Higgs Recoil Mass Study using Z→ll at ECM=250, 350 GeV and 500 GeV ILC

The 43rd General Meeting of the ILC Physics Working Group

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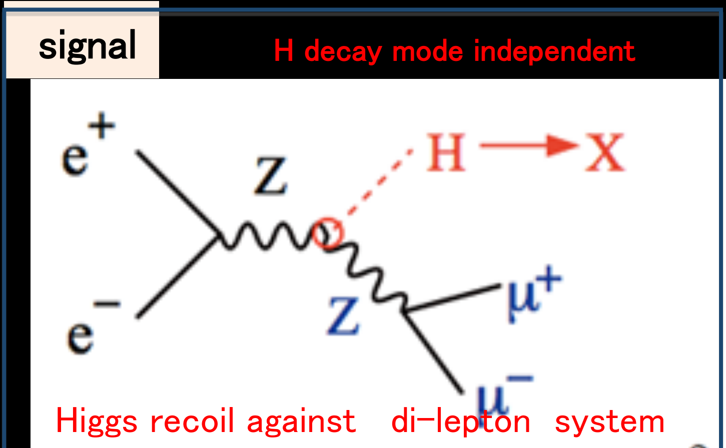
and the ILC Physics Working Group

Leptonic recoil mass study
@ECM = 250 GeV, 350 GeV, and 500 GeV

precise model-independent measurement of absolute Higgs cross section and recoil mass

- σ_{ZH} is a "must-have" for measurement of total Higgs width & couplings



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

- study impact of ECM and polarization

- By this time, measurement precision has been shown to (at least) meet the expectations in ILC physics documents
- Furthermore, leptonic recoil has been demonstrated to be model independent

ILC sample used in analysis

chanel	mH	ECM	L	Spin polarization	Detector simulation
e+e→Zh->μμh e+e→Zh->eeh	125 GeV	250 GeV 350 GeV 500 GeV	250 fb-1 333 fb-1 500 fb-1	P(e-,e+) = (-0.8,+0.3) (+0.8,-0.3)	Full ILD (ILD_01_v05 DBD ver.)

Progress since the last (42nd) General Meeting (June 13)

Last Time

- **The first full set of statistical error study results for each of the 12 scenarios**
  (3 ECM x 2 leptonic channels x 2 polarizations)
- **The first efforts to reduce signal bias**

Features of This Time

- **Add cut on visible energy**
  (separate analysis into visible and invisible parts)
- **Replaced likelihood cut with a TMVA based cut**
  ➔ improved xsec and mass precision
- **A more detailed study of mode independence**

Layout of this Talk

- **Evaluation of data analysis performance**
- **Comparison between different ECM and polarization**
- **demonstration of Higgs decay mode independence**
- **Summary & Plans**

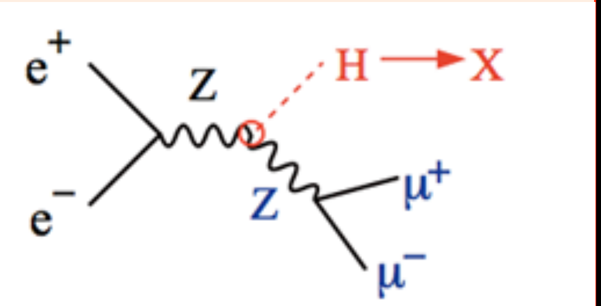
PART I

The Expected Precision of ZH cross section and Higgs Mass

Data Selection Method

Signal signature

a pair of isolated energetic leptons (μ / e) with invariant mass (M_{inv}) close to Z mass



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

Recoil mass

Dominant backgrounds	Signatures
• e+ e- → Z Z → l+ l- X :	forward Z production angle
• e+ e- → γ Z → γ l+ l- :	energetic ISR γ which balance dilepton pt
• e+ e- → W W → l+ l- ν ν :	broad M_{inv} distr.

- data selection is based on characteristics of signal / BG
- a final recoil mass window + TMVA cut at the end

Lepton Pair Candidate Selection

opposite +/− 1 charge

- E_cluster / P_total : < 0.5 (μ) / > 0.9 (e)
- **isolation (small cone energy)**
- Minv closest to Z mass
- χ 2 minimization based on Minv and Mrecoil
- |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**
- $\left|\overrightarrow{P_{t,sum}}\right| \equiv \left|\overrightarrow{P_{t,\gamma}} + \overrightarrow{P_{t,dl}}\right|$ **> 10 GeV**
- **|cos(θ_missing)| < 0.98**
- **|cos(θ_Z)| < 0.9**
- **100 GeV < Mrecoil < 200 GeV**
- **TMVA cut**

Example of ECM=350 GeV,

- Effective for cutting $\mu\mu$ / ee BG
- Use info of most energetic photon (pt_γ , cone energy)
- "protection limits" have been placed to minimize bias on signal

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

similar methods applied to all ECM and polarizations

Improvement in Data Selection Performance

Fitting range : 110–155 GeV (250 GeV) / 100–200 GeV (350 GeV) / 100–250 GeV (500 GeV)

(−0.8,+0.3)		Nsig	NBG	Significance (new)	Significance (old)
250GeV	Zmm	1920	3687	25.6	18.3
	Zee	1775	7880	18.07	14.4
350GeV	Zmm	1587	4635	20.12	17.7
	Zee	1328	6128	15.38	14.1
500GeV	Zmm	959	3869	13.8	11.1
	Zee	872	3899	12.6	8.7

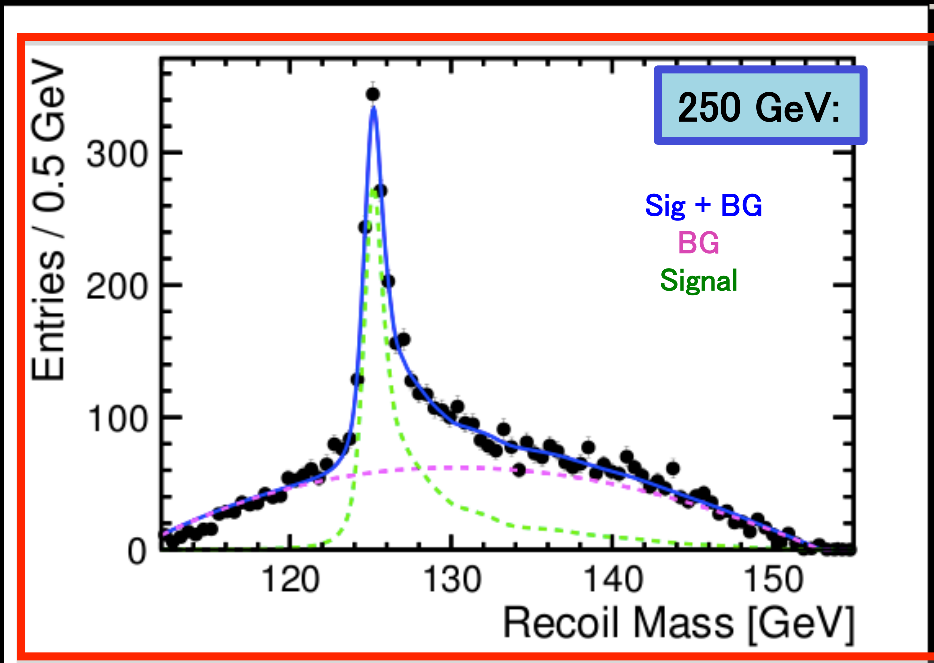
(+0.8,−0.3)					significance
250GeV	Zmm	1389	2614	21.95	19.7
	Zee	1177	4962	15.02	12.8
350GeV	Zmm	1094	2517	18.21	17
	Zee	858	3928	12.4	12.7
500GeV	Zmm	723	2650	12.45	9.9
	Zee	599	1641	12.66	8.9

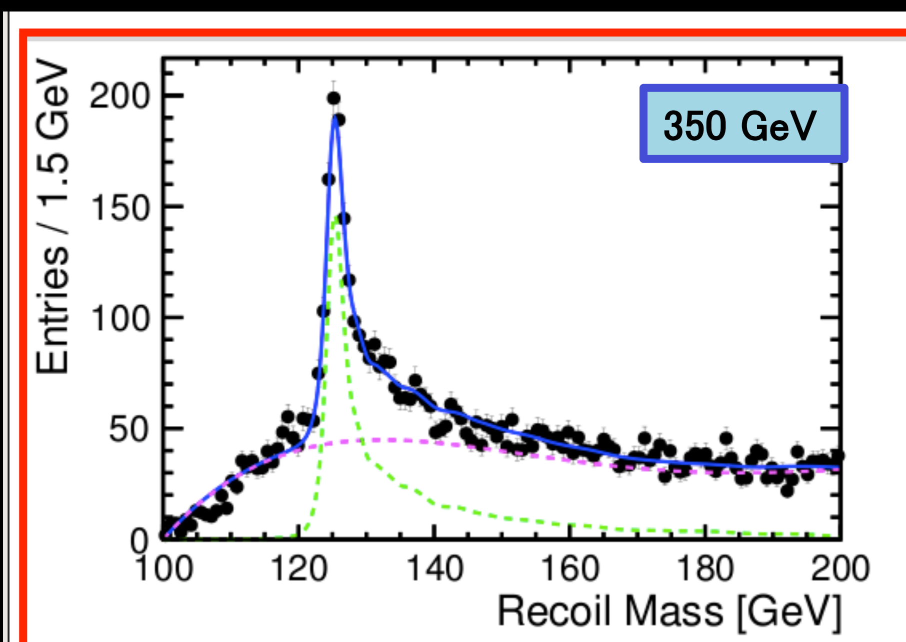
- Data selection improved by TMVA cut. (replaced likelihood cut)
- as much as 45 % rise in significance in some channels

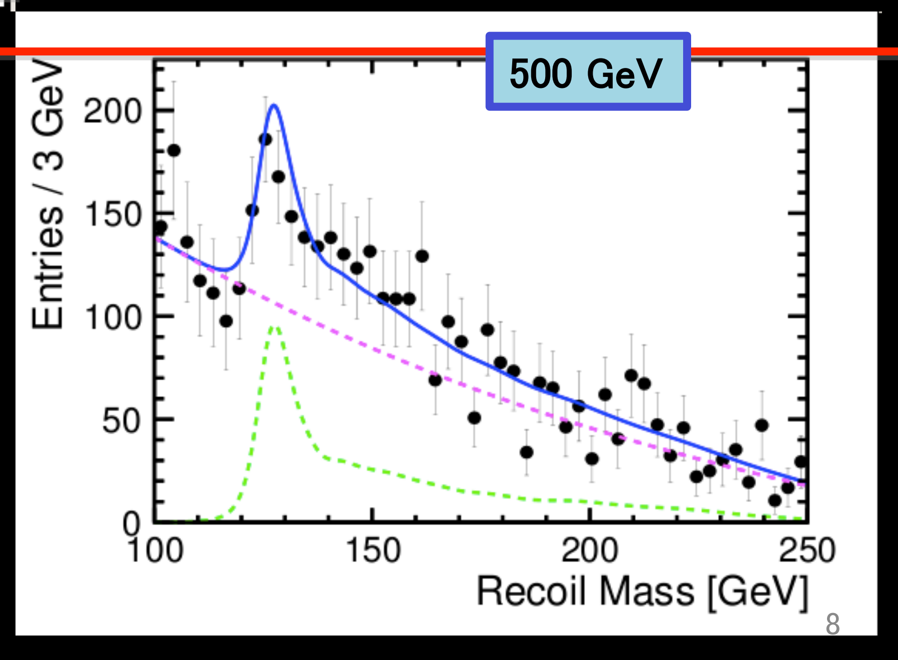
Reconstructed data recoil mass histogram

Z→μμ channel

Pol: (− 0.8, +0.3)



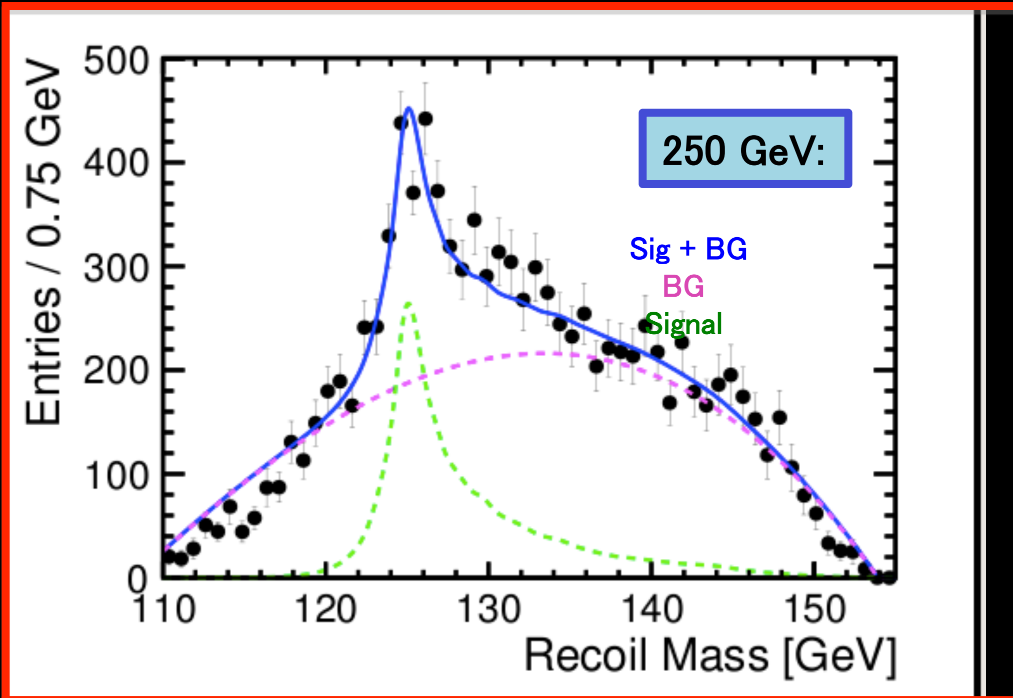


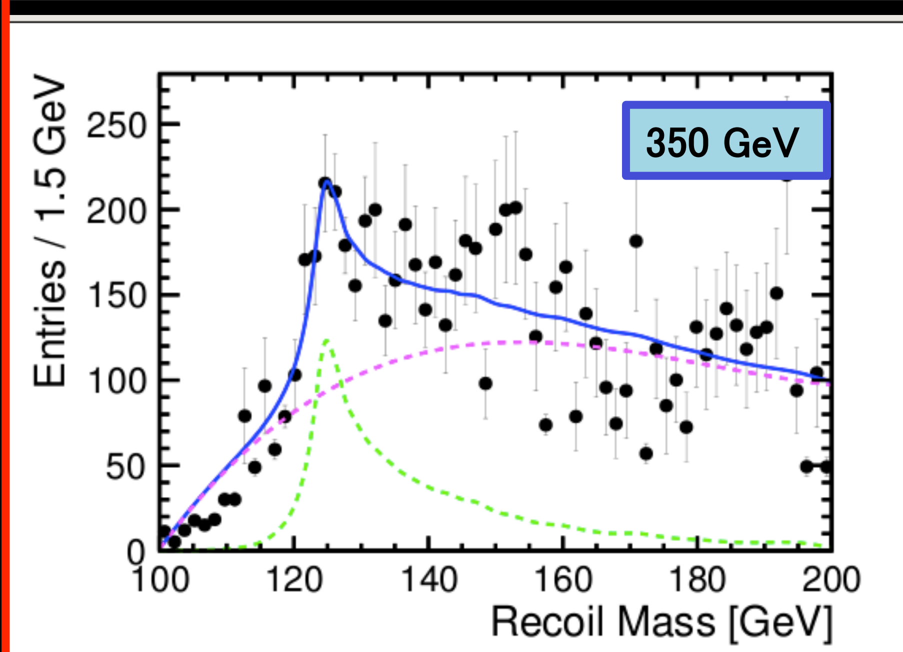


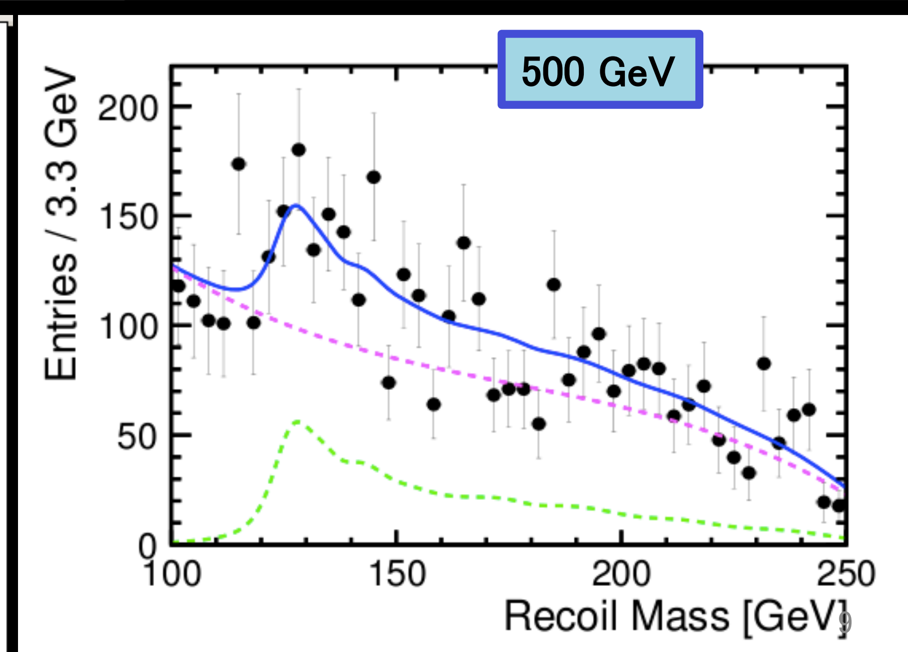
Reconstructed data
recoil mass histogram

