Higgs Recoil Study

ILC Physics meeting

May 29, 2015

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Current Status & New Activities

Last week:

- summarized analysis results using GPET for signal fitting
- studied effect of BG MC statistics on xsec measurement
- Discovered limitation of GPET for signal fitting (when applied to Zee channel)

This Week *NEW*

- transition to Kernel estimation method for signal fitting
- did analysis for both leptonic channels ($Z \rightarrow$mumu and $Z \rightarrow$ee)
  For ECM = 250 GeV, 350 GeV, 500 GeV

today will show a preliminary version of

"leptonic channel statistical error study results"

(−0.8,+0.3)		xsec err	mass err [MeV]
250GeV	Zmm	3.4%	41
	Zee	4.6%	105
	Total	2.7%	38
350GeV	Zmm	4.1%	106
	Zee	5.9%	237
	Total	3.3%	97
500GeV	Zmm	7.0%	565
	Zee	9.8%	1510
	Total	5.7%	529

Statistical error study results
Zee and Zmm combined

Systematic error of fitted recoil mass is now negligible
(mostly < a few MeV)

c.f. Systematic error due to GPET fitting was 200-300 MeV

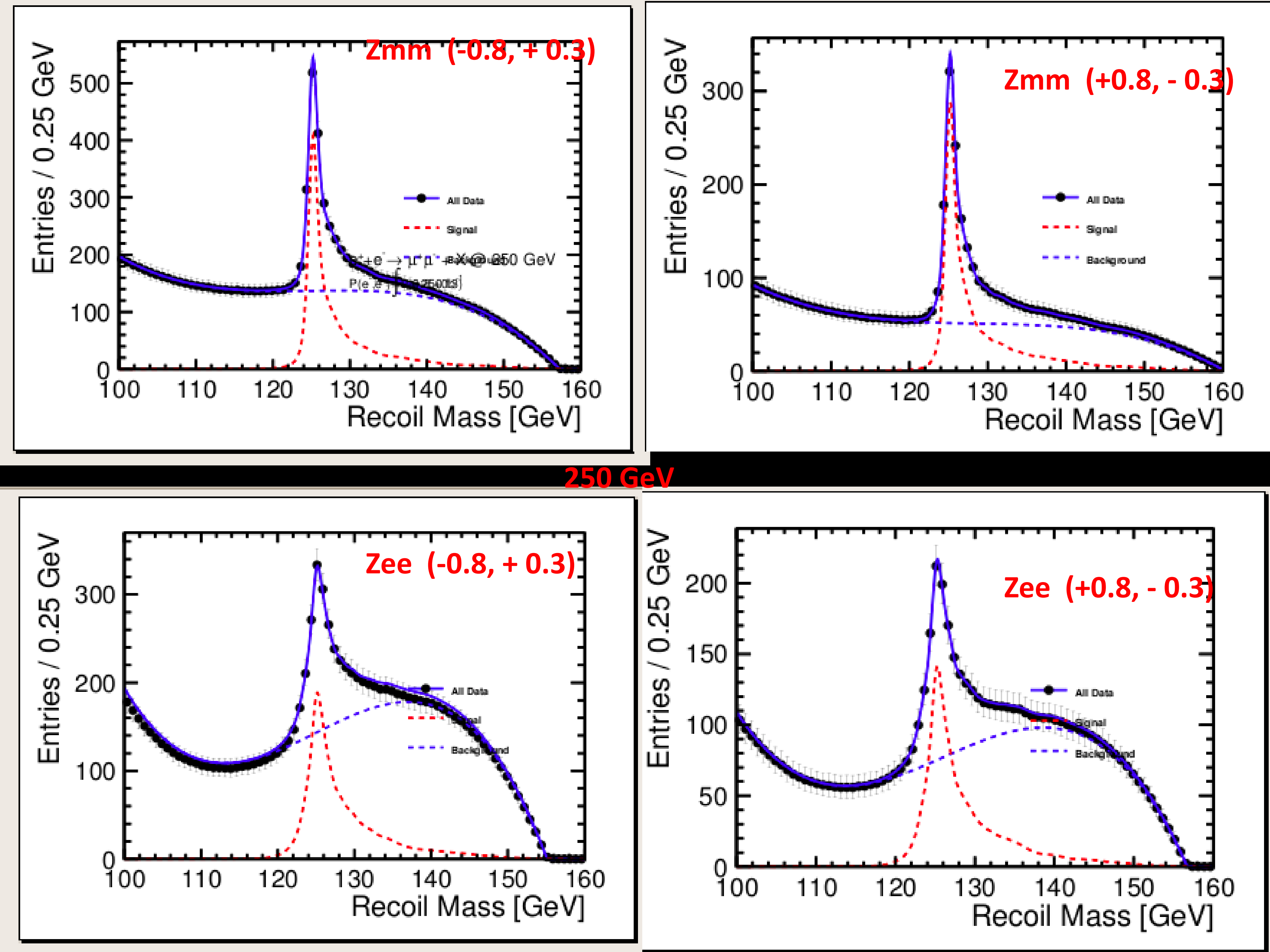
Xsec error
- 350 GeV 22% worse w.r.t. 250 GeV
- 500 GeV much worse

Mass error
- 350 GeV worse by factor of < 3

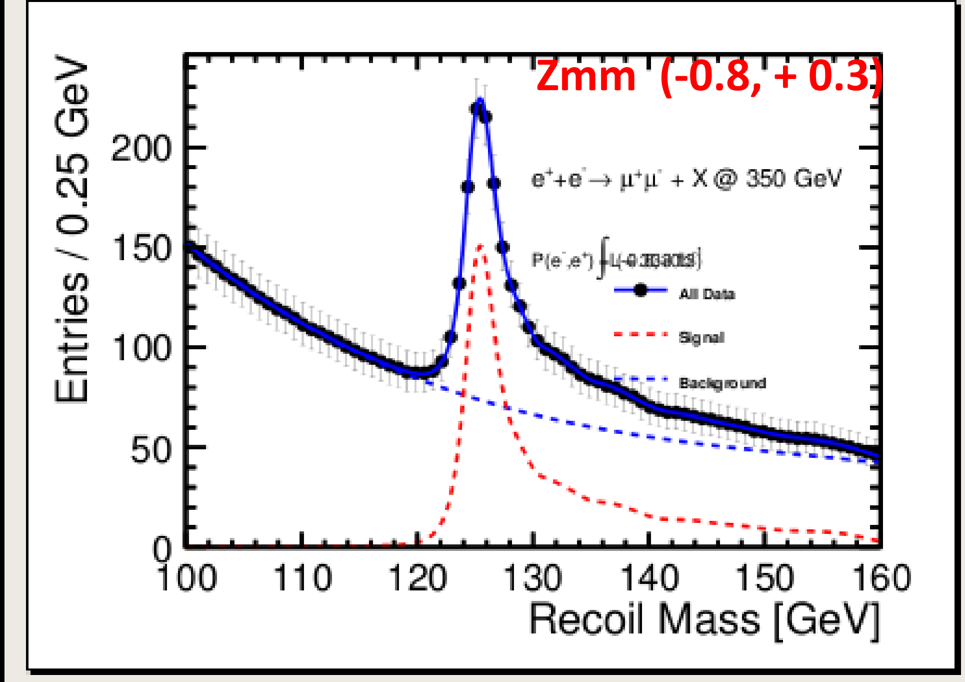
Note)
ALCW results was only for Zmm

(+0.8,−0.3)		xsec err	mass err [MeV]
250GeV	Zmm	3.6%	43.5
	Zee	4.8%	112
	Total	2.9%	41
350GeV	Zmm	4.5%	118
	Zee	6.6%	350
	Total	3.7%	111
500GeV	Zmm	8.0%	677
	Zee	9.6%	1490
	Total	6.1%	616

