Higgs decaying into ZZ*

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on behalf of HZZ analysis team

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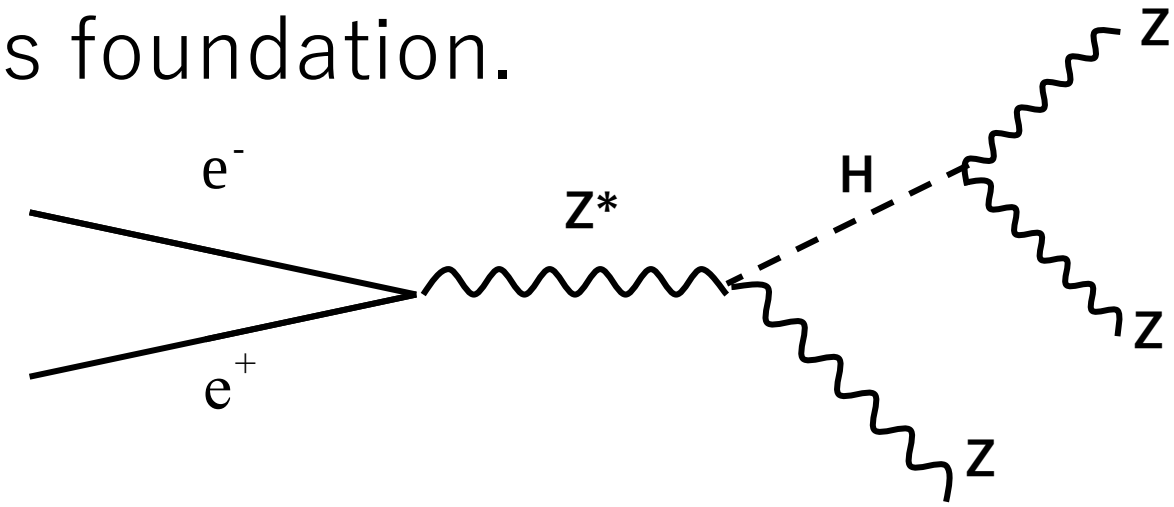
Introduction

・ HZZ analysis is one of key factors to deduce the Higgs boson width and its precision

$$\Gamma_H = \frac{\Gamma(H \to ZZ^*)}{\mathrm{BR}(H \to ZZ^*)} \propto \frac{\sigma(ZH)}{\mathrm{BR}(H \to ZZ^*)}$$

・ The state involves three Z bosons, thus it provides unique analysis foundation.

・ In general, small BR(H->ZZ) limits final precision.



HZZ channel

・ Since the state has 3 Z bosons, there are multiple combinations of final products.

・ $Z^*(->\mu^+\mu^-)H(->ZZ^*->jj\nu\nu)$ is one of promising candidate, owing to its relatively large statistics and clear signature.

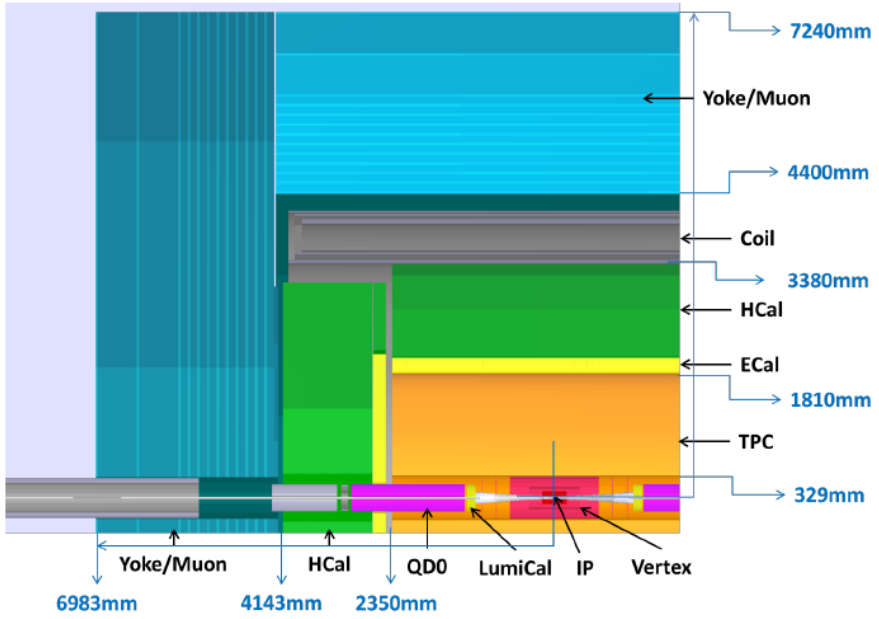
・This presentation summarizes the status of this channel.

Table : Possible combinations

Z / ZZ*				
e^+e^-	$\nu\nu jj$	$jj\nu\nu$		
$\mu^+\mu^-$	$\nu\nu jj$	$jj\nu\nu$		$jjjj$
$\nu\nu$	e^+e^- jj	jje^+e^-	$\mu^+\mu^-$ jj	$jj\mu^+\mu^-$
jj	e^+e^- $\nu\nu$	$\nu\nu e^+e^-$	$\mu^+\mu^-$ $\nu\nu$	$\nu\nu\ \mu^+\mu^-$

Monte Carlo Simulation

- CEPC_v4 (240GeV, 3T)
- Generator: Whizard 1.95
  (with ISR, L=5.6 ab^{-1}, M_{higgs}=125 GeV)
- Simulation :
  Geant4 and Mokka with ISR and bremsstrahlung effects
- Reconstruction:
  Marlin and ArborPFA



Data samples

- Signal : $Z^*(->\mu^+\mu^-)H(->ZZ^*)$

  /cefs/data/DstData/CEPC240/CEPC_v4/higgs/E240.Pe2e2h_zz.e0.p0.whizard195/

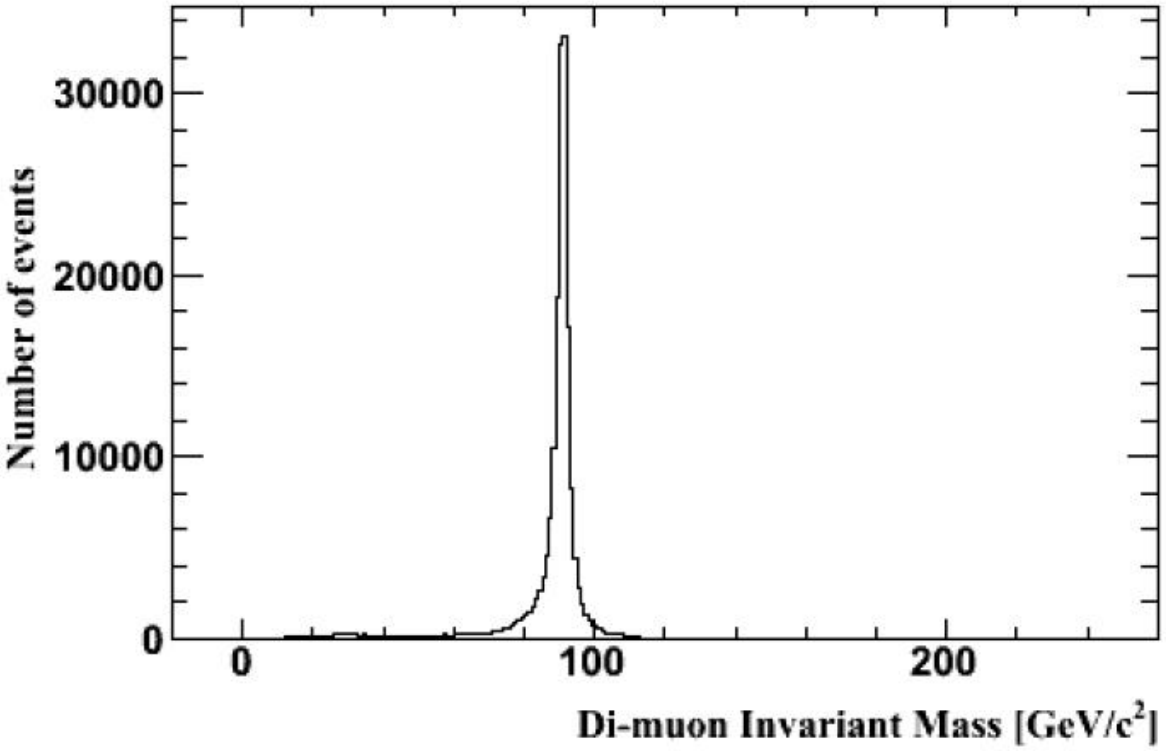
  (/cefs/data/DstData/CEPC240/CEPC_v4/higgs/smart_final_states/E240.Pllh_zz.e0.p0.whizard195/)

