Higgs Recoil Study

ILC Physics meeting

June 5, 2015

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Current Status & New Activities

Last week:

- showed first results of ZH analysis using Kernel function fitting
  (for all leptonic channels , ECM, and beam polarization)

This Week *NEW*

- observed in detail fitting of “data” (c.f. last week’s results based on Toy MC)
- signal: Kernel function : no big problem, but need to adjust to appropriate Kernel width, otherwise will affect mass stat error
- BG: need to select 2^{nd} order or 2rd order polynomial case by case

- assess residual 2f BG issue for Zee at ECM = 350 GeV, 500 GeV

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

Statistical error study results
Zee and Zmm combined

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

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

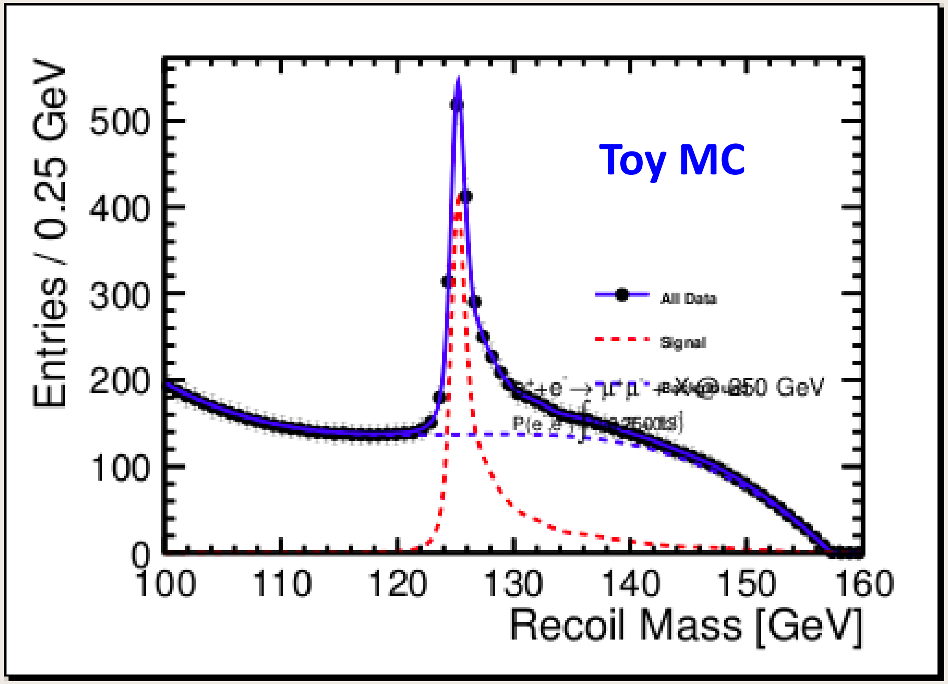
Xsec error
- 350 GeV 22% worse w.r.t. 250 GeV
- 500 GeV much worse

Mass error
- 350 GeV worse by factor of < 3

Note)
ALCW results was only for Zmm

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

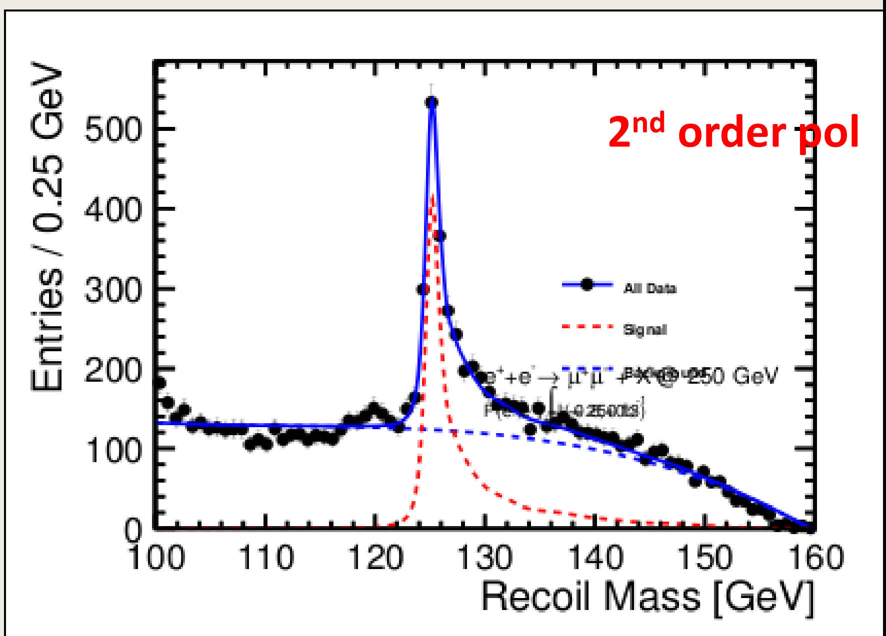
xsec error almost same as using GPET

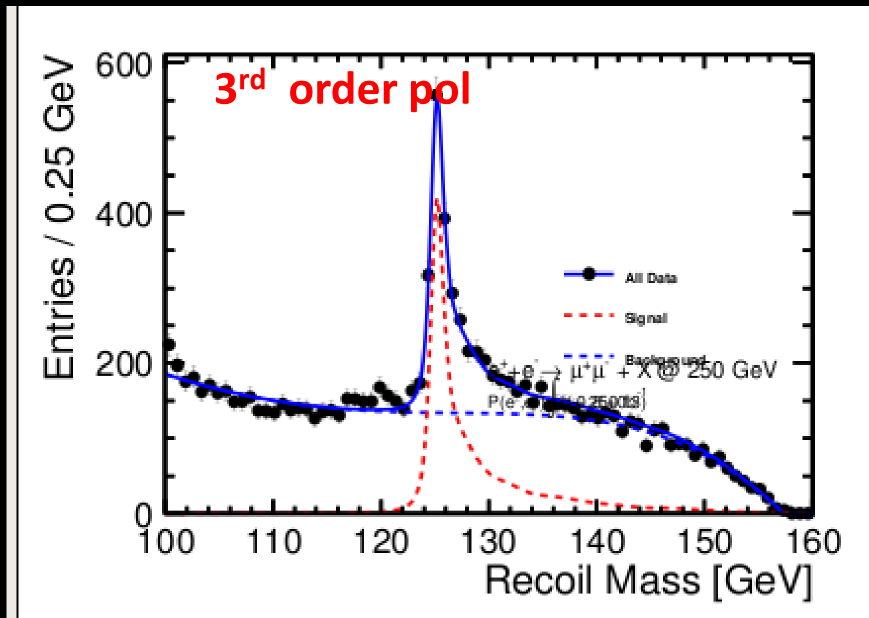


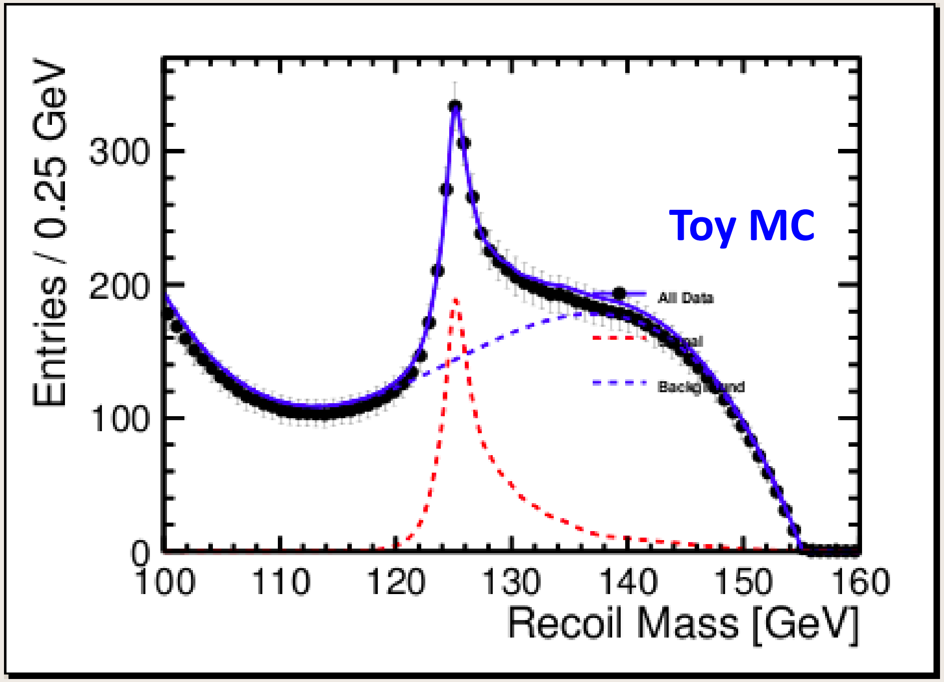
for Zmm BG fitting:
3rd order polynomial seems better than 2nd order polynomial

250 GeV

Zmm (-0.8, + 0.3)



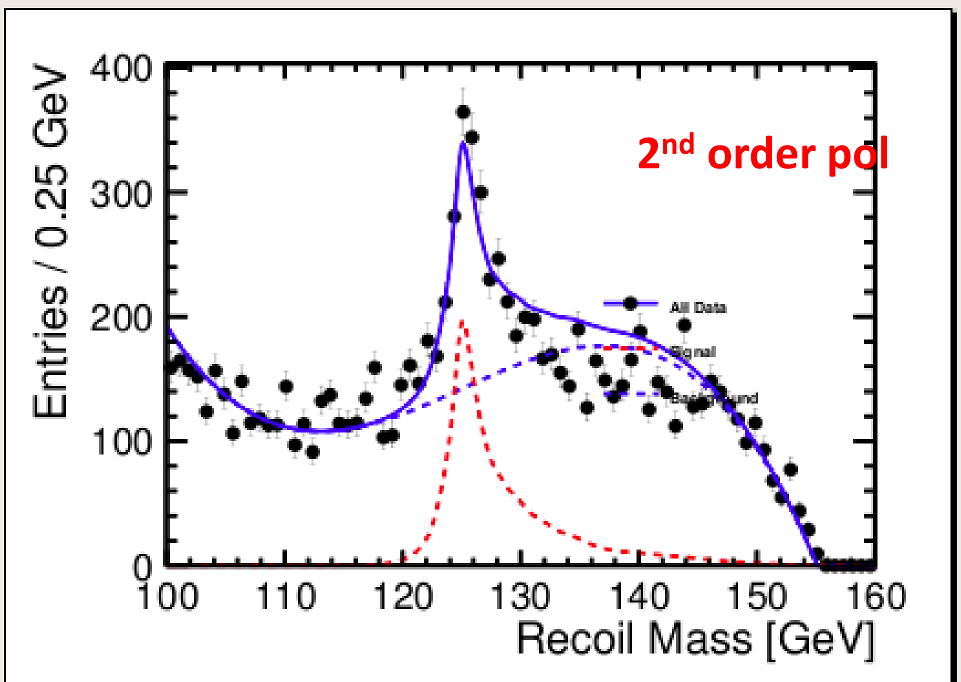


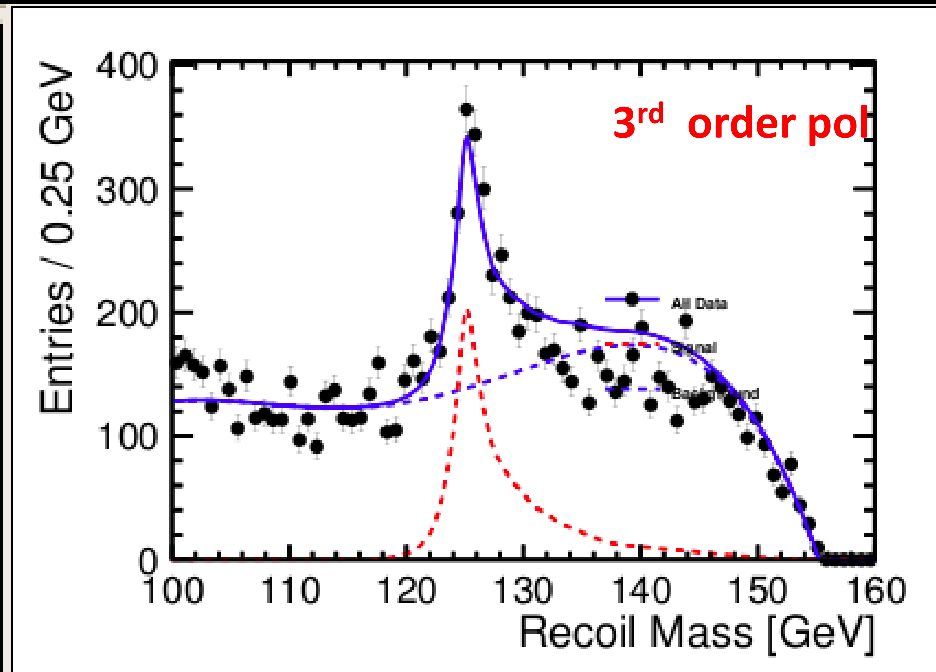


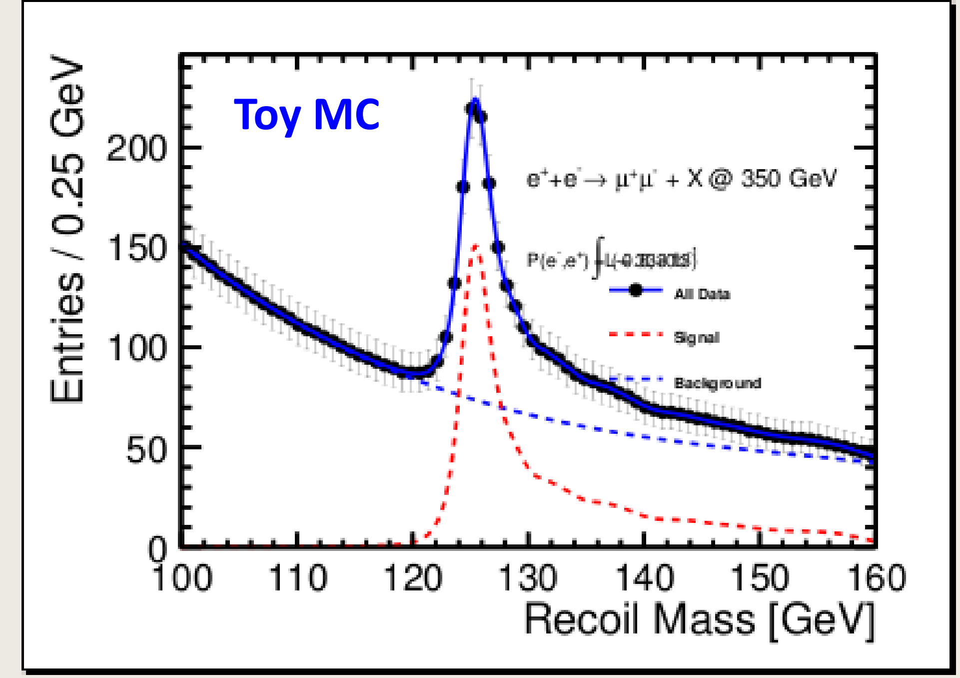
BUT for Zee BG fitting :
2^{nd} order polynomial is better than 3^{rd} order polynomial

250 GeV

Zee (-0.8, + 0.3)



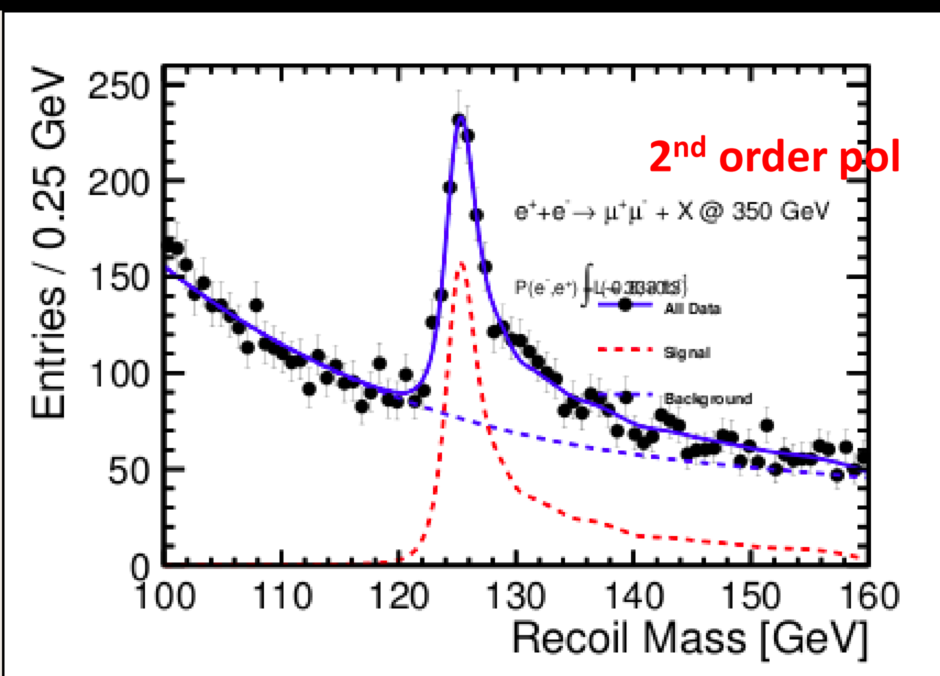




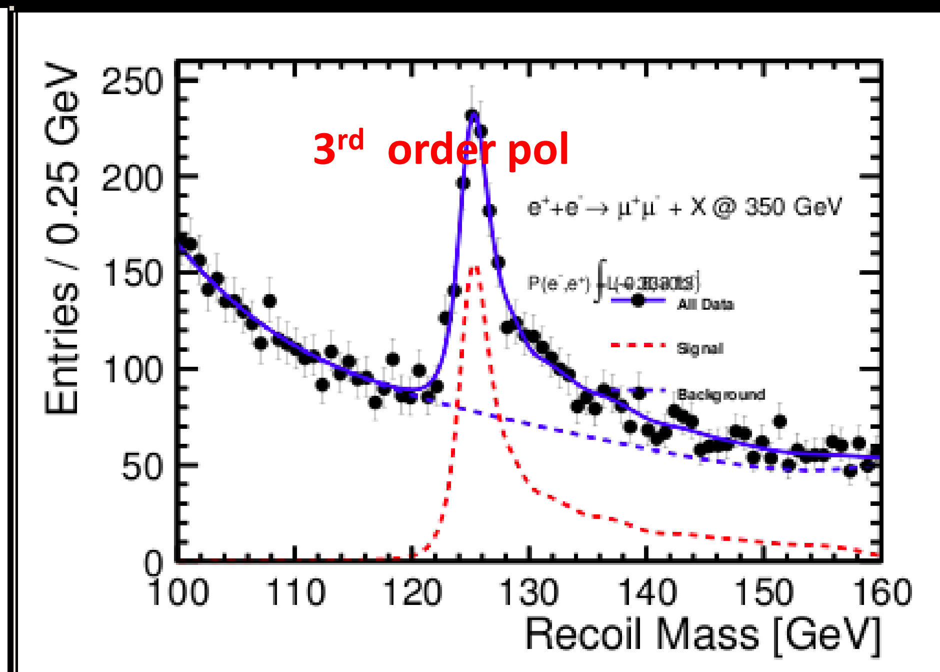
Toy MC
e+e- → μ+μ- + X @ 350 GeV
All Data
Signal
Background
Entries / 0.25 GeV
Recoil Mass [GeV]

350 GeV

Zmm



2nd order pol
e+e- → μ+μ- + X @ 350 GeV
All Data
Signal
Background
Entries / 0.25 GeV
Recoil Mass [GeV]

