Determination of branching ratios for Higgs to di-jet states and WW-fusion fraction at the ILC at 250 GeV CME

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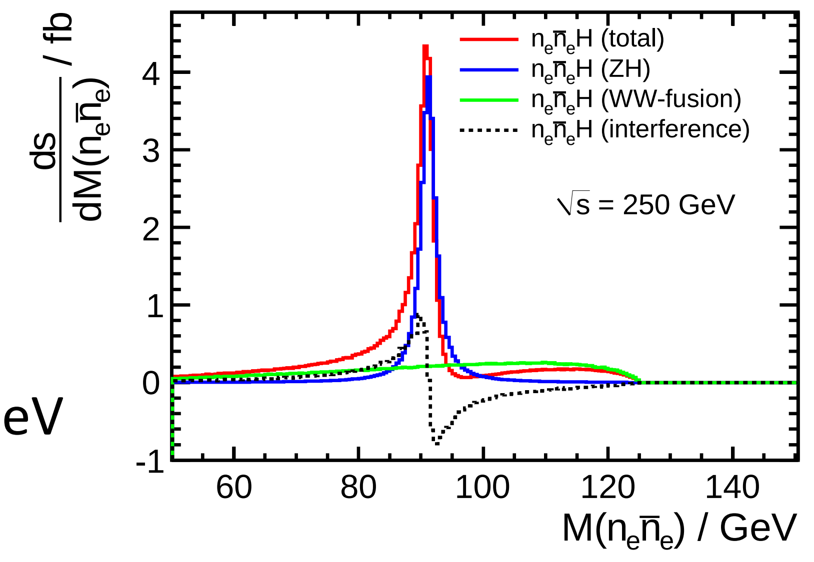
Motivation $e^- e^+ \to \nu\nu \mathrm{h} \to \nu\nu + 2\ \mathrm{jets}$

- What can we measure at the ILC @ 250 GeV?
- Branching Ratio of Higgs linear to mass
  - test the Standard Model
  - or find Higgs Doublet Model
- Analyzing simulation data
- Determine accuracies:
  - $BR(\mathrm{h} \to \mathrm{bb}\ /\ \mathrm{cc}\ /\ \mathrm{gg})$
  - WW-fusion cross section
- influence of beam background overlay
- cross section
  - left-handed: 129 fb @ 250 GeV
  - right-handed: 65 fb
  - P(-80, 30): 77.5 fb



Z-boson mass

Event Selection

- finding cut range
- maximize significance program structure
  - while change in siginificance
    - for cut in cut_list
      - looking for cut limit with highest siginificance
      - save cut limit
- after selection with cuts – template fit on b-/c-likeness histogram (2D).

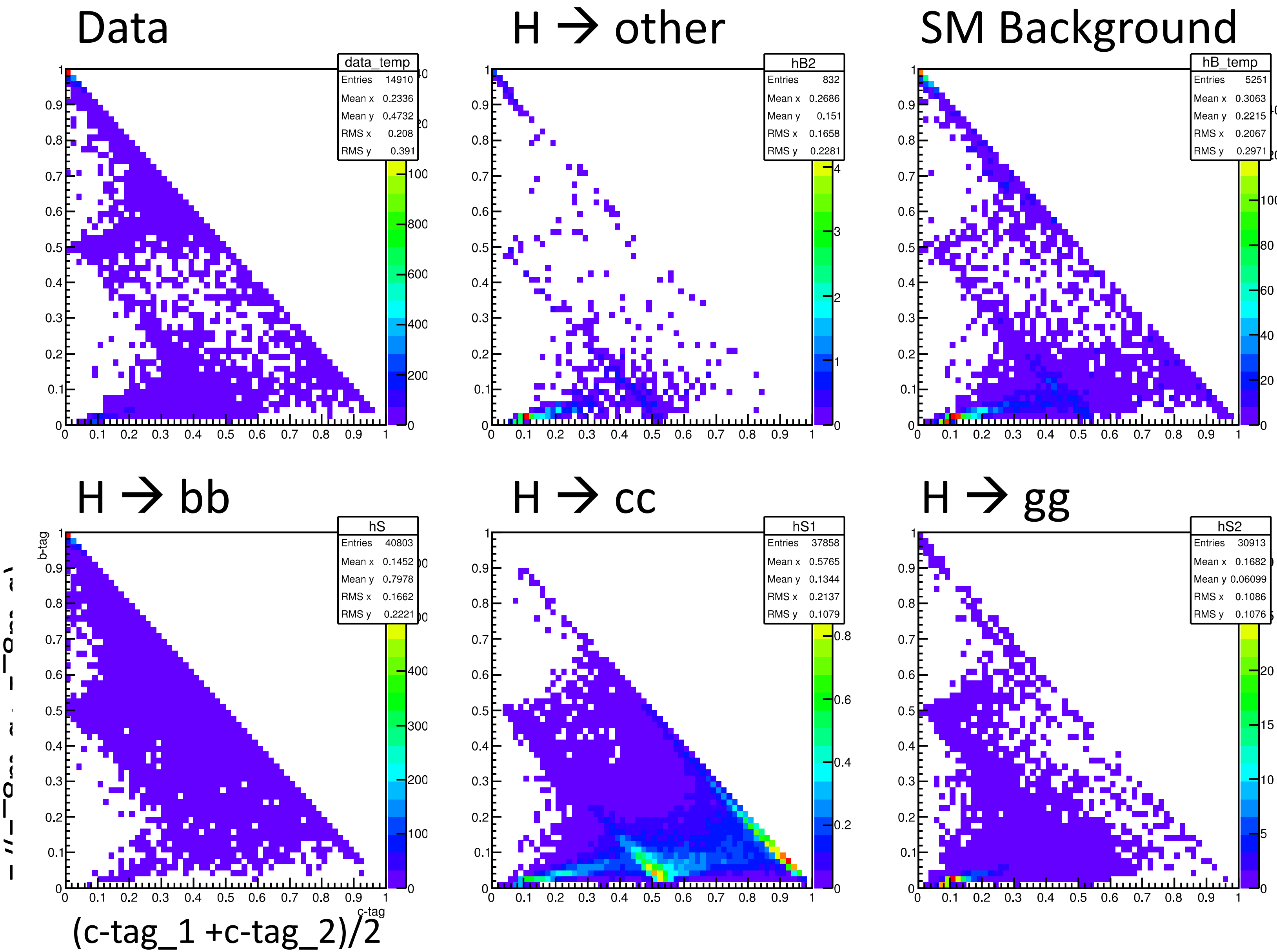
Cut flow

- Main background: semileptonic events
  - qqlv larger then qqvv
    - maybe isolated lepton finder needs tuning

