WW fusion measurement at the CEPC 360 GeV Runs

Hongbo Liao[1], Yingqi Hou[1], Taozhe Yu[1], Kaili Zhang[1], Gang Li[2]

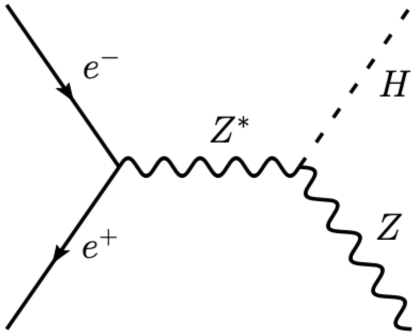
Approval meeting of Physics Benchmarks for RefTDR

June 18th

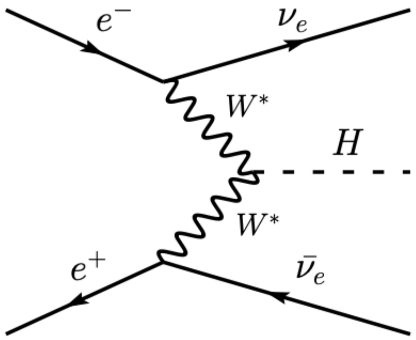
1.Institute of High Energy Physics, China

Motivation

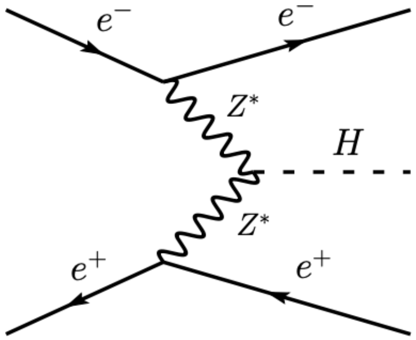
- In CEPC, Three are three main production of Higgs: ZH, WW fusion and ZZ fusion
- One indirect method to measure Higgs width is relate to ZH and WW fusion process
- Higgs width measured precision is relate to WW fusion, $H \to bb$ process



ZH



WW fusion



ZZ fusion

$$\Gamma_H/\Gamma_H^{\mathrm{SM}} = \frac{\mu_{ZH}^2 \mu_{WW\mathrm{fusion},H\to bb}}{\mu_{ZH,H\to WW^*}\mu_{ZH,H\to bb}}$$

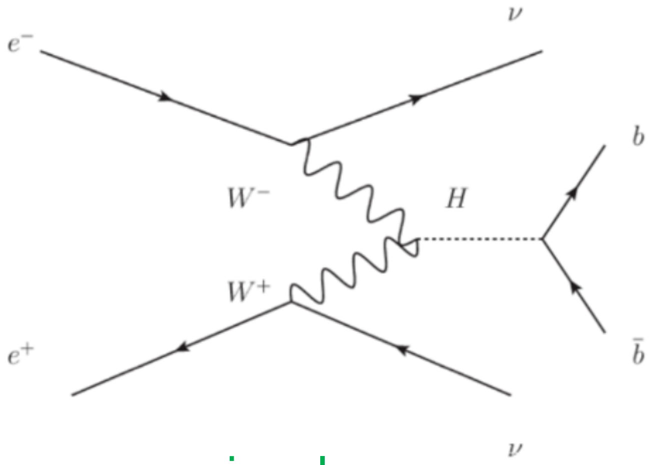
Γ_H^{SM}: Higgs width predicted by SM

μ: the signal strength

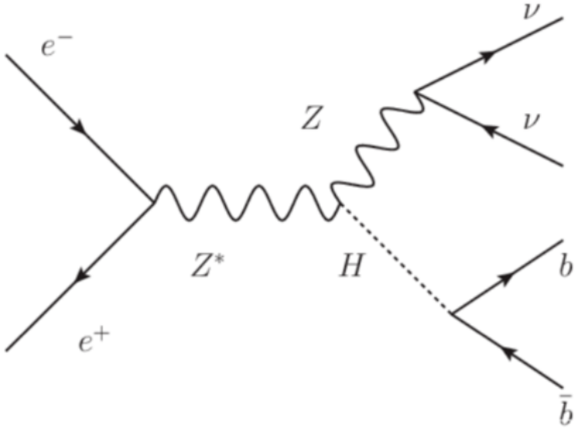
- Measure the WW fusion @ 360GeV
  - Standalone 240 GeV 20 ab^{-1} gives 1.5%, while 360 GeV 1 ab^{-1} alone gives 3.3%
  - These 2 points are independent, combine these two mass point giving <1%
  - Adding one mass point would significantly improve the constrain

The Challenge

- The most challenge is how to measure the irreducible background: ZH, Z→νν, H→bb
- These two process have absolutely same final states and have interference term



signal
WW fusion, H→bb



irreducible background
ZH, Z→νν, H→bb

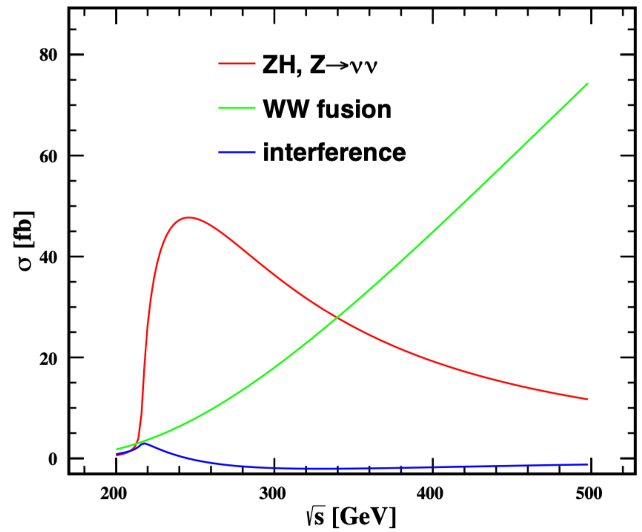


table: the fraction of ZH, WW fusion and Inter. in total

$\sqrt{s}$(GeV)	ZH(%)	WW fusion(%s)	Inter.(%s)	Inter./WW fusion
240	87.5	11.7	0.8	6.8%
250	86.3	14.3	-0.6	-4.3%
360	43.7	59.8	-3.5	-5.8%

- In 360GeV, Inter./WW fusion is -5.8%
- So if we want to make Higgs width measured precision ~ 1%, the inter. can't be ignore

Monte Carlo Sample

- Center of mass energy: 360 GeV
- Higgs sample
  - 100k, WW fusion, H→bb:
  - 100k , ZH, Z→vv, H→bb
  - Samples for interference can't not be generated by current software, but we can produce the inclusive vvH, H→bb sample, so the interference term can be calculate:

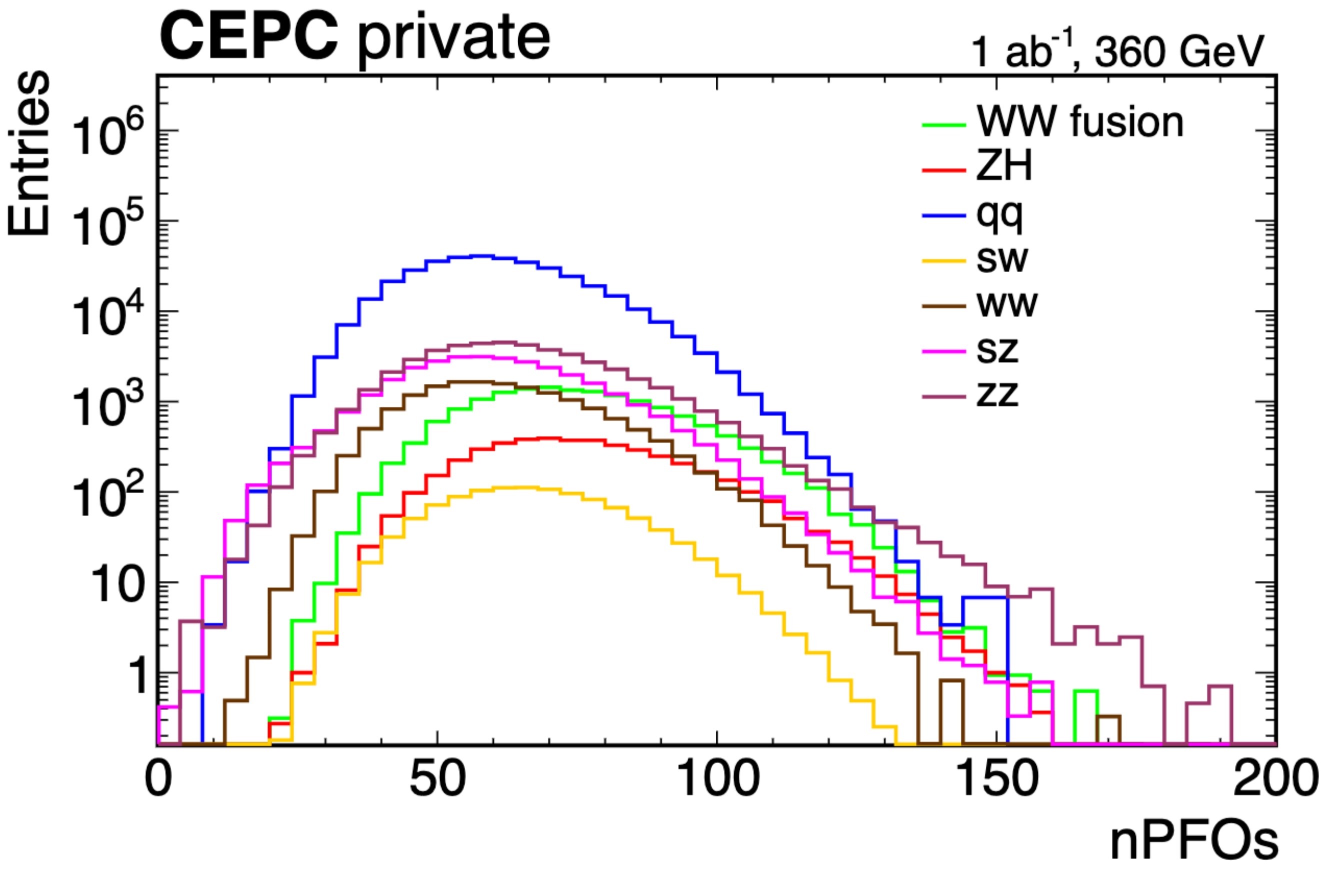
$$\sigma_{\text{interference}} = \sigma_{\text{inclusive}\nu_e\nu_e H} - \sigma_{WW\text{fusion}} - \sigma_{ZH\to\nu_e\nu_e H}$$

