Update on H->ZZ Measurements

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January 18th, 2020

“Physics Potential Study for Future e+e- Higgs Factories”, the IAS Program on High Energy Physics, HKUST IAS

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  - Brief introduction of the analysis flow
  - Result from $Z(\rightarrow\mu\mu)H(ZZ^*\rightarrow\nu\nu, qq)$ and swapped combinations
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- Discussion on probing the anomalous HZZ coupling
- Summary

Introduction to HZZ channel

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

・ Final states having ($\mu^+\mu^-$, jj, $\nu\nu$) are promising channels, owing to its clear signature. On the other hand, its low statistics could limit the final precision.

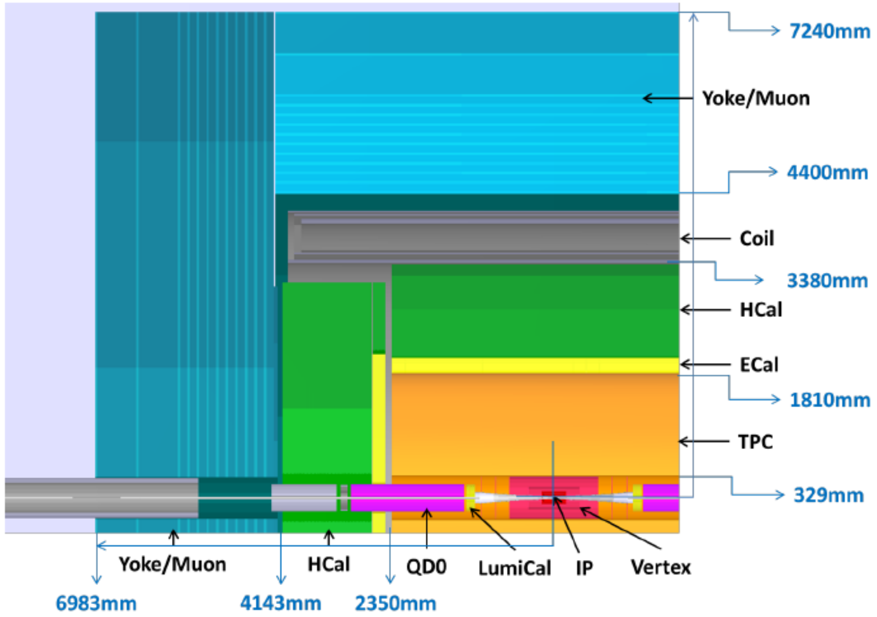
・This presentation summarizes the updated results from channels with the decay product combination of ($\mu\mu$, jj, $\nu\nu$) and a brief status report on channels with using electrons instead of muons.

Table : Promising decay product combinations

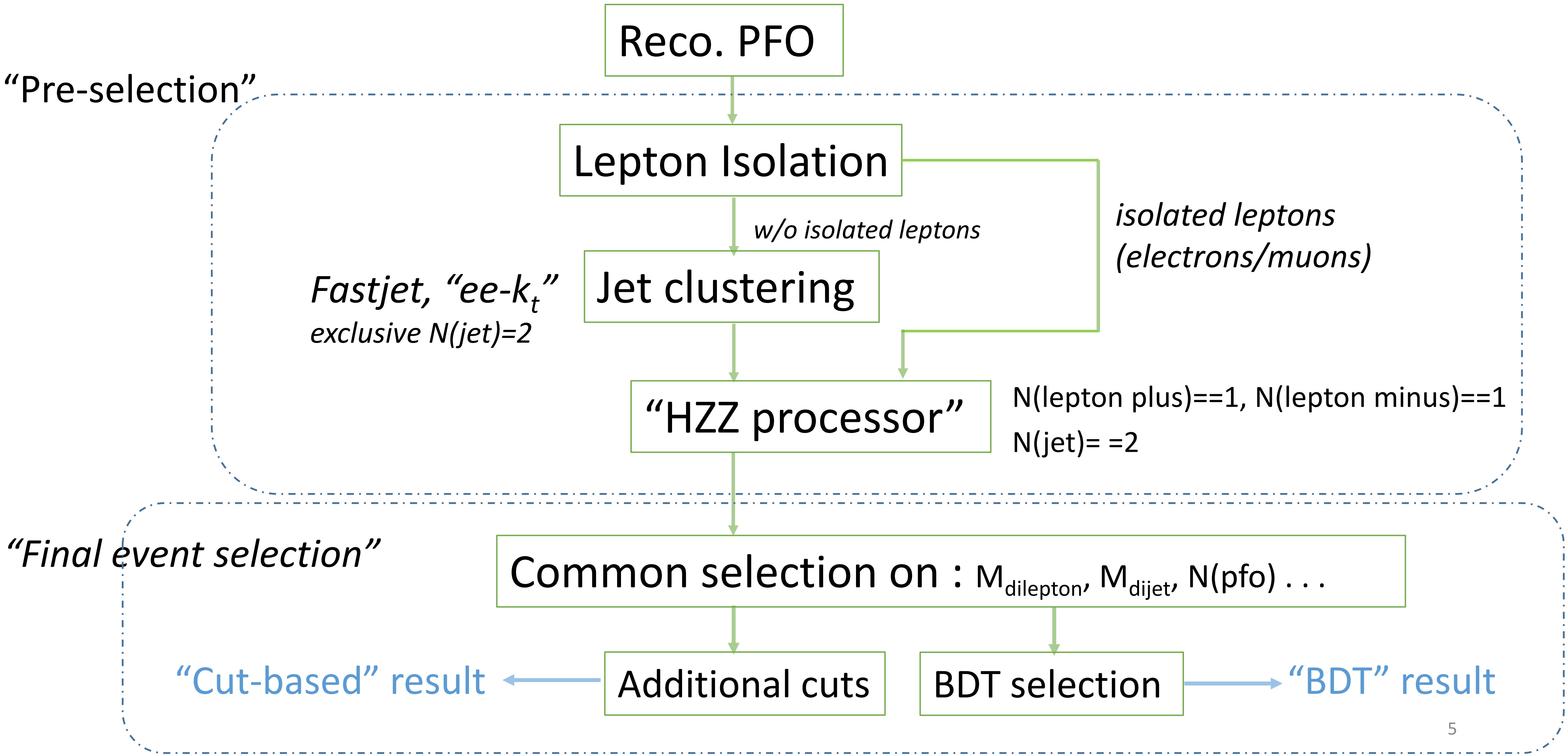
Z / ZZ*				
e^+e^-	$\nu\nu$jj	jj$\nu\nu$		
$\mu^+\mu^-$	$\nu\nu$jj	jj$\nu\nu$		jjjj
$\nu\nu$	e^+e^- jj	jje^+e^-	$\mu^+\mu^-$ jj	jj$\mu^+\mu^-$
jj	e^+e^- $\nu\nu$	$\nu\nu e^+e^-$	$\mu^+\mu^-$ $\nu\nu$	$\nu\nu$ $\mu^+\mu^-$

Monte Carlo Simulation

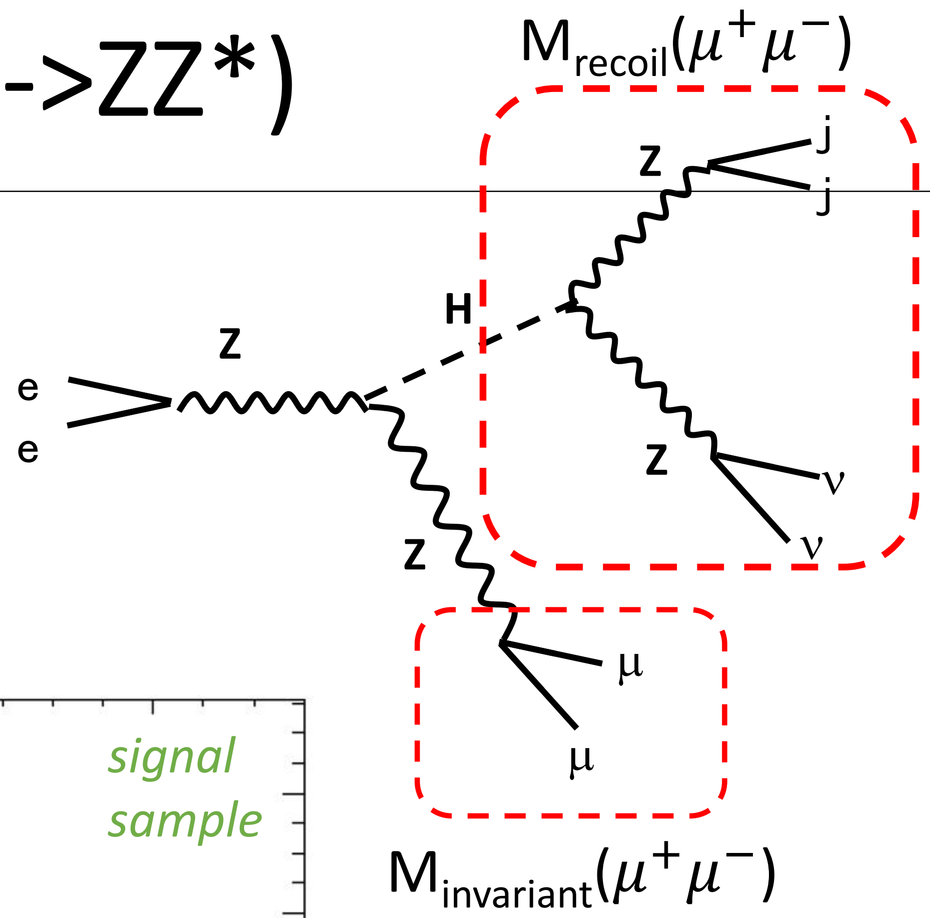
- CEPC_v4 (240GeV, 3T) configuration
- Generator: Whizard 1.95
  (with ISR, L=5.6 ab^{-1}, M_{higgs}=125 GeV)
- Simulation :
  Geant4 and Mokka with ISR and bremsstrahlung effects
- Reconstruction:
  Marlin and ArborPFA