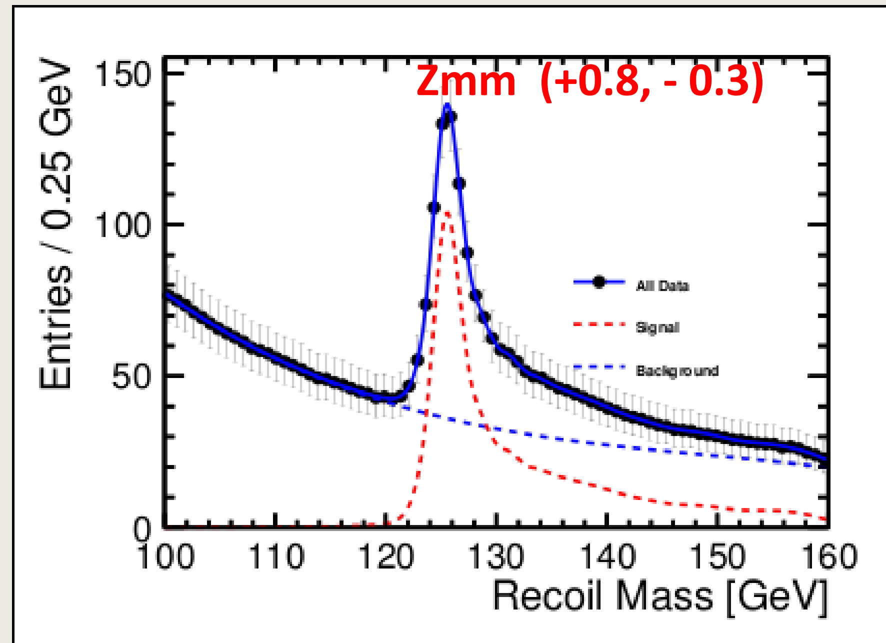
xsec error almost same as using GPET



Zmm (-0.8, + 0.3)
Zmm (+0.8, - 0.3)
250 GeV
Zee (-0.8, + 0.3)
Zee (+0.8, - 0.3)
Entries / 0.25 GeV
Recoil Mass [GeV]
All Data
Signal
Background

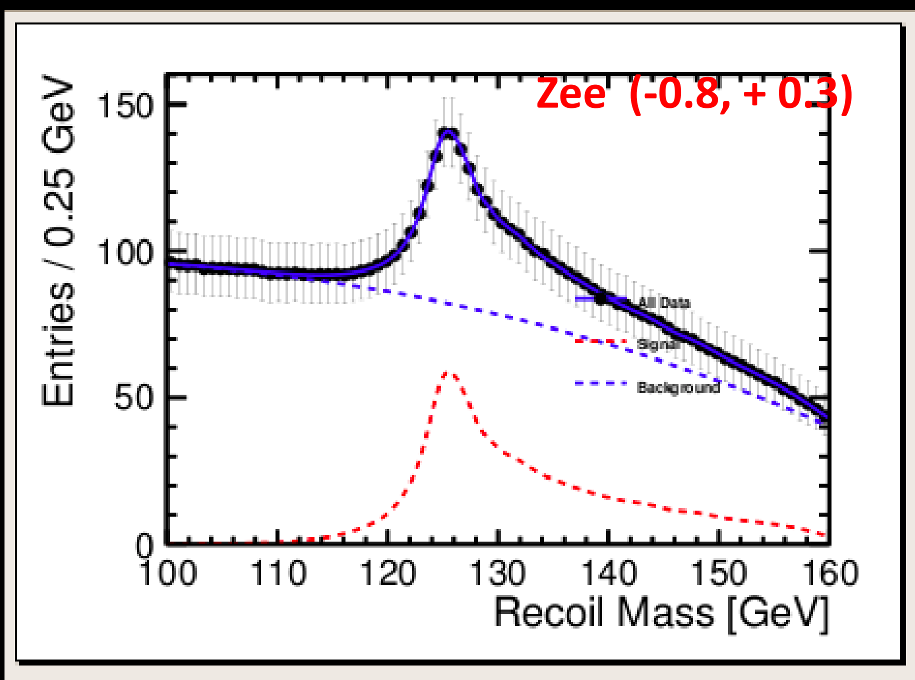


Zmm (-0.8, + 0.3)
e⁺+e⁻→ μ⁺μ⁻ + X @ 350 GeV
All Data
Signal
Background
Entries / 0.25 GeV
Recoil Mass [GeV]

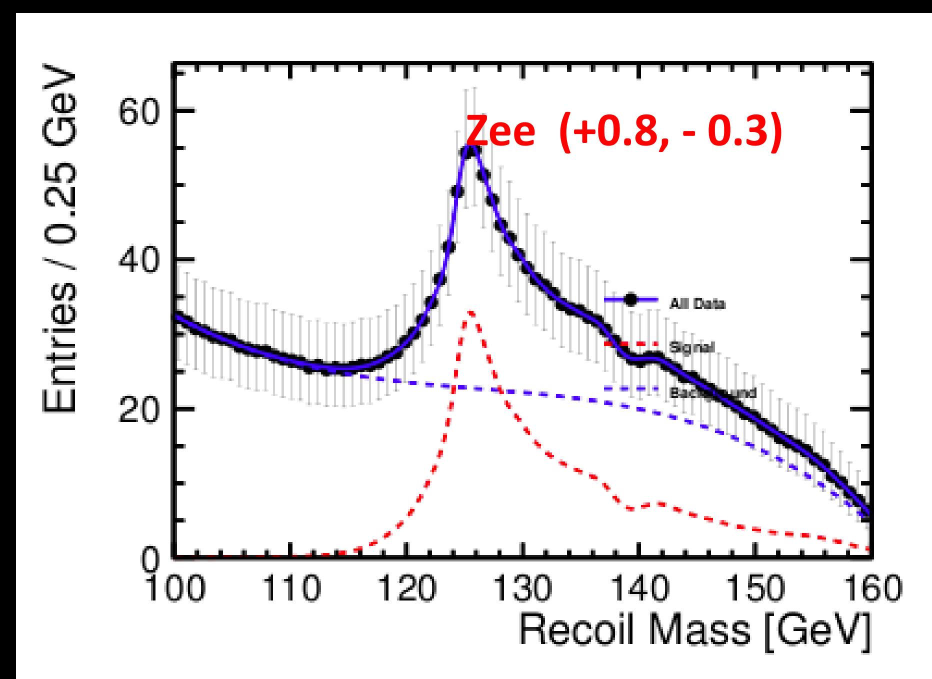


Zmm (+0.8, - 0.3)
All Data
Signal
Background
Entries / 0.25 GeV
Recoil Mass [GeV]