Z→ee channel

Pol: (− 0.8, +0.3)



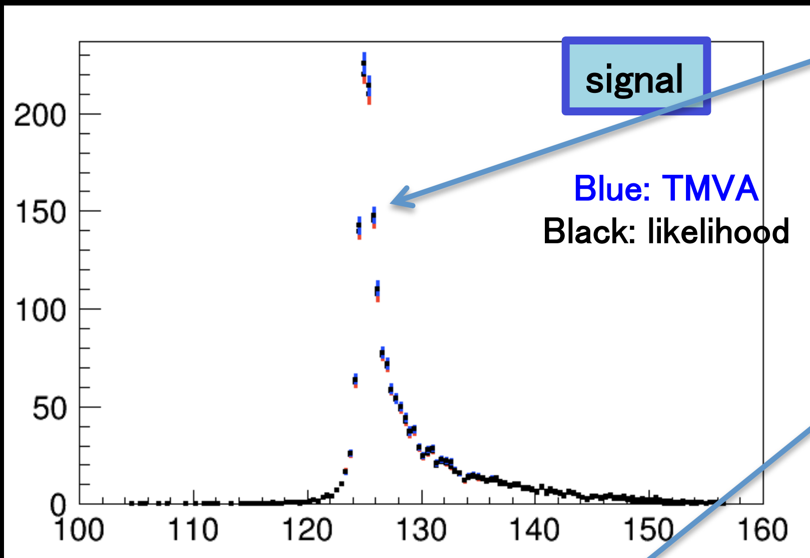


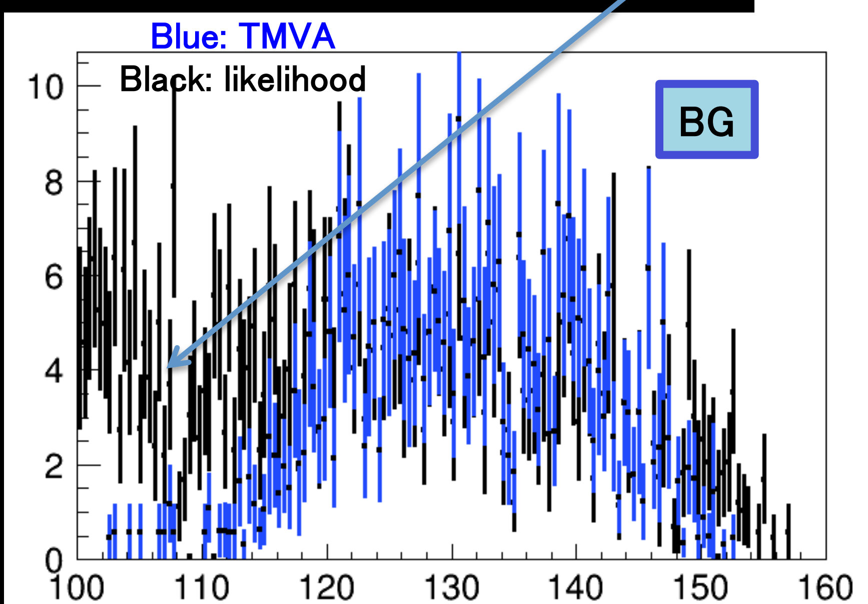


effect of TMVA cut

When TMVA is used in place of likelihood:

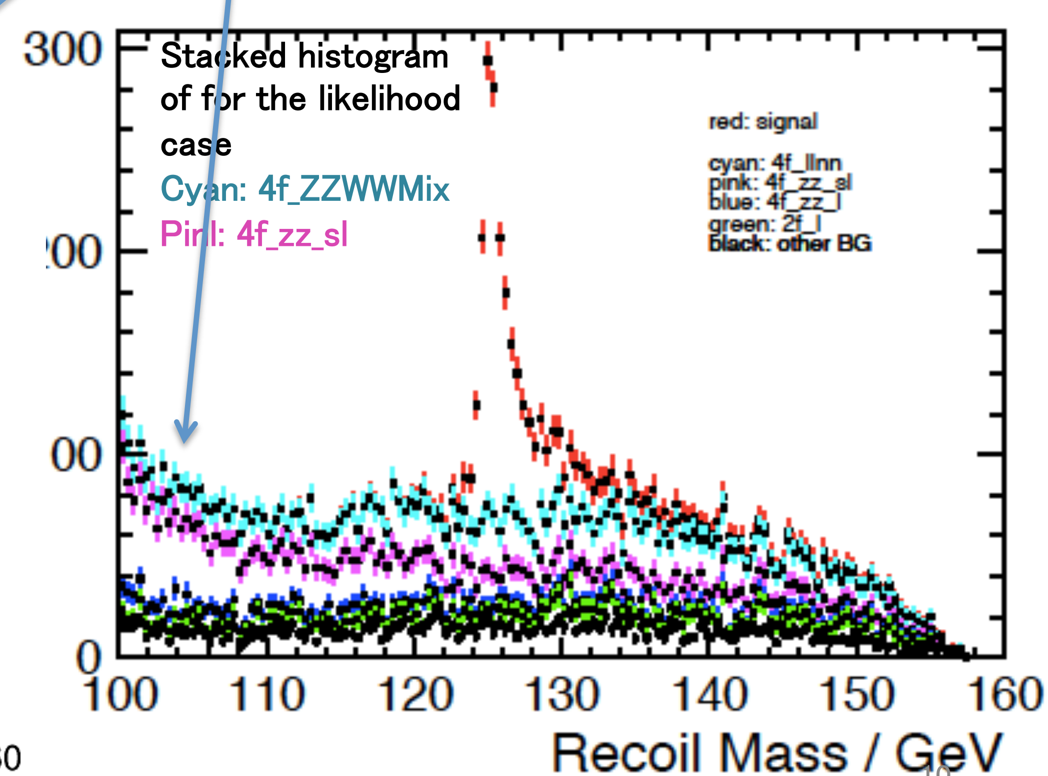
- signal is not much affected
- BG is greatly reduced in lower end mainly ll$\nu\nu$ (ZZWWMiix) and 4f_zz_sl BG





$Z \rightarrow \mu\mu$ channel

250 GeV : (− 0.8, + 0.3)

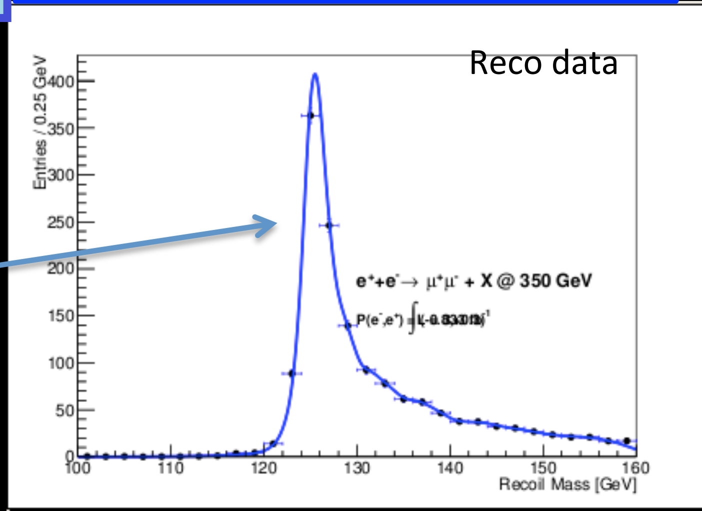


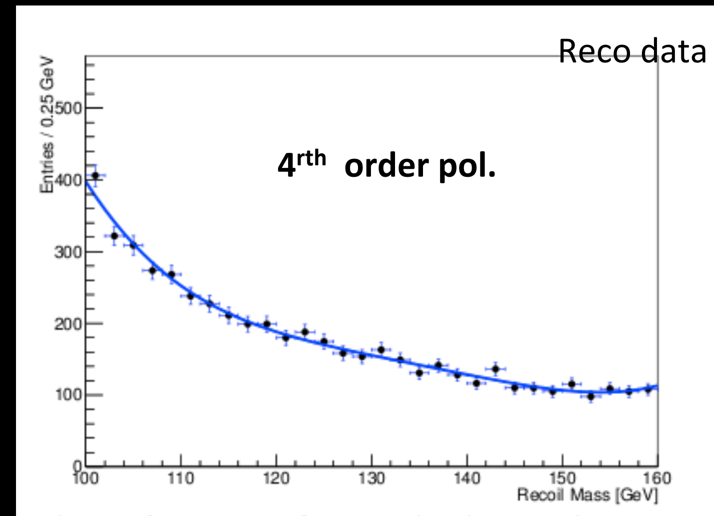
Fitting of recoil mass spectrum

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

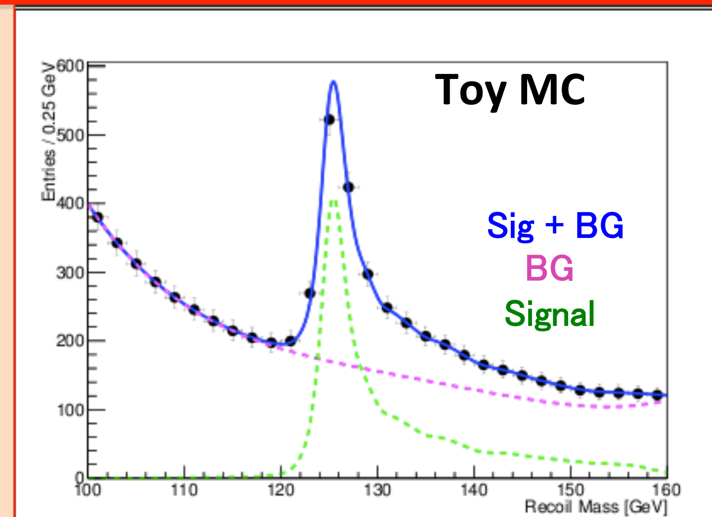
<u>goal:</u> test quality of fitting method

evaluate precision of xsec and recoil mass

<u>method</u>:

- 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**



Statistical error study results

ECM=250 GeV		xsec	mass[MeV]
Zmm	left	3.09%	36.2
	right	3.52%	41.5
Zee	left	4.29%	103
	right	5.04%	120
ECM=350 GeV			
Zmm	left	3.76%	97
	right	4.27%	111
Zee	left	5.13%	307
	right	5.91%	320
ECM=500GeV			
Zmm	left	6.17%	527
	right	6.97%	633
Zee	left	7.32%	1570
	right	7.34%	1550

Z→μμ and Z→ee combined

250GeV		xsec	mass[MeV]
	left	2.51%	34.2
	right	2.89%	39.2
350GeV			
	left	3.03%	92
	right	3.46%	105
500GeV			
	left	4.72%	500
	right	5.05%	586

xsec error

- 350 GeV is 20% worse w.r.t. 250 GeV
- Zee is worse by 40% w.r.t. Zmm
- right hand pol is worse by ~ 15 % w.r.t. left hand pol

Mass:

350 geV is 2-3 times worse w.r.t. 250 GeV

Combined Higgs visible and invisible decay results

ECM	Pol	xsec precision
250 GeV	left	**2.65%**
	right	**2.95%**
350 GeV	left	**3.27%**
	right	**3.63%**
500 GeV	left	**5.29%**
	right	**5.34%**

contribution from invisible decay is very small

Invisible decay results

BR(inv) upper limit	P(e-,e+) =(-0.8,+0.3)	P(e-,e+) =(+0.8,-0.3)
250 fb^{-1} @ 250 GeV	0.86%	0.61%
330 fb^{-1} @ 350 GeV	1.23%	1.10%
500 fb^{-1} @ 500 GeV	2.39%	1.73%

From Junping-san's talk at ALCW2015

Precision scaled to the H20 scenario

		xsec	Mass [MeV]
ECM=250GeV (2 ab−1)	left	1.14%	14.7
	right	2.20%	20.2
	combined	**1.01%**	**11.9**
ECM=350GeV (0.2 ab−1)		xsec	mass
	left	5.16%	144.5
	right	9.87%	285.6
	combined	**4.57%**	**128.9**
ECM=500GeV (4 ab−1)		xsec	mass
	left	2.96%	279.5
	right	2.99%	327.6
	combined	**2.10%**	**212.6**
All channels (full H20 run)		**xsec**	**mass**
		0.89%	**11.8**

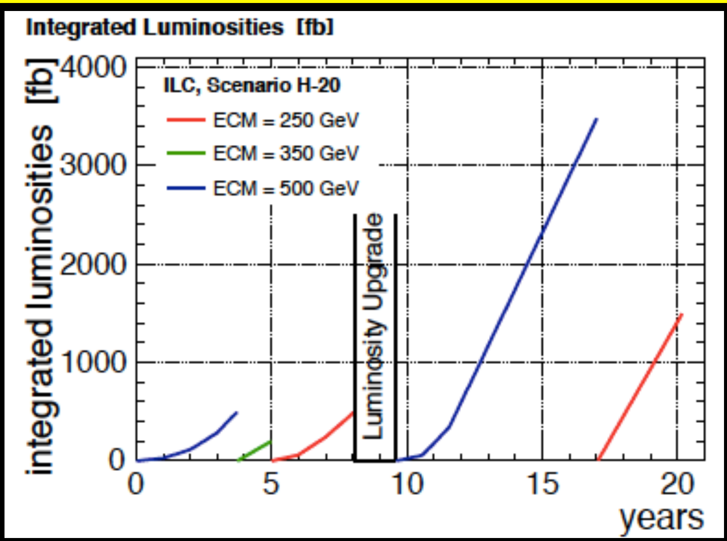
After the full H20 run:
σZH error 0.9%,
MH error : 12 MeV

Lumi	$\sqrt{s}$ [GeV]	$\int \mathscr{L} dt$ [fb^{-1}]
Physics run	500	500
Physics run	350	200
Physics run	250	500
Shutdown		
Physics run	500	3500
Physics run	250	1500

- Run long time at 250, 500 GeV, short at 350 GeV

polarization

	fraction with $sgn(P(e^-), P(e^+))$ =			
	(-,+)	(+,-)	(-,-)	(+,+)
$\sqrt{s}$	[%]	[%]	[%]	[%]
250 GeV	67.5	22.5	5	5
350 GeV	67.5	22.5	5	5
500 GeV	40	40	10	10



Residual BG in fitting range

250 GeV	Zmm		250 GeV	Zee	
1	4f_zz_sl	>45%	1	2f_bhabhag	>50%
2	2f_z_l	>20%	2	singleze_sl	>15%

350 GeV			350 GeV		
1	4f_zz_sl	>45%	1	2f_bhabhag	>45%
2	2f_z_l	>15%	2	singleze_sl	>20%

500 GeV			500 GeV		
1	4f_zz_sl	>35%	1	singleze_sl	>45%
2	2f_z_l	>30%	2	2f_bhabhag	>10%

ongoing efforts to further improve precision

- Still much room to improve Zee channel, and 500 GeV
- a better algorithm for brem recovery ?
- Improve training method of TMVA, add more variables, ect….

PART II
Higgs Decay Mode Independence

- It is crucial to not only achieve the goal precision but also to maintain Higgs decay mode independence

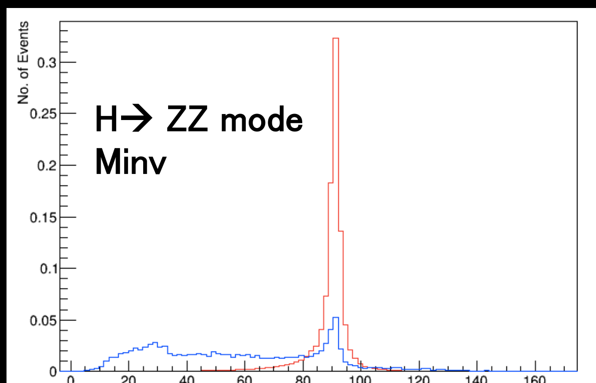
For the first time, leptonic recoil analysis has been demonstrated to be mode-independent!

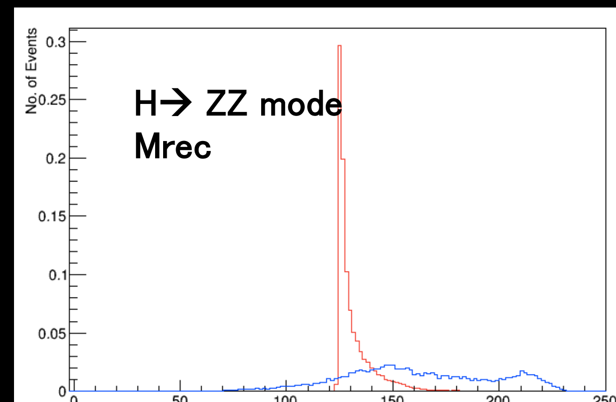
But there is still more room for improvement

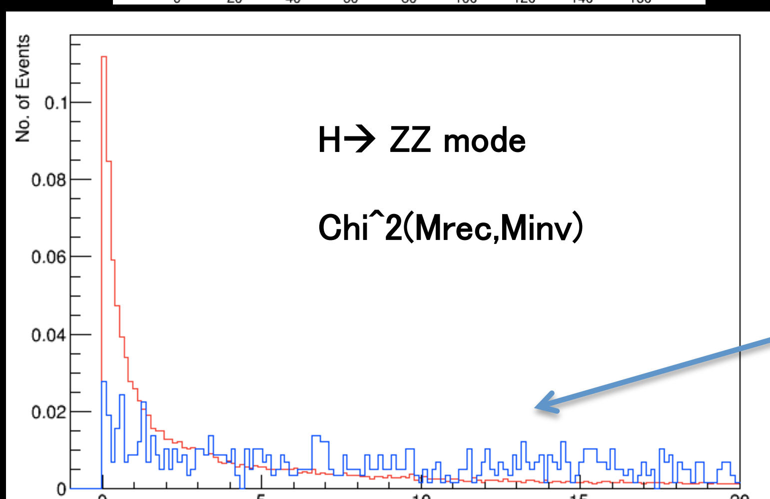
Details coming up ……..

