Higgs Recoil Mass Study at ECM=350 GeV and 250 GeV

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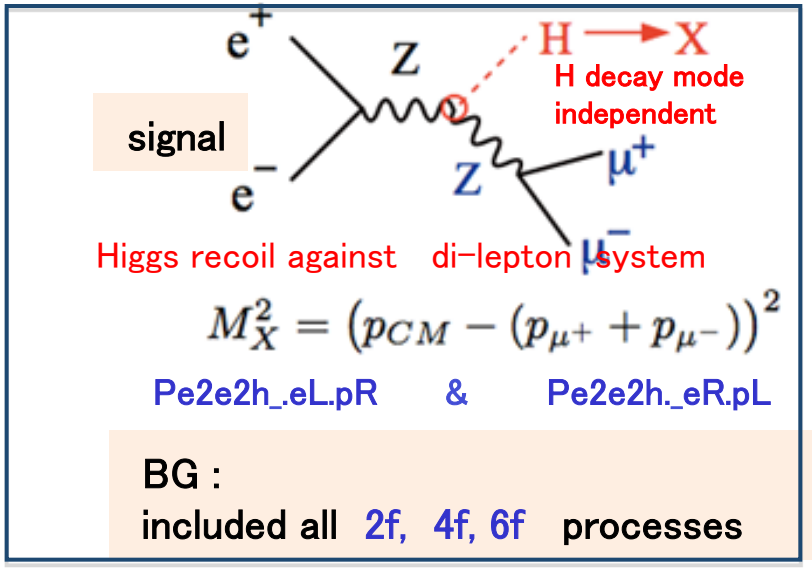
recoil mass study using e+e- → ZH → μ+μ-H
ECM = 350 GeV as well as ECM= 250 GeV,



Goal:

- precise measurement of Higgs cross section σ_H
- contribute to the decision for ILC run scenario

Many physics become important at Ec.m.s.= 350 GeV

ILC sample used in analysis

chanel	mh	ECM	L	Spin polarization	Detector simulation
e+e→Zh->μμh	125 GeV	350 GeV 250 GeV	333 fb-1 250 fb-1	P(e-,e+) = (-0.8,+0.3) (+0.8,-0.3)	Full ILD (ILD_01_v05 DBD ver.)

Layout of this Talk

- **Evaluation of data analysis performance:** focusing on σ_ZH measurement precision
- **Comparison with ECM=250 GeV and alternative polarization scenarios**
- **additional comments**
- **Summary & Plans**

Muon Candidate Selection

using conditions on

- charge,
- E_cluster / P_total < 0.5
- isolation (small cone energy)
- cos(track angle) < 0.98 & |D0/δD0| < 5

Best Z Candidate Selection

2 muon candidates with **opposite charge**

choose pair **with invariant mass closest to Z mass**

Final Selection

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

- **73 GeV < M_inv < 120 GeV**
- **10 GeV < pT_mumu < 140 GeV**
- **dptbal > 10 GeV**
- **Ebal < 230 GeV**
- **|cos(θ_Zpro)| < 0.9**
- **120 GeV < Mrecoil < 140 GeV**
- **Likelihood cut**

Data Selection Method

Experimented with various cut threshold to achieve highest sig eff and S/N raio

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
- **dptbal = Pt_dl − Pt_γ**
- Ebal = Eγ + E_dl

Results after selection

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

- Sig efficiency = 51 %
- S/B = 0.63, significance = 21.3

similar optimized for sqrt(s)=250 GeV and other polarization secenarios

recoil mass fitting method

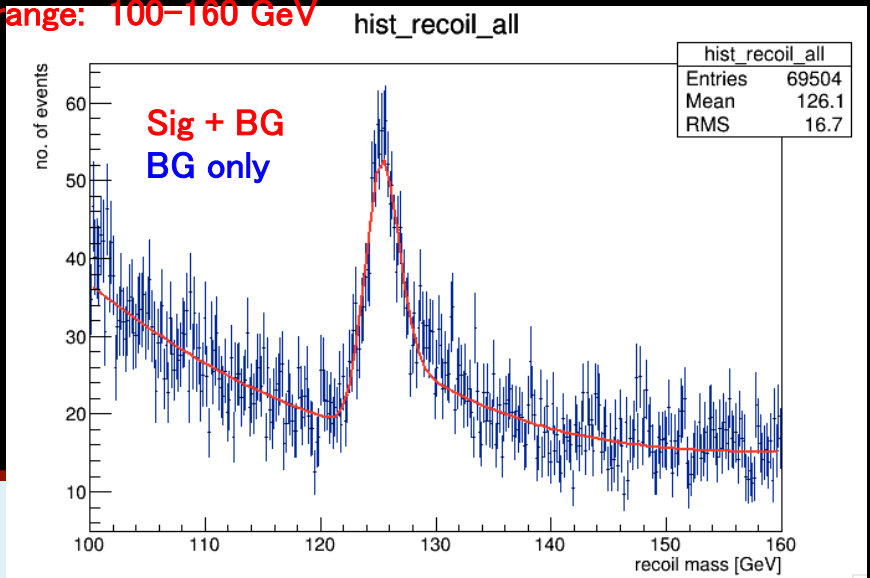
1st step:

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

2nd step :

fit Sig + BG : only float height and mean

fix others from step 1



◆ **SIGNAL: GPET:** 5 parameters :

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

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

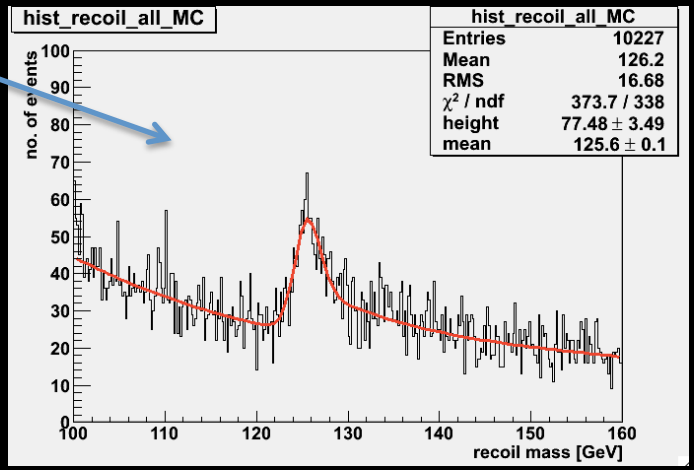
in terms of M_h、 xsec etc……

method:

generate MC events according to fitted "real" data

(Poisson distr.)

fit MC hist with same function as "data" → get Nsig, xsec



Compare ECM=350 GeV and ECM= 250 GeV , polarization (−0.8,+0.3) and (+0.8, −0.3)

Evaluated xsec error and validity of fitting using Toy MC generated from these fitted function shapes

	Nsig	Nbg	S/B ratio	significance	sig eff (before Mrec)	Δσ/σ(MC)
Ecm=350 GeV						
(−0.8,+0.3)	1171	1865	0.63	21.3	51% (82%)	3.98%
(+0.8,−0.3)	807	716	1.13	20.7	52% (82%)	4.40%
Nsig and Nbg in Mrecoil 120−140 GeV						
Ecm=250 GeV						
(−0.8,+0.3)	1703	3815	0.45	22.9	65% (76%)	3.31%
(+0.8,−0.3)	1178	1185	0.99	24.2	67% (76%)	3.49%

◆ ECM= 250 GeV (w.r.t. 350 GeV)

higher statistics, sharper recoil mass peak → 17 % better xsec precision

may need more optimization of analysis method to suppress BG

◆ for (+0.8, −0.3) : S/B much higher:

- WW BGs significantly suppressed , other major BGs less also
- however statistics is lower → cause for slightly worse xsec precision ?

Compare with results from AWLC2014 (Fermilab)

	S/B ratio	significance	sig eff	Δσ/σ(MC)	improvement
Ecm=350 GeV					
(−0.8,+0.3)	0.63	21.3	51%	4.0%	18.8%
(+0.8,−0.3)	1.13	20.7	52%	4.4%	12.0%
Ecm=250 GeV					
(−0.8,+0.3)	0.45	22.9	65%	3.3%	8.1%
(+0.8,−0.3)	0.99	24.2	67%	3.5%	−6.1%

Current April, 2015

AWLC14: May, 2014

	S/B ratio	significance	sig eff	Δσ/σ(MC)
Ecm=350 GeV				
(−0.8,+0.3)	0.40	17.7	48%	4.9%
(+0.8,−0.3)	0.75	17.8	48%	5.0%
Ecm=250 GeV				
(−0.8,+0.3)	0.37	21.7	66%	3.6%
(+0.8,−0.3)	0.81	22.7	64%	3.3%

Key improvement points

- Use of Likelihood cut
- Isolated lepton finder in processor (thanks to Junping-san)
  → removes all 4f_WW_sl BG
- Use info of cone energy around most energetic gamma
  → cut 2f_Z BG using dptbal = pt_dl − pt_γ while preventing bias on signal

Relative results

	Nsig	Nbg	S/B	sig eff	xsec err
Ecm=350 GeV (−0.8,+0.3)	0.69	0.49	1.41	0.98	1.2
Ecm=250 GeV (−0.8,+0.3)	1	1	1	1	1
Ecm=350 GeV (+0.8,−0.3)	0.69	0.6	1.13	0.97	1.26
Ecm=250 GeV (+0.8,−0.3)	1	1	1	1	1

ECM = 350 GeV vs 250 GeV

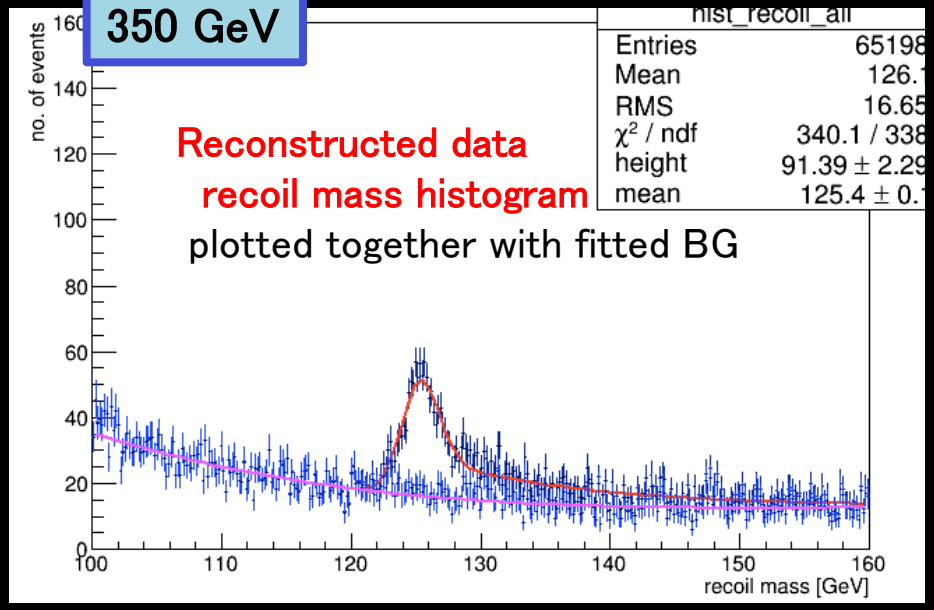
- xsec error is 17% better for 250 GeV
- Sig. eff almost same