- Background (stored under /cefs/data/DstData/CEPC240/CEPC_V4/)
  - 2 fermions (bhabha, e2e2, e3e3, qq, nn)
  - 4 fermions (zz_h0, zz_sl0, zz_l04, ww_h0,,,,)
  - Higgs (qq_X, e1e1_X, e2e2_X, e3e3_X, nnh_X)

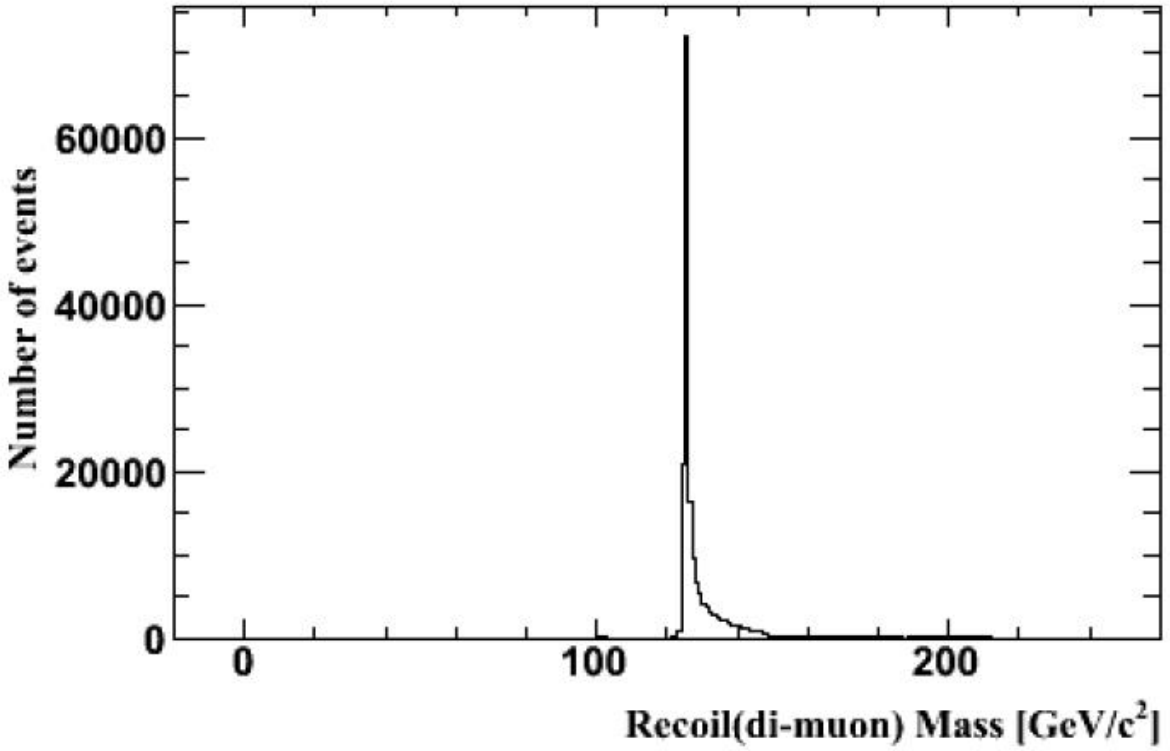
Please refer the details at http://cepcsoft.ihep.ac.cn/guides/Generation/docs/ExistingSamples/

Signature of Z*(->$\mu^+\mu^-$)H(->ZZ*)