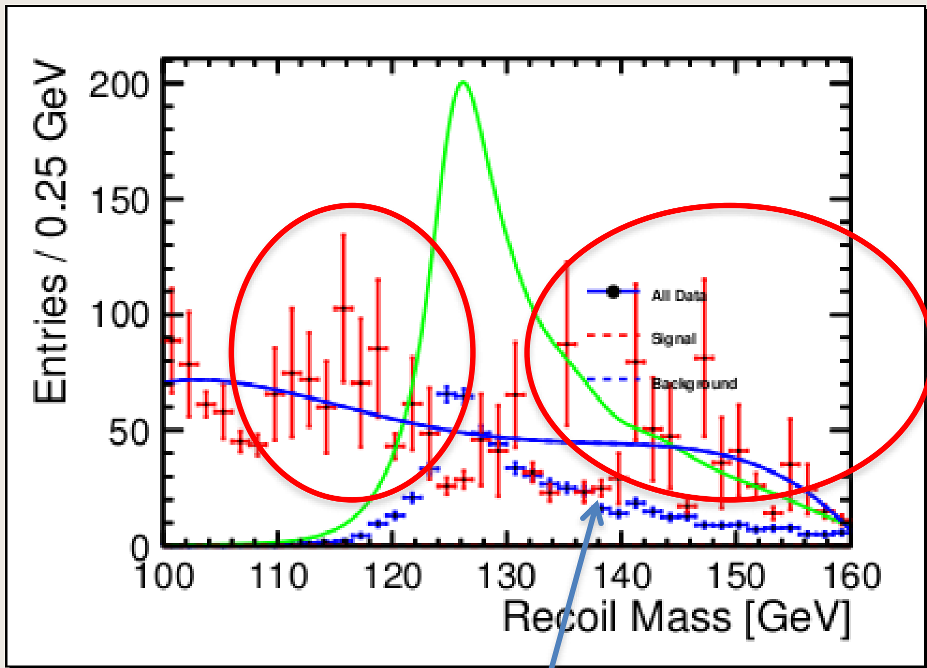


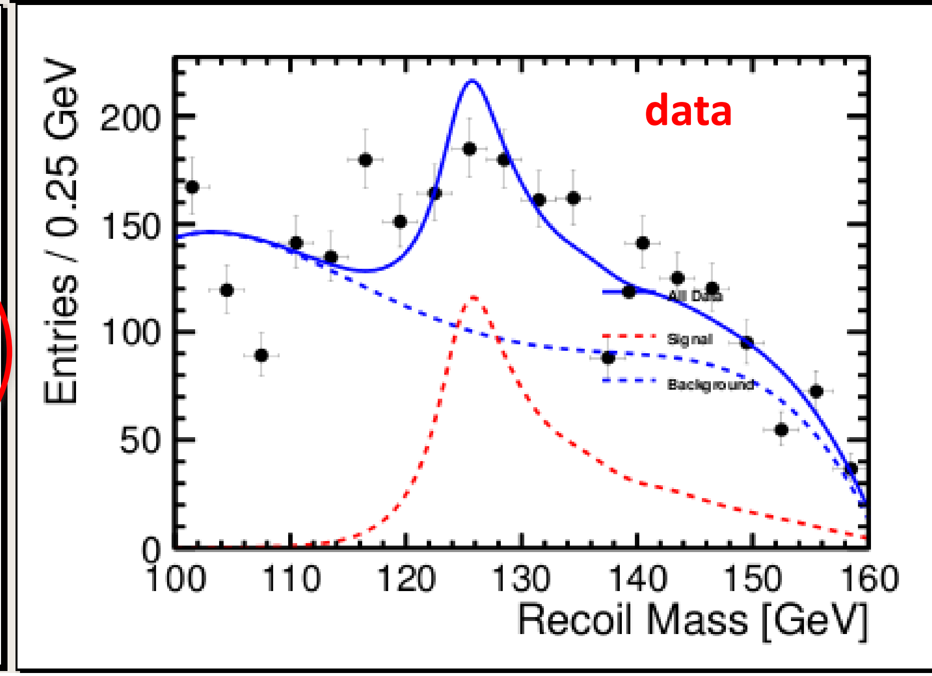
3rd order pol
e+e- → μ+μ- + X @ 350 GeV
All Data
Signal
Background
Entries / 0.25 GeV
Recoil Mass [GeV]

Things began to get difficult for Zee at 350 GeV

as well as both Zmm and Zee for 500 GeV

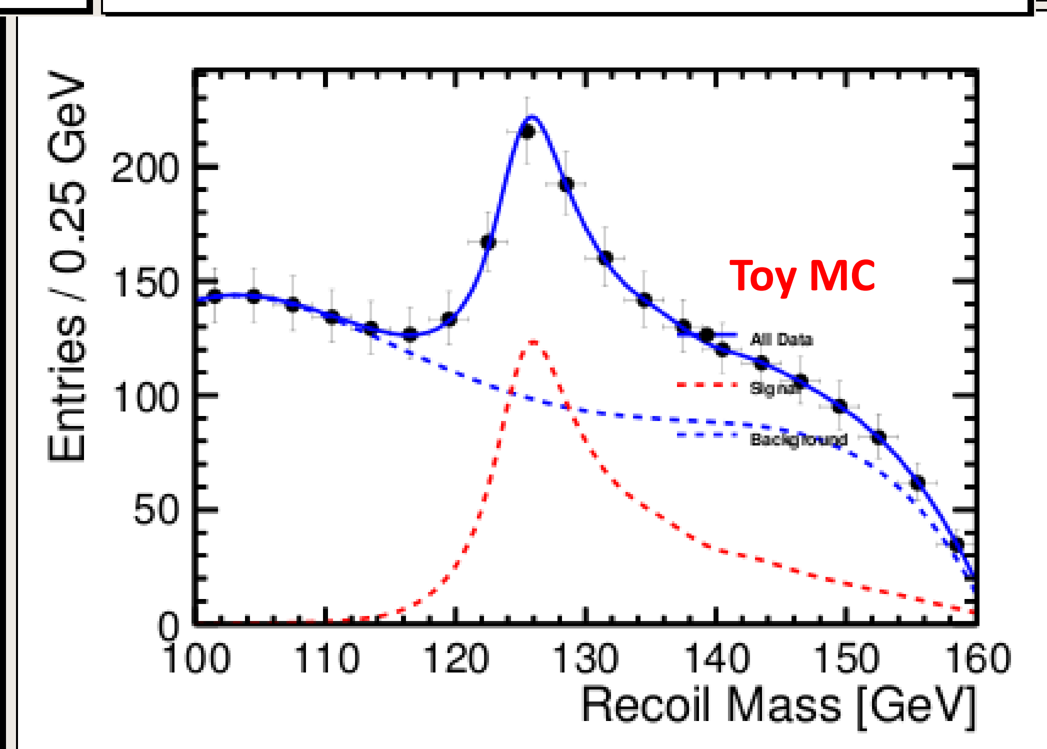
- wider recoil mass peak → need to adjust Kernel width
- low significance → need to improve BG rejection
- low MC statistics → need to investigate the effect





BG with low MC statistics (large weights)
very few events in some bins

in this case, mainly 2f_bhabhag



350 GeV,
Zee (+0.8,-0.3)

Realized 2f_z_bhabhag BG dominates residual BG (> 40%) in 100-160 GeV Mrecoil fitting region for Zee at ECM >= 350 GeV

❖ *Why a problem ?*

esp. for or right polarization , small MC statistics → large weights, stat error > 20%
(e.g. 2f_bb_rl : weight ~ 19 !!)
Poor BG fitting → degrades reliability of Toy MC results for xsec error

❖Need to confirm impact of MC statistics on xsec error for Zee channel as well !!
whole BG shape is changed due a particular BG
maybe only change the amount of 2f_bb BG (?)

❖ Tentative solution: use Ebal cut and (later on) try cosθmiss cut

Most of today's talk will be about understanding the nature of this 2f_bb BG in order to achieve further rejection

Muon Candidate Selection

opposite +/− 1 charge

- E_cluster / P_total < 0.5
- **isolation (small cone energy)**
  → removes nearly all 4f_WW_sl BG
- Minv closest to Z mass
- cos(track angle) < 0.98 & |D0/δD0| < 5

2f BG are being removed ina way to guarantee Higgs decay mode independence

Optimized in terms of signal significance and xsec measurement precision

definition

- M_inv : invariant mass of 2 muons
- pt_mumu : pt of reconstructed muons
- pt,γ : pt of most energetic photon
- θ_Zpro = Z production angle

Final Selection

- **73 < GeV < M_inv < 120 GeV**
- **10 GeV < pt_mumu < 140 GeV**
- $\left|\overrightarrow{P_{t,sum}}\right| \circ \left|\overrightarrow{P_{t,g}}+\overrightarrow{P_{t,dl}}\right|$ **> 10 GeV**
- **|cos(θ_Zpro)| < 0.9**
- **120 GeV < Mrecoil < 140 GeV**
- **Likelihood cut**

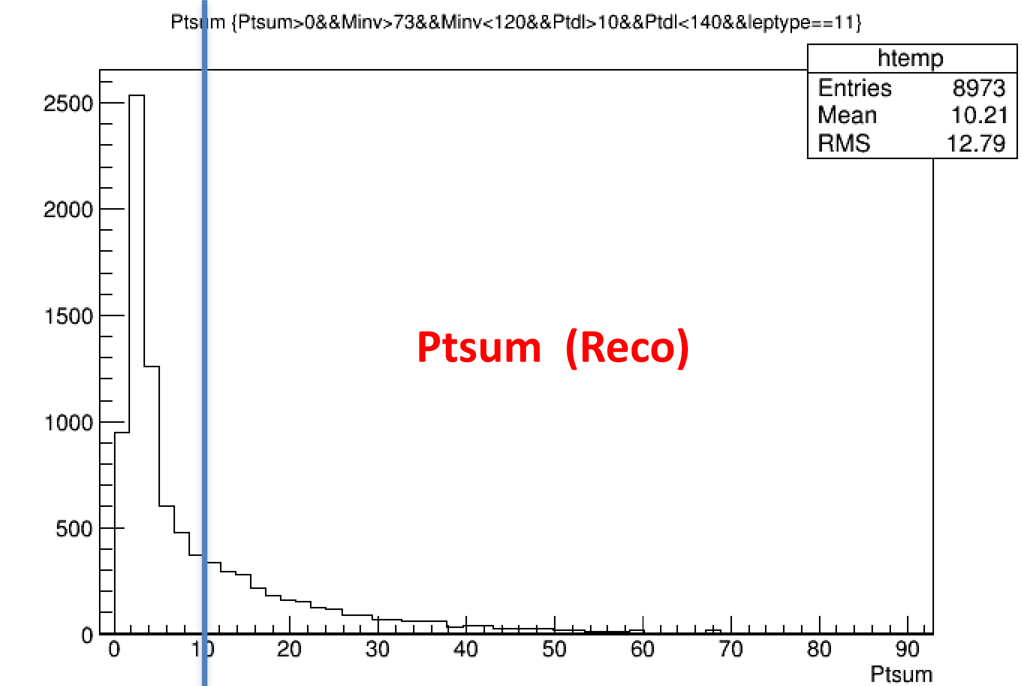
ECM=350 GeV, (-0.8,+0.3)

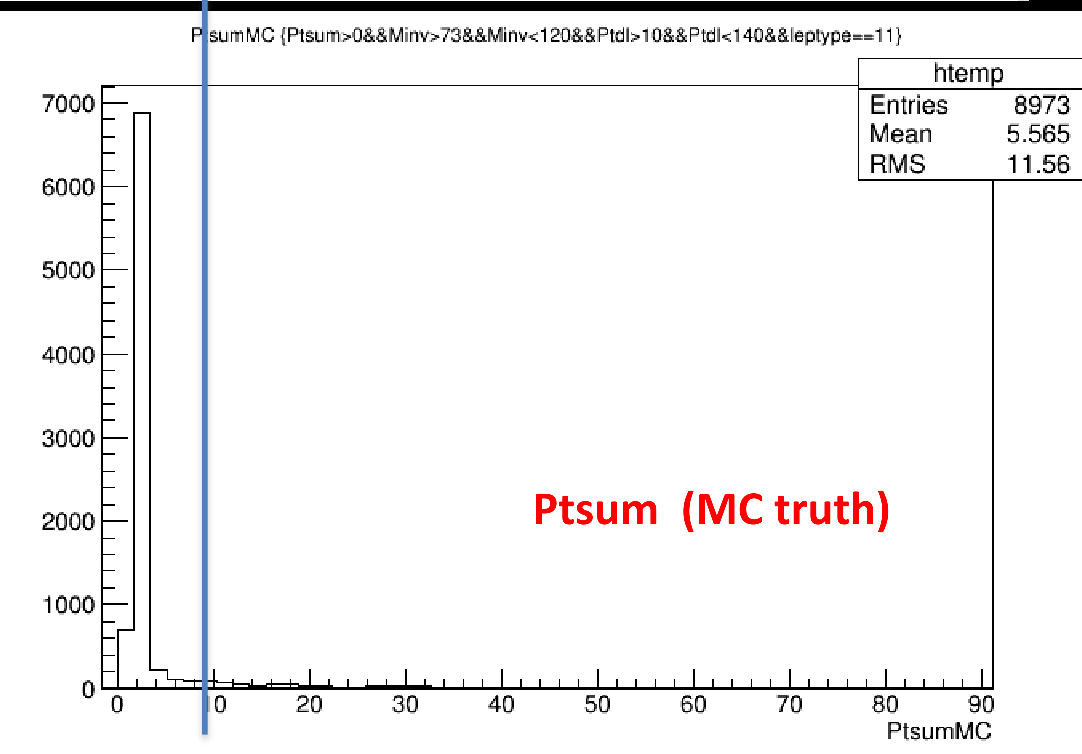
- **Use info of cone energy around most energetic gamma**

→ cut 2f_Z BG using info on pt_γ while prevent bias on signal

This Ptsum cut seemed not as effective as expected for Zee at 350 GeV

(c.f. Was very good for Zmm)





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 !!

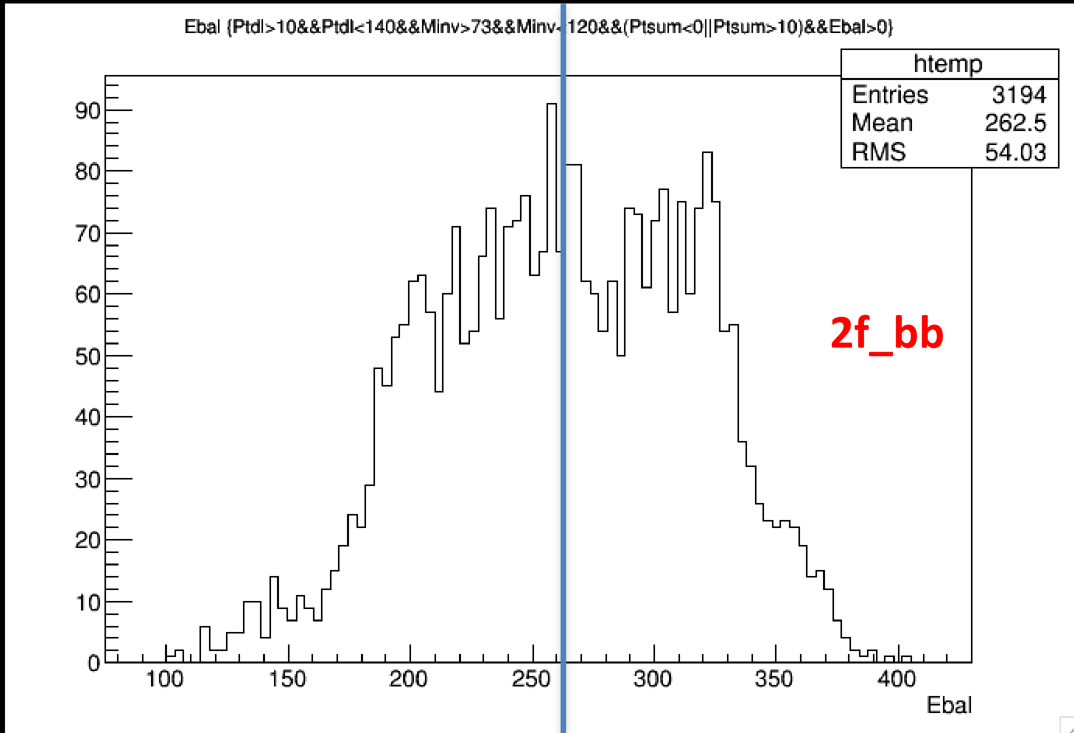
Ptdl should be near zero if no brem

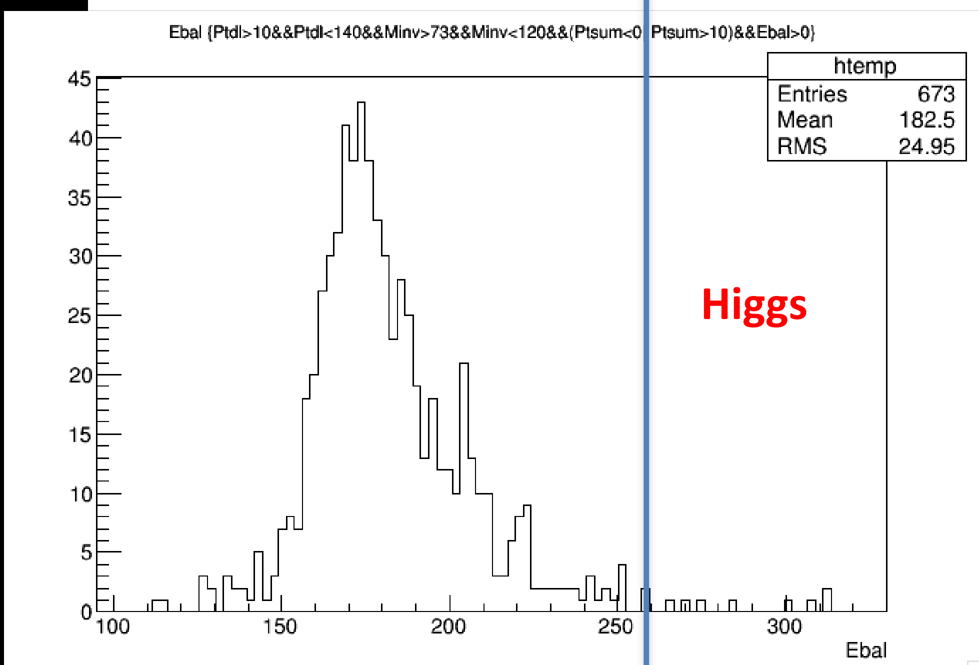
If one lepton emit brem and lose energy,

Pt_dl will incrrease

→ long Ptsum tail

→ Ptsum cut lose power





350 GeV, Zee (+0.8,-0.3)

By applying cut Ebal < 260 GeV
(Ebal = Eγ + Edl)

2f_z_leptonic BG
Reduced greatly
820 → 186

signal lost < 2 events

Events in fitting region 100 – 160 GeV 350 GeV, Zee (+0.8,-0.3)

By applying cut Ebal < 260 GeV: 2f_z_leptonic BG reduced greatly : 820 → 186

Before Ebal cut

		2f BG		4f_sl	4f_l		Total BG		Higgs	
Cut9	:	820.846	0	338.834	780.718	0	1940.4	604.486	604.31	11.9791

After Ebal cut

		2f BG		4f_sl	4f_l		Total BG		Higgs	
Cut9	:	186.321	0	332.587	778.278	0	1297.19	603.654	603.478	13.8417

signal lost only
1 event

so far ....

