Higgs Recoil Mass Study

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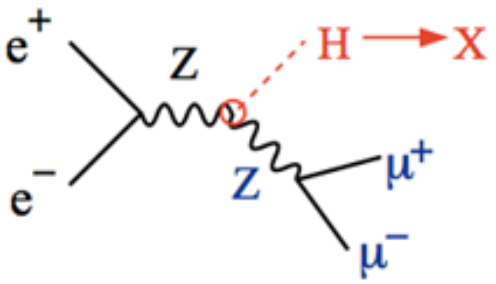
recoil mass study using e+e- → Zh → μ+μ-h
Ec.m.s. = 250 GeV, L = 250 fb-1
Ec.m.s. = 350 GeV, L = 333 fb-1

polarization:
(e−, e+) = (− 0.8, + 0.3)



Goal:

precise measurement of

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

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

What's new this week

- **updated results for 250 GeV**
  included all BG and signal processes
  calculate cross section error taking into account uncertainty of BG and efficiency

- Tried 20 x higher statistic signal samples (20000 fb)

- **first attempt at 350 GeV**

DBD Samples

Sample statistics 1000 fb-1

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

250 GeV

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

20 x Higher statistics data : /hsm/ilc/grid/storm/user/a/amiyamot/myprod/ild/dst-merged /250-TDR_ws/
reference: meta files and diagrams in http://ilcsoft.desy.de/dbd/generated/other.html

350 GeV

/grid/ilc/prod/ilc/mc-dbd/ild/dst-merged/350-TDR_ws/
List of samples: http://www-jlc.kek.jp/~miyamoto/CDS/prod_status/REC_ILD_o1_v05_350GeV.html

Lumosity

TDR baseline
sqrt(s)=250 GeV, Lumi=0.75 x 10^34 cm^-2 s^-1 → assume L = 250 fb-1
sqrt(s)=350 GeV, Lumi=1.0 x 10^34 cm^-2 s^-1 → assume L = 333 fb-1

Polarization: **(-0.8, + 0.3)** → compare with (+0.8, -0.3)

Signal sample:

Pe2e2h.eL.pR & Pe2e2h.eR.pL

relevant BG process for Zmumu

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

250 GeV

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

after all cuts, dominant BG are:

sqrt(s) = 250 GeV : #1) 2f_Z_l #2) 4f_ZZ_sl #3) 4f_ZZWWMix_l

sqrt(s) = 350 GeV : #1) 4f_ZZ_sl #2) 2f_Z_l #3) 4f_WW_sl

no ttbar BG left after data selection

Results for 250 GeV

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

Best Z Candidate Selection

2 mu candidates with **opposite charge**

if several possibilities :

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

Final Selection for 250 GeV

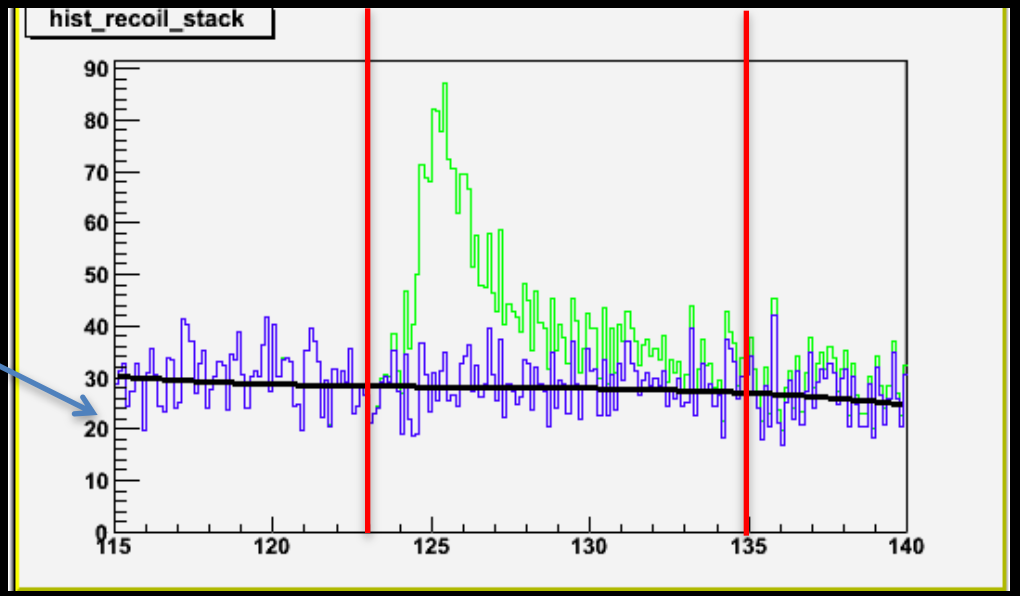
analysis after filling root files

- **84 GeV < M_mumu < 98 GeV**
- 123 GeV < Mrecoil < 135 GeV
- 10 GeV < pT_mumu < 70 GeV
- |cos(θ_Zpro)| < 0.91

  (Z production angle)

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

calculate recoil mass with correction for 14 mrad beam crossing angle



This Week ‘s updated results : 250 GeV

Calculation of Error of σmeas

- Case#1: ignore uncertainty of <B> i.e. MC statistics
- Case#2: taking into account uncertainty of ε and <B> *is this necessary ?*

Usual signal samples (1000 fb−1)

<n> = 1487 +/- 25
<ε> = 57.1 +/- 0.4 %
<n>/sqrt(<n>+<B>) = 20.6
<n>/<B>=0.40

If Case#1
Δσmeas> / <σmeas> = 4.9 %

If Case#2
Δσmeas> / <σmeas> = 6.5%

20 x high statistic signal samples (20000 fb−1)

<n> = 1469 +/- 25
<ε> = 56.4 +/- 0.1 %
<n>/sqrt(<n>+<B>) = 20.7
<n>/<B> = 0.40

Case#1
Δσmeas> / <σmeas> = 4.8 %

If Case#2
Δσmeas> / <σmeas> = 6.6%

No significant difference for higher statistic signal samples

Data selection : 123 – 135 GeV

Sqrt(s)= 250 GeV

	cut	signal	eff	BG_all	eff	S/B	S/sqrt(S+B)
	raw, no inv mass cut	2605	100.0%	6923287	100%	**0.000**	0.990
	track	1764	67.7%	27560	0.40%	0.064	10.301
	84 <M_inv <98	1601	61.5%	9364	0.14%	0.171	15.290
	10 <P_Tdl<70	1579	60.6%	4873	0.07%	0.324	19.658
final	**cos(θ Z)<0.91**	1487	57.1%	3724	0.05%	**0.399**	20.599

Signal efficiency 57 %

S/N → 0.40

Significance ~20.6

cut	4f_ZZ_l	4f_ZZ_sl	2f_Z_l	4f_WW_l	4f_WW_sl	4fSingleZee_l	4fSingleZnn_l	4f_ZZWWMix_l
raw, no inv mass cut	23972	214232	3248465	228894	2771978	167469	28534	239742
track	456	1971	11540	960	6984	530	408	4711
84 <M_inv <98	226	844	6636	210	138	106	240	964
10 <P_Tdl<70	202	820	2237	206	138	104	233	933
cos(θ Z)<0.91	166	710	1428	191	131	86	199	813

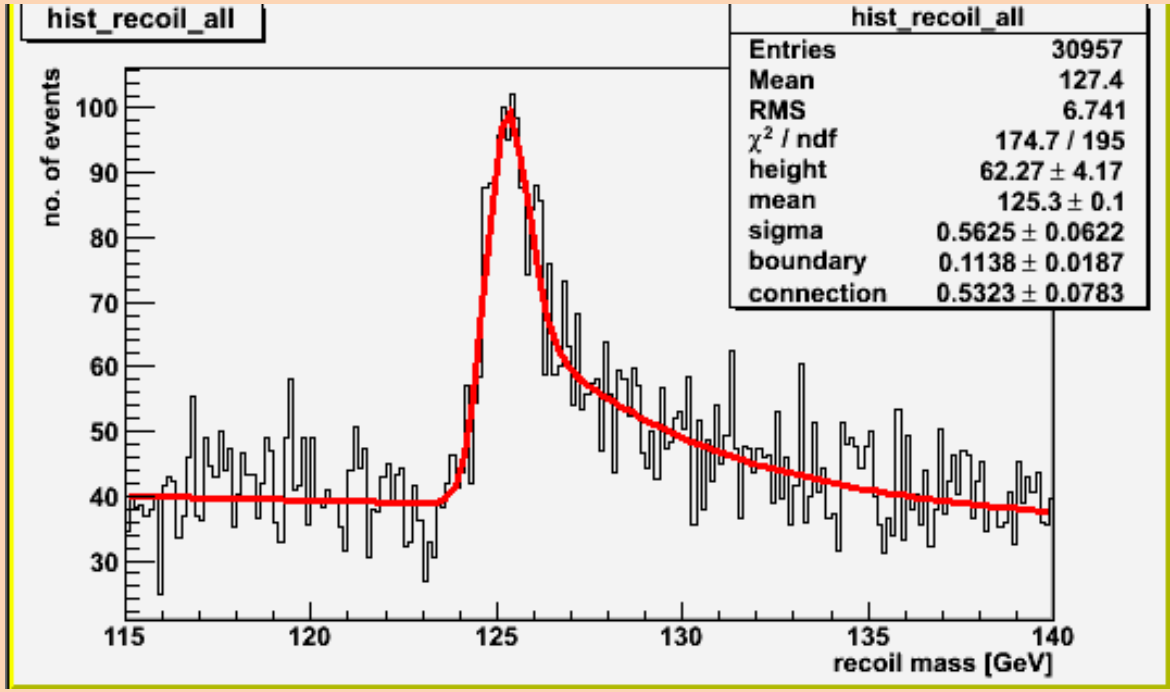
recoil mass

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)

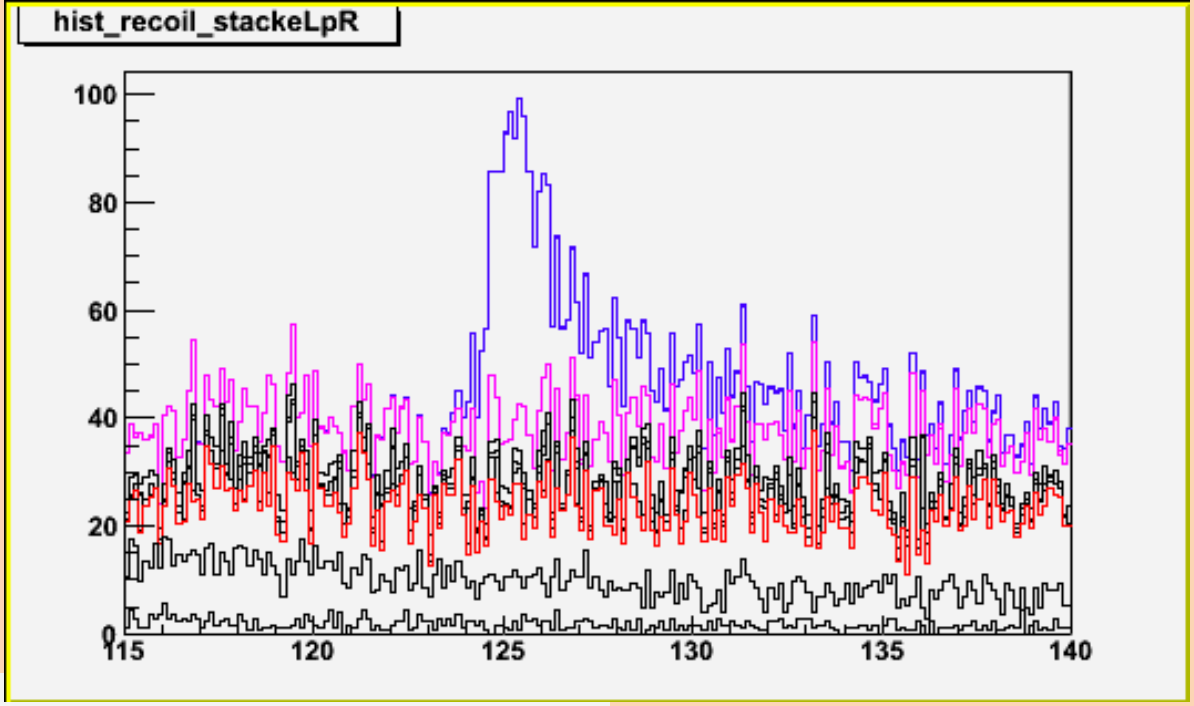
$$N\exp\left[-\frac{1}{2}\left(\frac{x-x_{mean}}{s}\right)^2\right] \quad \left(\frac{x-x_{mean}}{s}\right) \le k$$

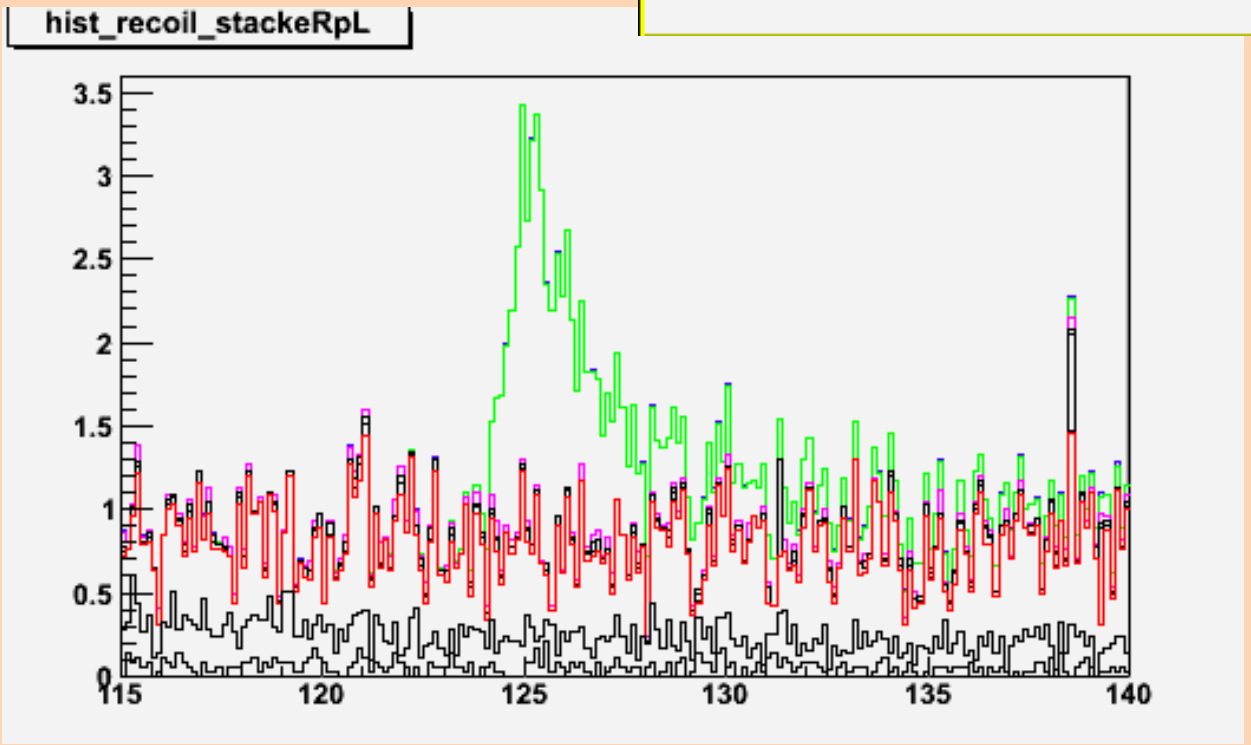
$$N\left[b\times\exp\left[-\frac{1}{2}\left(\frac{x-x_{mean}}{s}\right)^2\right]+(1-b)\exp\left[-k\left(\frac{x-x_{mean}}{s}\right)\right]\exp\left(k^2/2\right)\right] \quad \left(\frac{x-x_{mean}}{s}\right) > k$$

recoil mass (stacked)

