

Analysis of $H \rightarrow ZZ^*$

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Outline

- update on $ZZZ^* \rightarrow \nu\nu\mu\mu jj / \nu\nu jj\mu\mu$
- Current states of $H \rightarrow ZZ^*$ analysis

Current state

SM background : fastsimulation

ZZZ*	Yield	Object reconstructed	Signal Efficiency(%)	Main Background	Accuracy (%)	Comments
$\mu\mu\nu\nu q\bar{q}$	128	118	63.3	$h \rightarrow ww\&zz_sl$	12.9	Need a tau finder to increase the accuracy
$\mu\mu q\bar{q}\nu\nu$	128	125	-	$h \rightarrow bb\&zz_sl$	>25	
$e e\nu\nu q\bar{q}$	132	91	53.8	$h \rightarrow ww\&sz e_sl$	15.8	reconstructed efficiency of electron need to be improved
$e e q\bar{q}\nu\nu$	132	88	-	$h \rightarrow bb\&zz_sl$	>25	
$\nu\nu\mu\mu q\bar{q}$	152	121	61.4	$h \rightarrow t,w\&zz_sl$	11.0	
$\nu\nu q\bar{q}\mu\mu$	152	123	51.9	$h \rightarrow w,b\&zz_sl$	12.9	
$\nu\nu e e q\bar{q}$	151	118	43.1	$h \rightarrow w\&sz e_sl$	21.3	
$\nu\nu q\bar{q} e e$	151	134	-	$h \rightarrow bb\&sz e_sl$	>25	
$q\bar{q}\mu\mu\nu\nu$	135	115	-	$h \rightarrow tt\&zz_sl$	>25	Comparing to leptons&higgs channel,qq recoil mass couldn't offer enough distinguishing power to SM
$q\bar{q}\nu\nu\mu\mu$	135	122	-	$h \rightarrow t,w\&zz_sl$	>25	
$q\bar{q} e e\nu\nu$	127	107	-	$h \rightarrow tt\&sz e_sl$	>25	
$q\bar{q}\nu\nu e e$	127	123	-	$h \rightarrow t,w\&sz e_sl$	>25	
$\mu\mu\mu\mu q\bar{q}/q\bar{q}\mu\mu$	43	39	69.8	$h \rightarrow tt\&zz_sl$	19.9	Need a tau finder to increase the accuracy
$\mu\mu e e q\bar{q}/q\bar{q} e e$	43	39	60.5	$h \rightarrow tt\&zz_sl$	21.2	
$e e e e q\bar{q}/e e q\bar{q} e e$	43	33	-	$h \rightarrow tt\&sz e_sl$	>25	reconstructed efficiency of electron need to be
$e e \mu\mu q\bar{q}/e e q\bar{q}\mu\mu$	43	41	58.2	$h \rightarrow tt\&sz e_sl$	19.9	

pre-selection

objective-selection

Criteria Category	<i>vvH(VBF)</i>	<i>zz</i>	<i>zzorww</i>	<i>ww</i>
<i>Cut1</i>	216589	1482901	1536787	20434288
<i>Cut2</i>	216558	1335573	1422687	17251027
<i>Cut3</i>	199791	1081199	865073	1447307
<i>Efficiency</i>	82.40%	18.93%	4.81%	3.23%

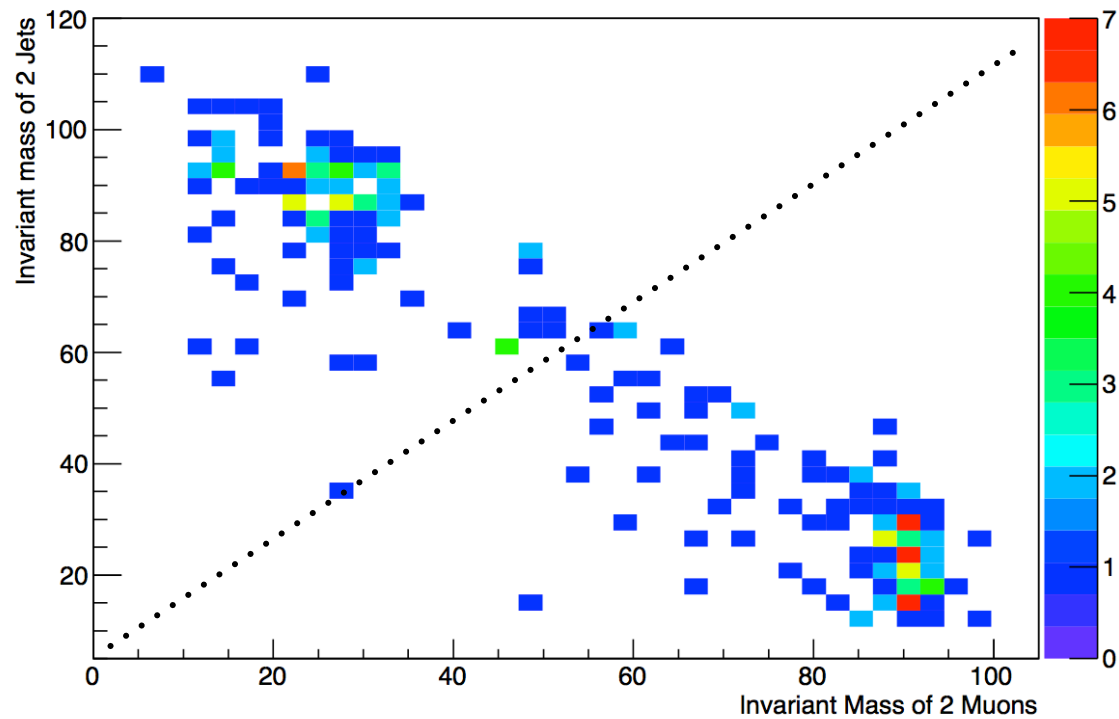
Criteria Category	<i>sw</i>	<i>sze</i>	<i>szeorsw</i>	<i>sznu</i>	<i>2fermion</i>
<i>Cut1</i>	13950666	206488	1003969	764480	0
<i>Cut2</i>	11402583	192824	936139	764359	0
<i>Cut3</i>	1847572	102329	363420	746257	0
<i>Efficiency</i>	10.64%	1.41%	28.86%	70.20%	0

Criteria	discription
<i>Cut1</i>	$20\text{GeV} \leq \text{total}P_t \leq 100\text{GeV}$
<i>Cut2</i>	Sum of all $\ P_t\ \leq 150\text{GeV}$
<i>Cut3</i>	Missing Mass $\geq 85\text{GeV}$

