Determination of Higgs Boson Width

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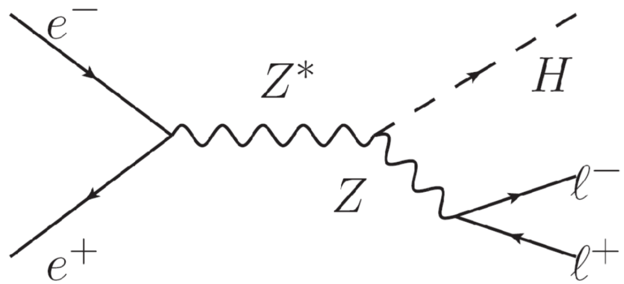
OUTLINE

- Methodology of Higgs Boson Width determination at CEPC
- Measurement of Br(H -> WW*)
- Measurement of Br(H -> ZZ*)
- Result
- Comparison
- Next step

basic observables at hadron collider & e+e- collider

$$N_{\text{event}(A\to h\to B)} \propto \sigma_{AB} \simeq \frac{\sigma(A\to h)\Gamma(h\to B)}{\Gamma_h} \propto \frac{g_A^2 g_B^2}{\Gamma_h}, \quad (1)$$

$$\Gamma_h = \frac{(g_A^2)^2}{(g_A^2 g_A^2/\Gamma_h)} \propto g_A^2 \frac{\sigma_A^{\text{inc}}}{\sigma_{AA}}; \quad (2)$$



$$m_h^2 = s + m_{dileptons}^2 - 2(E_1 + E_2)\sqrt{s}$$

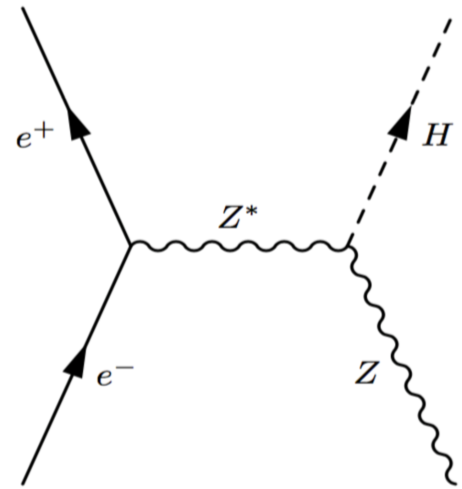
Hadron collider(LHC)	e^+e^- collider(CEPC/ILC…)
σ_{AB}	σ_{AB}
…	…
σ_A^{inc} ✗	σ_A^{inc}

We could measure σ_Z^{inc} using **recoil mass method** with Higgs' final state independently on CEPC/ILC…

O_1	σ_{ZH}
pre-CDR	**0.92**% for μμh channel, **1.49**% for eeh channel Zhenxing's **full simulation-based** analysis **0.65**% for qqh channel from pre-CDR(**fast-simulation-based** analysis) combine: **0.5%**

1/2: via Br(H->ZZ*)

$$\Gamma_h = \frac{(g_A^2)^2}{(g_A^2 g_A^2/\Gamma_h)} \propto g_A^2 \frac{\sigma_A^{\rm inc}}{\sigma_{AA}}; \quad (2)$$

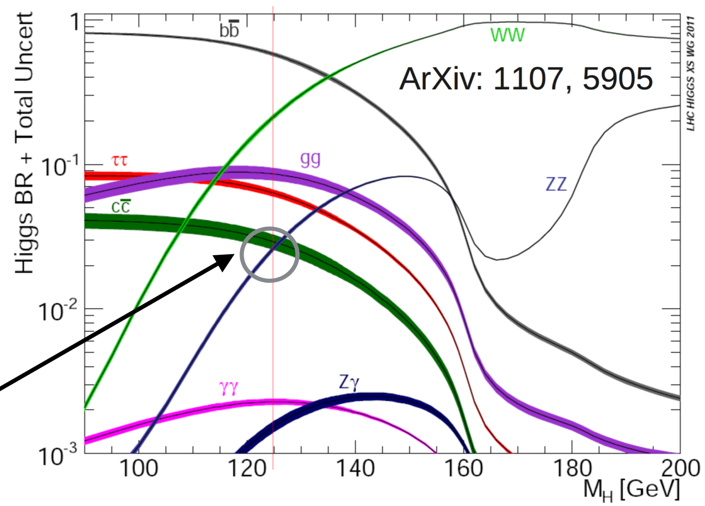


$$\Gamma_h \propto g_Z^2 \frac{\sigma_{ZH}}{\sigma_{ZZ}} \quad (4)$$

O1	σ_{ZH}
O2	$\sigma_{ZZ} = \sigma_{ZH} \times Br(H \to ZZ^*)$

$$\rightarrow \Gamma_h \propto \frac{O_1^2}{O_2}$$

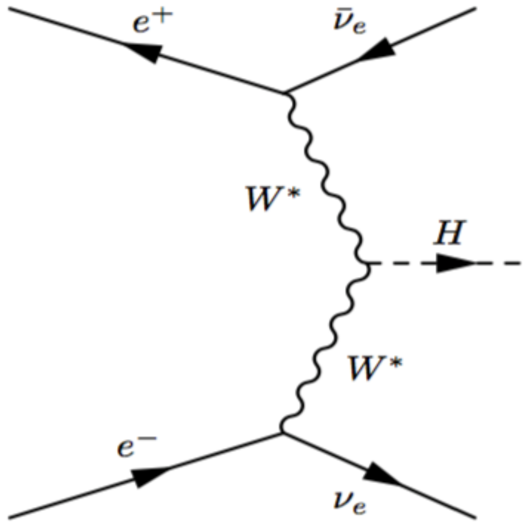
limited by the small branching ratio BR(2.7%)



2/2: via Br(H->WW*)

$$\Gamma_h = \frac{(g_A^2)^2 (g_B^2 g_C^2/\Gamma_h)}{(g_A^2 g_B^2/\Gamma_h)(g_A^2 g_C^2/\Gamma_h)} \propto g_A^2 \frac{\sigma_A^{\text{inc}} \sigma_{BC}}{\sigma_{AB}\sigma_{AC}} \qquad (3)$$

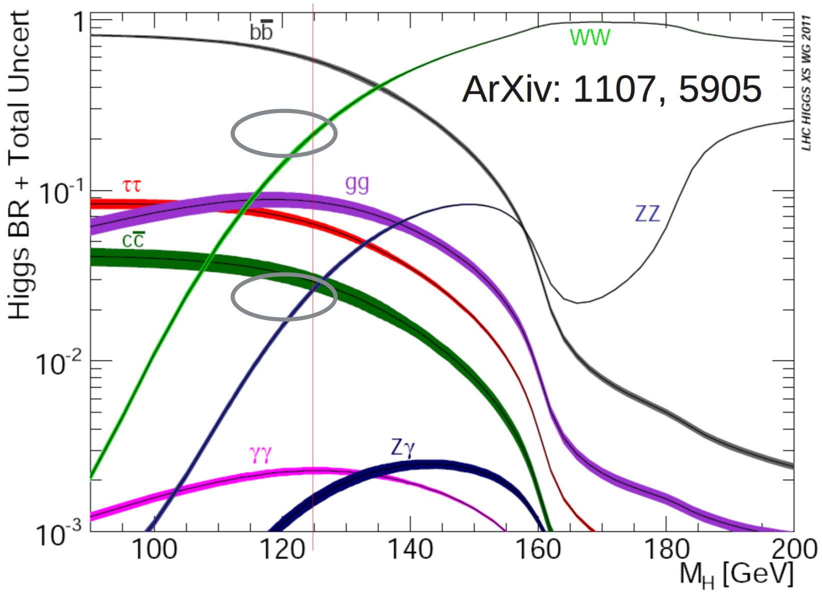
$$\Gamma_h \propto g_Z^2 \frac{\sigma_{ZH} \sigma_{Wb}}{\sigma_{ZW}\sigma_{Zb}} \qquad (5)$$



O_1	σ_{ZH}
O_2	σ_{ZZ} $=\sigma_{ZH}$ x Br(H -> ZZ*)
O_3	σ_{Wb} $=\sigma_{\nu\nu H}$ x Br(H -> bb)
O_4	σ_{ZW} $=\sigma_{ZH}$ x Br(H -> WW*)
O_5	σ_{Zb} $=\sigma_{ZH}$ x Br(H -> bb)

$$\Gamma_h \propto \frac{O_1^2 O_3}{O_4 O_5}$$

O_2	$\sigma_{ZZ} = \sigma_{ZH} \times Br(H \to ZZ^*)$
O_4	$\sigma_{ZW} = \sigma_{ZH} \times Br(H \to WW^*)$



Testbed for essential reco-algorithms (Jet Clustering, isolated lepton selection, Flavortag, tau finder) reconstruction, particle identification, etc.

