Higgs Recoil Mass Study

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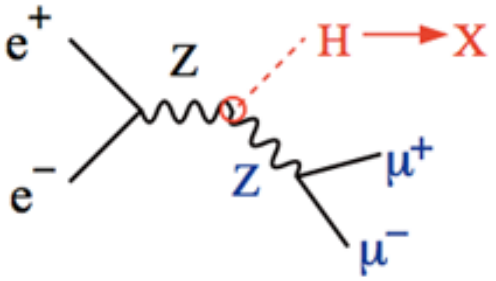
recoil mass study using e+e- → Zh → μ+μ-h @ Ec.m.s. = 250 GeV, L = 250 fb-1

polarization:
(e−, e+) = (0.8, 0.3)

Goal:

precise measurement of

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



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

Changes from previous week

- ☐ data selection optimization (adjust cut window for invariant mass and coplanarity)
  → **improved signal efficiency and significance**

- ☐ estimate error on efficiency and cross section
- ☐ compare with results between difference polarization
  (- 0.8, + 0.3) **vs** **(-0.8, 0)** **vs** **(0, 0)**
- ☐ added all signal and BG processes, just to make sure

DBD Samples

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

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
- 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

Next optimized these parameters

Final Selection from LAST WEEK

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_coplanarity < 3**
- |cos(θ_Zpro)| < 0.91 (Z production angle)

Best Z Candidate Selection

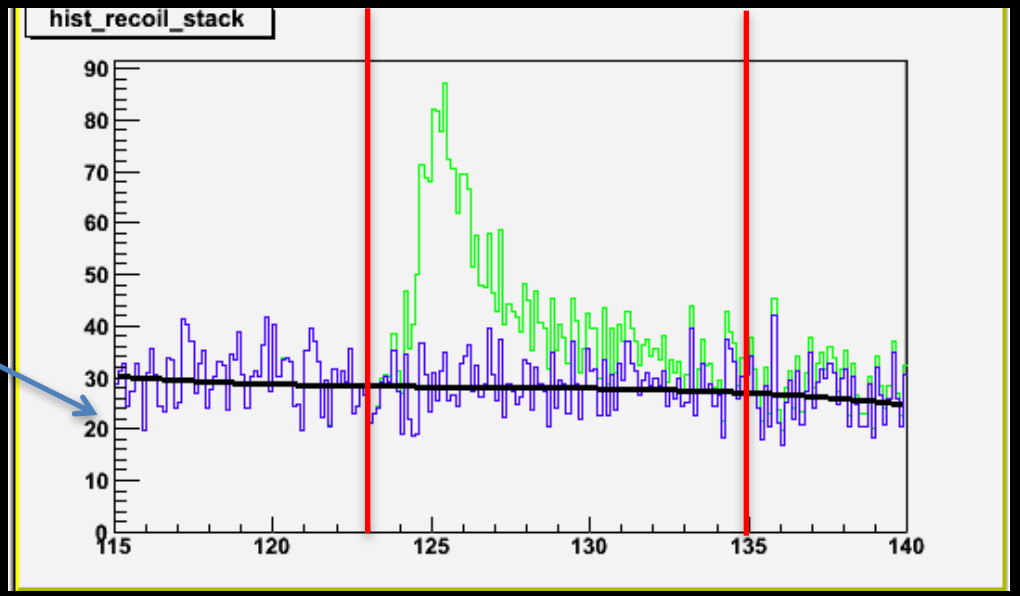
2 mu candidates with **opposite charge**

if several possibilities :

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

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

calculate recoil mass with correction for 14 mrad beam crossing angle



Final Selection Optimization #1

Wider Minv cut

- 84 GeV < M_mumu < 98 GeV
- 123 GeV < Mrecoil < 135 GeV
- 10 GeV < pT_mumu < 70 GeV
- mumu_coplanarity < 3

removed lower limit on coplanairty

- |cos(θ_Zpro)| < 0.91
  (Z production angle)

Final Selection Optimization #2

- 84 GeV < M_mumu < 98 GeV
- 123 GeV < Mrecoil < 135 GeV
- 10 GeV < pT_mumu < 70 GeV
- ~~mumu_coplanarity < 3~~

removed coplanarity cut

- |cos(θ_Zpro)| < 0.91
  (Z production angle)

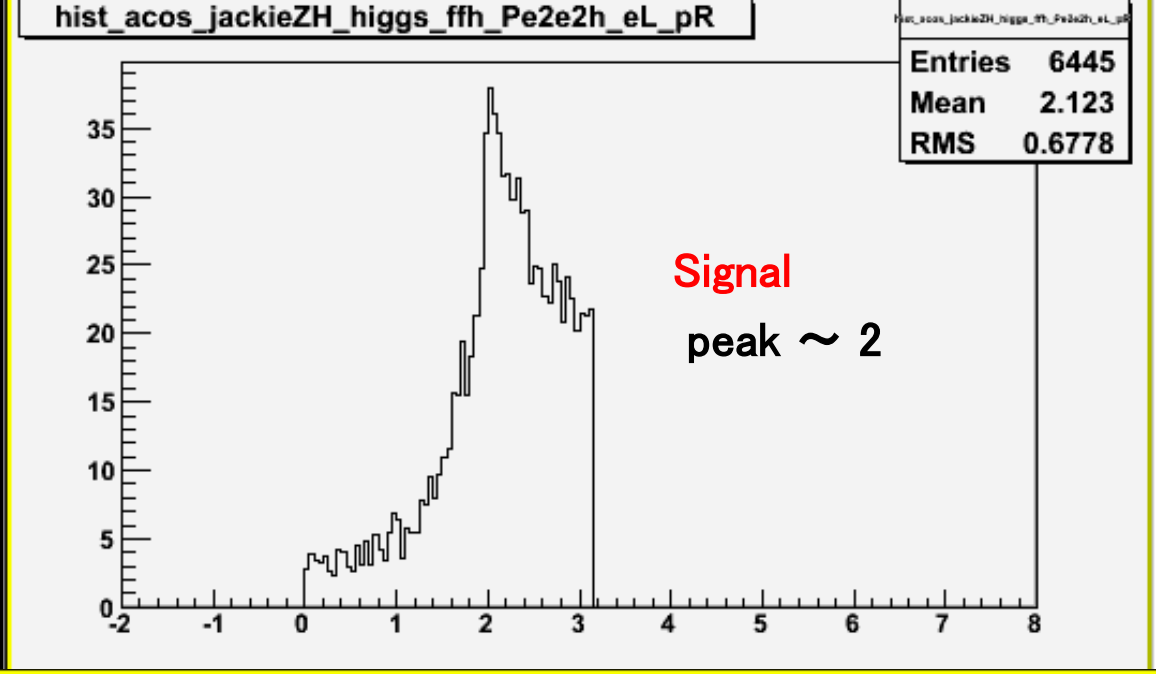
Comparison of Some Parameters between Signal and BG Processes

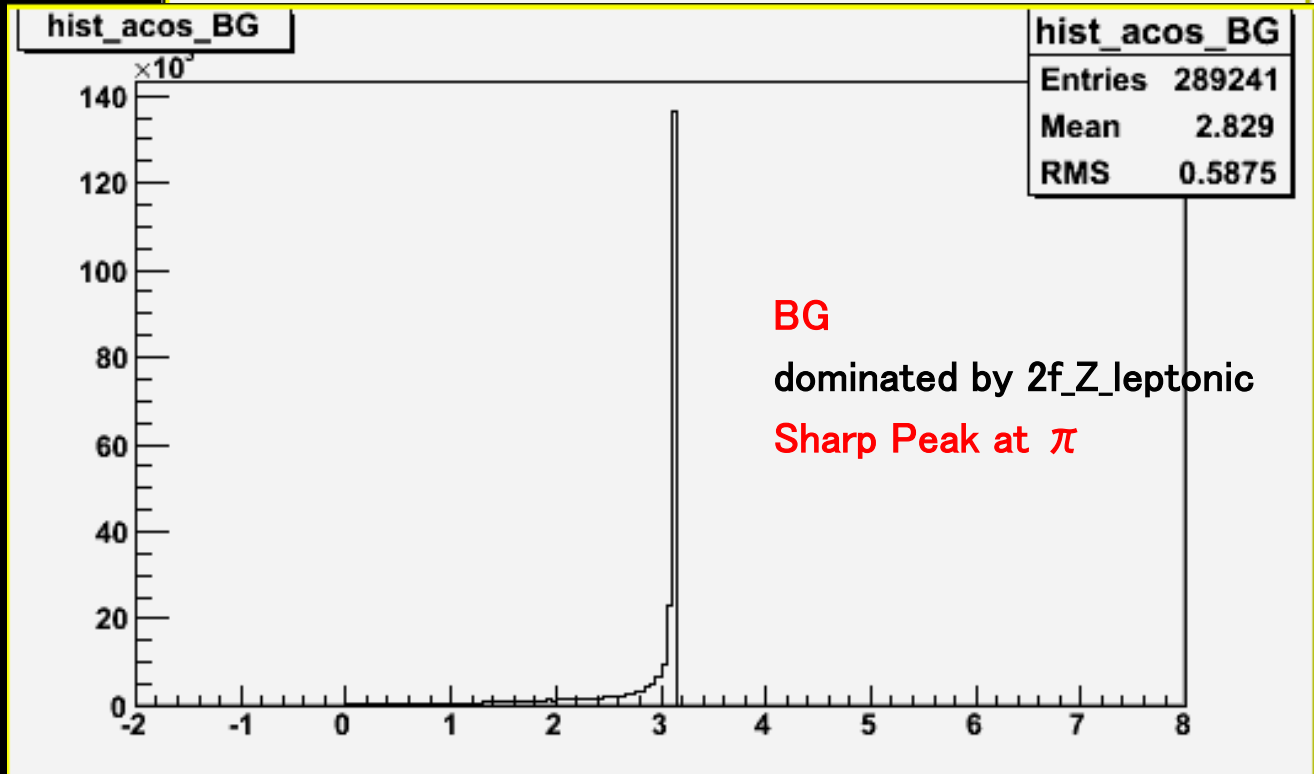
coplanarity、
before cut

Tried to cut:

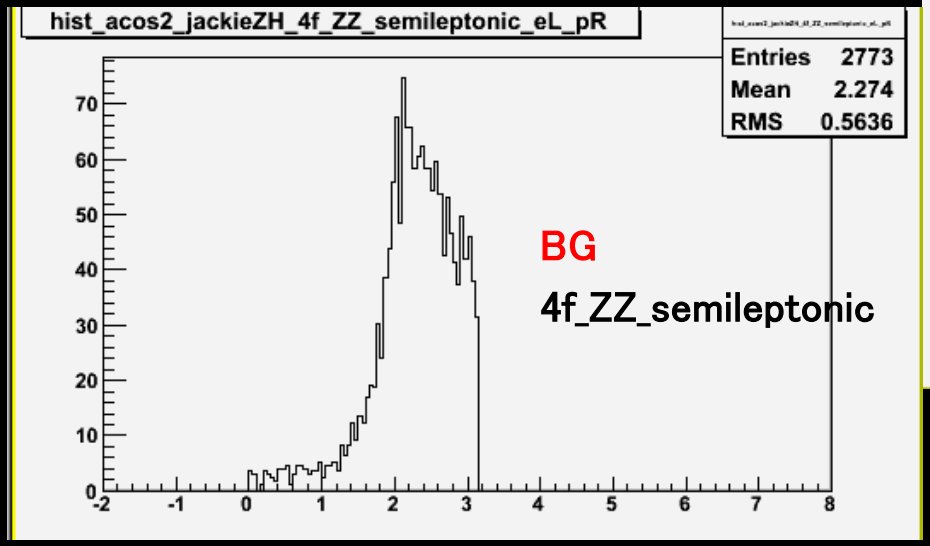
0.2 < cop < 3

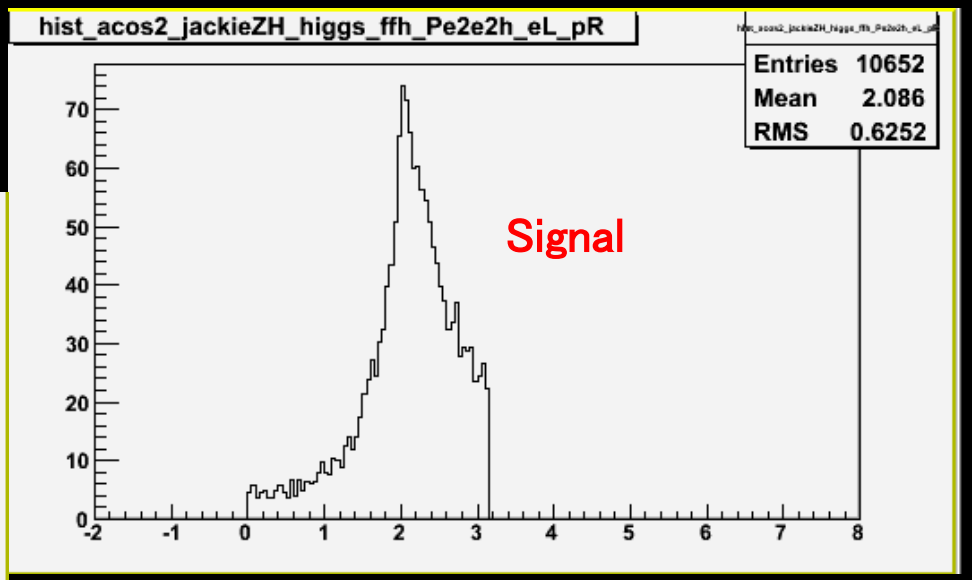
or just cop < 3



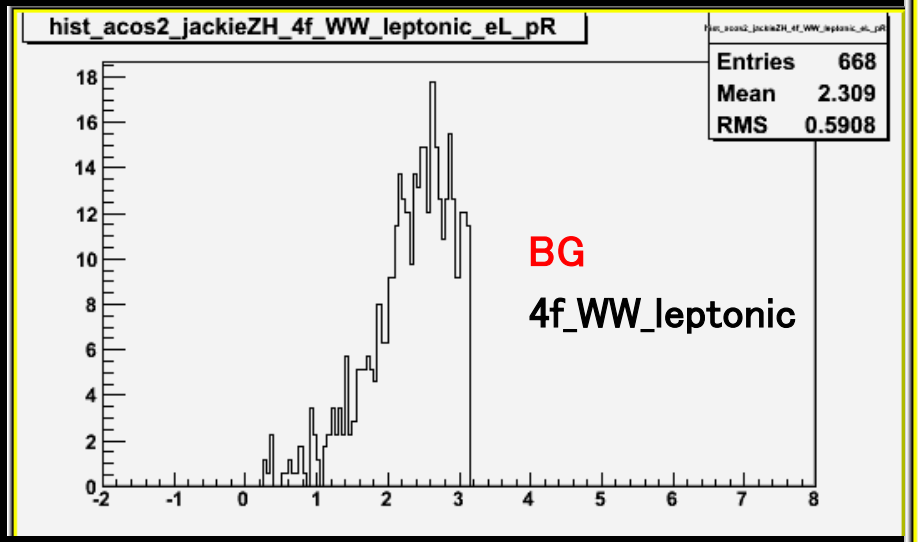


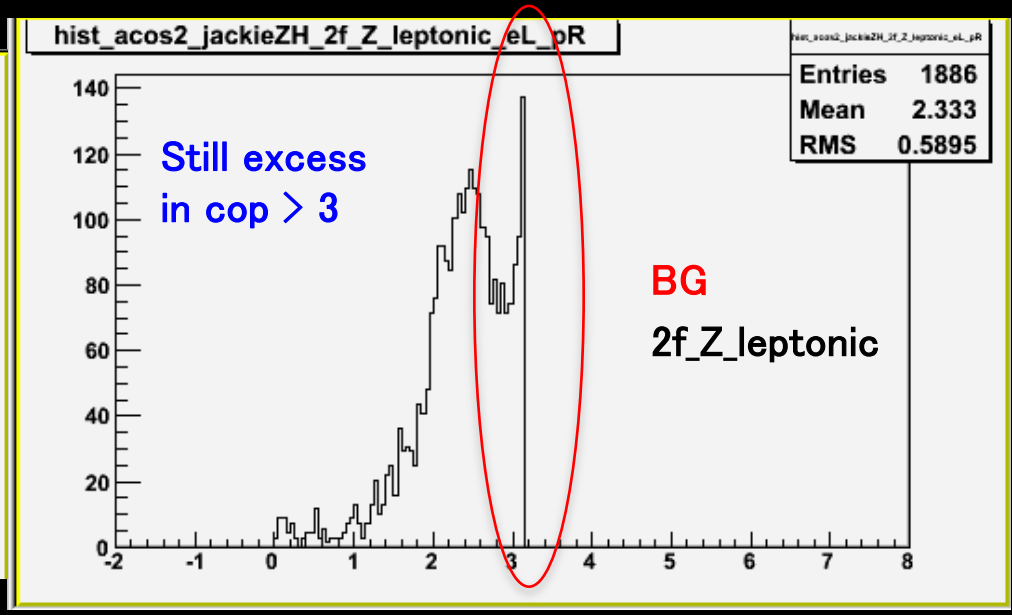
coplanarity, after all other cuts





Trying to decide whether to use coplanarity cut





Z production angle

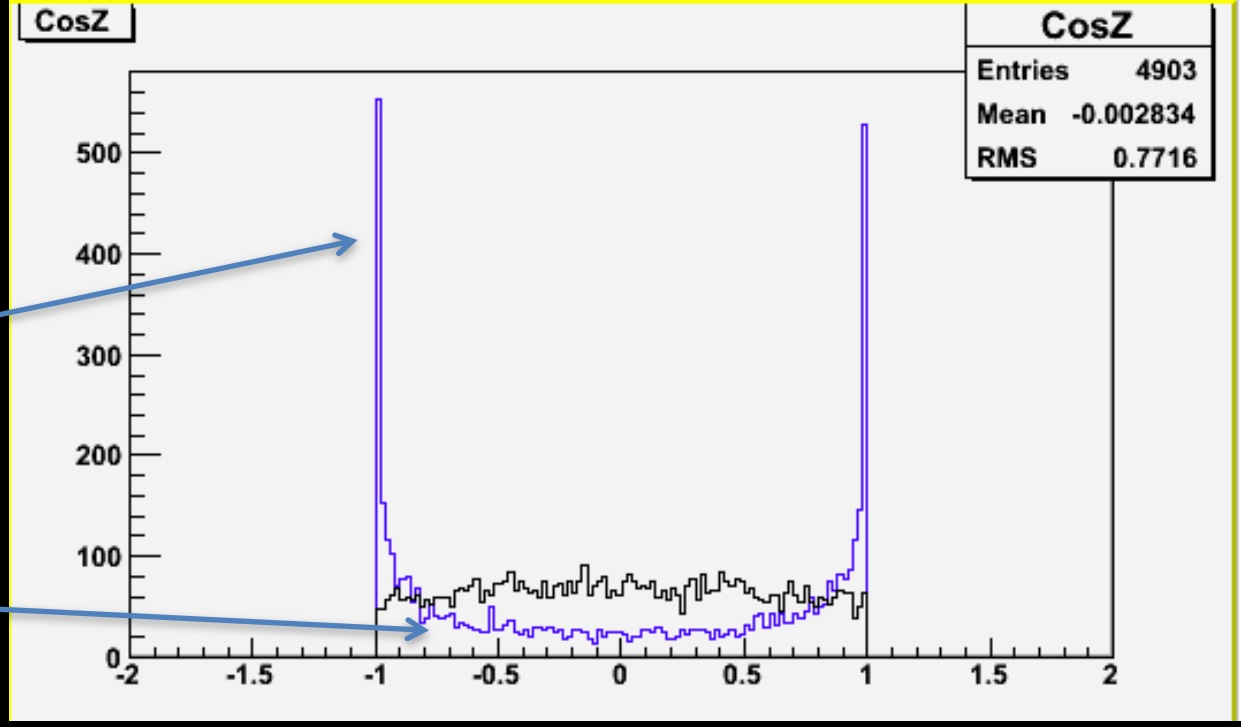
blue: BG (4f_ZZ_l

very forward

→ use for cut

Black: Signal

isotropic



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

BG Rejection Efficiency : 123 – 135 GeV : last week

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 %

S/N → 0.47

Significance ～20.3

Improvement after change to **coplanarity < 3 (remove lower limit)**
<S> = 1421, Sig eff 66 %, S/B = 0.47, S/sqrt(S+B) = 20.6

after M_rec cut ..... ***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
0.2 < cop < 3	156	680	1695	124	80	199	610
θZ	132	596	1164	115	69	175	537

NEWEST

BG Rejection Efficiency : 123 – 135 GeV

removed coplanarity altogether

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
84 <M_inv <98	1742	81%	15359	30.44%	0.120	13.321
123 <M_rec <135	1606	74%	9330	18.49%	0.183	15.357
10 <P_Tdl<70	1584	73%	4785	9.48%	0.363	19.848
cos(θ Z)<0.91	1491	69%	3637	7.21%	0.385	20.821

Signal efficiency 69 %

S/N → 0.39

Significance ~20.8

cut	4f_ZZ_l	4f_ZZ_sl	2f_Z_l	4f_WW_l	4fSingleZe	4fSingleZr	4f_ZZWWMix_l
no cut	989	4163	27574	5735	2295	810	8896
best mu	753	3251	19228	1543	880	668	7787
84 <M_inv <98	379	1407	11047	350	174	392	1612
123 <M_rec <135	229	854	6710	212	108	242	976
10 <P_Tdl<70	205	831	2259	208	105	235	944
cos(θ Z)<0.91	168	719	1447	193	86	200	824

