Status of $H \to \mu^+\mu^-$

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Outline

- Motivation
- Overview of the analysis for 3.5T
- $\boldsymbol{Z\mu\mu H\mu\mu}$ for 240GeV @ 3T
- Next step

Motivation

- Measurement of the rare $H \rightarrow \mu^+\mu^-$ decay
- Very low branching ratio of order of 10^{-4} predicted by the SM.
- Requires excellent muon identification efficiency and momentum resolution as well as a comprehensive background suppression.
- CEPC can use Recoil mass for Higgs measurement, which is not rely on model and Higgs decay channel
- Lepton collider has clearer background

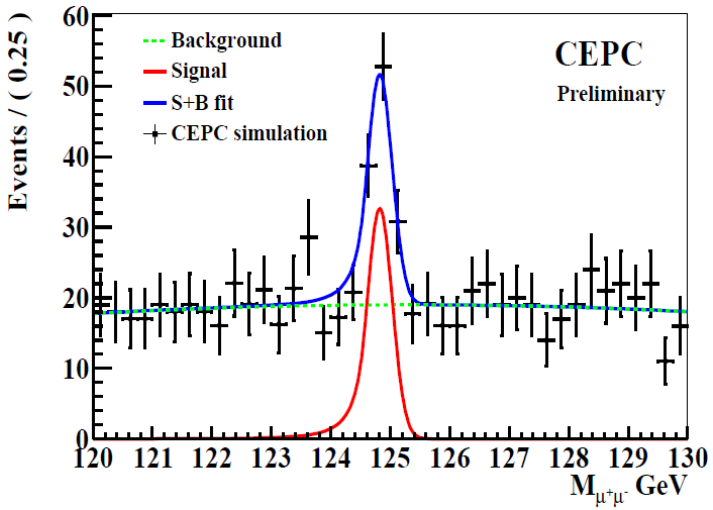
Results from other experiments

Detector	Signal	Lumi(fb^{-1})	Energy (TeV)	results
ATLAS	VBF+VH	4.5&20.3	7&8	Signal strength $=-0.6^{+3.6}_{-3.6}$ upper limit =7
CMS	GF+VBF+VH	5&19.7	7&8	Signal strength $=-0.9^{+3.6}_{-3.5}$ upper limit=7.4
HL-ATLAS	ggH+VBF+ VH+ttH	3000	14	Uncertainty of Higgs μ coupling =21% Significance =7σ
HL-CMS	0/1-jets(μμ) VBF(jj+μμ)	3000	14	uncertainty=[20,24]%
ILC	νν̄H	500	1	uncertainty=31% Significance =2.75σ
	qq̄H	250	0.25	Significance =1.1σ
	νν̄H	250	0.25	Significance =1.8σ
	qq̄H，νν̄H	2000	0.25	uncertainty=20.5%
	qq̄H，νν̄H	4000	0.25	uncertainty=17.5%

From Zhenwei

$Zq\bar{q}H\mu\mu$

Cut 变量	signal	ZZ	WW	ZZorWW	SingleZ	2f
初始条件	156.3	390775	183751	463361	101164	63217
120< $M_{\mu^+\mu^-}$ <130	141.6	3786	181	227	244	100
M_{j1}>4.2 M_{j2}>2.8	133.0	3216	111	0	9	60
M_{jj}>76.0	127.5	2917	2	0	8	59
90.9<$M^{\mu^+\mu^-}_{\text{recoil}}$ <93.5	75.2	893	0	0	0	0
20<$P_{T_{\mu^+\mu^-}}$ <64	74.5	777	0	0	0	0
-58<$P_{Z_{\mu^+\mu^-}}$ <58	74.5	748	0	0	0	0
$\cos\theta_{\mu^+}$>-0.98 $\cos\theta_{\mu^-}$<0.98	74.2	747	0	0	0	0
efficiency	47.5%					