cut / event type	$\nu\bar{\nu}$h	semileptonic	hadronic	other SM Bg	significance	efficiency
Expected	$1.94 \cdot 10^4$	$4.60 \cdot 10^6$	$2.37 \cdot 10^7$	$4.83 \cdot 10^8$	0.592	1
isoLepCuts	$1.76 \cdot 10^4$	$1.78 \cdot 10^6$	$2.34 \cdot 10^7$	$3.36 \cdot 10^8$	0.697	0.992
$N_{PFO,1} > 20$ and $N_{PFO,2} > 11$	$1.47 \cdot 10^4$	$8.48 \cdot 10^5$	$1.62 \cdot 10^7$	$2.11 \cdot 10^6$	2.77	0.907
80 GeV $< E_{vis} <$ 147 GeV	$1.34 \cdot 10^4$	$4.08 \cdot 10^5$	$4.91 \cdot 10^6$	$1.23 \cdot 10^6$	4.33	0.829
79.5 GeV $< M_Z <$ 131.5 GeV	$1.20 \cdot 10^4$	$2.22 \cdot 10^5$	$8.58 \cdot 10^5$	$4.55 \cdot 10^5$	8.1	0.753
104.5 GeV $< M_H <$ 132 GeV	$1.10 \cdot 10^4$	$7.16 \cdot 10^4$	$6.36 \cdot 10^4$	$1.87 \cdot 10^5$	16	0.69
21.5 GeV $< p_{t,mis} <$ 67.5 GeV	9810	$5.03 \cdot 10^4$	1642	2700	32.5	0.616
$\lvert p_{z,mis} \rvert <$ 55.5 GeV	9450	$3.49 \cdot 10^4$	1112	2400	36.3	0.594
thrust cuts [1]	7595	$1.78 \cdot 10^4$	972	1390	41.8	0.521
$p_{max,PFO} <$ 40.5 GeV	7449	$1.64 \cdot 10^4$	914	1290	42.4	0.512
$0.23 < Y_{12} < 0.91$ and $Y_{23} < 0.015$	4997	3345.2	630	426	50.7	0.367

[1] thrust cuts refers to 0.08 < majthrust < 0.5 and 0.77 < pthrust < 0.995 and 0.521 < minthrust < 0.35

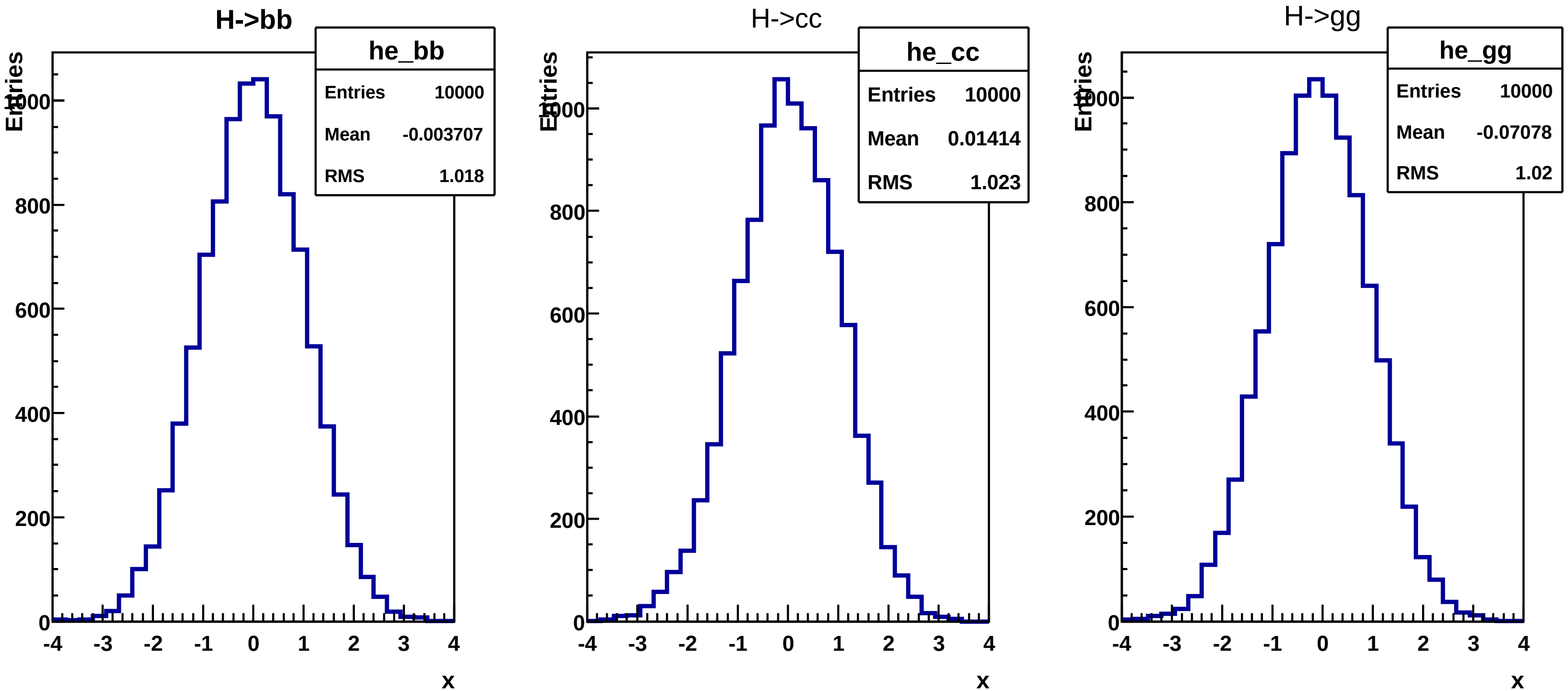
Fitting templates



Toy study

- Higgs to gluon slightly shifted

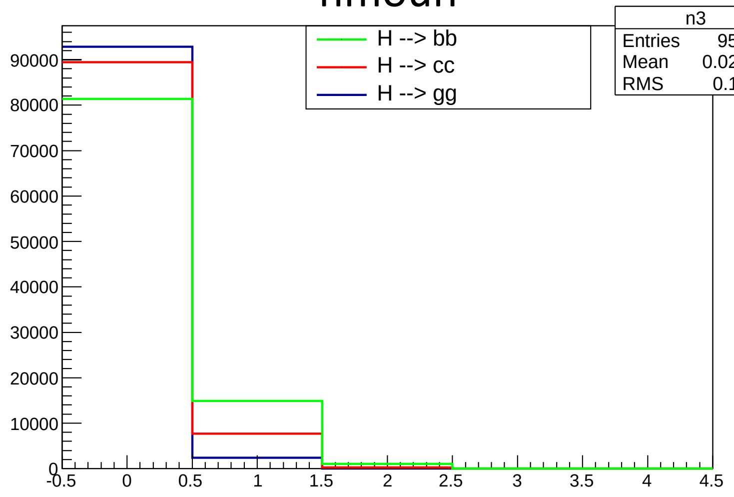
$$\frac{N - N_{fit}}{\sigma_{fit}}$$



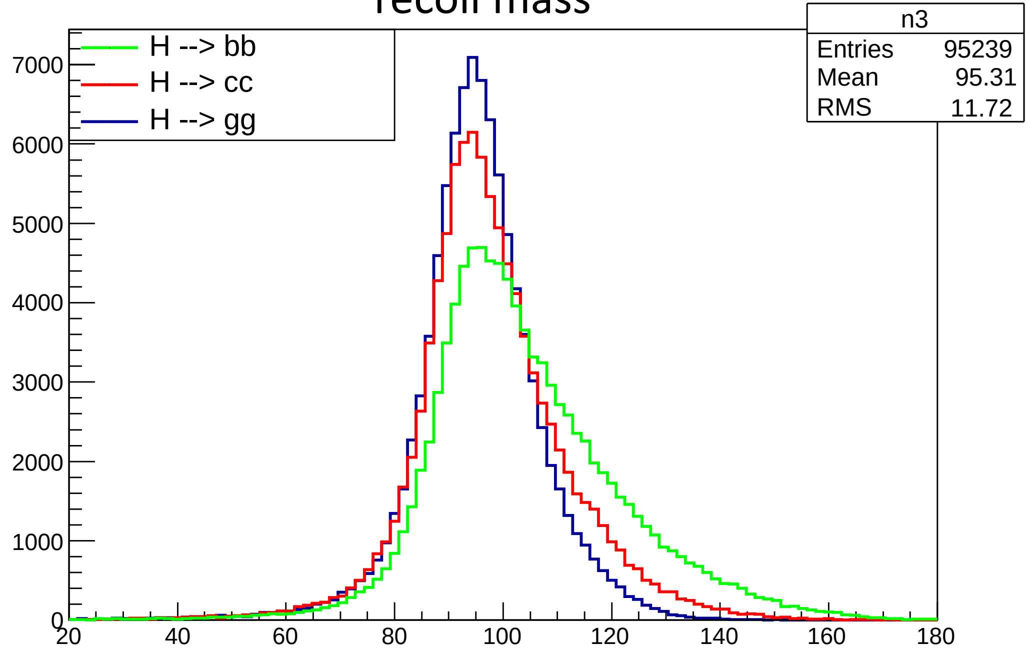
optimisation on each final state

- the final states are different in
  - detector resulution
  - number of events
  - nature of jets

