Higgs Recoil Mass Study

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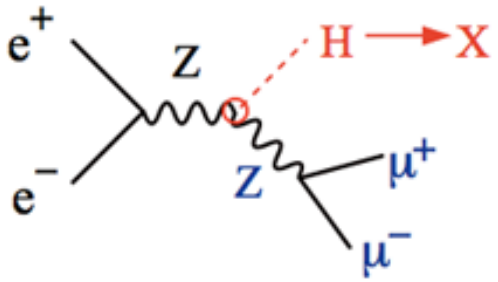
recoil mass study using e+e- → Zh → μ+μ-h
@ Ec.m.s. = 250 GeV, L = 250 fb-1

polarization:
(e−, e+) = (0.8, 0.3)

Goal:

precise measurement of

- **Higgs mass**
- **cross section** σ_H : $N = \sigma * L * \varepsilon$



Dimuon recoil mass → peak @ mh ～125 GeV

measure Higgs without having to look directly at Higgs !!

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

e+e- → Zh → μ+μ-h process is important for
model independent measurement of absolute Zh coupling :

$250\,\mathrm{fb}^{-1}@250\,\mathrm{GeV}$ $m_H = 125\,\mathrm{GeV}$

$$\Delta\sigma_H/\sigma_H = 2.6\%$$
$$\Delta m_H = 30\,\mathrm{MeV}$$
$$BR(\mathrm{invisible}) < 1\%\,@\,95\%\,\mathrm{C.L.}$$

ghZZ ^2 ∝ Γ(h → ZZ*) / Γtot

also useful for other couplings and branching ratios

from K. Fujii @ Higgs and Beyond, Sendai, June 2013

Changes from previous week

- corrected some bugs in analysis e.g. when selecting best muon pairs

- do track selection at beginning and change method
  before : dP/P^2 ←→ now: cos(trackAngle) ***details later***

- further optimization of BG rejection → improve signal efficiency

this time, efficiency table is made in narrow signal range using weighted events

Samples

for now, only used eLpR and eRpL

/grid/ilc/prod/ilc/mc-dbd/ild/dst-merged/250-TDR_ws/

Assign weight based on cross section, luminosity, polarization

event weight = pol_weight * (process_cross_section * assumed_integrated_luminosity)

/ (number_of_reconstructed_events)

Signal sample:

higgs_ffh/ILD_o1_v05/v01-16-p10_250

rv01-16-p10_250.sv01-14-01-p00.mILD_o1_v05.E250-TDR_ws.I106479.Pe2e2h.eL.pR-00001-DST.slcio

rv01-16-p10_250.sv01-14-01-p00.mILD_o1_v05.E250-TDR_ws.I106480.Pe2e2h.eR.pL-00001-DST.slcio

List of BG process for Zmumu

- 4f_ZZ_leptonic
- 4f_ZZ_semileptonic
- 2f_Z_leptonic
- 4f_WW_leptonic
- 4fSingleZee_leptonic
- 4fSingleZnunu_leptonic
- 4f_ZZWWMix_leptonic

dominant ones

eLpR	cross sec	weight
higgs	**17.14**	0.146
BG in order of large cross section		
2f_Z_l	**21226.4**	1.46
4f_ZZWWMix_l	**1636.04**	0.583
4f_WW_l	**1564.21**	0.573
4f_ZZ_sl	**1422.14**	0.583
4f_singleZee_l	**1084.1**	0.581
4f_singleZnn_l	**192.75**	0.47
4f_ZZ_l	**157.96**	0.578

Muon Selection

- reject neutrals
- Ptot > 5 GeV
- small E_cluster / P_total < 0.5
- opposite charge
- ■ Best track selection

  cos(track angle) < 0.95

  |D0/δD0| < 4

fixed & changed

Best Z Candidate Selection

2 mu candidates with **opposite charge**

if several possibilities :

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

Final Selection

analysis after filling root files

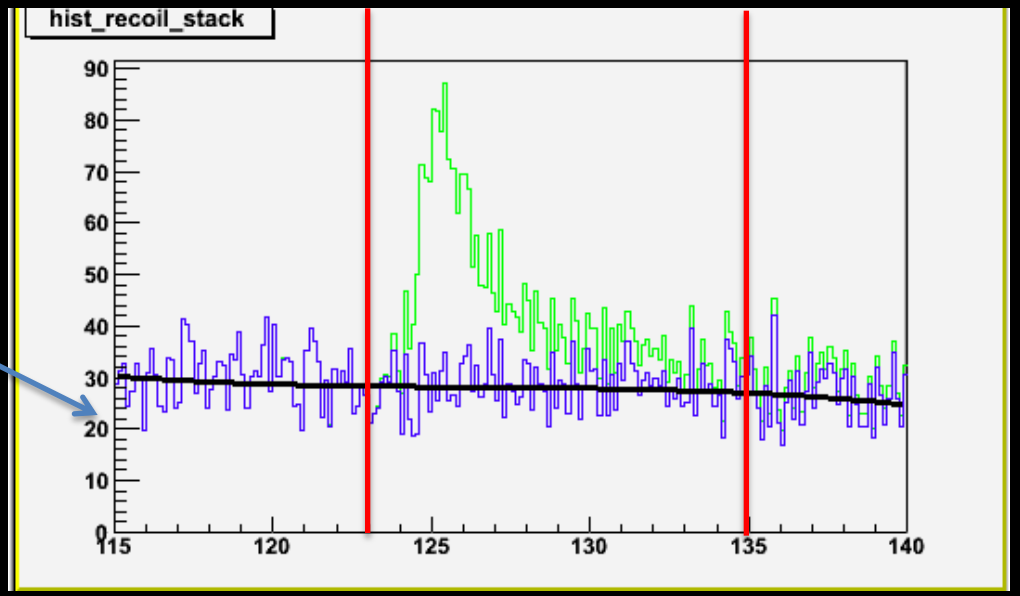
- **86 GeV < M_mumu < 95 GeV**
- **123 GeV < Mrecoil < 135 GeV**
- **10 GeV < pT_mumu < 70 GeV**
- **0.2 < mumu_acoplanarity < 3**
- **|cos(θ_Zpro)| < 0.91**

  (Z production angle)

changed

Evaluate data selection efficiency in within range of 123 – 135 GeV

calculate recoil mass with correction for 14 mrad beam crossing angle

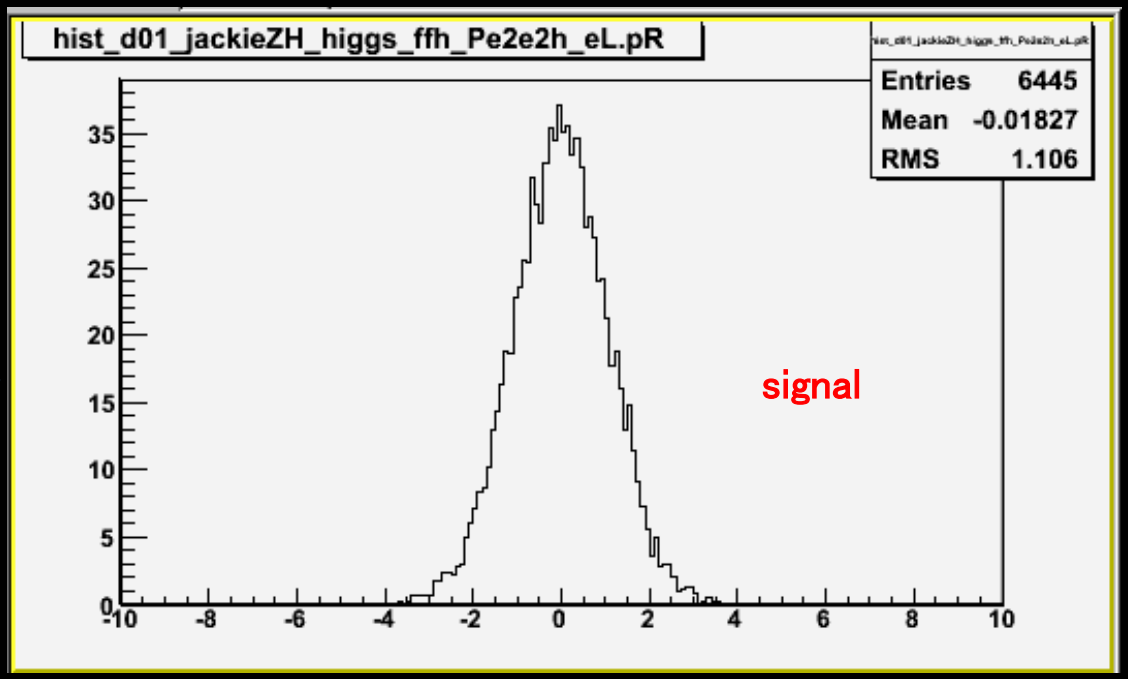


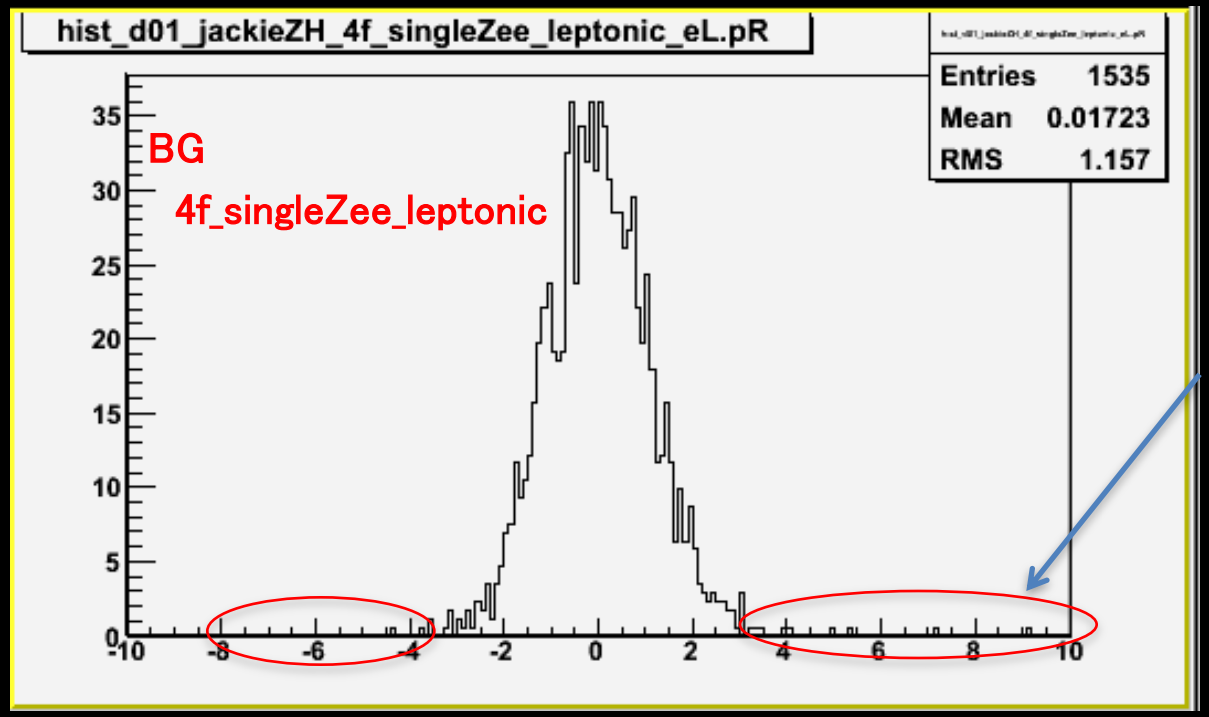
Comparison of Some Parameters between Signal and BG Processes