Comparing polarization

	Nsig	Nbg	S/B	sig eff	xsec err
Ecm=350 GeV (−0.8,+0.3)	1	1	1	1	1
(+0.8,−0.3)	0.69	0.38	1.80	1.02	1.11
Ecm=250 GeV (−0.8,+0.3)	1	1	1	1	1
(+0.8,−0.3)	0.69	0.31	2.23	1.03	1.05

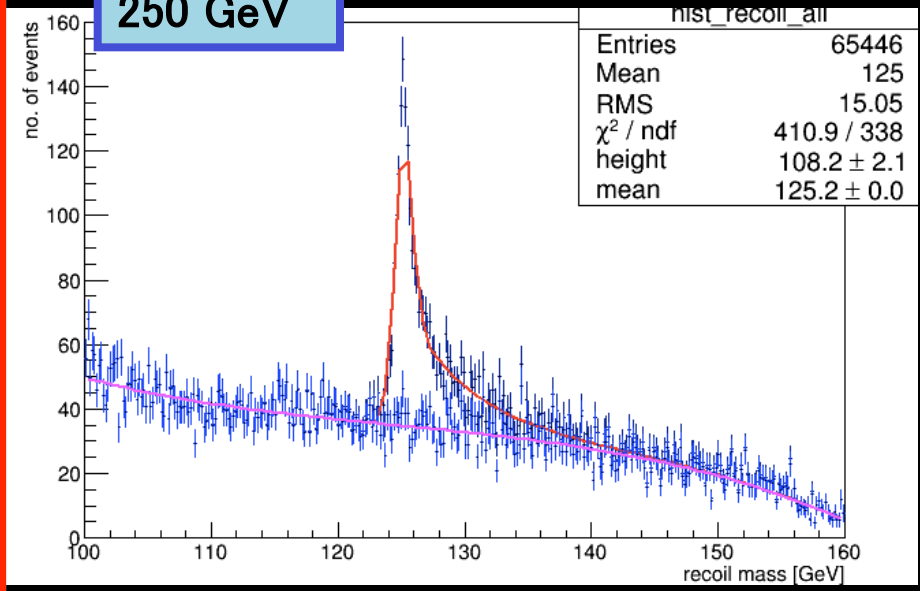
- xsec error is 10% better for left pol
- Sig. eff almost same

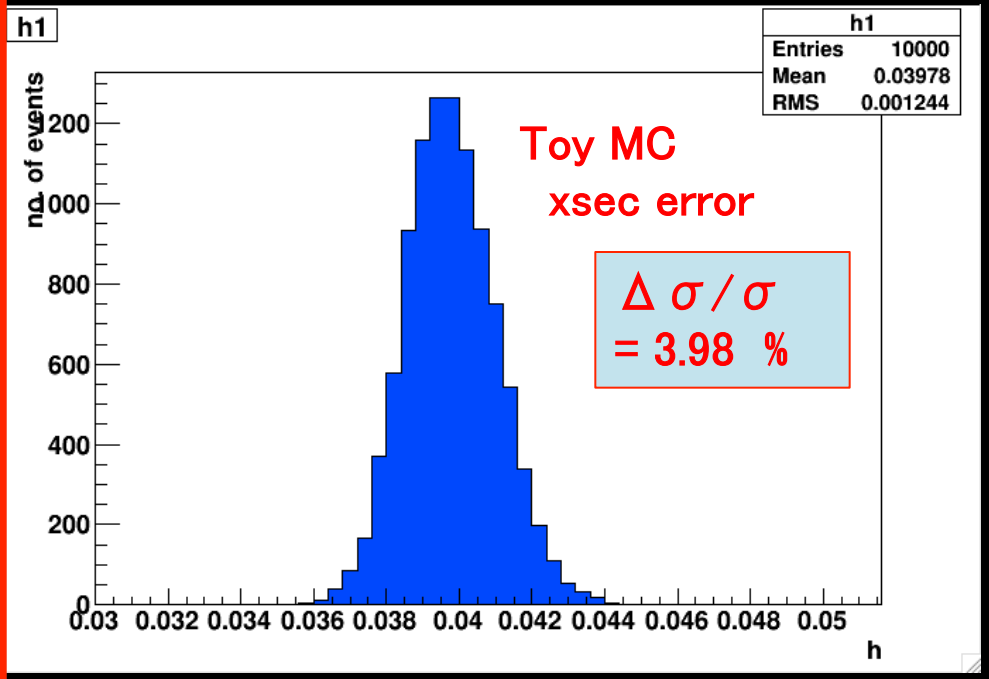
350 GeV



Reconstructed data
recoil mass histogram
plotted together with fitted BG

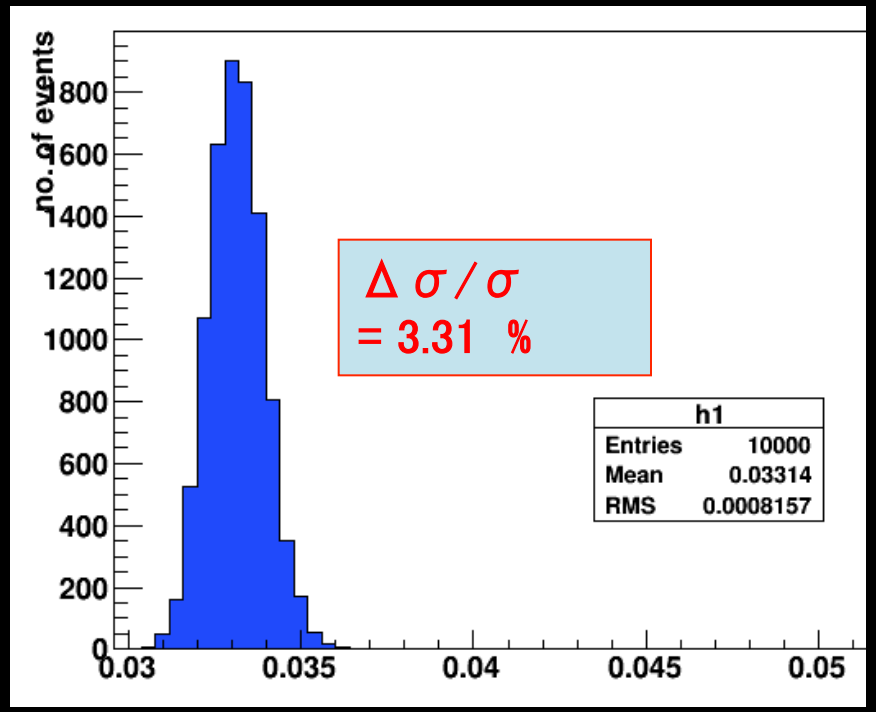
250 GeV





Toy MC
xsec error

$\Delta\sigma/\sigma$
= 3.98 %



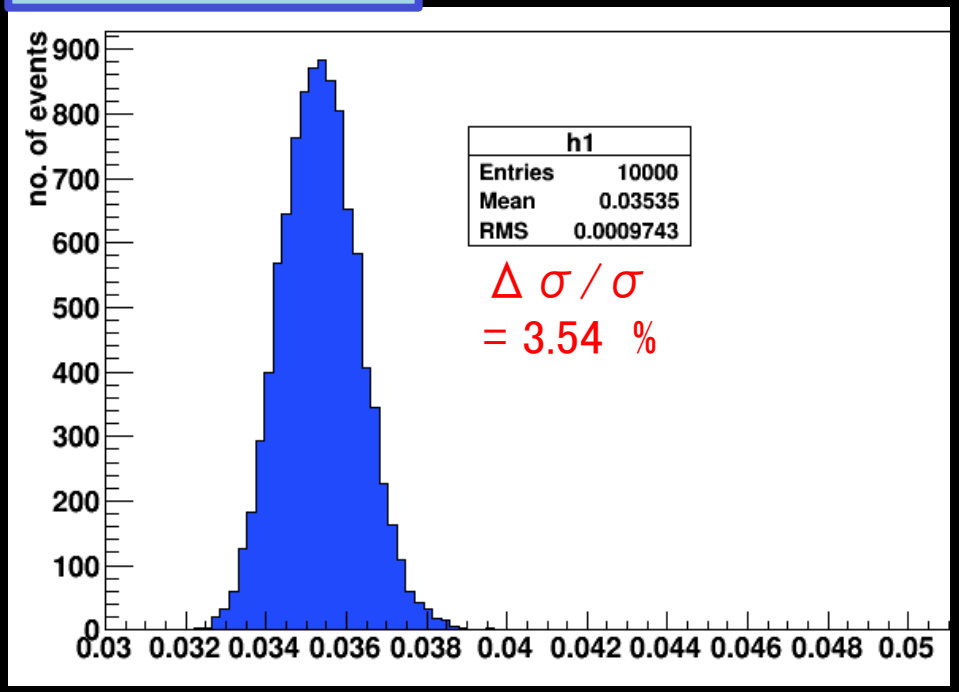
$\Delta\sigma/\sigma$
= 3.31 %

Toy MC study results
xsec error

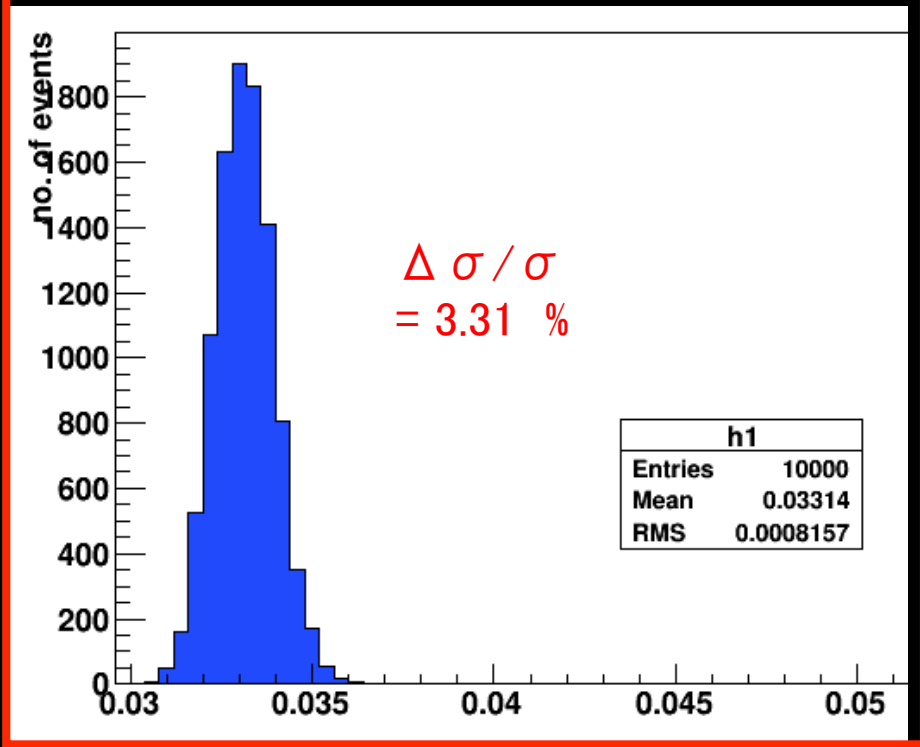
BG level is usually fixed for Toy MC
(optimistic scenario)

about 7 % worse if we float BG
(pessimistic scenario)