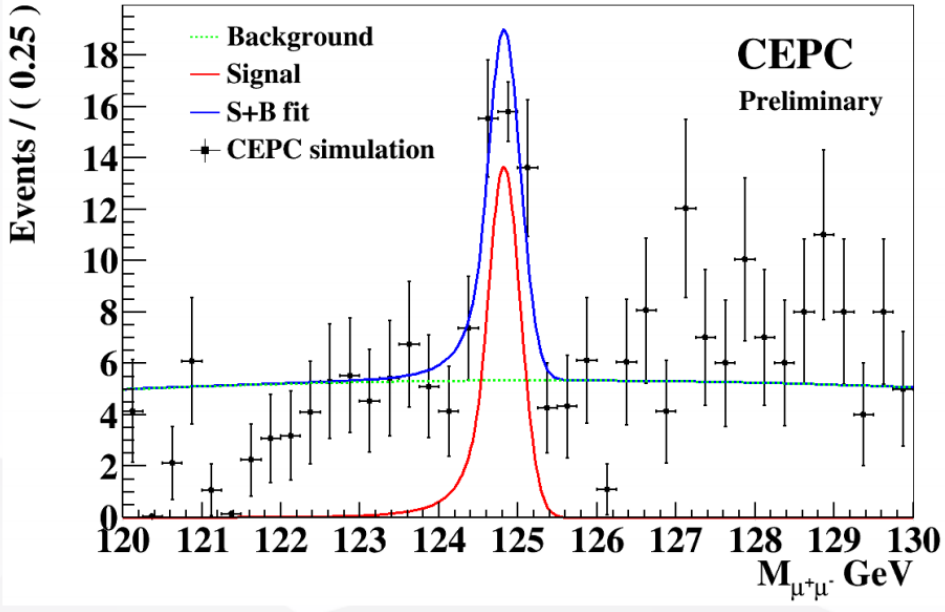
Main Bkg：$ZZ \to \mu\mu qq$

Signal number=79.6(71.6) $\pm$ 12.4
significance=8.12σ
uncertainty= [-16,17]%

From Zhenwei and Kaili

$Zq\bar{q}H\mu\mu$ for 240 GeV @ 3T

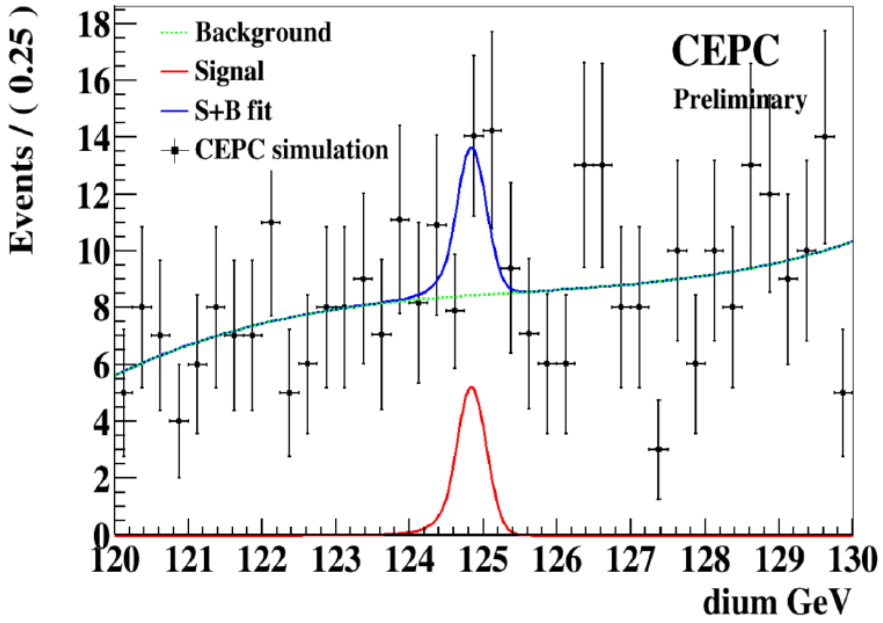
Cut	Signal	ZZ	WW	ZZorWW	SingleZ	Bkg	significance $\sigma=\sqrt{2(s+b)\ln(1+s/b)-s}$
Initial conditions	219.351	251561	5793	285	7909	265548	/
120< $M_{\mu^+\mu^-}$ <130	149.155	3641	131	41	405	4218	/
87<$M_{\mu\ \mu}$ <95	68.563	1422	0	0	29	1451	/
25< P_{Tu}<*64*	58.765	1155	0	0	20	1175	7.8522
-60< P_{Zu}<*20*	43.562	288	0	0	5	293	7.0526
20<ptj<60	27.186	195	0	0	3	198	5.5461