Impact parameter

D0/ δ D0

this cut will be more effective after stau-tau samples are included



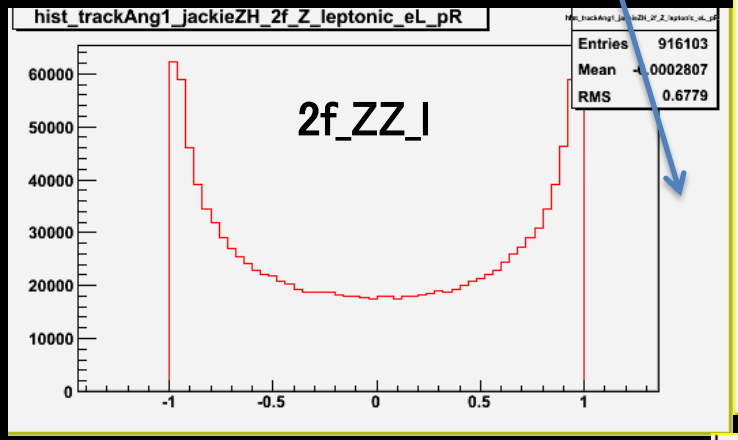


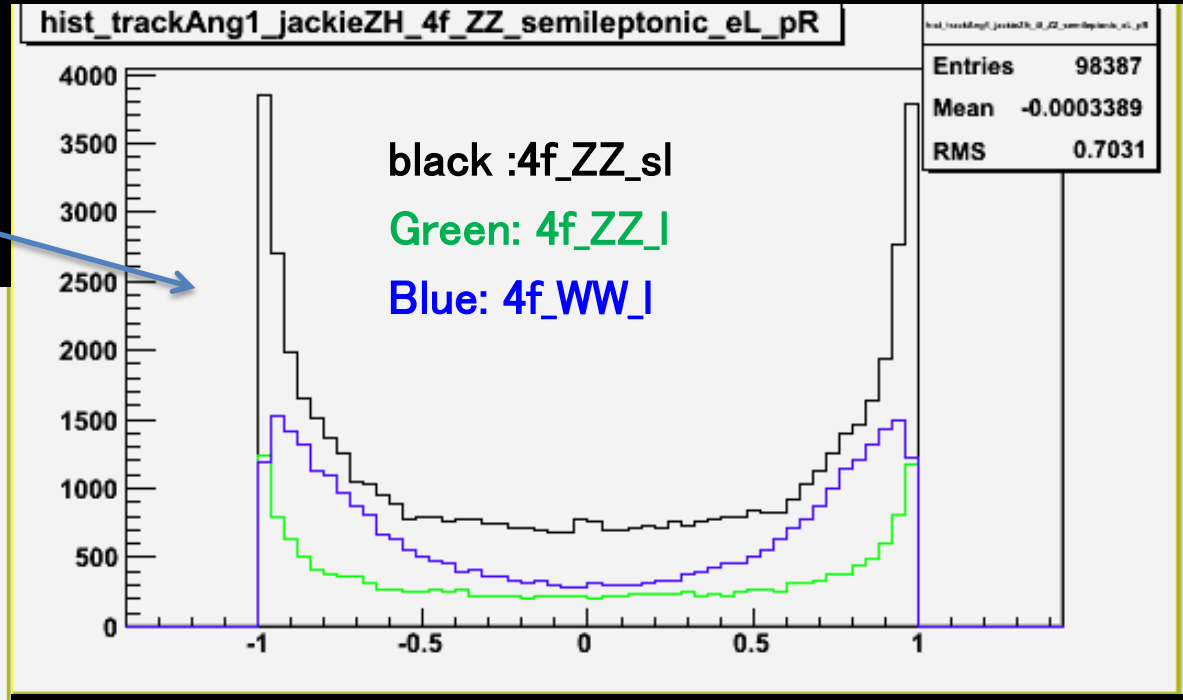
For some BG processes exceed +/− 4 slightly

do cut : $|D0/\delta D0| < 4$

Cos(track angle)

BG is More forward

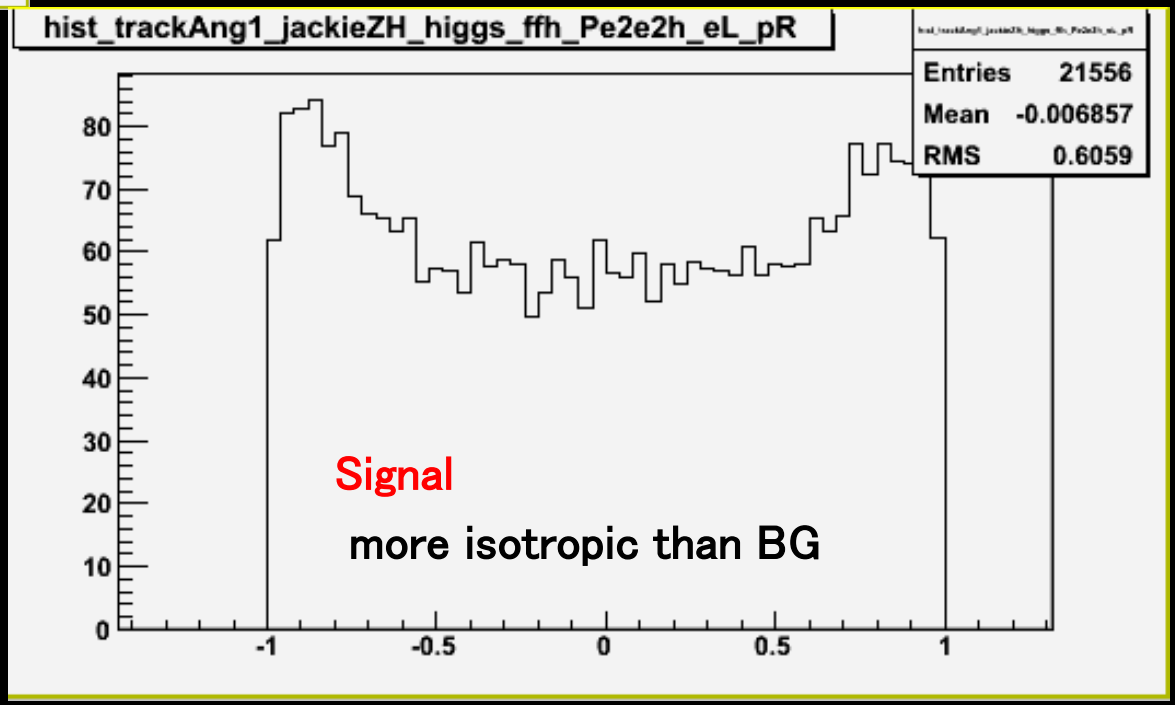




more straight-forward to use cos(trackAngle) than dP/P^2 for track quality selection

do cut :