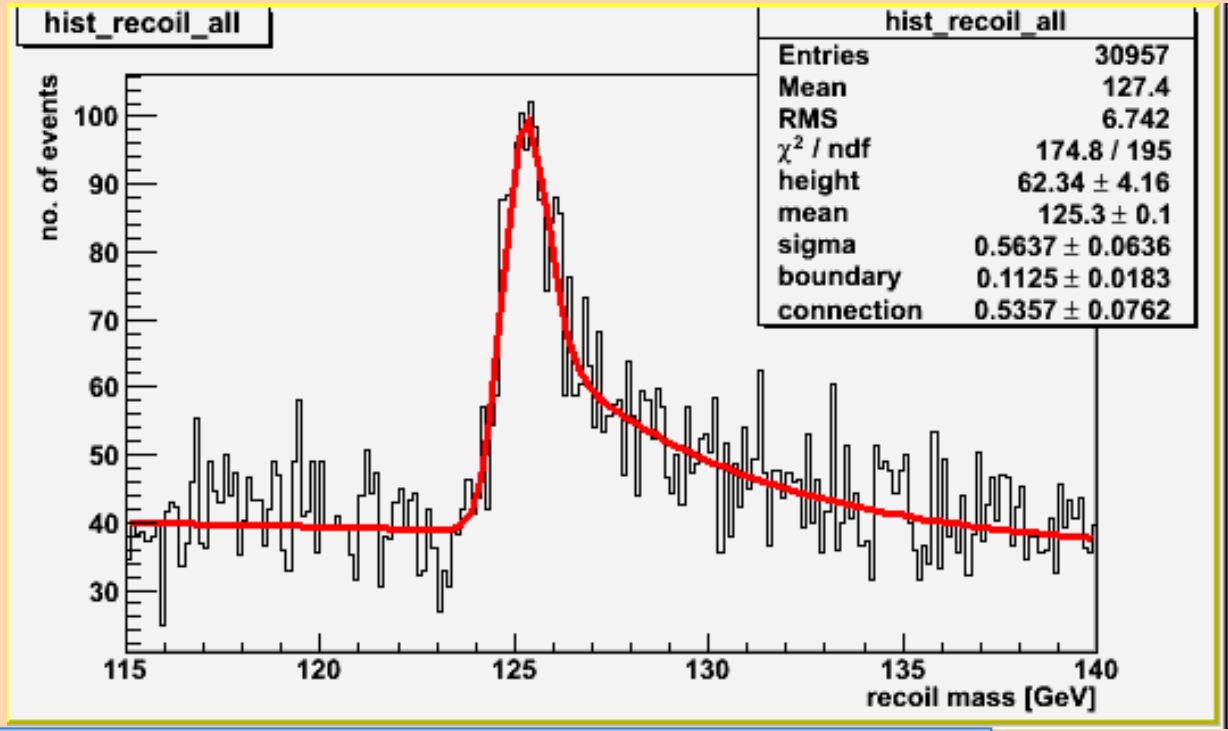
recoil mass

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)

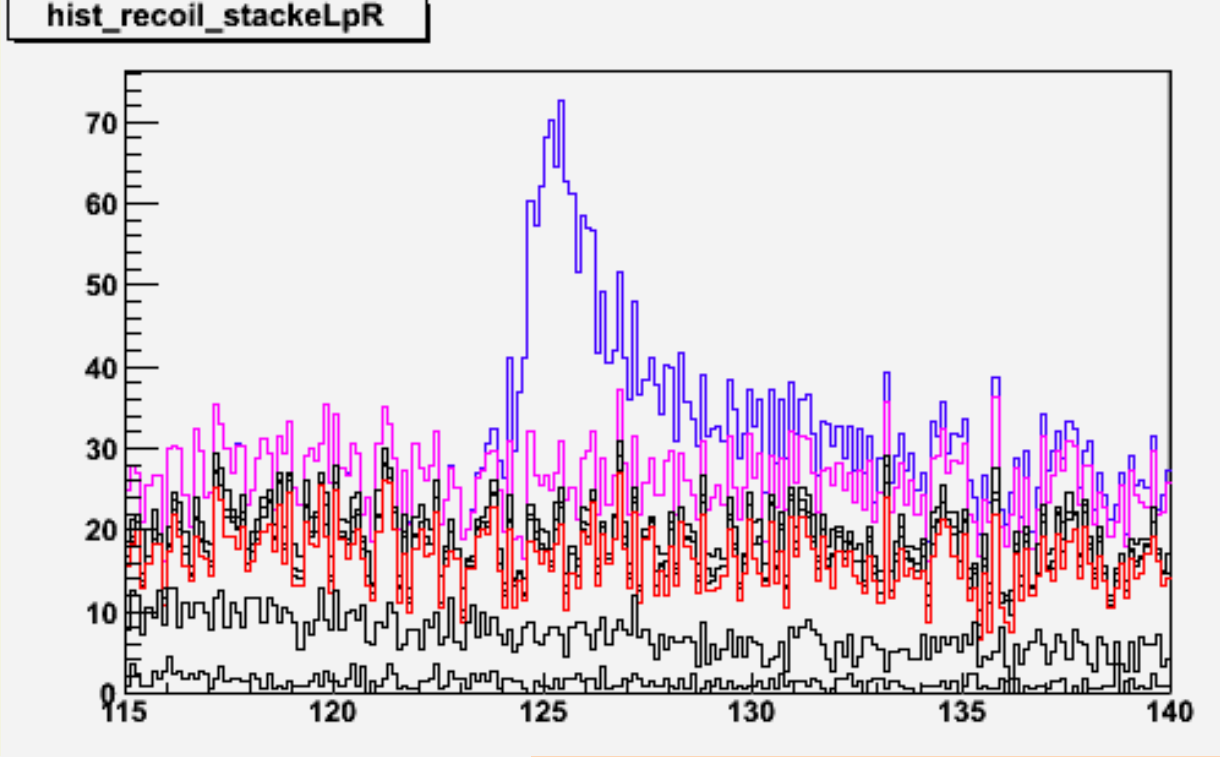
$$N\exp\left[-\frac{1}{2}\left(\frac{x-x_{mean}}{s}\right)^2\right] \qquad \frac{x-x_{mean}}{s} \le k$$

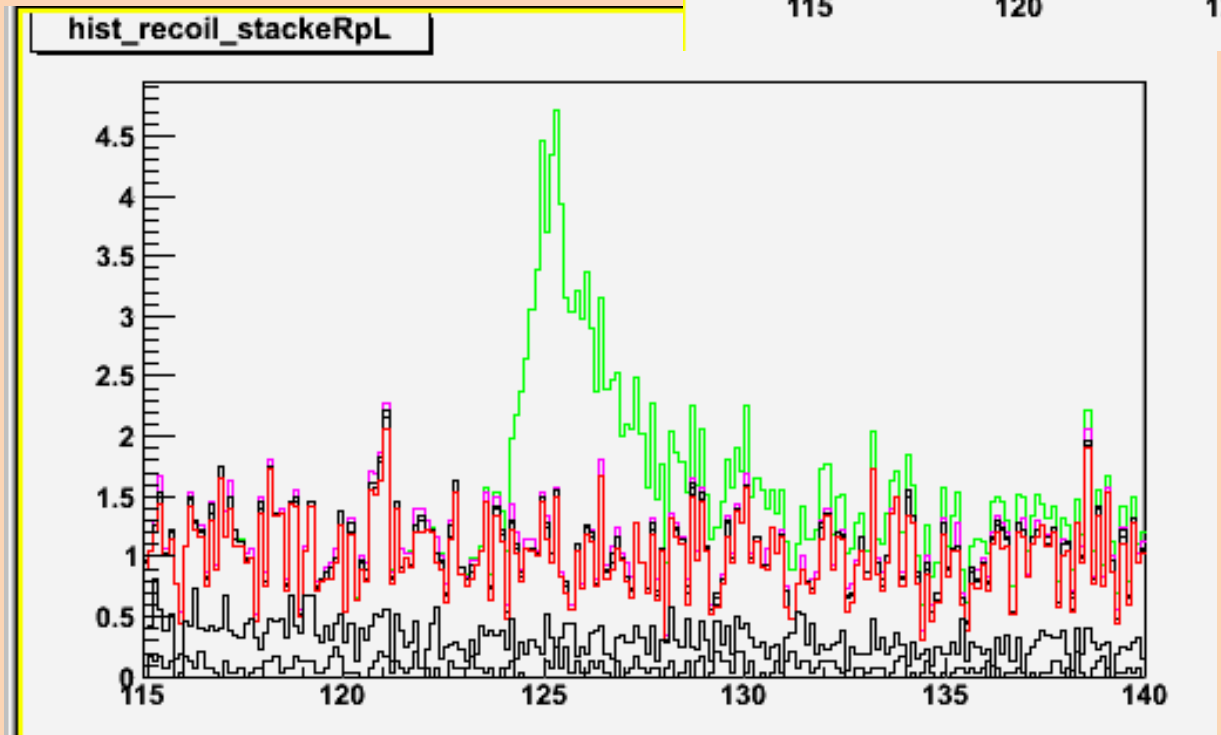
$$N\left[b\times\exp\left[-\frac{1}{2}\left(\frac{x-x_{mean}}{s}\right)^2\right]+(1-b)\exp\left[-k\left(\frac{x-x_{mean}}{s}-\frac{k}{2}\right)\right]\exp\left(k^2/2\right)\right] \qquad \frac{x-x_{mean}}{s} > k$$

recoil mass (stacked)

Red: 2f_Z_l

Pink: 4f_ZZWWMix_l : small for eRpL





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 : <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

My updated results:

- ε = 0.69
- < n> = 1491
- <Δn >/ <n > = sqrt((1-ε)/<n>) = 1.4 %
- purity : = <n> / sqrt(<n> + <B>) = 20.8

<n> = 1491 +/- 21

<Δσmeas> / <σmeas>
= 1 / sqrt(<n>*π) = 4.8 %

After including all BG and signal processes

added all other (possibly not relevant) signal and BG processes
signal : added Pqqh, Pnnh, Pe1e1h (Zee), Pe3e3h (Zττ)

what did I miss ?