250 GeV, float BG



250 GeV, fix BG



not a big degradation in xsec precision if I float BG
since I fit recoil mass spectrum over a wide range *GGOD*

dominant BG after final selection (Mrec 120–140 GeV + Likelihood cut)

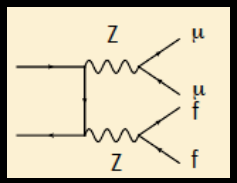
4f_ZZ_semileptonic : 991 *can't do anything*

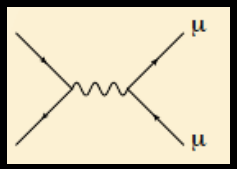
4f_ZZWWMix_leptonic: 320

vs

Higgs: 1171

	original		after Minv, pt		after dptbal		final	
P1: (−0.8,+0.3)								
P2: (+0.8,−0.3)	P1	P2	P1	P2	P1	P2	P1	P2
signal	2288	1543	2004	1355	1983	1339	1171	808
4f_ZZ_sl	188125	99900	16922	8051	16614	7883	991	416
4f_ZZWWMix_l	541187	35527	19325	1573	18024	1485	320	42
2f_Z_l	2227000	1757000	85335	57319	13182	8819	79	59





number of events after each selection step is in

/ home/ ilc / jackie / jackieZHProcessornew / data /

350 GeV: outputD1_350GeVP1.dat (−0.8, + 0.3), outputD1_350GeVP2.dat (+0.8, − 0.3)

250 GeV: outputD1_250GeVP1.dat (−0.8, + 0.3), outputD1_250GeVP2.dat (+0.8, − 0.3)

Note) These will continue to be optimized in days to come

Important NOT to cause mode dependence by dptbal selection

- dptbal cut is carefully done so as to minimize signal bias

- isolated photon finder: confirmed that almost all photons related to dptbal cut are isolated (small cone energy) i.e. not from Higgs decay

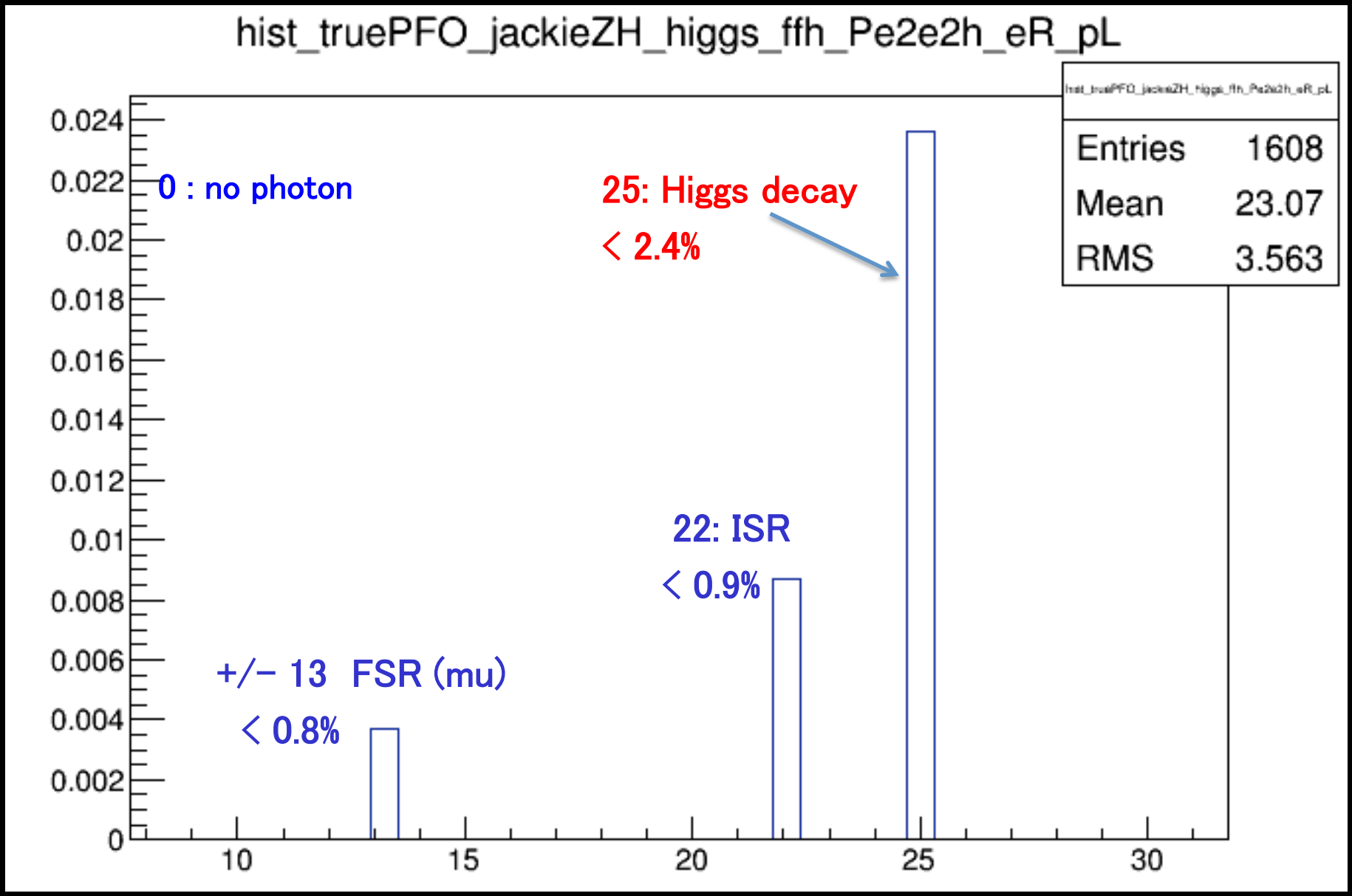
- In Higgs events, < 2.4% of photons are from Higgs decay
  (remaining are from ISR / FSR, > 95% of Higgs events have no photon tagged)

- ～1/5 of Higgs decay related photons removed by dptbal cut
  < 0.5% of total Higgs events

- However there is a slight finite bias
  H → τ τ mode receives heaviest effect

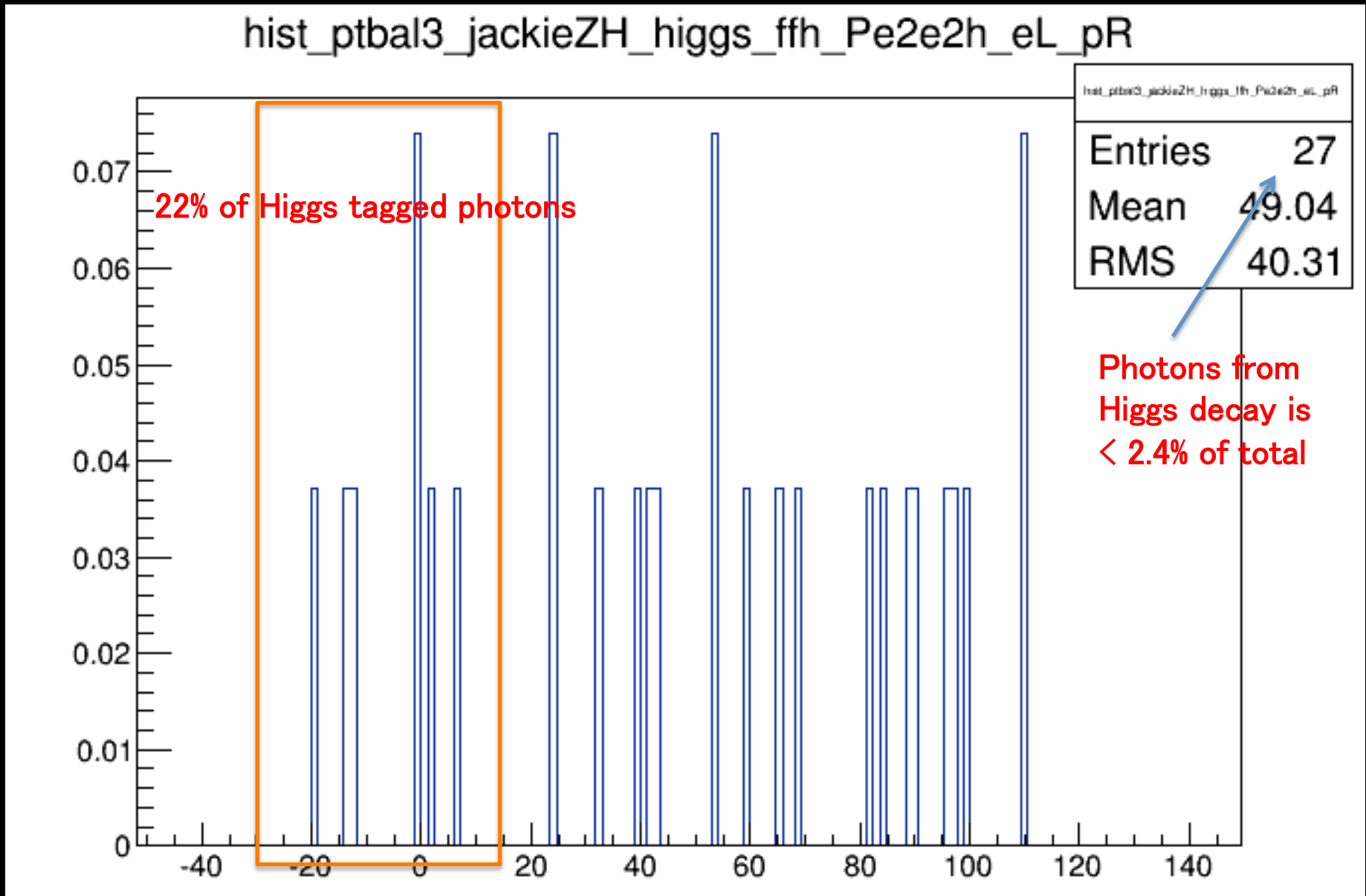
For further info on each mode, see
/ilc / home / jacki e/ jackieZHProcessornew / steer
mode1.dat mode2.dat

Distribution of PDG of photon parent



Out of photons from Higgs decay, about 22% removed by dptbal cut

➔ Total bias < 0.5% (2.4 % * 22%)



Additional comments about detector performance

issues noticed while studying dptbal cut

- There seem to be a “HOLE” where photon energy cannot be reconstructed between polar angle θ of 5 – 8 deg

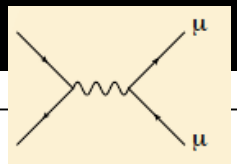
- LumiCal outer acceptance angle ～ 80 mrad (4.6 deg)
  (BeamCal is even more forward)

- HOLE is between ECAL endcap and LumiCal → *hopeless (?)*

- di-lepton pt can still be constructed well → not a concern for recoil mass study