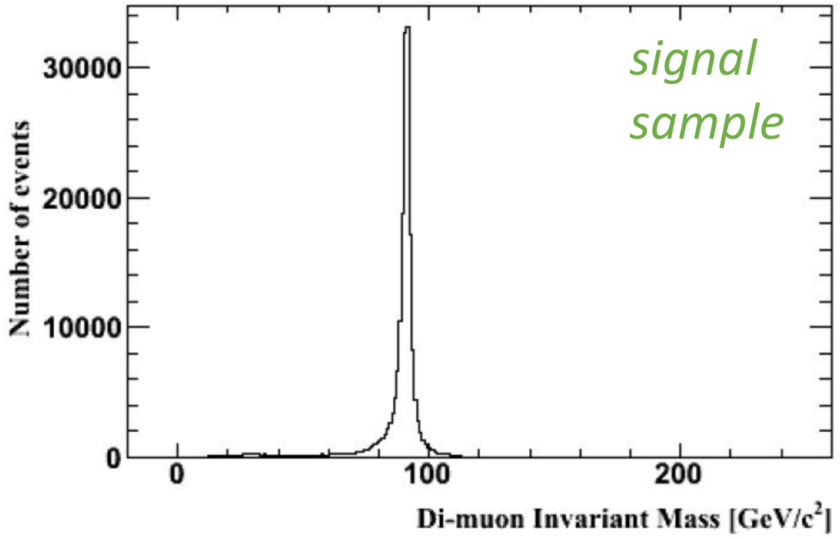
Analysis flow chart



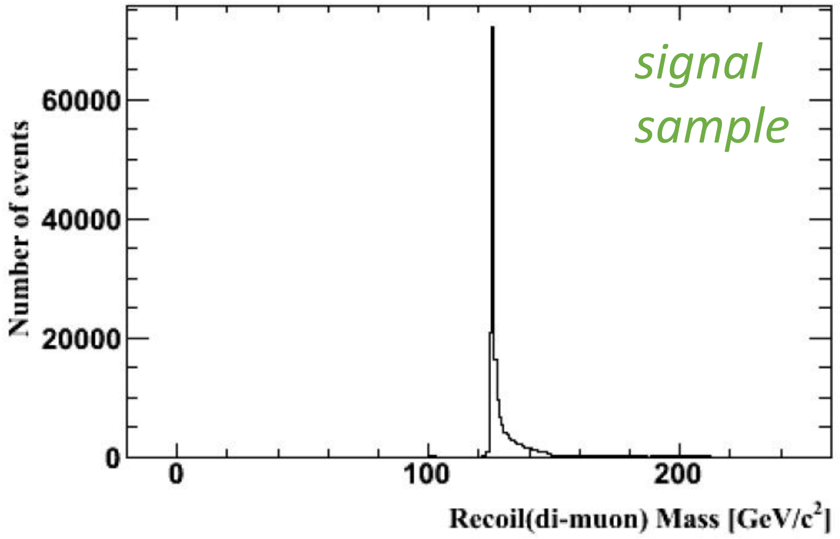
Signature of $Z(\to\mu^+\mu^-)H(\to ZZ^*)$



Identify two muons from initial Z boson using invariant & recoil mass as usual



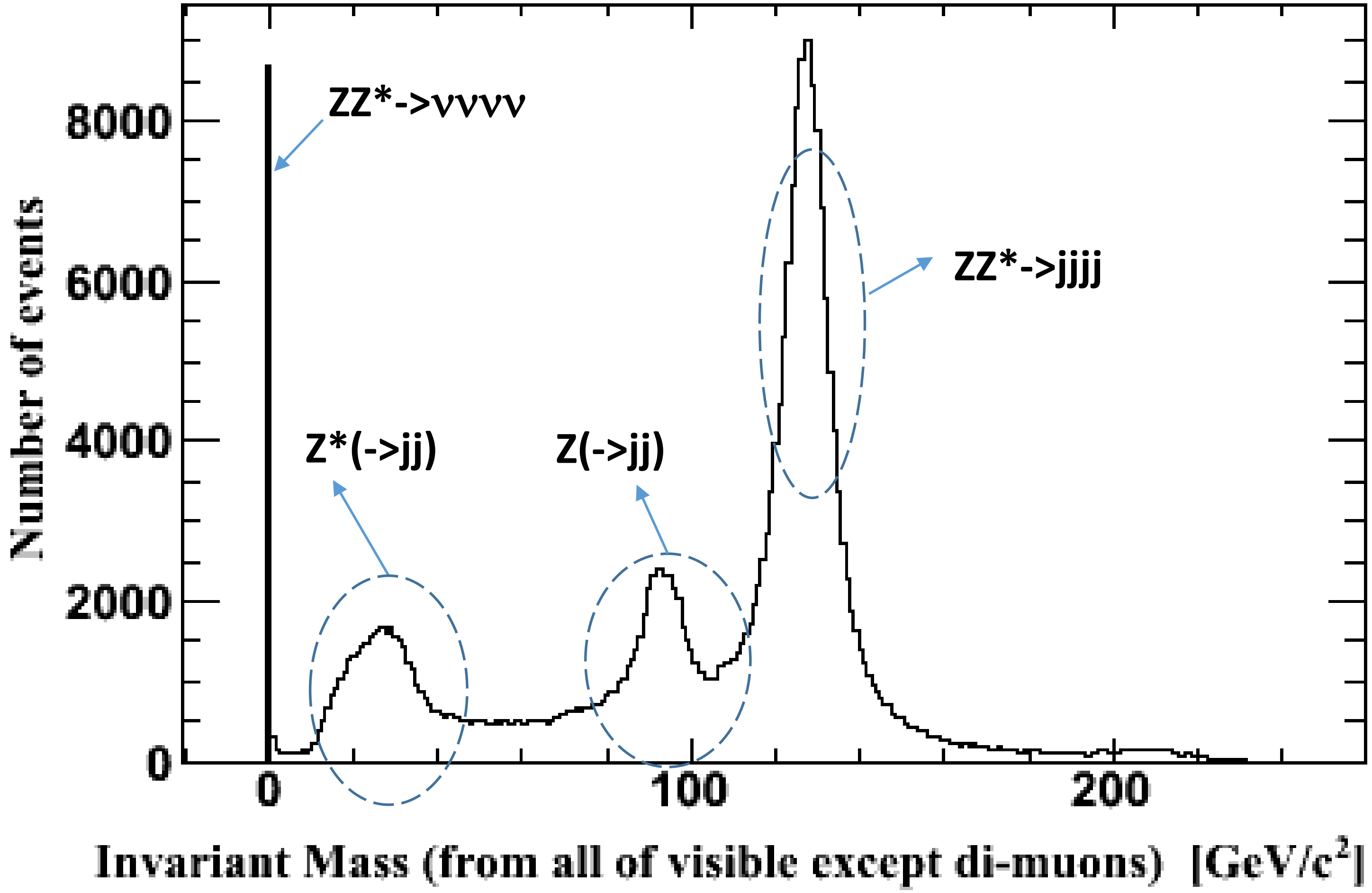
$M_{Invatiant}(\mu^+\mu^-)$



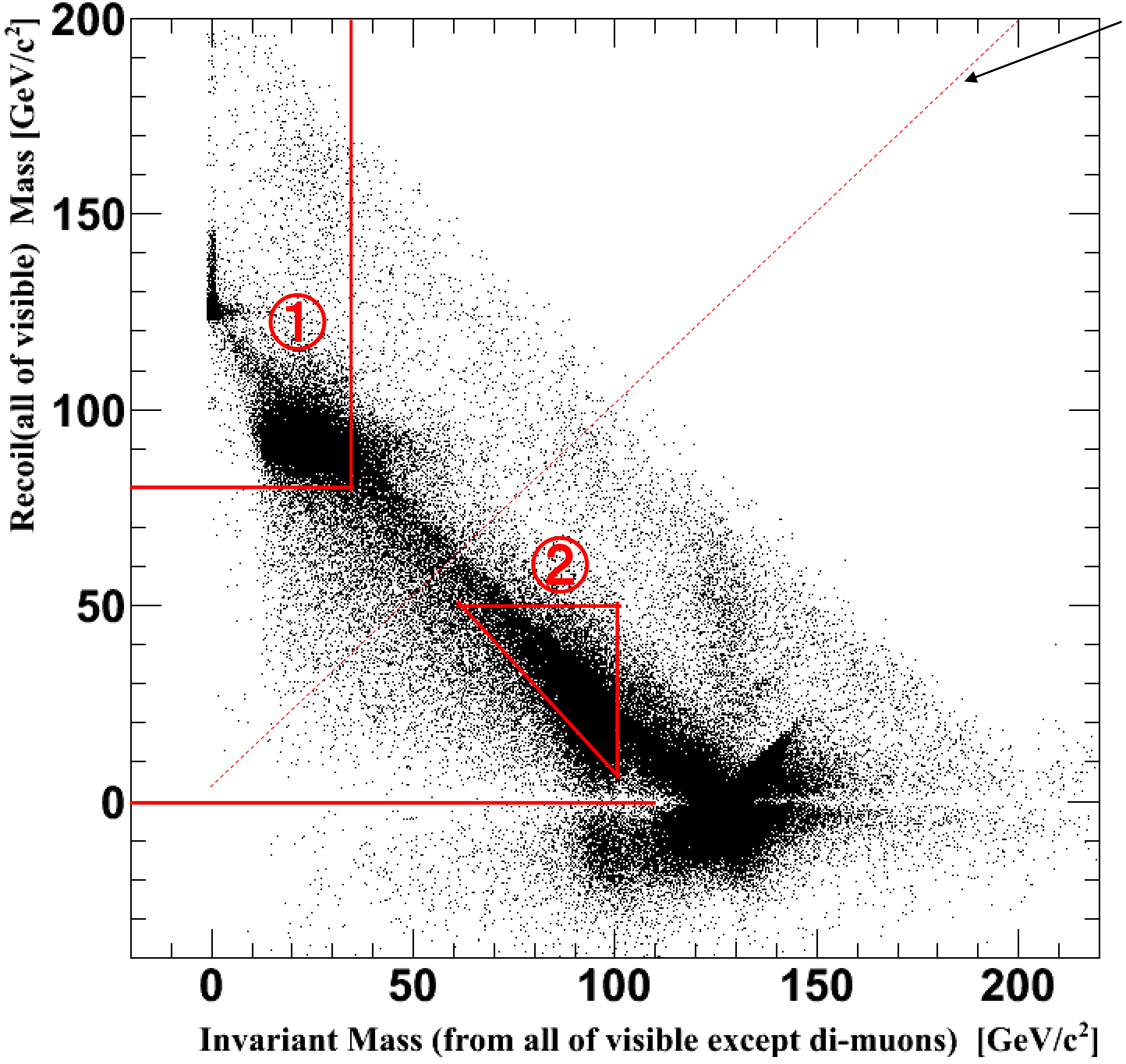
$M_{Recoil}(\mu^+\mu^-)$

Signature of Z(->μ⁺μ⁻)H(->ZZ*)