Events left after all cuts:

- **WW_sl ∼ 130** ***oh no…….***
- Pqqh <∼7
- Pnnh <∼4
- All others ∼0

Now results are (after all cuts) :

<S> = 1508, sig eff = 0.68, <S>/B = 0.40, <S>/sqrt(<S>+B) = 20.7

not that much difference

Compare different polarization scenarios

	(−0.8,0.3)	(−0.8,0)	(0,0)
$\langle \Delta S \rangle$	1491	1183	1005
efficiency	0.69	0.69	0.686
$\langle S \rangle / \mathrm{sqrt}(\langle S \rangle + \langle B \rangle)$	20.82	18.63	18.04
$\langle S \rangle / \langle B \rangle$	0.41	0.42	0.48
$\langle \Delta S \rangle / \langle S \rangle$	1.52%	1.62%	1.77%
$\langle \sigma \rangle / \sigma$	4.80%	5.37%	5.54%

Summary

- **Higgs recoil mass study using e+e- → Zh → μ+μ-h** @ Ec.m.s. = 250 GeV, L = 250 fb-1
- **improved data selection method**
- **included all other BG processes** (tau related , hadronic , ect…… just to be sure)
- updated results: **signal ε = 69%, S/B ~ 0.4, S/sqrt(S+B) ~20.7**
- **fitted recoil mass : 125.2 GeV +/- 70 MeV** ← *will aim for better precision*
- Compared different **polarization** scenarios : **(-0.8, 0.3) vs (-0.8, 0) vs (0,0)**

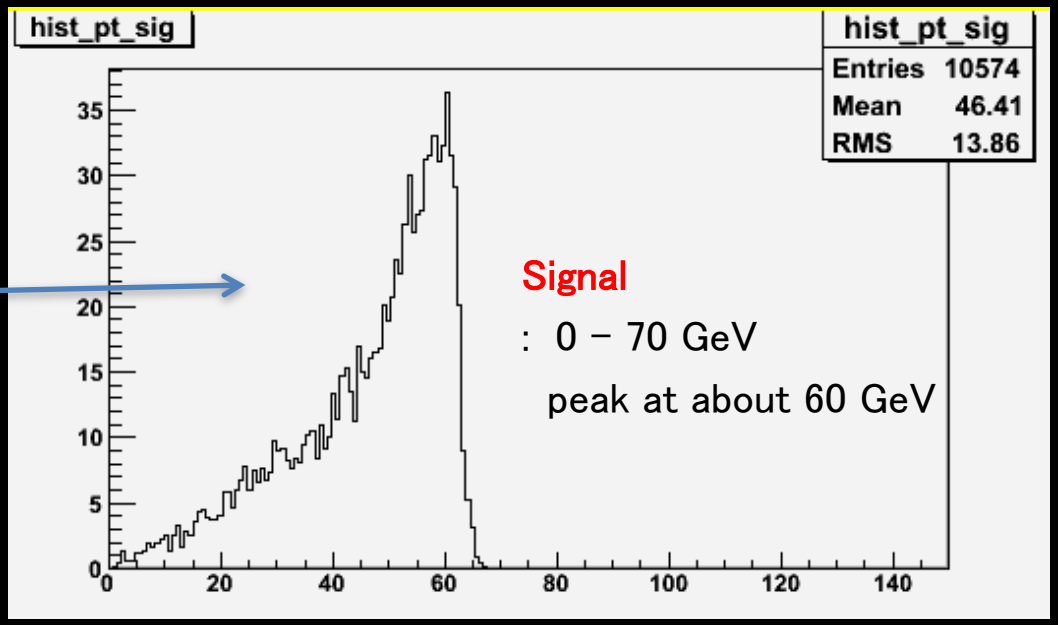
Further Plans

- **further optimize data selection method**
- try higher statistics (L=20000 fb-1) sample only available for 250 GeV (?)
- **move on soon to analysis at Ec.m.s. = 350 GeV**

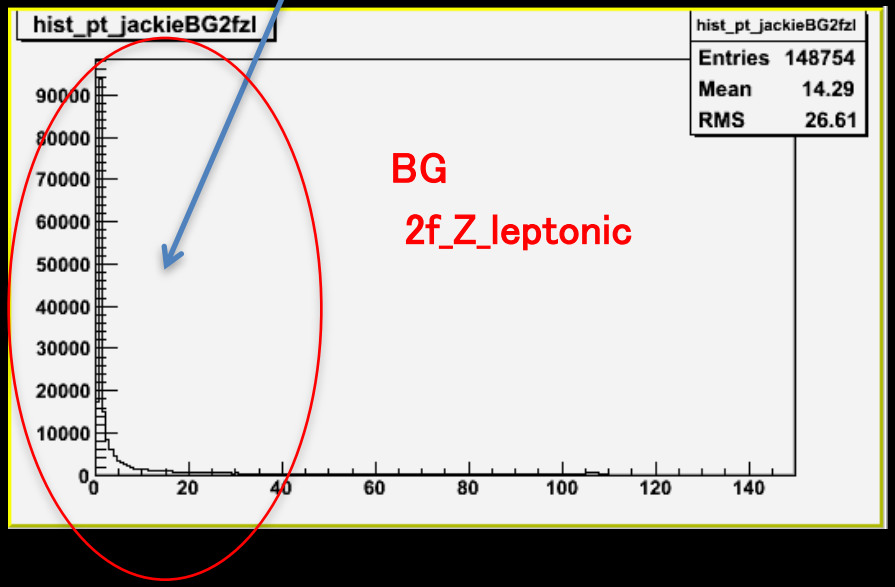
BACKUP

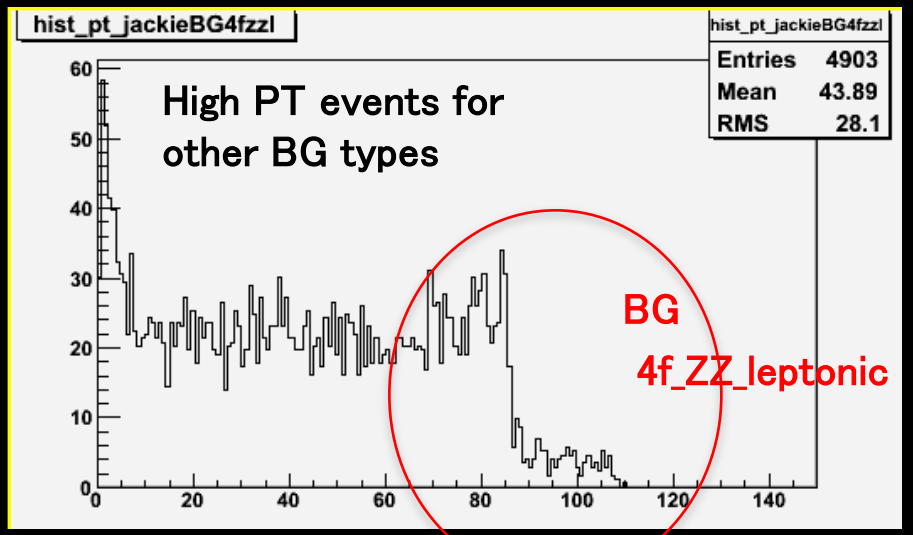
PT of dilepton system

do cut : 10 GeV< pT_dl < 70 GeV



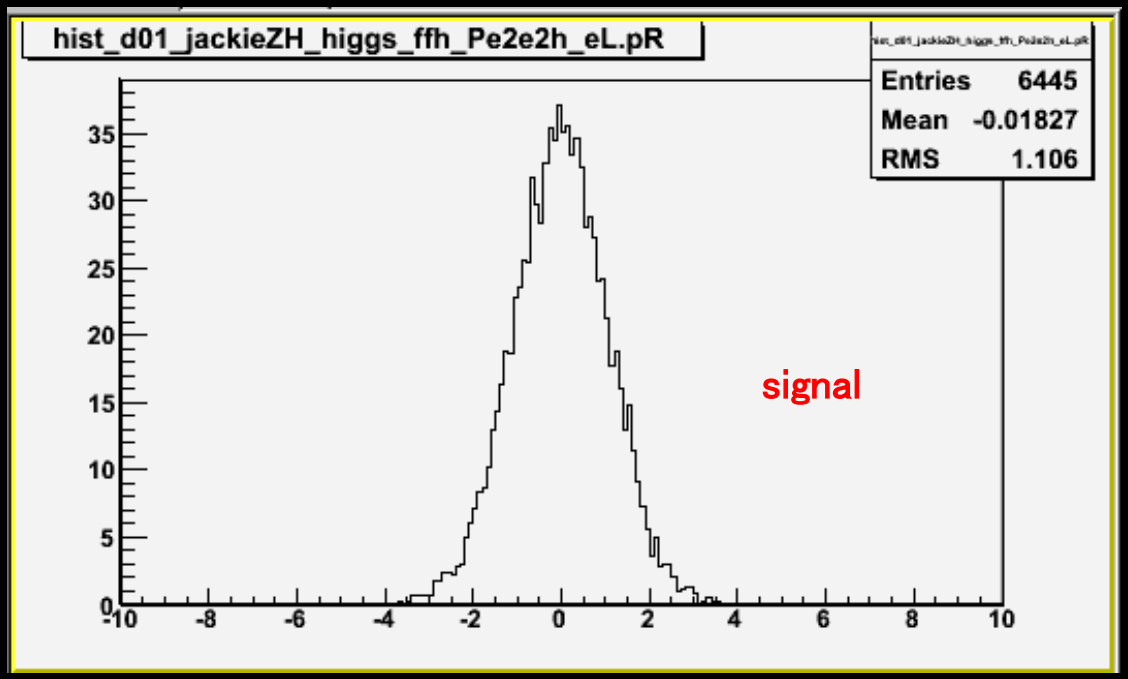
BG
dominated by 2f_Z_leptonic,
many low PT events