lepton > 2 GeV

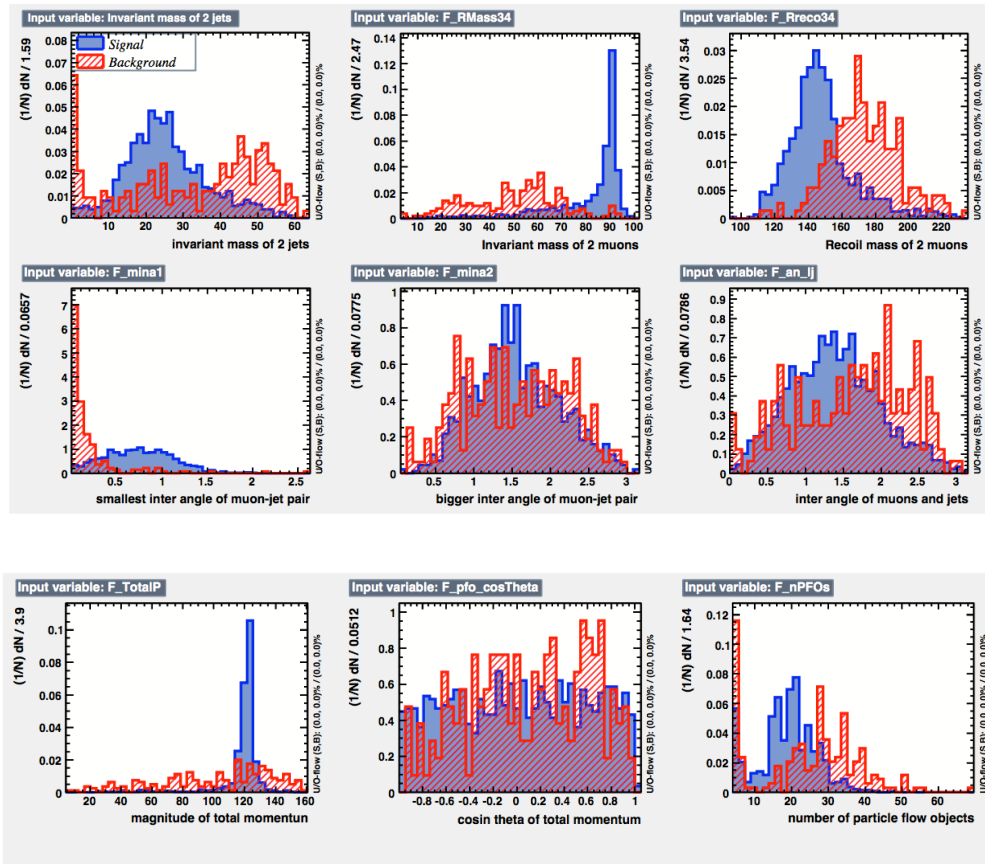
Jet > 2 pfos

di-Muon invariant mass VS di-jet invariant mass



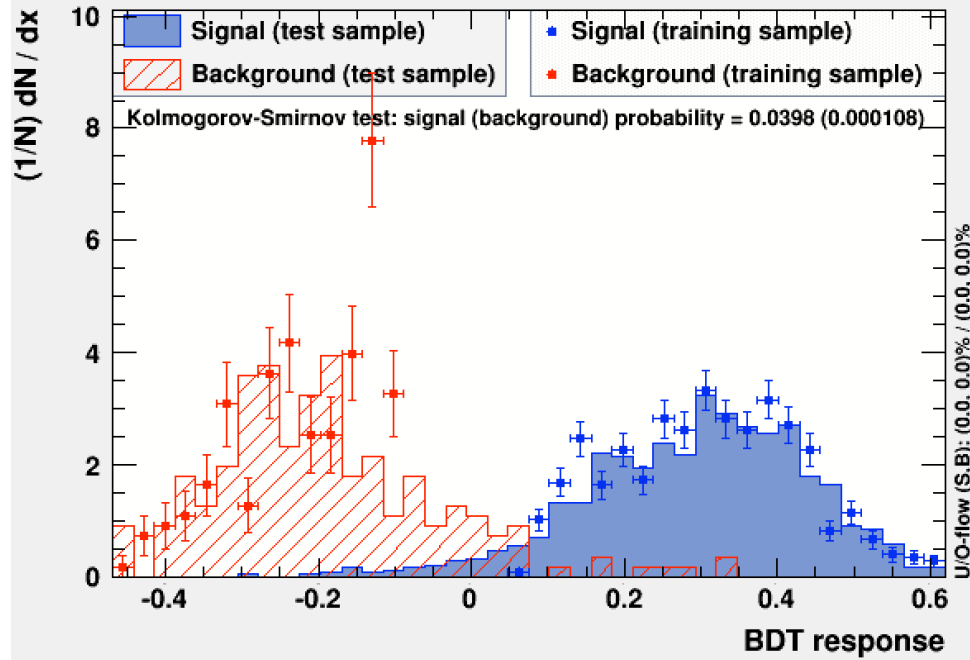
$\nu\nu\mu q q$ (channel 1)	152	123	113
$\nu\nu q q\mu\mu$ (channel 2)	153	127	120

variables for BDT

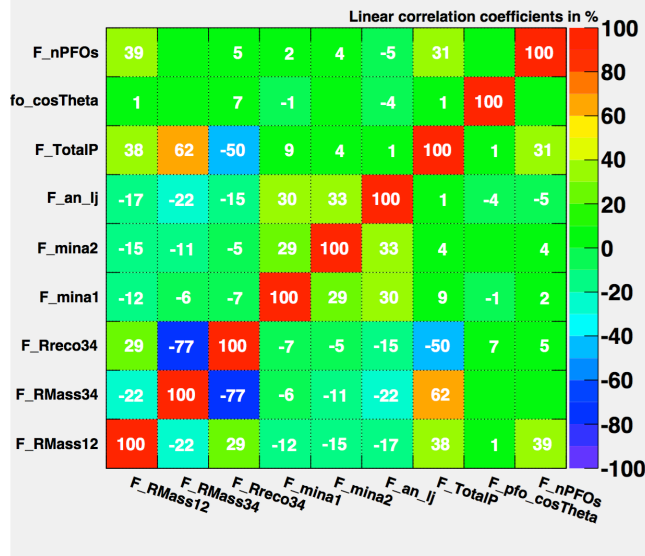


Variables	discription
R_{Mass12}	Invariant mass of 2 jets
R_{Mass34}	Invariant mass of 2 muons
R_{reco34}	recoil mass of 2 muons
$minA1$	inter angle of closer lepton-jet pair
$minA2$	inter angle of closer lepton-jet pair
an_{ij}	inter angle of 2 leptons and 2 jets
$TotalP$	magnitude total momentum
$Co\theta_{theta}$	cosin theta of total momentum
$npfos$	number of particle flow objects

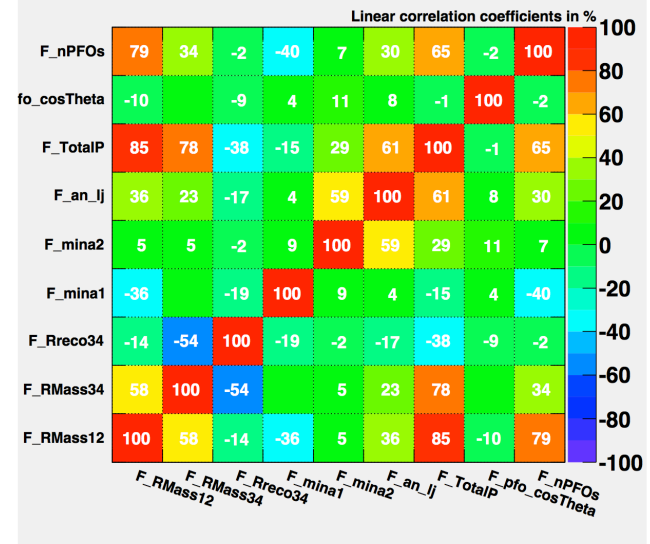
TMVA overtraining check for classifier: BDT



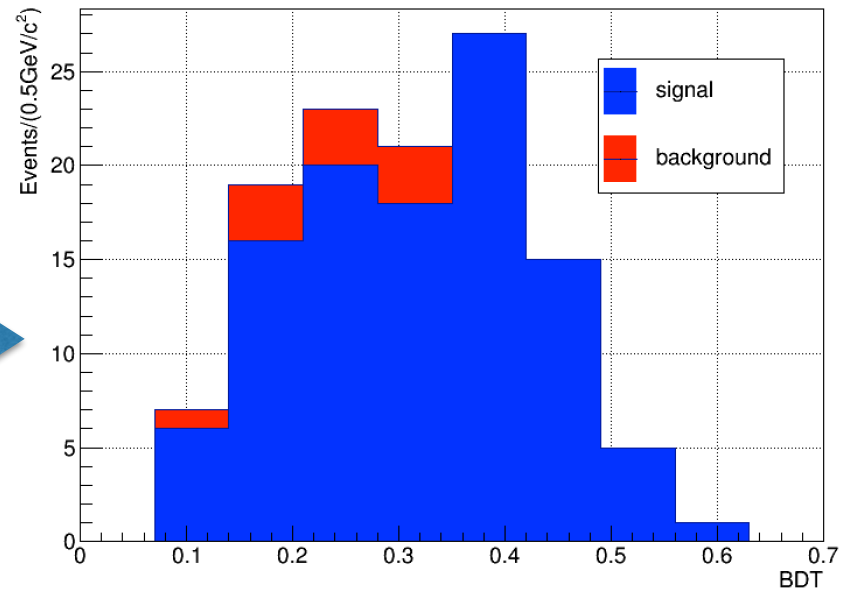
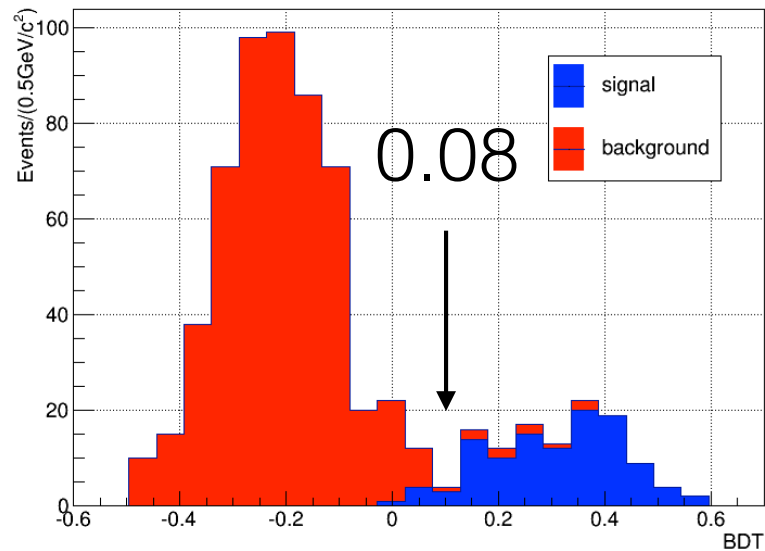
Correlation Matrix (signal)