Efforts to minimize Higgs Decay Mode Bias

- **"wrong lepton pairing" for H→ ZZ*, WW***
  at least one of the leptons from non-prompt Z decay
- Minv ~ MZ might be satisfied, but Mrec is deviated from Higgs mass
- leads to efficiency loss due to tighter cuts in later analysis







at least one wrong lepton
both leptons correct

solution:

select best pair by minimizing chi^2 based on Mrec and Minv

(previously: Minv closest to Z mass)

- **Some other bias due to photon-related cuts have been minimized as well**

Due to using chi^2(Mrec, Minv), lepton pairing mistake is reduced

ratio of at least one wrong lepton (when two real leptons exist,)

250 GeV	zz	ww
OLD	4.97%	1.46%
NEW	4.26%	1.37%

350 GeV	zz	ww
OLD	5.32%	2.00%
NEW	4.08%	1.42%

OLD:
Minv close to Z mass

NEW: chi^2(Mrec, minv)

Still room for improvement

～ 1/5 of wrong pairs would ultimately get selected as "best pair"

new strategies in progress !!

250 GeV	bb	cc	zz	ww	tautau	gg	γγ
total muons	93.70%	93.68%	93.86%	93.62%	93.89%	93.40%	93.70%
C1	93.70%	93.68%	89.61%	92.02%	93.33%	93.40%	93.62%
C2	0.00%	0%	0.39%	0.84%	0.20%	0%	0.08%
C3	0.00%	0%	3.61%	0.45%	0.26%	0%	0.00%
C4	0.00%	0%	0.25%	0.31%	0.09%	0%	0.00%
C5	0.00%	0%	0.00%	0.00%	0.00%	0%	0.00%

C1: correct

C2: two real leptons exist, only one wrong lepton

C3: two real leptons exist, both leptons wrong

C4: only 1 real lepton

C5: no real lepton

The residual Higgs decay mode is very small !!

$\sigma = N/L/\varepsilon$ :: $\Delta\sigma/\sigma = \Delta\varepsilon/\varepsilon$

	eff(final)	dev*BR
bb	73.94%	0.040%
cc	73.53%	−0.009%
gg	73.50%	−0.032%
tt	73.70%	0.006%
ww	74.07%	0.048%
zz	71.60%	0.017%
aa	72.21%	−0.004%
	Weighed avg	73.87%

- IF assume full knowledge of SM decay modes and BR : syst error 〜 0.05%

Efficiency values weighed by SM BR

	BR (SM)
bb	57.8%
cc	2.7%
gg	8.6%
tt	6.4%
ww	21.6%
zz	2.7%
aa	0.2%

Zmm

	bias1	bias2	bias3
250 GeV	0.048%	2.00%	0.80%
350 GeV	0.11%	2.10%	2.37%
500 GeV	0.13%	2.10%	1.52%

Zee

	bias1	bias2	bias3
250 GeV	0.110%	1.56%	0.73%
350 GeV	0.185%	3.40%	3.60%
500 GeV	0.04%	2.40%	2.74%

- Bias 1: IF assume full knowledge of SM decay modes and BR
- Bias 2: IF assume “no knowledge of BR” and ″no exotic decay
- Bias 3:: exclude γγ from Bias2

What about the possibility of unknown exotic decay modes ?➔ see next page

What about the possibility of unknown exotic decay modes ?

- So far, we have explored a wide kinematic range (the 7 known modes)
- **any exotic decay modes should resemble one of these modes**
- **Strategy: assign 10% of "unknown mode" to one of the known SM modes**
- **for the remaining part, we can make use of SM BR information**

Signature	Syst err
$\gamma\gamma$-like	0.15%
gg-like	0.06%
WW*-like	0.06%
bb-like	0.04%

Case of 250 GeV, Zmm

- some residual bias on $\gamma\gamma$ mode from Ptsum cut

From LHC data, it is unrealistic to expect large $\gamma\gamma$ BR ?

Pushing all 10% (big ratio !) of an unknown decay mode to a certain signature is a very pessimistic (conservative) assumption

Confirmed that efficiency is consistency within two sigmas between L and R polarizations (only ZZ* mode slightly out of bounds, due to angular distr.)

Owing to current design of analysis methods, for the first time, we can claim leptonic recoil is Higgs decay mode independent !

demonstrated for every single scenario (ECM, polarization, leptonic channel)

Remaining tasks:

investigate and reduce residual bias, starting with upstream, mistake in lepton pairing

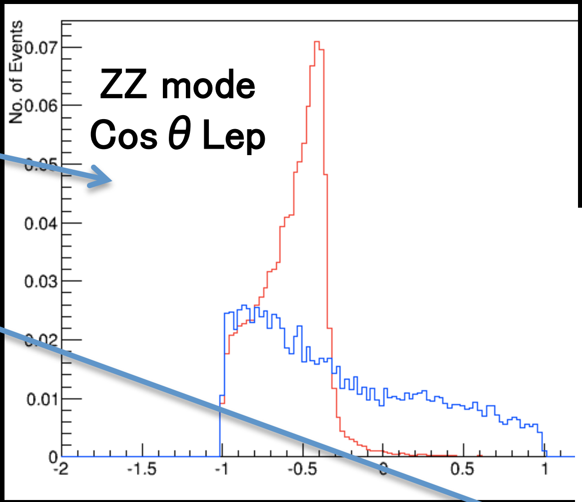
Strategies and ongoing efforts to further reduce bias

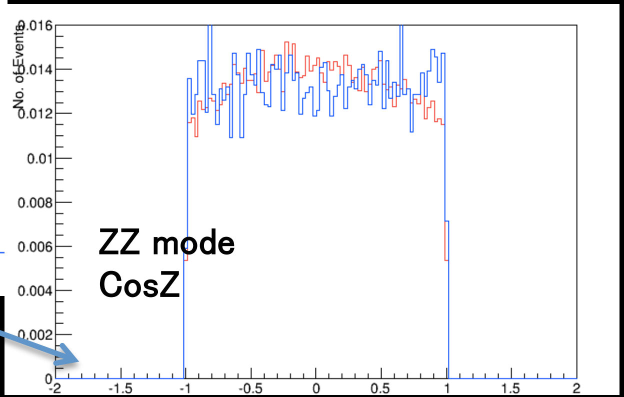
Select "best pair" using a likelihood formed from variables which are distinguishable between correct and worng pairs (TMVA)

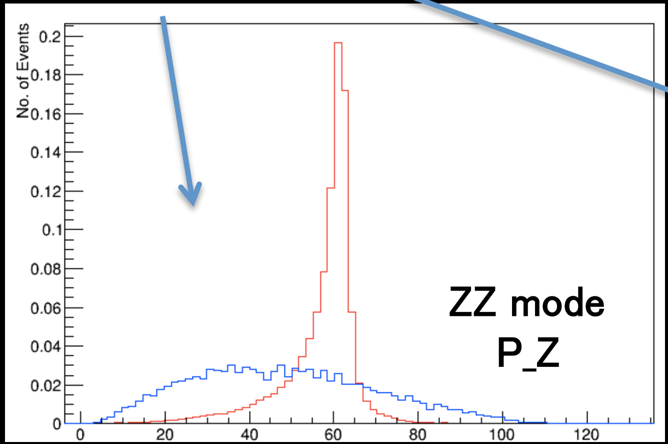
- Minv, Mrec
- cos θ betweem leptons
- Cos θ Z
- P_Z (momentum of Z)

at least one wrong lepton

both leptons correct







Summary

- Nearly **finalized leptonic recoil results for** ECM=250, 350, 500 GeV
- precision is compatible (better?) w.r.t. TDR and goals in H20 scenario
- improvements owing to Evis cut and TMVA cut

Z→μμ and Z→ee combined

		xsec	mass[MeV]
250GeV	left	2.65%	34.2
	right	2.95%	39.2
350GeV	left	3.27%	92
	right	3.63%	105
500GeV	left	5.29%	500
	right	5.34%	586

- **Detailed study of Higgs decay mode dependence (systematic errors)**
  using high statistics samples
  demonstrated mode bias is negligible even when compared with the best $\Delta\sigma$ stat (H20)
- **Further reduction of bias is ongoing** : new algorithm for lepton paring

- **First draft of paper on leptonic Higgs recoil is completed**

Title (preliminary) : **Leptonic Higgs Recoil Analysis at the ILC**

- Now undergoing modification from each new improvement
- Plan : complete paper by end of year (?)

Also writing another paper on study of Higgs mode independence

Plans and Goals

(1) finalize study of Higgs decay mode dependence

Succeed in developing new algorithm for lepton pairing

(2) **Attempt to further improve xsec and mass precisions**

try b-tagging for mass measurement (no need to be mode independent)

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

(4) **Begin hadronic recoil at 500 GeV**

investigate Higgs decay mode dependence the same way as I did for (1)

+ α: need higher statistics sample (esp BG) for 350 and 500 GeV

BACKUP

Other forms of Higgs Decay Mode Bias

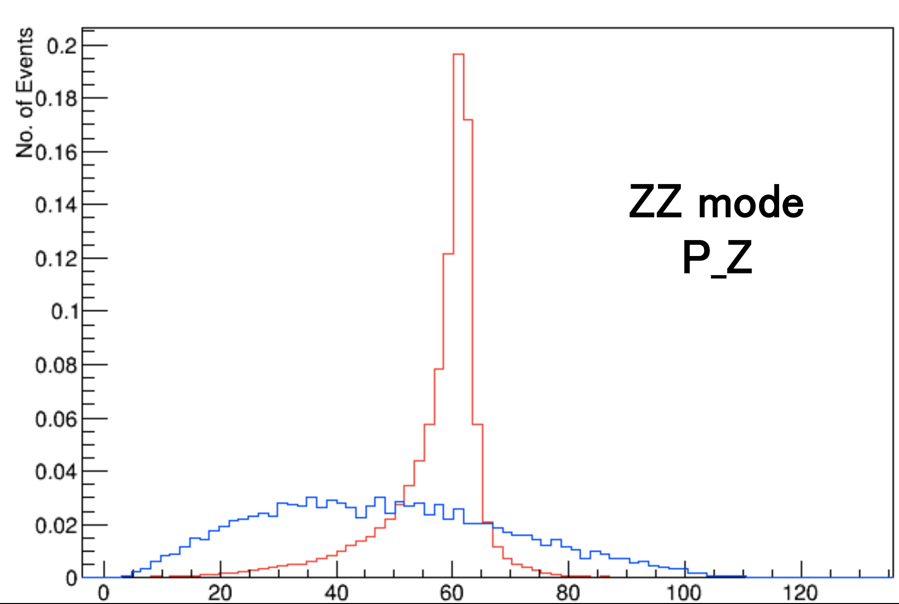
(1) efficiency of isolated lepton finder is lower for H→ gg mode
due to more overlap of jets from Higgs decay
solution:
used H→gg mode signal to train weights for TMVA

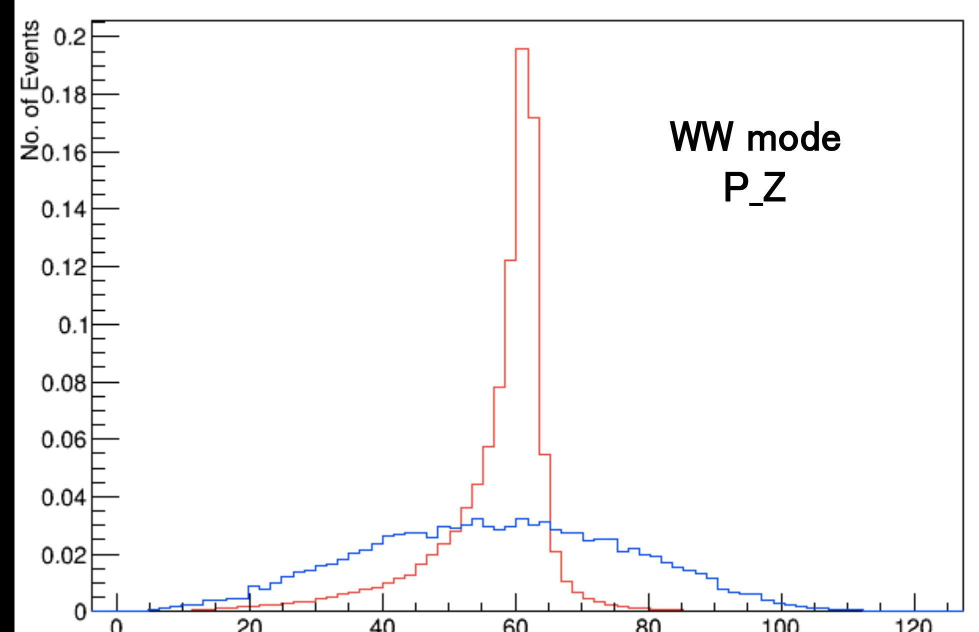
(2) bias due to non-lepton related cuts (cos(θmiss) cut and Ptsum)
related to missing energy and ISR γ

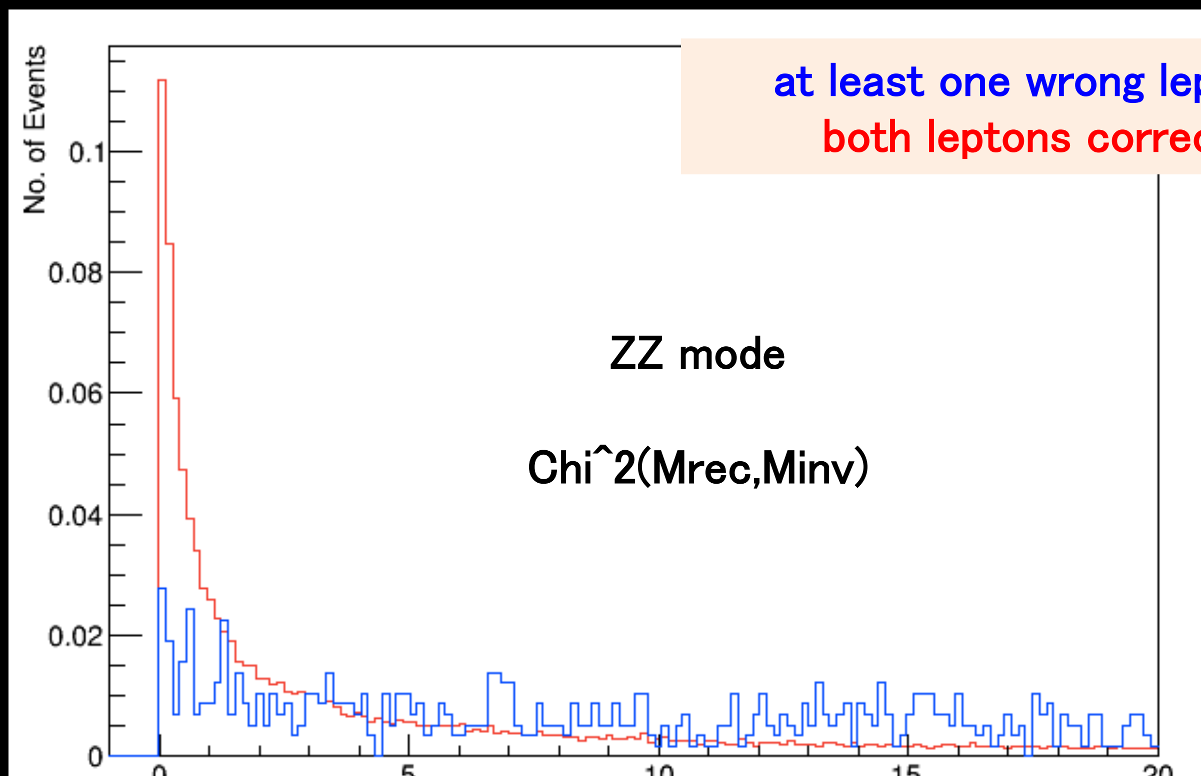
- solution:
- **targeted at removing 2f BG, not much more than leptons and γ**

In order to prevent Higgs events (with neutrinos in jets) to be cut away place safety protection as only cut if :: "Evis – Edl -Eγ < (*) GeV" && "cosθmiss > 0.98"
*** (protection limit) optimized for each channel**

