Higgs Recoil Study

ILC Physics meeting

May 21, 2015

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Current Status & New Activities

- **analysis done for Z→mumu channel at ECM = 250 GeV, 350 GeV, 500 GeV**
  → results summarized last week
  comparisons made between ECM and polarizations

- reform of analysis codes (～ finished after 1 month)

- **studied effect of uncertainty of BG statistics on xsec error**

- **analysis for Z→ee channel at ECM = 250 GeV, 350 GeV**

  discovered that GPET should not be used reliably for Zee anymore
  (details coming up)

→ Making transition to using Kernel estimation function

Compare of results between alternative ECM and polarizations

Ecm=250 GeV		Ecm=350 GeV		Ecm=500 GeV	
(−0.8,+0.3)	3.5%	(−0.8,+0.3)	4.1%	(−0.8,+0.3)	6.1%
(+0.8,−0.3)	3.6%	(+0.8,−0.3)	4.5%	(+0.8,−0.3)	7.2%

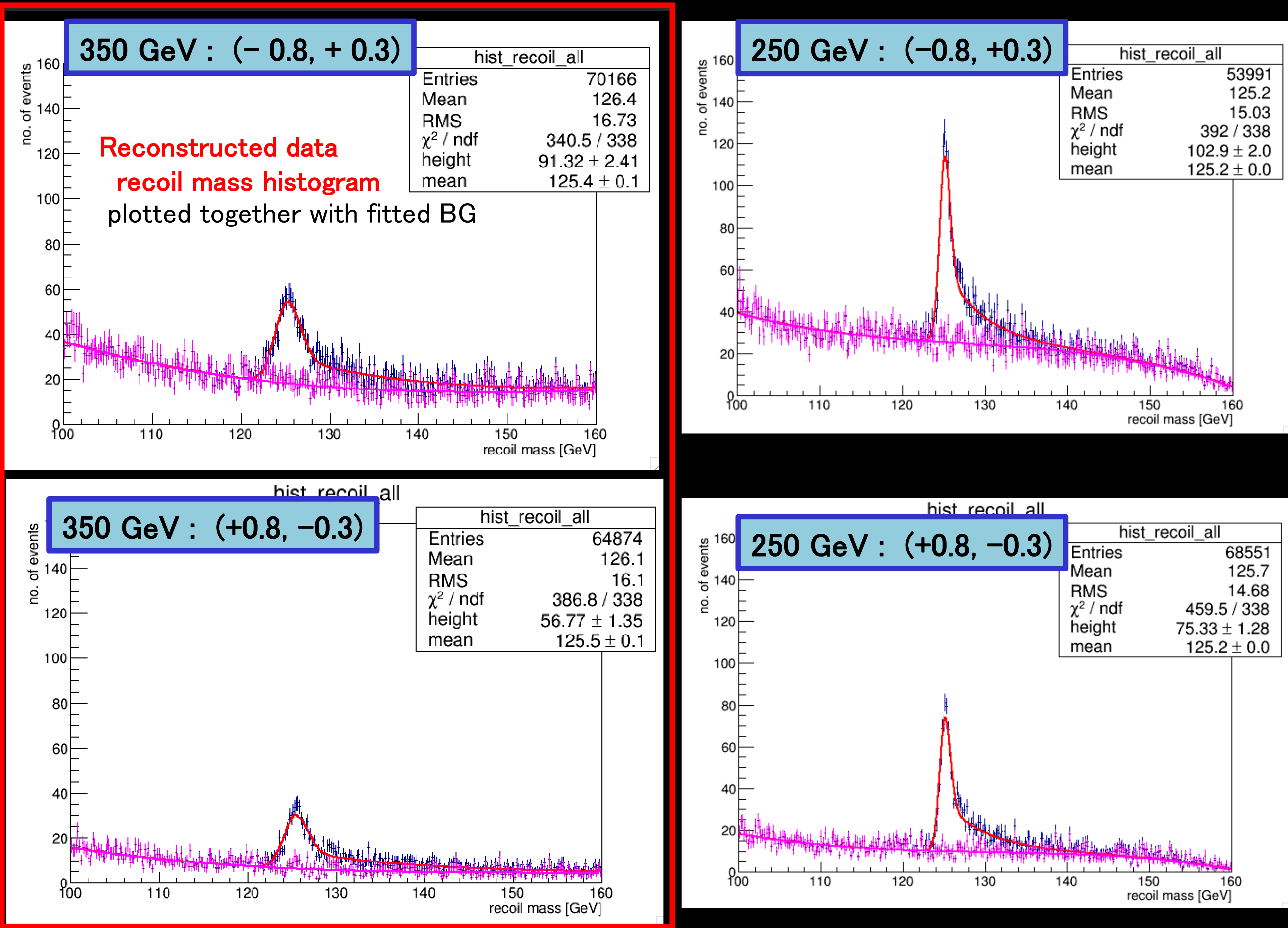
Current (April, 2015)

xsec precision is improved by 17%

from AWLC 2014 (@Fermilab)

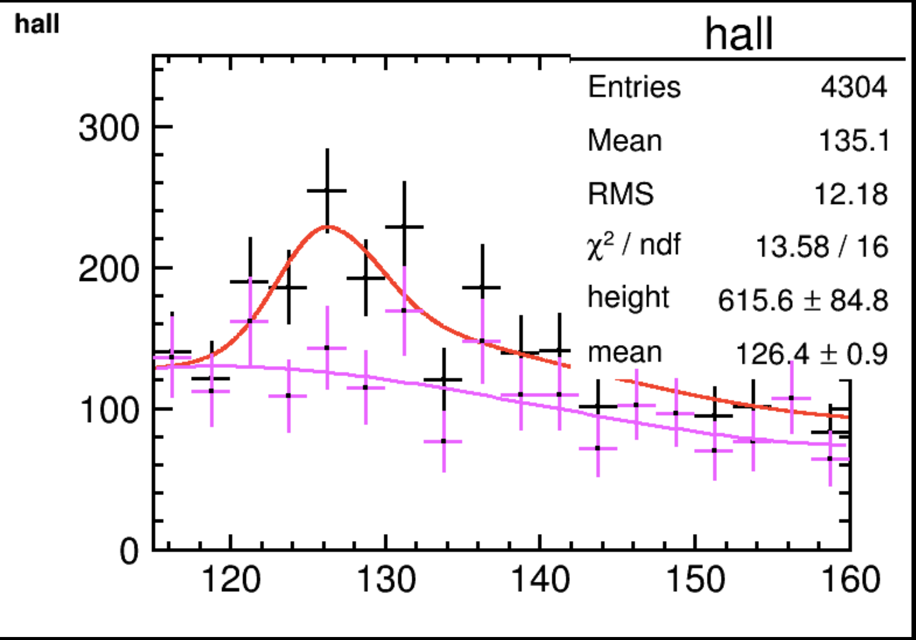
for ECM=350 GeV Pol (−0.8, + 0.3)

- **ECM= 250 GeV has 17 % better xsec precision** (w.r.t. 350 GeV)
  higher statistics, better momentum resolution → sharper recoil mass peak
- **Pol (+0.8, −0.3) has 10% worse xsec precision**
  although WW BGs significantly suppressed (higher S/B ratio), statistics is lower



350 GeV : (− 0.8, + 0.3)
hist_recoil_all
Entries 70166
Mean 126.4
RMS 16.73
χ² / ndf 340.5 / 338
height 91.32 ± 2.41
mean 125.4 ± 0.1
Reconstructed data
recoil mass histogram
plotted together with fitted BG
no. of events
recoil mass [GeV]
250 GeV : (−0.8, +0.3)
hist_recoil_all
Entries 53991
Mean 125.2
RMS 15.03
χ² / ndf 392 / 338
height 102.9 ± 2.0
mean 125.2 ± 0.0
no. of events
recoil mass [GeV]
350 GeV : (+0.8, −0.3)
hist_recoil_all
hist_recoil_all
Entries 64874
Mean 126.1
RMS 16.1
χ² / ndf 386.8 / 338
height 56.77 ± 1.35
mean 125.5 ± 0.1
no. of events
recoil mass [GeV]
250 GeV : (+0.8, −0.3)
hist_recoil_all
hist_recoil_all
Entries 68551
Mean 125.7
RMS 14.68
χ² / ndf 459.5 / 338
height 75.33 ± 1.28
mean 125.2 ± 0.0
no. of events
recoil mass [GeV]

At last week's meeting, I received comment about BG statistics



- *is lack of statistics a issue for 500 GeV?*

  major residual BG have large weights

Investigated error of # of BG based on binomial distribution

$$\delta \varepsilon = \mathrm{sqrt}(\varepsilon(1-\varepsilon)/N)$$

N: # of generated events

for 500 GeV, error of total BG is about 4.4%

(c.f. Poisson error sqrt(NBG) ~ 1%, But not appropriate for small statistics)

- even larger error for some major BG processes (4f_sl , 2f_l)

- for 250 , 350 GeV, binominal error < 1%, a little less than Poisson error.