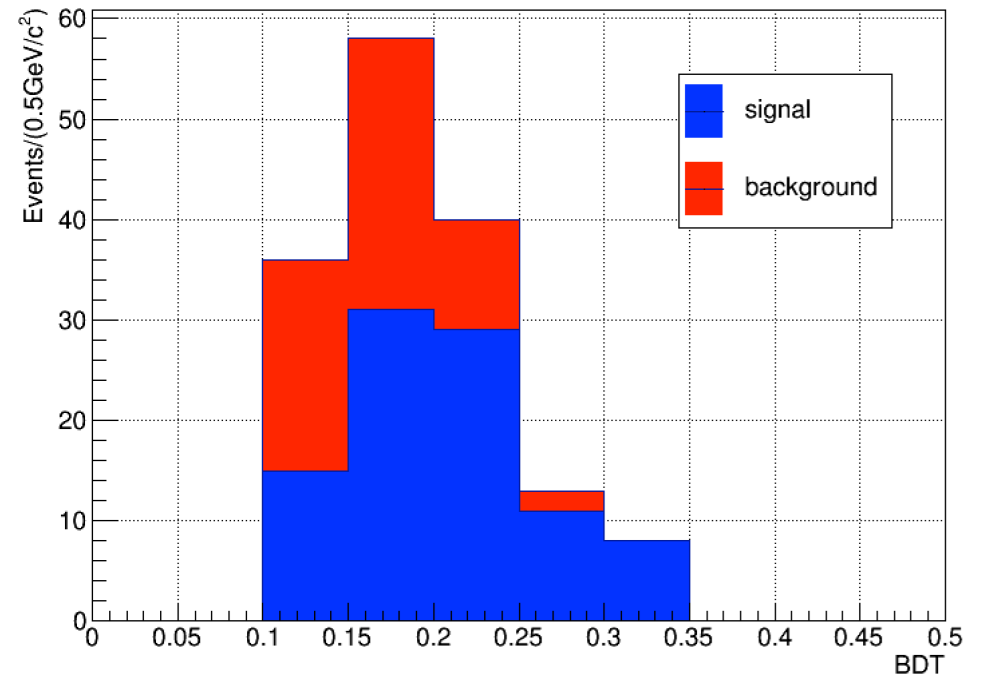
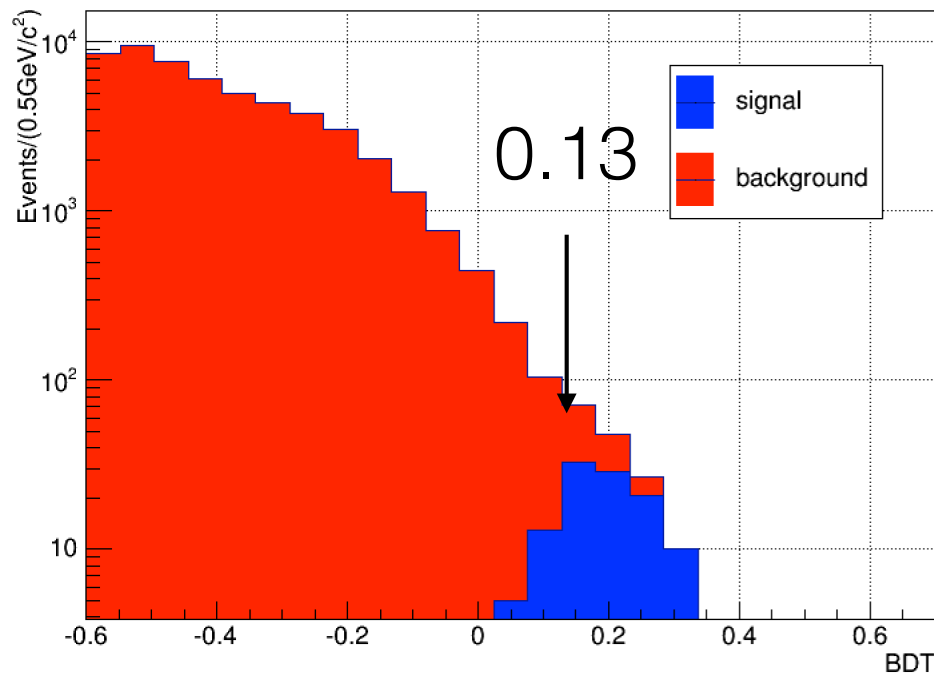
Correlation Matrix (background)



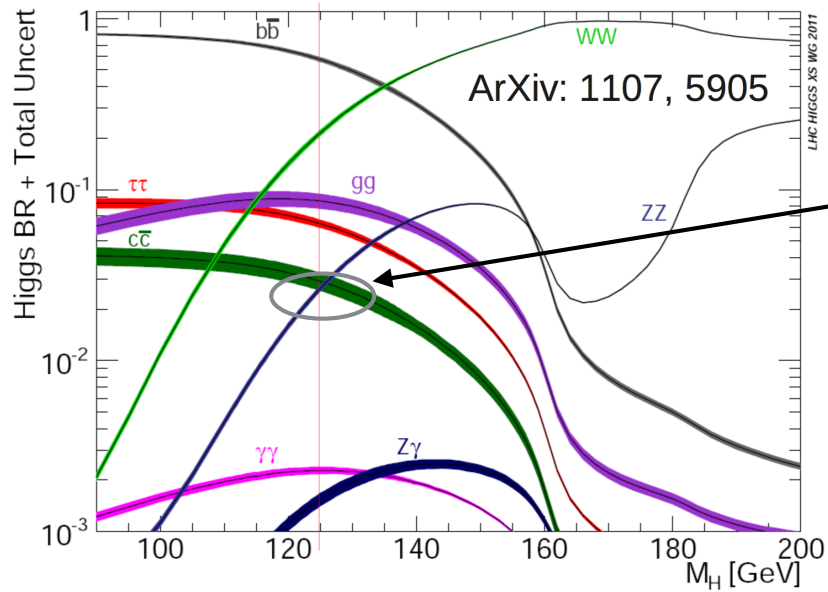
$ZZZ^* \rightarrow \nu\nu\mu + \mu - jj (10.0\%)$



$ZZZ^* \rightarrow \nu\nu jj\mu^+\mu^- (13.2\%)$

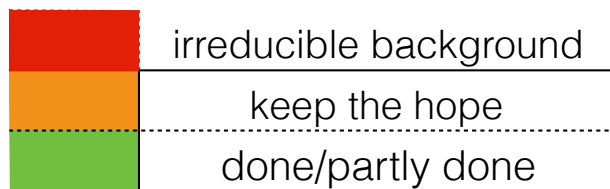


Current state



$H \rightarrow ZZ^* : 2.7\%$

$ZZ^* \setminus \text{iniZ}$	ll	taus	vv	qq
4q	888	444	2.64k	9.24k
2v+2q	508	254	1.51k	5.29k
2l+2q	170	85	508	1778
4v	73	36	216	756
2l+2v	49	24	145	508
4l	8	4	24	86
X+tau	120	60	356	1246

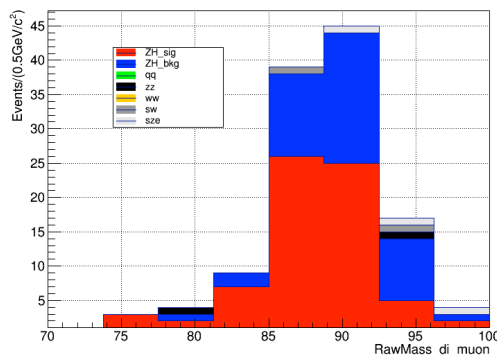


ZZZ* -> eevvjj

	sig	zh_bkg	qq	zz_sl	ww_sl	sw_sl	sz_sl
Yield	264	34484	99874234	2681457	25773352	17361538	6850366
event category	179	22972	1961	108	206	4441	61209
event category	91	1791	53	20	81	792	2915
final	71	40	0	2	0	7	4

- Pre_selection:
- e+e- variant mass (75,105)
- e+e- recoil mass(115,165)
- each lepton >2Gev
- pt of e pair > 10Gev

event-category
missing mass > jets' invariant mass



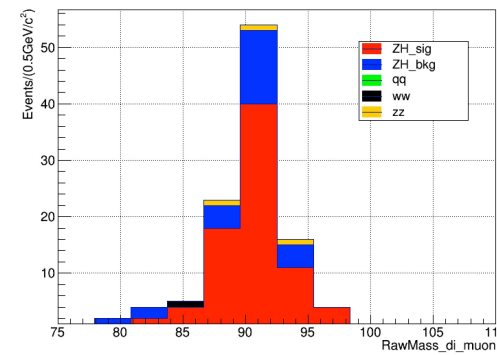
accuracy:15.8%

ZZZ* -> μμvvjj

	sig	ZH_bkg	qq	ww_sl	zz_sl
Yield	256	34356	99874234	25773352	2681457
event category	209	27536	862	1174	24548
event category	118	1916	16	282	944
final	81	24	0	1	4

- Pre-selection:
- μ+μ- variant mass (80,100)
- μ+μ- recoil mass(120,160)
- each lepton >2Gev
- pt of μ pair > 10Gev

event-category
missing mass > jets' invariant mass



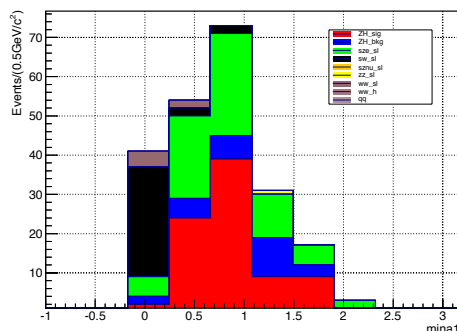
accuracy:12.9%

ZZZ* -> vveejj

	sig	zh_bkg	size_sl	sw_sl	ww_sl
Yield	302	20951	6850366	17361538	25773352
pre-selection	252	17241	86582	43805	110432
event category	118	733	46883	2765	1062
final	65	4	35	27	9

