Higgs Recoil Mass Study

ILC Physics Meeting

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Current Status & New Activities

Last week (General Meeting):

◆ showed full results of ZH analysis using Kernel function fitting (all leptonic channels , ECM, and beam polarization)

◆ confirmed minimum bias due to Ptsum cut using current nominal statistics samples

What 's NEW this week

◆ formed plan for Higgs recoil study based on discussions at General Meeting

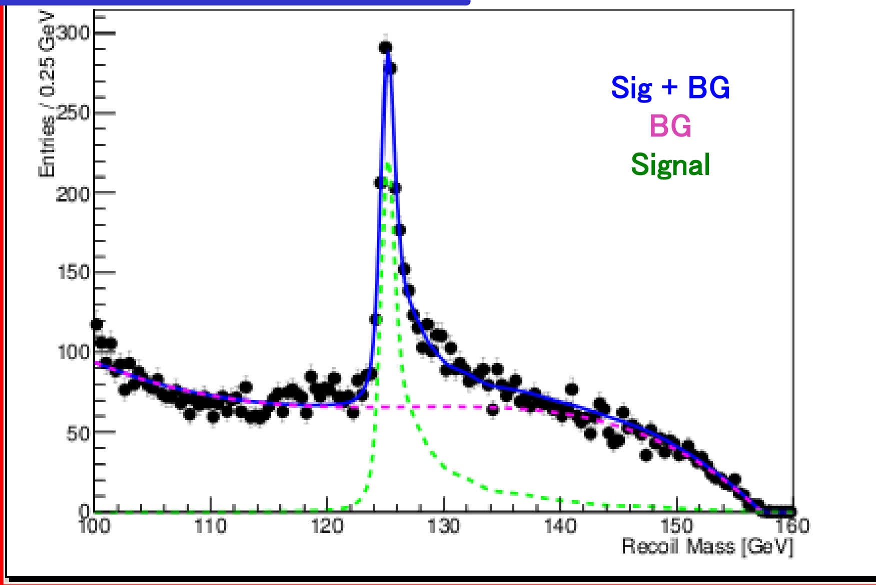
◆ checked Higgs decay mode dependence using high statistics sample generated for EACH DECAY MODE

+ investigate the bias using MC Truth Info.

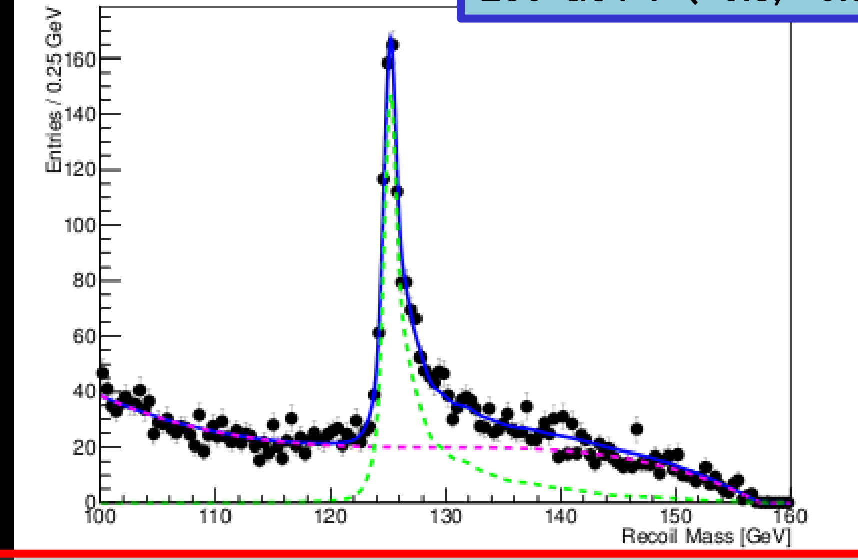
Z→μμ channel

Reconstructed data
recoil mass histogram

250 GeV : (− 0.8, + 0.3)



250 GeV : (+0.8, −0.3)



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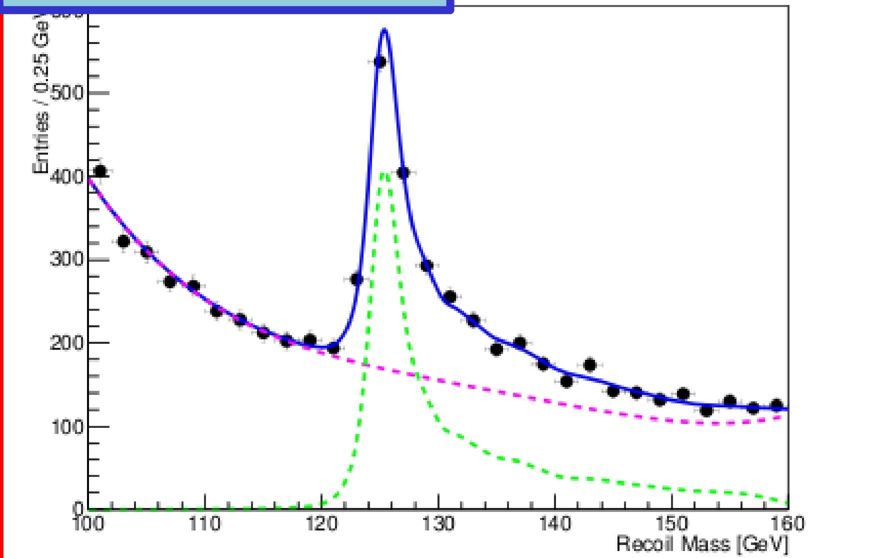

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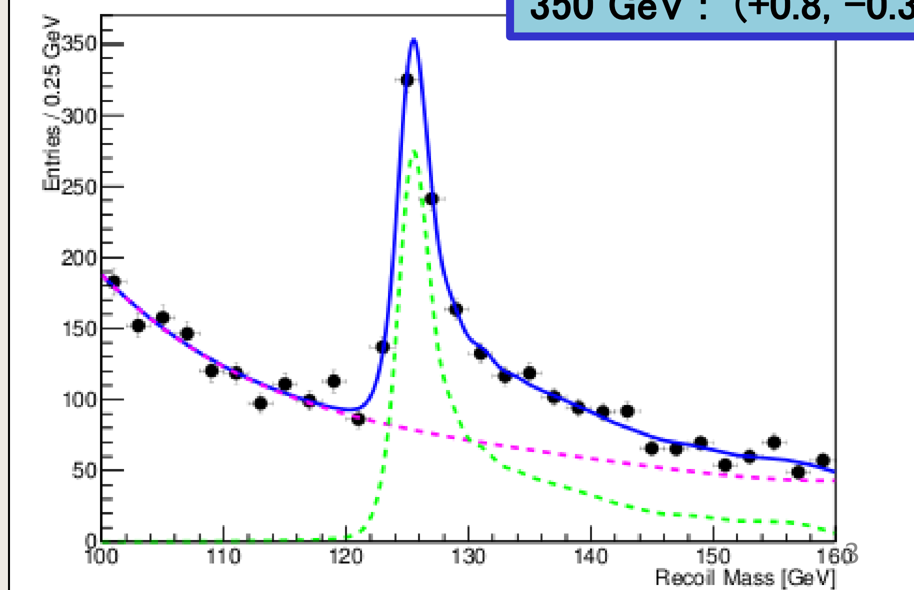


Statistical error study results
Z→μμ and Z→ee combined

(−0.8,+0.3)		xsec err	mass err [MeV]
250GeV	Zmm	3.35%	40.4
	Zee	4.76%	109
	Total	**2.74%**	**37.9**
350GeV	Zmm	3.90%	101
	Zee	5.63%	327
	Total	**3.21%**	**96.5**
500GeV	Zmm	6.95%	474
	Zee	9.89%	1540
	Total	**5.69%**	**453**

xsec error

- 350 GeV is 17 % worse w.r.t. 250 GeV
- 500 GeV is much worse
- Zee is worse by > 40% w.r.t. Zmm
- right hand pol is worse by 5 – 10 % w.r.t. left hand

Mass error

- 350 GeV is worse by factor of slightly less than 3 w.r.t. 250 GeV
- Zee is worse by a factor of 2 – 3 w.r.t. Zmm
- Systematic error of fitted recoil mass is negligible (< few MeV for 250 , 350 GeV)

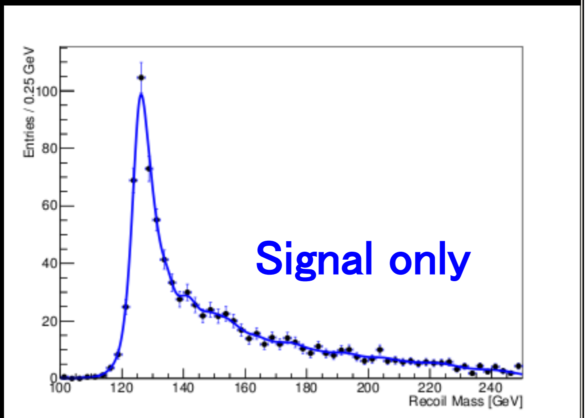
(+0.8,−0.3)		xsec err	mass err [MeV]
250GeV	Zmm	3.57%	40.5
	Zee	5.14%	121
	Total	**2.93%**	**38.4**
350GeV	Zmm	4.31%	112
	Zee	6.26%	296
	Total	**3.55%**	**105**
500GeV	Zmm	8.36%	613
	Zee	9.85%	1510
	Total	**6.37%**	**568**

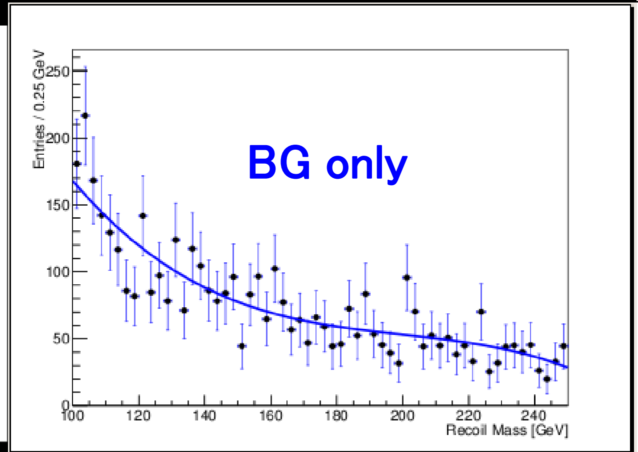
xsec error almost same as past results using GPET

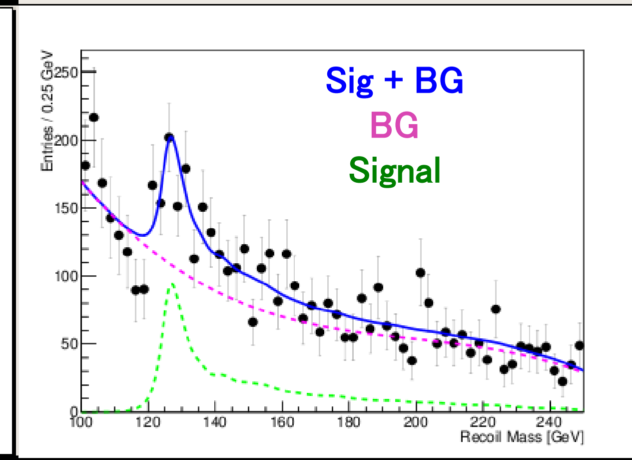
Can precision can be slightly improved if we fit over a wider range ? assuming we can neglect the H*→WW bump beyond 160 GeV

500 GeV, Zee (-0.8,+0.3)

fit in 100 – 250 GeV (c.f. 100-160 GeV)







		xsec error (%)		mass error (MeV)	
(−0.8,+0.3)		narrow	wide	narrow	wide
500GeV	Zmm	6.95%	6.50%	474	468
	Zee	9.89%	7.86%	1540	1540
	Total	**5.69%**	**5.01%**	**453**	**448**
(+0.8,−0.3)					
500GeV	Zmm	8.36%	7.27%	613	572
	Zee	9.85%	7.86%	1510	1530
	Total	**6.37%**	**5.33%**	**568**	**536**

10-20 % improvement on xsec and a few % on mass precision

Plans for Higgs Recoil Sudy

The importance of recoil mass measurement (both leptonic and hadronic) for H20 scenario has been emphasized.