nmoun



recoil mass



optimisation on each final state

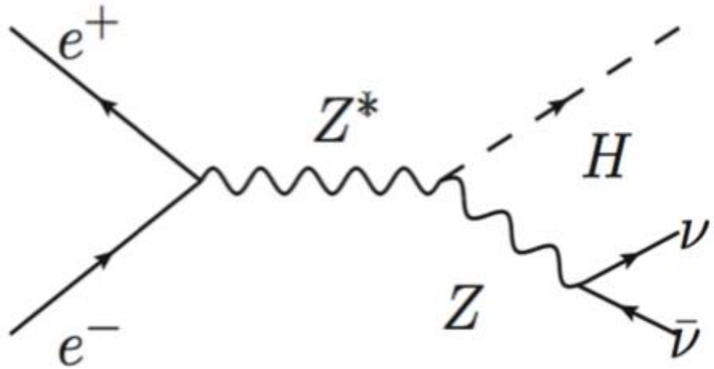
- the final states are different in
  - detector resulution
  - number of events
  - nature of jets
- maximize on $$\frac{N(\nu\nu H \to \nu\nu xx)}{\sqrt{N(\nu\nu H \to \nu\nu xx) + N(not[\nu\nu H \to dijet])}}$$

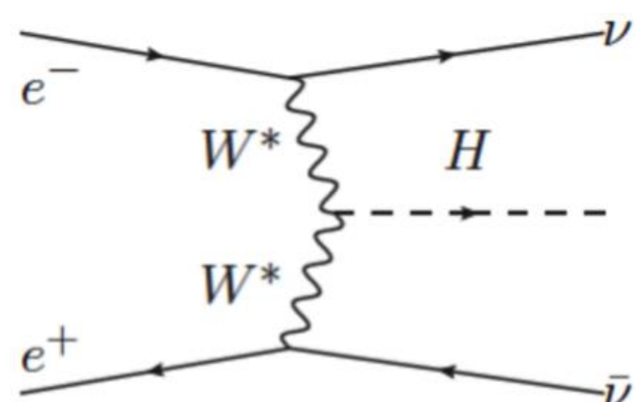
optimized on	$h \to b\bar{b}$	$h \to c\bar{c}$	$h \to gg$	$h \to b\bar{b}, c\bar{c}, gg$	expected
$N(h \to \bar{b}b)$	4020	1616	991	4248	11100
$N(h \to \bar{c}c)$	180	88	31.71	193	521
$N(h \to gg)$	436	123	455	470	1650
$N(Bg)$	3973	409	652	4297	$3.62 \cdot 10^8$

Higgs-Strahlung and WW-fusion

- two separate production in this channel
- branching ratio and Higgs-Strahlung cross section are collected from other studies
- results into an uncertainty of 32 %

$$\sigma_{WW} = \frac{N_{fit}(h \to bb)}{\mathcal{L} \cdot \epsilon_{WW} BR(h \to bb)} - \frac{\epsilon_{ZH}}{\epsilon_{WW}} \sigma_{ZH}$$





Feynman diagrams: Higgs-Strahlung WW-fusion

Fitting uncertainty

- WW-fusion production x-section ~ 32 %
- Higgs-Strahlung production x-section ~ 1.5 %
- bracketed values can not be determined with this method

by template fitting:

optimized on	$h \to b\bar{b}$	$h \to c\bar{c}$	$h \to gg$	$h \to b\bar{b}, c\bar{c}, gg$
$\frac{\Delta(\sigma \cdot BR(h\to\bar{b}b))}{\sigma \cdot BR_{SM}(h\to\bar{b}b)}$	1.81 %	2.62 %	3.47 %	1.82 %
$\frac{\Delta\sigma \cdot BR(h\to\bar{c}c)}{\sigma \cdot BR_{SM}(h\to\bar{c}c)}$	24.5 %	21.54 %	61.15 %	26.85 %
$\frac{\Delta\sigma \cdot BR(h\to gg)}{\sigma \cdot BR_{SM}(h\to gg)}$	16.52 %	29.41 %	10.05 %	16.15 %
$\frac{\Delta BR(h\to\bar{b}b)}{BR_{SM}(h\to\bar{b}b)}$	(4.8 %)	(5.2 %)	(5.7 %)	(4.8 %)
$\frac{\Delta BR(h\to\bar{c}c)}{BR_{SM}(h\to\bar{c}c)}$	25 %	22 %	61 %	27 %
$\frac{\Delta BR(h\to gg)}{BR_{SM}(h\to gg)}$	17 %	30 %	11 %	17 %

by TMVA:

optimized on	$h \to b\bar{b}$	$h \to c\bar{c}$	$h \to gg$	$h \to b\bar{b}, c\bar{c}, gg$
$\frac{\Delta\sigma \cdot BR(h\to\bar{b}b)}{\sigma \cdot BR_{SM}(h\to\bar{b}b)}$	1.75 %			1.73 %
$\frac{\Delta\sigma \cdot BR(h\to\bar{c}c)}{\sigma \cdot BR_{SM}(h\to\bar{c}c)}$		18.6 %		22.8 %
$\frac{\Delta\sigma \cdot BR(h\to gg)}{\sigma \cdot BR_{SM}(h\to gg)}$			6.3 %	9.7 %
$\frac{\Delta BR(h\to\bar{b}b)}{BR_{SM}(h\to\bar{b}b)}$	(4.8 %)			(4.8 %)
$\frac{\Delta BR(h\to\bar{c}c)}{BR_{SM}(h\to\bar{c}c)}$		19 %		23 %
$\frac{\Delta BR(h\to gg)}{BR_{SM}(h\to gg)}$			7.8 %	11 %

Hadronic Beam Background

- tested for mean 0, 0.2 and 0.4
- 0.2 in normal samples – 0.4 expected from DBD
- Toy Study:
  - Signal changed mean, Background mean 0.2

→ no influence on fit expected

- Significance:
  - Scaling number of events with and without overlay to the number in the corresponding signal file
    - but always using samples with mean 0.2

