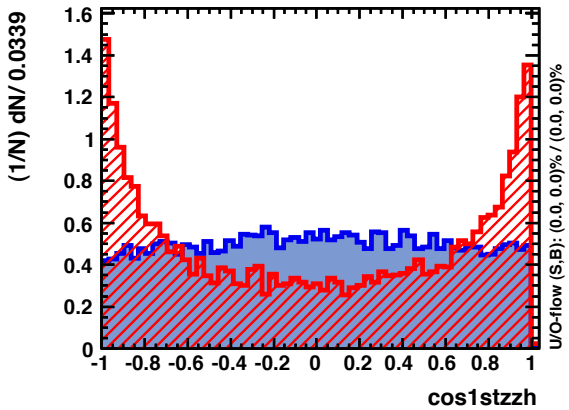


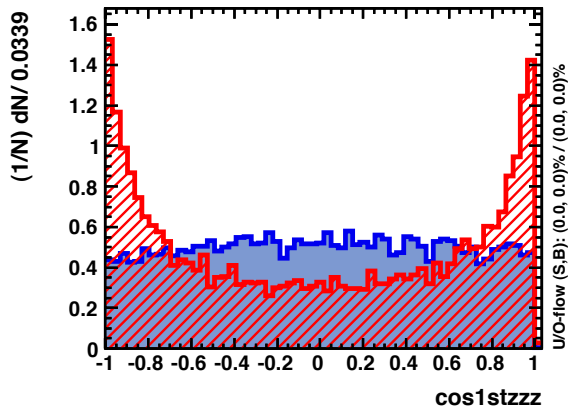


NN training: Input variables ZZZ/ZZH vs vvHH (2)