- SM sample
  - Integral luminosity: 1 ab^{-1}
  - 2 fermions: ee→qq
  - 4 fermions: ww, sw, zz, sz
- All samples are fully simulated with latest CEPCSW

Selection(I)

➢Number of particle flow objects distribution

- Hadronic final state has more nPFOs than leptonic final state
- Cut: 30<nPFOs<180 to veto the fully leptonic final states

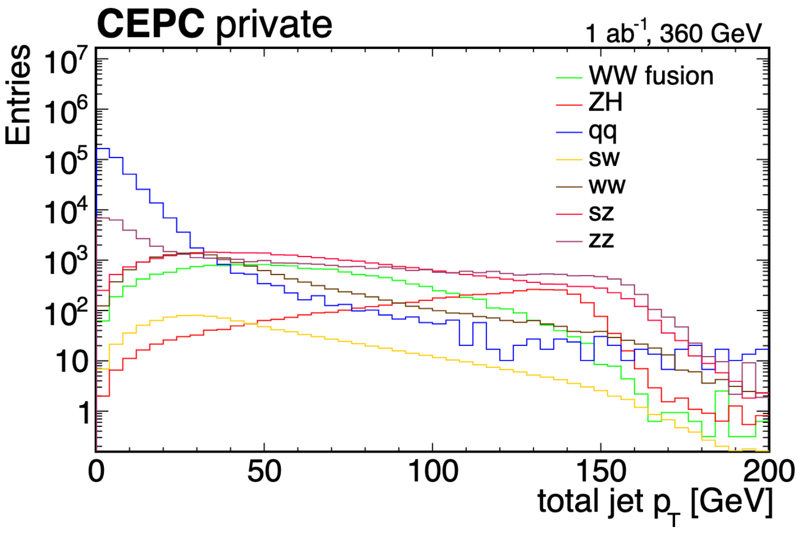


30<nPFOs<180

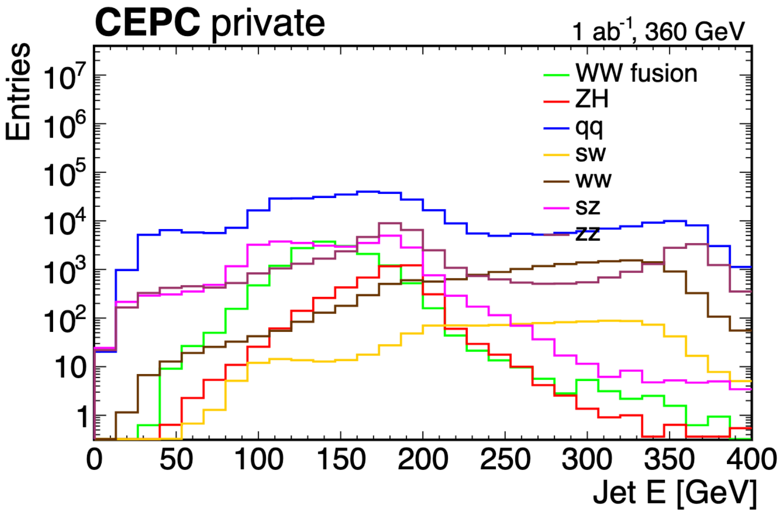
Selection(Ⅱ)

➢Kinematic variable

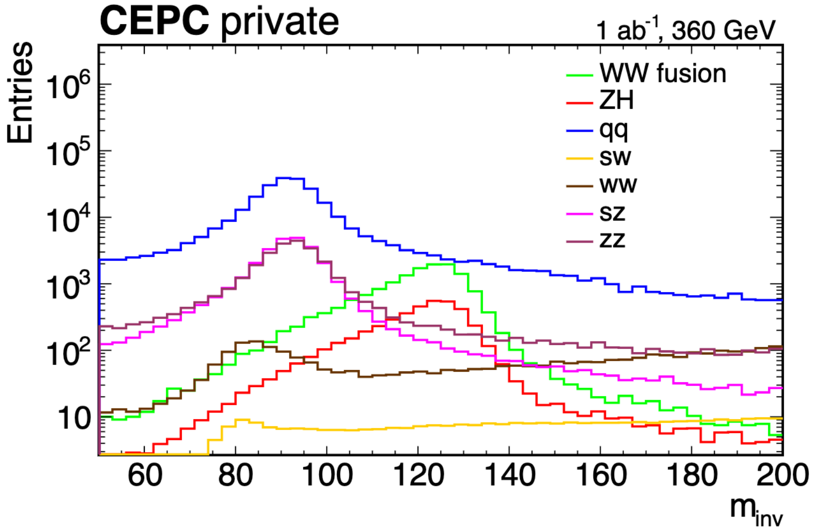
- Sum of jets pt: >10 GeV
- Sum of jets energy:[50, 250]GeV
- jets invariant mass: [100, 150]GeV, Higgs mass window
  - ✓can remove most of qq, W and Z background events



Jet p_T > 10GeV



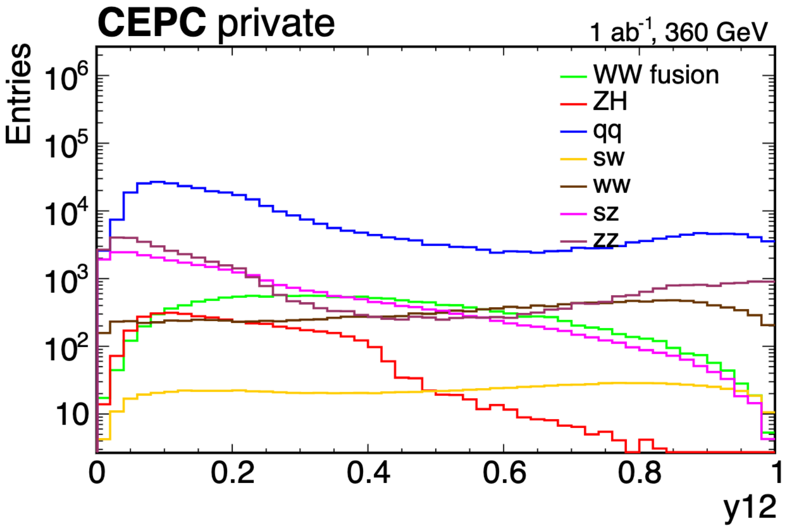
50GeV < Jet E < 250GeV



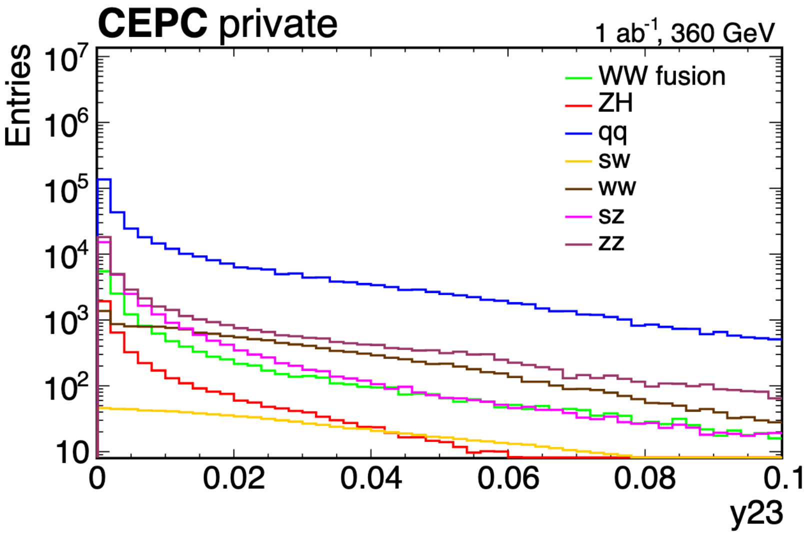
100GeV < m_{inv} < 150GeV

Selection(Ⅲ)

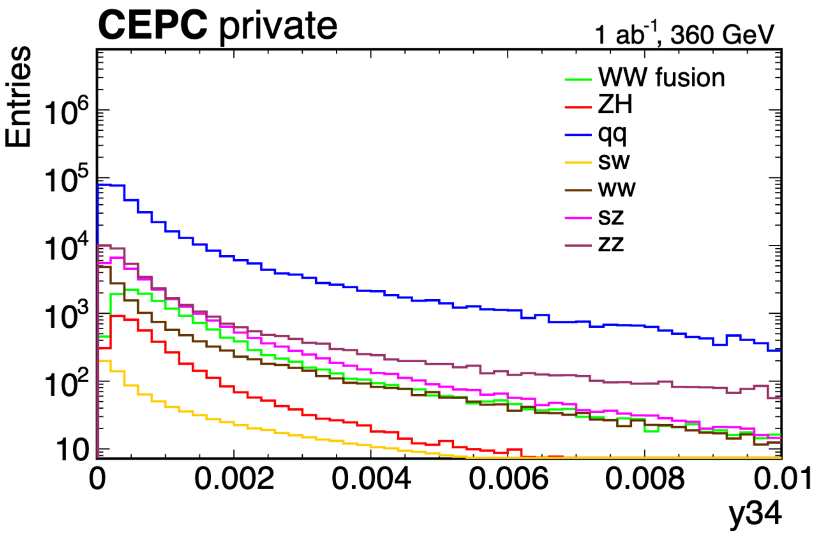
- ➢ $y_{i(i+1)}$: a variable related to the jet reconstruction process
  - the "distance" between the two jets merged while reducing the number of jets from $(i+1)$ jets to i jets
  - A di-jet event usually has big y_{12} value and small y_{23} , y_{34} value