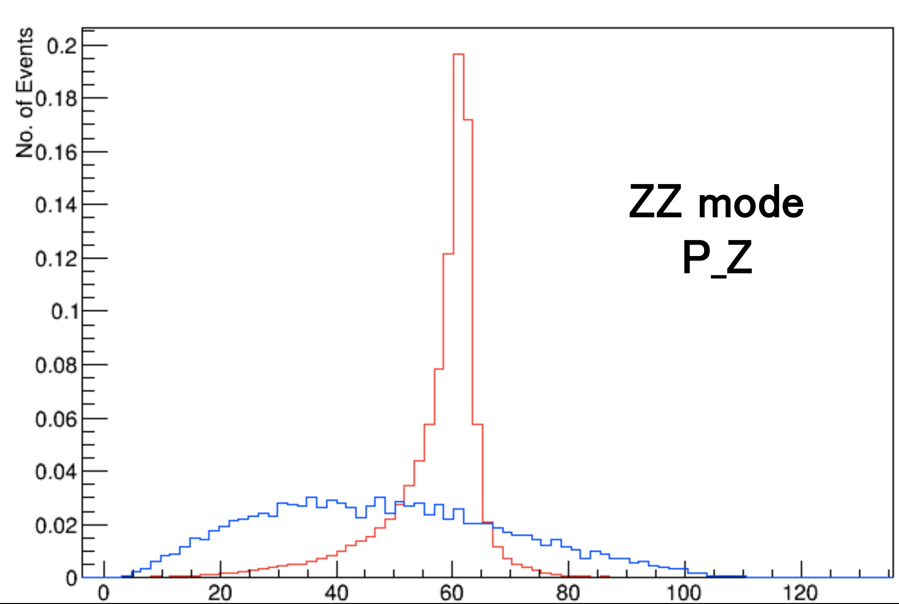
- **residual bias cannot be helped since cannot sacrifice xsec and mass precision**
- **Should be** negligible after weighing by BR

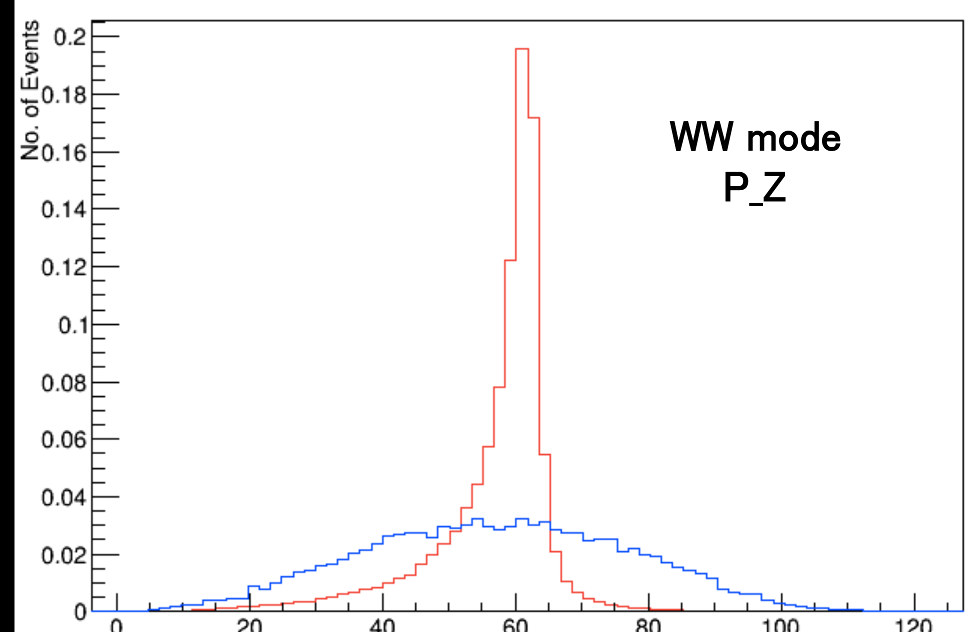


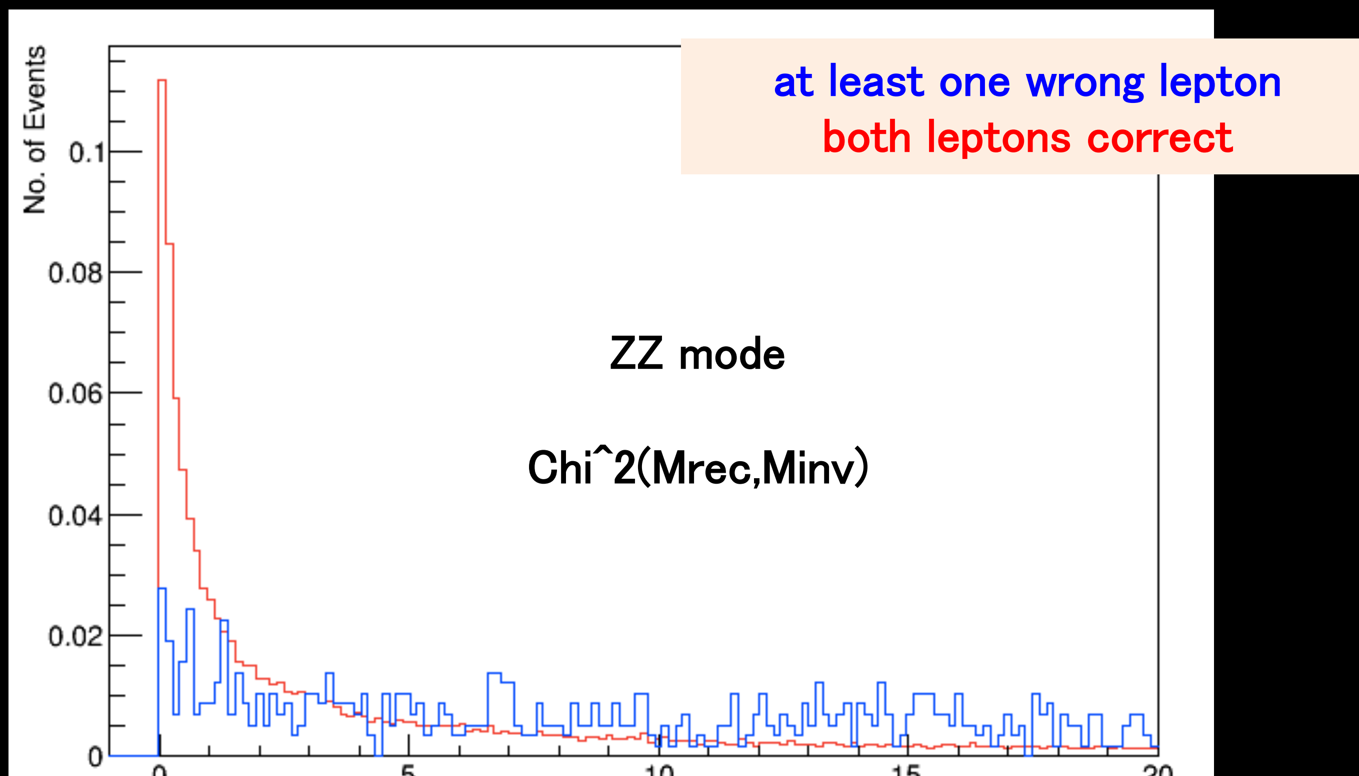


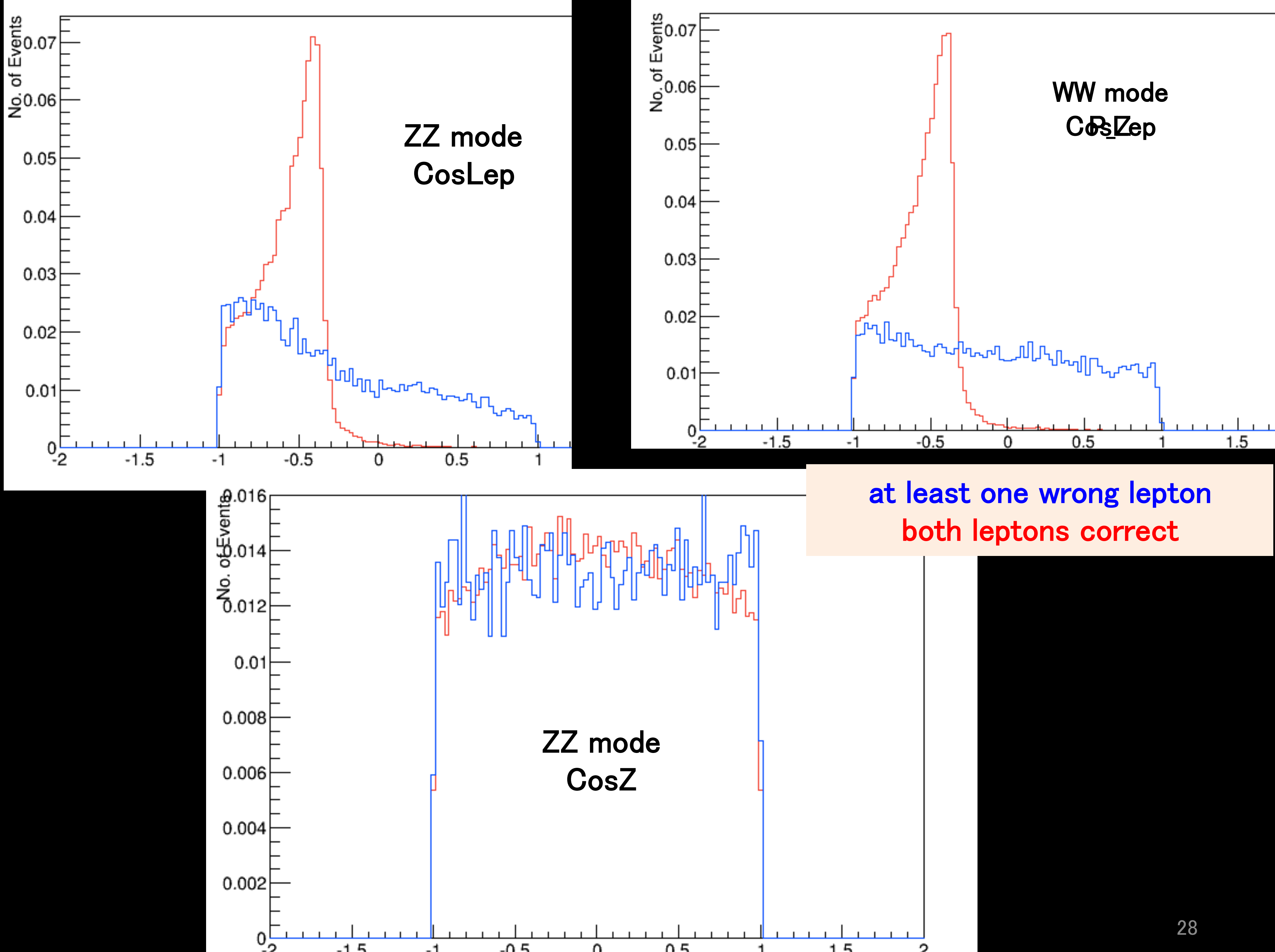


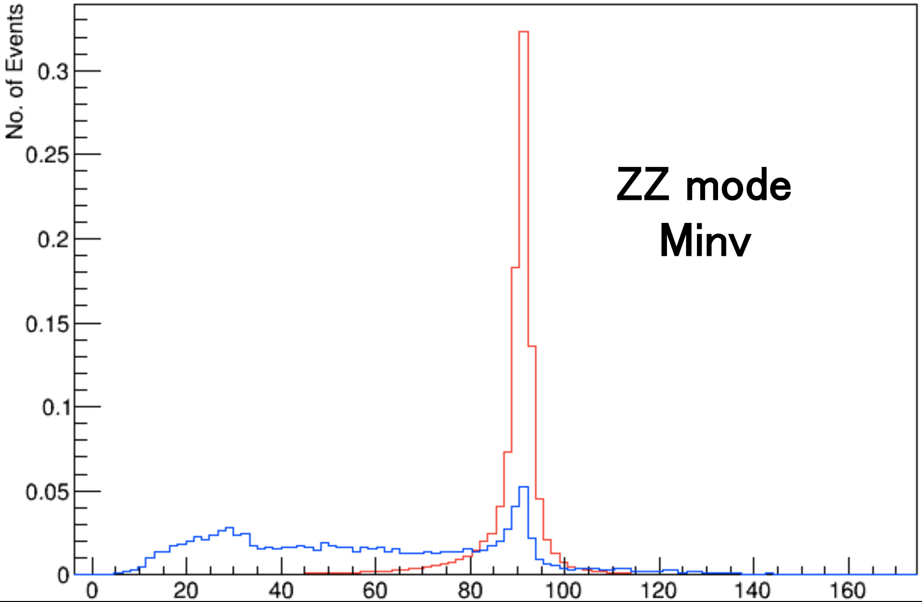
at least one wrong lepton
both leptons correct

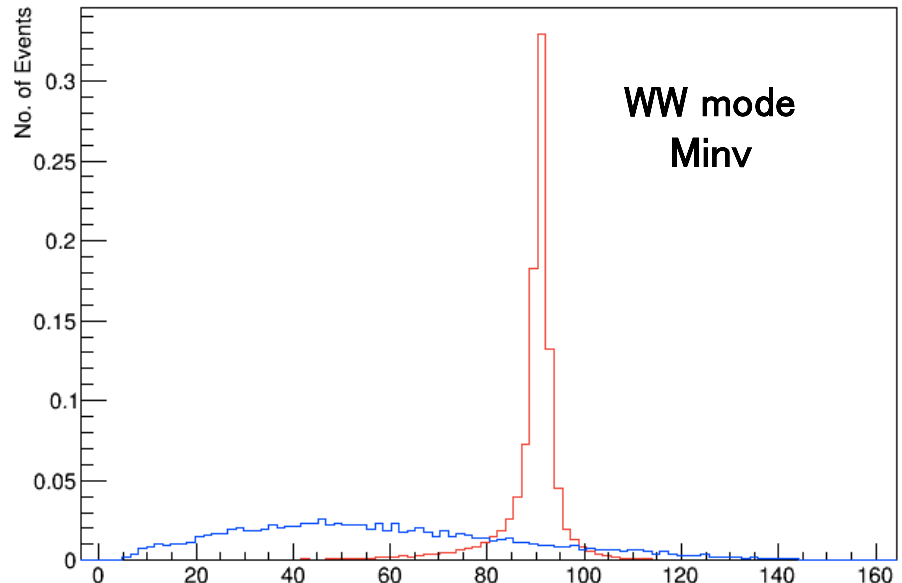

ZZ mode
P_Z
No. of Events


WW mode
P_Z
No. of Events


at least one wrong lepton
both leptons correct
ZZ mode
Chi^2(Mrec,Minv)
No. of Events

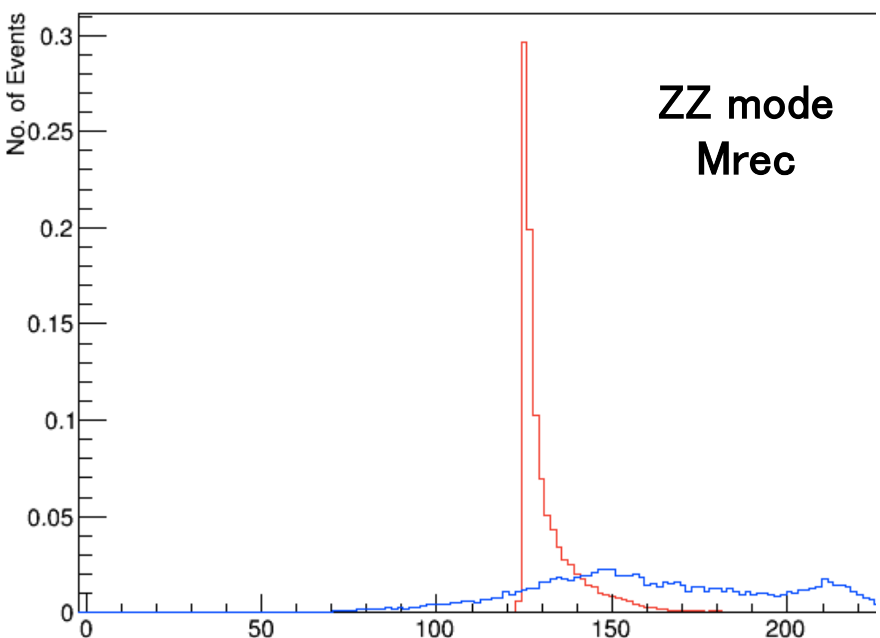

ZZ mode
CosLep
No. of Events
WW mode
ZZ mode
CosZ
at least one wrong lepton
both leptons correct

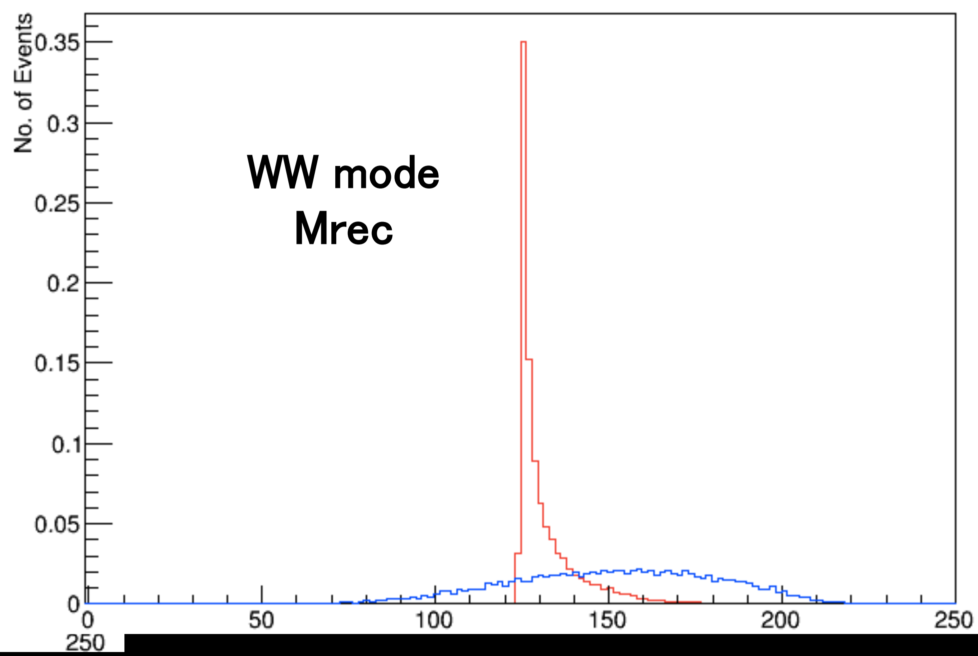




at least one wrong lepton

both leptons correct





Cut Efficiency Table , example shown for 250 GeV, Pol (−0.8,+0.3)