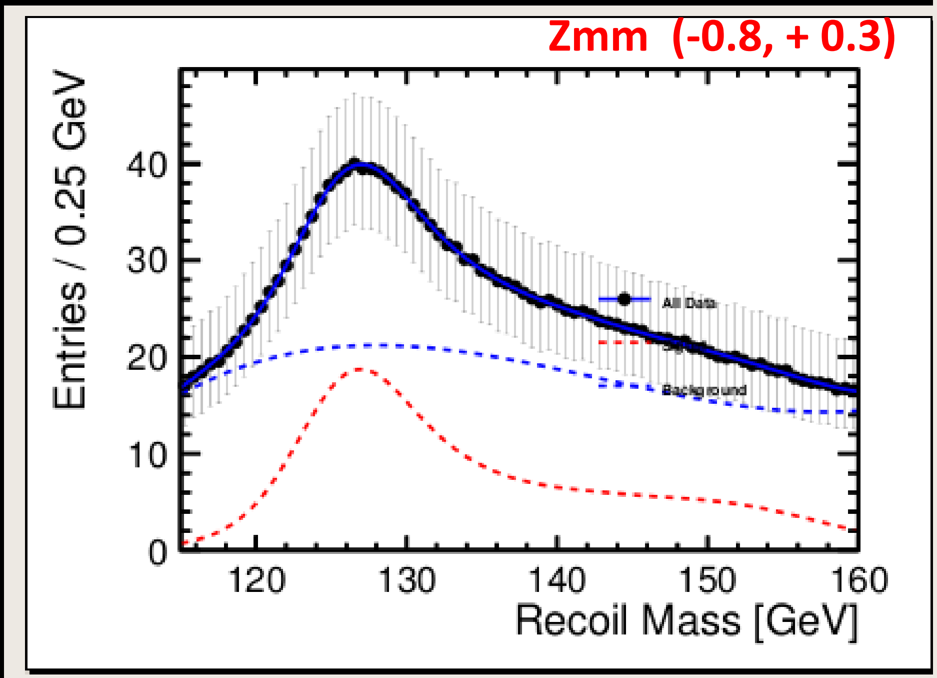
350 GeV

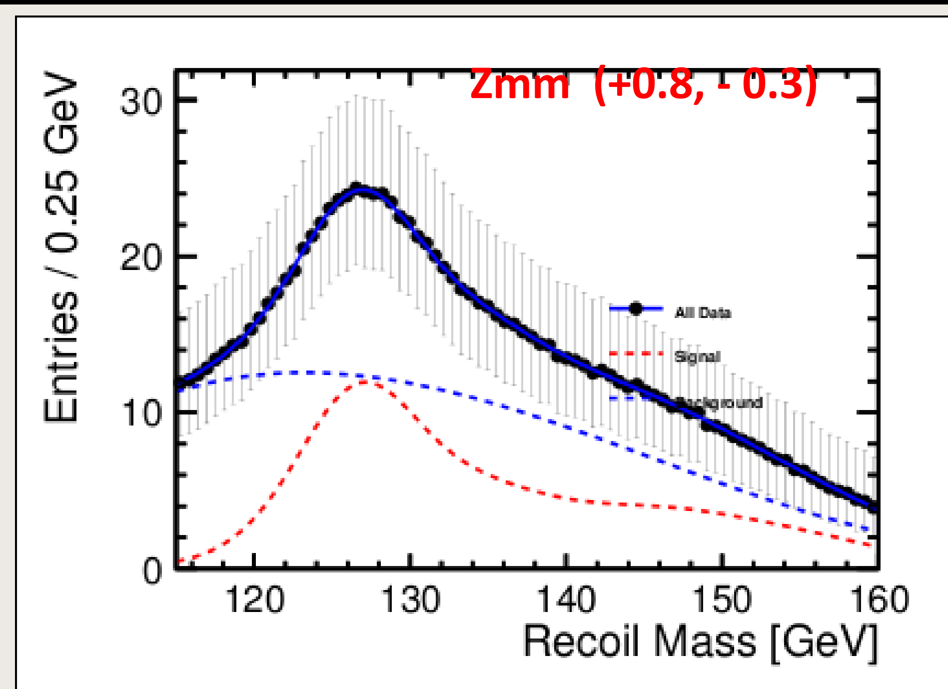


Zee (-0.8, + 0.3)
All Data
Signal
Background
Entries / 0.25 GeV
Recoil Mass [GeV]

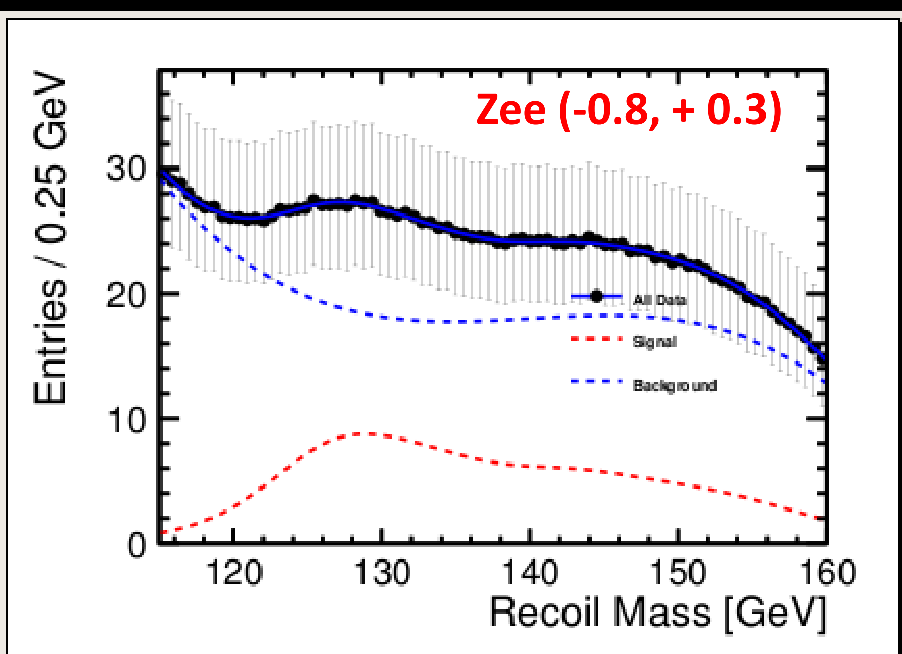


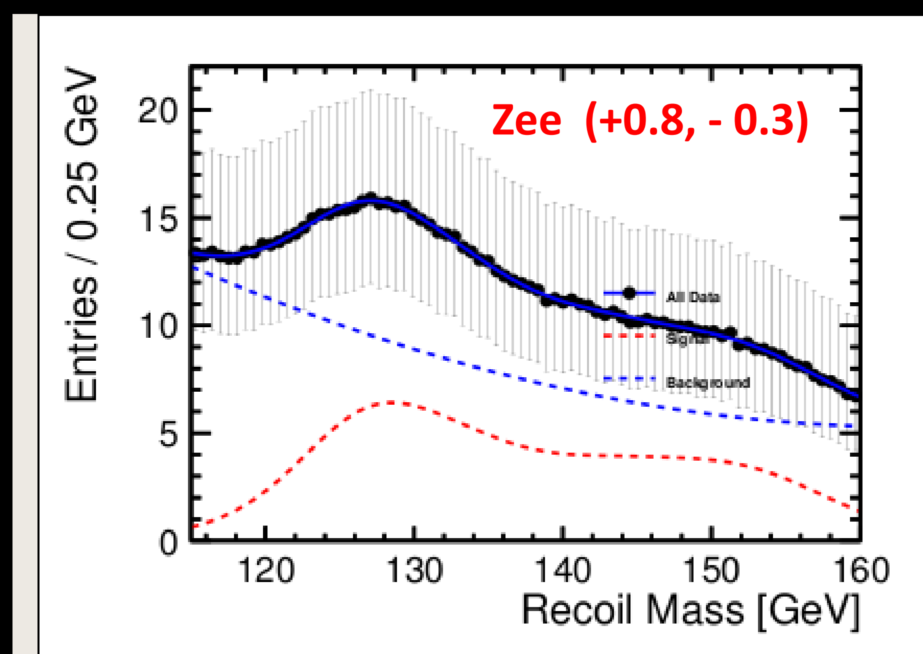
Zee (+0.8, - 0.3)
All Data
Signal
Entries / 0.25 GeV
Recoil Mass [GeV]


Zmm (-0.8, + 0.3)
Entries / 0.25 GeV
Recoil Mass [GeV]
All Data
Signal
Background
0
10
20
30
40
120
130
140
150
160


Zmm (+0.8, - 0.3)
Entries / 0.25 GeV
Recoil Mass [GeV]
All Data
Signal
Background
0
10
20
30
120
130
140
150
160