From Boqun and Haifeng

$Z\nu\bar{\nu}H\mu\mu$

Cut 变量	signal	ZZ	WW(SW)	ZZorWW	SingleZ	2f
初始条件	41.7	34901	121952	489686	25619	1635887
$120<M_{\mu^+\mu^-}<130$	38.4	382	16677	56029	315	49490
MET>8.5	37.9	291	16264	53740	305	8600
$90.8<M_{recoil_\mu}<93.4$	24.0	96	834	2034	79	184
$\cos\theta_{Z\mu^+}<0.999$	24.0	96	833	2034	79	126
$\cos\theta_{Z\mu^-}<0.999$	24.0	96	833	2034	79	57
$cos\theta_{\mu^+}>0$	12.0	33	28	108	25	10
$cos\theta_{\mu^-}<0$	9.1	22	11	86	17	9
efficiency	21.8%					



Cut-based:

Signal number=10.9(14.0) ± 6.2

Significance=1.91σ

uncertainty= [-34,38]%

TMVA

$cos\theta_{Z\mu^\pm}, cos\theta_{\mu^\pm}, MET, MEZ$

Signal number=11.0(12.3) ± 5.1

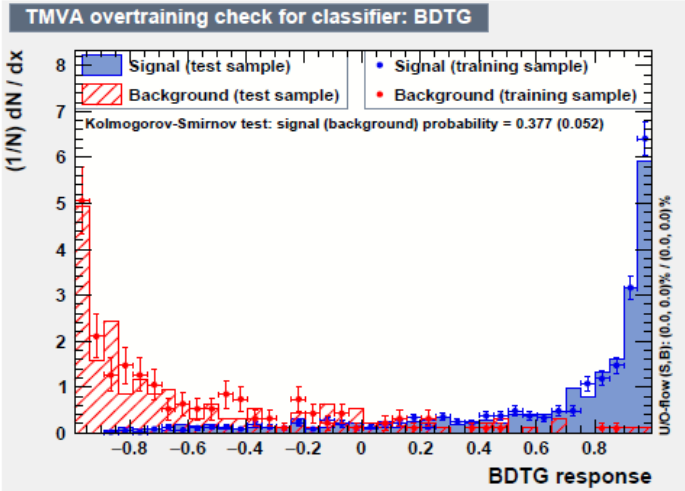
significance=2.63σ

uncertainty= [-30,32]%

From Zhenwei and Kaili

$ZeeH\mu\mu$

Cut 变量	signal	ZZ	WW(SW)	ZZorWW	SingleZ	2f
初始条件	4.7	18	0	9	22672	8.0
$120<M_{\mu^+\mu^-}<130$	4.3	0	0	0	747	0.0
$90.5<M_{recoil_\mu}<92.5$	2.5	0	0	0	34	0.0
$cos_{\mu^+\mu^-}<$-0.603	2.5	0	0	0	33	0.0
$P_{T_{\mu^+\mu^-}}<62.5$	2.5	0	0	0	31	0.0
$138.5<E_{\mu^+\mu^-}<139.7$	2.2	0	0	0	8	0.0
efficiency	46.8%					



Training variables :