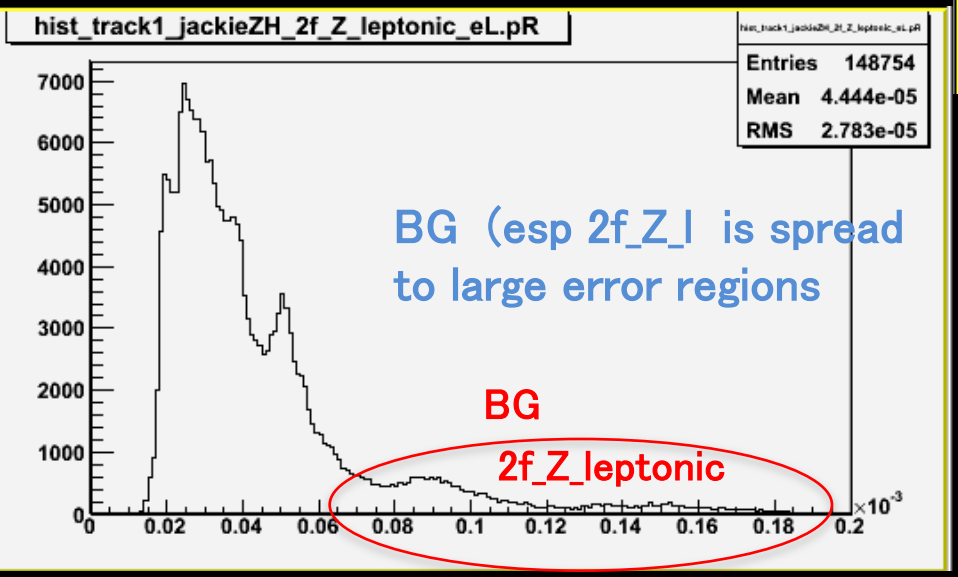
cos(trackAngle) < 0.95

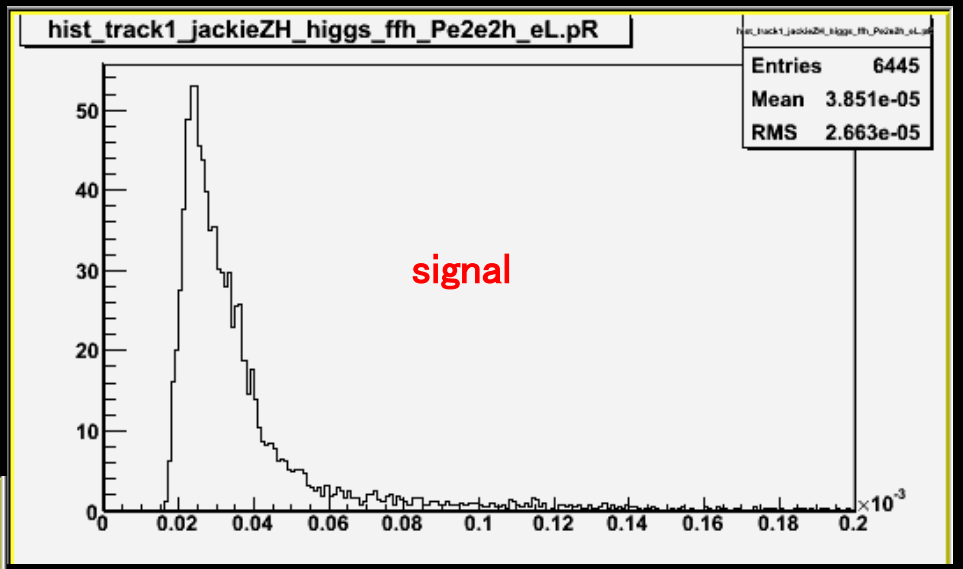


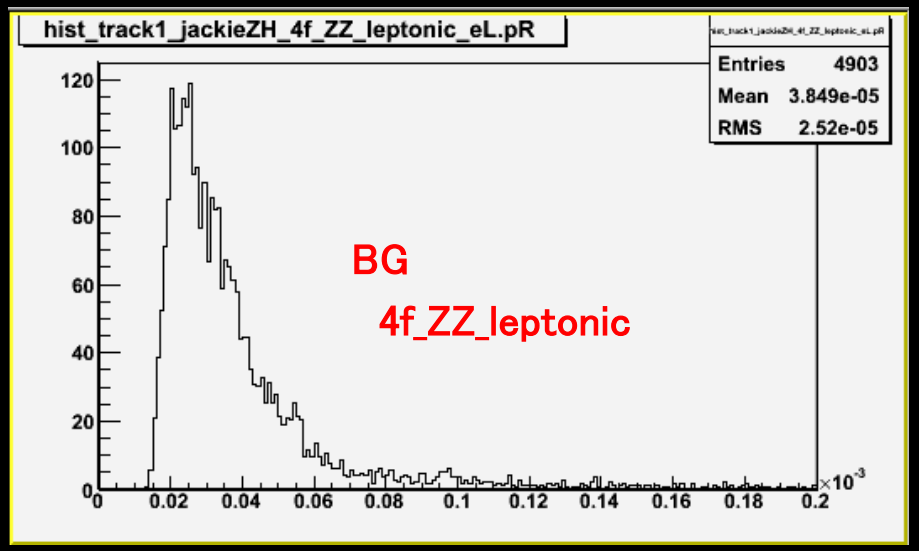
good track selection

dP/P^2

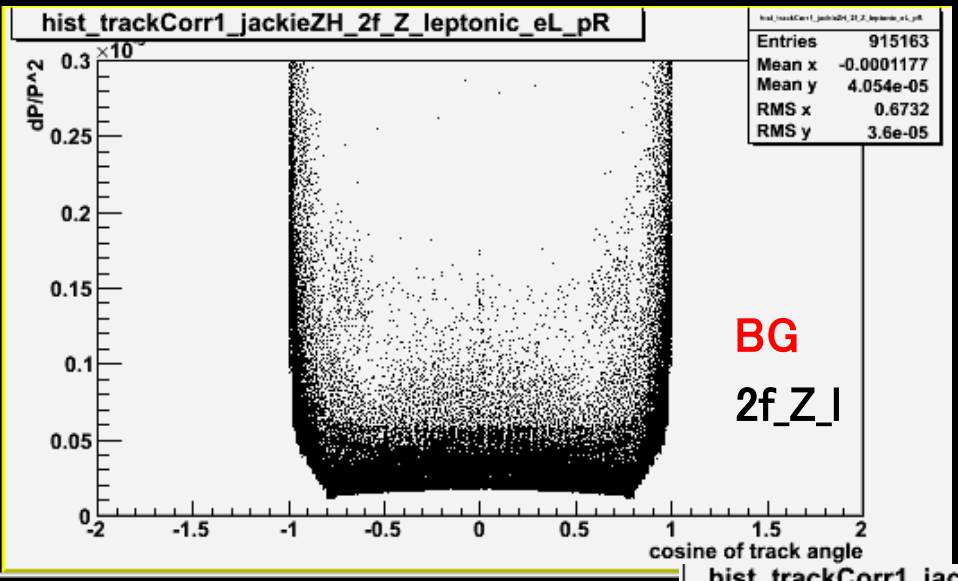
Used to do cut : $dp/p^2 < 5E-5$

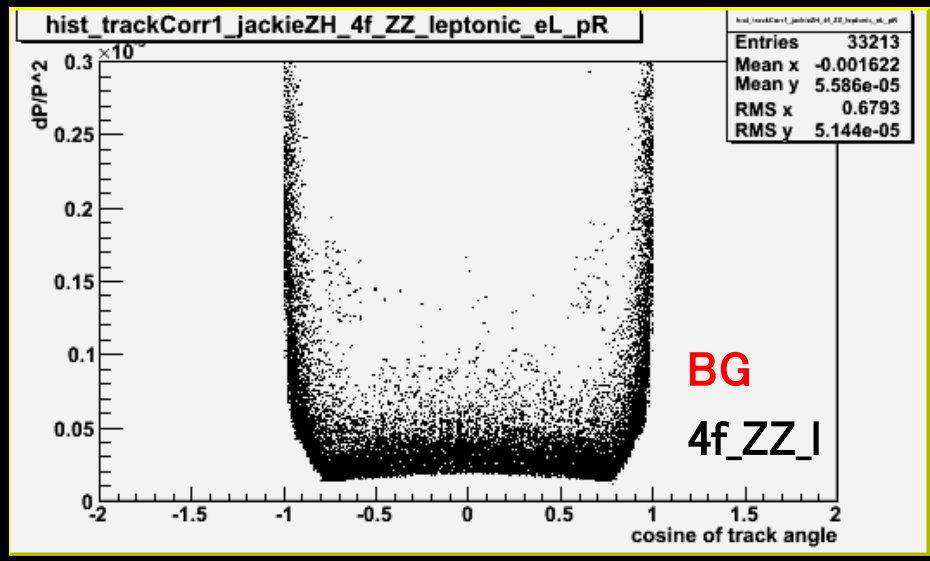


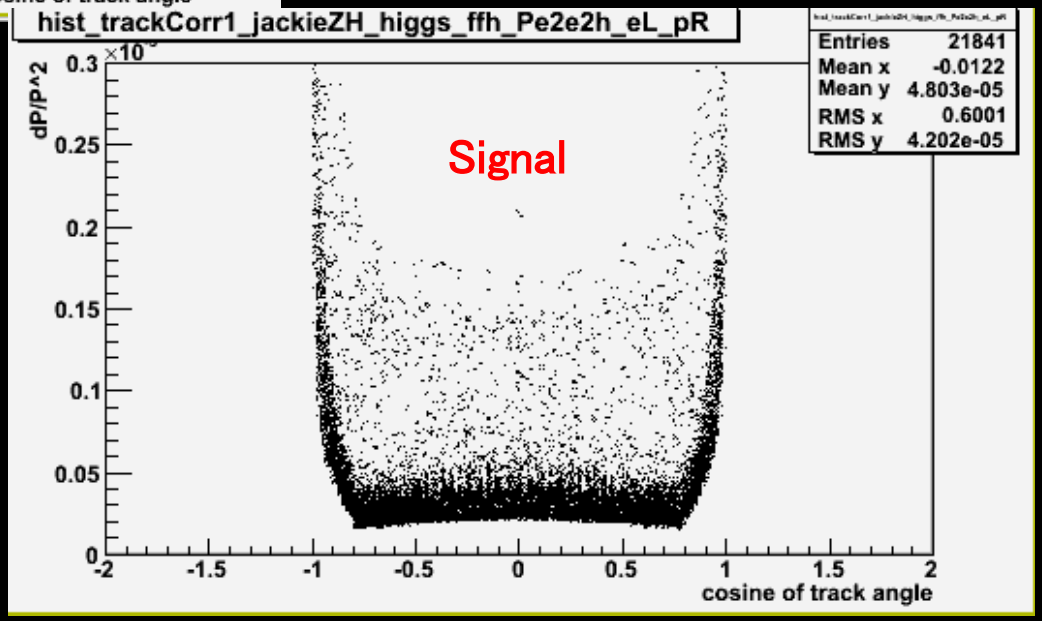




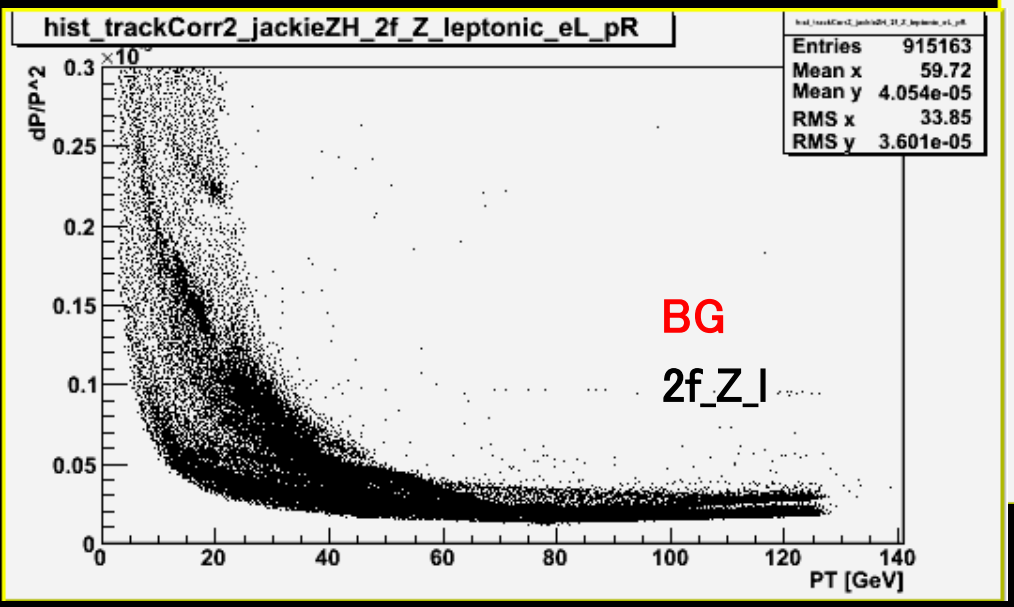
correlation between Cos(track angle) and dP/P^2