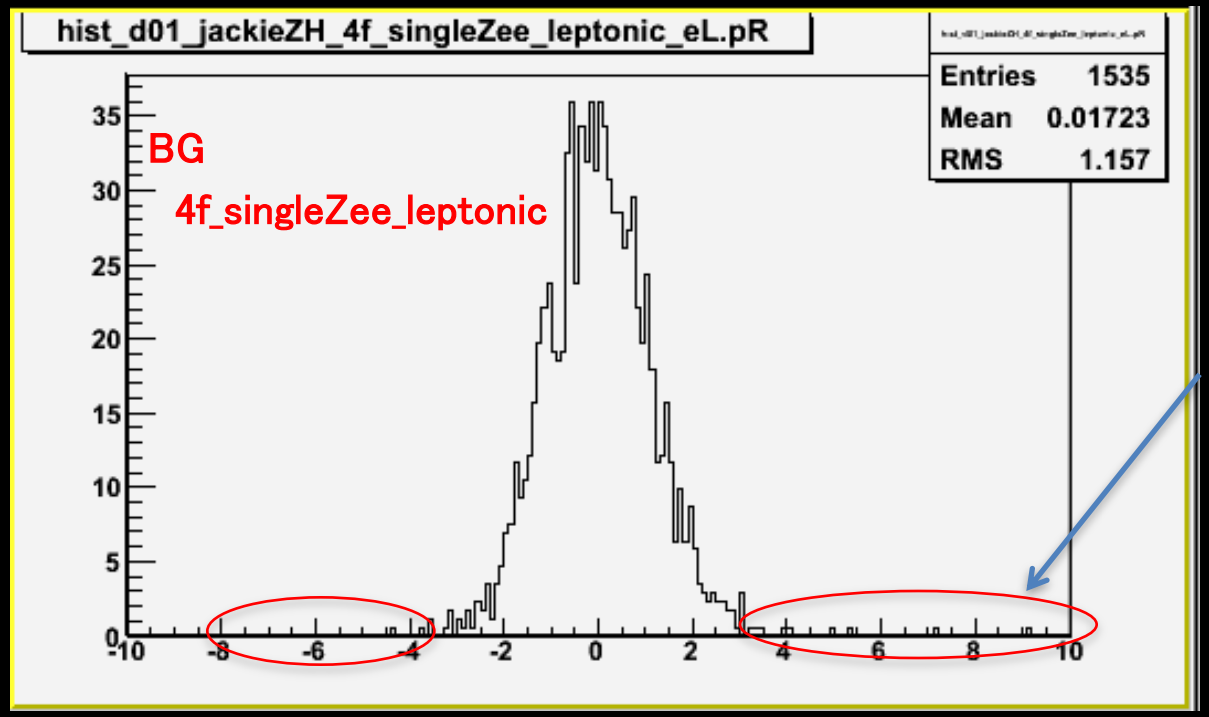




Impact parameter

D0/ δ D0



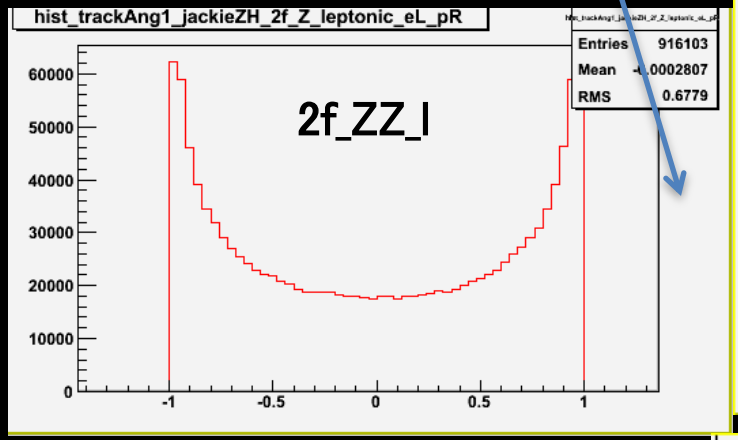


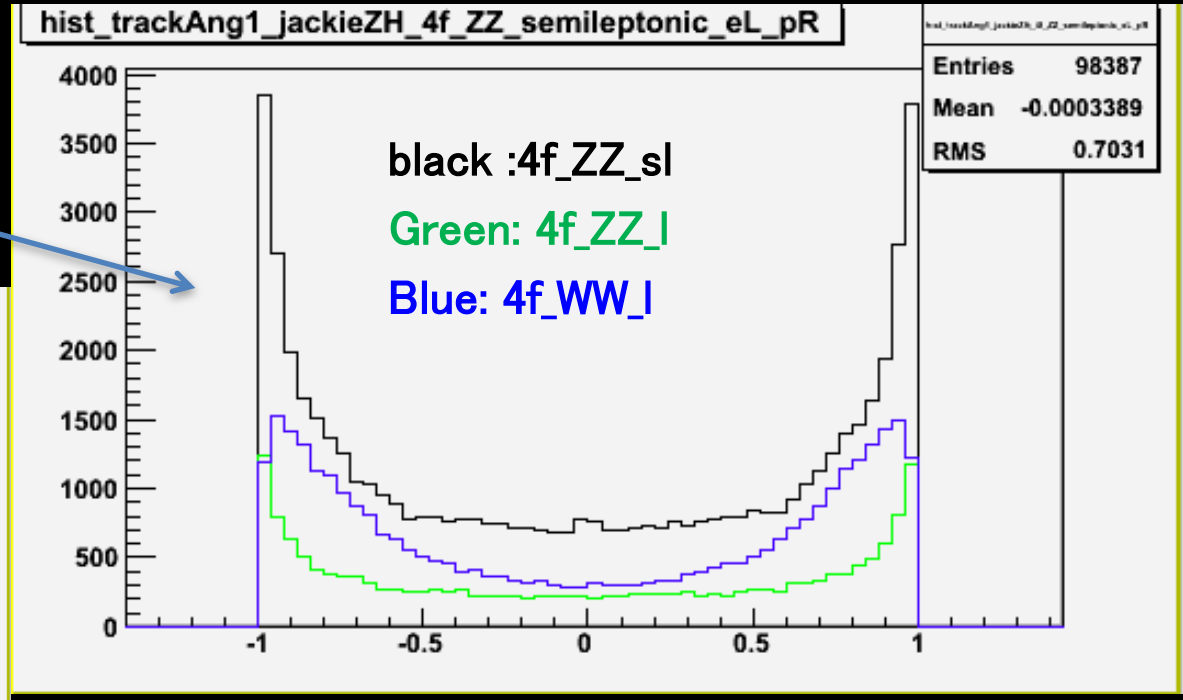
For some BG processes exceed +/− 4 slightly

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

Cos(track angle)

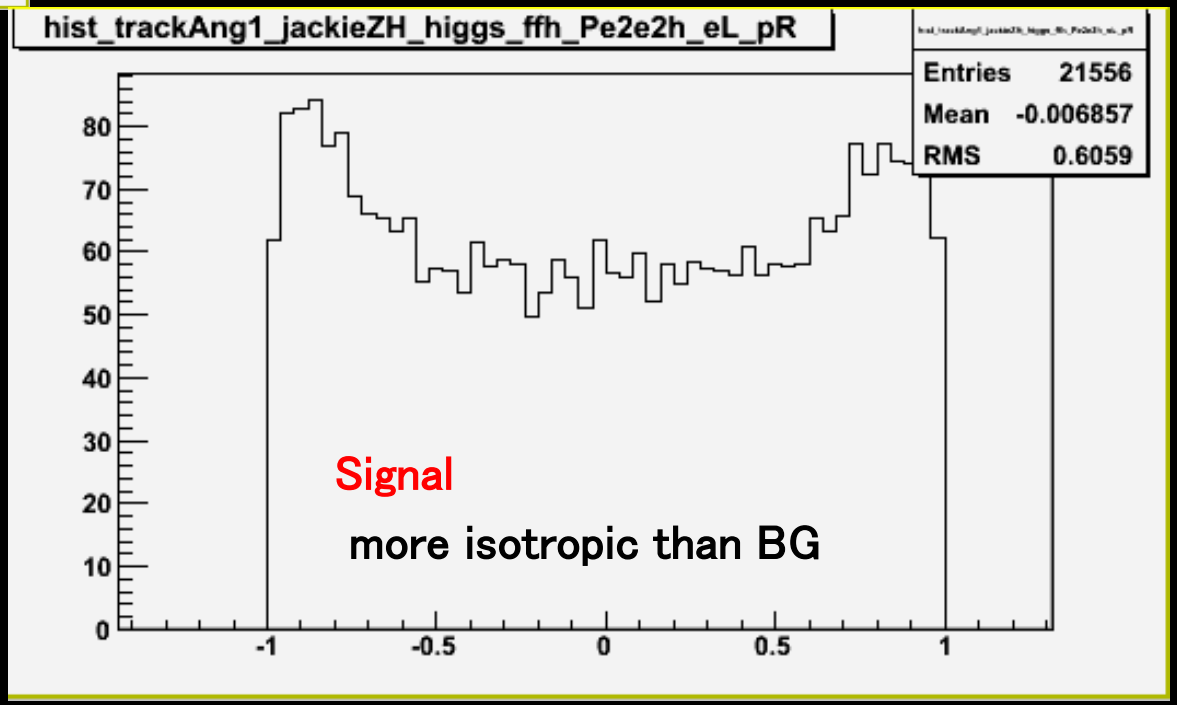
BG is More forward





do cut :

cos(trackAngle) < 0.95



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>) !!**

Estimate Stat errors

Error on <n> (<S>) depend on **binomial distr.**
if detect n out of n events : **efficiency = n/N**

stat error on n : $\Delta n = \mathrm{sqrt}(N*\varepsilon * (1-\varepsilon)) = \mathrm{sqrt}(n*(1-\varepsilon))$ $\Delta n/n = \mathrm{sqrt}((1-\varepsilon)/n)$
(c.f. If n is big → Poisson distr.: 1/sqrt(n))

higher ε, larger n is better

My updated results:

- ε = 0.66
- < n> = 1422 (= <S>)
- <Δn >/ <n > = sqrt((1-ε)/<n>) = 1.6 % → **<n> = 1422 +/- 23**

purity : sqrt(<n>*π) = **<n> / sqrt(<n> + <B>) = 20.6**
Error of cross section **<Δσmeas> / <σmeas> = 1 / sqrt(<n>*π) = 4.9 %**

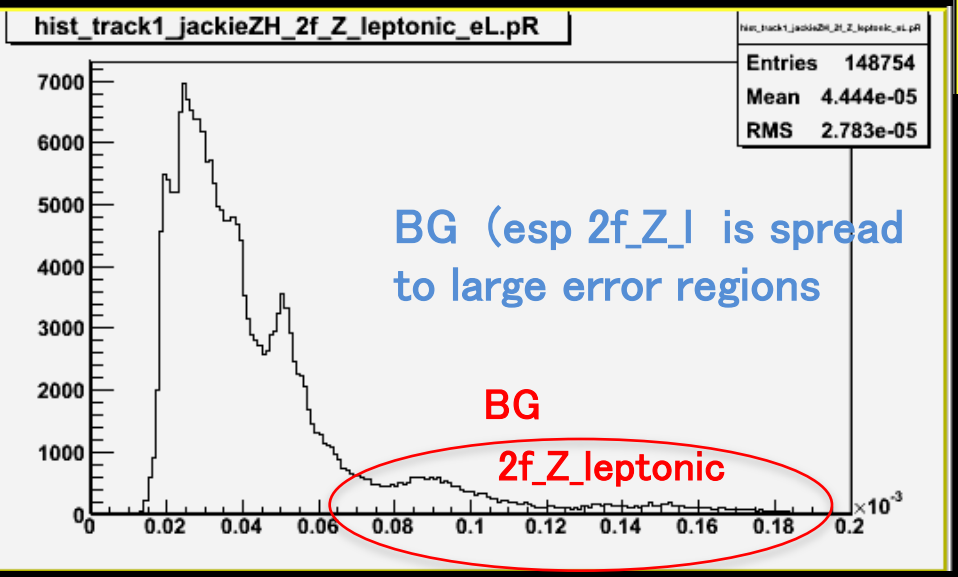
dependent on sample size → try higher statistics
Now integrated L = 2000 fb-1