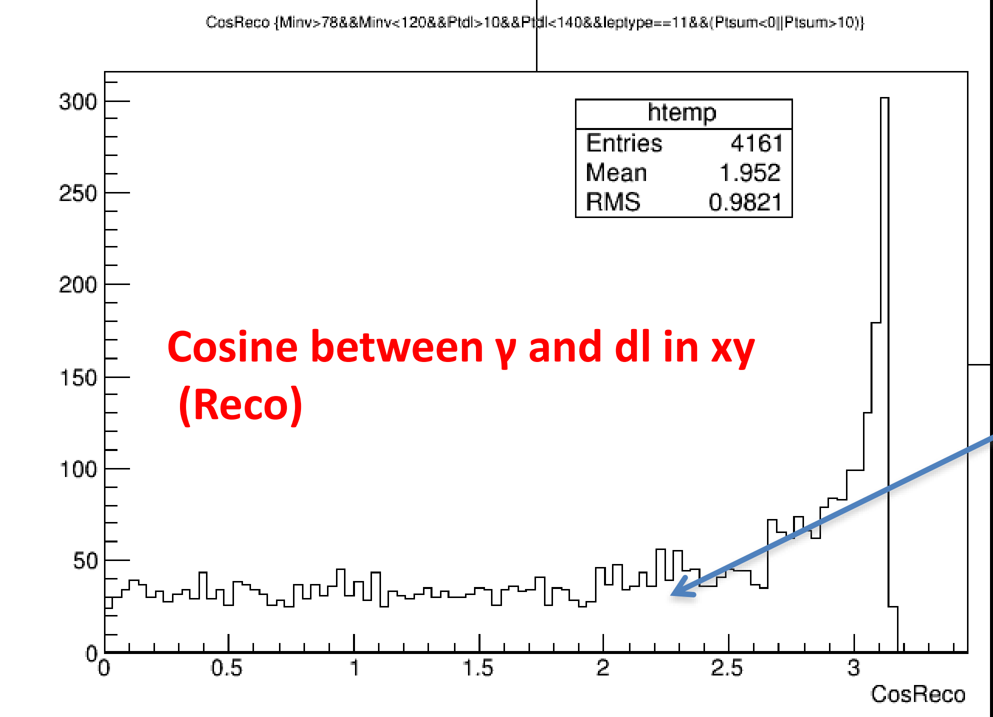
❖Ptsum discrepancy seems explained by

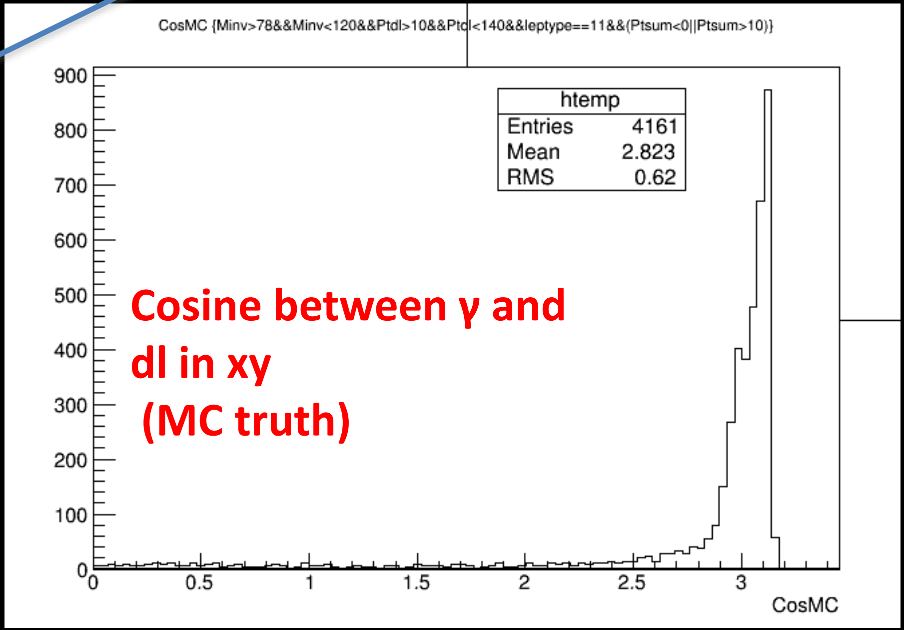
Energy is not measured ideally due to leptons lose energy due to brem

Obviously brem recovery is not perfect

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

How to explain the long isotropic tail for Reco ?

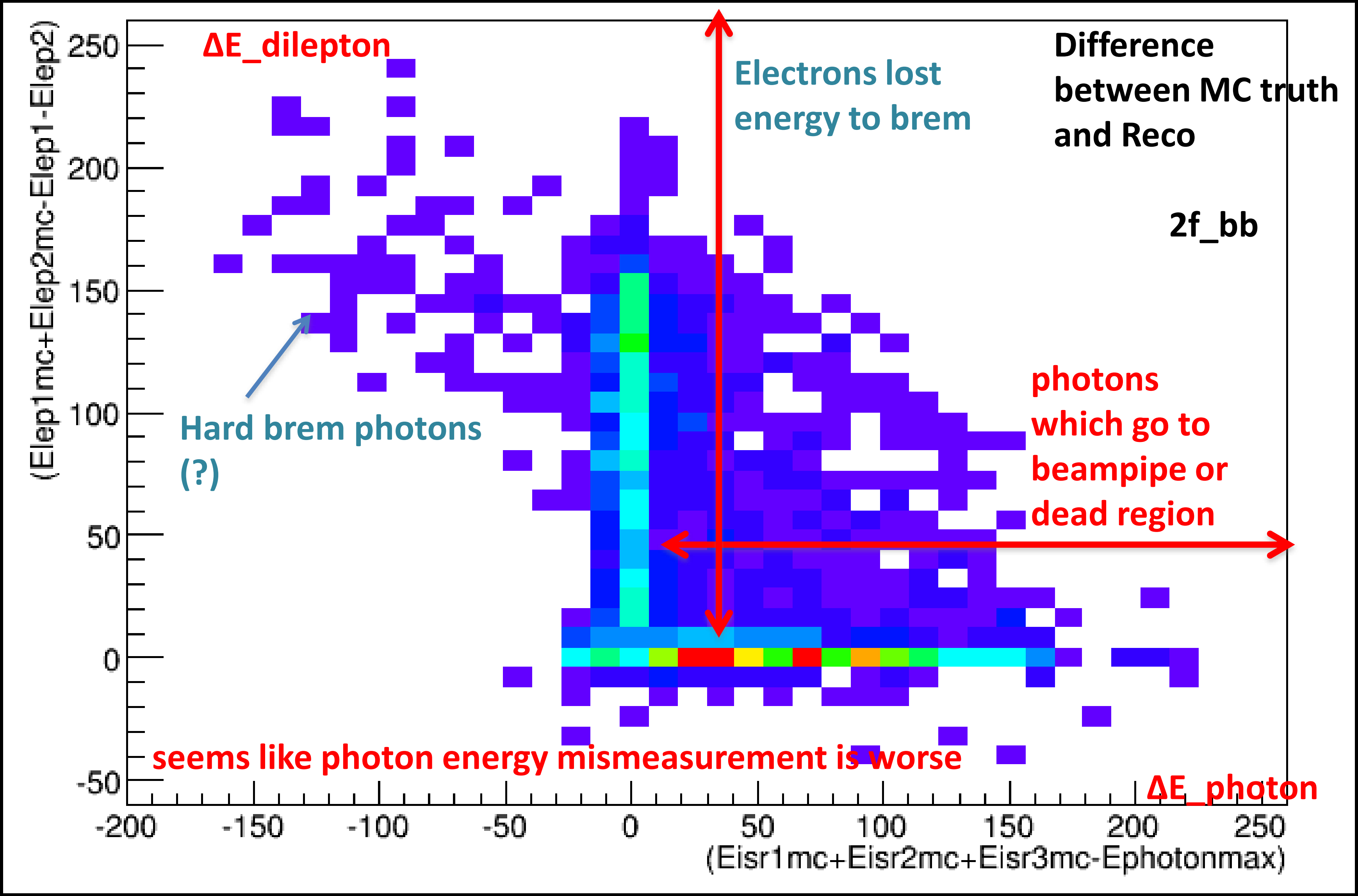




There are a few potential explanations

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

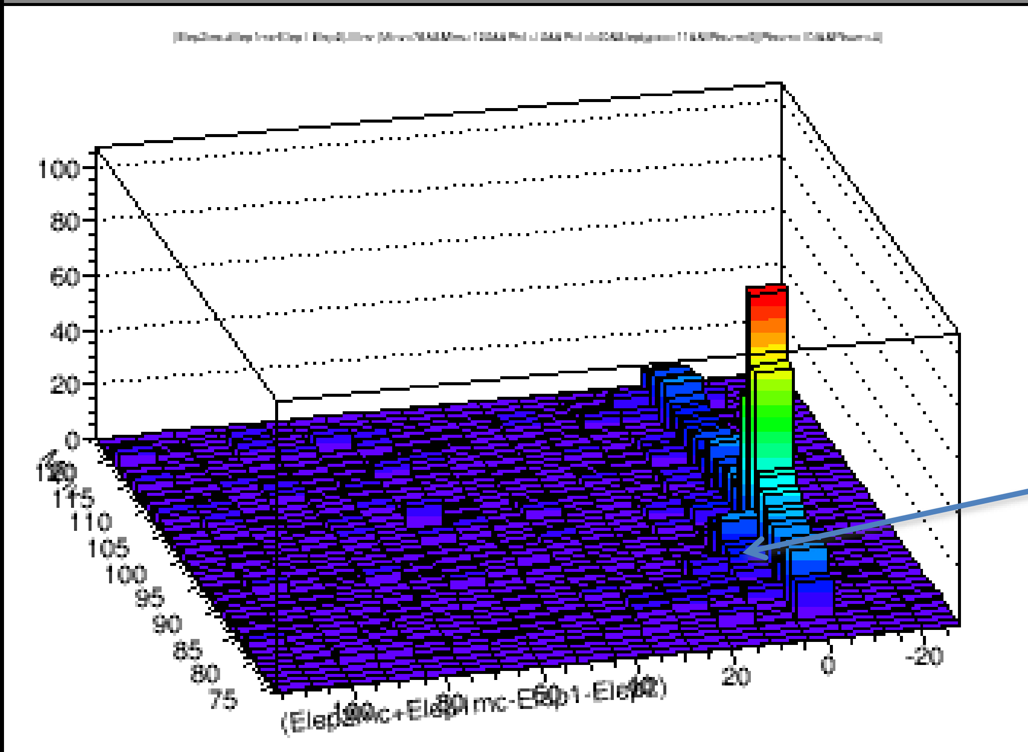
especially the long isotropic tail



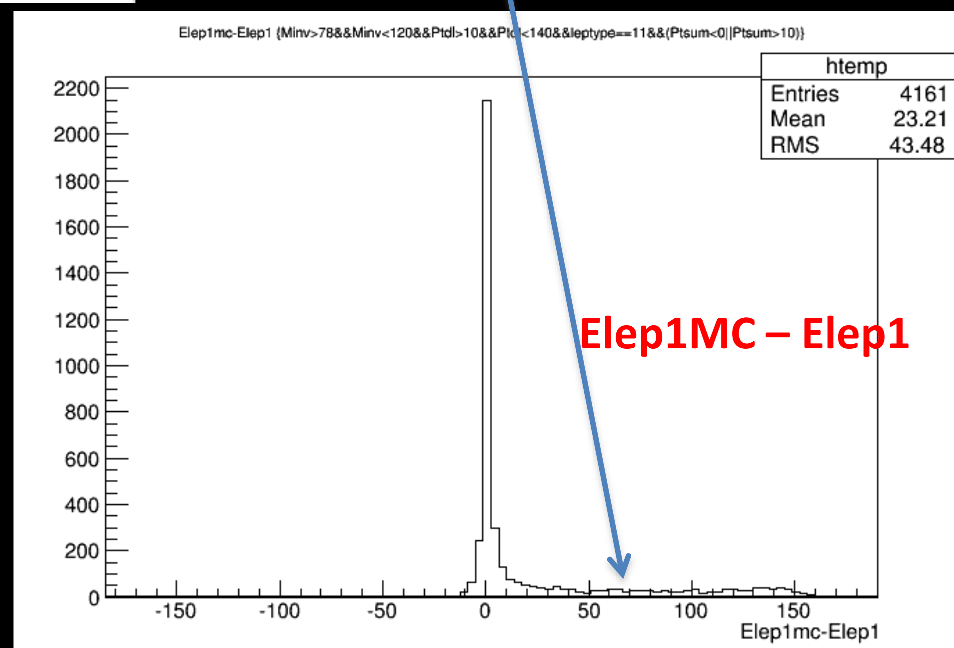
energy mis-measurements explain ONLY A PART of discrepancy in non - BTB ness

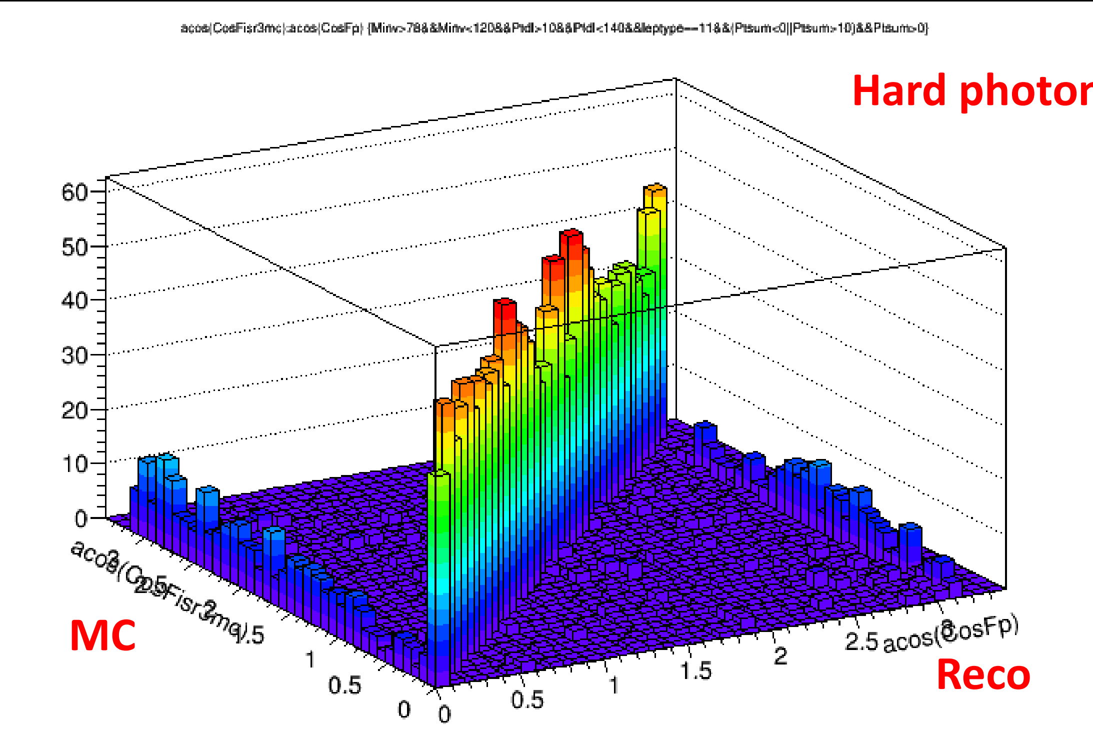
- leptons lose energy due to brem
- Photons go very forward to beampipe or dead regions of detector

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

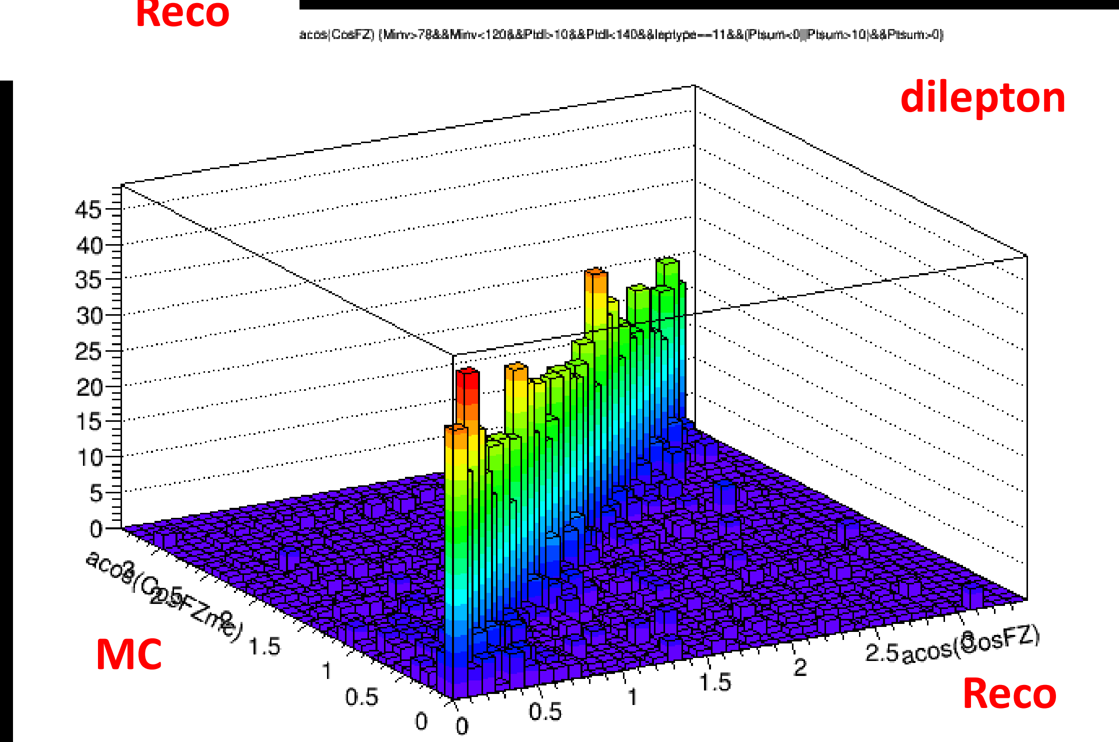


Events which emit brem contribute to lower Minv tail





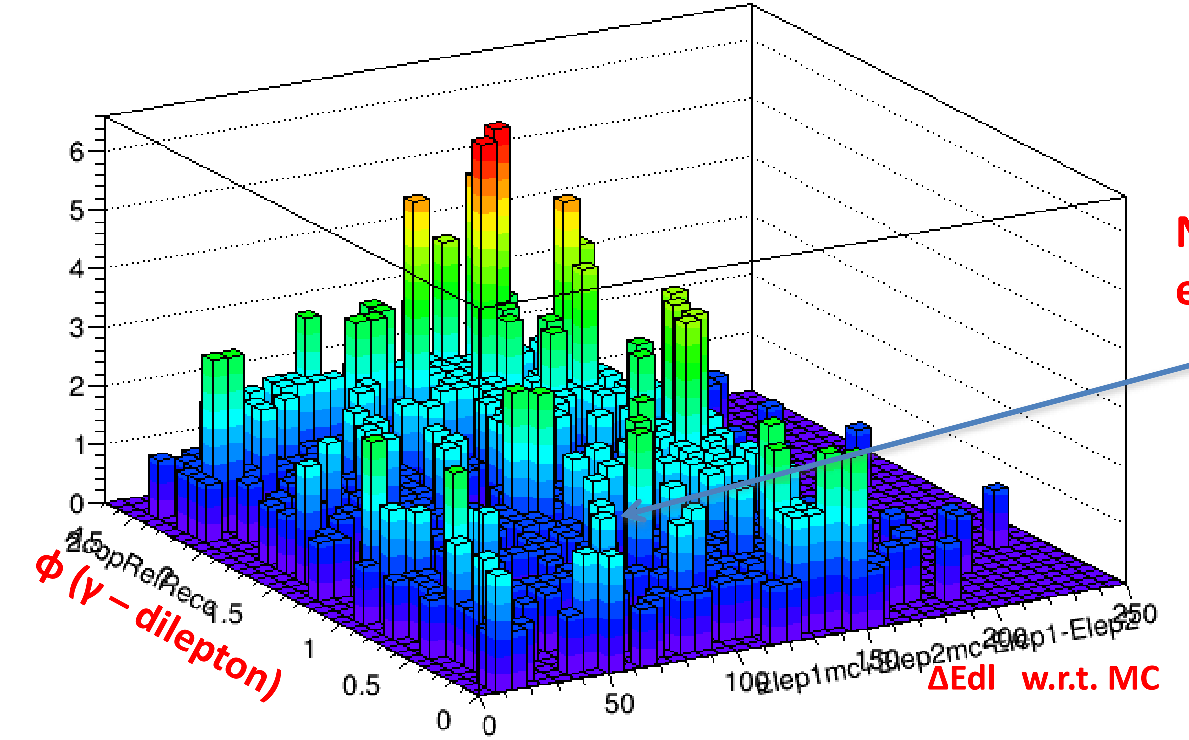
Angle ϕ in x-y plane



Angle precision seems not too bad for lepton and photon

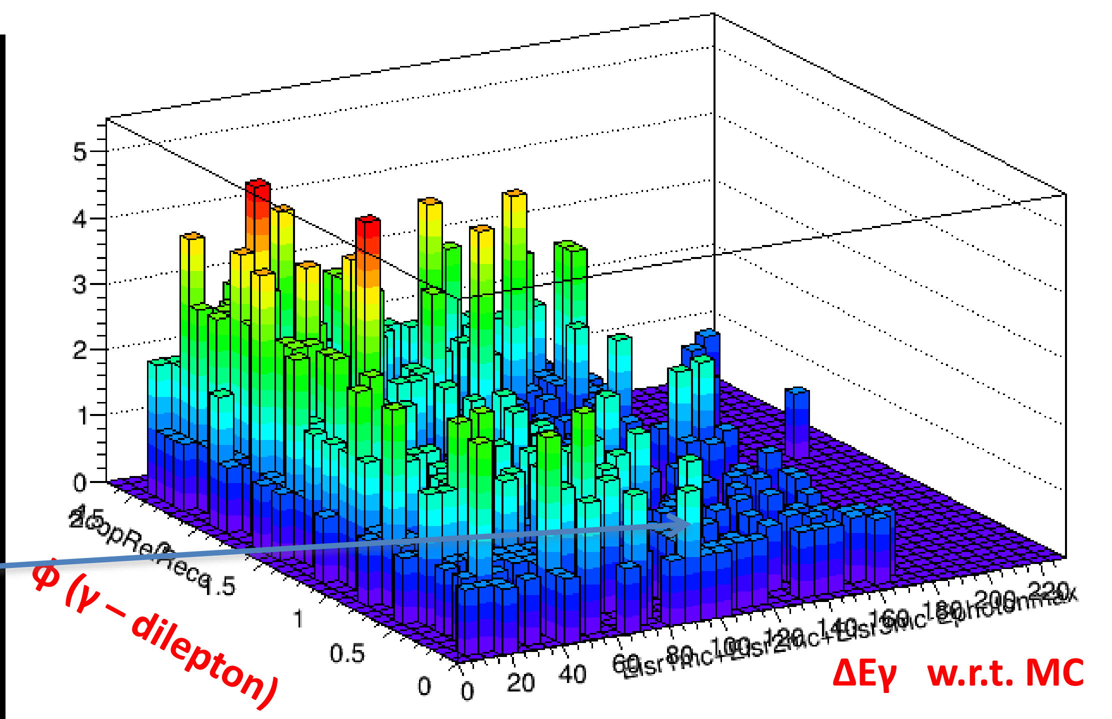
(photon slightly worse)