Red: 2f_Z_l

Pink: 4f_ZZWWMix_l : small for eRpL





Results for 350 GeV

Muon Selection

- reject neutrals
- Ptot > 5 GeV
- small E_cluster / P_total < 0.5
- opposite charge

■ **Best track selection**

cos(track angle) < 0.98

|D0/δD0| < 5

Best Z Candidate Selection

2 mu candidates with **opposite charge**

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

Final Selection for 350 GeV

- 84 GeV < M_mumu < 98 GeV
- 123 GeV < Mrecoil < 135 GeV
- 10 GeV < pT_mumu < 140 GeV
- coplanarity < 3
- |cos(θ_Zpro)| < 0.91 (Z production angle)

calculate recoil mass with correction for 14 mrad beam crossing angle

Evaluated within range of 123 – 135 GeV

L = 333 fb-1

<n> = 923 +/- 23

<ε> = 40.4 +/- 0.5 %

<n>/sqrt(<n>+<B>) = 16.6

<n>/<B>=0.42

Δσmeas> / <σmeas> = 6.0 %

8.8 % if consider BG uncertainty

L = 250 fb-1

<n> = 694 +/- 20

<ε> = 40.4 +/- 0.4 %

<n>/sqrt(<n>+<B>) = 14.4

<n>/<B>=0.42

Δσmeas> / <σmeas> = 6.9 %

9.5% if consider BG uncertainty

Compare different polarization scenarios

sqrt(s) = 350 GeV L = 333 fb-1

For now, keep same cut parameters as (-0.8, +0.3)
(they could be optimized)

(-0.8, + 0.3)

Pol weight(eLpR) = 0.9*0.65
Pol weight(eRpL) = 0.1*0.35

<n> = 923 +/- 23
<ε> = 40.4 +/- 0.5 %
<n>/sqrt(<n>+<B>) = 16.6
<n>/<B>=0.42

Δσmeas> / <σmeas> = 6.0 %
8.8 % if consider BG uncertainty

(+0.8, -0.3)

Pol weight(eLpR) = 0.1*0.35
Pol weight(eRpL) = 0.9*0.65

<n> = 625 +/- 19
<ε> = 40.4 +/- 0.5 %
<n>/sqrt(<n>+<B>) = 15.9
<n>/<B>=0.68

Δσmeas> / <σmeas> = 6.4 %
7.6 % if consider BG uncertainty

(-0.8, 0)

Pol weight(eLpR) = 0.9*0.5
Pol weight(eRpL) = 0.1*0.5

<n> = 733 +/- 21
<ε> = 40.4 +/- 0.5 %
<n>/sqrt(<n>+<B>) = 14.8
<n>/<B>=0.43

Δσmeas> / <σmeas> = 6.8 %
9.2% if consider BG uncertainty

Data selection : 123 – 135 GeV

Sqrt(s)= 350 GeV

with all 6f BG included, whizard events (no NRQCD correction?)

cut	signal	eff	BG_all	eff	S/B	S/sqrt(S+B)
raw	2288	100%	6242481	100.00%	**0.0004**	0.92
only best mu pair	1098	48%	37801	0.61%	0.0290	5.57
ΔD0/D0 < 5	1101	48%	35087	0.56%	0.0314	5.79
cos(trackAng)<0.98	1089	48%	31242	0.50%	0.0349	6.06
84 <M_inv <98	978	43%	6970	0.11%	**0.1403**	10.97
10 <P_Tdl<140	977	43%	4024	0.06%	0.2428	13.82
copl < 3	966	42%	3638	0.06%	0.266	14.24
cos(θ Z)<0.91	924	40%	2188	0.04%	0.422	16.57

Signal efficiency 40 %

S/N → 0.42

Significanc e ～16.6

cut	4f_ZZ_l	4f_ZZ_sl	2f_Z_l	4f_WW_l	4f_WW_sl	4fSingleZee_l	4fSingleZnn_l	4f_ZZWWMix_l	6f
raw	19632	188087	2226358	226193	2715937	243879	43056	541352	37989
only best mu pair	484	2204	11406	2386	6655	781	367	13516	2
ΔD0/D0 < 5	484	2218	11001	1044	5757	773	367	13441	2
cos(trackAng)<0.98	445	2023	9504	871	5069	479	326	12523	2
84 <M_inv <98	252	1042	4439	33	582	129	168	325	0
10 <P_Tdl<140	236	1027	1542	33	582	120	162	322	0
copl < 3	225	979	1323	27	502	111	158	313	0
cos(θ Z)<0.91	149	704	634	18	300	58	108	216	0

Data selection : 123 – 135 GeV

Sqrt(s)= 350 GeV

with ttbar physsim events (with NRQCD correction?)
no other 6f BGs

cut	signal	eff	BG_all	eff	S/B	S/sqrt(S+B)
raw, no inv mass cut	2288	100%	6204492	100%	**0.0004**	0.92
track	1089	47.6%	31240	0.50%	0.0349	6.06
84 <M_inv <98	978	42.7%	6970	0.11%	0.1403	10.97
10 <P_Tdl<140	977	42.7%	4024	0.06%	0.2428	13.82
copl < 3	966	42.2%	3638	0.06%	**0.2655**	14.24
cos(θ Z)<0.91	924	40.4%	2188	0.04%	0.4224	16.57

Signal efficiency 40 %

S/N → 0.42

Significance ~16.6

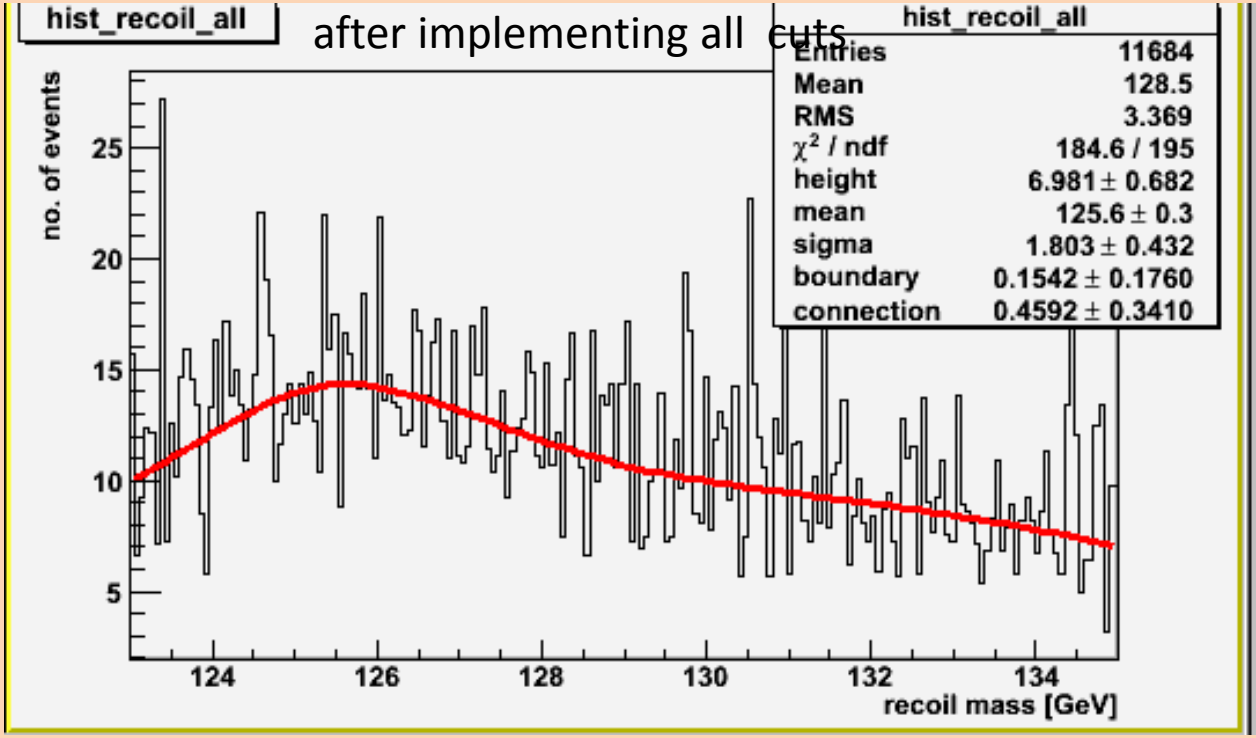
cut	4f_ZZ_l	4f_ZZ_sl	2f_Z_l	4f_WW_l	4f_WW_sl	4fSingleZee_l	4fSingleZnn_l	4f_ZZWWMix_l
raw, no inv mass cut	19632	188087	2226358	226193	2715937	243879	43056	541352
track	445	2023	9504	871	5069	479	326	12523
84 <M_inv <98	252	1042	4439	33	582	129	168	325
10 <P_Tdl<140	236	1027	1542	33	582	120	162	322
copl < 3	225	979	1323	27	502	111	158	313
cos(θ Z)<0.91	149	704	634	18	300	58	108	216

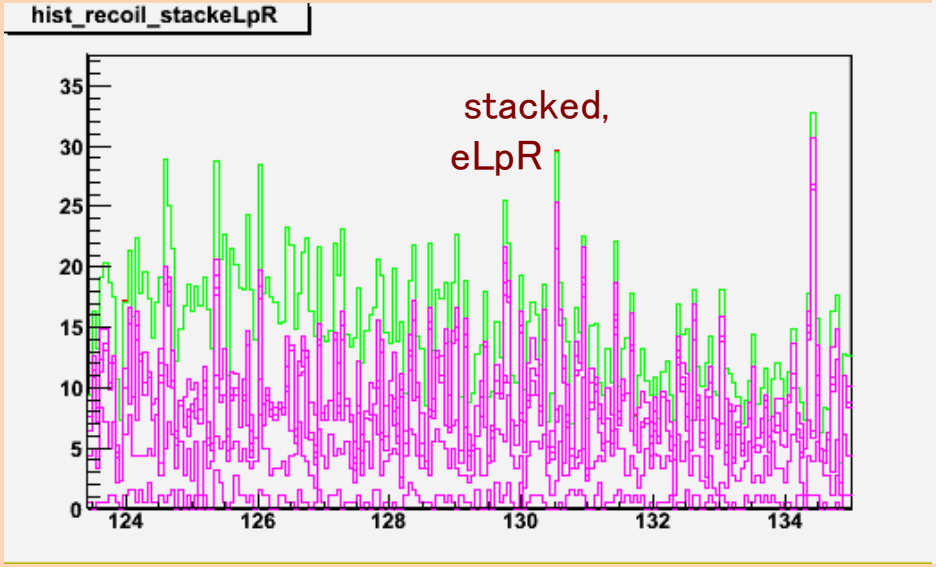
recoil mass

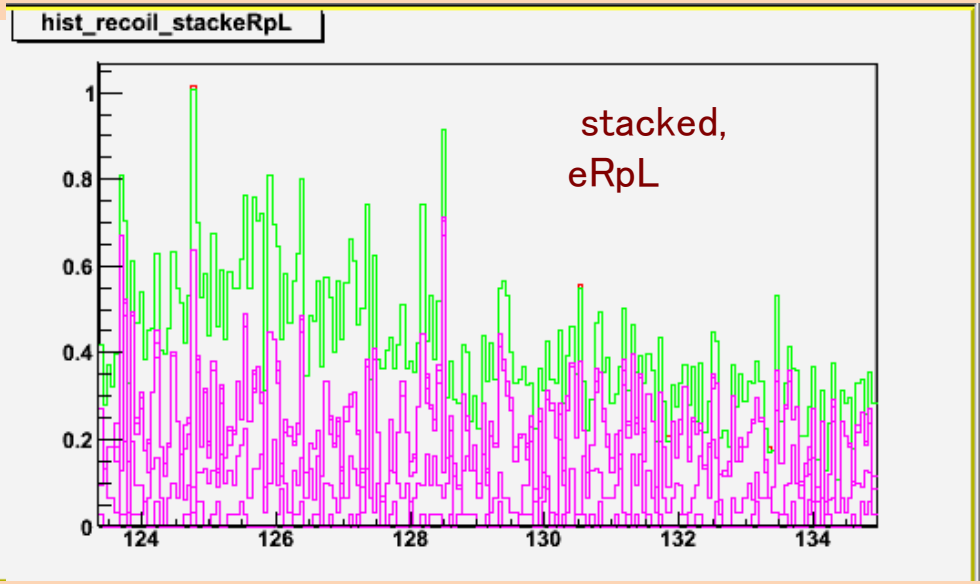
fitted **recoil mass** :

Mh =125.6 +/− 0.3 GeV

calculate recoil mass with correction for 14 mrad beam crossing angle







(-0.8, + 0.3)