$y_{12} > 0.1$



$y_{23} < 0.1$

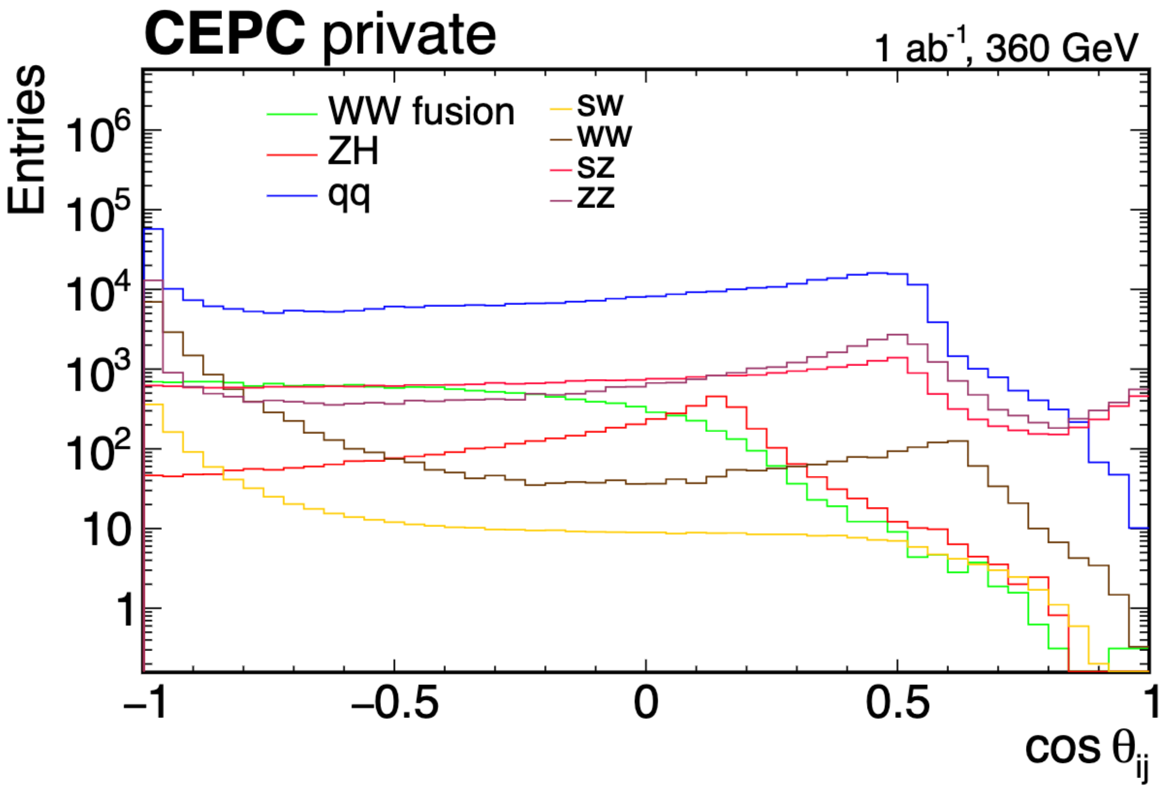


$y_{23} < 0.02$

Selection(IV)

➤The cosine of angle between two jets

- $-0.98 < cos\theta_{ij} < 0.25$
- lower bound to veto remained qq events
- upper bound according to distribution



$-0.98 < cos\theta_{ij} < 0.25$

Cutflow

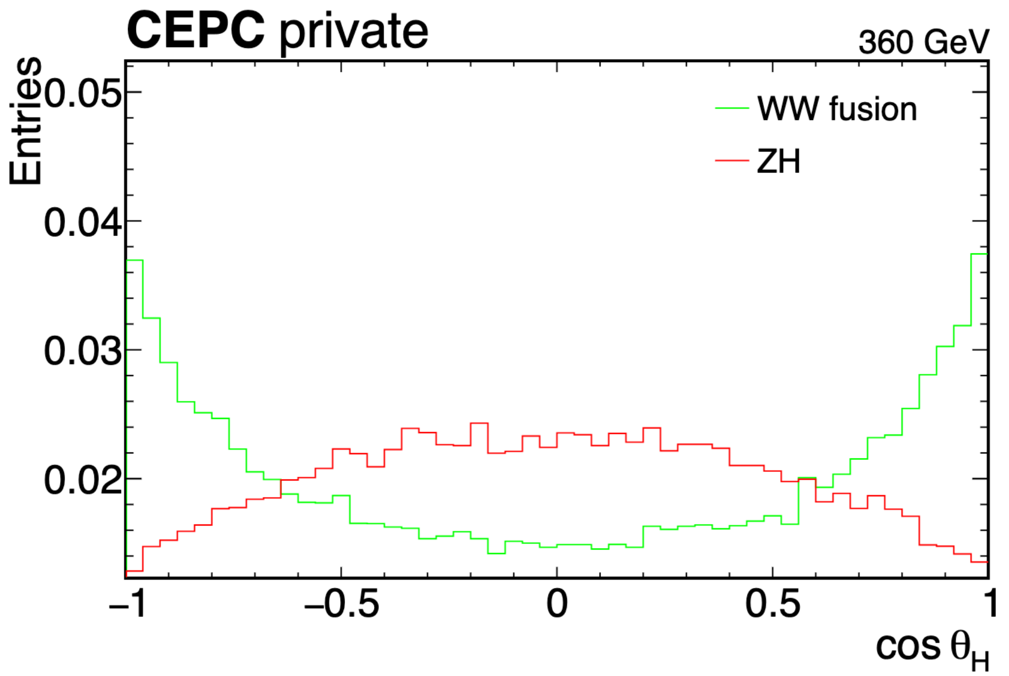
- WW fusion, H→bb and ZH process retain >50% efficiency after cut
- 2-fermion backgrounds are suppressed to 0.2%
- Other backgrounds become negligible

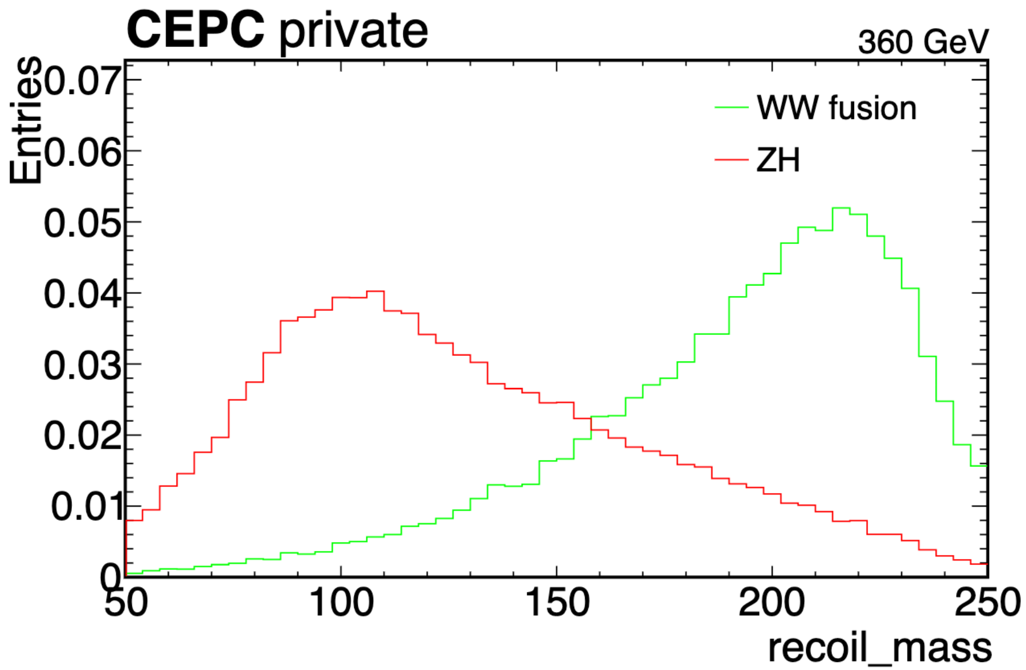
Process	WW fusion	ZH	qq	SW	WW	SZ	ZZ
Pre-selection	17209	4930	2123258	117427	1686000	178340	266300
$30 < \textbf{NPFO} < 180$	17196	4927	2103067	117105	1674708	172670	262188
$100\,\text{GeV} < E < 250\,\text{GeV}$	16667	4860	1501935	44023	468516	171306	151500
$p_T > 10\,\text{GeV}$	16272	4847	249395	43119	456289	148885	145116
Lepton-veto	15751	4611	245141	16366	187787	147061	141445
$100\,\text{GeV} < m_{\text{total}} < 150\,\text{GeV}$	14291	4055	62897	6744	47649	21893	24613
$50\,\text{GeV} < m_{\text{recoil}} < 250\,\text{GeV}$	14092	3765	40763	3674	26876	16802	14198
$y_{12} > 0.10$	12982	3030	33885	1707	12636	13114	9297
$-0.99 < \cos_{ij} < 0.25$	12742	2789	25714	1368	8154	10489	5658
b-tag	11499	2517	4650	13	78	1897	1023

- b-tag:
  - We training a model which can make 95% efficiency + 1% background rejection in Hqq
  - Have not imported it in formal CEPCSW

Signal extract strategy

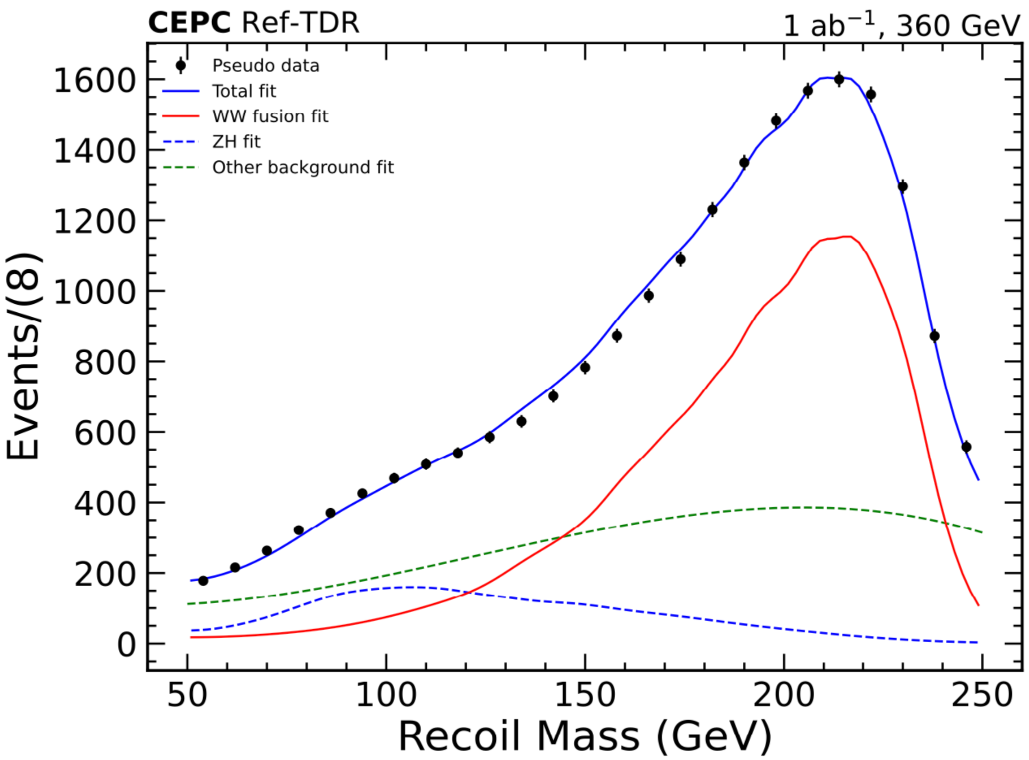
- There are two good variables to distinguish the WW fusion and ZH, H→bb(irreducible background)
  - ✓Higgs recoil mass
    - The recoil mass is calculated by $m_{recoil} = \sqrt{(\sqrt{s} - E_H)^2 - P_H^2}$
    - E_H and P_H is reconstructed Higgs energy and momentum
  - ✓Higgs polar angle
    - cosθ_H