- **improving leptonic recoil at 500 GeV AND beginning on hadronic recoil** may have higher priority than further improving precision of leptonic recoil at 250 (350) GeV ???

at least, these need to be done in parallel.

Plan:

(1) Investigate **Higgs decay mode dependence (= systematic errors) for 250 GeV** using high stat samples *just about done (?)*

(2) generate higher statistics sample for 350 and 500 GeV
then use these to further improve precision for leptonic channel
as well as do ZZ fusion analysis at 500 GeV

(3) Study **systematic error from beam spectrum** ***→ need much time***

(4) Begin **hadronic recoil at 500 GeV** *personally feel this is a priority*
strategy : for now carry out same method as what Miyamoto-san did for Snowmass
and investigate Higgs decay mode dependence the same way as I did for (1)

Immediate Plans

(1)Further Investigation of Higgs decay mode dependence (= systematic errors) for 250 GeV using high stat samples

- improve isolated lepton finder :
  incorporate Mrec requirement when selecting best lepton pair
- Add $H \rightarrow \gamma\gamma$ mode analysis

(2)Hadronic lepton recoil at 500 GeV
currently only starting…..

(3) Think of further strategies to improve leptonic recoil precision

Efficiency of each Higgs decay mode (after each cut)

250 GeV, Z$\mu\mu$ mode

250 GeV	bb	cc	tt	gg	ww	zz
cut0	92.41+/−0.09%	92.43+/−0.09%	93.27+/−0.08%	91.66+/−0.09%	92.64+/−0.08%	92.77+/−0.08%
cut1	90.85+/−0.09%	90.84+/−0.09%	91.40+/−0.09%	90.06+/−0.10%	90.72+/−0.09%	90.76+/−0.09%
cut2	88.92+/−0.10%	89.07+/−0.10%	89.39+/−0.09%	88.23+/−0.11%	88.53+/−0.10%	88.49+/−0.10%
cut3	88.71+/−0.10%	88.88+/−0.10%	89.20+/−0.10%	88.03+/−0.11%	88.29+/−0.10%	88.24+/−0.10%
cut4	88.66+/−0.10%	88.80+/−0.10%	88.73+/−0.10%	87.97+/−0.11%	88.18+/−0.10%	88.13+/−0.10%
cut5	88.16+/−0.10%	88.47+/−0.10%	87.99+/−0.10%	87.82+/−0.11%	87.43+/−0.11%	87.30+/−0.11%
cut6	81.72+/−0.13&	81.74+/−0.13%	81.62+/−0.13%	81.22+/−0.13%	81.04+/−0.14%	81.14+/−0.13%
cut7	72.4+/−0.15%	72.29+/−0.15%	72.33+/−0.14%	71.91+/−0.15%	71.67+/−0.14%	71.29+/−0.15%

Cut0: isolated μ selection
Cut1: loose Minv and Mrec window
Cut2: 73<Minv<120 GeV
Cut3: 10 < Pt_dl < 70 GeV
Cut4: Ptsum > 10 GeV
Cut5: cos(θ missing) < 0.98
Cut6: cos(θ Z) < 0.9
Cut7: 100 < Mrec 160 GeV

- tt, ZZ, WW affected by “mistaken lepton selection”
  c.f gg mode receive no particular bias (?)
- tt more biased by Ptsum cut
- diverse effect from cos(θ missing) cut

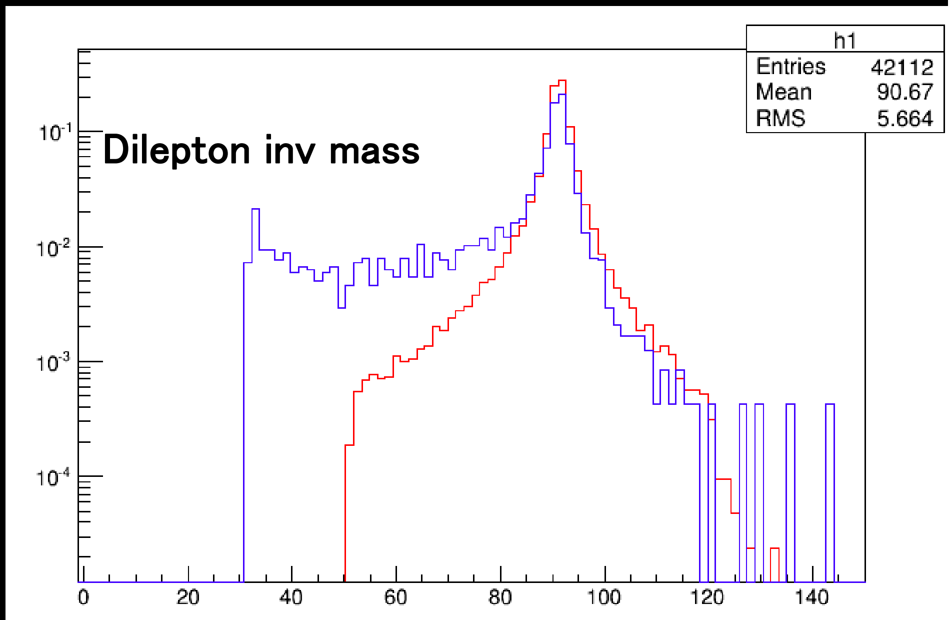
250 GeV	e2e2_Lpol				deviation	deviation
	N(100-160)	N_err	eff	eff_err	from avg	from ALL
bb	1885	5	72.40%	0.15%	0.42%	0.21%
cc	1882	5	72.29%	0.15%	0.31%	0.10%
tt	1883	5	72.33%	0.14%	0.35%	0.15%
gg	1872	5	71.91%	0.15%	-0.08%	-0.28%
ww	1866	5	71.67%	0.14%	-0.31%	-0.51%
zz	1856	5	71.29%	0.15%	-0.69%	-0.90%
all modes	1883	9	72.19%	0.27%		
		avg of 6	71.98%			

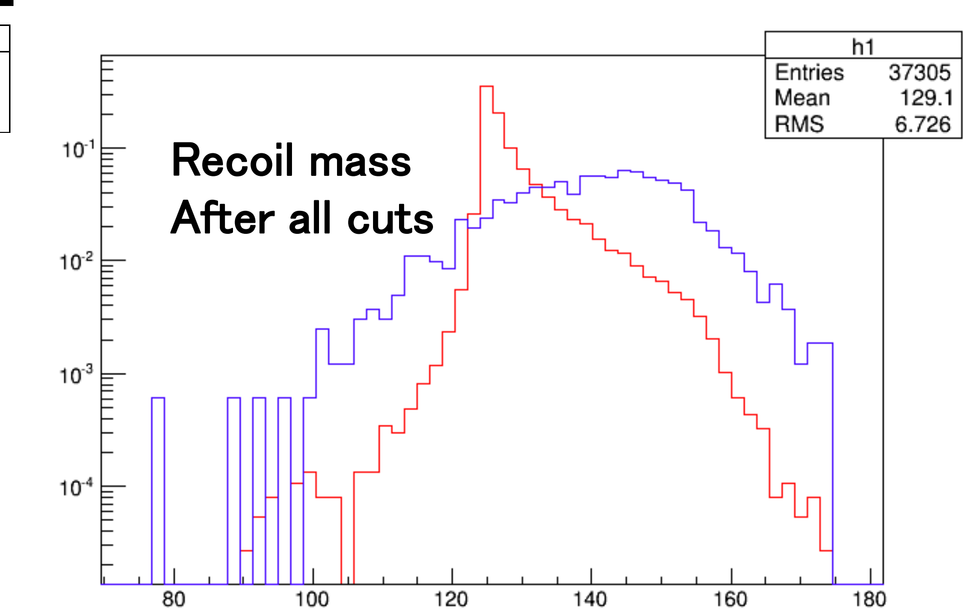
Efficiency of each Higgs decay mode **(after all cuts)**

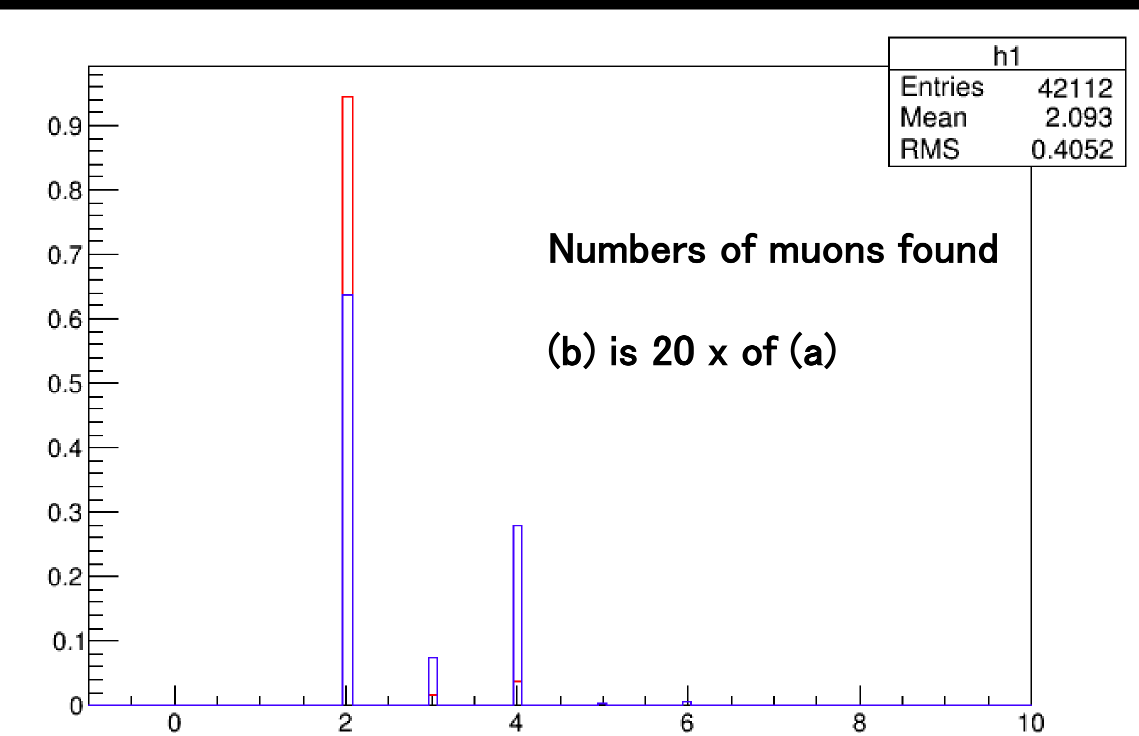
- systematic bias is < **1.3% for Zmm. < 4.2% for Zee**
- **H→zz, H→ww most affected**

(lepton pair containing lepton not from prompt Z decay)

250 GeV	e1e1_Lpol				deviation	deviation
	N(100-160)	deltaN	eff	eff_err	from avg	from ALL
bb	1491	6	54.65%	0.17%	-1.15%	-0.39%
cc	1497	6	54.86%	0.16%	-0.94%	-0.18%
tt	1480	6	54.21%	0.16%	-1.58%	-0.83%
gg	1484	6	54.38%	0.16%	-1.42%	-0.66%
ww	1469	6	53.83%	0.16%	-1.96%	-1.21%
zz	1442	6	52.83%	0.16%	-2.96%	-2.21%
all modes	1502	10	55.04%	0.28%		
		avg of 6	54.13%			