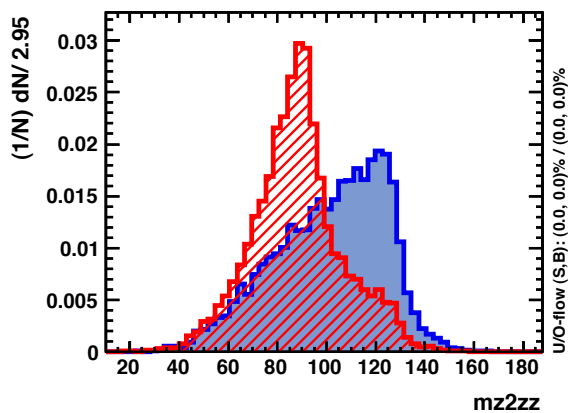
samples without overlay

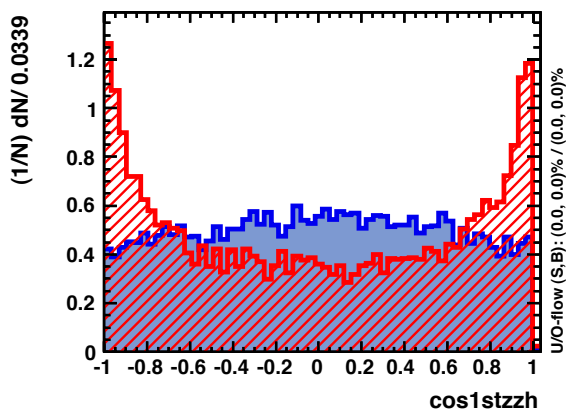


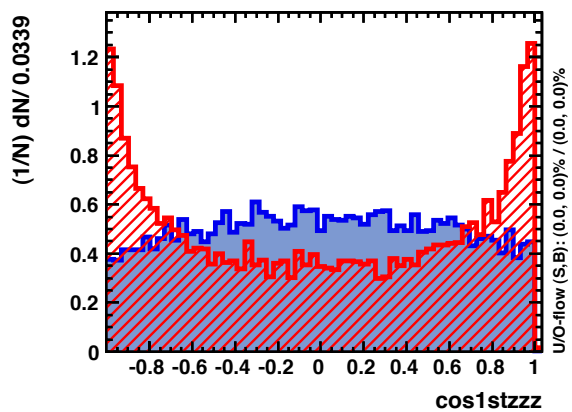




samples with overlay

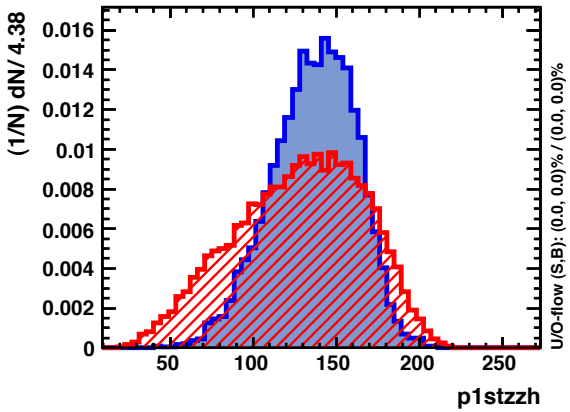


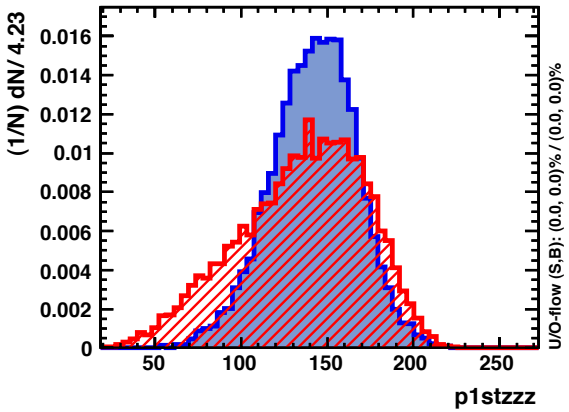




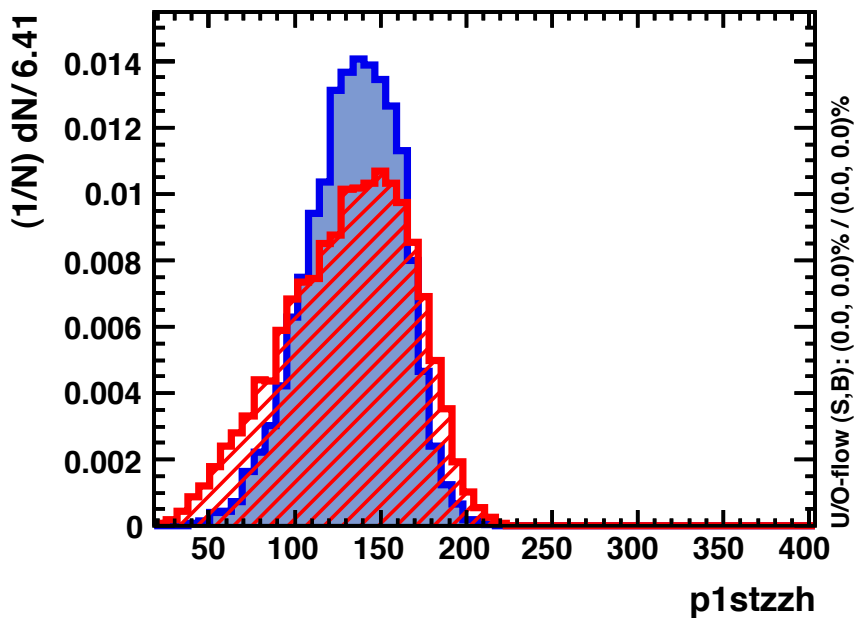
NN training: Input variables ZZZ/ZZH vs vvHH (3)