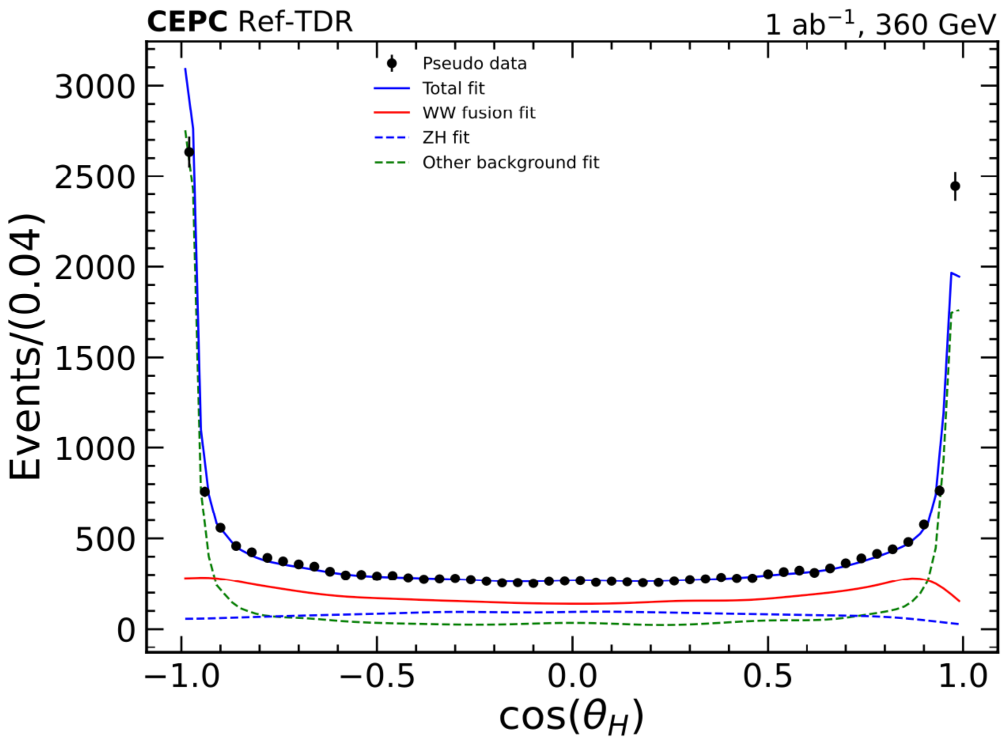




We will use fitting to extract the signal

Extract signal



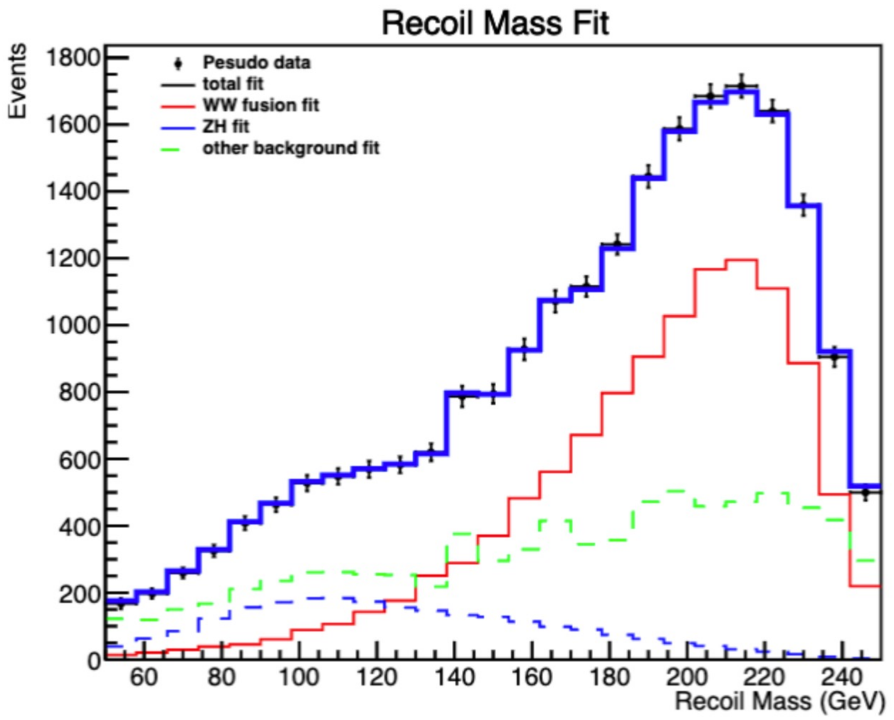


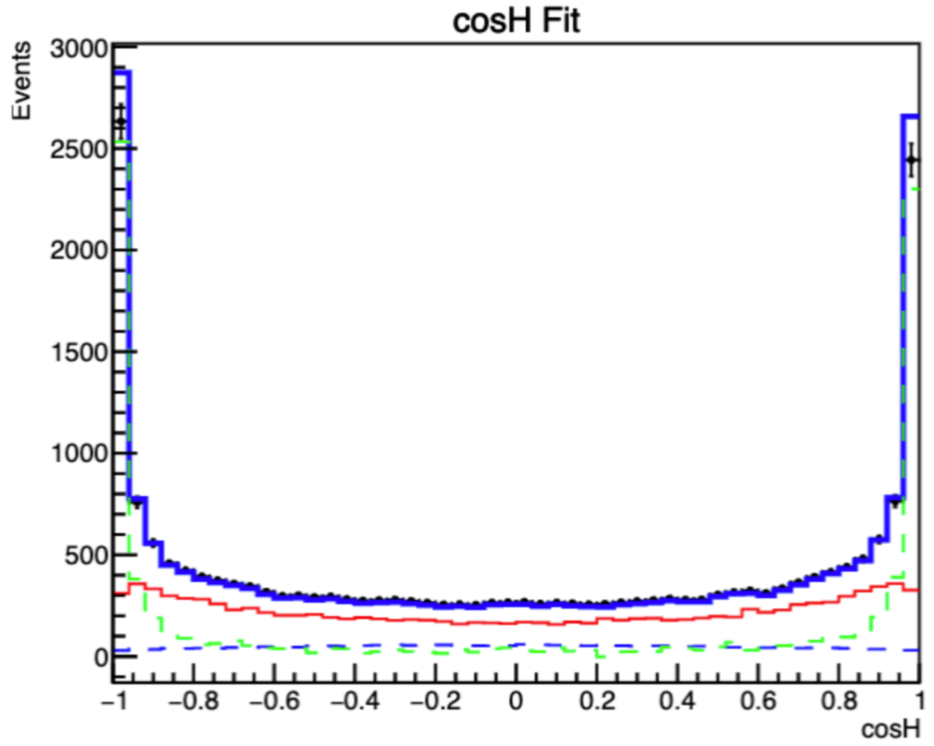
- 1D fit to estimate the
  - Pseudo data = inclusive sample + 2/4 fermion backgrounds
  - Other background = interference + 2/4 fermion backgrounds
  - WW fusion and ZH PDFs are get from MC and use Kernel Density Estimation method
  - Other background pdf is polynomial function

- The signal strength is determined by fitting
- The precision of signal strength
  - Recoil mass: 2.9%
  - $\cos\theta_H$: 4.5%

2D fit

- We also fit signal and background in (recoil mass, $\cos\theta_H$) 2 dimension.





➢ The precision of signal strength

- (Recoil mass, $\cos\theta_H$): 1.1%

Summary

- The precision of WW fusion strength relate to higgs width measured precision

$$\Gamma_H/\Gamma_H^{SM} = \frac{\mu_{ZH}^2 \mu_{WW\,\text{fusion},H\to bb}}{\mu_{ZH,H\to WW^*}\mu_{ZH,H\to bb}}$$

- We study the WW fusion measurement at 360GeV
  - 360 GeV run offers an independent measurement
  - The combined precision of the two runs can reach a remarkable precision.
- Study the selections
- Do fit in Higgs recoil mass and polar angle spectrum to get precision of signal strength
  - Recoil mass: 2.9%
  - $\cos\theta_H$: 4.5%
  - 2D: 1.1%

➢ Working in progress
  - Use machine learning to optimize selection
  - Apply the b tagging in formal analysis
  - Study the systematics