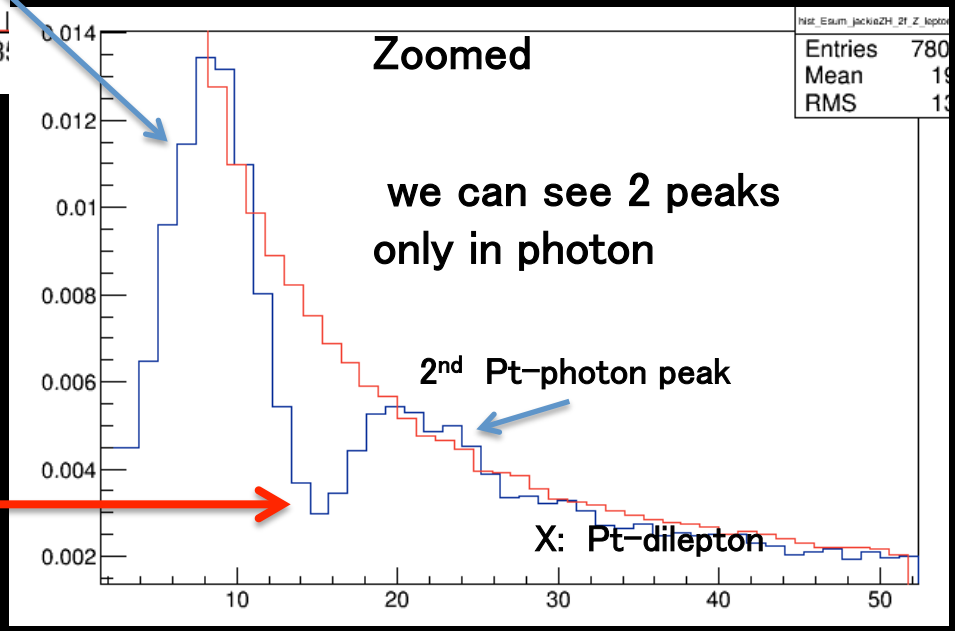
- However photon detection maybe an issue for SUSY / DM related research

2f_Z_leptonic BG （$\mu\ \mu$）



- Pt_dilepton distr is smooth
  Peak at 2.5 GeV (expected from crossing angle 14 mrad)

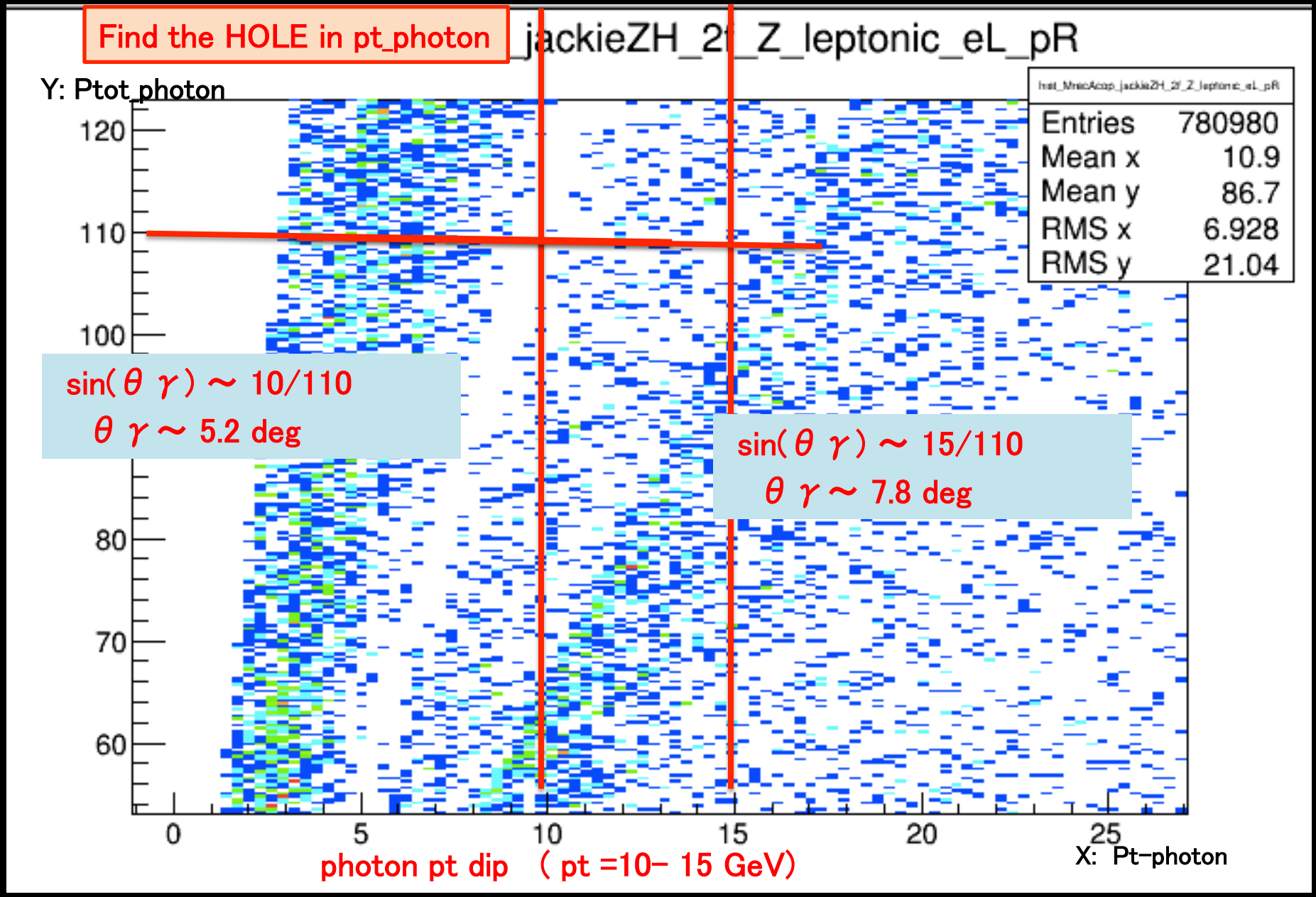
- However there is a dip in pt_photon !!!!
  (2−peak structure)



we need to explain this dip
(pt_photon − 15 GeV)

2f BG: Pt_γ vs Ptot_γ

$\sin(\theta\ \gamma) = Pt / Ptot$



Summary

Higgs recoil study using **e+e- → ZH → μ+μ-H** @ **ECM =350 GeV**, L = 333 fb-1

Goal: **contribute to deciding ILC run scenario and detector design optimization**

- **optimization of data selection method**
- compared with **Ec.m.s. = 250 GeV and different polarization scenarios : (-0.8, 0.3) vs (+ 0.8, -0.3)**

< Preliminary results >

350 GeV: **(-0.8, +0.3) Δσ / σ = 4.0 % , ε_sig～50%**
(+0.8, -0.3) Δσ / σ = 4.4 % ,

250 GeV: **(-0.8, +0.3) Δσ / σ = 3.3 % , ε_sig ～ 65%**
(+0.8, -0.3) Δσ / σ = 3.5 %

- **ECM= 250 GeV has better Δσ/σ by 17% w.r.t. ECM=350 GeV**
- (+0.8, -0.3) has better S/B , but lower statistics, 5-10% worse Δσ/ σ

significant improvements w.r.t. AWLC14 (@Fermilab May 2014) :
xsec precision better by ～ 19 % (350 GeV, (-0.8, + 0.3)

Plans

- the goal is always to cut more BG without losing too much signal
  especially must minimize bias on signal (cause of mode dependence)
- **implement similar methods to Zee channel**
  so we can get a more reliable comparison of ECM = 250 GeV vs 350 GeV

BACKUP

	rel loss after dptbal cut
bb	**0.6%**
tt	**4.0%**
ww	**1.1%**
cc	**0.9%**
gg	**1.0%**
zz	**1.6%**
mm	**0.0%**
aa	**50.0%**

For further info on each mode, see
/ilc / home / jacki e/ jackieZHProcessornew / steer
mode1.dat mode2.dat

2f BG Pt_γ vs Cos(θ γ)