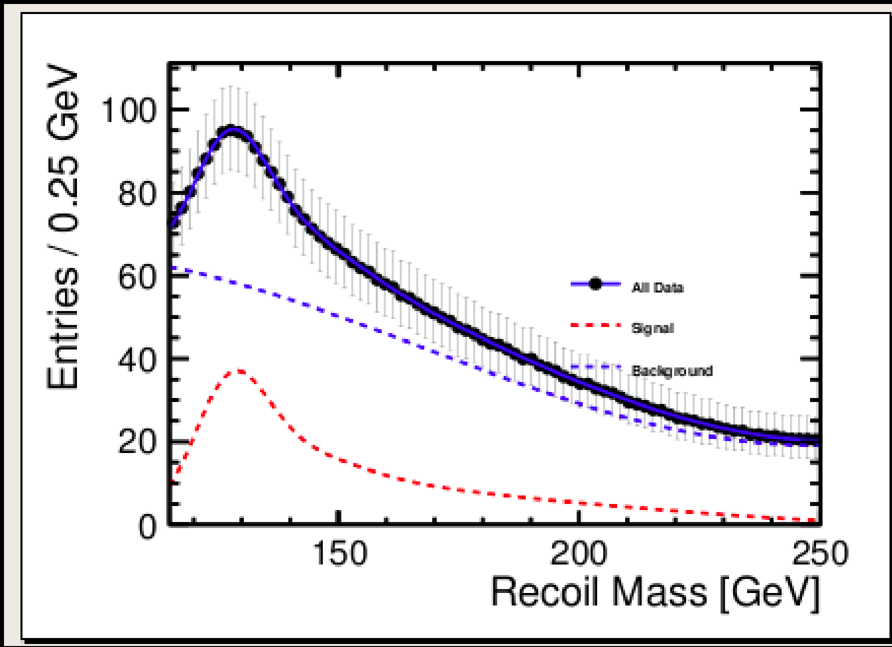
500 GeV

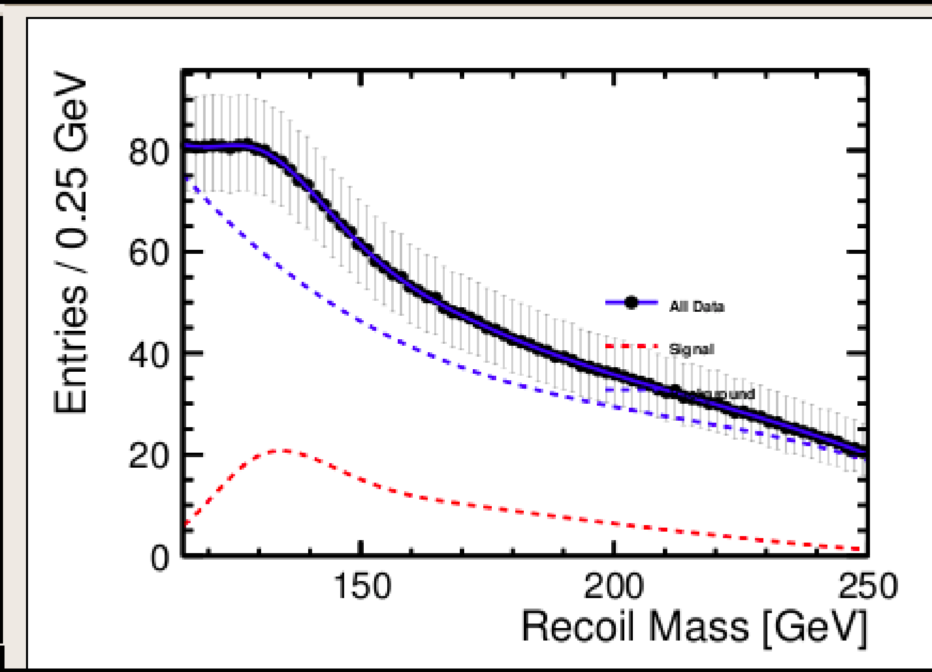

Zee (-0.8, + 0.3)
Entries / 0.25 GeV
Recoil Mass [GeV]
All Data
Signal
Background
0
10
20
30
120
130
140
150
160


Zee (+0.8, - 0.3)
Entries / 0.25 GeV
Recoil Mass [GeV]
All Data
Signal
Background
0
5
10
15
20
120
130
140
150
160

Assuming the H*→WW peak around 160 GeV is negligible

Fitting in wider range (115 – 160 GeV → 115 – 250 GeV) improves xsec precision





Zmm

7.0% → 6.6%

Zee

9.8 % → 8.0%

is lack of statistics a issue used to be a concern for 500 GeV?

major residual BG have large weights

At last week's meeting, I reported lack of MC statistic doesn't seem to be an issue

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 ~ 4.4% (> Poisson error)

- for 250 , 350 GeV, binominal error is < 1%,

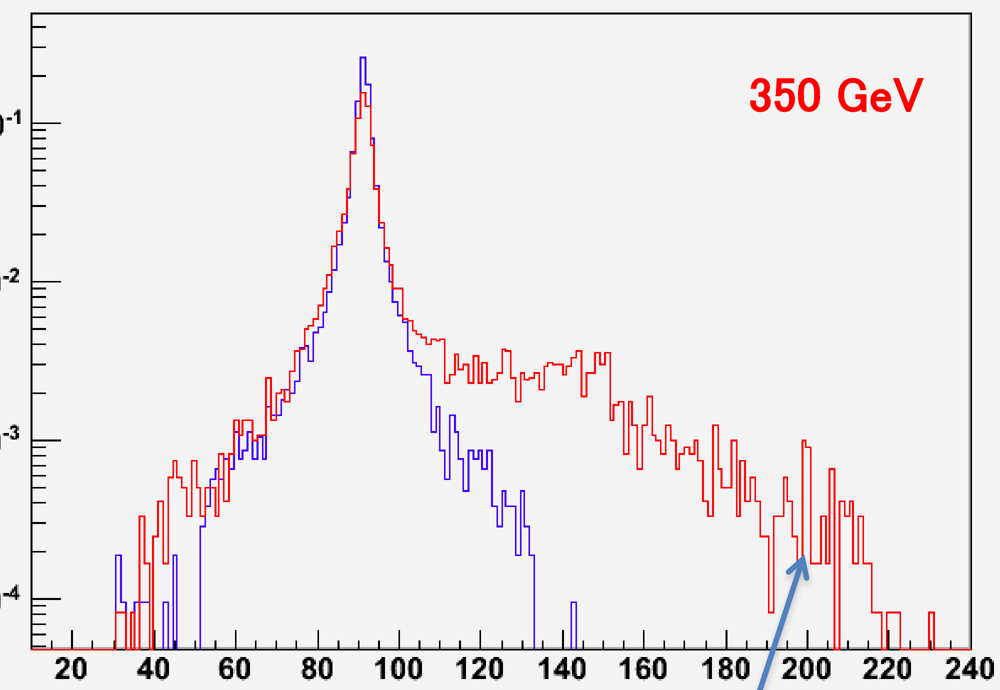
I changed BG level in Toy MC study to test the effect of BG uncertainty

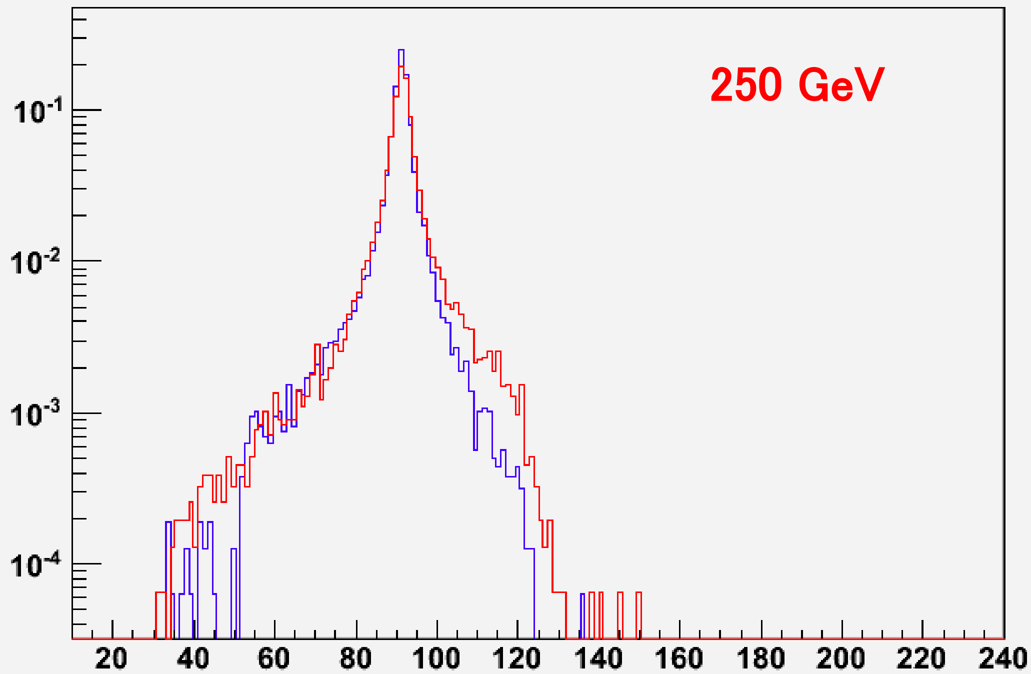
- for 500 GeV, only 1.2% effect on xsec error if BG change by 4.4%
- effect very much negligible for 250 GeV and 350 GeV

compare dilepton invariant mass distribution

Zee (red)

vs Zmumu (blue)





- Zmumu much sharper
- Zee has a long tail towards large inv. Mass (ZZ fusion)
- Broader width due to bremsstrahlung (partially recovered)