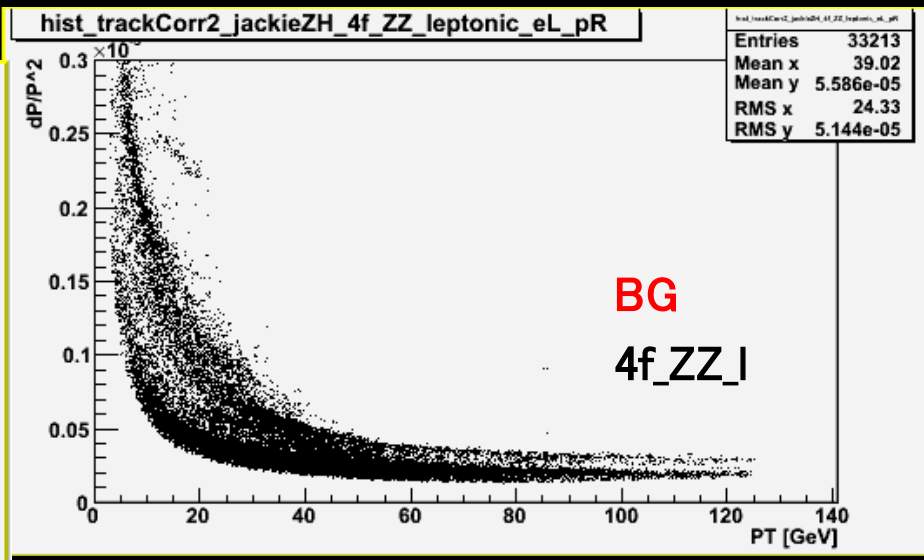


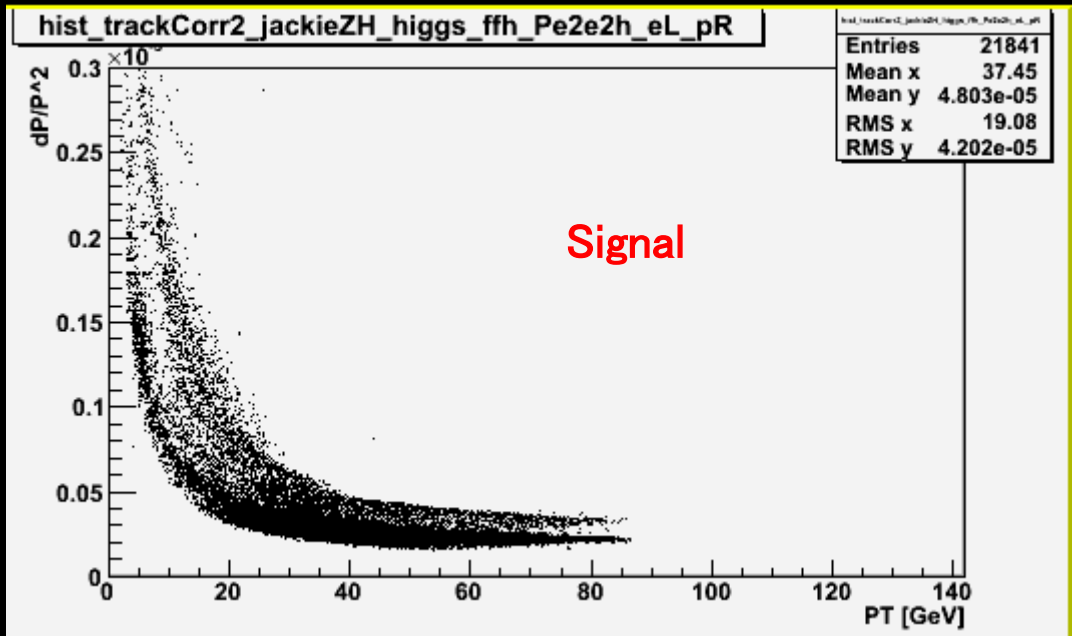




correlation between PT and dP/P^2

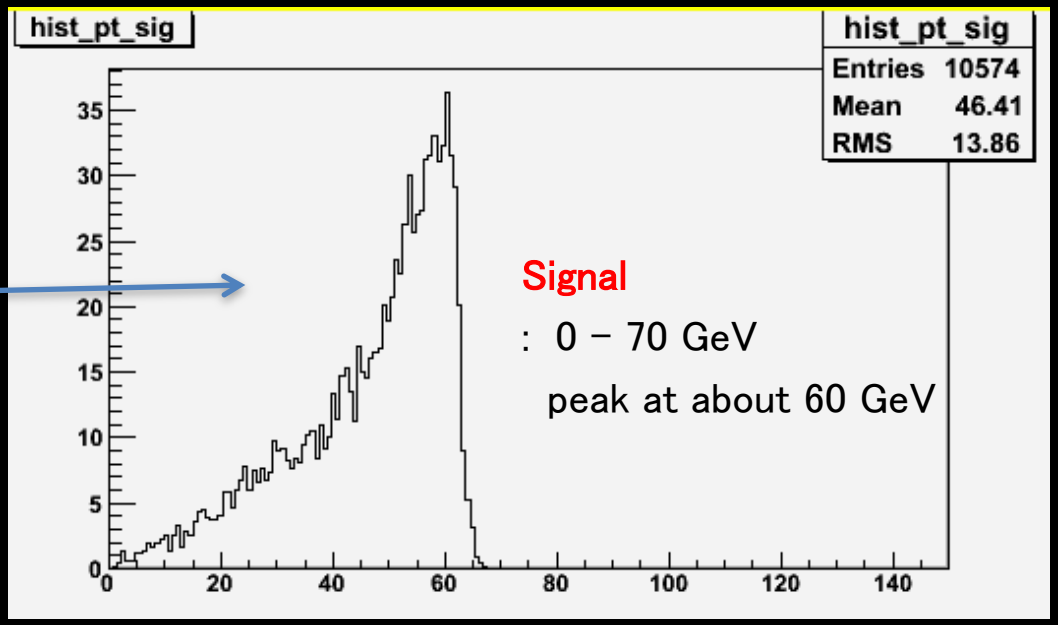




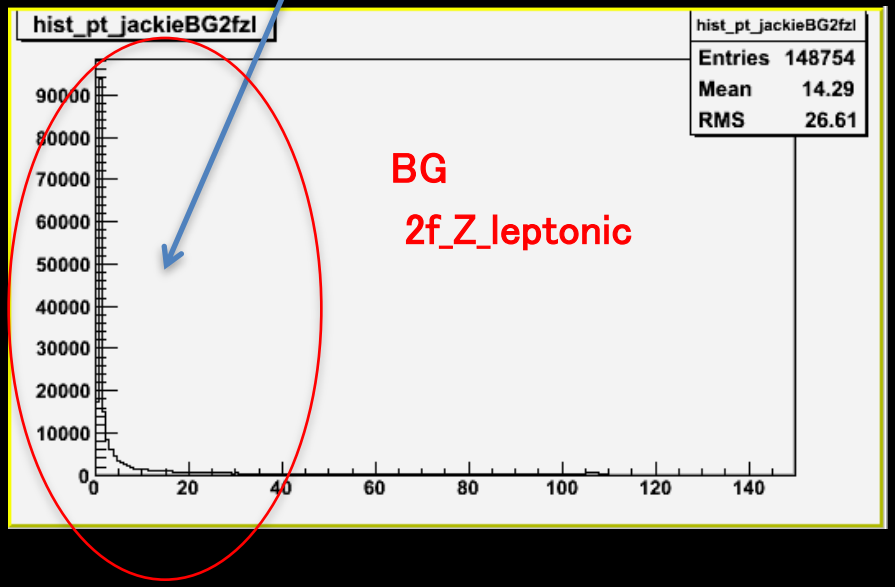


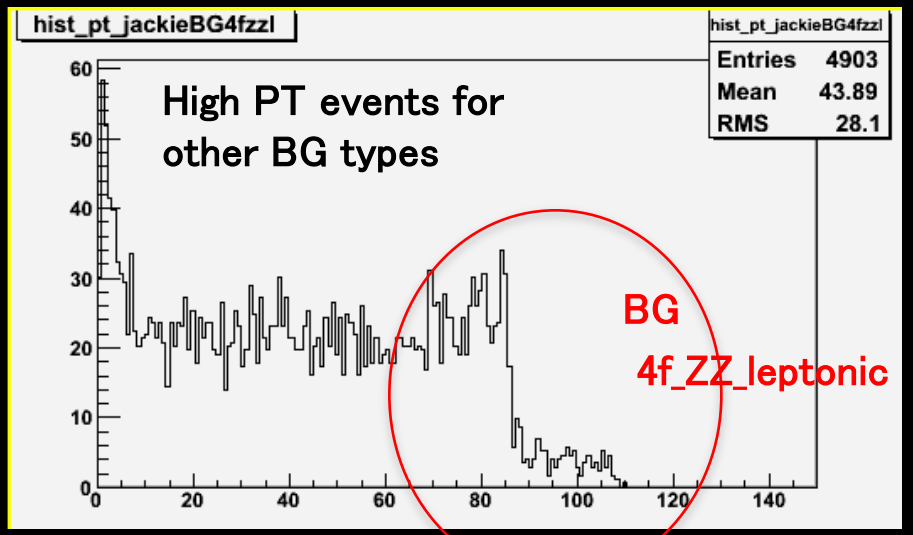
PT of dilepton system

do cut : 10 GeV< pT_dl < 70 GeV



BG
dominated by 2f_Z_leptonic,
many low PT events

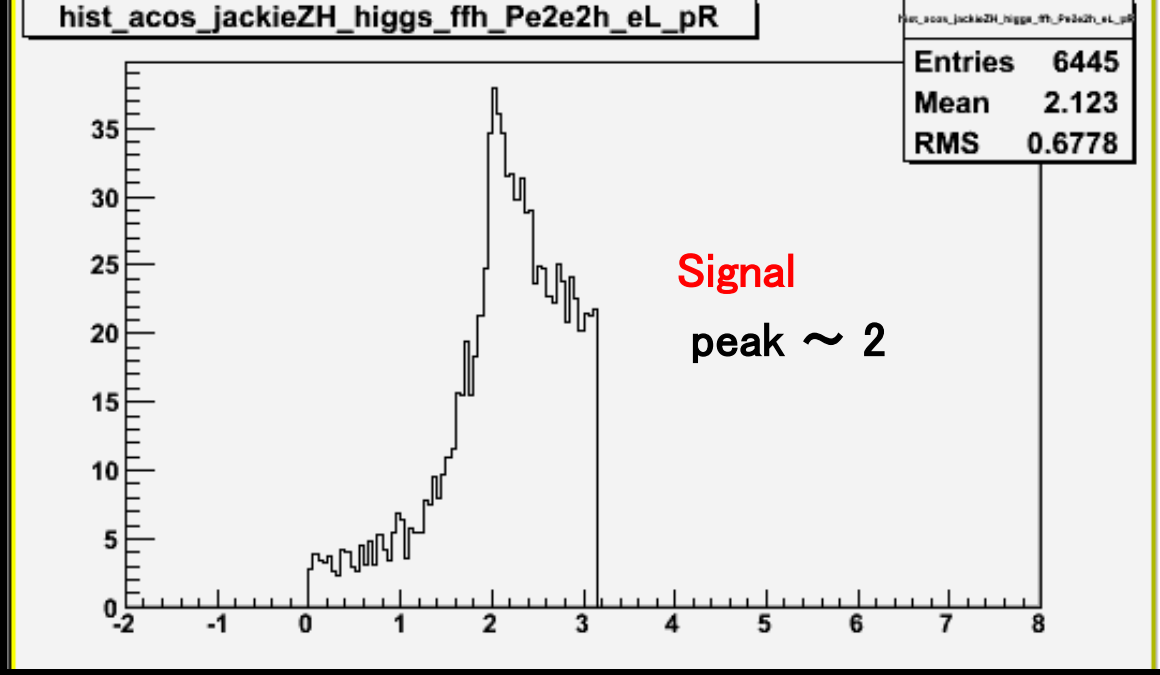


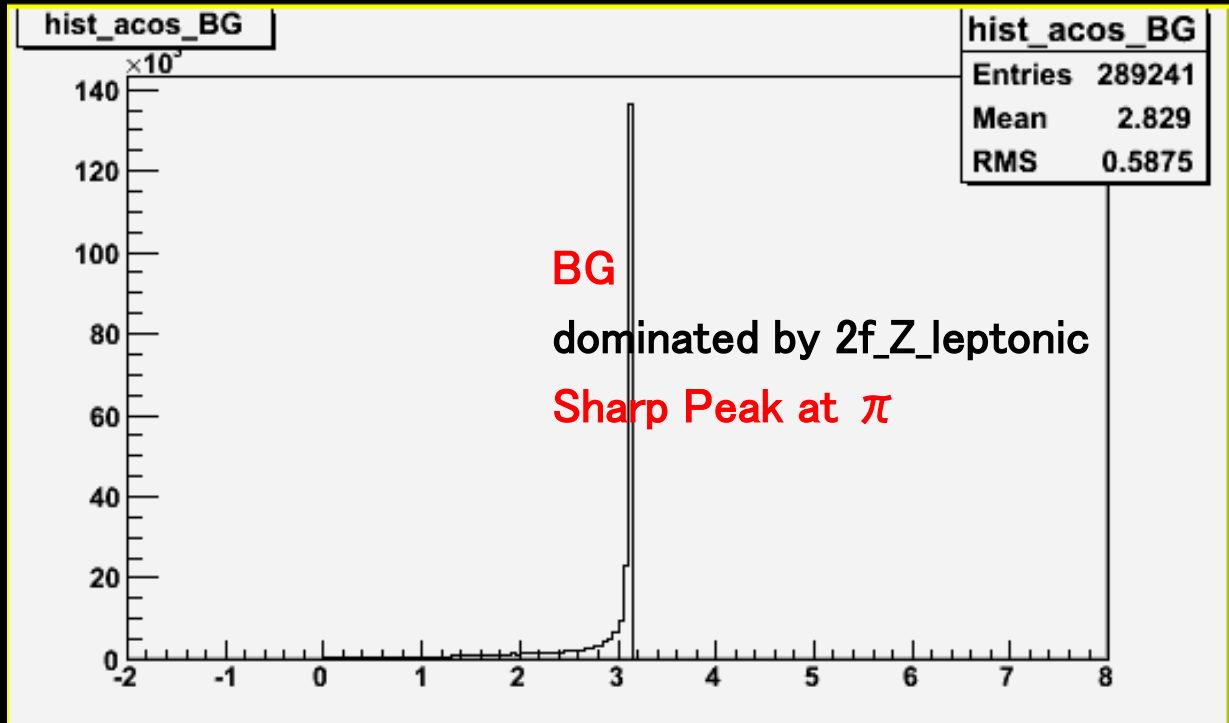


acoplanarity

do cut : 0.2 < acop < 3

```
fabs (atan2(py1,px1) - atan2(py2,px2))
if (acos>pi) {acos = 2*pi - acos;}
```