Thank you for your attention

Backup

FCC

Collider	HL-LHC	$\text{FCC-ee}_{240\rightarrow365}$	FCC-INT
Lumi (ab^{-1})	3	5 + 0.2 + 1.5	30
Years	10	3 + 1 + 4	25
g_{HZZ} (%)	1.5	0.18 / 0.17	0.17/0.16
g_{HWW} (%)	1.7	0.44 / 0.41	0.20/0.19
g_{Hbb} (%)	5.1	0.69 / 0.64	0.48/0.48
g_{Hcc} (%)	SM	1.3 / 1.3	0.96/0.96
g_{Hgg} (%)	2.5	1.0 / 0.89	0.52/0.5
$g_{\text{H}\tau\tau}$ (%)	1.9	0.74 / 0.66	0.49/0.46
$g_{\text{H}\mu\mu}$ (%)	4.4	8.9 / 3.9	0.43/0.43
$g_{\text{H}\gamma\gamma}$ (%)	1.8	3.9 / 1.2	0.32/0.32
$g_{\text{HZ}\gamma}$ (%)	11.	– / 10.	0.71/0.7
g_{Htt} (%)	3.4	10. / 3.1	1.0/0.95
κ_λ	+.29-.26	0.2-0.3	0.03
Γ_{H} (%)	SM	1.1	0.91
m_{H} (MeV)	30-50	3	3
BR_{inv} (%)	1.9	0.19	0.024
BR_{EXO} (%)	SM (0.0)	1.1	1

ee

hh

ee

hh

ee

Higgs cross section

Table 17: The information of the Higgs signal samples

Process	Final states	σ [fb]	ILC result [fb]	Events expected	Events generated
ffh_X	$h, f, \bar{f}$	211.01	208.77	1065619	1065111
qqh_X	$h, q, \bar{q}$	143.39	141.99	724097	723755
uuh_X	$h, u, \bar{u}$	24.52	–	123802	123733
ddh_X	$h, d, \bar{d}$	31.45	–	158830	158742
cch_X	$h, c, \bar{c}$	24.51	–	123766	123711
ssh_X	$h, s, \bar{s}$	31.46	–	158891	158803
bbh_X	$h, b, \bar{b}$	31.18	–	157479	157412
e1e1h_X	h, e^-, e^+	7.60	7.19	38357	99938
e2e2h_X	h, μ^-, μ^+	7.10	7.03	35849	99952
e3e3h_X	h, τ^-, τ^+	7.08	7.02	35770	99951
nnh_X	$h, \nu_{e,\mu,\tau}, \bar{\nu}_{e,\mu,\tau}$	48.96	48.43	247273	247167
n1n1h_X	$h, \nu_e, \bar{\nu}_e$	20.91	–	105574	105533
n2n2h_X	$h, \nu_\mu, \bar{\nu}_\mu$	14.03	–	70862	99961
n3n3h_X	$h, \nu_\tau, \bar{\nu}_\tau$	14.01	–	70773	99944

Two fermions background cross section

Table 18: The information of the two fermions background samples

Process	Final states	σ [fb]	ILC result [fb]	Events expected	Events generated
uu	$u, \bar{u}$	9995.35	10110.43	50476527	50476526
dd	$d, \bar{d}$	9808.71	10010.07	49533965	49533961
cc	$c, \bar{c}$	9974.20	10102.75	50369725	50369718
ss	$s, \bar{s}$	9805.39	9924.40	49517234	49517231
bb	$b, \bar{b}$	9803.04	9957.70	49505372	49504516
qq	$q, \bar{q}$	49561.30	50105.35	250284565	250283714
e2e2	$\mu^- \mu^+$	4967.58	4991.91	25086253	25086255
e3e3	$\tau^- \tau^+$	4374.94	4432.18	22093447	22093445
bhabha	e^-, e^+, γ	24992.21	24937.95	126210660	126210654

Four fermions cross section(1)

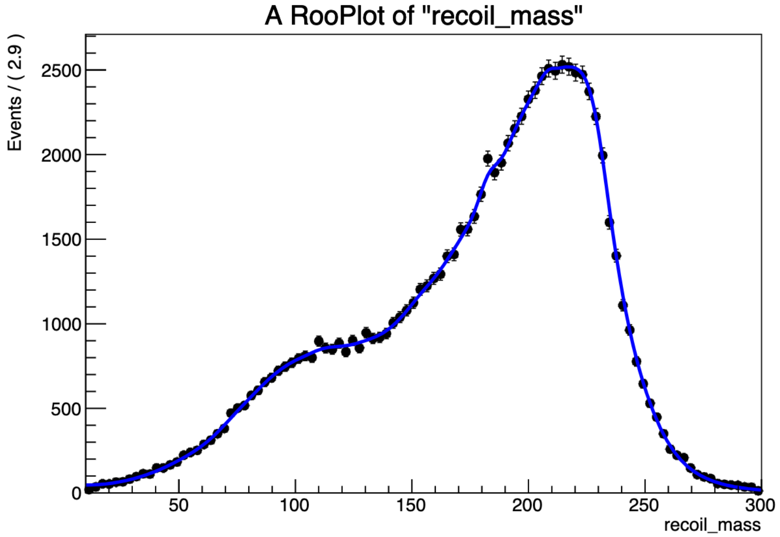
Table 19: The information of the four fermions background samples

Process	Final states	σ [fb]	ILC result [fb]	Events expected	Events generated
zz_h0utut	up, up, up, up	83.09	83.05	419604	419584
zz_h0dtdt	$down, down, down, down$	226.20	226.42	1142310	1142270
zz_h0uu_notd	$uq, uq, (sq, bq), (sq, bq)$	95.65	96.00	483032	483045
zz_h0cc_nots	$cq, cq, (dq, bq), (dq, bq)$	96.04	96.28	485002	485016
zz_sl0nu_up	$nu_{\mu,\tau}, nu_{\mu,\tau}, up, up$	81.72	81.86	412686	412709
zz_sl0nu_down	$nu_{\mu,\tau}, nu_{\mu,\tau}, down, down$	134.86	135.48	681043	681041
zz_sl0mu_up	mu, mu, up, up	82.38	83.10	416019	416008
zz_sl0mu_down	$mu, mu, down, down$	127.96	128.84	646198	646181
zz_sl0tau_up	tau, tau, up, up	39.78	40.02	200889	200882
zz_sl0tau_down	$tau, tau, down, down$	64.30	64.64	324715	324709
zz_l04tau	$\tau^-, \tau^+, \tau^-, \tau^+$	4.38	4.41	22119	100000
zz_l04mu	$\mu^-, \mu^+, \mu^-, \mu^+$	14.57	14.63	73578	100000
zz_l0taumu	$\tau^-, \tau^+, \mu^-, \mu^+$	17.54	17.73	88577	100000
zz_l0mumu	$\nu_\tau, \bar{\nu}_\tau, \mu^-, \mu^+$	18.17	18.34	91758	100000
zz_l0tautau	$\nu_\mu, \bar{\nu}_\mu, \tau^-, \tau^+$	9.20	9.27	46460	100000
ww_h0cuxx	$uq, cq, down, down$	3395.48	3413.36	17147189	17147188
ww_h0uubd	uq, uq, dq, bq	0.05	0.05	252	100000
ww_h0uusd	uq, uq, sq, bq	165.94	167.21	837997	838010
ww_h0ccbs	cq, cq, sq, bq	5.74	5.75	28987	100000
ww_h0ccds	cq, cq, sq, dq	165.57	166.30	836128	836128
ww_sl0muq	$mu, nu, up, down$	2358.69	2369.79	11911394	11911396
ww_sl0tauq	$tau, nu, up, down$	2351.98	2368.64	11877519	11877519
ww_l0ll	mu, tau, nu_μ, nu_τ	392.96	394.73	1984448	1984437

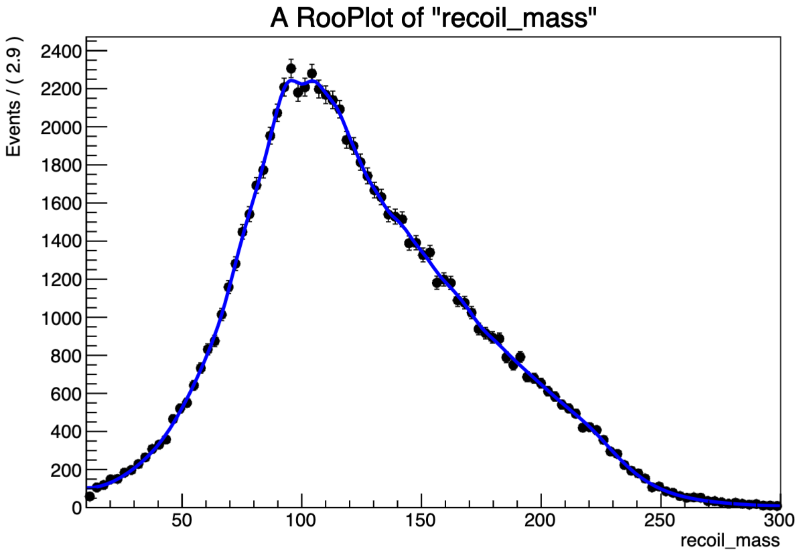
Four fermions cross section(2)

zzorww_h0udud	uq, uq, dq, dq	1570.40	1579.63	7930514	7930514
zzorww_h0cscs	cq, cq, sq, sq	1568.94	1572.41	7923141	7923140
zzorww_l0mumu	mu, mu, nu_μ, nu_μ	214.81	216.12	1084790	1084777
zzorww_l0tautau	$tau, tau, nu_\tau, nu_\tau$	205.84	206.38	1039492	1039510
sze_l0tau	e^-, e^+, τ^-, τ^+	150.14	150.30	758207	758206
sze_l0mu	e^-, e^+, μ^-, μ^+	852.18	850.70	4303527	4303528
sze_l0nunu	$e^-, e^+, \nu_{\mu,\tau}, \bar{\nu}_{\mu,\tau}$	29.62	29.41	149581	149583
sze_sl0uu	e, e, up, up	195.86	195.37	989093	989109
sze_sl0dd	$e, e, down, down$	128.72	128.20	650036	649940
sznu_l0mumu	$\nu_e, \bar{\nu}_e, \mu^-, \mu^+$	43.33	43.41	218816	218824
sznu_l0tautau	$\nu_e, \bar{\nu}_e, \tau^-, \tau^+$	14.57	14.61	73578	100000
sznu_sl0nu_up	$\nu_e, \bar{\nu}_e, up, up$	56.09	55.95	283254	283254
sznu_sl0nu_down	$\nu_e, \bar{\nu}_e, down, down$	91.28	90.95	460964	460961
sw_l0mu	$e, nu_e, mu, nu_{\mu,\tau}$	429.20	430.64	2167446	2167447
sw_l0tau	$e, nu_e, tau, nu_{\mu,\tau}$	429.42	430.27	2168556	2168556
sw_sl0qq	$e, nu_e, up, down$	2579.31	2581.03	13025535	13025535
szeorsw_l0l	$e^-, e^+, \nu_e, \bar{\nu}_e$	249.34	249.74	1259167	1259165