Next steps

- Kernel function fitting still need to be confirmed

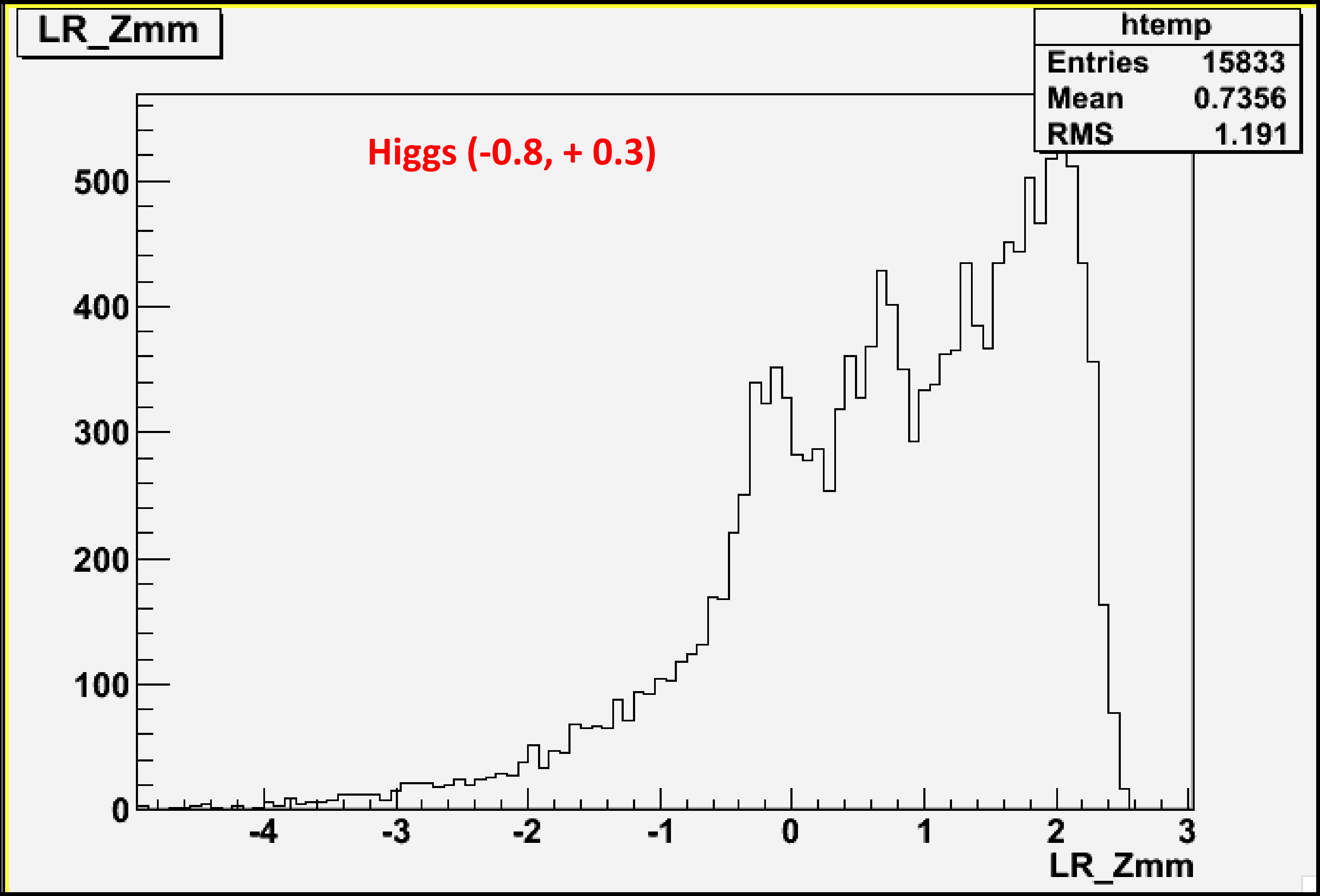
How can we improve xsec precision even further ?

- use **Ratio of signal likelihood and BG likelihood** (instead of only signal Likelihood)
  → **already tried, no improvement (?)**

- Attempt to **measure mass using only H→bb mode** much lower BG , so better precision ?

Ratio of signal Likelihood to BG likelihood

Template formed using Minv, CosZ, Pt_dl



BACKUP

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)

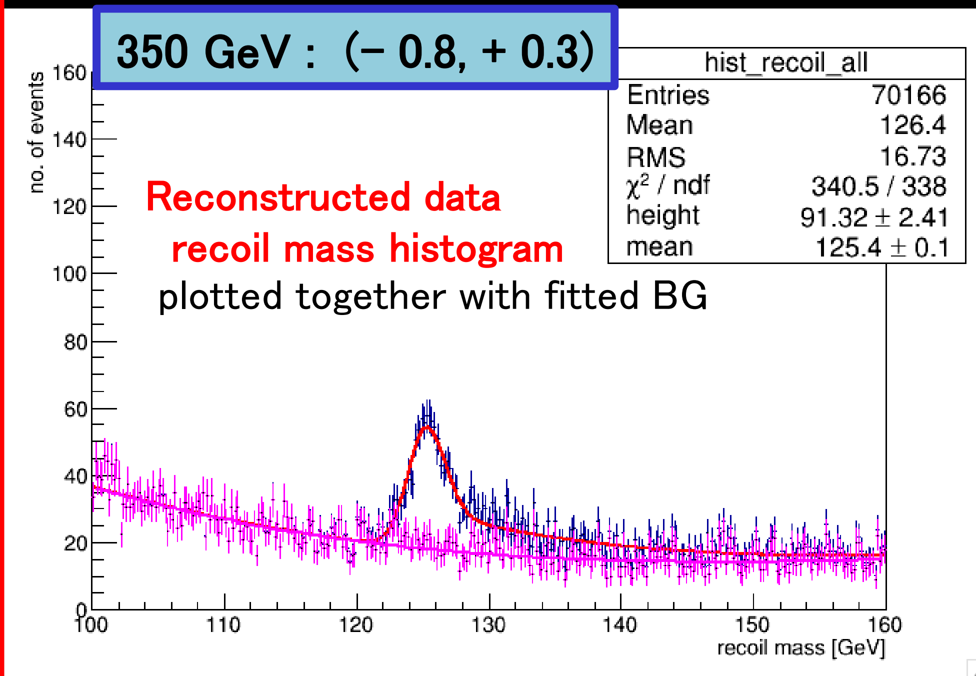
for ECM=350 GeV Pol (−0.8, + 0.3)

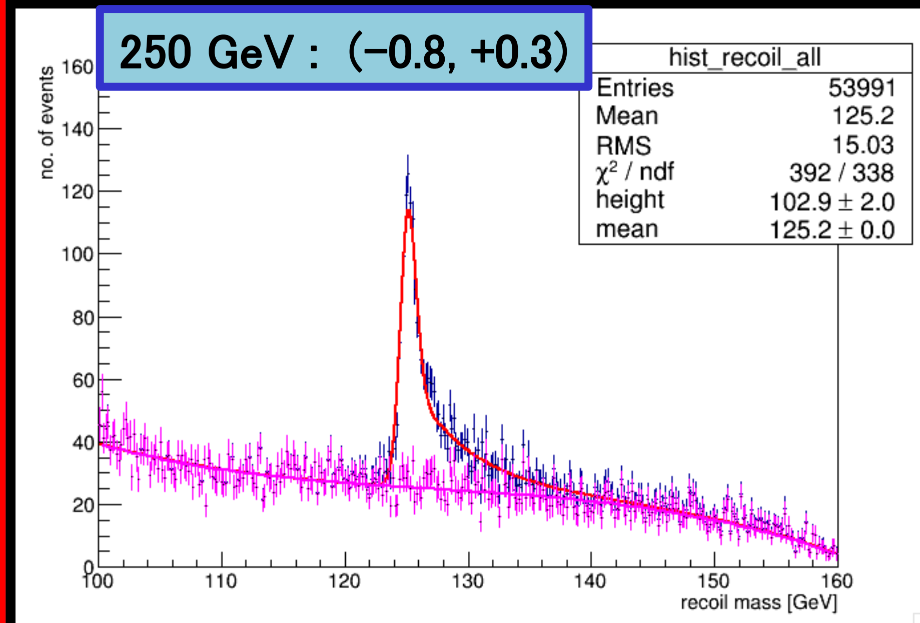
- **ECM= 250 GeV has 17 % better xsec precision** (w.r.t. 350 GeV)