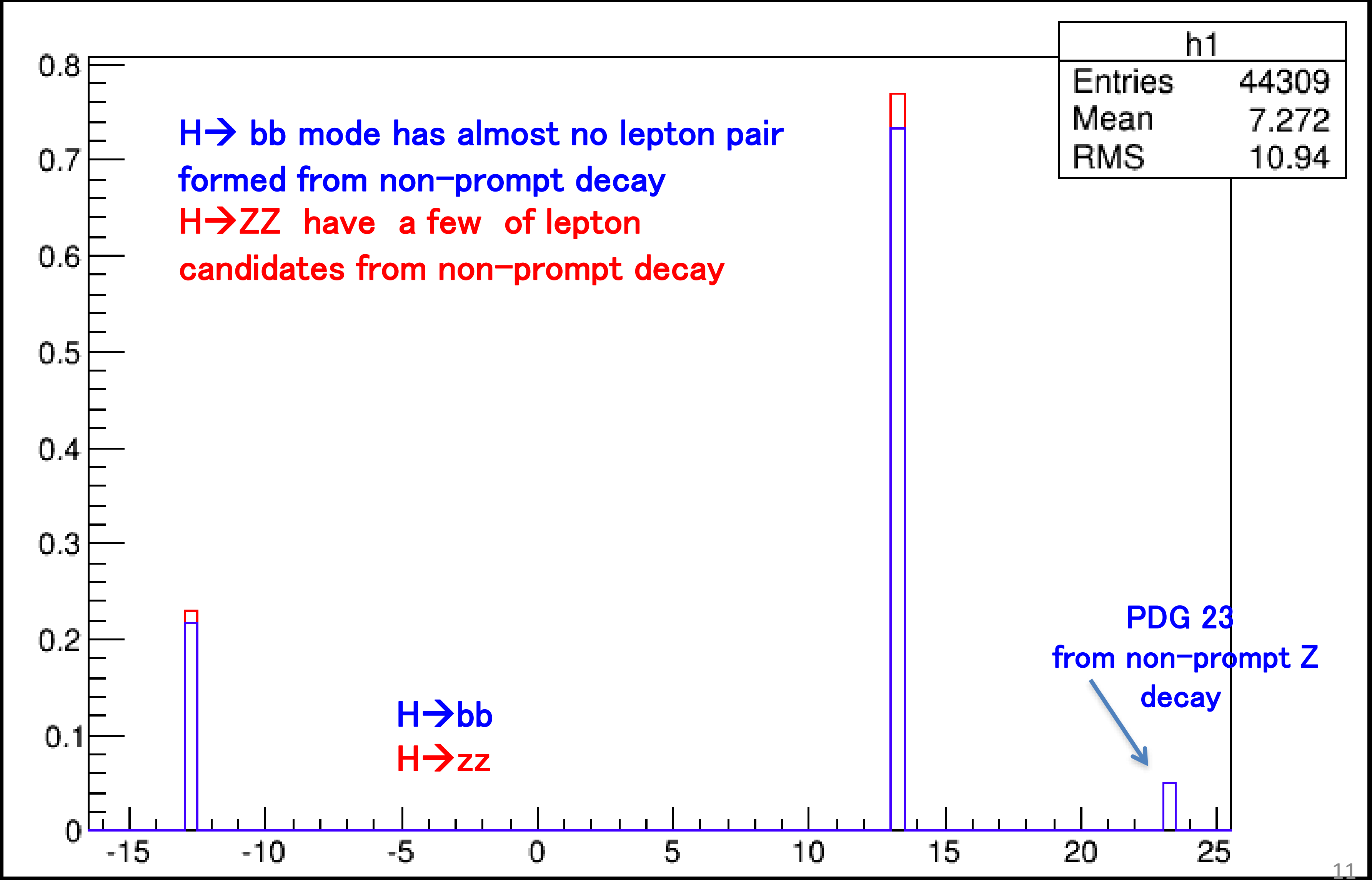


Z→mm, H→zz mode

(a) at least one lepton is not from prompt Z decay

(b)both leptons from prompt decay

Use MC truth to investigate parent PDG of feptons in “selected pair”
Z→mm



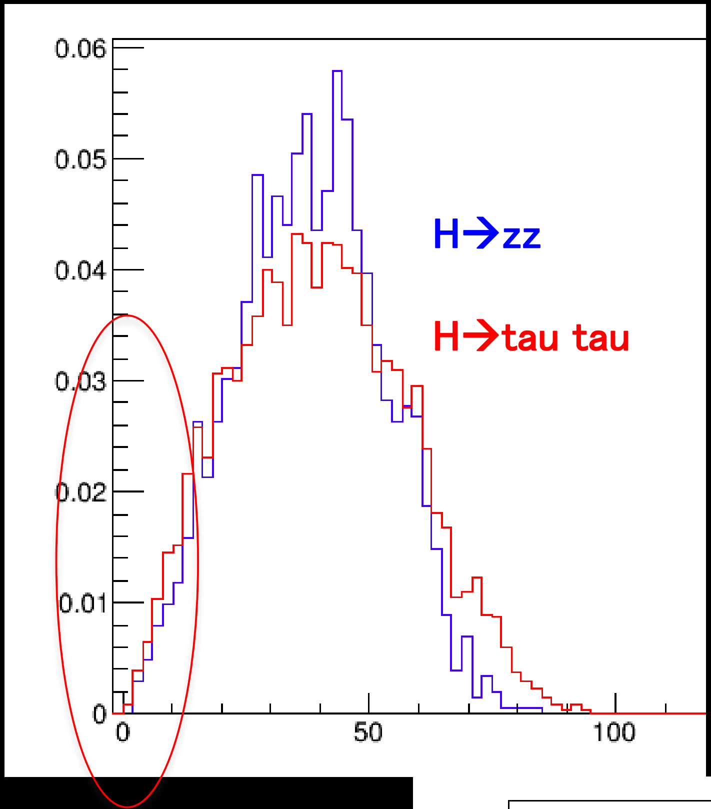
observation of Ptsum distr

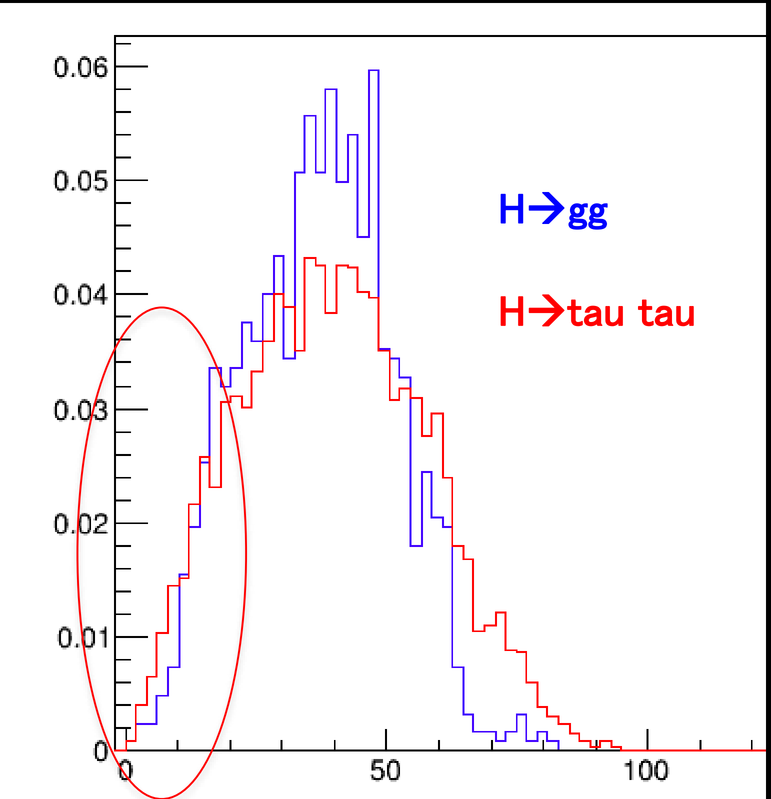
(at stage just before Ptsum cut)

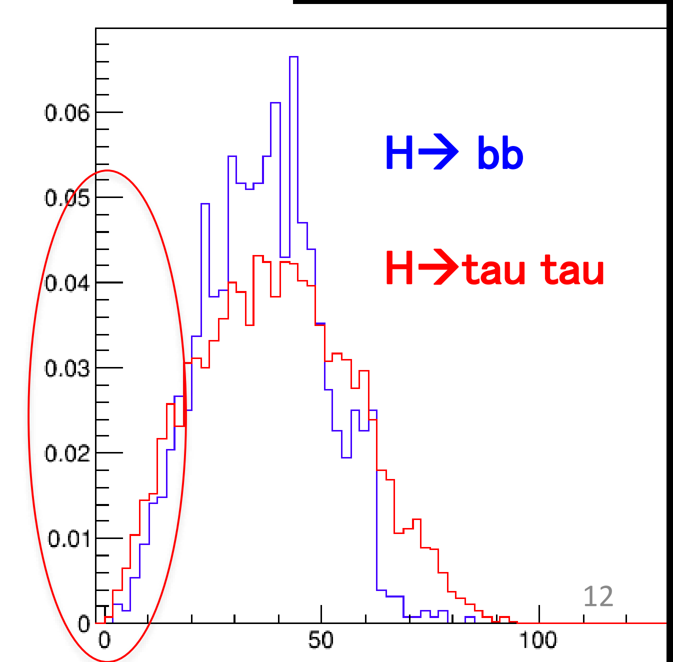
Zmm channel

Compare to other modes,

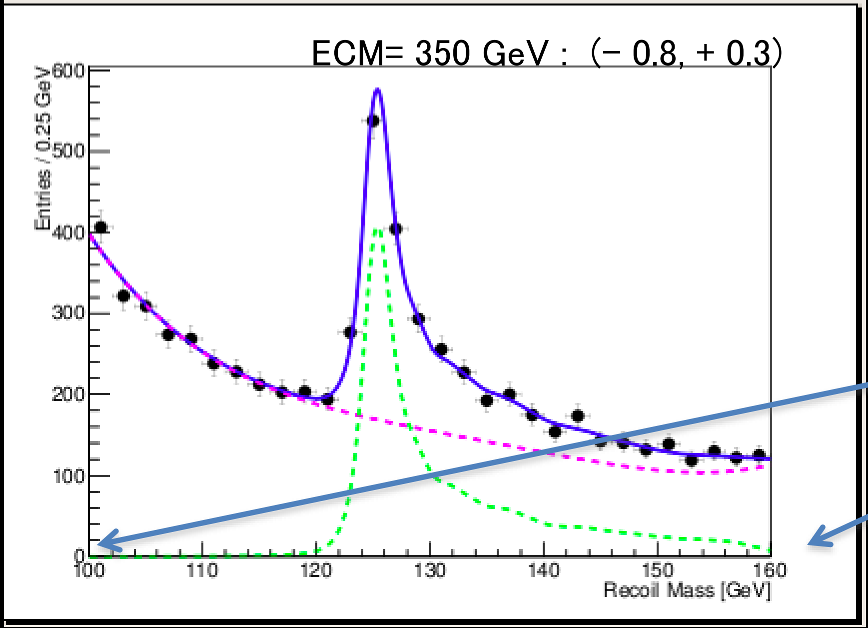
H→tau tau seem very slightly biased in region of Ptsum < 10







BACKUP



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

an improvement from previous studies

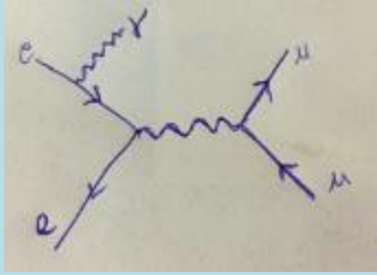
- BG level is usually fixed for Toy MC (optimistic scenario)
- xsec error is about 10 % worse if we float BG (pessimistic scenario)

  not a big degradation since I fit recoil mass spectrum over a wide range *GOOD*

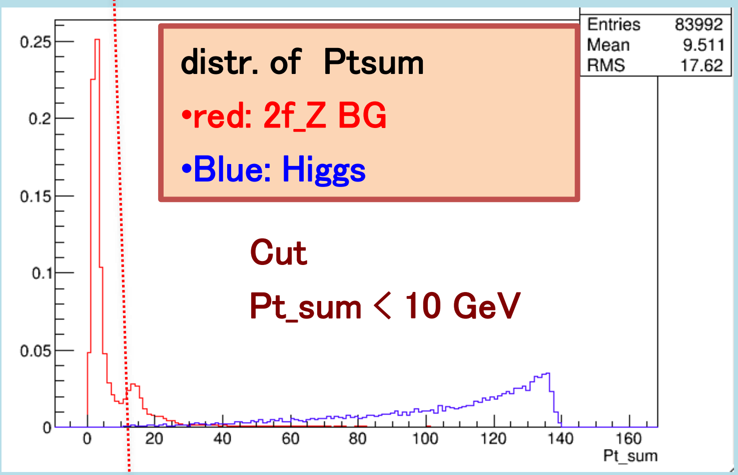
Example:

Zmm	xsec	Recoil mass	BG fluc
250GeV	3.35% → 3.62%	40 MeV, no change	1.23%
350GeV	3.90% → 4.39%	101 → 95 MeV	1.67%

Prevention of 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) caused signal bias (esp. H → τ τ , γ γ)

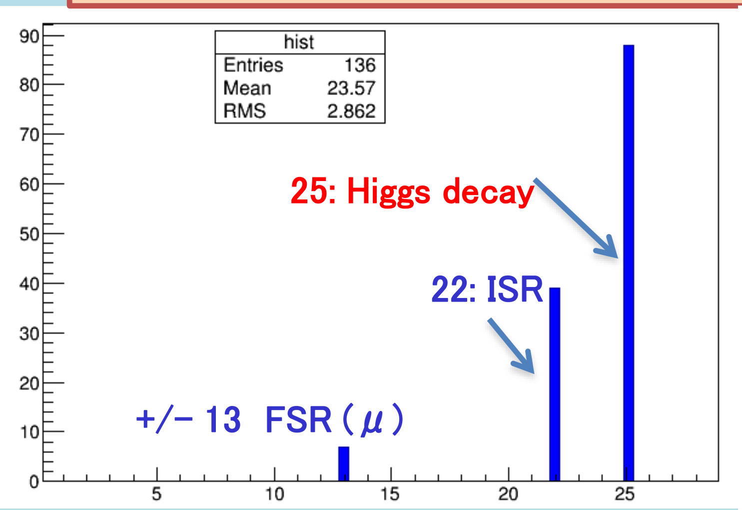


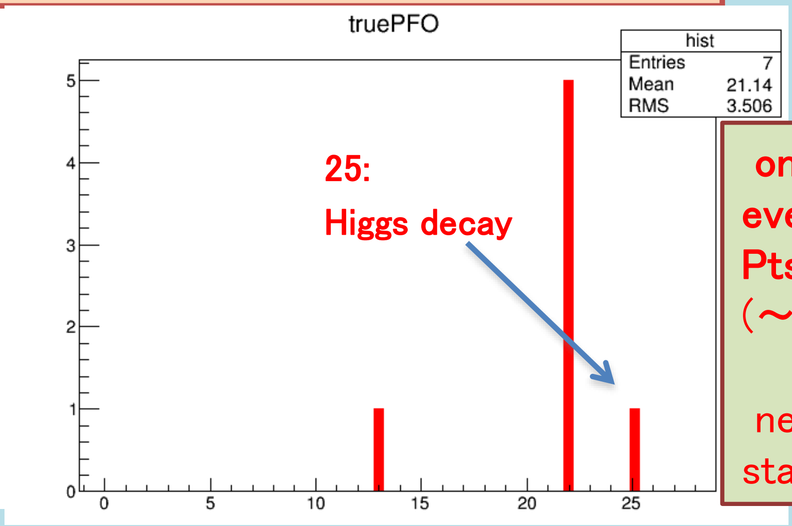
NEW #1 isolated photon finder: γ we look at have small cone energy) not from Higgs decay

NEW #2 Now use $|\vec{P}_{t,sum}|$ o $|\vec{P}_{t,g} + \vec{P}_{t,dl}|$ (instead of dptbal)

vector direction info singles out back to back events

PDG of γ for events removed by Ptsum /dptbal cut (250 GeV Zmm)





only < few unweighed events removed by Ptsum cut (∼ 0 weighed events)

negligible compared to statistical uncertainties

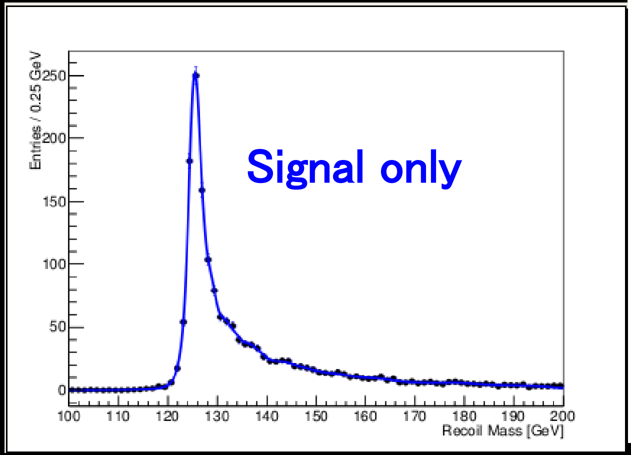
∼100 Higgs decay related γ events removed by dptbal cut !!

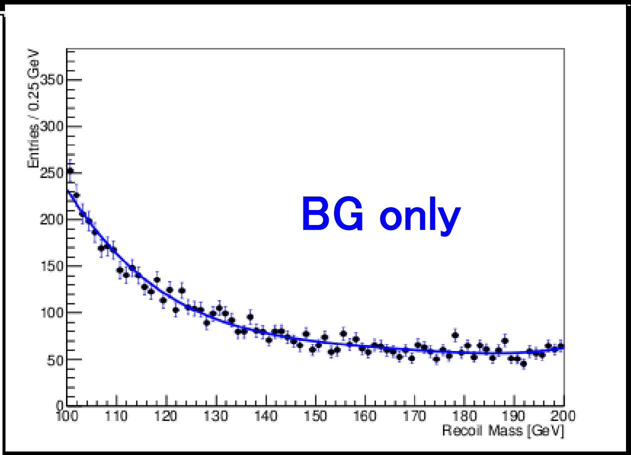
need more careful study of Higgs decay mode bias using high stat sample

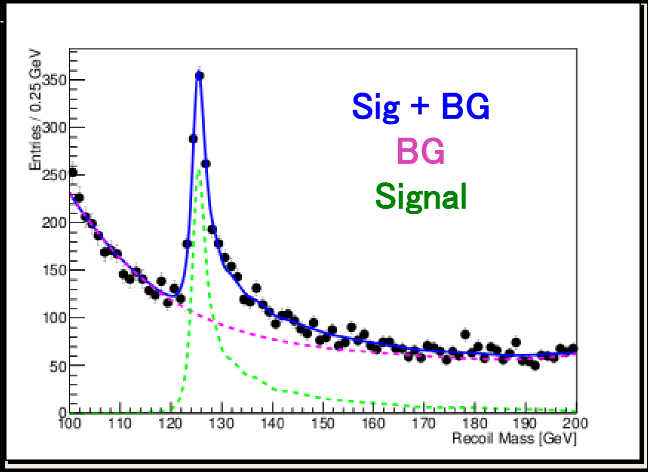
Can precision can be slightly improved if we fit over a wider range ??
assuming we can neglect the H*→WW bump beyond 160 GeV

350 GeV, Zee (-0.8,+0.3)

fit in 100 – 200 GeV (c.f. 100-160 GeV)







		xsec error (%)		mass error (MeV)	
(−0.8,+0.3)		narrow	wide	narrow	wide
350GeV	Zmm	3.90%	3.83%	101	103
	Zee	5.63%	5.48%	327	340
	Total	3.21%	3.14%	96.5	98.6
(+0.8,−0.3)					
350GeV	Zmm	4.31%	4.24%	112	113
	Zee	6.26%	6.15%	296	328
	Total	3.55%	3.49%	105	107

Not much room for improvement

Performance of data selection

in fitting range 100–160 GeV

(−0.8,+0.3)		significance	Nsig	Nbg
250GeV	Zmm	18.3	1879	8692
	Zee	14.4	1502	9394
350GeV	Zmm	17.7	1462	5332
	Zee	14.1	1156	5597
500GeV	Zmm	11.1	626	2572
	Zee	8.7	439	2087

(+0.8,−0.3)		significance	Nsig	Nbg
250GeV	Zmm	19.7	1264	2834
	Zee	12.8	1096	6231
350GeV	Zmm	17	1002	2486
	Zee	12.7	602	1627
500GeV	Zmm	9.9	414	1339
	Zee	8.9	325	1003

- In general, significance is 250 > 350 > 500 GeV, Zmm > Zee
- right hand polarization: case by case:
  (lower BG, but also smaller signal statistics)

Progress since the last (41th) General Meeting (April 11)

Last Time

- only $Z \rightarrow \mu\mu$ channel
- only ECM = 250 GeV and 350 GeV
- only study of xsec precision
- slight Higgs decay mode bias caused by BG rejection method

Features of This Time

- both $Z \rightarrow \mu\mu$ and $Z \rightarrow ee$ channels
- all three ECM (250 , 350 , 500 GeV)
- study of both xsec and mass precision
- signal bias is minimized due to improved techniques (details later)

\+ *deeper study of the signal and BG statistics of each channel*

- Currently converging towards a **full set of statistical error study results**
- **optimized data selection method for each of the 12 scenarios** (3 ECM x 2 leptonic channels x 2 polarizations) in aim of best xsec and mass precision
- Removed systematic bias due to method of fitting or data selection

Lepton Pair Candidate Selection

opposite +/− 1 charge

- E_cluster / P_total : ＜0.5 (μ) / ＞0.9 (e)
- isolation (small cone energy)
  → removes nearly all 4f_WW_sl BG
- Minv closest to Z mass
- |D0/δD0| < 5

Data selections designed 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_dl : pt of reconstructed lepton pair
- pt,γ : pt of most energetic photon
- θ_missing = polar angle of undetected particles
- θ_Z = Z production angle

Final Selection

- 73 <   GeV < M_inv < 120 GeV
- 10 GeV < pt_dl < 140 GeV
- $\left|\overrightarrow{P_{t,sum}}\right| \text{o} \left|\overrightarrow{P_{t,g}} + \overrightarrow{P_{t,dl}}\right|$ > 10 GeV
- |cos(θ_missing)| < 0.98
- |cos(θ_Z)| < 0.9
- 100 GeV < Mrecoil < 160 GeV
- Likelihood cut