→ Results into ~ 2% increase of uncertainty

Result Toy Study:

overlay mean	$\mu = 0$	$\mu = 0.2$	$\mu = 0.4$
$N_{fit}(\mathrm{h} \to \mathrm{b\bar{b}})$	4248	4248	4248
$\Delta N_{fit}(\mathrm{h} \to \mathrm{b\bar{b}})$	76.5	77.4	77.26
$N_{fit}(\mathrm{h} \to \mathrm{c\bar{c}})$	192.7	193.3	193.5
$\Delta N_{fit}(\mathrm{h} \to \mathrm{c\bar{c}})$	50.96	51.91	51.23
$N_{fit}(\mathrm{h} \to \mathrm{gg})$	469	470	470
$\Delta N_{fit}(\mathrm{h} \to \mathrm{gg})$	72.8	75.88	70.38

Result Significance Study:

overlay mean	$\mu = 0$	$\mu = 0.2$	$\mu = 0.4$
significance	53.37	51.87	50.79

Conclusion

- for gluon and charm final states separate cut optimization is useful
- Beam background influence is small
- Accuracy on WW-fusion production cross section 32 %
  - needs further study to develop direct measurement

	H -> bb	**H -> cc**	**H -> gg**
Accuracy branching ratio times cross section	1.8 %	22 % (19)	10 % (6)
Accuracy branching ratio	*	22 % (19)	11 % (8)

*Higgs to bottom branching ratio can not be measured from my analyais

embraced values from TMVA

Backup

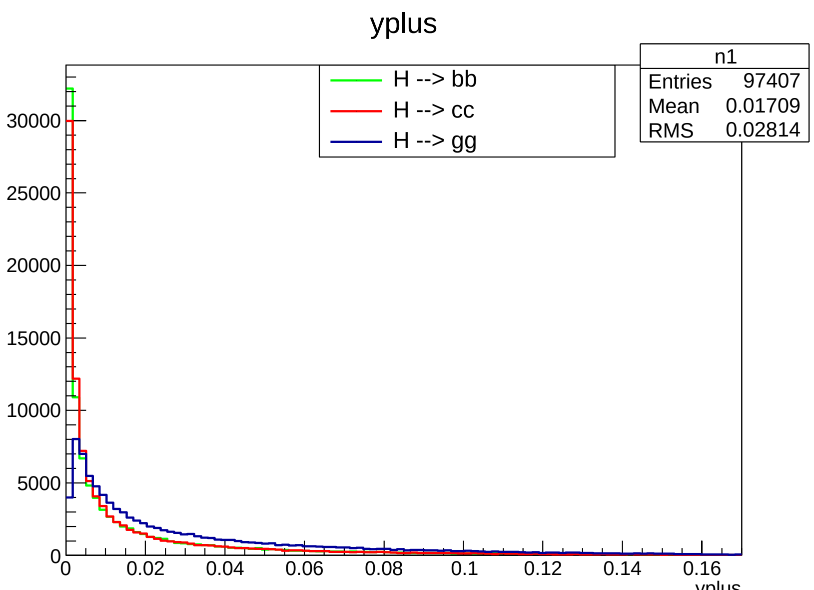
Significance after optimising

- with WW-fusion

optim on	bb	cc	gg	bb, cc, gg
Significance	50.6	38.3	32	50.7
Effi	0.347	0.137	0.111	0.367
Purity	0.551	0.803	0.689	0.523
Sig_bb	43.8	33.8	21.3	43.8
Sig_cc	1.95	1.81	0.655	1.97
Sig_gg	4.79	2.7	9.97	4.89

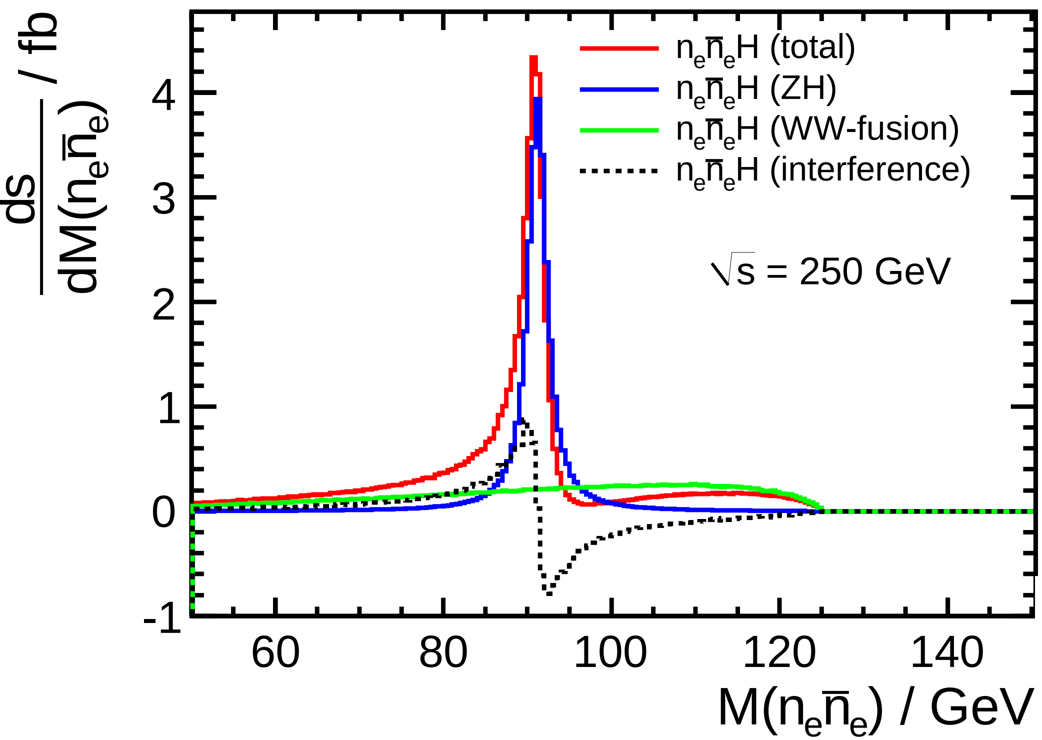
cut limits

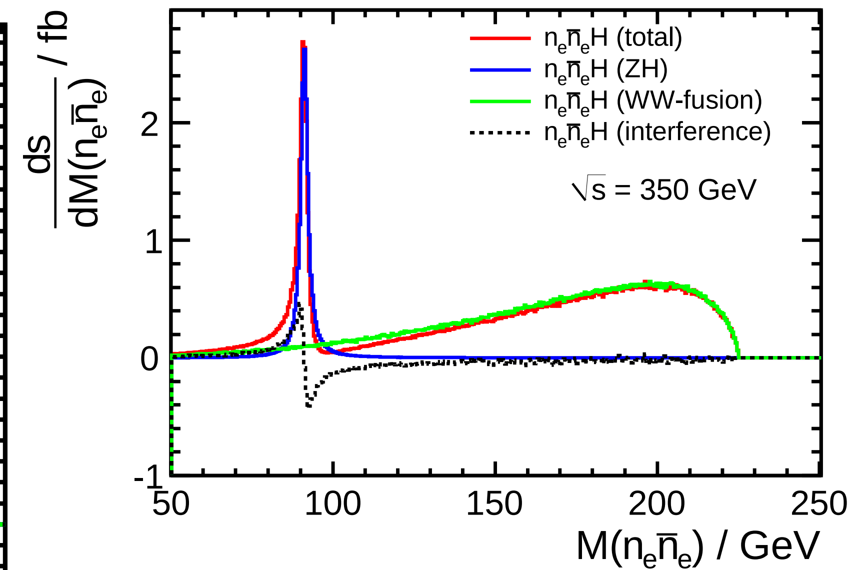
- gloun-events
  - sharper cuts on z and higgs mass
  - no mouns
  - maximal PFO Momenten smaller
  - different event shape