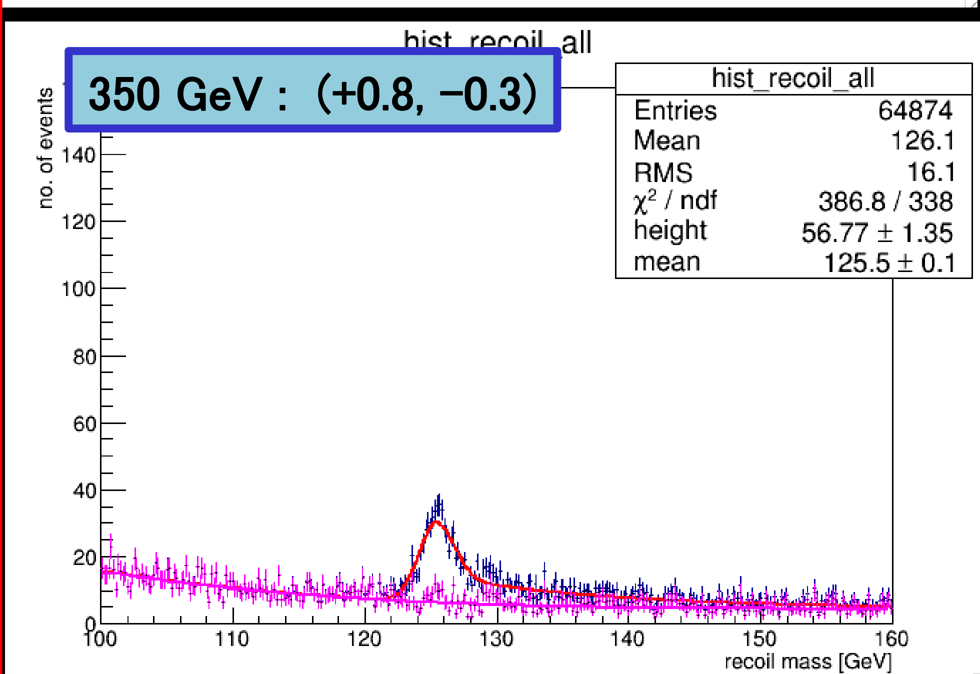
  higher statistics, better momentum resolution → sharper recoil mass peak

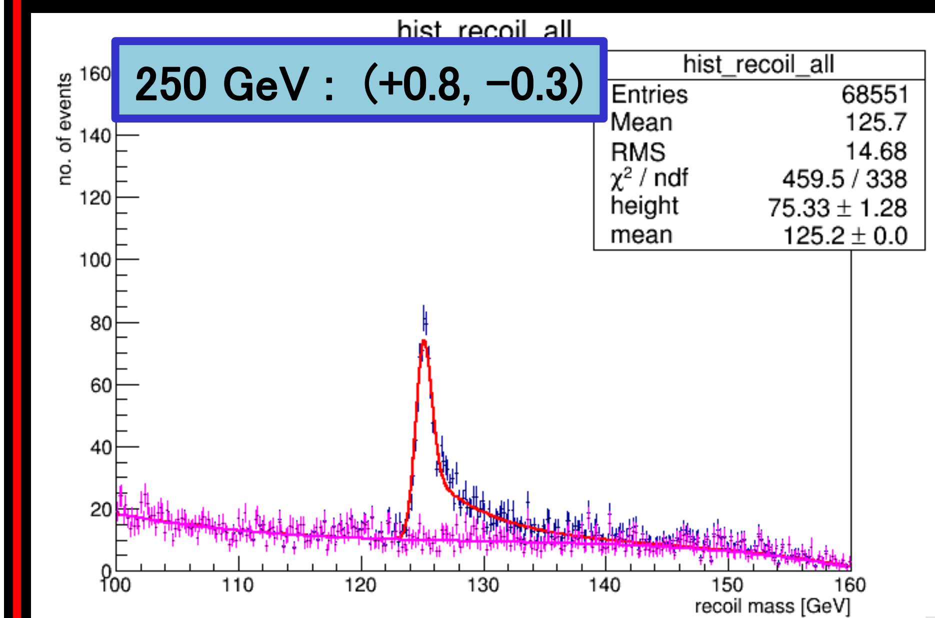
- **Pol (+0.8, −0.3) has 10% worse xsec precision**

  although WW BGs significantly suppressed (higher S/B ratio), statistics is lower


350 GeV : (− 0.8, + 0.3)
Reconstructed data
recoil mass histogram
plotted together with fitted BG
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
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]


hist_recoil_all
350 GeV : (+0.8, −0.3)
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]

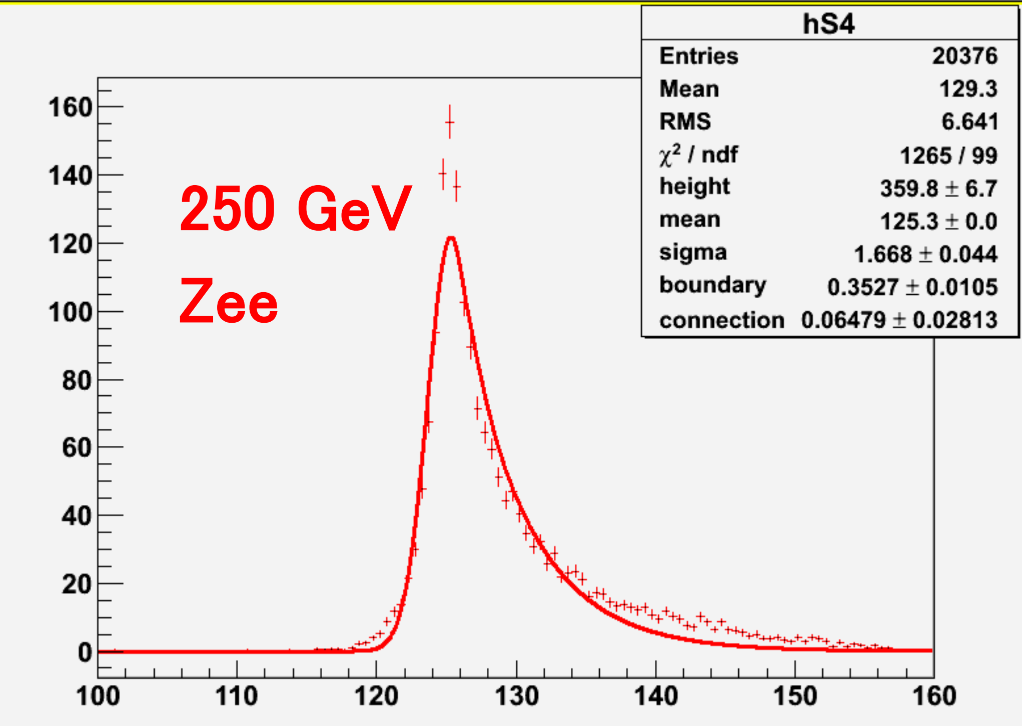

hist_recoil_all
250 GeV : (+0.8, −0.3)
hist_recoil_all
Entries 68551
Mean 125.7
RMS 14.68
χ² / ndf 459.5 / 338
height 75.33 ± 1.28
mean 125.2 ± 0.0
no. of events
recoil mass [GeV]