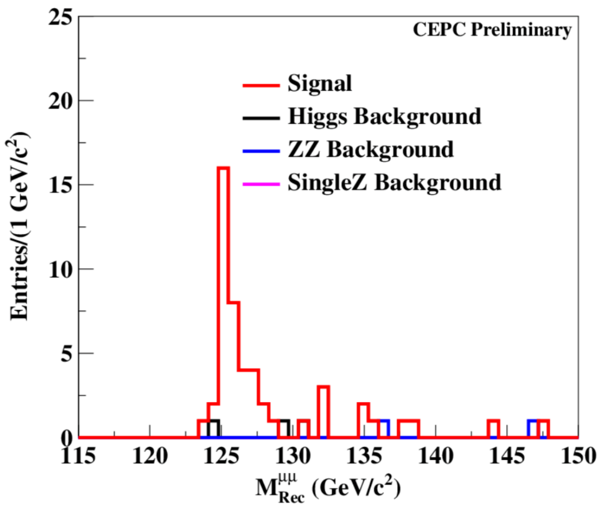
WW*\lniZ	ll	taus	vv	qq
4q	6.91K	3.45K	19.74K	69.1k
lvqq	4.53K	2.27K	12.94K	45.3k
lvlv	745	377	2.13K	7.45K
tau+X	3.2K	1.60K	9.14K	32.0K

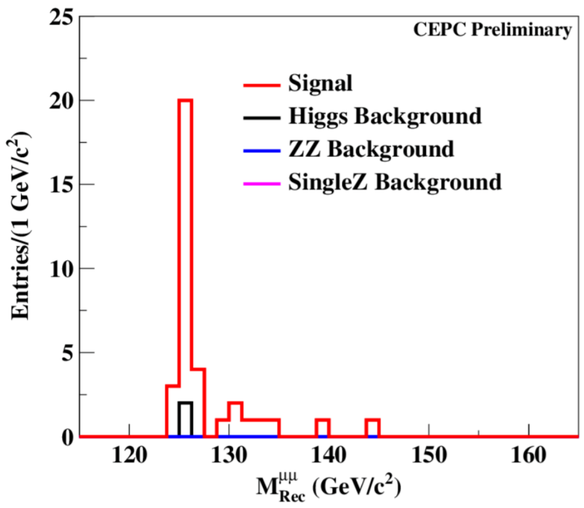
Normalize to 5 ab^{-1}

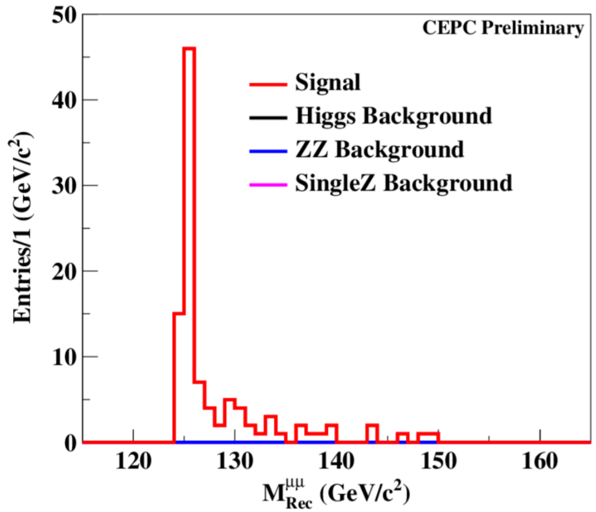
ZZ*\lniZ	ll	taus	vv	qq
4q	888	444	2.64k	9.24k
2v+2q	508	254	1.51k	5.29k
2l+2q	170	85	508	1778
4v	73	36	216	756
2l+2v	49	24	145	508
4l	8	4	24	86
X+tau	120	60	356	1246

Z->μμ,Br(H -> WW*->lvlv (μvμv,evev,μvev))

O4 $\sigma_{ZW} = \sigma_{ZH} \times Br(H \to WW^*)$







Category	Signal	ZH	ZZ	Single Z
Total	348	34624	5499688	7788916
$N_{ZPole} = 2; N_{Isolep} = 2; l = \mu$	77	129	5309	0
$80\ \text{GeV} < M^{\mu^+\mu^-}_{Inv} < 100\ \text{GeV}$	73	124	4143	0
$120\ \text{GeV} < M^{\mu^+\mu^-}_{Rec} < 150\ \text{GeV}$	66	118	2548	0
$N_{Remain} < 3$	66	56	2442	0
$10\ \text{GeV} < M^{\mu^+\mu^-}_{Inv} < 65\ \text{GeV}$	58	46	411	0
$40\ \text{GeV} < E_{Missing} < 100\ \text{GeV}$	55	26	231	0
$\sqrt{(\frac{D0}{sigD0})^2 + (\frac{Z0}{sigZ0})^2} < 5$	54	7	226	0
Total $P_T > 20$ GeV	52	3	3	0

Table 2: Cut chain of $\mu\mu$ final state

Obj Eff:88.51%
Sig Eff:59.77%
Rel Acu:14.65%

Category	Signal	ZH	ZZ	Single Z
Total	348	34624	5499688	7788916
$N_{ZPole} = 2; N_{Isolep} = 2; l = e$	61	114	4	1807
$80\ \text{GeV} < M^{\mu^+\mu^-}_{Inv} < 100\ \text{GeV}$	53	105	2	1165
$120\ \text{GeV} < M^{\mu^+\mu^-}_{Rec} < 150\ \text{GeV}$	52	101	1	726
$N_{Remain} < 3$	51	60	0	692
$10\ \text{GeV} < M^{e^+e^-}_{Inv} < 65\ \text{GeV}$	49	47	0	49
$35\ \text{GeV} < E_{Missing} < 100\ \text{GeV}$	49	27	0	31
$\sqrt{(\frac{D0}{sigD0})^2 + (\frac{Z0}{sigZ0})^2} < 6$	39	4	0	24
Total $P_T > 20$ GeV	36	4	0	0

Table 3: Cut chain of ee final state

Obj Eff:70.11%
Sig Eff:40.38%
Rel Acu:17.57%

Category	Signal	ZH	ZZ	Single Z
Total	348	34624	5499688	7788916
$N_{ZPole} = 2; N_{Isolep} = 2; l_1 = e, l_2 = \mu$	147	136	32	1
$80\ \text{GeV} < M^{\mu^+\mu^-}_{Inv} < 100\ \text{GeV}$	134	119	21	0
$120\ \text{GeV} < M^{\mu^+\mu^-}_{Rec} < 150\ \text{GeV}$	130	117	15	0
$N_{Remain} < 3$	130	89	3	0
$10\ \text{GeV} < M^{e\mu}_{Inv} < 65\ \text{GeV}$	123	79	3	0
$35\ \text{GeV} < E_{Missing} < 110\ \text{GeV}$	123	68	2	0
$\sqrt{(\frac{D0}{sigD0})^2 + (\frac{Z0}{sigZ0})^2} < 4$	105	0	0	0

Table 1: Cut chain of $e\mu$ final state

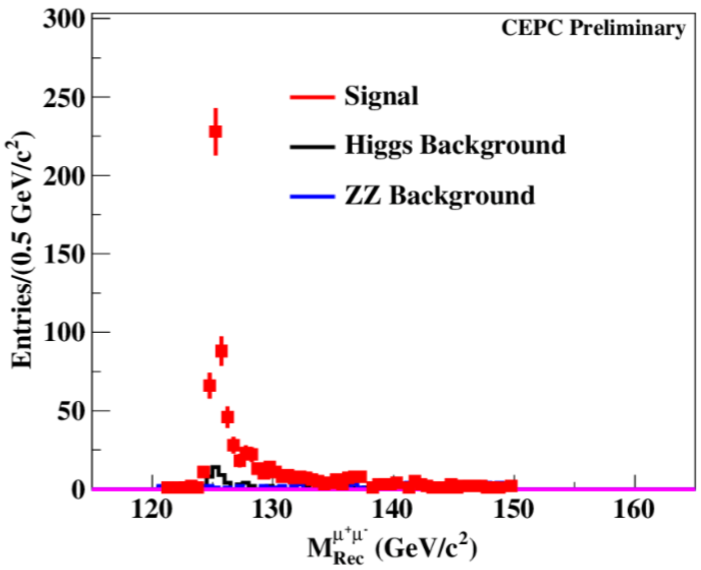
Obj Eff:84.47%
Sig Eff:60.34%
Rel Acu:9.76%

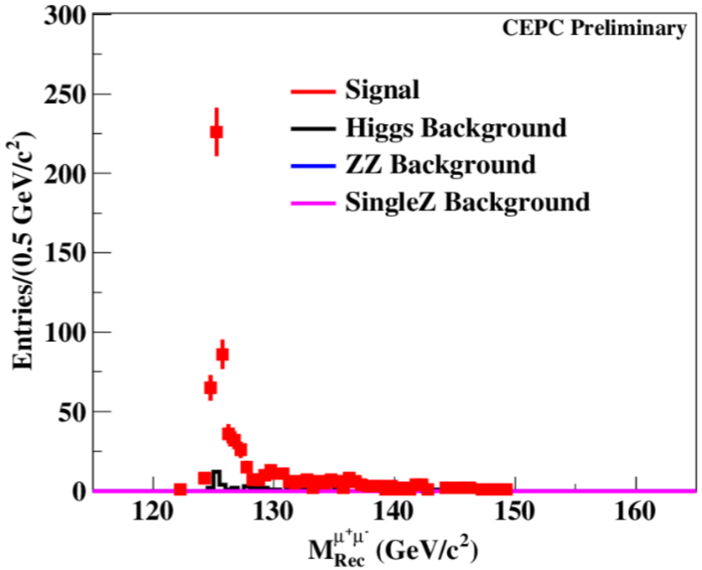
7.37% accuracy achieved with counting: improved by 2 times comparing to pre- CDR

Thanks to
1: Reconstruction - PID progress (Arbor)
2: Isolated lepton finder (Libo's work)
3: Event Selection optimization(Libo's work)

Z->μμ,Br(H -> WW*->lνqq (l = μ or e))

O4	$\sigma_{ZW} = \sigma_{ZH} \times Br(H \to WW^*)$





Category	Signal	*ZH*	*ZZ*	Single Z
Total	2215	32291	5499688	7788916
$N_{ZPole} = 2; N_{Isolep} = 1; N_{Jets} = 2; l = \mu$	988	1667	508	0
$80\ GeV/c^2 < M_{Inv}^{\mu^+\mu^-} < 100\ GeV/c^2$	879	1455	296	0
$120\ GeV/c^2 < M_{Rec}^{\mu^+\mu^-} < 150\ GeV/c^2$	853	1412	170	0
$M_{Missing}^2 < 2000\ GeV^2/c^4$	837	1074	142	0
$E_\mu > 15$ GeV	741	292	93	0
$15\ GeV/c^2 < M_{Rec}^{di-Jet} < 95\ GeV/c^2$	724	129	78	0
$\lvert \delta E_{Jets} \rvert < 50$ GeV	717	86	73	0

