Higgs recoil mass study

ILC Physics Meeting
3/13/2015

Jacqueline Yan (Univ. of Tokyo)

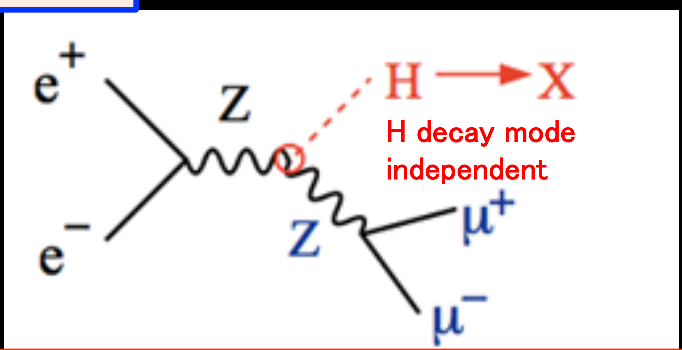
This week

- Further improvement of xsec precision and BG rejection
- new techniques in removing 2f_Z_leptonic BG while preventing signal loss
- implemented isolation cut for muon and gamma
- optimization of likelihood cut
- began applying to 250 GeV

ILC sample used in analysis

chanel	mh	ECM	L	Spin　polarization	Detector simulation
e+e→Zh->μμh	125 GeV	350 GeV	333 fb-1	P(e-,e+) = (-0.8,+0.3) (+0.8,-0.3)	Full ILD (ILD_01_v05 DBD ver.)

signal　Pe2e2h_.eL.pR　/　Pe2e2h._eR.pL



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

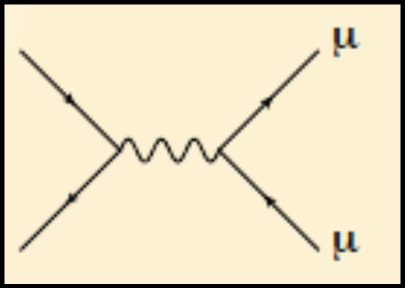
Higgs recoil against　di-lepton（μ μ）system

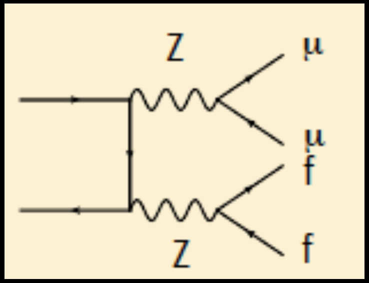
BG :

all　2f,　4f, 6f　processes

major BG after event selection:

2f_Z_l（μ μ), 4f_WWsl , 4f_ZZ_sl（μ μ ff,　μ μ ν ν）





History of past weeks

cuts		(both eLpR and eRpL) Nsig	Nbg	S/B ratio	sig eff	$\Delta\sigma/\sigma$ MC)	(only eLpR) 2f_Z_l	4f_WW_sl	4f_ZZ_sl
2 weeks ago		1056	2189	0.48	46.1 (74%)	4.39+/−0.00% (RMS: 0.16%)	225 (0.011%)	241 (0.009%)	950 (0.52%)
1 week ago (best result)		1062	2010	0.53	46.4 (74%)	4.27+/−0.00% (RMS: 0.15%)	95 (0.004%)	306 (0.010%)	967 (0.53%)
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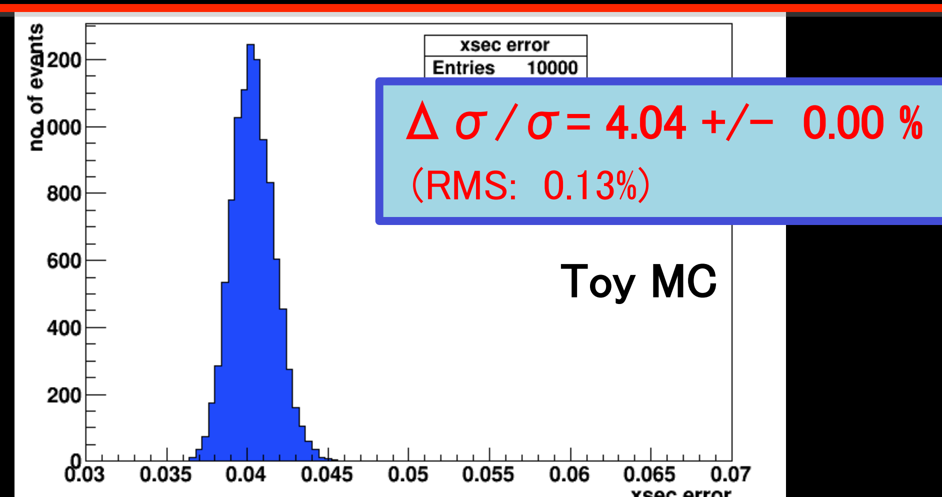
- Significant reduction in each major BG (25% reduction !!)
- improvement in xsec precision
- Signal efficiency before M_recoil cut is about 10% higher

<u>What contributed ??</u>

- More sophisticated methods to remove 2f_Z BG without losing much signal
- isolation cuts for muon and gamma
- usage of likelihood cut



Muon Selection

event selection

- reject neutrals
- P_total > 5 GeV
- E_cluster / P_total < 0.5
- cos(track angle) < 0.98 & |D0/δD0| < 5

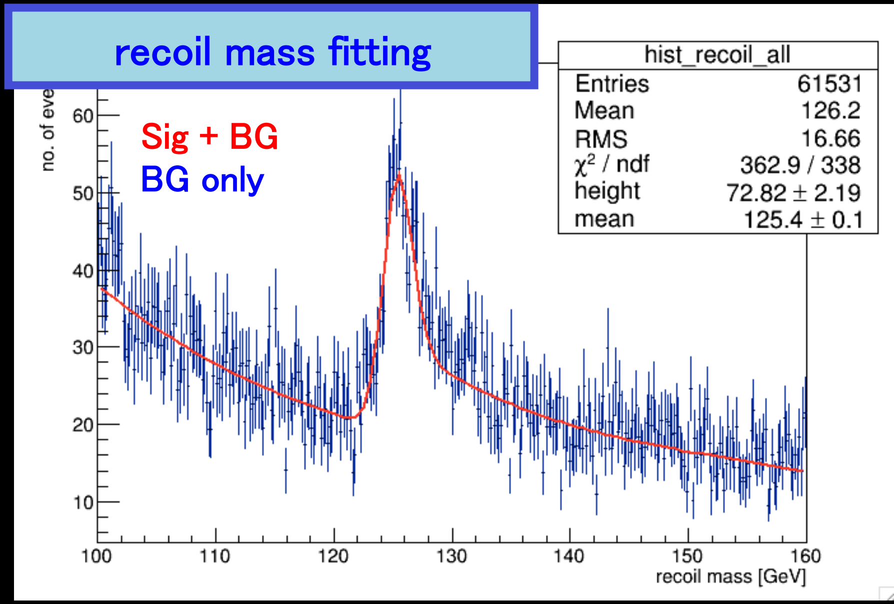
Best muon pair candidate Selection

- ➢ opposite charge
- ➢ invariant mass closest to Z mass

Final Selection

- 84 GeV < M_inv < 98 GeV
- 10 GeV < pT_mumu < 140 GeV
- dptbal = |pT_mumu – pTγ_max| > 10 GeV
-
- |cos(θ_Zpro)| < 0.91
- 120 GeV < Mrecoil < 140 GeV

Cut values optimized in terms of signal efficiency and $\Delta\sigma/\sigma$



- Signal : GPET
- BG: 3rd order polynomial

definition

- M_inv : invariant mass of 2 muons
- pT_mumu : pT of reconstructed muons
- pTγ_max : pT of most energetic photon
- θ_Zpro = Z production angle

This part is changed !!

Final Selection

- 84 GeV < M_inv < 98 GeV
- 10 GeV < pT_mumu < 140 GeV
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definition
- M_inv : invariant mass of 2 muons
- pT_mumu : pT of reconstructed muons
- pTγ_max : pT of most energetic photon
- θ_Zpro = Z production angle

- Econe_mu: cone energy (cosθ>0.9) around muon
- Econe_γ: cone energy (cosθ>0.9) around most energetic γ
- **Pt_sum = |Pt_dl – Pt_γ| (in vectors)**

Final Selection NEW

- **Econe_mu < 110 GeV**
- **73 GeV < M_inv < 120 GeV** widened
- 10 GeV < pT_mumu < 140 GeV
- **Econe_γ > 10 GeV (*)**
- **Pt_sum > 40 GeV**
- **dptbal = pT_mumu – pTγ_max > 60 GeV (*)**
- |cos(θ_Zpro)| < 0.91
- 120 GeV < Mrecoil < 140 GeV

Added isolation

Combine two types of pt_balance cuts

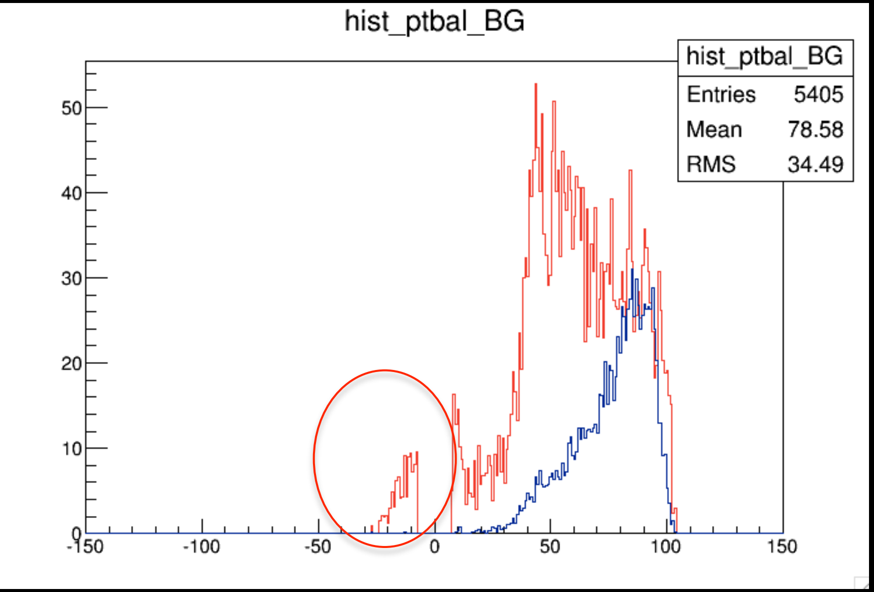
(*) used in coincidence with extra requirements to prevent signal loss

First of all….. *Thanks to Junping-san's suggestions*

Now I do dptbal > 10 GeV (instead of |dptbal| > 10 GeV

➔ some improvement

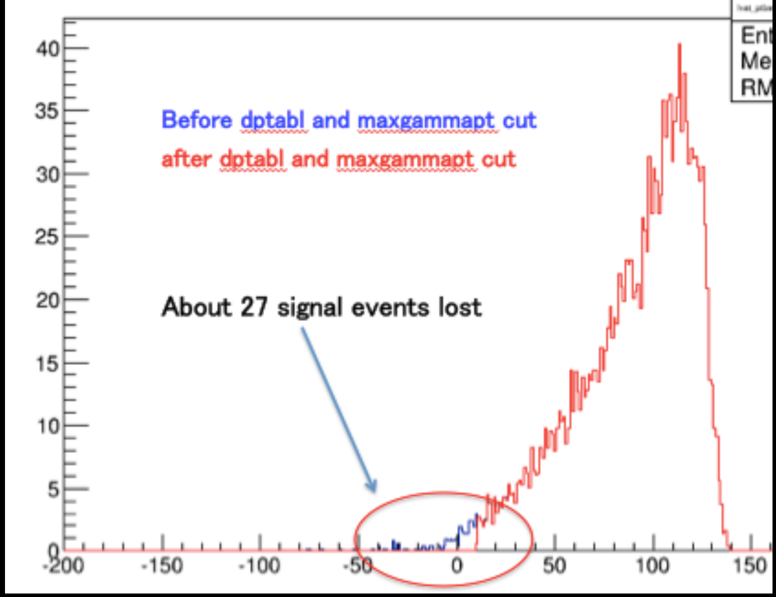
	Nsig	NBG	S/B	Δσ/σ(MC)
Old: |dptbal| > 10 GeV	1056	2189	0.48	4.39+/- 0.00 % (rms: 0.16%)
New : dptbal > 10 GeV	**1055**	**2119**	**0.50**	**4.33+/- 0.00 %** (rms: 0.15%)



NEW Concern

possible slight bias on signal due to dptbal cut

(I just didn't realize it before since I was observing events AFTER Mrecoil cut)



to escape bias on signal

I tried to cut events that can be identified as 2f_Z_leptonic BG

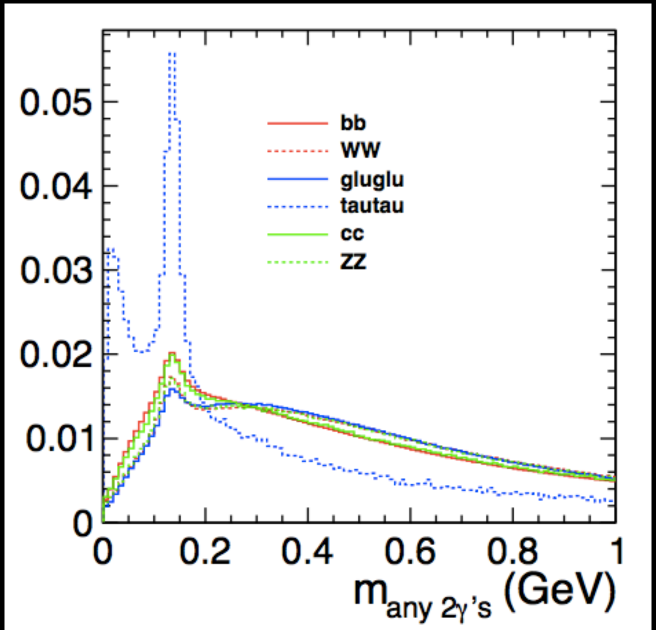
do if (A) && (B) continue

where (A, B) = conditions on

- (maxgammaPt) and (dPtbal)
- (cos θ bal) and (Ebal)

From Watanuki-san

H→ $\tau\ \tau$ mode is major cause of bias



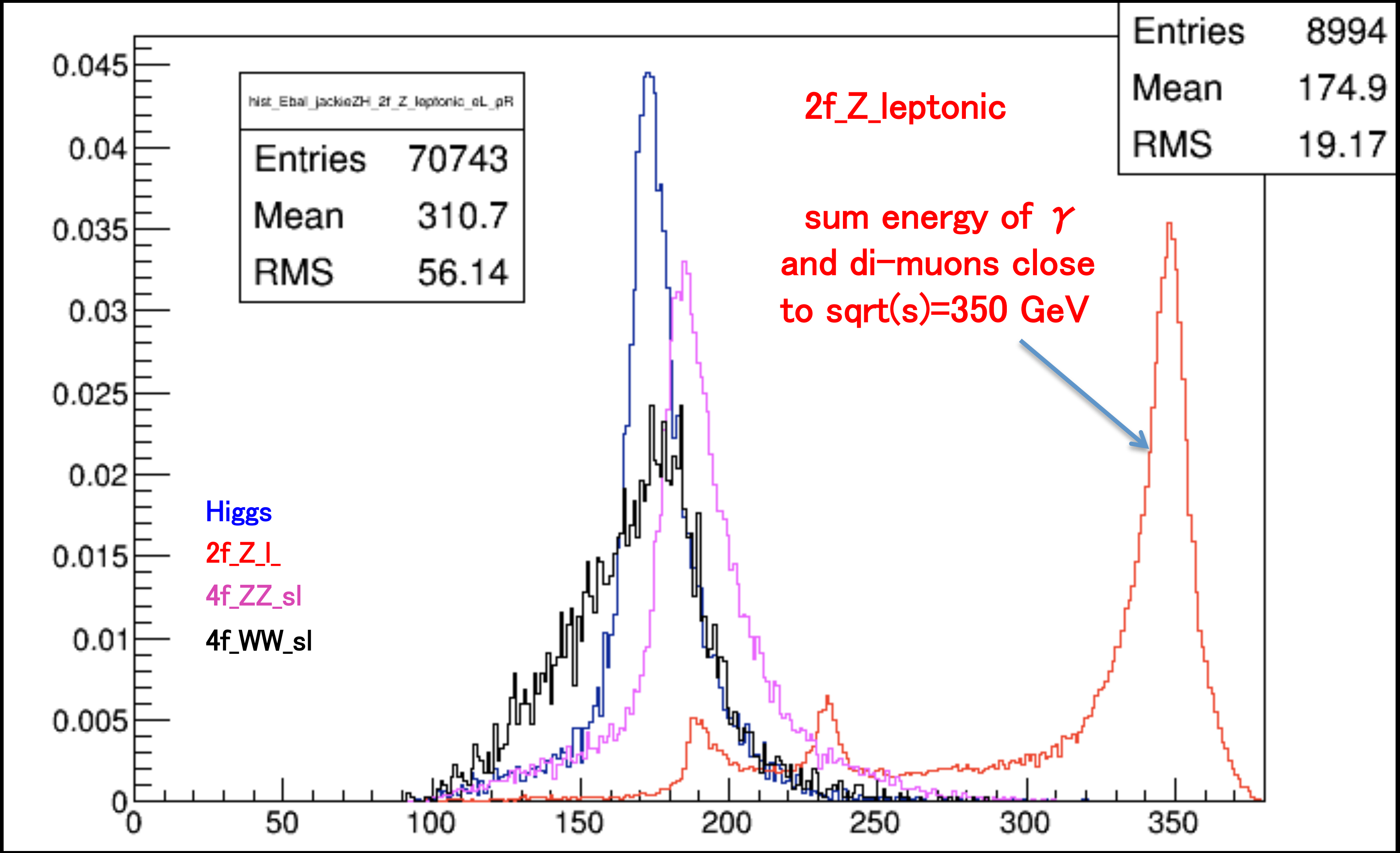
Added new variables to tree for γ momentum vectors

- cos θ bal = angle between γ and di-muon
- Ebal = (γ energy) – (di-muon energy)

I applied a condition to prevent signal bias

I required energy sum of γ and di-muon to be > 0.8 * sqrt(s)