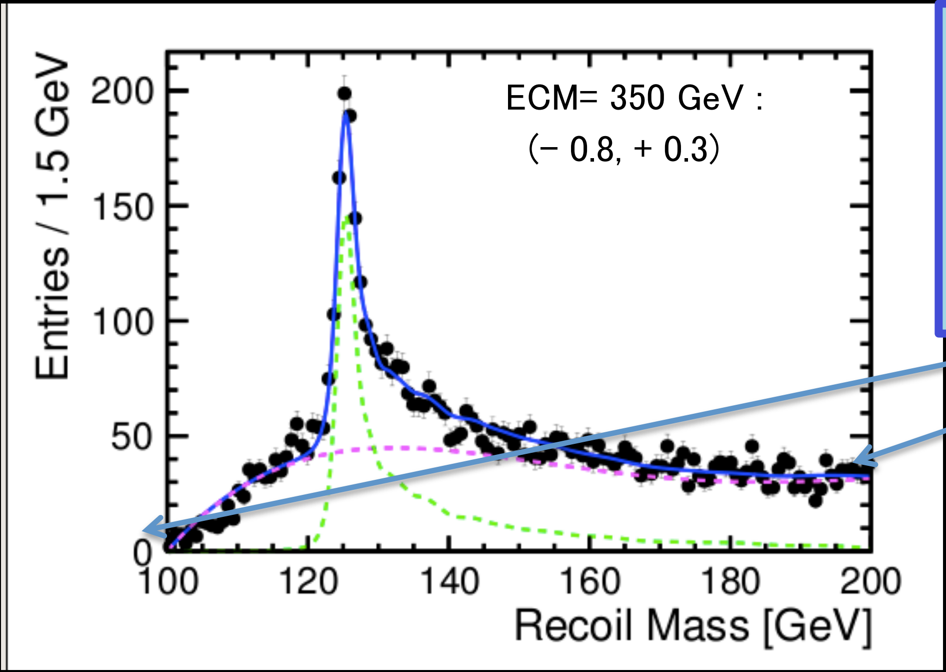
Zmm

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	93.7 +/- 0.1	93.68 +/- 0.1	93.4 +/- 0.11	93.89 +/- 0.1	93.62 +/- 0.1	93.86 +/- 0.1	93.7 +/-0.077
Cut1 :	93.7 +/- 0.1	93.68 +/- 0.1	93.4 +/- 0.11	93.89 +/- 0.1	93.62 +/- 0.1	93.86 +/- 0.1	93.7 +/-0.077
Cut2 :	92.12 +/- 0.11	92.06 +/- 0.12	91.76 +/- 0.12	92.17 +/- 0.11	91.95 +/- 0.11	92.29 +/- 0.11	91.24 +/-0.089
Cut3 :	90.09 +/- 0.12	90.2 +/- 0.13	89.84 +/- 0.13	90.21 +/- 0.12	90.05 +/- 0.12	90.45 +/- 0.12	89.38 +/-0.095
Cut4 :	89.88 +/- 0.13	90.01 +/- 0.13	89.64 +/- 0.13	90.01 +/- 0.12	89.84 +/- 0.12	90.24 +/- 0.12	89.21 +/-0.096
Cut5 :	89.83 +/- 0.13	89.94 +/- 0.13	89.57 +/- 0.13	89.54 +/- 0.13	89.74 +/- 0.13	90.13 +/- 0.12	87.38 +/- 0.1
Cut6 :	89.83 +/- 0.13	89.94 +/- 0.13	89.57 +/- 0.13	89.54 +/- 0.13	89.74 +/- 0.13	90.13 +/- 0.12	87.37 +/- 0.1
Cut7 :	83.16 +/- 0.15	83.03 +/- 0.15	82.8 +/- 0.15	82.88 +/- 0.15	83.14 +/- 0.15	83.56 +/- 0.15	80.89 +/- 0.12
Cut8 :	73.94 +/- 0.17	73.53 +/- 0.17	73.5 +/- 0.17	73.96 +/- 0.16	74.09 +/- 0.16	74.51 +/- 0.17	72.21 +/- 0.12
Cut9 :	73.94 +/- 0.17	73.53 +/- 0.17	73.5 +/- 0.17	73.7 +/- 0.16	74.07 +/- 0.16	71.6 +/- 0.17	72.21 +/- 0.12
Cut10:	73.94 +/- 0.17	73.53 +/- 0.17	73.5 +/- 0.17	73.7 +/- 0.16	74.07 +/- 0.16	71.6 +/- 0.17	72.21 +/- 0.12

Zee

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	89.08 +/- 0.13	88.89 +/- 0.13	88.5 +/- 0.13	88.99 +/- 0.13	89 +/- 0.13	89.18 +/- 0.13	89.43 +/- 0.09
Cut1 :	89.08 +/- 0.13	88.89 +/- 0.13	88.5 +/- 0.13	88.99 +/- 0.13	89 +/- 0.13	89.18 +/- 0.13	89.43 +/- 0.09
Cut2 :	87.28 +/- 0.14	87.16 +/- 0.14	86.68 +/- 0.14	87.09 +/- 0.14	87.26 +/- 0.14	87.29 +/- 0.14	86.53 +/-0.098
Cut3 :	85.15 +/- 0.14	85.01 +/- 0.14	84.51 +/- 0.14	84.84 +/- 0.14	85.1 +/- 0.14	85.09 +/- 0.14	84.34 +/- 0.1
Cut4 :	85.04 +/- 0.14	84.92 +/- 0.15	84.43 +/- 0.15	84.75 +/- 0.14	84.99 +/- 0.14	84.99 +/- 0.14	84.26 +/- 0.1
Cut5 :	84.99 +/- 0.14	84.84 +/- 0.15	84.36 +/- 0.15	84.29 +/- 0.15	84.89 +/- 0.14	84.88 +/- 0.14	82.54 +/- 0.11
Cut6 :	84.99 +/- 0.14	84.84 +/- 0.15	84.36 +/- 0.15	84.2 +/- 0.15	84.88 +/- 0.14	84.74 +/- 0.14	82.46 +/- 0.11
Cut7 :	78.76 +/- 0.16	78.69 +/- 0.16	78.12 +/- 0.16	78.21 +/- 0.16	78.67 +/- 0.16	78.78 +/- 0.16	76.45 +/- 0.11
Cut8 :	66.3 +/- 0.17	66.02 +/- 0.17	65.55 +/- 0.17	65.88 +/- 0.17	66.19 +/- 0.17	66.23 +/- 0.17	64.26 +/- 0.12
Cut9 :	66.3 +/- 0.17	66.02 +/- 0.17	65.55 +/- 0.17	65.65 +/- 0.17	66.17 +/- 0.17	63.75 +/- 0.17	64.26 +/- 0.12
Cut10:	66.3 +/- 0.17	66.02 +/- 0.17	65.55 +/- 0.17	65.65 +/- 0.17	66.17 +/- 0.17	63.75 +/- 0.17	64.26 +/- 0.12

cut0 lepton finder
cut1 lepton type
cut2 loose cuts on Otdl, Minv, Mrec
cut3 Minv
cut4 Ptdl
cut5 Ptsum
cut6 cosθmiss
cut7 cosθZ
cut8 TMVA
Cut9 Evis
Cut10 Mrec
(bias due to evis is cancelled after combining visible and invisible channels)



BG level fluctuation is controlled by fitting recoil mass over a wide range
(100 – 200 GeV for 350 GeV)

- BG level is usually fixed for Toy MC (optimistic scenario)
- xsec error is about 15-20 % worse if we float BG (pessimistic scenario)

Example:

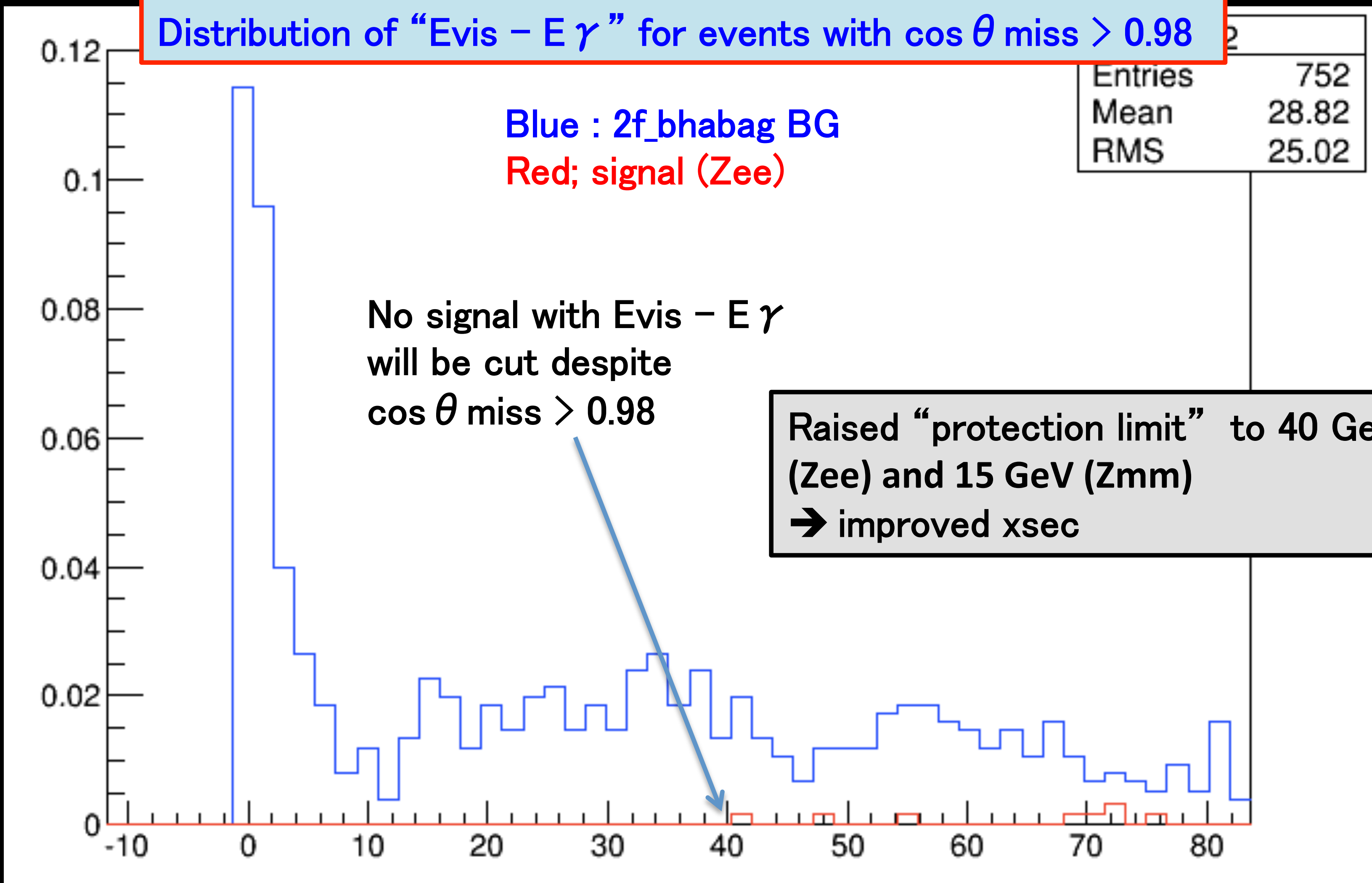
Zmm	xsec	BG fluc
250GeV	3.09% → 3.57% (16% worse)	1.37%
350GeV	3.76% → 4.49% (19% worse)	1.96%

try to improve efficiency of cos θ miss cut

Find "protection" which yields best signal–BG separation

observe distribution of Evis – E γ for 2f_BG and signal

Distribution of "Evis – E γ" for events with cos θ miss > 0.98

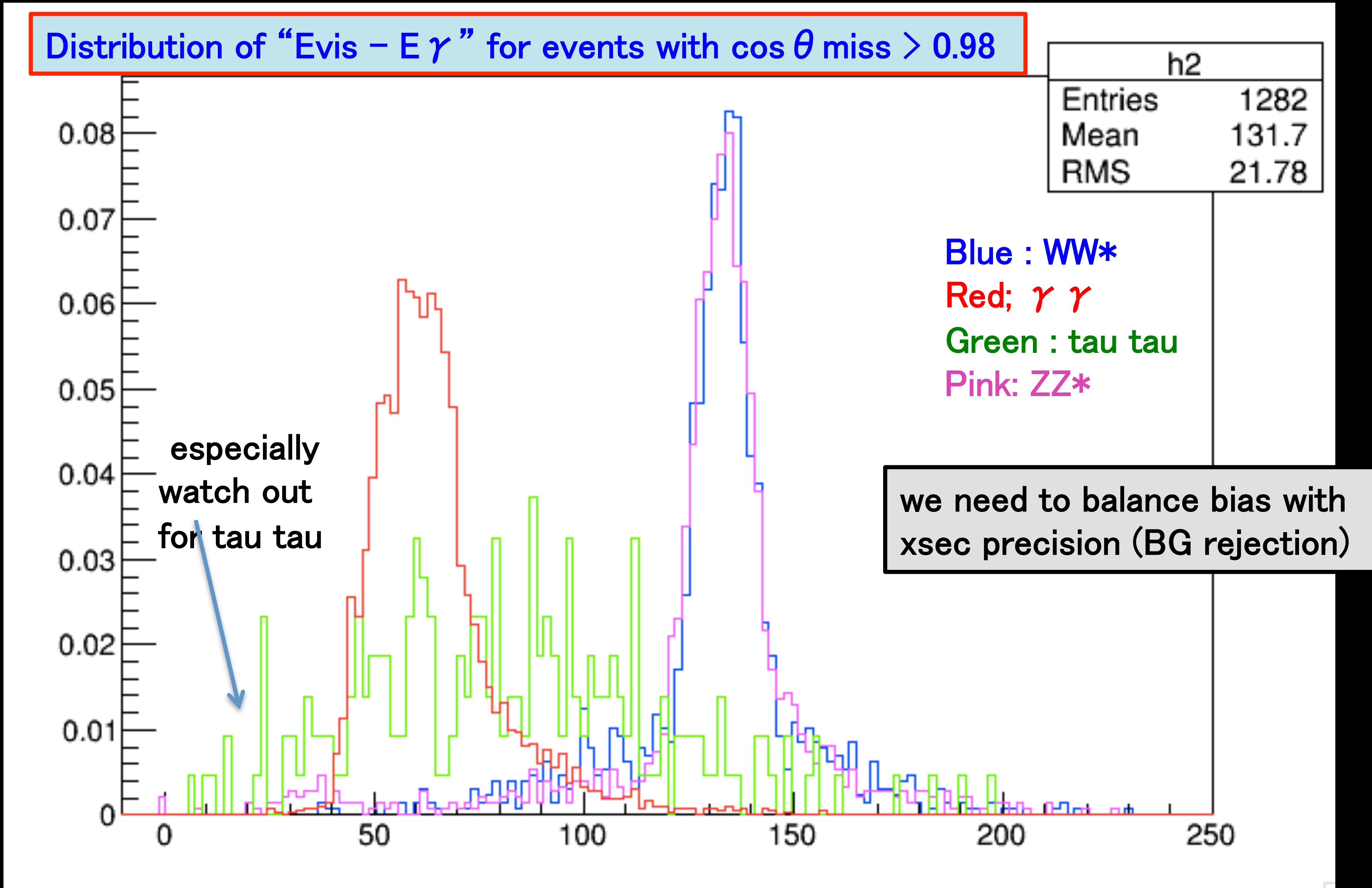


Raised "protection limit" to 40 GeV (Zee) and 15 GeV (Zmm)

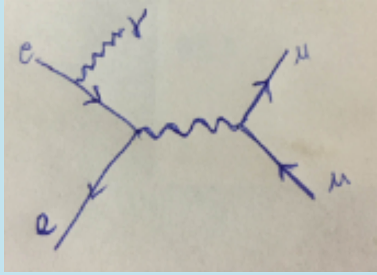
➔ improved xsec

try to improve efficiency of cos θ miss cut

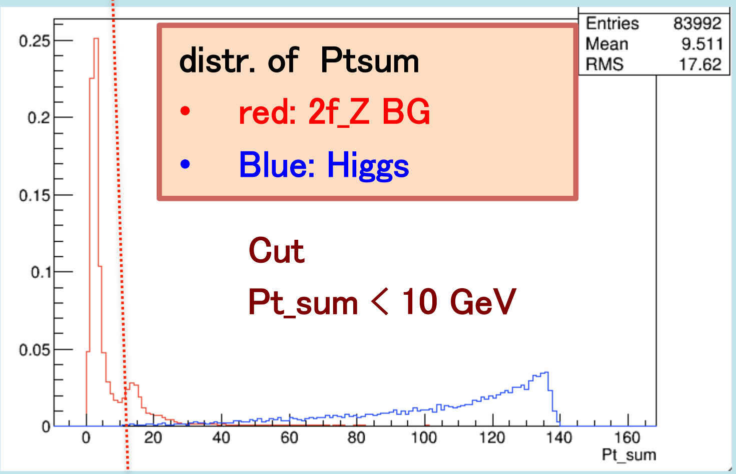
observe distribution of Evis − Eγ signal modes (Zee) using high statistics sample