Table 5: Cut chain of semi leptonic decay of $H \to WW^* \to \mu\nu qq$

Category	Signal	*ZH*	*ZZ*	Single Z
Total	2215	32291	5499688	7788916
$N_{ZPole} = 2; N_{Isolep} = 1; N_{Jets} = 2; l = e$	864	881	83	824
$80\ GeV/c^2 < M_{Inv}^{\mu^+\mu^-} < 100\ GeV/c^2$	774	738	52	472
$120\ GeV/c^2 < M_{Rec}^{\mu^+\mu^-} < 150\ GeV/c^2$	755	717	31	314
$M_{Missing}^2 < 2000\ GeV^2/c^4$	743	406	11	308
$10\ GeV < E_e < 70$ GeV	699	227	6	210
$15\ GeV/c^2 < M_{Rec}^{di-Jet} < 95\ GeV/c^2$	676	90	3	99
$N_{Remain} > 6$	670	65	3	4
$\lvert \delta E_{Jets} \rvert < 50$ GeV	663	43	1	1

Table 4: Cut chain of semi leptonic decay of $H \to WW^* \to e\nu qq$

Obj Eff:89.17% Rel Acu:4.13%
Sig Eff:64.71%

Obj Eff:77.98% Rel Acu:4.02%
Sig Eff:59.84%

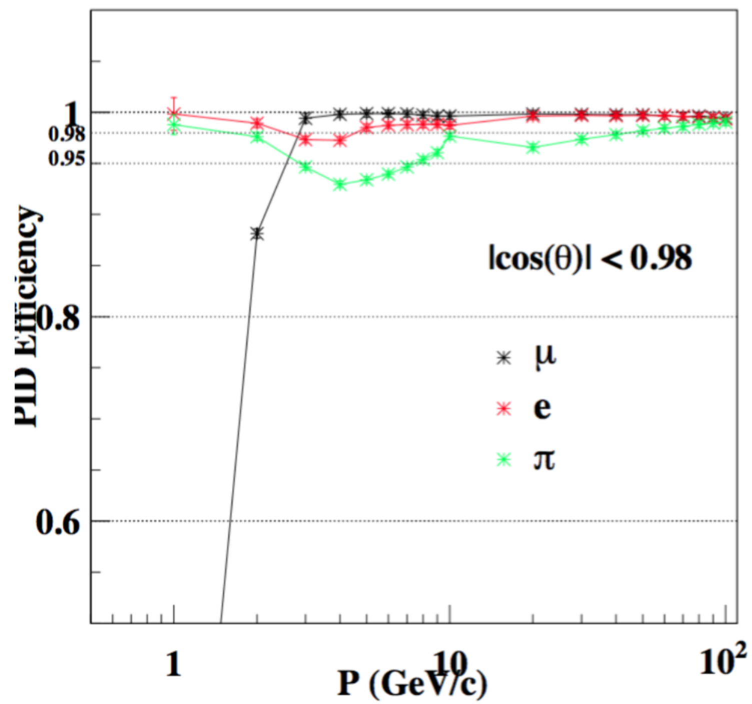
2.88% accuracy achieved with counting for lvqq channel

2.69%accuracy achieved with counting

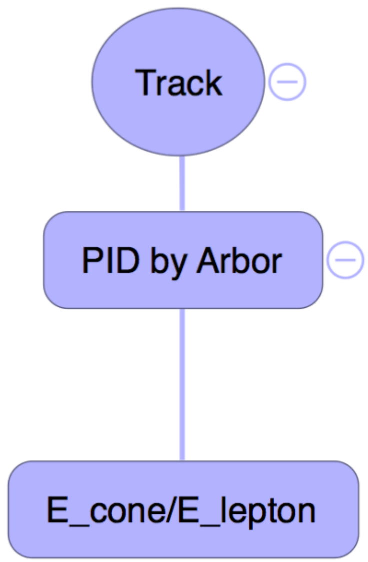
PID & Isolated lepton

E_{lepton}	Leptons' flavor	Full-leptonic Decay		Semi-leptonic Decay	
		Cone Angle[rad]	E_{Cone}/E_{Lepton}	Cone Angle[rad]	E_{Cone}/E_{Lepton}
5 GeV – 10 GeV	Muon	0.15	0.25	0.15	0.7
	Electron	0.3	1.1	0.3	0.9
10 GeV – 15 GeV	Muon	0.15	0.35	0.15	0.25
	Electron	0.3	0.75	0.3	0.75
> 15 GeV	Muon	0.15	0.3	0.15	0.25
	Electron	0.25	0.55	0.25	0.6

isolated-lepton parameters from Libo's work



PID result from Binsong's result



Final state table of Higgs -> ZZ* analysis

O_2	$\sigma_{ZZ} = \sigma_{ZH} \times Br(H \to ZZ^*)$

ZZ*\lniZ	$\mu^+\mu^-$	e^+e^-
vvqq	11.6%	15.1%
qqvv	126	126

ZZ*\lniZ	vv
μμqq	10.7%
qqμμ	12.3%
eeqq	18.6%
qqee	126

ZZ*\lniZ	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

ZZ*\lniZ	qq
μμvv	126
vvμμ	126
eevv	126
vvee	126

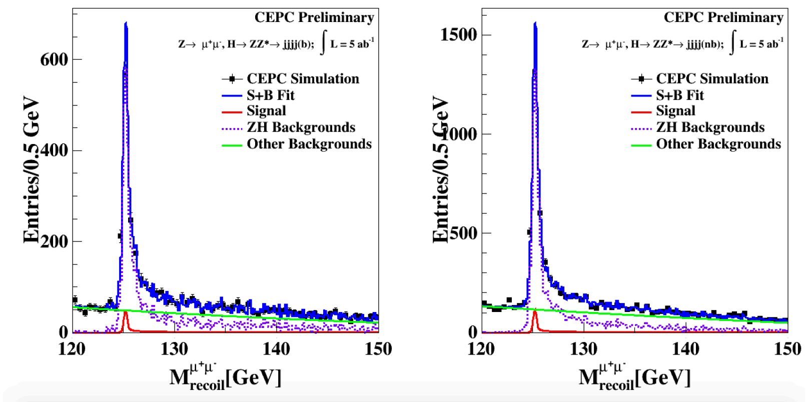
Result on cut base(RA < 20%)

Needs more optimise for better result

Needs more methods proving the analysis to get a conductive result

Br(H -> ZZ*->ZZZ*->llqqqq(l = e or μ))

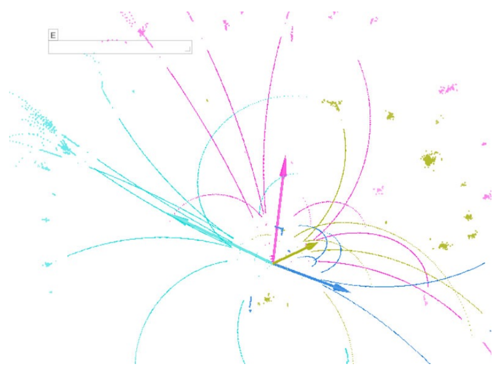
O_2	$\sigma_{ZZ} = \sigma_{ZH} \times Br(H \to ZZ^*)$



huge ZH background:ZH,H->WW*->qqqq,H->bb(4jets events (including 2jets from Z*) mixed up with 2jets events)
We could use the same analyse method on WW*->qqqq channel, high cross section and B-tag technique provide a promise result.

Rel Acu: 48.5%

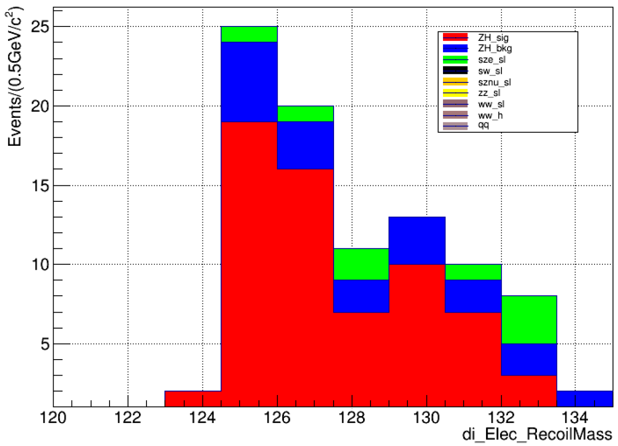
2 jets event



4 jets event

Br(H -> ZZ*->ZZZ*->llvvqq (l = e or μ))

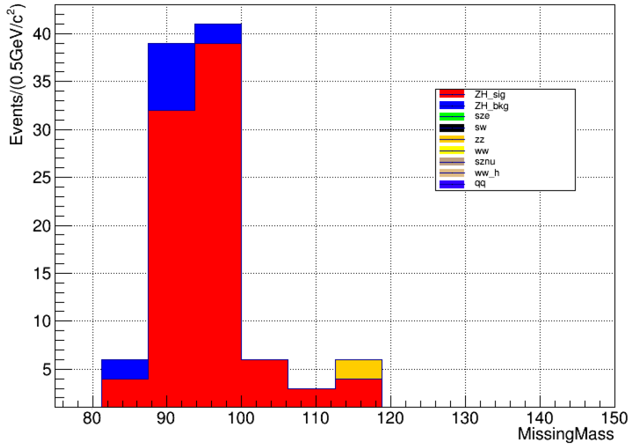
O₂	$\sigma_{ZZ} = \sigma_{ZH} \times Br(H \to ZZ^*)$