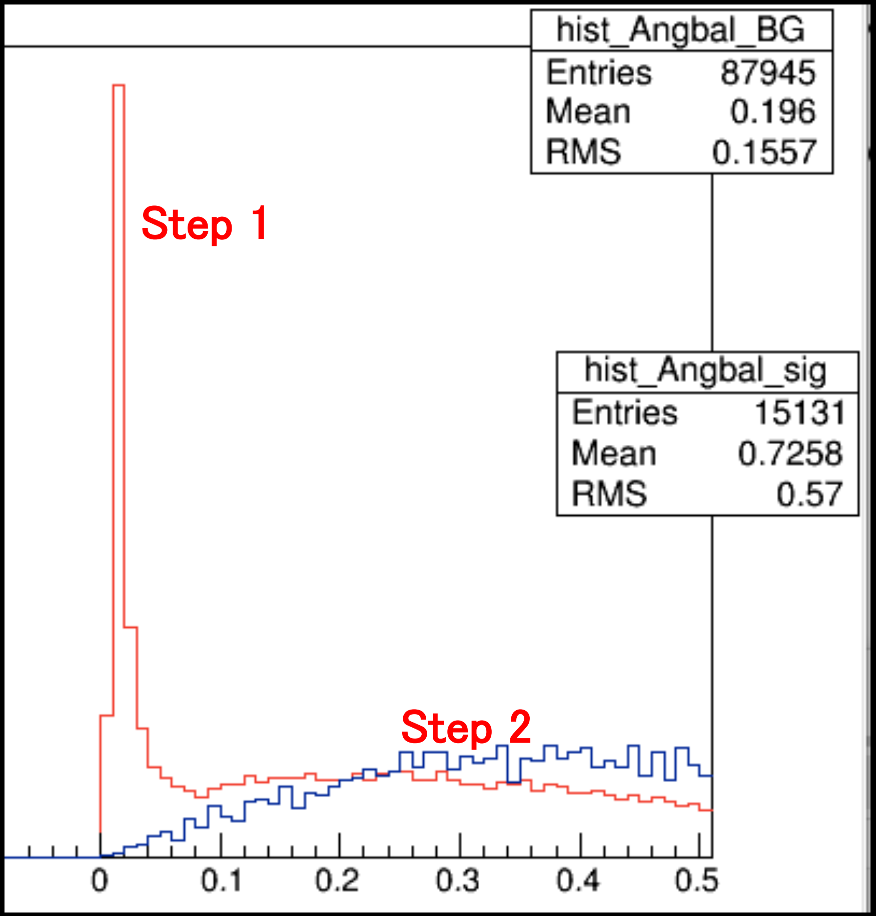
signature of 2f_Z_leptonic BG



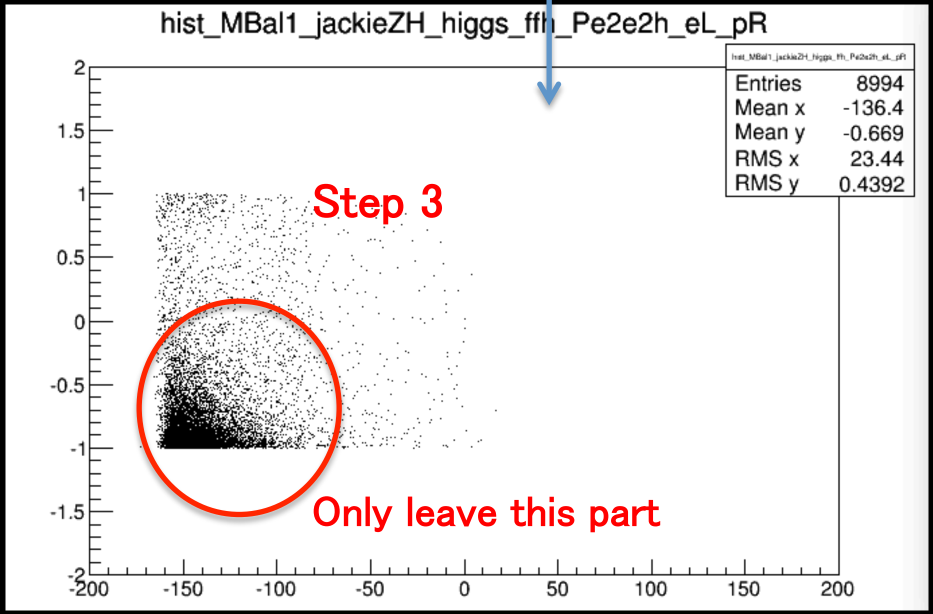
Last week's strategy in order to cut more BG

Divide into three cut regions

1. cut all events in sharp peak （θ bal < 0.045 rad)
2. then cut events satisfy both θ bal and Ebal conditions
3. Then leave events only in bottom left corner



- X: cos θ bal = angle between γ and di-muon
- Y: Ebal = (γ energy) − (di-muon energy)



I played around for a long time with the
event selection criteria and likelihood cut values

in aim of

- Highest signal to BG ratio
- Smallest xsec error

It seems that
Low BG improves xsec precision,
but NOT if signal efficiency is too low

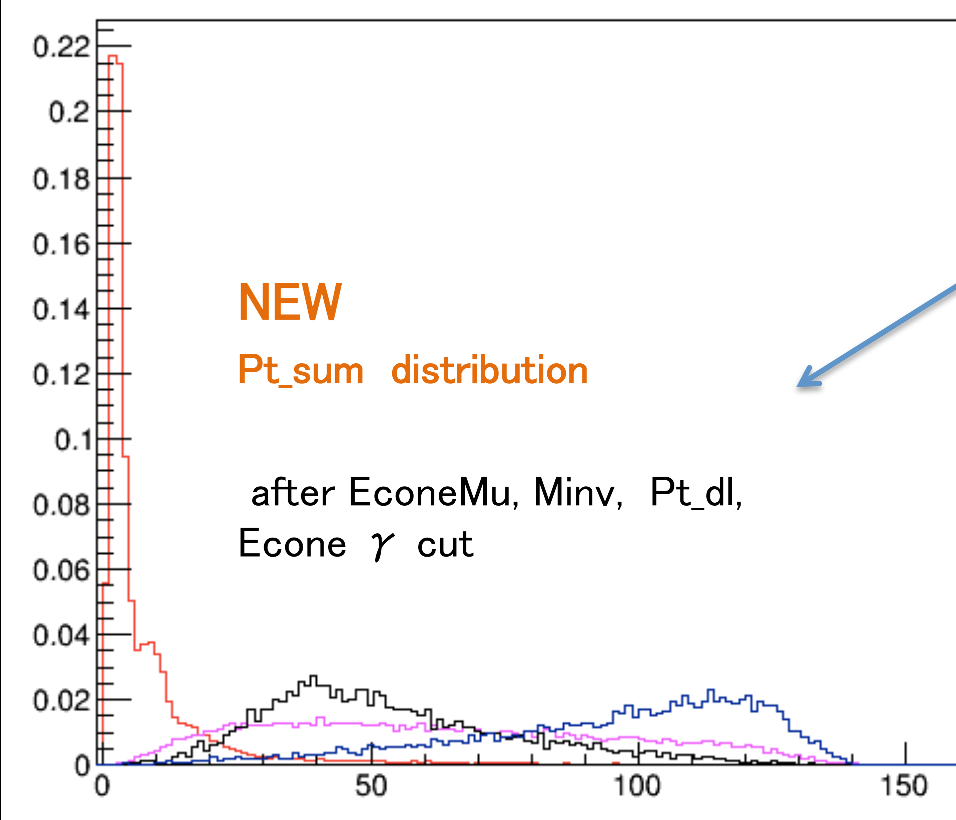
The best result from last week ・・・・・・・・・・・

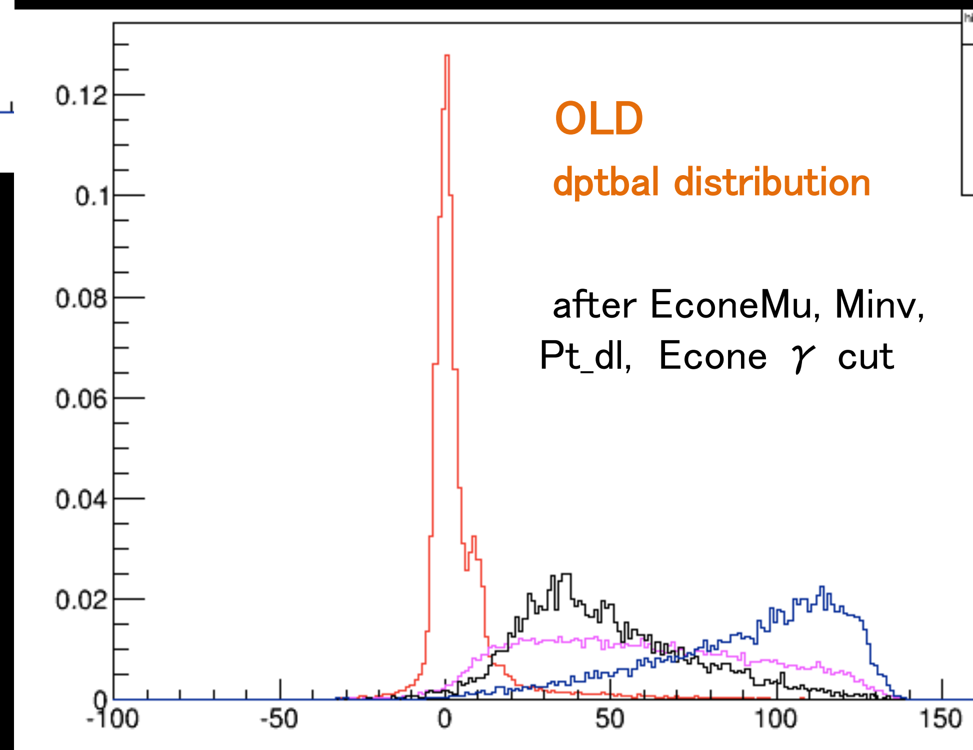
	Nsig	Nbg	S/B ratio	sig eff	$\Delta\sigma/\sigma$ MC)
2 weeks ago	1056	2189	0.48	46.1+/−0.5%	4.39+/−0.00%
This week					
Likelihood L1	Minv, CosZ, Pt, max γ Pt				
ln(L1)>−19.8	1057	2025	0.52	46.2+/−0.5%	4.29+/−0.00%
ln(L1)>−19	1026	1746	0.59	44.8+/−0.5%	4.16+/−0.00%
Likelihood L2	Minv, CosZ, Pt				
ln(L2)>−16	1062	2010	0.53	46.4+/−0.5%	4.27+/−0.00%

Maybe the last one is best ???

I tried a different type of pt_bal cut

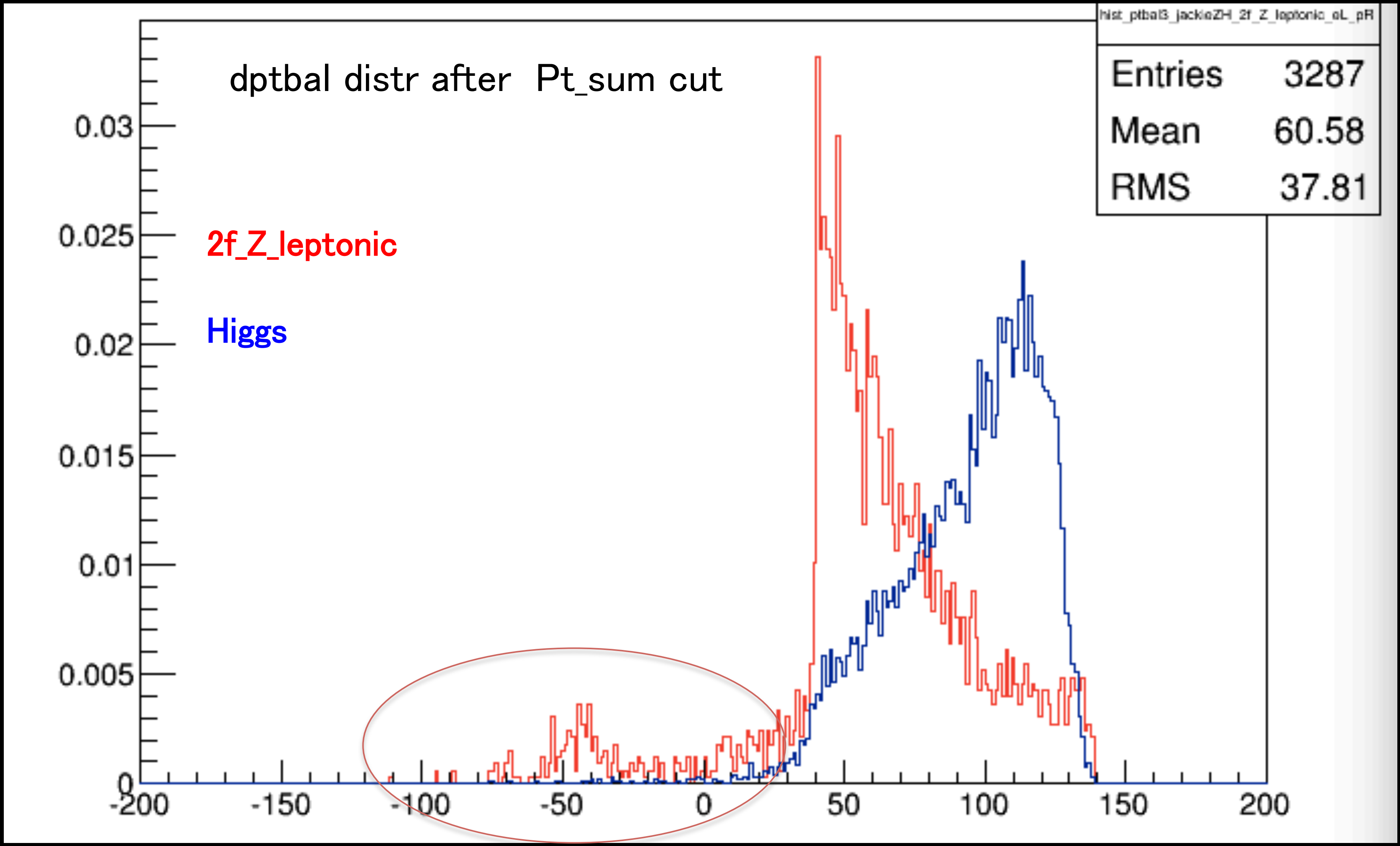
Pt_sum = |Pt_dl − Pt_γ| (in vectors)





After various tests, I found it is most effective to combine the two types

Still some BG events need to be cut after using Pt_sum cut



The strategies from last week helped me understand 2f_Z_leptonic BG better

but the combinations were too complex

Besides, we still have the problem of 4f_WW_semileptonic BG

This is where I began implementing isolation cuts for

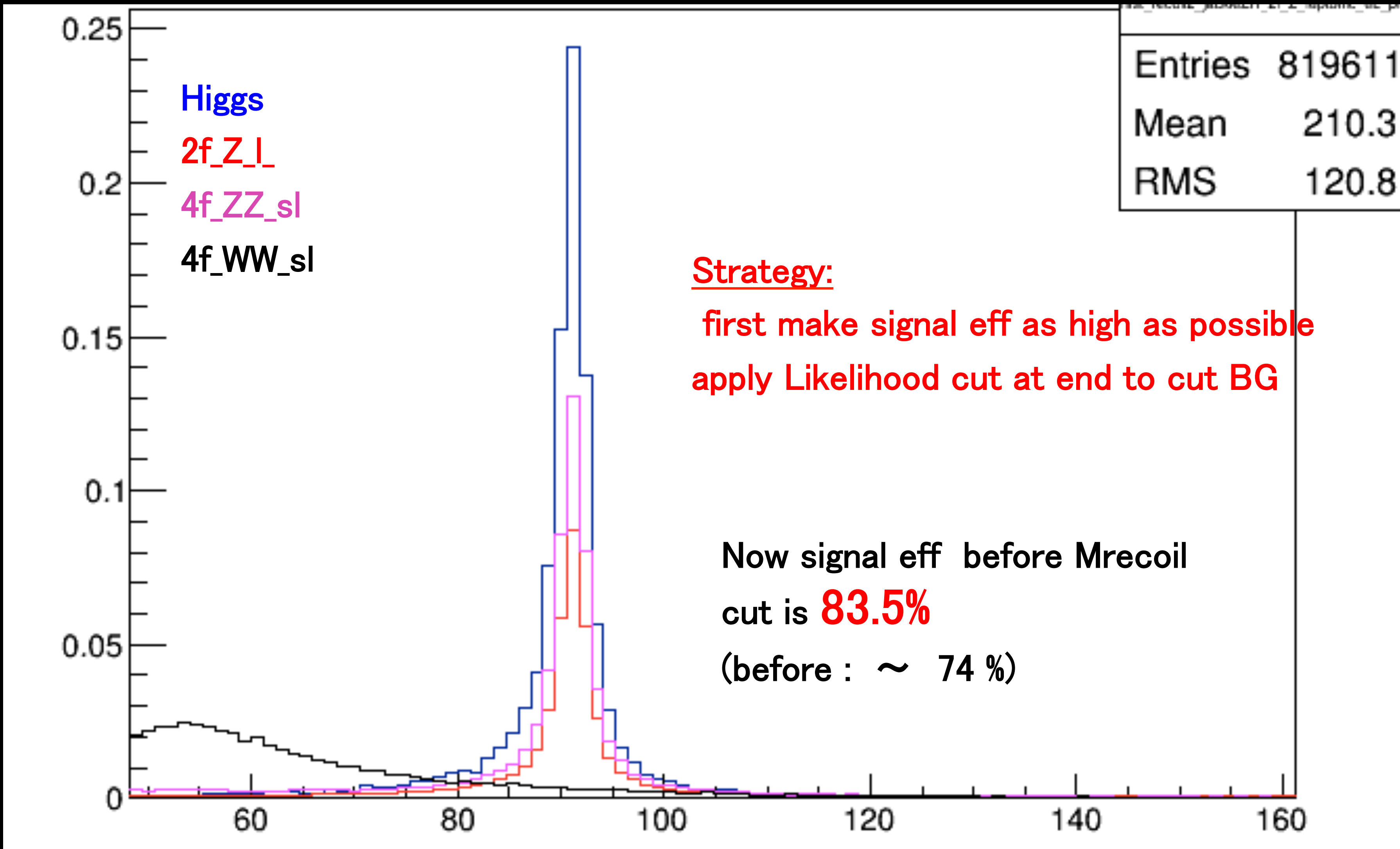
muon (against 4f_WW_sl)

and

gamma (against 2f_Z_leptonic)