 # Identify two muons from Z* using invariant & recoil mass as usual



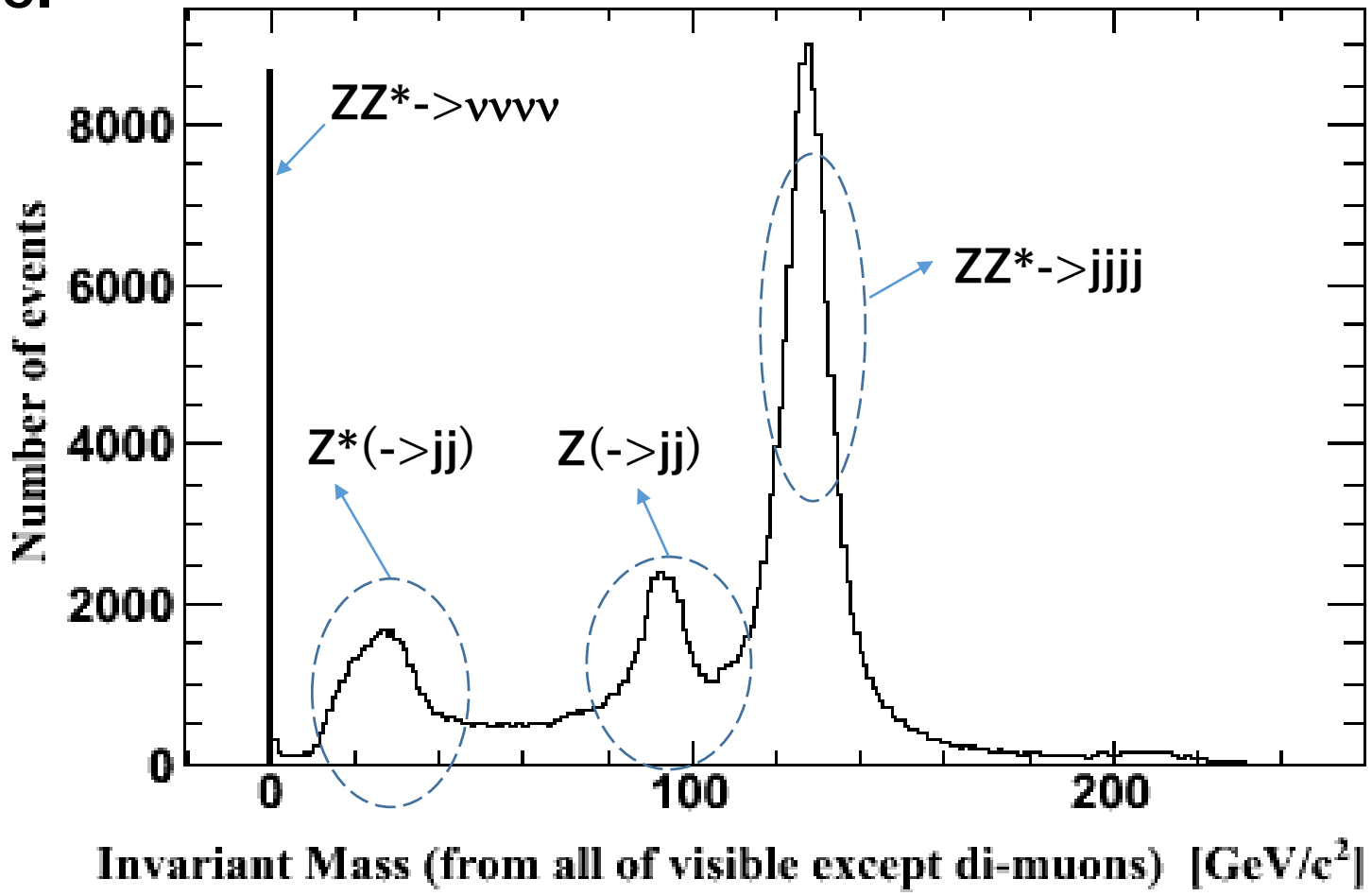
$M_{Invatiant}(\mu^+\mu^-)$



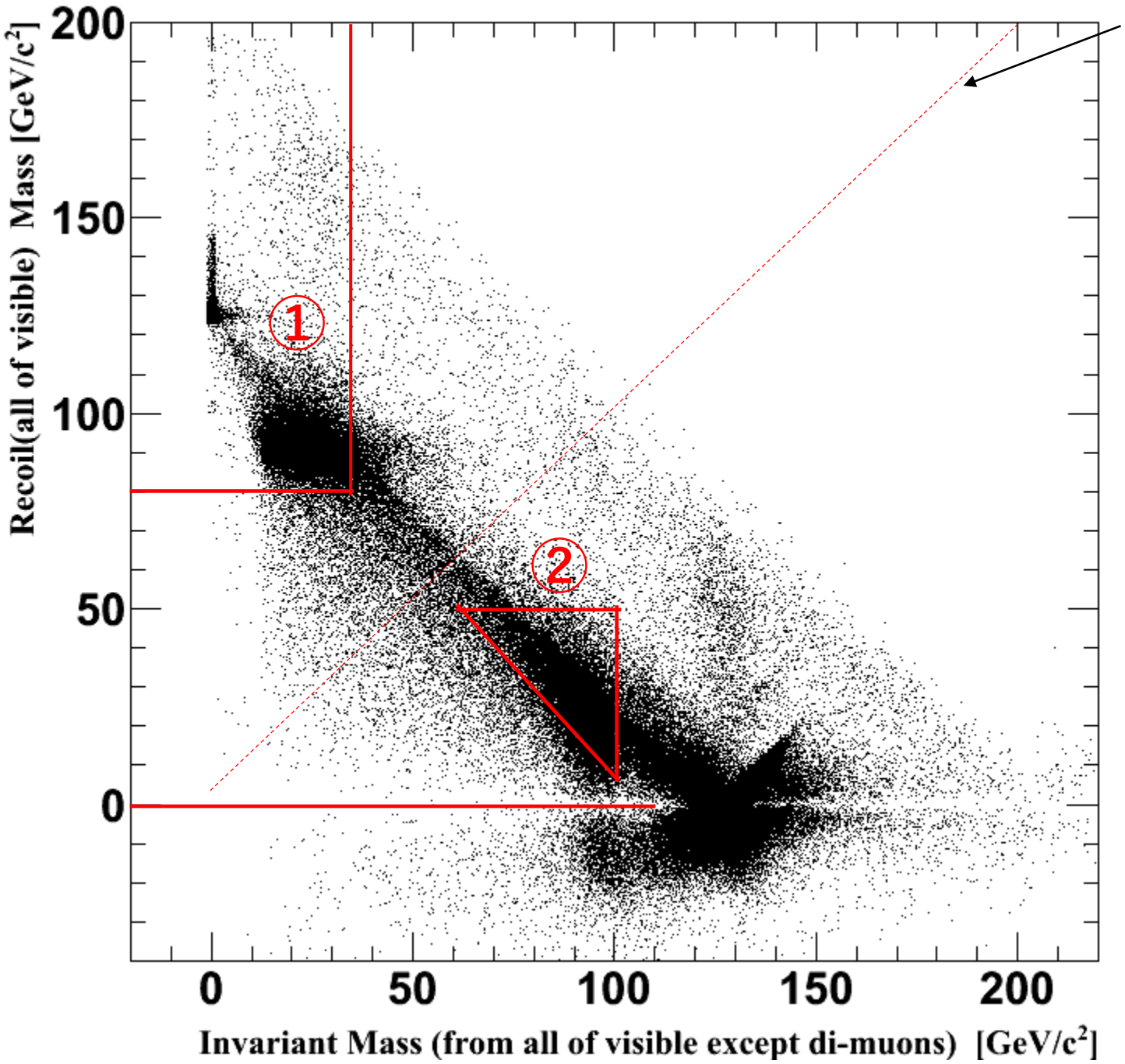
$M_{\mathrm{Recoil}}(\mu^+\mu^-)$

Signature of $Z^*(->\mu^+\mu^-)H(->ZZ^*)$

 # Distribution of invariant mass except two muons clearly shows each decay mode.



 # jet clustering
N(jet)=2

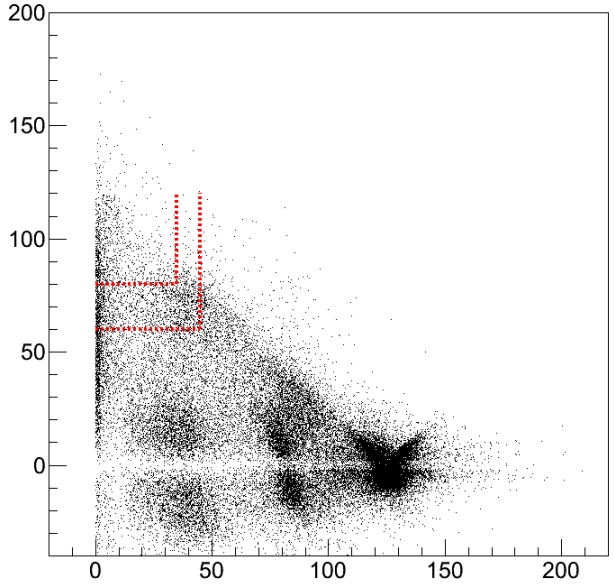


Missing Mass (Z->νν) = Dijet Mass (Z->jj)

Two regions are defined to suppress the backgrounds

Region ① : H->ZZ*->ννjj

Region ② : H->ZZ*->jjνν



Example. Z(–>μμ)H(->WW*) after pre-selection

① $Z(\mu^+\mu^-)H(Z->\nu\nu, Z^*->jj)$

Event Selection

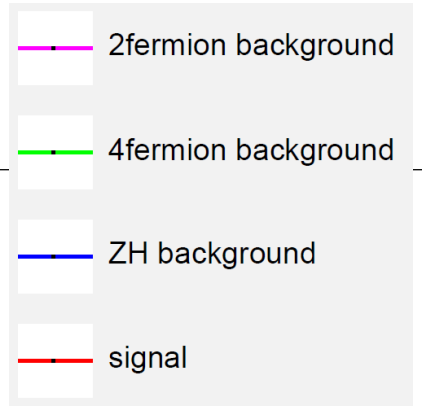
From this page, the work is done by Lingteng

Cut condition
Pre-selection (lepton isolation, Fastjet, PID) N(jet) = 2 , N(lepton) >= 2, $N(\mu^+)>=1$, $N(\mu^-)>=1$
$M_{missing} > M_{dijet}$
80 GeV < $M_{invariant}(\mu\mu)$ < 100 GeV
120 GeV < $M_{recoil}(\mu\mu)$ < 150 GeV
N(pfo)> 15
Pt(visible all) > 10 GeV
Min angle (muon⇔jet) > 0.3 rad.
$M_{missing}$ /M_{dijet} (selection of region ①)
Pt(jet) > 3 GeV, E(jet) > 5 GeV

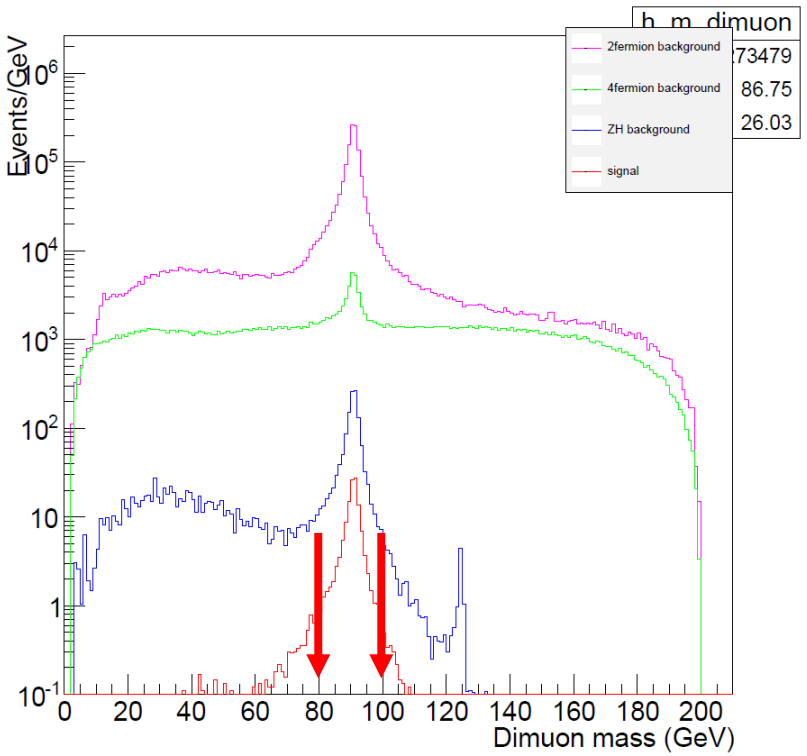
cut	signal	zh background	2f background	4f background
Raw events	1212	12557950	8828594187	1180400980
$Pre-selection$	817	31794	4170834	735206
$Signal\ or\ not$	270	31571	4170834	735206
$M_{miss} > M_{dijets}$	138	2132	1945599	240838
$80GeV < M_{\mu^+\mu^-} < 100GeV$	127	1254	1338593	48117
$120GeV < M_{Recoil} < 150GeV$	126	1227	152297	15384
$15 < N_{pfo}$	125	506	5953	760
$10GeV < Pt_{visible}$	118	462	783	321
$Min\ angle > 17.2°$	109	429	582	194
$M_{miss} > 80GeV, M_{dijets} < 35GeV$	79	90	553	78
$Pt_{jet1,2} > 3GeV, E_{jet1,2} > 5GeV$	68	72	0	8