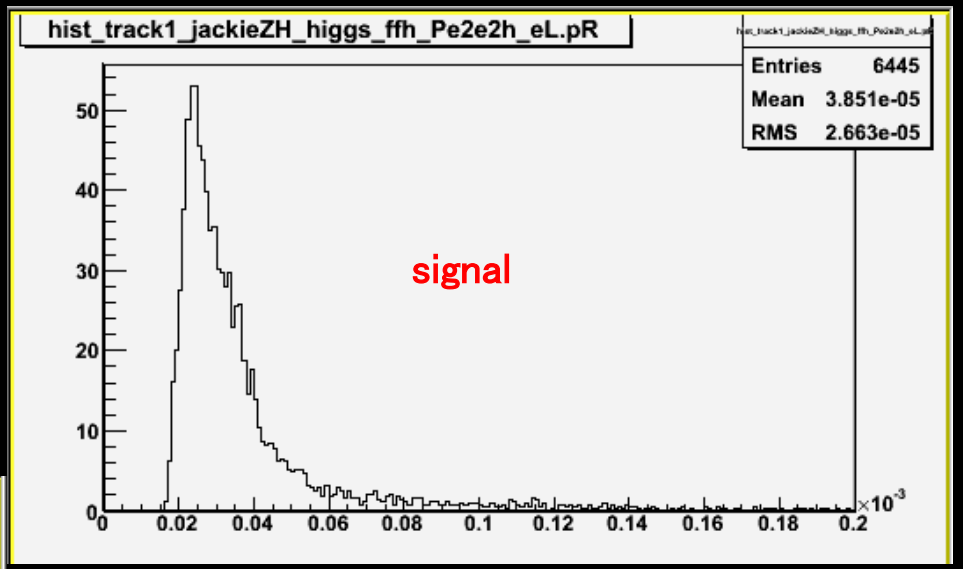
σs = <n> / (L*ε) = 1422/2000/0.66 = 1.077 fb

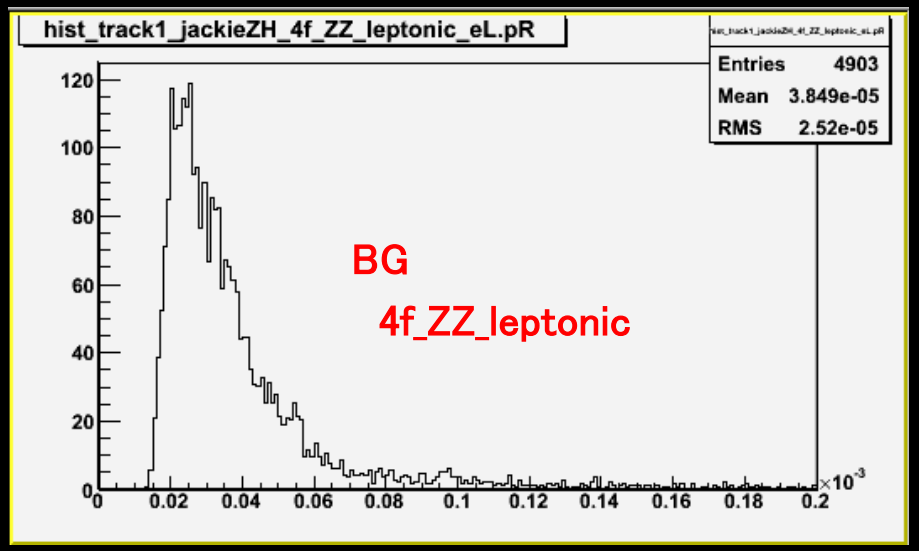
good track selection

dP/P^2

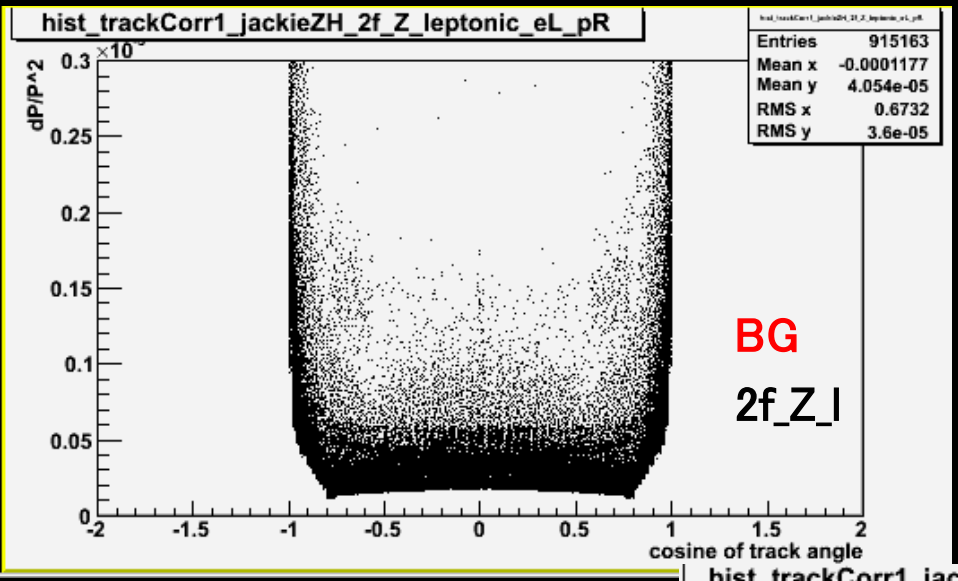
Used to do cut : $dp/p^2 < 5E-5$

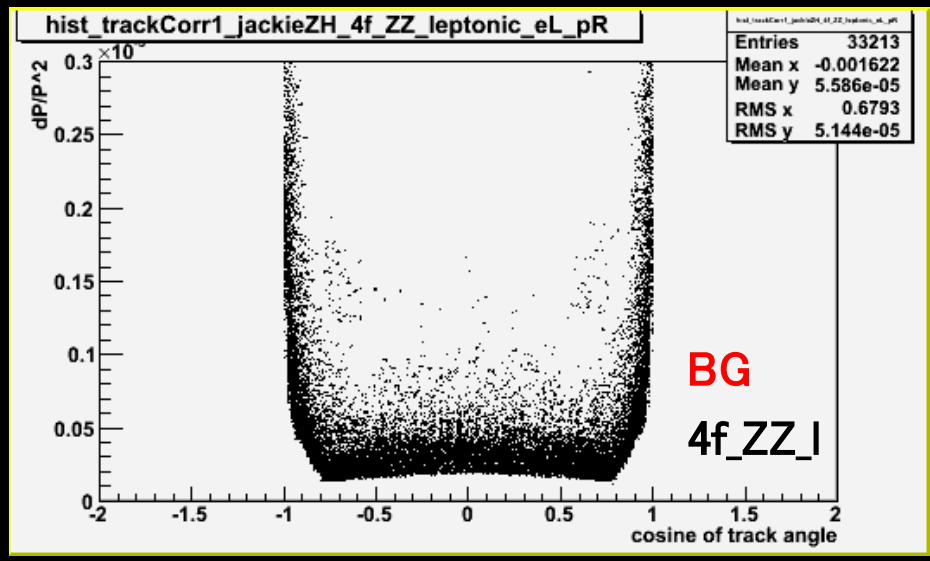


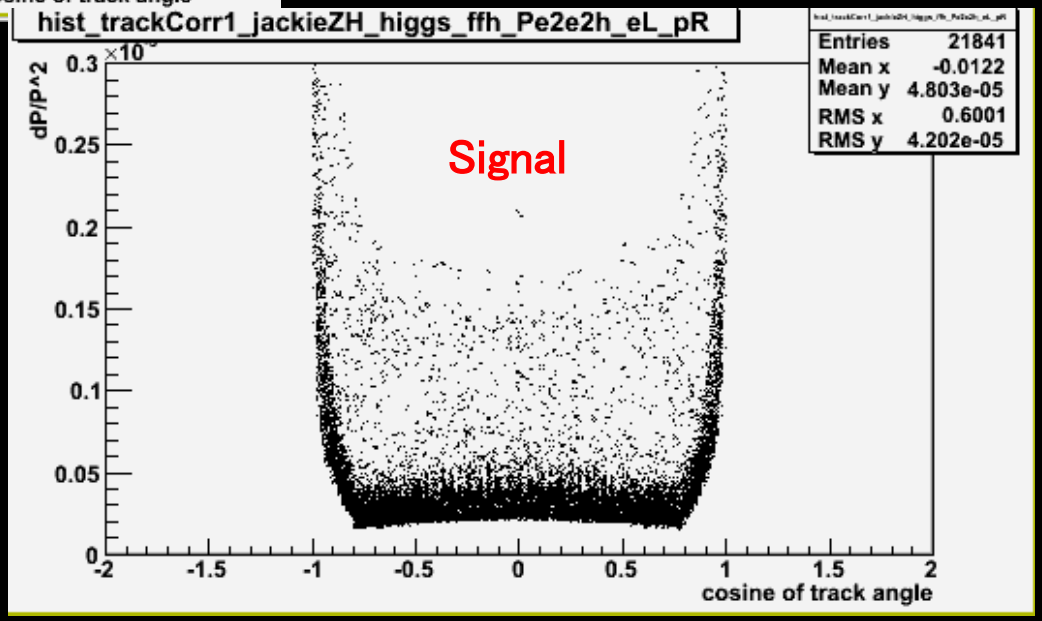




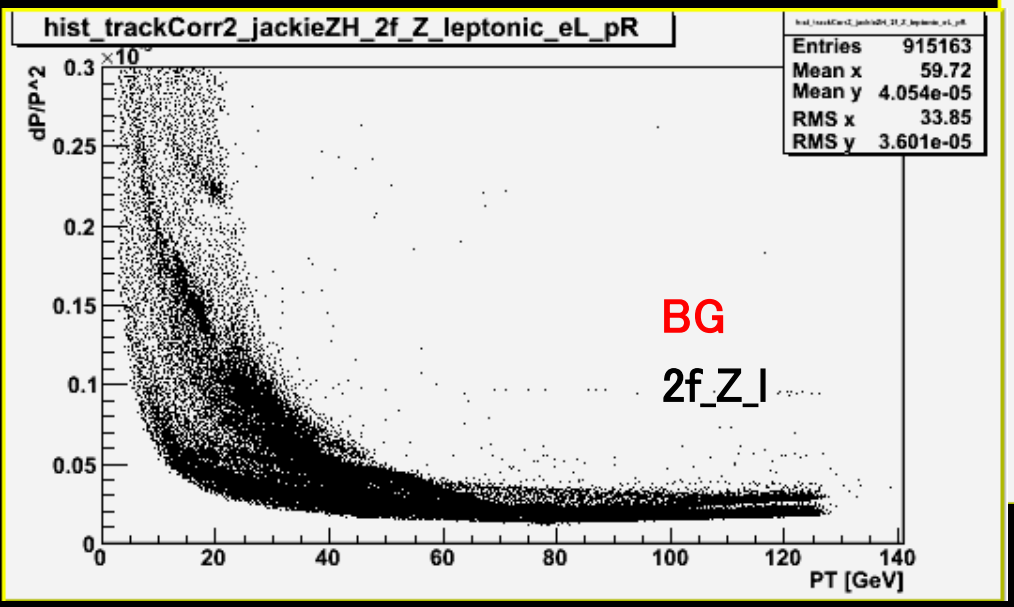
correlation between Cos(track angle) and dP/P^2