- Preselection-requirements:
- visible mass (0,180)
- visible energy (0,180)
- 2 same-flavour lepton > 2 Gev

event-category
leptons' invariant mass > jets'



accuracy:21.3%

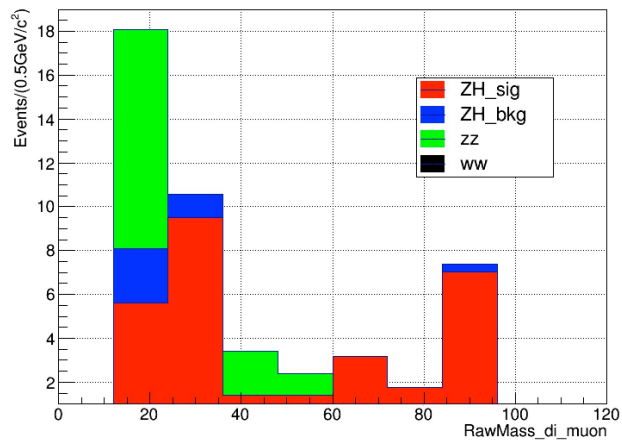
Result:
final state = $\mu\mu + \nu\nu + jj$
7.02%

final state = $ee + \nu\nu + jj$
12.7%

$ZZZ^* \rightarrow \mu\mu\mu\mu jj/jj\mu\mu$

	sig	ZH_bkg	ww_sl	zz_sl
Yield	43	34356	25773352	2681457
event category	39	1028	0	3963
final	30	4	0	13

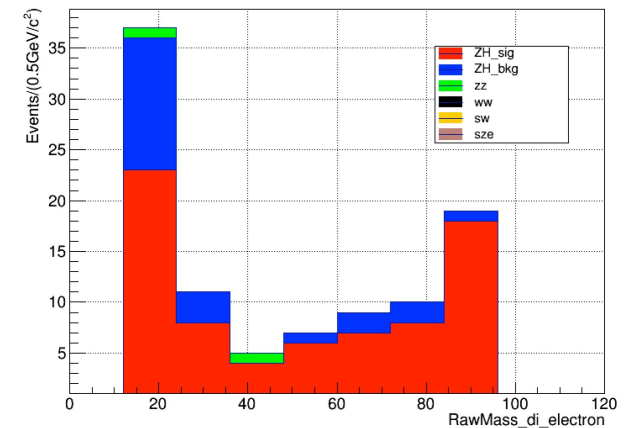
- Pre-selection:
- $\mu+\mu^-$ variant mass (80,100)
- $\mu+\mu^-$ recoil mass(120,160)
- each lepton $>2\text{Gev}$
- pt of μ pair $> 10\text{Gev}$



$ZZZ^* \rightarrow \mu\mu eejj/jjee$

	sig	zh_bkg	zz_sl	ww_sl	sw_sl	sze_sl
Yield	43	34484	2681457	25773352	17361538	6850366
event category	39	2108	6642	1414	1524	5282
final	27	8	2	0	0	0

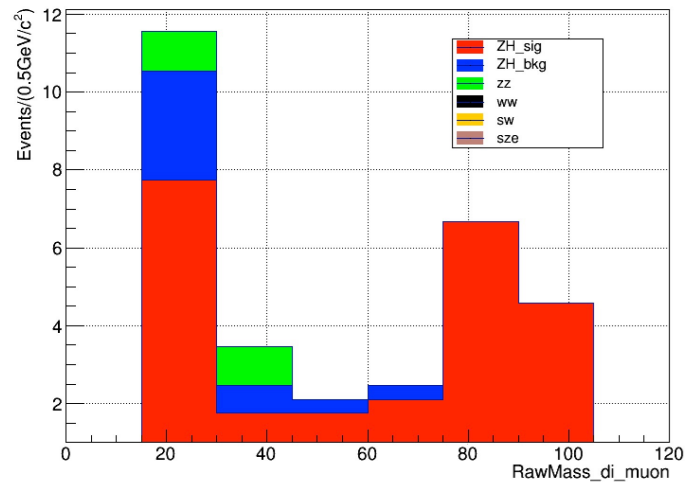
- Pre-selection:
- $\mu+\mu^-$ variant mass (80,100)
- $\mu+\mu^-$ recoil mass(120,160)
- each lepton $>2\text{Gev}$
- pt of μ pair $> 10\text{Gev}$



ZZZ* -> eeμμjj/jzμμ

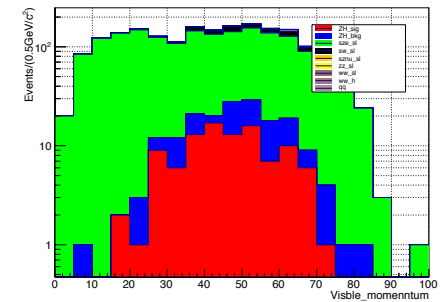
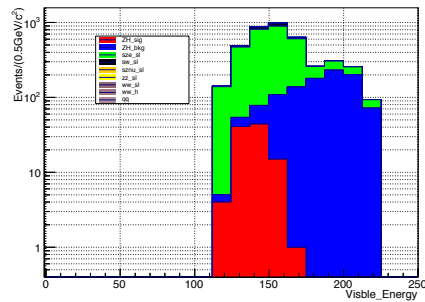
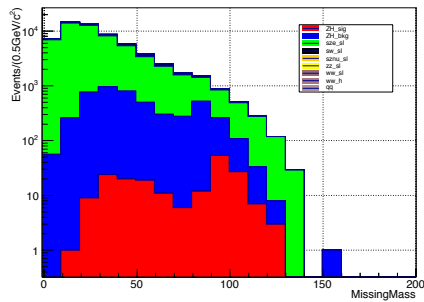
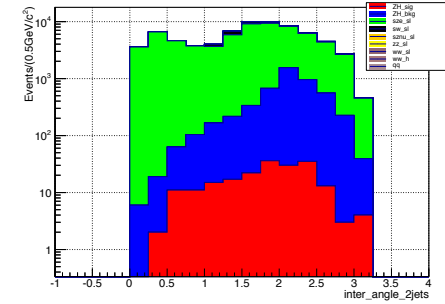
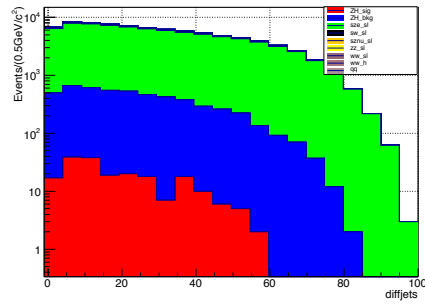
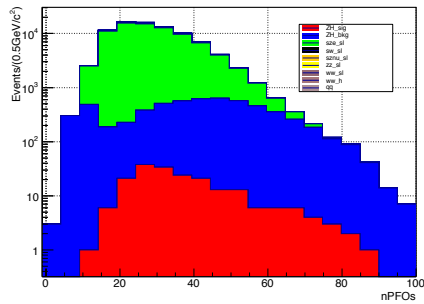
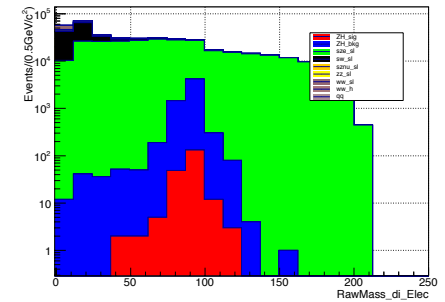
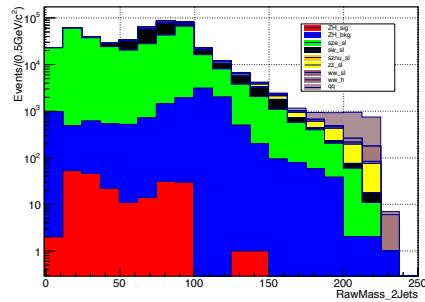
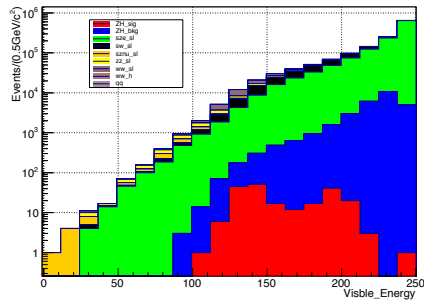
	sig	zh_bkg	zz_sl	ww_sl	sw_sl	sze_sl
Yield	43	34484	2681457	25773352	17361538	6850366
event category	41	970	6642	1414	1524	5282
final	26	4	2	0	0	0