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



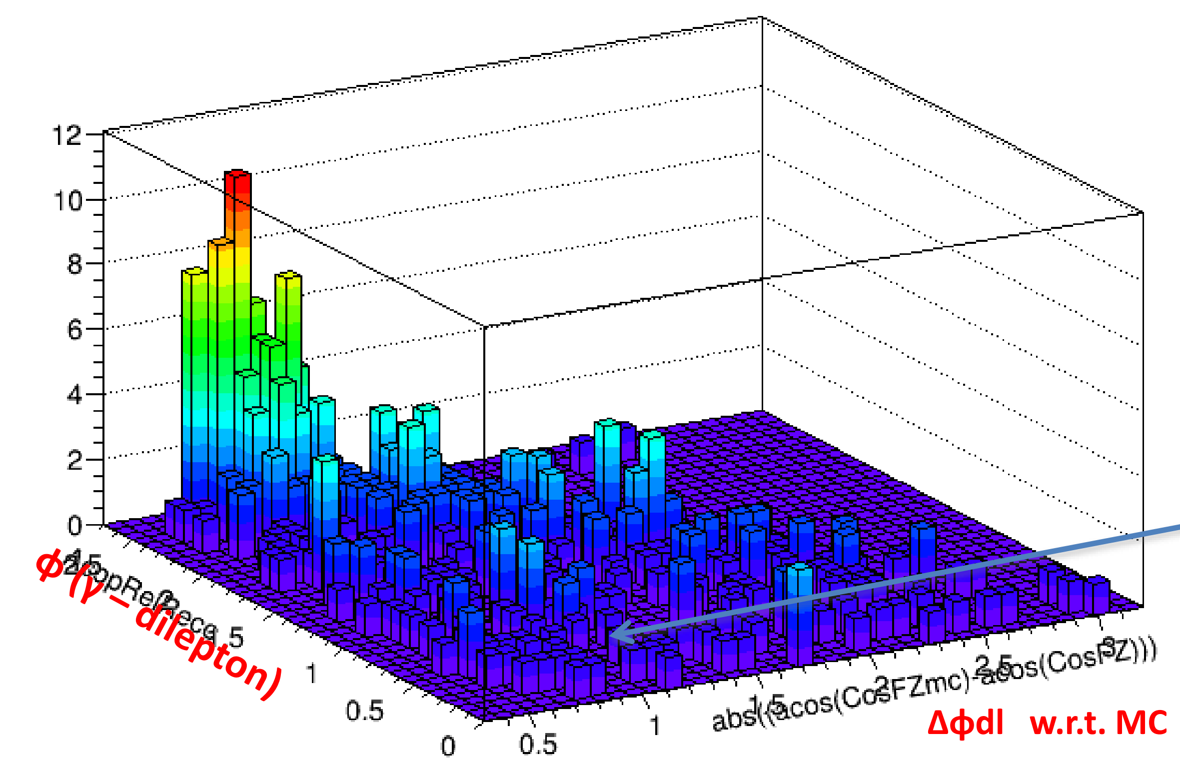
Not well measured dilepton energy: 60%

brem explains part of non-"BTB"

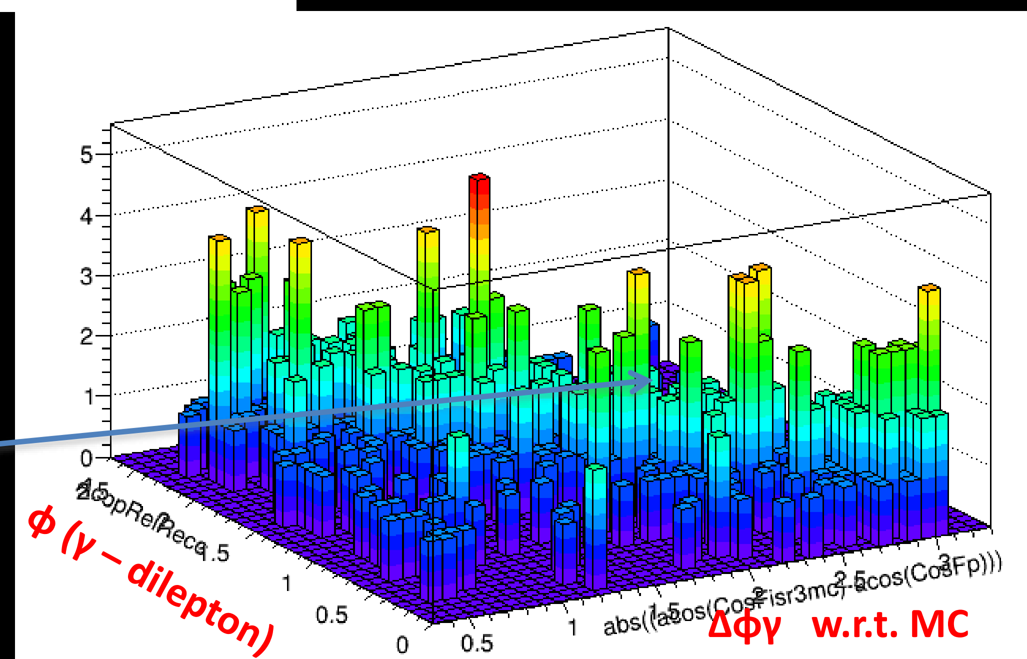


Not well measured γ energy: 55%

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

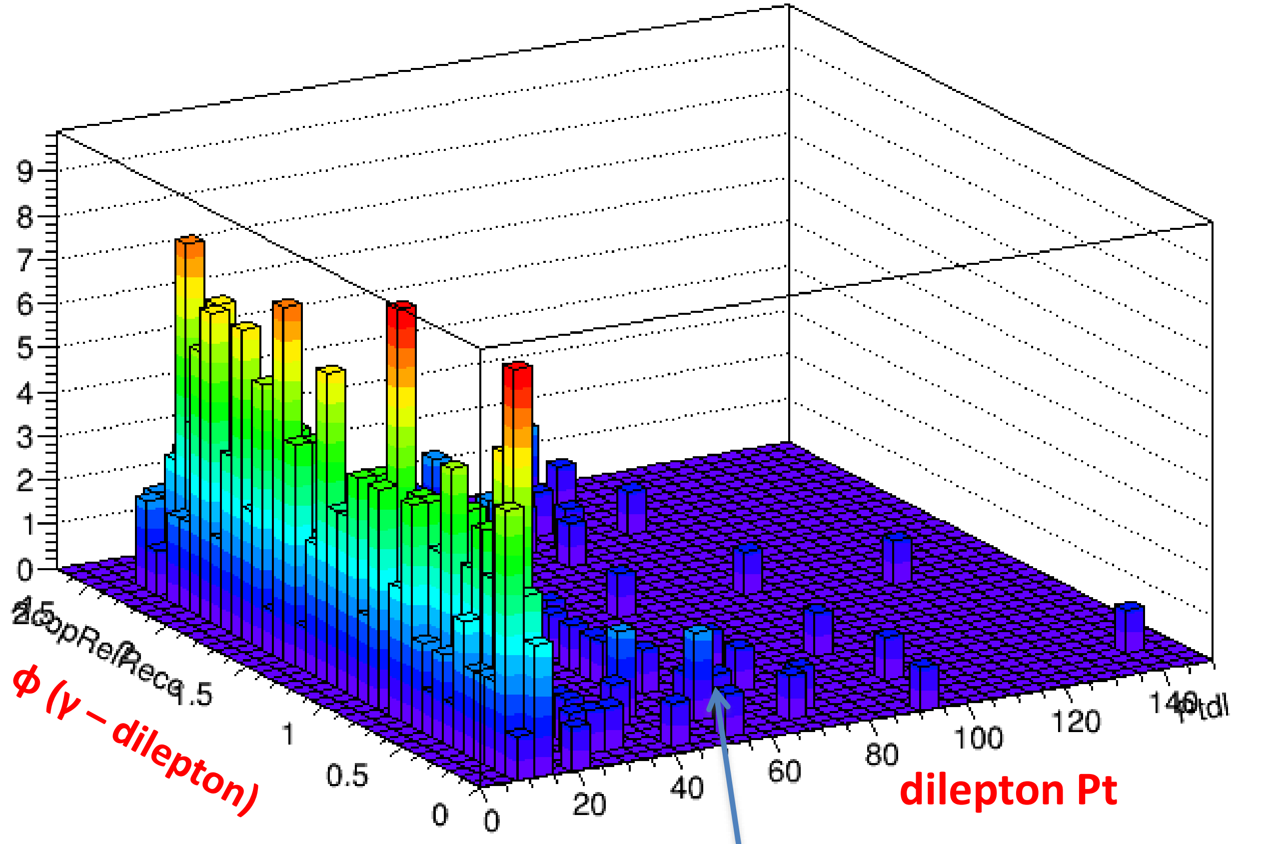


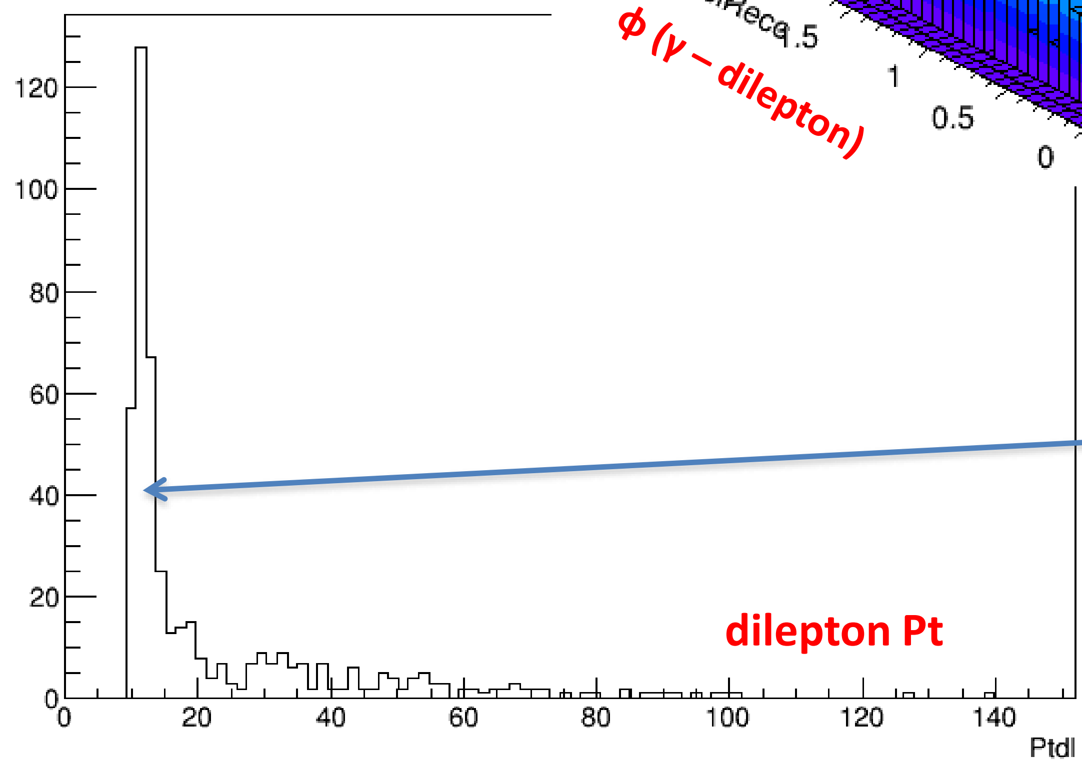
Not well measured dilepton angle : 40%



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 ?)

Conclusion

- **For fitting recoil mass: need to adjust fitting function case by case**
- Signal : Kernel width
- BG: 3rd order or 2nd order polynomial

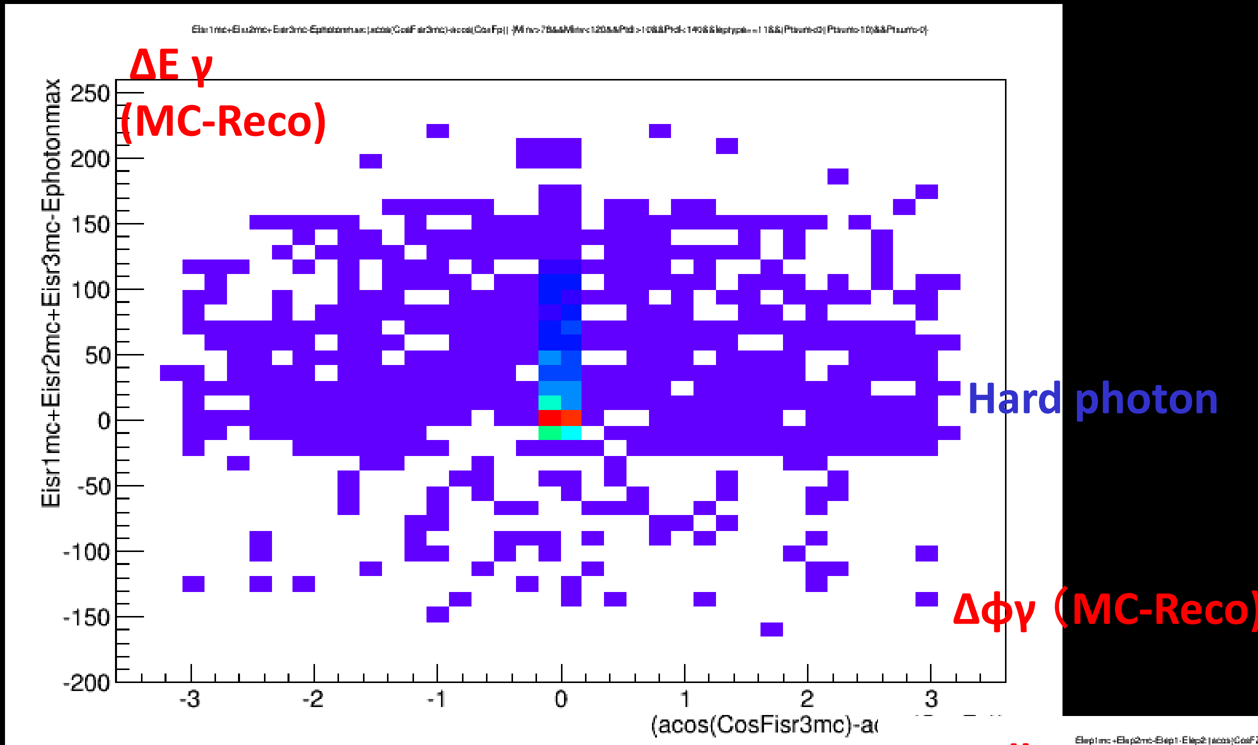
  important for reliable Toy MC study of xsec and mass precision

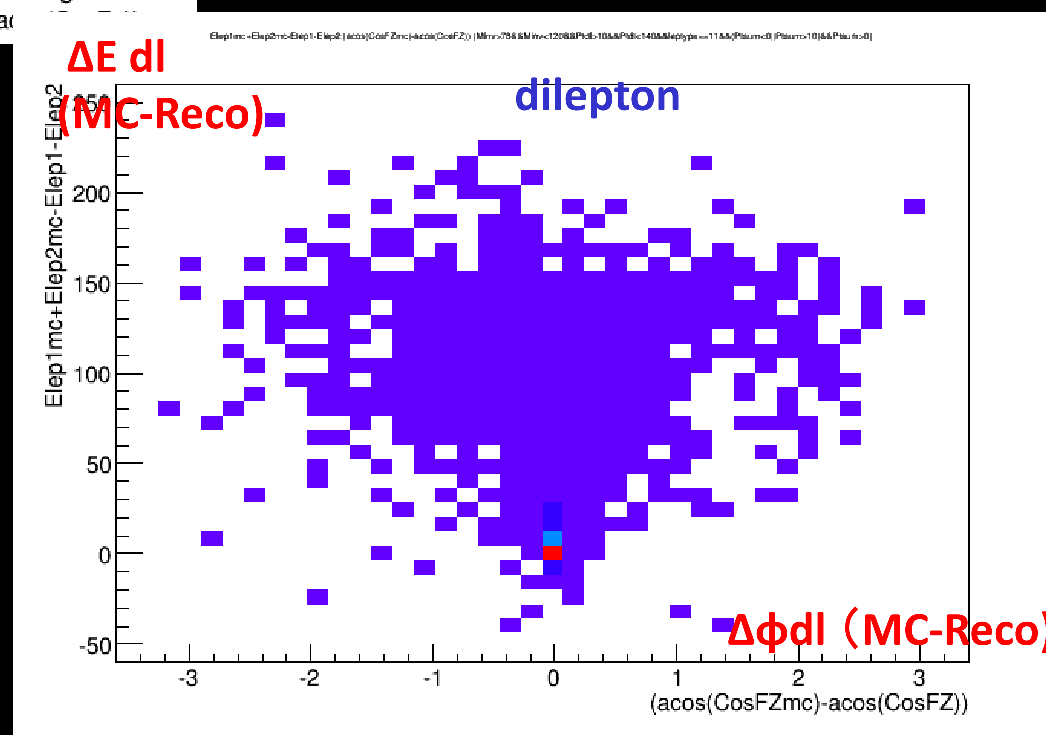
- **effort ongoing to understand and eliminate 2f BG**
- these are an issue for Zee at higher ECM
- brem and energy mis-measurement make some cuts difficult

Plans and Goals:

- further rejection of BG for Zee channel
- investigate effect of low MC statistics on xsec for Zee
- establish best fitting method (polynomial, Kernel width) for each ECM and lepton channel , move towards finalizing statistical error study