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



 # Jet clustering
N(jet)=2

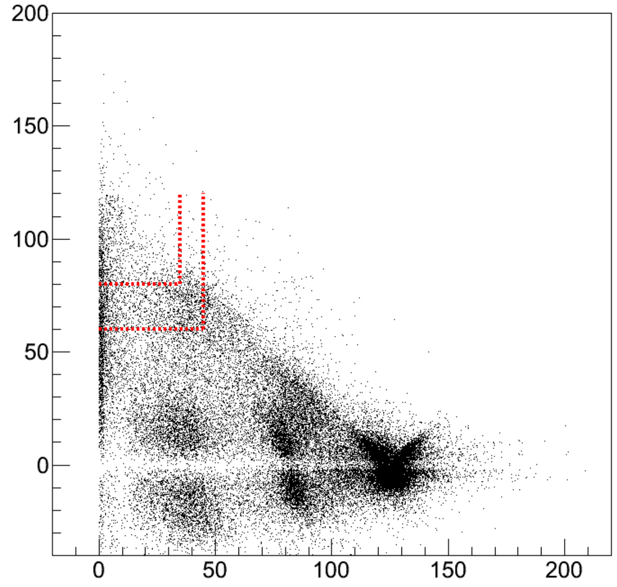


Missing Mass (Z->νν) = Dijet Mass (Z->jj)

Two regions are defined and separately analyzed

Region ① : H→ZZ*(Z→νν, Z*→qq)

Region ② : H→ZZ*(Z→qq, Z*→νν)



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

Cut Flow Table: Z(→μμ)H(Z→νν, Z*→qq)

Cut-based

cut	signal	zh background	2f background	4f background
$Expected$	1000	1140511	801811977	107203890
$Pre-selection$	616	30494	480828	515448
$Signal\ or\ not$	211	30282	480828	515448
$M_{missing} > M_{dijet}$	107	1608	115062	28809
$M_{\mu^+\mu^-}$	95	725	73741	6830
M^{rec}_{dimuon}	93	671	4911	1032
$N(pfo)$	89	253	1396	324
$Pt_{visible}$	85	235	261	77
$Angle_{min}$	81	225	216	64
$M_{missing},\ M_{dijet}$	63	65	0	6
$Pt_{jet1,2},\ E_{jet1,2}$	56	56	0	3
$not\ qqHZZ$	56	56	0	3
$not\ \nu\nu HZZ$	47	22	0	3

further cuts

Same cut procedures

BDT

Cut	Signal	ZH background	2f background	4f background
$Expected$	1000	1140511	801811977	107203890
$Pre-selection$	616	30494	480828	515424
$Signal\ or\ not$	211	30282	480828	515424
$M_{missing} > M_{dijet}$	107	1608	115062	28811
M_{dimuon}	95	725	73741	6833
M^{rec}_{dimuon}	95	706	7886	1359
$N(pfo)$	94	336	3268	574
$Pt_{visible}$	89	312	342	168
$BDT\ score$	66	36	14	11

BDT

At the end

$$\frac{S}{\sqrt{S+B}} = 5.54$$

Note that the cut-based analysis has iterative optimization on cut positions, which results slight difference of numbers from the table below.

$$\frac{S}{\sqrt{S+B}} = 5.86$$

BDT part

Example from Z(→μμ)H(Z→νν, Z*→qq)

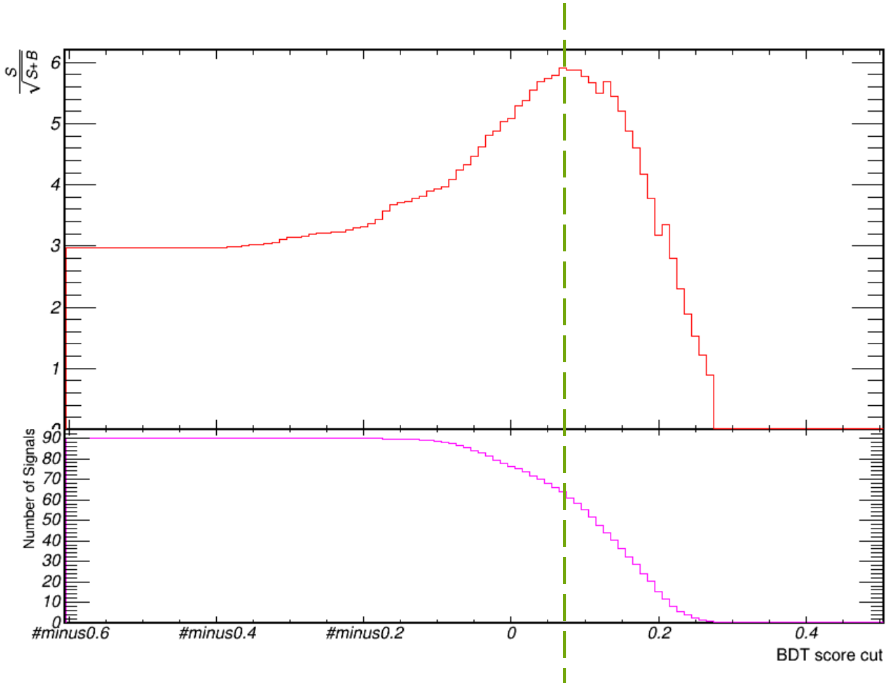
Variables used in the BDT

$P_{\text{all visible}}$	$E_{\text{leading-jet}}$	$\text{Cos}(\theta)$
$Pt_{\text{all visible}}$	$E_{\text{sub-leading-jet}}$	($\text{RecoilM}_{\text{dimuon}}$)
M_{dijet}	N(pfo)	($M_{\text{all visible}}$)
M_{dimuon}	$\text{Angle}_{\text{(dijet-dimuon)}}$	

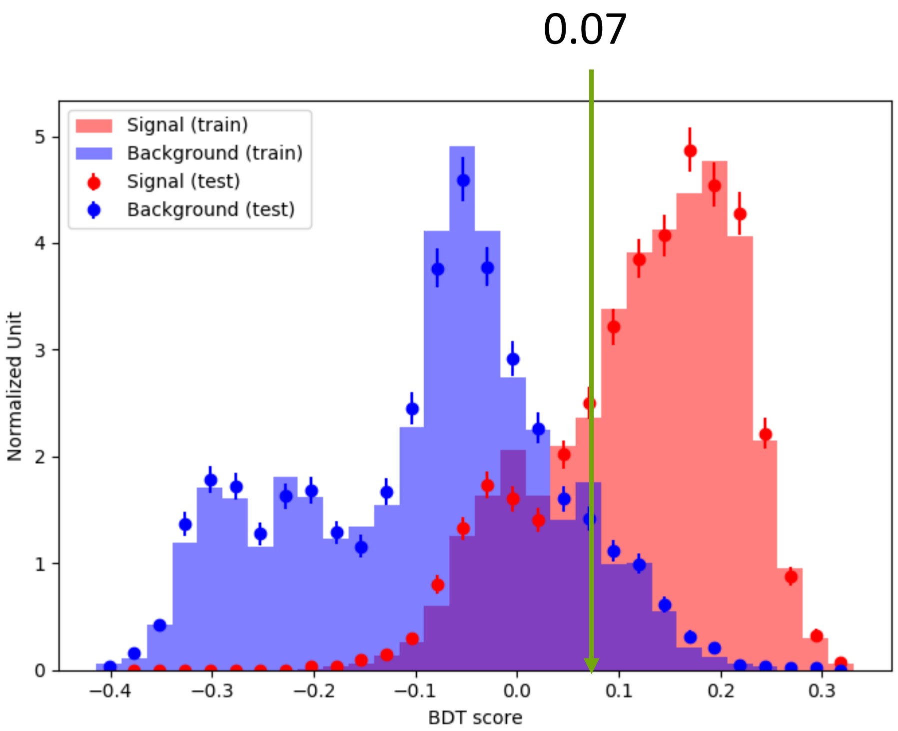
BDT cut position optimization

Chose the position where the significance estimator becomes max

- $\dfrac{S}{\sqrt{S+B}}$



Signal & Background



Cut Flow Table: $Z(\to\mu\mu)H(Z\to qq, Z^*\to\nu\nu)$

Cut-based

cut	signal	zh background	2f background	4f background
$Expected$	1000	1140511	801811977	107203890
$Pre-selection$	616	30494	480828	515448
$Signal\ or\ not$	211	30282	480828	515448
$M_{dijet} < M_{missing}$	103	28674	365766	486638
$M_{\mu^+\mu^-}$	92	22473	215445	239022
M^{rec}_{dimuon}	90	21802	13226	17787
$N(pfo)$	87	16327	186	14406
$Pt_{visible}$	66	3423	0	744
$Angle_{min}$	64	3294	0	711
$M_{missing},\ M_{dijet}$	43	703	0	200
$Pt_{jet1,2},\ E_{jet1,2}$	38	589	0	189
$not\ qqHZZ$	35	510	0	175
$not\ \nu\nu HZZ$	35	510	0	175