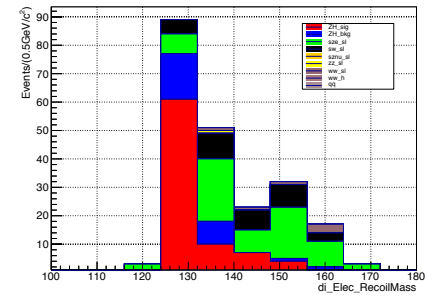
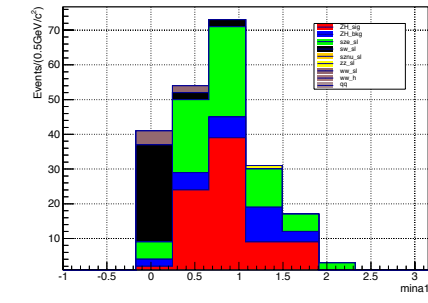
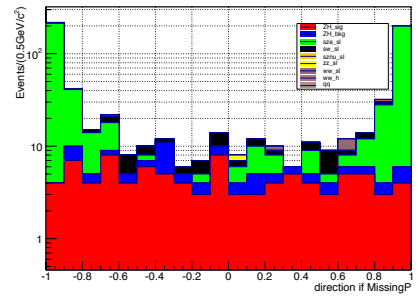
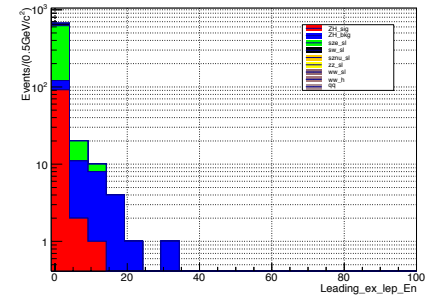
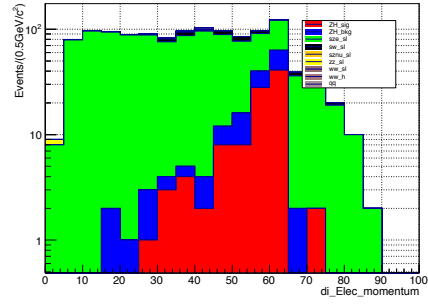
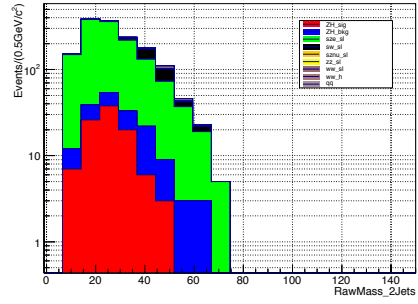
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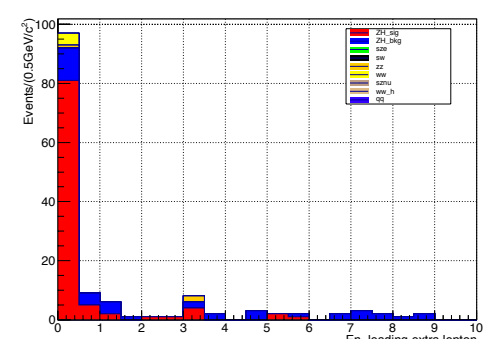
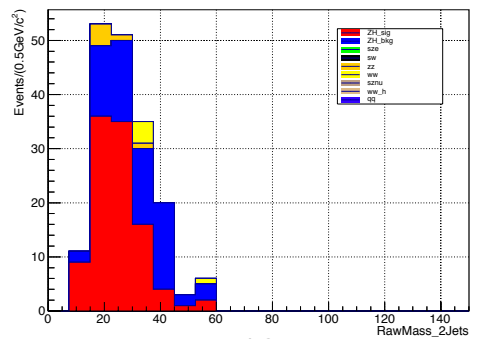
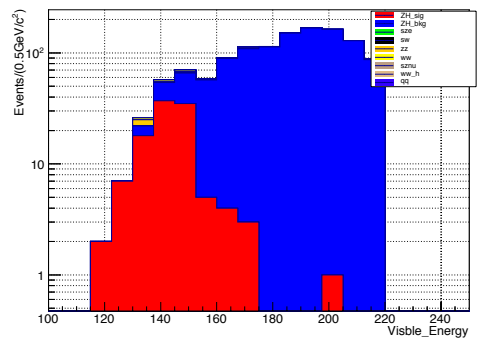
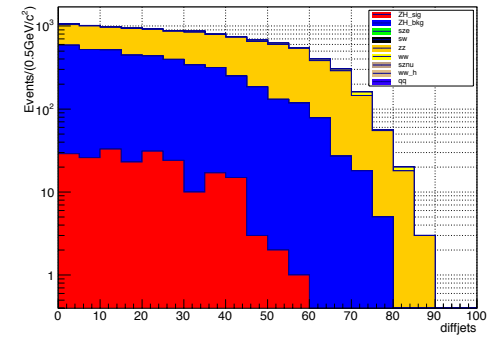
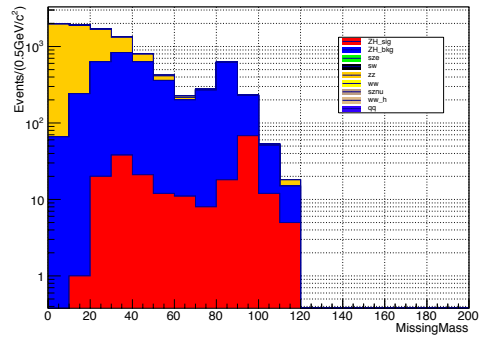
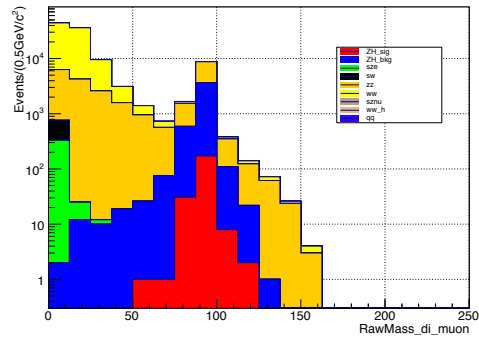
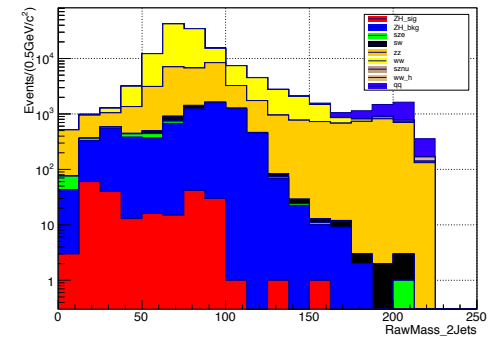
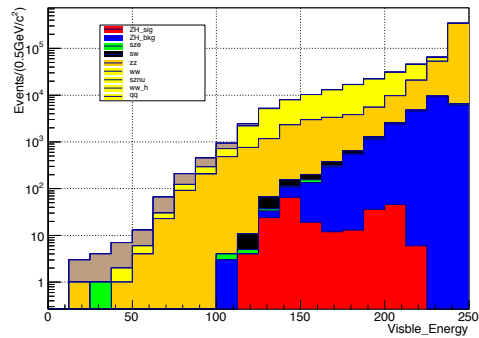
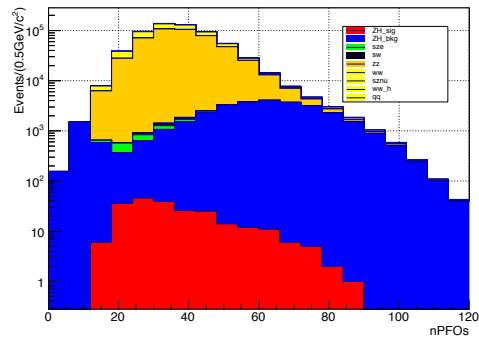
Back Up

$ZZZ^* \rightarrow eevvjj$

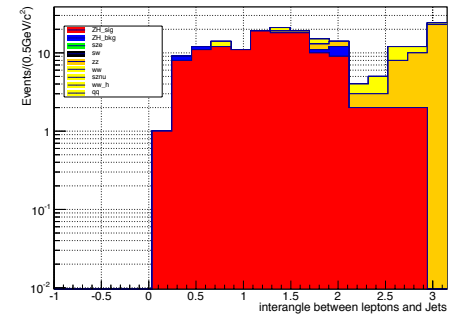
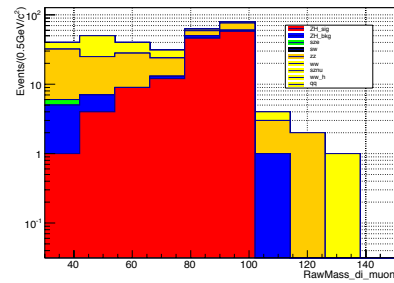
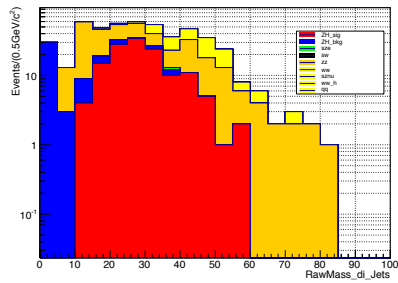
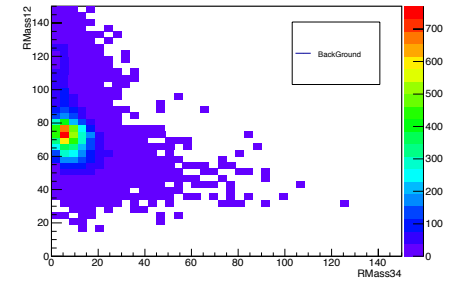
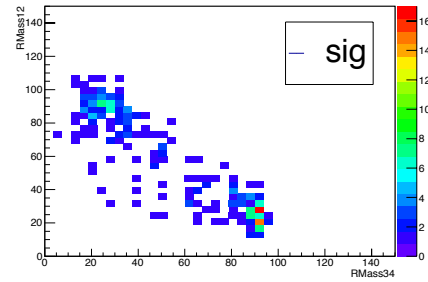
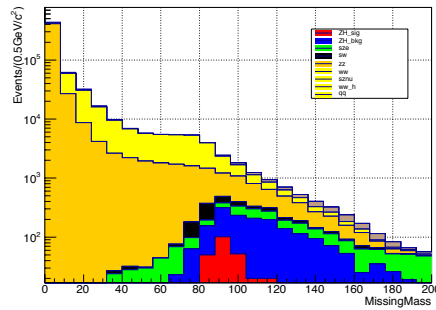