ZZZ*->μμvvqq

Cut Chain and corresponding
will be show in the backup

Obj Eff:92.8%
Sig Eff:51.6%
Rel Acu: 11.6%



ZZZ*->eevvqq

Cut Chain and corresponding
will be show in the backup

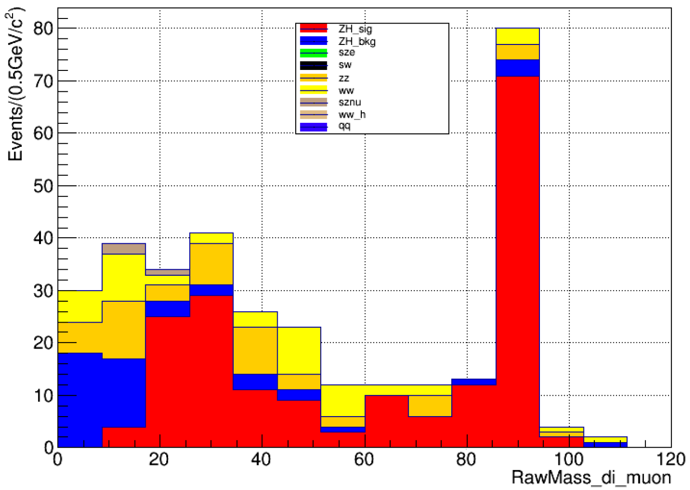
Obj Eff:92.9%
Sig Eff:69.8%
Rel Acu: 15.1%

9% accuracy achieved with counting

background remain | Tau event

Br(H -> ZZ*->ZZZ*->vvllqq/vvllqq(l = e or μ))

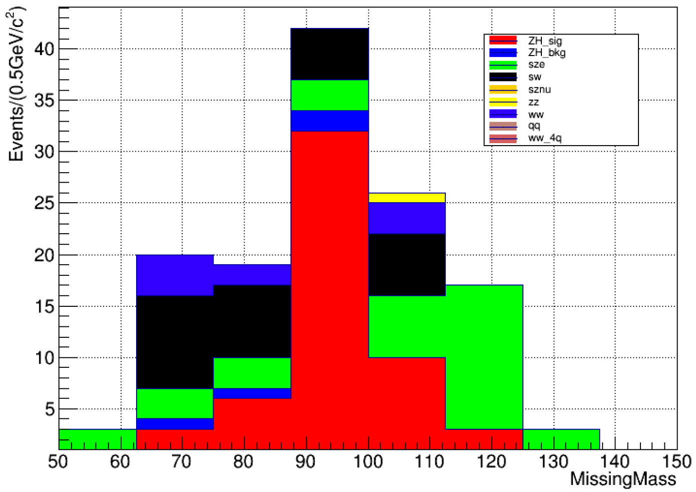
O_2	$\sigma_{ZZ} = \sigma_{ZH}$ x Br(H -> ZZ*)



ZZZ*->vvμμqq/qqμμ

Cut Chain and corresponding will be show in the backup

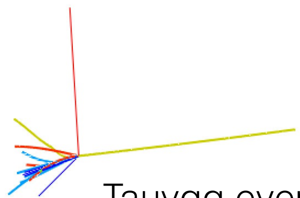
Obj Eff:92.8%
Sig Eff:51.6%
Rel Acu: 8.4%



ZZZ*->vveeqq

Cut Chain and corresponding will be show in the backup

Obj Eff:92.9%
Sig Eff:69.8%
Rel Acu: 17.2%



Tauvqq event

background remain	Tau event

7.4% accuracy achieved with counting
6.8% accuracy achieved with contribution of WW fusion events, match the result of **6.9%** in pre-CDR which is based on fast-simulation of parton level

5.4% accuracy achieved with counting combine these 5 sub channel

Result

$$\Gamma_h \propto g_Z^2 \frac{\sigma_Z^{\rm inc}\sigma_{Wb}}{\sigma_{ZW}\sigma_{Zb}}$$ WW method

$$\Gamma_h = \frac{(g_A^2)^2}{(g_A^2 g_A^2/\Gamma_h)} \propto g_A^2 \frac{\sigma_A^{\rm inc}}{\sigma_{AA}};$$ ZZ method

O_1	σ_{ZH}	0.5% from pre-CDR
O_2	$\sigma_{ZZ} = \sigma_{ZH}$ x Br(H -> ZZ*)	4.3% extrapolated from TLEP
O_3	$\sigma_{Wb} = \sigma_{\nu\nu H}$ x Br(H -> bb)	2.8% from pre-CDR
O_4	$\sigma_{ZW} = \sigma_{ZH}$ x Br(H -> WW*)	1.38% latest result from Libo's work combined with the result extrapolated from ILC result (1.5% at PreCDR)
O_5	$\sigma_{Zb} = \sigma_{ZH}$ x Br(H -> bb)	0.28% from pre-CDR

Total Higgs width relative precision

ww method	3.3%
zz method	4.4%

comparison

- H->WW;
  - To ILC: covers Z->ll channel (ILC only covers Z(vv)H(WW->qqqq) & Z(qq)H(WW->lvqq)); (Ono. Higgs branching ratios study for DBD Jan. 12 2013)
  - To preCDR: signal efficiency improved by 2 times: due to the improvement of reconstruction algorithm and PID;
- H->ZZ;
  - To ILC: sub channel separation according to final state objects; In ILC analysis, H->WW background seems missing (arxiv:1310.0763)
  - To TLEP: 4.3% extrapolated from ww fusion channel; Considering we have already get a relative accuracy at 5.4%, 7% extra relative accuracy is needed to match TLEP's result, achievable via ZZZ*->4l+2q and neutrino channel in our estimation.
  - To PreCDR: covers 3 major additional channel; agree with fast simulation result in vvllqq channel (6.8% Full Simulation compare to 6.9% Fast Simulation).

Plan for Higgs -> ZZ* analysis

- Cut base -> TMVA
- process all of standard model with full simulation
- Including other channels with leptonic final states
- valid tau finder for H->WW*/ZZ* analysis environment
- more powerful distinguishing variables or jet clustering algorithm to tag low-energy jets

Back up

Cut Chain of ZZZ*->eevvjj

	signal	ZH_bkg	sze_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

Cut Chain of ZZZ*->μμvvjj

	signal	ZH_bkg	sze_sl	sw_sl	zz_sl	ww_sl	sznu_sl	ww_h	qq
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

Cut Chain of ZZZ*->vvμμjj

	signal	ZH_bkg	sze_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

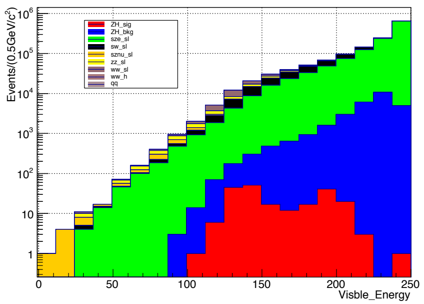
Cut Chain of ZZZ*->vvjjμμ

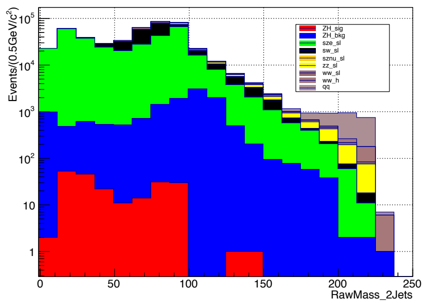
	signal	ZH_bkg	sze_sl	sw_sl	zz_sl	ww_sl	sznu_sl	ww_h	qq
final_state	231	1268	1165	601	468485	113680	834	2109	9251
Missingmass(58,128)	221	865	533	533	7961	14984	477	0	35
Invariant mass of Muons is less than that of jets	113	823	532	533	7747	14903	477	0	35
mina1&mina2	108	485	319	395	5622	4508	192	0	19
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

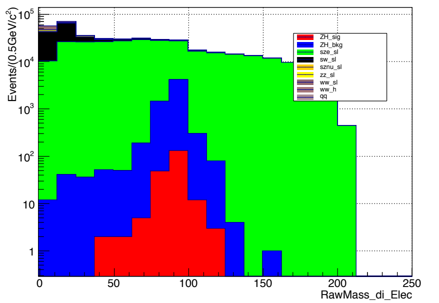
Cut Chain of ZZZ*->vveejj

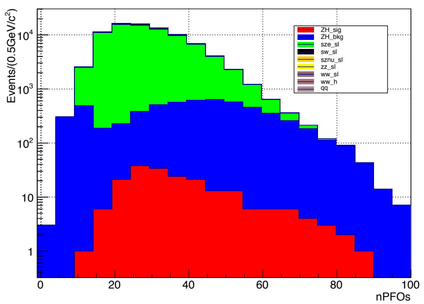
	signal	ZH_bkg	sze_sl	sw_sl	zz_sl	ww_sl	sznu_sl	ww_h(4q)	qq(1%)(2f)
final state	189	8632	1.39E+06	105756	15627	18296	684	2520	7574
missing-mass(58,138)	184	7136	34688	12099	7505	13850	454	3	21
Invariant mass of Muons is larger than that of jets	85	69	21763	1162	193	367	0	0	1
Invariant mass of 2 jets and 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

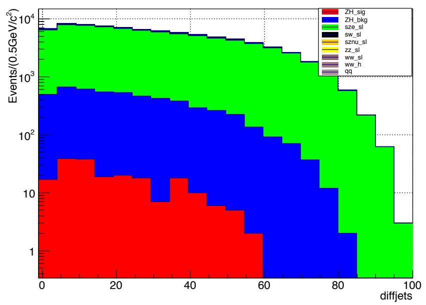
ZZZ*->eevvjj

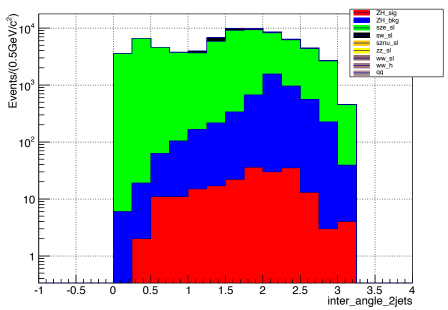

Events/(0.5GeV/c^2)
Visble_Energy
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

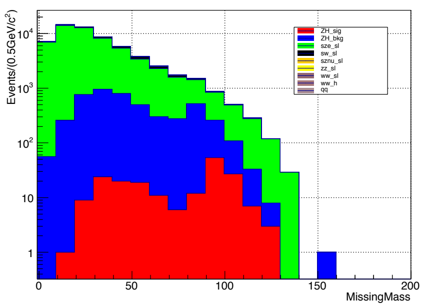

Events/(0.5GeV/c^2)
RawMass_2Jets
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