Efficiency of event selection ~ 49%

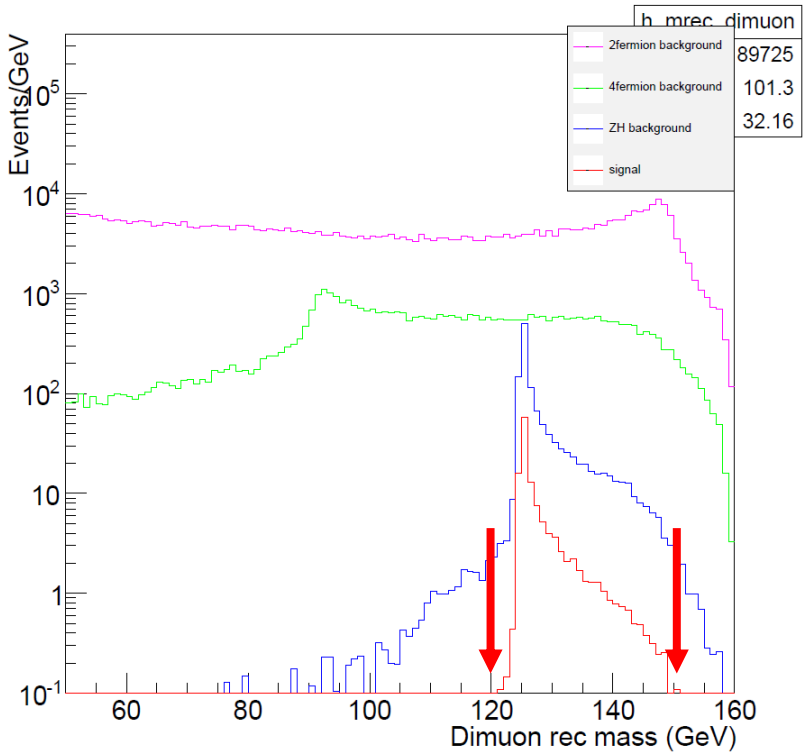
Distributions - I.



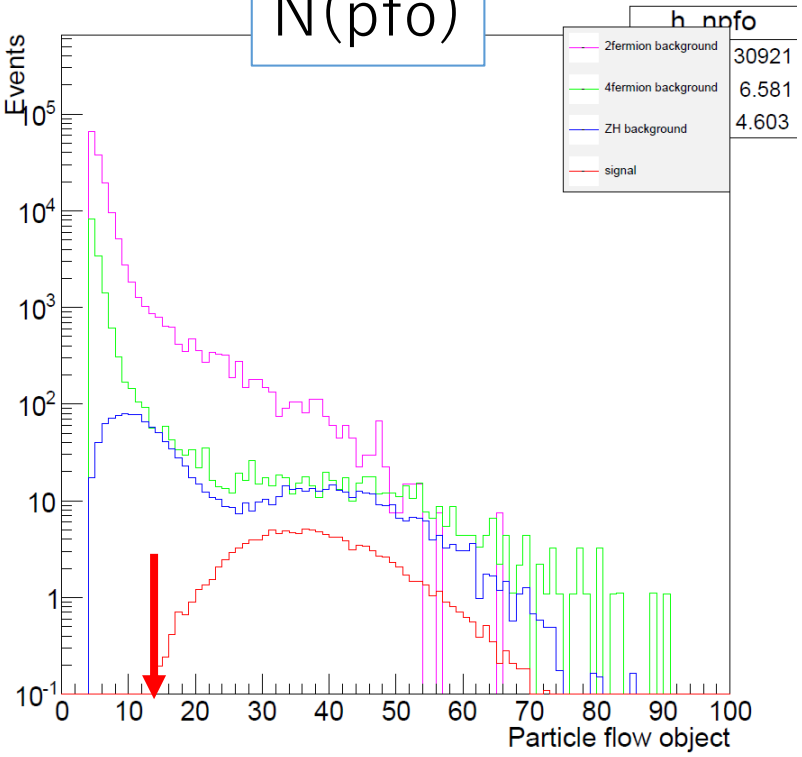
$M_{invariant}(\mu\mu)$



$M_{recoil}(\mu\mu)$



N(pfo)

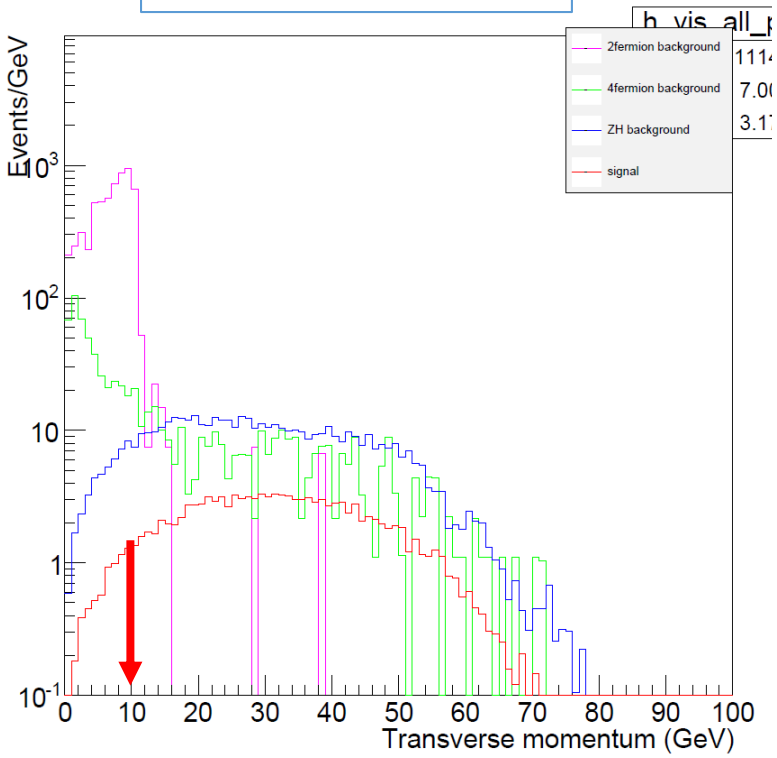


① $Z(\mu^+\mu^-)H(Z\to\nu\nu, Z^*\to jj)$

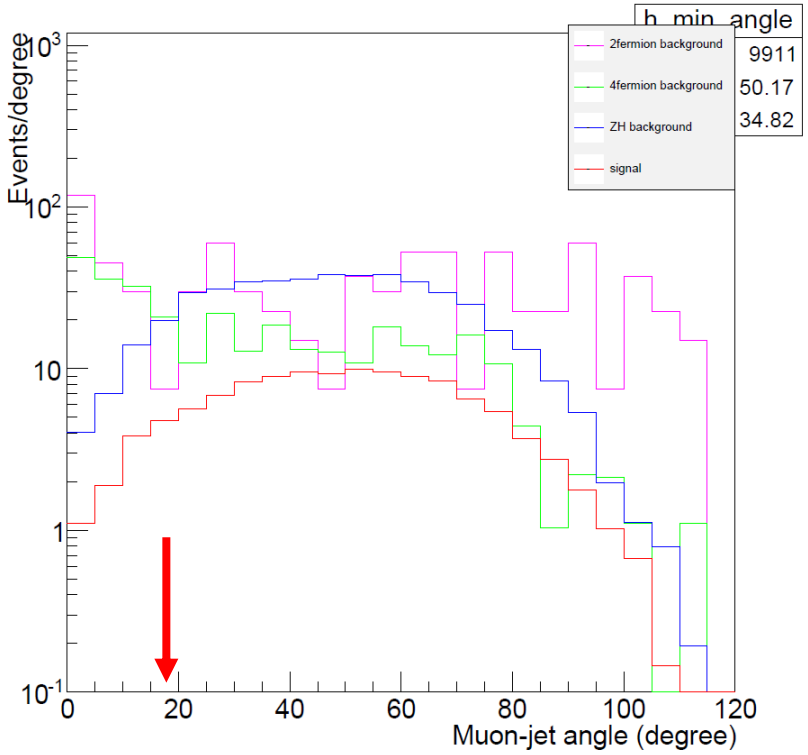
Distributions - II.