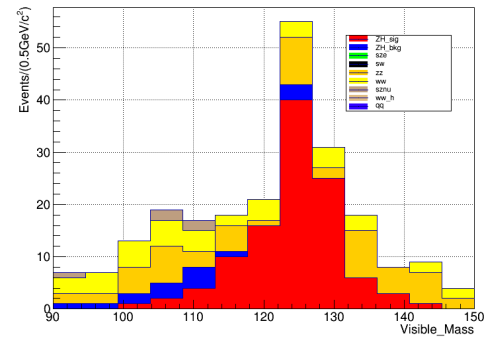
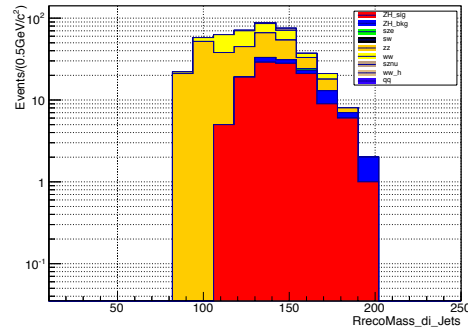
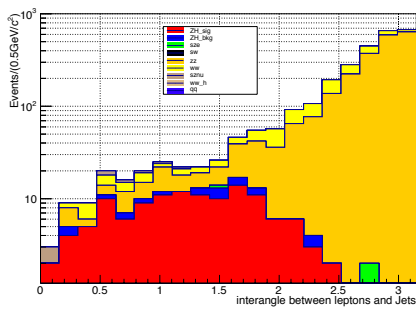
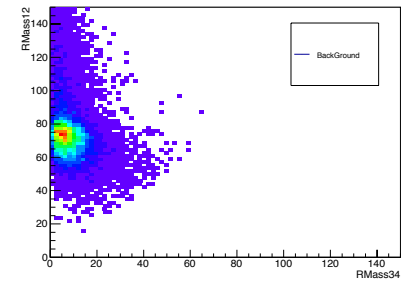
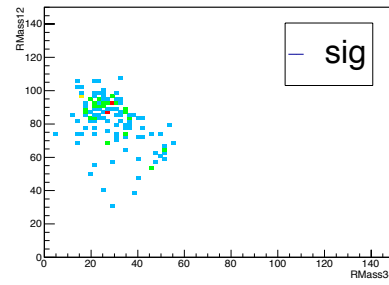
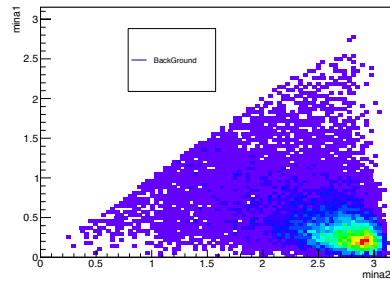
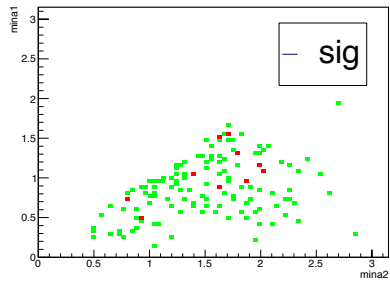
$ZZZ^* \rightarrow \mu\mu\nu\nu jj$



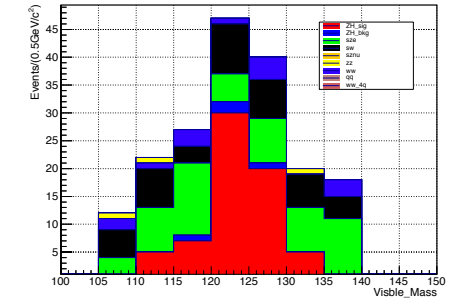
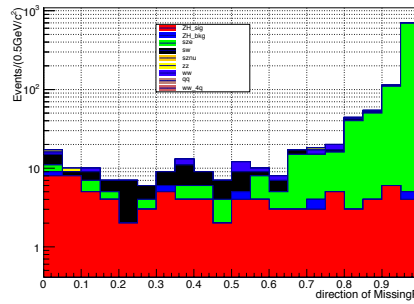
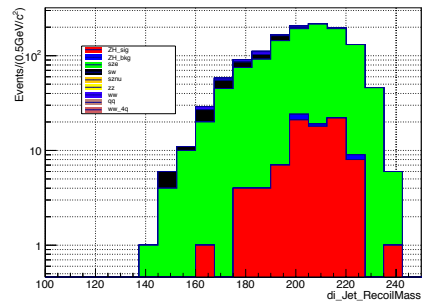
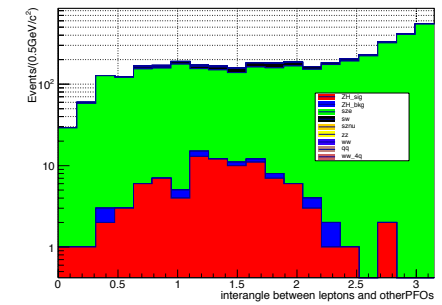
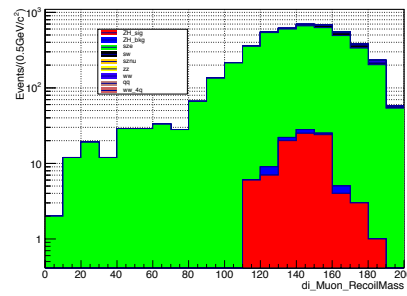
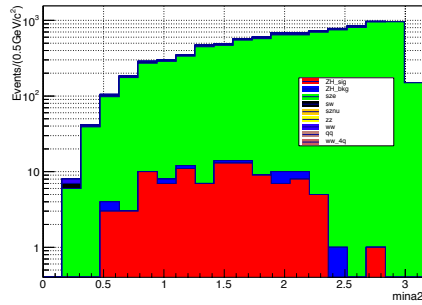
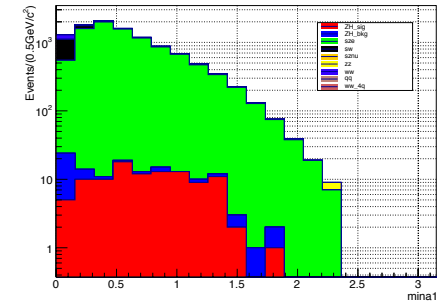
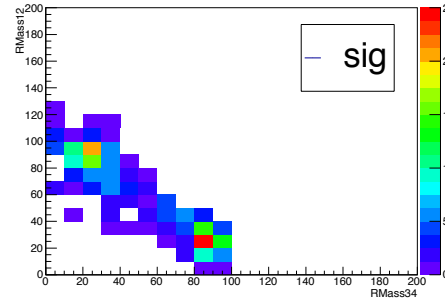
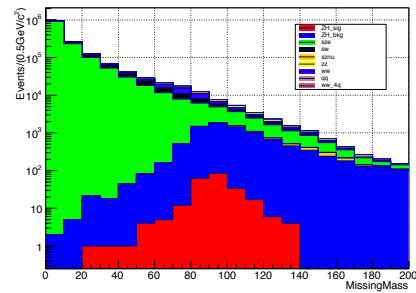
$$ZZZ^* \rightarrow \nu\nu\mu\mu jj$$



$$ZZZ^* \rightarrow \nu\nu jj\mu\mu$$



$ZZZ^* \rightarrow \nu\bar{\nu}e\bar{e}j\bar{j}$



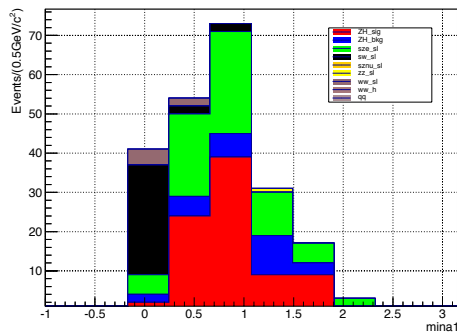
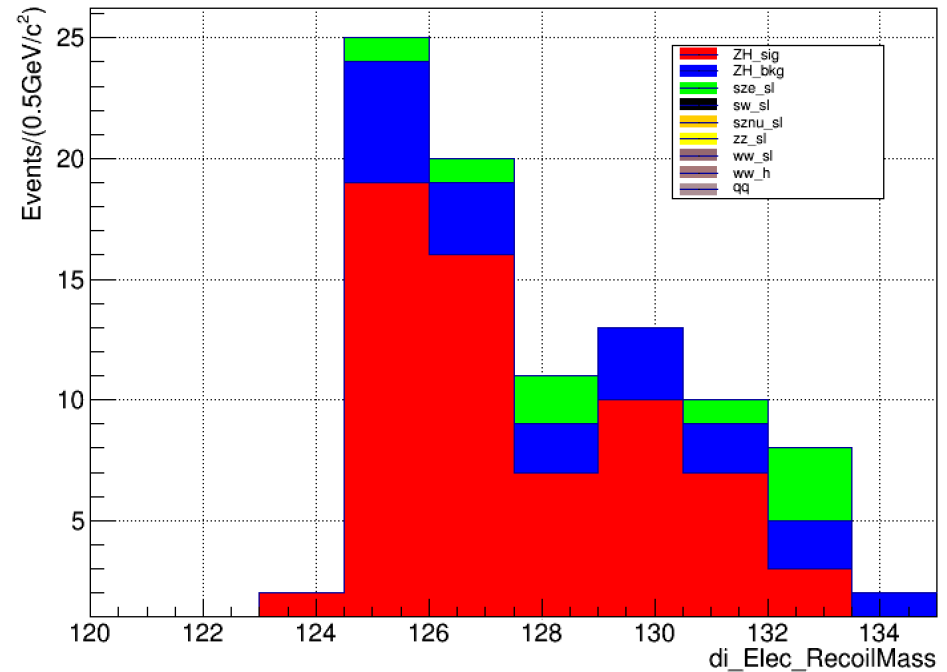
$ZZ^*\backslash\text{iniZ}$	e^+e^-	$\mu^+\mu^-$
vvqq	126	126
qqvv	126	