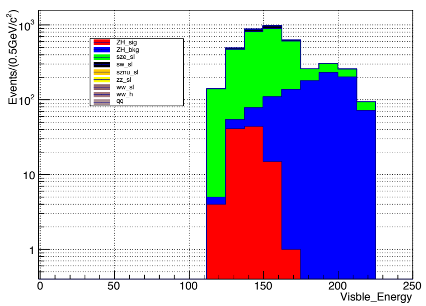

Events/(0.5GeV/c^2)
RawMass_di_Elec
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

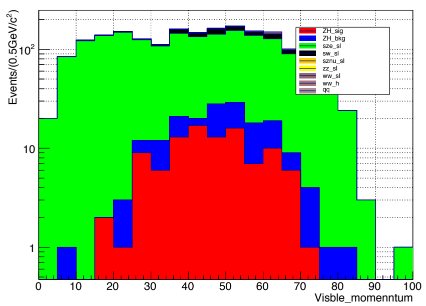

Events/(0.5GeV/c^2)
nPFOs
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

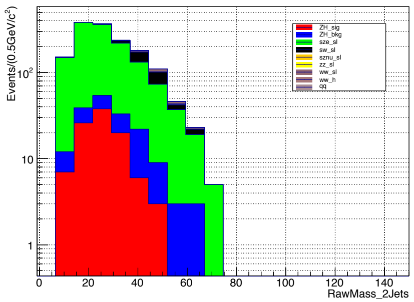

Events/(0.5GeV/c^2)
diffjets
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

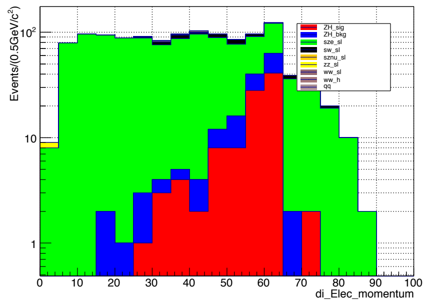

Events/(0.5GeV/c^2)
inter_angle_2jets
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

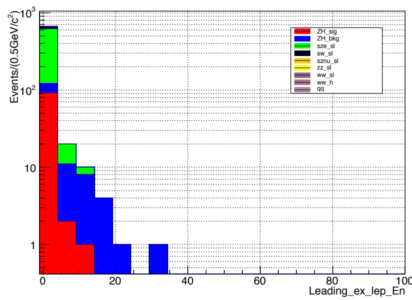

Events/(0.5GeV/c^2)
MissingMass
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

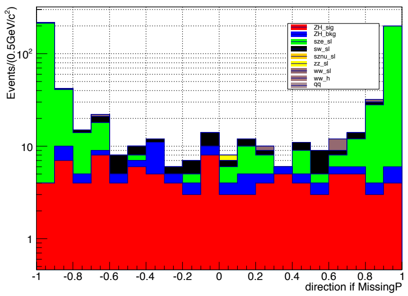

Events/(0.5GeV/c^2)
Visble_Energy
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

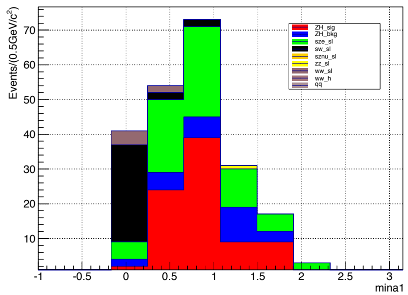

Events/(0.5GeV/c^2)
Visble_momenntum
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

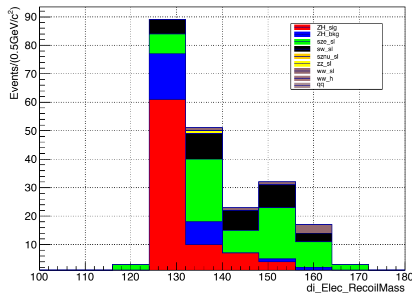

Events/(0.5GeV/c²)
RawMass_2Jets
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq


Events/(0.5GeV/c²)
di_Elec_momentum
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

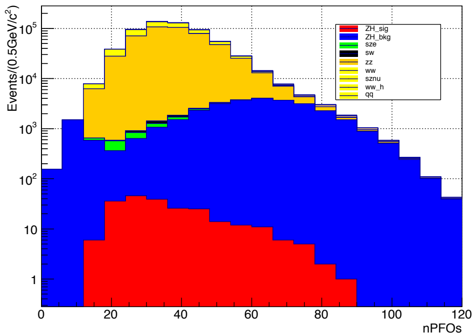

Events/(0.5GeV/c²)
Leading_ex_lep_En
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

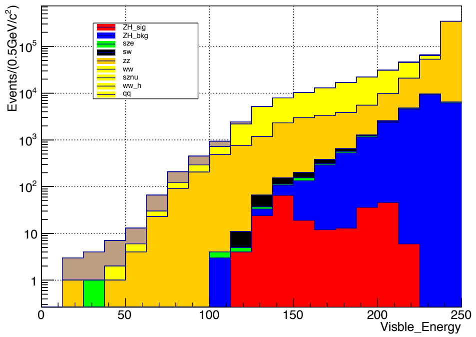

Events/(0.5GeV/c²)
direction if MissingP
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

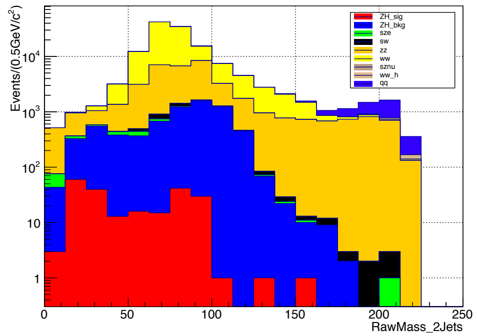

Events/(0.5GeV/c²)
mina1
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

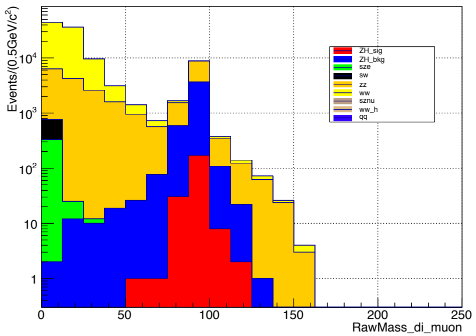

Events/(0.5GeV/c²)
di_Elec_RecoilMass
ZH_sig
ZH_bkg
sze_sl
sw_sl
sznu_sl
zz_sl
ww_sl
ww_h
qq