$$\frac{S}{\sqrt{S+B}} = 1.30$$

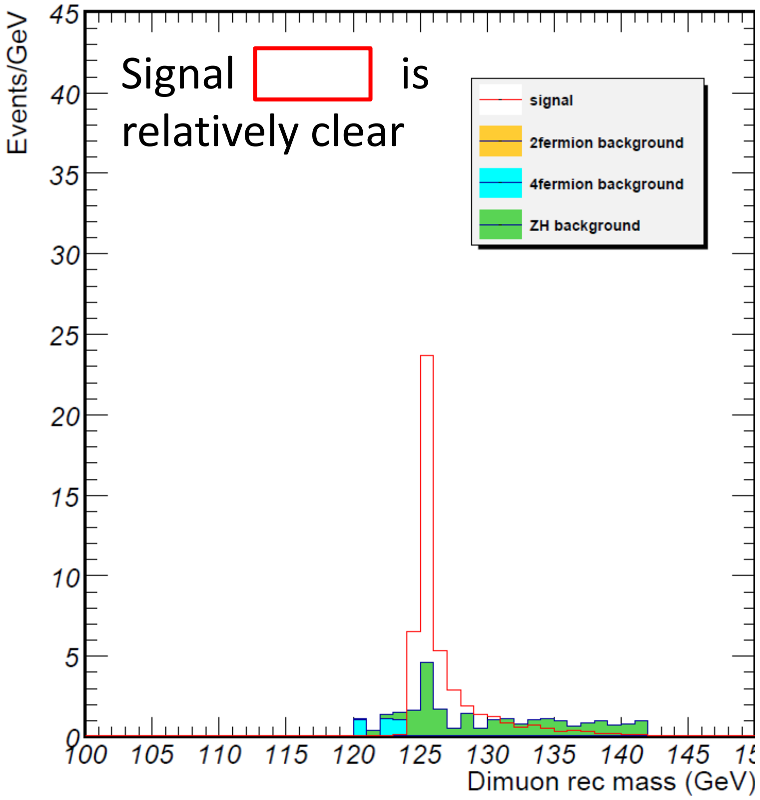
BDT

Cut	Signal	ZH background	2f background	4f background
$Expected$	1000	1140511	801811977	107203890
$Pre-selection$	616	30494	480828	515424
$Signal\ or\ not$	211	30282	480828	515424
$M_{missing} < M_{dijet}$	103	28674	365766	486613
M_{dimuon}	92	22473	215445	239023
M^{rec}_{dimuon}	92	22379	17363	20611
$N(pfo)$	89	16760	321	16304
$Pt_{visible}$	74	4341	59	1273
$BDT\ score$	63	1073	7	494

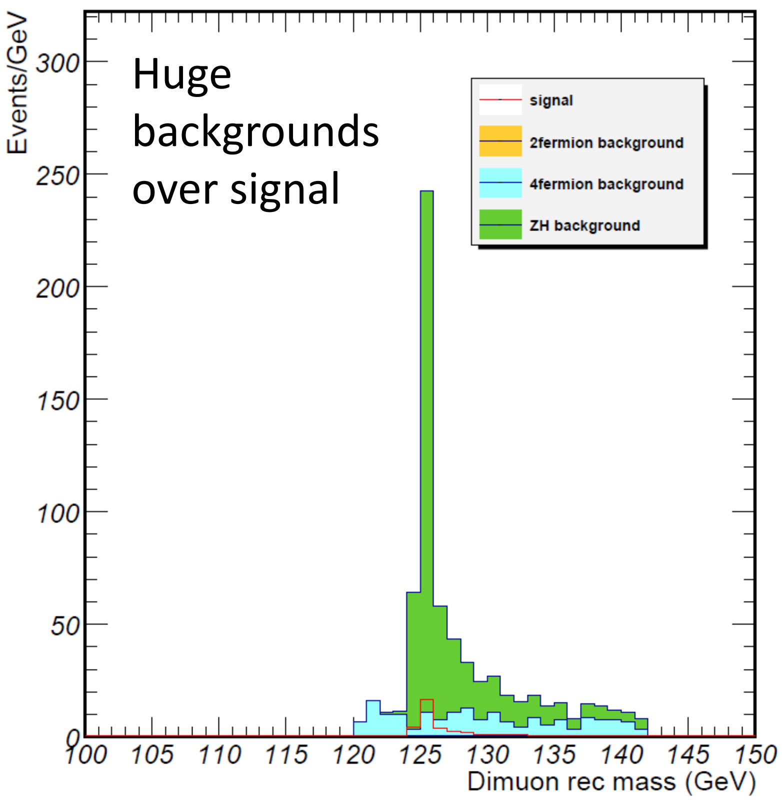
$$\frac{S}{\sqrt{S+B}} = 1.55$$

Recoil Mass(μμ) distributions

➢ Cut based results



$Z(\to\mu\mu)H(Z\to\nu\nu, Z^*\to qq)$



$Z(\to\mu\mu)H(Z\to qq, Z^*\to\nu\nu)$

Major backgrounds

$Z(\to\mu\mu)H(Z\to\nu\nu, Z^*\to qq)$ Side

name	scale	final
e2e2h_e3e3	0.023968	1
e2e2h_ww	0.08176	9
nnh_zz	0.06832	11
zz_sl0tau_up	1.10880522921	1
zz_l0taumu	1.0404004004	2

Event Number

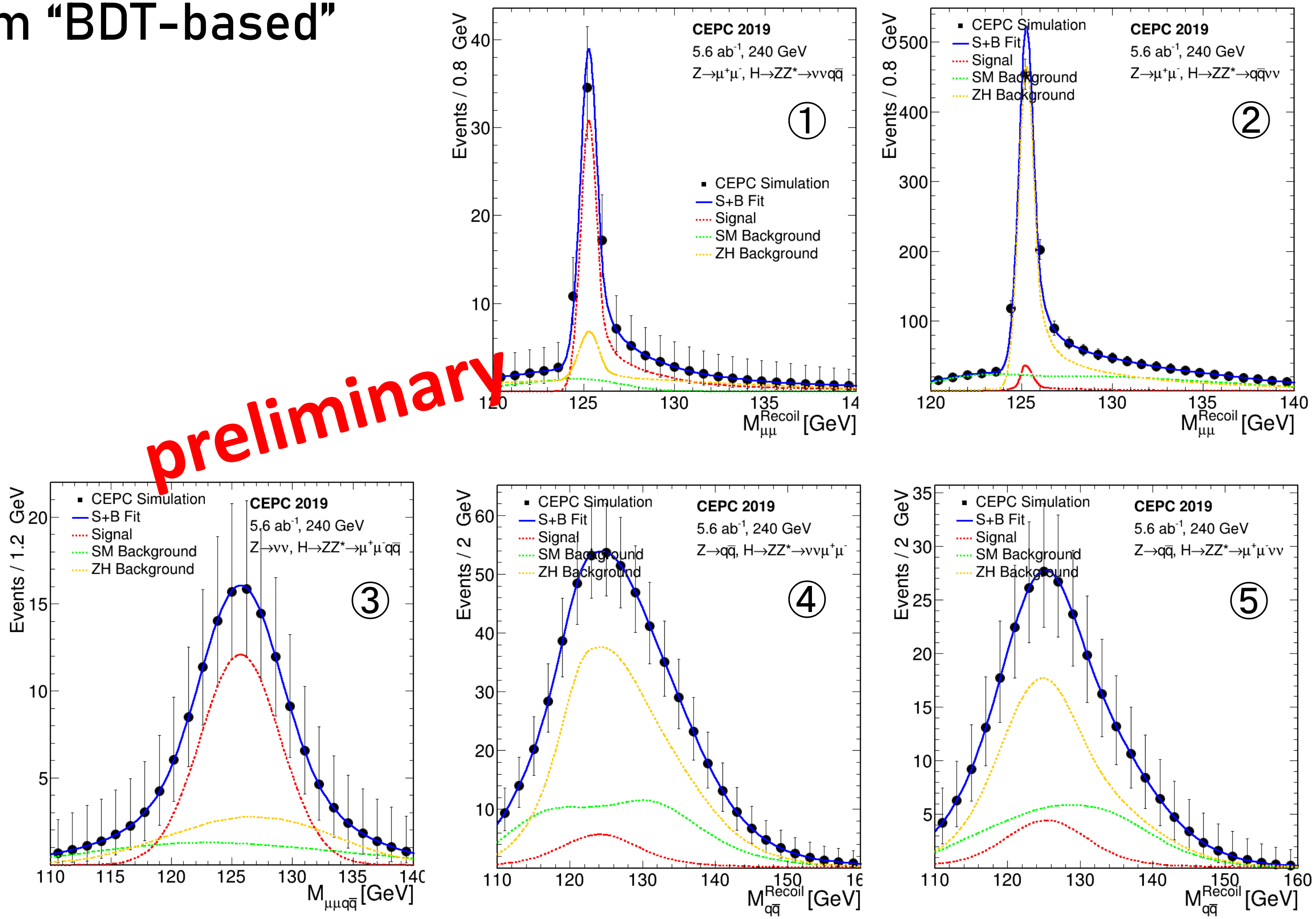
$Z(\to\mu\mu)H(Z\to qq, Z^*\to\nu\nu)$ Side

name	scale	final
e2e2h_bb	0.21896	297
e2e2h_ww	0.08176	180
qqh_zz	0.20216	13
zz_sl0mu_up	1.09032214858	33
zz_sl0mu_down	1.08025726079	137

Signal fitting results and the yield precision

Those distributions are from “BDT-based” results.