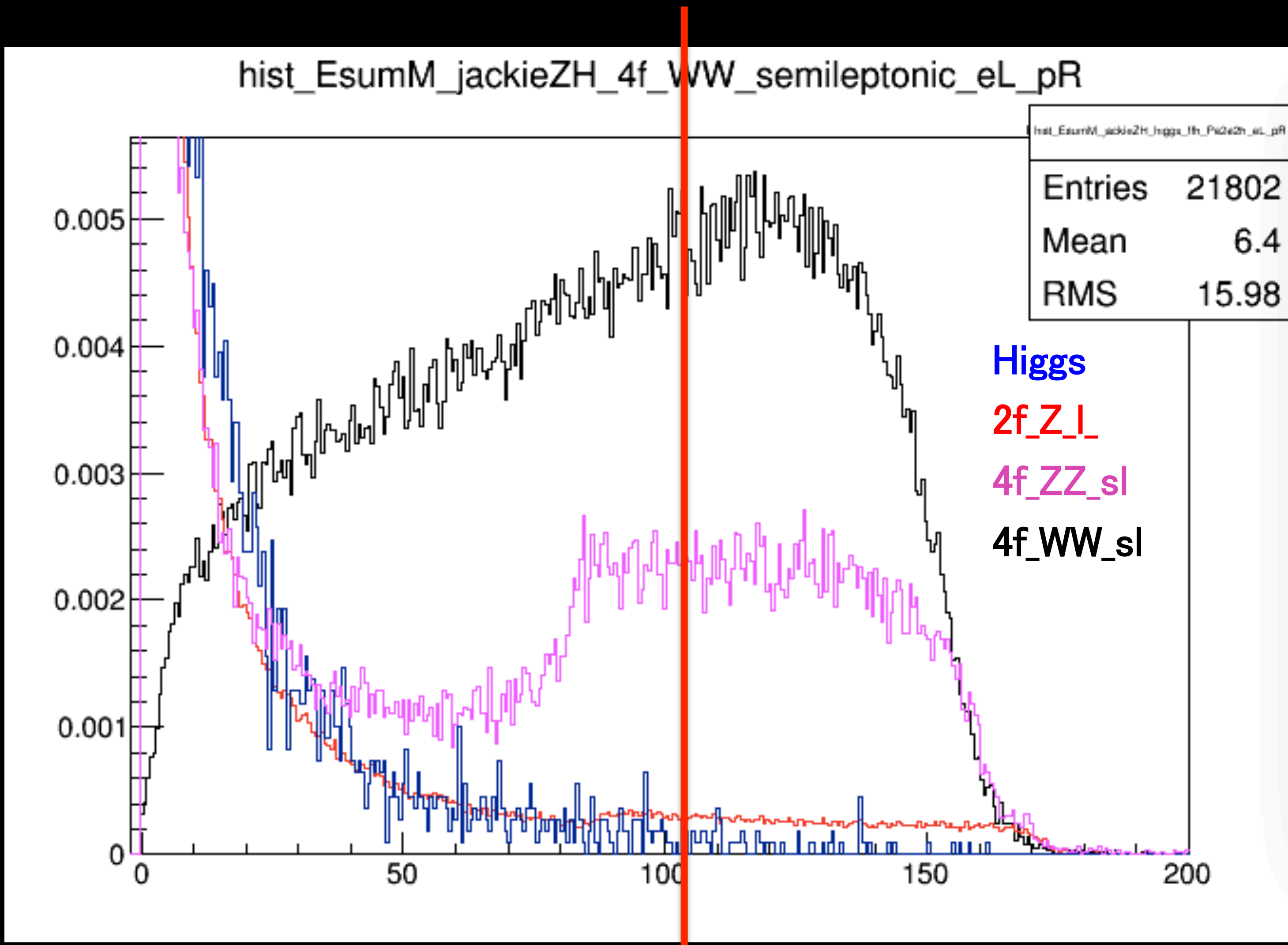
Reoptimization of invariant mass cut : widened the Minv window

- Before : 84 <Minv< 98 GeV : lose 10% signal
- Now: 73 <Minv < 120 GeV : lose 5% signal



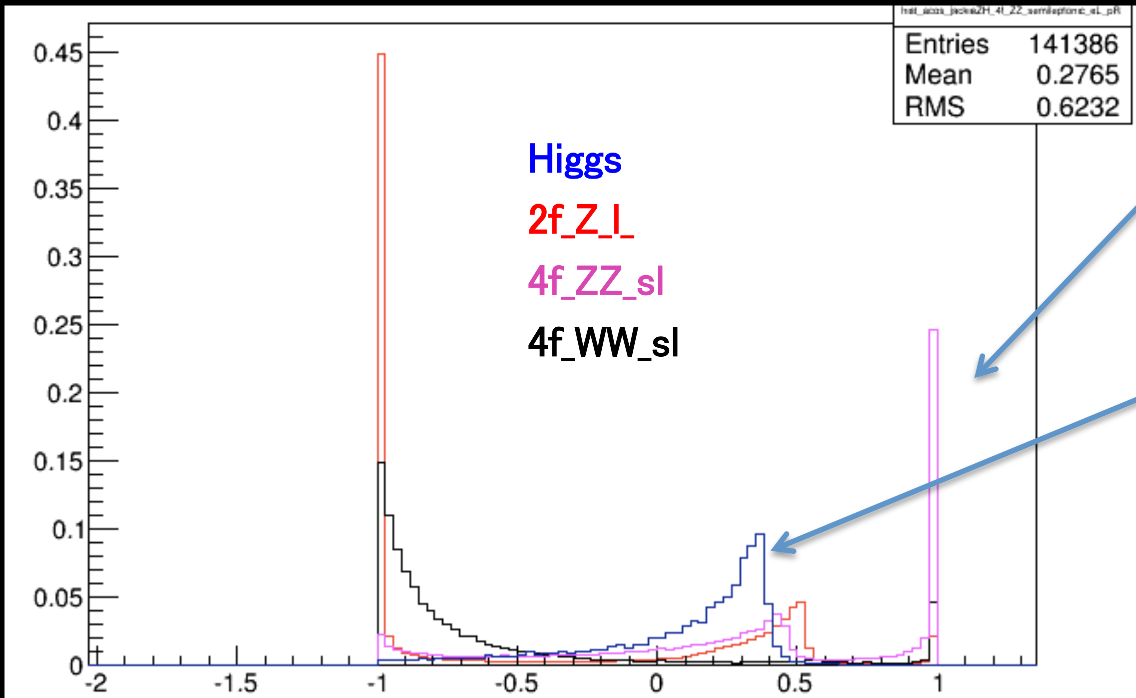
Cone energy around muon （~ 26 deg）

Effective for removing 4f_WW_sl BG



cut above 110 GeV

cosine of angle between two muons (before invariant mass cut)



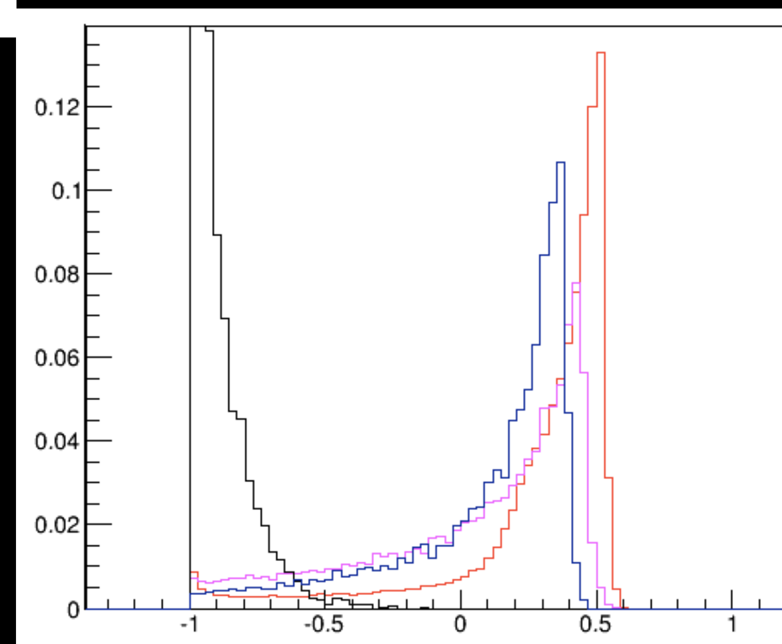
4f_ZZ_sl muons are quite collinear (> 25%)

Muons from Higgs ievents are not collinear GOOD

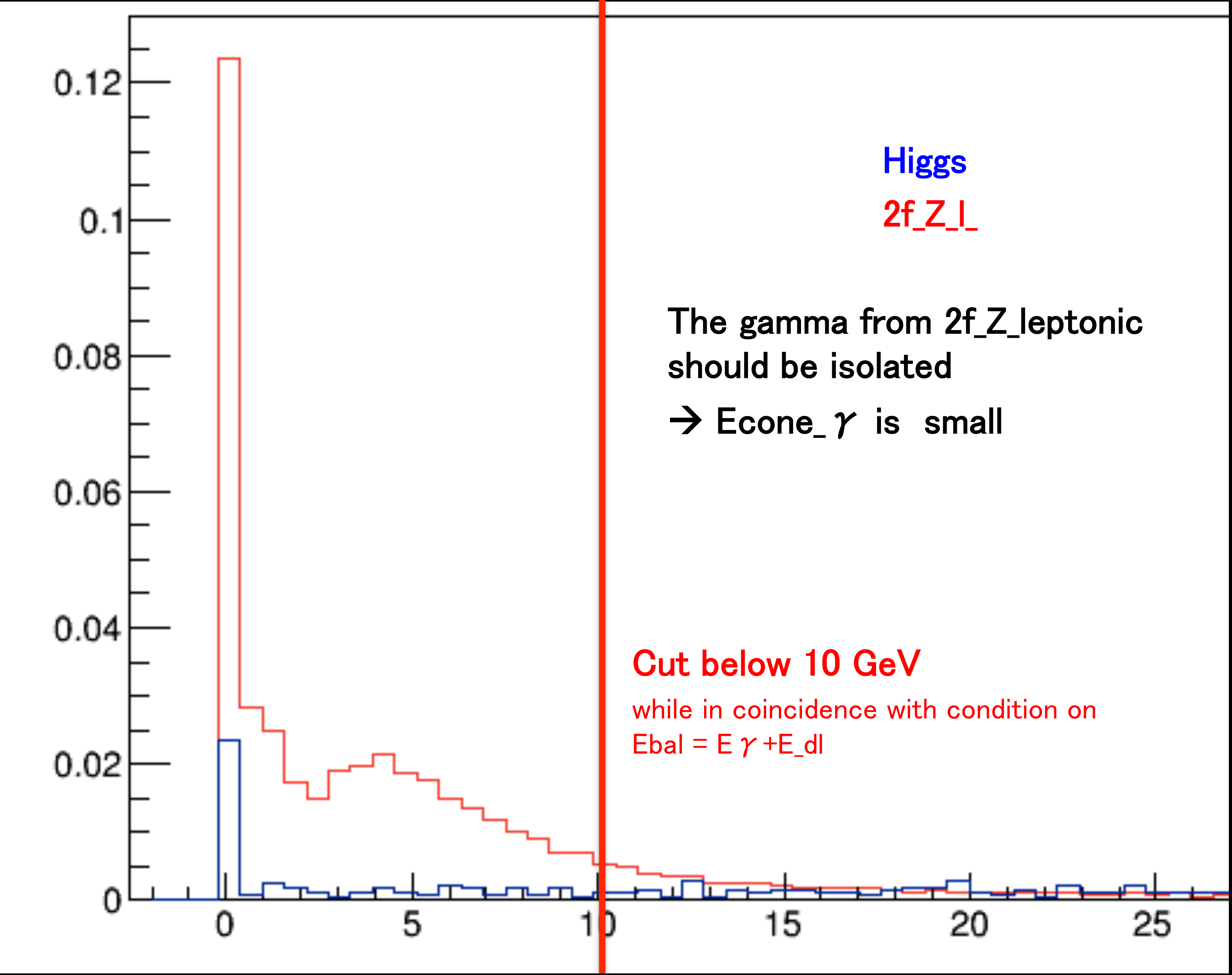
→ should not cause signal bias

after invariant mass cut

collinear muon events are removed anyways



Cone energy around most energetic gamma
(～ 26 deg)



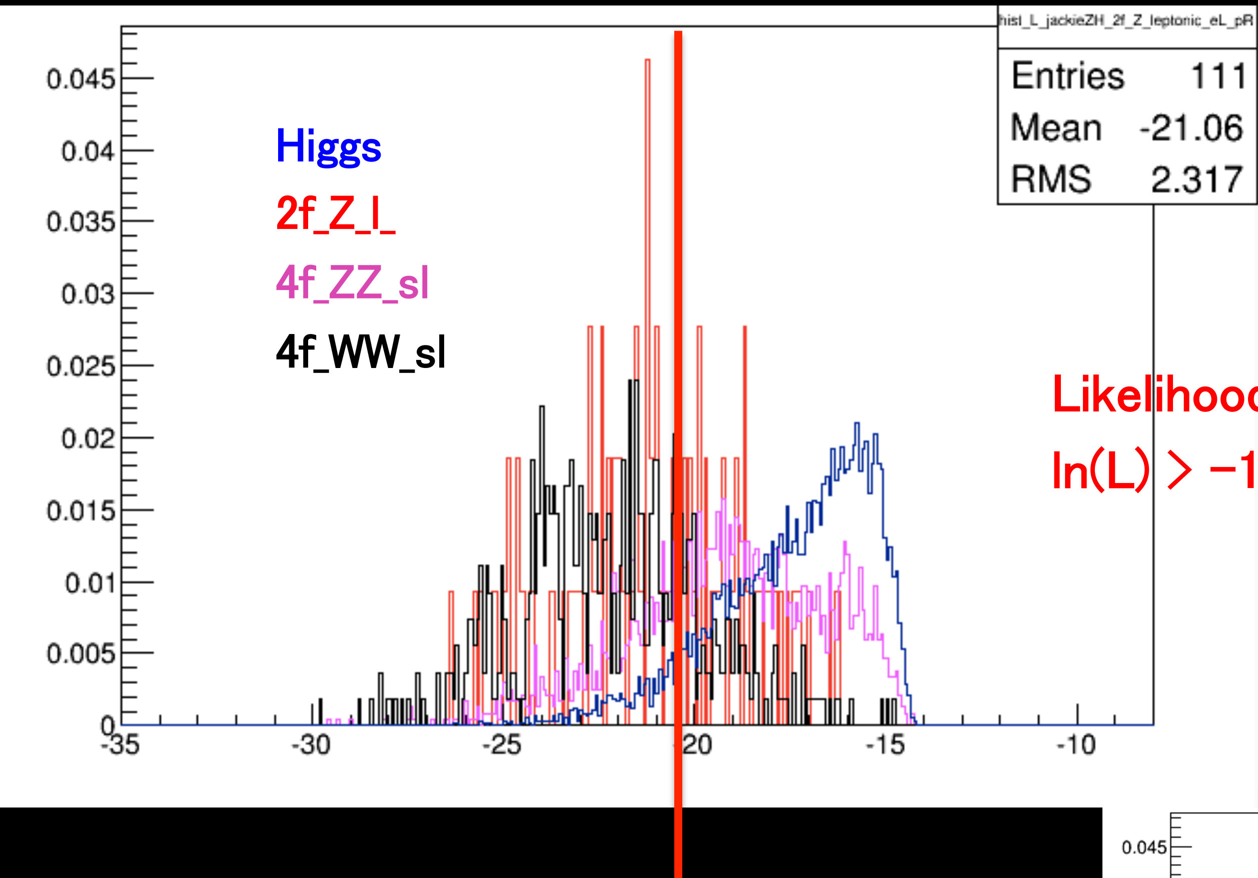
The gamma from 2f_Z_leptonic should be isolated

→ Econe_γ is small

Cut below 10 GeV

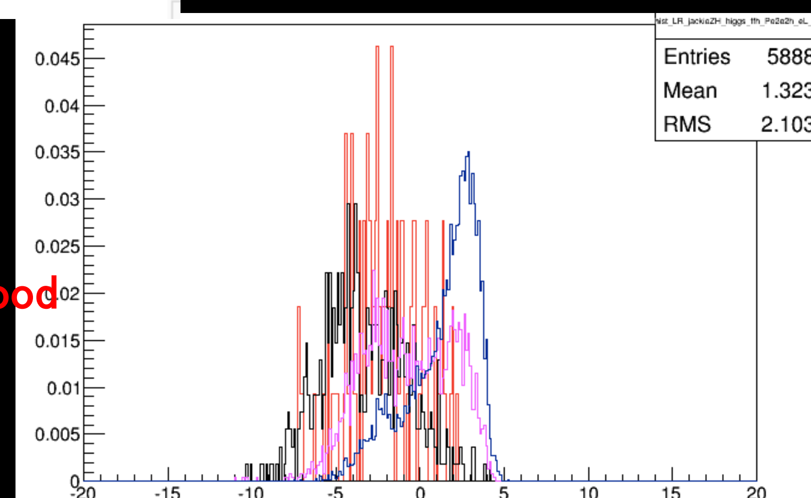
while in coincidence with condition on Ebal = Eγ +E_dl

Likelihood function: L = P(M_inv) * P(Pt) * P(CosZ) * P(Pt_sum)