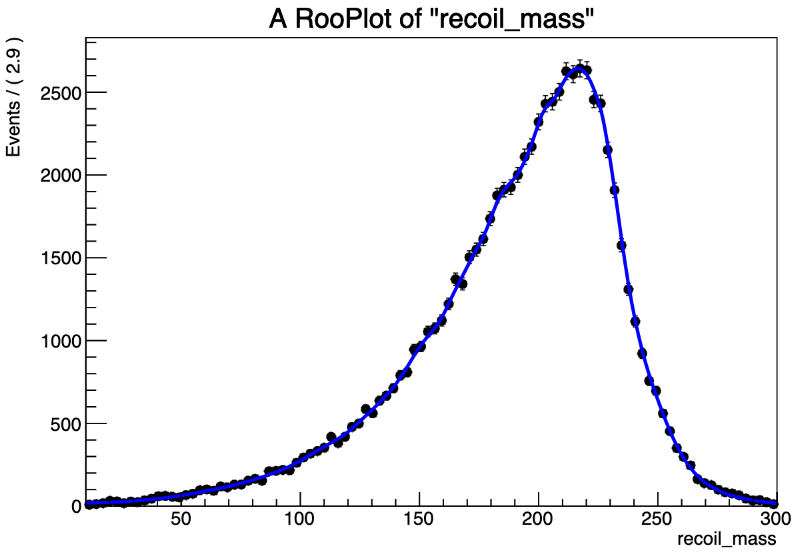
Sample Fit



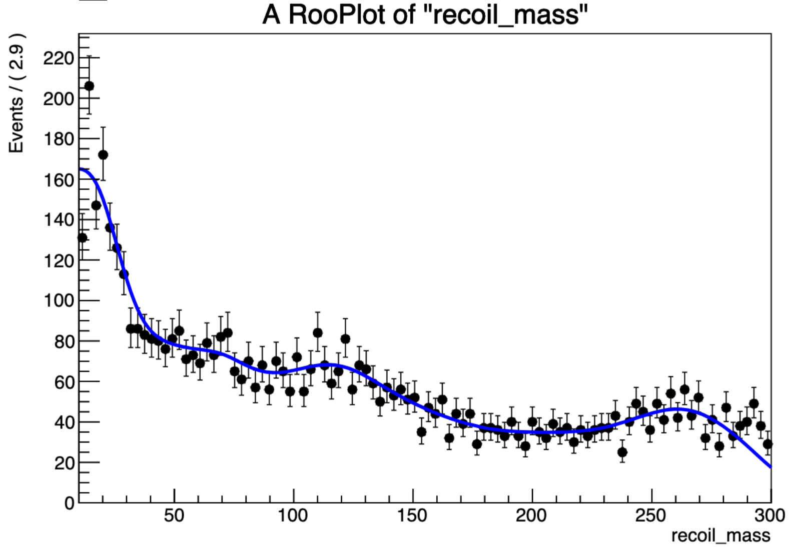
inclusive vv_h



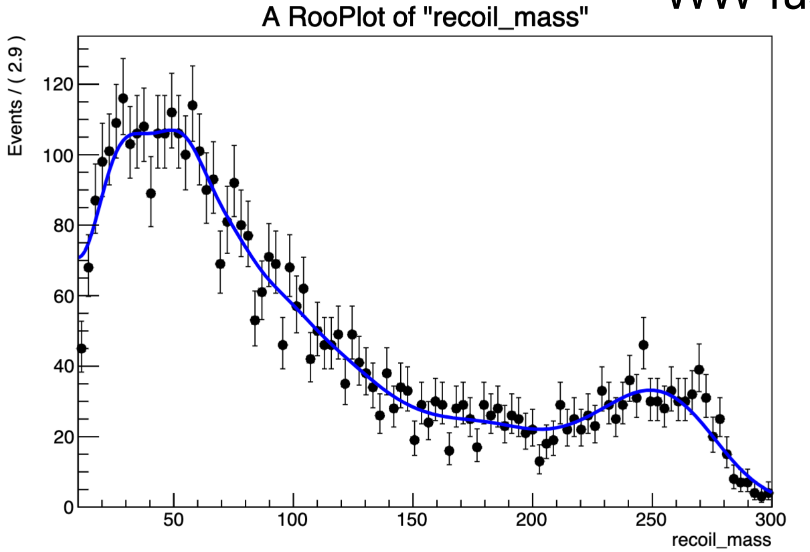
ZH



WW fusion



qq

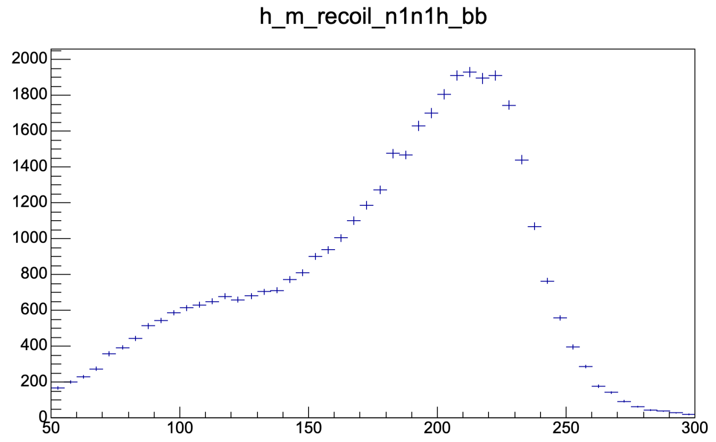


4fermion

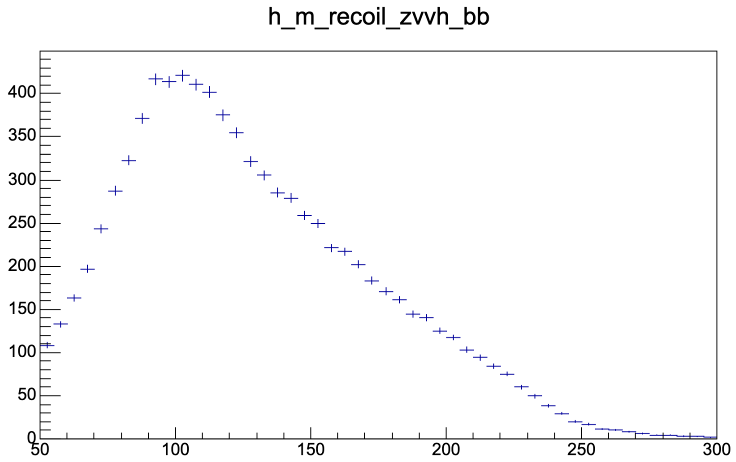
Don’t apply any cut

Interference

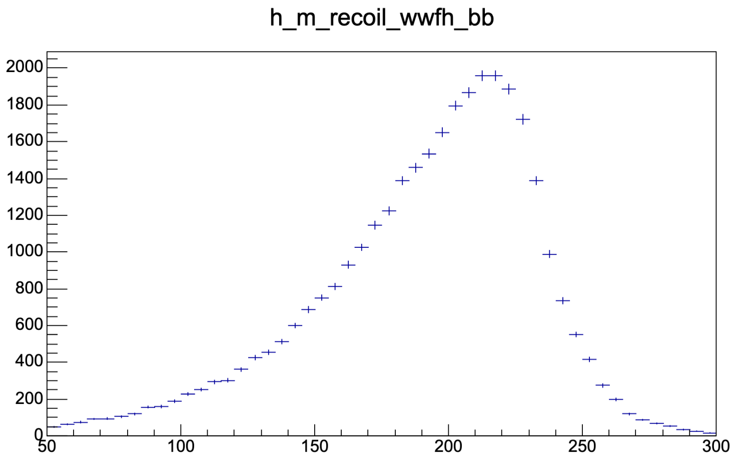
$$\sigma_{\text{interference}} = \sigma_{\text{inclusive}\nu_e\nu_e H} - \sigma_{WW\text{fusion}} - \sigma_{ZH\rightarrow\nu_e\nu_e H}$$