$M_{\mu^+\mu^-}$, $M^{\mu^+\mu^-}_{recoil}$, $E_{\mu^+\mu^-}$,

$M_{e^+e^-}$, $M^{e^+e^-}_{recoil}$, $cos\theta_{\mu^+\mu^-}$

$cos\theta_{\mu^\pm}$ $P_{T_{\mu^+\mu^-}}$ $P_{Z_{\mu^+\mu^-}}$

Cut-based significance=0.74σ

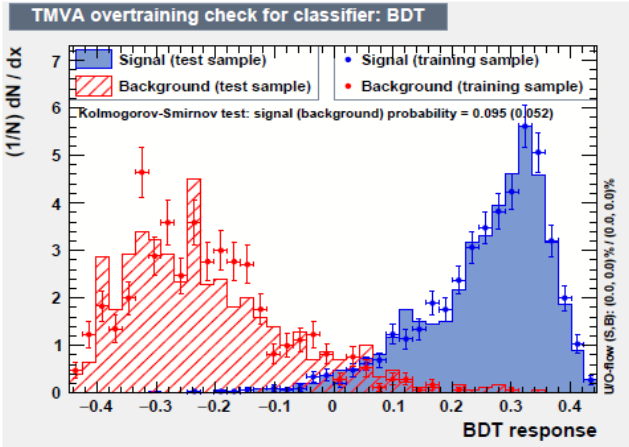
TMVA significance=1.5σ

From Zhenwei and Kaili

From Zhenwei and Kaili

$Z\mu\mu H\mu\mu$

Category	signal	ZZ	WW(SW)	ZZorWW	SingleZ	2f
Preselection	6.6	17631.0	0	0	0	0.0
$120<E_{\mu^+\mu^-}<130$	6.0	1685.2	0	0	0	0.0
$90.6< M_{recoil_\mu} <93.4$	3.9	128.8	0	0	0	0.0
$90.2<M_{\mu^+\mu^-}$(Z)<92.8	3.2	58.1	0	0	0	0.0
$cos_{\mu^+\mu^-}$(H)<-0.603	3.2	50.0	0	0	0	0.0
$cos_{\mu^+\mu^-}$(Z)<-0.364	3.2	47.0	0	0	0	0.0
$138.0<E_{\mu^+\mu^-}$(H)<139.8	3.0	15.5	0	0	0	0.0
$P_{T_{\mu^+\mu^-}}$(H)<62.5	3.0	14.7	0	0	0	0.0
efficiency	45.5%					



Training variables :

$M_{\mu^+\mu^-}(H)$, $M^{\mu^+\mu^-}_{recoil}(H)$, $E_{\mu^+\mu^-}(H)$, $M_{\mu^+\mu^-}(Z)$, $M^{\mu^+\mu^-}_{recoil}(Z)$, $cos\theta_{\mu^+\mu^-}$

Cut-based Significance=1.2σ

TMVA significance=1.5σ

$Z\mu\mu H\mu\mu$ for 240 GeV @ 3T

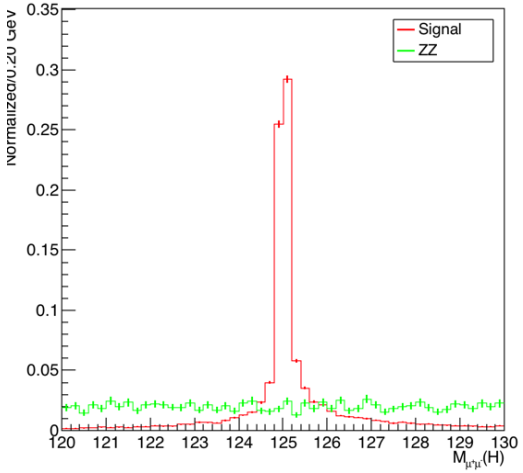
- Signal: $e^+e^- \to Z(\mu^+\mu^-)H(\mu^+\mu^-)$
  - 3T with 240 GeV with total events of 100k
  - /home/bes/lig/higgs/data/SimReco/wo_BS/CEPC_v4/higgs/smart_final_states/E240.PIlh_e2e2.e0.p0.whizard195/

- Dominant Bkg: ZZ to 4mu
  - 3.5T with 250 GeV with total events of 100k
  - /cefs/data/RecData/CEPC250/CEPC_v1/4fermions/E250.Pzz_l.e0.p0.whizard195/04mu/

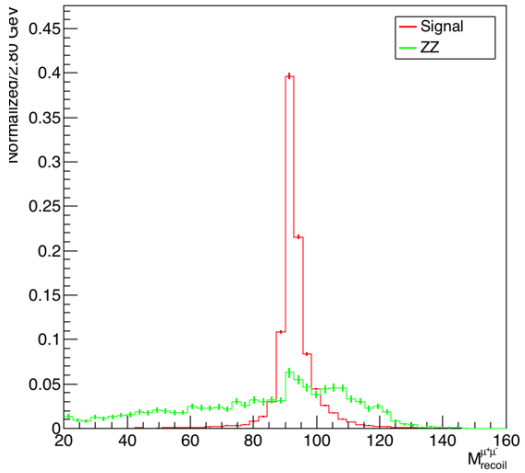
- Framework:
  - Using FSClasserProcessor, require 4 muons in the final status
  - combination to minimize $\delta = (\frac{pair1.M}{\Delta Z})^2 + (\frac{pair2.M}{\Delta H})^2$ $\Delta Z = 2.25, \Delta H = 0.0625$

Signal and Bkg comparison (after $120 < \mathrm{M}_{\mu^+\mu^-}(H) < 130\ GeV$)