Find the HOLE in pt_photon

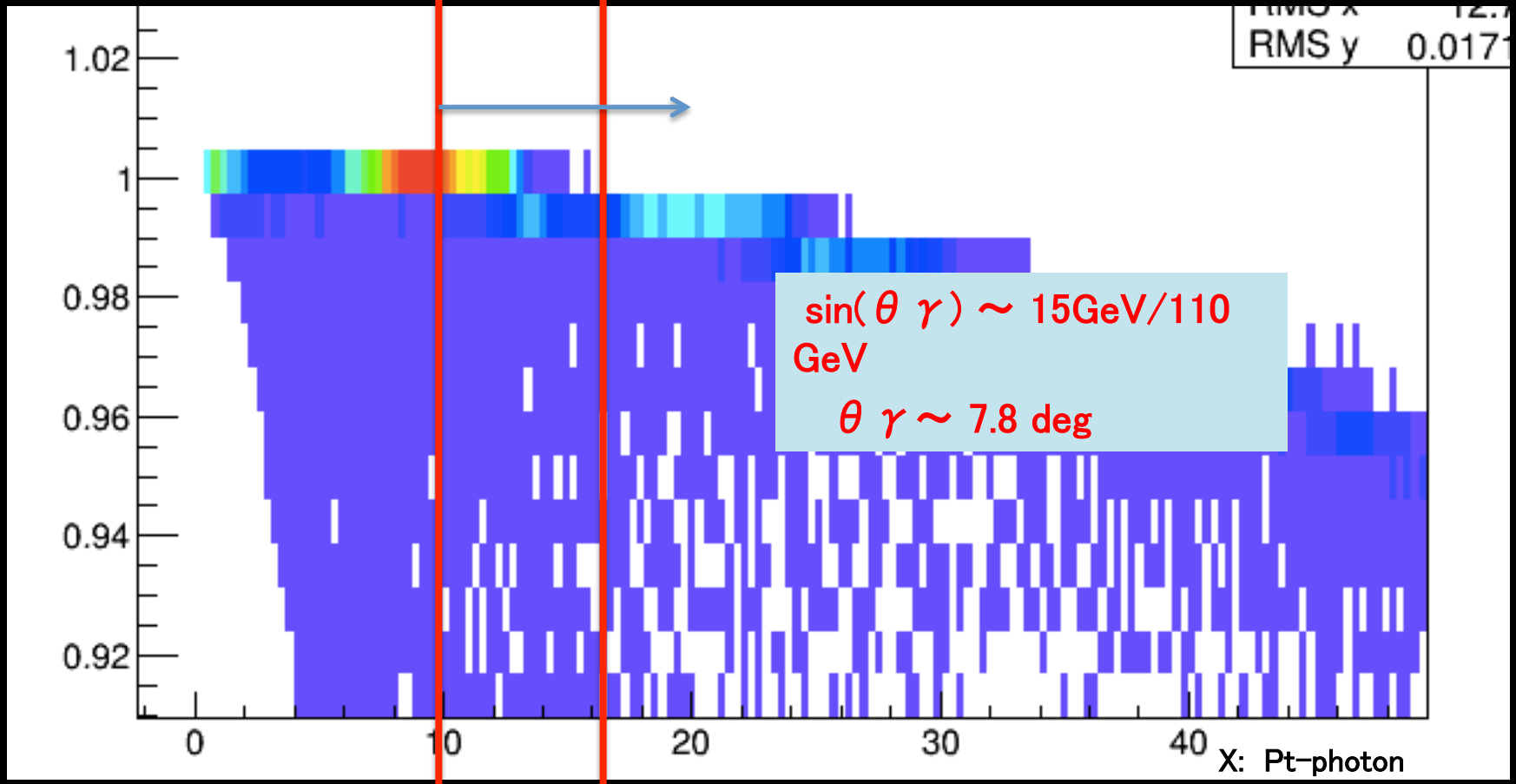
Not requiring non-zero γ energy

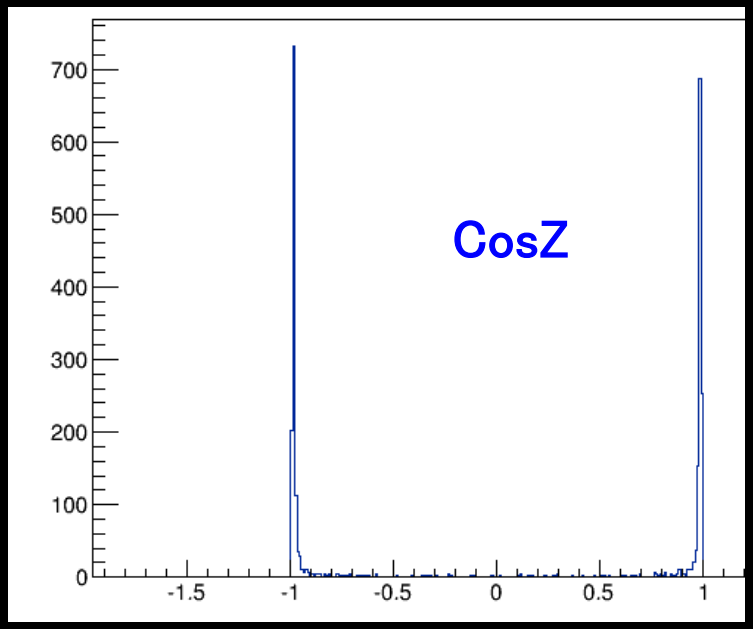
peak is at 10 GeV

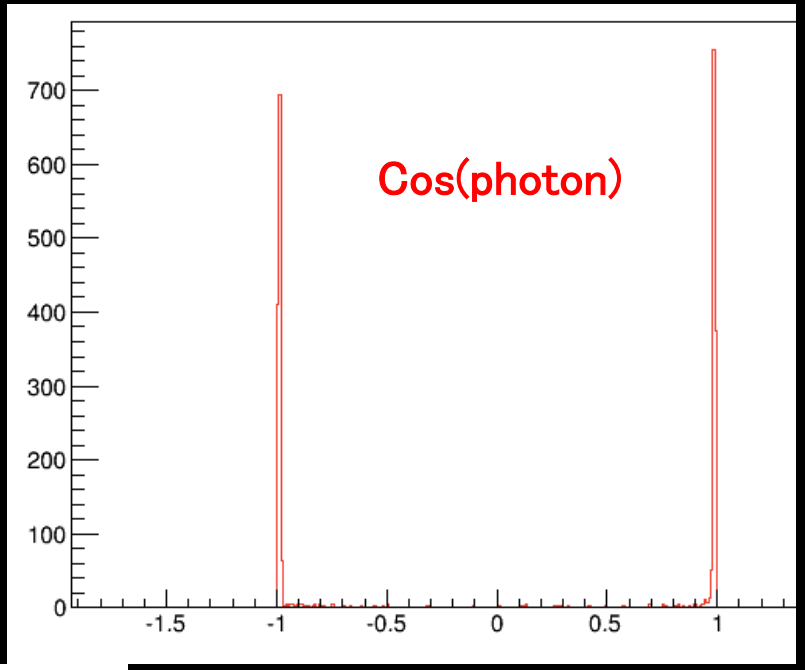
very forward direction

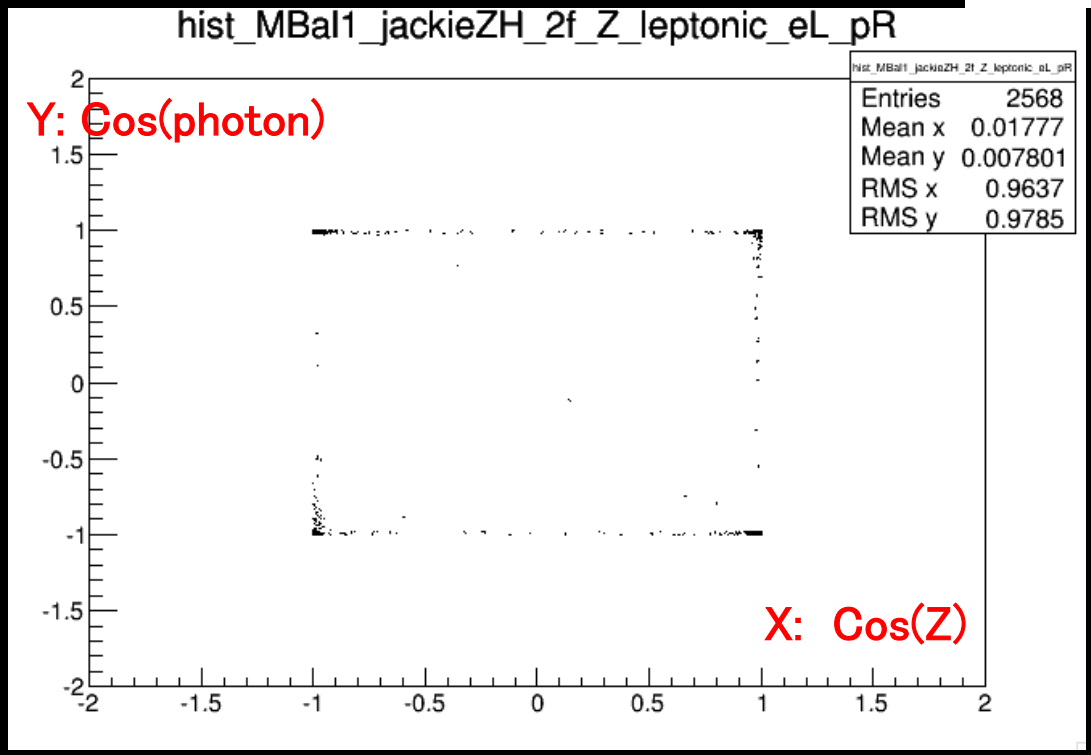
it seems photon pt dip is around 15 GeV

cos(θ γ) > 0.995









2f BG : only for region :

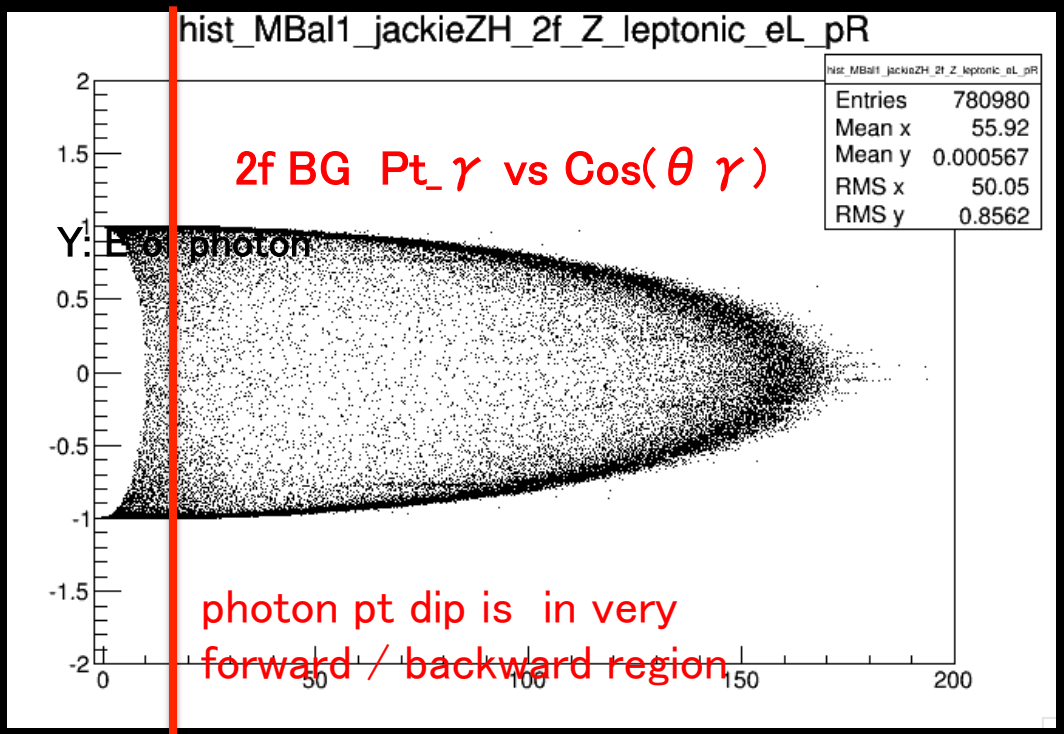
- 10 < dptbal < 18 GeV
- 10 < pt_dl < 40 GeV