Example of ECM=350 GeV,

- Effective for cutting $\mu\,\mu$ / ee BG
- Use info of most energetic photon (pt_γ , cone energy)

meanwhile minimize bias on signal

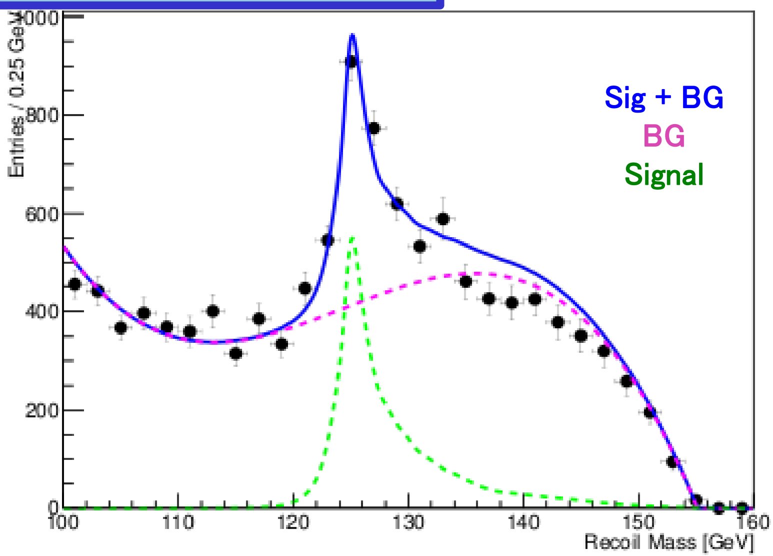
red box:
key improvements w.r.t. previous studies

similar methods applied to all ECM and polarizations

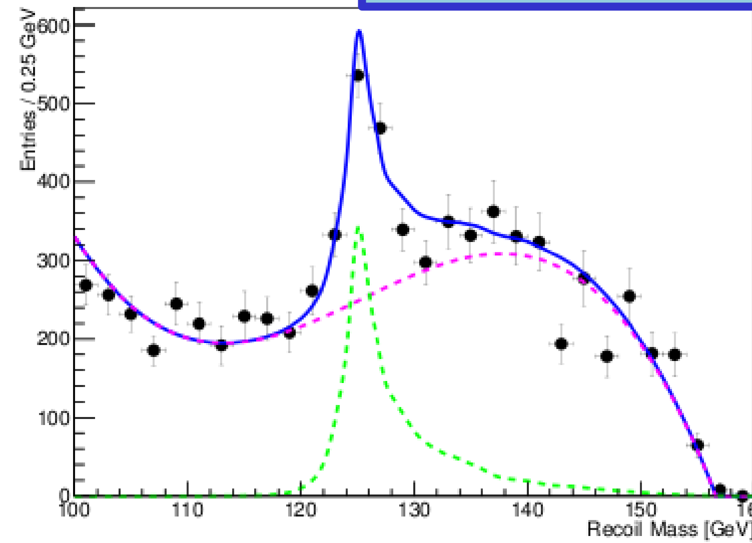
Reconstructed data
recoil mass histogram

Z→ee channel

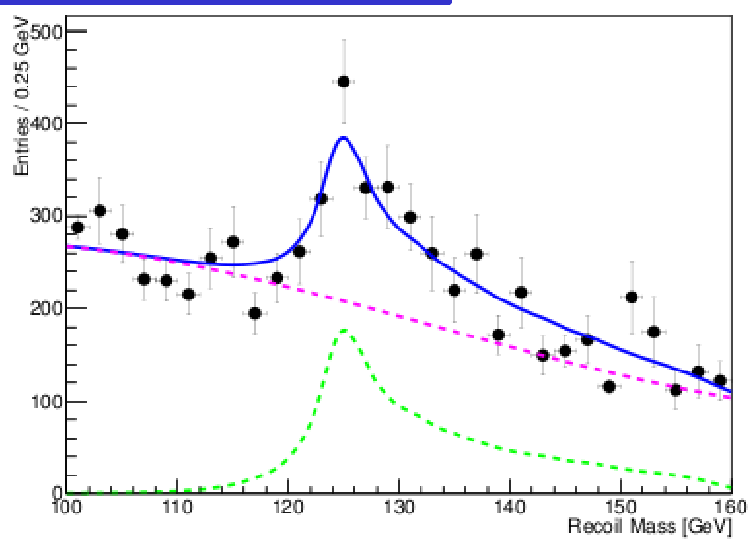
250 GeV : (− 0.8, + 0.3)



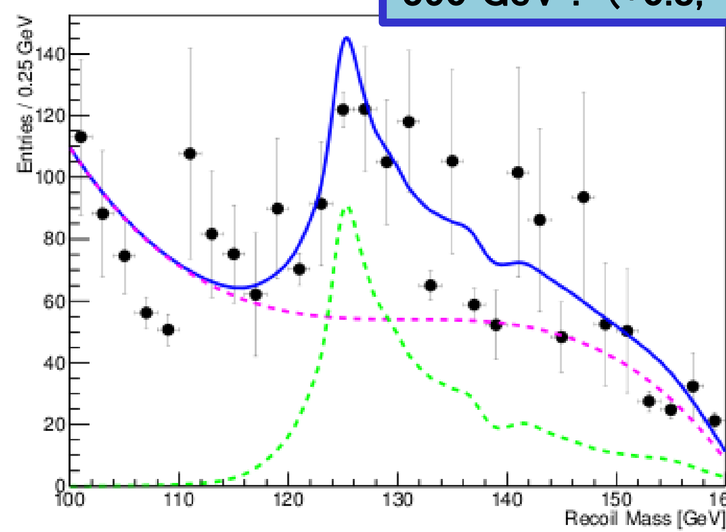
250 GeV : (+0.8, −0.3)



350 GeV : (−0.8, +0.3)

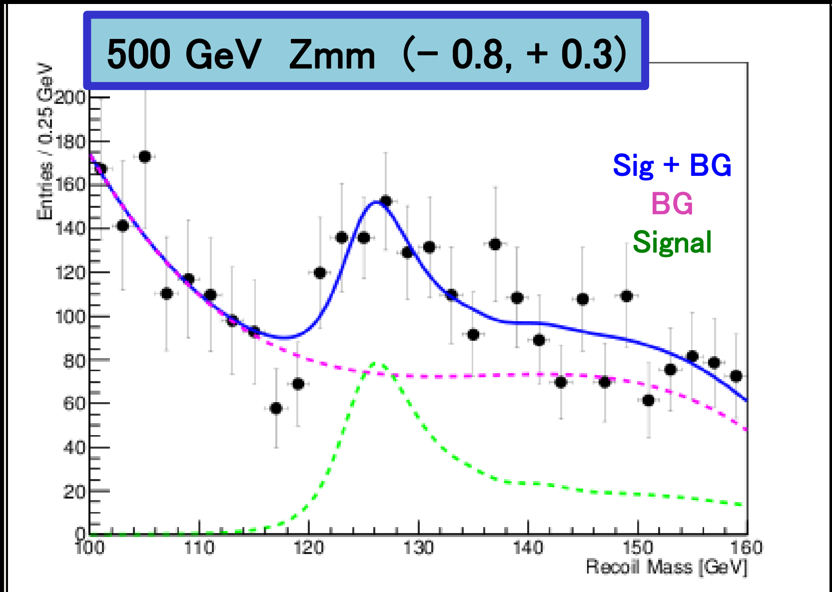


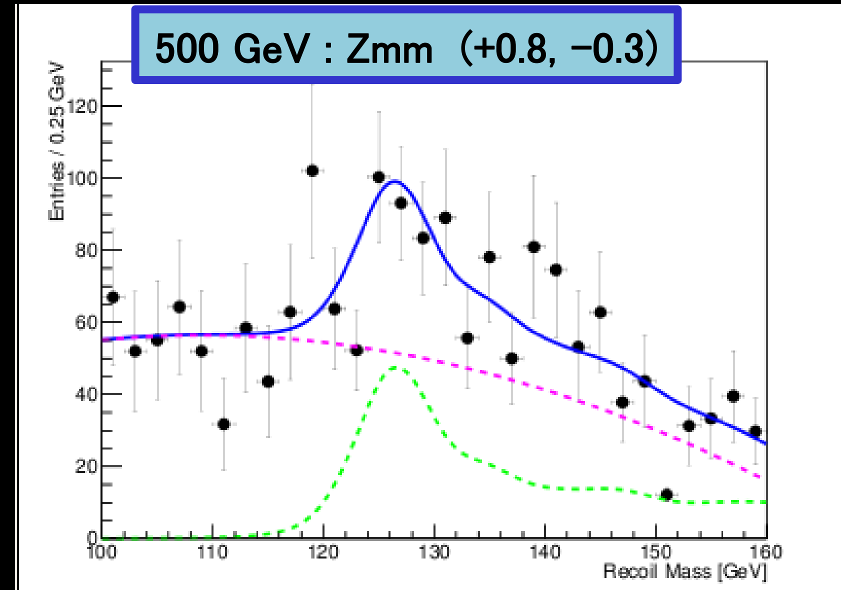
350 GeV : (+0.8, −0.3)