<ε> = 40.4 +/- 0.5 %

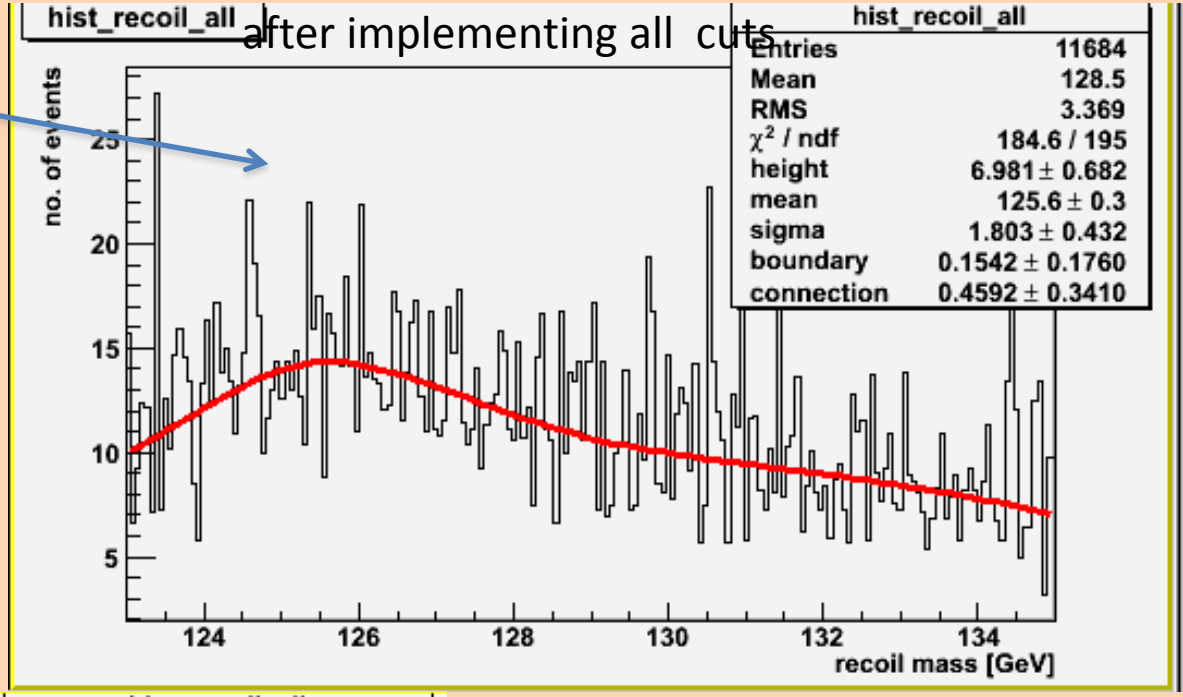
<n>/sqrt(<n>+<B>) = 16.6

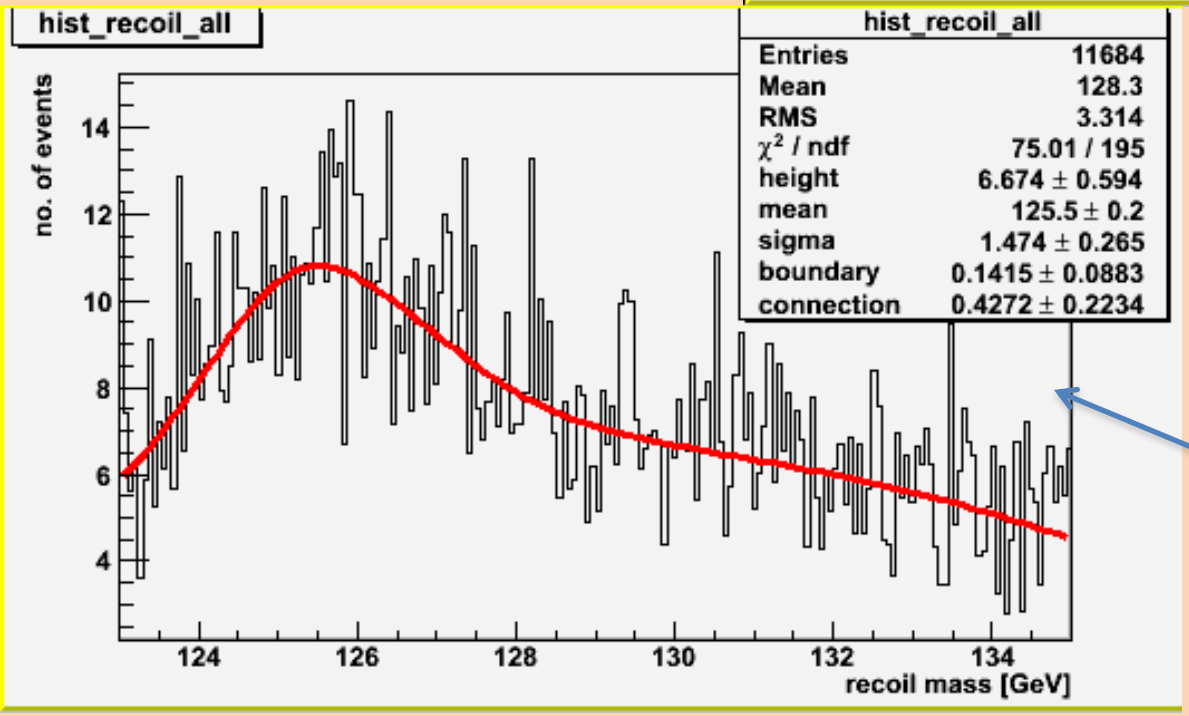
<n>/<B>=0.42

fitted recoil mass :

Mh =125.6 +/− 0.3 GeV

after implementing all cuts





(+0.8, - 0.3)

<ε> = 40.4 +/- 0.5 %

<n>/sqrt(<n>+<B>) = 15.8

<n>/<B>=0.68

fitted recoil mass :

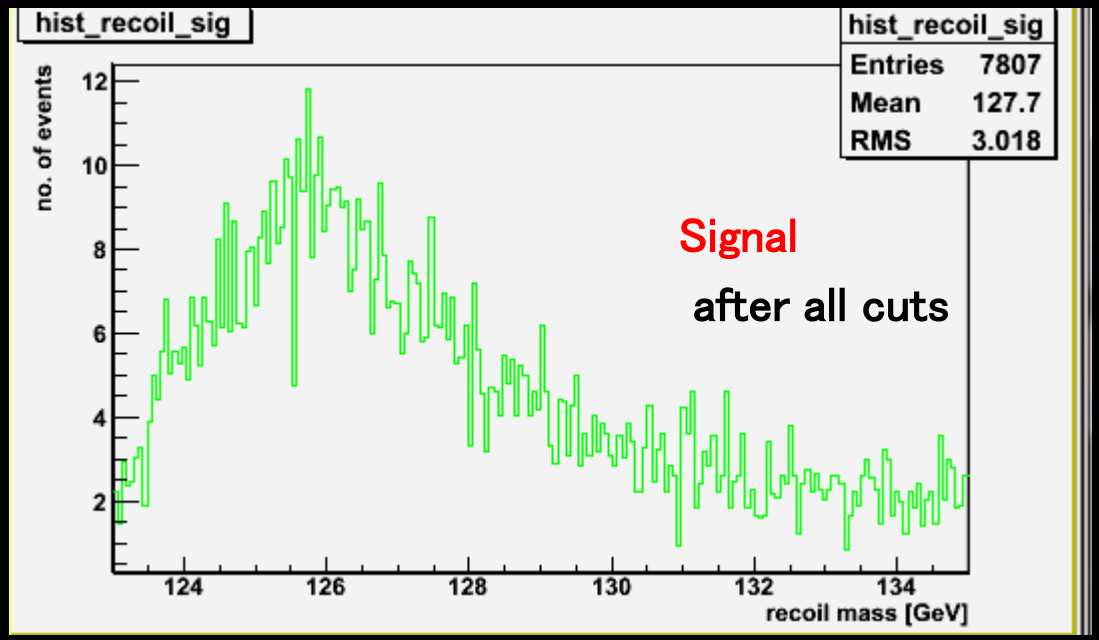
Mh =125.6 +/− 0.2 GeV

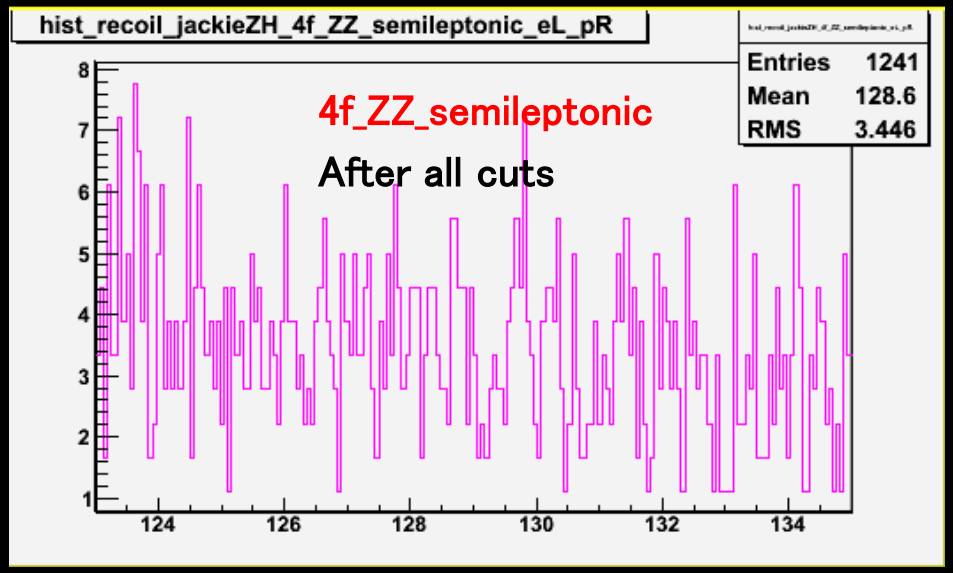
recoil mass 350 GeV

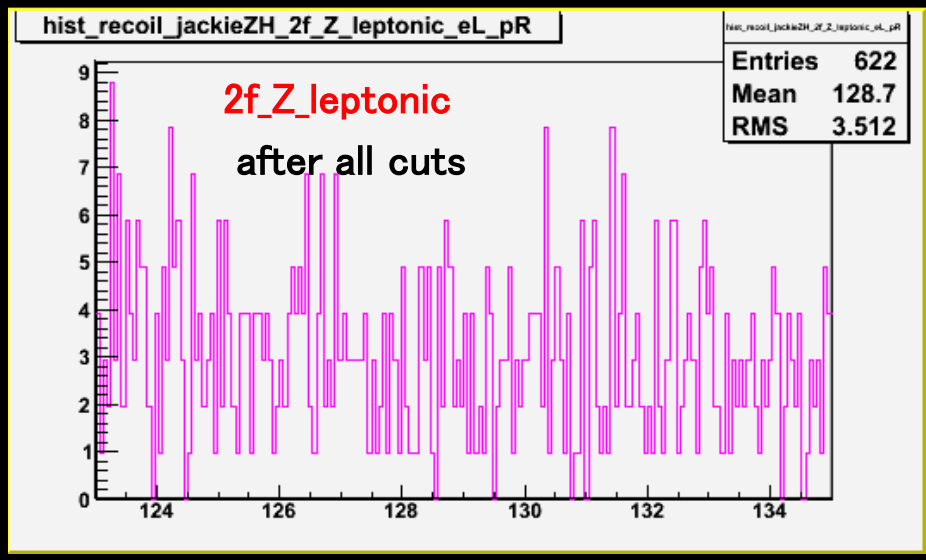
After cuts

There is still too much BG left

covers up signal peak !!



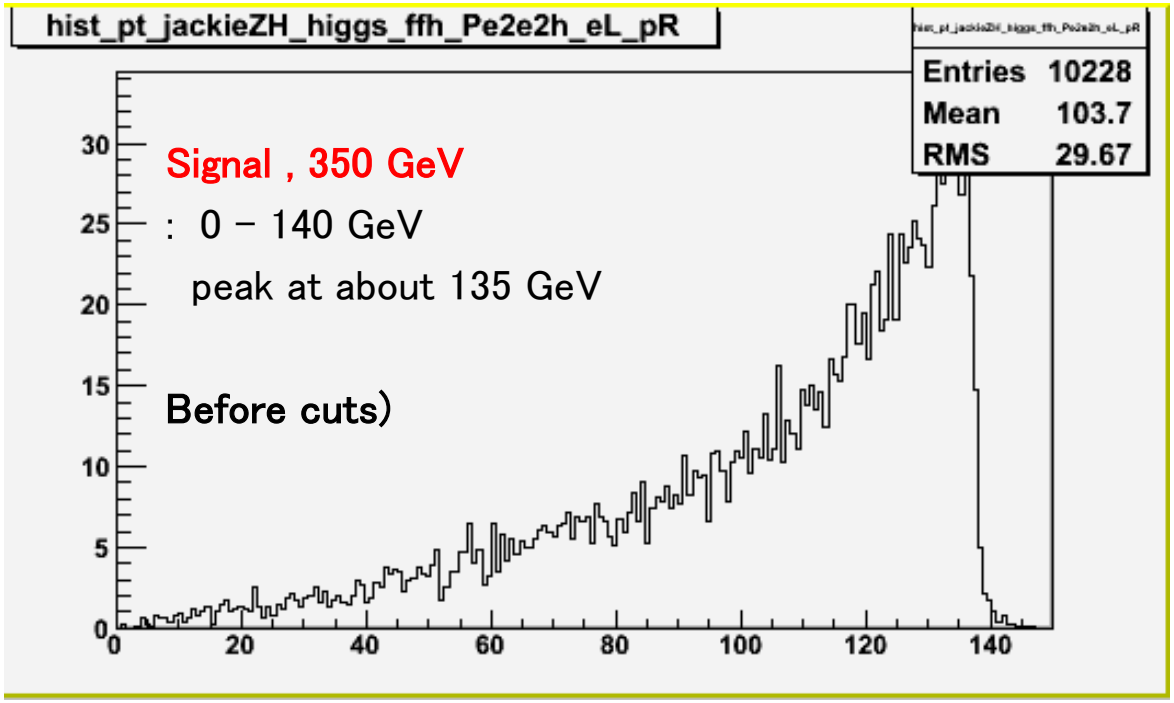


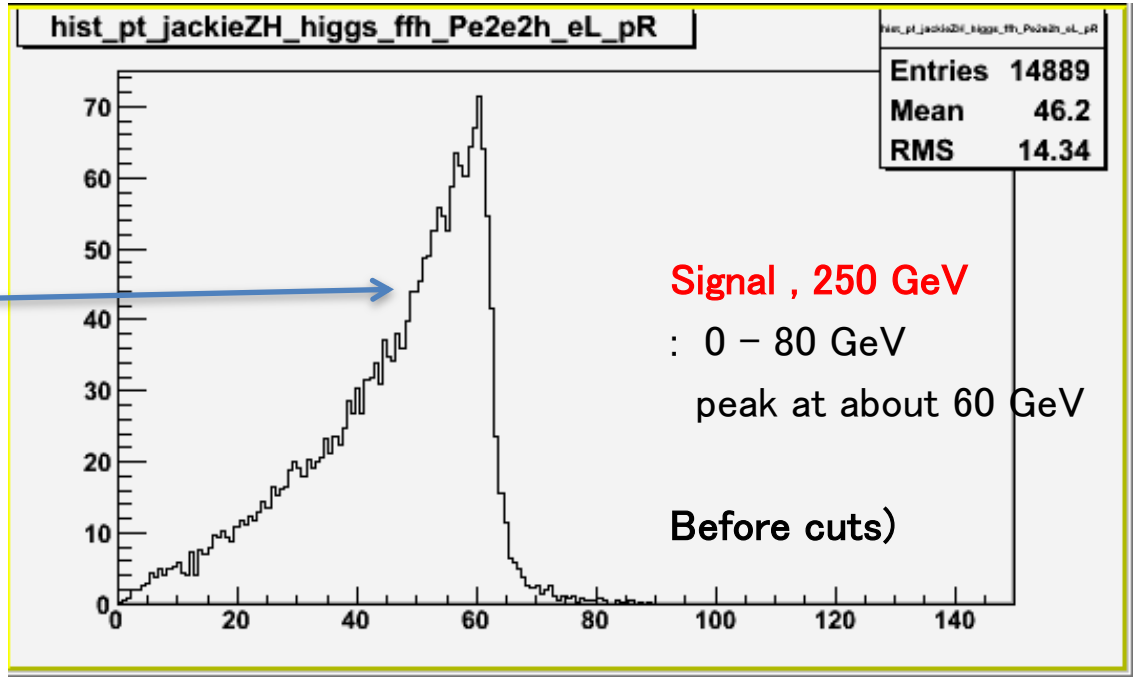


dilepton PT, 350 GeV

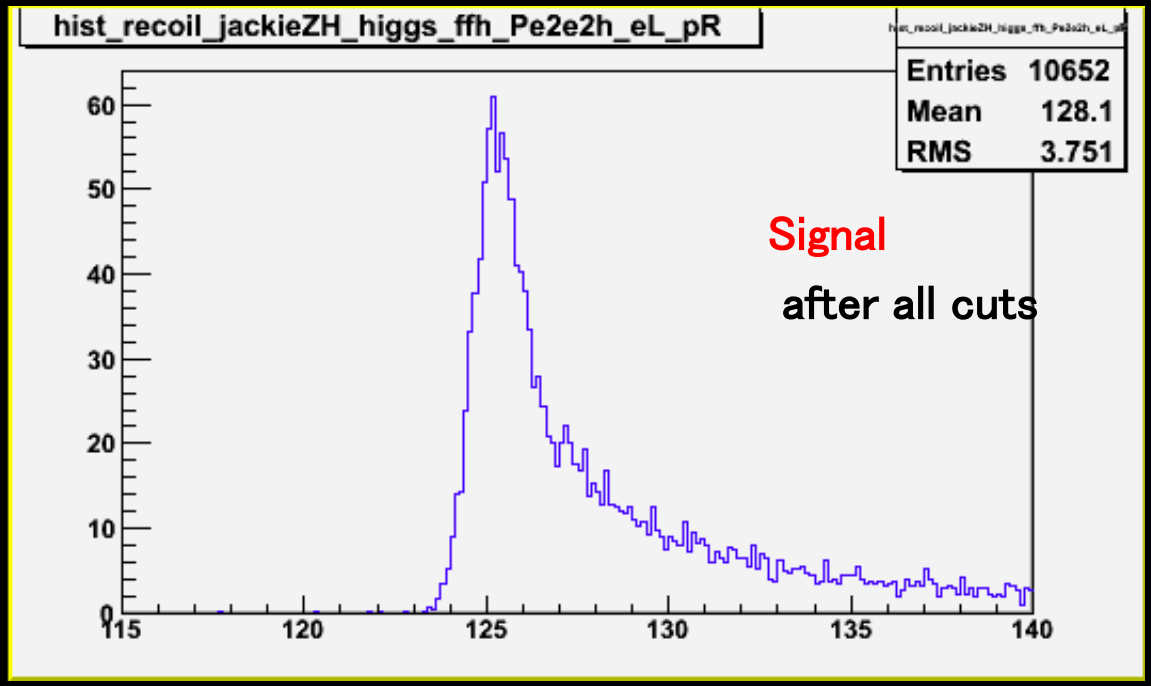
do cut :