BACKUP

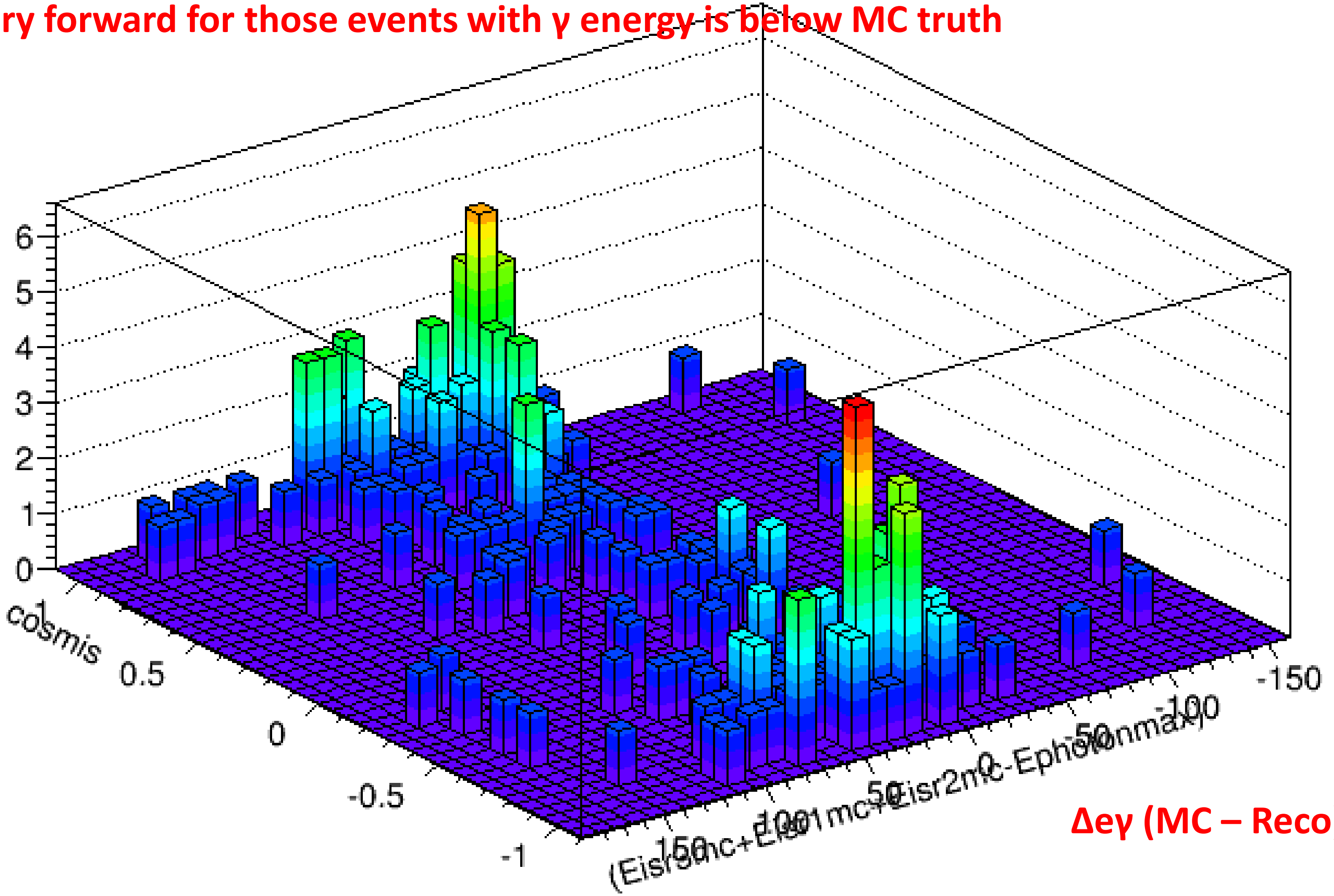




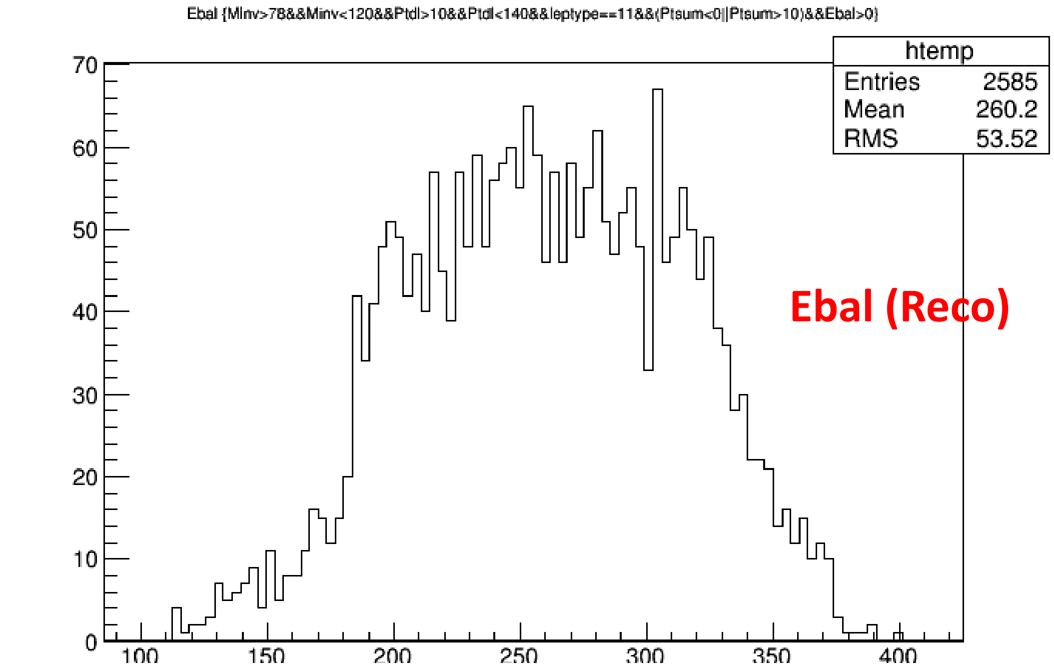
No clear correlation between energy mis-measurement and angle mis-measurement

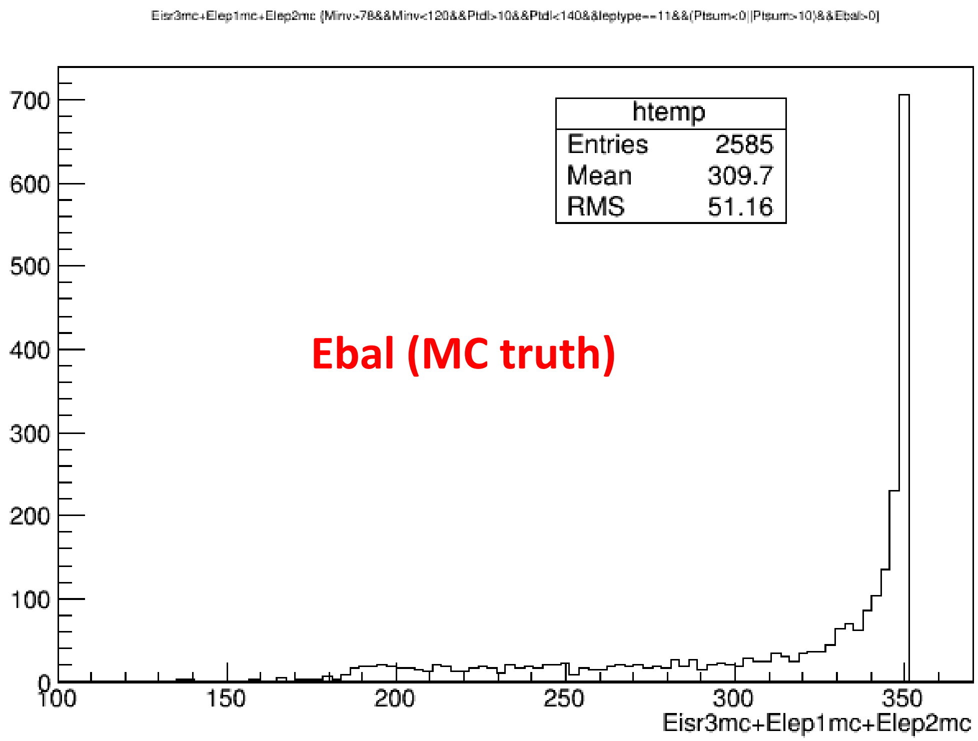
cos(miss) = cosθ of undetected particles

very forward for those events with γ energy is below MC truth



2f_bb

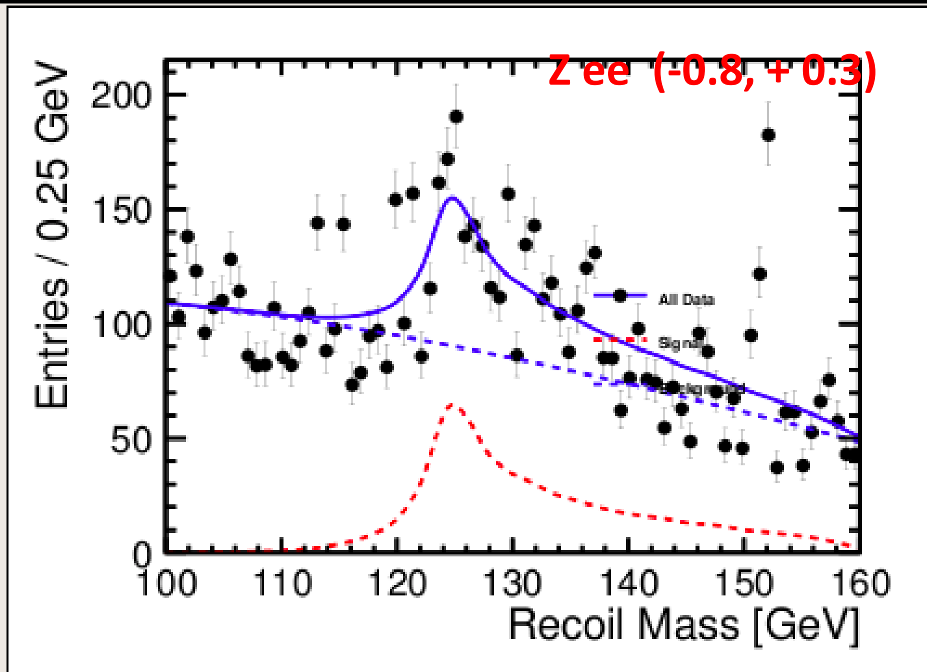


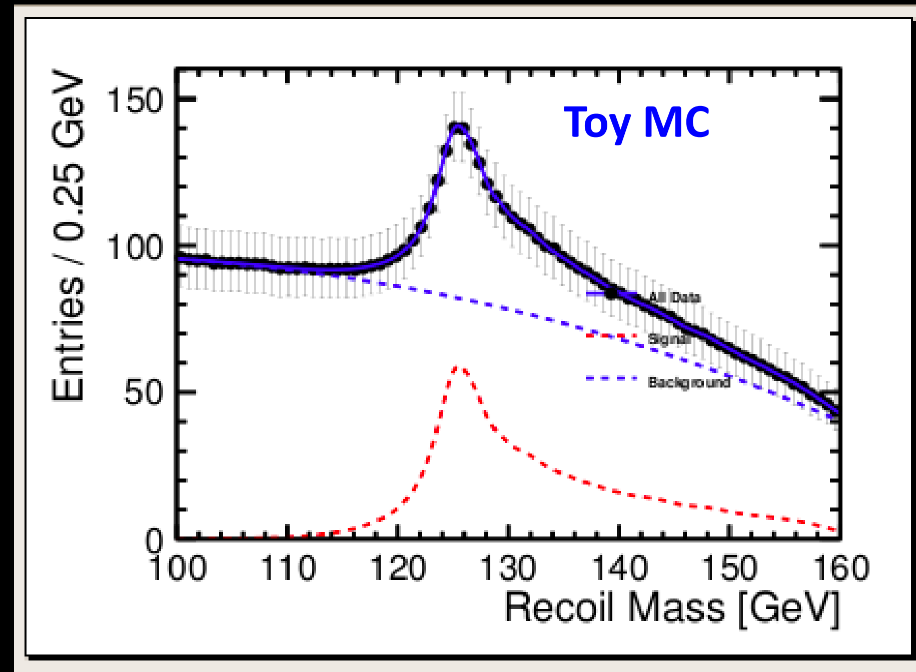


similarly distribution of
Ebal = Eγ + Edl
is affected by leptons which lost
energy due to brem

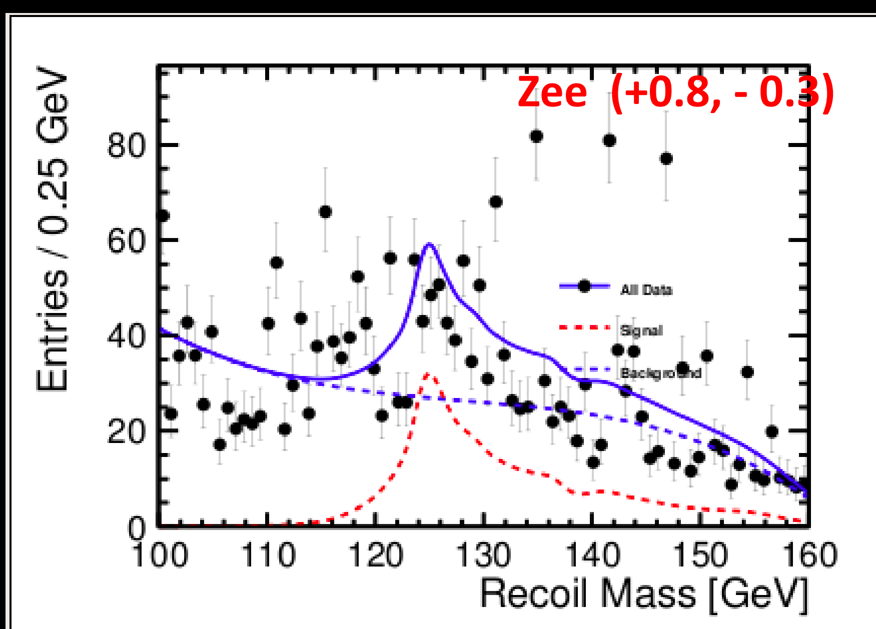
for events after Ptsum cut

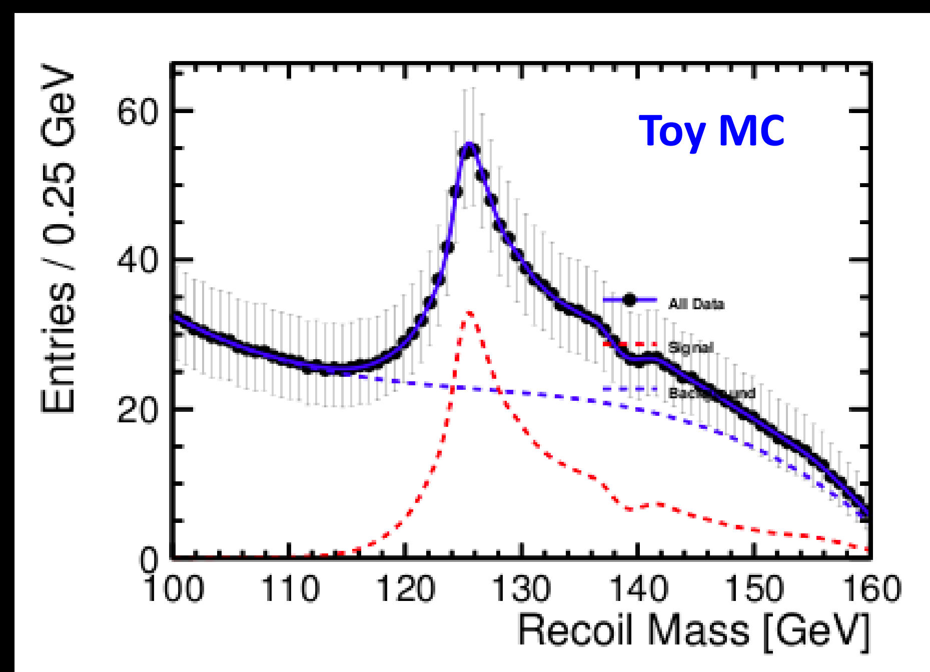
2f_bb


Z ee (-0.8, + 0.3)
Entries / 0.25 GeV
0
50
100
150
200
100
110
120
130
140
150
160
Recoil Mass [GeV]
All Data
Signal
Background


Toy MC
Entries / 0.25 GeV
0
50
100
150
100
110
120
130
140
150
160
Recoil Mass [GeV]
All Data
Signal
Background

350 GeV


Zee (+0.8, - 0.3)
Entries / 0.25 GeV
0
20
40
60
80
100
110
120
130
140
150
160
Recoil Mass [GeV]
All Data
Signal
Background


Toy MC
Entries / 0.25 GeV
0
20
40
60
100
110
120
130
140
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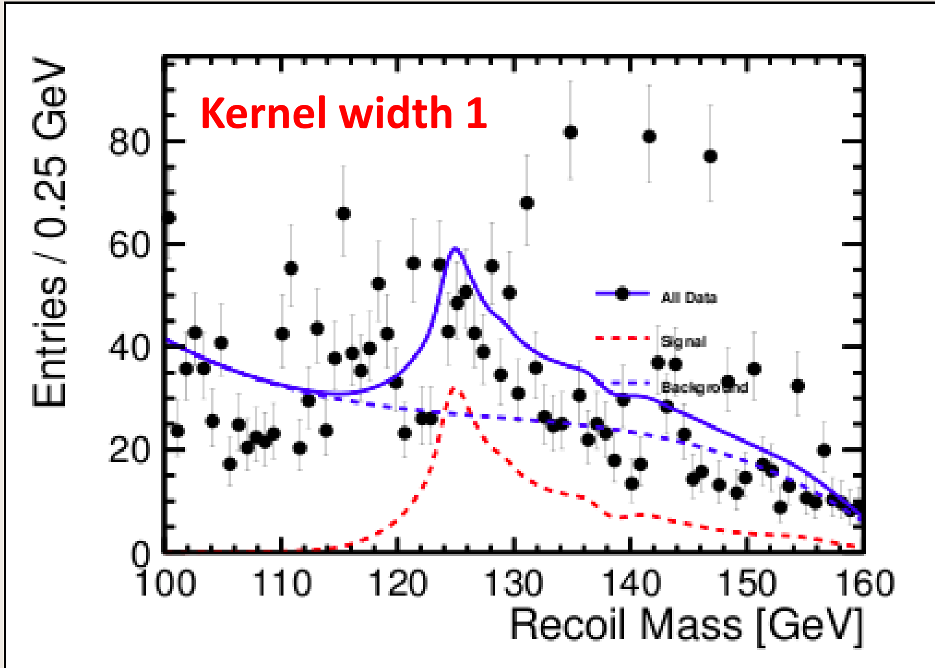
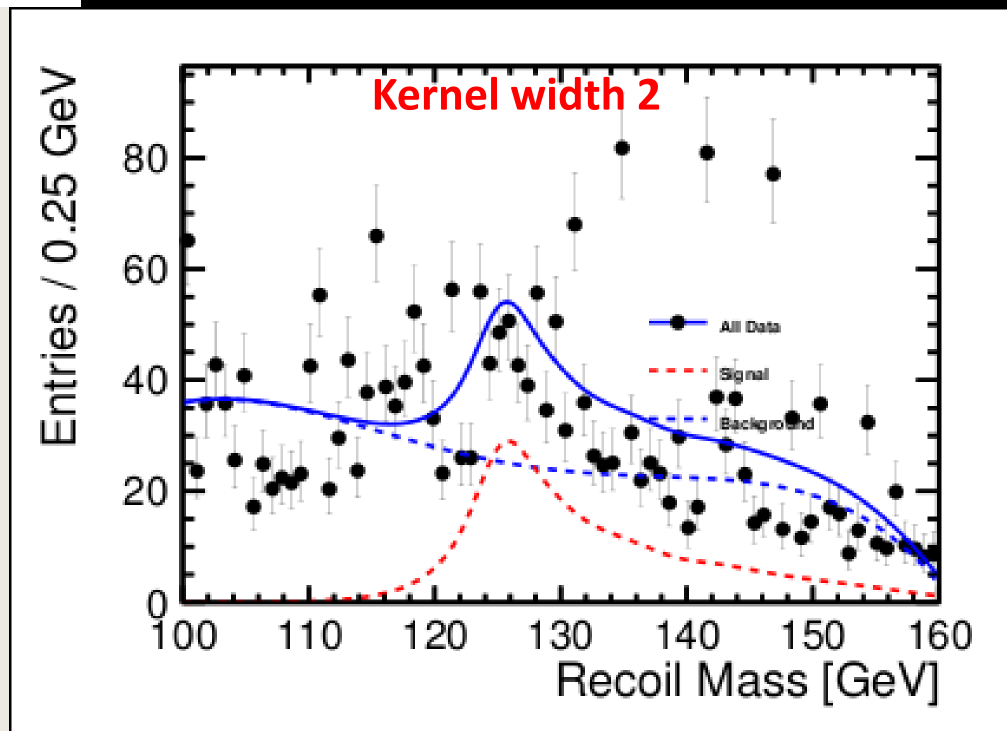
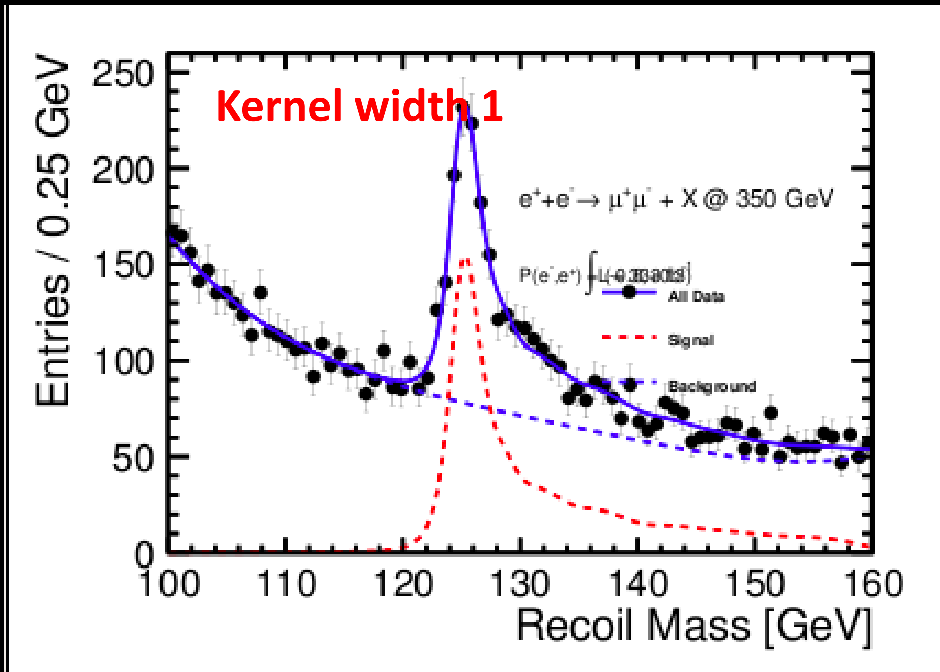
160
Recoil Mass [GeV]
All Data
Signal
Background