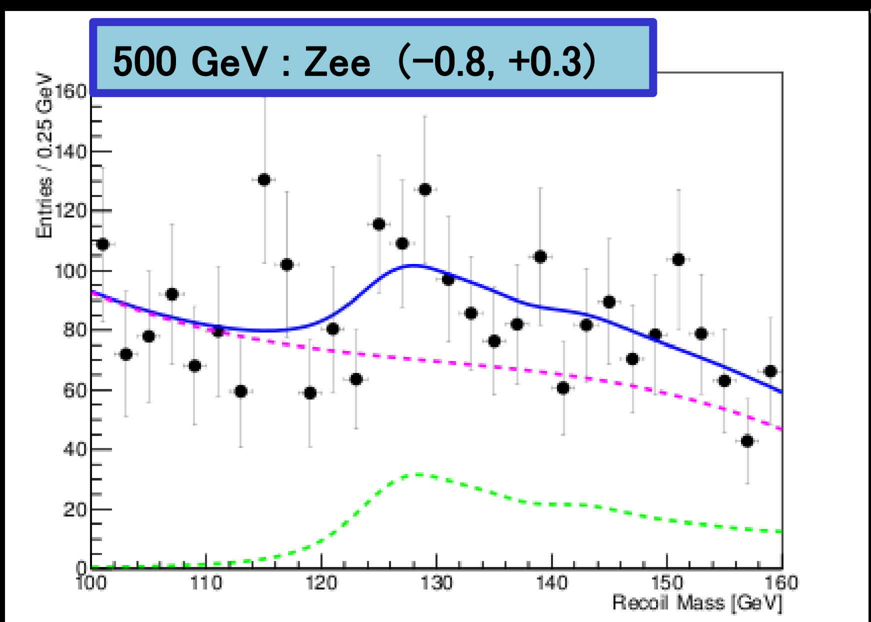


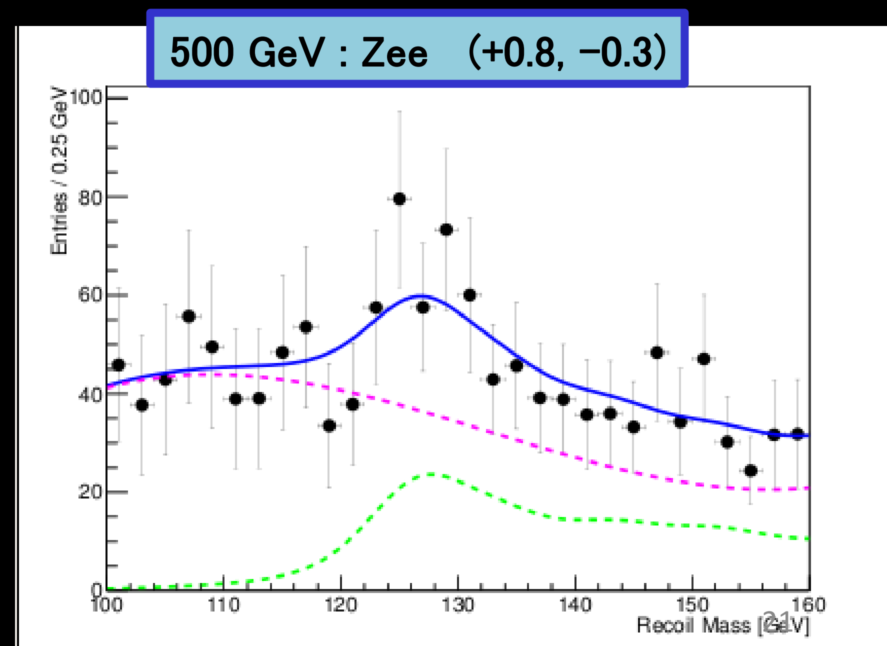
500 GeV

many challenges remaining : low statistics, low S/B ratio , ect…



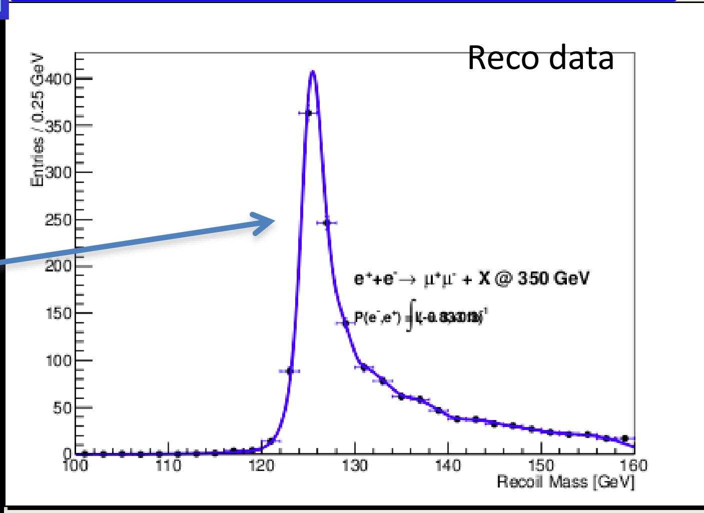




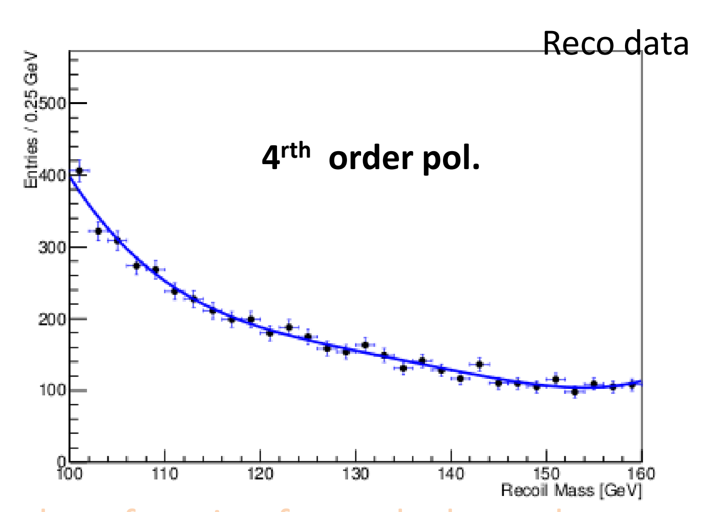


Fitting of recoil mass spectrum

Signal : Kernel function



BG : 3rd or 4rth order polynomial



Kernel function fitting does not cause significant systematic bias in recoil mass
(c.f. GPET)

Observe distribution to determine best function for each channel

Toy MC study

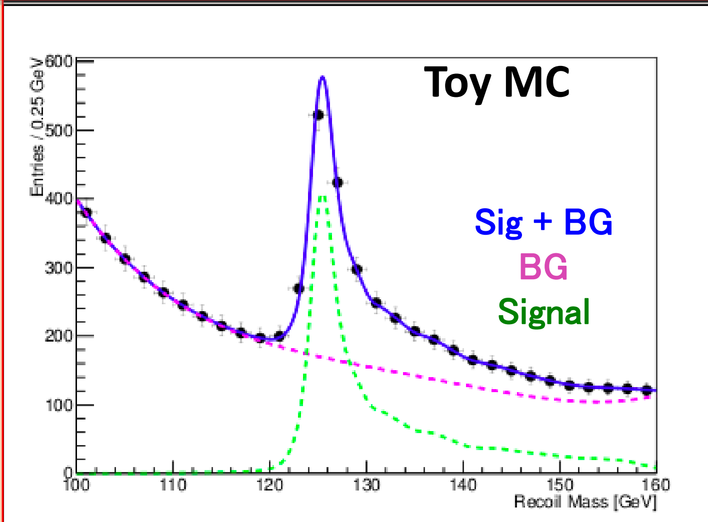
goal: test quality of fitting method

evaluate precision of xsec and recoil mass

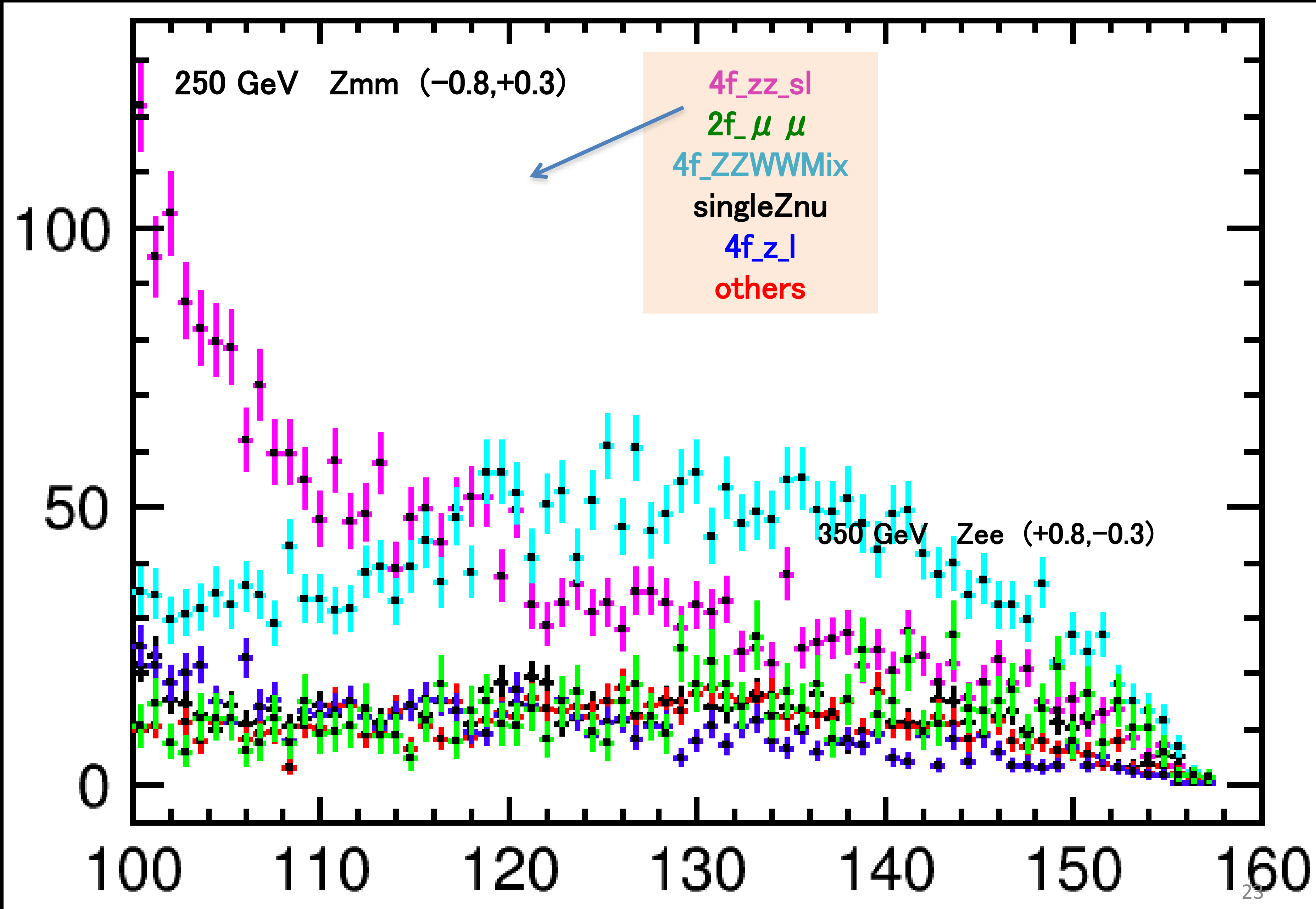
method :

- generate MC events with 1000 x statistics according to fitted result of “real” data
- fit Toy events with same function : Kernel + polynomial

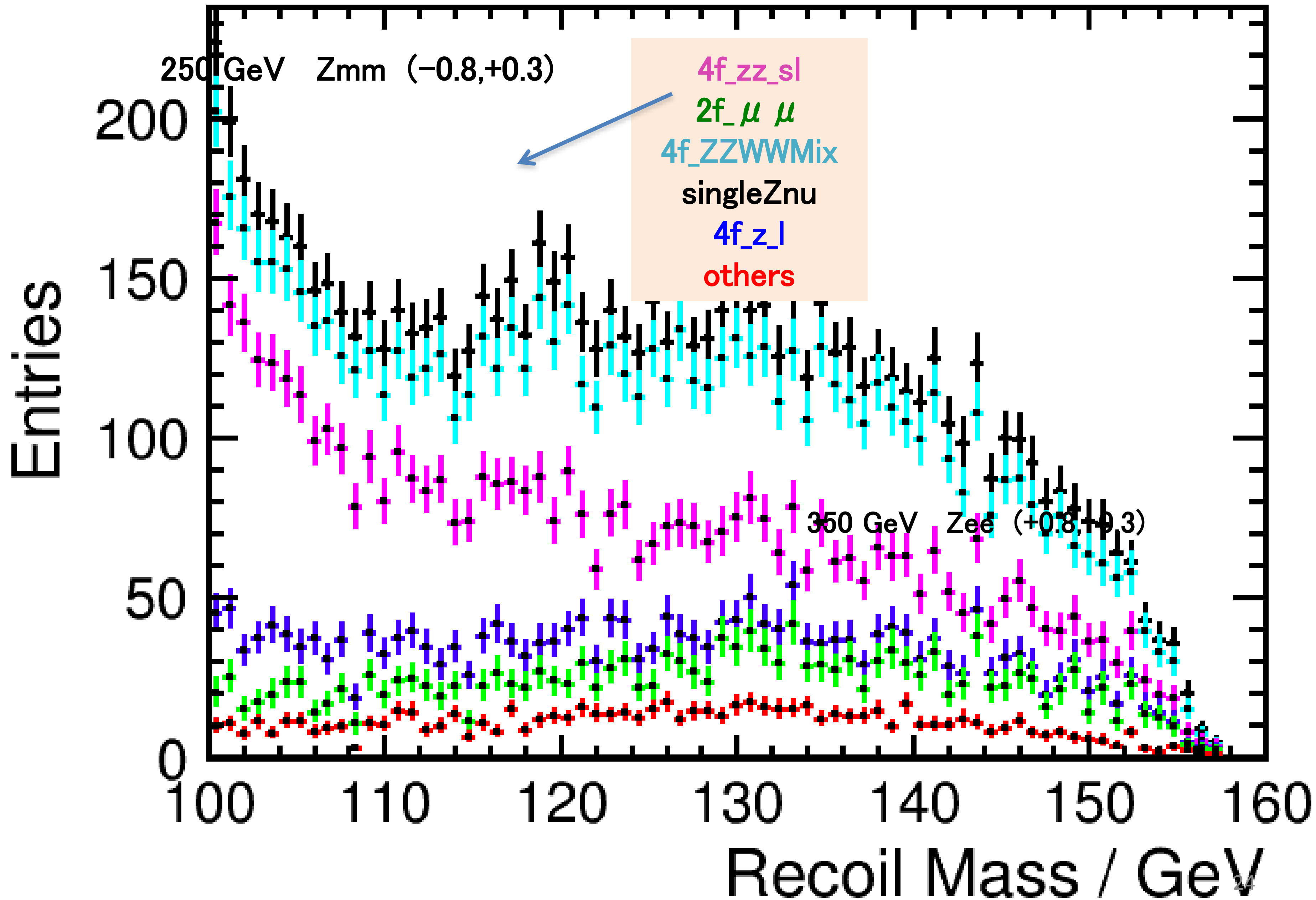
→ get signal yield, mass shift, and errors