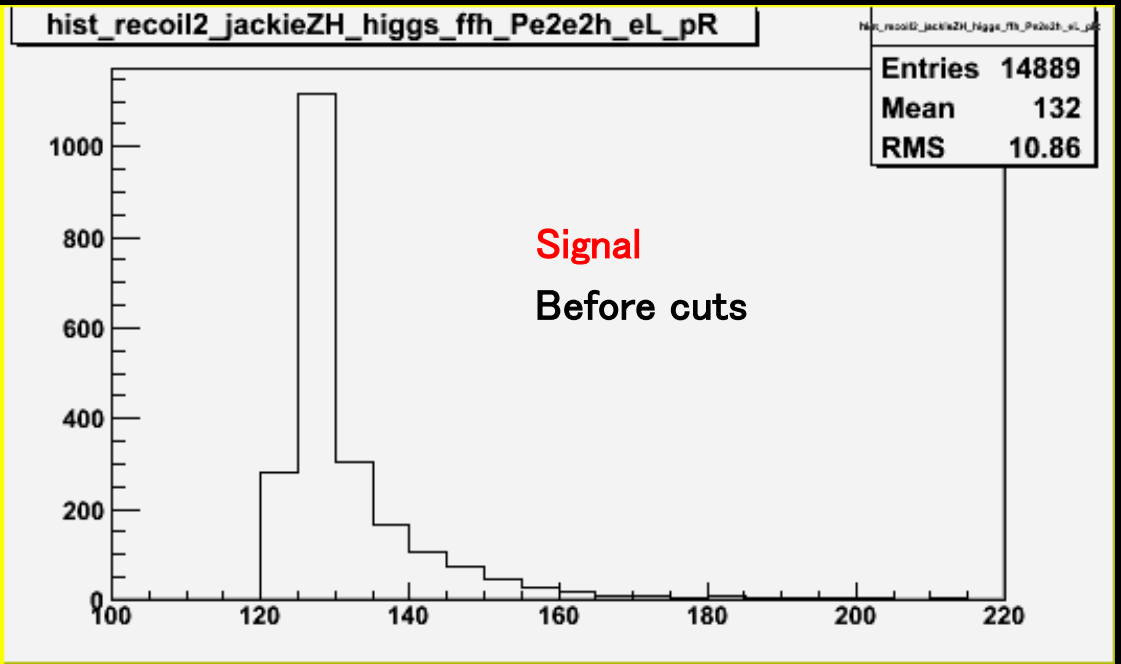
10 GeV< pT_dl < 140 GeV





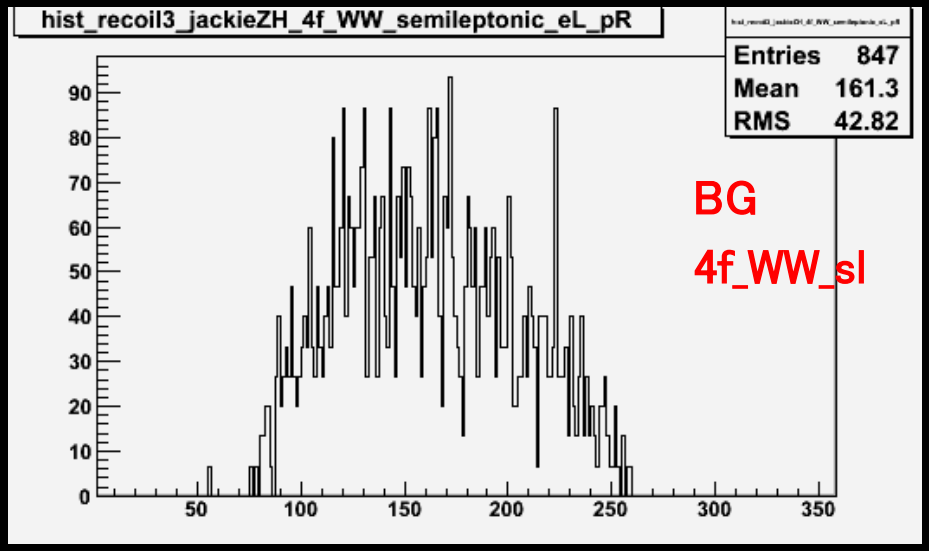
recoil mass of signal, 250 GeV

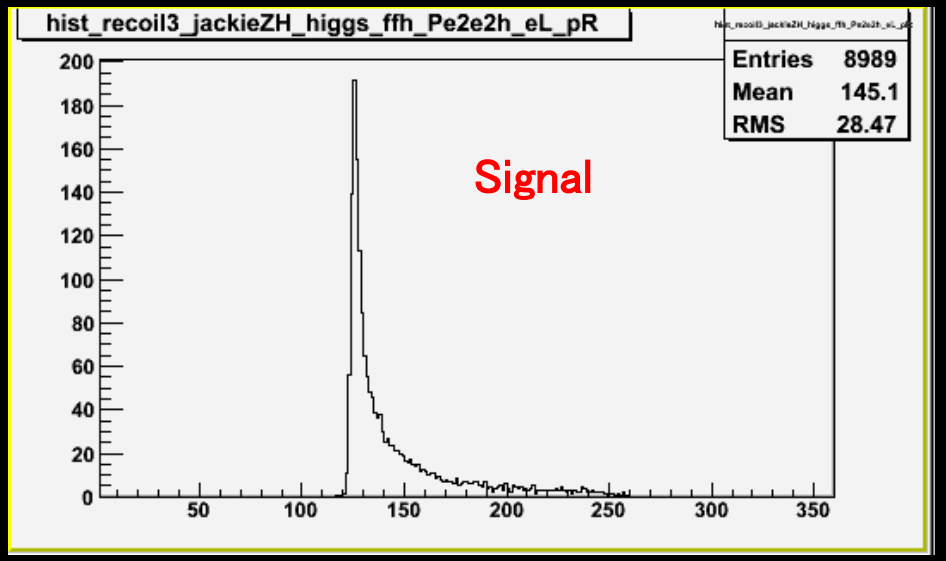


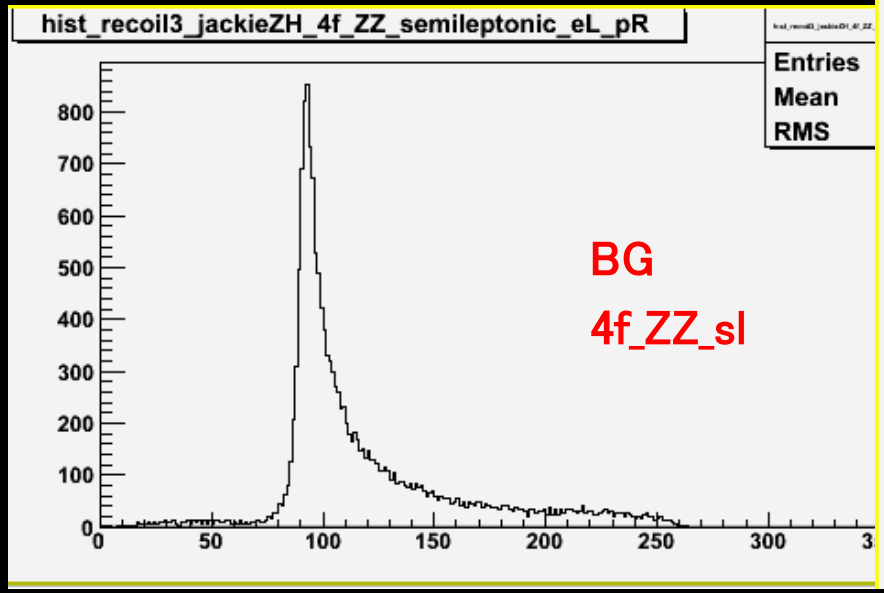


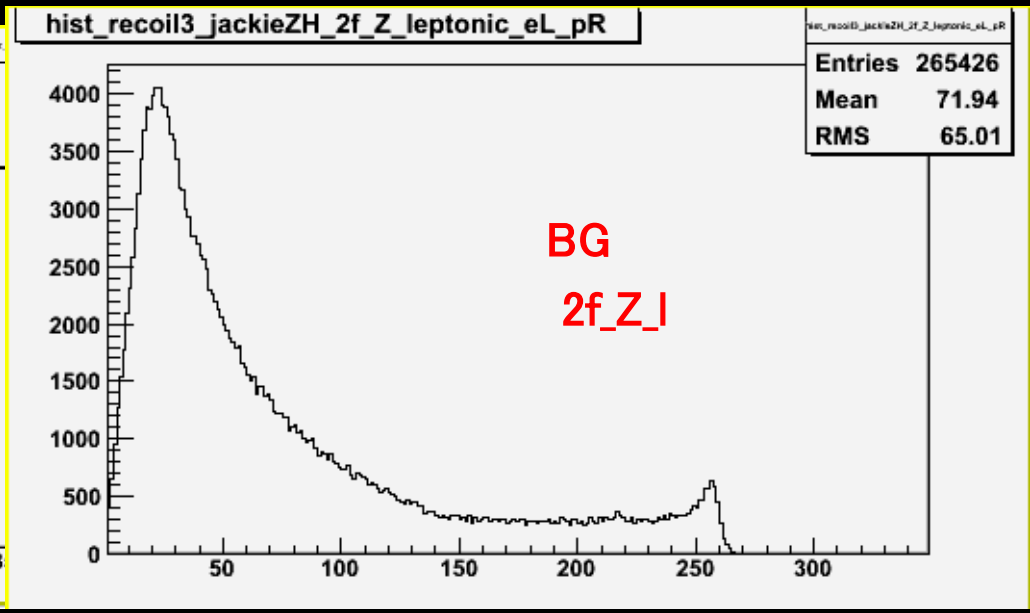
recoil mass 350 GeV

After inv mass cut





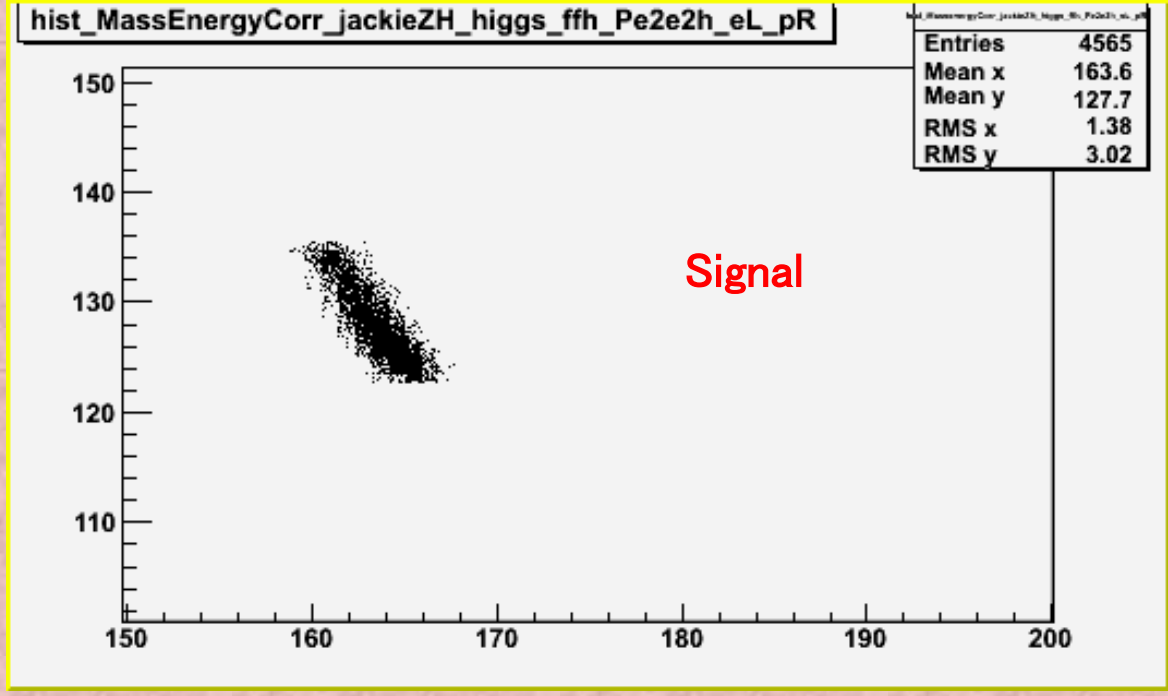


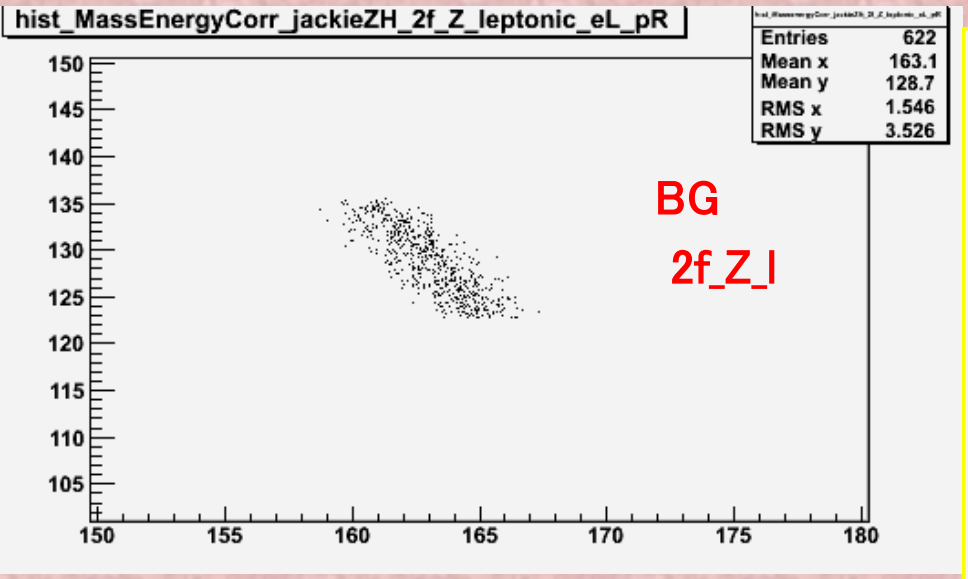


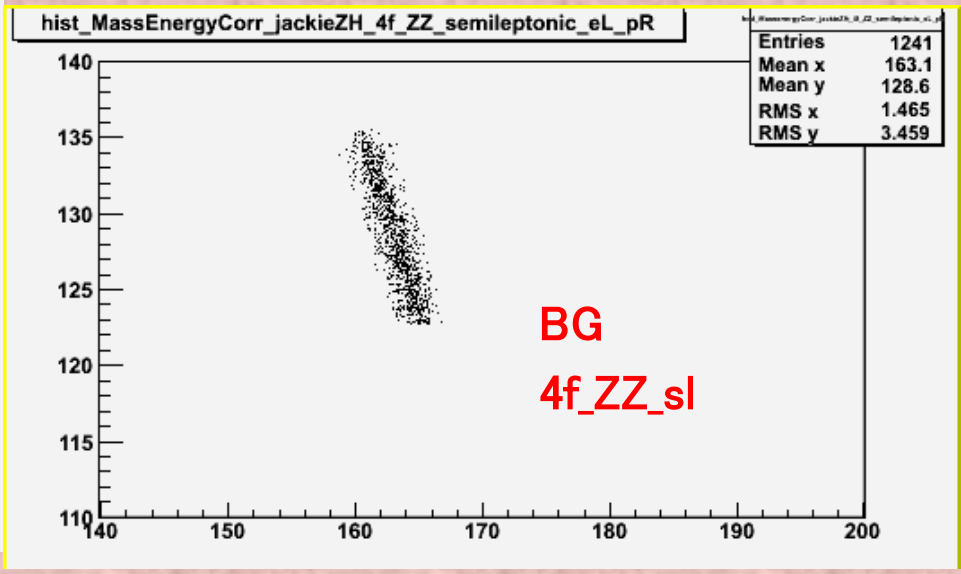
X axis : Z energy

Y axis : recoil mass

After cut







Summary

- **Higgs recoil mass study using e+e- → Zh → μ+μ-h**
  @ Ec.m.s. = 250 GeV, L = 250 fb-1 and **@ Ec.m.s =350 GeV, L = 333 fb-1**