350 GeV

Zee (+0.8, - 0.3)



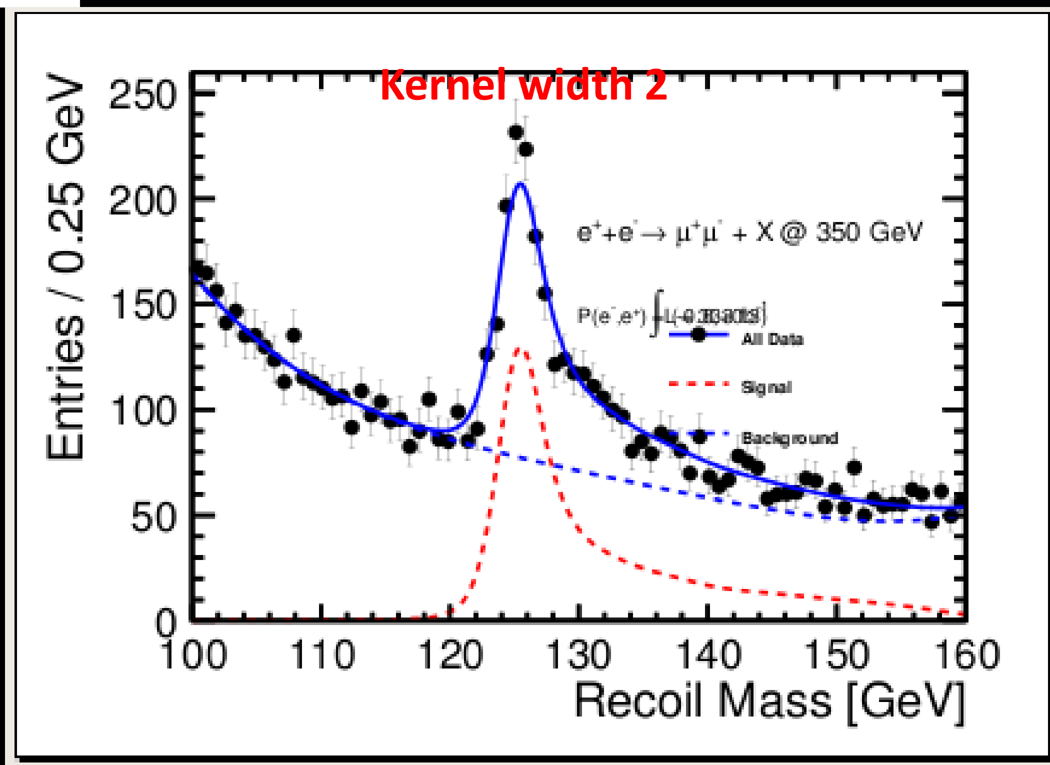


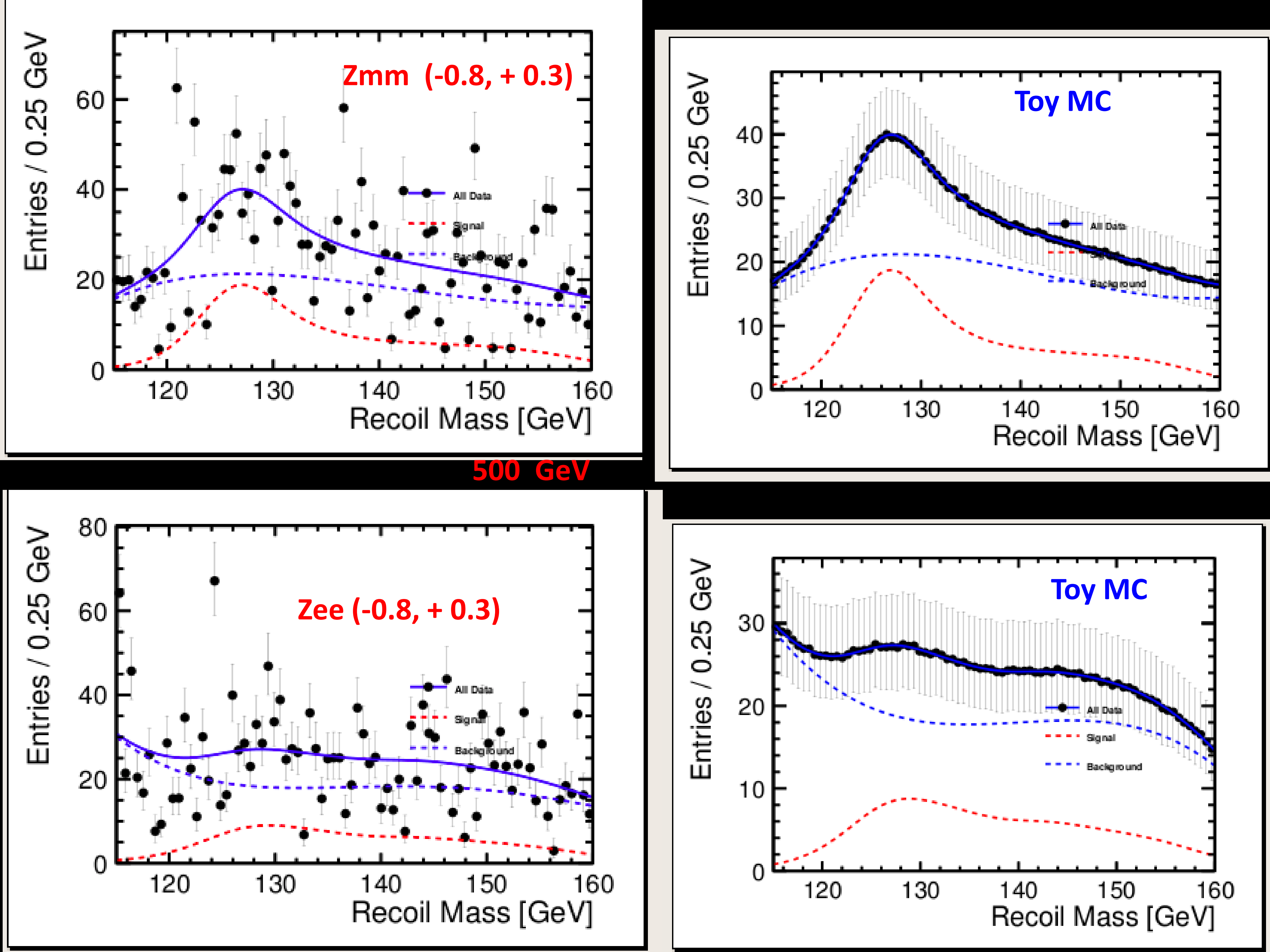


350 GeV

Zmm (-0.8, -+0.3)

but wider Kernel width doesn't go well for sharp peaks



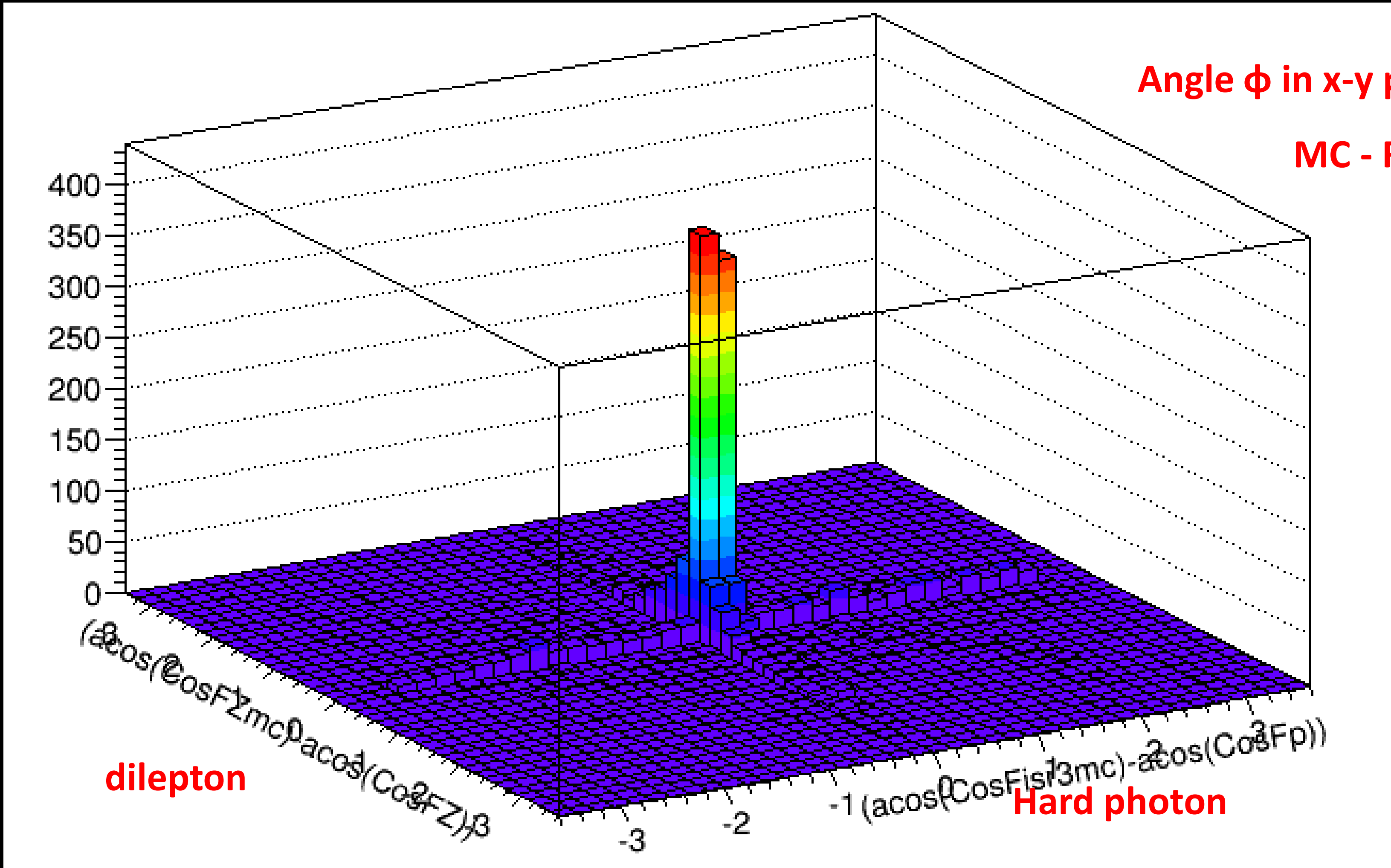

Zmm (-0.8, + 0.3)
Entries / 0.25 GeV
Recoil Mass [GeV]
All Data
Signal
Background
Toy MC
500 GeV
Zee (-0.8, + 0.3)
Toy MC

Process	2f_l	2f_h	4f_l	4f_sl	4f_h	BG	llH	Signal	Signf
Cross Section	31457.1	22965.7	1483.22	1700.82	1114.1	58720.9	15.9295	6.67532	
Generated	4.90006e+06	2.48454e+06	3.98801e+06	5.30646e+06	2.70846e+06	1.93875e+07	68024	29426	
Expected	1.04752e+07	7.64759e+06	493911	566373	370996	1.95541e+07	5304.53	2222.88	0.502619
Cut0	1.26161e+06	74.2555	55581.3	41944	1.22808	1.35921e+06	3132.19	1681.56	1.44068
Cut1	1.01279e+06	74.2555	40741.9	31587.5	1.22808	1.08519e+06	1689.41	1678.8	1.61031
Cut2	589076	18.8311	23488.6	23925.8	1.09388	636511	1552.05	1544.1	1.93305
Cut3	291280	11.0465	16381.1	15474.5	1.09388	323148	1548.71	1540.95	2.70427
Cut4	147624	2.32989	8872.17	9543.16	0.100935	166042	1400.7	1398.38	3.41738
Cut5	147283	2.32989	8797.3	9386.21	0.100935	165469	1396.99	1394.67	3.4142
Cut6	96920.4	2.32989	8574.72	9342.89	0.100935	114840	1396.68	1394.36	4.08979
Cut7	42346	1.39794	4569.24	4994.47	0	51911.2	1304.85	1302.53	5.64635
Cut8	1237.72	0	425.847	926.741	0	2590.31	669.283	668.731	11.7131
Cut9	820.846	0	338.834	780.718	0	1940.4	604.486	604.31	11.9791
Cut10	212.315	0	101.49	240.328	0	554.133	452.202	452.202	14.2548

Process	2f_l	2f_h	4f_l	4f_sl	4f_h	BG	llH	Signal	Signf
Cross Section	31457.1	22965.7	1483.22	1700.82	1114.1	58720.9	15.9295	6.67532	
Generated	4.90006e+06	2.48454e+06	3.98801e+06	5.30646e+06	2.70846e+06	1.93875e+07	68024	29426	
Expected	1.04752e+07	7.64759e+06	493911	566373	370996	1.95541e+07	5304.53	2222.88	0.502619
Cut0	1.26161e+06	74.2555	55581.3	41944	1.22808	1.35921e+06	3132.19	1681.56	1.44068
Cut1	1.01279e+06	74.2555	40741.9	31587.5	1.22808	1.08519e+06	1689.41	1678.8	1.61031
Cut2	589076	18.8311	23488.6	23925.8	1.09388	636511	1552.05	1544.1	1.93305
Cut3	291280	11.0465	16381.1	15474.5	1.09388	323148	1548.71	1540.95	2.70427
Cut4	147624	2.32989	8872.17	9543.16	0.100935	166042	1400.7	1398.38	3.41738
Cut5	147283	2.32989	8797.3	9386.21	0.100935	165469	1396.99	1394.67	3.4142
Cut6	67866.8	2.32989	8384.68	9284.03	0.100935	85537.9	1394.87	1392.55	4.723
Cut7	31080.5	1.39794	4477.15	4967.22	0	40526.2	1303.04	1300.72	6.35981
Cut8	339.534	0	415.929	923.908	0	1679.37	668.451	667.899	13.7841
Cut9	186.321	0	332.587	778.278	0	1297.19	603.654	603.478	13.8417
Cut10	23.9965	0	98.1336	239.188	0	361.318	451.769	451.769	15.8434