Channel	Precision
① Z(→μμ)H(Z→νν, Z*→qq)	15.10 %
② Z(→μμ)H(Z→qq, Z*→νν)	56.76 %
③ Z(→νν)H(ZZ*→μμ, qq)	13.45 %
④ Z(→qq)H(Z→νν, Z*→μμ)	50.89 %
⑤ Z(→qq)H(Z→μμ, Z*→νν)	45.60 %
All combined	9.49 %



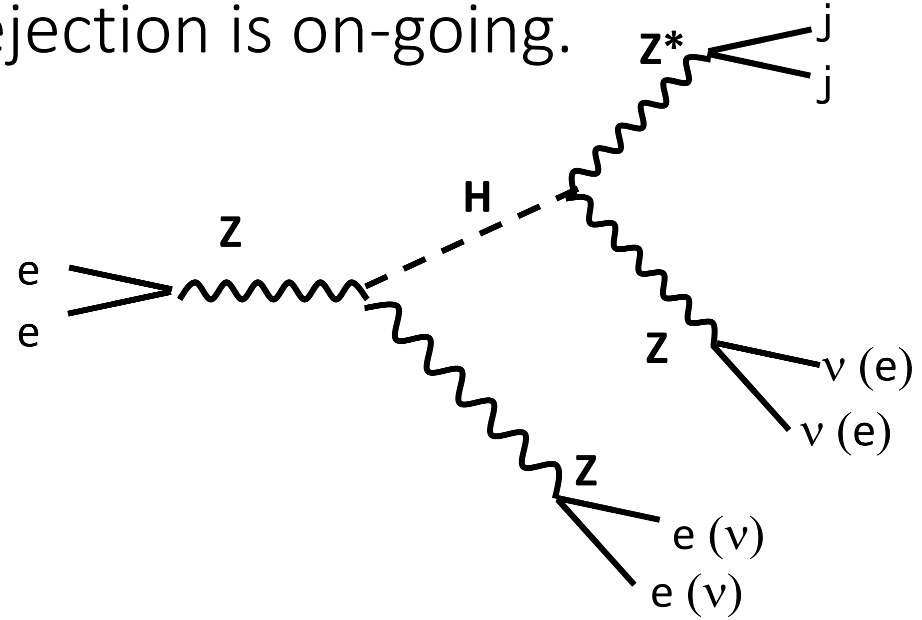
We are trying to improve further our analysis now actively

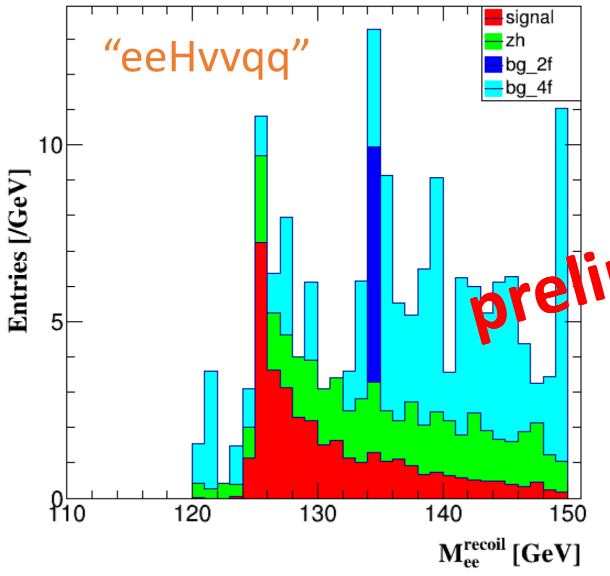
Other decay combination:

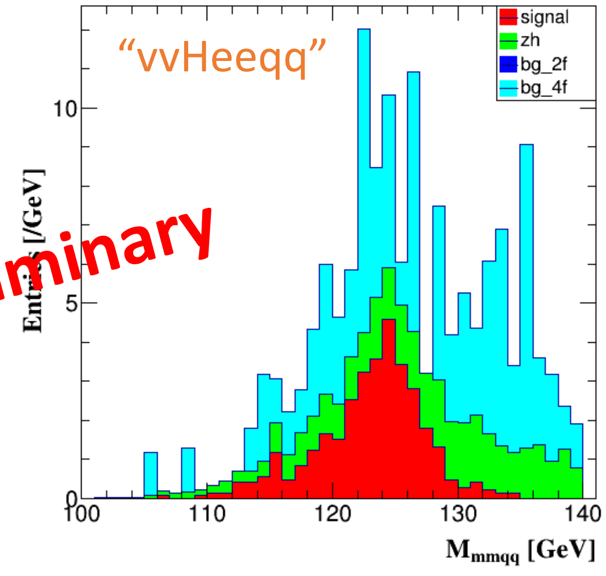
Under study

$Z(\rightarrow ee)H(ZZ^* \rightarrow \nu\nu qq)$ / $Z(\rightarrow \nu\nu)H(ZZ^* \rightarrow eeqq)$

- Decay modes, where replacing muons to electrons, likely to have similar level of the HZZ yield precision .
- Compared with the muon channels, they have higher backgrounds due to slight difference of the resolution. Further study on background rejection is on-going.







Roughly estimated precision (not by fitting) : ~33%. Need further optimizations

An investigation about probing anomalous coupling of HZZ vertex along with the HZZ analysis

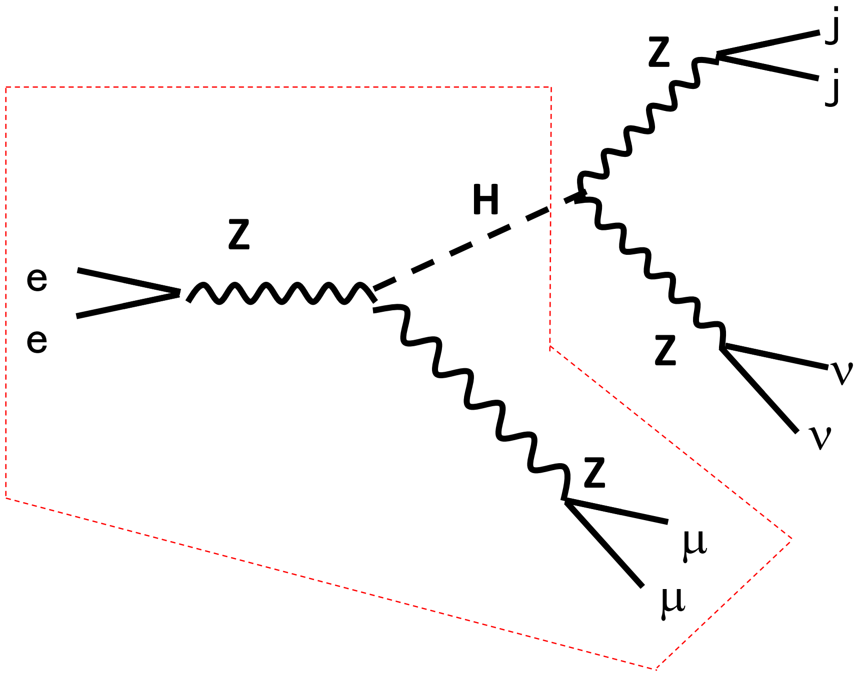
Motivation

-- To probe the anomalous couplings on HZZ vertex,
differential observables are used and compared with EFT models.

-- Reaction of ee/pp->Z(l^+l^-)H(bb) is the process discussed in many places,
not only its simple picture but also owing to its statistics and S/N.

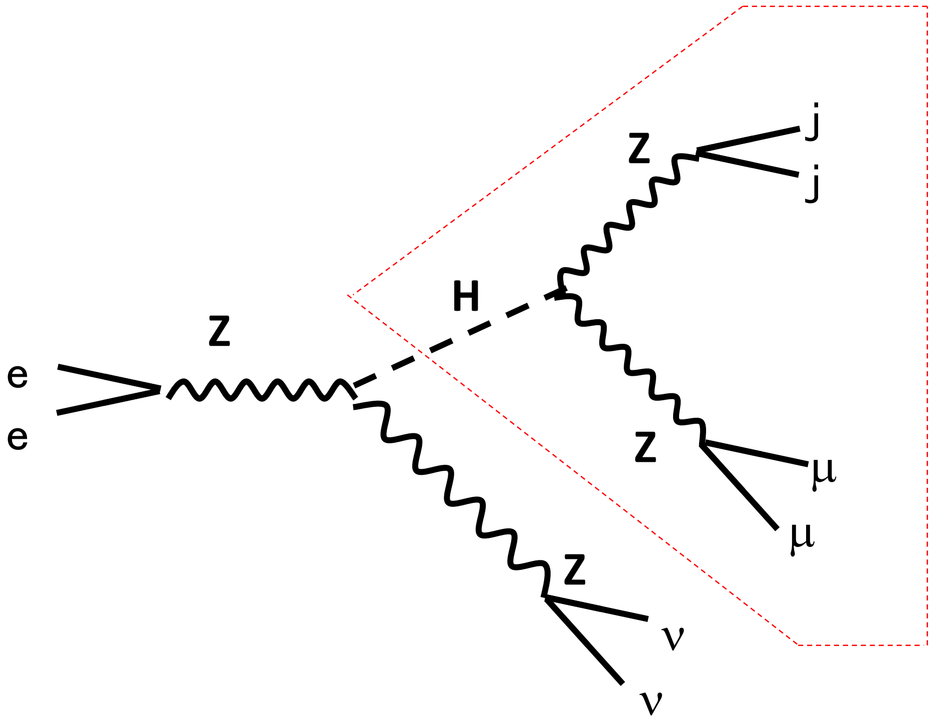
Here, we try to explore it via the channels we are analyzing,
shown in previous pages.

Case1: $Z(\mu^+\mu^-)H(ZZ^*\text{->}\nu\nu, jj)$



- Much lower statistics than H->bb

Case2: $Z(\nu\nu)H(ZZ^*\text{->}\mu\mu, jj)$



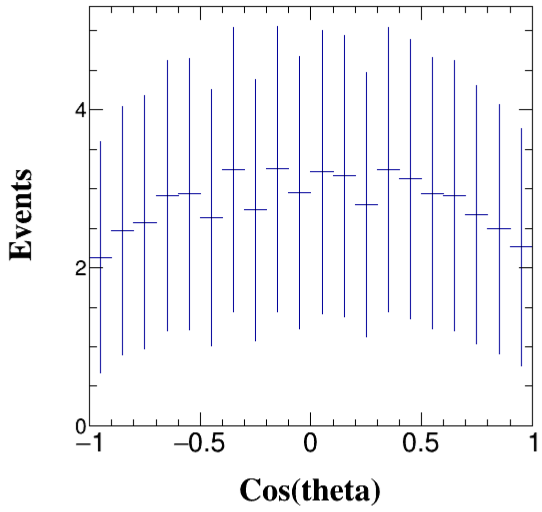
- One of motivation to use these HZZ channels, having different √s

Case 1 has been chosen (because of rather simple kinematics) as a first trial and presented in the following pages.