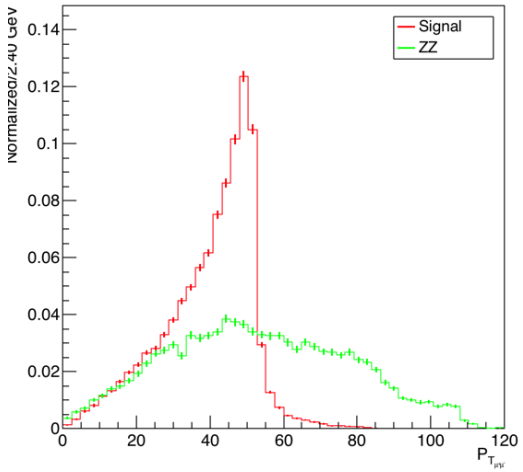
$\mathrm{M}_{\mu^+\mu^-}(H)$



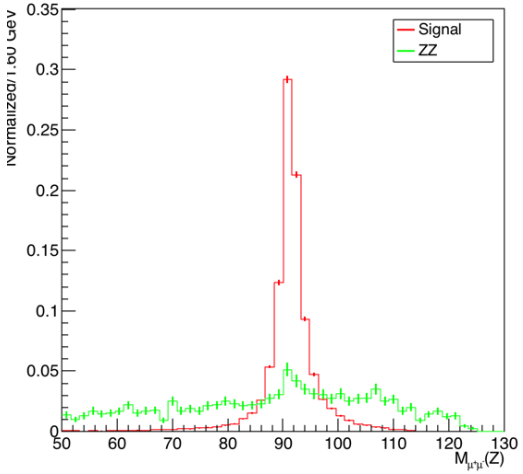
$M^{\mathrm{recoil}}_{\mu^+\mu^-}(H)$



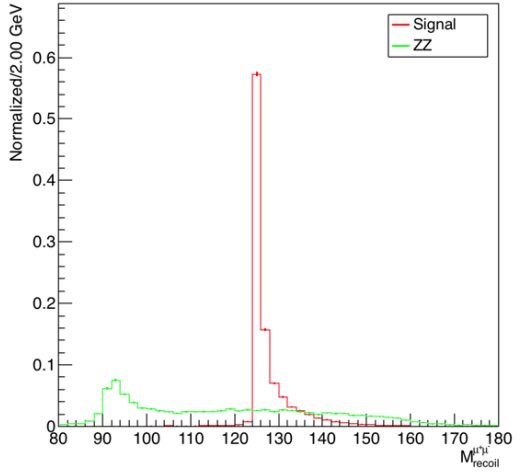
$Pt_{\mu^+\mu^-}(H)$



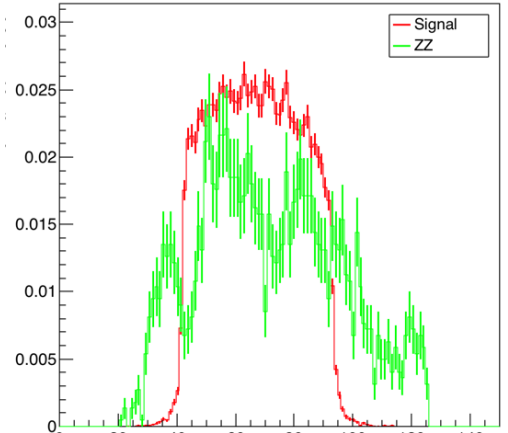
$\mathrm{M}_{\mu^+\mu^-}(Z)$



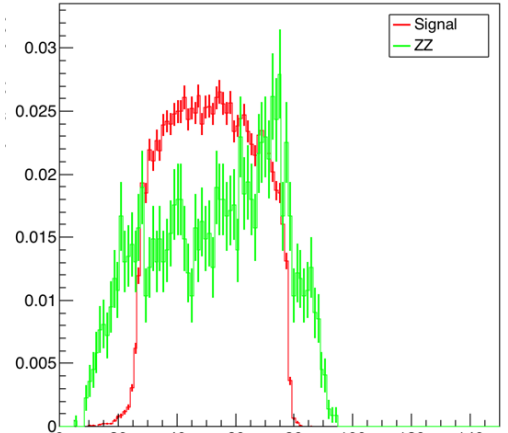
$M^{\mathrm{recoil}}_{\mu^+\mu^-}(Z)$



$p^{H}_{\mu^+,\mu^-}$

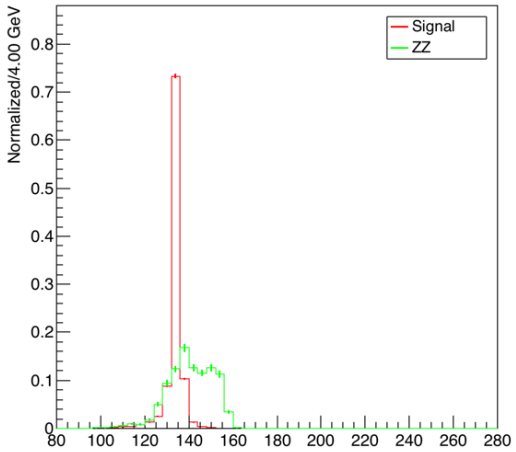


$p^{Z}_{\mu^+,\mu^-}$

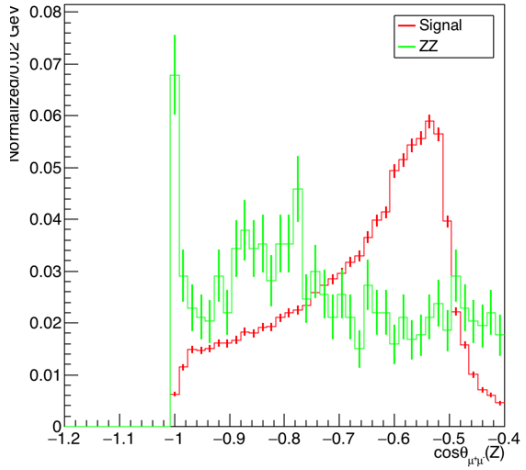


Signal and Bkg comparison (after $120 < \mathrm{M}_{\mu^+\mu^-}(H) < 130\ GeV$)