2fermion background
4fermion background
ZH background
signal

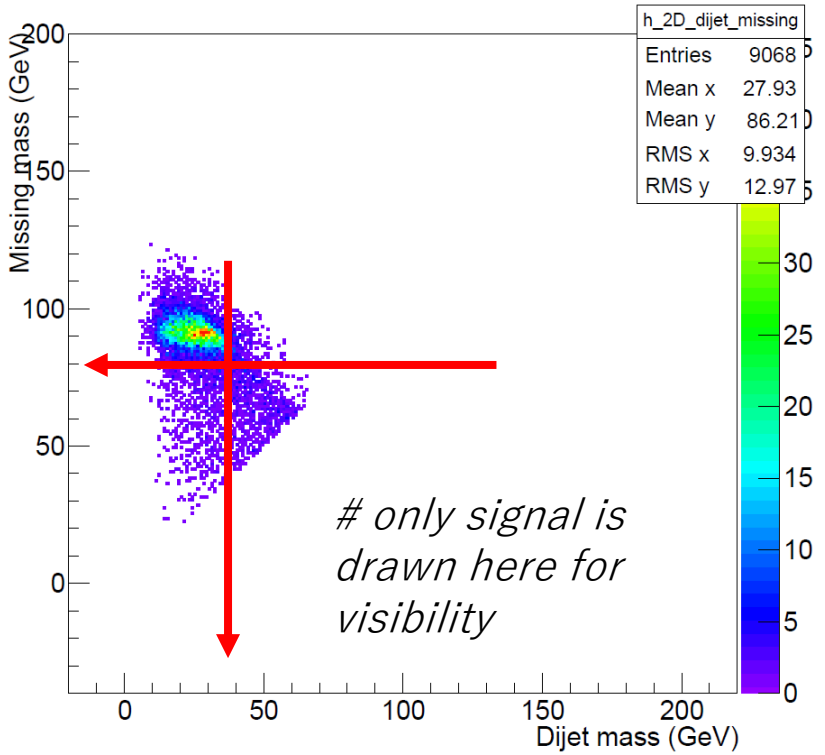
Pt(visible all)



Min angle (lepton⇔jet)

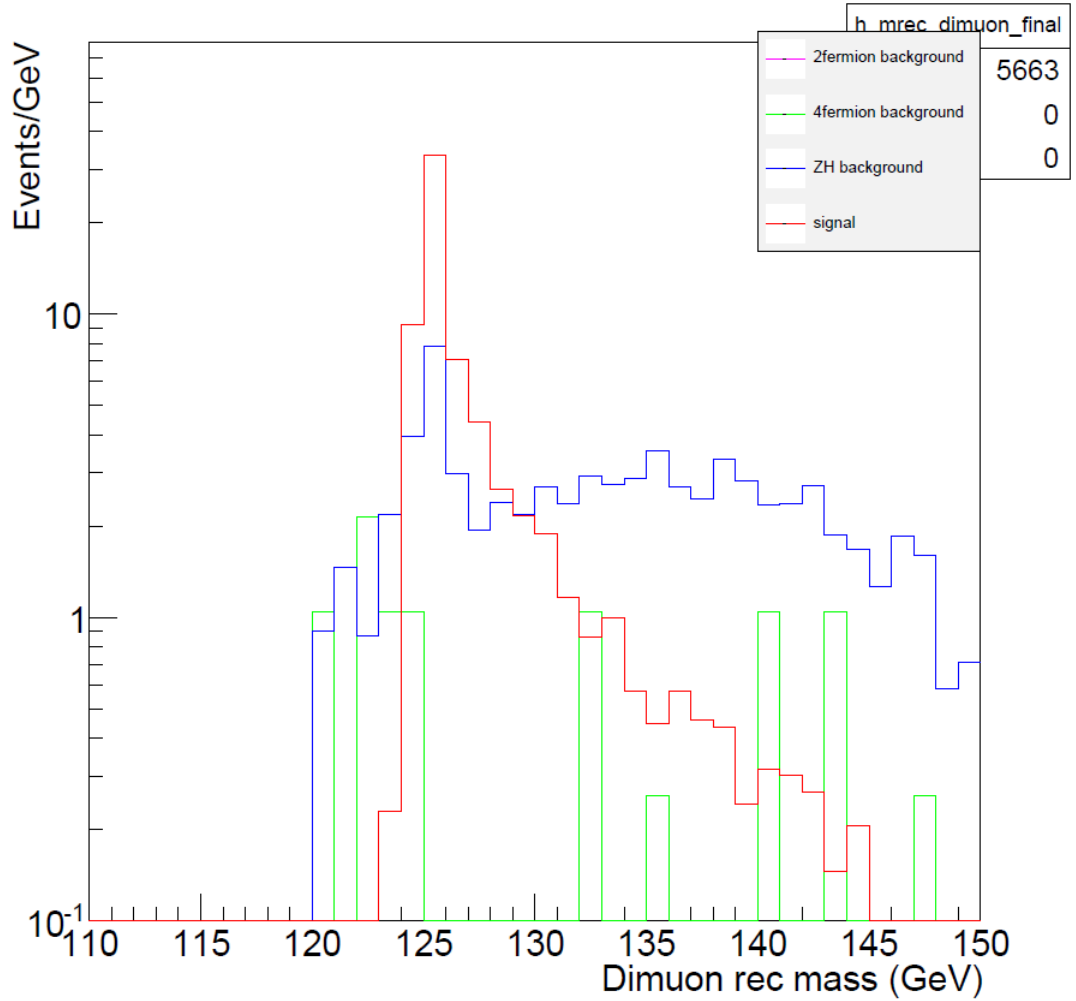


Missing Mass vs Di-jet Mass



① $Z(\mu^+\mu^-)H(Z\to\nu\nu, Z^*\to jj)$

Recoil mass after all of cuts applied



Table： major background components

name	scale	final
e2e2h_ww	0.0818403	12
nnh_zz	0.0683871	55

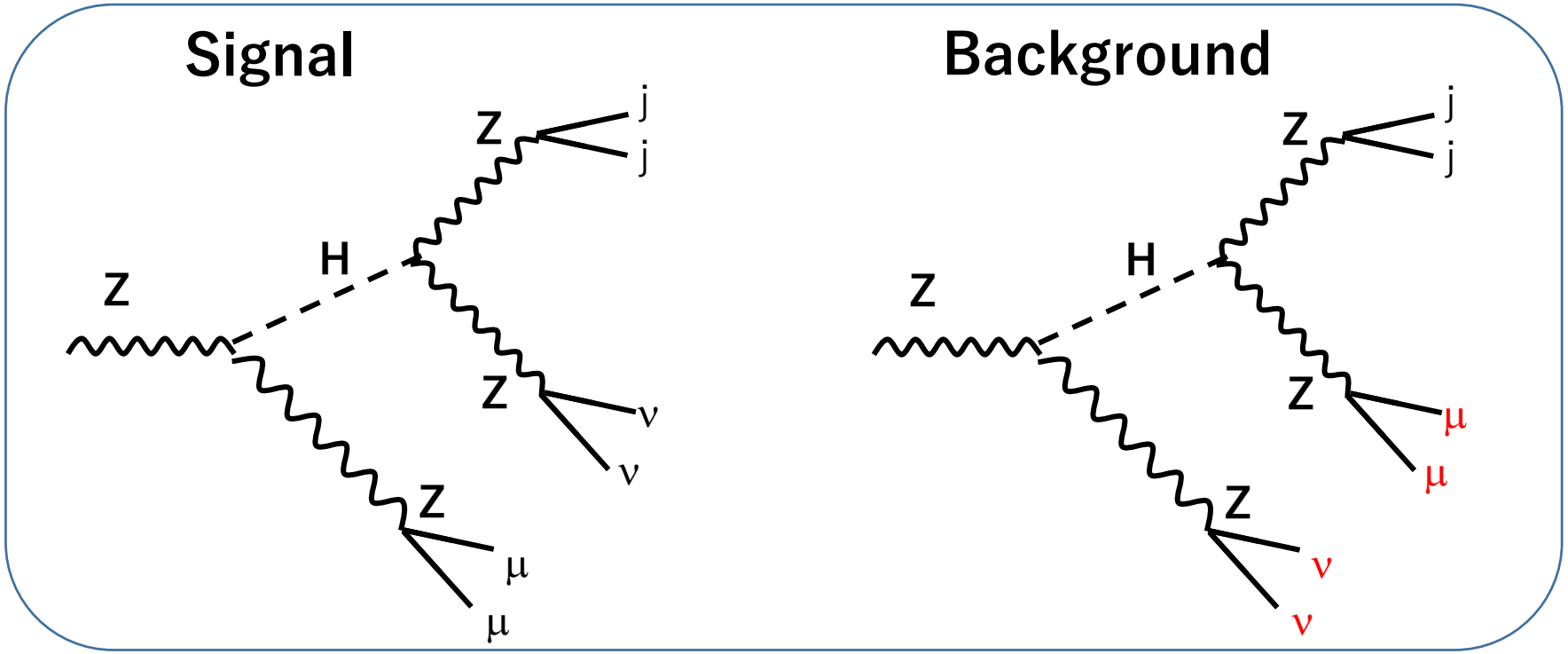
① $Z(\mu^+\mu^-)H(Z\to\nu\nu, Z^*\to jj)$

Background

- Major background

  -- Z(->νν)Higgs(ZZ*) (and Z(->μμ)Higgs(WW*))

  -- Using the recoil mass of Z* boson reduces this background events.
  But still its contamination is not negligible