I changed the BG level in Toy MC study to test the effect of BG uncertainty on xsec error

- for 500 GeV, only 1.2% effect if BG change by 4.4%
- only 2.5% even if BG change by as much as 10%
- effect on xsec error is very much negligible for 250 GeV and 350 GeV

	Toy MC						
250GeV							
	nominal BG	BG + 1%	Diff	BG + 4%	Diff	BG + 10%	Diff
xsec error (relative)	3.29	3.29	0.21%	3.31	0.76%	3.35	1.86%
350 GeV							
	nominal	BG + 1%	Diff	BG + 4%	Diff	BG + 10%	Diff
xsec error (relative)	4.19	4.20	0.19%	4.22	0.74%	4.27	1.93%
500 GeV							
	nominal			BG + 4.4%	Diff	BG + 10%	Diff
xsec error (relative)	6.46			6.54	1.24%	6.62	2.48%

similar results if float BG normalization in Toy MC

First results for Z→ ee channel analysis

- For Zee, due to bremsstrahlung ,

  signal shape is more non-Gaussian (left side of GPET)

  even if brem recovery is implemented

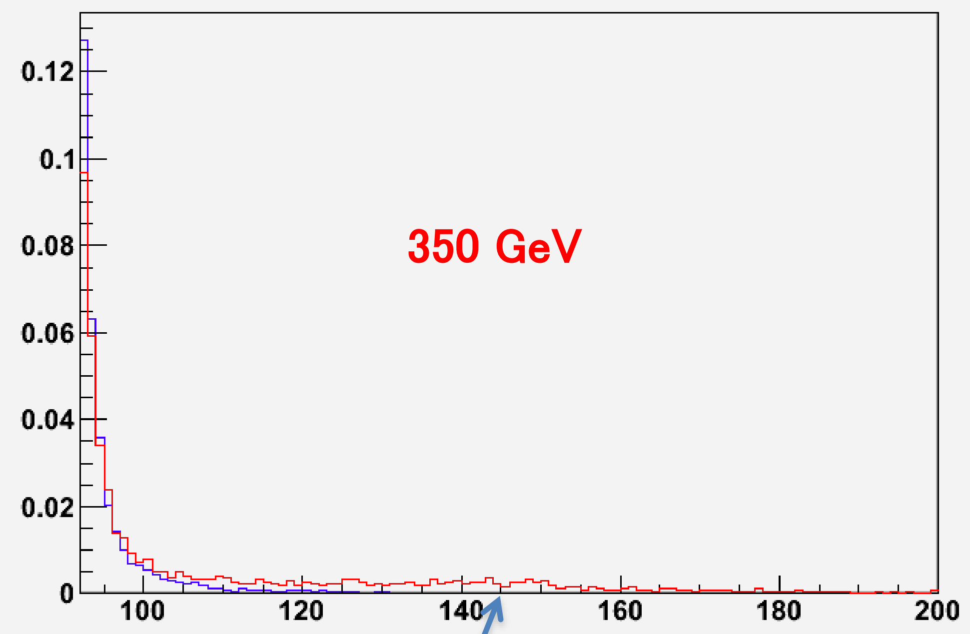
- GPET should no longer be used, even for statistical error study

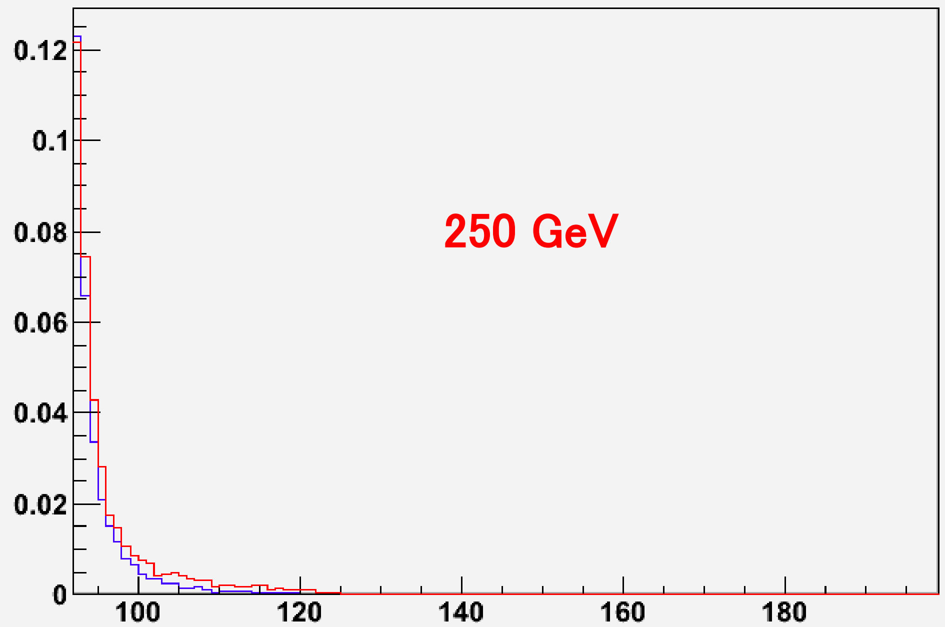
- for 250 GeV, maybe still OK (?)
- problem gets serious for 350 GeV

  (also issue of interference with ZZ fusion process xsec increasing) compare dilepton invariant mass distribution

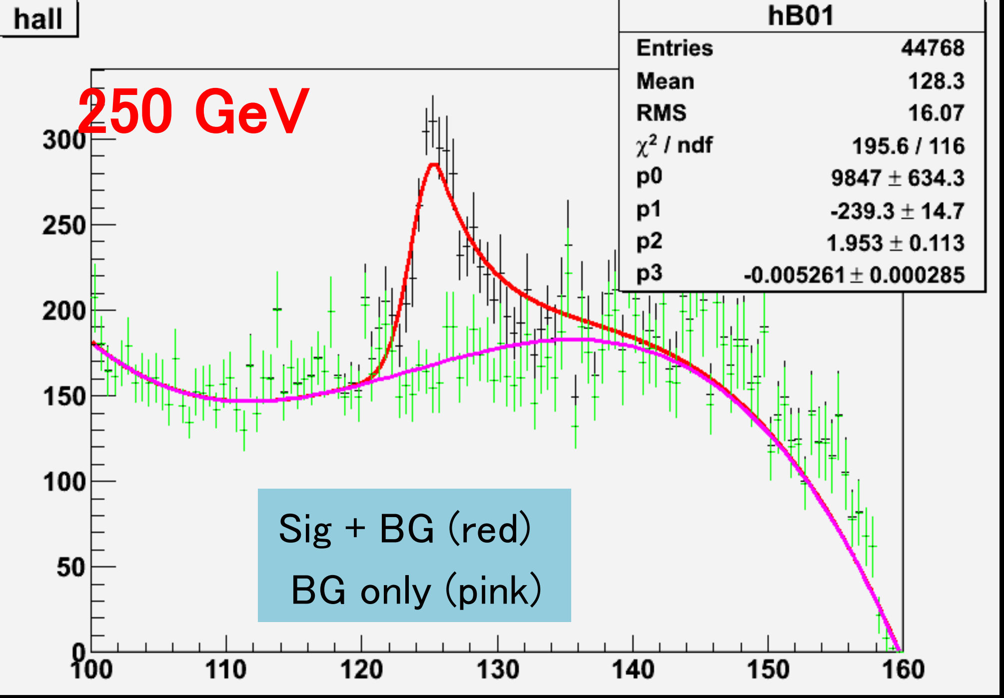
Zee (red)

vs Zmumu (blue)





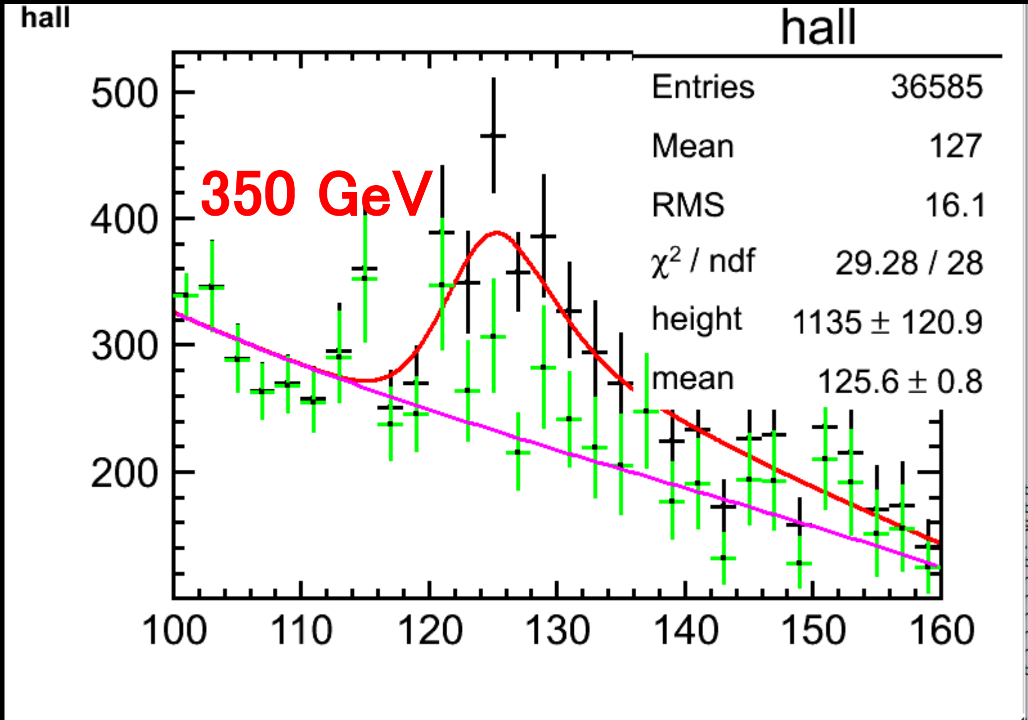
- Zmumu much sharper
- Zee has a long tail towards large inv. Mass (ZZ fusion)