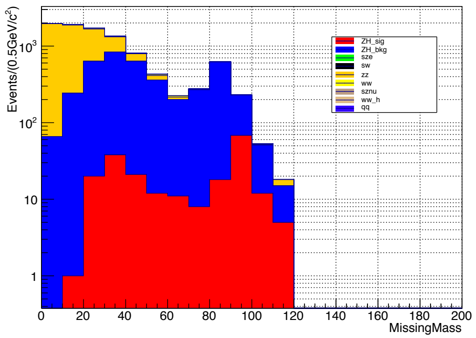
ZZZ*->μμννjj

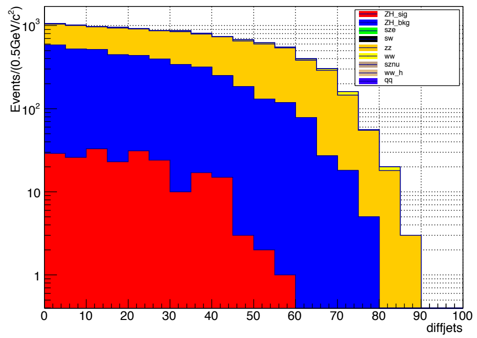

Events/(0.5GeV/c^2)
nPFOs
ZH_sig
ZH_bkg
sze
sw
zz
ww
sznu
ww_h
qq

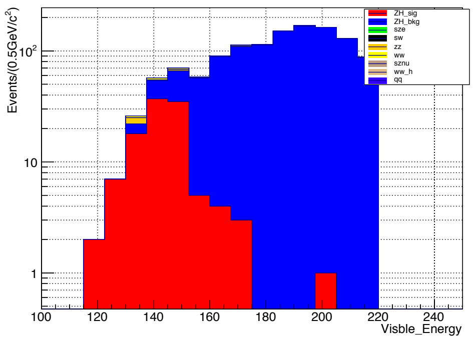

Events/(0.5GeV/c^2)
Visble_Energy
ZH_sig
ZH_bkg
sze
sw
zz
ww
sznu
ww_h
qq

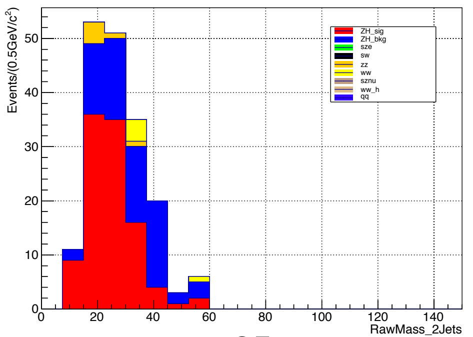

Events/(0.5GeV/c^2)
RawMass_2Jets
ZH_sig
ZH_bkg
sze
sw
zz
ww
sznu
ww_h
qq

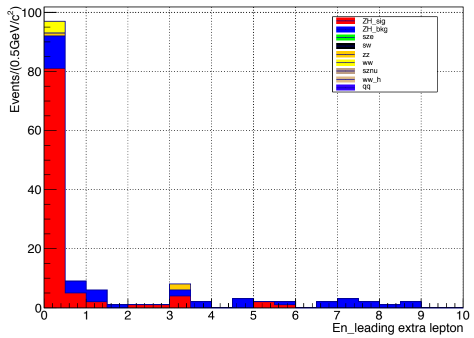

Events/(0.5GeV/c^2)
RawMass_di_muon
ZH_sig
ZH_bkg
sze
sw
zz
ww
sznu
ww_h
qq


Events/(0.5GeV/c^2)
MissingMass
ZH_sig
ZH_bkg
sze
sw
zz
ww
sznu
ww_h
qq

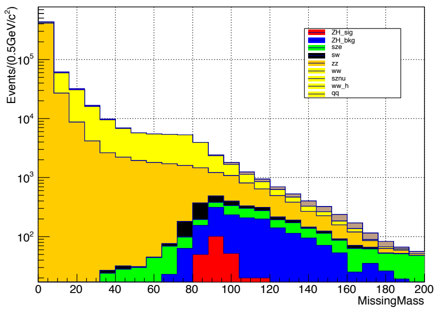

Events/(0.5GeV/c^2)
diffjets
ZH_sig
ZH_bkg
sze
sw
zz
ww
sznu
ww_h
qq


Events/(0.5GeV/c^2)
Visble_Energy
ZH_sig
ZH_bkg
sze
sw
zz
ww
sznu
ww_h
qq

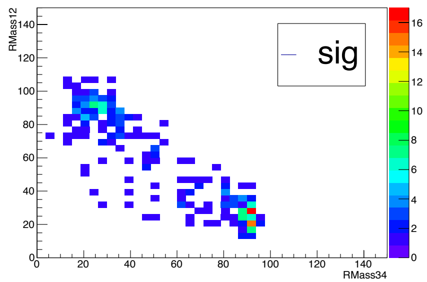

Events/(0.5GeV/c^2)
RawMass_2Jets
ZH_sig
ZH_bkg
sze
sw
zz
ww
sznu
ww_h
qq


Events/(0.5GeV/c^2)
En_leading extra lepton
ZH_sig
ZH_bkg
sze
sw
zz
ww
sznu
ww_h
qq

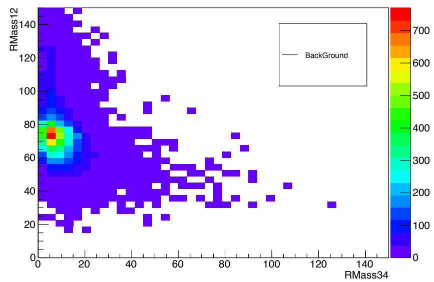
ZZZ*->vvμμjj



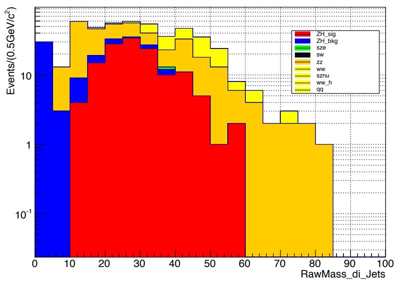
Events/(0.5GeV/c²)
ZH_sig
ZH_bkg
sze
sw
zz
ww
sznu
ww_h
qq
MissingMass



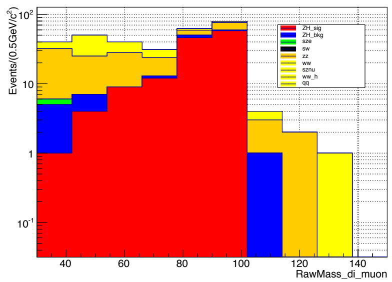
RMass12
sig
RMass34



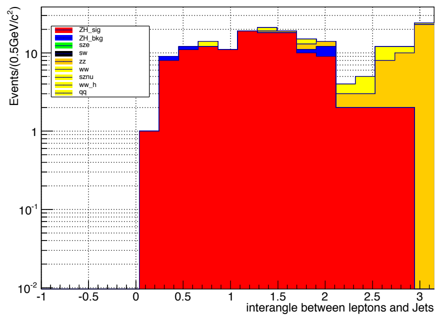
RMass12
BackGround
RMass34



Events/(0.5GeV/c²)
RawMass_di_Jets

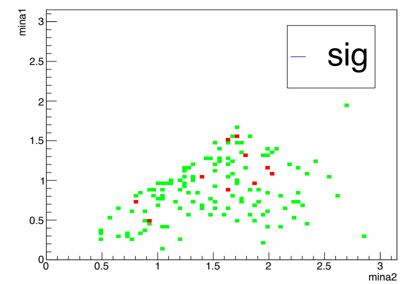


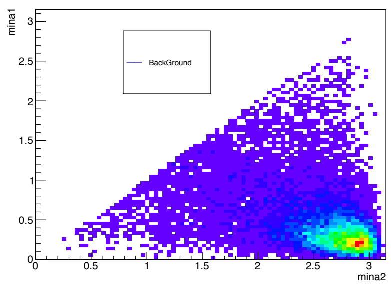
Events/(0.5GeV/c²)
RawMass_di_muon

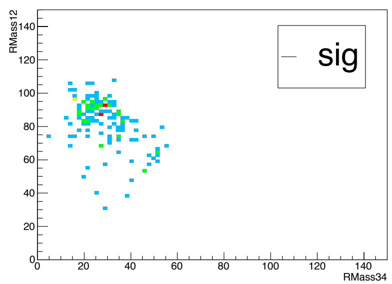


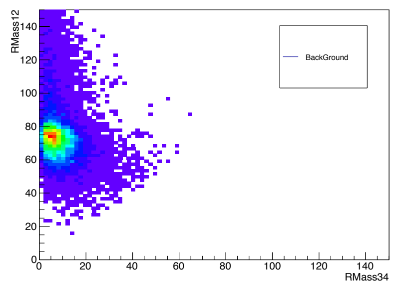
Events/(0.5GeV/c²)
interangle between leptons and Jets