② $Z(\mu^+\mu^-)H(Z^*->\nu\nu, Z->jj)$

Event Selection

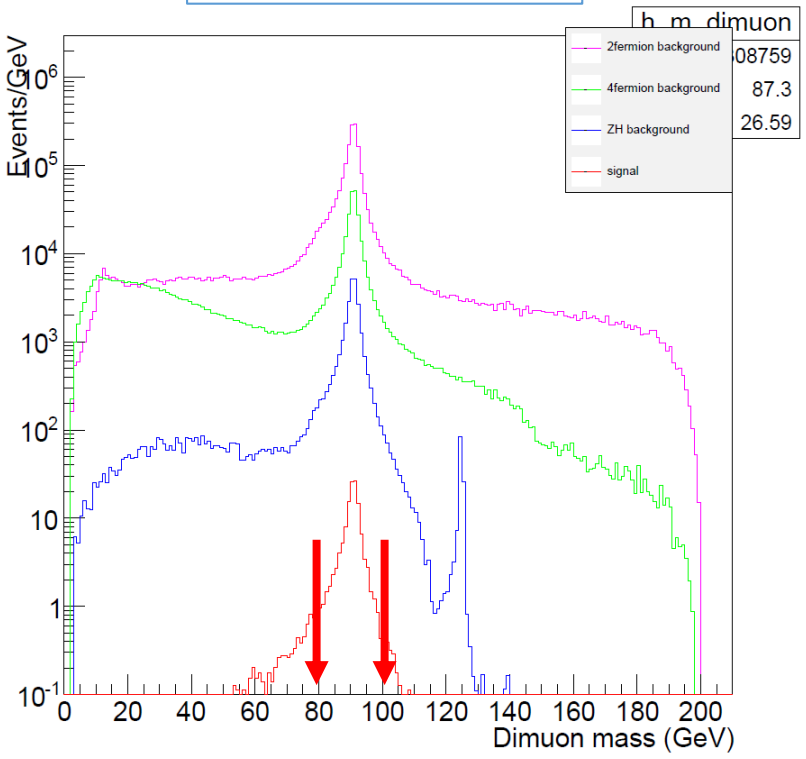
Cut condition (red : change from ①)
Pre-selection (lepton isolation, Fastjet, PID) N(jet) = 2 , N(lepton) >= 2, $N(\mu^+)>=1$, $N(\mu^-)>=1$
$M_{missing} < M_{dijet}$
80 GeV < $M_{invariant}(\mu\mu)$ < 100 GeV
120 GeV < $M_{recoil}(\mu\mu)$ < 150 GeV
30 < N(pfo) < 100
10 GeV < Pt(visible all) < 50 GeV
(π/2) rad. > Min angle (muon⇔jet) > 0.3 rad.
$M_{missing}$ /M_{dijet} (selection of region ②)
10 GeV < Pt(jet) < 65 GeV, 25 GeV < E(jet) < 80 GeV
10° < Polar Angle(jet) < 170°

cut	signal	zh background	2f background	4f background
Raw events	1266	12557950	8828594187	1180400980
Pre – selection	854	31794	4170834	735206
Signal or not	282	31571	4170834	735206
$M_{miss} > M_{dijets}$	138	29438	2225234	494368
$80GeV < M_{\mu^+\mu^-} < 100GeV$	126	24273	1543274	250618
$120GeV < M_{Recoil} < 150GeV$	125	24159	93570	22035
$30 < N_{pfo}$	122	18136	321	18956
$10GeV < Pt_{visible} < 50GeV$	100	4612	59	1636
$17.2° < Min\ angle < 90°$	94	4352	59	1422
$M_{miss}M_{dijets}$	59	850	0	308
Single jet	52	706	0	283

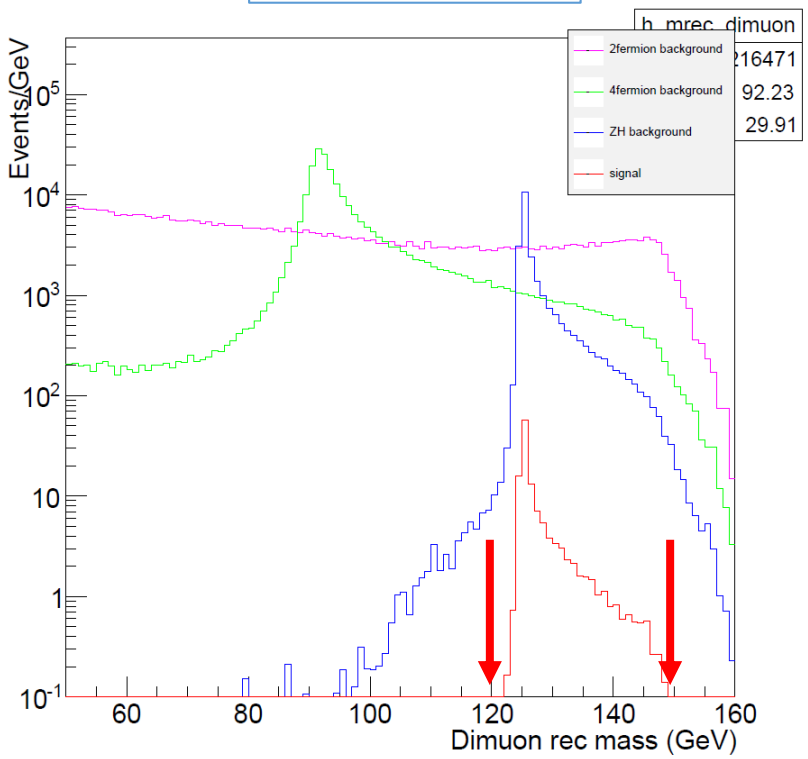
Efficiency of event selection ~ 38%

Distributions - I.

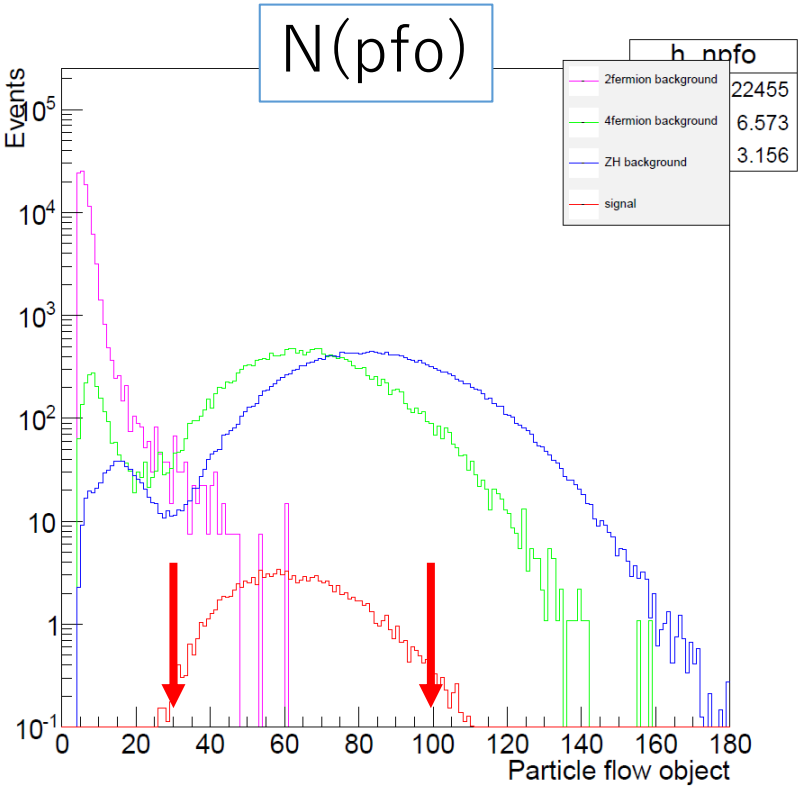
$M_{invariant}(\mu\mu)$



$M_{recoil}(\mu\mu)$



N(pfo)