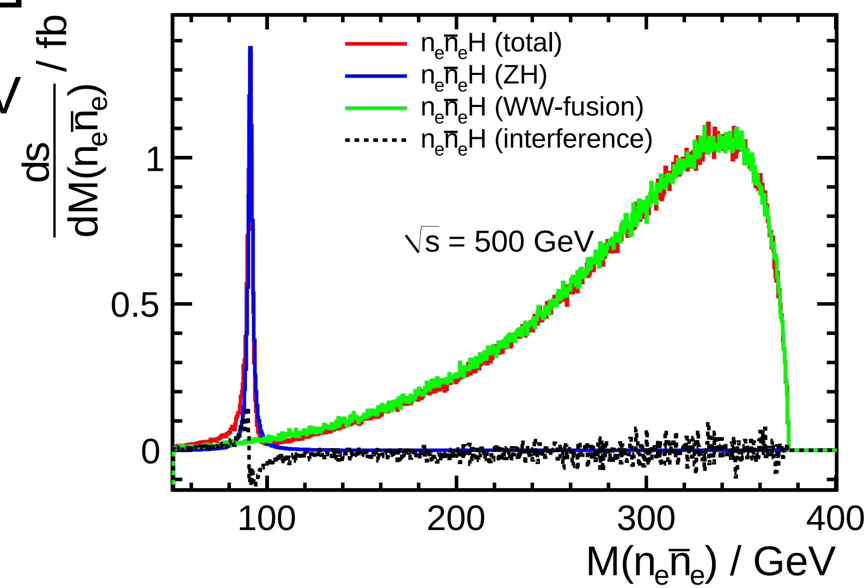


optim on	bb	cc	gg	bb, cc, gg
npfos1>	20	14	30	20
npfos2>	11	9	23	11
maxPFOMomentum<	40.5	42.5	26.5	40.5
mass_z<	131.5	107.5	123.5	131.5
mass_z>	81.5	82	83	79.5
mass_higgs>	104.5	117	117.5	104.5
mass_higgs<	132	129	130	132
mom_t<	66.5	66.5	68	67.5
mom_t>	25.5	34	21	21.5
Abs(mom_z)<	55	49	57	55.5
majthrust<	0.5	0.48	0.56	0.5
pthrust>	0.8	0.83	0.64	0.77
minthrust<	0.35	0.3	0.47	0.35
minthrust>	0	0	0.09	0.03
nmuon<	4	3	1	4
y12>	0.29	0.285	0	0.29
y12<	0.955	0.885	0.96	0.91
yplus<	0.015	0.005	0.055	0.015
majthrust>	0.08	0.15	0	0.08

Interverance depandent on CME





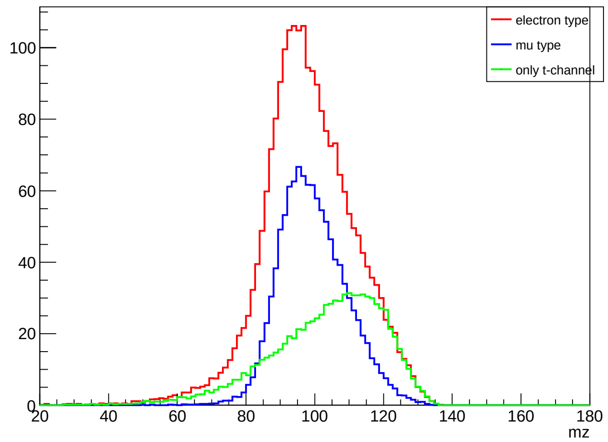


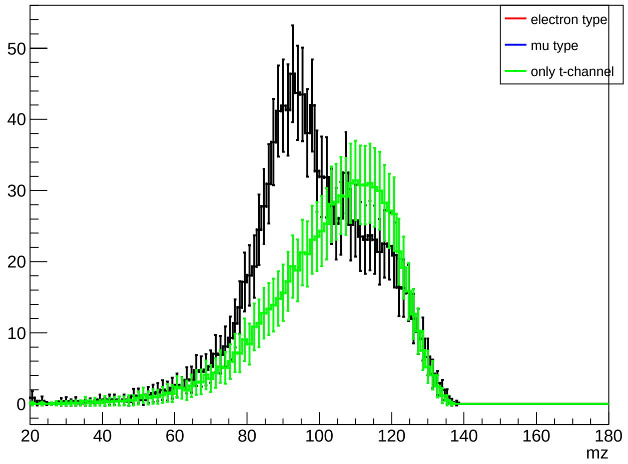
- @ 250 Interverence is important to study

plots by Junping

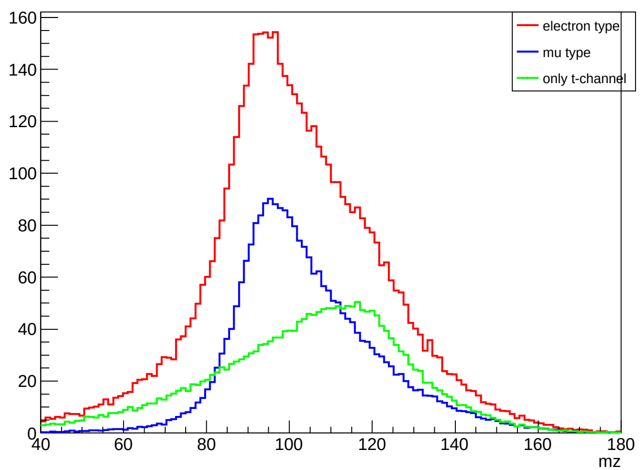
Interverance of ZH/WW in Z-mass

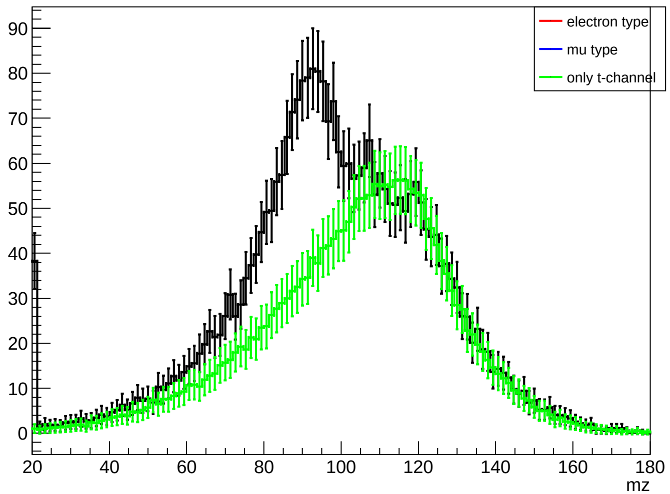
- Recon. Z-mass cut Sig ~ 43





- Recon. Z-mass





Fitting uncertainty

- with WW-fusion

optim on	bb	cc	gg	bb, cc, gg	bb with WW
BG	3.14	12.84	9.69	3.07	3.12
BG in %	3.14	12.84	9.69	3.07	3.12
bb in %	1.82	2.65	3.53	1.79	1.78
cc in %	26.43	25.14	210.32	19.35	30.44