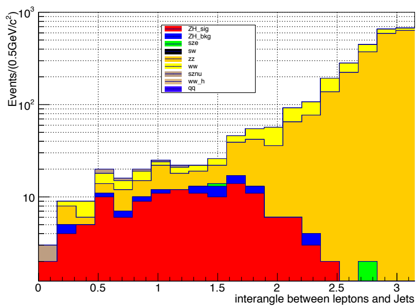
ZZZ*->vvjjμμ

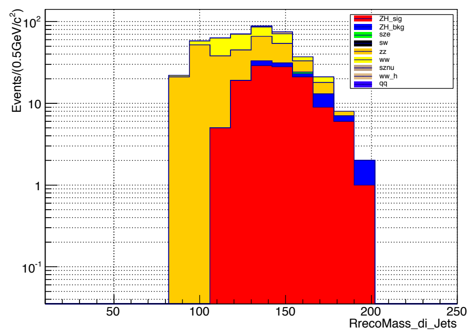

sig
mina1
mina2

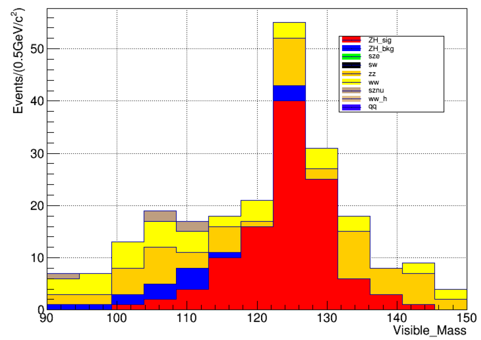

BackGround
mina1
mina2


sig
RMass12
RMass34

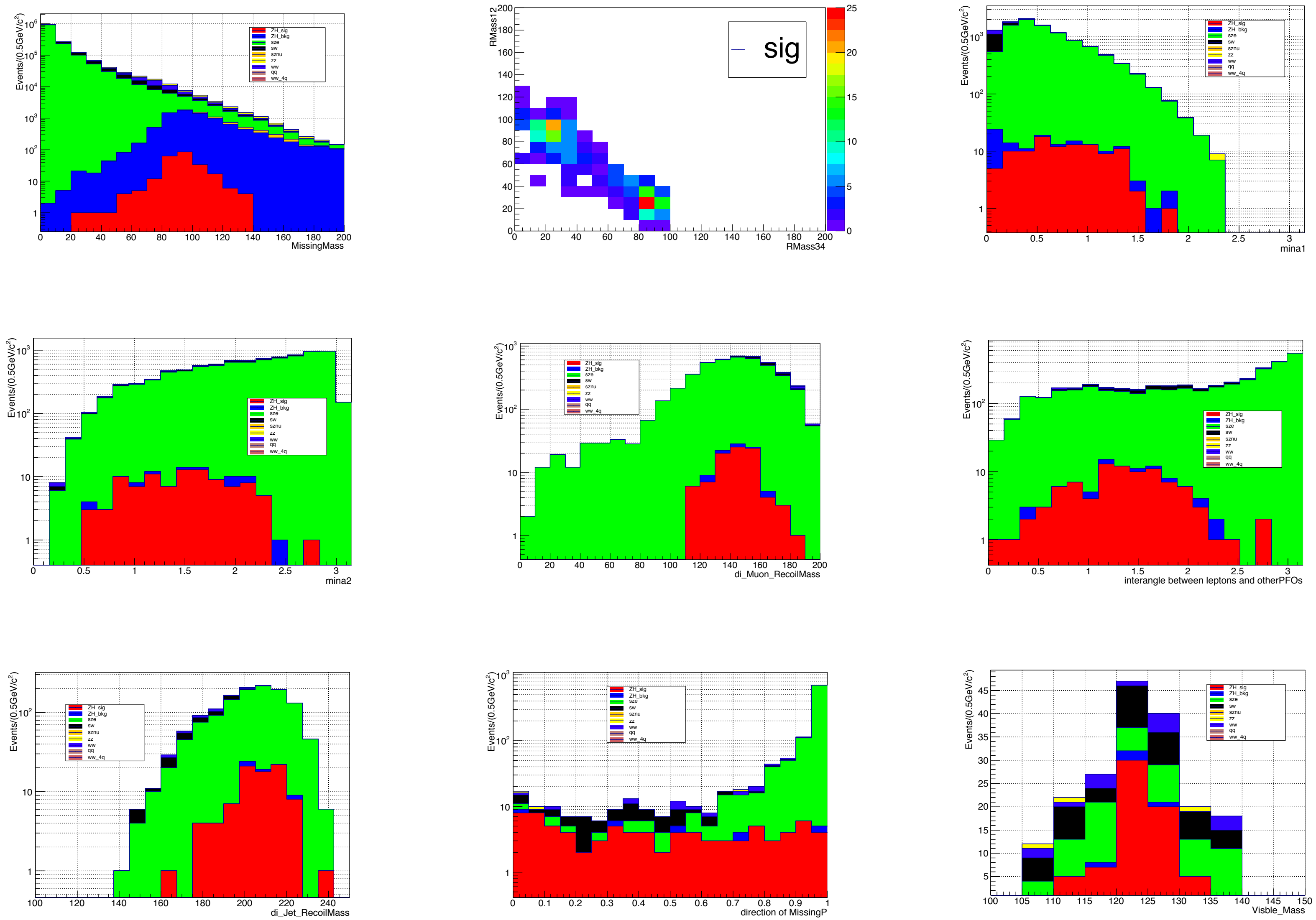

BackGround
RMass12
RMass34

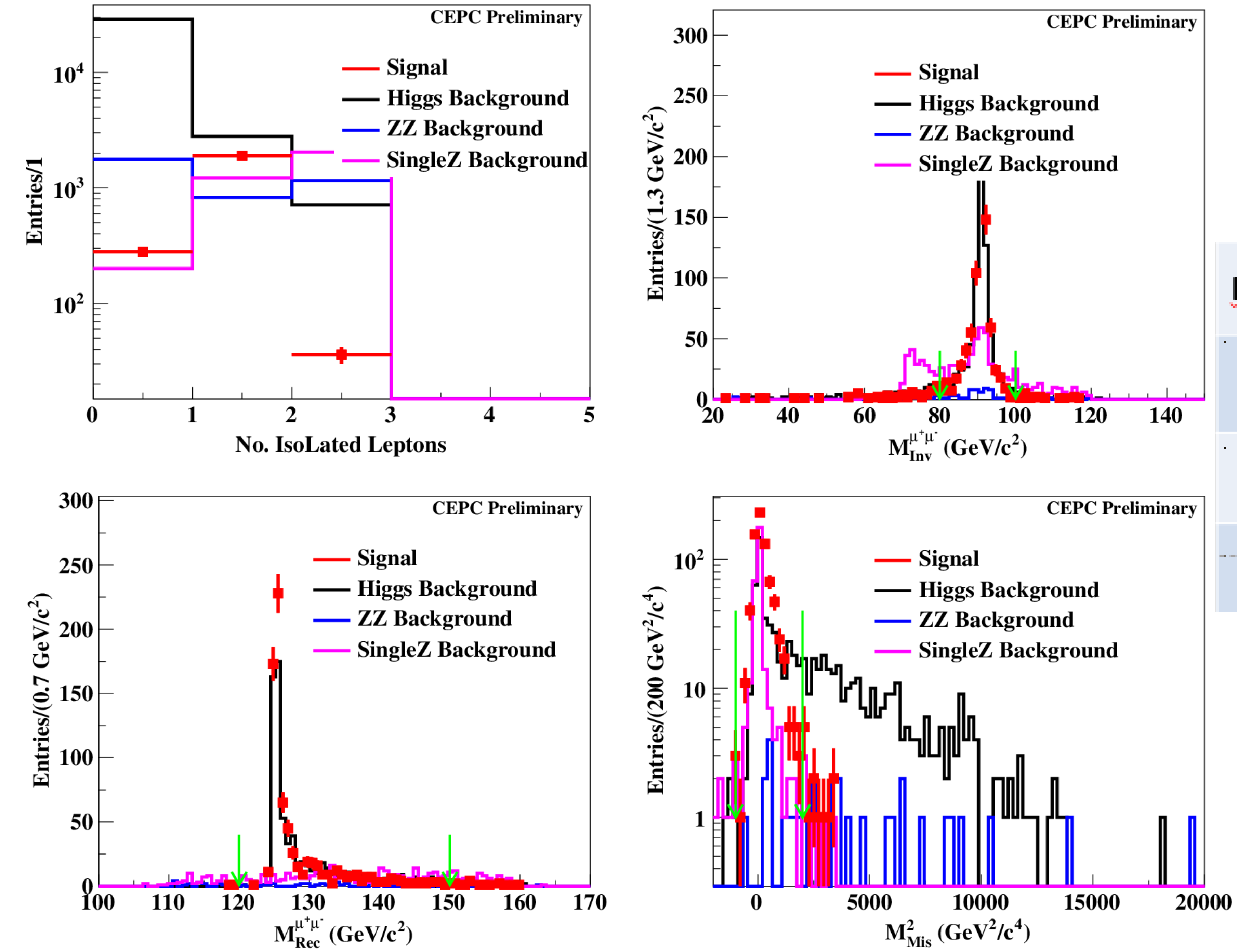

Events/(0.5GeV/c²)
interangle between leptons and Jets


Events/(0.5GeV/c²)
RrecoMass_di_Jets


Events/(0.5GeV/c²)
Visible_Mass

ZZZ*->vveejj


Events/(0.5GeV/c^2)
MissingMass
ZH_sig
ZH_bkg
sze
sw
sznu
zz
ww
qq
ww_4q
RMass12
RMass34
sig
mina1
mina2
di_Muon_RecoilMass
interangle between leptons and otherPFOs
di_Jet_RecoilMass
direction of MissingP
Visble_Mass