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

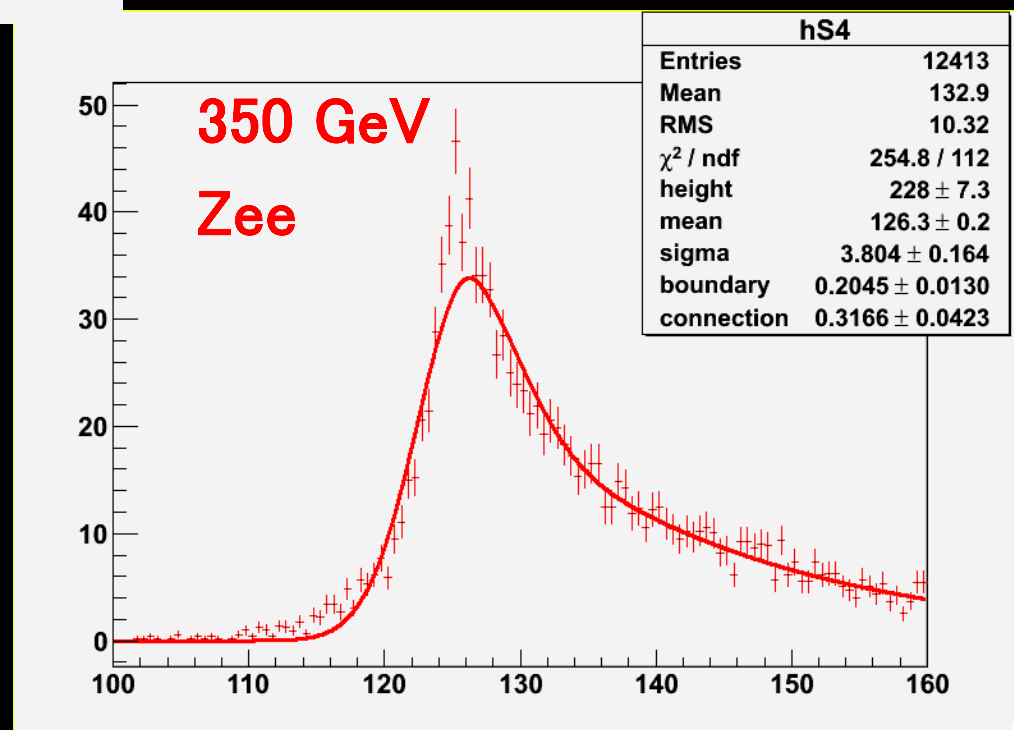
- for 500 GeV, only 1.2% effect if BG change by 4.4%
- only 2.5% even if BG change by as much as 10%
- effect on xsec error is very much negligible for 250 GeV and 350 GeV

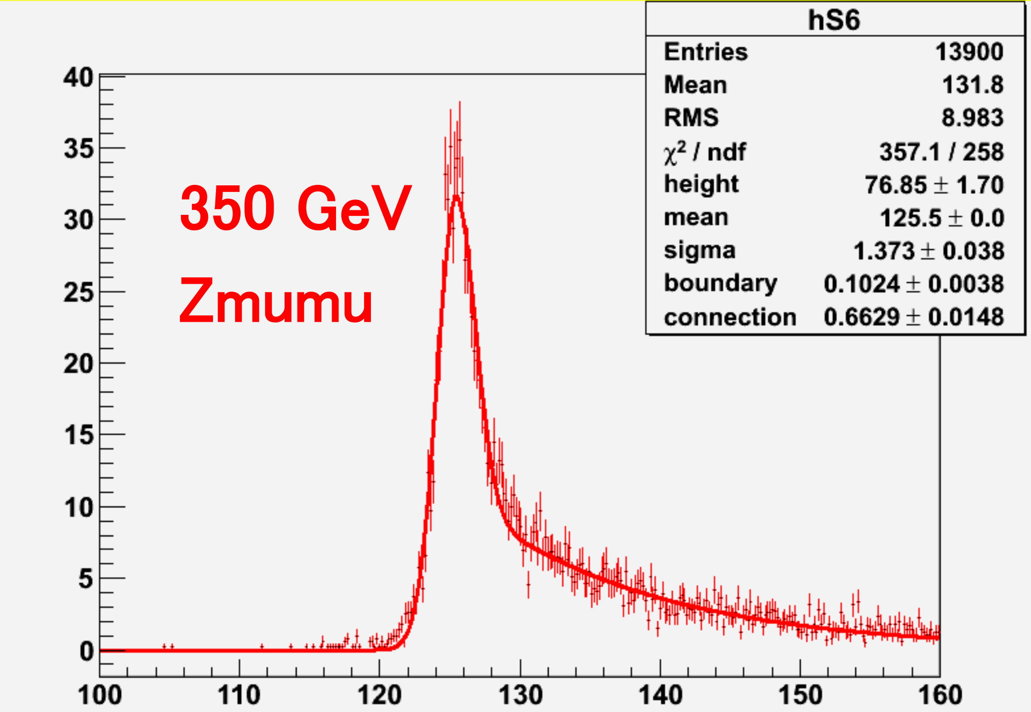
	Toy MC						
250GeV							
	nominal BG	BG + 1%	Diff	BG + 4%	Diff	BG + 10%	Diff
xsec error (relative)	3.29	3.29	0.21%	3.31	0.76%	3.35	1.86%
350 GeV							
	nominal	BG + 1%	Diff	BG + 4%	Diff	BG + 10%	Diff
xsec error (relative)	4.19	4.20	0.19%	4.22	0.74%	4.27	1.93%
500 GeV							
	nominal			BG + 4.4%	Diff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

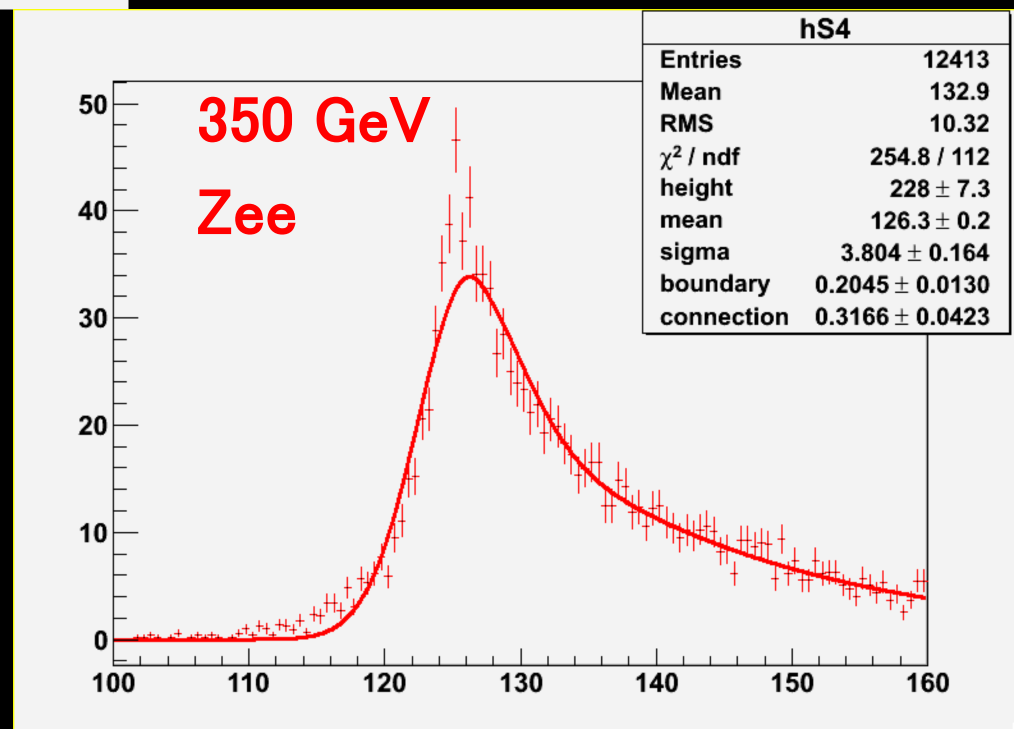

250 GeV
Zee
hS4
Entries 20376
Mean 129.3
RMS 6.641
χ² / ndf 1265 / 99
height 359.8 ± 6.7
mean 125.3 ± 0.0
sigma 1.668 ± 0.044
boundary 0.3527 ± 0.0105
connection 0.06479 ± 0.02813

Sig only


350 GeV
Zee
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


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
0 5 10 15 20 25 30 35 40
100 110 120 130 140 150 160

Sig only


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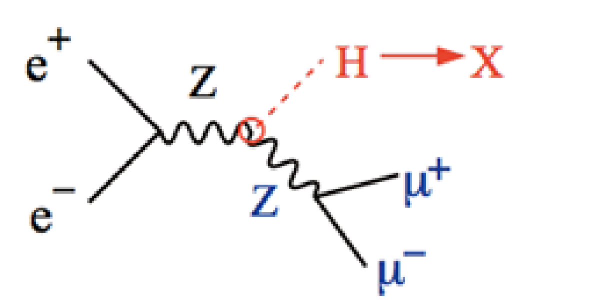
χ² / ndf 254.8 / 112
height 228 ± 7.3
mean 126.3 ± 0.2
sigma 3.804 ± 0.164
boundary 0.2045 ± 0.0130
connection 0.3166 ± 0.0423
350 GeV
Zee
0 10 20 30 40 50
100 110 120 130 140 150 160