- WW-fusion turned of

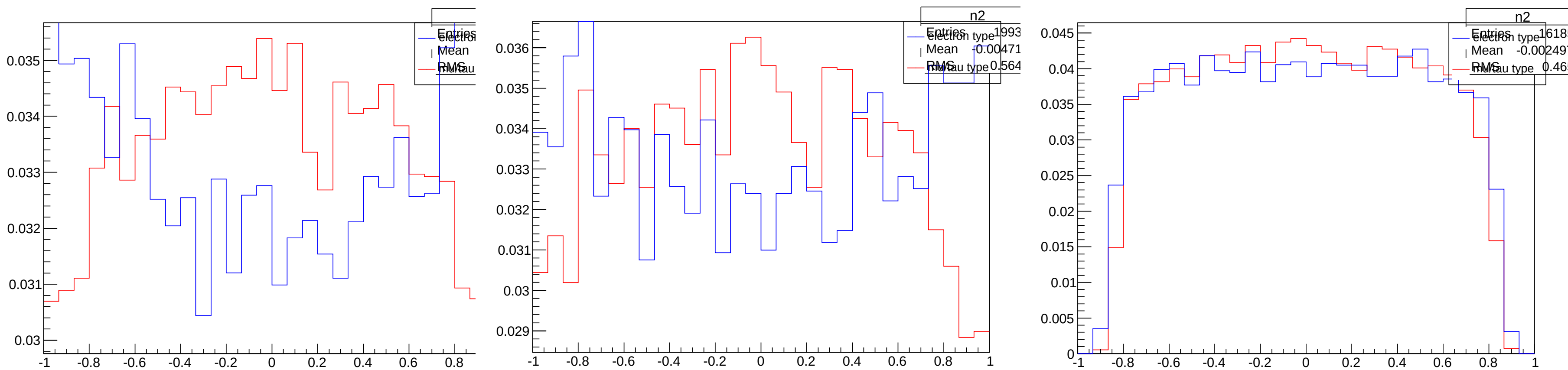
optim on	bb	cc	gg	bb, cc, gg	bb with WW
BG	3.26	15.12	10.38	3.27	3.13
bb	1.8	2.6	3.64	1.77	1.8
cc	20.03	30.81	143.4	19.95	21.81
gg	15.43	18.44	11.57	16.74	13.73