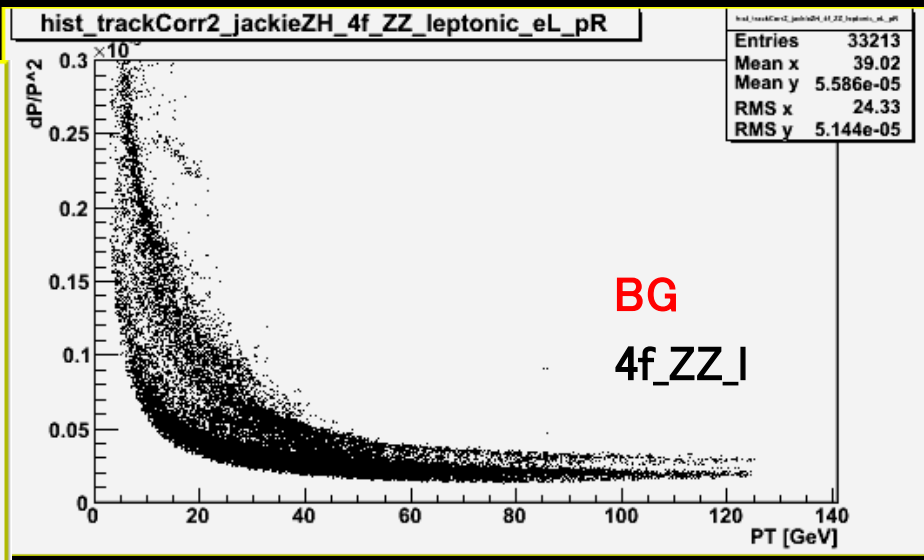


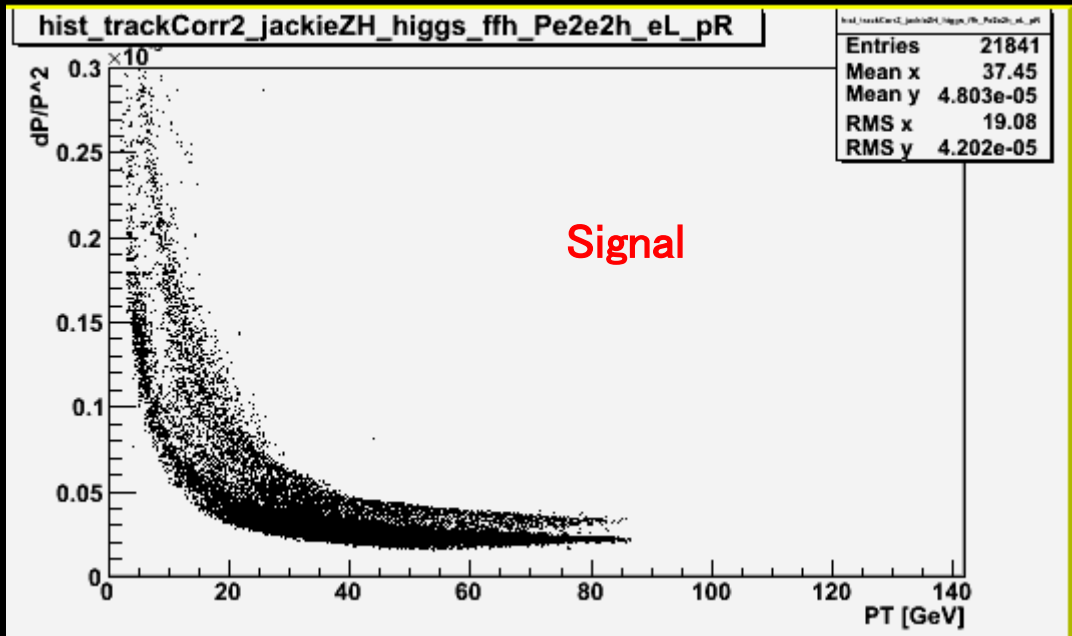




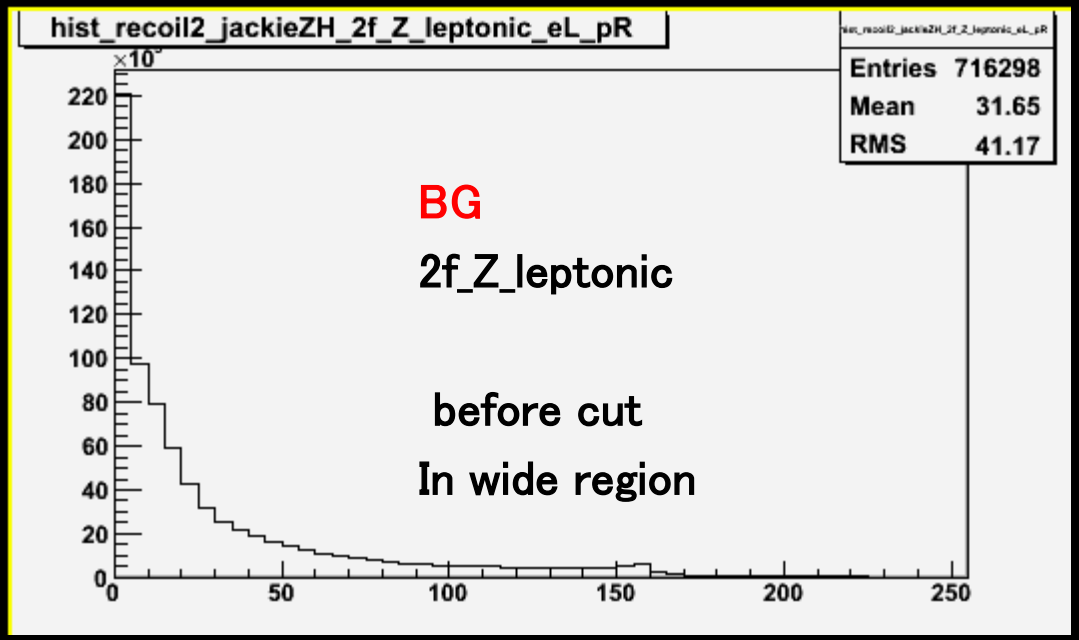
correlation between PT and dP/P^2

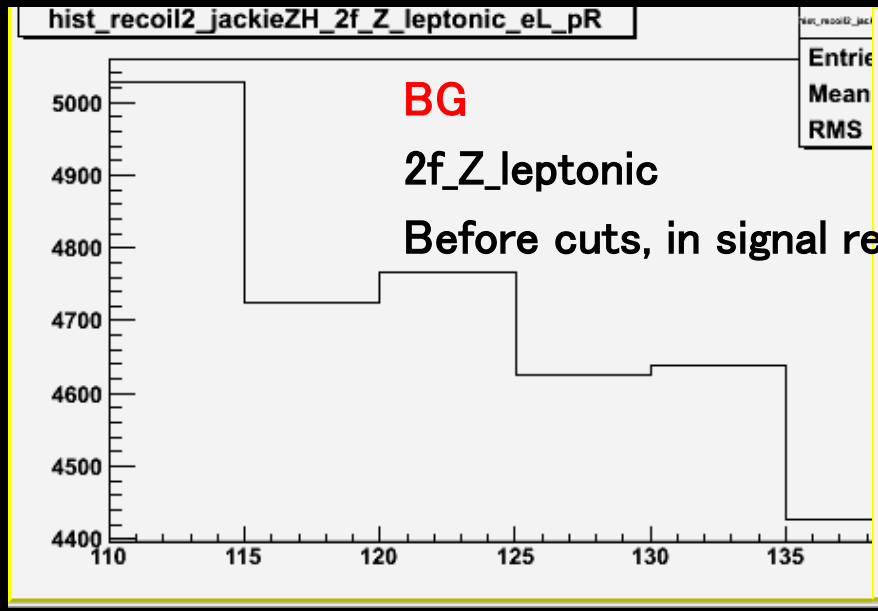


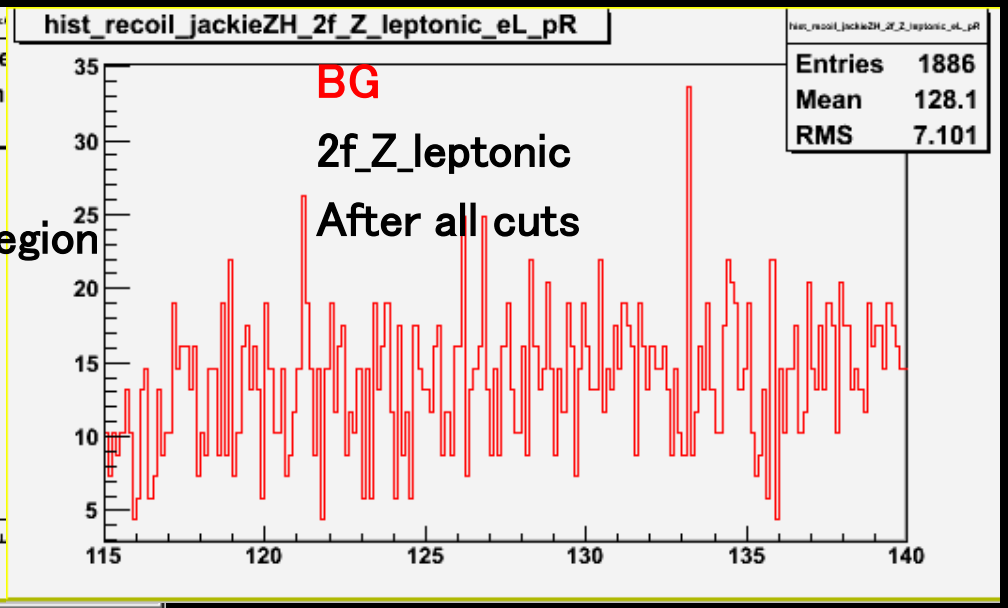




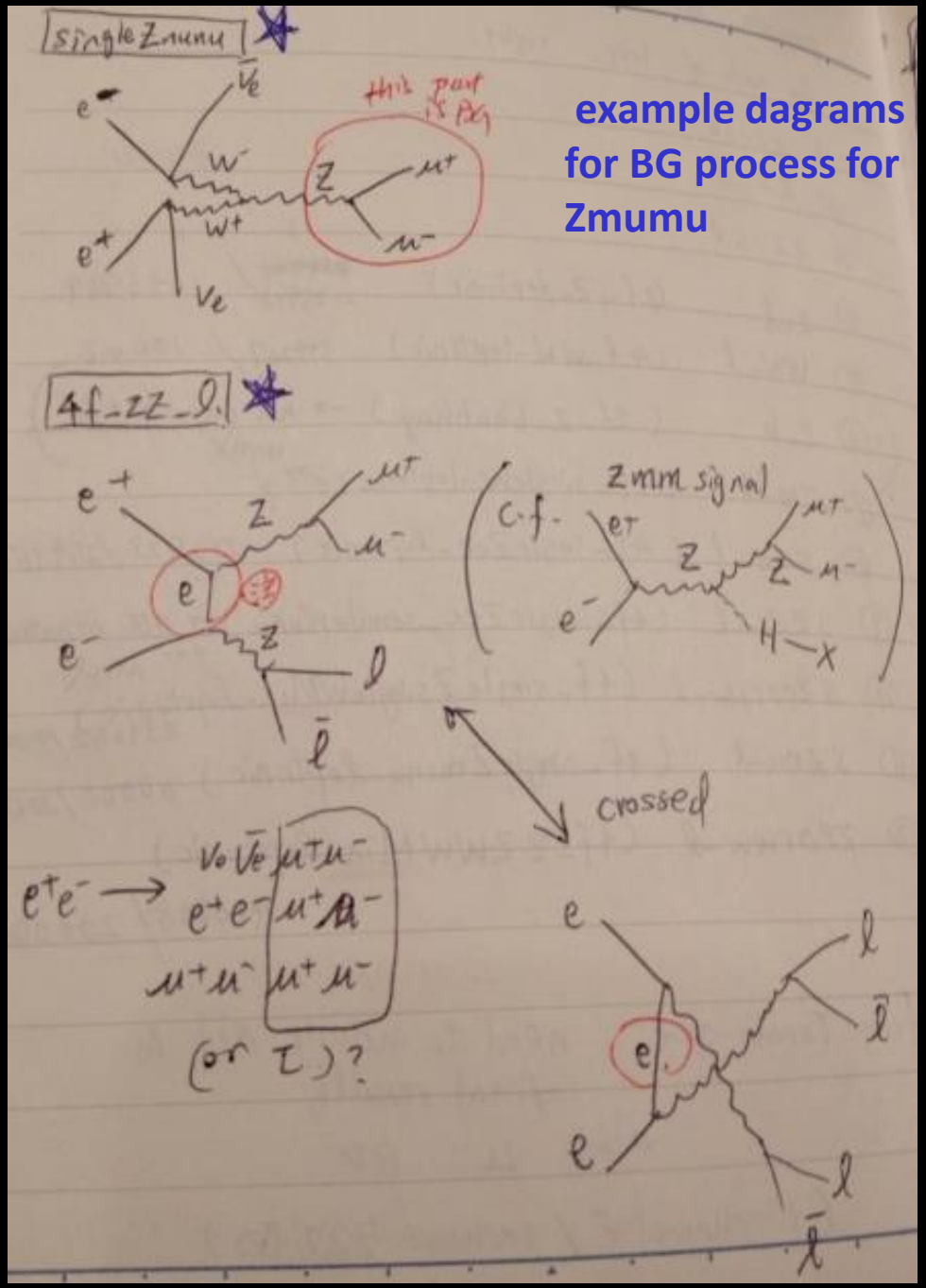
Recoil mass of 2f_Z_leptonic before and after all cuts