Likelihood cut

ln(L) > −19.8 seems best



tried to use ratio of signal likelihood to BG likelihood
but not effective

History of past weeks

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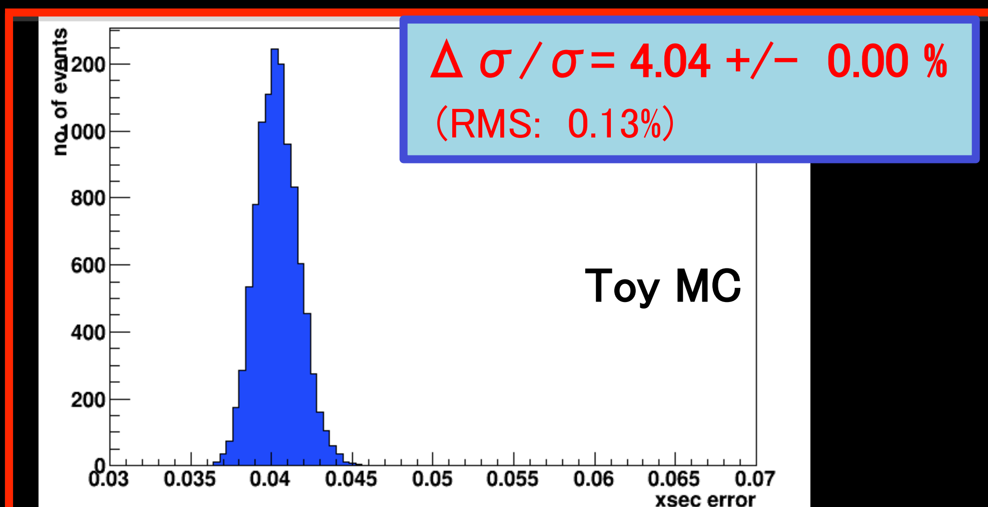
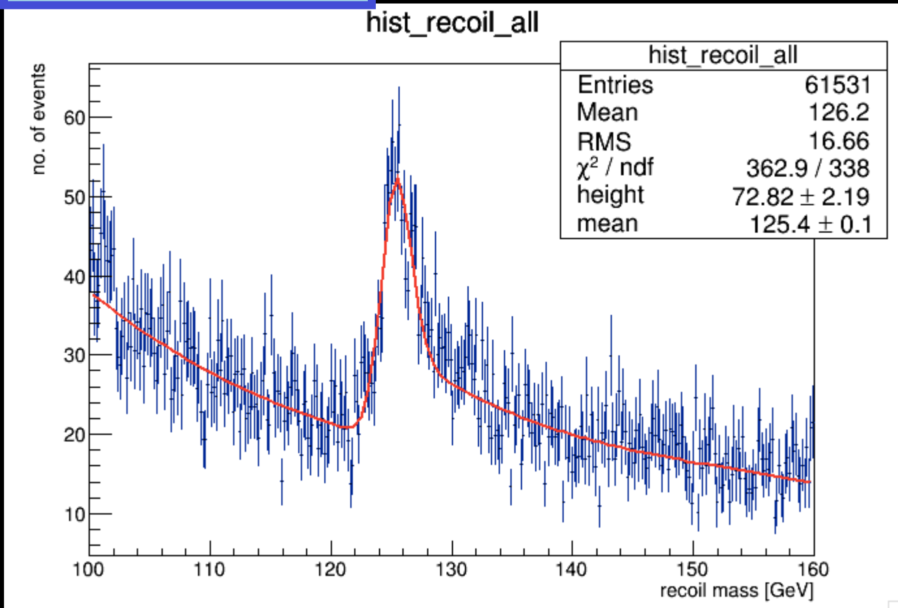
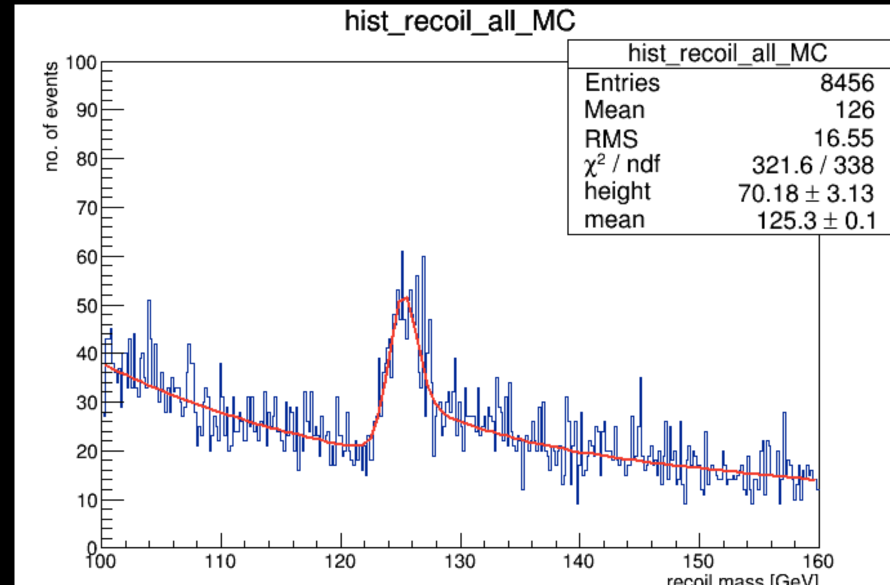


2 weeks ago:

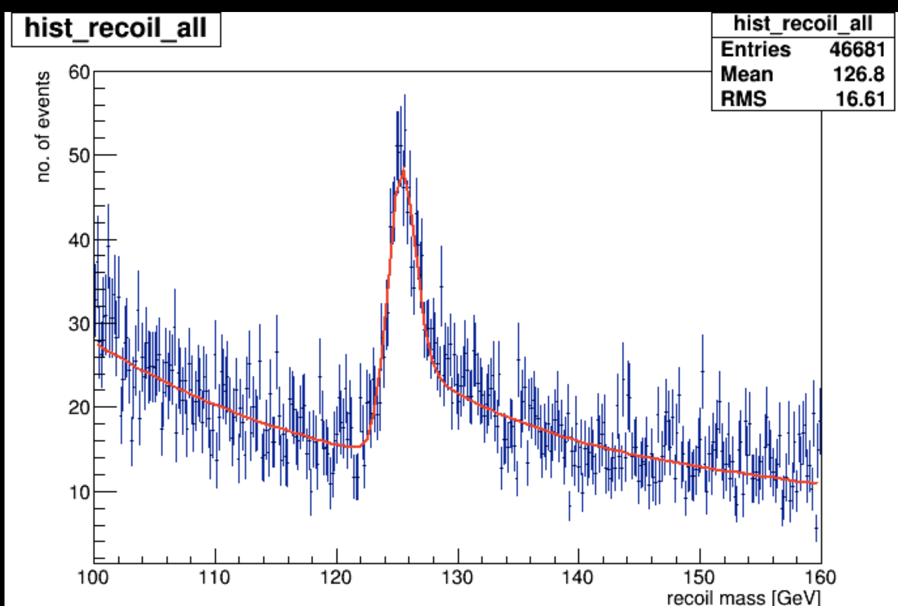
Fit range: 100–160 GeV

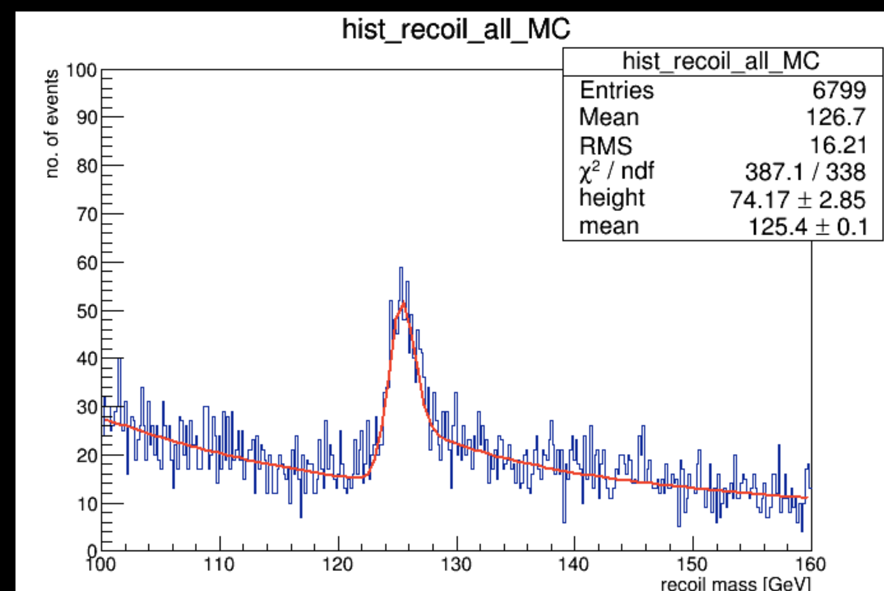




NEWEST

BG is reduced





Conclusion

(1)Significant reduction in BG
(2) improved xsec precision : now 4.0 %

These are mainly due to
- new strategies in pt_bal cut
- isolation cuts for muon and gamma
- gain in signal

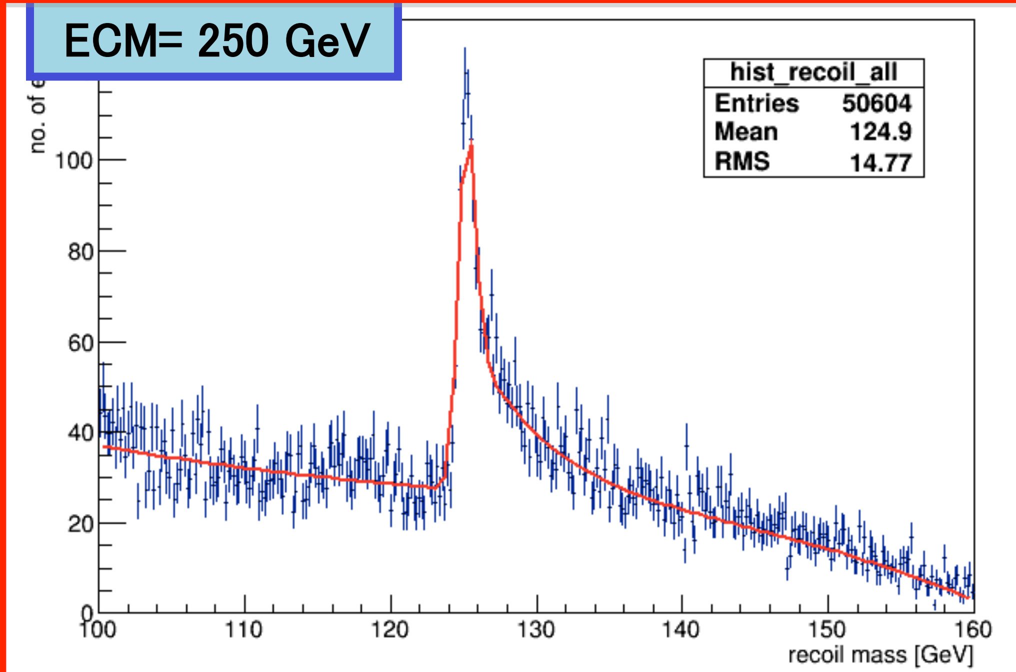
Next steps :

How can I make xsec error go below 4% ????

However, for now …….. I will apply similar method to
other polarization scenarios and **ECM= 250 GeV**
and **compare**

In time for **ALCW15** (physics session)

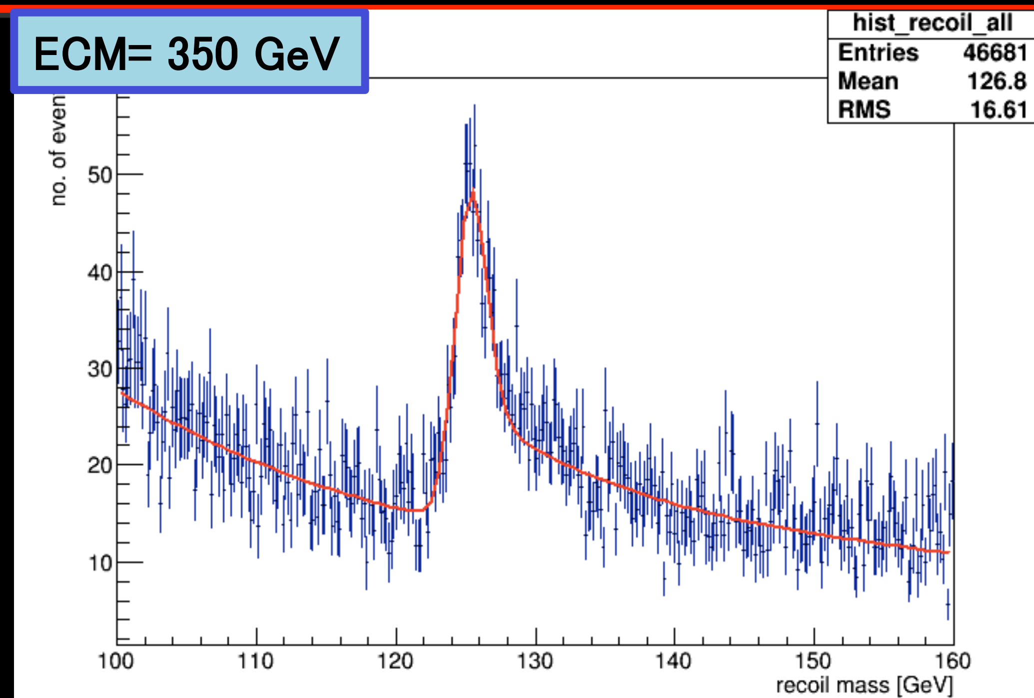
Preview on re-visit of E_CM = 250 GeV



250 GeV:

Δ σ / σ = 3.46 +/- 0.00 % (Toy MC)

- Major residual BG for 250 GeV
- 4f_ZZWWMix_l
- 4f_ZZ_l
- 4f_WW_l

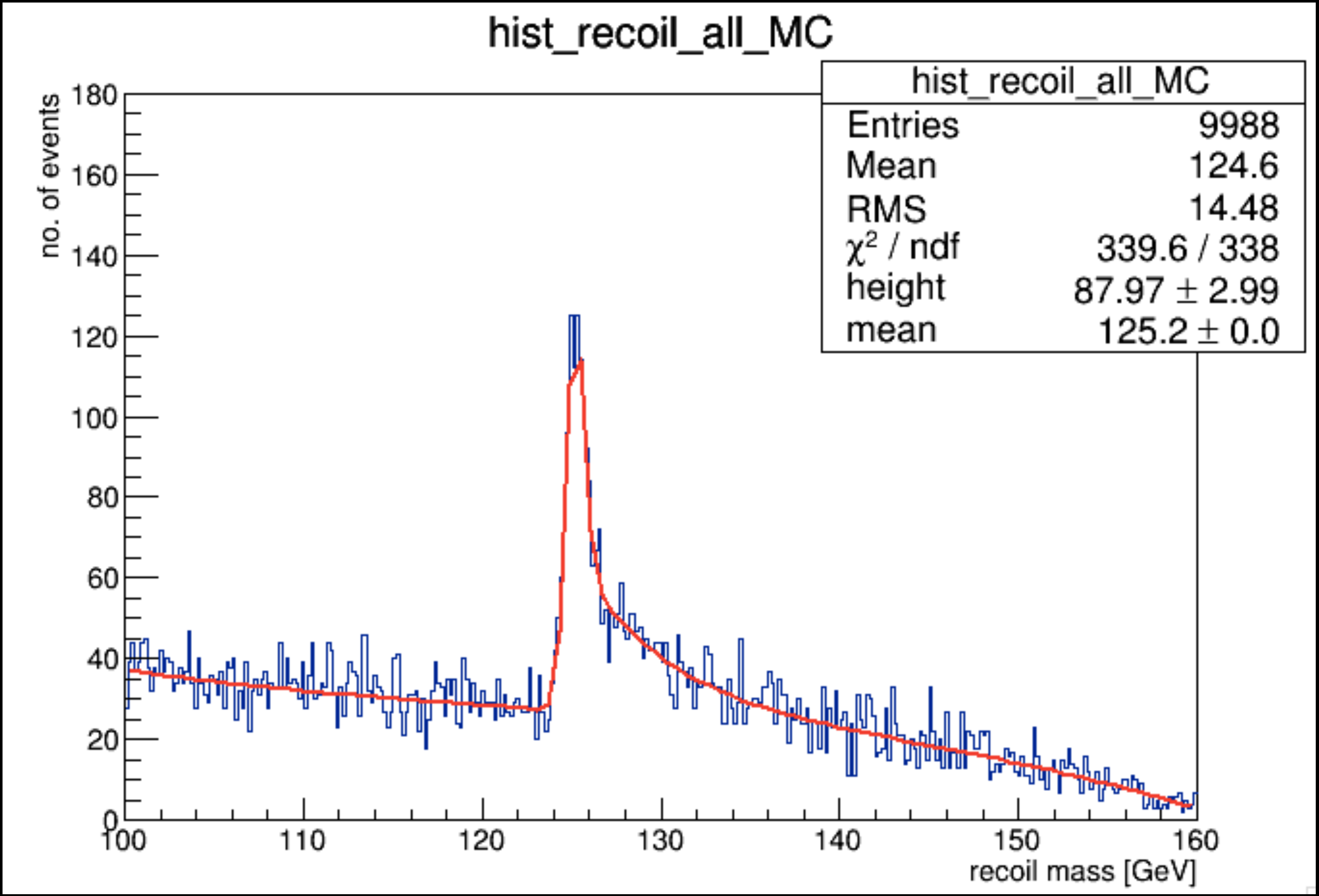


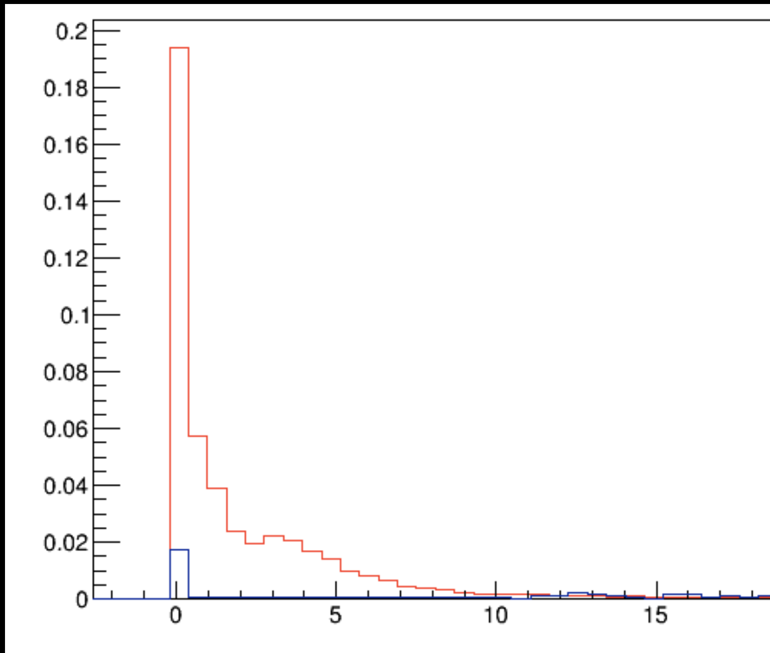
350 GeV

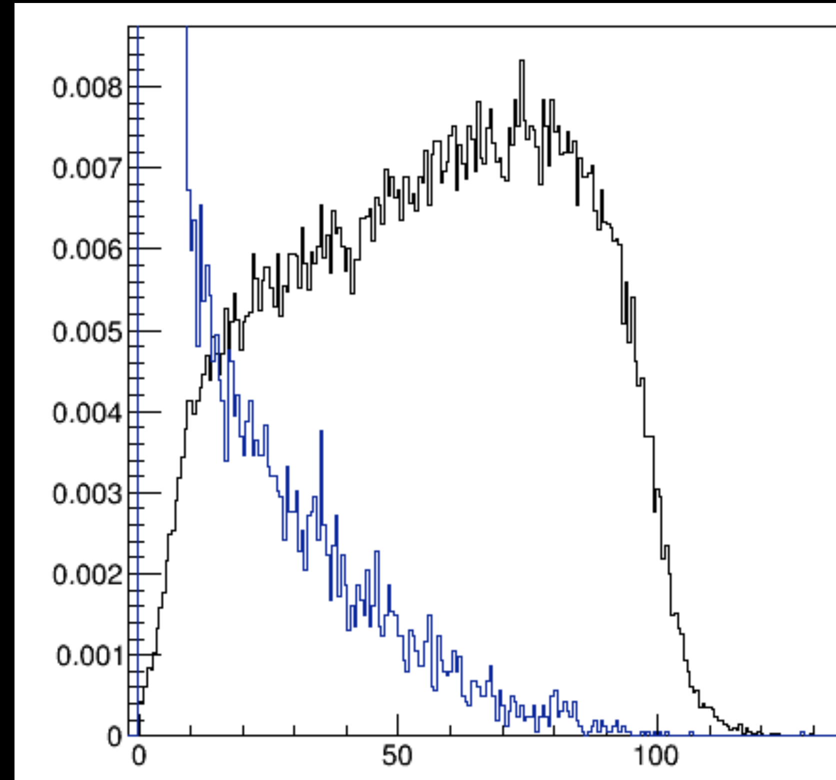
Δ σ / σ = 4.04 +/- 0.00 % (Toy MC)