• The main background:

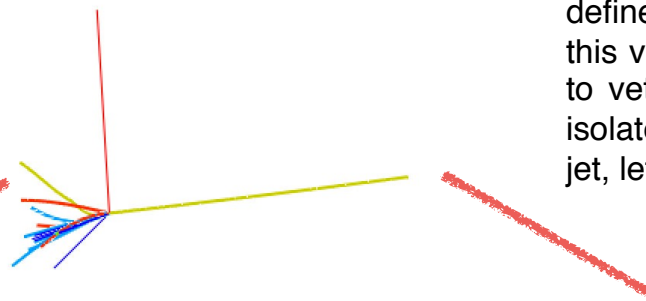
- $e^+e^- \rightarrow e^+e^-qq$; $e^+e^- \rightarrow \text{Tau Tau}qq$;
- $e^+e^- \rightarrow e^+\nu_e qq$; $e^+e^- \rightarrow ZH \rightarrow e^+e^- WW^* \rightarrow e^+e^- evqq/\text{Tauvqq}$
- $e^+e^- \rightarrow ZH \rightarrow e^+e^- bb$

	signal	ZH_bkg	szs_sl	sw_sl	zz_sl	ww_sl	sznu_sl	ww_4q	qq
Total									
final state	214	28892	1.39E+06	107346	15627	18296	684	2520	7574
VisEn(100,225)	213	13139	324146	99336	14634	18104	421	214	2580
Invariant mass of 2 jets(10,100)	209	6206	285061	88486	9799	15575	156	0	20
Invariant mass of 2 leptons(73,118)	199	5836	76623	3292	96	188	0	0	2
npfos[14,85]	199	5047	75787	3284	94	187	0	0	2
difference of 2 jets<55	199	4716	63292	2925	82	181	0	0	2
Interanglr of 2 jets(0.5,3)	193	4658	52749	2915	75	181	0	0	2
missingmass>75	105	961	2766	158	13	39	0	0	0
VisEn<155	101	79	1626	105	4	25	0	0	0
visible_p(18,71)	100	75	1200	100	3	25	0	0	0
Invariant mass of 2 jets<41	97	57	1039	42	2	9	0	0	0
leptons' P(29,65)	95	51	511	37	1	8	0	0	0
lead_exlep_en<4	92	29	500	37	1	8	0	0	0
abs(Costheta)<0.81	83	26	71	32	1	6	0	0	0
mina1>0.25	81	24	66	4	1	2	0	0	0
RrecoMass of 2 jets>134	65	19	12	0	0	0	0	0	0

we can get a relative precision of **15.1%** from this single channel.



$\mu\nu_\mu qq$ event



For we have 4 visible objects in final states, 2 electrons and 2 jets, boost them into their centre-of-mass frame. we define the smallest inter angle of electron-jet pair as m_{in1} , then define the inter angle of the rest pair as m_{in2} , this variable has a strong discriminating power to veto the $e+e \rightarrow \nu\nu jj$ events where the fake isolated leptons are always lie in the cone of jet, let m_{in1} be larger than 0.25.

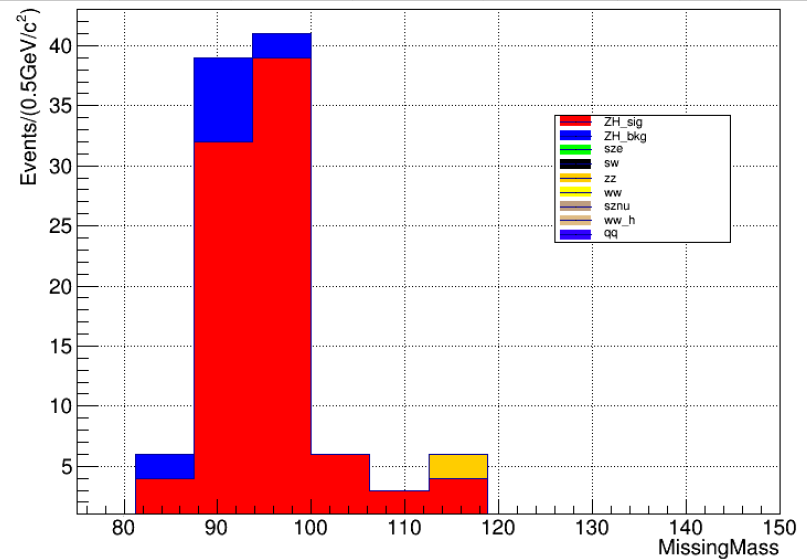
fake isolated lepton

Isolated lepton

	signa	ZH_bkg	sze_sl	sw_sl	zz_sl	ww_sl	sznu_sl	ww_h	qq
Total									
final_state	229	31211	1165	601	468485	113680	834	2109	9251
nPFOs(15,80)	225	24380	1147	601	465646	113171	825	1685	9114
Visible Energy(119,220)	222	6706	385	520	31947	92116	159	119	2353
Invariant mass of 2 jets(10,96)	216	4302	343	435	21965	79251	108	0	4
Invariant mass of 2 Muons (76,120)	214	4150	0	0	6403	207	0	0	0
difference of 2 jets<56	214	3934	0	0	5300	153	0	0	0
missingmass>68	112	1105	0	0	11	9	0	0	0
Visible Energy<155	103	65	0	0	6	5	0	0	0
Invariant mass of 2 jets<38	98	46	0	0	6	4	0	0	0
Leading_extra_En < 5	94	21	0	0	6	4	0	0	0
missing mass > 86	88	11	0	0	2	0	0	0	0

The main background:
 $e^+e^- \rightarrow \text{Tau}^+\text{Tau}^-qq$;
 $e^+e^- \rightarrow \mu^\pm\nu_\mu qq$;
 $e^+e^- \rightarrow ZH \rightarrow e^+e^- WW^* \rightarrow \text{Tau}\nu qq$

All of these events are
 $ZH \rightarrow \mu\mu WW^* \rightarrow \mu\mu \text{ Tau } \nu qq$



$ZZ^* \setminus \text{iniZ}$	e^+e^-	$\mu^+\mu^-$
$\nu\nu qq$	126	126
$qq\nu\nu$	126	126

we can get a relative precision of **11.6%** from this single channel.

	signal	ZH_bkg	szc_sl	sw_sl	zz_sl	ww_sl	sznu_sl	ww_h	qq
final_state	231	1268	1165	601	468485	113680	834	2109	925
Missingmass(58,128)	221	865	533	533	7961	14984	477	0	35
Invariant mass of Muons is larger than that of jets	109	42	1	0	214	81	0	0	0
Invariant mass of 2 jets (13,49)	105	14	1	0	138	62	0	0	0
Invariant mass of 2 muons(60,95)	101	4	0	0	45	16	0	0	0
Interangle between jets and muons<2.3	97	4	0	0	7	7	0	0	0



All of these events includes Tau

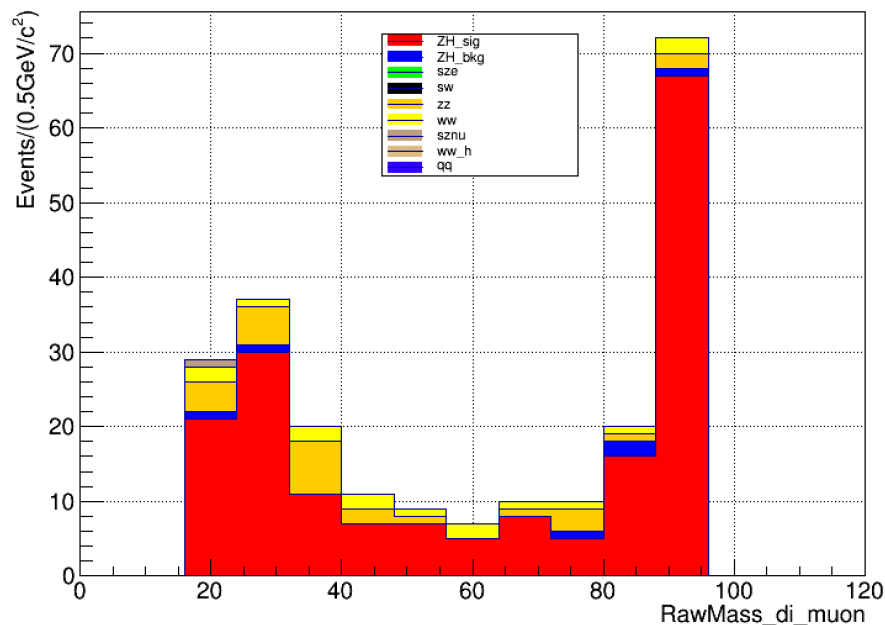
- The main background:
- $e^+e^- \rightarrow \text{Tau}^+\text{Tau}^-qq$;
- $e^+e^- \rightarrow \nu\nu qq$;
- $e^+e^- \rightarrow \mu^\pm\nu_\mu qq$;
- $e^+e^- \rightarrow ZH \rightarrow e^+e^- WW^* \rightarrow \text{Tau}\nu qq$