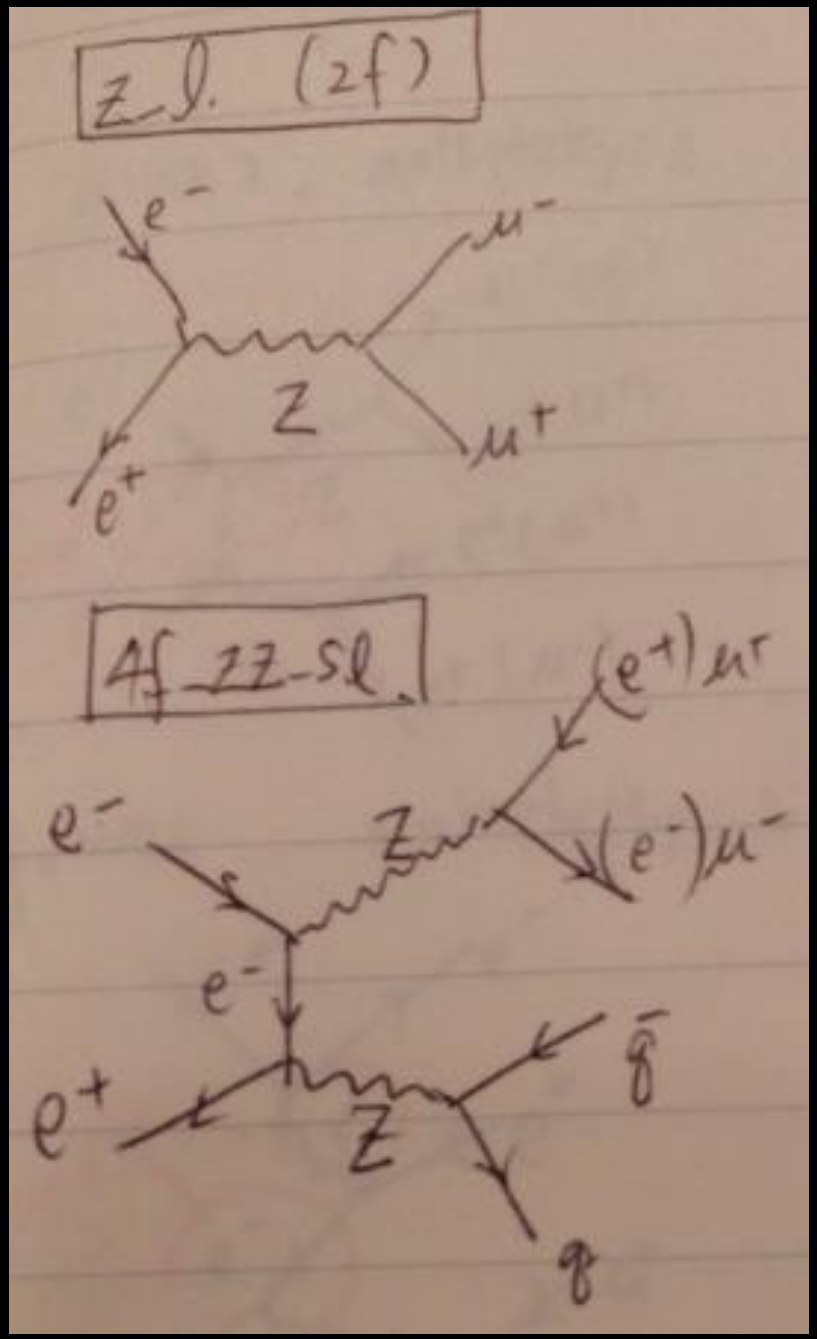


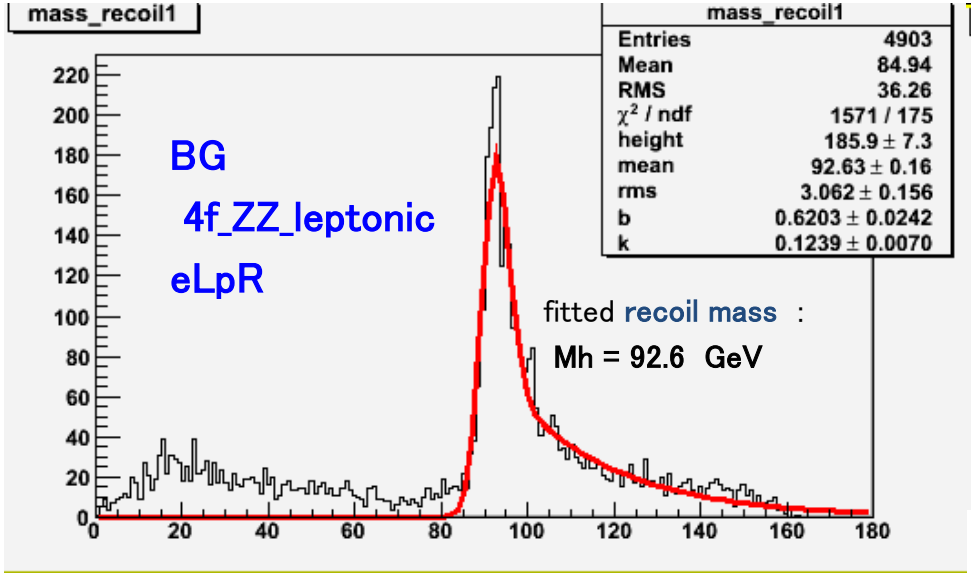


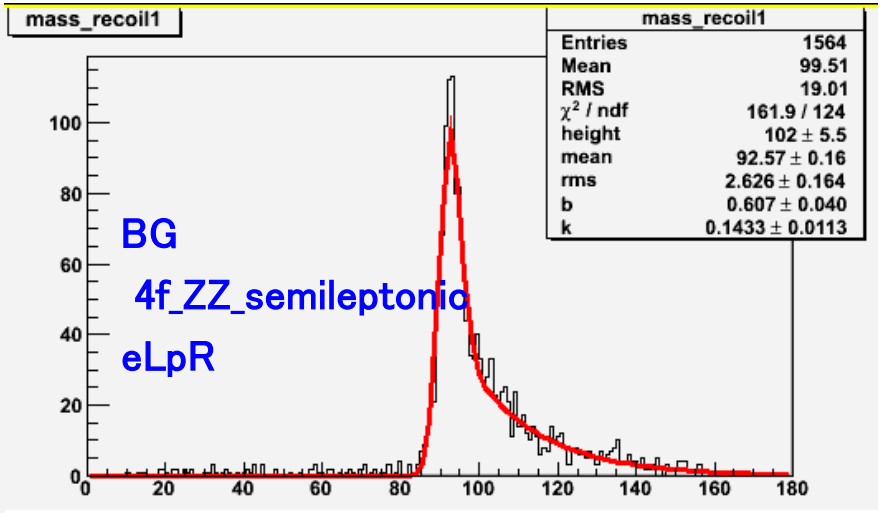


example dagrams for BG process for Zmumu









recoil mass distribution for some BG processes

2f_Z_leptonic

This may be causing high energy BG in combined histogram