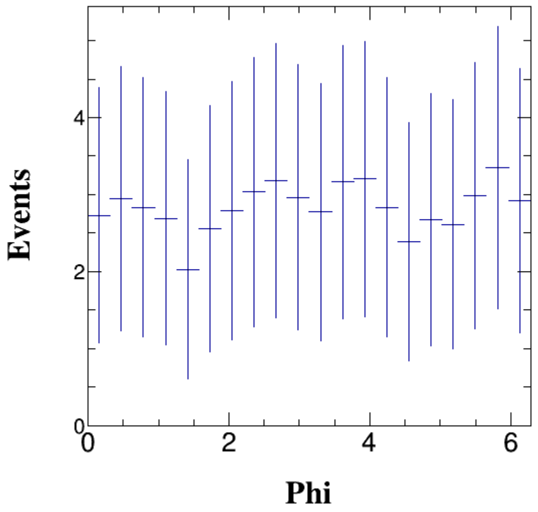
Differential observables

- Analysis process of $Z(\mu^+\mu^-)H(ZZ^*\to\nu\nu, jj)$ is applied on the signal $Z(\mu^+\mu^-)H(ZZ^*)$ sample.
- Background is not considered this time

cos(Θ)



ϕ



(h->)ZZ for this case

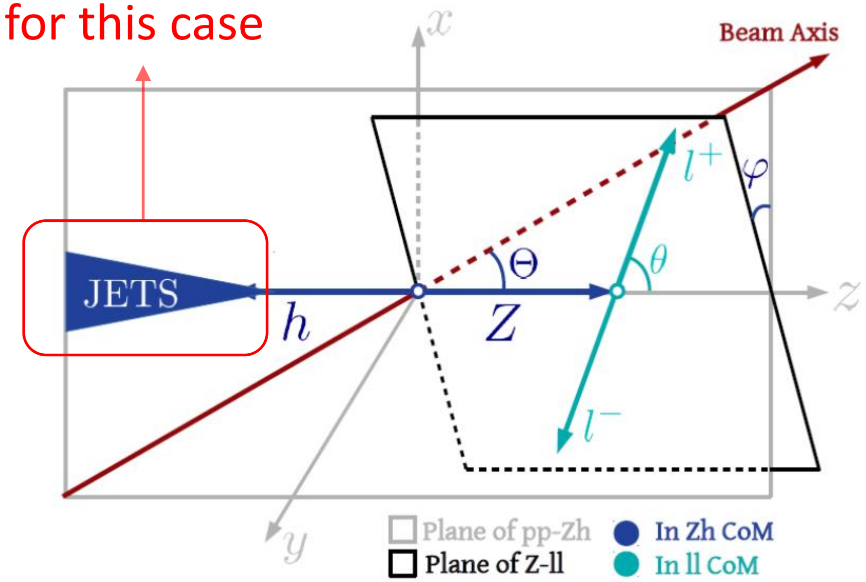


Diagram showing the angles used here.
(from the ref. shown in next page)

Angular variables are defined as usual and are shown in left figure.

EFT model

-- We have referred :

"Resolving the tensor structure of the higgs coupling to Z-bosons via Higgs-strahlung", Shankha Banerjee, Rick S. Gupta, Joey Y. Reiness and Michael Spannowsky, arXiv:1905.02728

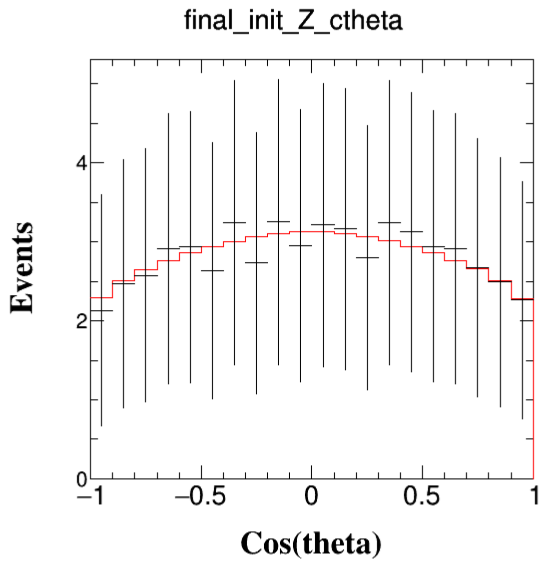
$$\boxed{\begin{aligned}\Delta\mathcal{L}_6^{hZ\bar{f}f} \supset & \, \delta\hat{g}^h_{ZZ}\frac{2m_Z^2}{v}h\frac{Z^\mu Z_\mu}{2} + \sum_f g^h_{Zf}\frac{h}{v}Z_\mu\bar{f}\gamma^\mu f \\ & + \kappa_{ZZ}\frac{h}{2v}Z^{\mu\nu}Z_{\mu\nu} + \tilde{\kappa}_{ZZ}\frac{h}{2v}Z^{\mu\nu}\tilde{Z}_{\mu\nu}.\end{aligned}}$$

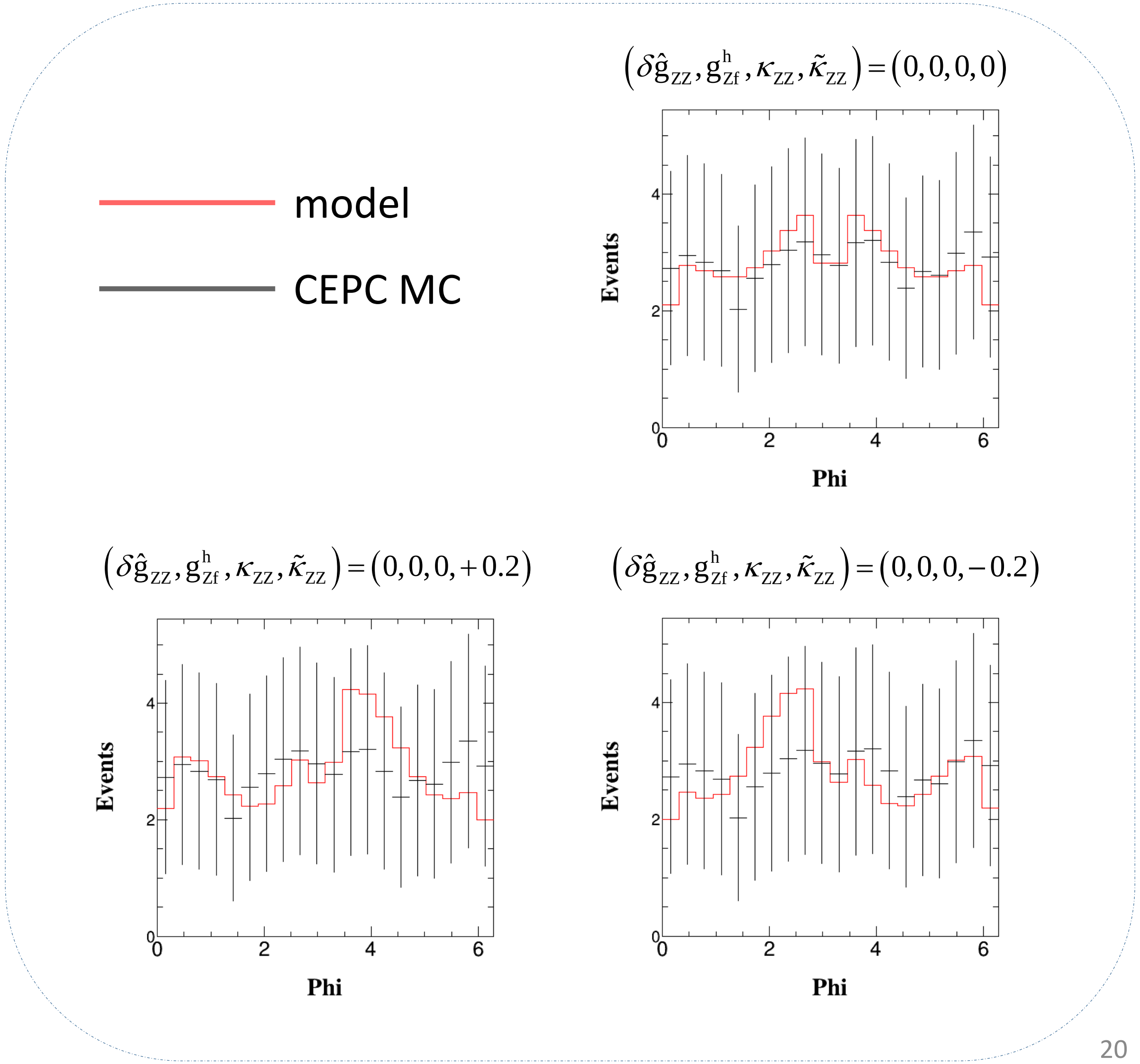
-- Amplitude is given in analytical form at first order (√s/Mz), and we have tried to reproduce the differential observables based on the formula.

-- Application to our analysis with this approximation would be an issue.

Comparison of the EFT model with the MC data

-- Normalization factor is obtinned from the fitting of the analysis result with the model$_{SM}$





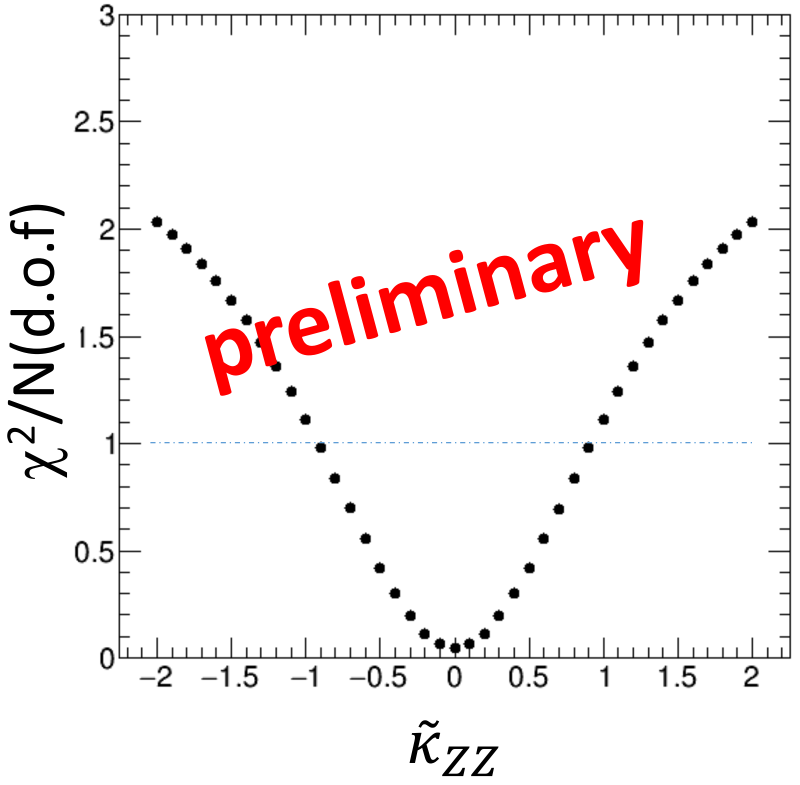
Status

・The lower statistics might lead poorer limitation on the anomalous couplings

Further steps would be . . .