Angle ϕ in x-y plane

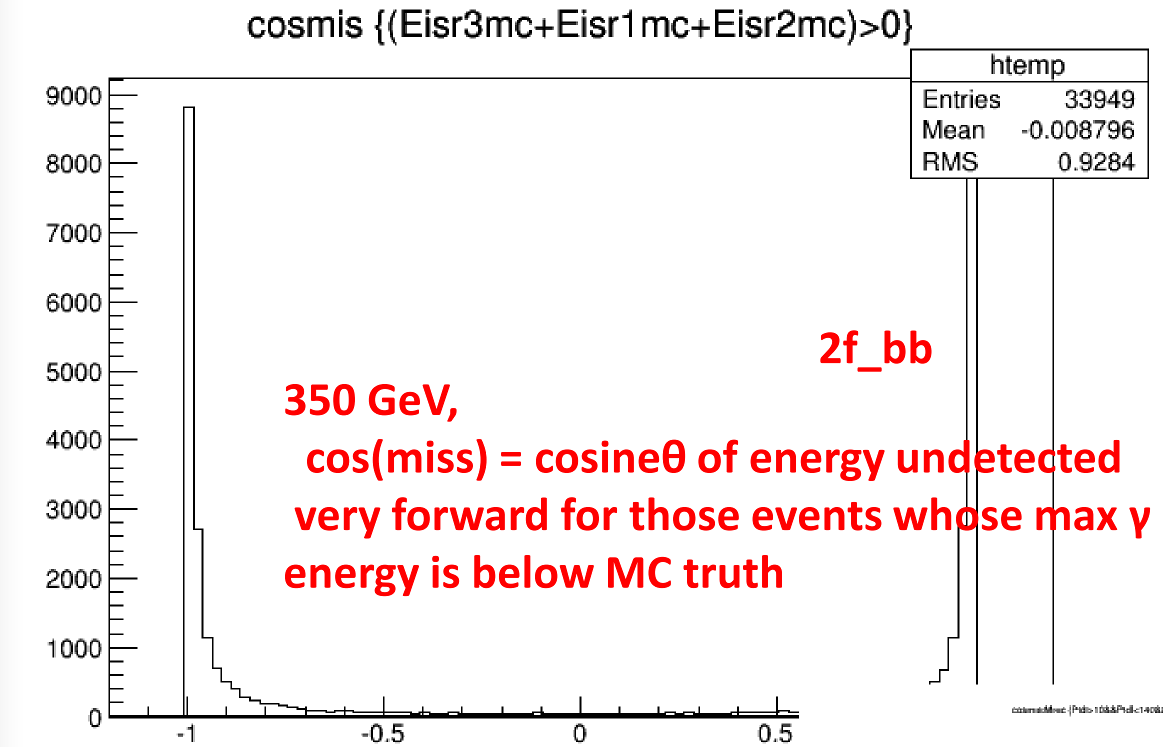
MC - Reco



dilepton

Hard photon

Angle resolution seems worse (broader distr) for photon than for lepton

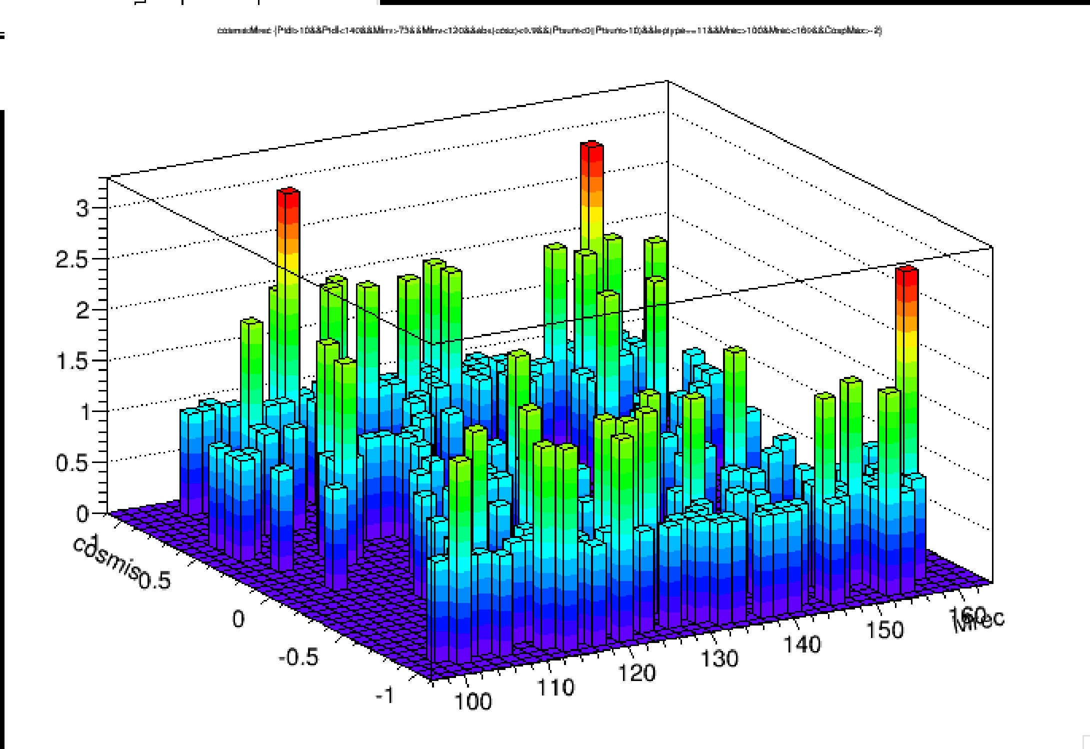


2f_bb

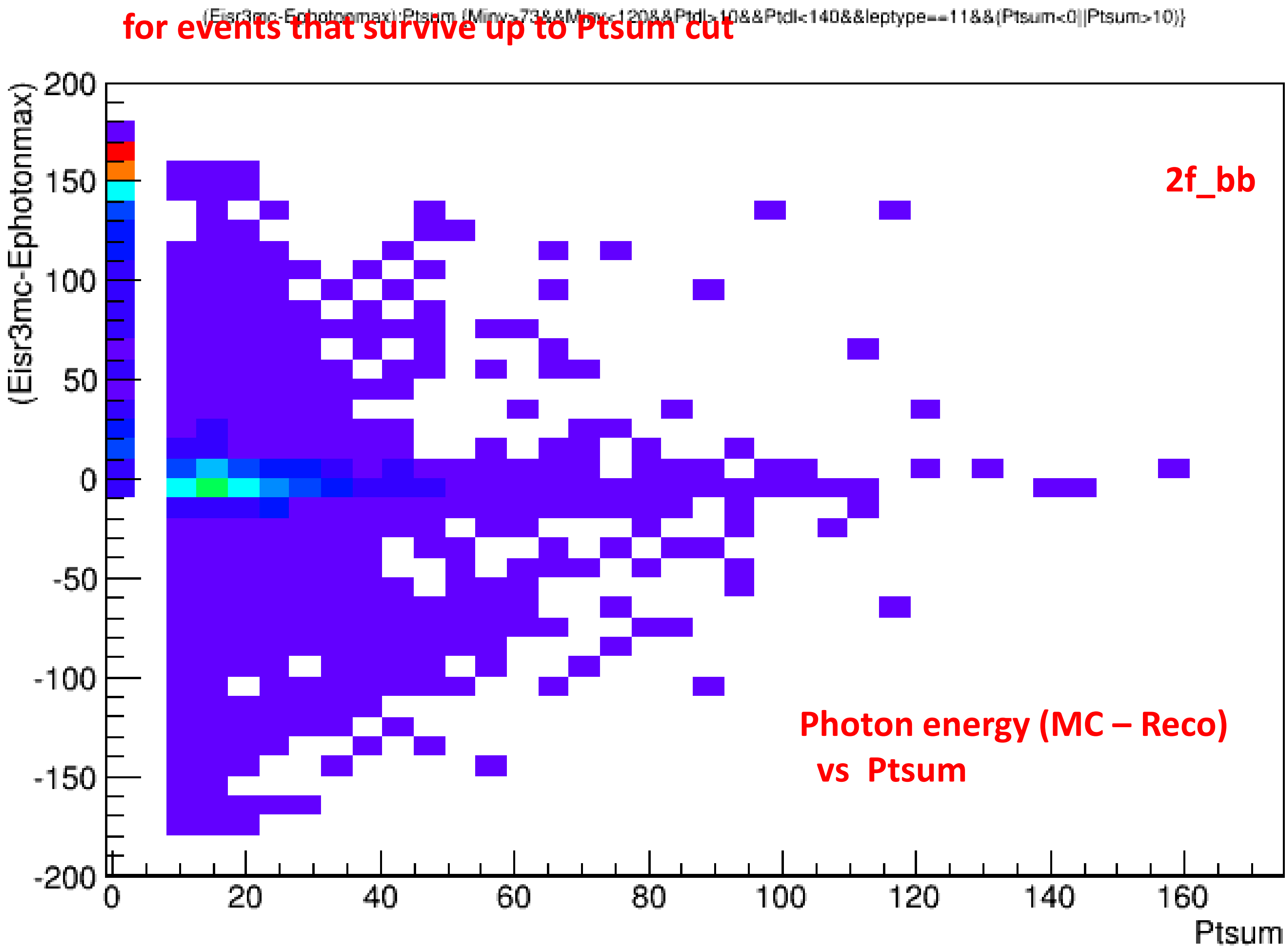
350 GeV,

cos(miss) = cosineθ of energy undetected very forward for those events whose max γ energy is below MC truth

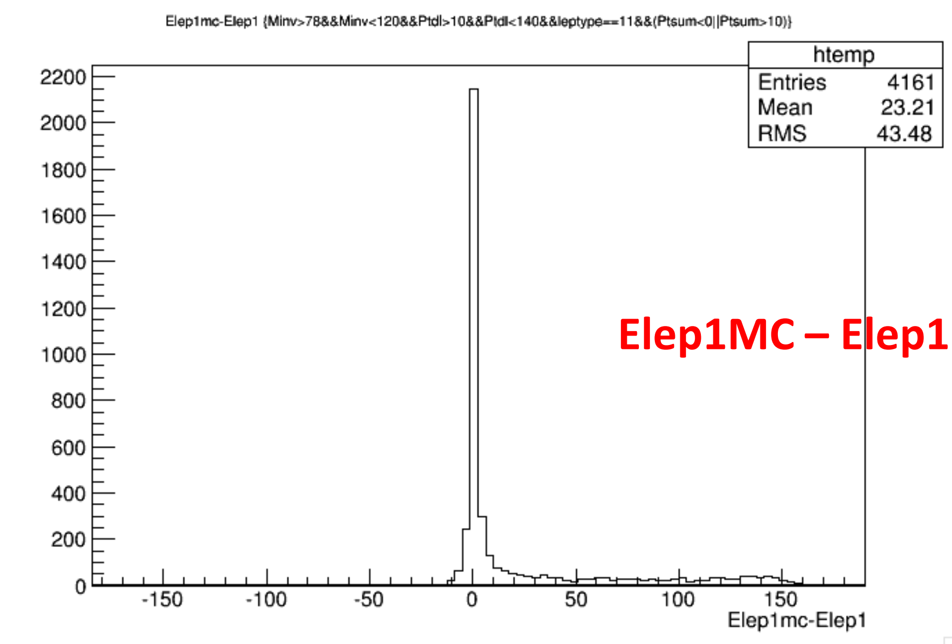
cos(miss) vs Mrec

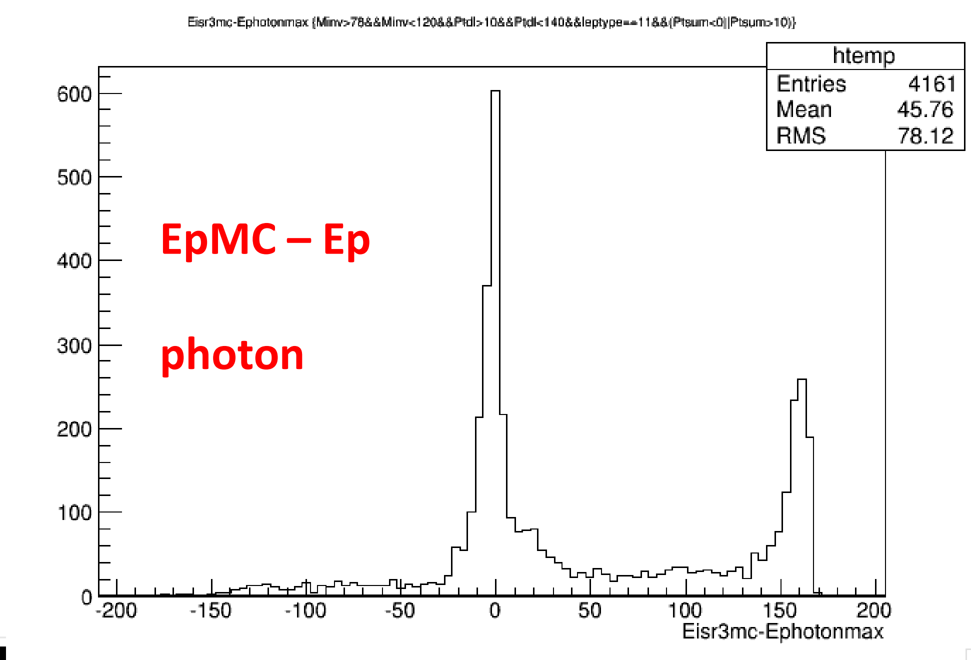


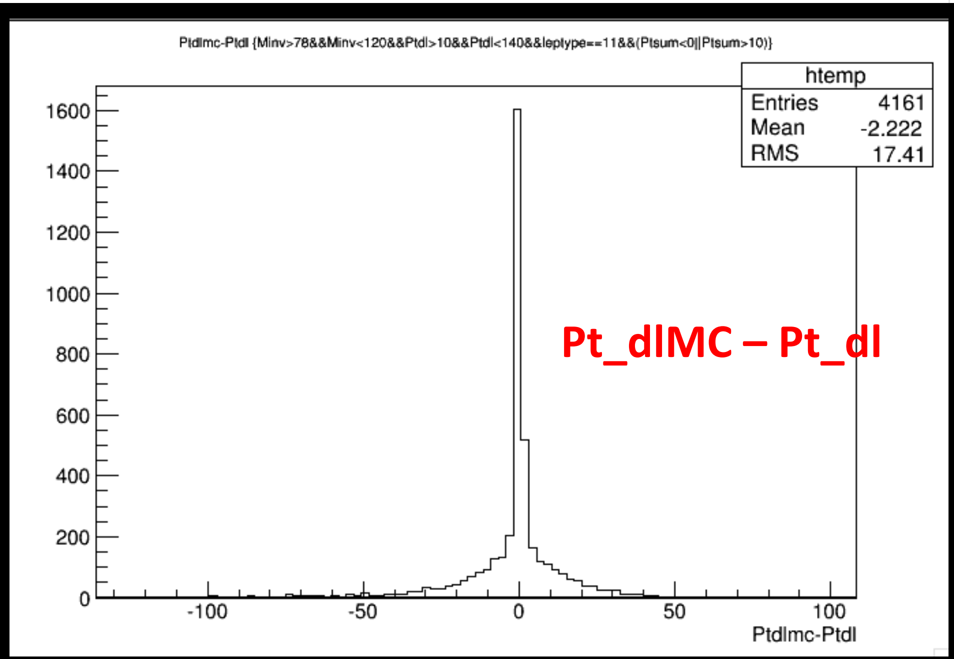
for events that survive up to Ptsum cut

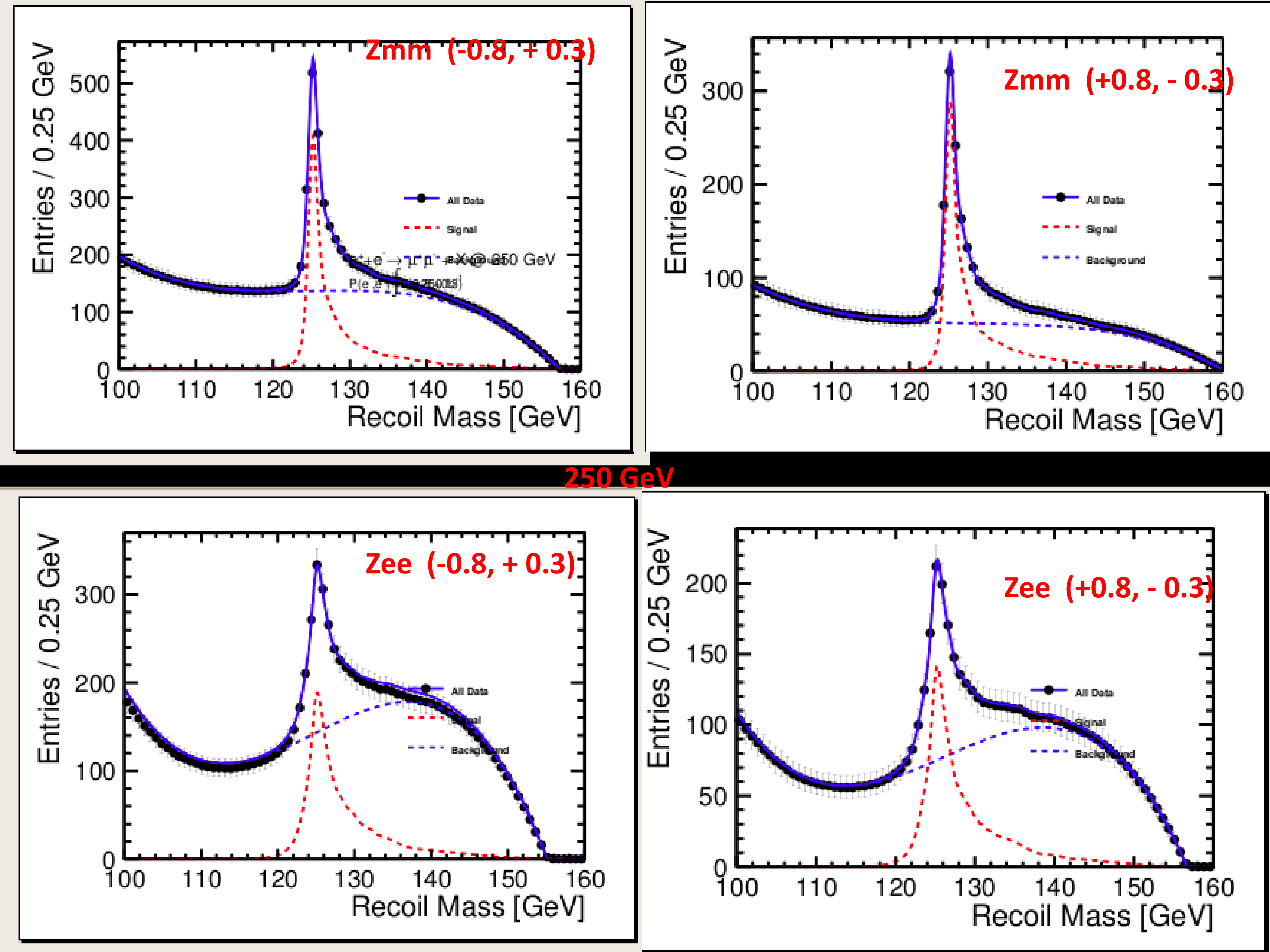


for events that survive up to Ptsum cut

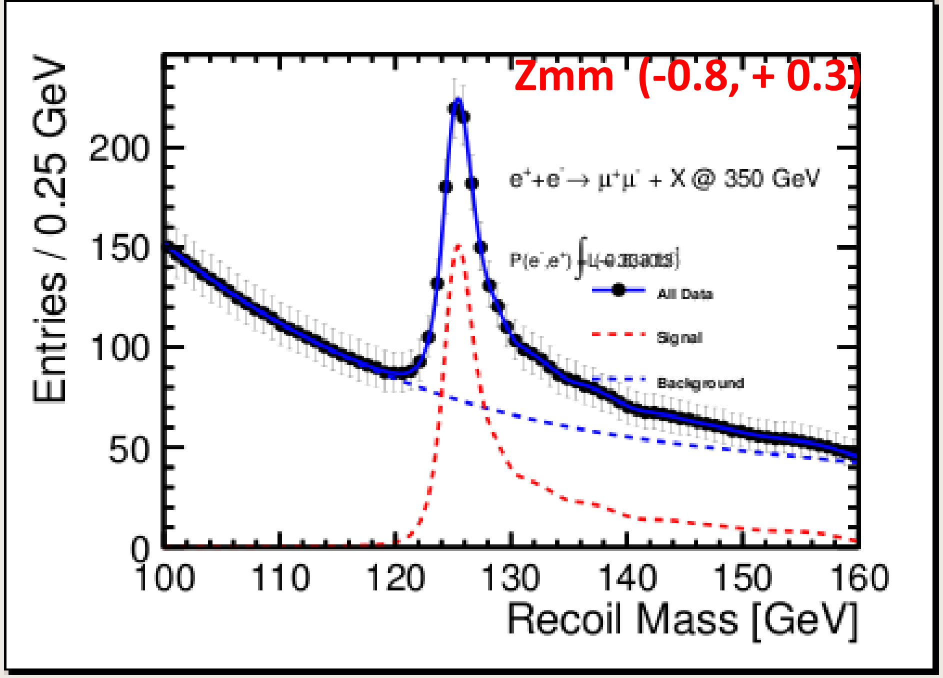


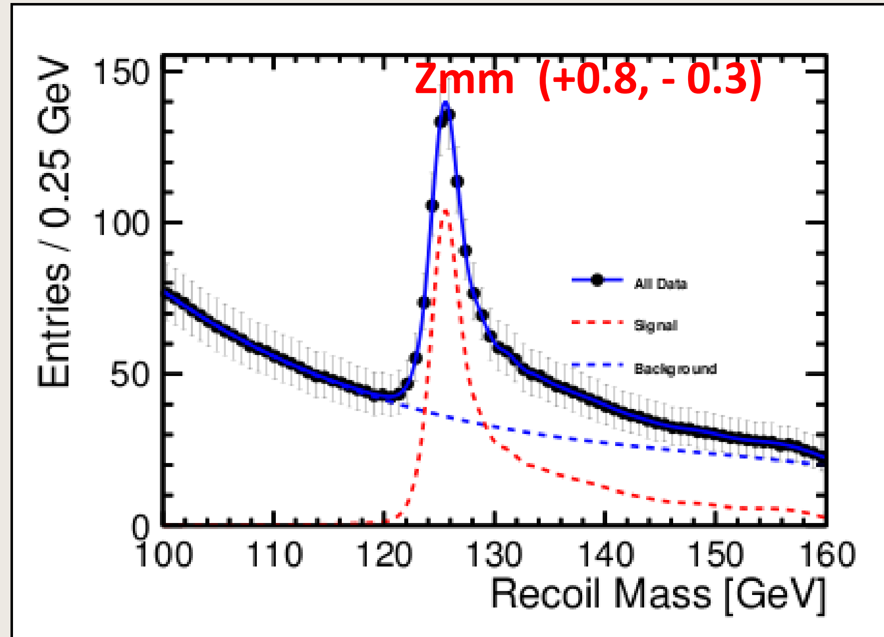




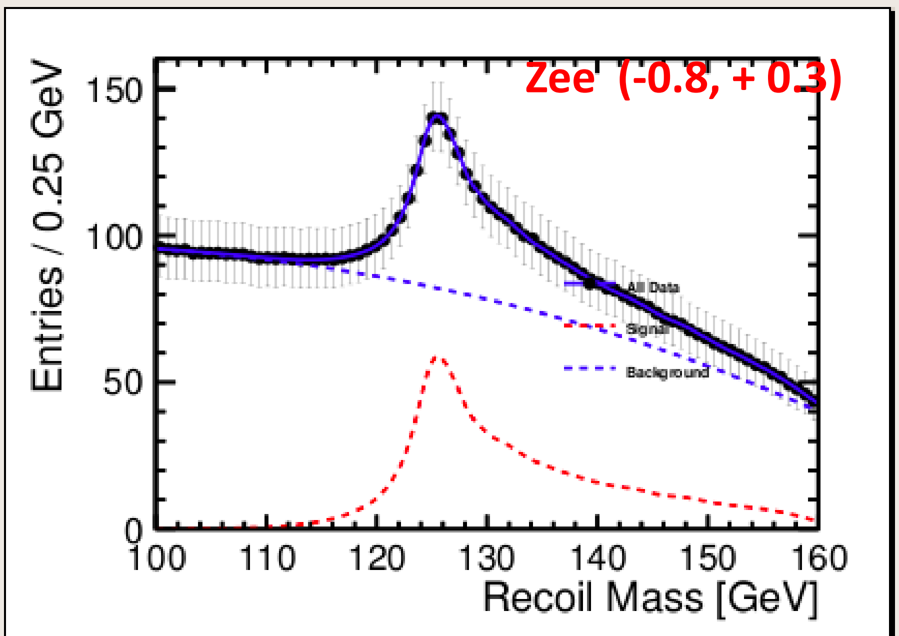


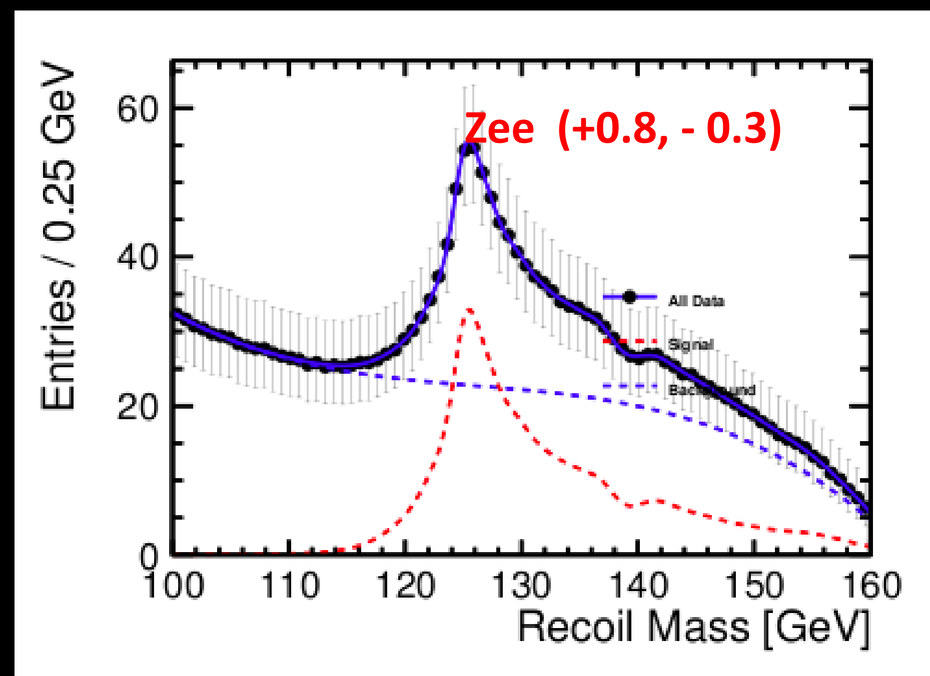
Zmm (-0.8, + 0.3)
Zmm (+0.8, - 0.3)
250 GeV
Zee (-0.8, + 0.3)
Zee (+0.8, - 0.3)
All Data
Signal
Background
Entries / 0.25 GeV
Recoil Mass [GeV]