- **optimized data selection method**
- Compared cross section error with (without) considering BG MC statistics
- tried higher statistic samples (250 GeV only)

- updated results:
  250 GeV:
- **ε_sig = 57.1 +/-0.4 %,** S/B ~ 0.04, **significance ~20.6**
  Δσmeas> / <σmeas> = 4.9 % (6.5%)
  fitted recoil mass : 125.2 GeV +/- 70 MeV

  350 GeV:
- **ε_sig = 40.4 +/-0.4 %,** S/B ~ 0.42, **significance ~16.6**
  Δσmeas> / <σmeas> = 6.0 % (8.8%)
- fitted recoil mass : 125.6 +/- 0.3 GeV

- Compared different **polarization** scenarios : **(-0.8, 0.3) vs (+ 0.8, -0.3) vs (0,0)**

Further Plans

- **focus on analysis at Ec.m.s. = 350 GeV**

- **how to cut much more BG without losing too much signal ?**
  - find out why lots of signal lost after track quality selection
  - further optimization of data cut values, add dPT,bal cut

- **improve fitting method**
  - Multiple step fitting, fix values from previous fit
  - evaluate efficiency by integrating fitted curve (c.f. integrate histogram**)**

BACKUP

DBD Samples

350 GeV

/grid/ilc/prod/ilc/mc-dbd/ild/dst-merged/350-TDR_ws/

Most important 6f BG

2048 May 29 18:05 WW + two other charged leptons (2 other ch leptons could be mu mu)

and the 2 samples with "Z":

2048 May 29 18:05 Z + four up type quarks

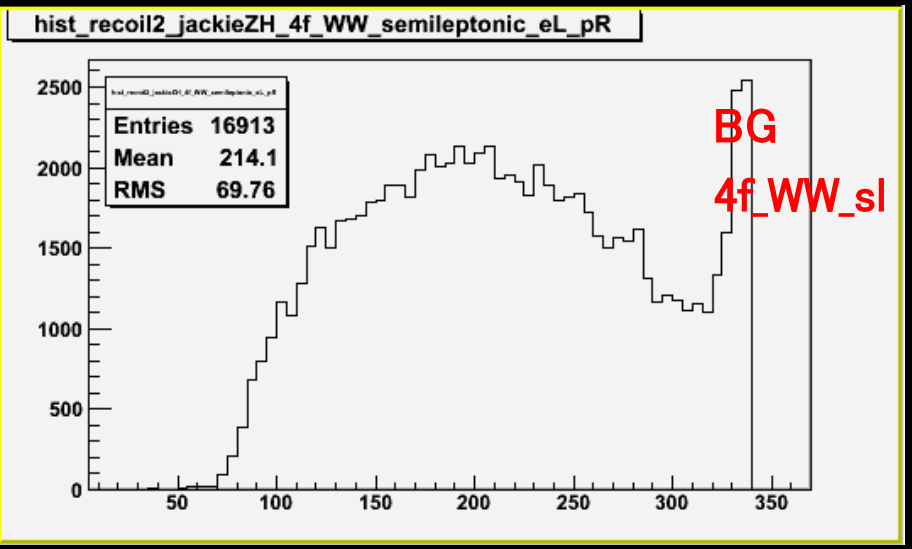
2048 May 29 18:05 Z + four down type quarks

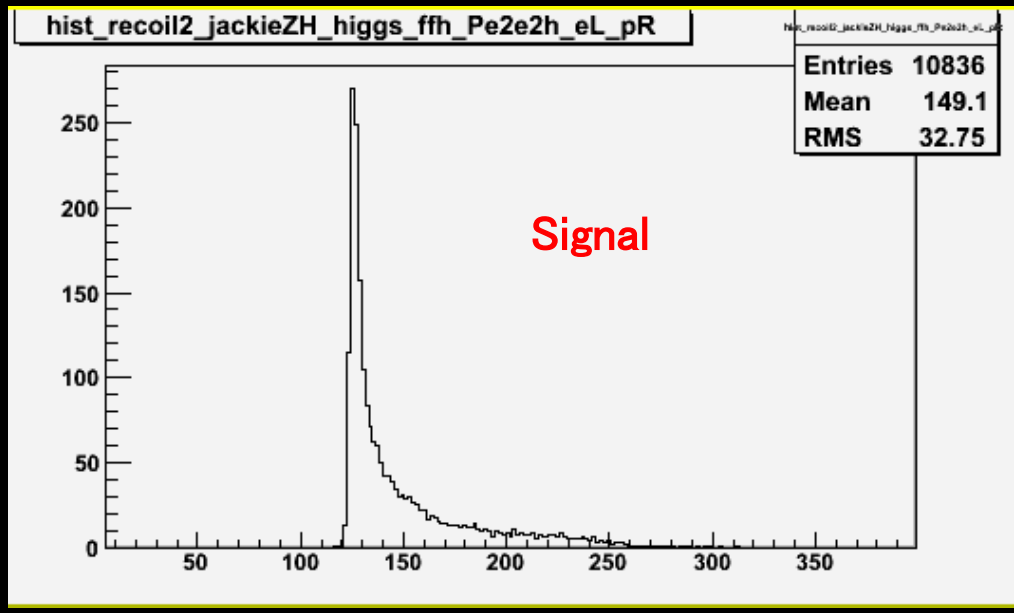
List of files

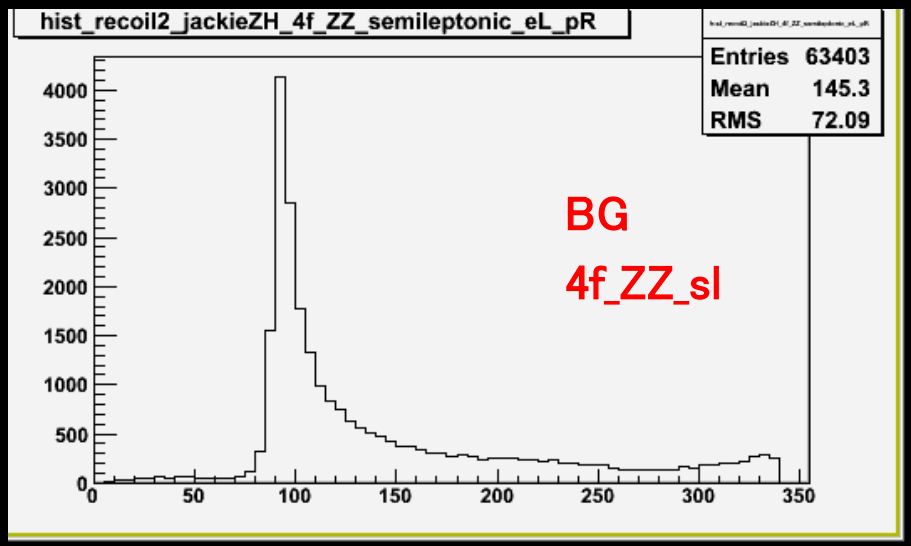
http://www-jlc.kek.jp/~miyamoto/CDS/prod_status/REC_ILD_o1_v05_350GeV.html

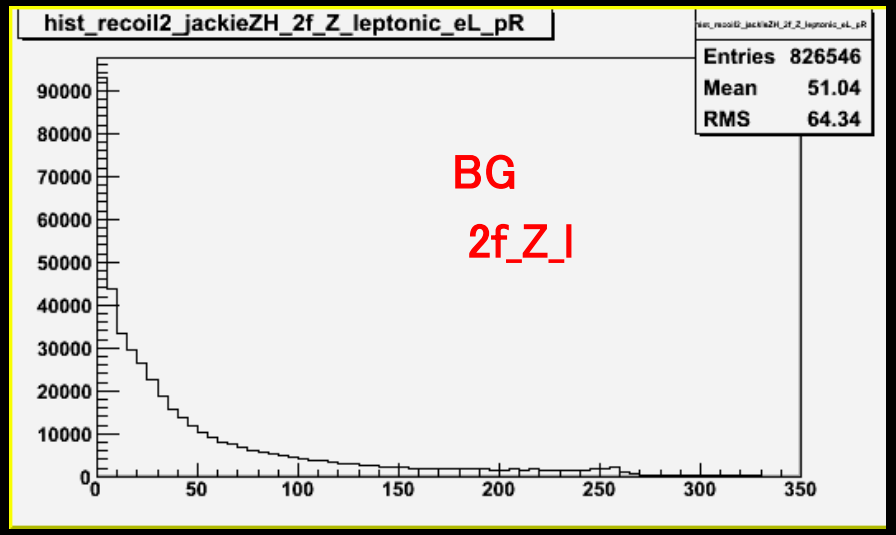
recoil mass 350 GeV

Before cut





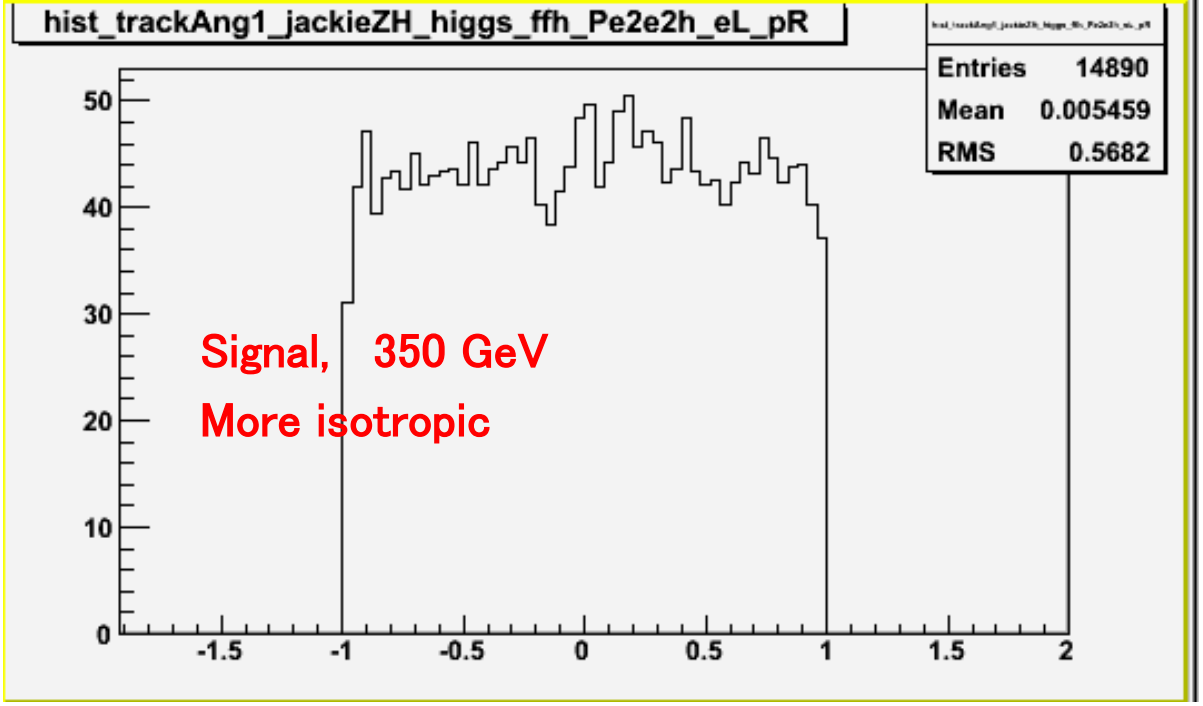




Cos(track angle), 350 GeV

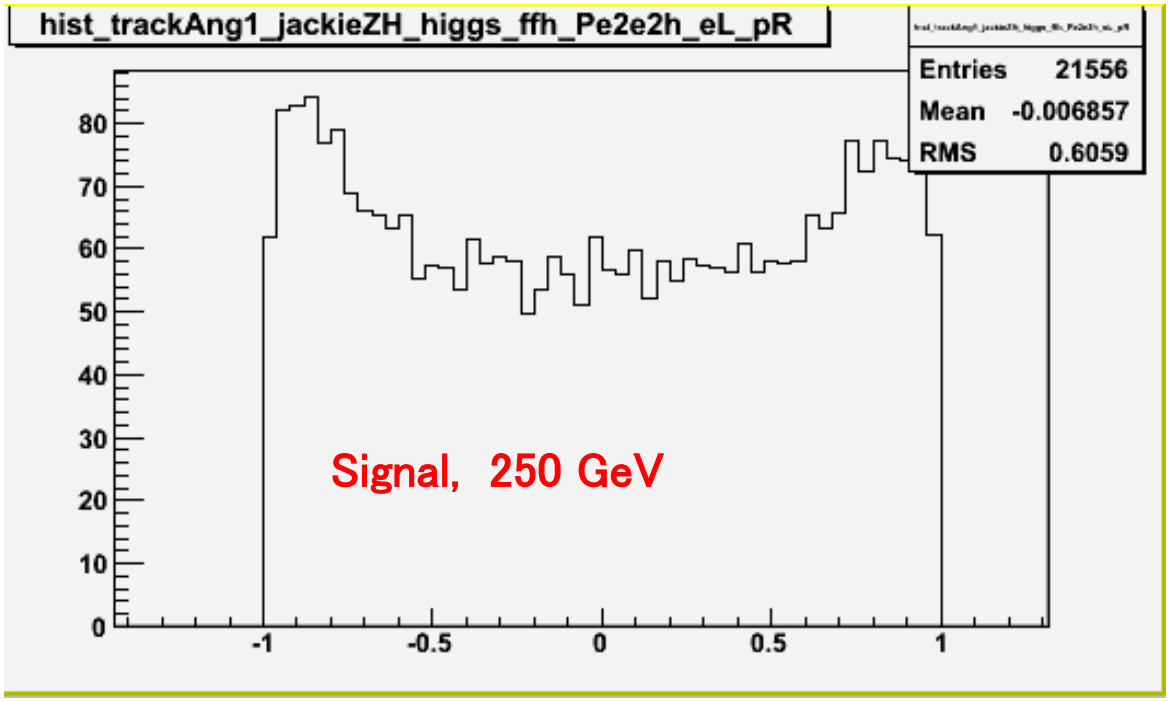
do cut

cos(trackAngle) < 0.98



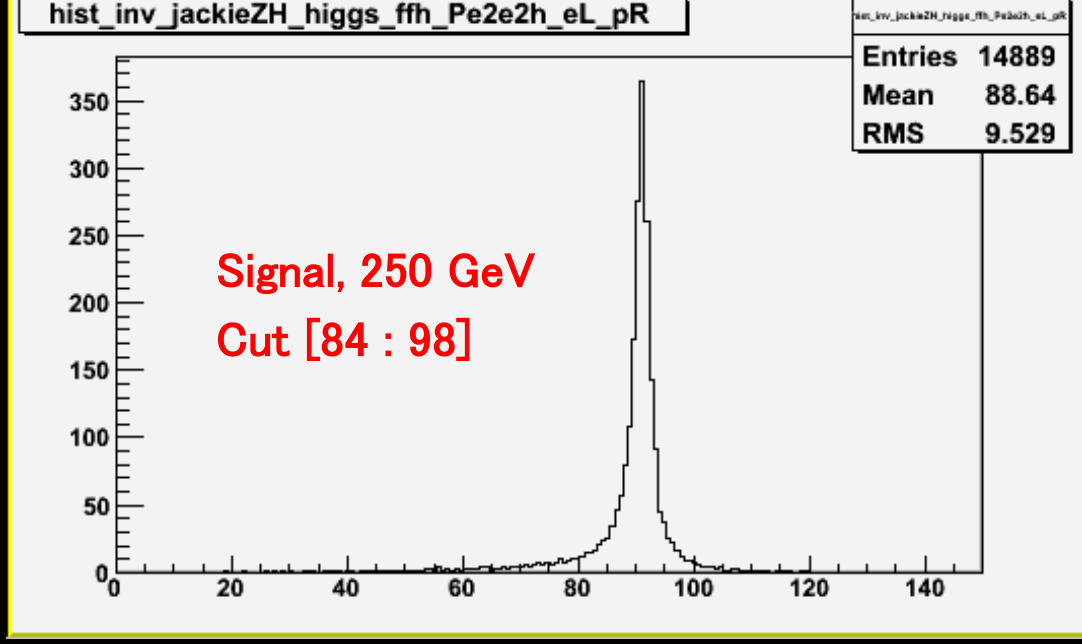
do cut :