Fitting WW-fraction

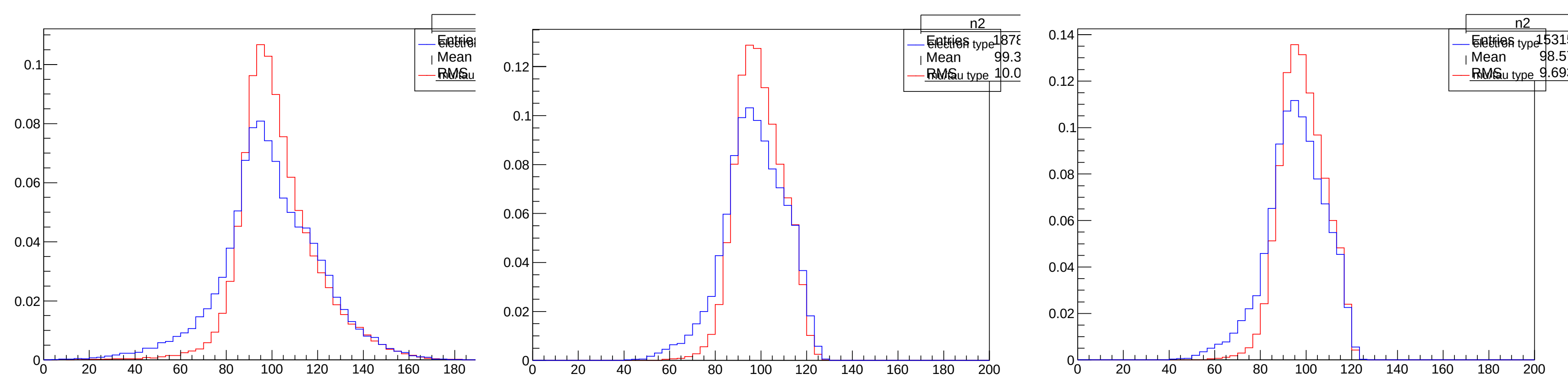
electron neutrinos

mu/tau neutrinos

- cosh — no cuts — no mpt cut — all cuts



- Z-mass — no cuts — no mpt cut — all cuts

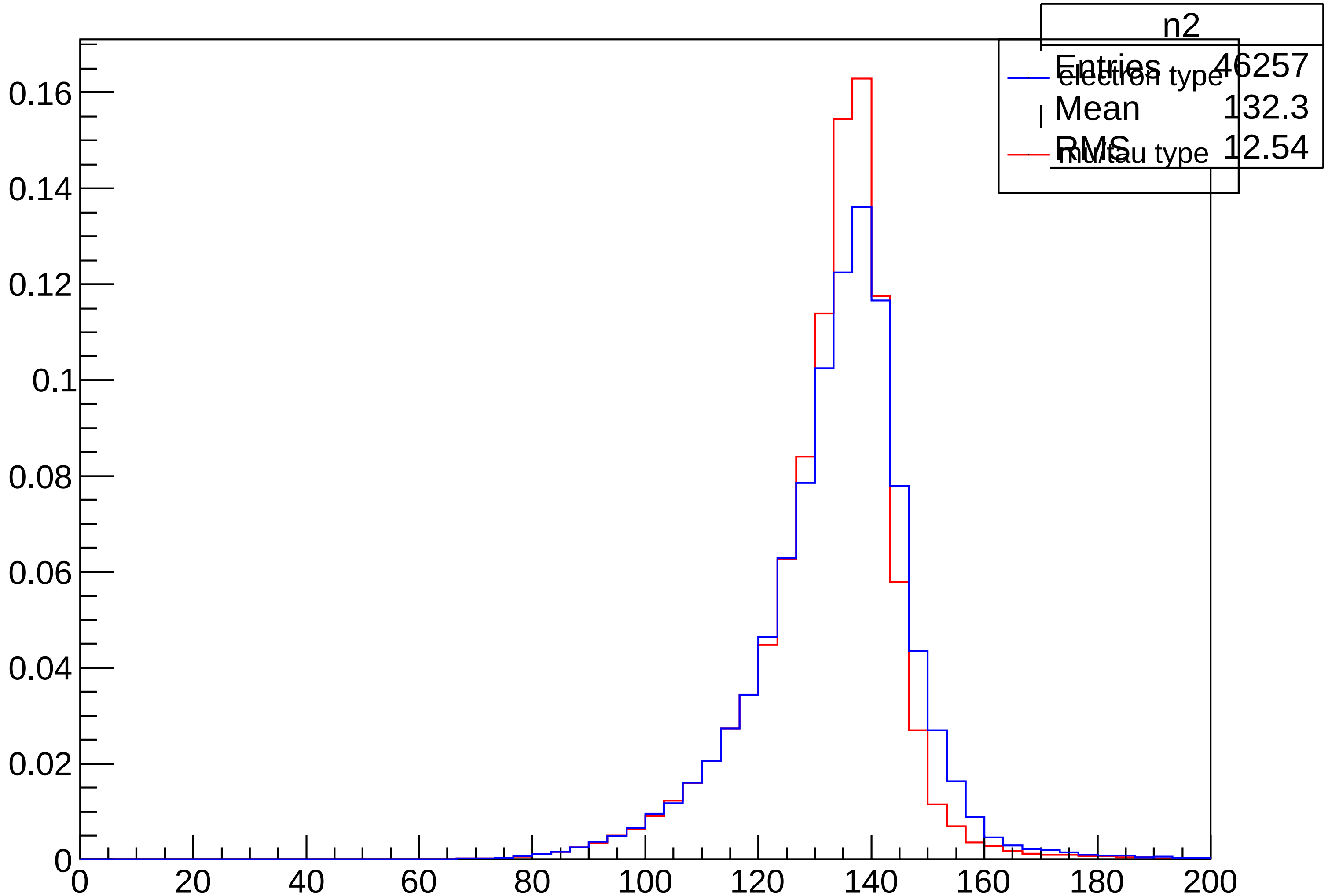


Compare to Ono/Miyamoto's paper

CM energy (GeV)	250		
Cut names	condition	Sig.	Bkg.
Generated		19360	44827100
Missing mass (GeV)	$80 < M_{miss} < 140$	15466	6214050
Transverse P (GeV)	$20 < P_T < 70$	13727	549340
Longitudinal P (GeV)	$\|P_L\| < 60$	13342	392401
# of charged tracks	$N_{chd} > 10$	12936	374877
Maximum P (GeV)	$P_{max} < 30$	11743	205038
Y_{23} value	$Y_{23} < 0.02$	7775	74439
Y_{12} value	$0.2 < Y_{12} < 0.8$	7438	62584
Di-jet mass (GeV)	$100 < M_{jj} < 130$	6691	19061
Likelihood ratio	$LR > 0.165$	6293	10940
Significance (Efficiency)	$S/\sqrt{S+B}$	47.9 (32.5%)	

	vvH	BG
Expected	19383	5.11E+08
isoLepCuts	17644	3.62E+08
npfo	14677	1.92E+07
E_vis	13338	6.55E+06
Z-Mass	12013	1.54E+06
Higgs-mass	10977	321243
missMo_t	9807	54591
missMo_z	9451	38490
majthrust	8369	24327
pthrust	7598	20220
minthrust	7590	20171
maxPFOMom	7450	18586
y-Cuts	4994	4407
	51,5	(25,7 %)

evis



n2
Entries 46257
Mean 132.3
RMS 12.54
electron type
mu/tau type
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
20
40
60
80
100
120
140
160
180
200

Comparing fitting result

	$X = x_1 + x_2$			$X = x_1 * x_2 / (x_1 * x_2 + (1 - x_1)(1 - x_2))$		
	Reconst. N	abso. Error	rel. Error	Reconst. N	abso. Error	rel. Error
numBack	6290.00	103.00	2 %	6523.30	141.00	2 %
bb	4080.70	70.20	2 %	4089.20	74.30	2 %
cc	162.38	24.10	15 %	193.78	50.70	26 %
gg	582.03	58.20	10 %	410.78	77.10	19 %

TABLE IV: Summary of template fitting results r_s and accuracies of $(\sigma \cdot Br)$ and Br after correcting σ for an accuracy of 2.5% at $\sqrt{s} = 250$ GeV assuming $\mathcal{L} = 250$ fb^{-1} with $(e^-, e^+) = (-0.8, +0.3)$.

	$\nu\bar{\nu}H$	$q\bar{q}H$	e^+e^-H	$\mu^+\mu^-H$	comb.
$r_{b\bar{b}}$	1.00±0.02	1.00±0.01	1.00±0.04	1.00±0.03	1.00±0.01
$r_{c\bar{c}}$	1.02±0.11	1.01±0.10	1.02±0.27	1.01±0.23	1.02±0.07
r_{gg}	1.02±0.14	1.02±0.13	1.05±0.33	1.02±0.24	1.02±0.09
$\frac{\Delta(\sigma \cdot Br)}{\sigma \cdot Br}(H \to b\bar{b})$ (%)	1.7	1.5	3.8	3.3	1.0
$\frac{\Delta(\sigma \cdot Br)}{\sigma \cdot Br}(H \to c\bar{c})$ (%)	11.2	10.2	26.8	22.6	6.9
$\frac{\Delta(\sigma \cdot Br)}{\sigma \cdot Br}(H \to gg)$ (%)	13.9	13.1	31.3	33.0	8.5
$\frac{\Delta Br}{Br}(H \to b\bar{b})$ (%)	3.0	2.9	5.7	4.5	2.7
$\frac{\Delta Br}{Br}(H \to c\bar{c})$ (%)	11.4	10.5	31.3	22.8	7.3
$\frac{\Delta Br}{Br}(H \to gg)$ (%)	14.2	13.3	33.1	24.0	8.9

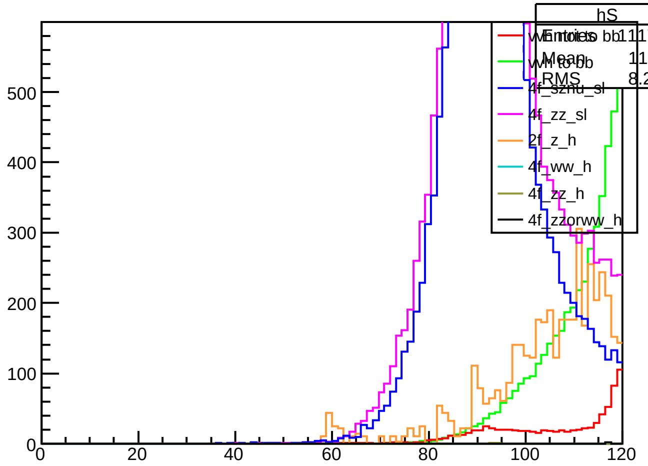
Compare to Claude Düring's study

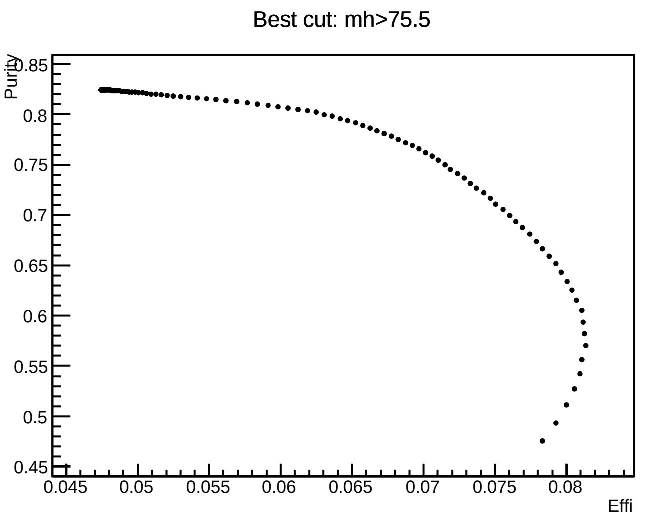
Process	expected	pre-selection	Cut1	Cut2	Cut3	Cut4	Cut5	Cut6	Cut7	Cut8
$\nu\bar{\nu}H$(fusion)	3426	2663	2070	2023	1577	1053	965	547	519	507
$\nu\bar{\nu}H(ZH)$	1.4×10^4	10918	8356	8356	7448	4860	4594	2574	2546	2546
$\nu_l\bar{\nu}_l b\bar{b}$	3.05×10^4	23012	1040	1040	878	421	390	224	193	187
$\nu_l\bar{\nu}_l q\bar{q}$	1.19×10^5	88998	5548	5545	4714	2408	2271	15	9	9
$q\bar{q}l^+l^-$	2.99×10^5	153540	6196	5922	1760	588	508	65	38	36
$q\bar{q}l\nu$	1.73×10^6	1.15×10^6	181973	177193	134047	22654	20533	111	73	65
$q\bar{q}q\bar{q}$	3.91×10^6	1.15×10^6	782	728	3	1	0	0	0	0
$q\bar{q}$	26.02×10^6	17.27×10^6	852321	794892	1507	1199	683	289	152	152
BG	32.104×10^6	19.846×10^6	1.047×10^6	985320	142909	27271	24385	1404	465	449