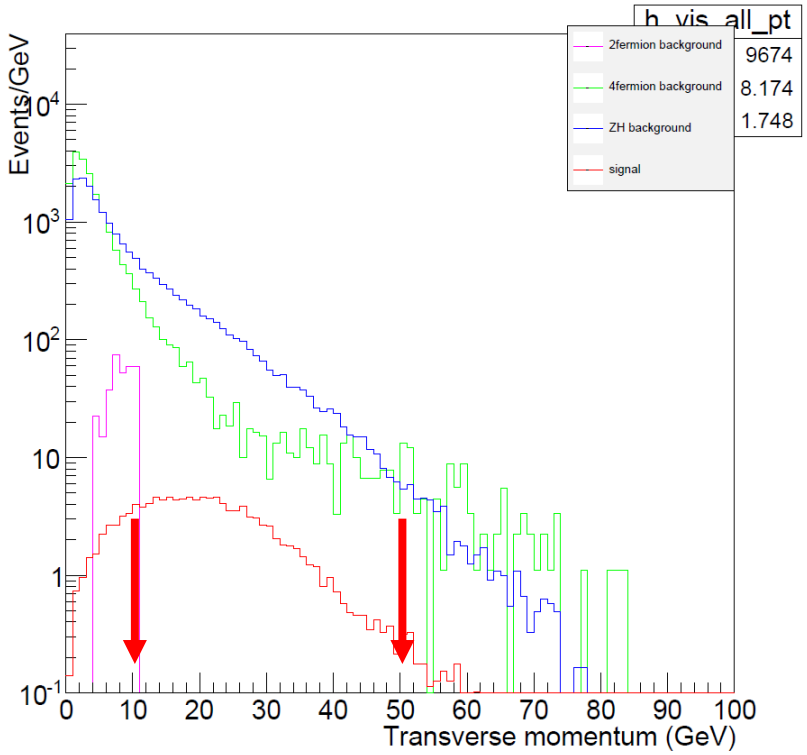


② $Z(\mu^+\mu^-)H(Z^*\to\nu\nu, Z\to jj)$

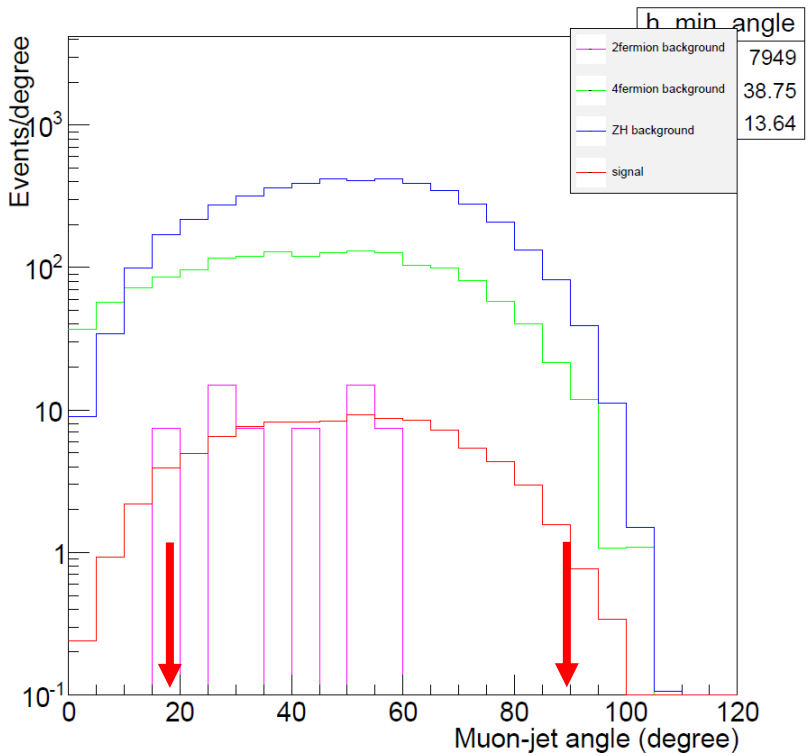
Distributions - II.

2fermion background
4fermion background
ZH background
signal

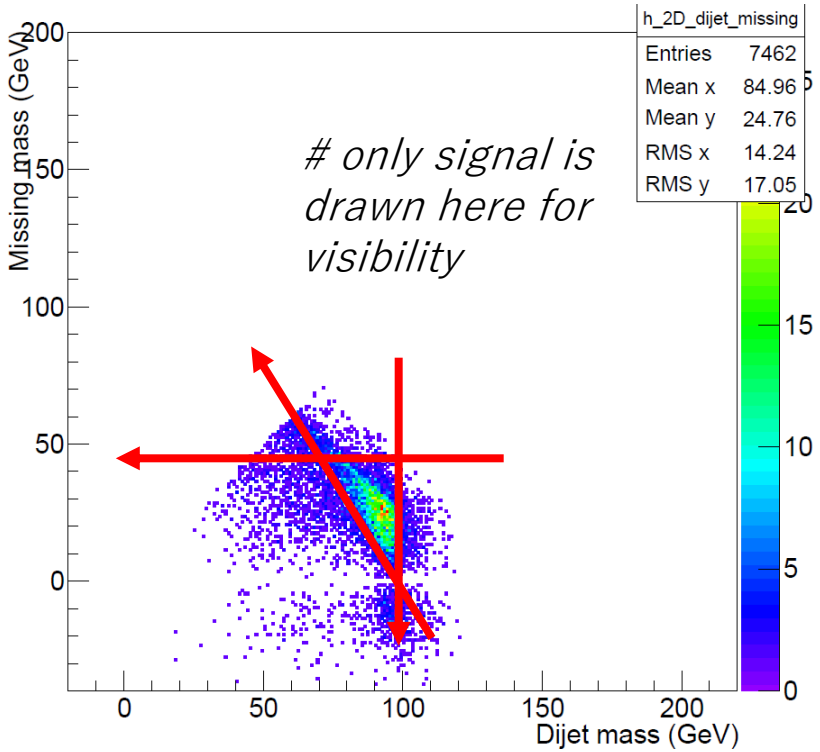
Pt(visible all)



Min angle (lepton⇔jet)