Pt = sin(θ) * Ptot

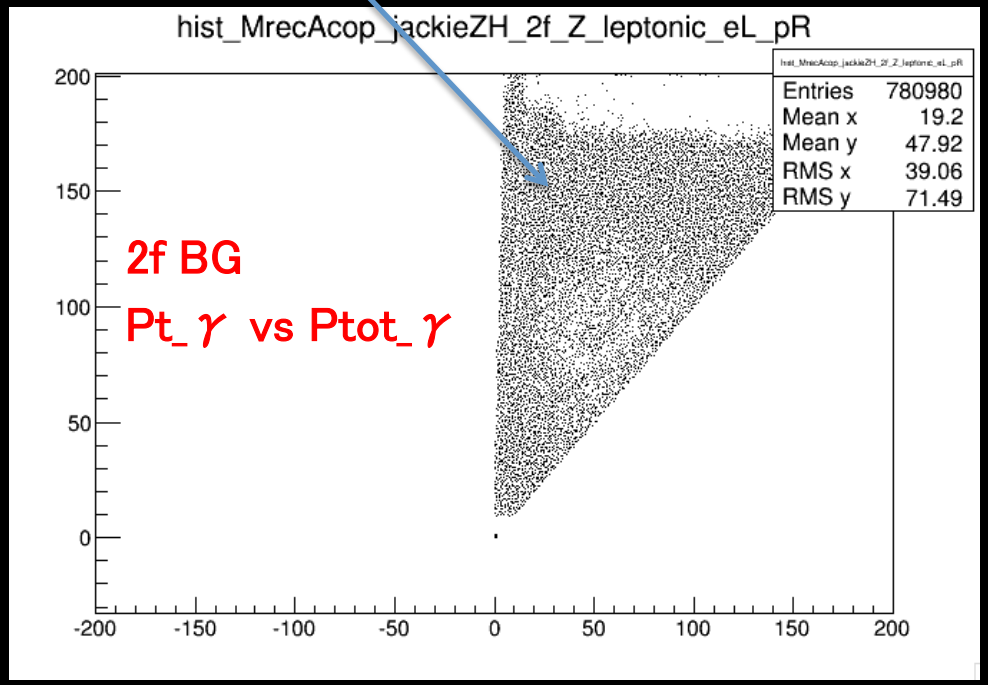
Ptot = fixed

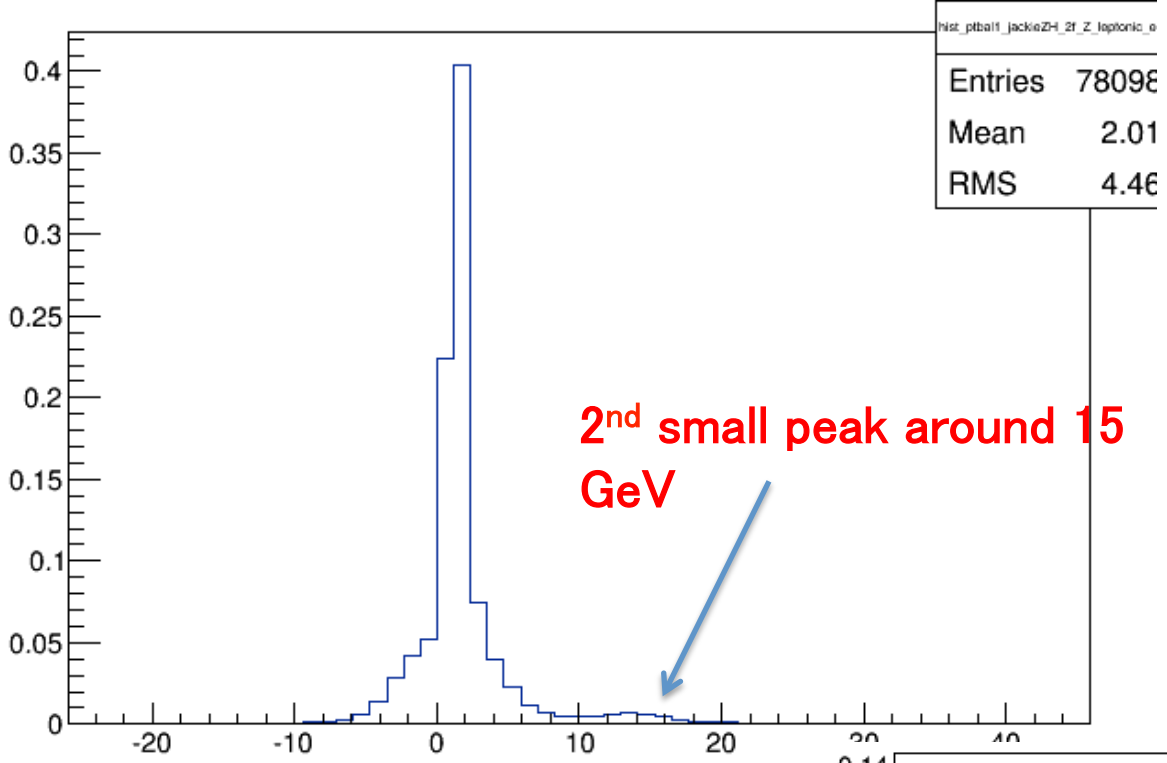
so small Pt

←→ very forward / backward



High photon energy but low pt ←→ go to beam pipe



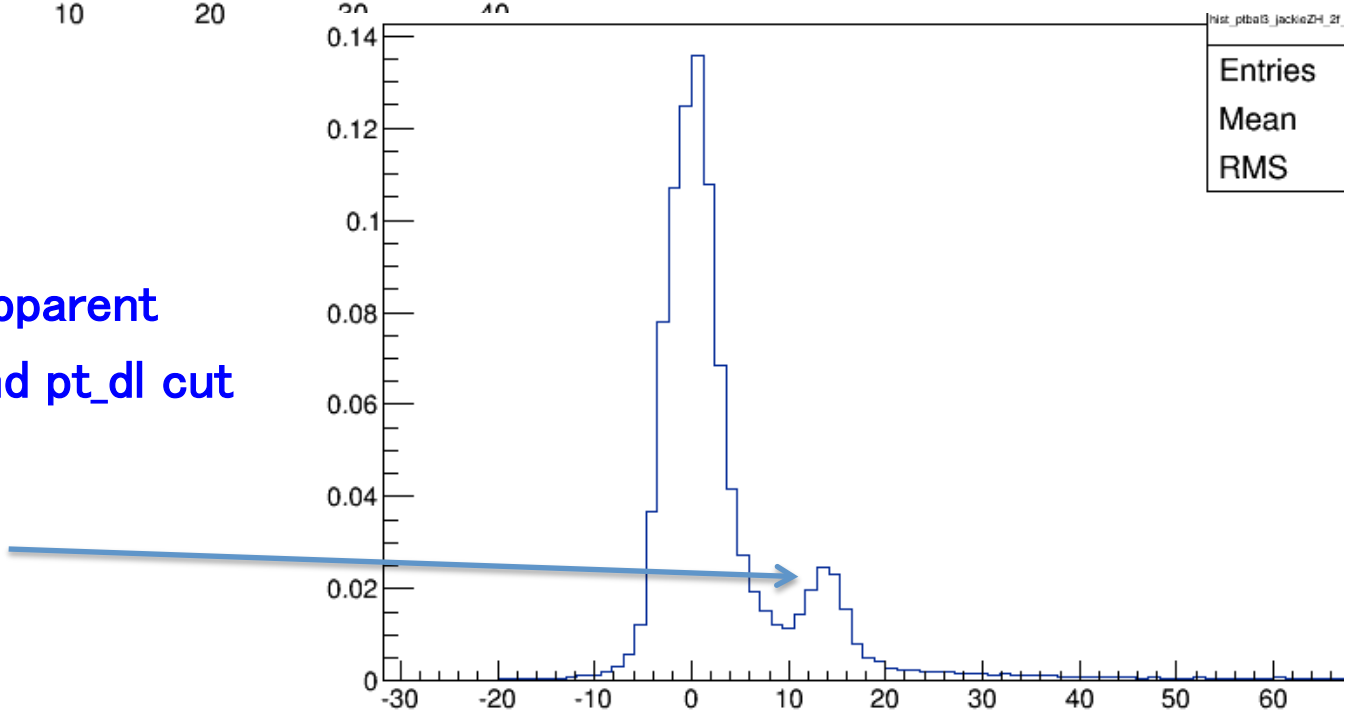


Distribution of dptbal

before any final cuts

2nd small peak around 15 GeV

Let's investigate the reason for this excess

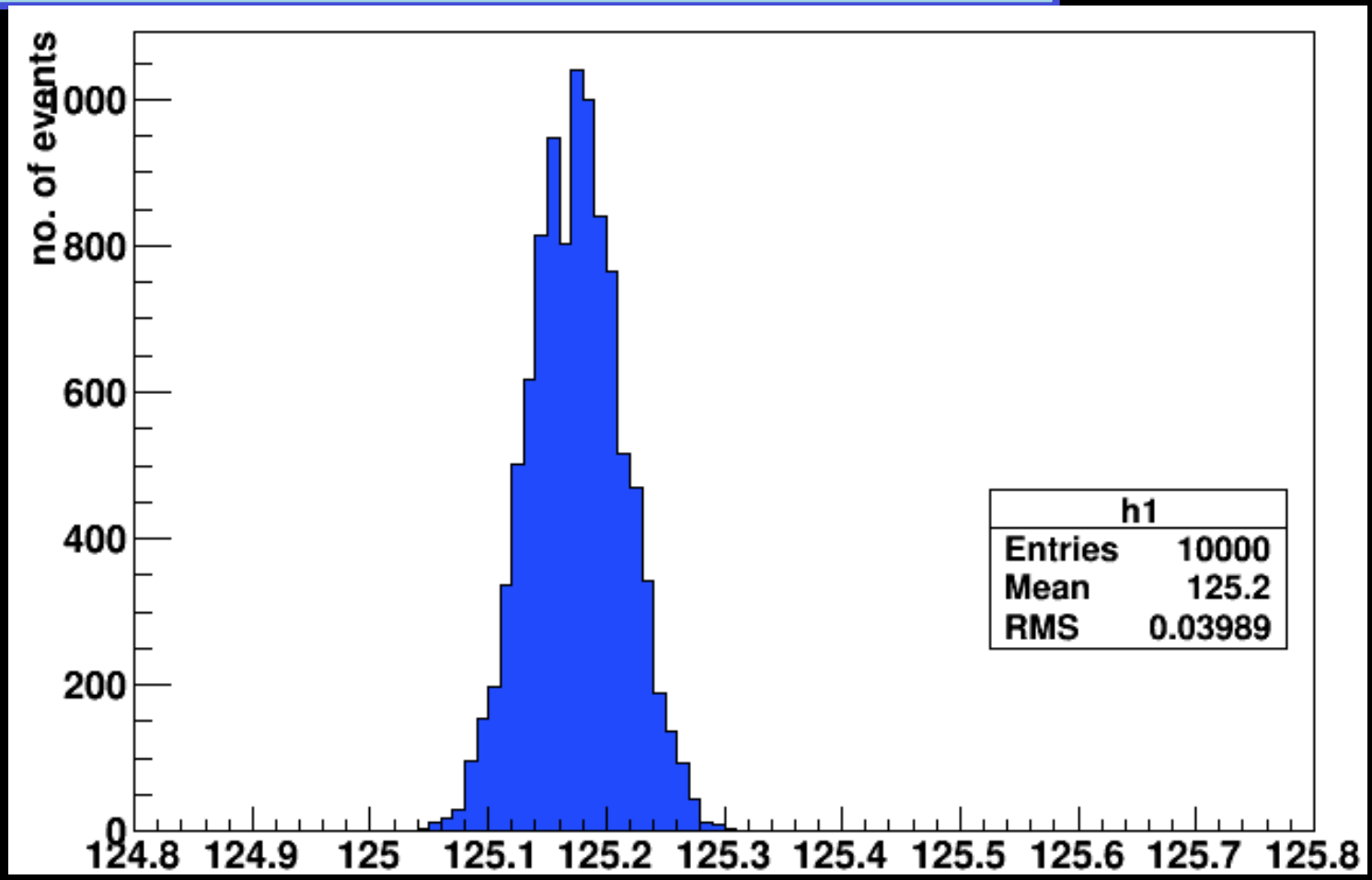


2nd peak more apparent after Minv cut and pt_dl cut

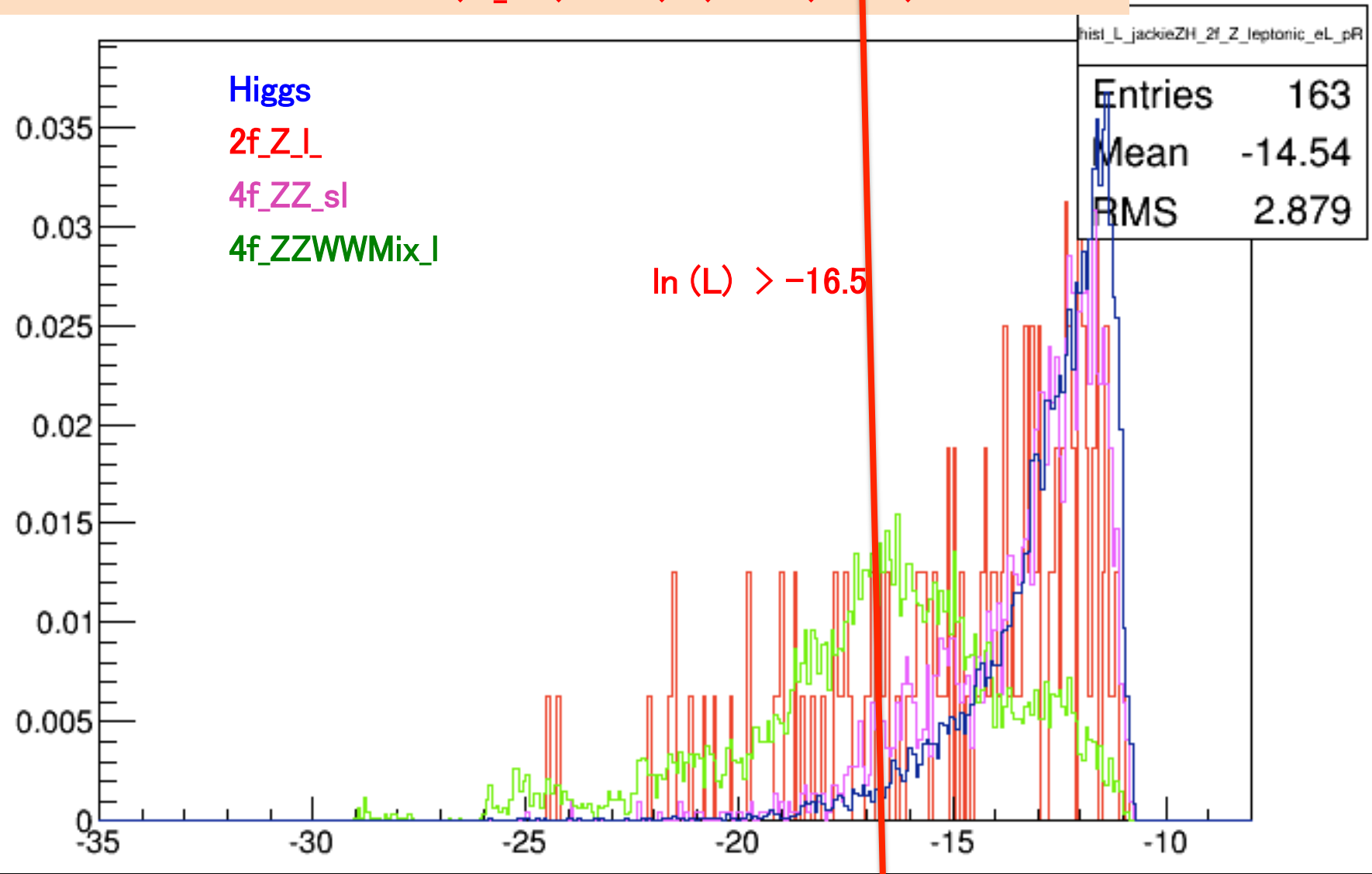
ECM = 350 GeV

Toy MC : fitted Higgs recoil mass

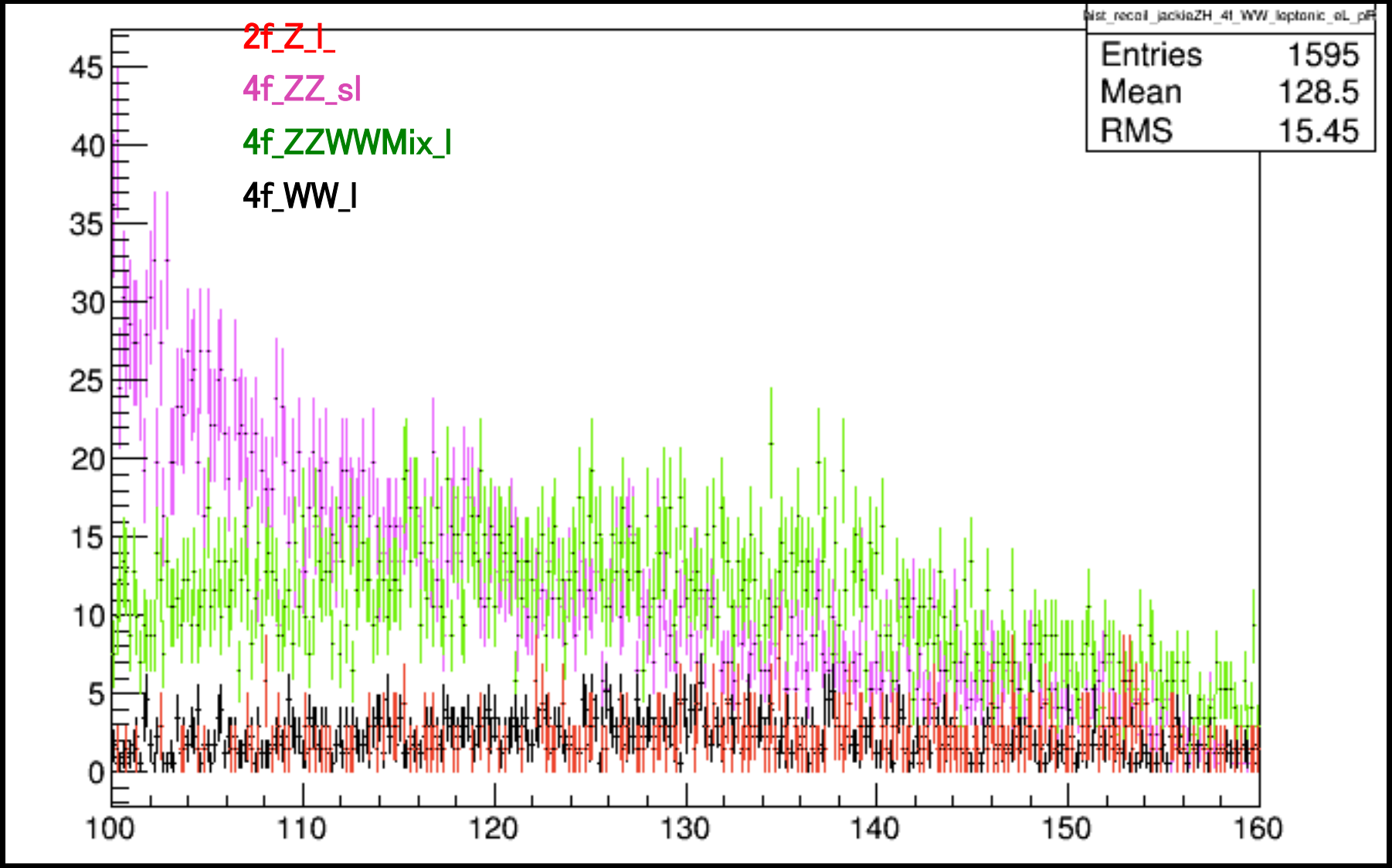