Xsec error (Toy MC)

250 GeV

- 3.6% if fix BG
- 4.9% if float BG



Xsec error (Toy MC)

350 GeV

- 7.4 % if float BG

combined stat error of both leptonic channels

250 GeV;

2.4% (Zmumu: 3.3% and Zee: 3.6%)

(fix BG in Toy MC)

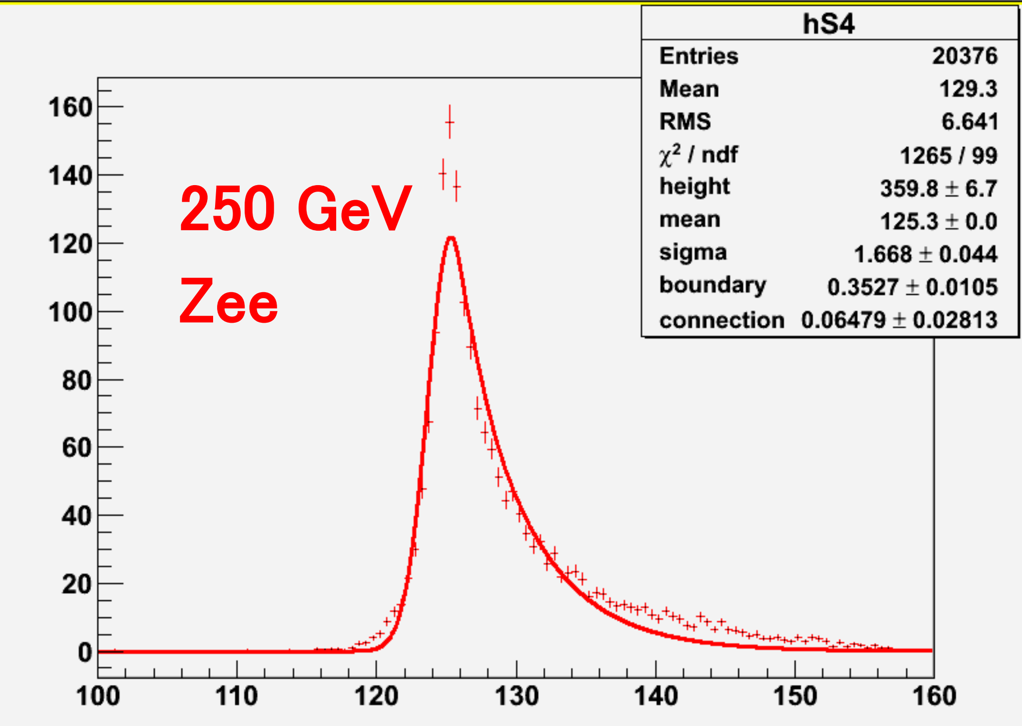
2.8% (Zmumu: 3.4% and Zee 4.9%)

(float BG)

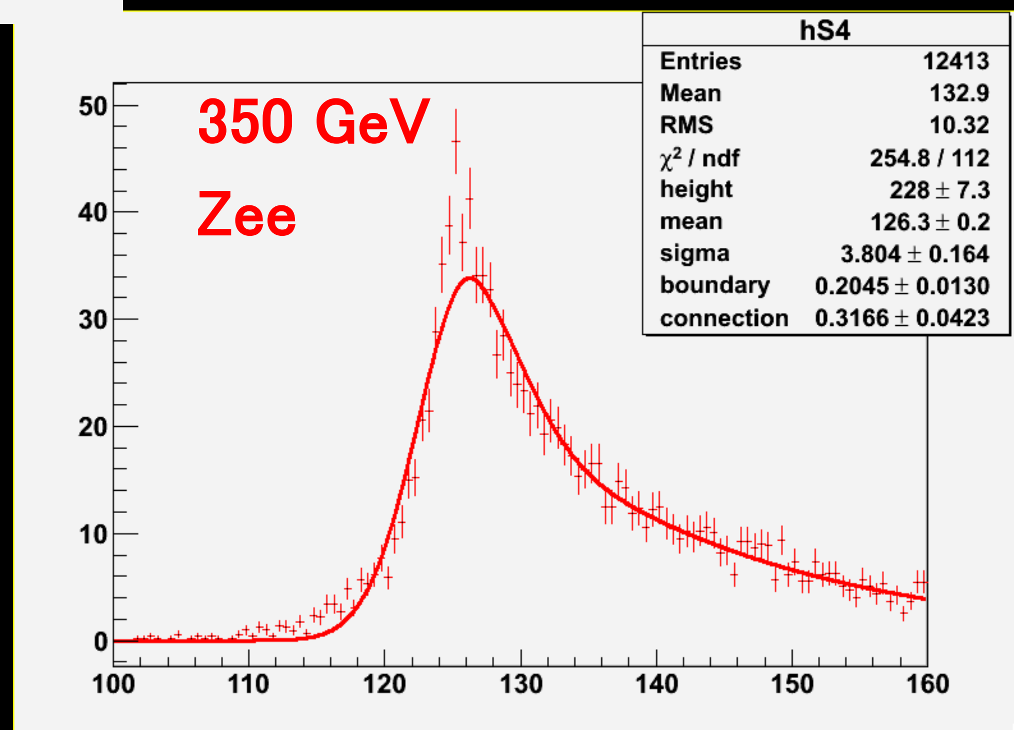
350 GeV:

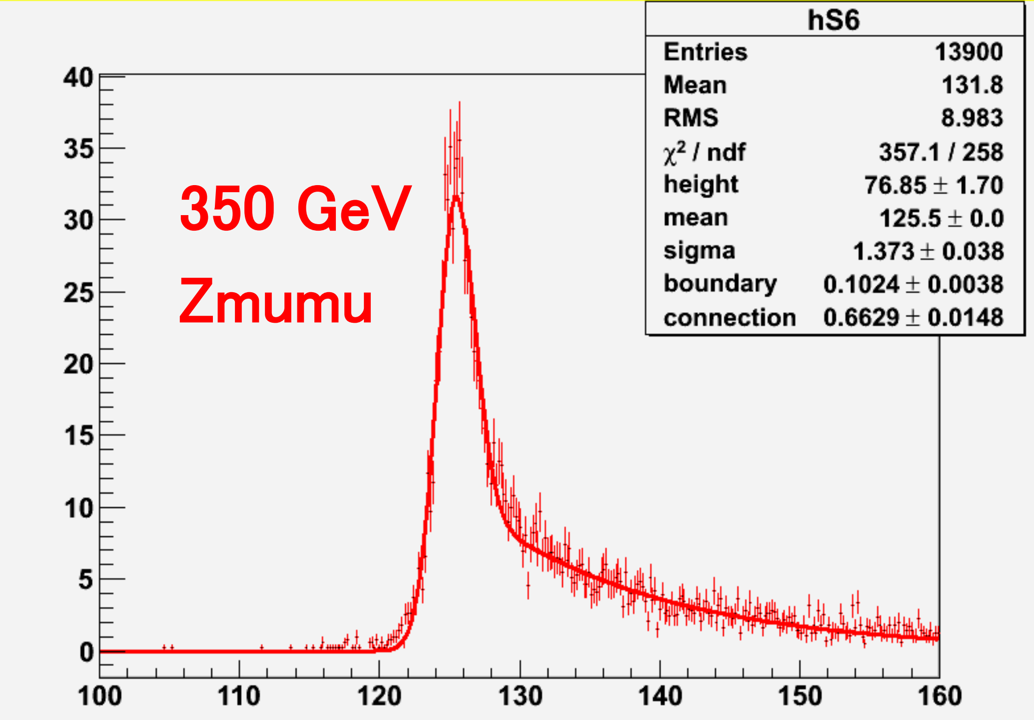
3.6% (Zmumu : 4.1% and Zee: 7.4%)

(float BG)