・Include backgrounds, to have more accurate estimation

・Try to open the HZZ side. (Case2)



Beyond these HZZ channels, re-visit on the production channel, Z(->ll)H(->bb), and/or, Z(->qq)H(->bb) serve as good comparisons.

Summary

- Progress Status on HZZ analysis using the CEPC_v4 MC samples
  - We have analyzed 3 combinations of Z boson decays
    ($\mu\mu H\nu\nu qq/qq\nu\nu$, $\nu\nu H\mu\mu qq/qq\mu\mu$, $qqH\mu\mu\nu\nu/\nu\nu\mu\mu$)
  - Two electron channels are studied with the same framework.
    ($eeH\nu\nu qq$, $\nu\nu Heeqq$)
  - An exploration has been done on the application of the EFT model for this channel.
- Next Step
  - Further improvement and optimization on event selections for the HZZ analysis.

Thank you very much !

Backup

Data samples

- Signal

  $Z(\rightarrow\mu\mu)H(ZZ^*\rightarrow\nu\nu, qq)$: /cefs/data/DstData/CEPC240/CEPC_v4/higgs/E240.Pe2e2h_zz.e0.p0.whizard195/

  $Z(\rightarrow\nu\nu)H(ZZ^*\rightarrow\mu\mu, qq)$: /cefs/data/DstData/CEPC240/CEPC_v4/higgs/E240.Pnnh_zz.e0.p0.whizard195/

  $Z(\rightarrow qq)H(ZZ^*\rightarrow\mu\mu, \nu\nu)$: /cefs/data/DstData/CEPC240/CEPC_v4/higgs/E240.Pqqh_zz.e0.p0.whizard195/

- Background (stored under /cefs/data/DstData/CEPC240/CEPC_V4/)

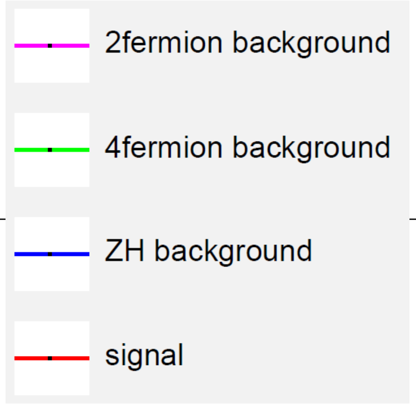
  - "2 fermions" (bhabha, e2e2, e3e3, qq, nn)

  - "4 fermions" (zz_h0, zz_sl0, zz_l04, ww_h0,,,,)

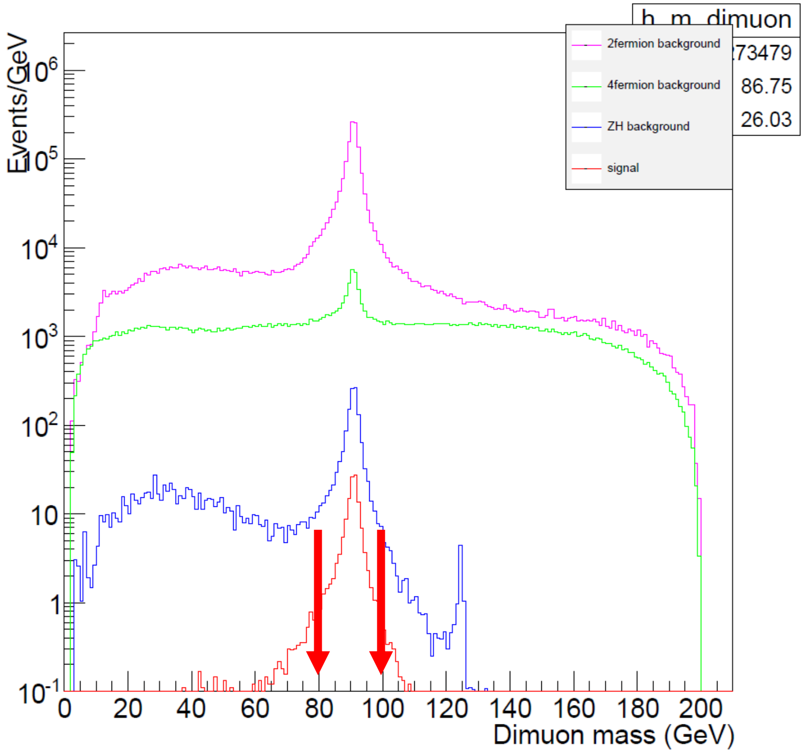
  - "ZH" (==other Higgs decays) (qqh_**, e1e1h_**, e2e2h_**, e3e3h_**, nnh_**)

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

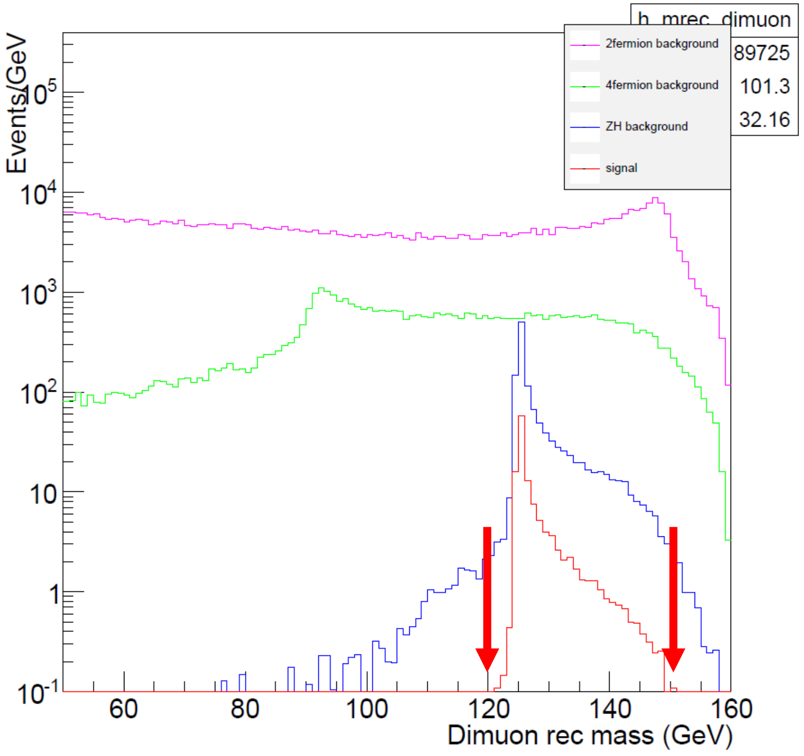
Distributions - I.



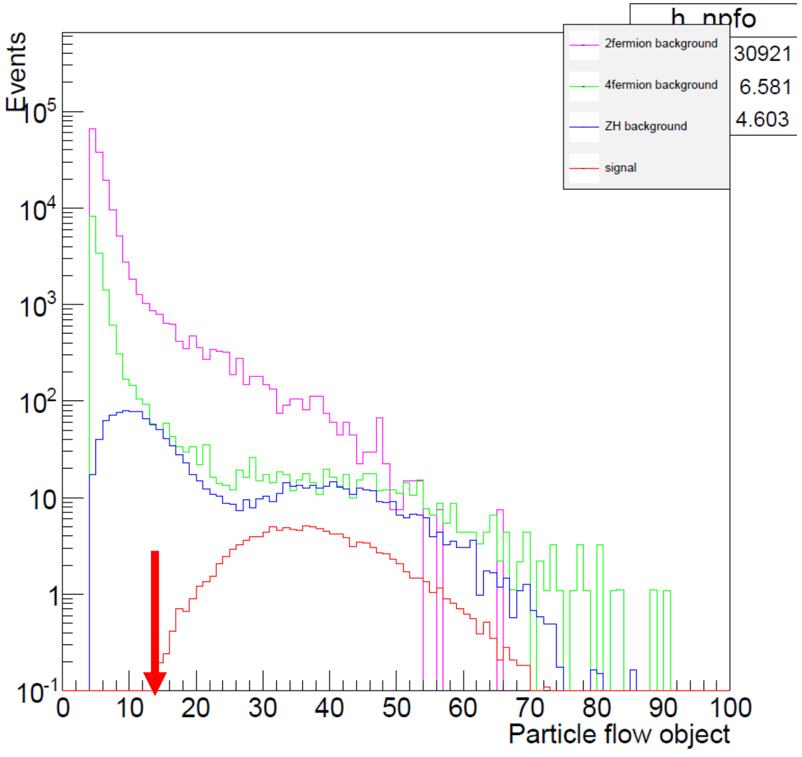
$M_{invariant}(\mu\mu)$



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



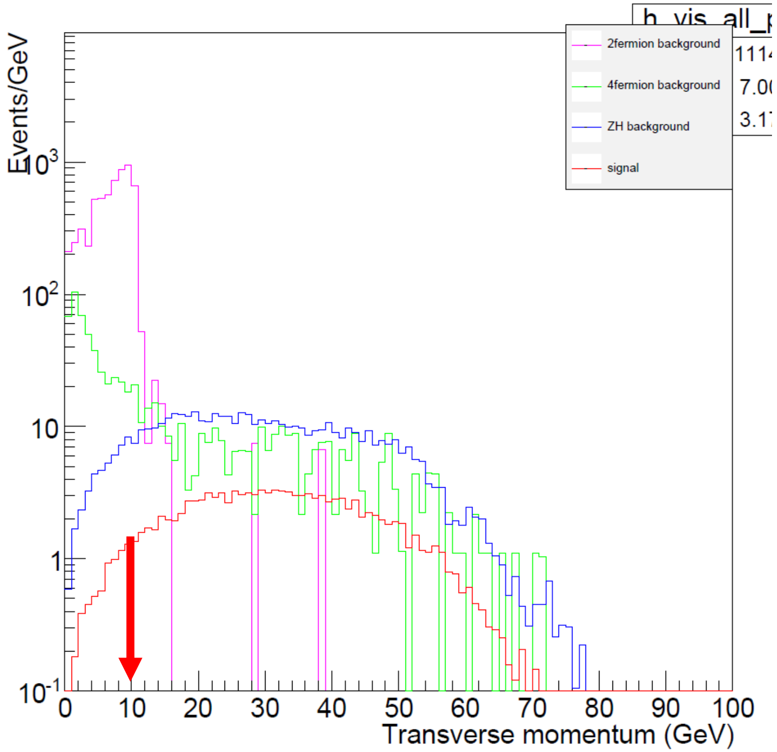
N(pfo)