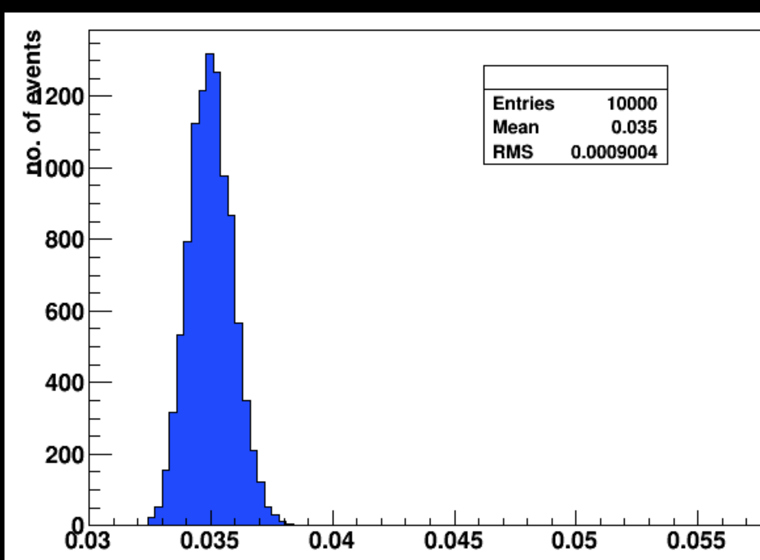
- Major residual BG for 350 GeV
- 4f_WW_sl
- 4f_ZZ_l
- 2f_Z_l

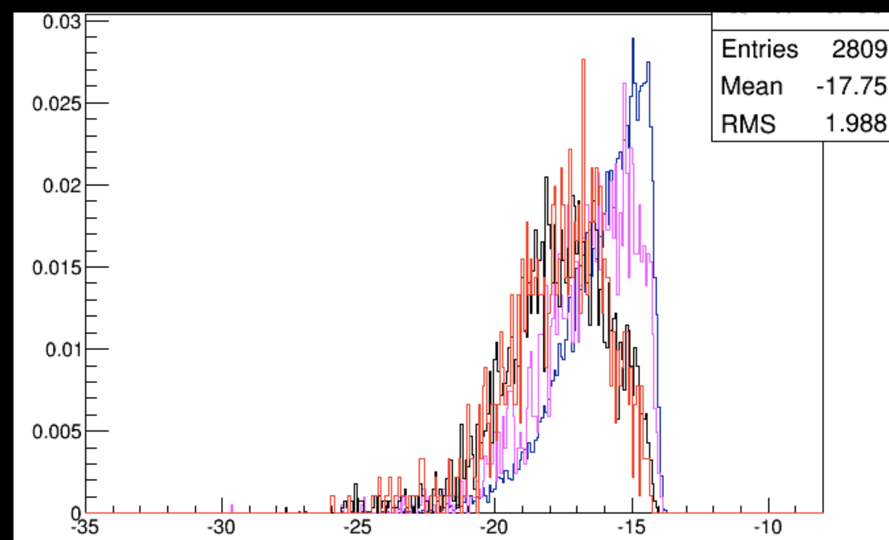
BACKUP


hist_recoil_all_MC
hist_recoil_all_MC
Entries 9988
Mean 124.6
RMS 14.48
χ² / ndf 339.6 / 338
height 87.97 ± 2.99
mean 125.2 ± 0.0
no. of events
0
20
40
60
80
100
120
140
160
180
100
110
120
130
140
150
160
recoil mass [GeV]


0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15

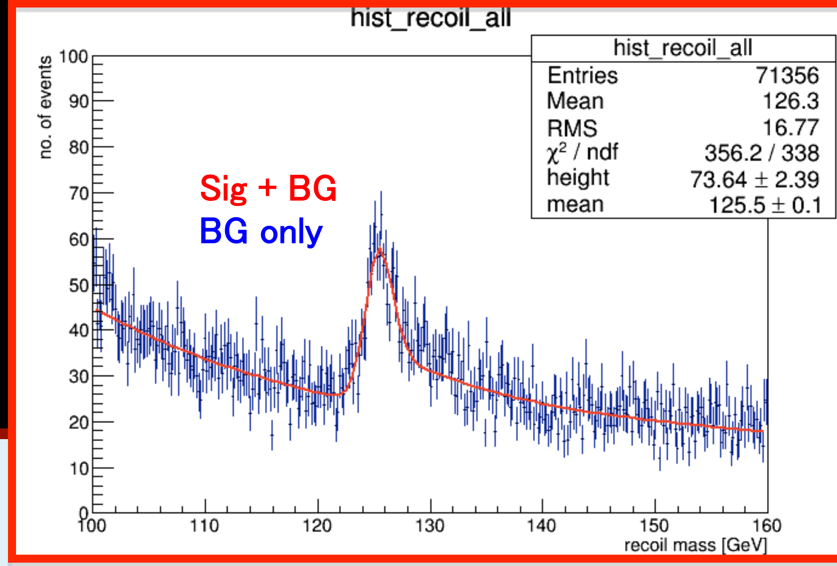

0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0
50
100


no. of events
Entries 10000
Mean 0.035
RMS 0.0009004
1200
1000
800
600
400
200
0
0.03
0.035
0.04
0.045
0.05
0.055


Entries 2809
Mean -17.75
RMS 1.988
0.03
0.025
0.02
0.015
0.01
0.005
0
-35
-30
-25
-20
-15
-10

recoil mass fitting method

Fit range: 100–160 GeV



<u>1st step:</u>

- Fit only signal with GPET float all 5 pars
- Fit only BG: 3rd order polynomial

<u>2nd step :</u>

fit Sig + BG : only float height and mean

fix others from step 1

◆ **SIGNAL: GPET:** 5 parameters :

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

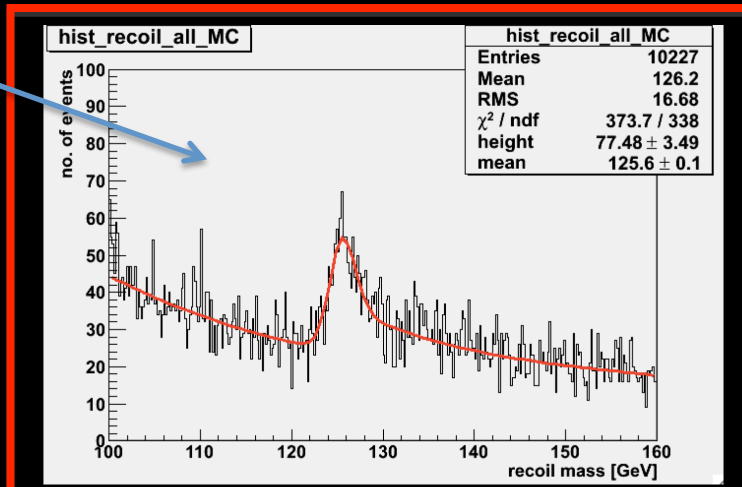
Gaus (left-side) ,

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

Gaus + expo (right side)

Toy MC study

Toy MC 10000 seeds



<u>goal:</u> test quality of fitting method

in terms of M_h、 xsec etc……

<u>method</u>:

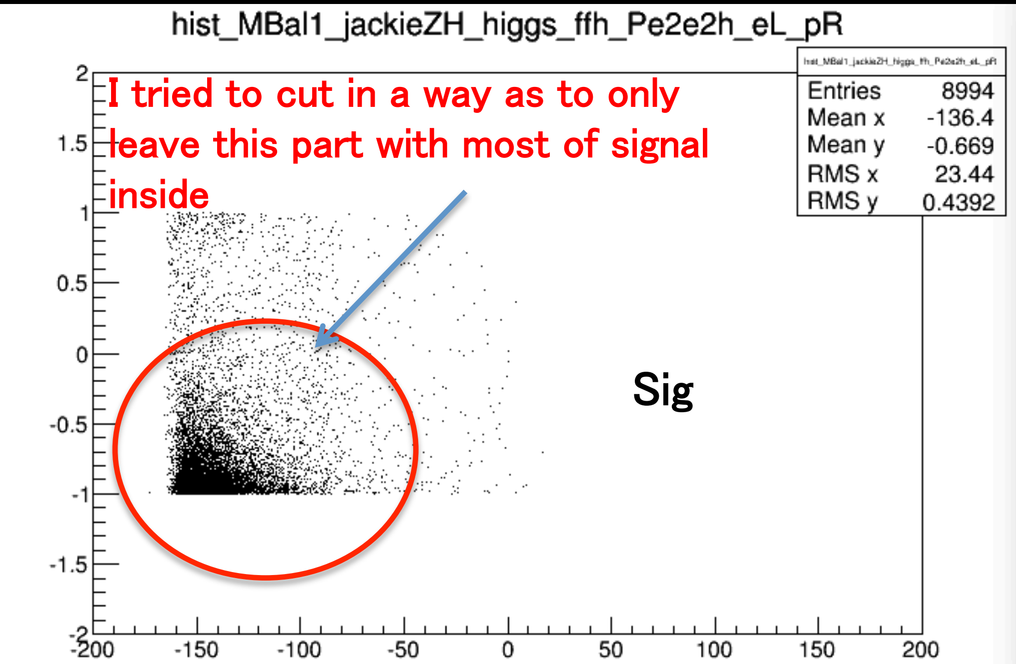
generate MC events according to fittied "real" data

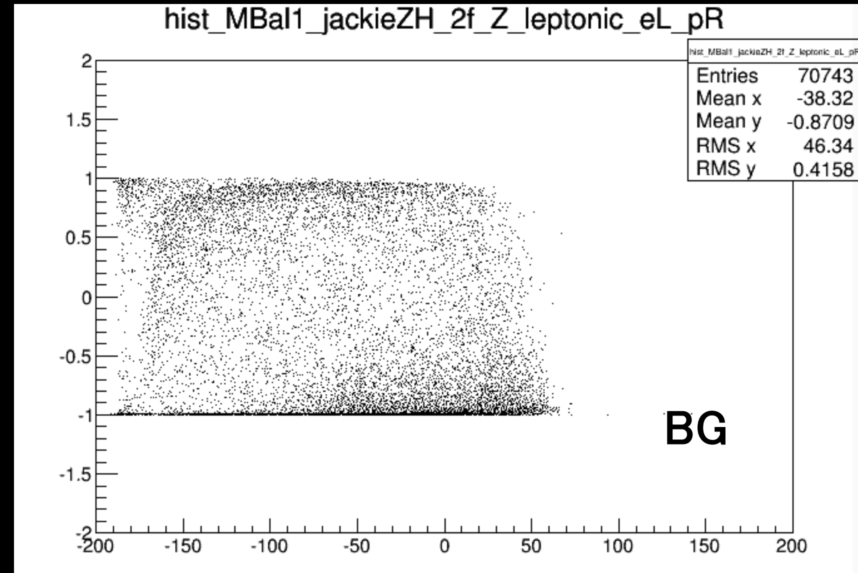
(Poisson)

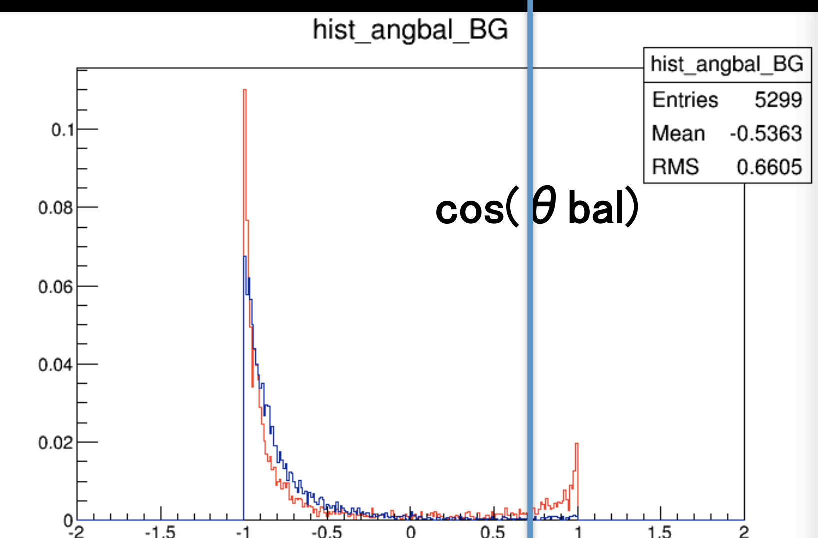
fit MC hist with same GPET function → get Nsig, xsec

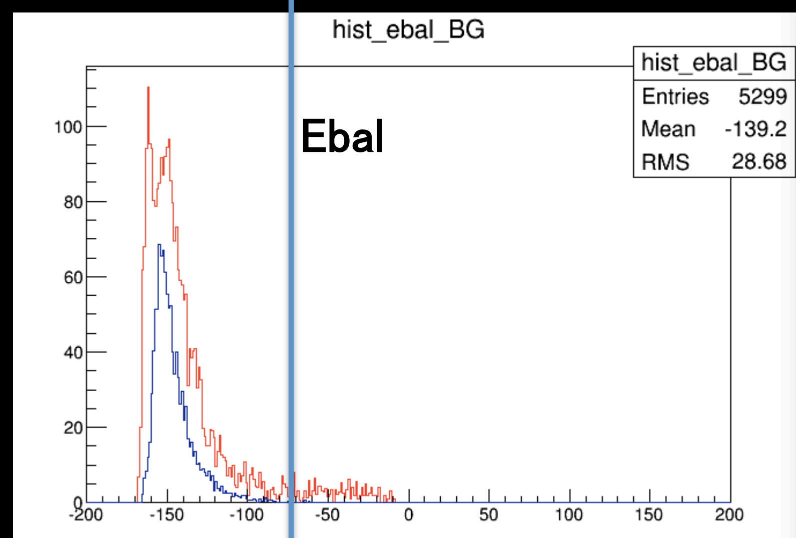
X: Ebal
Y: cos(θ bal)