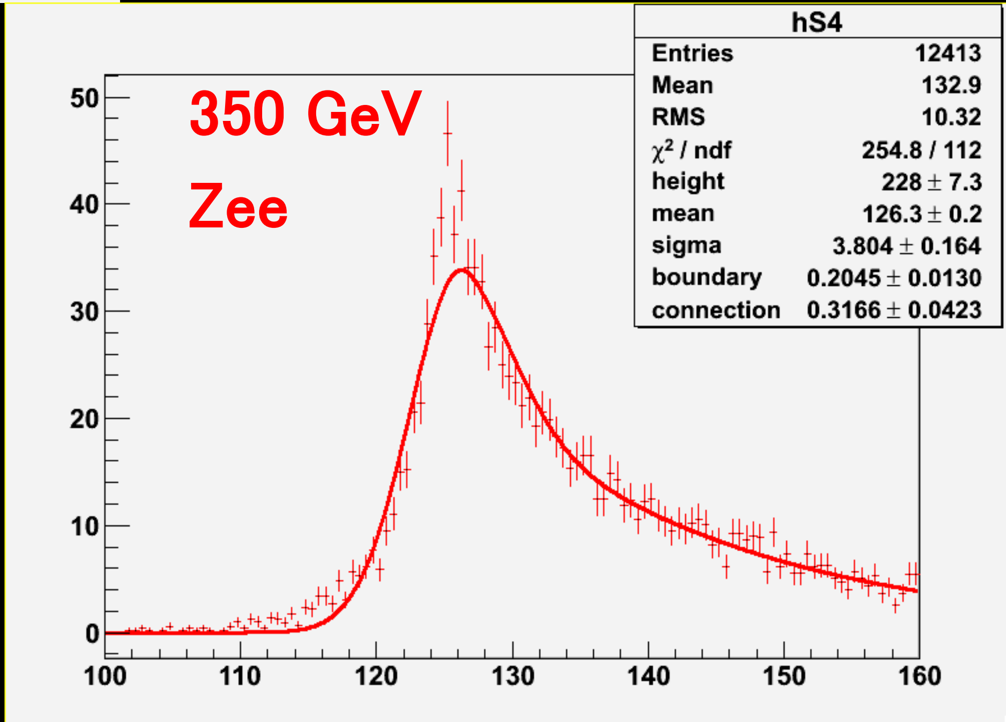

hS4
Entries 20376
Mean 129.3
RMS 6.641
χ² / ndf 1265 / 99
height 359.8 ± 6.7
mean 125.3 ± 0.0
sigma 1.668 ± 0.044
boundary 0.3527 ± 0.0105
connection 0.06479 ± 0.02813
250 GeV
Zee
0
20
40
60
80
100
120
140
160
100
110
120
130
140
150
160

Sig only


hS4
Entries 12413
Mean 132.9
RMS 10.32
χ² / ndf 254.8 / 112
height 228 ± 7.3
mean 126.3 ± 0.2
sigma 3.804 ± 0.164
boundary 0.2045 ± 0.0130
connection 0.3166 ± 0.0423
350 GeV
Zee
0
10
20
30
40
50
100
110
120
130
140
150
160


hS6
Entries 13900
Mean 131.8
RMS 8.983
χ² / ndf 357.1 / 258
height 76.85 ± 1.70
mean 125.5 ± 0.0
sigma 1.373 ± 0.038
boundary 0.1024 ± 0.0038
connection 0.6629 ± 0.0148
350 GeV
Zmumu

Sig only


hS4
Entries 12413
Mean 132.9
RMS 10.32
χ² / ndf 254.8 / 112
height 228 ± 7.3
mean 126.3 ± 0.2
sigma 3.804 ± 0.164
boundary 0.2045 ± 0.0130
connection 0.3166 ± 0.0423
350 GeV
Zee

Conclusions

- **Checked effect of BG statistics on xsec error**
- **first results for Z→ee channel**
- **realized limitation of GPET for Zee at 350 GeV**
- **analysis code has been improved for better efficiency**

Plans

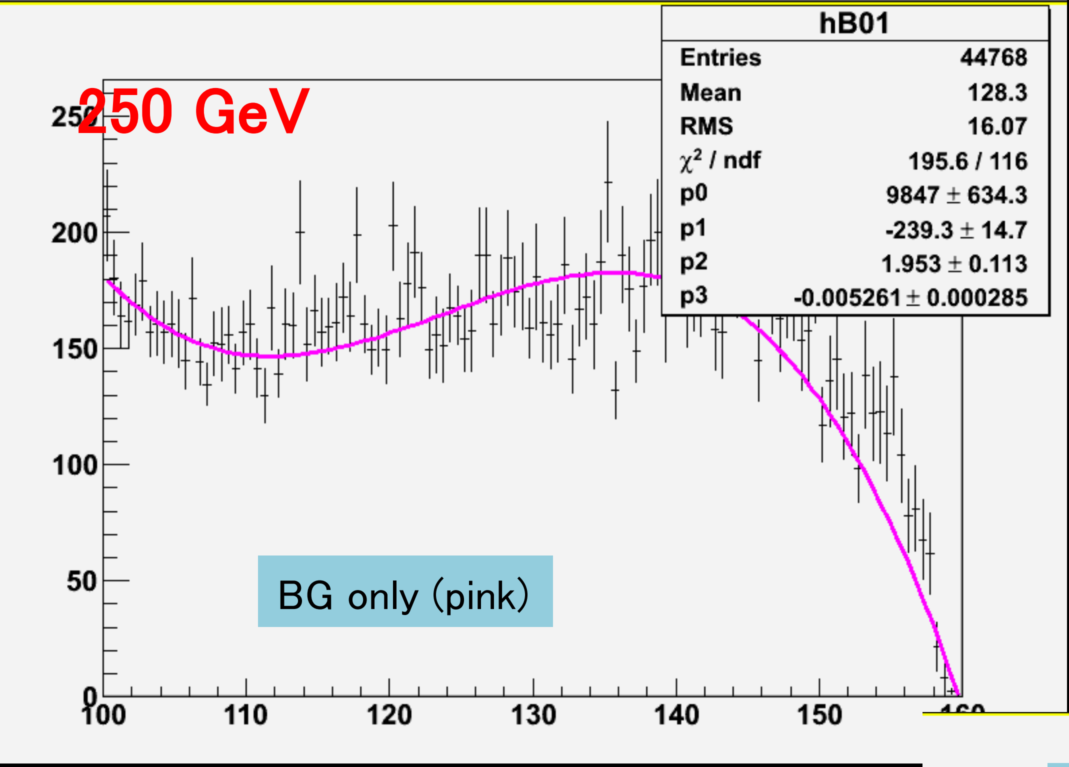
- **analysis for Z→mumu and Z→ee channel at ECM = 250 GeV, 350 GeV, 500 GeV using Kernel estimation function**

combine both leptonic channels for a reliable estimate of statistical errors at each ECM

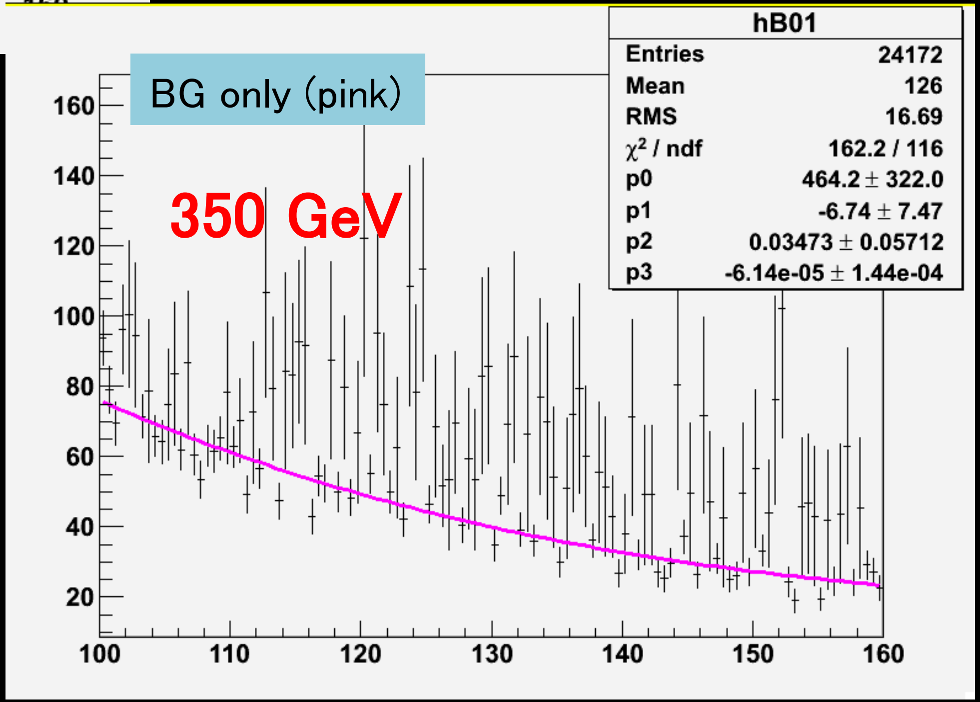
◆ also do analysis for **ZZ fusion process**

◆ **study systematic errors**

BACKUP



250 GeV
hB01
Entries 44768
Mean 128.3
RMS 16.07
χ² / ndf 195.6 / 116
p0 9847 ± 634.3
p1 -239.3 ± 14.7
p2 1.953 ± 0.113
p3 -0.005261 ± 0.000285
BG only (pink)



350 GeV
hB01
Entries 24172
Mean 126
RMS 16.69
χ² / ndf 162.2 / 116
p0 464.2 ± 322.0
p1 -6.74 ± 7.47
p2 0.03473 ± 0.05712
p3 -6.14e-05 ± 1.44e-04
BG only (pink)