Z production angle

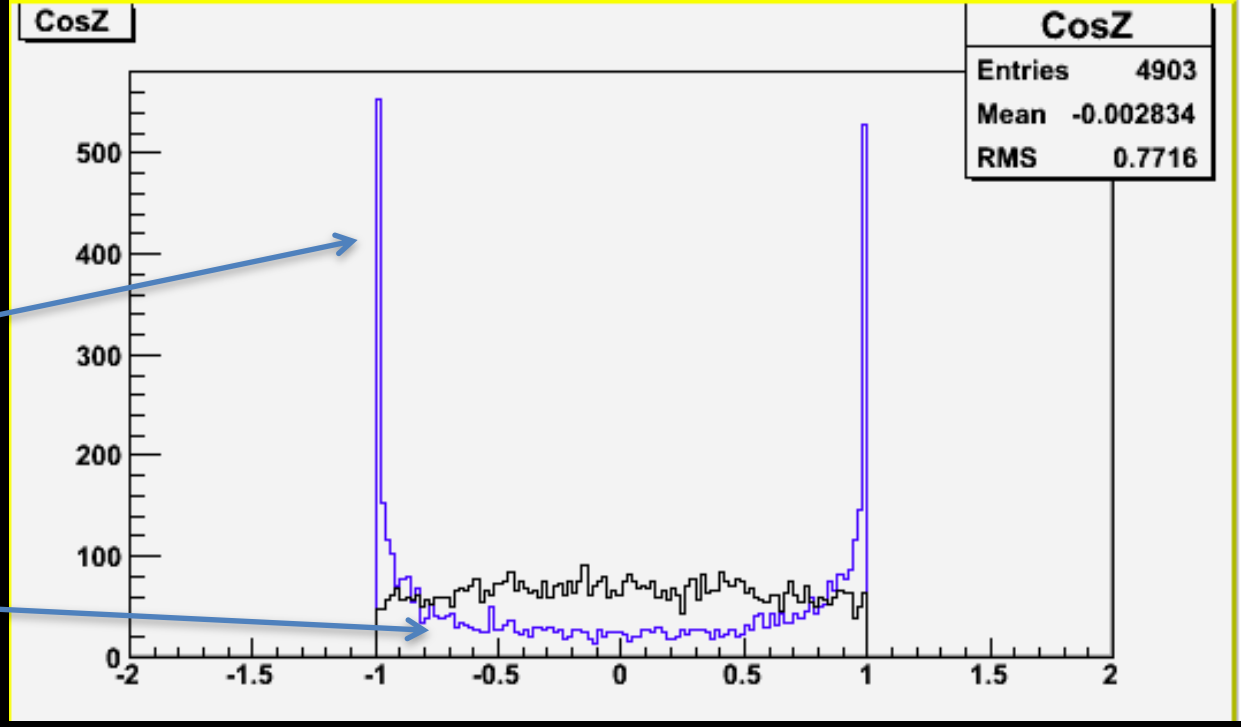
blue: BG (4f_ZZ_l

very forward

→ use for cut

Black: Signal

isotropic



do cut : $|\cos(\theta\_Zpro)| < 0.91$

BG Rejection Efficiency : 123 – 135 GeV

if wider M_inv cut (80-100 GeV) S/N = 0.37
not as good
if no initial track selection: S/N = 0.22

cut	signal	eff	BG_all	eff	S/N	S/sqrt(S+N)
no cut	2160	100%	50461	100%	0.043	9.416
best mu	1938	90%	34109	67.59%	0.057	10.207
M_inv	1600	74%	13283	26.32%	0.120	13.115
M_rec	1482	69%	8097	16.05%	0.183	15.142
P_Tdl	1463	68%	4032	7.99%	0.363	19.736
acop	1366	63%	3546	7.03%	0.385	19.490
θZ	1296	60%	2788	5.53%	0.465	20.280

Signal efficiency 60%

BG reduced to 6 %

S/N improved to 0.47

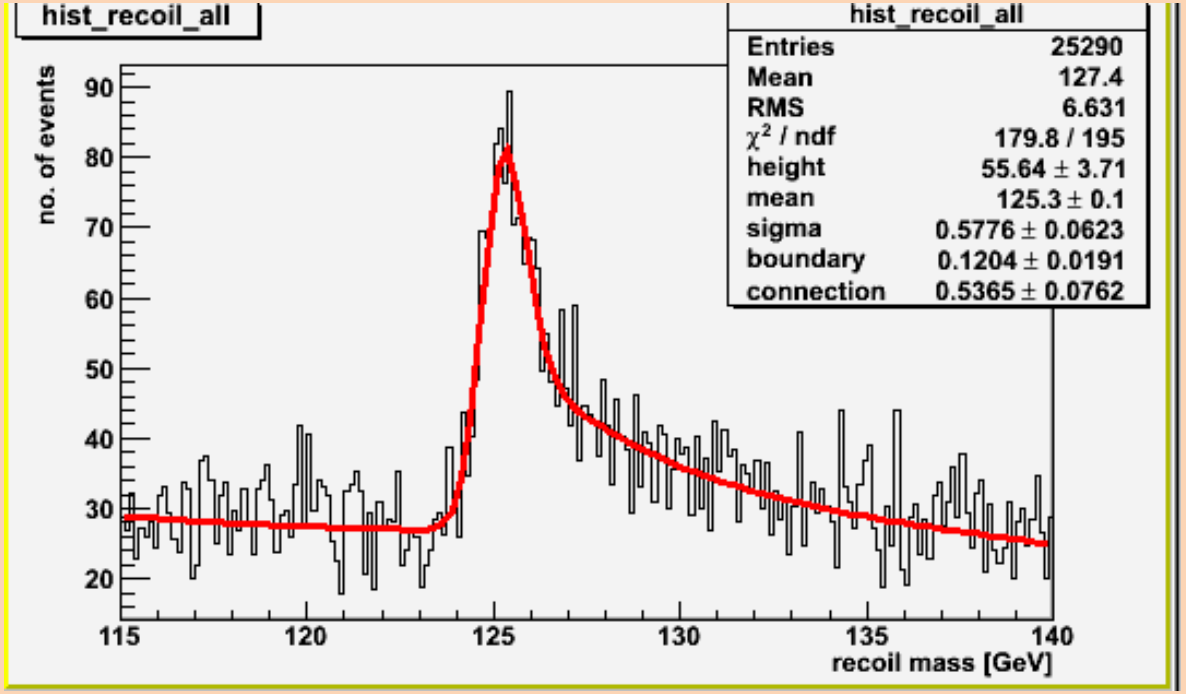
after M_rec cut .....

PT_dl and cosθZ cut seem quite effective for improving S/N

cut	4f_ZZ_l	4f_ZZ_sl	2f_Z_l	4f_WW_l	4fSingleZee_l	4fSingleZnn_l	4f_ZZWWMix_l
no cut	989	4163	27574	5735	2295	810	8896
best mu	753	3251	19228	1543	880	668	7787
M_inv	337	1264	9865	219	151	356	1091
M_rec	204	765	6011	136	95	224	663
P_Tdl	181	742	2021	134	92	218	643
acop	156	680	1695	124	80	199	610
θZ	132	596	1164	115	69	175	537

recoil mass

after implementing all cuts



fitted **recoil mass** :

Mh = 125.3 GeV +/− 70 MeV

calculate recoil mass with correction for 14 mrad beam crossing angle

- **BG: 3rd order polynomial**
- **signal : GPET:** 5 parameters : Gaus (left−side) , Gaus + expo (right side)

$$N\exp\left[-\frac{1}{2}\left(\frac{x-x_{mean}}{s}\right)^2\right] \quad \left(\frac{x-x_{mean}}{s}\right) \le k$$

$$N\left[b\times\exp\left[-\frac{1}{2}\left(\frac{x-x_{mean}}{s}\right)^2\right]+(1-b)\exp\left[-k\left(\frac{x-x_{mean}}{s}\right)\right]\exp\left(k^2/2\right)\right] \quad \left(\frac{x-x_{mean}}{s}\right) > k$$

Summary

- **Higgs recoil mass study using e+e- → Zh → μ+μ-h** @ Ec.m.s. = 250 GeV, L = 250 fb-1
- changes made to data selection method
- updated results:
  signal efficiency ε = 60%, S/N ～ 0.47, S/sqrt(S+BG) ～20, BG effficiency → 5.5 %
- **fitted recoil mass : 125.2 GeV +/- 70 MeV** ← *will aim for better precision*

Further Plans

- **optimize data selection method** → ***want higher signal efficiency***
  study distribution of various parameters
- **include eLpL & eRpR + other BG processes** (tau related , hadronic , ect…… just to be sure)
- **estimate mass resolution using pseudo-experiments**
- **analyze scenario of unpolarized beam** ***ILC will be commissioned with unpolarized beam ??***
- **in near future, analysis at Ec.m.s. = 350 GeV**

Thank You everyone for Listening

Thank you to

Daniel-san, Fujii-san, Suehara-san, Tanabe-san, Watanuki-san, Miyamoto-san and others

for your help and advice

BACKUP

BG Rejection Efficiency : 115 – 140 GeV

cut	signal	eff	BG_all	eff	S/N	S/sqrt(S+N)
no cut	2519	100%	1155348	100%	0.003	1074.871
best mu	2263	90%	975546	84.44%	0.003	987.697
M_inv	1748	69%	286945	24.84%	0.003	535.672
M_rec	1600	64%	16635	1.44%	0.093	128.977
P_Tdl	1579	63%	8361	0.72%	0.109	91.438
acop	1475	59%	7357	0.64%	0.206	85.773
θZ	1400	56%	5768	0.50%	0.220	75.947