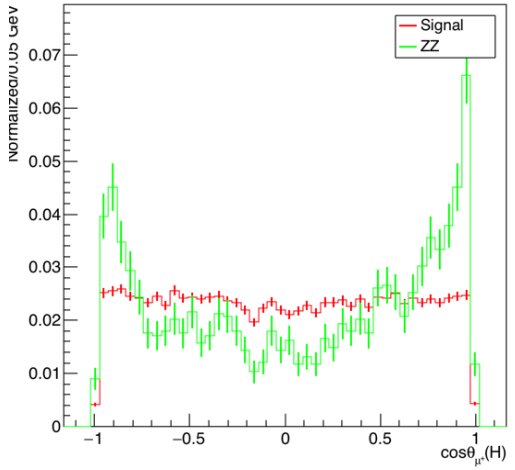
$\mathrm{E}_{\mu^+\mu^-}(H)$



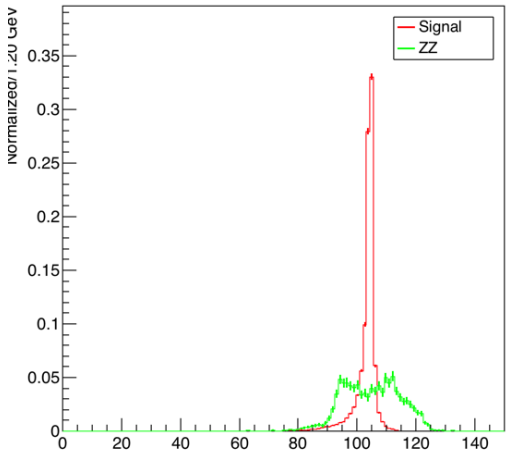
$cos\theta_{\mu^+\mu^-}(Z)$



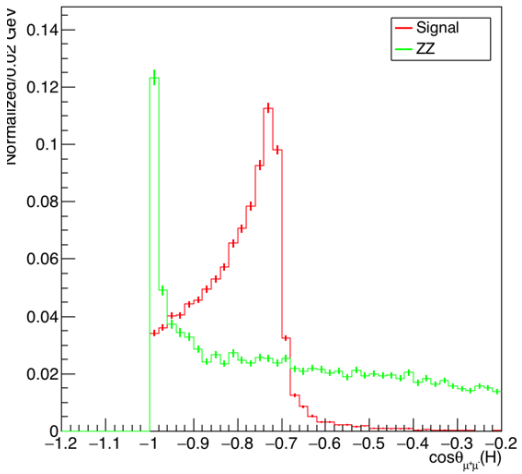
$cos\theta_{\mu^+}(H)$



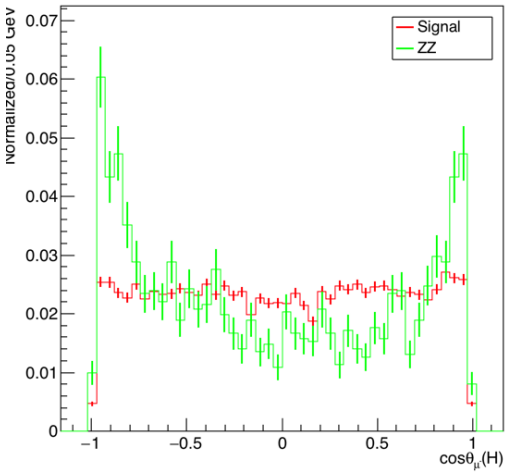
$\mathrm{E}_{\mu^+\mu^-}(Z)$