Missing Mass vs Di-jet Mass



② $Z(\mu^+\mu^-)H(Z^*\to\nu\nu, Z\to jj)$

Recoil mass after all of cuts applied

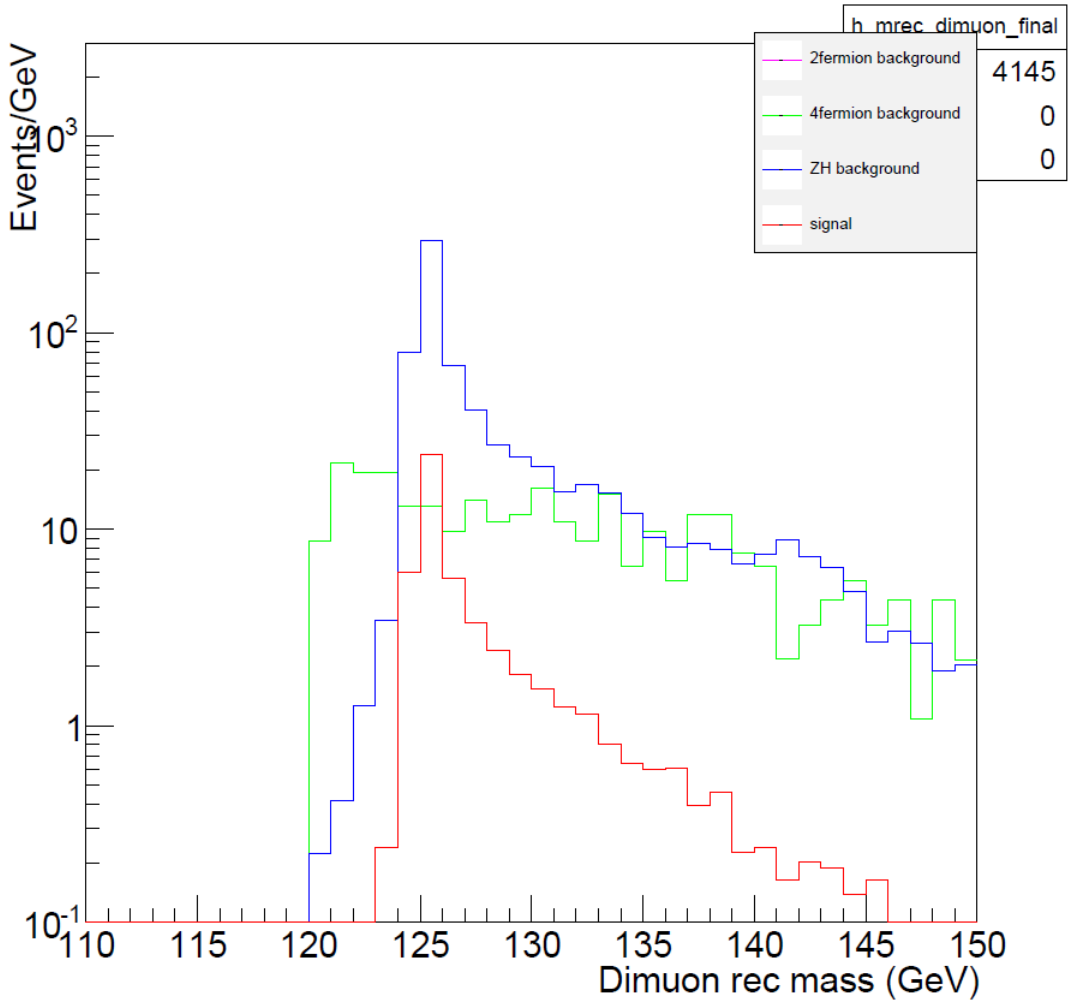


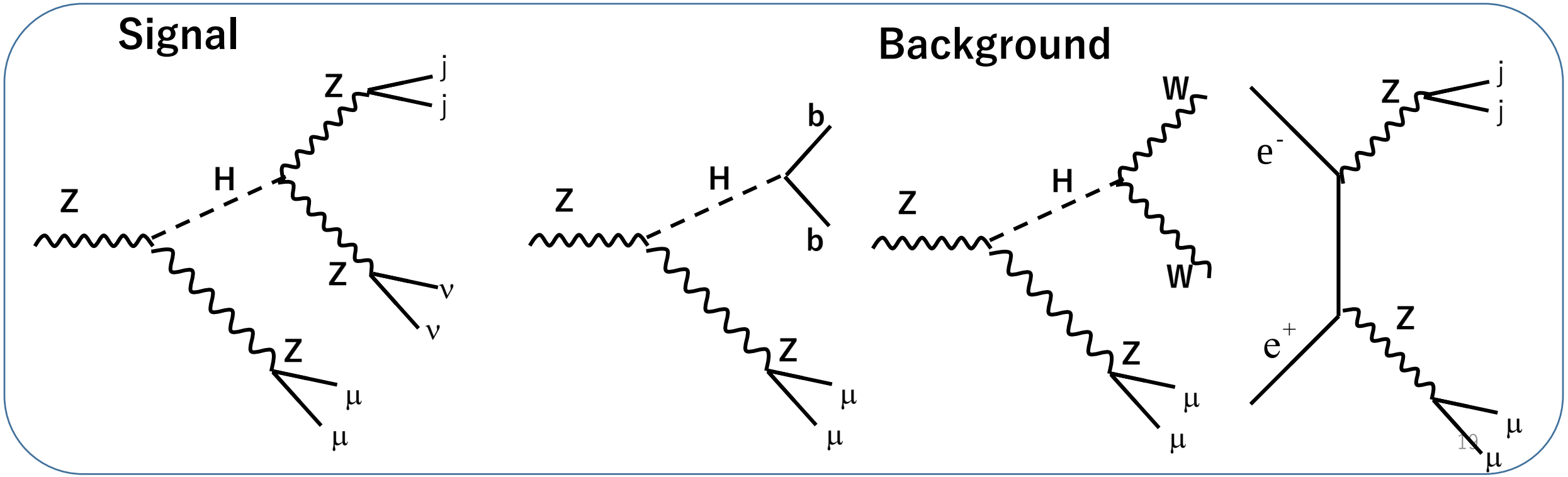
Table : major background components

name	scale	final
e2e2h_bb	0.21917505	436
e2e2h_ww	0.0818403	202
qqh_e3e3	0.48487575	16
qqh_zz	0.20235855	33
zz_sl0mu_up	1.09139300069	60
zz_sl0mu_down	1.08131822774	207

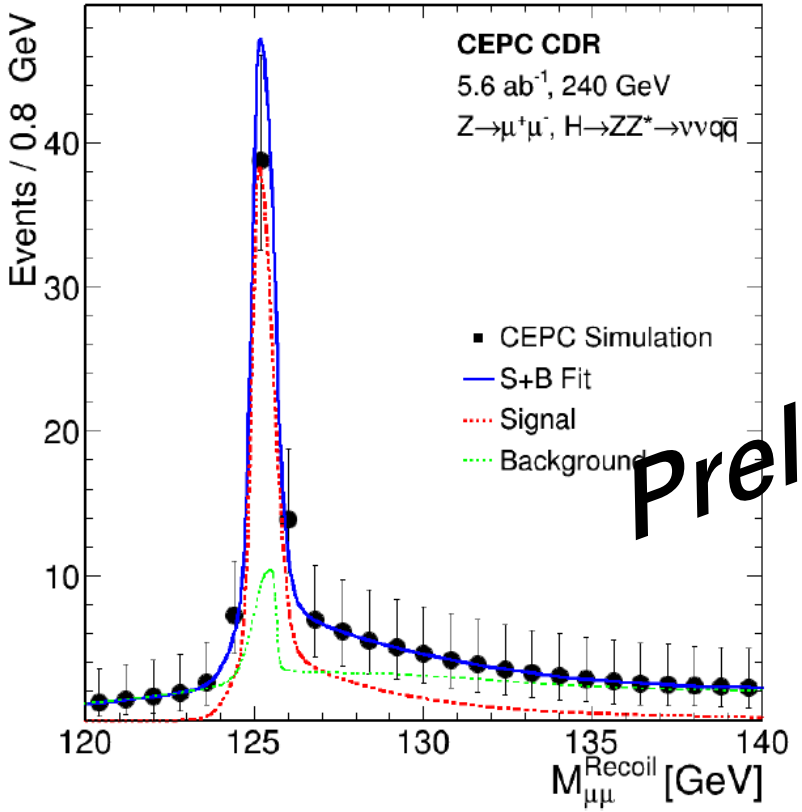
② $Z(\mu^+\mu^-)H(Z^*\to\nu\nu, Z\to jj)$

Background II.

- Major background
  -- Higgs decays (H->bb, H->WW*), and 4 fermions (ZZ process)
  -- Significant overlap. It seems it is not easy to reduce the background level as former case though further suppression could be achieved

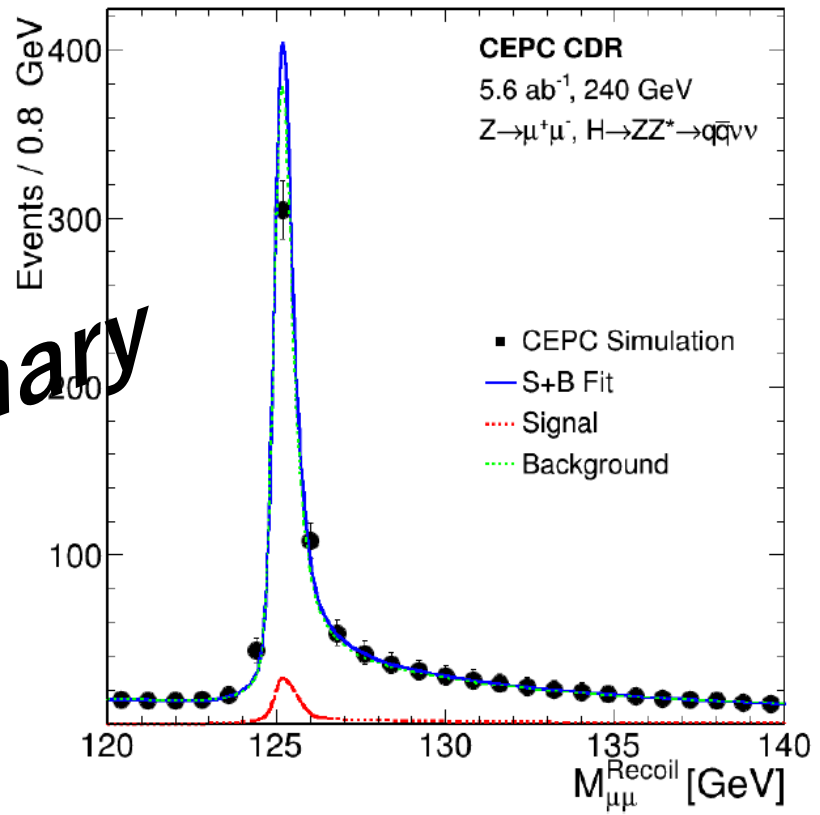


Signal-to-background ratio with fitting



$$\frac{\sqrt{S+B}}{S} = 11.2\%$$

① $Z(\mu^+\mu^-)H(Z\text{->}\nu\nu, Z^*\text{->}jj)$



$$\frac{\sqrt{S+B}}{S} = 40.3\%$$

② $Z(\mu^+\mu^-)H(Z^*\text{->}\nu\nu, Z\text{->}jj)$

Preliminary

What's the next ?

In my mind :

-- Look the other channels (i.e. Z(->ee)Higgs(ZZ*) channel)

-- Comparison of cut-based analysis with the BDT method

-- Further background suppression. (i.e. using flavor tag info.)

-- Combination of ZH channels

-- ...

Additional info.

- A student from IHEP side will join and take over the analysis.
  - would start to reproduce current results
- $Z(\nu\nu)$Higgs(->ZZ*) channel has been analyzed by Alex S. (UW)
  - Two students from USTC now participate the HZZ analysis

- We had already discussions and will share the information in future.

Summary

-- HZZ analysis with some particular decay modes has been done with the CEPC-V4 configuration.

-- We will continue the activity together with new members.

-- Any suggestions are welcome !

Thank you for your attention !