125.2 GeV



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



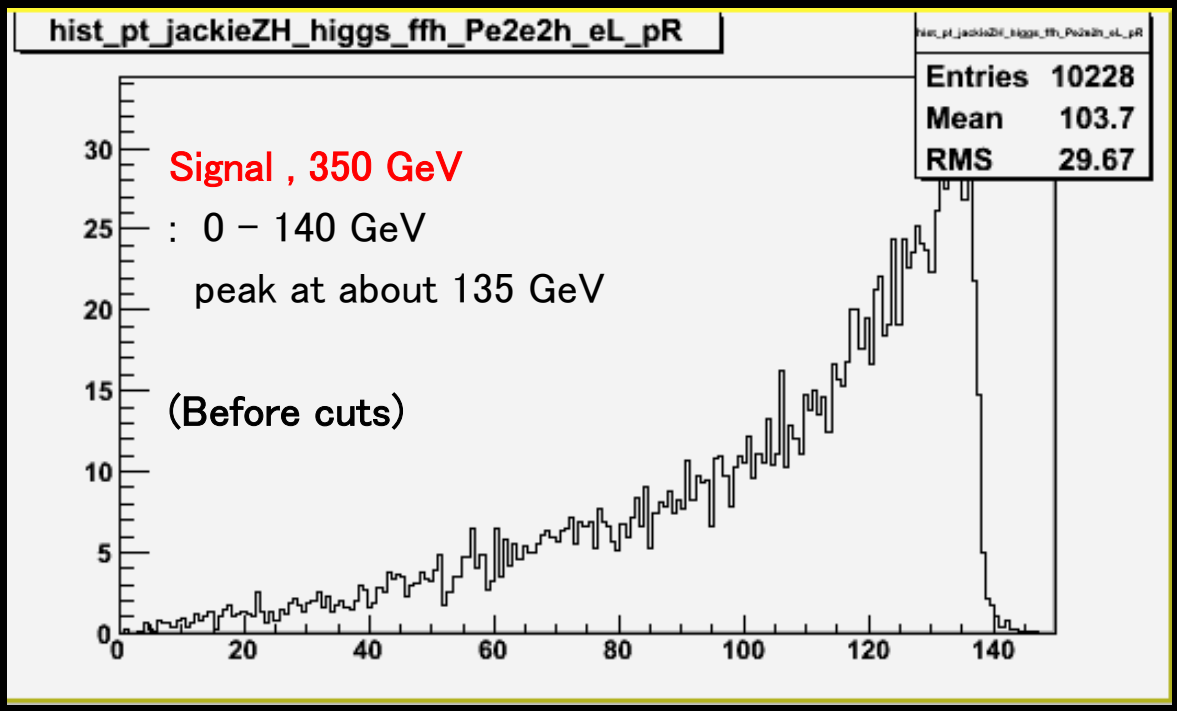
BG Recoil Mass

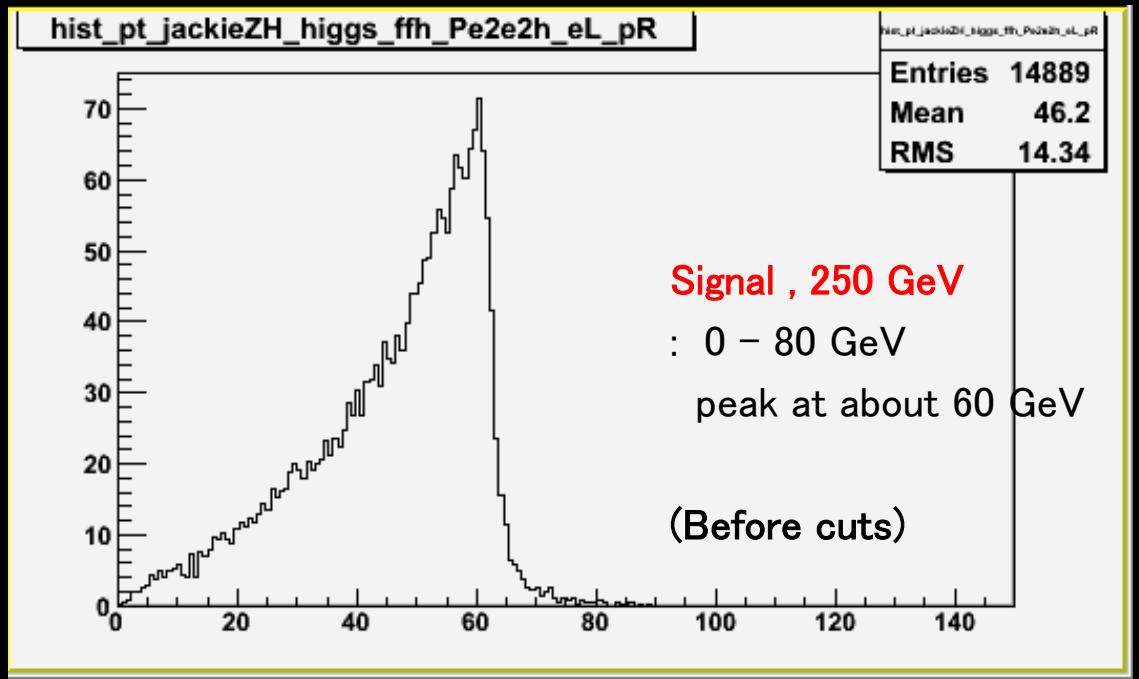


dilepton PT, 350 GeV

do cut :

10 GeV< pT_dl < 140 GeV



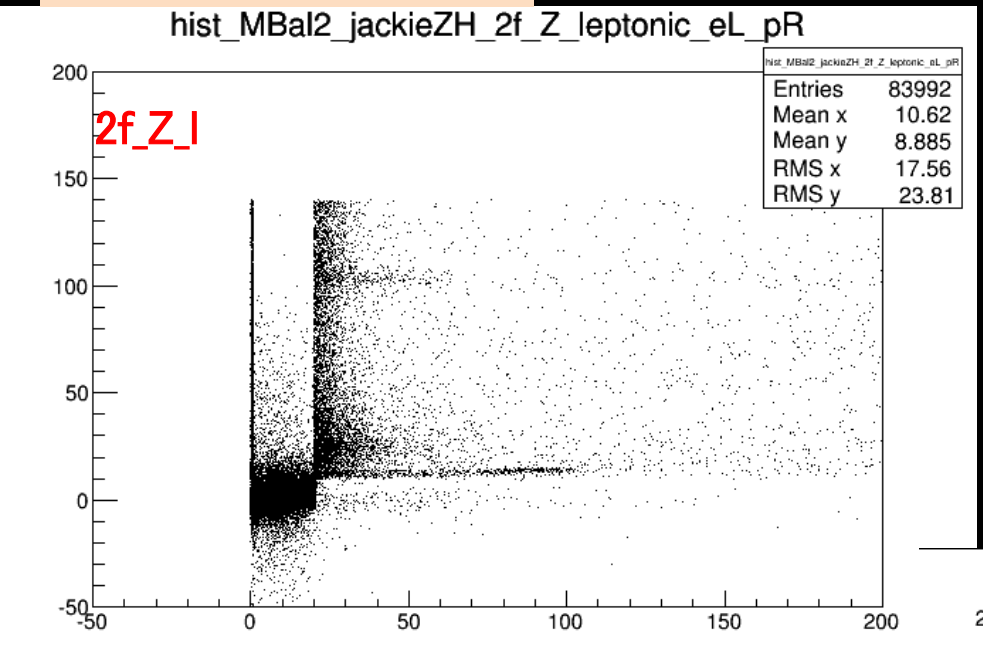


2D distr. Of

X: Econe_γ

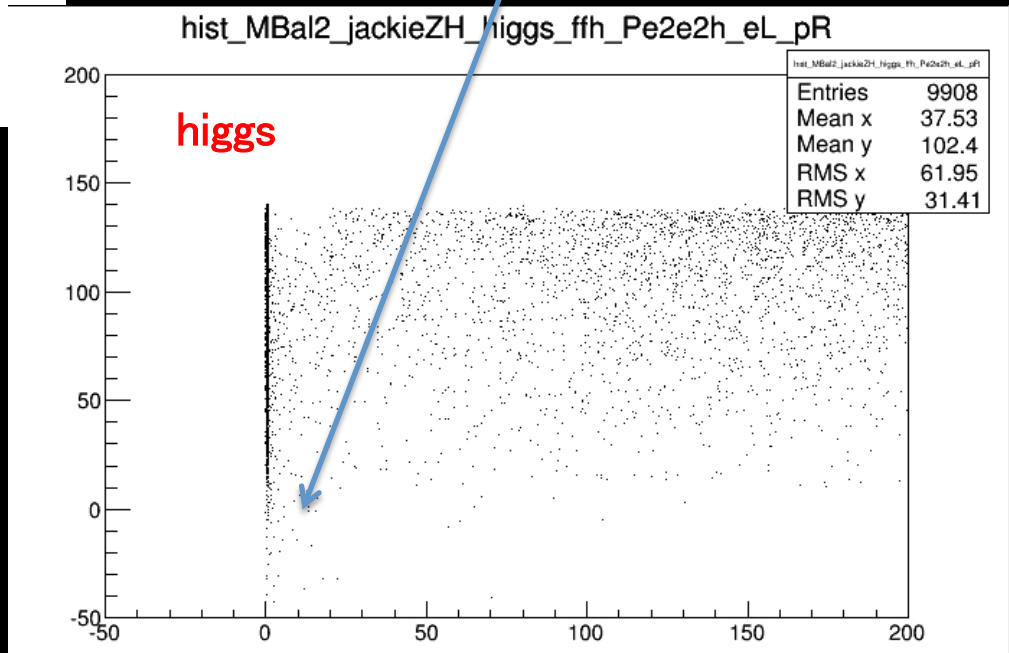
Y: dptabl

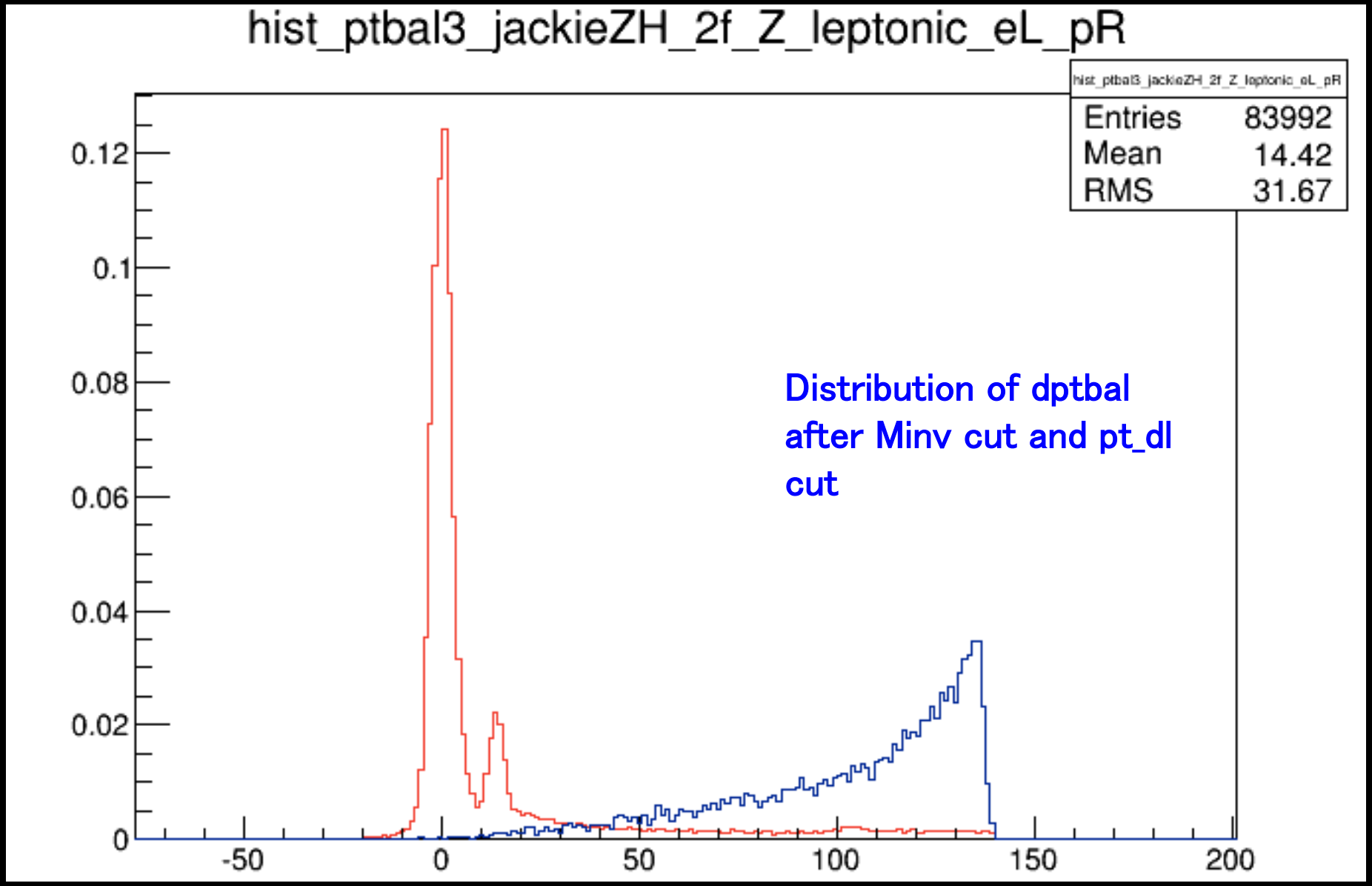
New: corrected condition for selecting photons (EcalE/Etot > 0.9)



It seems that most higgs events that have dptbal < 10 GeV are isolated (i.e. small Econe)

so it may be OK to cut these events




hist_ptbal3_jackieZH_2f_Z_leptonic_eL_pR
hist_ptbal3_jackieZH_2f_Z_leptonic_eL_pR
Entries 83992
Mean 14.42
RMS 31.67
0.12
0.1
0.08
0.06
0.04
0.02
0
-50
0
50
100
150
200
Distribution of dptbal after Minv cut and pt_dl cut

Pe2e2h_.eL.pR & Pe2e2h._eR.pL

- 4f_ZZ_leptonic
- 4f_ZZ_semileptonic
- 2f_Z_leptonic
- 4f_WW_leptonic
- 4f_WW_semileptonic
- 4fSingleZee_leptonic
- 4fSingleZnunu_leptonic
- 4f_ZZWWMix_leptonic
- 6f backgrounds (sqrt(s)=350 GeV)

note that difference from past studies maybe sue to:

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