Signal efficiency 56 %

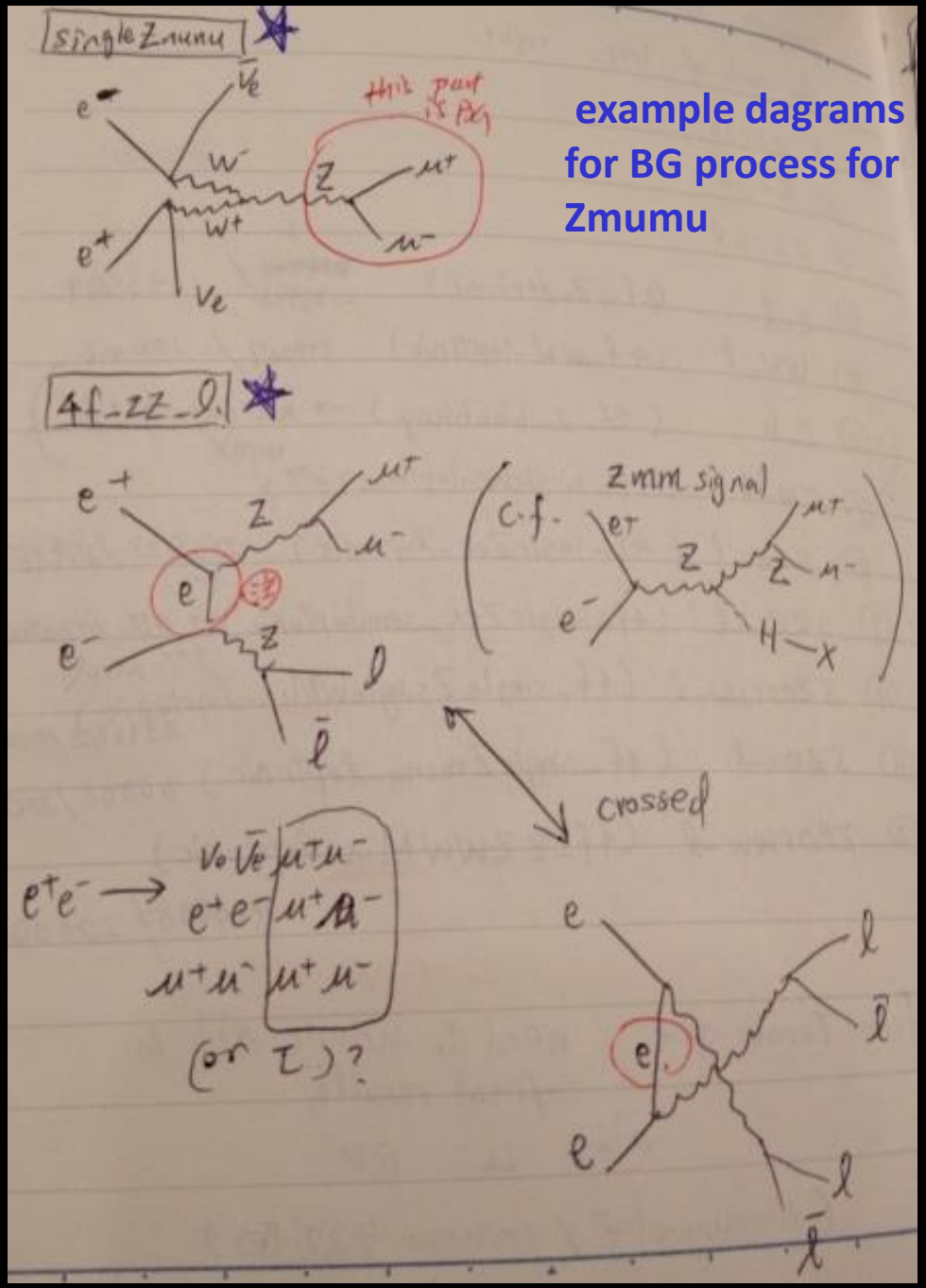
S/N ～0.22

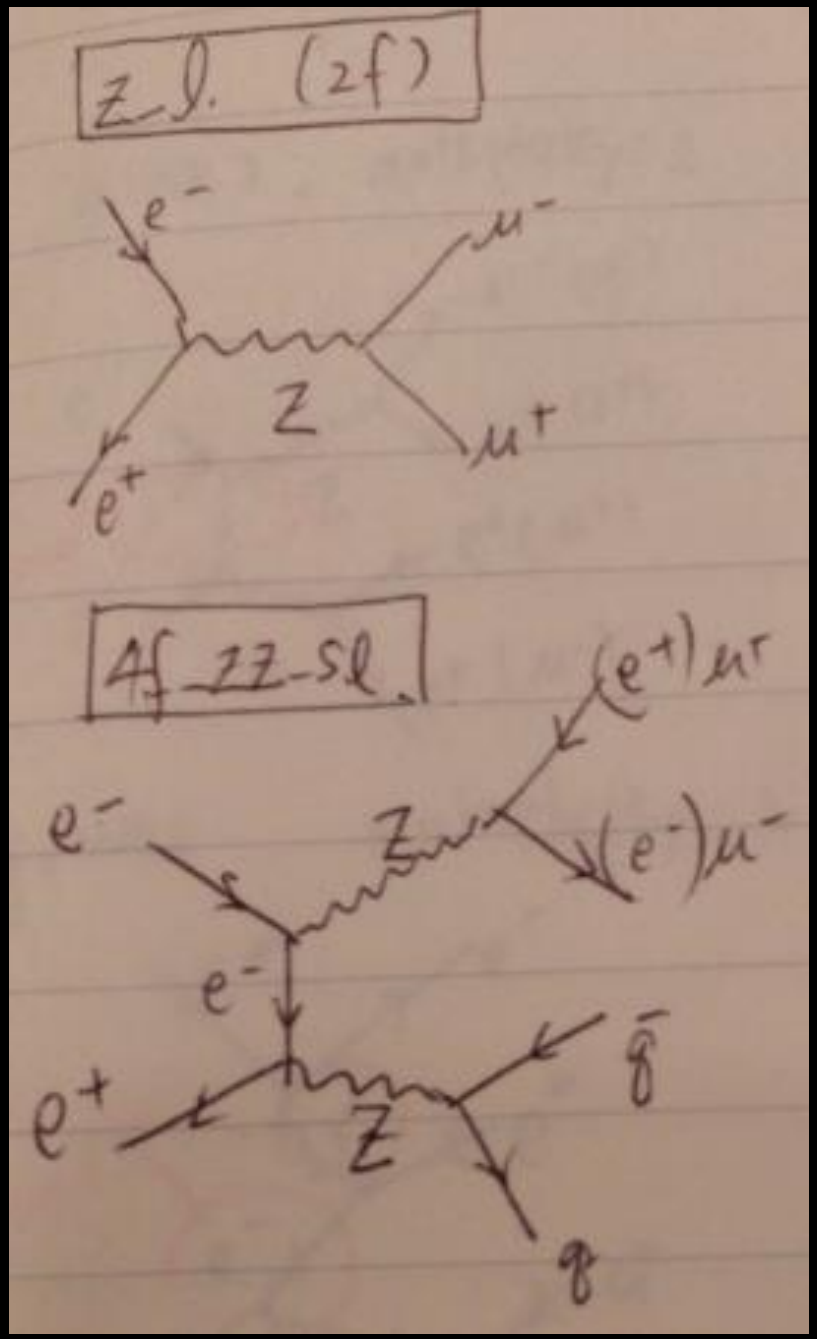
after M_rec cut .....

PT_dl, cosθZ, and acop cut seem quite effective for improving S/N

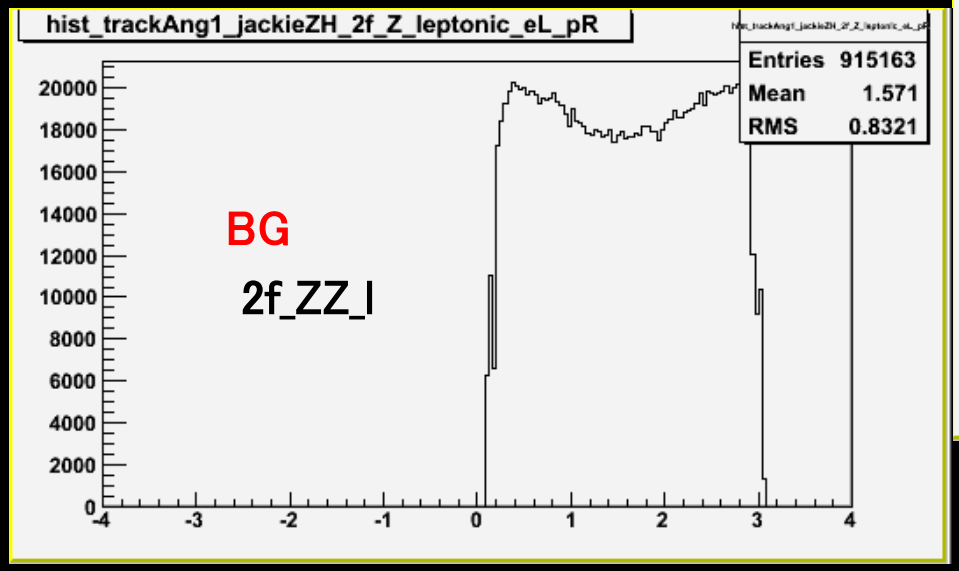
cut	4f_ZZ_l	4f_ZZ_sl	2f_Z_l	4f_WW_l	4fSingleZee_l	4fSingleZnn_l	4f_ZZWWMix_l
no cut	11745	48063	907810	33606	29804	7260	115192
best mu	9284	36246	807757	9658	12669	5526	94406
M_inv	4354	15617	257419	708	1452	2136	5262
M_rec	602	3167	32862	232	183	432	1238
P_Tdl	403	1724	4024	265	191	439	1314
acop	359	1568	3358	244	168	405	1255
θZ	304	1371	2247	229	140.6	358	1118

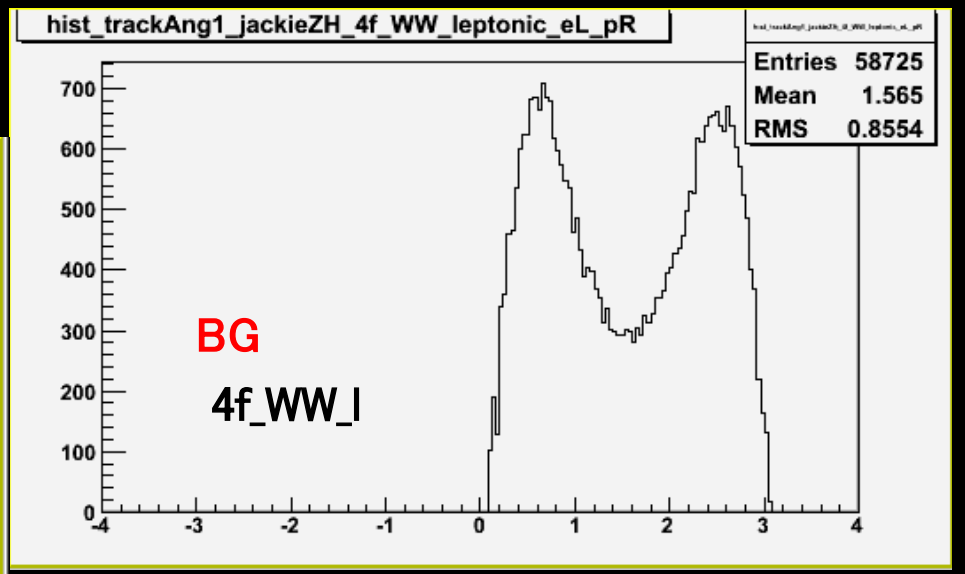
example dagrams for BG process for Zmumu

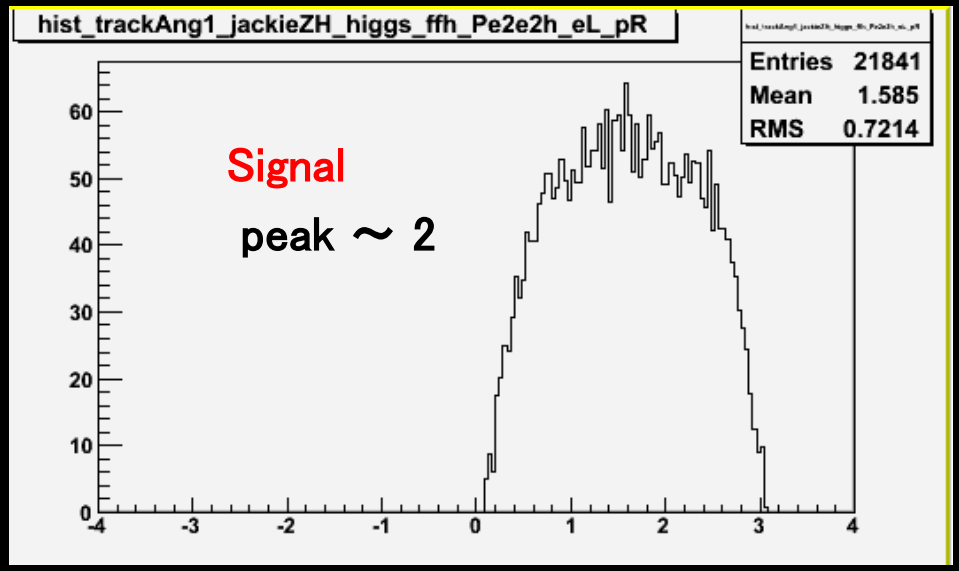


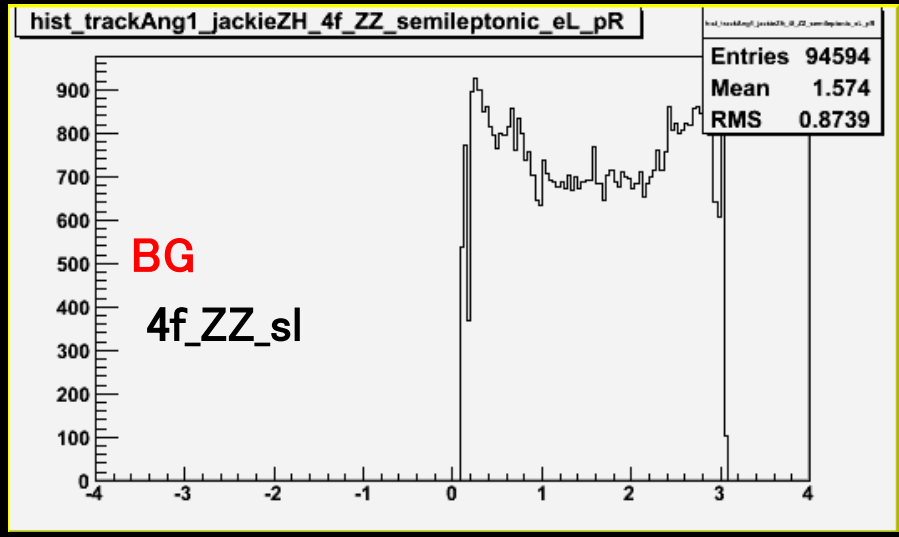


track angle


hist_trackAng1_jackieZH_2f_Z_leptonic_eL_pR
Entries 915163
Mean 1.571
RMS 0.8321
BG
2f_ZZ_l