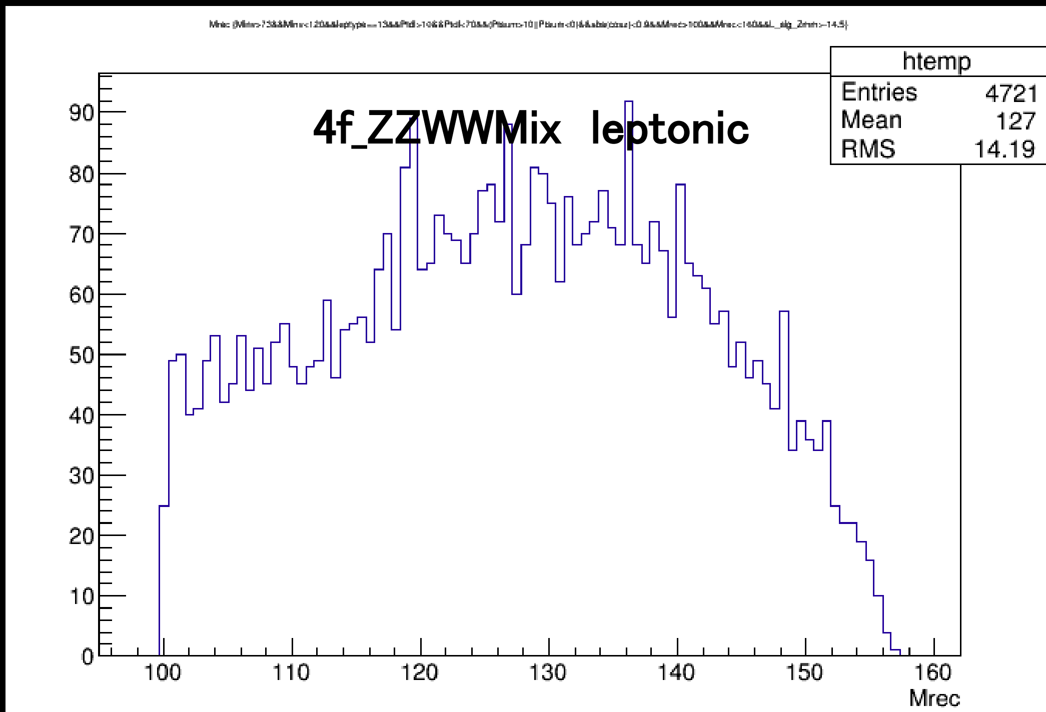
250 GeV Zmm left pol

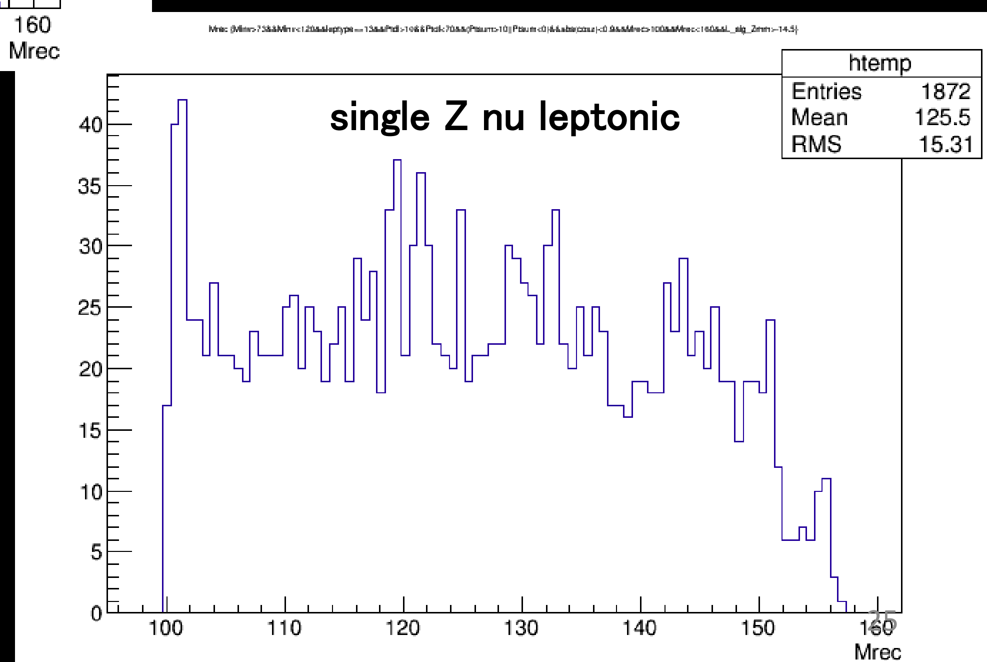


250 GeV Zmm left pol

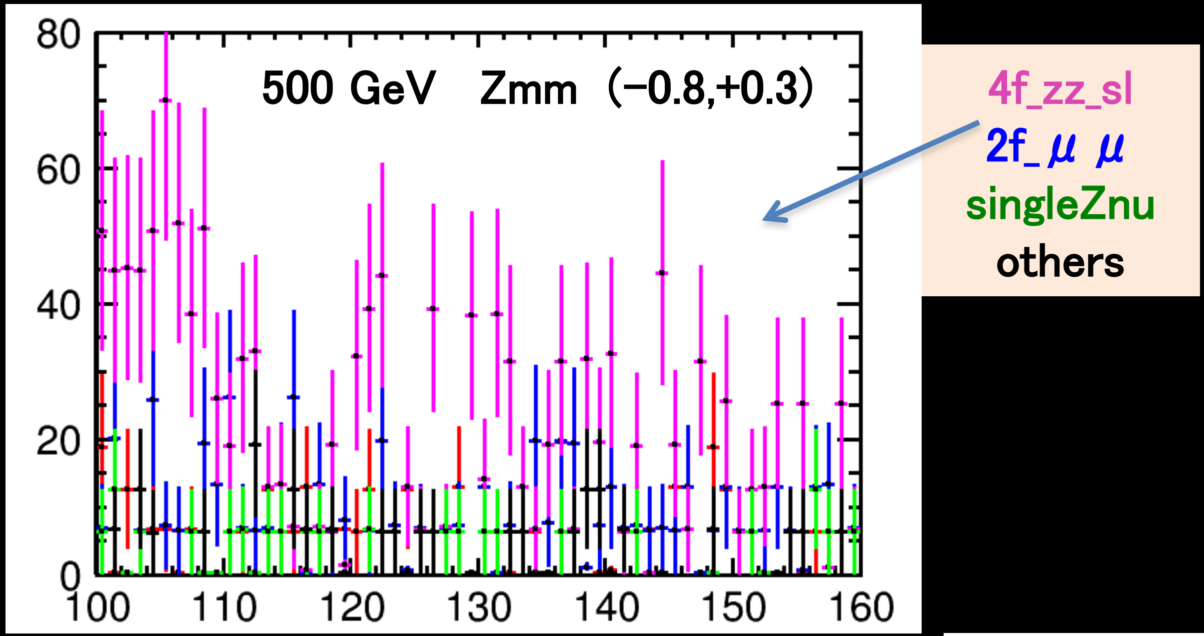


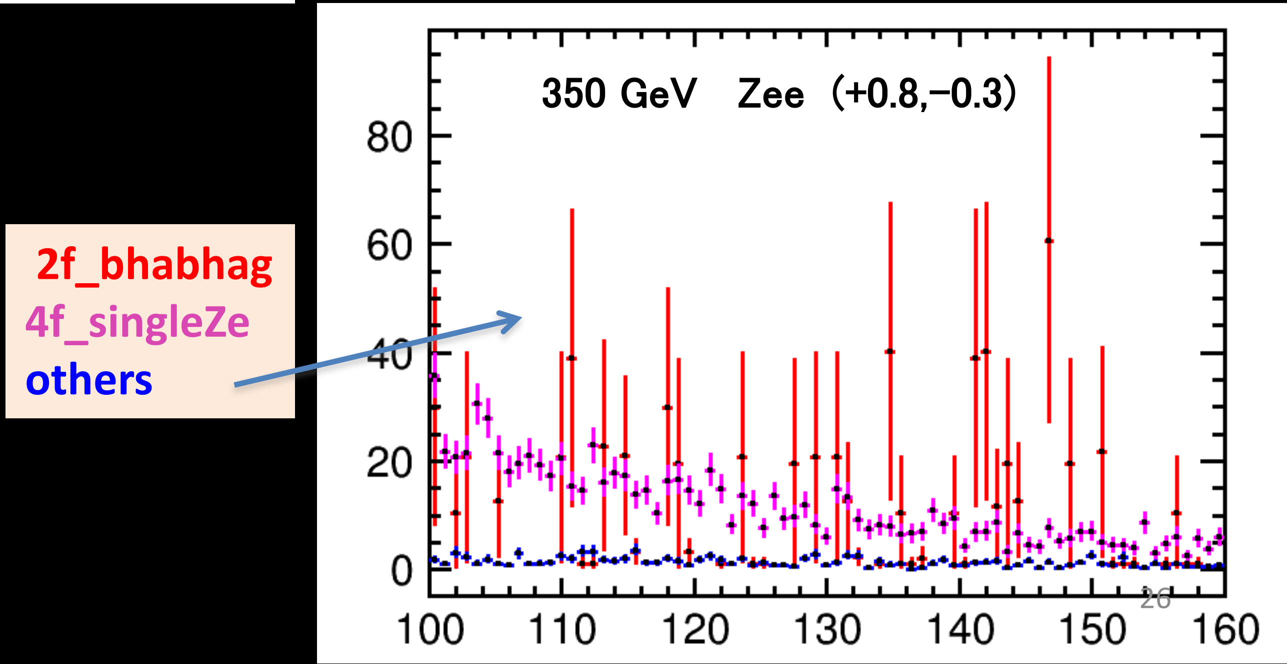
Recoil mass region aftre all cuts in 100 – 160 GeV





Dominant BG with low MC statistics cause large errorbars
(a technical problem planned to be solved by generating higher statistics samples)