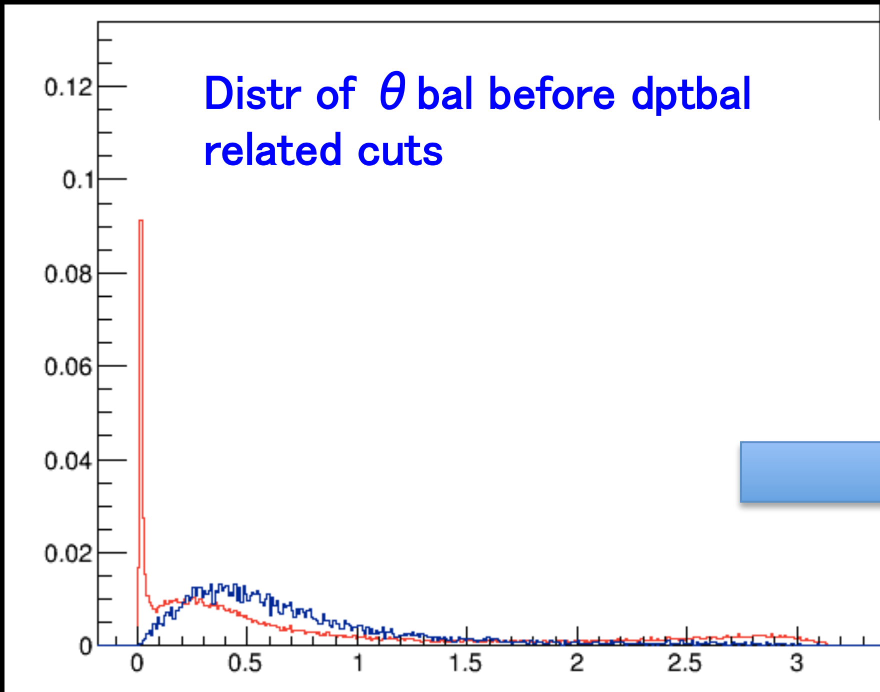
2D distribution before maxgammapt cut

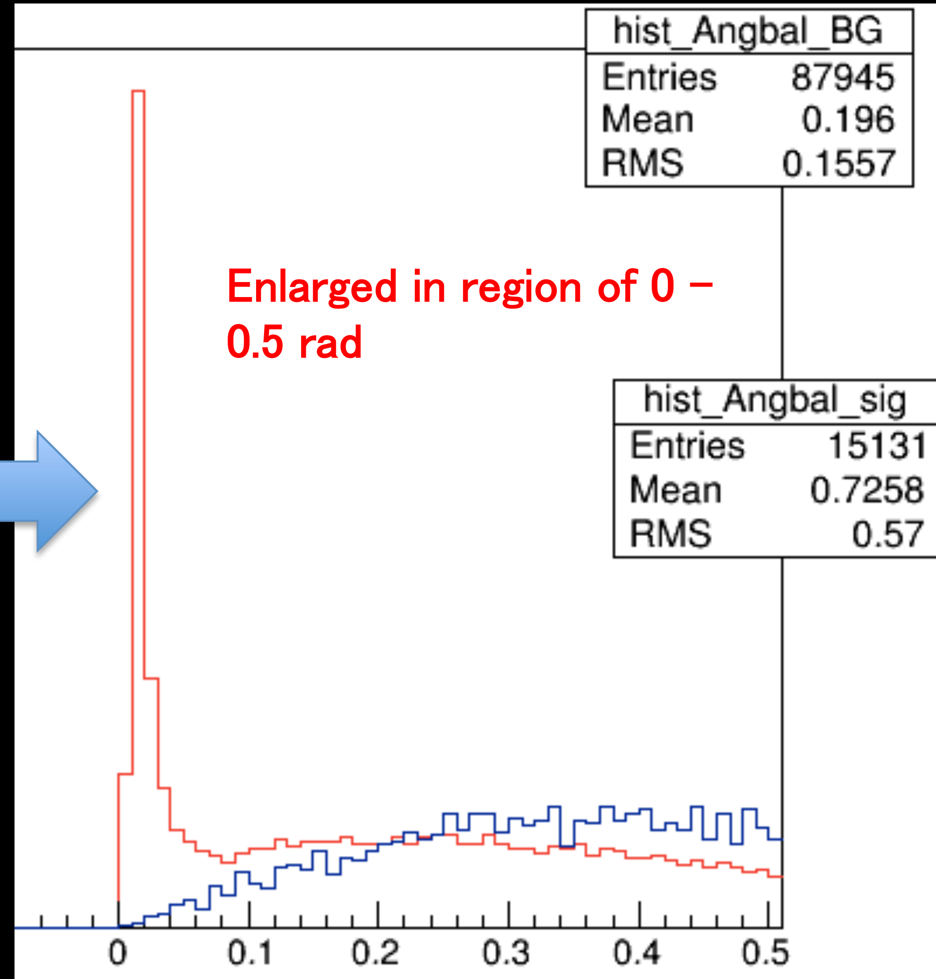






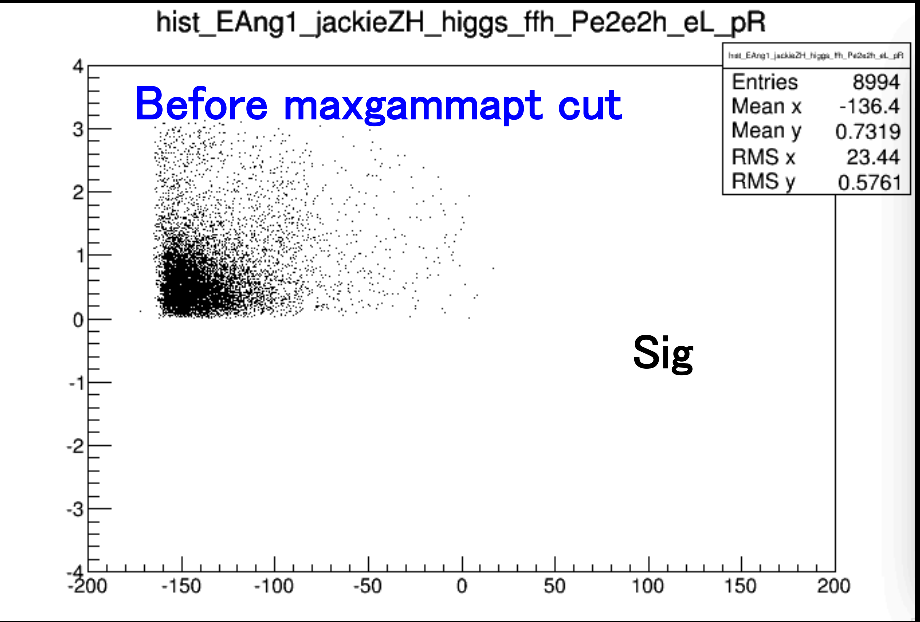


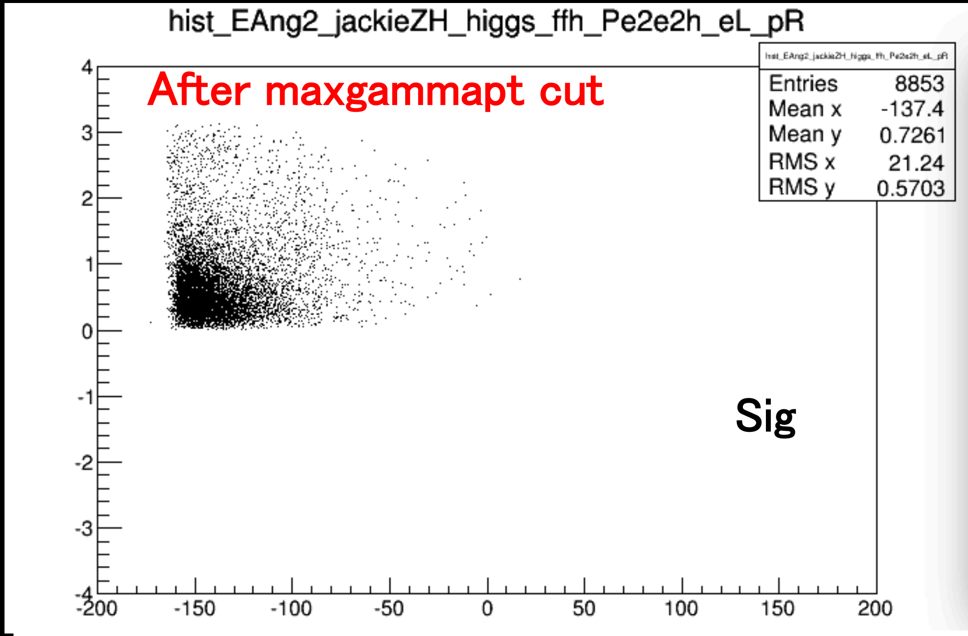


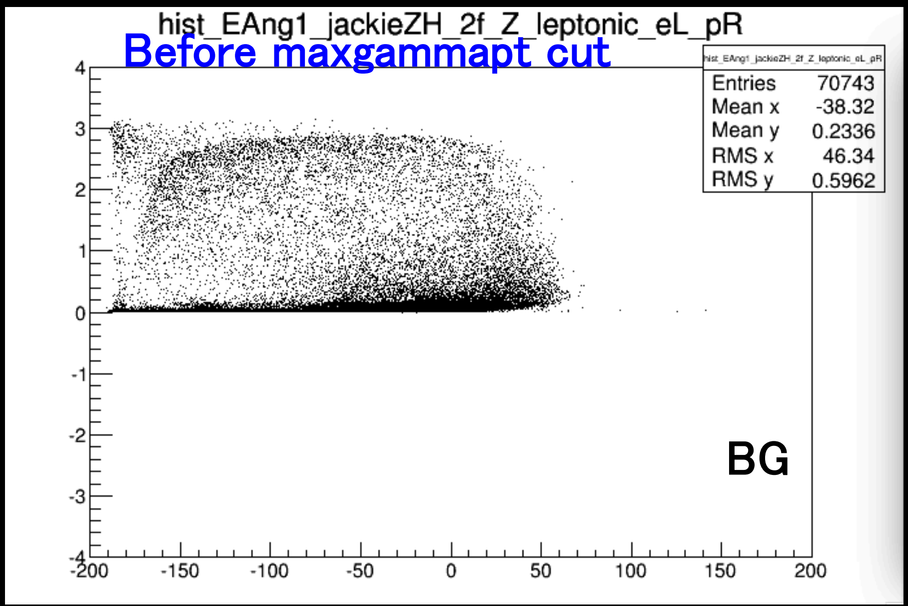


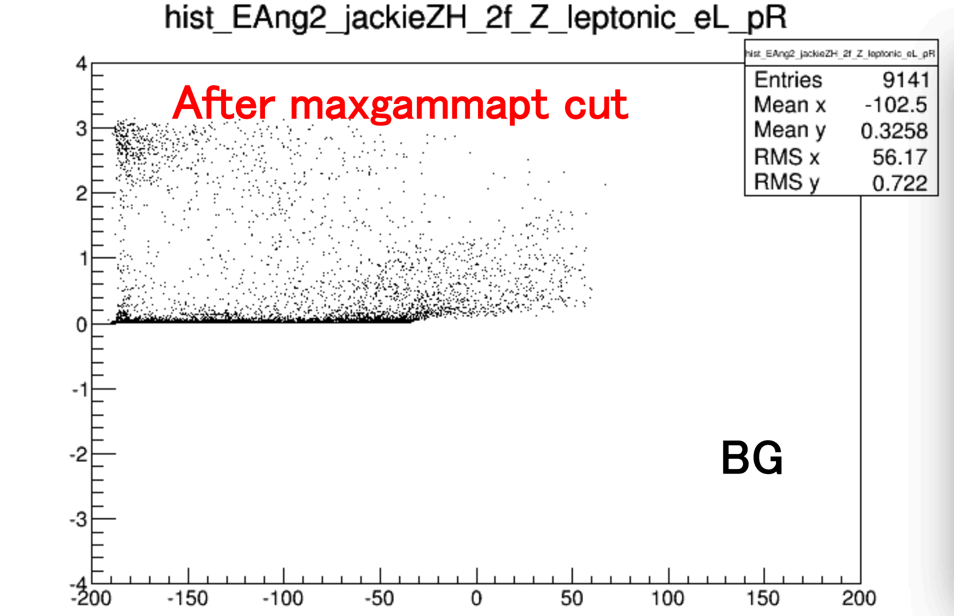
- $\cos\theta$ bal = angle between γ and di-muon
- Ebal = (γ energy) – (di-muon energy)

X: Ebal
Y: PI − θ bal



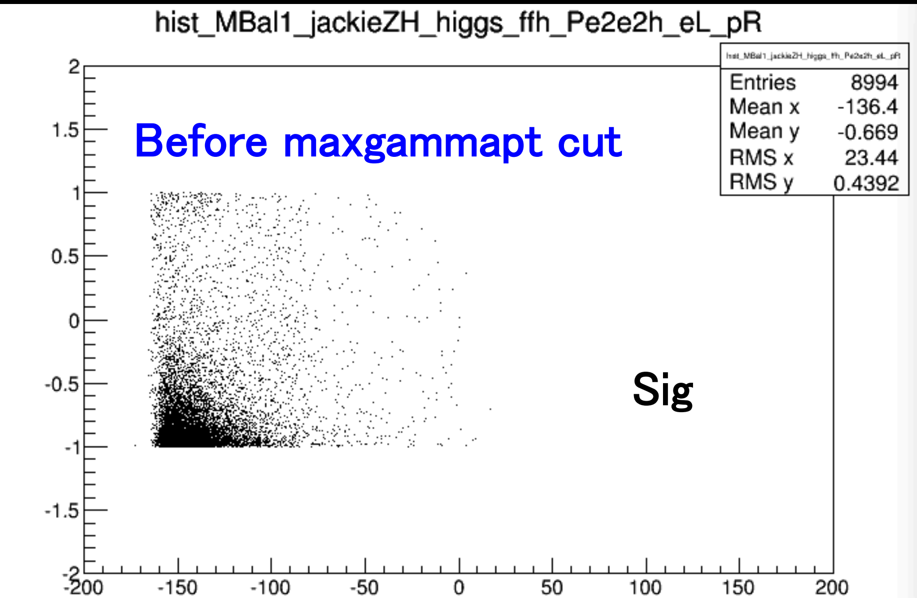


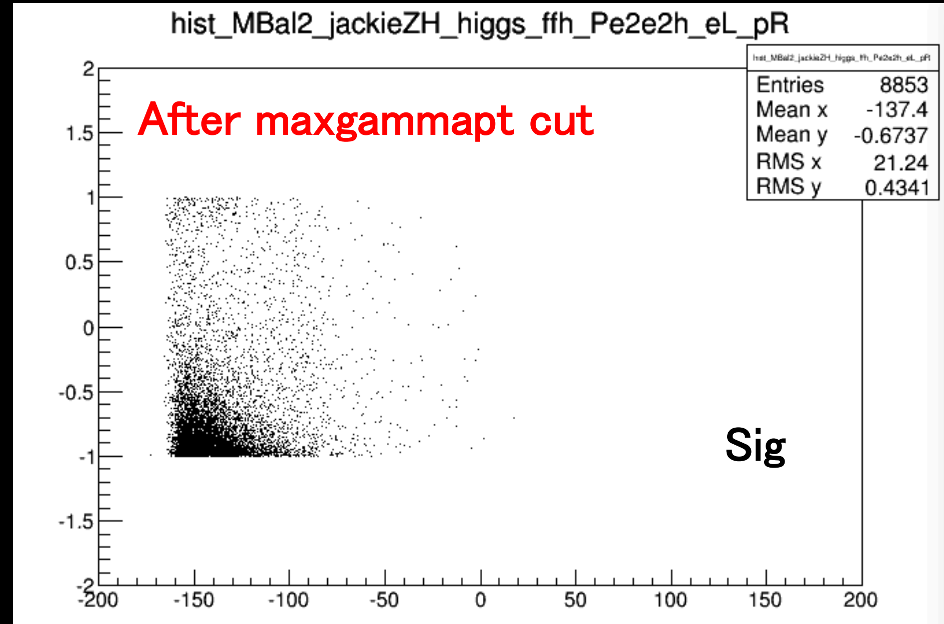


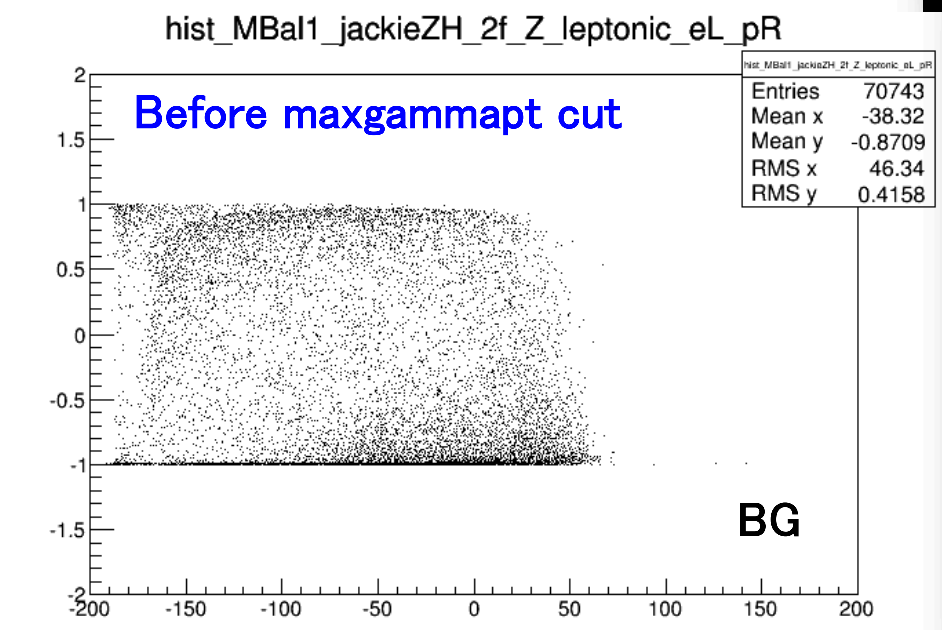


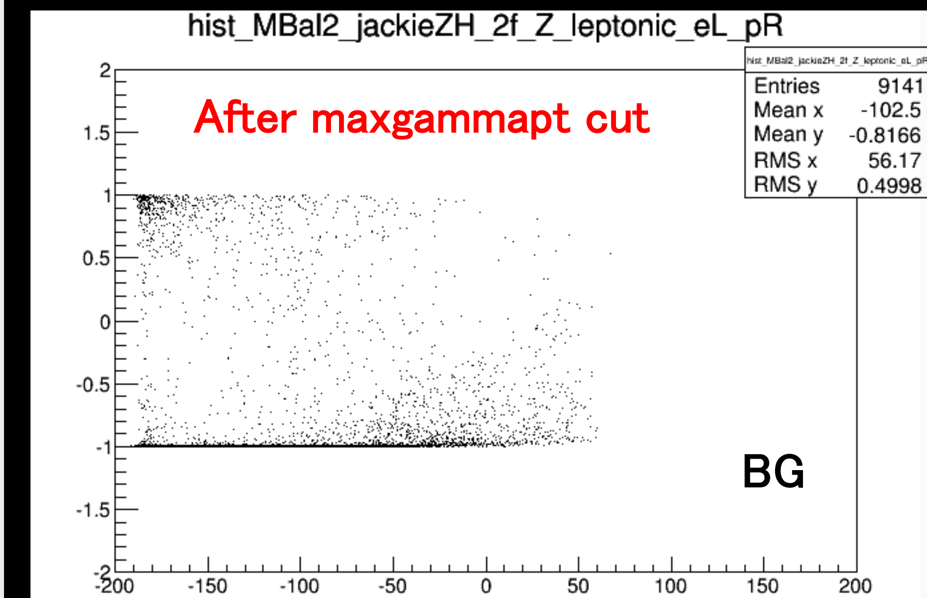
X: Ebal
Y: cos(θ bal)

- cos θ bal = angle between γ and di−muon
- Ebal = (γ energy) − (di−muon energy)





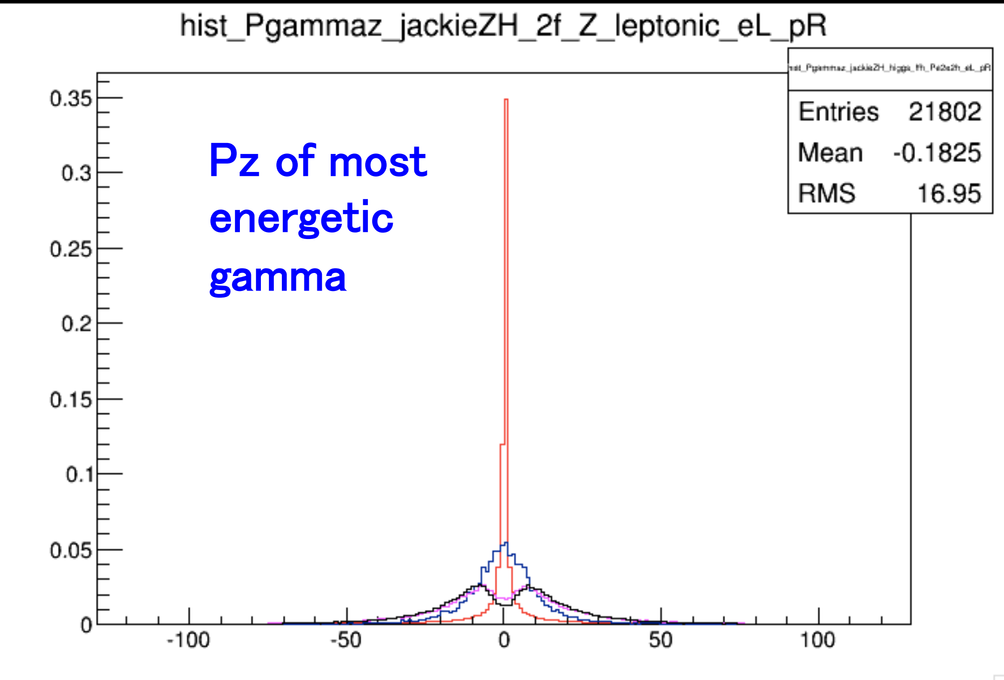


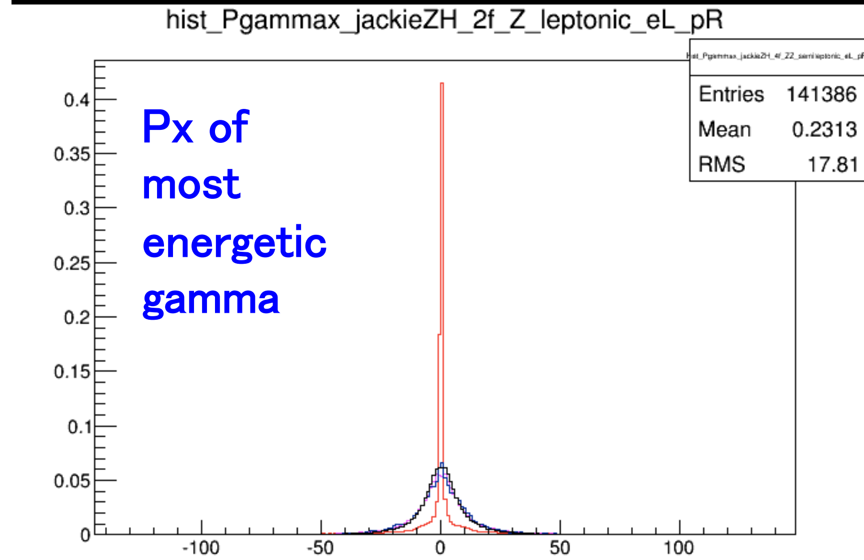


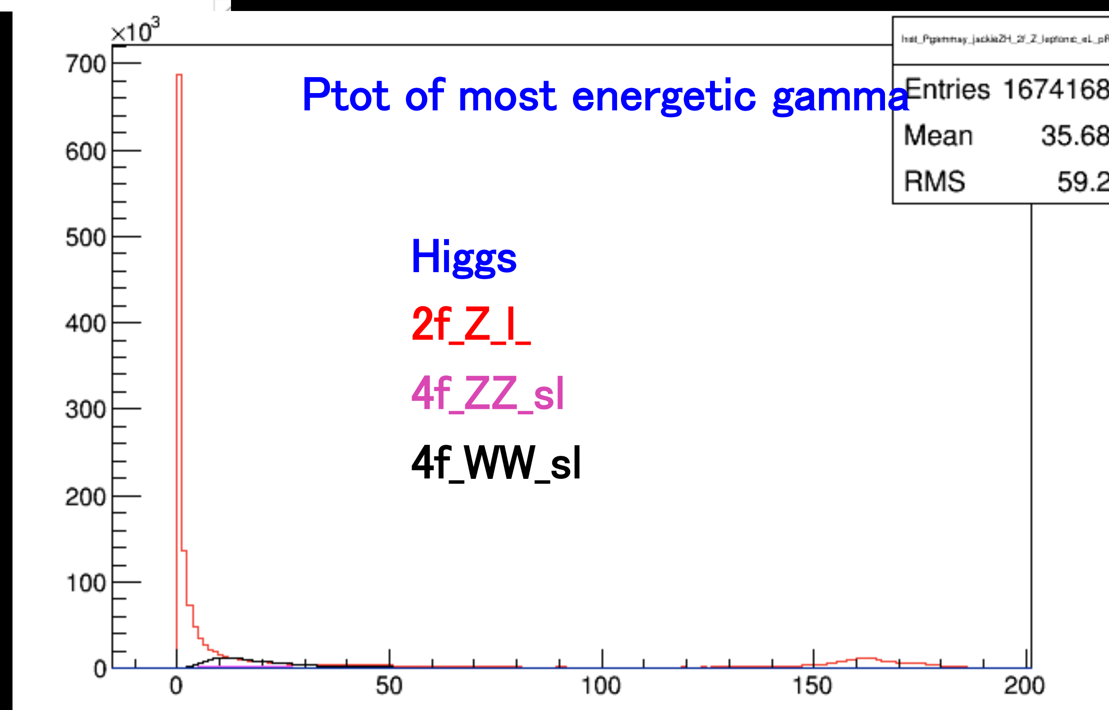
slight improvement w.r.t. just using ptbal info.