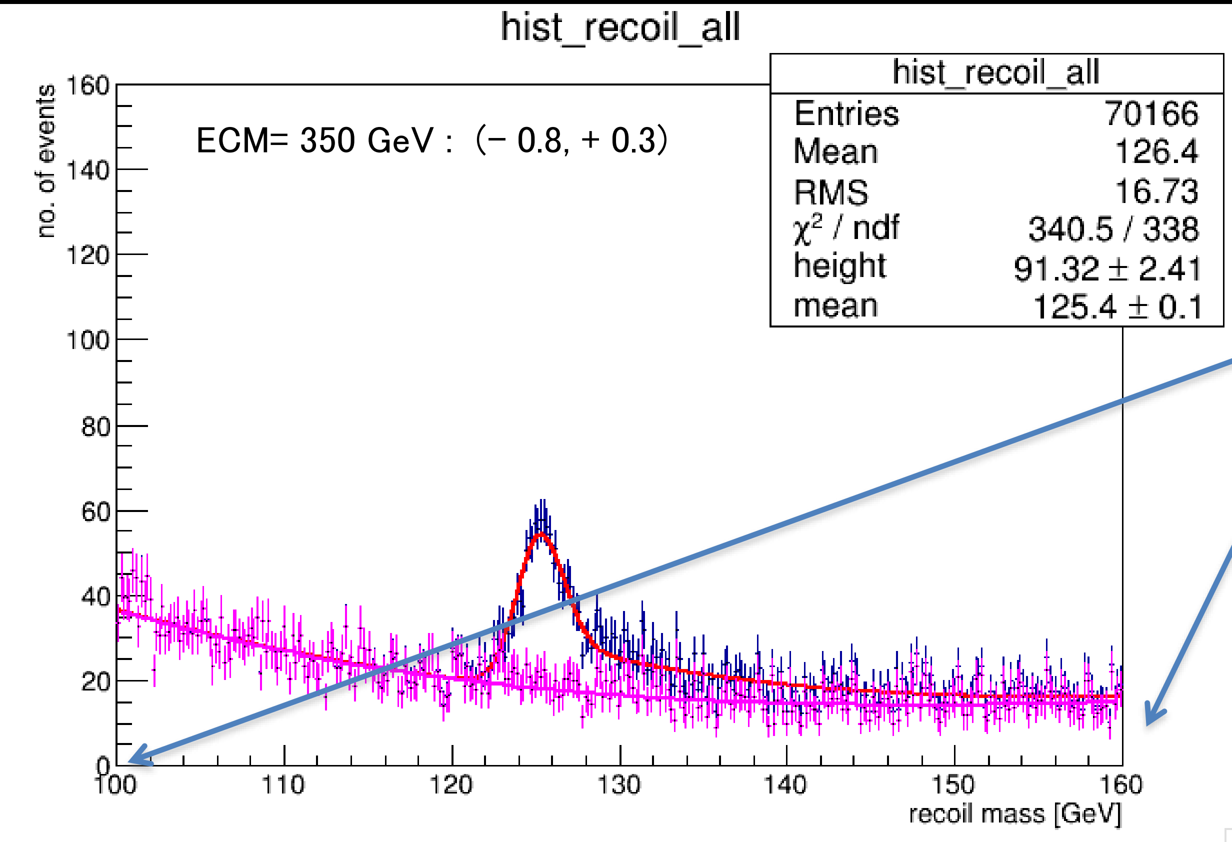
350 GeV, Zee

Reduction Table

Process	2f_l	2f_h	4f_l	4f_sl	4f_h	BG	llH	Signal	Signf
Cross Section	33504.6	38610.7	4901.08	14500.1	12561.9	104078	23.9705	10.2442	
Generated	4.90006e+06	2.48454e+06	3.98801e+06	5.30646e+06	2.70846e+06	1.93875e+07	68024	29426	
Expected	1.1157e+07	1.28574e+07	1.63206e+06	4.82853e+06	4.18311e+06	3.46581e+07	7982.19	3411.31	0.579387
Cut0	1.56517e+06	74.2882	150510	69264.6	11.2676	1.78503e+06	4711.27	2566.47	1.91841
Cut1	1.16873e+06	74.2882	111383	48096	11.2676	1.32829e+06	2577.83	2561.67	2.22052
Cut2	567876	47.6625	59965.9	33841.7	3.96336	661735	2262.91	2254	2.76612
Cut3	335754	47.6625	49592.2	27719	3.96336	413117	2218.99	2210.28	3.42963
Cut4	230057	38.9425	33285.5	22464.7	1.68706	285847	2085.73	2082.29	3.88057
Cut5	220309	38.9425	32570.2	21271	1.68706	274190	2077.89	2074.45	3.94674
Cut6	95460.1	38.9425	32225	21212.2	1.68706	148938	2076.85	2073.41	5.33551
Cut7	41891.1	23.3655	21838.4	12537	0	76289.9	1944.41	1940.97	6.93938
Cut8	4936.97	0	3599.67	6008.8	0	14545.4	1533.95	1532.17	12.0829
Cut9	2087.62	0	1769.2	3202	0	7058.82	1206.78	1206.77	13.2735
Cut10	942.706	0	579.292	984.066	0	2506.06	859.039	859.039	14.8086

250 GeV, Zee

Process	2f_l	2f_h	4f_l	4f_sl	4f_h	BG	llH	Signal	Signf
Cross Section	38177.2	78046.5	5655.66	18398.1	16799.7	157077	31.7221	10.9174	
Generated	5.76948e+06	3.17329e+06	3.14632e+06	4.9795e+06	2.74204e+06	1.98106e+07	86948	30756	
Expected	9.54431e+06	1.95116e+07	1.41391e+06	4.59952e+06	4.19993e+06	3.92693e+07	7930.54	2729.34	0.435499
Cut0	2.54509e+06	221.59	223999	73635.1	4.57566	2.84295e+06	4829.89	2406.51	1.42605
Cut1	1.92046e+06	221.59	161009	50130	4.57566	2.13182e+06	2417.64	2403.33	1.6451
Cut2	862240	149.727	99861.4	36498.1	2.30532	998752	2320.92	2308.27	2.30704
Cut3	419821	69.2392	46120.3	25465.9	0	491476	2239.46	2236.27	3.18263
Cut4	367393	57.5536	38397.4	19471.4	0	425320	2235.65	2232.46	3.41419
Cut5	108946	57.5536	38024.3	19414.1	0	166442	2234.27	2231.23	5.43273
Cut6	66109.5	57.5536	37622.4	19314.4	0	123104	2228.86	2225.82	6.28721
Cut7	27381.2	46.7425	28376.9	12826.5	0	68631.4	2069.14	2066.11	7.77036
Cut8	7574.79	1.74909	11273.2	7972.55	0	26822.3	1873.97	1871.4	11.0472
Cut9	5336.31	1.74909	8727.95	4683.21	0	18749.2	1867.4	1864.83	12.9876
Cut10	1739.49	0.874544	3692.96	1502.16	0	6935.48	1685.36	1684.43	18.1417



BG level fluctuation is controlled by fitting recoil mass over a wide range (100 – 160 GeV)

This is an improvement from previous studies

- BG level is usually fixed for Toy MC (optimistic scenario)
- xsec error is about 10 % worse if we float BG (pessimistic scenario)
  not a big degradation since I fit recoil mass spectrum over a wide range
  GOOD

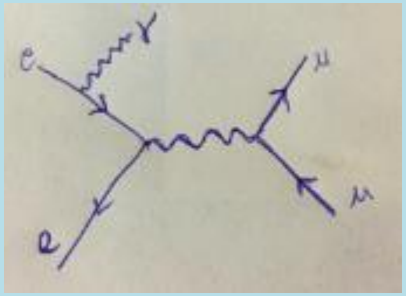
$\Delta\sigma/\sigma$ (fix BG) = 4.07 % → $\Delta\sigma/\sigma$ (float BG) = 4.46 %

Measures were taken to prevent signal bias i.e. Higgs decay mode dependence

- the “traditional” dptbal (= |Pt,dl | − |Pt, γ |) cut

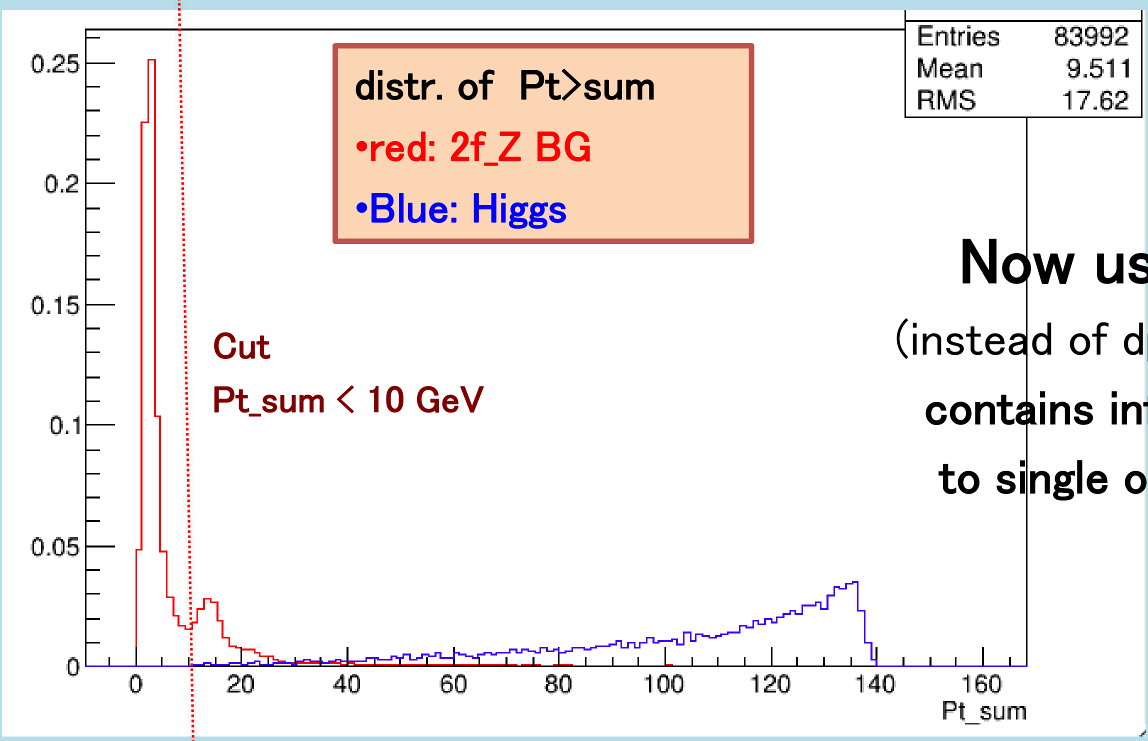
  for removing 2f BG (γ back–to back w.r.t. di–lepton)

  used to be a concern for signal bias （esp. H → $\tau\tau$, H→ $\gamma\gamma$ ）



- **isolated photon finder:** *NEW*

  confirms almost all γ we look at have small cone energy) i.e. not from Higgs decay