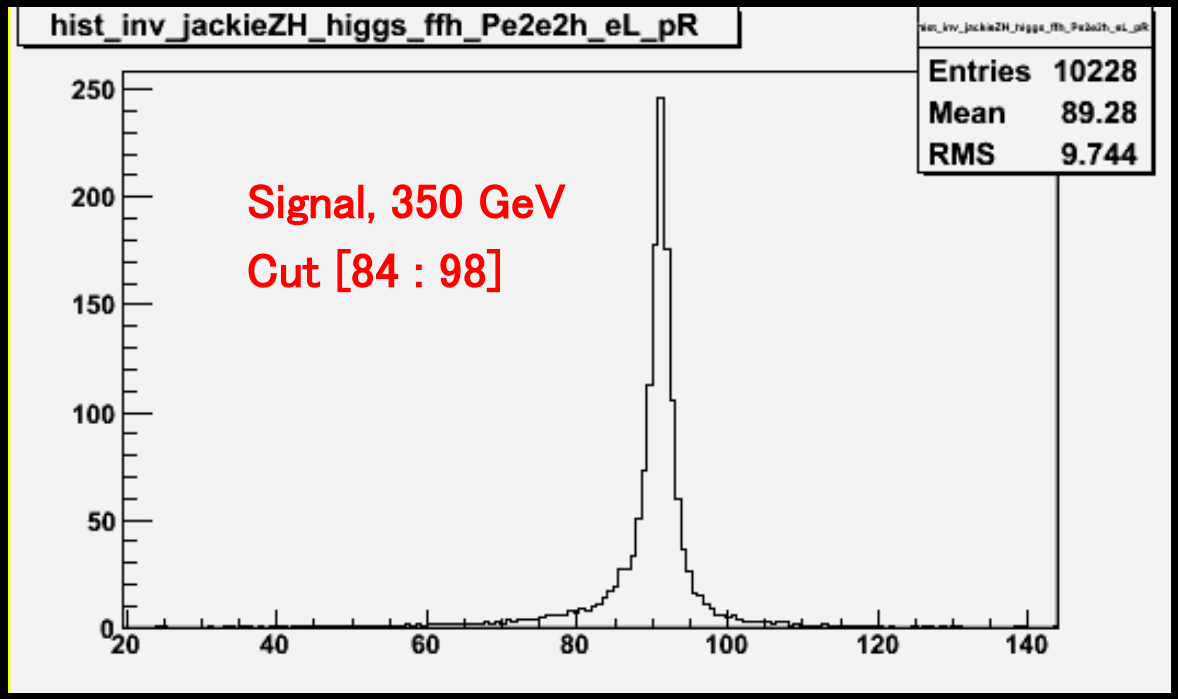
cos(trackAngle) < 0.95



invariant mass

before cut

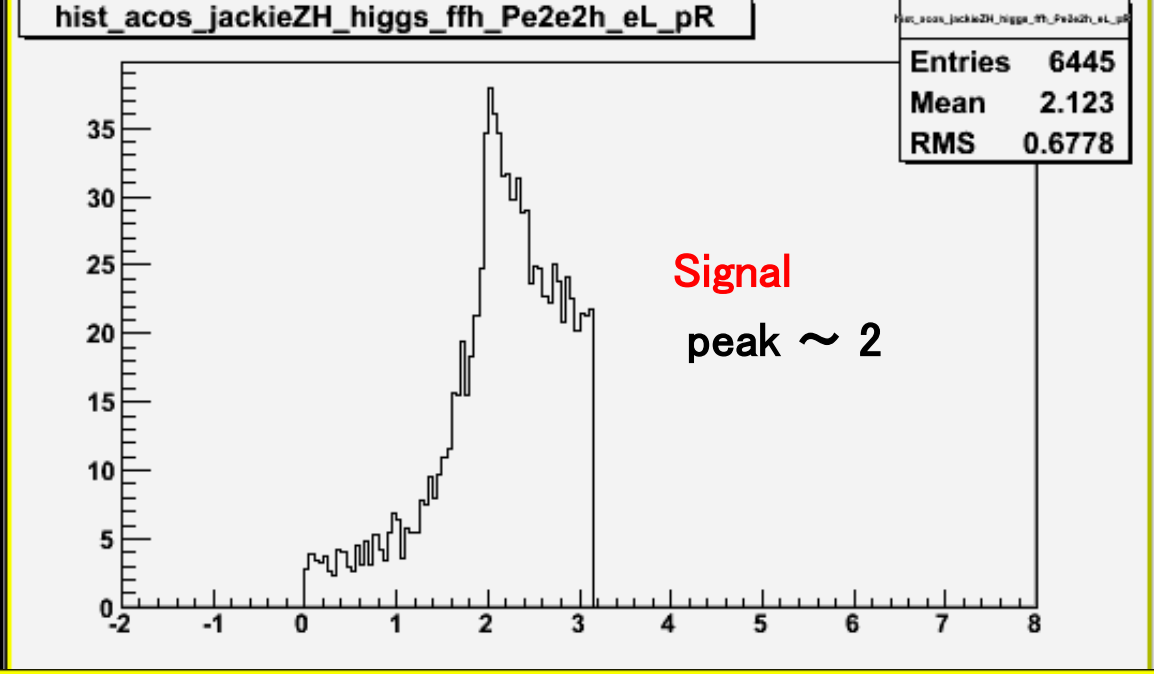


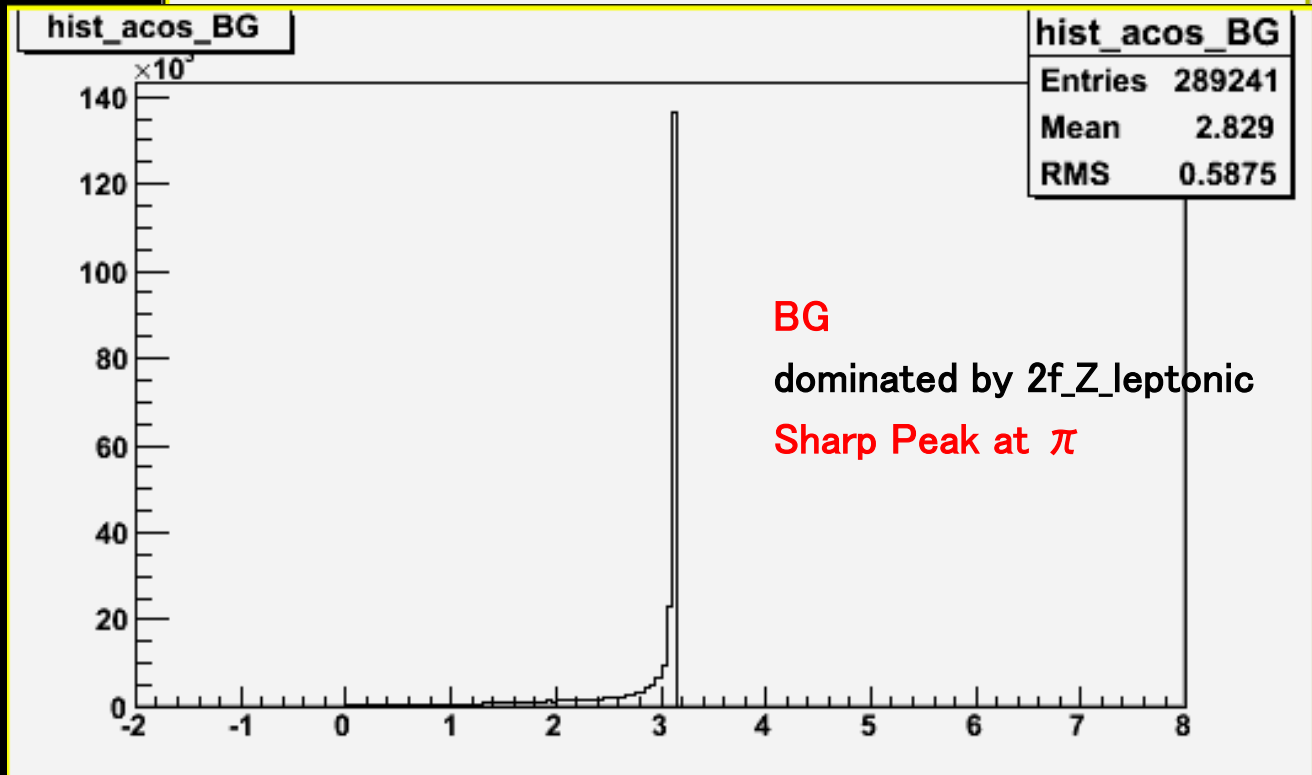


coplanarity, before cut ,
250 GeV

No coplanarity cut applied

wanted to maintain high signal eff.



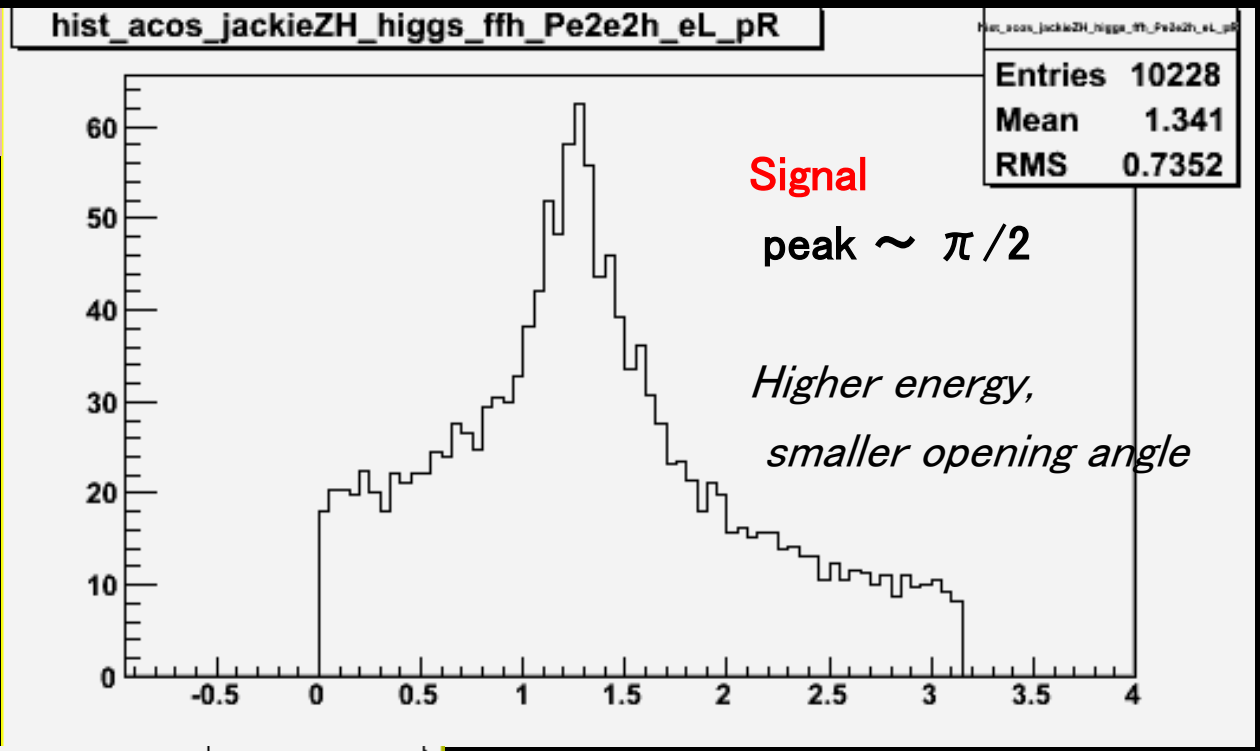


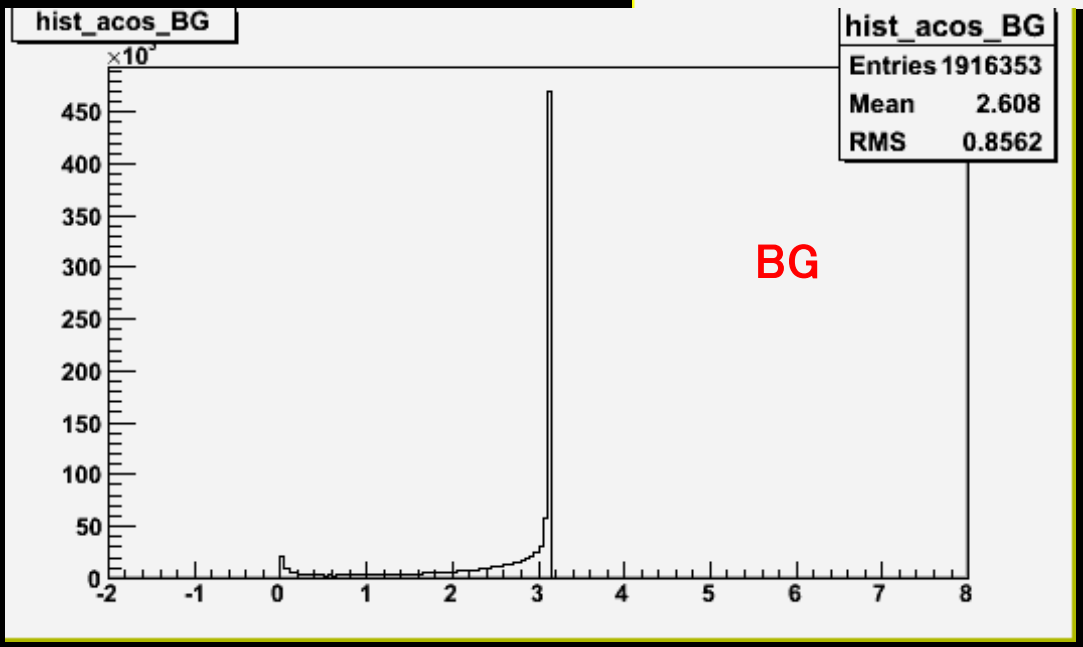
coplanarity, before cut 350 GeV

Cut:

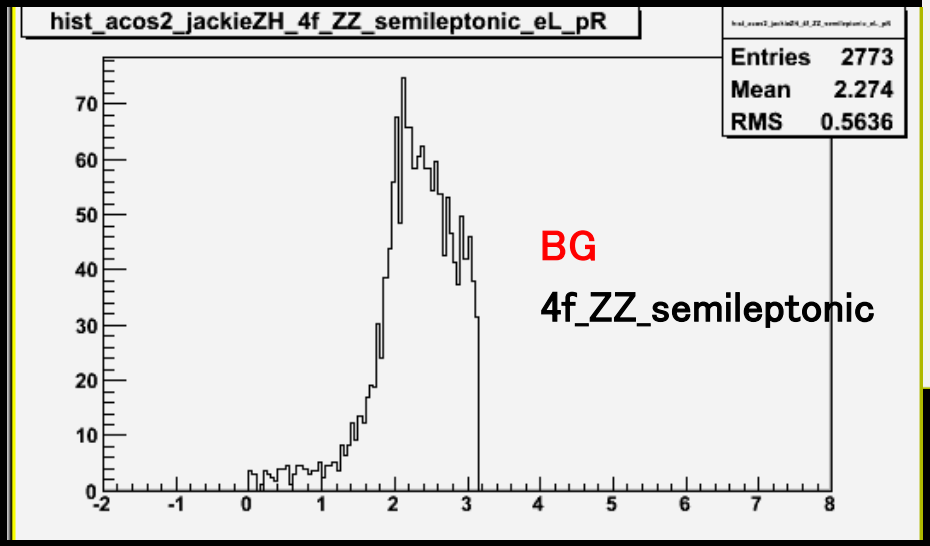
coplanarity ＜ 0.29

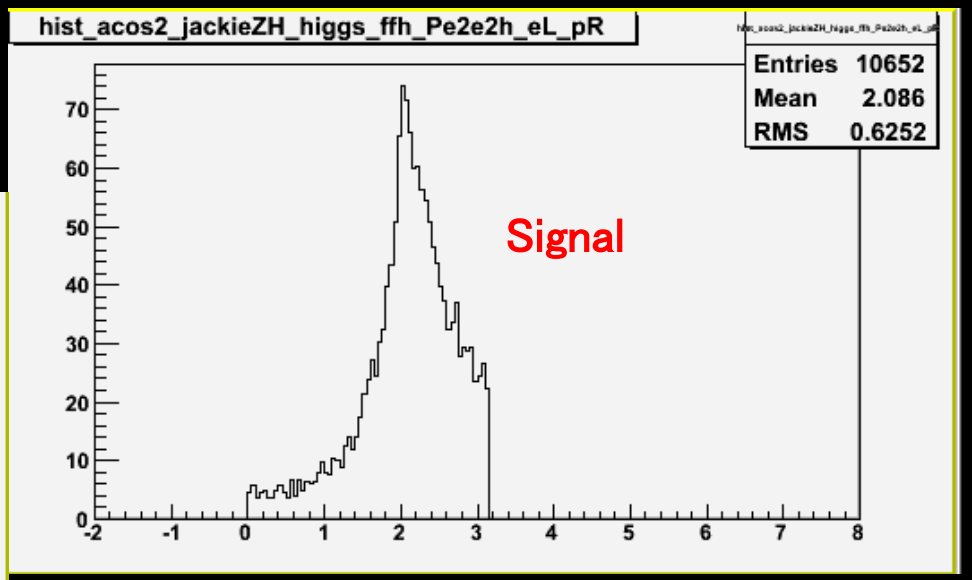
in order to remove more BG



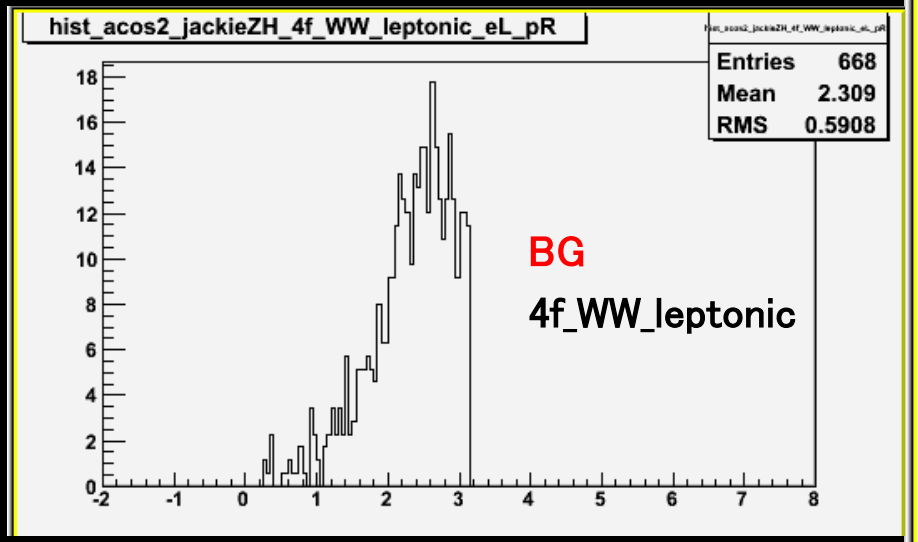


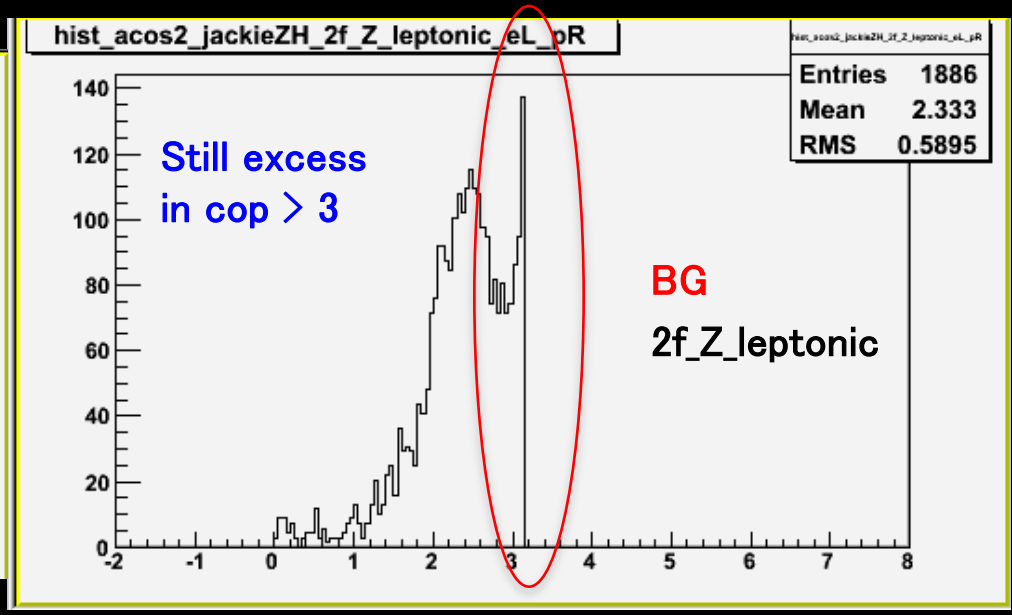
coplanarity, after all other cuts





Trying to decide whether to use coplanarity cut





Z production angle

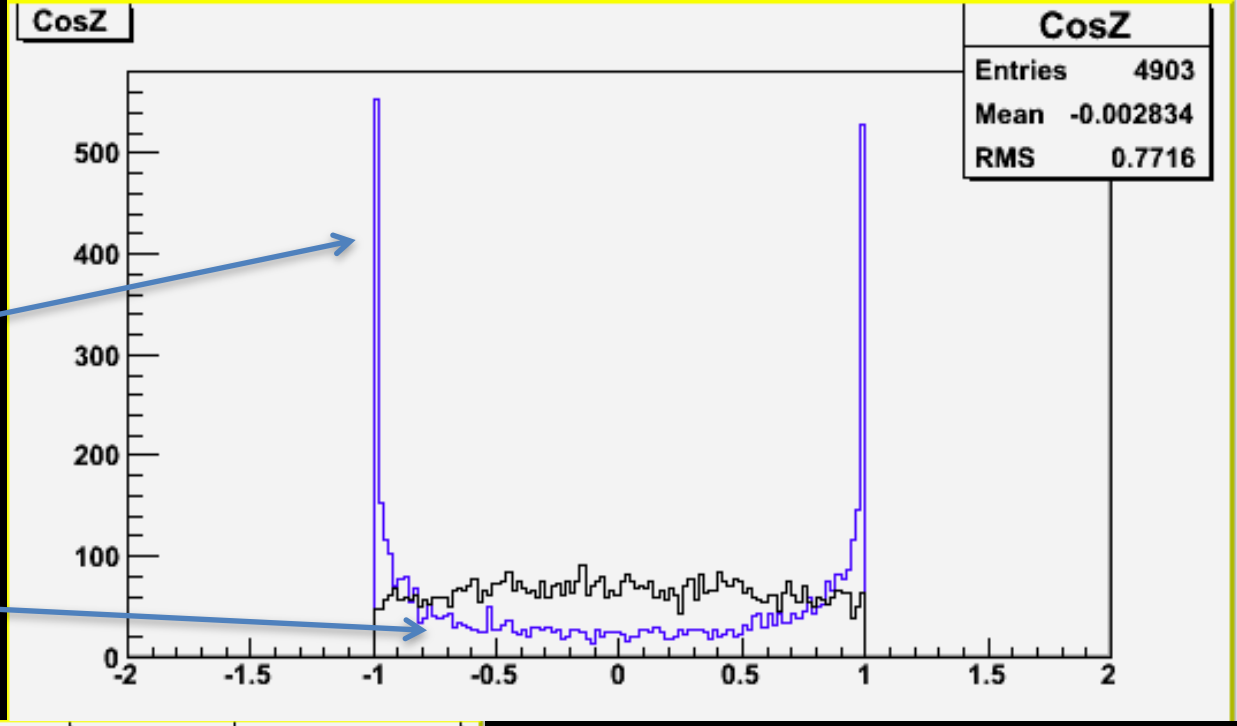
blue: BG (4f_ZZ_l

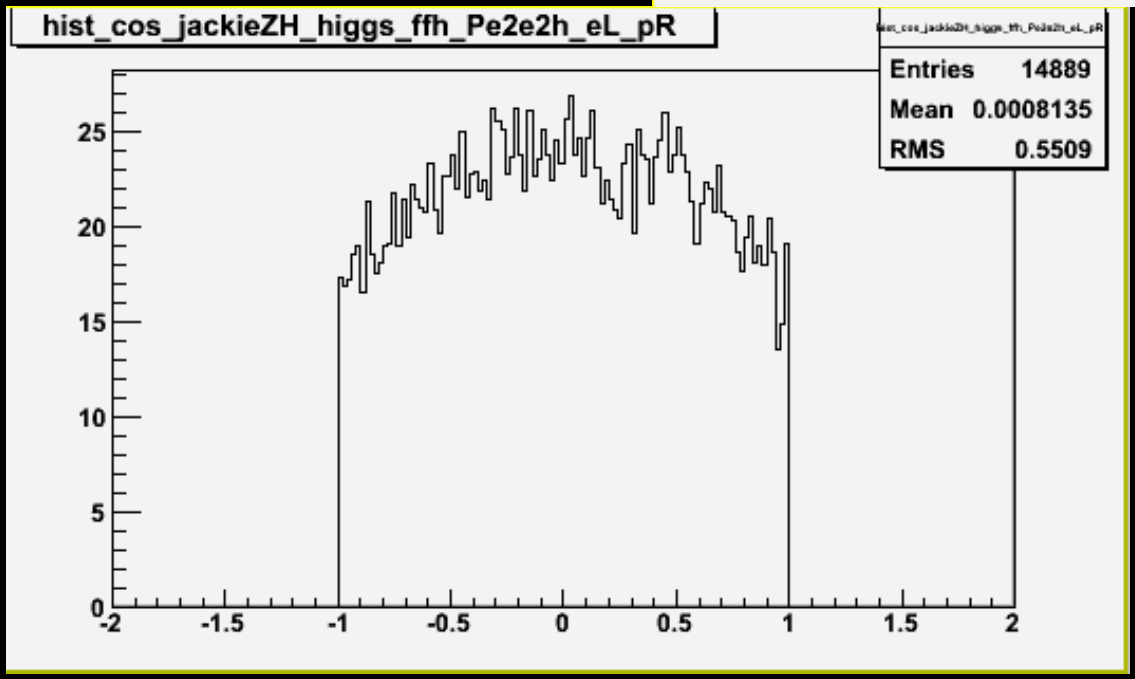
very forward

→ use for cut

Black: Signal

isotropic



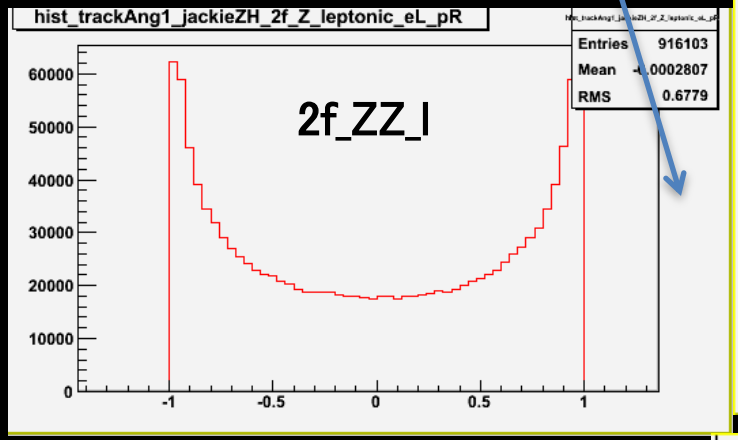


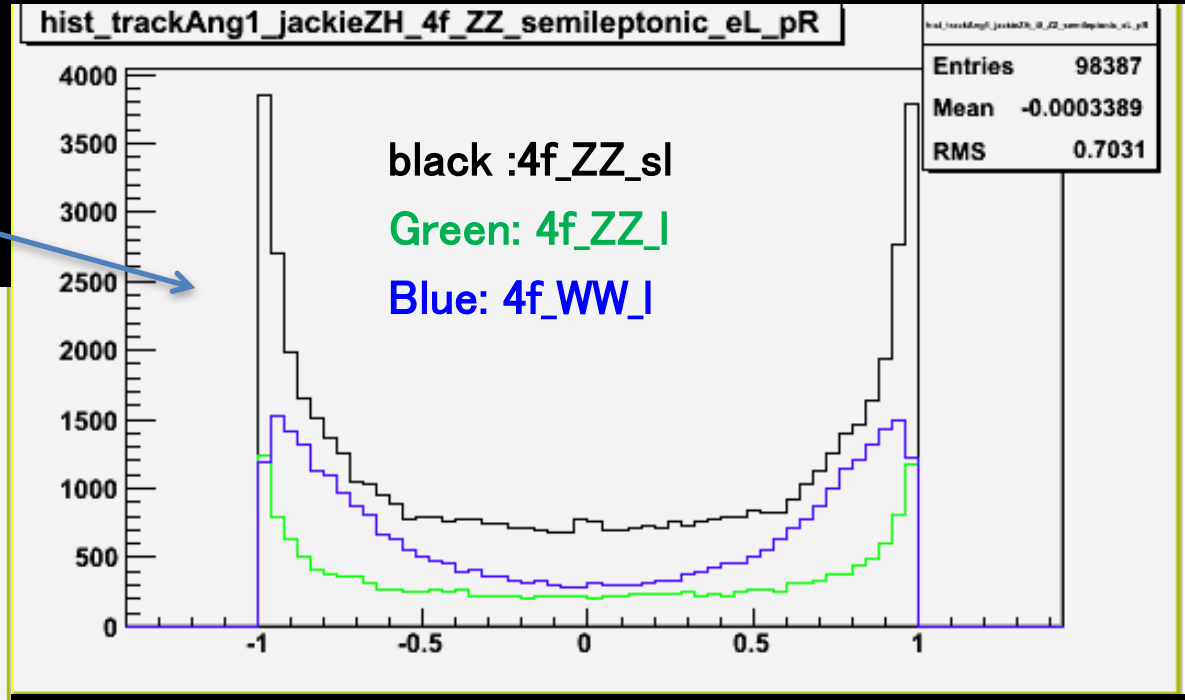
do cut :