	Nsig	NBG	S/B	Eff_sig
dptbal > 10 GeV	1100	2771	0.40	48.0+/-0.5%
dptbal > 15 GeV	1099	2711	0.41	48.0+/-0.5%
(cos(θbal)<0.6) &&(Ebal<-70)	1076	2336	0.46	47.0+/-0.5%
(cos(θbal)<0.8) &&(Ebal<-70)	1083	2431	0.45	47.3+/-0.5%

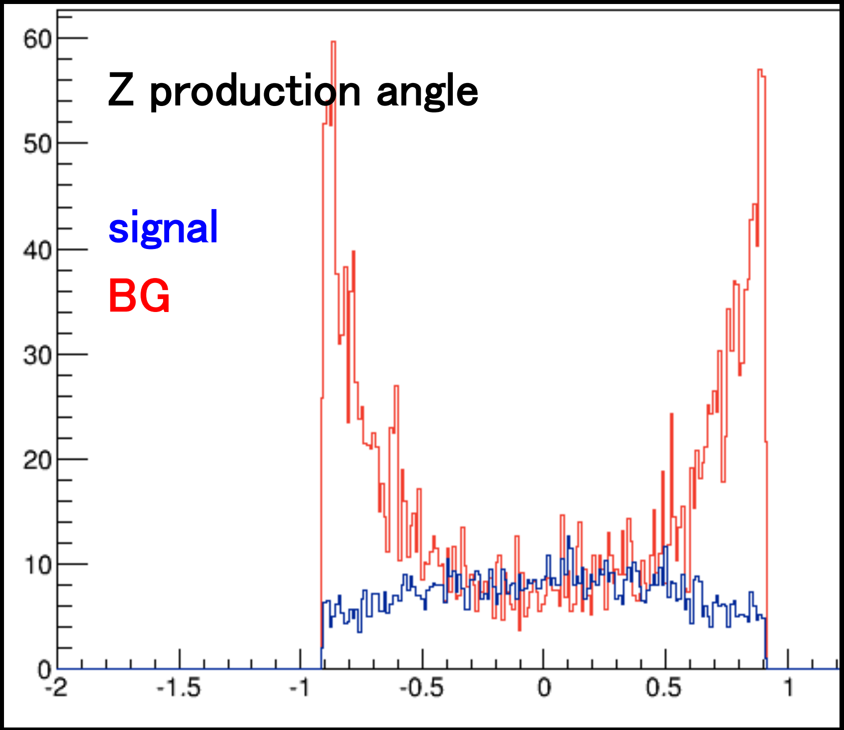
- cos θ bal = angle between γ and di–muon
- Ebal = (γ energy) – (di–muon energy)

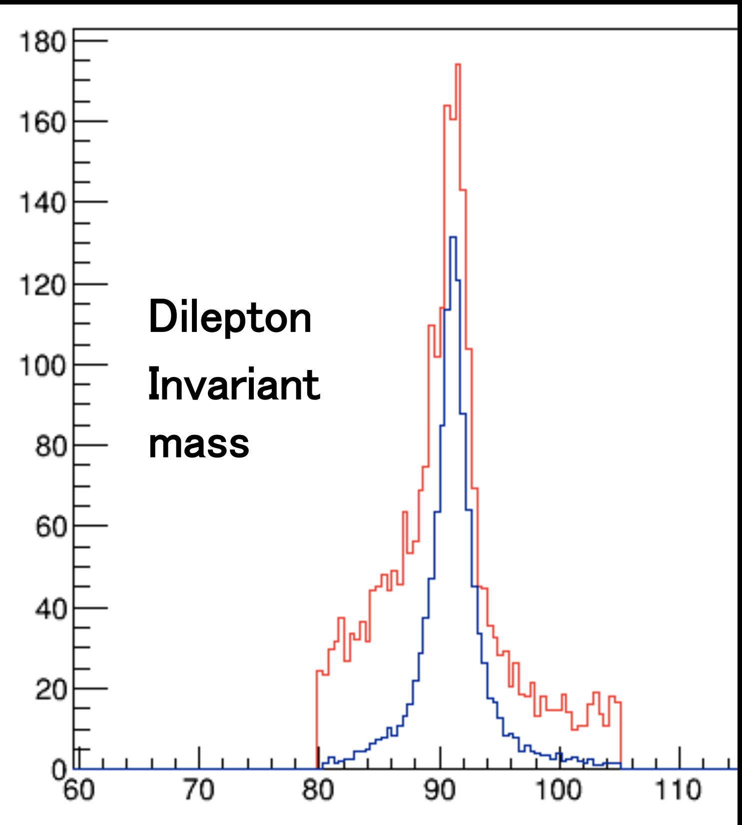

hist_Pgammaz_jackieZH_2f_Z_leptonic_eL_pR
Entries 21802
Mean -0.1825
RMS 16.95
Pz of most energetic gamma
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-100
-50
0
50
100

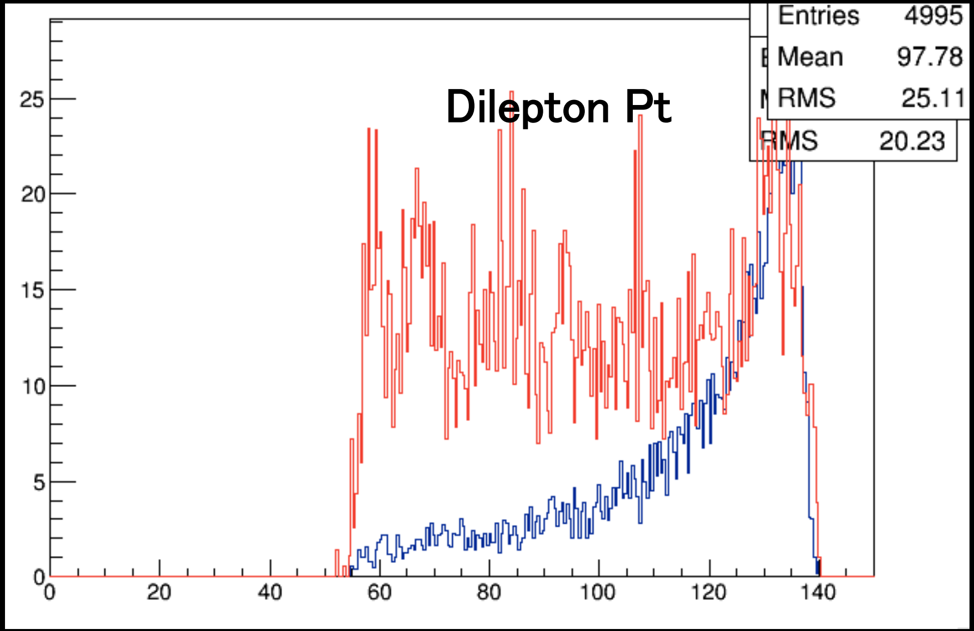

hist_Pgammax_jackieZH_2f_Z_leptonic_eL_pR
Entries 141386
Mean 0.2313
RMS 17.81
Px of most energetic gamma
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-100
-50
0
50
100


×10^3
Entries 1674168
Mean 35.68
RMS 59.2
Ptot of most energetic gamma
Higgs
2f_Z_l_
4f_ZZ_sl
4f_WW_sl
700
600
500
400
300
200
100
0
0
50
100
150
200

formed using templates
for signal events







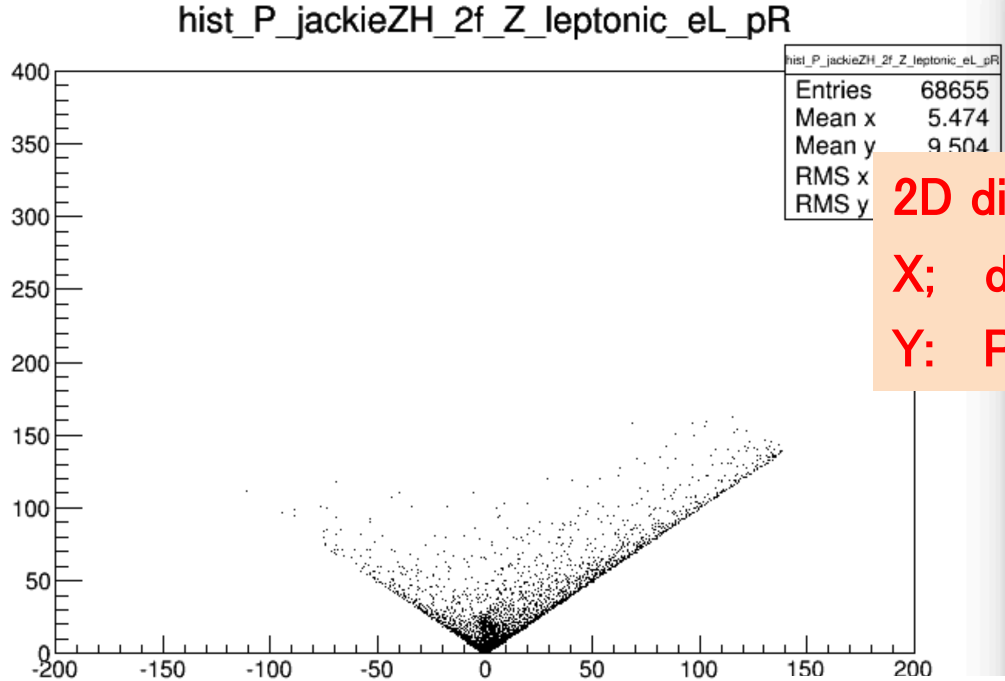
Chose the conditions that give relatively high signal efficiency and low BG

- then played with likelihood cut
- and observed cross section measurement precision

cuts		(both eLpR and eRpL) Nsig	Nbg	S/B ratio	sig eff	Δσ/σMC)		(only eLpR) 2f_Z_l	4f_WW_sl	4f_ZZ_sl
last week		1056	2189	0.48	46.1+/−0.5%	4.39+/−0.00%	(RMS: 0.16%)	225 (0.011%)	241 (0.009%)	950 (0.52%)
this week										
Likelihood L1 using Minv, CosZ, Pt, max γ Pt	ln(L1)>−19.8	1057	2025	0.52	46.2+/−0.5%	4.29+/−0.00%	(RMS: 0.15%)	28 (0.002%)	377 (0.014%)	967 (0.53%)
	ln(L1)>−19	1026	1746	0.59	44.8+/−0.5%	4.16+/−0.00%	(RMS: 0.15%)	25 (0.001%)	270 (0.010%)	868 (0.48%)
Likelihood L2 using Minv, CosZ, Pt	ln(L2)>−15.8	1054	1949	0.54	46.1+/−0.5%	4.28+/−0.00%	(RMS: 0.15%)	90 (0.004%)	285 (0.010%)	947 (0.52%)
	ln(L2)>−16	1062	2010	0.53	46.4+/−0.5%	4.27+/−0.00%	(RMS: 0.15%)	95 (0.004%)	306 (0.010%)	967 (0.53%)

<u>Observations</u>

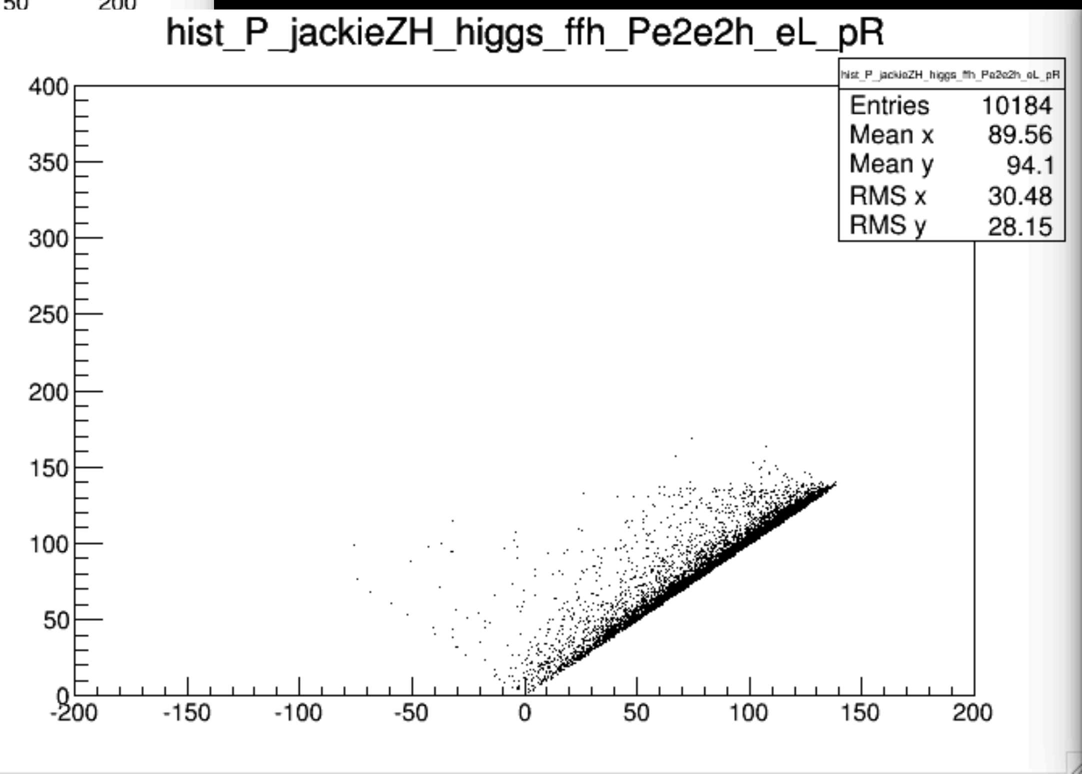
- Likelihhod cut using max γ Pt (L1) is effective for 2f_Z_leptonic
- It is hard to cut 4f_ZZ_semileptonic BG without removing too much signal
- Residual 4f_WW_semileptonic BG depends on likelihood cut value
- → can resolve by adding muon isolation cut (?)