Now use $\left|\overrightarrow{P_{t,sum}}\right| \equiv \left|\overrightarrow{P_{t,g}} + \overrightarrow{P_{t,dl}}\right|$ *NEW*

(instead of dptbal)

contains info on vector direction

to single out back to back events

Owing to the improved data selection methods, Higgs decay mode dependence is minimized

Shows effect of isolated γ finder

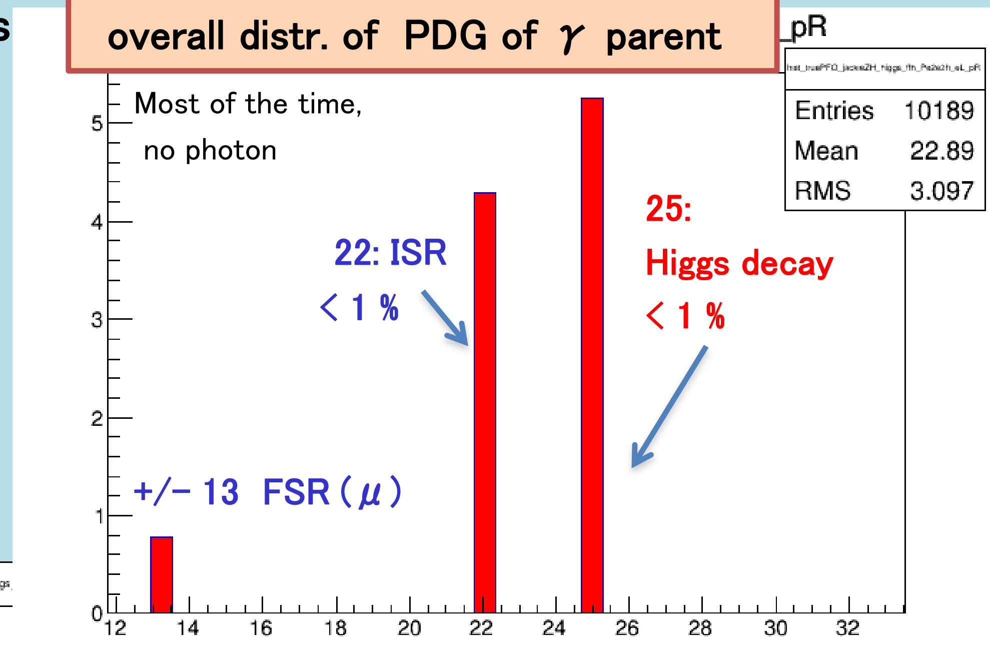
total signal loss due to Pt_sum < 10 events

out of this,

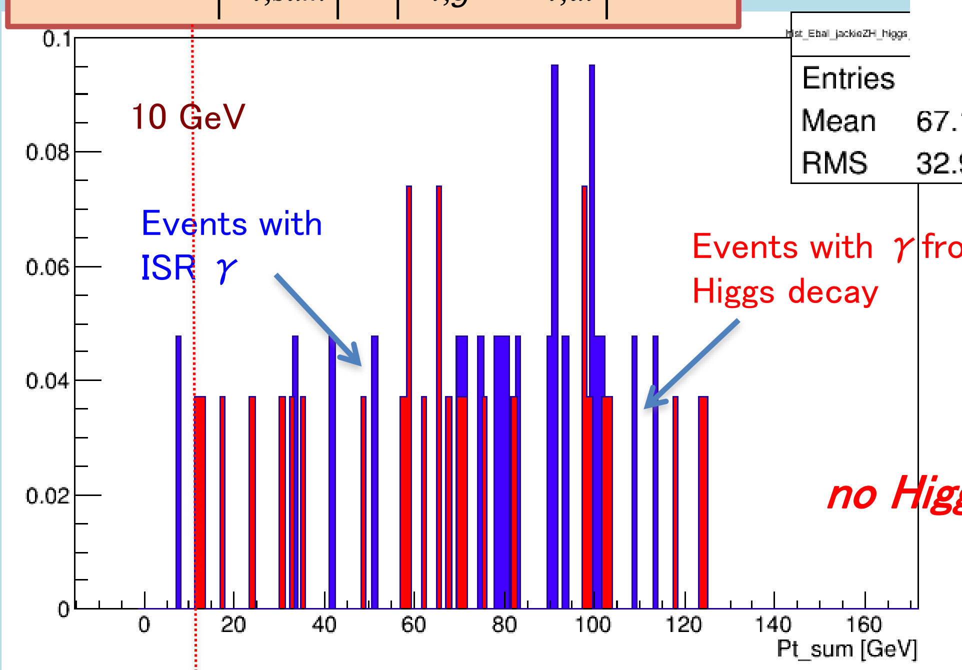
events with γ from Higgs decay < 1

for any ECM, polarization

overall distr. of PDG of γ parent



distr. of $\left|\overrightarrow{P_{t,sum}}\right| \circ \left|\overrightarrow{P_{t,g}}+\overrightarrow{P_{t,dl}}\right|$



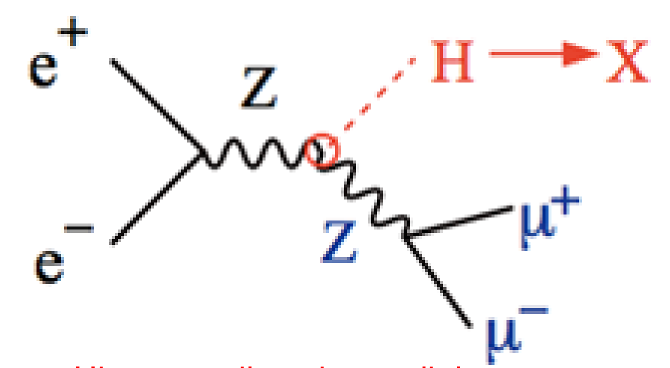
no Higgs decay mode bias caused by Pt_sum cut

Research Plan

(ongoing and in near future)

◆ **recoil mass study using leptonic channels**
e+e- → ZH → μ+μ-H (e+e-H)

at alternative
center of mass energies (ECM)
and beam polarization



Higgs recoil against di-lepton system

$$M_X^2 = (p_{CM} - (p_{\mu^+} + p_{\mu^-}))^2$$

Goal:

precise model-independent measurement of absolute Higgs cross section

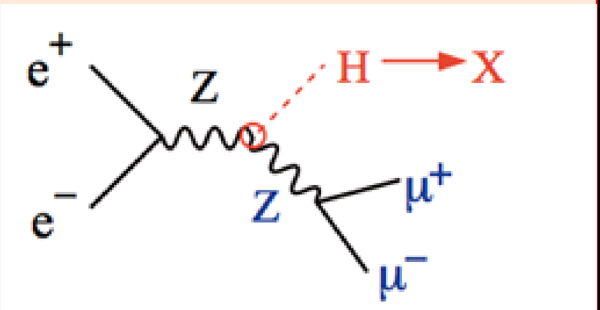
a "must-have" for measurement of total Higgs width and Higgs couplings

- **study impact of ECM and polarization on precision of σ_{ZH} and m_h**

  → contribute to decision for ILC run scenario

Data Selection Method

Signal signature



$$M_X^2 = (p_{CM} - (p_{\mu^+} + p_{\mu^-}))^2$$

Recoil mass

a pair of isolated energetic muons with
di-lepton invariant mass ($M_{\mu+\mu-}$) close to Z mass

Dominant backgrounds

- e+ e- → Z Z → μ+ μ- X : forward Z production angle
- e+ e- → γ Z → γ μ+ μ- : energetic γ , pt balanced with di-lepton
- e+ e- → W W → μ+ μ- ν ν : broad $M_{\mu+\mu-}$ distr.

recoil mass effective for cutting BG

Muon Candidate Selection

opposite +/− 1 charge

- E_cluster / P_total < 0.5
- isolation (small cone energy)
  → removes nearly all 4f_WW_sl BG
- Minv closest to Z mass
- cos(track angle) < 0.98 & |D0/δD0| < 5

Data selections done in a way to guarantee Higgs decay mode independence

Optimized in terms of signal significance and xsec measurement precision

definition

- M_inv : invariant mass of 2 muons
- pt_mumu : pt of reconstructed muons
- pt,γ : pt of most energetic photon
- θ_Zpro = Z production angle