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)



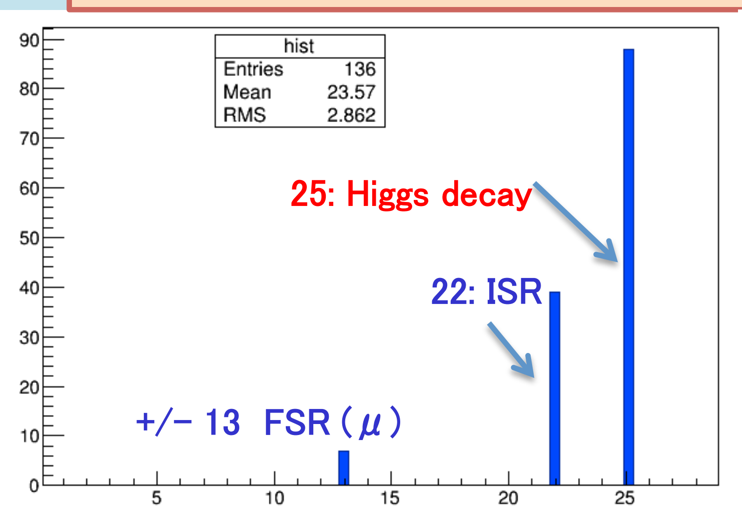
NEW #1 isolated photon finder: γ we look at have small cone energy) not from Higgs decay

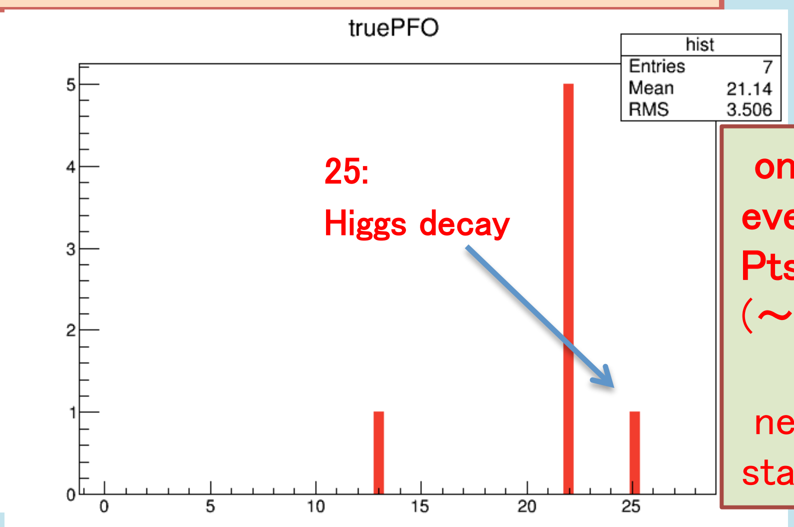
NEW #2 Now use (instead of dptbal)

$$\left|\overrightarrow{P_{t,sum}}\right| \equiv \left|\overrightarrow{P_{t,\gamma}} + \overrightarrow{P_{t,dl}}\right|$$

vector direction info singles out back to back events

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





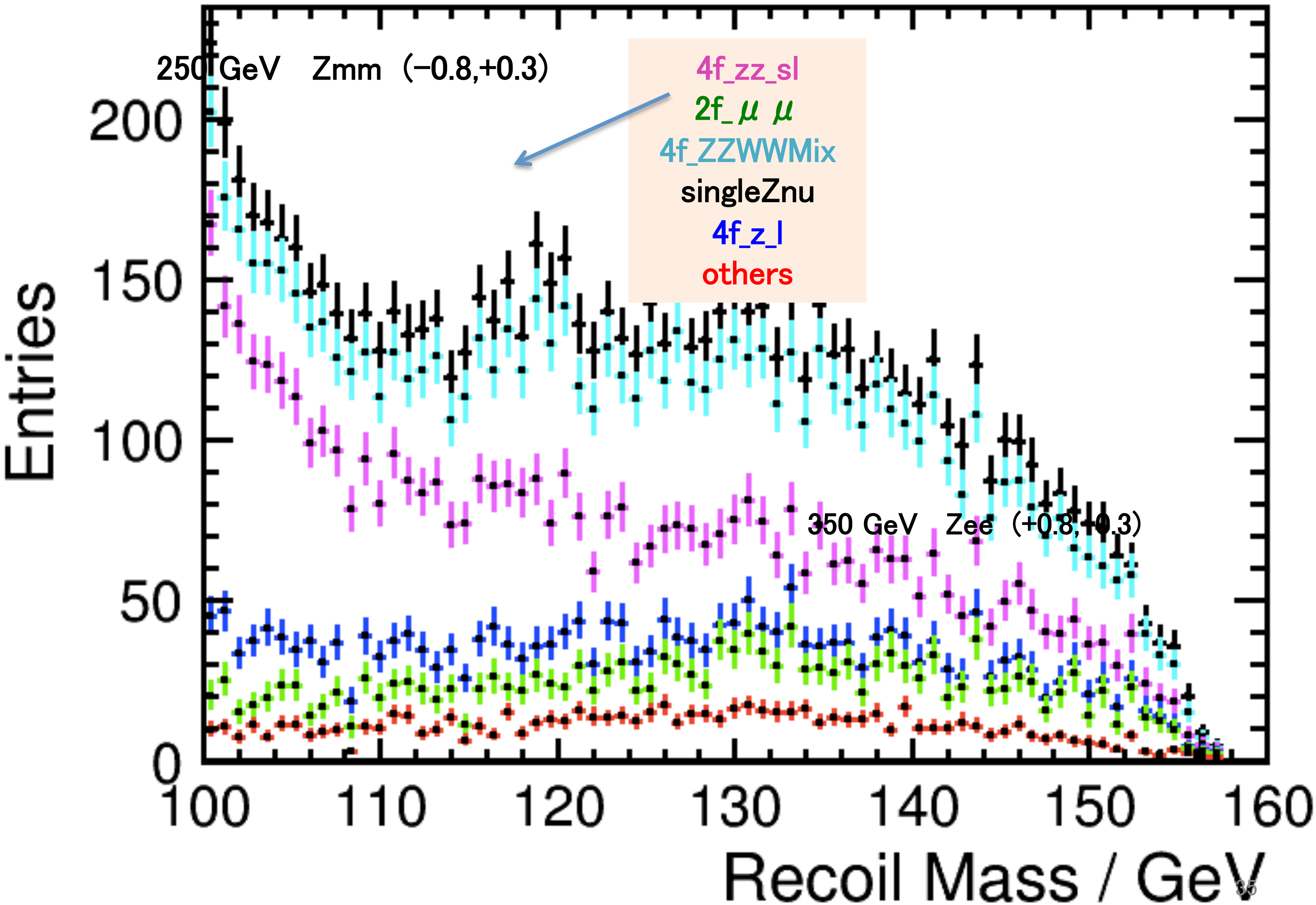
only < few unweighed events removed by Ptsum cut (～ 0 weighed events)

negligible compared to statistical uncertainties

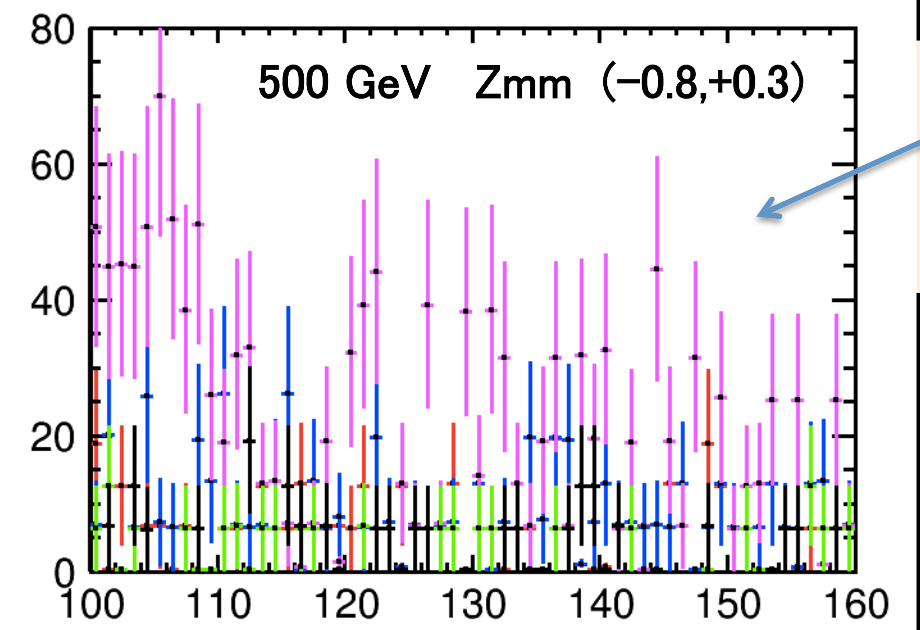
～100 Higgs decay related γ events removed by dptbal cut !!

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

250 GeV Zmm left pol

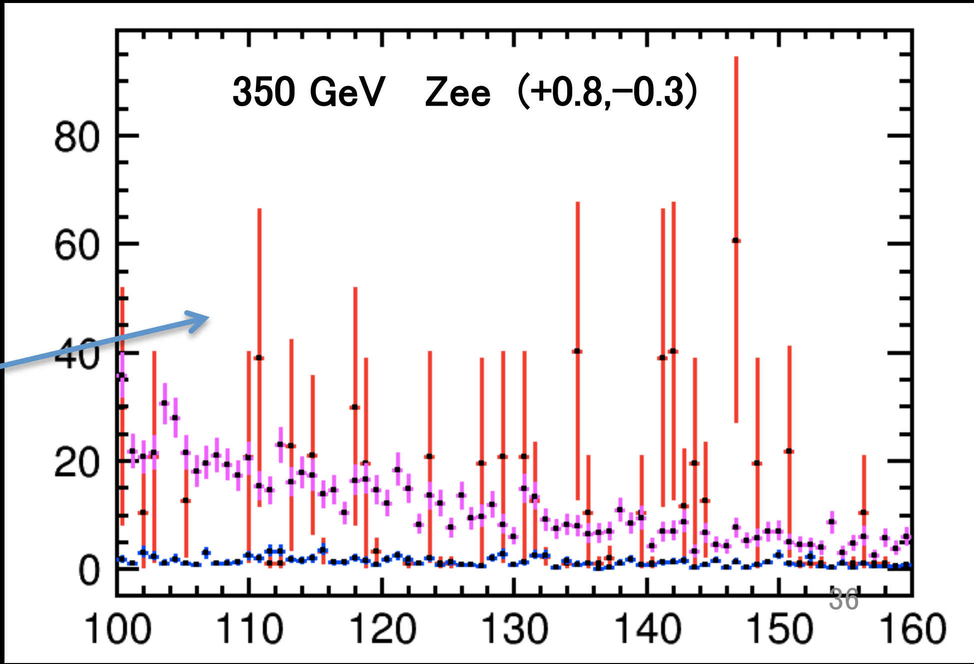


Dominant BG with low MC statistics cause large errorbars
(a technical problem planned to be solved by generating higher statistics samples)



4f_zz_sl
2f_μ μ
singleZnu
others

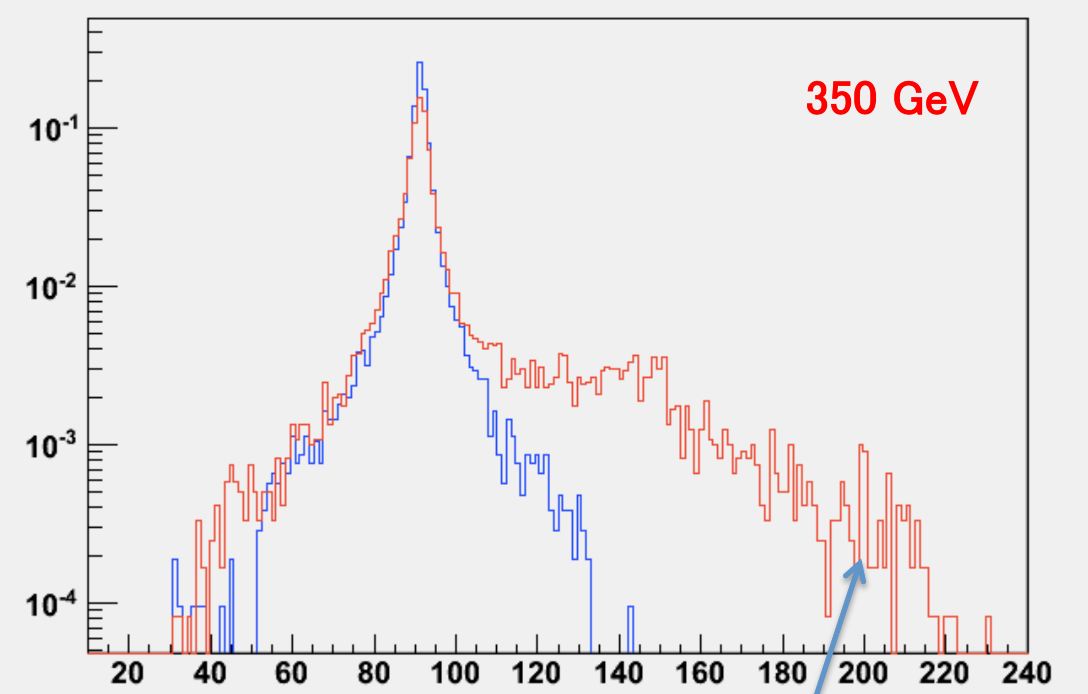
2f_bhabhag
4f_singleZe
others

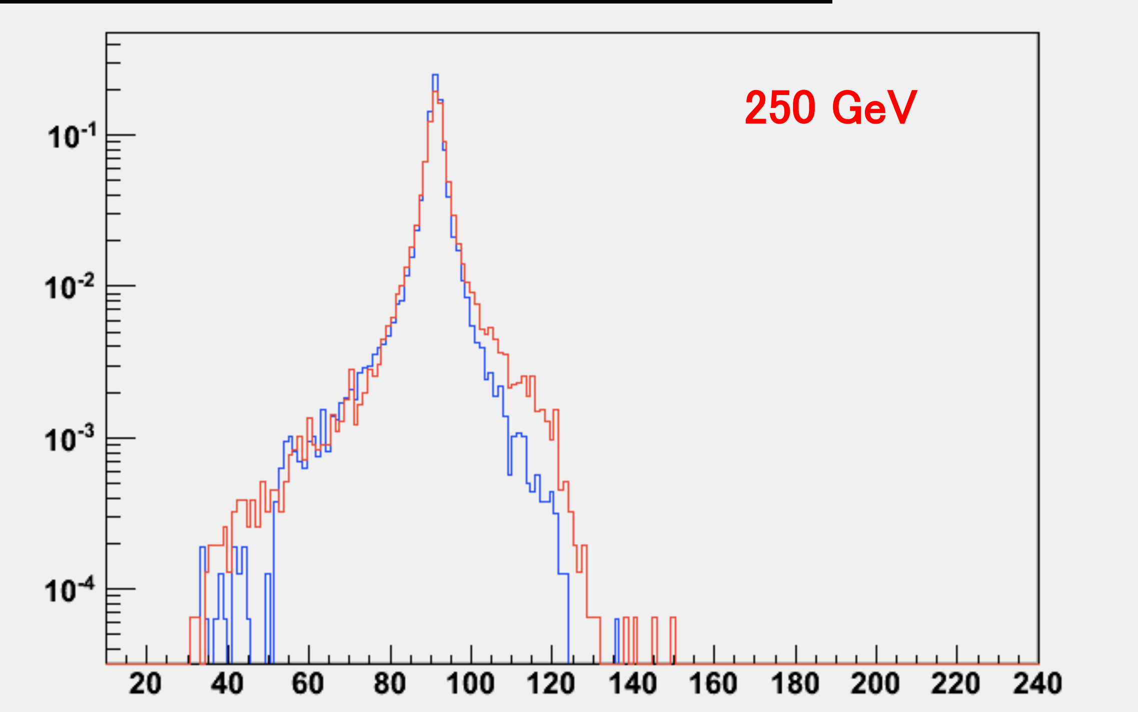


compare dilepton invariant mass distribution

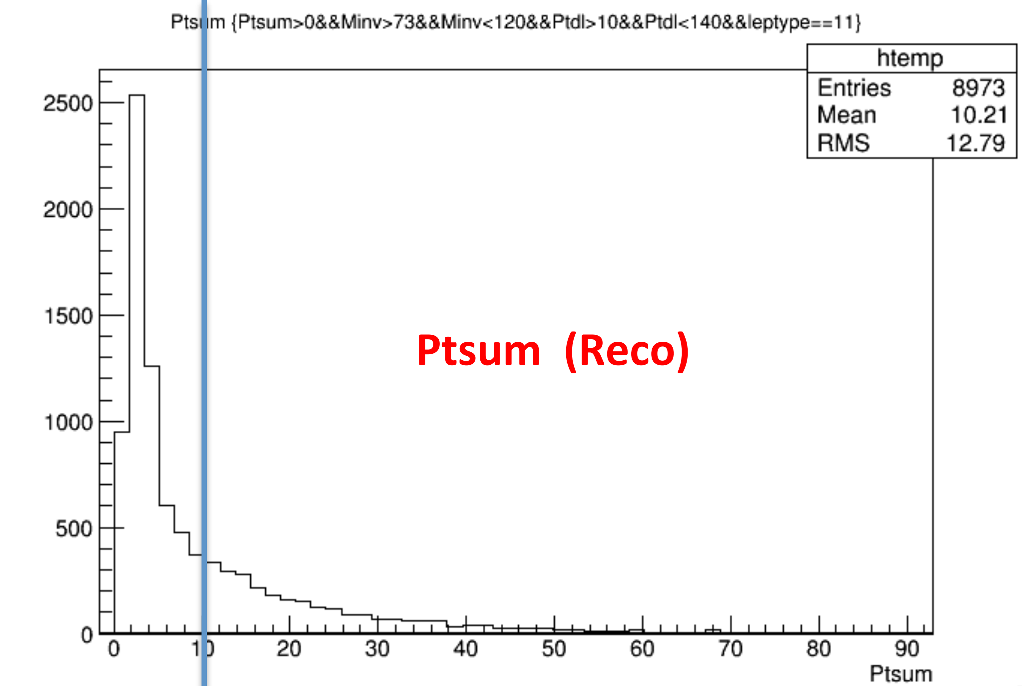
Zee (red)