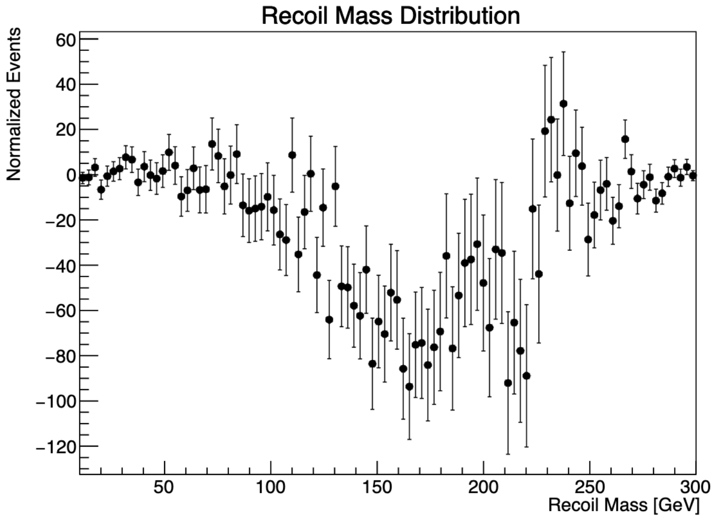
inclusive vv_h



ZH



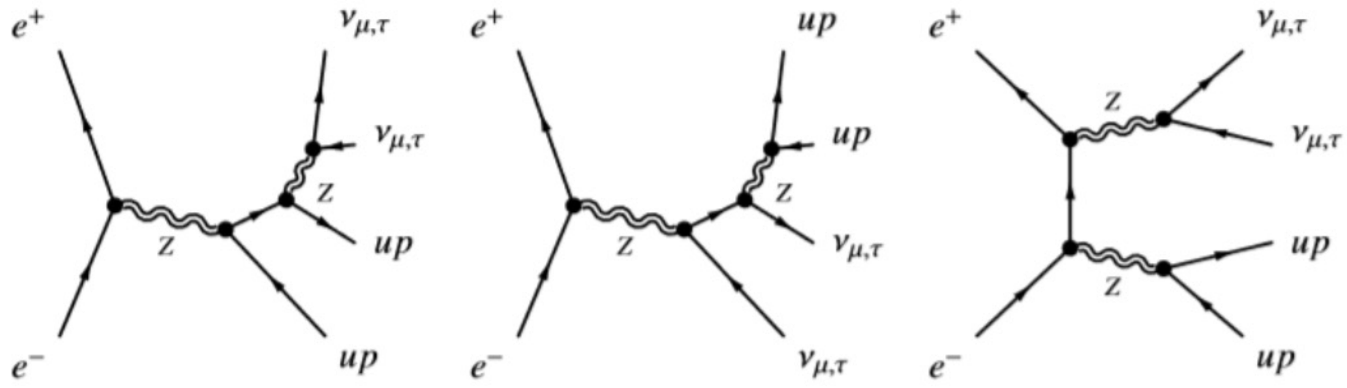
WW fusion



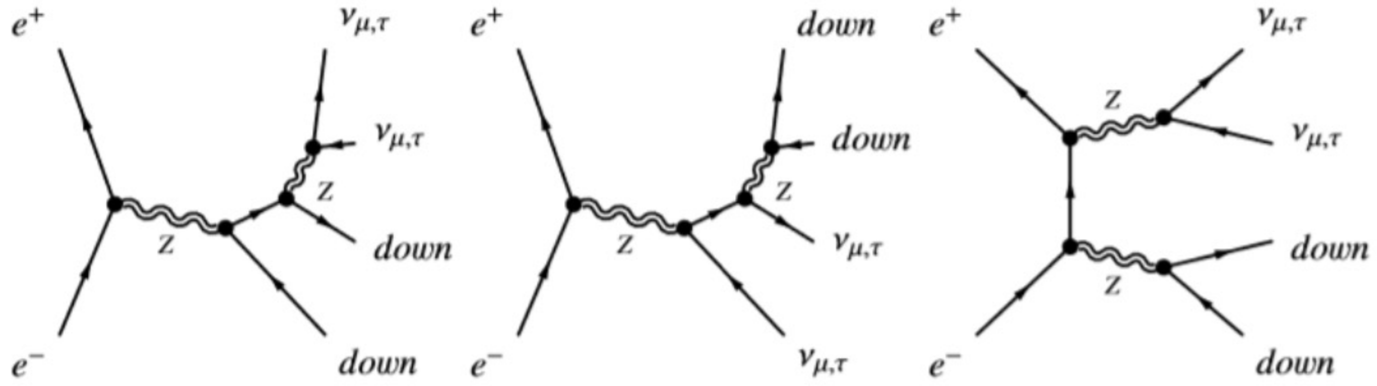
- Here the ZH, WW fusion and inclusive samples have be normalized