Final Selection

- **73 < GeV < M_inv < 120 GeV**
- **10 GeV < pt_mumu < 140 GeV**
- $\left|\overrightarrow{P_{t,sum}}\right| \circ \left|\overrightarrow{P_{t,g}} + \overrightarrow{P_{t,dl}}\right|$ **> 10 GeV**
- **|cos(θ_Zpro)| < 0.9**
- **120 GeV < Mrecoil < 140 GeV**
- **Likelihood cut**

ECM=350 GeV, (-0.8,+0.3)

- **Use info of cone energy around most energetic gamma**

→ cut 2f_Z BG using info on pt_γ while prevent bias on signal

In red box: key improvement points w.r.t. previous studies

similar methods for other ECM and polarizations

Performance of data selection

	Nsig	Nbg	S/B ratio	significance	sig eff (before Mrec)
Ecm=350 GeV					
(−0.8,+0.3)	1172	2068	0.57	20.6	51% (83%)
(+0.8,−0.3)	776	774	1.00	19.7	49% (83%)
Ecm=250 GeV					
(−0.8,+0.3)	1579	2831	0.56	23.8	61% (72%)
(+0.8,−0.3)	1182	1182	1.00	24.3	68% (72%)

dominant BG after final selection

pol: (−0.8,+0.3)	original	after inv. mass pt_dl cut	after Pt,sum cut	final
signal	2288	2004	2003	1172
4f_ZZ_sl	188125	16962	16924	989
4f_ZZWWMix_l	541187	19295	19225	325
2f_Z_l	2227000	85335	21246	269
4f_WW_sl	2732980	17	17	0

(Mrec 120−140 GeV + Likelihood cut) → 4f_ZZ_sl

Balanced pt of γ and di−lepton → 2f_Z_l

Isolated lepton finder → 4f_WW_sl

Toy MC study results
Fitted Higgs mass

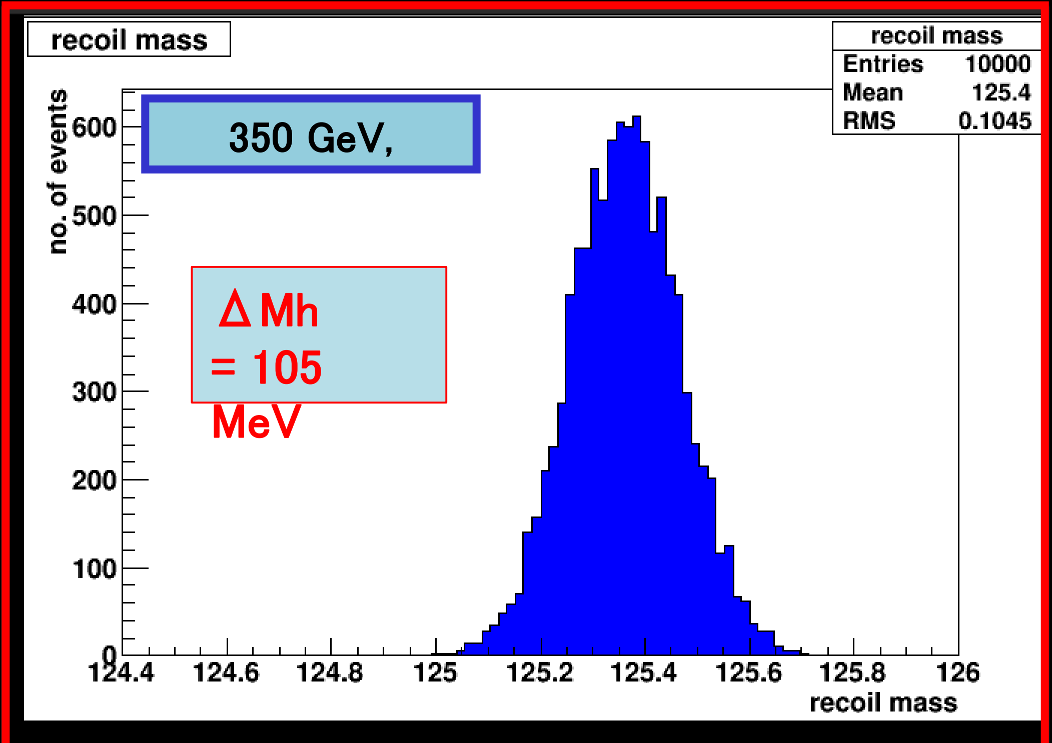
Statistical error (RMS) is :

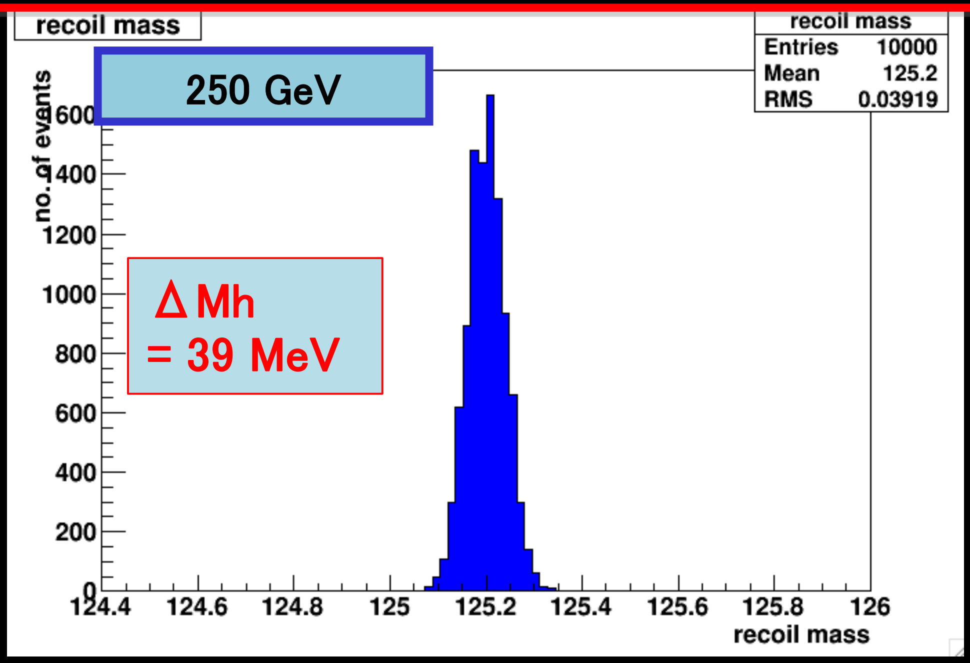
105 MeV (0.08%) for ECM=350 GeV

and

39 MeV (0.03%) for ECM=250 GeV

systematic bias of fitted mass still need to be studied



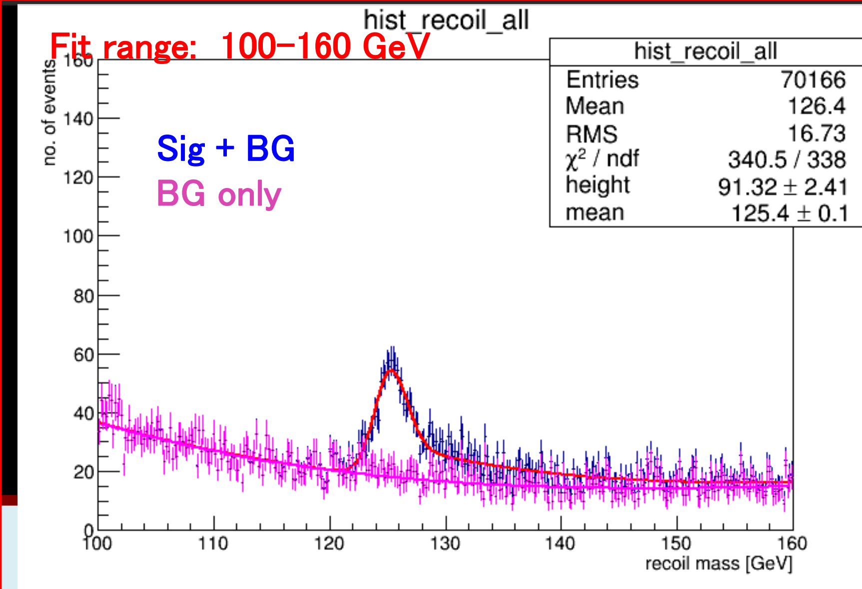


recoil mass fitting method

- Fit signal with GPET

  Gaussian Peak with Exponential Tail

- Fit BG with 3rd order polynomial



◆ **SIGNAL: GPET:** 5 parameters :

$$\frac{N}{\sqrt{\pi}\sigma}\exp\left\{-\frac{1}{2}\left(\frac{x-x_{mean}}{\sigma}\right)^2\right\} \qquad \left(\frac{x-x_{mean}}{\sigma}\le k\right)$$