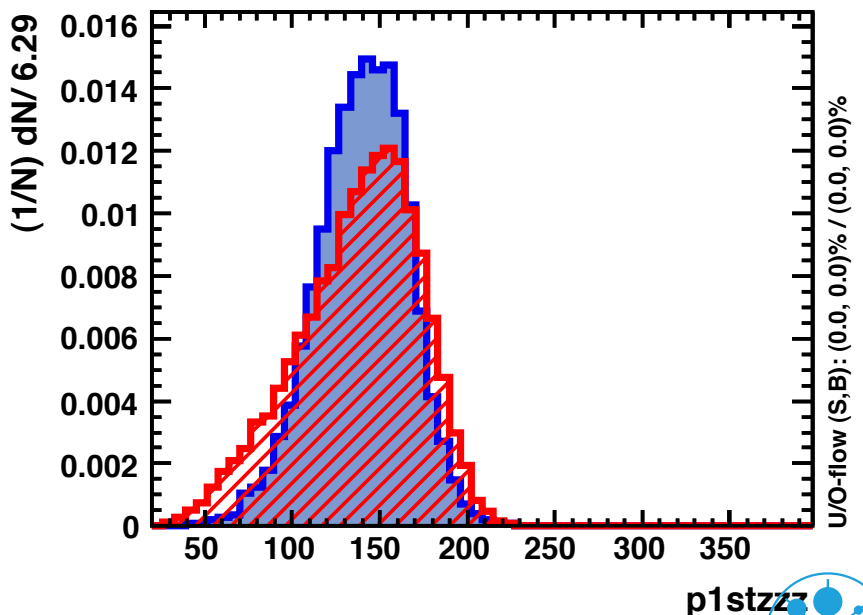
samples without overlay



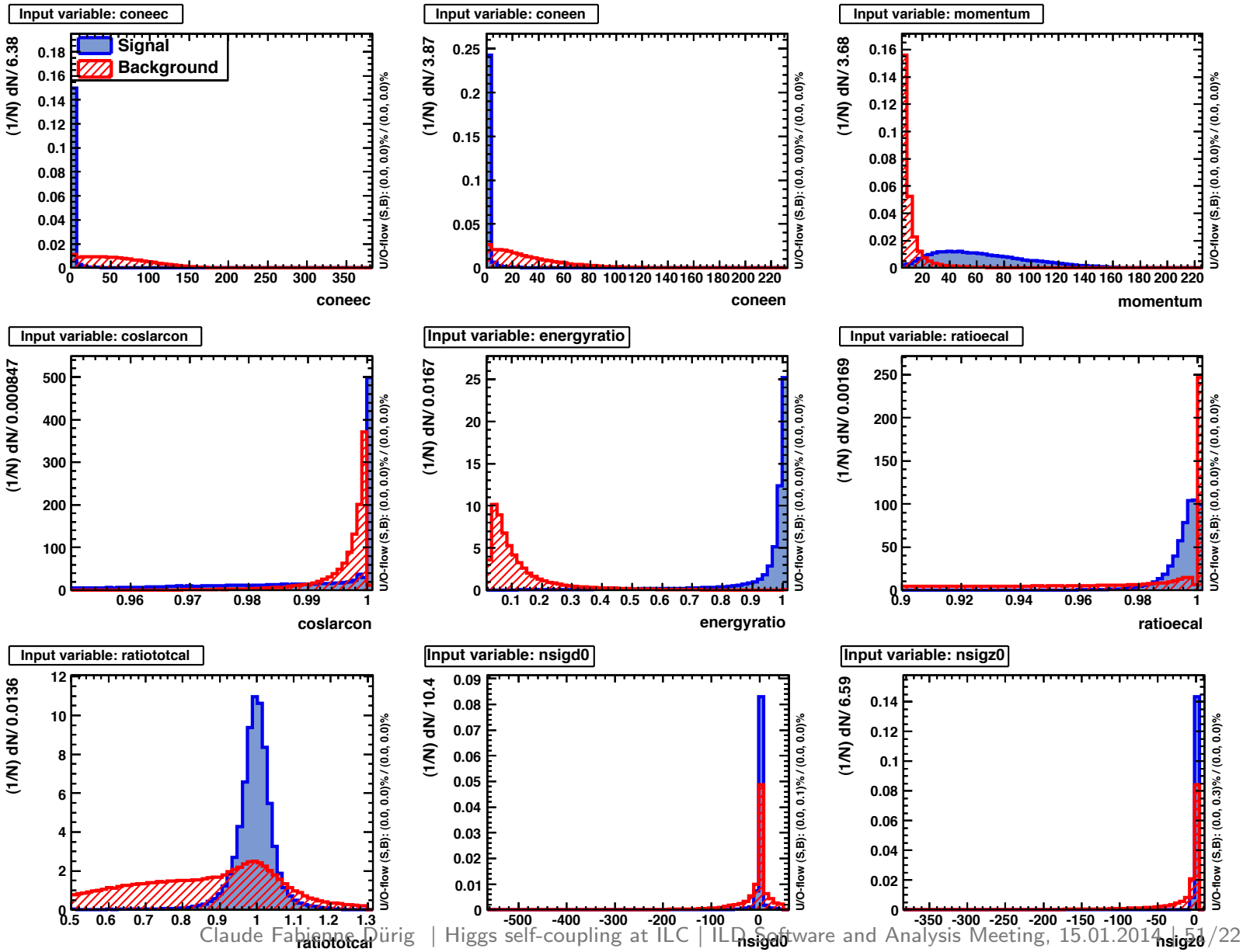


samples with overlay





New DiLeptonSelection: NN training - Electrons



New DiLeptonSelection: NN training - Muons