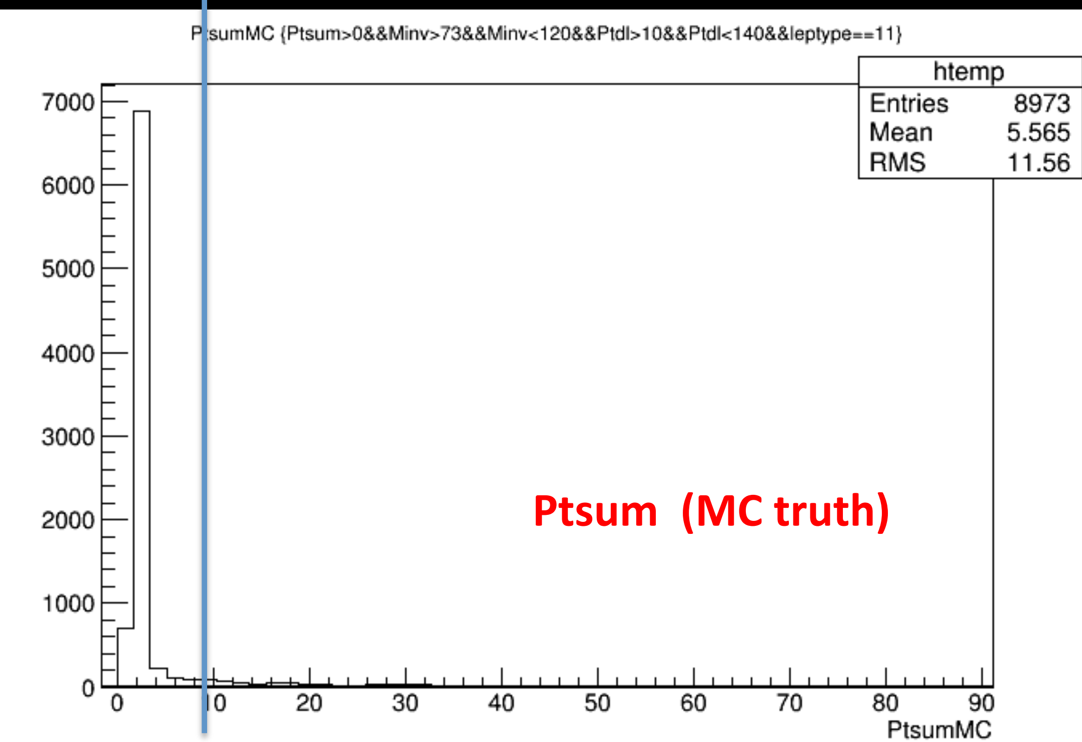
vs Zmumu (blue)





- 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

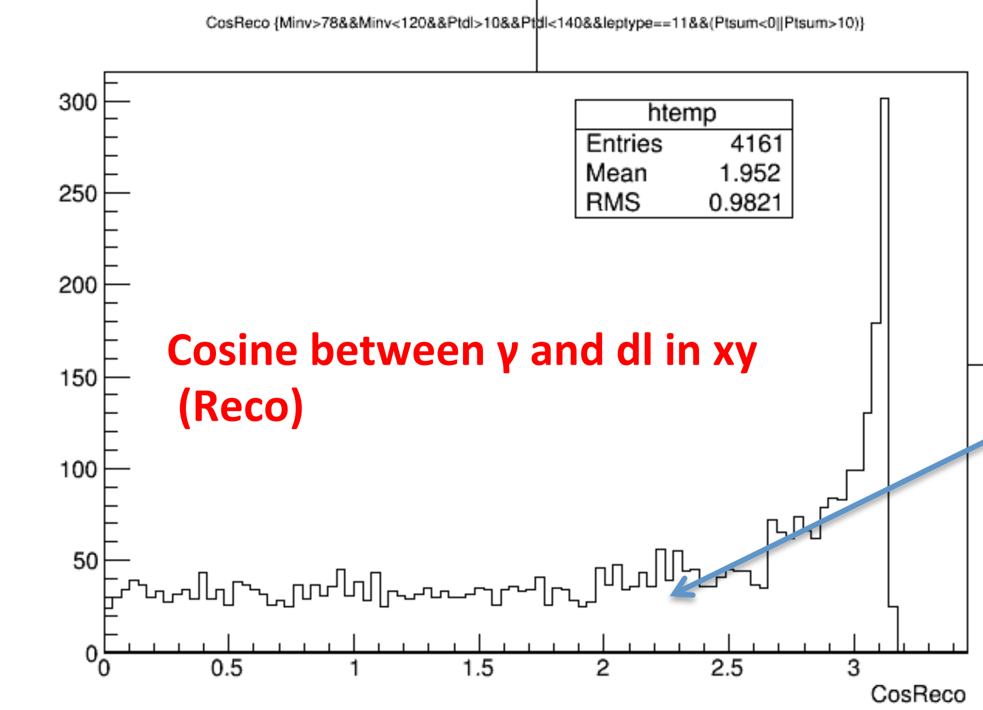
2f_bb

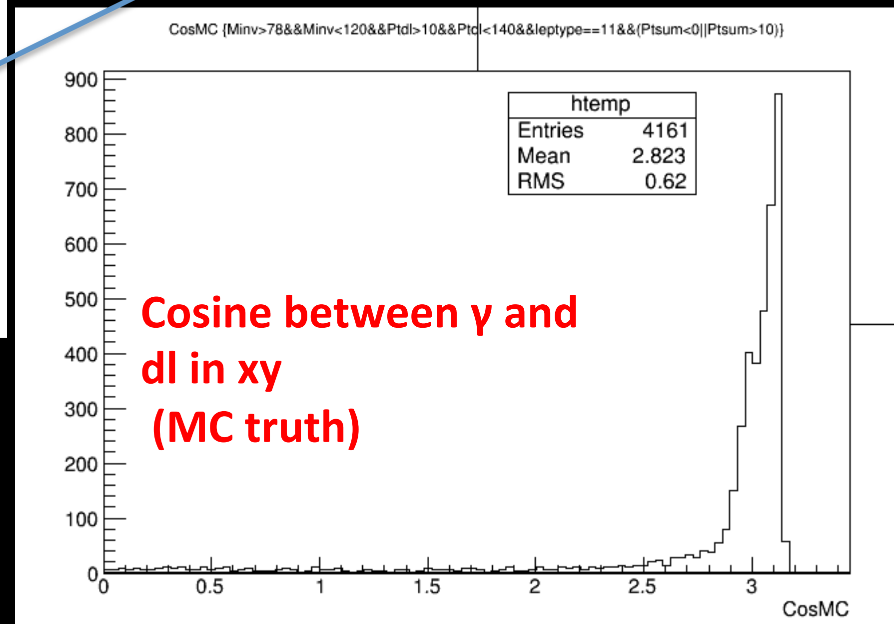
Realized a large difference in Ptsum between Reconstructed particles and MC Truth

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 ?

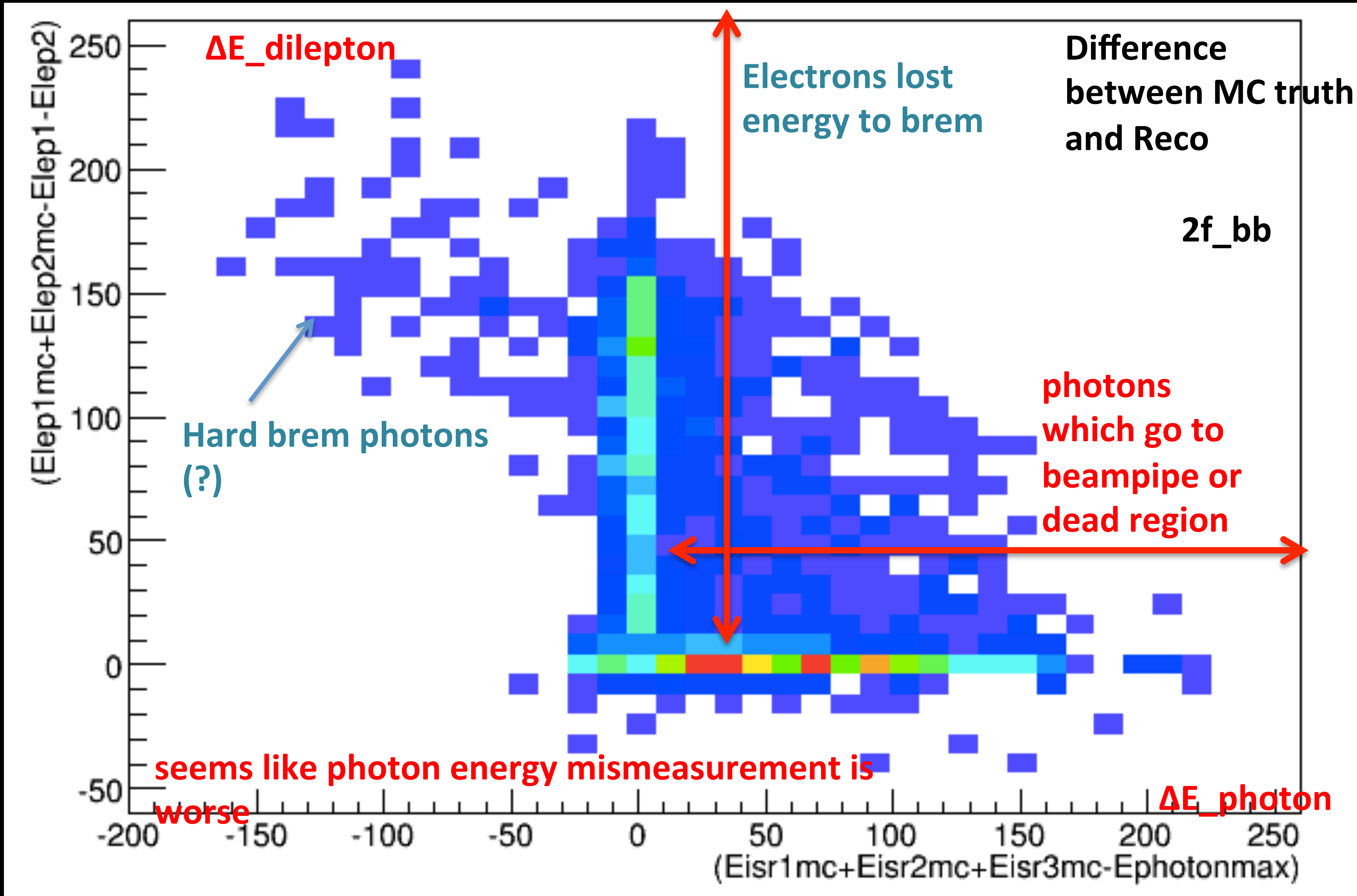




There are a few potential explanations

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

especially the long isotropic tail

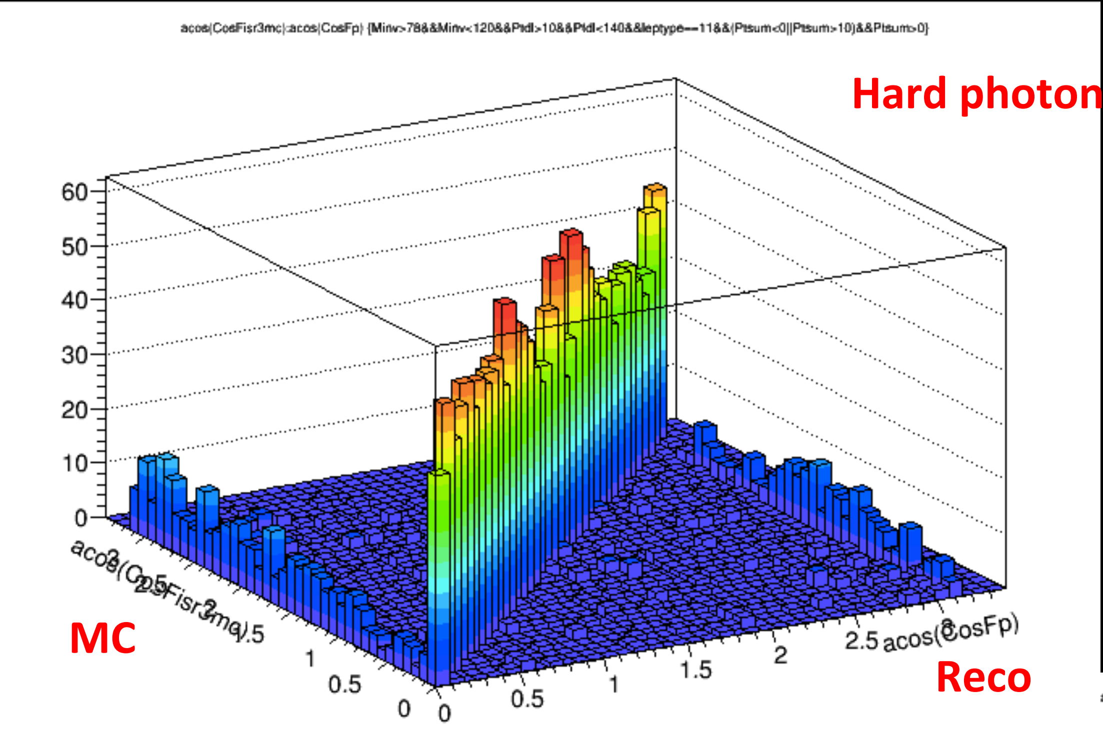


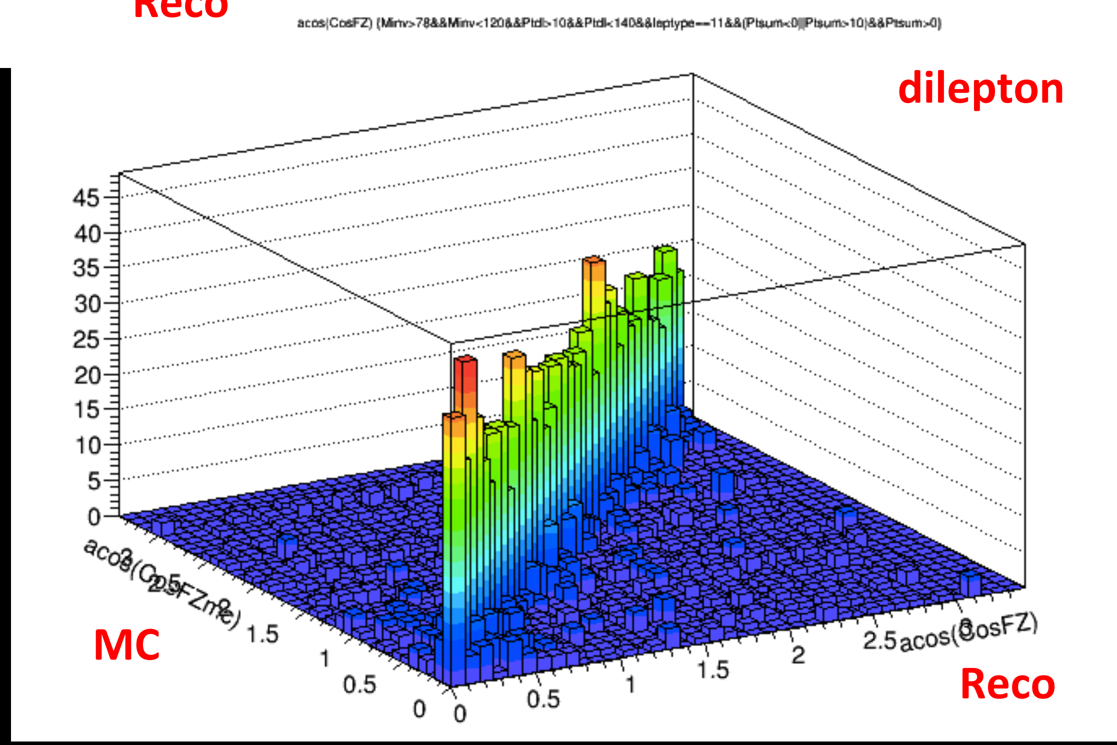
energy mis-measurements explain ONLY A PART of discrepancy in non - BTB ness