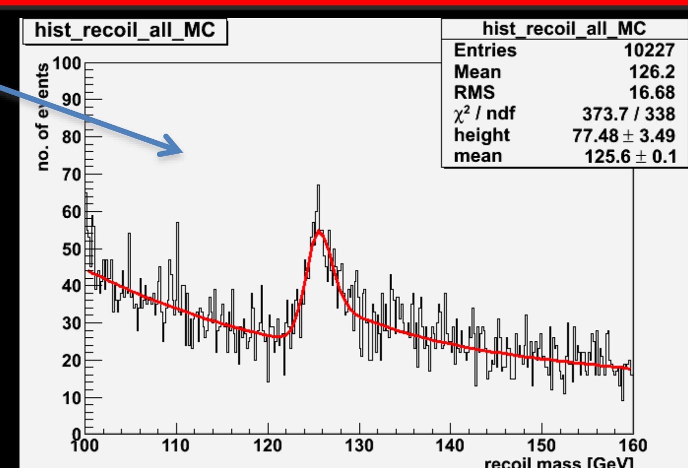
Gaus (left-side) ,

$$\frac{N}{\sqrt{\pi}\sigma}\left[b\cdot\exp\left\{-\frac{1}{2}\left(\frac{x-x_{mean}}{\sigma}\right)^2\right\}+(1-b)\exp\left\{-k\left(\frac{x-x_{mean}}{\sigma}\right)\right\}\exp\left(k^2/2\right)\right] \qquad \left(\frac{x-x_{mean}}{\sigma}\ge k\right)$$

Gaus + expo (right side)

Toy MC study

Toy MC 10000 seeds



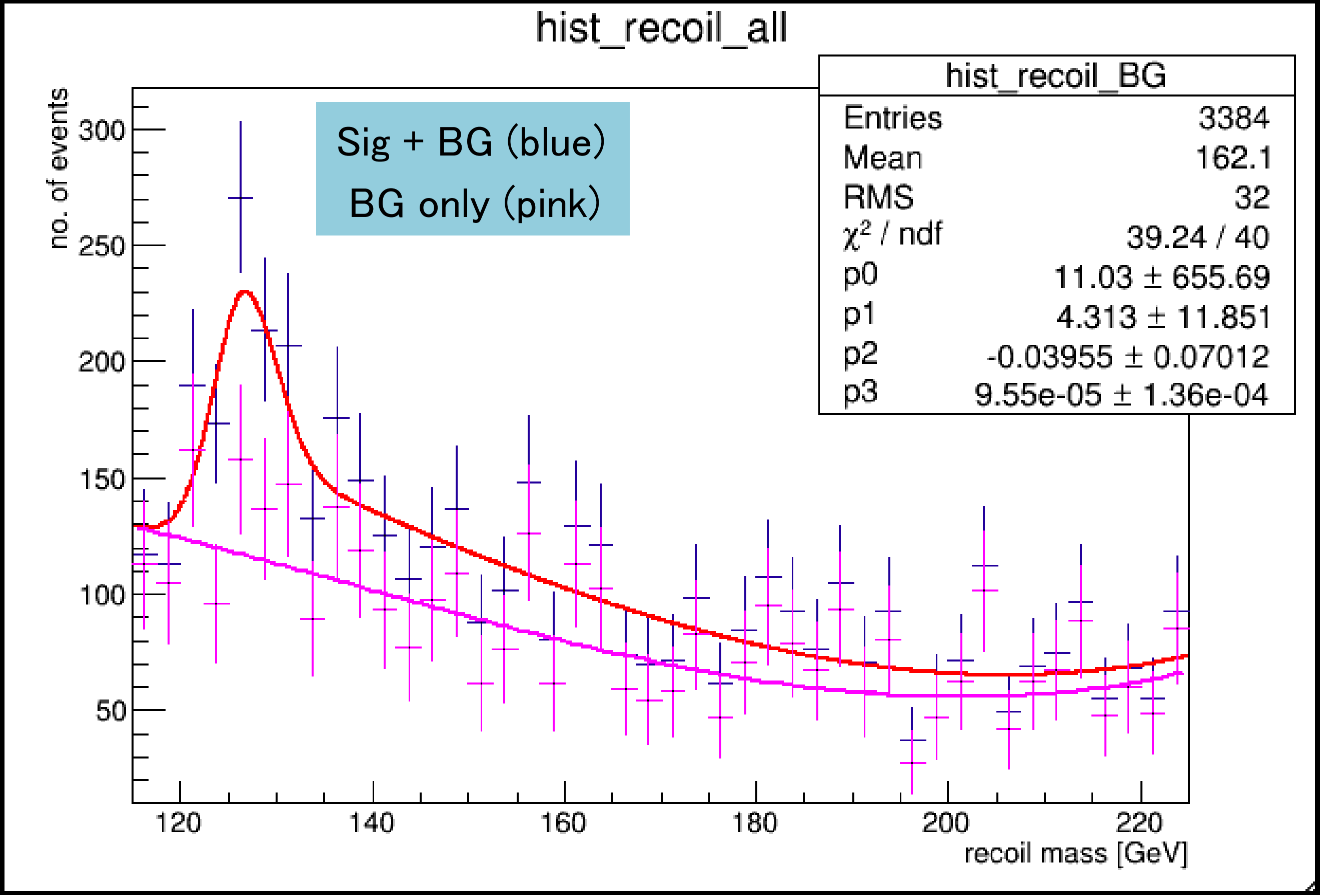
goal: test quality of fitting method

evaluate xsec precision

method:

generate MC events according to fitted "real" data (Poisson distr.)

fit MC hist with same function as "data" → get Nsig, If we ignore issue of H*→WW peak beyond 160 GeV threshold and fit in a wider range for 500 GeV

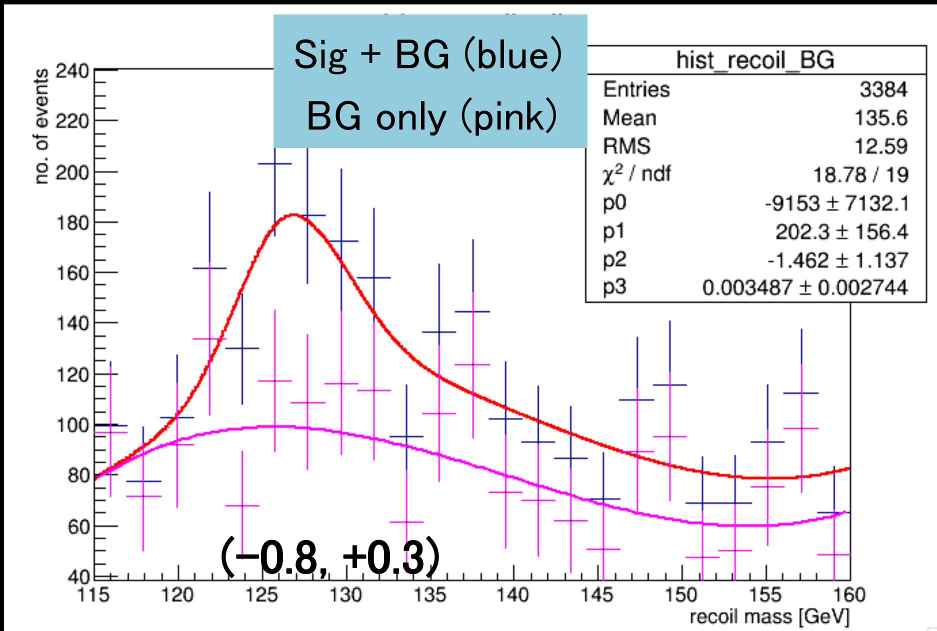


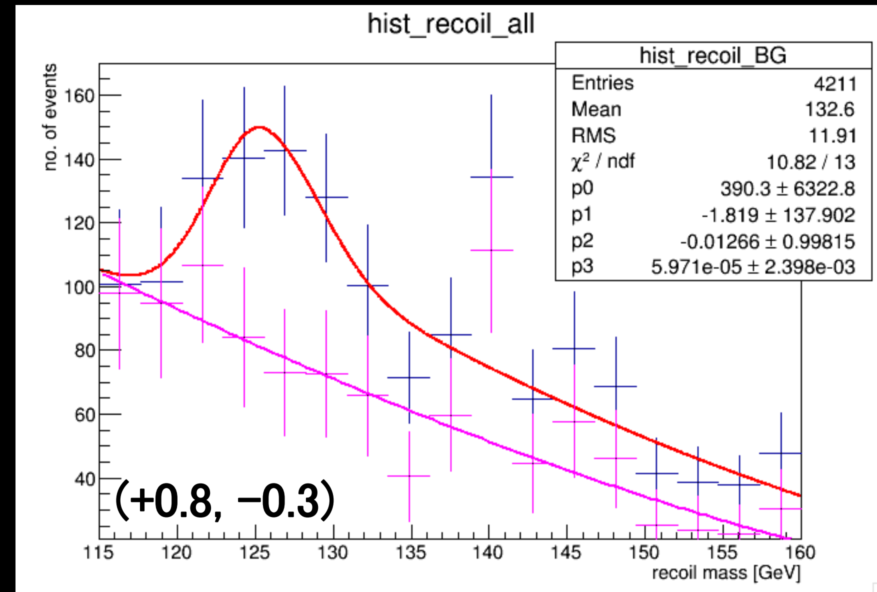
Fitting over a wider range 115 – 225 GeV

Better xsec error in this case ～ 5 %

we can still achieve this if we use the appropriate fitting function (?)

Recently I have analyzed 500 GeV results as well





Fitting over a wider range 115 – 225 GeV

Many challenges

- lower signal cross section
- signal peak buried in BG
- Difficulties in fitting

From Toy MC study,

500 GeV xsec error 6– 8%

Zmumu signal xsec

- 250 GeV : 17.14 fb
- 350 GeV: 11.31 fb
- 500 GeV: 5.679 fb

(∼ 1/2 of 350 GeV, 1/3 of 250 GeV)