$$H \rightarrow WW^{*} \rightarrow e\nu qq$$

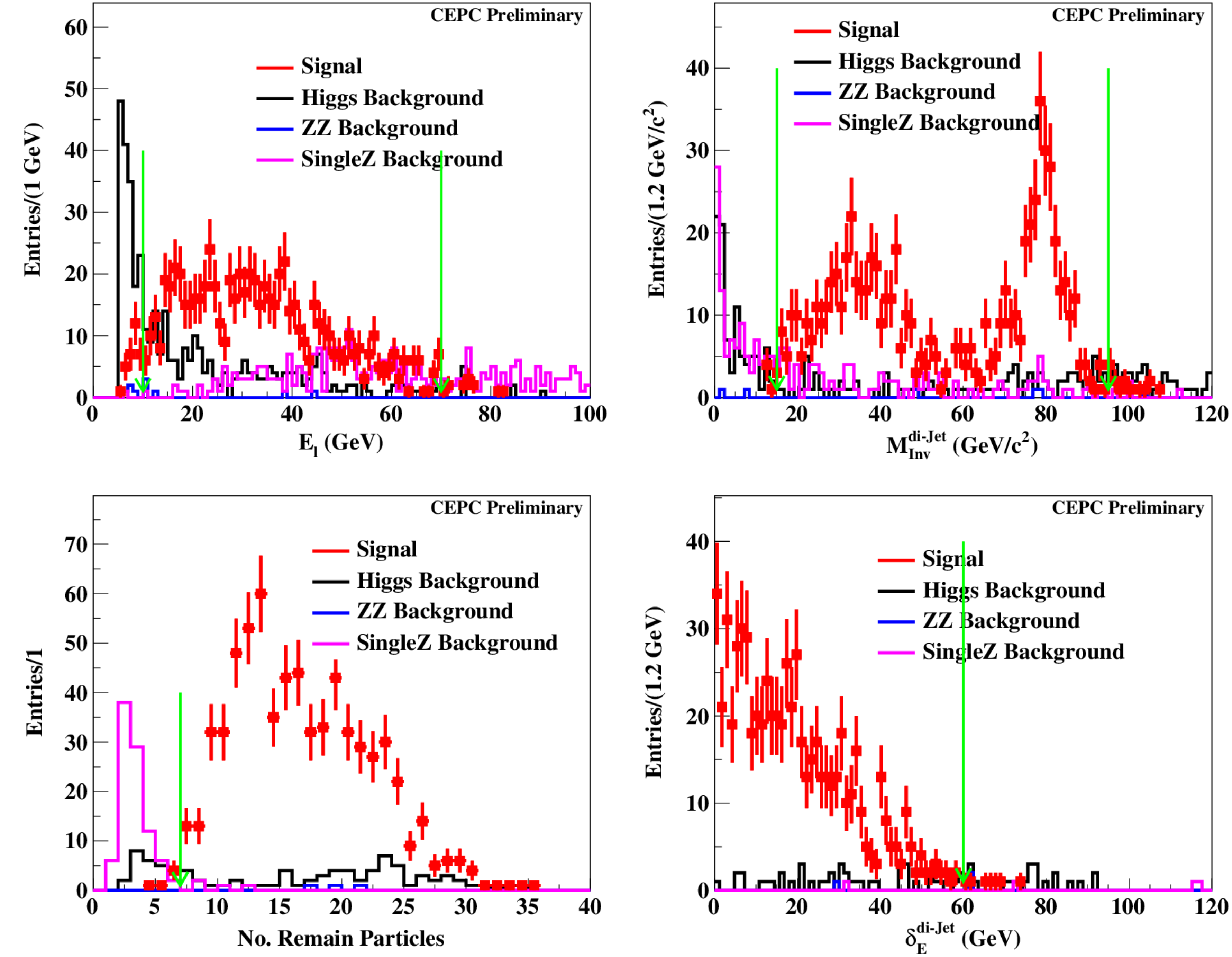
NIsoLep = 1, Nzpole = 2, Njet = 2, e

$80\text{GeV} < Mass_{Inv}^{\mu+\mu-} < 100\text{GeV}$

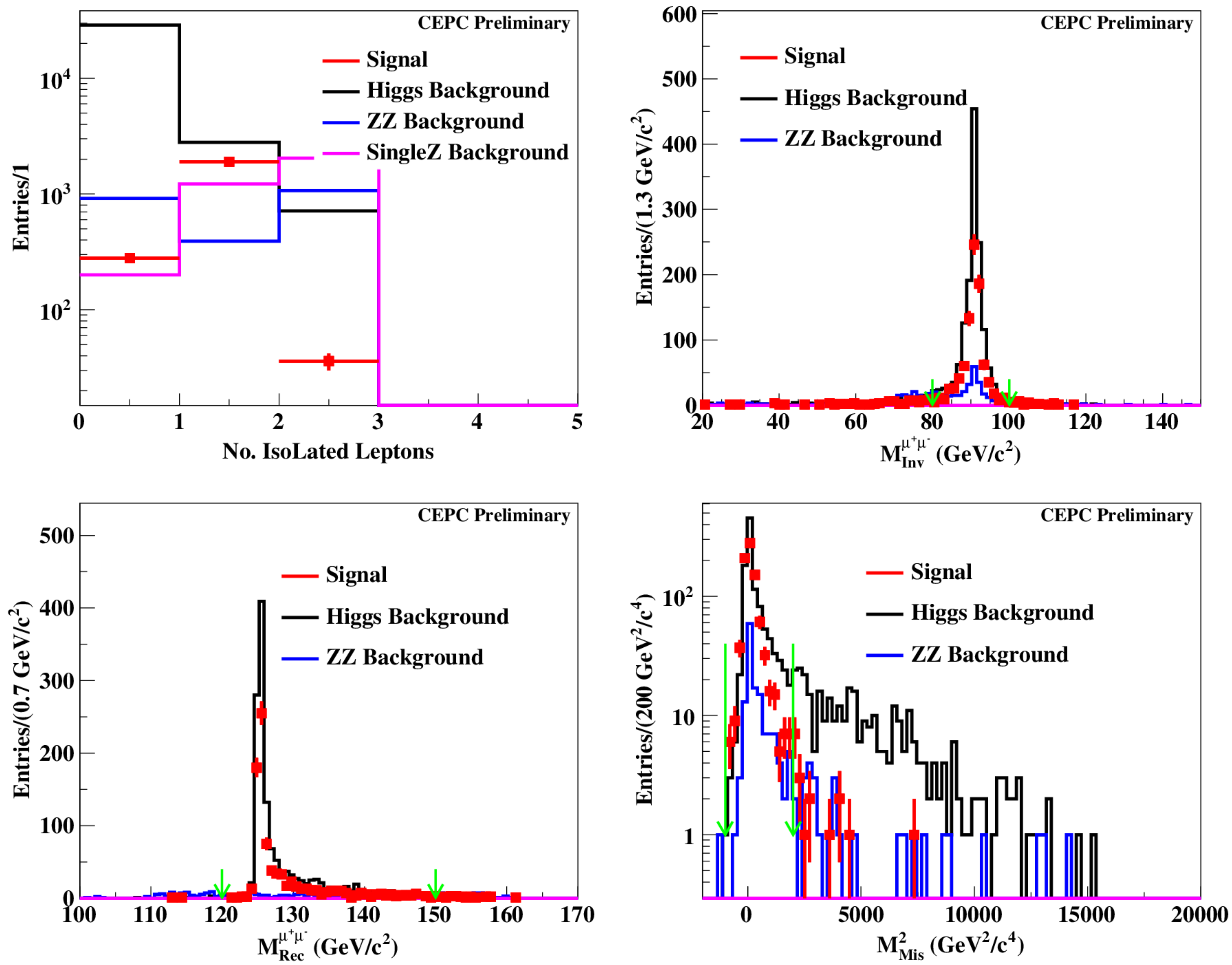
$120\text{GeV} < Mass_{Rec}^{\mu+\mu-} < 150\text{GeV}$

$-1000 < M^{2}{}_{Missing} < 2000$

$$H \to WW^* \to e\nu qq$$



10GeV < E_lepton < 70GeV
$15GeV < Mass_{Rec}^{di-jet} < 95GeV$
No. Remain Particle >6
|E_jet1-E_Jet2|<60



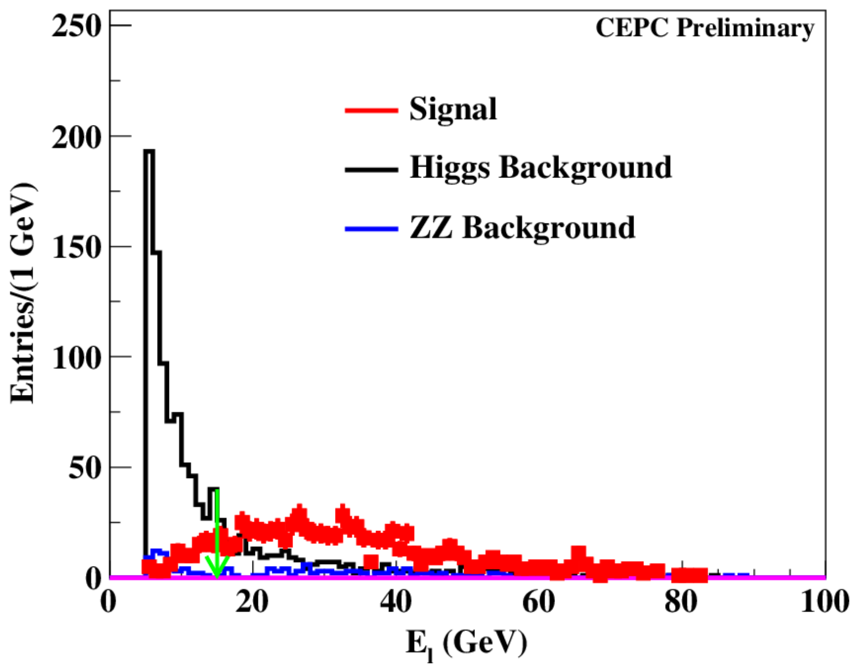
$H \to WW^* \to \mu\nu qq$

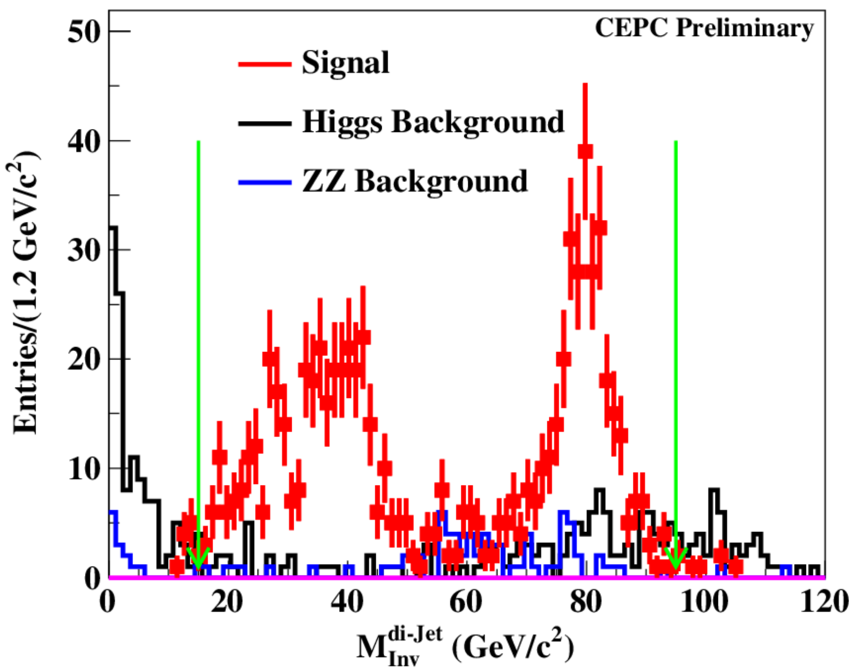
NIsoLep = 1,Nzpole = 2,Njet = 2,u

80GeV < $Mass^{\mu+\mu-}_{Inv}$ < 100GeV

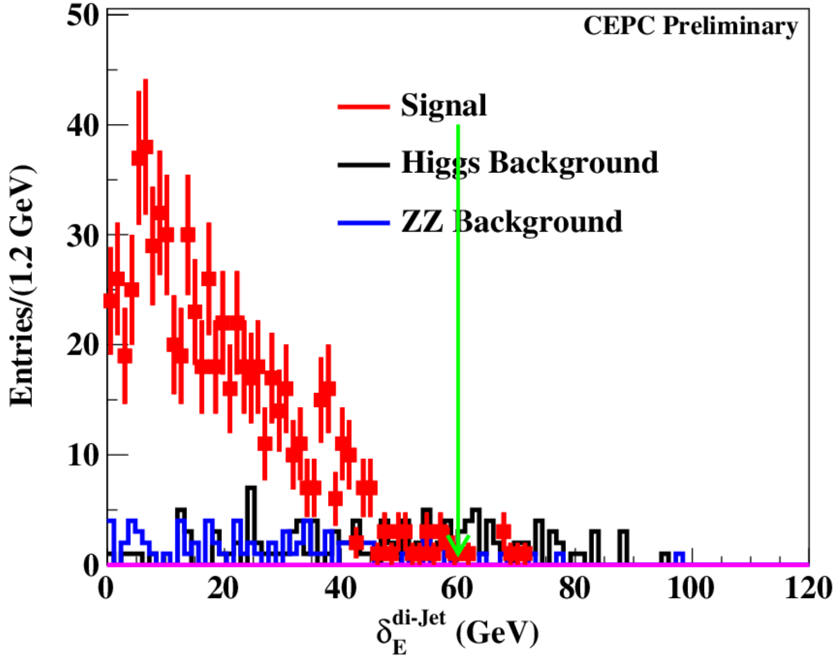
120GeV < $Mass^{\mu+\mu-}_{Rec}$ < 150GeV

-1000 < $M^2{}_{Missing}$ < 2000





$$H \rightarrow WW^{*} \rightarrow \mu\nu qq$$



E_lepton > 15GeV
$15\text{GeV} < Mass_{Rec}^{di-jet} < 95\text{GeV}$
|E_jet1-E_Jet2|<60