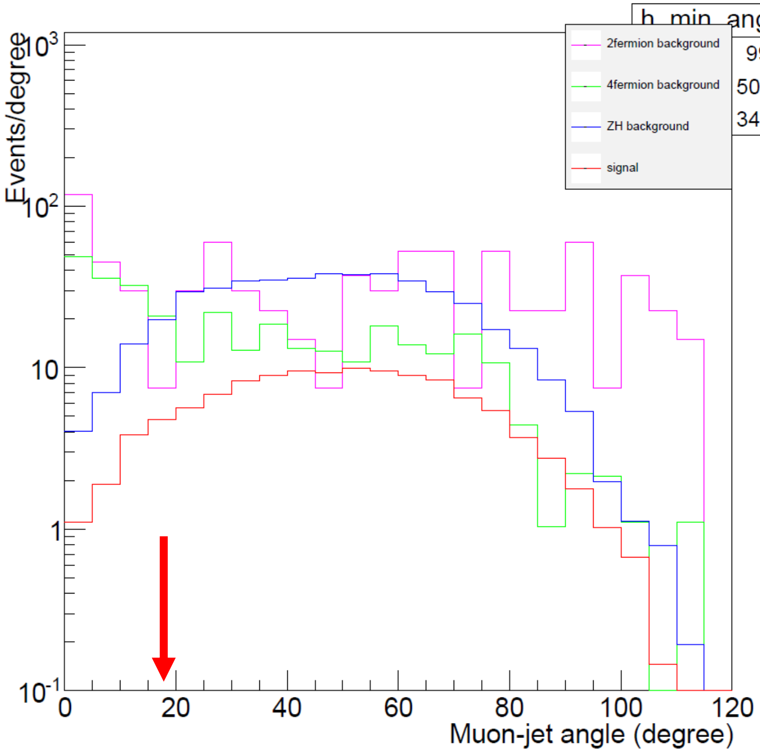
$Z(\rightarrow\mu\mu)H(Z\rightarrow\nu\nu, Z^*\rightarrow qq)$

Distributions - II.

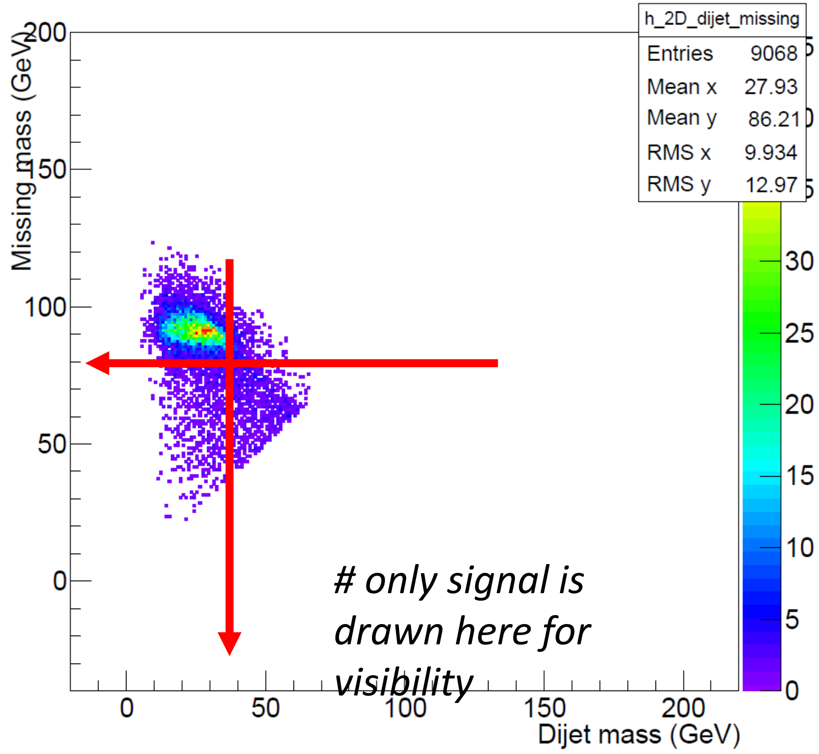
Pt(visible all)



Min. angle (lepton⇔jet)



Missing Mass vs Di-jet Mass



$Z(\rightarrow \mu\mu)H(Z\rightarrow \nu\nu, Z^*\rightarrow qq)$

Cut Flow: $Z(\to\nu\nu)H(ZZ^*\to\mu\mu, qq)$

Cut-based

cut	signal	zh background	2f background	4f background
$Expected$	6844	1140511	801811977	107203890
$Pre-selection$	238	30494	480828	515424
$Signal\ or\ not$	226	30268	480828	515424
$N(pfo)$	198	10580	61902	268708
$M_{visible}$	175	450	9694	6533
$cos\ \theta$	126	328	132	414
M_{dimuon}	109	211	118	239
$P_{visible}$	87	87	0	55
M_{dijet}	81	77	0	33
$E_{leading\ jet}$	76	61	0	18
$E_{subleading\ jet}$	74	60	0	15
$Angle_{\mu j}$	72	57	0	11
$M_{\mu^+\mu^-}$	70	49	0	11
$cos\ \theta_{visible}$	70	49	0	11
$M^{rec}_{visible}$	67	46	0	9
$not\ \mu^+\mu^- HZZ$	60	31	0	9
$not\ qqHZZ$	58	21	0	8

BDT

Cut	Signal	ZH background	2f background	4f background
$Expected$	6844	1140511	801811977	107203890
$Pre-selection$	238	30494	480828	515424
$Signal\ or\ not$	226	30268	480828	515424
$N(pfo)$	226	29861	152634	444218
$M_{visible}$	201	710	15429	10306
$cos\ \theta$	144	510	367	831
$BDT\ score$	87	42	0	23

Cut Flow: Z(→qq)H(Z→νν, Z*→μμ)

Cut-based

cut	signal	zh background	2f background	4f background
$Expected$	20254	1140511	801811977	107203890
$Pre-selection$	826	30494	480828	515424
$Signal\ or\ not$	203	30291	480828	515424
$M_{missing} > M_{dimuon}$	94	3179	18606	40769
$N(pfo)$	91	2502	2050	15114
$M_{visible}$	76	1326	118	3582
$cos\ \theta$	60	1061	0	1131
M^{rec}_{dimuon}	45	379	0	659
$P_{visible}$	43	348	0	583
M_{dijet}	41	289	0	502
$E_{leading\ jet}$	40	277	0	322
$E_{subleading\ jet}$	39	270	0	268
$Angle_{\mu j}$	39	264	0	240
M_{dimuon}	39	246	0	229
$cos\theta_{visible}$	37	233	0	202
$M^{rec}_{visible}$	37	210	0	119
$Pt_{visible}$	37	210	0	119
$not\mu^+\mu^-HZZ$	37	210	0	119
$not\nu$	30	166	0	110

BDT

Cut	Signal	ZH background	2f background	4f background
$Expected$	20254	1140511	801811977	107203890
$Pre-selection$	826	30494	480828	515424
$Signal\ or\ not$	203	30291	480828	515424
$M_{missing} > M_{dimuon}$	94	3179	18606	40769
$N(pfo)$	91	2502	2050	15114
M_{dijet}	85	1793	14	6178
$cos\ \theta$	67	1439	0	2175
$M_{visible}$	67	1345	0	1476
$BDT\ score$	46	377	0	233

Cut Flow: Z(→qq)H(Z→μμ, Z*→νν)

Cut-based

cut	signal	zh background	2f background	4f background
$Expected$	20254	1140511	801811977	107203890
$Pre-selection$	826	30494	480828	515424
$Signal\ or\ not$	203	30291	480828	515424
$M_{dimuon} > M_{missing}$	108	27112	462222	474655
$N(pfo)$	104	21274	17185	318984
$M_{visible}$	86	3138	261	25231
$cos\ \theta$	69	2345	0	6503
M^{rec}_{dimuon}	50	626	0	708
$P_{visible}$	48	542	0	572
M_{dijet}	45	325	0	404
$E_{leading\ jet}$	44	302	0	277
$E_{subleading\ jet}$	44	300	0	238
$Angle_{\mu j}$	43	272	0	217
M_{dimuon}	39	177	0	101
$cos\theta_{visible}$	38	165	0	57
$M^{rec}_{visible}$	33	149	0	51
$Pt_{visible}$	33	147	0	45
$not\mu^+\mu^-HZZ$	33	147	0	45
$not\nu\nu HZZ$	33	147	0	45

BDT

Cut	Signal	ZH background	2f background	4f background
$Expected$	20254	1140511	801811977	107203890
$Pre-selection$	826	30494	480828	515424
$Signal\ or\ not$	203	30291	480828	515424
$M_{missing} < M_{dimuon}$	108	27112	462222	474655
$N(pfo)$	106	21480	27891	332167
M_{dijet}	103	4833	141	265479
$cos\ \theta$	80	3576	7	156099
$M_{visible}$	77	2913	0	8750
$BDT\ score$	37	167	0	148