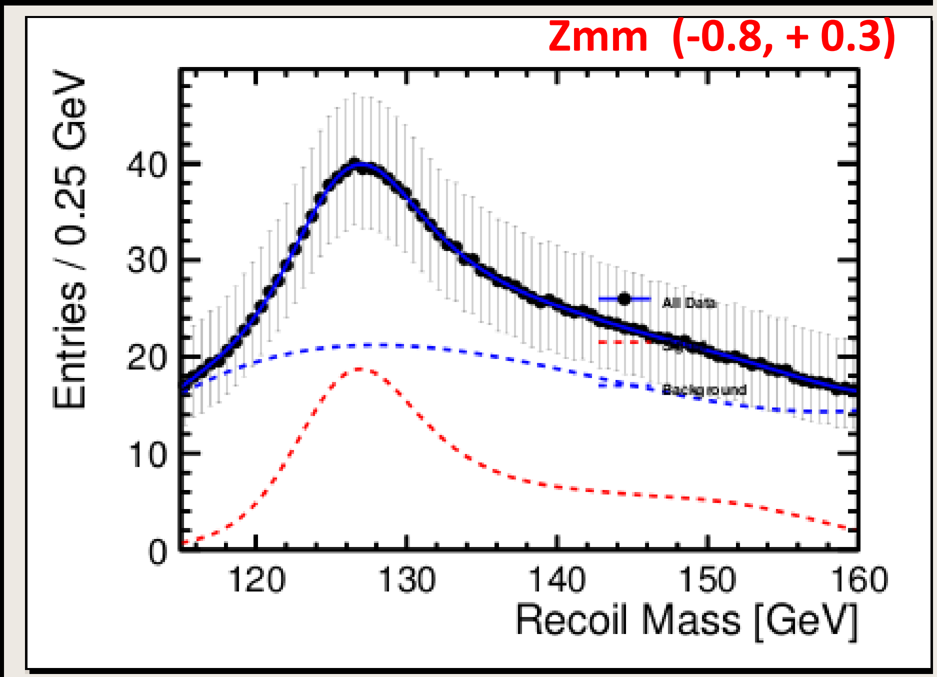

Zmm (-0.8, + 0.3)
e⁺+e⁻ → μ⁺μ⁻ + X @ 350 GeV
All Data
Signal
Background
Entries / 0.25 GeV
Recoil Mass [GeV]

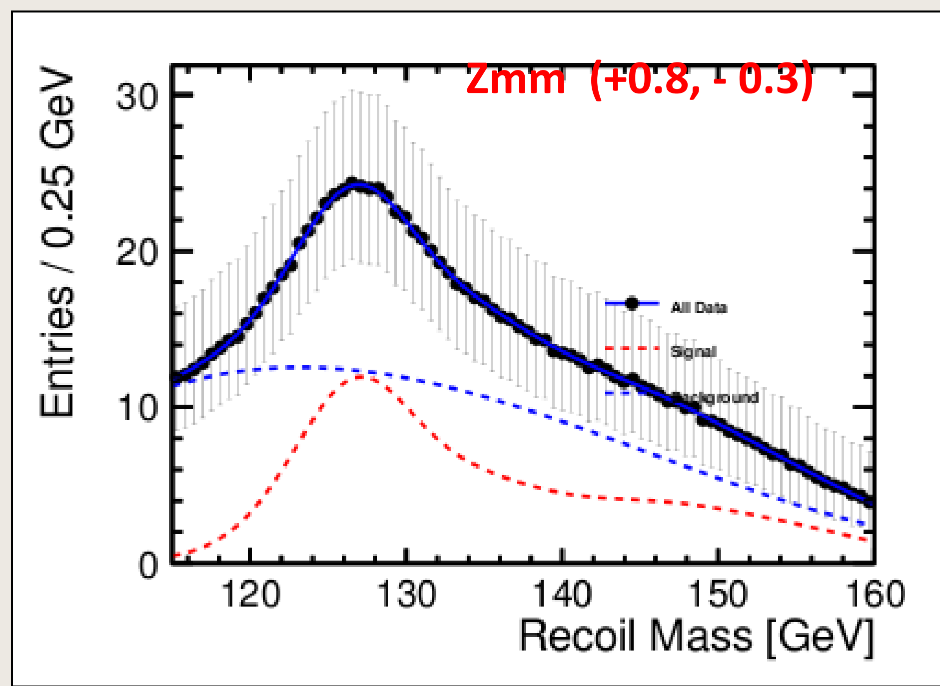

Zmm (+0.8, - 0.3)
All Data
Signal
Background
Entries / 0.25 GeV
Recoil Mass [GeV]

350 GeV

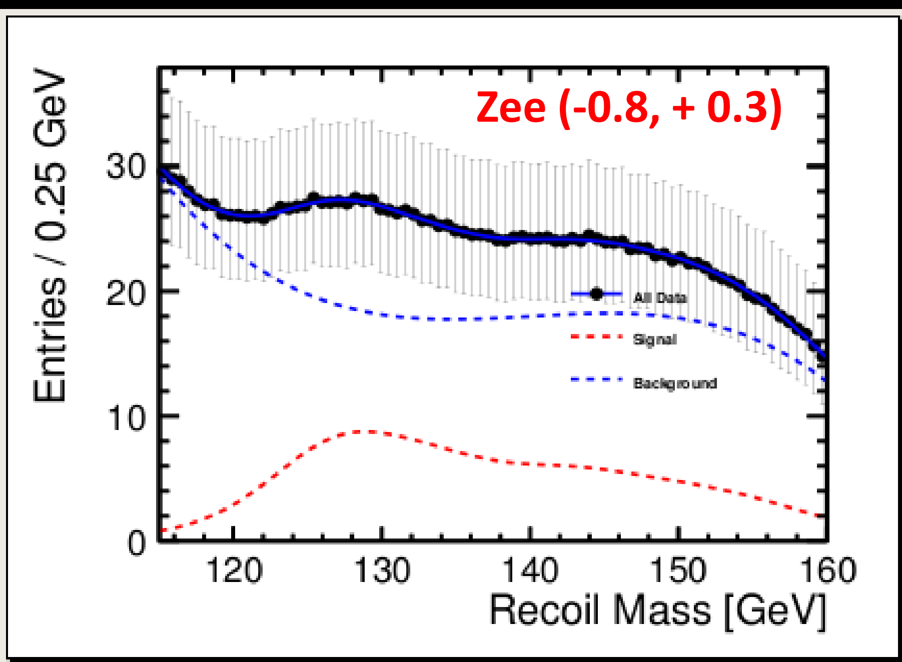

Zee (-0.8, + 0.3)
All Data
Signal
Background
Entries / 0.25 GeV
Recoil Mass [GeV]

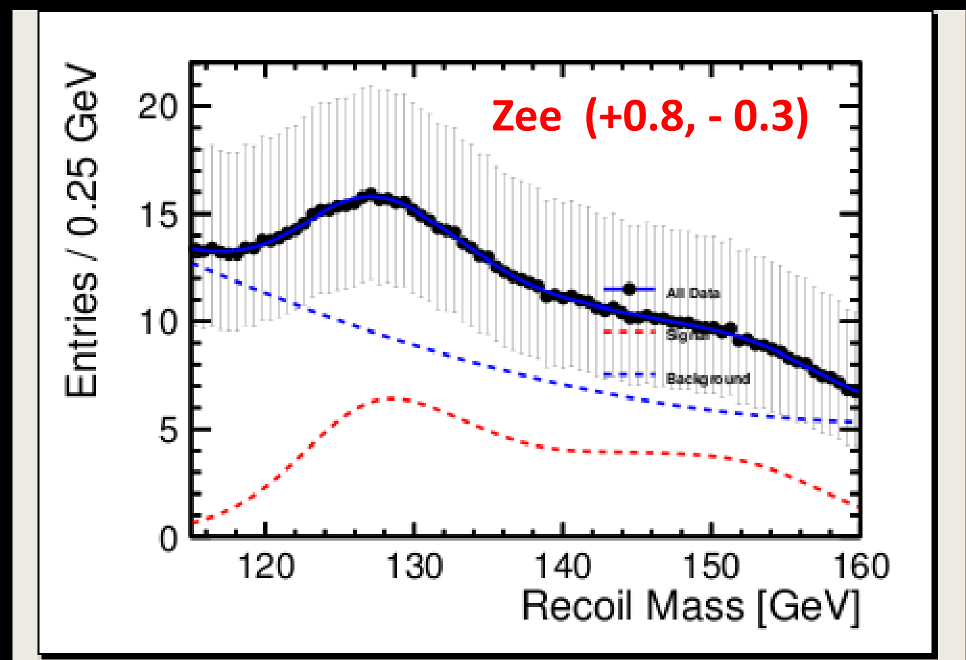

Zee (+0.8, - 0.3)
All Data
Signal
Entries / 0.25 GeV
Recoil Mass [GeV]


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


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

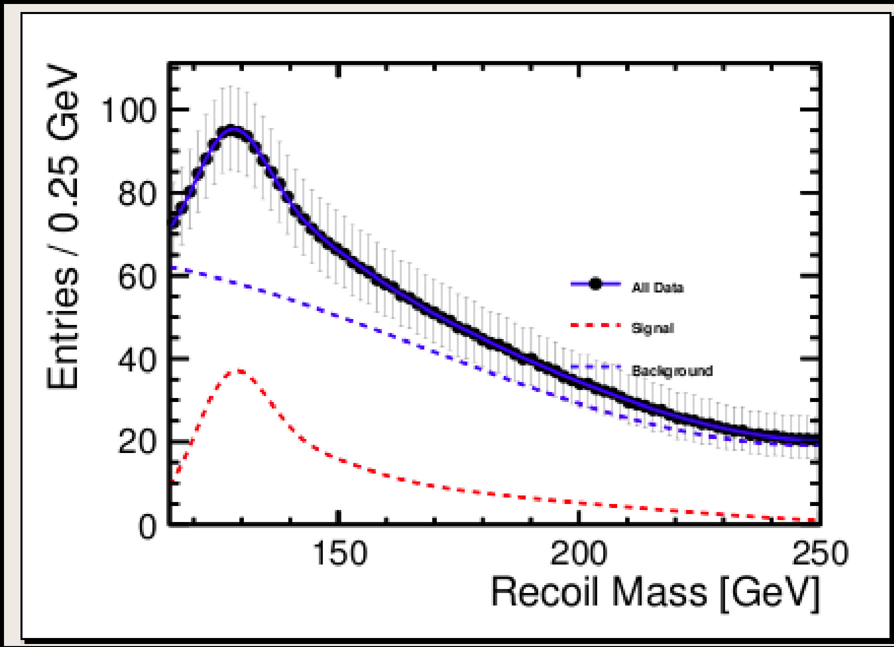
500 GeV

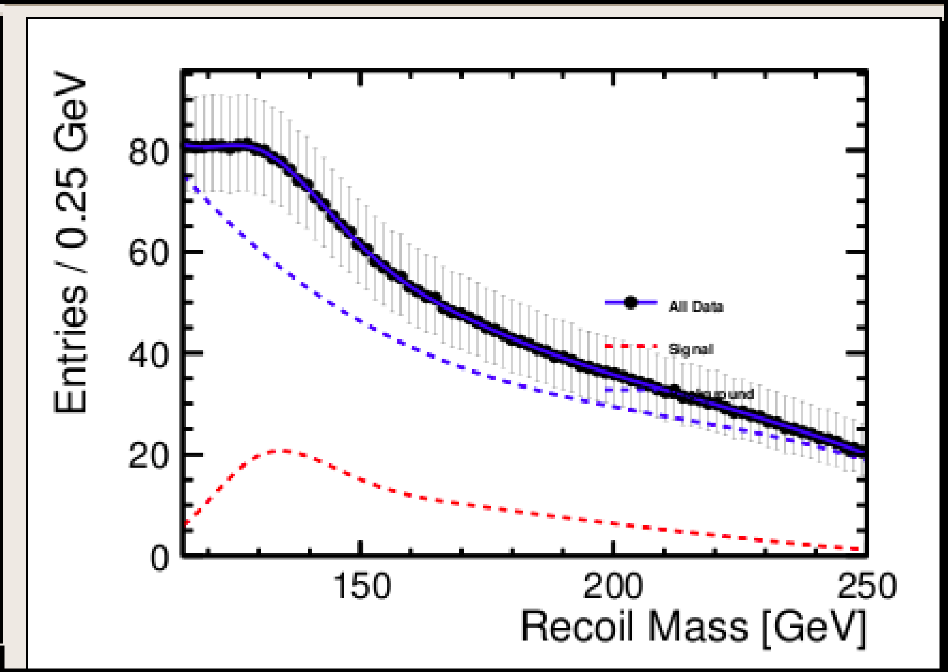

Zee (-0.8, + 0.3)
Entries / 0.25 GeV
0
10
20
30
120
130
140
150
160
Recoil Mass [GeV]
All Data
Signal
Background


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

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

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





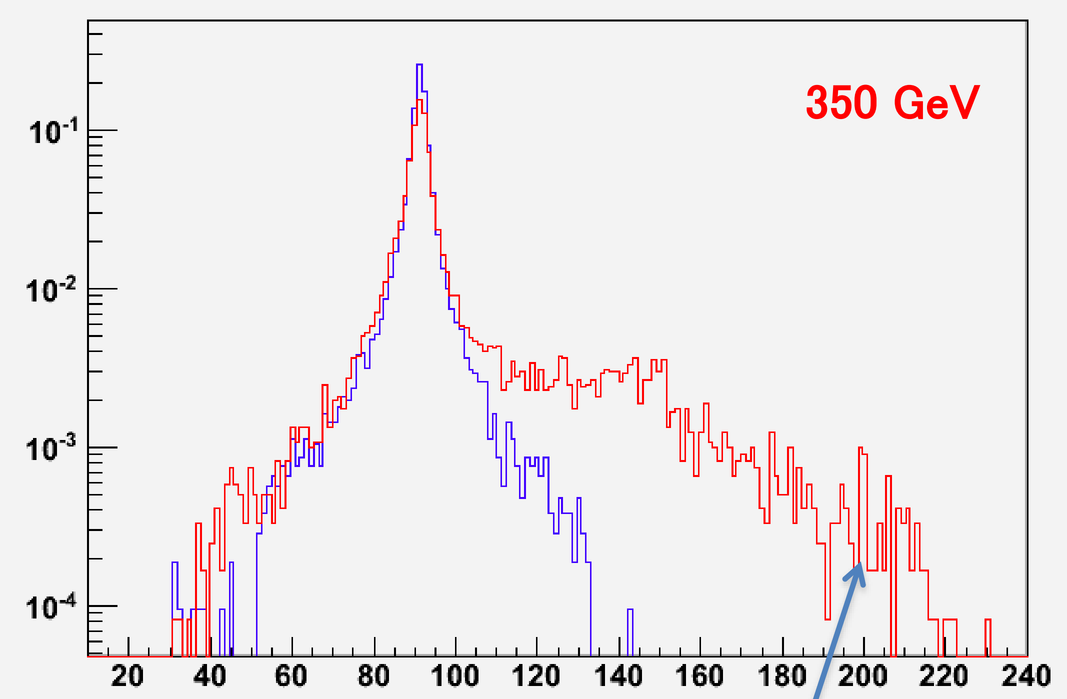
Zmm
7.0% → 6.6%

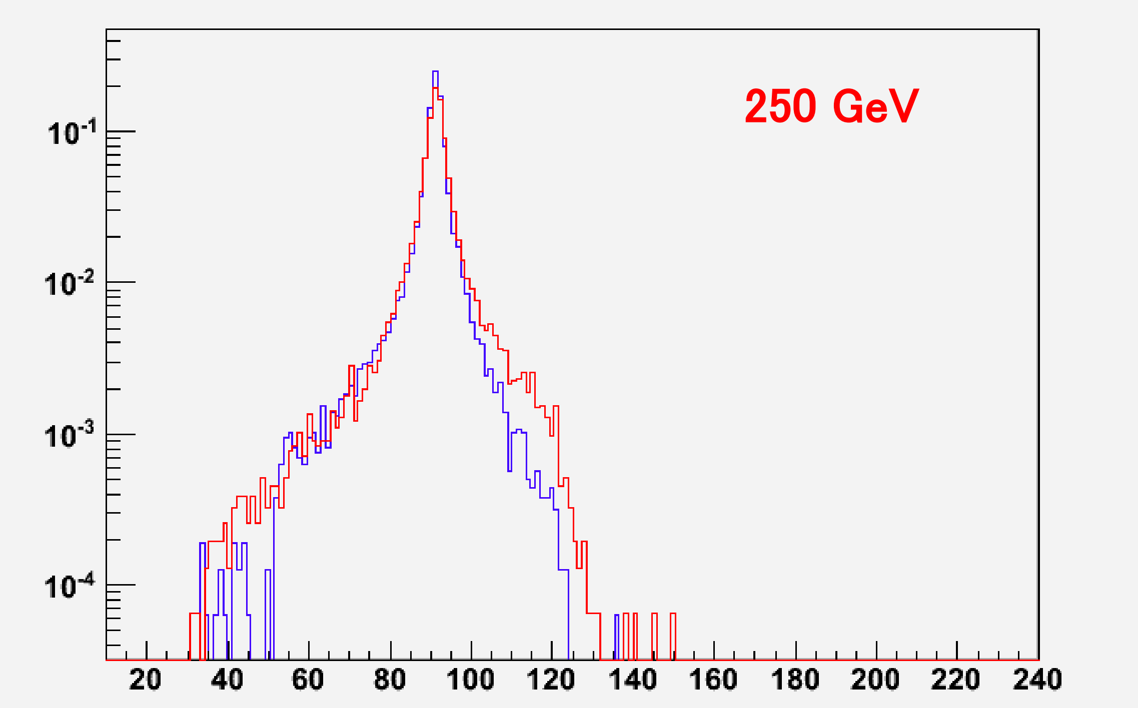
Zee
9.8 % → 8.0%

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)

Compare of results between alternative ECM and polarizations

Ecm=250 GeV		Ecm=350 GeV		Ecm=500 GeV	
(−0.8,+0.3)	3.5%	(−0.8,+0.3)	4.1%	(−0.8,+0.3)	6.1%
(+0.8,−0.3)	3.6%	(+0.8,−0.3)	4.5%	(+0.8,−0.3)	7.2%

Current (April, 2015)

xsec precision is improved by 17%

from AWLC 2014 (@Fermilab)

for ECM=350 GeV Pol (−0.8, + 0.3)

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

  higher statistics, better momentum resolution → sharper recoil mass peak

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

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