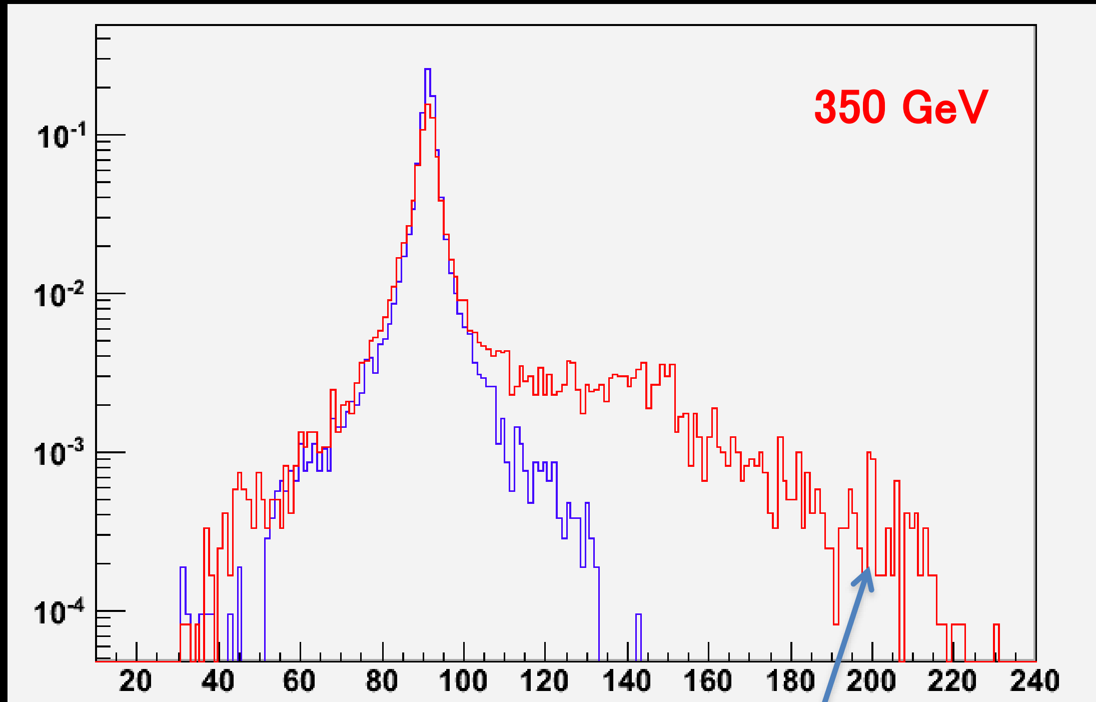


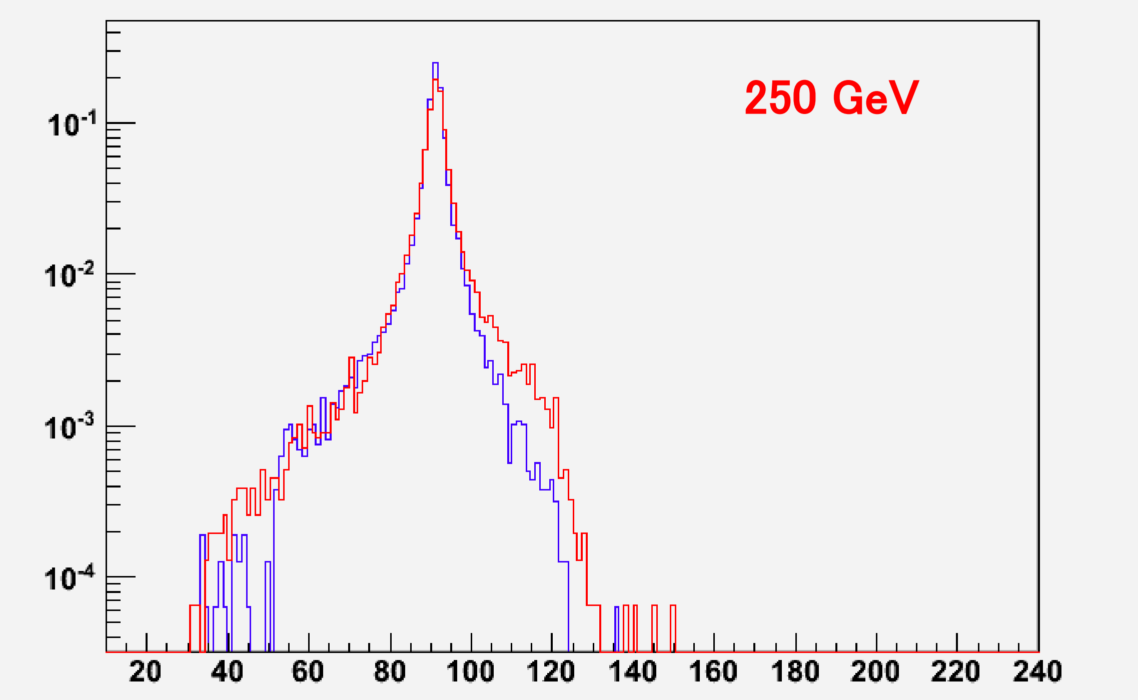


compare dilepton invariant mass distribution

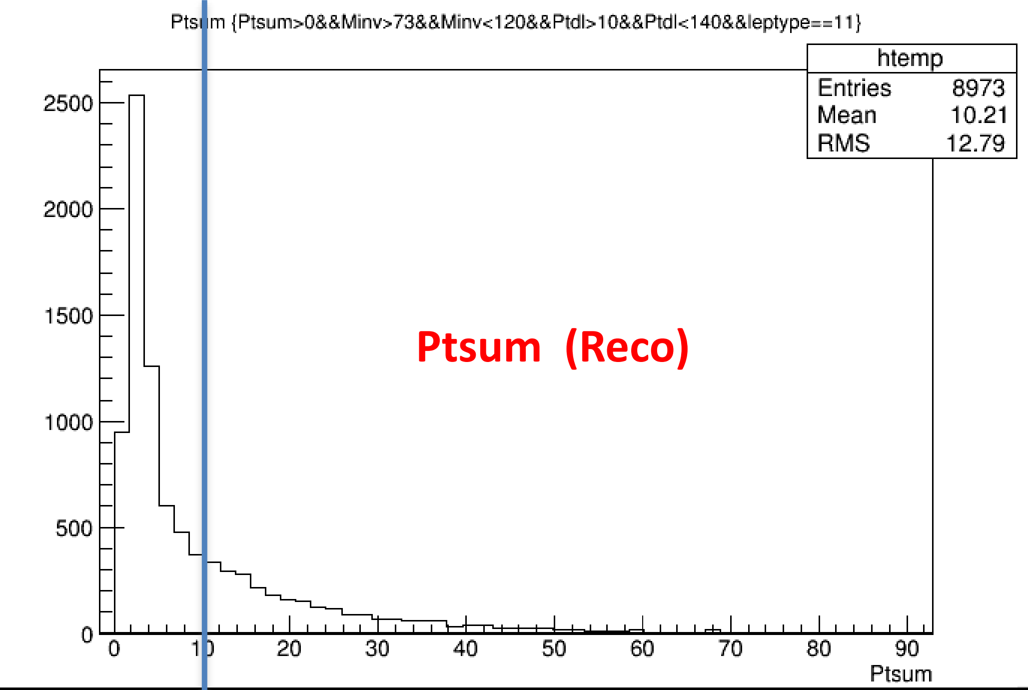
Zee (red)

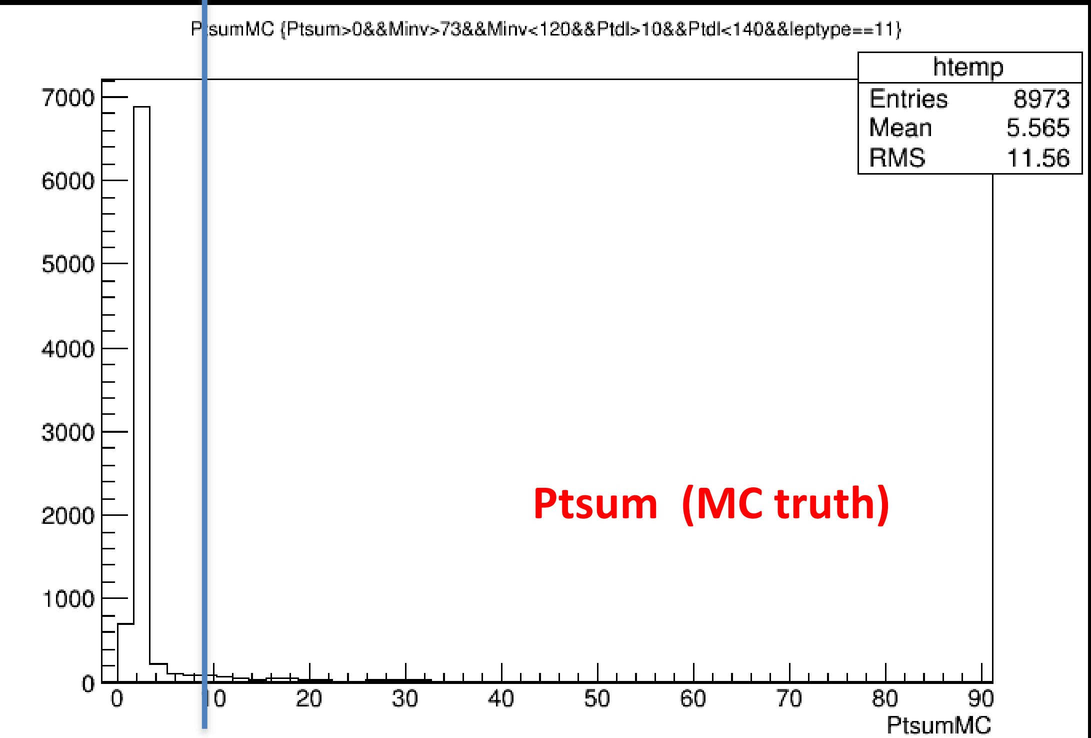
vs Zmumu (blue)





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





events before Ptsum cut

2f_bb

Realized a large difference in Ptsum between Reconstructed particles and MC Truth

Ptsum if formed from sum of vectors !!

Ptdl should be near zero if no brem

If one lepton emit brem and lose energy,

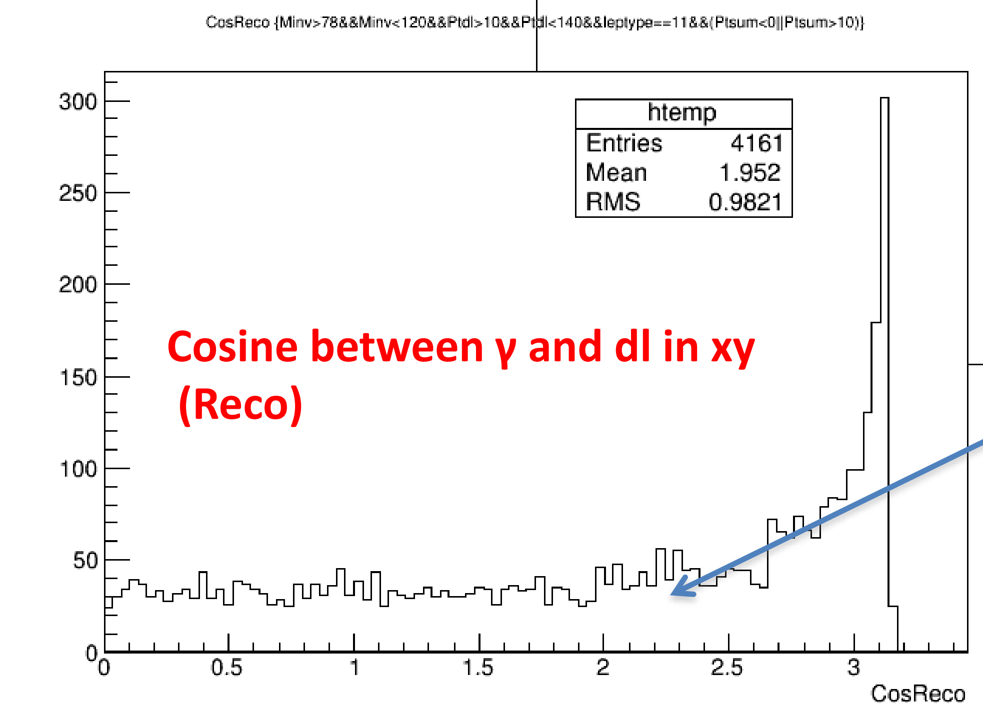
Pt_dl will incrrease

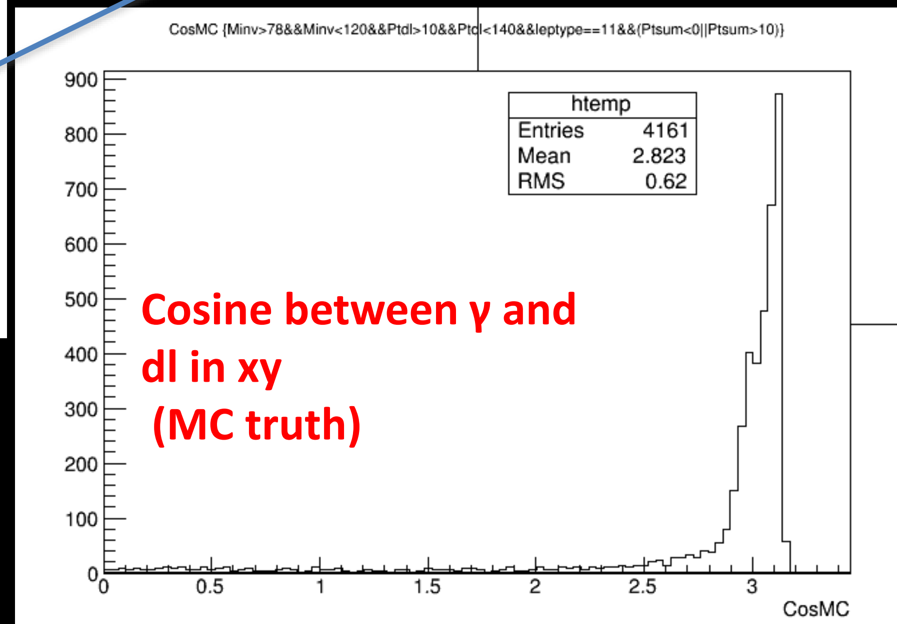
→ long Ptsum tail

→ Ptsum cut lose power

MC truth is much more back-to-back (as expected)

How to explain the long isotropic tail for Reco ?





There are a few potential explanations

From here on we will investigate the reason for the non-back-to-back ness

especially the long isotropic tail