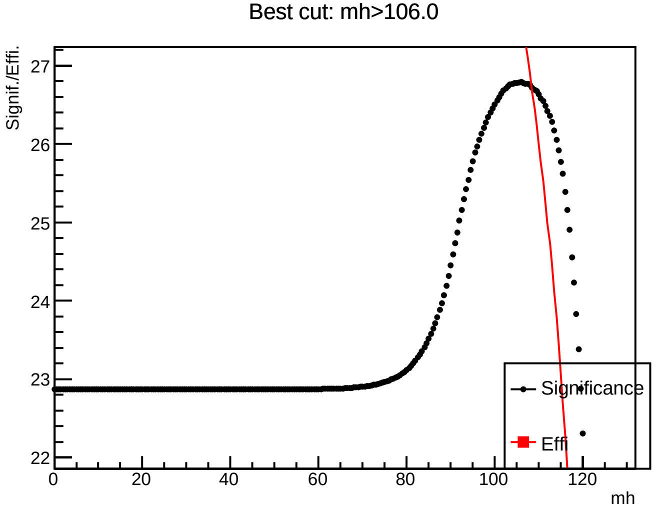
	Expected	isoLepCuts	npfo	E_vis	Z-Mass	Higgs-mass	missMo_t	missMo_z	cosTHiggs	B-Tag	all cuts
vvH(fusion)	3960	3610	3280	2890	2570	2410	1970	1830	1830	1240	1170
vvH(ZH)	1.54E+04	1.54E+04	1.54E+04	1.54E+04	1.54E+04	1.54E+04	9970	9890	9880	6530	6250
vvbb	3.31E+04	3.31E+04	3.31E+04	3.31E+04	3.31E+04	3.31E+04	2630	2160	2150	2020	1570
vvqq	1.26E+05	1.26E+05	3.31E+04	3.31E+04	3.31E+04	3.31E+04	3.31E+04	9420	9420	104	54.8
qqll	2.18E+05	2.18E+05	2.18E+05	18700	7630	3900	1380	1140	1140	394	251
qqlv	4.22E+06	4.22E+06	4.22E+06	4.22E+06	4.22E+06	4.22E+06	4.22E+06	4.22E+06	4.22E+06	1190	677
qqqq	4.20E+06	4.20E+06	4.20E+06	486	331	217	5.6	5.6	5.6	0.717	0.132
qq	1.95E+07	1.95E+07	1.95E+07	1.95E+07	1.95E+07	1.95E+07	3550	2470	2450	1710	1510

- qqll before zz_sl + zee_sl (now only to l+l-)
- qqlv before only sw_sl (now + ww_sl)

How I decided on cuts







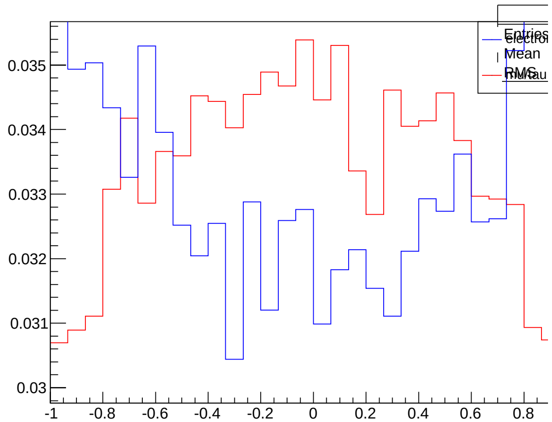
Fitting WW-fraction

electron neutrinos

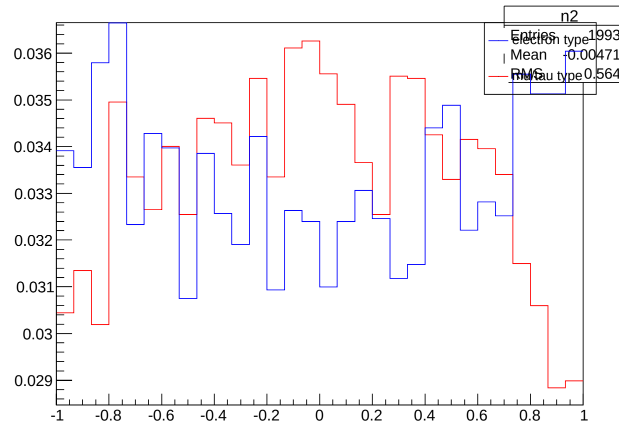
mu/tau neutrinos

- cosh

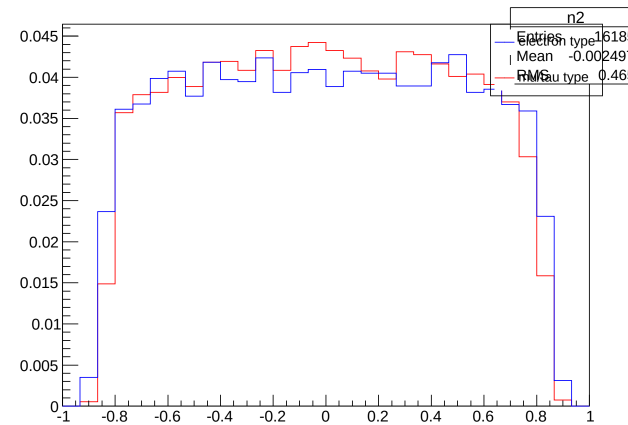
no cuts



no mpt cut

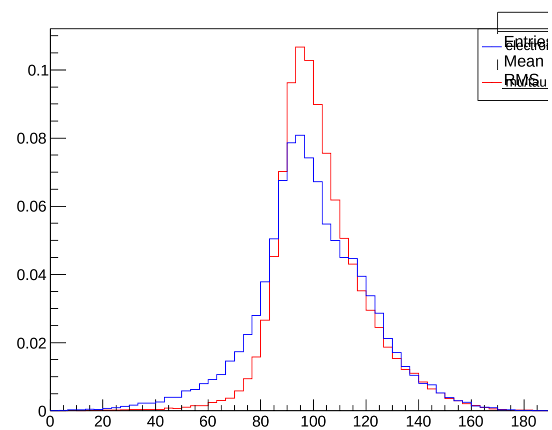


all cuts



- Z-mass

no cuts



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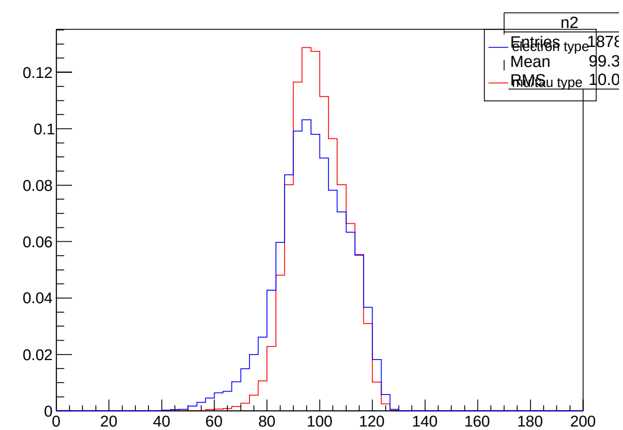

all cuts