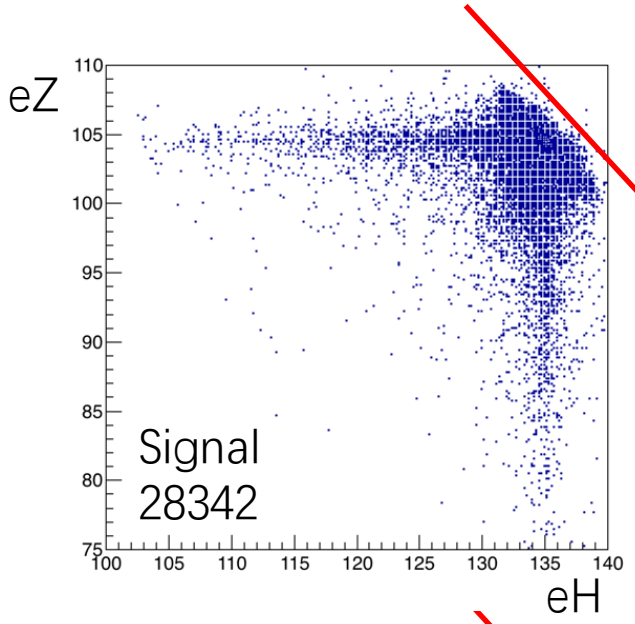
$cos\theta_{\mu^+\mu^-}(H)$

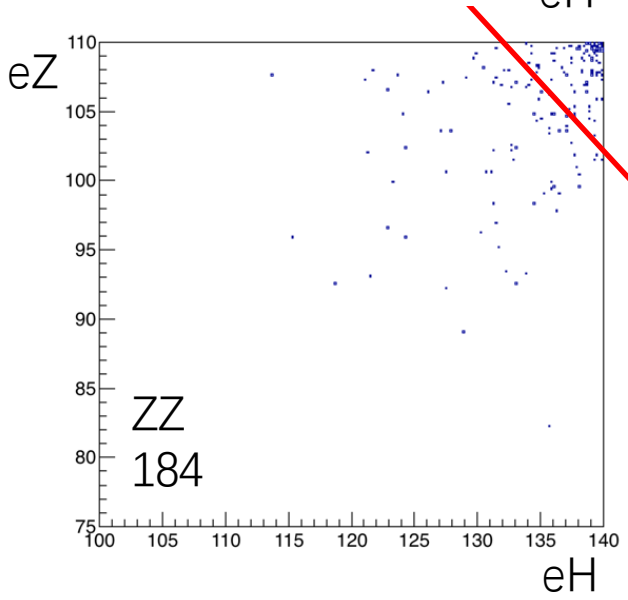


$cos\theta_{\mu^-}(H)$



2D cut for eH and eZ





$120 < \mathrm{M}_{\mu^+\mu^-}(H) < 130\ GeV$

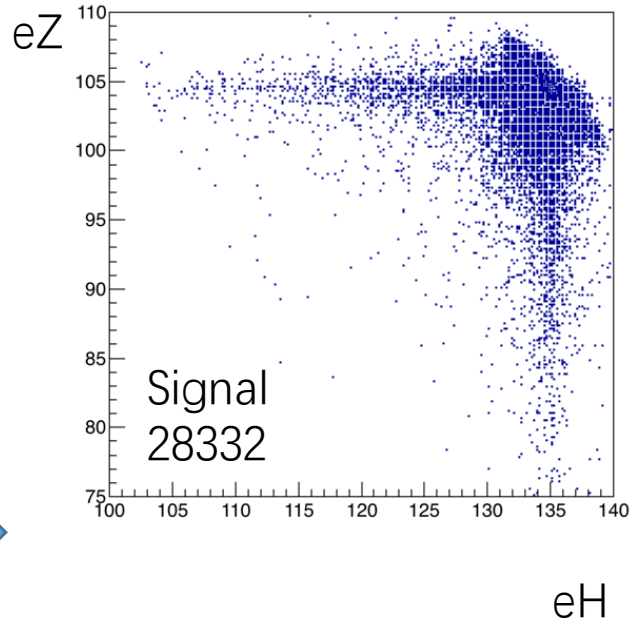
$80 < \mathrm{M}_{\mu^+\mu^-}(Z) < 100\ GeV$