ZZ background Feynman diagram

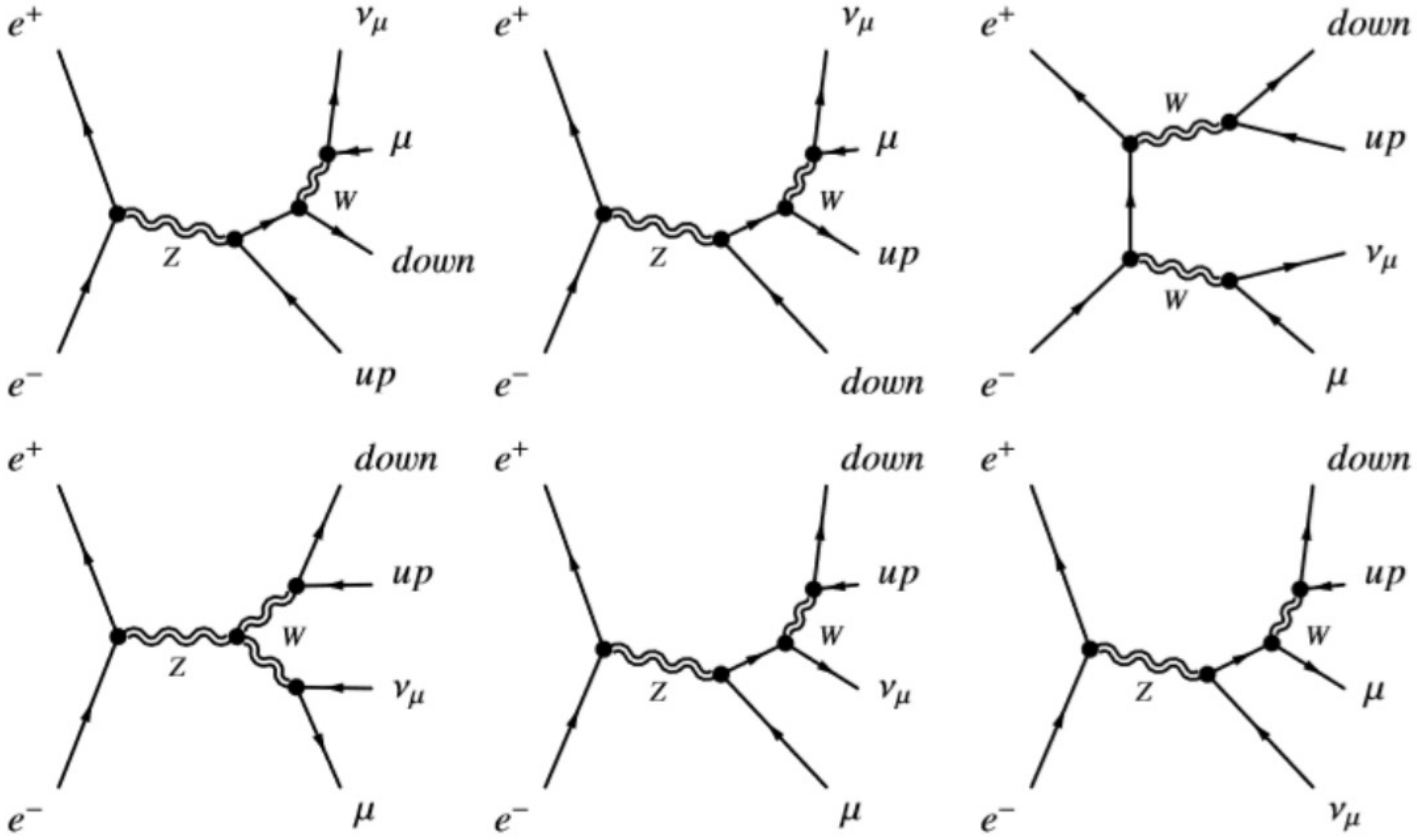
6.5 zz_sl0nu_up



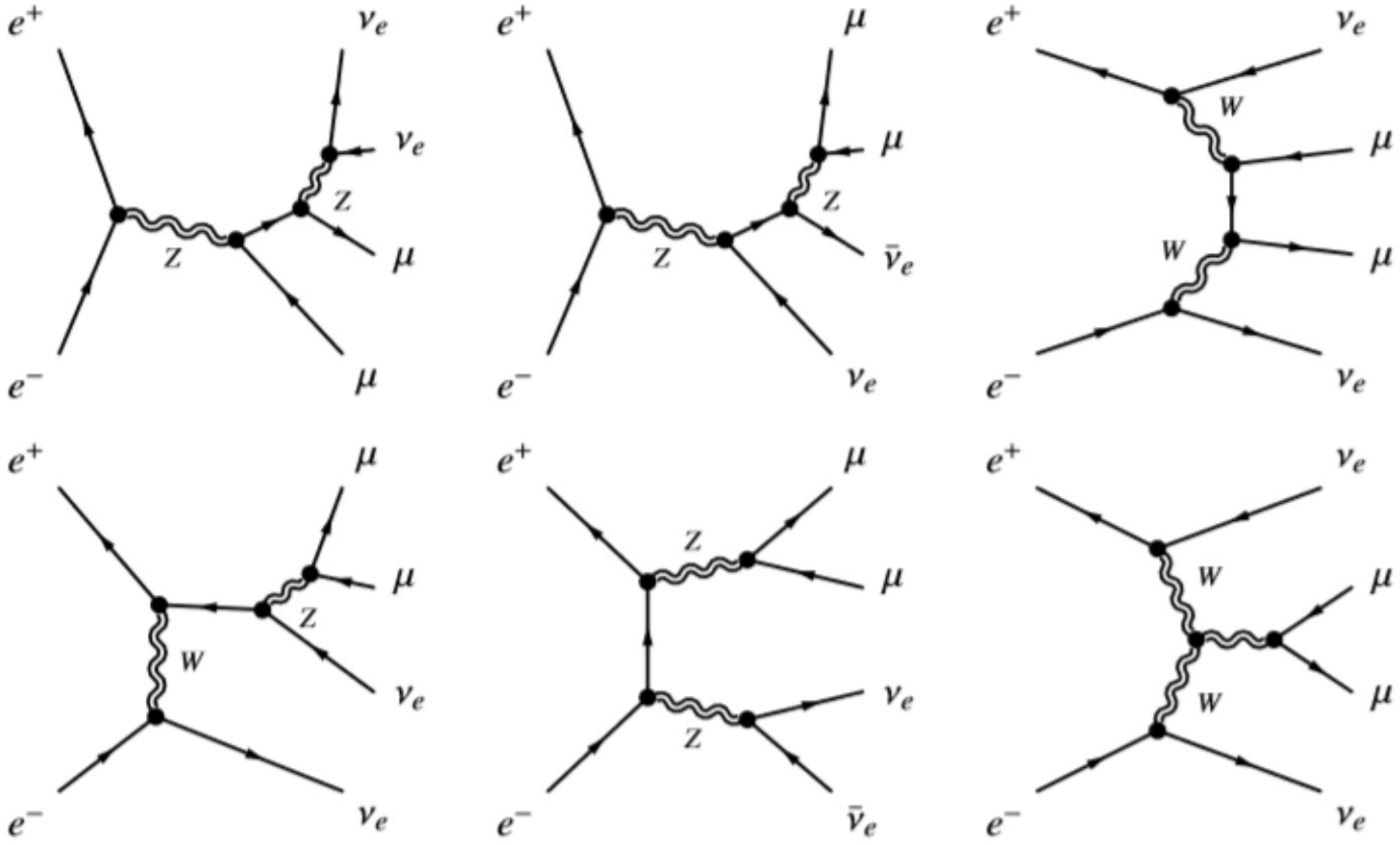
6.6 zz_sl0nu_down



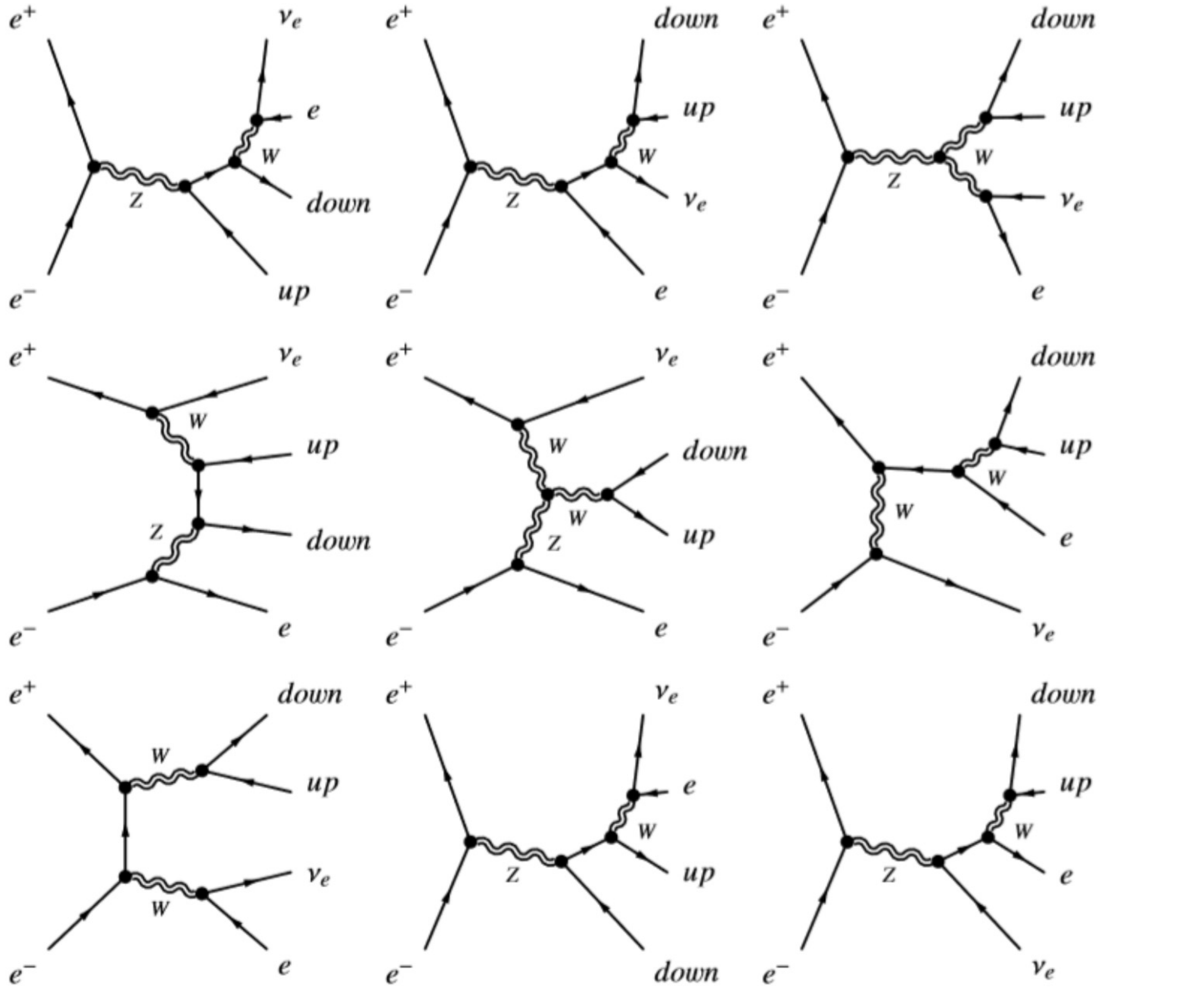
WW background Feynman diagram



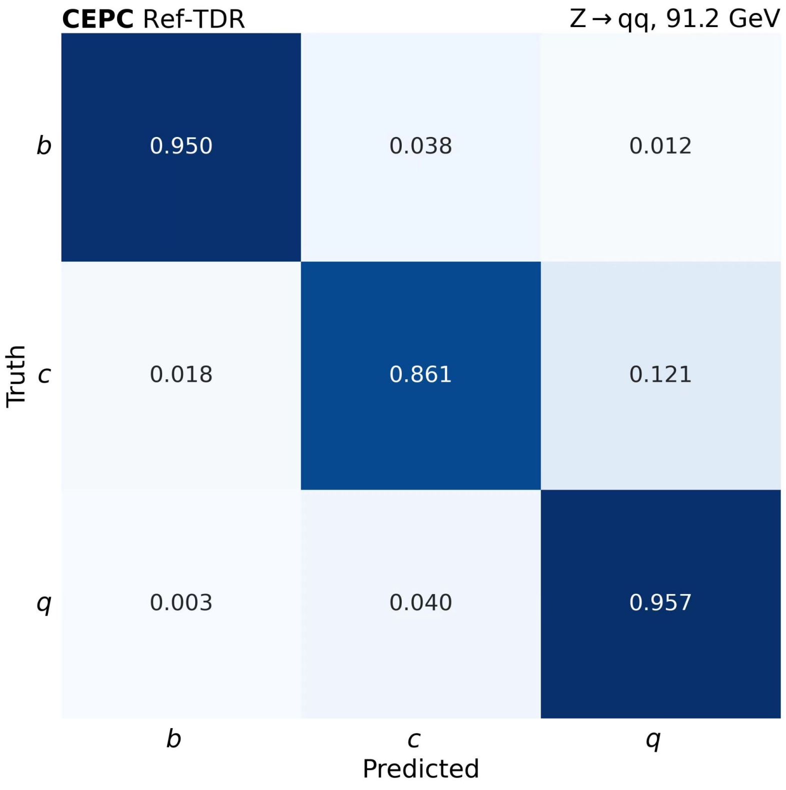
SZ background Feynman diagram



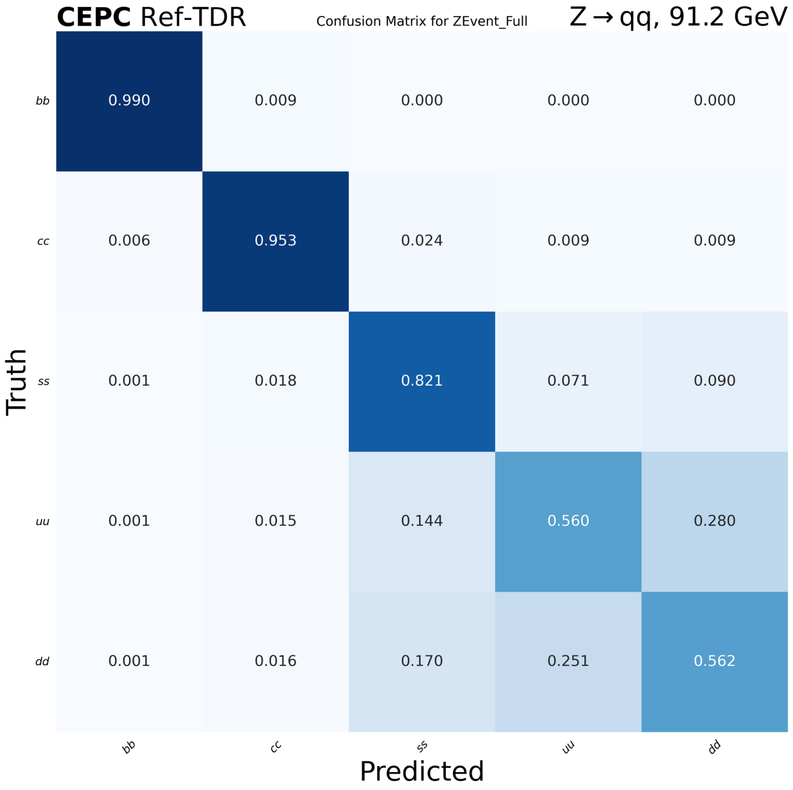
SW background Feynman diagram

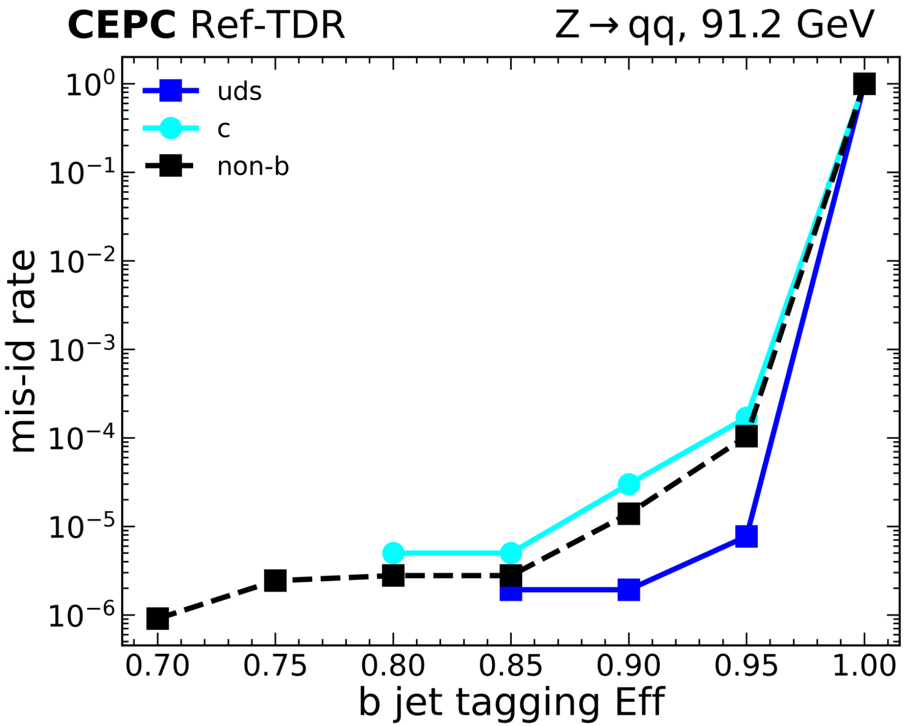


b tagging efficiency



old





new

The fit result

- Recoil mass 2.93%

N_others_bkg	= 7801.47	+/-	468.19	(limited)
N_wwfh_bb	= 10628.3	+/-	311.763	(limited)
N_znnh_bb	= 2034.62	+/-	203.194	(limited)

- cosH 4.57%

N_others_bkg	= 8207.53	+/-	130.431	(limited)
N_wwfusionh_bb	= 9237.98	+/-	422.483	(limited)
N_zn1n1h_bb	= 4000.89	+/-	366.28	(limited)

- 2D 1.1%

N_others_bkg	= 7943.55	+/-	117.897	(limited)
N_wwfusionh_bb	= 11149.7	+/-	139.574	(limited)
N_zn1n1h_bb	= 2349.41	+/-	80.503	(limited)