Data Selection Method

Signal signature

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



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

Recoil 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**
- $\left|\overrightarrow{P_{t,sum}}\right| \text{o} \left|\overrightarrow{P_{t,g}} + \overrightarrow{P_{t,dl}}\right|$ **> 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

Toy MC study results
Fitted Higgs mass

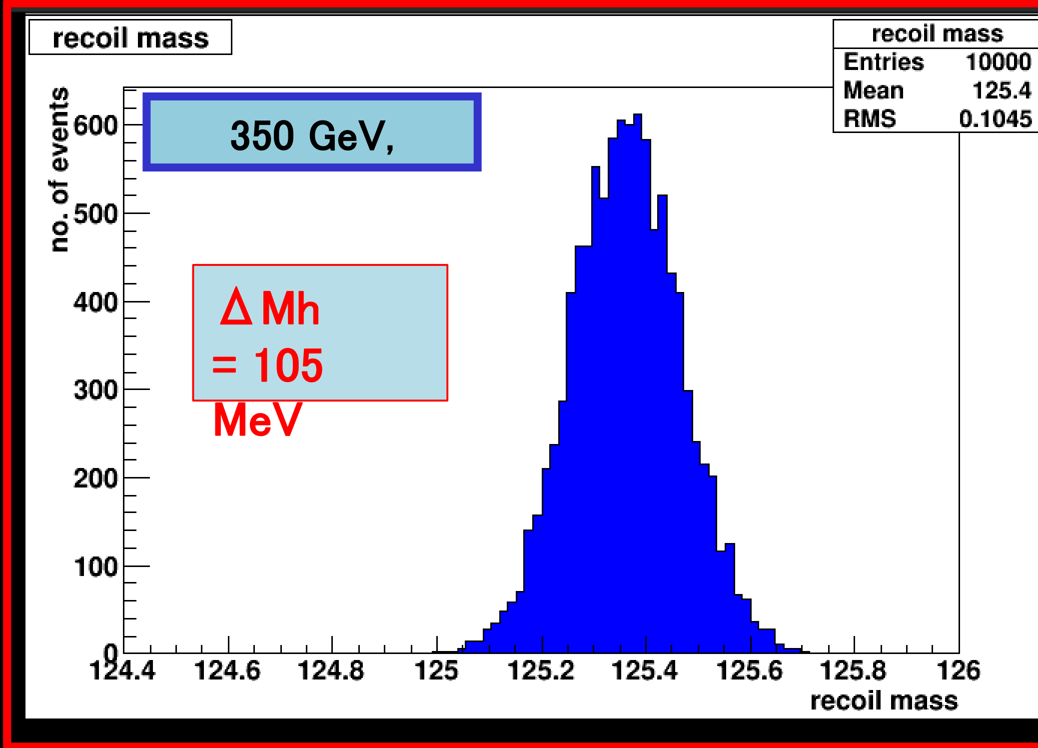
Statistical error (RMS) is :

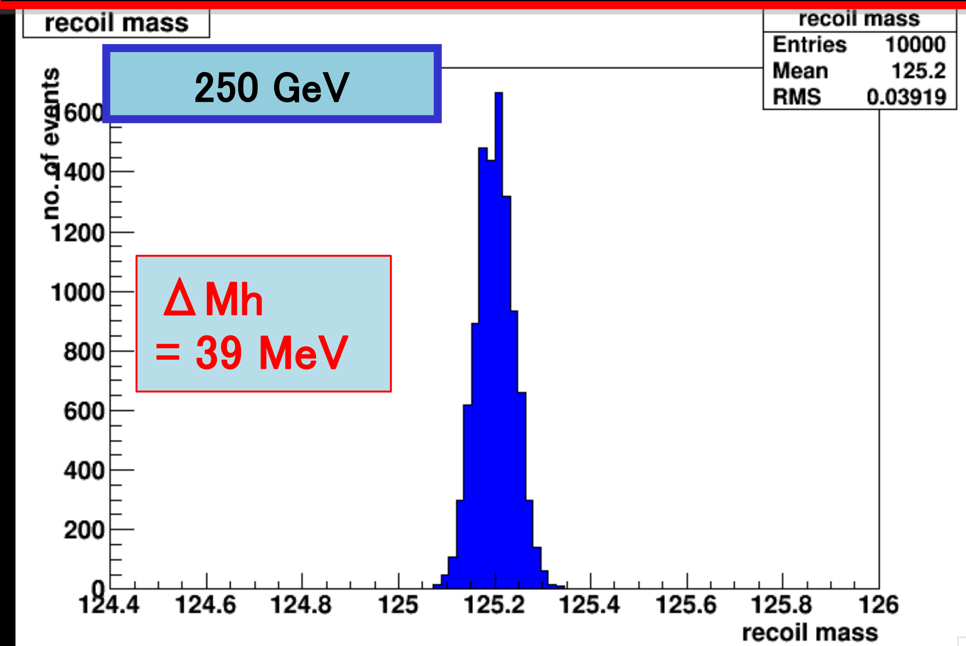
105 MeV (0.08%) for ECM=350 GeV

and

39 MeV (0.03%) for ECM=250 GeV

systematic bias of fitted mass still need to be studied



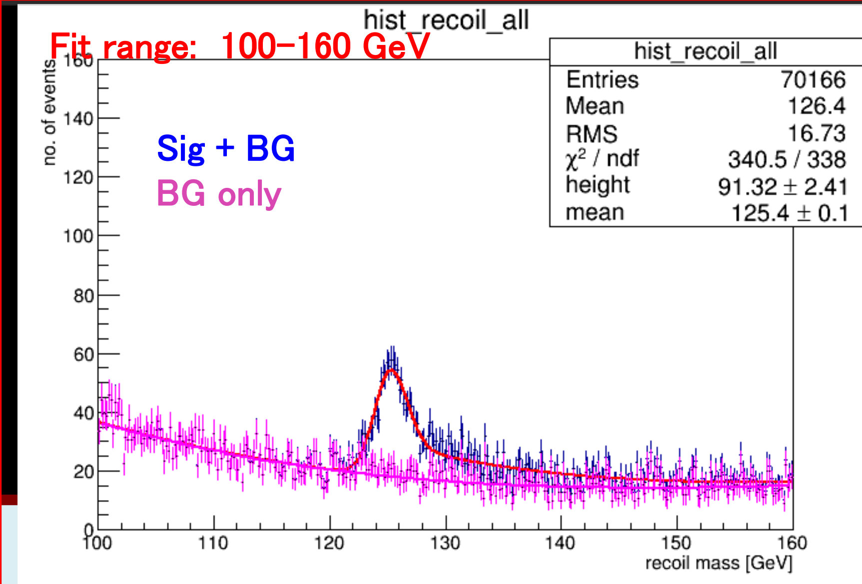


recoil mass fitting method

- Fit signal with **GPET**

  Gaussian Peak with Exponential Tail

- Fit BG with 3rd order polynomial



◆ SIGNAL: GPET: 5 parameters :

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

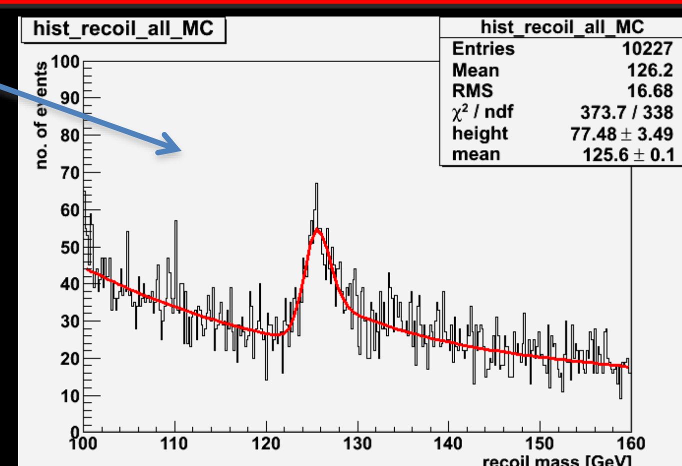
Gaus (left-side) ,

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

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,