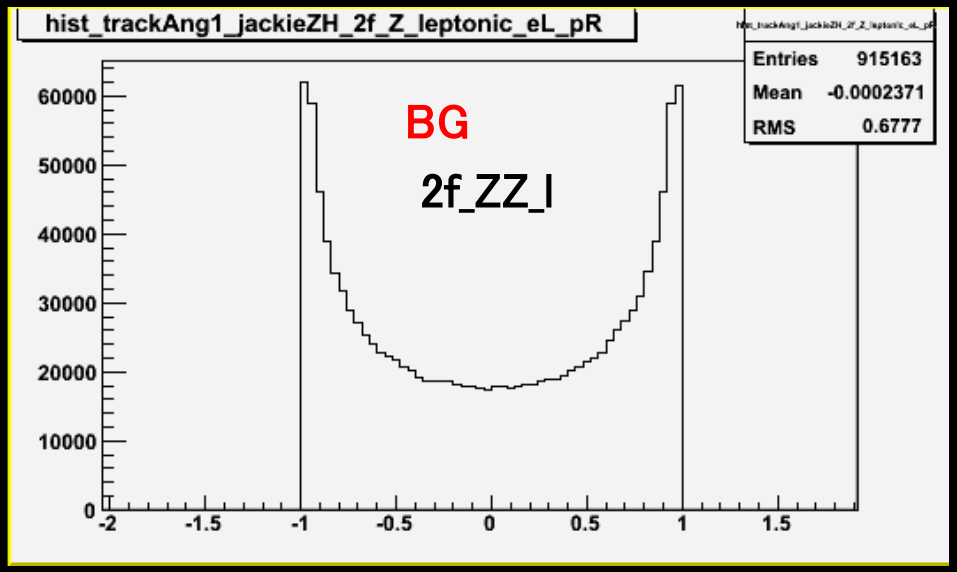

hist_trackAng1_jackieZH_4f_WW_leptonic_eL_pR
Entries 58725
Mean 1.565
RMS 0.8554
BG
4f_WW_l

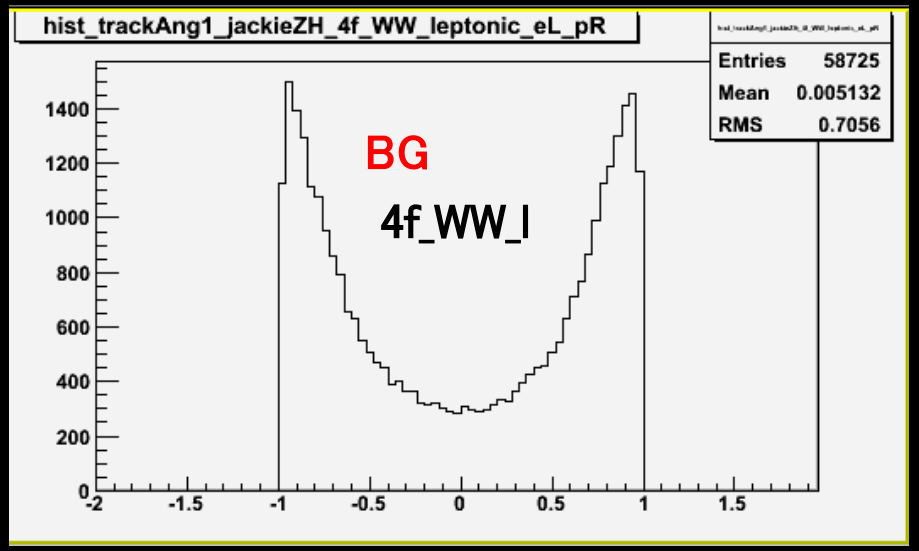

hist_trackAng1_jackieZH_higgs_ffh_Pe2e2h_eL_pR
Entries 21841
Mean 1.585
RMS 0.7214
Signal
peak ～ 2

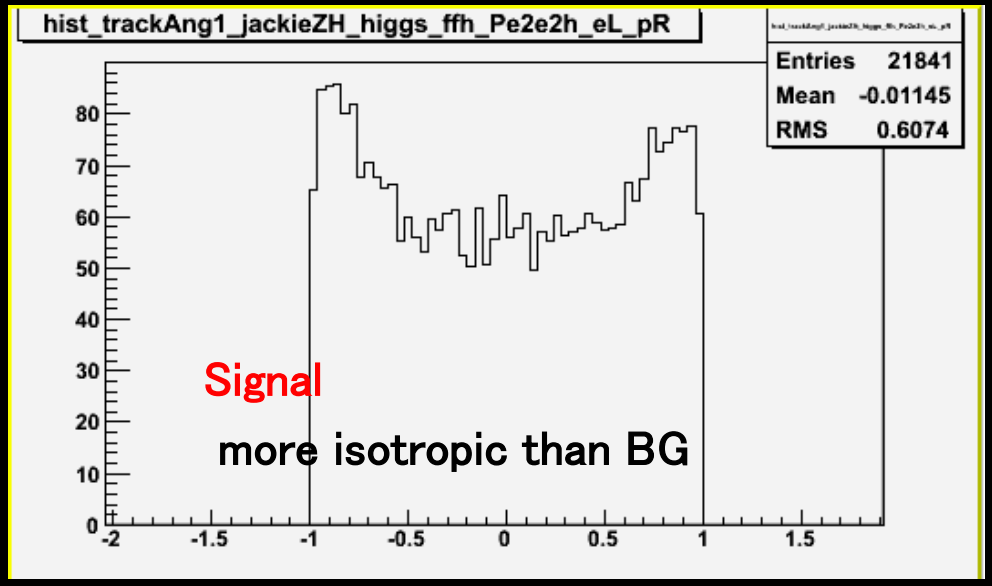

hist_trackAng1_jackieZH_4f_ZZ_semileptonic_eL_pR
Entries 94594
Mean 1.574
RMS 0.8739
BG
4f_ZZ_sl

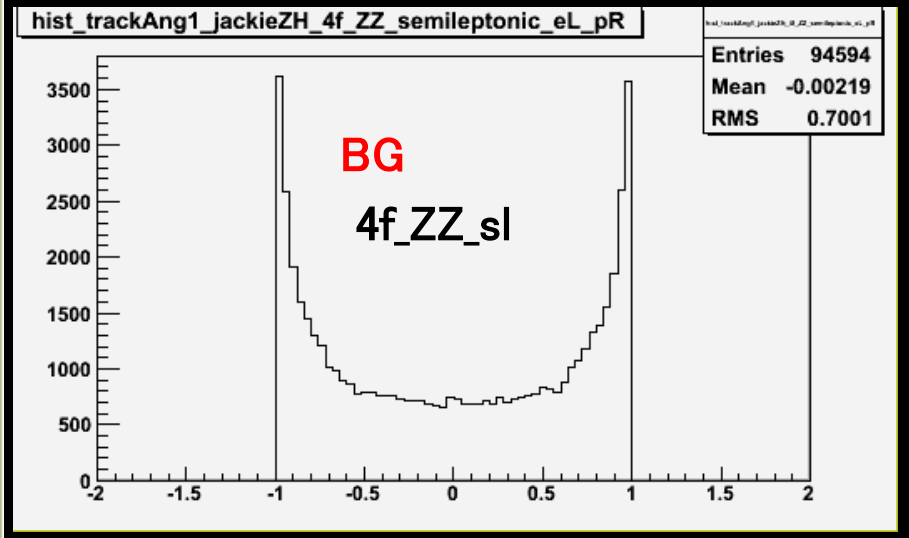
Cos(track angle)

BG is More forward









BG Rejection Efficiency (OLD)

cut	signal	eff	BG_all	eff	S/N
no cut	35795	100%	2196102	100%	0.02
M_inv	10574	29.54%	289241	13.17%	0.04
M_rec	9669	27.01%	14558	0.66%	0.66
P_Tdl	9532	26.63%	8792	0.40%	1.08
acop	8692	24.28%	7384	0.34%	1.18
θZ	8218	22.96%	6054	0.28%	1.36
dP/P^2	5820	16.26%	4195	0.19%	1.39
D0/δD0	5788	16.17%	3925	0.18%	1.47

Maybe cut too much signal

BG reduced to 0.2% !!

S/N improved to ～1.5

after M_rec cut .....

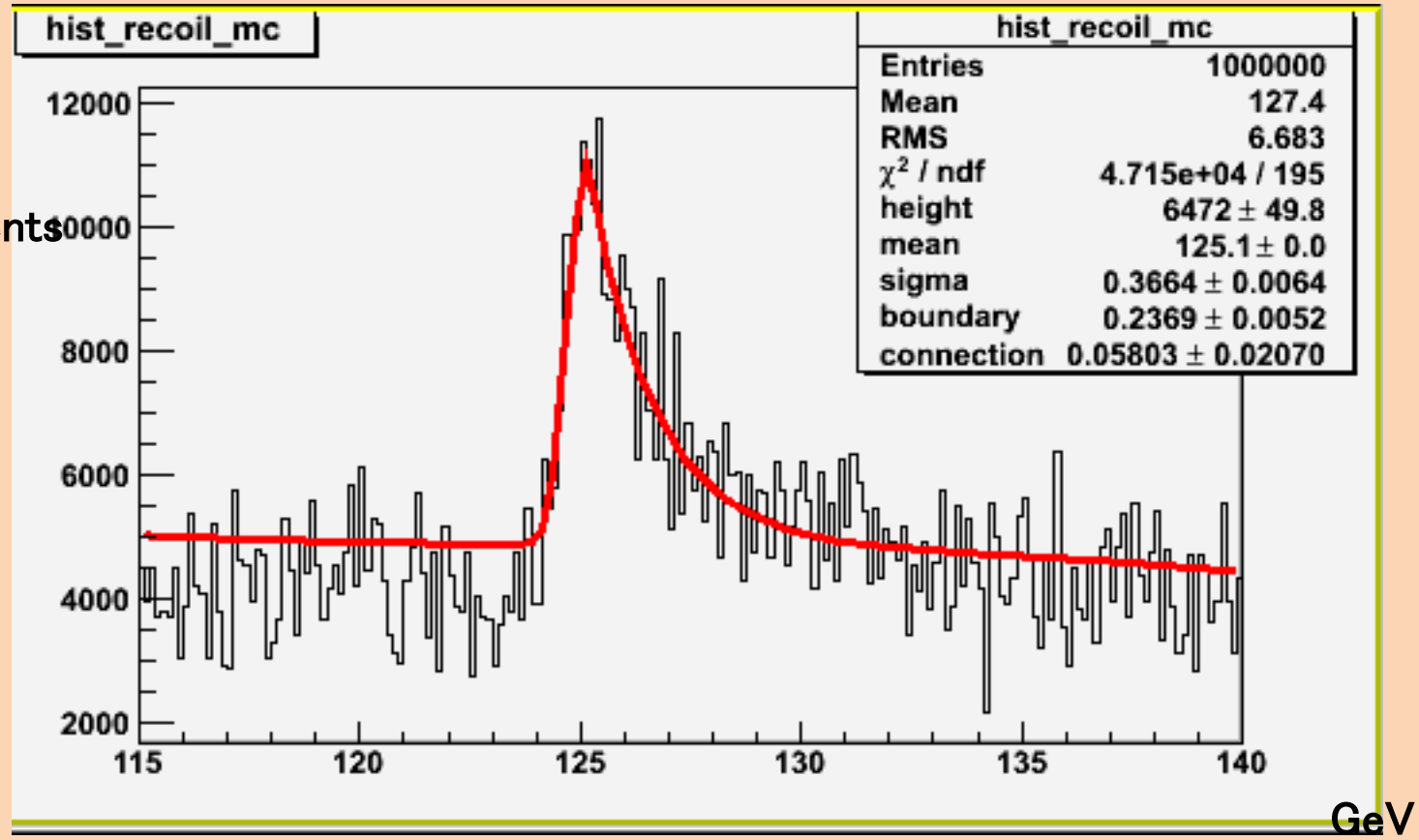
PT_dl, cosθZ, and acop cut seem quite effective for improving S/N