- leptons lose energy due to brem
- Photons go very forward to beampipe or dead regions of detector

Other parts : angle resolution (?), More than 1 hard ISR photon (still needs confirmation)

Angle ϕ in x-y plane

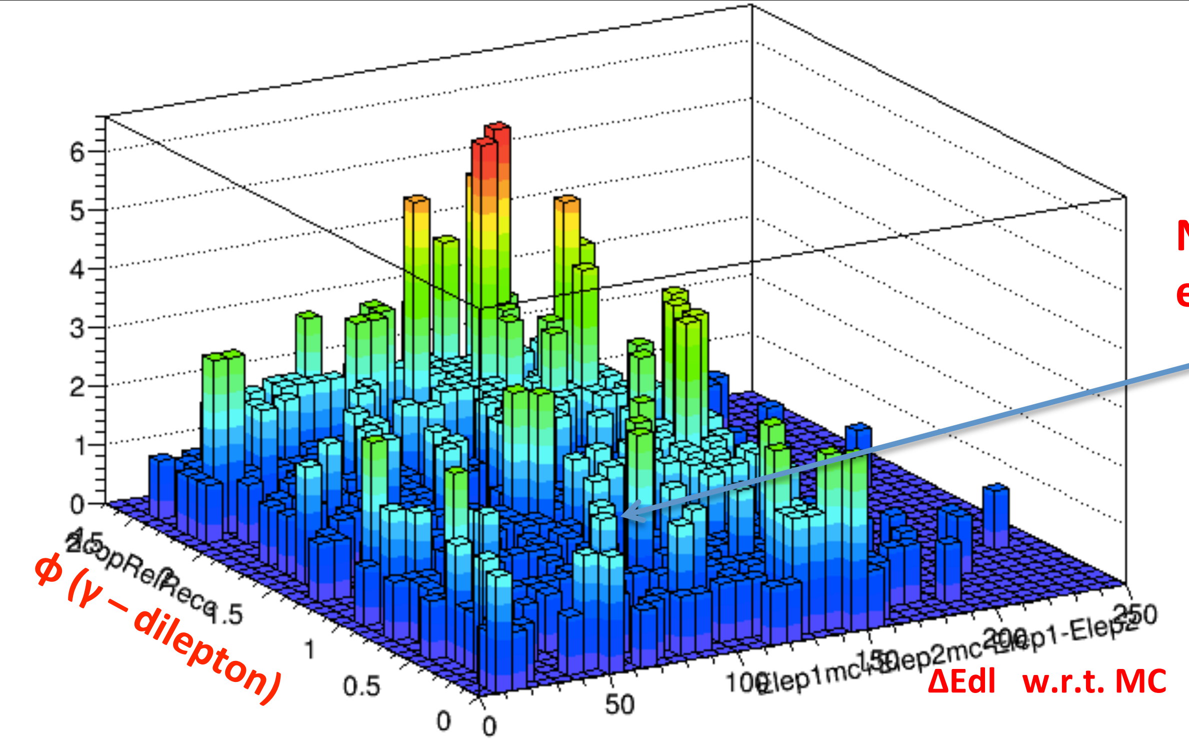




Angle precision seems not too bad for lepton and photon

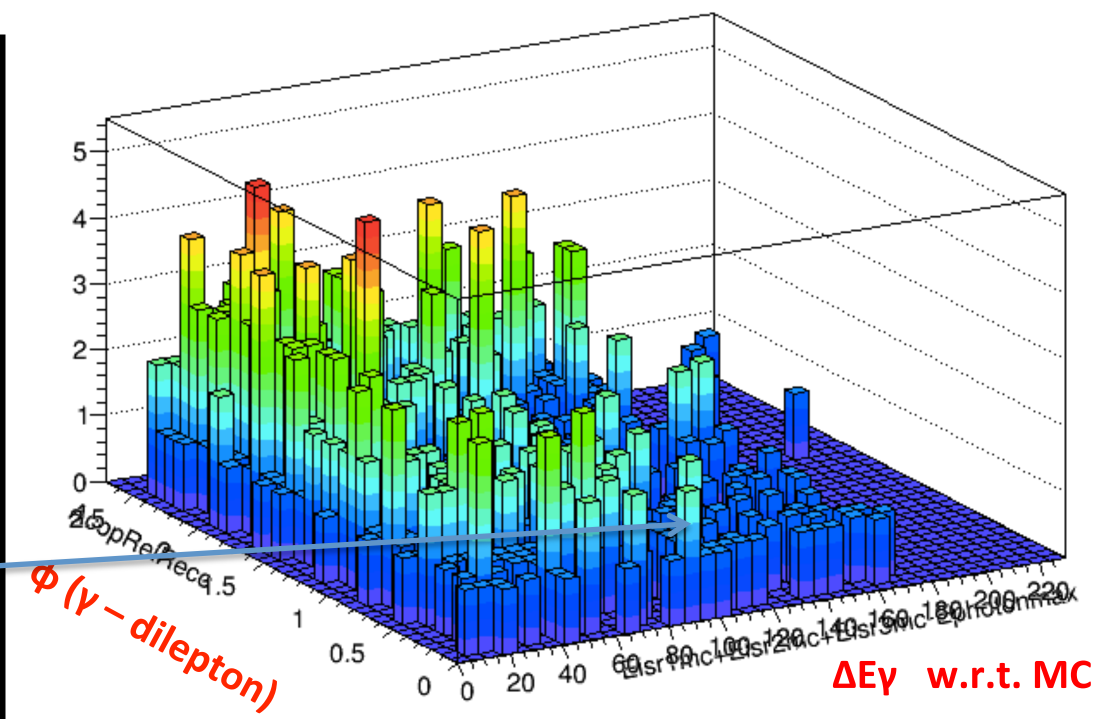
(photon slightly worse)

Only events with non-"back-to-back" ness (angle < 2.5 rad)



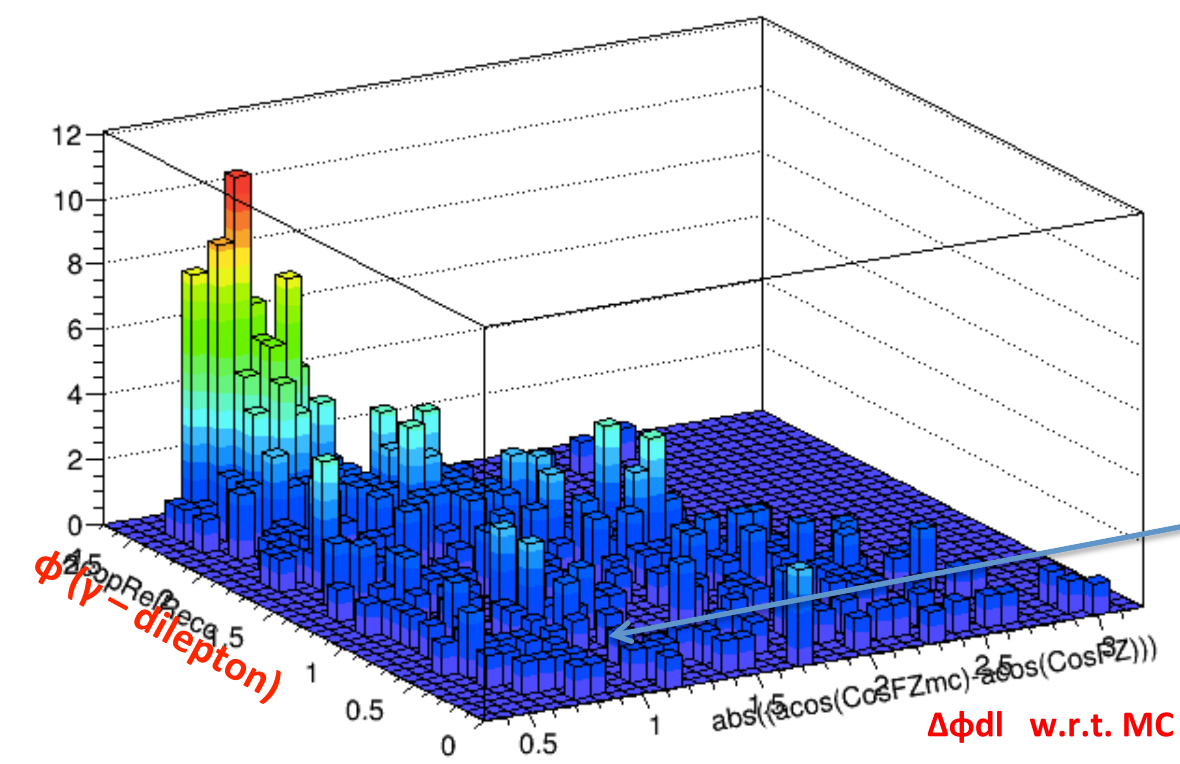
Not well measured dilepton energy: 60%

brem explains part of non-"BTB"

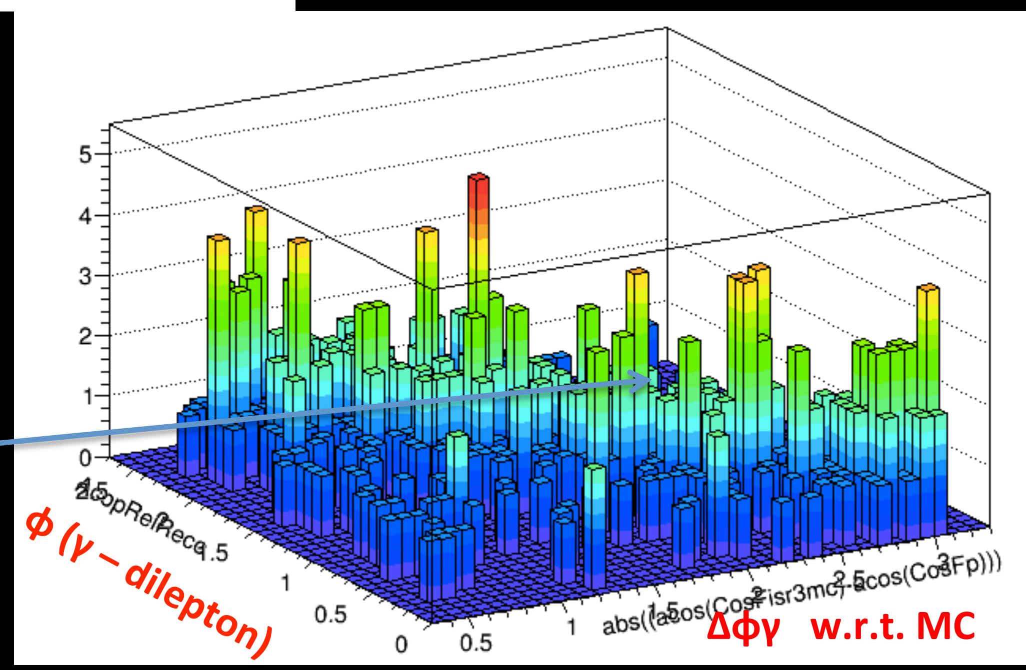


Not well measured γ energy: 55%

Only events with non-"back-to-back" ness (angle < 2.5 rad)

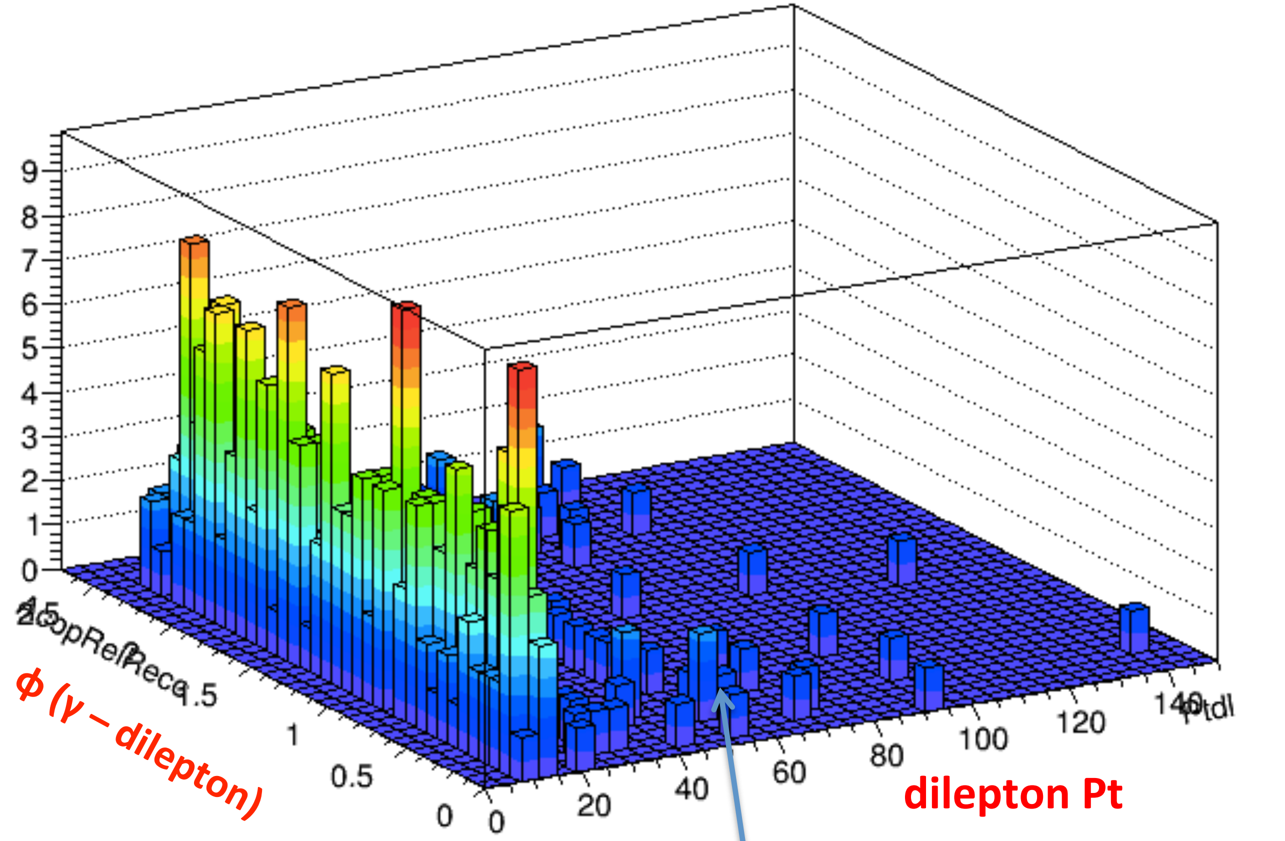


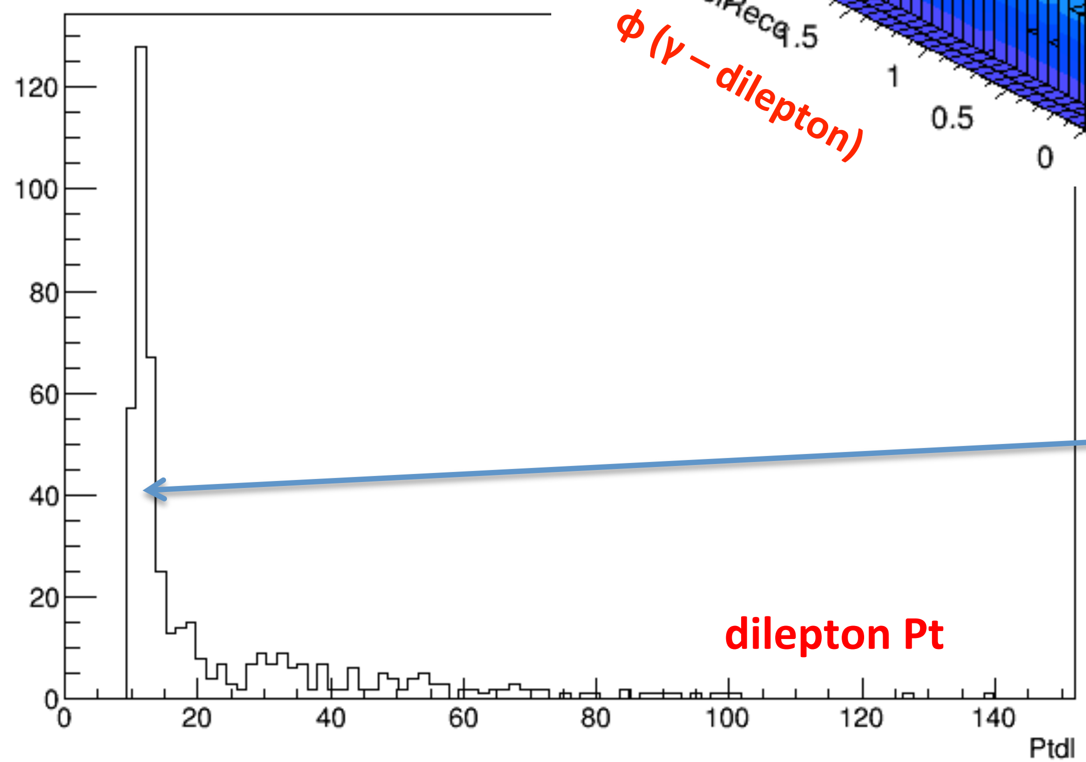
Not well measured dilepton angle : 40%



Not well measured γ angle : 45%

events with non-”back-to-back” ness (angle < 2.5rad)
and well measured dilepton energy and angles





For these events, dilepton Pt is very small
(limit of Pt resolution ?)