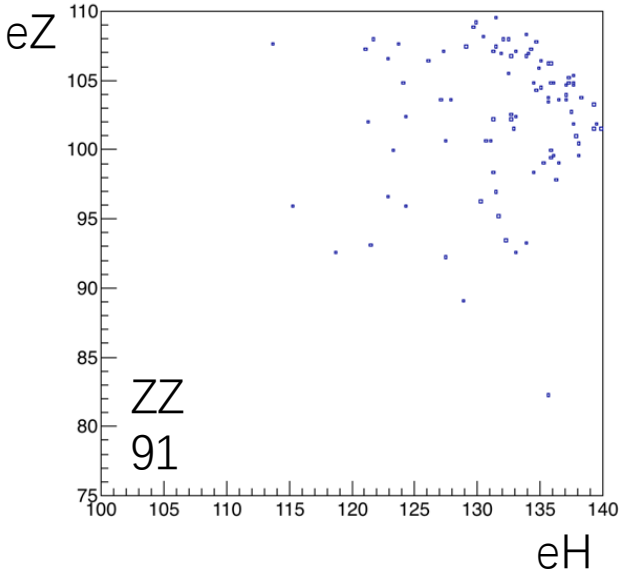
$100 < E_{\mu^+\mu^-}(H) < 150\ GeV$

$95 < E_{\mu^+\mu^-}(Z) < 110\ GeV$

$eZ < -0.8*eH+215.6$

Bkg reduced 50%





Cut Flow

Selection	Signal	ZZ
Pre-selection	6.60	23175
$120 < \mathrm{M}_{\mu^+\mu^-}(H) < 130\ GeV$	5.41	2219
$80 < \mathrm{M}_{\mu^+\mu^-}(Z) < 100\ GeV$	5.02	649
$100 < E_{\mu^+\mu^-}(H) < 150\ GeV$	5.02	462
$95 < E_{\mu^+\mu^-}(Z) < 110\ GeV$	5.01	184
$E_{\mu^+\mu^-}(Z) < -0.8E_{\mu^+\mu^-}(H) + 215.6$	5.01	91
$P_{T_{\mu^+\mu^-}}(H) < 55\ GeV$	4.92	75
$p^H_{\mu^+,\mu^-} > 35\ GeV$ $p^Z_{\mu^+,\mu^-} > 15\ GeV$	4.91	70
$cos\theta_{\mu^+\mu^-}(H) < -0.65$ $cos\theta_{\mu^+\mu^-}(Z) < -0.4$	4.86	47
$120 < M^{\mathrm{recoil}}_{\mu^+\mu^-}(Z) < 130\ GeV$ $80 < M^{\mathrm{recoil}}_{\mu^+\mu^-}(H) < 105 GeV$	4.23	5
Efficiency	64.09%	

Compare with 3.5T results

Category	signal	ZZ	WW(SW)	ZZorWW	SingleZ	2f
Preselection	6.6	17631.0	0	0	0	0.0
120<$E_{\mu^+\mu^-}$<130	6.0	1685.2	0	0	0	0.0
90.6< M_{recoil_μ} <93.4	3.9	128.8	0	0	0	0.0
90.2<$M_{\mu^+\mu^-}$(Z)<92.8	3.2	58.1	0	0	0	0.0
$cos_{\mu^+\mu^-}$(H)<-0.603	3.2	50.0	0	0	0	0.0
$cos_{\mu^+\mu^-}$(Z)<-0.364	3.2	47.0	0	0	0	0.0
138.0<$E_{\mu^+\mu^-}$(H)<139.8	3.0	15.5	0	0	0	0.0
$P_{T_{\mu^+\mu^-}}$(H)<62.5	3.0	14.7	0	0	0	0.0
efficiency	45.5%					

Significance $\approx \frac{S}{\sqrt{S+B}} = 1.39\sigma$

Next step

- Understand the physics meaning of selections
- Optimize the events selection, try more variables to lower the bkg
- Generate other bkg to check the contribution after selection
- Generating the background for $e^+e^- \to Z(e^+e^-)H(\mu^+\mu^-)$ channel