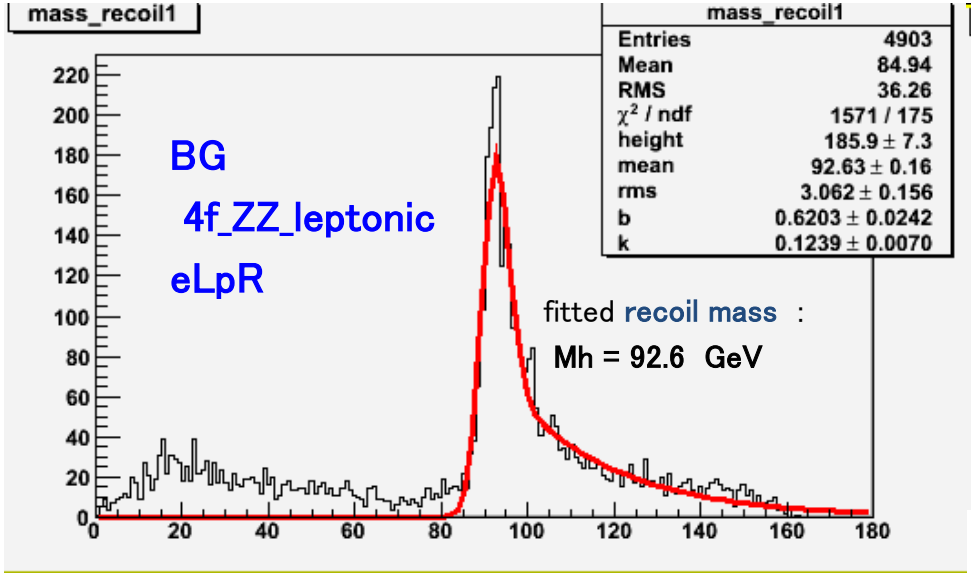
cut	4f_ZZ_l	4f_ZZ_sl	2f_Z_l	4f_WW_l	4fSingleZee_l	4fSingleZnn_l	4f_ZZWWMix_l
no cut	58330	145289	1606715	60118	97197	22282	206166
M_inv	7968	20901	246006	2360	2371	3535	6100
M_rec	827	2224	8169	930	295	626	1497
P_Tdl	750	2141	2676	910	277	598	1440
acop	629	1860	2001	780	240	530	1346
θZ	527	1634	1342	701	183	480	1193
dP/P^2	357	1224	895	356	123	373	867
D0/δD0	351	1208	891	126	121	372	856

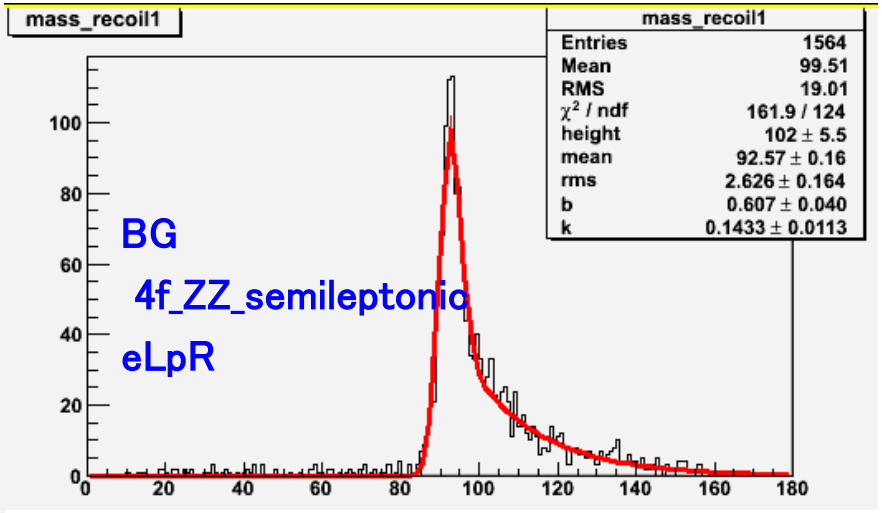
Toy MC

pseudo experiment

Generated 1000000 events
according to histogram



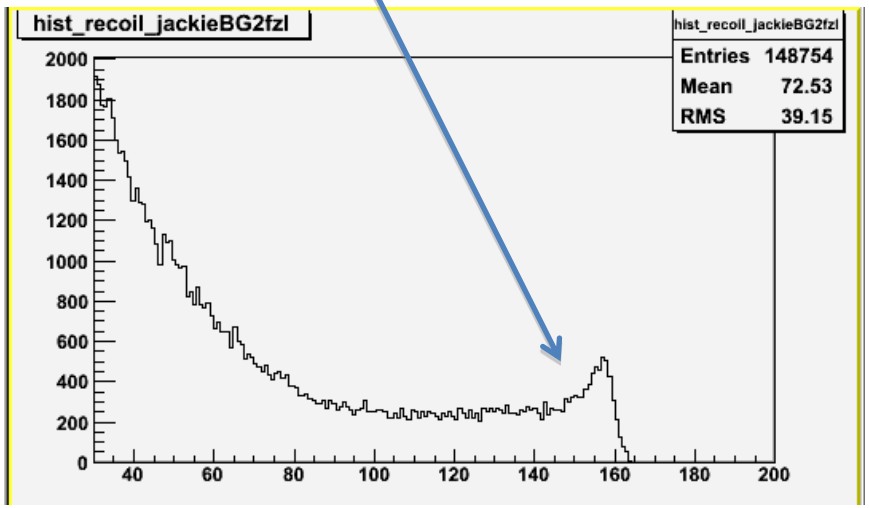


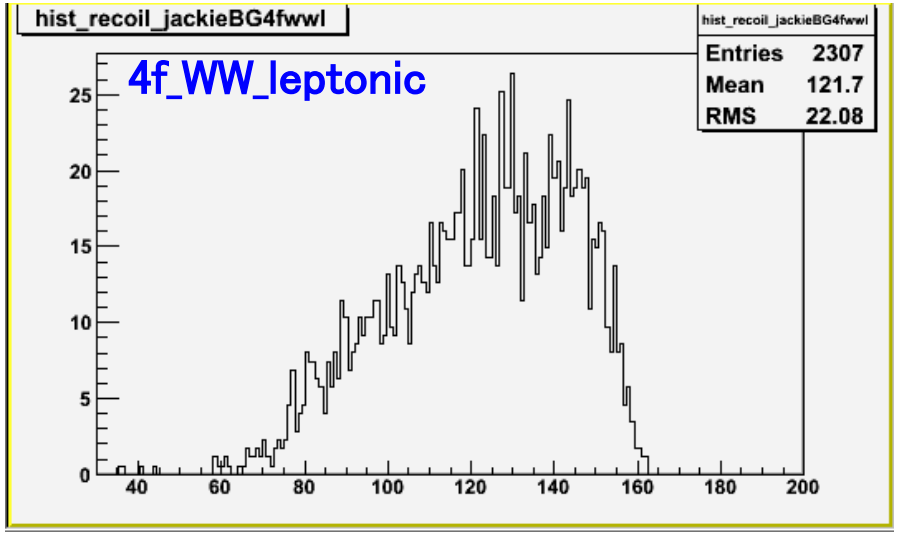


recoil mass distribution for some BG processes

2f_Z_leptonic

This may be causing high energy BG in combined histogram





Calculation of Event Weight

Assign weight based on cross section, luminosity, polarization

event weight = pol_weight * (process_cross_section * assumed_integrated_luminosity)
/ (number_of_reconstructed_events)

Ec.m.s = 250 GeV

luminosity 250fb−1

ILC polarization: ex) if eLpR : (PL+PR)/ (PL−PR) : (e−, e+) = (0.8, 0.3) :

- for electron: 90% is left−handed (10% is right handed)
- for positron: 65% is left (35% is right)

```
jackieZH_higgs_ffh_Pe2e2h_eL_pR    cross section  17.1432    weight 0.146252
jackieZH_4f_ZZ_leptonic_eL_pR    cross section  157.96    weight 0.577543
jackieZH_4f_ZZ_semileptonic_eL_pR    cross section  1422.14    weight 0.583475
jackieZH_2f_Z_leptonic_eL_pR    cross section  21226.4    weight 1.46019
jackieZH_4f_WW_leptonic_eL_pR    cross section  1564.21    weight 0.57305
jackieZH_4f_singleZee_leptonic_eL_pR    cross section  1084.09    weight 0.580925
jackieZH_4f_singleZsingleWMix_leptonic_eL_pR    cross section  922.048    weight 0.583633
jackieZH_4f_singleZnunu_leptonic_eL_pR    cross section  192.753    weight 0.469835
jackieZH_4f_ZZWWMix_leptonic_eL_pR    cross section  1636.04    weight 0.58329
jackieZH_higgs_ffh_Pe2e2h_eR_pL    cross section  11.1593    weight 0.00889048
jackieZH_4f_ZZ_leptonic_eR_pL    cross section  99.5061    weight 0.0290226
jackieZH_4f_ZZ_semileptonic_eR_pL    cross section  713.526    weight 0.0349498
jackieZH_2f_Z_leptonic_eR_pL    cross section  16470    weight 0.0875124
jackieZH_4f_WW_leptonic_eR_pL    cross section  14.6917    weight 0.0128553
jackieZH_4f_singleZee_leptonic_eR_pL    cross section  1019.52    weight 0.0349882
jackieZH_4f_singleZsingleWMix_leptonic_eR_pL    cross section  21.5941    weight 0.0236186
jackieZH_4f_singleZnunu_leptonic_eR_pL    cross section  39.3186    weight 0.0172019
jackieZH_4f_ZZWWMix_leptonic_eR_pL    cross section  53.9555    weight 0.0236055
```

BG with large cross section

- 2f_Z_leptonic
- 4fZZWWMix_leptonic(eLpR)
- 4f_ZZ_semileptonic(eLpR)
- 4f_WW_leptonic(eLpR)

BG with large weight

- 2f_Z_leptonic

other BGs gave similar weights

```
jackieZH_higgs_ffh_Pe2e2h_eL_pR    weighted events 1387.78    unweighted events9489    raw events 17143
jackieZH_4f_ZZ_leptonic_eL_pR    weighted events 357.499    unweighted events619    raw events 40000
jackieZH_4f_ZZ_semileptonic_eL_pR    weighted events 1336.74    unweighted events2291    raw events 356465
jackieZH_2f_Z_leptonic_eL_pR    weighted events 1975.64    unweighted events1353    raw events 2125992
jackieZH_4f_WW_leptonic_eL_pR    weighted events 201.141    unweighted events351    raw events 399207
jackieZH_4f_singleZee_leptonic_eL_pR    weighted events 127.223    unweighted events219    raw events 272923
jackieZH_4f_singleZsingleWMix_leptonic_eL_pR    weighted events 0    unweighted events0    raw events 231052
jackieZH_4f_singleZnunu_leptonic_eL_pR    weighted events 338.751    unweighted events721    raw events 60000
jackieZH_4f_ZZWWMix_leptonic_eL_pR    weighted events 1020.76    unweighted events1750    raw events 410208
jackieZH_higgs_ffh_Pe2e2h_eR_pL    weighted events 52.605    unweighted events5917    raw events 10983
jackieZH_4f_ZZ_leptonic_eR_pL    weighted events 11.4349    unweighted events394    raw events 30000
jackieZH_4f_ZZ_semileptonic_eR_pL    weighted events 29.8121    unweighted events853    raw events 178638
jackieZH_2f_Z_leptonic_eR_pL    weighted events 79.0237    unweighted events903    raw events 1646769
jackieZH_4f_WW_leptonic_eR_pL    weighted events 0.128553    unweighted events10    raw events 10000
jackieZH_4f_singleZee_leptonic_eR_pL    weighted events 3.18392    unweighted events91    raw events 254967
jackieZH_4f_singleZsingleWMix_leptonic_eR_pL    weighted events 0    unweighted events0    raw events 8000
jackieZH_4f_singleZnunu_leptonic_eR_pL    weighted events 2.58029    unweighted events150    raw events 20000
jackieZH_4f_ZZWWMix_leptonic_eR_pL    weighted events 4.22539    unweighted events179    raw events 20000

sig:    weighted events:   1440.39    unweighted events: 15406
BG:     weighted events:   5488.14    unweighted events: 9884
all:    weighted events:   6928.53    unweighted events: 25290
```