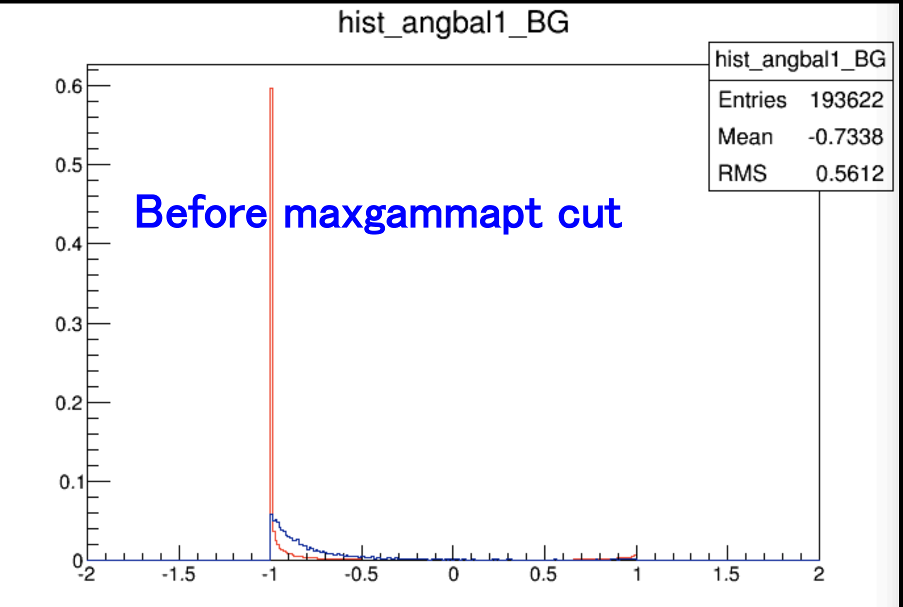


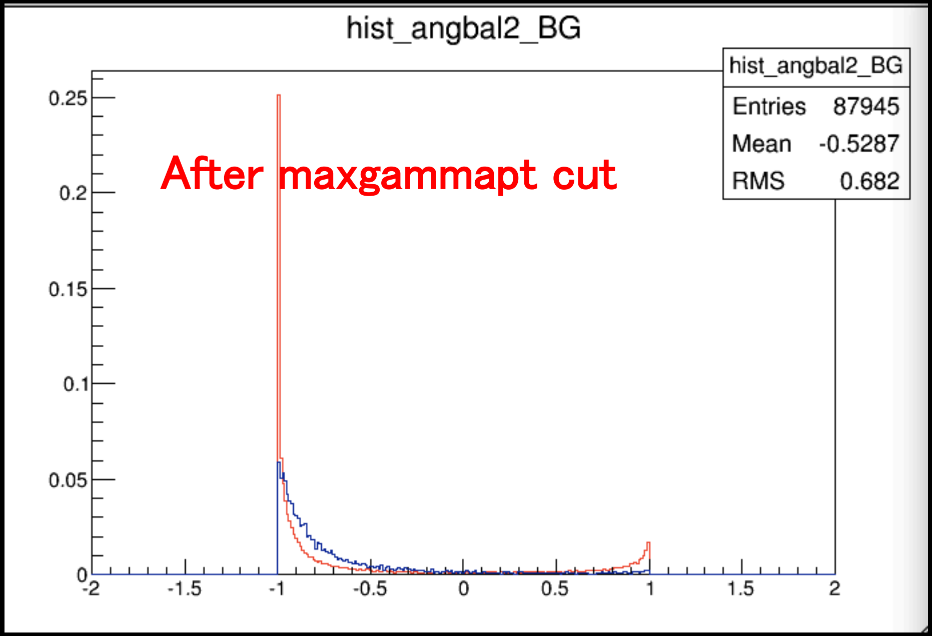
2D distr of

X; dptbal = pt_dl − pt_γ

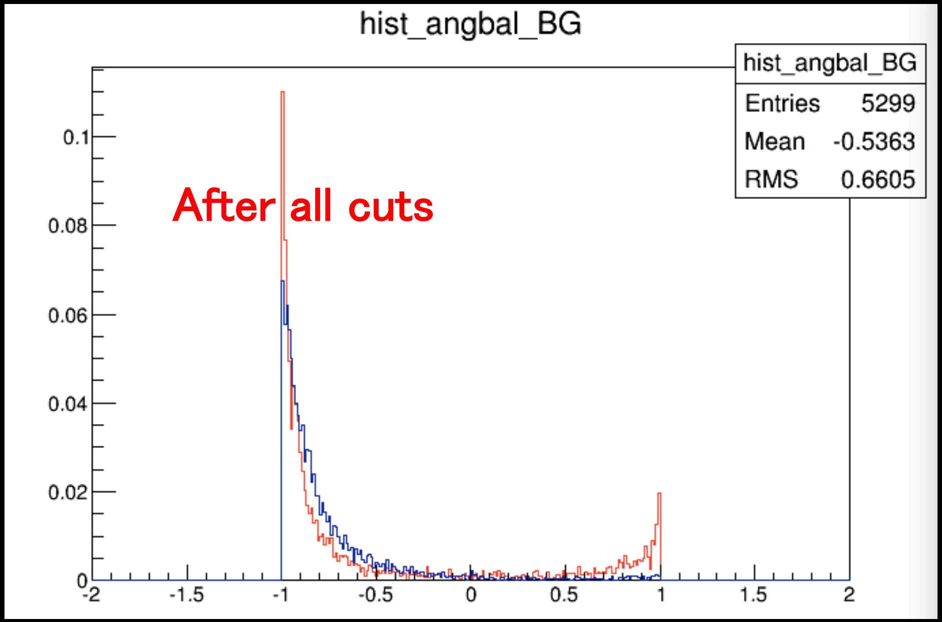
Y: Pt_sum = |Pt_dl − Pt_γ| (in vectors)



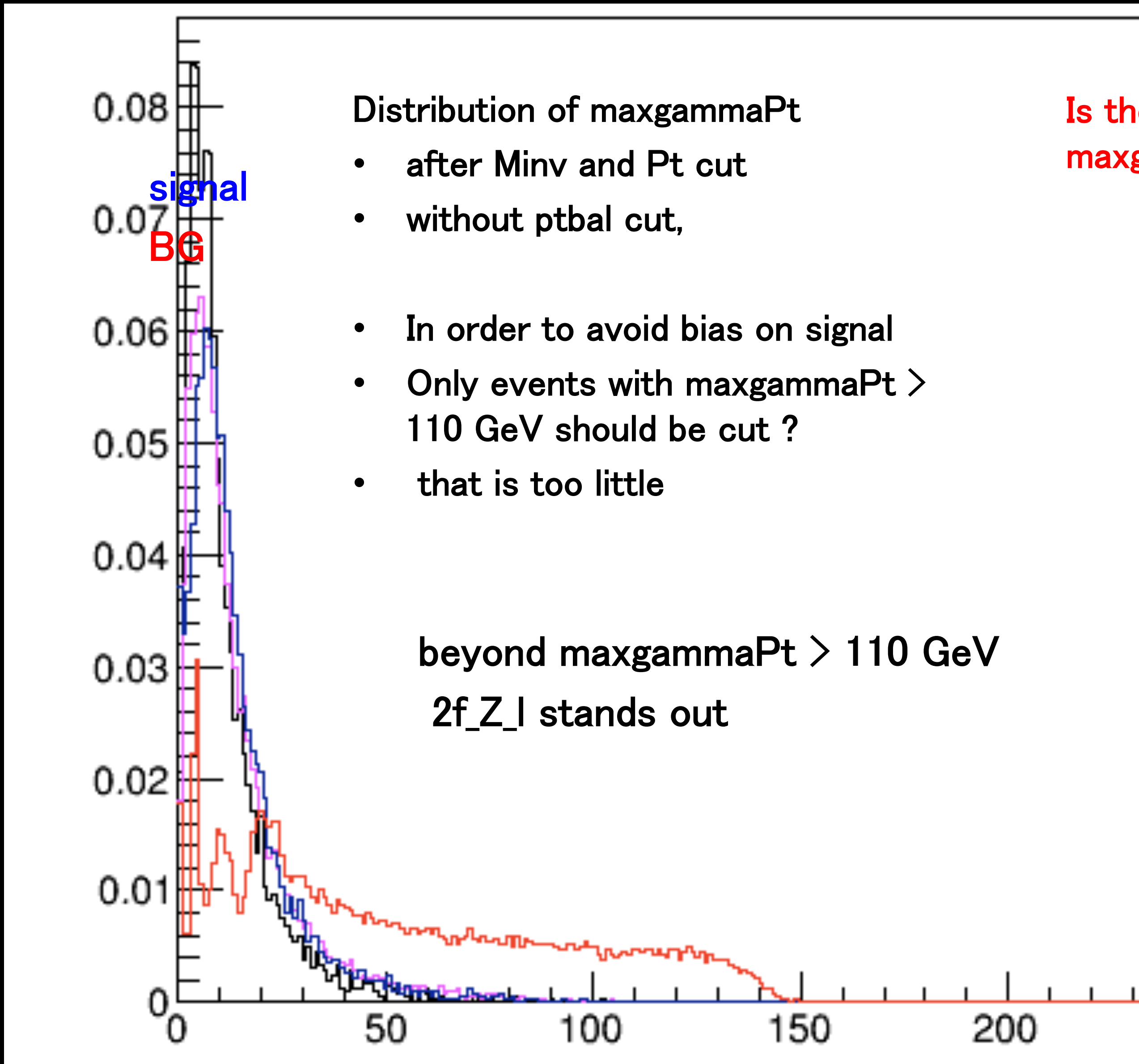




Distr of cos(θ bal)



Is there some way to combine info of maxgammaPt and dptbal ?



Distribution of maxgammaPt

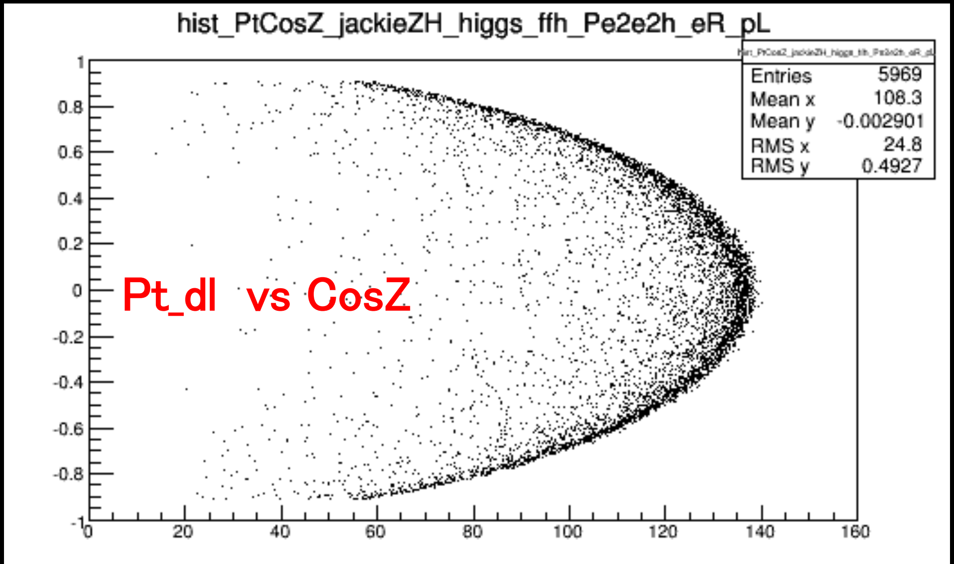
- after Minv and Pt cut
- without ptbal cut,

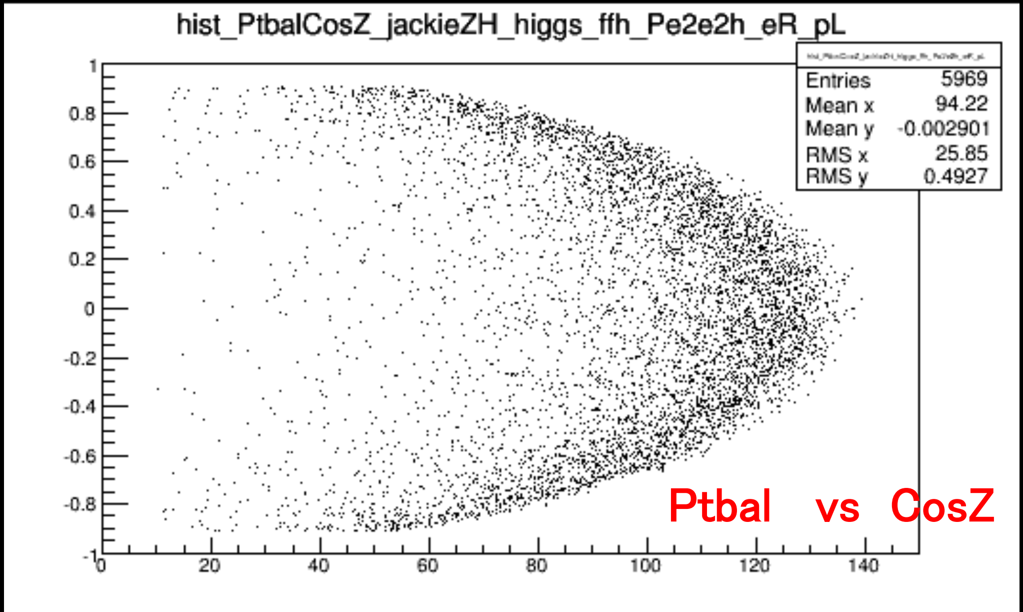
- In order to avoid bias on signal
- Only events with maxgammaPt > 110 GeV should be cut ?
- that is too little

beyond maxgammaPt > 110 GeV

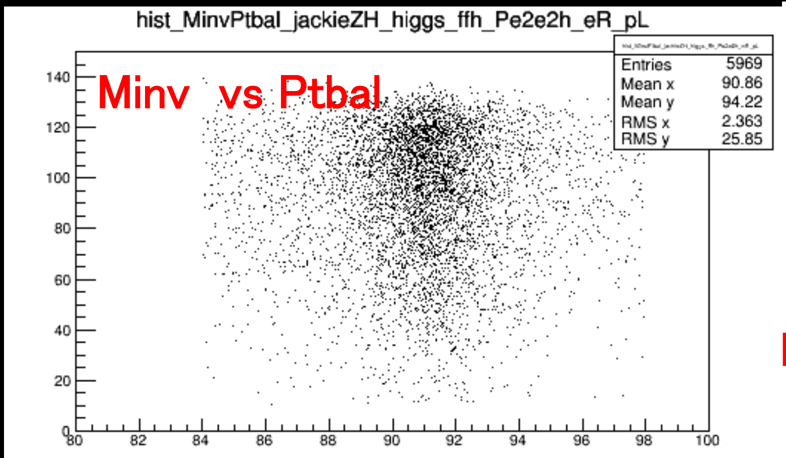
2f_Z_l stands out

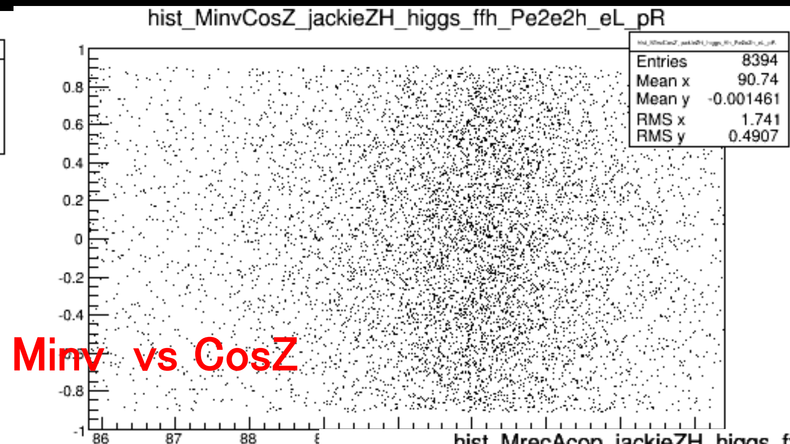
Parameters showing correlation: not good for likelihood cut (?)

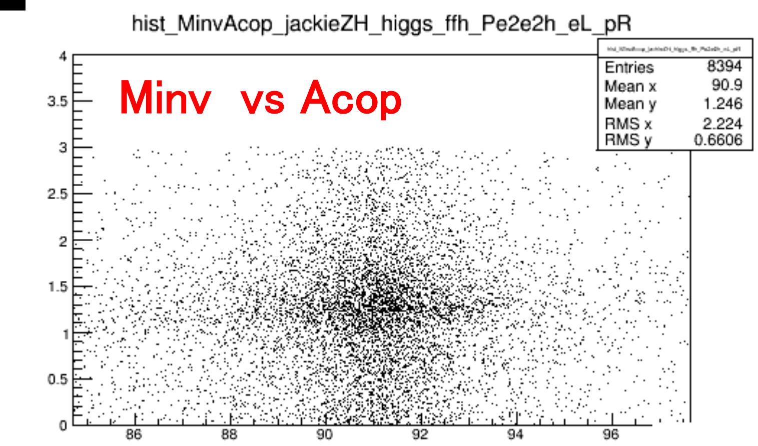


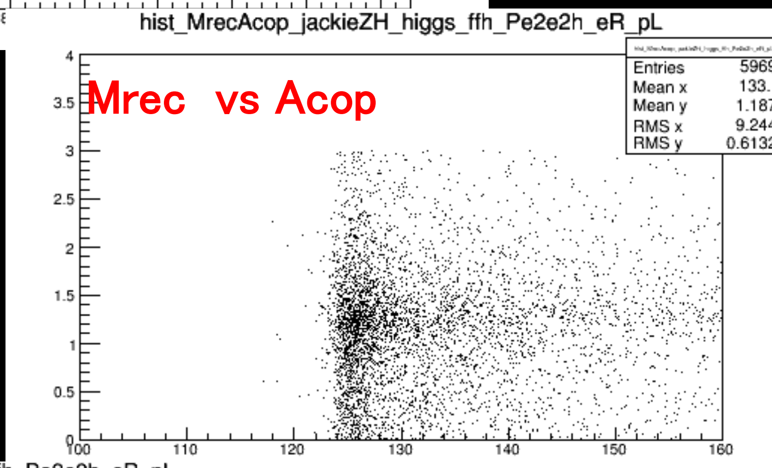


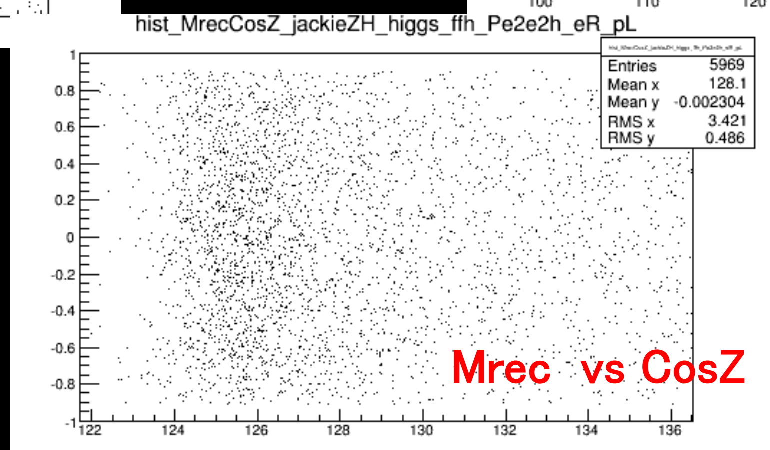
Parameters with no apparent correlation: good for likelihood cut (?)











断面積測定の精度の評価 ： 異なるECMとビーム偏極の比較 NEW

ECM	Pol	ε	Δσ/σ	xsec [fb]	Nsig	significance
350 GeV	(−0.8,+0.3)	47.7+/−0.5%	4.9+/−0.2%	6.71+/−0.34	1092+/−55	17.7
	(+0.8,−0.3)	47.8+/−0.5%	5.0+/−0.2%	4.53+/−0.26	720+/−41	17.8
250 GeV	(−0.8,+0.3)	66.4+/−0.5%	3.6+/−0.1%	10.52+/−0.38	1747+/−64	21.7
	(+0.8,−0.3)	64.4+/−0.5%	3.3+/−0.1%	8.68+/−0.30	1398+/−48	22.7

注） この表の fitting範囲は115−150 GeV （AWLC14 @ Fermilabより）
現在350 GeV のみ範囲を広げて、 Δσ/σが 4.7 +/− 0.2 % へ改善した

比較#1: ECM =350 GeV ←→ ECM = 250 GeV :

ECM= 250 GeVの方がΔσ/σ と Mh 精度 が良い *μの運動量測定の分解能は低いPTほど良い*

比較#2: Pol: （−0.8,+0.3）←→（+0.8, −0.3）:

- 異なる偏極の間でΔσ/σに大きな差がなさそう
- （+0.8, −0.3）: 統計が少ないが、S/B がずっと高い : WW BGが顕著に抑制

注意） 先行studyとの色んな違い :

- assumed L (350, 250 GeV) = (333 , 250 fb-1) vs RDR: (300 fb-1, 188 fb-1)
- このstudy : ALL 2f, 4f, 6f BGs (whizard generator) vs only WW, ZZ (pythia generator ?)

results for sqrt(s) =250 GeV , L = 250 fb-1

evaluated using Toy MC generated from fitted function shapes

250 GeV	ε	Δσ/σ	xsec	Nsig	S/N	significance
(−0.8,+0.3)	66.4+/−0.5%	3.6+/−0.1%	10.52+/−0.38	1747+/−64	0.37	21.7
(+0.8,−0.3)	64.4+/−0.5%	3.3+/−0.1%	8.68+/−0.30	1398+/−48	0.81	22.7