$ZZ^*\backslash \text{init}Z$	$\nu\nu$
$\mu\mu qq$	126
$qq\mu\mu$	126
$eeqq$	126
$qqee$	126

	signal	ZH_bkg	sz_e_sl	sw_sl	zz_sl	ww_sl	sznu_sl	ww_h	qq
final_state	231	1268	1165	601	468485	113680	834	2109	9251
Missingmass(58,128)	221	865	533	533	7961	14984	477	0	35
Invariant mass of Muons is less than that of jets	113	823	532	533	7747	14903	477	0	35
mina1&mina2	108	485	319	395	5622	4508	192	0	19
Invariant mass of 2 jets(53,107)	105	161	256	347	4251	3662	158	0	1
Invariant mass of 2 muons(16,55)	100	13	4	0	2215	419	7	0	0
Interangle of jets and muons	88	12	1	0	116	60	7	0	0
recoil mass of 2 jets>116	87	12	1	0	69	44	7	0	0
visible_Mass(112,140)	82	3	0	0	19	8	1	0	0



All of these events includes Tau



ZZ*\nltz	vv
$\mu\mu qq$	126
$qq\mu\mu$	126
$eeqq$	126
$qqee$	126

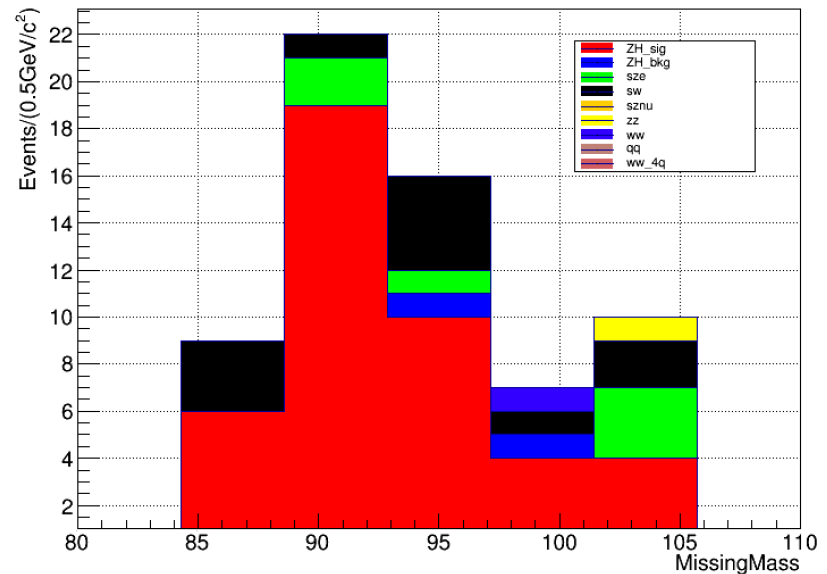
we can get a relative precision of 8.6% from this single channel.

	signal	ZH_bkg	size_sl	sw_sl	zz_sl	ww_sl	sznu_sl	ww_h(4q)	qq(1%)(2f)
final state	189	8632	1.39E+06	105756	15627	18296	684	2520	7574
missing-mass(58,138)	184	7136	34688	12099	7505	13850	454	3	21
Invariant mass of Muons is larger than that of jets	85	69	21763	1162	193	367	0	0	1
Invariant mass of 2 jets and 2 muons	84	33	9550	871	44	286	0	0	0
mina1>0.2	78	11	8732	258	28	85	0	0	0
mina2(0.66,2.26)	72	9	4514	176	18	53	0	0	0
recoil mass of 2 muons(108,184)	72	9	3673	168	4	36	0	0	0
Interangle of jets and muons <2.3	70	9	1904	140	4	36	0	0	0
recoil mass of 2 jets(178,227)	68	5	928	45	3	20	0	0	0
abs(Costheta)<0.81	56	4	55	41	3	14	0	0	0
visible mass(114,135)	54	4	35	27	1	9	0	0	0
missing mass (84,105)	43	2	6	11	1	1	0	0	0

• The main background:

- $e^+ e^- \rightarrow e^+ e^- qq$;
- $e^+ e^- \rightarrow \text{Tau}^+ \text{Tau}^- qq$;
- $e^+ e^- \rightarrow e^+ \nu_e qq$;
- $e^+ e^- \rightarrow ZH \rightarrow e^+ e^- WW^* \rightarrow e^+ e^- e\nu qq / \text{Tau}\nu qq$
- $e^+ e^- \rightarrow ZH \rightarrow e^+ e^- bb$

ZZ*\nitZ	vv
$\mu\mu qq$	126
$qq\mu\mu$	126
$eeqq$	126
$qqee$	126



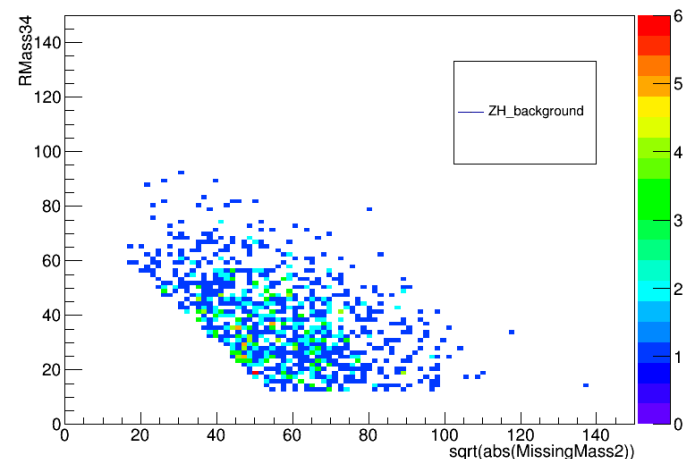
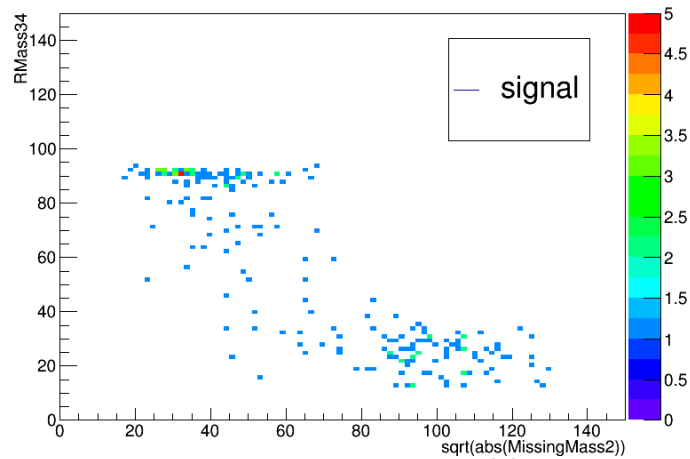
we can get a relative precision of **18.6%** from this single channel.

	signal	ZH_bkg	sw_sl	sz_e_sl	sznu_sl	ww_sl	zz_sl	4q	2q
final_s tate	237	14225	601	1165	834	113680	468485	2109	9251
Prese lection	213	2474	0	0	16	1423	1916	0	3
$\mu\mu\nu\nu$	106	2036	0	0	16	1242	1153	0	3
$\nu\nu\mu\mu$	107	438	0	0	0	181	763	0	0

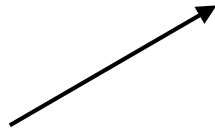
H->TauTau:1299
H->WW*-> $\mu\nu$ tauv:392
tauvtauv:14
 $\mu\nu\mu\nu$:769

all of these events include Tau

ZZ*\nu\nu	qq
$\mu\mu\nu\nu$	126
$\nu\nu\mu\mu$	126
eevv	126
vvee	126

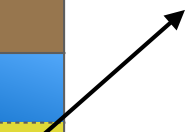


ZZ*\nitZ	vv
$\mu\mu qq$	126
$qq\mu\mu$	126
$eeqq$	126
$qqee$	126



	signal	ZH_bkg	sz_e_sl	sw_sl	zz_sl	ww_sl	sznu_sl	ww_h	qq
missing mass	88	3697	49983	2757	0	63	142	0	2
mina1&mina2	85	3575	46431	856	0	52	54	0	0
direction of missingP	73	2727	14310	466	0	36	28	0	0
volume of jj_n	68	1818	7899	390	0	29	26	0	0

ZZ*\niZ	e⁺e⁻	$\mu^+\mu^-$
$vvqq$	126	126
$qqvv$	126	126



	signal	ZH_bkg	sz_e_sl	sw_sl	zz_sl	ww_sl	sznu_sl	ww_h	qq
missing mass	102	2829	0	0	5289	144	0	0	0
mina1&mina2	100	2779	0	0	4962	77	0	0	0
direction of missingP	98	2254	0	0	2785	65	0	0	0
volume of jj_n	95	1688	0	0	2556	65	0	0	0
direction of missingP	91	1501	0	0	1806	64	0	0	0
voloum	80	804	0	0	90	53	0	0	0
Max_Min_angle	75	557	0	0	30	19	0	0	0
MissingMass	75	498	0	0	21	16	0	0	0

All of these events includes Tau

H->bb:262
 ww*->tauv qq:207
 -> $\mu\nu$ qq:35