$|\cos(\theta\_Zpro)| < 0.91$

Cos(track angle) ,
250 GeV

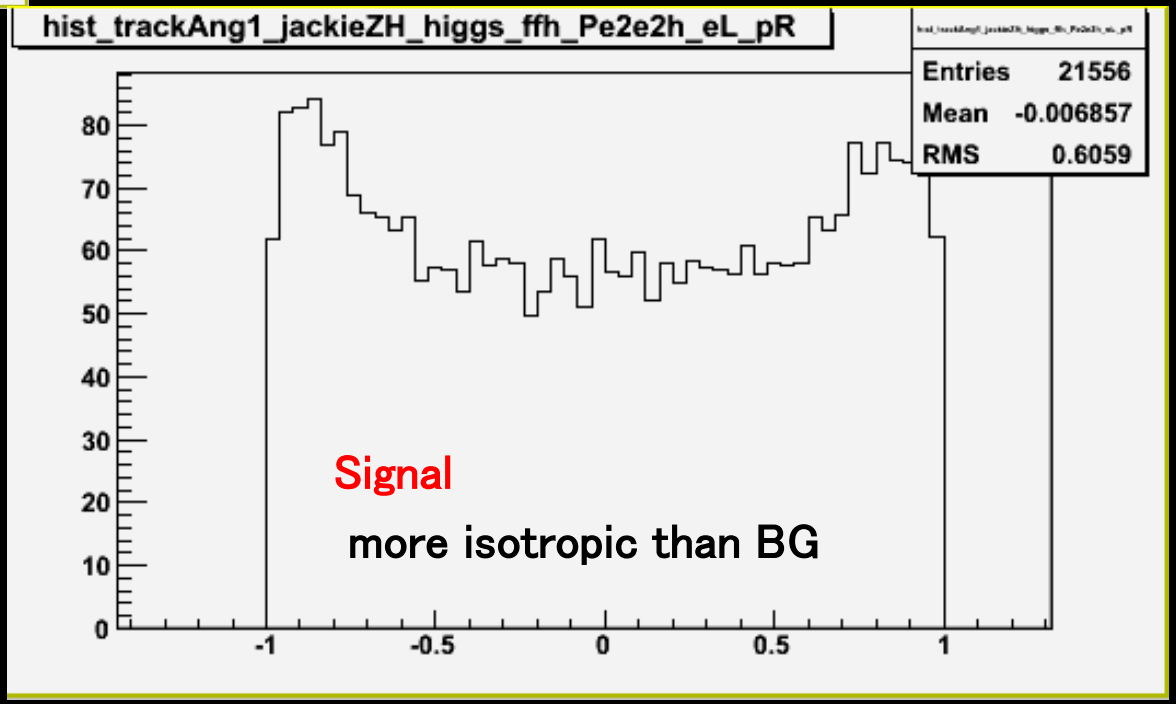
BG is More forward





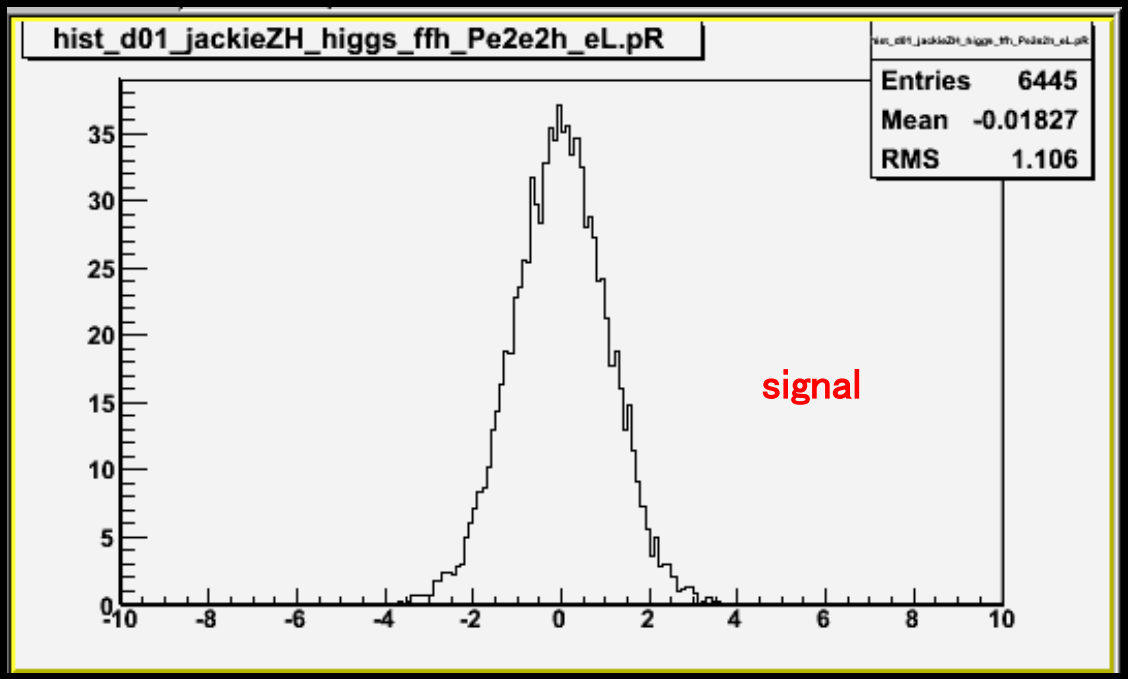
do cut :

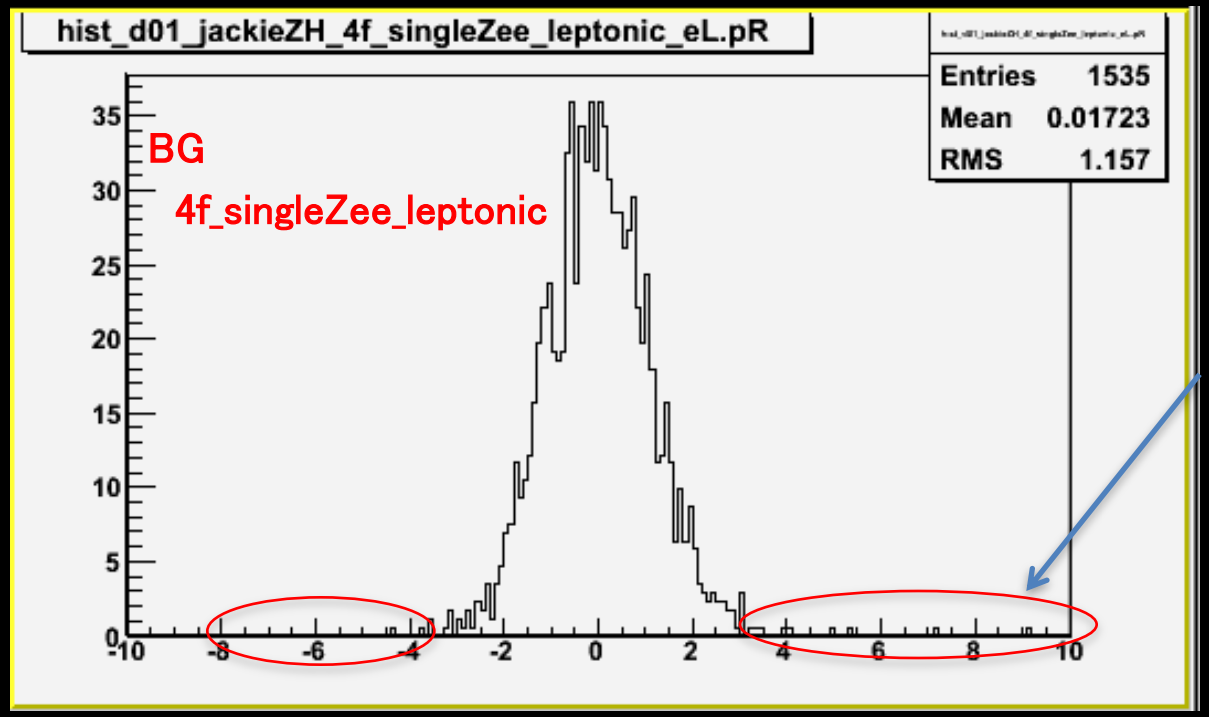
cos(trackAngle) < 0.95



Impact parameter

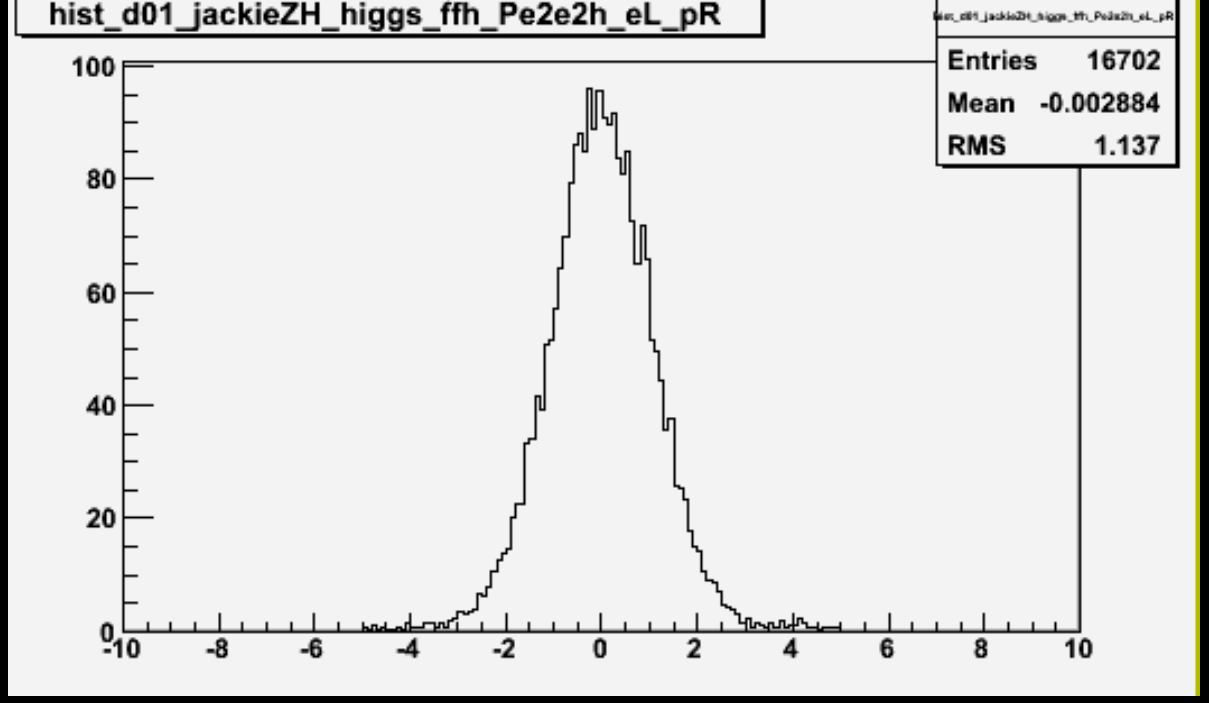
D0/ δ D0

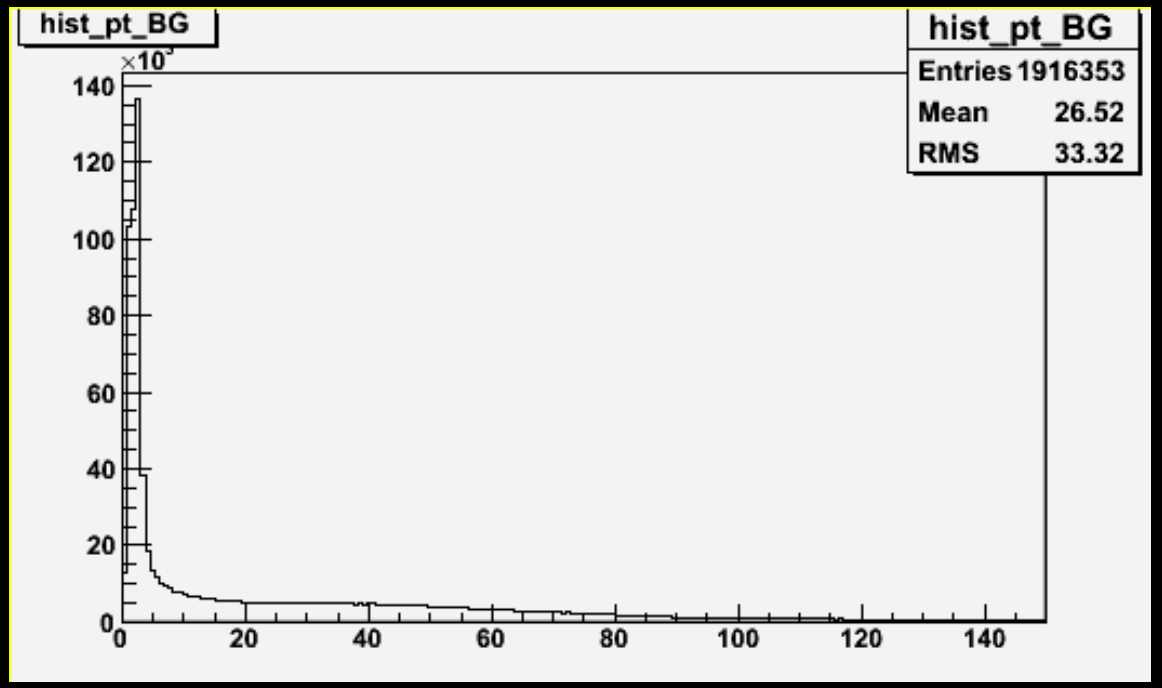




For some BG processes exceed +/− 4 slightly

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


hist_d01_jackieZH_higgs_ffh_Pe2e2h_eL_pR
Entries 16702
Mean -0.002884
RMS 1.137
100
80
60
40
20
0
-10
-8
-6
-4
-2
0
2
4
6
8
10


hist_pt_BG
hist_pt_BG
Entries 1916353
Mean 26.52
RMS 33.32
×10³
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140

statistic error of cross section σs

we want to **maximize** **significance = <S>/ sqrt(<S> + <B>)**

i.e. optimize (efficiency ε) x (purity π= <S> / <N>)

expected # of signal events **⟨S⟩ = ε * L* σs** (L: integrated Luminosity)

assume ⟨B⟩ in signal region is "known" with small uncertainty

if observe N events and ignore uncertanty of Bg and eff :

<Δσmeas> / <σmeas> = **inversely of {significance = <S> / sqrt(<S> + <B>) }**

Error on efficiency = n/N

binomial distr.

if detect n signal events out of N events : **efficiency = n/N** (assume N is constant)

stat error on n : Δn = sqrt(N*ε*(1-ε)) ➔ Δn/n = sqrt((1-ε)/n))

higher ε, larger n is better

How to estimate error of cross section σs ?

when measuring σs , we want to **maximize** **<S>/ sqrt(<S> + <B>)**

i.e. optimize **(efficiency ε) x (purity π)**

Why ??

A:

- expected # of signal events **⟨S⟩ = ε * L* σs** (L: integrated Luminosity)
- **Expected # of BG events ⟨B⟩ in signal region**

assume <B> is "known" with small uncertainty compared to stat. error on <S>

- total # of events **<N> = <S> + <B>** = ε * L* σs + <B>

if observe N events : σmeas = (N - <B>) / (ε*L)

Stat error < Δσmeas> = ΔN / (ε*L) = sqrt(<N>)/(ε*L)

Purity π = <S>/ (<S>+<B>) = <S> / <N>

sqrt(<S>*π) = <S> / sqrt(<S>+<B>)

<N> = <S> / π = ε * L* σs / π

<Δσmeas> = sqrt(ε * L* σs/π) / (ε * L) = sqrt(σs/ε * L* π))

<Δσmeas> / <σmeas> = 1/ sqrt(ε * L* σs*π) = 1 / sqrt(<S>*π)

➔ **σs measurement error is inversely proportional to <S> / sqrt(<S> + <B>) !!**

example dagrams for BG process for Zmumu